Searches for Dark Matter particles at the International Linear Collider (ILC)

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Outline

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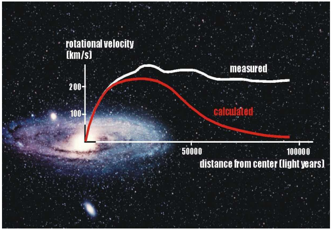
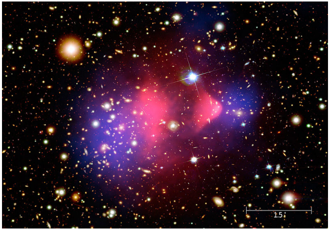
Introduction

WIMP searches: Direct and Indirect detection, Colliders

WHY Dark Matter ?

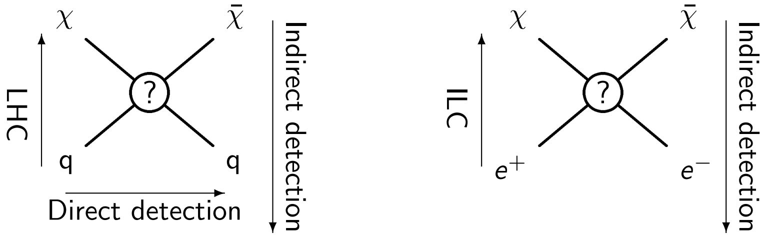
- Strong evidence from multiple sources





- Nature/Interactions with visible matter unknown
- One of the strongest hints for "particle" new physics
- Strong motivation for weak up to few TeV scale DM
- Testable at colliders

Possibility to reach WIMPs



Direct detection

- Elastic scattering of primordial WIMPs on nucleons in a large detector (e.g. LXe). No sensitivity to WIMP-lepton coupling

Indirect detection

- WIMPs annihilation in galaxy, observe decay products registered by the big telescopes. Sensitivity to WIMP coupling to leptons, limited mass range

Colliders

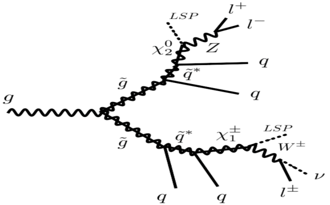
- Produce WIMPs or supersymmetry particles at pp or e^+e^- colliders

WIMPs at Colliders

Two basic ways to produce WIMPs at colliders:

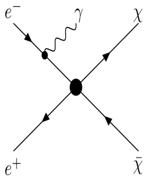
In cascade decay of supersymmetric or exotic particle

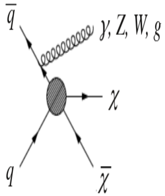
- Production in decay can dominate but is model-dependent
  (new particle in addition to WIMP!)



Direct production

- Direct production is less model-dependent,
  and is not yet strongly constrained.
  Will be my focus in this talk



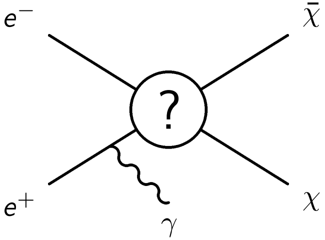


Outline

Model-independent WIMP searches at ILC: the idea

How? χ is after all invisible ?!

Trick! Demand an ISR γ in the detector and nothing else.



Signal:

- WIMP pair production with ISR: $e^+e^- \to \chi\bar{\chi}\gamma$
- Backgrounds :
  - Irreducible $e^+e^- \to \nu\bar{\nu}(N)\gamma$
  - Reducible :
    - radiative Bhabha scattering $e^+e^- \to e^+e^-\gamma$
    - $e^+e^- \to \gamma(N)\gamma$, N=0,1,2
    - ....

Event Generation and Reconstruction

Monte Carlo:

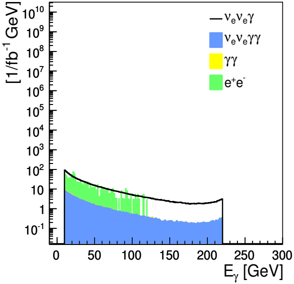
- ILD 00 SM DSTs at 500 GeV
- signal: reweighting of $\nu\nu\gamma$ process

Event reconstruction:

- Particle Flow: Pandora algorithm
- Require at least one photon with
  $E_\gamma > 10$ GeV
  $|cos(\Theta)| < 0.997$
- no tracks

Systematic errors:

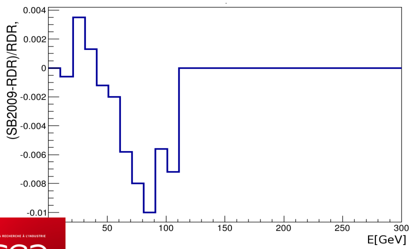
- Luminosity measurement
- Polarization measurement
- Beam spectrum
- Photon selection

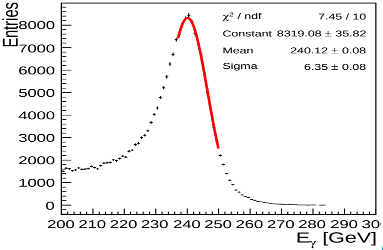


Photon energy distribution of the selected signal-like events of the SM background after all cuts

Systematic errors

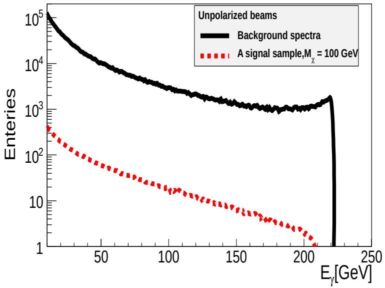
- Luminosity measurement $\delta\mathcal{L}/\mathcal{L} = 0.11$ % (arXiv:1304.4082)
- $\delta P_{e^-}/P_{e^-} = 0.25$ % and $\delta P_{e^+}/P_{e^+} = 0.25$ % (TDR)
- Beam spectrum: The relative deviation between the SB-2009 and RDR beam parameter sets in the photon energy region from 10 to 100 GeV.
- Photon selection $\delta\varepsilon/\varepsilon = 0.43\%$ from normalization to radiative Z-return.



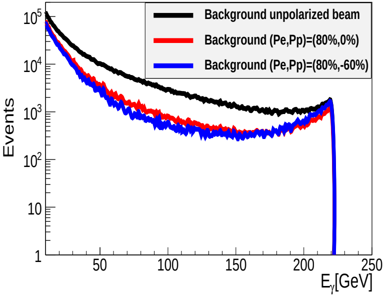


Signal and Background

Signal and background



Sum of all background processes: $\nu\nu(N)\gamma$, $\gamma\gamma$, e^+e^-



$P(e^+e^-)$	$N_{bg}^{tot}, L = 500 fb^{-1}$	$N_{bg}^{\nu\nu\gamma}, L = 500 fb^{-1}$	$\nu\nu\gamma$	Bhabha
(0%,0%)	1.85e+06	1.24e+06	67 %	23 %
(+80%,-60%)	788046	204218	25 %	75 %

Cosmological Approach

In models where the relic density Ω_{dm} depends on rate for $\chi\chi \to$ SM-particles, crossing-symmetry tells us what $e^+e^- \to \chi\chi$ is.

Signal cross section:

$$\frac{d\sigma}{dx\ d\cos\Theta} \approx \frac{\alpha\kappa_e^{pol}\sigma_{\rm an}}{16\pi}\frac{1+(1-x)^2}{x\sin\Theta^2}2^{2J_0}(2S_\chi+1)^2\left(1-\frac{4M_\chi^2}{(1-x)s}\right)^{1/2+J_0}$$

where κ_e^{pol} is polarization dependent annihilation fraction to e^+e^- σ_{an} -from cosmological observation. There is $x = \frac{2E_\gamma}{\sqrt{s}}$ and E_γ is the photon energy and center-of-mass energy $\sqrt{s}$ correspondingly.

$$\kappa_e^{pol} = \frac{1}{4}(1+P_{e^-})[(1+P_{e^+})\kappa(e_-^R e_+^L)+(1-P_{e^+})\kappa(e_-^R e_+^R)]$$
$$+\frac{1}{4}(1-P_{e^-})[(1+P_{e^+})\kappa(e_-^L e_+^L)+(1-P_{e^+})\kappa(e_-^L e_+^R)]$$

Effective Operator Approach

Coupling of WIMP to electron and positron :

$$\mathcal{O}_V = (\overline{\chi}\gamma_\mu\chi)(\bar{l}\gamma^\mu l), \qquad (vector)$$
$$\mathcal{O}_S = (\overline{\chi}\chi)(\bar{l}l), \qquad (scalar, s-channel)$$
$$\mathcal{O}_A = (\overline{\chi}\gamma_\mu\gamma_5\chi)(\bar{l}\gamma^\mu\gamma^5 l), \qquad (axial-vector)$$

Double differential cross section for Vector operator :

$\sigma_{LR} = \sigma_{RL}$:

$$\frac{d\sigma}{dx\, d\cos\Theta} = \frac{\alpha}{12\pi^2}\frac{s}{\Lambda^4}\frac{(1-x+2\mu^2)}{x\sin^2\Theta}\sqrt{\frac{1-x-4\mu^2}{1-x}}(4(1-x)+x^2(1+\cos^2\Theta))$$

Λ is energy scale that provides the coupling and $x = \frac{2E_\gamma}{\sqrt{s}}$, $\mu = \frac{M_\chi}{\sqrt{s}}$

$\sigma_{RR} = \sigma_{LL} = 0$

For Axial-vector and Scalar s-channel operators :

$\sigma_{RR} = \sigma_{LL} \neq 0$

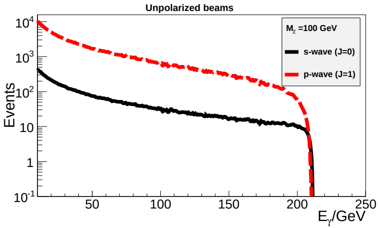
$\sigma_{LR} = \sigma_{RL} = 0$

Parameters Overview

Cosmology approach

Free parameters:

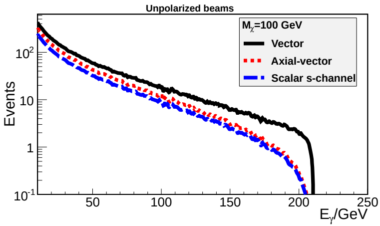
- M_χ - WIMP mass
- S_χ - WIMP spin
- k_e - Fraction of WIMP pair annihilation into e^+e^-, $\sigma \sim \kappa_e^{pol}$
- J - Angular momentum of dominant partial wave



Effective operator approach

Free parameters:

- M_χ - WIMP mass
- S_χ - WIMP spin $= \frac{1}{2}$
- Λ - energy scale of the new physics that provides the coupling, $\sigma \sim \frac{1}{\Lambda^4}$
- Choice of operator



Analysis strategy

The aim of this studies:

Calculate sensitivity of the ILC to WIMP searches.

$\Longrightarrow$ The modified frequentist approach was chosen as a method for this studies.

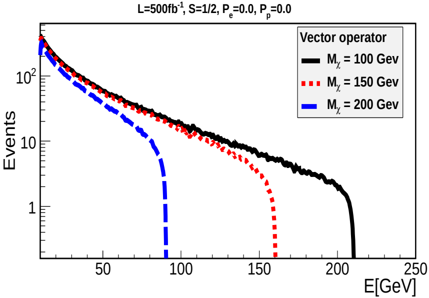
Modified Frequentist Approach

$CL_S \equiv CL_{S+B}/CL_B$, where

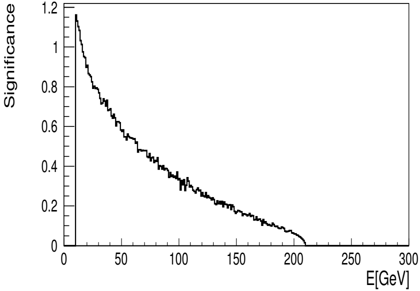
- CL_B will be integral of probability distribution function for Background from -∞ to D
- CL_{S+B} will be integral of probability distribution function for (Signal+Background) from -∞ to D

Shape information

Photons spectrum for different WIMP mass



Significance in every bin



Channels with higher significance helps to improve sensitivity

Outline

Results

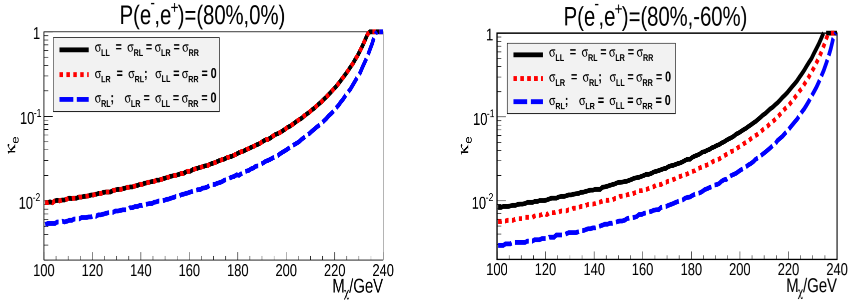
Cosmological Approach

Effective Operator Approach

Comparison to CMS

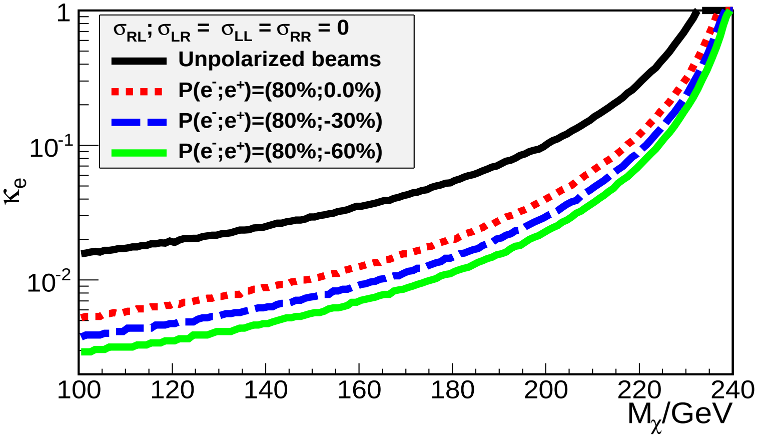
Sensitivity for 3σ Observation in Cosmological Approach

$$S_\chi{=}1,\ L = 500 fb^{-1},\ \sqrt{s} = 500\ \text{GeV}$$



Annihilation fraction(k_e) of few percent is enough to observe WIMPs at ILC

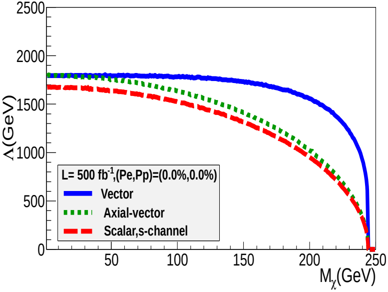
Polarization dependence in Cosmological Approach



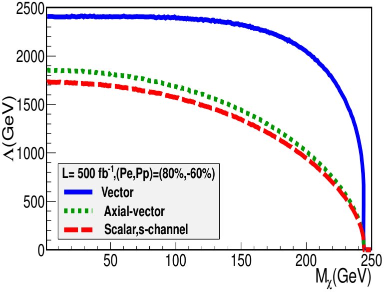
Polarization gains nearly order of magnitude

Sensitivity for 3σ Observation in Effective Operator Approach

Unpolarized beams



$P(e^+e^-)$=(80%;-60%)

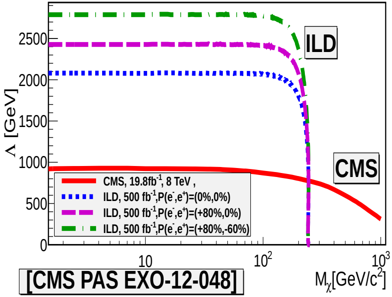


Using polarized beams, we can increase sensitivity.
Here presented helicity configuration optimal for Vector operator

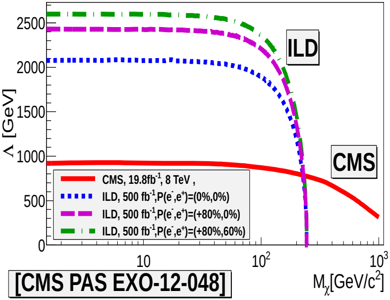
Comparison of ILC limits with CMS

Exclusion limits at 90% CL

Vector operator



Axial-vector operator



ILC can place limit on Λ up to $\sim$ 2.7 TeV

Outline

Conclusion

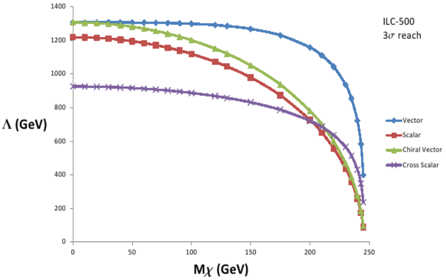
Conclusion

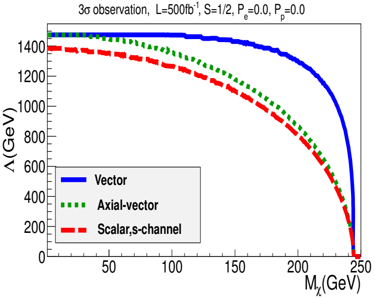
- Model-independent WIMP searches at the ILC are complementary to LHC, direct and indirect detection .
- Presented results for different theoretical approaches:
  - Cosmological Approach: Annihilation fraction(k_e) of few percent is enough to observe WIMPs
  - Effective Operator Approach: 3σ Observation up to $\Lambda \sim 2.5$ TeV.
- Polarisation is important to reduce $\nu\bar{\nu}\gamma$ background and can to distinguish models.

BACKUP

Comparison with previous studies:

3σ observation, $\mathcal{L} = 500\ fb^{-1}$, $P(e^+e^-)$=(0.0;0.0) From JHEP 1305 (2013) 138, in this caclulation only $\nu\bar{\nu}\gamma$ are used



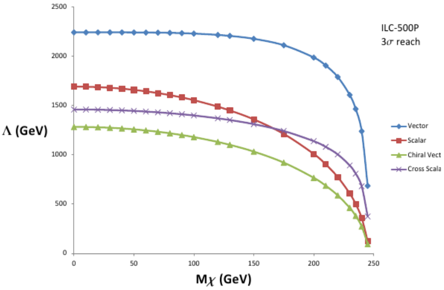


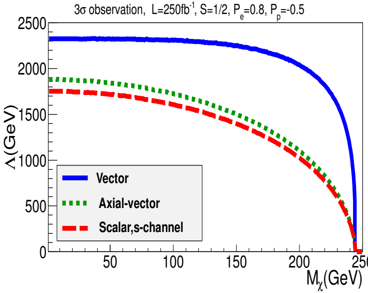
Results are within $\sim$ 100 GeV. Reason: different background cross-section. We allow additional ISR $\nu\bar{\nu}(N)\gamma$,where N=1,2,3

Comparison with previous studies:

3σ observation, $\mathcal{L} = 250\ fb^{-1}$, $P(e^+e^-)$=(0.8;-0.5)

From JHEP 1305 (2013) 138

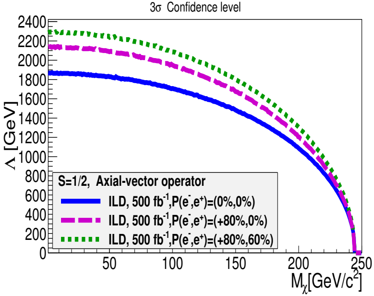




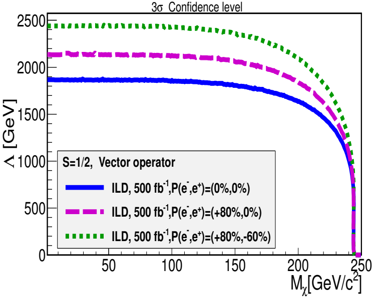
Agrees well for polarized beams.

Improvement of beam polarization

Axial-vector operator

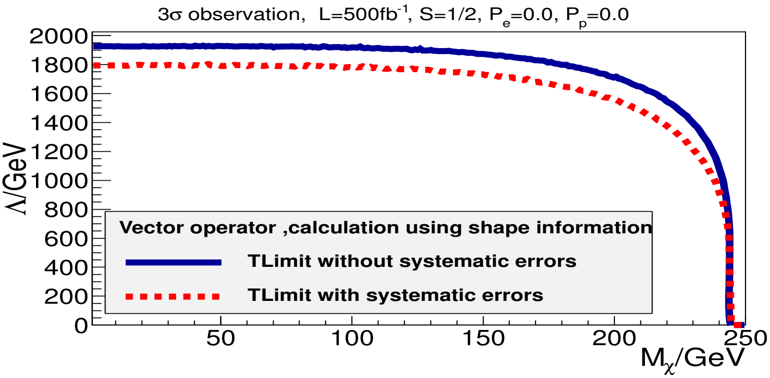


Vector operator



- Electron polarization improves limit on Λ by $\sim$ 200 GeV.
- Positron polarization improves limit on Λ by another $\sim$ 200-300 GeV, depending on operator.

Impact of systematic errors



Implementation of systematic errors decreases the limit on Λ by $\sim$ 100 GeV