The simulation of the Electron Tracking Compton Camera with a gaseous time projection chamber and a scintillator

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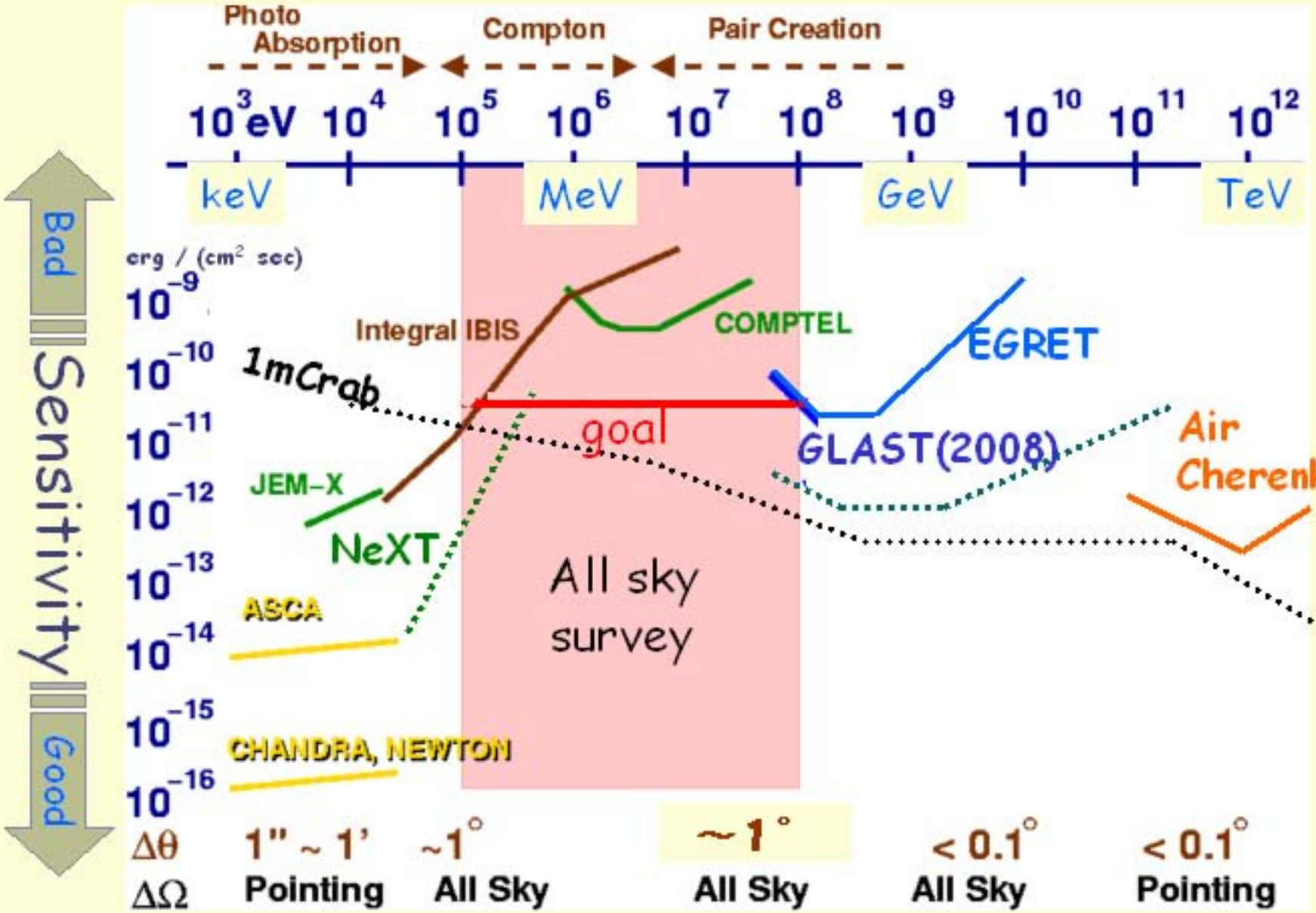
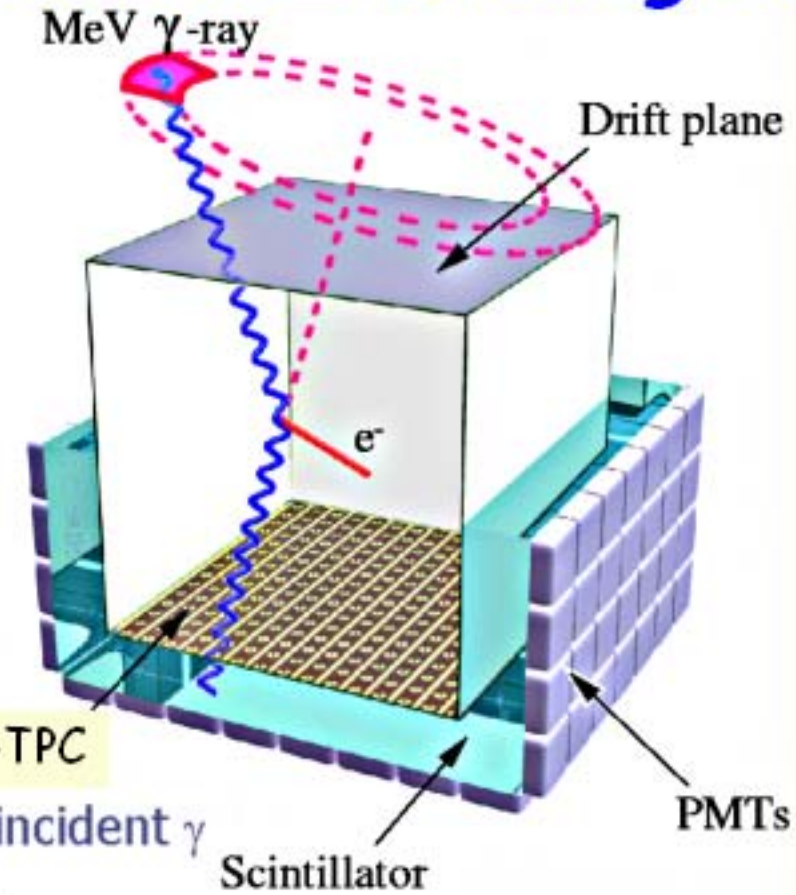
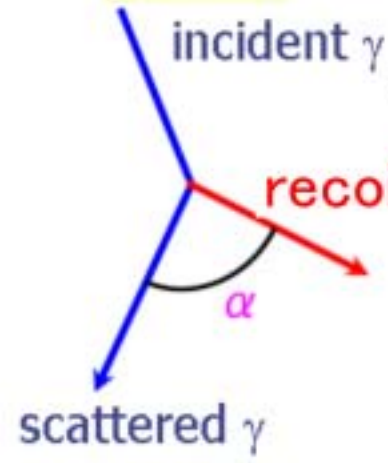
- Introduction
- GSO Pixel Scinti. Camera
  & Time Projection Chamber
- Compton Camera
- Summary

Sensitivity of X/Gamma-ray observations



Electron-Tracking Compton Imaging





- gaseous TPC : Tracker
  track and energy of recoil electron
- Scintillator : Absorber
  position and energy of scattered gamma

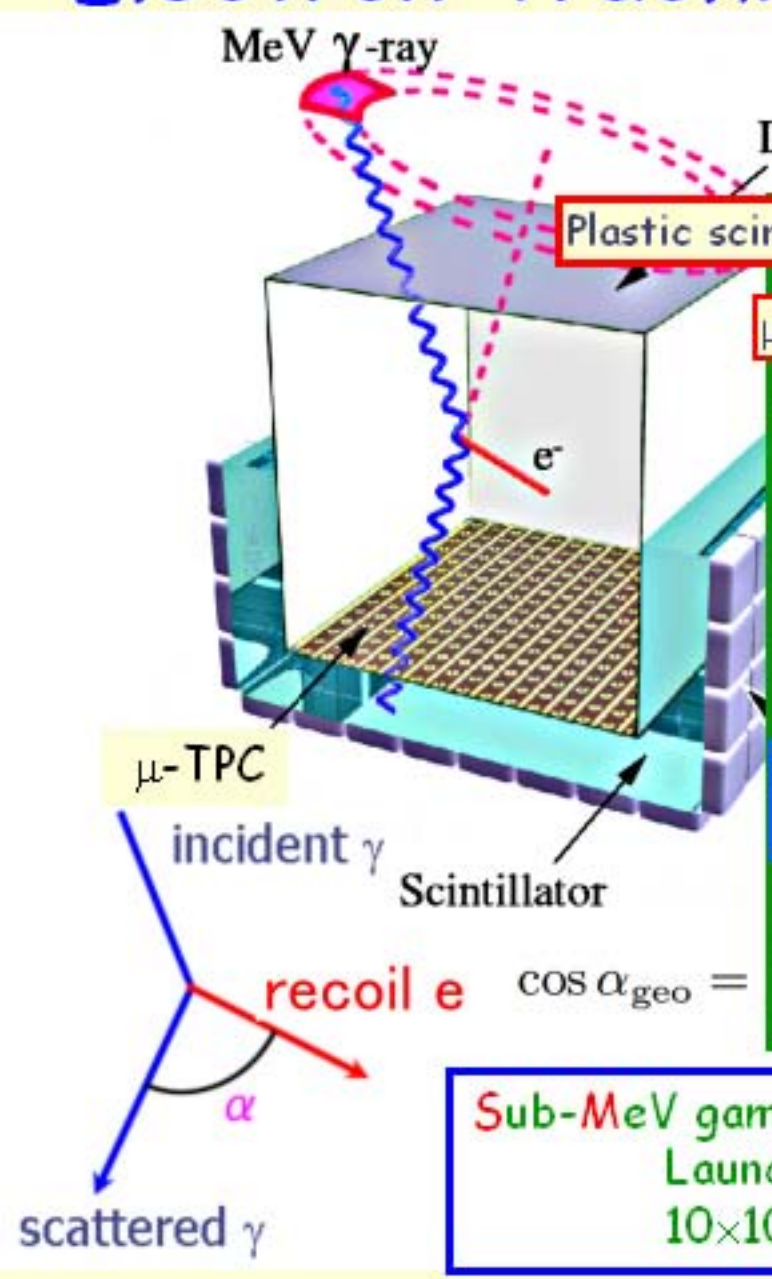
Reconstruct Compton scattering event by event

- 1 photon ⇒ direction + energy
- Large FOV (~3str)
- Kinematical background rejection

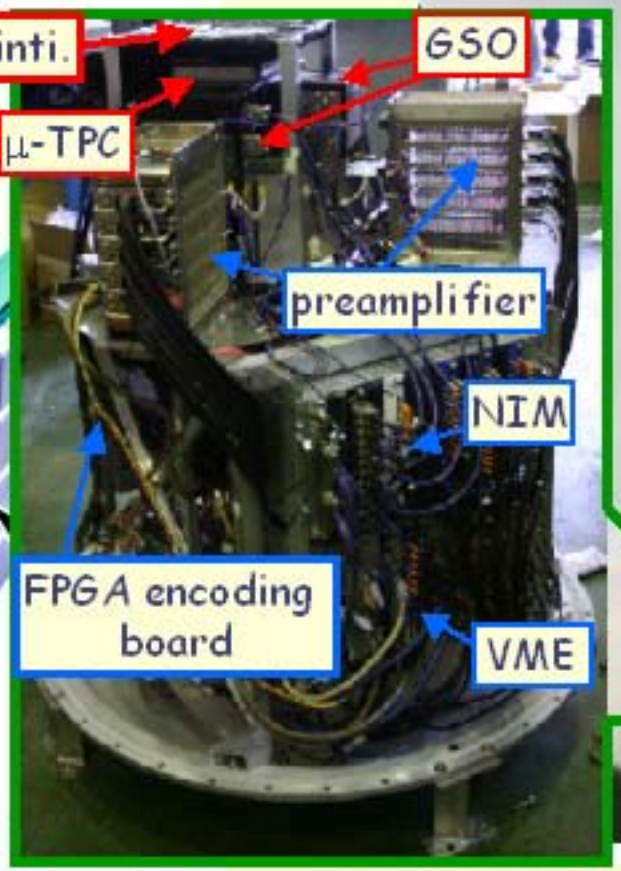
$$\cos\alpha_{\mathrm{geo}} = \vec{g}\cdot\vec{e} \Longleftrightarrow \cos\alpha_{\mathrm{kin}} = \left(1-\frac{m_e c^2}{E_\gamma}\right)\sqrt{\frac{K_e}{K_e+2m_e c^2}}$$

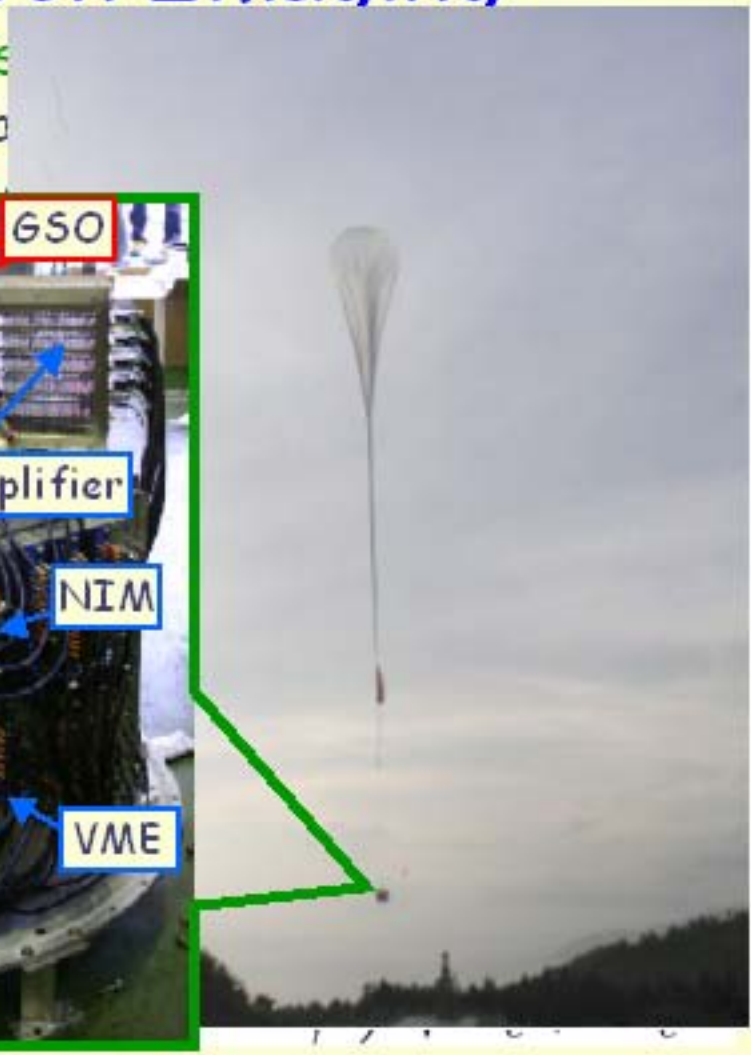
Sub-MeV gamma-ray Imaging Loaded-on-balloon Experiment
Launched on September 1, 2006
10×10×14cm³ TPC + GSO Pixel Scintillator arrays

Electron-Tracking Compton Imaging



$$\cos\alpha_{geo} =$$





Sub-MeV gamma-ray Imaging Loaded-on-balloon Experiment
Launched on September 1, 2006
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SMILE-I Geometry

Vessel
$C_{10}H_{10}O_2$ 40%
SiO_2 60%

Plastic Scintillator
(C_9H_{10})

PMT (SiO_2)

GEM

μ-PIC

Cu + $C_{14}H_{22}O_4N_2$

14cm

10cm

Al

Pixel Scinti.
(Gd_2SiO_5)

TPC gas
Xe 80% + Ar 18% +C_2H_6 2%

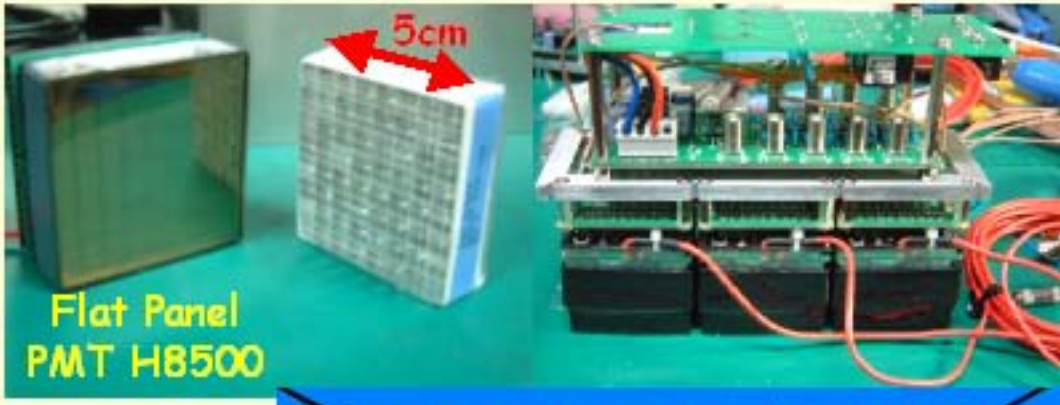
Physics List for SMILE-I

- Gant4.9.0_p01
- Gamma-ray detection ⇒ Electromagnetic Processes
- Background simulation ⇒ Hadronic Processes
- Based on the physics list of
  'examples/advanced/underground_physics'
- The several alterations
  - Compton/Rayleigh scattering for gamma
    ⇒ LECSCompton/Rayleigh
    For the Doppler broadening
    (http://public.lanl.gov/mkippen/actsim/g4lecs)
  - For the charged particles
    ⇒ G4StepLimiter in TPC
    Tracing the tracks with the pitch of less than 40 μm

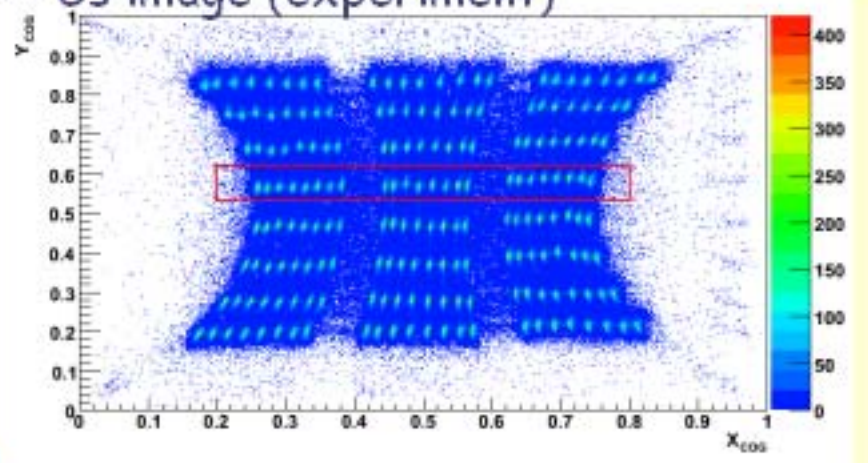
GSO Pixel Scintillator Array

Simulation of Absorber

- Scintillator : GSO(Ce)
- Pixel size : 6×6×13 mm^3
- 8×8 pixels ⇒ 1 array
- 3 PMTs ⇒ 1 unit
- Photo readout : H8500 (HPK)
  - gain uniformity is not good
    (Min:Max = 1:2~4)
  - light cross-talk at window
    (~40% leaks to surrounding pixels)
- 4 channels readout with resistive chain
  - incomplete quantization
  - distorted image
- Energy resolution :
  - Average 10.9% (662keV, FWHM)
    - inside (6×6 pixels) : 10.5%
    - outside (28 pixels) : 11.5%



^{137}Cs image (experiment)

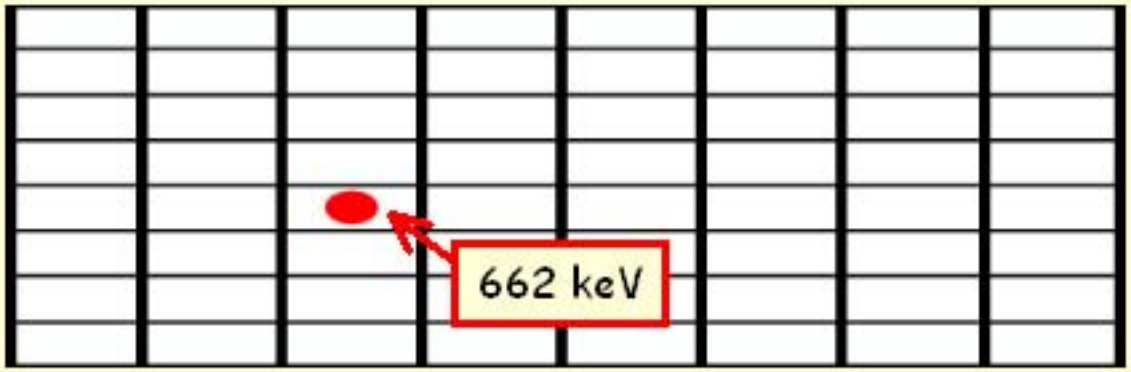


Simulation of Absorber

1. Geant4 ⇒ pixel ID, deposit energy E
2. Obtain the light cross-talk rate l_i of each pixel.

center	1
horizontal	Gauss (mean: 0.153, RMS: 0.0265)
diagonal	Gauss (mean: 0.0323, RMS: 0.00951)

3. Calculate the detected charge of each anode considering with energy resolution.
   Gauss (mean: El_i, RMS: $1.2\times(El_i)^{0.5}$)
4. multiply the gain map of PMT by the detected energy.
5. Divide the obtained charge to 4 channel readouts using a template.
6. Add the pedestal to each readout.
7. reconstruct the image by the charges of 4 channel readouts.



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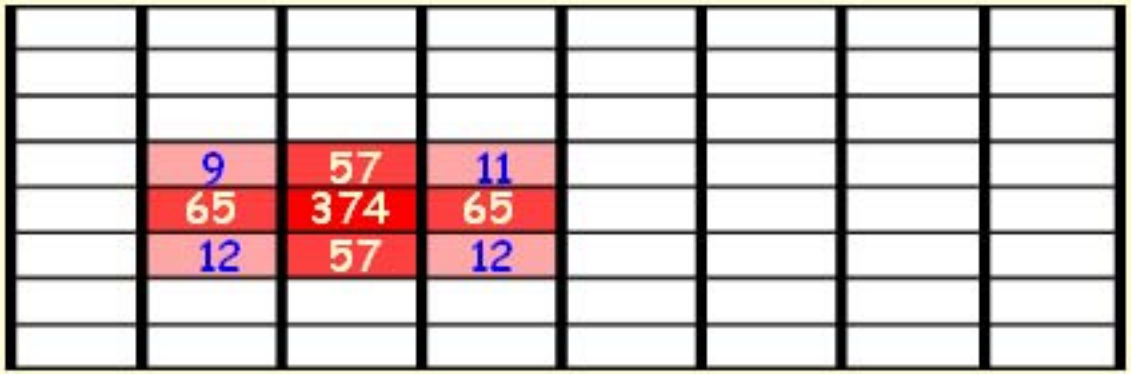

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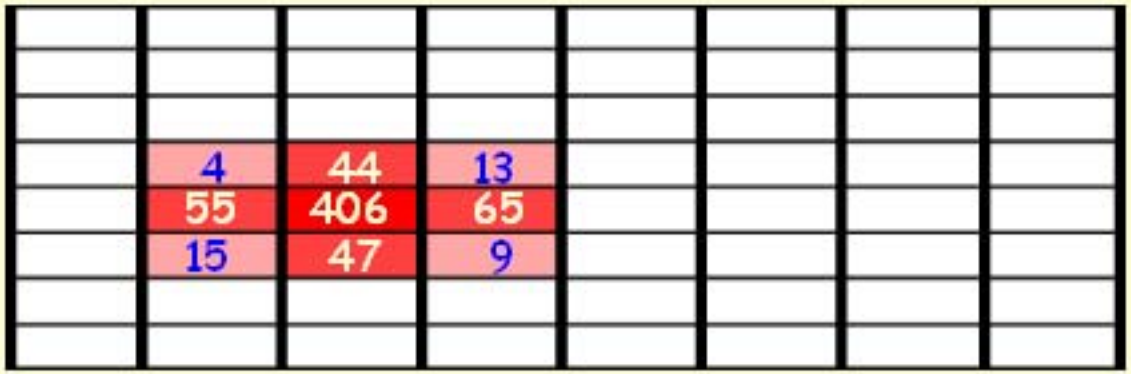

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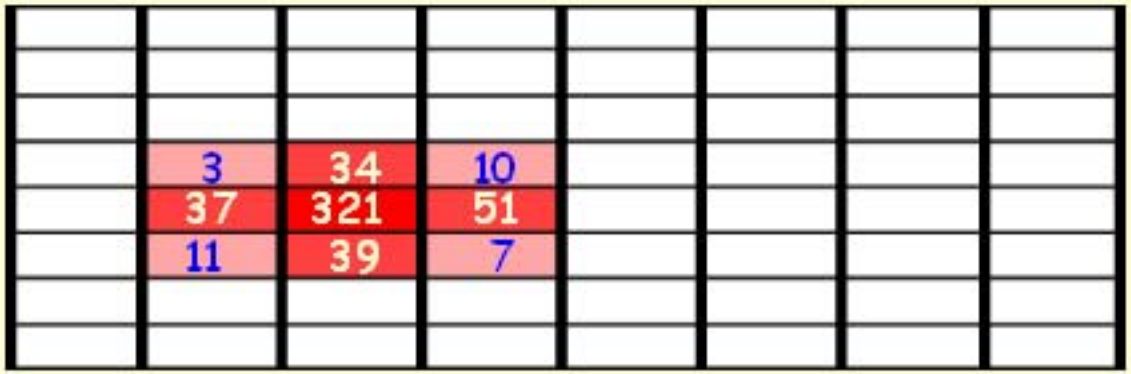

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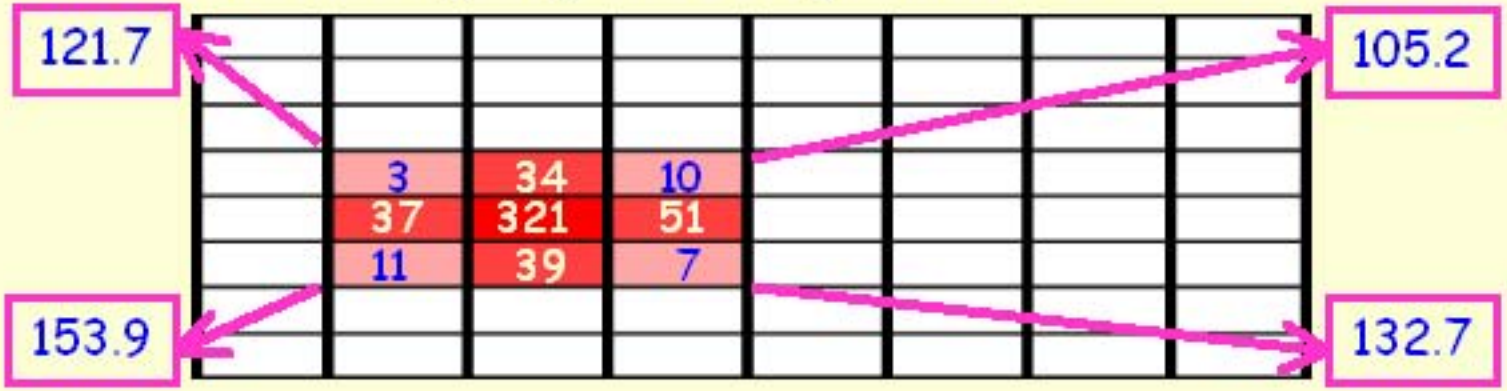

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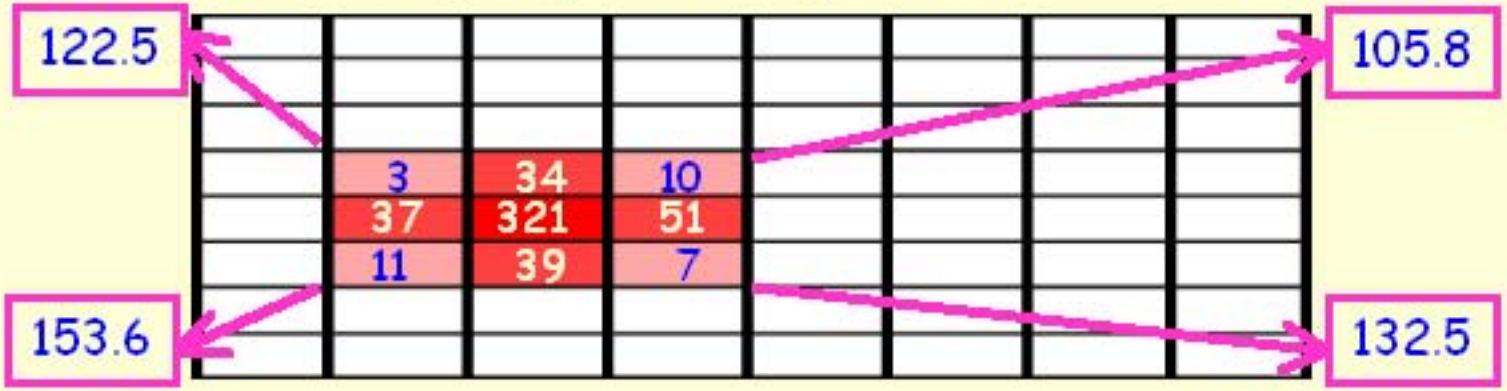

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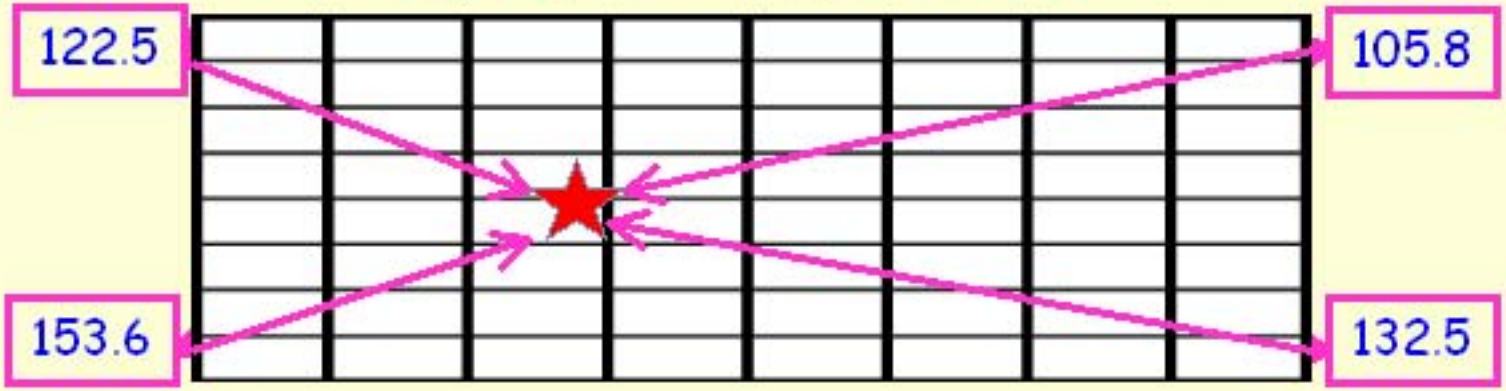

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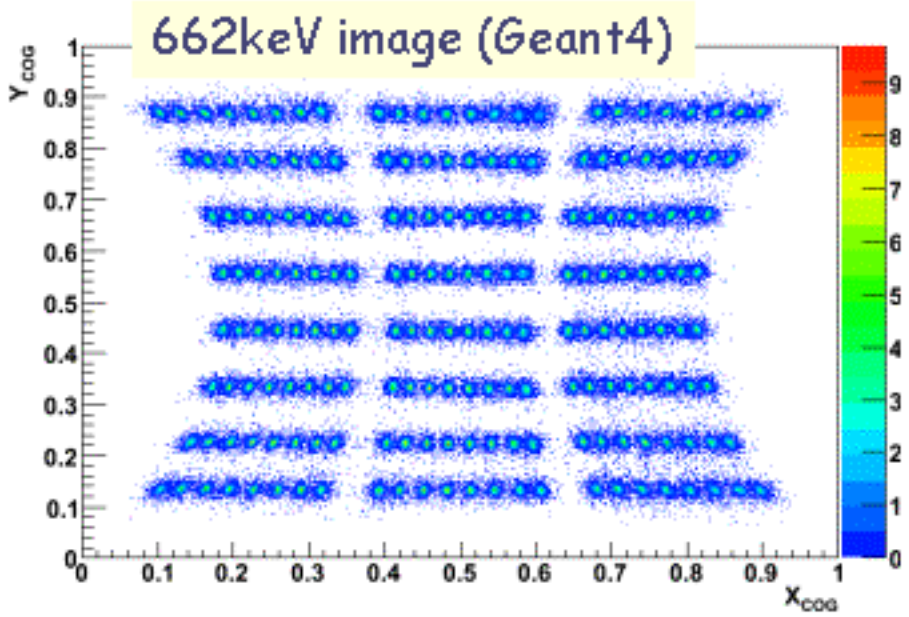
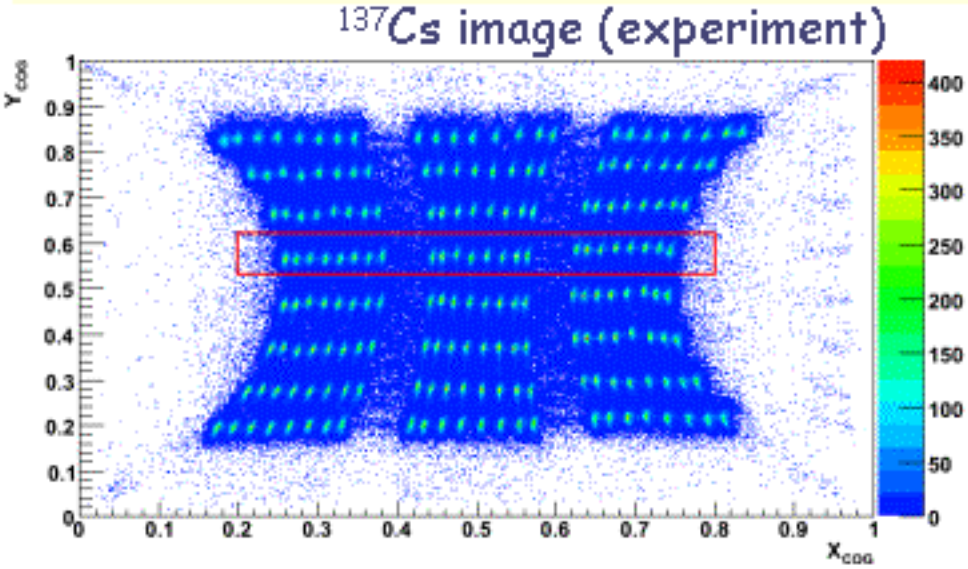
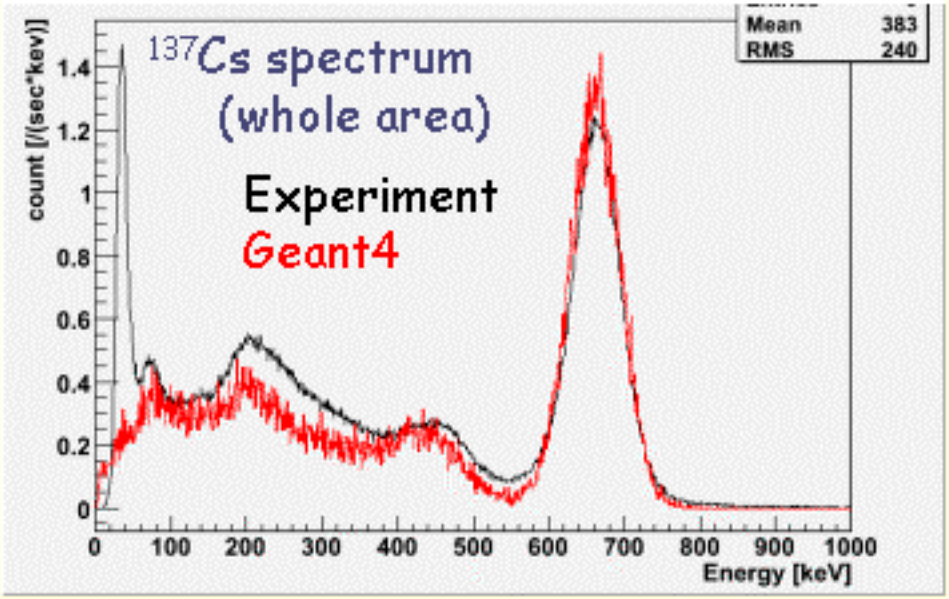






Energy resolution

Geant4

Whole : 11.3%

inside : 10.5%

outside : 12.3%

Experiment

Whole : 10.9%

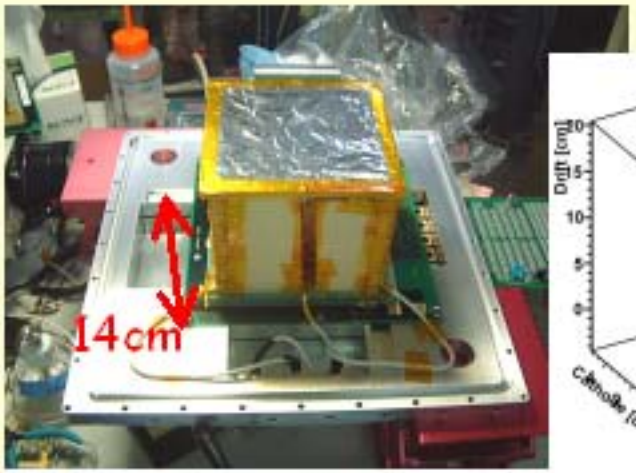
inside : 10.5%

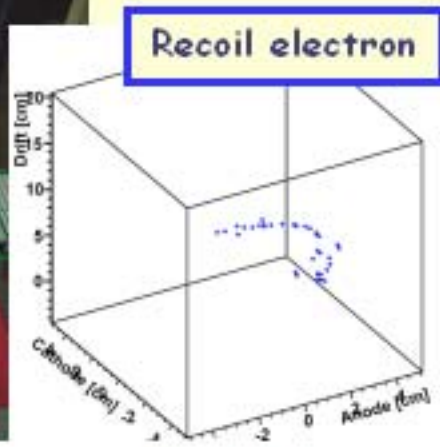
outside : 11.5%

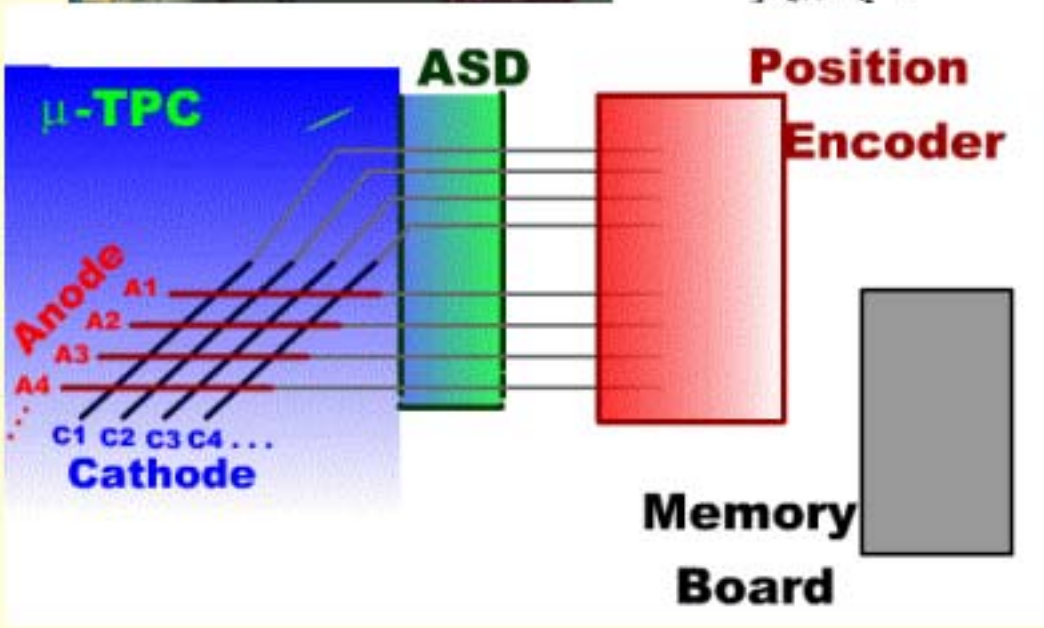
Electron Tracker

Simulation of Tracker

- Gas : Xe 80% + Ar 18% + C_2H_6 2%
  1atm, sealed, 10×10×14 cm^3
- w value : 23 eV
- Diffusion : (Magboltz simulation)
  transverse 0.52mm/√cm
  longitudinal 0.28mm/√cm
- Strip readout (0.40mm pitch)
- Gas Gain : ~30000
- Preamp : τ=16 nsec, C=1pF
- Drift velocity (V_d=400V/cm) :
  measured 2.4 cm/μsec
- calculate the track points
  with 100 MHz
- Energy resolution :
  ~45% (22.2keV, FWHM)
- Position resolution : ~0.5mm

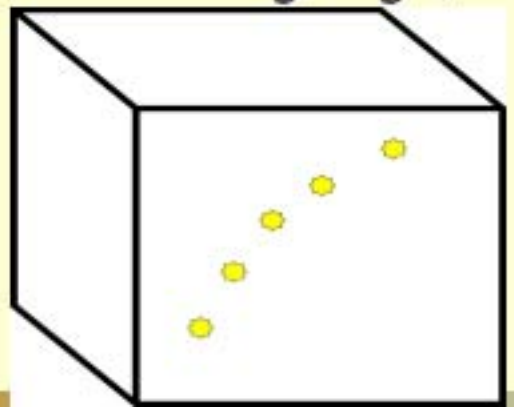






Simulation of Tracker

1. Geant4 $\Rightarrow$ position **x**, deposit Energy E (pitch < 40 μm)
2. Obtain the number n of ionized electron at **x**.
   Poisson (mean: E/w)
3. Calculate the diffusion which is the function of the drift length d.
   transverse Gauss (RMS: $0.52\sqrt{d}$ mm)
   longitudinal Gauss (RMS: $0.28\sqrt{d}$ mm)
4. Quantize to the strip readout and sampling clock.
   x/y 0.4 mm pitch $\Leftarrow$ readout pitch of 400 μm
   z 0.24 mm pitch
   $\Leftarrow$ drift velocity 2.4 cm/μsec, 100MHz sampling
5. Calculate the detected charge considering with energy resolution.
6. Calculate the wave form using the response template of the preamp.
7. take the leading edge, and take the coincidence between x and y.



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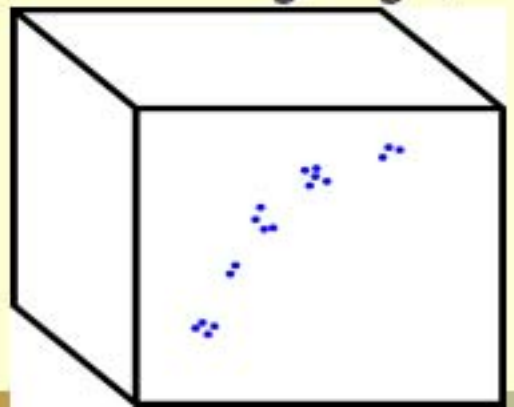

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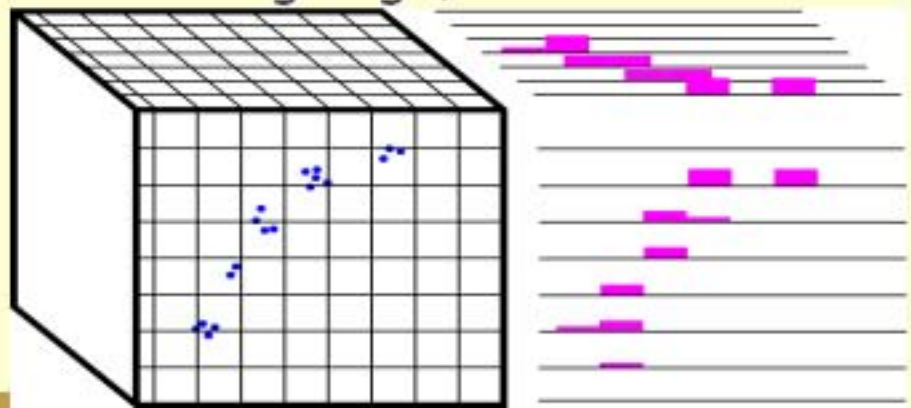

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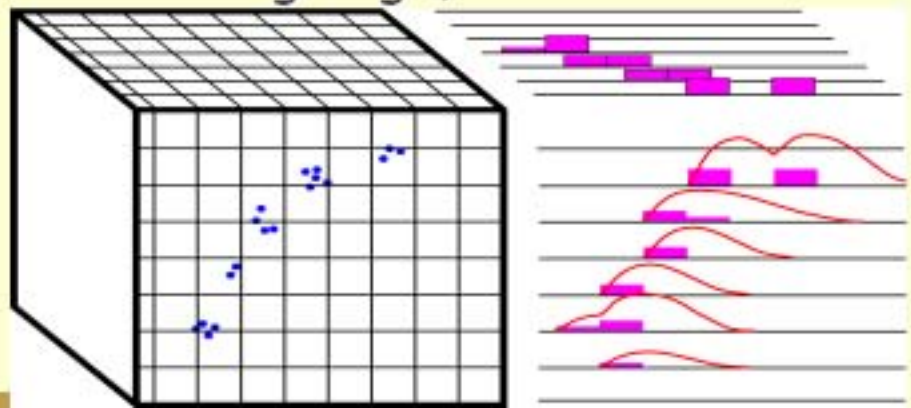

Simulation of Tracker

1. Geant4 ⇒ position **x**, deposit Energy *E* (pitch < 40 μm)
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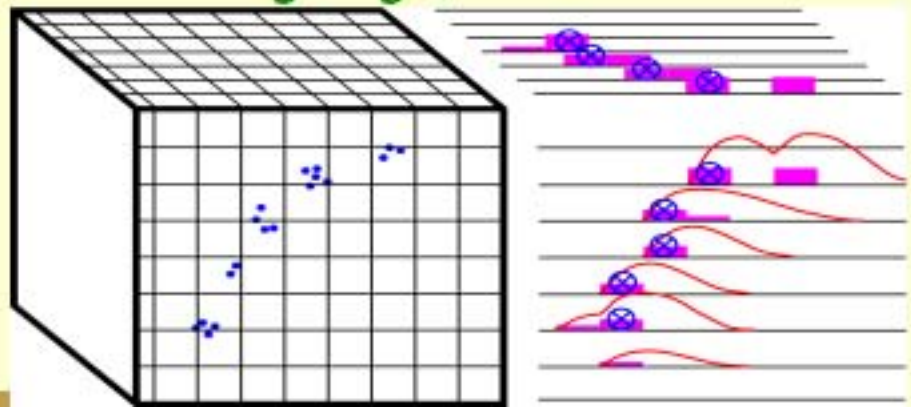
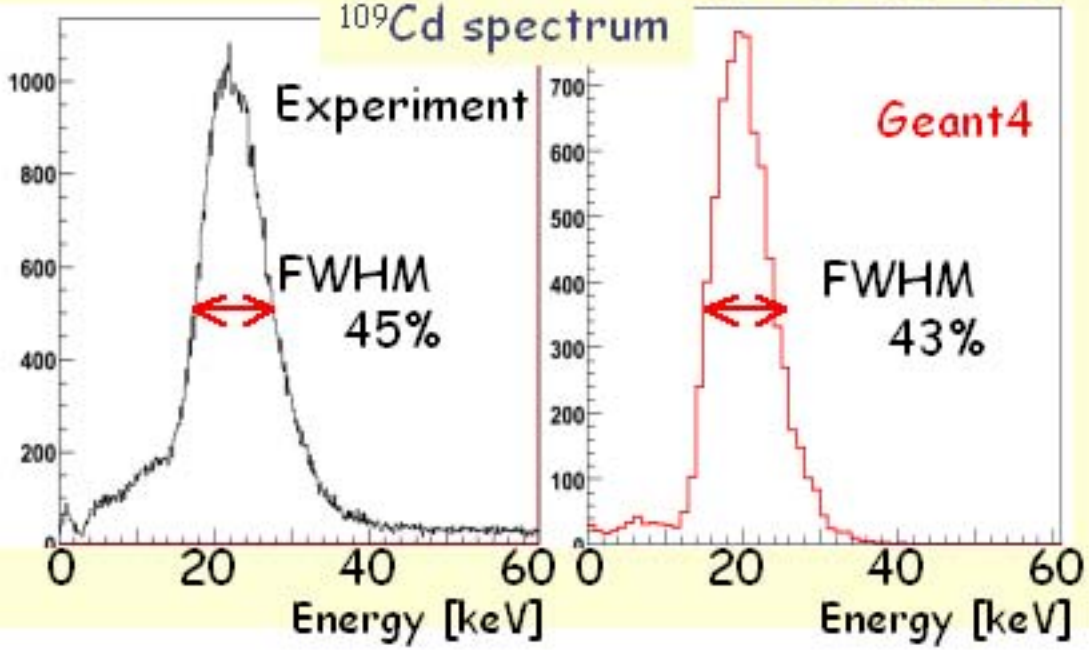
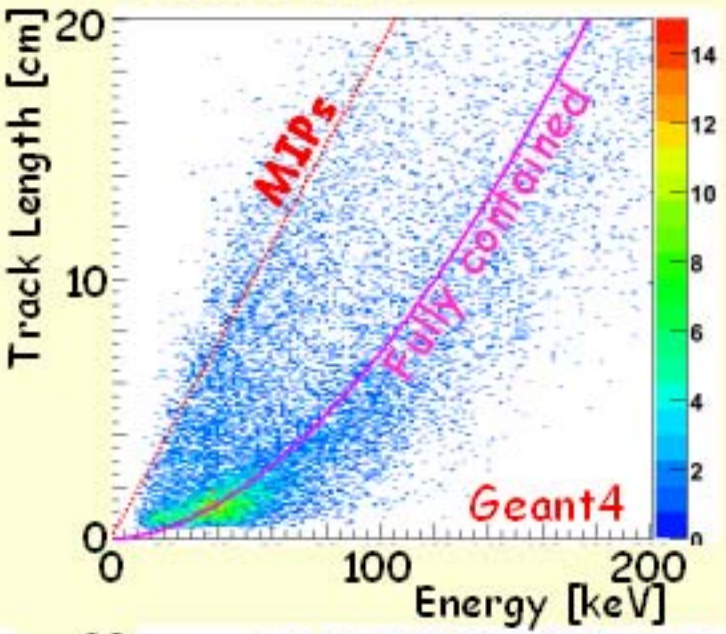
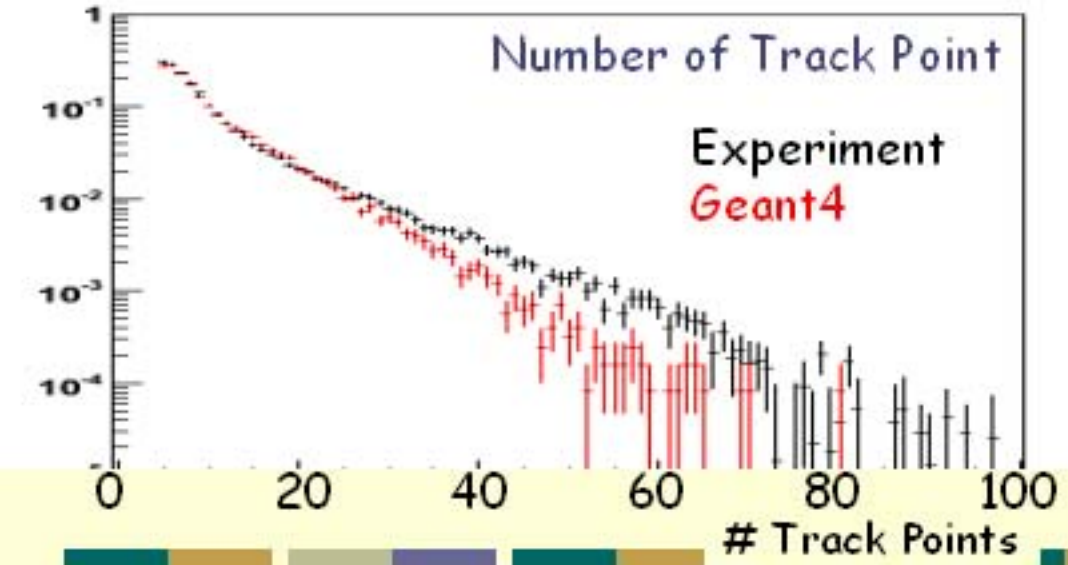


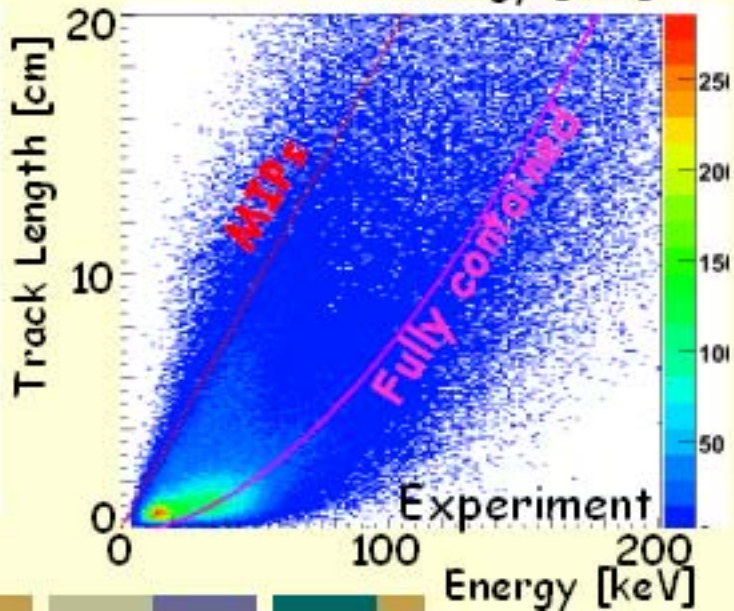
X	y	Z
3.5	3.5	2
5.5	2	3
7	1	4

Simulation of Tracker



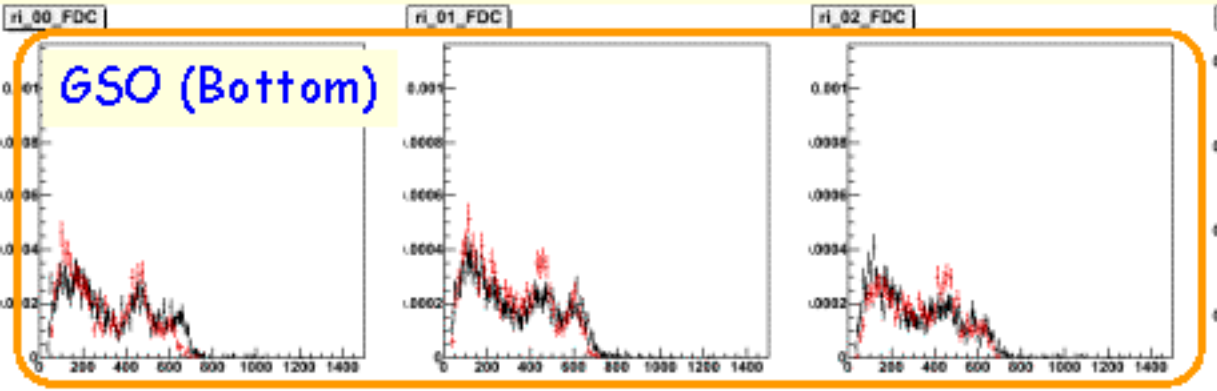


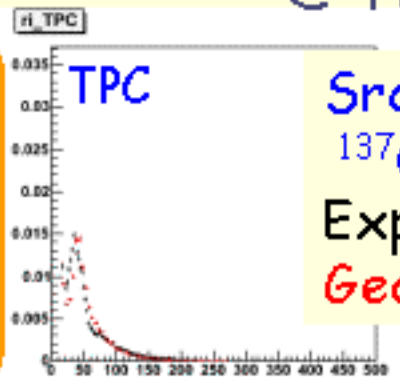




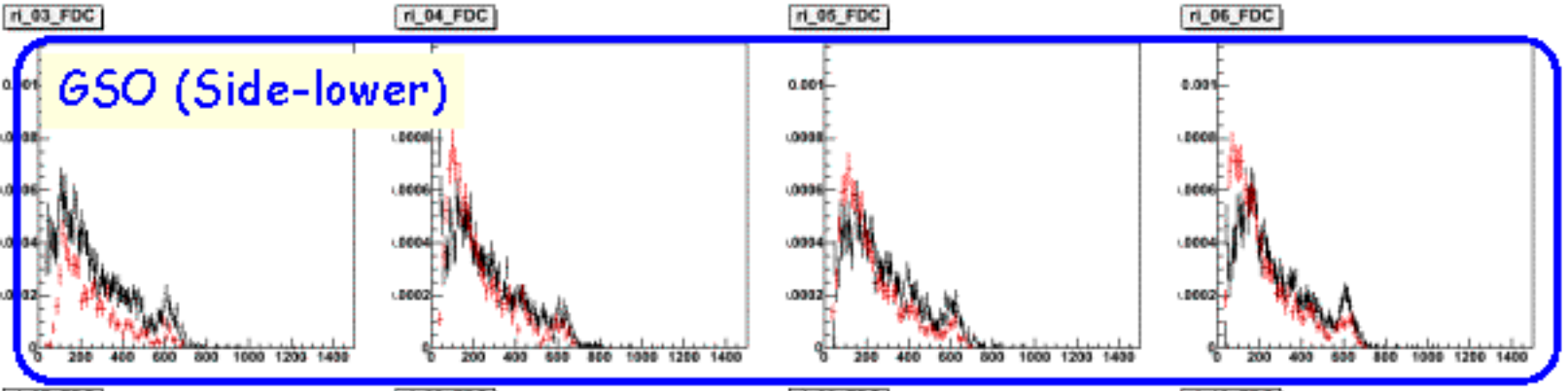
Electron Tracking Compton Camera (ETCC)

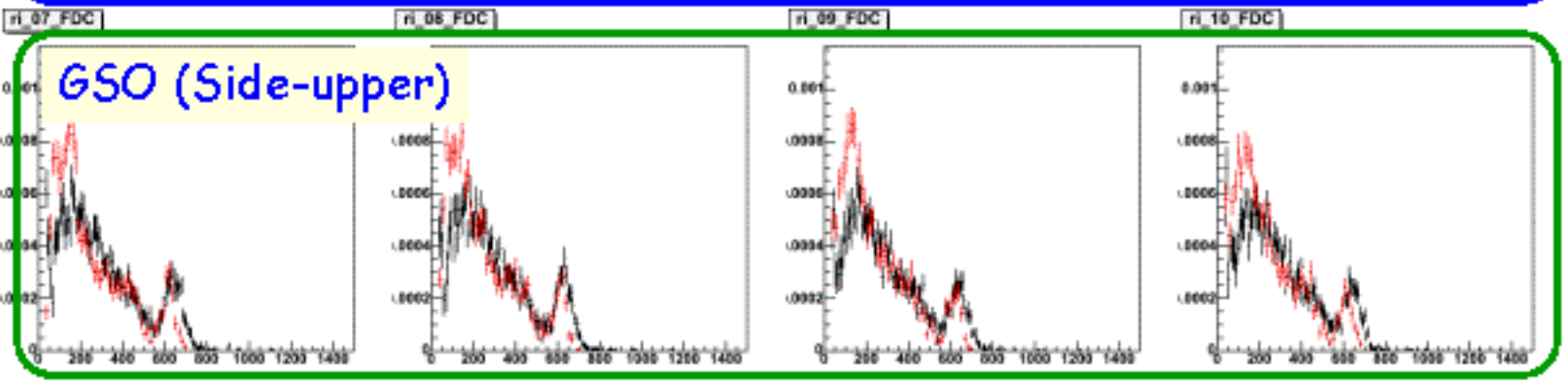
Spectra of GSO units/TPC @ fiducial cut





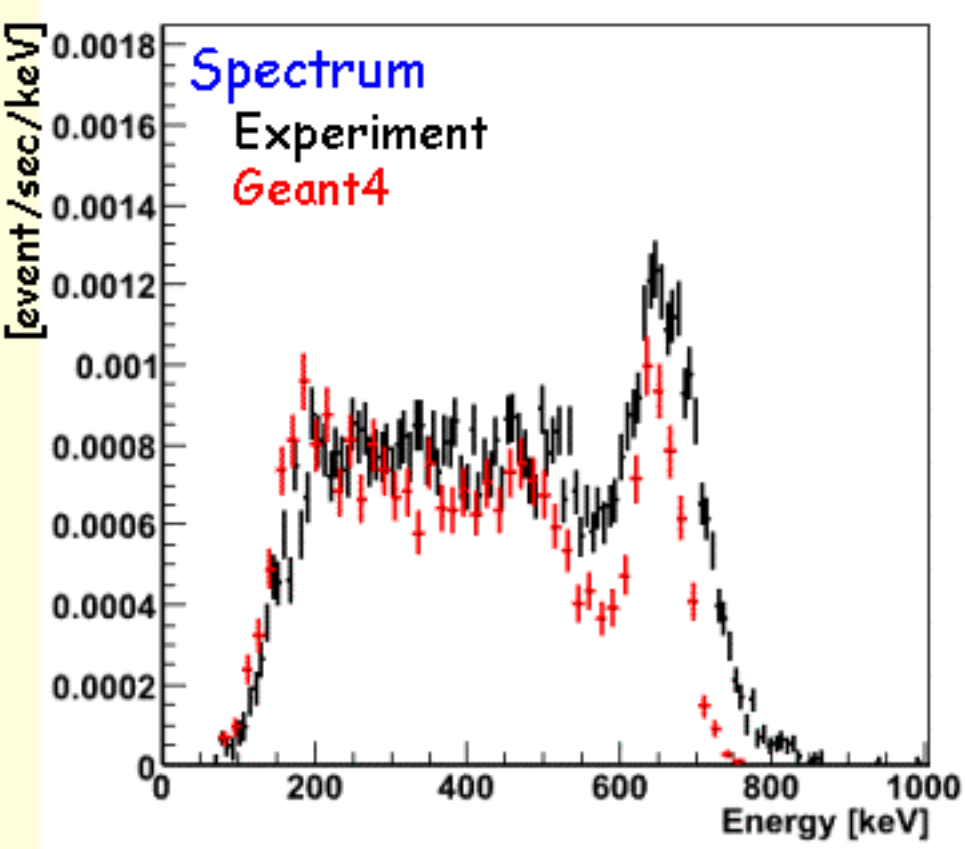
Src:
^{137}Cs (662keV)
Experiment
Geant4

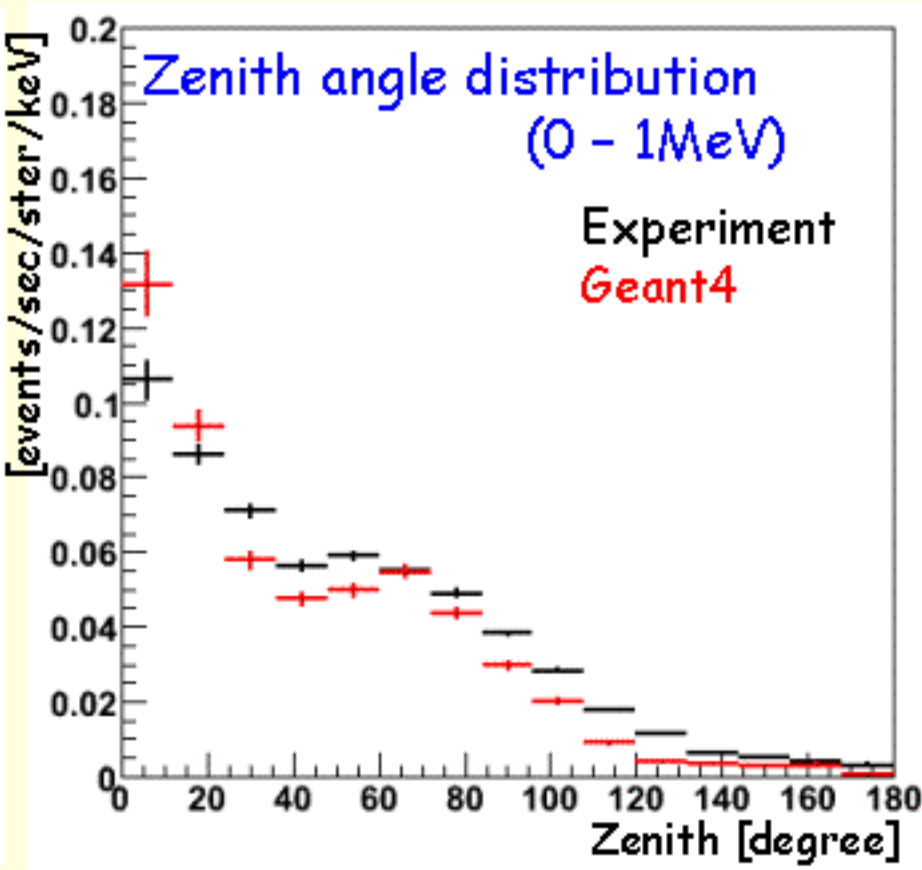




Reconstruction of gamma-ray

Src: ^{137}Cs (662keV), on-axis, 55cm from window



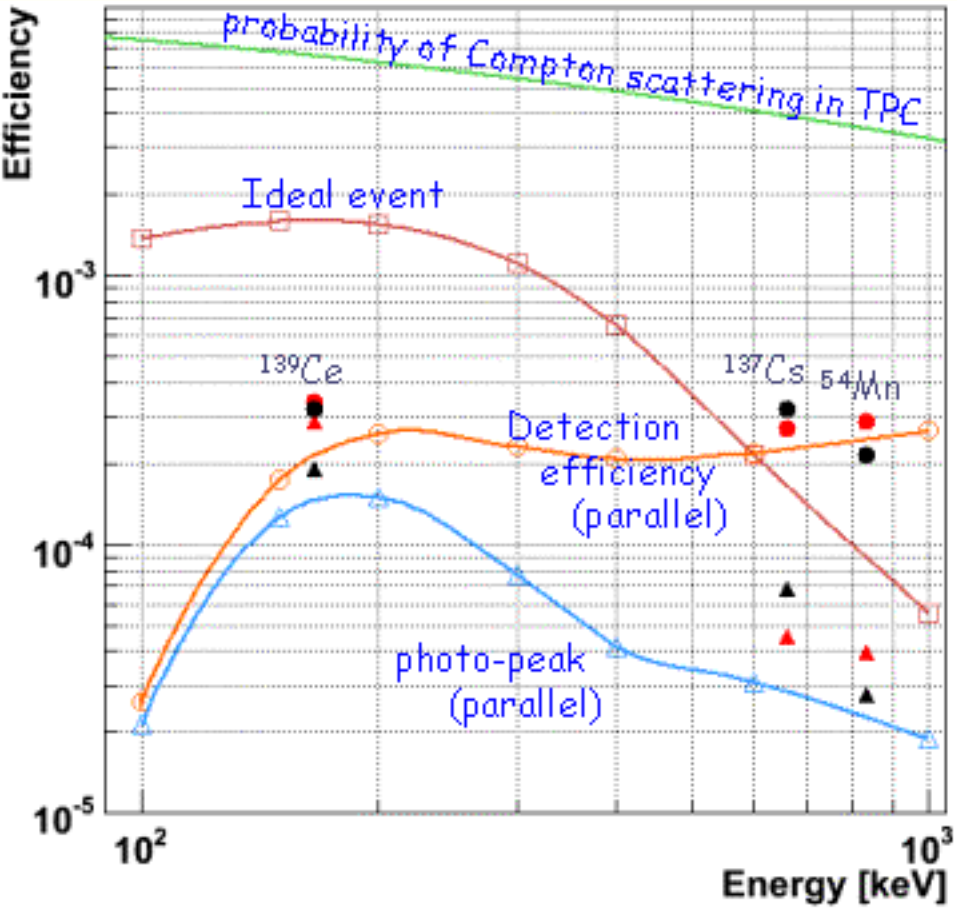


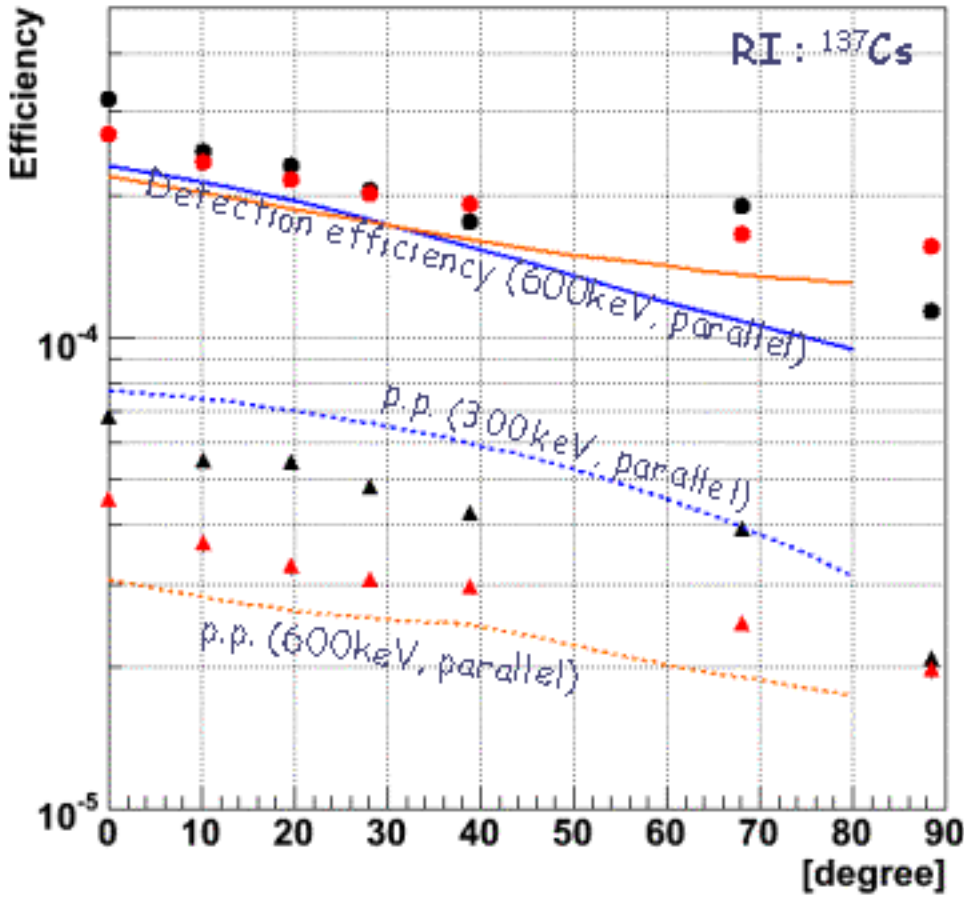
- We succeeded in the reconstruction of gamma-rays by both experiment and simulation.
- The simulation are roughly consistent with the experiment.

Detection Efficiency & FOV

●: Detection Efficiency for RI source
▲: Photo-peak for RI source

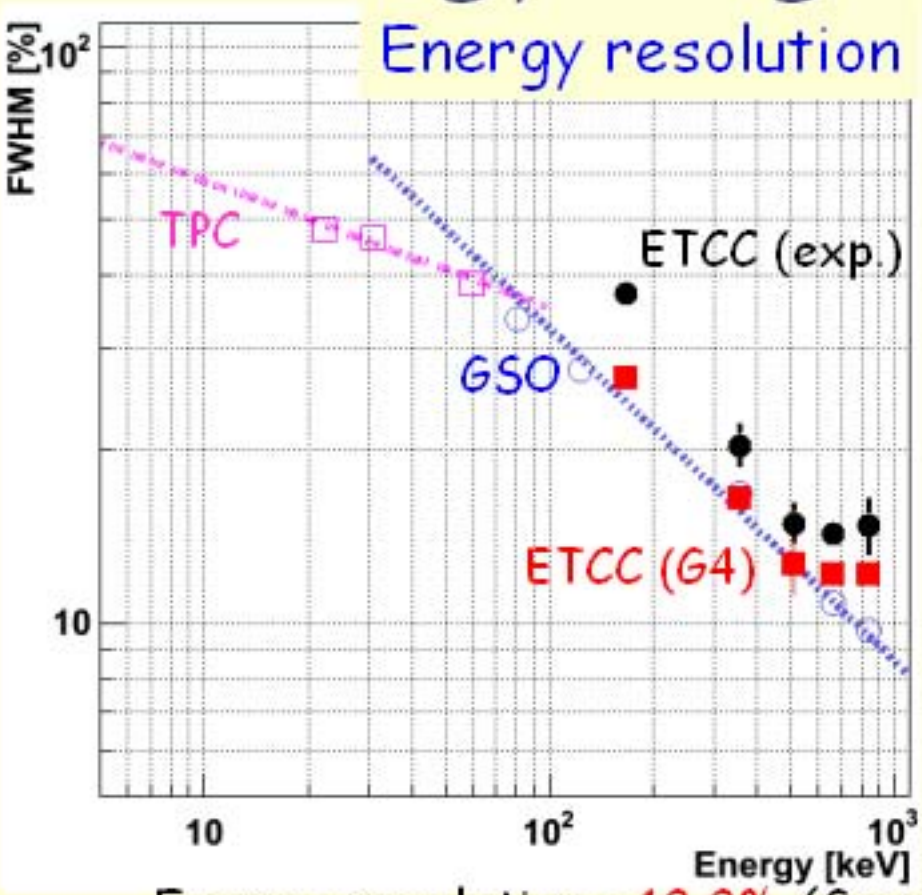
Black : Experiment
Red : Geant4

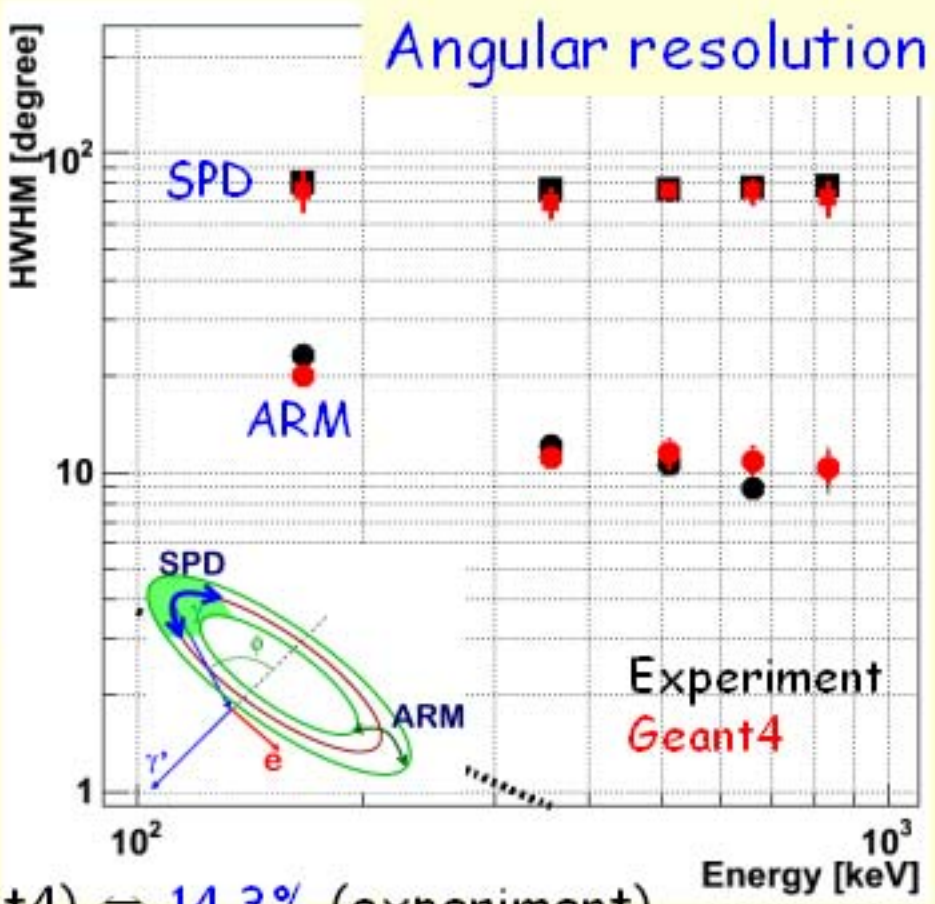




Detection efficiency : ~2.5×10^{-4}
Field Of View : ~4 steradian (FWHM)

Energy/Angular Resolution





Energy resolution : 12.2% (Geant4) ⇔ 14.3% (experiment)
@ 662keV FWHM

Angular resolution : ARM 10.9° (Geant4) ⇔ 8.9° (experiment)
SPD 75.1° (Geant4) ⇔ 77.8° (experiment)
@ 662keV HWHM

Summery & Future Work

- We constructed the simulator for the Electron Tracking Compton Camera (ETCC).
- Absorber :

  Energy resolution, Distorted image ⇒ roughly consistent
- Tracker :

  Energy resolution, Tracking ⇒ roughly consistent
- ETCC :

  Detection Efficiency, Energy resolution, Angular resolution

  ⇒ roughly consistent with calibration

In more detail...

- Gas gain distribution for 1 electron
- Update the response template of preamp
- Electrical noise
- etc...

⇒

- Check the rejection power for p/n
- Background simulation at balloon altitude
- Study for the analysis
- Design for the next balloon experiment