Tracking down the (un)usual suspects

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ALCPG 07, Working Group IV:
Charged Particle Momentum Measurement,
V0 Reconstruction,
Identification of Stable Charged Particles

"Likely" challenges for track measurement at ILC

Theorists always want the **perfect detector**, but **how perfect** does it need to be?

Signatures, observables and desired precision strongly depend on **model for new physics**

→ Try to capture some of the main issues

→ Might serve as guideline for discussing detector design requirements

Maybe not all signals that I discuss actually are a problem for the detector design!

- Track momentum measurement for **soft leptons**
- **Lepton ID** at high energies: small signal of large backgrounds
- **Precision measurements** of masses
- Tracking in the **forward/backward** region of the detector
- Identification and measurement of **tau leptons**

Soft leptons

Several models predict **almost degenerate** new particles with **conserved quantum number**

$\longrightarrow$ Lightest new state X is stable,
next-to-lightest state decays into X and soft leptons/hadrons

Examples:

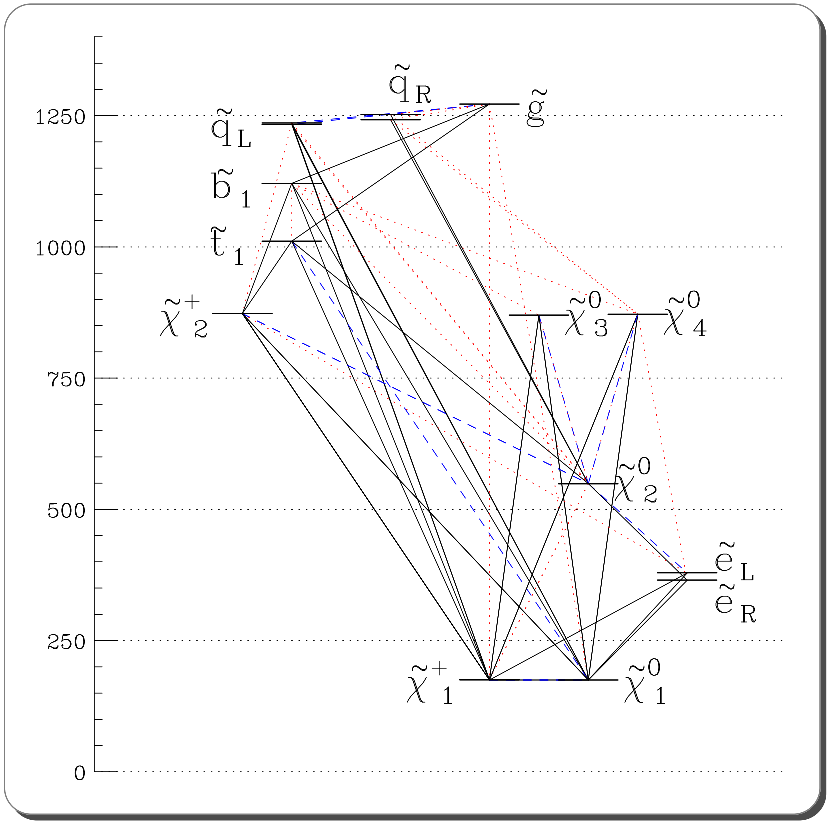
Barr et al. '02

- Anomaly mediated SUSY breaking:

  Chargino $\tilde{\chi}_1^{\pm}$ is almost degenerate with neutralino $\tilde{\chi}_1^0$.
  Typical mass differences
  $\Delta m \equiv m_{\tilde{\chi}_1^{\pm}} - m_{\tilde{\chi}_1^0}$: a few 100 MeV.

  For $\Delta m \lesssim 200$ MeV: visible $\tilde{\chi}_1^{\pm}$ tracks

  For $\Delta m \gtrsim 200$ MeV: $\tilde{\chi}_1^{\pm}$ decays promptly, but soft products



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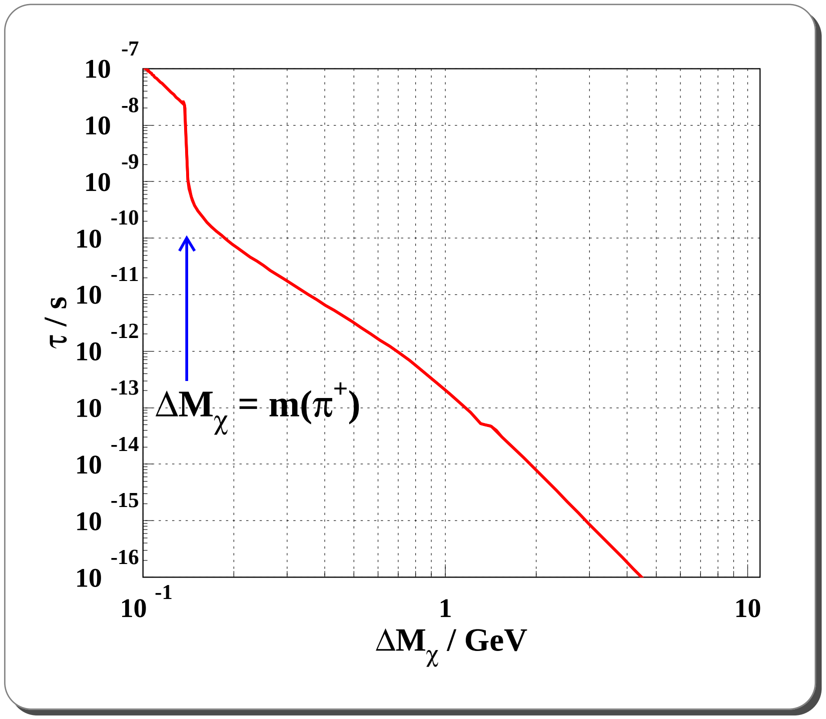


Soft leptons

- Universal extra dimensions: Appelquist, Cheng, Dobrescu '01

  Each SM particle is accompanied by tower of Kaluza-Klein excitations

  At **tree-level** the n-th KK particles have degenerate mass $m_n = n/R$
  ($R =$ size of compact extra dimension)

  Loop corrections lift degeneracy by several per-cent, but there is also unkown effect of **fundamental high-energy theory**
  $\longrightarrow$ Mass differences of **per-mille** level possible

Challenges:

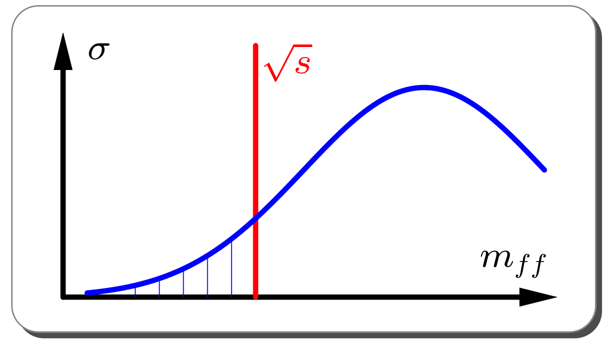
- Find tracks with 200 MeV $< p <$ 1 GeV
- Measure their momemtum (important for understanding model)
- Distinguish $e, \mu, \tau, \pi^{\pm}$

High energy lepton ID

Small new physics excess w/o kinematic features over SM background

Example: contact interactions through heavy gauge bosons $M_{Z'} > 1$ TeV

- Small Z–Z' mixing
  $\longrightarrow$ negligible effect on Z-pole data



- Propagator effects of Z' modify

$$e^+e^- \xrightarrow{\gamma, Z, Z'} f\bar{f}$$

$\longrightarrow$ High luminosity 500–1000 fb^{-1} allows sensitivity for $M_{Z'} \gg \sqrt{s}$

- Sensitive observables:
  - total cross-section σ_{tot}
  - forward-backward asymmetry A_{FB}
- With beam polarization
  - left-right asymmetry A_{LR}
  - polarization asymmetry A_{pol}

$$A_{\text{FB}} = \frac{\sigma_{\text{F}} - \sigma_{\text{B}}}{\sigma_{\text{tot}}}$$

$$A_{\text{LR}} = \frac{\sigma_{\text{L}} - \sigma_{\text{R}}}{\sigma_{\text{tot}}}$$

$$A_{\text{pol}} = \frac{(\sigma_{\text{L}} - \sigma_{\text{R}})_{\text{F}} - (\sigma_{\text{L}} - \sigma_{\text{R}})_{\text{B}}}{\sigma_{\text{tot}}}$$

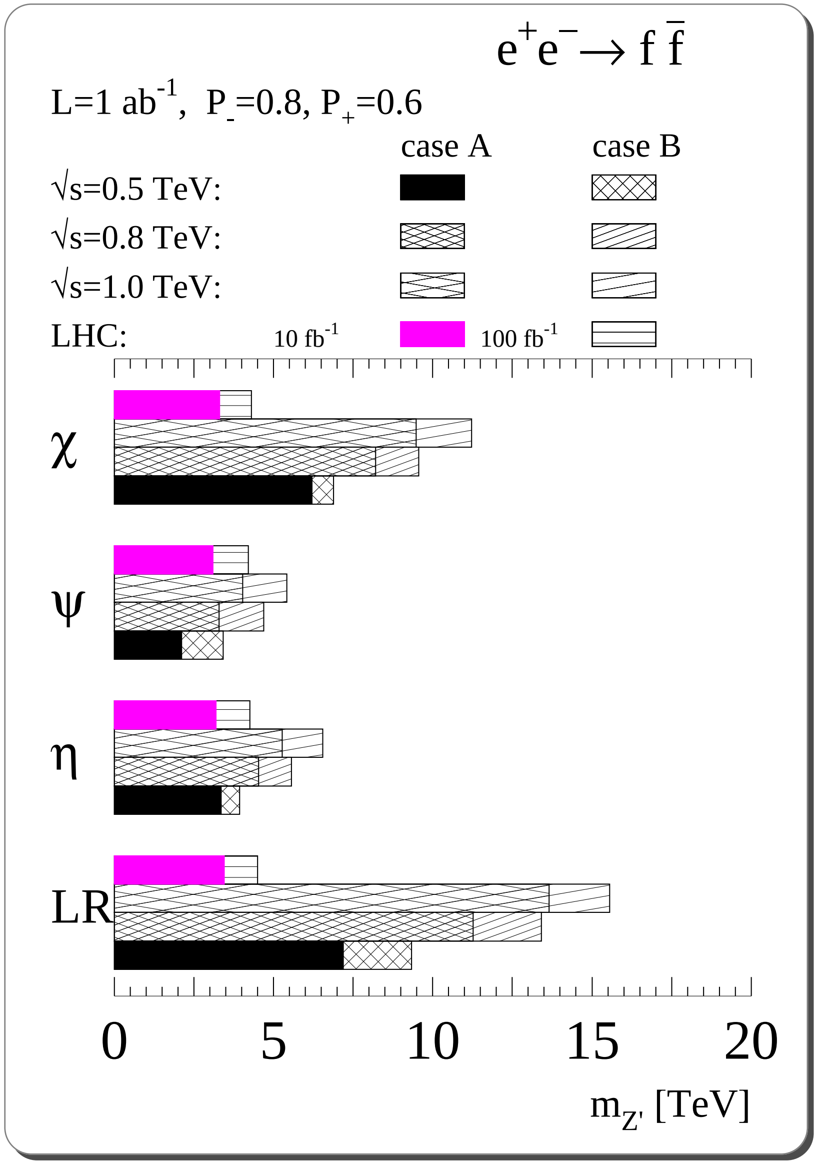
High energy lepton ID

- Look for deviations from SM background

$$e^+e^- \xrightarrow{\gamma^*, Z^*} f\bar{f}$$

Challenges:

- How well can we identify leptons at $p_l \sim 500$ GeV ?
- Can hard hadrons fake $\mu^{\pm}$s?
- Can we distinguish $e^{\pm}, \tau^{\pm}$ from hadrons?



case A,B : different assumptions about sys. errors

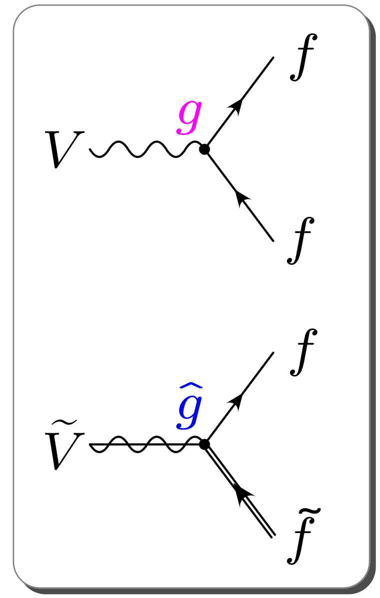
S. Riemann '00

High energy lepton ID

Understanding of lepton ID also relevant for precision measurements

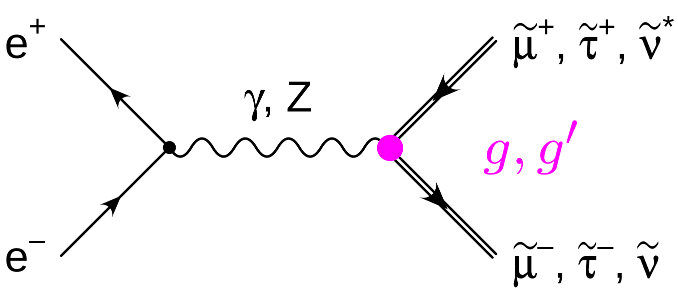
Example: test of coupling relations via cross-section measurement

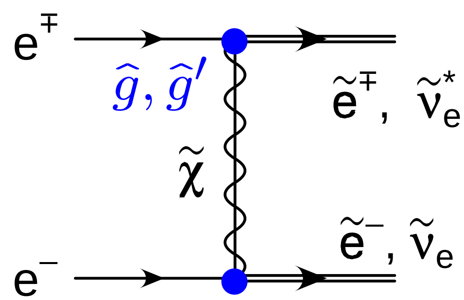
Fundamental supersymmetry relation



> Gauge coupling g = Yukawa coupling $\hat{g}$

Can be tested in slepton production with prec. $< 1\%$





g' U(1) coupl.
g SU(2) coupl.

> **Challenge:** Control lepton ID to level $\ll 1\%$

High energy lepton ID

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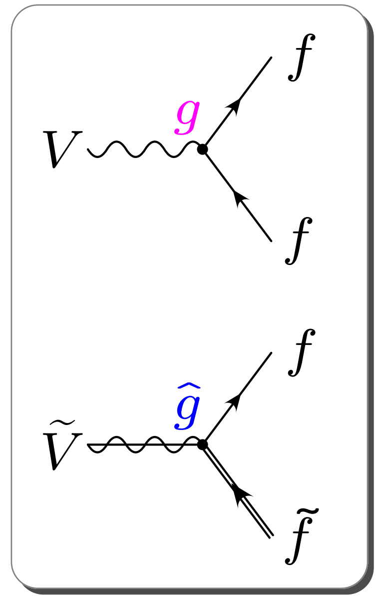

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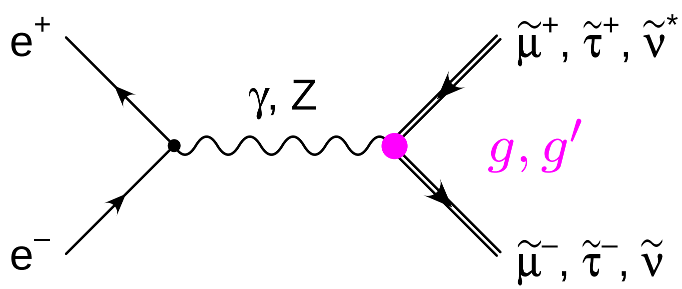
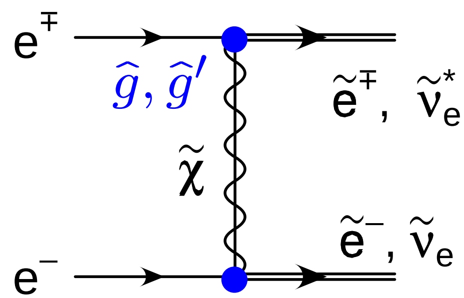




g' U(1) coupl.
g SU(2) coupl.

$\longrightarrow$ Similar relations exist for extra dim., holographic models, ...

Precision measurements

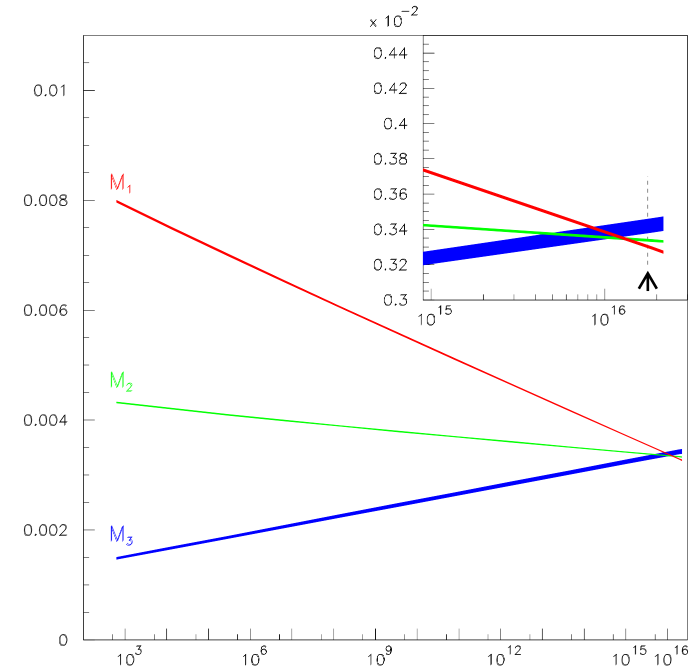
Can tell story about underlying structure (at high energies)

Example: precision measurements of SUSY parameters

Slepton and gaugino masses determined through decay distributions
$\longrightarrow$ Systematic error limited largely through **tracking**

Assuming resolution
$\Delta(1/p) = 5 \times 10^{-5}\ \mathrm{GeV}^{-1}$
one can

- Test mechanism of unification
- Disentangle several high scales



Blair, Porod, Zerwas '03

> Challenge:
> Meet goal $5 \times 10^{-5}\ \mathrm{GeV}^{-1}$

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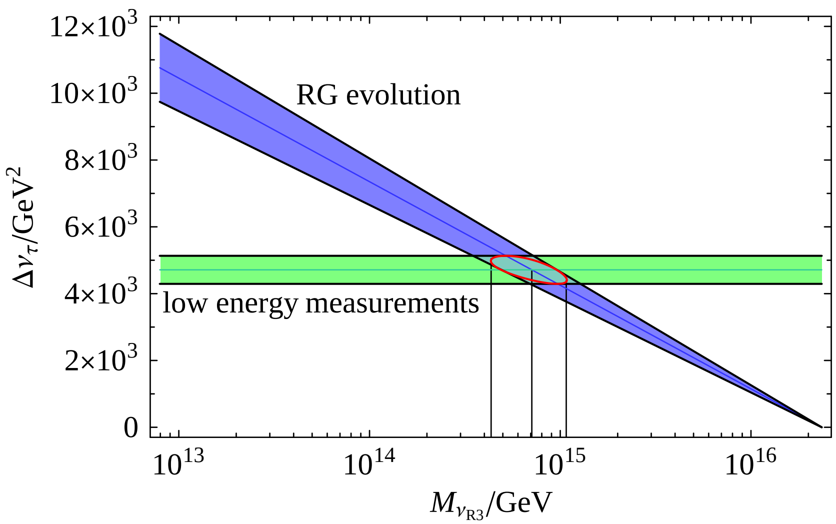


Freitas, Porod, Zerwas '05

Challenge:
Meet goal 5×10^{-5} GeV^{-1}

Forward/backward tracking

- Understanding $\gamma\gamma$ background (for missing energy signals)

Mostly $\gamma\gamma$ background can be vetoed with help of forward calometry (BeamCal)

However: low-angle tracking could help to actually measure this background precisely

$\longrightarrow$ Could improve Monte-Carlos and veto efficiency

$\longrightarrow$ C. Berger 'Tuesday

- Luminosity spectrum and beam energy

Could be extracted with small theory error from low-angle (20-140 mrad) Bhabha scattering $\longrightarrow$ A. Juste 'Tuesday

- Measuring anomalous triple gauge boson couplings

Forward/backward tracking: Triple gauge boson couplings

$$\mathcal{L}_{WWV} = i\, g_{WWV} \Big[g_1^V V_\mu (W_\nu^- W^{+\mu\nu} - W^{-\mu\nu} W_\nu^+) + \kappa_V W_\mu^- W_\nu^+ V^{\mu\nu}$$
$$+ \frac{\lambda_V}{M_{\mathrm{W}}^2} W_{\rho\mu}^- W_\mu^{+\nu} V^{\nu\rho} + + i\, g_4^V W_\mu^- W_\nu^+ (\partial^\mu V^\nu + \partial^\nu V^\mu)$$
$$+ i\, g_5^V \epsilon_{\mu\nu\rho\sigma} (W^{-\mu} \partial^\rho W^{+\nu} - W^{+\nu} \partial^\rho W^{-\mu}) V^\sigma$$
$$+ \frac{\tilde{\kappa}_V}{2} \epsilon_{\mu\nu\rho\sigma} W^{-\mu} W^{+\nu} V^{\rho\sigma} + \frac{\tilde{\lambda}_V}{2M_{\mathrm{W}}^2} \epsilon_{\mu\nu\rho\sigma} W_\mu^{-\lambda} W^{+\lambda\nu} V^{\rho\sigma}$$

$$V = \gamma, Z, \qquad g_{WW\gamma} = e,\ g_{WWZ} = e c_{\mathrm{W}}/s_{\mathrm{W}}, \qquad V_{\mu\nu} = \partial_\mu V_\nu - \partial_\nu V_\mu$$

In Standard Model: $g_1^V = \kappa_V = 1, \qquad \lambda_V = g_4^V = g_5^V = \tilde{\kappa}_V = \tilde{\lambda}_V = 0$

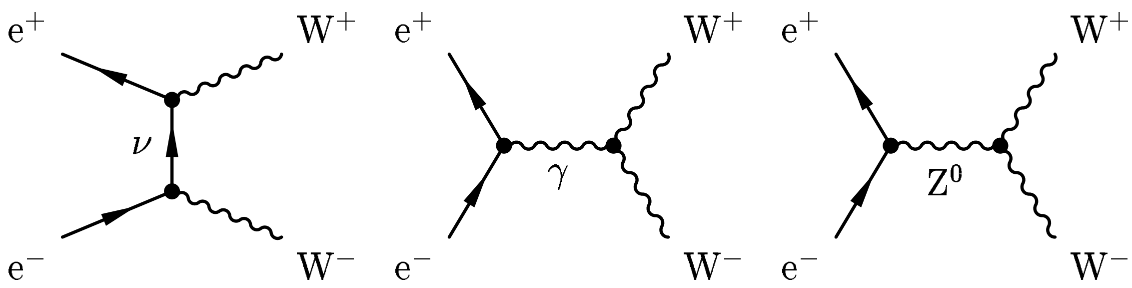
U(1)$_{\mathrm{em}}$ invariance: $g_1^\gamma(q^2 = 0) = 1, \qquad g_5^\gamma(q^2 = 0) = 0$

SU(2) invariance: $\Delta\kappa_\gamma = -\frac{c_{\mathrm{W}}}{s_{\mathrm{W}}}(\Delta\kappa_Z - \Delta g_1^Z), \qquad \lambda_\gamma = \lambda_Z$

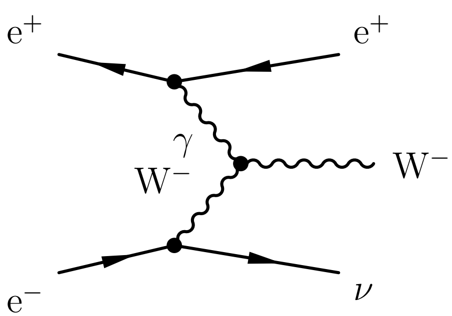
C, P-conservation: $g_4^V = g_5^V = \tilde{\kappa}_V = \tilde{\lambda}_V = 0$

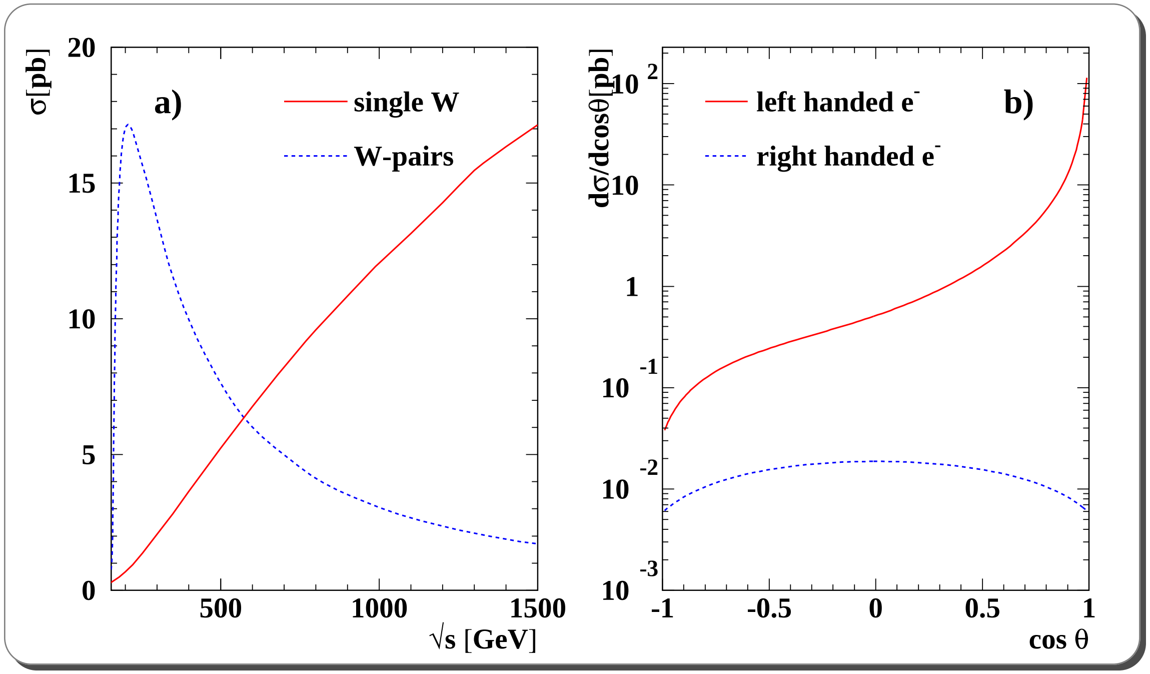
Forward/backward tracking: Triple gauge boson couplings

At high energies W-bosons can be produced in **pairs**:



or **singly**:



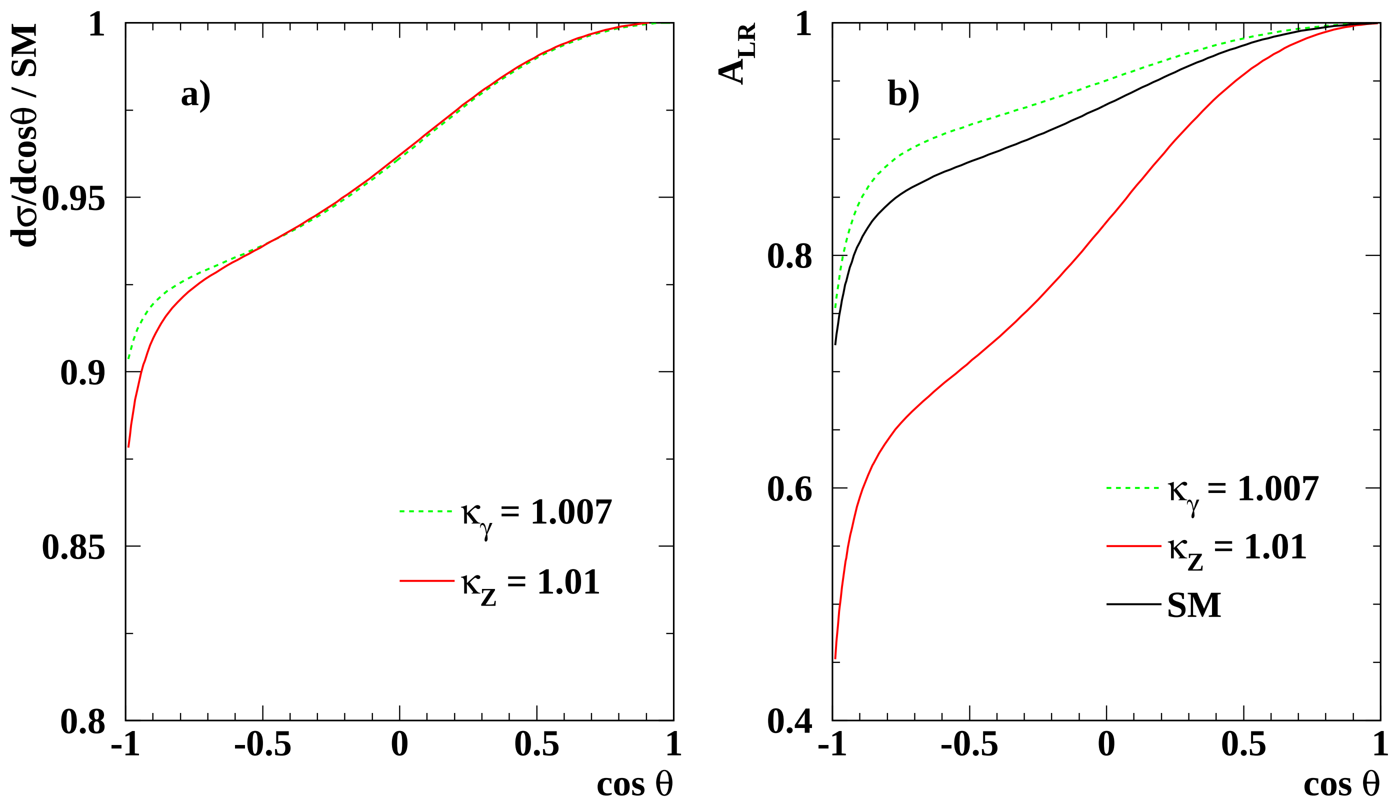


W pair cross-section is strongly asymmetric in beam polarization and scattering angle

Forward/backward tracking: Triple gauge boson couplings

Single $\boldsymbol{W}$ production sensitive to $WW\gamma$ couplings

Double $\boldsymbol{W}$ production sensitive to $WW\gamma$ and WWZ couplings
$\longrightarrow$ Discrimination with beam polarization

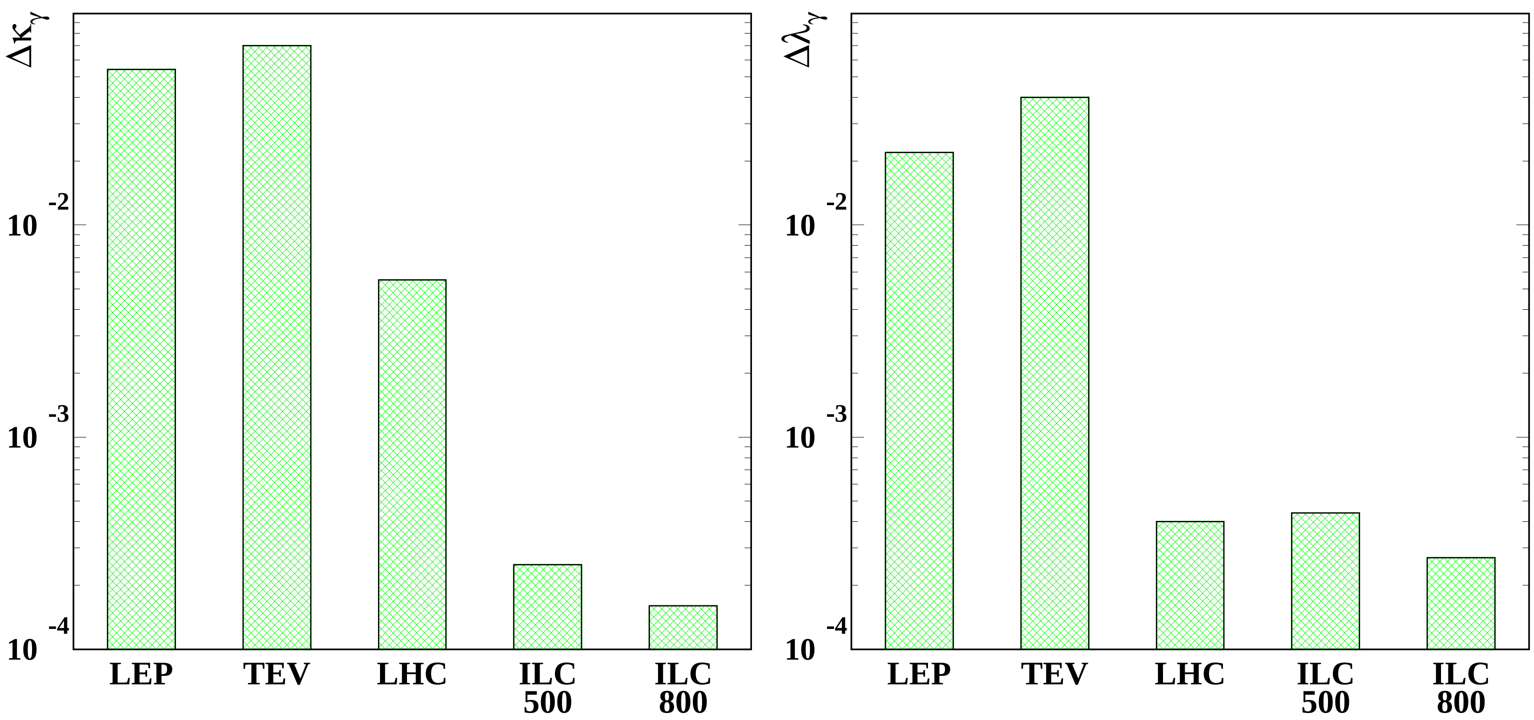


Main sensitivity near $\cos\theta_W =$ -1

(Suppression of t-channel)

Forward/backward tracking: Triple gauge boson couplings

Menges '01



Best sensitivty of ILC at large $\sqrt{s} \sim 1$ TeV

$\longrightarrow$ Forward region becomes more important

Challenges:

- Push tracking to low values of $\cos\theta$ without sacrifice
- Could we measure W decay products without tracker?

Tau leptons

Large Yukawa couplings in 3rd generation often lead to dominance of taus in leptonic new physics signals

Example: SUSY with large $\tan\beta$

Issues:

- Signatures with many taus
  e.g. $e^+e^- \to \tilde{\chi}_2^0\tilde{\chi}_2^0 \to \tau^+\tau^-\tau^+\tau^-\tilde{\chi}_1^0\tilde{\chi}_1^0$

- Signatures with soft taus
  e.g. stau-neutralino co-annihilation
  $\longrightarrow$ Helps to bring SUSY in agreement with dark matter abundance
  Typical mass differences $\Delta m \equiv m_{\tilde{\tau}_1} - m_{\tilde{\chi}_1^0} \sim \mathcal{O}(5\ \mathrm{GeV})$

Soft tau leptons

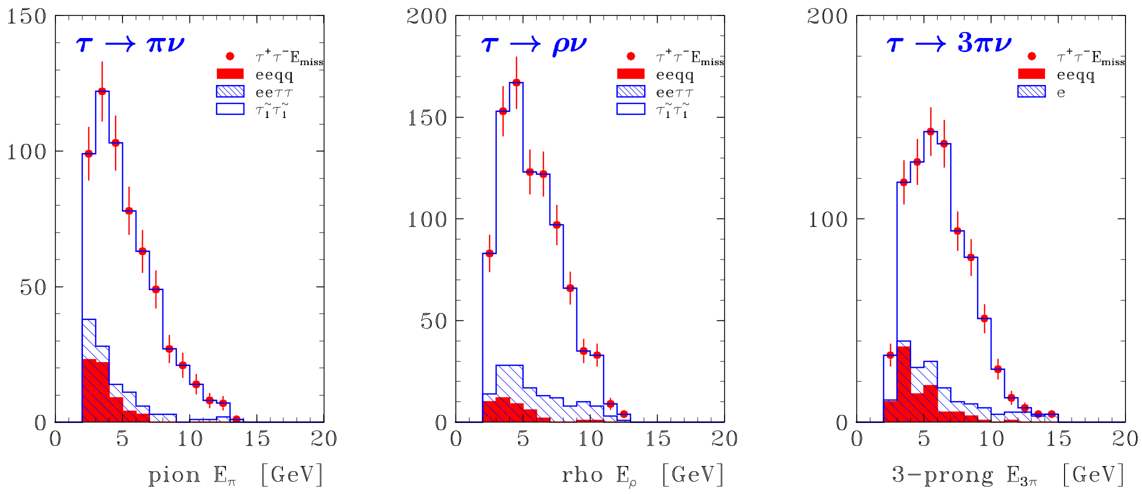


Figure 6: Hadron energy spectra E_π of $\tau \to \pi\nu_\tau$, E_ρ of $\tau \to \rho\nu_\tau$ and $E_{3\pi}$ of $\tau \to 3\pi\nu_\tau$ decays from the reaction $e^+_L e^-_R \to \tilde{\tau}_1\tilde{\tau}_1 \to \tau^+\tilde{\chi}^0_1\,\tau^-\tilde{\chi}^0_1$ and two-photon production assuming head-on collision. Model D', $m_{\tilde{\tau}_1} = 217.5$ GeV, $\Delta m = 5.1$ GeV, $\sqrt{s} = 600$ GeV and $\mathcal{L} = 300$ fb^{-1}

U. Martyn '04

Challenges:

- Identify multi-tau states with high efficiency and purity
- Identify soft taus ($p_T \sim 5$ GeV)
- Measure momentum of soft tau (decay products)

Conclusions

- Detector requirements are **model-dependent**

- Beyond-LEP-precision tracking always is a **benefit**, but often not **necessity**
  Important for understanding **details** of new physics
  $\longrightarrow$ *particular strength of ILC!*

- Similar for charged particle ID

- Both **soft** and **hard** tracks are relevant in many models

Radions

- The **radion** corresponds to fluctuations of the size of the extra dimension

- Radions have various cosmological implications:
  - Dark matter
  - Inflation
  - Cosmoligcal perturbations

- Radions ϕ can mix with the Higgs boson, *i.e.* have an effect on $e^+e^- \to ZH, Z\phi$

  $\rightarrow$ Precise analysis of the $Z \to \mu^+\mu^-$ recoil spectrum essential for discovering radion effects

  $\rightarrow$ Good muon momentum resolution
  $\rightarrow$ Accurate knowledge of muon ID efficiency