Model Independent WIMP Searches

with Polarized Beams at the ILC

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DESY

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Outline

Outline

Single Photon Events and WIMPs at the ILC

WIMP Dark Matter

- 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

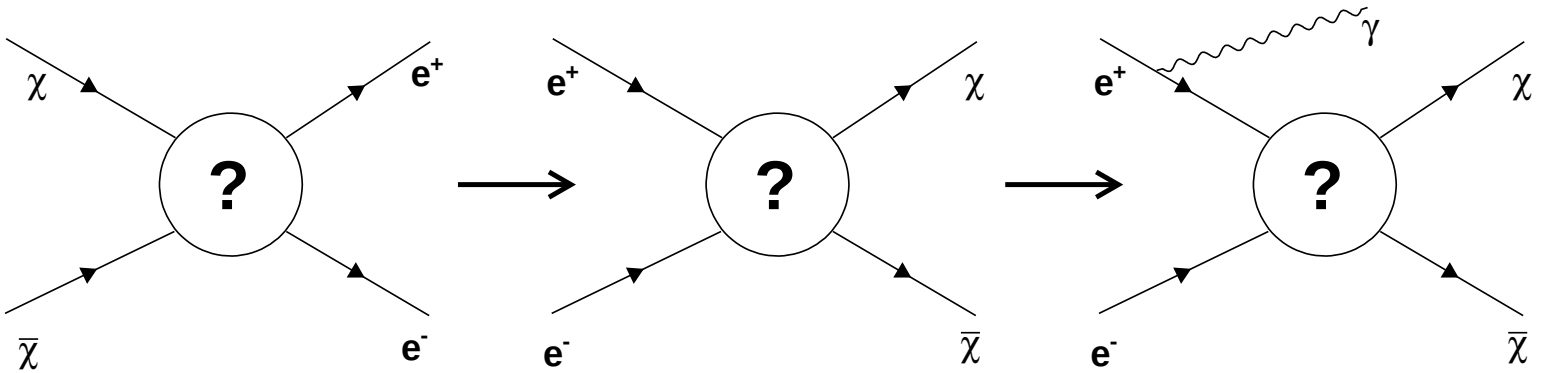
- $e^+e^- \to \chi\chi$.
- WIMPs leave detector without further interaction.
- Detection via ISR: $e^+e^- \to \chi\chi\gamma$.
- Missing $\not{E}$.
- Dominant background: $e^+e^- \to \nu\nu(N)\gamma$.
- Other backgrounds: $e^+e^- \to \gamma\gamma$, radiative Bhabha-scattering.

Model Independent Production Cross Section

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

Model independence

- Assume only one DM candidate.
- Constrain WIMP pair annihilation XSec from observation.
- Crossing Symmetrie (annihilation $\Rightarrow$ production).
- ISR.



Model Independent Production Cross Section

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

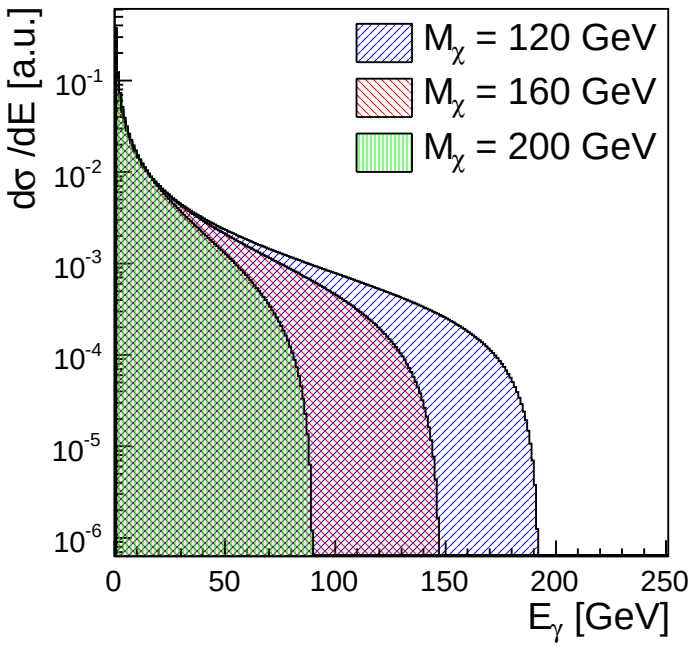
$$x = \frac{E_\gamma}{\sqrt{s}}$$

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.
  - $J_0 = 0$: s-wave annihilation/production.
  - $J_0 = 1$: p-wave annihilation/production.

Model Independent Production Cross Section

Mass dependent signal cut-off.



Parameters:

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- S_χ: Spin, scale factor.
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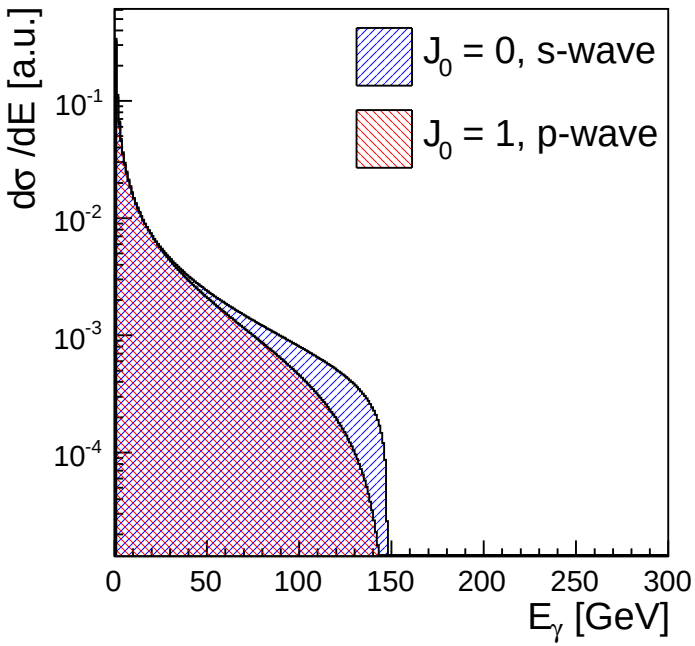
Model Independent Production Cross Section

Signal shape at threshold provides information on partial wave (s- or p-wave).



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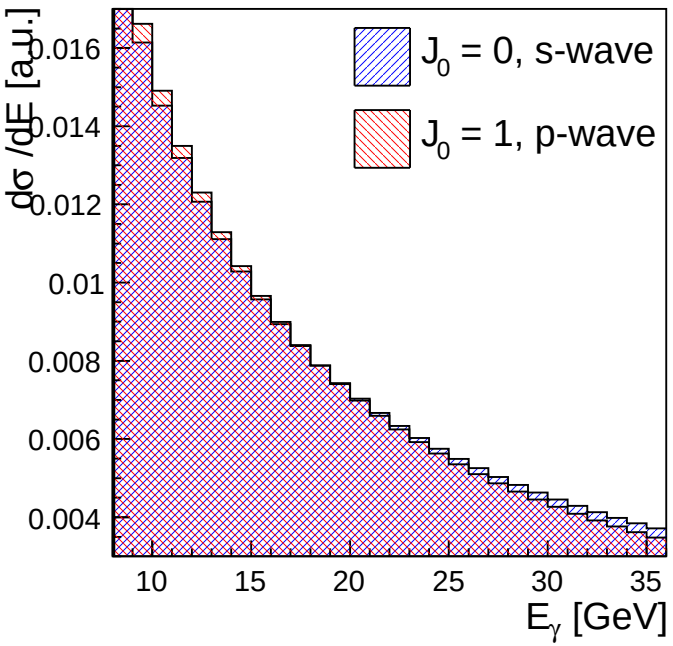
Model Independent Production Cross Section

Crossover for s-wave and p-wave signal with same cross section.
($\Rightarrow$ important later)

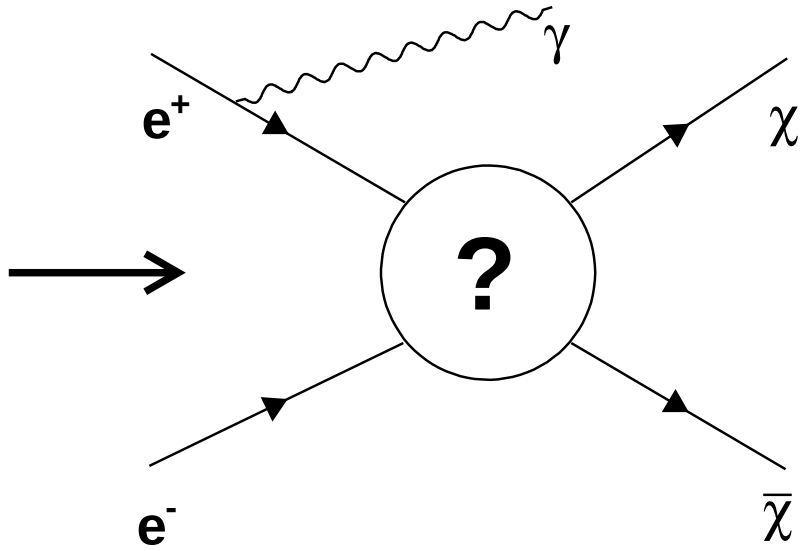


Parameters:

- $\kappa_e(P_e, P_p)$: 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

Is it possible to extract
Masses and J_0 from data?
Required Luminosity,
Polarised beams?
What can we learn about
the question mark?



Parameters:

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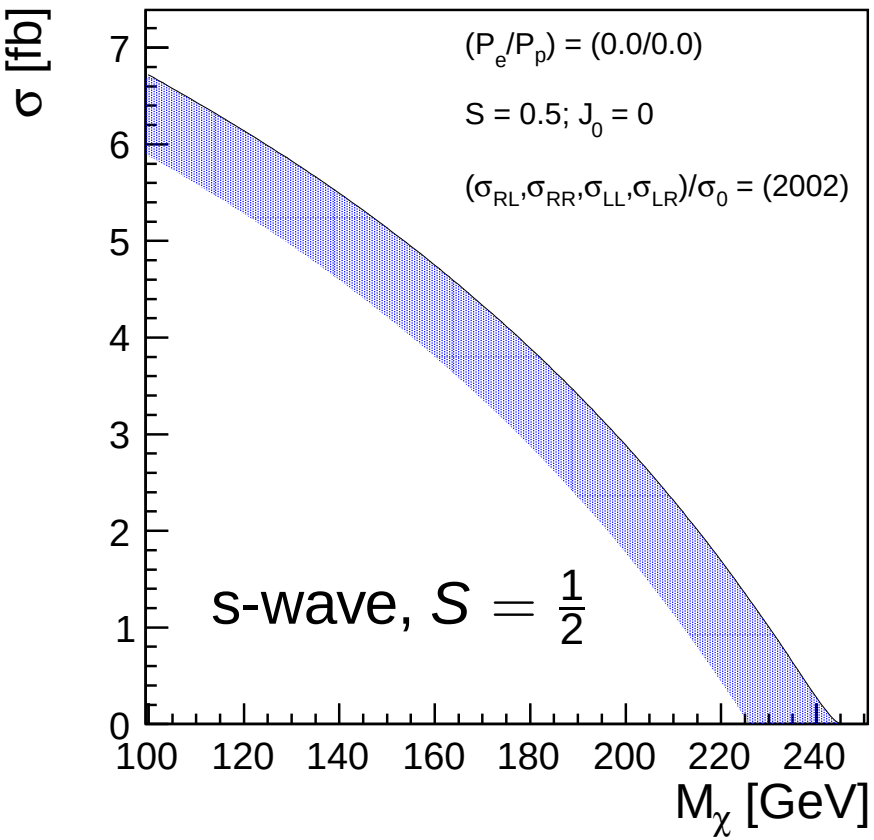
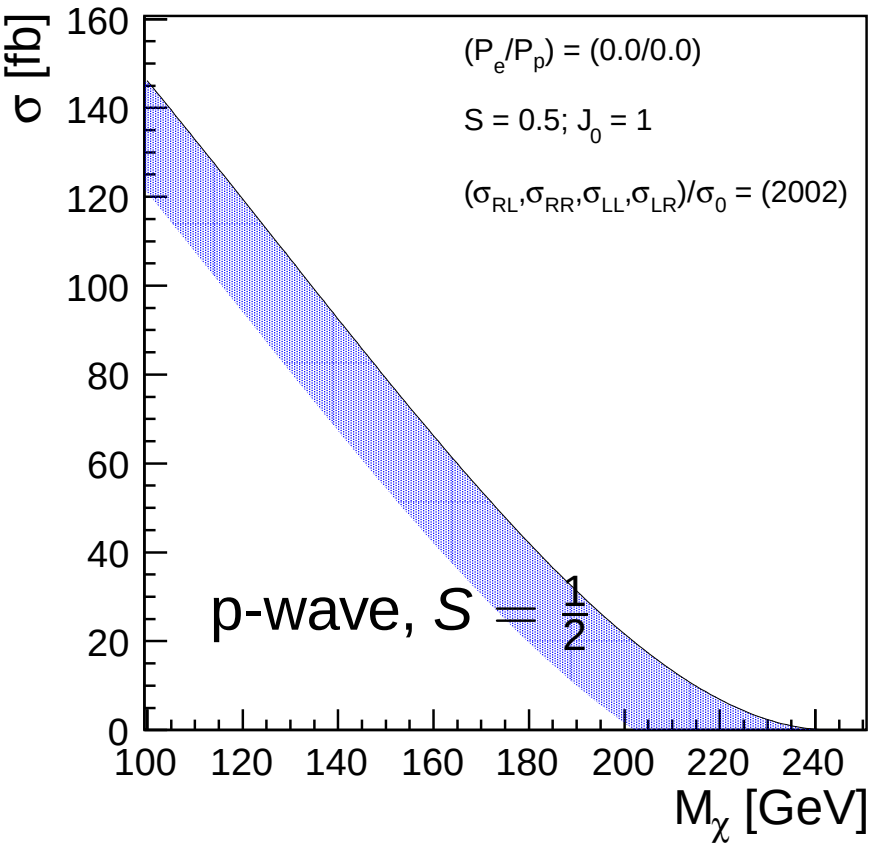
- M_χ, $J_0 \rightarrow$ shape, J_0 dominant partial wave.

Cross Sections in DM Picture





- $10.0\ \mathrm{GeV} < E_\gamma < 220.0\ \mathrm{GeV}$ and $|\cos(\Theta_\gamma)| < 0.98$.
- Assumption: WIMPs couple **ONLY** to e^+e^-.
- $\sqrt{s} = 500$ GeV. Unpolarised beams.

Outline

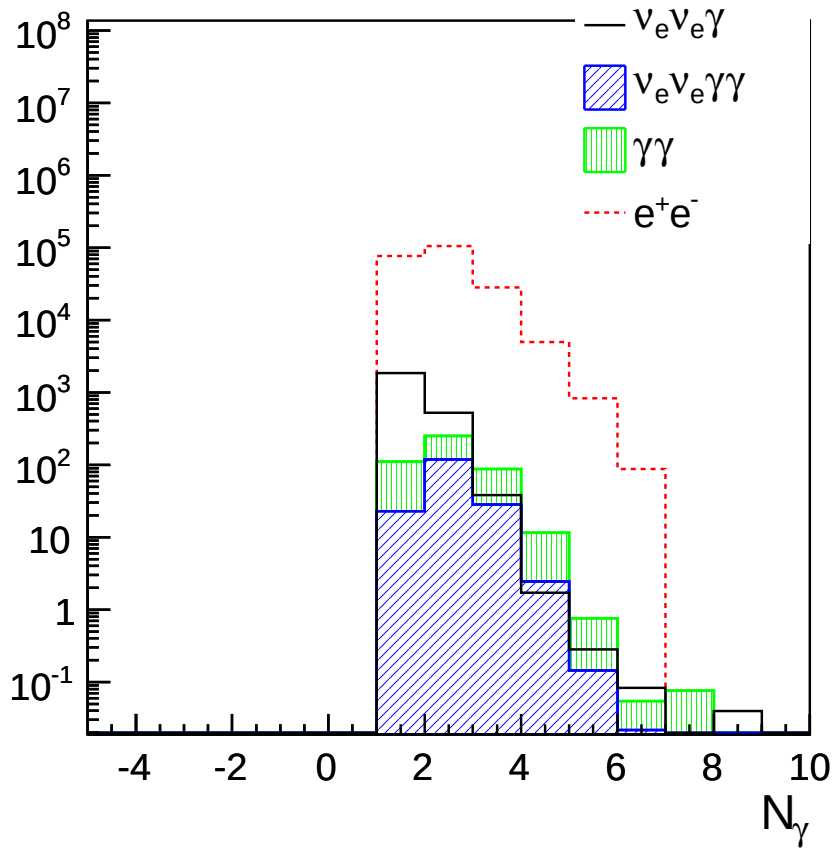
Analysis Strategy

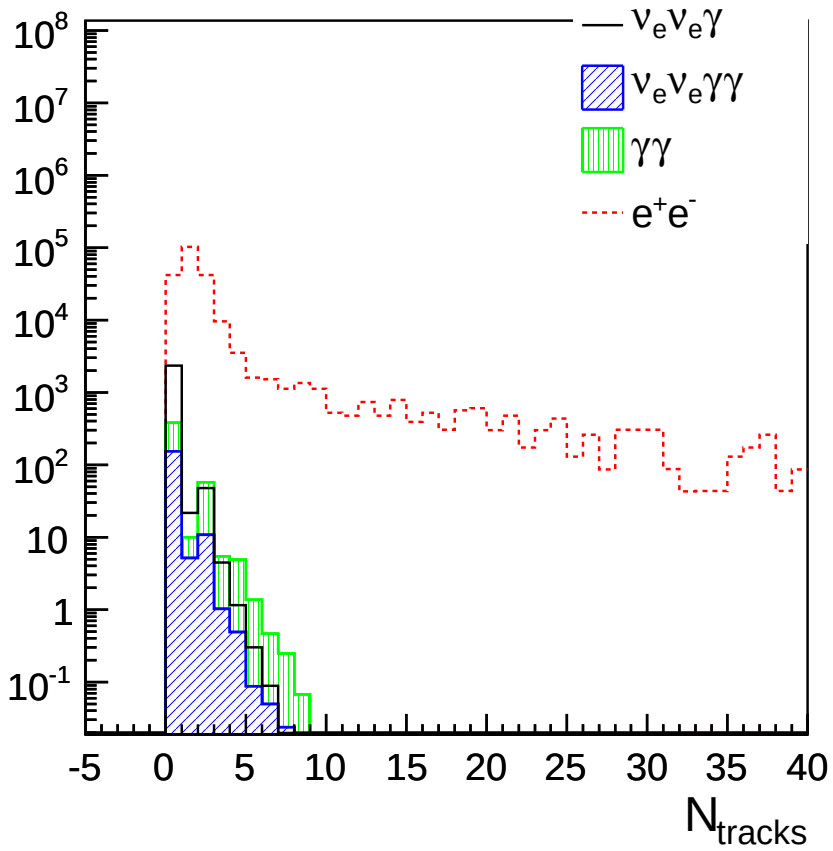
- Full detector simulation of relevant backgrounds (SLAC-SM mass production 2008, ILD00). 140 fb^{-1} of $e^+e^- \rightarrow \nu\nu\gamma$.
- Selection of dominant irreducible background: $e^+e^- \rightarrow \nu\nu\gamma$.
- Division of simulated data into three subsamples:
  - Background sample.
  - Signal sample.
  - Template sample to generate expected distributions.
- Signal generation by reweighting of $\nu\nu\gamma$ with $\sigma(\chi\chi\gamma)/\sigma(\nu\nu\gamma)$.
- χ^2 comparison of Data (S+B) with Templates (S+B).

Remarks

- All presented results preliminary.
- No systematic uncertainties included.
- Analysis limited by low simulated statistics.

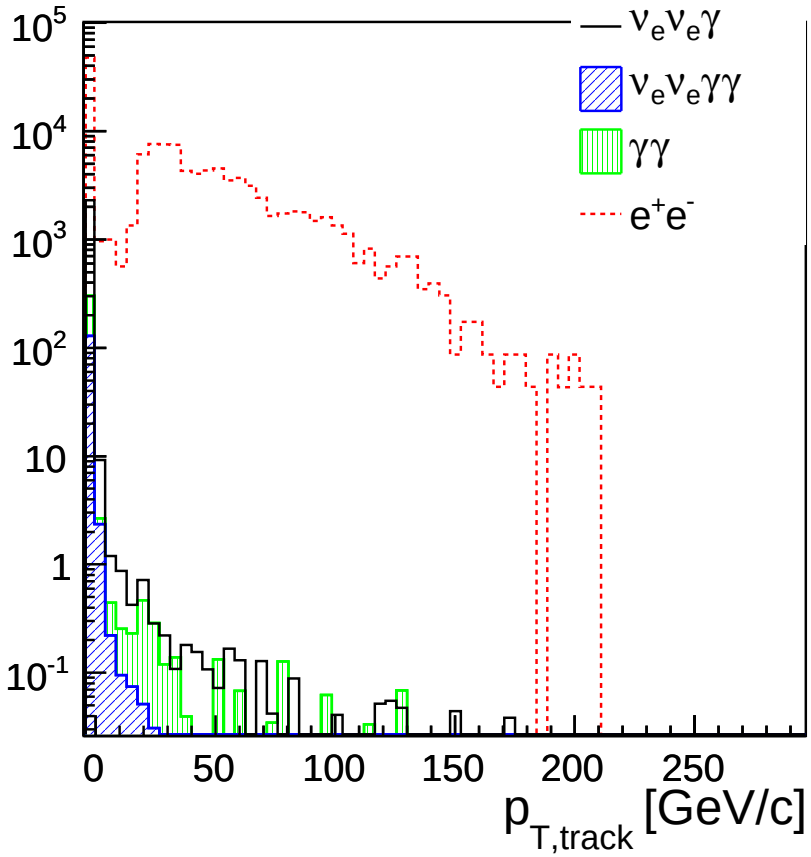
Selection of $\nu\nu\gamma$ Background

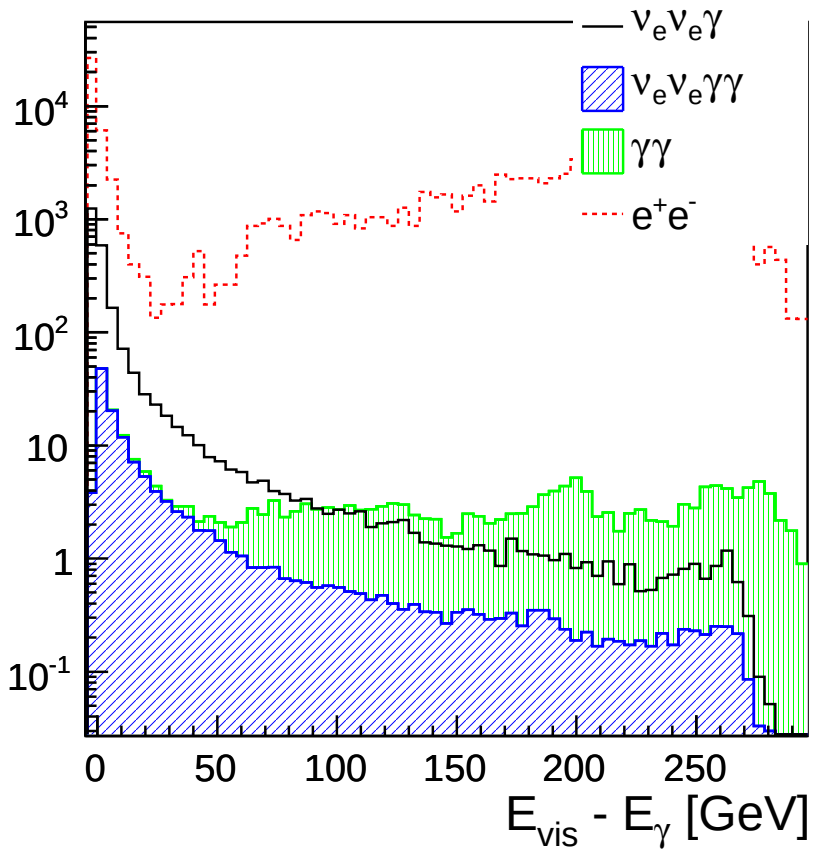




- Signal region: $10.0\ \mathrm{GeV} < E_\gamma < 220.0\ \mathrm{GeV}$; $|\cos(\Theta_\gamma)| < 0.98$.
- $N_\gamma \leq 2$.
- $N_{tracks} \leq 2$.

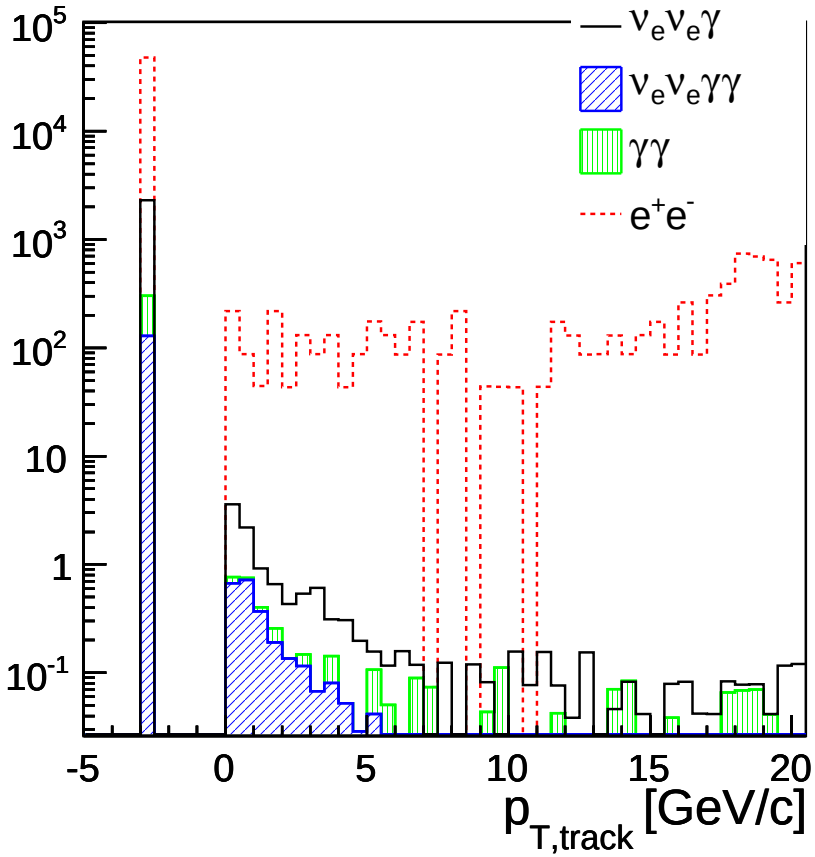
Selection of $\nu\nu\gamma$ Background

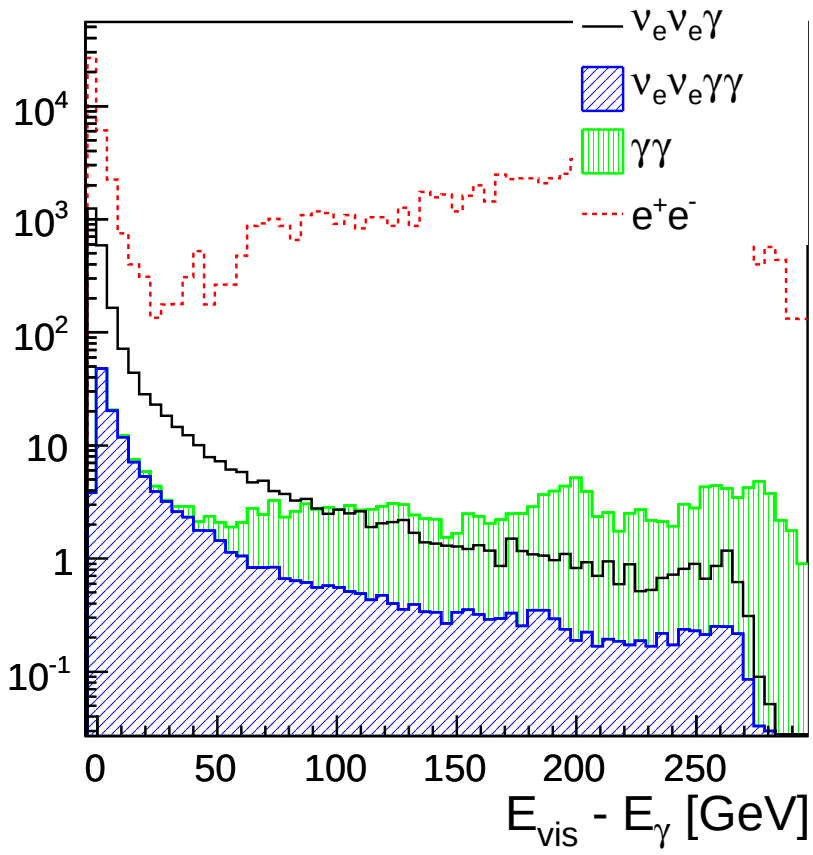




- $p_T < 3.0$.
- $E_{vis} - E_\gamma < 20.0$ GeV and $E_{char} < 2.0$ GeV.
- Bhabha rejection with BeamCal.

Selection of $\nu\nu\gamma$ Background





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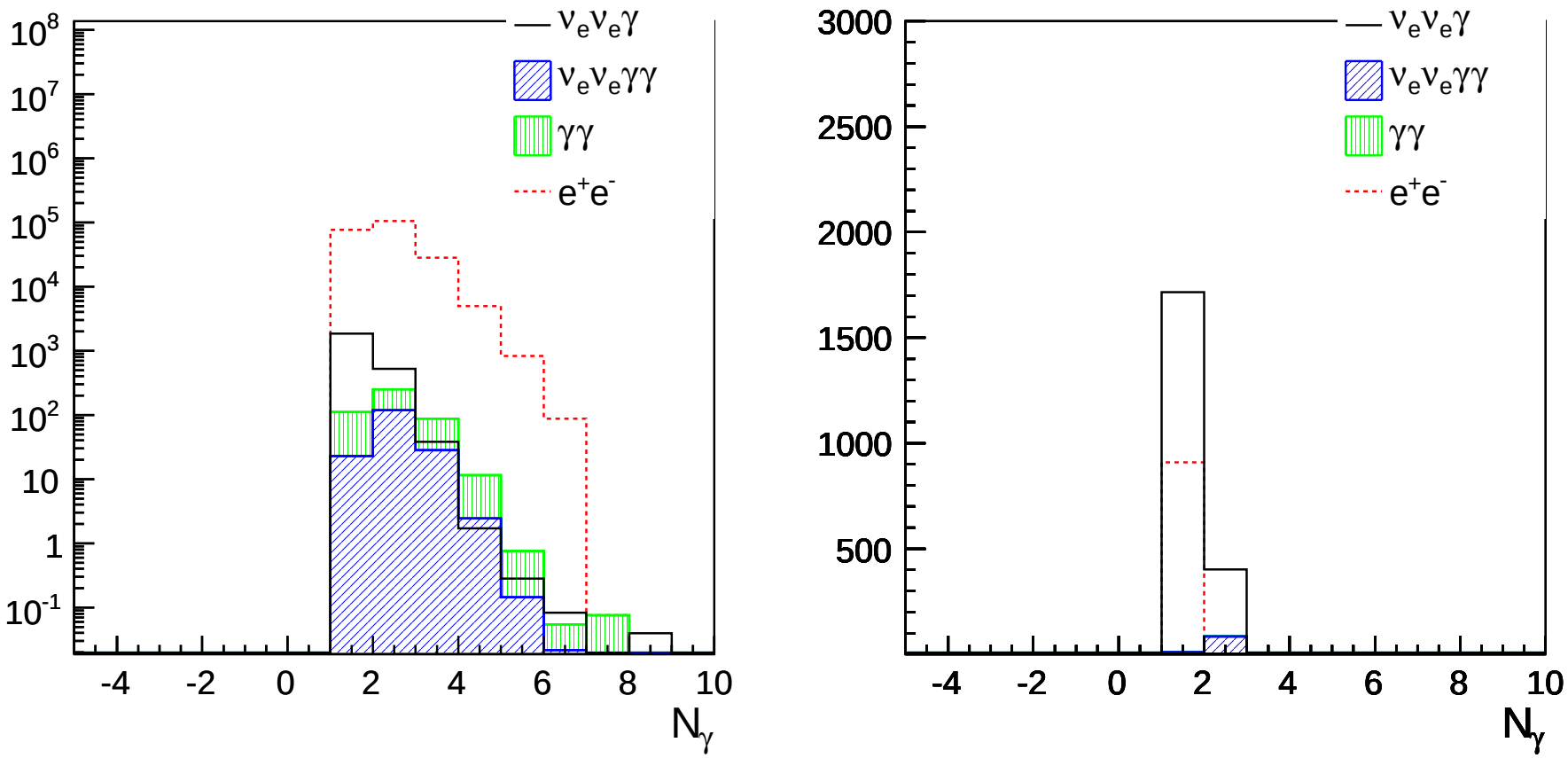
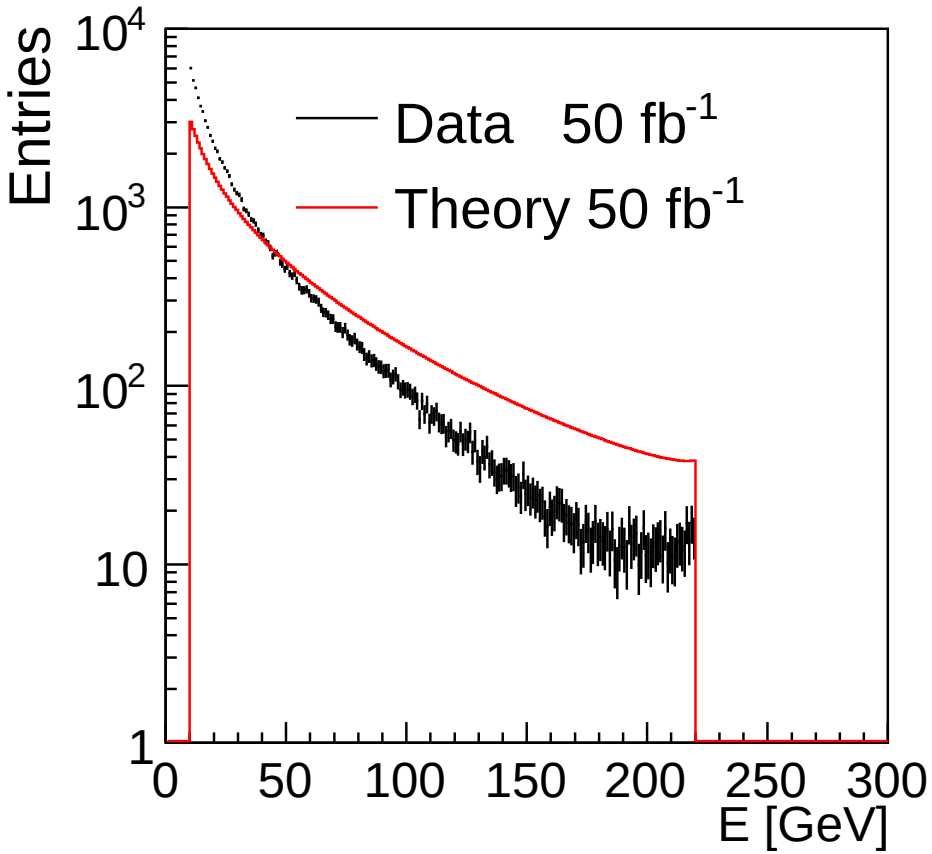
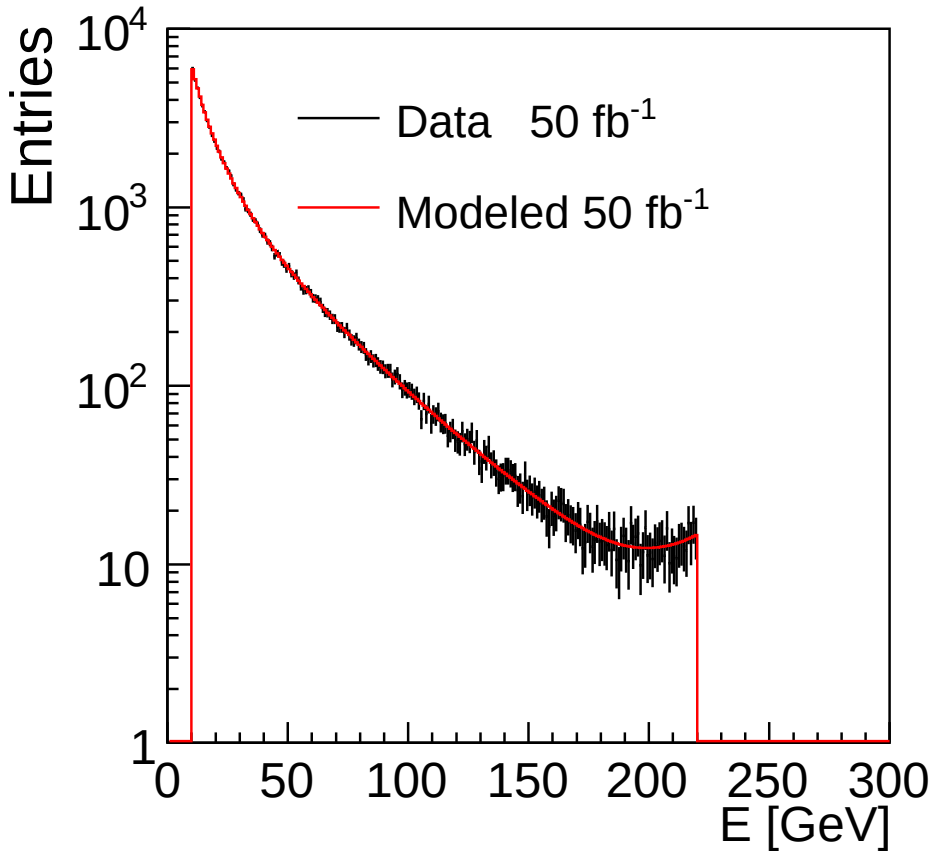
Selection of $\nu\nu\gamma$ Background



- Selection efficiency of $\nu\nu\gamma \Rightarrow$ signal $\approx 70\%$.
- S/B $= \mathcal{O}(\%)$.

Background: Data and Expectation Templates





- Background expectation modeled from template sample (black) $\sim 50\ \text{fb}^{-1} \Rightarrow$ low statistics!
- Tree level expectation ($\nu\nu\gamma$, red) corrected for detector effects and beam energy spectrum (full simulation).

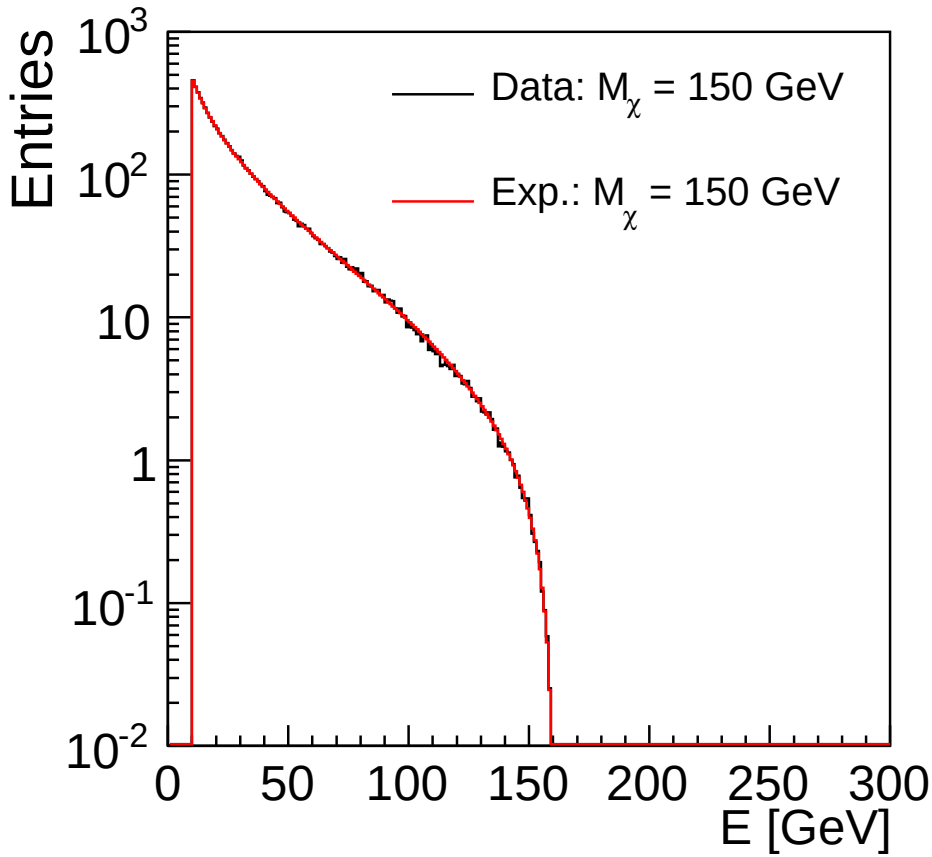
Signal: Data and Expectation Templates

Data

Signal simulation by reweighting $\nu\nu\gamma$ signal sample. ($\sim 50\ \mathrm{fb}^{-1}$)

Expectation

Reweighting of background expectation template.



Outline

Polarised Cross Sections

Cross section can be rewritten as:

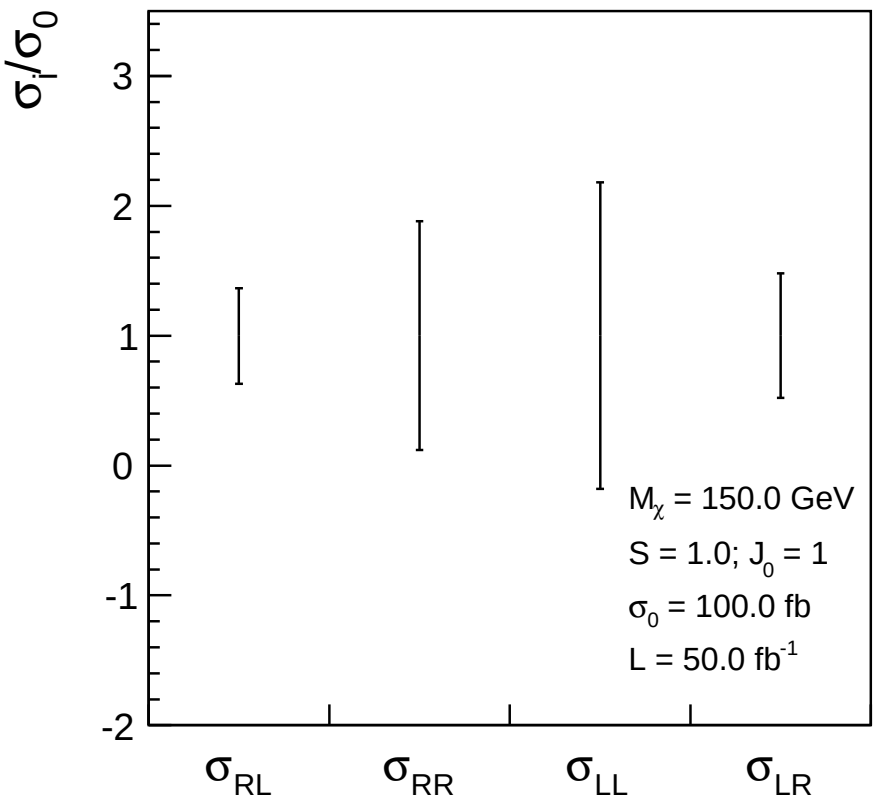
$$\begin{aligned}\sigma_{P_{e^-}P_{e^+}} = \frac{1}{4}((1+P_{e^-})(1+P_{e^+})\sigma_{RR} + (1-P_{e^-})(1-P_{e^+})\sigma_{LL} \\ +(1+P_{e^-})(1-P_{e^+})\sigma_{RL} + (1-P_{e^-})(1+P_{e^+})\sigma_{LR})\end{aligned}$$

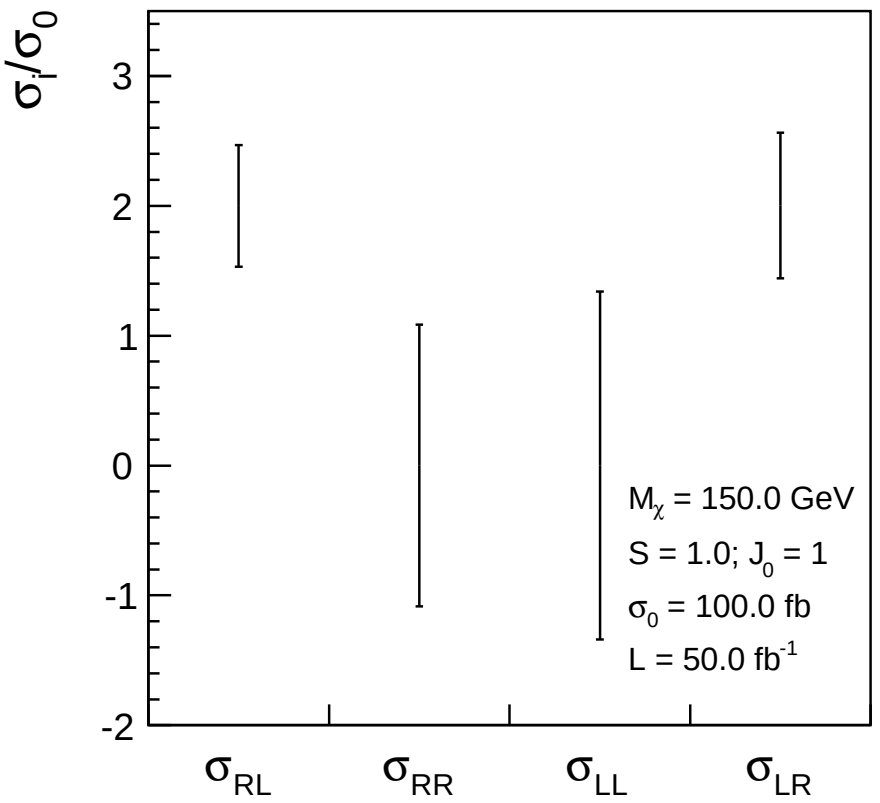
σ_{RR}: Cross section if beams 100% right-handed polarised.
Measurement of $\sigma_{RR}, \sigma_{LL}, \sigma_{LR}, \sigma_{RL}$ with data taken with four different polarisation configurations (P_{e^-}/P_{e^+}).

Two scenarios

- $\sigma_{RR} = \sigma_{LL} = \sigma_{LR} = \sigma_{RL} = \sigma_0$
- $\sigma_{LR} = \sigma_{RL} = 2 \times \sigma_0; \quad \sigma_{RR} = \sigma_{LL} = 0$

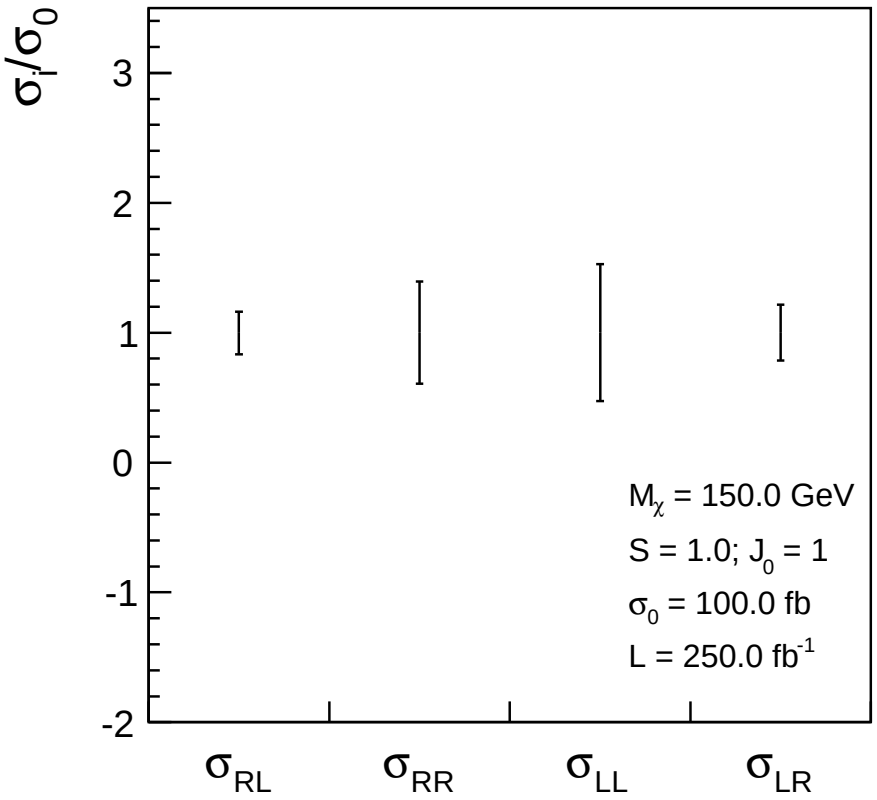
Polarised Cross Sections

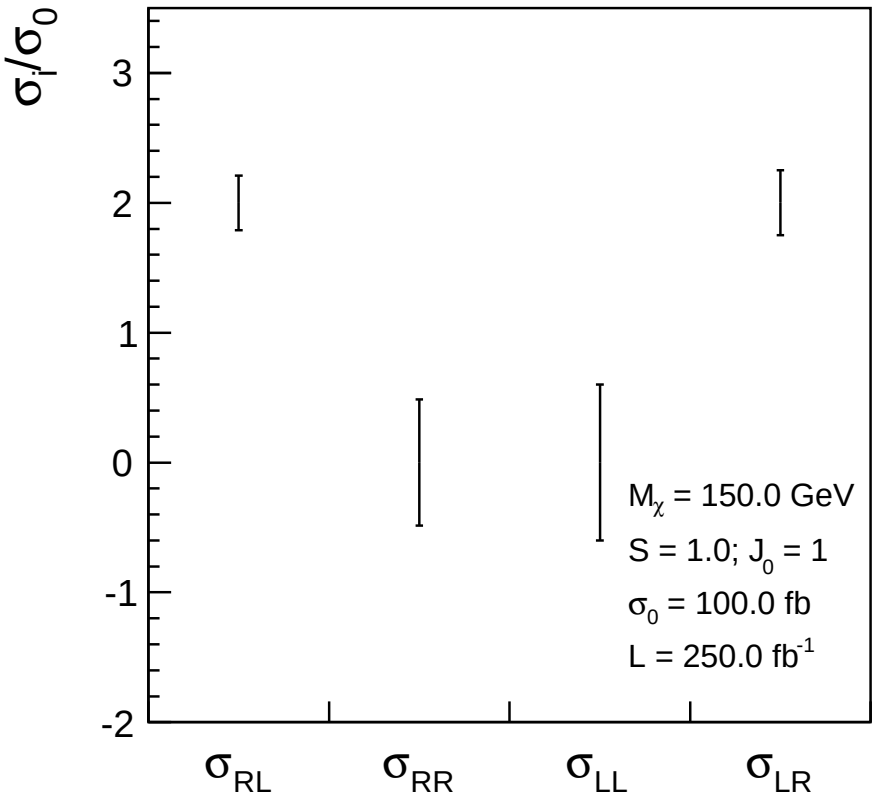




- 50 fb^{-1} each of $(P_{e^-}/P_{e^+}) = (0.8/-0.3), (0.8/-0.6), (-0.8/0.3), (-0.8/0.6)$.
- $\sigma_0 = 100$ fb, 150 GeV p-wave WIMP.
- Scenarios indistinguishable.

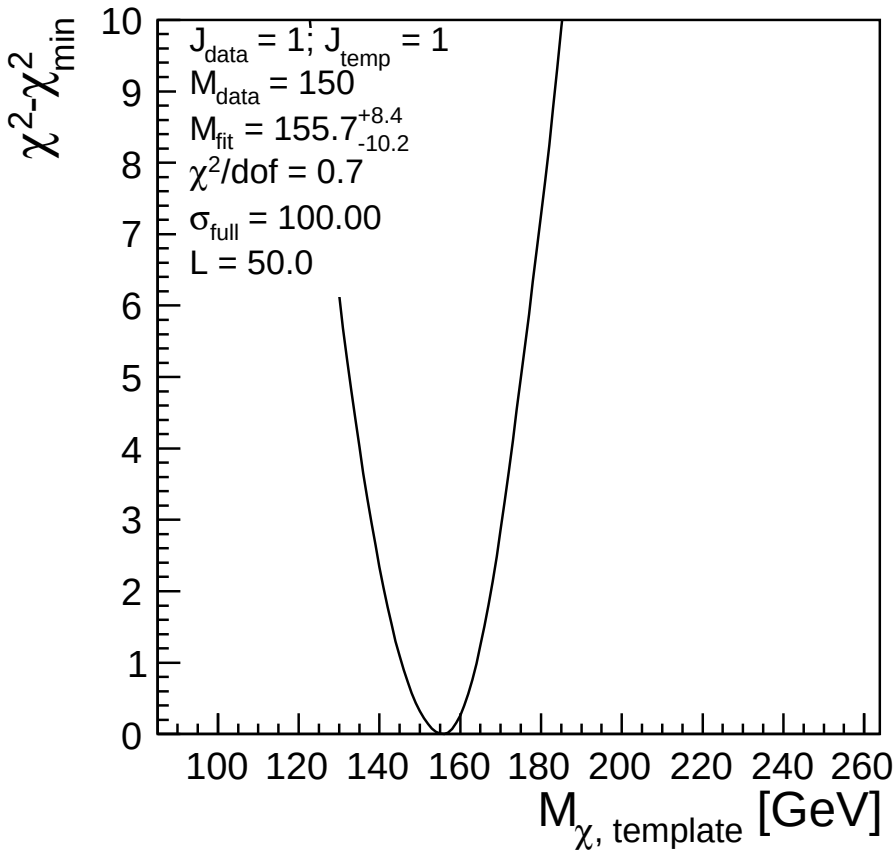
Polarised Cross Sections

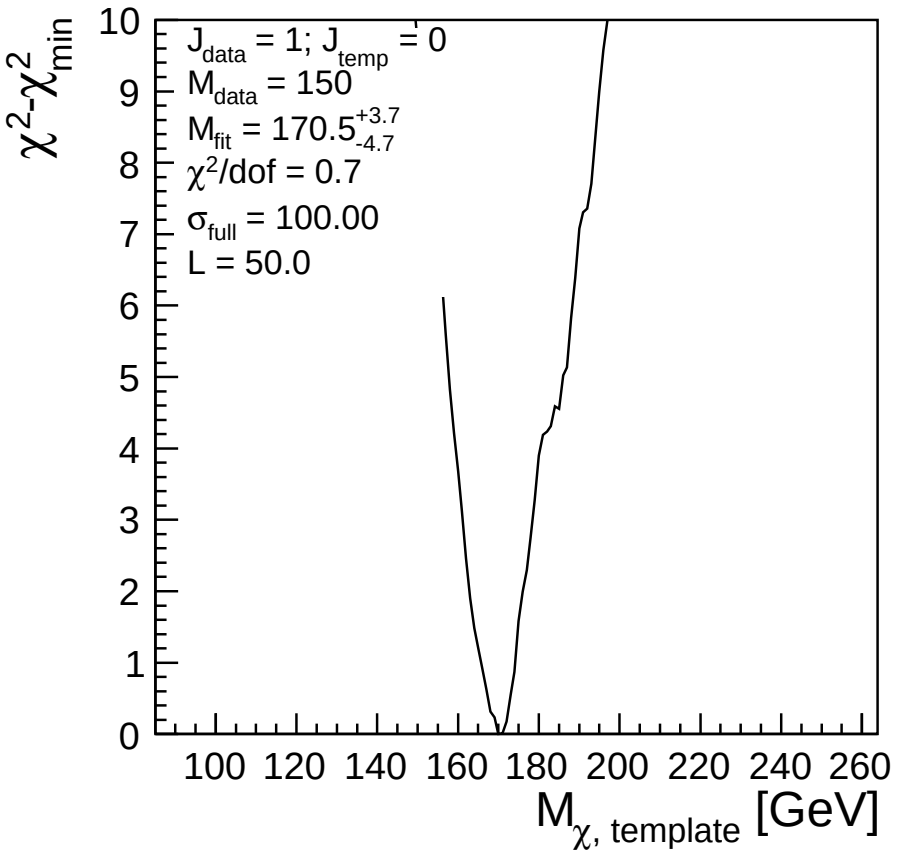




- 250 fb^{-1} each of $(P_{e^-}/P_{e^+}) = (0.8/-0.3), (0.8/-0.6), (-0.8/0.3), (-0.8/0.6)$.
- $\sigma_0 = 100$ fb, 150 GeV p-wave WIMP.
- σ_{ii} determined to 50%, scenarios clearly distinguishable.

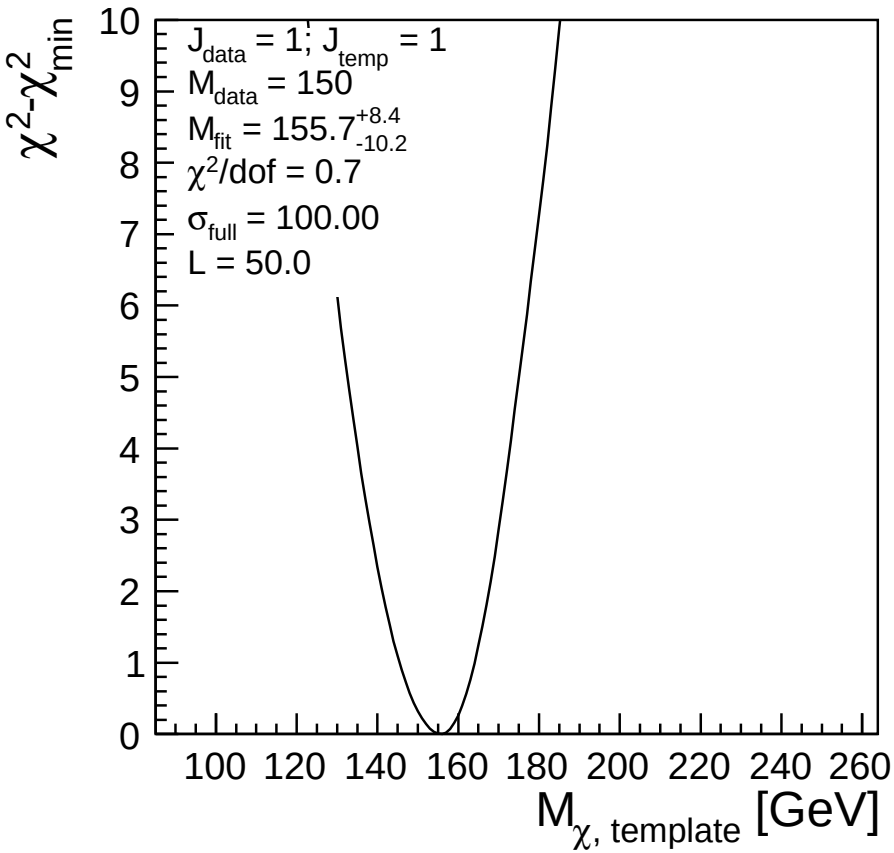
Mass Determination (Template Method)

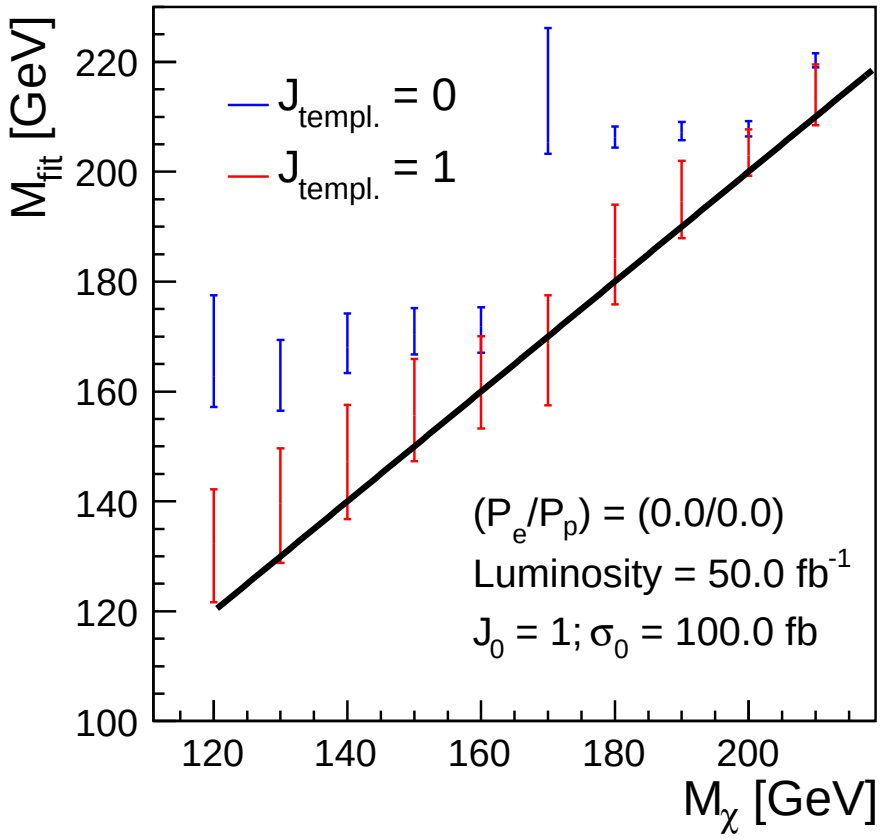




- p-wave 150 GeV WIMP, $\sigma = 100$ fb. $\mathcal{L} = 50$ fb^{-1}.
- Mass recovered with correct assumption $J_0 = 1$ (left).
- Wrong assumption $J_0 = 0$ fits to 170 GeV.

Mass Determination (Template Method)





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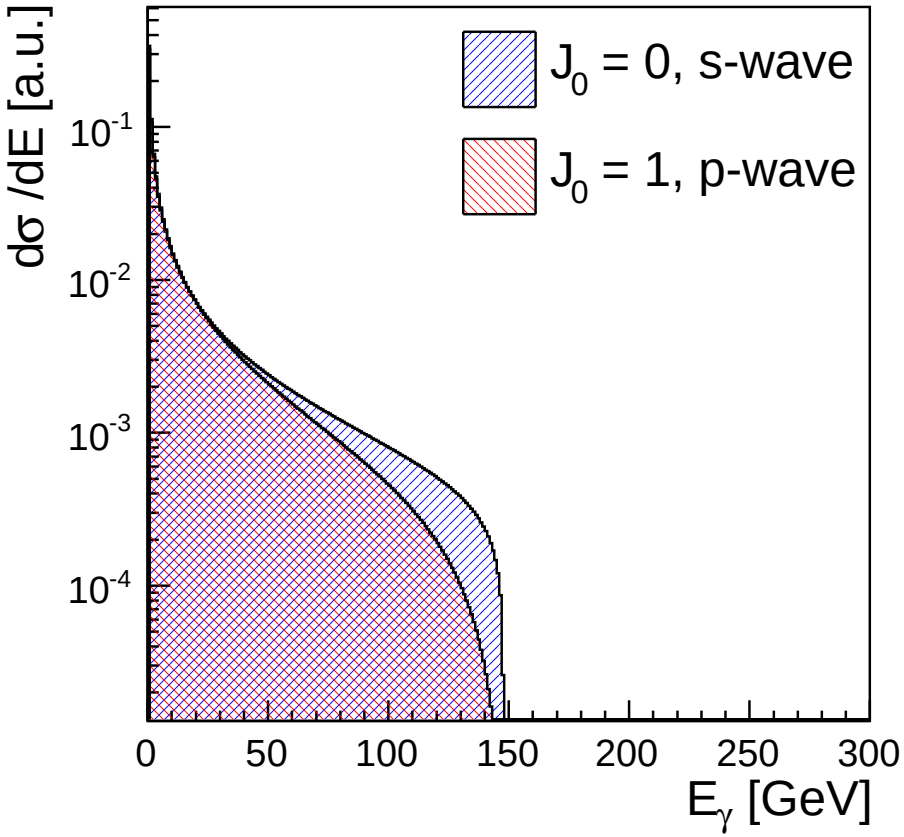
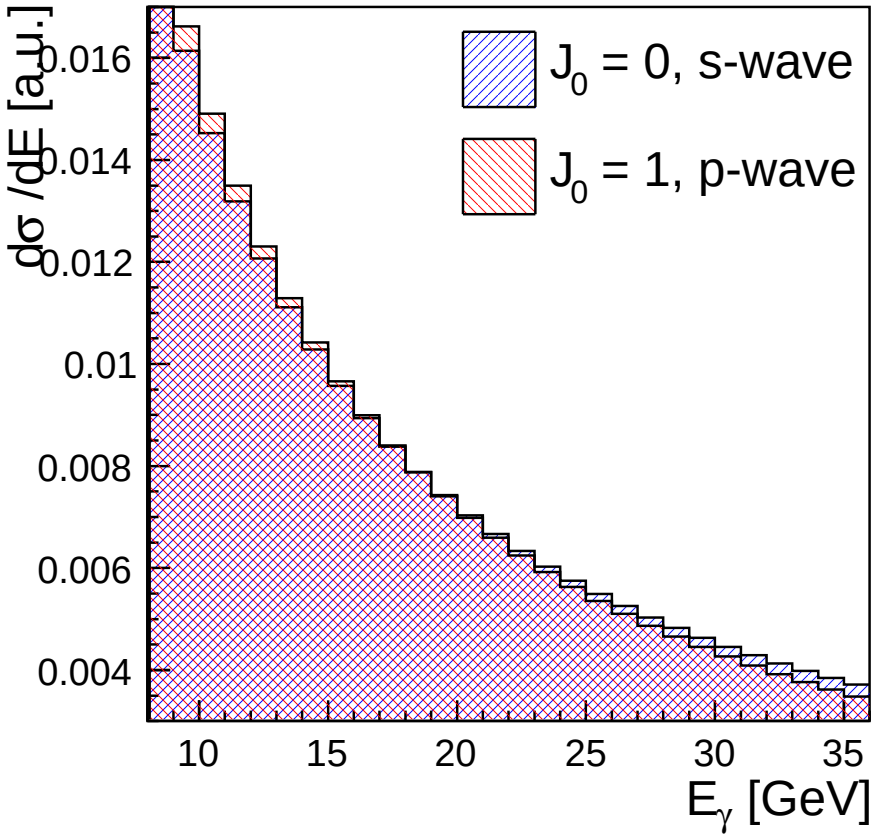
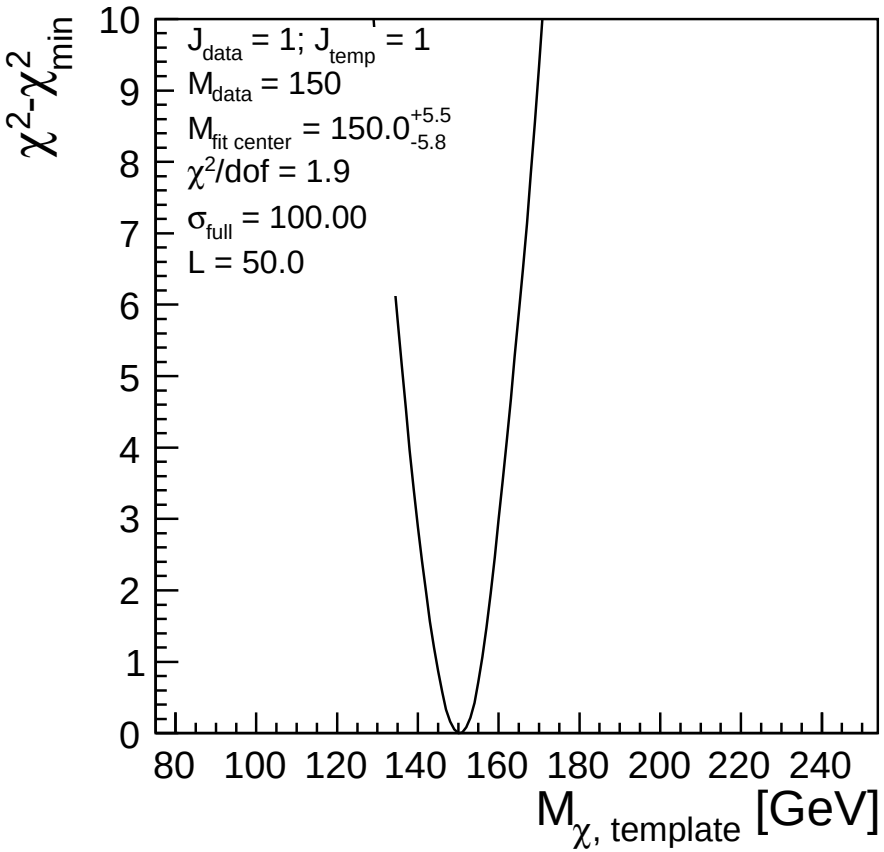
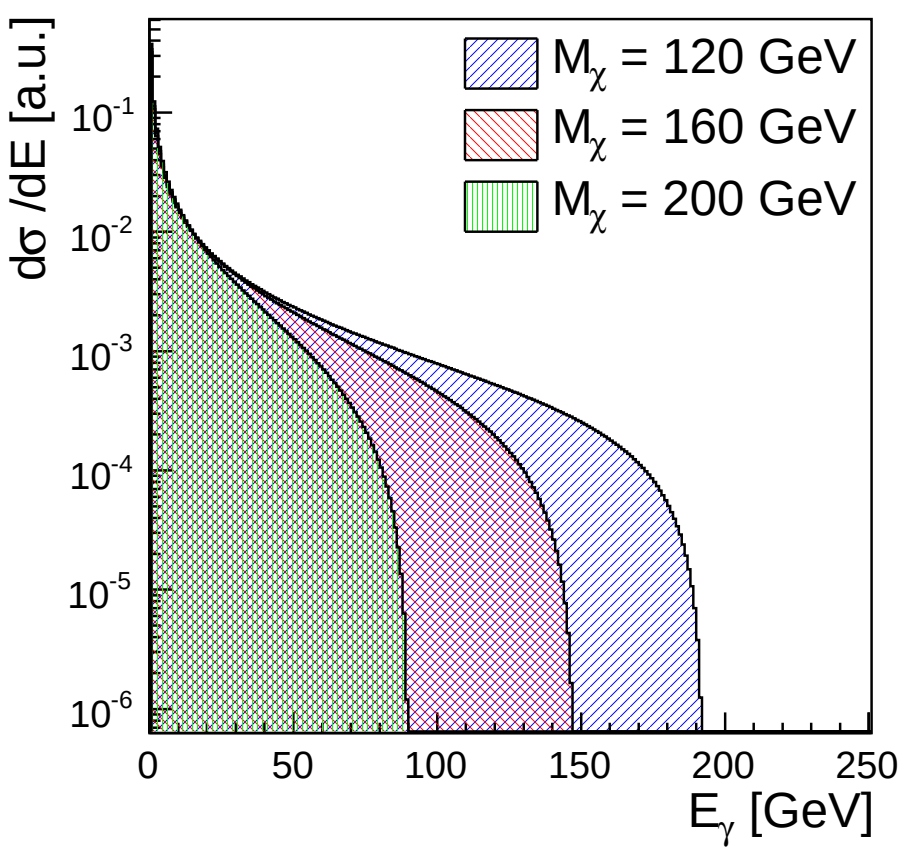




- No sensitivity to shape of threshold due to low statistics.
- Threshold shape drowns in background statistics.
- Sensitivity to cross over point at low energy.

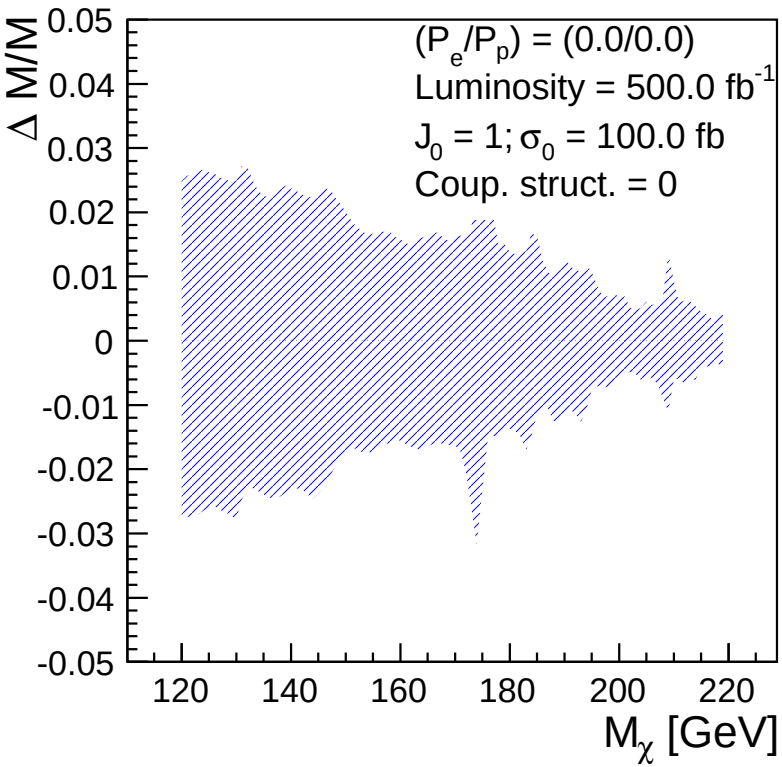
Mass Determination (Template Method)

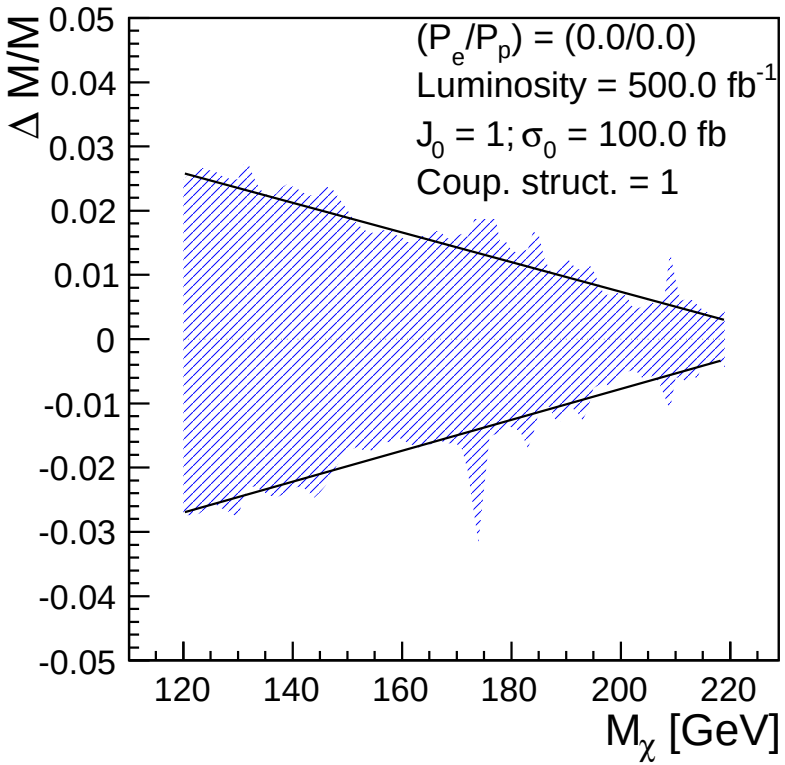




- $P_e = 0.8$, background supression: $\Delta M :\sim 9 \rightarrow\sim 6$ GeV.
- With enough statistics the threshold should be much better visible/detectable.
- Scan of threshold should give information on J_0.

Mass Determination, $P_{e^-} = 0\%$ $P_{e^+} = 0\%$





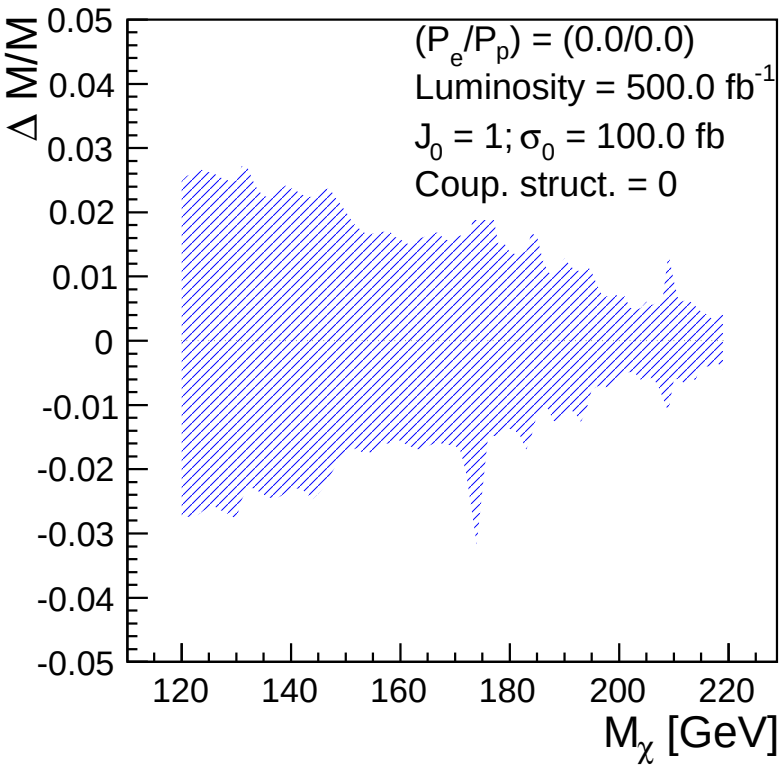
$\sigma_{RR} = \sigma_{LL} = \sigma_{LR} = \sigma_{RL}$

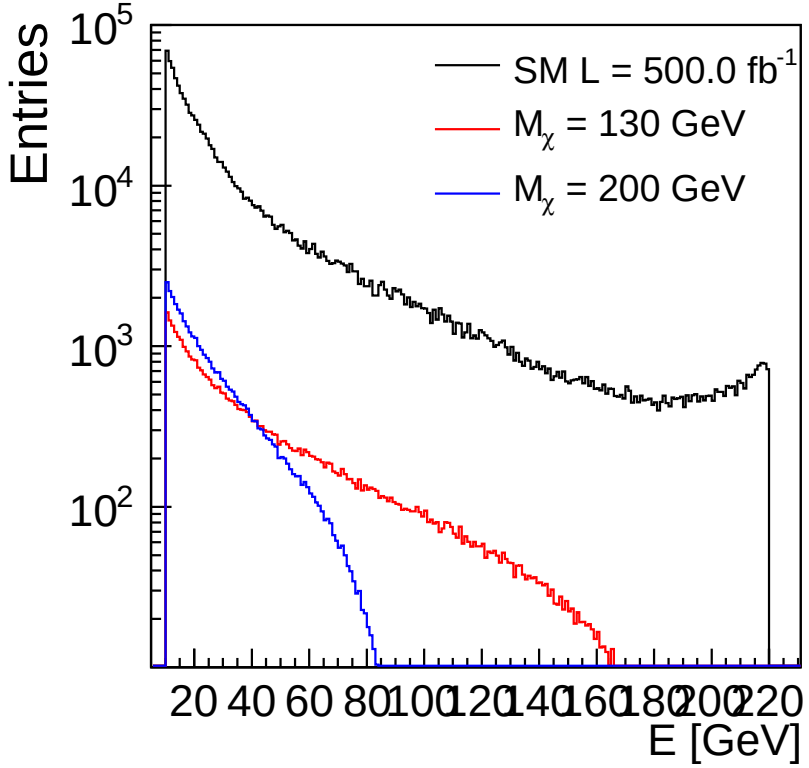
- $\Delta M/M$ from $\sim 2.5\%$ at $M = 120$ to 0.5% at $M = 220$.

$\sigma_{LR} = \sigma_{RL}; \sigma_{RR} = \sigma_{LL} = 0$

- $\Delta M/M$ from $\sim 2.5\%$ at $M = 120$ to 0.5% at $M = 220$.

Mass Determination, $P_{e^-} = 0\%$ $P_{e^+} = 0\%$





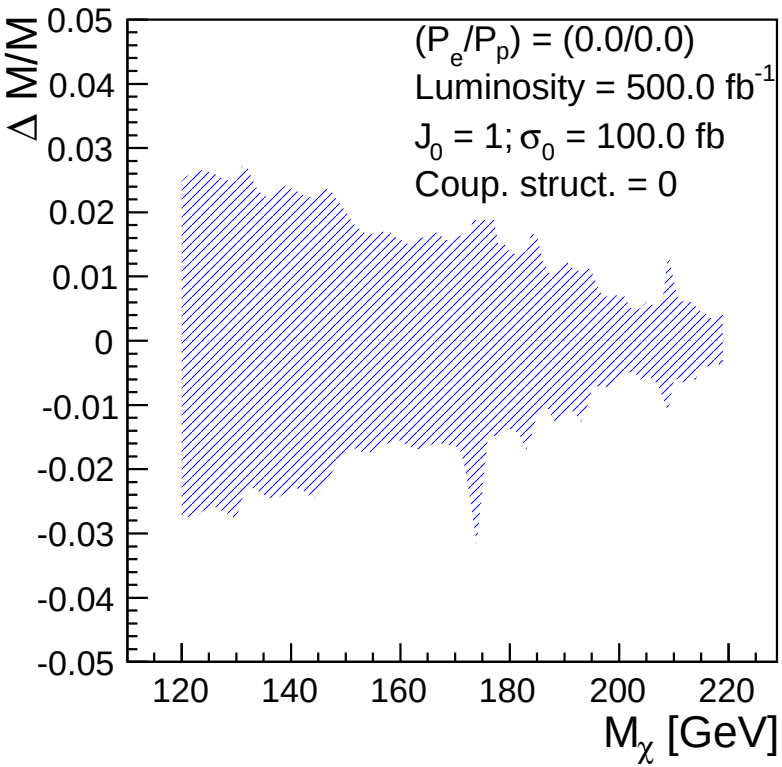
$\sigma_{RR} = \sigma_{LL} = \sigma_{LR} = \sigma_{RL}$

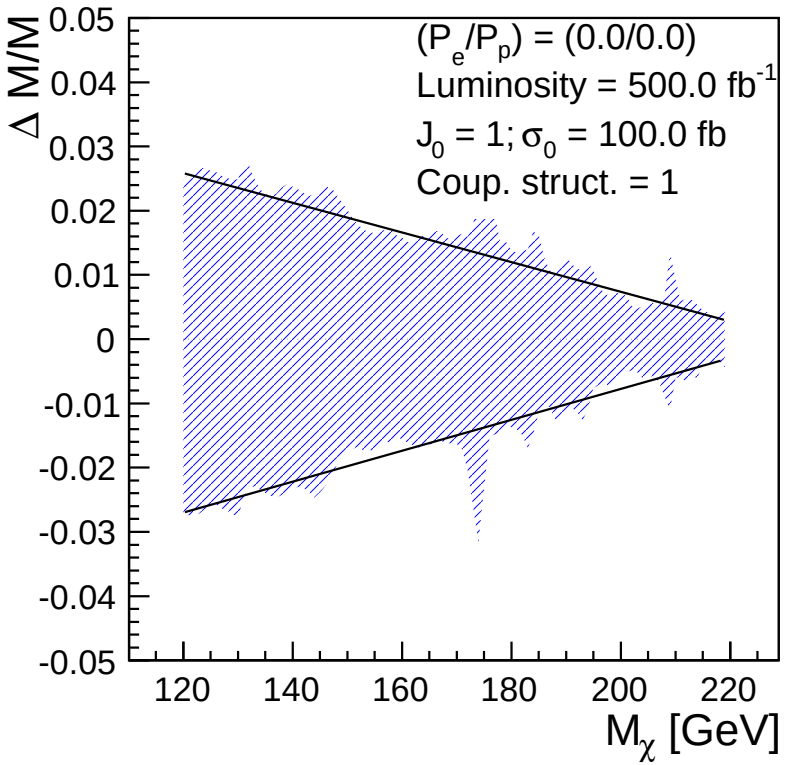
- $\Delta M/M$ from $\sim 2.5\%$ at $M = 120$ to 0.5% at $M = 220$.

$\sigma_{LR} = \sigma_{RL}; \sigma_{RR} = \sigma_{LL} = 0$

- $\Delta M/M$ from $\sim 2.5\%$ at $M = 120$ to 0.5% at $M = 220$.

Mass Determination, $P_{e^-} = 0\%$ $P_{e^+} = 0\%$





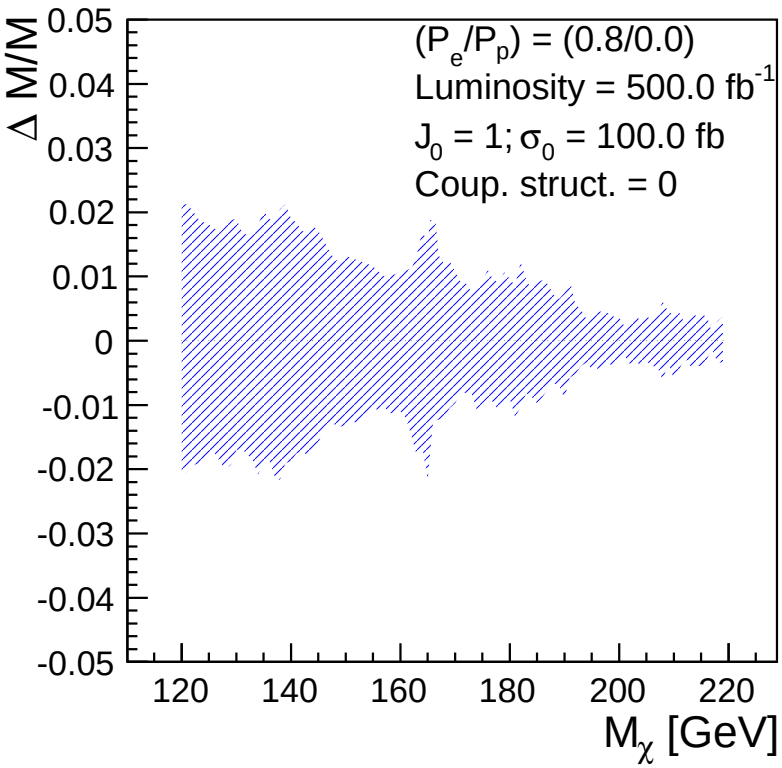
$\sigma_{RR} = \sigma_{LL} = \sigma_{LR} = \sigma_{RL}$

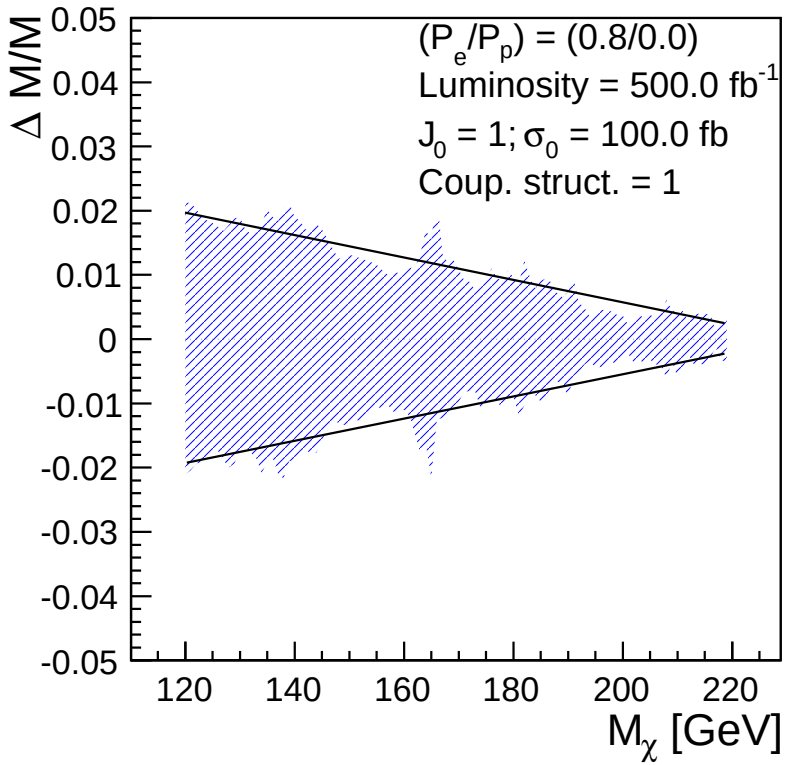
- $\Delta M/M$ from $\sim 2.5\%$ at $M = 120$ to 0.5% at $M = 220$.

$\sigma_{LR} = \sigma_{RL}; \sigma_{RR} = \sigma_{LL} = 0$

- $\Delta M/M$ from $\sim 2.5\%$ at $M = 120$ to 0.5% at $M = 220$.

Mass Determination, $P_{e^-} = 80\%$ $P_{e^+} = 0\%$





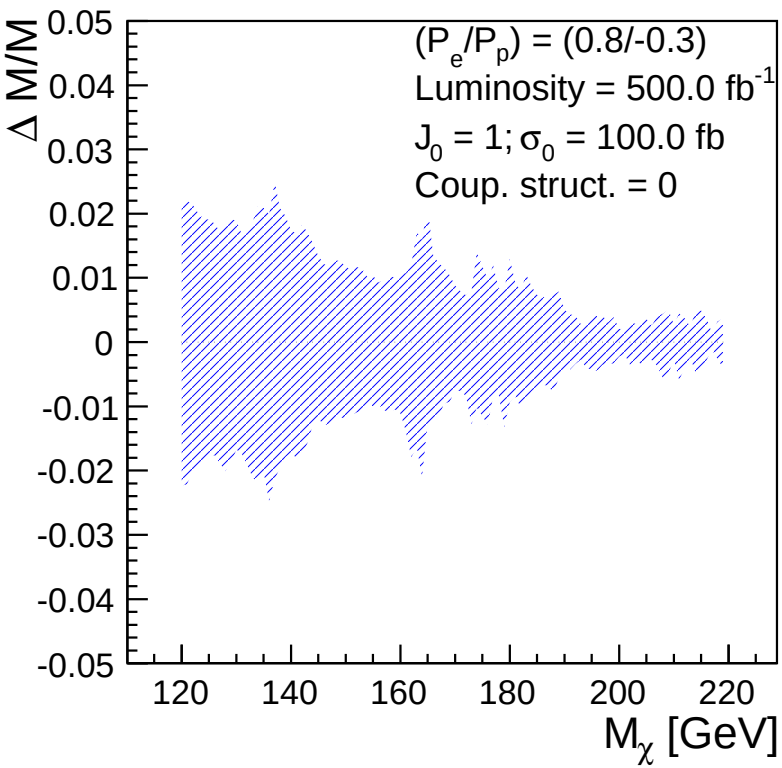
$\sigma_{RR} = \sigma_{LL} = \sigma_{LR} = \sigma_{RL}$

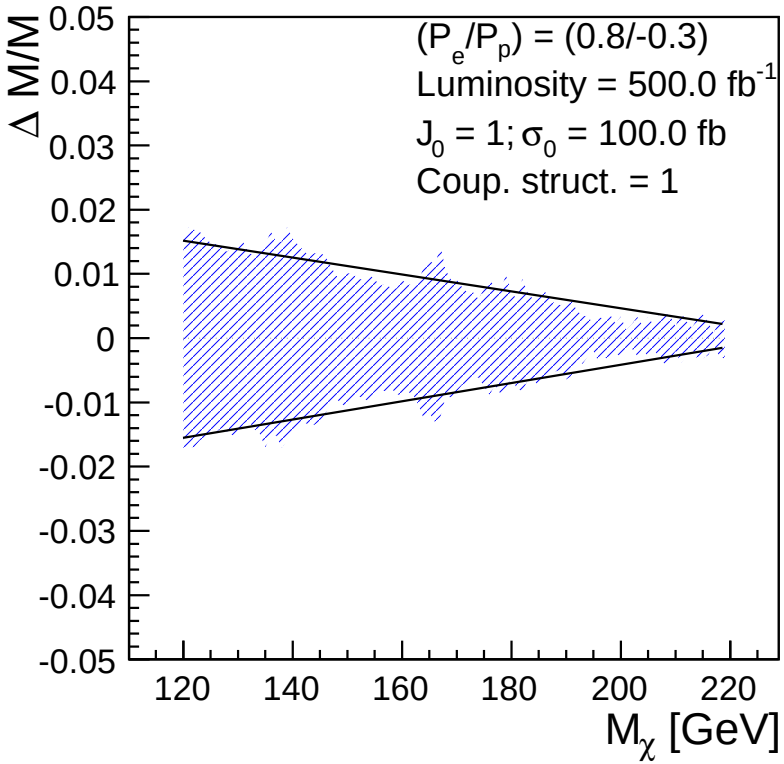
- Increased resolution
  Factor $\sim 2/3$.

$\sigma_{LR} = \sigma_{RL}; \sigma_{RR} = \sigma_{LL} = 0$

- Increased resolution
  Factor $\sim 2/3$.

Mass Determination, $P_{e^-} = 80\%$ $P_{e^+} = -30\%$





$\sigma_{RR} = \sigma_{LL} = \sigma_{LR} = \sigma_{RL}$

- Only small change in resolution with positron polarisation.

$\sigma_{LR} = \sigma_{RL}; \sigma_{RR} = \sigma_{LL} = 0$

- Additional resolution increase by 3/4.

Outline

Summary

- WIMP detection with ISR, model independent approach.
- SM background dominated environment.
- Full simulation of ILD detector.
- Analysis incorporates detector and beam energy spectrum effects.
- Signal simulation by reweighting irreducible background.
- Extrapolation from 200 to 1000 fb^{-1}: Chiral structure of WIMP couplings can be determined.
- Mass determination with template method.
- $\Delta M/M \approx \mathcal{O}(\%)$.
- Polarised beams increase mass resolution by factor ≈ 2, coupling dependent.

Outlook

- Systematic uncertainties.
- More statistics.
- Extraction of J_0.
- If possible: Interpretation in DM picture (smaller cross sections).