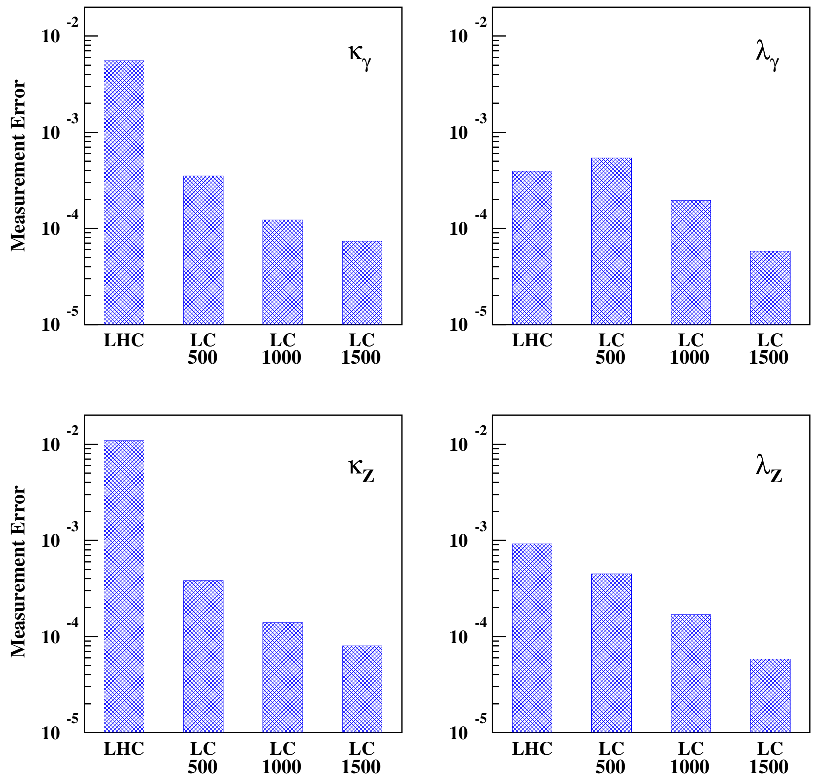
Prospects for Exotics and Extra Dimensions at Future e^+e^- LC

Outline

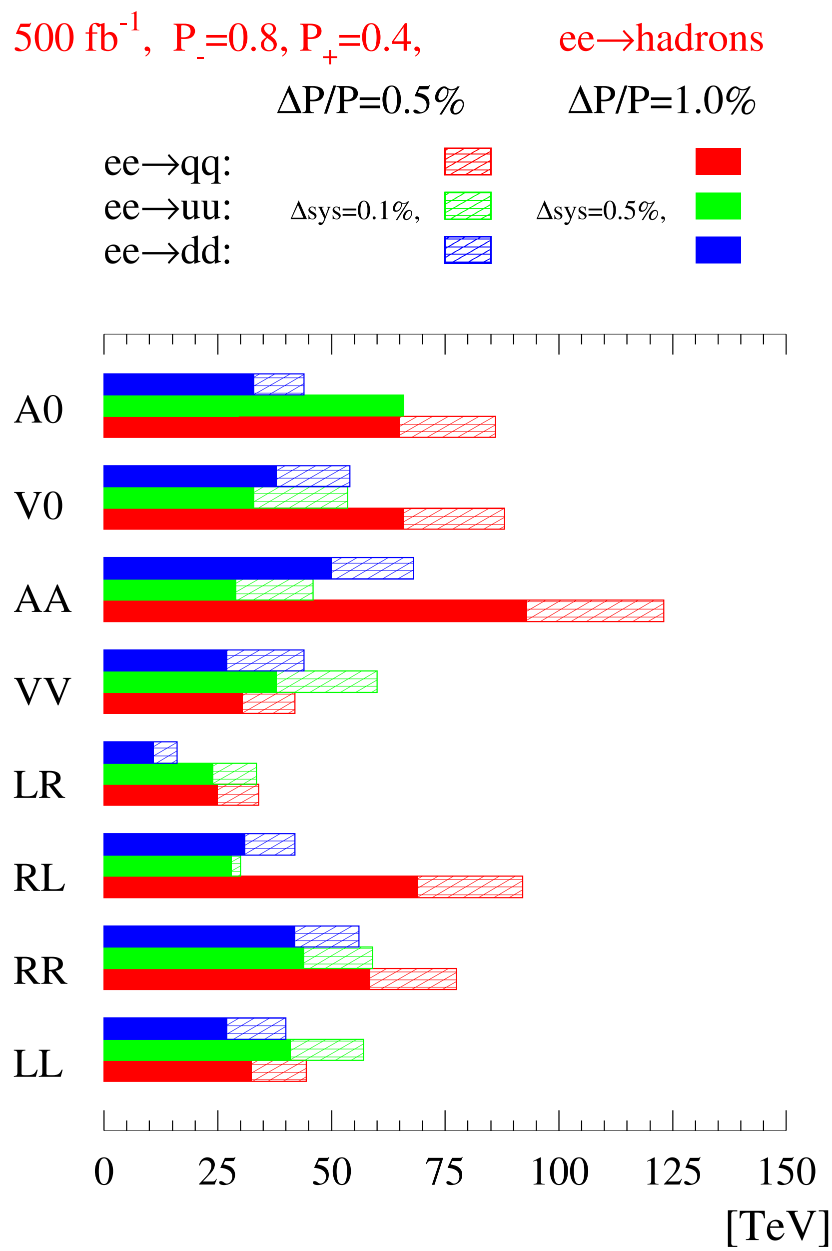
- Comments
- ADD scenario
- Warped extra dimension

Comments

- The LC can do better than LHC when precision (polarization) is needed.
- Detailed study of particle properties.
- Many topics: anomalous couplings, contact interactions, leptoquarks, non-commutative theories, etc.



➪ Four-fermion interactions S. Riemann



➪ LHC $\Longrightarrow$ $\mathcal{O}(20)$ TeV

Extra dimensions

- Are there extra dimensions? Why 4?
- Quantum Mechanics $\oplus$ General Relativity

"$\Longrightarrow$" extra dimensions!

- Natural scale: $M_P = 1/\sqrt{G_N} \simeq 10^{19}$ GeV
- New developments $\Longrightarrow$ lower scale, maybe

TeV's

- How do we discover extra dimensions?
- They are small: $r_c < 190\ \mu$m for $\delta = 2$ Hoyle et al.
- Extra dimensions $\Longrightarrow$ effective 4D theory
- Basic property: Kaluza-Klein excitations

$$\phi(x,y) = \sum_k e^{i\frac{ky}{R}} \phi^{(k)}(x) \quad \rightarrow \quad m_k^2 = m_0^2 + \left(\frac{2\pi k}{R}\right)^2$$

- Degrees of freedom depend on the fields

propagating in the extra dimensions. Model dependent.

ADD Scenario

- δ compact large extra dimensions Arkani-Hamed, Dimopoulos, and Dvali

$$F(r) = \frac{m_1 m_2}{M_S^{2+\delta}} \frac{1}{r^{2+\delta}} \to M_P^2 \simeq M_S^{2+\delta} R^\delta$$

- Can we have $M_S = 1$ TeV?

δ	R	ΔM	
1	10^{13} m	–	excluded
2	1 mm	10^{-3} eV	marginal
6	10 Fermi	10 MeV	OK

- WAIT: this changes the SM phenomenology $\Longrightarrow$ SM particle do NOT propagate in the bulk

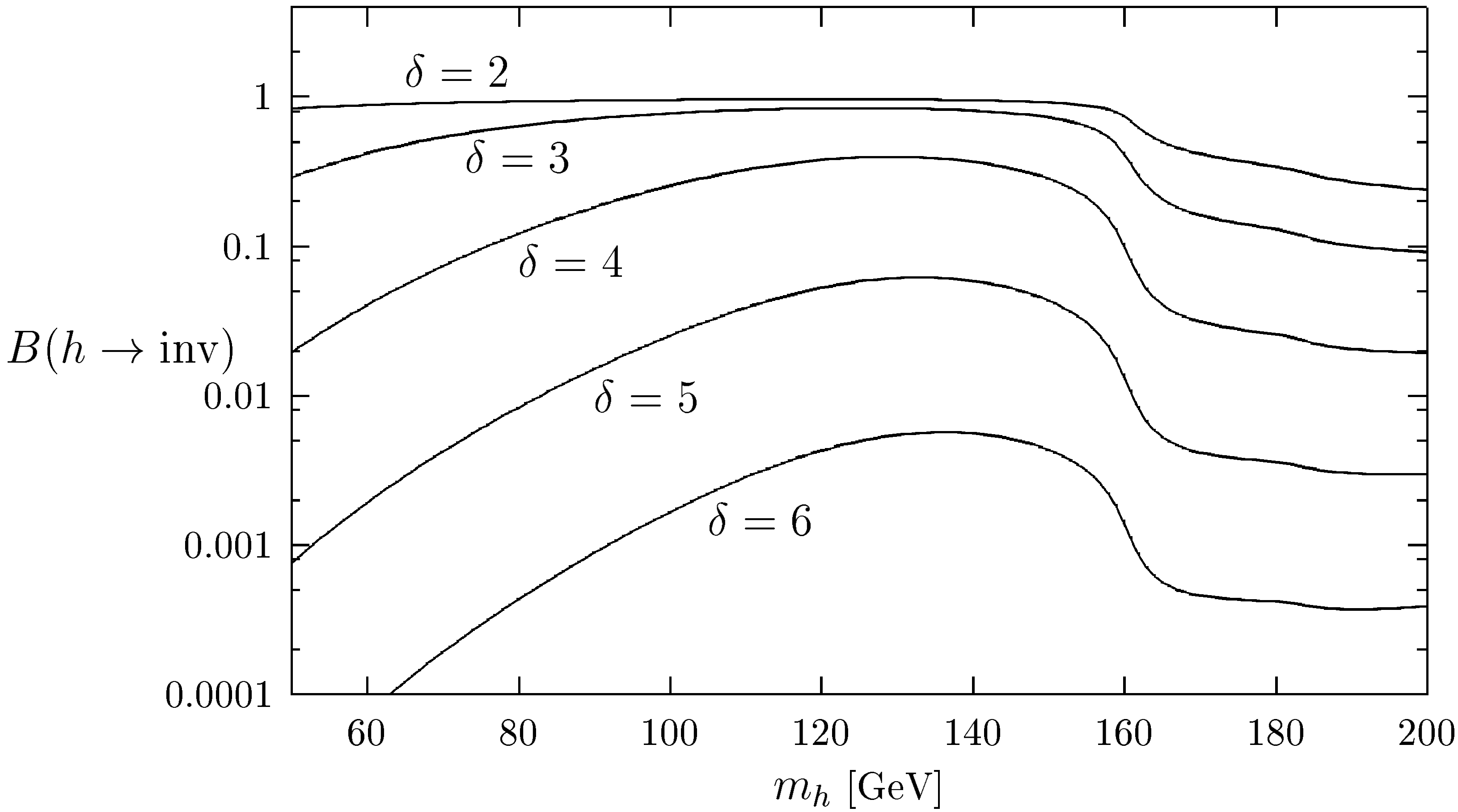
- We will consider only gravitons propagating in the extra dimensions.

- New 4d particles

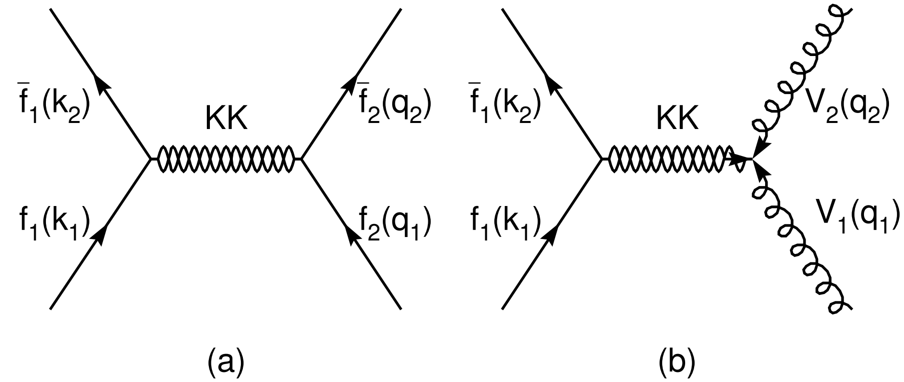
Particle	interaction with SM
spin-2 KK tower	$\frac{1}{\overline{M}_P} h^{(n)}_{\mu\nu} T^{\mu\nu}$
spin-1 KK tower	decoupled
spin-0 KK tower	$\frac{1}{\overline{M}_P} h^{(n)}_0 T^{\mu}{}_{\mu}$

- $h^{(n)}_{\mu\nu}$ and $h^{(n)}_0$ are “stable” at collider energies $\Longrightarrow$ E_{miss}.
- This description should break up at energies larger than M_S

Phenomenology can change with further interactions $\xi R H^2$ Giudice, Rattazi, Wells



➪ Indirect search: KK graviton exchange



➪ Sum over KK modes replaces M_P by M_S.

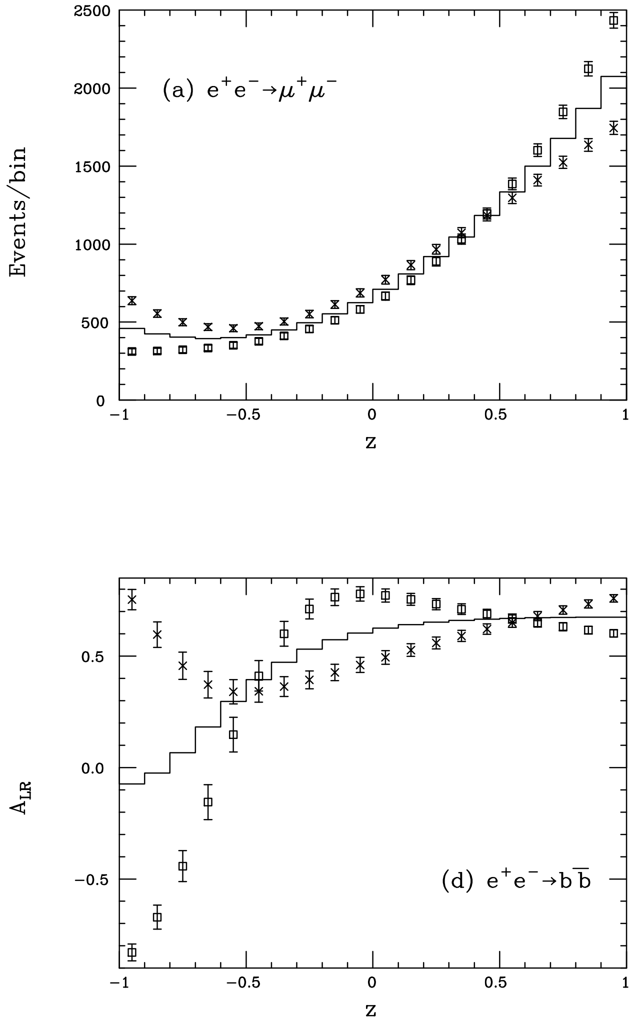
$$\sigma \simeq \sigma_{SM} + \left(\frac{E}{M_S}\right)^4 \tilde{\sigma}_I + \left(\frac{E}{M_S}\right)^8 \tilde{\sigma}_G \qquad \text{insensitive to } \delta$$

➪ Potential bounds at LC Hewett, Rizzo hep-ph/9910255

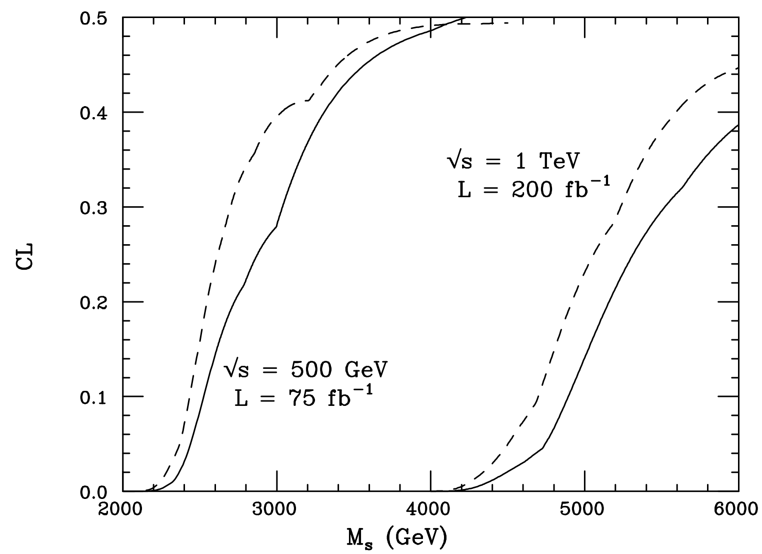
➪ 100 fb^{-1}

$e^+e^- \to f\bar{f}$	$6.5\sqrt{s}$
$e^+e^- \to e^+e^-$	$6.2\sqrt{s}$
$e^+e^- \to \gamma\gamma$	$3.2\sqrt{s}$
$e^+e^- \to WW/ZZ$	$5.5\sqrt{s}$

Determination of the graviton spin



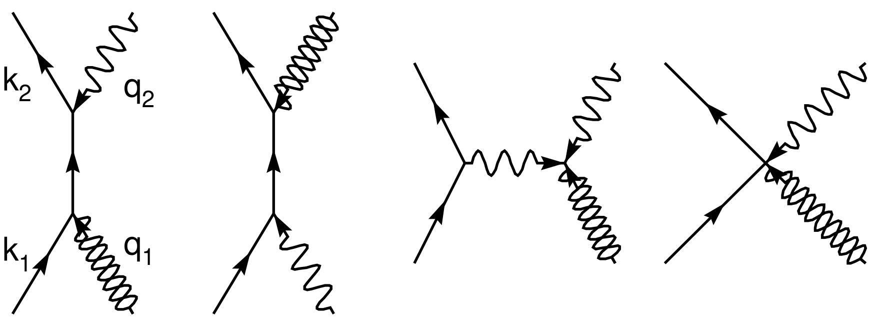
- angular dependence and LR asymmetry Hewett
- CL of spin-1 fit
- λ/M_S^4



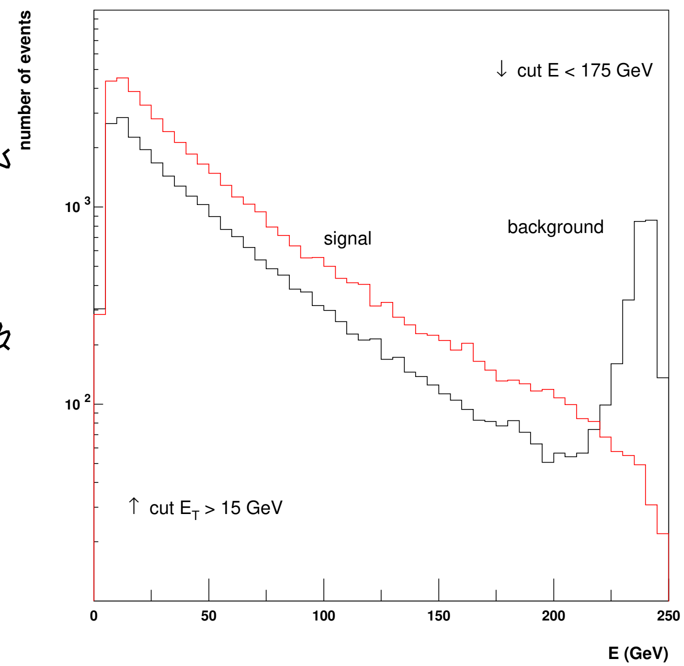
Direct searches: Graviton emission Giudice, Rattazzi, Wells, Mirabelli, Perelstein, Peskin

$$\frac{d^2\sigma}{dt\ dm_G} = \frac{2\pi^{\delta/2}}{\Gamma(\delta/2)}\ \frac{M_P^2}{M_S^{2+\delta}} m_G^{\delta-1} \frac{d\sigma(m_G)}{dt} \Longrightarrow \quad \sigma \simeq \left(\frac{E}{M_S}\right)^{2+\delta} \tilde{\sigma}$$

- $e^+e^- \quad \rightarrow \quad \gamma G^{(n)}$

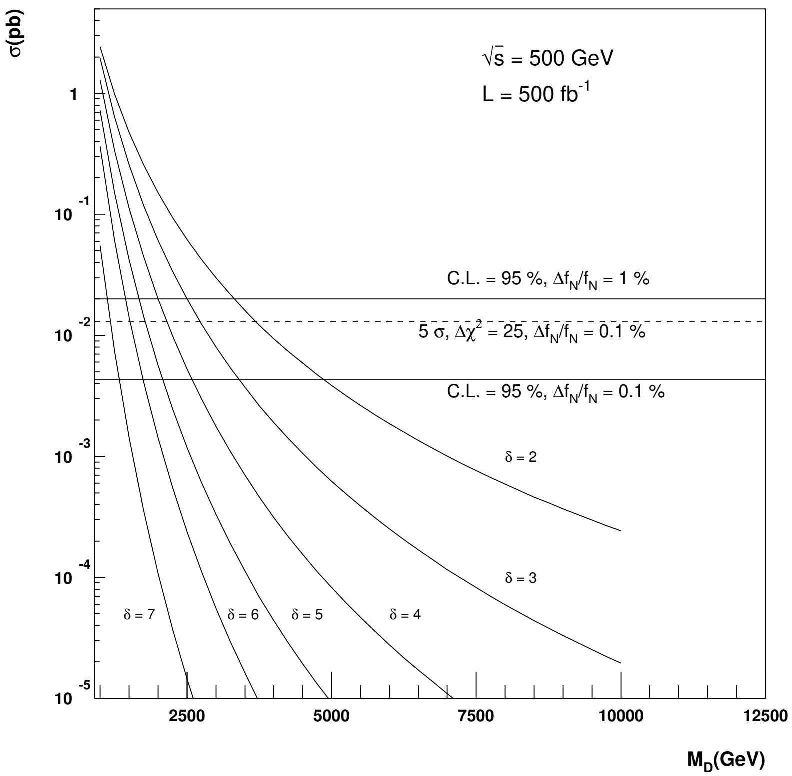


(a) (b) (c) (d)



- Background $e^+e^- \rightarrow \nu\bar{\nu}\gamma$
- $\sigma_{SM} = 5.3$ fb at $\sqrt{s} = 500$ GeV

➪ Attainable bounds Wilson, Vest, Cheung, Keung ...



δ	95% CL (500 fb^{-1})
2	4.8 (7.9) TeV
3	3.4 (5.1) TeV
4	2.7 (3.6) TeV
5	2.2 (2.8) TeV
6	1.7 (2.3) TeV
7	1.3 (1.7) TeV

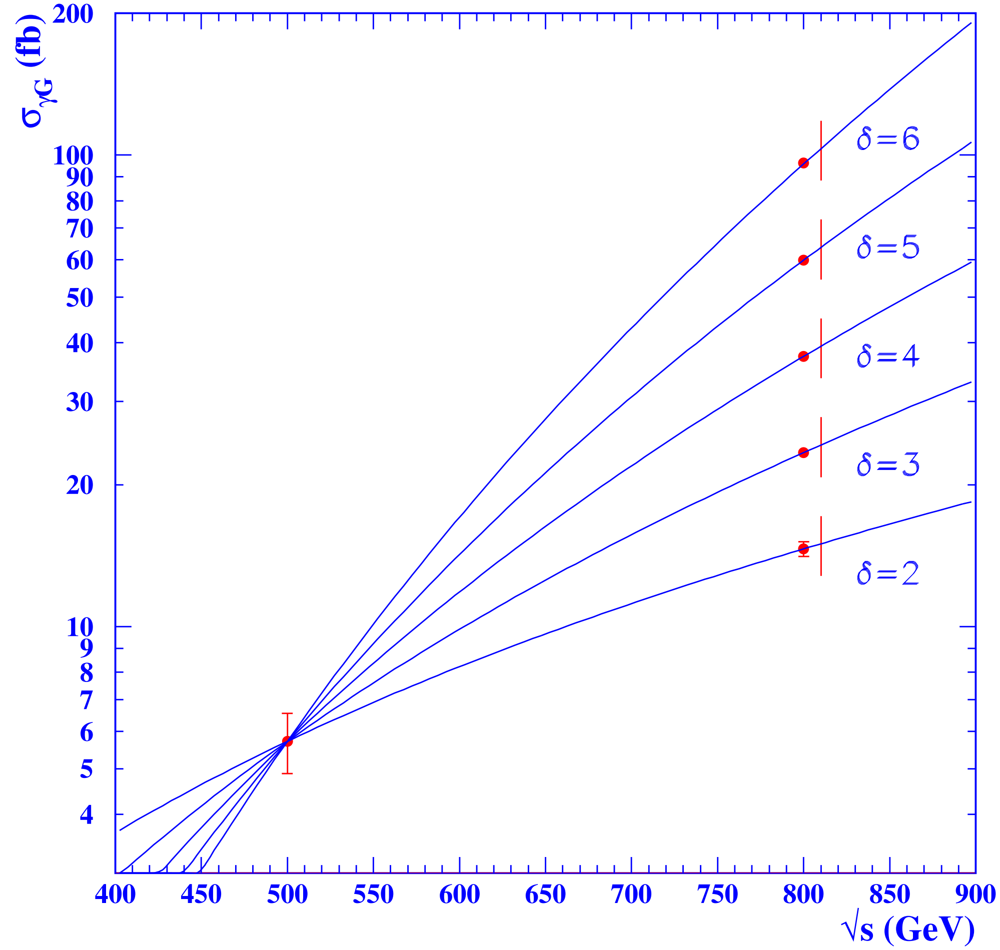
➪ Slower increase on the bounds with $\mathcal{L}$

➪ 50% increase at 800 GeV.

➪ How can we determine δ?Wilson

➪ Use the strong δ and $\sqrt{s}$ dependence of the total cross section!

➪ Measure $\sigma_{\gamma G}$ at 500 and 800 GeV.



$e^+e^- \to f\bar{f}G^{(n)}$

O.E, Magro, Mathews, and Mercadante, hep-ph/0103053

- $f = \mu$ very clean signal.
- $q\bar{q} \implies$ best limits
- SM backgrounds:

$e^+e^- \to WW/ZZ \to \nu\nu f\bar{f}$

$e^+e^- \to \nu\nu Z^\star \to \nu\nu f\bar{f}$

$e^+e^- \to q\bar{q}'[e]\nu$

- Acceptance cuts:

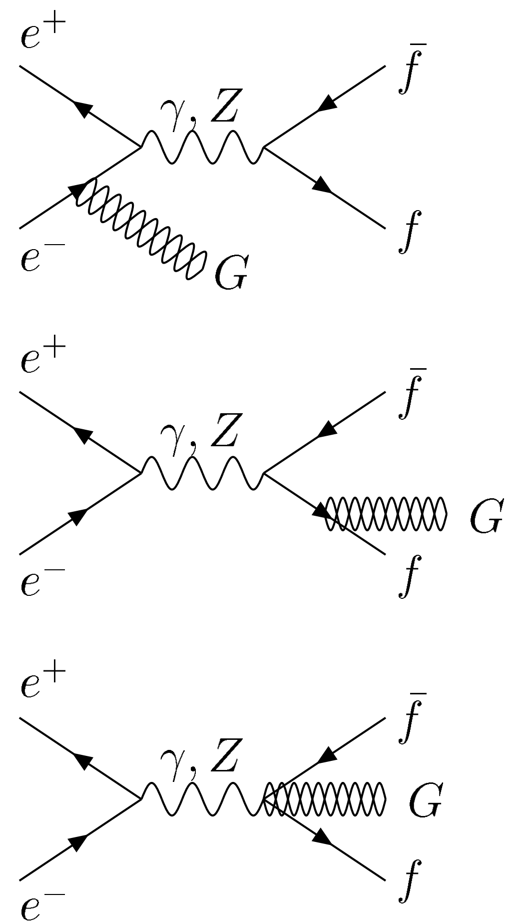
$\not{p}_T > 10$ GeV; $p_T^f > 5$ GeV;

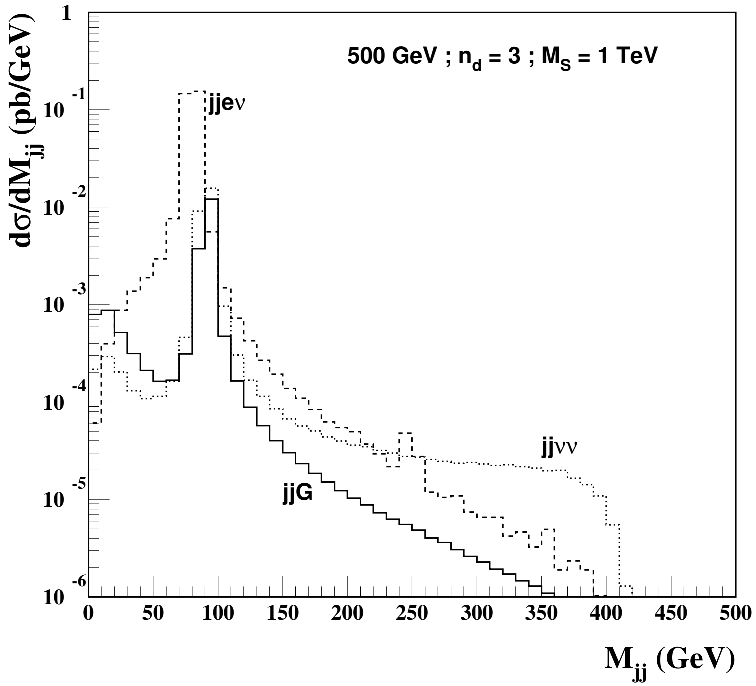
$|\cos\theta^f| < 0.98$; $\Delta R > 0.4$

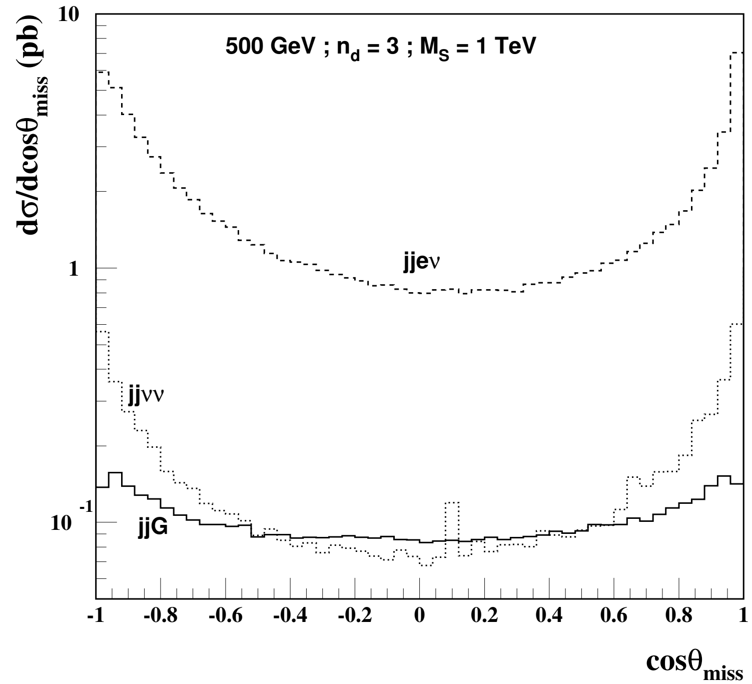
- Hadronic case

$\sigma_{SM} = 286 \oplus 3300$ fb

$\sigma^{1TeV}_{signal} = 700$–$3$ fb





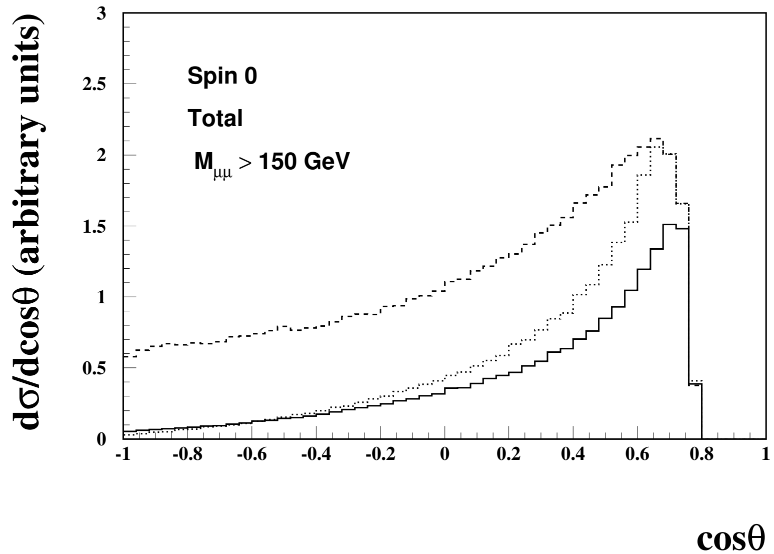


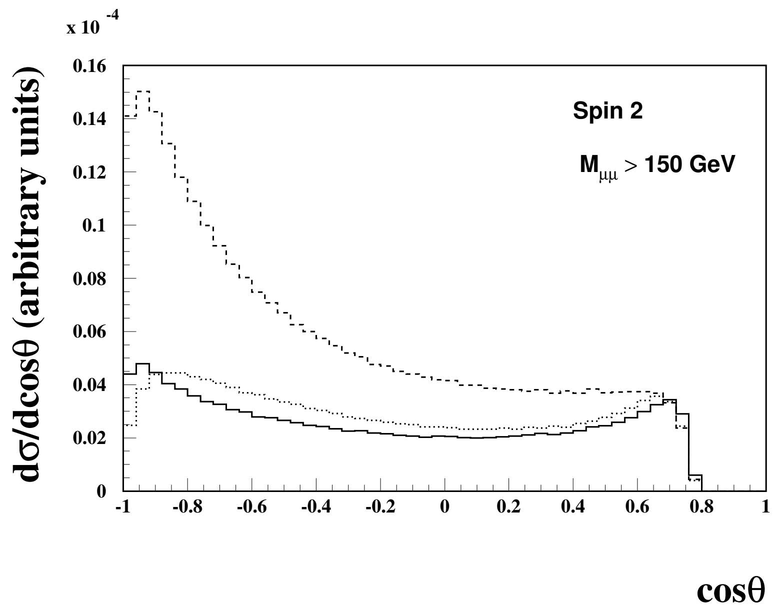
- $M_{jj} > 85$ GeV or < 35 GeV
- $|\cos\theta_{miss}| < 0.8$
- We also eliminate $Z \to \nu\nu$ with $M_{miss} > 200$ GeV.
- $\sigma_{SM} = 285$ fb (factor of 20) and σ_{signal} reduced by less than 2.

- 95% CL bounds

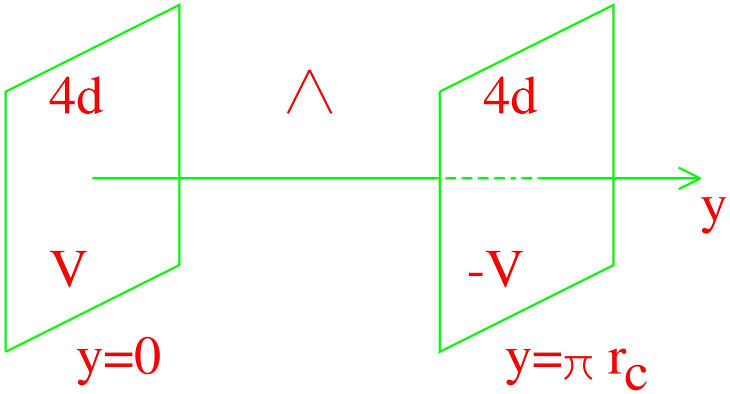
δ	95% CL (500 fb^{-1})
2	4.1 TeV
3	2.5 TeV
4	1.8 TeV
5	1.4 TeV
6	1.2 TeV
7	1.1 TeV

- Possible to determine the spin of the graviton





Warped extra dimension



- 5D non-factorizable geometry Randall and Sundrum
- extra dimension $=S^1/Z_2$ orbifold
- $ds^2 = e^{-2kr_c y}\eta_{\mu\nu}dx^\mu dx^\nu - r_c^2 dy^2$
- $\Lambda = -24M_5^3k^2 = -kV$ and $\overline{M}_P^2 = \frac{M_5^3}{k}(1-e^{-2kr_c\pi})$
- Masses are diluted as $m = m_0\; e^{-kr_c\pi}$
- TeV scales at $y=\pi$ if $kr_c \simeq 12$
- KK gravitons are quite different:

$m_n = x_n k e^{-kr_c\pi} = \mathcal{O}(100$ GeV–TeV$)$ with $J_1(x_n) = 0$

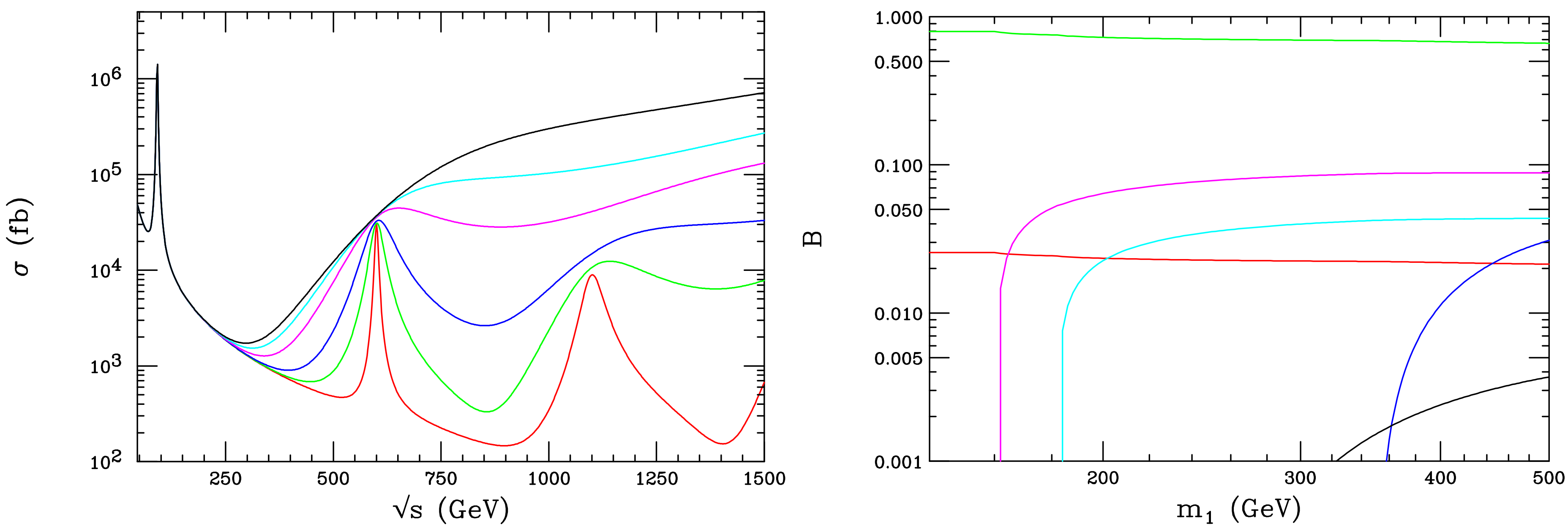
- Interaction with SM particles

$$-\frac{1}{\overline{M}_P} T^{\mu\nu} h^{(0)}_{\mu\nu} - \frac{1}{\Lambda_\pi} T^{\mu\nu} \sum_{n=1}^{\infty} h^{(n)}_{\mu\nu}$$

with $\Lambda_\pi = \overline{M}_P e^{-k r_c \pi}$

- Phenomenological parameters: Λ_π and $k/\overline{M}_P$

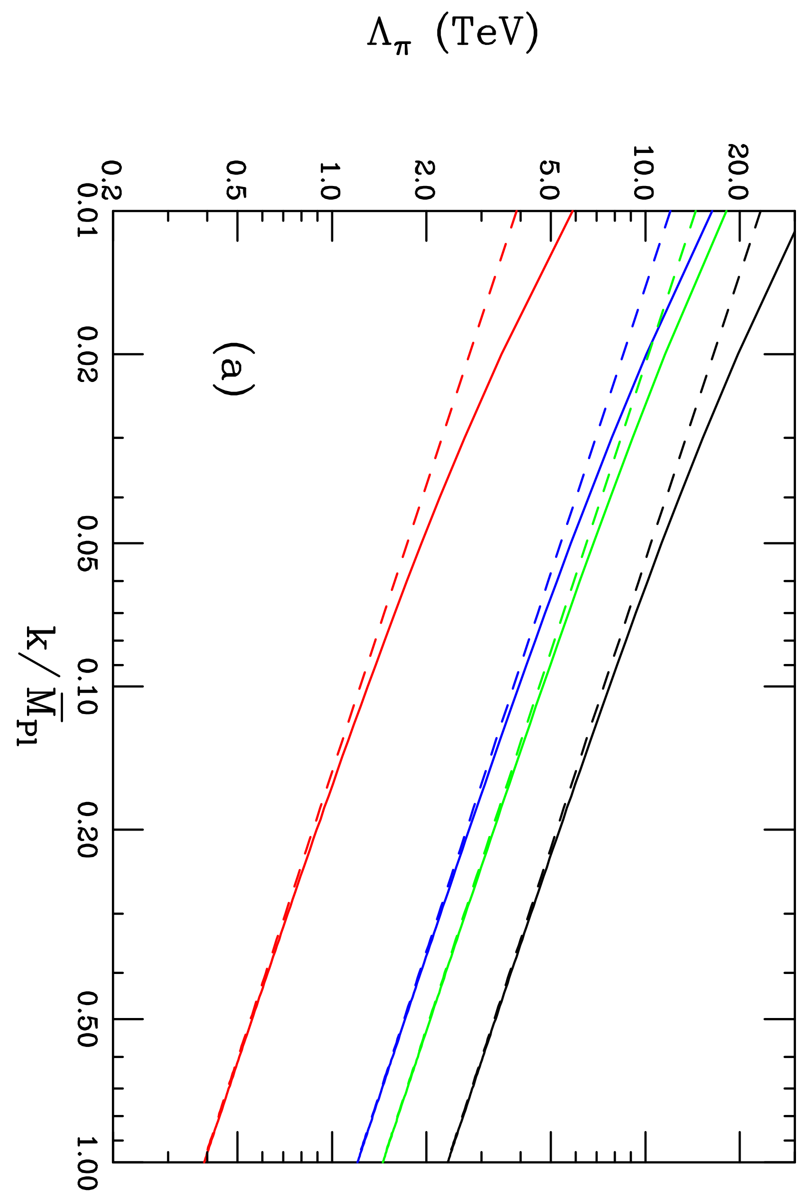
- KK gravitons are individually produced and observable! Davousdiasl, Hewett, Rizzo



- LC can lead to strong bounds

$k/\overline{M}_P$	95% CL Λ_π
0.01	20 TeV
0.1	5 TeV
1	1.5 TeV

- $\sqrt{s} = 500$ GeV and 500 fb^{-1}



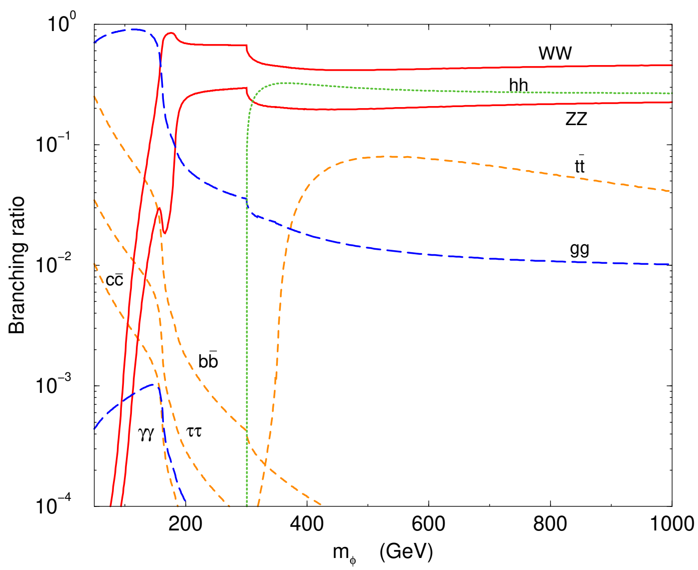
➪ RS model $\Longrightarrow$ 4D massless scalar

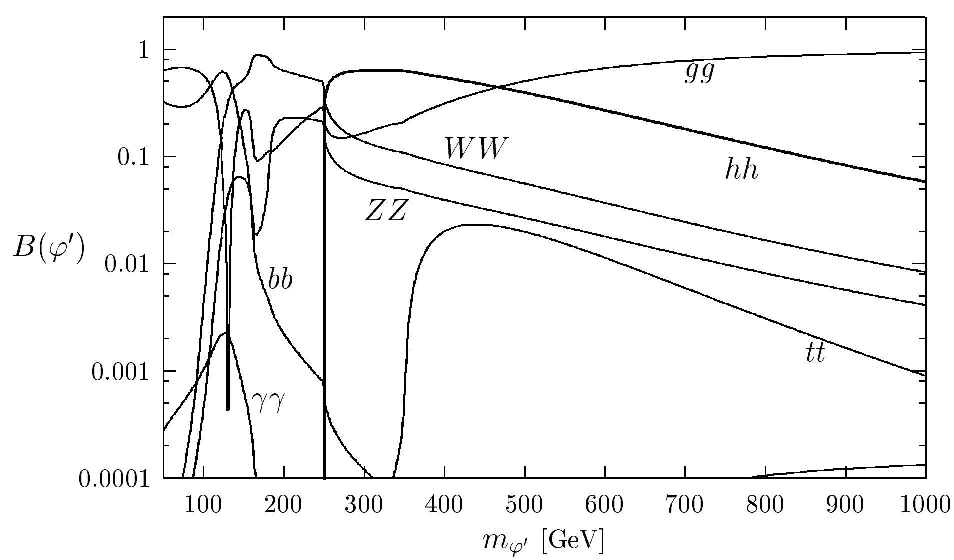
$$ds^2 = e^{-2ky\varphi(x)}\,\eta_{\mu\nu}dx^\mu dx^\nu - \varphi^2(x)dy^2$$

with $\langle\varphi\rangle = r_c$. Stabilization mechanism $\Longrightarrow$ φ acquires a mass.

➪ Radion is the lightest new particle. Its effective interactions are

$$\frac{\varphi}{\Lambda_\varphi}T^\mu_\mu$$





➪ Radions are hard to hide in a LC K. Cheung

➪ Production like a Higgs

$$
\begin{aligned}
e^+e^- &\to Z\varphi \\
e^+e^- &\to \nu\bar{\nu}\varphi \\
e^+e^- &\to e^+e^-\varphi
\end{aligned}
$$

➪ The radion properties can be studied in detail