

Performance of the Gamma-ray Imaging Detector with Micro-TPC

Cosmic-Ray Group

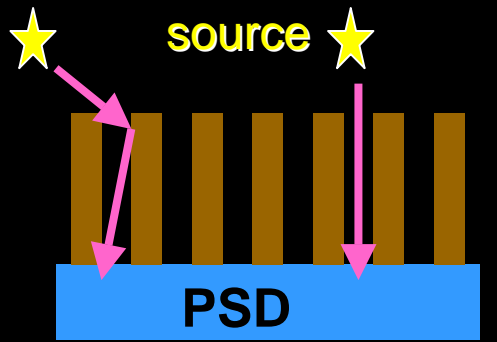
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Contents

- Principle of the gamma-ray imaging detector with gaseous time projection chamber & scintillation camera
- Development of the prototype detector
 - TPC with microelectrode readout
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- Summary

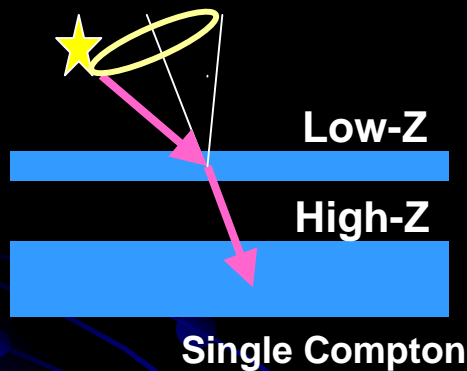
Conventional Methods of Gamma-ray Imaging



1. Collimator + Position Sensitive Detector

Narrow FOV, background due to scattered gamma-ray.

Energy band is below 1MeV.

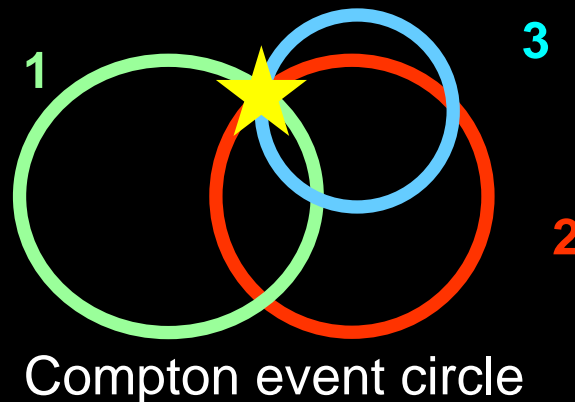
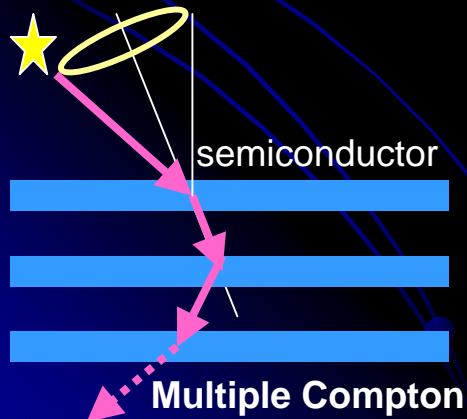


2. Compton Camera

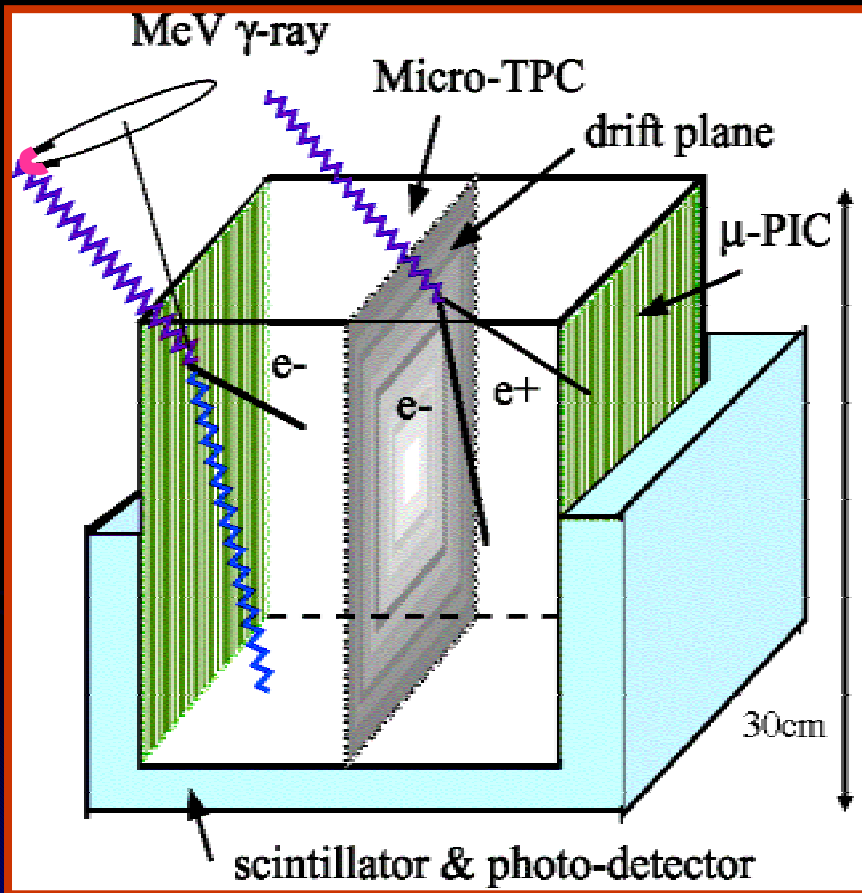
3 events are required to know incident direction.

Low sensitivity for diffuse gamma-ray source.

poor efficiency of rejecting internal background.



Proposed Novel Gamma-ray Imaging Detector



Gaseous TPC

precise measurement of
3D track & energy of recoil e^-

Scintillation Camera

position & energy of scattered



direction & energy of incident
on small segment of Compton circle.
event by event reconstruction

We can take full tracking of Compton scattering process !
Need no collimator.

Features

Full tracking of Compton scattering process without collimator leads...

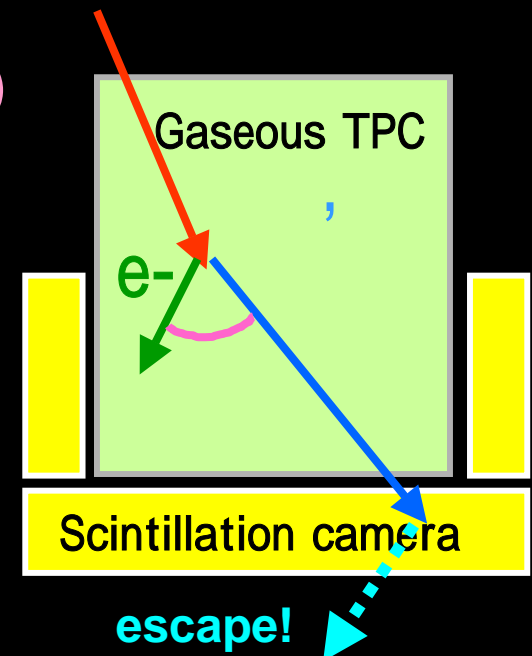
- wide FOV & no background from collimator.
- event by event reconstruction of incident gamma-ray.
- wide energy band with low energy threshold (>200keV)
- high efficiency of BGD rejection

Inconsistency between measured α and

$$\cos\alpha = E_e(E_{sg} - mc^2) / (E_{sg} \sqrt{E_e^2 + 2E_e mc^2})$$

Application to

- astrophysics
- radioactive pollution monitor
- medical imaging

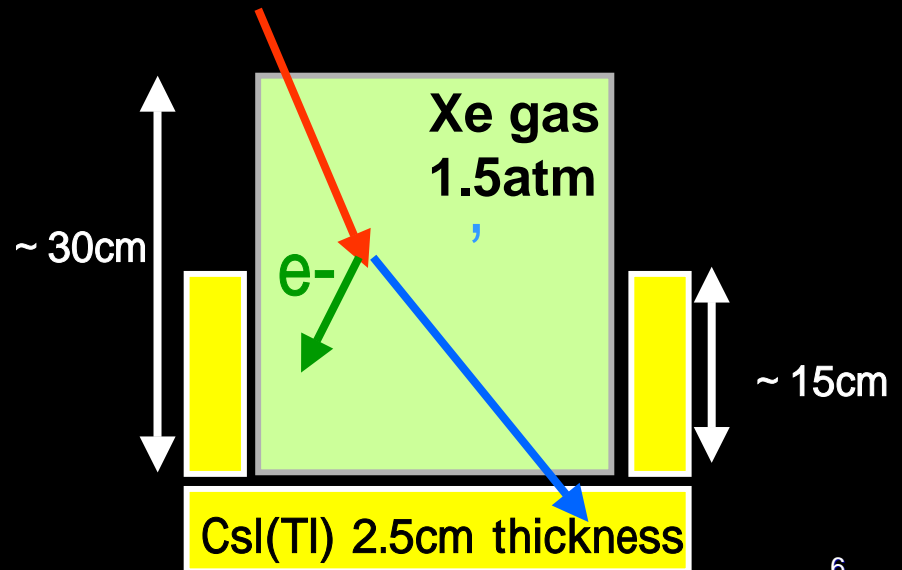
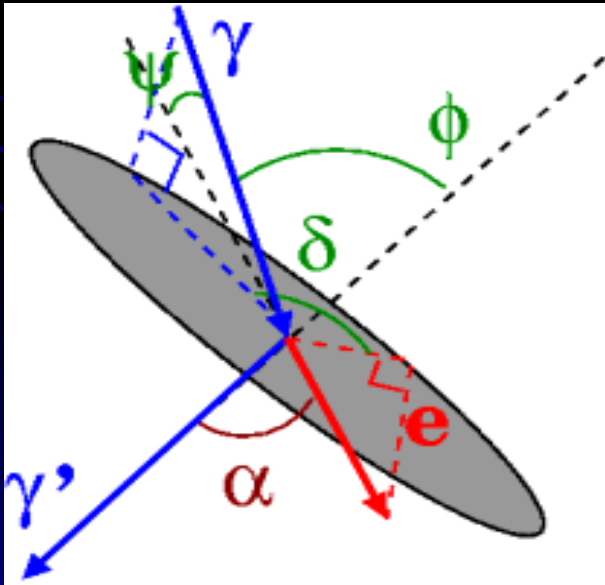


Monte Carlo Simulation(Geant4)

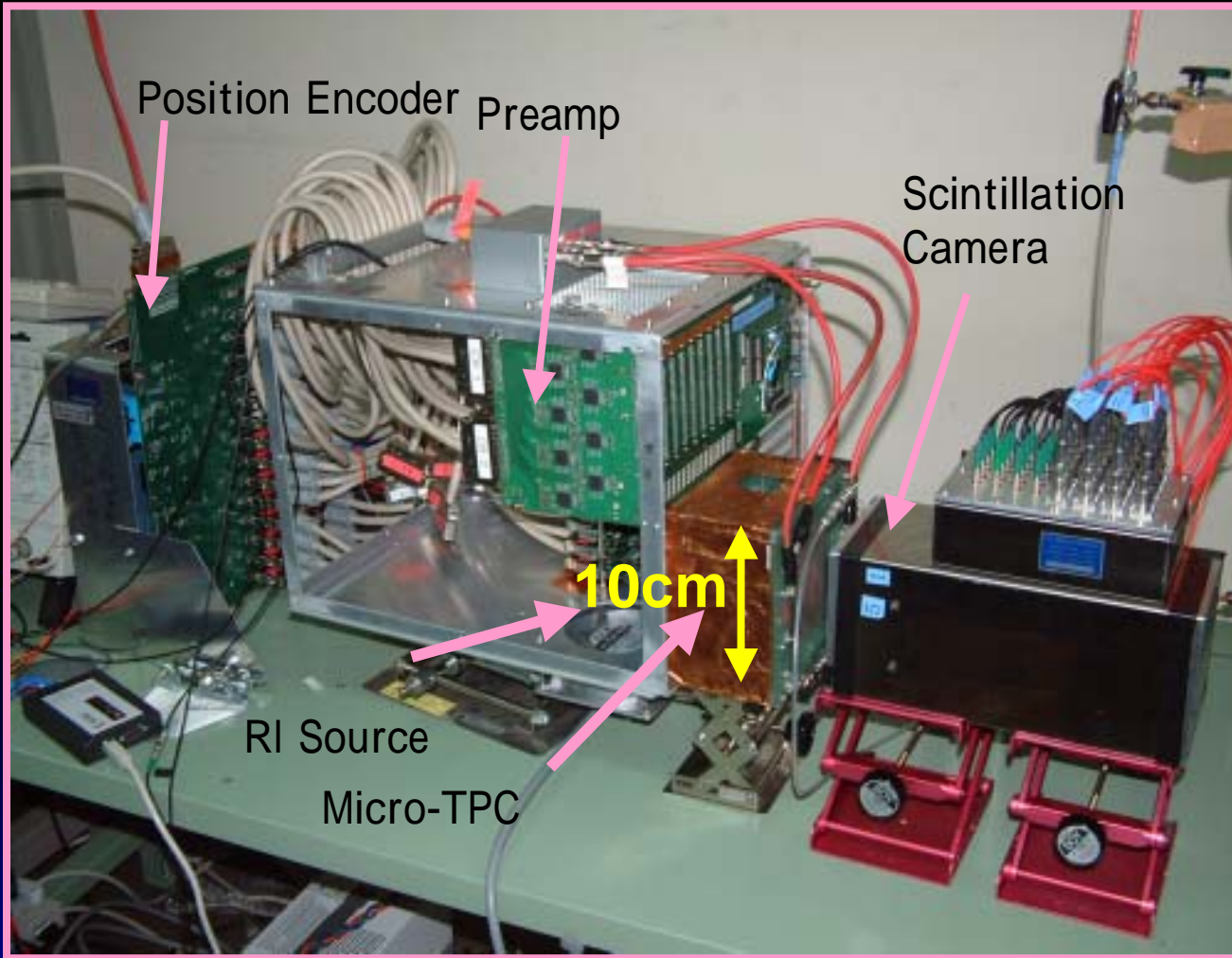
TPC : 30cm cubic , Xe 1.5 atm, 400um electrode spacing

Scintillation Camera : CsI(Tl) 2.5cm thickness, 5mm pixel, No DOI

- low energy threshold ($>200\text{keV}$)
- large field of view ($\sim 2\text{str FWHM}@1\text{MeV}$)
- detection efficiency ($1\%@1\text{MeV}$)
- angular resolution ($\Delta\phi = 5^\circ$, $\Delta\delta = 10^\circ \text{ FWHM}@1\text{MeV}$)



Prototype detector



TPC with microelectrode

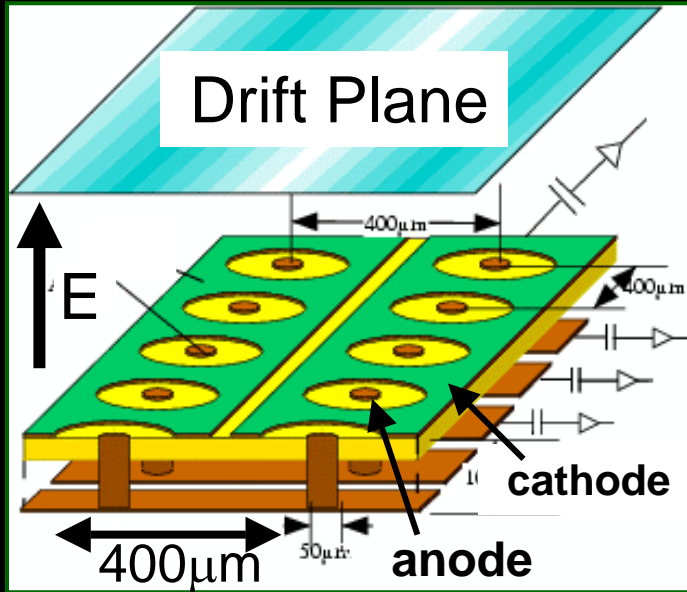


Anger camera



No Veto Shield !

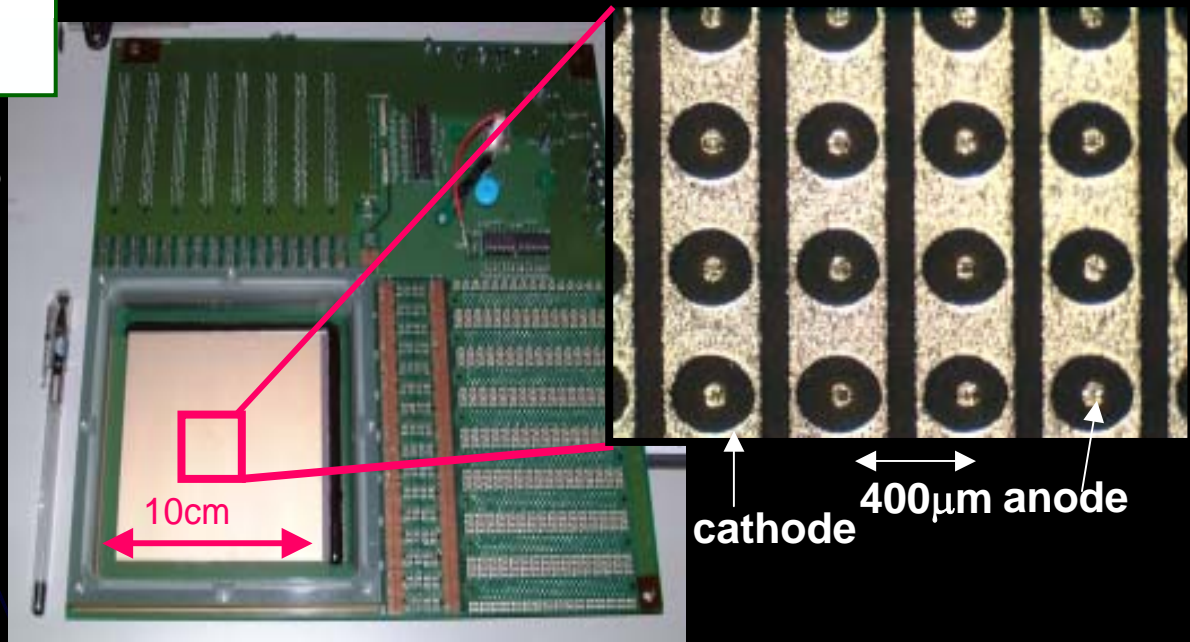
Micro Pixel Chamber



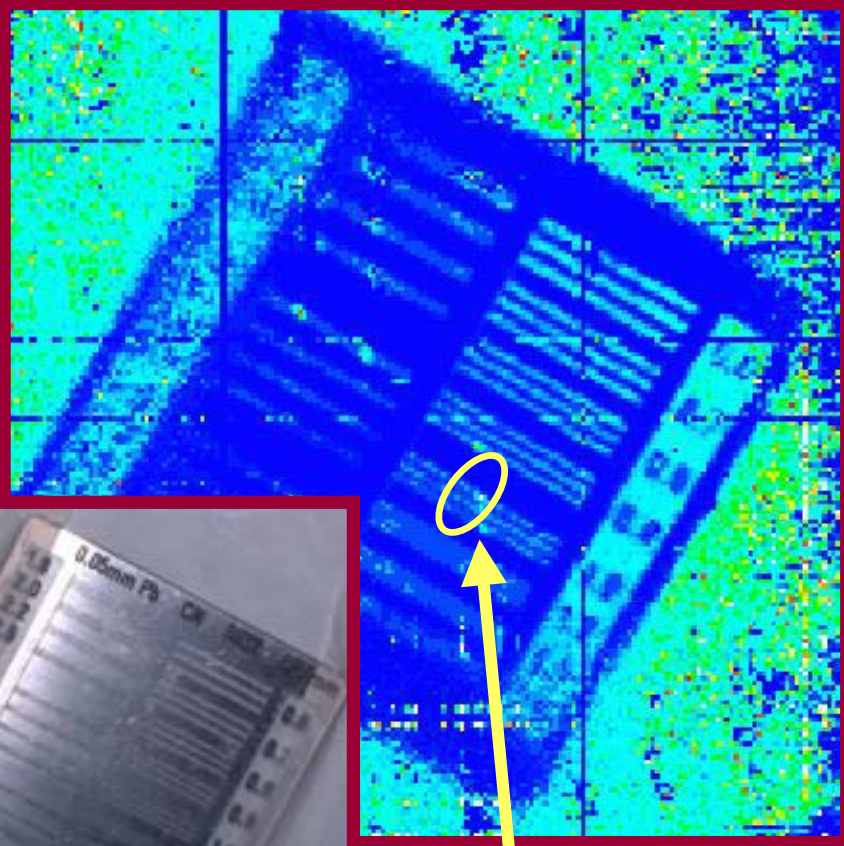
- 400 μm spacing anodes & cathodes
- 100 μm polyimide substrate
- 10cm \times 10cm effective area
- Max gain \sim 15,000 (Ar:C₂H₆, 1atm)
- Energy Res. 30% @ 5.9keV (Ar:C₂H₆, 1atm)
- Stable operation \sim 1000h @ gain 5000

A.Ochi et al, Nucl. Instr. Meth. A471(2001)264

- Fine position resolution
- Low risk of discharge
- PCB Technology
- Low cost large area, mass-pro.

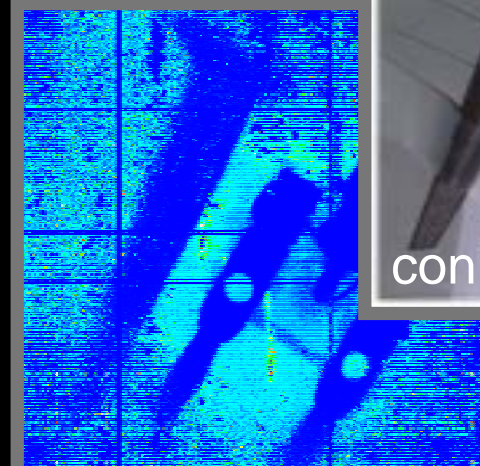


2D X-ray images (Xe:C₂H₆ , 1atm, 2mm drift length)



1mm slits

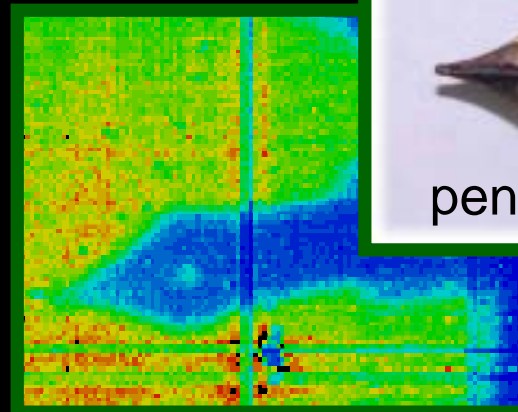
Lead test chart



connectors



pen



position resolution ~ 160um

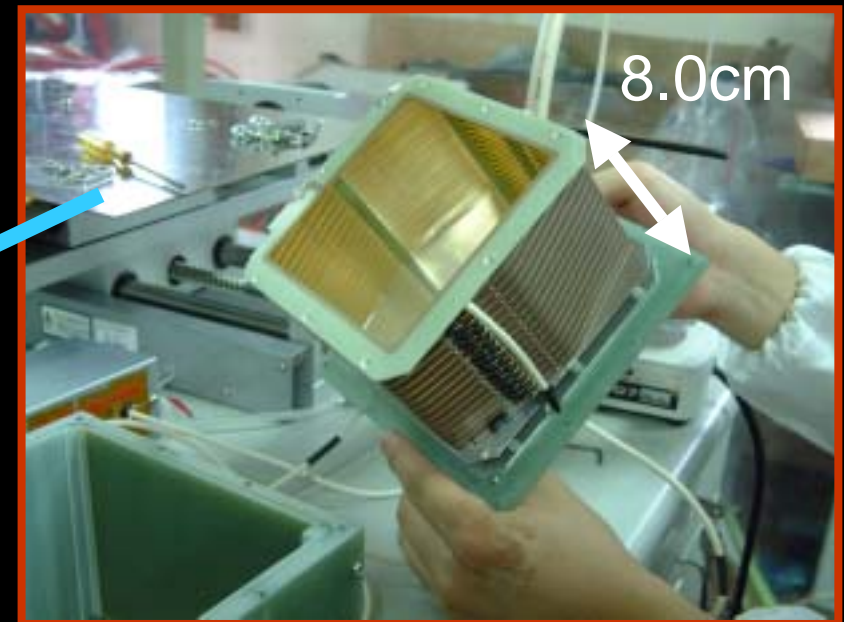
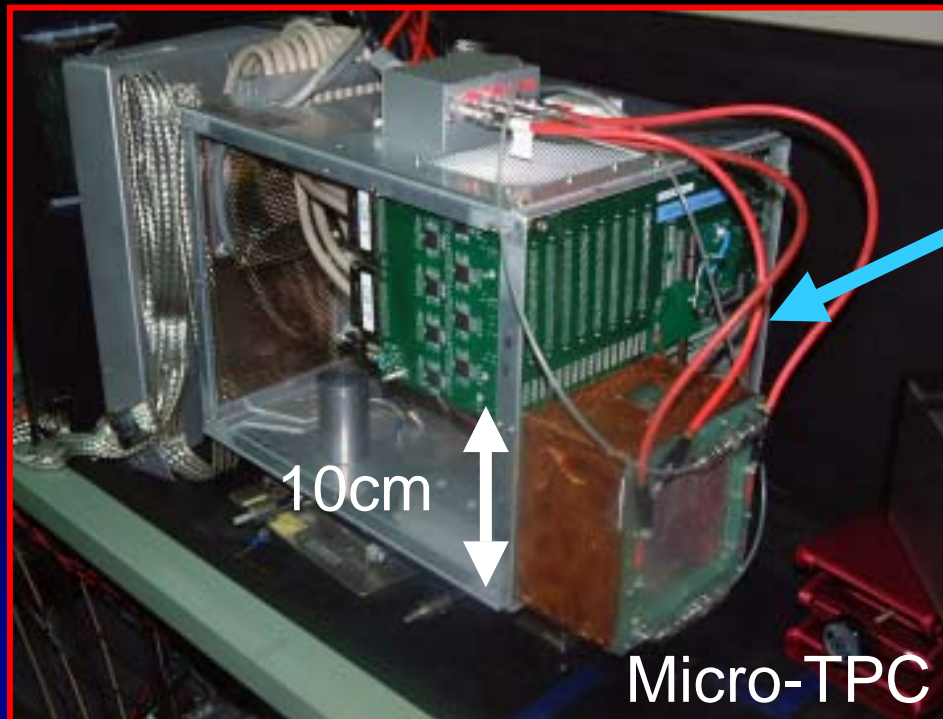
K.Miuchi et al, 2002 IEEE Trans.Nucl.Sci.2002

Gaseous TPC with Micro Pixel Chamber

TPC: measure 3D Particle Tracks (originally developed for HEP)

8.0cm drift length field cage, 0.4 kV/cm electric field
10cm × 10cm Micro Pixel Chamber

Micro-TPC



H.Kubo et al, hep-ex/20030108

TPC Electronics

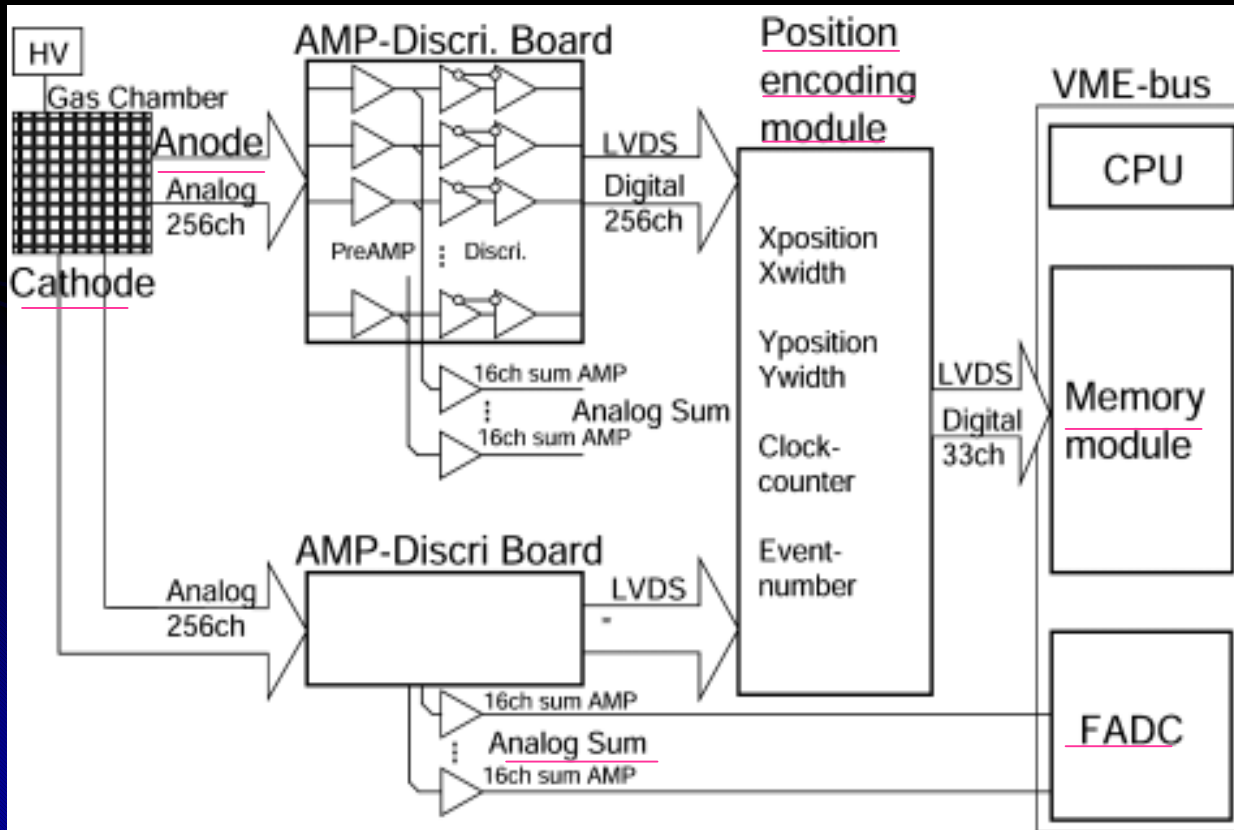
- 80ns Amplifier-Shaper-Discriminator IC (4ch/1 chip)
- Position-Encoder with 5 FPGAs with 20MHz
- Flash ADC/16ch

Preamp-board



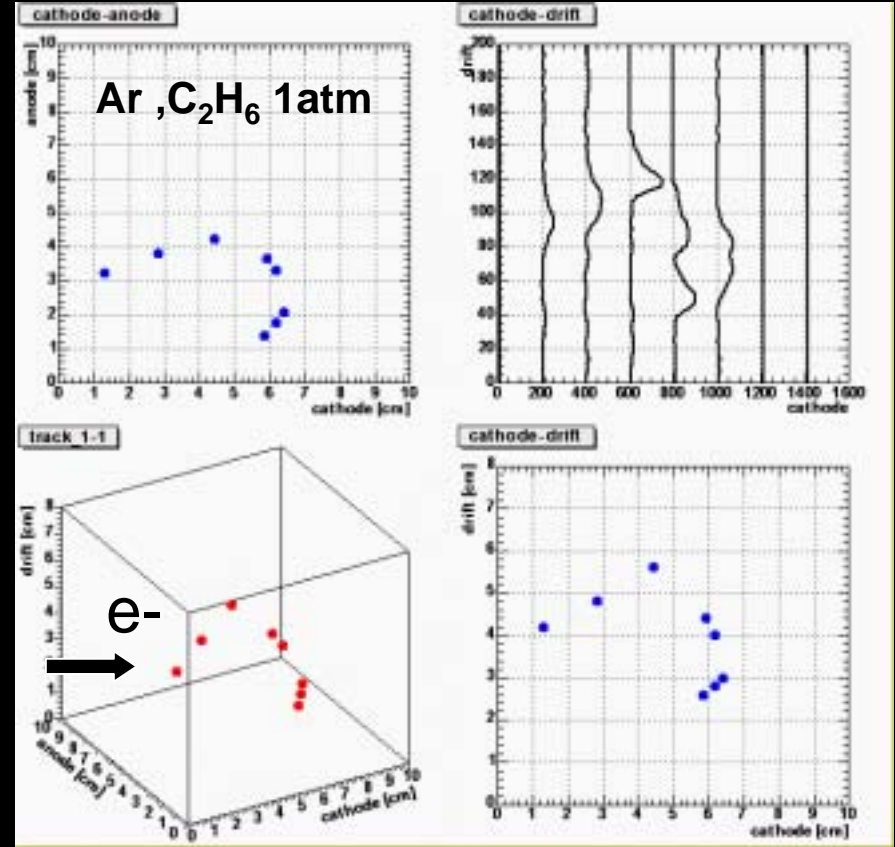
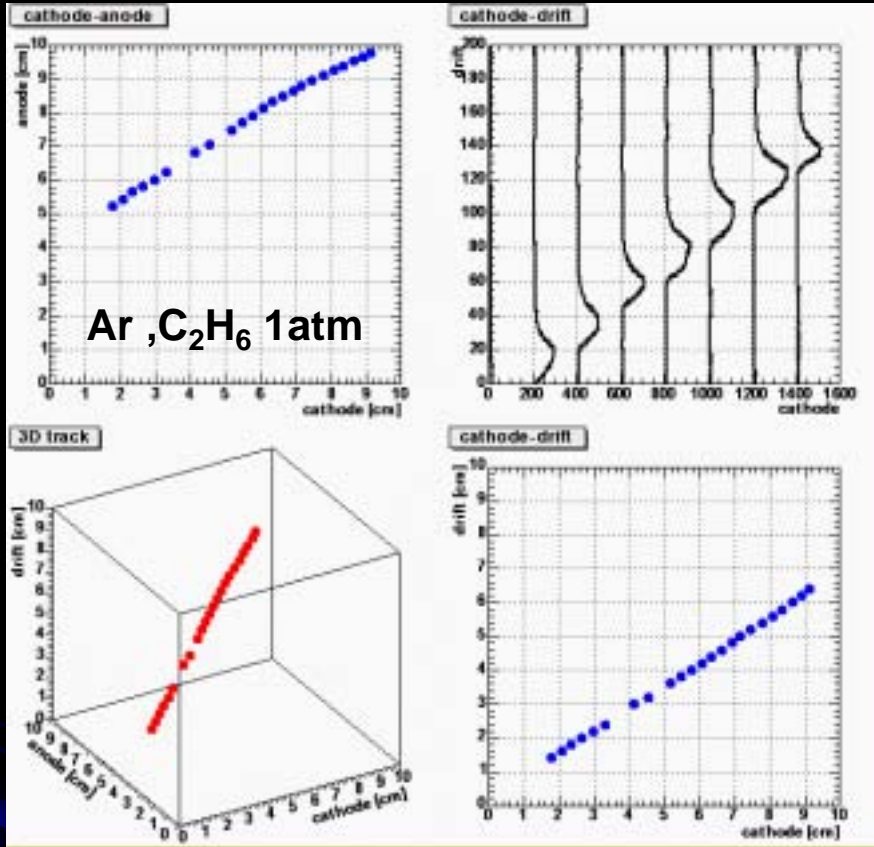
16cm

Encoder-board



Proton track (~0.8 GeV)

Electron track (^{90}Sr , Q ~2 MeV)



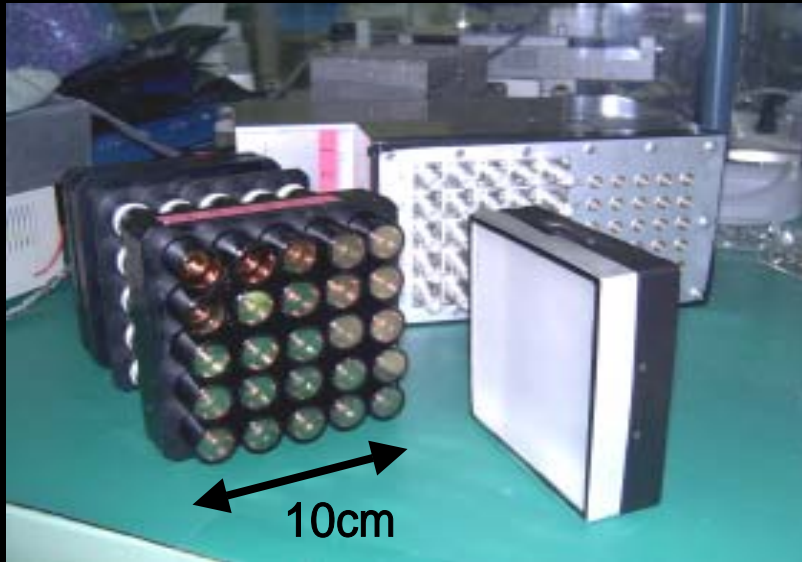
• Depth information

← elapsed time from trigger of scintillation camera.

• Start & End points of tracks ← from dE/dx .

• TPC gas gain **up** → more precise track !

Scintillation Camera



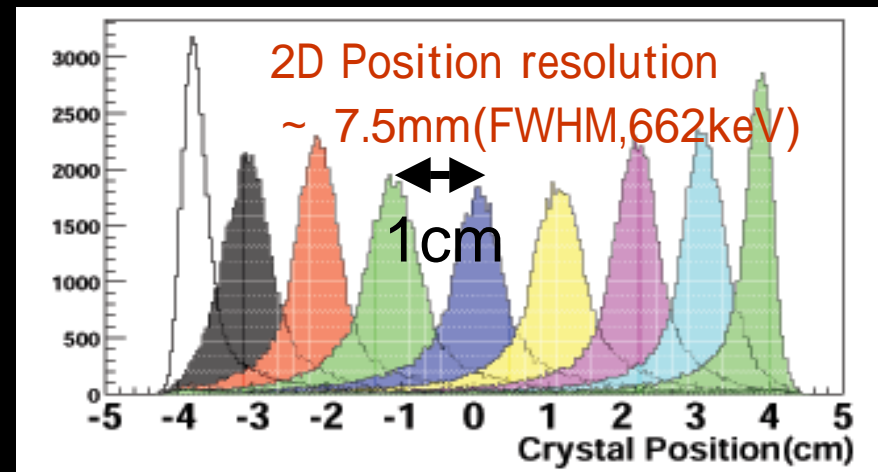
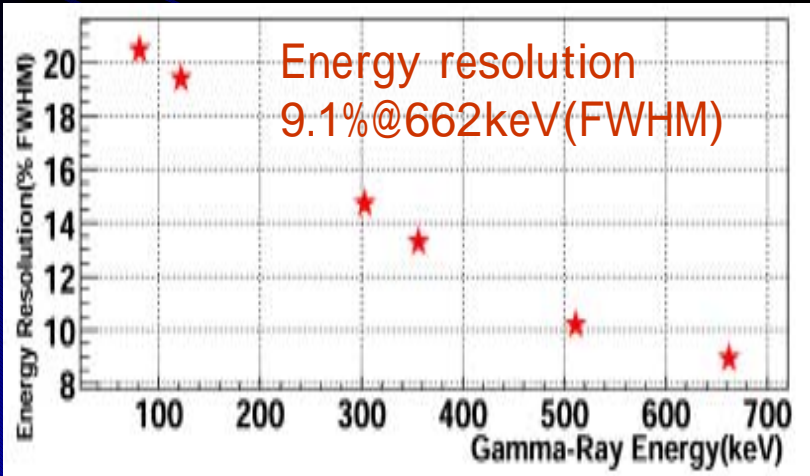
classical Anger camera

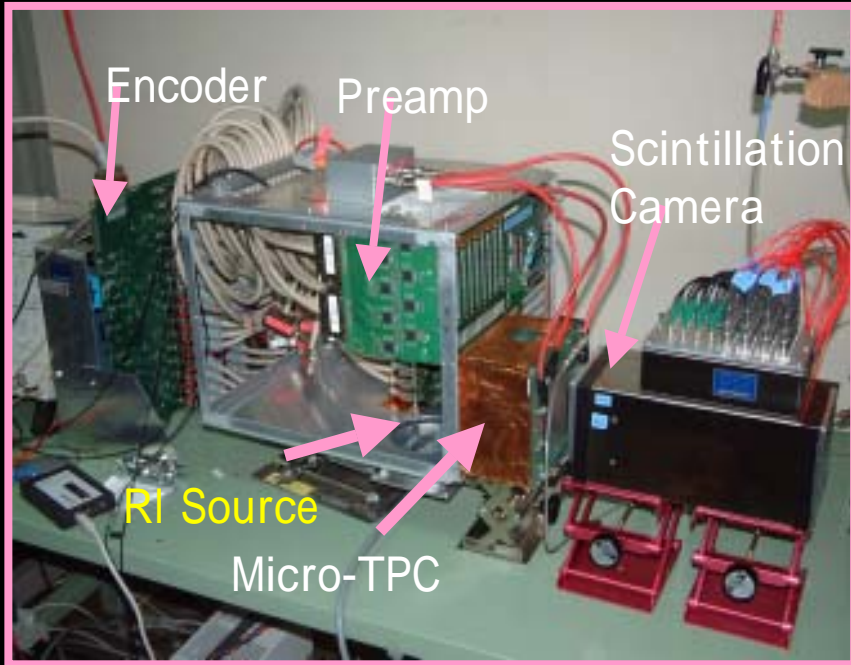
4" x 4" x 1" NaI(Tl) scintillator

5 x 5 Hamamatsu $\frac{3}{4}$ " R1166 PMTs

Photocathode cover 40%

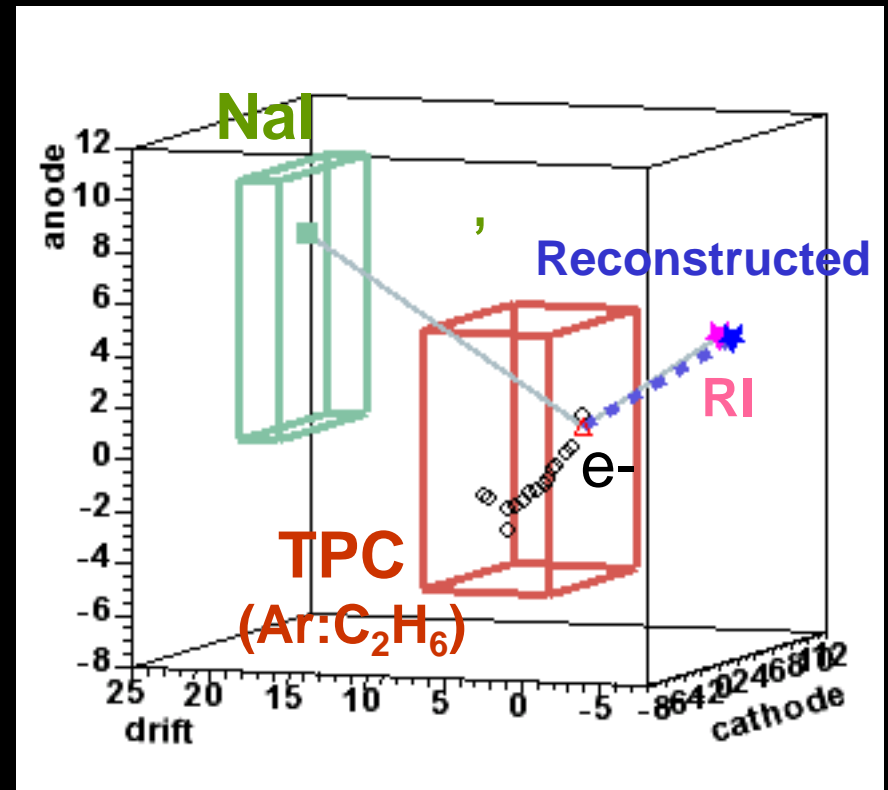
No DOI information





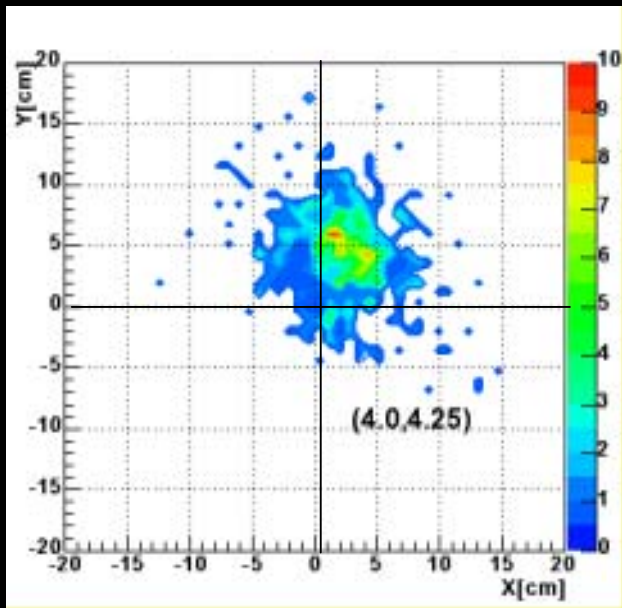
Typical Reconstructed Event

- Red zone** : TPC
- Green zone** : scintillation camera
- Scattered gamma-ray in NaI
- Electron track in TPC
- RI Source
- Reconstructed

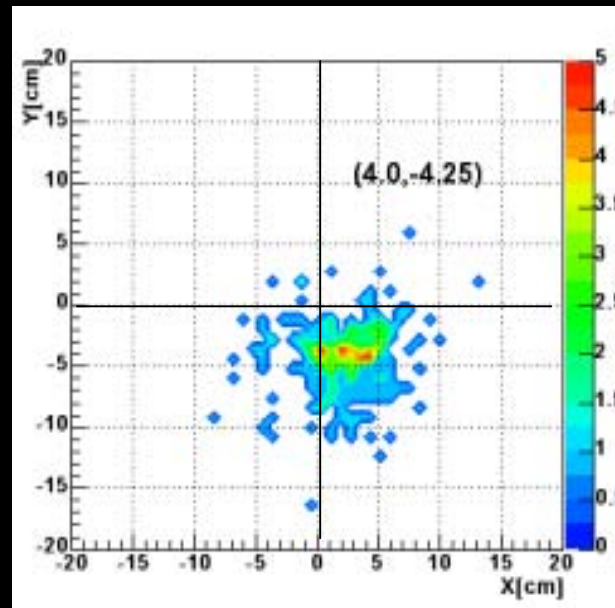


Reconstructed Image

^{137}Cs 662keV RI source, e^- energy not used



30° move

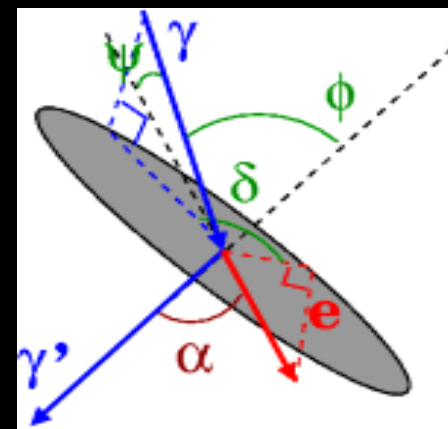


Reconstruction is successful, using
We established a new gamma-ray
imaging method !

cut No ghost event

Angular Resolution (1σ)

$\Delta\delta = 25^\circ$, $\Delta\phi = 15^\circ$ Need more TPC gas gain !



Future Works

Micro -TPC

Improvement of gas gain (required X 5)

Study of electrodes (electron collection efficiency 30% \rightarrow 95%), X 3

Quality control for uniformity of structure X 2

Xe Gas 1.5 atm dE/dx X 4.5

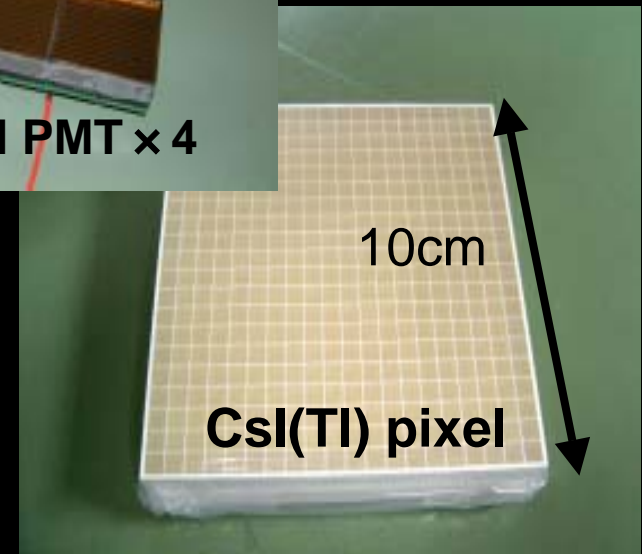
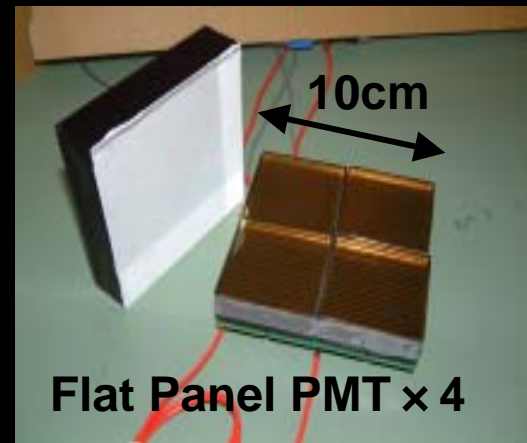
Scintillation camera

Developing following types

Large Area PIN Photodiode Array

with Hamamatsu (10cm X 10cm, 5mm pitch)

H8500 Hamamatsu Flat Panel PMT



Summary

- Novel gamma-ray imaging detector with gaseous Micro-TPC & scintillation camera
- Tracking of full Compton scattering process
- Small prototype has been developed

Micro-TPC : 10cm × 10cm × 8cm TPC with Micro Pixel Chamber

Scintillation camera : 10cm × 10cm × 2.5cm NaI(Tl) scintillator + 25PMTs

- Gamma-ray reconstruction was successful.
- More improvements are planned for good performance .