Extra Dimensions and More...

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Outline

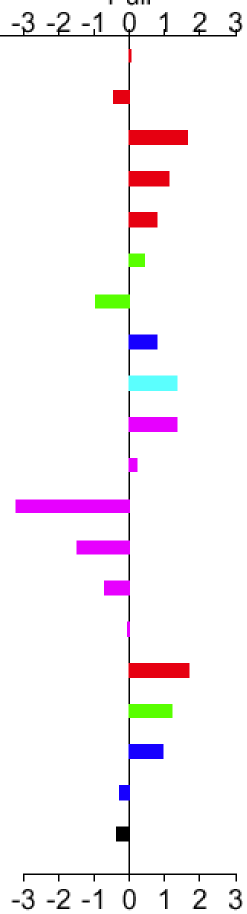
- Extra Dimensions...
  - Large Extra Dimensions: Theory and Phenomenology
  - Current Limits on Large Extra Dimensions
    - Cosmological Constraints
    - Gravity at Short Distances
    - LEP2 Searches for Large Extra Dimensions
    - HERA Searches for Large Extra Dimensions
    - Tevatron Searches for Large Extra Dimensions
  - Sensitivity of Future Collider Experiments
- ...and More
  - Infinite Extra Dimensions
  - Timelike Extra Dimensions
  - Extra Dimensions and Strings
  - Unusual Signatures for Extra Dimensions
- Conclusions

Life Within the Standard Model

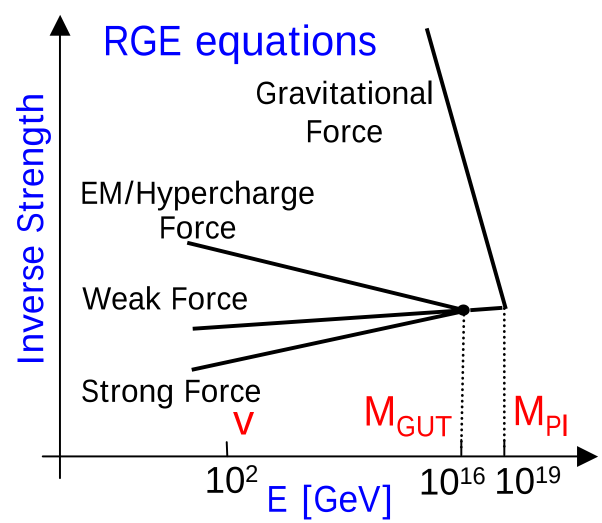
- ...is boringly precise:

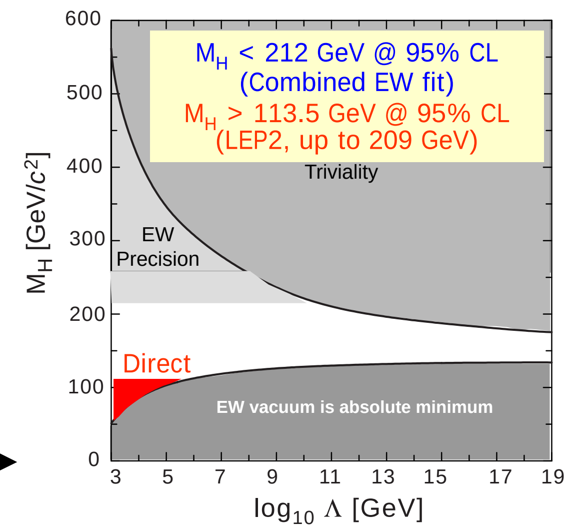
Winter 2001

	Measurement	Pull
m_Z [GeV]	91.1875 ± 0.0021	.04
Γ_Z [GeV]	2.4952 ± 0.0023	-.46
σ^0_{hadr} [nb]	41.540 ± 0.037	1.62
R_l	20.767 ± 0.025	1.09
$A^{0,l}_{fb}$	0.01714 ± 0.00095	.79
A_e	0.1498 ± 0.0048	.41
A_τ	0.1439 ± 0.0041	-.96
$\sin^2\theta^{lept}_{eff}$	0.2322 ± 0.0010	.78
m_W [GeV]	80.446 ± 0.040	1.32
R_b	0.21664 ± 0.00068	1.32
R_c	0.1729 ± 0.0032	.20
$A^{0,b}_{fb}$	0.0982 ± 0.0017	-3.20
$A^{0,c}_{fb}$	0.0689 ± 0.0035	-1.48
A_b	0.921 ± 0.020	-.68
A_c	0.667 ± 0.026	-.05
A_l	0.1513 ± 0.0021	1.68
$\sin^2\theta_W$	0.2255 ± 0.0021	1.20
m_W [GeV]	80.452 ± 0.062	.95
m_t [GeV]	174.3 ± 5.1	-.27
$\Delta\alpha^{(5)}_{had}(m_Z)$	0.02761 ± 0.00036	-.36



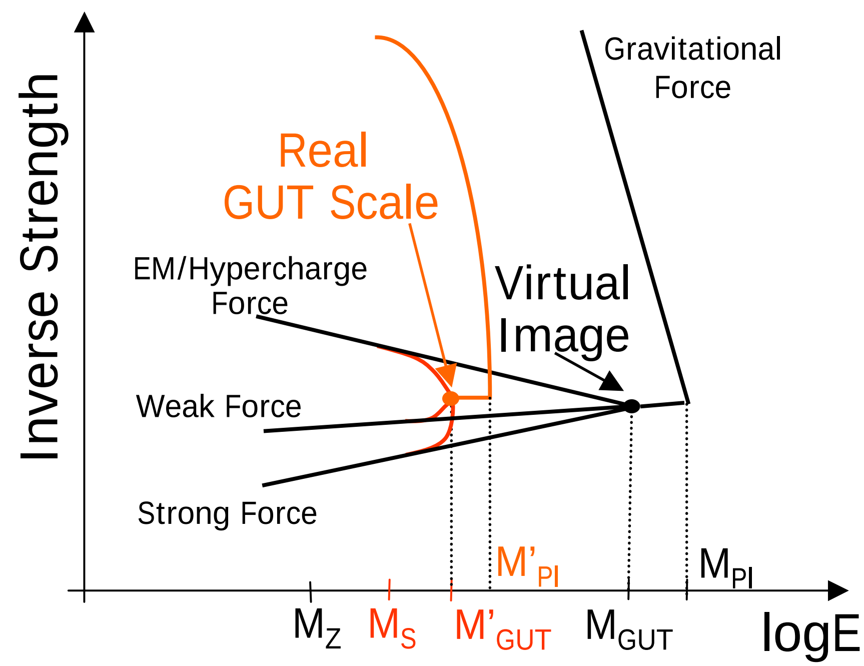
- ...but not at all boring:
  - Standard Model accommodates, but does not explain:
    - EWSB
    - CP-violation
    - Fermion masses
  - Higgs self-coupling is positive, which leads to a triviality problem that bounds m_H from above
  - The natural m_H value is Λ, where Λ is the scale of new physics; if SM is the ultimate theory up to GUT scale, an extremely precise ($\sim(v/m_{GUT})^2$) fine-tuning is required





Life Beyond the Standard Model

- We have to conclude that the SM is just an effective theory, a low-energy approximation of a more complete model that explains things postulated in the SM
- This new theory takes over at a scale Λ comparable to the mass of the Higgs boson, i.e. $\Lambda \sim 1$ TeV
- Two main candidates for such a theory are:
  - SUSY (SUGRA, GMSB, AMSB)
  - Strong Dynamics (TC, ETC, topcolor, top see-saw, ...)
- But: what if there is no other scale, and the SM model is correct up to the Planck scale?
- Arkani-Hamed, Dimopoulos, Dvali (ADD) (1998): what if fundamental Planck scale is only ~ 1 TeV?!!
- Gravity is made strong at a TeV scale due to existence of extra spatial dimensions where only gravity propagates
- SM particles are confined to a 3D "brane"
- Low energy GUT unification is also possible with extra dimensions: Dienes, Dudas, Ghergetta (1998)

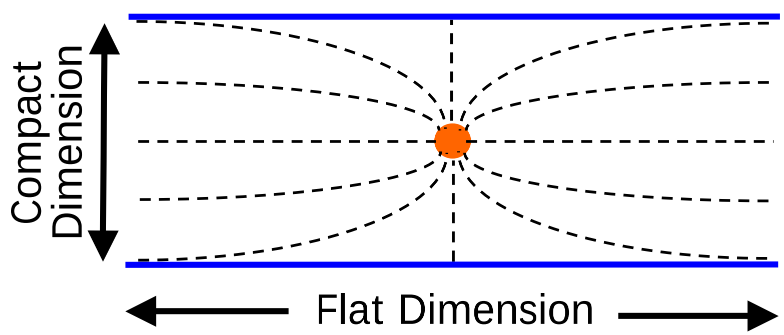


A Crazy Idea? – But it Could Work!

- What about Newton's law?

$$V(r) = \frac{1}{M_{Pl}^2}\frac{m_1 m_2}{r} \to \frac{1}{\left(M_{Pl}^{[3+n]}\right)^{n+2}}\frac{m_1 m_2}{r^{n+1}}$$

- Ruled out for flat extra dimensions, but has not been ruled out for sufficiently small compactified extra dimensions:



$$V(r) \propto \frac{1}{\left(M_{Pl}^{[3+n]}\right)^{n+2}}\frac{m_1 m_2}{R^n r} \text{ for } r >> R$$

M_S – effective Planck Scale

- But: how to make gravity strong?
- $G'_N = 1/M_S^2 \sim G_F \Rightarrow M_S \sim 1$ TeV

$$M_S^{n+2} \propto M_{Pl}^2 / R^n$$

- More precisely, from Gauss's law:

$$R = \frac{1}{2\sqrt{\pi}M_S}\left(\frac{M_{Pl}}{M_S}\right)^{2/n} \propto \begin{cases} 8\times 10^{12}\,m, & n=1 \\ 0.7\,mm, & n=2 \\ 3\,nm, & n=3 \\ 6\times 10^{-12}\,m, & n=4 \end{cases}$$

- Amazing as it is, but no one has tested Newton's law to distances less than ~ 1mm
- Therefore, large spatial extra dimensions compactified at a sub-millimeter scale are, in principle, allowed!

Shakespeare on Compact Dimensions

"…Why bastard? wherefore base?

When my dimensions are as well compact,

My mind as generous, and my shape as true,

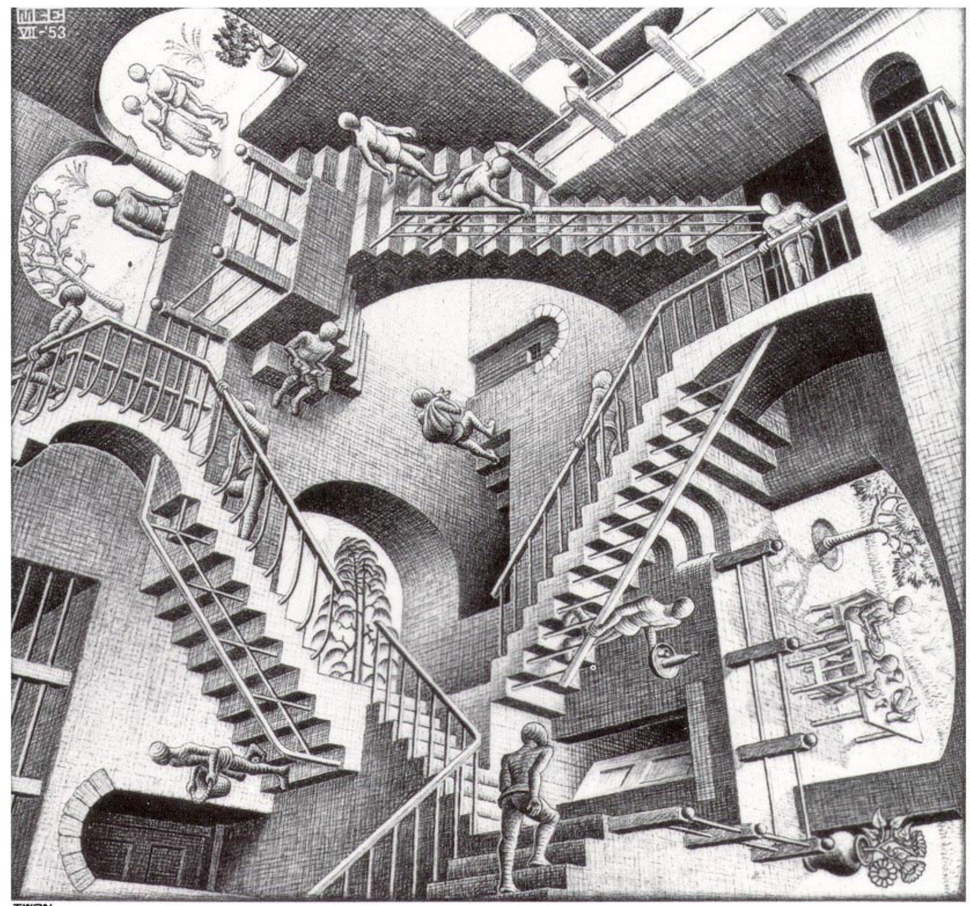
As honest madam's issue?"

(Edmund, bastard son to Gloucester)

Shakespeare, King Lear, Act 1, Scene 2

Examples of Compactified Spatial Dimensions

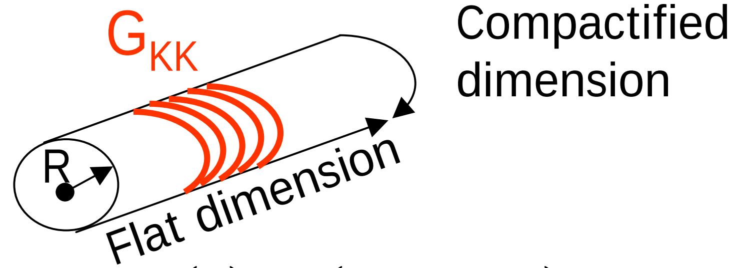
M.C.Escher, Mobius Strip II (1963)



M.C.Escher, Relativity (1953)

An Importance of Being Compact

- Compactified dimensions offer a way to increase tremendously gravitational interaction due to a large number of the available “winding” modes
- This tower of excitations is known as Kaluza-Klein modes, and such gravitons propagating in the compactified extra dimensions are called Kaluza-Klein gravitons, G_{KK}
- From the point of view of a 3+1-dimensional space time, the Kaluza-Klein graviton modes are massive, with the mass per excitation more ~ 1/R
- Since the mass per excitation mode is so small (e.g. 400 eV for n = 3, or 0.2 MeV for n = 4), a very large number of modes can be excited at high energies



$$\phi(x) = \phi(x + 2\pi k R), \; k = 0, 1, 2 \cdots$$

$$M(G_{KK}) = \sqrt{P_x^2} = 2\pi k / R$$

- Each Kaluza-Klein graviton mode couples with the gravitational strength
- For a large number of modes, accessible at high energies, gravitational coupling is therefore enhanced drastically
- Low energy precision measurements are not sensitive to the ADD effects

Using the Extra Dimension Paradigm

- EWSB from extra dimensions:
  - Hall, Kolda, PL **B459**, 213 (1999) (lifted Higgs mass constraints)
  - Antoniadis, Benakli, Quiros, NP **B583**, 35 (2000) (EWSB from strings in ED)
  - Cheng, Dobrescu, Hill, NP **B589**, 249 (2000) (strong dynamics from ED)
  - Mirabelli, Schmaltz, PR **D61**, 113011 (2000) (Yukawa couplings from split left- and right-handed fermions in ED)
  - Barbieri, Hall, Namura, hep-ph/0011311 (radiative EWSB via t-quark in the bulk)
- Flavor/CP physics from ED:
  - Arkani-Hamed, Hall, Smith, Weiner, PR **D61**, 116003 (2000) (flavor/CP breaking fields on distant branes in ED)
  - Huang, Li, Wei, Yan, hep-ph/0101002 (CP-violating phases from moduli fields in ED)
- Neutrino masses and oscillations from ED:
  - Arkani-Hamed, Dimopoulos, Dvali, March-Russell, hep-ph/9811448 (light Dirac neutrinos from right-handed neutrinos in the bulk or light Majorana neutrinos from lepton number breaking on distant branes)
  - Dienes, Dudas, Gherghetta, NP **B557**, 25 (1999) (light neutrinos from right-handed neutrinos in ED or ED see-saw mechanism)
  - Dienes, Sarcevic, PL **B500**, 133 (2001) (neutrino oscillations w/o mixing via couplings to bulk fields)
- Many other topics from Higgs to dark matter

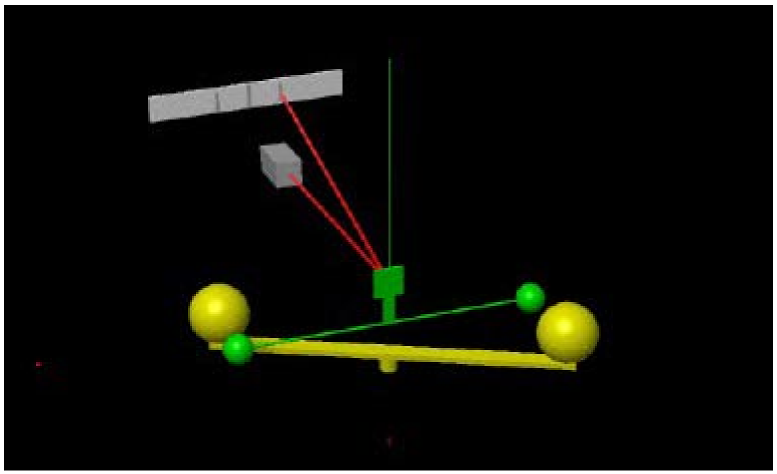
See Ina Sarcevic's talk for detail

Cosmological Limits on Large Extra Dimensions

- Supernova cooling due to the graviton emission
  - Any new cooling mechanism would decrease the thought-to-be dominant cooling by the neutrino emission
  - Tightest limits on any additional cooling sources come from the measurement of the SN1987A neutrino flux by the Kamiokande and IMB
  - Application to the ADD scenario [Cullen and Perelstein, PRL **83**, 268 (1999)]:
    - M_S > 30 TeV (n=2)
    - M_S > 4 TeV (n=3)
  - NLO calculations for G_{KK} and dilaton emission [Hanhart, Phillips, Reddy, and Savage, nucl-th/0007016]:
    - M_S > 25 TeV (n=2)
    - M_S > 1.7 TeV (n=3)
- Distortion of the cosmic diffuse gamma radiation (CDG) spectrum due to the $G_{KK} \to \gamma\gamma$ decays
  - Best CDG measurement come from the COMPTEL instrument in the 800 KeV - 30 MeV range
  - Application to the ADD scenario [Hall and Smith, PRD **60**, 085008 (1999)]:
    - M_S > 100 TeV (n=2)
    - M_S > 5 TeV (n=3)
- Caveat: there are many known (and unknown!) uncertainties, so the cosmological bounds are reliable only as an order of magnitude estimate
- Still, n=2 seems to be excluded

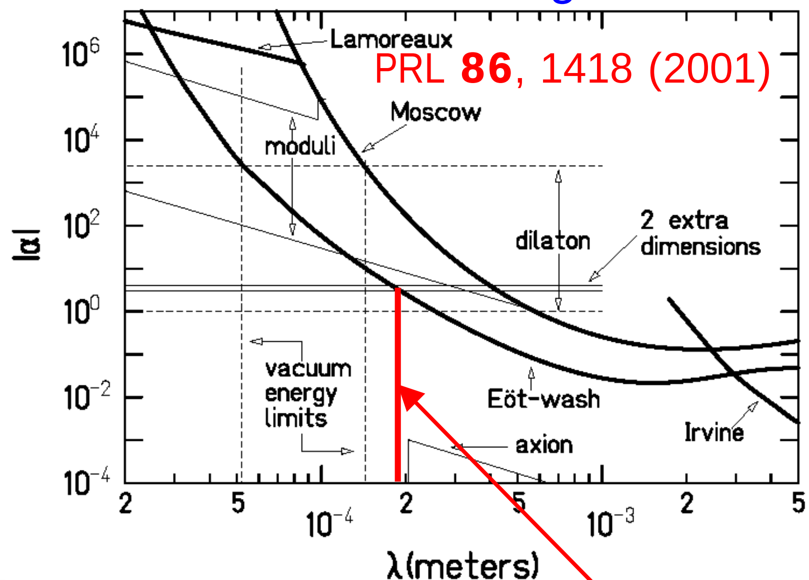
Current Limits from Gravity Experiments

- 1798: Cavendish experiment (torsion balance)

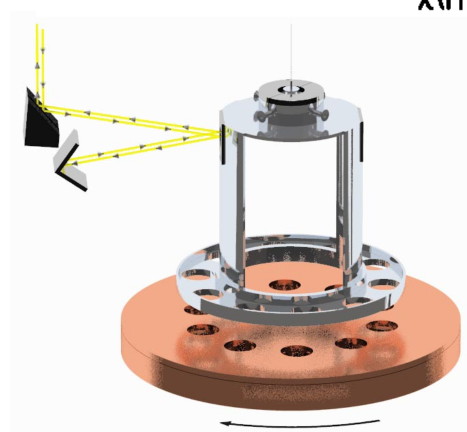


E.Adelberger et al.

PRL **86**, 1418 (2001)



- Mid-1970-ies: a number of Cavendish-type experiments searching for the "fifth forth" via deviations from Newton's law
- Sensitivity vanishes quickly for distances less than 1 mm
- Major background: Van der Waals and Casimir forces
- High-energy colliders are the only means to probe gravity at shorter (sub-micron) distances



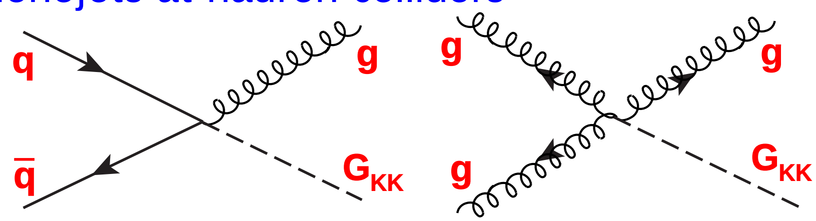
The Eöt-Wash results rule out n=2 extra dimensions for R > 0.19 mm (or M_S < 1.9 TeV)

Collider Signatures for Large Extra Dimensions

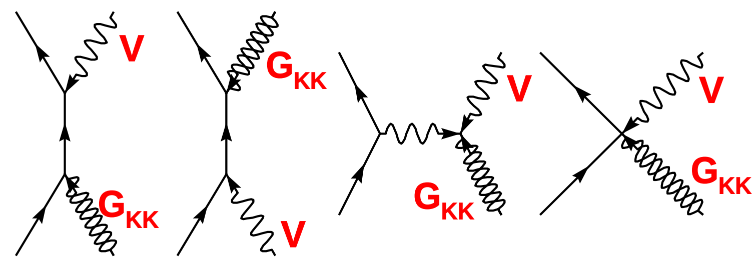
- Kaluza-Klein gravitons couple to the momentum tensor, and therefore contribute to most of the SM processes
- For Feynman rules for G_{KK} see:
  - Han, Lykken, Zhang, PR **D59**, 105006 (1999)
  - Giudice, Rattazzi, Wells, Nucl. Phys. **B544**, 3 (1999)
- Since graviton can propagate in the bulk, energy and momentum are not conserved in the G_{KK} emission from the point of view of our 3+1 space-time
- Since the spin 2 graviton in generally has a bulk momentum component, its spin from the point of view of our brane can appear as 0, 1, or 2
- Depending on whether the G_{KK} leaves our world or remains virtual, the collider signatures include single photons/Z/jets with missing E_T or fermion/vector boson pair production

Real Graviton Emission

Monojets at hadron colliders

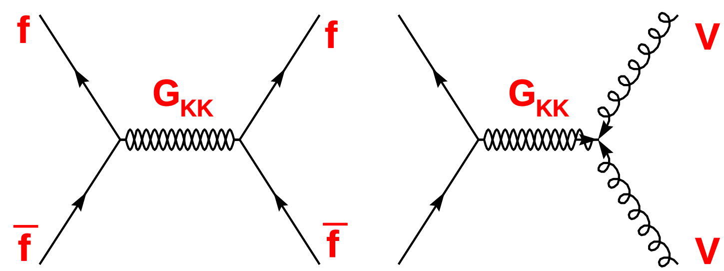


Single VB at hadron or e^+e^- colliders



Virtual Graviton Emission

Fermion or VB pairs at hadron or e^+e^- colliders

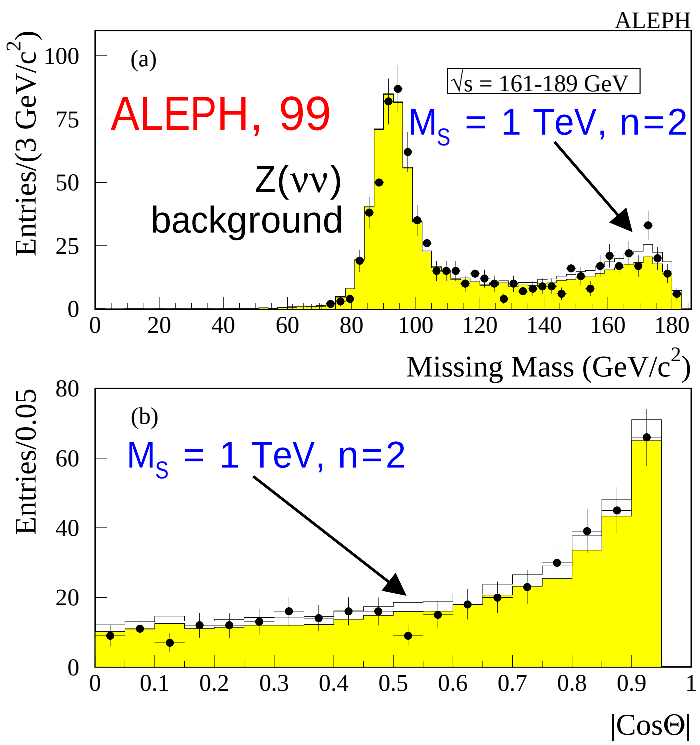


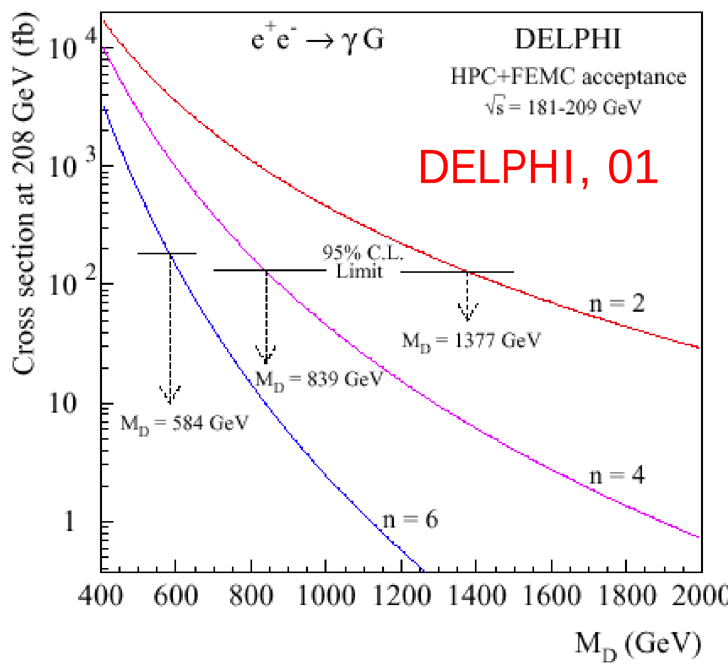
LEP2 Searches for Direct Graviton Emission

- $e^+e^- \rightarrow \gamma G_{KK}$
  - Photon + ME_T signature
  - "Recycling" of the GMSB analyses
  - ALEPH (2D-fit), DELPHI, L3 (x), OPAL (event counting)

$$\frac{d^2\sigma}{dxdz} = \frac{\alpha}{32s}\frac{\pi^{\frac{n}{2}}}{\Gamma\left(\frac{n}{2}\right)}\left(\frac{\sqrt{s}}{M_S}\right)^{n+2} f(x,z),\ x = \frac{2E_\gamma}{\sqrt{s}},\ z = \cos\theta$$

$$f(x,z) = \frac{2(1-x)^{\frac{n}{2}-1}}{x(1-z^2)}\left[(2-x)^2(1-x+x^2) - 3x^2(1-x)z^2 - x^4z^4\right]$$





Theory:

[Giudice, Rattazzi, Wells, Nucl. Phys. **B544**, 3 (1999) and corrected version: hep-ph/9811291]

Experiment:

ALEPH-CONF-2001-011

DELPHI Eur. Phys. J **C17,** 53 (2000); CONF 452 (2001)

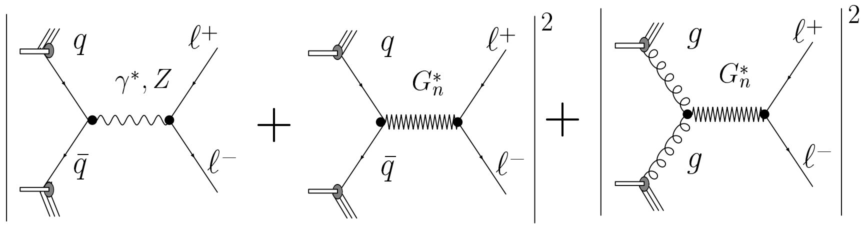
L3: Phys. Lett. **B470**, 268 (1999)

OPAL: CERN-EP-2000-050, Eur. Phys. J. **C18**, 253 (2000)

Results:
M_S > 1.3-0.6 TeV for n=2-6 (DELPHI)
ALEPH, L3, OPAL – slightly worse

Virtual Graviton Effects

- In the case of pair production via virtual graviton, gravity effects interfere with the SM (e.g., l^+l^- at hadron colliders):



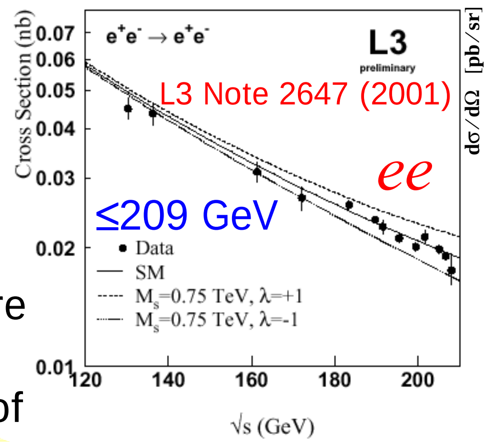
- Therefore, production cross section has three terms: SM, interference, and direct gravity effects
- The sum in KK states is divergent in the effective theory, so in order to calculate the cross sections, an explicit cut-off is required
- An expected value of the cut-off is ≈ M_S, as this is the scale at which the effective theory breaks down, and the string theory needs to be used to calculate production
- Unfortunately, a number of similar papers calculating the virtual graviton effects appeared simultaneously
- Hence, there are three major conventions on how to write the effective Lagrangian:
  - Hewett, Phys. Rev. Lett. **82**, 4765 (1999)
  - Giudice, Rattazzi, Wells, Nucl. Phys. **B544**, 3 (1999); revised version, hep-ph/9811291
  - Han, Lykken, Zhang, Phys. Rev. **D59**, 105006 (1999); revised version, hep-ph/9811350
- Fortunately (after a lot of discussions and revisions) all three conventions turned out to be completely equivalent and only the definitions of M_S are different:

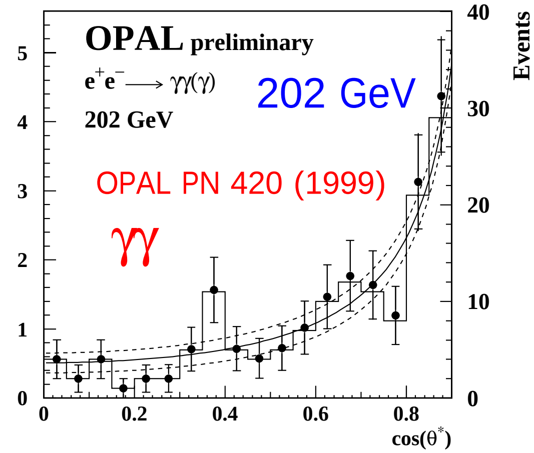
$$\frac{d^2\sigma}{d\cos\theta^* dM} = \frac{d^2\sigma_{SM}}{d\cos\theta^* dM} + \frac{a(n)}{M_S^4} f_1(\cos\theta^*, M) + \frac{b(n)}{M_S^8} f_2(\cos\theta^*, M)$$

LEP2 Search for Virtual Graviton Effects – ff/$\gamma\gamma$

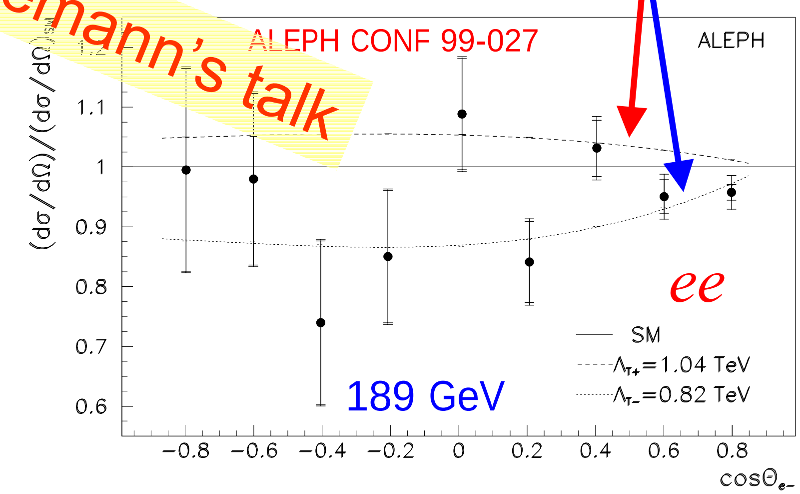
- LEP2 Collaborations looked at difermion and diboson production due to the G_{KK} exchange
- Unfortunately, different formalisms were used by different collaborations, and sometimes even within a collaboration, which makes results non-trivial to compare and combine
- Internal inconsistency could affect some of the combined limits
- Most sensitive channels are:
  - Dielectron s- and t-channel production
  - Diphoton production
- Limits on M_S(Hewett) ~ 0.8-1.2 TeV
- Bibliography:
  - ALEPH: CONF 99-027, 2000-005, 2000-030
  - DELPHI: CONF 355, 363, 427, 430 (2000); 464 (2001); PL **B491**, 67 (2000)
  - L3: PL **B464**, 135; **B470**, 281 (1999); Notes 2647, 2648 (2001)
  - OPAL: EPJ **C13,** 553, *ibid.* **C18,** 253 (2000); Notes PN 420 (1999), PN 469, 471 (2001)

See Sabine Riemann's talk





N.B. All LEP Collaborations considered both interference signs



LEP2 Lower 95% CL M_S(Hewett) Limits (TeV)

Experiment	$e^+e^- \to \gamma G$ n=2	n=3	n=4	n=5	n=6	$e^+e^- \to ZG$ n=2	n=3	n=4	n=5	n=6
ALEPH	1.28	0.97	0.78	0.66	0.57	0.35	0.22	0.17	0.14	0.12
DELPHI	1.38	**1.02**	0.84	**0.68**	0.58					
L3	1.02	0.81	0.67	0.58	0.51	0.60	0.38	0.29	**0.24**	**0.21**
OPAL	1.09	0.86	0.71	0.61	0.53					

Color coding
≤184 GeV
≤189 GeV
>200 GeV
λ=-1 λ=+1 GL

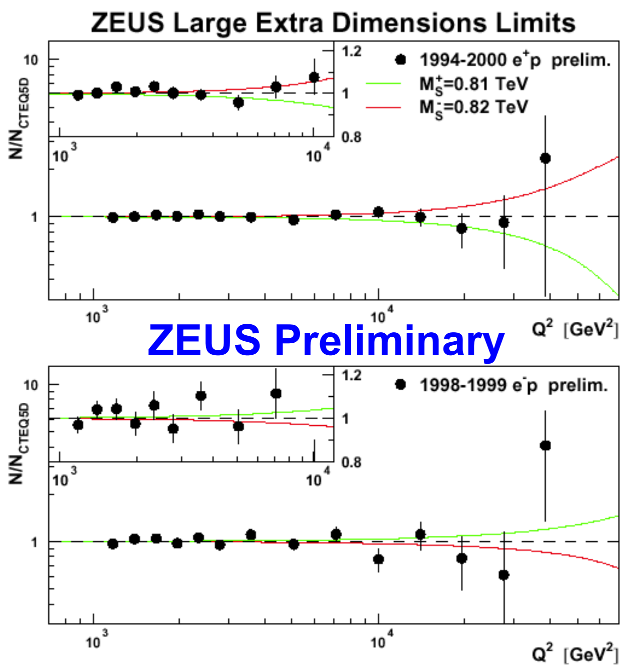
Virtual Graviton Exchange

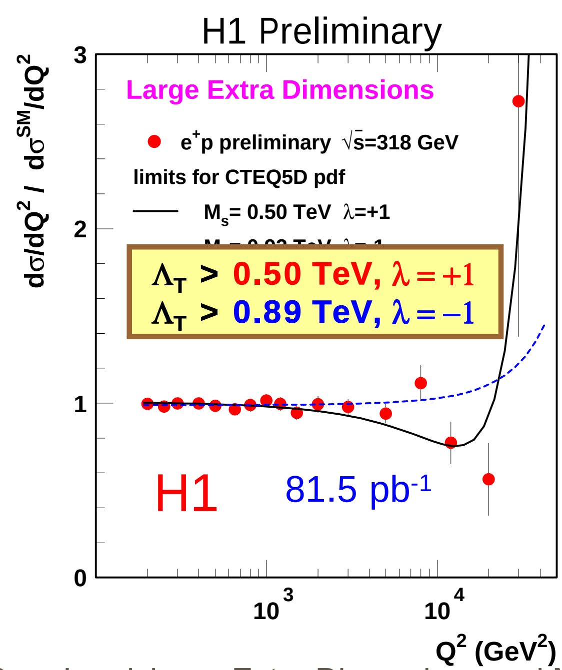
Experiment	e^+e^-	$\mu^+\mu^-$	$\tau^+\tau^-$	qq	ff	$\gamma\gamma$	WW	ZZ	**Combined**
ALEPH	1.04 0.81	0.65 0.67	0.60 0.62	0.53/0.57 0.49/0.49 (bb)	1.05 0.84	0.81 0.82			0.75/1.00 (<189)
DELPHI		0.59 0.73	0.56 0.65		0.60 0.76	0.70 0.77			0.60/0.76 (ff) (<202)
L3	0.98 1.06	0.56 0.69	0.58 0.54	0.49 0.49	0.84 1.00	0.99 0.84	0.68 0.79	1.2 **?** 1.2 **?**	1.3/1.2 (<202) **?**
OPAL	1.15 1.00	0.62 0.66			0.62 0.66	0.89 0.83		0.63 0.74	1.17/1.03 (<209)

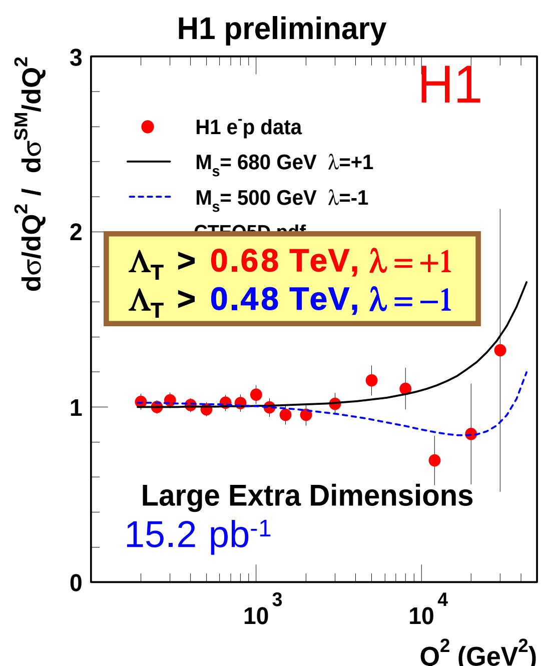
HERA Search for Virtual Graviton Effects

- $e^{\pm}p \rightarrow e^{\pm}p$
  - t-channel exchange, similar to Bhabha scattering diagrams; based on the GRW formalism (H1, set limits on Λ_T, but call it M_S) or Hewett's formalism (ZEUS)
  - Usual SM, Z/γ^* interference, and direct G_{KK} terms
  - Analysis method: fit to the $d\sigma/dQ^2$ distribution
  - Current H1 limits: Λ_T > 0.63/0.93 TeV (M_S > 0.56/0.83 TeV)
  - Current ZEUS limits: M_S > 0.81/0.82 TeV
  - Expected sensitivity up to 1 TeV with the ultimate HERA data set

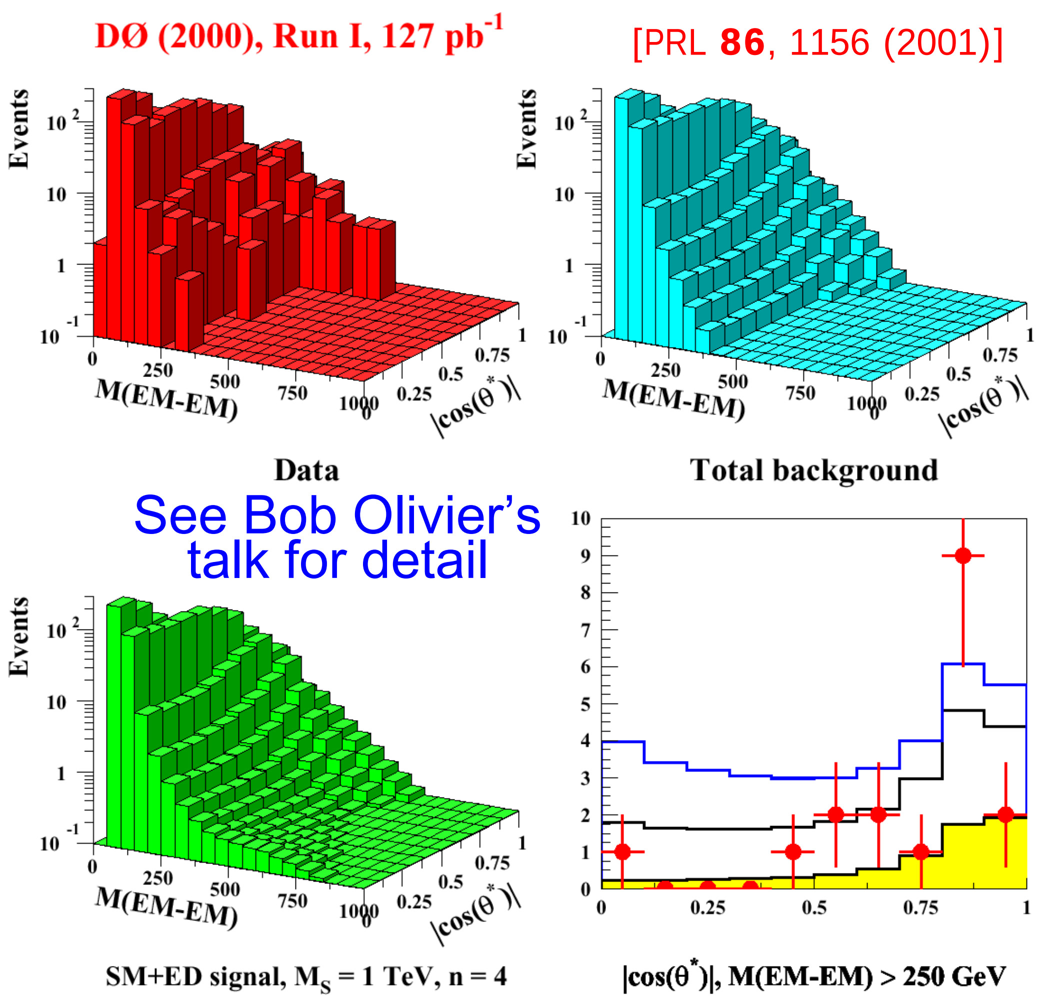
Phys. Lett. **B479**, 358 (2000) – e^+p, 35.6 pb^{-1}







Hadron Colliders: Virtual Graviton Effects



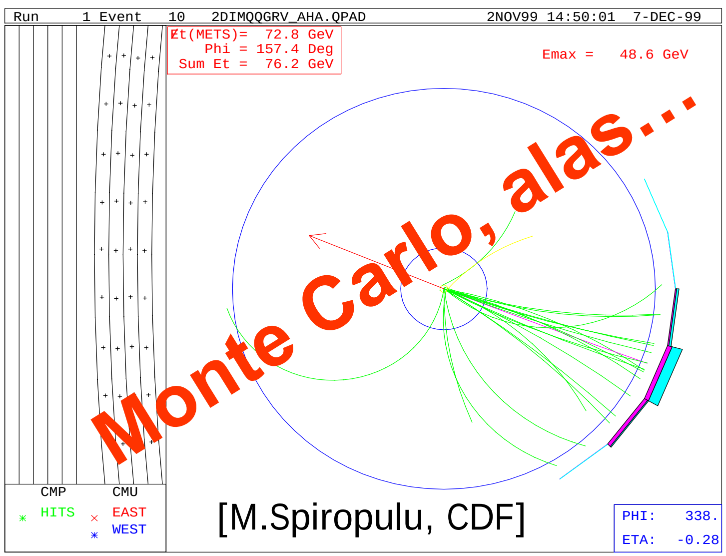
See Bob Olivier's talk for detail

- High-mass, low |cosθ| tail is a characteristic signature of LED
- 2-dimensional method resolves this tail from the high-mass, high |cosθ| tail due to collinear divergencies in the SM diphoton production
- No excess of events is seen at high masses and low scattering angles, where the signal is expected to exhibit itself
- Limits on the effective Planck scale:
  - M_S(Hewett) > 1.1/1.0 TeV ($\lambda = +1/-1$)
  - Λ_T(GRW) > 1.2 TeV
  - M_S(HLZ) > 1.0-1.4 TeV (n=2-7)
- Sensitivity in Run II and at the LHC:

	Run II, 2 fb^{-1}	Run II, 20 fb^{-1}	LHC, 100 fb^{-1}
$e^+e^- + \mu^+\mu^-$	1.3-1.9 TeV	1.7-2.7 TeV	6.5-10 TeV
$\gamma\gamma$	1.5-2.4 TeV	2.0-3.4 TeV	7.5-12 TeV
$e^+e^- + \mu^+\mu^- + \gamma\gamma$	**1.5-2.5 TeV**	**2.1-3.5 TeV**	**7.9-13 TeV**

Hadron Colliders: Real Graviton Emission

- $q\bar{q}/gg \rightarrow q/gG_{KK}$
  - jets + ME_T final state
  - Z(νν)+jets is irreducible background
  - Important instrumental backgrounds from jet mismeasurement, cosmics, etc.
  - Both CDF and DØ are pursuing this search



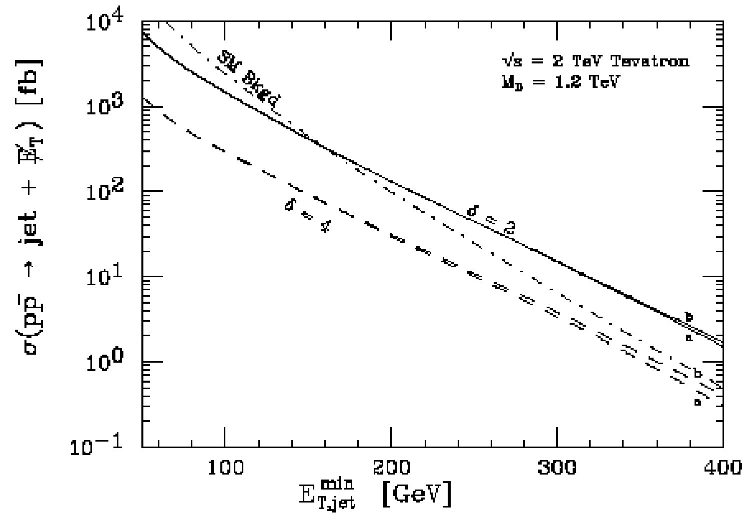
[M.Spiropulu, CDF]

Note that the sensitivity estimates are optimistic, as they ignore copious instrumental backgrounds.

Theory:

[Giudice, Rattazzi, Wells, Nucl. Phys. **B544**, 3 (1999) and corrected version, hep-ph/9811291]

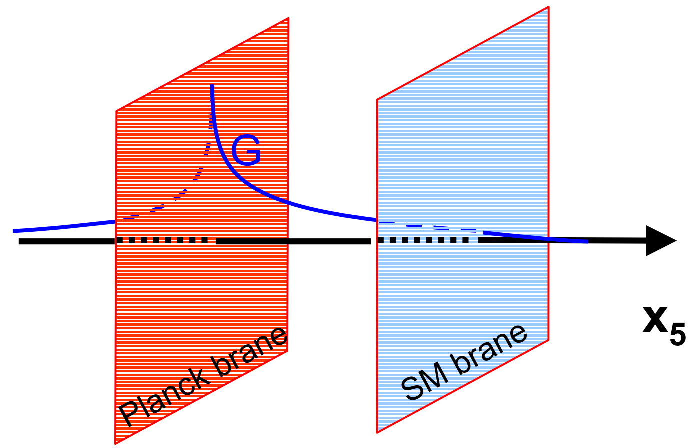
[Mirabelli, Perelstein, Peskin, PRL **82**, 2236 (1999)]

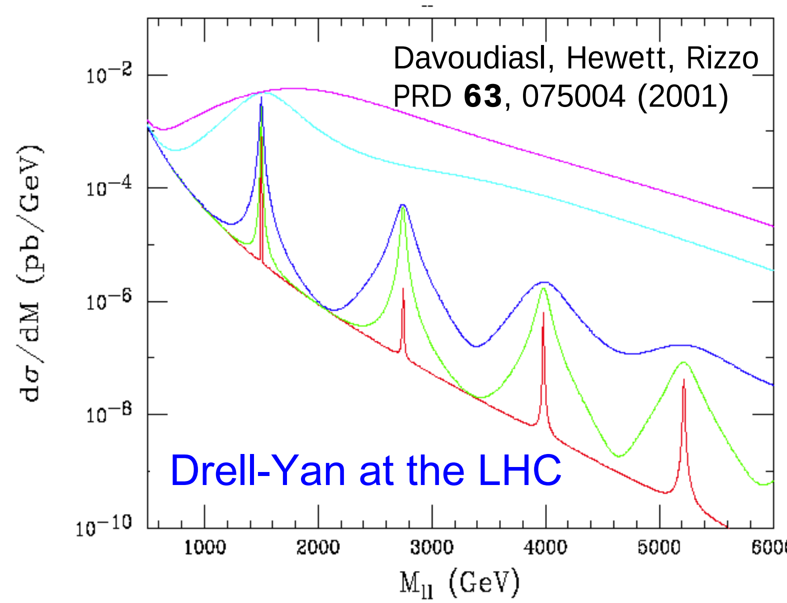


n	M_S reach, Run I	M_S reach, Run II	M_S reach, LHC 100 fb^{-1}
2	1100 GeV	1400 GeV	8.5 TeV
3	950 GeV	1150 GeV	6.8 TeV
4	850 GeV	1000 GeV	5.8 TeV
5	700 GeV	900 GeV	5.0 TeV

New Ripples in Extra Dimensions

- Randall-Sundrum (RS) scenario
  [PRL **83**, 3370 (1999); PRL **83**, 4690 (1999)]
  - Gravity can be localized near a brane due to the non-factorizable geometry of a 5-dimensional space
  - \+ brane (RS) – no low energy effects
  - +– branes (RS) – TeV Kaluza-Klein modes of gauge bosons
  - ++ branes (Lykken-Randall) – low energy collider phenomenology, similar to ADD with n=6
  - –+– branes (Gregory-Rubakov-Sibiryakov) – infinite volume extra dimensions, possible cosmological effects
  - +–+ branes (Kogan et al.) – very light KK state, low energy collider phenomenology

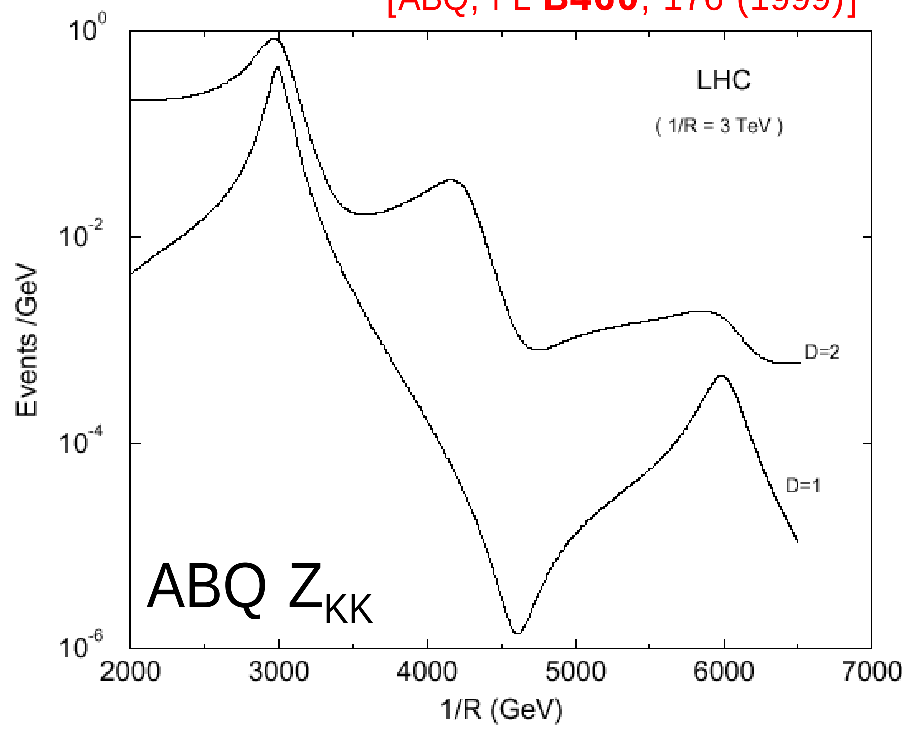




New Ripples in Extra Dimensions (cont'd)

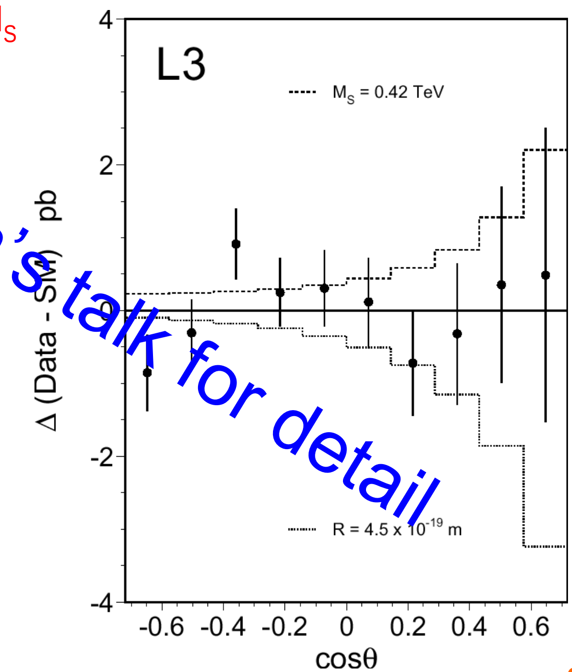
- Intermediate-size "longitudinal" extra dimensions with ~TeV^{-1} radius
  Antoniadis/Benaklis/Quiros
  [PL **B460**, 176 (1999)]
  - SM gauge bosons can propagate in these extra dimensions
  - Expect Z_{KK}, W_{KK}, g_{KK} resonances
  - Effects also will be seen in the virtual exchange of the Kaluza-Klein modes of vector bosons at lower energies
- Time-like extra dimensions
  Dvali/Gabadadze/Senjanovic
  [hep-ph/9910207]
  - tachionic G_{KK}, possible to solve hierarchy problem, cosmological effects – see Satoshi Matsuda's talk for detail

[ABQ, PL **B460**, 176 (1999)]



Stringy Models

- Recent attempts to embed the idea of large extra dimensions in string models:
  - Shiu/Shrock/Tye
    [Phys. Lett. B **458**, 274 (1999)]
    - Type I string theory on a Z_n orbifold
    - Consider resulting twisted moduli fields which sit on the fixed points of the orbifolds and their effects on gg $\rightarrow$ gg scattering
    - These fields acquire mass ~1 TeV due to SUSY breaking, and their coupling with the bulk fields is suppressed by the volume factor
    - Since they couple to gravitons, these fields can produce bulk KK modes of the latter
    - Current sensitivity to the string scale, M_S, from CDF/DØ dijet data is ~1 TeV
- Cullen/Perelstein/Peskin,
  [Phys. Rev. D **62**, 055012 (2000)]
  - Embed QED into Type IIB string theory with n=6
  - Calculate corrections to $e^+e^- \rightarrow \gamma\gamma$ and Bhabha scattering due to string Regge excitations
  - L3 has set limit M_S > 0.57 TeV @ 95% CL
  - Also calculate $e^+e^-, gg \rightarrow \gamma G$ cross section
  - Another observable effect is a resonance in $q\bar{q} \rightarrow g^*$ at M_S

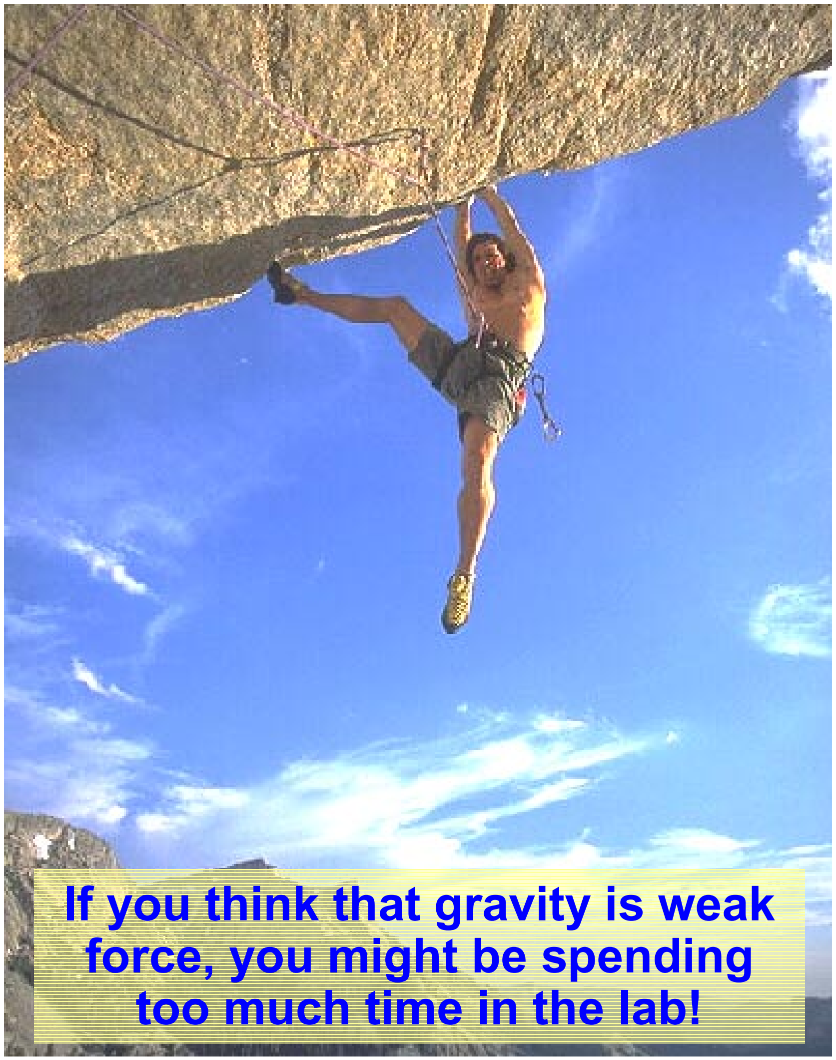


See Ian Kogan's talk for detail

Black Hole Production

- Once the c.m. energy exceeds the compactification scale, M_S, a critical energy density is achieved and the black hole is formed
- Not to worry about the Earth being sucked into such a black hole; they should be constantly formed by cosmic rays
- The temperature of such a black hole is: $T = M_{Pl}^2/M \to M_S^2/M \times O(M/M_S) \sim M_S$
- For $M_S \sim T = 1$ TeV, the black body spectrum peaks at 250 GeV, and therefore the BH technically evaporates by emitting a single energetic photon – not quite a black body!
- Moreover, the lifetime of such a black hole is only $\sim 10^{-29}$ s
- The Scwartzchild radius of such a black hole is $\sim 1/M_S$, i.e. it's $\sim$ de Broglie wavelength; it's not clear of one could even consider such an object as a bound state
- Other possibility is evaporation in the bulk via G_{KK}, in which case the signature is a deficit of high-s events
  - At a hadron collider it's easy to tweak p.d.f. to account for such a deficit
  - At a lepton collider it's hard to establish that the beams have not missed each other in one of the better established spatial dimensions
  - Unlikely due to the s-wave dominance Emparan, Horowitz, Mayer [PRL **85**, 499 (2000)]
- Interesting possibility for a black hole is to have a color 'hair' that holds it to our brane; if the color quantum number is conserved, the black hole could be metastable and live seconds or even days before it decays in a large number of hadrons
  - Look for events not in time with the accelerator clock with such a distinct signature (Dvali, GL, Matchev)

Conclusions

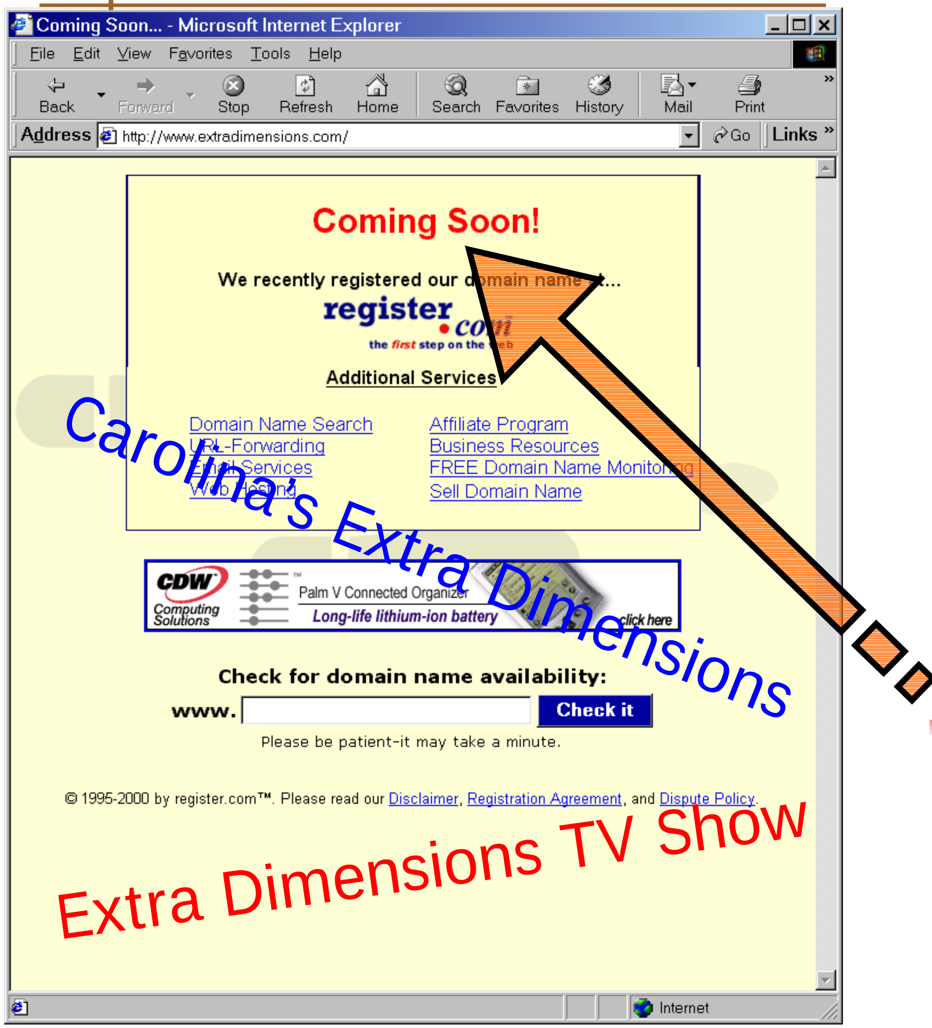


- "To be able to practice five things everywhere under heaven constitutes perfect virtue... [They are] gravity, generosity of soul, sincerity, earnestness, and kindness."

  Confucius, *The Confucian Analects*

Conclusions: Second Try

http://www.extradimensions.com



On 2/15/00 patent 6,025,810 was issued to David Strom for a "hyper-light-speed antenna." The concept is deceptively simple: "The present invention takes a transmission of energy, and instead of sending it through normal time and space, it pokes a small hole into another dimension, thus sending the energy through a place which allows transmission of energy to exceed the speed of light." According to the patent, this portal "allows energy from another dimension to accelerate plant growth." - from the AIP's "What's New", 3/17/00

- Stay tuned – next generation of collider experiments has a good chance to solve the mystery of large extra dimensions (and more)!