Randall - Sundrum Warped Extra Dimensions at Linear Colliders

- Basics (thanks, Hooman!!)
- SM on the Brane { below or above threshold ? / Contact int's or resonances ? }
- SM peeled off the Brane { The bulk gets crowded }
- Summary + comparison with ADD/LED scenario

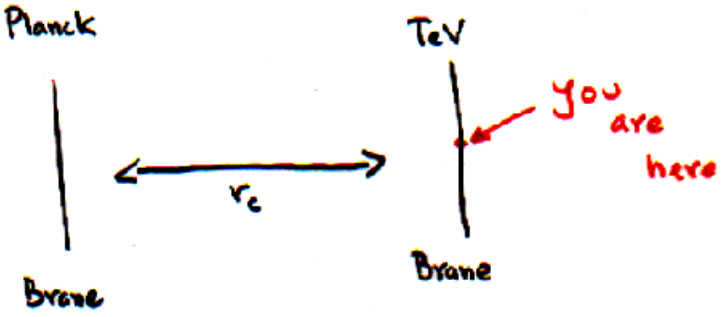
Based on work in

Davoudiasl, Hewett + R.

PRL 84, 2080 (2000)
PLB 473, 43 (2000)
hep-ph/0006041 (PRD)
hep-ph/0006097 (PLB)
hep-ph/0010066

TG Rizzo
LCWS2000
10/2000

Basics:
(on the wall)



- $\bar{M}_{Pl}^2 = M_{5d}^3 / k$ ✱ $kr_c \approx 11-12$ to solve hierarchy problem
- $\Lambda_\pi = \bar{M}_{Pl}\, e^{-\pi k r_c}$
- $m_n [C^{(n)}] = x_n k e^{-\pi k r_c}$ w/ $J_1(x_n) = 0$

$$\mathcal{L} = -\left\{ \frac{1}{\bar{M}_{Pl}} h_{\mu\nu}^{(0)} + \frac{1}{\Lambda_\pi} \sum_n h_{\mu\nu}^{(n)} \right\} T^{\mu\nu}$$

$\Rightarrow$ fix $\boxed{m_1}$ and $\boxed{c = k/\bar{M}_{Pl}}$ †† + all other parameters known

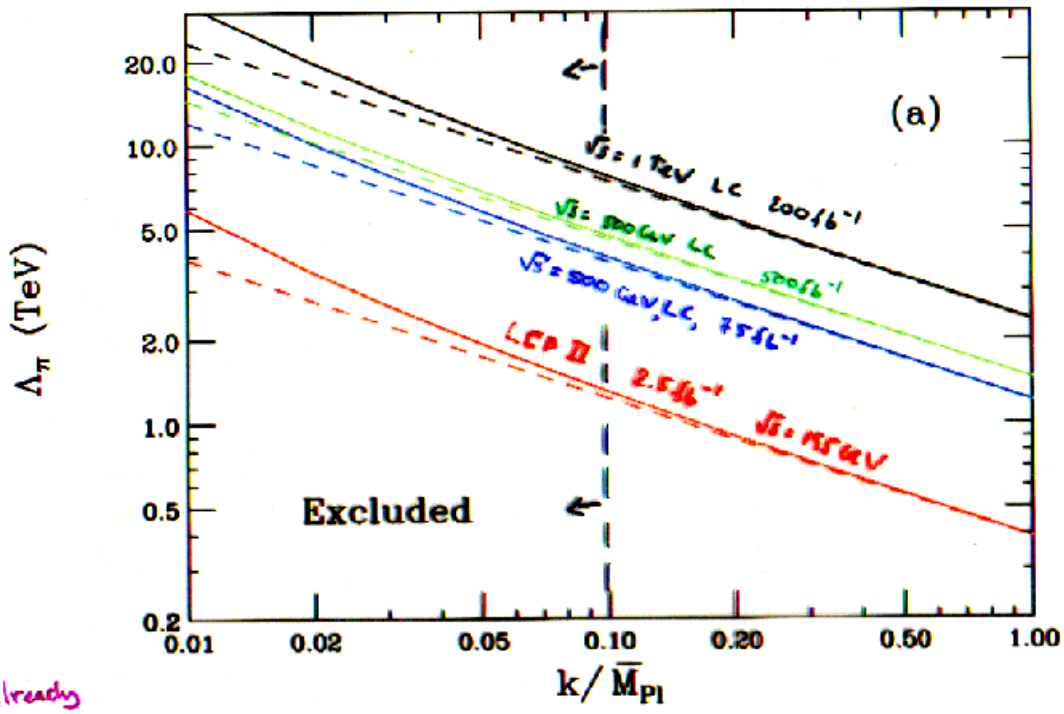
off the wall: $\boxed{1}$ more parameter ν : $\sim O(1)$

Common fermion mass parameter (F~~C~~NC)

$\Rightarrow$ everything fixed - not bad!

†† c cannot be too small $\rightarrow$ hierarchy again $\gtrsim 10^{-2}$ BUT c cannot be too large Curvature constraint [?] $c \lesssim 1$?

CI Constraints on Randall-Sundrum Model



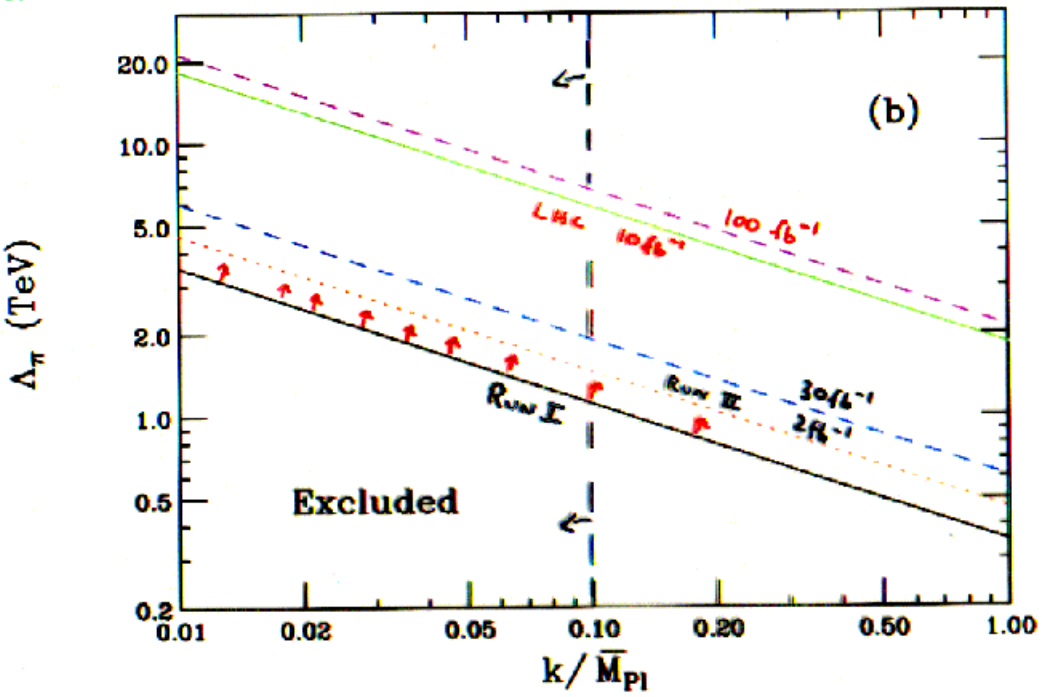
Already

$k/\bar{m}_{Pl}$ much smaller than 10^{-2}

looks bad for hierarchy problem solution...

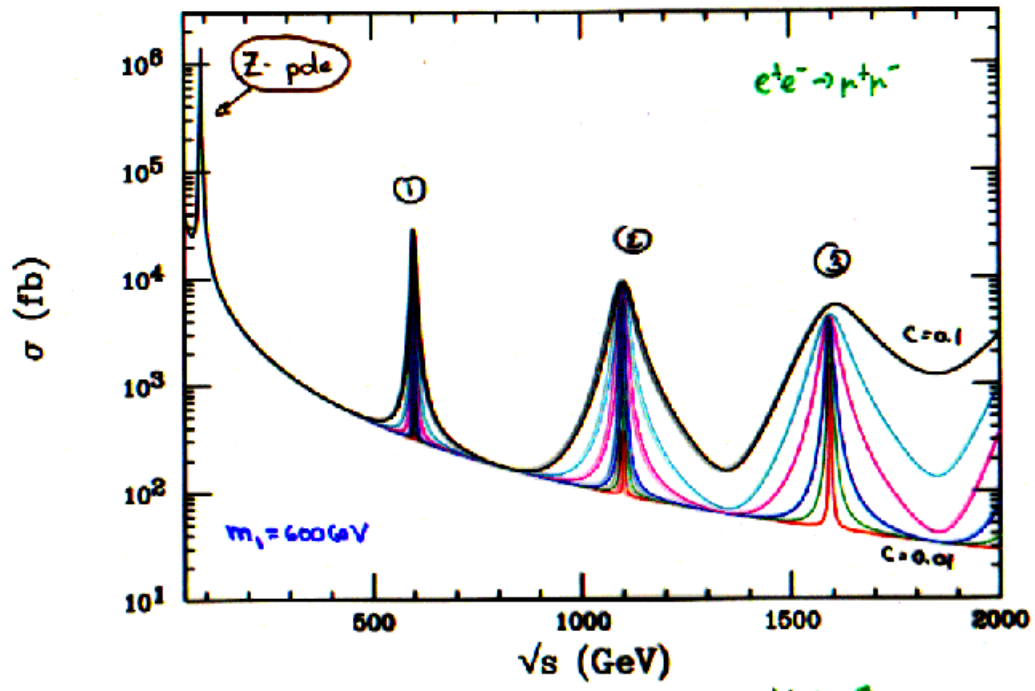
Contact Interactions

CI Constraints on Randall-Sundrum Model



At some point identifying Λ_π as not the weak scale → another hierarchy

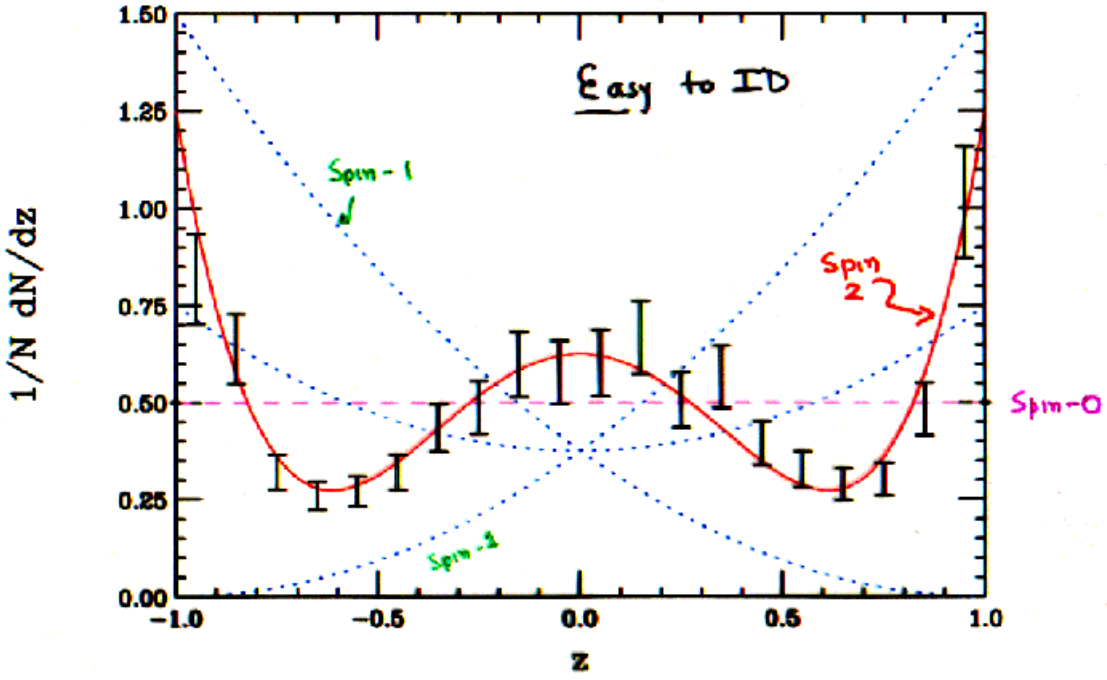
Graviton resonances at LC



Not Equally Spaced

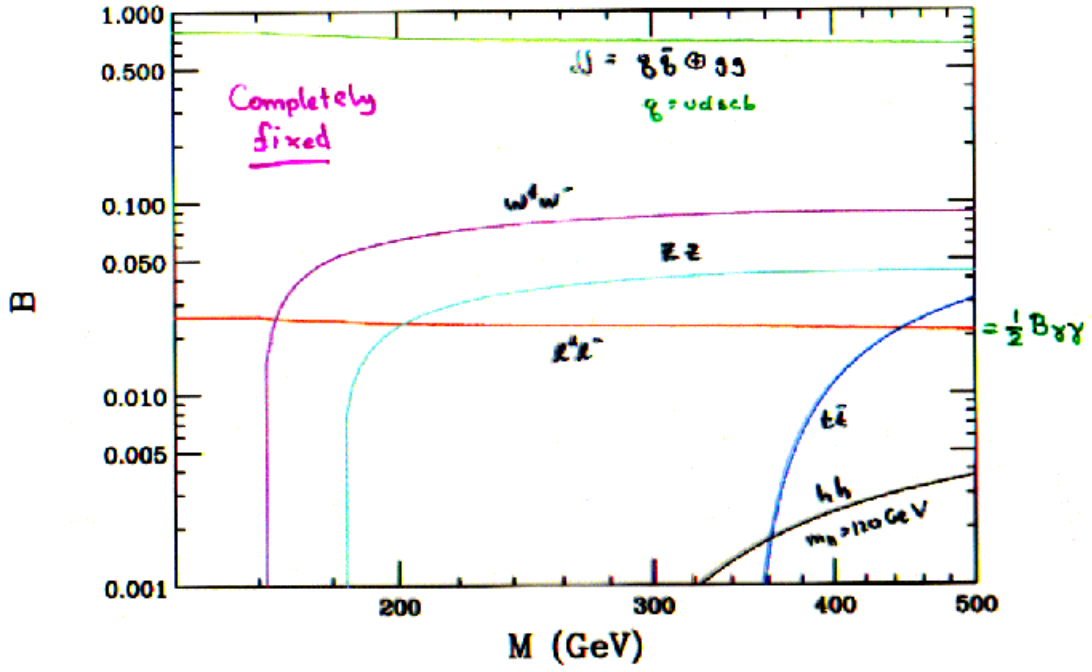
Γ increases with both c and m_n

$f\bar{f} \to \bar{f}'f'$ on a graviton resonance



SM on wall

RS Graviton branching fractions

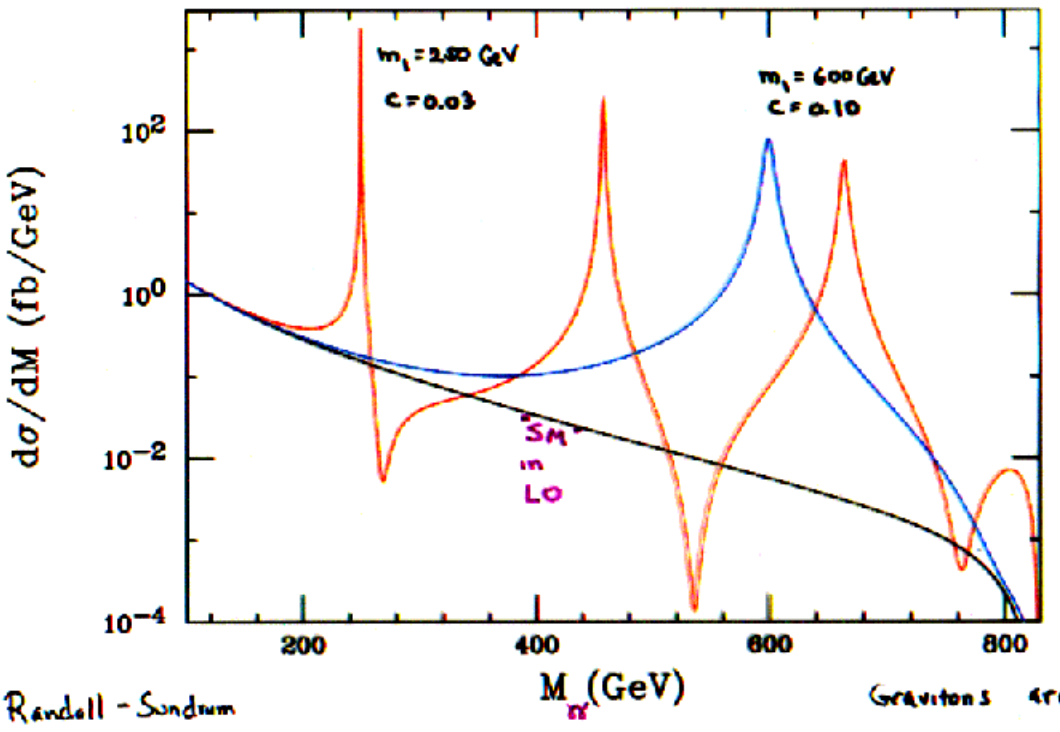


→ $B_{\gamma\gamma} = 2\, B_{\ell^+\ell^-}$

1st graviton mass

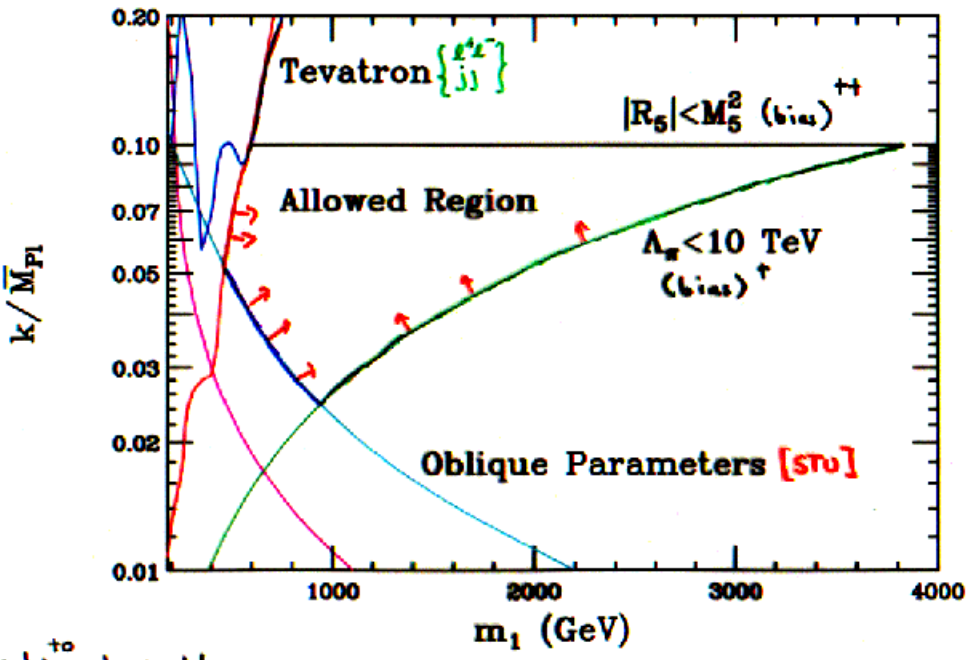
$\sqrt{s} = 1$ TeV

$\gamma\gamma \to b\bar{b}$



Randall - Sundrum model

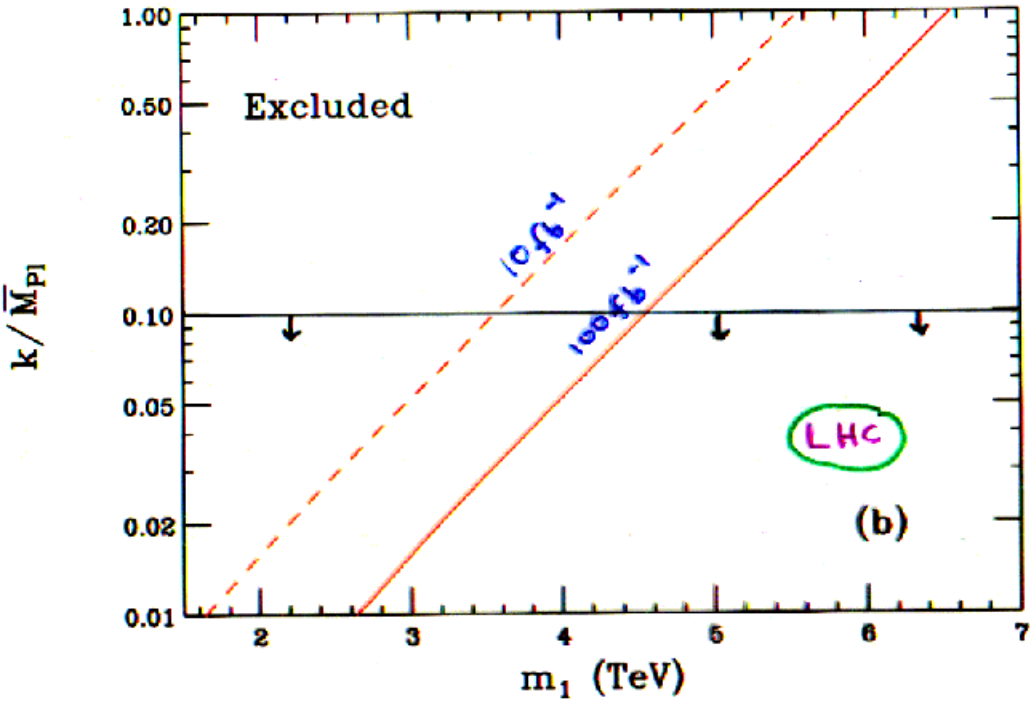
Gravitons are everywhere !



† solve hierarchy problem to

†† no higher order curvature : unless Gauss-Bonnet (Kim, Kyae + Lee) $R^2 - 4R_{AB}R^{AB} + R_{ABCD}R^{ABCD}$

Drell-Yan Constraints on Randall-Sundrum Model



- SM off the wall : gauges only ? NO !

$$g^{(n)} / g^{(0)}_{[SM]} = \sqrt{2\pi k r_c} \approx 8 \,!\,!$$ Strong coupling !

Tower exchanges alter precision EWK data !!

$\therefore$ must be heavy ["V" analysis, Ribbon walls]

$\Rightarrow m_1^{gauge} \gtrsim 25$ TeV $\rightarrow M_1^{grav} \gtrsim 40$ TeV

$\Rightarrow \lambda_\pi \gtrsim 100$ TeV too far from weak scale

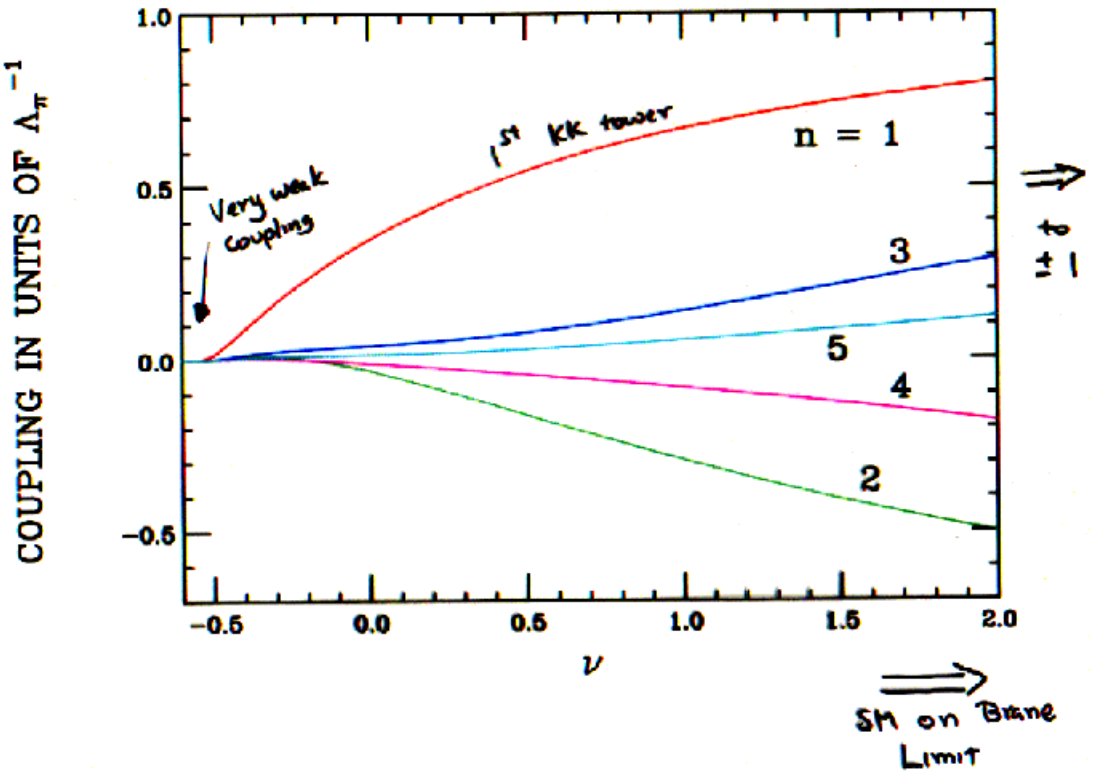
- Fermions $\oplus$ Gauges in Bulk : weaken bound for some range of $\underline{\nu}$ WHY?

$\Rightarrow$ { Graviton + Gauge couplings of fermions now depend on $\underline{\underline{\nu}}$ .... }

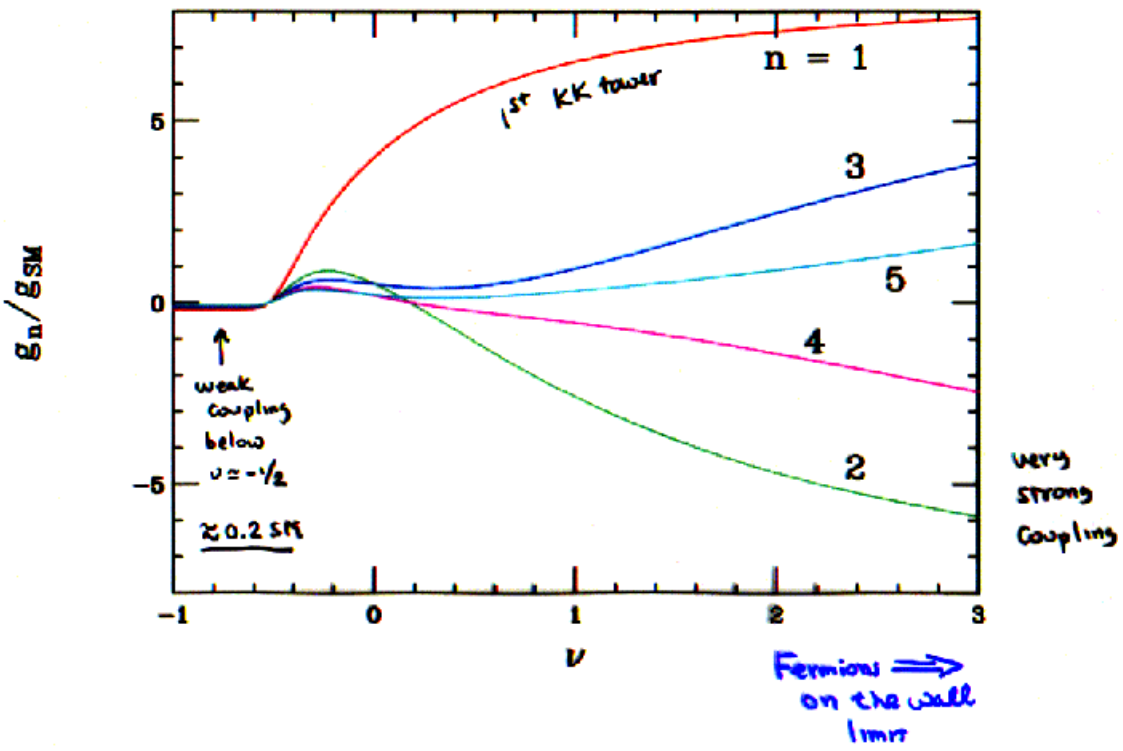
- For 'large' ν we recover "fermions on the wall" limit ...

{ Grossman + Neubert
Gherghetta + Pomarol
⋮ }

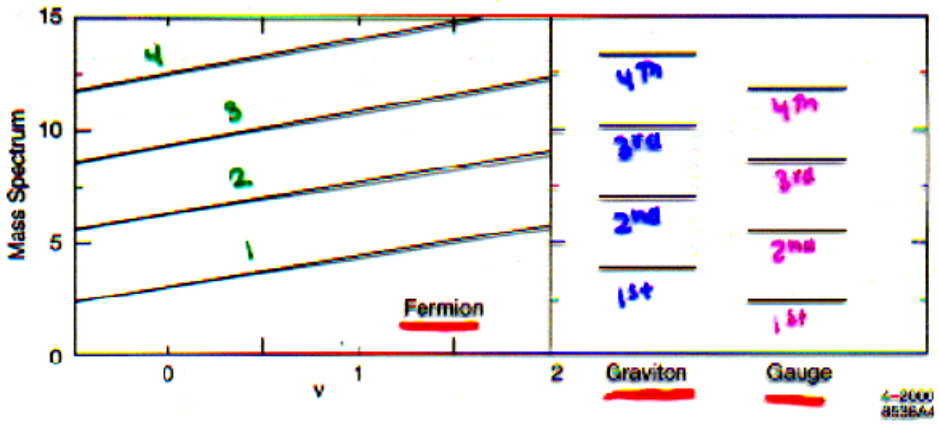
Graviton Coupling to fermions



Gauge Tower to fermion coupling strength



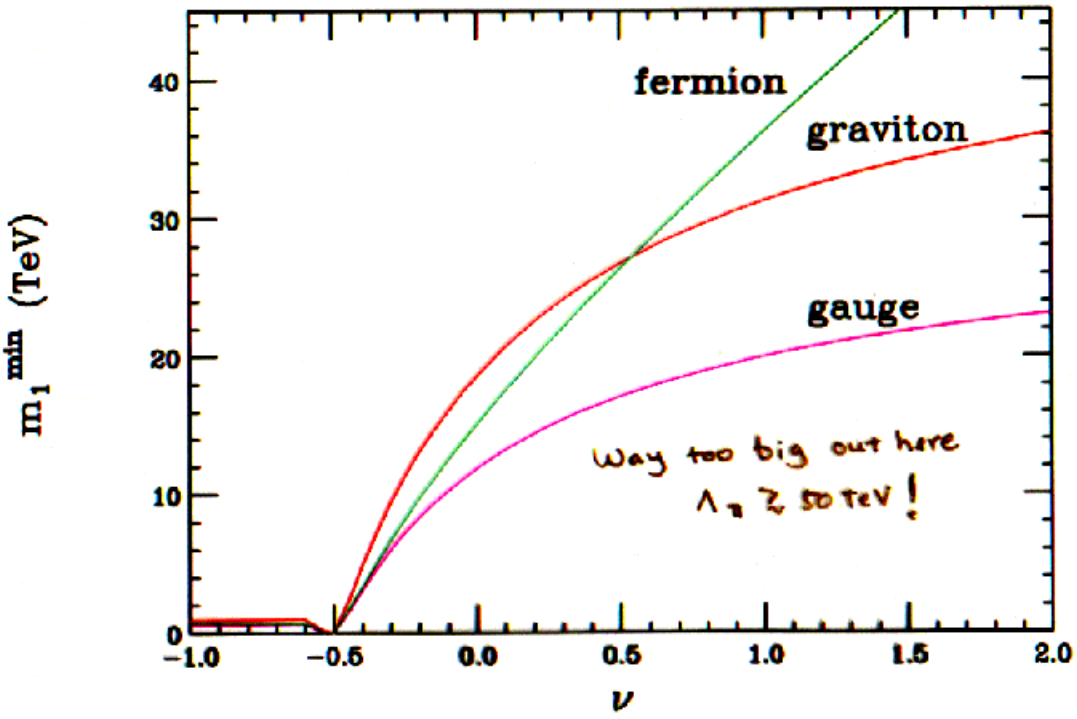
KK Fermion Masses, relative to gravitons + gauges are ν dependent....

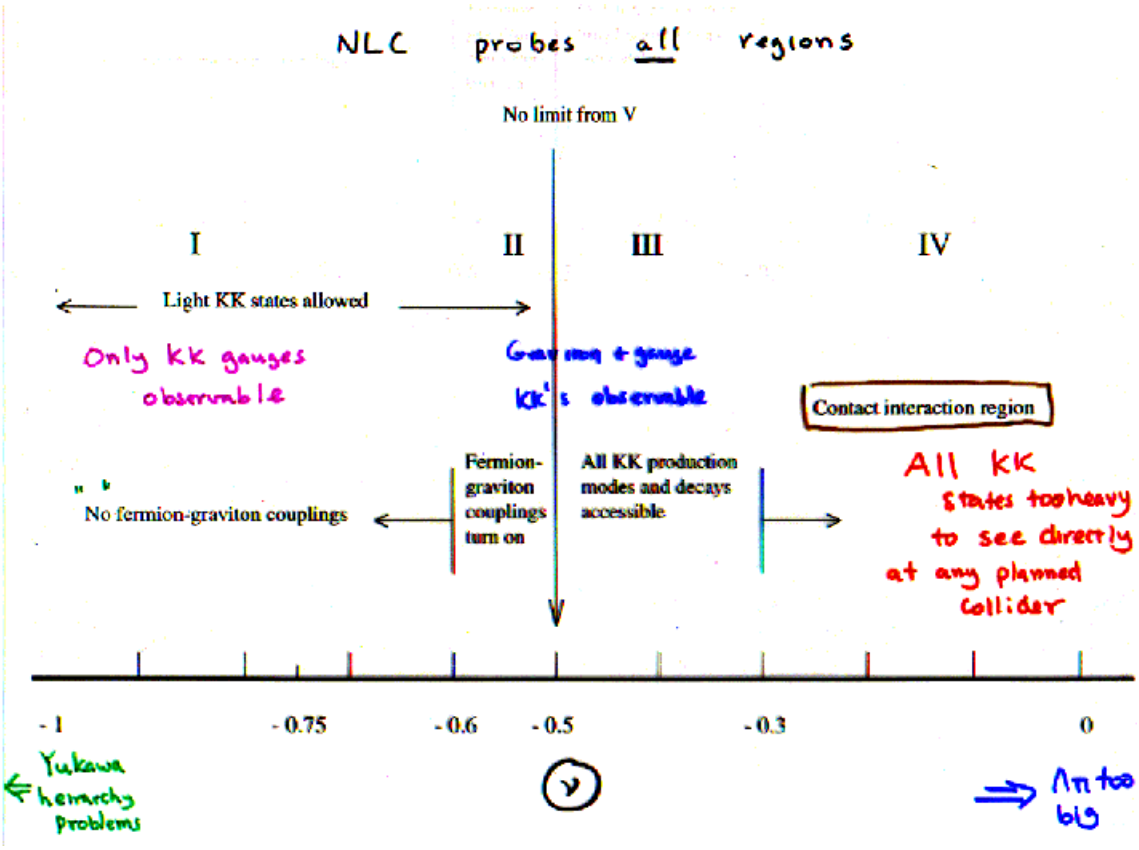


$m_n^f \approx A_n |\nu + \tfrac{1}{2}| + B_n$

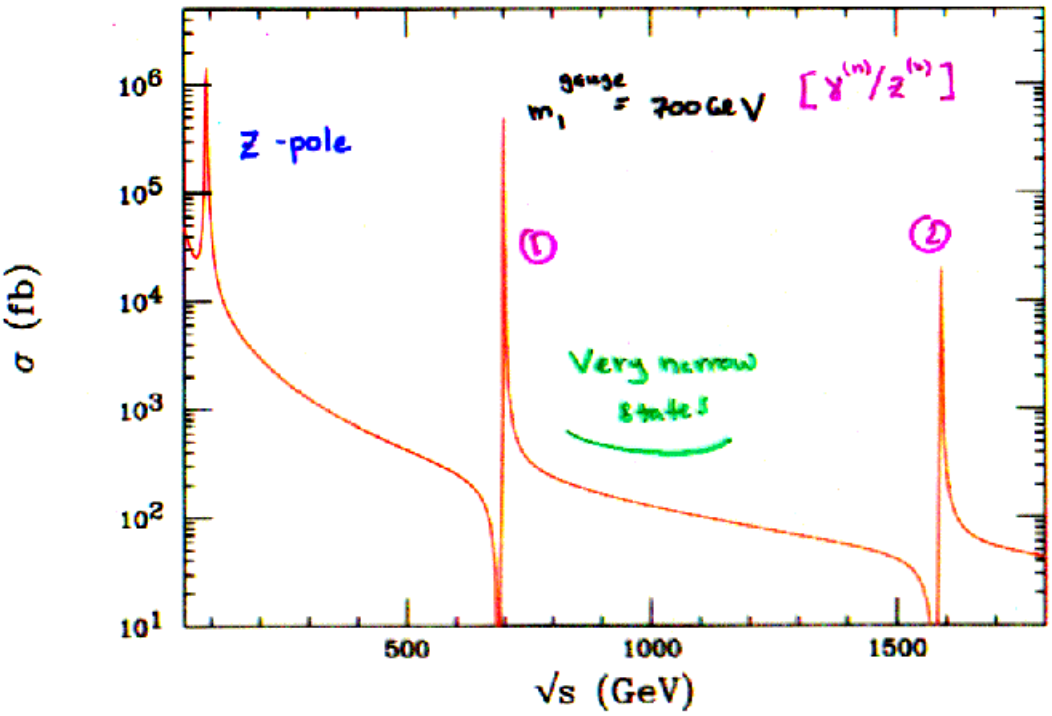
For a fixed ν, specifying any one mass gives all others!!

Precision Measurements Bound on Masses



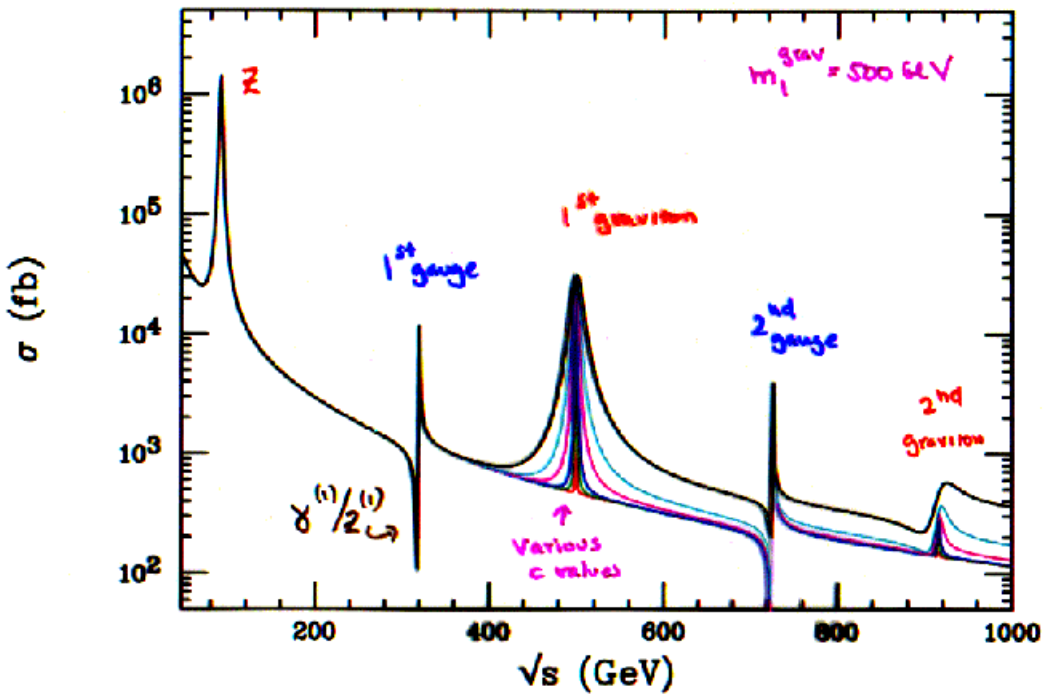

NLC probes all regions
No limit from V
I
II
III
IV
Light KK states allowed
Only kk gauges observable
Graviton + gauge KK's observable
Contact interaction region
No fermion-graviton couplings
Fermion-graviton couplings turn on
All KK production modes and decays accessible
All KK states too heavy to see directly at any planned collider
-1
-0.75
-0.6
-0.5
-0.3
0
Yukawa hierarchy problems
Λn too big

$e^+e^- \to \mu^+\mu^-$ Region I



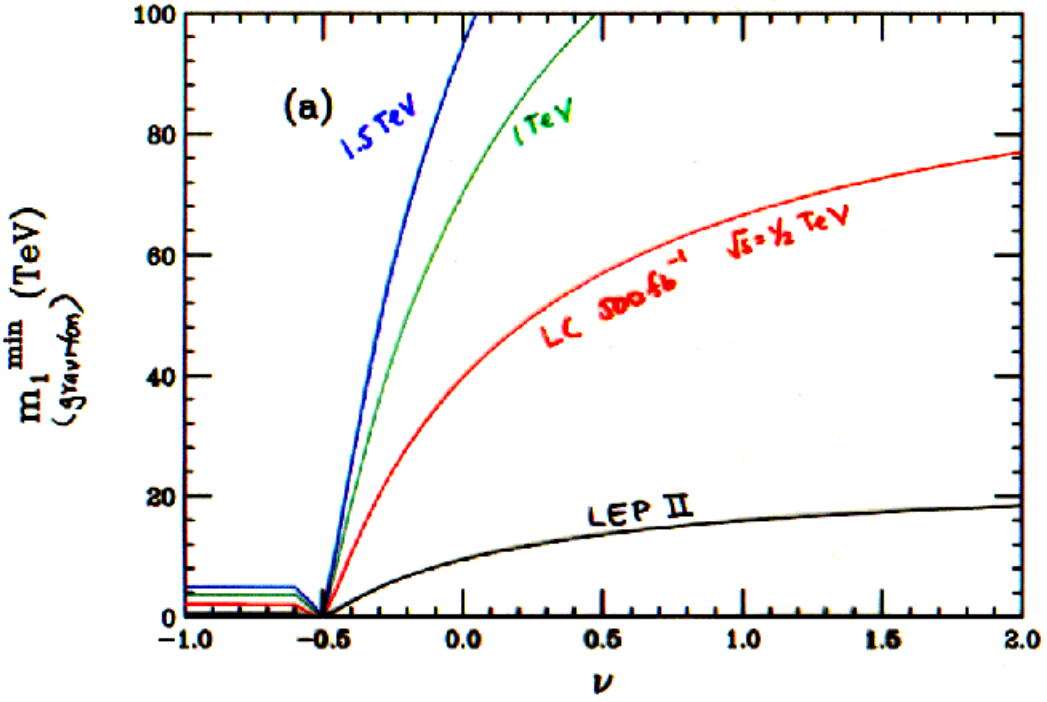
NO graviton resonances BUT there are very narrow gauge KK's

$e^+e^- \to \mu^+\mu^-$ @ LC $\qquad \nu \approx -0.45$



Regions II + III

LC Contact Int. reach { gauge + graviton }



Region IV

Comparisons

	ADD/LED	RS/WED
Deviations from Newton's Law at ~100 μm?	Yes, if n=2 otherwise not	No
Astrophysical Constraints?	Strong if n=2 otherwise not [supernova]	model Dependent [Cosmic Rays]
missing E signals at colliders?	Yes	No
New dim-8 operators from virtual gravitons?	Yes	Yes, if below threshold
Graviton Resonances?	No	Yes
SM in Bulk?	No, unless n>2 and some dimi are TeV scale	Yes

Conclusions :

- LC's can probe important aspects of RS model whether or not SM is on the wall
- Production of BOTH graviton + gauge KK resonances would be extremely interesting ...