μ-PICによる MeV-γ線カメラの開発

2006/01/26 MPGD研究会

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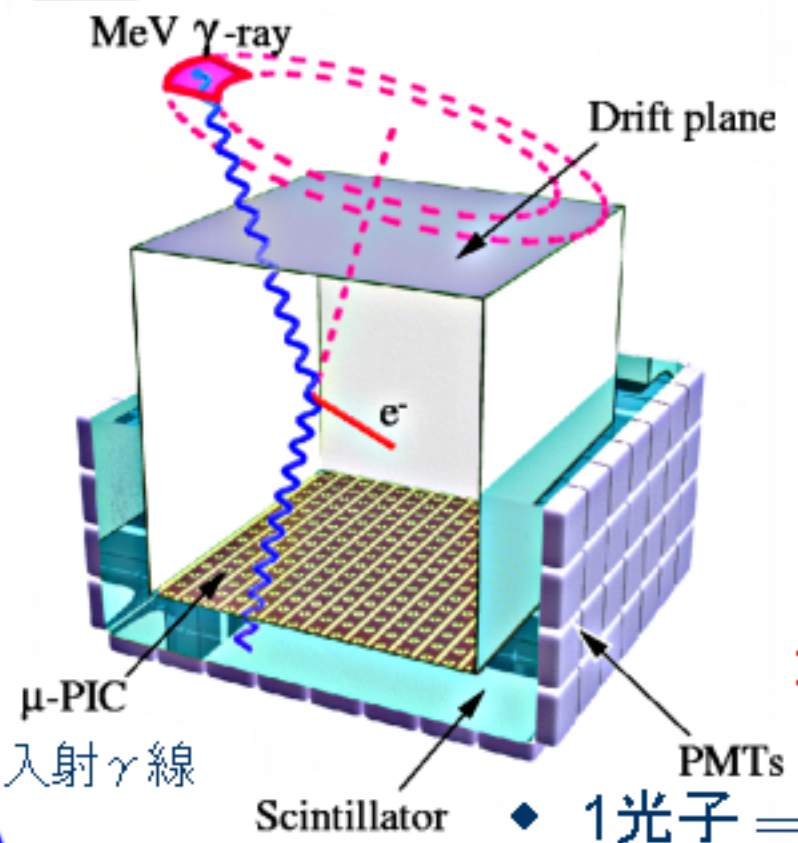
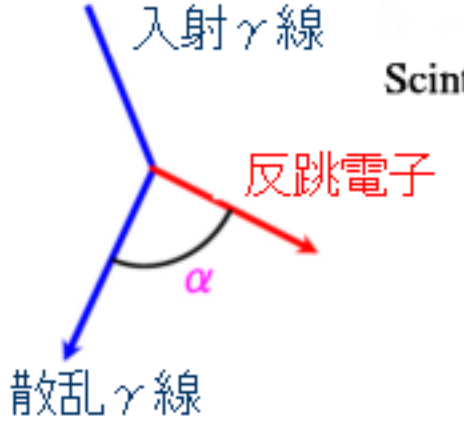
1. Advanced Compton camera
2. Components of camera
3. Performance of prototype
4. For balloon experiment

Advanced Compton Imaging



- micro-TPC (μ-PIC)
  反跳電子の飛跡とenergy
- Scintillator
  散乱γ線の吸収点の位置とenergy

光子毎にCompton散乱を再現



- 1光子 ⇒ 到来方向 + energy
- 大きな視野 (~3str)
- 強力なbackground除去能力

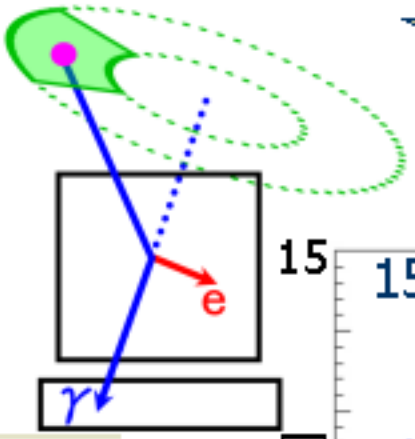
$$\cos\alpha_{\mathrm{geo}} = \vec{g}\cdot\vec{e} \Longleftrightarrow \cos\alpha_{\mathrm{kin}} = \left(1-\frac{m_e c^2}{E_\gamma}\right)\sqrt{\frac{K_e}{K_e+2m_e c^2}}$$

従来のCompton imagingとの比較

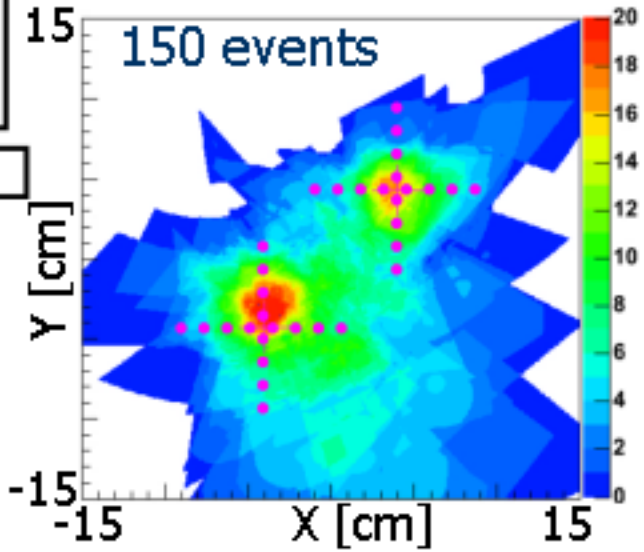
Advanced Compton法

電子の反跳方向の測定

- 到来方向を一意に決定
- 誤差は扇型



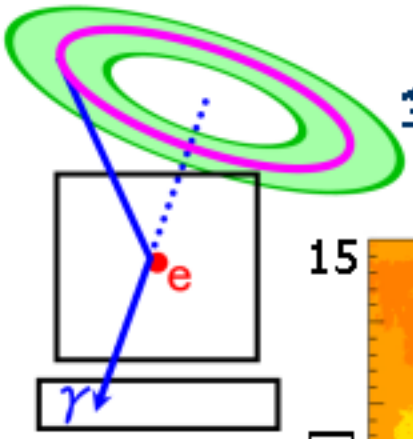
少ないeventでも
2つの線源を分離



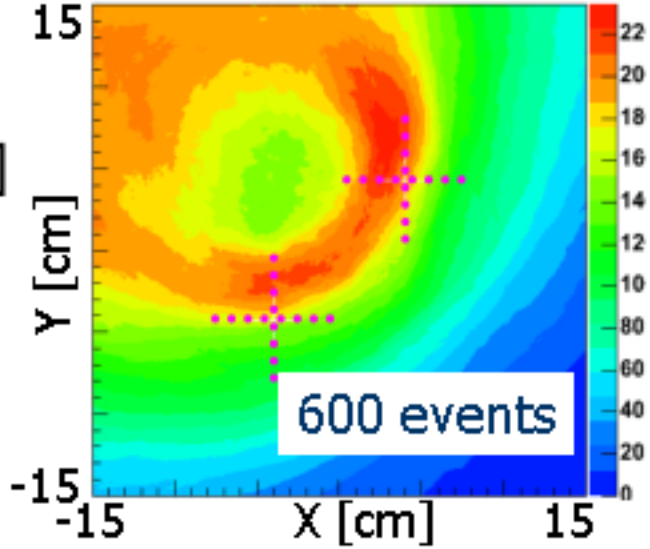
Classical Compton法

電子の反跳方向を破棄

- 到来方向を円形に制限
- 誤差はドーナツ型



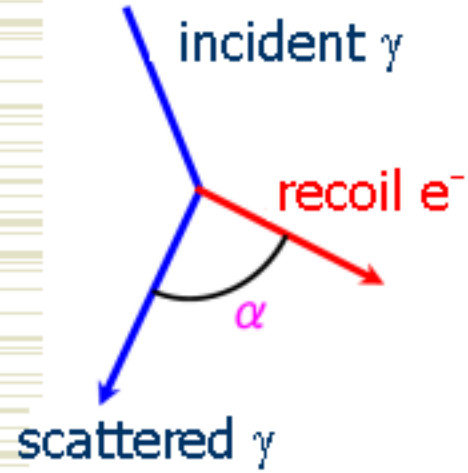
全体的に広がった
ぼけたimage

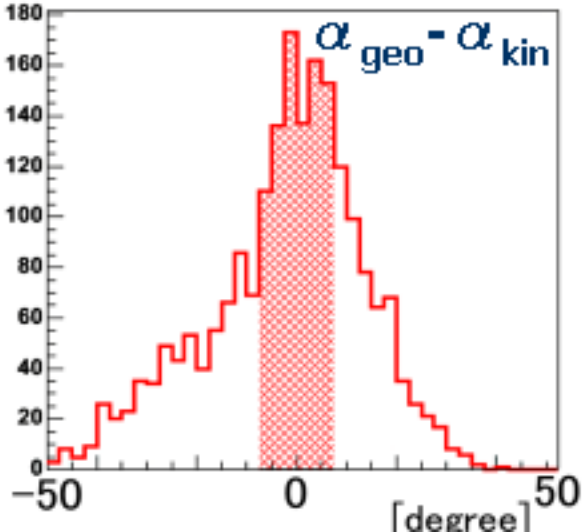


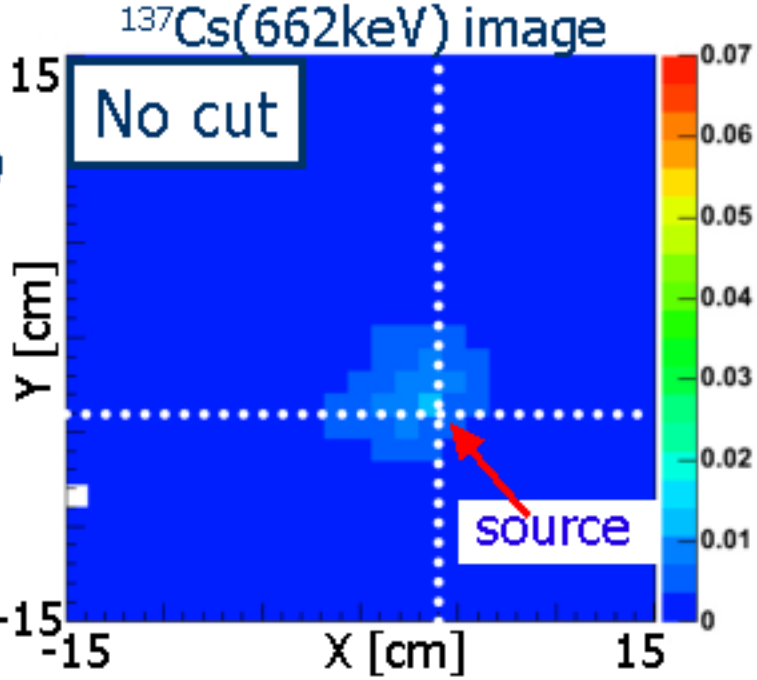
Background rejection

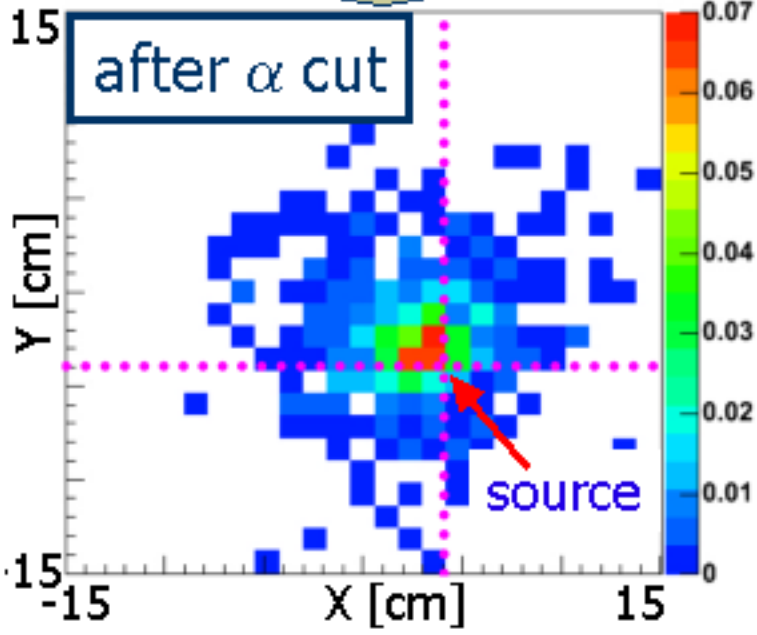
α_{geo}：幾何学的なα
α_{kin}：運動学からのα

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

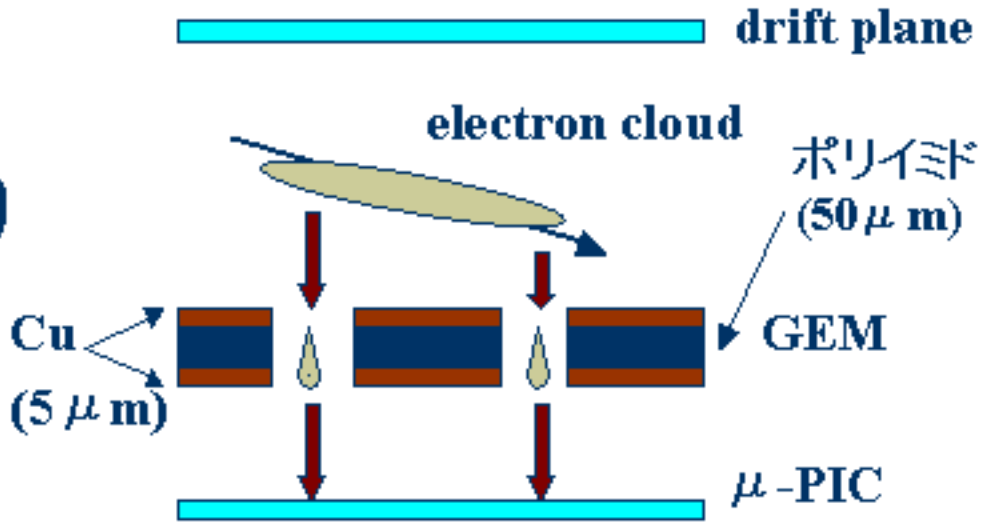






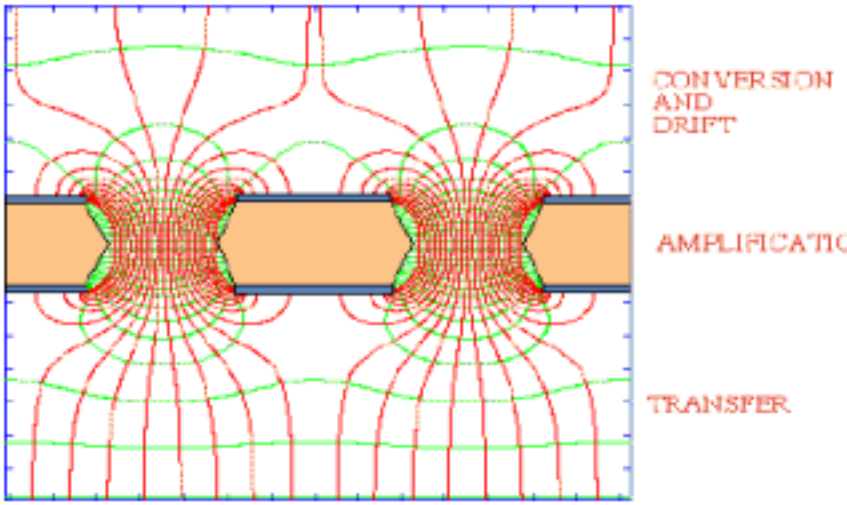


μ-TPC (1)

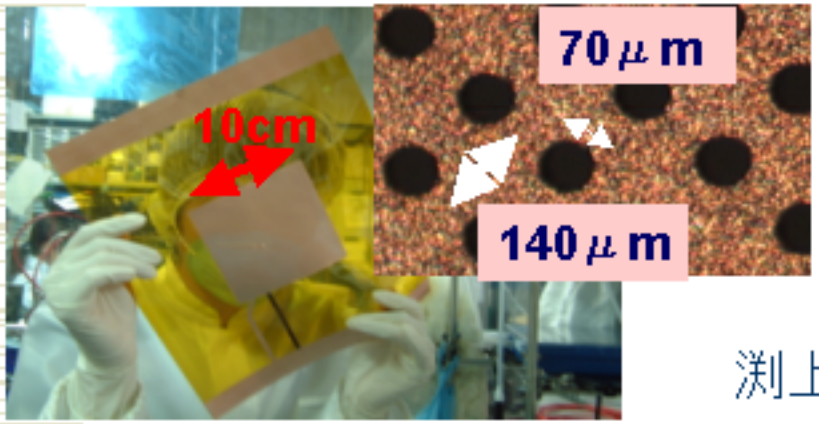


- μ-PICの安定gain : ~6000
- MIPを捕らえるのに必要なgain : > 2×10^4

GEMでちょっと増幅
→ μ-PICでもっと増幅

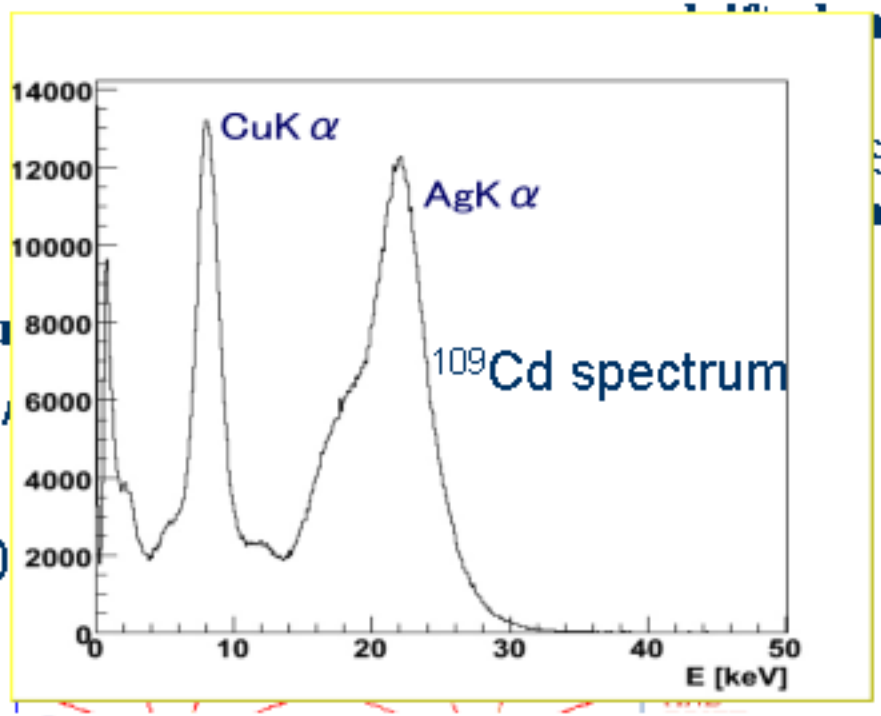


GEM (Gas Electron Multiplier)
F. Sauli et.al (1997)



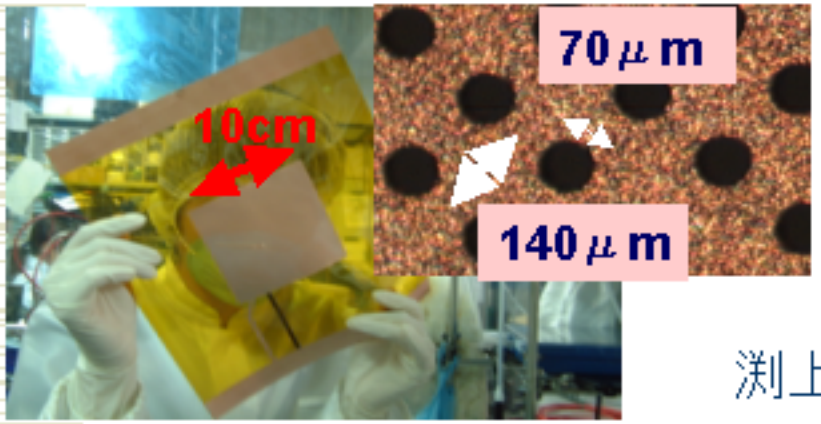
渕上ミクロ製（東大CNS浜垣研のコピー品）

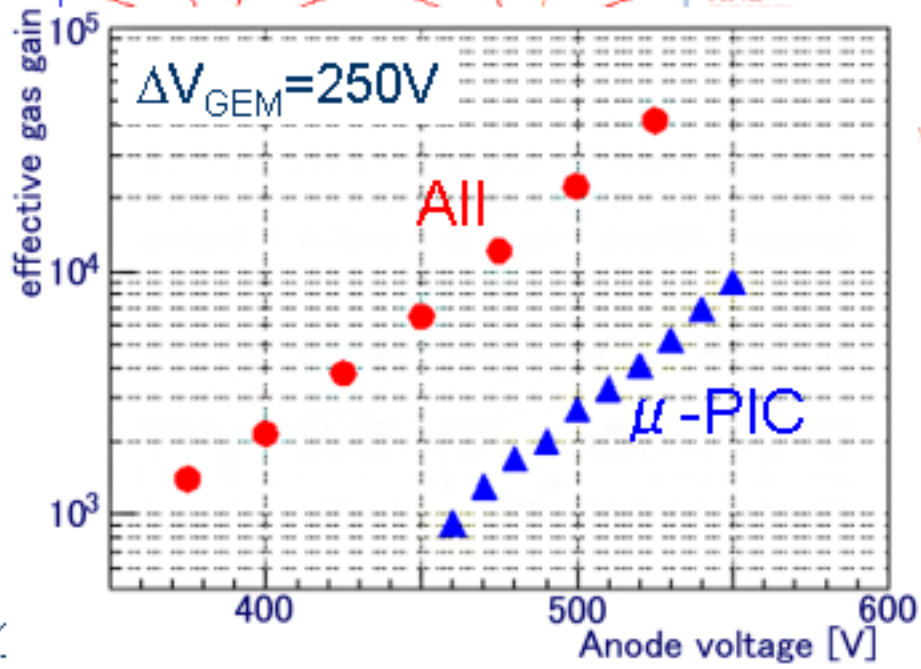
μ-TPC (1)

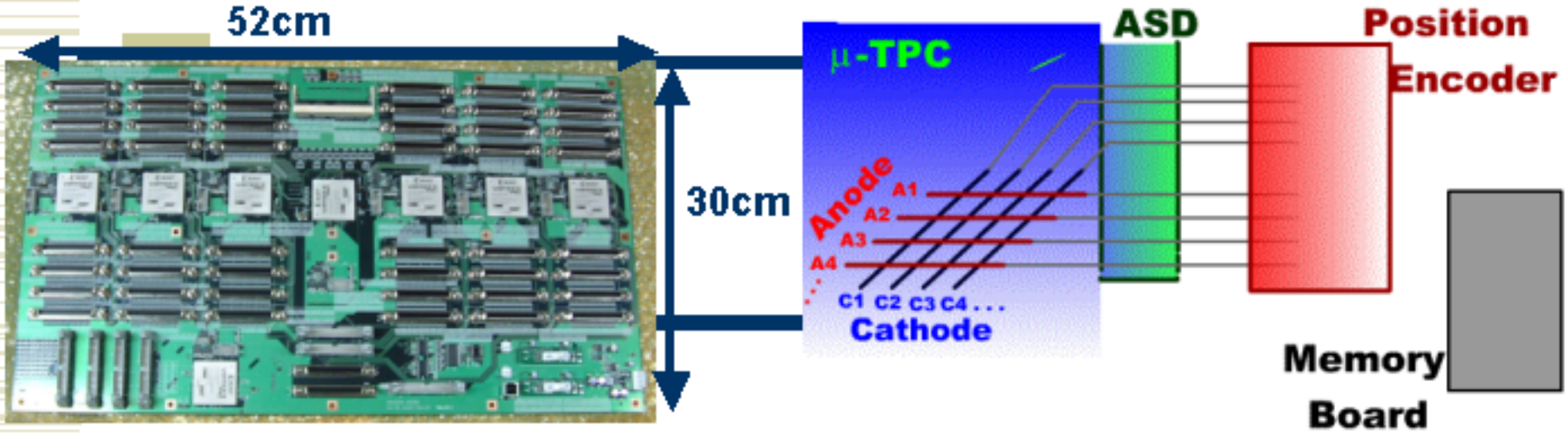


- μ-PICの安定gain : ~6000
- MIPを捕らえるのに必要なgain : > 2×10

GEMでちょっと増幅
→ μ-PICでもっと増幅

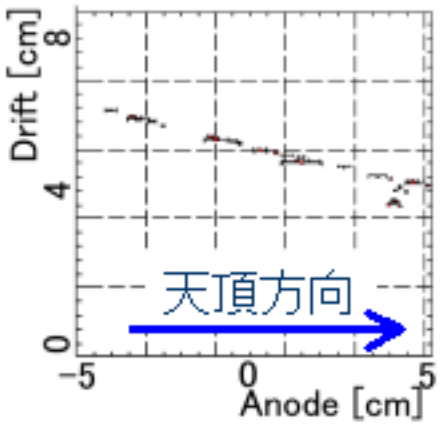


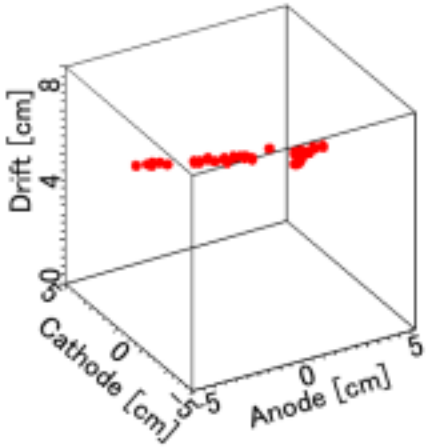




Position Encoder

- 100MHz clock
- 8 FPGAs
- 1536ch LVDS input



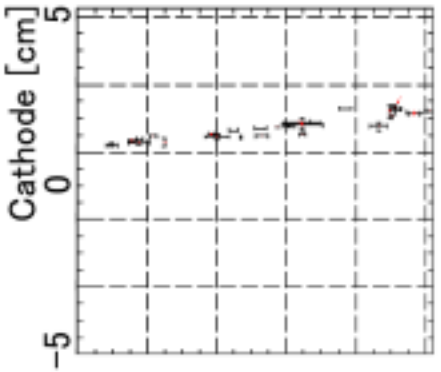


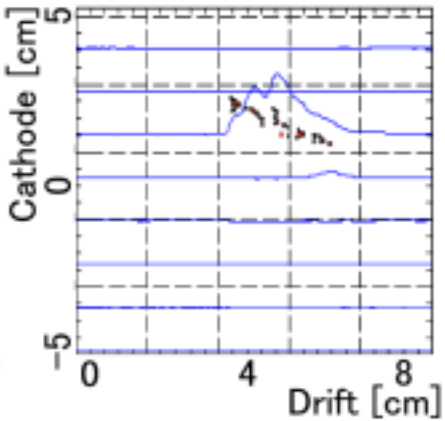
Cosmic muon track →

- (hit point > 3)/(trigger) ~97%
- position resolution σ~370μm

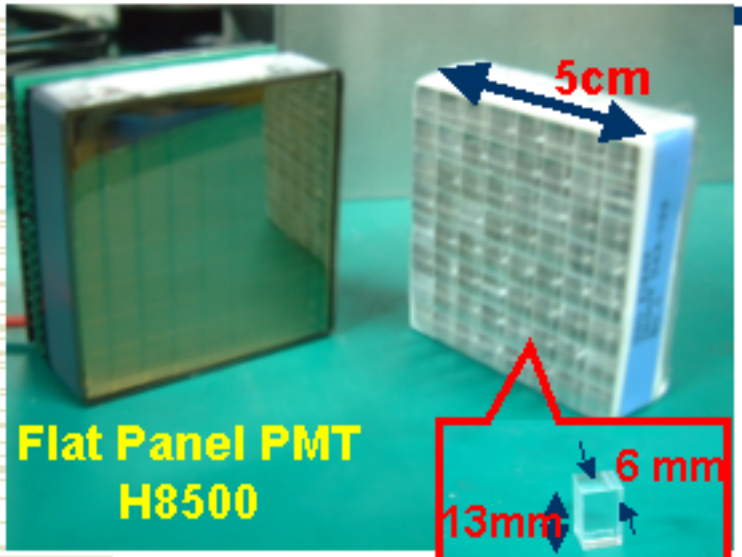
Ar 90% + C_2H_6 10%, gas-flow

E_{Drift}=400V/cm

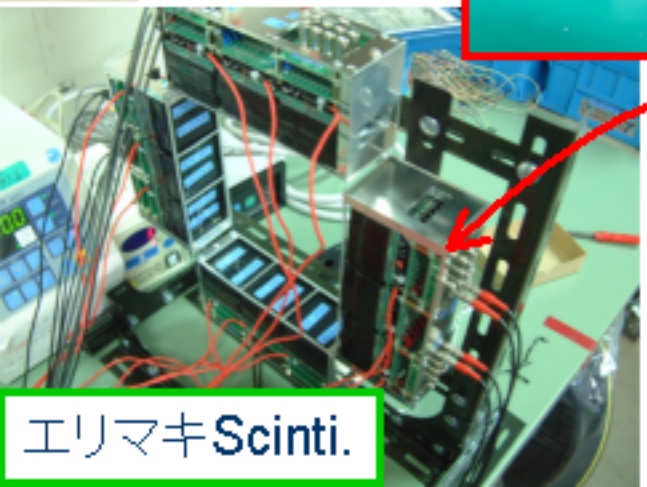


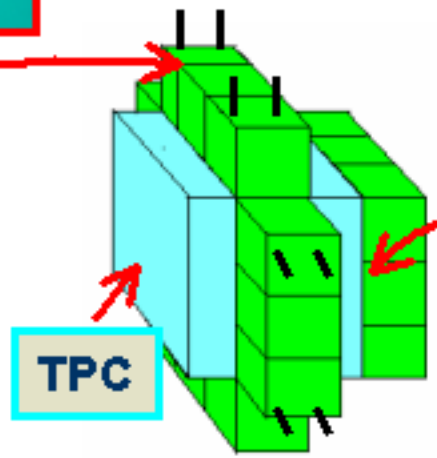


GSO Pixel Scinti. Array

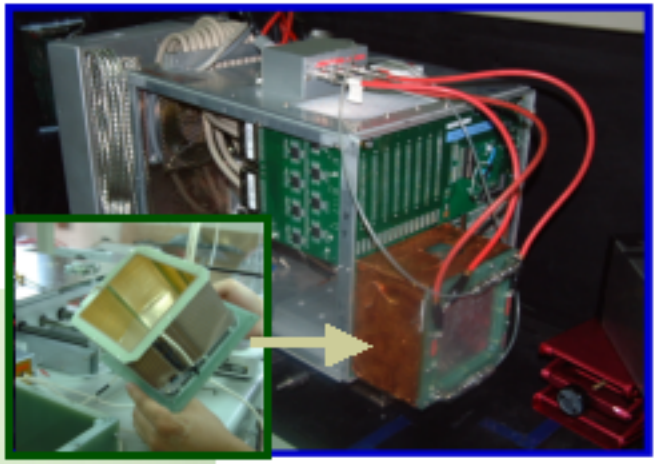


- Position res. : ~6mm
- Energy res. : ~9% (662keV, FWHM)
- Effective area : ~82%
- Readout : 4ch/192pixels @ side
  16ch/192pixels @ bottom





MeV-γ camera setup



Memory board

Encoder board

Scintillator

40cm

RI source

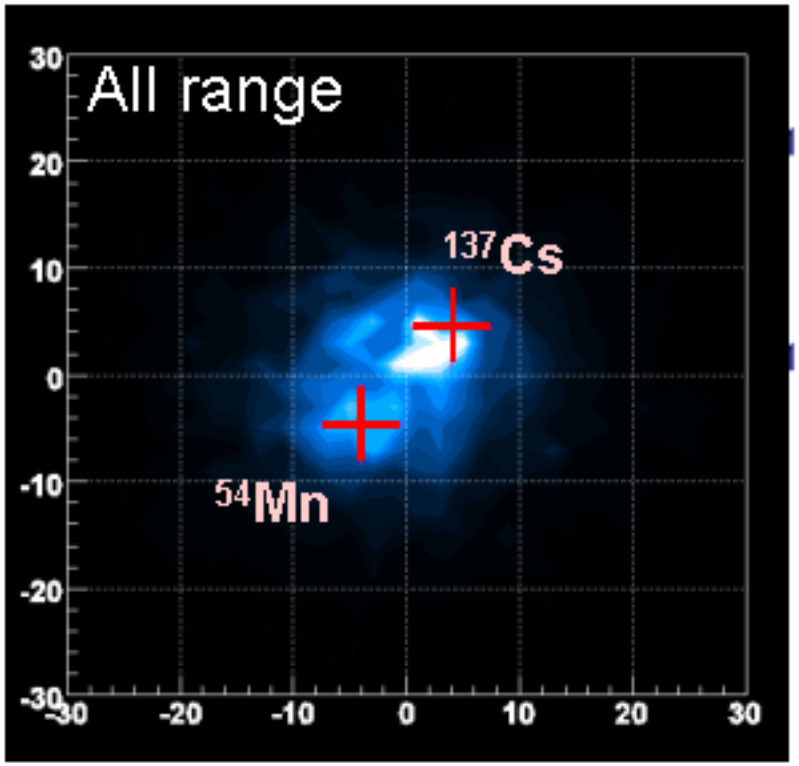
micro-TPC (μ-PIC)

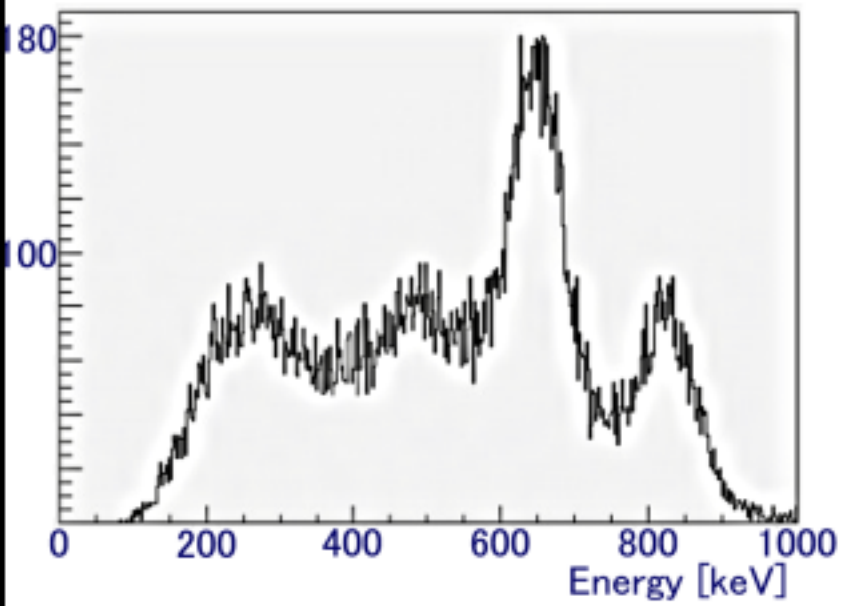
microTPC
10×10×8 cm^3
Ar+C2H6(9:1)
1atm, gas-flow

Scintillator
＋PMTs
位置分解能 ~6mm (FWHM)
エネルギー分解能 ~9% (662keV,FWHM)

MeV-γ imaging

^{137}Cs : 662keV, 0.89MBq
^{54}Mn: 835keV, 0.65MBq





MeV-γ

^{137}Cs : 662keV, 0.89MBq
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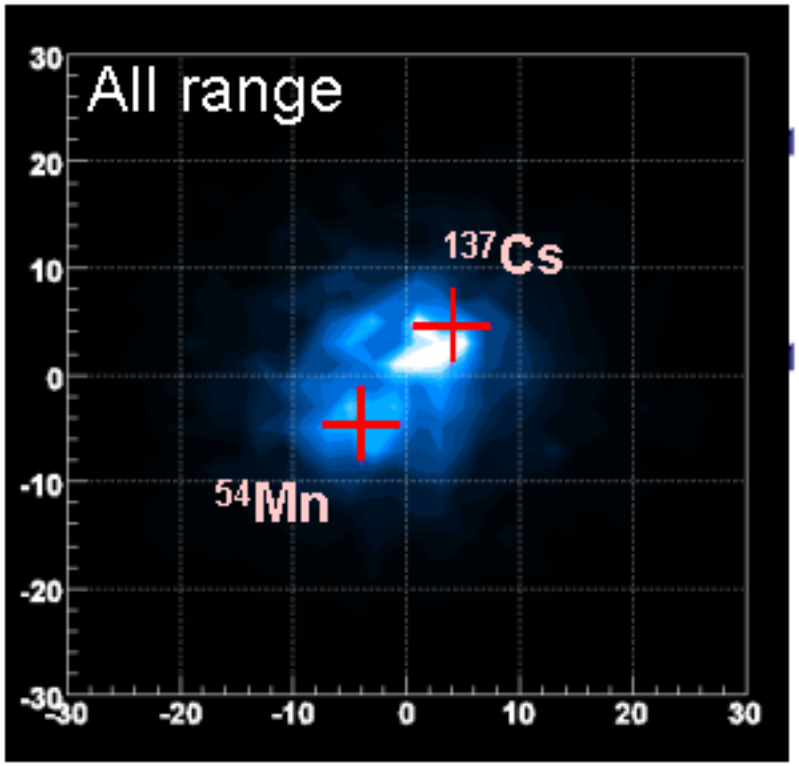
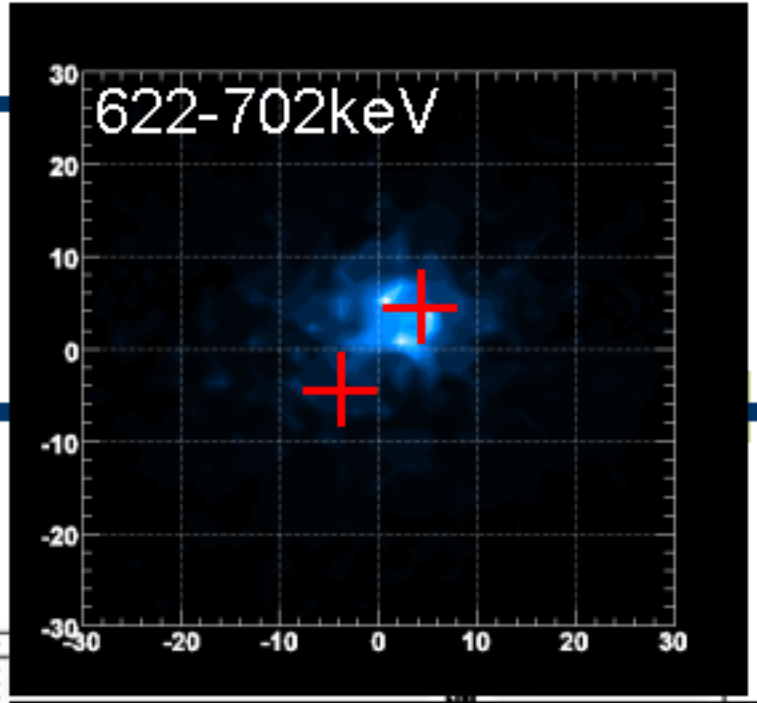
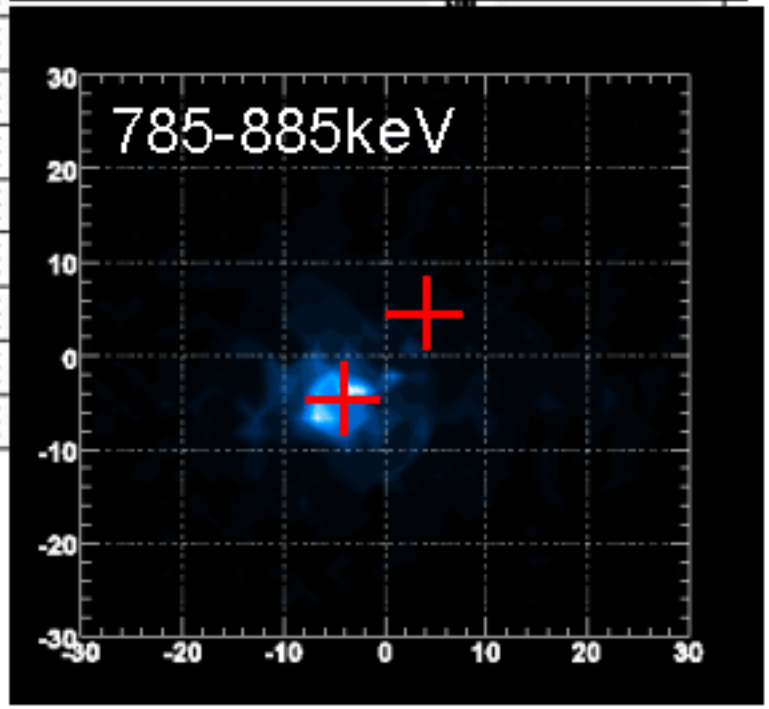
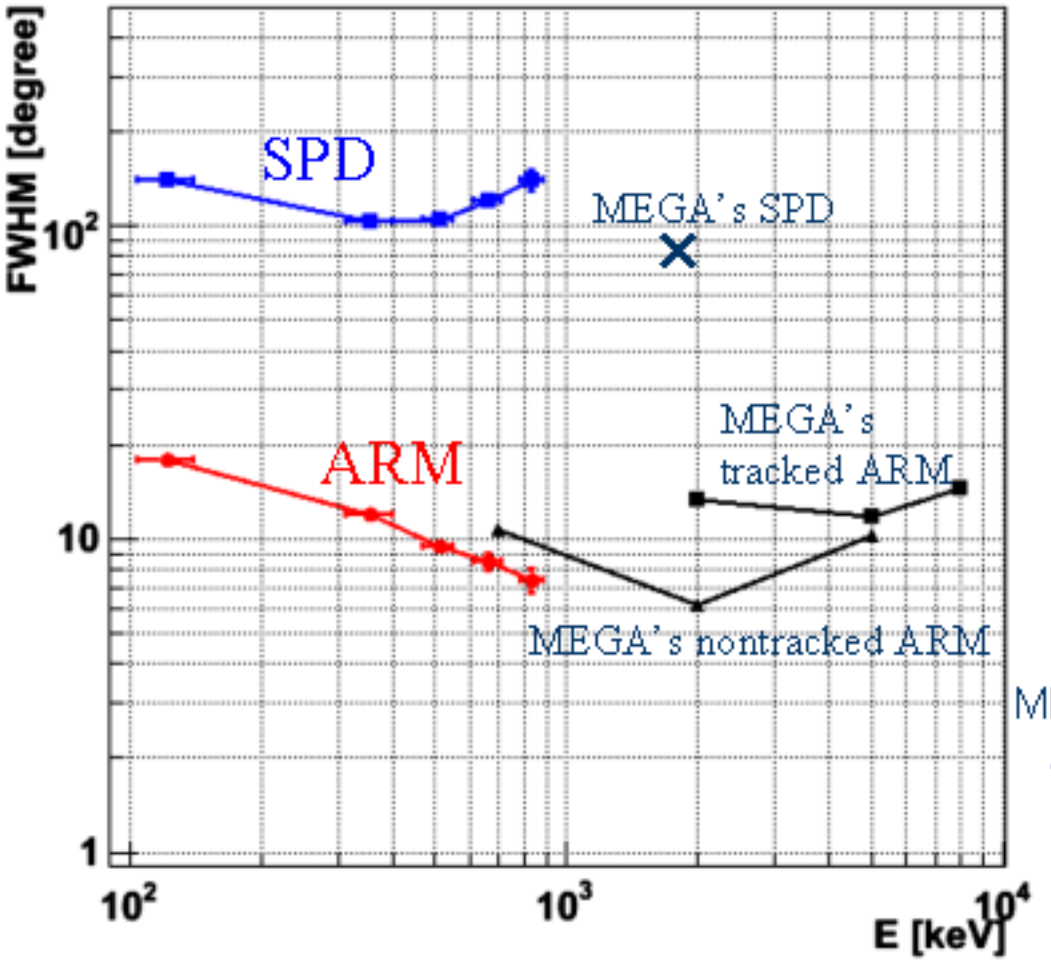
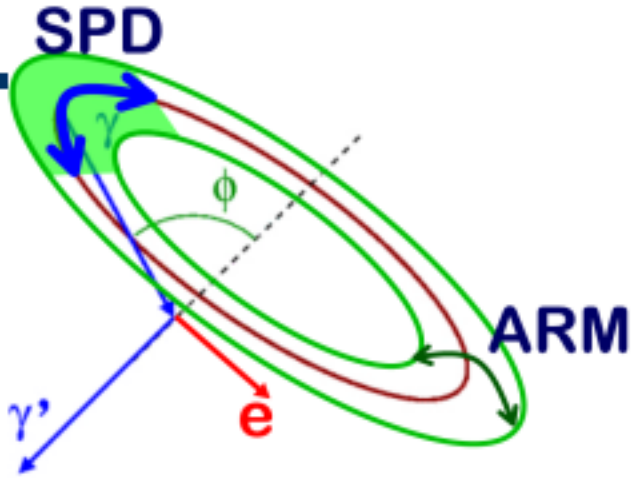






Angular Resolution



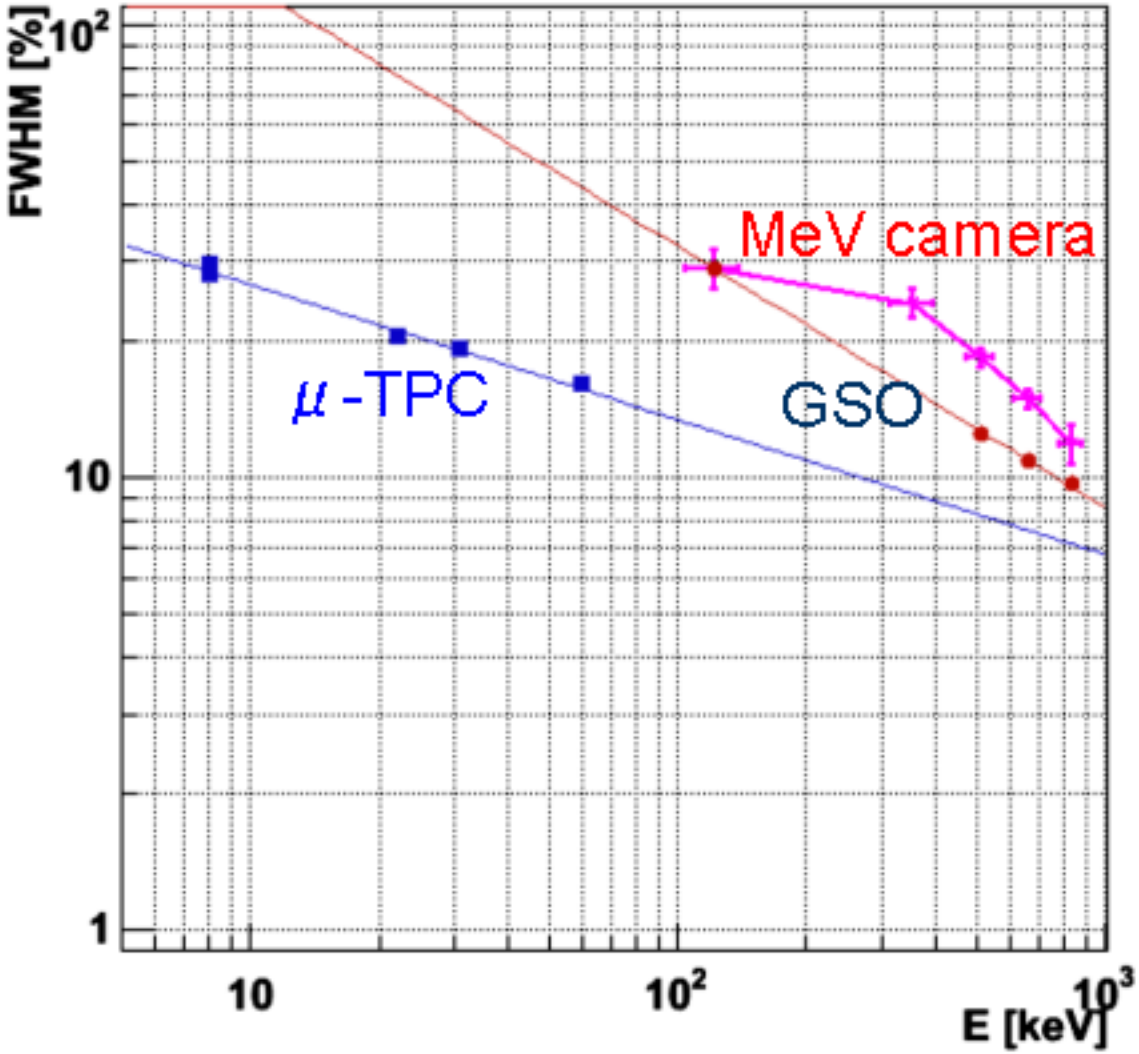


- Energy range
  100~900 keV
- ARM
  8.5° @ 662keV
- SPD
  120° @ 662keV

MEGA's data :
A. Zolgauer, et al.,
IEEE Nucl. Sci. Sym. Conf. (2003)

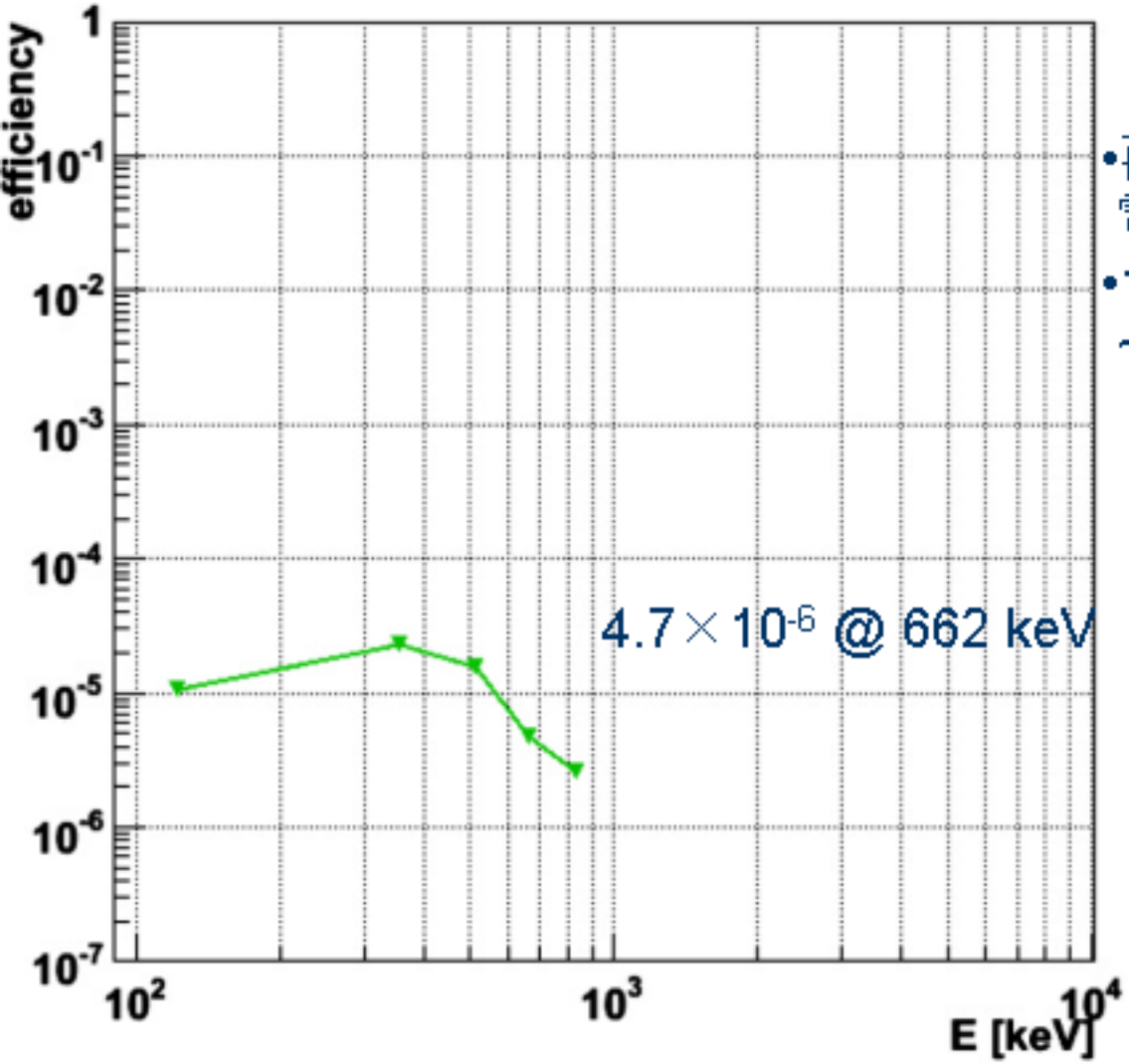
ARM : Angular Resolution Measure（散乱角決定精度）
SPD : Scatter Plane Deviation（散乱平面決定精度）

Energy Resolution



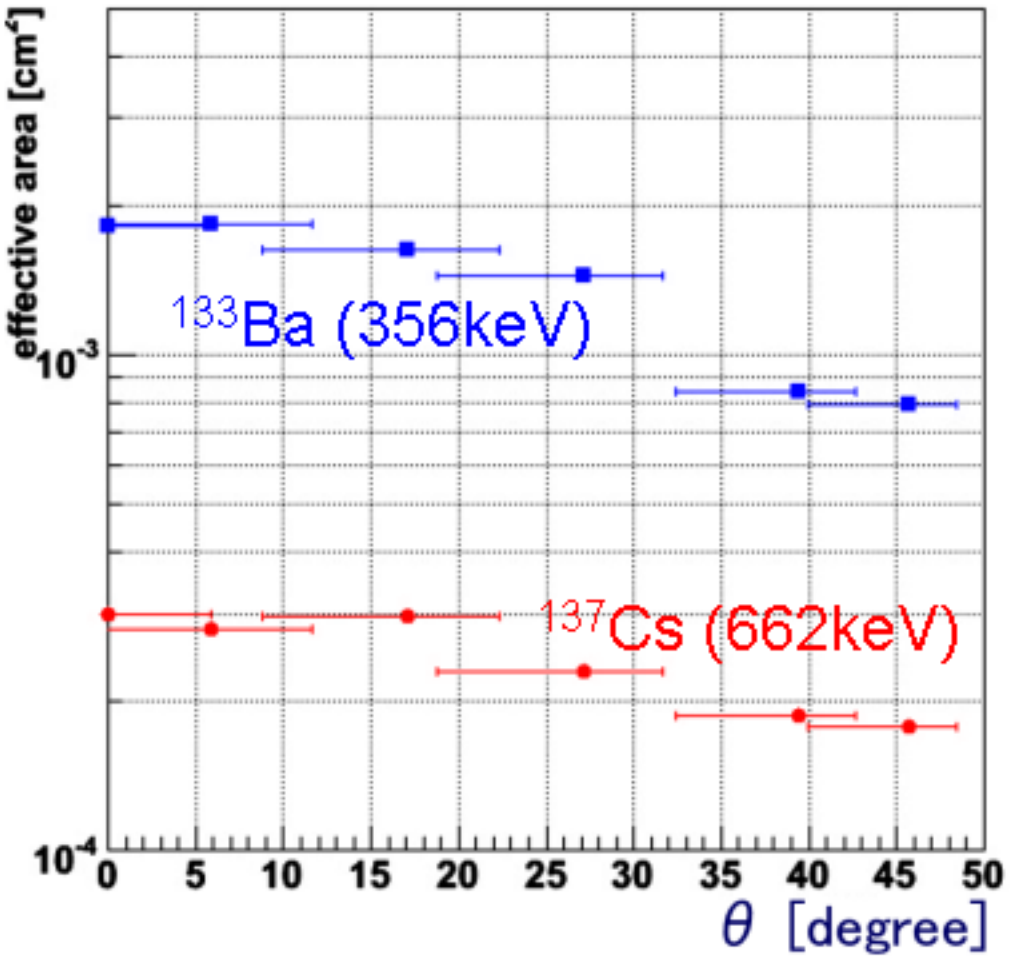
- μ-TPC
  20% @ 22.2keV
- GSO
  9% @ 662keV
- MeV camera
  15% @ 662keV

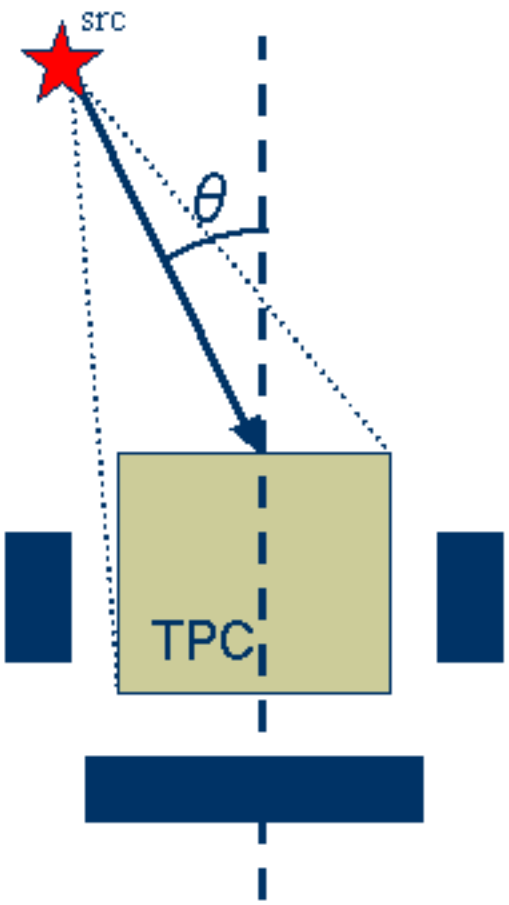
Efficiency



- 再構成するには
  電子がTPC内で止まる必要がある
- $10 \times 10 \times 8 cm^3$の体積では、
  ~60keVまでの電子しか止まらない

Field of View

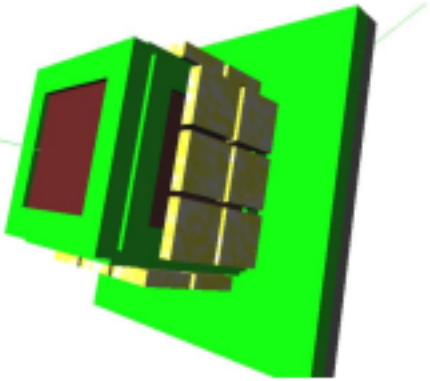


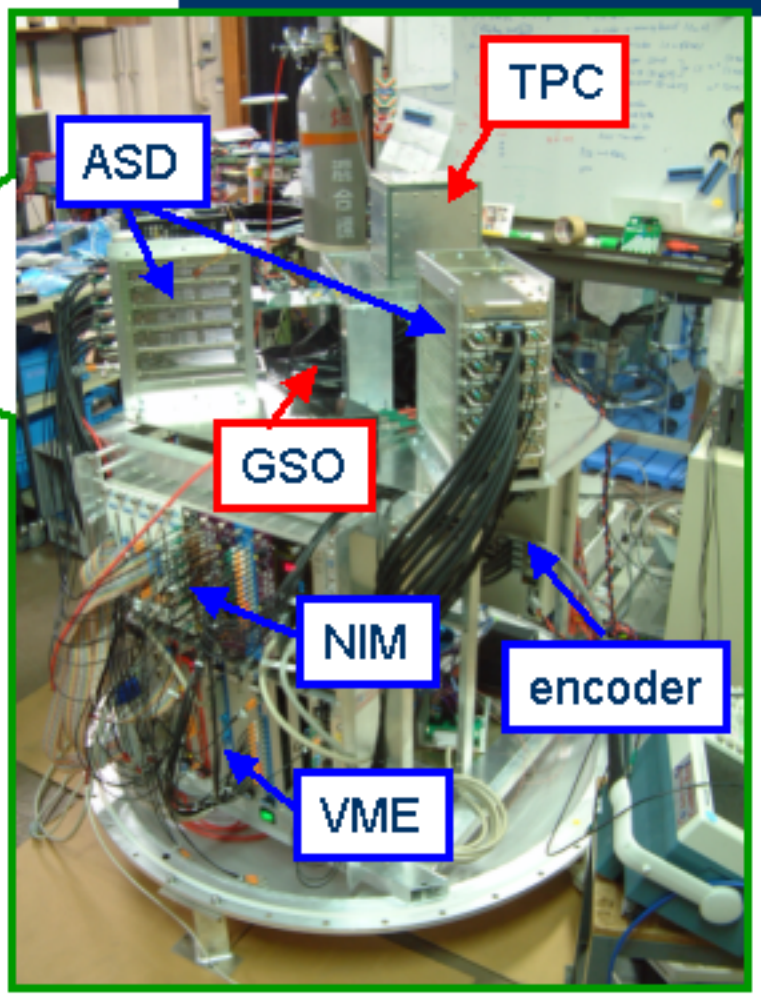


HWHM ~35°
FOV ~ 1 str

Sub-MeV γ-ray Imaging Loaded-on-balloon Experiment

for cosmic diffuse gamma-ray

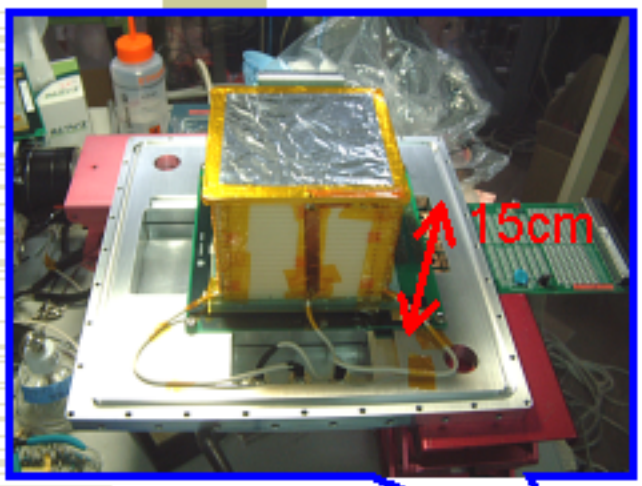




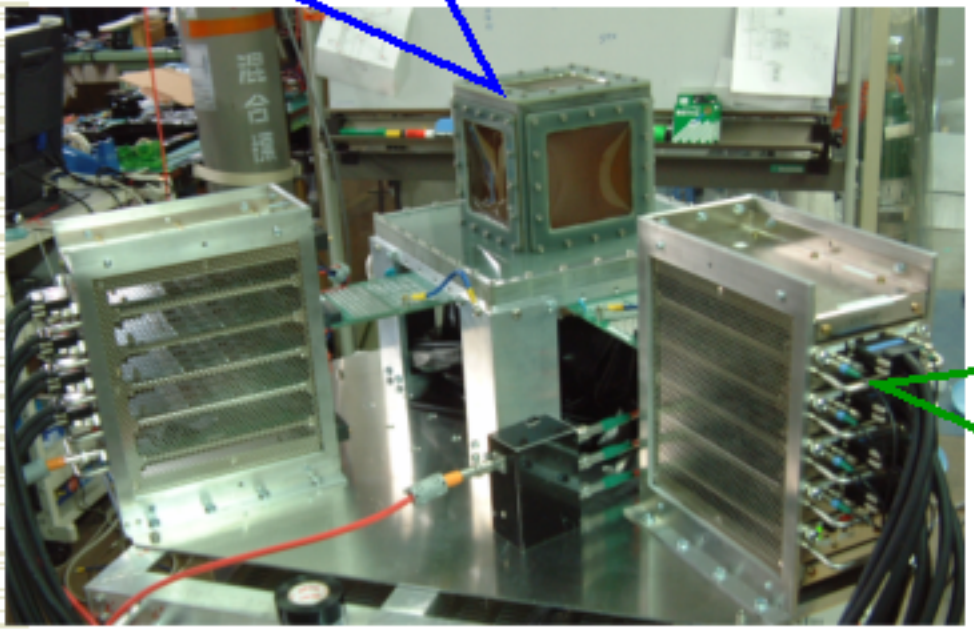
- Energy range : 100keV ~ 1MeV
- TPC : 10×10×15cm^3
- GSO :3×3PMTs@bottom
  4×(3×2)PMTs@side
  33 PMTs
- Frame : 1.45×1.2×1.35m^3
- Vessel : ϕ1m×1.4m
- PI Mass : ~250kg
- Power : ~250W (system)

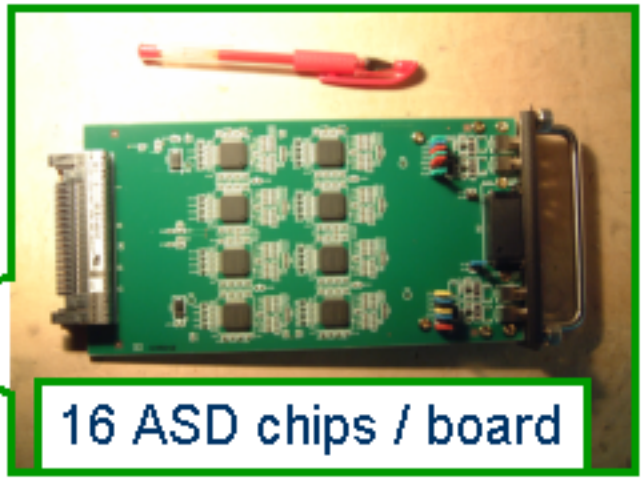
2006年度の放球を
目指して試験中

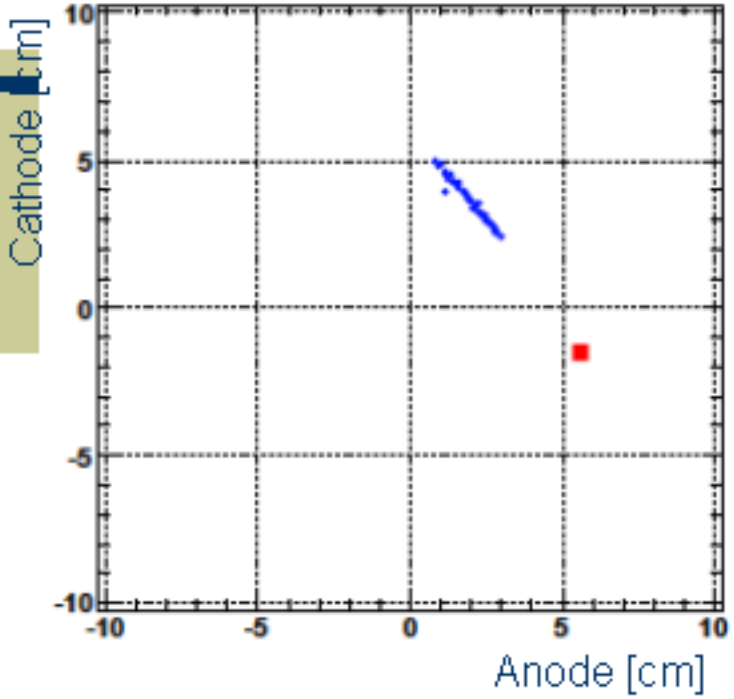
Flight Model TPC

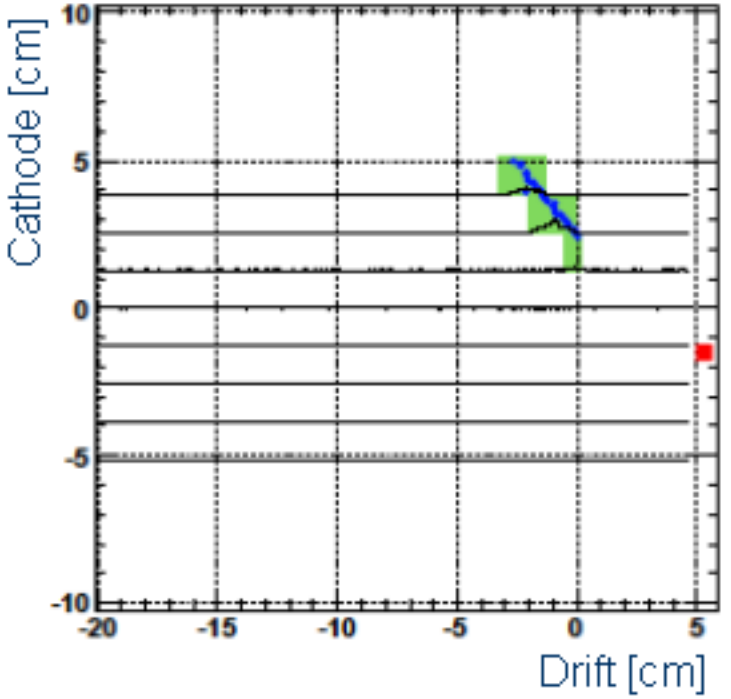


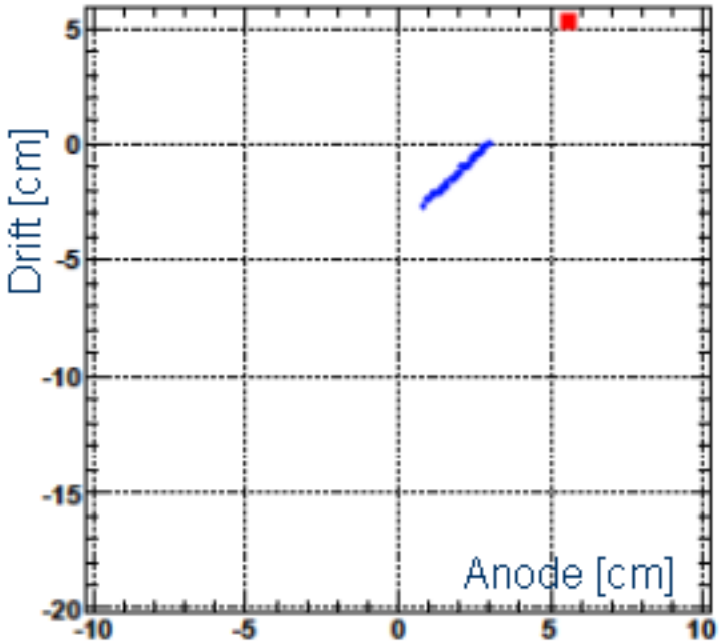
- Xe 80% + Ar 18% + C_2H_6 2% (mass ratio)
  1atm, sealed, ρ=3.97mg/cm^3
- Volume : 10×10×15cm^3











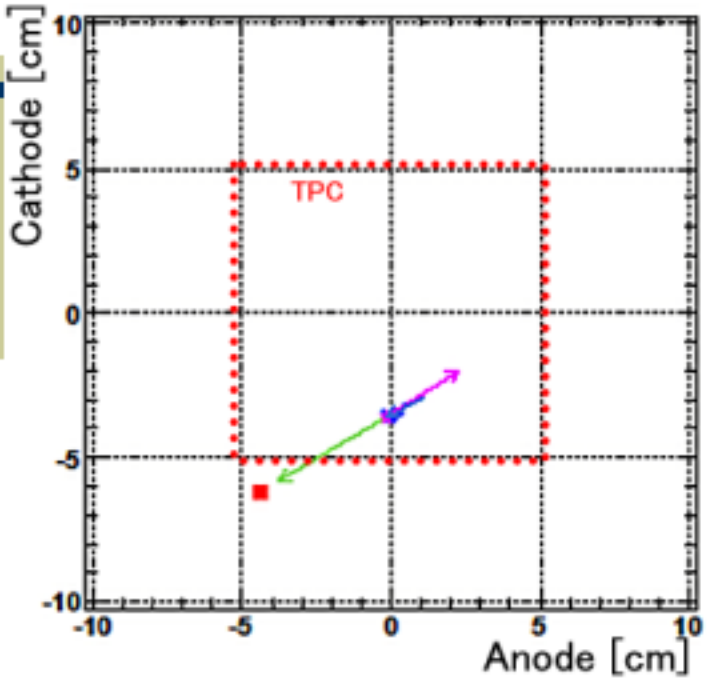
Energy : 2236.2 [keV]

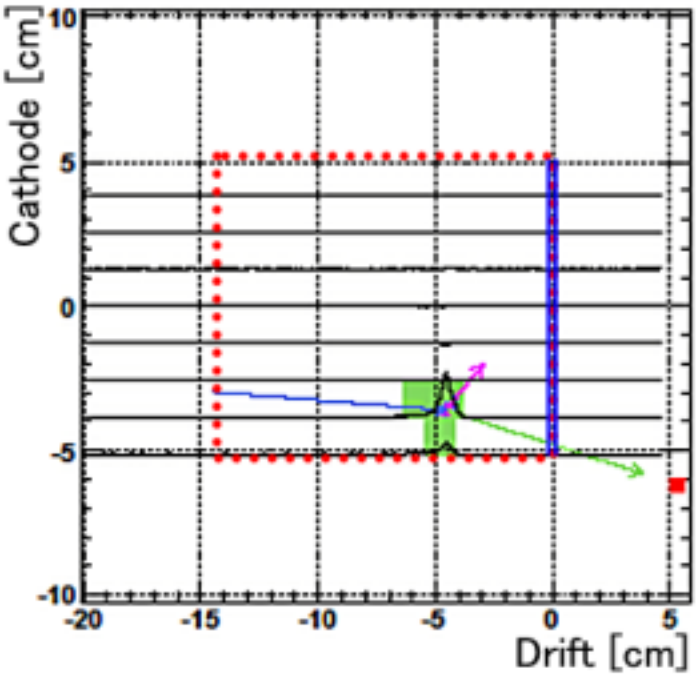
γ : 2214.7 [keV]

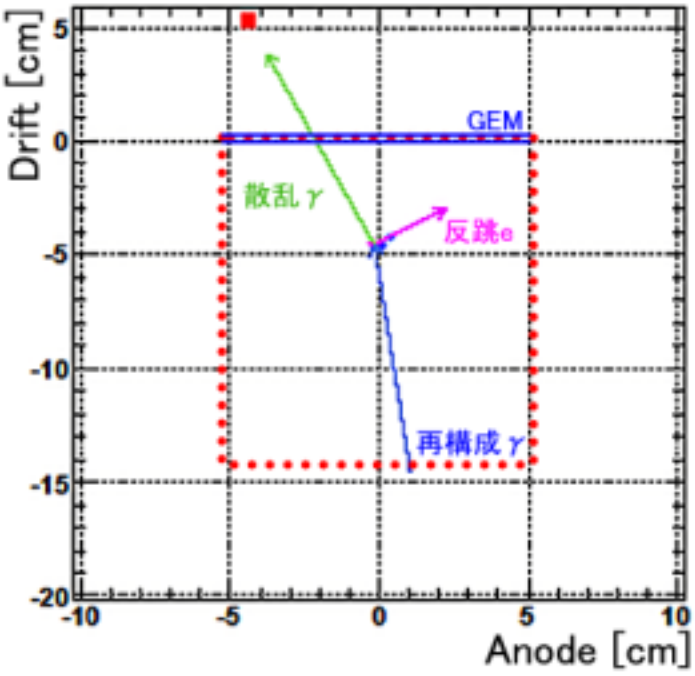
e : 21.5 [keV]

α_{geo} : 169.8°

α_{kin} : 83.7°







Energy : 632.9 [keV]

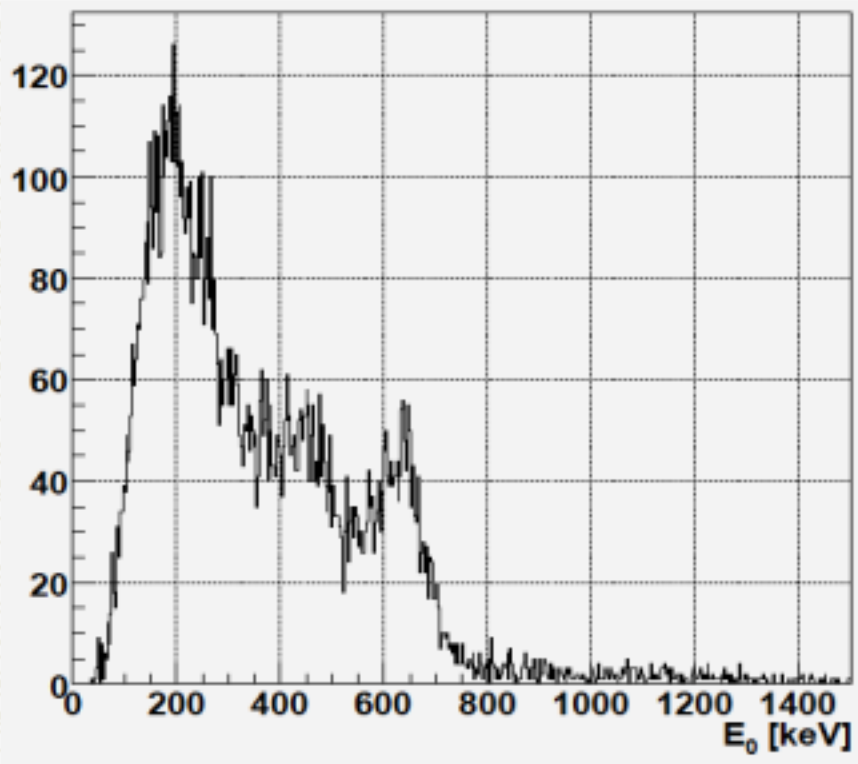
γ : 592.4 [keV]

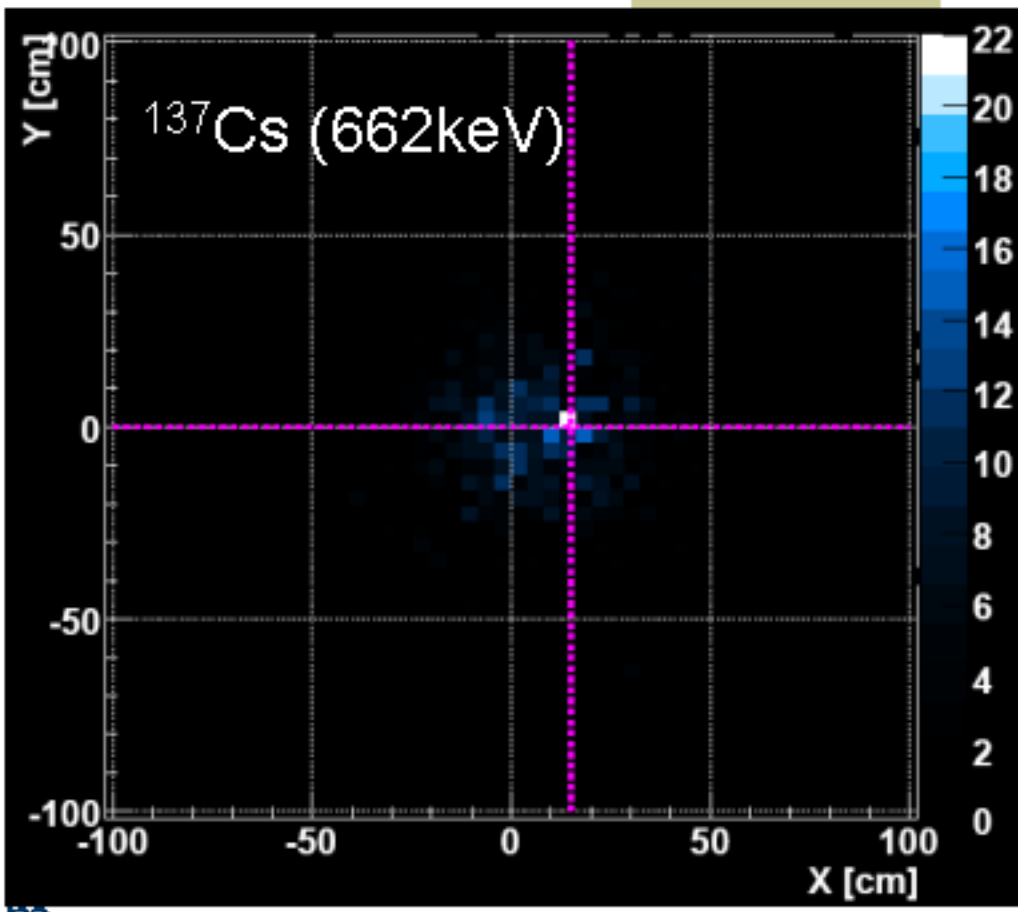
e : 40.5 [keV]

α_{geo} : 87.8°

α_{kin} : 88.5°

First light





線源とwindowの距離：50cm

Summary

- GEM+μ-PIC, 100MHz動作のmicro-TPC
- GSO + H8500 Pixel Scintillator Array
  （底面:576 pixel　側面:4×192 pixel）
- Energyと到来方向の2つを同時に再構成
- prototypeのperformance (662keV)
  - Energy range : 100 keV ~ 1 MeV
  - Energy resolution : 15%　　ARM : 8.5°　　SPD : 120°
  - Efficiency : 4.7×10^{-6}　　FOV : ~1str
- 気球実験(SMILE)にむけFlight Modelを試験中
- TPCの大容積化も平行して開発中

おわり。