Single Photon Events

WIMP Searches and Constraining the Neutralino Sector

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Outline

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Single Photon Events and DM at the ILC

WIMP Dark Matter Component

- Masses of 0.1–1 TeV
- In thermal equilibrium with SM soup after inflation
- Weak interactions naturally give observed relic density
- In SUSY with conserved R-Parity: LSP: $\tilde{\chi}_1^0$ or $\tilde{G}$

Pair production at ILC

- $e^+e^- \to \chi\chi$
- WIMPs leave detector without further interaction
- Detection via ISR: $e^+e^- \to \chi\chi\gamma$
- Missing $\not{E}$
- Dominant background: $e^+e^- \to \nu\nu(N)\gamma$
- Other background: Bhabha-scattering

Motivation I

Detector issues, R&D

- Convergance of detector models (LDC + GLD $\rightarrow$ ILD)
- Detailed detector simulations exist
- In the run-up for the TDR questions arrise:
  - In order to do precision physics:
  - Do we understand our detectors: e. g. energy resolution?
  - What about hermiticity, 4π-detector?
  - Do we understand beam-related backgrounds enough?
- Reconstruction algorithm at high level of sophistication
  - Does the PFlow concept work
  - Jet-energy resolution
  - Photon recognition

We have all the tools to tackle these questions with full simulation studies, and many of them are on the way.

Motivation II

Physics I, SUSY

- SPE increase the reach on $\tilde{\chi}_1^0$ searches to $M_{\tilde{\chi}_1^0} \leq 250$ GeV
- Study direct $\tilde{\chi}_1^0$ pair production
- Another method to determine:
  - $M_{\tilde{\chi}_1^0}$
  - σ
  - Spin of exchange particle
- Get additional information on Neutralino sector, might be important in CP-violating scenarios

Physics II

- Ideal channel to search model independent for new physics
- Well understood SM background: $e^+e^- \rightarrow \nu\nu(N)\gamma$
- Large S/B$\sim 10^{-1}$–10^{-2}, Infer σ and M_χ of generic WIMPs

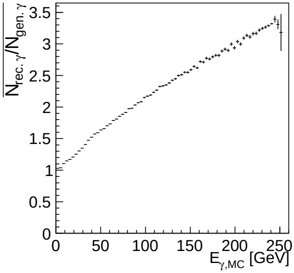
Outline

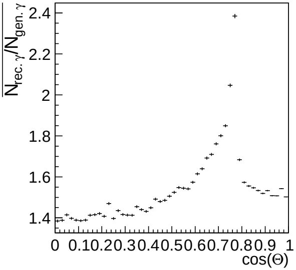
Reconstruction, Photon Splitting

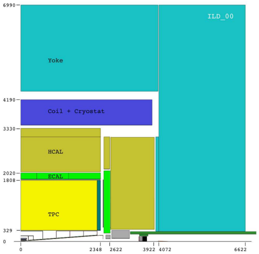
ILD00, Reconstruction with Marlin/Pandora

Photon splitting

- On average ≥ 1 photon candidate reconstructed per MC photon
- High energetic very forward photons in Barrel/Endcap region
- Conversions in TPC Endplate, no tracking before ECAL





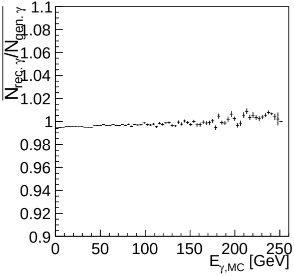


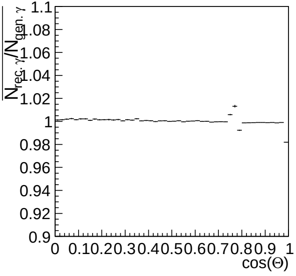
Reconstruction, Photon Splitting

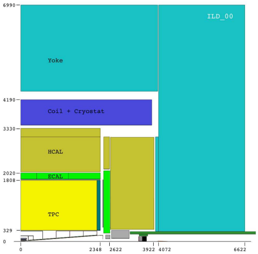
`ILD00`, Reconstruction with Marlin/Pandora

Photon splitting

- On average $\geq$ 1 photon candidate reconstructed per MC photon
- High energetic very forward photons in Barrel/Endcap region
- Apply merging procedure





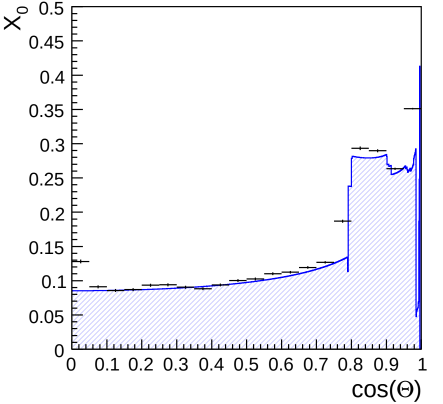


Radiation Length

Simple consistency check of data and detector description

Comparison between X_0 from LOI and $\nu\nu\gamma$

- $X_0(\frac{N_{conv}}{N})$
- X_0 from simulation resembles LOI information
- Deviations in very forward region
- Beampipe



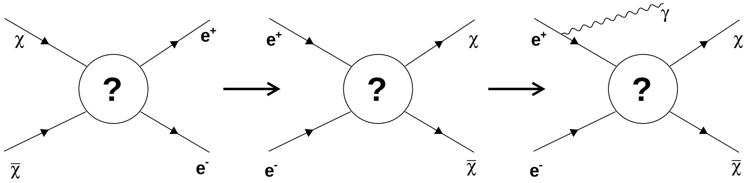
Outline

Model Independent Production Cross Section

Birkedal *et al.* [hep-ph/0403004]

Model independence

- Assume only one DM candidate, no co-annihilation
- Constrain WIMP pair annihilation XSec from observation
- Crossing Symmetrie (annihilation $\Rightarrow$ production)
- ISR



Model independent production cross section

$$\frac{d\sigma}{dx} \sim \kappa_e(P_e, P_p) 2^{2J_0} (2S_\chi + 1)^2 \left(1 - \frac{4M_\chi^2}{(1-x)s}\right)^{1/2+J_0}$$

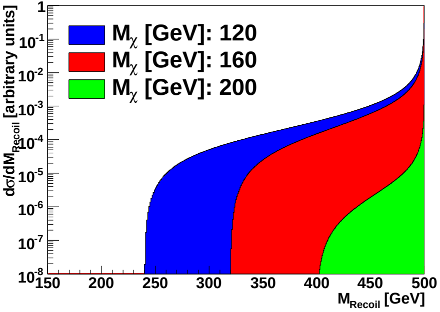
Parameters:

- $\kappa_e(P_e, P_p)$: Helicity dependent annihilation fraction to e^+e^-
- S_χ: Spin, scale factor
- M_χ, J_0 $\rightarrow$ shape, J_0 dominant partial wave

Model independent production cross section

Cut-off in signal cross section determines WIMP mass

Energy resolution crucial



Parameters:

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- S_χ: Spin, scale factor
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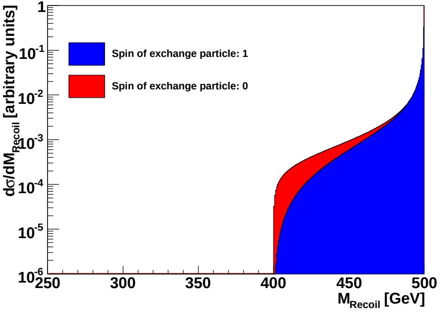
Model independent production cross section

Signal shape at threshold provides information on partial wave, or Spin of exchange particle in SUSY scenarios.
Energy resolution crucial



Parameters:

- $\kappa_e(P_e, P_p)$: Helicity dependent annihilation fraction to e^+e^-
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Model independent production cross section

What can we learn about the question mark?

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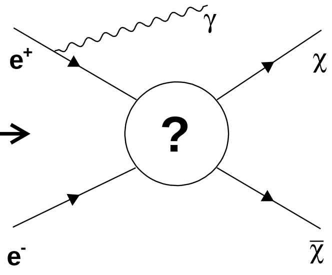


Parameters:

- $\kappa_e(P_e, P_p)$: Helicity dependent annihilation fraction to e^+e^-
- S_χ: Spin, scale factor
- M_χ, J_0 $\rightarrow$ shape, J_0 dominant partial wave

Scope of analysis

Sensitivity study: What can we see in a background dominated environment?

Limits on:

- Cross section
- Coupling parameter κ
- Mass resolution
- Determination of partial wave J_0

Machine and detector

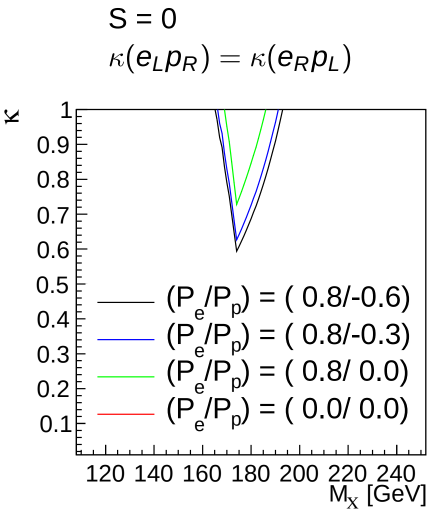
- Beam polarisation, especially positrons
- Influence of detector resolution

Outline

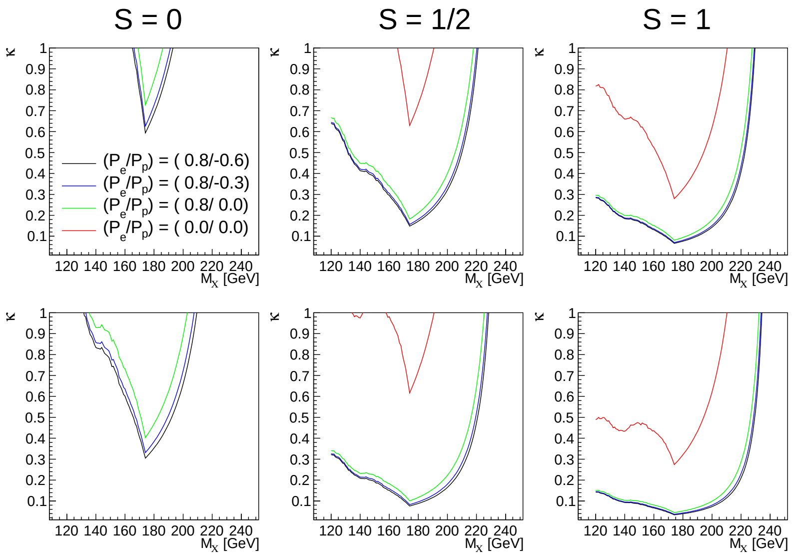
2σ reach on κ ($\mathcal{L} = 200\ \text{fb}^{-1}$)

Search strategy

- For each mass hypothesis:
- Apply mass dependent cuts on photon energy
- Lower cut ensures non-relativistic WIMPS
- Upper cut given by kinematic limit
- Test different polarisations
- mSUGRA interpretation: "typical":$\kappa \approx 0.3$ in bulk of parameter space



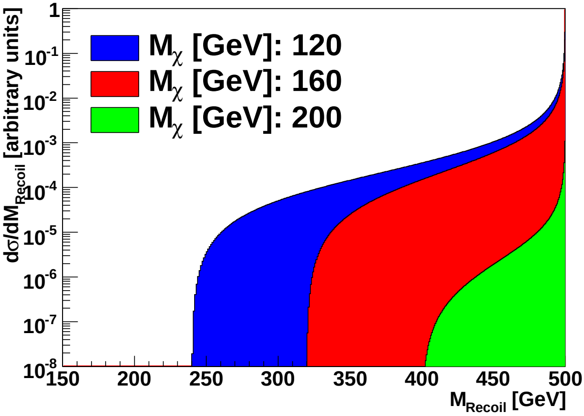
2σ reach on κ ($\mathcal{L} = 200\ \mathrm{fb}^{-1}$)



$\kappa(e_L p_R) = \kappa(e_R p_L)$

$\kappa(e_R p_L)$

Measurement of M_χ

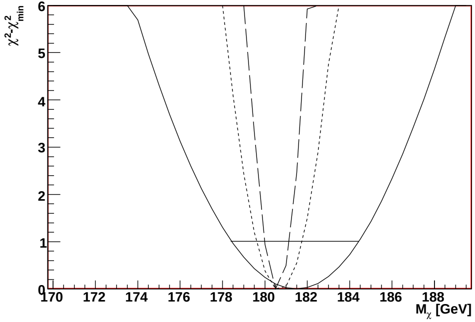


Find Cut-off in detected photon energies

Measurement of M_χ (2007)

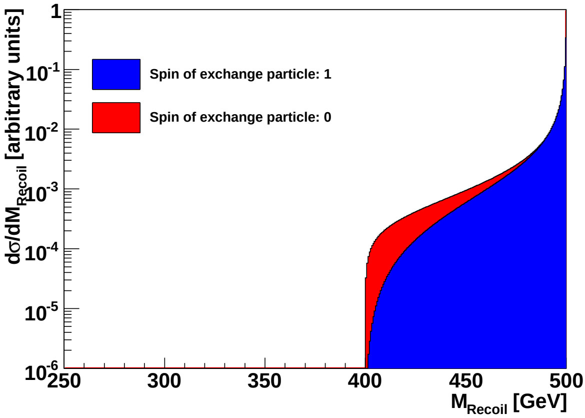
Template fit

- Fixed parameters:
  - $M_\chi = 180$ GeV
  - $\kappa = 0.3$
  - $S = 1$
  - $J_0 = 1$
  - $\mathcal{L} = 500\ \mathrm{fb}^{-1}$
- Different polarisations
  - (0.0,0.0) (solid)
  - (0.8,0.0) (dotted)
  - (0.8,-0.6) (dashed)



- Resolution typically 3 GeV to 1 GeV over large range of parameters
- Polarisation dependent

Simultaneous fit of M_χ, σ and J_0

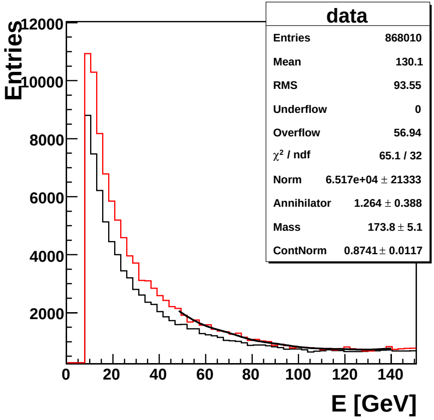


Find Cut-off in detected photon energies, measure shape at threshold

Simultaneous Determination of M_χ, σ_{bg}, σ_{sig} and J_0

M_{in}: 180 GeV; J_{in}: 1

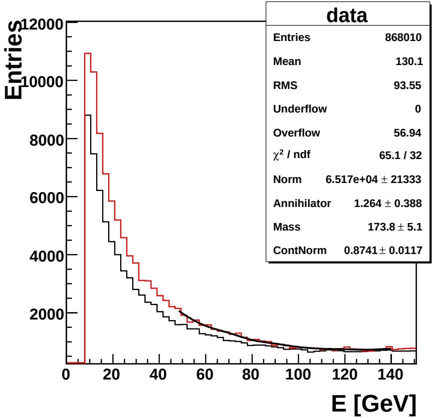
- Energy spectrum of ISR photons
- Background (black)
- Signal (red)
- Simultaneous fit of spectrum to S+B spectrum
- Four Free parameters:
  - Normalisation of background
  - Normalisation of signal
  - M_χ
  - J_0



Simultaneous Determination of M_χ, σ_{bg}, σ_{sig} and J_0

M_{in}: 180 GeV; J_{in}: 1

- $M = 173.8 \pm 5.1$ GeV
- $J = 1.264 \pm 0.338$
- J = 0 excluded
- First attempt, only one model point
- Improvements expected with better description of background shape



Summary

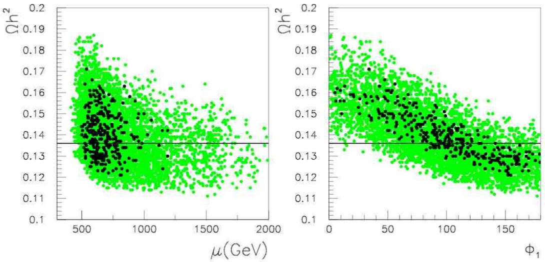
- WIMP detection with ISR, model independent approach
- Full simulation of ILD detector
- Sensitivity to coupling $\kappa \Leftrightarrow$ cross section
- Increase of reach with polarised beams
- Work in progress: Mass and J determination
- To do: handling of background
- Incorporate other backgrounds, systematics ...

Motivation II

G. Belanger *et al.*, [hep-ph] 0803.2584

Example, CPVMSSM at ILC

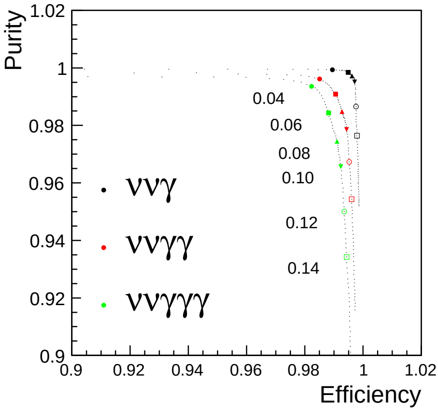
- Neutralino LSP dominantly Bino
- Only τ's and E_T^{miss} at ILC
- Relic density $\Omega h^2 = 0.130$
- CPV phase ϕ_1



Reconstruction, Efficiency

Merge photon candidates

- Collect all photon candidates in cone from IP
- High purity: No missmatch
- High efficiency: All candidates matched
- Cone opening angle of 0.04 rad seems good choice



Simulation and data

SM background (SLAC mass production)

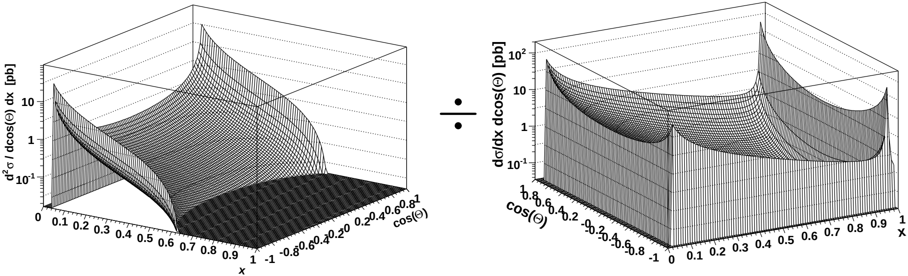
`ILD00, Mokka 06-07`

Process	$N_{rec.events}$	$\mathcal{L}$ per Pol. $[\mathrm{fb}^{-1}]$
$\nu_e\nu_e\gamma$ (-1.0/1.0)	1,999,766	133
$\nu_e\nu_e\gamma$ (1.0/-1.0)	99,320	250
$\nu_e\nu_e\gamma\gamma$	510,000	250
$\nu_e\nu_e\gamma\gamma\gamma$	36,000	250
$\nu_\mu\nu_\mu\gamma$	250,000	250
$\nu_\mu\nu_\mu\gamma\gamma$	50,000	250
$\nu_\mu\nu_\mu\gamma\gamma\gamma$	5,000	250
$\nu_\tau\nu_\tau\gamma$	250,000	250
$\nu_\tau\nu_\tau\gamma\gamma$	50,000	250
$\nu_\tau\nu_\tau\gamma\gamma\gamma$	5,000	250
Total	$\approx$3,300,000	

Signal weights

Signal Simulation

- Reweighting of $\nu\nu\gamma$ proceses
- Event weight $w = \frac{\sigma_{\chi\chi\gamma}}{\sigma_{\nu\nu\gamma}}$
- Only one simulation and reconstruction cycle needed



Example signal plot