Probing Kaluza-Klein leptons at the International Linear Collider

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hep-ph/0502031, PLB 628 (2005) 141

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 $= (-1)^n$ is conserved (similar to SUSY R_p) LKP (γ_1) is stable.
- $m_E = \sqrt{m_e^2 + 1/R^2} \simeq m_{\gamma_1}$
  Radiative corrections lift this degeneracy $\Rightarrow E_1 \overset{100\%}{\longrightarrow} e\gamma_1$
- $e^+e^- \to E_1^+ E_1^-$, Final state $e^+e^- +$ Missing energy
  Study based on $\sqrt{s} = 1$ TeV (upgraded ILC).

Radiative Corrections

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

- $\mathcal{L}_{\rm kin} = Z\partial_\mu\Phi\partial^\mu\Phi - Z_5\partial_5\Phi\partial^5\Phi$
- $\partial_5\Phi\partial^5\Phi \Rightarrow m_n = n/R$.
  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 fixed 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:

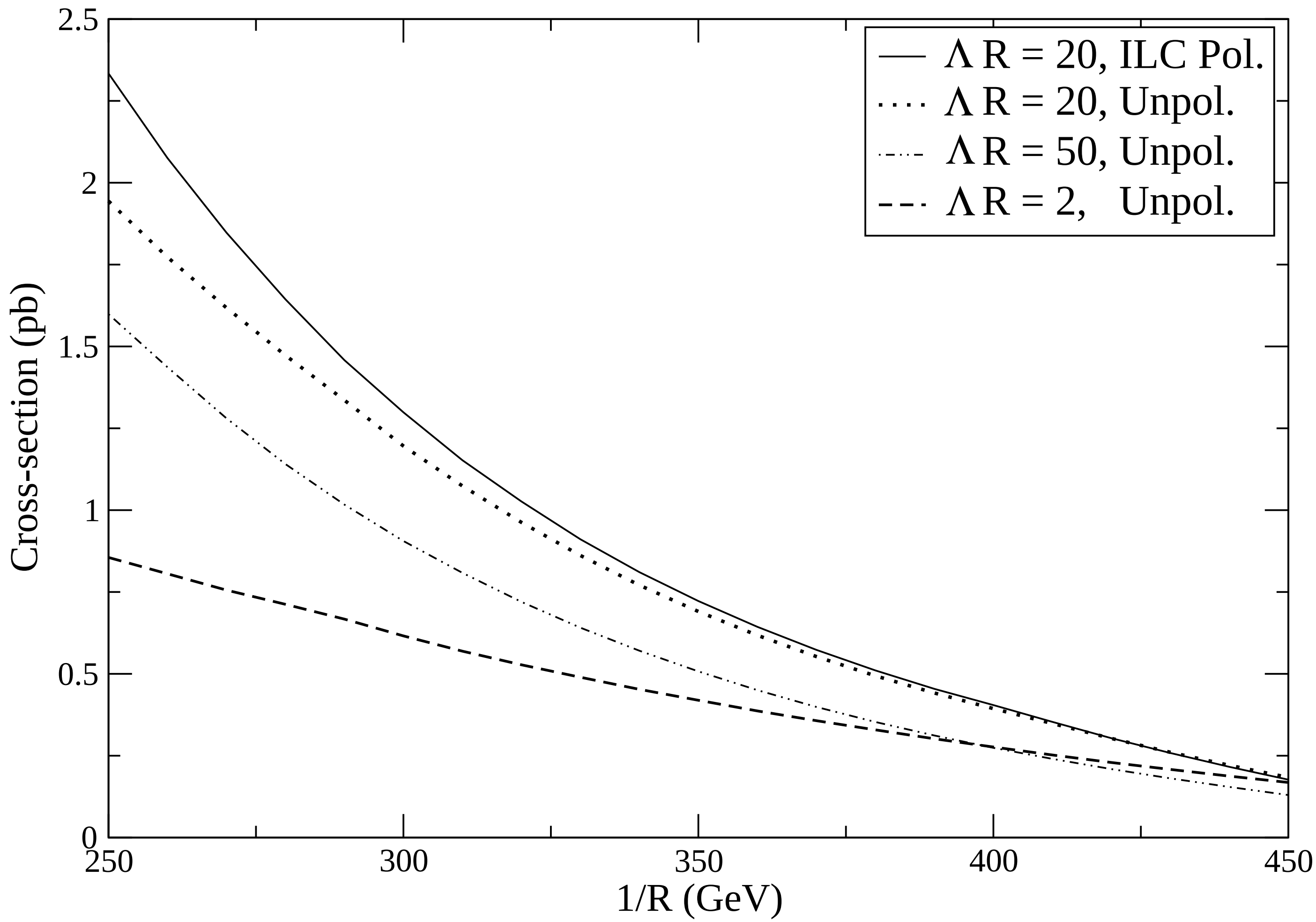
$\mathcal{L} = (\mathcal{N}_n, \mathcal{E}_n)^T$

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

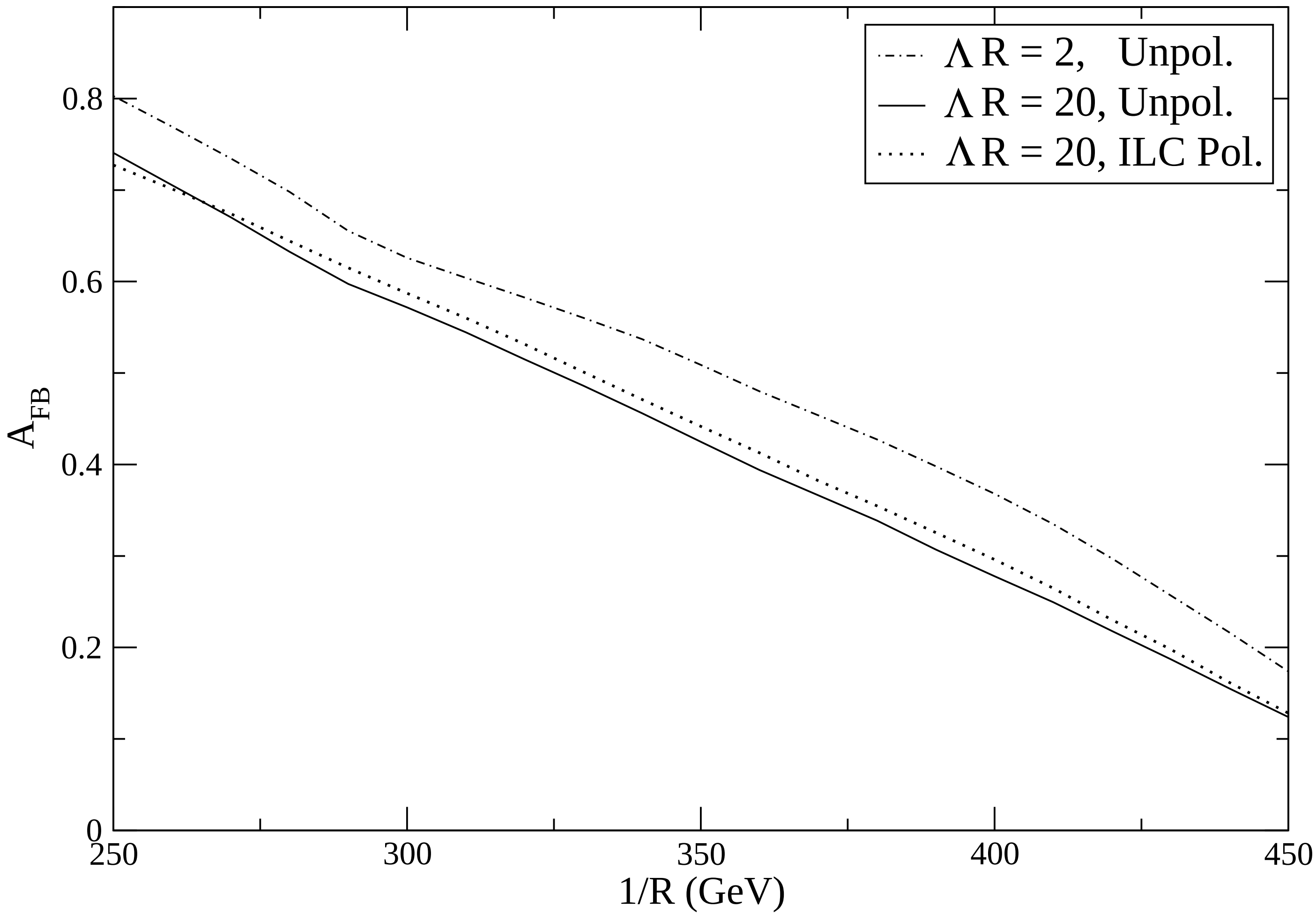
Signal processes

- Pair Production $e^+e^- \to E_1^+ E_1^-$
  $\Rightarrow E_1 \stackrel{100\%}{\longrightarrow} e\gamma_1$.
- s channel mediated by γ/Z, t channel by γ_1/Z_1 and γ_1^5/Z_1^5.
- Same final 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 specific 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.

Discriminating UED from SUSY

Ques: 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?

Ans: Angular distribution (Toy scenario: t-channel only)

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

Chargino production can be controlled by tuning polarizations.

LHC/ILC synergy

- LHC is a discovery machine. Precision studies will have to be done at ILC.
- 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 hadron collider! Some studies have been done (Smillie, Webber [hep-ph/0507170]).
- γ_2, Z_2 resonant production possible through KK no violating couplings. Studied in the context of LHC (Datta, Kong, Matchev [hep-ph/0509246]), and ILC (Bhattacherjee, Kundu [hep-ph/0508170]).

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.
- KK states are to be discovered at LHC, but for their precision measurements ILC is a must!
- Indirect effects: KK top quark loop can alter $h \to gg$. Study of $\sigma(e^+e^- \to l^+l^- \ + \ 2 \, \mathrm{jets})/\sigma(e^+e^- \to l^+l^- \ + \ b\bar{b})$ might reveal some effects! (Datta, Rai [hep-ph/0509277]).