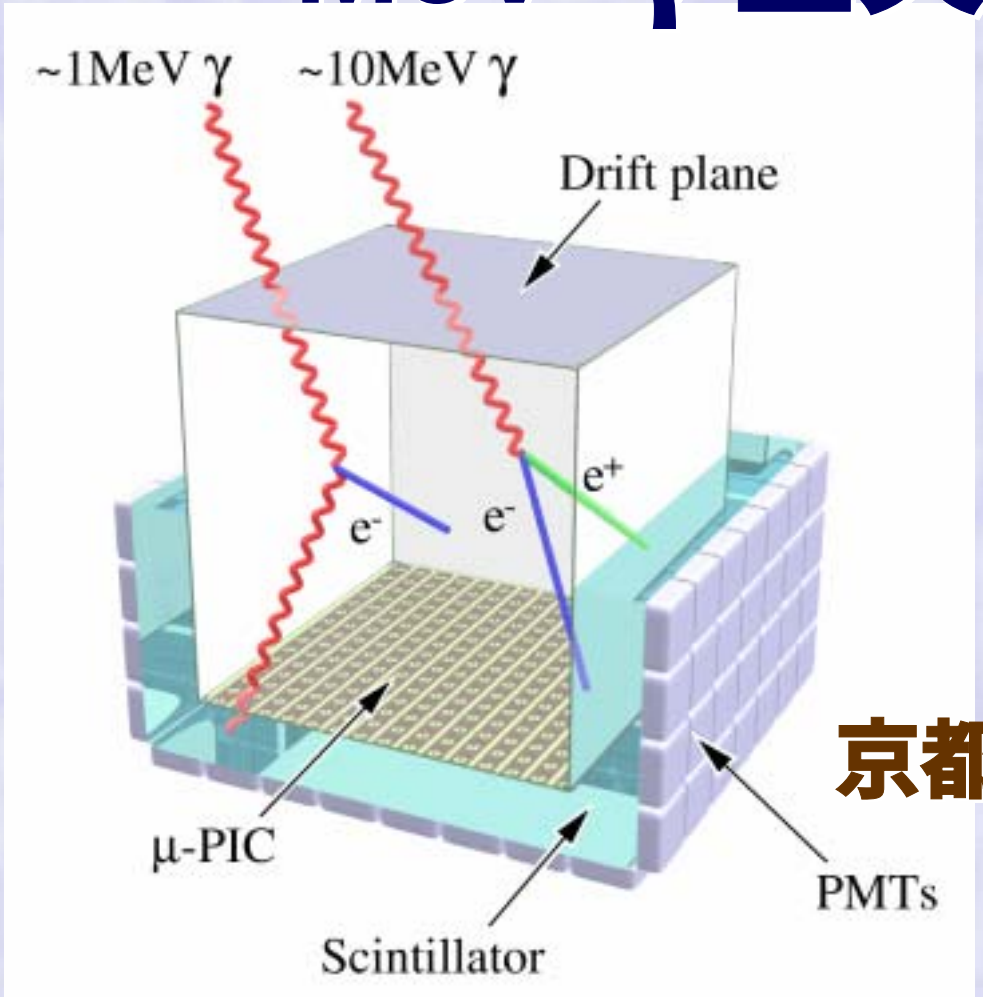
MeV-γ全天探索計画

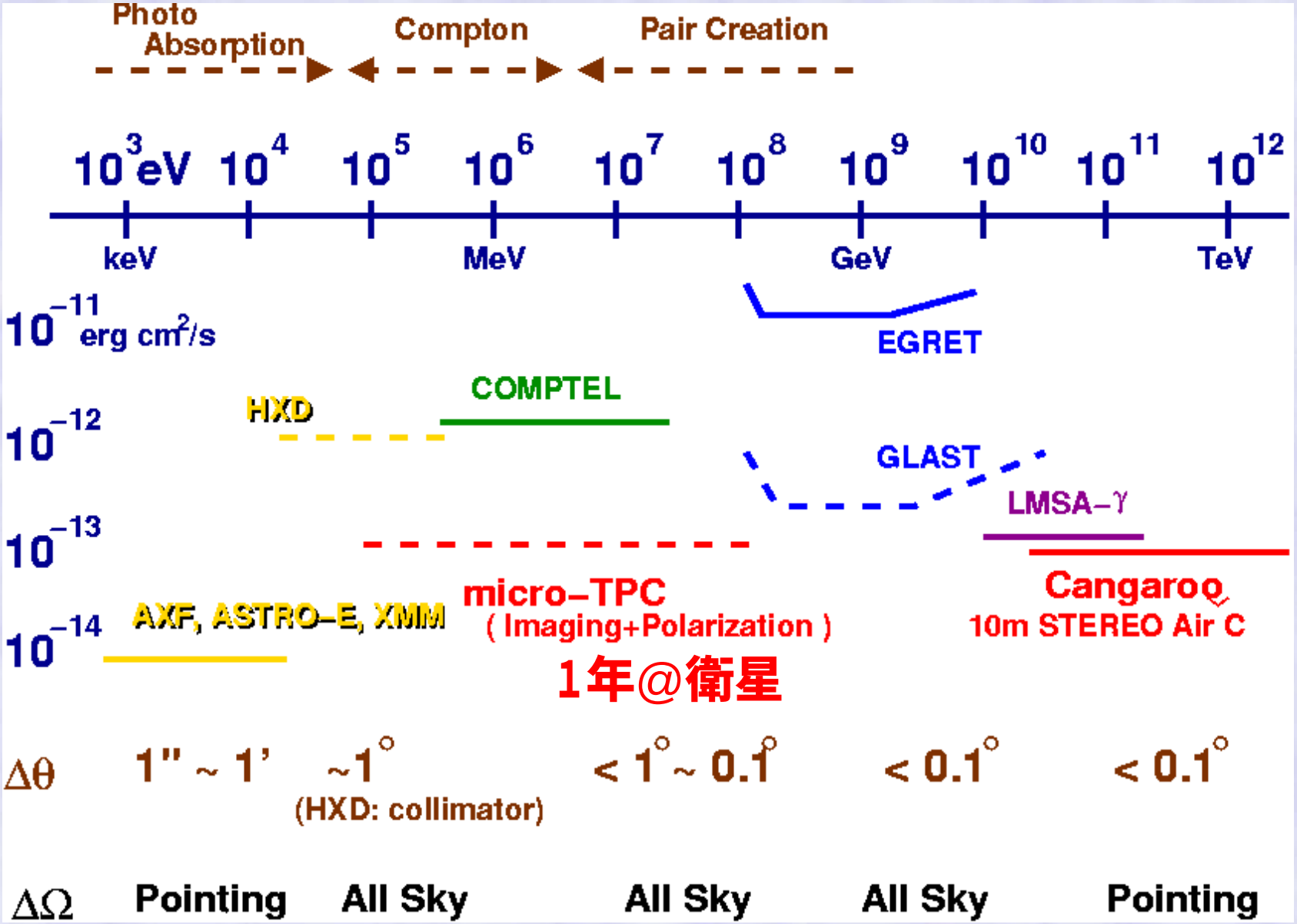


- MeV-γ 天文学
- MeV-γ 検出器
- MeV-γ 計画

京都大学 理学研究科 助手
身内賢太朗

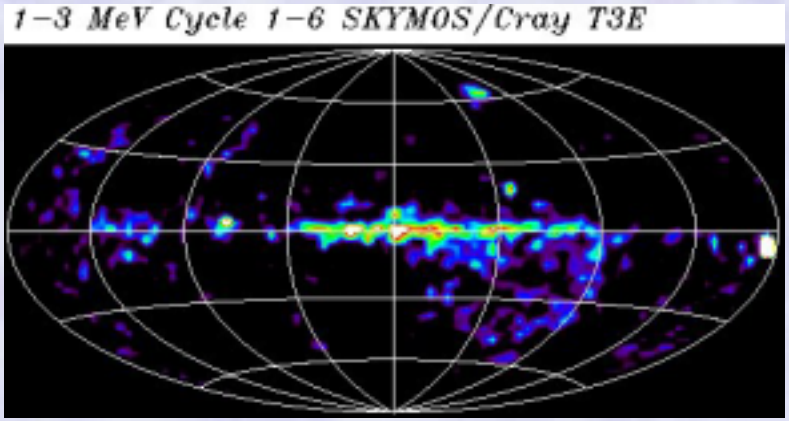
谷森達、窪秀利、身内賢太郎
竹田敦、永吉勉、植野優、折戸玲子、高田淳史

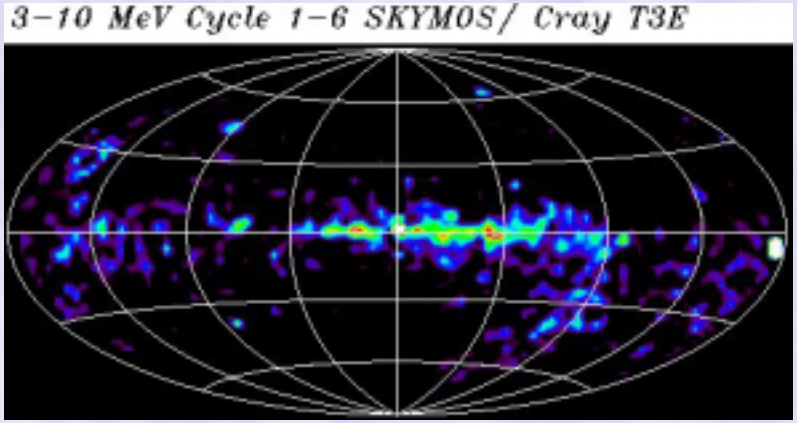
1. MeV Gamma-Ray Astronomy

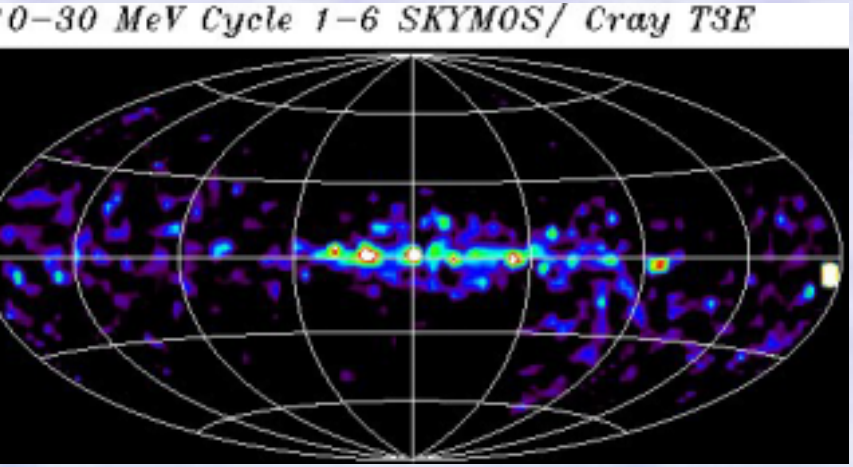


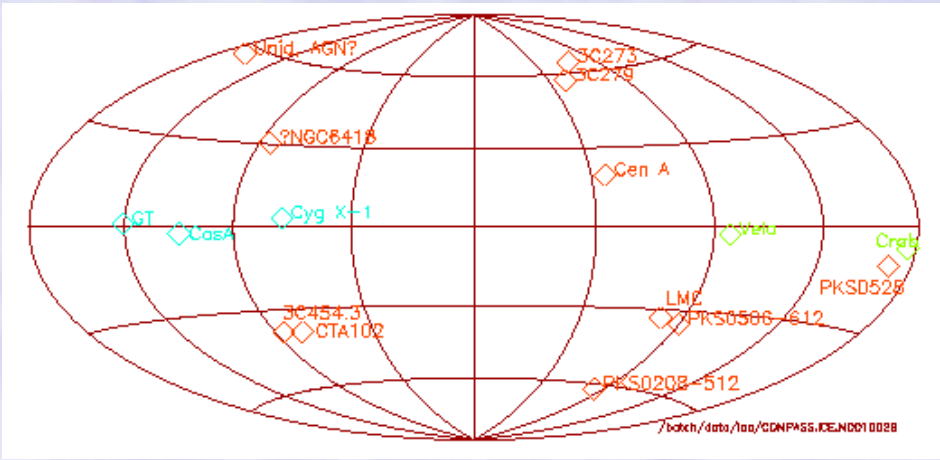
COMPTEL Results

Intense Diffuse Galactic and Extra Galactic gamma-rays









Expected Sources in MeV Region

- Black Hole; Binaries, Galactic Center, AGNs, Primordial BH, 511keV
- Pulsars
- AGN jets; OVV(可視激変光銀河), Blazar
- Galaxies; π^0 peak due to Cosmic Ray
- SNRs; Al, Ti, Nuclear Gamma
- Diffuse; Extra and Galactic
- Gamma Ray Bursts; Polarization

ADAF (Advection Dominated Accretion Flow)

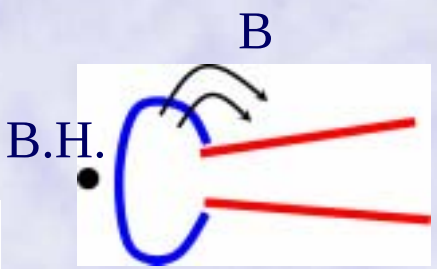
1. Low Radiation Rate
2. High Temperature

$$T_e \sim 10^9 \mathrm{K}$$

$$T_{ion} \sim 10^{12} \mathrm{K} \quad (\geq 100 MeV)$$

$$\sim \frac{1}{10} m_p \quad \textbf{(Virial velocity)}$$

$$= \frac{GMm_p}{r_{sw}}$$



3. Expansion ⇒ Thick Disk

α ⇒ Increase

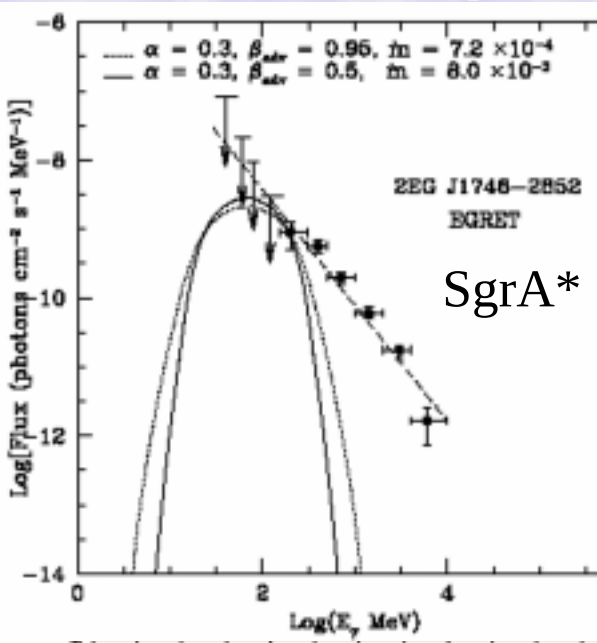
Slim Disk $T_{e,i} \quad 10^5 \sim 10^7 \mathrm{K}$ (Keplar Motion)

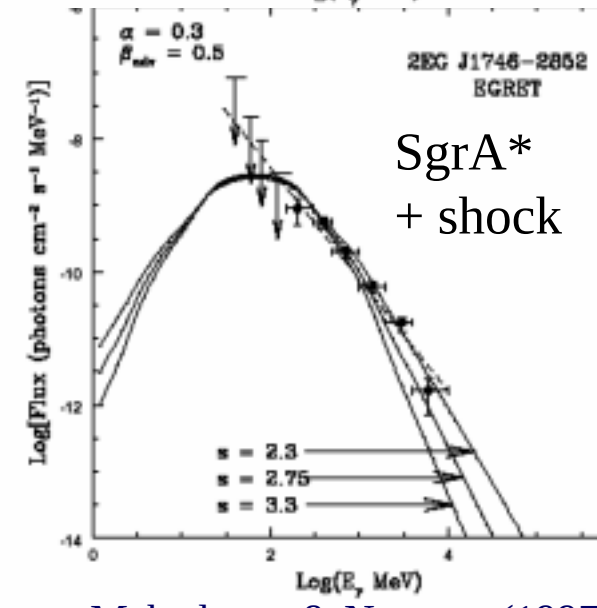
Example. Sgr.A*, M87

Very Low X-ray Intensity B.H.

•Thermal γ Expected

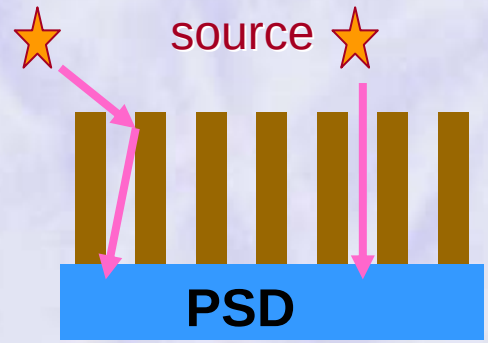
⇒ Corresponding to field around Event Horizon!





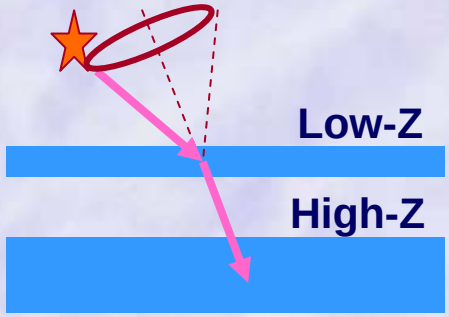
Mahadevan & Narayan (1997

2. MeV-γ Imaging Detectors



1.Collimator +Position Sensitive Detector

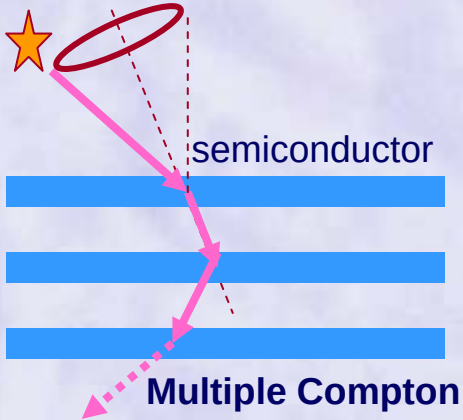
Narrow FOV
Background from collimator
Energy < 1MeV

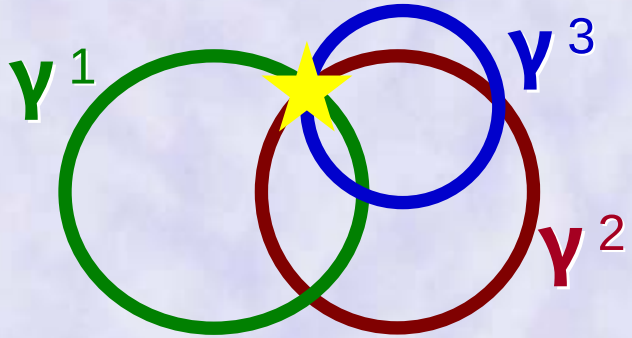


Single Compton

2.Compton Camera

3 events are required
Diffuse gamma-ray source ×
Background





Compton event circle

半導体多重コンプトンカメラ

- 多重コンプトンカメラの概念

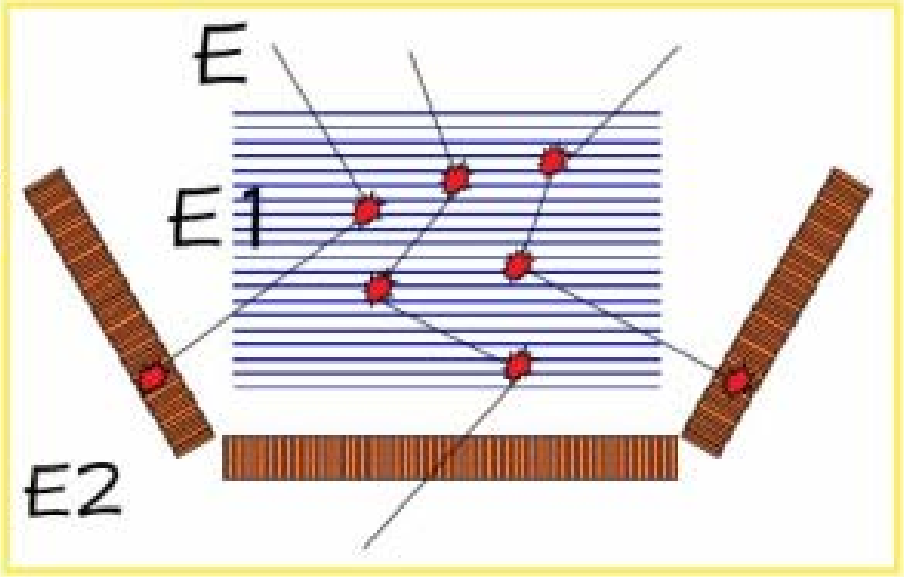
  Kamae et al. 1987 NIM A260, 254

- 多層に積んだ散乱体(D1)とそれをとりかこむ吸収体(D2)
  - 要求事項
    - 高いエネルギー分解能
    - 高い位置分解能

$$E = E1 + E2$$

$$\cos\tilde{\varphi} = 1 - \frac{m_0c^2}{E_2} + \frac{m_0c^2}{E_1 + E_2}$$

散乱体は、低いエネルギーのガンマ線にはSiが、高いエネルギーにはCdTeが適している
(Compton/Photo Abs Ratio)



- 大面積 (~m²)

ISAS 高橋グループ

狭視野、高感度

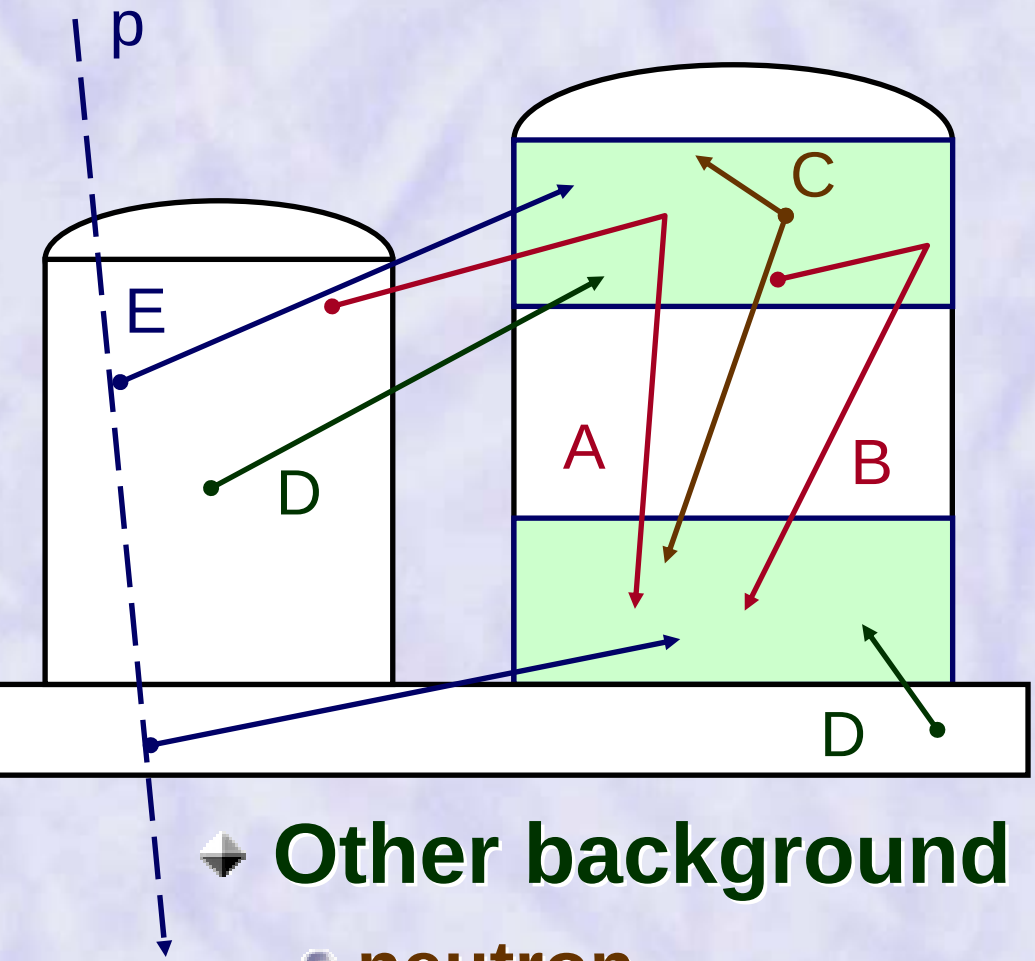
我々の計画と相補的

Takahashi et al. IEEE N.S. 2002 in press

Background of COMPTEL

J.Ryan
(Astronomy with radioactivities, 2003)

- γ-ray background



A, B：internal γ

C：two γ

D：random coincidence

E: proton-induced γ

- Other background
  - neutron
  - electron

Our Detector

- **Full Tracking of the Compton process**

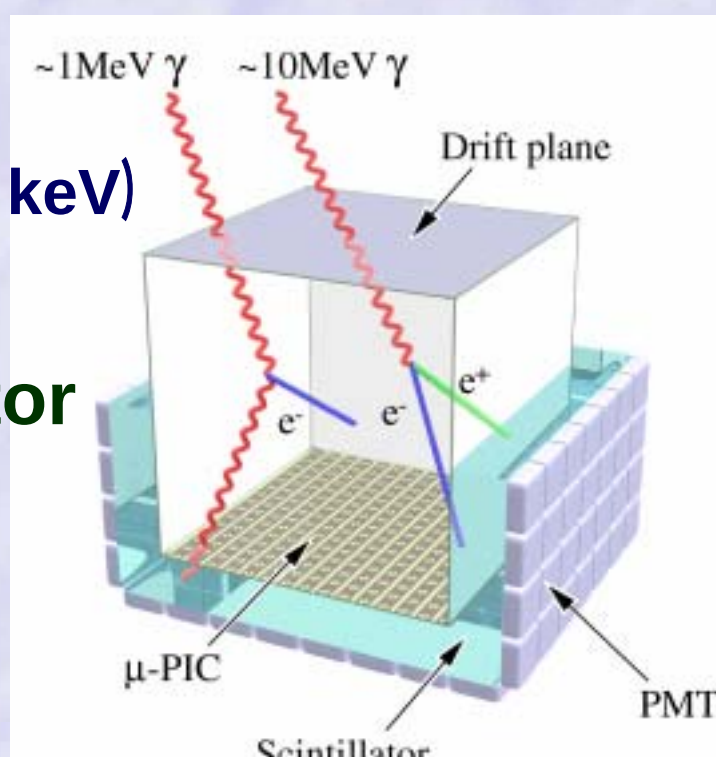
  Micro-TPC (Gas detector) for a recoiled election

  +

  Pixel Scintillator for a scattered gamma-ray

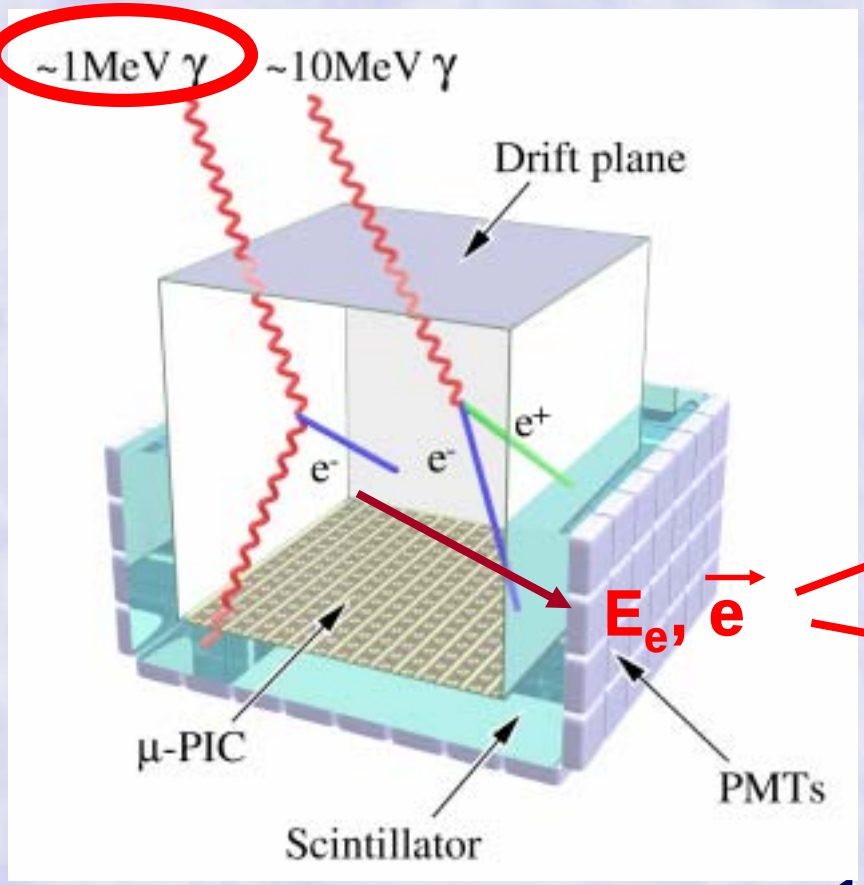
  - **Full reconstruction**
  - **Kinematical cut (α-cut)**
  - **Track image, *dE/dx***
  - **Low energy sensitivity (100 keV)**
  - **Large field of view (~2str)**

- **30cm-cubic prototype Detector**
  - For balloon borne exp.(2006)
  - ~3000 γ from Crab (8hrs.)

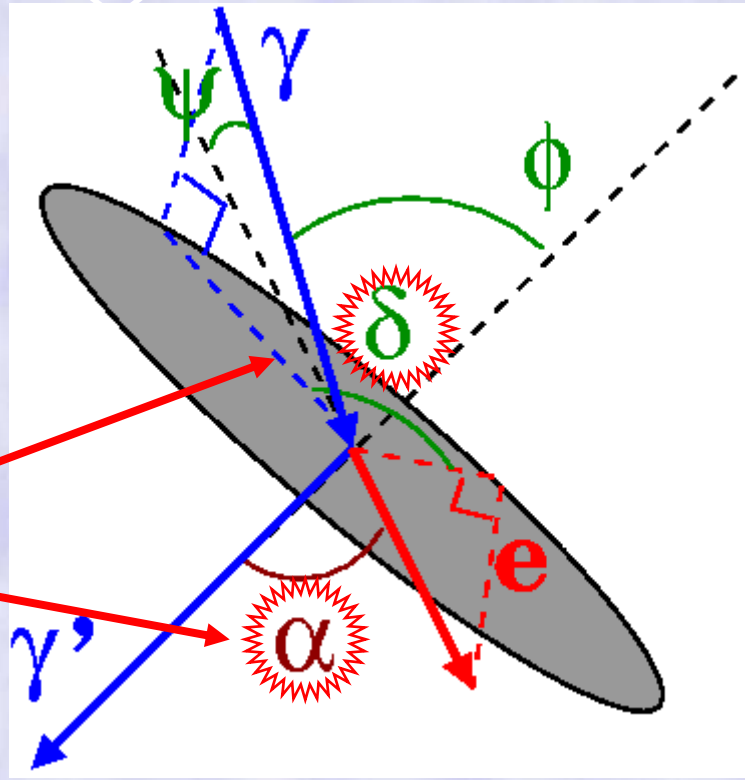


Reconstruction

SCHEMATICS



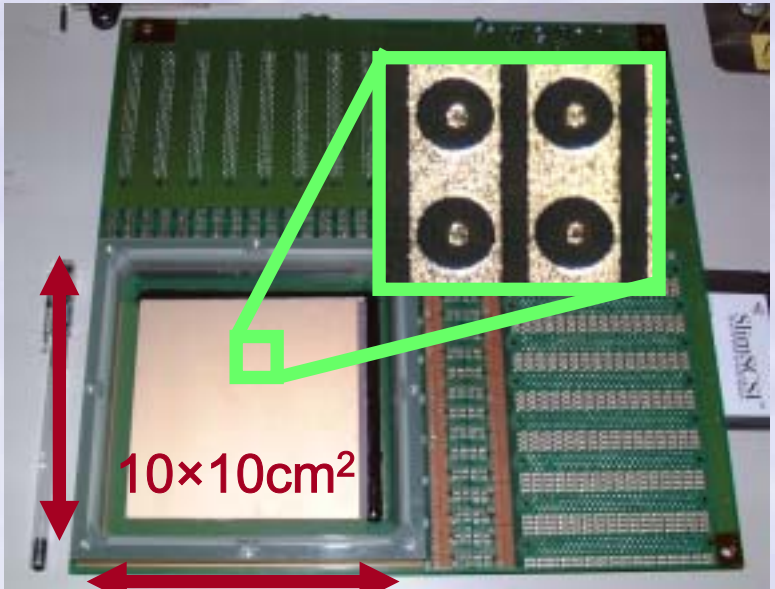
RECONSTRUCTION

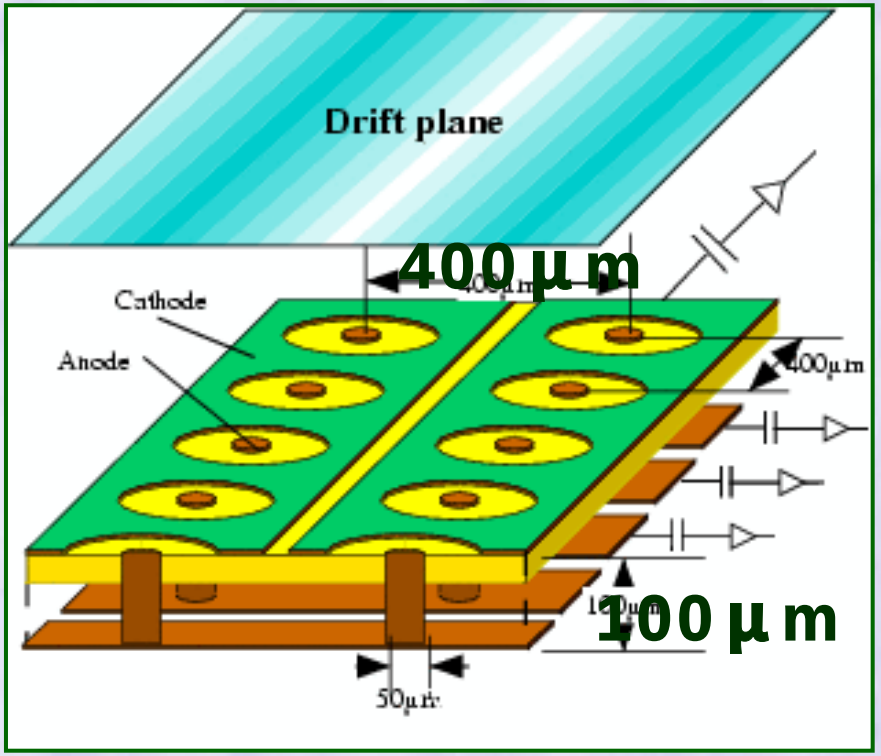


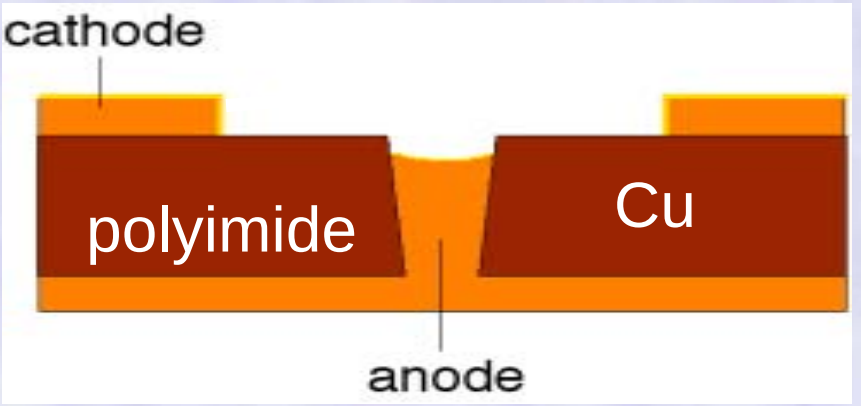
- ✓ 1 **γ** ⇒ 1 direction
- ✓ **α** ⇒ background rejection

μ-PIC Detector

- **Micro Pixel Chamber**
  256anode + 256 cathode strips
- **Fine position resolution**
- **High gain**
- **Discharge damage: little**

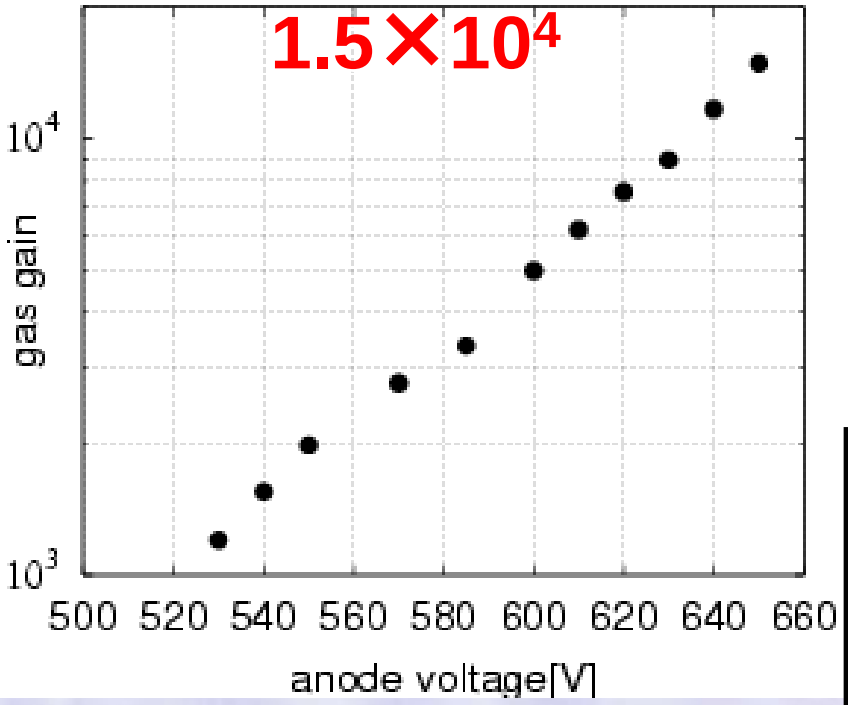






μ-PIC detector : performance

- gas gain (Ar:C_2H_6 8:2)



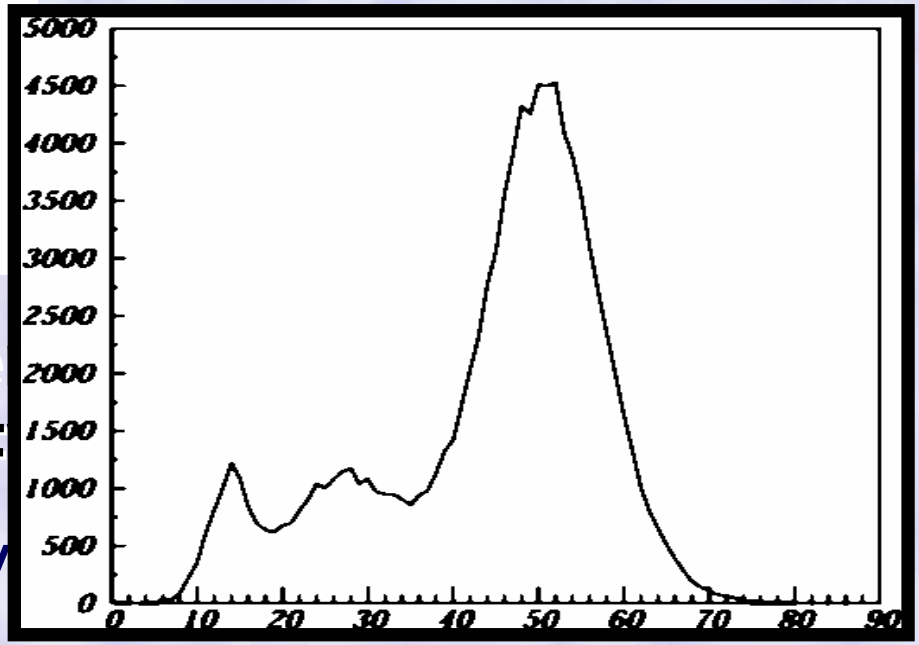
high gain (~15000)

stable operation

(1000 hours with gain 5000)

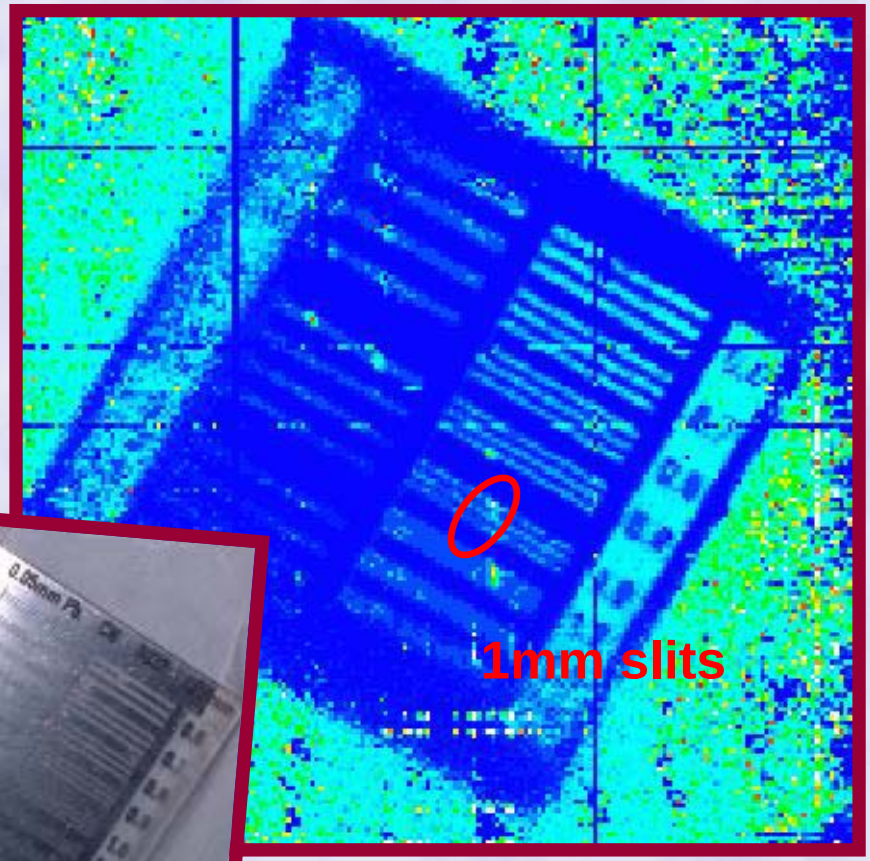
- Spectroscopy
  - energy resolution FWHM30%@5.9keV

- e
  F



μ-PIC Detector: X-ray imaging

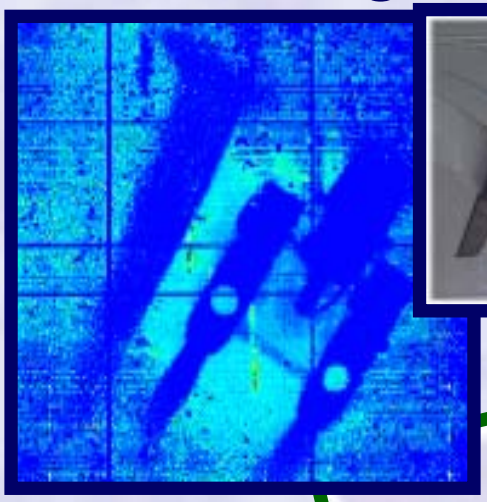
- **Test chart image**
  ($Xe:C_2H_6$ 7:3)

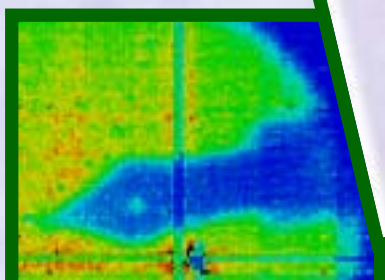


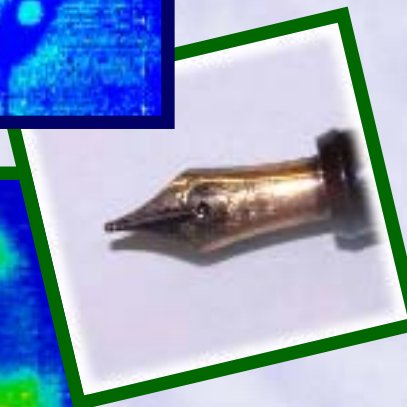
spatial resolution

knife edge test
160 μm resolution

other images



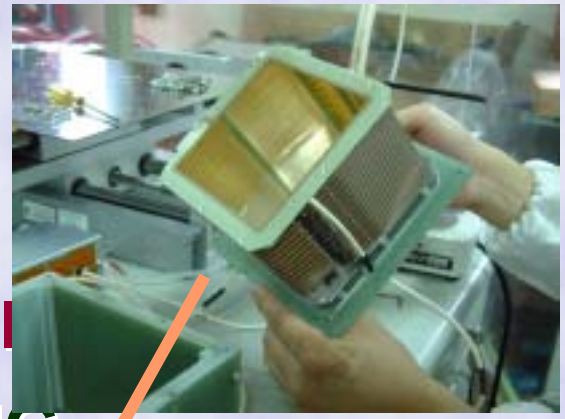


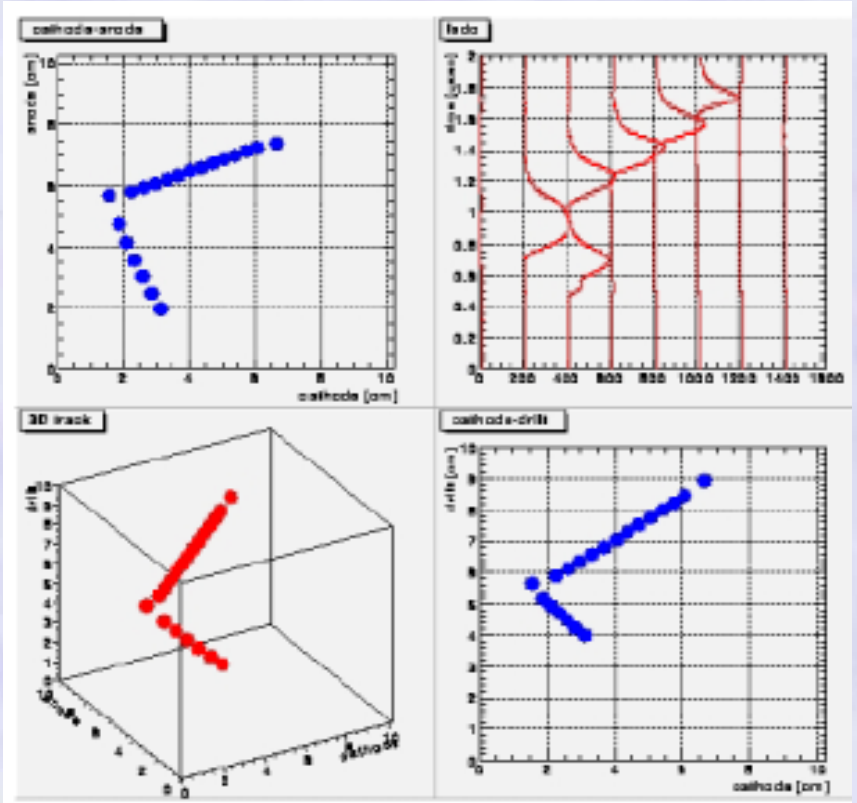


Micro-TPC (3D-Track Imaging)

- **Field cage**
  - **8cm drift length**
  - **0.4 kV/cm electric fiel**
- **+10×10cm² μ-PIC**

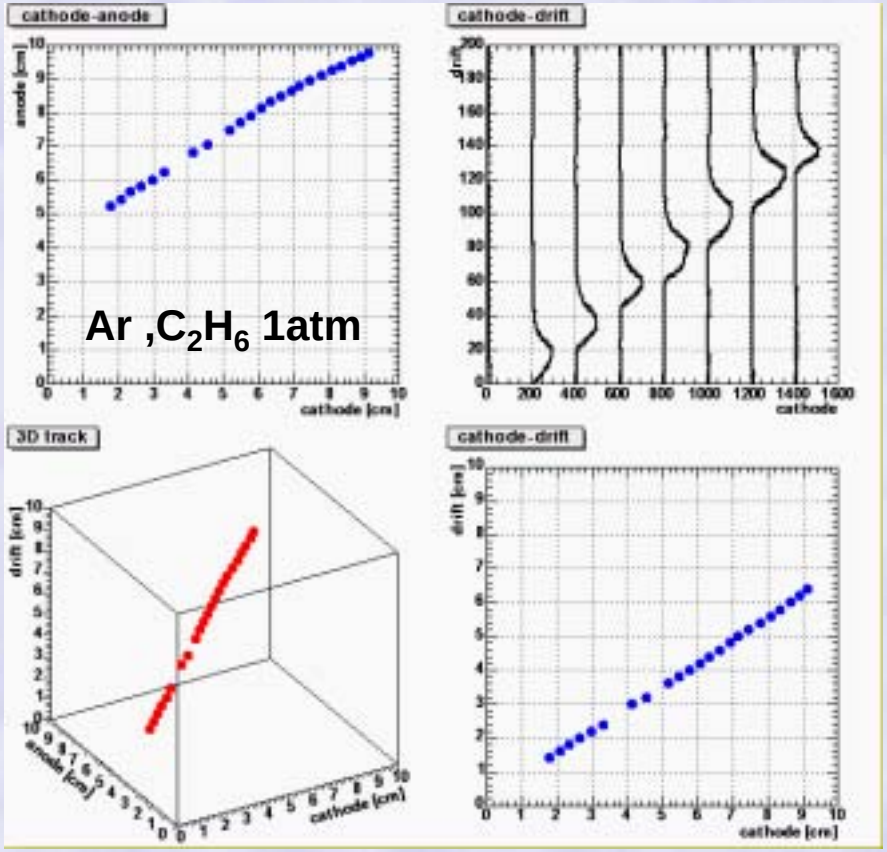
➡ **micro-TPC**

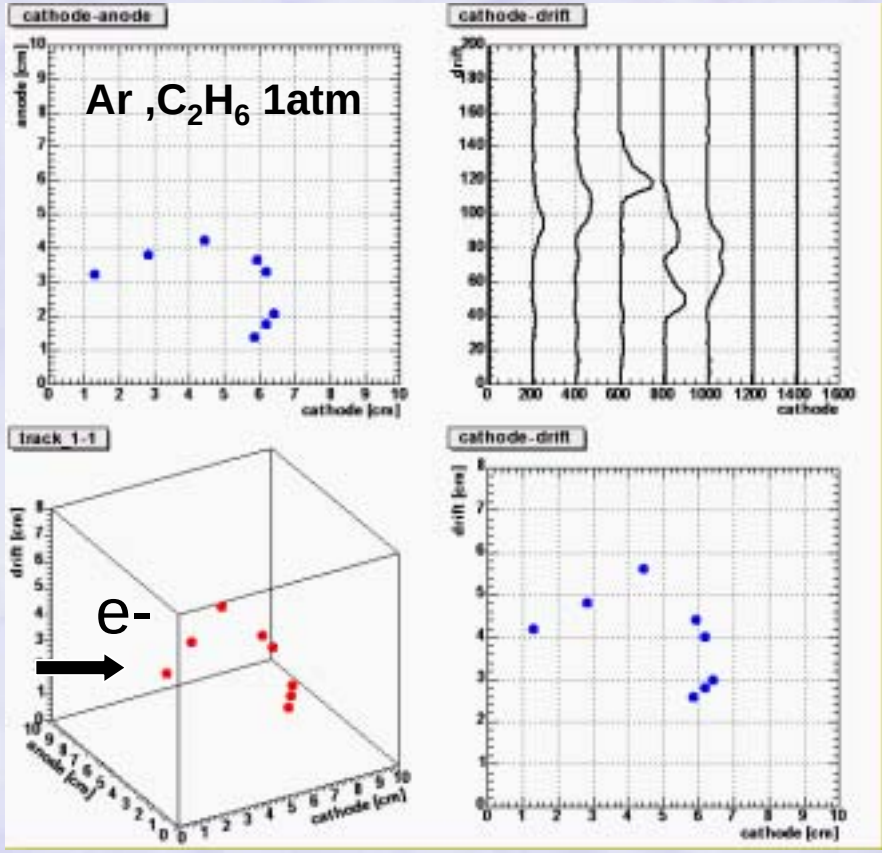




Micro-TPC : tracking performance

proton track(~0.8GeV) electron track (^{90}Sr,Q$_\beta$ 2.3MeV)

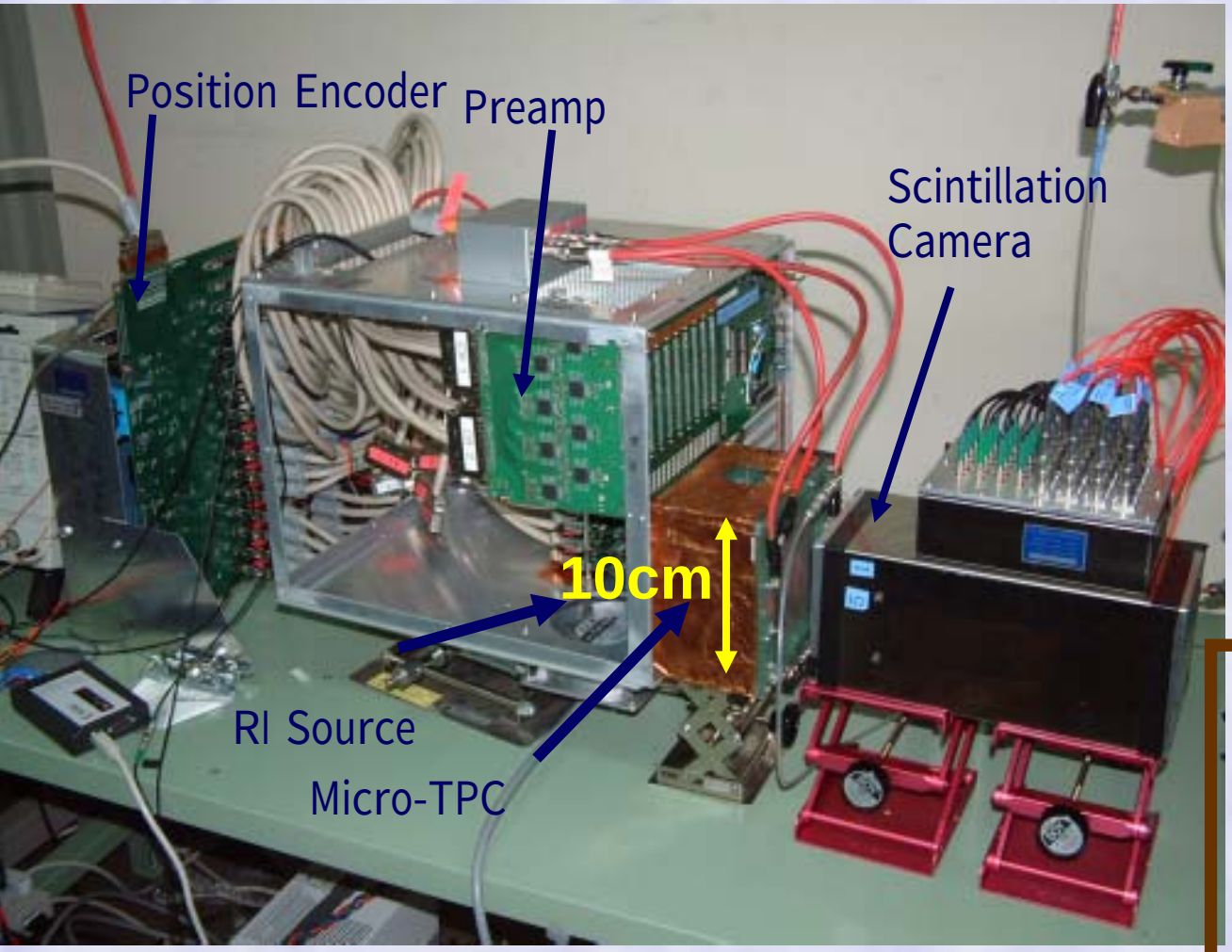




- Drift time ⇒ Depth information
- dE/dx ⇒ track direction
- TPC gas gain + clock up ⇒more precise track !

Prototype detector

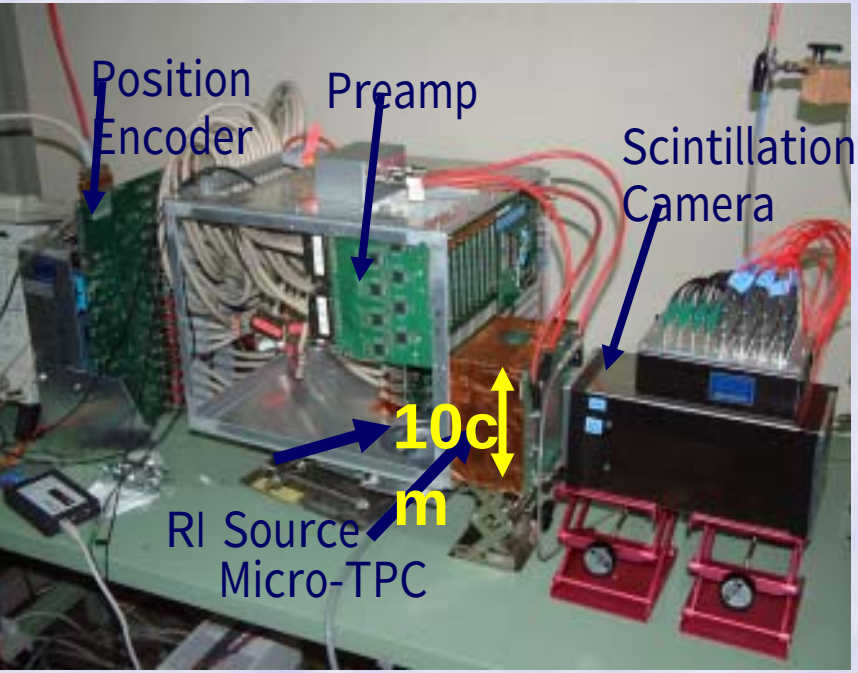
Anger camera



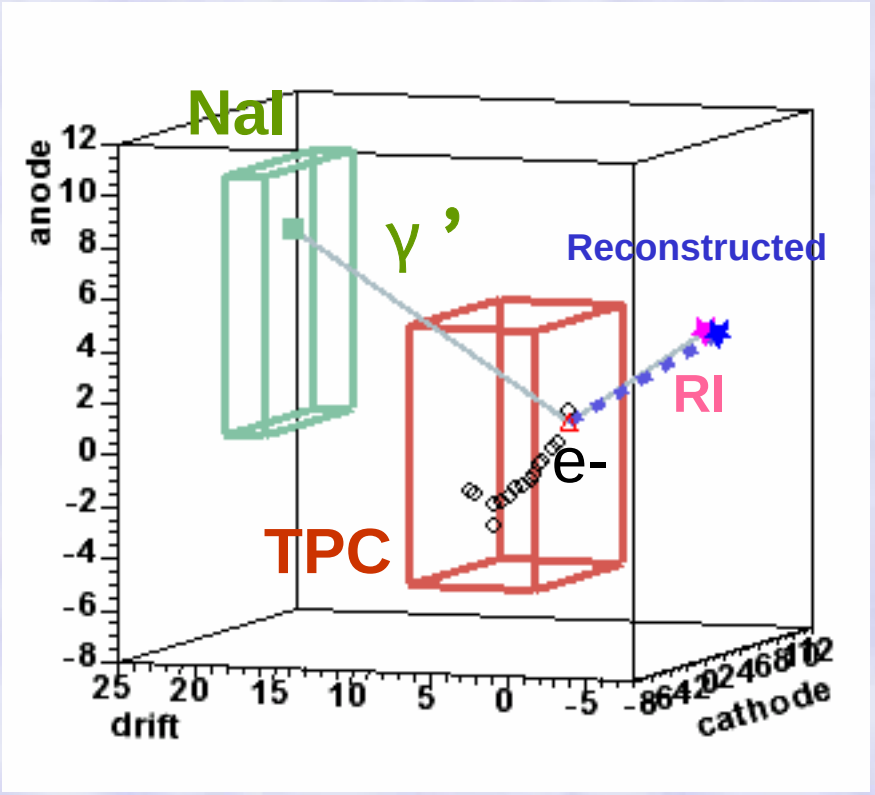
No Veto or Shield !

micro-TPC
10×10×8 cm^3
Ar +C_2H_6 (9:1)
NaI (Tl) Angur
4”×4”×1” 25 PMTs

γ-ray imaging test



Typical Reconstructed Event



Red zone :TPC

Green zone :scintillation camera

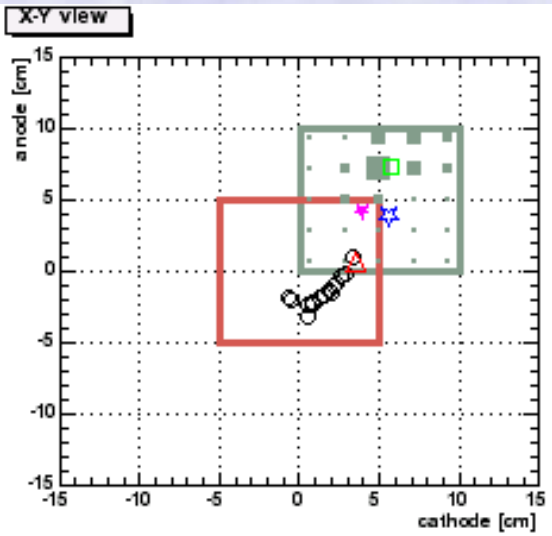
- **Scattered gamma-ray in NaI**
- **Electron track in TPC**
- **RI Source**
- **Reconstructed**

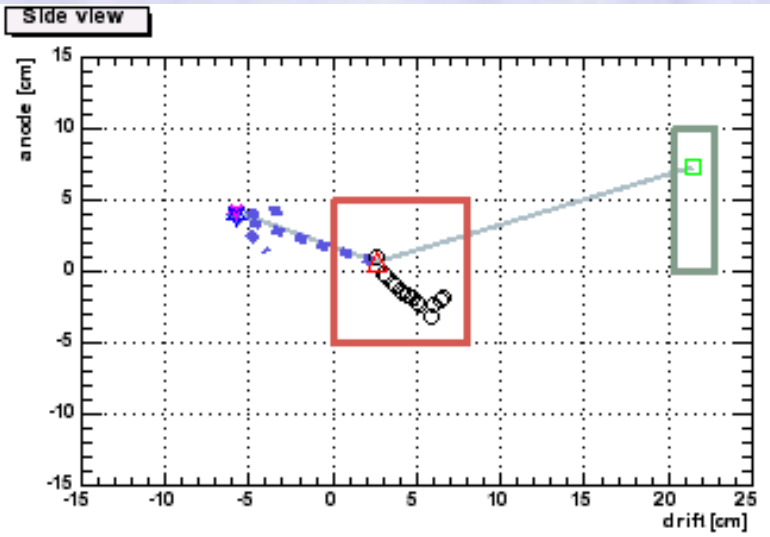
uPIC6 20030613 per5

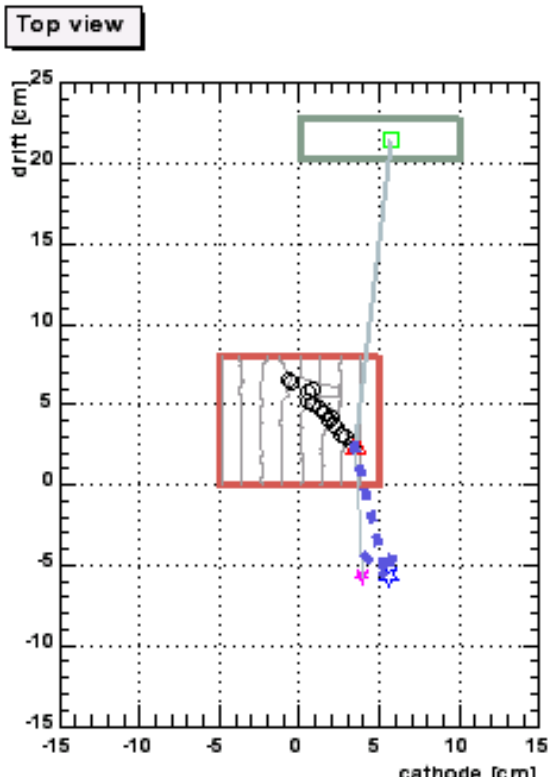
file 268 event 84

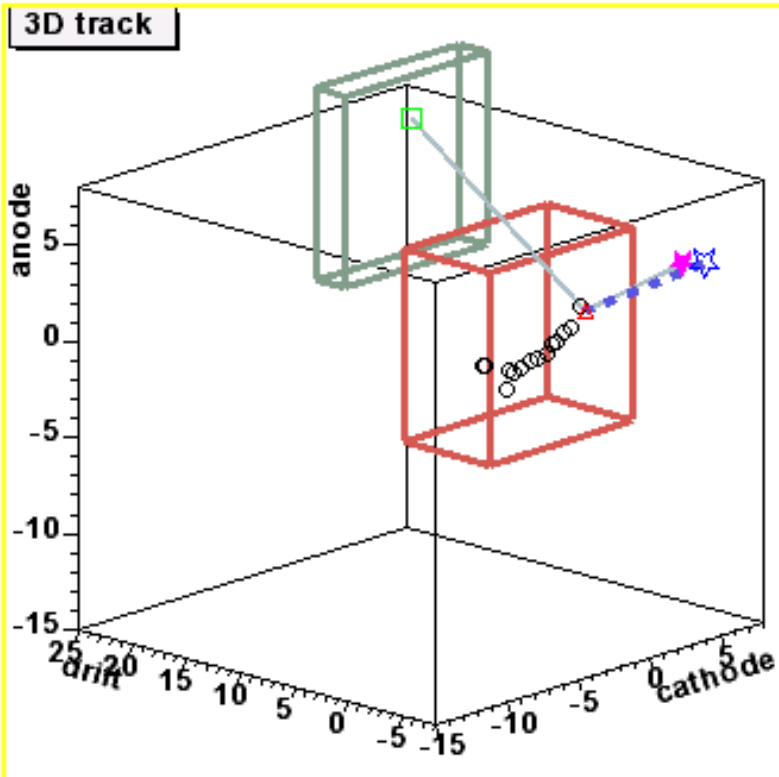
✡ Reconstructed
✶ Source Position
□ NaI hit
△ Compton point

nhit: 15
Source: 662.0 keV
NaI: 482.2 keV
α = 89.6°
ϕ = 44.6°
ψ = 46.7°
$\alpha/(\phi+\psi)$ = 0.98



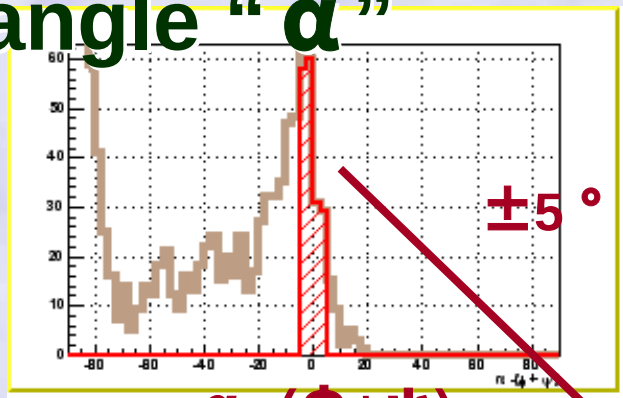


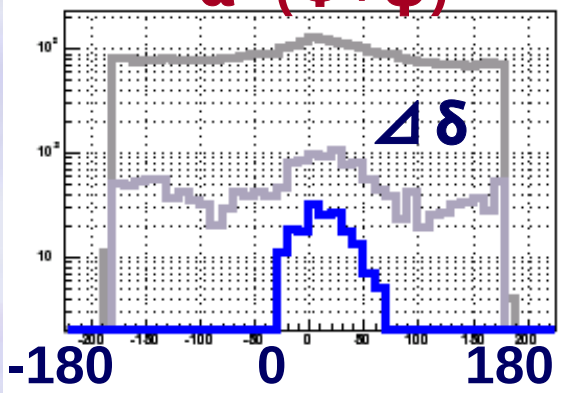


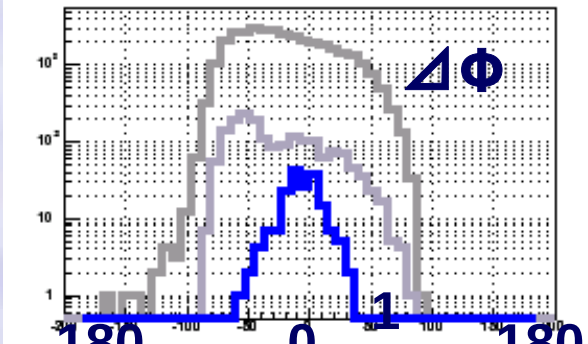


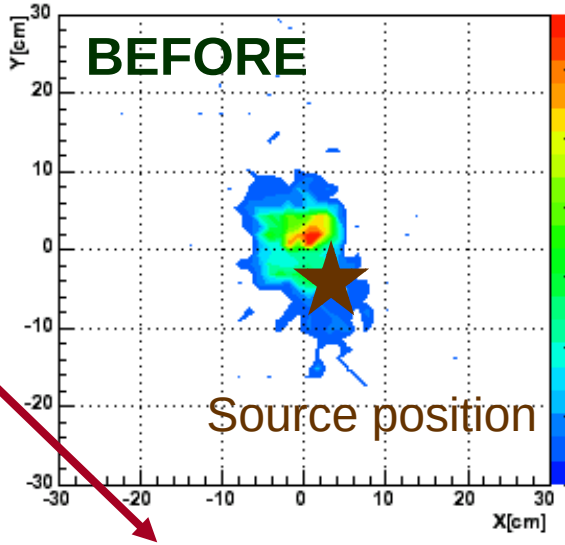
Background rejection (α cut)

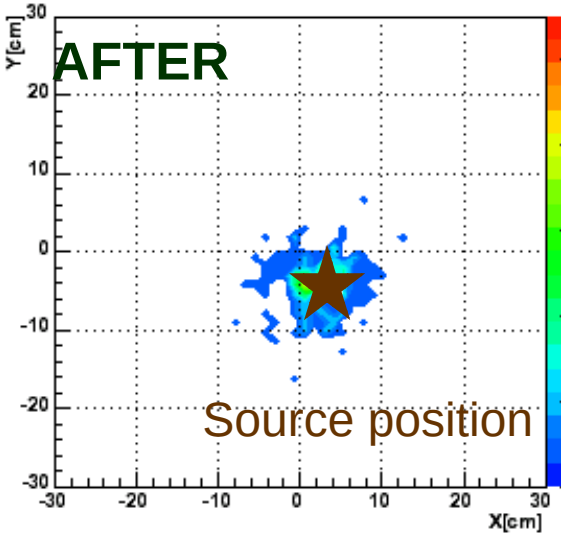
- Redundant angle " α "

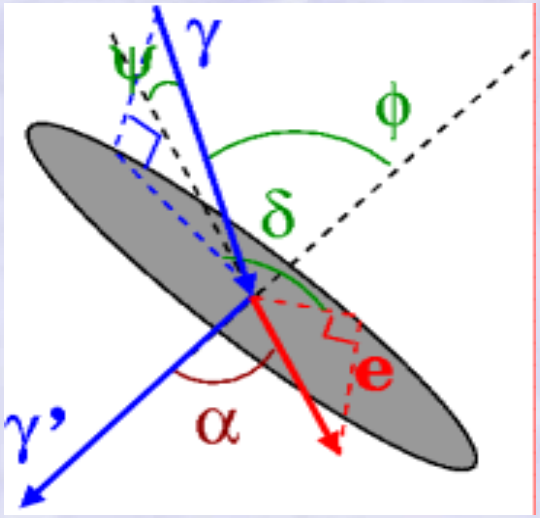








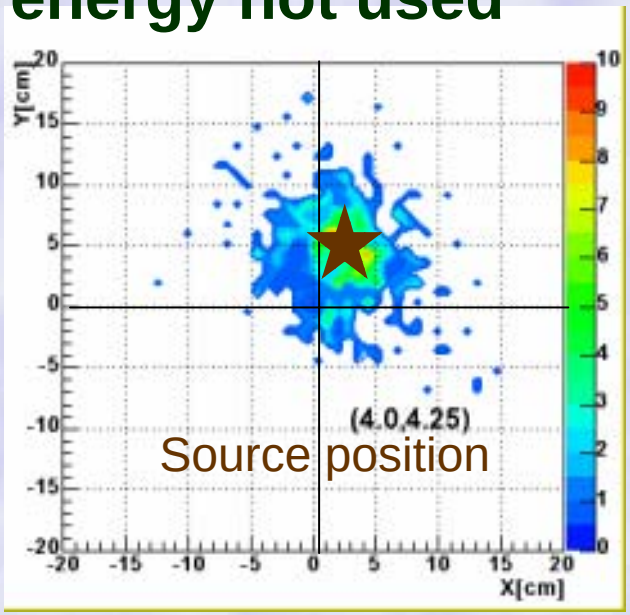




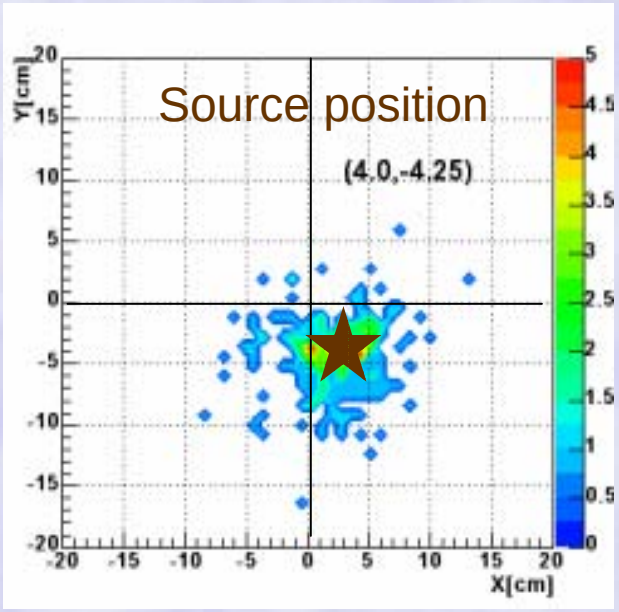
Reconstructed Image

^{137}Cs 662keV RI source (5cmfrom micro-TPC)

e- energy not used



8cm move



using **α** cut →No ghost event !

Angular Resolution(1 σ)

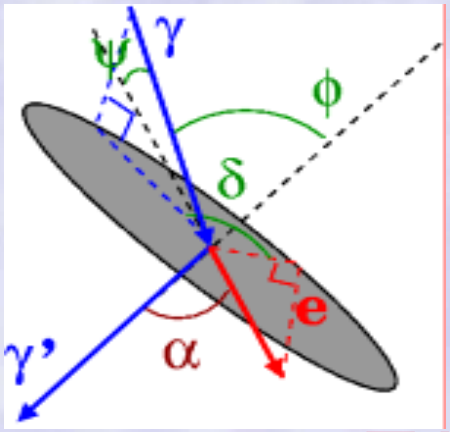
⊿δ = 25 °

⊿Φ= 15 °

→ **⊿δ < 10 ° (MC)**

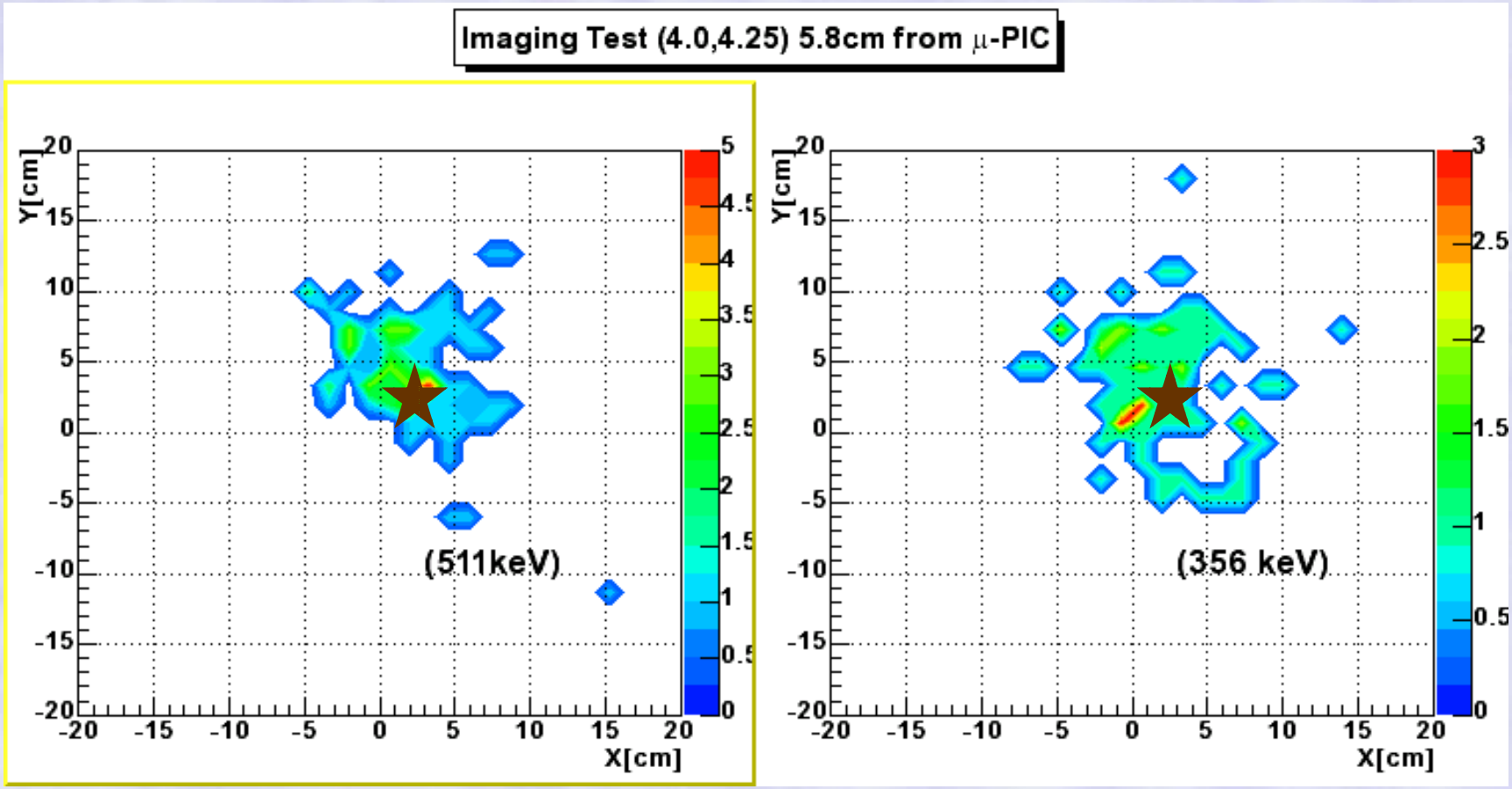
⊿Φ< 7 ° (MC)

TPC gain ×5



IT WORKS!

low energy γ-ray



Future Works

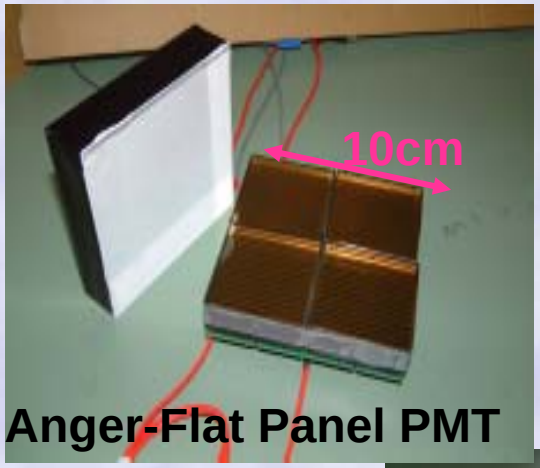
Micro-TPC

Improvement of gain (required X 5)

- Study of electrodes (electron collection efficiency 30% ->95%), X 3
- Quality control for uniformity of structure X 2
- Sampling pitch 0.4mm -> 0.8mm X 2
- New amplifier IC chip (Time constant 16ns -> 80ns X 3) done
- Xe Gas 1.5 atm dE/dx X 4.5

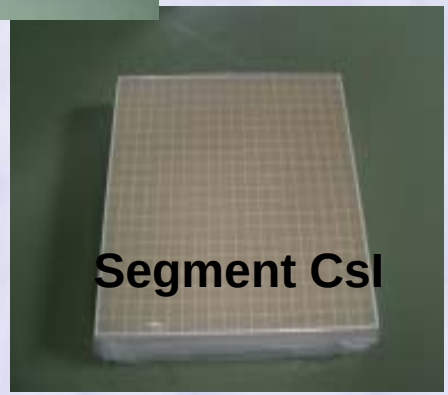
Scintillation camera

- Required performance (Res.(FWHM), 2mm,7%@662keV)
- Under studying following types



Anger-Flat Panel PMT

shape		plane	Segment	Segment
readout		FP-PMT	FP-PMT	Pin-D.Array



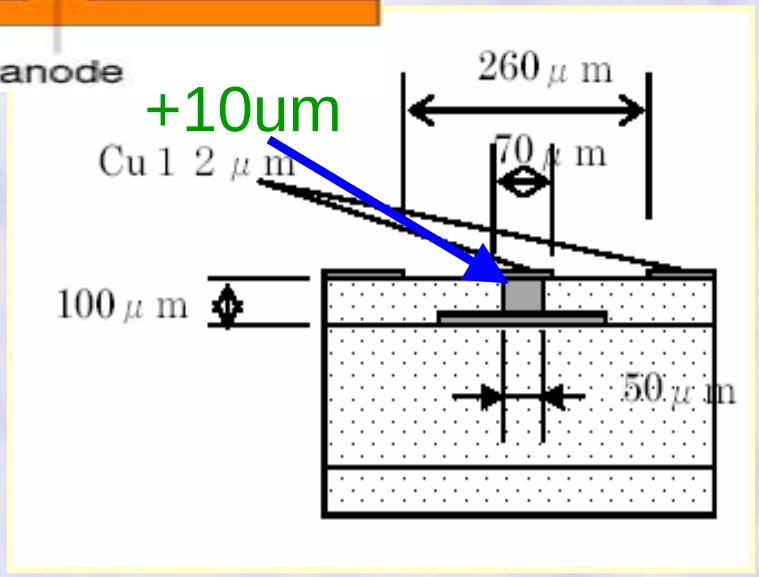
Segment CsI and Pin –D. Array 10cm X 10cm, 5mm pitch

Study of Electrodes (height of Anode)

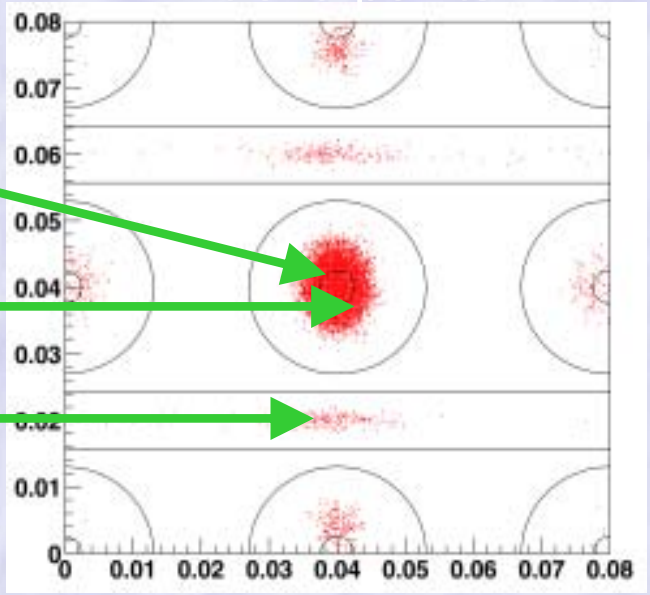
Collection efficiency 30 ->97%

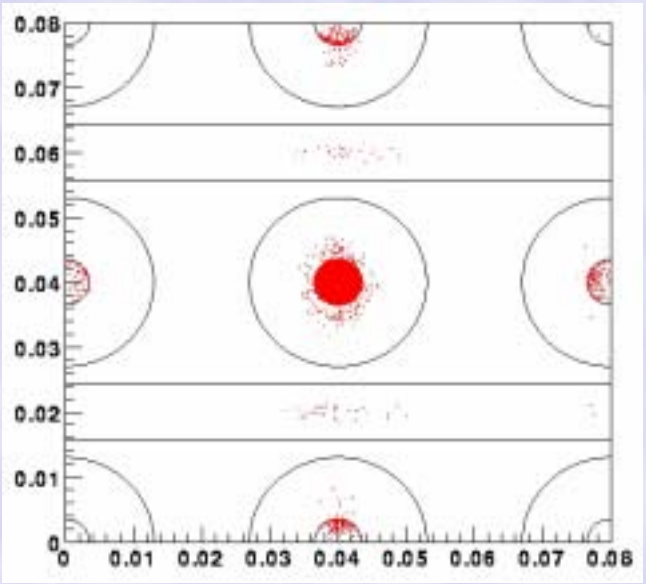
Near pin 65-> 2%

Cathode gap 4 -> 1%



Drift end points





開発状況まとめ

- プロトタイプ検出器でコンセプト実証
- 今後フライトモデル製作及び性能向上
- 2006年に気球実験

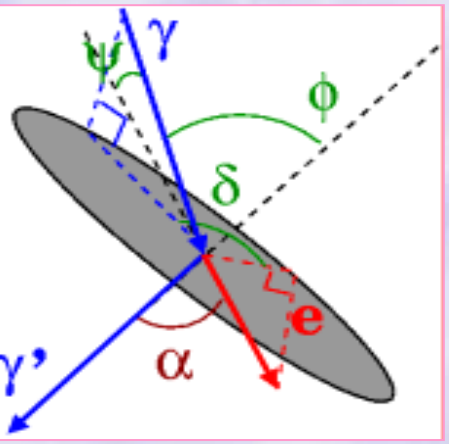
研究計画概要

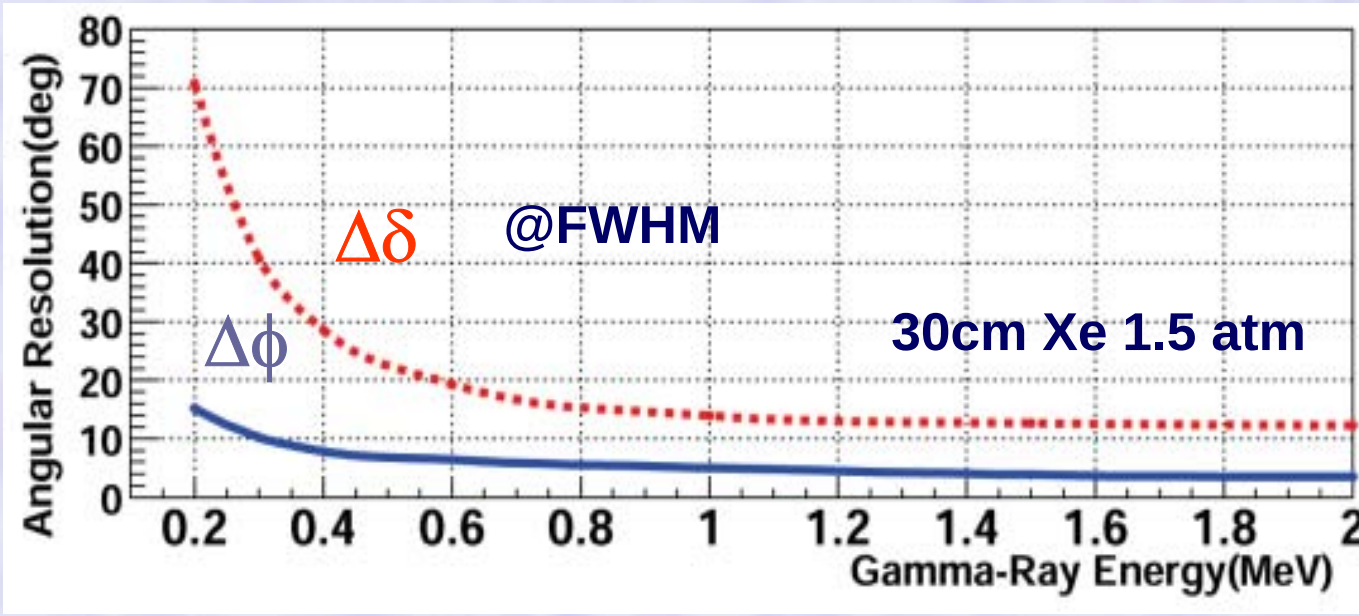
- 研究計画：　衛星搭載
  - ~2006年度　特定領域(A)　計画研究
    2006年夏：MeV検出器(30cm角)完成、気球実験
    ⇒　南極周回長期観測計画（50cm角、5年程度）
    ⇒　衛星搭載型検出器の開発へ（50cm角×n）
- 研究体制：　新領域の立ち上げ
  - 現在は京都大学宇宙線研究室（スタッフ3名+学生数名）
  - 将来的には宇宙研（高橋グループ）等とMeV領域研究グループを立ち上げも
- 予算規模
  - 数億円（南極周回計画）

Angular Resolution

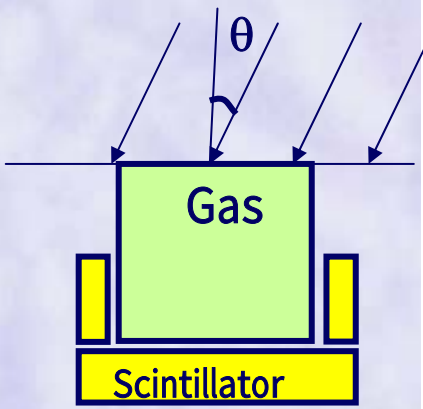
$\Delta\phi$: Angular Resolution Measure(ARM)

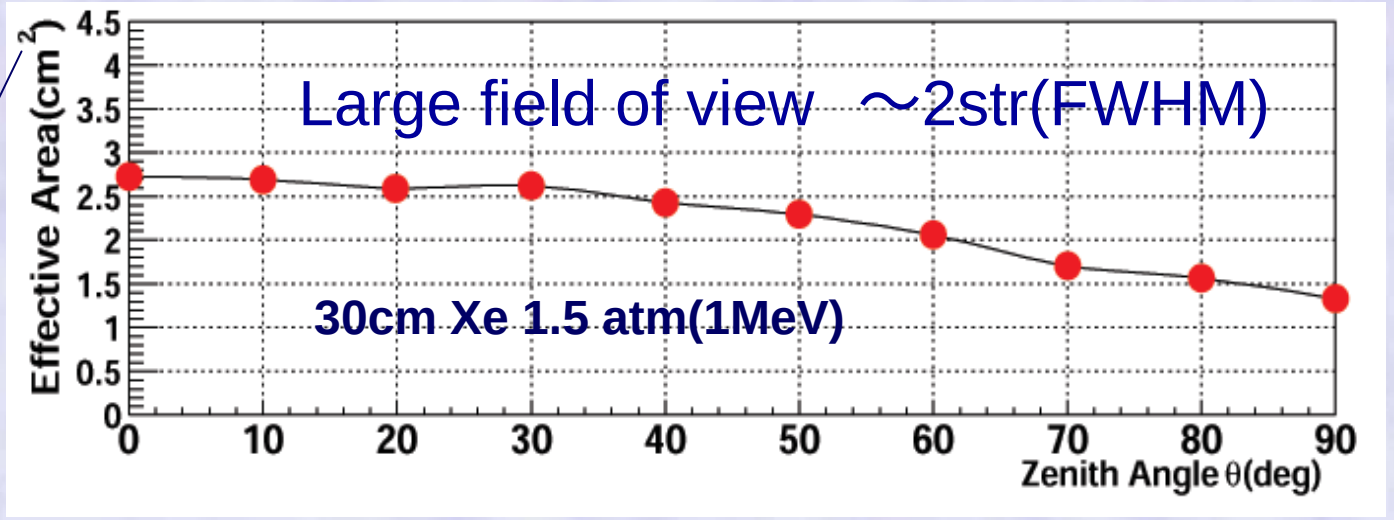
$\Delta\delta$: Scatter Plane Deviation(SPD)



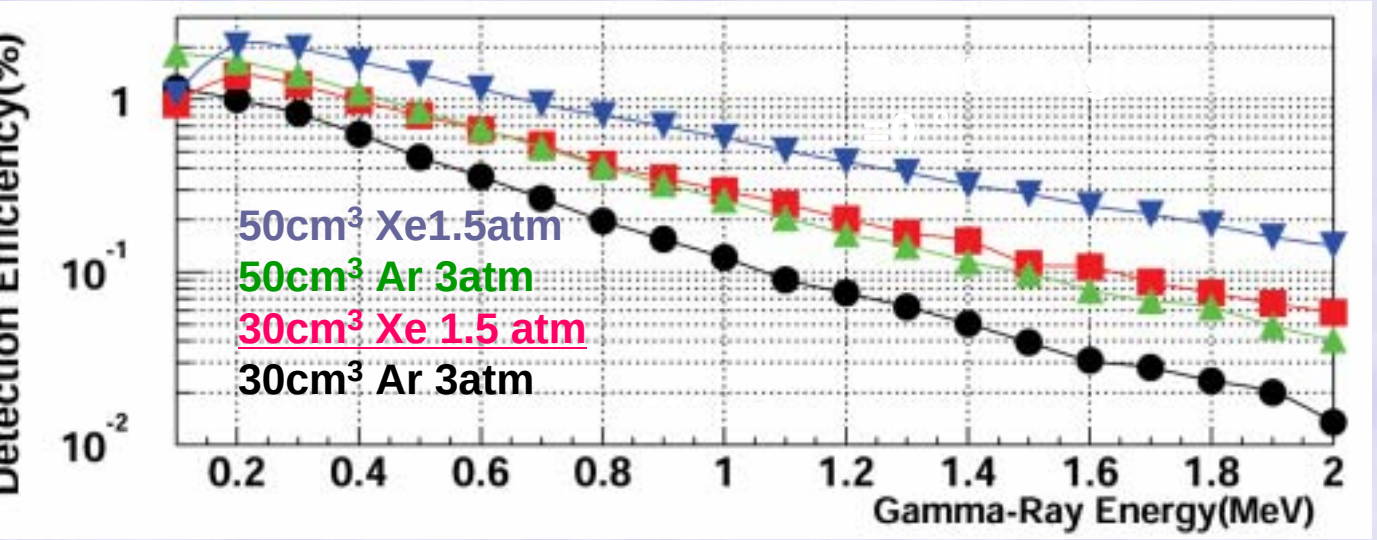


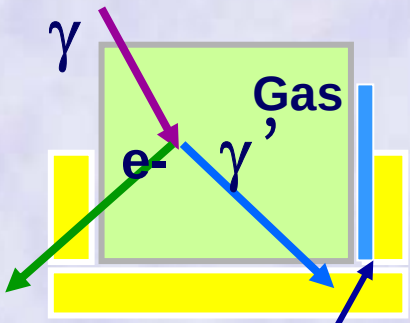
Effective Area



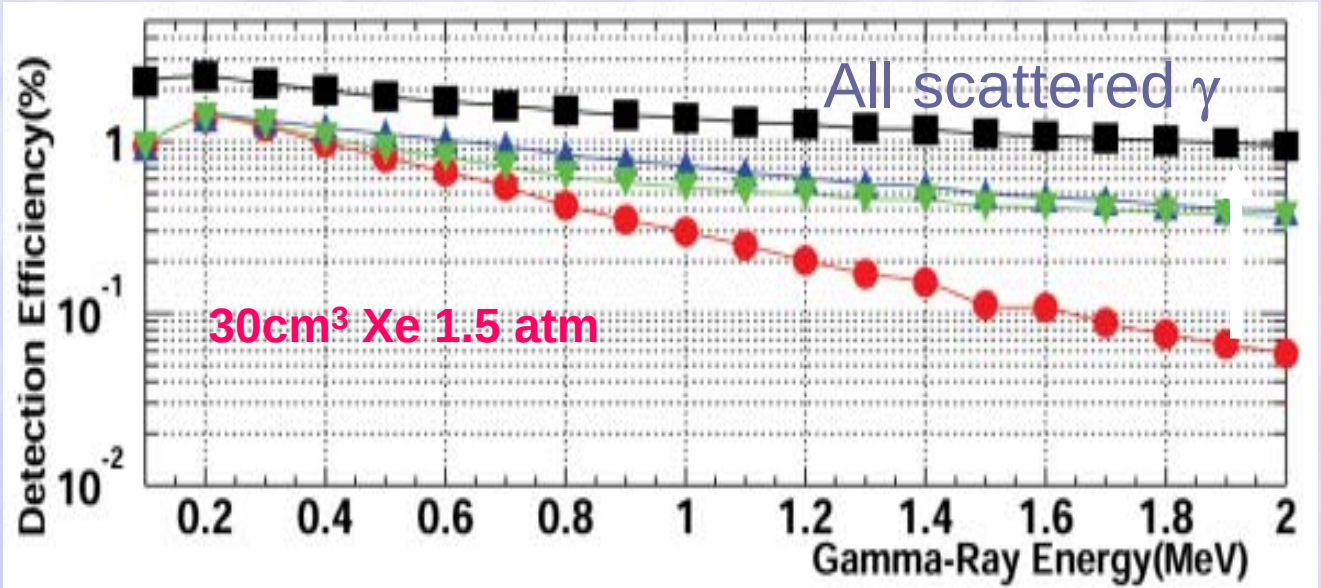


Detection Efficiency





Silicon pad



Through going electron
(δ also improved)