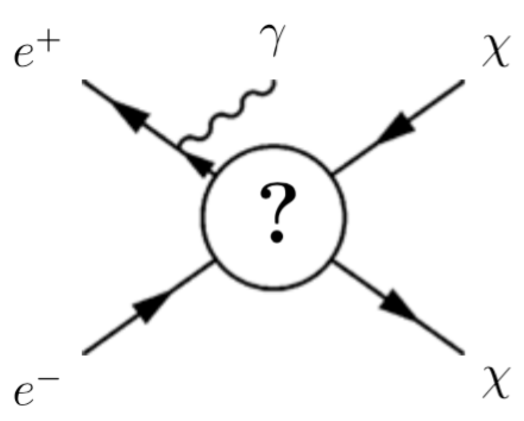
Beam Spectrum, Bhabha Veto & Photon Reconstruction for Mono-photon Analysis

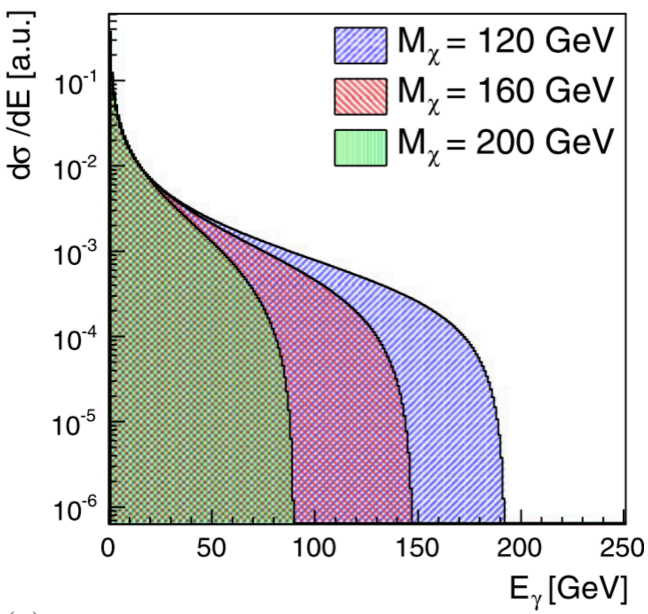
Moritz Habermehl, Jenny List (DESY)
& Tomohiko Tanabe (U. Tokyo)

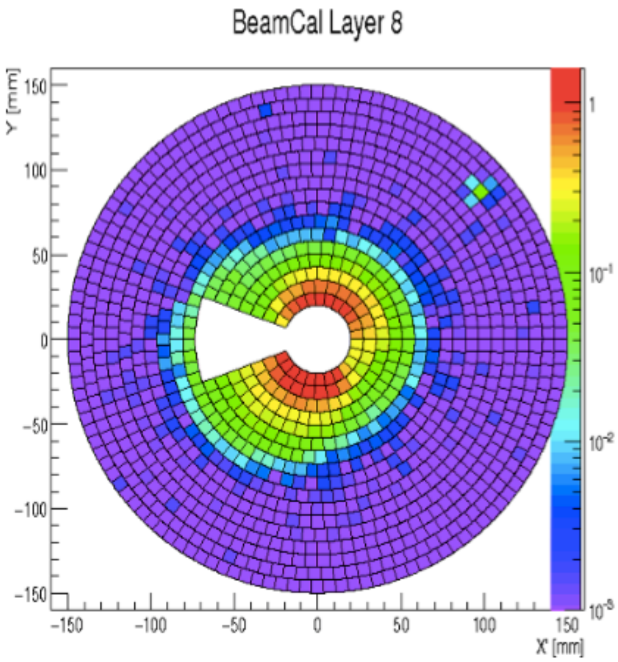
November 3, 2015
LCWS2015 @ Whistler
[Simulation, Detector Performance, Reconstruction]

Outline

1. **Introduction and current status**
2. Reconstructing beam energy spectrum from beam parameters
3. Bhabha veto with BeamCal
4. Event generator issues
5. Photon reconstruction with newly-tuned PandoraPFA







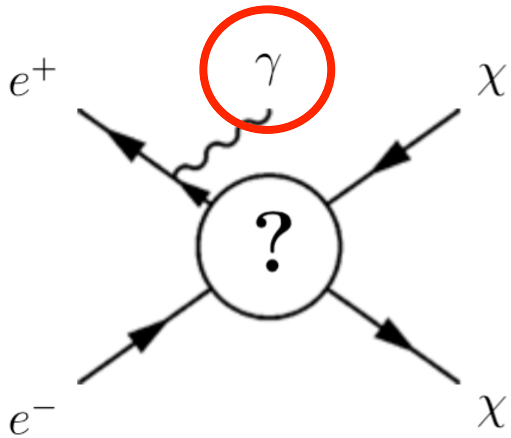
WIMP search at ILC

Weakly Interacting Massive Particles (WIMPs):

- dark matter candidates
- collider searches complementary to direct detection

At ILC, search for WIMP pair production tagged by

- an initial state radiation (**ISR**) photon
- missing energy + missing momentum



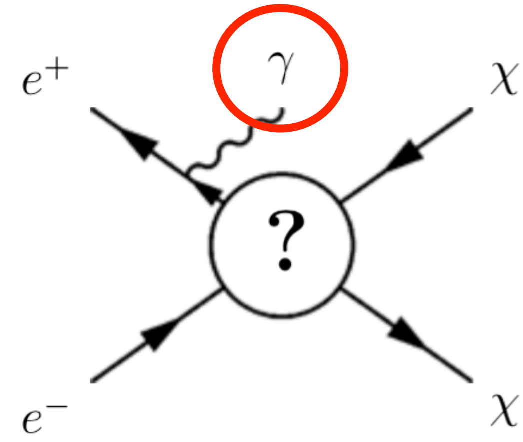
i.e. **Search for mono-photon events**

Observables: $\mathbf{E_\gamma}$, $\mathbf{\theta_\gamma}$

Significance in ILC physics case:

Mono-photon search is relevant in *every* (non-) discovery scenario of the LHC

Signal and Backgrounds



Signal

WIMP pair production with ISR photon

e+ e- → DM DM **γ**

Selection of single, energetic photon.

Backgrounds

Radiative neutrino production

e+ e- → ν ν **γ**

→ ν ν **γ γ** …

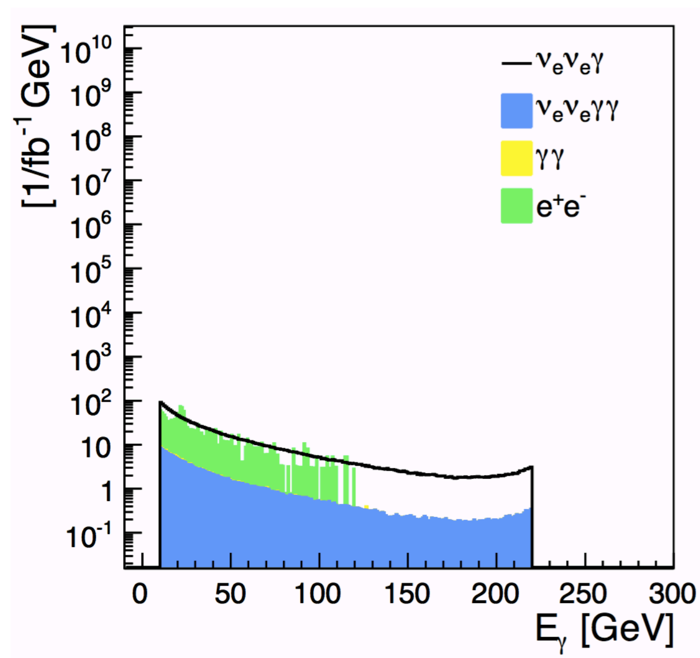
Contribution will be known / can be calibrated.

Bhabha scattering

e+ e- → e+ e- **γ**

where the electrons go down the beam pipe undetected.

Coverage of forward detectors crucial.



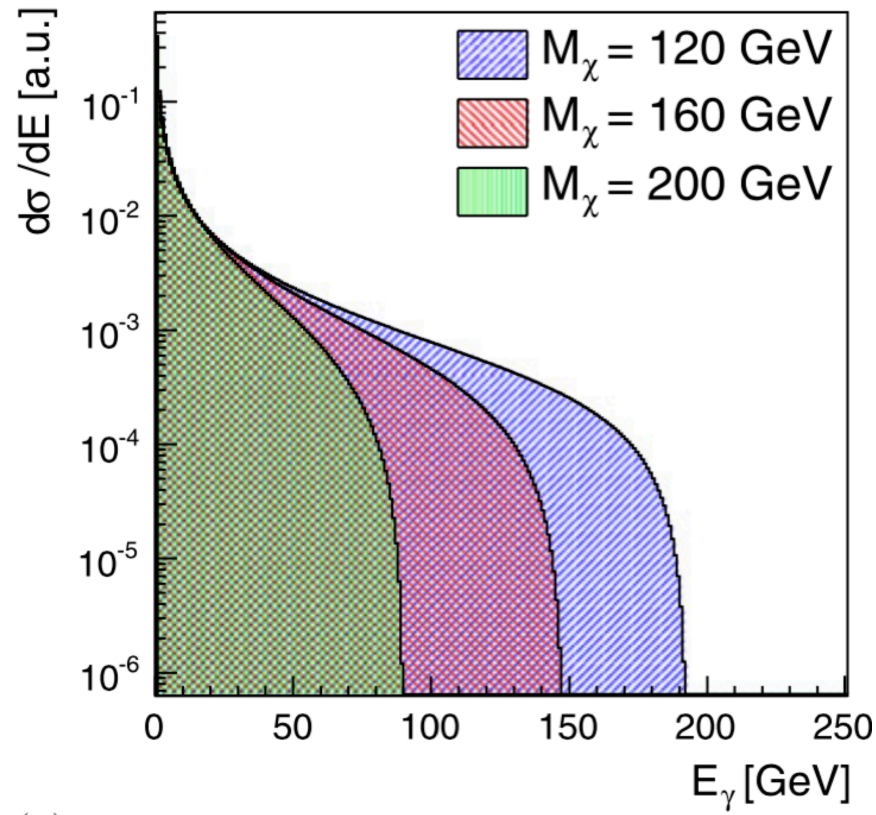
[C.Bartels, Ph.D. Thesis at DESY]

Status of Simulation

Geant4-based full simulation study

- Publication:
  C. Bartels, M. Berggren, J. List, EPJC 72:2213 [arXiv:1206.6639]

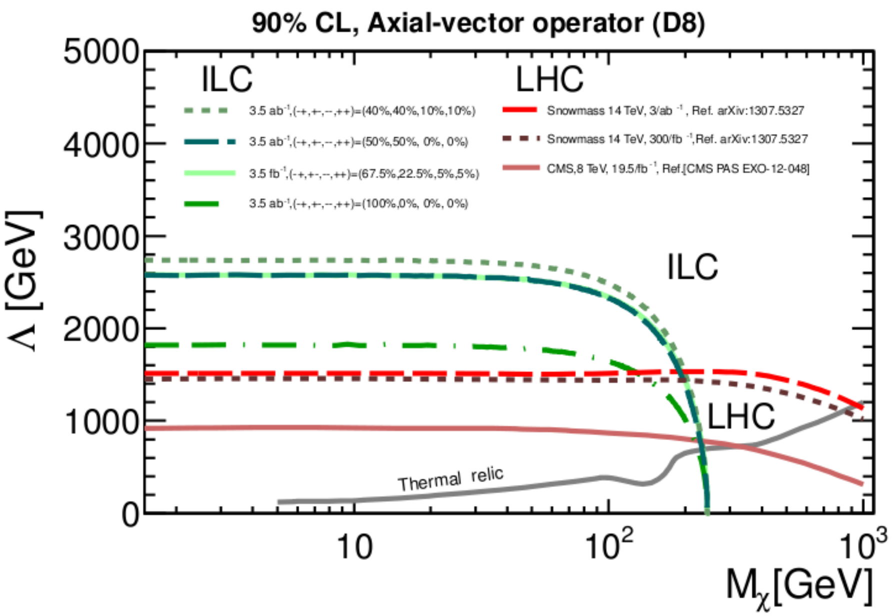
- $\sqrt{s}$ = 500 GeV
- 1 GeV < M_{WIMP} < 250 GeV
- WHIZARD 1.96
- ilcsoft v01-06
- Beam parameters: RDR
- Detector models:
  LDC_PrimeSc_02, ILD_00



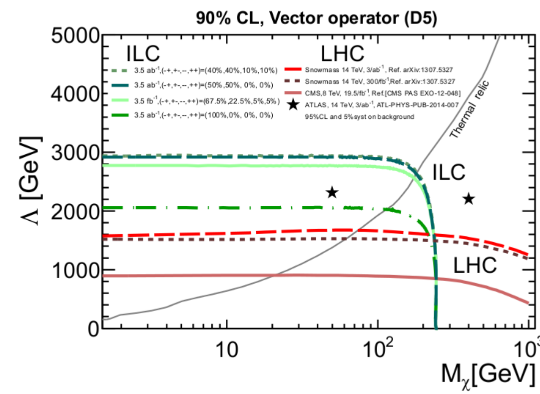
Update plan:

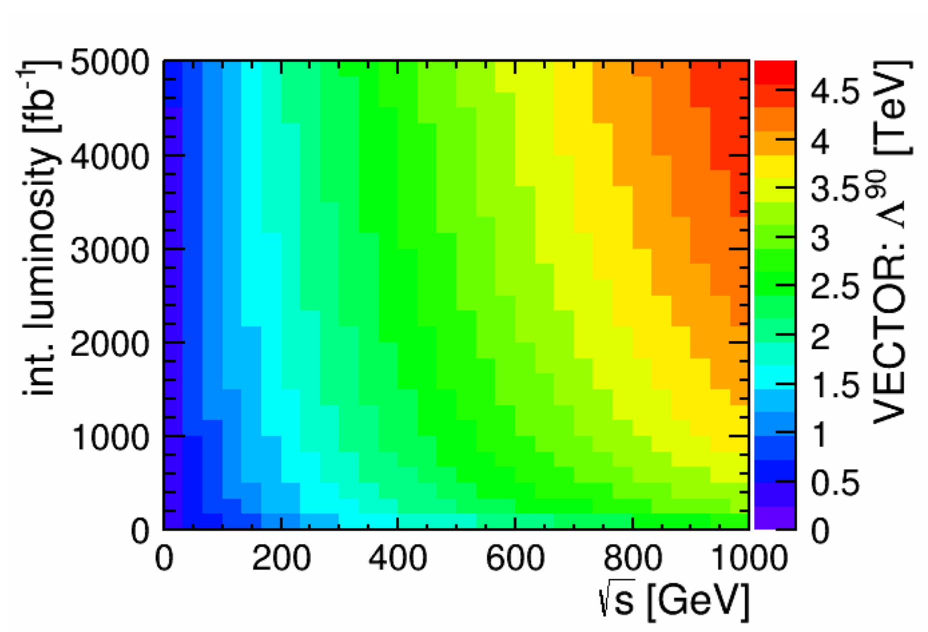
- Other $\sqrt{s}$, WHIZARD 2, latest software tools,
  TDR parameters, ILD_v1_o5 model

Application: Effective Operators

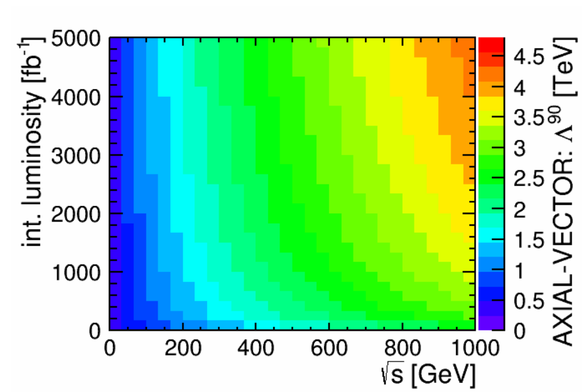


Interpretation in terms of effective operators
[A. Chaus, J. List, M. Titov]





Extrapolation to other √s
[M. Habermehl, J. List]
See: AWLC2015 talk by Habermehl



Systematic Uncertainties

The systematic uncertainties were estimated as follows

- Luminosity: $\delta L/L = 0.11\%$
- Polarization: $\delta P/P = 0.25\%$ per beam
- Photon reconstruction efficiency: $\delta\varepsilon/\varepsilon = 0.15\%$
  - with control sample e+e- → μμγ

- **Beam energy spectrum: $\delta E/E = 0.5\sim1.5\%$**
  - **accounting full difference between RDR and SB2009 shapes**
  - **a conservative choice, but this is the dominant effect (!)**

Shape information is also beneficial for phenomenological studies.

At $\sqrt{s}$=500 GeV, Lumi=500 fb-1, the statistical uncertainty becomes comparable to the total systematic uncertainty.

→ **Improving the beam energy spectrum systematics crucial**

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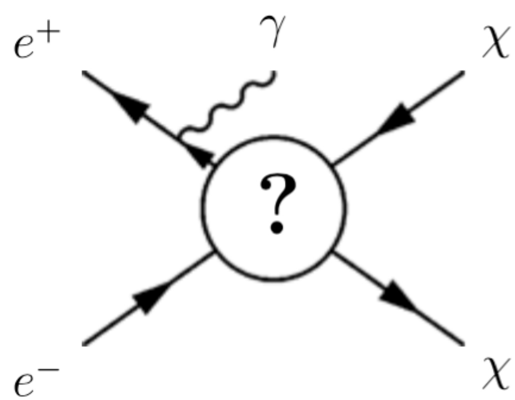
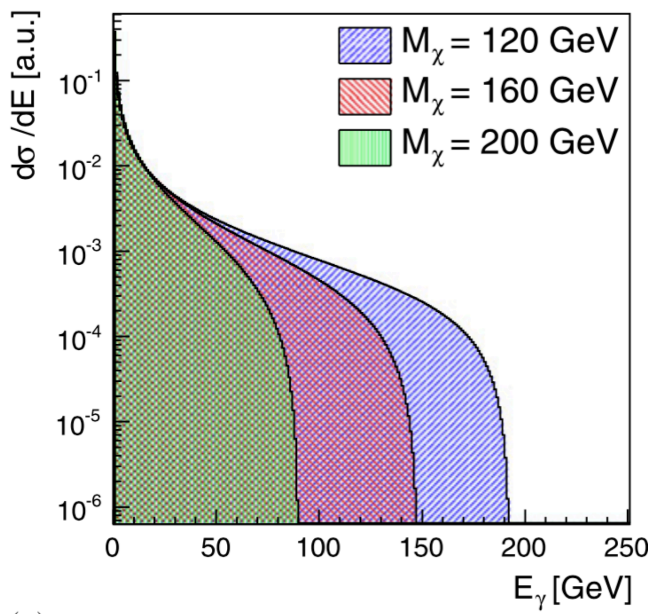
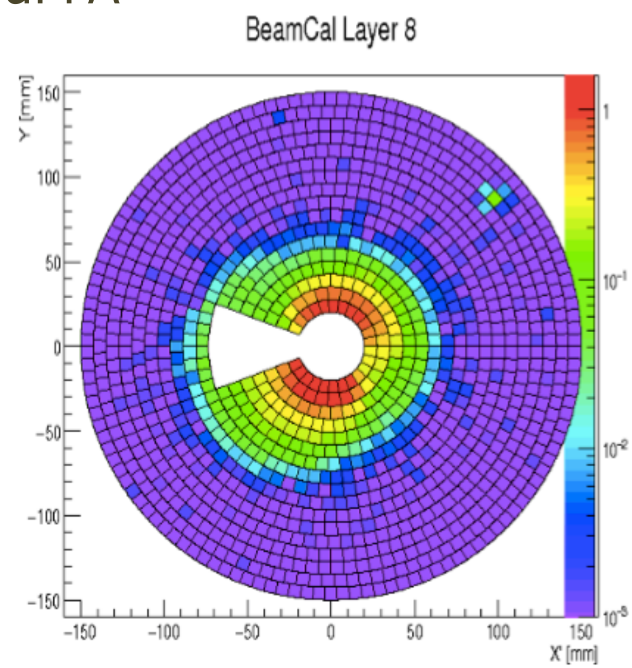
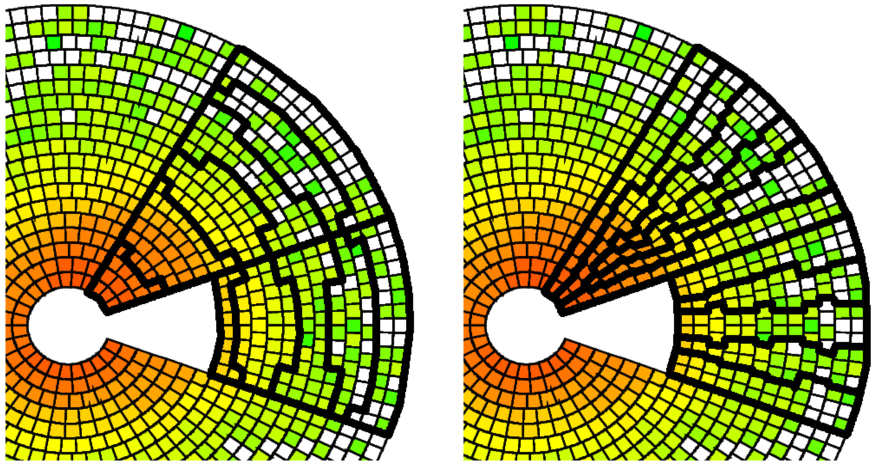






Beam Energy Spectrum Reco.

[Ch. Grah, A. Sapronov, JINST 3 (2008) P10004]
Beam parameter determination from beamstrahlung photons & incoherent e+e- pairs hitting the BeamCal (and GamCal)
→ Reconstruction of beam parameters from data



[N. Ruof, M. Habermehl, J. List]
Study impact of varying beam parameters on the beam energy spectrum.
→ Method to reconstruct beam energy spectrum from the measured beam parameters including errors.
→ To be compared with Bhabha method by S. Poss & A. Sailer
→ Feed to study of systematic uncertainty in mono-photon analysis

Beam Parameters

[N. Ruof, M. Habermehl, J. List]

Beam Parameters that were studied:

- **N** : number of particles per bunch
- **σ_x, σ_y, σ_z** : bunch size
- **ε_x, ε_y** : emittance
- **W_x, W_y** : waist shifts

Formulas for head-on collision with Gaussian beams:

Luminosity
$$\mathcal{L} = f_{\mathrm{rep}} \frac{n_b N^2}{4\pi\sigma_x\sigma_y}$$

Energy loss from beamstrahlung
$$\delta_{\mathrm{BS}} \propto \frac{N^2}{\sigma_z(\sigma_x + \sigma_y)^2}$$

Using **GuineaPig** simulations, it was determined that

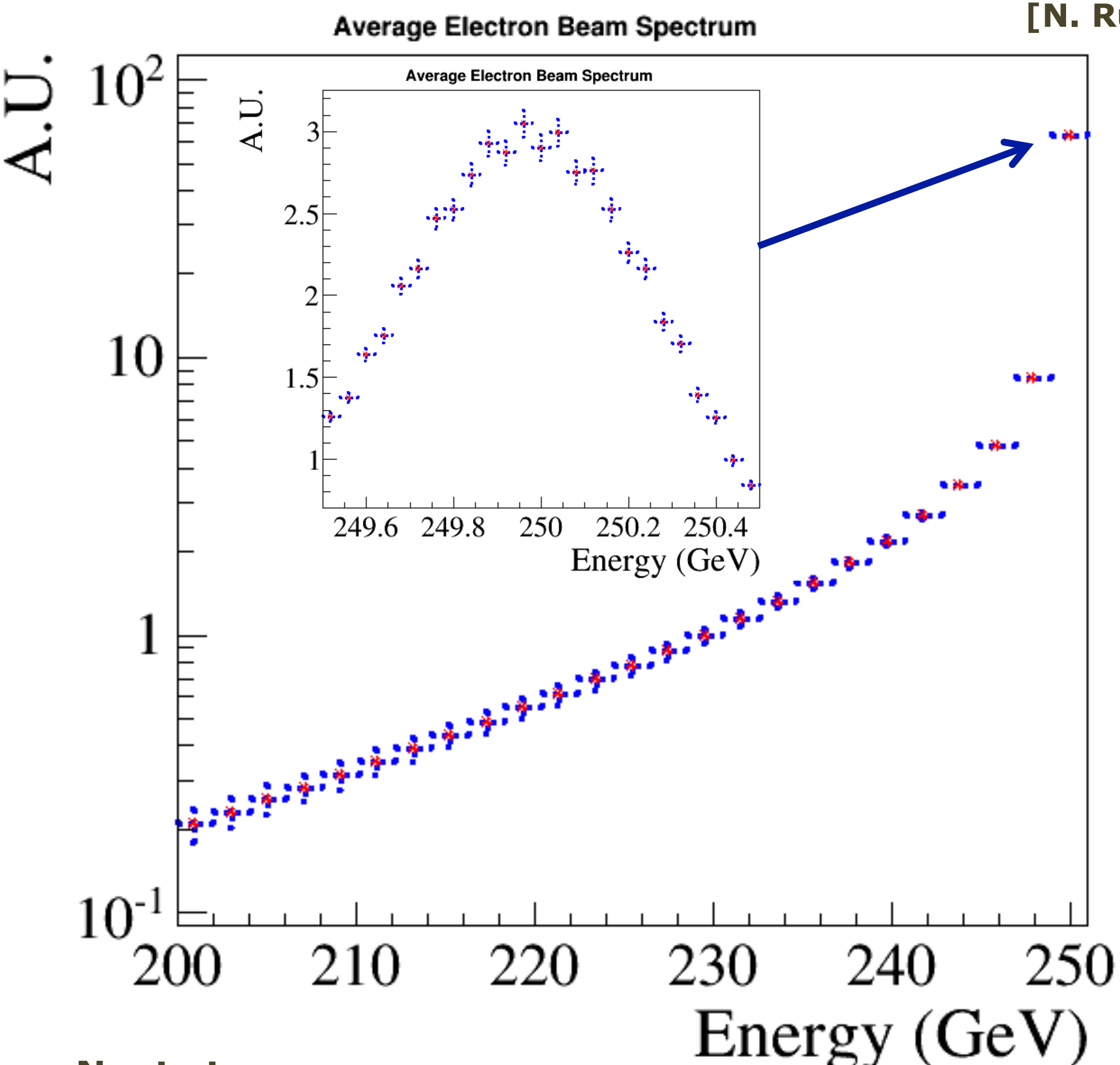
Luminosity is affected by: **N, σ_x, σ_y, ε_x, ε_y, W_y**

Energy loss is affected by: **N, σ_x, ε_x**

Interest in beam energy spectrum shape and not overall normalization

→ Vary **N, σ_x, ε_x** ; fix all other parameters to nominal values

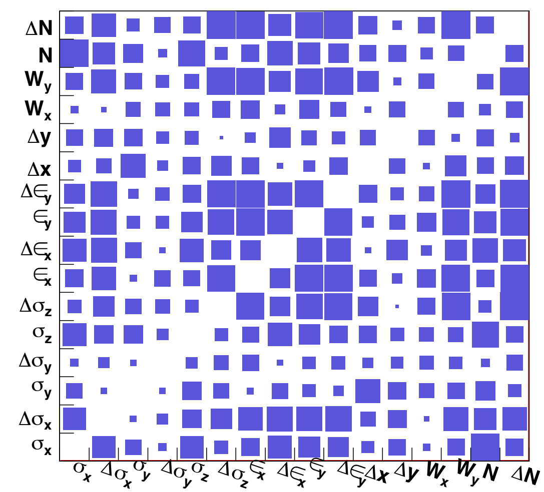
[N. Ruof, M. Habermehl, J. List]



Based on 200 GuineaPig simulations around DBD parameters.

Variation of beam parameters within the errors obtained by Grah & Sapronov (assumes presence of GamCal).

Includes full correlations:



Next steps:

- Provide reweighting functions for use in other studies
- Comparison with Bhabha method (S. Poss, A. Sailer)

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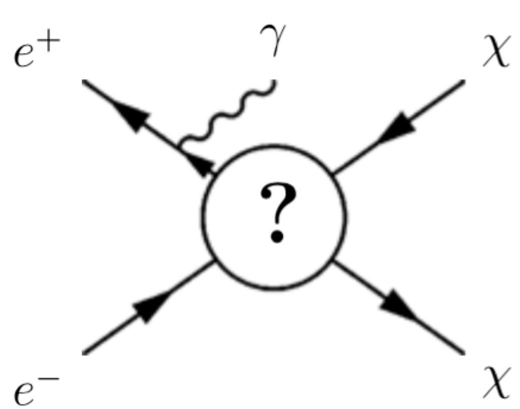
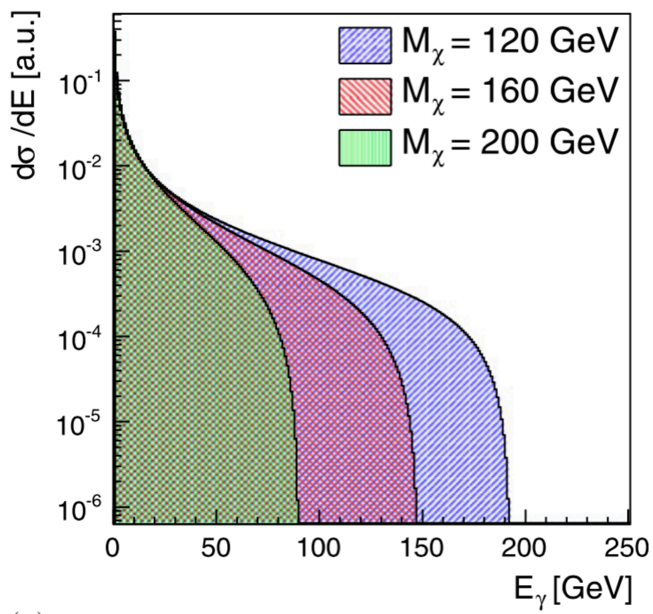
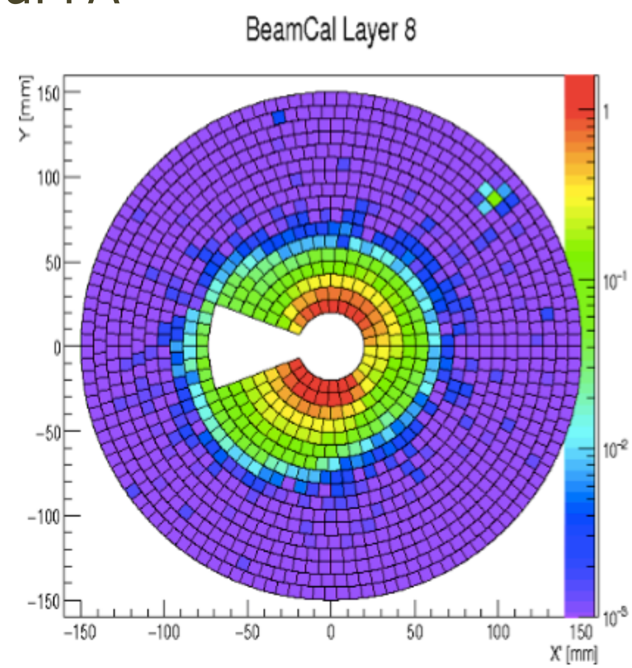






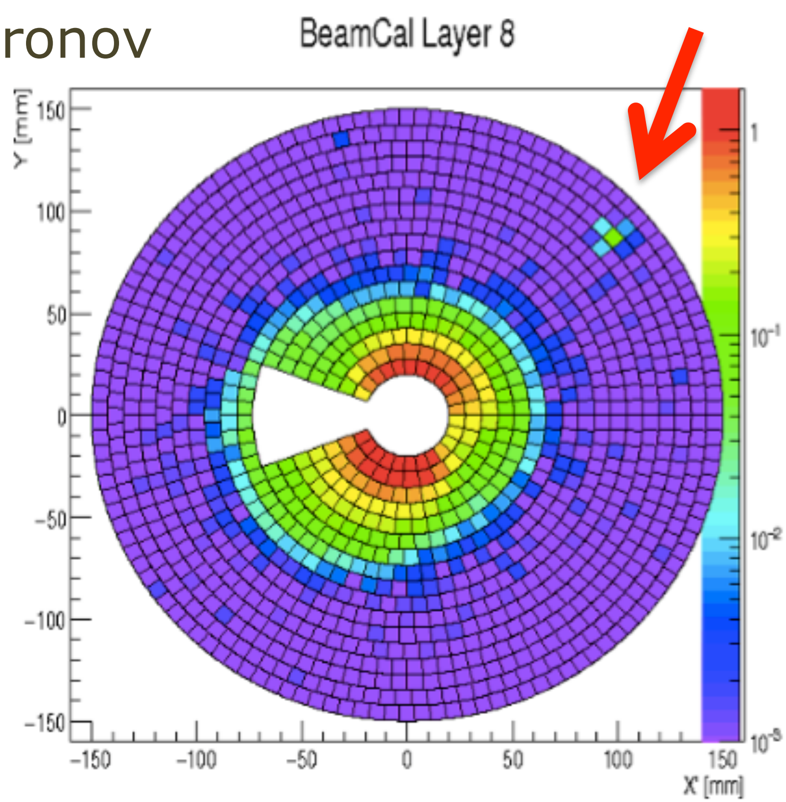
BeamCal Reconstruction

[M. Habermehl]

Bhabha veto is crucial for mono-photon searches.
Necessary to harness full information of BeamCal for these very forward events.

BeamCal reconstruction:
- Marlin processor: BeamCalClusterReco
- Developed by A. Sailer and A. Sapronov for CLIC
- Improved reconstruction, with control of fake rates

Optimization for ILC ongoing:
- Pair backgrounds overlaid
- TDR beam parameters
- $\sqrt{s}$ = 500 GeV



BeamCal Reconstruction

[M. Habermehl]

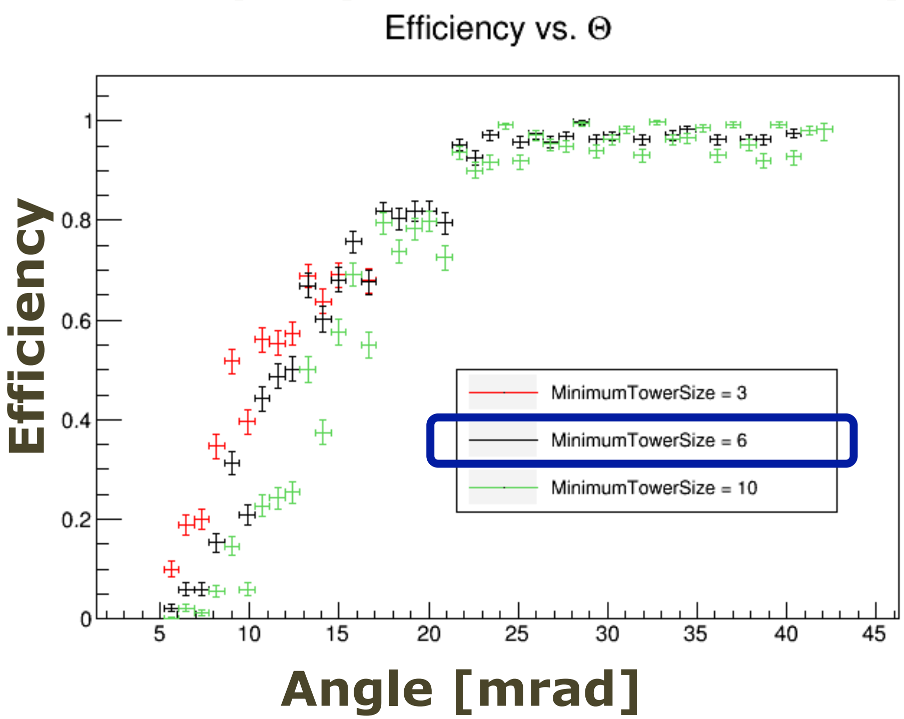
Optimizing for ILC using Particle Gun samples.

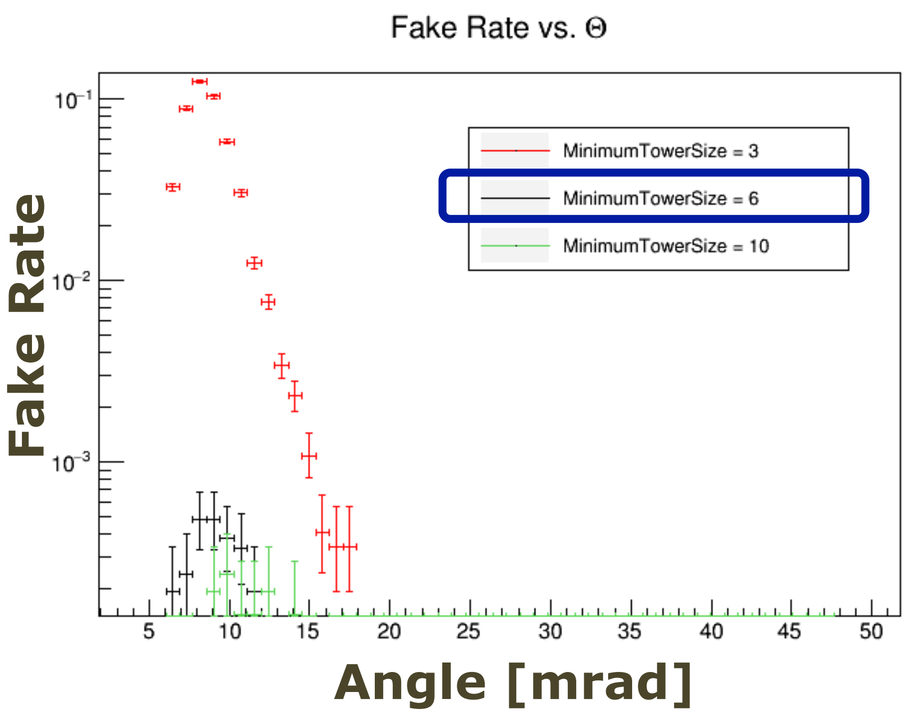
- electrons at 200 GeV → works out of the box
- electrons at 50 GeV → optimization work ongoing

Results for 50 GeV electrons (preliminary):

ETPadMin = 0.01 GeV, MinimumTowerSize = 6,
StartLookingInLayer = 2

Example (MinimumTowerSize):





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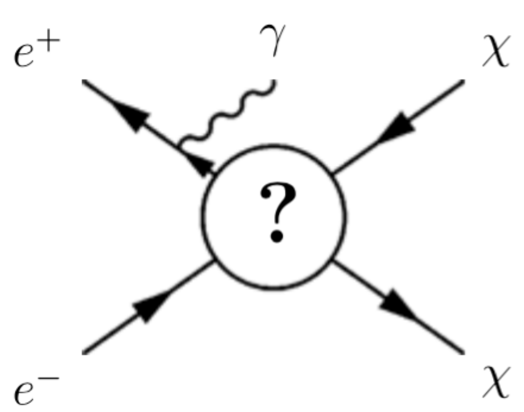

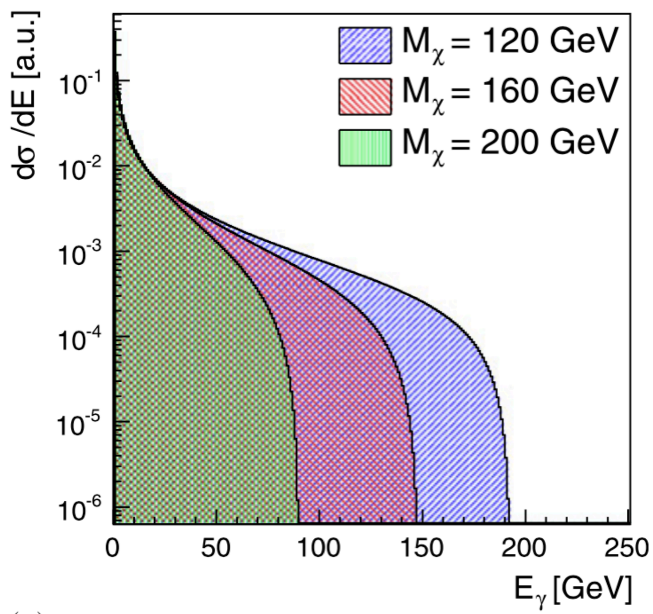

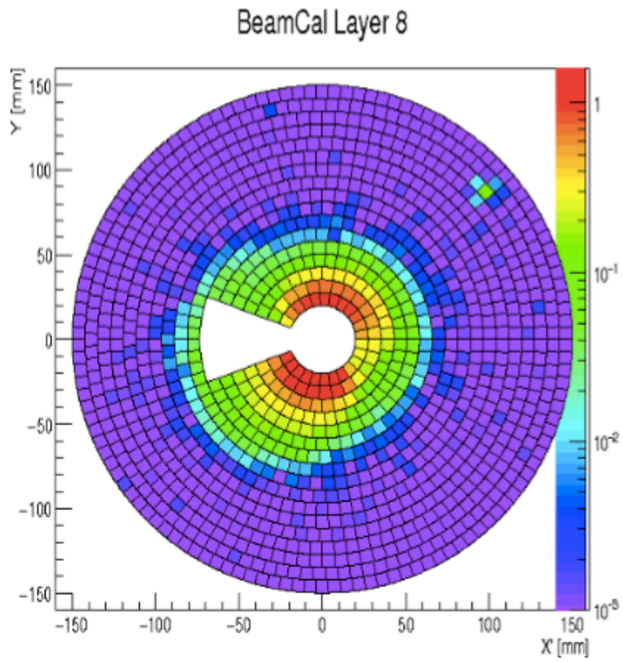

Issues on Event Generators

In the previous study, there was (small) **double-counting of photons**

- Soft ISR photons
- Photons explicitly in matrix element

To be addressed by generating events with photons explicitly in matrix element, with ISR turned off.

Also take advantage of improvements in WHIZARD 2, such as

- CIRCE2 interface, allows **parametrized beam spectrum**
  - will be used for the systematics studies

Other issues:

- **Bhabha scattering:** require generation of new events
  - Hard photon (for ISR tag)
  - Small angle for electron (test BeamCal)
  - To be tested with WHIZARD 2 and compare with other generators e.g. BHWIDE

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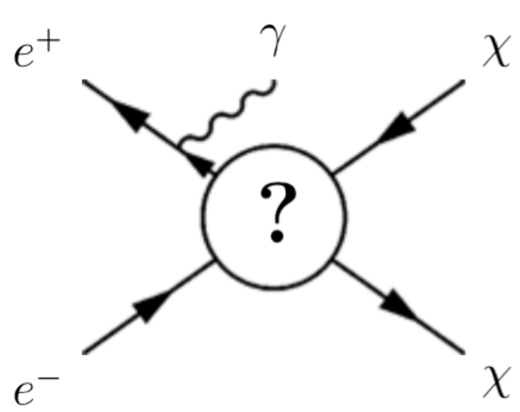
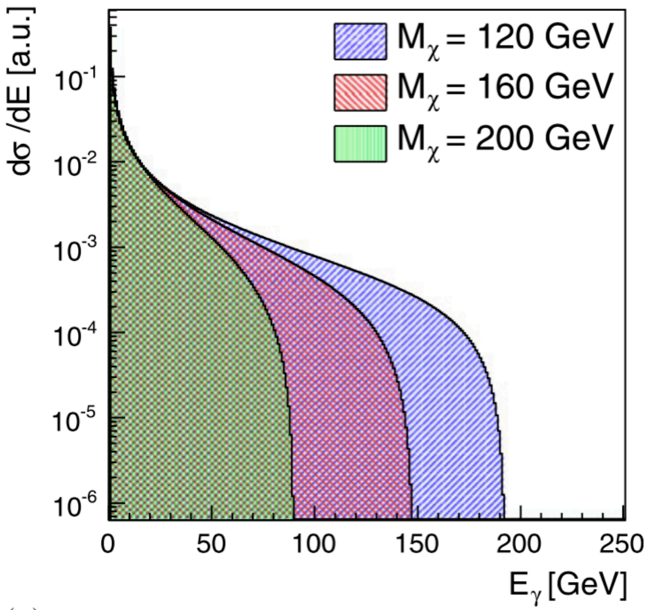
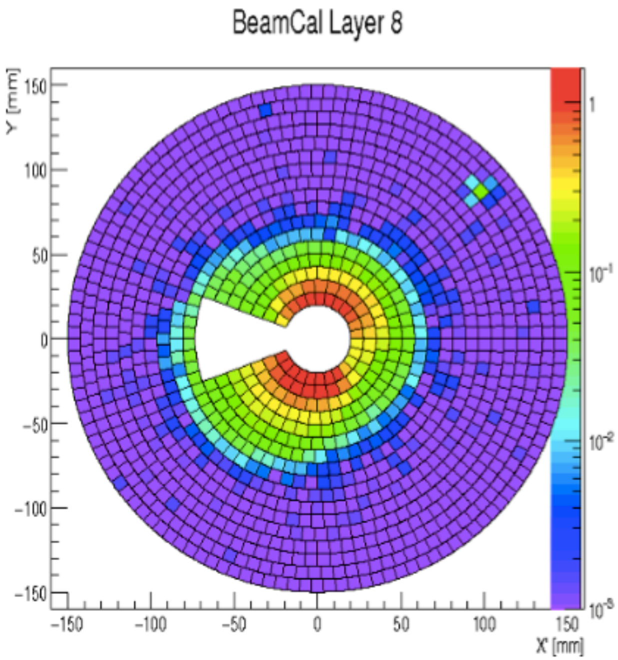






Photon Reconstruction

- First look at photon reconstruction using newly-tuned PandoraPFA
  - Take advantage of the **improved photon fragmentation** (B. Xu)
    - PandoraSettingsDefaultNewPhoton.xml

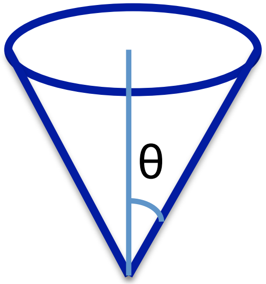
- Tested using e+e- → ννγ sample (WHIZARD 1.95-DBD)
  - $\sqrt{s}$=500 GeV ; P(e-,e+)=(-1,1)
  - Detector simulation: ILD_o1_v05

- Comparison of photon reconstruction:
  1) **v01-16-02** (DBD)
  2) **v01-17-08** (improved photon finding in Pandora)

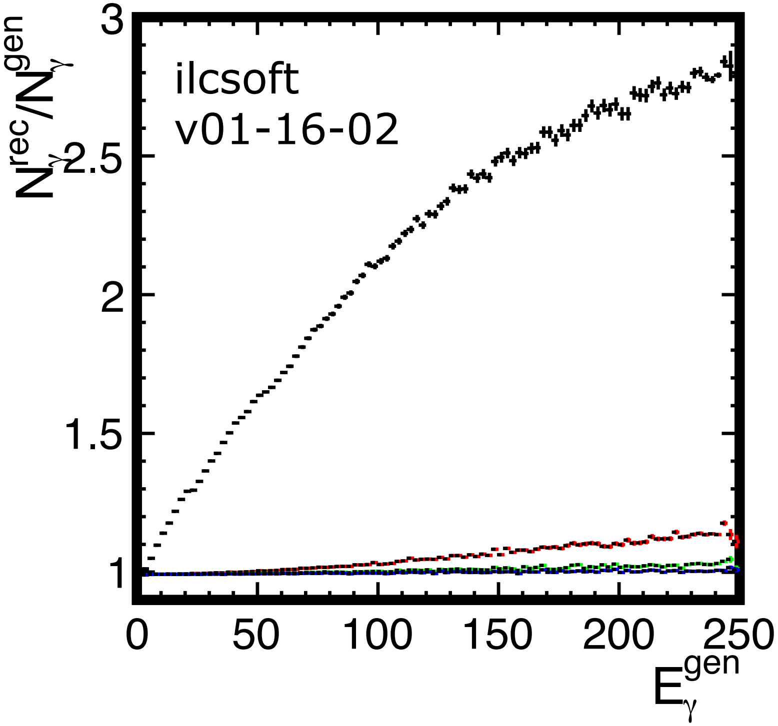
Photon Fragmentation

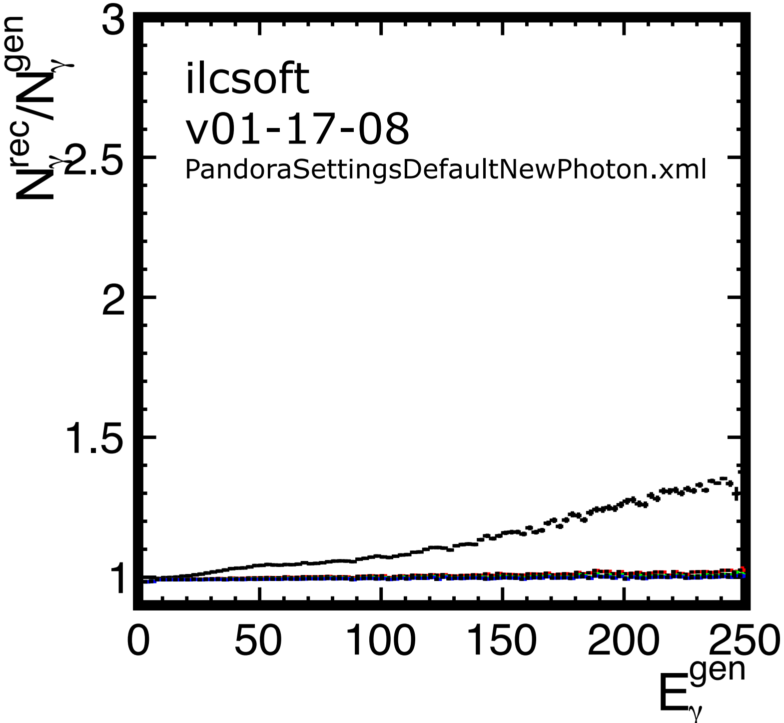
Mono-photons: simple yet relevant environment to test new software

Comparison of number of reconstructed photons vs. number of generated photons (=1 here)



Black: Native PandoraPFOs
(**Red**, **Green**, **Blue**): re-clustering applied with cone angle **cosθ** : (**0.03**, **0.04**, **0.05**)





Improvement in fragmentation seen as expected

→ Impact on photon energy resolution is now being studied.

Summary

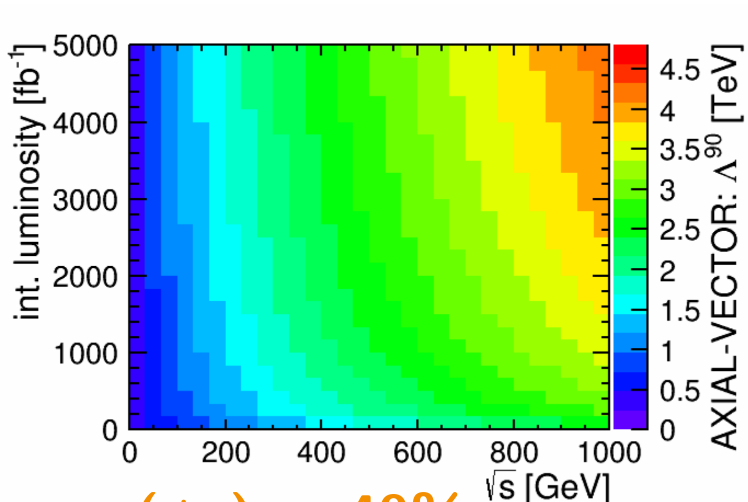
Update of mono-photon analysis is ongoing, motivated by the ILC physics case and recent surge of new tools.

A range of software-related issues, relevant for (but not limited to) mono-photon analysis, is being investigated, including:

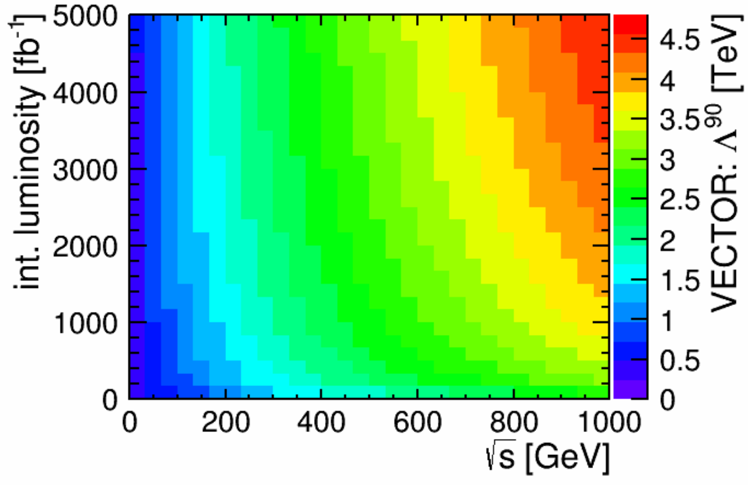
- New method to reconstruct the **beam energy spectrum** using beam parameters was developed.
  - To be used to control the beam spectrum **systematics**.
- **BeamCal reconstruction**, developed for CLIC, is being optimized for ILC.
  - To be used for **Bhabha veto**
- Issues related to event generators:
  - Improvements by using **WHIZARD2** ; Bhabha considerations
- Testing **photon reconstruction** using the latest tuning of PandoraPFA.

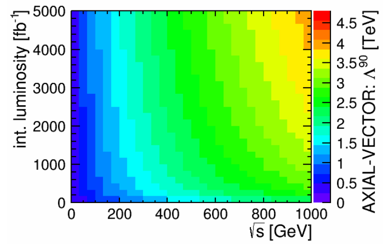
Additional Slides

Λ^{reach} at different $\sqrt{s}$ and integrated luminosities



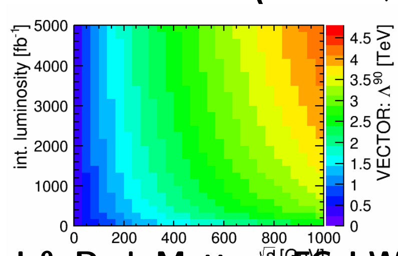
(+-) = 40%





(+-) = 22.5%

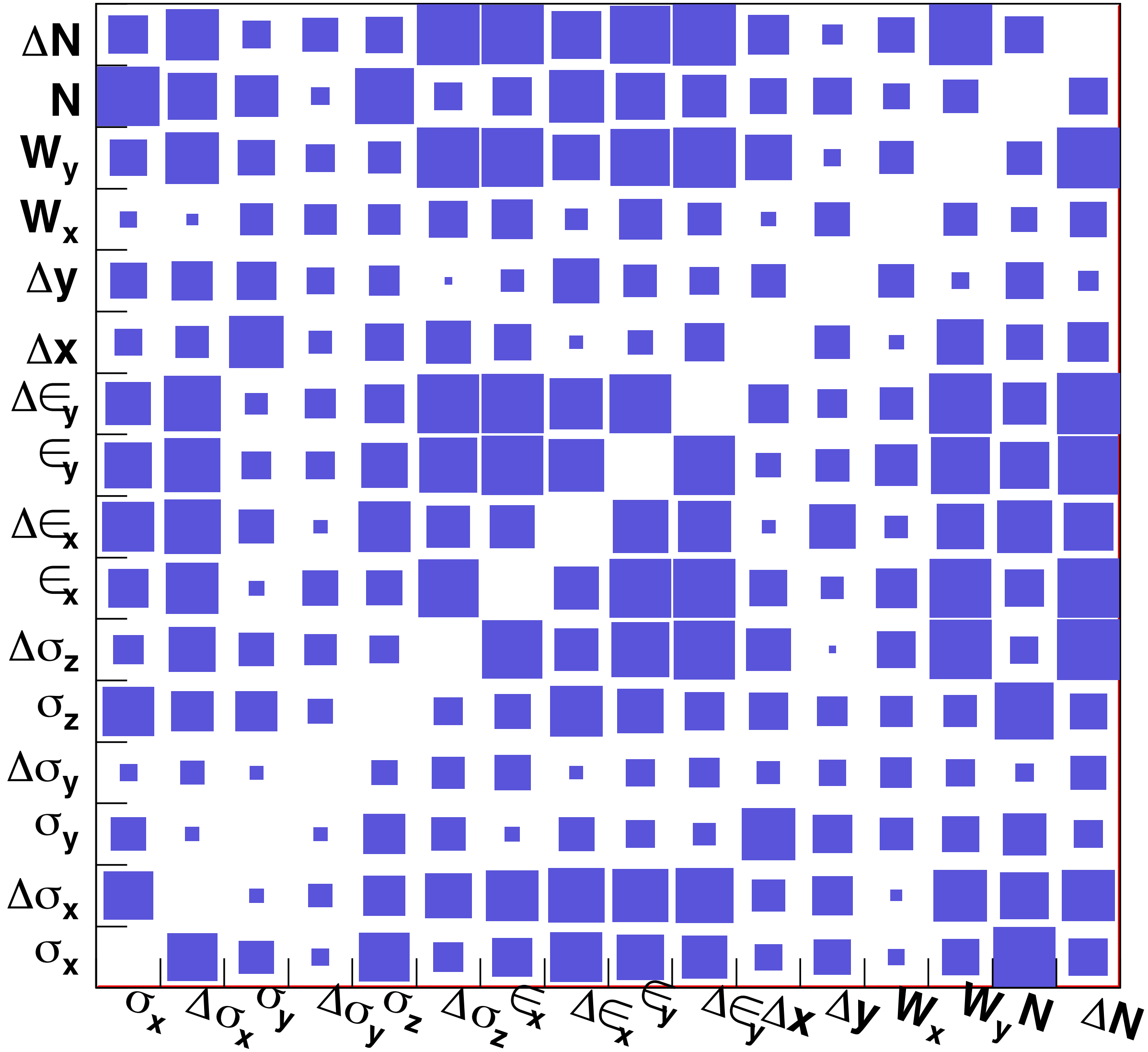
- allows to give estimates for Λ^{reach}
  - for different time scales
  (- for different running scenarios)
- e.g.: after 4 years (500 fb^{-1}) at $\sqrt{s}$=250 GeV: $\Lambda^{reach} \approx 1.5$ TeV
- more LR/RL
  $\Rightarrow \Lambda^{reach}_{vector} > \Lambda^{reach}_{axial-vector}$
- (40%, **40%**, 10%, 10%) better than (67.5%,**22.5%**,5%, 5%)



(+-) = 22.5%

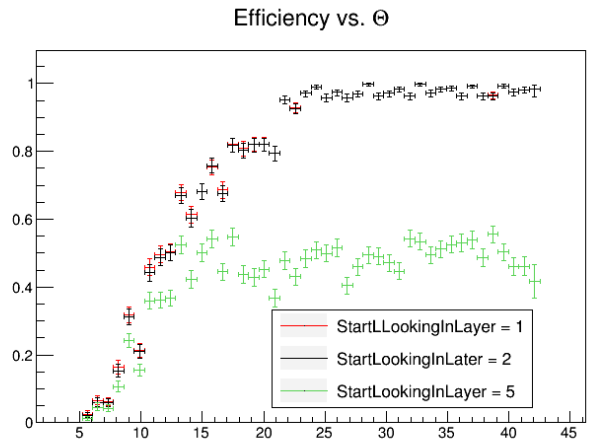
Correlation Matrix

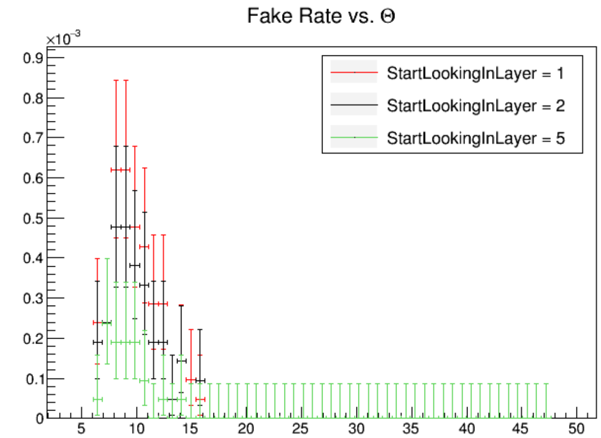
$$X = \frac{1}{2}(X_{e^-} + X_{e^+}) \qquad \Delta X = X_{e^-} - X_{e^+}$$



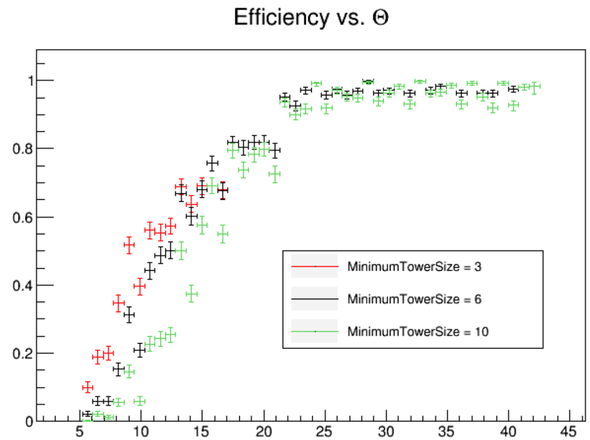
Tuning of the new BCal Reconstruction

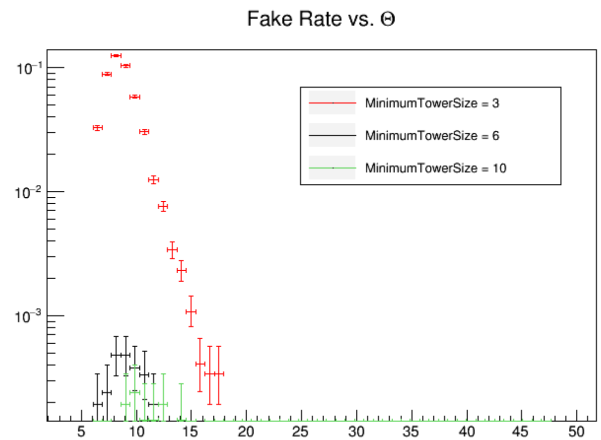
- StartLookingInLayer = 1 / **2** / 5





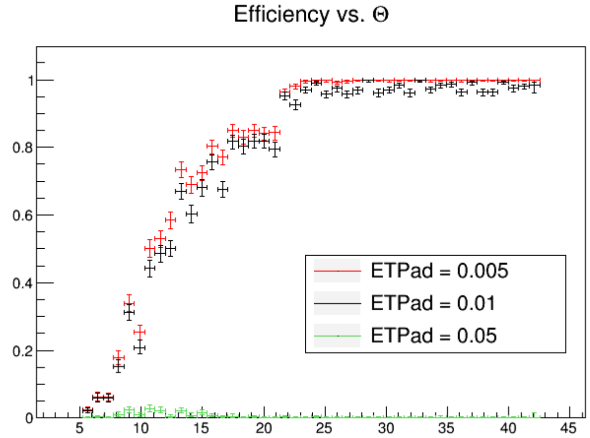
- MinimumTowerSize = 3 / **6** / 10

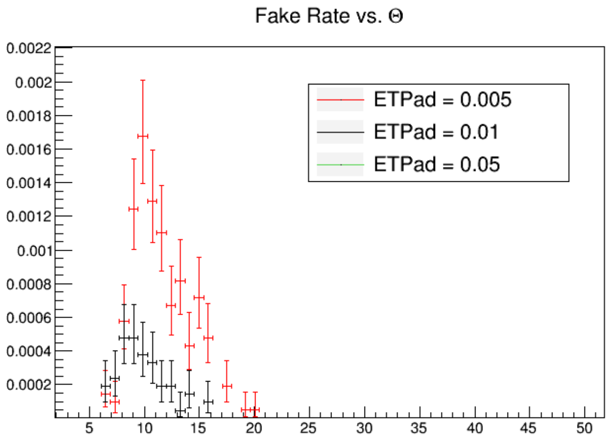




Tuning of the new BCal Reconstruction

- ETPadMin = 0.005 / **0.01** / 0.05





- SigmaCut = 1 / **2** / 3