# Detector Validation for Dark Matter Searches at 380 GeV

OUTLINE

- Software and detector parameter list
- $e^+ e^- \rightarrow x\ x\ \gamma$ cross sections at 380 GeV
- Validation results focusing on:
  Photon detection efficiency
  Electron detection efficiency
  Background veto efficiency
- Summary and Outlook

# Software

- Event generation Whizard 2.3.1
  380 GeV beam spectrum; Generator cut on γ only
- Event simulation and reconstruction software:
  ILCSoft-2017-08-23, CLIC_o3_v13
- Processors:
  TruthTrackFinder
  Pandora, BeamcalReco, LumicalReco
- Pandora provides particle id for leptons photons and hadrons. For Beamcal and Lumical there is no particle id; it is fixed to electron.
- No pair background was  overlaid.

# DM Searches Processes at 380 GeV

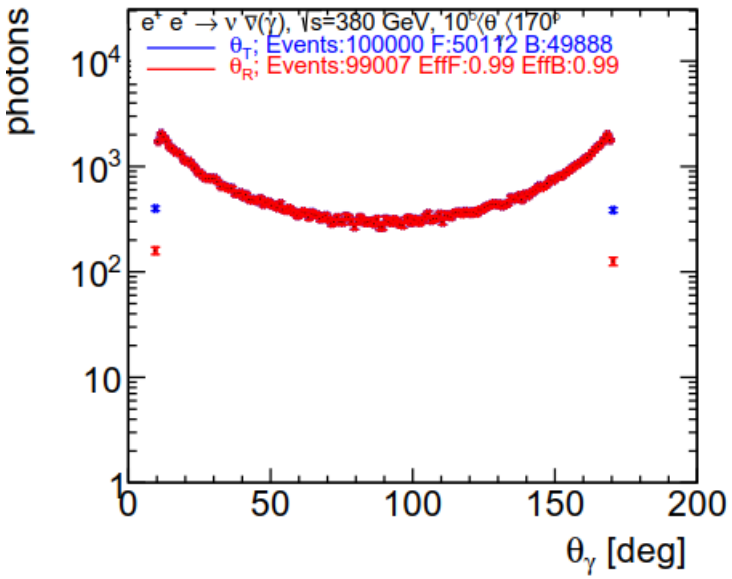
| Process | √s [GeV] | Cuts | σ [fb] |
|---|---|---|---|
| $e^+ e^- \to \chi_\circ \tilde{\chi}_\circ \gamma$ (S) | 380 | $10° < \theta\gamma < 170°$ , $E\gamma > 10$ GeV | $1.0\ 10^2$ |
| $e^+ e^- \to \nu \bar{\nu} \gamma$ (IB) | 380 | $10° < \theta\gamma < 170°$ , $E\gamma > 10$ GeV | $2.7\ 10^3$ |
| $e^+ e^- \to e^+ e^- \gamma$ (B1) | 380 | $10° < \theta\gamma < 170°$ , $E\gamma > 10$ GeV | $8.9\ 10^4$ |
| $e^+ e^- \to \gamma \gamma$ (B2) | 380 | $10° < \theta\gamma < 170°$ , $E\gamma > 10$ GeV | $3.9\ 10^3$ |
| $e^+ e^- \to \mu^+ \mu^- \gamma$ (B3) | 380 | $10° < \theta\gamma < 170°$ , $E\gamma > 10$ GeV | $3.6\ 10^2$ |
| $e^+ e^- \to \tau^+ \tau^- \gamma$ (B4) | 380 | $10° < \theta\gamma < 170°$ , $E\gamma > 10$ GeV | $2.8\ 10^2$ |

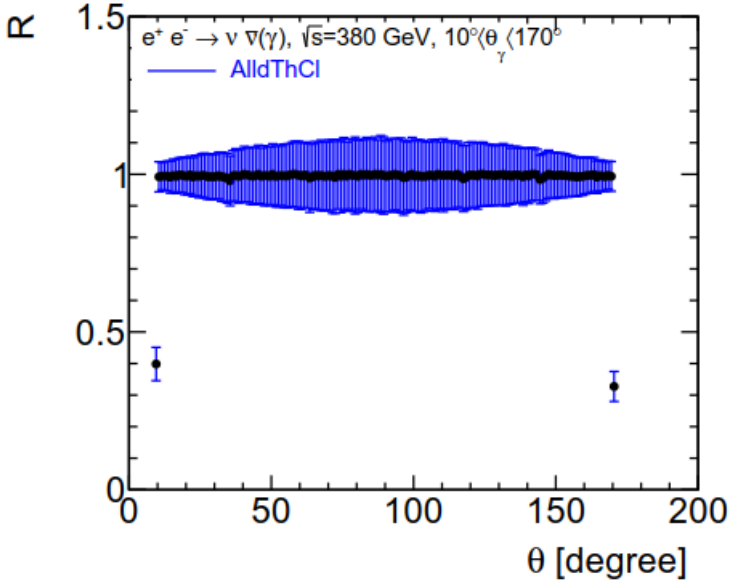
Processes used for the current validation studies:

Data samples generated with $10° < \theta\gamma < 170°$ , $E\gamma > 10$ GeV

- Essential to reduces the rate of reducible background events which mimic mono or multiphoton events to have a good sensitivity to new physics when looking for excess in $e^+ e^- \to \nu \bar{\nu} \gamma$ (IB)

# Photon Detection Efficiency

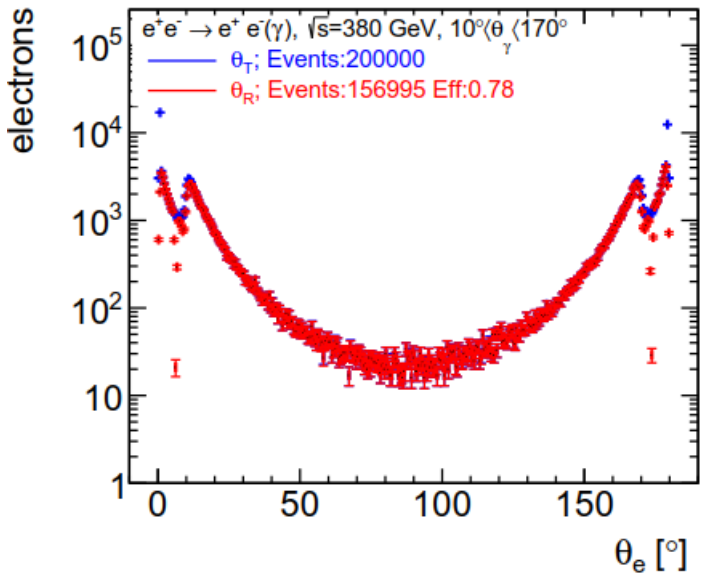


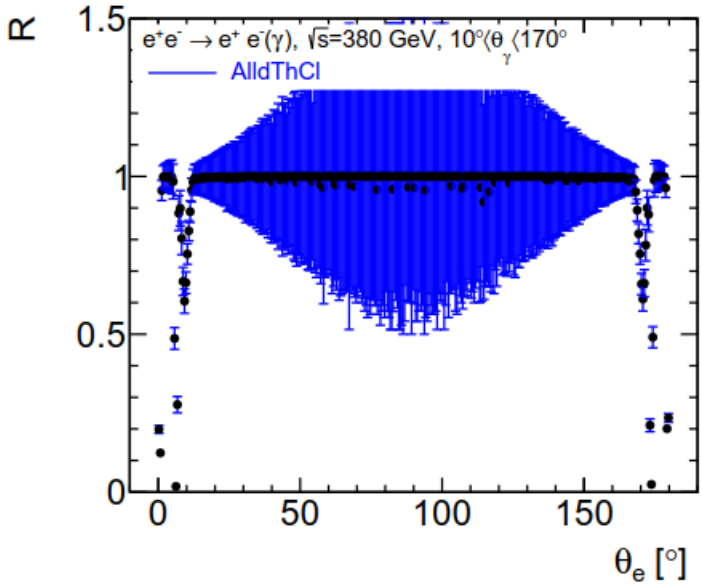




Left : dN/dθγ True(blue) and Reconstructed(red)

Right: dεγ/dθγ; the reconstruction efficiency is > 99% over a large θ range; it decreases to 40% ~ 9.5˚ and 170.5˚; Ecal crack. Events with θ<10 or θ>170 ?; beam crossing boost. Analysis cut after reconstruction 10°<θγ<170° discards these events.

# Electron Detection Efficiency

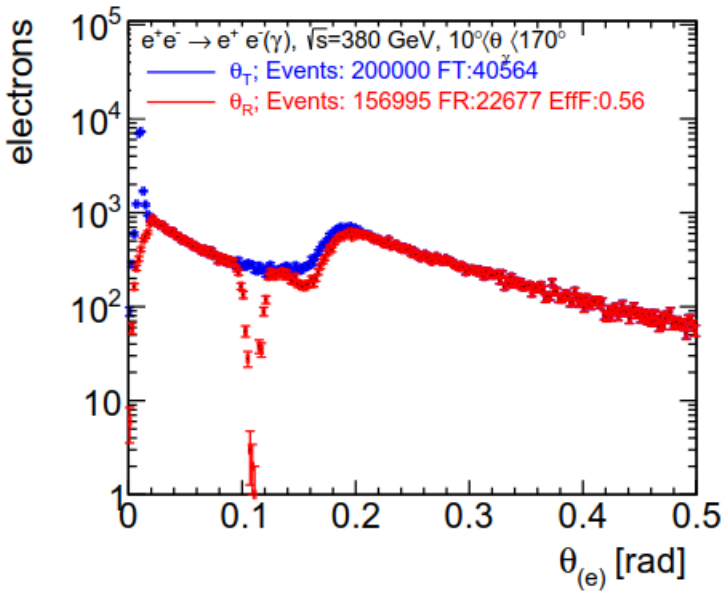


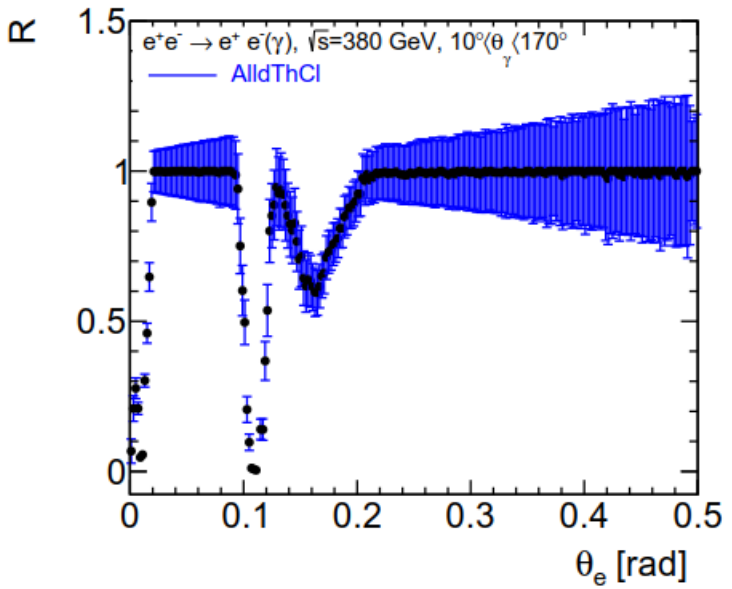




Left : dN/dθe; True(blue) and Reconstructed e (red)

Right: dε/dθe the reconstruction efficiency is ~ 0.99 except in the F/B regions <12 and > 168˚; => zoom in F region.

# Electron Detection Efficiency




Left: dN/dθe ; Right: dε/dθe

The e reconstruction efficiency is poor in 3 regions

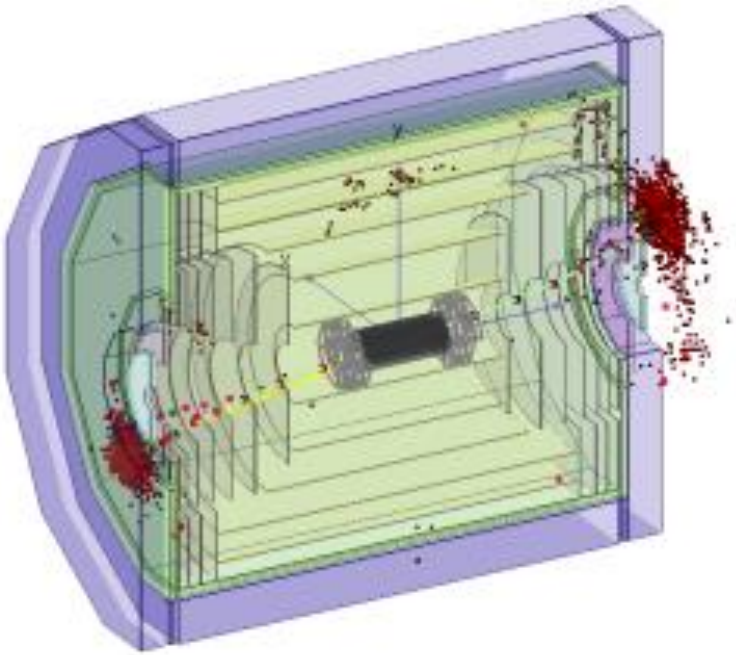
θe< 25 mrad: Beam pipe, Beamcal transition region

θe~100 mrad: StS beam pipe

170 mrad < θe <200 mrad: Ecal crack and end of tracker

=> Display of $e^+ e^- \rightarrow e^+ e^- \gamma$ events

# Event 1296 Ecal crack

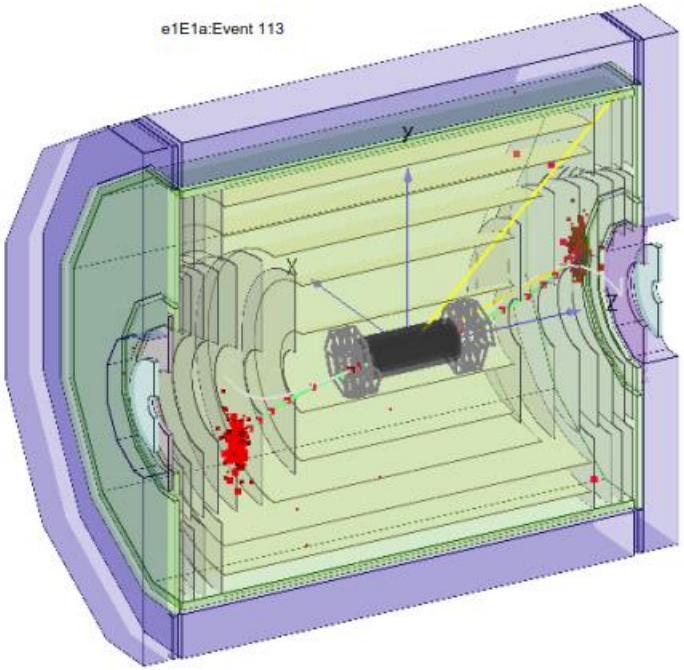


$e^+ e^- \rightarrow e^+ e^- \gamma$ event:

- $e^-$ at 9.6°: the track is well reconstructed but the $e^-$ is identified as a $\pi^-$ (no ecal cluster, Ecal crack )
- $e^+$ at 170.6° the track is not reconstructed, the $e^-$ is reconstructed as N (Ecal crack)

e id unreliable, but the tracking and Hcal energy measurement allow event veto.

# Event 113 Tracking

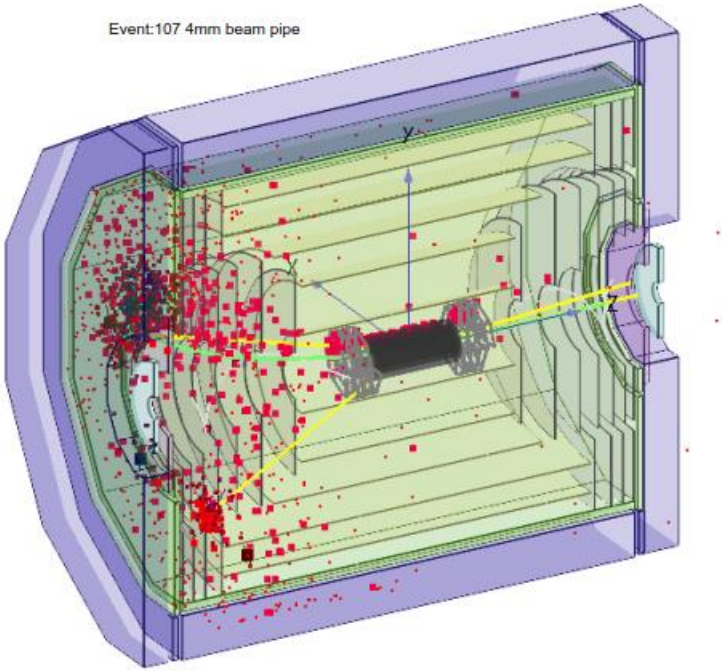



$e^+ e^- \rightarrow e^+ e^- \gamma$ event:

- $e^-$ at 12°: the track is not reconstructed and the $e^-$ is identified as a γ ; Ecal energy measurement.
- $e^+$ at 168°: the track is not reconstructed, the $e^-$ is reconstructed as a γ

e id unreliable but Ecal energy measurement allow event veto

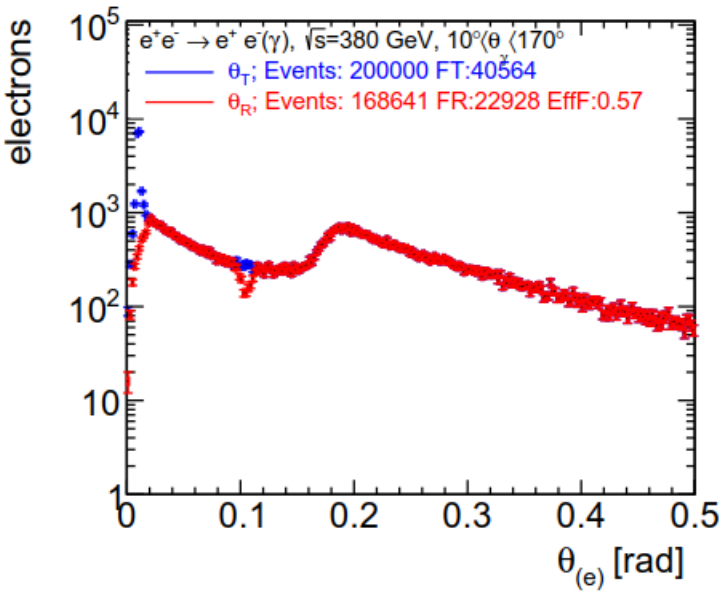
# Event 107

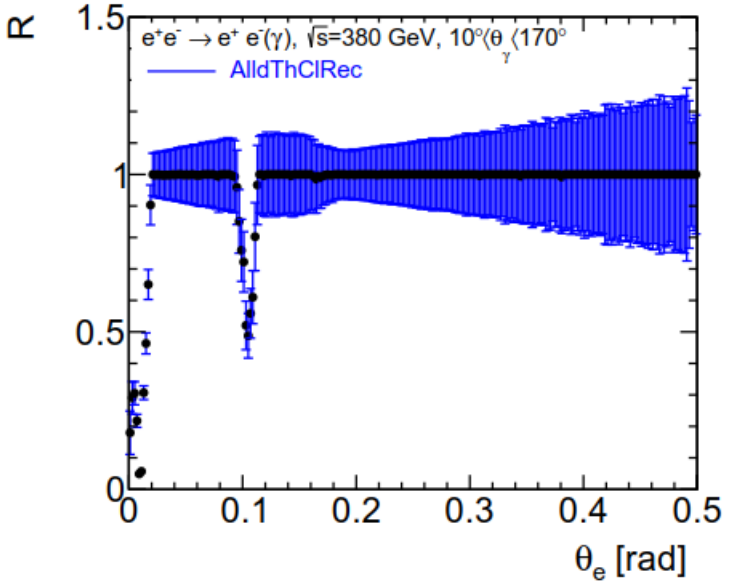



$e^+ e^- \rightarrow e^+ e^- \gamma$ event:

- The $e^-$ at $\theta$=10 mrad is in the beam pipe and the $e^+$ at $\theta$=173.9° showers in the StS beam pipe. It creates hits but no cluster is reconstructed in the Lumical.
- => Event not rejected

# Electron Detection Efficiency




Left: dN/dθe (T and R) ; Right: dε/dθ

For reconstructed e or γ or N matched with a true e

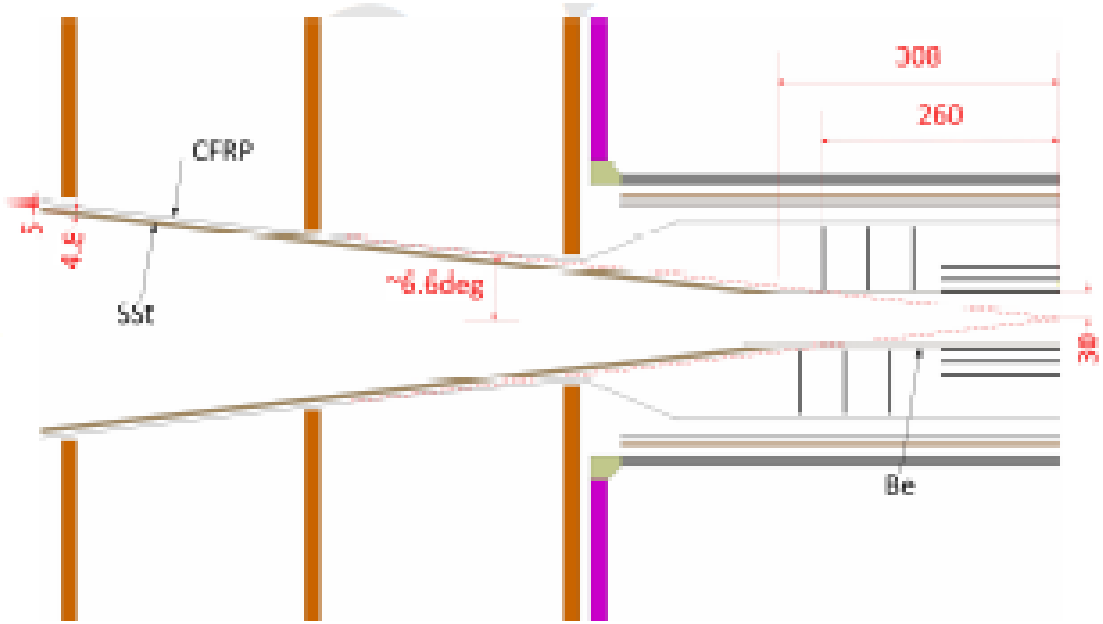
the detection efficiency ~ 170-200 mrad is increased to ~99%

The efficiency ~ 100 mrad is increased to ~ 50%

For 12˚ <θ< 168˚ the particle ID is unreliable or impossible.

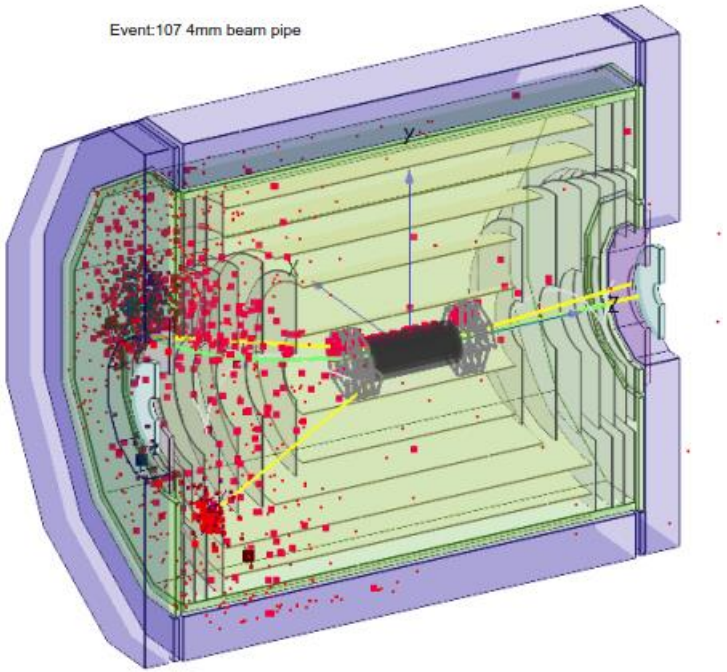
Improve efficiency ~ 100 mrad ?

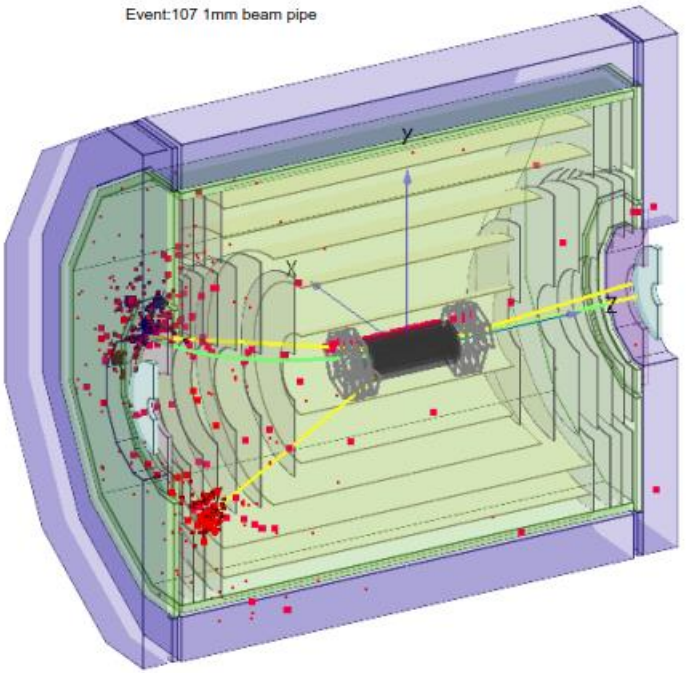
# Beam Pipe




The stainless steel conical beam pipe has a thickness of 4 mm at 310 mm of IP and 4.8 mm close to the Lumical.
It has a half cone angle of 6.6˚. It creates a dead region of ~ 15 mrad. Andre has designed a beam pipe with a thickness of 1 mm at 310 mm from the IP and 4.8 mm in front of the Lumical

# Event 107



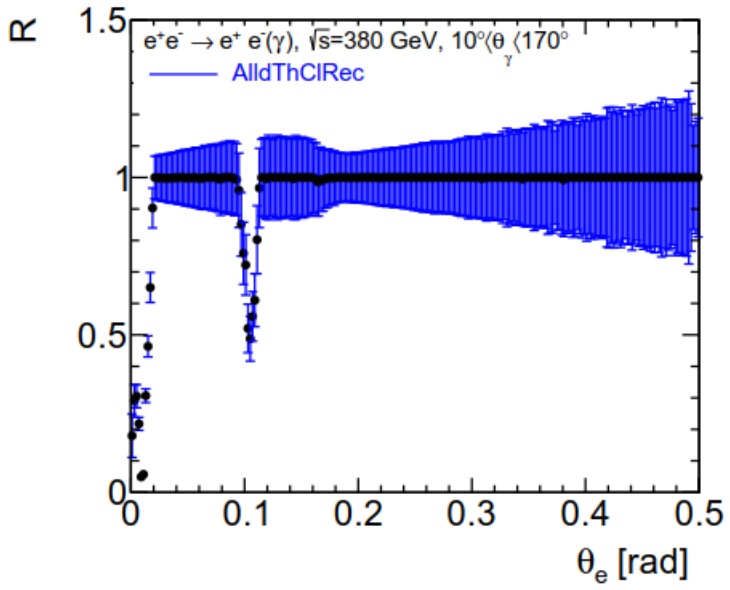



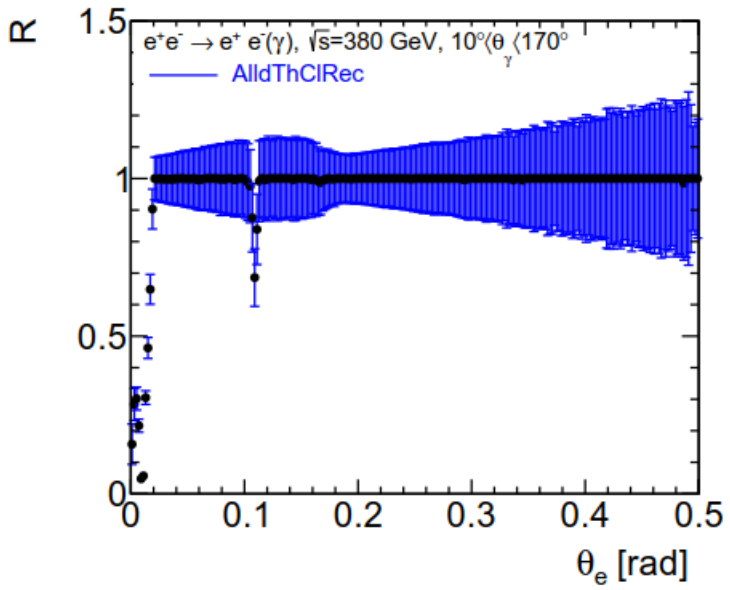

$e^+ e^- \rightarrow e^+ e^- \gamma$ event:

4 mm beam pipe (left); 128 GeV $e^+$ ; no energy cluster in Lumical => event not rejected.

1 mm thickness (right); 128 GeV $e^+$ matched with 2 clusters In Lumical having 41 and 25 GeV => event rejected.

# Electron Detection Efficiency



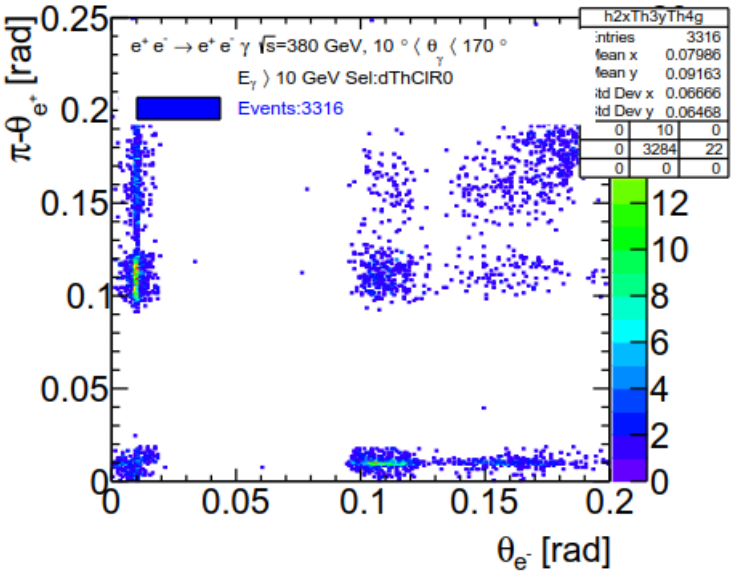

Left: dε/dθ; StS beam pipe of 4.8 mm; ε ~ 50%

Right: dε/dθ; StS beam pipe of 1 mm

The detection efficiency increases to > 70%,

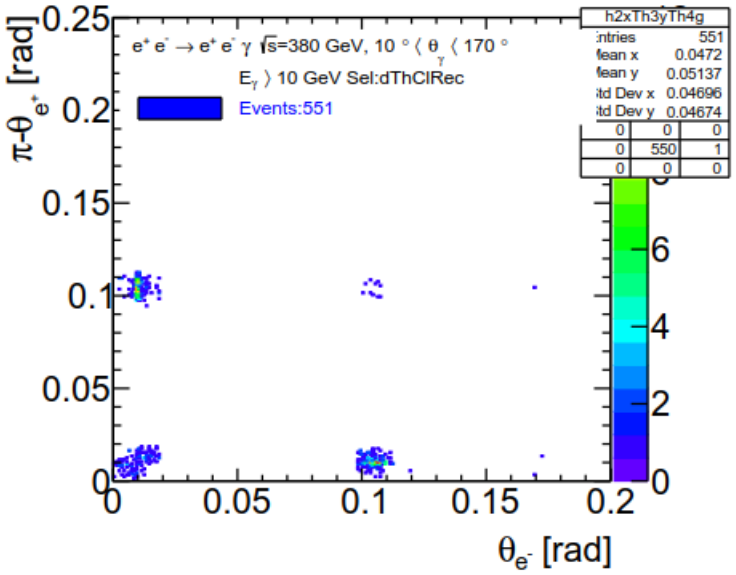
Single particle detection efficiency -> Background event veto.

# Event Veto Inefficiency; 4mm BP




dN/dθe⁻d(π-θ)e⁺ for events without reconstructed e⁻ and e⁺ and without Ecal, Hcal energy veto; inefficiency ~ 3.3% => 2937 fb. The e detection inefficiency in the region 90 mrad < θ < 200 mrad in combination with the inefficiency for θ < 25 mrad is the largest contribution

# Event Veto Inefficiency; 4mm BP

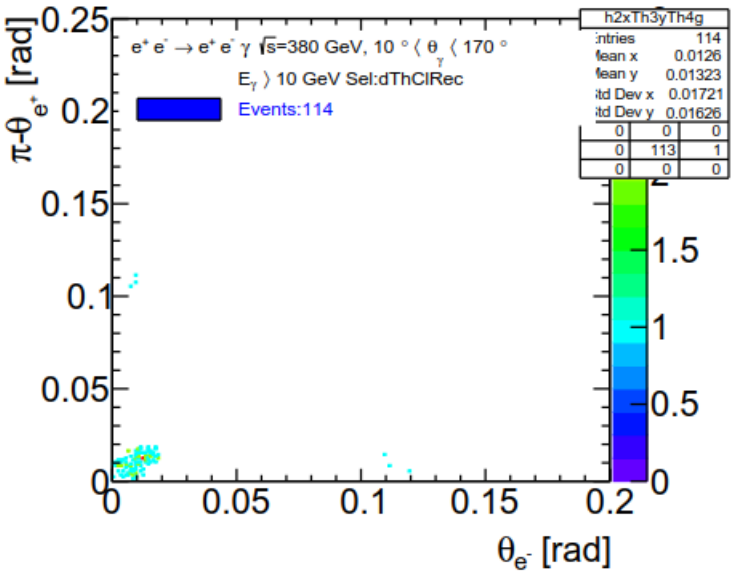



dN/dθe⁻d(π-θ)e⁺; Events without reconstructed e⁻ requiring the energy deposit E in Ecal, Hcal or Lumical E<5 GeV => Veto inefficiency ~ 0.6% => 490 fb.

For θe⁻ and π-θe⁺< 25 mrad; Inef ~ 0.1% => 100 fb (20%)

Inefficiency dominated by events with one e < 25 mrad and the other in the crack due to StS beam pipe.

# Event Veto Inefficiency; 1mm BP




$dN/d\theta e^- d(\pi-\theta)e^+$; Events without reconstructed $e^-$ requring the energy deposit in Ecal, Hcal, Beamcal or Lumical E<5 GeV
Veto inefficiency reduced by a factor 5 to ~ 0.1% => 101 fb.
Most events have $\theta e^-$ and $\pi-\theta e^+$< 25 mrad

# B Cross Sections before and after Energy deposit veto

| Process | √s [GeV] | Cuts | σ [fb] | σ[fb] |
|---|---|---|---|---|
| $e^+ e^- \rightarrow \nu \nu \gamma$ (IB) | 380 | $10° < \theta\gamma < 170°$ , $E\gamma > 10$ GeV | $2.7\ 10^3$ | $2.7\ 10^3$ |
| $e^+ e^- \rightarrow e^+ e^- \gamma$ (B1) | 380 | $10° < \theta\gamma < 170°$ , $E\gamma > 10$ GeV | $8.9\ 10^4$ | $4.9\ 10^2$ |
| $e^+ e^- \rightarrow \gamma \gamma$ (B2) | 380 | $10° < \theta\gamma < 170°$ , $E\gamma > 10$ GeV | $3.9\ 10^3$ | <0.01 |
| $e^+ e^- \rightarrow \mu^+ \mu^- \gamma$ (B3) | 380 | $10° < \theta\gamma < 170°$ , $E\gamma > 10$ GeV | $3.6\ 10^2$ | 0.02 |
| $e^+ e^- \rightarrow \tau^+ \tau^- \gamma$ (B4) | 380 | $10° < \theta\gamma < 170°$ , $E\gamma > 10$ GeV | $2.8\ 10^2$ | 0.01 |

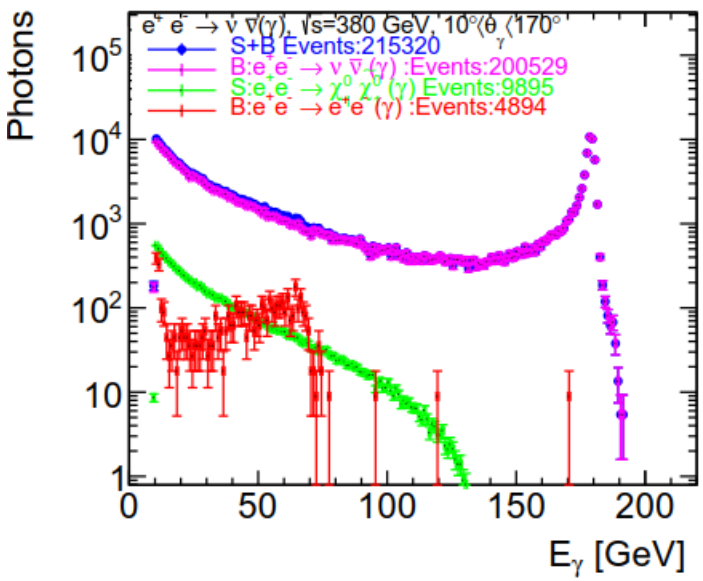
B Cross sections for 4 mm B.P before and after veto

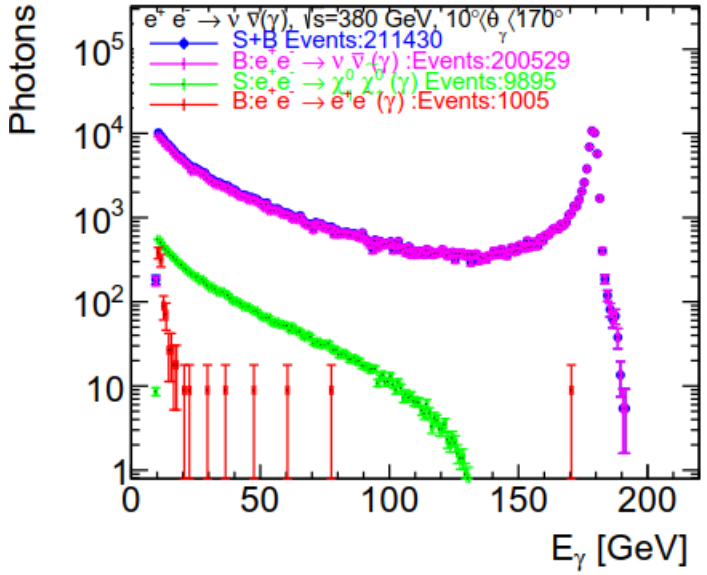
After veto B2, …B4 <=0.02 fb. B1 = 490 fb.

With a 1mm StS beam pipe B2 is reduced to 101 fb.

Is this level of background adequate for the DM searches?

# dN/dEγ; 4/1 mm beam pipe



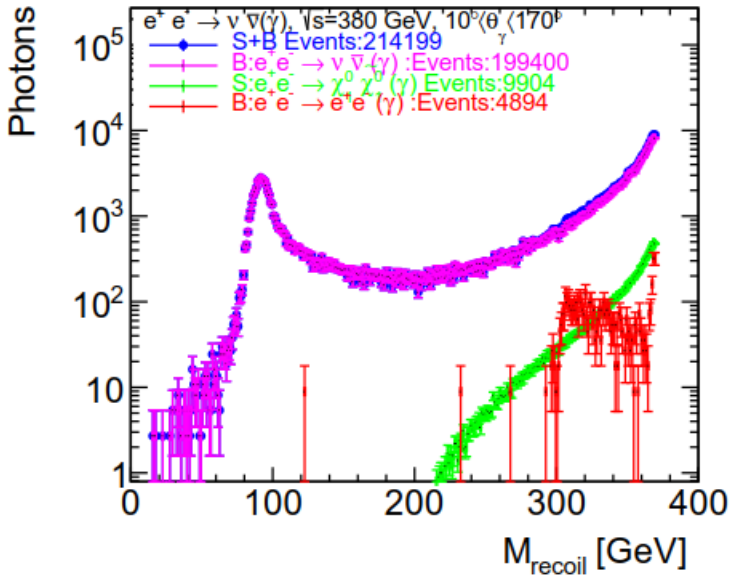



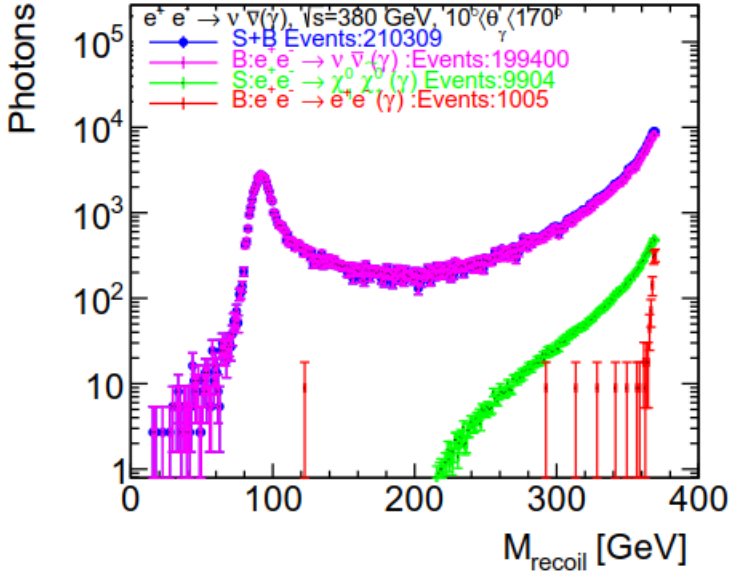

Left : dN/dEγ for S+IB+B1, S, IB , B1 for 4mm beam pipe

Right: dN/dEγ for S+IB+B1, S, IB , B1 for 1mm beam pipe

With a 4 mm beam pipe B1, $e^+ e^- \to e^+ e^- \gamma$ is affecting significantly the energy distribution in the region Eγ<80 GeV

# dN/dMRecγ; 4/1 mm beam pipe




Left : dN/dMRec for S+IB+B1, S, IB , B1 for 4mm beam pipe
Right: dN/dMrec for S+IB+B1, S, IB , B1 for 1mm beam pipe
With the 4 mm beam pipe the B1, $e^+ e^- \rightarrow e^+ e^- \gamma$ is affecting the recoil mass distribution for M>300 GeV. It makes the excess and mass measurement difficult.

# Summary

$e^+ e^- \rightarrow X X \gamma$ were used to study the γ and e detection efficiency at 380 GeV without pair background overlaid.

- For events with $10° < \Theta\gamma < 170°$ the γ reconstruction efficiency is ~ 99%.
- The $e^-$ (γ, N) reconstruction efficiency is ~ 99% for $1° < \Theta\gamma < 179°$except for $\Theta$~ 6° and $\theta$~174° ; StS conical beam pipe location. It affects the veto efficiency for searches with missing energy.
- Reducing the beam pipe thickness improves the veto efficiency allowing to reduce the background cross section to a level adequate for DM searches.

# Outlook

Perform the same study at 380 GeV with pair background and γγ-> hadrons overlaid.
Check γ energy resolution and its impact on the DM mass measurement.

# Backup