Modelindependent WIMP Searches at the ILC

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DESY

LCWS 2008 - Cosmological Connections

Introduction Data Analysis Sensitivity Mass Resolution Summary And Outlook

Modelindependent WIMP Searches at the ILC

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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: $e^+e^- \rightarrow \nu \bar{\nu} \gamma$



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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 $\chi \overline{\chi} \to X_i \overline{X_i}$ $X_i = e, q, \nu, g, ...$ (no $\tilde{\tau} \tilde{\chi}_1^0$ coannihilation)
- Annihilation cross section σ_{an} determined by Ω_{DM}

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

Cross-section Derivation

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



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

Cross section derivation

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



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

Cross section derivation

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



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

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}



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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!

Considered 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!

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Detector Optimization & Letters of Intent

Timeline for Detector Concepts

- follows machine schedule
- Letters of Intent due March '09
- will be reviewed by International Detector Advisory Group of experimentalists and theoreticians



 promissing concepts will be asked to provide a more detailed design in time with Technical Design Phase II of the machine

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Detector Optimization & Letters of Intent

ILD = GLD + LDC

- various "flavours" of GLD and LDC studied in full simulation (Jupiter / Mokka)
- ▶ varying TPC radius, B-field, # of calorimeter layers, ...
- September 2008: ILD's parameters for Lol fixed
- nearly finished: implementation into simulation, testing, adapting reconstruction algorithms
- any day now: start of MC mass production of about:
 - ▶ 500 fb⁻¹ Standard Model at $E_{\rm CM} = 500$ GeV
 - plus SUSY: SPS1a', Point 5
 - SM Higgs + backgrounds at $E_{\rm CM} = 250$ GeV

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Event Generation

Standard Model Background

- SLAC SM Whizard sample http://confluence.slac.stanford.edu/display/ilc/Standard+Model+Data+Samples
- incl. beamstrahlung, beam energy spread from GUINEA PIG for nominal ILC beam parameters
- Currently using $e^+e^- \rightarrow \nu \overline{\nu} \gamma + ISR$

▶ 800k events (10 fb⁻¹) at
$$\sqrt{s} = 500 GeV$$



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Event Generation

Signal

- Reweighting background according to WIMP cross section
- Benefit: only one MC production needed
- Problem: predicted signal cross-section assumes one collinear photon per event, event sample contains one "hard" photon plus ISR, beamstrahlung



 \Rightarrow need to calculate center-of-mass energy of hard subprocess before applying weight

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Detector Simulation and Reconstruction Full GEANT 4 based detector simulation

- within the optimization of the ILD detector concept
 - LDCPrime_02Sc
 - 3.5 Tesla magnetic field
 - high granularity Si–W electromagnetic calorimeter
 - extended coverage in forward region (Fwd trackers, LumiCal)
- Mokka 06-06-p03

Reconstruction with MarlinReco 01-04

- Particle Flow: Pandora algorithm
- require:
 - $E_{\gamma} > 10 \text{ GeV}$
 - $6^{\circ} < \theta_{\gamma} < 174^{\circ}$
 - for resolution studies: angular match to generated photon

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A simulated event



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Photon Energy Reconstruction

Energy of most energetic photon

► Z⁰-resonance recoil at 240 GeV

- at generator level...
- ... and after simulation and reconstruction
- width of reconstructed Z recoil peak 6.4 GeV
- but not out of the box.....



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Cluster Splitting

Particle Flow...

- leads to splitting of high energy clusters and identifies them as individual photons
- ► ⇒ Photon deficit at high energies

Merging of photons

- recombine neighboring photons
- ► \Rightarrow significant improvement at high E_{γ}



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Effect of new detector model & reconstruction?

Changes

- Detector: LDC \rightarrow ILD
- ▶ Reconstruction: Wolf → Pandora
- small goodies: correction for cracks in calorimeters, ...
- ► ⇒ significantly improved energy reconstruction!
- ➤ ⇒ expect significant improvement of results, which should outweigh effects of additional backgrounds



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Sensitivity

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

- 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
 - unpolarised beams
 - e^- polarisation only ($P_{e^-} = 0.8$)
 - additional e^+ polarisation ($P_{e^+} = 0.6$)

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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: P & H conserving



coupling: e_L^- / e_R^+



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

Polarisation:

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

additional e^+ ($P_{e^+} = 0.6$)

coupling: P & H conserving



coupling: e_L^- / e_R^+



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Recoil Mass Spectrum

WIMP:

- ▶ P-wave annihilator (J=1)
- $M_{\chi} = 180 \text{ GeV}$

•
$$S_{\chi} = 1$$

•
$$\kappa_e = 1$$

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

WIMP signal kicks in at $M_{recoil} = 360 \text{ GeV}$



- for sensitivity calculation, E and θ are used instead of recoil mass
- the following results have not yet been updated!

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- χ² test on recoil mass distributions
- $\int Ldt = 200 fb^{-1}$
- again for the three polarisation scenarios

WIMP (Case 1):

- ▶ P-wave annihilator (J=1), S_{\chi} = 1
- couplings P & H conversing
- ▶ $M_{\chi} = 150 \text{ GeV}$

• $\kappa_e = 0.3$



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

•
$$P_{e^-} = 0.8, P_{e^+} = 0.6$$
:

$$M_\chi = 150.4 \pm 0.7~{
m GeV}$$

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- χ² test on recoil mass distributions
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WIMP (Case 1):

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



•
$$P_{e^-} = 0.8, P_{e^+} = 0.0$$
:

$$M_\chi = 150.5 \pm 1.0~{
m GeV}$$

•
$$P_{e^-} = 0.8, P_{e^+} = 0.6$$
:

$$\textit{M}_{\chi} = 150.3 \pm 0.6 ~\rm{GeV}$$

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- χ² test on recoil mass distributions
- $\int Ldt = 200 fb^{-1}$
- again for the three polarisation scenarios

WIMP (Case 2):

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

• $\kappa_e = 0.3$



•
$$P_{e^-} = 0.8, P_{e^+} = 0.0$$
:

$$M_\chi = 181.0 \pm 1.7$$
 GeV

•
$$P_{e^-} = 0.8, P_{e^+} = 0.6$$
:

$$M_\chi = 180.5 \pm 0.9~{
m GeV}$$

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- χ² test on recoil mass distributions
- $\int Ldt = 200 fb^{-1}$
- again for the three polarisation scenarios

WIMP (Case 2):

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



- $P_{e^-} = 0.8, P_{e^+} = 0.0$:
 - $M_\chi = 180.7 \pm 1.3~{
 m GeV}$

•
$$P_{e^-} = 0.8, P_{e^+} = 0.6$$
:

$$\textit{M}_{\chi} = 180.5 \pm 0.6 ~\rm{GeV}$$

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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)

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Summary

- previous analysis (c.f. LCWS '07) is being upgraded to more realistic detector simulation
- reconstruction improvements
- Good chance of model-independent WIMP detection at ILC
- Beam polarisation enhances significantly the reach as well as the mass resolution
- mass resolutions down to 0.6 GeV (c.f. SUSY LSP mass from cascade decays: about 0.1 GeV)
- Additional e⁺ polarisation increases the sensitivity by the same factor as e⁻ polarisation alone
- first look into new detector model & reconstruction upgrades promisses improved results

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Outlook

- Repeat with the ILD detector parameters for the Letter of Intent (due March 09)
- Include reducible (experimental) backgrounds
- Include machine backgrounds (pairs!)
- Have a look at SUSY scenarios in which radiative Neutralino production is the only open SUSY channel at the ILC