Radiative production of neutralinos

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Outline: radiative neutralino production

$$e^{+} + e^{-} \rightarrow \tilde{\chi}_1^0 + \tilde{\chi}_1^0 + \gamma$$

- Introduction and motivation
- Signal and background
- Beam polarization dependence, and the parameter point SPS 1a'
- Experimental study (Christoph Bartels, PhD)
- Summary and conclusions

Introduction and motivation

- Supersymmetry is an attractive model beyond the Standard Model.

- New SUSY particles have to be found at colliders.

- ILC: lightest states can be studied first.

- Discovery at colliders:

  direct: **decay products** of neutralinos, charginos, sleptons (ILC)

  squarks, gluinos (LHC)

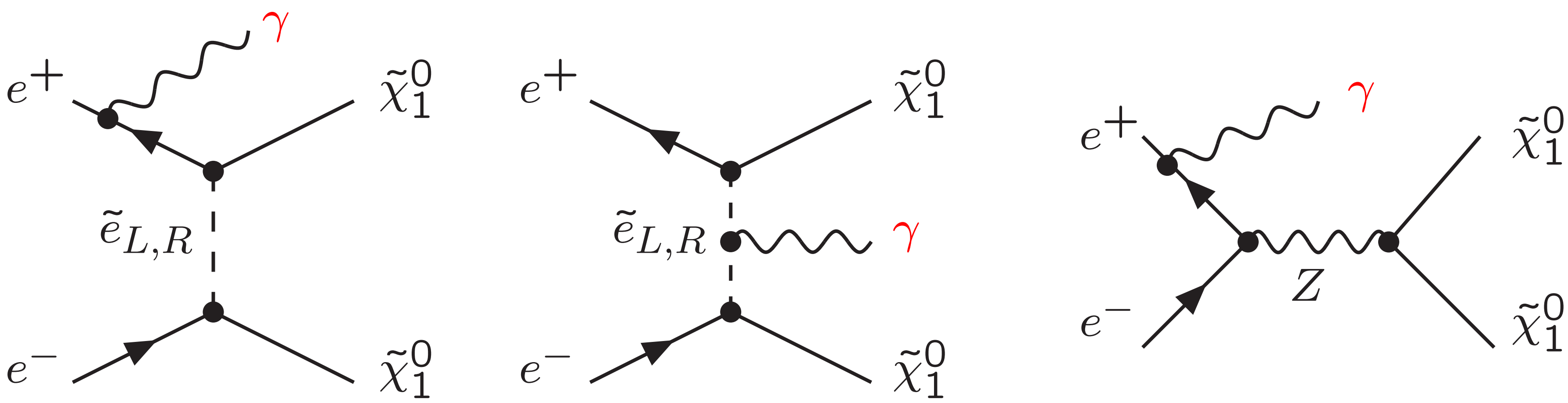
  indirect: **missing energy** due to two stable LSPs (R-parity cons.)

Radiative production of neutralinos

$$e^+ + e^- \to \tilde{\chi}_1^0 + \tilde{\chi}_1^0 + \gamma$$

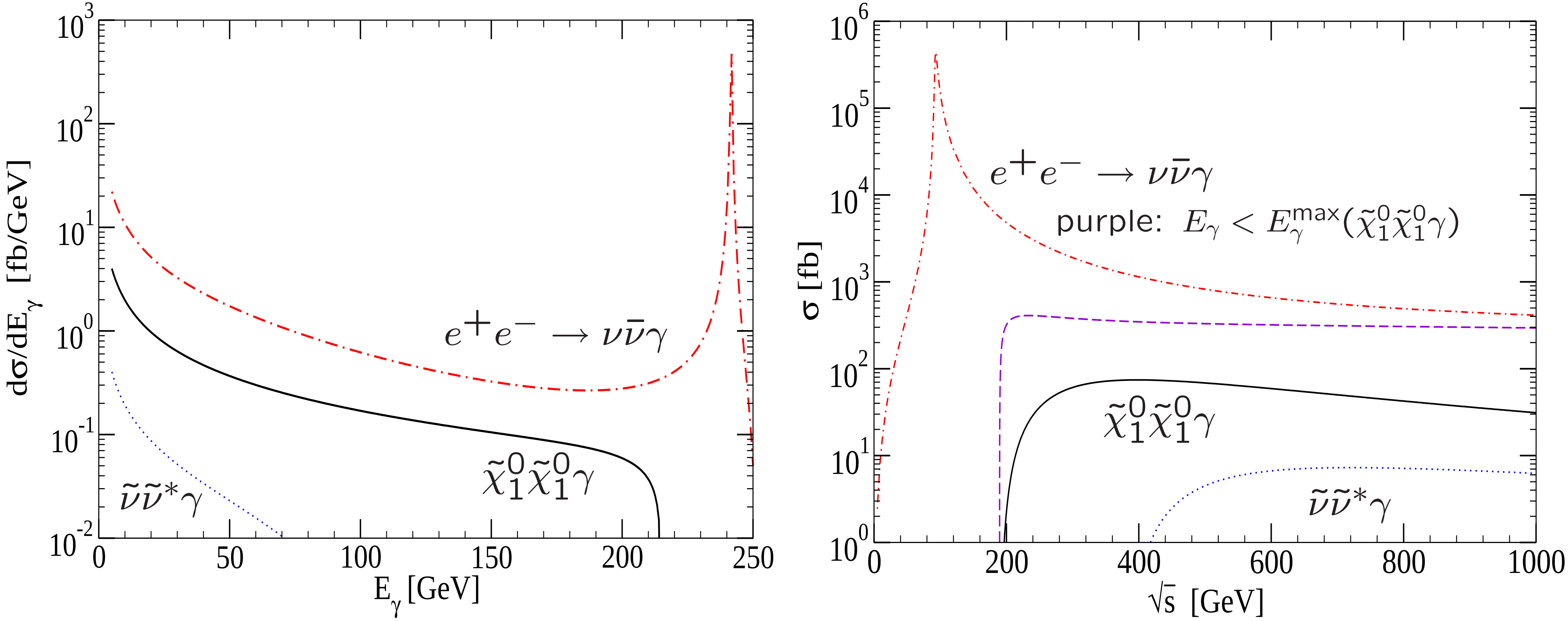
Proceeds via selectron $\tilde{e}_{L,R}$ and Z boson exchange

Signal: High energetic photon γ and missing energy



This is the lightest SUSY state to be produced!!!

Energy distribution and $\sqrt{s}$ dependence: signal and background



$\sqrt{s} = 500$ GeV (left), beam polarization: $(P_{e^-}, P_{e^+}) = (0.8, -0.6)$,
SUSY parameter point SPS 1a'

Signal and background

- Signal: $e^+ + e^- \to \tilde{\chi}_1^0 + \tilde{\chi}_1^0 + \gamma$
- Background:

– SM: $e^+ + e^- \to \nu + \bar{\nu} + \gamma$ (dominant, order of 3.3 pb)

– MSSM: $e^+ + e^- \to \tilde{\nu} + \tilde{\nu}^* + \gamma$ (negligible in most scenarios)

- (theoretical) significance: $S = \frac{N_S}{\sqrt{N_B + N_S}}$ (should be at least > 1)

  events: $N = \mathcal{L}\,\sigma$

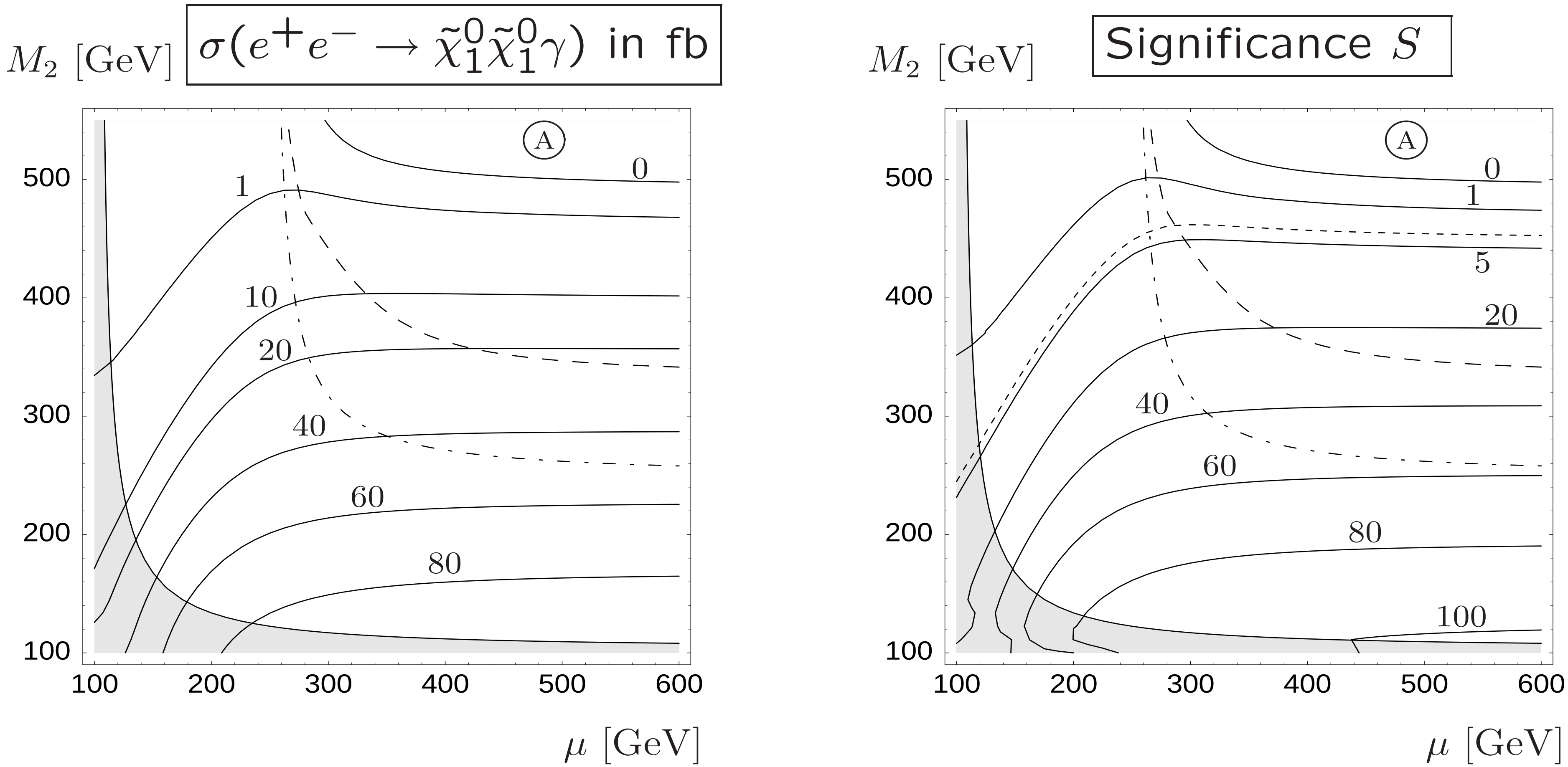
- situation at LEP:

  Luminosity $\mathcal{L} \approx \mathcal{O}(100\ \text{pb}^{-1}) \Rightarrow$ we find $S < 0.1$

- at ILC: high lumi $\mathcal{L} \approx 500\ \text{fb}^{-1}$ and polarized beams!

  $\Rightarrow$ Will show that signal can well be observed!

Dependence on μ and M_2



$\sqrt{s} = 500$ GeV, $\mathcal{L} = 500$ fb^{-1}; $(P_{e^+}, P_{e^-}) = (-0.6, 0.8)$, $m_0 = 100$ GeV

kinematical limits: $\tilde{\chi}^0_1\tilde{\chi}^0_1\gamma$ (A); $\tilde{\chi}^0_1\tilde{\chi}^0_2$ (dashed line); $\tilde{\chi}^+_1\tilde{\chi}^-_1$ (dot-dashed)

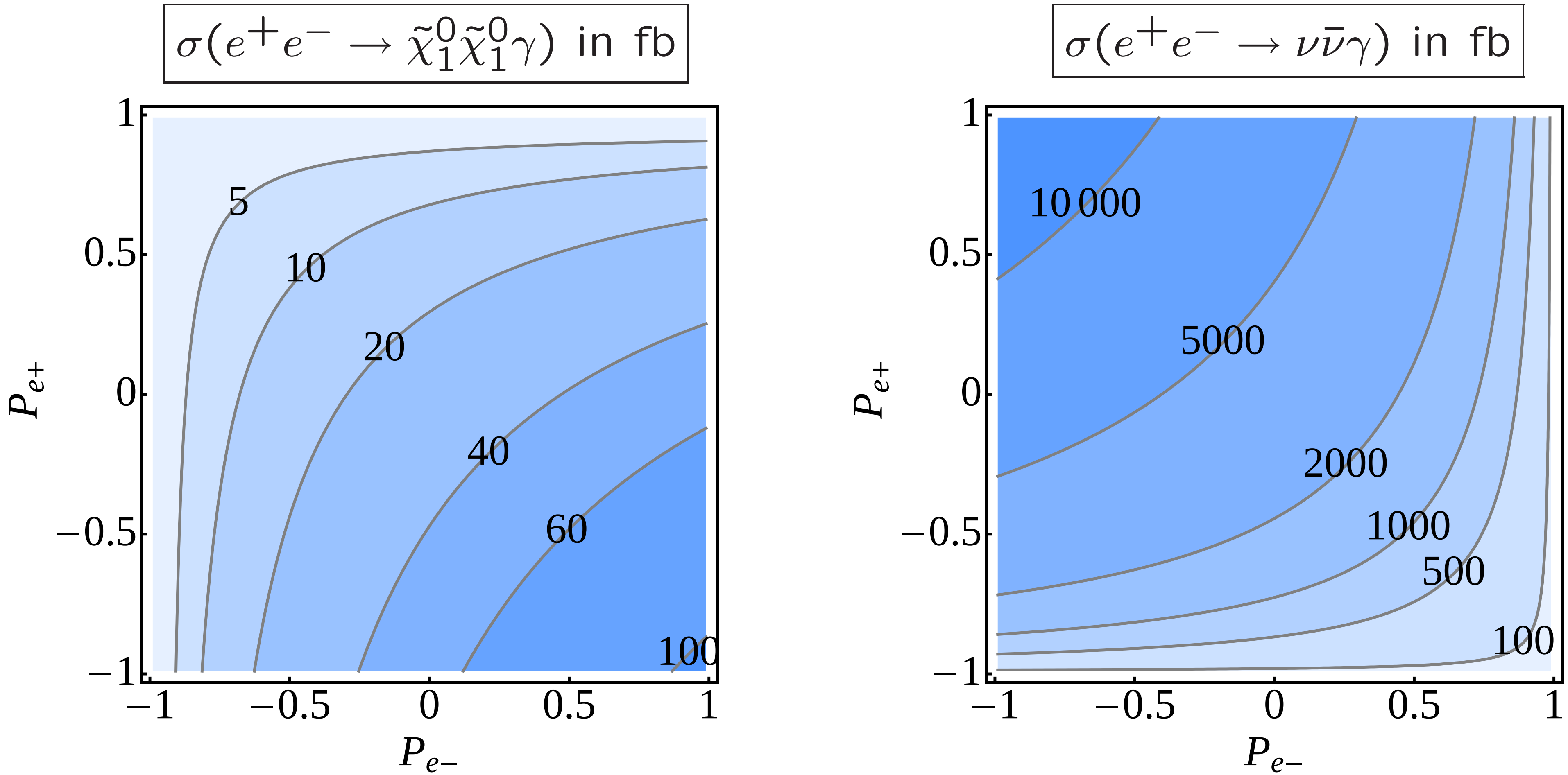
Study the benchmark scenario SPS 1a'

$M_{1/2}$	M_0	$\tan\beta$	Sig(μ)	A_0
250 GeV	70 GeV	10	$+1$	300 GeV

- Provides a widely studied, viable SUSY scenario:
  - allowed mass spectrum (besides LHC excluded $\tilde{q}$, $\tilde{g}$)
  - compatible with constraints: BR($b \to s\gamma$), $(g-2)_\mu$, ρ, Ω_{CDM}

- Represents an optimal scenario for us:
  - Light neutralinos and sleptons enhance production cross section.
  - LSP is 97% bino: strong coupling to right sleptons $\Rightarrow$ beam polarizations enhance signal AND suppress $\nu\bar{\nu}\gamma$!!

Beam polarization dependence for SPS 1a'



$\sqrt{s} = 500$ GeV, for SPS 1a' scenario:

$\mu = 396$ GeV, $M_2 = 193$ GeV $\Rightarrow m_{\tilde{\chi}_1^0} = 98$ GeV, $m_{\tilde{e}_R} = 125$ GeV

Theoretical significance for SPS 1a'

$S = \frac{N_{\rm S}}{\sqrt{N_{\rm S}+N_{\rm B}}}$ and $N = \mathcal{L} \times \sigma$

signal: $\sigma_S(e^+e^- \to \tilde{\chi}_1^0\tilde{\chi}_1^0\gamma)$

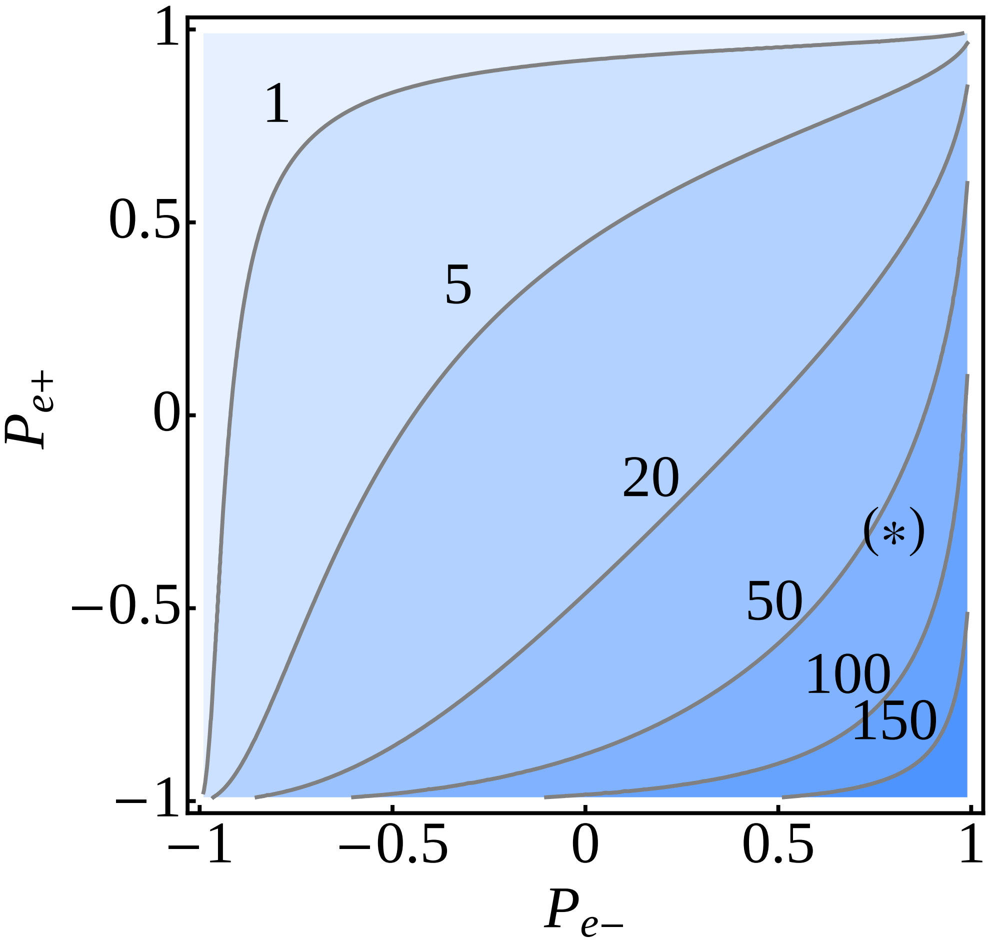
BG: $\sigma_{\rm B}(e^+e^- \to \nu\bar{\nu}\gamma)$

plot for $\mathcal{L} = 500$ fb^{-1}

These results motivate to perform a detailed experimental study:

⇒ **Christoph Bartels, DESY**

for realistic ILC conditions $(P_{e^-}, P_{e^+}) = (0.8, -0.3)$, see $(*)$



Experimental study for SPS 1a'

- Study performed by Christoph Bartels and Jenny List, DESY. (DESY PhD Thesis)

- Here only short summary of results, for more details: see talk by Christoph on Tuesday.

Analysis strategy

- Observables: - Photon event rate for cross section measurements
  - Photon energy distribution for mass measurements

- Use different beam polarizations: coupling structure of cross section

$$\sigma = (1+P_{e-})(1+P_{e+}), \sigma_{RR} + (1-P_{e-})(1-P_{e+})\,\sigma_{LL}$$
$$+(1+P_{e-})(1-P_{e+}), \sigma_{RL} + (1-P_{e-})(1+P_{e+}), \sigma_{LR}$$

- Use sample ($\gamma\nu\bar{\nu}$ + Bhabha BG) from ILD Letter of Intent studies ($150\ \mathrm{fb}^{-1}$, created with MC `Whizard` + full detector simulation)

- Create signal sample by re-weighting: $w = \frac{\sigma(\chi\chi\gamma)}{\sigma(\nu\bar{\nu}\gamma)}$
  - needed due to limited CPU time
  - to avoid statistical correlation, split the samples

Main backgrounds and cuts

reducible

- reject Bhabha scattering: tag forward e^- in beam calorimeter
- Initial state radiation (ISR) reduced by 'signal definition':
  10 GeV $< E_\gamma <$ 220 GeV, and $|\cos(\theta_\gamma)| < 0.98$
- Reduce multi-photon and hadronic/leptonic final states:
  cut on exclusive energy: $E_{\text{vis}} - E_\gamma < 20$ GeV

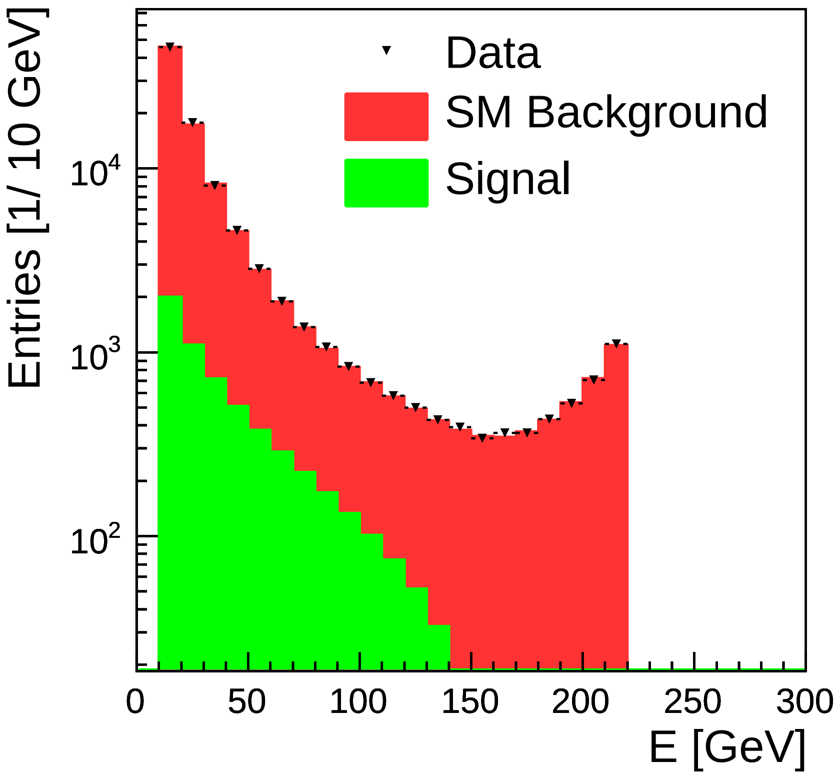
irreducible

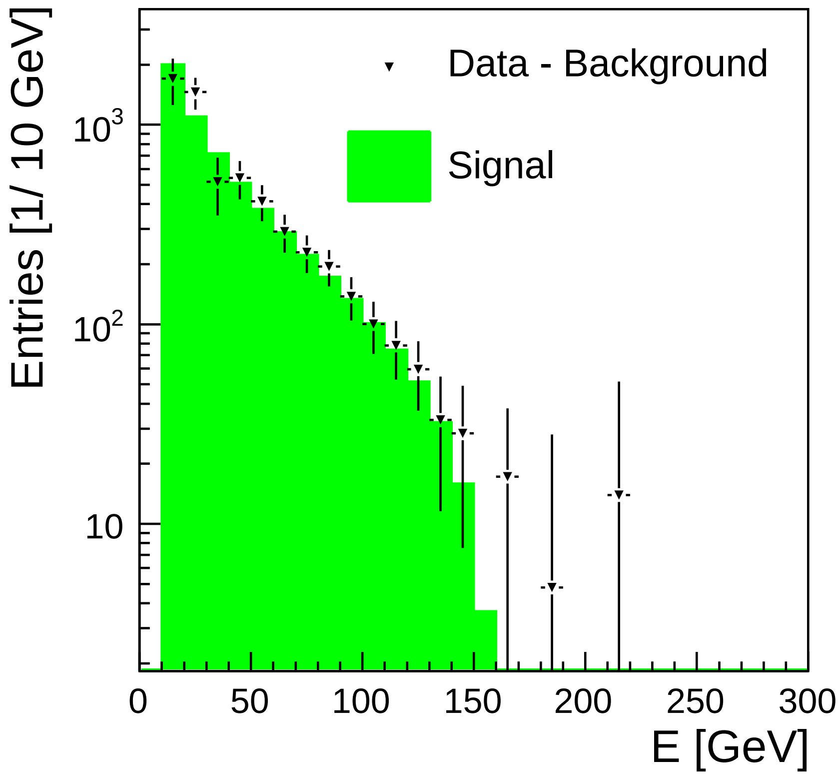
- SM $\nu\bar{\nu}n\gamma$ events (up to $n = 5$) : maximal track $p_{\text{T}} < 3$ GeV

(a bit p_{T} necessary to allow for track overlays of beamstrahlung + $\gamma\gamma$ events)

$\Rightarrow 70 - 90\%$ of $\nu\bar{\nu}\gamma$ events selected (dep. on beam polarization), all other backgrounds negligible

Background subtraction





Example of photon spectrum for a 150 GeV LSP, corresponding to $\sqrt{s} = 500$ GeV, $\mathcal{L} = 50$ fb^{-1}, $(P_{e^-}, P_{e^+}) = (0.8, -0.3)$,

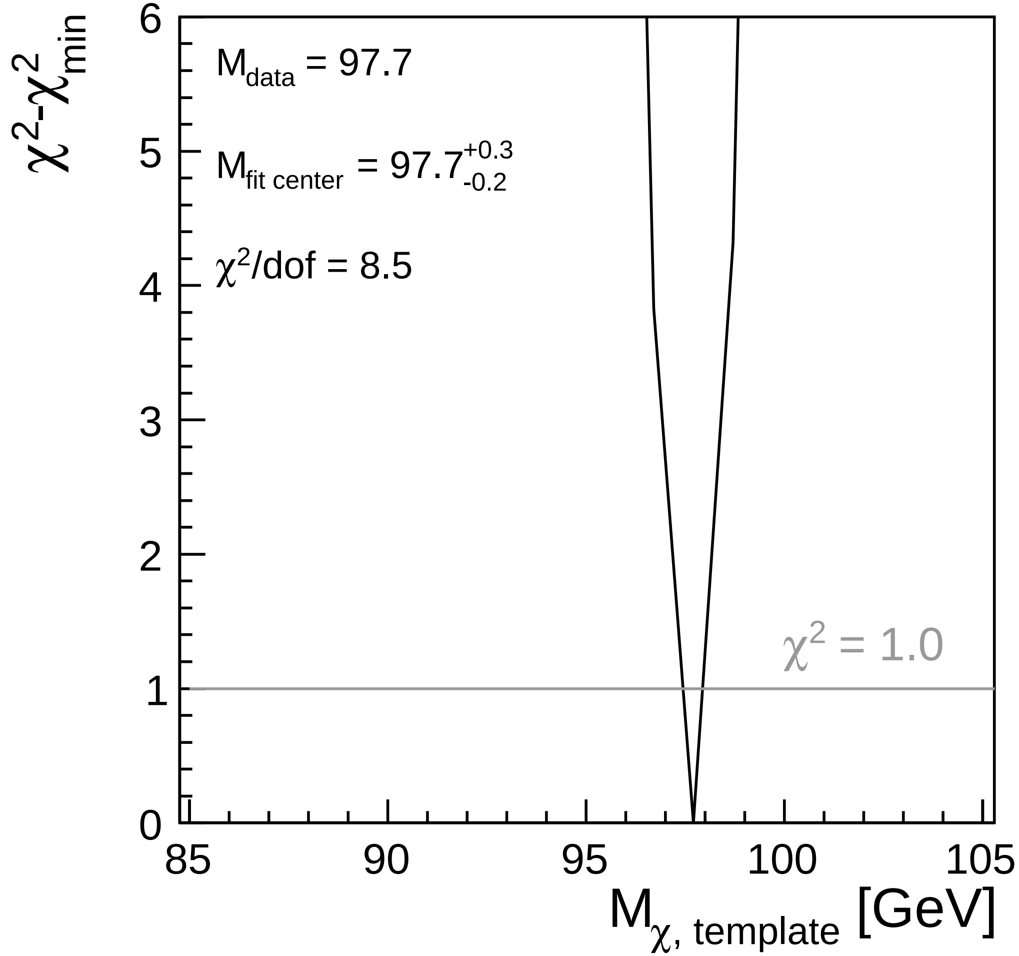
Results I: LSP Mass

- χ^2 fit of the photon energy distribution.

- $m_{\tilde{\chi}} = 97.7 \pm 0.5(\text{stat}) \pm 2.2(\text{sys})$

- Error determined by systematics: beam energy spectrum distorts the signal spectrum

- full difference between RDR and SB2009 beam energy spectrum assumed as uncertainty $\Rightarrow$ important to measure beam spectrum precisely!



Results II: cross sections and coupling structure

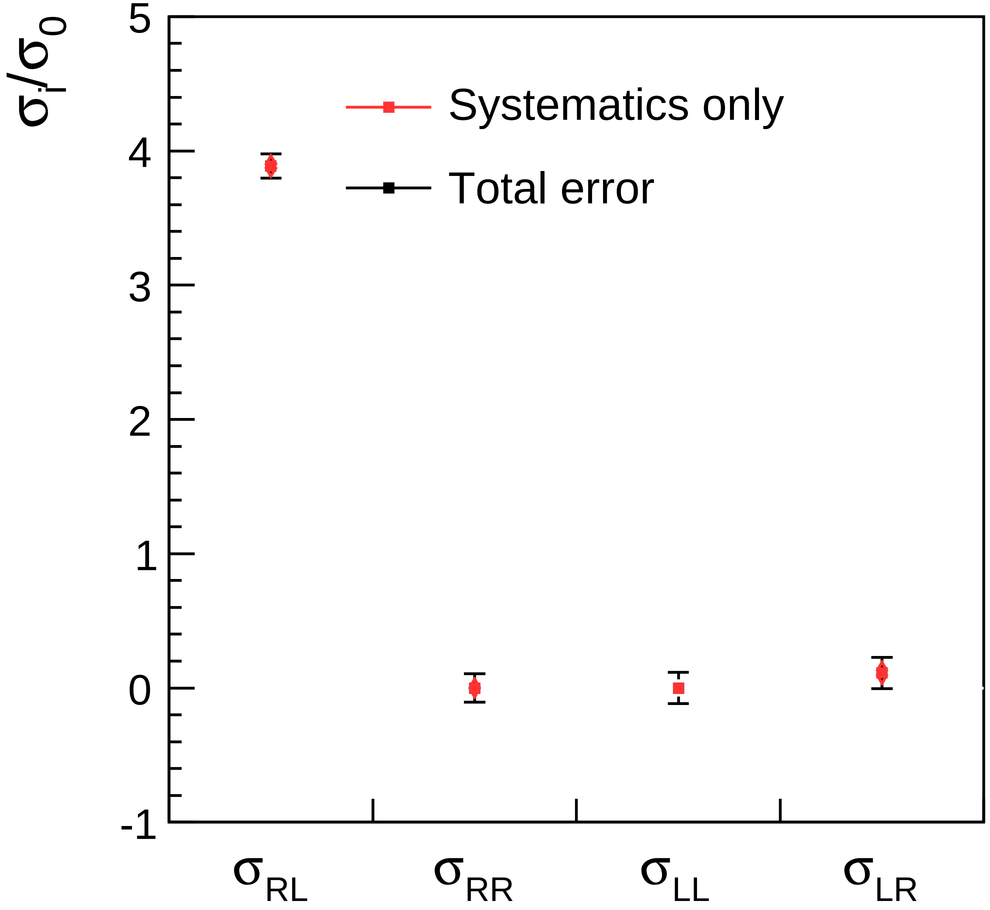
$$\sigma = (1+P_{e-})(1+P_{e+})\sigma_{RR} + (1-P_{e-})(1-P_{e+})\sigma_{LL} + (1+P_{e-})(1-P_{e+})\sigma_{RL} + (1-P_{e-})(1+P_{e+})\sigma_{LR}$$

- combination:

$\sigma_0 = 131 \pm 1.3 - 1.8(\text{stat}) \pm 3.9 - 5.7(\text{sys})$

errors for $|P_{e+}| = 0.3 - 0.6$

- error determined by polarization measurement, $0.25\% - 0.1\%$



Systematic errors and uncertainties

most relevant for cross section determination:

- beam polarization measurement $\delta P/P = 0.25\%$ to 0.1% (dominant)

- luminosity measurement $\delta \mathcal{L}/\mathcal{L} = 0.01\%$

- selection efficiency $\delta\epsilon/\epsilon = 2.0\%$

most relevant for mass and σ determination:

- beam energy spectrum + scale

Summary and conclusions $e^+e^- \to \tilde{\chi}_1^0\tilde{\chi}_1^0\gamma$

- $\tilde{\chi}_1^0\tilde{\chi}_1^0\gamma$ is the lightest SUSY state to be produced.

- Cannot be observed at LEP (low luminosity, no polarized beams).

- At ILC, polarized beams enhance signal and reduce background.

- Experimental study for the ILC (Christoph Bartels, DESY):

  - cross sections and $\tilde{\chi}_1^0$ mass to be determined at the percent level

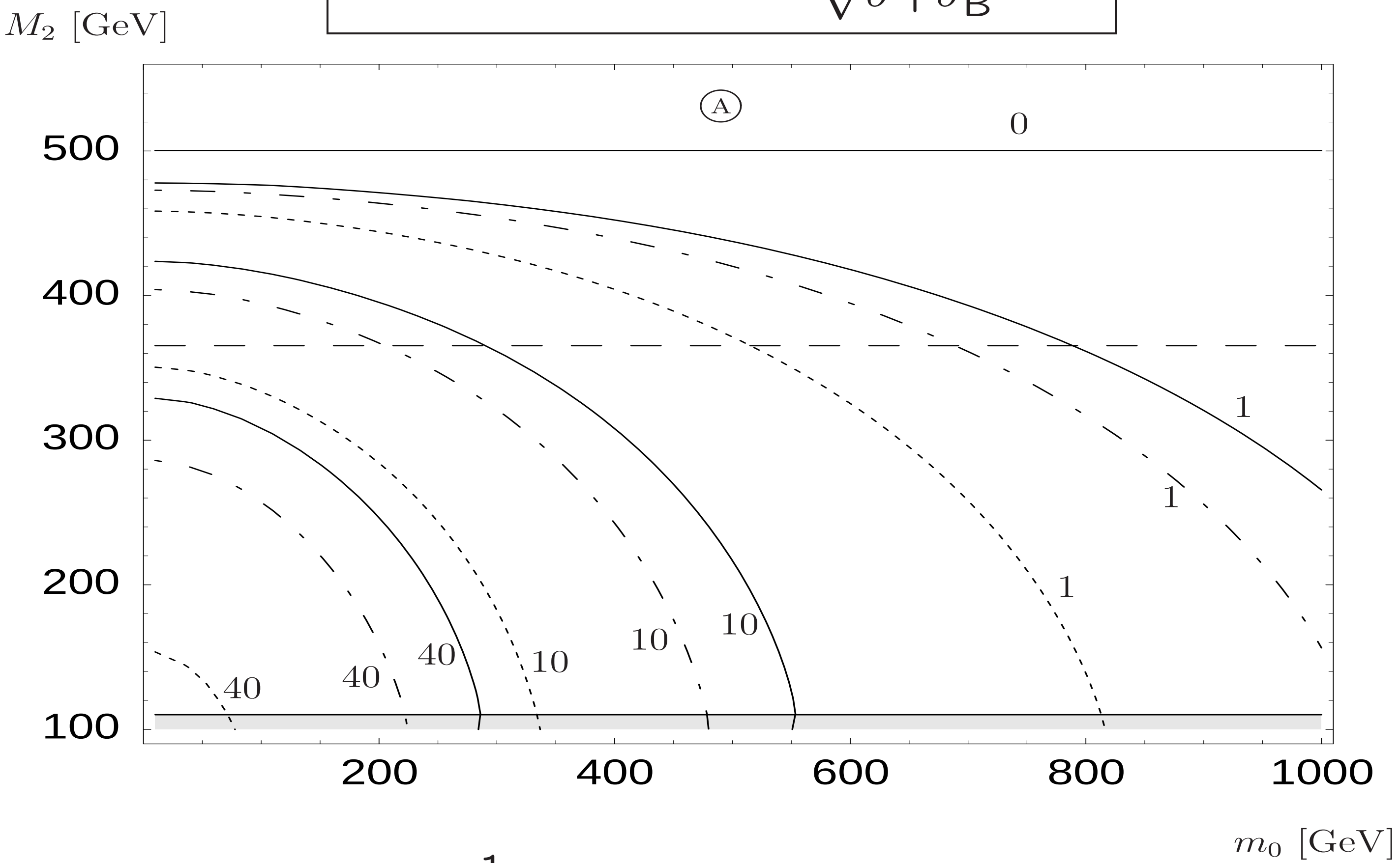
  - errors are comparable to alternative measurements
    (e.g. mass determination via edges in inv. mass distributions)

  - high positron polarization and its precise measurement:
    reduce statistical errors considerably (about factor of 2)

Backup slides

Dependence on $\tilde{e}_R$-mass for different beam polarizations

Significance $S = \frac{\sigma}{\sqrt{\sigma + \sigma_B}} \sqrt{\mathcal{L}}$



$\sqrt{s} = 500$ GeV, $\mathcal{L} = 500$ fb^{-1}; $\mu = 500$ GeV, $\tan\beta = 10$

dotted: $(P_{e^-}, P_{e^+}) = (0, 0)$; dot-dashed: $(0.8, 0)$; solid: $(0.8, -0.6)$