

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. n indicates the number of extra dimensions.

Limits not encoded here are summarized in the “Extra Dimensions” review.

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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 δ toroidal extra dimensions of equal size, $\alpha = 8\delta/3$. Quoted bounds are for $\delta = 2$ unless otherwise noted.

VALUE (μm)	CL%	DOCUMENT ID	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •			
	95	1 MASUDA 09	Torsion pendulum
		2 GERACI 08	Microcantilever
		3 TRENKEL 08	Newton's constant
		4 DECCA 07A	Torsion oscillator
< 30	95	5 KAPNER 07	Torsion pendulum
< 47	95	6 TU 07	Torsion pendulum
		7 SMULLIN 05	Microcantilever
<130	95	8 HOYLE 04	Torsion pendulum
		9 CHIAVERINI 03	Microcantilever
$\lesssim 200$	95	10 LONG 03	Microcantilever
<190	95	11 HOYLE 01	Torsion pendulum
		12 HOSKINS 85	Torsion pendulum

¹ MASUDA 09 obtain improved constraints on non-Newtonian forces with strengths $10^9 \lesssim |\alpha| \lesssim 10^{11}$ and length scales $R = 1.0\text{--}2.9 \mu\text{m}$. See their Fig. 3. This bound does not place limits on the size of extra flat dimensions.

² 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.

³ TRENKEL 08 uses two independent measurements of Newton's constant G to constrain new forces with strength $|\alpha| \simeq 10^{-4}$ and length scales $R = 0.02\text{--}1 \text{ m}$. See their Fig. 1. This bound does not place limits on the size of extra flat dimensions.

⁴ DECCA 07A search for new forces and obtain bounds in the region with strengths $|\alpha| \simeq 10^{13}\text{--}10^{18}$ and length scales $R = 20\text{--}86 \text{ nm}$. See their Fig. 6. This bound does not place limits on the size of extra flat dimensions.

⁵ 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.

⁶ 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.

- ⁷ SMULLIN 05 search for new forces, and obtain bounds in the region with strengths $\alpha \simeq 10^3-10^8$ and length scales $R = 6-20 \mu\text{m}$. See their Figs. 1 and 16 for details on the bound. This work does not place limits on the size of extra flat dimensions.
- ⁸ HOYLE 04 search for new forces, probing α 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.
- ⁹ CHIAVERINI 03 search for new forces, probing α above 10^4 and λ 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.
- ¹⁰ LONG 03 search for new forces, probing α down to 3, and distances down to about $10\mu\text{m}$. See their Fig. 4 for details on the bound.
- ¹¹ HOYLE 01 search for new forces, probing α 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 $\alpha \geq 3$.
- ¹² 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.

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 μm for $\delta=2$.

VALUE (μm)	CL%	DOCUMENT ID	TECN	COMMENT
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●				
< 245	95	13 AALTONEN	08AC CDF	$p\bar{p} \rightarrow \gamma G, jG$
< 615	95	14 ABAZOV	08S D0	$p\bar{p} \rightarrow \gamma G$
< 0.916	95	15 DAS	08	Supernova cooling
< 350	95	16 ABULENCIA,A	06 CDF	$p\bar{p} \rightarrow jG$
< 270	95	17 ABDALLAH	05B DLPH	$e^+e^- \rightarrow \gamma G$
< 210	95	18 ACHARD	04E L3	$e^+e^- \rightarrow \gamma G$
< 480	95	19 ACOSTA	04C CDF	$\bar{p}p \rightarrow jG$
< 0.00038	95	20 CASSE	04	Neutron star γ sources
< 610	95	21 ABAZOV	03 D0	$\bar{p}p \rightarrow jG$
< 0.96	95	22 HANNESTAD	03	Supernova cooling
< 0.096	95	23 HANNESTAD	03	Diffuse γ background
< 0.051	95	24 HANNESTAD	03	Neutron star γ sources
< 0.00016	95	25 HANNESTAD	03	Neutron star heating
< 300	95	26 HEISTER	03C ALEP	$e^+e^- \rightarrow \gamma G$
		27 FAIRBAIRN	01	Cosmology
< 0.66	95	28 HANHART	01	Supernova cooling
		29 CASSISI	00	Red giants
<1300	95	30 ACCIARRI	99S L3	$e^+e^- \rightarrow ZG$

Limits on R from On-Shell Production of Gravitons: $\delta \geq 3$

This section includes limits similar to those in the previous section, but for $\delta = 3$ extra dimensions. Bounds are given in nm for $\delta = 3$. Entries are also shown for papers examining models with $\delta > 3$.

<u>VALUE (nm)</u>	<u>CL%</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●				
< 2.8	95	13 AALTONEN	08AC CDF	$p\bar{p} \rightarrow \gamma G, jG$
< 4.56	95	14 ABAZOV	08S D0	$p\bar{p} \rightarrow \gamma G$
< 2.09	95	15 DAS	08	Supernova cooling
< 3.6	95	16 ABULENCIA,A	06 CDF	$p\bar{p} \rightarrow jG$
< 3.5	95	17 ABDALLAH	05B DLPH	$e^+e^- \rightarrow \gamma G$
< 2.9	95	18 ACHARD	04E L3	$e^+e^- \rightarrow \gamma G$
	95	19 ACOSTA	04C CDF	$\bar{p}p \rightarrow jG$
< 0.0042	95	20 CASSE	04	Neutron star γ sources
< 6.1	95	21 ABAZOV	03 D0	$\bar{p}p \rightarrow jG$
< 1.14	95	22 HANNESTAD	03	Supernova cooling
< 0.025	95	23 HANNESTAD	03	Diffuse γ background
< 0.11	95	24 HANNESTAD	03	Neutron star γ sources
< 0.0026	95	25 HANNESTAD	03	Neutron star heating
< 3.9	95	26 HEISTER	03C ALEP	$e^+e^- \rightarrow \gamma G$
		27 FAIRBAIRN	01	Cosmology
< 0.8	95	28 HANHART	01	Supernova cooling
		29 CASSISI	00	Red giants
<18	95	30 ACCIARRI	99S L3	$e^+e^- \rightarrow ZG$

¹³ AALTONEN 08AC search for $p\bar{p} \rightarrow \gamma G$ and $p\bar{p} \rightarrow jG$ at $\sqrt{s} = 1.96$ TeV with 2.0 fb^{-1} and 1.1 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 $\delta \leq 6$.

¹⁴ ABAZOV 08S search for $p\bar{p} \rightarrow \gamma G$, using 1 fb^{-1} of data at $\sqrt{s} = 1.96$ 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 δ .

¹⁵ DAS 08 obtain a limit on R from Kaluza-Klein graviton cooling of SN1987A due to plasmon-plasmon annihilation.

¹⁶ ABULENCIA,A 06 search for $p\bar{p} \rightarrow jG$ using 368 pb^{-1} of data at $\sqrt{s} = 1.96$ TeV. See their Table II for bounds for all $\delta \leq 6$.

¹⁷ ABDALLAH 05B search for $e^+e^- \rightarrow \gamma G$ at $\sqrt{s} = 180\text{--}209$ 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.

¹⁸ 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.

¹⁹ ACOSTA 04C search for $\bar{p}p \rightarrow jG$ 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 $\delta = 4, 6$.

²⁰ CASSE 04 obtain a limit on R from the gamma-ray emission of point γ 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.

²¹ 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 δ . We quote results without the approximate NLO scaling introduced in the paper.

²² 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.

- 23 HANNESTAD 03 obtain a limit on R from gravitons emitted in supernovae and which subsequently decay, contaminating the diffuse cosmic γ background. Limits for all $\delta \leq 7$ are given in their Tables V and VI. These limits supersede those in HANNESTAD 02.
- 24 HANNESTAD 03 obtain a limit on R from gravitons emitted in two recent supernovae and which subsequently decay, creating point γ sources. Limits for all $\delta \leq 7$ are given in their Tables V and VI. These limits are corrected in the published erratum.
- 25 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.
- 26 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 .
- 27 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.
- 28 HANHART 01 obtain bounds on R from limits on graviton cooling of supernova SN 1987a using numerical simulations of proto-neutron star neutrino emission.
- 29 CASSISI 00 obtain rough bounds on M_D (and thus R) from red giant cooling for $\delta=2,3$. See their paper for details.
- 30 ACCIARRI 99S search for $e^+ e^- \rightarrow Z G$ at $\sqrt{s}=189$ GeV. Limits on the gravity scale are found in their Table 2, for $\delta \leq 4$.

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 λ , 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."

VALUE (TeV)	CL%	DOCUMENT ID	TECN	COMMENT
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●				
> 1.48	95	31 ABAZOV	09AE D0	$p\bar{p} \rightarrow$ dijet, angular distrib.
> 1.45	95	32 ABAZOV	09D D0	$p\bar{p} \rightarrow e^+ e^-, \gamma\gamma$
> 1.1 (> 1.0)	95	33 SCHAEEL	07A ALEP	$e^+ e^- \rightarrow e^+ e^-$
> 0.898 (> 0.998)	95	34 ABDALLAH	06C DLPH	$e^+ e^- \rightarrow \ell^+ \ell^-$
> 0.853 (> 0.939)	95	35 GERDES	06	$p\bar{p} \rightarrow e^+ e^-, \gamma\gamma$
> 0.96 (> 0.93)	95	36 ABAZOV	05V D0	$p\bar{p} \rightarrow \mu^+ \mu^-$
> 0.78 (> 0.79)	95	37 CHEKANOV	04B ZEUS	$e^\pm p \rightarrow e^\pm X$
> 0.805 (> 0.956)	95	38 ABBIENDI	03D OPAL	$e^+ e^- \rightarrow \gamma\gamma$
> 0.7 (> 0.7)	95	39 ACHARD	03D L3	$e^+ e^- \rightarrow ZZ$
> 0.82 (> 0.78)	95	40 ADLOFF	03 H1	$e^\pm p \rightarrow e^\pm X$
> 1.28 (> 1.25)	95	41 GIUDICE	03 RVUE	
> 20.6 (> 15.7)	95	42 GIUDICE	03 RVUE	Dim-6 operators
> 0.80 (> 0.85)	95	43 HEISTER	03C ALEP	$e^+ e^- \rightarrow \gamma\gamma$
> 0.84 (> 0.99)	95	44 ACHARD	02D L3	$e^+ e^- \rightarrow \gamma\gamma$
> 1.2 (> 1.1)	95	45 ABBOTT	01 D0	$p\bar{p} \rightarrow e^+ e^-, \gamma\gamma$
> 0.60 (> 0.63)	95	46 ABBIENDI	00R OPAL	$e^+ e^- \rightarrow \mu^+ \mu^-$

> 0.63	(> 0.50)	95	46	ABBIENDI	00R	OPAL	$e^+e^- \rightarrow \tau^+\tau^-$
> 0.68	(> 0.61)	95	46	ABBIENDI	00R	OPAL	$e^+e^- \rightarrow \mu^+\mu^-, \tau^+\tau^-$
			47	ABREU	00A	DLPH	$e^+e^- \rightarrow \gamma\gamma$
> 0.680	(> 0.542)	95	48	ABREU	00S	DLPH	$e^+e^- \rightarrow \mu^+\mu^-, \tau^+\tau^-$
> 15–28		99.7	49	CHANG	00B	RVUE	Electroweak
> 0.98		95	50	CHEUNG	00	RVUE	$e^+e^- \rightarrow \gamma\gamma$
> 0.29–0.38		95	51	GRAESSER	00	RVUE	$(g-2)_\mu$
> 0.50–1.1		95	52	HAN	00	RVUE	Electroweak
> 2.0	(> 2.0)	95	53	MATHEWS	00	RVUE	$\bar{p}p \rightarrow jj$
> 1.0	(> 1.1)	95	54	MELE	00	RVUE	$e^+e^- \rightarrow VV$
			55	ABBIENDI	99P	OPAL	
			56	ACCIARRI	99M	L3	
			57	ACCIARRI	99S	L3	
> 1.412	(> 1.077)	95	58	BOURILKOV	99		$e^+e^- \rightarrow e^+e^-$

- 31 ABAZOV 09AE use dijet angular distributions in 0.7 fb^{-1} of data from $p\bar{p}$ collisions at $\sqrt{s} = 1.96 \text{ TeV}$ to place lower bounds on Λ_T (equivalent to their M_S), here converted to M_{TT} .
- 32 ABAZOV 09D use 1.05 fb^{-1} of data from $p\bar{p}$ collisions at $\sqrt{s} = 1.96 \text{ TeV}$ to place lower bounds on Λ_T (equivalent to their M_S), here converted to M_{TT} .
- 33 SCHAEEL 07A use e^+e^- collisions at $\sqrt{s} = 189\text{--}209 \text{ GeV}$ to place lower limits on Λ_T , here converted to limits on M_{TT} .
- 34 ABDALLAH 06C use e^+e^- collisions at $\sqrt{s} \sim 130\text{--}207 \text{ GeV}$ to place lower limits on M_{TT} , which is equivalent to their definition of M_S . Bound shown includes all possible final state leptons, $\ell = e, \mu, \tau$. Bounds on individual leptonic final states can be found in their Table 31.
- 35 GERDES 06 use 100 to 110 pb^{-1} of data from $p\bar{p}$ collisions at $\sqrt{s} = 1.8 \text{ TeV}$, as recorded by the CDF Collaboration during Run I of the Tevatron. Bound shown includes a K -factor of 1.3. Bounds on individual e^+e^- and $\gamma\gamma$ final states are found in their Table I.
- 36 ABAZOV 05V use 246 pb^{-1} of data from $p\bar{p}$ collisions at $\sqrt{s} = 1.96 \text{ TeV}$ to search for deviations in the differential cross section to $\mu^+\mu^-$ from graviton exchange.
- 37 CHEKANOV 04B search for deviations in the differential cross section of $e^\pm p \rightarrow e^\pm X$ with 130 pb^{-1} of combined data and Q^2 values up to $40,000 \text{ GeV}^2$ to place a bound on M_{TT} .
- 38 ABBIENDI 03D use e^+e^- collisions at $\sqrt{s}=181\text{--}209 \text{ GeV}$ to place bounds on the ultra-violet scale M_{TT} , which is equivalent to their definition of M_S .
- 39 ACHARD 03D look for deviations in the cross section for $e^+e^- \rightarrow ZZ$ from $\sqrt{s} = 200\text{--}209 \text{ GeV}$ to place a bound on M_{TT} .
- 40 ADLOFF 03 search for deviations in the differential cross section of $e^\pm p \rightarrow e^\pm X$ at $\sqrt{s}=301$ and 319 GeV to place bounds on M_{TT} .
- 41 GIUDICE 03 review existing experimental bounds on M_{TT} and derive a combined limit.
- 42 GIUDICE 03 place bounds on Λ_6 , the coefficient of the gravitationally-induced dimension-6 operator $(2\pi\lambda/\Lambda_6^2)(\sum \bar{f}\gamma_\mu\gamma^5 f)(\sum \bar{f}\gamma^\mu\gamma^5 f)$, using data from a variety of experiments. Results are quoted for $\lambda=\pm 1$ and are independent of δ .
- 43 HEISTER 03C use e^+e^- collisions at $\sqrt{s}= 189\text{--}209 \text{ GeV}$ to place bounds on the scale of dim-8 gravitational interactions. Their M_S^\pm is equivalent to our M_{TT} with $\lambda=\pm 1$.
- 44 ACHARD 02 search for s -channel graviton exchange effects in $e^+e^- \rightarrow \gamma\gamma$ at $E_{\text{cm}} = 192\text{--}209 \text{ GeV}$.
- 45 ABBOTT 01 search for variations in differential cross sections to e^+e^- and $\gamma\gamma$ final states at the Tevatron.
- 46 ABBIENDI 00R uses e^+e^- collisions at $\sqrt{s}= 189 \text{ GeV}$.

- 47 ABREU 00A search for s -channel graviton exchange effects in $e^+e^- \rightarrow \gamma\gamma$ at $E_{\text{cm}}=189\text{--}202$ GeV.
- 48 ABREU 00S uses e^+e^- collisions at $\sqrt{s}=183$ and 189 GeV. Bounds on μ and τ individual final states given in paper.
- 49 CHANG 00B derive 3σ limit on $M_{\mathcal{T}\mathcal{T}}$ 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.
- 50 CHEUNG 00 obtains limits from anomalous diphoton production at OPAL due to graviton exchange. Original limit for $\delta=4$. However, unknown UV theory renders δ dependence unreliable. Original paper works in HLZ convention.
- 51 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."
- 52 HAN 00 calculates corrections to gauge boson self-energies from KK graviton loops and constrain them using S and T . Bounds on $M_{\mathcal{T}\mathcal{T}}$ range from 0.5 TeV ($\delta=6$) to 1.1 TeV ($\delta=2$); see text. Limits have strong dependence, $\lambda^{\delta+2}$, on unknown λ coefficient.
- 53 MATHEWS 00 search for evidence of graviton exchange in CDF and $D\bar{D}$ dijet production data. See their Table 2 for slightly stronger δ -dependent bounds. Limits expressed in terms of $\widetilde{M}_S^4 = M_{\mathcal{T}\mathcal{T}}^4/8$.
- 54 MELE 00 obtains bound from KK graviton contributions to $e^+e^- \rightarrow VV$ ($V=\gamma, W, Z$) at LEP. Authors use Hewett conventions.
- 55 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.
- 56 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.
- 57 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.
- 58 BOURILKOV 99 performs global analysis of LEP data on e^+e^- collisions at $\sqrt{s}=183$ and 189 GeV. Bound is on $\Lambda_{\mathcal{T}}$.

Direct Limits on Gravitational or String Mass Scale

This section includes limits on the fundamental gravitational scale and/or the string scale from processes which depend directly on one or the other of these scales.

<u>VALUE (TeV)</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
• • • We do not use the following data for averages, fits, limits, etc. • • •			
$\gtrsim 1\text{--}2$	59 ANCHORDOQ.02B	RVUE	Cosmic Rays
>0.49	60 ACCIARRI 00P	L3	$e^+e^- \rightarrow e^+e^-$
59 ANCHORDOQUI 02B derive bound on M_D from non-observation of black hole production in high-energy cosmic rays. Bound is stronger for larger δ , but depends sensitively on threshold for black hole production.			
60 ACCIARRI 00P uses e^+e^- collisions at $\sqrt{s}=183$ and 189 GeV. Bound on string scale M_S from massive string modes. M_S is defined in hep-ph/0001166 by $M_S(1/\pi)^{1/8}\alpha^{-1/4} = M$ where $(4\pi G)^{-1} = M^{n+2}R^n$.			

Limits on $1/R = M_c$

This section includes limits on $1/R = M_c$, the compactification scale in models with TeV extra dimensions, 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.

<u>VALUE (TeV)</u>	<u>CL%</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●				
>1.59	95	61 ABAZOV	09AE D0	$p\bar{p} \rightarrow$ dijet, angular dist.
>0.6	95	62 HAISCH	07 RVUE	$\bar{B} \rightarrow X_s \gamma$
>0.6	90	63 GOGOLADZE	06 RVUE	Electroweak
>3.3	95	64 CORNET	00 RVUE	Electroweak
> 3.3–3.8	95	65 RIZZO	00 RVUE	Electroweak
61 ABAZOV 09AE use dijet angular distributions in 0.7 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.				
62 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.				
63 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.				
64 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.				
65 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).				

Limits on Kaluza-Klein Gravitons in Warped Extra Dimensions

This sections 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. Experimental bounds depend strongly on the warp parameter, k . See the "Extra Dimensions" review for a full discussion.

<u>VALUE</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●			
	66 AALTONEN	08S CDF	$p\bar{p} \rightarrow G \rightarrow ZZ$
	67 ABAZOV	08J D0	$p\bar{p} \rightarrow G \rightarrow e^+e^-, \gamma\gamma$
	68 AALTONEN	07G CDF	$p\bar{p} \rightarrow G \rightarrow \gamma\gamma$
	69 AALTONEN	07H CDF	$p\bar{p} \rightarrow G \rightarrow e\bar{e}$
	70 ABAZOV	05N D0	$p\bar{p} \rightarrow G \rightarrow \ell\ell, \gamma\gamma$
	71 ABULENCIA	05A CDF	$p\bar{p} \rightarrow G \rightarrow \ell\bar{\ell}$
66 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 fb^{-1} of data. See their Fig. 8 for limits on $\sigma \cdot \text{B}(G \rightarrow ZZ)$ versus the graviton mass.			
67 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 fb^{-1} of data. For warp parameter values of k/\overline{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.			
68 AALTONEN 07G use $p\bar{p}$ collisions at 1.96 TeV to search for KK gravitons in warped extra dimensions. They search for graviton resonances decaying to photons using 1.2 fb^{-1} of data. For warp parameter values of $k/\overline{M}_P = 0.1, 0.05,$ and 0.01 the bounds			

on the graviton mass are 850, 694, and 230 GeV, respectively. See their Fig. 3 for more details.

- 69 AALTONEN 07H use $p\bar{p}$ collisions at 1.96 TeV to search for KK gravitons in warped extra dimensions. They search for graviton resonances decaying to electrons using 1.3 fb^{-1} of data. For a warp parameter value of $k/\overline{M}_P = 0.1$ 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 $k/\overline{M}_P = 0.1$ a graviton mass lower bound of 889 GeV.
- 70 ABAZOV 05N use $p\bar{p}$ collisions at 1.96 TeV to search for KK gravitons in warped extra dimensions. They search for graviton resonances decaying to muons, electrons or photons, using 260 pb^{-1} of data. For warp parameter values of $k/\overline{M}_P = 0.1, 0.05, \text{ and } 0.01$, the bounds on the graviton mass are 785, 650 and 250 GeV respectively. See their Fig. 3 for more details.
- 71 ABULENCIA 05A use $p\bar{p}$ collisions at 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^{-1} of data. For warp parameter values of $k/\overline{M}_P = 0.1, 0.05, \text{ and } 0.01$, the bounds on the graviton mass are 710, 510 and 170 GeV respectively.

Limits on Mass of Radion

This section includes limits on mass of radion, usually in context of Randall-Sundrum models. See the "Extra Dimension Review" for discussion of model dependence.

VALUE (GeV)	DOCUMENT ID	TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •			
	72 ABBIENDI	05	OPAL $e^+e^- \rightarrow Z$ radion
$\gtrsim 35$	73 MAHANTA	00	$Z \rightarrow$ radion $\ell\bar{\ell}$
>120	74 MAHANTA	00B	$p\bar{p} \rightarrow$ radion $\rightarrow \gamma\gamma$

- 72 ABBIENDI 05 use e^+e^- collisions at $\sqrt{s} = 91 \text{ GeV}$ and $\sqrt{s} = 189\text{--}209 \text{ GeV}$ to place bounds on the radion mass in the RS model. See their Fig. 5 for bounds that depend on the radion-Higgs mixing parameter ξ and on $\Lambda_W = \Lambda_\phi/\sqrt{6}$. No parameter-independent bound is obtained.
- 73 MAHANTA 00 obtain bound on radion mass in the RS model. Bound is from Higgs boson search at LEP I.
- 74 MAHANTA 00B uses $p\bar{p}$ collisions at $\sqrt{s} = 1.8 \text{ TeV}$; production via gluon-gluon fusion. Authors assume a radion vacuum expectation value of 1 TeV.

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