

# Extra Dimensions

For explanation of terms used and discussion of significant model dependence of following limits, see the "Extra Dimensions" review. Footnotes describe originally quoted limit.  $\delta$  indicates the number of extra dimensions.

Limits not encoded here are summarized in the "Extra Dimensions" review, where the latest unpublished results are also described.

See the related review(s):

[Extra Dimensions](#)

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## Limits on $R$ from Deviations in Gravitational Force Law

This section includes limits on the size of extra dimensions from deviations in the Newtonian ( $1/r^2$ ) gravitational force law at short distances. Deviations are parametrized by a gravitational potential of the form  $V = -(G m m'/r) [1 + \alpha \exp(-r/R)]$ . For  $\delta$  toroidal extra dimensions of equal size,  $\alpha = 8\delta/3$ . Quoted bounds are for  $\delta = 2$  unless otherwise noted.

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VALUE ( $\mu\text{m}$ )	CL%	DOCUMENT ID	TECN	COMMENT
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●				
< 37	95	<sup>1</sup> BLAKEMORE	21	Optical levitation
		<sup>2</sup> HEACOCK	21	Neutron scattering
		<sup>3</sup> LEE	20	Torsion pendulum
		<sup>4</sup> TAN	20A	Torsion pendulum
		<sup>5</sup> BERGE	18	MICR Space accelerometer
		<sup>6</sup> FAYET	18A	MICR Space accelerometer
		<sup>7</sup> KLIMCHITSK...	17A	Torsion oscillator
		<sup>8</sup> XU	13	Nuclei properties
		<sup>9</sup> BEZERRA	11	Torsion oscillator
		<sup>10</sup> SUSHKOV	11	Torsion pendulum
		<sup>11</sup> BEZERRA	10	Microcantilever
		<sup>12</sup> MASUDA	09	Torsion pendulum
		<sup>13</sup> GERACI	08	Microcantilever
		<sup>14</sup> TRENKEL	08	Newton's constant
		<sup>15</sup> DECCA	07A	Torsion oscillator
< 37	95	<sup>16</sup> KAPNER	07	Torsion pendulum
< 47	95	<sup>17</sup> TU	07	Torsion pendulum
< 130	95	<sup>18</sup> SMULLIN	05	Microcantilever
		<sup>19</sup> HOYLE	04	Torsion pendulum
$\lesssim 200$	95	<sup>20</sup> CHIAVERINI	03	Microcantilever
		<sup>21</sup> LONG	03	Microcantilever
< 190	95	<sup>22</sup> HOYLE	01	Torsion pendulum
		<sup>23</sup> HOSKINS	85	Torsion pendulum

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OCCUR=2

<sup>1</sup> BLAKEMORE 21 obtain constraints on non-Newtonian forces with strengths  $|\alpha| \gtrsim 10^8$  and length scales  $R > 10 \mu\text{m}$ . See their Fig. 4 for more details including comparison with previous searches.

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<sup>2</sup> HEACOCK 21 obtain constraints on non-Newtonian forces with strengths  $10^{18} \lesssim |\alpha| \lesssim 10^{25}$  and length scales  $R \simeq 0.02\text{--}10 \text{ nm}$ . See their Figure 3 for more details. This improves the results of HADDOCK 18. These constraints do not place limits on the size of extra flat dimensions.

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<sup>3</sup> LEE 20 search for new forces probing a range of  $|\alpha| \simeq 0.1\text{--}10^5$  and length scales  $R \simeq 7\text{--}90 \mu\text{m}$ . For  $\delta = 1$  the bound on  $R$  is  $30 \mu\text{m}$ . See their Fig. 5 for details on the bound.

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<sup>4</sup> TAN 20A search for new forces probing a range of  $|\alpha| \simeq 4 \times 10^{-3}\text{--}1 \times 10^2$  and length scales  $R \simeq 40\text{--}350 \mu\text{m}$ . See their Fig. 6 for details on the bound.

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- <sup>5</sup>BERGE 18 uses results from the MICROSCOPE experiment to obtain constraints on non-Newtonian forces with strengths  $10^{-11} \lesssim |\alpha| \lesssim 10^{-7}$  and length scales  $R \gtrsim 10^5$  m. See their Figure 1 for more details. These constraints do not place limits on the size of extra flat dimensions.
- <sup>6</sup>FAYET 18A uses results from the MICROSCOPE experiment to obtain constraints on an EP-violating force possibly arising from a new U(1) gauge boson. For  $R \gtrsim 10^7$  m the limits are  $|\alpha| \lesssim$  a few  $10^{-13}$  to a few  $10^{-11}$  depending on the coupling, corresponding to  $|\epsilon| \lesssim 10^{-24}$  for the coupling of the new spin-1 or spin-0 mediator. These constraints do not place limits on the size of extra flat dimensions. This extends the results of FAYET 18.
- <sup>7</sup>KLIMCHITSKAYA 17A uses an experiment that measures the difference of Casimir forces to obtain bounds on non-Newtonian forces with strengths  $|\alpha| \simeq 10^5\text{--}10^{17}$  and length scales  $R = 0.03\text{--}10$   $\mu\text{m}$ . See their Fig. 3. These constraints do not place limits on the size of extra flat dimensions.
- <sup>8</sup>XU 13 obtain constraints on non-Newtonian forces with strengths  $|\alpha| \simeq 10^{34}\text{--}10^{36}$  and length scales  $R \simeq 1\text{--}10$  fm. See their Fig. 4 for more details. These constraints do not place limits on the size of extra flat dimensions.
- <sup>9</sup>BEZERRA 11 obtain constraints on non-Newtonian forces with strengths  $10^{11} \lesssim |\alpha| \lesssim 10^{18}$  and length scales  $R = 30\text{--}1260$  nm. See their Fig. 2 for more details. These constraints do not place limits on the size of extra flat dimensions.
- <sup>10</sup>SUSHKOV 11 obtain improved limits on non-Newtonian forces with strengths  $10^7 \lesssim |\alpha| \lesssim 10^{11}$  and length scales  $0.4 \mu\text{m} < R < 4 \mu\text{m}$  (95% CL). See their Fig. 2. These bounds do not place limits on the size of extra flat dimensions. However, a model dependent bound of  $M_* > 70$  TeV is obtained assuming gauge bosons that couple to baryon number also propagate in  $(4 + \delta)$  dimensions.
- <sup>11</sup>BEZERRA 10 obtain improved constraints on non-Newtonian forces with strengths  $10^{19} \lesssim |\alpha| \lesssim 10^{29}$  and length scales  $R = 1.6\text{--}14$  nm (95% CL). See their Fig. 1. This bound does not place limits on the size of extra flat dimensions.
- <sup>12</sup>MASUDA 09 obtain improved constraints on non-Newtonian forces with strengths  $10^9 \lesssim |\alpha| \lesssim 10^{11}$  and length scales  $R = 1.0\text{--}2.9 \mu\text{m}$  (95% CL). See their Fig. 3. This bound does not place limits on the size of extra flat dimensions.
- <sup>13</sup>GERACI 08 obtain improved constraints on non-Newtonian forces with strengths  $|\alpha| > 14,000$  and length scales  $R = 5\text{--}15 \mu\text{m}$ . See their Fig. 9. This bound does not place limits on the size of extra flat dimensions.
- <sup>14</sup>TRENKEL 08 uses two independent measurements of Newton's constant  $G$  to constrain new forces with strength  $|\alpha| \simeq 10^{-4}$  and length scales  $R = 0.02\text{--}1$  m. See their Fig. 1. This bound does not place limits on the size of extra flat dimensions.
- <sup>15</sup>DECCA 07A search for new forces and obtain bounds in the region with strengths  $|\alpha| \simeq 10^{13}\text{--}10^{18}$  and length scales  $R = 20\text{--}86$  nm. See their Fig. 6. This bound does not place limits on the size of extra flat dimensions.
- <sup>16</sup>KAPNER 07 search for new forces, probing a range of  $|\alpha| \simeq 10^{-3}\text{--}10^5$  and length scales  $R \simeq 10\text{--}1000 \mu\text{m}$ . For  $\delta = 1$  the bound on  $R$  is  $44 \mu\text{m}$ . For  $\delta = 2$ , the bound is expressed in terms of  $M_*$ , here translated to a bound on the radius. See their Fig. 6 for details on the bound.
- <sup>17</sup>TU 07 search for new forces probing a range of  $|\alpha| \simeq 10^{-1}\text{--}10^5$  and length scales  $R \simeq 20\text{--}1000 \mu\text{m}$ . For  $\delta = 1$  the bound on  $R$  is  $53 \mu\text{m}$ . See their Fig. 3 for details on the bound.
- <sup>18</sup>SMULLIN 05 search for new forces, and obtain bounds in the region with strengths  $\alpha \simeq 10^3\text{--}10^8$  and length scales  $R = 6\text{--}20 \mu\text{m}$ . See their Figs. 1 and 16 for details on the bound. This work does not place limits on the size of extra flat dimensions.
- <sup>19</sup>HOYLE 04 search for new forces, probing  $\alpha$  down to  $10^{-2}$  and distances down to  $10 \mu\text{m}$ . Quoted bound on  $R$  is for  $\delta = 2$ . For  $\delta = 1$ , bound goes to  $160 \mu\text{m}$ . See their Fig. 34 for details on the bound.
- <sup>20</sup>CHIAVERINI 03 search for new forces, probing  $\alpha$  above  $10^4$  and  $\lambda$  down to  $3 \mu\text{m}$ , finding no signal. See their Fig. 4 for details on the bound. This bound does not place limits on the size of extra flat dimensions.
- <sup>21</sup>LONG 03 search for new forces, probing  $\alpha$  down to 3, and distances down to about  $10 \mu\text{m}$ . See their Fig. 4 for details on the bound.
- <sup>22</sup>HOYLE 01 search for new forces, probing  $\alpha$  down to  $10^{-2}$  and distances down to  $20 \mu\text{m}$ . See their Fig. 4 for details on the bound. The quoted bound is for  $\alpha \geq 3$ .
- <sup>23</sup>HOSKINS 85 search for new forces, probing distances down to 4 mm. See their Fig. 13 for details on the bound. This bound does not place limits on the size of extra flat dimensions.

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NODE=S071DGF;LINKAGE=L

NODE=S071DGF;LINKAGE=HL

NODE=S071DGF;LINKAGE=HK

### Limits on $R$ from On-Shell Production of Gravitons: $\delta = 2$

This section includes limits on on-shell production of gravitons in collider and astrophysical processes. Bounds quoted are on  $R$ , the assumed common radius of the flat extra dimensions, for  $\delta = 2$  extra dimensions. Studies often quote bounds in terms of derived parameter; experiments are actually sensitive to the masses of the KK gravitons:  $m_{\vec{n}} = |\vec{n}|/R$ . See the Review on "Extra Dimensions" for details. Bounds are given in  $\mu\text{m}$  for  $\delta = 2$ .

VALUE ( $\mu\text{m}$ )	CL%	DOCUMENT ID	TECN	COMMENT
< <b>3.8</b>	95	1 AAD	21F ATLS	$pp \rightarrow jG$
< <b>0.00016</b>	95	2 HANNESTAD	03	Neutron star heating

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OCCUR=4

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

< 56	95	<sup>3</sup> SIRUNYAN	21A	CMS	$pp \rightarrow ZG$	
< 4.1	95	<sup>4</sup> TUMASYAN	21D	CMS	$pp \rightarrow jG$	
		<sup>5</sup> SIRUNYAN	17AQ	CMS	$pp \rightarrow \gamma G$	
< 90	95	<sup>6</sup> AABOUD	16F	ATLS	$pp \rightarrow \gamma G$	
		<sup>7</sup> KHACHATRYAN	16N	CMS	$pp \rightarrow \gamma G$	
		<sup>8</sup> AAD	15CS	ATLS	$pp \rightarrow \gamma G$	
< 127	95	<sup>9</sup> AAD	13C	ATLS	$pp \rightarrow \gamma G$	
< 34.4	95	<sup>10</sup> AAD	13D	ATLS	$pp \rightarrow jj$	
< 0.0087	95	<sup>11</sup> AJELLO	12	FLAT	Neutron star $\gamma$ sources	
< 245	95	<sup>12</sup> AALTONEN	08AC	CDF	$p\bar{p} \rightarrow \gamma G, jG$	
< 615	95	<sup>13</sup> ABAZOV	08S	D0	$p\bar{p} \rightarrow \gamma G$	
< 0.916	95	<sup>14</sup> DAS	08		Supernova cooling	
< 350	95	<sup>15</sup> ABULENCIA, A	06	CDF	$p\bar{p} \rightarrow jG$	
< 270	95	<sup>16</sup> ABDALLAH	05B	DLPH	$e^+e^- \rightarrow \gamma G$	
< 210	95	<sup>17</sup> ACHARD	04E	L3	$e^+e^- \rightarrow \gamma G$	
< 480	95	<sup>18</sup> ACOSTA	04C	CDF	$p\bar{p} \rightarrow jG$	
< 0.00038	95	<sup>19</sup> CASSE	04		Neutron star $\gamma$ sources	
< 610	95	<sup>20</sup> ABAZOV	03	D0	$p\bar{p} \rightarrow jG$	
< 0.96	95	<sup>21</sup> HANNESTAD	03		Supernova cooling	
< 0.096	95	<sup>22</sup> HANNESTAD	03		Diffuse $\gamma$ background	OCCUR=2
< 0.051	95	<sup>23</sup> HANNESTAD	03		Neutron star $\gamma$ sources	OCCUR=3
< 300	95	<sup>24</sup> HEISTER	03C	ALEP	$e^+e^- \rightarrow \gamma G$	
		<sup>25</sup> FAIRBAIRN	01		Cosmology	
< 0.66	95	<sup>26</sup> HANHART	01		Supernova cooling	
		<sup>27</sup> CASSISI	00		Red giants	
<1300	95	<sup>28</sup> ACCIARRI	99S	L3	$e^+e^- \rightarrow ZG$	

<sup>1</sup> AAD 21F search for  $pp \rightarrow jG$ , using  $139 \text{ fb}^{-1}$  of data at  $\sqrt{s} = 13 \text{ TeV}$  to place lower limits on  $M_D$  for two to six extra dimensions (see their Table X), from which this bound on  $R$  is derived. This limit supersedes that in AABOUD 18I.

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<sup>2</sup> HANNESTAD 03 obtain a limit on  $R$  from the heating of old neutron stars by the surrounding cloud of trapped KK gravitons. Limits for all  $\delta \leq 7$  are given in their Tables V and VI. These limits supersede those in HANNESTAD 02.

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<sup>3</sup> SIRUNYAN 21A search for  $pp \rightarrow ZG$ , using  $137 \text{ fb}^{-1}$  of data at  $\sqrt{s} = 13 \text{ TeV}$  to place lower limits on  $M_D$  for two to seven extra dimensions (see their Figure 12), from which this bound on  $R$  is derived. These limits supersede those obtained in SIRUNYAN 18BV.

NODE=S0710S6;LINKAGE=L

<sup>4</sup> TUMASYAN 21D search for  $pp \rightarrow jG$ , using  $137 \text{ fb}^{-1}$  of data at  $\sqrt{s} = 13 \text{ TeV}$  to place lower limits on  $M_D$  for two to seven extra dimensions (see their Table 3), from which this bound on  $R$  is derived. This limit supersedes that in SIRUNYAN 18S.

NODE=S0710S6;LINKAGE=N

<sup>5</sup> SIRUNYAN 17AQ search for  $pp \rightarrow \gamma G$ , using  $12.9 \text{ fb}^{-1}$  of data at  $\sqrt{s} = 13 \text{ TeV}$  to place limits on  $M_D$  for three to six extra dimensions (see their Table 3).

NODE=S0710S6;LINKAGE=H

<sup>6</sup> AABOUD 16F search for  $pp \rightarrow \gamma G$ , using  $3.2 \text{ fb}^{-1}$  of data at  $\sqrt{s} = 13 \text{ TeV}$  to place limits on  $M_D$  for two to six extra dimensions (see their Figure 9), from which this bound on  $R$  is derived.

NODE=S0710S6;LINKAGE=E

<sup>7</sup> KHACHATRYAN 16N search for  $pp \rightarrow \gamma G$ , using  $19.6 \text{ fb}^{-1}$  of data at  $\sqrt{s} = 8 \text{ TeV}$  to place limits on  $M_D$  for three to six extra dimensions (see their Table 5).

NODE=S0710S6;LINKAGE=G

<sup>8</sup> AAD 15CS search for  $pp \rightarrow \gamma G$ , using  $20.3 \text{ fb}^{-1}$  of data at  $\sqrt{s} = 8 \text{ TeV}$  to place lower limits on  $M_D$  for two to six extra dimensions (see their Fig. 18).

NODE=S0710S6;LINKAGE=C

<sup>9</sup> AAD 13C search for  $pp \rightarrow \gamma G$ , using  $4.6 \text{ fb}^{-1}$  of data at  $\sqrt{s} = 7 \text{ TeV}$  to place bounds on  $M_D$  for two to six extra dimensions, from which this bound on  $R$  is derived.

NODE=S0710S6;LINKAGE=GA

<sup>10</sup> AAD 13D search for the dijet decay of quantum black holes in  $4.8 \text{ fb}^{-1}$  of data produced in  $pp$  collisions at  $\sqrt{s} = 7 \text{ TeV}$  to place bounds on  $M_D$  for two to seven extra dimensions, from which these bounds on  $R$  are derived. Limits on  $M_D$  for all  $\delta \leq 7$  are given in their Table 3.

NODE=S0710S6;LINKAGE=TA

<sup>11</sup> AJELLO 12 obtain a limit on  $R$  from the gamma-ray emission of point  $\gamma$  sources that arise from the photon decay of KK gravitons which are gravitationally bound around neutron stars. Limits for all  $\delta \leq 7$  are given in their Table 7.

NODE=S0710S6;LINKAGE=AJ

<sup>12</sup> AALTONEN 08AC search for  $p\bar{p} \rightarrow \gamma G$  and  $p\bar{p} \rightarrow jG$  at  $\sqrt{s} = 1.96 \text{ TeV}$  with  $2.0 \text{ fb}^{-1}$  and  $1.1 \text{ fb}^{-1}$  respectively, in order to place bounds on the fundamental scale and size of the extra dimensions. See their Table III for limits on all  $\delta \leq 6$ .

NODE=S0710S;LINKAGE=LO

<sup>13</sup> ABAZOV 08S search for  $p\bar{p} \rightarrow \gamma G$ , using  $1 \text{ fb}^{-1}$  of data at  $\sqrt{s} = 1.96 \text{ TeV}$  to place bounds on  $M_D$  for two to eight extra dimensions, from which these bounds on  $R$  are derived. See their paper for intermediate values of  $\delta$ .

NODE=S0710S;LINKAGE=BA

<sup>14</sup> DAS 08 obtain a limit on  $R$  from Kaluza-Klein graviton cooling of SN1987A due to plasmon-plasmon annihilation.

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<sup>15</sup> ABULENCIA, A 06 search for  $p\bar{p} \rightarrow jG$  using  $368 \text{ pb}^{-1}$  of data at  $\sqrt{s} = 1.96 \text{ TeV}$ . See their Table II for bounds for all  $\delta \leq 6$ .

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<sup>16</sup> ABDALLAH 05B search for  $e^+e^- \rightarrow \gamma G$  at  $\sqrt{s} = 180\text{--}209 \text{ GeV}$  to place bounds on the size of extra dimensions and the fundamental scale. Limits for all  $\delta \leq 6$  are given in their Table 6. These limits supersede those in ABREU 00Z.

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- 17 ACHARD 04E search for  $e^+e^- \rightarrow \gamma G$  at  $\sqrt{s} = 189\text{--}209$  GeV to place bounds on the size of extra dimensions and the fundamental scale. See their Table 8 for limits with  $\delta \leq 8$ . These limits supersede those in ACCIARRI 99R.
- 18 ACOSTA 04C search for  $p\bar{p} \rightarrow jG$  at  $\sqrt{s} = 1.8$  TeV to place bounds on the size of extra dimensions and the fundamental scale. See their paper for bounds on  $\delta = 4, 6$ .
- 19 CASSE 04 obtain a limit on  $R$  from the gamma-ray emission of point  $\gamma$  sources that arises from the photon decay of gravitons around newly born neutron stars, applying the technique of HANNESTAD 03 to neutron stars in the galactic bulge. Limits for all  $\delta \leq 7$  are given in their Table I.
- 20 ABAZOV 03 search for  $p\bar{p} \rightarrow jG$  at  $\sqrt{s}=1.8$  TeV to place bounds on  $M_D$  for 2 to 7 extra dimensions, from which these bounds on  $R$  are derived. See their paper for bounds on intermediate values of  $\delta$ . We quote results without the approximate NLO scaling introduced in the paper.
- 21 HANNESTAD 03 obtain a limit on  $R$  from graviton cooling of supernova SN1987a. Limits for all  $\delta \leq 7$  are given in their Tables V and VI.
- 22 HANNESTAD 03 obtain a limit on  $R$  from gravitons emitted in supernovae and which subsequently decay, contaminating the diffuse cosmic  $\gamma$  background. Limits for all  $\delta \leq 7$  are given in their Tables V and VI. These limits supersede those in HANNESTAD 02.
- 23 HANNESTAD 03 obtain a limit on  $R$  from gravitons emitted in two recent supernovae and which subsequently decay, creating point  $\gamma$  sources. Limits for all  $\delta \leq 7$  are given in their Tables V and VI. These limits are corrected in the published erratum.
- 24 HEISTER 03C use the process  $e^+e^- \rightarrow \gamma G$  at  $\sqrt{s} = 189\text{--}209$  GeV to place bounds on the size of extra dimensions and the scale of gravity. See their Table 4 for limits with  $\delta \leq 6$  for derived limits on  $M_D$ .
- 25 FAIRBAIRN 01 obtains bounds on  $R$  from over production of KK gravitons in the early universe. Bounds are quoted in paper in terms of fundamental scale of gravity. Bounds depend strongly on temperature of QCD phase transition and range from  $R < 0.13 \mu\text{m}$  to  $0.001 \mu\text{m}$  for  $\delta=2$ ; bounds for  $\delta=3,4$  can be derived from Table 1 in the paper.
- 26 HANHART 01 obtain bounds on  $R$  from limits on graviton cooling of supernova SN 1987a using numerical simulations of proto-neutron star neutrino emission.
- 27 CASSISI 00 obtain rough bounds on  $M_D$  (and thus  $R$ ) from red giant cooling for  $\delta=2,3$ . See their paper for details.
- 28 ACCIARRI 99S search for  $e^+e^- \rightarrow ZG$  at  $\sqrt{s}=189$  GeV. Limits on the gravity scale are found in their Table 2, for  $\delta \leq 4$ .

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NODE=S0710S;LINKAGE=ZB

NODE=S0710S;LINKAGE=HA

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NODE=S0710S;LINKAGE=3H

NODE=S0710S;LINKAGE=F

NODE=S0710S;LINKAGE=HT

NODE=S0710S;LINKAGE=CS

NODE=S0710S;LINKAGE=S9

## Mass Limits on $M_{TT}$

This section includes limits on the cut-off mass scale,  $M_{TT}$ , of dimension-8 operators from KK graviton exchange in models of large extra dimensions. Ambiguities in the UV-divergent summation are absorbed into the parameter  $\lambda$ , which is taken to be  $\lambda = \pm 1$  in the following analyses. Bounds for  $\lambda = -1$  are shown in parenthesis after the bound for  $\lambda = +1$ , if appropriate. Different papers use slightly different definitions of the mass scale. The definition used here is related to another popular convention by  $M_{TT}^4 = (2/\pi) \Lambda_T^4$ , as discussed in the above Review on "Extra Dimensions."

NODE=S071GEX

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VALUE (TeV)	CL%	DOCUMENT ID	TECN	COMMENT
> 9.02	95	1 SIRUNYAN 18DD CMS		$p\bar{p} \rightarrow$ dijet, ang. distrib.
>20.6 (> 15.7)	95	2 GIUDICE 03 RVUE		Dim-6 operators
• • • We do not use the following data for averages, fits, limits, etc. • • •				
> 8.3 (>7.1)	95	3 HAYRAPETY...24AJ CMS		$p\bar{p} \rightarrow \gamma\gamma$
> 6.7	95	4 SIRUNYAN 21N CMS		$p\bar{p} \rightarrow e^+e^-, \mu^+\mu^-$
> 6.9	95	5 SIRUNYAN 19AC CMS		$p\bar{p} \rightarrow e^+e^-, \mu^+\mu^-, \gamma\gamma$
> 6.5	95	6 AABOUD 17AP ATLS		$p\bar{p} \rightarrow \gamma\gamma$
> 3.8	95	7 AAD 14BE ATLS		$p\bar{p} \rightarrow e^+e^-, \mu^+\mu^-$
> 3.2	95	8 AAD 13E ATLS		$p\bar{p} \rightarrow e^+e^-, \mu^+\mu^-, \gamma\gamma$
		9 BAAK 12 RVUE		Electroweak
> 0.90 (>0.92)	95	10 AARON 11C H1		$e^\pm p \rightarrow e^\pm X$
> 1.48	95	11 ABAZOV 09AE D0		$p\bar{p} \rightarrow$ dijet, ang. distrib.
> 1.45	95	12 ABAZOV 09D D0		$p\bar{p} \rightarrow e^+e^-, \gamma\gamma$
> 1.1 (> 1.0)	95	13 SCHAELE 07A ALEP		$e^+e^- \rightarrow e^+e^-$
> 0.898 (> 0.998)	95	14 ABDALLAH 06C DLPH		$e^+e^- \rightarrow \ell^+\ell^-$
> 0.853 (> 0.939)	95	15 GERDES 06		$p\bar{p} \rightarrow e^+e^-, \gamma\gamma$
> 0.96 (> 0.93)	95	16 ABAZOV 05V D0		$p\bar{p} \rightarrow \mu^+\mu^-$
> 0.78 (> 0.79)	95	17 CHEKANOV 04B ZEUS		$e^\pm p \rightarrow e^\pm X$
> 0.805 (> 0.956)	95	18 ABBIENDI 03D OPAL		$e^+e^- \rightarrow \gamma\gamma$
> 0.7 (> 0.7)	95	19 ACHARD 03D L3		$e^+e^- \rightarrow ZZ$
> 0.82 (> 0.78)	95	20 ADLOFF 03 H1		$e^\pm p \rightarrow e^\pm X$
> 1.28 (> 1.25)	95	21 GIUDICE 03 RVUE		
> 0.80 (> 0.85)	95	22 HEISTER 03C ALEP		$e^+e^- \rightarrow \gamma\gamma$
> 0.84 (> 0.99)	95	23 ACHARD 02D L3		$e^+e^- \rightarrow \gamma\gamma$
> 1.2 (> 1.1)	95	24 ABBOTT 01 D0		$p\bar{p} \rightarrow e^+e^-, \gamma\gamma$
> 0.60 (> 0.63)	95	25 ABBIENDI 00R OPAL		$e^+e^- \rightarrow \mu^+\mu^-$

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21 GIUDICE 03 review existing experimental bounds on $M_{TT}$ and derive a combined limit.	NODE=S071GEX;LINKAGE=GA
22 HEISTER 03C use $e^+e^-$ collisions at $\sqrt{s}=189\text{--}209$ GeV to place bounds on the scale of dim-8 gravitational interactions. Their $M_S^\pm$ is equivalent to our $M_{TT}$ with $\lambda=\pm 1$ .	NODE=S071GEX;LINKAGE=3H
23 ACHARD 02 search for $s$ -channel graviton exchange effects in $e^+e^- \rightarrow \gamma\gamma$ at $E_{\text{cm}}=192\text{--}209$ GeV.	NODE=S071GEX;LINKAGE=CD
24 ABBOTT 01 search for variations in differential cross sections to $e^+e^-$ and $\gamma\gamma$ final states at the Tevatron.	NODE=S071GEX;LINKAGE=AB
25 ABBIENDI 00R uses $e^+e^-$ collisions at $\sqrt{s}=189$ GeV.	NODE=S071GEX;LINKAGE=A
26 ABREU 00A search for $s$ -channel graviton exchange effects in $e^+e^- \rightarrow \gamma\gamma$ at $E_{\text{cm}}=189\text{--}202$ GeV.	NODE=S071GEX;LINKAGE=EA
27 ABREU 00S uses $e^+e^-$ collisions at $\sqrt{s}=183$ and $189$ GeV. Bounds on $\mu$ and $\tau$ individual final states given in paper.	NODE=S071GEX;LINKAGE=S
28 CHANG 00B derive $3\sigma$ limit on $M_{TT}$ of $(28,19,15)$ TeV for $\delta=(2,4,6)$ respectively assuming the presence of a torsional coupling in the gravitational action. Highly model dependent.	NODE=S071GEX;LINKAGE=CG
29 CHEUNG 00 obtains limits from anomalous diphoton production at OPAL due to graviton exchange. Original limit for $\delta=4$ . However, unknown $UV$ theory renders $\delta$ dependence unreliable. Original paper works in HLZ convention.	NODE=S071GEX;LINKAGE=CH
30 GRAESSER 00 obtains a bound from graviton contributions to $g-2$ of the muon through loops of $0.29$ TeV for $\delta=2$ and $0.38$ TeV for $\delta=4,6$ . Limits scale as $\lambda^{1/2}$ . However calculational scheme not well-defined without specification of high-scale theory. See the "Extra Dimensions Review."	NODE=S071GEX;LINKAGE=GR
31 HAN 00 calculates corrections to gauge boson self-energies from KK graviton loops and constrain them using $S$ and $T$ . Bounds on $M_{TT}$ range from $0.5$ TeV ( $\delta=6$ ) to $1.1$ TeV ( $\delta=2$ ); see text. Limits have strong dependence, $\lambda^{\delta+2}$ , on unknown $\lambda$ coefficient.	NODE=S071GEX;LINKAGE=HN
32 MATHEWS 00 search for evidence of graviton exchange in CDF and DØ dijet production data. See their Table 2 for slightly stronger $\delta$ -dependent bounds. Limits expressed in terms of $\tilde{M}_S^4 = M_{TT}^4/8$ .	NODE=S071GEX;LINKAGE=MT
33 MELE 00 obtains bound from KK graviton contributions to $e^+e^- \rightarrow VV$ ( $V=\gamma, W, Z$ ) at LEP. Authors use Hewett conventions.	NODE=S071GEX;LINKAGE=ME
34 ABBIENDI 99P search for $s$ -channel graviton exchange effects in $e^+e^- \rightarrow \gamma\gamma$ at $E_{\text{cm}}=189$ GeV. The limits $G_+ > 660$ GeV and $G_- > 634$ GeV are obtained from combined $E_{\text{cm}}=183$ and $189$ GeV data, where $G_\pm$ is a scale related to the fundamental gravity scale.	NODE=S071GEX;LINKAGE=AP
35 ACCIARRI 99M search for the reaction $e^+e^- \rightarrow \gamma G$ and $s$ -channel graviton exchange effects in $e^+e^- \rightarrow \gamma\gamma, W^+W^-, ZZ, e^+e^-, \mu^+\mu^-, \tau^+\tau^-, q\bar{q}$ at $E_{\text{cm}}=183$ GeV. Limits on the gravity scale are listed in their Tables 1 and 2.	NODE=S071GEX;LINKAGE=B3
36 ACCIARRI 99S search for the reaction $e^+e^- \rightarrow ZG$ and $s$ -channel graviton exchange effects in $e^+e^- \rightarrow \gamma\gamma, W^+W^-, ZZ, e^+e^-, \mu^+\mu^-, \tau^+\tau^-, q\bar{q}$ at $E_{\text{cm}}=189$ GeV. Limits on the gravity scale are listed in their Tables 1 and 2.	NODE=S071GEX;LINKAGE=DQ
37 BOURILKOV 99 performs global analysis of LEP data on $e^+e^-$ collisions at $\sqrt{s}=183$ and $189$ GeV. Bound is on $\Lambda_T$ .	NODE=S071GEX;LINKAGE=C

### Limits on $1/R = M_c$

This section includes limits on  $1/R = M_c$ , the compactification scale in models with one TeV-sized extra dimension, due to exchange of Standard Model KK excitations. Bounds assume fermions are not in the bulk, unless stated otherwise. See the "Extra Dimensions" review for discussion of model dependence.

VALUE (TeV)	CL%	DOCUMENT ID	TECN	COMMENT
<b>&gt;4.16</b>	95	<sup>1</sup> AAD	12CC ATLS	$pp \rightarrow \ell\bar{\ell}$
<b>&gt;6.1</b>		<sup>2</sup> BARBIERI	04 RVUE	Electroweak
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●				
		<sup>3</sup> FLORES	23 RVUE	minimal universal extra dims
		<sup>4</sup> AVNISH	21 RVUE	$pp \rightarrow$ multijet
		<sup>5</sup> AABOUD	18AV ATLS	$pp \rightarrow t\bar{t}t\bar{t}$
		<sup>6</sup> AABOUD	18CE ATLS	$pp \rightarrow t\bar{t}t\bar{t}$
>3.8	95	<sup>7</sup> ACCOMANDO	15 RVUE	Electroweak
>3.40	95	<sup>8</sup> KHACHATRY...15T	CMS	$pp \rightarrow \ell X$
		<sup>9</sup> CHATRCHYAN13AQ	CMS	$pp \rightarrow \ell X$
>1.38	95	<sup>10</sup> CHATRCHYAN13W	CMS	$pp \rightarrow \gamma\gamma, \delta=6, M_D=5$ TeV
>0.715	95	<sup>11</sup> EDELHAUSER	13 RVUE	$pp \rightarrow \ell\bar{\ell} + X$
>1.40	95	<sup>12</sup> AAD	12CP ATLS	$pp \rightarrow \gamma\gamma, \delta=6, M_D=5$ TeV
>1.23	95	<sup>13</sup> AAD	12X ATLS	$pp \rightarrow \gamma\gamma, \delta=6, M_D=5$ TeV
>0.26	95	<sup>14</sup> ABAZOV	12M D0	$p\bar{p} \rightarrow \mu\mu$
>0.75	95	<sup>15</sup> BAAK	12 RVUE	Electroweak
		<sup>16</sup> FLACKE	12 RVUE	Electroweak

NODE=S071KK

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>0.43	95	17	NISHIWAKI	12	RVUE	$H \rightarrow WW, \gamma\gamma$
>0.729	95	18	AAD	11F	ATLS	$pp \rightarrow \gamma\gamma, \delta=6, M_D=5 \text{ TeV}$
>0.961	95	19	AAD	11X	ATLS	$pp \rightarrow \gamma\gamma, \delta=6, M_D=5 \text{ TeV}$
>0.477	95	20	ABAZOV	10P	D0	$p\bar{p} \rightarrow \gamma\gamma, \delta=6, M_D=5 \text{ TeV}$
>1.59	95	21	ABAZOV	09AE	D0	$p\bar{p} \rightarrow \text{dijet, angular dist.}$
>0.6	95	22	HAISCH	07	RVUE	$\bar{B} \rightarrow X_s \gamma$
>0.6	90	23	GOGOLADZE	06	RVUE	Electroweak
>3.3	95	24	CORNET	00	RVUE	Electroweak
> 3.3–3.8	95	25	RIZZO	00	RVUE	Electroweak

- <sup>1</sup> AAD 12CC use 4.9 and 5.0 fb<sup>-1</sup> of data from  $pp$  collisions at  $\sqrt{s} = 7 \text{ TeV}$  in the dielectron and dimuon channels, respectively, to place a lower bound on the mass of the lightest KK  $Z/\gamma$  boson (equivalent to  $1/R = M_C$ ). The limit quoted here assumes a flat prior corresponding to when the pure  $Z/\gamma$  KK cross section term dominates. See their Section 15 for more details. NODE=S071KK;LINKAGE=GA
- <sup>2</sup> BARBIERI 04 use electroweak precision observables to place a lower bound on the compactification scale  $1/R$ . Both the gauge bosons and the Higgs boson are assumed to propagate in the bulk. NODE=S071KK;LINKAGE=F
- <sup>3</sup> FLORES 23 use a number of 13 TeV Run 2 searches at the LHC to place constraints on the compactification scale  $1/R$  and cutoff scale  $\Lambda$  in the minimal universal extra dimension model with Standard Model fields propagating in the bulk (see their Fig.6). NODE=S071KK;LINKAGE=N
- <sup>4</sup> AVNISH 21 perform a study on the ATLAS collaboration search for multiple jets plus missing transverse energy from  $pp$  collisions at  $\sqrt{s} = 13 \text{ TeV}$  and integrated luminosity of 139 fb<sup>-1</sup>, to place constraints on the compactification scale and cutoff scale  $\Lambda$  in universal extra dimension models with Standard Model fields propagating in the bulk. NODE=S071KK;LINKAGE=M
- <sup>5</sup> AABOUD 18AV use 36.1 fb<sup>-1</sup> of data from  $pp$  collisions at  $\sqrt{s} = 13 \text{ TeV}$  in final states with multiple b-jets, to place a lower bound on the compactification scale in a model with two universal extra dimensions. Assuming the radii of the two extra dimensions are equal, a lower limit of 1.8 TeV for the Kaluza-Klein mass is obtained. NODE=S071KK;LINKAGE=J
- <sup>6</sup> AABOUD 18CE use 36.1 fb<sup>-1</sup> of data from  $pp$  collisions at  $\sqrt{s} = 13 \text{ TeV}$  in final states with same-charge leptons and b-jets, to place a lower bound on the compactification scale in a model with two universal extra dimensions. Assuming the radii of the two extra dimensions are equal, a lower limit of 1.45 TeV for the Kaluza-Klein mass is obtained. NODE=S071KK;LINKAGE=L
- <sup>7</sup> ACCOMANDO 15 use electroweak precision observables to place a lower bound on the compactification scale  $1/R$ . See their Fig. 2 for the bound as a function of  $\sin\beta$ , which parametrizes the VEV contribution from brane and bulk Higgs fields. The quoted value is for the minimum bound which occurs at  $\sin\beta = 0.45$ . NODE=S071KK;LINKAGE=H
- <sup>8</sup> KHACHATRYAN 15T use 19.7 fb<sup>-1</sup> of data from  $pp$  collisions at  $\sqrt{s} = 8 \text{ TeV}$  to place a lower bound on the compactification scale  $1/R$ . NODE=S071KK;LINKAGE=G
- <sup>9</sup> CHATRCHYAN 13AQ use 5.0 fb<sup>-1</sup> of data from  $pp$  collisions at  $\sqrt{s} = 7 \text{ TeV}$  and a further 3.7 fb<sup>-1</sup> of data at  $\sqrt{s} = 8 \text{ TeV}$  to place a lower bound on the compactification scale  $1/R$ , in models with universal extra dimensions and Standard Model fields propagating in the bulk. See their Fig. 5 for the bound as a function of the universal bulk fermion mass parameter  $\mu$ . NODE=S071KK;LINKAGE=E
- <sup>10</sup> CHATRCHYAN 13W use diphoton events with large missing transverse momentum in 4.93 fb<sup>-1</sup> of data produced from  $pp$  collisions at  $\sqrt{s} = 7 \text{ TeV}$  to place a lower bound on the compactification scale in a universal extra dimension model with gravitational decays. The bound assumes that the cutoff scale  $\Lambda$ , for the radiative corrections to the Kaluza-Klein masses, satisfies  $\Lambda/M_C = 20$ . The model parameters are chosen such that the decay  $\gamma^* \rightarrow G\gamma$  occurs with an appreciable branching fraction. NODE=S071KK;LINKAGE=C
- <sup>11</sup> EDELHAUSER 13 use 19.6 and 20.6 fb<sup>-1</sup> of data from  $pp$  collisions at  $\sqrt{s} = 8 \text{ TeV}$  analyzed by the CMS Collaboration in the dielectron and dimuon channels, respectively, to place a lower bound on the mass of the second lightest Kaluza-Klein  $Z/\gamma$  boson (converted to a limit on  $1/R = M_C$ ). The bound assumes Standard Model fields propagating in the bulk and that the cutoff scale  $\Lambda$ , for the radiative corrections to the Kaluza-Klein masses, satisfies  $\Lambda/M_C = 20$ . NODE=S071KK;LINKAGE=D
- <sup>12</sup> AAD 12CP use diphoton events with large missing transverse momentum in 4.8 fb<sup>-1</sup> of data produced from  $pp$  collisions at  $\sqrt{s} = 7 \text{ TeV}$  to place a lower bound on the compactification scale in a universal extra dimension model with gravitational decays. The bound assumes that the cutoff scale  $\Lambda$ , for the radiative corrections to the Kaluza-Klein masses, satisfies  $\Lambda/M_C = 20$ . The model parameters are chosen such that the decay  $\gamma^* \rightarrow G\gamma$  occurs with an appreciable branching fraction. NODE=S071KK;LINKAGE=GD
- <sup>13</sup> AAD 12X use diphoton events with large missing transverse momentum in 1.07 fb<sup>-1</sup> of data produced from  $pp$  collisions at  $\sqrt{s} = 7 \text{ TeV}$  to place a lower bound on the compactification scale in a universal extra dimension model with gravitational decays. The bound assumes that the cutoff scale  $\Lambda$ , for the radiative corrections to the Kaluza-Klein masses, satisfies  $\Lambda/M_C = 20$ . The model parameters are chosen such that the decay  $\gamma^* \rightarrow G\gamma$  occurs with an appreciable branching fraction. NODE=S071KK;LINKAGE=DG
- <sup>14</sup> ABAZOV 12M use same-sign dimuon events in 7.3 fb<sup>-1</sup> of data from  $p\bar{p}$  collisions at  $\sqrt{s} = 1.96 \text{ TeV}$  to place a lower bound on the compactification scale  $1/R$ , in models with universal extra dimensions where all Standard Model fields propagate in the bulk. NODE=S071KK;LINKAGE=AZ
- <sup>15</sup> BAAK 12 use electroweak precision observables to place a lower bound on the compactification scale  $1/R$ , in models with universal extra dimensions and Standard Model fields propagating in the bulk. Bound assumes a 125 GeV Higgs mass. See their Fig. 25 for the bound as a function of the Higgs mass. NODE=S071KK;LINKAGE=BK

- <sup>16</sup> FLACKE 12 use electroweak precision observables to place a lower bound on the compactification scale  $1/R$ , in models with universal extra dimensions and Standard Model fields propagating in the bulk. See their Fig. 1 for the bound as a function of the universal bulk fermion mass parameter  $\mu$ .
- <sup>17</sup> NISHIWAKI 12 use up to  $2 \text{ fb}^{-1}$  of data from the ATLAS and CMS experiments that constrains the production cross section of a Higgs-like particle to place a lower bound on the compactification scale  $1/R$  in universal extra dimension models. The quoted bound assumes Standard Model fields propagating in the bulk and a 125 GeV Higgs mass. See their Fig. 1 for the bound as a function of the Higgs mass.
- <sup>18</sup> AAD 11F use diphoton events with large missing transverse energy in  $3.1 \text{ pb}^{-1}$  of data produced from  $pp$  collisions at  $\sqrt{s} = 7 \text{ TeV}$  to place a lower bound on the compactification scale in a universal extra dimension model with gravitational decays. The bound assumes that the cutoff scale  $\Lambda$ , for the radiative corrections to the Kaluza-Klein masses, satisfies  $\Lambda/M_C = 20$ . The model parameters are chosen such that the decay  $\gamma^* \rightarrow G\gamma$  occurs with an appreciable branching fraction.
- <sup>19</sup> AAD 11X use diphoton events with large missing transverse energy in  $36 \text{ pb}^{-1}$  of data produced from  $pp$  collisions at  $\sqrt{s} = 7 \text{ TeV}$  to place a lower bound on the compactification scale in a universal extra dimension model with gravitational decays. The bound assumes that the cutoff scale  $\Lambda$ , for the radiative corrections to the Kaluza-Klein masses, satisfies  $\Lambda/M_C = 20$ . The model parameters are chosen such that the decay  $\gamma^* \rightarrow G\gamma$  occurs with an appreciable branching fraction.
- <sup>20</sup> ABAZOV 10P use diphoton events with large missing transverse energy in  $6.3 \text{ fb}^{-1}$  of data produced from  $p\bar{p}$  collisions at  $\sqrt{s} = 1.96 \text{ TeV}$  to place a lower bound on the compactification scale in a universal extra dimension model with gravitational decays. The bound assumes that the cutoff scale  $\Lambda$ , for the radiative corrections to the Kaluza-Klein masses, satisfies  $\Lambda/M_C = 20$ . The model parameters are chosen such that the decay  $\gamma^* \rightarrow G\gamma$  occurs with an appreciable branching fraction.
- <sup>21</sup> ABAZOV 09AE use dijet angular distributions in  $0.7 \text{ fb}^{-1}$  of data from  $p\bar{p}$  collisions at  $\sqrt{s} = 1.96 \text{ TeV}$  to place a lower bound on the compactification scale.
- <sup>22</sup> HAISCH 07 use inclusive  $\bar{B}$ -meson decays to place a Higgs mass independent bound on the compactification scale  $1/R$  in the minimal universal extra dimension model.
- <sup>23</sup> GOGOLADZE 06 use electroweak precision observables to place a lower bound on the compactification scale in models with universal extra dimensions. Bound assumes a 115 GeV Higgs mass. See their Fig. 3 for the bound as a function of the Higgs mass.
- <sup>24</sup> CORNET 00 translates a bound on the coefficient of the 4-fermion operator  $(\bar{\ell}\gamma_\mu\tau^a\ell)(\bar{\ell}\gamma^\mu\tau^a\ell)$  derived by Hagiwara and Matsumoto into a limit on the mass scale of KK  $W$  bosons.
- <sup>25</sup> RIZZO 00 obtains limits from global electroweak fits in models with a Higgs in the bulk (3.8 TeV) or on the standard brane (3.3 TeV).

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NODE=S071KK;LINKAGE=AB

NODE=S071KK;LINKAGE=ZO

NODE=S071KK;LINKAGE=HA

NODE=S071KK;LINKAGE=GO

NODE=S071KK;LINKAGE=B

NODE=S071KK;LINKAGE=A

## Limits on Kaluza-Klein Gravitons in Warped Extra Dimensions

This section places limits on the mass of the first Kaluza-Klein (KK) excitation of the graviton in the warped extra dimension model of Randall and Sundrum. Bounds in parenthesis assume Standard Model fields propagate in the bulk. Experimental bounds depend strongly on the warp parameter,  $k$ . See the "Extra Dimensions" review for a full discussion.

Here we list limits for the value of the warp parameter  $k/\overline{M}_P = 0.1$ .

VALUE (TeV)	CL%	DOCUMENT ID	TECN	COMMENT
<b>&gt;4.78</b>	95	<sup>1</sup> SIRUNYAN	21N CMS	$pp \rightarrow G \rightarrow e^+e^-, \mu^+\mu^-$
• • • We do not use the following data for averages, fits, limits, etc. • • •				
>4.8	95	<sup>2</sup> HAYRAPETY...24AE	CMS	$pp \rightarrow G \rightarrow HH$
		<sup>3</sup> HAYRAPETY...24AJ	CMS	$pp \rightarrow G \rightarrow \gamma\gamma$
		<sup>4</sup> TUMASYAN	24B CMS	$pp \rightarrow G \rightarrow HH$
		<sup>5</sup> TUMASYAN	23AP CMS	$pp \rightarrow G \rightarrow WW, ZZ$
		<sup>6</sup> AAD	22F ATLS	$pp \rightarrow G \rightarrow HH$
		<sup>7</sup> TUMASYAN	22D CMS	$pp \rightarrow G \rightarrow WW$
		<sup>8</sup> TUMASYAN	22J CMS	$pp \rightarrow G \rightarrow ZZ$
		<sup>9</sup> TUMASYAN	22R CMS	$pp \rightarrow G \rightarrow ZZ$
		<sup>10</sup> TUMASYAN	22U CMS	$pp \rightarrow G \rightarrow HH$
>4.5	95	<sup>11</sup> AAD	21AF ATLS	$pp \rightarrow G \rightarrow ZZ$
		<sup>12</sup> AAD	21AY ATLS	$pp \rightarrow G \rightarrow \gamma\gamma$
		<sup>13</sup> AAD	20AT ATLS	$pp \rightarrow G \rightarrow WW, ZZ$
		<sup>14</sup> AAD	20C ATLS	$pp \rightarrow G \rightarrow HH$
		<sup>15</sup> AAD	20T ATLS	$pp \rightarrow G \rightarrow b\bar{b}$
>2.6	95	<sup>16</sup> SIRUNYAN	20AI CMS	$pp \rightarrow G \rightarrow jj$
		<sup>17</sup> SIRUNYAN	20F CMS	$pp \rightarrow G \rightarrow HH$
		<sup>18</sup> AABOUD	19O ATLS	$pp \rightarrow G \rightarrow HH$
		<sup>19</sup> AAD	19D ATLS	$pp \rightarrow G \rightarrow WW, ZZ$
		<sup>20</sup> SIRUNYAN	19BE CMS	$pp \rightarrow G \rightarrow HH$
		<sup>21</sup> AABOUD	18BI ATLS	$pp \rightarrow G \rightarrow t\bar{t}$

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		22	AABOUD	18CJ ATLS	$pp \rightarrow G \rightarrow VV, VH, \ell\bar{\ell}$
		23	AABOUD	18CQ ATLS	$pp \rightarrow G \rightarrow HH$
		24	AABOUD	18CW ATLS	$pp \rightarrow G \rightarrow HH$
		25	SIRUNYAN	18AF CMS	$pp \rightarrow G \rightarrow HH$
		26	SIRUNYAN	18AS CMS	$pp \rightarrow G \rightarrow ZZ$
		27	SIRUNYAN	18CWCMS	$pp \rightarrow G \rightarrow HH$
		28	SIRUNYAN	18I CMS	$pp \rightarrow G \rightarrow b\bar{b}$
		29	AAD	16R ATLS	$pp \rightarrow G \rightarrow WW, ZZ$
		30	AAD	15AZ ATLS	$pp \rightarrow G \rightarrow WW$
		31	AAD	15CP ATLS	$pp \rightarrow G \rightarrow WW, ZZ$
>2.68	95	32	AAD	14V ATLS	$pp \rightarrow G \rightarrow e^+e^-, \mu^+\mu^-$
>1.23 (>0.84)	95	33	AAD	13A ATLS	$pp \rightarrow G \rightarrow WW$
>0.94 (>0.71)	95	34	AAD	13AO ATLS	$pp \rightarrow G \rightarrow WW$
>2.23	95	35	AAD	13AS ATLS	$pp \rightarrow \gamma\gamma, e^+e^-, \mu^+\mu^-$
>0.845	95	36	AAD	12AD ATLS	$pp \rightarrow G \rightarrow ZZ$
		37	AALTONEN	12V CDF	$p\bar{p} \rightarrow G \rightarrow ZZ$
		38	BAAK	12 RVUE	Electroweak
		39	AALTONEN	11G CDF	$p\bar{p} \rightarrow G \rightarrow ZZ$
>1.058	95	40	AALTONEN	11R CDF	$p\bar{p} \rightarrow G \rightarrow e^+e^-, \gamma\gamma$
>0.754	95	41	ABAZOV	11H D0	$p\bar{p} \rightarrow G \rightarrow WW$
>0.607		42	AALTONEN	10N CDF	$p\bar{p} \rightarrow G \rightarrow WW$
>1.05		43	ABAZOV	10F D0	$p\bar{p} \rightarrow G \rightarrow e^+e^-, \gamma\gamma$
		44	AALTONEN	08S CDF	$p\bar{p} \rightarrow G \rightarrow ZZ$
>0.90		45	ABAZOV	08J D0	$p\bar{p} \rightarrow G \rightarrow e^+e^-, \gamma\gamma$
		46	AALTONEN	07G CDF	$p\bar{p} \rightarrow G \rightarrow \gamma\gamma$
>0.889		47	AALTONEN	07H CDF	$p\bar{p} \rightarrow G \rightarrow e\bar{e}$
>0.785		48	ABAZOV	05N D0	$p\bar{p} \rightarrow G \rightarrow \ell\ell, \gamma\gamma$
>0.71		49	ABULENCIA	05A CDF	$p\bar{p} \rightarrow G \rightarrow \ell\bar{\ell}$

<sup>1</sup> SIRUNYAN 21N use 137 (140) fb<sup>-1</sup> of data from  $pp$  collisions at  $\sqrt{s} = 13$  TeV to search for dilepton resonances in the dielectron (dimuon) channel. See Table 6 for other limits with warp parameter values  $k/\bar{M}_P = 0.01$  and 0.05. This updates the results of SIRUNYAN 18BB.

NODE=S071RSG;LINKAGE=KB

<sup>2</sup> HAYRAPETYAN 24AE use 138 fb<sup>-1</sup> of data from  $pp$  collisions at  $\sqrt{s} = 13$  TeV to search for Higgs boson pair production in the  $b\bar{b}WW$  final state. See their Figure 19 for limits on the cross section times branching fraction as a function of the KK graviton mass for  $k/\bar{M}_P = 0.3, 0.5$  and 1.

NODE=S071RSG;LINKAGE=SB

<sup>3</sup> HAYRAPETYAN 24AJ use 138 fb<sup>-1</sup> of data from  $pp$  collisions at  $\sqrt{s} = 13$  TeV, in the diphoton channel to place a lower limit on the mass of the lightest KK graviton. See their paper for limits with other warp parameter values  $k/\bar{M}_P = 0.01$  and 0.2. This updates the results of SIRUNYAN 18DU.

NODE=S071RSG;LINKAGE=TB

<sup>4</sup> TUMASYAN 24B use 138 fb<sup>-1</sup> of data from  $pp$  collisions at  $\sqrt{s} = 13$  TeV to search for Higgs boson pair production in the  $\gamma\gamma b\bar{b}$  final state. See their Figure 6 for limits on the cross section times branching fraction as a function of the KK graviton mass assuming  $k/\bar{M}_P = 0.5$  and 1. This updates the result of SIRUNYAN 19.

NODE=S071RSG;LINKAGE=UB

<sup>5</sup> TUMASYAN 23AP use 138 fb<sup>-1</sup> of data from  $pp$  collisions at  $\sqrt{s} = 13$  TeV to search for  $WW, ZZ$  diboson resonances in the  $q\bar{q}q\bar{q}$  final states. See their Figure 7 for the limit on the cross section times branching fraction as a function of the KK graviton mass. Assuming  $k/\bar{M}_P = 0.5$ , a graviton mass is excluded below 1400 GeV. This updates the result of SIRUNYAN 20Q.

NODE=S071RSG;LINKAGE=RB

<sup>6</sup> AAD 22F use 126–139 fb<sup>-1</sup> of data from  $pp$  collisions at  $\sqrt{s} = 13$  TeV to search for Higgs boson pair production in the  $b\bar{b}b\bar{b}$  final state. See their Figure 14 for limits on the cross section times branching fraction as a function of the KK graviton mass. Assuming  $k/\bar{M}_P = 1$ , gravitons in the mass range 298–1460 GeV are excluded. This updates the results of AABOUD 19A.

NODE=S071RSG;LINKAGE=MB

<sup>7</sup> TUMASYAN 22D use 137 fb<sup>-1</sup> of data from  $pp$  collisions at  $\sqrt{s} = 13$  TeV to search for  $WW$  resonances in  $\ell\nu q\bar{q}$  final states ( $\ell = e, \mu$ ). See their Figure 6 for the limit on the KK graviton mass as a function of the cross section times branching fraction, including theoretical values for  $k/\bar{M}_P = 0.5$ . This updates the results of SIRUNYAN 18AX.

NODE=S071RSG;LINKAGE=NB

<sup>8</sup> TUMASYAN 22J use 137 fb<sup>-1</sup> of data from  $pp$  collisions at  $\sqrt{s} = 13$  TeV to search for  $ZZ$  resonances in the  $\nu\bar{\nu}q\bar{q}$  final state. See their Figure 10 for the limit on the KK graviton mass as a function of the cross section times branching fraction, assuming  $k/\bar{M}_P = 0.5$ . This updates the result of SIRUNYAN 18BK.

NODE=S071RSG;LINKAGE=OB

<sup>9</sup> TUMASYAN 22R use 138 fb<sup>-1</sup> of data from  $pp$  collisions at  $\sqrt{s} = 13$  TeV to search for  $ZZ$  resonances in  $\ell\ell q\bar{q}$  final states ( $\ell = e, \mu$ ). See their Figure 8 for the limit on the KK graviton mass as a function of the cross section times branching fraction. Assuming  $k/\bar{M}_P = 0.5$ , a graviton mass is excluded below 1200 GeV. This updates the result of SIRUNYAN 18DJ.

NODE=S071RSG;LINKAGE=PB

<sup>10</sup> TUMASYAN 22U use 138 fb<sup>-1</sup> of data from  $pp$  collisions at  $\sqrt{s} = 13$  TeV to search for Higgs boson pair production in the  $b\bar{b}q\bar{q}'\ell\nu, b\bar{b}\ell\nu\ell\nu$  and  $b\bar{b}\ell\nu\nu\ell\nu$  final states ( $\ell = e, \mu$ ). See their Figure 7 for limits on the cross section times branching fraction as a function of the KK graviton mass, including theoretical values for  $k/\bar{M}_P = 0.3$  and 0.5. This updates the results of SIRUNYAN 19CF and SIRUNYAN 18F.

NODE=S071RSG;LINKAGE=QB

- 11 AAD 21AF use  $139 \text{ fb}^{-1}$  of data from  $pp$  collisions at  $\sqrt{s} = 13 \text{ TeV}$  to search for  $ZZ$  resonances in the  $\ell\ell\ell\ell$  and  $\ell\ell\nu\bar{\nu}$  final states ( $\ell=e, \mu$ ). See their Figure 8 for the limit on the cross section times branching fraction as a function of the KK graviton mass, including theoretical values for  $k/\bar{M}_P = 1$ . This updates the results of AAD 15AU and AABOUD 18BF. NODE=S071RSG;LINKAGE=JB
- 12 AAD 21AY use  $139 \text{ fb}^{-1}$  of data from  $pp$  collisions at  $\sqrt{s} = 13 \text{ TeV}$  in the diphoton channel to place a lower limit on the mass of the lightest KK graviton. This updates the results of AABOUD 17AP. NODE=S071RSG;LINKAGE=LB
- 13 AAD 20AT use  $139 \text{ fb}^{-1}$  of data from  $pp$  collisions at  $\sqrt{s} = 13 \text{ TeV}$  to search for diboson resonances in semileptonic final states ( $\ell\nu qq, \ell\ell qq, \nu\nu qq$ ). See their Figure 15 for the limit on the cross section times branching fraction as a function of the KK graviton mass. Lower limits on the graviton mass are also given for  $k/\bar{M}_P = 1$ . This updates the results of AABOUD 18AK and AABOUD 18AL. NODE=S071RSG;LINKAGE=IB
- 14 AAD 20C use  $36.1 \text{ fb}^{-1}$  of data from  $pp$  collisions at  $\sqrt{s} = 13 \text{ TeV}$  to search for Higgs boson pair production in the  $b\bar{b}b\bar{b}, b\bar{b}W^+W^-$ , and  $b\bar{b}\tau^+\tau^-$  final states. See their Figure 5(b)(c) for limits on the cross section as a function of the KK graviton mass. In the case of  $k/\bar{M}_P = 1$  and 2, gravitons are excluded in the mass range 260–3000 GeV and 260–1760 GeV, respectively. NODE=S071RSG;LINKAGE=CB
- 15 AAD 20T use  $139 \text{ fb}^{-1}$  of data from  $pp$  collisions at  $\sqrt{s} = 13 \text{ TeV}$  to search for narrow resonances decaying to bottom quark pairs. See their Figure 7 for the limit on the product of the cross section, branching fraction, acceptance and  $b$ -tagging efficiency as a function of the KK graviton mass. In the case of  $k/\bar{M}_P = 0.2$ , KK gravitons in the mass range 1.25–2.8 TeV are excluded. NODE=S071RSG;LINKAGE=EB
- 16 SIRUNYAN 20AI use  $137 \text{ fb}^{-1}$  of data from  $pp$  collisions at  $\sqrt{s} = 13 \text{ TeV}$  to search for dijet resonances. See their Figure 6 for the limit on the product of the cross section, branching fraction and acceptance as a function of the KK graviton mass. This updates the results of SIRUNYAN 18BO. NODE=S071RSG;LINKAGE=FB
- 17 SIRUNYAN 20F use  $35.9 \text{ fb}^{-1}$  of data from  $pp$  collisions at  $\sqrt{s} = 13 \text{ TeV}$  to search for Higgs boson pair production in the  $b\bar{b}ZZ$  final state. See their Figure 4 for limits on the cross section times branching fraction as a function of the KK graviton mass, and Figure 5 for limits as a function of  $k/\bar{M}_P$ . NODE=S071RSG;LINKAGE=GB
- 18 AABOUD 19O use  $36.1 \text{ fb}^{-1}$  of data from  $pp$  collisions at  $\sqrt{s} = 13 \text{ TeV}$  to search for Higgs boson pair production in the  $b\bar{b}WW$  final state. See their Figure 12 for limits on the cross section times branching fraction as a function of the KK graviton mass for  $k/\bar{M}_P = 1$  and  $k/\bar{M}_P = 2$ . NODE=S071RSG;LINKAGE=XA
- 19 AAD 19D use  $139 \text{ fb}^{-1}$  of data from  $pp$  collisions at  $\sqrt{s} = 13 \text{ TeV}$  to search for diboson resonances in the all-hadronic final state. See their Figure 9(b) for the limit on the cross section times branching fraction as a function of the KK graviton mass, including theoretical values for  $k/\bar{M}_P = 1$ . This updates the results of AABOUD 18F. NODE=S071RSG;LINKAGE=BB
- 20 SIRUNYAN 19BE use  $35.9 \text{ fb}^{-1}$  of data from  $pp$  collisions at  $\sqrt{s} = 13 \text{ TeV}$  to search for Higgs boson pair production by combining the results from four final states:  $b\bar{b}\gamma\gamma, b\bar{b}\tau\bar{\tau}, b\bar{b}b\bar{b}$ , and  $b\bar{b}VV$ . See their Figure 7 for limits on the cross section times branching fraction as a function of the KK graviton mass. NODE=S071RSG;LINKAGE=ZA
- 21 AABOUD 18BI use  $36.1 \text{ fb}^{-1}$  of data from  $pp$  collisions at  $\sqrt{s} = 13 \text{ TeV}$  to search for top-quark pairs decaying into the lepton-plus jets topology. See their Figure 16 for the limit on the KK graviton mass as a function of the cross section times branching fraction, including theoretical values for  $k/\bar{M}_P = 1$ . NODE=S071RSG;LINKAGE=CA
- 22 AABOUD 18CJ combine the searches for heavy resonances decaying into bosonic and leptonic final states from  $36.1 \text{ fb}^{-1}$  of  $pp$  collision data at  $\sqrt{s} = 13 \text{ TeV}$ . The lower limit on the KK graviton mass, with  $k/\bar{M}_P = 1$ , is 2.3 TeV. NODE=S071RSG;LINKAGE=QA
- 23 AABOUD 18CQ use  $36.1 \text{ fb}^{-1}$  of data from  $pp$  collisions at  $\sqrt{s} = 13 \text{ TeV}$  to search for Higgs boson pair production in the  $b\bar{b}\tau^+\tau^-$  final state. See their Figure 2 for limits on the cross section times branching fraction as a function of the KK graviton mass. Assuming  $k/\bar{M}_P = 1$ , gravitons in the mass range 325–885 GeV are excluded. NODE=S071RSG;LINKAGE=RA
- 24 AABOUD 18CW use  $36.1 \text{ fb}^{-1}$  of data from  $pp$  collisions at  $\sqrt{s} = 13 \text{ TeV}$  to search for Higgs boson pair production in the  $\gamma\gamma b\bar{b}$  final state. See their Figure 7 for limits on the cross section times branching fraction as a function of the KK graviton mass. NODE=S071RSG;LINKAGE=SA
- 25 SIRUNYAN 18AF use  $35.9 \text{ fb}^{-1}$  of data from  $pp$  collisions at  $\sqrt{s} = 13 \text{ TeV}$  to search for Higgs boson pair production in the  $b\bar{b}b\bar{b}$  final state. See their Figure 9 for limits on the cross section times branching fraction as a function of the KK graviton mass, including theoretical values for  $k/\bar{M}_P = 0.5$ . This updates the results of KHACHATRYAN 15R. NODE=S071RSG;LINKAGE=HA
- 26 SIRUNYAN 18AS use  $35.9 \text{ fb}^{-1}$  of data from  $pp$  collisions at  $\sqrt{s} = 13 \text{ TeV}$  to search for  $ZZ$  resonances in the  $\ell\ell\nu\bar{\nu}$  final state ( $\ell=e, \mu$ ). See their Figure 5 for the limit on the KK graviton mass as a function of the cross section times branching fraction, including theoretical values for  $k/\bar{M}_P = 0.1, 0.5$ , and 1.0. NODE=S071RSG;LINKAGE=IA
- 27 SIRUNYAN 18CW use  $35.9 \text{ fb}^{-1}$  of data from  $pp$  collisions at  $\sqrt{s} = 13 \text{ TeV}$  to search for Higgs boson pair production in the  $b\bar{b}b\bar{b}$  final state. See their Figure 8 for limits on the cross section times branching fraction as a function of the KK graviton mass, including theoretical values for  $k/\bar{M}_P = 0.5$ . NODE=S071RSG;LINKAGE=NA
- 28 SIRUNYAN 18I use  $19.7 \text{ fb}^{-1}$  of data from  $pp$  collisions at  $\sqrt{s} = 8 \text{ TeV}$  to search for narrow resonances decaying to bottom quark pairs. See their Figure 3 for the limit on the KK graviton mass as a function of the cross section times branching fraction in the mass range of 325–1200 GeV. NODE=S071RSG;LINKAGE=OA

- 29 AAD 16R use  $20.3 \text{ fb}^{-1}$  of data from  $pp$  collisions at  $\sqrt{s} = 8 \text{ TeV}$  to place a lower bound on the mass of the lightest KK graviton. See their Figure 4 for the limit on the KK graviton mass as a function of the cross section times branching fraction. NODE=S071RSG;LINKAGE=M
- 30 AAD 15AZ use  $20.3 \text{ fb}^{-1}$  of data from  $pp$  collisions at  $\sqrt{s} = 8 \text{ TeV}$  to place a lower bound on the mass of the lightest KK graviton. See their Figure 2 for limits on the KK graviton mass as a function of the cross section times branching ratio. NODE=S071RSG;LINKAGE=K
- 31 AAD 15CP use  $20.3 \text{ fb}^{-1}$  of data from  $pp$  collisions at  $\sqrt{s} = 8 \text{ TeV}$  to place a lower bound on the mass of the lightest KK graviton. See their Figures 6b and 6c for the limit on the KK graviton mass as a function of the cross section times branching fraction. NODE=S071RSG;LINKAGE=L
- 32 AAD 14V use  $20.3 (20.5) \text{ fb}^{-1}$  of data from  $pp$  collisions at  $\sqrt{s} = 8 \text{ TeV}$  in the dielectron (dimuon) channels to place a lower bound on the mass of the lightest KK graviton. This updates the results of AAD 12CC . NODE=S071RSG;LINKAGE=B
- 33 AAD 13A use  $4.7 \text{ fb}^{-1}$  of data from  $pp$  collisions at  $\sqrt{s} = 7 \text{ TeV}$  in the  $\ell\nu\ell\nu$  channel, to place a lower bound on the mass of the lightest KK graviton. NODE=S071RSG;LINKAGE=DD
- 34 AAD 13AO use  $4.7 \text{ fb}^{-1}$  of data from  $pp$  collisions at  $\sqrt{s} = 7 \text{ TeV}$  in the  $\ell\nu jj$  channel, to place a lower bound on the mass of the lightest KK graviton. NODE=S071RSG;LINKAGE=N
- 35 AAD 13AS use  $4.9 \text{ fb}^{-1}$  of data from  $pp$  collisions at  $\sqrt{s} = 7 \text{ TeV}$  in the diphoton channel to place lower limits on the mass of the lightest KK graviton. The diphoton channel is combined with previous results in the dielectron and dimuon channels to set the best limit. See their Table 2 for warp parameter values  $k/\bar{M}_P$  between 0.01 and 0.1. This updates the results of AAD 12Y . NODE=S071RSG;LINKAGE=A
- 36 AAD 12AD use  $1.02 \text{ fb}^{-1}$  of data from  $pp$  collisions at  $\sqrt{s} = 7 \text{ TeV}$  to search for KK gravitons in a warped extra dimension decaying to  $ZZ$  dibosons in the  $lljj$  and  $llll$  channels ( $\ell=e, \mu$ ). The limit is quoted for the combined  $lljj + llll$  channels. See their Figure 5 for limits on the cross section  $\sigma(G \rightarrow ZZ)$  as a function of the graviton mass. NODE=S071RSG;LINKAGE=AD
- 37 AALTONEN 12V use  $6 \text{ fb}^{-1}$  of data from  $p\bar{p}$  collisions at  $\sqrt{s} = 1.96 \text{ TeV}$  to search for KK gravitons in a warped extra dimension decaying to  $ZZ$  dibosons in the  $lljj$  and  $llll$  channels ( $\ell=e, \mu$ ). It provides improved limits over the previous analysis in AALTONEN 11G. See their Figure 16 for limits from all channels combined on the cross section times branching ratio  $\sigma(p\bar{p} \rightarrow G^* \rightarrow ZZ)$  as a function of the graviton mass. NODE=S071RSG;LINKAGE=EN
- 38 BAAK 12 use electroweak precision observables to place a lower bound on the compactification scale  $k e^{-\pi k R}$ , assuming Standard Model fields propagate in the bulk and the Higgs is confined to the IR brane. See their Fig. 27 for more details. NODE=S071RSG;LINKAGE=BK
- 39 AALTONEN 11G use  $2.5\text{--}2.9 \text{ fb}^{-1}$  of data from  $p\bar{p}$  collisions at  $\sqrt{s} = 1.96 \text{ TeV}$  to search for KK gravitons in a warped extra dimension decaying to  $ZZ$  dibosons via the  $eeee$ ,  $ee\mu\mu$ ,  $\mu\mu\mu\mu$ ,  $eejj$ , and  $\mu\mu jj$  channels. See their Fig. 20 for limits on the cross section  $\sigma(G \rightarrow ZZ)$  as a function of the graviton mass. NODE=S071RSG;LINKAGE=LN
- 40 AALTONEN 11R uses  $5.7 \text{ fb}^{-1}$  of data from  $p\bar{p}$  collisions at  $\sqrt{s} = 1.96 \text{ TeV}$  in the dielectron channel to place a lower bound on the mass of the lightest graviton. It provides combined limits with the diphoton channel analysis of AALTONEN 11U. For warp parameter values  $k/\bar{M}_P$  between 0.01 to 0.1 the lower limit on the mass of the lightest graviton is between 612 and 1058 GeV. See their Table I for more details. NODE=S071RSG;LINKAGE=AT
- 41 ABAZOV 11H use  $5.4 \text{ fb}^{-1}$  of data from  $p\bar{p}$  collisions at  $\sqrt{s} = 1.96 \text{ TeV}$  to place a lower bound on the mass of the lightest graviton. Their 95% C.L. exclusion limit does not include masses less than 300 GeV. NODE=S071RSG;LINKAGE=BA
- 42 AALTONEN 10N use  $2.9 \text{ fb}^{-1}$  of data from  $p\bar{p}$  collisions at  $\sqrt{s} = 1.96 \text{ TeV}$  to place a lower bound on the mass of the lightest graviton. NODE=S071RSG;LINKAGE=LO
- 43 ABAZOV 10F use  $5.4 \text{ fb}^{-1}$  of data from  $p\bar{p}$  collisions at  $\sqrt{s} = 1.96 \text{ TeV}$  to place a lower bound on the mass of the lightest graviton. For warp parameter values of  $k/\bar{M}_P$  between 0.01 and 0.1 the lower limit on the mass of the lightest graviton is between 560 and 1050 GeV. See their Fig. 3 for more details. NODE=S071RSG;LINKAGE=AO
- 44 AALTONEN 08S use  $p\bar{p}$  collisions at  $\sqrt{s} = 1.96 \text{ TeV}$  to search for KK gravitons in warped extra dimensions. They search for graviton resonances decaying to four electrons via two  $Z$  bosons using  $1.1 \text{ fb}^{-1}$  of data. See their Fig. 8 for limits on  $\sigma \cdot \text{B}(G \rightarrow ZZ)$  versus the graviton mass. NODE=S071RSG;LINKAGE=LT
- 45 ABAZOV 08J use  $p\bar{p}$  collisions at  $\sqrt{s} = 1.96 \text{ TeV}$  to search for KK gravitons in warped extra dimensions. They search for graviton resonances decaying to electrons and photons using  $1 \text{ fb}^{-1}$  of data. For warp parameter values of  $k/\bar{M}_P$  between 0.01 and 0.1 the lower limit on the mass of the lightest excitation is between 300 and 900 GeV. See their Fig. 4 for more details. NODE=S071RSG;LINKAGE=AZ
- 46 AALTONEN 07G use  $p\bar{p}$  collisions at  $\sqrt{s} = 1.96 \text{ TeV}$  to search for KK gravitons in warped extra dimensions. They search for graviton resonances decaying to photons using  $1.2 \text{ fb}^{-1}$  of data. For warp parameter values of  $k/\bar{M}_P = 0.1, 0.05$ , and  $0.01$  the bounds on the graviton mass are 850, 694, and 230 GeV, respectively. See their Fig. 3 for more details. See also AALTONEN 07H. NODE=S071RSG;LINKAGE=AA
- 47 AALTONEN 07H use  $p\bar{p}$  collisions at  $\sqrt{s} = 1.96 \text{ TeV}$  to search for KK gravitons in warped extra dimensions. They search for graviton resonances decaying to electrons using  $1.3 \text{ fb}^{-1}$  of data. For a warp parameter value of  $k/\bar{M}_P = 0.1$  the bound on the graviton mass is 807 GeV. See their Fig. 4 for more details. A combined analysis with the diphoton data of AALTONEN 07G yields for  $k/\bar{M}_P = 0.1$  a graviton mass lower bound of 889 GeV. NODE=S071RSG;LINKAGE=AL
- 48 ABAZOV 05N use  $p\bar{p}$  collisions at  $\sqrt{s} = 1.96 \text{ TeV}$  to search for KK gravitons in warped extra dimensions. They search for graviton resonances decaying to muons, electrons or photons, using  $260 \text{ pb}^{-1}$  of data. For warp parameter values of  $k/\bar{M}_P = 0.1, 0.05$ , and  $0.01$ , the bounds on the graviton mass are 785, 650 and 250 GeV respectively. See their Fig. 3 for more details. NODE=S071RSG;LINKAGE=AB

- <sup>49</sup> ABULENCIA 05A use  $p\bar{p}$  collisions at  $\sqrt{s} = 1.96$  TeV to search for KK gravitons in warped extra dimensions. They search for graviton resonances decaying to muons or electrons, using 200 pb<sup>-1</sup> of data. For warp parameter values of  $k/\bar{M}_P = 0.1, 0.05$ , and 0.01, the bounds on the graviton mass are 710, 510 and 170 GeV respectively.

NODE=S071RSG;LINKAGE=AU

### Limits on Kaluza-Klein Gluons in Warped Extra Dimensions

This section places limits on the mass of the first Kaluza-Klein (KK) excitation of the gluon in warped extra dimension models with Standard Model fields propagating in the bulk. Bounds are given for a specific benchmark model with  $\Gamma/m = 15.3\%$  where  $\Gamma$  is the width and  $m$  the mass of the KK gluon. See the “Extra Dimensions” review for more discussion.

NODE=S071KKG

NODE=S071KKG

VALUE (TeV)	CL%	DOCUMENT ID	TECN	COMMENT
<b>&gt;3.8</b>	95	<sup>1</sup> AABOUD	18BI ATLS	$g_{KK} \rightarrow t\bar{t} \rightarrow \ell j$
• • • We do not use the following data for averages, fits, limits, etc. • • •				
		<sup>2</sup> HAYRAPETYAN 24G	CMS	$g_{KK} \rightarrow Rj \rightarrow jjj$
		<sup>3</sup> AABOUD	19AS ATLS	$g_{KK} \rightarrow t\bar{t} \rightarrow jj$
		<sup>4</sup> SIRUNYAN	19AL CMS	$g_{KK} \rightarrow tT$
>2.5	95	<sup>5</sup> CHATRCHYAN 13BM	CMS	$g_{KK} \rightarrow t\bar{t}$
		<sup>6</sup> CHEN	13A	$\bar{B} \rightarrow X_s \gamma$
>1.5	95	<sup>7</sup> AAD	12BV ATLS	$g_{KK} \rightarrow t\bar{t} \rightarrow \ell j$

NODE=S071KKG

<sup>1</sup> AABOUD 18BI use 36.1 fb<sup>-1</sup> of data from  $pp$  collisions at  $\sqrt{s} = 13$  TeV. This result updates AAD 13AQ.

NODE=S071KKG;LINKAGE=E

<sup>2</sup> HAYRAPETYAN 24G use 138 fb<sup>-1</sup> of data from  $pp$  collisions at  $\sqrt{s} = 13$  TeV to place limits on a KK gluon decaying to gluons via a spin-0 radion,  $R$ . See their Figure 3 for limits on the cross section times branching fraction as a function of the KK gluon mass and various values of the radion mass. This updates the results of TUMASYAN 22C.

NODE=S071KKG;LINKAGE=I

<sup>3</sup> AABOUD 19AS use 36.1 fb<sup>-1</sup> of data from  $pp$  collisions at  $\sqrt{s} = 13$  TeV. An upper bound of 3.4 TeV is placed on the KK gluon mass for  $\Gamma/m = 30\%$ .

NODE=S071KKG;LINKAGE=F

<sup>4</sup> SIRUNYAN 19AL use 35.9 fb<sup>-1</sup> of data from  $pp$  collisions at  $\sqrt{s} = 13$  TeV to place limits on a KK gluon decaying to a top quark and a heavy vector-like fermion,  $T$ . KK gluon masses between 1.5 and 2.3 TeV and between 2.0 and 2.4 TeV are excluded for  $T$  masses of 1.2 and 1.5 TeV, respectively.

NODE=S071KKG;LINKAGE=G

<sup>5</sup> CHATRCHYAN 13BM use 19.7 fb<sup>-1</sup> of data from  $pp$  collisions at  $\sqrt{s} = 8$  TeV. Bound is for a width of approximately 15–20% of the KK gluon mass.

NODE=S071KKG;LINKAGE=D

<sup>6</sup> CHEN 13A place limits on the KK mass scale for a specific warped model with custodial symmetry and bulk fermions. See their Figures 4 and 5.

NODE=S071KKG;LINKAGE=C

<sup>7</sup> AAD 12BV use 2.05 fb<sup>-1</sup> of data from  $pp$  collisions at  $\sqrt{s} = 7$  TeV.

NODE=S071KKG;LINKAGE=A

### Black Hole Production Limits

NODE=S071405

#### Semiclassical Black Holes

VALUE (GeV)	DOCUMENT ID	TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •			
	<sup>1</sup> SIRUNYAN	18DA CMS	$pp \rightarrow \text{multijet}$
	<sup>2</sup> AAD	16N ATLS	$pp \rightarrow \text{multijet}$
	<sup>3</sup> AAD	16O ATLS	$pp \rightarrow \ell + (\ell\ell/\ell j/jj)$
	<sup>4</sup> AAD	13AW ATLS	$pp \rightarrow \mu\mu$

NODE=S071BGR  
NODE=S071BGR

<sup>1</sup> SIRUNYAN 18DA use 35.9 fb<sup>-1</sup> of data from  $pp$  collisions at  $\sqrt{s} = 13$  TeV to search for semiclassical black holes decaying to multijet final states. No excess of events above the expected level of standard model background was observed. Exclusions at 95% CL are set on the mass threshold for black hole production as a function of the higher-dimensional Planck scale for rotating and nonrotating black holes under several model assumptions (ADD, 2, 4, 6 extra dimensions model) in the 7.1–10.3 TeV range. These limits supersede those in SIRUNYAN 17CP.

NODE=S071BGR;LINKAGE=E

<sup>2</sup> AAD 16N use 3.6 fb<sup>-1</sup> of data from  $pp$  collisions at  $\sqrt{s} = 13$  TeV to search for semiclassical black hole decays to multijet final states. No excess of events above the expected level of Standard Model background was observed. Exclusion contours at 95% C.L. are set on the mass threshold for black hole production versus higher-dimensional Planck scale for rotating black holes (ADD, 6 extra dimensions model).

NODE=S071BGR;LINKAGE=A

<sup>3</sup> AAD 16O use 3.2 fb<sup>-1</sup> of data from  $pp$  collisions at  $\sqrt{s} = 13$  TeV to search for semiclassical black hole decays to high-mass final states with leptons and jets. No excess of events above the expected level of Standard Model background was observed. Exclusion contours at 95% C.L. are set on the mass threshold for black hole production versus higher-dimensional Planck scale for rotating black holes (ADD, 2 to 6 extra dimensions).

NODE=S071BGR;LINKAGE=B

<sup>4</sup> AAD 13AW use 20.3 fb<sup>-1</sup> of data from  $pp$  collisions at  $\sqrt{s} = 8$  TeV to search for semiclassical black hole decays to like-sign dimuon final states using large track multiplicity. No excess of events above the expected level of Standard Model background was observed. Exclusion contours at 95% C.L. are set on the mass threshold for black hole production versus higher-dimensional Planck scale in various extra dimensions, rotating and non-rotating models.

NODE=S071BGR;LINKAGE=C

## Quantum Black Holes

VALUE (GeV)

DOCUMENT ID

TECN

COMMENT

NODE=S071BHQ  
NODE=S071BHQ

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

1	AAD	24S	ATLS	$pp \rightarrow \ell j$
2	AAD	23CB	ATLS	$pp \rightarrow e\mu, e\tau, \mu\tau$
3	TUMASYAN	23AW	CMS	$pp \rightarrow \tau\nu$
4	TUMASYAN	23BC	CMS	$pp \rightarrow \gamma j$
5	TUMASYAN	23H	CMS	$pp \rightarrow e\mu, e\tau, \mu\tau$
6	AAD	20T	ATLS	$pp \rightarrow jj$
7	AABOUD	18BA	ATLS	$pp \rightarrow \gamma j$
8	SIRUNYAN	18AT	CMS	$pp \rightarrow e\mu$
9	SIRUNYAN	18DD	CMS	$pp \rightarrow$ dijet, ang. distrib.
10	SIRUNYAN	17CP	CMS	$pp \rightarrow jj$
11	KHACHATRY...	16BE	CMS	$pp \rightarrow e\mu$
12	KHACHATRY...	15V	CMS	$pp \rightarrow jj$
13	AAD	14V	ATLS	$pp \rightarrow ee, \mu\mu$
14	CHATRCHYAN	13A	CMS	$pp \rightarrow jj$

<sup>1</sup> AAD 24S use  $140 \text{ fb}^{-1}$  of data from  $pp$  collisions at  $\sqrt{s} = 13 \text{ TeV}$  to search for quantum black hole decays to final states with high-invariant-mass lepton + jet. No excess of events above the expected level of Standard Model background was observed. Exclusion limits at 95% C.L. are set on mass thresholds for black hole production in an ADD (6 extra dimensions) model and the Randall-Sundrum (one extra dimension) model. The resulting lower mass threshold limits in the ADD (RS) models are 9.2 (6.8) TeV. The ADD limit supersedes that in AAD 14AL.

NODE=S071BHQ;LINKAGE=U

<sup>2</sup> AAD 23CB use  $139 \text{ fb}^{-1}$  of data from  $pp$  collisions at  $\sqrt{s} = 13 \text{ TeV}$  to search for quantum black hole decays with different-flavor high-mass dilepton final states. No excess of events above the expected level of Standard Model background was observed. Exclusion limits at 95% C.L. are set on mass thresholds for black hole production in ADD (6 extra dimensions) and RS1 models. Assuming the black hole mass threshold is equal to the higher-dimensional Planck scale, mass thresholds below 5.9 (3.8), 5.2 (3.0), and 5.1 (3.0) TeV are excluded in the  $e\mu$ ,  $e\tau$  and  $\mu\tau$  channels for the ADD (RS1) models, respectively. These limits supersede those in AABOUD 18CM.

NODE=S071BHQ;LINKAGE=Q

<sup>3</sup> TUMASYAN 23AW use  $138 \text{ fb}^{-1}$  of data from  $pp$  collisions at  $\sqrt{s} = 13 \text{ TeV}$  to search for quantum black hole decays in the tau lepton plus missing transverse momentum final state. Assuming the black hole mass threshold is equal to the higher-dimensional Planck scale, threshold masses below 6.6 TeV are excluded in the ADD model with four extra dimensions (see their Figure 8).

NODE=S071BHQ;LINKAGE=R

<sup>4</sup> TUMASYAN 23BC use  $138 \text{ fb}^{-1}$  of data from  $pp$  collisions at  $\sqrt{s} = 13 \text{ TeV}$  to search for quantum black hole decays to final states with a photon and a jet. No excess of events above the expected level of Standard Model background was observed. Exclusion limits at 95% C.L. are set on mass thresholds for black hole production in ADD (6 extra dimensions) and RS1 models. Assuming the black hole mass threshold is equal to the higher-dimensional Planck scale, mass thresholds below 7.5 TeV and 5.2 TeV are excluded for the ADD and RS1 models, respectively (see their Figure 9).

NODE=S071BHQ;LINKAGE=S

<sup>5</sup> TUMASYAN 23H use  $138 \text{ fb}^{-1}$  of data from  $pp$  collisions at  $\sqrt{s} = 13 \text{ TeV}$  to search for quantum black hole decays with different-flavor high-mass dilepton final states. No excess of events above the expected level of Standard Model background was observed. Exclusion limits at 95% C.L. are set on mass thresholds for black hole production in the ADD model (with 4 extra dimensions). Assuming the black hole mass threshold is equal to the higher-dimensional Planck scale, mass thresholds below 5.6, 5.2, and 5.0 TeV are excluded in the  $e\mu$ ,  $e\tau$  and  $\mu\tau$  channels, respectively.

NODE=S071BHQ;LINKAGE=P

<sup>6</sup> AAD 20T use  $139 \text{ fb}^{-1}$  of data from  $pp$  collisions at  $\sqrt{s} = 13 \text{ TeV}$  to search for quantum black hole decays to final states with dijets. No excess of events above the expected level of Standard Model background was observed. Exclusion limits at 95% C.L. are set on mass thresholds for black hole production in an ADD (6 extra dimensions) model. Assuming the black hole mass threshold is equal to the higher-dimensional Planck scale, mass thresholds below 9.4 TeV are excluded. This limit supersedes AABOUD 17AK.

NODE=S071BHQ;LINKAGE=O

<sup>7</sup> AABOUD 18BA use  $36.7 \text{ fb}^{-1}$  of data from  $pp$  collisions at  $\sqrt{s} = 13 \text{ TeV}$  to search for quantum black hole decays to final states with a photon and a jet. No excess of events above the expected level of Standard Model background was observed. Exclusion limits at 95% C.L. are set on mass thresholds for black hole production in ADD (6 extra dimensions) and RS1 models. Assuming the black hole mass threshold is equal to the Planck scale, mass thresholds below 7.1 TeV and 4.4 TeV are excluded for the ADD and RS1 models, respectively. These limits supersede those in AAD 16AI.

NODE=S071BHQ;LINKAGE=A

<sup>8</sup> SIRUNYAN 18AT use  $35.9 \text{ fb}^{-1}$  of data from  $pp$  collisions at  $\sqrt{s} = 13 \text{ TeV}$  to search for quantum black hole decays to  $e\mu$  final states. In Figure 4, lower mass limits of 5.3, 5.5 and 5.6 TeV are placed in a model with 4, 5 and 6 extra dimensions, respectively, and a lower mass limit of 3.6 TeV is found for a single warped dimension.

NODE=S071BHQ;LINKAGE=B

<sup>9</sup> SIRUNYAN 18DD use  $35.9 \text{ fb}^{-1}$  of data from  $pp$  collisions at  $\sqrt{s} = 13 \text{ TeV}$  to search for quantum black hole decays in dijet angular distributions. A lower mass limit of 5.9 (8.2) TeV is placed in the RS (ADD) model with one (six) extra dimension(s).

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<sup>10</sup> SIRUNYAN 17CP use  $2.3 \text{ fb}^{-1}$  of data from  $pp$  collisions at  $\sqrt{s} = 13 \text{ TeV}$  to search for quantum black holes decaying to dijet final states. No excess of events above the expected level of standard model background was observed. Limits on the quantum black hole mass threshold are set as a function of the higher-dimensional Planck scale, under

NODE=S071BHQ;LINKAGE=L

the assumption that the mass threshold must exceed the above Planck scale. Depending on the model, mass thresholds in the range up to 5.1–9.0 TeV are excluded.

- 11 KHACHATRYAN 16BE use  $19.7 \text{ fb}^{-1}$  of data from  $pp$  collisions at  $\sqrt{s} = 8 \text{ TeV}$  to search for quantum black holes undergoing lepton flavor violating decay to the  $e\mu$  final state. No excess of events above the expected level of standard model background was observed. Exclusion limits at 95% CL are set on mass thresholds for black hole production in the ADD (2–6 flat extra dimensions), RS1 (1 warped extra dimension), and a model with a Planck scale at the TeV scale from a renormalization of the gravitational constant (no extra dimensions). Limits on the black hole mass threshold are set assuming that it is equal to the higher-dimensional Planck scale. Mass thresholds for quantum black holes in the range up to 3.15–3.63 TeV are excluded in the ADD model. In the RS1 model, mass thresholds below 2.81 TeV are excluded in the PDG convention for the Schwarzschild radius. In the model with no extra dimensions, mass thresholds below 1.99 TeV are excluded.
- 12 KHACHATRYAN 15V use  $19.7 \text{ fb}^{-1}$  of data from  $pp$  collisions at  $\sqrt{s} = 8 \text{ TeV}$  to search for quantum black holes decaying to dijet final states. No excess of events above the expected level of standard model background was observed. Exclusion limits at 95% CL are set on mass thresholds for black hole production in the ADD (2–6 flat extra dimensions) and RS1 (1 warped extra dimension) model. Limits on the black hole mass threshold are set as a function of the higher-dimensional Planck scale, under the assumption that the mass threshold must exceed the above Planck scale. Depending on the model, mass thresholds in the range up to 5.0–6.3 TeV are excluded. This paper supersedes CHATRCHYAN 13AD.
- 13 AAD 14v use  $20.3 (20.5) \text{ fb}^{-1}$  of data in the dielectron (dimuon) channels from  $pp$  collisions at  $\sqrt{s} = 8 \text{ TeV}$  to search for quantum black hole decays involving high-mass dilepton resonances. No excess of events above the expected level of Standard Model background was observed. Exclusion limits at 95% C.L. are set on mass thresholds for black hole production in ADD (6 extra dimensions) and RS1 models. Assuming the black hole mass threshold is equal to the higher-dimensional Planck scale, mass thresholds below 3.65 TeV and 2.24 TeV are excluded for the ADD and RS1 models, respectively.
- 14 CHATRCHYAN 13A use  $5 \text{ fb}^{-1}$  of data from  $pp$  collisions at  $\sqrt{s} = 7 \text{ TeV}$  to search for quantum black holes decaying to dijet final states. No excess of events above the expected level of standard model background was observed. Exclusion limits at 95% CL are set on mass thresholds for black hole production in the ADD (2–6 flat extra dimensions) and RS (1 warped extra dimension) model. Limits on the black hole mass threshold are set as a function of the higher-dimensional Planck scale, under assumption that the mass threshold must exceed the above Planck scale. Depending on the model, mass thresholds in the range up to 4.0–5.3 TeV are excluded.

NODE=S071BHQ;LINKAGE=K

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AAD	12Y	PL B710 538	G. Aad <i>et al.</i>	(ATLAS Collab.)	REFID=54161
AALTONEN	12V	PR D85 012008	T. Aaltonen <i>et al.</i>	(CDF Collab.)	REFID=54361
ABAZOV	12M	PRL 108 131802	V.M. Abazov <i>et al.</i>	(D0 Collab.)	REFID=54209
AJELLO	12	JCAP 1202 012	M. Ajello <i>et al.</i>	(Fermi-LAT Collab.)	REFID=54444
BAAK	12	EPJ C72 2003	M. Baak <i>et al.</i>	(Gfitter Group)	REFID=54138
FLACKE	12	PR D85 126007	T. Flacke, C. Pasold	(WURZ)	REFID=54500
NISHIWAKI	12	PL B707 506	K. Nishiwaki <i>et al.</i>	(KOBE, OSAK)	REFID=54151
AAD	11F	PRL 106 121803	G. Aad <i>et al.</i>	(ATLAS Collab.)	REFID=16559
AAD	11X	EPJ C71 1744	G. Aad <i>et al.</i>	(ATLAS Collab.)	REFID=53926
AALTONEN	11G	PR D83 112008	T. Aaltonen <i>et al.</i>	(CDF Collab.)	REFID=16433
AALTONEN	11R	PRL 107 051801	T. Aaltonen <i>et al.</i>	(CDF Collab.)	REFID=16455
AALTONEN	11U	PR D83 011102	T. Aaltonen <i>et al.</i>	(CDF Collab.)	REFID=53703
AARON	11C	PL B705 52	F. D. Aaron <i>et al.</i>	(H1 Collab.)	REFID=53845

ABAZOV	11H	PRL 107 011801	V.M. Abazov <i>et al.</i>	(D0 Collab.)	REFID=16473
BEZERRA	11	PR D83 075004	V.B. Bezerra <i>et al.</i>		REFID=16525
SUSHKOV	11	PRL 107 171101	A.O. Sushkov <i>et al.</i>		REFID=53828
AALTONEN	10N	PRL 104 241801	T. Aaltonen <i>et al.</i>	(CDF Collab.)	REFID=53313
ABAZOV	10F	PRL 104 241802	V.M. Abazov <i>et al.</i>	(D0 Collab.)	REFID=53318
ABAZOV	10P	PRL 105 221802	V.M. Abazov <i>et al.</i>	(D0 Collab.)	REFID=53443
BEZERRA	10	PR D81 055003	V.B. Bezerra <i>et al.</i>		REFID=53391
ABAZOV	09AE	PRL 103 191803	V.M. Abazov <i>et al.</i>	(D0 Collab.)	REFID=53064
ABAZOV	09D	PRL 102 051601	V.M. Abazov <i>et al.</i>	(D0 Collab.)	REFID=52649
MASUDA	09	PRL 102 171101	M. Masuda, M. Sasaki	(ICRR)	REFID=52844
AALTONEN	08AC	PRL 101 181602	T. Aaltonen <i>et al.</i>	(CDF Collab.)	REFID=52563
AALTONEN	08S	PR D78 012008	T. Aaltonen <i>et al.</i>	(CDF Collab.)	REFID=52373
ABAZOV	08J	PRL 100 091802	V.M. Abazov <i>et al.</i>	(D0 Collab.)	REFID=52388
ABAZOV	08S	PRL 101 011601	V.M. Abazov <i>et al.</i>	(D0 Collab.)	REFID=52397
DAS	08	PR D78 063011	P.K. Das, V.H.S. Kumar, P.K. Suresh		REFID=52530
GERACI	08	PR D78 022002	A.A. Geraci <i>et al.</i>	(STAN)	REFID=52417
TRENKEL	08	PR D77 122001	C. Trenkel		REFID=52408
AALTONEN	07G	PRL 99 171801	T. Aaltonen <i>et al.</i>	(CDF Collab.)	REFID=52012
AALTONEN	07H	PRL 99 171802	T. Aaltonen <i>et al.</i>	(CDF Collab.)	REFID=52013
DECCA	07A	EPJ C51 963	R.S. Decca <i>et al.</i>		REFID=51880
HAISCH	07	PR D76 034014	U. Haisch, A. Weiler		REFID=51860
KAPNER	07	PRL 98 021101	D.J. Kapner <i>et al.</i>		REFID=51607
SCHAEI	07A	EPJ C49 411	S. Schaei <i>et al.</i>	(ALEPH Collab.)	REFID=51743
TU	07	PRL 98 201101	L.-C. Tu <i>et al.</i>		REFID=51808
ABDALLAH	06C	EPJ C45 589	J. Abdallah <i>et al.</i>	(DELPHI Collab.)	REFID=51224
ABULENCIA,A	06	PRL 97 171802	A. Abulencia <i>et al.</i>	(CDF Collab.)	REFID=51434
GERDES	06	PR D73 112008	D. Gerdes <i>et al.</i>		REFID=51286
GOGOLADZE	06	PR D74 093012	I. Gogoladze, C. Macesanu		REFID=51544
ABAZOV	05N	PRL 95 091801	V.M. Abazov <i>et al.</i>	(D0 Collab.)	REFID=50740
ABAZOV	05V	PRL 95 161602	V.M. Abazov <i>et al.</i>	(D0 Collab.)	REFID=50927
ABDALLAH	05B	EPJ C38 395	J. Abdallah <i>et al.</i>	(DELPHI Collab.)	REFID=50448
ABULENCIA	05A	PRL 95 252001	A. Abulencia <i>et al.</i>	(CDF Collab.)	REFID=51009
SMULLIN	05	PR D72 122001	S.J. Smullin <i>et al.</i>		REFID=51007
ACHARD	04E	PL B587 16	P. Achard <i>et al.</i>	(L3 Collab.)	REFID=49893
ACOSTA	04C	PRL 92 121802	D. Acosta <i>et al.</i>	(CDF Collab.)	REFID=49935
BARBIERI	04	NP B703 127	R. Barbieri <i>et al.</i>		REFID=55653
CASSE	04	PRL 92 111102	M. Casse <i>et al.</i>		REFID=50055
CHEKANOV	04B	PL B591 23	S. Chekanov <i>et al.</i>	(ZEUS Collab.)	REFID=49912
HOYLE	04	PR D70 042004	C.D. Hoyle <i>et al.</i>	(WASH)	REFID=51084
ABAZOV	03	PRL 90 251802	V.M. Abazov <i>et al.</i>	(D0 Collab.)	REFID=49443
ABBIENDI	03D	EPJ C26 331	G. Abbiendi <i>et al.</i>	(OPAL Collab.)	REFID=49290
ACHARD	03D	PL B572 133	P. Achard <i>et al.</i>	(L3 Collab.)	REFID=49556
ADLOFF	03	PL B568 35	C. Adloff <i>et al.</i>	(H1 Collab.)	REFID=49522
CHIAVERINI	03	PRL 90 151101	J. ChIAVERINI <i>et al.</i>		REFID=49357
GIUDICE	03	NP B663 377	G.F. Giudice, A. Strumia		REFID=49427
HANNESTAD	03	PR D67 125008	S. Hannestad, G.G. Raffelt		REFID=49536
Also		PR D69 029901(errat.)	S. Hannestad, G.G. Raffelt		REFID=50033
HEISTER	03C	EPJ C28 1	A. Heister <i>et al.</i>	(ALEPH Collab.)	REFID=49379
LONG	03	NAT 421 922	J.C. Long <i>et al.</i>		REFID=49699
ACHARD	02	PL B524 65	P. Achard <i>et al.</i>	(L3 Collab.)	REFID=48524
ACHARD	02D	PL B531 28	P. Achard <i>et al.</i>	(L3 Collab.)	REFID=48663
HANNESTAD	02	PRL 88 071301	S. Hannestad, G. Raffelt		REFID=48698
ABBOTT	01	PRL 86 1156	B. Abbott <i>et al.</i>	(D0 Collab.)	REFID=48041
FAIRBAIRN	01	PL B508 335	M. Fairbairn		REFID=48264
HANHART	01	PL B509 1	C. Hanhart <i>et al.</i>		REFID=48160
HOYLE	01	PRL 86 1418	C.D. Hoyle <i>et al.</i>		REFID=48082
ABBIENDI	00R	EPJ C13 553	G. Abbiendi <i>et al.</i>	(OPAL Collab.)	REFID=47644
ABREU	00A	PL B491 67	P. Abreu <i>et al.</i>	(DELPHI Collab.)	REFID=47825
ABREU	00S	PL B485 45	P. Abreu <i>et al.</i>	(DELPHI Collab.)	REFID=47716
ABREU	00Z	EPJ C17 53	P. Abreu <i>et al.</i>	(DELPHI Collab.)	REFID=47790
CASSISI	00	PL B481 323	S. Cassisi <i>et al.</i>		REFID=47907
CHANG	00B	PRL 85 3765	L.N. Chang <i>et al.</i>		REFID=47823
CHEUNG	00	PR D61 015005	K. Cheung		REFID=47885
CORNET	00	PR D61 037701	F. Cornet, M. Relano, J. Rico		REFID=47888
GRAESSER	00	PR D61 074019	M.L. Graesser		REFID=47889
HAN	00	PR D62 125018	T. Han, D. Marfatia, R.-J. Zhang		REFID=47896
MATHEWS	00	JHEP 0007 008	P. Mathews, S. Raychaudhuri, K. Sridhar		REFID=49019
MELE	00	PR D61 117901	S. Mele, E. Sanchez		REFID=47892
RIZZO	00	PR D61 016007	T.G. Rizzo, J.D. Wells		REFID=47887
ABBIENDI	99P	PL B465 303	G. Abbiendi <i>et al.</i>	(OPAL Collab.)	REFID=47290
ACCIARRI	99M	PL B464 135	M. Acciarri <i>et al.</i>	(L3 Collab.)	REFID=47229
ACCIARRI	99R	PL B470 268	M. Acciarri <i>et al.</i>	(L3 Collab.)	REFID=47322
ACCIARRI	99S	PL B470 281	M. Acciarri <i>et al.</i>	(L3 Collab.)	REFID=47323
BOURILKOV	99	JHEP 9908 006	D. Bourilkov		REFID=47332
HOSKINS	85	PR D32 3084	J.K. Hoskins <i>et al.</i>		REFID=49700