Development of an advanced Compton camera with gaseous TPC and scintillator

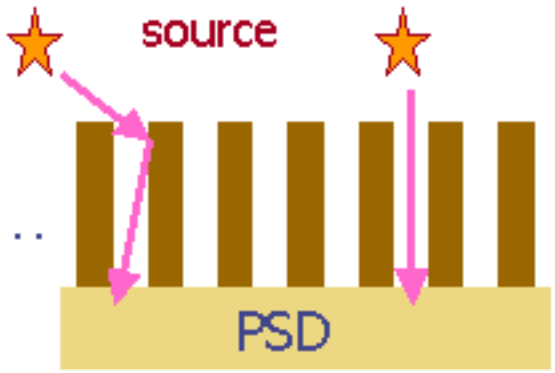
Kyoto University
dept. of physics

A.Takada,

K.Hattori, H.Kubo, K.Miuchi, T.Nagayoshi,
H.Nishimura, Y.Okada, R.Orito, H.Sekiya,
A.Takeda, T.Tanimori

- MeV gamma-ray imaging
  & Compton imaging
- μ-PIC & micro-TPC
- performance of prototype camera
- summary

MeV gamma-ray imaging for single gamma



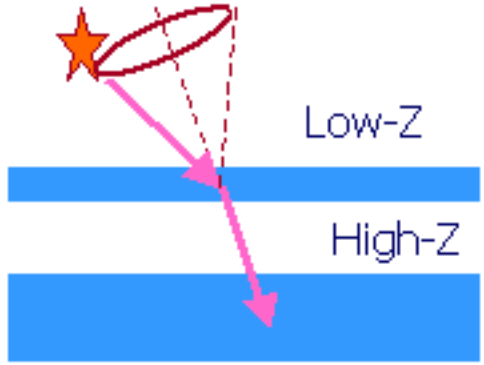
sub MeV ~ MeV gamma-ray Imaging for…

- MeV gamma-ray Astronomy
- Medical Imaging (SPECT/PET)

➢ Collimator + position-sensitive detector

⇒ SPECT, OSSE(CGRO satellite)

- narrow FOV
- background from collimator
- Energy < 1MeV

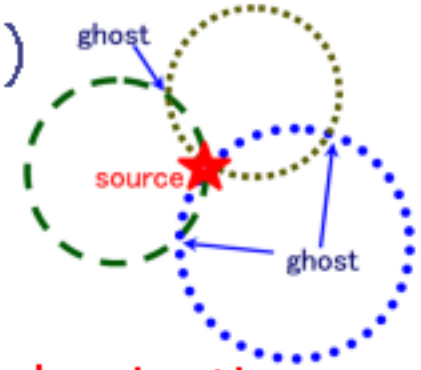


➢ Classical Compton imaging

⇒ Compton CT, COMPTEL(CGRO satellite)

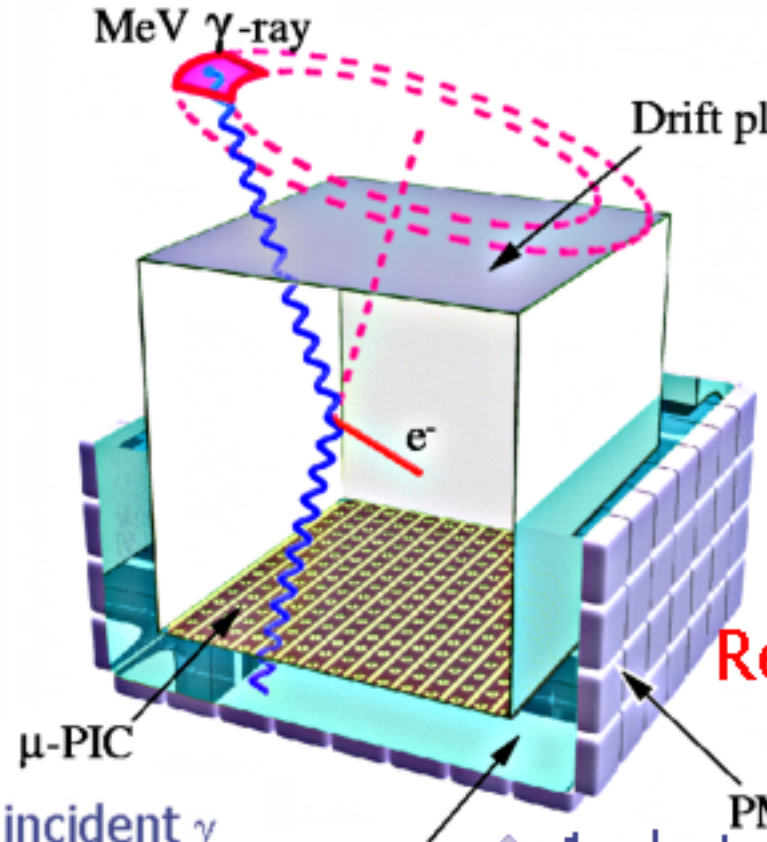
- only event circle $\cos\phi = 1 - m_e c^2 \left(\frac{1}{E_2} - \frac{1}{E_1 + E_2}\right)$
- no background rejection
- direction of recoil electron is unknown

Single Compton



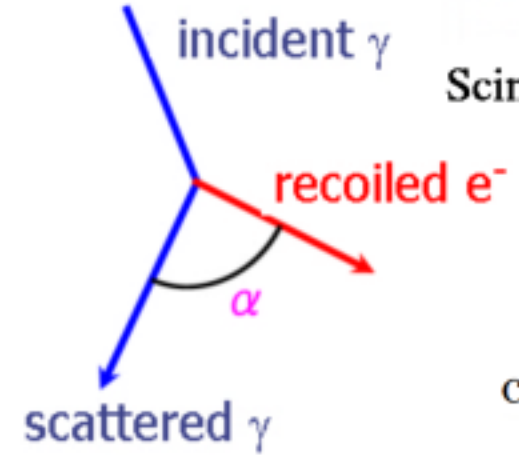
⇒ A new method with a good background rejection

Advanced Compton Imaging



- micro-TPC (μ-PIC)
  track and energy of recoil electron
- Scintillator
  position and energy of scattered gamma

Reconstruct Compton scattering event by event

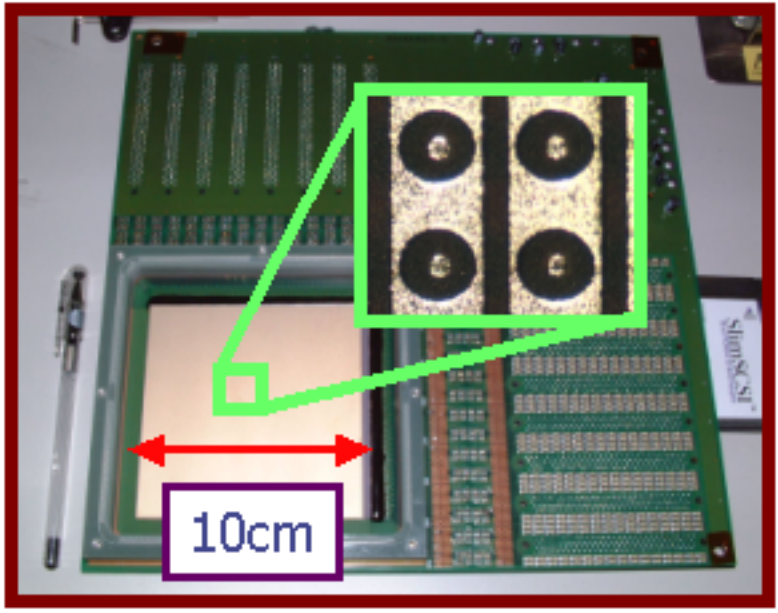


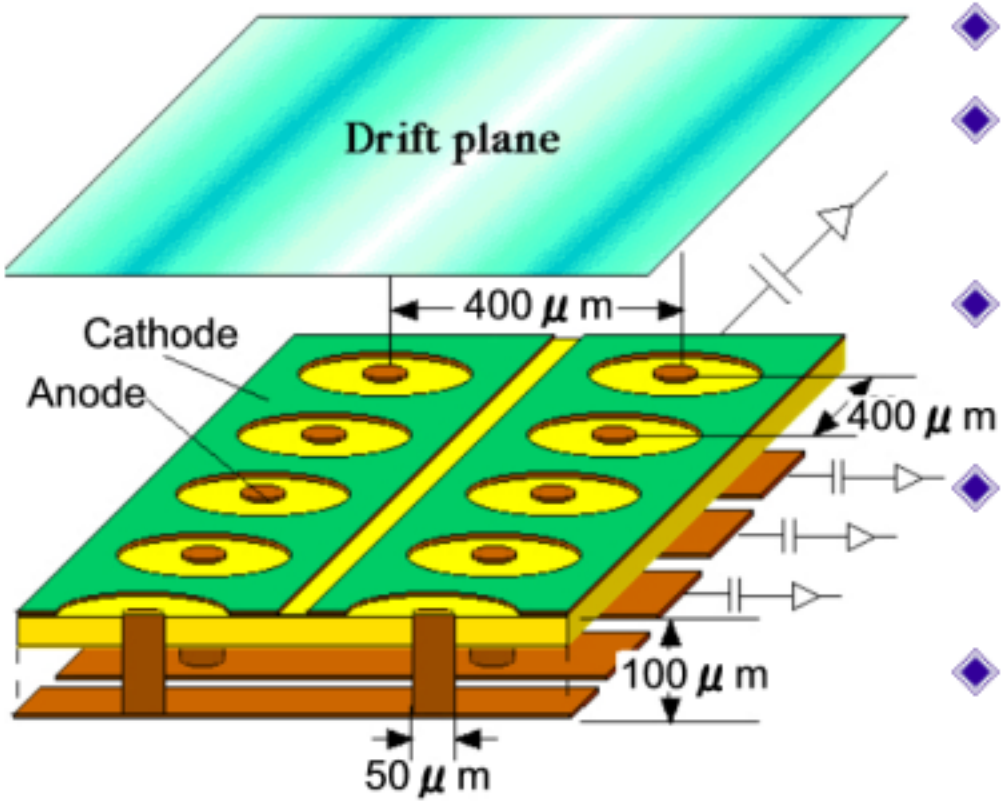
- 1 photon ⟹ direction + energy
- Large FOV (~3str)
- Kinematical background rejection

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

The character and structure of μ-PIC

- 2D readout (~65000pixels)
- Large detection area (10cm×10cm)
- Print Circuit Board technology



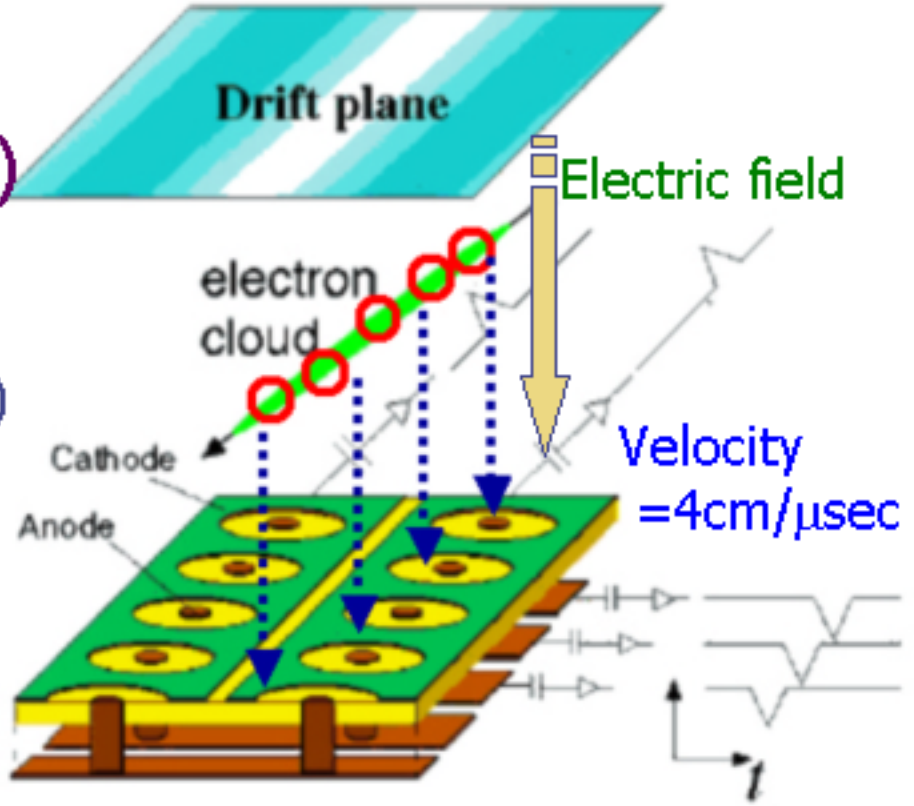


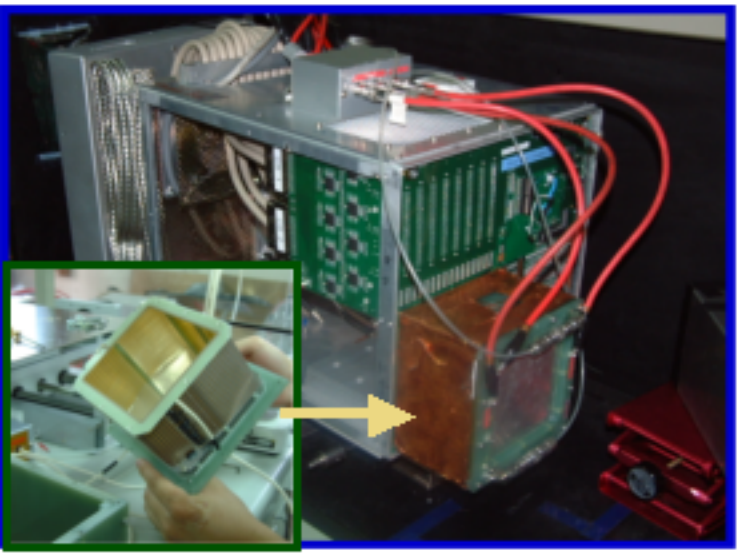
- max gas gain ~16000
- energy resolution
  30% @ 5.9keV (100cm^2)
- stable operation for 1000h
  @ gas gain ~6000
- good gas gain uniformity
  4.5% @ 100cm^2
- fine position resolution
  (~120μm)

micro-TPC
(Time Projection Chamber)

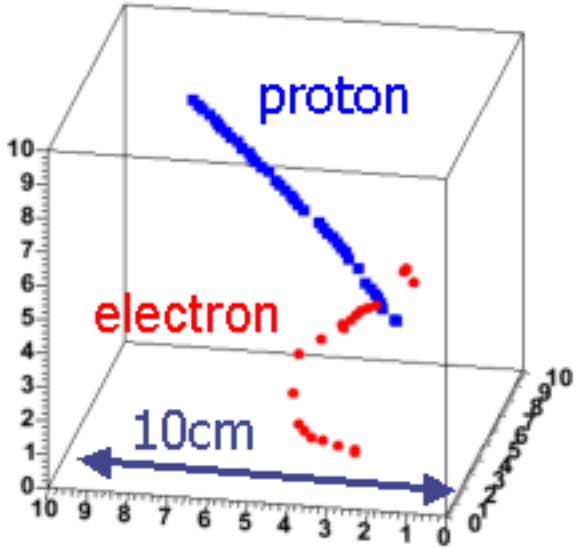
- ✓ 10cm×10cm μ-PIC
  - $\Rightarrow$ 2D hit position
- ✓ 8cm drift cage (E=0.4kV/cm)
  - $\Rightarrow$ drift time

micro-TPC
$\Rightarrow$ 3D position information

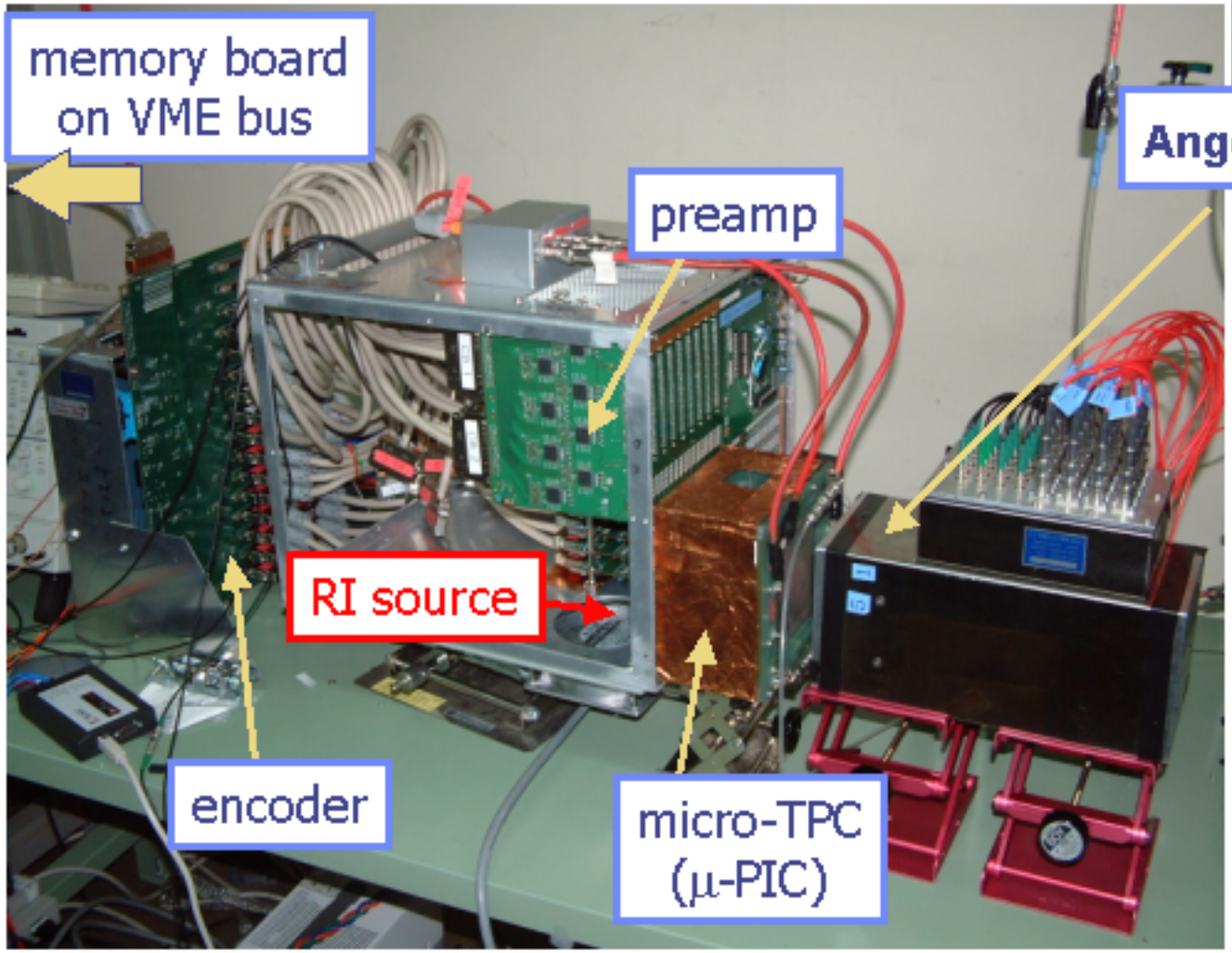


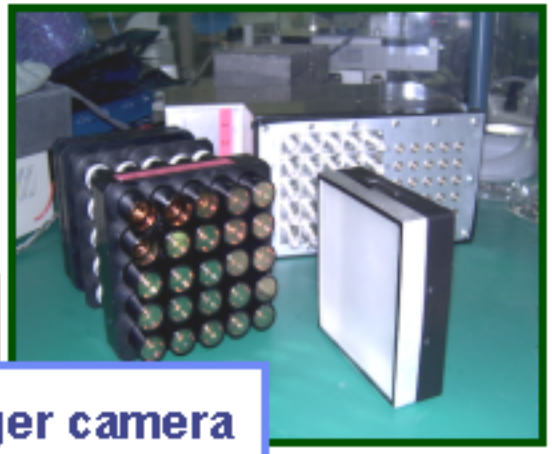


Typical tracks
Ar 90% C_2H_6 10%
gas gain ~5000
proton
E ~1MeV
electron
E ~500keV



Prototype Compton camera





micro TPC
10×10×8 cm^3
Ar +C_2H_6 (9:1)
NaI(Tl) Anger
4″×4″×1″ 25 PMTs
position resolution
~6.7mm (FWHM)
energy resolution
~9%
(662keV, FWHM)

No Veto or Shield !

Typical event

uPIC8/20031017/per1 Cs137
track 648-65

E_γ : 566.25 keV
K_e : 126.60 keV
E_0 : 692.85 keV

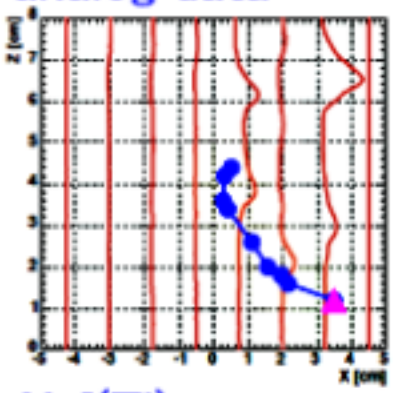
α_{geo} = 91.18°
α_{kin} = 88.14°
ϕ = 33.37°
ψ = 54.77°

$L_e \leq 1.18 \times 10^{-3} K_e^{2.2} + 1$
$\alpha_{geo} \geq \alpha_{kin} - 5°$
χ^2_{track} = 0.03
$|\alpha_{geo} - \alpha_{kin}|$ = 3.04°

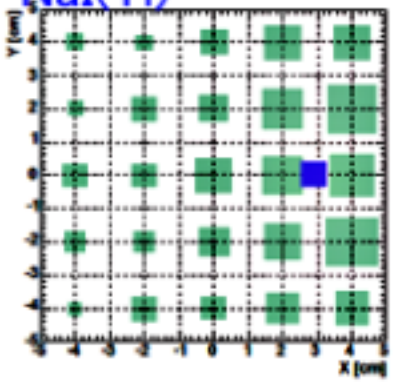
θ = 13.09°
$\Delta\phi$ = -3.11°
$\Delta\delta$ = -21.81°

● : source position
★ : reconstruted
▲ : Compton point
■ : NaI hit

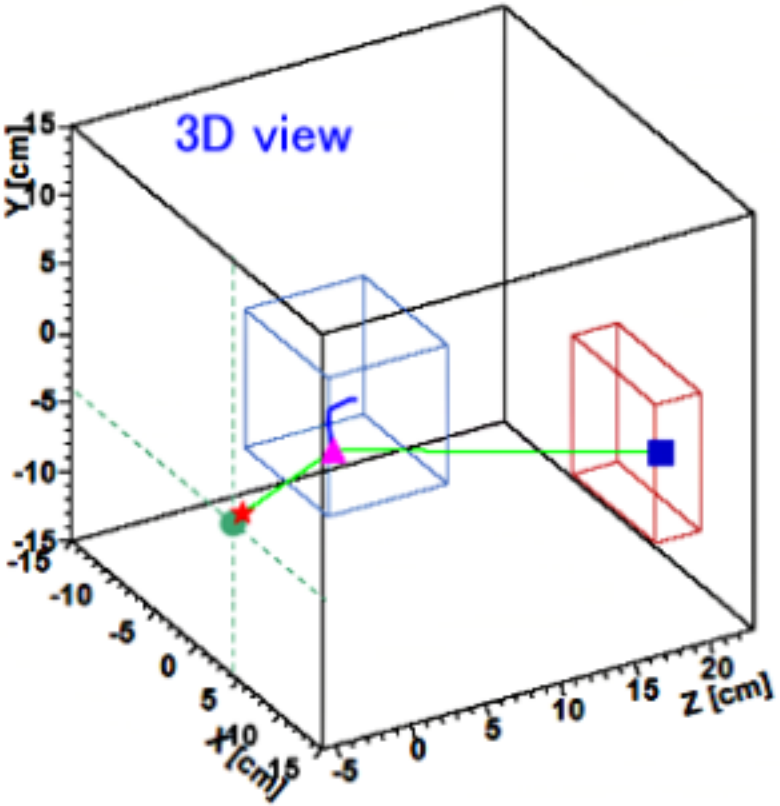
analog data



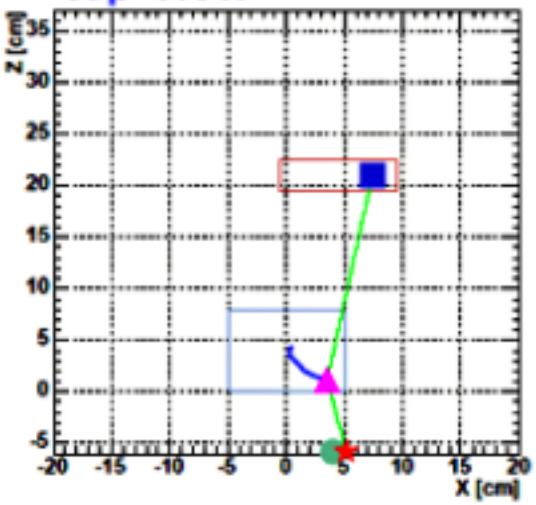
NaI(TI)



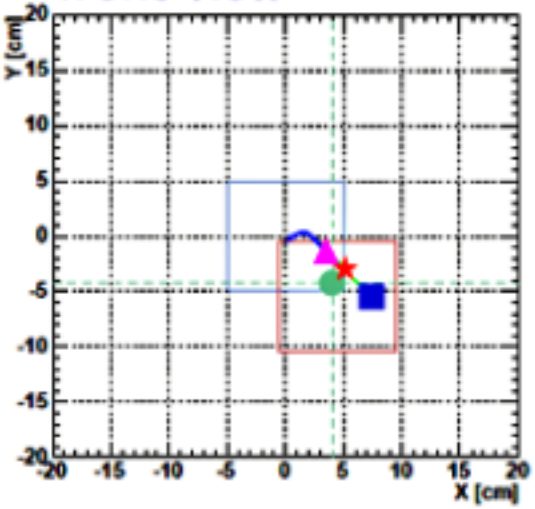
3D view



top view



front view



Gamma-ray imaging

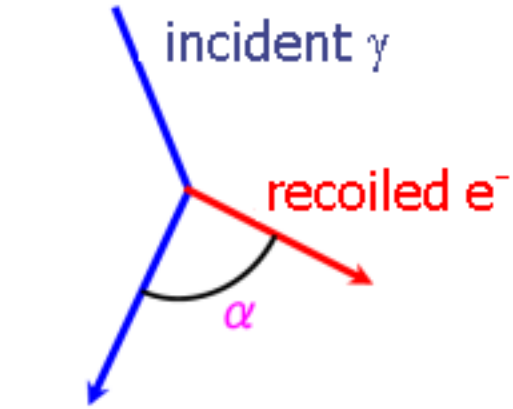
track of recoil e^-
energy and direction of scattered γ
energy of incident γ : known

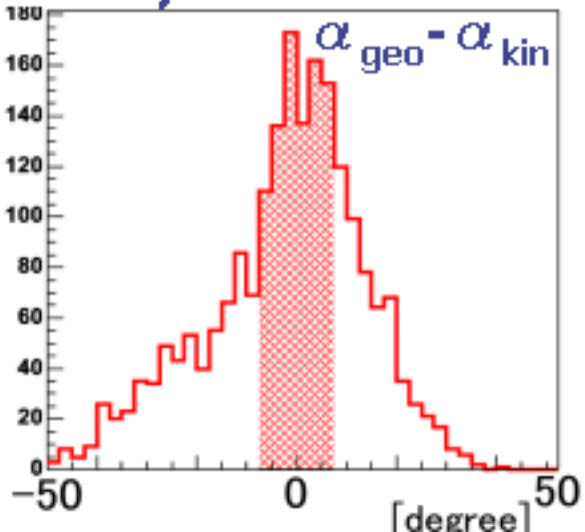
reconstruction

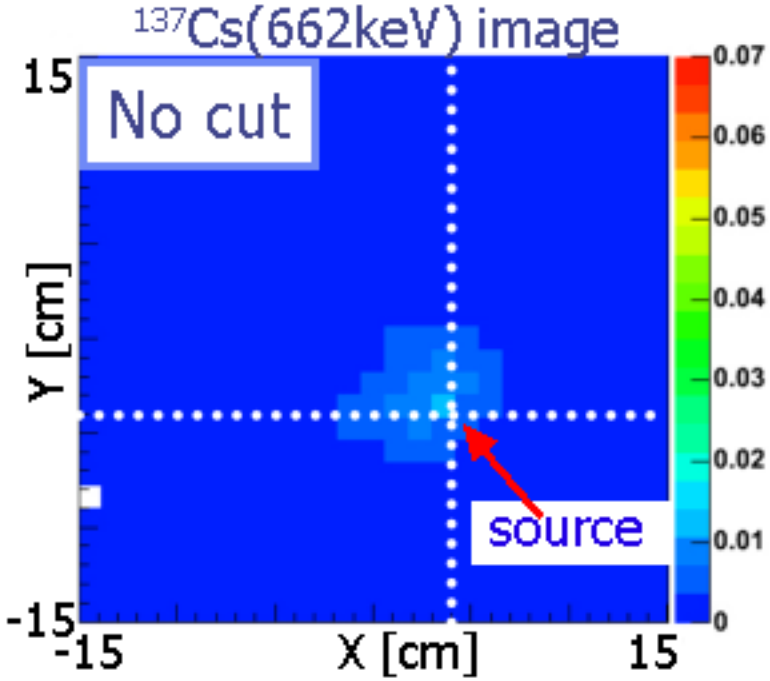
- Background rejection

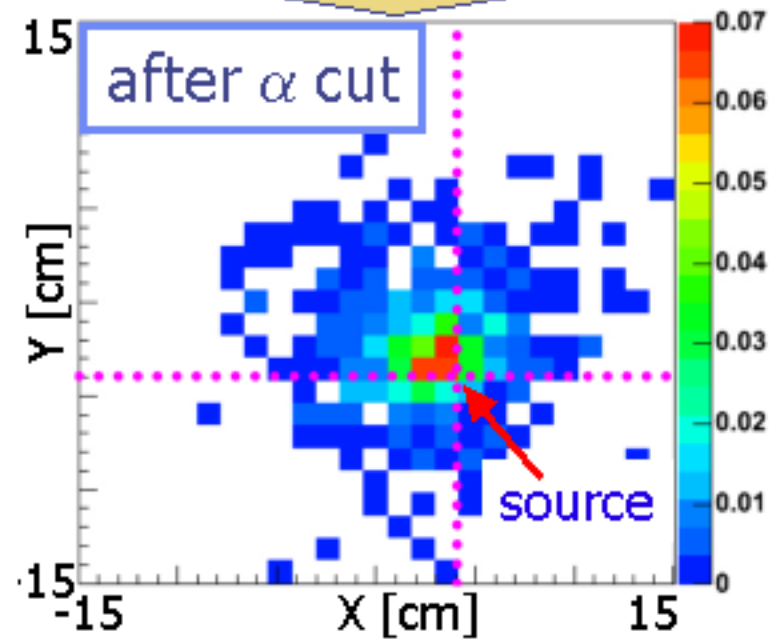
α_{geo} : measured α
α_{kin} : calculated α from energy information

α cut
$\alpha_{geo} \sim \alpha_{kin}$







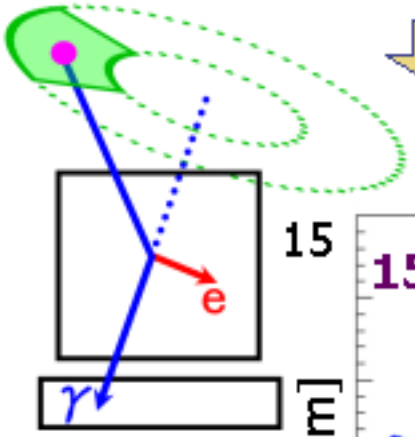


Comparison with the classical Compton method

Advanced Compton Meth.

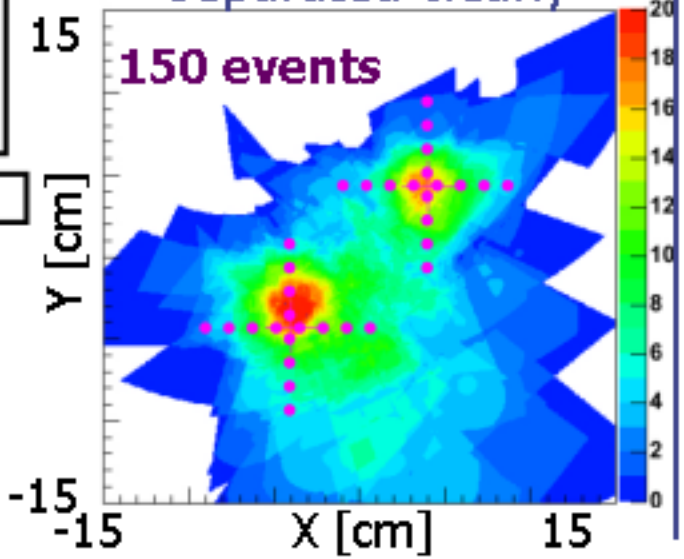
Using the electron tracks

- complete direction within sector form error region



Simply overlay

2 sources were separated clearly

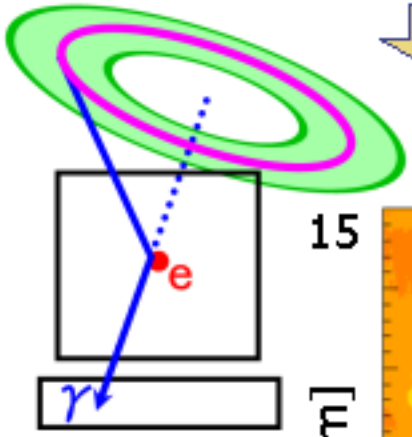


^{137}Cs(1MBq)×2, Advanced Compton

Classical Compton Meth.

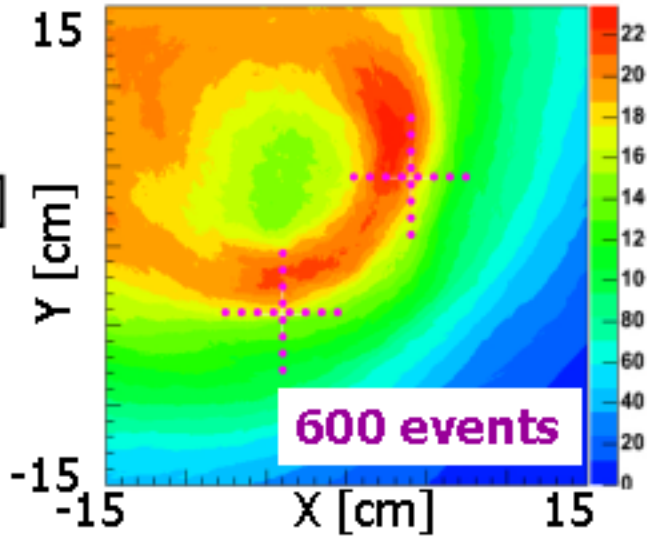
Not using the electron tracks

- only event circle within ring form error region



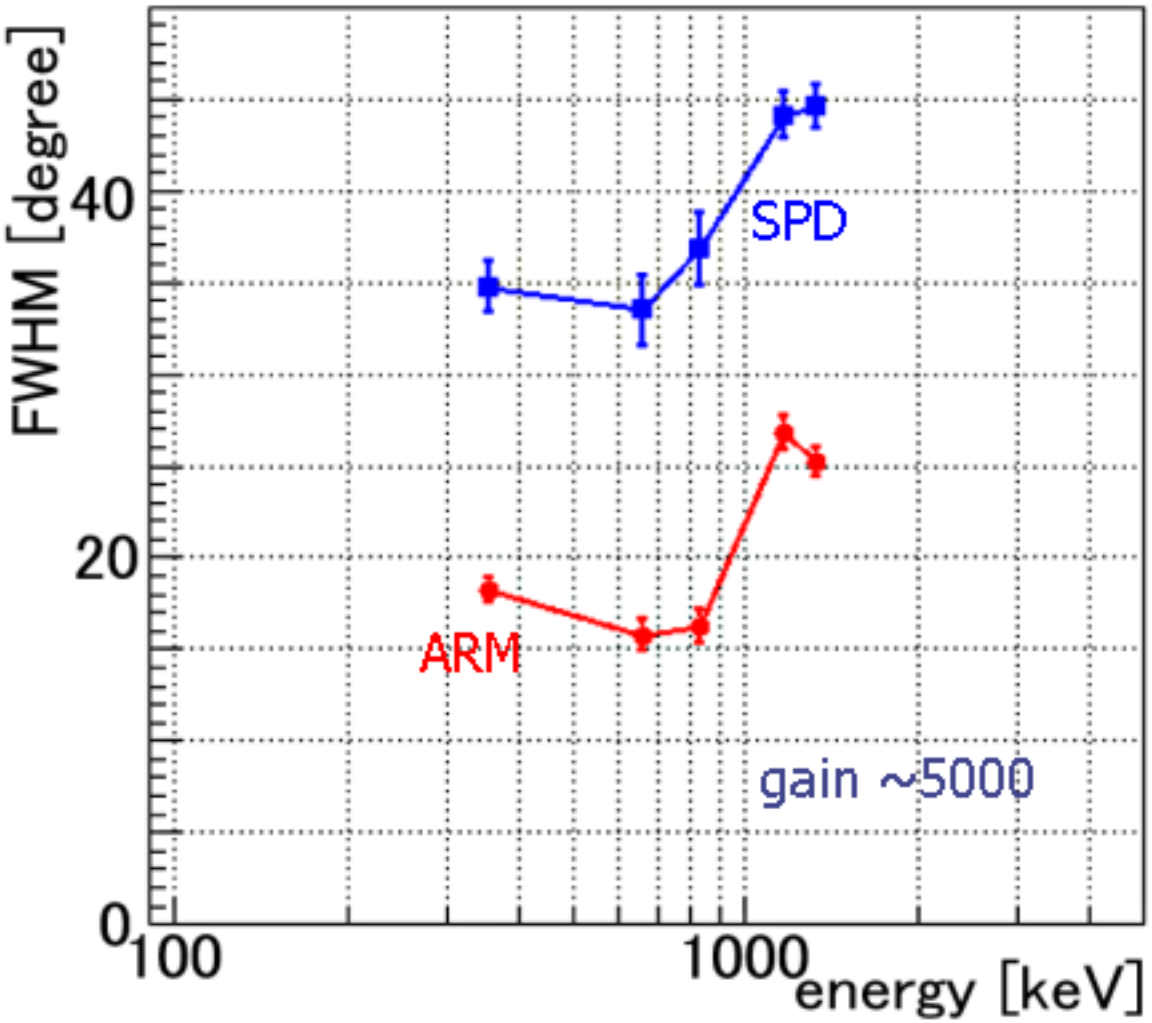
Simply overlay

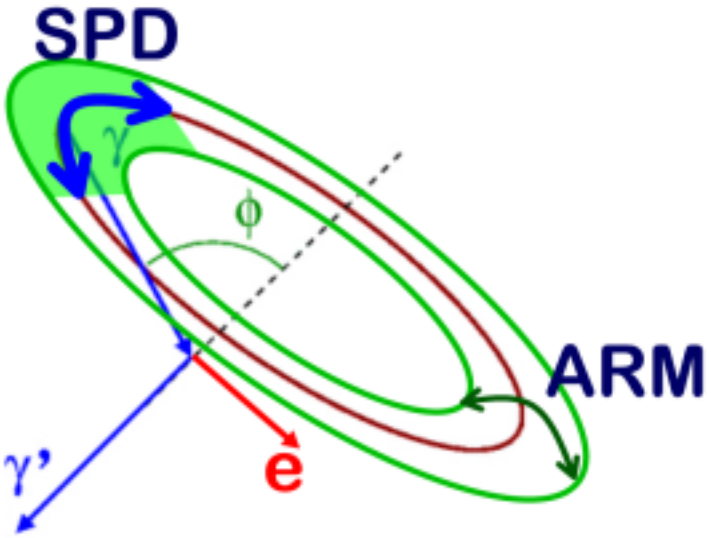
Hard to separate 2 sources



^{137}Cs(1MBq)×2, Classical Compton

Angular resolution





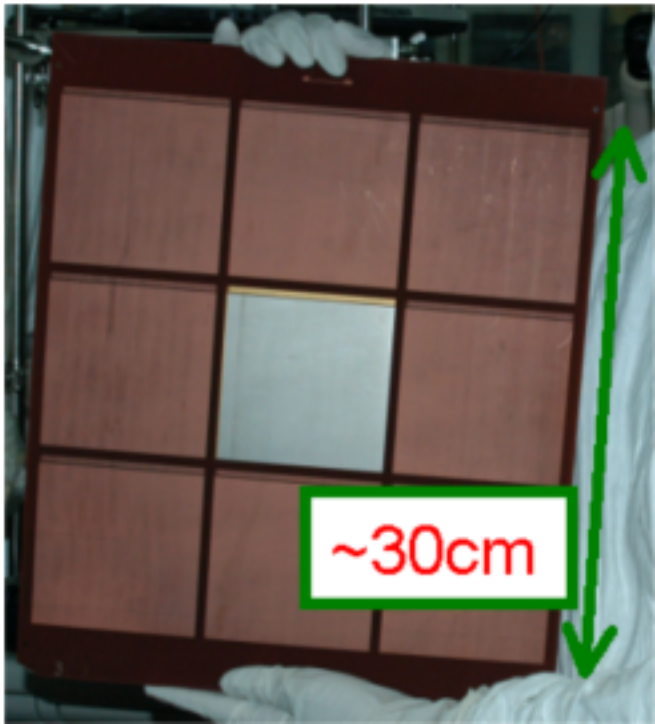
- ✓ ARM (Angular Resolution Measure) 16° @ 662keV FWHM
- ✓ SPD (Scatter Plane Deviation) 34° @ 662keV FWHM

for each gamma-ray

Prospects

- Scintillator
  : pixelization(multi-anode PMT), large area
  ⇒ higher position resolution & efficiency
- micro-TPC : 10cm cube ⇒ 30cm cube
  ⇒ catch the energy of recoil electrons
  higher efficiency
- Gas study

Pixel-type scintillator



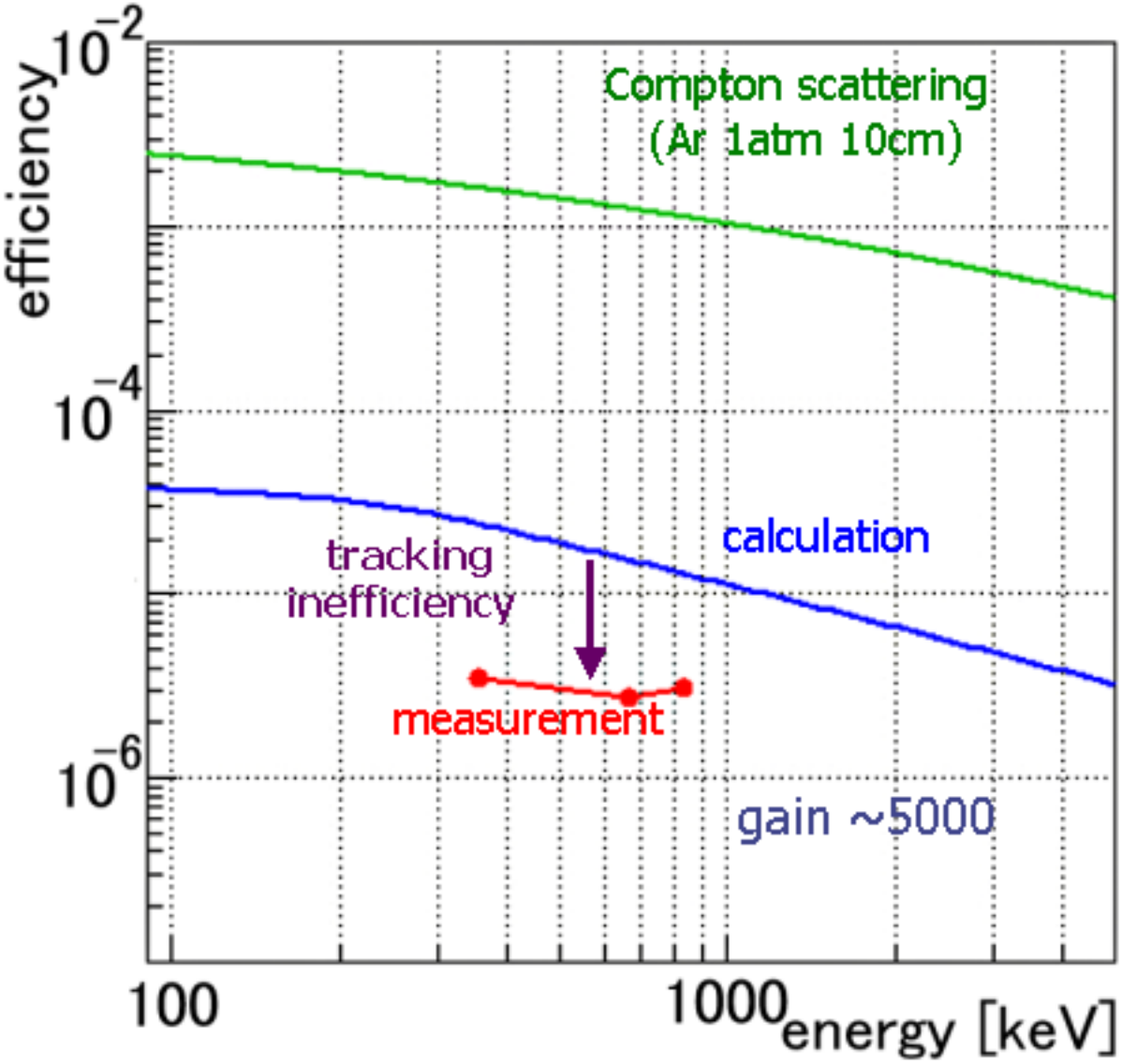
Summary

- ✓ Event by event reconstruction well established
  - ⇒ the principle was proved
- ✓ Good background rejection capability
  - ⇒ higher S/N than that of classical Compton
- ✓ Prototype performance (for 662keV)
  - ARM(FWHM) 16°
  - SPD(FWHM) 34°

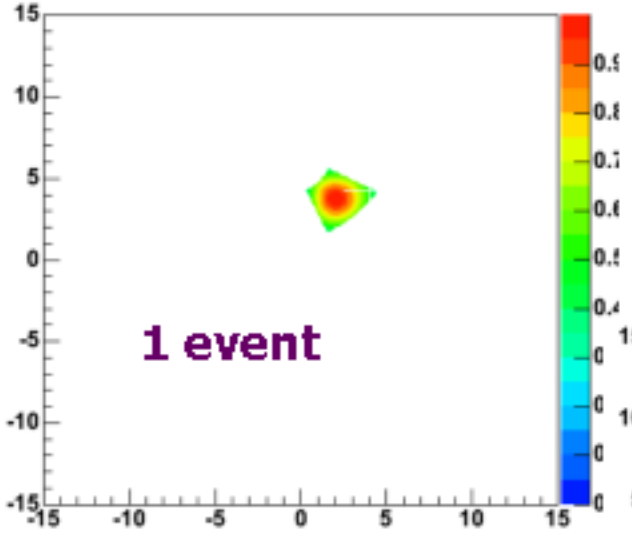
Goal	500keV(FWHM)	ARM ~7°	SPD ~20°
	1MeV(FWHM)	ARM ~5°	SPD ~10°

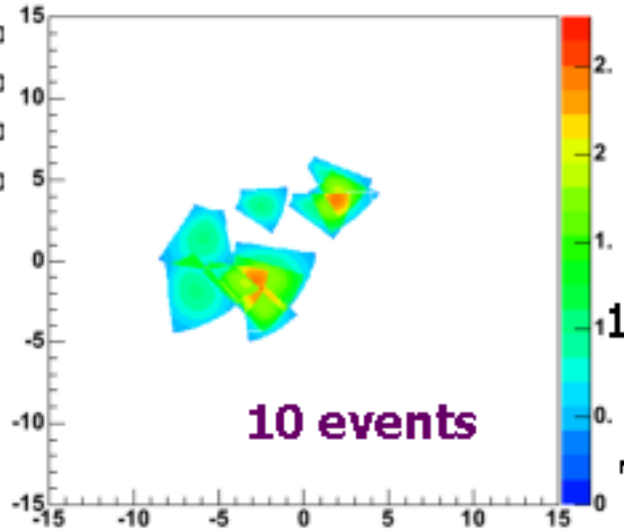
Thank you

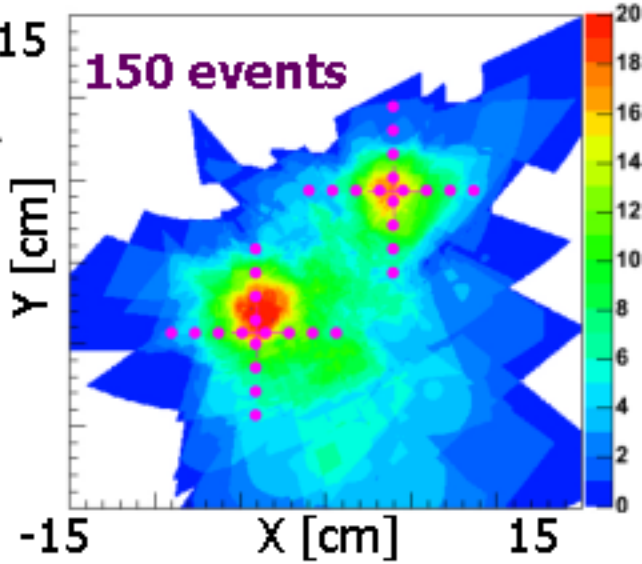
Efficiency


efficiency
10^{-2}
10^{-4}
10^{-6}
Compton scattering
(Ar 1atm 10cm)
calculation
tracking
inefficiency
measurement
gain ~5000
100
1000
energy [keV]

Simply overlay sectors



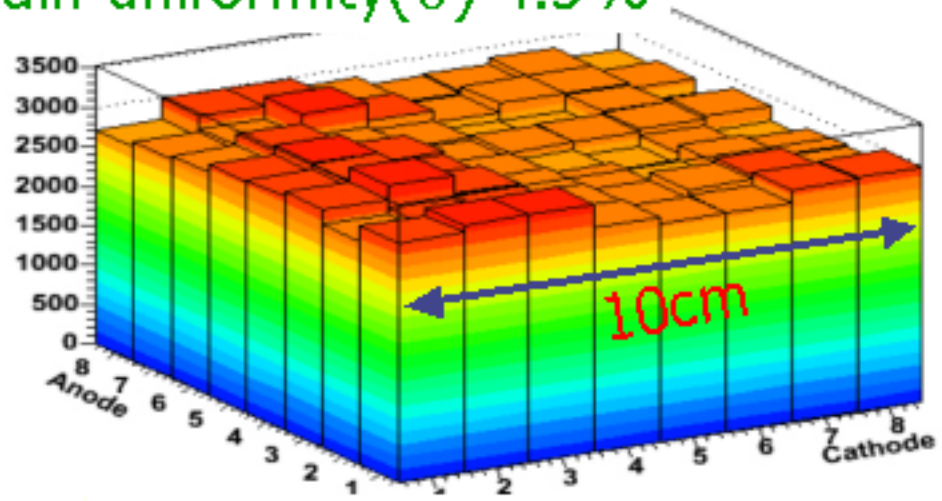




Not use Maximum Entropy Method!

μ-PIC as an X-ray detector

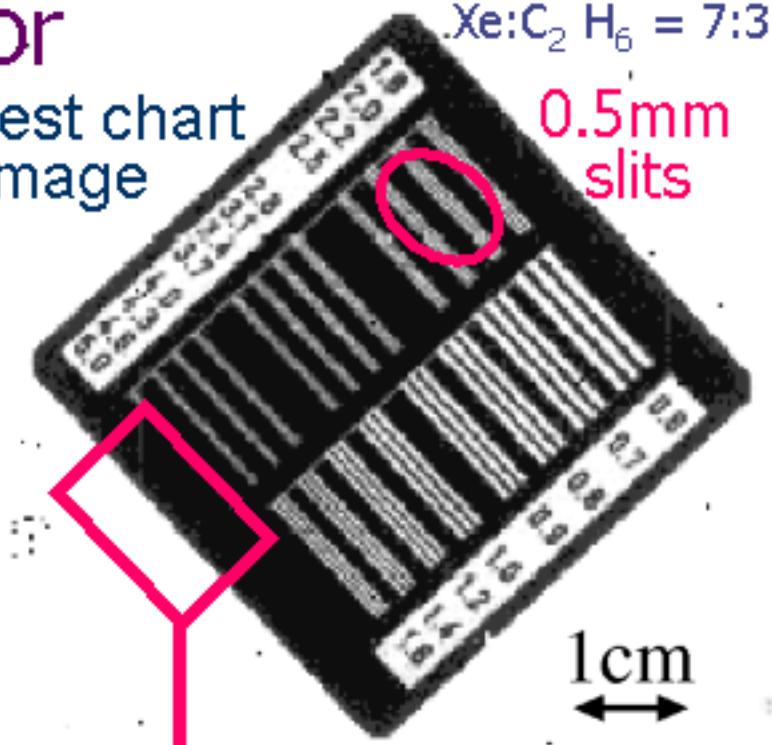
Gain uniformity(σ) 4.5%



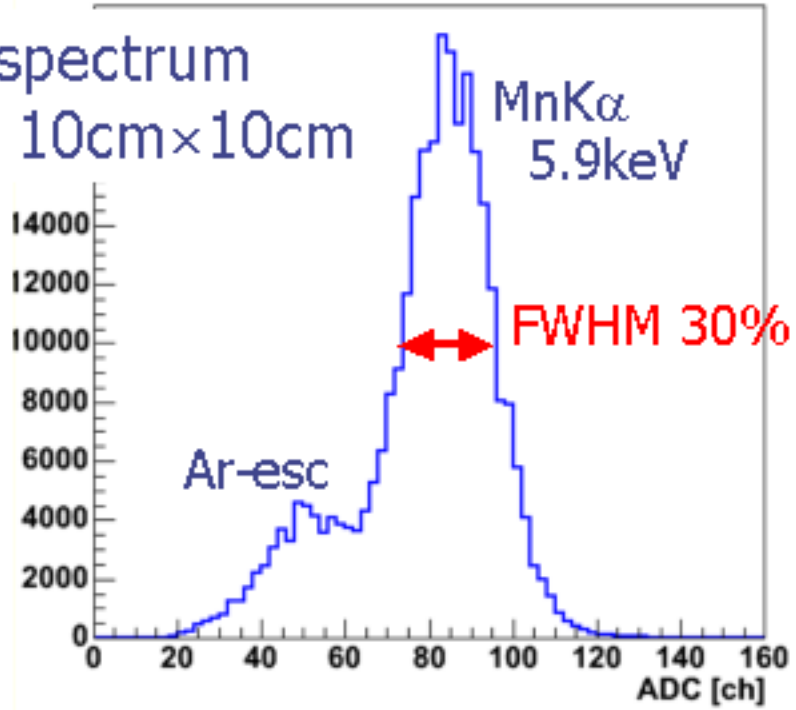
Xe:C_2H_6 = 7:3

Test chart image

0.5mm slits



^{55}Fe spectrum @ 10cm×10cm



Knife edge test