Model-independent WIMP searches at ILC with single photon

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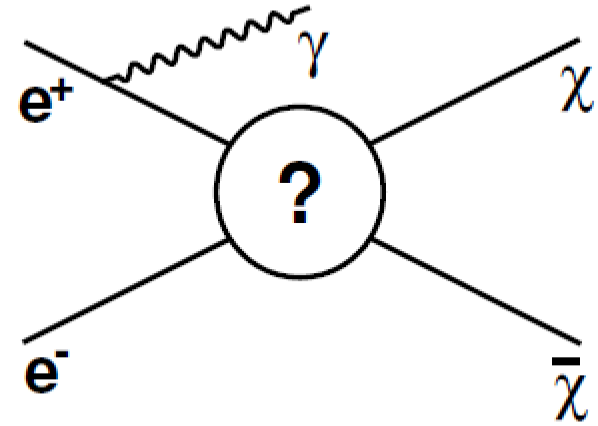
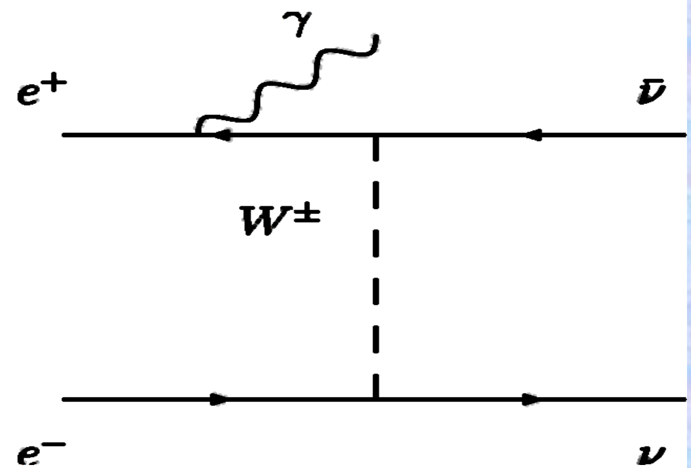
Model - Independent WIMP Searches

➢ Search for direct WIMP pair production (with ISR photon) at colliders:

e+e- → $\chi\chi\gamma$



➢ Main background: e+e- → $\nu\nu\gamma$



❖ ILC Study:

- Observation / exclusion reach
- Effects of luminosity / beam polarization

❖ Interpretation of the results using two theoretical approaches

❖ ILC/LHC Comparison

➢ Comparison with theory-level studies (M. Perelstein et al, JHEP 1305 (2013) 138) for polarized and unpolarized beams → good agreement observed & sensitivity improved by advanced statistical treatment

→ see talk Jenny List, 2014 LCWS Meeting, Chicago, May 10-14, 2014

Theory: Cosmological Approach

Signal cross section:

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

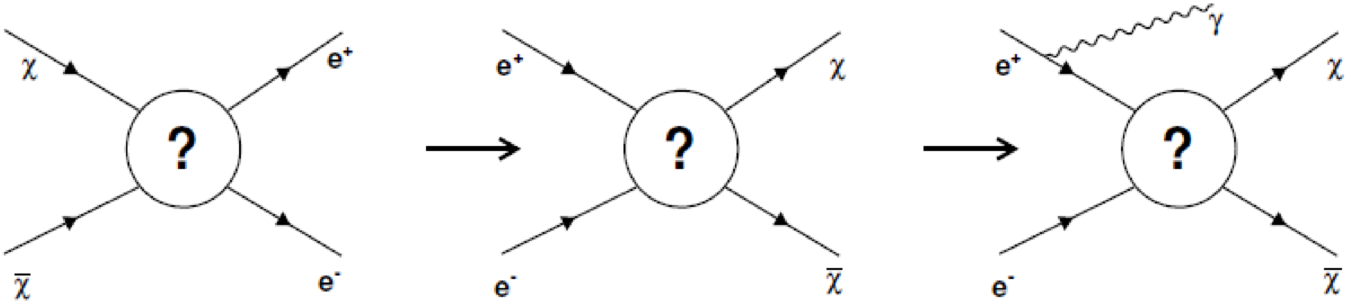
$$\frac{d\sigma}{dx\, d\cos\Theta} \approx \frac{\alpha \kappa_e^{pol} \sigma_{\rm an}}{16\pi} \frac{1+(1-x)^2}{x \sin\Theta^2} 2^{2J_0} (2S_\chi + 1)^2 \left(1 - \frac{4M_\chi^2}{(1-x)s}\right)^{1/2+J_0}$$

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.

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

Signal cross section derivation:

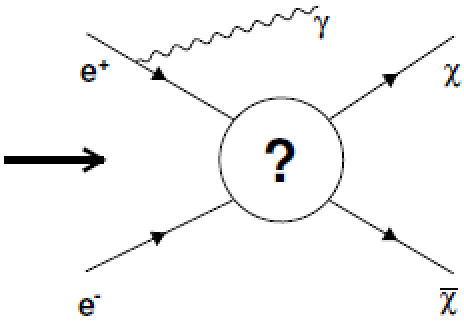
- Annihilation cross section σ_{an} determined by Ω_{DM}
- Crossing symmetry: $\sigma_{an} \rightarrow \sigma\ (e+e- \rightarrow \chi\chi)$
- Inclusion of ISR photon: $\sigma\ (e+e- \rightarrow \chi\chi)$



Theory: Effective Operator Approach

Parametrize "?" (coupling of WIMP to electron and positron) as:

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



POLARIZATION DEPENDENCE:

Double differential cross-section for Vector operator:

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

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

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:

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

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

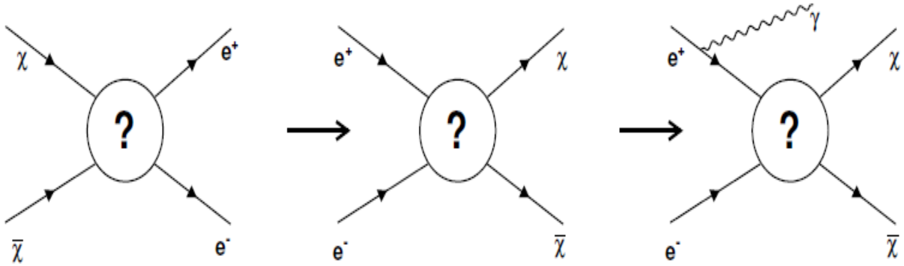
Theoretical Approaches: Cosmological vs Effective Operator

COSMOLOGICAL APPROACH

FREE PARAMETERS:

- $M\chi$ – WIMP mass
- $S\chi$ – WIMP spin
- κ_e - fraction of WIMP pair annihilation into e+e- ($s \sim \kappa_e$ pol)
- J – angular momentum of dominant partial wave

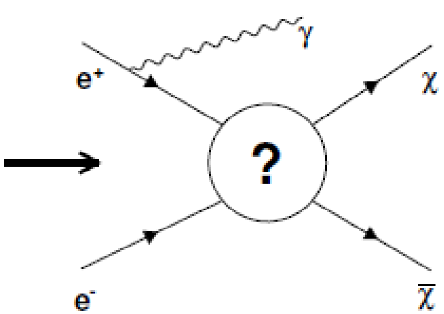
From Cosmological observation: σ_{an}



EFFECTIVE OPERATOR APPROACH

FREE PARAMETERS:

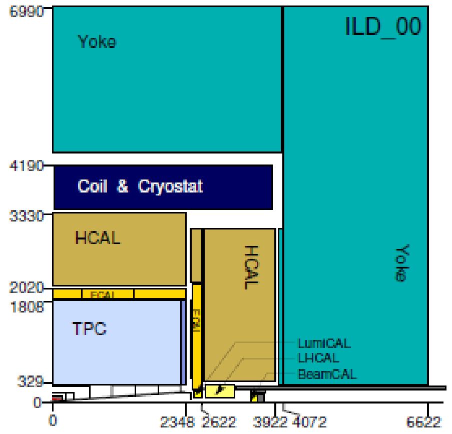
- $M\chi$ – WIMP mass
- $S\chi$ – WIMP spin = ½
- Λ – energy scale of New Physics ($\sigma \sim 1/\Lambda^4$)
- Choice of operator (vector; axial; scalar, s-channel)

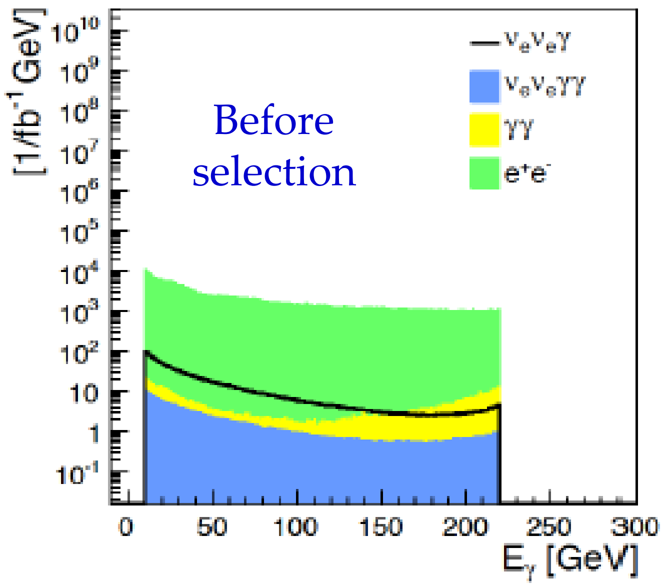


Detector Simulation and Reconstruction

Monte Carlo (used LOI):

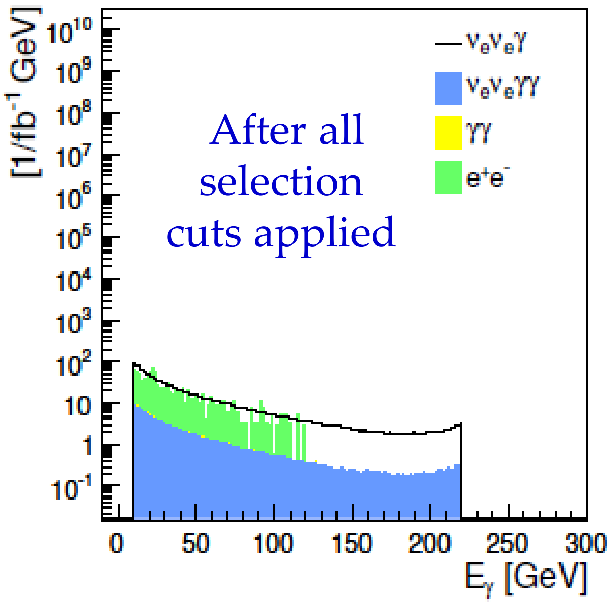
- SM: ILD 00 SM DSTs at 500 GeV
- Signal: reweighting of $\nu\nu\gamma$ process





Event reconstruction:

- Particle Flow: Pandora algorithm
- At least one photon with $E\gamma > 10$ GeV and $|\cos(\Theta)| < 0.997$
- No track with $p_T^{track} > 3$ GeV
- $E_{vis} - E_\gamma < 20$ GeV
- Beam Calo veto on high energetic e/ γ



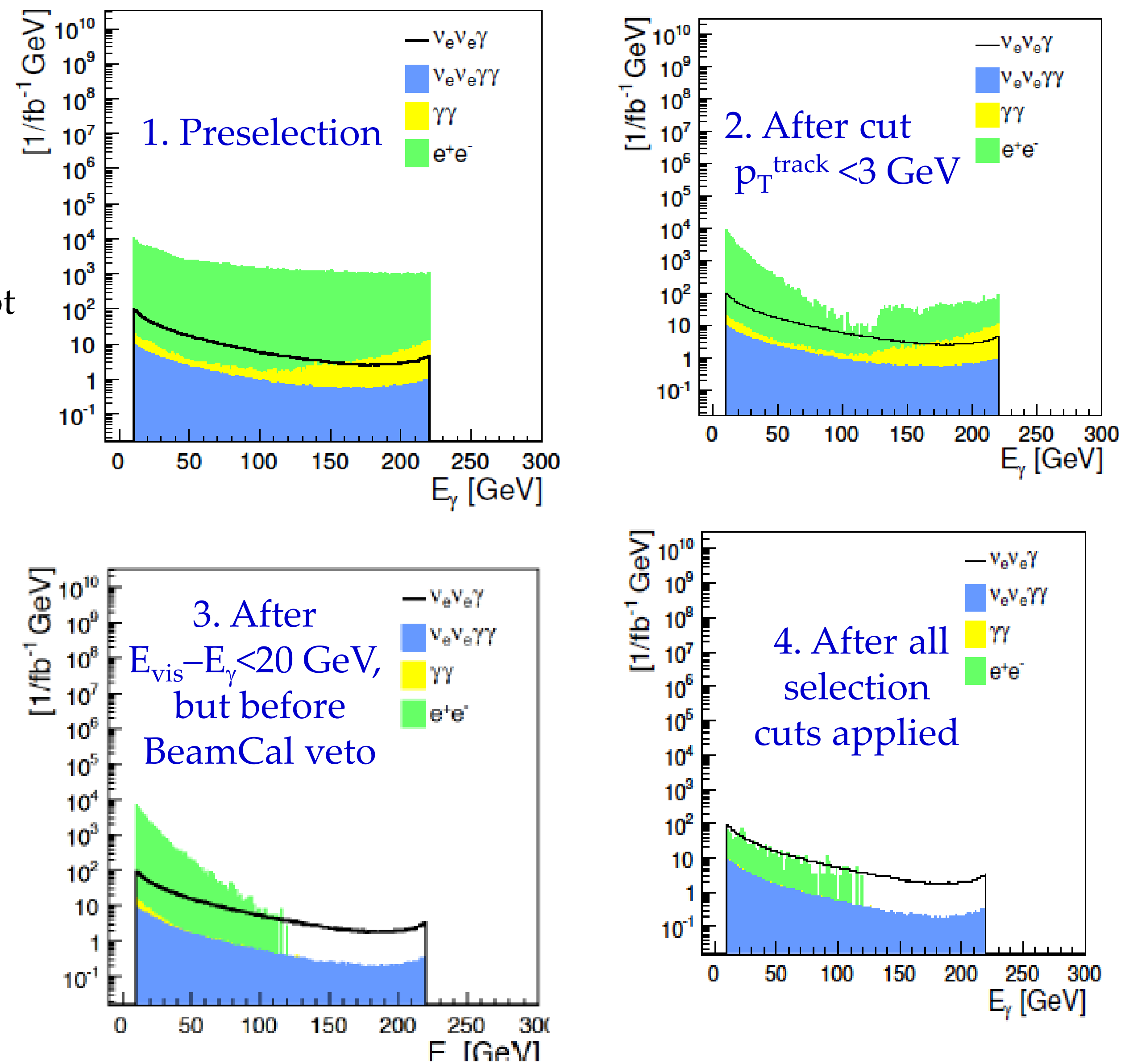
Selection Cuts and Irreducible Background

Irreducible background:

Radiative Bhabha's:

$e^+e^- \rightarrow e^+e^- \gamma$

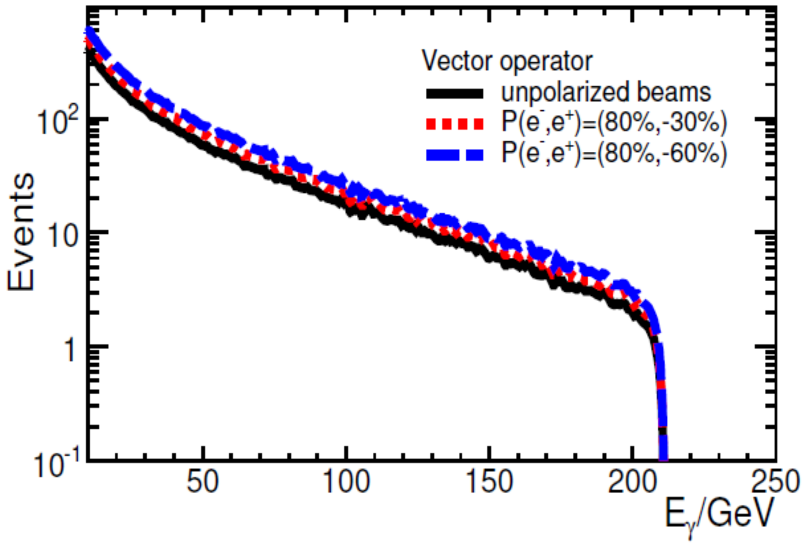
- Mimicks signal if e+e- is not detected
- Crucial to apply veto from BeamCal
- Forward e+/e-tagging capabilities are very important
- Smaller crossing angle would be advantageous
- Note: current study based on RDR beam parameters



Signal and Backgrounds

SIGNAL EVENTS:

→ no significant difference in shape between polarized and unpolarized beams (vector-operator, Λ = 1580 GeV)

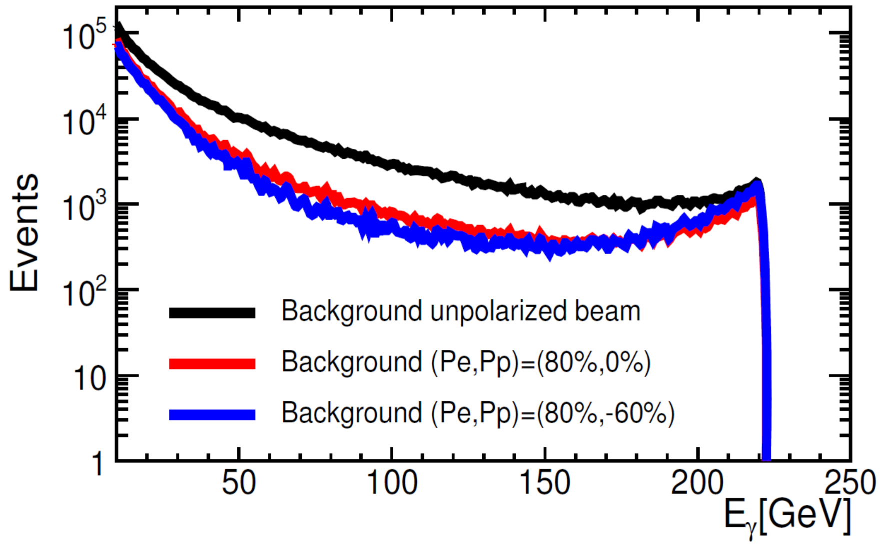


Number of signal events for different polarizations/operators (Mχ = 100 GeV)

Operator	(0%,0%)	(+80%,0%)	(+80%,-60%)	(+80%,+60%)
Vector	8504	8504	12586	4422
Axal-vector	6156	6156	3201	9112
Scalar s-channel	4641	4641	2413	6869

Sum of all background processes: ννγ, γγ, e+e-:

Using positron polarization number of ννγ background events can be suppressed by 80%:



Breakdown of different backgrounds for several e-/e+ polarizations:

$(P_{e^-}; P_{e^+})$	N_{bg}, events	$N_{bg}^{\nu\nu\gamma}$, events	Instr. bg	$\nu\nu\gamma$
(0%,0%)	1856502	1119549	40 %	60 %
(+80%,0%)	906636	269073	70 %	30 %
(+80%,-60%)	788045	168599	79 %	21 %

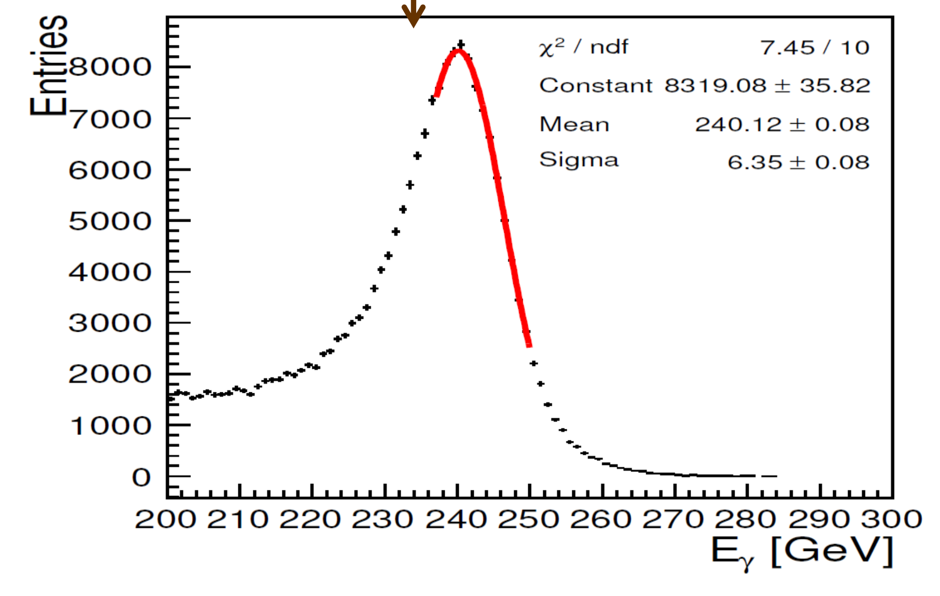
Systematic Uncertainties

Different sources are considered:

- Luminosity: δL/ L = 0:11% (arXiv:1304.4082)
- Polarization: δP/P = 0.25% per beam

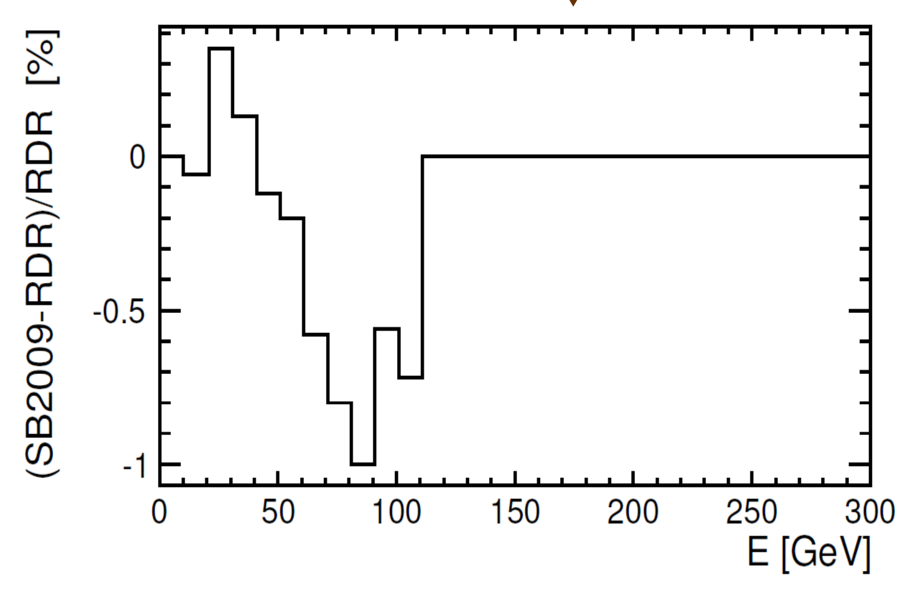
- Beam energy spectrum: full difference between the RDR and SB2009 beam parameters (3.5 % total or shape info)

- Photon reconstruction efficiency: assume statistics of control sample e+e- → Zγ → μμγ (δε/ε = 0.43% from normalization to radiative Z-return)

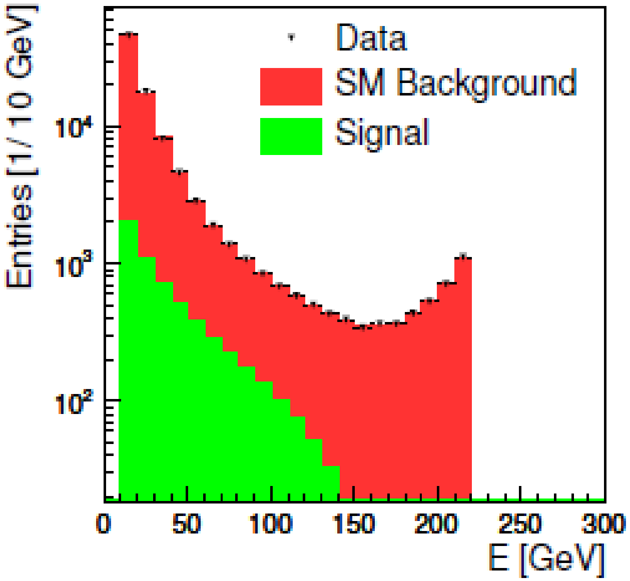


Systematic uncertainties (all uncorrelated):

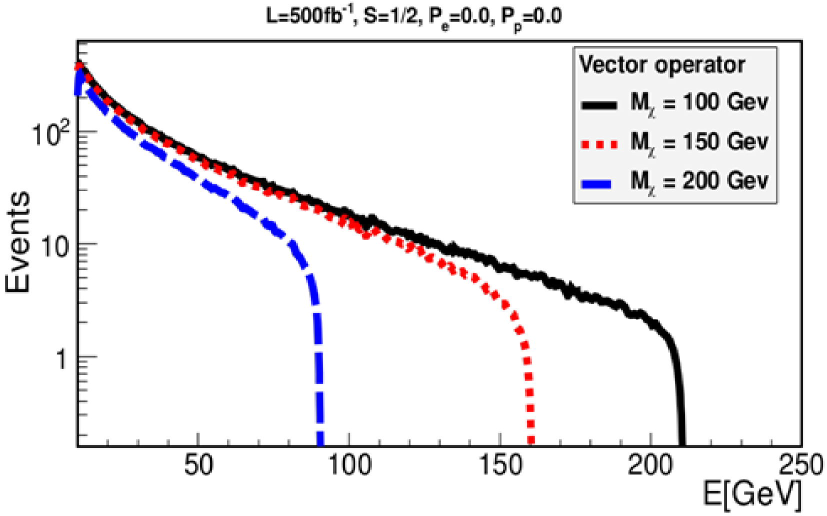
		shape exp.	counting exp.
Source	S,B or both	size	
$\mathcal{L}$	both	$1.1 \cdot 10^{-3}$	
P_{e-}	both	$2.5 \cdot 10^{-3}$	
P_{e+}	both	$2.5 \cdot 10^{-3}$	
Photon selection	both	$4.3 \cdot 10^{-3}$	
Beam spectrum	both	Fig. 7.14	$3.5 \cdot 10^{-2}$



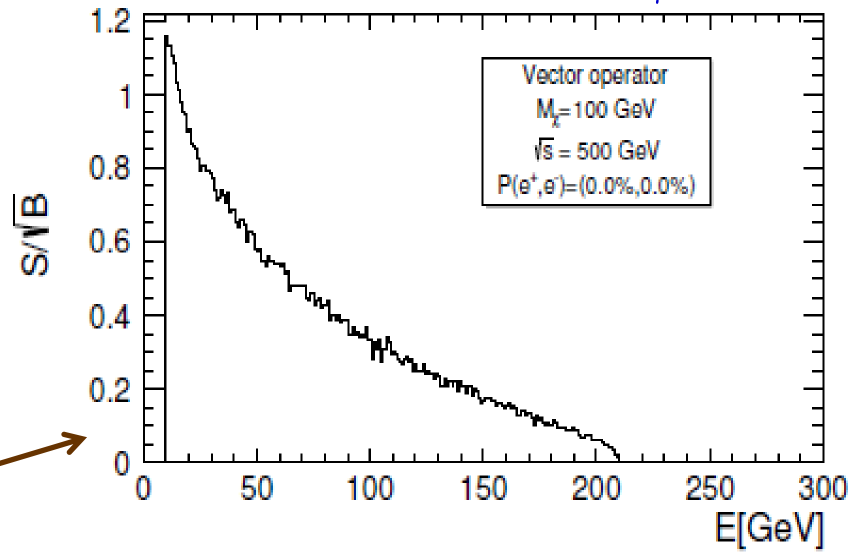
Exploiting Shape Information



Photon spectrum for different WIMP masses



Significance in each E_γ bin:



Counting experiment:

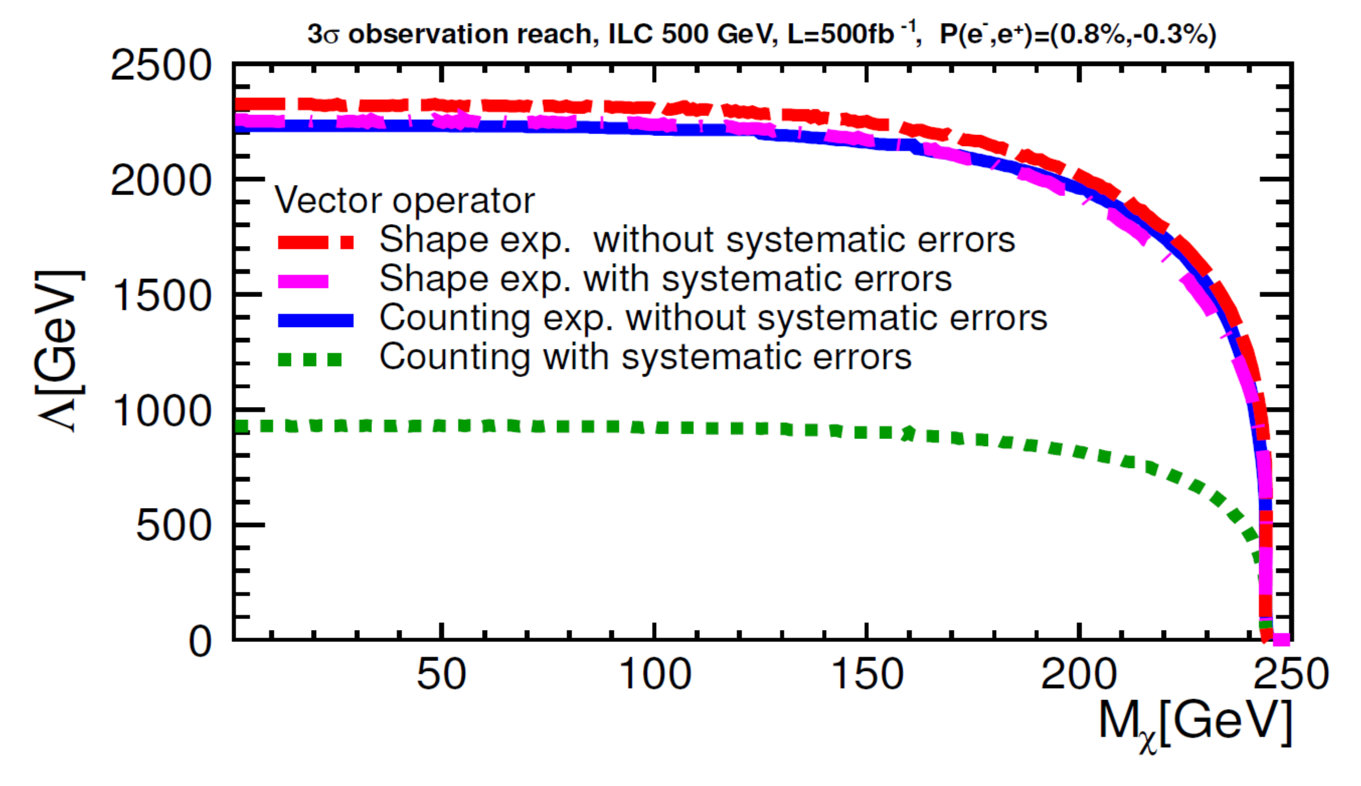
- Total number of signal S and background B events
- Significance S/sqrt (B)

Fractional event counting:

- Si/sqrt(Bi) per bin
- Weight events according to significance of their bin
- Gains over counting experiment when significance depends on observable

Exploiting Shape Information

- Consider systematic uncertainties in weight definition (P. Bock,JHEP 0701(2007)080,Eq.36
- Equivalent approach: fitting of nuissance parameters
- Limits are set using Modified Frequentist Approach: CLs = CL_{S+B}/CL_B

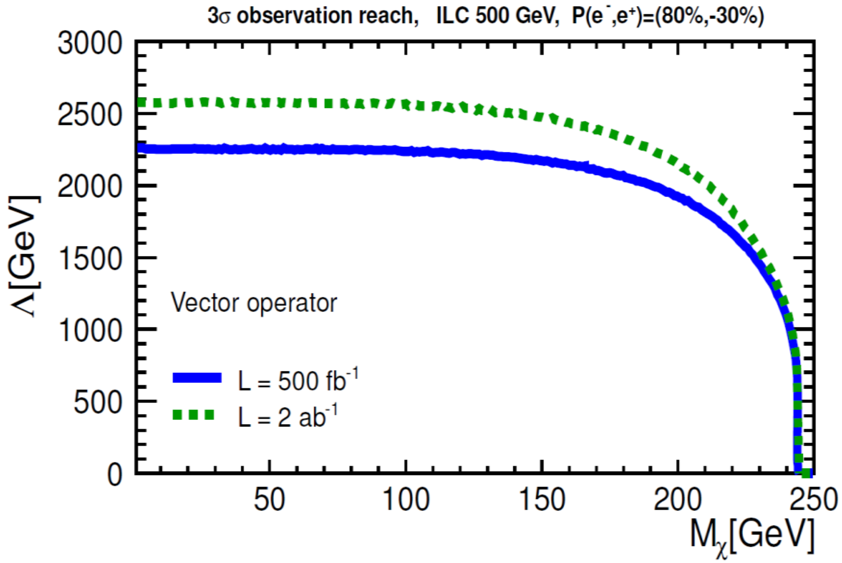


Use of discriminating variable (shape information) in CL calculation drastically reduces impact of systematic uncertainties!

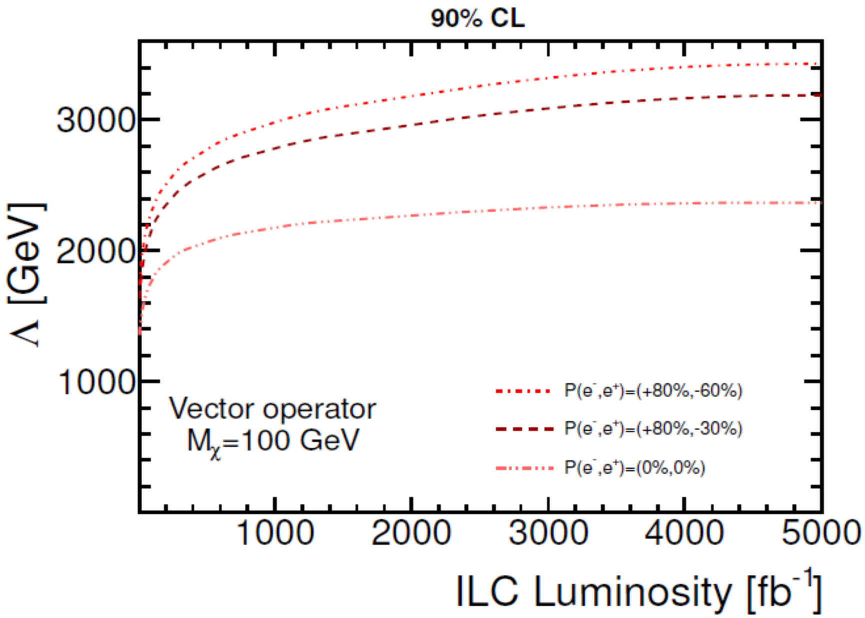
Effect of Integrated Luminosity

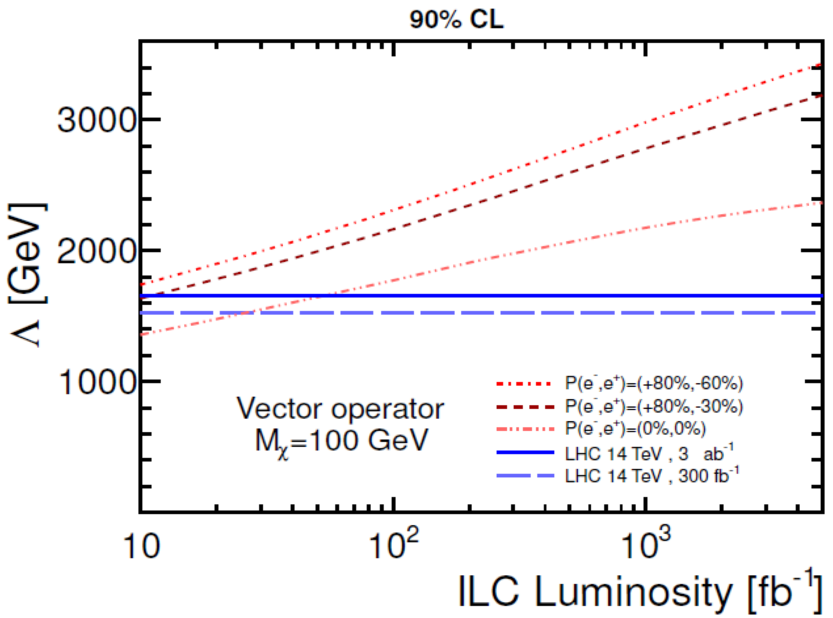
Increased reach in Λ with luminosity:

- 3σ Observation:
  → 500 fb^{-1} → 2 ab^{-1}: gain 10% (Sχ =1/2, vector operator) → less than sqrt(N) due to systematics



- 90% CL Exclusion:
  → significant improvement up to L ~ 1 ab^{-1}
  → positron polarization helps to increase reach in Λ by 200-400 GeV





3σ Observation – Cosmological Approach

- 3 different assumptions on chirality of WIMP-SM interaction

  - Solid line: WIMP couplings are independent from electron/positron helicity

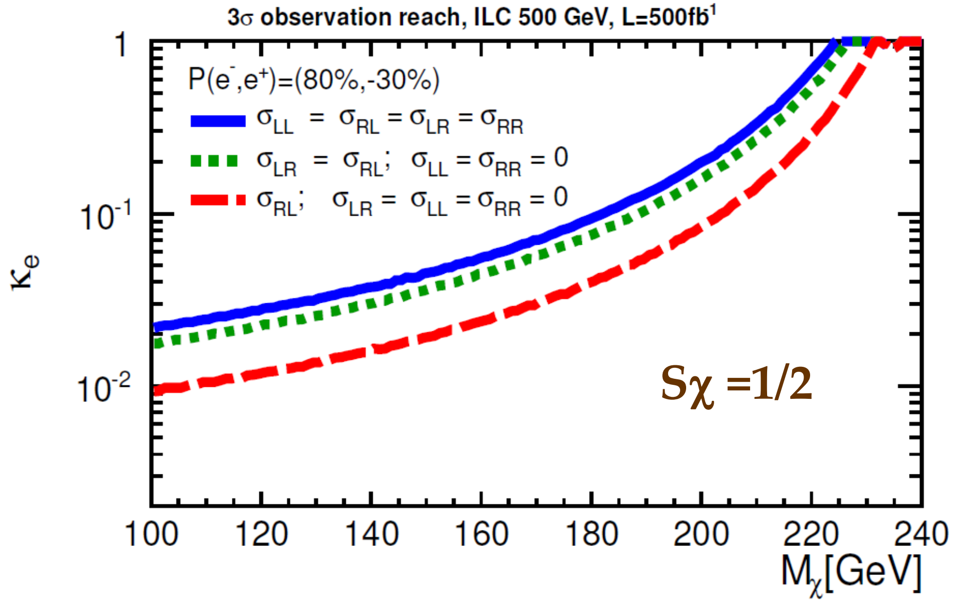
  - Dotted line: helicity and parity conserving model: $\sigma_{LR} = \sigma_{RL}$

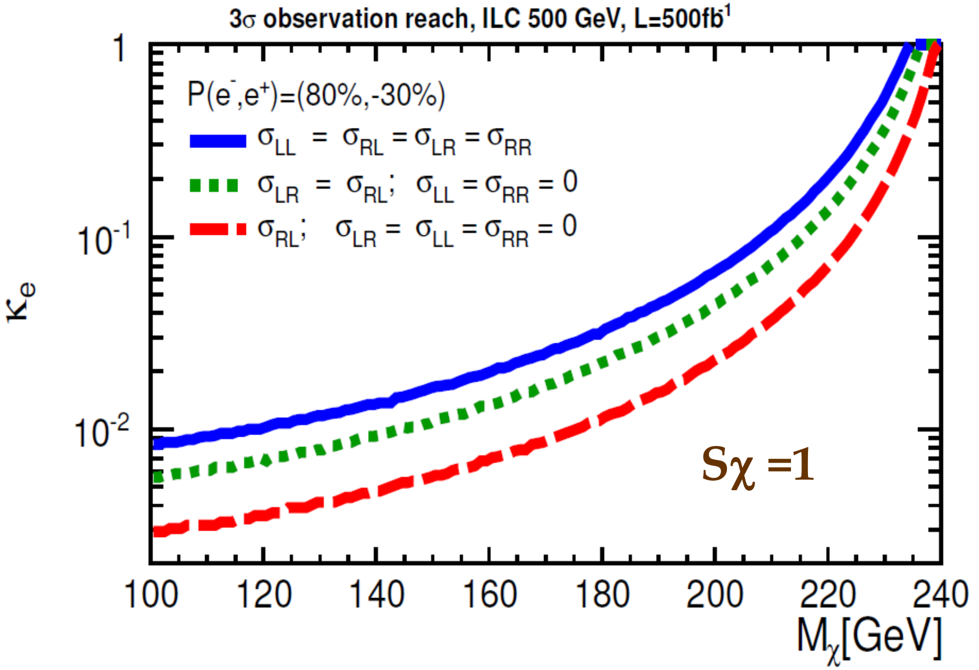
  - Dashed: WIMPs couple to right-handed electron and left-handed positron

- P(e-; e+) = (+80%;-30%)

- Two possible WIMP spins: $S\chi = 1$ and $S\chi = 1/2$ (WIMP branching ratio is smaller)

ILC can observed WIMP signal if annihilation fraction (κ_e) to e+e- is at least ~ 0.3 - 1 %





3σ Observation – Effective Operators Approach

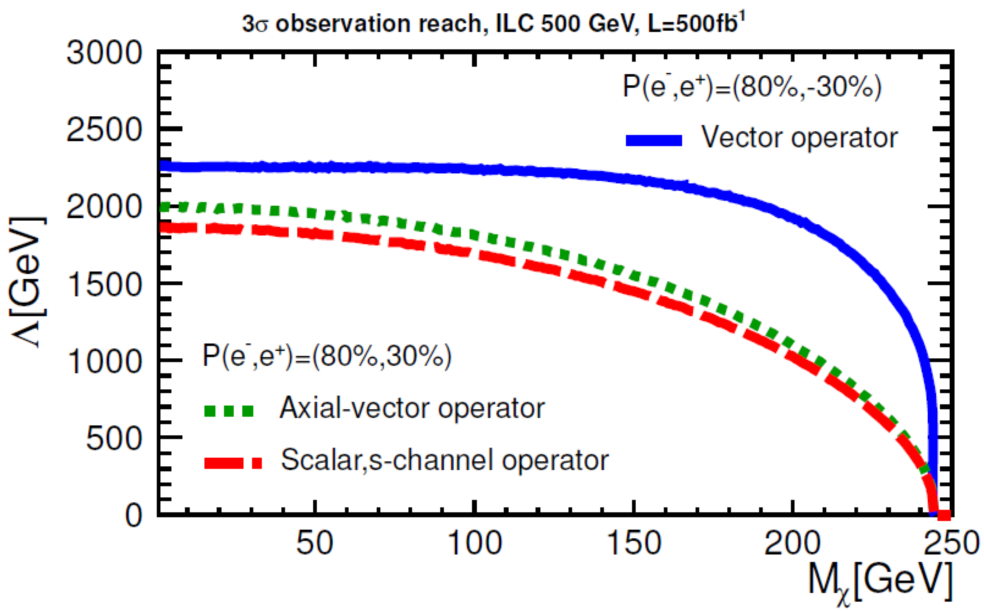
- ❖ Using fixed luminosity and "the most optimal" polarization configuration:

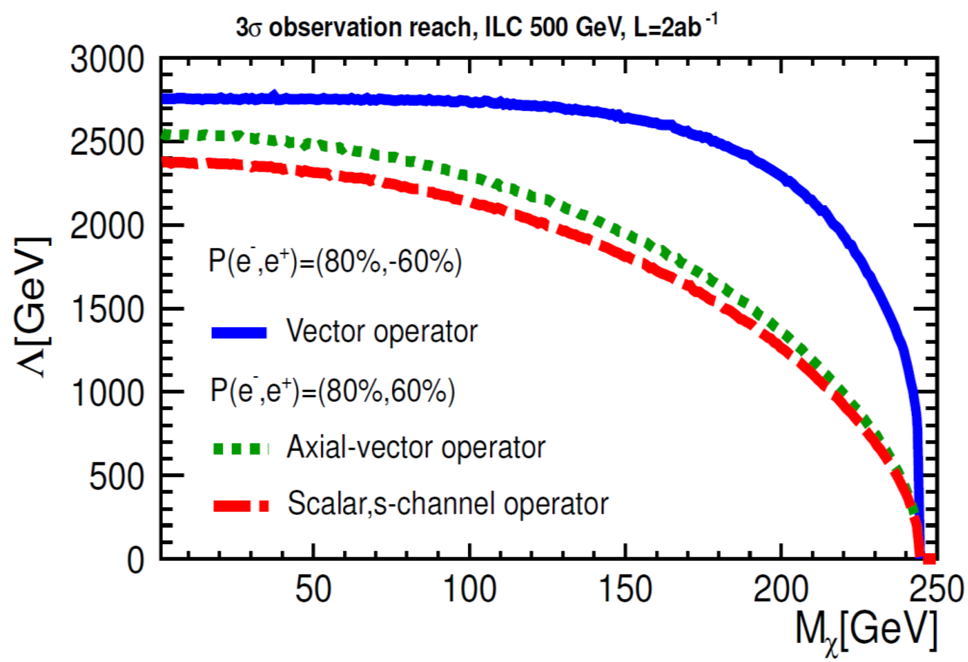
- 3 different operators (all for $S\chi = 1/2$):

 - Vector,
 - Axial-vector,
 - Scalar (s-channel)

- «Pessimistic» scenario: 500 fb^{-1}
  P(e-; e+) = (+80%;30%)

- «Optimistic scenario: 2 ab^{-1}
  P(e-; e+) = (+80%;60%)





ILC can observe signal

up to Λ ~ 2 – 2.5 TeV

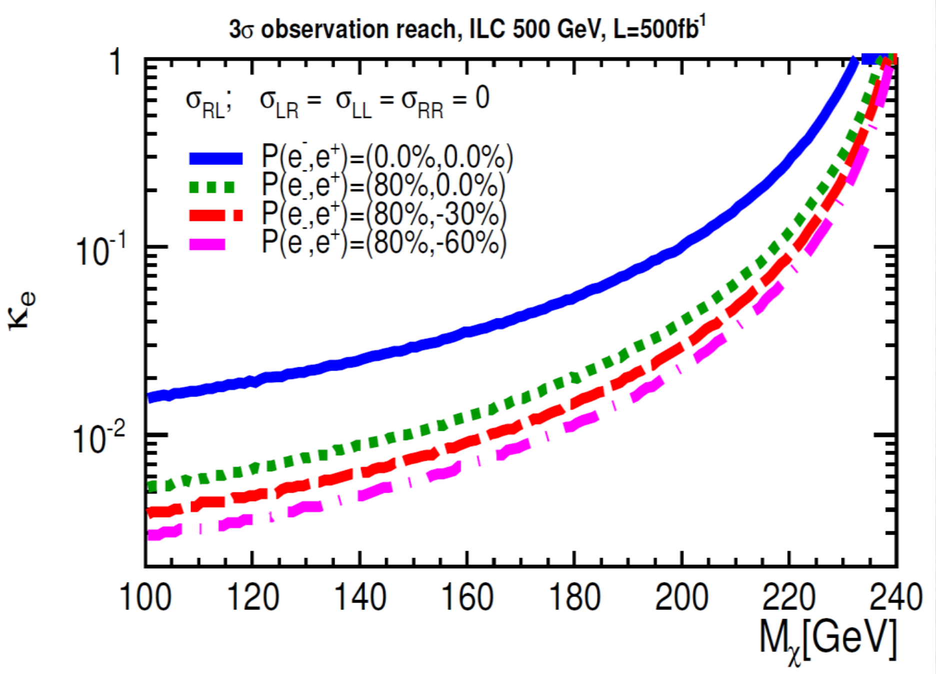
Effect of Beam Polarization

- P(e-) = +80% reduces SM νν-background by 1/10 (bkg. dominates by Bhabhas)
  → 70% improvement in sensitivity

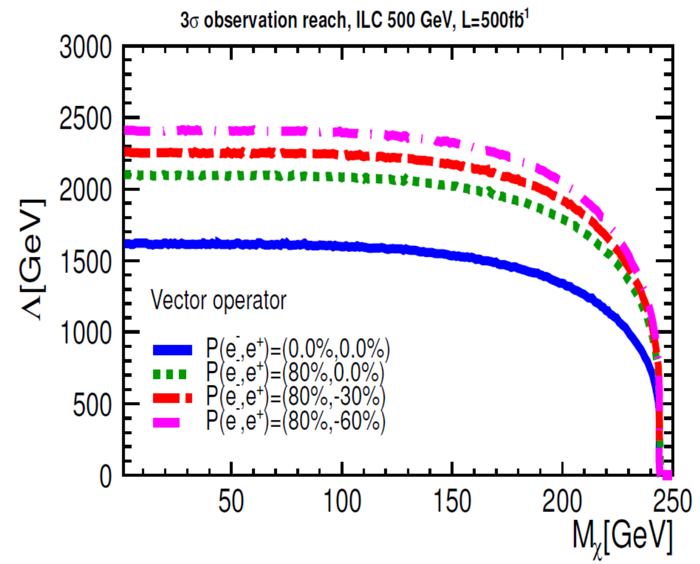
- Choose sgn (P(e+)) according to type of interaction, e.g.:

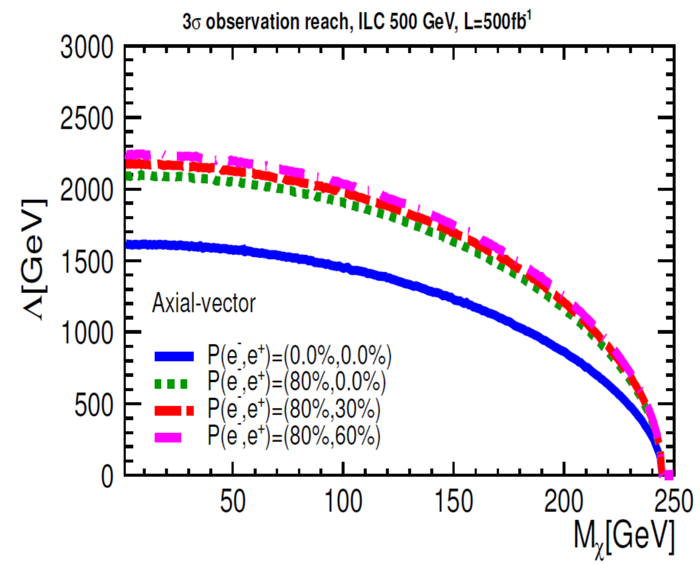
  - Sgn (P(e+)) = - for σ_{RL} in κ approach (Sχ = 1, p-wave)

  - Sgn (P(e+)) = + for axial-vector operator
  - Sgn (P(e+)) = - for vector operator (Sχ = 1/2)

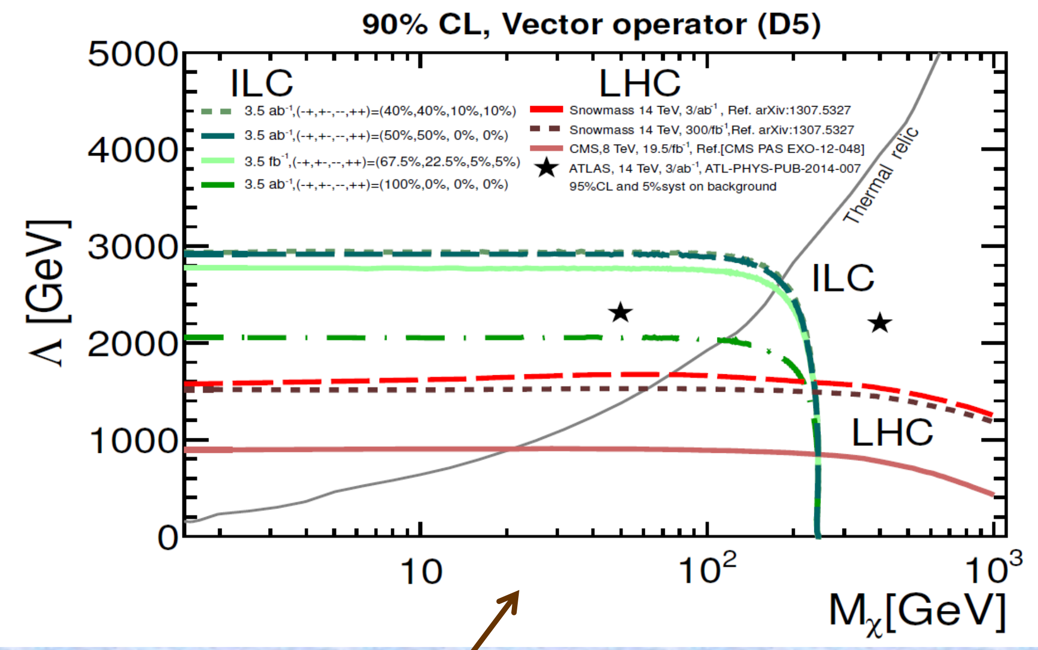


- Flipping sgn(P(e+)) allows to determine type of operator!



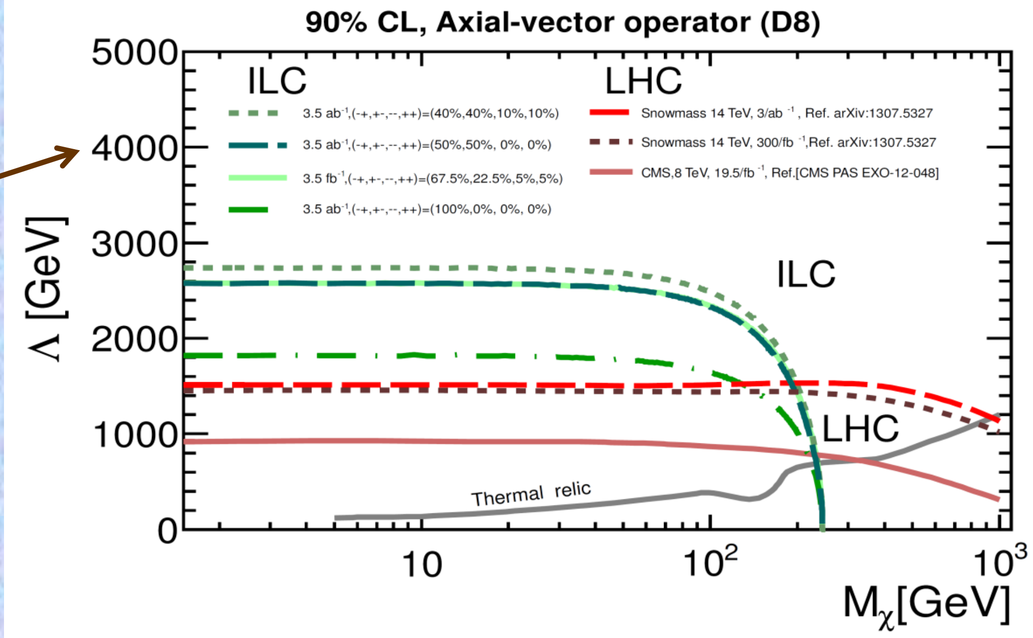


Comparison of ILC / LHC Projections



- LHC/ILC Complementary:
  LHC (ILC) limits assume pure coupling to hadrons (leptons), respectively
- ILC can place limit on Λ up to ~3 TeV

- Vector operator (« spin independent »), Sχ =1/2
- Axial-vector operator (« spin dependent »), Sχ =1/2

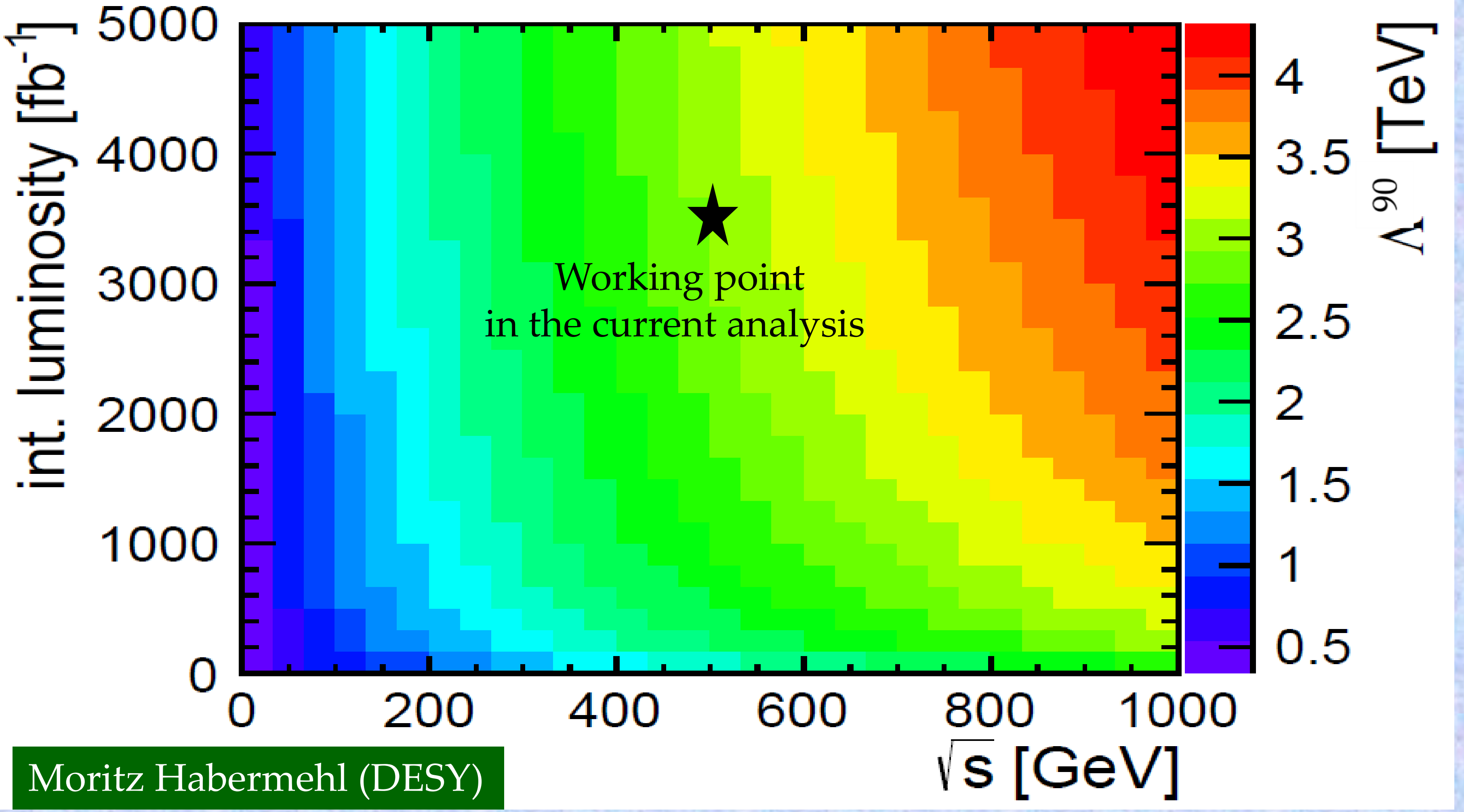


- ILC results are presented for L=3.5 ab^{-1},assuming luminosity sharing between different polarization configurations

Extrapolation of the ILC Exclusion Limits

Using 90% CL exclusion reach for E = 500 GeV, L = 3.5 ab^{-1}, Mχ = 10 GeV for vector operator and assuming split of luminosity running (LR=40%,RL=40%,LL=10%,RR=10%)

→ extrapolate exclusion limit (Λ^{90}) as the function of integrated luminosity and ILC center-of-mass energy



Moritz Habermehl (DESY)

Summary and Outlook

- ILC provides orthogonal and independent information, by probing WIMP-lepton interaction, regardless whether LHC discovers or excludes dark matter candidates:
  → cosmological approach: annihilation fractions of 0.3-1% sufficient to observe WIMPs
  → operator approach: reach up to 2 - 3 TeV for sqrt(s) = 500 GeV

- The power of having both beams polarized demonstrated
  → Positron polarisation essential to determine type of operator