Single Photon Processes at the ILC

Dark Matter, SUSY and The Optimal Detector

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ILD Workshop Zeuthen
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Outline

Single Photon Processes @ ILC

- SM
- Dark Matter
- SUSY

Optimisation of the Detector Concept

- Optimisation
- Benchmarks
- Analysis

Progress in the last months

- Monte Carlo Generators
- Event Weights
- Energy Resolution
- New Detector Model

Summary

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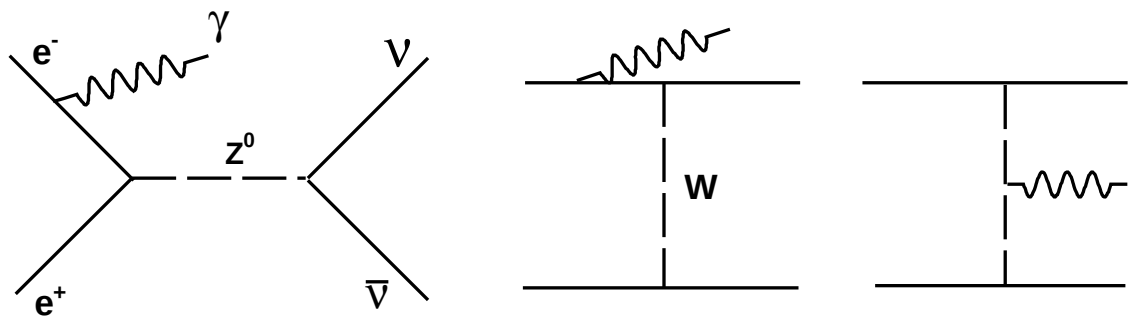
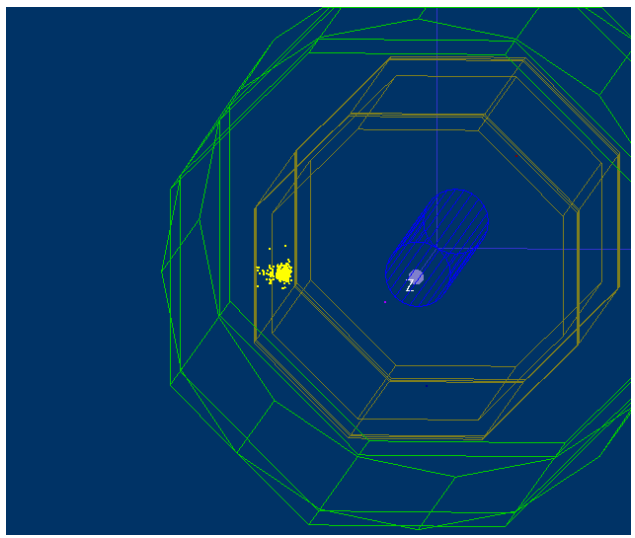
SM Single Photon Events

Single Photon and $\not{E}$



- SM $\nu\bar{\nu}\gamma$
- Single photon and $\not{E}$
- Cross section polarisation dependent

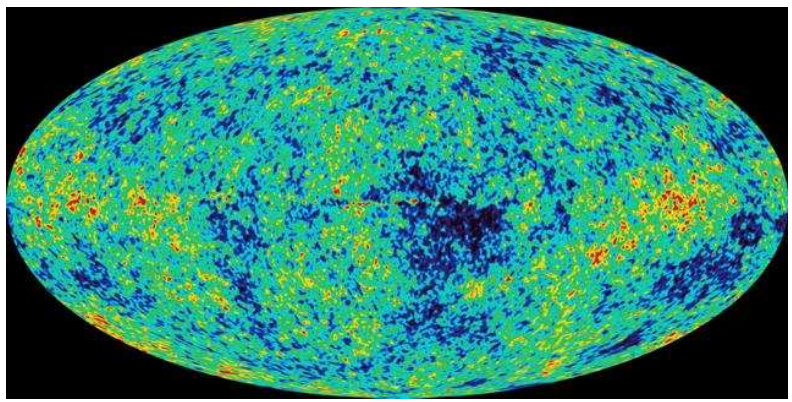


BSM Physics and Single Photon Events

Cosmological Dark Matter

Cosmological Dark Matter

- WMAP
- Cosmic Microwave Background
- 2.7 K
- Analysis of fluctuations



WMAP:

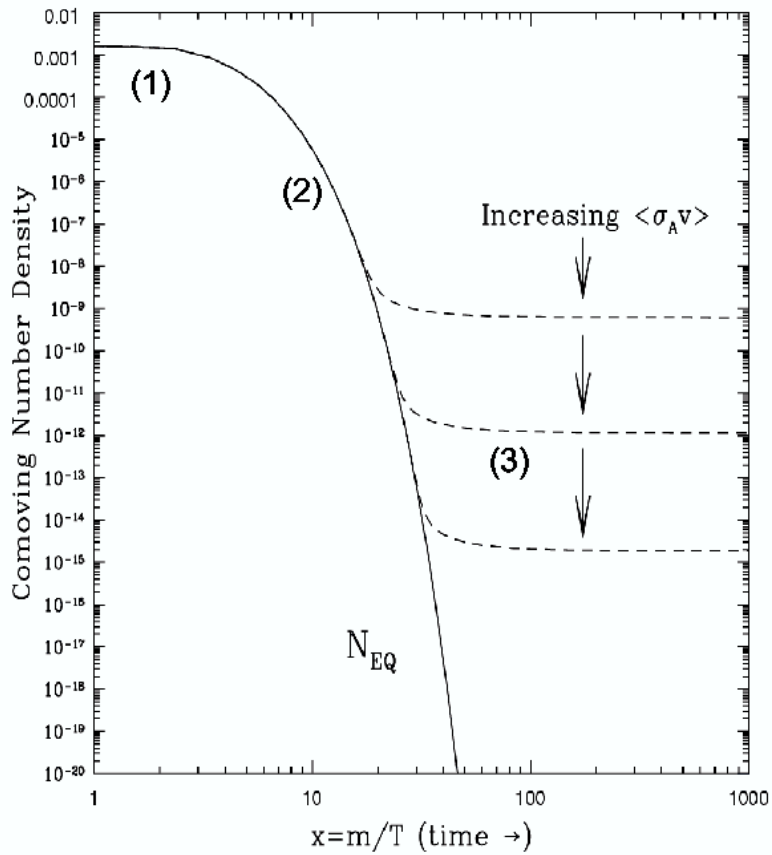
$$\boxed{\Omega_{\mathrm{DM}} = (21 \pm 2)\%}$$

Favoured DM candidate: WIMPs

WIMPs and Single Photon Events

From Cosmology to ILC

- DM as thermal relic
  $n \sim e^{-m_\chi/kT}$
- Expansion of universe $\rightarrow$ 'freezeout'
- Crossing symmetry: relation between $\sigma(\chi\chi \rightarrow e^-e^+)$ and $\sigma(e^-e^+ \rightarrow \chi\chi)$
- Emission of photon



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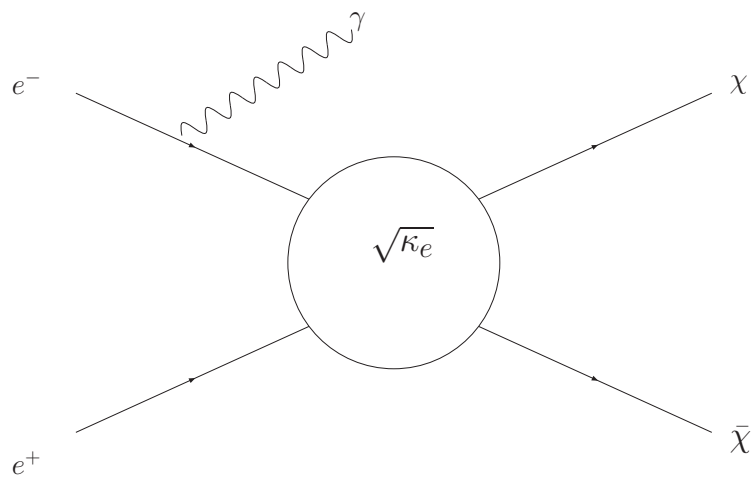


Cross section for $e^+e^- \rightarrow \chi\chi\gamma$

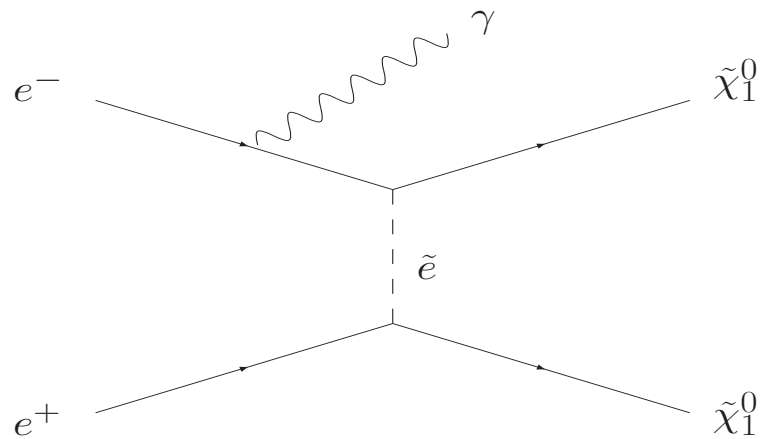
- Model independent
- Parameter: annihilation fraction to electrons κ_e

SUSY and Single Photon Events

Radiative Neutralino Production and Beam Polarisation

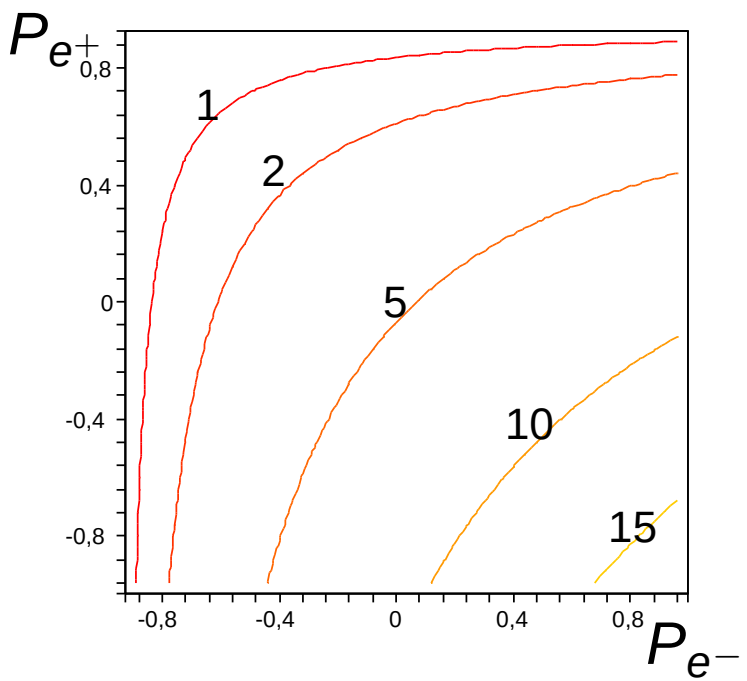
SUSY:

- Extension to Standard model (SM)
- DM candidates: $\tilde{\chi}_1^0$ or $\tilde{G}$



Radiative neutralino production

- Only kinematicly allowed process, if other SUSY masses > $\sqrt{s}/2$
- Signal cross section in fb
- $m_{\chi_1^0} = 180$ GeV



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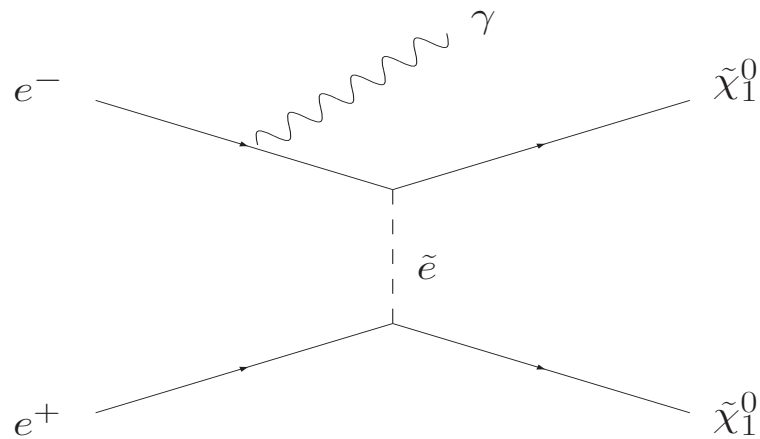
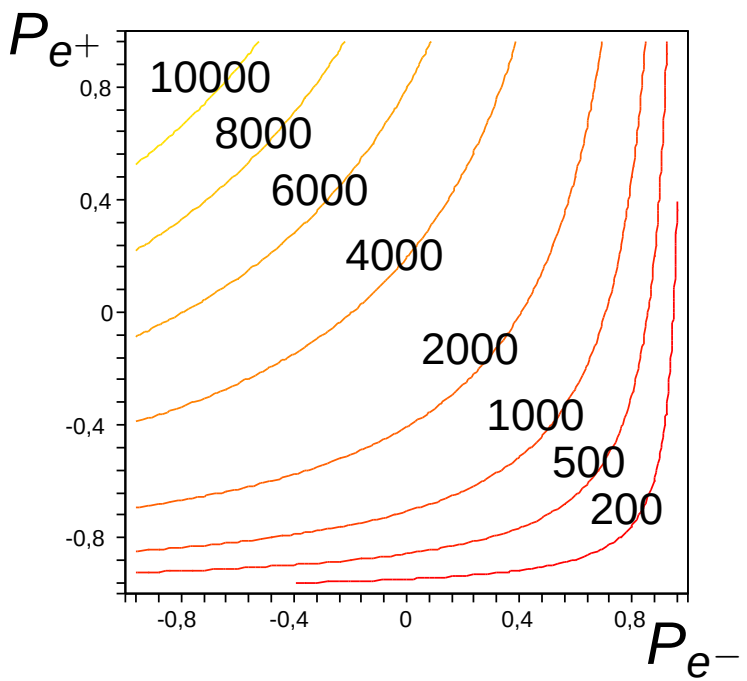


Radiative neutralino production

- Only kinematicly allowed process, if other SUSY masses > $\sqrt{s}/2$
- Background cross section in fb



SUSY and Single Photon Events

Radiative Neutralino Production and Beam Polarisation

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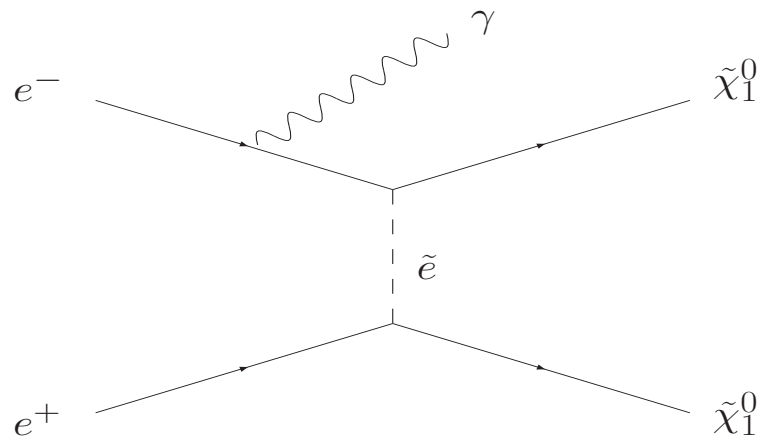
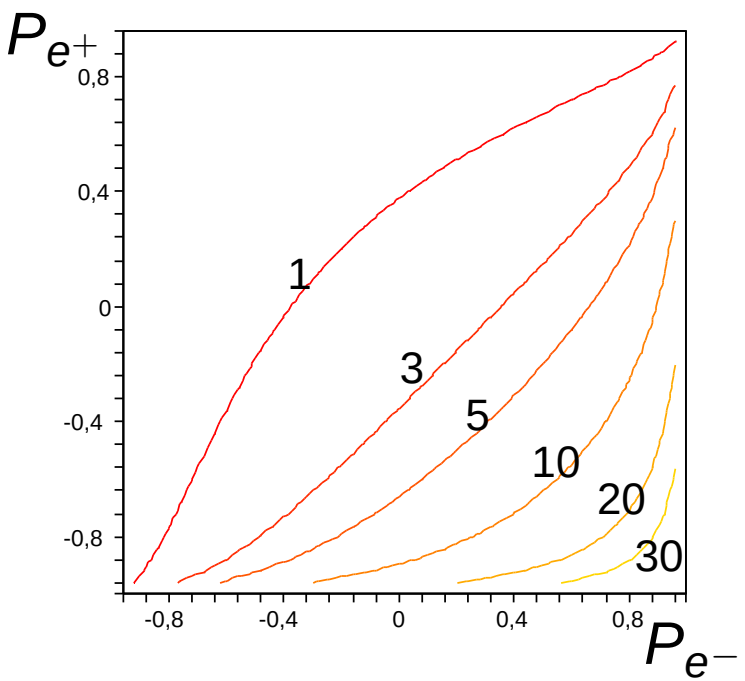


Radiative neutralino production

- Only kinematicly allowed process, if other SUSY masses > $\sqrt{s}/2$
- Significance $\frac{N_{sig}}{\sqrt{N_{bg}+N_{sig}}}$
- $\mathcal{L} = 500^{-1}\text{fb}$



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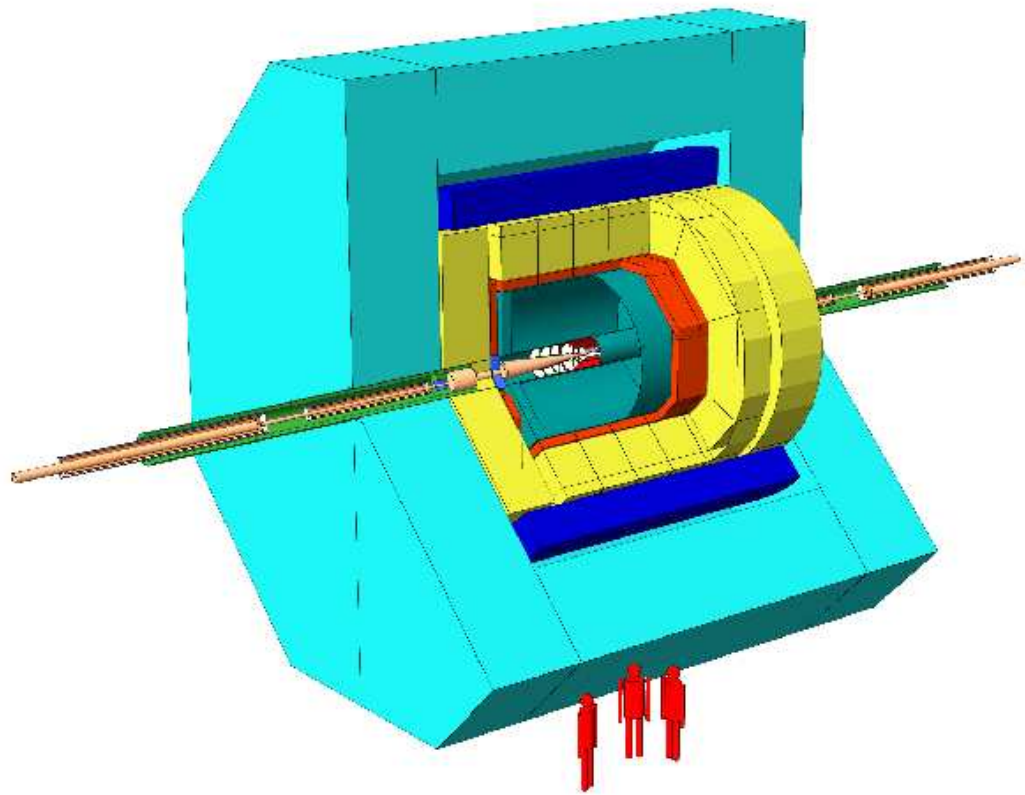
LDC'

Optimisation of The Detector Concept

Parameters

- Size of Time Projection Chamber ⇔ Size of Coil
- B-Field ⇔ innermost vertex layer
- Calorimeter cell size ⇔ cost
- Layout of forward region

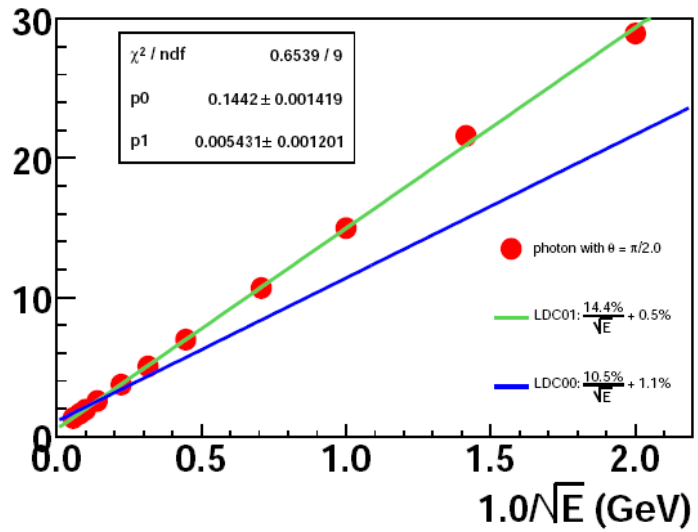


LDC Optimisation with Single Photon Events

Optimisation Goals of this Anlaysis

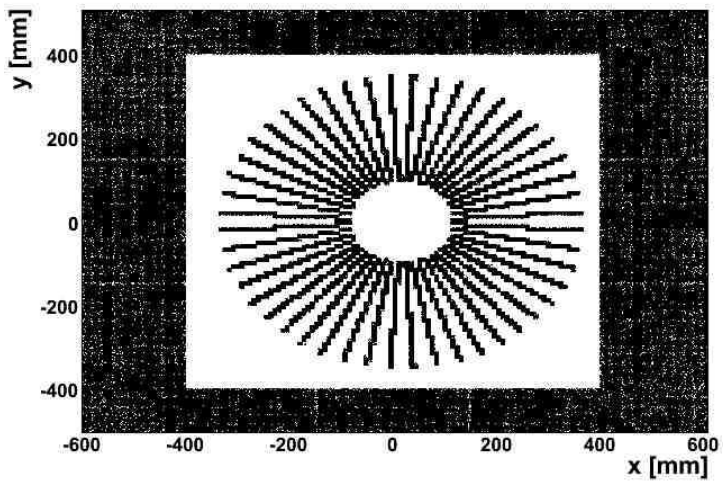
Detector benchmarks

- ECAL resolution:
  $\frac{\Delta E}{E} = \frac{14.4\%}{\sqrt{E}}$
- Hermeticity
- Fake $\not{E}$ rejection (LumiCal)



Furthermore

- Photon ID (PFlow)



LDC Optimisation with Single Photon Events

Optimisation Goals of this Anlaysis

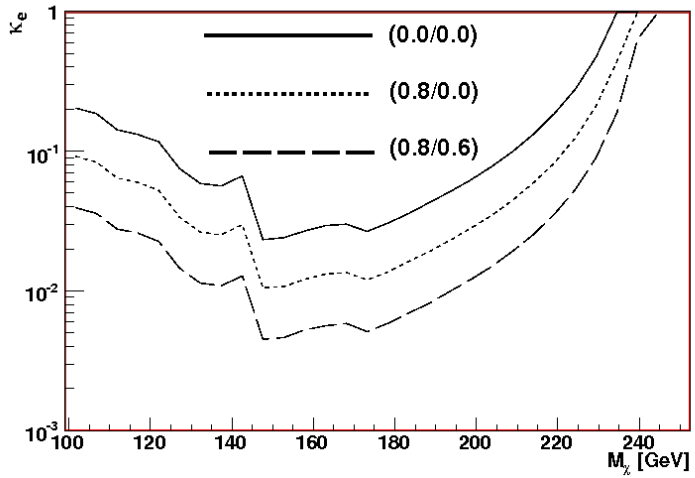
Analysis benchmarks

LCWS Hamburg 2007

Model independent

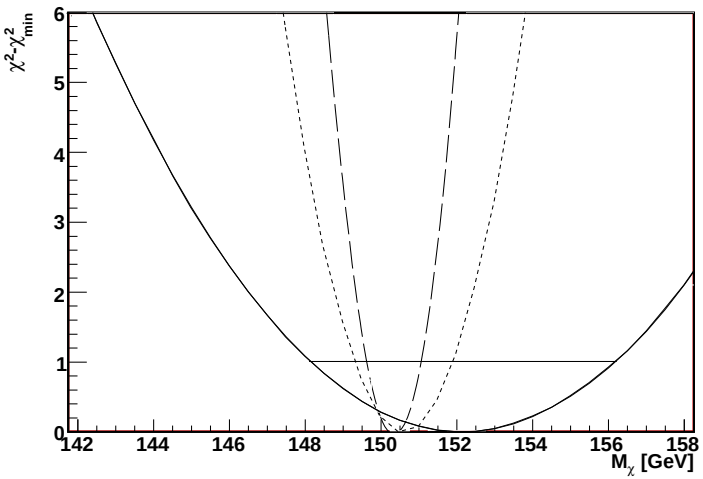
- Lowest visible κ_e
- WIMP mass resolution

Here: polarisation increases reach and resolution by $\sim$ 6-10



SUSY

- $\int \mathcal{L}dt$ for 5 σ observation of $\tilde{\chi}_1^0$
- $\tilde{\chi}_1^0$ mass resolution



DM Searches at the ILC

in Full Simulation of the LDC

From theory:

- Cosmology: WIMP cross section $\longrightarrow \sigma_{sig}$
- SUSY: neutralino cross section $\longrightarrow \sigma_{sig}$
- SM: $\nu\bar{\nu}\gamma$ background cross section $\longrightarrow \sigma_{bg}$

Analysis procedure (status LCWS Valencia/Hamburg)

- SM $\nu\bar{\nu}\gamma$ sample $\sim 500\,\mathrm{fb}^{-1}, \mathcal{O}(10^6)$ events (`NUNUGPV`)
- Detector simulation (`Mokka 6.1`)
- Digitisation (`MokkaCaloDigi`)
- Reconstruction (`Wolf`) and selection
- Assign weights $\frac{\sigma_{sig}}{\sigma_{bg}}(E_\gamma, \Theta_\gamma)$
- Search :)

Benefit: one sample covers full parameter space

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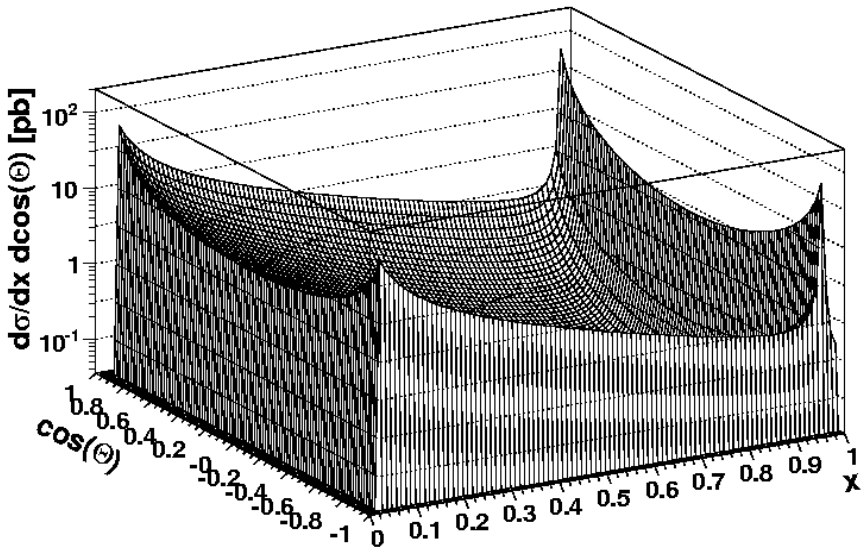
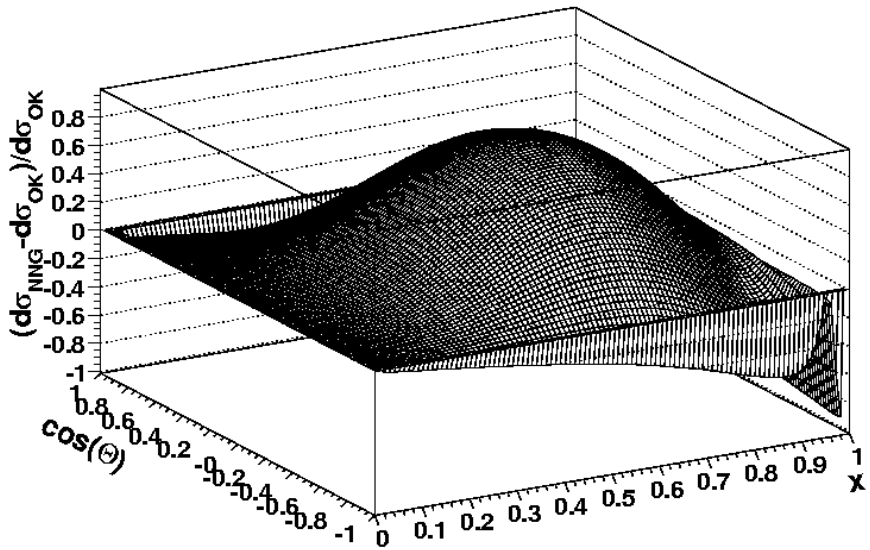
Monte Carlo Generators and Cross Sections

Comparison between NUNUGPV, Whizard and LO Calculation, $\frac{d\sigma}{dx\,d\cos\Theta}$ [pb] with $x = \frac{2E_\gamma}{\sqrt{s}}$





Cross section

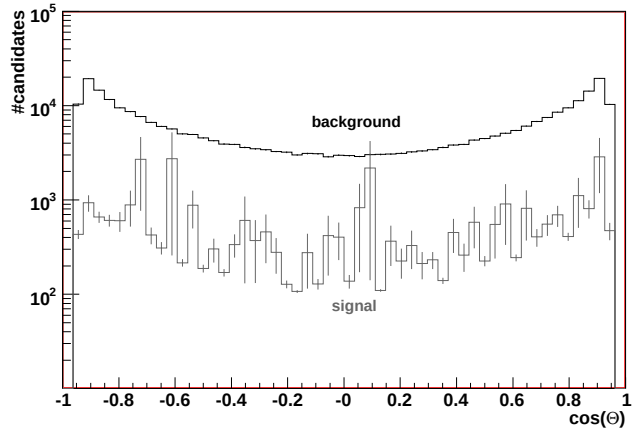
Relative differences

- Up to 80% deviations in some regions of phase space, discussion with authors
- Use whizard for event generation
- LO calculation for weight evaluation

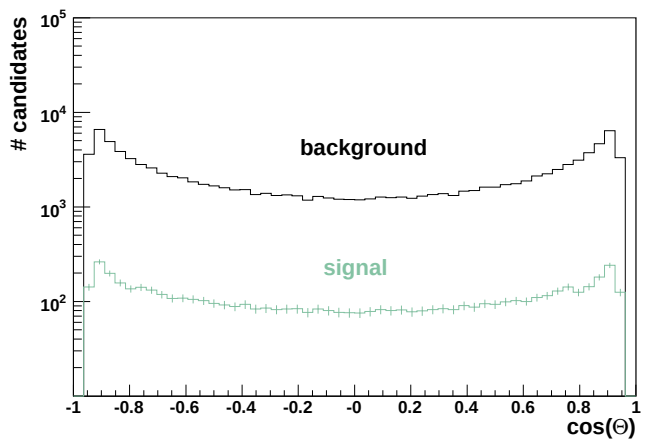
Event Weights

$\frac{\sigma_{sig}}{\sigma_{bg}}(E_\gamma, \Theta_\gamma)$ with LO Calculation

- σ_{bg} created from event sample
- Fluctuations in signal distribution



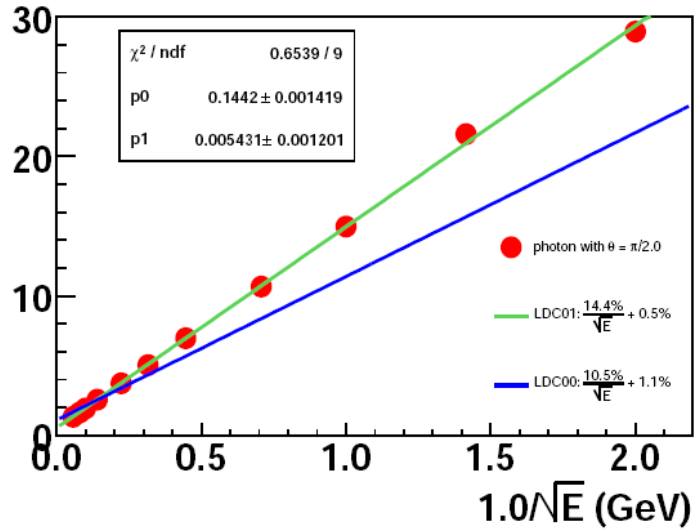
- σ_{bg} from exact LO cross section calculation
- Weights smoothed

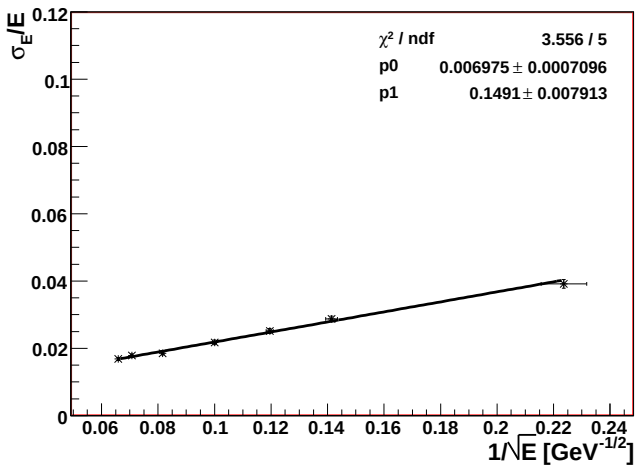


Energy Resolution

Tests with Single Particle Gun

- Aim for energy resolution $\frac{\Delta E}{E} = \frac{14.4\%}{\sqrt{E}}$ (LDC01)
- Test with particle gun
- $20 < \mathrm{E}_\gamma < 240$ GeV at 90°
- Resolution at $\frac{\Delta E}{E} = \frac{14.9\%}{\sqrt{E}}$
- Calibration of simulation for MC events
- Full calorimetric energy
- Try with Photon ID next



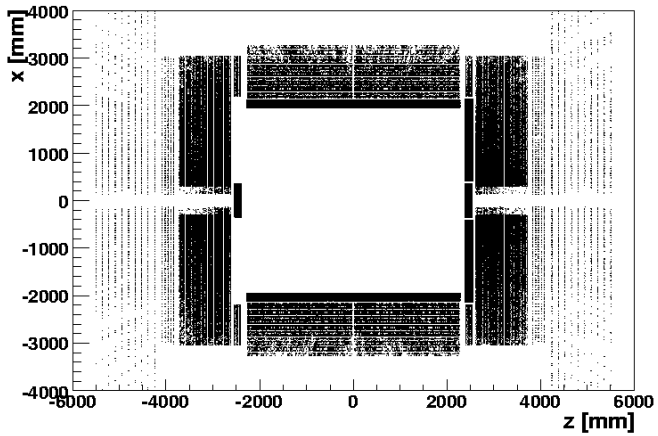


New Detector Model

LDC01_05Sc

LDC01Sc → LDC01_05Sc

- Under construction
- New default
- Missing endcap

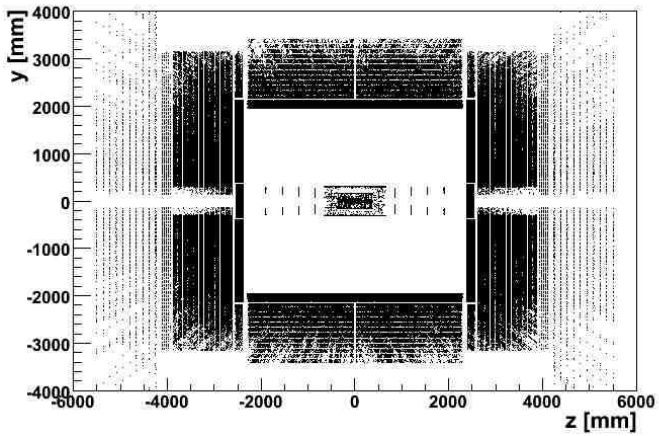


New Detector Model

LDC01_05Sc

LDC01Sc → LDC01_05Sc

- Under construction
- New default
- Missing endcap
- Solved

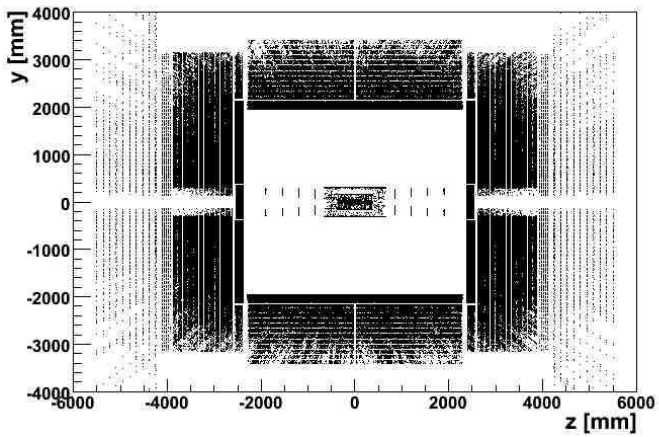


New Detector Model

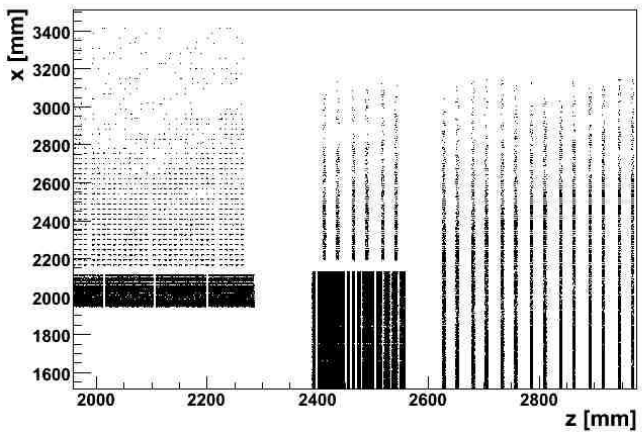
LDC01_05Sc

LDC01Sc → LDC01_05Sc

- Under construction
- New default
- Missing endcap
- Solved



- HCAL barrel ring
- Will change?



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Conclusions

- Single photon events are an interesting BSM signal in model-independent DM scenarios and SUSY
- LDC Optimisation effort can benefit from single photon events
- Model-independent WIMP searches possible at ILC
- Polarisation very important
- $\tilde{\chi}_1^0\tilde{\chi}_1^0\gamma$ gives highest accessible mass range for $\tilde{\chi}_1^0$ up to $m_{\chi_1^0} \simeq \sqrt{s}/2$
- LDC01_05Sc is under construction
- Generator comparison $\rightarrow$ Whizard
- Weight problem solved

Summary

Things to Come

- Inclusion of SLAC sample for other SM backgrounds
  - Beamstrahlung, energy spread, crossing angle $\Rightarrow$ luminosity spectrum
  - Full simulation of new LDC01_05Sc
- Reconstruction with new PFA algorithms
  - PhotonFinder (P. Krsostonic)
  - TrackBasedPFlow (O. Wendt)
  - PandoraPFA (M. Thomson)
- Analysis of SUSY scenario
- Comparison of different detector models

Thank You

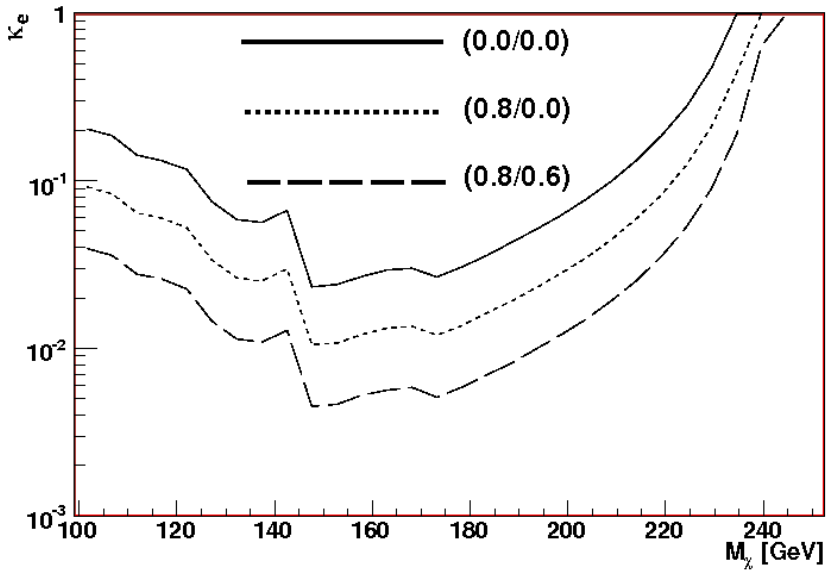
Outline

Results

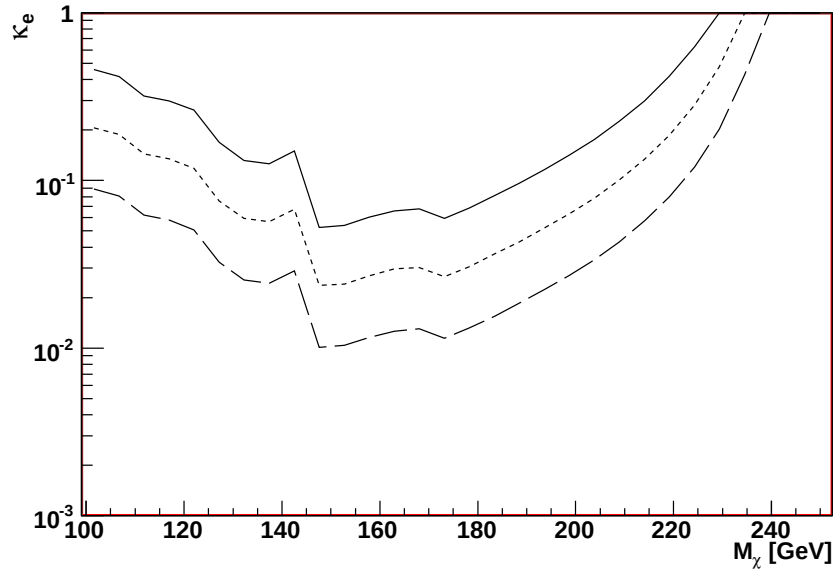
- Sensitivity
- Mass Resolution

Sensitivity

ILC Reach on Lowest Visible κ_e, LDC Version 1



S=1

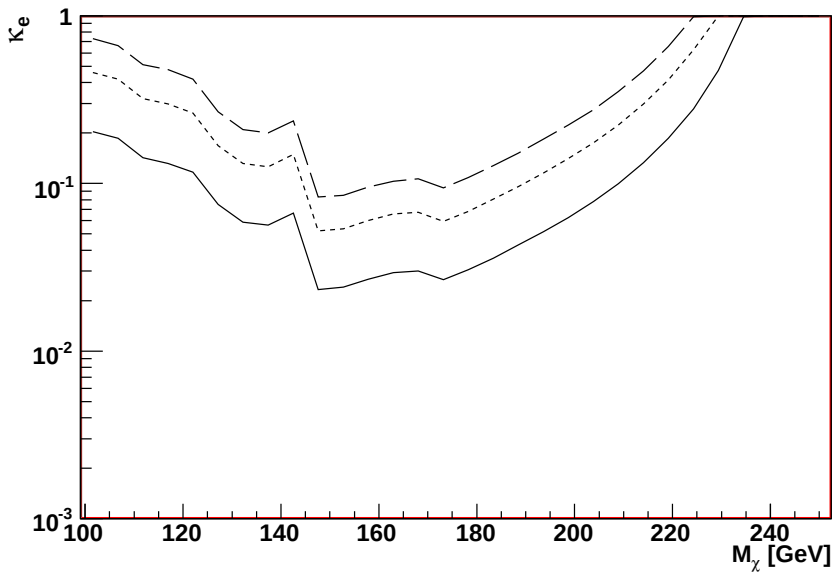


S=1/2

- Parity and Helicity conserved
- $\mathcal{L} = 500\,\mathrm{fb}^{-1}$
- Polarisation enhances S/B ratio by factor $8 \sim 10$

Sensitivity

ILC Reach on Lowest Visible κ_e



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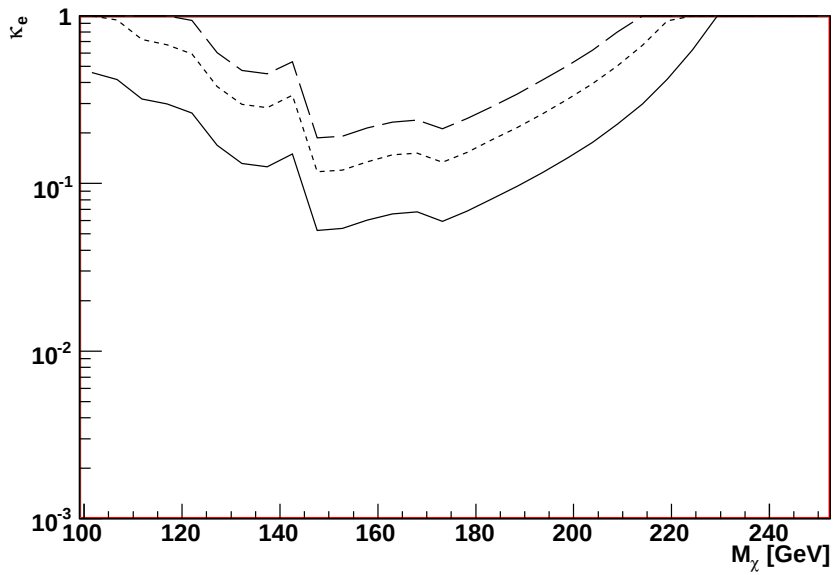
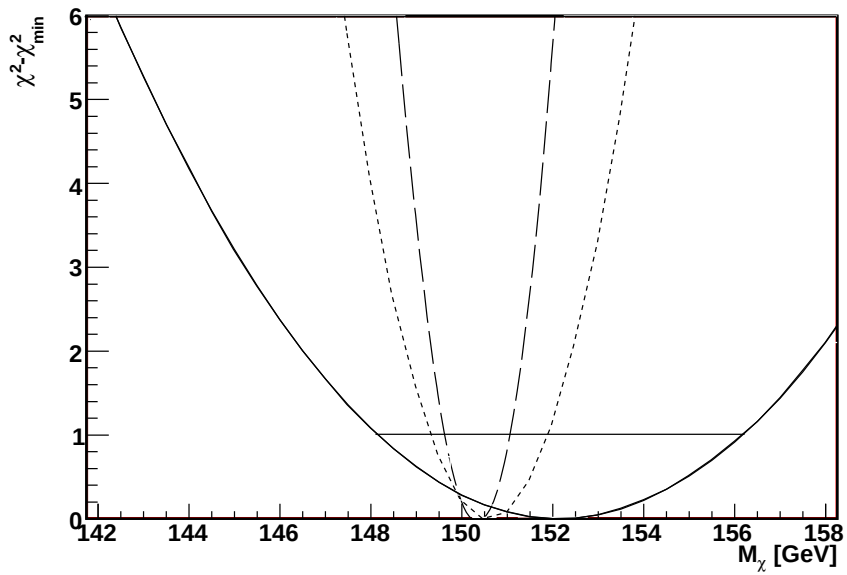


S=1/2

- Standard Model weak interaction like
- $\mathcal{L} = 500\,\mathrm{fb}^{-1}$
- Polarisation decreases S/B ratio

Mass Resolution

Mass Resolution of WIMPs



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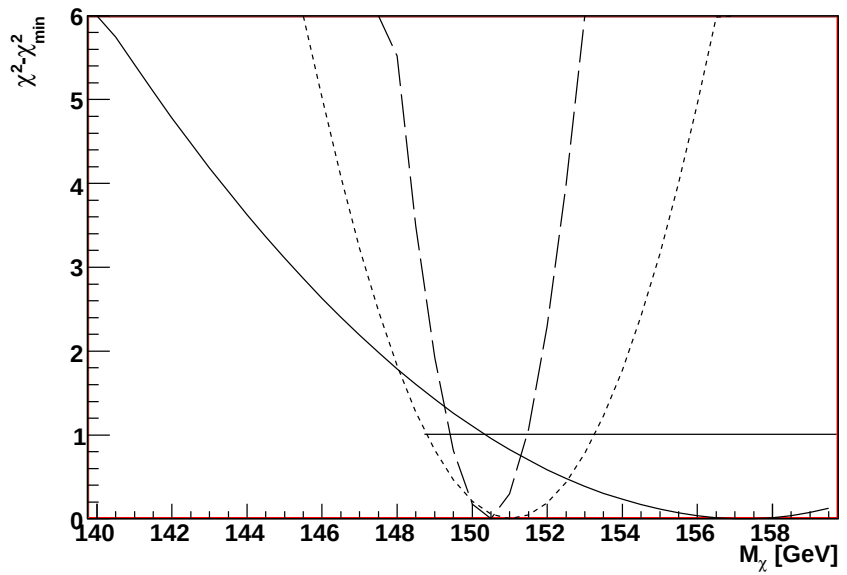


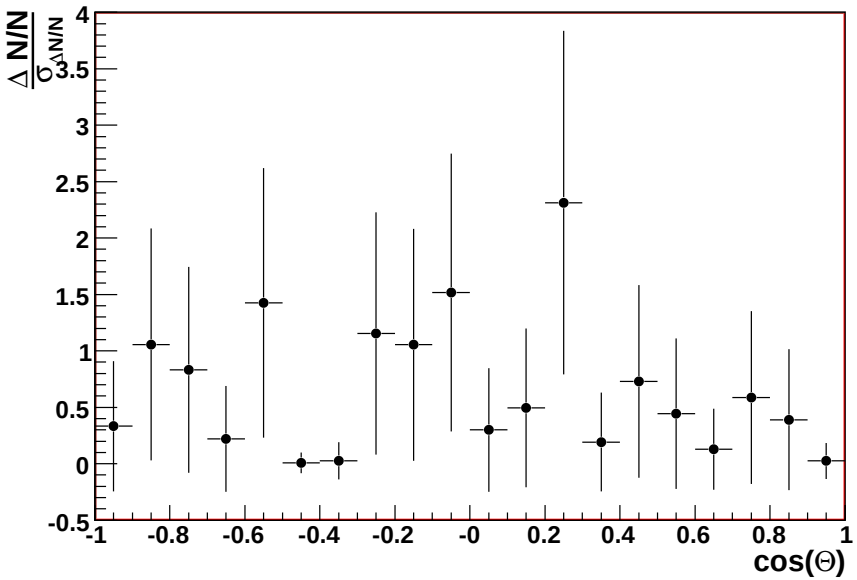
S=1/2

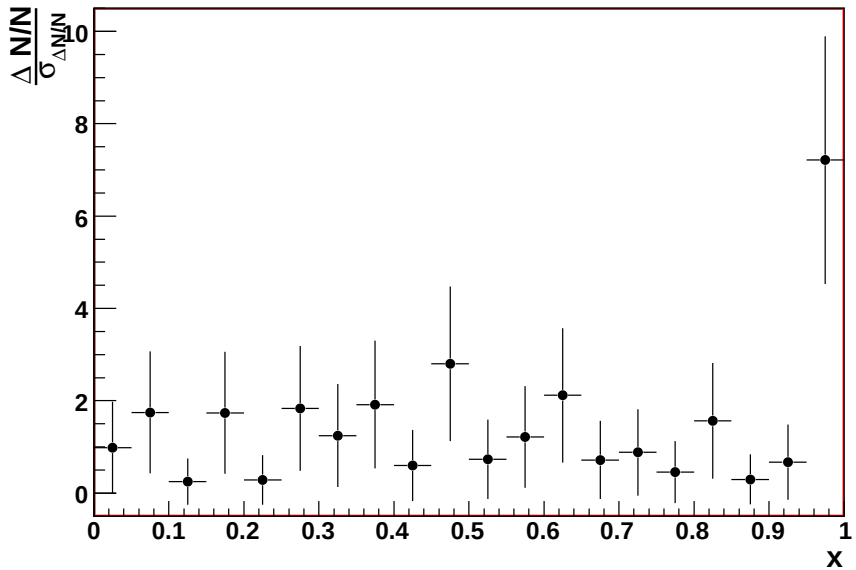
- Parity and Helicity conserved
- $\mathcal{L} = 170\,\mathrm{fb}^{-1}$
- Polarisation increases resolution by factor ~ 6

Monte Carlo Generators

NUNUGPV$_{mod}$ vs Whizard w and w/o ISR

- 10^6 single photon events, no ISR
- $\sqrt{s} = 500$ GeV



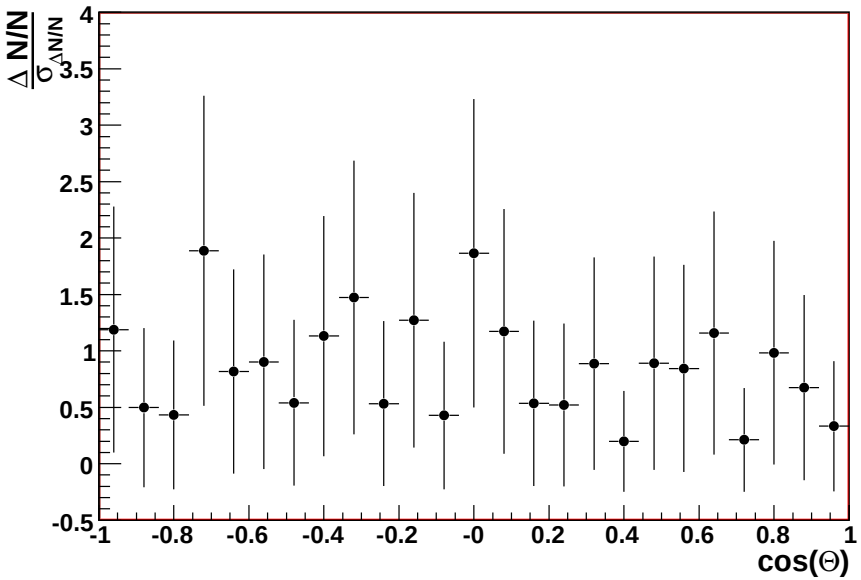


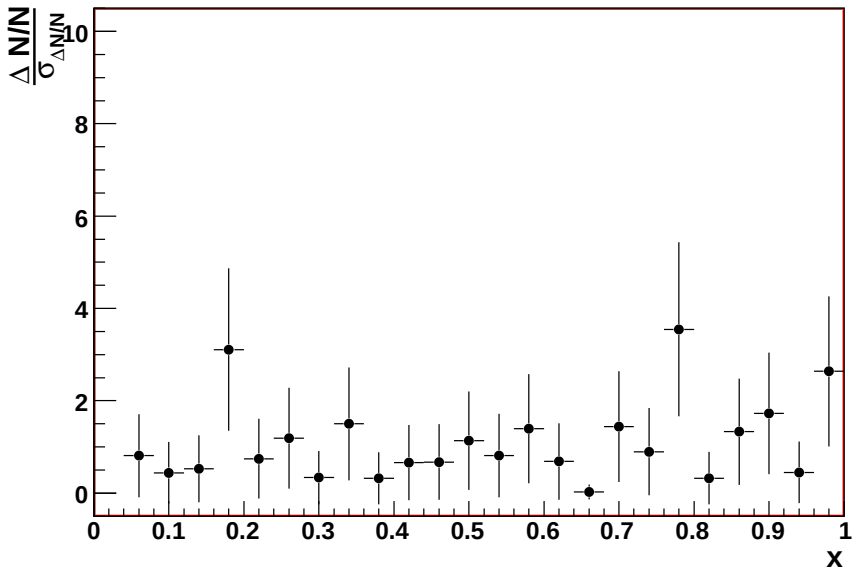
- Consistency within 1-1.5 σ (stat.)
- Except at $x = 0.967$ (radiative Z^0 return)
  - Integration routine in NUNUGPV$_{mod}$

Monte Carlo Generators

NUNUGPV$_{mod}$ vs Whizard w and w/o ISR

- 10^5 single photon events with 2 add. ISR photons
- $\sqrt{s} = 500$ GeV





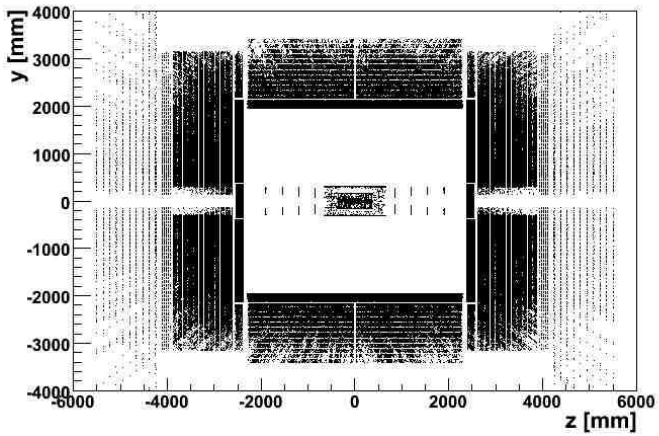
- Consistency within 1-1.5 σ (stat.)

$\Rightarrow$ Whizard chosen for compatibility

New Detector Model

LDC01_05Sc

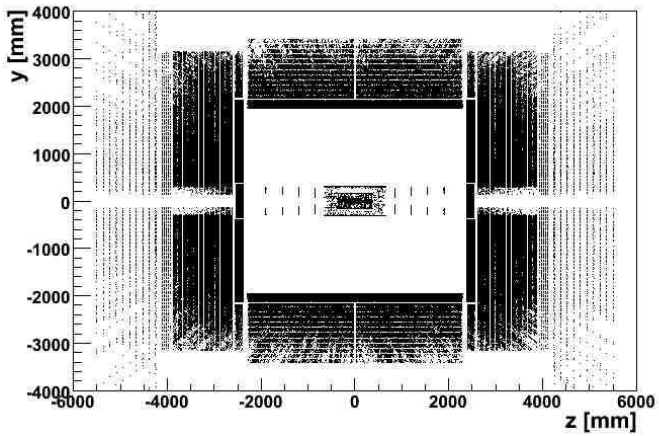
- New default

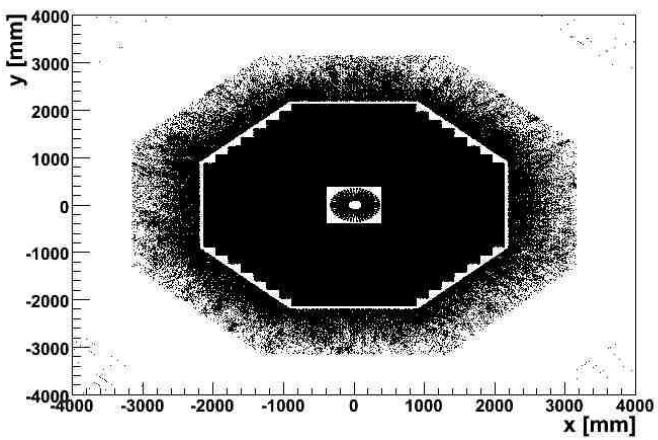


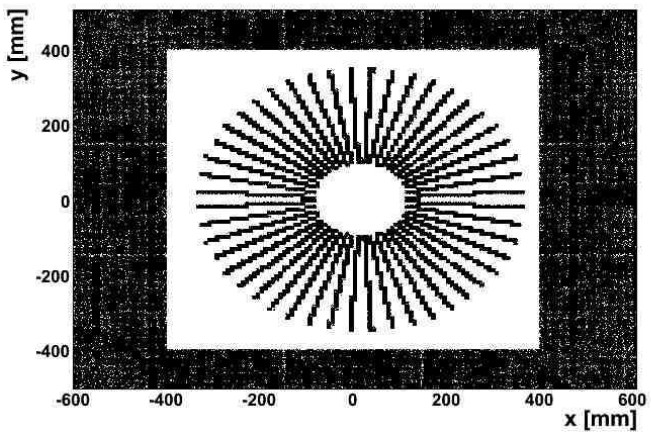
New Detector Model

LDC01_05Sc

- New default
- LumiCal implemented



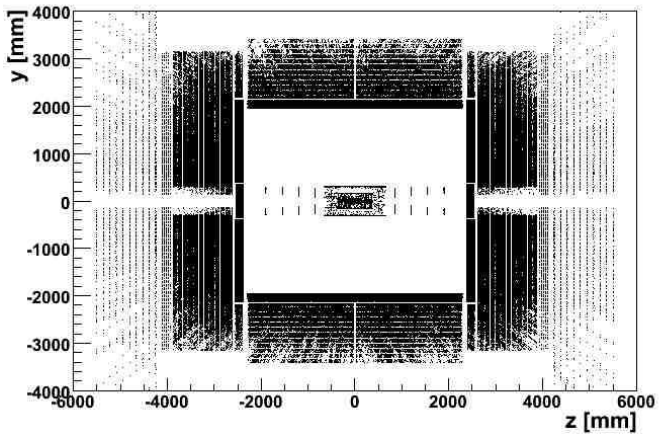


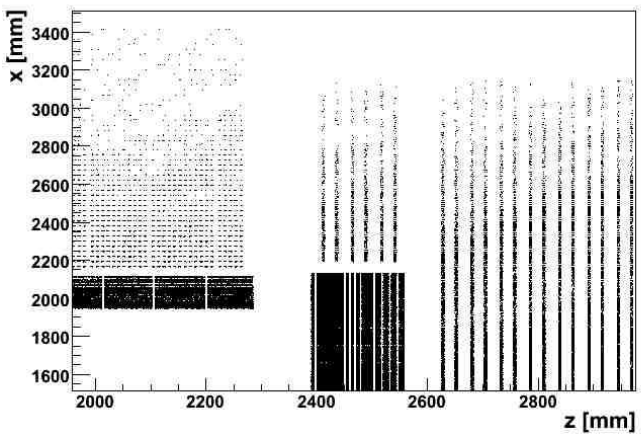


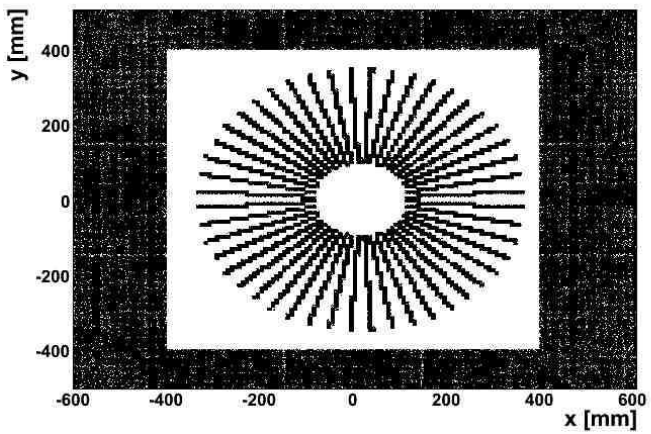
New Detector Model

LDC01_05Sc

- New default
- LumiCal implemented
- HCAL rings

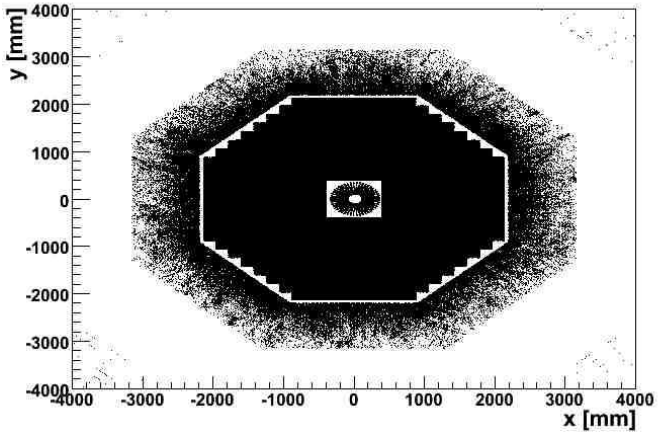




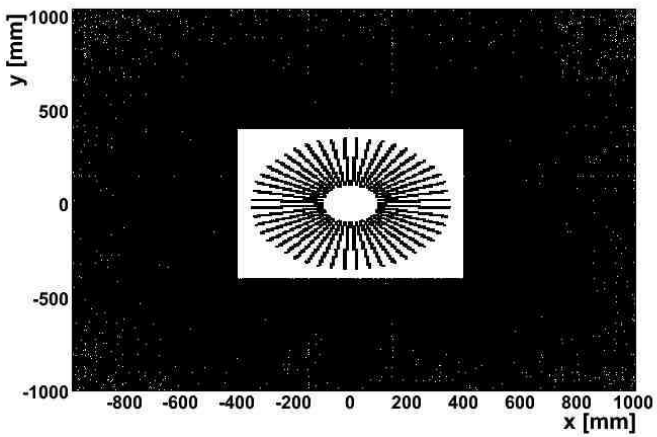


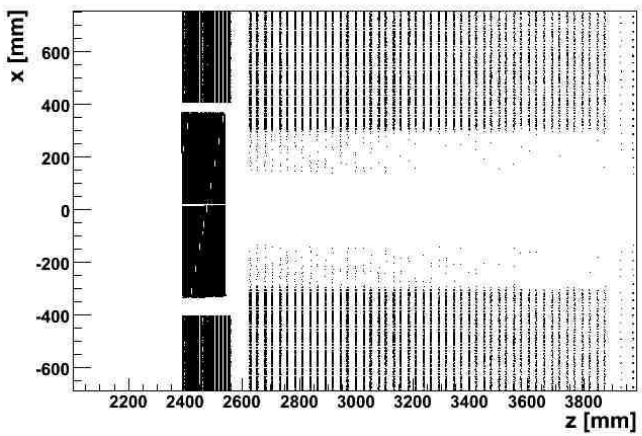
New Detector Model

LDC01_05Sc



- r, ϕ, z
- local x, y, z
- global x, y, z
- excentric
- rotated
- Missing: “ECAL plugs”





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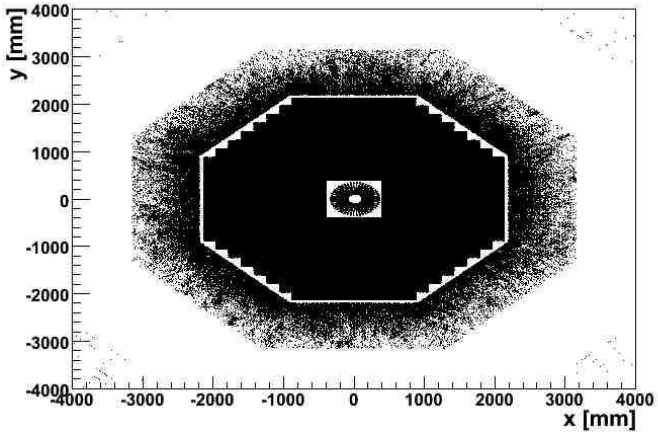

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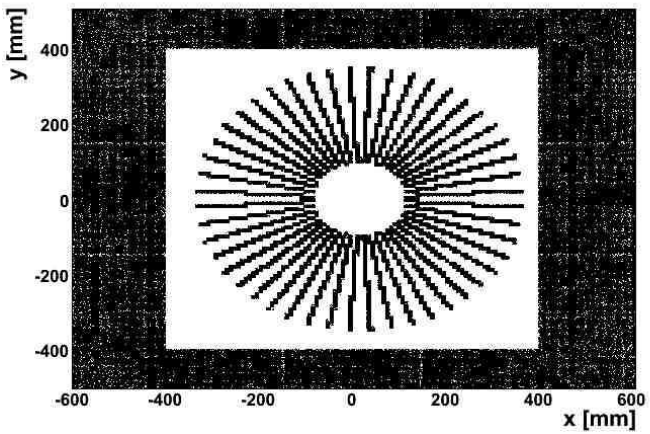
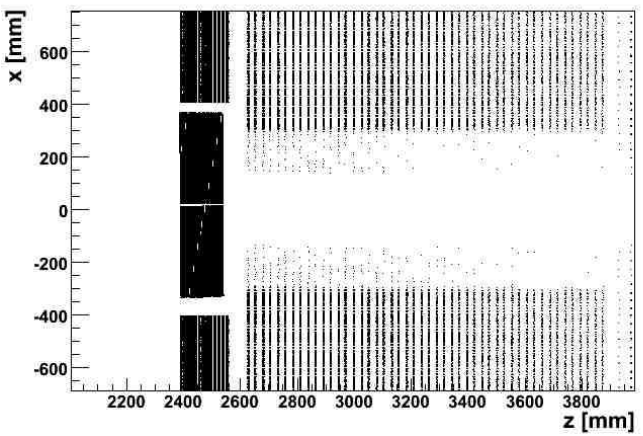
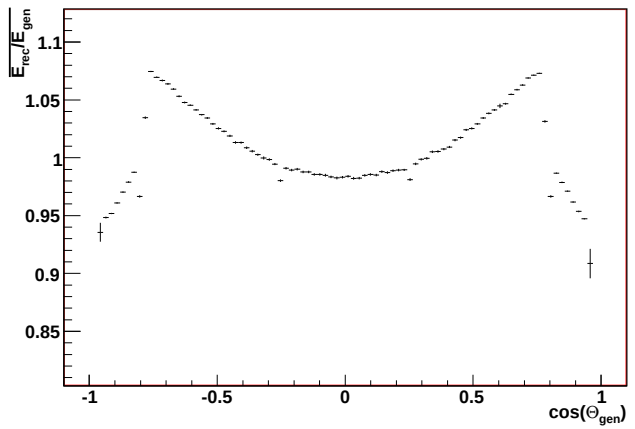


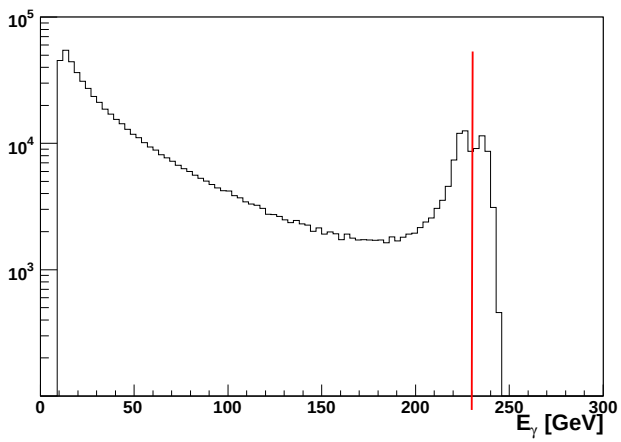


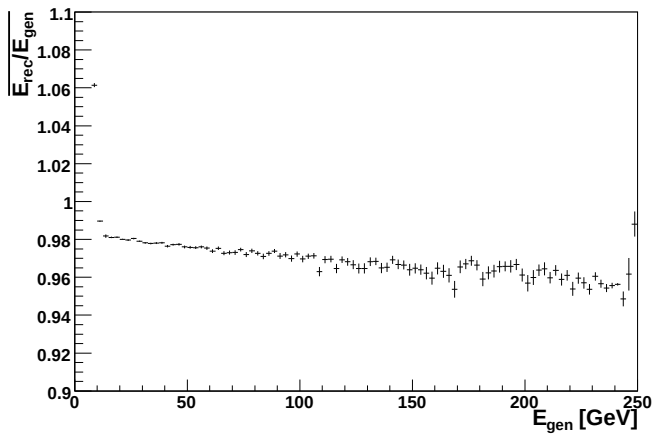
Calibration Issues

Digitisation and Manual Calibration

- One set of calibration constants (MokkaCaloDigi)
- Angular and energy dependance



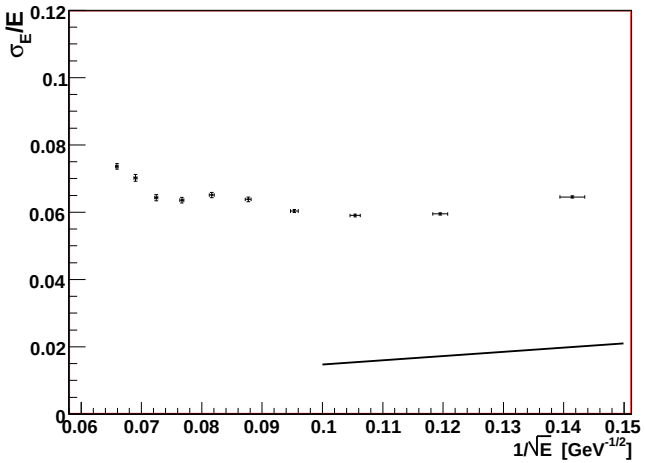


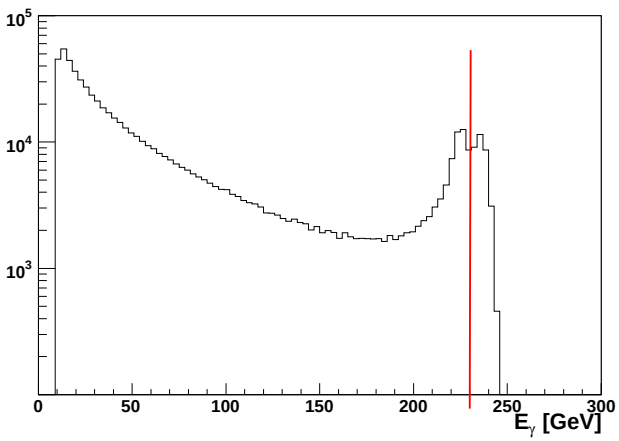


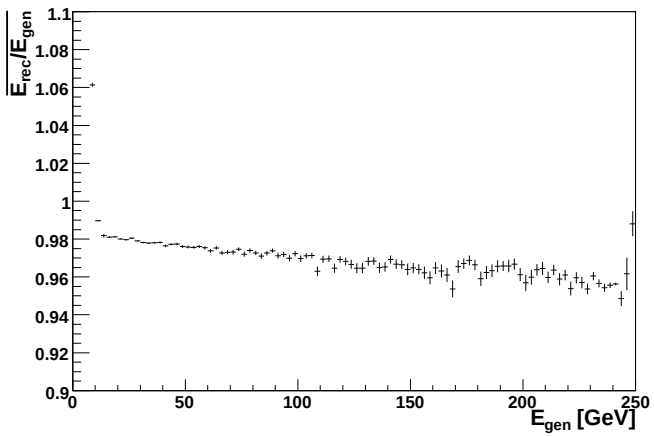
Calibration Issues

Digitisation and Manual Calibration

- One set of calibration constants (MokkaCaloDigi)
- Angular and energy dependance
- Degradation of energy resolution



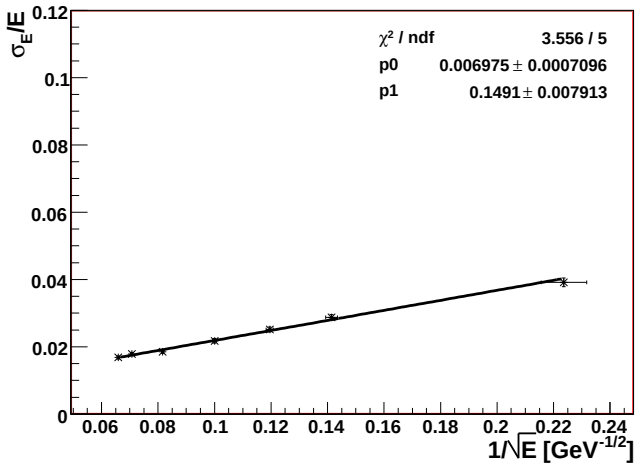


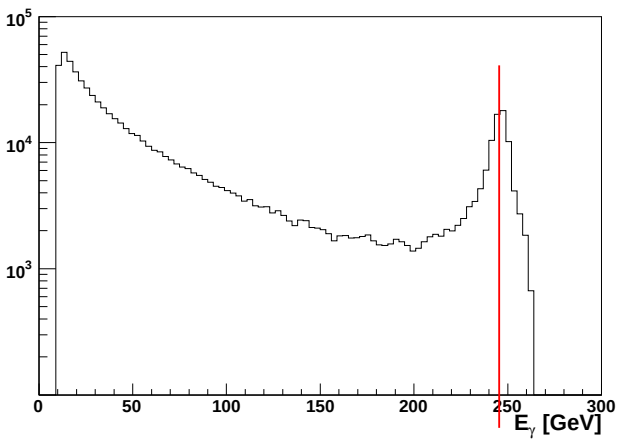


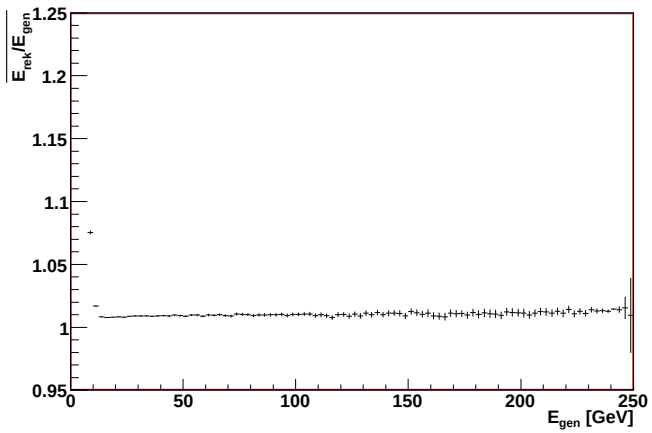
Calibration Issues

Digitisation and Manual Calibration

- Manual calibration
- Barrel, endcaps and transition region





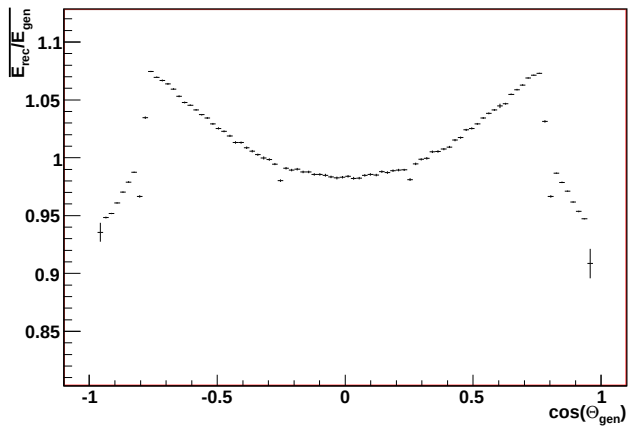


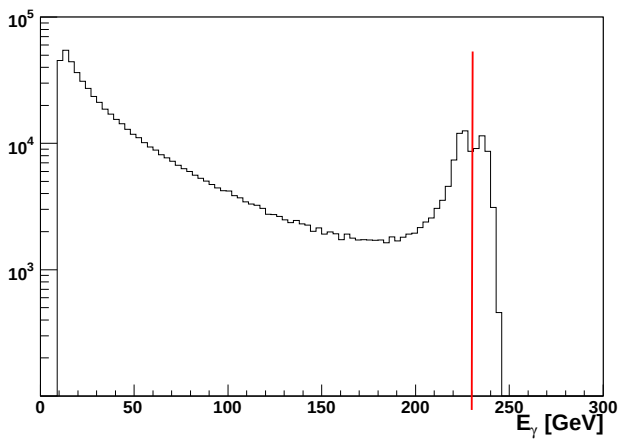
Calibration Issues

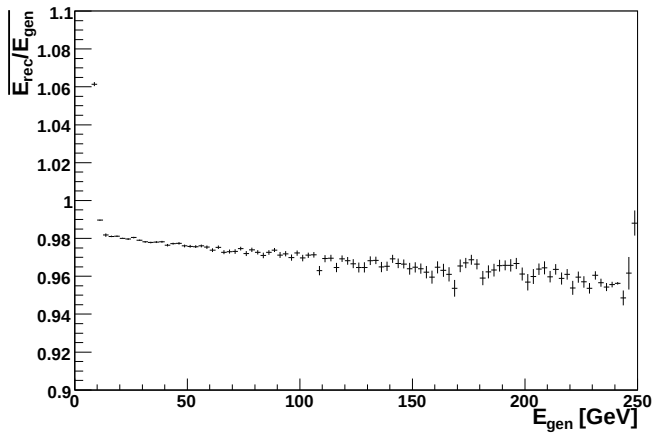
Digitisation and Manual Calibration

LCWS

- One set of calibration constants (MokkaCaloDigi)
- Angular and energy dependance
- Degradation of energy resolution





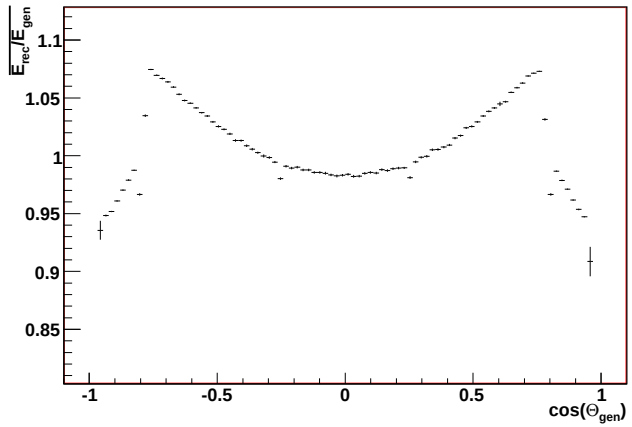


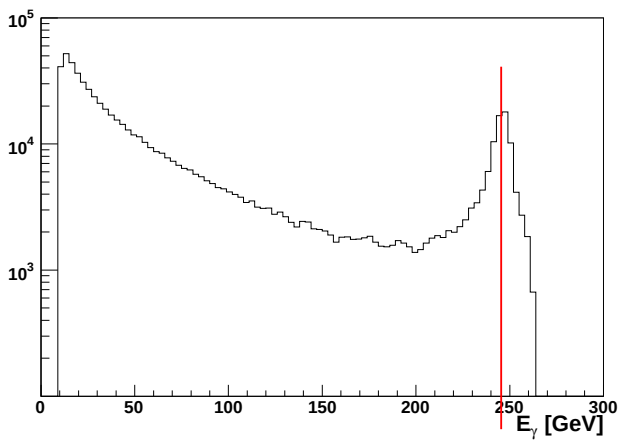
Calibration Issues

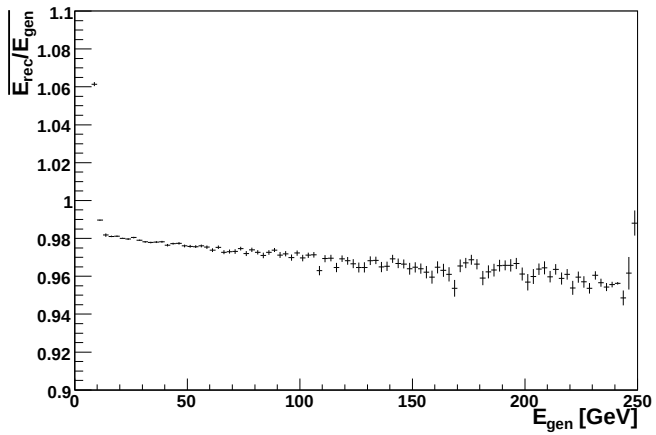
Digitisation and Manual Calibration

Now

- Manual calibration
- Barrel, endcaps and transition region



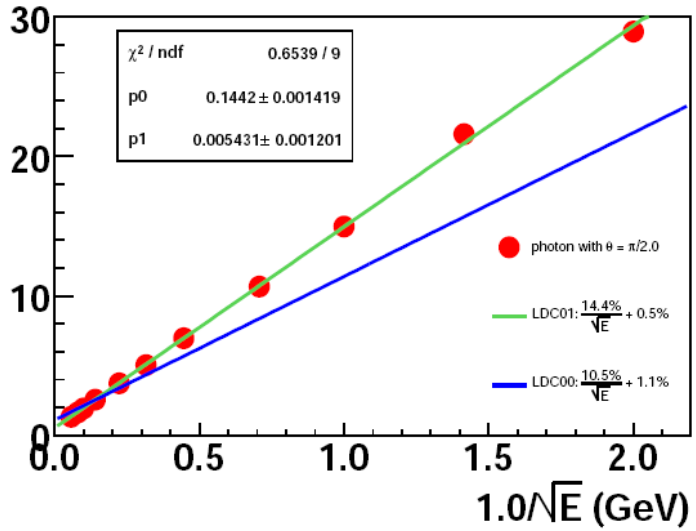


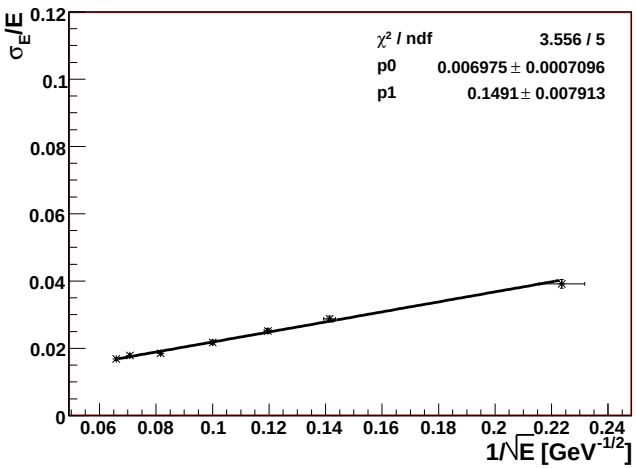


Energy Resolution

Tests with Single Particle Gun

- Aim for energy resolution $\frac{\Delta E}{E} = \frac{14.4\%}{\sqrt{E}}$ (LDC01)
- Test with particle gun
- $20 < \mathrm{E}_\gamma < 240$ GeV at 90°
- Resolution at $\frac{\Delta E}{E} = \frac{14.9\%}{\sqrt{E}}$
- Calibration of simulation for MC events
- Caveat: no reconstruction





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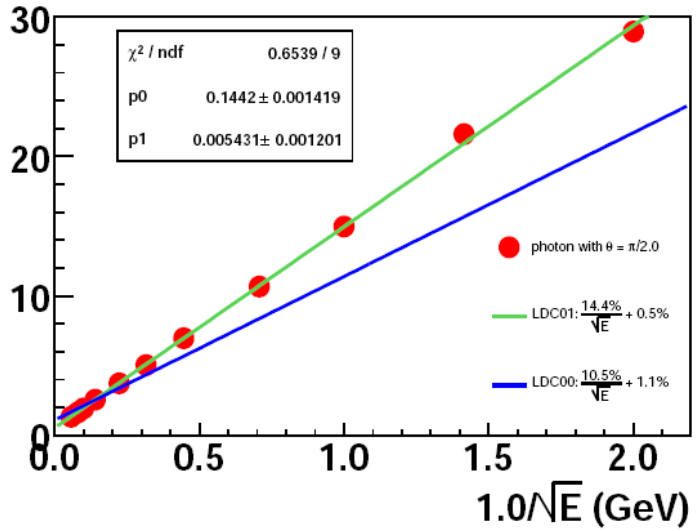
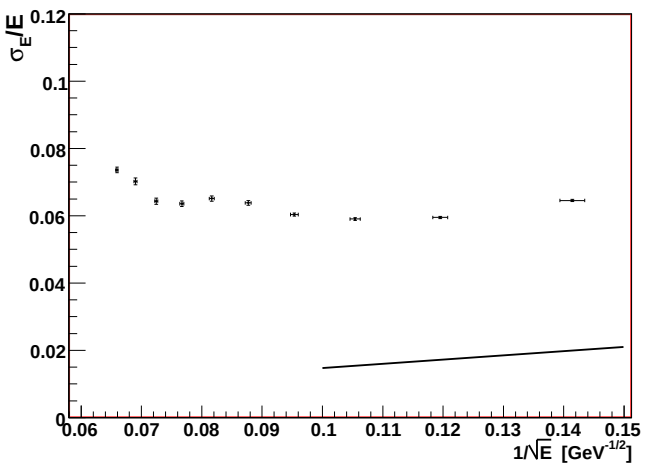
- Calibration of simulation for MC events
- With full event reconstruction
- Try with Photon ID again

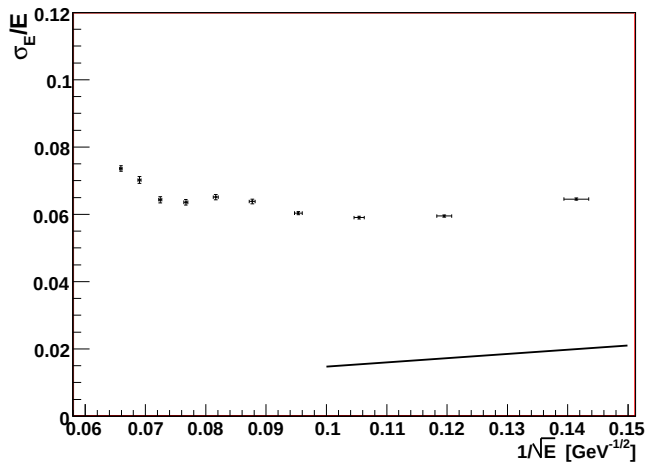




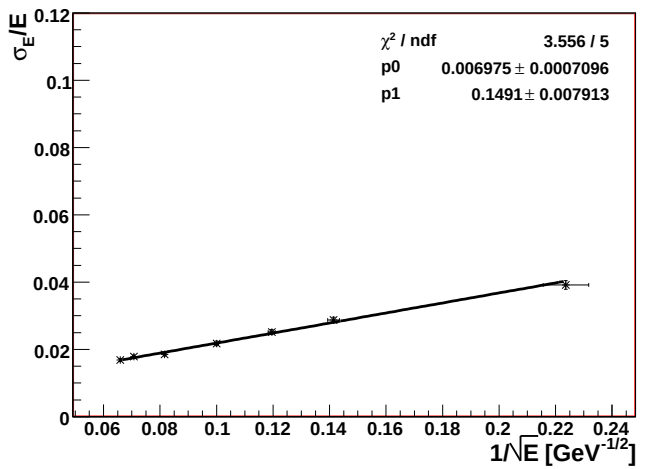
Calibration Issues

Energy Resolution with Full Reconstruction

- Full event reconstrution
- Energy resolution far above $\frac{\Delta E}{E} = \frac{14.4\%}{\sqrt{E}}$
- Wrong calibration constants
- Cluster splitting



- Tests with particle gun
- $20 < \mathrm{E}_\gamma < 240$ GeV at 90°
- Caveat: no reconstruction
- Try with Photon ID next



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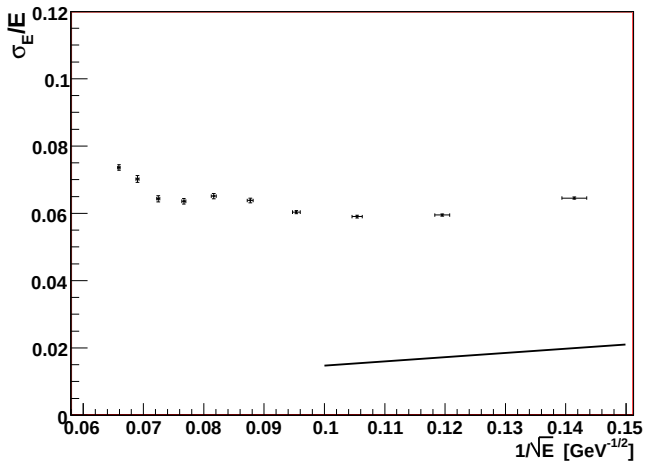

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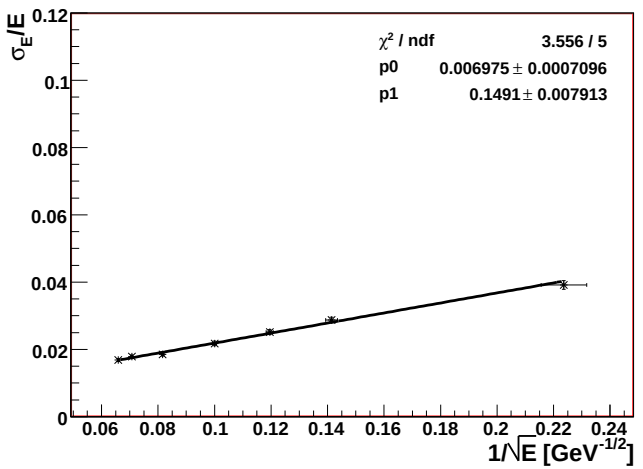


SUSY and Single Photon Events

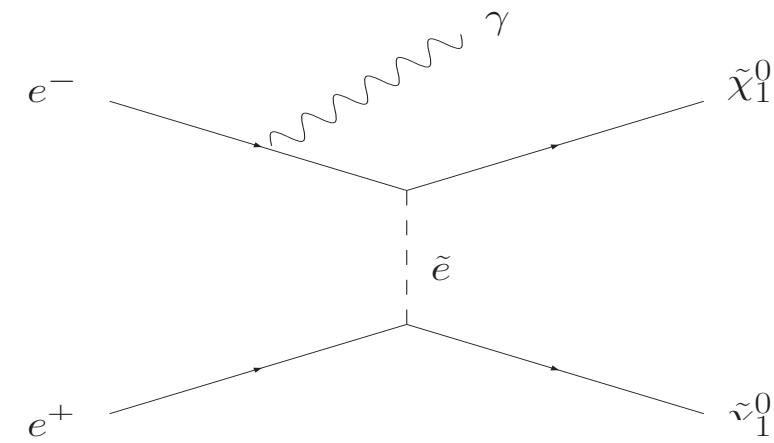
Supersymmetry

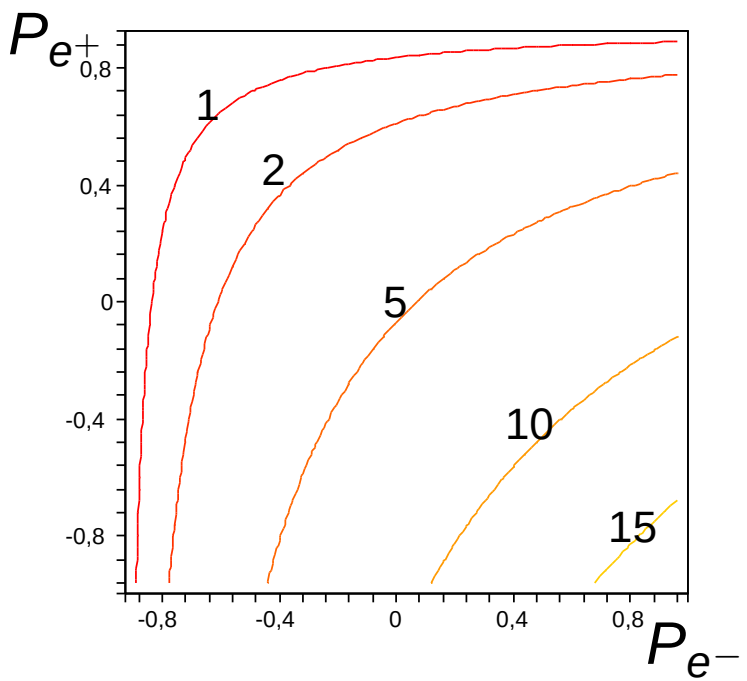
SUSY:

- Extension to Standard model (SM)
- Predicts superpartners
- Grand unification possible
- DM candidates: $\tilde{\chi}_1^0$ or $\tilde{G}$

Single photon events:

- Radiative neutralino production
- Only kinematicly allowed process, if other SUSY masses > $\sqrt{s}/2$





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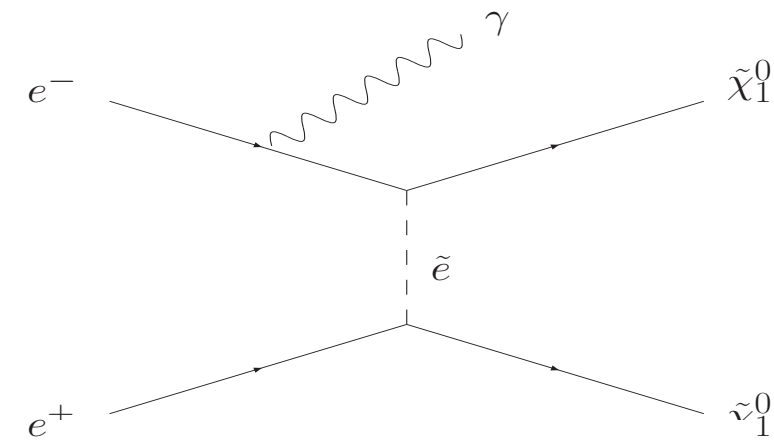

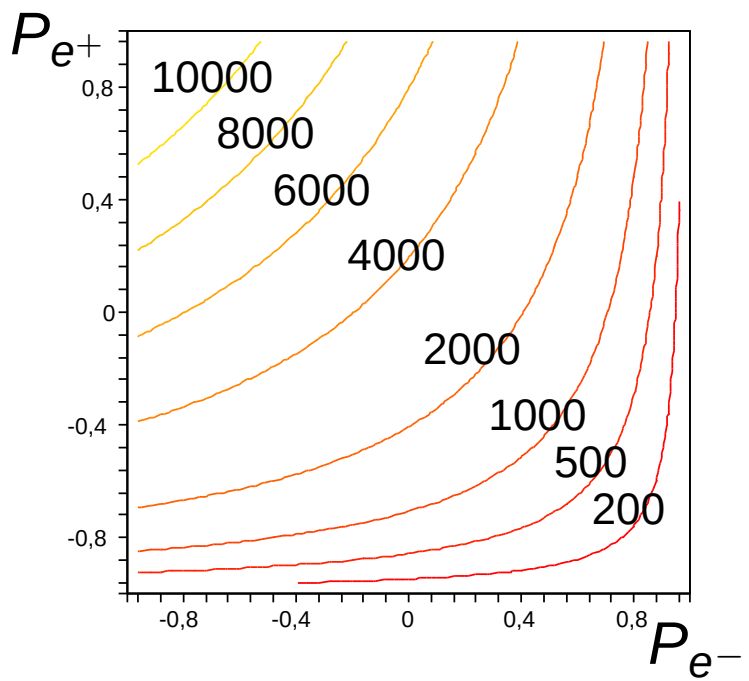

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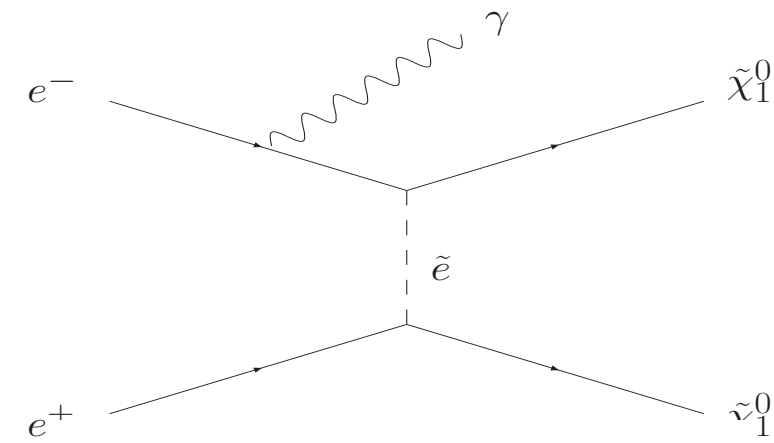
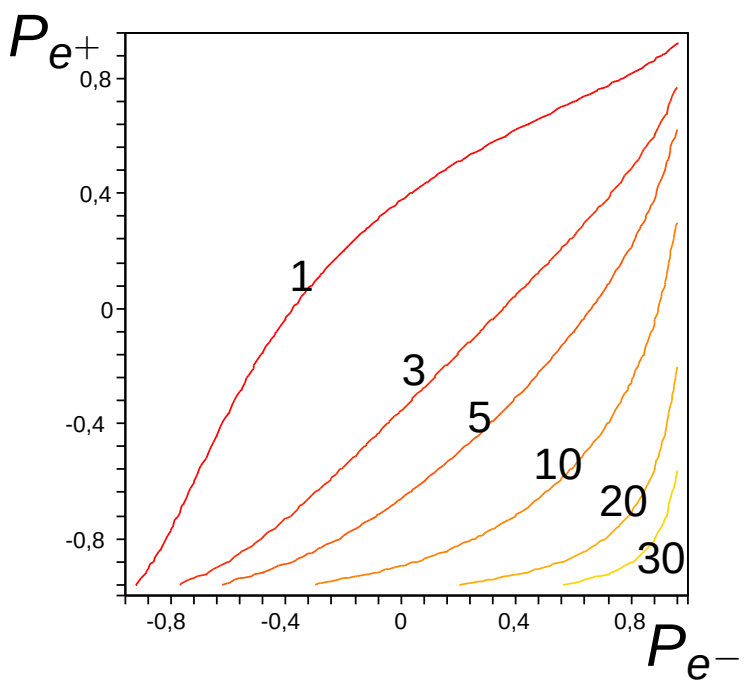




Summary

Conclusions

- Single photon events are an interesting BSM signal as well in model-independent DM scenarios and SUSY
- LDC Optimisation effort can benefit from single photon events
- Model-independent WIMP search possible at ILC
- Polarisation very important
- $\tilde{\chi}_1^0\tilde{\chi}_1^0\gamma$ gives highest accessible mass range for $\tilde{\chi}_1^0$ up to $m_{\chi_1^0} \simeq \sqrt{s}/2$

Summary

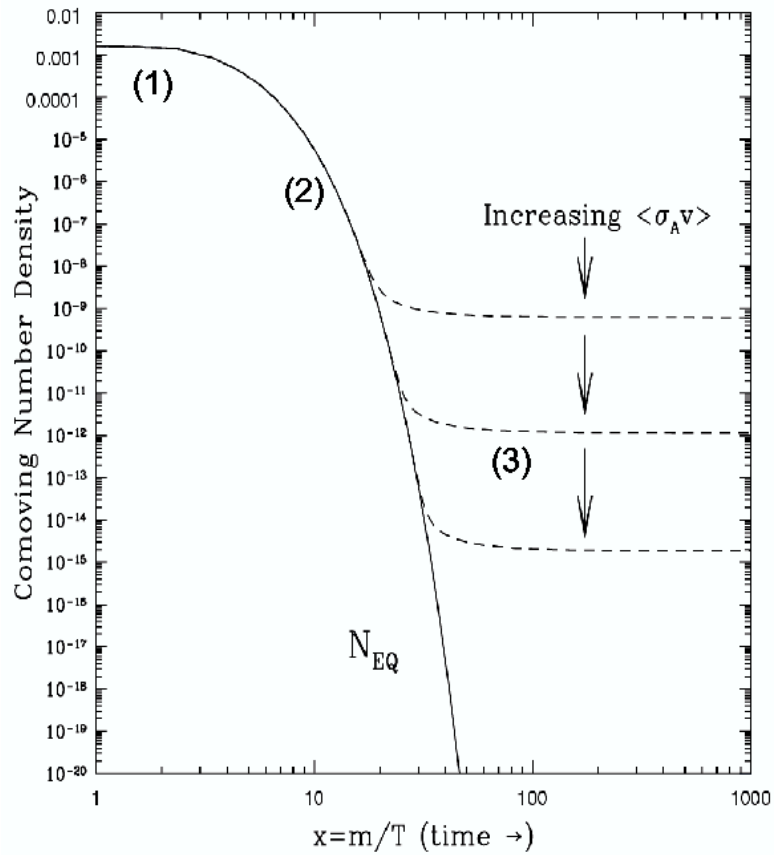
Things to Come

- Inclusion of other SM backgrounds
- Use new LDC and ILD detector simulations
- Comparison of different detector designs
- Analysis of SUSY scenario

WIMPs and Single Photon Events

From Cosmology to ILC

- DM as thermal relic
  $n \sim e^{-m_\chi/kT}$
- Expansion of universe $\rightarrow$ 'freezeout'
- Crossing symmetry:
  $\frac{\sigma(\chi\chi \rightarrow e^- e^+)}{\sigma(e^- e^+ \rightarrow \chi\chi)} = 2\frac{v_e^2(2S_e+1)^2}{v_\chi^2(2S_\chi+1)^2}$
- Emission of photon



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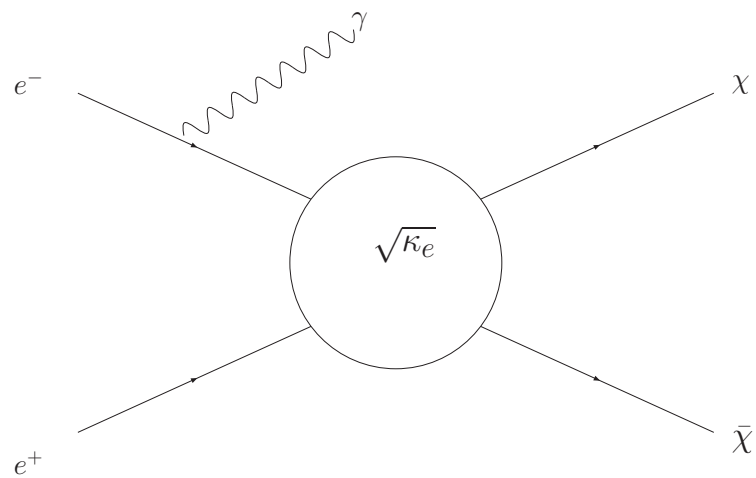

Cross section for $e^+e^- \rightarrow \chi\chi\gamma$

- Model independent
- Parameter: annihilation fraction to electrons κ_e