Probing KK leptons at the ILC

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G.B., P. Dey, A. Kundu, A. Raychaudhuri, Phys Lett B 628 (2005) 141

UED @ LHC: G.B., A. Datta, S.K. Majee, A. Raychaudhuri, Nucl Phys B 821 (2009) 48

A one-slide summary

- UED: all SM particles access the 5th dim.
- $R^{-1} \geq 250$ GeV ($g_\mu - 2$, FCNC, $Z \to b\bar{b}$, ρ)
- Compactification S^1/Z_2. Compactification breaks Lorentz symmetry. Also, translational invariance is lost along y, and $p_5 = n/R$ is not conserved.
- KK parity $= (-1)^n$ conserved (similar to R_p). LKP (γ_1) stable.
- $m_E = \sqrt{m_e^2 + 1/R^2} \simeq m_{\gamma_1}$

  Radiative corrections lift this degeneracy $\Rightarrow E_1 \stackrel{100\%}{\longrightarrow} e\gamma_1$
- $e^+e^- \to E_1^+ E_1^-$, Final state $e^+e^- +$ Missing energy
  Study based on $\sqrt{s} = 1$ TeV (upgraded ILC).
- At LHC, with 100-300 fb^{-1} luminosity, KK states of order 1 TeV can be spotted.
- LHC/ILC synergy very important for distinguishing between different scenarios (e.g. UED spectrum mimics *compressed* SUSY).

Radiative Corrections

(Cheng, Matchev, Schmaltz; Georgi, Grant, Hailu)

- $\mathcal{L}_{\text{kin}} = Z\partial_\mu\Phi\partial^\mu\Phi - Z_5\partial_5\Phi\partial^5\Phi$
- $\partial_5\Phi\partial^5\Phi \Rightarrow m_n = n/R$.
  If $Z = Z_5$, no corrections to KK masses.
- But, $Z \neq Z_5$ due to Lorentz violation $\Rightarrow \Delta m_n \propto (Z - Z_5)$.
- BULK Corrections: When loops can sense comp.,
  $\Delta m_n^2 \sim \beta/16\pi^4 R^2$. ($R \to \infty$, exact Lorentz symmetry).
- ORBIFOLD Corrections: Dominant corrections due to loss of translational invariance, 'localized' at fi xed points,
  $\Delta m_n = m_n(\beta/16\pi^2)\ln(\Lambda^2/\mu^2)$.
- Splitting between E_1 and γ_1 a few GeV.

Mass Splittings

R^{-1}	ΛR	$M_{\hat{\mathcal{E}}_1}$	$M_{\mathcal{E}_1}$	M_{W_1}	M_{Z_1}	M_{γ_1}
250	20	252.7	257.5	276.5	278.1	251.6
	50	253.6	259.7	280.6	281.9	251.9
350	20	353.8	360.4	379.0	379.7	351.4
	50	355.0	363.6	384.9	385.4	351.5
450	20	454.9	463.4	482.9	483.3	451.1
	50	456.4	467.5	490.6	490.8	451.1

Table 1: SU(2) doublets $\mathcal{L}_{L,R}$ vectorial:

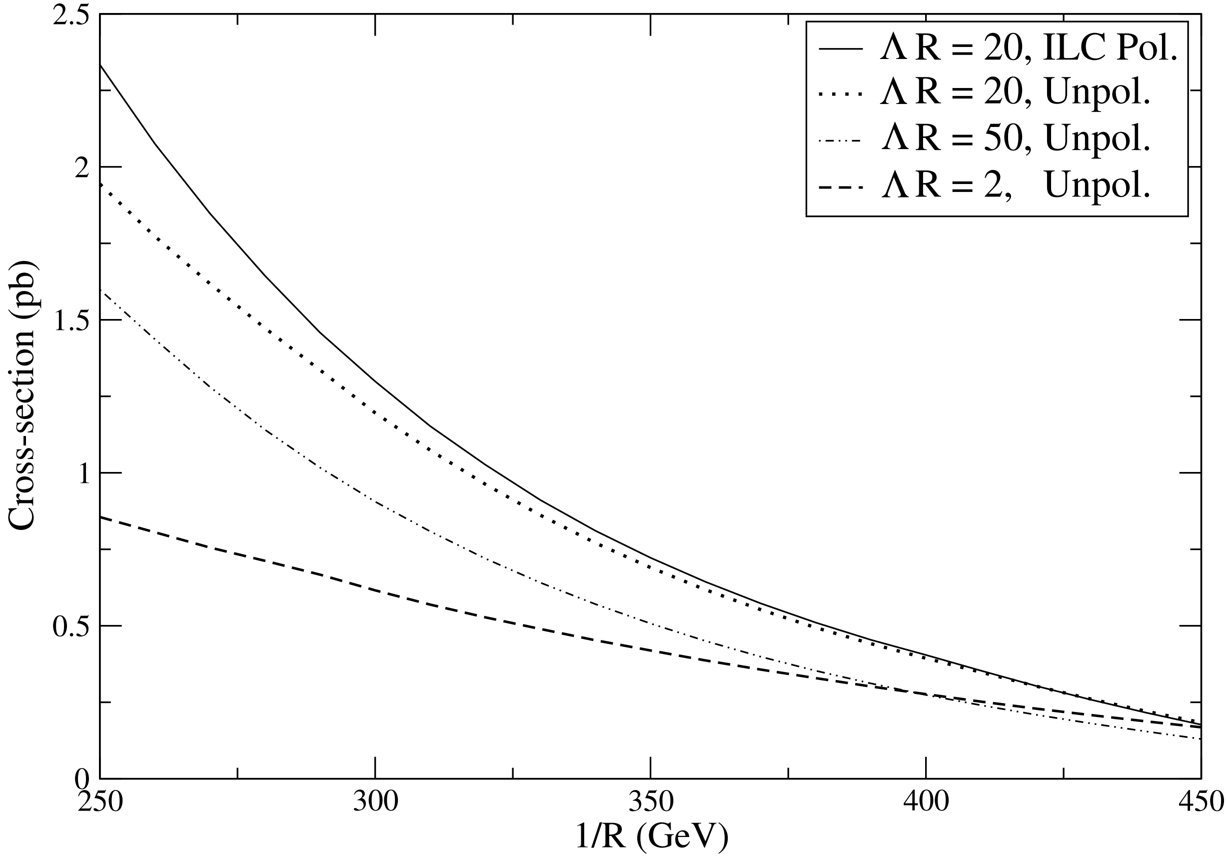
$\mathcal{L} = (\mathcal{N}_n, \mathcal{E}_n)^T$

SU(2) singlets vectorial: $\hat{\mathcal{E}}_{n(L,R)}$.

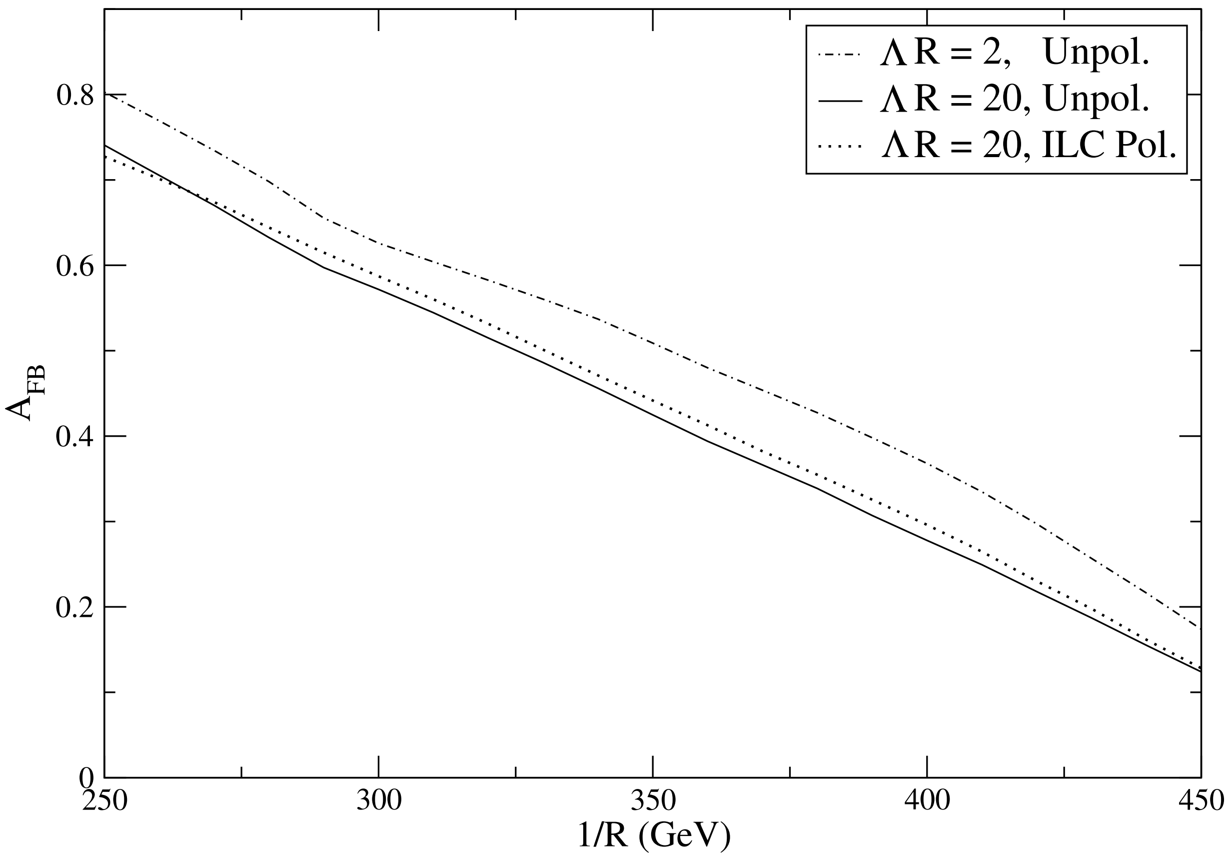
Signal processes

- Pair Production $e^+e^- \to E_1^+ E_1^-$
  $\Rightarrow E_1 \stackrel{100\%}{\to} e\gamma_1$.
- s channel mediated by γ/Z, t channel by γ_1/Z_1 and γ_1^5/Z_1^5.
- Same fi nal state can be obtained by $e^+e^- \to W_1^+ W_1^-$.
- s channel mediated by γ/Z, t channel by $\mathcal{N}_{1L}$.
- Roughly, $\sigma(E_1^\pm) \sim \sigma(W_1^\pm)$, but for the latter there is a BR suppression ($1/9$) into specifi c flavor.
- We can vary initial polarizations. ILC benchmark: 80% for electron, 50% for positron.

Cross sections



Forward-backward asymmetries



Standard Model background

- Two-photon events constitute a serious background ($\sigma \sim 10^4$ pb).

  $$e^+e^- \to e^+e^- \, (\rightsquigarrow \text{ Missing energy}) + \gamma^*\gamma^* \, (\rightsquigarrow \text{ soft } e^+e^-)$$

  Such background can be reduced by studying FB asymmetry, and acoplanarity w.r.t. the beam direction.

- $e^+e^- \to (WW, ZZ, e\nu W, eeZ, \cdots) \to e^+e^- + \not{E}$

- Rapidity cuts: $15^\circ < \theta < 165^\circ$

  Energy cuts: $0.5 < E_e < 20$ GeV.

♣ Or, count $\mu^+\mu^- +$ Missing Energy events, which serve as normalisation of e^+e^-.

Discriminating UED from SUSY

♣ How to distinguish $e^+e^- \to E_1^+ E_1^-$ from $e^+e^- \to \tilde{e}^+\tilde{e}^-$ by looking at $e^+e^- +$ Missing energy?

$\Longrightarrow$ Angular distribution (Toy scenario: t-channel only)

$$\frac{d\sigma}{d\cos\theta}(FF:SS) \quad \sim \quad \frac{A + B\cos\theta + C\cos^2\theta}{\sin^2\theta}$$

Chargino production can be controlled by tuning polarizations.

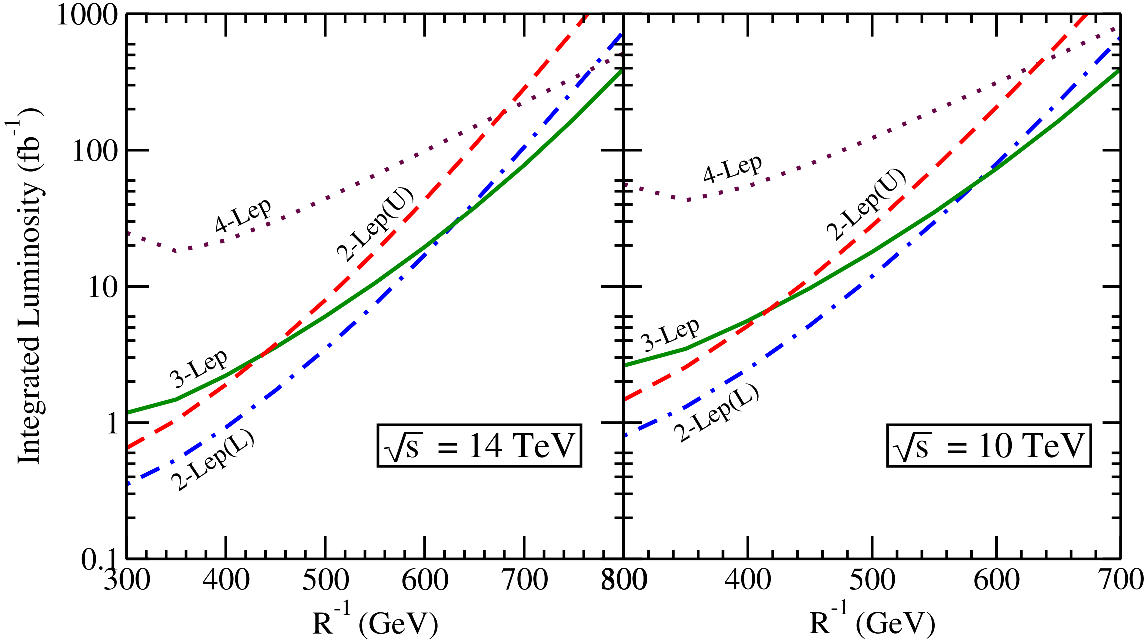
♣ UED cross section is 4 to 5 times larger than SUSY cross section for similar couplings and masses.

LHC/ILC synergy

- LHC is a discovery machine. Precision studies will have to be done at ILC. Relation between ILC and LHC is similar to LEP and UA1/UA2.
- Accuracy of slepton/klepton mass measurement $\Delta m \sim 5$ GeV at LHC, but (0.2 - 1) GeV at ILC.
- Spin correlation can be used to discriminate between UED and SUSY. Difficult at LHC, since reconstruction of rest frame of decaying particles very difficult in the presence of large missing energy. If SUSY spectrum is compressed like UED, it is hard to discriminate (Barr; Smillie and Webber).
- γ_2, Z_2 resonant production possible through KK no violating couplings. Studied in the context of LHC (Datta, Kong, Matchev), and ILC (Bhattacherjee, Kundu).
- γ_2, Z_2 'resonant' production through combined effects of ISR and *beamstrahlung*. From simultaneous study of their decays into dijets and the decay of $Z^1 Z^1$ pair into $4\ell +$ missing energy, 'concrete' statements about UED can be made (Bhattacherjee, Kundu, Rai, Raychaudhuri).

LHC reach

- $\sigma(Q^1Q^1) > \sigma(Q^1V^1) > \sigma(V^1V^1)$
- Final state: $n(1-4)$ leptons, only 1 jet, Missing energy (2 γ_1).
- Reach of R^{-1}: 700-800 GeV for $\mathcal{L} =$ 100-300 fb^{-1}.



Conclusions

- KK electrons will give forward-peaked events due to t-channel dominance. FB asymmetries will be large. Careful analysis required to control backgrounds. Polarizations might be useful.
- Study of angular distributions help discriminating different scenarios. Even if discovered at LHC ($\sim$ 1 TeV KK states), to decipher *what they actually are* we need ILC.
- Indirect effects: KK states can alter $gg \to h \to \gamma\gamma$.

  Flat: Petriello; Datta and Rai
  Warped: Cacciapaglia, Deandrea and Llodra-Perez; Bhattacharyya and Ray.