



$$I(J^P) = 0(\frac{1}{2}^+)$$

$$\text{Charge} = \frac{2}{3} e \quad \text{Top} = +1$$

See the related review(s):

[Top Quark](#)

### t-QUARK MASS

We first list the direct measurements of the top quark mass which employ the event kinematics and then list the measurements which extract a top quark mass from the measured  $t\bar{t}$  cross-section using theory calculations. A discussion of the definition of the top quark mass in these measurements can be found in the review "The Top Quark."

For earlier search limits see PDG 96, Physical Review **D54** 1 (1996). We no longer include a compilation of indirect top mass determinations from Standard Model Electroweak fits in the Listings (our last compilation can be found in the Listings of the 2007 partial update). For a discussion of current results see the reviews "The Top Quark" and "Electroweak Model and Constraints on New Physics."

#### t-Quark Mass (Direct Measurements)

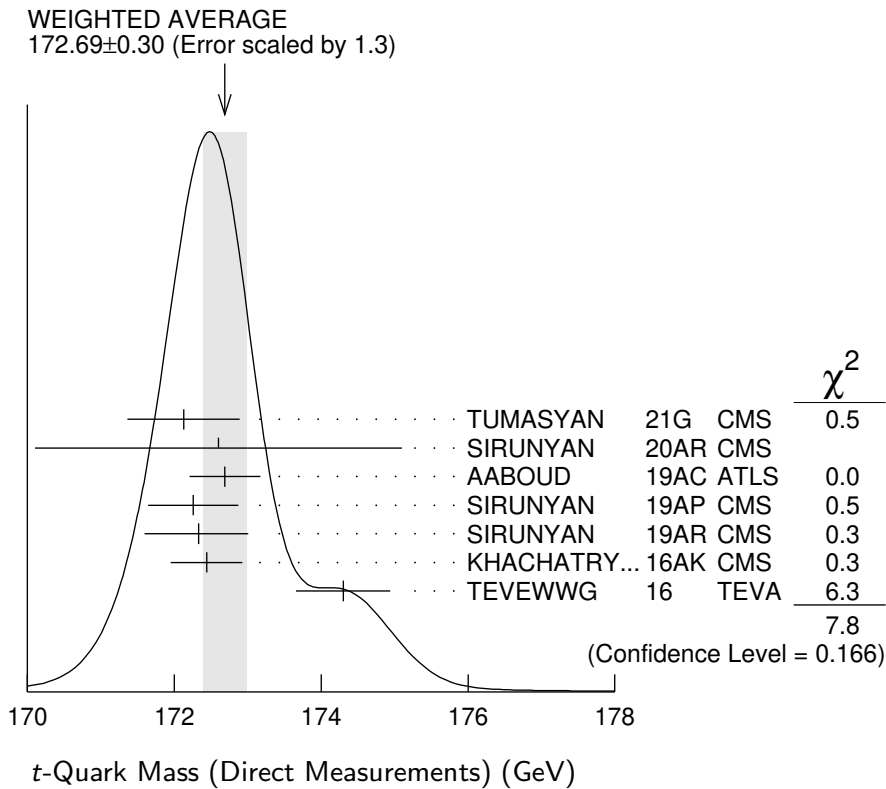
The following measurements extract a  $t$ -quark mass from the kinematics of  $t\bar{t}$  events. They are sensitive to the top quark mass used in the MC generator that is usually interpreted as the pole mass, but the theoretical uncertainty in this interpretation is hard to quantify. See the review "The Top Quark" and references therein for more information.

OUR AVERAGE of  $172.69 \pm 0.30$  GeV is an average of top mass measurements from LHC and Tevatron Runs. The latest Tevatron average,  $174.30 \pm 0.35 \pm 0.54$  GeV, was provided by the Tevatron Electroweak Working Group (TEVEWWG).

<u>VALUE (GeV)</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
<b>172.69 ± 0.30 OUR AVERAGE</b>	Error includes scale factor of 1.3. See the ideogram below.		
172.13 <sup>+0.76</sup> <sub>-0.77</sub>	1 TUMASYAN	21G CMS	$t$ -channel single top production
172.6 ± 2.5	2 SIRUNYAN	20AR CMS	jet mass from boosted top
172.69 ± 0.25 ± 0.41	3 AABOUD	19AC ATLS	7, 8 TeV ATLAS combination
172.26 ± 0.07 ± 0.61	4 SIRUNYAN	19AP CMS	lepton+jets, all-jets channels
172.33 ± 0.14 <sup>+0.66</sup> <sub>-0.72</sub>	5 SIRUNYAN	19AR CMS	dilepton channel ( $e\mu, 2e, 2\mu$ )
172.44 ± 0.13 ± 0.47	6 KHACHATRY...	16AK CMS	7, 8 TeV CMS combination
174.30 ± 0.35 ± 0.54	7 TEVEWWG	16 TEVA	Tevatron combination
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●			
172.08 ± 0.39 ± 0.82	8 AABOUD	19AC ATLS	$\ell + \geq 4j$ ( $2b$ )
172.34 ± 0.20 ± 0.70	9 SIRUNYAN	19AP CMS	$\geq 6$ jets ( $\geq 2b$ )
172.25 ± 0.08 ± 0.62	10 SIRUNYAN	18DE CMS	$\ell + \geq 4j$ ( $2b$ )
173.72 ± 0.55 ± 1.01	11 AABOUD	17AH ATLS	$\geq 5$ jets ( $2b$ )
174.95 ± 0.40 ± 0.64	12 ABAZOV	17B D0	$\ell +$ jets and dilepton channels
172.95 ± 0.77 <sup>+0.97</sup> <sub>-0.93</sub>	13 SIRUNYAN	17L CMS	$t$ -channel single top production
170.8 ± 9.0	14 SIRUNYAN	17N CMS	jet mass in highly-boosted $t\bar{t}$ events

$172.22 \pm 0.18$	$^{+0.89}_{-0.93}$	15	SIRUNYAN	17O	CMS	Dilepton channel
$172.99 \pm 0.41$	$\pm 0.74$	16	AABOUD	16T	ATLS	dilepton channel
$172.84 \pm 0.34$	$\pm 0.61$	17	AABOUD	16T	ATLS	combination of ATLAS
$173.32 \pm 1.36$	$\pm 0.85$	18	ABAZOV	16	D0	$\ell\ell + \cancel{E}_T + \geq 2j$ ( $\geq 2b$ )
$173.93 \pm 1.61$	$\pm 0.88$	19	ABAZOV	16D	D0	$\ell\ell + \cancel{E}_T + \geq 2j$ ( $\geq 2b$ )
$172.35 \pm 0.16$	$\pm 0.48$	20,21	KHACHATRY...	16AK	CMS	$\ell + \geq 4j$ ( $2b$ )
$172.32 \pm 0.25$	$\pm 0.59$	20,21	KHACHATRY...	16AK	CMS	$\geq 6$ jets ( $2b$ )
$172.82 \pm 0.19$	$\pm 1.22$	20,22	KHACHATRY...	16AK	CMS	$(ee/\mu\mu) + \cancel{E}_T + \geq 2b, e\mu + \geq 2b$
$173.68 \pm 0.20$	$^{+1.58}_{-0.97}$	23	KHACHATRY...	16AL	CMS	semi- + di-leptonic channels
$173.5 \pm 3.0$	$\pm 0.9$	24	KHACHATRY...	16CB	CMS	$t \rightarrow (W \rightarrow \ell\nu)(b \rightarrow J/\psi X \rightarrow \mu^+ \mu^- X)$
$175.1 \pm 1.4$	$\pm 1.2$	25	AAD	15AW	ATLS	small $\cancel{E}_T$ , $\geq 6$ jets ( $2b$ -tag)
$172.99 \pm 0.48$	$\pm 0.78$	26	AAD	15BF	ATLS	$\ell +$ jets and dilepton
$171.5 \pm 1.9$	$\pm 2.5$	27	AALTONEN	15D	CDF	$\ell\ell + \cancel{E}_T + \geq 2j$
$175.07 \pm 1.19$	$^{+1.55}_{-1.58}$	28	AALTONEN	14N	CDF	small $\cancel{E}_T$ , 6–8 jets ( $\geq 1b$ -tag)
$174.98 \pm 0.58$	$\pm 0.49$	29	ABAZOV	14C	D0	$\ell + \cancel{E}_T + 4$ jets ( $\geq 1b$ -tag)
$173.49 \pm 0.69$	$\pm 1.21$	30	CHATRCHYAN	14C	CMS	$\geq 6$ jets ( $\geq 2b$ -tag)
$173.93 \pm 1.64$	$\pm 0.87$	31	AALTONEN	13H	CDF	$\cancel{E}_T + \geq 4$ jets ( $\geq 1b$ )
$173.9 \pm 0.9$	$^{+1.7}_{-2.1}$	32	CHATRCHYAN	13S	CMS	$\ell\ell + \cancel{E}_T + \geq 2b$ -tag (MT2( $T$ ))
$174.5 \pm 0.6$	$\pm 2.3$	33	AAD	12I	ATLS	$\ell + \cancel{E}_T + \geq 4$ jets ( $\geq 1b$ ), MT
$172.85 \pm 0.71$	$\pm 0.85$	34	AALTONEN	12AI	CDF	$\ell + \cancel{E}_T + \geq 4j$ (0,1,2b) template
$172.7 \pm 9.3$	$\pm 3.7$	35	AALTONEN	12AL	CDF	$\tau_h + \cancel{E}_T + 4j$ ( $\geq 1b$ )
$173.18 \pm 0.56$	$\pm 0.75$	36	AALTONEN	12AP	TEVA	CDF, D0 combination
$172.5 \pm 1.4$	$\pm 1.5$	37	AALTONEN	12G	CDF	6–8 jets with $\geq 1b$
$173.7 \pm 2.8$	$\pm 1.5$	38	ABAZOV	12AB	D0	$\ell\ell + \cancel{E}_T + \geq 2j$ ( $\nu$ WT)
$173.9 \pm 1.9$	$\pm 1.6$	39	ABAZOV	12AB	D0	$\ell\ell + \cancel{E}_T + \geq 2j$ ( $\nu$ WT+MWT)
$172.5 \pm 0.4$	$\pm 1.5$	40	CHATRCHYAN	12BA	CMS	$\ell\ell + \cancel{E}_T + \geq 2j$ ( $\geq 1b$ ), AMWT
$173.49 \pm 0.43$	$\pm 0.98$	41	CHATRCHYAN	12BP	CMS	$\ell + \cancel{E}_T + \geq 4j$ ( $\geq 2b$ )
$172.4 \pm 1.4$	$\pm 1.3$	42	AALTONEN	11AC	CDF	$\ell + \cancel{E}_T + 4$ jets ( $\geq 1b$ -tag)
$172.3 \pm 2.4$	$\pm 1.0$	43	AALTONEN	11AK	CDF	Repl. by AALTONEN 13H
$172.1 \pm 1.1$	$\pm 0.9$	44	AALTONEN	11E	CDF	$\ell +$ jets and dilepton
$176.9 \pm 8.0$	$\pm 2.7$	45	AALTONEN	11T	CDF	$\ell + \cancel{E}_T + 4$ jets ( $\geq 1b$ -tag), $p_T(\ell)$ shape
$174.94 \pm 0.83$	$\pm 1.24$	46	ABAZOV	11P	D0	$\ell + \cancel{E}_T + 4$ jets ( $\geq 1b$ -tag)
$174.0 \pm 1.8$	$\pm 2.4$	47	ABAZOV	11R	D0	dilepton + $\cancel{E}_T + \geq 2$ jets
$175.5 \pm 4.6$	$\pm 4.6$	48	CHATRCHYAN	11F	CMS	dilepton + $\cancel{E}_T +$ jets
$173.0 \pm 0.9$	$\pm 0.9$	49	AALTONEN	10AE	CDF	$\ell + \cancel{E}_T + 4$ jets ( $\geq 1b$ -tag), ME method
$169.3 \pm 2.7$	$\pm 3.2$	50	AALTONEN	10C	CDF	dilepton + $b$ -tag (MT2+NWA)
$170.7 \pm 6.3$	$\pm 2.6$	51	AALTONEN	10D	CDF	$\ell + \cancel{E}_T + 4$ jets ( $b$ -tag)
$174.8 \pm 2.4$	$^{+1.2}_{-1.0}$	52	AALTONEN	10E	CDF	$\geq 6$ jets, vtx $b$ -tag
$180.5 \pm 12.0$	$\pm 3.6$	53	AALTONEN	09AK	CDF	$\ell + \cancel{E}_T +$ jets (soft $\mu$ $b$ -tag)
$172.7 \pm 1.8$	$\pm 1.2$	54	AALTONEN	09J	CDF	$\ell + \cancel{E}_T + 4$ jets ( $b$ -tag)
$171.1 \pm 3.7$	$\pm 2.1$	55	AALTONEN	09K	CDF	6 jets, vtx $b$ -tag
$171.9 \pm 1.7$	$\pm 1.1$	56	AALTONEN	09L	CDF	$\ell +$ jets, $\ell\ell +$ jets
$171.2 \pm 2.7$	$\pm 2.9$	57	AALTONEN	09O	CDF	dilepton
$165.5 \pm 3.4$	$^{+3.4}_{-3.3}$	58	AALTONEN	09X	CDF	$\ell\ell + \cancel{E}_T$ ( $\nu\phi$ weighting)

174.7 ± 4.4 ± 2.0	59	ABAZOV	09AH D0	dilepton + <i>b</i> -tag ( $\nu$ WT+MWT)
170.7 $\begin{smallmatrix} + 4.2 \\ - 3.9 \end{smallmatrix}$ ± 3.5	60,61	AALTONEN	08C CDF	dilepton, $\sigma_{t\bar{t}}$ constrained
171.5 ± 1.8 ± 1.1	62	ABAZOV	08AH D0	$\ell + \cancel{E}_T + 4$ jets
177.1 ± 4.9 ± 4.7	63,64	AALTONEN	07 CDF	6 jets with $\geq 1$ <i>b</i> vtx
172.3 $\begin{smallmatrix} + 10.8 \\ - 9.6 \end{smallmatrix}$ ± 10.8	65	AALTONEN	07B CDF	$\geq 4$ jets ( <i>b</i> -tag)
174.0 ± 2.2 ± 4.8	66	AALTONEN	07D CDF	$\geq 6$ jets, vtx <i>b</i> -tag
170.8 ± 2.2 ± 1.4	67,68	AALTONEN	07I CDF	lepton + jets ( <i>b</i> -tag)
173.7 ± 4.4 $\begin{smallmatrix} + 2.1 \\ - 2.0 \end{smallmatrix}$	64,69	ABAZOV	07F D0	lepton + jets
176.2 ± 9.2 ± 3.9	70	ABAZOV	07W D0	dilepton (MWT)
179.5 ± 7.4 ± 5.6	70	ABAZOV	07W D0	dilepton ( $\nu$ WT)
164.5 ± 3.9 ± 3.9	68,71	ABULENCIA	07D CDF	dilepton
180.7 $\begin{smallmatrix} + 15.5 \\ - 13.4 \end{smallmatrix}$ ± 8.6	72	ABULENCIA	07J CDF	lepton + jets
170.3 $\begin{smallmatrix} + 4.1 \\ - 4.5 \end{smallmatrix}$ $\begin{smallmatrix} + 1.2 \\ - 1.8 \end{smallmatrix}$	68,73	ABAZOV	06U D0	lepton + jets ( <i>b</i> -tag)
173.2 $\begin{smallmatrix} + 2.6 \\ - 2.4 \end{smallmatrix}$ ± 3.2	74,75	ABULENCIA	06D CDF	lepton + jets
173.5 $\begin{smallmatrix} + 3.7 \\ - 3.6 \end{smallmatrix}$ ± 1.3	61,74	ABULENCIA	06D CDF	lepton + jets
165.2 ± 6.1 ± 3.4	68,76	ABULENCIA	06G CDF	dilepton
170.1 ± 6.0 ± 4.1	61,77	ABULENCIA	06V CDF	dilepton
178.5 ± 13.7 ± 7.7	78,79	ABAZOV	05 D0	6 or more jets
180.1 ± 3.6 ± 3.9	80,81	ABAZOV	04G D0	lepton + jets
176.1 ± 5.1 ± 5.3	82	AFFOLDER	01 CDF	lepton + jets
176.1 ± 6.6	83	AFFOLDER	01 CDF	dilepton, lepton+jets, all-jets
172.1 ± 5.2 ± 4.9	84	ABBOTT	99G D0	di-lepton, lepton+jets
176.0 ± 6.5	85,86	ABE	99B CDF	dilepton, lepton+jets, all-jets
167.4 ± 10.3 ± 4.8	86,87	ABE	99B CDF	dilepton
168.4 ± 12.3 ± 3.6	81	ABBOTT	98D D0	dilepton
173.3 ± 5.6 ± 5.5	81,88	ABBOTT	98F D0	lepton + jets
175.9 ± 4.8 ± 5.3	87,89	ABE	98E CDF	lepton + jets
161 ± 17 ± 10	87	ABE	98F CDF	dilepton
172.1 ± 5.2 ± 4.9	90	BHAT	98B RVUE	dilepton and lepton+jets
173.8 ± 5.0	91	BHAT	98B RVUE	dilepton, lepton+jets, all-jets
173.3 ± 5.6 ± 6.2	81	ABACHI	97E D0	lepton + jets
186 ± 10 ± 5.7	87,92	ABE	97R CDF	6 or more jets
199 $\begin{smallmatrix} + 19 \\ - 21 \end{smallmatrix}$ ± 22		ABACHI	95 D0	lepton + jets
176 ± 8 ± 10		ABE	95F CDF	lepton + <i>b</i> -jet
174 ± 10 $\begin{smallmatrix} + 13 \\ - 12 \end{smallmatrix}$		ABE	94E CDF	lepton + <i>b</i> -jet



- <sup>1</sup> TUMASYAN 21G based on  $35.9 \text{ fb}^{-1}$  of  $pp$  data at  $\sqrt{s} = 13 \text{ TeV}$ . Events are selected by requiring  $1\ell + 2\text{jets}(1b \text{ jet})$  final state.
- <sup>2</sup> SIRUNYAN 20AR based on  $35.9 \text{ fb}^{-1}$  of  $pp$  data at  $\sqrt{s} = 13 \text{ TeV}$ . The products of the hadronic decay of a top quark with  $p_T > 400 \text{ GeV}$ , in the  $\ell + \text{jets}$  channel of  $t\bar{t}$  are reconstructed as a single jet. The top quark mass is determined from the normalized differential cross section measurement in the  $m_{\text{jet}}$  distribution.
- <sup>3</sup> AABOUD 19AC is an ATLAS combination of 7 and 8 TeV top-quark mass determination in the dilepton, lepton + jets, and all jets channels.
- <sup>4</sup> SIRUNYAN 19AP based on  $35.9 \text{ fb}^{-1}$  of  $pp$  data at  $\sqrt{s} = 13 \text{ TeV}$ . A combined measurement using the lepton+jets and all-jets channels through a single likelihood function. See SIRUNYAN 18DE and SIRUNYAN 19AP below.
- <sup>5</sup> SIRUNYAN 19AR based on  $35.9 \text{ fb}^{-1}$  of  $pp$  data at  $\sqrt{s} = 13 \text{ TeV}$ . Obtained from a simultaneous fit of the cross section and the top quark mass in the POWHEG simulation. The cross section is used also to extract the  $\overline{\text{MS}}$  mass and the strong coupling constant for different PDF sets.
- <sup>6</sup> KHACHATRYAN 16AK based on  $19.7 \text{ fb}^{-1}$  of  $pp$  data at  $\sqrt{s} = 8 \text{ TeV}$ . Combination of the three top mass measurements in KHACHATRYAN 16AK and with the CMS results at  $\sqrt{s} = 7 \text{ TeV}$ .
- <sup>7</sup> TEVEWWG 16 is the latest Tevatron average (July 2016) provided by the Tevatron Electroweak Working Group. It takes correlated uncertainties into account and has a  $\chi^2$  of 10.8 for 11 degrees of freedom.
- <sup>8</sup> AABOUD 19AC based on  $20.2 \text{ fb}^{-1}$  in  $pp$  collisions at  $\sqrt{s} = 8 \text{ TeV}$ . Uses optimized event selection to suppress less-well-reconstructed events and template fits to determine  $m_t$  together with a global jet energy scale factor and a relative  $b$ -to-light-jet energy scale factor.
- <sup>9</sup> SIRUNYAN 19AP based on  $35.9 \text{ fb}^{-1}$  of  $pp$  data at  $\sqrt{s} = 13 \text{ TeV}$ . A kinematical fit is applied to each event assuming the signal event topology.  $m_t$  is determined simultaneously with a jet energy scale factor (JSF). The second error represents stat.+JSF. Modeling uncertainties are larger than in the measurements at  $\sqrt{s} = 7$  and 8 TeV because of the use of new alternative color reconnection models.

- 10 SIRUNYAN 18DE based on  $35.9 \text{ fb}^{-1}$  of  $pp$  data at  $\sqrt{s} = 13 \text{ TeV}$ .  $m_t$  is determined simultaneously with an overall jet energy scale factor constrained by the mass of the hadronically decayed  $W$ . Compared to the Run 1 analysis a more advanced treatment of modeling uncertainties are employed, in particular concerning color-reconnection models.
- 11 AABOUD 17AH based on  $20.2 \text{ fb}^{-1}$  of  $pp$  data at  $\sqrt{s} = 8 \text{ TeV}$ . Uses template fits to the ratio of the masses of three-jets (from  $t$  candidate) and dijets (from  $W$  candidate), to suppress jet energy scale uncertainty. Large QCD background is modelled using a data-driven method.
- 12 ABAZOV 17B is a combination of measurements of the top quark mass by D0 in the lepton+jets and dilepton channels, using all data collected in Run I (1992–1996) at  $\sqrt{s} = 1.8 \text{ TeV}$  and Run II (2001–2011) at  $\sqrt{s} = 1.96 \text{ TeV}$  of the Tevatron, corresponding to integrated luminosities of  $0.1 \text{ fb}^{-1}$  and  $9.7 \text{ fb}^{-1}$ , respectively.
- 13 SIRUNYAN 17L based on  $19.7 \text{ fb}^{-1}$  of  $pp$  data at  $\sqrt{s} = 8 \text{ TeV}$ .  $m_t$  is reconstructed from a fit to the invariant mass distribution of  $\mu\nu b$ , where  $p_T^{miss}$  and  $W$  mass constraint are used to reconstruct  $\nu$  momentum. The number of events for various contributions, except for the  $t$ -channel single top one, are fixed to the values extracted from simulation. Superseded by TUMASYAN 21G.
- 14 SIRUNYAN 17N based on  $19.7 \text{ fb}^{-1}$  of  $pp$  data at  $\sqrt{s} = 8 \text{ TeV}$ . The fully hadronic decay of a highly-boosted  $t$  is reconstructed in the  $\ell$ +jets channel and unfolded at the particle level. The sensitivity of the peak position of the  $m_{jet}$  distribution is used to test quality of the modelling by the simulation.
- 15 SIRUNYAN 17O based on  $19.7 \text{ fb}^{-1}$  of  $pp$  data at  $\sqrt{s} = 8 \text{ TeV}$ . Analysis is based on the kinematical observables  $M(b\ell)$ ,  $M_{T2}$  and  $M(b\ell\nu)$ . A fit is performed to determine  $m_t$  and an overall jet energy scale factor simultaneously.
- 16 AABOUD 16T based on  $20.2 \text{ fb}^{-1}$  of  $pp$  data at  $\sqrt{s} = 8 \text{ TeV}$ . The analysis is refined using the  $p_T$  and invariant mass distributions of  $\ell$ + $b$ -jet system. A combination with measurements from  $\sqrt{s} = 7 \text{ TeV}$  data in the dilepton and lepton+jets channels gives  $172.84 \pm 0.34 \pm 0.61 \text{ GeV}$ .
- 17 AABOUD 16T is an ATLAS combination of 8 TeV top-quark mass in the dilepton channel with previous measurements from  $\sqrt{s} = 7 \text{ TeV}$  data in the dilepton and lepton + jets channels.
- 18 ABAZOV 16 based on  $9.7 \text{ fb}^{-1}$  of data in  $p\bar{p}$  collisions at  $\sqrt{s} = 1.96 \text{ TeV}$ . Employs improved fit to minimize statistical errors and improved jet energy calibration, using lepton + jets mode, which reduces error of jet energy scale. Based on previous determination in ABAZOV 12AB with increased integrated luminosity and improved fit and calibrations.
- 19 ABAZOV 16D based on  $9.7 \text{ fb}^{-1}$  of data in  $p\bar{p}$  collisions at  $\sqrt{s} = 1.96 \text{ TeV}$ , using the matrix element technique. Based on previous determination in ABAZOV 11R with increased integrated luminosity. There is a strong correlation with the determination in ABAZOV 16. (See ABAZOV 17B.)
- 20 KHACHATRYAN 16AK based on  $19.7 \text{ fb}^{-1}$  of  $pp$  data at  $\sqrt{s} = 8 \text{ TeV}$ . Combination of the three top mass measurements in KHACHATRYAN 16AK and with the CMS results at  $\sqrt{s} = 7 \text{ TeV}$  gives  $172.44 \pm 0.13 \pm 0.47 \text{ GeV}$ .
- 21 The top mass and jet energy scale factor are determined by a fit.
- 22 Uses the analytical matrix weighting technique method.
- 23 KHACHATRYAN 16AL based on  $19.7 \text{ fb}^{-1}$  in  $pp$  collisions at  $\sqrt{s} = 8 \text{ TeV}$ . Determined from the invariant mass distribution of leptons and reconstructed secondary vertices from  $b$  decays using only charged particles. The uncertainty is dominated by modeling of  $b$  fragmentation and top  $p_T$  distribution.
- 24 KHACHATRYAN 16CB based on 666 candidate reconstructed events corresponding to  $19.7 \text{ fb}^{-1}$  of  $pp$  data at  $\sqrt{s} = 8 \text{ TeV}$ . The measurement exploits correlation of  $m_t$  with  $M(J/\psi\ell)$  in the same top quark decay, using a high-purity event sample. A study on modeling of  $b$ -quark fragmentation is given in Sec.3.3.
- 25 AAD 15AW based on  $4.6 \text{ fb}^{-1}$  of  $pp$  data at  $\sqrt{s} = 7 \text{ TeV}$ . Uses template fits to the ratio of the masses of three-jets (from  $t$  candidate) and dijets (from  $W$  candidate). Large background from multijet production is modeled with data-driven methods.

- 26 AAD 15BF based on  $4.6 \text{ fb}^{-1}$  in  $pp$  collisions at  $\sqrt{s} = 7 \text{ TeV}$ . Using a three-dimensional template likelihood technique the lepton plus jets ( $\geq 1b$ -tagged) channel gives  $172.33 \pm 0.75 \pm 1.02 \text{ GeV}$ , while exploiting a one dimensional template method using  $m_{\ell b}$  the dilepton channel (1 or  $2b$ -tags) gives  $173.79 \pm 0.54 \pm 1.30 \text{ GeV}$ . The results are combined.
- 27 AALTONEN 15D based on  $9.1 \text{ fb}^{-1}$  of  $p\bar{p}$  data at  $\sqrt{s} = 1.96 \text{ TeV}$ . Uses a template technique to fit a distribution of a variable defined by a linear combination of variables sensitive and insensitive to jet energy scale to optimize reduction of systematic errors.  $b$ -tagged and non- $b$ -tagged events are separately analyzed and combined.
- 28 Based on  $9.3 \text{ fb}^{-1}$  of  $p\bar{p}$  data at  $\sqrt{s} = 1.96 \text{ TeV}$ . Multivariate algorithm is used to discriminate signal from backgrounds, and templates are used to measure  $m_t$ .
- 29 Based on  $9.7 \text{ fb}^{-1}$  of  $p\bar{p}$  data at  $\sqrt{s} = 1.96 \text{ TeV}$ . A matrix element method is used to calculate the probability of an event to be signal or background, and the overall jet energy scale is constrained *in situ* by  $m_W$ . See ABAZOV 15G for further details.
- 30 Based on  $3.54 \text{ fb}^{-1}$  of  $pp$  data at  $\sqrt{s} = 7 \text{ TeV}$ . The mass is reconstructed for each event employing a kinematic fit of the jets to a  $t\bar{t}$  hypothesis. The combination with the previous CMS measurements in the dilepton and the lepton+jets channels gives  $173.54 \pm 0.33 \pm 0.96 \text{ GeV}$ .
- 31 Based on  $8.7 \text{ fb}^{-1}$  in  $p\bar{p}$  collisions at  $\sqrt{s} = 1.96 \text{ TeV}$ . Events with an identified charged lepton or small  $\cancel{E}_T$  are rejected from the event sample, so that the measurement is statistically independent from those in the  $\ell + \text{jets}$  and all hadronic channels while being sensitive to those events with a  $\tau$  lepton in the final state.
- 32 Based on  $5.0 \text{ fb}^{-1}$  of  $pp$  data at  $\sqrt{s} = 7 \text{ TeV}$ . CHATRCHYAN 13S studied events with di-lepton +  $\cancel{E}_T + \geq 2 b$ -jets, and looked for kinematical endpoints of  $MT_2$ ,  $MT_{2T}$ , and subsystem variables.
- 33 AAD 12l based on  $1.04 \text{ fb}^{-1}$  of  $pp$  data at  $\sqrt{s} = 7 \text{ TeV}$ . Uses 2d-template analysis (MT) with  $m_t$  and jet energy scale factor (JSF) from  $m_W$  mass fit.
- 34 Based on  $8.7 \text{ fb}^{-1}$  of data in  $p\bar{p}$  collisions at  $1.96 \text{ TeV}$ . The JES is calibrated by using the dijet mass from the  $W$  boson decay.
- 35 Use the ME method based on  $2.2 \text{ fb}^{-1}$  of data in  $p\bar{p}$  collisions at  $1.96 \text{ TeV}$ .
- 36 Combination based on up to  $5.8 \text{ fb}^{-1}$  of data in  $p\bar{p}$  collisions at  $1.96 \text{ TeV}$ .
- 37 Based on  $5.8 \text{ fb}^{-1}$  of data in  $p\bar{p}$  collisions at  $1.96 \text{ TeV}$  the quoted value is  $m_t = 172.5 \pm 1.4(\text{stat}) \pm 1.0(\text{JES}) \pm 1.1(\text{syst}) \text{ GeV}$ . The measurement is performed with a likelihood fit technique which simultaneously determines  $m_t$  and JES (Jet Energy Scale).
- 38 Based on  $4.3 \text{ fb}^{-1}$  of data in  $p$ - $p$  collisions at  $1.96 \text{ TeV}$ . The measurement reduces the JES uncertainty by using the single lepton channel study of ABAZOV 11P.
- 39 Combination with the result in  $1 \text{ fb}^{-1}$  of preceding data reported in ABAZOV 09AH as well as the MWT result of ABAZOV 11R with a statistical correlation of 60%.
- 40 Based on  $5.0 \text{ fb}^{-1}$  of  $pp$  data at  $\sqrt{s} = 7 \text{ TeV}$ . Uses an analytical matrix weighting technique (AMWT) and full kinematic analysis (KIN).
- 41 Based on  $5.0 \text{ fb}^{-1}$  of  $pp$  data at  $\sqrt{s} = 7 \text{ TeV}$ . The first error is statistical and JES combined, and the second is systematic. Ideogram method is used to obtain 2D likelihood for the kinematical fit with two parameters  $m_{\text{top}}$  and JES.
- 42 Based on  $3.2 \text{ fb}^{-1}$  in  $p\bar{p}$  collisions at  $\sqrt{s} = 1.96 \text{ TeV}$ . The first error is from statistics and JES combined, and the latter is from the other systematic uncertainties. The result is obtained using an unbinned maximum likelihood method where the top quark mass and the JES are measured simultaneously, with  $\Delta_{JES} = 0.3 \pm 0.3(\text{stat})$ .
- 43 Based on  $5.7 \text{ fb}^{-1}$  in  $p\bar{p}$  collisions at  $\sqrt{s} = 1.96 \text{ TeV}$ . Events with an identified charged lepton or small  $\cancel{E}_T$  are rejected from the event sample, so that the measurement is statistically independent from those in the  $\ell + \text{jets}$  and all hadronic channels while being sensitive to those events with a  $\tau$  lepton in the final state. Supersedes AALTONEN 07B.
- 44 AALTONEN 11E based on  $5.6 \text{ fb}^{-1}$  in  $p\bar{p}$  collisions at  $\sqrt{s} = 1.96 \text{ TeV}$ . Employs a multi-dimensional template likelihood technique where the lepton plus jets (one or two  $b$ -tags) channel gives  $172.2 \pm 1.2 \pm 0.9 \text{ GeV}$  while the dilepton channel yields  $170.3 \pm 2.0 \pm 3.1 \text{ GeV}$ . The results are combined. OUR EVALUATION includes the measurement in the dilepton channel only.

- 45 Uses a likelihood fit of the lepton  $p_T$  distribution based on  $2.7 \text{ fb}^{-1}$  in  $p\bar{p}$  collisions at  $\sqrt{s} = 1.96 \text{ TeV}$ .
- 46 Based on  $3.6 \text{ fb}^{-1}$  in  $p\bar{p}$  collisions at  $\sqrt{s} = 1.96 \text{ TeV}$ . ABAZOV 11P reports  $174.94 \pm 0.83 \pm 0.78 \pm 0.96 \text{ GeV}$ , where the first uncertainty is from statistics, the second from JES, and the last from other systematic uncertainties. We combine the JES and systematic uncertainties. A matrix-element method is used where the JES uncertainty is constrained by the  $W$  mass. ABAZOV 11P describes a measurement based on  $2.6 \text{ fb}^{-1}$  that is combined with ABAZOV 08AH, which employs an independent  $1 \text{ fb}^{-1}$  of data.
- 47 Based on a matrix-element method which employs  $5.4 \text{ fb}^{-1}$  in  $p\bar{p}$  collisions at  $\sqrt{s} = 1.96 \text{ TeV}$ . Superseded by ABAZOV 12AB.
- 48 Based on  $36 \text{ pb}^{-1}$  of  $pp$  collisions at  $\sqrt{s} = 7 \text{ TeV}$ . A Kinematic Method using  $b$ -tagging and an analytical Matrix Weighting Technique give consistent results and are combined. Superseded by CHATRCHYAN 12BA.
- 49 Based on  $5.6 \text{ fb}^{-1}$  in  $p\bar{p}$  collisions at  $\sqrt{s} = 1.96 \text{ TeV}$ . The likelihood calculated using a matrix element method gives  $m_t = 173.0 \pm 0.7(\text{stat}) \pm 0.6(\text{JES}) \pm 0.9(\text{syst}) \text{ GeV}$ , for a total uncertainty of  $1.2 \text{ GeV}$ .
- 50 Based on  $3.4 \text{ fb}^{-1}$  of  $p\bar{p}$  collisions at  $\sqrt{s} = 1.96 \text{ TeV}$ . The result is obtained by combining the MT2 variable method and the NWA (Neutrino Weighting Algorithm). The MT2 method alone gives  $m_t = 168.0^{+4.8}_{-4.0}(\text{stat}) \pm 2.9(\text{syst}) \text{ GeV}$  with smaller systematic error due to small JES uncertainty.
- 51 Based on  $1.9 \text{ fb}^{-1}$  in  $p\bar{p}$  collisions at  $\sqrt{s} = 1.96 \text{ TeV}$ . The result is from the measurement using the transverse decay length of  $b$ -hadrons and that using the transverse momentum of the  $W$  decay muons, which are both insensitive to the JES (jet energy scale) uncertainty. OUR EVALUATION uses only the measurement exploiting the decay length significance which yields  $166.9^{+9.5}_{-8.5}(\text{stat}) \pm 2.9(\text{syst}) \text{ GeV}$ . The measurement that uses the lepton transverse momentum is excluded from the average because of a statistical correlation with other samples.
- 52 Based on  $2.9 \text{ fb}^{-1}$  of  $p\bar{p}$  collisions at  $\sqrt{s} = 1.96 \text{ TeV}$ . The first error is from statistics and JES uncertainty, and the latter is from the other systematics. Neural-network-based kinematical selection of 6 highest  $E_T$  jets with a vtx  $b$ -tag is used to distinguish signal from background. Superseded by AALTONEN 12G.
- 53 Based on  $2 \text{ fb}^{-1}$  of data at  $\sqrt{s} = 1.96 \text{ TeV}$ . The top mass is obtained from the measurement of the invariant mass of the lepton ( $e$  or  $\mu$ ) from  $W$  decays and the soft  $\mu$  in  $b$ -jet. The result is insensitive to jet energy scaling.
- 54 Based on  $1.9 \text{ fb}^{-1}$  of data at  $\sqrt{s} = 1.96 \text{ TeV}$ . The first error is from statistics and jet energy scale uncertainty, and the latter is from the other systematics. Matrix element method with effective propagators.
- 55 Based on  $943 \text{ pb}^{-1}$  of data at  $\sqrt{s} = 1.96 \text{ TeV}$ . The first error is from statistical and jet-energy-scale uncertainties, and the latter is from other systematics. AALTONEN 09K selected 6 jet events with one or more vertex  $b$ -tags and used the tree-level matrix element to construct template models of signal and background.
- 56 Based on  $1.9 \text{ fb}^{-1}$  of data at  $\sqrt{s} = 1.96 \text{ TeV}$ . The first error is from statistical and jet-energy-scale (JES) uncertainties, and the second is from other systematics. Events with lepton + jets and those with dilepton + jets were simultaneously fit to constrain  $m_t$  and JES. Lepton + jets data only give  $m_t = 171.8 \pm 2.2 \text{ GeV}$ , and dilepton data only give  $m_t = 171.2^{+5.3}_{-5.1} \text{ GeV}$ .
- 57 Based on  $2 \text{ fb}^{-1}$  of data at  $\sqrt{s} = 1.96 \text{ TeV}$ . Matrix Element method. Optimal selection criteria for candidate events with two high  $p_T$  leptons, high  $\cancel{E}_T$ , and two or more jets with and without  $b$ -tag are obtained by neural network with neuroevolution technique to minimize the statistical error of  $m_t$ .
- 58 Based on  $2.9 \text{ fb}^{-1}$  of data at  $\sqrt{s} = 1.96 \text{ TeV}$ . Mass  $m_t$  is estimated from the likelihood for the eight-fold kinematical solutions in the plane of the azimuthal angles of the two neutrino momenta.
- 59 Based on  $1 \text{ fb}^{-1}$  of data at  $\sqrt{s} = 1.96 \text{ TeV}$ . Events with two identified leptons, and those with one lepton plus one isolated track and a  $b$ -tag were used to constrain  $m_t$ . The

- result is a combination of the  $\nu$ WT ( $\nu$  Weighting Technique) result of  $176.2 \pm 4.8 \pm 2.1$  GeV and the MWT (Matrix-element Weighting Technique) result of  $173.2 \pm 4.9 \pm 2.0$  GeV.
- 60 Reports measurement of  $170.7^{+4.2}_{-3.9} \pm 2.6 \pm 2.4$  GeV based on  $1.2 \text{ fb}^{-1}$  of data at  $\sqrt{s} = 1.96$  TeV. The last error is due to the theoretical uncertainty on  $\sigma_{t\bar{t}}$ . Without the cross-section constraint a top mass of  $169.7^{+5.2}_{-4.9} \pm 3.1$  GeV is obtained.
- 61 Template method.
- 62 Result is based on  $1 \text{ fb}^{-1}$  of data at  $\sqrt{s} = 1.96$  TeV. The first error is from statistics and jet energy scale uncertainty, and the latter is from the other systematics.
- 63 Based on  $310 \text{ pb}^{-1}$  of data at  $\sqrt{s} = 1.96$  TeV.
- 64 Ideogram method.
- 65 Based on  $311 \text{ pb}^{-1}$  of data at  $\sqrt{s} = 1.96$  TeV. Events with 4 or more jets with  $E_T > 15$  GeV, significant missing  $E_T$ , and secondary vertex  $b$ -tag are used in the fit. About 44% of the signal acceptance is from  $\tau\nu + 4$  jets. Events with identified  $e$  or  $\mu$  are vetoed to provide a statistically independent measurement.
- 66 Based on  $1.02 \text{ fb}^{-1}$  of data at  $\sqrt{s} = 1.96$  TeV. Superseded by AALTONEN 12G.
- 67 Based on  $955 \text{ pb}^{-1}$  of data  $\sqrt{s} = 1.96$  TeV.  $m_t$  and JES (Jet Energy Scale) are fitted simultaneously, and the first error contains the JES contribution of 1.5 GeV.
- 68 Matrix element method.
- 69 Based on  $425 \text{ pb}^{-1}$  of data at  $\sqrt{s} = 1.96$  TeV. The first error is a combination of statistics and JES (Jet Energy Scale) uncertainty, which has been measured simultaneously to give  $\text{JES} = 0.989 \pm 0.029(\text{stat})$ .
- 70 Based on  $370 \text{ pb}^{-1}$  of data at  $\sqrt{s} = 1.96$  TeV. Combined result of MWT (Matrix-element Weighting Technique) and  $\nu$ WT ( $\nu$  Weighting Technique) analyses is  $178.1 \pm 6.7 \pm 4.8$  GeV.
- 71 Based on  $1.0 \text{ fb}^{-1}$  of data at  $\sqrt{s} = 1.96$  TeV. ABULENCIA 07D improves the matrix element description by including the effects of initial-state radiation.
- 72 Based on  $695 \text{ pb}^{-1}$  of data at  $\sqrt{s} = 1.96$  TeV. The transverse decay length of the  $b$  hadron is used to determine  $m_t$ , and the result is free from the JES (jet energy scale) uncertainty.
- 73 Based on  $\sim 400 \text{ pb}^{-1}$  of data at  $\sqrt{s} = 1.96$  TeV. The first error includes statistical and systematic jet energy scale uncertainties, the second error is from the other systematics. The result is obtained with the  $b$ -tagging information. The result without  $b$ -tagging is  $169.2^{+5.0+1.5}_{-7.4-1.4}$  GeV. Superseded by ABAZOV 08AH.
- 74 Based on  $318 \text{ pb}^{-1}$  of data at  $\sqrt{s} = 1.96$  TeV.
- 75 Dynamical likelihood method.
- 76 Based on  $340 \text{ pb}^{-1}$  of data at  $\sqrt{s} = 1.96$  TeV.
- 77 Based on  $360 \text{ pb}^{-1}$  of data at  $\sqrt{s} = 1.96$  TeV.
- 78 Based on  $110.2 \pm 5.8 \text{ pb}^{-1}$  at  $\sqrt{s} = 1.8$  TeV.
- 79 Based on the all hadronic decays of  $t\bar{t}$  pairs. Single  $b$ -quark tagging via the decay chain  $b \rightarrow c \rightarrow \mu$  was used to select signal enriched multijet events. The result was obtained by the maximum likelihood method after bias correction.
- 80 Obtained by re-analysis of the lepton + jets candidate events that led to ABBOTT 98F. It is based upon the maximum likelihood method which makes use of the leading order matrix elements.
- 81 Based on  $125 \pm 7 \text{ pb}^{-1}$  of data at  $\sqrt{s} = 1.8$  TeV.
- 82 Based on  $\sim 106 \text{ pb}^{-1}$  of data at  $\sqrt{s} = 1.8$  TeV.
- 83 Obtained by combining the measurements in the lepton + jets [AFFOLDER 01], all-jets [ABE 97R, ABE 99B], and dilepton [ABE 99B] decay topologies.
- 84 Obtained by combining the D0 result  $m_t$  (GeV) =  $168.4 \pm 12.3 \pm 3.6$  from 6 di-lepton events (see also ABBOTT 98D) and  $m_t$  (GeV) =  $173.3 \pm 5.6 \pm 5.5$  from lepton+jet events (ABBOTT 98F).
- 85 Obtained by combining the CDF results of  $m_t$  (GeV)= $167.4 \pm 10.3 \pm 4.8$  from 8 dilepton events,  $m_t$  (GeV)= $175.9 \pm 4.8 \pm 5.3$  from lepton+jet events (ABE 98E), and  $m_t$



(GeV)= $186.0 \pm 10.0 \pm 5.7$  from all-jet events (ABE 97R). The systematic errors in the latter two measurements are changed in this paper.

<sup>86</sup> See AFFOLDER 01 for details of systematic error re-evaluation.

<sup>87</sup> Based on  $109 \pm 7 \text{ pb}^{-1}$  of data at  $\sqrt{s} = 1.8 \text{ TeV}$ .

<sup>88</sup> See ABAZOV 04G.

<sup>89</sup> The updated systematic error is listed. See AFFOLDER 01, appendix C.

<sup>90</sup> Obtained by combining the  $D\bar{D}$  results of  $m_t(\text{GeV})=168.4 \pm 12.3 \pm 3.6$  from 6 dilepton events and  $m_t(\text{GeV})=173.3 \pm 5.6 \pm 5.5$  from 77 lepton+jet events.

<sup>91</sup> Obtained by combining the  $D\bar{D}$  results from dilepton and lepton+jet events, and the CDF results (ABE 99B) from dilepton, lepton+jet events, and all-jet events.

<sup>92</sup> Based on the first observation of all hadronic decays of  $t\bar{t}$  pairs. Single  $b$ -quark tagging with jet-shape variable constraints was used to select signal enriched multi-jet events. The updated systematic error is listed. See AFFOLDER 01, appendix C.

### $t$ -Quark Mass from Cross-Section Measurements

The top quark  $\overline{\text{MS}}$  or pole mass can be extracted from a measurement of  $\sigma(t\bar{t})$  by using theory calculations. We quote below the  $\overline{\text{MS}}$  mass. See the review “The Top Quark” and references therein for more information.

VALUE (GeV)	DOCUMENT ID	TECN	COMMENT
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#### **$162.5^{+2.1}_{-1.5}$ OUR AVERAGE**

$162.9 \pm 0.5 \pm 1.0^{+2.1}_{-1.2}$	<sup>1</sup> AAD	19G ATLS	$\ell + \cancel{E}_T + \geq 5 j (2b-j)$
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$160.0^{+4.8}_{-4.3}$	<sup>2</sup> ABAZOV	11S D0	$\sigma(t\bar{t}) + \text{theory}$
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• • • We do not use the following data for averages, fits, limits, etc. • • •

<sup>3</sup> ABAZOV	09AG D0	cross sects, theory + exp
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<sup>4</sup> ABAZOV	09R D0	cross sects, theory + exp
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<sup>1</sup> AAD 19G based on  $20.2 \text{ fb}^{-1}$  of data in  $pp$  collisions at  $\sqrt{s} = 8 \text{ TeV}$ . Normalized  $t\bar{t} + 1\text{-jet}$  differential cross section as a function of  $t\bar{t}j$  invariant mass is measured in the  $\ell + \text{jets}$  mode. The unfolded parton-level distribution is compared with the NLO QCD prediction. The three errors are from statistics, systematics, and theory.

<sup>2</sup> Based on  $5.3 \text{ fb}^{-1}$  in  $p\bar{p}$  collisions at  $\sqrt{s} = 1.96 \text{ TeV}$ . ABAZOV 11S uses the measured  $t\bar{t}$  production cross section of  $8.13^{+1.02}_{-0.90} \text{ pb}$  [ABAZOV 11E] in the lepton plus jets channel to obtain the top quark  $\overline{\text{MS}}$  mass by using an approximate NNLO computation (MOCH 08, LANGENFELD 09). The corresponding top quark pole mass is  $167.5^{+5.4}_{-4.9} \text{ GeV}$ . A different theory calculation (AHRENS 10, AHRENS 10A) is also used and yields  $m_t^{\overline{\text{MS}}} = 154.5^{+5.0}_{-4.3} \text{ GeV}$ .

<sup>3</sup> Based on  $1 \text{ fb}^{-1}$  of data at  $\sqrt{s} = 1.96 \text{ TeV}$ . Uses the  $\ell + \text{jets}$ ,  $\ell\ell$ , and  $\ell\tau + \text{jets}$  channels. ABAZOV 09AG extract the pole mass of the top quark using two different calculations that yield  $169.1^{+5.9}_{-5.2} \text{ GeV}$  (MOCH 08, LANGENFELD 09) and  $168.2^{+5.9}_{-5.4} \text{ GeV}$  (KIDONAKIS 08).

<sup>4</sup> Based on  $1 \text{ fb}^{-1}$  of data at  $\sqrt{s} = 1.96 \text{ TeV}$ . Uses the  $\ell\ell$  and  $\ell\tau + \text{jets}$  channels. ABAZOV 09R extract the pole mass of the top quark using two different calculations that yield  $173.3^{+9.8}_{-8.6} \text{ GeV}$  (MOCH 08, LANGENFELD 09) and  $171.5^{+9.9}_{-8.8} \text{ GeV}$  (CACCIARI 08).

## ***t*-Quark Pole Mass from Cross-Section Measurements**

<u>VALUE (GeV)</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
<b>172.5±0.7 OUR AVERAGE</b>			
173.1 <sup>+2.0</sup> <sub>-2.1</sub>	1 AAD	20Q ATLS	$e + \mu + 1$ or 2 $b$ -jets
171.1±0.4±0.9 <sup>+0.7</sup> <sub>-0.3</sub>	2 AAD	19G ATLS	$\ell + \cancel{E}_T + \geq 5 j$ (2 $b$ -j)
173.2±0.9±0.8±1.2	3 AABOUD	17BC ATLS	$e + \mu + \geq 1b$ jets
170.6±2.7	4 SIRUNYAN	17W CMS	$\ell + \geq 1j$
172.8±1.1 <sup>+3.3</sup> <sub>-3.1</sub>	5 ABAZOV	16F D0	$\ell\ell, \ell + \text{jets}$ channels
173.8 <sup>+1.7</sup> <sub>-1.8</sub>	6 KHACHATRYAN...16AW	CMS	$e + \mu + \cancel{E}_T + \geq 0j$
173.7 <sup>+2.3</sup> <sub>-2.1</sub>	7 AAD	15BWATLS	$\ell + \cancel{E}_T + \geq 5j$ (2 $b$ -tag)
172.9 <sup>+2.5</sup> <sub>-2.6</sub>	8 AAD	14AY ATLS	$pp$ at $\sqrt{s} = 7, 8$ TeV
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●			
170.5±0.8	9 SIRUNYAN	20BV CMS	$t\bar{t}$ normalized multi-differential cross sections
176.7 <sup>+3.0</sup> <sub>-2.8</sub>	10 CHATRCHYAN 14	CMS	$pp$ at $\sqrt{s} = 7$ TeV

<sup>1</sup> AAD 20Q based on 36.1 fb<sup>-1</sup> of  $pp$  data at  $\sqrt{s} = 13$  TeV. The result is obtained from the inclusive cross section measurement and the NNLO+NNLL prediction.

<sup>2</sup> AAD 19G based on 20.2 fb<sup>-1</sup> of data in  $pp$  collisions at  $\sqrt{s} = 8$  TeV. Normalized  $t\bar{t} + 1$ -jet differential cross section as a function of  $t\bar{t}j$  invariant mass is measured in the  $\ell + \text{jets}$  mode. The unfolded parton-level distribution is compared with the NLO QCD prediction. The three errors are from statistics, systematics, and theory.

<sup>3</sup> AABOUD 17BC based on 20.2 fb<sup>-1</sup> of  $pp$  data at  $\sqrt{s} = 8$  TeV. The pole mass is extracted from a fit of NLO predictions to eight single lepton and dilepton differential distributions, while simultaneously constraining uncertainties due to PDFs and QCD scales. The three reported uncertainties come from statistics, experimental systematics, and theoretical sources.

<sup>4</sup> SIRUNYAN 17W based on 2.2 fb<sup>-1</sup> of  $pp$  data at  $\sqrt{s} = 13$  TeV. Events are categorized according to the jet multiplicity and the number of  $b$ -tagged jets. The pole mass is obtained from the inclusive cross section measurement and the NNLO prediction.

<sup>5</sup> ABAZOV 16F based on 9.7 fb<sup>-1</sup> of data in  $p\bar{p}$  collisions at  $\sqrt{s} = 1.96$  TeV. The result is obtained from the inclusive cross section measurement and the NNLO+NNLL prediction.

<sup>6</sup> KHACHATRYAN 16AW based on 5.0 fb<sup>-1</sup> of  $pp$  collisions at 7 TeV and 19.7 fb<sup>-1</sup> at 8 TeV. The 7 TeV data include those used in CHATRCHYAN 14. The result is obtained from the inclusive cross sections.

<sup>7</sup> AAD 15BW based on 4.6 fb<sup>-1</sup> of  $pp$  data at  $\sqrt{s} = 7$  TeV. Uses normalized differential cross section for  $t\bar{t} + 1$  jet as a function of the inverse of the invariant mass of the  $t\bar{t} + 1$  jet system. The measured cross section is corrected to the parton level. Then a fit to the data using NLO + parton shower prediction is performed.

<sup>8</sup> AAD 14AY used  $\sigma(t\bar{t})$  for  $e\mu$  events. The result is a combination of the measurements  $m_t = 171.4 \pm 2.6$  GeV based on 4.6 fb<sup>-1</sup> of data at 7 TeV and  $m_t = 174.1 \pm 2.6$  GeV based on 20.3 fb<sup>-1</sup> of data at 8 TeV.

<sup>9</sup> SIRUNYAN 20BV based on 35.9 fb<sup>-1</sup> of  $pp$  data at  $\sqrt{s} = 13$  TeV. The error accounts for both experimental and theoretical uncertainties. Events containing two oppositely charged leptons are used. The pole mass is particularly sensitive to the  $t\bar{t}$  invariant mass distribution close to the threshold. However, the Coulomb and soft gluon resummation effects are not taken into account, hence, an additional theoretical uncertainty of order +1 GeV is assumed.

<sup>10</sup> CHATRCHYAN 14 used  $\sigma(t\bar{t})$  from  $pp$  collisions at  $\sqrt{s} = 7$  TeV measured in CHATRCHYAN 12AX to obtain  $m_t(\text{pole})$  for  $\alpha_s(m_Z) = 0.1184 \pm 0.0007$ . The errors have been corrected in KHACHATRYAN 14K.

### $m_t - m_{\bar{t}}$

Test of *CPT* conservation. OUR AVERAGE assumes that the systematic uncertainties are uncorrelated.

VALUE (GeV)	DOCUMENT ID	TECN	COMMENT
<b>-0.15 ± 0.20 OUR AVERAGE</b>	Error includes scale factor of 1.1.		
0.83 <sup>+1.79</sup> <sub>-1.35</sub>	<sup>1</sup> TUMASYAN 21G	CMS	t-channel single top production
-0.15 ± 0.19 ± 0.09	<sup>2</sup> CHATRCHYAN 17	CMS	$\ell + \cancel{E}_T + \geq 4j$ ( $\geq 1b$ j)
0.67 ± 0.61 ± 0.41	<sup>3</sup> AAD 14	ATLS	$\ell + \cancel{E}_T + \geq 4j$ ( $\geq 2$ b-tags)
-1.95 ± 1.11 ± 0.59	<sup>4</sup> AALTONEN 13E	CDF	$\ell + \cancel{E}_T + \geq 4j$ (0,1,2 b-tags)
-0.44 ± 0.46 ± 0.27	<sup>5</sup> CHATRCHYAN 12Y	CMS	$\ell + \cancel{E}_T + \geq 4j$
0.8 ± 1.8 ± 0.5	<sup>6</sup> ABAZOV 11T	D0	$\ell + \cancel{E}_T + 4$ jets ( $\geq 1$ b-tag)
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●			
-3.3 ± 1.4 ± 1.0	<sup>7</sup> AALTONEN 11K	CDF	Repl. by AALTONEN 13E
3.8 ± 3.4 ± 1.2	<sup>8</sup> ABAZOV 09AA	D0	$\ell + \cancel{E}_T + 4$ jets ( $\geq 1$ b-tag)
<sup>1</sup> TUMASYAN 21G based on 35.9 fb <sup>-1</sup> of $pp$ data at $\sqrt{s} = 13$ TeV. Events are selected by requiring $1\ell + 2\text{jets}(1b \text{ jet})$ final state. An average top mass of 172.13 <sup>+0.76</sup> <sub>-0.77</sub> GeV/c <sup>2</sup> is obtained.			
<sup>2</sup> CHATRCHYAN 17 based on 19.6 fb <sup>-1</sup> of $pp$ data at $\sqrt{s} = 8$ TeV and an average top mass of 172.84 ± 0.10 (stat) GeV is obtained.			
<sup>3</sup> Based on 4.7 fb <sup>-1</sup> of $pp$ data at $\sqrt{s} = 7$ TeV and an average top mass of 172.5 GeV/c <sup>2</sup> .			
<sup>4</sup> Based on 8.7 fb <sup>-1</sup> of $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV and an average top mass of 172.5 GeV/c <sup>2</sup> .			
<sup>5</sup> Based on 4.96 fb <sup>-1</sup> of $pp$ data at $\sqrt{s} = 7$ TeV. Based on the fitted $m_t$ for $\ell^+$ and $\ell^-$ events using the Ideogram method.			
<sup>6</sup> Based on a matrix-element method which employs 3.6 fb <sup>-1</sup> in $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV.			
<sup>7</sup> Based on a template likelihood technique which employs 5.6 fb <sup>-1</sup> in $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV.			
<sup>8</sup> Based on 1 fb <sup>-1</sup> of data in $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV.			

### t-quark DECAY WIDTH

VALUE (GeV)	CL%	DOCUMENT ID	TECN	COMMENT
<b>1.42<sup>+0.19</sup><sub>-0.15</sub> OUR AVERAGE</b>		Error includes scale factor of 1.4.		
1.76 ± 0.33 <sup>+0.79</sup> <sub>-0.68</sub>		<sup>1</sup> AABOUD 18AZ	ATLS	$\ell + \cancel{E}_T + \geq 4j$ ( $\geq 1$ b)
1.36 ± 0.02 <sup>+0.14</sup> <sub>-0.11</sub>		<sup>2</sup> KHACHATRY...14E	CMS	$\ell\ell + \cancel{E}_T + 2-4\text{jets}$ (0-2b-tag)
2.00 <sup>+0.47</sup> <sub>-0.43</sub>		<sup>3</sup> ABAZOV 12T	D0	$\Gamma(t \rightarrow bW)/B(t \rightarrow bW)$

• • • We do not use the following data for averages, fits, limits, etc. • • •

< 6.38	95	<sup>4</sup> AALTONEN	13Z CDF	$\ell + \cancel{E}_T + \geq 4j (\geq 0 b)$ , direct
$1.99^{+0.69}_{-0.55}$		<sup>5</sup> ABAZOV	11B D0	Repl. by ABAZOV 12T
> 1.21	95	<sup>5</sup> ABAZOV	11B D0	$\Gamma(t \rightarrow Wb)$
< 7.6	95	<sup>6</sup> AALTONEN	10AC CDF	$\ell + \text{jets}$ , direct
<13.1	95	<sup>7</sup> AALTONEN	09M CDF	$m_t(\text{rec})$ distribution

<sup>1</sup> Based on  $20.2 \text{ fb}^{-1}$  of  $pp$  data at  $\sqrt{s} = 8 \text{ TeV}$ .  $\Gamma_t$  is measured using a template fit to the reconstructed invariant mass of the  $b$ -jet of the semileptonically decaying top quark and the corresponding lepton, and the angular distance between  $j_b$  and  $j_l$  in hadronic top decay. Signal templates are generated by reweighting events at parton-level to Breit-Wigner distribution with different  $\Gamma_t$  hypotheses for  $m_t = 172.5 \text{ GeV}$ . The result is consistent with the NNLO SM prediction of  $1.322 \text{ GeV}$ .

<sup>2</sup> Based on  $19.7 \text{ fb}^{-1}$  of  $pp$  data at  $\sqrt{s} = 8 \text{ TeV}$ . The result is obtained by combining the measurement of  $R = \Gamma(t \rightarrow Wb) / \Gamma(t \rightarrow Wq (q=b,s,d))$  and a previous CMS measurement of the  $t$ -channel single top production cross section of CHATRCHYAN 12BQ, by using the theoretical calculation of  $\Gamma(t \rightarrow Wb)$  for  $m_t = 172.5 \text{ GeV}$ .

<sup>3</sup> Based on  $5.4 \text{ fb}^{-1}$  of data in  $p\bar{p}$  collisions at  $1.96 \text{ TeV}$ .  $\Gamma(t \rightarrow bW) = 1.87^{+0.44}_{-0.40} \text{ GeV}$  is obtained from the observed  $t$ -channel single top quark production cross section, whereas  $B(t \rightarrow bW) = 0.90 \pm 0.04$  is used assuming  $\sum_q B(t \rightarrow qW) = 1$ . The result is valid for  $m_t = 172.5 \text{ GeV}$ . See the paper for the values for  $m_t = 170$  or  $175 \text{ GeV}$ .

<sup>4</sup> Based on  $8.7 \text{ fb}^{-1}$  of data. The two sided 68% CL interval is  $1.10 \text{ GeV} < \Gamma_t < 4.05 \text{ GeV}$  for  $m_t = 172.5 \text{ GeV}$ .

<sup>5</sup> Based on  $2.3 \text{ fb}^{-1}$  in  $p\bar{p}$  collisions at  $\sqrt{s} = 1.96 \text{ TeV}$ . ABAZOV 11B extracted  $\Gamma_t$  from the partial width  $\Gamma(t \rightarrow Wb) = 1.92^{+0.58}_{-0.51} \text{ GeV}$  measured using the  $t$ -channel single top production cross section, and the branching fraction  $\text{br}(t \rightarrow Wb) = 0.962^{+0.068}_{-0.066}(\text{stat})^{+0.064}_{-0.052}(\text{syst})$ . The  $\Gamma(t \rightarrow Wb)$  measurement gives the 95% CL lowerbound of  $\Gamma(t \rightarrow Wb)$  and hence that of  $\Gamma_t$ .

<sup>6</sup> Results are based on  $4.3 \text{ fb}^{-1}$  of data in  $p\bar{p}$  collisions at  $\sqrt{s} = 1.96 \text{ TeV}$ . The top quark mass and the hadronically decaying  $W$  boson mass are reconstructed for each candidate events and compared with templates of different top quark width. The two sided 68% CL interval is  $0.3 \text{ GeV} < \Gamma_t < 4.4 \text{ GeV}$  for  $m_t = 172.5 \text{ GeV}$ .

<sup>7</sup> Based on  $955 \text{ pb}^{-1}$  of  $p\bar{p}$  collision data at  $\sqrt{s} = 1.96 \text{ TeV}$ . AALTONEN 09M selected  $t\bar{t}$  candidate events for the  $\ell + \cancel{E}_T + \text{jets}$  channel with one or two  $b$ -tags, and examine the decay width dependence of the reconstructed  $m_t$  distribution. The result is for  $m_t = 175 \text{ GeV}$ , whereas the upper limit is lower for smaller  $m_t$ .

## **$t$ DECAY MODES**

Mode	Fraction ( $\Gamma_i/\Gamma$ )	Confidence level
$\Gamma_1$ $Wq (q = b, s, d)$		
$\Gamma_2$ $Wb$		
$\Gamma_3$ $e\nu_e b$	$(11.10 \pm 0.30) \%$	
$\Gamma_4$ $\mu\nu_\mu b$	$(11.40 \pm 0.20) \%$	
$\Gamma_5$ $\tau\nu_\tau b$	$(10.7 \pm 0.5) \%$	
$\Gamma_6$ $q\bar{q}b$	$(66.5 \pm 1.4) \%$	
$\Gamma_7$ $\gamma q (q=u,c)$	$[a] < 1.8$	$\times 10^{-4}$ 95%
$\Gamma_8$ $H^+ b, H^+ \rightarrow \tau\nu_\tau$		

**$\Delta T = 1$  weak neutral current ( $T1$ ) modes**

$\Gamma_9$	$Zq(q=u,c)$	$T1$	$[b] < 5$	$\times 10^{-4}$	95%
$\Gamma_{10}$	$Hu$	$T1$	$< 1.9$	$\times 10^{-4}$	95%
$\Gamma_{11}$	$Hc$	$T1$	$< 7.3$	$\times 10^{-4}$	95%
$\Gamma_{12}$	$\ell^+ \bar{q}q' (q=d,s,b; q'=u,c)$	$T1$	$< 1.6$	$\times 10^{-3}$	95%

**Lepton Family number ( $LF$ ) violating modes**

$\Gamma_{13}$	$e^\pm \mu^\mp c$	$LF$	$< 8.9$	$\times 10^{-7}$
$\Gamma_{14}$	$e^\pm \mu^\mp u$	$LF$	$< 7$	$\times 10^{-8}$

[a] This limit is for  $\Gamma(t \rightarrow \gamma q)/\Gamma(t \rightarrow Wb)$ .

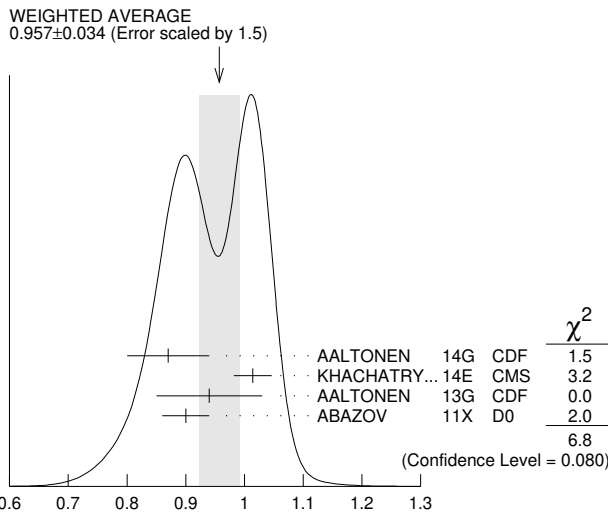
[b] This limit is for  $\Gamma(t \rightarrow Zq)/\Gamma(t \rightarrow Wb)$ .

**$t$  BRANCHING RATIOS**

**$\Gamma(Wb)/\Gamma(Wq(q = b, s, d))$   $\Gamma_2/\Gamma_1$**

OUR AVERAGE assumes that the systematic uncertainties are uncorrelated.

<u>VALUE</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
<b><math>0.957 \pm 0.034</math> OUR AVERAGE</b>	Error includes scale factor of 1.5. See the ideogram below.		
$0.87 \pm 0.07$	<sup>1</sup> AALTONEN 14G	CDF	$\ell\ell + \cancel{E}_T + \geq 2j$ (0,1,2 $b$ -tag)
$1.014 \pm 0.003 \pm 0.032$	<sup>2</sup> KHACHATRY...14E	CMS	$\ell\ell + \cancel{E}_T + 2,3,4j$ (0-2 $b$ -tag)
$0.94 \pm 0.09$	<sup>3</sup> AALTONEN 13G	CDF	$\ell + \cancel{E}_T + \geq 3$ jets ( $\geq 1b$ -tag)
$0.90 \pm 0.04$	<sup>4</sup> ABAZOV 11X	D0	
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●			
$0.97^{+0.09}_{-0.08}$	<sup>5</sup> ABAZOV 08M	D0	$\ell + n$ jets with 0,1,2 $b$ -tag
$1.03^{+0.19}_{-0.17}$	<sup>6</sup> ABAZOV 06K	D0	
$1.12^{+0.21}_{-0.19} \quad ^{+0.17}_{-0.13}$	<sup>7</sup> ACOSTA 05A	CDF	Repl. by AALTONEN 13G
$0.94^{+0.26}_{-0.21} \quad ^{+0.17}_{-0.12}$	<sup>8</sup> AFFOLDER 01C	CDF	



$\Gamma(Wb)/\Gamma(Wq(q = b, s, d))$

<sup>1</sup> Based on  $8.7 \text{ fb}^{-1}$  of data. This measurement gives  $|V_{tb}| = 0.93 \pm 0.04$  and  $|V_{tb}| > 0.85$  (95% CL) in the SM.

- <sup>2</sup> Based on  $19.7 \text{ fb}^{-1}$  of  $pp$  data at  $\sqrt{s} = 8 \text{ TeV}$ . The result is obtained by counting the number of  $b$  jets per  $t\bar{t}$  signal events in the dilepton channel. The  $t\bar{t}$  production cross section is measured to be  $\sigma(t\bar{t}) = 238 \pm 1 \pm 15 \text{ pb}$ , in good agreement with the SM prediction and the latest CMS measurement of CHATRCHYAN 14F. The measurement gives  $R > 0.995$  (95% CL), or  $|V_{tb}| > 0.975$  (95% CL) in the SM, requiring  $R \leq 1$ .
- <sup>3</sup> Based on  $8.7 \text{ fb}^{-1}$  of  $p\bar{p}$  collisions at  $\sqrt{s} = 1.96 \text{ TeV}$ . Measure the fraction of  $t \rightarrow Wb$  decays simultaneously with the  $t\bar{t}$  cross section. The correlation coefficient between those two measurements is  $-0.434$ . Assume unitarity of the  $3 \times 3$  CKM matrix and set  $|V_{tb}| > 0.89$  at 95% CL.
- <sup>4</sup> Based on  $5.4 \text{ fb}^{-1}$  of data. The error is statistical and systematic combined. The result is a combination of  $0.95 \pm 0.07$  from  $\ell + \text{jets}$  channel and  $0.86 \pm 0.05$  from  $\ell\ell$  channel.  $|V^{tb}| = 0.95 \pm 0.02$  follows from the result by assuming unitarity of the  $3 \times 3$  CKM matrix.
- <sup>5</sup> Result is based on  $0.9 \text{ fb}^{-1}$  of data. The 95% CL lower bound  $R > 0.79$  gives  $|V_{tb}| > 0.89$  (95% CL).
- <sup>6</sup> ABAZOV 06K result is from the analysis of  $t\bar{t} \rightarrow \ell\nu + \geq 3 \text{ jets}$  with  $230 \text{ pb}^{-1}$  of data at  $\sqrt{s} = 1.96 \text{ TeV}$ . It gives  $R > 0.61$  and  $|V_{tb}| > 0.78$  at 95% CL. Superseded by ABAZOV 08M.
- <sup>7</sup> ACOSTA 05A result is from the analysis of lepton + jets and di-lepton + jets final states of  $t\bar{t}$  candidate events with  $\sim 162 \text{ pb}^{-1}$  of data at  $\sqrt{s} = 1.96 \text{ TeV}$ . The first error is statistical and the second systematic. It gives  $R > 0.61$ , or  $|V_{tb}| > 0.78$  at 95% CL.
- <sup>8</sup> AFFOLDER 01C measures the top-quark decay width ratio  $R = \Gamma(Wb)/\Gamma(Wq)$ , where  $q$  is a  $d$ ,  $s$ , or  $b$  quark, by using the number of events with multiple  $b$  tags. The first error is statistical and the second systematic. A numerical integration of the likelihood function gives  $R > 0.61$  (0.56) at 90% (95%) CL. By assuming three generation unitarity,  $|V_{tb}| = 0.97^{+0.16}_{-0.12}$  or  $|V_{tb}| > 0.78$  (0.75) at 90% (95%) CL is obtained. The result is based on  $109 \text{ pb}^{-1}$  of data at  $\sqrt{s} = 1.8 \text{ TeV}$ .

### $\Gamma(e\nu_e b)/\Gamma_{\text{total}}$ $\Gamma_3/\Gamma$

VALUE	DOCUMENT ID	TECN	COMMENT
<b><math>0.111 \pm 0.003</math></b>	<sup>1</sup> AAD	15CC ATLS	$\ell + \text{jets}, \ell\ell + \text{jets}, \ell\tau_h + \text{jets}$

<sup>1</sup> AAD 15CC based on  $4.6 \text{ fb}^{-1}$  of  $pp$  data at  $\sqrt{s} = 7 \text{ TeV}$ . The original value is given by  $13.3 \pm 0.4 \pm 0.5\%$ , which includes electrons from the decay of  $\tau$  leptons. It is assumed that the top branching ratios to leptons and jets add up to one and that only SM processes contribute to the background. The event selection criteria are optimized for the  $\ell\tau_h + \text{jets}$  channel. We have converted the original value to eliminate contributions of electrons from  $\tau$ 's, by using the AAD 15CC measurements of the branching ratios to  $\mu$  and  $\tau$  channels, as well as the PDG values of  $\tau$  branching ratios into  $e$  and  $\mu$  channels.

### $\Gamma(\mu\nu_\mu b)/\Gamma_{\text{total}}$ $\Gamma_4/\Gamma$

VALUE	DOCUMENT ID	TECN	COMMENT
<b><math>0.114 \pm 0.002</math></b>	<sup>1</sup> AAD	15CC ATLS	$\ell + \text{jets}, \ell\ell + \text{jets}, \ell\tau_h + \text{jets}$

<sup>1</sup> AAD 15CC based on  $4.6 \text{ fb}^{-1}$  of  $pp$  data at  $\sqrt{s} = 7 \text{ TeV}$ . The original value is given by  $13.4 \pm 0.3 \pm 0.5\%$ , which includes muons from the decay of  $\tau$  leptons. It is assumed that the top branching ratios to leptons and jets add up to one and that only SM processes contribute to the background. The event selection criteria are optimized for the  $\ell\tau_h + \text{jets}$  channel. We have converted the original value to eliminate contributions of muons from  $\tau$ 's, by using the AAD 15CC measurements of the branching ratios to  $\mu$  and  $\tau$  channels, as well as the PDG values of  $\tau$  branching ratios into  $e$  and  $\tau$  channels.

$\Gamma(\tau\nu_\tau b)/\Gamma_{\text{total}}$   $\Gamma_5/\Gamma$

<u>VALUE</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
<b>0.107 ± 0.005 OUR AVERAGE</b>			
0.1050 ± 0.0009 ± 0.0071	<sup>1</sup> SIRUNYAN	20V CMS	$\ell\tau_h + \geq 3 \text{ jets } (\geq 1b\text{-tag})$
0.112 ± 0.009	<sup>2</sup> AAD	15CC ATLS	$\ell+\text{jets}, \ell\ell+\text{jets}, \ell\tau_h+\text{jets}$
0.096 ± 0.028	<sup>3</sup> AALTONEN	14A CDF	$\ell+\tau_h + \geq 2\text{jets } (\geq 1b\text{-tag})$
	<sup>4</sup> ABULENCIA	06R CDF	$\ell\tau + \text{jets}$
	<sup>5</sup> ABE	97V CDF	$\ell\tau + \text{jets}$

• • • We do not use the following data for averages, fits, limits, etc. • • •

<sup>1</sup> SIRUNYAN 20V based on 35.9 fb<sup>-1</sup> of  $pp$  data at  $\sqrt{s} = 13$  TeV.  $t\bar{t}$  events are selected in the  $t\bar{t} \rightarrow (\ell\nu_\ell)(\tau_h\nu_\tau)b\bar{b}$  mode, where  $\tau_h$  refers to the hadronic decays of  $\tau$ . The branching ratio is determined with respect to the  $t\bar{t}$  inclusive cross section extrapolated from the light dilepton mode. The ratio of the  $t\bar{t}$  production cross sections in the  $\ell\tau_h$  and  $\ell\ell$  channels yields  $0.973 \pm 0.009 \pm 0.066$ , consistent with lepton universality.

<sup>2</sup> AAD 15CC based on 4.6 fb<sup>-1</sup> of  $pp$  data at  $\sqrt{s} = 7$  TeV. The original value is given by  $7.0 \pm 0.3 \pm 0.5\%$ , which includes only the hadronic decay of  $\tau$  leptons. It is assumed that the top branching ratios to leptons and jets add up to one and that only SM processes contribute to the background. The event selection criteria are optimized for the  $\ell\tau_h + \text{jets}$  channel. We have converted the original value to include leptonic decays of  $\tau$ 's, by using the AAD 15CC measurements of the branching ratios to  $e$  and  $\mu$  channels, as well as the PDG values of  $\tau$  branching ratios into  $e$  and  $\mu$  channels.

<sup>3</sup> Based on 9 fb<sup>-1</sup> of data. The measurement is in the channel  $t\bar{t} \rightarrow (b\nu)(b\tau\nu)$ , where  $\tau$  decays into hadrons ( $\tau_h$ ), and  $\ell$  ( $e$  or  $\mu$ ) include  $\ell$  from  $\tau$  decays ( $\tau_\ell$ ). The result is consistent with lepton universality.

<sup>4</sup> ABULENCIA 06R looked for  $t\bar{t} \rightarrow (\ell\nu_\ell)(\tau\nu_\tau)b\bar{b}$  events in 194 pb<sup>-1</sup> of  $p\bar{p}$  collisions at  $\sqrt{s} = 1.96$  TeV. 2 events are found where  $1.00 \pm 0.17$  signal and  $1.29 \pm 0.25$  background events are expected, giving a 95% CL upper bound for the partial width ratio  $\Gamma(t \rightarrow \tau\nu q) / \Gamma_{SM}(t \rightarrow \tau\nu q) < 5.2$ .

<sup>5</sup> ABE 97V searched for  $t\bar{t} \rightarrow (\ell\nu_\ell)(\tau\nu_\tau)b\bar{b}$  events in 109 pb<sup>-1</sup> of  $p\bar{p}$  collisions at  $\sqrt{s} = 1.8$  TeV. They observed 4 candidate events where one expects  $\sim 1$  signal and  $\sim 2$  background events. Three of the four observed events have jets identified as  $b$  candidates.

$\Gamma(q\bar{q}b)/\Gamma_{\text{total}}$   $\Gamma_6/\Gamma$

<u>VALUE</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
<b>0.665 ± 0.004 ± 0.013</b>	<sup>1</sup> AAD	15CC ATLS	$\ell+\text{jets}, \ell\ell+\text{jets}, \ell\tau_h+\text{jets}$

<sup>1</sup> AAD 15CC based on 4.6 fb<sup>-1</sup> of  $pp$  data at  $\sqrt{s} = 7$  TeV. Branching ratio of top quark into  $b$  and jets. It is assumed that the top branching ratios to leptons and jets add up to one and that only SM processes contribute to the background. The event selection criteria are optimized for the  $\ell\tau_h + \text{jets}$  channel.

$\Gamma(\gamma q(q=u,c))/\Gamma_{\text{total}}$   $\Gamma_7/\Gamma$

<u>VALUE</u>	<u>CL%</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
<b>&lt;2.8 × 10<sup>-5</sup></b>	95	<sup>1</sup> AAD	20B ATLS	$B(t \rightarrow \gamma u)$ , left-handed $t u \gamma$ coupling
<b>&lt;6.1 × 10<sup>-5</sup></b>	95	<sup>1</sup> AAD	20B ATLS	$B(t \rightarrow \gamma u)$ , right-handed $t u \gamma$ coupling
<b>&lt;2.2 × 10<sup>-4</sup></b>	95	<sup>1</sup> AAD	20B ATLS	$B(t \rightarrow \gamma c)$ , left-handed $t c \gamma$ coupling
<b>&lt;1.8 × 10<sup>-4</sup></b>	95	<sup>1</sup> AAD	20B ATLS	$B(t \rightarrow \gamma c)$ , right-handed $t c \gamma$ coupling
<1.3 × 10 <sup>-4</sup>	95	<sup>2</sup> KHACHATRY...16AS	CMS	$B(t \rightarrow \gamma u)$
<1.7 × 10 <sup>-3</sup>	95	<sup>2</sup> KHACHATRY...16AS	CMS	$B(t \rightarrow \gamma c)$
<5.9 × 10 <sup>-3</sup>	95	<sup>3</sup> CHEKANOV	03 ZEUS	$B(t \rightarrow \gamma u)$

• • • We do not use the following data for averages, fits, limits, etc. • • •

<0.0064	95	<sup>4</sup> AARON	09A H1	$t \rightarrow \gamma u$
<0.0465	95	<sup>5</sup> ABDALLAH	04C DLPH	$B(\gamma c \text{ or } \gamma u)$
<0.0132	95	<sup>6</sup> AKTAS	04 H1	$B(t \rightarrow \gamma u)$
<0.041	95	<sup>7</sup> ACHARD	02J L3	$B(t \rightarrow \gamma c \text{ or } \gamma u)$
<0.032	95	<sup>8</sup> ABE	98G CDF	$t\bar{t} \rightarrow (Wb) (\gamma c \text{ or } \gamma u)$

<sup>1</sup> AAD 20B based on  $81 \text{ fb}^{-1}$  of data in  $pp$  collisions at  $\sqrt{s} = 13 \text{ TeV}$ . FCNC through single top production in association with a photon is searched for in the mode  $\ell\gamma + \cancel{E}_T + 1j$  ( $b$ -tag). Anomalous FCNC left-handed and right-handed couplings are searched for, which result in different kinematical properties of top decay such as the lepton distribution. Limits are set on the  $tq\gamma$  couplings in an effective field theory.

<sup>2</sup> KHACHATRYAN 16AS based on  $19.8 \text{ fb}^{-1}$  of data in  $pp$  collisions at  $\sqrt{s} = 8 \text{ TeV}$ . FCNC through single top production in association with a photon is searched for in the mode  $\mu + \gamma + \cancel{E}_T + \geq 1j$  ( $0,1b$ ). Bounds on the anomalous FCNC couplings are given by  $\kappa_{t u \gamma} < 0.025$  and  $\kappa_{t c \gamma} < 0.091$ .

<sup>3</sup> CHEKANOV 03 looked for single top production via FCNC in the reaction  $e^\pm p \rightarrow e^\pm (t \text{ or } \bar{t}) X$  in  $130.1 \text{ pb}^{-1}$  of data at  $\sqrt{s}=300\text{--}318 \text{ GeV}$ . No evidence for top production and its decay into  $bW$  was found. The result is obtained for  $m_t=175 \text{ GeV}$  when  $B(\gamma c)=B(Zq)=0$ , where  $q$  is a  $u$  or  $c$  quark. Bounds on the effective  $t\text{--}u\text{--}\gamma$  and  $t\text{--}u\text{--}Z$  couplings are found in their Fig. 4. The conversion to the constraint listed is from private communication, E. Gallo, January 2004.

<sup>4</sup> AARON 09A looked for single top production via FCNC in  $e^\pm p$  collisions at HERA with  $474 \text{ pb}^{-1}$ . The upper bound of the cross section gives the bound on the FCNC coupling  $\kappa_{t u \gamma}/\Lambda < 1.03 \text{ TeV}^{-1}$ , which corresponds to the result for  $m_t = 175 \text{ GeV}$ .

<sup>5</sup> ABDALLAH 04C looked for single top production via FCNC in the reaction  $e^+ e^- \rightarrow \bar{t}c$  or  $\bar{t}u$  in  $541 \text{ pb}^{-1}$  of data at  $\sqrt{s}=189\text{--}208 \text{ GeV}$ . No deviation from the SM is found, which leads to the bound on  $B(t \rightarrow \gamma q)$ , where  $q$  is a  $u$  or a  $c$  quark, for  $m_t = 175 \text{ GeV}$  when  $B(t \rightarrow Zq)=0$  is assumed. The conversion to the listed bound is from private communication, O. Yushchenko, April 2005. The bounds on the effective  $t\text{--}q\text{--}\gamma$  and  $t\text{--}q\text{--}Z$  couplings are given in their Fig. 7 and Table 4, for  $m_t = 170\text{--}180 \text{ GeV}$ , where most conservative bounds are found by choosing the chiral couplings to maximize the negative interference between the virtual  $\gamma$  and  $Z$  exchange amplitudes.

<sup>6</sup> AKTAS 04 looked for single top production via FCNC in  $e^\pm$  collisions at HERA with  $118.3 \text{ pb}^{-1}$ , and found 5 events in the  $e$  or  $\mu$  channels. By assuming that they are due to statistical fluctuation, the upper bound on the  $t u \gamma$  coupling  $\kappa_{t u \gamma} < 0.27$  (95% CL) is obtained. The conversion to the partial width limit, when  $B(\gamma c) = B(Zu) = B(Zc) = 0$ , is from private communication, E. Perez, May 2005.

<sup>7</sup> ACHARD 02J looked for single top production via FCNC in the reaction  $e^+ e^- \rightarrow \bar{t}c$  or  $\bar{t}u$  in  $634 \text{ pb}^{-1}$  of data at  $\sqrt{s}= 189\text{--}209 \text{ GeV}$ . No deviation from the SM is found, which leads to a bound on the top-quark decay branching fraction  $B(\gamma q)$ , where  $q$  is a  $u$  or  $c$  quark. The bound assumes  $B(Zq)=0$  and is for  $m_t= 175 \text{ GeV}$ ; bounds for  $m_t=170 \text{ GeV}$  and  $180 \text{ GeV}$  and  $B(Zq) \neq 0$  are given in Fig. 5 and Table 7.

<sup>8</sup> ABE 98G looked for  $t\bar{t}$  events where one  $t$  decays into  $q\gamma$  while the other decays into  $bW$ . The quoted bound is for  $\Gamma(\gamma q)/\Gamma(Wb)$ .

**$\Gamma(H^+ b, H^+ \rightarrow \tau\nu_\tau)/\Gamma_{\text{total}}$   $\Gamma_8/\Gamma$**

<u>VALUE (%)</u>	<u>CL%</u>	<u>DOCUMENT ID</u>	<u>TECN</u>
<0.25	95	<sup>1</sup> AABOUD	18BWATLS

<sup>1</sup> AABOUD 18BW based on  $36.1 \text{ fb}^{-1}$  of  $pp$  data at  $\sqrt{s} = 13 \text{ TeV}$ . In the mass range of  $m_{H^+} = 90\text{--}160 \text{ GeV}$ , assuming the SM cross section for the  $t\bar{t}$  production, the upper limit for the branching fraction  $B(t \rightarrow bH^+) \times B(H^+ \rightarrow \tau\nu_\tau)$  ranges between 0.25% and 0.031%.



$\Gamma(Zq(q=u,c))/\Gamma_{\text{total}}$

$\Gamma_g/\Gamma$

Test for  $\Delta T=1$  weak neutral current. Allowed by higher-order electroweak interaction.

VALUE (units $10^{-3}$ )	CL%	DOCUMENT ID	TECN	COMMENT
< <b>0.17</b>	95	1 AABOUD 18AT ATLS		$t \rightarrow Z u$
< <b>0.24</b>	95	1 AABOUD 18AT ATLS		$t \rightarrow Z c$
< 0.22	95	2 SIRUNYAN 17E CMS		$t \rightarrow Z u$
< 0.49	95	2 SIRUNYAN 17E CMS		$t \rightarrow Z c$
< 0.7	95	3 AAD 16D ATLS		$t \rightarrow Z q (q = u, c)$
< <b>0.5</b>	95	4 CHATRCHYAN 14S CMS		$t \rightarrow Z q (q = u, c)$
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●				
< 0.6	95	5 CHATRCHYAN 14S CMS		$t \rightarrow Z q (q = u, c)$
< 2.1	95	6 CHATRCHYAN 13F CMS		$t \rightarrow Z q (q = u, c)$
< 7.3	95	7 AAD 12BT ATLS		$t\bar{t} \rightarrow \ell^+ \ell^- \ell'^{\pm} + \cancel{E}_T + \text{jets}$
< 32	95	8 ABAZOV 11M D0		$t \rightarrow Z q (q = u, c)$
< 83	95	9 AALTONEN 09AL CDF		$t \rightarrow Z q (q=c)$
< 37	95	10 AALTONEN 08AD CDF		$t \rightarrow Z q (q = u, c)$
< $1.59 \times 10^2$	95	11 ABDALLAH 04C DLPH		$e^+ e^- \rightarrow \bar{t} c \text{ or } \bar{t} u$
< $1.37 \times 10^2$	95	12 ACHARD 02J L3		$e^+ e^- \rightarrow \bar{t} c \text{ or } \bar{t} u$
< $1.4 \times 10^2$	95	13 HEISTER 02Q ALEP		$e^+ e^- \rightarrow \bar{t} c \text{ or } \bar{t} u$
< $1.37 \times 10^2$	95	14 ABBIENDI 01T OPAL		$e^+ e^- \rightarrow \bar{t} c \text{ or } \bar{t} u$
< $1.7 \times 10^2$	95	15 BARATE 00S ALEP		$e^+ e^- \rightarrow \bar{t} c \text{ or } \bar{t} u$
< $3.3 \times 10^2$	95	16 ABE 98G CDF		$t\bar{t} \rightarrow (Wb)(Zc \text{ or } Zu)$

<sup>1</sup> Based on  $36.1 \text{ fb}^{-1}$  of  $pp$  data at  $\sqrt{s} = 13 \text{ TeV}$ . The final states  $t\bar{t} \rightarrow \ell^+ \ell^- \ell'^{\pm} \nu + \text{jets}$  ( $\ell, \ell' = e, \mu$ ) are investigated and no significant excess over the SM background contributions is observed.

<sup>2</sup> SIRUNYAN 17E based on  $19.7 \text{ fb}^{-1}$  of  $pp$  data at  $\sqrt{s} = 8 \text{ TeV}$ . The final states  $t\bar{t} \rightarrow \ell^+ \ell^- \ell'^{\pm} \nu + \text{jets}$  ( $\ell, \ell' = e, \mu$ ) are investigated and the cross section  $\sigma(pp \rightarrow tZq \rightarrow \ell\nu b\ell^+ \ell^- q) = 10^{+8}_{-7} \text{ fb}$  is measured, giving no sign of FCNC decays of the top quark.

<sup>3</sup> AAD 16D based on  $20.3 \text{ fb}^{-1}$  of  $pp$  data at  $\sqrt{s} = 8 \text{ TeV}$ . The FCNC decay is searched for in  $t\bar{t}$  events in the final state  $(bW)(qZ)$  when both  $W$  and  $Z$  decay leptonically, giving 3 charged leptons.

<sup>4</sup> CHATRCHYAN 14S combined search limit from this and CHATRCHYAN 13F data.

<sup>5</sup> Based on  $19.7 \text{ fb}^{-1}$  of  $pp$  data at  $\sqrt{s} = 8 \text{ TeV}$ . The flavor changing decay is searched for in  $t\bar{t}$  events in the final state  $(bW)(qZ)$  when both  $W$  and  $Z$  decay leptonically, giving 3 charged leptons.

<sup>6</sup> Based on  $5.0 \text{ fb}^{-1}$  of  $pp$  data at  $\sqrt{s} = 7 \text{ TeV}$ . Search for FCNC decays of the top quark in  $t\bar{t} \rightarrow \ell^+ \ell^- \ell'^{\pm} \nu + \text{jets}$  ( $\ell, \ell' = e, \mu$ ) final states found no excess of signal events.

<sup>7</sup> Based on  $2.1 \text{ fb}^{-1}$  of  $pp$  data at  $\sqrt{s} = 7 \text{ TeV}$ .

<sup>8</sup> Based on  $4.1 \text{ fb}^{-1}$  of data. ABAZOV 11M searched for FCNC decays of the top quark in  $t\bar{t} \rightarrow \ell^+ \ell^- \ell'^{\pm} \nu + \text{jets}$  ( $\ell, \ell' = e, \mu$ ) final states, and absence of the signal gives the bound.

<sup>9</sup> Based on  $p\bar{p}$  data of  $1.52 \text{ fb}^{-1}$ . AALTONEN 09AL compared  $t\bar{t} \rightarrow WbWb \rightarrow \ell\nu bj\bar{j}b$  and  $t\bar{t} \rightarrow ZcWb \rightarrow \ell\ell c j\bar{j}b$  decay chains, and absence of the latter signal gives the bound. The result is for 100% longitudinally polarized  $Z$  boson and the theoretical  $t\bar{t}$  production cross section. The results for different  $Z$  polarizations and those without the cross section assumption are given in their Table XII.

<sup>10</sup> Result is based on  $1.9 \text{ fb}^{-1}$  of data at  $\sqrt{s} = 1.96 \text{ TeV}$ .  $t\bar{t} \rightarrow WbZq$  or  $ZqZq$  processes have been looked for in  $Z + \geq 4$  jet events with and without  $b$ -tag. No signal leads to the bound  $B(t \rightarrow Zq) < 0.037$  (0.041) for  $m_t = 175$  (170) GeV.

<sup>11</sup> ABDALLAH 04C looked for single top production via FCNC in the reaction  $e^+ e^- \rightarrow \bar{t} c$  or  $\bar{t} u$  in  $541 \text{ pb}^{-1}$  of data at  $\sqrt{s}=189\text{--}208 \text{ GeV}$ . No deviation from the SM is found,

which leads to the bound on  $B(t \rightarrow Zq)$ , where  $q$  is a  $u$  or a  $c$  quark, for  $m_t = 175$  GeV when  $B(t \rightarrow \gamma q) = 0$  is assumed. The conversion to the listed bound is from private communication, O. Yushchenko, April 2005. The bounds on the effective  $t$ - $q$ - $\gamma$  and  $t$ - $q$ - $Z$  couplings are given in their Fig. 7 and Table 4, for  $m_t = 170$ – $180$  GeV, where most conservative bounds are found by choosing the chiral couplings to maximize the negative interference between the virtual  $\gamma$  and  $Z$  exchange amplitudes.

- 12 ACHARD 02J looked for single top production via FCNC in the reaction  $e^+ e^- \rightarrow \bar{t}c$  or  $\bar{t}u$  in  $634 \text{ pb}^{-1}$  of data at  $\sqrt{s} = 189$ – $209$  GeV. No deviation from the SM is found, which leads to a bound on the top-quark decay branching fraction  $B(Zq)$ , where  $q$  is a  $u$  or  $c$  quark. The bound assumes  $B(\gamma q) = 0$  and is for  $m_t = 175$  GeV; bounds for  $m_t = 170$  GeV and  $180$  GeV and  $B(\gamma q) \neq 0$  are given in Fig. 5 and Table 7. Table 6 gives constraints on  $t$ - $c$ - $e$ - $e$  four-fermi contact interactions.
- 13 HEISTER 02Q looked for single top production via FCNC in the reaction  $e^+ e^- \rightarrow \bar{t}c$  or  $\bar{t}u$  in  $214 \text{ pb}^{-1}$  of data at  $\sqrt{s} = 204$ – $209$  GeV. No deviation from the SM is found, which leads to a bound on the branching fraction  $B(Zq)$ , where  $q$  is a  $u$  or  $c$  quark. The bound assumes  $B(\gamma q) = 0$  and is for  $m_t = 174$  GeV. Bounds on the effective  $t$ - ( $c$  or  $u$ )- $\gamma$  and  $t$ - ( $c$  or  $u$ )- $Z$  couplings are given in their Fig. 2.
- 14 ABBIENDI 01T looked for single top production via FCNC in the reaction  $e^+ e^- \rightarrow \bar{t}c$  or  $\bar{t}u$  in  $600 \text{ pb}^{-1}$  of data at  $\sqrt{s} = 189$ – $209$  GeV. No deviation from the SM is found, which leads to bounds on the branching fractions  $B(Zq)$  and  $B(\gamma q)$ , where  $q$  is a  $u$  or  $c$  quark. The result is obtained for  $m_t = 174$  GeV. The upper bound becomes 9.7% (20.6%) for  $m_t = 169$  (179) GeV. Bounds on the effective  $t$ - ( $c$  or  $u$ )- $\gamma$  and  $t$ - ( $c$  or  $u$ )- $Z$  couplings are given in their Fig. 4.
- 15 BARATE 00S looked for single top production via FCNC in the reaction  $e^+ e^- \rightarrow \bar{t}c$  or  $\bar{t}u$  in  $411 \text{ pb}^{-1}$  of data at c.m. energies between 189 and 202 GeV. No deviation from the SM is found, which leads to a bound on the branching fraction. The bound assumes  $B(\gamma q) = 0$ . Bounds on the effective  $t$ - ( $c$  or  $u$ )- $\gamma$  and  $t$ - ( $c$  or  $u$ )- $Z$  couplings are given in their Fig. 4.
- 16 ABE 98G looked for  $t\bar{t}$  events where one  $t$  decays into three jets and the other decays into  $qZ$  with  $Z \rightarrow \ell\ell$ . The quoted bound is for  $\Gamma(Zq)/\Gamma(Wb)$ .

$\Gamma(Hu)/\Gamma_{\text{total}}$					$\Gamma_{10}/\Gamma$
VALUE (units $10^{-3}$ )	CL%	DOCUMENT ID	TECN	COMMENT	
<b>&lt;0.19</b>	95	1 TUMASYAN 22A	CMS	$t \rightarrow Hu (H \rightarrow \gamma\gamma)$	
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●					
<0.79	95	2 TUMASYAN 22K	CMS	$t \rightarrow Hu (H \rightarrow bb)$	
<5.2	95	3 AABOUD 19S	ATLS	$t \rightarrow Hu (H \rightarrow bb)$	
<1.7	95	4 AABOUD 19S	ATLS	$t \rightarrow Hu (H \rightarrow \tau\tau)$	
<1.2	95	5 AABOUD 19S	ATLS	combination of $t \rightarrow Hu$ ( $H \rightarrow WW, ZZ, \tau\tau,$ $\gamma\gamma, b\bar{b}$ )	
<1.9	95	6 AABOUD 18X	ATLS	$t \rightarrow Hu (H \rightarrow WW, ZZ,$ $\tau\tau)$	
<4.7	95	7 SIRUNYAN 18BC	CMS	$t \rightarrow Hu (H \rightarrow bb)$	
<2.4	95	8 AABOUD 17AV	ATLS	$t \rightarrow Hu (H \rightarrow \gamma\gamma)$	
<5.5	95	9 KHACHATRY...17I	CMS	$t \rightarrow Hu (H \rightarrow WW, ZZ,$ $\tau\tau, \gamma\gamma, b\bar{b})$	
<6.1	95	10 AAD 15CO	ATLS	$t \rightarrow Hu (H \rightarrow bb)$	
<7.9	95	11 AAD 14AA	ATLS	$t \rightarrow Hq (q=u,c; H \rightarrow \gamma\gamma)$	
1 TUMASYAN 22A based on $137 \text{ fb}^{-1}$ at $\sqrt{s} = 13$ TeV of $pp$ data. The processes considered include both the associated production of a single top quark with a Higgs boson and the decay $t \rightarrow Hu$ in $t\bar{t}$ production using $H \rightarrow \gamma\gamma$ .					

- <sup>2</sup> TUMASYAN 22K based on  $137 \text{ fb}^{-1}$  at  $\sqrt{s} = 13 \text{ TeV}$  of  $pp$  data. Uses events with one isolated lepton and multiple jets (including  $\geq 2b$ -jets). Deep neural networks are used for kinematical event reconstruction.
- <sup>3</sup> AABOUD 19S based on  $36.1 \text{ fb}^{-1}$  at  $\sqrt{s} = 13 \text{ TeV}$  of  $pp$  data. Uses events with one isolated lepton and multiple jets (several of them  $b$ -tagged with high purity). A multivariate analysis is performed to distinguish the signal from backgrounds.
- <sup>4</sup> AABOUD 19S based on  $36.1 \text{ fb}^{-1}$  at  $\sqrt{s} = 13 \text{ TeV}$  of  $pp$  data. Uses events with one or two hadronically decaying  $\tau$  and multiple jets. A multivariate analysis is performed to distinguish the signal from backgrounds.
- <sup>5</sup> AABOUD 19S based on  $36.1 \text{ fb}^{-1}$  at  $\sqrt{s} = 13 \text{ TeV}$  of  $pp$  data. The searches using  $H \rightarrow bb$  and  $H \rightarrow \tau_h \tau_h$  are combined with searches in diphoton and multilepton final states. The upper limit on the Yukawa coupling  $|Y_{tuH}| < 0.066$  (95% CL) is obtained.
- <sup>6</sup> AABOUD 18X based on  $36.1 \text{ fb}^{-1}$  at  $\sqrt{s} = 13 \text{ TeV}$  of  $pp$  data.  $\ell\ell(\text{same sign}) + \geq 4j$  mode and  $\ell\ell\ell + \geq 2j$  mode are targeted and specialized boosted decision trees are used to distinguish signals from backgrounds.
- <sup>7</sup> SIRUNYAN 18BC based on  $35.9 \text{ fb}^{-1}$  at  $\sqrt{s} = 13 \text{ TeV}$  of  $pp$  data. Two channels  $pp \rightarrow tH$  and  $pp \rightarrow t\bar{t}$  in final states with one isolated lepton and  $\geq 3$  jets with  $\geq 2$   $b$  jets are considered assuming a single  $tHu$  FCNC coupling. Reconstructed kinematical variables are fed into a multivariate analysis and no significant deviation is observed from the predicted background.
- <sup>8</sup> AABOUD 17AV based on  $36.1 \text{ fb}^{-1}$  at  $\sqrt{s} = 13 \text{ TeV}$  of  $pp$  data. Search for  $t\bar{t}$  events, where the other top quark decays hadronically or semi-leptonically.
- <sup>9</sup> KHACHATRYAN 17I based on  $19.7 \text{ fb}^{-1}$  of  $pp$  data at  $\sqrt{s} = 8 \text{ TeV}$ , using the topologies  $t\bar{t} \rightarrow Hq + Wb$ , where  $q = u, c$ .
- <sup>10</sup> AAD 15CO based on  $20.3 \text{ fb}^{-1}$  at  $\sqrt{s} = 8 \text{ TeV}$  of  $pp$  data. Searches for  $t\bar{t}$  events, where the other top quark decays semi-leptonically. Exploits high multiplicity of  $b$ -jets and uses a likelihood discriminant. Combining with other ATLAS searches for different Higgs decay modes,  $B(t \rightarrow Hc) < 0.46\%$  and  $B(t \rightarrow Hu) < 0.45\%$  are obtained.
- <sup>11</sup> AAD 14AA based on  $4.7 \text{ fb}^{-1}$  at  $\sqrt{s} = 7 \text{ TeV}$  and  $20.3 \text{ fb}^{-1}$  at  $\sqrt{s} = 8 \text{ TeV}$  of  $pp$  data. The upper-bound is for the sum of  $\text{Br}(t \rightarrow Hc)$  and  $\text{Br}(t \rightarrow Hu)$ . Search for  $t\bar{t}$  events, where the other top quark decays hadronically or semi-leptonically. The upper bound constrains the  $H$ - $t$ - $c$  Yukawa couplings  $\sqrt{|Y_{t c_L}^H|^2 + |Y_{t c_R}^H|^2} < 0.17$  (95% CL).

$\Gamma(Hc)/\Gamma_{\text{total}}$

$\Gamma_{11}/\Gamma$

VALUE (units $10^{-3}$ )	CL%	DOCUMENT ID	TECN	COMMENT
<b>&lt; 0.73</b>	95	<sup>1</sup> TUMASYAN 22A	CMS	$t \rightarrow Hc (H \rightarrow \gamma\gamma)$
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●				
< 0.94	95	<sup>2</sup> TUMASYAN 22K	CMS	$t \rightarrow Hc (H \rightarrow bb)$
< 1.1	95	<sup>3</sup> AABOUD 19S	ATLS	combination of $t \rightarrow Hc$ ( $H \rightarrow WW, ZZ, \tau\tau, \gamma\gamma, b\bar{b}$ )
< 4.2	95	<sup>4</sup> AABOUD 19S	ATLS	$t \rightarrow Hc (H \rightarrow bb)$
< 1.9	95	<sup>5</sup> AABOUD 19S	ATLS	$t \rightarrow Hc (H \rightarrow \tau\tau)$
< 1.6	95	<sup>6</sup> AABOUD 18X	ATLS	$t \rightarrow Hc (H \rightarrow WW, ZZ, \tau\tau)$
< 4.7	95	<sup>7</sup> SIRUNYAN 18BC	CMS	$t \rightarrow Hc (H \rightarrow bb)$
< 2.2	95	<sup>8</sup> AABOUD 17AV	ATLS	$t \rightarrow Hc (H \rightarrow \gamma\gamma)$
< 4	95	<sup>9</sup> KHACHATRY...17I	CMS	$t \rightarrow Hc (H \rightarrow WW, ZZ, \tau\tau, \gamma\gamma, b\bar{b})$
< 5.6	95	<sup>10</sup> AAD 15CO	ATLS	$t \rightarrow Hc (H \rightarrow bb)$
< 7.9	95	<sup>11</sup> AAD 14AA	ATLS	$t \rightarrow Hq (q=u,c; H \rightarrow \gamma\gamma)$

<13	95	<sup>12</sup> CHATRCHYAN14R	CMS	$t \rightarrow Hc$ ( $H \rightarrow \geq 2 \ell$ )
< 5.6	95	<sup>13</sup> KHACHATRYAN14Q	CMS	$t \rightarrow Hc$ ( $H \rightarrow \gamma\gamma$ or leptons)

- <sup>1</sup> TUMASYAN 22A based on  $137 \text{ fb}^{-1}$  at  $\sqrt{s} = 13 \text{ TeV}$  of  $pp$  data. The processes considered include both the associated production of a single top quark with a Higgs boson and the decay  $t \rightarrow Hc$  in  $t\bar{t}$  production using  $H \rightarrow \gamma\gamma$ .
- <sup>2</sup> TUMASYAN 22K based on  $137 \text{ fb}^{-1}$  at  $\sqrt{s} = 13 \text{ TeV}$  of  $pp$  data. Uses events with one isolated lepton and multiple jets (including  $\geq 2b$ -jets). Deep neural networks are used for kinematical event reconstruction.
- <sup>3</sup> AABOUD 19S based on  $36.1 \text{ fb}^{-1}$  at  $\sqrt{s} = 13 \text{ TeV}$  of  $pp$  data. The searches using  $H \rightarrow bb$  and  $H \rightarrow \tau_h\tau_h$  are combined with searches in diphoton and multilepton final states. The upper limit on the Yukawa coupling  $|Y_{tcH}| < 0.064$  (95% CL) is obtained.
- <sup>4</sup> AABOUD 19S based on  $36.1 \text{ fb}^{-1}$  at  $\sqrt{s} = 13 \text{ TeV}$  of  $pp$  data. Uses events with one isolated lepton and multiple jets (several of them  $b$ -tagged with high purity). A multivariate analysis is performed to distinguish the signal from backgrounds.
- <sup>5</sup> AABOUD 19S based on  $36.1 \text{ fb}^{-1}$  at  $\sqrt{s} = 13 \text{ TeV}$  of  $pp$  data. Uses events with one or two hadronically decaying  $\tau$  and multiple jets. A multivariate analysis is performed to distinguish the signal from backgrounds.
- <sup>6</sup> AABOUD 18X based on  $36.1 \text{ fb}^{-1}$  at  $\sqrt{s} = 13 \text{ TeV}$  of  $pp$  data.  $\ell\ell$ (same sign) +  $\geq 4j$  mode and  $\ell\ell\ell$  +  $\geq 2j$  mode are targeted and specialized boosted decision trees are used to distinguish signals from backgrounds.
- <sup>7</sup> SIRUNYAN 18BC based on  $35.9 \text{ fb}^{-1}$  at  $\sqrt{s} = 13 \text{ TeV}$  of  $pp$  data. Two channels  $pp \rightarrow tH$  and  $pp \rightarrow t\bar{t}$  in final states with one isolated lepton and  $\geq 3$  jets with  $\geq 2$   $b$  jets are considered assuming a single  $tHc$  FCNC coupling. Reconstructed kinematical variables are fed into a multivariate analysis and no significant deviation is observed from the predicted background.
- <sup>8</sup> AABOUD 17AV based on  $36.1 \text{ fb}^{-1}$  at  $\sqrt{s} = 13 \text{ TeV}$  of  $pp$  data. Search for  $t\bar{t}$  events, where the other top quark decays hadronically or semi-leptonically. The upper bound on the  $H$ - $t$ - $c$  Yukawa couplings is 0.090 (95% CL).
- <sup>9</sup> KHACHATRYAN 17I based on  $19.7 \text{ fb}^{-1}$  of  $pp$  data at  $\sqrt{s} = 8 \text{ TeV}$ , using the topologies  $t\bar{t} \rightarrow Hq+Wb$ , where  $q=u, c$ .
- <sup>10</sup> AAD 15CO based on  $20.3 \text{ fb}^{-1}$  at  $\sqrt{s} = 8 \text{ TeV}$  of  $pp$  data. Searches for  $t\bar{t}$  events, where the other top quark decays semi-leptonically. Exploits high multiplicity of  $b$ -jets and uses a likelihood discriminant. Combining with other ATLAS searches for different Higgs decay modes,  $B(t \rightarrow Hc) < 0.46\%$  and  $B(t \rightarrow Hu) < 0.45\%$  are obtained.
- <sup>11</sup> AAD 14AA based on  $4.7 \text{ fb}^{-1}$  at  $\sqrt{s} = 7 \text{ TeV}$  and  $20.3 \text{ fb}^{-1}$  at  $\sqrt{s} = 8 \text{ TeV}$  of  $pp$  data. The upper-bound is for the sum of  $\text{Br}(t \rightarrow Hc)$  and  $\text{Br}(t \rightarrow Hu)$ . Search for  $t\bar{t}$  events, where the other top quark decays hadronically or semi-leptonically. The upper bound constrains the  $H$ - $t$ - $c$  Yukawa couplings  $\sqrt{|Y_{tcL}^H|^2 + |Y_{tcR}^H|^2} < 0.17$  (95% CL).
- <sup>12</sup> Based on  $19.5 \text{ fb}^{-1}$  of  $pp$  data at  $\sqrt{s} = 8 \text{ TeV}$ . Search for final states with 3 or more isolated high  $E_T$  charged leptons ( $\ell = e, \mu$ ) bounds the  $t \rightarrow Hc$  decay in  $t\bar{t}$  events when  $H$  decays contain a pair of leptons. The upper bound constrains the  $H$ - $t$ - $c$  Yukawa couplings  $\sqrt{|Y_{tcL}^H|^2 + |Y_{tcR}^H|^2} < 0.21$  (95% CL).
- <sup>13</sup> KHACHATRYAN 14Q based on  $19.5 \text{ fb}^{-1}$  at  $\sqrt{s} = 8 \text{ TeV}$  of  $pp$  data. Search for final states with  $\geq 3$  isolated charged leptons or with a photon pair accompanied by  $\geq 1$  lepton(s).

$\Gamma(\ell^+ \bar{q} q' (q=d,s,b; q'=u,c))/\Gamma_{\text{total}}$					$\Gamma_{12}/\Gamma$
VALUE	CL%	DOCUMENT ID	TECN	COMMENT	
<b>&lt;1.6 x 10<sup>-3</sup></b>	95	<sup>1</sup> CHATRCHYAN 14O	CMS	$\mu + \text{dijets}$	

• • • We do not use the following data for averages, fits, limits, etc. • • •

$<1.7 \times 10^{-3}$  95 <sup>1</sup> CHATRCHYAN140 CMS  $e + \text{dijets}$

<sup>1</sup> Based on  $19.5 \text{ fb}^{-1}$  of  $pp$  data at  $\sqrt{s} = 8 \text{ TeV}$ . Baryon number violating decays of the top quark are searched for in  $t\bar{t}$  production events where one of the pair decays into hadronic three jets.

$\Gamma(e^\pm \mu^\mp c) / \Gamma_{\text{total}}$   $\Gamma_{13} / \Gamma$

VALUE	DOCUMENT ID	TECN	COMMENT
$<8.9 \times 10^{-7}$	<sup>1</sup> TUMASYAN 22Z	CMS	$pp$ at 13 TeV

<sup>1</sup> TUMASYAN 22Z analysis includes both the production ( $c \rightarrow e\mu t$ ) and decay ( $t \rightarrow e\mu c$ ) modes of the top quark through CFLV interactions. With no significant excess over the standard model expectation, the limits are set at 95% CL on the  $B(t \rightarrow e\mu c)$  of  $1.31 \times 10^{-6}$ ,  $0.89 \times 10^{-6}$ ,  $2.59 \times 10^{-6}$  for vector-, scalar-, and tensor-like CLFV four-fermion effective interactions, respectively.

$\Gamma(e^\pm \mu^\mp u) / \Gamma_{\text{total}}$   $\Gamma_{14} / \Gamma$

VALUE	DOCUMENT ID	TECN	COMMENT
$<7 \times 10^{-8}$	<sup>1</sup> TUMASYAN 22Z	CMS	$pp$ at 13 TeV

<sup>1</sup> TUMASYAN 22Z analysis includes both the production ( $u \rightarrow e\mu t$ ) and decay ( $t \rightarrow e\mu u$ ) modes of the top quark through CFLV interactions. With no significant excess over the standard model expectation, the limits are set at 95% CL on the  $B(t \rightarrow e\mu u)$  of  $0.13 \times 10^{-6}$ ,  $0.07 \times 10^{-6}$ ,  $0.25 \times 10^{-6}$  for vector-, scalar-, and tensor-like CLFV four-fermion effective interactions, respectively.

### t-quark EW Couplings

$W$  helicity fractions in top decays.  $F_0$  is the fraction of longitudinal and  $F_+$  the fraction of right-handed  $W$  bosons.  $F_{V+A}$  is the fraction of  $V+A$  current in top decays. The effective Lagrangian (cited by ABAZOV 08AI) has terms  $f_1^L$  and  $f_1^R$  for  $V-A$  and  $V+A$  couplings,  $f_2^L$  and  $f_2^R$  for tensor couplings with  $b_R$  and  $b_L$  respectively.

### $F_0$

VALUE	DOCUMENT ID	TECN	COMMENT
<b><math>0.693 \pm 0.013</math> OUR AVERAGE</b>			

0.693 ± 0.009 ± 0.011 <sup>1</sup> AAD 20Y LHC ATLAS+CMS combined

0.726 ± 0.066 ± 0.067 <sup>2</sup> AALTONEN 13D CDF  $F_0 = B(t \rightarrow W_0 b)$

0.682 ± 0.030 ± 0.033 <sup>3</sup> CHATRCHYAN13BH CMS  $F_0 = B(t \rightarrow W_0 b)$

0.67 ± 0.07 <sup>4</sup> AAD 12BG ATLS  $F_0 = B(t \rightarrow W_0 b)$

0.722 ± 0.062 ± 0.052 <sup>5</sup> AALTONEN 12Z TEVA  $F_0 = B(t \rightarrow W_0 b)$

0.669 ± 0.078 ± 0.065 <sup>6</sup> ABAZOV 11C D0  $F_0 = B(t \rightarrow W_0 b)$

0.91 ± 0.37 ± 0.13 <sup>7</sup> AFFOLDER 00B CDF  $F_0 = B(t \rightarrow W_0 b)$

• • • We do not use the following data for averages, fits, limits, etc. • • •

0.70 ± 0.05 <sup>8</sup> AABOUD 17BB ATLS  $F_0 = 1 - f_1$ , Repl by AAD 20Y

0.681 ± 0.012 ± 0.023 <sup>9</sup> KHACHATRY...16BU CMS  $F_0 = B(t \rightarrow W_0 b)$ , Repl by AAD 20Y

0.70 ± 0.07 ± 0.04 <sup>10</sup> AALTONEN 10Q CDF Repl. by AALTONEN 12Z

0.62 ± 0.10 ± 0.05 <sup>11</sup> AALTONEN 09Q CDF Repl. by AALTONEN 10Q

$0.425 \pm 0.166 \pm 0.102$	<sup>12</sup> ABAZOV	08B	D0	Repl. by ABAZOV 11C
$0.85^{+0.15}_{-0.22} \pm 0.06$	<sup>13</sup> ABULENCIA	07I	CDF	$F_0 = B(t \rightarrow W_0 b)$
$0.74^{+0.22}_{-0.34}$	<sup>14</sup> ABULENCIA	06U	CDF	$F_0 = B(t \rightarrow W_0 b)$
$0.56 \pm 0.31$	<sup>15</sup> ABAZOV	05G	D0	$F_0 = B(t \rightarrow W_0 b)$

- <sup>1</sup> AAD 20Y based on about  $20 \text{ fb}^{-1}$  of  $p\bar{p}$  data at  $\sqrt{s} = 8 \text{ TeV}$  for each experiment. The first error stands for the sum of the statistical and background uncertainties, and the second error for the remaining systematic uncertainties. The measurements used events with one lepton and different jet multiplicities in the final state. The result is consistent with the NNLO SM prediction of  $0.687 \pm 0.005$  for  $m_t = 172.8 \pm 1.3 \text{ GeV}$ .
- <sup>2</sup> Based on  $8.7 \text{ fb}^{-1}$  of data in  $p\bar{p}$  collisions at  $\sqrt{s} = 1.96 \text{ TeV}$  using  $t\bar{t}$  events with  $\ell + \cancel{E}_T + \geq 4 \text{ jets} (\geq 1 b)$ , and under the constraint  $F_0 + F_+ + F_- = 1$ . The statistical errors of  $F_0$  and  $F_+$  are correlated with correlation coefficient  $\rho(F_0, F_+) = -0.69$ .
- <sup>3</sup> Based on  $5.0 \text{ fb}^{-1}$  of  $p\bar{p}$  data at  $\sqrt{s} = 7 \text{ TeV}$ . CHATRCHYAN 13BH studied  $t\bar{t}$  events with large  $\cancel{E}_T$  and  $\ell + \geq 4 \text{ jets}$  using a constrained kinematic fit.
- <sup>4</sup> Based on  $1.04 \text{ fb}^{-1}$  of  $p\bar{p}$  data at  $\sqrt{s} = 7 \text{ TeV}$ . AAD 12BG studied  $t\bar{t}$  events with large  $\cancel{E}_T$  and either  $\ell + \geq 4j$  or  $\ell\ell + \geq 2j$ . The uncertainties are not independent,  $\rho(F_0, F_-) = -0.96$ .
- <sup>5</sup> Based on  $2.7$  and  $5.1 \text{ fb}^{-1}$  of CDF data in  $\ell + \text{jets}$  and dilepton channels, and  $5.4 \text{ fb}^{-1}$  of D0 data in  $\ell + \text{jets}$  and dilepton channels.  $F_0 = 0.682 \pm 0.035 \pm 0.046$  if  $F_+ = 0.0017(1)$ , while  $F_+ = -0.015 \pm 0.018 \pm 0.030$  if  $F_0 = 0.688(4)$ , where the assumed fixed values are the SM prediction for  $m_t = 173.3 \pm 1.1 \text{ GeV}$  and  $m_W = 80.399 \pm 0.023 \text{ GeV}$ .
- <sup>6</sup> Results are based on  $5.4 \text{ fb}^{-1}$  of data in  $p\bar{p}$  collisions at  $1.96 \text{ TeV}$ , including those of ABAZOV 08B. Under the SM constraint of  $f_0 = 0.698$  (for  $m_t = 173.3 \text{ GeV}$ ,  $m_W = 80.399 \text{ GeV}$ ),  $f_+ = 0.010 \pm 0.022 \pm 0.030$  is obtained.
- <sup>7</sup> AFFOLDER 00B studied the angular distribution of leptonic decays of  $W$  bosons in  $t \rightarrow Wb$  events. The ratio  $F_0$  is the fraction of the helicity zero (longitudinal)  $W$  bosons in the decaying top quark rest frame.  $B(t \rightarrow W_+ b)$  is the fraction of positive helicity (right-handed) positive charge  $W$  bosons in the top quark decays. It is obtained by assuming the Standard Model value of  $F_0$ .
- <sup>8</sup> AABOUD 17BB based on  $20.2 \text{ fb}^{-1}$  of  $p\bar{p}$  data at  $\sqrt{s} = 8 \text{ TeV}$ . Triple-differential decay rate of top quark in the  $t$ -channel single-top production is used to simultaneously determine five generalized  $Wtb$  couplings as well as the top polarization. No assumption is made for the other couplings. See this paper for constraints on other couplings not included here. The paper reported  $f_1$ , and we converted it to  $F_0$ .
- <sup>9</sup> KHACHATRYAN 16BU based on  $19.8 \text{ fb}^{-1}$  of  $p\bar{p}$  data at  $\sqrt{s} = 8 \text{ TeV}$  using  $t\bar{t}$  events with  $\ell + \cancel{E}_T + \geq 4 \text{ jets} (\geq 2 b)$ . The errors of  $F_0$  and  $F_-$  are correlated with a correlation coefficient  $\rho(F_0, F_-) = -0.87$ . The result is consistent with the NNLO SM prediction of  $0.687 \pm 0.005$  for  $m_t = 172.8 \pm 1.3 \text{ GeV}$ .
- <sup>10</sup> Results are based on  $2.7 \text{ fb}^{-1}$  of data in  $p\bar{p}$  collisions at  $\sqrt{s} = 1.96 \text{ TeV}$ .  $F_0$  result is obtained by assuming  $F_+ = 0$ , while  $F_+$  result is obtained for  $F_0 = 0.70$ , the SM value. Model independent fits for the two fractions give  $F_0 = 0.88 \pm 0.11 \pm 0.06$  and  $F_+ = -0.15 \pm 0.07 \pm 0.06$  with correlation coefficient of  $-0.59$ . The results are for  $m_t = 175 \text{ GeV}$ .
- <sup>11</sup> Results are based on  $1.9 \text{ fb}^{-1}$  of data in  $p\bar{p}$  collisions at  $\sqrt{s} = 1.96 \text{ TeV}$ .  $F_0$  result is obtained assuming  $F_+ = 0$ , while  $F_+$  result is obtained for  $F_0 = 0.70$ , the SM values. Model independent fits for the two fractions give  $F_0 = 0.66 \pm 0.16 \pm 0.05$  and  $F_+ = -0.03 \pm 0.06 \pm 0.03$ .
- <sup>12</sup> Based on  $1 \text{ fb}^{-1}$  at  $\sqrt{s} = 1.96 \text{ TeV}$ .
- <sup>13</sup> Based on  $318 \text{ pb}^{-1}$  of data at  $\sqrt{s} = 1.96 \text{ TeV}$ .
- <sup>14</sup> Based on  $200 \text{ pb}^{-1}$  of data at  $\sqrt{s} = 1.96 \text{ TeV}$ .  $t \rightarrow Wb \rightarrow \ell\nu b$  ( $\ell = e$  or  $\mu$ ). The errors are stat + syst.

<sup>15</sup> ABAZOV 05G studied the angular distribution of leptonic decays of  $W$  bosons in  $t\bar{t}$  candidate events with lepton + jets final states, and obtained the fraction of longitudinally polarized  $W$  under the constraint of no right-handed current,  $F_+ = 0$ . Based on 125  $\text{pb}^{-1}$  of data at  $\sqrt{s} = 1.8$  TeV.

### $F_-$

<u>VALUE</u>	<u>CL%</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
<b><math>0.315 \pm 0.010</math> OUR AVERAGE</b>				
$0.315 \pm 0.006 \pm 0.009$		<sup>1</sup> AAD	20Y LHC	ATLAS+CMS combined
$0.310 \pm 0.022 \pm 0.022$		<sup>2</sup> CHATRCHYAN 13BH	CMS	$F_- = B(t \rightarrow W_- b)$
$0.32 \pm 0.04$		<sup>3</sup> AAD	12BG ATLS	$F_- = B(t \rightarrow W_- b)$
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●				
$> 0.264 \pm 0.044$	95	<sup>4</sup> AABOUD	17BB ATLS	$F_- = f_1(1 - f_1^+)$ , Repl. by AAD 20Y
$0.323 \pm 0.008 \pm 0.014$		<sup>5</sup> KHACHATRYAN 16BU	CMS	$F_- = B(t \rightarrow W_- b)$ , Repl. by AAD 20Y

<sup>1</sup> AAD 20Y based on about 20  $\text{fb}^{-1}$  of  $pp$  data at  $\sqrt{s} = 8$  TeV for each experiment. The first error stands for the sum of the statistical and background uncertainties, and the second error for the remaining systematic uncertainties. The measurements used events with one lepton and different jet multiplicities in the final state. The result is consistent with the NNLO SM prediction of  $0.311 \pm 0.005$  for  $m_t = 172.8 \pm 1.3$  GeV.

<sup>2</sup> Based on 5.0  $\text{fb}^{-1}$  of  $pp$  data at  $\sqrt{s} = 7$  TeV. CHATRCHYAN 13BH studied  $tt$  events with large  $\cancel{E}_T$  and  $\ell + \geq 4$  jets using a constrained kinematic fit.

<sup>3</sup> Based on 1.04  $\text{fb}^{-1}$  of  $pp$  data at  $\sqrt{s} = 7$  TeV. AAD 12BG studied  $tt$  events with large  $\cancel{E}_T$  and either  $\ell + \geq 4j$  or  $\ell\ell + \geq 2j$ . The uncertainties are not independent,  $\rho(F_0, F_-) = -0.96$ .

<sup>4</sup> AABOUD 17BB based on 20.2  $\text{fb}^{-1}$  of  $pp$  data at  $\sqrt{s} = 8$  TeV. Triple-differential decay rate of top quark in the  $t$ -channel single-top production is used to simultaneously determine five generalized  $Wtb$  couplings as well as the top polarization. No assumption is made for the other couplings. The authors reported  $f_1 = 0.30 \pm 0.05$  and  $f_1^+ < 0.120$  which we converted to  $F_- = f_1(1 - f_1^+)$ . See this paper for constraints on other couplings not included here.

<sup>5</sup> KHACHATRYAN 16BU based on 19.8  $\text{fb}^{-1}$  of  $pp$  data at  $\sqrt{s} = 8$  TeV using  $t\bar{t}$  events with  $\ell + \cancel{E}_T + \geq 4$  jets ( $\geq 2 b$ ). The errors of  $F_0$  and  $F_-$  are correlated with a correlation coefficient  $\rho(F_0, F_-) = -0.87$ . The result is consistent with the NNLO SM prediction of  $0.311 \pm 0.005$  for  $m_t = 172.8 \pm 1.3$  GeV.

### $F_+$

<u>VALUE</u>	<u>CL%</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
<b><math>-0.005 \pm 0.007</math> OUR AVERAGE</b>				
$-0.008 \pm 0.005 \pm 0.006$		<sup>1</sup> AAD	20Y LHC	ATLAS+CMS combined
$-0.045 \pm 0.044 \pm 0.058$		<sup>2</sup> AALTONEN	13D CDF	$F_+ = B(t \rightarrow W_+ b)$
$0.008 \pm 0.012 \pm 0.014$		<sup>3</sup> CHATRCHYAN 13BH	CMS	$F_+ = B(t \rightarrow W_+ b)$
$0.01 \pm 0.05$		<sup>4</sup> AAD	12BG ATLS	$F_+ = B(t \rightarrow W_+ b)$
$0.023 \pm 0.041 \pm 0.034$		<sup>5</sup> ABAZOV	11C D0	$F_+ = B(t \rightarrow W_+ b)$
$0.11 \pm 0.15$		<sup>6</sup> AFFOLDER	00B CDF	$F_+ = B(t \rightarrow W_+ b)$
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●				
$< 0.036 \pm 0.006$	95	<sup>7</sup> AABOUD	17BB ATLS	$F_+ = f_1 f_1^+$ , Repl. by AAD 20Y
$-0.004 \pm 0.005 \pm 0.014$		<sup>8</sup> KHACHATRYAN 16BU	CMS	$F_+ = B(t \rightarrow W_+ b)$ , Repl. by AAD 20Y

$-0.033 \pm 0.034 \pm 0.031$		<sup>9</sup> AALTONEN	12Z	TEVA	$F_+ = B(t \rightarrow W_+ b)$
$-0.01 \pm 0.02 \pm 0.05$		<sup>10</sup> AALTONEN	10Q	CDF	Repl. by AALTONEN 13D
$-0.04 \pm 0.04 \pm 0.03$		<sup>11</sup> AALTONEN	09Q	CDF	Repl. by AALTONEN 10Q
$0.119 \pm 0.090 \pm 0.053$		<sup>12</sup> ABAZOV	08B	D0	Repl. by ABAZOV 11C
$0.056 \pm 0.080 \pm 0.057$		<sup>13</sup> ABAZOV	07D	D0	$F_+ = B(t \rightarrow W_+ b)$
$0.05 \begin{smallmatrix} +0.11 \\ -0.05 \end{smallmatrix} \pm 0.03$		<sup>14</sup> ABULENCIA	07I	CDF	$F_+ = B(t \rightarrow W_+ b)$
$< 0.26$	95	<sup>14</sup> ABULENCIA	07I	CDF	$F_+ = B(t \rightarrow W_+ b)$
$< 0.27$	95	<sup>15</sup> ABULENCIA	06U	CDF	$F_+ = B(t \rightarrow W_+ b)$
$0.00 \pm 0.13 \pm 0.07$		<sup>16</sup> ABAZOV	05L	D0	$F_+ = B(t \rightarrow W_+ b)$
$< 0.25$	95	<sup>16</sup> ABAZOV	05L	D0	$F_+ = B(t \rightarrow W_+ b)$
$< 0.24$	95	<sup>17</sup> ACOSTA	05D	CDF	$F_+ = B(t \rightarrow W_+ b)$

<sup>1</sup> AAD 20Y based on about  $20 \text{ fb}^{-1}$  of  $pp$  data at  $\sqrt{s} = 8 \text{ TeV}$  for each experiment. The first error stands for the sum of the statistical and background uncertainties, and the second error for the remaining systematic uncertainties. The measurements used events with one lepton and different jet multiplicities in the final state. The result is estimated from the measurements of  $F_0$  and  $F_-$  assuming unitarity. The value is consistent with the NNLO SM prediction of  $0.0017 \pm 0.0001$  for  $m_t = 172.8 \pm 1.3 \text{ GeV}$ .

<sup>2</sup> Based on  $8.7 \text{ fb}^{-1}$  of data in  $p\bar{p}$  collisions at  $\sqrt{s} = 1.96 \text{ TeV}$  using  $t\bar{t}$  events with  $\ell + \cancel{E}_T + \geq 4 \text{ jets} (\geq 1 b)$ , and under the constraint  $F_0 + F_+ + F_- = 1$ . The statistical errors of  $F_0$  and  $F_+$  are correlated with correlation coefficient  $\rho(F_0, F_+) = -0.69$ .

<sup>3</sup> Based on  $5.0 \text{ fb}^{-1}$  of  $pp$  data at  $\sqrt{s} = 7 \text{ TeV}$ . CHATRCHYAN 13BH studied  $tt$  events with large  $\cancel{E}_T$  and  $\ell + \geq 4 \text{ jets}$  using a constrained kinematic fit.

<sup>4</sup> Based on  $1.04 \text{ fb}^{-1}$  of  $pp$  data at  $\sqrt{s} = 7 \text{ TeV}$ . AAD 12BG studied  $tt$  events with large  $\cancel{E}_T$  and either  $\ell + \geq 4j$  or  $\ell\ell + \geq 2j$ .

<sup>5</sup> Results are based on  $5.4 \text{ fb}^{-1}$  of data in  $p\bar{p}$  collisions at  $1.96 \text{ TeV}$ , including those of ABAZOV 08B. Under the SM constraint of  $f_0 = 0.698$  (for  $m_t = 173.3 \text{ GeV}$ ,  $m_W = 80.399 \text{ GeV}$ ),  $f_+ = 0.010 \pm 0.022 \pm 0.030$  is obtained.

<sup>6</sup> AFFOLDER 00B studied the angular distribution of leptonic decays of  $W$  bosons in  $t \rightarrow Wb$  events. The ratio  $F_0$  is the fraction of the helicity zero (longitudinal)  $W$  bosons in the decaying top quark rest frame.  $B(t \rightarrow W_+ b)$  is the fraction of positive helicity (right-handed) positive charge  $W$  bosons in the top quark decays. It is obtained by assuming the Standard Model value of  $F_0$ .

<sup>7</sup> AABOUD 17BB based on  $20.2 \text{ fb}^{-1}$  of  $pp$  data at  $\sqrt{s} = 8 \text{ TeV}$ . Triple-differential decay rate of top quark in the  $t$ -channel single-top production is used to simultaneously determine five generalized  $Wtb$  couplings as well as the top polarization. No assumption is made for the other couplings. The authors reported  $f_1 = 0.30 \pm 0.05$  and  $f_1^+ < 0.120$  which we converted to  $F_+ = f_1 f_1^+$ . See this paper for constraints on other couplings not included here.

<sup>8</sup> KHACHATRYAN 16BU based on  $19.8 \text{ fb}^{-1}$  of  $pp$  data at  $\sqrt{s} = 8 \text{ TeV}$  using  $t\bar{t}$  events with  $\ell + \cancel{E}_T + \geq 4 \text{ jets} (\geq 2 b)$ . The result is consistent with the NNLO SM prediction of  $0.0017 \pm 0.0001$  for  $m_t = 172.8 \pm 1.3 \text{ GeV}$ .

<sup>9</sup> Based on  $2.7$  and  $5.1 \text{ fb}^{-1}$  of CDF data in  $\ell + \text{jets}$  and dilepton channels, and  $5.4 \text{ fb}^{-1}$  of D0 data in  $\ell + \text{jets}$  and dilepton channels.  $F_0 = 0.682 \pm 0.035 \pm 0.046$  if  $F_+ = 0.0017(1)$ , while  $F_+ = -0.015 \pm 0.018 \pm 0.030$  if  $F_0 = 0.688(4)$ , where the assumed fixed values are the SM prediction for  $m_t = 173.3 \pm 1.1 \text{ GeV}$  and  $m_W = 80.399 \pm 0.023 \text{ GeV}$ .

<sup>10</sup> Results are based on  $2.7 \text{ fb}^{-1}$  of data in  $p\bar{p}$  collisions at  $\sqrt{s} = 1.96 \text{ TeV}$ .  $F_0$  result is obtained by assuming  $F_+ = 0$ , while  $F_+$  result is obtained for  $F_0 = 0.70$ , the SM value. Model independent fits for the two fractions give  $F_0 = 0.88 \pm 0.11 \pm 0.06$  and  $F_+ =$



$-0.15 \pm 0.07 \pm 0.06$  with correlation coefficient of  $-0.59$ . The results are for  $m_t = 175$  GeV.

- 11 Results are based on  $1.9 \text{ fb}^{-1}$  of data in  $p\bar{p}$  collisions at  $\sqrt{s} = 1.96$  TeV.  $F_0$  result is obtained assuming  $F_+ = 0$ , while  $F_+$  result is obtained for  $F_0 = 0.70$ , the SM values. Model independent fits for the two fractions give  $F_0 = 0.66 \pm 0.16 \pm 0.05$  and  $F_+ = -0.03 \pm 0.06 \pm 0.03$ .
- 12 Based on  $1 \text{ fb}^{-1}$  at  $\sqrt{s} = 1.96$  TeV.
- 13 Based on  $370 \text{ pb}^{-1}$  of data at  $\sqrt{s} = 1.96$  TeV, using the  $\ell + \text{jets}$  and dilepton decay channels. The result assumes  $F_0 = 0.70$ , and it gives  $F_+ < 0.23$  at 95% CL.
- 14 Based on  $318 \text{ pb}^{-1}$  of data at  $\sqrt{s} = 1.96$  TeV.
- 15 Based on  $200 \text{ pb}^{-1}$  of data at  $\sqrt{s} = 1.96$  TeV.  $t \rightarrow Wb \rightarrow \ell\nu b$  ( $\ell = e$  or  $\mu$ ). The errors are stat + syst.
- 16 ABAZOV 05L studied the angular distribution of leptonic decays of  $W$  bosons in  $t\bar{t}$  events, where one of the  $W$ 's from  $t$  or  $\bar{t}$  decays into  $e$  or  $\mu$  and the other decays hadronically. The fraction of the "+" helicity  $W$  boson is obtained by assuming  $F_0 = 0.7$ , which is the generic prediction for any linear combination of V and A currents. Based on  $230 \pm 15 \text{ pb}^{-1}$  of data at  $\sqrt{s} = 1.96$  TeV.
- 17 ACOSTA 05D measures the  $m_{\ell^+b}^2$  distribution in  $t\bar{t}$  production events where one or both  $W$ 's decay leptonically to  $\ell = e$  or  $\mu$ , and finds a bound on the V+A coupling of the  $tbW$  vertex. By assuming the SM value of the longitudinal  $W$  fraction  $F_0 = B(t \rightarrow W_0 b) = 0.70$ , the bound on  $F_+$  is obtained. If the results are combined with those of AFFOLDER 00B, the bounds become  $F_{V+A} < 0.61$  (95% CL) and  $F_+ < 0.18$  (95%CL), respectively. Based on  $109 \pm 7 \text{ pb}^{-1}$  of data at  $\sqrt{s} = 1.8$  TeV (run I).

### $F_{V+A}$

VALUE	CL%	DOCUMENT ID	TECN	COMMENT
$< 0.29$	95	<sup>1</sup> ABULENCIA	07G CDF	$F_{V+A} = B(t \rightarrow Wb_R)$
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●				
$-0.06 \pm 0.22 \pm 0.12$		<sup>1</sup> ABULENCIA	07G CDF	$F_{V+A} = B(t \rightarrow Wb_R)$
$< 0.80$	95	<sup>2</sup> ACOSTA	05D CDF	$F_{V+A} = B(t \rightarrow Wb_R)$

<sup>1</sup> Based on  $700 \text{ pb}^{-1}$  of data at  $\sqrt{s} = 1.96$  TeV.

<sup>2</sup> ACOSTA 05D measures the  $m_{\ell^+b}^2$  distribution in  $t\bar{t}$  production events where one or both  $W$ 's decay leptonically to  $\ell = e$  or  $\mu$ , and finds a bound on the V+A coupling of the  $tbW$  vertex. By assuming the SM value of the longitudinal  $W$  fraction  $F_0 = B(t \rightarrow W_0 b) = 0.70$ , the bound on  $F_+$  is obtained. If the results are combined with those of AFFOLDER 00B, the bounds become  $F_{V+A} < 0.61$  (95% CL) and  $F_+ < 0.18$  (95%CL), respectively. Based on  $109 \pm 7 \text{ pb}^{-1}$  of data at  $\sqrt{s} = 1.8$  TeV (run I).

### $f_1^R$

VALUE	CL%	DOCUMENT ID	TECN	COMMENT
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●				
$-0.11 < f_1^R < 0.16$	95	<sup>1</sup> AAD	20Y LHC	ATLAS+CMS combined
$ f_1^R/f_2^L  < 0.37$	95	<sup>2</sup> AABOUD	17BB ATLS	$t$ -channel single top
$ f_1^R  < 0.16$	95	<sup>3</sup> KHACHATRY...	17G CMS	$t$ -channel single- $t$ prod.
$-0.20 < \text{Re}(V_{tb} f_1^R) < 0.23$	95	<sup>4</sup> AAD	12BG ATLS	Constr. on $Wtb$ vtx
$(V_{tb} f_1^R)^2 < 0.93$	95	<sup>5</sup> ABAZOV	12E D0	Single-top
$ f_1^R ^2 < 0.30$	95	<sup>6</sup> ABAZOV	12I D0	single- $t$ + $W$ helicity

$ f_1^R ^2 < 1.01$	95	7 ABAZOV	09J D0	$ f_1^L  = 1,  f_2^L  =  f_2^R  = 0$
$ f_1^R ^2 < 2.5$	95	8 ABAZOV	08AI D0	$ f_1^L ^2 = 1.8^{+1.0}_{-1.3}$

- <sup>1</sup> AAD 20Y based on about 20 fb<sup>-1</sup> of *pp* data at  $\sqrt{s} = 8$  TeV for each experiment. The measurements used events with one lepton and different jet multiplicities in the final state. The measurements of  $F_0$  and  $F_-$  are used to set the limit. The limit is obtained by assuming the other couplings to have their SM values.
- <sup>2</sup> AABOUD 17BB based on 20.2 fb<sup>-1</sup> of *pp* data at  $\sqrt{s} = 8$  TeV. Triple-differential decay rate of top quark is used to simultaneously determine five generalized *Wtb* couplings as well as the top polarization. No assumption is made for the other couplings. See this paper for constraints on other couplings not included here.
- <sup>3</sup> KHACHATRYAN 17G based on 5.0 and 19.7 fb<sup>-1</sup> of *pp* data at  $\sqrt{s} = 7$  and 8 TeV, respectively. A Bayesian neural network technique is used to discriminate between signal and backgrounds. This is a 95% CL exclusion limit obtained by a three-dimensional fit with simultaneous variation of  $(f_1^L, f_1^R, f_2^R)$ .
- <sup>4</sup> Based on 1.04 fb<sup>-1</sup> of *pp* data at  $\sqrt{s} = 7$  TeV. AAD 12BG studied *tt* events with large  $\cancel{E}_T$  and either  $\ell + \geq 4j$  or  $\ell\ell + \geq 2j$ .
- <sup>5</sup> Based on 5.4 fb<sup>-1</sup> of data. For each value of the form factor quoted the other two are assumed to have their SM value. Their Fig. 4 shows two-dimensional posterior probability density distributions for the anomalous couplings.
- <sup>6</sup> Based on 5.4 fb<sup>-1</sup> of data in *p $\bar{p}$*  collisions at 1.96 TeV. Results are obtained by combining the limits from the *W* helicity measurements and those from the single top quark production.
- <sup>7</sup> Based on 1 fb<sup>-1</sup> of data at *p $\bar{p}$*  collisions  $\sqrt{s} = 1.96$  TeV. Combined result of the *W* helicity measurement in *t $\bar{t}$*  events (ABAZOV 08B) and the search for anomalous *tbW* couplings in the single top production (ABAZOV 08AI). Constraints when  $f_1^L$  and one of the anomalous couplings are simultaneously allowed to vary are given in their Fig. 1 and Table 1.
- <sup>8</sup> Result is based on 0.9 fb<sup>-1</sup> of data at  $\sqrt{s} = 1.96$  TeV. Single top quark production events are used to measure the Lorentz structure of the *tbW* coupling. The upper bounds on the non-standard couplings are obtained when only one non-standard coupling is allowed to be present together with the SM one,  $f_1^L = V_{tb}^*$ .

## $f_2^L$

VALUE	CL%	DOCUMENT ID	TECN	COMMENT
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●				
$-0.08 < f_2^L < 0.05$	95	1 AAD	20Y LHC	ATLAS+CMS combined
$ f_2^L/f_1^L  < 0.29$	95	2 AABOUD	17BB ATLS	<i>t</i> -channel single top
$ f_2^L  < 0.057$	95	3 KHACHATRY...17G	CMS	<i>t</i> -channel single- <i>t</i> prod.
$-0.14 < \text{Re}(f_2^L) < 0.11$	95	4 AAD	12BG ATLS	Constr. on <i>Wtb</i> vtx
$(V_{tb} f_2^L)^2 < 0.13$	95	5 ABAZOV	12E D0	Single-top
$ f_2^L ^2 < 0.05$	95	6 ABAZOV	12I D0	single- <i>t</i> + <i>W</i> helicity
$ f_2^L ^2 < 0.28$	95	7 ABAZOV	09J D0	$ f_1^L  = 1,  f_1^R  =  f_2^R  = 0$
$ f_2^L ^2 < 0.5$	95	8 ABAZOV	08AI D0	$ f_1^L ^2 = 1.4^{+0.6}_{-0.5}$

- <sup>1</sup> AAD 20Y based on about 20 fb<sup>-1</sup> of *pp* data at  $\sqrt{s} = 8$  TeV for each experiment. The measurements used events with one lepton and different jet multiplicities in the final state. The measurements of  $F_0$  and  $F_-$  are used to set the limit. The limit is obtained by assuming the other couplings to have their SM values.
- <sup>2</sup> AABOUD 17BB based on 20.2 fb<sup>-1</sup> of *pp* data at  $\sqrt{s} = 8$  TeV. Triple-differential decay rate of top quark is used to simultaneously determine five generalized *Wtb* couplings as

well as the top polarization. No assumption is made for the other couplings. See this paper for constraints on other couplings not included here.

- <sup>3</sup> KHACHATRYAN 17G based on 5.0 and 19.7 fb<sup>-1</sup> of  $pp$  data at  $\sqrt{s} = 7$  and 8 TeV, respectively. A Bayesian neural network technique is used to discriminate between signal and backgrounds. This is a 95% CL exclusion limit obtained by a three-dimensional fit with simultaneous variation of  $(f_1^L, f_2^L, f_2^R)$ .
- <sup>4</sup> Based on 1.04 fb<sup>-1</sup> of  $pp$  data at  $\sqrt{s} = 7$  TeV. AAD 12BG studied  $tt$  events with large  $\cancel{E}_T$  and either  $\ell + \geq 4j$  or  $\ell\ell + \geq 2j$ .
- <sup>5</sup> Based on 5.4 fb<sup>-1</sup> of data. For each value of the form factor quoted the other two are assumed to have their SM value. Their Fig. 4 shows two-dimensional posterior probability density distributions for the anomalous couplings.
- <sup>6</sup> Based on 5.4 fb<sup>-1</sup> of data in  $p\bar{p}$  collisions at 1.96 TeV. Results are obtained by combining the limits from the  $W$  helicity measurements and those from the single top quark production.
- <sup>7</sup> Based on 1 fb<sup>-1</sup> of data at  $p\bar{p}$  collisions  $\sqrt{s} = 1.96$  TeV. Combined result of the  $W$  helicity measurement in  $t\bar{t}$  events (ABAZOV 08B) and the search for anomalous  $tbW$  couplings in the single top production (ABAZOV 08AI). Constraints when  $f_1^L$  and one of the anomalous couplings are simultaneously allowed to vary are given in their Fig. 1 and Table 1.
- <sup>8</sup> Result is based on 0.9 fb<sup>-1</sup> of data at  $\sqrt{s} = 1.96$  TeV. Single top quark production events are used to measure the Lorentz structure of the  $tbW$  coupling. The upper bounds on the non-standard couplings are obtained when only one non-standard coupling is allowed to be present together with the SM one,  $f_1^L = V_{tb}^*$ .

**$f_2^R$**

VALUE	CL%	DOCUMENT ID	TECN	COMMENT
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●				
$-0.04 < f_2^R < 0.02$	95	<sup>1</sup> AAD	20Y LHC	ATLAS+CMS combined
$-0.12 < \text{Re}(f_2^R/f_1^L) < 0.17$	95	<sup>2</sup> AABOUD	17BB ATLS	$t$ -channel single top
$-0.07 < \text{Im}(f_2^R/f_1^L) < 0.06$	95	<sup>2</sup> AABOUD	17BB ATLS	$t$ -channel single top
$-0.18 < \text{Im}(f_2^R) < 0.06$	95	<sup>3</sup> AABOUD	17I ATLS	$t$ -channel single top
$-0.049 < f_2^R < 0.048$	95	<sup>4</sup> KHACHATRY...17G	CMS	$t$ -channel single top
$-0.36 < \text{Re}(f_2^R/f_1^L) < 0.10$	95	<sup>5</sup> AAD	16AK ATLS	Single-top
$-0.17 < \text{Im}(f_2^R/f_1^L) < 0.23$	95	<sup>5</sup> AAD	16AK ATLS	Single-top
$-0.08 < \text{Re}(f_2^R) < 0.04$	95	<sup>6</sup> AAD	12BG ATLS	Constr. on $Wtb$ vtx
$(V_{tb} f_2^R)^2 < 0.06$	95	<sup>7</sup> ABAZOV	12E D0	Single-top
$ f_2^R ^2 < 0.12$	95	<sup>8</sup> ABAZOV	12I D0	single- $t$ + $W$ helicity
$ f_2^R ^2 < 0.23$	95	<sup>9</sup> ABAZOV	09J D0	$ f_1^L =1,  f_1^R = f_2^L =0$
$ f_2^R ^2 < 0.3$	95	<sup>10</sup> ABAZOV	08AI D0	$ f_1^L ^2 = 1.4^{+0.9}_{-0.8}$

<sup>1</sup> AAD 20Y based on about 20 fb<sup>-1</sup> of  $pp$  data at  $\sqrt{s} = 8$  TeV for each experiment. The measurements used events with one lepton and different jet multiplicities in the final state. The measurements of  $F_0$  and  $F_-$  are used to set the limit. The limit is obtained by assuming the other couplings to have their SM values.

<sup>2</sup> AABOUD 17BB based on 20.2 fb<sup>-1</sup> of  $pp$  data at  $\sqrt{s} = 8$  TeV. Triple-differential decay rate of top quark is used to simultaneously determine five generalized  $Wtb$  couplings as well as the top polarization. No assumption is made for the other couplings. See this paper for constraints on other couplings not included here.

- <sup>3</sup> AABOUD 17I based on  $20.2 \text{ fb}^{-1}$  of  $pp$  data at  $\sqrt{s} = 8 \text{ TeV}$ . A cut-based analysis is used to discriminate between signal and backgrounds. All anomalous couplings other than  $\text{Im}(f_2^R)$  are assumed to be zero. See this paper for a number of other asymmetries and measurements that are not included here.
- <sup>4</sup> KHACHATRYAN 17G based on  $5.0$  and  $19.7 \text{ fb}^{-1}$  of  $pp$  data at  $\sqrt{s} = 7$  and  $8 \text{ TeV}$ , respectively. A Bayesian neural network technique is used to discriminate between signal and backgrounds. This is a 95% CL exclusion limit obtained by a three-dimensional fit with simultaneous variation of  $(f_1^L, f_2^L, f_2^R)$ .
- <sup>5</sup> AAD 16AK based on  $4.6 \text{ fb}^{-1}$  of  $pp$  data at  $\sqrt{s} = 7 \text{ TeV}$ . The results are obtained from an analysis of angular distributions of the decay products of single top quarks, assuming  $f_1^R = f_2^L = 0$ . The fraction of decays containing transversely polarized  $W$  is measured to be  $F_+ + F_- = 0.37 \pm 0.07$ .
- <sup>6</sup> Based on  $1.04 \text{ fb}^{-1}$  of  $pp$  data at  $\sqrt{s} = 7 \text{ TeV}$ . AAD 12BG studied  $t\bar{t}$  events with large  $\cancel{E}_T$  and either  $\ell + \geq 4j$  or  $\ell\bar{\ell} + \geq 2j$ .
- <sup>7</sup> Based on  $5.4 \text{ fb}^{-1}$  of data. For each value of the form factor quoted the other two are assumed to have their SM value. Their Fig. 4 shows two-dimensional posterior probability density distributions for the anomalous couplings.
- <sup>8</sup> Based on  $5.4 \text{ fb}^{-1}$  of data in  $p\bar{p}$  collisions at  $1.96 \text{ TeV}$ . Results are obtained by combining the limits from the  $W$  helicity measurements and those from the single top quark production.
- <sup>9</sup> Based on  $1 \text{ fb}^{-1}$  of data at  $p\bar{p}$  collisions  $\sqrt{s} = 1.96 \text{ TeV}$ . Combined result of the  $W$  helicity measurement in  $t\bar{t}$  events (ABAZOV 08B) and the search for anomalous  $t b W$  couplings in the single top production (ABAZOV 08A1). Constraints when  $f_1^L$  and one of the anomalous couplings are simultaneously allowed to vary are given in their Fig. 1 and Table 1.
- <sup>10</sup> Result is based on  $0.9 \text{ fb}^{-1}$  of data at  $\sqrt{s} = 1.96 \text{ TeV}$ . Single top quark production events are used to measure the Lorentz structure of the  $t b W$  coupling. The upper bounds on the non-standard couplings are obtained when only one non-standard coupling is allowed to be present together with the SM one,  $f_1^L = V_{tb}^*$ .

### $|f_{LV} V_{tb}|$

Assumed that the top-quark-related CKM matrix elements obey the relation  $|V_{td}|, |V_{ts}| \ll |V_{tb}|$  and a form factor  $f_{LV}$  is determined for each production mode and centre-of-mass energy.

VALUE	DOCUMENT ID	TECN	COMMENT
<b><math>0.995 \pm 0.021</math> OUR AVERAGE</b>			
$0.988 \pm 0.024$	<sup>1</sup> SIRUNYAN	20AZ CMS	13 TeV, $t$ -channel single top
$1.02 \pm 0.04 \pm 0.02$	<sup>2</sup> AABOUD	19R LHC	ATLAS + CMS at 7, 8 TeV

<sup>1</sup> SIRUNYAN 20AZ based on  $35.9 \text{ fb}^{-1}$  of  $pp$  data at  $\sqrt{s} = 13 \text{ TeV}$ . Final states enriched in single top quark  $t$ -channel events are used. Several theories beyond the standard model are considered, and by releasing all constraints among the involved parameters. Under the standard model assumption of CKM unitarity, the values are found to be  $|V_{tb}| > 0.970$  and  $|V_{td}|^2 + |V_{ts}|^2 < 0.057$ , both at 95% CL.

<sup>2</sup> The combination of single-top production cross-section measurements in the  $t$ -channel,  $t W$ , and  $s$ -channel production modes from ATLAS and CMS at  $\sqrt{s} = 7$  and  $8 \text{ TeV}$ .

### $|f_{LV} \sqrt{|V_{td}|^2 + |V_{ts}|^2}|$

Assumed that the top-quark-related CKM matrix elements obey the relation  $|V_{td}|, |V_{ts}| \ll |V_{tb}|$  and a form factor  $f_{LV}$  is determined for each production mode and centre-of-mass energy.

VALUE	DOCUMENT ID	TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •			
$0.24 \pm 0.12$	<sup>1</sup> SIRUNYAN	20AZ CMS	$t$ -channel single top

<sup>1</sup>We report the square root of SIRUNYAN 20AZ result based on  $35.9 \text{ fb}^{-1}$  of  $pp$  data at  $\sqrt{s} = 13 \text{ TeV}$  measured  $|V_{td}|^2 + |V_{ts}|^2 = 0.06 \pm 0.06$  using final states enriched in single top quark  $t$ -channel events by releasing all constraints from unitarity of the CKM matrix within the SM. Under the standard model assumption of CKM unitarity, the values are found to be  $|V_{tb}| > 0.970$  and  $|V_{td}|^2 + |V_{ts}|^2 < 0.057$ , both at 95% CL.

### Chromo-magnetic dipole moment $\mu_t = g_s \hat{\mu}_t / m_t$

VALUE	CL%	DOCUMENT ID	TECN	COMMENT
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• • • We do not use the following data for averages, fits, limits, etc. • • •

$-0.024^{+0.013+0.016}_{-0.009-0.011}$		<sup>1</sup> SIRUNYAN	20AM CMS	$\ell$ +jets
$-0.014 < \hat{\mu}_t < 0.004$	95	<sup>2</sup> SIRUNYAN	19BX CMS	$\ell\ell + \geq 2j (\geq 1b)$
$-0.053 < \text{Re}(\hat{\mu}_t) < 0.026$	95	<sup>3</sup> KHACHATRYAN...16AI	CMS	$\ell\ell + \geq 2j (\geq 1b)$

<sup>1</sup>SIRUNYAN 20AM based on  $35.9 \text{ fb}^{-1}$  of  $pp$  data at  $\sqrt{s} = 13 \text{ TeV}$ .  $t\bar{t}$  with low and high boosts are reconstructed through a fit of the kinematic distributions. The  $q\bar{q}$  initial subprocess is separated using different dependencies of the distributions on the initial states, and the linearized forward-backward asymmetry is measured to be  $A_{FB}^{(1)} = 0.048^{+0.095+0.020}_{-0.087-0.029}$ .

<sup>2</sup>SIRUNYAN 19BX based on  $35.9 \text{ fb}^{-1}$  of  $pp$  data at  $\sqrt{s} = 13 \text{ TeV}$ . A set of parton-level normalized differential cross sections is measured to extract coefficients of the spin-dependent  $t\bar{t}$  production density matrix. The coefficients are compared with the NLO MC simulations and with the NLO QCD calculation including EW corrections.

<sup>3</sup>KHACHATRYAN 16AI based on  $19.5 \text{ fb}^{-1}$  of  $pp$  data at  $\sqrt{s} = 8 \text{ TeV}$ , using lepton angular distributions as a function of the  $t\bar{t}$ -system kinematical variables.

### Chromo-electric dipole moment $d_t = g_s \hat{d}_t / m_t$

VALUE	CL%	DOCUMENT ID	TECN	COMMENT
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• • • We do not use the following data for averages, fits, limits, etc. • • •

$ \hat{d}_t  < 0.03$	95	<sup>1</sup> SIRUNYAN	20AM CMS	$\ell$ +jets
$-0.020 < \hat{d}_t < 0.012$	95	<sup>2</sup> SIRUNYAN	19BX CMS	$\ell\ell + \geq 2j (\geq 1b)$
$-0.068 < \text{Im}(\hat{d}_t) < 0.067$	95	<sup>3</sup> KHACHATRYAN...16AI	CMS	$\ell\ell + \geq 2j (\geq 1b)$

<sup>1</sup>SIRUNYAN 20AM based on  $35.9 \text{ fb}^{-1}$  of  $pp$  data at  $\sqrt{s} = 13 \text{ TeV}$ .  $t\bar{t}$  with low and high boosts are reconstructed through a fit of the kinematic distributions. The  $q\bar{q}$  initial subprocess is separated using different dependences of the distributions on the initial states, and the linearized forward-backward asymmetry is measured to be  $A_{FB}^{(1)} = 0.048^{+0.095+0.020}_{-0.087-0.029}$ .

<sup>2</sup>SIRUNYAN 19BX based on  $35.9 \text{ fb}^{-1}$  of  $pp$  data at  $\sqrt{s} = 13 \text{ TeV}$ . A set of parton-level normalized differential cross sections is measured to extract coefficients of the spin-dependent  $t\bar{t}$  production density matrix and constrain the anomalous chromomagnetic and chromoelectric dipole moments of the top quark. The coefficients are compared with the NLO MC simulations and with the NLO QCD calculation including EW corrections.

<sup>3</sup>KHACHATRYAN 16AI based on  $19.5 \text{ fb}^{-1}$  of  $pp$  data at  $\sqrt{s} = 8 \text{ TeV}$ , using lepton angular distributions as a function of the  $t\bar{t}$ -system kinematical variables.

### Spin Correlation in $t\bar{t}$ Production in $p\bar{p}$ Collisions

$C$  is the correlation strength parameter,  $f$  is the ratio of events with correlated  $t$  and  $\bar{t}$  spins (SM prediction:  $f = 1$ ), and  $\kappa$  is the spin correlation coefficient. See "The Top Quark" review for more information.

VALUE	DOCUMENT ID	TECN	COMMENT
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• • • We do not use the following data for averages, fits, limits, etc. • • •

$0.89 \pm 0.22$	<sup>1</sup> ABAZOV	16A D0	$f (\ell\ell + \geq 2 \text{ jets}, \ell + \geq 4 \text{ jets})$
$0.85 \pm 0.29$	<sup>2</sup> ABAZOV	12B D0	$f (\ell\ell + \geq 2 \text{ jets}, \ell + \geq 4 \text{ jets})$

$1.15^{+0.42}_{-0.43}$	<sup>3</sup> ABAZOV	12B D0	$f(\ell + \cancel{E}_T + \geq 4 \text{ jets})$
$0.60^{+0.50}_{-0.16}$	<sup>4</sup> AALTONEN	11AR CDF	$\kappa(\ell + \cancel{E}_T + \geq 4 \text{ jets})$
$0.74^{+0.40}_{-0.41}$	<sup>5</sup> ABAZOV	11AE D0	$f(\ell\ell + \cancel{E}_T + \geq 2 \text{ jets})$
$0.10 \pm 0.45$	<sup>6</sup> ABAZOV	11AF D0	$C(\ell\ell + \cancel{E}_T + \geq 2 \text{ jets})$

<sup>1</sup> ABAZOV 16A based on  $9.7 \text{ fb}^{-1}$  of data. A matrix element method is used. It corresponds to evidence of spin correlation at  $4.2\sigma$  and is in agreement with the NLO SM prediction  $0.80^{+0.01}_{-0.02}$ .

<sup>2</sup> This is a combination of the lepton + jets analysis presented in ABAZOV 12B and the dilepton measurement of ABAZOV 11AE. It provides a  $3.1 \sigma$  evidence for the  $t\bar{t}$  spin correlation.

<sup>3</sup> Based on  $5.3 \text{ fb}^{-1}$  of data. The error is statistical and systematic combined. A matrix element method is used.

<sup>4</sup> Based on  $4.3 \text{ fb}^{-1}$  of data. The measurement is based on the angular study of the top quark decay products in the helicity basis. The theory prediction is  $\kappa \approx 0.40$ .

<sup>5</sup> Based on  $5.4 \text{ fb}^{-1}$  of data using a matrix element method. The error is statistical and systematic combined. The no-correlation hypothesis is excluded at the 97.7% CL.

<sup>6</sup> Based on  $5.4 \text{ fb}^{-1}$  of data. The error is statistical and systematic combined. The NLO QCD prediction is  $C = 0.78 \pm 0.03$ . The neutrino weighting method is used for reconstruction of kinematics.

### Spin Correlation in $t\bar{t}$ Production in $pp$ Collisions

Spin correlation,  $f_{SM}$ , measures the strength of the correlation between the spins of the pair produced  $t\bar{t}$ .  $f_{SM} = 1$  for the SM, while  $f_{SM} = 0$  for no spin correlation.

VALUE	DOCUMENT ID	TECN	COMMENT
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●			
$0.90 \pm 0.07 \pm 0.09 \pm 0.01$	<sup>1</sup> SIRUNYAN	19BX CMS	$C_{kk}$ in $\ell\ell + \geq 2j (\geq 1b)$
$1.13 \pm 0.32 \pm 0.32^{+0.10}_{-0.13}$	<sup>1</sup> SIRUNYAN	19BX CMS	$C_{rr}$ in $\ell\ell + \geq 2j (\geq 1b)$
$1.01 \pm 0.04 \pm 0.05 \pm 0.01$	<sup>1</sup> SIRUNYAN	19BX CMS	$C_{nn}$ in $\ell\ell + \geq 2j (\geq 1b)$
$0.94 \pm 0.17 \pm 0.26 \pm 0.01$	<sup>1</sup> SIRUNYAN	19BX CMS	$C_{rk} + C_{kr}$ in $\ell\ell + \geq 2j (\geq 1b)$
$0.98 \pm 0.03 \pm 0.04 \pm 0.01$	<sup>1</sup> SIRUNYAN	19BX CMS	$(C_{kk} + C_{rr} + C_{nn})/3$ in $\ell\ell + \geq 2j (\geq 1b)$
$0.74 \pm 0.07 \pm 0.19^{+0.06}_{-0.08}$	<sup>1</sup> SIRUNYAN	19BX CMS	$A_{\cos\phi}^{lab}$ in $\ell\ell + \geq 2j (\geq 1b)$
$1.05 \pm 0.03 \pm 0.08^{+0.09}_{-0.12}$	<sup>1</sup> SIRUNYAN	19BX CMS	$A_{ \Delta\phi(\ell\ell) }$ in $\ell\ell + \geq 2j (\geq 1b)$
$1.12^{+0.12}_{-0.15}$	<sup>2</sup> KHACHATRY...16A	CMS	$\ell\ell + \geq 2j (\geq 1b)$
$0.72 \pm 0.08^{+0.15}_{-0.13}$	<sup>3</sup> KHACHATRY...16X	CMS	$\mu + 4,5j$
$1.20 \pm 0.05 \pm 0.13$	<sup>4</sup> AAD	15J ATLS	$\Delta\phi(\ell\ell)$ in $\ell\ell + \geq 2j (\geq 1b)$
$1.19 \pm 0.09 \pm 0.18$	<sup>5</sup> AAD	14BB ATLS	$\Delta\phi(\ell\ell)$ in $\ell\ell + \geq 2j$ events
$1.12 \pm 0.11 \pm 0.22$	<sup>5</sup> AAD	14BB ATLS	$\Delta\phi(\ell j)$ in $\ell + \geq 4j$ events
$0.87 \pm 0.11 \pm 0.14$	<sup>5,6</sup> AAD	14BB ATLS	S-ratio in $\ell\ell + \geq 2j$ events
$0.75 \pm 0.19 \pm 0.23$	<sup>5,7</sup> AAD	14BB ATLS	$\cos\theta(\ell^+) \cos\theta(\ell^-)$ in $\ell\ell + \geq 2j$ events

0.83±0.14±0.18      <sup>5,8</sup> AAD      14BB ATLS       $\cos\theta(\ell^+)\cos\theta(\ell^-)$  in  $\ell\ell + \geq 2j$  events

<sup>1</sup> SIRUNYAN 19BX based on 35.9 fb<sup>-1</sup> of  $pp$  data at  $\sqrt{s} = 13$  TeV. A set of parton-level normalized differential cross sections sensitive to coefficients of the spin-dependent  $t\bar{t}$  production density matrix is measured. The distributions and coefficients are compared with the NLO MC simulations and with the NLO QCD calculation including EW corrections. Three errors are from statistics, experimental systematics, and theory.

<sup>2</sup> KHACHATRYAN 16AI based on 19.5 fb<sup>-1</sup> of  $pp$  data at  $\sqrt{s} = 8$  TeV, using lepton angular distributions as a function of the  $t\bar{t}$ -system kinematical variables.

<sup>3</sup> KHACHATRYAN 16X based on 19.7 fb<sup>-1</sup> of  $pp$  data at  $\sqrt{s} = 8$  TeV. Uses a template fit method. Spin correlation strength in the helicity basis is given by  $A_{\text{hel}} = 0.23 \pm 0.03^{+0.05}_{-0.04}$ .

<sup>4</sup> AAD 15J based on 20.3 fb<sup>-1</sup> of  $pp$  data at  $\sqrt{s} = 8$  TeV. Uses a fit including a linear superposition of  $\Delta\phi$  distribution from the SM NLO simulation with coefficient  $f_{SM}$  and from  $t\bar{t}$  simulation without spin correlation with coefficient  $(1 - f_{SM})$ .

<sup>5</sup> Based on 4.6 fb<sup>-1</sup> of  $pp$  data at  $\sqrt{s} = 7$  TeV. The results are for  $m_t = 172.5$  GeV.

<sup>6</sup> The S-ratio is defined as the SM spin correlation in the like-helicity gluon-gluon collisions normalized to the no spin correlation case; see eq.(6) for the LO expression.

<sup>7</sup> The polar angle correlation along the helicity axis.

<sup>8</sup> The polar angle correlation along the direction which maximizes the correlation.

### $t$ -quark FCNC Couplings $\kappa^{utg}/\Lambda$ and $\kappa^{ctg}/\Lambda$

VALUE (TeV <sup>-1</sup> )	CL%	DOCUMENT ID	TECN	COMMENT
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• • • We do not use the following data for averages, fits, limits, etc. • • •

		<sup>1</sup> AAD	22T ATLS	$ug \rightarrow t, cg \rightarrow t$
<0.0041	95	<sup>2</sup> KHACHATRY...17G	CMS	$ \kappa^{tug} /\Lambda$
<0.018	95	<sup>2</sup> KHACHATRY...17G	CMS	$ \kappa^{tcg} /\Lambda$
<0.010	95	<sup>3</sup> AAD	16AS ATLS	$\kappa^{tug}/\Lambda$
<0.023	95	<sup>3</sup> AAD	16AS ATLS	$\kappa^{tcg}/\Lambda$
<0.0069	95	<sup>4</sup> AAD	12BP ATLS	$t^{tug}/\Lambda$ ( $t^{tcg} = 0$ )
<0.016	95	<sup>4</sup> AAD	12BP ATLS	$t^{tcg}/\Lambda$ ( $t^{tug} = 0$ )
<0.013	95	<sup>5</sup> ABAZOV	10K D0	$\kappa^{tug}/\Lambda$
<0.057	95	<sup>5</sup> ABAZOV	10K D0	$\kappa^{tcg}/\Lambda$
<0.018	95	<sup>6</sup> AALTONEN	09N CDF	$\kappa^{tug}/\Lambda$ ( $\kappa^{tcg} = 0$ )
<0.069	95	<sup>6</sup> AALTONEN	09N CDF	$\kappa^{tcg}/\Lambda$ ( $\kappa^{tug} = 0$ )
<0.037	95	<sup>7</sup> ABAZOV	07V D0	$\kappa^{utg}/\Lambda$
<0.15	95	<sup>7</sup> ABAZOV	07V D0	$\kappa^{ctg}/\Lambda$

<sup>1</sup> AAD 22T based on 139 fb<sup>-1</sup> of  $pp$  data at  $\sqrt{s} = 13$  TeV. The results are obtained from the 95% CL upper limits on the single top-quark productions  $\sigma(ug \rightarrow t) \cdot B(t \rightarrow bW) \cdot B(W \rightarrow \ell\nu) < 3.0$  pb and  $\sigma(cg \rightarrow t) \cdot B(t \rightarrow bW) \cdot B(W \rightarrow \ell\nu) < 4.7$  pb. These are interpreted as limits on couplings in an EFT  $|C_{uG}^{ut}|/\Lambda^2 < 0.057$  TeV<sup>-2</sup> and  $|C_{uG}^{ct}|/\Lambda^2 < 0.14$  TeV<sup>-2</sup>. The results also correspond to  $B(t \rightarrow ug) < 6.1 \times 10^{-5}$  and  $B(t \rightarrow cg) < 3.7 \times 10^{-4}$ .

<sup>2</sup> KHACHATRYAN 17G based on 5.0 and 19.7 fb<sup>-1</sup> of  $pp$  data at  $\sqrt{s} = 7$  and 8 TeV, respectively.  $t$ -channel single top production is used. The result corresponds to  $B(t \rightarrow ug) < 2.0 \times 10^{-5}$  or  $B(t \rightarrow cg) < 4.1 \times 10^{-4}$ .

<sup>3</sup> AAD 16AS based on 20.3 fb<sup>-1</sup> of  $pp$  data at  $\sqrt{s} = 8$  TeV. The results are obtained from the 95% CL upper limit on the single top-quark production  $\sigma(qg \rightarrow t) \cdot B(t \rightarrow bW) \cdot B(W \rightarrow l\nu) < 2.9$  pb,  $B(t \rightarrow ug) < 4.0 \times 10^{-5}$  and  $B(t \rightarrow cg) < 20 \times 10^{-5}$ .

- <sup>4</sup> Based on  $2.05 \text{ fb}^{-1}$  of  $pp$  data at  $\sqrt{s} = 7 \text{ TeV}$ . The results are obtained from the 95% CL upper limit on the single top-quark production  $\sigma(qg \rightarrow t) \cdot \text{B}(t \rightarrow bW) < 3.9 \text{ pb}$ , for  $q=u$  or  $q=c$ ,  $\text{B}(t \rightarrow ug) < 5.7 \times 10^{-5}$  and  $\text{B}(t \rightarrow ug) < 2.7 \times 10^{-4}$ .
- <sup>5</sup> Based on  $2.3 \text{ fb}^{-1}$  of data in  $p\bar{p}$  collisions at  $\sqrt{s} = 1.96 \text{ TeV}$ . Upper limit of single top quark production cross section  $0.20 \text{ pb}$  and  $0.27 \text{ pb}$  via FCNC  $t$ - $u$ - $g$  and  $t$ - $c$ - $g$  couplings, respectively, lead to the bounds without assuming the absence of the other coupling.  $\text{B}(t \rightarrow u + g) < 2.0 \times 10^{-4}$  and  $\text{B}(t \rightarrow c + g) < 3.9 \times 10^{-3}$  follow.
- <sup>6</sup> Based on  $2.2 \text{ fb}^{-1}$  of data in  $p\bar{p}$  collisions at  $\sqrt{s} = 1.96 \text{ TeV}$ . Upper limit of single top quark production cross section  $\sigma(u(c) + g \rightarrow t) < 1.8 \text{ pb}$  (95% CL) via FCNC  $t$ - $u$ - $g$  and  $t$ - $c$ - $g$  couplings lead to the bounds.  $\text{B}(t \rightarrow u + g) < 3.9 \times 10^{-4}$  and  $\text{B}(t \rightarrow c + g) < 5.7 \times 10^{-3}$  follow.
- <sup>7</sup> Result is based on  $230 \text{ pb}^{-1}$  of data at  $\sqrt{s} = 1.96 \text{ TeV}$ . Absence of single top quark production events via FCNC  $t$ - $u$ - $g$  and  $t$ - $c$ - $g$  couplings lead to the upper bounds on the dimensioned couplings,  $\kappa^{utg}/\Lambda$  and  $\kappa^{ctg}/\Lambda$ , respectively.

### $t$ -Quark Yukawa Coupling from $t\bar{t}$ Kinematic Distributions in $pp$ Collisions

The ratio of  $t$ -quark Yukawa coupling to its standard model predicted value.

VALUE	DOCUMENT ID	TECN	COMMENT
• • •	We do not use the following data for averages, fits, limits, etc. • • •		
$1.16^{+0.24}_{-0.35}$	<sup>1</sup> SIRUNYAN	20BH CMS	$\ell\ell$ ( $\ell=e,\mu$ ) + jets ( $\geq 2b_j$ ) + $\cancel{E}_T$
$1.07^{+0.34}_{-0.43}$	<sup>2</sup> SIRUNYAN	19BY CMS	$\ell$ +jets, $t\bar{t}$ threshold

- <sup>1</sup> SIRUNYAN 20BH based on  $137 \text{ fb}^{-1}$  of data at  $\sqrt{s} = 13 \text{ TeV}$ . Kinematic distributions of  $t\bar{t}$  are compared with predictions by different values of the top Yukawa coupling in loop corrections, where the scaling of the SM coupling is used within the  $\kappa$ -framework. The  $\cancel{E}_T$  cut applies only to the same-flavor dilepton, not  $e\mu$  events.
- <sup>2</sup> SIRUNYAN 19BY based on  $35.8 \text{ fb}^{-1}$  of data at  $\sqrt{s} = 13 \text{ TeV}$ . Experimental sensitivity is enhanced in the low  $M_{t\bar{t}}$  region. The distributions of  $M_{t\bar{t}}$ ,  $|y_t - y_{\bar{t}}|$ , and the number of reconstructed jets are compared with predictions by different Yukawa couplings which include NNLO QCD and NLO EW corrections.

### $\sigma(Ht\bar{t})/\sigma(Ht\bar{t})_{SM}$

VALUE	CL%	DOCUMENT ID	TECN	COMMENT
• • •	We do not use the following data for averages, fits, limits, etc. • • •			
$1.43^{+0.33+0.21}_{-0.31-0.15}$		<sup>1</sup> AAD	20Z ATLS	$Ht\bar{t}$ ( $H \rightarrow \gamma\gamma$ )
$1.38^{+0.29+0.21}_{-0.27-0.11}$		<sup>2</sup> SIRUNYAN	20AS CMS	$Ht\bar{t}$ ( $H \rightarrow \gamma\gamma$ )
$0.72 \pm 0.24 \pm 0.38$		<sup>3</sup> SIRUNYAN	19R CMS	$Ht\bar{t}$ ( $H \rightarrow b\bar{b}$ , $t\bar{t} \rightarrow \ell$ +jets or dilepton)
$0.9 \pm 0.7 \pm 1.3$		<sup>4</sup> SIRUNYAN	18BD CMS	$Ht\bar{t}$ ( $H \rightarrow b\bar{b}$ , $t\bar{t} \rightarrow$ all jets)
$1.26^{+0.31}_{-0.26}$		<sup>5</sup> SIRUNYAN	18L CMS	combination of CMS
$< 6.7$	95	<sup>6</sup> AAD	15 ATLS	$Ht\bar{t}$ ; $H \rightarrow \gamma\gamma$
$2.8 \pm 1.0$		<sup>7</sup> KHACHATRY...14H	CMS	$H \rightarrow b\bar{b}, \tau_h\tau_h, \gamma\gamma, WW/ZZ(\text{leptons})$

- <sup>1</sup> AAD 20Z based on  $139 \text{ fb}^{-1}$  of  $pp$  data at  $13 \text{ TeV}$ . Assuming a  $CP$ -even coupling the  $t\bar{t}H$  process is observed with a significance of  $5.2 \sigma$ , and the measured  $\sigma_{t\bar{t}H} \cdot B_{\gamma\gamma} = 1.64^{+0.38+0.17}_{-0.36-0.14} \text{ fb}$ . A  $CP$ -mixing angle  $|\alpha| > 43^\circ$  is excluded at 95% CL.



- <sup>2</sup> SIRUNYAN 20AS based on  $137 \text{ fb}^{-1}$  of  $pp$  data at 13 TeV. The  $t\bar{t}H$  process is observed with a significance of  $6.6 \sigma$ , and the measured  $\sigma_{t\bar{t}H} \cdot B_{\gamma\gamma} = 1.56^{+0.33+0.09}_{-0.30-0.08} \text{ fb}$ . The fractional contribution of the  $CP$ -odd component is measured to be  $f_{CP}^{t\bar{t}H} = 0.00 \pm 0.33$ .
- <sup>3</sup> SIRUNYAN 19R based on  $35.9 \text{ fb}^{-1}$  of  $pp$  data at 13 TeV. Multivariate techniques are employed to separate the signal from the dominant  $t\bar{t}$ +jets background. The result is for  $m_H = 125 \text{ GeV}$ . The measured ratio corresponds to a signal significance of  $1.6\sigma$  above the background-only hypothesis.
- <sup>4</sup> SIRUNYAN 18BD based on  $35.9 \text{ fb}^{-1}$  of  $pp$  data at 13 TeV. A combined fit of signal and background templates to data is performed in six event categories separated by jet and  $b$ -jet multiplicities. An upper limit of 3.8 is obtained for the cross section ratio.
- <sup>5</sup> SIRUNYAN 18L based on up to 5.1, 19.7, and  $35.9 \text{ fb}^{-1}$  of  $pp$  data at 7, 8, and 13 TeV, respectively. An excess of events is observed, with a significance of 5.2 standard deviations, over the expectation from the background-only hypothesis. The result is for the Higgs boson mass of 125.09 GeV.
- <sup>6</sup> Based on  $4.5 \text{ fb}^{-1}$  of data at 7 TeV and  $20.3 \text{ fb}^{-1}$  at 8 TeV. The result is for  $m_H = 125.4 \text{ GeV}$ . The measurement constrains the top quark Yukawa coupling strength parameter  $\kappa_t = Y_t/Y_t^{SM}$  to be  $-1.3 < \kappa_t < 8.0$  (95% CL).
- <sup>7</sup> Based on  $5.1 \text{ fb}^{-1}$  of  $pp$  data at 7 TeV and  $19.7 \text{ fb}^{-1}$  at 8 TeV. The results are obtained by assuming the SM decay branching fractions for the Higgs boson of mass 125.6 GeV. The signal strength for individual Higgs decay channels are given in Fig. 13, and the preferred region in the  $(\kappa_V, \kappa_f)$  space is given in Fig. 14.

### Single $t$ -Quark Production Cross Section in $p\bar{p}$ Collisions at $\sqrt{s} = 1.8 \text{ TeV}$

Direct probe of the  $tbW$  coupling and possible new physics at  $\sqrt{s} = 1.8 \text{ TeV}$ .

VALUE (pb)	CL%	DOCUMENT ID	TECN	COMMENT
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• • • We do not use the following data for averages, fits, limits, etc. • • •

<24	95	<sup>1</sup> ACOSTA	04H CDF	$p\bar{p} \rightarrow tb + X, tqb + X$
<18	95	<sup>2</sup> ACOSTA	02 CDF	$p\bar{p} \rightarrow tb + X$
<13	95	<sup>3</sup> ACOSTA	02 CDF	$p\bar{p} \rightarrow tqb + X$

<sup>1</sup> ACOSTA 04H bounds single top-quark production from the  $s$ -channel  $W$ -exchange process,  $q'\bar{q} \rightarrow t\bar{b}$ , and the  $t$ -channel  $W$ -exchange process,  $q'g \rightarrow qt\bar{b}$ . Based on  $\sim 106 \text{ pb}^{-1}$  of data.

<sup>2</sup> ACOSTA 02 bounds the cross section for single top-quark production via the  $s$ -channel  $W$ -exchange process,  $q'\bar{q} \rightarrow t\bar{b}$ . Based on  $\sim 106 \text{ pb}^{-1}$  of data.

<sup>3</sup> ACOSTA 02 bounds the cross section for single top-quark production via the  $t$ -channel  $W$ -exchange process,  $q'g \rightarrow qt\bar{b}$ . Based on  $\sim 106 \text{ pb}^{-1}$  of data.

### Single $t$ -Quark Production Cross Section in $p\bar{p}$ Collisions at $\sqrt{s} = 1.96 \text{ TeV}$

Direct probes of the  $tbW$  coupling and possible new physics at  $\sqrt{s} = 1.96 \text{ TeV}$ .

OUR AVERAGE assumes that the systematic uncertainties are uncorrelated.

VALUE (pb)	CL%	DOCUMENT ID	TECN	COMMENT
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• • • We do not use the following data for averages, fits, limits, etc. • • •

$3.53^{+1.25}_{-1.16}$		<sup>1</sup> AALTONEN	16 CDF	$s$ - + $t$ -channels ( $0\ell + \cancel{E}_T + 2,3j$ ( $\geq 1b$ -tag))
$2.25^{+0.29}_{-0.31}$		<sup>2</sup> AALTONEN	15H TEVA	$t$ -channel
$3.30^{+0.52}_{-0.40}$		<sup>2,3</sup> AALTONEN	15H TEVA	$s$ - + $t$ -channels
$1.12^{+0.61}_{-0.57}$		<sup>4</sup> AALTONEN	14K CDF	$s$ -channel ( $0\ell + \cancel{E}_T + 2,3j$ ( $\geq 1b$ -tag))

$1.41^{+0.44}_{-0.42}$		<sup>5</sup>	AALTONEN	14L	CDF	$s$ -channel ( $\ell + \cancel{E}_T + 2j$ ( $\geq 1b$ -tag))
$1.29^{+0.26}_{-0.24}$		<sup>6</sup>	AALTONEN	14M	TEVA	$s$ -channel (CDF + D0)
$3.04^{+0.57}_{-0.53}$		<sup>7</sup>	AALTONEN	14O	CDF	$s + t + Wt$ ( $\ell + \cancel{E}_T + 2$ or 3 jets ( $\geq 1b$ -tag))
$1.10^{+0.33}_{-0.31}$		<sup>8</sup>	ABAZOV	13O	D0	$s$ -channel
$3.07^{+0.54}_{-0.49}$		<sup>8</sup>	ABAZOV	13O	D0	$t$ -channel
$4.11^{+0.60}_{-0.55}$		<sup>8</sup>	ABAZOV	13O	D0	$s$ - + $t$ -channels
$0.98 \pm 0.63$		<sup>9</sup>	ABAZOV	11AA	D0	$s$ -channel
$2.90 \pm 0.59$		<sup>9</sup>	ABAZOV	11AA	D0	$t$ -channel
$3.43^{+0.73}_{-0.74}$		<sup>10</sup>	ABAZOV	11AD	D0	$s$ - + $t$ -channels
$1.8^{+0.7}_{-0.5}$		<sup>11</sup>	AALTONEN	10AB	CDF	$s$ -channel
$0.8 \pm 0.4$		<sup>11</sup>	AALTONEN	10AB	CDF	$t$ -channel
$4.9^{+2.5}_{-2.2}$		<sup>12</sup>	AALTONEN	10U	CDF	$\cancel{E}_T$ + jets decay
$3.14^{+0.94}_{-0.80}$		<sup>13</sup>	ABAZOV	10	D0	$t$ -channel
$1.05 \pm 0.81$		<sup>13</sup>	ABAZOV	10	D0	$s$ -channel
$< 7.3$	95	<sup>14</sup>	ABAZOV	10J	D0	$\tau$ + jets decay
$2.3^{+0.6}_{-0.5}$		<sup>15</sup>	AALTONEN	09AT	CDF	$s$ - + $t$ -channel
$3.94 \pm 0.88$		<sup>16</sup>	ABAZOV	09Z	D0	$s$ - + $t$ -channel
$2.2^{+0.7}_{-0.6}$		<sup>17</sup>	AALTONEN	08AH	CDF	$s$ - + $t$ -channel
$4.7 \pm 1.3$		<sup>18</sup>	ABAZOV	08I	D0	$s$ - + $t$ -channel
$4.9 \pm 1.4$		<sup>19</sup>	ABAZOV	07H	D0	$s$ - + $t$ -channel
$< 6.4$	95	<sup>20</sup>	ABAZOV	05P	D0	$p\bar{p} \rightarrow tb + X$
$< 5.0$	95	<sup>20</sup>	ABAZOV	05P	D0	$p\bar{p} \rightarrow tqb + X$
$< 10.1$	95	<sup>21</sup>	ACOSTA	05N	CDF	$p\bar{p} \rightarrow tqb + X$
$< 13.6$	95	<sup>21</sup>	ACOSTA	05N	CDF	$p\bar{p} \rightarrow tb + X$
$< 17.8$	95	<sup>21</sup>	ACOSTA	05N	CDF	$p\bar{p} \rightarrow tb + X, tqb + X$

<sup>1</sup> AALTONEN 16 based on  $9.5 \text{ fb}^{-1}$  of data. This includes, as a part, the result of AALTONEN 14K. Combination of this result with that of AALTONEN 14O gives a  $s + t$  cross section of  $3.02^{+0.49}_{-0.48} \text{ pb}$  and  $|V_{tb}| > 0.84$  (95% CL).

<sup>2</sup> AALTONEN 15H based on  $9.7 \text{ fb}^{-1}$  of data per experiment. The result is for  $m_t = 172.5 \text{ GeV}$ , and is a combination of the CDF measurements (AALTONEN 16) and the D0 measurements (ABAZOV 13O) on the  $t$ -channel single  $t$ -quark production cross section. The result is consistent with the NLO+NNLL SM prediction and gives  $|V_{tb}| = 1.02^{+0.06}_{-0.05}$  and  $|V_{tb}| > 0.92$  (95% CL).

<sup>3</sup> AALTONEN 15H is a combined measurement of  $s$ -channel single top cross section by CDF + D0. AALTONEN 14M is not included.

<sup>4</sup> Based on  $9.45 \text{ fb}^{-1}$  of data, using neural networks to separate signal from backgrounds. The result is for  $m_t = 172.5 \text{ GeV}$ . Combination of this result with the CDF measurement in the 1 lepton channel AALTONEN 14L gives  $1.36^{+0.37}_{-0.32} \text{ pb}$ , consistent with the SM prediction, and is 4.2 sigma away from the background only hypothesis.

<sup>5</sup> Based on  $9.4 \text{ fb}^{-1}$  of data, using neural networks to separate signal from backgrounds. The result is for  $m_t = 172.5 \text{ GeV}$ . The result is 3.8 sigma away from the background only hypothesis.

- <sup>6</sup> Based on  $9.7 \text{ fb}^{-1}$  of data per experiment. The result is for  $m_t = 172.5 \text{ GeV}$ , and is a combination of the CDF measurements AALTONEN 14L, AALTONEN 14K and the D0 measurement ABAZOV 130 on the  $s$ -channel single  $t$ -quark production cross section. The result is consistent with the SM prediction of  $1.05 \pm 0.06 \text{ pb}$  and the significance of the observation is of 6.3 standard deviations.
- <sup>7</sup> Based on  $7.5 \text{ fb}^{-1}$  of data. Neural network is used to discriminate signals ( $s$ -,  $t$ - and  $Wt$ -channel single top production) from backgrounds. The result is consistent with the SM prediction, and gives  $|V_{tb}| = 0.95 \pm 0.09(\text{stat} + \text{syst}) \pm 0.05(\text{theory})$  and  $|V_{tb}| > 0.78$  (95% CL). The result is for  $m_t = 172.5 \text{ GeV}$ .
- <sup>8</sup> Based on  $9.7 \text{ fb}^{-1}$  of data. Events with  $\ell + \cancel{E}_T + 2$  or 3 jets (1 or 2  $b$ -tag) are analysed, assuming  $m_t = 172.5 \text{ GeV}$ . The combined  $s$ - +  $t$ -channel cross section gives  $|V_{tb} f_1^L| = 1.12_{-0.08}^{+0.09}$ , or  $|V_{tb}| > 0.92$  at 95% CL for  $f_1^L = 1$  and a flat prior within  $0 \leq |V_{tb}|^2 \leq 1$ .
- <sup>9</sup> Based on  $5.4 \text{ fb}^{-1}$  of data. The error is statistical + systematic combined. The results are for  $m_t = 172.5 \text{ GeV}$ . Results for other  $m_t$  values are given in Table 2 of ABAZOV 11AA.
- <sup>10</sup> Based on  $5.4 \text{ fb}^{-1}$  of data and for  $m_t = 172.5 \text{ GeV}$ . The error is statistical + systematic combined. Results for other  $m_t$  values are given in Table III of ABAZOV 11AD. The result is obtained by assuming the SM ratio between  $tb$  ( $s$ -channel) and  $tqb$  ( $t$ -channel) productions, and gives  $|V_{tb} f_1^L| = 1.02_{-0.11}^{+0.10}$ , or  $|V_{tb}| > 0.79$  at 95% CL for a flat prior within  $0 < |V_{tb}|^2 < 1$ .
- <sup>11</sup> Based on  $3.2 \text{ fb}^{-1}$  of data. For combined  $s$ - +  $t$ -channel result see AALTONEN 09AT.
- <sup>12</sup> Result is based on  $2.1 \text{ fb}^{-1}$  of data. Events with large missing  $E_T$  and jets with at least one  $b$ -jet without identified electron or muon are selected. Result is obtained when observed  $2.1 \sigma$  excess over the background originates from the signal for  $m_t = 175 \text{ GeV}$ , giving  $|V_{tb}| = 1.24_{-0.29}^{+0.34} \pm 0.07(\text{theory})$ .
- <sup>13</sup> Result is based on  $2.3 \text{ fb}^{-1}$  of data. Events with isolated  $\ell + \cancel{E}_T + 2, 3, 4$  jets with one or two  $b$ -tags are selected. The analysis assumes  $m_t = 170 \text{ GeV}$ .
- <sup>14</sup> Result is based on  $4.8 \text{ fb}^{-1}$  of data. Events with an isolated reconstructed tau lepton, missing  $E_T + 2, 3$  jets with one or two  $b$ -tags are selected. When combined with ABAZOV 09Z result for  $e + \mu$  channels, the  $s$ - and  $t$ -channels combined cross section is  $3.84_{-0.83}^{+0.89} \text{ pb}$ .
- <sup>15</sup> Based on  $3.2 \text{ fb}^{-1}$  of data. Events with isolated  $\ell + \cancel{E}_T +$  jets with at least one  $b$ -tag are analyzed and  $s$ - and  $t$ -channel single top events are selected by using the likelihood function, matrix element, neural-network, boosted decision tree, likelihood function optimized for  $s$ -channel process, and neural-networked based analysis of events with  $\cancel{E}_T$  that has sensitivity for  $W \rightarrow \tau\nu$  decays. The result is for  $m_t = 175 \text{ GeV}$ , and the mean value decreases by  $0.02 \text{ pb/GeV}$  for smaller  $m_t$ . The signal has 5.0 sigma significance. The result gives  $|V_{tb}| = 0.91 \pm 0.11 (\text{stat+syst}) \pm 0.07 (\text{theory})$ , or  $|V_{tb}| > 0.71$  at 95% CL.
- <sup>16</sup> Based on  $2.3 \text{ fb}^{-1}$  of data. Events with isolated  $\ell + \cancel{E}_T + \geq 2$  jets with 1 or 2  $b$ -tags are analyzed and  $s$ - and  $t$ -channel single top events are selected by using boosted decision tree, Bayesian neural networks and the matrix element method. The signal has 5.0 sigma significance. The result gives  $|V_{tb}| = 1.07 \pm 0.12$ , or  $|V_{tb}| > 0.78$  at 95% CL. The analysis assumes  $m_t = 170 \text{ GeV}$ .
- <sup>17</sup> Result is based on  $2.2 \text{ fb}^{-1}$  of data. Events with isolated  $\ell + \cancel{E}_T + 2, 3$  jets with at least one  $b$ -tag are selected, and  $s$ - and  $t$ -channel single top events are selected by using likelihood, matrix element, and neural network discriminants. The result can be interpreted as  $|V_{tb}| = 0.88_{-0.12}^{+0.13}(\text{stat} + \text{syst}) \pm 0.07(\text{theory})$ , and  $|V_{tb}| > 0.66$  (95% CL) under the  $|V_{tb}| < 1$  constraint.

- <sup>18</sup> Result is based on  $0.9 \text{ fb}^{-1}$  of data. Events with isolated  $\ell + \cancel{E}_T + 2, 3, 4$  jets with one or two  $b$ -vertex-tag are selected, and contributions from  $W + \text{jets}$ ,  $t\bar{t}$ ,  $s$ - and  $t$ -channel single top events are identified by using boosted decision trees, Bayesian neural networks, and matrix element analysis. The result can be interpreted as the measurement of the CKM matrix element  $|V_{tb}| = 1.31^{+0.25}_{-0.21}$ , or  $|V_{tb}| > 0.68$  (95% CL) under the  $|V_{tb}| < 1$  constraint.
- <sup>19</sup> Result is based on  $0.9 \text{ fb}^{-1}$  of data. This result constrains  $V_{tb}$  to  $0.68 < |V_{tb}| \leq 1$  at 95% CL.
- <sup>20</sup> ABAZOV 05P bounds single top-quark production from either the  $s$ -channel  $W$ -exchange process,  $q'\bar{q} \rightarrow t\bar{b}$ , or the  $t$ -channel  $W$ -exchange process,  $q'g \rightarrow qt\bar{b}$ , based on  $\sim 230 \text{ pb}^{-1}$  of data.
- <sup>21</sup> ACOSTA 05N bounds single top-quark production from the  $t$ -channel  $W$ -exchange process ( $q'g \rightarrow qt\bar{b}$ ), the  $s$ -channel  $W$ -exchange process ( $q'\bar{q} \rightarrow t\bar{b}$ ), and from the combined cross section of  $t$ - and  $s$ -channel. Based on  $\sim 162 \text{ pb}^{-1}$  of data.

### t-channel Single $t$ Production Cross Section in $pp$ Collisions at $\sqrt{s} = 7 \text{ TeV}$

Direct probe of the  $tbW$  coupling and possible new physics at  $\sqrt{s} = 7 \text{ TeV}$ .

VALUE (pb)	DOCUMENT ID	TECN	COMMENT
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●			
$67.5 \pm 5.7$	<sup>1</sup> AABOUD	19R LHC	combination of ATLAS+CMS
$68 \pm 2 \pm 8$	<sup>2</sup> AAD	14BI ATLS	$\ell + \cancel{E}_T + 2j$ or $3j$
$83 \pm 4 \begin{smallmatrix} +20 \\ -19 \end{smallmatrix}$	<sup>3</sup> AAD	12CH ATLS	$t$ -channel $\ell + \cancel{E}_T + (2,3)j$ (1b)
$67.2 \pm 6.1$	<sup>4</sup> CHATRCHYAN12BQ	CMS	$t$ -channel $\ell + \cancel{E}_T + \geq 2j$ (1b)
$83.6 \pm 29.8 \pm 3.3$	<sup>5</sup> CHATRCHYAN11R	CMS	$t$ -channel

- <sup>1</sup> AABOUD 19R based on  $1.17$  to  $5.1 \text{ fb}^{-1}$  of data from ATLAS and CMS at  $7 \text{ TeV}$ .
- <sup>2</sup> Based on  $4.59 \text{ fb}^{-1}$  of data, using neural networks for signal and background separation.  $\sigma(tq) = 46 \pm 1 \pm 6 \text{ pb}$  and  $\sigma(\bar{t}q) = 23 \pm 1 \pm 3 \text{ pb}$  are separately measured, as well as their ratio  $R = \sigma(tq)/\sigma(\bar{t}q) = 2.04 \pm 0.13 \pm 0.12$ . The results are for  $m_t = 172.5 \text{ GeV}$ , and those for other  $m_t$  values are given by eq.(4) and Table IV. The measurements give  $|V_{tb}| = 1.02 \pm 0.07$  or  $|V_{tb}| > 0.88$  (95% CL).
- <sup>3</sup> Based on  $1.04 \text{ fb}^{-1}$  of data. The result gives  $|V_{tb}| = 1.13^{+0.14}_{-0.13}$  from the ratio  $\sigma(\text{exp})/\sigma(\text{th})$ , where  $\sigma(\text{th})$  is the SM prediction for  $|V_{tb}| = 1$ . The 95% CL lower bound of  $|V_{tb}| > 0.75$  is found if  $|V_{tb}| < 1$  is assumed.  $\sigma(t) = 59^{+18}_{-16} \text{ pb}$  and  $\sigma(\bar{t}) = 33^{+13}_{-12} \text{ pb}$  are found for the separate single  $t$  and  $\bar{t}$  production cross sections, respectively. The results assume  $m_t = 172.5 \text{ GeV}$  for the acceptance.
- <sup>4</sup> Based on  $1.17 \text{ fb}^{-1}$  of data for  $\ell = \mu$ ,  $1.56 \text{ fb}^{-1}$  of data for  $\ell = e$  at  $7 \text{ TeV}$  collected during 2011. The result gives  $|V_{tb}| = 1.020 \pm 0.046(\text{meas}) \pm 0.017(\text{th})$ . The 95% CL lower bound of  $|V_{tb}| > 0.92$  is found if  $|V_{tb}| < 1$  is assumed. The results assume  $m_t = 172.5 \text{ GeV}$  for the acceptance.
- <sup>5</sup> Based on  $36 \text{ pb}^{-1}$  of data. The first error is statistical + systematic combined, the second is luminosity. The result gives  $|V_{tb}| = 1.114 \pm 0.22(\text{exp}) \pm 0.02(\text{th})$  from the ratio  $\sigma(\text{exp})/\sigma(\text{th})$ , where  $\sigma(\text{th})$  is the SM prediction for  $|V_{tb}| = 1$ . The 95% CL lower bound of  $|V_{tb}| > 0.62$  (0.68) is found from the 2D (BDT) analysis under the constraint  $0 < |V_{tb}|^2 < 1$ .

### t-channel Single $t$ Production Cross Section in $pp$ Collisions at $\sqrt{s} = 8 \text{ TeV}$

VALUE (pb)	DOCUMENT ID	TECN	COMMENT
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●			
$87.7 \pm 5.8$	<sup>1</sup> AABOUD	19R LHC	combination of ATLAS+CMS
$89.6 \begin{smallmatrix} +7.1 \\ -6.3 \end{smallmatrix}$	<sup>2</sup> AABOUD	17T ATLS	$\ell + \cancel{E}_T + 2j$ (1b j)

- $83.6 \pm 2.3 \pm 7.4$  <sup>3</sup> KHACHATRY...14F CMS  $\ell + \cancel{E}_T + \geq 2 j$  (1,2 b, 1 forward j)
- <sup>1</sup> AABOUD 19R based on 12.2 to 20.3 fb<sup>-1</sup> of data from ATLAS and CMS at 8 TeV.
- <sup>2</sup> AABOUD 17T based on 20.2 fb<sup>-1</sup> of data. A maximum-likelihood fit to neural-network discriminant distributions is used to separate signal and background events. Individual cross sections are measured as  $\sigma(tq) = 56.7_{-3.8}^{+4.3}$  pb and  $\sigma(\bar{t}q) = 32.9_{-2.7}^{+3.0}$  pb, while their ratio is given by  $\sigma(tq)/\sigma(\bar{t}q) = 1.72 \pm 0.09$ . A lower limit  $|V_{tb}| > 0.92$  (95% CL) is obtained. Measured total and differential cross sections are described well by the SM.
- <sup>3</sup> Based on 19.7 fb<sup>-1</sup> of data. The  $t$  and  $\bar{t}$  production cross sections are measured separately as  $\sigma_{t-ch.}(t) = 53.8 \pm 1.5 \pm 4.4$  pb and  $\sigma_{t-ch.}(\bar{t}) = 27.6 \pm 1.3 \pm 3.7$  pb, respectively, as well as their ratio  $R_{t-ch.} = \sigma_{t-ch.}(t)/\sigma_{t-ch.}(\bar{t}) = 1.95 \pm 0.10 \pm 0.19$ , in agreement with the SM predictions. Combination with a previous CMS result at  $\sqrt{s} = 7$  TeV [CHATRCHYAN 12BQ] gives  $|V_{tb}| = 0.998 \pm 0.038 \pm 0.016$ . Also obtained is the ratio  $R_{8/7} = \sigma_{t-ch.}(8\text{TeV})/\sigma_{t-ch.}(7\text{TeV}) = 1.24 \pm 0.08 \pm 0.12$ .

### s-channel Single $t$ Production Cross Section in $pp$ Collisions at $\sqrt{s} = 8$ TeV

VALUE (pb)	DOCUMENT ID	TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •			
$4.9 \pm 1.4$	<sup>1</sup> AABOUD	19R LHC	ATLAS + CMS
$4.8 \pm 0.8_{-1.3}^{+1.6}$	<sup>2</sup> AAD	16U ATLS	$\ell + \cancel{E}_T + 2b$
$13.4 \pm 7.3$	<sup>3</sup> KHACHATRY...16AZ	CMS	$\ell + \cancel{E}_T + 2b$
$5.0 \pm 4.3$	<sup>4</sup> AAD	15A ATLS	$\ell + \cancel{E}_T + 2b$

- <sup>1</sup> AABOUD 19R based on 12.2 to 20.3 fb<sup>-1</sup> of data from ATLAS and CMS at 8 TeV.
- <sup>2</sup> AAD 16U based on 20.3 fb<sup>-1</sup> of data, using a maximum-likelihood fit of a matrix element method discriminant. The same data set as in AAD 15A is used. The result corresponds to an observed significance of  $3.2\sigma$ .
- <sup>3</sup> KHACHATRYAN 16AZ based on 19.7 fb<sup>-1</sup> of data, using a multivariate analysis to separate signal and backgrounds. The same method is applied to 5.1 fb<sup>-1</sup> of data at  $\sqrt{s} = 7$  TeV, giving  $7.1 \pm 8.1$  pb. Combining both measurements, the observed significance is  $2.5\sigma$ . A best fit value of  $2.0 \pm 0.9$  is obtained for the combined ratio of the measured values and SM expectations.
- <sup>4</sup> AAD 15A based on 20.3 fb<sup>-1</sup> of data, using a multivariate analysis to separate signal and backgrounds. The 95% CL upper bound of the cross section is 14.6 pb. The results are consistent with the SM prediction of  $5.61 \pm 0.22$  pb at approximate NNLO.

### t-channel Single $t$ Production Cross Section in $pp$ Collisions at $\sqrt{s} = 13$ TeV

VALUE (pb)	DOCUMENT ID	TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •			
$130 \pm 1 \pm 19$	<sup>1</sup> SIRUNYAN	20D CMS	$\sigma(tq), \ell + \cancel{E}_T + \geq 2 j$
$77 \pm 1 \pm 12$	<sup>1</sup> SIRUNYAN	20D CMS	$\sigma(\bar{t}q), \ell + \cancel{E}_T + \geq 2 j$
$156 \pm 5 \pm 27 \pm 3$	<sup>2</sup> AABOUD	17H ATLS	$\sigma(tq), \ell + \cancel{E}_T + 2 j$ (1b, 1 forward j)
$91 \pm 4 \pm 18 \pm 2$	<sup>2</sup> AABOUD	17H ATLS	$\sigma(\bar{t}q), \ell + \cancel{E}_T + 2 j$ (1b, 1 forward j)
$154 \pm 8 \pm 9 \pm 19 \pm 4$	<sup>3</sup> SIRUNYAN	17AA CMS	$\sigma(tq), \mu + \geq 2 j$ (1b)
$85 \pm 10 \pm 4 \pm 11 \pm 2$	<sup>3</sup> SIRUNYAN	17AA CMS	$\sigma(\bar{t}q), \mu + \geq 2 j$ (1b)

- <sup>1</sup> SIRUNYAN 20D based on 35.9 fb<sup>-1</sup> of data. Different categories of jet and b jet multiplicity and multivariate discriminators are used to separate signal and background events. The cross section ratio is measured to be  $\sigma(tq)/\sigma(\bar{t}q) = 1.68 \pm 0.02 \pm 0.05$ . CKM matrix element is obtained as  $|f_{LV} V_{tb}| = 0.98 \pm 0.07(\text{exp}) \pm 0.02(\text{theo})$  where  $f_{LV}$  is an anomalous form factor. All results are in agreement with the SM.
- <sup>2</sup> AABOUD 17H based on 3.2 fb<sup>-1</sup> of data. A maximum-likelihood fit to neural-network discriminant distributions is used to separate signal and background events. The third

error is for luminosity. The cross section ratio is measured to be  $\sigma(tq)/\sigma(\bar{t}q) = 1.72 \pm 0.09 \pm 0.18$ . A lower limit  $|V_{tb}| > 0.84$  (95% CL) is obtained. All results are in agreement with the SM.

<sup>3</sup>SIRUNYAN 17AA based on  $2.2 \text{ fb}^{-1}$  of data. A multivariate discriminator is used to separate signal and background events. The four errors are from statistics, experimental systematics, theory, and luminosity. The cross section ratio is measured to be  $\sigma(tq)/\sigma(\bar{t}q) = 1.81 \pm 0.18 \pm 0.15$ . CKM matrix element is obtained as  $|V_{tb}| = 1.05 \pm 0.07(\text{exp}) \pm 0.02(\text{theo})$ . All results are in agreement with the SM.

### $t\bar{t}H$ Production Cross Section in $pp$ Collisions at $\sqrt{s} = 13 \text{ TeV}$

VALUE (fb)	DOCUMENT ID	TECN	COMMENT
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• • • We do not use the following data for averages, fits, limits, etc. • • •

$33 \pm 31^{+22}_{-17}$	<sup>1</sup> AAD	22Q ATLS	$H \rightarrow \tau\tau$
$670 \pm 90^{+110}_{-100}$	<sup>2</sup> AABOUD	18BK ATLS	$H \rightarrow b\bar{b}, WW^* \tau\tau, \gamma\gamma, ZZ^*$

<sup>1</sup>AAD 22Q based on  $139 \text{ fb}^{-1}$  of data. The measured value includes  $B(H \rightarrow \tau\tau)$  and corresponds to the rapidity range  $|y_H| < 2.5$ . The value is consistent with the SM prediction, where  $B(H \rightarrow \tau\tau) = 6.3\%$  for  $m_H = 125.09 \text{ GeV}$ .

<sup>2</sup>AABOUD 18BK based on  $79.8 \text{ fb}^{-1}$  of data. The observed significance is  $5.8\sigma$  relative to the background-only hypothesis. The measurement is consistent with the NLO SM prediction of  $507^{+35}_{-50} \text{ fb}$ . See Table 3 and Fig. 5 for measurements of individual modes. Combined with the measurements at 7 and 8 TeV, the observed significance is  $6.3\sigma$ .

### $Wt$ Production Cross Section in $pp$ Collisions at $\sqrt{s} = 7 \text{ TeV}$

VALUE (pb)	DOCUMENT ID	TECN	COMMENT
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• • • We do not use the following data for averages, fits, limits, etc. • • •

$16.3 \pm 4.1$	<sup>1</sup> AABOUD	19R LHC	ATLAS + CMS combined
$16^{+5}_{-4}$	<sup>2</sup> CHATRCHYAN	13C CMS	$t+W$ channel, $2\ell + \cancel{E}_T + 1b$

<sup>1</sup>AABOUD 19R based on 1.17 to  $5.1 \text{ fb}^{-1}$  of data from ATLAS and CMS at 7 TeV.

<sup>2</sup>Based on  $4.9 \text{ fb}^{-1}$  of data. The result gives  $V_{tb} = 1.01^{+0.16}_{-0.13}(\text{exp})^{+0.03}_{-0.04}(\text{th})$ .  $V_{tb} > 0.79$  (95% CL) if  $V_{tb} < 1$  is assumed. The results assume  $m_t = 172.5 \text{ GeV}$  for the acceptance.

### $Wt$ Production Cross Section in $pp$ Collisions at $\sqrt{s} = 8 \text{ TeV}$

VALUE (pb)	DOCUMENT ID	TECN	COMMENT
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• • • We do not use the following data for averages, fits, limits, etc. • • •

$26 \pm 7$	<sup>1</sup> AAD	21AT ATLS	$\ell + \geq 3j$
$23.1 \pm 3.6$	<sup>2</sup> AABOUD	19R LHC	ATLAS + CMS combined
$23.0 \pm 1.3^{+3.2}_{-3.5} \pm 1.1$	<sup>3</sup> AAD	16B ATLS	$2\ell + \cancel{E}_T + 1b$
$23.4 \pm 5.4$	<sup>4</sup> CHATRCHYAN	14AC CMS	$t+W$ channel, $2\ell + \cancel{E}_T + 1b$

<sup>1</sup>AAD 21AT based on  $20.2 \text{ fb}^{-1}$  of data. In this single lepton channel, only single neutrino is emitted, so that both  $W$  and  $t$  can be reconstructed. A neural network is trained to separate signal from background. The measured cross section agrees with the NLO+NNLL SM prediction of  $22.4 \pm 0.6(\text{scale}) \pm 1.4(\text{PDF}) \text{ pb}$ .

<sup>2</sup>AABOUD 19R based on 12.2 to  $20.3 \text{ fb}^{-1}$  of data from ATLAS and CMS at 8 TeV.

<sup>3</sup>AAD 16B based on  $20.3 \text{ fb}^{-1}$  of data. The result gives  $|V_{tb}| = 1.01 \pm 0.10$  and  $|V_{tb}| > 0.80$  (95% CL) without assuming unitarity of the CKM matrix. The results assume  $m_t = 172.5 \text{ GeV}$  for the acceptance.

<sup>4</sup>Based on  $12.2 \text{ fb}^{-1}$  of data. Events with two oppositely charged leptons, large  $\cancel{E}_T$  and a  $b$ -tagged jet are selected, and a multivariate analysis is used to separate the signal from the backgrounds. The result is consistent with the SM prediction of  $22.2 \pm 0.6(\text{scale}) \pm 1.4(\text{PDF}) \text{ pb}$  at approximate NNLO.

### **$Wt$ Production Cross Section in $pp$ Collisions at $\sqrt{s} = 13$ TeV**

<u>VALUE (pb)</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
• • • We do not use the following data for averages, fits, limits, etc. • • •			
89 ± 4 ± 12	<sup>1</sup> TUMASYAN	21E CMS	1ℓ + jets
94 ± 10 <sup>+28</sup> / <sub>-22</sub> ± 2	<sup>2</sup> AABOUD	18H ATLS	ℓ <sup>+</sup> ℓ <sup>-</sup> + ≥ 1j
63.1 ± 1.8 ± 6.4 ± 2.1	<sup>3</sup> SIRUNYAN	18DL CMS	e <sup>±</sup> μ <sup>∓</sup> + ≥ 1j( <i>b</i> -tag)

<sup>1</sup> TUMASYAN 21E based on 36 fb<sup>-1</sup> of data. A boosted decision tree is used to separate the signal from the dominant  $t\bar{t}$  backgrounds. The result corresponds to an observation with a significance exceeding 5  $\sigma$  and is consistent with the NNLO QCD prediction of 71.7 ± 1.8(scale) ± 3.4(PDF) pb or with the approximate NNNLO SM prediction of 79.5 <sup>+1.9</sup>/<sub>-1.8</sub>(scale) <sup>+2.0</sup>/<sub>-1.4</sub>(PDF) pb.

<sup>2</sup> AABOUD 18H based on 3.2 fb<sup>-1</sup> of data. The last error is from luminosity. A multivariate analysis is used to separate the signal from the backgrounds. The result is consistent with the NLO+NNLL SM prediction of 71.7 ± 1.8(scale) ± 3.4(PDF) pb.

<sup>3</sup> SIRUNYAN 18DL based on 35.9 fb<sup>-1</sup> of data. The last error is from luminosity. A multivariate analysis is used to separate the signal from the backgrounds. The result is consistent with the NLO+NNLL SM prediction of 71.7 ± 1.8(scale) ± 3.4(PDF) pb.

### **$Zt$ Production Cross Section in $pp$ Collisions at $\sqrt{s} = 13$ TeV**

<u>VALUE (fb)</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
• • • We do not use the following data for averages, fits, limits, etc. • • •			
87.9 <sup>+7.5</sup> / <sub>-7.3</sub> <sup>+7.3</sup> / <sub>-6.0</sub>	<sup>1</sup> TUMASYAN	22L CMS	3ℓ + ≥ 2j (≥ 1bj)
97 ± 13 ± 7	<sup>2</sup> AAD	20AB ATLS	3ℓ + 1,2j + 1bj
111 ± 13 <sup>+11</sup> / <sub>-9</sub>	<sup>3</sup> SIRUNYAN	19BF CMS	3ℓ + ≥ 2j (≥ 1bj)
600 ± 170 ± 140	<sup>4</sup> AABOUD	18AE ATLS	3ℓ + 1j + 1bj
123 <sup>+33</sup> / <sub>-31</sub> <sup>+29</sup> / <sub>-23</sub>	<sup>5</sup> SIRUNYAN	18Z CMS	3ℓ + 1j + 1bj

<sup>1</sup> TUMASYAN 22L based on 138 fb<sup>-1</sup> of data at 13 TeV. The result is for a dilepton invariant masses above 30 GeV. It agrees with the NLO SM prediction of 94.2 <sup>+1.9</sup>/<sub>-1.8</sub>(scale) ± 2.5(PDF) fb. The ratio of  $t$  and  $\bar{t}$  production cross sections is measured as 2.37 <sup>+0.56</sup>/<sub>-0.42</sub> <sup>+0.27</sup>/<sub>-0.13</sub>. The spin asymmetry is measured to be 0.54 ± 0.16 ± 0.06. Both measurements are in agreement with the SM predictions.

<sup>2</sup> AAD 20AB based on 139 fb<sup>-1</sup> of data at 13 TeV. Neural networks are used to discriminate  $tZq$  signal from backgrounds. The result is for the cross section  $\sigma(pp \rightarrow t\ell^+\ell^-q)$ , including non-resonant dilepton pairs, for dilepton invariant masses above 30 GeV and is consistent with the NLO SM prediction of 102 <sup>+5</sup>/<sub>-2</sub> fb.

<sup>3</sup> SIRUNYAN 19BF based on 77.4 fb<sup>-1</sup> of data. Two BDT's are used in the analysis: one to discriminate prompt leptons from non-prompt ones; and one to discriminate  $tZq$  signal from backgrounds. The result is for the cross section  $\sigma(pp \rightarrow tZq \rightarrow t\ell^+\ell^-q)$  for dilepton invariant masses above 30 GeV and is consistent with the NLO SM prediction of 94.2 ± 3.1 fb.

<sup>4</sup> AABOUD 18AE based on 36.1 fb<sup>-1</sup> of data. A multivariate analysis is used to separate the signal from the backgrounds. The result is consistent with the NLO SM prediction of 800 fb with a scale uncertainty of <sup>+6.1</sup>/<sub>-7.4</sub>%.

<sup>5</sup> SIRUNYAN 18Z based on 35.9 fb<sup>-1</sup> of data. A multivariate analysis is used to separate the signal from the backgrounds. The result is for the cross section  $\sigma(pp \rightarrow tZq \rightarrow Wb\ell^+\ell^-q)$  and is consistent with the NLO SM prediction of 94.2 <sup>+1.9</sup>/<sub>-1.8</sub>(scale) ± 2.5(PDF) fb. Superseded by SIRUNYAN 19BF.

### Single $t$ -Quark Production Cross Section in $e p$ Collisions

VALUE (pb)	CL%	DOCUMENT ID	TECN	COMMENT
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●				
<0.25	95	<sup>1</sup> AARON	09A H1	$e^\pm p \rightarrow e^\pm t X$
<0.55	95	<sup>2</sup> AKTAS	04 H1	$e^\pm p \rightarrow e^\pm t X$
<0.225	95	<sup>3</sup> CHEKANOV	03 ZEUS	$e^\pm p \rightarrow e^\pm t X$

<sup>1</sup> AARON 09A looked for single top production via FCNC in  $e^\pm p$  collisions at HERA with  $474 \text{ pb}^{-1}$  of data at  $\sqrt{s} = 301\text{--}319 \text{ GeV}$ . The result supersedes that of AKTAS 04.

<sup>2</sup> AKTAS 04 looked for single top production via FCNC in  $e^\pm$  collisions at HERA with  $118.3 \text{ pb}^{-1}$ , and found 5 events in the  $e$  or  $\mu$  channels while  $1.31 \pm 0.22$  events are expected from the Standard Model background. No excess was found for the hadronic channel. The observed cross section of  $\sigma(e p \rightarrow e t X) = 0.29^{+0.15}_{-0.14} \text{ pb}$  at  $\sqrt{s} = 319 \text{ GeV}$  gives the quoted upper bound if the observed events are due to statistical fluctuation.

<sup>3</sup> CHEKANOV 03 looked in  $130.1 \text{ pb}^{-1}$  of data at  $\sqrt{s} = 301$  and  $318 \text{ GeV}$ . The limit is for  $\sqrt{s} = 318 \text{ GeV}$  and assumes  $m_t = 175 \text{ GeV}$ .

### $t\bar{t}$ Production Cross Section in $p\bar{p}$ Collisions at $\sqrt{s} = 1.8 \text{ TeV}$

Only the final combined  $t\bar{t}$  production cross sections obtained from Tevatron Run I by the CDF and D0 experiments are quoted below.

VALUE (pb)	DOCUMENT ID	TECN	COMMENT
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●			
$5.69 \pm 1.21 \pm 1.04$	<sup>1</sup> ABAZOV	03A D0	Combined Run I data
$6.5^{+1.7}_{-1.4}$	<sup>2</sup> AFFOLDER	01A CDF	Combined Run I data

<sup>1</sup> Combined result from  $110 \text{ pb}^{-1}$  of Tevatron Run I data. Assume  $m_t = 172.1 \text{ GeV}$ .

<sup>2</sup> Combined result from  $105 \text{ pb}^{-1}$  of Tevatron Run I data. Assume  $m_t = 175 \text{ GeV}$ .

### $t\bar{t}$ Production Cross Section in $p\bar{p}$ Collisions at $\sqrt{s} = 1.96 \text{ TeV}$

Unless otherwise noted the first quoted error is from statistics, the second from systematic uncertainties, and the third from luminosity. If only two errors are quoted the luminosity is included in the systematic uncertainties.

VALUE (pb)	DOCUMENT ID	TECN	COMMENT
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●			
$7.26 \pm 0.13^{+0.57}_{-0.50}$	<sup>1</sup> ABAZOV	16F D0	$\ell\ell, \ell + \text{jets}$ channels
$8.1 \pm 2.1$	<sup>2</sup> AALTONEN	14A CDF	$\ell + \tau_h + \geq 2 \text{ jets } (\geq 1b\text{-tag})$
$7.60 \pm 0.20 \pm 0.29 \pm 0.21$	<sup>3</sup> AALTONEN	14H TEVA	$\ell\ell, \ell + \text{jets}, \text{all-jets channels}$
$8.0 \pm 0.7 \pm 0.6 \pm 0.5$	<sup>4</sup> ABAZOV	14K D0	$\ell + \cancel{E}_T + \geq 4 \text{ jets } (\geq 1b\text{-tag})$
$7.09 \pm 0.84$	<sup>5</sup> AALTONEN	13AB CDF	$\ell\ell + \cancel{E}_T + \geq 2 \text{ jets}$
$7.5 \pm 1.0$	<sup>6</sup> AALTONEN	13G CDF	$\ell + \cancel{E}_T + \geq 3 \text{ jets } (\geq 1b\text{-tag})$
$8.8 \pm 3.3 \pm 2.2$	<sup>7</sup> AALTONEN	12AL CDF	$\tau_h + \cancel{E}_T + 4j (\geq 1b)$
$8.5 \pm 0.6 \pm 0.7$	<sup>8</sup> AALTONEN	11D CDF	$\ell + \cancel{E}_T + \text{jets } (\geq 1b\text{-tag})$
$7.64 \pm 0.57 \pm 0.45$	<sup>9</sup> AALTONEN	11W CDF	$\ell + \cancel{E}_T + \text{jets } (\geq 1b\text{-tag})$
$7.99 \pm 0.55 \pm 0.76 \pm 0.46$	<sup>10</sup> AALTONEN	11Y CDF	$\cancel{E}_T + \geq 4 \text{ jets } (0,1,2 b\text{-tag})$
$7.78^{+0.77}_{-0.64}$	<sup>11</sup> ABAZOV	11E D0	$\ell + \cancel{E}_T + \geq 2 \text{ jets}$
$7.56^{+0.63}_{-0.56}$	<sup>12</sup> ABAZOV	11Z D0	Combination
$6.27 \pm 0.73 \pm 0.63 \pm 0.39$	<sup>13</sup> AALTONEN	10AA CDF	Repl. by AALTONEN 13AB
$7.2 \pm 0.5 \pm 1.0 \pm 0.4$	<sup>14</sup> AALTONEN	10E CDF	$\geq 6 \text{ jets}, \text{vtx } b\text{-tag}$
$7.8 \pm 2.4 \pm 1.6 \pm 0.5$	<sup>15</sup> AALTONEN	10V CDF	$\ell + \geq 3 \text{ jets}, \text{soft-}e b\text{-tag}$



$7.70 \pm 0.52$	16	AALTONEN	10W	CDF	$\ell + \cancel{E}_T + \geq 3$ jets + $b$ -tag, norm. to $\sigma(Z \rightarrow \ell\ell)_{TH}$
$6.9 \pm 2.0$	17	ABAZOV	10I	D0	$\geq 6$ jets with 2 $b$ -tags
$6.9 \pm 1.2 \begin{smallmatrix} +0.8 \\ -0.7 \end{smallmatrix} \pm 0.4$	18	ABAZOV	10Q	D0	$\tau_h$ + jets
$9.6 \pm 1.2 \begin{smallmatrix} +0.6 \\ -0.5 \end{smallmatrix} \pm 0.6$	19	AALTONEN	09AD	CDF	$\ell\ell + \cancel{E}_T$ / vtx $b$ -tag
$9.1 \pm 1.1 \begin{smallmatrix} +1.0 \\ -0.9 \end{smallmatrix} \pm 0.6$	20	AALTONEN	09H	CDF	$\ell + \geq 3$ jets + $\cancel{E}_T$ / soft $\mu$ $b$ -tag
$8.18 \begin{smallmatrix} +0.98 \\ -0.87 \end{smallmatrix}$	21	ABAZOV	09AG	D0	$\ell +$ jets, $\ell\ell$ and $\ell\tau$ + jets
$7.5 \pm 1.0 \begin{smallmatrix} +0.7 \\ -0.6 \end{smallmatrix} \begin{smallmatrix} +0.6 \\ -0.5 \end{smallmatrix}$	22	ABAZOV	09R	D0	$\ell\ell$ and $\ell\tau$ + jets
$8.18 \begin{smallmatrix} +0.90 \\ -0.84 \end{smallmatrix} \pm 0.50$	23	ABAZOV	08M	D0	$\ell +$ n jets with 0,1,2 $b$ -tag
$7.62 \pm 0.85$	24	ABAZOV	08N	D0	$\ell +$ n jets + $b$ -tag or kinematics
$8.5 \begin{smallmatrix} +2.7 \\ -2.2 \end{smallmatrix}$	25	ABULENCIA	08	CDF	$\ell^+ \ell^-$ ( $\ell = e, \mu$ )
$8.3 \pm 1.0 \begin{smallmatrix} +2.0 \\ -1.5 \end{smallmatrix} \pm 0.5$	26	AALTONEN	07D	CDF	$\geq 6$ jets, vtx $b$ -tag
$7.4 \pm 1.4 \pm 1.0$	27	ABAZOV	07O	D0	$\ell\ell +$ jets, vtx $b$ -tag
$4.5 \begin{smallmatrix} +2.0 \\ -1.9 \end{smallmatrix} \begin{smallmatrix} +1.4 \\ -1.1 \end{smallmatrix} \pm 0.3$	28	ABAZOV	07P	D0	$\geq 6$ jets, vtx $b$ -tag
$6.4 \begin{smallmatrix} +1.3 \\ -1.2 \end{smallmatrix} \pm 0.7 \pm 0.4$	29	ABAZOV	07R	D0	$\ell + \geq 4$ jets
$6.6 \pm 0.9 \pm 0.4$	30	ABAZOV	06X	D0	$\ell +$ jets, vtx $b$ -tag
$8.7 \pm 0.9 \begin{smallmatrix} +1.1 \\ -0.9 \end{smallmatrix}$	31	ABULENCIA	06Z	CDF	$\ell +$ jets, vtx $b$ -tag
$5.8 \pm 1.2 \begin{smallmatrix} +0.9 \\ -0.7 \end{smallmatrix}$	32	ABULENCIA,A	06C	CDF	missing $E_T$ + jets, vtx $b$ -tag
$7.5 \pm 2.1 \begin{smallmatrix} +3.3 \\ -2.2 \end{smallmatrix} \begin{smallmatrix} +0.5 \\ -0.4 \end{smallmatrix}$	33	ABULENCIA,A	06E	CDF	6–8 jets, $b$ -tag
$8.9 \pm 1.0 \begin{smallmatrix} +1.1 \\ -1.0 \end{smallmatrix}$	34	ABULENCIA,A	06F	CDF	$\ell + \geq 3$ jets, $b$ -tag
$8.6 \begin{smallmatrix} +1.6 \\ -1.5 \end{smallmatrix} \pm 0.6$	35	ABAZOV	05Q	D0	$\ell +$ n jets
$8.6 \begin{smallmatrix} +3.2 \\ -2.7 \end{smallmatrix} \pm 1.1 \pm 0.6$	36	ABAZOV	05R	D0	di-lepton + n jets
$6.7 \begin{smallmatrix} +1.4 \\ -1.3 \end{smallmatrix} \begin{smallmatrix} +1.6 \\ -1.1 \end{smallmatrix} \pm 0.4$	37	ABAZOV	05X	D0	$\ell +$ jets / kinematics
$5.3 \pm 3.3 \begin{smallmatrix} +1.3 \\ -1.0 \end{smallmatrix}$	38	ACOSTA	05S	CDF	$\ell +$ jets / soft $\mu$ $b$ -tag
$6.6 \pm 1.1 \pm 1.5$	39	ACOSTA	05T	CDF	$\ell +$ jets / kinematics
$6.0 \begin{smallmatrix} +1.5 \\ -1.6 \end{smallmatrix} \begin{smallmatrix} +1.2 \\ -1.3 \end{smallmatrix}$	40	ACOSTA	05U	CDF	$\ell +$ jets/kinematics + vtx $b$ -tag
$5.6 \begin{smallmatrix} +1.2 \\ -1.1 \end{smallmatrix} \begin{smallmatrix} +0.9 \\ -0.6 \end{smallmatrix}$	41	ACOSTA	05V	CDF	$\ell +$ n jets
$7.0 \begin{smallmatrix} +2.4 \\ -2.1 \end{smallmatrix} \begin{smallmatrix} +1.6 \\ -1.1 \end{smallmatrix} \pm 0.4$	42	ACOSTA	04I	CDF	di-lepton + jets + missing $E_T$

<sup>1</sup> ABAZOV 16F based on  $9.7 \text{ fb}^{-1}$  of data. The result is for  $m_t = 172.5 \text{ GeV}$ , and the  $m_t$  dependence is shown in Table V and Fig. 9. The result agrees with the NNLO+NNLL SM prediction of  $7.35 \begin{smallmatrix} +0.23 \\ -0.27 \end{smallmatrix} \text{ pb}$ .

<sup>2</sup> Based on  $9 \text{ fb}^{-1}$  of data. The measurement is in the channel  $t\bar{t} \rightarrow (b\ell\nu)(b\tau\nu)$ , where  $\tau$  decays into hadrons ( $\tau_h$ ), and  $\ell$  ( $e$  or  $\mu$ ) include  $\ell$  from  $\tau$  decays ( $\tau_\ell$ ). The result is for  $m_t = 173 \text{ GeV}$ .

<sup>3</sup> Based on  $8.8 \text{ fb}^{-1}$  of data. Combination of CDF and D0 measurements given, respectively, by  $\sigma(t\bar{t}; \text{CDF}) = 7.63 \pm 0.31 \pm 0.36 \pm 0.16 \text{ pb}$ ,  $\sigma(t\bar{t}; \text{D0}) = 7.56 \pm 0.20 \pm 0.32 \pm$

- 0.46 pb. All the results are for  $m_t = 172.5$  GeV. The  $m_t$  dependence of the mean value is parametrized in eq. (1) and shown in Fig. 2.
- 4 Based on  $9.7 \text{ fb}^{-1}$  of data. Differential cross sections with respect to  $m_{tt}$ ,  $|y(\text{top})|$ ,  $E_T(\text{top})$  are shown in Figs. 9, 10, 11, respectively, and are compared to the predictions of MC models.
  - 5 Based on  $8.8 \text{ fb}^{-1}$  of  $p\bar{p}$  collisions at  $\sqrt{s} = 1.96$  TeV.
  - 6 Based on  $8.7 \text{ fb}^{-1}$  of  $p\bar{p}$  collisions at  $\sqrt{s} = 1.96$  TeV. Measure the  $t\bar{t}$  cross section simultaneously with the fraction of  $t \rightarrow Wb$  decays. The correlation coefficient between those two measurements is  $-0.434$ . Assume unitarity of the  $3 \times 3$  CKM matrix and set  $|V_{tb}| > 0.89$  at 95% CL.
  - 7 Based on  $2.2 \text{ fb}^{-1}$  of data in  $p\bar{p}$  collisions at 1.96 TeV. The result assumes the acceptance for  $m_t = 172.5$  GeV.
  - 8 Based on  $1.12 \text{ fb}^{-1}$  and assumes  $m_t = 175$  GeV, where the cross section changes by  $\pm 0.1$  pb for every  $\mp 1$  GeV shift in  $m_t$ . AALTONEN 11D fits simultaneously the  $t\bar{t}$  production cross section and the  $b$ -tagging efficiency and find improvements in both measurements.
  - 9 Based on  $2.7 \text{ fb}^{-1}$ . The first error is from statistics and systematics, the second is from luminosity. The result is for  $m_t = 175$  GeV. AALTONEN 11W fits simultaneously a jet flavor discriminator between  $b$ -,  $c$ -, and light-quarks, and find significant reduction in the systematic error.
  - 10 Based on  $2.2 \text{ fb}^{-1}$ . The result is for  $m_t = 172.5$  GeV. AALTONEN 11Y selects multi-jet events with large  $\cancel{E}_T$ , and vetoes identified electrons and muons.
  - 11 Based on  $5.3 \text{ fb}^{-1}$ . The error is statistical + systematic + luminosity combined. The result is for  $m_t = 172.5$  GeV. The results for other  $m_t$  values are given in Table XII and eq.(10) of ABAZOV 11E.
  - 12 Combination of a dilepton measurement presented in ABAZOV 11Z (based on  $5.4 \text{ fb}^{-1}$ ), which yields  $7.36^{+0.90}_{-0.79}$  (stat+syst) pb, and the lepton + jets measurement of ABAZOV 11E. The result is for  $m_t = 172.5$  GeV. The results for other  $m_t$  values is given by eq.(5) of ABAZOV 11A.
  - 13 Based on  $2.8 \text{ fb}^{-1}$ . The result is for  $m_t = 175$  GeV.
  - 14 Based on  $2.9 \text{ fb}^{-1}$ . Result is obtained from the fraction of signal events in the top quark mass measurement in the all hadronic decay channel.
  - 15 Based on  $1.7 \text{ fb}^{-1}$ . The result is for  $m_t = 175$  GeV. AALTONEN 10V uses soft electrons from  $b$ -hadron decays to suppress  $W$ +jets background events.
  - 16 Based on  $4.6 \text{ fb}^{-1}$ . The result is for  $m_t = 172.5$  GeV. The ratio  $\sigma(t\bar{t} \rightarrow \ell + \text{jets}) / \sigma(Z/\gamma^* \rightarrow \ell\ell)$  is measured and then multiplied by the theoretical  $Z/\gamma^* \rightarrow \ell\ell$  cross section of  $\sigma(Z/\gamma^* \rightarrow \ell\ell) = 251.3 \pm 5.0$  pb, which is free from the luminosity error.
  - 17 Based on  $1 \text{ fb}^{-1}$ . The result is for  $m_t = 175$  GeV.  $7.9 \pm 2.3$  pb is found for  $m_t = 170$  GeV. ABAZOV 10I uses a likelihood discriminant to separate signal from background, where the background model was created from lower jet-multiplicity data.
  - 18 Based on  $1 \text{ fb}^{-1}$ . The result is for  $m_t = 170$  GeV. For  $m_t = 175$  GeV, the result is  $6.3^{+1.2}_{-1.1}(\text{stat}) \pm 0.7(\text{syst}) \pm 0.4(\text{lumi})$  pb. Cross section of  $t\bar{t}$  production has been measured in the  $t\bar{t} \rightarrow \tau_h + \text{jets}$  topology, where  $\tau_h$  denotes hadronically decaying  $\tau$  leptons. The result for the cross section times the branching ratio is  $\sigma(t\bar{t}) \cdot B(t\bar{t} \rightarrow \tau_h + \text{jets}) = 0.60^{+0.23+0.15}_{-0.22-0.14} \pm 0.04$  pb for  $m_t = 170$  GeV.
  - 19 Based on  $1.1 \text{ fb}^{-1}$ . The result is for  $B(W \rightarrow \ell\nu) = 10.8\%$  and  $m_t = 175$  GeV; the mean value is 9.8 for  $m_t = 172.5$  GeV and 10.1 for  $m_t = 170$  GeV. AALTONEN 09AD used high  $p_T$   $e$  or  $\mu$  with an isolated track to select  $t\bar{t}$  decays into dileptons including  $\ell = \tau$ . The result is based on the candidate event samples with and without vertex  $b$ -tag.
  - 20 Based on  $2 \text{ fb}^{-1}$ . The result is for  $m_t = 175$  GeV; the mean value is 3% higher for  $m_t = 170$  GeV and 4% lower for  $m_t = 180$  GeV.
  - 21 Result is based on  $1 \text{ fb}^{-1}$  of data. The result is for  $m_t = 170$  GeV, and the mean value decreases with increasing  $m_t$ ; see their Fig. 2. The result is obtained after combining  $\ell$

- + jets,  $\ell\ell$ , and  $\ell\tau$  final states, and the ratios of the extracted cross sections are  $R^{\ell\ell/\ell j} = 0.86^{+0.19}_{-0.17}$  and  $R^{\ell\tau/\ell\ell-\ell j} = 0.97^{+0.32}_{-0.29}$ , consistent with the SM expectation of  $R = 1$ . This leads to the upper bound of  $B(t \rightarrow bH^+)$  as a function of  $m_{H^+}$ . Results are shown in their Fig. 1 for  $B(H^+ \rightarrow \tau\nu) = 1$  and  $B(H^+ \rightarrow c\bar{s}) = 1$  cases. Comparison of the  $m_t$  dependence of the extracted cross section and a partial NNLO prediction gives  $m_t = 169.1^{+5.9}_{-5.2}$  GeV.
- 22 Result is based on  $1 \text{ fb}^{-1}$  of data. The result is for  $m_t = 170$  GeV, and the mean value changes by  $-0.07 [m_t(\text{GeV})-170]$  pb near the reference  $m_t$  value. Comparison of the  $m_t$  dependence of the extracted cross section and a partial NNLO QCD prediction gives  $m_t = 171.5^{+9.9}_{-8.8}$  GeV. The  $\ell\tau$  channel alone gives  $7.6^{+4.9+3.5+1.4}_{-4.3-3.4-0.9}$  pb and the  $\ell\ell$  channel gives  $7.5^{+1.2+0.7+0.7}_{-1.1-0.6-0.5}$  pb.
- 23 Result is based on  $0.9 \text{ fb}^{-1}$  of data. The first error is from stat + syst, while the latter error is from luminosity. The result is for  $m_t=175$  GeV, and the mean value changes by  $-0.09 \text{ pb} \cdot [m_t(\text{GeV})-175]$ .
- 24 Result is based on  $0.9 \text{ fb}^{-1}$  of data. The cross section is obtained from the  $\ell + \geq 3$  jet event rates with 1 or 2  $b$ -tag, and also from the kinematical likelihood analysis of the  $\ell + 3, 4$  jet events. The result is for  $m_t=172.6$  GeV, and its  $m_t$  dependence shown in Fig. 3 leads to the constraint  $m_t = 170 \pm 7$  GeV when compared to the SM prediction.
- 25 Result is based on  $360 \text{ pb}^{-1}$  of data. Events with high  $p_T$  oppositely charged dileptons  $\ell^+\ell^-$  ( $\ell = e, \mu$ ) are used to obtain cross sections for  $t\bar{t}$ ,  $W^+W^-$ , and  $Z \rightarrow \tau^+\tau^-$  production processes simultaneously. The other cross sections are given in Table IV.
- 26 Based on  $1.02 \text{ fb}^{-1}$  of data. Result is for  $m_t = 175$  GeV. Secondary vertex  $b$ -tag and neural network selections are used to achieve a signal-to-background ratio of about 1/2.
- 27 Based on  $425 \text{ pb}^{-1}$  of data. Result is for  $m_t = 175$  GeV. For  $m_t = 170.9$  GeV,  $7.8 \pm 1.8(\text{stat} + \text{syst})$  pb is obtained.
- 28 Based on  $405 \pm 25 \text{ pb}^{-1}$  of data. Result is for  $m_t = 175$  GeV. The last error is for luminosity. Secondary vertex  $b$ -tag and neural network are used to separate the signal events from the background.
- 29 Based on  $425 \text{ pb}^{-1}$  of data. Assumes  $m_t = 175$  GeV.
- 30 Based on  $\sim 425 \text{ pb}^{-1}$ . Assuming  $m_t = 175$  GeV. The first error is combined statistical and systematic, the second one is luminosity.
- 31 Based on  $\sim 318 \text{ pb}^{-1}$ . Assuming  $m_t = 178$  GeV. The cross section changes by  $\pm 0.08$  pb for each  $\mp$  GeV change in the assumed  $m_t$ . Result is for at least one  $b$ -tag. For at least two  $b$ -tagged jets,  $t\bar{t}$  signal of significance greater than  $5\sigma$  is found, and the cross section is  $10.1^{+1.6+2.0}_{-1.4-1.3}$  pb for  $m_t = 178$  GeV.
- 32 Based on  $\sim 311 \text{ pb}^{-1}$ . Assuming  $m_t = 178$  GeV. For  $m_t = 175$  GeV, the result is  $6.0 \pm 1.2^{+0.9}_{-0.7}$ . This is the first CDF measurement without lepton identification, and hence it has sensitivity to the  $W \rightarrow \tau\nu$  mode.
- 33 ABULENCIA,A 06E measures the  $t\bar{t}$  production cross section in the all hadronic decay mode by selecting events with 6 to 8 jets and at least one  $b$ -jet. S/B = 1/5 has been achieved. Based on  $311 \text{ pb}^{-1}$ . Assuming  $m_t = 178$  GeV.
- 34 Based on  $\sim 318 \text{ pb}^{-1}$ . Assuming  $m_t = 178$  GeV. Result is for at least one  $b$ -tag. For at least two  $b$ -tagged jets, the cross section is  $11.1^{+2.3+2.5}_{-1.9-1.9}$  pb.
- 35 ABAZOV 05Q measures the top-quark pair production cross section with  $\sim 230 \text{ pb}^{-1}$  of data, based on the analysis of  $W$  plus  $n$ -jet events where  $W$  decays into  $e$  or  $\mu$  plus neutrino, and at least one of the jets is  $b$ -jet like. The first error is statistical and systematic, and the second accounts for the luminosity uncertainty. The result assumes  $m_t = 175$  GeV; the mean value changes by  $(175-m_t(\text{GeV})) \times 0.06$  pb in the mass range 160 to 190 GeV.

- <sup>36</sup> ABAZOV 05R measures the top-quark pair production cross section with 224–243 pb<sup>-1</sup> of data, based on the analysis of events with two charged leptons in the final state. The result assumes  $m_t = 175$  GeV; the mean value changes by  $(175 - m_t(\text{GeV})) \times 0.08$  pb in the mass range 160 to 190 GeV.
- <sup>37</sup> Based on 230 pb<sup>-1</sup>. Assuming  $m_t = 175$  GeV.
- <sup>38</sup> Based on 194 pb<sup>-1</sup>. Assuming  $m_t = 175$  GeV.
- <sup>39</sup> Based on  $194 \pm 11$  pb<sup>-1</sup>. Assuming  $m_t = 175$  GeV.
- <sup>40</sup> Based on  $162 \pm 10$  pb<sup>-1</sup>. Assuming  $m_t = 175$  GeV.
- <sup>41</sup> ACOSTA 05V measures the top-quark pair production cross section with  $\sim 162$  pb<sup>-1</sup> data, based on the analysis of  $W$  plus n-jet events where  $W$  decays into  $e$  or  $\mu$  plus neutrino, and at least one of the jets is  $b$ -jet like. Assumes  $m_t = 175$  GeV.
- <sup>42</sup> ACOSTA 04I measures the top-quark pair production cross section with  $197 \pm 12$  pb<sup>-1</sup> data, based on the analysis of events with two charged leptons in the final state. Assumes  $m_t = 175$  GeV.

### Ratio of the Production Cross Sections of $t\bar{t}\gamma$ to $t\bar{t}$ at $\sqrt{s} = 1.96$ TeV

VALUE	DOCUMENT ID	TECN	COMMENT
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• • • We do not use the following data for averages, fits, limits, etc. • • •

$0.024 \pm 0.009$	<sup>1</sup> AALTONEN	11Z CDF	$E_T(\gamma) > 10$ GeV, $ \eta(\gamma)  < 1.0$
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<sup>1</sup> Based on 6.0 fb<sup>-1</sup> of data. The error is statistical and systematic combined. Events with lepton +  $\cancel{E}_T$  +  $\geq 3$  jets ( $\geq 1b$ ) with and without central, high  $E_T$  photon are measured. The result is consistent with the SM prediction of  $0.024 \pm 0.005$ . The absolute production cross section is measured to be  $0.18 \pm 0.08$  fb. The statistical significance is 3.0 standard deviations.

### $t\bar{t}$ Production Cross Section in $pp$ Collisions at $\sqrt{s} = 7$ TeV

VALUE (pb)	CL%	DOCUMENT ID	TECN	COMMENT
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• • • We do not use the following data for averages, fits, limits, etc. • • •

$< 1.7$	95	<sup>1</sup> AAD	12BE ATLS	$\ell^+ \ell^+ + \cancel{E}_T + \geq 2j + \text{HT}$
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<sup>1</sup> Based on 1.04 fb<sup>-1</sup> of  $pp$  data at  $\sqrt{s} = 7$  TeV. The upper bounds are the same for LL, LR and RR chiral components of the two top quarks.

### $t\bar{t}$ Production Cross Section in $pp$ Collisions at $\sqrt{s} = 5.02$ TeV

Unless otherwise noted the first quoted error is from statistics, the second from systematic uncertainties, and the third from luminosity. If only two errors are quoted the luminosity is included in the systematic uncertainties.

VALUE (pb)	DOCUMENT ID	TECN	COMMENT
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• • • We do not use the following data for averages, fits, limits, etc. • • •

$60.7 \pm 5.0 \pm 2.8 \pm 1.1$	<sup>1</sup> TUMASYAN	22T CMS	$e + \mu + \geq 2$ jets
$63.0 \pm 4.1 \pm 3.0$	<sup>2</sup> TUMASYAN	22T CMS	combination of $e + \mu$ $+ \geq 2$ jets, $\ell + \text{jets}$
$69.5 \pm 6.1 \pm 5.6 \pm 1.6$	<sup>3</sup> SIRUNYAN	18AQ CMS	$\ell + \text{jets}$ , $\ell\ell + \text{jets}$

<sup>1</sup> TUMASYAN 22T based on 302 pb<sup>-1</sup> of data from  $pp$  collisions at  $\sqrt{s} = 5.02$  TeV. The errors are from statistics, systematics and luminosity.

<sup>2</sup> Combination of the measurement by TUMASYAN 22T and the measurement in the  $\ell + \text{jets}$  channel by SIRUNYAN 18AQ. The errors are from statistics and systematics + luminosity. The result is in agreement with the NNLO+NNLL SM prediction  $66.8^{+2.9}_{-3.1}$  pb.

<sup>3</sup> SIRUNYAN 18AQ based on 27.4 pb<sup>-1</sup> of data from  $pp$  collisions at  $\sqrt{s} = 5.02$  TeV. The result is in agreement with the NNLO SM prediction  $68.9^{+1.9}_{-2.3}(\text{scale}) \pm 2.3(\text{PDF})^{+1.4}_{-1.0}(\alpha_s)$  pb.

**$t\bar{t}$  Production Cross Section in  $pp$  Collisions at  $\sqrt{s} = 7$  TeV**

Unless otherwise noted the first quoted error is from statistics, the second from systematic uncertainties, and the third from luminosity. If only two errors are quoted the luminosity is included in the systematic uncertainties.

VALUE (pb)	DOCUMENT ID	TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •			
$161.7 \pm 6.0 \pm 12.0 \pm 3.6$	<sup>1</sup> KHACHATRY...17B	CMS	$\ell + \cancel{E}_T + \geq 4j$ ( $\geq 1b$ )
$173.6 \pm 2.1 \pm 4.5 \pm 3.8$	<sup>2</sup> KHACHATRY...16AW	CMS	$e + \mu + \cancel{E}_T + \geq 0j$
$181.2 \pm 2.8 \pm 10.8$	<sup>3</sup> AAD	15BO ATLS	$e + \mu + \cancel{E}_T + \geq 0j$
$178 \pm 3 \pm 16 \pm 3$	<sup>4</sup> AAD	15CC ATLS	$\ell + \text{jets}, \ell\ell + \text{jets}, \ell\tau_h + \text{jets}$
	<sup>5</sup> AAIJ	15R LHCb	$\mu + \geq 1j(b\text{-tag})$ forward region
$182.9 \pm 3.1 \pm 6.4$	<sup>6</sup> AAD	14AY ATLS	$e + \mu + 1$ or $2b$ jets
$194 \pm 18 \pm 46$	<sup>7</sup> AAD	13X ATLS	$\tau_h + \cancel{E}_T + \geq 5j$ ( $\geq 2b$ )
$139 \pm 10 \pm 26$	<sup>8</sup> CHATRCHYAN 13AY	CMS	$\geq 6$ jets with 2 $b$ -tags
$158.1 \pm 2.1 \pm 10.8$	<sup>9</sup> CHATRCHYAN 13BB	CMS	$\ell + \cancel{E}_T + \text{jets}(\geq 1 b\text{-tag})$
$152 \pm 12 \pm 32$	<sup>10</sup> CHATRCHYAN 13BE	CMS	$\tau_h + \cancel{E}_T + \geq 4$ jets ( $\geq 1 b$ )
$177 \pm 20 \pm 14 \pm 7$	<sup>11</sup> AAD	12B ATLS	Repl. by AAD 12BF
$176 \pm 5 \pm 14 \pm 8$	<sup>12</sup> AAD	12BF ATLS	$\ell\ell + \cancel{E}_T + \geq 2j$
$187 \pm 11 \pm 18 \pm 6$	<sup>13</sup> AAD	12BO ATLS	$\ell + \cancel{E}_T + \geq 3j$ with $b$ -tag
$186 \pm 13 \pm 20 \pm 7$	<sup>14</sup> AAD	12CG ATLS	$\ell + \tau_h + \cancel{E}_T + \geq 2j$ ( $\geq 1b$ )
$143 \pm 14 \pm 22 \pm 3$	<sup>15</sup> CHATRCHYAN 12AC	CMS	$\ell + \tau_h + \cancel{E}_T + \geq 2j$ ( $\geq 1b$ )
$161.9 \pm 2.5 \pm 5.1 \pm 3.6$	<sup>16</sup> CHATRCHYAN 12AX	CMS	$\ell\ell + \cancel{E}_T + \geq 2b$
$145 \pm 31 \pm 42 \pm 27$	<sup>17</sup> AAD	11A ATLS	$\ell + \cancel{E}_T + \geq 4j, \ell\ell + \cancel{E}_T + \geq 2j$
$173 \pm 39 \pm 32 \pm 7$	<sup>18</sup> CHATRCHYAN 11AA	CMS	$\ell + \cancel{E}_T + \geq 3$ jets
$168 \pm 18 \pm 14 \pm 7$	<sup>19</sup> CHATRCHYAN 11F	CMS	$\ell\ell + \cancel{E}_T + \text{jets}$
$154 \pm 17 \pm 6$	<sup>20</sup> CHATRCHYAN 11Z	CMS	Combination
$194 \pm 72 \pm 24 \pm 21$	<sup>21</sup> KHACHATRY...11A	CMS	$\ell\ell + \cancel{E}_T + \geq 2$ jets

<sup>1</sup> KHACHATRYAN 17B based on  $5.0 \text{ fb}^{-1}$  of data, using a binned likelihood fit of templates to the data. Also the ratio  $\sigma(t\bar{t}; 8 \text{ TeV})/\sigma(t\bar{t}; 7 \text{ TeV}) = 1.43 \pm 0.04 \pm 0.07 \pm 0.05$  is reported. The results are in agreement with NNLO SM predictions.

<sup>2</sup> KHACHATRYAN 16AW based on  $5.0 \text{ fb}^{-1}$  of data, using a binned likelihood fit to differential distributions of  $b$ -tagged and non- $b$ -tagged jets. The result is in good agreement with NNLO SM predictions.

<sup>3</sup> Based on  $4.6 \text{ fb}^{-1}$  of data. Uses a template fit to distributions of  $\cancel{E}_T$  and jet multiplicities to measure simultaneously  $t\bar{t}$ ,  $WW$ , and  $Z/\gamma^* \rightarrow \tau\tau$  cross sections, assuming  $m_t = 172.5 \text{ GeV}$ .

<sup>4</sup> AAD 15CC based on  $4.6 \text{ fb}^{-1}$  of data. The event selection criteria are optimized for the  $\ell\tau_h + \text{jets}$  channel. Using only this channel  $183 \pm 9 \pm 23 \pm 3 \text{ pb}$  is derived for the cross section.

<sup>5</sup> AAIJ 15R, based on  $1.0 \text{ fb}^{-1}$  of data, reports  $0.239 \pm 0.053 \pm 0.033 \pm 0.024 \text{ pb}$  cross section for the forward fiducial region  $p_T(\mu) > 25 \text{ GeV}$ ,  $2.0 < \eta(\mu) < 4.5$ ,  $50 \text{ GeV} < p_T(b) < 100 \text{ GeV}$ ,  $2.2 < \eta(b) < 4.2$ ,  $\Delta R(\mu, b) > 0.5$ , and  $p_T(\mu+b) > 20 \text{ GeV}$ . The three errors are from statistics, systematics, and theory. The result agrees with the SM NLO prediction.

<sup>6</sup> AAD 14AY reports  $182.9 \pm 3.1 \pm 4.2 \pm 3.6 \pm 3.3 \text{ pb}$  value based on  $4.6 \text{ fb}^{-1}$  of data. The four errors are from statistics, systematic, luminosity, and the 0.66% beam energy uncertainty. We have combined the systematic uncertainties in quadrature. The

result is for  $m_t = 172.5\text{GeV}$ ; for other  $m_t$ ,  $\sigma(m_t) = \sigma(172.5\text{GeV}) \times [1 - 0.0028 \times (m_t - 172.5\text{GeV})]$ . The result is consistent with the SM prediction at NNLO.

- 7 Based on  $1.67\text{ fb}^{-1}$  of data. The result uses the acceptance for  $m_t = 172.5\text{ GeV}$ .
- 8 Based on  $3.54\text{ fb}^{-1}$  of data.
- 9 Based on  $2.3\text{ fb}^{-1}$  of data.
- 10 Based on  $3.9\text{ fb}^{-1}$  of data.
- 11 Based on  $35\text{ pb}^{-1}$  of data for an assumed top quark mass of  $m_t = 172.5\text{ GeV}$ .
- 12 Based on  $0.70\text{ fb}^{-1}$  of data. The 3 errors are from statistics, systematics, and luminosity. The result uses the acceptance for  $m_t = 172.5\text{ GeV}$ .
- 13 Based on  $35\text{ pb}^{-1}$  of data. The 3 errors are from statistics, systematics, and luminosity. The result uses the acceptance for  $m_t = 172.5\text{ GeV}$  and  $173 \pm 17^{+18}_{-16} \pm 6\text{ pb}$  is found without the  $b$ -tag.
- 14 Based on  $2.05\text{ fb}^{-1}$  of data. The hadronic  $\tau$  candidates are selected using a BDT technique. The 3 errors are from statistics, systematics, and luminosity. The result uses the acceptance for  $m_t = 172.5\text{ GeV}$ .
- 15 Based on  $2.0\text{ fb}^{-1}$  and  $2.2\text{ fb}^{-1}$  of data for  $\ell = e$  and  $\ell = \mu$ , respectively. The 3 errors are from statistics, systematics, and luminosity. The result uses the acceptance for  $m_t = 172.5\text{ GeV}$ .
- 16 Based on  $2.3\text{ fb}^{-1}$  of data. The 3 errors are from statistics, systematics, and luminosity. The result uses the profile likelihood-ratio (PLB) method and an assumed  $m_t$  of  $172.5\text{ GeV}$ .
- 17 Based on  $2.9\text{ pb}^{-1}$  of data. The result for single lepton channels is  $142 \pm 34^{+50}_{-31}\text{ pb}$ , while for the dilepton channels is  $151^{+78+37}_{-62-24}\text{ pb}$ .
- 18 Result is based on  $36\text{ pb}^{-1}$  of data. The first uncertainty corresponds to the statistical and systematic uncertainties, and the second corresponds to the luminosity.
- 19 Based on  $36\text{ pb}^{-1}$  of data. The ratio of  $t\bar{t}$  and  $Z/\gamma^*$  cross sections is measured as  $\sigma(pp \rightarrow t\bar{t})/\sigma(pp \rightarrow Z/\gamma^* \rightarrow e^+e^-/\mu^+\mu^-) = 0.175 \pm 0.018(\text{stat}) \pm 0.015(\text{syst})$  for  $60 < m_{\ell\ell} < 120\text{ GeV}$ , for which they use an NNLO prediction for the denominator cross section of  $972 \pm 42\text{ pb}$ .
- 20 Result is based on  $36\text{ pb}^{-1}$  of data. The first error is from statistical and systematic uncertainties, and the second from luminosity. This is a combination of a measurement in the dilepton channel (CHATRCHYAN 11F) and the measurement in the  $\ell + \text{jets}$  channel (CHATRCHYAN 11Z) which yields  $150 \pm 9 \pm 17 \pm 6\text{ pb}$ .
- 21 Result is based on  $3.1 \pm 0.3\text{ pb}^{-1}$  of data.

### $t\bar{t}$ Production Cross Section in $pp$ Collisions at $\sqrt{s} = 8\text{ TeV}$

Unless otherwise noted the first quoted error is from statistics, the second from systematic uncertainties, and the third from luminosity. If only two errors are quoted the luminosity is included in the systematic uncertainties.

VALUE (pb)	DOCUMENT ID	TECN	COMMENT
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●			
$248.3 \pm 0.7 \pm 13.4 \pm 4.7$	1 AABOUD	18BH ATLS	$\ell + \cancel{E}_T + \geq 4j (\geq 1b)$
$239 \pm 4 \pm 28 \pm 5$	2 AABOUD	17Z ATLS	$\tau_h + \cancel{E}_T + \geq 2j (\geq 2b)$
$228.5 \pm 3.8 \pm 13.7 \pm 6.0$	3 KHACHATRY...17B	CMS	$\ell + \cancel{E}_T + \geq 4j (\geq 1b)$
$242.9 \pm 1.7 \pm 8.6$	4 AAD	16BK ATLS	$e + \mu + 1$ or $2b$ jets
$244.9 \pm 1.4^{+6.3}_{-5.5} \pm 6.4$	5 KHACHATRY...16AW	CMS	$e + \mu + \cancel{E}_T + \geq 0j$
$275.6 \pm 6.1 \pm 37.8 \pm 7.2$	6 KHACHATRY...16BC	CMS	$\geq 6j (\geq 2b)$
$260 \pm 1^{+24}_{-25}$	7 AAD	15BP ATLS	$\ell + \cancel{E}_T + \geq 3j (\geq 1b)$
	8 AAIJ	15R LHCb	$\mu + \geq 1j(b\text{-tag})$ forward region
$242.4 \pm 1.7 \pm 10.2$	9 AAD	14AY ATLS	$e + \mu + 1$ or $2b$ jets

239	$\pm 2$	$\pm 11$	$\pm 6$	<sup>10</sup> CHATRCHYAN 14F	CMS	$\ell\ell + \cancel{E}_T + \geq 2j$ ( $\geq 1$ <i>b</i> -tag)
257	$\pm 3$	$\pm 24$	$\pm 7$	<sup>11</sup> KHACHATRYAN 14S	CMS	$\ell + \tau_h + \cancel{E}_T + \geq 2j$ ( $\geq 1b$ )

<sup>1</sup> AABOUD 18BH based on 20.2 fb<sup>-1</sup> of data. The result is for  $m_t = 172.5$  GeV. To reduce effects of uncertainties in the jet energy scale and *b*-tagging efficiency, they are included as nuisance parameters in the fit of discriminant distributions, after separating selected events into three regions. Furthermore the *W*+jets background distribution is modelled using *Z*+jets event data.

<sup>2</sup> AABOUD 17Z based on 20.2 fb<sup>-1</sup> of data, using the mode  $t\bar{t} \rightarrow \tau\nu q'\bar{q}b\bar{b}$  with  $\tau$  decaying hadronically. Single prong and 3 prong decays of  $\tau$  are separately analyzed. The result is consistent with the SM. The third quoted uncertainty is due to luminosity.

<sup>3</sup> KHACHATRYAN 17B based on 19.6 fb<sup>-1</sup> of data, using a binned likelihood fit of templates to the data. Also the ratio  $\sigma(t\bar{t}; 8 \text{ TeV})/\sigma(t\bar{t}; 7 \text{ TeV}) = 1.43 \pm 0.04 \pm 0.07 \pm 0.05$  is reported. The results are in agreement with NNLO SM predictions.

<sup>4</sup> AAD 16BK is an update of the value from AAD 14AY using the improved luminosity calibration. The value  $242.9 \pm 1.7 \pm 5.5 \pm 5.1 \pm 4.2$  pb is reported, where we have combined the systematic uncertainties in quadrature. Also the ratio  $\sigma(t\bar{t}; 8\text{TeV})/\sigma(t\bar{t}; 7\text{TeV}) = 1.328 \pm 0.024 \pm 0.015 \pm 0.038 \pm 0.001$  has been updated. The former result is consistent with the SM predictions at NNLO, while the latter result is 2.1  $\sigma$  below the expectation.

<sup>5</sup> KHACHATRYAN 16AW based on 19.7 fb<sup>-1</sup> of data, using a binned likelihood fit to differential distributions of *b*-tagged and non-*b*-tagged jets. The result is in good agreement with NNLO SM predictions.

<sup>6</sup> KHACHATRYAN 16BC based on 18.4 fb<sup>-1</sup> of data. The last uncertainty is due to luminosity. Cuts on kinematical fit probability and  $\Delta R(b,b)$  are imposed. The major QCD background is determined from the data. The result is for  $m_t = 172.5$  GeV and in agreement with the SM prediction. The top quark  $p_T$  spectra, also measured, are significantly softer than theoretical predictions.

<sup>7</sup> AAD 15BP based on 20.3 fb<sup>-1</sup> of data. The result is for  $m_t = 172.5$  GeV and in agreement with the SM prediction  $253^{+13}_{-15}$  pb at NNLO+NNLL. Superseded by AABOUD 18BH.

<sup>8</sup> AAIJ 15R, based on 2.0 fb<sup>-1</sup> of data, reports  $0.289 \pm 0.043 \pm 0.040 \pm 0.029$  pb cross section for the forward fiducial region  $p_T(\mu) > 25$  GeV,  $2.0 < \eta(\mu) < 4.5$ ,  $50 \text{ GeV} < p_T(b) < 100 \text{ GeV}$ ,  $2.2 < \eta(b) < 4.2$ ,  $\Delta R(\mu,b) > 0.5$ , and  $p_T(\mu+b) > 20 \text{ GeV}$ . The three errors are from statistics, systematics, and theory. The result agrees with the SM NLO prediction.

<sup>9</sup> AAD 14AY reports  $242.4 \pm 1.7 \pm 5.5 \pm 7.5 \pm 4.2$  pb value based on 20.3 fb<sup>-1</sup> of data. The four errors are from statistics, systematic, luminosity, and the 0.66% beam energy uncertainty. We have combined the systematic uncertainties in quadrature. The result is for  $m_t = 172.5\text{GeV}$ ; for other  $m_t$ ,  $\sigma(m_t) = \sigma(172.5\text{GeV}) \times [1 - 0.0028 \times (m_t - 172.5\text{GeV})]$ . Also measured is the ratio  $\sigma(t\bar{t}; 8\text{TeV})/\sigma(t\bar{t}; 7\text{TeV}) = 1.326 \pm 0.024 \pm 0.015 \pm 0.049 \pm 0.001$ . The results are consistent with the SM predictions at NNLO.

<sup>10</sup> Based on 5.3 fb<sup>-1</sup> of data. The result is for  $m_t = 172.5$  GeV, and a parametrization is given in eq.(6.1) for the mean value at other  $m_t$  values. The result is in agreement with the SM prediction  $252.9^{+6.4}_{-8.6}$  pb at NNLO.

<sup>11</sup> Based on 19.6 fb<sup>-1</sup> of data. The measurement is in the channel  $t\bar{t} \rightarrow (b\ell\nu)(b\tau\nu)$ , where  $\tau$  decays into hadrons ( $\tau_h$ ). The result is for  $m_t = 172.5$  GeV. For  $m_t = 173.3$  GeV, the cross section is lower by 3.1 pb.

### $t\bar{t}$ Production Cross Section in *pp* Collisions at $\sqrt{s} = 13 \text{ TeV}$

VALUE (pb)	DOCUMENT ID	TECN	COMMENT
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• • • We do not use the following data for averages, fits, limits, etc. • • •

791	$\pm 1$	$\pm 21$	$\pm 14$	<sup>1</sup> TUMASYAN	21J	CMS	$1\ell + \text{jets}$
830	$\pm 0.4$	$\pm 36$	$\pm 14$	<sup>2</sup> AAD	20AH	ATLS	$\ell + \geq 4 \text{ jets}$ ( $\geq 1b$ -tag)

826.4 ± 3.6 ± 11.5 ± 15.8	<sup>3</sup> AAD	20Q ATLS	$e\mu + 1$ or 2 $b$ -jets
781 ± 7 ± 62 ± 20	<sup>4</sup> SIRUNYAN	20V CMS	$\ell\tau_h + \geq 3$ jets ( $\geq 1b$ -tag)
803 ± 2 ± 25 ± 20	<sup>5</sup> SIRUNYAN	19AR CMS	dilepton channel ( $e\mu, 2e, 2\mu$ )
	<sup>6</sup> SIRUNYAN	19P CMS	dilepton channel
815 ± 9 ± 38 ± 19	<sup>7</sup> KHACHATRYAN...17N	CMS	$e\mu + \geq 2j$ ( $\geq 1b$ j)
888 ± 2 $^{+26}_{-28}$ ± 20	<sup>8</sup> SIRUNYAN	17W CMS	$\ell + \geq 1j$
818 ± 8 ± 35	<sup>9</sup> AABOUD	16R ATLS	$e + \mu + 1$ or 2 $b$ jets
746 ± 58 ± 53 ± 36	<sup>10</sup> KHACHATRYAN...16J	CMS	$e + \mu + \geq 2j$

<sup>1</sup> TUMASYAN 21J result is based on 137 fb<sup>-1</sup> of data. The last uncertainty is due to the beam luminosity. The result is in agreement with the SM prediction of 832 $^{+40}_{-46}$  pb at NNLO+NNLL. Measurements of differential and double-differential cross sections are also presented.

<sup>2</sup> AAD 20AH based on 139 fb<sup>-1</sup> of data. The last quoted uncertainty is due to the beam luminosity. The result is for  $m_t = 172.5$  GeV and in agreement with the SM prediction of 832 $^{+20}_{-29}$ (scale) ± 35(PDF+α(s)) pb at NNLO+NNLL.

<sup>3</sup> AAD 20Q reports 826.4 ± 3.6 ± 11.5 ± 15.7 ± 1.9 pb based on 36.1 fb<sup>-1</sup> of data at 13 TeV. The four errors stem from statistics, systematic effects, luminosity, and beam energy, respectively. We have combined luminosity and beam energy uncertainties in quadrature. The result is in agreement with the SM prediction 832 $^{+20}_{-29}$ (scale) ± 35(PDF+α(s)) pb at NNLO+NNLL for  $m_t = 172.5$  GeV.

<sup>4</sup> SIRUNYAN 20V based on 35.9 fb<sup>-1</sup> of  $pp$  data at  $\sqrt{s} = 13$  TeV. The last uncertainty is due to beam luminosity. The  $t\bar{t}$  production cross section is measured in the  $t\bar{t} \rightarrow (\ell\nu_\ell)(\tau_h\nu_\tau)b\bar{b}$  final state, where  $\tau_h$  refers to the hadronic decays of  $\tau$ . The result is for  $m_t = 172.5$  GeV and in agreement with the SM prediction at NNLO+NNLL.

<sup>5</sup> SIRUNYAN 19AR based on 35.9 fb<sup>-1</sup> of data. Obtained from the visible cross section measured using a template fit to multidifferential distributions categorized according to the  $b$ -tagged jet multiplicity. The result is for  $m_t = 172.5$  GeV and in agreement with the SM prediction at NNLO+NNLL.

<sup>6</sup> SIRUNYAN 19P reports differential  $t\bar{t}$  cross sections measured using dilepton events at 13 TeV with 35.9 fb<sup>-1</sup> and compared to NLO predictions.

<sup>7</sup> KHACHATRYAN 17N based on 2.2 fb<sup>-1</sup> of data. The last quoted uncertainty is due to the beam luminosity. This measurement supersedes that of KHACHATRYAN 16J.

<sup>8</sup> SIRUNYAN 17W based on 2.2 fb<sup>-1</sup> of  $pp$  data at  $\sqrt{s} = 13$  TeV. Events are categorized according to the jet multiplicity and the number of  $b$ -tagged jets. A likelihood fit is performed to the event distributions to compare to the NNLO+NNLL prediction.

<sup>9</sup> AABOUD 16R reported value 818 ± 8 ± 27 ± 19 ± 12 pb based on 3.2 fb<sup>-1</sup> of data. The four errors are from statistics, systematic, luminosity, and beam energy. We have combined the systematic uncertainties in quadrature. The result is in agreement with the SM prediction 832 $^{+20}_{-29}$ (scale) ± 35(PDF+α(s)) pb at NNLO+NNLL for  $m_t = 172.5$  GeV.

<sup>10</sup> KHACHATRYAN 16J based on 43 pb<sup>-1</sup> of data. The last uncertainty is due to luminosity. The result is for  $m_t = 172.5$  GeV and in agreement with the SM prediction 832 $^{+20}_{-29}$ (scale) ± 35(PDF+α(s)) pb at NNLO+NNLL.

### **$t\bar{t}$ Production Cross Section in Nucleus-Nucleus Collisions**

VALUE (μbarn)	DOCUMENT ID	TECN	COMMENT
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• • • We do not use the following data for averages, fits, limits, etc. • • •

2.03 $^{+0.71}_{-0.64}$	<sup>1</sup> SIRUNYAN	20BC CMS	Pb-Pb collisions, dilepton + $b$ -jets
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$2.54^{+0.84}_{-0.74}$  <sup>2</sup> SIRUNYAN 20BC CMS Pb-Pb collisions, dilepton only

<sup>1</sup> SIRUNYAN 20BC based on  $(1.7 \pm 0.1)$  nb<sup>-1</sup> of lead-lead collision data at a nucleon-nucleon c.m. energy of 5.02 TeV. It makes use of the final-state dilepton kinematic properties together with requirements on the number of *b*-jets. The measured value is compatible with QCD predictions.

<sup>2</sup> SIRUNYAN 20BC based on  $(1.7 \pm 0.1)$  nb<sup>-1</sup> of lead-lead collision data at a nucleon-nucleon c.m. energy of 5.02 TeV. It makes use of the final-state dilepton kinematic properties alone. The measured value is compatible with QCD predictions.

### $t\bar{t} t\bar{t}$ Production Cross Section in $pp$ Collisions at $\sqrt{s} = 8$ TeV

VALUE (fb)	CL%	DOCUMENT ID	TECN	COMMENT
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• • • We do not use the following data for averages, fits, limits, etc. • • •

<23	95	<sup>1</sup> AAD	15AR ATLS	$\ell + \cancel{E}_T + \geq 5j$ ( $\geq 2 b$ )
<70	95	<sup>2</sup> AAD	15BY ATLS	$\geq 2\ell + \cancel{E}_T + \geq 2j$ ( $\geq 1 b$ )
<32	95	<sup>3</sup> KHACHATRY...14R	CMS	$\ell + \cancel{E}_T + \geq 6j$ ( $\geq 2 b$ )

<sup>1</sup> AAD 15AR based on 20.3 fb<sup>-1</sup> of data. A fit to  $H_T$  distributions in multi-channels classified by the number of jets and of *b*-tagged jets is performed.

<sup>2</sup> AAD 15BY based on 20.3 fb<sup>-1</sup> of data. A same-sign lepton pair is required. An excess over the SM prediction reaches  $2.5\sigma$  for hypotheses involving heavy resonances decaying into  $t\bar{t}t\bar{t}$ .

<sup>3</sup> Based on 19.6 fb<sup>-1</sup> of data, using a multivariate analysis to separate signal from backgrounds. About  $\sigma(t\bar{t}t\bar{t}) = 1$  fb is expected in the SM.

### $t\bar{t} t\bar{t}$ Production Cross Section in $pp$ Collisions at $\sqrt{s} = 13$ TeV

VALUE (fb)	CL%	DOCUMENT ID	TECN	COMMENT
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• • • We do not use the following data for averages, fits, limits, etc. • • •

26 $^{+17}_{-15}$		<sup>1</sup> AAD	21BC ATLS	$\ell$ or $\ell^+ \ell^-$ + jets
24 $^{+7}_{-6}$		<sup>2</sup> AAD	21BC ATLS	combination of $1\ell/2\ell(\text{OS})$ and $2\ell(\text{SS})/3\ell$
24 $^{+7}_{-6}$		<sup>3</sup> AAD	20AR ATLS	(same-sign $2\ell$ ) or $\geq 3\ell$ + jets
12.6 $^{+5.8}_{-5.2}$		<sup>4</sup> SIRUNYAN	20C CMS	(same-sign $2\ell$ ) or $3\ell$ + jets
<47	95	<sup>5</sup> AABOUD	19AP ATLS	$\ell + \ell^+ \ell^-$ channels
<49	95	<sup>6</sup> AABOUD	19AP ATLS	combination of ATLAS
13 $^{+11}_{-9}$		<sup>7</sup> SIRUNYAN	19CN CMS	combination of CMS
<48	95	<sup>8</sup> SIRUNYAN	19CN CMS	$\ell$ +jets, $\ell^+ \ell^-$ +jets channels
<69	95	<sup>9</sup> AABOUD	18CE ATLS	$\geq 2\ell(\text{same sign}) + \cancel{E}_T + \geq 1bj$
16.9 $^{+13.8}_{-11.4}$		<sup>10</sup> SIRUNYAN	18BU CMS	$t\bar{t}t\bar{t} \rightarrow$ (same sign $2\ell$ or $\geq 3\ell$ ) + $\geq 4j$ ( $\geq 2b$ )
<94	95	<sup>11</sup> SIRUNYAN	17AB CMS	$\ell$ +jets, $\ell^+ \ell^-$ +jets channels
<42	95	<sup>12</sup> SIRUNYAN	17S CMS	(same sign $2\ell$ )+ $\cancel{E}_T + \geq 2j$

<sup>1</sup> AAD 21BC result is based on 139 fb<sup>-1</sup> of data. The events are categorized according to the number of jets and how likely to contain *b*-hadrons and a multivariate analysis is used to discriminate the signal from backgrounds. The result corresponds to observed significance of  $1.9\sigma$ .

<sup>2</sup> AAD 21BC combines the results of the four-top-quark production cross section measured from the  $1\ell$ /opposite-sign  $2\ell$  channel with that from the same-sign  $2\ell/3\ell$  channel

(AAD 20AR). The result corresponds to observed significance of  $4.7\sigma$  and is consistent within  $2.0\sigma$  with the NLO (QCD+EW) SM prediction of  $12.0 \pm 2.4$  fb.

- <sup>3</sup> AAD 20AR based on  $139 \text{ fb}^{-1}$  of data. Jet multiplicity, jet flavor and event kinematics are used in a multivariate analysis to discriminate the signal from backgrounds. The result corresponds to observed significance of  $4.3\sigma$  and is consistent within  $1.7\sigma$  with the NLO (QCD+EW) SM prediction of  $12.0 \pm 2.4$  fb.
- <sup>4</sup> SIRUNYAN 20C based on  $137 \text{ fb}^{-1}$  of data. Both cut-based and multivariate approaches are taken to discriminate the signal from backgrounds. The result is in agreement with the NLO (QCD+EW) SM prediction of  $12.0^{+2.2}_{-2.5}$  fb. The measurement constrains the top quark Yukawa coupling strength parameter to be  $|Y_t/Y_t^{SM}| < 1.7$  (95% CL). It is also used to constrain an oblique parameter of the Higgs boson.
- <sup>5</sup> AABOUD 19AP based on  $36.1 \text{ fb}^{-1}$  of data. The upper limit corresponds to 5.1 times the NLO SM cross section.
- <sup>6</sup> AABOUD 19AP limit from data combined with AABOUD 18CE. The upper limit corresponds to 5.3 times the NLO SM cross section. Also a limit on the four-top-quark contact interaction of  $|C_{4t}|/\Lambda^2 < 1.9 \text{ TeV}^{-2}$  (95% CL) is obtained in an EFT model.
- <sup>7</sup> SIRUNYAN 19CN based on  $35.8 \text{ fb}^{-1}$  of data, combined with SIRUNYAN 18BU. The results are also interpreted in the effective field theory framework.
- <sup>8</sup> SIRUNYAN 19CN based on  $35.8 \text{ fb}^{-1}$  of data. A multivariate analysis using global event and jet properties is performed to discriminate from  $t\bar{t}$  background.
- <sup>9</sup> AABOUD 18CE based on  $36.1 \text{ fb}^{-1}$  of proton-proton data taken at  $\sqrt{s} = 13 \text{ TeV}$ . Events including a same-sign lepton pair are used. The result is consistent with the NLO SM cross section of  $9.2$  fb.
- <sup>10</sup> SIRUNYAN 18BU based on  $35.9 \text{ fb}^{-1}$  of proton-proton data taken at  $\sqrt{s} = 13 \text{ TeV}$ . Yields from signal regions and control regions defined based on  $N_{jets}$ ,  $N_b$  and  $N_l$  are combined in a maximum-likelihood fit. The result is in agreement with the NLO SM prediction  $9.2^{+2.9}_{-2.4}$  fb. The measurement constrains the top quark Yukawa coupling strength parameter to be  $|Y_t/Y_t^{SM}| < 2.1$  (95% CL).
- <sup>11</sup> SIRUNYAN 17AB based on  $2.6 \text{ fb}^{-1}$  of data. A multivariate analysis is used to discriminate between  $t\bar{t}t\bar{t}$  signal and  $t\bar{t}$  background. A combination with a previous search (CMS, KHACHATRYAN 16BJ) in the same-sign dilepton channel gives an upper limit of  $69$  fb (95% CL), corresponding to  $7.4 \cdot$ (SM prediction).
- <sup>12</sup> SIRUNYAN 17S based on  $35.9 \text{ fb}^{-1}$ . The limit is in agreement with the NLO SM prediction  $9.2^{+2.9}_{-2.4}$  fb. Superseded by SIRUNYAN 18BU. The signal events are also used to constrain various new physics models.

### $t\bar{t}W$ Production Cross Section in $pp$ Collisions at $\sqrt{s} = 8 \text{ TeV}$

VALUE (fb)	DOCUMENT ID	TECN	COMMENT
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• • • We do not use the following data for averages, fits, limits, etc. • • •

$170^{+90}_{-80} \pm 70$	<sup>1</sup> KHACHATRYAN 14N	CMS	$t\bar{t}W \rightarrow$ same sign dilepton + $\cancel{E}_T$ + jets
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<sup>1</sup> Based on  $19.5 \text{ fb}^{-1}$  of data. The result is consistent with the SM prediction of  $\sigma(t\bar{t}W) = 206^{+21}_{-23}$  fb.

### $t\bar{t}W$ Production Cross Section in $pp$ Collisions at $\sqrt{s} = 13 \text{ TeV}$

VALUE (pb)	DOCUMENT ID	TECN	COMMENT
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• • • We do not use the following data for averages, fits, limits, etc. • • •

$0.87 \pm 0.13 \pm 0.14$	<sup>1</sup> AABOUD	19AR ATLS	2,3,4 $\ell$ + $\cancel{E}_T$ + jets
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- <sup>1</sup>TUMASYAN 22W measured fiducial inclusive and differential cross-sections for  $pp \rightarrow t\bar{t}\gamma$  at 13 TeV with  $138 \text{ fb}^{-1}$  of data. The results are in agreement with the SM predictions. The results are used to constrain anomalous couplings of the top quark in the SMEFT framework.
- <sup>2</sup>TUMASYAN 21H measured fiducial inclusive and differential cross-sections for  $pp \rightarrow t\bar{t}\gamma$  at 13 TeV with  $137 \text{ fb}^{-1}$  of data. The results are in agreement with the SM predictions. The results are used to constrain anomalous couplings of the top quark in the SMEFT framework.
- <sup>3</sup>AABOUD 19AD measured fiducial inclusive and differential cross-sections for  $pp \rightarrow t\bar{t}\gamma$  at 13 TeV with  $36.1 \text{ fb}^{-1}$  of data. The results are in agreement with the theoretical predictions.

### **f(Q<sub>0</sub>): t $\bar{t}$ Fraction of Events with a Veto on Additional Central Jet Activity in pp Collisions at $\sqrt{s} = 7 \text{ TeV}$**

Q<sub>0</sub> denotes the threshold of the additional jet  $p_T$ .

VALUE (%)	DOCUMENT ID	TECN	COMMENT
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●			
$80.0 \pm 1.1 \pm 1.6$	<sup>1</sup> CHATRCHYAN 14AE CMS		Q <sub>0</sub> = 75 GeV ( $ y  < 2.4$ )
$92.0 \pm 0.7 \pm 0.8$	<sup>1</sup> CHATRCHYAN 14AE CMS		Q <sub>0</sub> = 150 GeV ( $ y  < 2.4$ )
$98.0 \pm 0.3 \pm 0.3$	<sup>1</sup> CHATRCHYAN 14AE CMS		Q <sub>0</sub> = 300 GeV ( $ y  < 2.4$ )
$56.4 \pm 1.3^{+2.6}_{-2.8}$	<sup>2</sup> AAD	12BL ATLS	Q <sub>0</sub> = 25 GeV ( $ y  < 2.1$ )
$84.7 \pm 0.9 \pm 1.0$	<sup>2</sup> AAD	12BL ATLS	Q <sub>0</sub> = 75 GeV ( $ y  < 2.1$ )
$95.2^{+0.5}_{-0.6} \pm 0.4$	<sup>2</sup> AAD	12BL ATLS	Q <sub>0</sub> = 150 GeV ( $ y  < 2.1$ )

<sup>1</sup> CHATRCHYAN 15 based on  $5.0 \text{ fb}^{-1}$  of data. The  $t\bar{t}$  events are selected in the dilepton and lepton + jets decay channels. For other values of Q<sub>0</sub> see Table 5.

<sup>2</sup> Based on  $2.05 \text{ fb}^{-1}$  of data. The  $t\bar{t}$  events are selected in the dilepton decay channel with two identified  $b$ -jets.

### **Fraction of t $\bar{t}$ + multi-jet Events in pp Collisions at $\sqrt{s} = 7 \text{ TeV}$**

VALUE	DOCUMENT ID	TECN	COMMENT
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●			
	<sup>1</sup> AAD	15D ATLS	$\ell + \cancel{E}_T + n_j$ ( $n=3$ to 8)
$0.332 \pm 0.090$	<sup>2</sup> CHATRCHYAN 14AE CMS		$t\bar{t}(\ell\ell) + 0 \text{ jet } (E_T > 30\text{GeV})$
$0.436 \pm 0.098$	<sup>2</sup> CHATRCHYAN 14AE CMS		$t\bar{t}(\ell\ell) + 1 \text{ jet } (E_T > 30\text{GeV})$
$0.232 \pm 0.125$	<sup>2</sup> CHATRCHYAN 14AE CMS		$t\bar{t}(\ell\ell) + \geq 2 \text{ jet } (E_T > 30\text{GeV})$

<sup>1</sup> Based on  $4.6 \text{ fb}^{-1}$  of data. Fiducial  $t\bar{t}$  production cross section is presented as a function of the jet multiplicity for up to eight jets with the jet  $p_T$  threshold of 25, 40, 60, and 80 GeV, and as a function of jet  $p_T$  up to the 5th jet. MC models can be discriminated by using data for high jet multiplicity and by  $p_T$  distributions of the leading and 5th jet.

<sup>2</sup> Based on  $5.0 \text{ fb}^{-1}$  of data. Events with two oppositely charged leptons, large  $\cancel{E}_T$  and jets with at least 1  $b$ -tag are used to measure the fraction of  $t\bar{t}$  plus additional jets. The gap fraction ( $n=0$  jet rate) as a function of the jet  $p_T$  and that of  $H_T$ , the scalar sum of the  $p_T$ 's of additional jets, is shown in Fig. 8.

### $t\bar{t}$ Charge Asymmetry ( $A_C$ ) in $pp$ Collisions at $\sqrt{s} = 7$ TeV

$A_C = (N(\Delta|y| > 0) - N(\Delta|y| < 0)) / (N(\Delta|y| > 0) + N(\Delta|y| < 0))$  where  $\Delta|y| = |y_t| - |y_{\bar{t}}|$  is the difference between the absolute values of the top and antitop rapidities and  $N$  is the number of events with  $\Delta|y|$  positive or negative.

VALUE (%)	DOCUMENT ID	TECN	COMMENT
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●			
$0.5 \pm 0.7 \pm 0.6$	<sup>1</sup> AABOUD	18AMLHC	ATLAS+CMS combination (lepton + jets)
$2.1 \pm 2.5 \pm 1.7$	<sup>2</sup> AAD	15AJ ATLS	$ll + \cancel{E}_T + \geq 2j$
$0.6 \pm 1.0$	<sup>3</sup> AAD	14I ATLS	$l + \cancel{E}_T + \geq 4j (\geq 1b)$
$-1.0 \pm 1.7 \pm 0.8$	<sup>4</sup> CHATRCHYAN	14D CMS	$ll + \cancel{E}_T + \geq 2j (\geq 1b)$
$-1.9 \pm 2.8 \pm 2.4$	<sup>5</sup> AAD	12BK ATLS	$l + \cancel{E}_T + \geq 4j (\geq 1b)$
$0.4 \pm 1.0 \pm 1.1$	<sup>6</sup> CHATRCHYAN	12BB CMS	$l + \cancel{E}_T + \geq 4j (\geq 1b)$
$-1.3 \pm 2.8^{+2.9}_{-3.1}$	<sup>7</sup> CHATRCHYAN	12BS CMS	$l + \cancel{E}_T + \geq 4j (\geq 1b)$

<sup>1</sup> ATLAS and CMS combination based on the data of AAD 14I and CHATRCHYAN 12BB. It takes into account the correlations of the measurements and systematic errors. The result is in agreement with the SM prediction (NLO QCD + NLO EW).

<sup>2</sup> AAD 15AJ based on  $4.6 \text{ fb}^{-1}$  of data. After kinematic reconstruction the top quark momenta are corrected for detector resolution and acceptance effects by unfolding, using parton level information of the MC generators. The lepton charge asymmetry is measured as  $A_C^l = 0.024 \pm 0.015 \pm 0.009$ . All the measurements are consistent with the SM predictions.

<sup>3</sup> Based on  $4.7 \text{ fb}^{-1}$  of data. The result is consistent with the SM prediction of  $A_C = 0.0123 \pm 0.0005$ . The asymmetry is  $0.011 \pm 0.018$  if restricted to those events where  $\beta_Z(t\bar{t}) > 0.6$ , which is also consistent with the SM prediction of  $0.020^{+0.006}_{-0.007}$ .

<sup>4</sup> Based on  $5.0 \text{ fb}^{-1}$  of data. The lepton charge asymmetry is measured as  $A_C^l = 0.009 \pm 0.0010 \pm 0.006$ .  $A_C^l$  dependences on  $m_{t\bar{t}}$ ,  $|y(t\bar{t})|$ , and  $p_T(t\bar{t})$  are given in Fig. 5. All measurements are consistent with the SM predictions.

<sup>5</sup> Based on  $1.04 \text{ fb}^{-1}$  of data. The result is consistent with  $A_C = 0.006 \pm 0.002$  (MC at NLO). No significant dependence of  $A_C$  on  $m_{t\bar{t}}$  is observed.

<sup>6</sup> Based on  $5.0 \text{ fb}^{-1}$  of data at 7 TeV.

<sup>7</sup> Based on  $1.09 \text{ fb}^{-1}$  of data. The result is consistent with the SM predictions.

### $t\bar{t}$ Charge Asymmetry ( $A_C$ ) in $pp$ Collisions at $\sqrt{s} = 8$ TeV

VALUE (%)	DOCUMENT ID	TECN	COMMENT
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●			
$0.55 \pm 0.23 \pm 0.25$	<sup>1</sup> AABOUD	18AMLHC	ATLAS+CMS combination (lepton + jets)
$2.1 \pm 1.6$	<sup>2</sup> AAD	16AE ATLS	$ll + \cancel{E}_T + \geq 2j$
$0.9 \pm 0.5$	<sup>3</sup> AAD	16AZ ATLS	$l + \cancel{E}_T + \geq 4j$
$4.2 \pm 3.2$	<sup>4</sup> AAD	16T ATLS	$m_{t\bar{t}} > 0.75 \text{ TeV},   y_t  -  y_{\bar{t}}   < 2, l + \cancel{E}_T + \text{jets}$
$1.1 \pm 1.1 \pm 0.7$	<sup>5</sup> KHACHATRY...	16AD CMS	$ll + \cancel{E}_T + \geq 2j (\geq 1b)$
$0.33 \pm 0.26 \pm 0.33$	<sup>6</sup> KHACHATRY...	16AH CMS	$l + \cancel{E}_T + \geq 4j (\geq 1b)$
$0.10 \pm 0.68 \pm 0.37$	<sup>7</sup> KHACHATRY...	16T CMS	$l + \cancel{E}_T + \geq 4j (\geq 1b)$

<sup>1</sup> ATLAS and CMS combination based on the data of AAD 16AZ and KHACHATRYAN 16AH. It takes into account the correlations of the measurements and systematic errors. A combination of the differential measurements of the charge asymmetry is also presented. The results are in agreement with the SM prediction (NNLO QCD + NLO EW).

- <sup>2</sup> AAD 16AE is based on 20.3 fb<sup>-1</sup> of data. After kinematic reconstruction, the top quark momenta are corrected for detector resolution and acceptance effects by unfolding, using parton level information of the MC generators. The lepton charge asymmetry is measured as  $A_C^{\ell\ell} = 0.008 \pm 0.006$ . All the measurements are consistent with the SM predictions.
- <sup>3</sup> AAD 16AZ based on 20.3 fb<sup>-1</sup> of data. All the differential and inclusive measurements are statistically limited and consistent with the SM predictions.
- <sup>4</sup> AAD 16T based on 20.3 fb<sup>-1</sup> of data. Uses reconstruction techniques for the decay topology of highly boosted top quarks. The observed asymmetry is transformed by unfolding to a parton-level result in the shown fiducial region. The result is consistent with the NLO SM prediction.
- <sup>5</sup> KHACHATRYAN 16AD based on 19.5 fb<sup>-1</sup> of data. The lepton charge asymmetry is measured as  $A_C^{\ell\ell} = 0.003 \pm 0.006 \pm 0.003$ . All the measurements are consistent with the SM predictions.
- <sup>6</sup> KHACHATRYAN 16AH based on 19.6 fb<sup>-1</sup> of data. The same data set as in KHACHATRYAN 16T is used. A template technique is used, which is sensitive to the charge anti-symmetric component of the  $t\bar{t}$  rapidity distributions and statistically advantageous. The result is consistent with the SM predictions.
- <sup>7</sup> KHACHATRYAN 16T based on 19.7 fb<sup>-1</sup> of data. The same data set as in KHACHATRYAN 16AH is used. After kinematic reconstruction the top quark momenta are corrected for detector resolution and acceptance effects by unfolding, using parton level information of the MC generators. All the measurements are consistent with the SM predictions.

### **$t$ -quark Polarization in $t\bar{t}$ Events in $p\bar{p}$ Collisions at $\sqrt{s} = 1.96$ TeV**

VALUE	DOCUMENT ID	TECN	COMMENT
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• • • We do not use the following data for averages, fits, limits, etc. • • •

0.070 ± 0.055	<sup>1</sup> ABAZOV	17	D0 $\ell + \cancel{E}_T + \geq 3j (\geq 1b)$
-0.102 ± 0.061	<sup>2</sup> ABAZOV	17	D0 $\ell + \cancel{E}_T + \geq 3j (\geq 1b)$
0.040 ± 0.035	<sup>3</sup> ABAZOV	17	D0 $\ell + \cancel{E}_T + \geq 3j (\geq 1b)$
0.113 ± 0.091 ± 0.019	<sup>4</sup> ABAZOV	15K	D0 $A_{FB}^{\ell}$ in $\ell\ell + \cancel{E}_T + \geq 2j (\geq 1b)$

- <sup>1</sup> ABAZOV 17 based on 9.7 fb<sup>-1</sup> of data. The value is top quark polarization times spin analyzing power in the beam basis. Combination with the result of ABAZOV 15K yields  $0.081 \pm 0.048$ . This result together with the helicity polarization is shown in a 2-dimensional plot in Fig.4. These results are consistent with the SM prediction.
- <sup>2</sup> ABAZOV 17 based on 9.7 fb<sup>-1</sup> of data. The value is top quark polarization times spin analyzing power in the helicity basis. The result is consistent with the SM prediction. This result together with the beam polarization is shown in a 2-dimensional plot in Fig.4.
- <sup>3</sup> ABAZOV 17 based on 9.7 fb<sup>-1</sup> of data. The value is top quark polarization times spin analyzing power in the transverse basis. The result is consistent with the SM prediction.
- <sup>4</sup> ABAZOV 15K based on 9.7 fb<sup>-1</sup> of data. The value is top quark polarization times spin analyzing power in the beam basis. The result is consistent with the SM prediction of  $-0.0019 \pm 0.0005$ .

### **$t$ -quark Polarization in $t\bar{t}$ Events in $pp$ Collisions at $\sqrt{s} = 7$ TeV**

The double differential distribution in polar angles,  $\theta_1$  ( $\theta_2$ ) of the decay particle of the top (anti-top) decay products, is parametrized as  $(1/\sigma)d\sigma/(d\cos\theta_1 d\cos\theta_2) = (1/4) ( 1 + A_t \cos\theta_1 + A_{\bar{t}} \cos\theta_2 - C \cos\theta_1 \cos\theta_2 )$ . The charged lepton is used to tag  $t$  or  $\bar{t}$ . The coefficient  $A_t$  and  $A_{\bar{t}}$  measure the average helicity of  $t$  and  $\bar{t}$ , respectively.  $A_{CPC} = A_t = A_{\bar{t}}$  assumes  $CP$  conservation, whereas  $A_{CPV} = A_t = -A_{\bar{t}}$  corresponds to maximal  $CP$  violation.

VALUE	DOCUMENT ID	TECN	COMMENT
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• • • We do not use the following data for averages, fits, limits, etc. • • •

-0.035 ± 0.014 ± 0.037	<sup>1</sup> AAD	13BE	ATLS $A_{CPC}$
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$$0.020 \pm 0.016^{+0.013}_{-0.017} \quad {}^1 \text{AAD} \quad 13\text{BE ATLS} \quad A_{CPV}$$

<sup>1</sup> Based on  $4.7 \text{ fb}^{-1}$  of data using the final states containing one or two isolated electrons or muons and jets with at least one  $b$ -tag.

### $t$ -quark Polarization in $t\bar{t}$ Events in $pp$ Collisions at $\sqrt{s} = 8 \text{ TeV}$

$A_t$ ,  $A_{\bar{t}}$ ,  $A_{CPC}$ ,  $A_{CPV}$ , and  $A_C$  are defined in header texts in the subsections, just above.

VALUE	DOCUMENT ID	TECN	COMMENT
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●			
$-0.044 \pm 0.038 \pm 0.027$	<sup>1</sup> AABOUD	17G ATLS	$A_t$
$-0.064 \pm 0.040 \pm 0.027$	<sup>1</sup> AABOUD	17G ATLS	$A_{\bar{t}}$
$0.296 \pm 0.093 \pm 0.037$	<sup>1</sup> AABOUD	17G ATLS	$A_C$
$-0.022 \pm 0.058$	<sup>2</sup> KHACHATRYAN 16AI	CMS	$A_{CPC}$
$0.000 \pm 0.016$	<sup>2</sup> KHACHATRYAN 16AI	CMS	$A_{CPV}$

<sup>1</sup> AABOUD 17G based on  $20.2 \text{ fb}^{-1}$  of  $pp$  data, using events with two leptons and two or more jets with at least one  $b$ -tag. Determined from measurements of 15 top quark spin observables. The second error corresponds to a variation of  $m_t$  about 172.5 GeV by 0.7 GeV. The values are consistent with the NLO SM predictions.

<sup>2</sup> KHACHATRYAN 16AI based on  $19.5 \text{ fb}^{-1}$  of  $pp$  data at  $\sqrt{s} = 8 \text{ TeV}$ , using events with two leptons and two or more jets with at least one  $b$ -tag. Determined from the lepton angular distributions as a function of the  $t\bar{t}$ -system kinematical variables.

### $t$ -quark Polarization in Single Top Events in $pp$ Collisions at $\sqrt{s} = 8 \text{ TeV}$

VALUE	CL%	DOCUMENT ID	TECN	COMMENT
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●				
$>0.72$	95	<sup>1</sup> AABOUD	17BB ATLS	$\alpha_\ell P$ ; t-channel
$0.97 \pm 0.05 \pm 0.11$		<sup>2</sup> AABOUD	17I ATLS	$\alpha_\ell P$ ; t-channel
$0.25 \pm 0.08 \pm 0.14$		<sup>3</sup> AABOUD	17I ATLS	$(F_+ + F_-)P$ ; t-channel
$0.26 \pm 0.03 \pm 0.10$		<sup>4</sup> KHACHATRYAN 16B0	CMS	$(\alpha_\mu P)/2$ ; t-channel

<sup>1</sup> AABOUD 17BB based on  $20.2 \text{ fb}^{-1}$  of  $pp$  data. Triple-differential decay rate of top quark is used to simultaneously determine five generalized  $Wtb$  couplings as well as the top polarization.  $\alpha_\ell$  denotes the spin analyzing power of charged lepton, and the spin axis of the top polarization  $P$  is taken along the spectator-quark momentum in the top rest frame. The value is compatible with the SM prediction of about 0.9.

<sup>2</sup> AABOUD 17I based on  $20.2 \text{ fb}^{-1}$  of  $pp$  data. A cut-based analysis is used to discriminate between signal and backgrounds.  $\alpha_\ell$  denotes the spin analyzing power of charged lepton, and the spin axis of the top polarization  $P$  is taken along the spectator-quark momentum in the top rest frame. See this paper for a number of other asymmetries and measurements that are not included here.

<sup>3</sup> AABOUD 17I based on  $20.2 \text{ fb}^{-1}$  of  $pp$  data. A cut-based analysis is used to discriminate between signal and backgrounds.  $F_\pm$  denotes  $W$  helicity fraction, and the spin axis of the top polarization  $P$  is taken along the spectator-quark momentum in the top rest frame. See this paper for a number of other asymmetries and measurements that are not included here.

<sup>4</sup> KHACHATRYAN 16B0 based on  $19.7 \text{ fb}^{-1}$  of data. A high-purity sample with a muon is selected by a multivariate analysis. The value is the top spin asymmetry, given by one half of the spin analyzing power  $\alpha_\mu$  ( $=1$  at LO of SM) times the top polarization,  $P$ , where the spin axis is defined as the direction of the untagged jet in the top rest frame. The value is compatible with the SM prediction of 0.44 with a  $2.0\sigma$  deviation.

### **$t$ -quark Polarization in Single Top Events in $pp$ Collisions at $\sqrt{s} = 13$ TeV**

<u>VALUE</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●			
$0.01 \pm 0.18$	<sup>1</sup> AAD	22Z ATLS	$P_{x'}$ ( $t$ , transverse component)
$-0.029 \pm 0.027$	<sup>1</sup> AAD	22Z ATLS	$P_{y'}$ ( $t$ , normal component)
$0.91 \pm 0.10$	<sup>1</sup> AAD	22Z ATLS	$P_{z'}$ ( $t$ , parallel component)
$-0.02 \pm 0.20$	<sup>1</sup> AAD	22Z ATLS	$P_{x'}$ ( $\bar{t}$ , transverse component)
$-0.007 \pm 0.051$	<sup>1</sup> AAD	22Z ATLS	$P_{y'}$ ( $\bar{t}$ , normal component)
$-0.79 \pm 0.16$	<sup>1</sup> AAD	22Z ATLS	$P_{z'}$ ( $\bar{t}$ , parallel component)
$0.440 \pm 0.070$	<sup>2</sup> SIRUNYAN	20R CMS	$(\alpha_\ell P)/2$ ; $t$ -channel

<sup>1</sup>AAD 22Z based on  $139 \text{ fb}^{-1}$  of data. Three components of  $t$  or  $\bar{t}$  polarization vector (defined in the  $t$  or  $\bar{t}$  rest frame) are measured in  $t$ -channel single top production using  $\ell$  momentum distribution in the  $\ell + \cancel{E}_T + 2j$  (with 1 of them  $b$ -jet) channel. The measured values are in agreement with NNLO SM prediction. Constraints on the Wilson coefficients of SMEFT are obtained as  $-0.9 < C_{tW} < 1.4$  and  $-0.8 < C_{itW} < 0.2$ .

<sup>2</sup>SIRUNYAN 20R based on  $36.1 \text{ fb}^{-1}$  of data. Differential cross sections for  $t$ -channel single top production are measured using  $1\ell + 2,3$ -jet mode and found to be in good agreement with SM predictions. The value is the top spin asymmetry, given by  $1/2$  of the spin analyzing power  $\alpha_\ell$  ( $=1$  at LO of SM) times the top polarization  $P$ , where the spin axis is defined as the direction of the spectator quark in the top rest frame at the parton level. It is in good agreement with the NLO SM prediction of 0.436.

### **$gg \rightarrow t\bar{t}$ Fraction in $p\bar{p}$ Collisions at $\sqrt{s} = 1.96$ TeV**

<u>VALUE</u>	<u>CL%</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●				
$< 0.33$	68	<sup>1</sup> AALTONEN	09F CDF	$t\bar{t}$ correlations
$0.07 \pm 0.14 \pm 0.07$		<sup>2</sup> AALTONEN	08AG CDF	low $p_T$ number of tracks

<sup>1</sup>Based on  $955 \text{ pb}^{-1}$ . AALTONEN 09F used differences in the  $t\bar{t}$  production angular distribution and polarization correlation to discriminate between  $gg \rightarrow t\bar{t}$  and  $q\bar{q} \rightarrow t\bar{t}$  subprocesses. The combination with the result of AALTONEN 08AG gives  $0.07^{+0.15}_{-0.07}$ .

<sup>2</sup>Result is based on  $0.96 \text{ fb}^{-1}$  of data. The contribution of the subprocesses  $gg \rightarrow t\bar{t}$  and  $q\bar{q} \rightarrow t\bar{t}$  is distinguished by using the difference between quark and gluon initiated jets in the number of small  $p_T$  ( $0.3 \text{ GeV} < p_T < 3 \text{ GeV}$ ) charged particles in the central region ( $|\eta| < 1.1$ ).

### **$A_{FB}$ of $t\bar{t}$ in $p\bar{p}$ Collisions at $\sqrt{s} = 1.96$ TeV**

$A_{FB}$  = Forward-backward asymmetry.

<u>VALUE (%)</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●			
$12.8 \pm 2.1 \pm 1.4$	<sup>1</sup> AALTONEN	18 TEVA	CDF, D0 combination
$17.5 \pm 5.6 \pm 3.1$	<sup>2</sup> ABAZOV	15K D0	$A_{FB}^\ell$ in $\ell\ell + \cancel{E}_T + \geq 2j$ ( $\geq 1b$ )
$7.2 \pm 6.0$	<sup>3</sup> AALTONEN	14F CDF	$A_{FB}^\ell$ in dilepton channel ( $\ell\ell + \cancel{E}_T + \geq 2j$ )
$7.6 \pm 8.2$	<sup>3</sup> AALTONEN	14F CDF	$A_{FB}^{\ell\ell}$ in dilepton channel ( $\ell\ell + \cancel{E}_T + \geq 2j$ )
$4.2 \pm 2.3^{+1.7}_{-2.0}$	<sup>4</sup> ABAZOV	14G D0	$A_{FB}^\ell$ ( $\ell + \cancel{E}_T + \geq 3j$ ( $0,1 \geq 2b$ ))
$10.6 \pm 3.0$	<sup>5</sup> ABAZOV	14H D0	$A_{FB}$ ( $\ell + \cancel{E}_T + \geq 3j$ ( $\geq 1b$ ))
$20.1 \pm 6.7$	<sup>6</sup> AALTONEN	13AD CDF	$a_1/a_0$ in $\ell + \cancel{E}_T + \geq 4j$ ( $\geq 1b$ )
$-0.2 \pm 3.1$	<sup>6</sup> AALTONEN	13AD CDF	$a_3, a_5, a_7$ in $\ell + \cancel{E}_T + \geq 4j$ ( $\geq 1b$ )



16.4 ± 4.7	7	AALTONEN	13S	CDF	$\ell + \cancel{E}_T + \geq 4$ jets ( $\geq 1b$ -tag)
9.4 <sup>+</sup> <sub>-</sub> 3.2 2.9	8	AALTONEN	13X	CDF	$\ell + \cancel{E}_T + \geq 4$ jets ( $\geq 1b$ -tag)
11.8 ± 3.2	9	ABAZOV	13A	D0	$\ell\ell$ & $\ell+$ jets comb.
-11.6 ± 15.3	10	AALTONEN	11F	CDF	$m_{t\bar{t}} < 450$ GeV
47.5 ± 11.4	10	AALTONEN	11F	CDF	$m_{t\bar{t}} > 450$ GeV
19.6 ± 6.5	11	ABAZOV	11AH	D0	$\ell + \cancel{E}_T + \geq 4$ jets ( $\geq 1b$ -tag)
17 ± 8	12	AALTONEN	08AB	CDF	$p\bar{p}$ frame
24 ± 14	12	AALTONEN	08AB	CDF	$t\bar{t}$ frame
12 ± 8 ± 1	13	ABAZOV	08L	D0	$\ell + \cancel{E}_T + \geq 4$ jets

<sup>1</sup> AALTONEN 18 based on 9–10 fb<sup>-1</sup> of  $p\bar{p}$  data at  $\sqrt{s} = 1.96$  TeV. The value is the asymmetry in the number of reconstructed  $t\bar{t}$  events with rapidity  $y_t > y_{\bar{t}}$  and those with  $y_t < y_{\bar{t}}$ . The combined fits to CDF and D0 single lepton and  $\ell\ell$  asymmetries give  $A_{FB}^\ell = 0.073 \pm 0.016 \pm 0.012$  and  $A_{FB}^{\ell\ell} = 0.108 \pm 0.043 \pm 0.016$ , respectively. The results are consistent with the SM predictions.

<sup>2</sup> ABAZOV 15K based on 9.7 fb<sup>-1</sup> of data. The result is consistent with the SM predictions. By combining with the previous D0 measurement in the  $\ell + \text{jet}$  channel ABAZOV 14H,  $A_{FB}^\ell = 0.118 \pm 0.025 \pm 0.013$  is obtained.

<sup>3</sup> AALTONEN 14F based on 9.1 fb<sup>-1</sup> of data.  $A_{FB}^\ell$  and  $A_{FB}^{\ell\ell}$  denote, respectively, the asymmetries  $(N(x>0) - N(x<0))/N_{tot}$  for  $x = q_\ell \eta_\ell$  ( $q_\ell$  is the charge of  $\ell$ ) and  $x = \eta_{\ell^+} - \eta_{\ell^-}$ . Both results are consistent with the SM predictions. By combining with the previous CDF measurement in the  $\ell + \text{jet}$  channel AALTONEN 13X,  $A_{FB}^\ell = 0.098^{+0.028}_{-0.026}$  is obtained. The combined result is about two sigma larger than the SM prediction of  $A_{FB}^\ell = 0.038 \pm 0.003$ .

<sup>4</sup> Based on 9.7 fb<sup>-1</sup> of  $p\bar{p}$  data at  $\sqrt{s} = 1.96$  TeV. The asymmetry is corrected for the production level for events with  $|y_\ell| < 1.5$ . Asymmetry as functions of  $E_T(\ell)$  and  $|y_\ell|$  are given in Figs. 7 and 8, respectively. Combination with the asymmetry measured in the dilepton channel [ABAZOV 13P] gives  $A_{FB}^\ell = 4.2 \pm 2.0 \pm 1.4$  %, in agreement with the SM prediction of 2.0%.

<sup>5</sup> Based on 9.7 fb<sup>-1</sup> of data of  $p\bar{p}$  data at  $\sqrt{s} = 1.96$  TeV. The measured asymmetry is in agreement with the SM predictions of  $8.8 \pm 0.9$  % [BERNREUTHER 12], which includes the EW effects. The dependences of the asymmetry on  $|y(t) - y(\bar{t})|$  and  $m_{t\bar{t}}$  are shown in Figs. 9 and 10, respectively.

<sup>6</sup> Based on 9.4 fb<sup>-1</sup> of data. Reported  $A_{FB}$  values come from the determination of  $a_i$  coefficients of  $d\sigma/d(\cos\theta_t) = \sum_i a_i P_i(\cos(\theta_t))$  measurement. The result of  $a_1/a_0 = (40 \pm 12)$  % seems higher than the NLO SM prediction of  $(15^{+7}_{-3})$  %.

<sup>7</sup> Based on 9.4 fb<sup>-1</sup> of data. The quoted result is the asymmetry at the parton level.

<sup>8</sup> Based on 9.4 fb<sup>-1</sup> of data. The observed asymmetry is to be compared with the SM prediction of  $A_{FB}^\ell = 0.038 \pm 0.003$ .

<sup>9</sup> Based on 5.4 fb<sup>-1</sup> of data. ABAZOV 13A studied the dilepton channel of the  $t\bar{t}$  events and measured the leptonic forward-backward asymmetry to be  $A_{FB}^\ell = 5.8 \pm 5.1 \pm 1.3$  %, which is consistent with the SM (QCD+EW) prediction of  $4.7 \pm 0.1$  %. The result is obtained after combining the measurement  $(15.2 \pm 4.0)$  % in the  $\ell + \text{jets}$  channel ABAZOV 11AH. The top quark helicity is measured by using the neutrino weighting method to be consistent with zero in both dilepton and  $\ell + \text{jets}$  channels.

<sup>10</sup> Based on 5.3 fb<sup>-1</sup> of data. The error is statistical and systematic combined. Events with lepton +  $\cancel{E}_T + \geq 4$  jets ( $\geq 1b$ ) are used. AALTONEN 11F also measures the asymmetry as a function of the rapidity difference  $|y_t - y_{\bar{t}}|$ . The NLO QCD predictions [MCFM] are  $(4.0 \pm 0.6)$  % and  $(8.8 \pm 1.3)$  % for  $m_{t\bar{t}} < 450$  and  $> 450$  GeV, respectively.

- <sup>11</sup> Based on  $5.4 \text{ fb}^{-1}$  of data. The error is statistical and systematic combined. The quoted asymmetry is obtained after unfolding to be compared with the MC@NLO prediction of  $(5.0 \pm 0.1)\%$ . No significant difference between the  $m_{t\bar{t}} < 450$  and  $> 450$  GeV data samples is found. A corrected asymmetry based on the lepton from a top quark decay of  $(15.2 \pm 4.0)\%$  is measured to be compared to the MC@NLO prediction of  $(2.1 \pm 0.1)\%$ .
- <sup>12</sup> Result is based on  $1.9 \text{ fb}^{-1}$  of data. The  $FB$  asymmetry in the  $t\bar{t}$  events has been measured in the  $\ell + \text{jets}$  mode, where the lepton charge is used as the flavor tag. The asymmetry in the  $p\bar{p}$  frame is defined in terms of  $\cos(\theta)$  of hadronically decaying  $t$ -quark momentum, whereas that in the  $t\bar{t}$  frame is defined in terms of the  $t$  and  $\bar{t}$  rapidity difference. The results are consistent ( $\leq 2\sigma$ ) with the SM predictions.
- <sup>13</sup> Result is based on  $0.9 \text{ fb}^{-1}$  of data. The asymmetry in the number of  $t\bar{t}$  events with  $y_t > y_{\bar{t}}$  and those with  $y_t < y_{\bar{t}}$  has been measured in the lepton + jets final state. The observed value is consistent with the SM prediction of  $0.8\%$  by MC@NLO, and an upper bound on the  $Z' \rightarrow t\bar{t}$  contribution for the SM  $Z$ -like couplings is given in in Fig. 2 for  $350 \text{ GeV} < m_{Z'} < 1 \text{ TeV}$ .

### **$t$ -Quark Electric Charge**

<u>VALUE</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
<b><math>0.64 \pm 0.02 \pm 0.08</math></b>	<sup>1</sup> AAD	13AY ATLS	$\ell + \cancel{E}_T + \geq 4 \text{ jets } (\geq 1 b)$
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●			
	<sup>2</sup> ABAZOV	14D D0	$\ell + \cancel{E}_T + \geq 4 \text{ jets } (\geq 2 b)$
	<sup>3</sup> AALTONEN	13J CDF	$p\bar{p}$ at 1.96 TeV
	<sup>4</sup> AALTONEN	10S CDF	Repl. by AALTONEN 13J
	<sup>5</sup> ABAZOV	07C D0	fraction of $ q =4e/3$ pair

- <sup>1</sup> AAD 13AY result is based on  $2.05 \text{ fb}^{-1}$  of  $pp$  data at  $\sqrt{s} = 7 \text{ TeV}$ , the result is obtained by reconstructing  $t\bar{t}$  events in the lepton + jets final state, where  $b$ -jet charges are tagged by the jet-charge algorithm. This measurement excludes the charge  $-4/3$  assignment to the top quark at more than 8 standard deviations.
- <sup>2</sup> ABAZOV 14D result is based on  $5.3 \text{ fb}^{-1}$  of  $p\bar{p}$  data at  $\sqrt{s}=1.96 \text{ TeV}$ . The electric charge of  $b + W$  system in  $t\bar{t}$  candidate events is measured from the charges of the leptons from  $W$  decay and in  $b$  jets. Under the assumption that the  $b + W$  system consists of the sum of the top quark and the charge  $-4/3$  quark  $b'(-4/3)$  of the same mass, the top quark fraction is found to be  $f = 0.88 \pm 0.13$  (stat)  $\pm 0.11$  (syst), or the upper bound for the  $b'(-4/3)$  contamination of  $1 - f < 0.46$  (95% CL).
- <sup>3</sup> AALTONEN 13J excludes the charge  $-4/3$  assignment to the top quark at 99% CL, using  $5.6 \text{ fb}^{-1}$  of data in  $p\bar{p}$  collisions at  $\sqrt{s} = 1.96 \text{ TeV}$ . Result is obtained by reconstructing  $t\bar{t}$  events in the lepton + jets final state, where  $b$ -jet charges are tagged by the jet-charge algorithm.
- <sup>4</sup> AALTONEN 10S excludes the charge  $-4/3$  assignment for the top quark [CHANG 99] at 95%CL, using  $2.7 \text{ fb}^{-1}$  of data in  $p\bar{p}$  collisions at  $\sqrt{s} = 1.96 \text{ TeV}$ . Result is obtained by reconstructing  $t\bar{t}$  events in the lepton + jets final state, where  $b$ -jet charges are tagged by the SLT (soft lepton tag) algorithm.
- <sup>5</sup> ABAZOV 07C reports an upper limit  $\rho < 0.80$  (90% CL) on the fraction  $\rho$  of exotic quark pairs  $Q\bar{Q}$  with electric charge  $|q| = 4e/3$  in  $t\bar{t}$  candidate events with high  $p_T$  lepton, missing  $E_T$  and  $\geq 4$  jets. The result is obtained by measuring the fraction of events in which the quark pair decays into  $W^- + b$  and  $W^+ + \bar{b}$ , where  $b$  and  $\bar{b}$  jets are discriminated by using the charge and momenta of tracks within the jet cones. The maximum CL at which the model of CHANG 99 can be excluded is 92%. Based on  $370 \text{ pb}^{-1}$  of data at  $\sqrt{s} = 1.96 \text{ TeV}$ .

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AAD	15D	JHEP 1501 020	G. Aad <i>et al.</i>	(ATLAS Collab.)
AAD	15J	PRL 114 142001	G. Aad <i>et al.</i>	(ATLAS Collab.)
AAIJ	15R	PRL 115 112001	R. Aaij <i>et al.</i>	(LHCb Collab.)
AALTONEN	15D	PR D92 032003	T. Aaltonen <i>et al.</i>	(CDF Collab.)
AALTONEN	15H	PRL 115 152003	T. Aaltonen <i>et al.</i>	(CDF, D0 Collab.)
ABAZOV	15G	PR D91 112003	V.M. Abazov <i>et al.</i>	(D0 Collab.)
ABAZOV	15K	PR D92 052007	V.M. Abazov <i>et al.</i>	(D0 Collab.)
CHATRCHYAN	15	EPJ C75 216 (errat.)	S. Chatrchyan <i>et al.</i>	(CMS Collab.)
AAD	14	PL B728 363	G. Aad <i>et al.</i>	(ATLAS Collab.)
AAD	14AA	JHEP 1406 008	G. Aad <i>et al.</i>	(ATLAS Collab.)
AAD	14AY	EPJ C74 3109	G. Aad <i>et al.</i>	(ATLAS Collab.)
AAD	14BB	PR D90 112016	G. Aad <i>et al.</i>	(ATLAS Collab.)
AAD	14BI	PR D90 112006	G. Aad <i>et al.</i>	(ATLAS Collab.)
AAD	14I	JHEP 1402 107	G. Aad <i>et al.</i>	(ATLAS Collab.)
AALTONEN	14A	PR D89 091101	T. Aaltonen <i>et al.</i>	(CDF Collab.)
AALTONEN	14F	PRL 113 042001	T. Aaltonen <i>et al.</i>	(CDF Collab.)
Also		PRL 117 199901 (errat.)	T. Aaltonen <i>et al.</i>	(CDF Collab.)
AALTONEN	14G	PRL 112 221801	T. Aaltonen <i>et al.</i>	(CDF Collab.)
AALTONEN	14H	PR D89 072001	T. Aaltonen <i>et al.</i>	(CDF and D0 Collab.)
AALTONEN	14K	PRL 112 231805	T. Aaltonen <i>et al.</i>	(CDF Collab.)
AALTONEN	14L	PRL 112 231804	T. Aaltonen <i>et al.</i>	(CDF Collab.)
AALTONEN	14M	PRL 112 231803	T. Aaltonen <i>et al.</i>	(CDF and D0 Collab.)
AALTONEN	14N	PR D90 091101	T. Aaltonen <i>et al.</i>	(CDF Collab.)
AALTONEN	14O	PRL 113 261804	T. Aaltonen <i>et al.</i>	(CDF Collab.)
ABAZOV	14C	PRL 113 032002	V.M. Abazov <i>et al.</i>	(D0 Collab.)
Also		PR D91 112003	V.M. Abazov <i>et al.</i>	(D0 Collab.)
ABAZOV	14D	PR D90 051101	V.M. Abazov <i>et al.</i>	(D0 Collab.)
ABAZOV	14G	PR D90 072001	V.M. Abazov <i>et al.</i>	(D0 Collab.)
ABAZOV	14H	PR D90 072011	V.M. Abazov <i>et al.</i>	(D0 Collab.)
ABAZOV	14K	PR D90 092006	V.M. Abazov <i>et al.</i>	(D0 Collab.)
CHATRCHYAN	14	PL B728 496	S. Chatrchyan <i>et al.</i>	(CMS Collab.)
CHATRCHYAN	14AC	PRL 112 231802	S. Chatrchyan <i>et al.</i>	(CMS Collab.)
CHATRCHYAN	14AE	EPJ C74 3014	S. Chatrchyan <i>et al.</i>	(CMS Collab.)
Also		EPJ C75 216 (errat.)	S. Chatrchyan <i>et al.</i>	(CMS Collab.)
CHATRCHYAN	14C	EPJ C74 2758	S. Chatrchyan <i>et al.</i>	(CMS Collab.)
CHATRCHYAN	14D	JHEP 1404 191	S. Chatrchyan <i>et al.</i>	(CMS Collab.)
CHATRCHYAN	14F	JHEP 1402 024	S. Chatrchyan <i>et al.</i>	(CMS Collab.)
CHATRCHYAN	14O	PL B731 173	S. Chatrchyan <i>et al.</i>	(CMS Collab.)
CHATRCHYAN	14R	PR D90 032006	S. Chatrchyan <i>et al.</i>	(CMS Collab.)
CHATRCHYAN	14S	PRL 112 171802	S. Chatrchyan <i>et al.</i>	(CMS Collab.)
KHACHATRYAN	14E	PL B736 33	V. Khachatryan <i>et al.</i>	(CMS Collab.)
KHACHATRYAN	14F	JHEP 1406 090	V. Khachatryan <i>et al.</i>	(CMS Collab.)
KHACHATRYAN	14H	JHEP 1409 087	V. Khachatryan <i>et al.</i>	(CMS Collab.)
KHACHATRYAN	14K	PL B738 526 (errat.)	S. Chatrchyan <i>et al.</i>	(CMS Collab.)
KHACHATRYAN	14N	EPJ C74 3060	V. Khachatryan <i>et al.</i>	(CMS Collab.)
KHACHATRYAN	14Q	PR D90 112013	V. Khachatryan <i>et al.</i>	(CMS Collab.)
KHACHATRYAN	14R	JHEP 1411 154	V. Khachatryan <i>et al.</i>	(CMS Collab.)
KHACHATRYAN	14S	PL B739 23	V. Khachatryan <i>et al.</i>	(CMS Collab.)
AAD	13AY	JHEP 1311 031	G. Aad <i>et al.</i>	(ATLAS Collab.)
AAD	13BE	PRL 111 232002	G. Aad <i>et al.</i>	(ATLAS Collab.)
AAD	13X	EPJ C73 2328	G. Aad <i>et al.</i>	(ATLAS Collab.)
AALTONEN	13AB	PR D88 091103	T. Aaltonen <i>et al.</i>	(CDF Collab.)
AALTONEN	13AD	PRL 111 182002	T. Aaltonen <i>et al.</i>	(CDF Collab.)
AALTONEN	13D	PR D87 031104	T. Aaltonen <i>et al.</i>	(CDF Collab.)
AALTONEN	13E	PR D87 052013	T. Aaltonen <i>et al.</i>	(CDF Collab.)
AALTONEN	13G	PR D87 111101	T. Aaltonen <i>et al.</i>	(CDF Collab.)
AALTONEN	13H	PR D88 011101	T. Aaltonen <i>et al.</i>	(CDF Collab.)
AALTONEN	13J	PR D88 032003	T. Aaltonen <i>et al.</i>	(CDF Collab.)
AALTONEN	13S	PR D87 092002	T. Aaltonen <i>et al.</i>	(CDF Collab.)
AALTONEN	13X	PR D88 072003	T. Aaltonen <i>et al.</i>	(CDF Collab.)
AALTONEN	13Z	PRL 111 202001	T. Aaltonen <i>et al.</i>	(CDF Collab.)
ABAZOV	13A	PR D87 011103	V.M. Abazov <i>et al.</i>	(D0 Collab.)
ABAZOV	13O	PL B726 656	V.M. Abazov <i>et al.</i>	(D0 Collab.)
ABAZOV	13P	PR D88 112002	V.M. Abazov <i>et al.</i>	(D0 Collab.)
CHATRCHYAN	13AY	JHEP 1305 065	S. Chatrchyan <i>et al.</i>	(CMS Collab.)
CHATRCHYAN	13BB	PL B720 83	S. Chatrchyan <i>et al.</i>	(CMS Collab.)
CHATRCHYAN	13BE	EPJ C73 2386	S. Chatrchyan <i>et al.</i>	(CMS Collab.)
CHATRCHYAN	13BH	JHEP 1310 167	S. Chatrchyan <i>et al.</i>	(CMS Collab.)
CHATRCHYAN	13C	PRL 110 022003	S. Chatrchyan <i>et al.</i>	(CMS Collab.)
CHATRCHYAN	13F	PL B718 1252	S. Chatrchyan <i>et al.</i>	(CMS Collab.)

CHATRCHYAN	13S	EPJ C73 2494	S. Chatrchyan <i>et al.</i>	(CMS Collab.)
AAD	12B	PL B707 459	G. Aad <i>et al.</i>	(ATLAS Collab.)
AAD	12BE	JHEP 1204 069	G. Aad <i>et al.</i>	(ATLAS Collab.)
AAD	12BF	JHEP 1205 059	G. Aad <i>et al.</i>	(ATLAS Collab.)
AAD	12BG	JHEP 1206 088	G. Aad <i>et al.</i>	(ATLAS Collab.)
AAD	12BK	EPJ C72 2039	G. Aad <i>et al.</i>	(ATLAS Collab.)
AAD	12BL	EPJ C72 2043	G. Aad <i>et al.</i>	(ATLAS Collab.)
AAD	12BO	PL B711 244	G. Aad <i>et al.</i>	(ATLAS Collab.)
AAD	12BP	PL B712 351	G. Aad <i>et al.</i>	(ATLAS Collab.)
AAD	12BT	JHEP 1209 139	G. Aad <i>et al.</i>	(ATLAS Collab.)
AAD	12CG	PL B717 89	G. Aad <i>et al.</i>	(ATLAS Collab.)
AAD	12CH	PL B717 330	G. Aad <i>et al.</i>	(ATLAS Collab.)
AAD	12I	EPJ C72 2046	G. Aad <i>et al.</i>	(ATLAS Collab.)
AALTONEN	12AI	PRL 109 152003	T. Aaltonen <i>et al.</i>	(CDF Collab.)
AALTONEN	12AL	PRL 109 192001	T. Aaltonen <i>et al.</i>	(CDF Collab.)
AALTONEN	12AP	PR D86 092003	T. Aaltonen <i>et al.</i>	(CDF, D0 Collab.)
AALTONEN	12G	PL B714 24	T. Aaltonen <i>et al.</i>	(CDF Collab.)
AALTONEN	12Z	PR D85 071106	T. Aaltonen <i>et al.</i>	(CDF, D0 Collab.)
ABAZOV	12AB	PR D86 051103	V.M. Abazov <i>et al.</i>	(D0 Collab.)
ABAZOV	12B	PRL 108 032004	V.M. Abazov <i>et al.</i>	(D0 Collab.)
ABAZOV	12E	PL B708 21	V.M. Abazov <i>et al.</i>	(D0 Collab.)
ABAZOV	12I	PL B713 165	V.M. Abazov <i>et al.</i>	(D0 Collab.)
ABAZOV	12T	PR D85 091104	V.M. Abazov <i>et al.</i>	(D0 Collab.)
BERNREUTH...	12	PR D86 034026	W. Bernreuther, Z.-G. Si	(AACH, SHDN)
CHATRCHYAN	12AC	PR D85 112007	S. Chatrchyan <i>et al.</i>	(CMS Collab.)
CHATRCHYAN	12AX	JHEP 1211 067	S. Chatrchyan <i>et al.</i>	(CMS Collab.)
CHATRCHYAN	12BA	EPJ C72 2202	S. Chatrchyan <i>et al.</i>	(CMS Collab.)
CHATRCHYAN	12BB	PL B717 129	S. Chatrchyan <i>et al.</i>	(CMS Collab.)
CHATRCHYAN	12BP	JHEP 1212 105	S. Chatrchyan <i>et al.</i>	(CMS Collab.)
CHATRCHYAN	12BQ	JHEP 1212 035	S. Chatrchyan <i>et al.</i>	(CMS Collab.)
CHATRCHYAN	12BS	PL B709 28	S. Chatrchyan <i>et al.</i>	(CMS Collab.)
CHATRCHYAN	12Y	JHEP 1206 109	S. Chatrchyan <i>et al.</i>	(CMS Collab.)
AAD	11A	EPJ C71 1577	G. Aad <i>et al.</i>	(ATLAS Collab.)
AALTONEN	11AC	PR D84 071105	T. Aaltonen <i>et al.</i>	(CDF Collab.)
AALTONEN	11AK	PRL 107 232002	T. Aaltonen <i>et al.</i>	(CDF Collab.)
AALTONEN	11AR	PR D83 031104	T. Aaltonen <i>et al.</i>	(CDF Collab.)
AALTONEN	11D	PR D83 071102	T. Aaltonen <i>et al.</i>	(CDF Collab.)
AALTONEN	11E	PR D83 111101	T. Aaltonen <i>et al.</i>	(CDF Collab.)
AALTONEN	11F	PR D83 112003	T. Aaltonen <i>et al.</i>	(CDF Collab.)
AALTONEN	11K	PRL 106 152001	T. Aaltonen <i>et al.</i>	(CDF Collab.)
AALTONEN	11T	PL B698 371	T. Aaltonen <i>et al.</i>	(CDF Collab.)
AALTONEN	11W	PR D84 031101	T. Aaltonen <i>et al.</i>	(CDF Collab.)
AALTONEN	11Y	PR D84 032003	T. Aaltonen <i>et al.</i>	(CDF Collab.)
AALTONEN	11Z	PR D84 031104	T. Aaltonen <i>et al.</i>	(CDF Collab.)
ABAZOV	11A	PL B695 88	V.M. Abazov <i>et al.</i>	(D0 Collab.)
ABAZOV	11AA	PL B705 313	V.M. Abazov <i>et al.</i>	(D0 Collab.)
ABAZOV	11AD	PR D84 112001	V.M. Abazov <i>et al.</i>	(D0 Collab.)
ABAZOV	11AE	PRL 107 032001	V.M. Abazov <i>et al.</i>	(D0 Collab.)
ABAZOV	11AF	PL B702 16	V.M. Abazov <i>et al.</i>	(D0 Collab.)
ABAZOV	11AH	PR D84 112005	V.M. Abazov <i>et al.</i>	(D0 Collab.)
ABAZOV	11B	PRL 106 022001	V.M. Abazov <i>et al.</i>	(D0 Collab.)
ABAZOV	11C	PR D83 032009	V.M. Abazov <i>et al.</i>	(D0 Collab.)
ABAZOV	11E	PR D84 012008	V.M. Abazov <i>et al.</i>	(D0 Collab.)
ABAZOV	11M	PL B701 313	V.M. Abazov <i>et al.</i>	(D0 Collab.)
ABAZOV	11P	PR D84 032004	V.M. Abazov <i>et al.</i>	(D0 Collab.)
ABAZOV	11R	PRL 107 082004	V.M. Abazov <i>et al.</i>	(D0 Collab.)
ABAZOV	11S	PL B703 422	V.M. Abazov <i>et al.</i>	(D0 Collab.)
ABAZOV	11T	PR D84 052005	V.M. Abazov <i>et al.</i>	(D0 Collab.)
ABAZOV	11X	PRL 107 121802	V.M. Abazov <i>et al.</i>	(D0 Collab.)
ABAZOV	11Z	PL B704 403	V.M. Abazov <i>et al.</i>	(D0 Collab.)
CHATRCHYAN	11AA	EPJ C71 1721	S. Chatrchyan <i>et al.</i>	(CMS Collab.)
CHATRCHYAN	11F	JHEP 1107 049	S. Chatrchyan <i>et al.</i>	(CMS Collab.)
CHATRCHYAN	11R	PRL 107 091802	S. Chatrchyan <i>et al.</i>	(CMS Collab.)
CHATRCHYAN	11Z	PR D84 092004	S. Chatrchyan <i>et al.</i>	(CMS Collab.)
KHACHATRY...	11A	PL B695 424	V. Khachatryan <i>et al.</i>	(CMS Collab.)
AALTONEN	10AA	PR D82 052002	T. Aaltonen <i>et al.</i>	(CDF Collab.)
AALTONEN	10AB	PR D82 112005	T. Aaltonen <i>et al.</i>	(CDF Collab.)
AALTONEN	10AC	PRL 105 232003	T. Aaltonen <i>et al.</i>	(CDF Collab.)
AALTONEN	10AE	PRL 105 252001	T. Aaltonen <i>et al.</i>	(CDF Collab.)
AALTONEN	10C	PR D81 031102	T. Aaltonen <i>et al.</i>	(CDF Collab.)
AALTONEN	10D	PR D81 032002	T. Aaltonen <i>et al.</i>	(CDF Collab.)

AALTONEN	10E	PR D81 052011	T. Aaltonen <i>et al.</i>	(CDF Collab.)
AALTONEN	10Q	PRL 105 042002	T. Aaltonen <i>et al.</i>	(CDF Collab.)
AALTONEN	10S	PRL 105 101801	T. Aaltonen <i>et al.</i>	(CDF Collab.)
AALTONEN	10U	PR D81 072003	T. Aaltonen <i>et al.</i>	(CDF Collab.)
AALTONEN	10V	PR D81 092002	T. Aaltonen <i>et al.</i>	(CDF Collab.)
AALTONEN	10W	PRL 105 012001	T. Aaltonen <i>et al.</i>	(CDF Collab.)
ABAZOV	10	PL B682 363	V.M. Abazov <i>et al.</i>	(D0 Collab.)
ABAZOV	10I	PR D82 032002	V.M. Abazov <i>et al.</i>	(D0 Collab.)
ABAZOV	10J	PL B690 5	V.M. Abazov <i>et al.</i>	(D0 Collab.)
ABAZOV	10K	PL B693 81	V.M. Abazov <i>et al.</i>	(D0 Collab.)
ABAZOV	10Q	PR D82 071102	V.M. Abazov <i>et al.</i>	(D0 Collab.)
AHRENS	10	JHEP 1009 097	V. Ahrens <i>et al.</i>	(MAINZ, HEIDH)
AHRENS	10A	NPBPS 205-206 48	V. Ahrens <i>et al.</i>	(MAINZ, HEIDH)
AALTONEN	09AD	PR D79 112007	T. Aaltonen <i>et al.</i>	(CDF Collab.)
AALTONEN	09AK	PR D80 051104	T. Aaltonen <i>et al.</i>	(CDF Collab.)
AALTONEN	09AL	PR D80 052001	T. Aaltonen <i>et al.</i>	(CDF Collab.)
AALTONEN	09AT	PRL 103 092002	T. Aaltonen <i>et al.</i>	(CDF Collab.)
AALTONEN	09F	PR D79 031101	T. Aaltonen <i>et al.</i>	(CDF Collab.)
AALTONEN	09H	PR D79 052007	T. Aaltonen <i>et al.</i>	(CDF Collab.)
AALTONEN	09J	PR D79 072001	T. Aaltonen <i>et al.</i>	(CDF Collab.)
AALTONEN	09K	PR D79 072010	T. Aaltonen <i>et al.</i>	(CDF Collab.)
AALTONEN	09L	PR D79 092005	T. Aaltonen <i>et al.</i>	(CDF Collab.)
AALTONEN	09M	PRL 102 042001	T. Aaltonen <i>et al.</i>	(CDF Collab.)
AALTONEN	09N	PRL 102 151801	T. Aaltonen <i>et al.</i>	(CDF Collab.)
AALTONEN	09O	PRL 102 152001	T. Aaltonen <i>et al.</i>	(CDF Collab.)
AALTONEN	09Q	PL B674 160	T. Aaltonen <i>et al.</i>	(CDF Collab.)
AALTONEN	09X	PR D79 072005	T. Aaltonen <i>et al.</i>	(CDF Collab.)
AARON	09A	PL B678 450	F.D. Aaron <i>et al.</i>	(H1 Collab.)
ABAZOV	09AA	PRL 103 132001	V.M. Abazov <i>et al.</i>	(D0 Collab.)
ABAZOV	09AG	PR D80 071102	V.M. Abazov <i>et al.</i>	(D0 Collab.)
ABAZOV	09AH	PR D80 092006	V.M. Abazov <i>et al.</i>	(D0 Collab.)
ABAZOV	09J	PRL 102 092002	V.M. Abazov <i>et al.</i>	(D0 Collab.)
ABAZOV	09R	PL B679 177	V.M. Abazov <i>et al.</i>	(D0 Collab.)
ABAZOV	09Z	PRL 103 092001	V.M. Abazov <i>et al.</i>	(D0 Collab.)
LANGENFELD	09	PR D80 054009	U. Langenfeld, S. Moch, P. Uwer	
AALTONEN	08AB	PRL 101 202001	T. Aaltonen <i>et al.</i>	(CDF Collab.)
AALTONEN	08AD	PRL 101 192002	T. Aaltonen <i>et al.</i>	(CDF Collab.)
AALTONEN	08AG	PR D78 111101	T. Aaltonen <i>et al.</i>	(CDF Collab.)
AALTONEN	08AH	PRL 101 252001	T. Aaltonen <i>et al.</i>	(CDF Collab.)
AALTONEN	08C	PRL 100 062005	T. Aaltonen <i>et al.</i>	(CDF Collab.)
ABAZOV	08AH	PRL 101 182001	V.M. Abazov <i>et al.</i>	(D0 Collab.)
ABAZOV	08AI	PRL 101 221801	V.M. Abazov <i>et al.</i>	(D0 Collab.)
ABAZOV	08B	PRL 100 062004	V.M. Abazov <i>et al.</i>	(D0 Collab.)
ABAZOV	08I	PR D78 012005	V.M. Abazov <i>et al.</i>	(D0 Collab.)
ABAZOV	08L	PRL 100 142002	V.M. Abazov <i>et al.</i>	(D0 Collab.)
ABAZOV	08M	PRL 100 192003	V.M. Abazov <i>et al.</i>	(D0 Collab.)
ABAZOV	08N	PRL 100 192004	V.M. Abazov <i>et al.</i>	(D0 Collab.)
ABULENCIA	08	PR D78 012003	A. Abulencia <i>et al.</i>	(CDF Collab.)
CACCIARI	08	JHEP 0809 127	M. Cacciari <i>et al.</i>	
KIDONAKIS	08	PR D78 074005	N. Kidonakis, R. Vogt	
MOCH	08	PR D78 034003	S. Moch, P. Uwer	(BERL, KARLE)
AALTONEN	07	PRL 98 142001	T. Aaltonen <i>et al.</i>	(CDF Collab.)
AALTONEN	07B	PR D75 111103	T. Aaltonen <i>et al.</i>	(CDF Collab.)
AALTONEN	07D	PR D76 072009	T. Aaltonen <i>et al.</i>	(CDF Collab.)
AALTONEN	07I	PRL 99 182002	T. Aaltonen <i>et al.</i>	(CDF Collab.)
ABAZOV	07C	PRL 98 041801	V.M. Abazov <i>et al.</i>	(D0 Collab.)
ABAZOV	07D	PR D75 031102	V.M. Abazov <i>et al.</i>	(D0 Collab.)
ABAZOV	07F	PR D75 092001	V.M. Abazov <i>et al.</i>	(D0 Collab.)
ABAZOV	07H	PRL 98 181802	V.M. Abazov <i>et al.</i>	(D0 Collab.)
ABAZOV	07O	PR D76 052006	V.M. Abazov <i>et al.</i>	(D0 Collab.)
ABAZOV	07P	PR D76 072007	V.M. Abazov <i>et al.</i>	(D0 Collab.)
ABAZOV	07R	PR D76 092007	V.M. Abazov <i>et al.</i>	(D0 Collab.)
ABAZOV	07V	PRL 99 191802	V.M. Abazov <i>et al.</i>	(D0 Collab.)
ABAZOV	07W	PL B655 7	V.M. Abazov <i>et al.</i>	(D0 Collab.)
ABULENCIA	07D	PR D75 031105	A. Abulencia <i>et al.</i>	(CDF Collab.)
ABULENCIA	07G	PRL 98 072001	A. Abulencia <i>et al.</i>	(CDF Collab.)
ABULENCIA	07I	PR D75 052001	A. Abulencia <i>et al.</i>	(CDF Collab.)
ABULENCIA	07J	PR D75 071102	A. Abulencia <i>et al.</i>	(CDF Collab.)
ABAZOV	06K	PL B639 616	V.M. Abazov <i>et al.</i>	(D0 Collab.)
ABAZOV	06U	PR D74 092005	V.M. Abazov <i>et al.</i>	(D0 Collab.)
ABAZOV	06X	PR D74 112004	V.M. Abazov <i>et al.</i>	(D0 Collab.)

ABULENCIA	06D	PRL 96 022004	A. Abulencia <i>et al.</i>	(CDF Collab.)
Also		PR D73 032003	A. Abulencia <i>et al.</i>	(CDF Collab.)
Also		PR D73 092002	A. Abulencia <i>et al.</i>	(CDF Collab.)
ABULENCIA	06G	PRL 96 152002	A. Abulencia <i>et al.</i>	(CDF Collab.)
Also		PR D74 032009	A. Abulencia <i>et al.</i>	(CDF Collab.)
ABULENCIA	06R	PL B639 172	A. Abulencia <i>et al.</i>	(CDF Collab.)
ABULENCIA	06U	PR D73 111103	A. Abulencia <i>et al.</i>	(CDF Collab.)
ABULENCIA	06V	PR D73 112006	A. Abulencia <i>et al.</i>	(CDF Collab.)
ABULENCIA	06Z	PRL 97 082004	A. Abulencia <i>et al.</i>	(CDF Collab.)
ABULENCIA,A	06C	PRL 96 202002	A. Abulencia <i>et al.</i>	(CDF Collab.)
ABULENCIA,A	06E	PR D74 072005	A. Abulencia <i>et al.</i>	(CDF Collab.)
ABULENCIA,A	06F	PR D74 072006	A. Abulencia <i>et al.</i>	(CDF Collab.)
ABAZOV	05	PL B606 25	V.M. Abazov <i>et al.</i>	(D0 Collab.)
ABAZOV	05G	PL B617 1	V.M. Abazov <i>et al.</i>	(D0 Collab.)
ABAZOV	05L	PR D72 011104	V.M. Abazov <i>et al.</i>	(D0 Collab.)
ABAZOV	05P	PL B622 265	V.M. Abazov <i>et al.</i>	(D0 Collab.)
Also		PL B517 282	V.M. Abazov <i>et al.</i>	(D0 Collab.)
Also		PR D63 031101	B. Abbott <i>et al.</i>	(D0 Collab.)
Also		PR D75 092007	V.M. Abazov <i>et al.</i>	(D0 Collab.)
ABAZOV	05Q	PL B626 35	V.M. Abazov <i>et al.</i>	(D0 Collab.)
ABAZOV	05R	PL B626 55	V.M. Abazov <i>et al.</i>	(D0 Collab.)
ABAZOV	05X	PL B626 45	V.M. Abazov <i>et al.</i>	(D0 Collab.)
ACOSTA	05A	PRL 95 102002	D. Acosta <i>et al.</i>	(CDF Collab.)
ACOSTA	05D	PR D71 031101	D. Acosta <i>et al.</i>	(CDF Collab.)
ACOSTA	05N	PR D71 012005	D. Acosta <i>et al.</i>	(CDF Collab.)
ACOSTA	05S	PR D72 032002	D. Acosta <i>et al.</i>	(CDF Collab.)
ACOSTA	05T	PR D72 052003	D. Acosta <i>et al.</i>	(CDF Collab.)
ACOSTA	05U	PR D71 072005	D. Acosta <i>et al.</i>	(CDF Collab.)
ACOSTA	05V	PR D71 052003	D. Acosta <i>et al.</i>	(CDF Collab.)
ABAZOV	04G	NAT 429 638	V.M. Abazov <i>et al.</i>	(D0 Collab.)
ABDALLAH	04C	PL B590 21	J. Abdallah <i>et al.</i>	(DELPHI Collab.)
ACOSTA	04H	PR D69 052003	D. Acosta <i>et al.</i>	(CDF Collab.)
ACOSTA	04I	PRL 93 142001	D. Acosta <i>et al.</i>	(CDF Collab.)
AKTAS	04	EPJ C33 9	A. Aktas <i>et al.</i>	(H1 Collab.)
ABAZOV	03A	PR D67 012004	V.M. Abazov <i>et al.</i>	(D0 Collab.)
CHEKANOV	03	PL B559 153	S. Chekanov <i>et al.</i>	(ZEUS Collab.)
ACHARD	02J	PL B549 290	P. Achard <i>et al.</i>	(L3 Collab.)
ACOSTA	02	PR D65 091102	D. Acosta <i>et al.</i>	(CDF Collab.)
HEISTER	02Q	PL B543 173	A. Heister <i>et al.</i>	(ALEPH Collab.)
ABBIENDI	01T	PL B521 181	G. Abbiendi <i>et al.</i>	(OPAL Collab.)
AFFOLDER	01	PR D63 032003	T. Affolder <i>et al.</i>	(CDF Collab.)
AFFOLDER	01A	PR D64 032002	T. Affolder <i>et al.</i>	(CDF Collab.)
AFFOLDER	01C	PRL 86 3233	T. Affolder <i>et al.</i>	(CDF Collab.)
AFFOLDER	00B	PRL 84 216	T. Affolder <i>et al.</i>	(CDF Collab.)
BARATE	00S	PL B494 33	S. Barate <i>et al.</i>	(ALEPH Collab.)
ABBOTT	99G	PR D60 052001	B. Abbott <i>et al.</i>	(D0 Collab.)
ABE	99B	PRL 82 271	F. Abe <i>et al.</i>	(CDF Collab.)
Also		PRL 82 2808 (erratum)	F. Abe <i>et al.</i>	(CDF Collab.)
CHANG	99	PR D59 091503	D. Chang, W. Chang, E. Ma	
ABBOTT	98D	PRL 80 2063	B. Abbott <i>et al.</i>	(D0 Collab.)
ABBOTT	98F	PR D58 052001	B. Abbott <i>et al.</i>	(D0 Collab.)
ABE	98E	PRL 80 2767	F. Abe <i>et al.</i>	(CDF Collab.)
ABE	98F	PRL 80 2779	F. Abe <i>et al.</i>	(CDF Collab.)
ABE	98G	PRL 80 2525	F. Abe <i>et al.</i>	(CDF Collab.)
BHAT	98B	IJMP A13 5113	P.C. Bhat, H.B. Prosper, S.S. Snyder	
ABACHI	97E	PRL 79 1197	S. Abachi <i>et al.</i>	(D0 Collab.)
ABE	97R	PRL 79 1992	F. Abe <i>et al.</i>	(CDF Collab.)
ABE	97V	PRL 79 3585	F. Abe <i>et al.</i>	(CDF Collab.)
PDG	96	PR D54 1	R. M. Barnett <i>et al.</i>	(PDG Collab.)
ABACHI	95	PRL 74 2632	S. Abachi <i>et al.</i>	(D0 Collab.)
ABE	95F	PRL 74 2626	F. Abe <i>et al.</i>	(CDF Collab.)
ABE	94E	PR D50 2966	F. Abe <i>et al.</i>	(CDF Collab.)
Also		PRL 73 225	F. Abe <i>et al.</i>	(CDF Collab.)