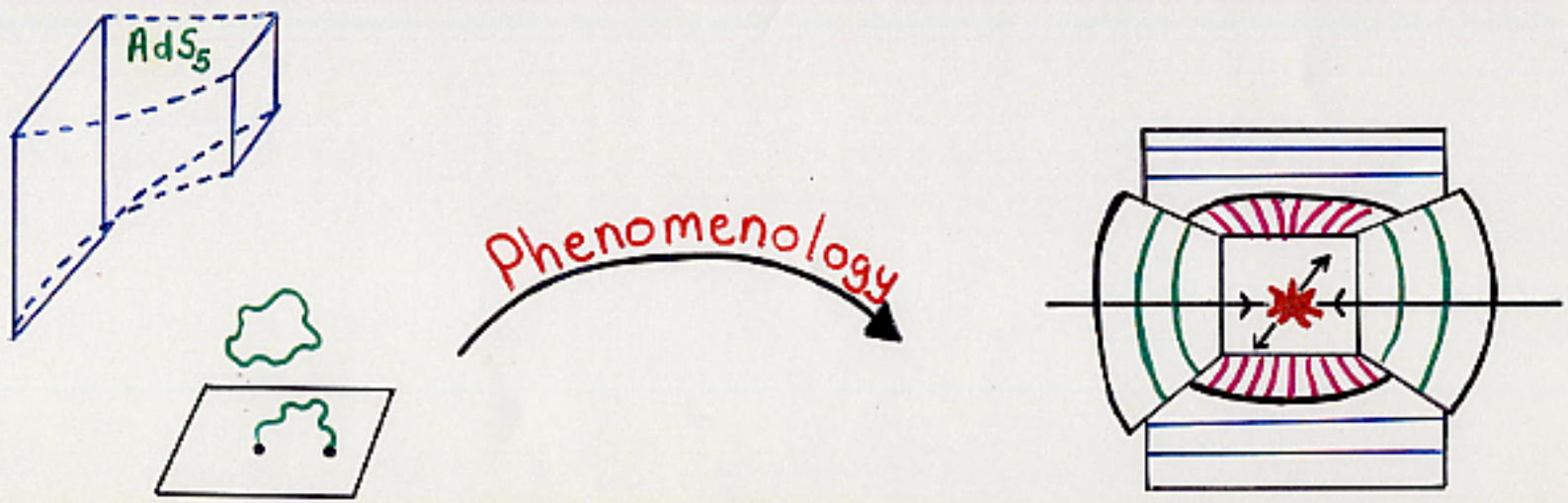
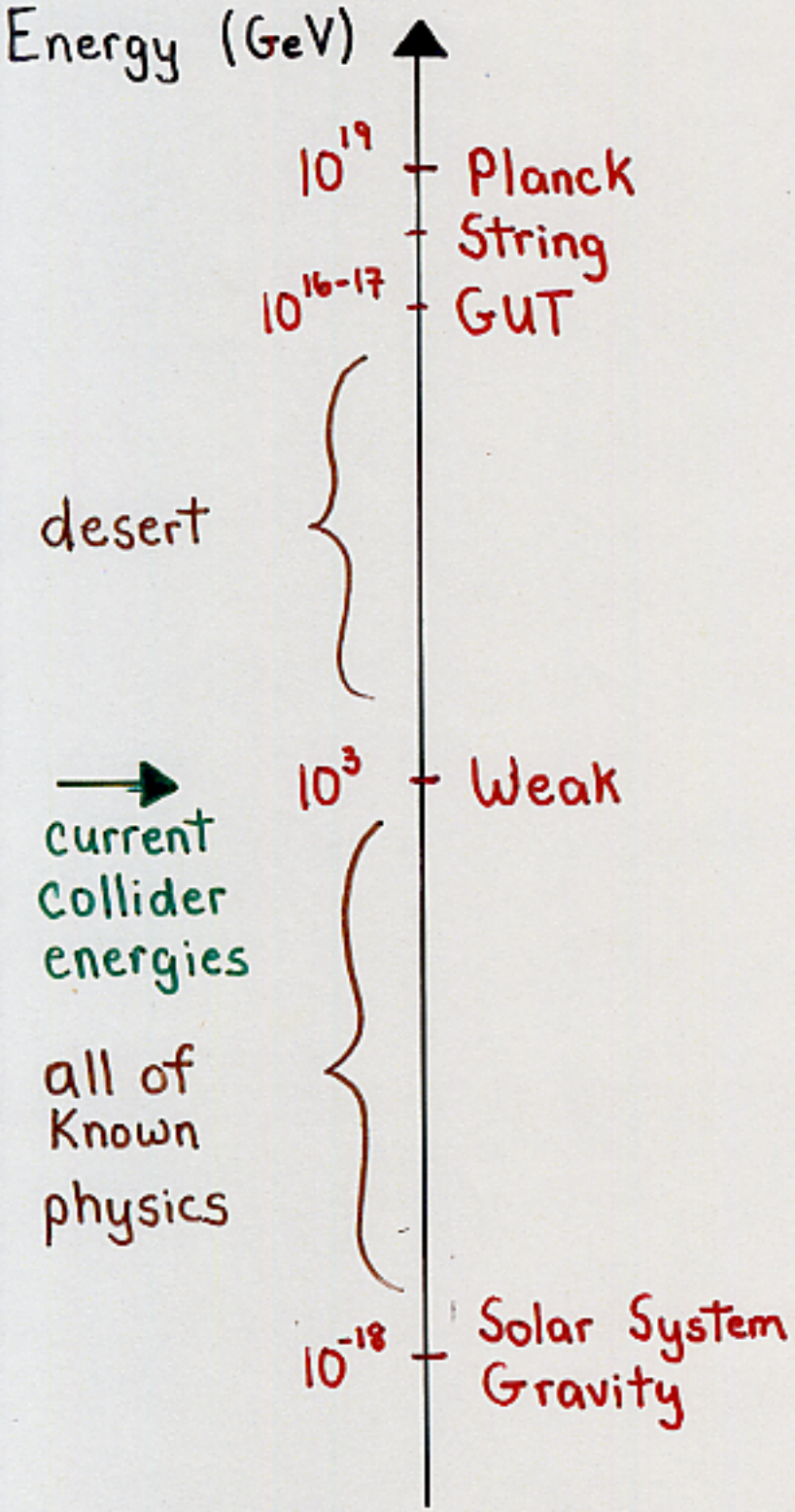
Probes of Spacetime Geometries

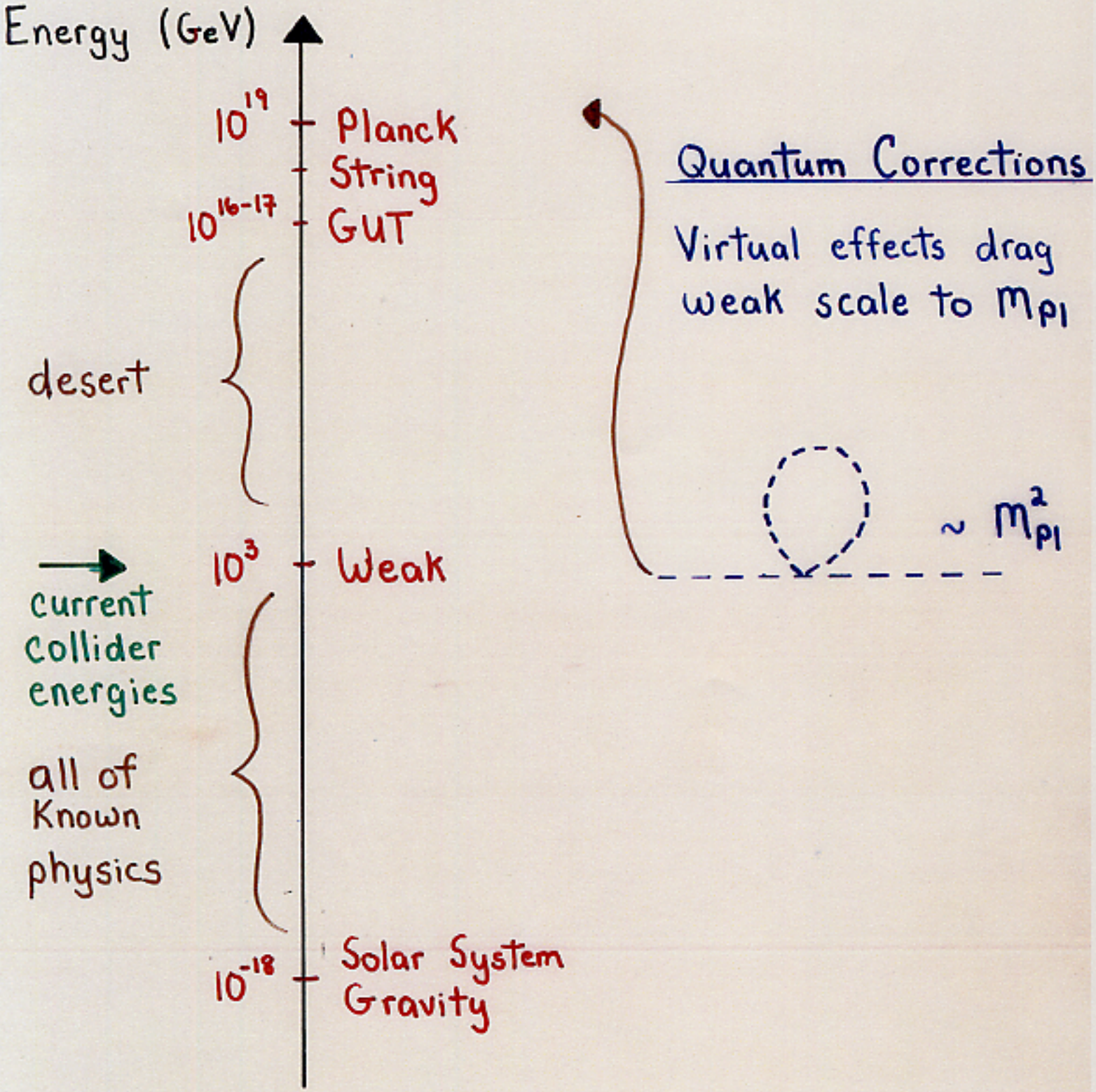


$$X_\mu X_\nu - X_\nu X_\mu \neq 0$$

The Hierarchy

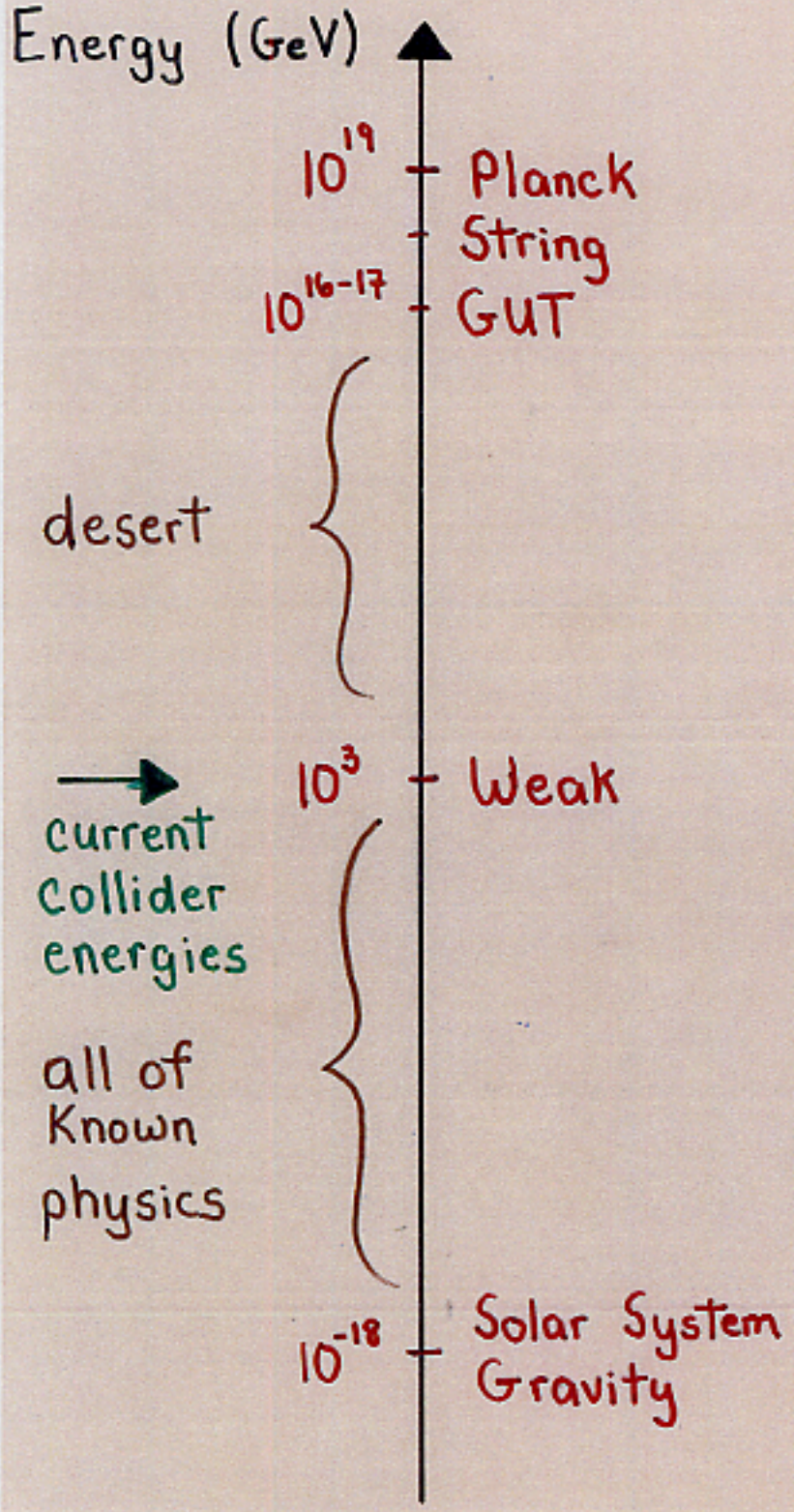


The Hierarchy Problem



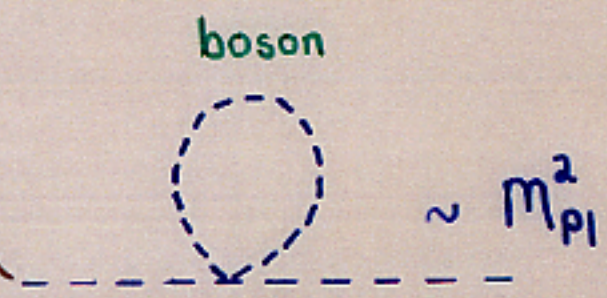
The Hierarchy ~~Problem~~ Solution

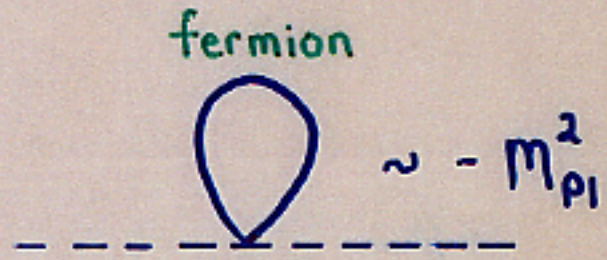
Supersymmetry!



Quantum Corrections

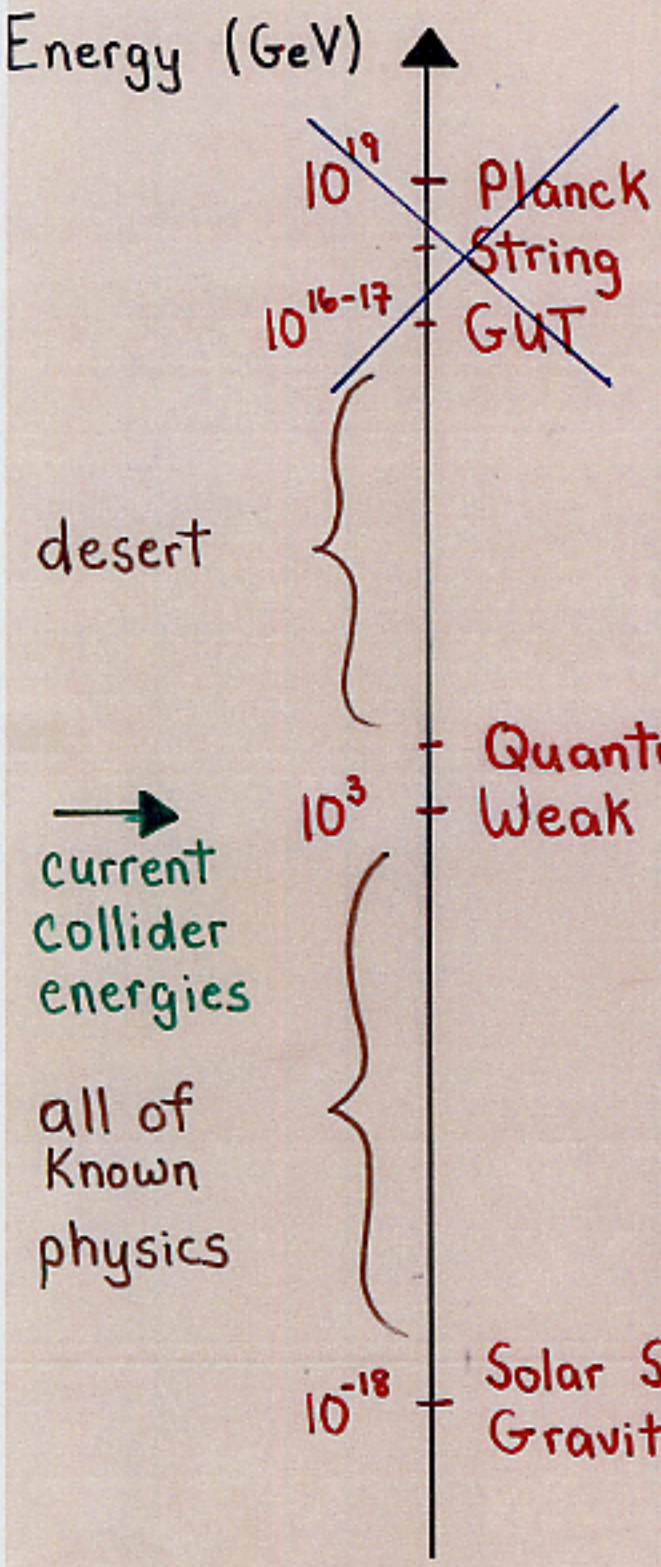
Virtual effects drag weak scale to m_{Pl}





Large virtual effects cancel order by order in perturbation theory

The Hierarchy ~~Problem~~ Solution



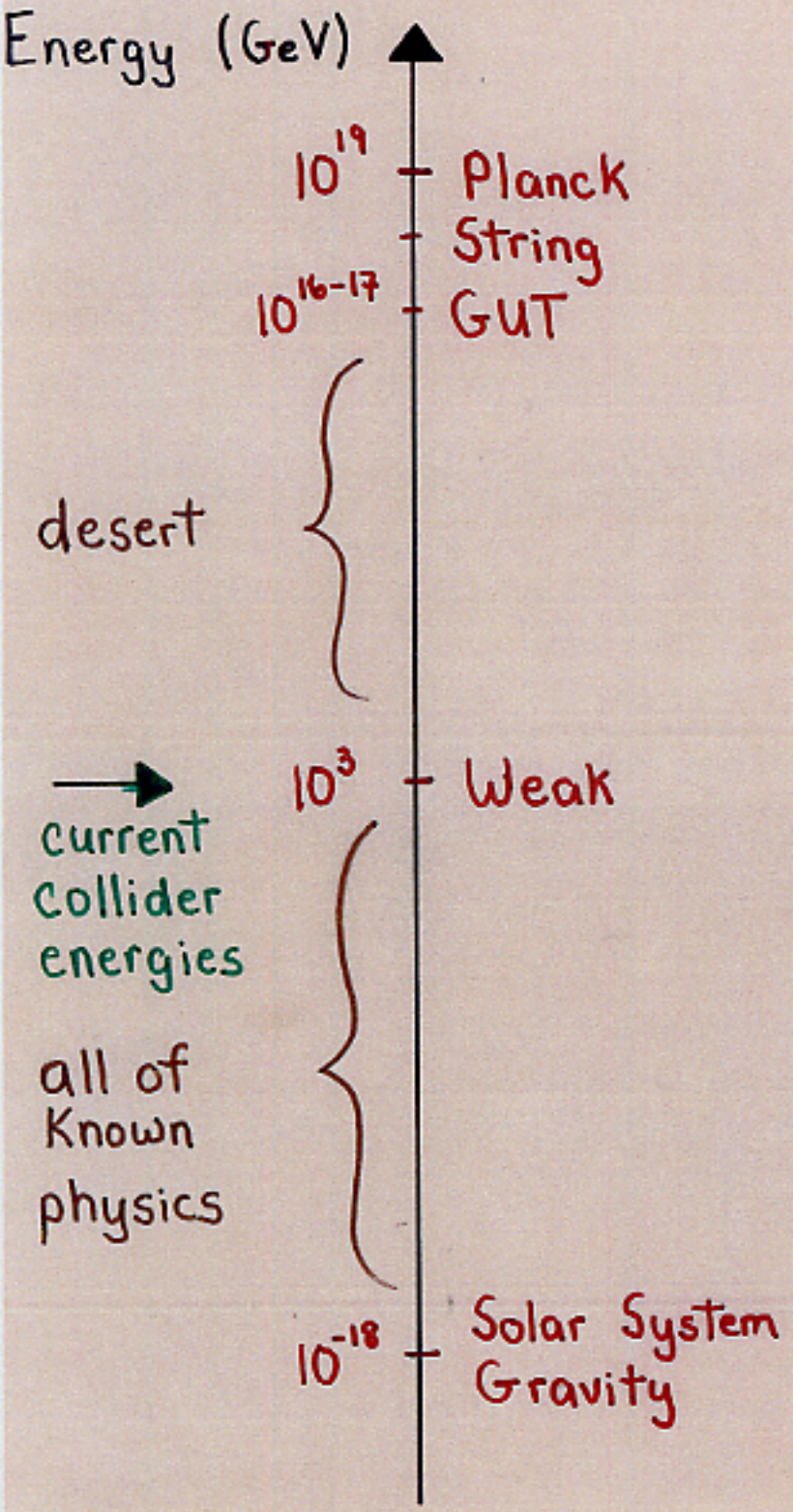
Extra Dimensions!

Model I:
Large Extra Dimension

= Fundamental scale in $4+\delta$ dimensions

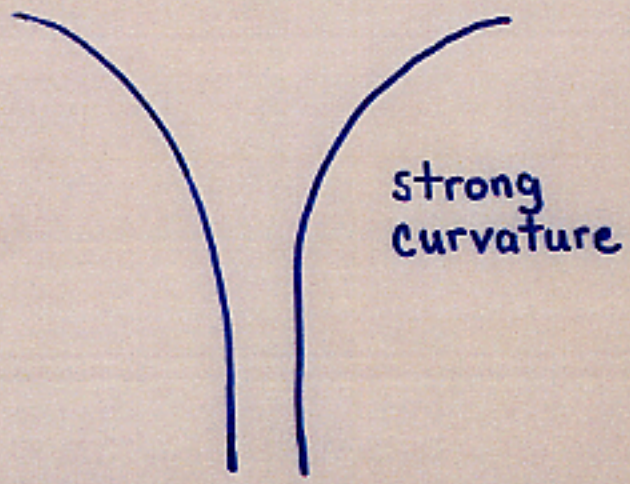
$$m_{Pl}^2 = V_\delta \, m_D^{2+\delta}$$

The Hierarchy ~~Problem~~ Solution



Extra Dimensions!

Model II:
Warped Extra Dims



$$\Lambda_{WK} = M_{Pl}\, e^{-Kr\pi}$$

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L'effet placebo, ça marche >68

L'accélérateur à piétons >78

Sur la piste des mondes parallèles

Les physiciens explorent les dimensions cachées de l'Univers

>42

T 02578 - 1018 - F: 3,50 €

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ALERTE AUX MICROBES

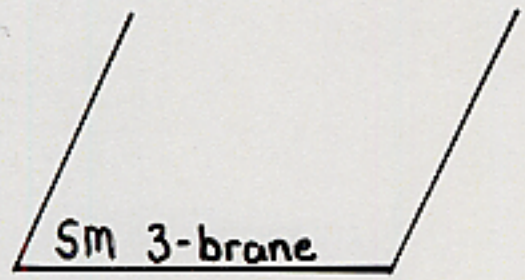
Les maladies infectieuses reviennent

Physics of Branes: Spatial Dimensional Subspace

Our 3+1-dim subspace = 3-brane

Embedded in $D = 3 + 6 + 1$ space = bulk

Bulk

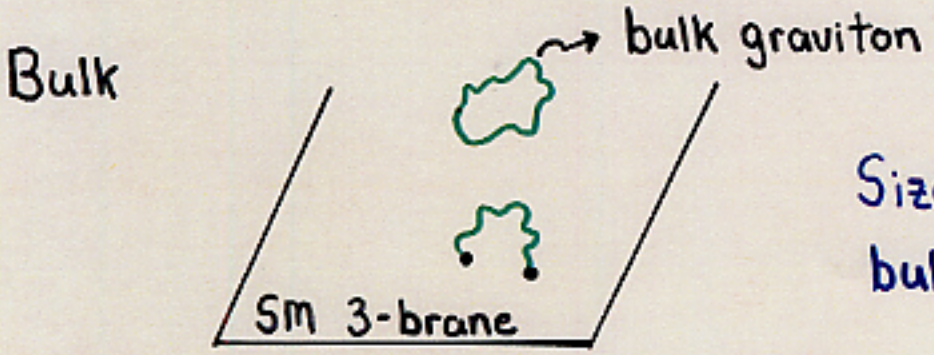


Size + geometry of bulk can vary

Physics of Branes: Spatial Dimensional Subspace

Our 3+1-dim subspace = 3-brane

Embedded in $D = 3+6+1$ space = bulk

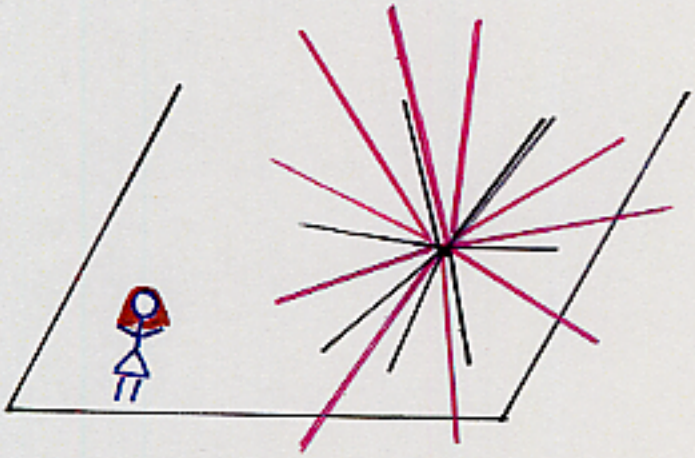


Size + geometry of bulk can vary

String Theory provides mechanism to 'localize' fields on brane

- Gauge theories live on brane
- Gauge particles live at end of strings
- Closed strings are neutral
  - ⇒ can pop off brane = bulk gravitons

Compactification



Standard Model forces stuck on 3-brane

Gravitational fields spread out over all spacetime

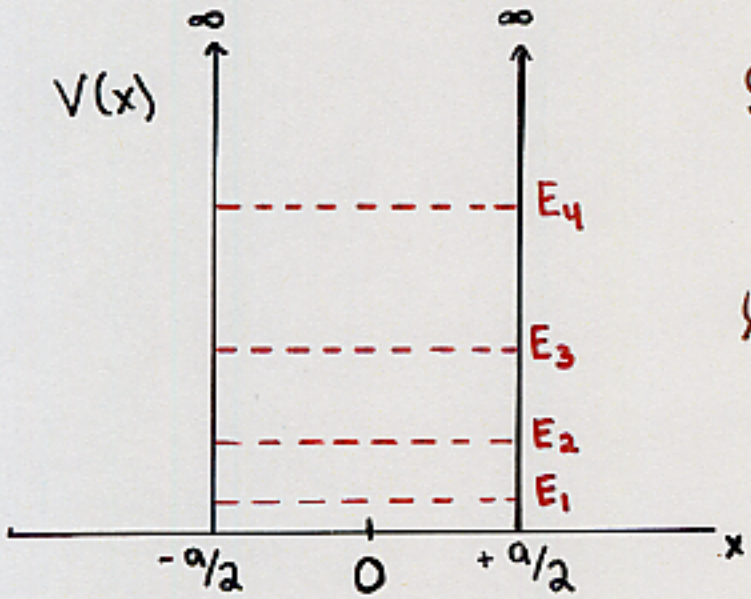
Are gravitational fields diluting too quickly?

⇒ Extra dimensions must be compactified!

$F_{Gr} \sim \frac{1}{r^2}$ recovered on 3-brane

Particle in a Box

Infinite Square-Well potential



Sol'n to Schroedinger Eqn

$$\psi_n(x) = \begin{cases} A_n \cos K_n x, & n = 1, 3, 5, \\ B_n \sin K_n x, & n = 2, 4, 6 \end{cases}$$

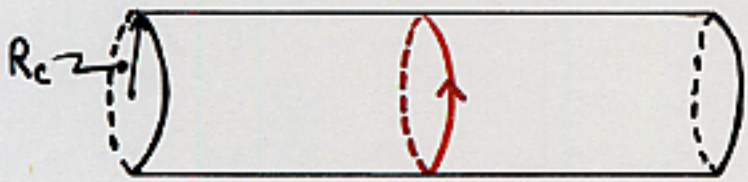
where $K_n = n\pi/a$

Momentum of the particle is <u>Quantized!</u>

$E_n \sim n^2/a^2$ (non-relativistic)

Compactification: Bulk Fields

Bulk fields expand into Kaluza-Klein towers



δ-d Kinetic motion is quantized!

$$p_\delta^2 = \frac{\vec{n}\cdot\vec{n}}{R_c^2}$$

mode numbers $\vec{n} = (n_1, n_2, \ldots n_\delta)$
label KK excitation state

Appears as tower of massive particles in 4-d

$$\Phi(x_\mu, y_i) = \sum_{\vec{n}=0}^{\infty} \phi^{(\vec{n})}(x_\mu)\, e^{i\vec{n}\cdot\vec{y}/R_c} \cdot \frac{1}{\sqrt{V_\delta}}$$

for periodic $y_i \to y_i + 2\pi R_c$ Flat space

with mass, $m_{\vec{n}}^2 = \dfrac{\vec{n}\cdot\vec{n}}{R_c^2}$

KK tower of evenly spaced states
each with identical spin + quantum numbers

Comments:

- Experimental observation of KK states:

  Signals existence of extra dimensions

- Properties of KK states:

  Determined by geometry of extra dimensions
  Measured by experiment

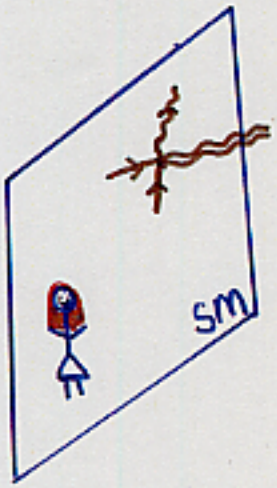
- Note: Traditional String theory

$$m_n = n/R_c \sim m_{string} \sim m_{Pl}$$

Large Extra Dimensions

Arkani-Hamed,
Dimopoulos, Dvali
SLAC-PUB-7801

Motivation: Solve the hierarchy problem by removing it!



SM fields confined to 3-brane

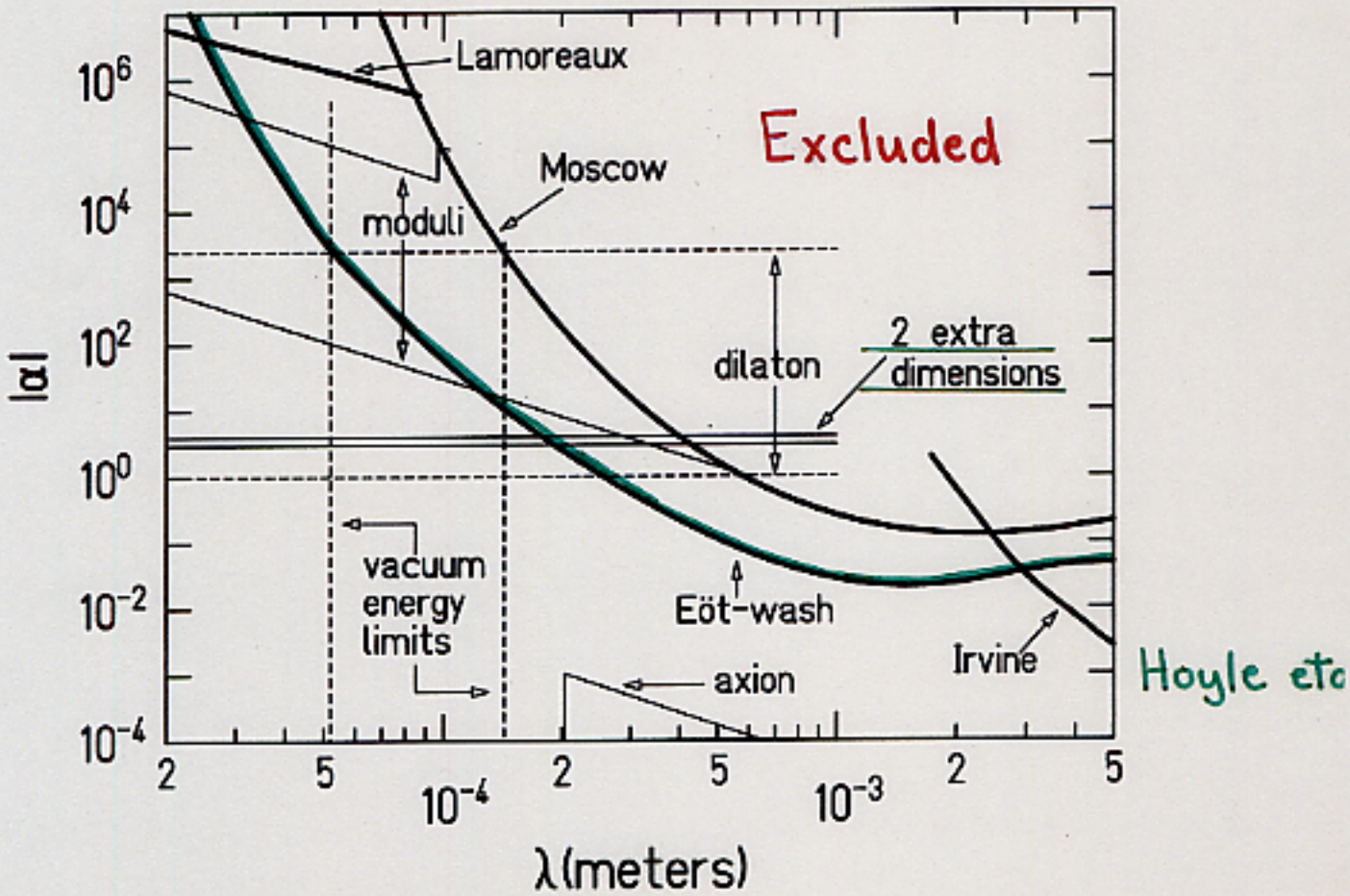
Gravity becomes strong in the bulk

Gauss' Law: $M_{Pl}^2 = V_\delta M_D^{2+\delta}$; $V_\delta \sim R_c^\delta$

M_D = Fundamental scale in the bulk
$\simeq$ TeV

$\delta = 1$	$R_c \sim 10^{11}$ m	Excluded!
2	0.4 mm	$m_c = 1/R_c \sim 5 \times 10^{-4}$ eV
4	10^{-5} mm	20 KeV
6	30 fm	7 MeV

Constraints from Cavendish-type experiments



$$V_{Gravity} \sim \frac{m_1 m_2}{M_D^{2+\delta}} \frac{1}{r^{\delta+1}} \qquad (r < R_c)$$

$$\sim \frac{m_1 m_2}{M_{Pl}^2} \frac{1}{r} \qquad (r > R_c)$$

For $\delta = 2$: $\lambda \leq 220\,\mu$ $[M_D \geq 1.6$ TeV$]$

Constraints from Astrophysics/Cosmology

(*) Supernova Cooling

Cullen + Perelstein
Barger et al
Savage et al

$NN \to NN + G_n$ can cool supernova too rapidly

(*) Cosmic Diffuse γ Rays

$NN \to NN + G_n$
$\hookrightarrow \gamma\gamma$

Hannestad + Raffel

$\nu\bar{\nu} \to G_n \to \gamma\gamma$

Hall + Smith

(*) Matter Dominated Early Universe

Fairbairn

too many KK states

(*) Neutron Star Heat Excess

Hannestad + Raffel

$NN \to NN + G_n$
$\hookrightarrow$ becomes trapped in neutron star halo + heats it

Summary of Constraints on M_D (TeV)

	$\delta =$ 2	3	4	5
Supernova Cooling	30	2.5		
Cosmic Diffuse γ-Rays				
SNe	80	7		
$\nu\bar{\nu}$ Annihilation	110	5		
Reheating	170	20	5	1.5
Neutron Star	450	30		
Overclosure of Universe	$6.5/\sqrt{h}$			
Matter Dominated Universe	85	7	1.5	
Neutron Star Heat Excess	1700	60	4	1.0

Low M_D disfavored for $\delta \leq 3$

Bulk Metric: Linearized Quantum Gravity

$$G_{AB} = \eta_{AB} + \frac{h_{AB}(x^\mu, y^a)}{m_D^{\delta/2+1}}$$

$A = 0, \ldots, 3+\delta$
$\mu = 0,1,2,3$
$a = 4, \ldots, 3+\delta$

Interactions:

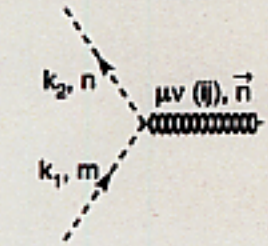
$$S_{int} = \frac{-1}{m_D^{\delta/2+1}} \int d^4x\, d^\delta y\; h_{AB}(x^\mu, y^a)\, T_{AB}(x^\mu, y^a)$$

- Perform Graviton KK reduction
- Expand h_{AB} into KK tower
- SM on 3-brane
  - $\Rightarrow$ Set $T_{AB} = \eta^\mu{}_A\, \eta^\nu{}_B\, T_{\mu\nu}\, \delta(y^a)$
- Pick a gauge
- Integrate over $d^\delta y$

$\Rightarrow$ Interactions of Graviton KK states with SM fields on 3-brane

Feynman Rules - Graviton KK tower

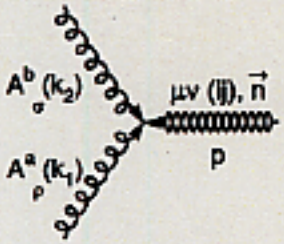
Massless 0-mode + KK states have identical coupling to matter



$\bar{h}^{\vec{n}}_{\mu\nu}\,\Phi\Phi$: $\quad -i\,\kappa/2\,\delta_{mn}\,(m^2_\Phi\,\eta_{\mu\nu} + C_{\mu\nu,\rho\sigma}\,k_1^\rho\,k_2^\sigma)$

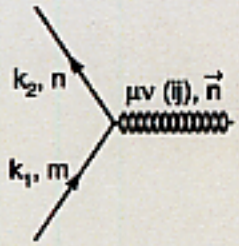
$\bar{\phi}^{\vec{n}}_{ij}\,\Phi\Phi$: $\quad i\,\omega\,\kappa\,\delta_{ij}\,\delta_{mn}\,(k_1 \cdot k_2 - 2\,m^2_\Phi)$

$\kappa \sim \frac{1}{M_{Pl}}$



$\bar{h}^{\vec{n}}_{\mu\nu}\,AA$: $\quad -i\,\kappa/2\,\delta^{ab}\,((m^2_A + k_1 \cdot k_2)\,C_{\mu\nu,\rho\sigma} + D_{\mu\nu,\rho\sigma}(k_1, k_2) + \xi^{-1}\,E_{\mu\nu,\rho\sigma}(k_1, k_2))$

$\bar{\phi}^{\vec{n}}_{ij}\,AA$: $\quad i\,\omega\,\kappa\,\delta_{ij}\,\delta^{ab}\,(\eta_{\rho\sigma}\,m^2_A + \xi^{-1}\,(k_{1\rho}\,p_\sigma + k_{2\sigma}\,p_\rho))$



$\bar{h}^{\vec{n}}_{\mu\nu}\,\psi\psi$: $\quad -i\,\kappa/8\,\delta_{mn}\,(\gamma_\mu\,(k_{1\nu} + k_{2\nu}) + \gamma_\nu\,(k_{1\mu} + k_{2\mu}) - 2\,\eta_{\mu\nu}\,(\not{k}_1 + \not{k}_2 - 2\,m_\psi))$

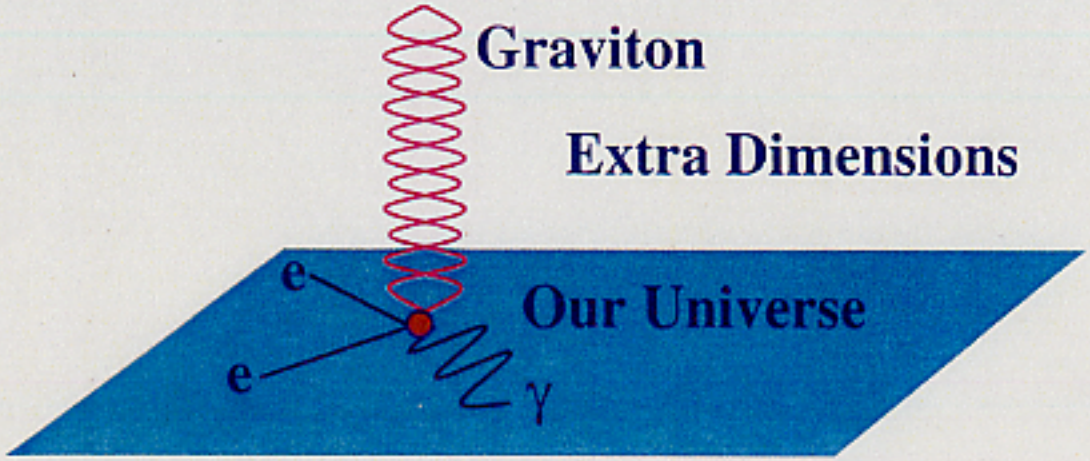
$\bar{\phi}^{\vec{n}}_{ij}\,\psi\psi$: $\quad i\,\omega\,\kappa\,\delta_{ij}\,\delta_{mn}\,(3/4\,\not{k}_1 + 3/4\,\not{k}_2 - 2\,m_\psi)$

Figure 4: Three-point vertex Feynman rules. The KK states are plot in double-sinusoidal curves. The symbols $C_{\mu\nu,\rho\sigma}$, $D_{\mu\nu,\rho\sigma}(k_1, k_2)$ and $E_{\mu\nu,\rho\sigma}(k_1, k_2)$ are defined in Eqs. (A.10), (A.11) and (A.12) respectively. m_Φ, m_A and m_ψ are masses of the scalar, vector and fermion. $\omega = \sqrt{\frac{2}{3(n+2)}}$, $\kappa = \sqrt{16\pi G_N}$ and ξ is the gauge-fixing parameter.

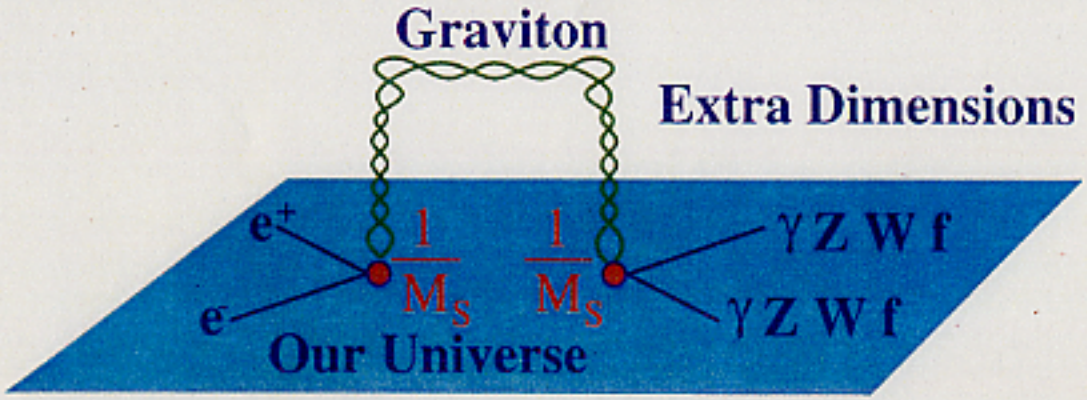
Han, Lykken, Zhang
Giudice, Rattazzi, Wells

Search Strategy

Direct Search: 1 photon or 1 Z boson + missing energy.



Indirect Search: Look for deviations from $(d\sigma/d\Omega)_{SM}$.



Graviton Tower Exchange $\quad XX \to G_n \to YY$

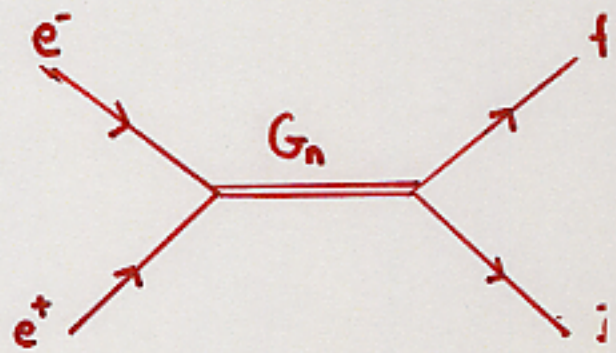
Search for 1) Deviations in SM processes

2) New processes! $(gg \to \ell^+\ell^-)$

Angular distributions reveal spin-2 exchange

Consider $e^+e^- \to f\bar{f}$

$$\mathcal{M} = \frac{1}{16\, m_{Pl}^2} \sum_{\vec{n}} \frac{T^e_{\mu\nu}\, P^{\mu\nu\lambda\sigma}\, T^f_{\lambda\sigma}}{s - m_n^2 + i\epsilon}$$



G_n are densely packed!

$(M_D R_c)^\delta$ states are exchanged! $\quad (\sim 10^{32}$ for $\delta = 2)$

$$\Rightarrow \sum_{\vec{n}} \to \int dm^2\, \rho(m^2)$$

$$\frac{1}{m_{Pl}^2} \sum_{\vec{n}} \frac{1}{s - m_n^2} \to \frac{1}{M_D^4}$$

JLH, PRL 99

Giudice, Rattazzi, L

Poor theoretical control!

$\int$ KK propagators is divergent

$\Rightarrow$ Sensitivity to <u>unknown</u> ultraviolet physics

Approaches:

- 'Naive' cut-off — JLH; Giudice etal; Han etal
- Brane fluctuations — Bando etal
- Weakly Coupled string theory — Dudas, Mourad; Accomando etal; Cullen etal

Cut-off Approach

Contact interaction limit for G_n exchange

Examine leading dimension-8 operators
& constrain the cut-off m_H

$$\mathcal{M} = \frac{\lambda}{m_H^4} \left\{ \begin{array}{l} \bar{f}\gamma^\mu f \bar{\ell}\gamma_\mu \ell (p_{\bar{f}} - p_f)\cdot(p_{\bar{\ell}} - p_\ell) \\ + \bar{f}\gamma^\mu f \bar{\ell}\gamma^\nu \ell (p_{\bar{f}} - p_f)_\nu (p_{\bar{\ell}} - p_\ell)_\mu \end{array} \right\}$$

taking $\lambda = \pm 1$

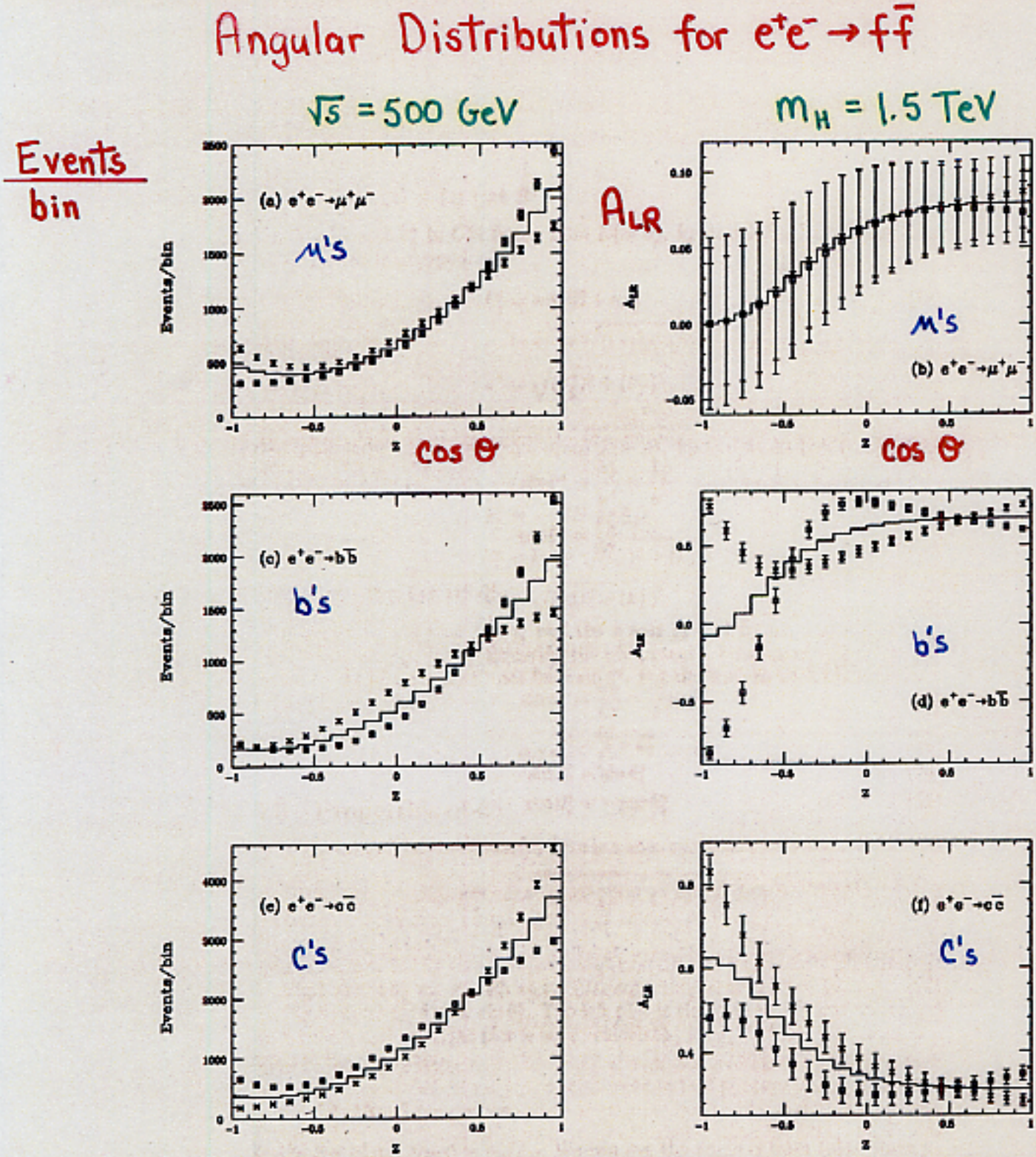


Figure 1: Bin integrated angular distribution and z-dependent Left-Right asymmetry for $e^+e^- \to \mu^+\mu^-, b\bar{b}, c\bar{c}$. In each case, the solid histogram represents the SM, while the 'data' points are for $M_s = 1.5$ TeV with $\lambda = \pm 1$. The error bars correspond to the statistics in each bin.

Drell-Yan Production

Tevatron

LHC

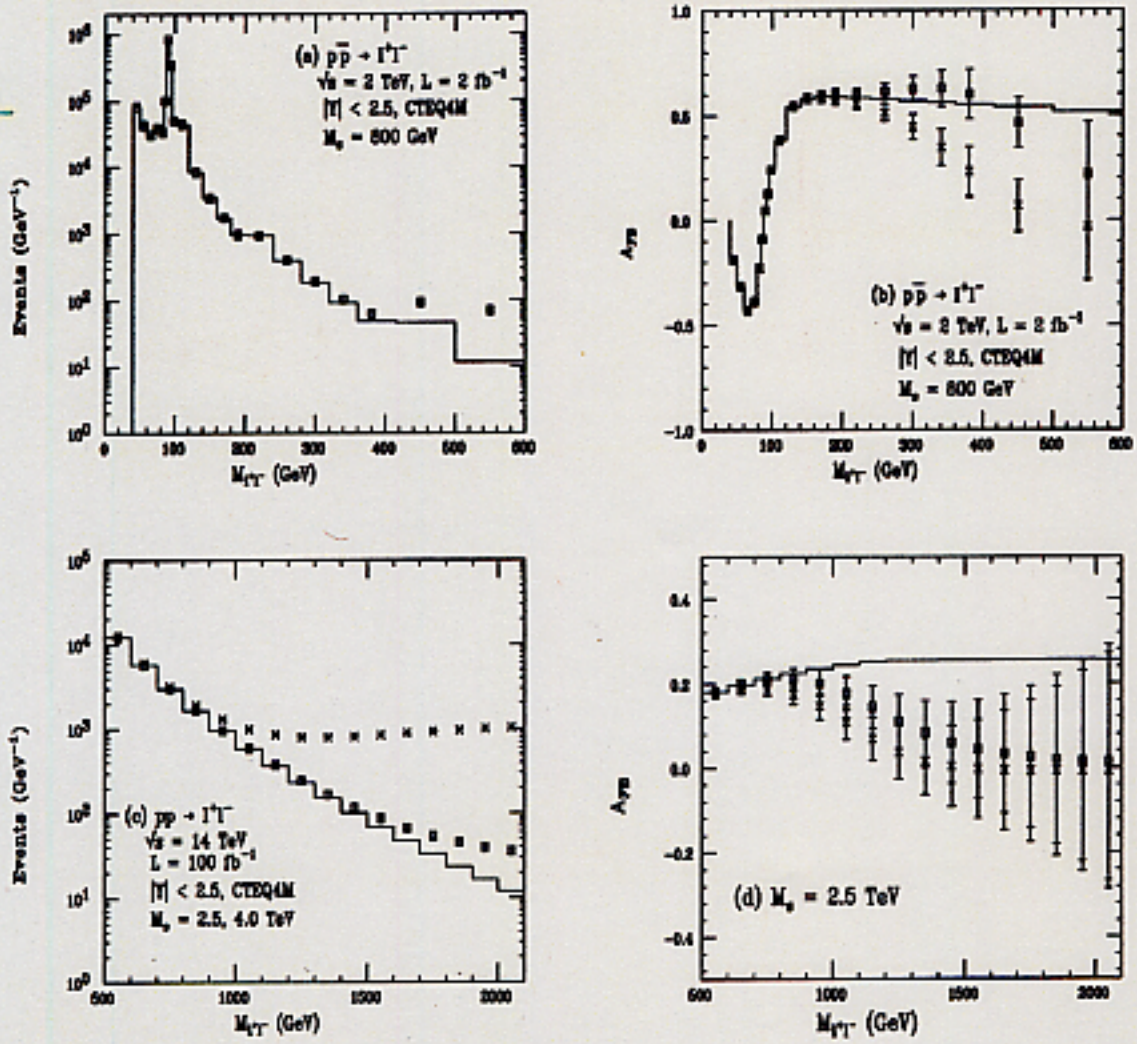


Figure 3: Bin integrated lepton pair invariant mass distribution and forward-backward asymmetry for Drell-Yan production at the Main Injector and the LHC. The SM is represented by the solid histogram. The data points represent graviton exchanges with (a) $M_s = 800$ GeV and $\lambda = +1$ or -1, (b) $M_s = 800$ GeV and $\lambda = +1$ and -1, (c) $M_s = 2.5$ and 4.0 TeV and $\lambda = +1$ or -1, (d) $M_s = 2.5$ TeV and $\lambda = +1$ and -1.

Limits from Virtual G_{KK} Effects

H. Zheng

- Different notations used in different processes:
  - M_D is the fundamental mass scale – real graviton
  - M_S is the ultraviolet cutoff of the divergent sum over the KK excitations – virtual effects
- No exact relation between M_D and M_S is available
- M_D and M_S are expected to be of the same order

Hewett convention

DØ [PRL 86 (2001) 1156]: Ms (λ = +1) > 1.1 TeV; Ms (λ = -1) > 1.0 TeV

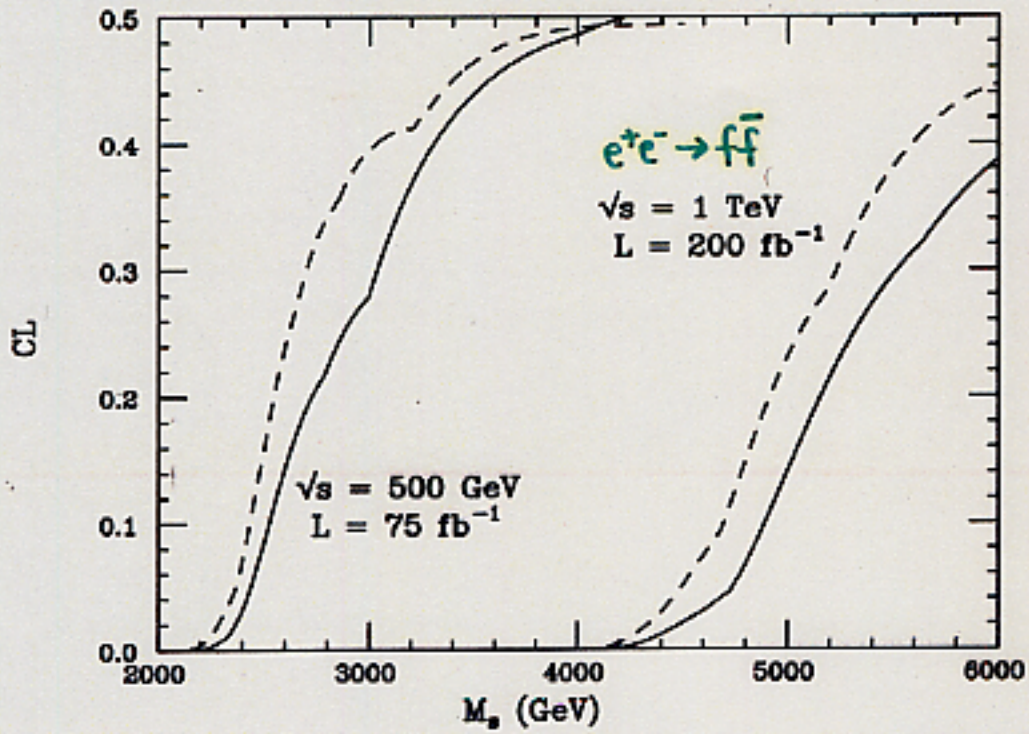
LEP Combined Results [hep-ex/0111063 v2]: Ms (λ = +1) > 1.0 TeV; Ms (λ = -1) > 1.1 TeV

CDF Preliminary [hep-ex/0111063 v2]: Ms (λ = +1) > 0.8 TeV; Ms (λ = -1) > 0.9 TeV

Search Reach of Future Colliders

LC:	$e^+e^- \to f\bar{f}$	$\sqrt{s} = 500$ GeV	$M_H = 4.1$ TeV
		1 TeV	7.2
	$\gamma\gamma \to \gamma\gamma$		3.5
	$\gamma\gamma \to WW$		13.0
	$e\gamma \to e\gamma$		8.0
LHC:	$pp \to \ell^+\ell^-$		7.5
	$pp \to \gamma\gamma$		7.1

Confidence Level of fit of spin-2 data to spin-1 hypothesis



LC determines spin-2 up to kinematic limit

JLH PRL99

Graviton Tower Emission

Giudice, Rattazzi, Wells
Mirabelli, Perelstein, Peskin

- $e^+e^- \to \gamma/Z + G_n$
- $q\bar{q} \to g + G_n$
- $Z \to f\bar{f} + G_n$

G_n appears as $\not{E}_T$
Model independent - Probes M_D directly
Sensitive to δ

Parameterized by density of states

$$\sigma \sim \frac{1}{M_{Pl}^2} (E R_c)^\delta \to \frac{1}{M_D^2}\left(\frac{E}{M_D}\right)^\delta$$

Discovery Reach for M_D (TeV)

$e^+e^- \to \gamma + G_n$	$\sqrt{s} = 800$ GeV	$\delta = 2$	4	6
Tesla TDR	$P_{-+} = 0$	5.9	3.5	2.5
	$P_- = 0.8$	8.3	4.4	2.9
	$P_- = 0.8$, $P_+ = 0.6$	10.4	5.1	3.3
$pp \to g + G_n$	LHC	$\delta = 2$	3	4
Hinchliffe + Vacavant		4-8.9	4.5-6.8	5.0-5.8

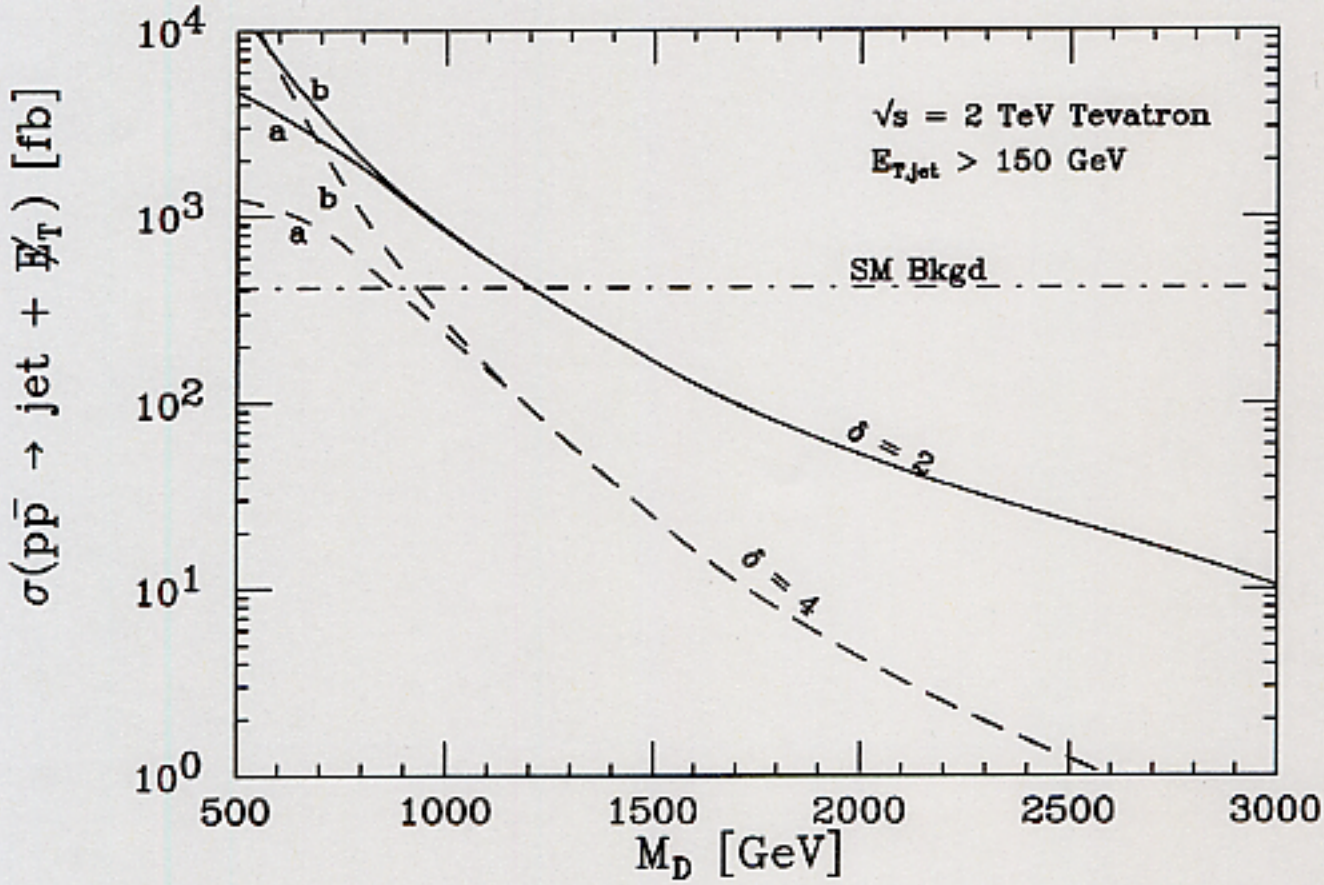
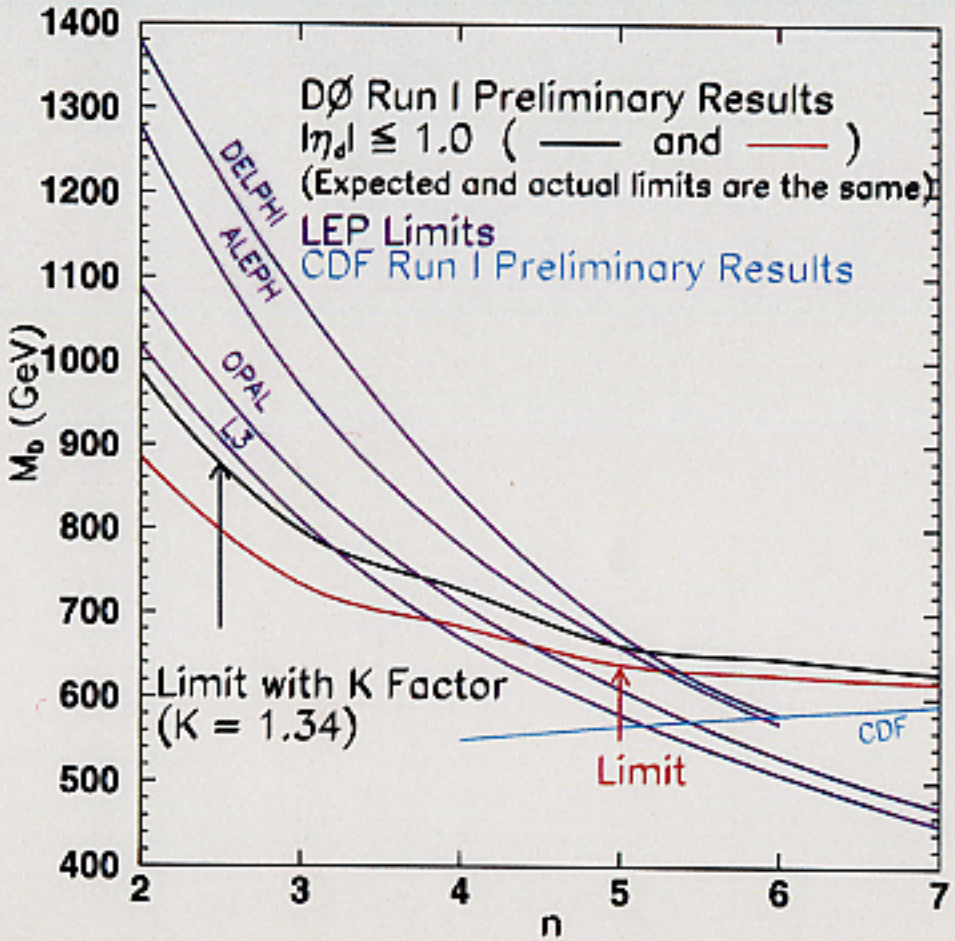


Figure 8: The total jet + nothing cross-section versus M_D at the Tevatron ($\sqrt{s} = 2\,\text{TeV}$) integrated for all $E_{T,\text{jet}} > 150\,\text{GeV}$ with the requirement that $|\eta_{\text{jet}}| < 3.0$. The Standard Model background is the dash-dotted line, and the signal is plotted as solid and dashed lines for $\delta = 2$ and 4 extra dimensions. The a (b) lines are constructed by integrating the cross-section over $\hat{s} < M_D^2$ (all $\hat{s}$).

Limits


DØ Run I Preliminary Results
$|\eta_d| \leq 1.0$ (—— and ——)
(Expected and actual limits are the same)
LEP Limits
CDF Run I Preliminary Results
DELPHI
ALEPH
OPAL
L3
CDF
Limit with K Factor
(K = 1.34)
Limit
M_D (GeV)
n
1400
1300
1200
1100
1000
900
800
700
600
500
400
2
3
4
5
6
7

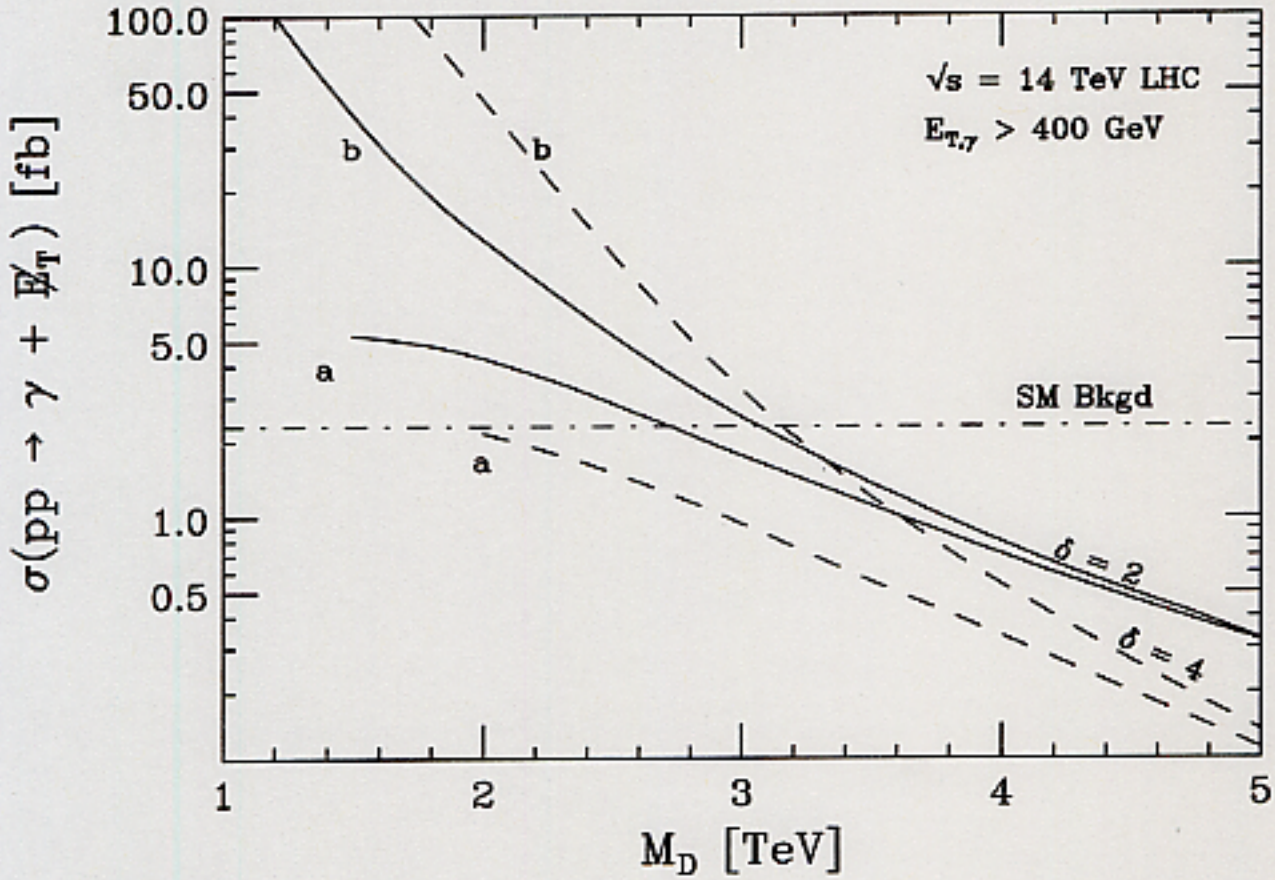


Figure 6: The total γ + nothing cross-section versus M_D at the LHC integrated for all $E_{T,\gamma} > 400\,\mathrm{GeV}$ with the requirement that $|\eta_\gamma| < 2.5$. The Standard Model background is the dash-dotted line, and the signal is plotted as solid lines for $\delta = 2$ and 4 extra dimensions. The a (b) lines are constructed by integrating the cross-section over $\hat{s} < M_D^2$ (all $\hat{s}$).

Limits from $G_{KK}\gamma$ Emission

H. Zheng

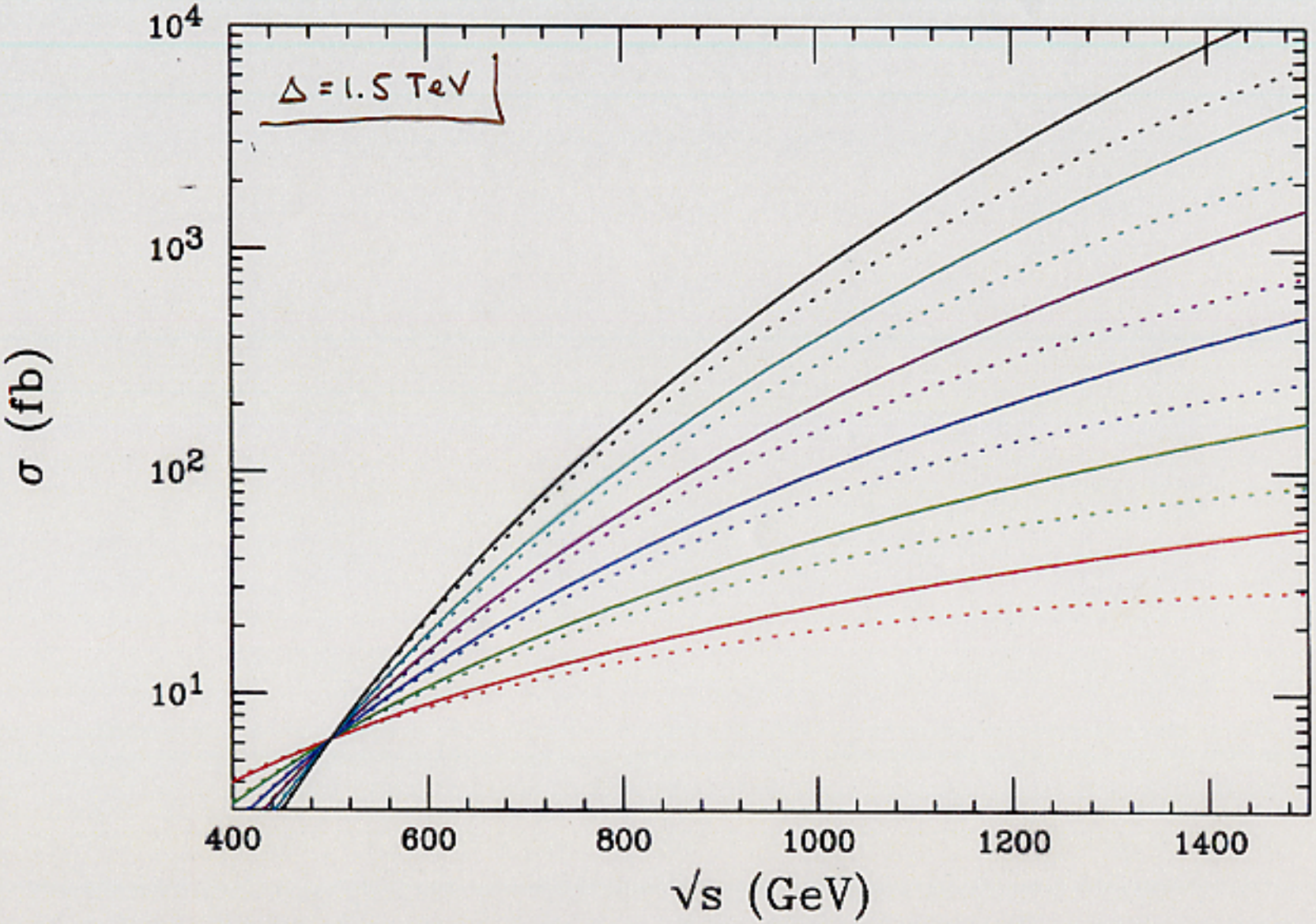
LEP: B. Vachon; hep-ex/0201029 v2

n	2	3	4	5	6	7
ALEPH (189-209 GeV) M_D Limit (TeV)	1.28	0.97	0.78	0.66	0.57	—
DELPHI (181-209 GeV) M_D Limit (TeV)	1.38	—	0.84	—	0.58	—
L3 (189 GeV) M_D Limit (TeV)	1.02	0.81	0.67	0.58	0.51	0.45
OPAL (189 GeV) M_D Limit (TeV)	1.09	0.86	0.71	0.61	0.53	0.47

CDF: hep-ex/0205057

n	4	6	8
M_D Limit (TeV)	0.55	0.58	0.60

Determination of Number of Extra Dimensions

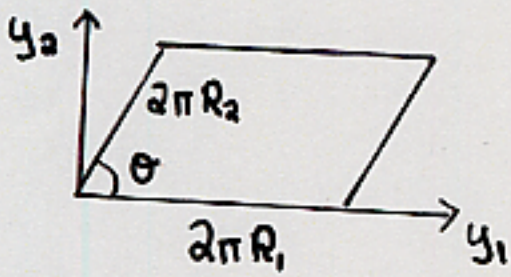


Normalized to $m_D = 5$ TeV, $\delta = 2$ at $\sqrt{s} = 500$ GeV

Shape versus Volume

Dienes

Shape moduli can shift KK spectrum

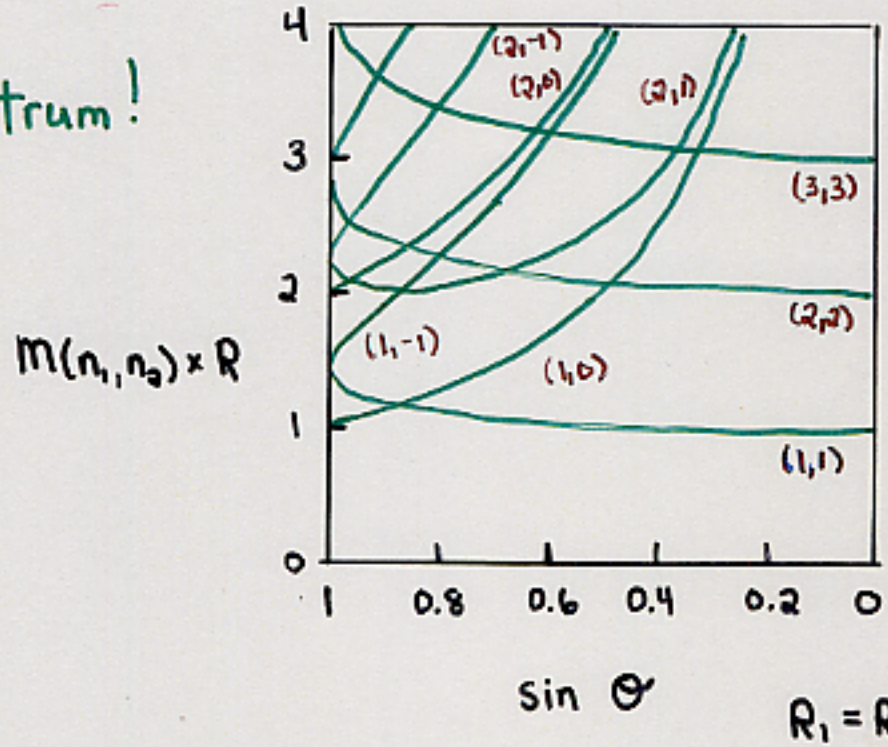


2-Dimensional Example

θ = shape moduli

$$m_{\vec{n}}^2 = \frac{1}{\sin^2\theta}\left[\frac{n_1^2}{R_1^2} + \frac{n_2^2}{R_2^2} - 2\frac{n_1 n_2}{R_1 R_2}\cos\theta\right]$$

Distorts Spectrum!



$R_1 = R_2 = R$

Phenomenology of a Supersymmetric Bulk

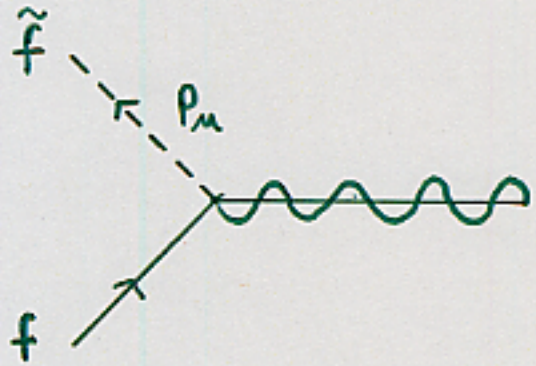
JLH, Sadri
hep-ph/0204

Large Extra Dimensions with
Supersymmetric bulk: stabilizes radii
breaks SUSY

N=2 SUSY in bulk breaks to N=1 SUSY on brane

Full supermultiplet in bulk

Compactify ⇒ KK towers of gravitons + gravatinos!



$\bar{\Omega}^{(n)}_\nu$ $\qquad \dfrac{-i}{\sqrt{2}\,\bar{m}_{Pl}}\, p_\mu \gamma^\mu \gamma^\nu$

t-channel gravitino KK exchange in $\tilde{f}\bar{\tilde{f}}$

Rarita-Schwinger propagator $f(m_{\tilde{n}}^{\alpha})$ $\quad \alpha = -2, -1, 0, 1$

Leading order contribution is dim-6!

Contributions to $e^+e^- \to \tilde{e}^+_{L,R}\, \tilde{e}^-_{L,R}$

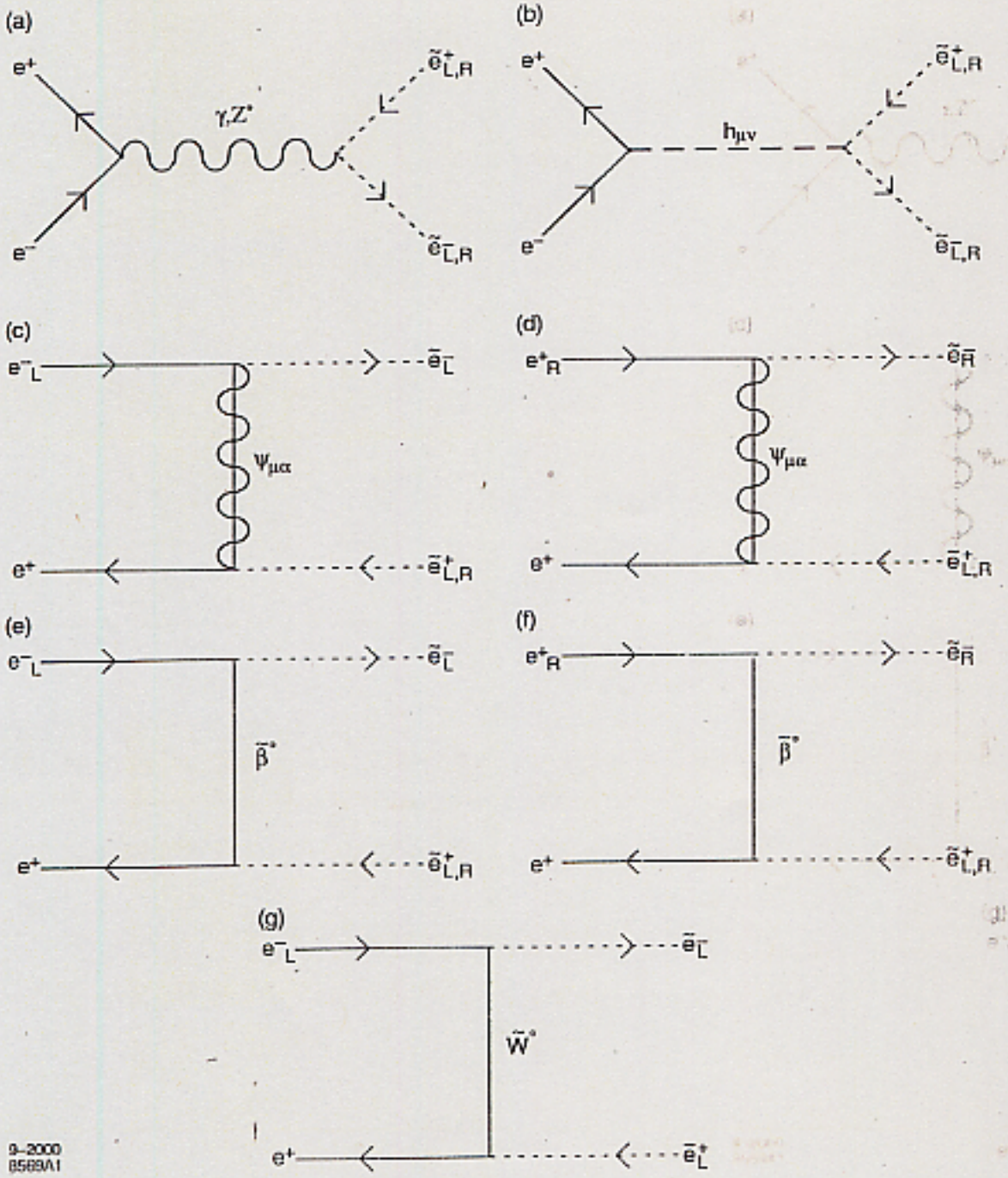
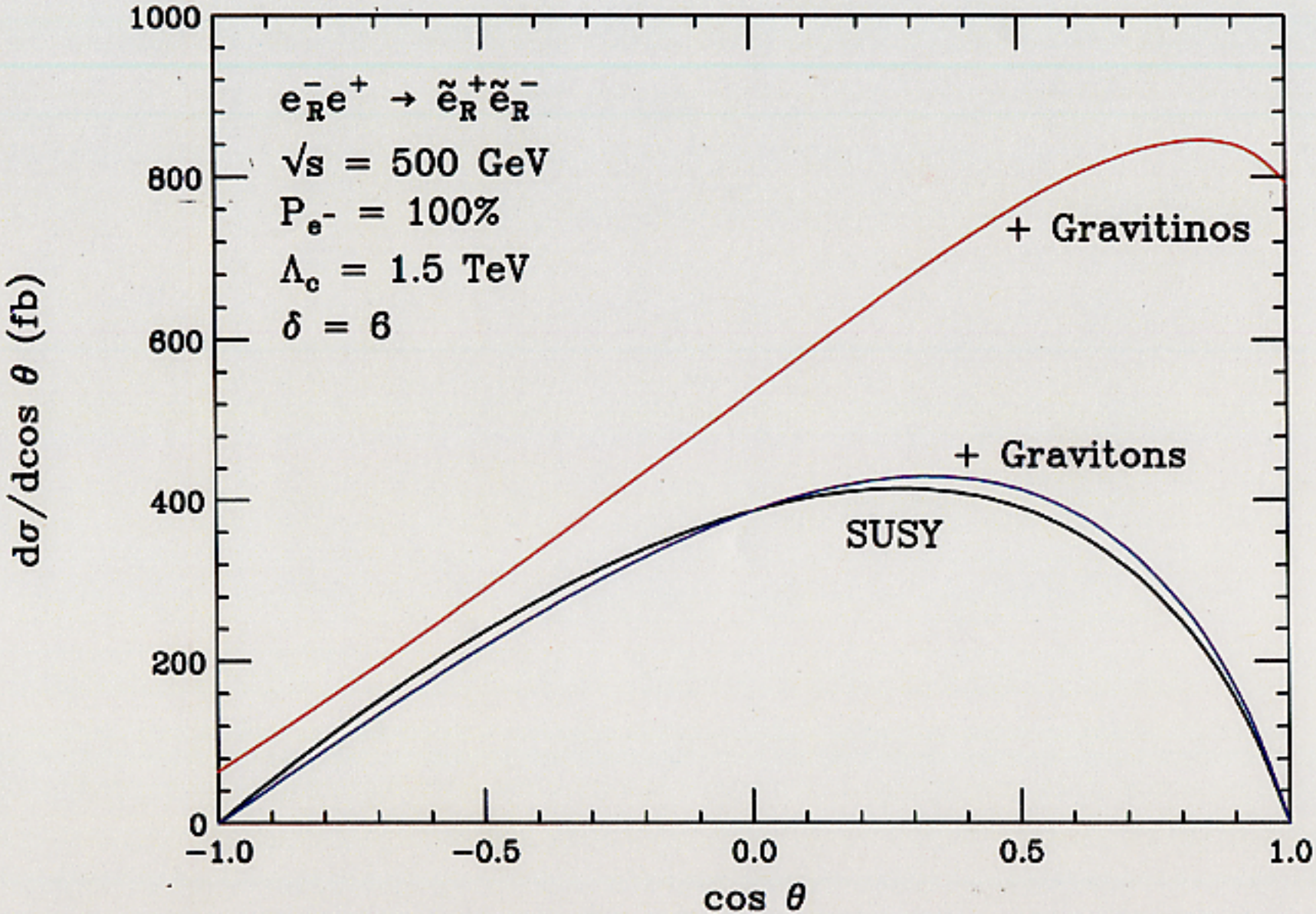
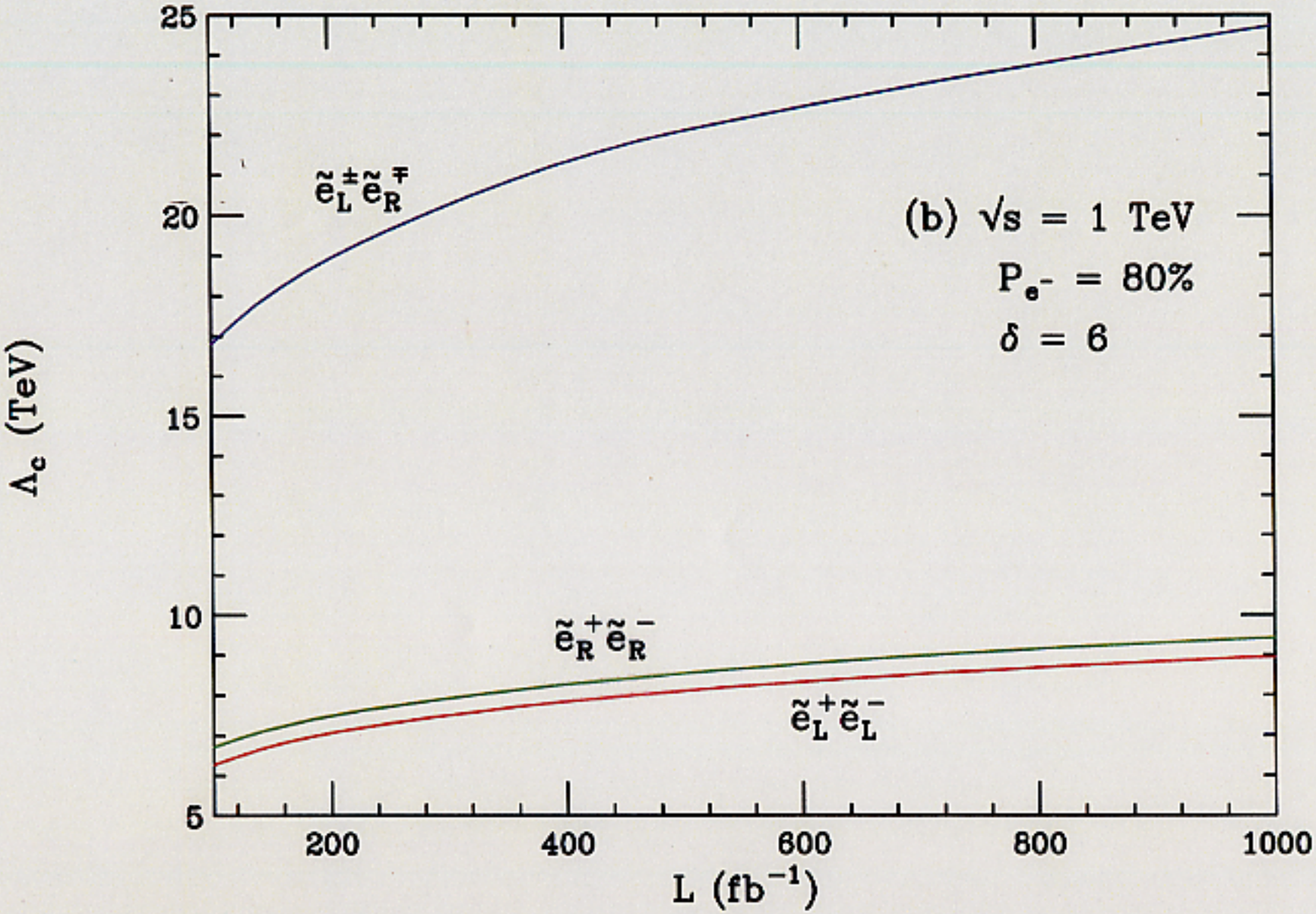


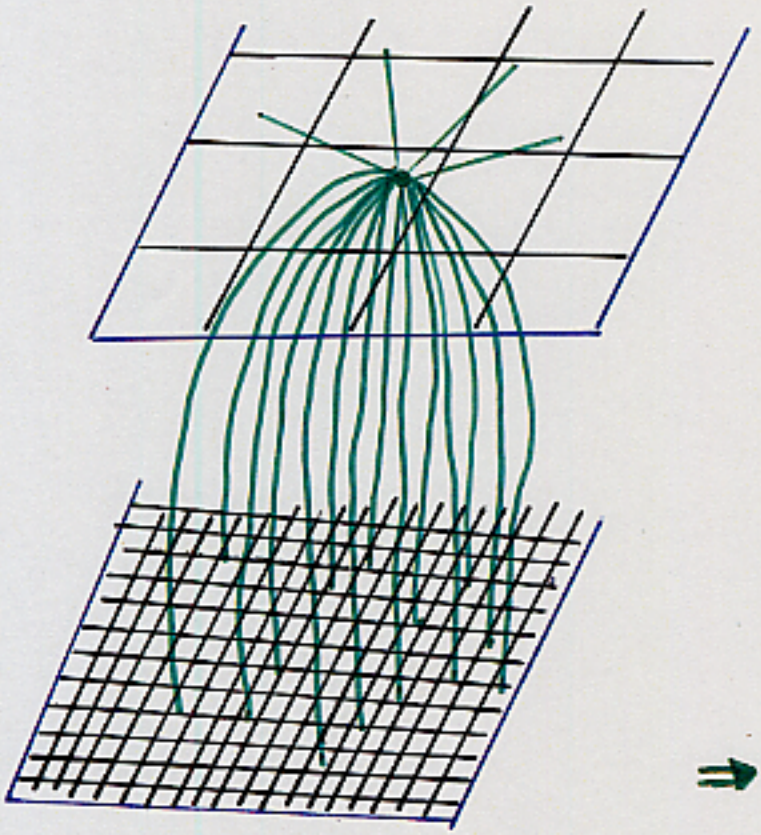
Figure 2: Various processes contributing to scalar pair production.


$e_R^- e^+ \to \tilde{e}_R^+ \tilde{e}_R^-$
$\sqrt{s}$ = 500 GeV
P_{e^-} = 100%
Λ_c = 1.5 TeV
δ = 6
+ Gravitinos
+ Gravitons
SUSY
$d\sigma/d\cos\theta$ (fb)
$\cos\theta$
1000
800
600
400
200
0
−1.0
−0.5
0.0
0.5
1.0

Search Reach for m_H/Λ_c



Non-Factorizable Curved Geometry – 'Warped' Space



Area of each grid is equal

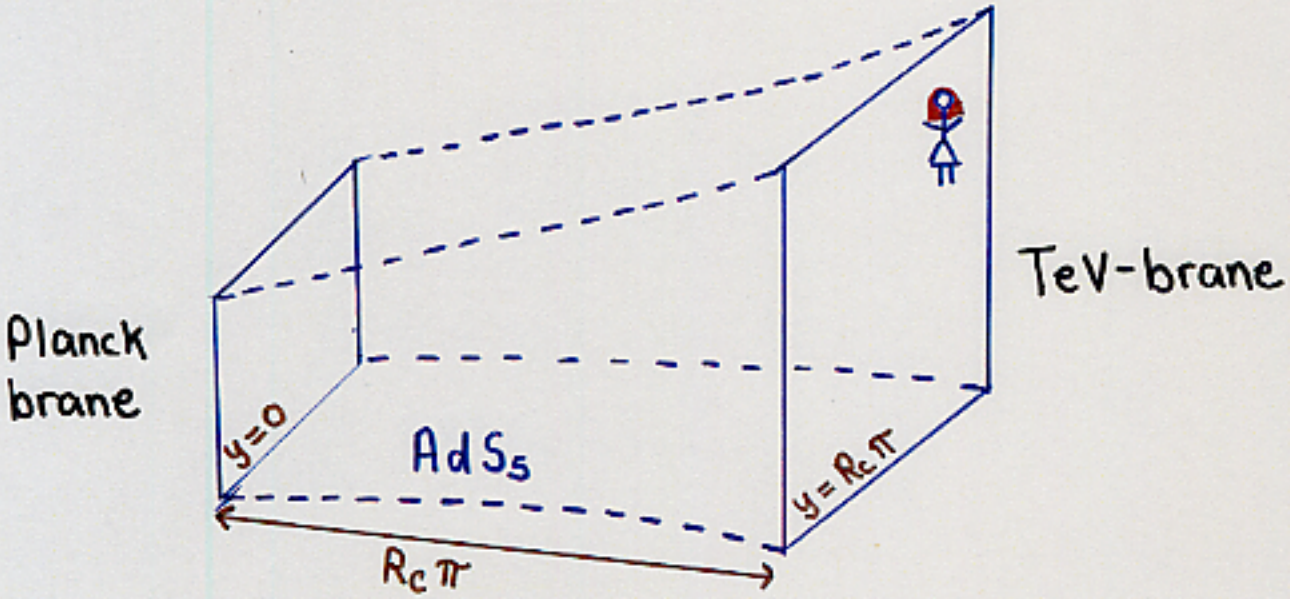
Field lines spread out faster with more volume

⇒ Drop to bottom brane

Gravity appears weak on top brane!

Localized Gravity

Randall, Sundrum



Bulk = Slice of AdS_5

$\Lambda_5 = -24 M_5^3 K^2$

K → curvature scale

5-D non-factorizable geometry:

$$ds^2 = e^{-2ky} \eta_{\mu\nu} dx^\mu dx^\nu - dy^2$$

e^{-2ky} → Warp factor

$M_5 \sim M_{Pl} \sim K$ ⇒ no additional hierarchies!

Physical scales on SM 3-brane:

$$\Lambda_\pi = e^{-KR_c\pi} M_{Pl}$$

$$\simeq \text{TeV} \quad \text{if} \quad KR_c \sim 11$$

Naturally stabilized via Goldberger - Wise

Hierarchy is generated by an exponential!

4-d Effective Theory

Davoudiasl, JLH, Rizzi
PRL 00

Linear expansion of flat metric

$$G_{AB} = e^{-2ky}\left(\eta_{AB} + \frac{h_{AB}(x^\mu, y)}{m_5^{3/2}}\right)$$

Expand into KK tower

$$h_{AB}(x^\mu, y) = \sum_{n=0}^{\infty} h_{AB}^{(n)}(x^\mu)\,\frac{\chi_h^{(n)}(y)}{\sqrt{R_c}}$$

Employ Boundary Conditions + find

$$\chi_h^{(n)}(y) = \frac{e^{2ky}}{N_n}\left[J_2\left(\frac{m_n}{k}e^{ky}\right) + \alpha_n Y_2\left(\frac{m_n}{k}e^{ky}\right)\right]$$

$$m_n = x_n k e^{-kR_c\pi} \quad \text{with } J_1(x_n) = 0$$

$$= x_n \Lambda_\pi \frac{k}{m_{Pl}}$$

$\Rightarrow$ KK excitations are not evenly spaced!

Phenomenology governed by 2 free parameters

Λ_π / m_1 and k/m_{Pl}

$\sim$ TeV $\quad\quad \lesssim 0.1$

[5-d curvature: $|R_5| = 20k^2 < m_5^2$]

Interactions

$$\mathcal{L} \sim \frac{-1}{M_5^{3/2}} T^{AB}(x^\mu, y)\, h_{AB}(x^\mu, y), \qquad y = R_c \pi$$

$$= \frac{-1}{m_{Pl}} T^{\alpha\beta}(x)\, h^{(0)}_{\alpha\beta}(x) - \frac{1}{\Lambda_\pi} T^{\alpha\beta}(x) \sum_{n=1}^{\infty} h^{(n)}_{\alpha\beta}(x)$$

zero-mode decouples

TeV-strength couplings
Can be produced directly

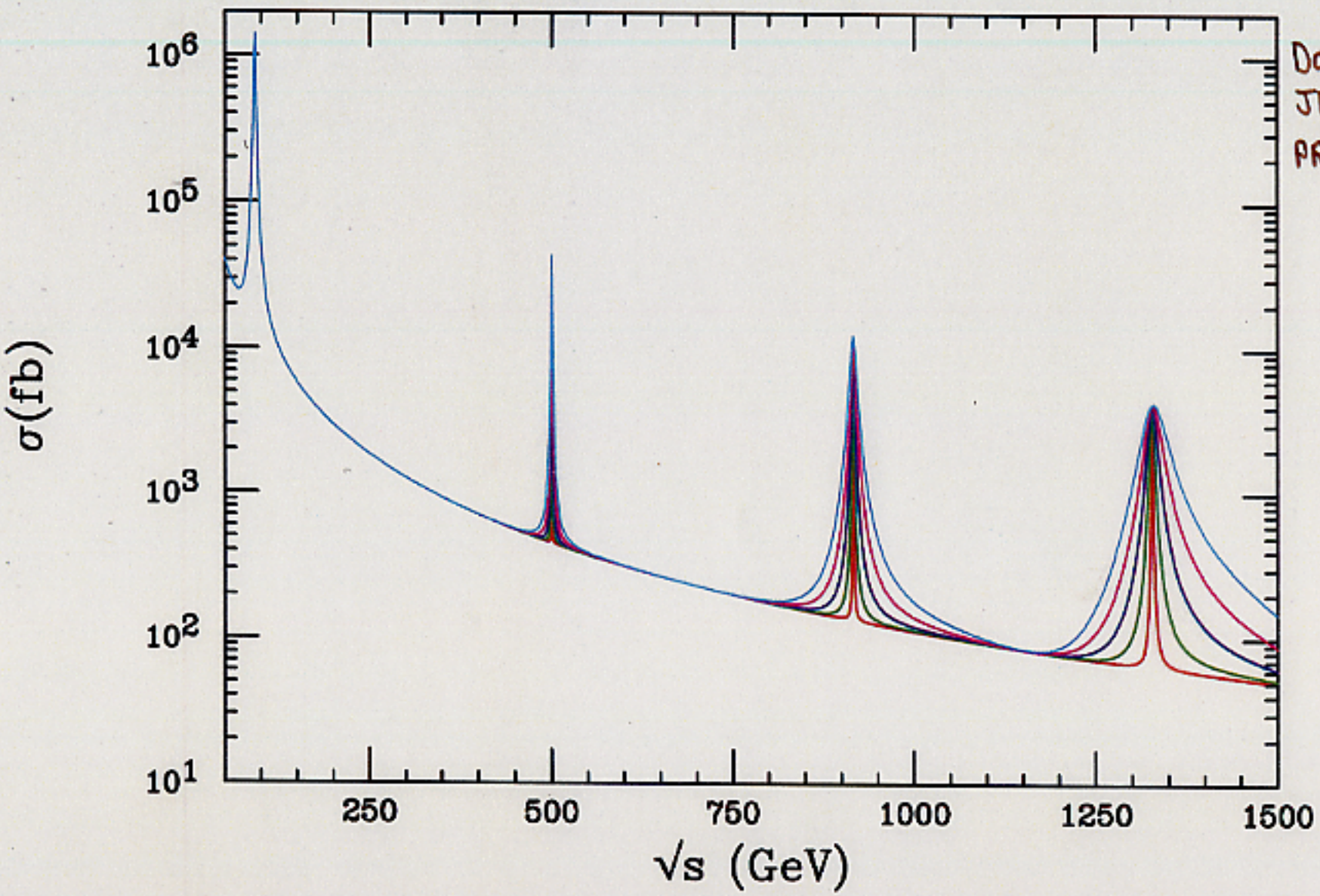
Phenomenology

- Graviton resonance production
- 'Light, skinny' Gravitons $[k/m_{Pl} \lesssim 0.01]$
- Below resonance virtual exchange [contact ints]
- Graviton induced cosmic rays
- SM fields in the bulk
- KK contributions to EW oblique parameters
- KK contributions to $g-2/\mu$

Davoudiasl, JLH, Rizzo
PRL 00
PLB 00
PRD 01
PLB 00
PRD 02

JLH, Petriello, Rizzo
hep-ph/0203091

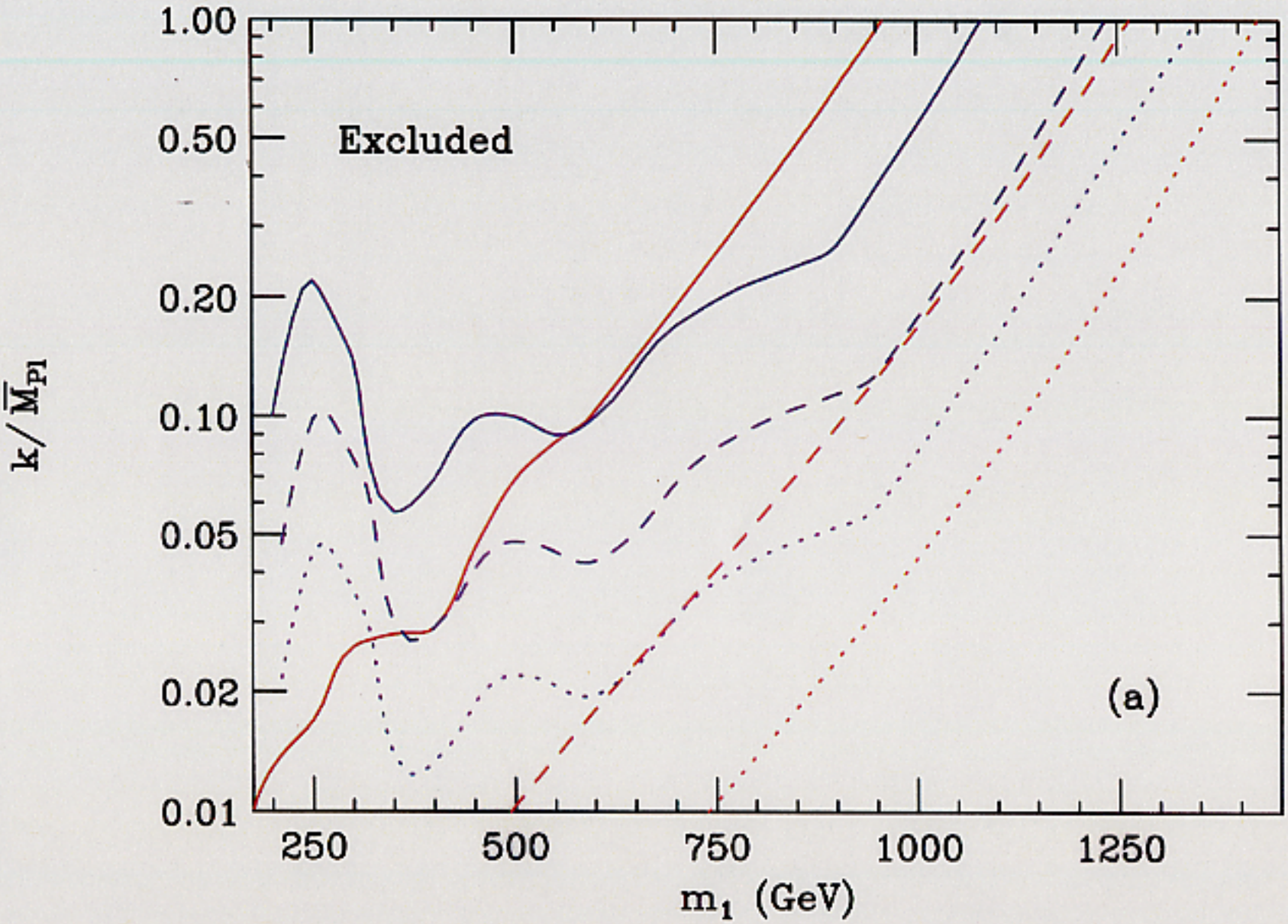
$e^+e^- \to \mu^+\mu^-$ Line Shape



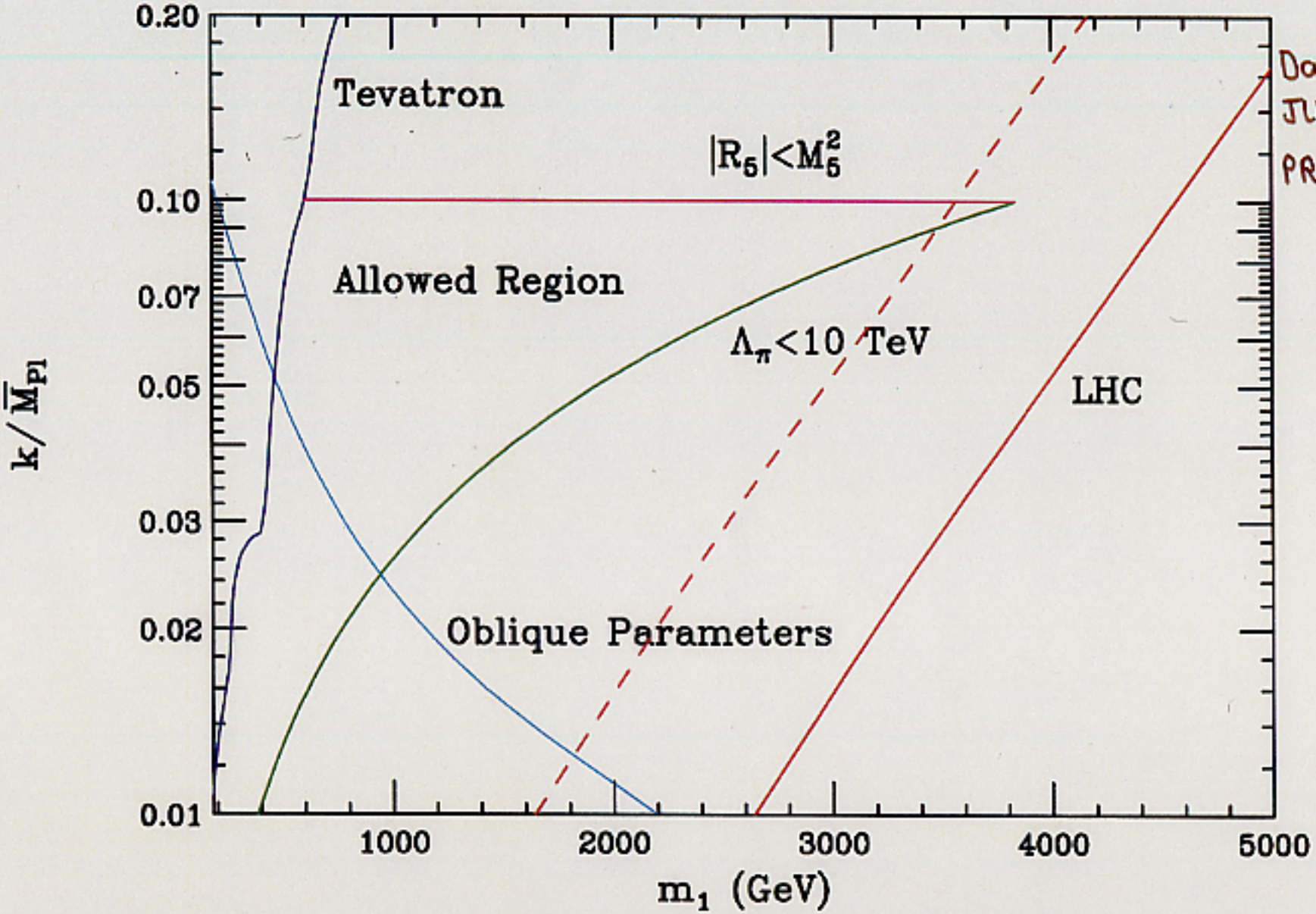
Davoudiasl, JLH, Rizzo PRL 00

LC becomes a Graviton Factory!

Tevatron Bump Search

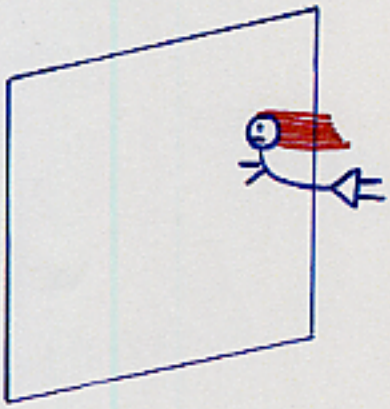


Summary of Theory + Experimental Constraints



Davoudiasl
JLH, Rizzo
PRD 01

Peeling the SM off the Wall

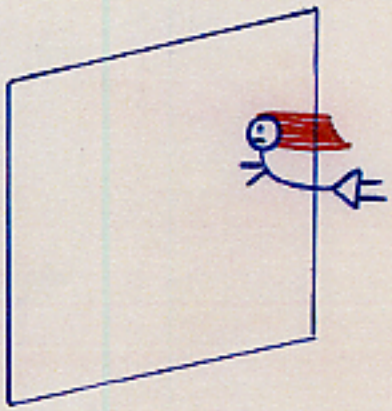


Model building scenarios require SM bulk fields

- Gauge coupling unification
- Supersymmetry breaking
- γ Mass spectrum
- Fermion Mass hierarchy

⋮

Peeling the SM off the Wall



Model building scenarios require SM bulk fields

- Gauge coupling unification
- Supersymmetry breaking
- ν Mass spectrum
- Fermion Mass hierarchy

⋮

Gauge Fields in bulk alone:

Davoudiasl, JLH, Rizzo
PLB 00

→ Gauge boson KK towers

with $g_{KK} = 8.4\, g_{SM}$

EW Data: $m_1^A > 25$ TeV → $\Lambda_\pi \gtrsim 100$ TeV !

Fix: Add SM Fermions in the bulk

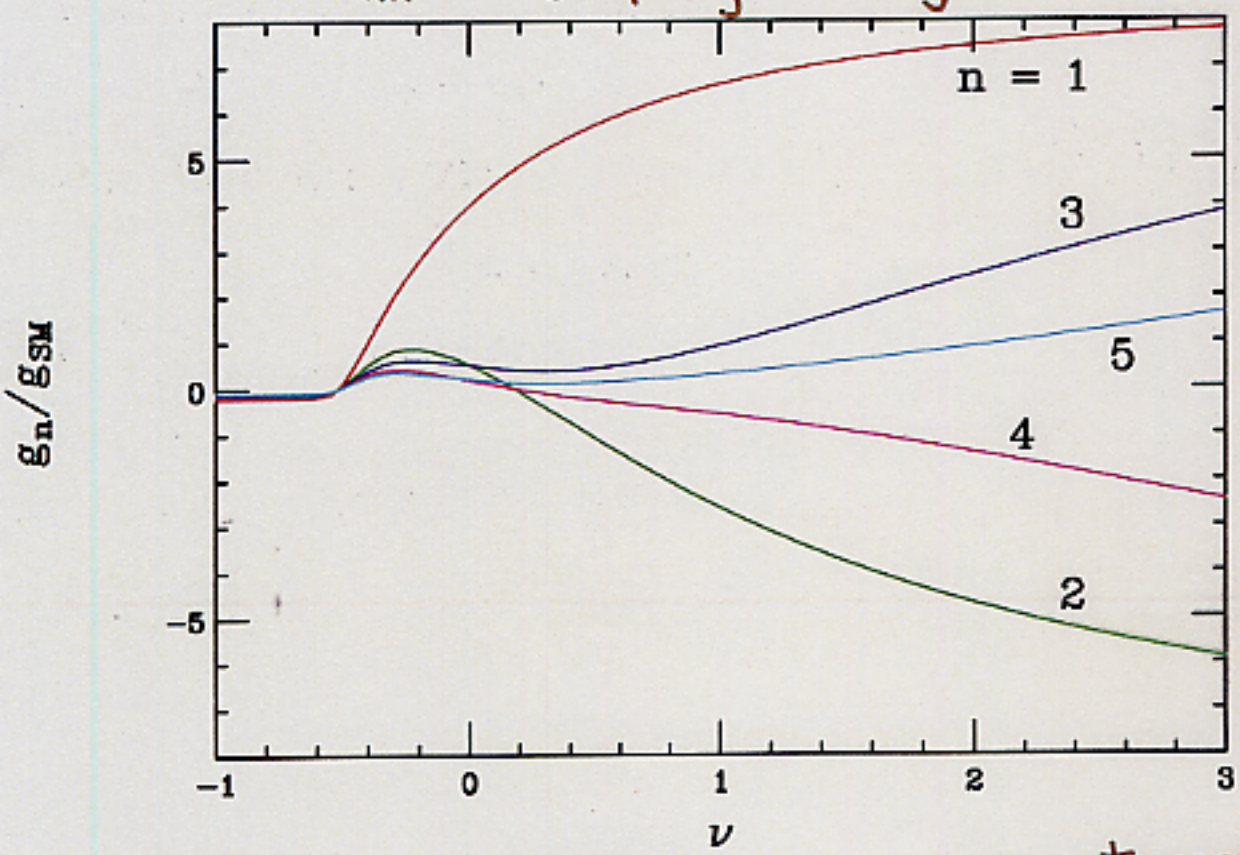
⇒ Introduces 3RD parameter

$$m_f^{bulk} = \nu k, \qquad \nu \sim \mathcal{O}(1)$$

Zero-mode KK fermions couple weaker than brane fermions

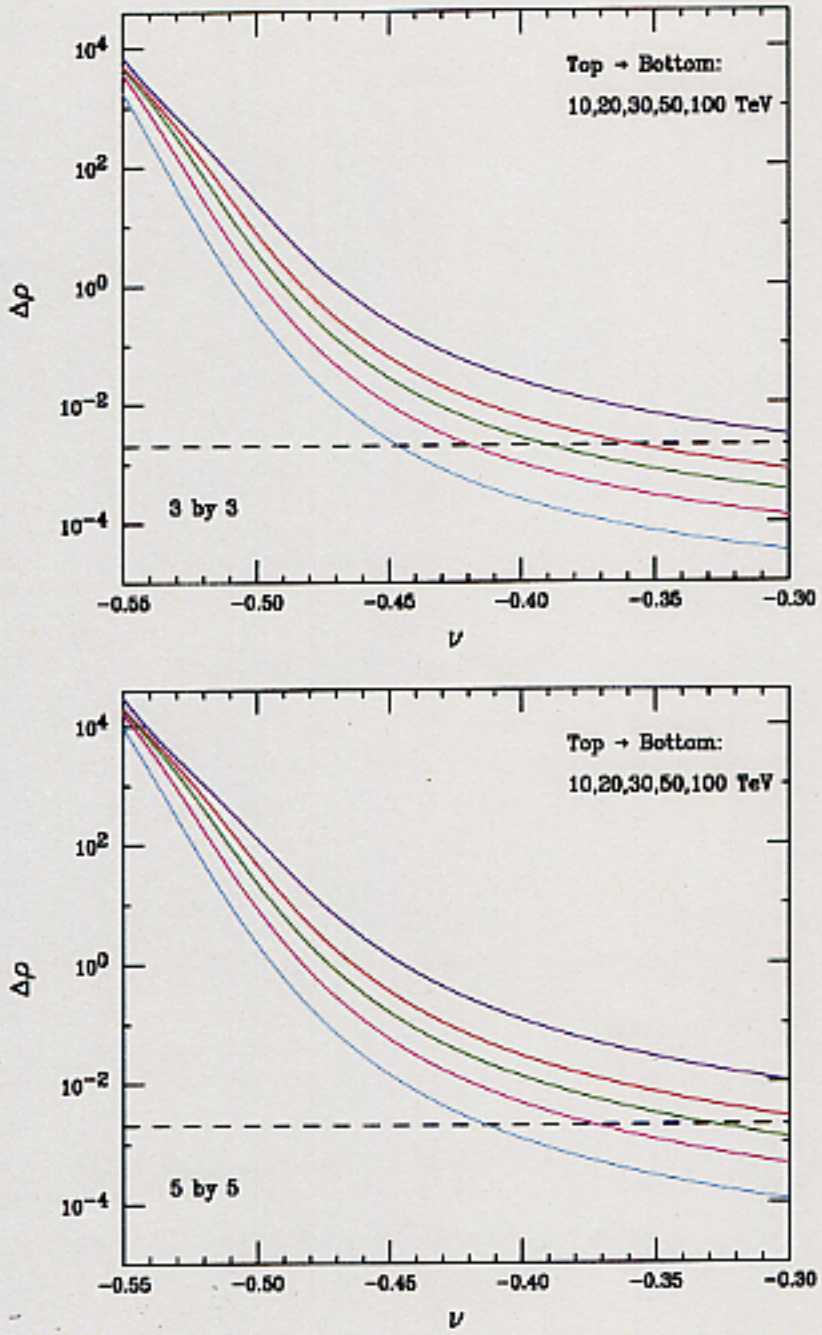
⇒ Serious reduction in collider sensitivity!

$A_{KK}\, f\bar{f}$ coupling strength



towards Planck brane ⟵ fermions localized ⟶ towards TeV-brane

Large top-quark – KK top-quark mixing!



JLH, Petriello, Rizzo hep-ph/0203091

Figure 3: Contributions to $\Delta\rho$ from the zero modes and first KK level (top), and from the zero modes and first two KK levels (bottom). The dashed black line indicates where $\Delta\rho = 2 \times 10^{-3}$.

⇒ Localize 3rd generation on TeV-brane

General Summary:

- Kaluza-Klein towers of bulk fields signal existence of extra dimensions

- Properties of KK towers reveal geometry of extra dimensions

- If underlying physics is related to TeV-scale
  ⇒ signatures at TeV colliders!

Fine-Tuned Summary

Large Extra-Dimensions: Large, Flat

Tower of weakly interacting, evenly spaced, almost continuous KK graviton states

Numerous at collider energies ⇒ observable in emission + exchange

LHC + NLC probe $M_D \sim 6\text{-}10$ TeV

NLC determines M_D, δ, spin-2 nature of KK states

Localized Gravity: Warped

Graviton KK tower: $m_1 \sim$ TeV, TeV^{-1} couplings
spacing given by $J_1(x_n) = 0$

Direct spin-2 resonance production

LHC probes parameter space

NLC becomes graviton factory

SM in the bulk is interesting, but problematic