

t' (4th Generation) Quark, Searches for

t' (2/3)-quark/hadron mass limits in $p\bar{p}$ and pp collisions

| VALUE (GeV) | CL% | DOCUMENT ID | TECN | COMMENT |
|---|-----|-----------------|-----------|--|
| >1600 | 95 | 1 AAD | 23AV ATLS | $B(t' \rightarrow Zt) = 1$ |
| > 960 | 95 | 2 TUMASYAN | 23AX CMS | EW production, $t' \rightarrow Ht$ ($H \rightarrow \gamma\gamma$) |
| >1500 | 95 | 3 TUMASYAN | 23V CMS | $B(t' \rightarrow ht) = 1$ |
| > 980 | 95 | 4 AABOUD | 18CE ATLS | $\geq 2\ell + \cancel{E}_T + \geq 1bj$ |
| >1030 | 95 | 5,6 AABOUD | 18CP ATLS | 2,3 ℓ , singlet model |
| >1210 | 95 | 5,7 AABOUD | 18CP ATLS | 2,3 ℓ , doublet model |
| >1310 | 95 | 8,9 AABOUD | 18CR ATLS | singlet t' . ATLAS combination |
| >1370 | 95 | 8,10 AABOUD | 18CR ATLS | t' in a weak isospin doublet (t', b'). ATLAS combination. |
| >1140 | 95 | 11 SIRUNYAN | 18BMCMS | Wb, Zt, ht modes |
| > 845 | 95 | 12 SIRUNYAN | 18Q CMS | $B(t' \rightarrow Wq) = 1$ ($q=d,s$) |
| >1295 | 95 | 13 SIRUNYAN | 18W CMS | $B(t' \rightarrow Wb) = 1$ |
| > 860 | 95 | 14 SIRUNYAN | 17AU CMS | |
| > 735 | 95 | 15 AAD | 14AZ ATLS | $B(b' \rightarrow Wt) = 1$ |
| > 350 | 95 | 16 AAD | 12BC ATLS | $B(t' \rightarrow Wq)=1$ ($q=d,s,b$) |
| > 420 | 95 | 17 AAD | 12C ATLS | $t' \rightarrow Xt$ ($m_X < 140$ GeV) |
| > 685 | 95 | 18 CHATRCHYAN | 12BH CMS | $m_{b'} = m_{t'}$ |
| > 557 | 95 | 19 CHATRCHYAN | 12P CMS | $t'\bar{t}' \rightarrow W^+bW^-\bar{b} \rightarrow b\ell^+\nu\bar{b}\ell^-\bar{\nu}$ |
| ● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ● | | | | |
| >1470 | 95 | 20 AAD | 23AG ATLS | $B(t' \rightarrow Zt) = 1$ |
| >1280 | 95 | 21 SIRUNYAN | 19AQ CMS | $B(t' \rightarrow Zt) = 1$ |
| >1370 | 95 | 22 SIRUNYAN | 19BWCMS | $B(t' \rightarrow ht) = 1$ |
| >1010 | 95 | 23 AABOUD | 18CL ATLS | $B(t' \rightarrow ht) = 1$ |
| >1160 | 95 | 24 AABOUD | 17L ATLS | $B(t' \rightarrow Zt) = 1$ |
| > 770 | 95 | 25 AAD | 15AR ATLS | $B(t' \rightarrow Wb) = 1$ |
| > 590 | 95 | 26 AAD | 15BY ATLS | Wb, Zt, ht modes |
| > 745 | 95 | 27 KHACHATRY... | 15AI CMS | $B(t' \rightarrow ht) = 1$ |
| > 700 | 95 | 28 CHATRCHYAN | 14A CMS | $B(t' \rightarrow Wb) = 1$ |
| > 706 | 95 | 28 CHATRCHYAN | 14A CMS | $B(t' \rightarrow Zt) = 1$ |
| > 782 | 95 | 28 CHATRCHYAN | 14A CMS | $B(t' \rightarrow ht) = 1$ |
| > 656 | 95 | 29 AAD | 13F ATLS | $B(t' \rightarrow Wb) = 1$ |
| > 625 | 95 | 30 CHATRCHYAN | 13I CMS | $B(t' \rightarrow Zt) = 1$ |
| > 404 | 95 | 31 AAD | 12AR ATLS | $B(t' \rightarrow Wb) = 1$ |
| > 570 | 95 | 32 CHATRCHYAN | 12BC CMS | $t'\bar{t}' \rightarrow W^+bW^-\bar{b}$ |
| > 400 | 95 | 33 AALTONEN | 11AH CDF | $t' \rightarrow Xt$ ($m_X < 70$ GeV) |
| > 358 | 95 | 34 AALTONEN | 11AL CDF | $t' \rightarrow Wb$ |
| > 340 | 95 | 34 AALTONEN | 11AL CDF | $t' \rightarrow Wq$ ($q=d,s,b$) |
| > 360 | 95 | 35 AALTONEN | 11O CDF | $t' \rightarrow Xt$ ($m_X < 100$ GeV) |
| > 285 | 95 | 36 ABAZOV | 11Q D0 | $t' \rightarrow Wq$ ($q=d,s,b$) |
| > 256 | 95 | 37,38 AALTONEN | 08H CDF | $t' \rightarrow Wq$ |

- ¹ AAD 23AV based on 139 fb^{-1} of pp data at $\sqrt{s} = 13 \text{ TeV}$. Pair production of vector-like t' is searched for in the mode $\ell^\pm \ell^\mp + \geq 2j$ ($\geq 1b$ -tagged) + \cancel{E}_T or with 3ℓ . The data are consistent with the SM background predictions and limits are obtained for different branching ratios.
- ² TUMASYAN 23AX based on 138 fb^{-1} of pp data at $\sqrt{s} = 13 \text{ TeV}$. A vector-like t' is searched for in the $t + H$ ($H \rightarrow \gamma\gamma$) decay channel. EW production via a coupling to third-generation quarks of $\kappa_T = 0.25$ is assumed. The branching fractions are assumed to be 50, 25, and 25%, respectively, for bW , tZ , and tH decays.
- ³ TUMASYAN 23V based on 138 fb^{-1} of pp data at $\sqrt{s} = 13 \text{ TeV}$. Pair production of vector-like t' is searched for in the single-lepton, same-sign charge dilepton and multi-lepton channels. The data are consistent with the SM background predictions and limits are obtained for different branching ratios. Masses below 1.48 TeV are excluded for all decays to third generation quarks.
- ⁴ AABOUD 18CE based on 36.1 fb^{-1} of proton-proton data taken at $\sqrt{s} = 13 \text{ TeV}$. Events including a same-sign lepton pair are used. The limit is for a singlet model, assuming the branching ratios of t' into Zt , Wb and Ht as predicted by the model.
- ⁵ AABOUD 18CP based on 36.1 fb^{-1} of pp data at $\sqrt{s} = 13 \text{ TeV}$. Pair and single production of vector-like t' are searched for with at least one t' decaying into Zt . In the case of $B(t' \rightarrow Zt) = 1$, the limit is $m_{t'} > 1340 \text{ GeV}$.
- ⁶ The limit is for the singlet model, assuming that the branching ratios into Zt , Wb , and Ht add up to one.
- ⁷ The limit is for the doublet model, assuming that the branching ratios into Zt , Wb , and Ht add up to one.
- ⁸ AABOUD 18CR based on 36.1 fb^{-1} of pp data at $\sqrt{s} = 13 \text{ TeV}$. A combination of searches for the pair-produced vector-like t' in various decay channels ($t' \rightarrow Wb$, Zt , ht). Also a model-independent limit is obtained as $m_{t'} > 1.31 \text{ TeV}$, assuming that the branching ratios into Zt , Wb and ht add up to one.
- ⁹ The limit is for the singlet t' .
- ¹⁰ The limit is for t' in a weak isospin doublet (t', b') and $|V_{t'b}| \ll |V_{tb'}|$.
- ¹¹ SIRUNYAN 18BM based on 35.9 fb^{-1} of pp data at $\sqrt{s} = 13 \text{ TeV}$. The limit is for the pair-produced vector-like t' . Three channels (single lepton, same-charge 2 leptons, or at least 3 leptons) are considered for various branching fraction combinations. Assuming $B(tH) = 1$, the limit is 1270 GeV and for $B(tZ) = 1$ it is 1300 GeV.
- ¹² SIRUNYAN 18Q based on 19.7 fb^{-1} of pp data at $\sqrt{s} = 8 \text{ TeV}$. The limit is for the pair-produced vector-like t' that couple only to light quarks. Constraints for other decay channels (Zq and Hq) are also given in the paper.
- ¹³ SIRUNYAN 18W based on 35.8 fb^{-1} of pp data at $\sqrt{s} = 13 \text{ TeV}$. The limit is for the vector-like t' pair-produced by strong interaction using lepton-plus-jets mode and assuming that $B(t' \rightarrow Wb)$ is 100% of the production cross section and branching fraction to Wb for any new pair-produced heavy quark decaying to this channel as a narrow resonance.
- ¹⁴ SIRUNYAN 17AU based on $2.3\text{-}2.6 \text{ fb}^{-1}$ of pp data at $\sqrt{s} = 13 \text{ TeV}$. Limit on pair-produced singlet vector-like t' using one lepton and several jets. The mass bound is given for a t' transforming as a singlet under the electroweak symmetry group, assumed to decay through W , Z or Higgs boson (which decays to jets) and to a third generation quark. For a doublet, the limit is $>830 \text{ GeV}$. Other limits are also given in the paper.
- ¹⁵ Based on 20.3 fb^{-1} of pp data at $\sqrt{s} = 8 \text{ TeV}$. No significant excess over SM expectation is found in the search for pair production or single production of t' in the events with dilepton from a high p_T Z and additional jets ($\geq 1 b$ -tag). If instead of $B(b' \rightarrow Wt) = 1$ an electroweak singlet with $B(b' \rightarrow Wt) \sim 0.45$ is assumed, the limit reduces to 685 GeV.

- ¹⁶ Based on 1.04 fb^{-1} of pp data at $\sqrt{s} = 7 \text{ TeV}$. No signal is found for the search of heavy quark pair production that decay into W and a quark in the events with dileptons, large \cancel{E}_T , and ≥ 2 jets.
- ¹⁷ Based on 1.04 fb^{-1} of data in pp collisions at 7 TeV . AAD 12C looked for $t'\bar{t}'$ production followed by t' decaying into a top quark and X , an invisible particle, in a final state with an isolated high- P_T lepton, four or more jets, and a large missing transverse energy. No excess over the SM $t\bar{t}$ production gives the upper limit on $t'\bar{t}'$ production cross section as a function of $m_{t'}$ and m_X . The result is obtained for $B(t' \rightarrow Wt) = 1$.
- ¹⁸ Based on 5 fb^{-1} of pp data at $\sqrt{s} = 7 \text{ TeV}$. CHATRCHYAN 12BH searched for QCD and EW production of single and pair of degenerate 4th generation quarks that decay to Wb or Wt . Absence of signal in events with one lepton, same-sign dileptons or tri-leptons gives the bound. With a mass difference of $25 \text{ GeV}/c^2$ between $m_{t'}$ and $m_{b'}$, the corresponding limit shifts by about $\pm 20 \text{ GeV}/c^2$.
- ¹⁹ Based on 5.0 fb^{-1} of pp data at $\sqrt{s} = 7 \text{ TeV}$. CHATRCHYAN 12P looked for $t'\bar{t}'$ production events with two isolated high p_T leptons, large \cancel{E}_T , and 2 high p_T jets with b -tag. The absence of signal above the SM background gives the limit for $B(t' \rightarrow Wb) = 1$.
- ²⁰ AAD 23AG based on 139 fb^{-1} of pp data at $\sqrt{s} = 13 \text{ TeV}$. Pair production of vector-like top or b_s is searched for in the mode $1\ell + \geq 4j (\geq 1b\text{-tagged}) + \cancel{E}_T$. The data are consistent with the SM background predictions and limits are obtained for different branching ratios. Masses below 1.59 TeV are excluded assuming a mass-degenerate vector-like doublet (t', b') model.
- ²¹ SIRUNYAN 19AQ based on 35.9 fb^{-1} of pp data at $\sqrt{s} = 13 \text{ TeV}$. Pair production of vector-like t' is searched for with one t' decaying into Zt and the other t' decaying into Wb , Zt , ht . Events with an opposite-sign lepton pair consistent with coming from Z and jets are used. Mass limits are obtained for a variety of branching ratios of t' .
- ²² SIRUNYAN 19BW based on 35.9 fb^{-1} of pp data at $\sqrt{s} = 13 \text{ TeV}$. The limit is for the pair-produced vector-like t' using all-hadronic final state. The analysis is made for the Wb , Zt , ht modes and mass limits are obtained for a variety of branching ratios.
- ²³ AABOUD 18CL based on 36.1 fb^{-1} of pp data at $\sqrt{s} = 13 \text{ TeV}$. The limit is for the pair-produced vector-like t' using all-hadronic final state. The analysis is also made for the Wb , Zt , ht modes and mass limits are obtained for a variety of branching ratios.
- ²⁴ AABOUD 17L based on 36.1 fb^{-1} of pp data at $\sqrt{s} = 13 \text{ TeV}$. No signal is found in the search for heavy quark pair production that decay into Zt followed by $Z \rightarrow \nu\nu$ in the events with one lepton, large \cancel{E}_T , and ≥ 4 jets. The lower mass limit $0.87 (1.05) \text{ TeV}$ is obtained for the singlet (doublet) model with other possible decay modes.
- ²⁵ AAD 15AR based on 20.3 fb^{-1} of pp data at $\sqrt{s} = 8 \text{ TeV}$. Used lepton-plus-jets final state. See Fig. 20 for mass limits in the plane of $B(t' \rightarrow Ht)$ vs. $B(t' \rightarrow Wb)$ from a combination of $t'\bar{t}' \rightarrow Wb + X$ and $t'\bar{t}' \rightarrow Ht + X$ searches. Any branching ratio scenario is excluded for mass below 715 GeV .
- ²⁶ AAD 15BY based on 20.3 fb^{-1} of pp data at $\sqrt{s} = 8 \text{ TeV}$. Limit on pair-produced vector-like t' assuming the branching fractions to W , Z , and h modes of the singlet model. Used events containing $\geq 2\ell + \cancel{E}_T + \geq 2j (\geq 1b)$ and including a same-sign lepton pair.
- ²⁷ KHACHATRYAN 15AI based on 19.7 fb^{-1} of pp data at $\sqrt{s} = 8 \text{ TeV}$. The search exploits all-hadronic final states by tagging boosted Higgs boson using jet substructure and b -tagging.
- ²⁸ Based on 19.5 fb^{-1} of pp data at $\sqrt{s} = 8 \text{ TeV}$. The t' quark is pair produced and is assumed to decay into three different final states of bW , tZ , and th . The search is carried out using events with at least one isolated lepton.
- ²⁹ Based on 4.7 fb^{-1} of pp data at $\sqrt{s} = 7 \text{ TeV}$. No signal is found for the search of heavy quark pair production that decay into W and a b quark in the events with a high p_T

- isolated lepton, large \cancel{E}_T and at least 3 jets (≥ 1 b -tag). Vector-like quark of charge $2/3$ with $400 < m_{t'} < 550$ GeV and $B(t' \rightarrow Wb) > 0.63$ is excluded at 95% CL.
- 30 Based on 5.0 fb^{-1} of pp data at $\sqrt{s} = 7$ TeV. CHATRCHYAN 13I looked for events with one isolated electron or muon, large \cancel{E}_T , and at least four jets with large transverse momenta, where one jet is likely to originate from the decay of a bottom quark.
- 31 Based on 1.04 fb^{-1} of pp data at $\sqrt{s} = 7$ TeV. No signal is found in the search for pair produced heavy quarks that decay into W boson and a b quark in the events with a high p_T isolated lepton, large \cancel{E}_T and at least 3 jets (≥ 1 b -tag).
- 32 Based on 5.0 fb^{-1} of pp data at $\sqrt{s} = 7$ TeV. CHATRCHYAN 12BC looked for $t'\bar{t}'$ production events with a single isolated high p_T lepton, large \cancel{E}_T and at least 4 high p_T jets with a b -tag. The absence of signal above the SM background gives the limit for $B(t' \rightarrow Wb) = 1$.
- 33 Based on 5.7 fb^{-1} of data in $p\bar{p}$ collisions at 1.96 TeV. AALTONEN 11AH looked for $t'\bar{t}'$ production followed by t' decaying into a top quark and X , an invisible particle, in the all hadronic decay mode of $t\bar{t}$. No excess over the SM $t\bar{t}$ production gives the upper limit on $t'\bar{t}'$ production cross section as a function of $m_{t'}$ and m_X . The result is obtained for $B(t' \rightarrow Xt) = 1$.
- 34 Based on 5.6 fb^{-1} of data in $p\bar{p}$ collisions at 1.96 TeV. AALTONEN 11AL looked for $\ell + \geq 4j$ events and set upper limits on $\sigma(t'\bar{t}')$ as functions of $m_{t'}$.
- 35 Based on 4.8 fb^{-1} of data in $p\bar{p}$ collisions at 1.96 TeV. AALTONEN 11O looked for $t'\bar{t}'$ production signal when t' decays into a top quark and X , an invisible particle, in $\ell + \cancel{E}_T + \text{jets}$ channel. No excess over the SM $t\bar{t}$ production gives the upper limit on $t'\bar{t}'$ production cross section as a function of $m_{t'}$ and m_X . The result is obtained for $B(t' \rightarrow Xt) = 1$.
- 36 Based on 5.3 fb^{-1} of data in $p\bar{p}$ collisions at 1.96 TeV. ABAZOV 11Q looked for $\ell + \cancel{E}_T + \geq 4j$ events and set upper limits on $\sigma(t'\bar{t}')$ as functions of $m_{t'}$.
- 37 Searches for pair production of a new heavy top-like quark t' decaying to a W boson and another quark by fitting the observed spectrum of total transverse energy and reconstructed t' mass in the lepton + jets events.
- 38 HUANG 08 reexamined the t' mass lower bound of 256 GeV obtained in AALTONEN 08H that assumes $B(b' \rightarrow qZ) = 1$ for $q = u, c$ which does not hold when $m_{b'} < m_{t'} - m_W$ or the mixing $\sin^2(\theta_{bt'})$ is so tiny that the decay occurs outside of the vertex detector.

Fig. 1 gives that lower bound on $m_{t'}$ in the plane of $\sin^2(\theta_{bt'})$ and $m_{b'}$.

$t'(5/3)$ -quark/hadron mass limits in $p\bar{p}$ and pp collisions

| VALUE (GeV) | CL% | DOCUMENT ID | TECN | COMMENT |
|---|-----|------------------|-----------|--|
| >1460 | 95 | 1 AAD | 23AG ATLS | $t'(5/3) \rightarrow tW^+$ |
| >1330 | 95 | 2 SIRUNYAN | 19T CMS | $t'_R(5/3) \rightarrow tW^+$ |
| >1300 | 95 | 2 SIRUNYAN | 19T CMS | $t'_L(5/3) \rightarrow tW^+$ |
| >1190 | 95 | 3 AABOUD | 18CE ATLS | $\geq 2\ell + \cancel{E}_T + \geq 1bj$ |
| >1020 | 95 | 4 SIRUNYAN | 17J CMS | $t'_R(5/3) \rightarrow tW^+$ |
| > 990 | 95 | 4 SIRUNYAN | 17J CMS | $t'_L(5/3) \rightarrow tW^+$ |
| > 750 | 95 | 5 AAD | 15BY ATLS | $t'(5/3) \rightarrow tW^+$ |
| > 840 | 95 | 6 AAD | 15Z ATLS | $t'(5/3) \rightarrow tW^+$ |
| > 800 | 95 | 7 CHATRCHYAN 14T | CMS | $t'(5/3) \rightarrow tW^+$ |
| • • • We do not use the following data for averages, fits, limits, etc. • • • | | | | |
| >1350 | 95 | 8 AABOUD | 18AW ATLS | $t'(5/3) \rightarrow tW^+$ |

- ¹ AAD 23AG based on 139 fb^{-1} of pp data at $\sqrt{s} = 13 \text{ TeV}$. Pair production of vector-like top or b' is searched for in the mode $1\ell + \geq 4j (\geq 1b\text{-tagged}) + \cancel{E}_T$. The data are consistent with the SM background predictions and limits are obtained for different branching ratios.
- ² SIRUNYAN 19T based on 35.9 fb^{-1} of pp data at $\sqrt{s} = 13 \text{ TeV}$. Signals are searched in the final states of t' pair production, with same-sign leptons (which come from a t' decay) or a single lepton (which comes from a W out of $4W$ s), along with jets, and no excess over the SM expectation is found.
- ³ AABOUD 18CE based on 36.1 fb^{-1} of proton-proton data taken at $\sqrt{s} = 13 \text{ TeV}$. Events including a same-sign lepton pair are used. The limit is for the pair-produced vector-like t' . With single t' production included, assuming $t'tW$ coupling of one, the limit is $m_{t'} > 1.6 \text{ TeV}$.
- ⁴ SIRUNYAN 17J based on 2.3 fb^{-1} of pp data at $\sqrt{s} = 13 \text{ TeV}$. Signals are searched in the final states of t' pair production, with same-sign leptons (which come from a t' decay) or a single lepton (which comes from a W out of $4W$ s), along with jets, and no excess over the SM expectation is found.
- ⁵ AAD 15BY based on 20.3 fb^{-1} of pp data at $\sqrt{s} = 8 \text{ TeV}$. Limit on $t'(5/3)$ in pair and single production assuming its coupling to Wt is equal to one. Used events containing $\geq 2\ell + \cancel{E}_T + \geq 2j (\geq 1b)$ and including a same-sign lepton pair.
- ⁶ AAD 15Z based on 20.3 fb^{-1} of pp data at $\sqrt{s} = 8 \text{ TeV}$. Used events with $\ell + \cancel{E}_T + \geq 6j (\geq 1b)$ and at least one pair of jets from weak boson decay, sensitive to the final state $b\bar{b}W^+W^-W^+W^-$.
- ⁷ CHATRCHYAN 14T based on 19.5 fb^{-1} of pp data at $\sqrt{s} = 8 \text{ TeV}$. Non-observation of anomaly in H_T distribution in the same-sign dilepton events leads to the limit when pair produced $t'(5/3)$ quark decays exclusively into t and W^+ , resulting in the final state with $b\bar{b}W^+W^-W^+W^-$.
- ⁸ AABOUD 18AW based on 36.1 fb^{-1} of pp data at $\sqrt{s} = 13 \text{ TeV}$. Limit on $t'(5/3)$ in pair production assuming its coupling to Wt is equal to one. Lepton-plus-jets final state is used, characterized by $\ell + \cancel{E}_T + \text{jets} (\geq 1b\text{-tagged})$.

$t'(2/3)$ mass limits from single production in $p\bar{p}$ and pp collisions

| VALUE (GeV) | CL% | DOCUMENT ID | TECN | COMMENT |
|----------------|-----|---------------------|-----------|---|
| >950 | 95 | ¹ AAD | 16AV ATLS | $qg \rightarrow q't'b, B(t' \rightarrow Wb)=0.5$ |
| >403 | 95 | ² ABAZOV | 11F D0 | $qd \rightarrow q't' \rightarrow q'(Wd)$ $\tilde{\kappa}_{dt'}=1, B(t' \rightarrow Wd)=1$ |
| >551 | 95 | ² ABAZOV | 11F D0 | $qu \rightarrow qt' \rightarrow q(Zu)$ $\tilde{\kappa}_{ut'}=\sqrt{2}, B(t' \rightarrow Zu)=1$ |

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

- ³ AAD 22G ATLS $t' \rightarrow Ht$, singlet t'
- ⁴ TUMASYAN 22X CMS $t' \rightarrow Zt$

- ¹ AAD 16AV based on 20.3 fb^{-1} of pp data at $\sqrt{s} = 8 \text{ TeV}$. No significant excess over SM expectation is found in the search for a fully reconstructed vector-like t' in the mode $\ell + \cancel{E}_T + \geq 2j (\geq 1b)$. A veto on massive large-radius jets is used to reject the $t\bar{t}$ background.
- ² ABAZOV 11F based on 5.4 fb^{-1} of data in $p\bar{p}$ collisions at 1.96 TeV . It looked for single production of t' via the Z or E coupling to the first generation up or down quarks, respectively. Model independent cross section limits for the single production processes $p\bar{p} \rightarrow t'q \rightarrow (Wd)q$, and $p\bar{p} \rightarrow t'q \rightarrow (Zd)q$ are given in Figs. 3 and 4, respectively, and the mass limits are obtained for the model of ATRE 09 with degenerate bi-doublets of vector-like quarks.

³ AAD 22G based on 139 fb^{-1} of pp data at $\sqrt{s} = 13 \text{ TeV}$. No significant excess over SM expectation is found in the search for a vector-like t' in the Ht decay channel, where H and t are reconstructed as single jets. The mass range between 1.0 and 2.3 TeV is targeted and 95% CL limits on the production section times the decay branching fraction are set depending on the coupling and mass of t' .

⁴ TUMASYAN 22X based on 137 fb^{-1} of pp data at $\sqrt{s} = 13 \text{ TeV}$. No significant excess over SM expectation is found in the search for a vector-like t' in the Zt decay channel, where Z decays to neutrinos and t decays hadronically. The 95% CL limits on the production section times the decay branching fraction are set depending on the coupling and mass of t' .

$t'(5/3)$ mass limits from single production in $p\bar{p}$ and pp collisions

| VALUE (GeV) | DOCUMENT ID | TECN | COMMENT |
|-------------|-------------|------|---------|
|-------------|-------------|------|---------|

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

¹ SIRUNYAN 19AI CMS $tW \rightarrow t'(5/3) \rightarrow tW$

¹ SIRUNYAN 19AI based on 35.9 fb^{-1} of pp data at $\sqrt{s} = 13 \text{ TeV}$. Exclusion limits are set on the product of the production cross section and branching fraction for the $b'(-1/3) + t$ and $t'(5/3) + t$ modes as a function of the vector-like quark mass in Fig. 8 and Tab. 2 for relative vector-like quark widths between 1 and 30% for left- and right-handed vector-like quark couplings. No significant deviation from the SM prediction is observed.

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| AALTONEN | 08H | PRL 100 161803 | T. Aaltonen <i>et al.</i> | (CDF Collab.) |
| HUANG | 08 | PR D77 037302 | P.Q. Hung, M. Sher | (UVA, WILL) |
