Modelindependent WIMP Searches at the ILC

Christoph Bartels, Jenny List

DESY

LCWS 2007

Model-independent WIMP searches

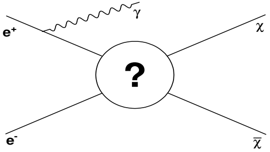
study:

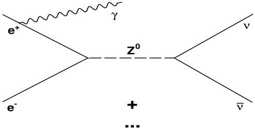
- sensitivity
- mass resolution
- benefits of beam polarisation

... with full detector simulation!

using:

- WIMP pair production with ISR: $e^+e^- \rightarrow \chi\bar{\chi}\gamma$
- main background process: $e^+e^- \rightarrow \nu\bar{\nu}\gamma$





A Model-independent Approach

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

What does model-independent mean?:

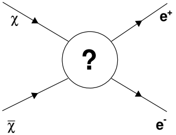
- **No** assumptions on the nature of the WIMP interactions
- Dark Matter consists of only one kind of particle
- WIMP pairs annihilate directly into SM particles $\chi\overline{\chi} \rightarrow X_i\overline{X_i}$
  $X_i = e, q, \nu, g, ...$ (no $\tilde{\tau}\tilde{\chi}_1^0$ coannihilation)
- Annihilation cross section σ_{an} determined by Ω_{DM}

A Model-independent Approach

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

Cross-section Derivation

- Annihilation cross section σ_{an} determined by Ω_{DM}



A Model-independent Approach

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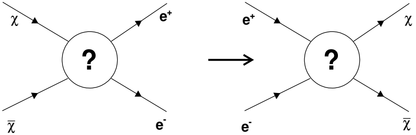
Cross section derivation

- Annihilation cross section σ_{an} determined by Ω_{DM}
- Crossing symmetry: $\sigma_{an} \rightarrow \sigma(e^+e^- \rightarrow \chi\overline{\chi})$



A Model-independent Approach

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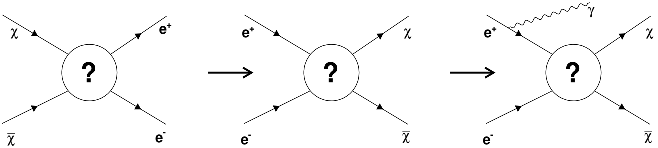
Cross section derivation

- Annihilation cross section σ_{an} determined by Ω_{DM}
- Crossing symmetry: $\sigma_{an} \to \sigma(e^+e^- \to \chi\overline{\chi})$
- Inclusion of ISR: $\sigma(e^+e^- \to \chi\overline{\chi}\gamma)$



A Model-independent Approach

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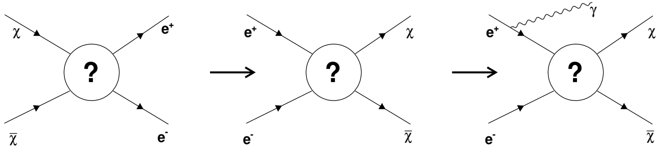
Cross section parameters

- Free:
  - κ_e Fraction of WIMP pair annihilation into e^+e-
  - M_χ WIMP mass
  - S_χ WIMP spin
  - J Angular momentum of dominant partial wave
- From cosmological observation: σ_{an}



Influence of Beam Polarisation

- Main irreducible background: $e^- e^+ \rightarrow \nu\bar{\nu}\gamma$ is strongly suppressed for $e^+_L e^-_R$
- WIMP couplings to electrons may have different behaviour!

Possible cases for **WIMP** couplings to electrons

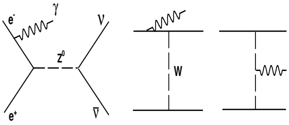
- like SM charged weak interaction $\kappa(e^-_L e^+_R)$
- parity and helicity conserving $\kappa(e^-_L e^+_R) = \kappa(e^-_R e^+_L)$
- opposite SM charged weak interaction $\kappa(e^-_R e^+_L)$

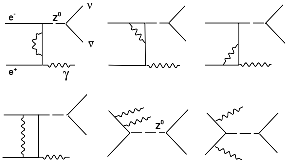
Expect enhancement of S/B ratio by polarisation!

Event Generation

Background:

- NUNUGPV: $e^+e^- \rightarrow \nu\overline{\nu}\gamma(\gamma\gamma)$ (used at LEP2)





- $1.2 \cdot 10^6$ events generated at $\sqrt{s} = 500 GeV$
- At least one photon with 8 GeV $< E_\gamma <$ 250 GeV and $15^o < \Theta_\gamma < 165^o$ in each event

Signal:

- Reweighting background according to WIMP cross section
- Benefit: only one MC production needed

Detector Simulation and Reconstruction

Full GEANT 4 based detector simulation

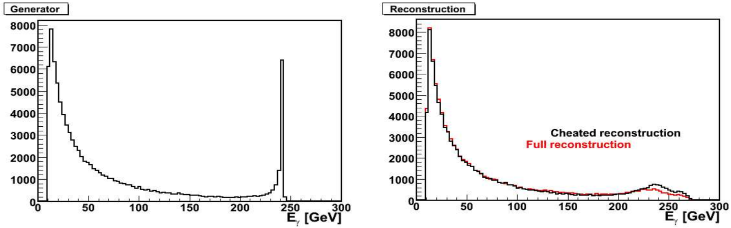
- Large Detector Concept
  - LDC01Sc
  - 4 Tesla magnetic field
- Mokka 6.1

Reconstruction with MarlinReco

- Particle Flow as implemented in WOLF algorithm
- require:
  - $E_\gamma > 10$ GeV
  - $20^\circ < \theta_\gamma < 160^\circ$
  - for resolution studies: angular match to generated photon

Photon Energy Spectra

Energy of highest energy photons:



Full reconstruction

- Z^0-resonance at 240 GeV heavily smeared
- Fewer photons reconstructed at high energies than with cheaters

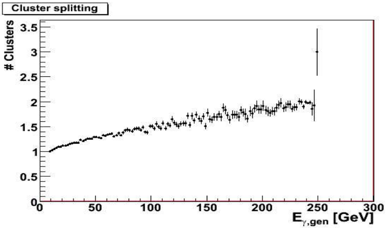
Cheated reconstruction

- Slightly better reconstruction

Cluster Splitting

Splitting of large clusters

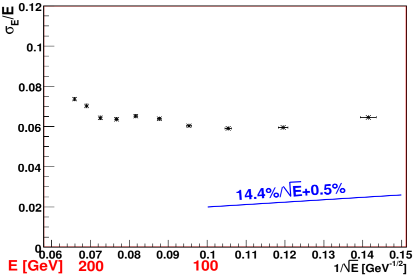
- Large clusters are split up, and identified as individual photons
- $\Rightarrow$ Photon deficit at high energies



Merging of photons

- $\Rightarrow$ recombine neighboring photons
- Combined photon spectrum close to cheated photon spectrum

Energy Resolution

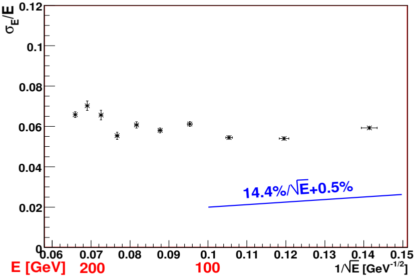


Averaged over full detector

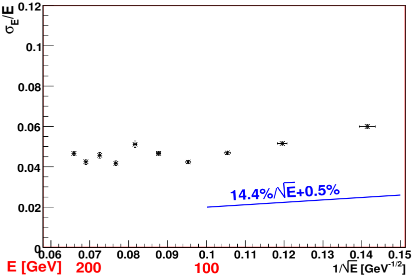
- Photon energy resolution roughly constant at 6%
- Significantly worse than design goal, has to be investigated!
- Further analysis certainly influenced by this behavior

Energy Resolution

Barrel



Endcaps



Investigate with

- single particle gun
- other photon finders (P.Krstonosic, Pandora)

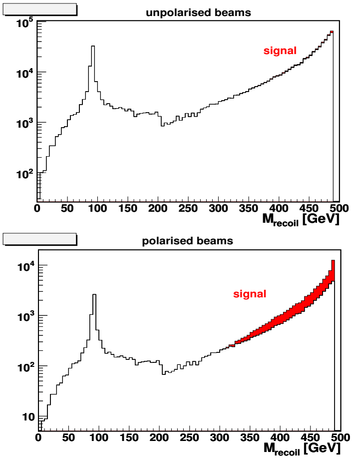
Recoil Mass Spectrum

WIMP:

- P-wave annihilator (J=1)
- $M_\chi = 150$ GeV
- $S_\chi = 1$
- $\kappa_e = 0.3$

$$M^2_{recoil} = s - 2\sqrt{s}E_\gamma$$

WIMP signal kicks in at $M_{recoil} = 316$ GeV



Sensitivity

Reach for 3σ observation with $\int Ldt = 500fb^{-1}$

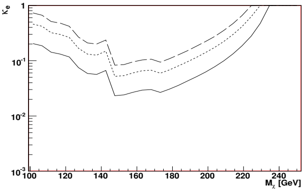
- Method: fractional event counting implemented in ROOT::TLimit
- WIMP spin
  - **Case 1:** P-wave (J=1), $S_\chi = 1$ WIMP
  - **Case 2:** P-wave (J=1), $S_\chi = \frac{1}{2}$ WIMP
- WIMP couplings
  - coupling to e_L^- and e_R^+
  - coupling to e_R^- and e_L^+
  - parity and helicity conserving couplings
- Polarisation
  - unpolarisaed beams
  - e^- polarisation only ($P_{e^-} = 0.8$)
  - additional e^+ polarisation ($P_{e^+} = 0.6$)

Case 1: P-wave (J=1), $S_\chi = 1$ WIMP

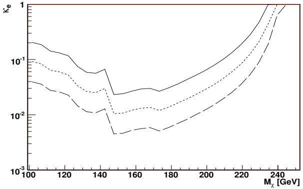
Polarisation:

- **full line:** unpolarised beams
- **dotted line:**
  e^- only ($P_{e^-} = 0.8$)
- **dashed line:**
  additional e^+ ($P_{e^+} = 0.6$)

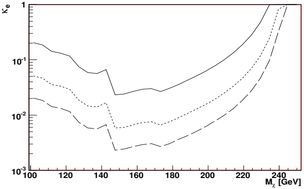
coupling: e_L^- / e_R^+



coupling: P & H conserving



coupling: e_R^- / e_L^+

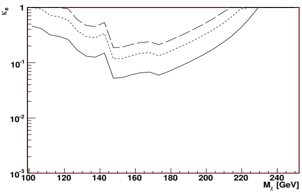


Case 2: P-wave (J=1), $S_\chi = \frac{1}{2}$ WIMP

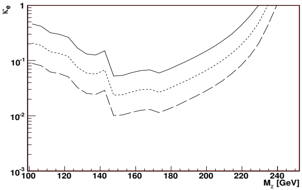
Polarisation:

- **full line:** unpolarised beams
- **dotted line:**
  e^- only ($P_{e^-} = 0.8$)
- **dashed line:**
  additional e^+ ($P_{e^+} = 0.6$)

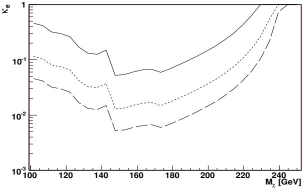
coupling: e^-_L / e^+_R



coupling: P & H conserving

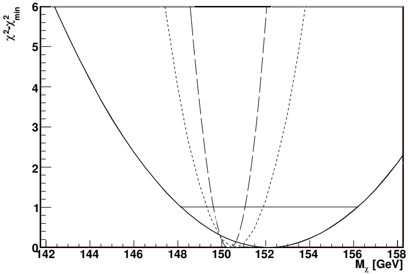


coupling: e^-_R / e^+_L



Mass Resolution

- χ^2 test on recoil mass distributions
- $\int Ldt = 200fb^{-1}$
- again for the three polarisation scenarios



WIMP (Case 1):

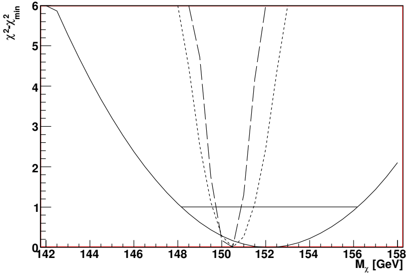
- P-wave annihilator (J=1), $S_\chi = 1$
- couplings P & H conversing
- $M_\chi = 150$ GeV
- $\kappa_e = 0.3$

Mass resolution

- $P_{e^-} = 0.8, P_{e^+} = 0.0$: $M_\chi = 150.5 \pm 1.3$ GeV
- $P_{e^-} = 0.8, P_{e^+} = 0.6$: $M_\chi = 150.4 \pm 0.7$ GeV

Mass Resolution

- χ^2 test on recoil mass distributions
- $\int Ldt = 200fb^{-1}$
- again for the three polarisation scenarios



WIMP (Case 1):

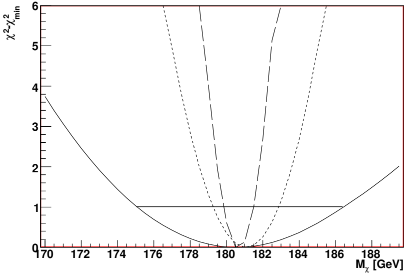
- P-wave annihilator (J=1), $S_\chi = 1$
- couplings: $e_R^- \ / \ e_L^+$
- $M_\chi = 150$ GeV
- $\kappa_e = 0.3$

Mass resolution

- $P_{e^-} = 0.8, P_{e^+} = 0.0$: $M_\chi = 150.5 \pm 1.0$ GeV
- $P_{e^-} = 0.8, P_{e^+} = 0.6$: $M_\chi = 150.3 \pm 0.6$ GeV

Mass Resolution

- χ^2 test on recoil mass distributions
- $\int Ldt = 200fb^{-1}$
- again for the three polarisation scenarios



WIMP (Case 2):

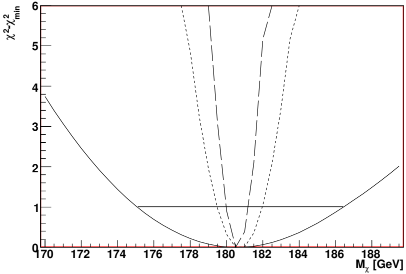
- P-wave annihilator (J=1), $S_\chi = \frac{1}{2}$
- couplings: P & H conserving
- $M_\chi = 180$ GeV
- $\kappa_e = 0.3$

Mass resolution

- $P_{e^-} = 0.8, P_{e^+} = 0.0$: $M_\chi = 181.0 \pm 1.7$ GeV
- $P_{e^-} = 0.8, P_{e^+} = 0.6$: $M_\chi = 180.5 \pm 0.9$ GeV

Mass Resolution

- χ^2 test on recoil mass distributions
- $\int Ldt = 200fb^{-1}$
- again for the three polarisation scenarios



WIMP (Case 2):

- P-wave annihilator (J=1), $S_\chi = \frac{1}{2}$
- couplings: e_R^- / e_L^+
- $M_\chi = 180$ GeV
- $\kappa_e = 0.3$

Mass resolution

- $P_{e^-} = 0.8, P_{e^+} = 0.0$:

  $M_\chi = 180.7 \pm 1.3$ GeV
- $P_{e^-} = 0.8, P_{e^+} = 0.6$:

  $M_\chi = 180.5 \pm 0.6$ GeV

Benefits Of Beam Polarisation

Benefits

- 80% Polarisation of the e^- beam increases the sensitivity by a factor of 2 to 3
- Additionally 60% e^+ polarisation gives another increase in sensitivity by a factor of 2 as well as in the mass resolution (compared to e^- polarisation)

Summary

- Analyses in full simulation are possible already
- Reconstruction needs users
- Detector optimisation is ongoing
- Good chance of model-independent WIMP detection at the ILC
- Beam polarisation enhances significantly the reach as well as the mass resolution
- Additional e^+ polarisation increases the sensitivity by the same factor as e^- polarisation alone

Outlook

- Understand energy resolution
- Use better photon reconstruction (Pandora, photon finder by P. Krstonosic)
- Include reducible (experimental) backgrounds
- Include beamstrahlung / machine backgrounds
- Study different variations of detector concept
- Have a look at SUSY scenarios in which radiative Neutralino production is the only open SUSY channel at the ILC ($\rightarrow$ talk by O.Kittel in SUSY / Polarisation sessions)