Gamma-ray Imaging with a Large micro-TPC and a Scintillation Camera

Kyoto University dept. of physics

Cosmic-ray group

K. Hattori

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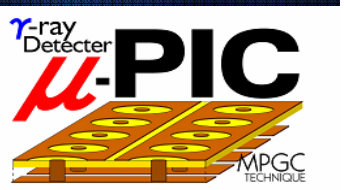
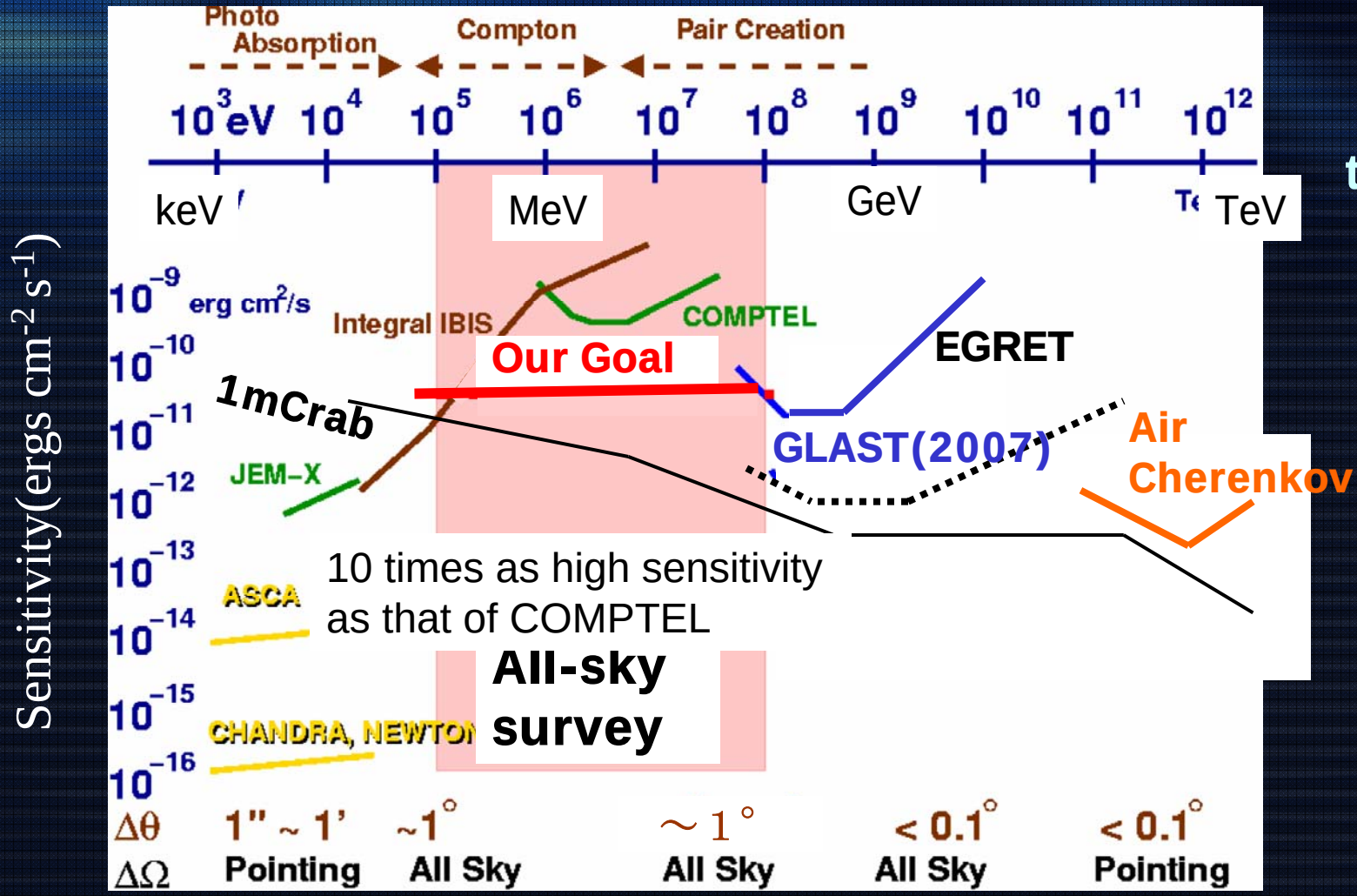


Detection Sensitivity in the X/gamma-ray band

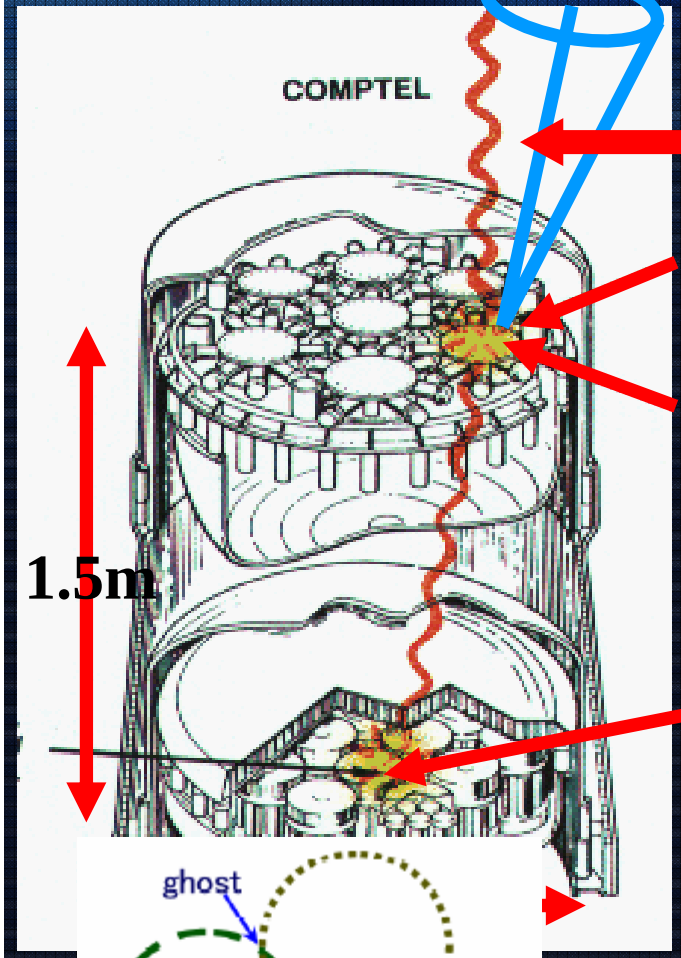


MeV band
- ✓COMPTEL (CGRO)
- ✓INTEGRAL

MeV band ・・・・・Low sensitivity

Principle of Classical Compton Imaging

Photon · · · · · main interaction in MeV band



Compton scattering

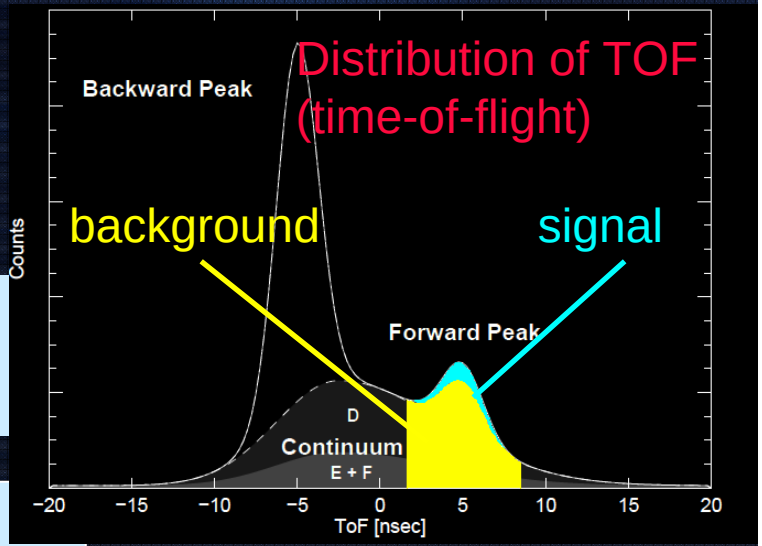
incident gamma-ray

liquid scintillator

Recoil electron
energy loss, location, time

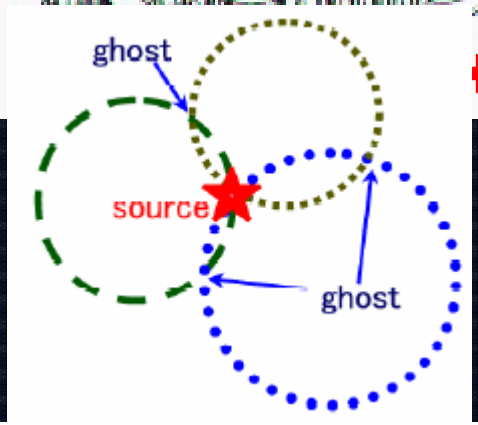
NaI(Tl) scintillator

Scattered gamma-ray
Energy loss, location, time



G. **Weidenspointner**' et al., 2001. A&A 368, 347.

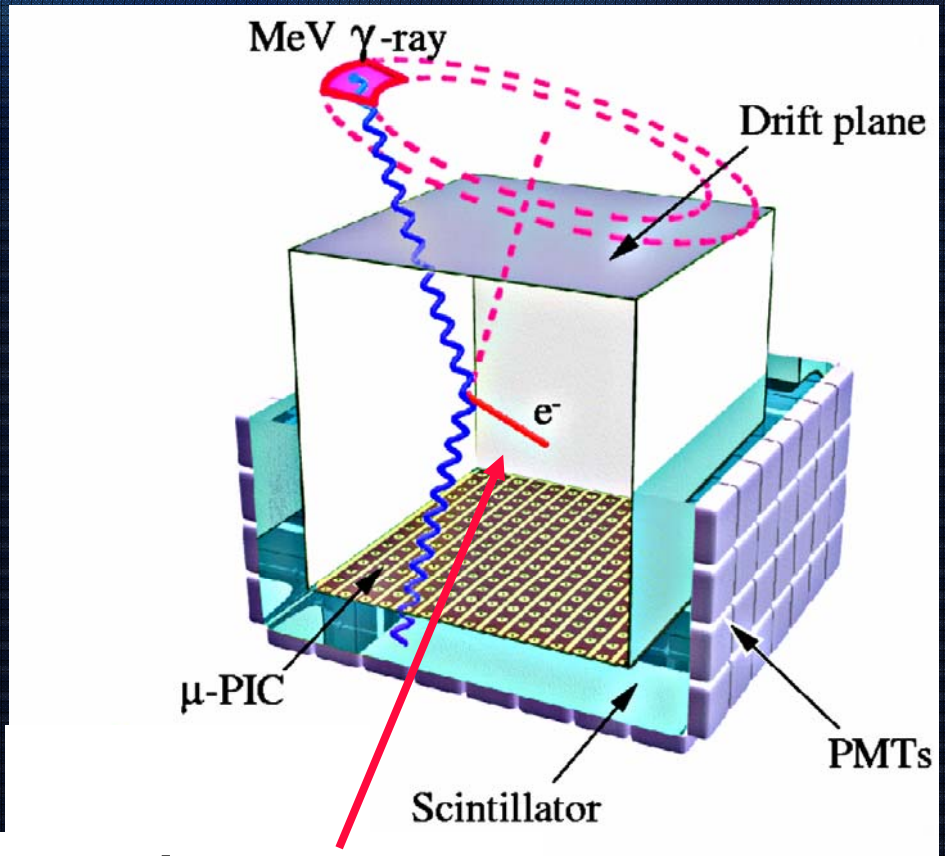
Recoil electrons are not tracked



The origin of a single event can be restricted by the "event circle"
The gamma-ray originated at the point of overlap
→ low background rejection power

Principle of Advanced Compton Camera

based on **Micro Pixel Chamber(μ -PIC)**



2-dimensional imaging gaseous detector

micro-TPC (gas detector)
energy and **track**
of a recoil electron

Anger camera scintillation detector
NaI(Tl)(surrounding micro-TPC)
energy and position of
a scattered gamma-ray

Having tracks of recoil electrons…
1photon :
reconstructed completely
energy and direction

gas detector
less collisions
the direction of recoil electron
→less error

High background rejection power

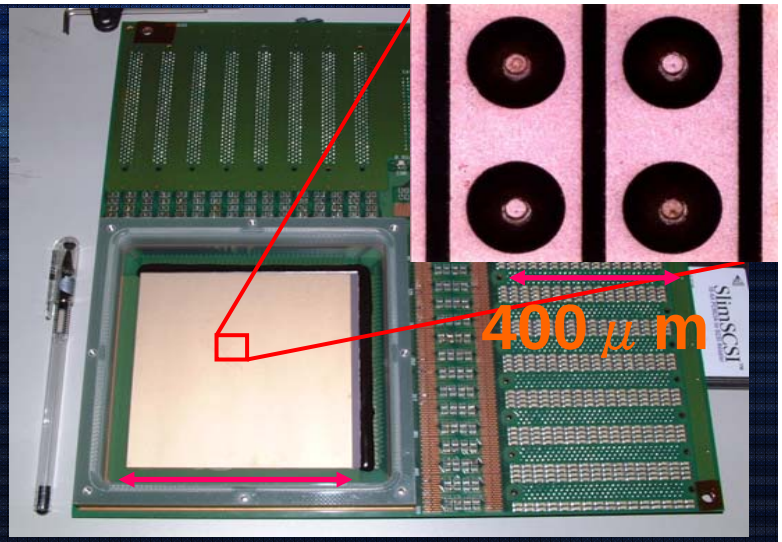
PIC

Unnecessary to use a TOF value and a collimator

μ –PIC (Micro Pixel Chamber)

2-dimensional imaging gaseous detector
electrode pitch 400 μ m

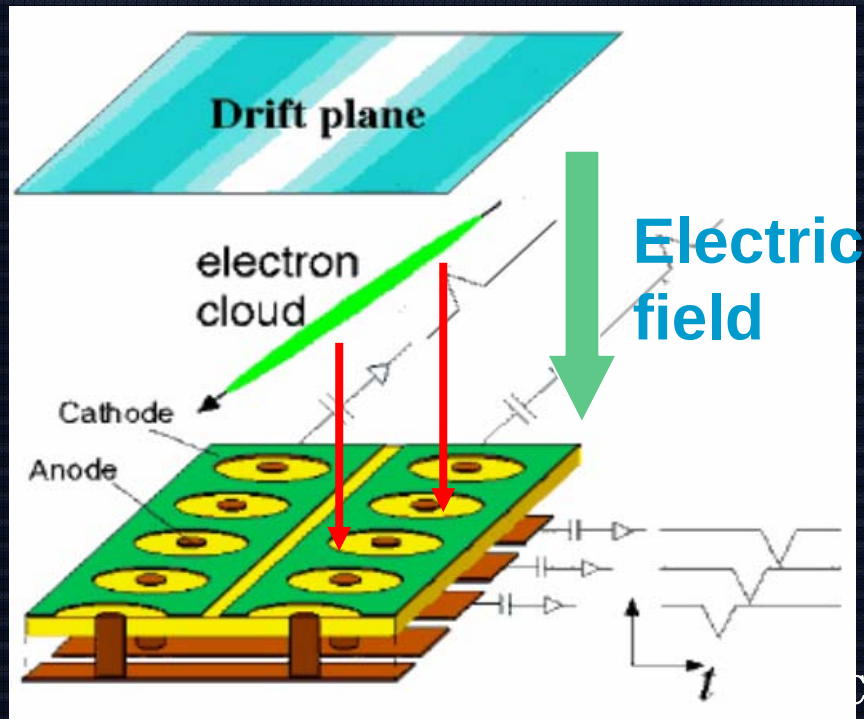
prototype of Compton camera based on a μ -PIC with a detection area of 10 cm ×10 cm

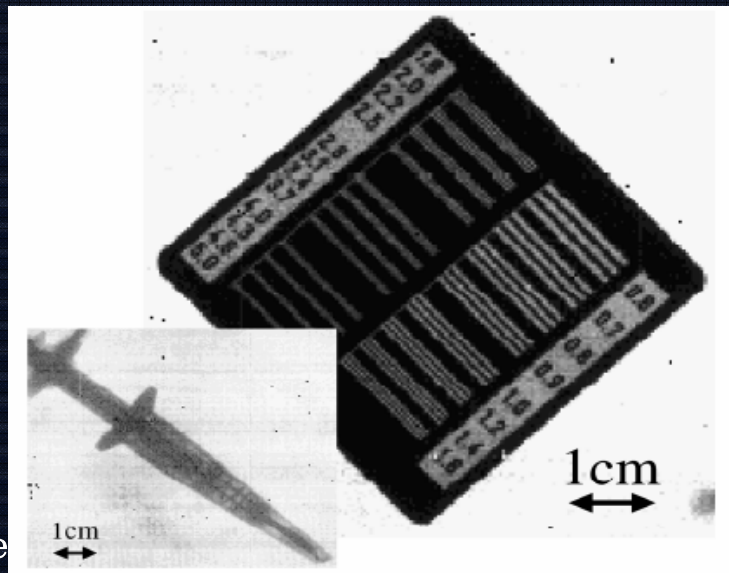


Max gas gain ～ 15000

Stable operation @gas gain ~ 6000

position resolution ~120 μ m

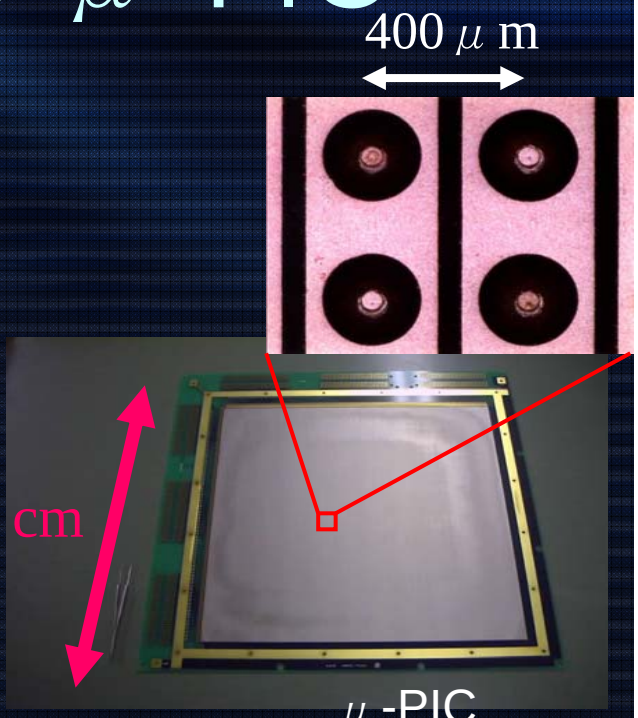




Development of large μ-PIC

Goal 10 times as high sensitivity as that of COMPTEL
To attain goal…..
prototype (10 cm × 10 cm) is not enough

large μ-PIC with a detection area of 30 cm ×30 cm
→ gain max : 7,000
stable gas gain : 2,000



To detect Compton events ・・・・・ detection of **recoil electrons**
using the micro-TPC
Energy loss of recoil electrons ～ 2 ~ 3 × MIPs (Minimum Ionizing Particle)
→ required gas gain 2×10^4
(We have not achieved because of discharge)
Another electron multiplier is necessary

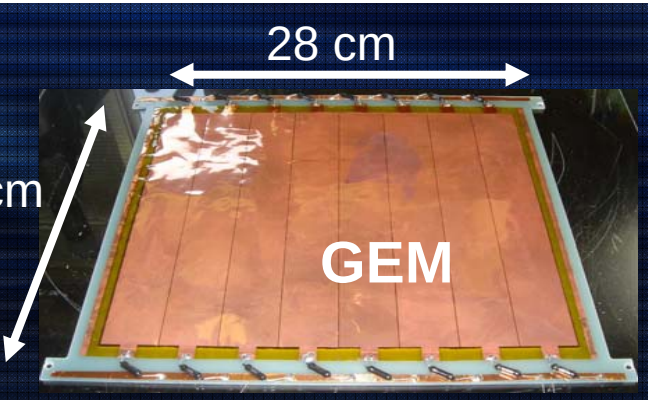
GEM **(Gas Electron Multiplier)**
F.Sauli(1997)
operated @ low gas gain(~10)

Instrumentation

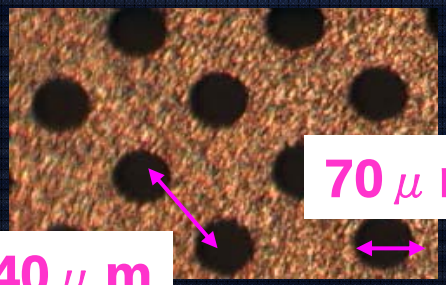
γ-ray Detecter μ-PIC MPGC TECHNIQUE

Micro-TPC based on μ-PIC and GEM

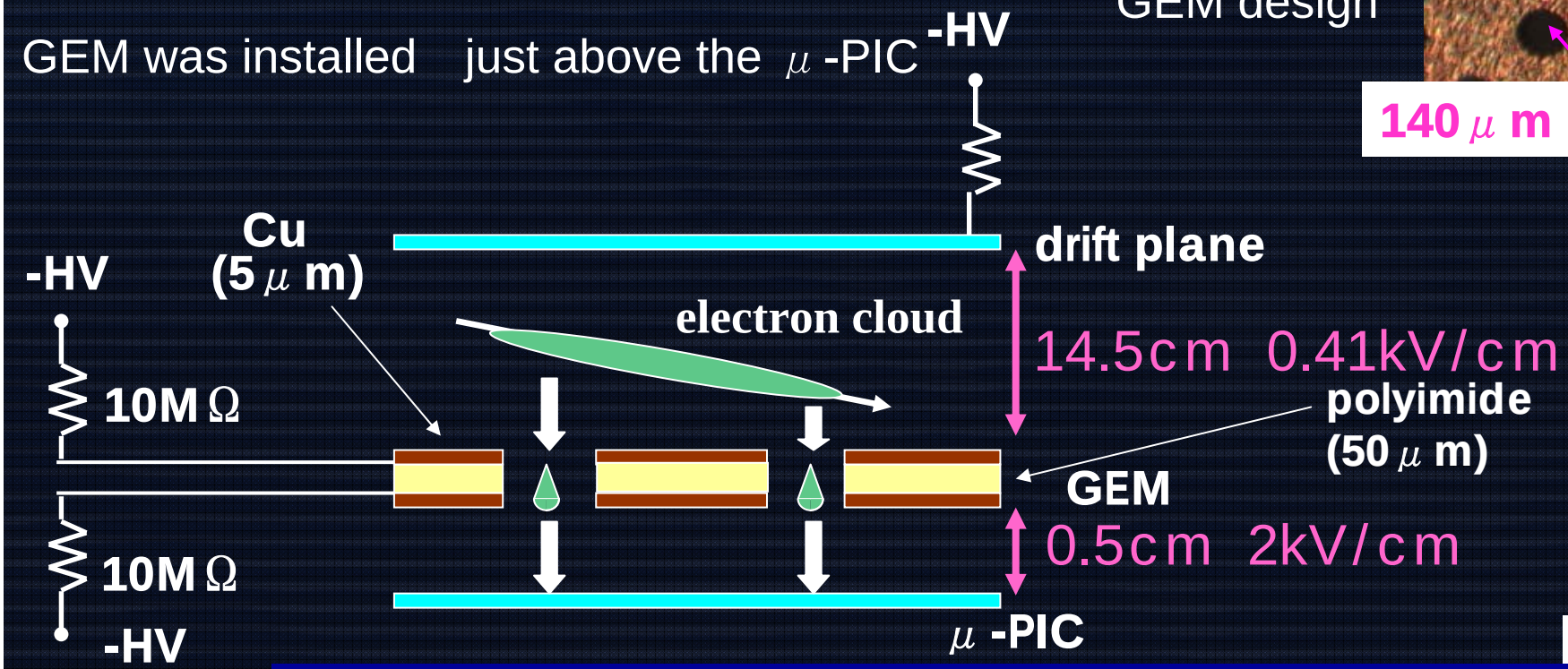
segmented GEM (8 segments)
to reduce capacitance and thus damage caused by discharge
23 cm × 28 cm (limited by material size)
Scienergy Co. Ltd, Japan



Standard GEM design

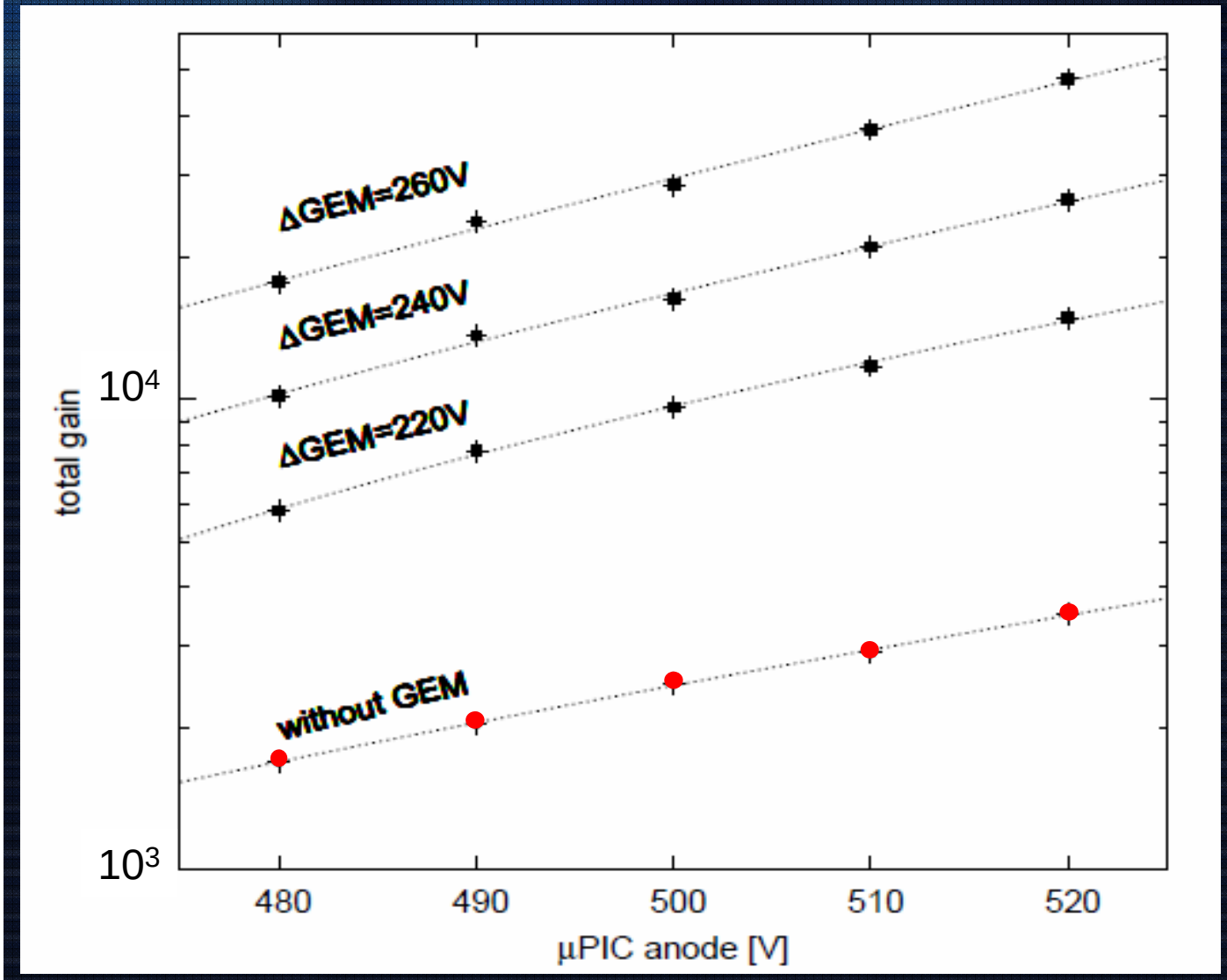


GEM was installed just above the μ-PIC



A charged particle runs in the micro-TPC and makes electron clouds, and then electorn clouds are pre-amplified by the GEM and then the μ-PIC

Performance of μ-PIC and GEM



using
Ar-C2H6(90:10) gas
1atm

Maximum gas gain
of 5×10^4

Stable gas gain
2×10^4

μ-PIC 2×10^3

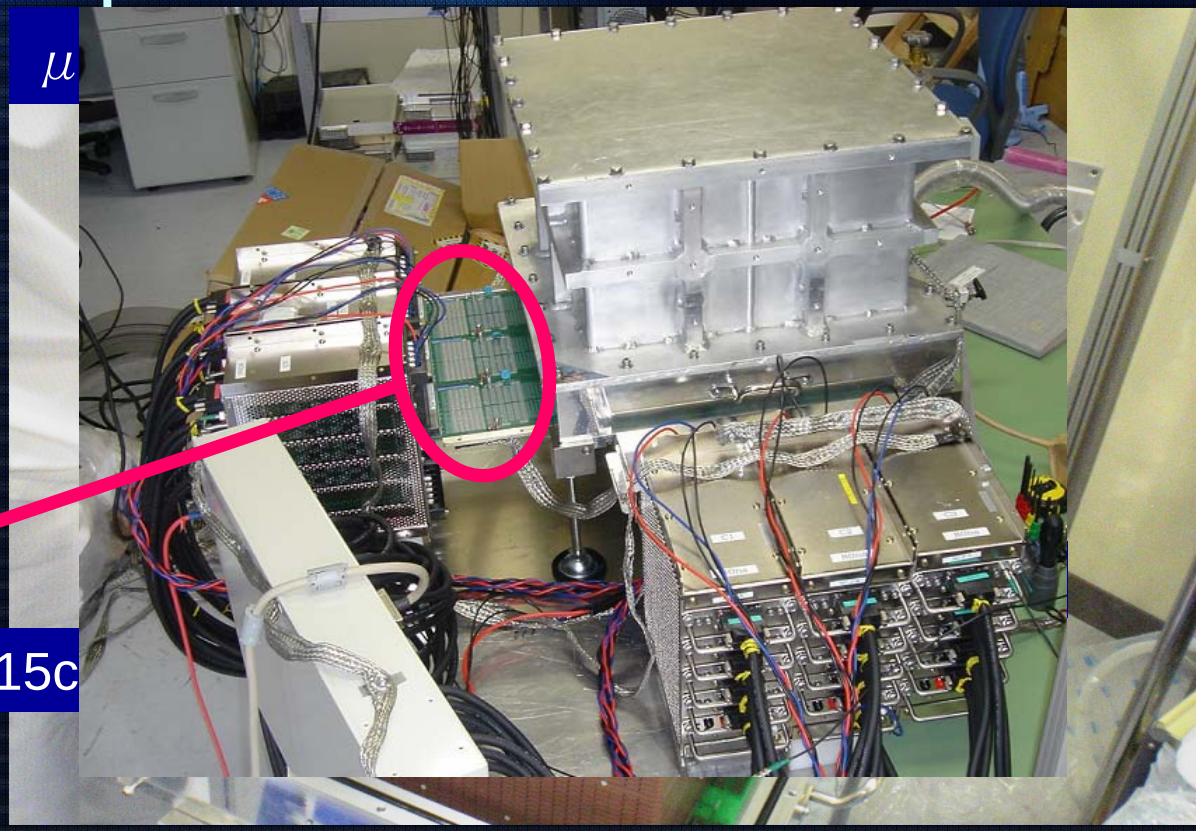
$\times$

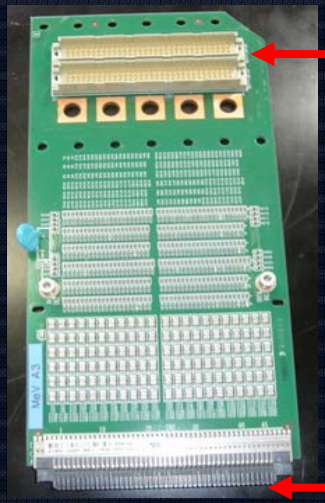
GEM 10

Micro-TPC was kept in the sealed vessel

The micro-TPC was set in a aluminum vessel filled with Ar-C_2H_6(90:10) gas to a pressure of 1 atm sealed for the duration of the measurements.

Anode:768ch + cathode:768ch
→Signals from the μ-PIC are sent via the printed boards

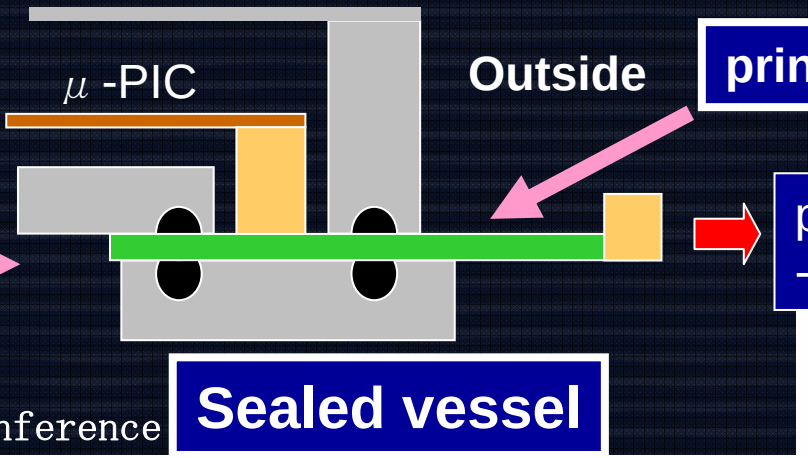




from μ-PIC

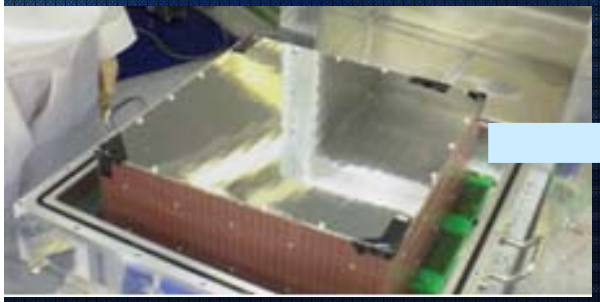
256ch per board

to pre-amplifiers



DAQ system

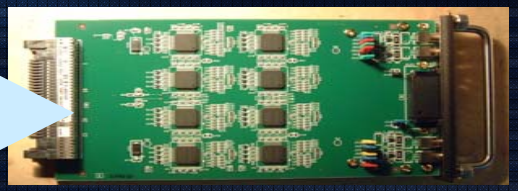
micro-TPC



anode 768 ch
cathode 768h

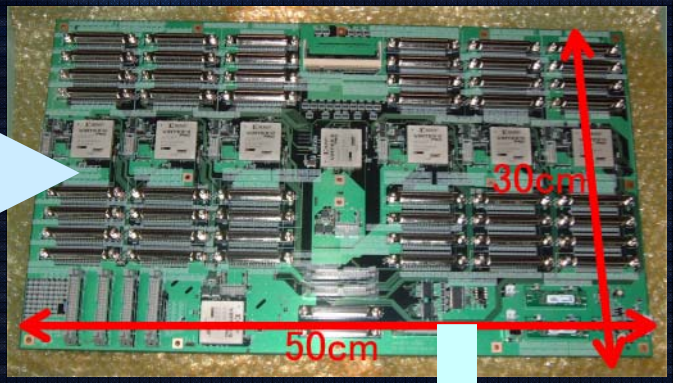
ASD (amplifier-shaper-discriminator)

1536 ch digital



summed analog (8ch)

Position encoding module (100MHz FPGA)

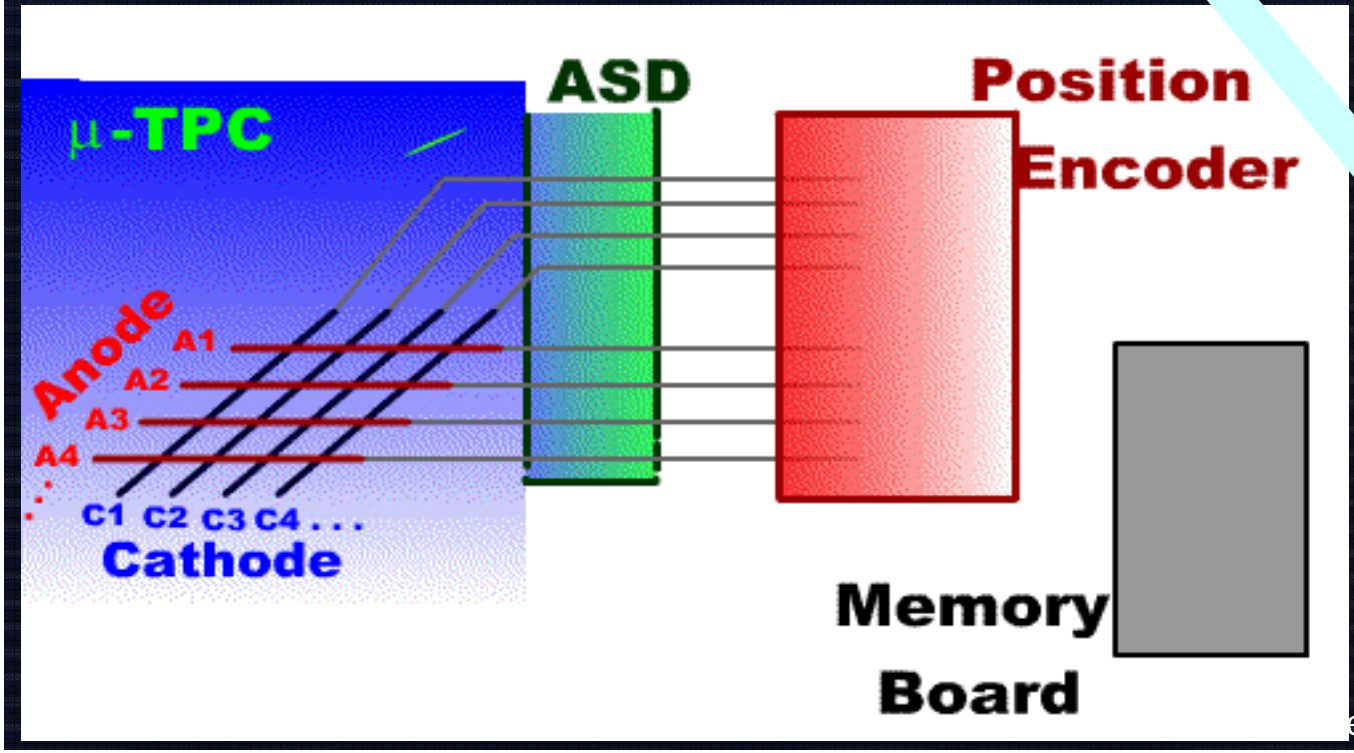


VME Memory Board

Recording anode and Cathode coincident positon and the timing

VME FADC 100MHz 8ch ×3

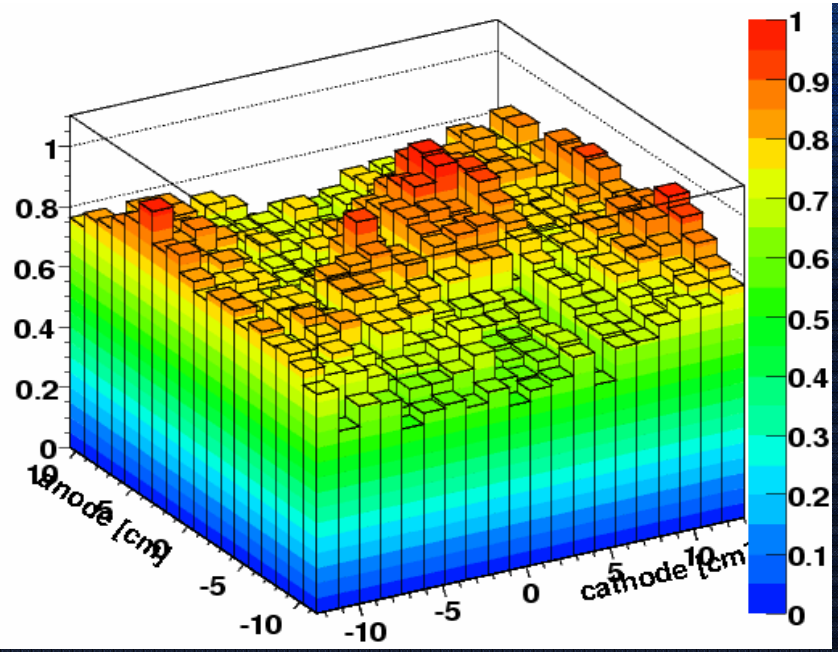
Recording summed analog signals



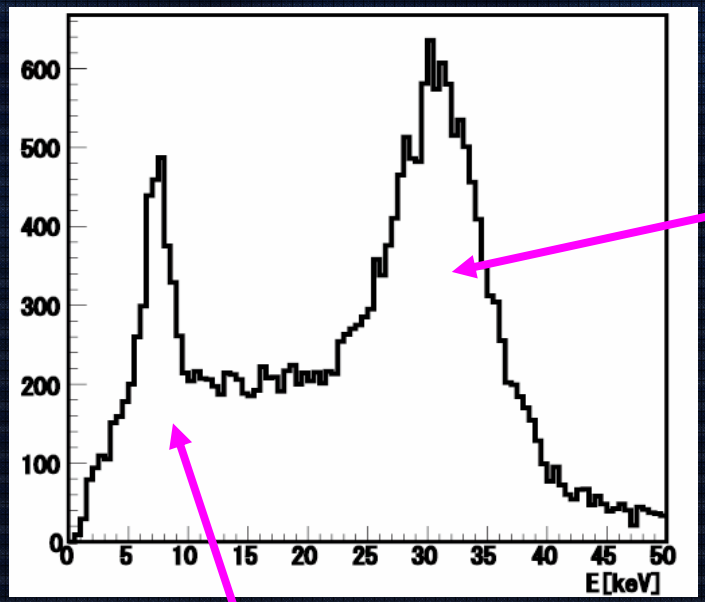
entation

γ-ray Detecter μ-PIC MPGC TECHNIQUE

Performance of the micro-TPC(1)



Gain uniformity rms 13.9 %
10cm ×10cm μ-PIC 5%

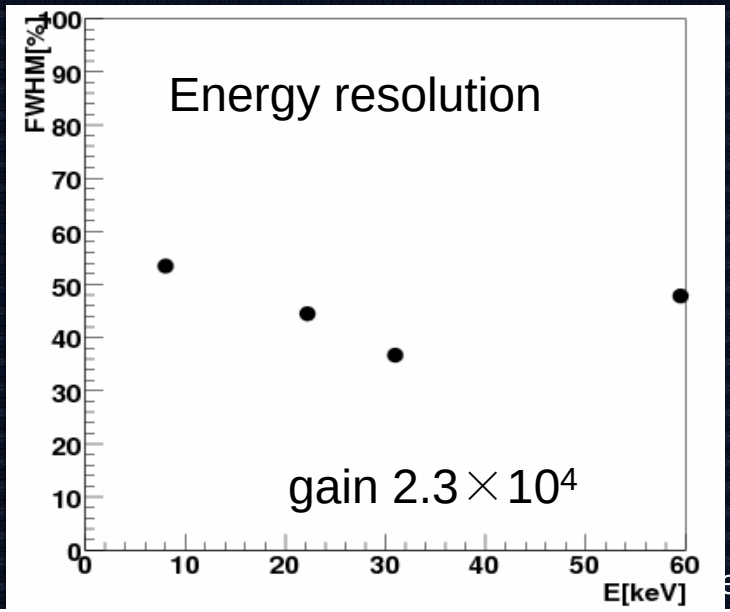


direct X-ray
(31 keV)

Irradiation of ^{133}Ba with the whole detector

gain 2.3×10^4

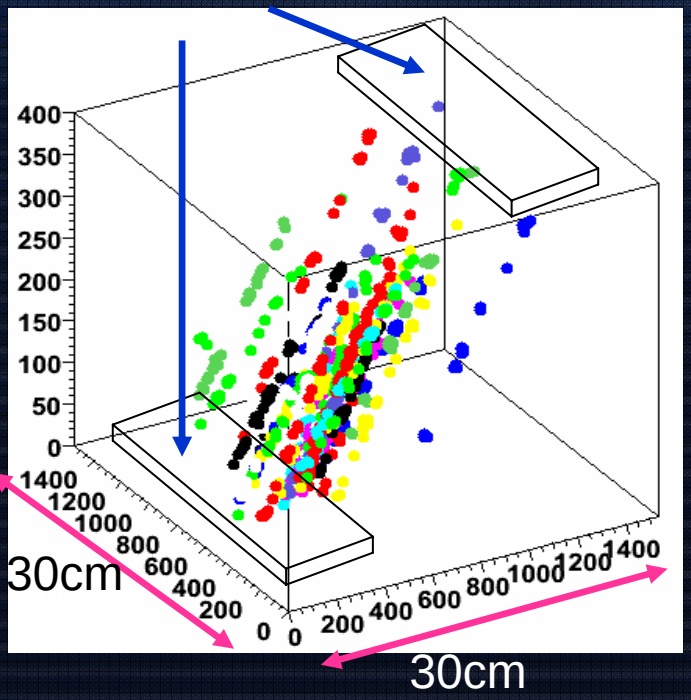
the peak of copper fluorescent X-rays at 8.0 keV, generated at the GEM and the μ-PIC by the original X-rays from 133Ba



the energy resolution was worse at 59.5 keV
It might be due to the saturation of the ASD chips

Performance of the micro-TPC(2)

Two plastic scintillators were used in coincidence for cosmic muon trigger



Position resolution

Difference between hit points and tracks obtained from fitting

$$\sigma(l) = \sigma^2_{\text{detctor}} + \sigma^2_{\text{diffusion}}$$
$$= \sigma^2_{\text{detector}} + (D\sqrt{l})^2$$

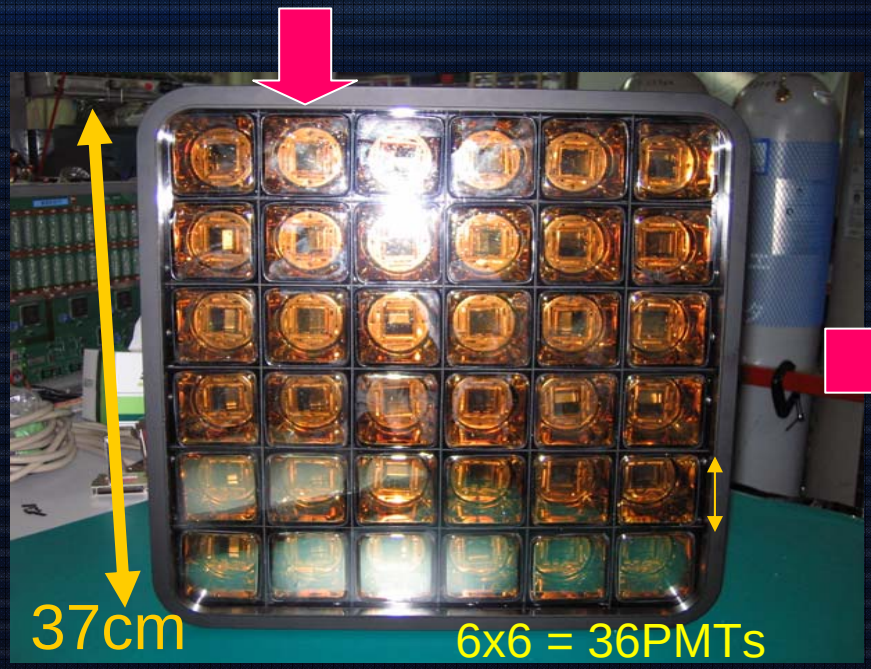
$$\sigma_{\text{detector}} = 0.51\ \text{mm}, \quad D = 0.37\ \text{mm}$$

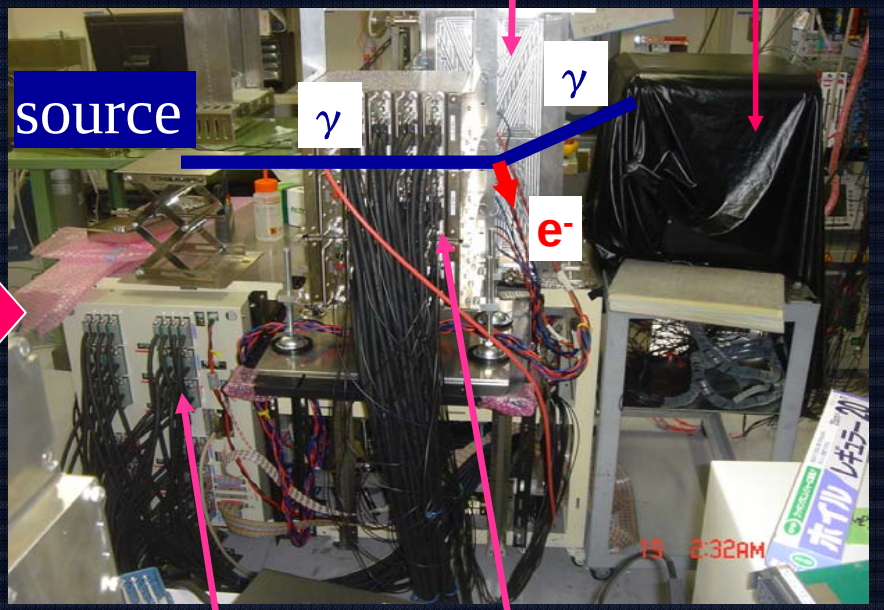
Total gas gain of 5×10^4

Compton Camera

Anger camera scintillation detector for scattered gamma-rays

A large NaI(Tl) crystal and 6×6PMTs





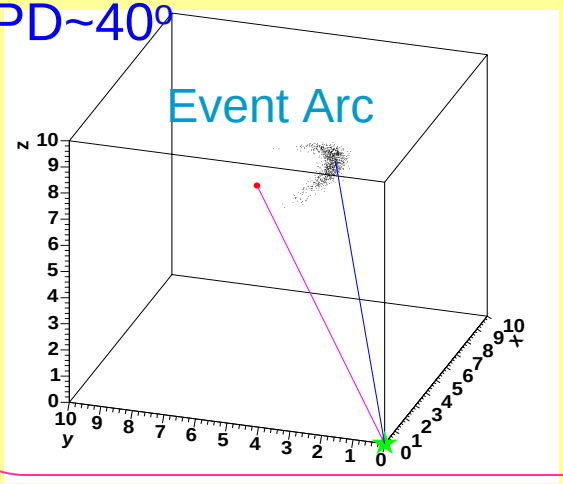
- **Position resolution < 11mm(FWHM)**
- **Effective Area (No image distortion) ~30x30cm²**
- **Energy Resolution 7.4%(FWHM)@662keV,11.2%(FWHM)@80keV**
- **Dynamic range 80keV-1.5 MeV**

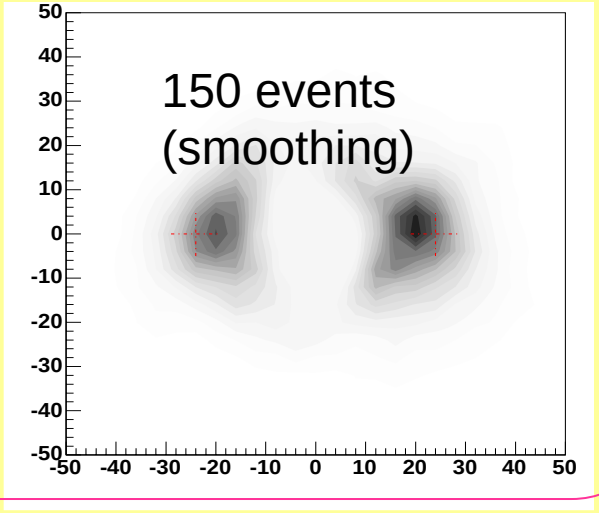
Prototype of Advanced Compton Camera

Imaging Quality (662keV two sources)

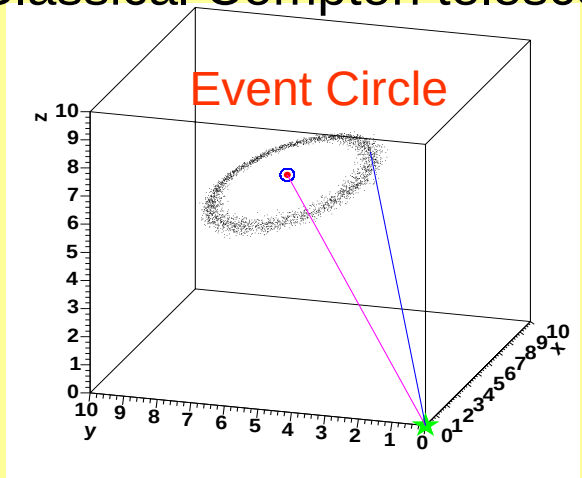
Electron-tracking telescope

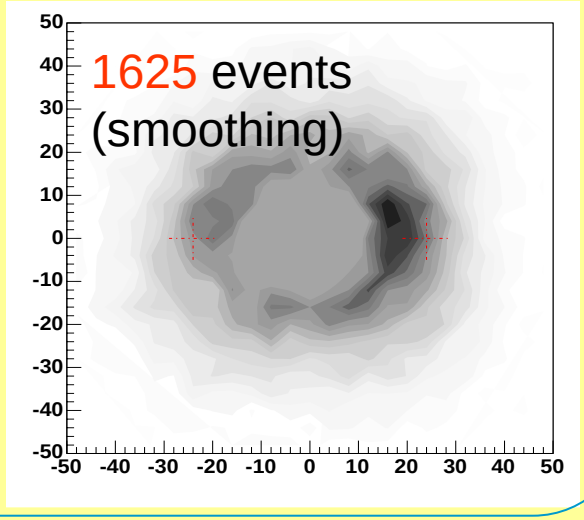
SPD~40°





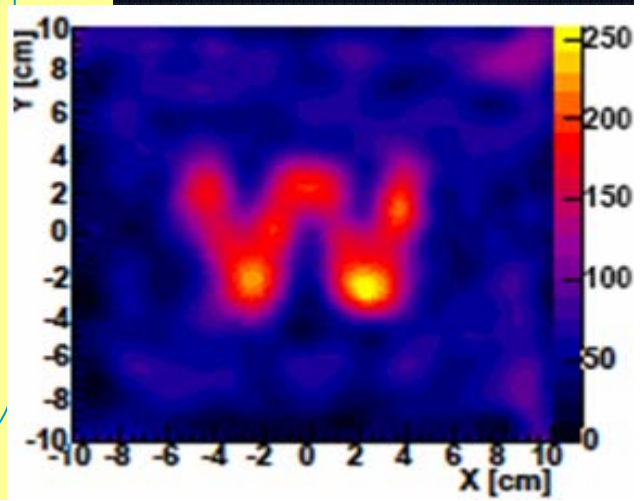
Classical Compton telescope





We have developed Prototype of Compton Camera based on 10cm×10cm μ -PIC

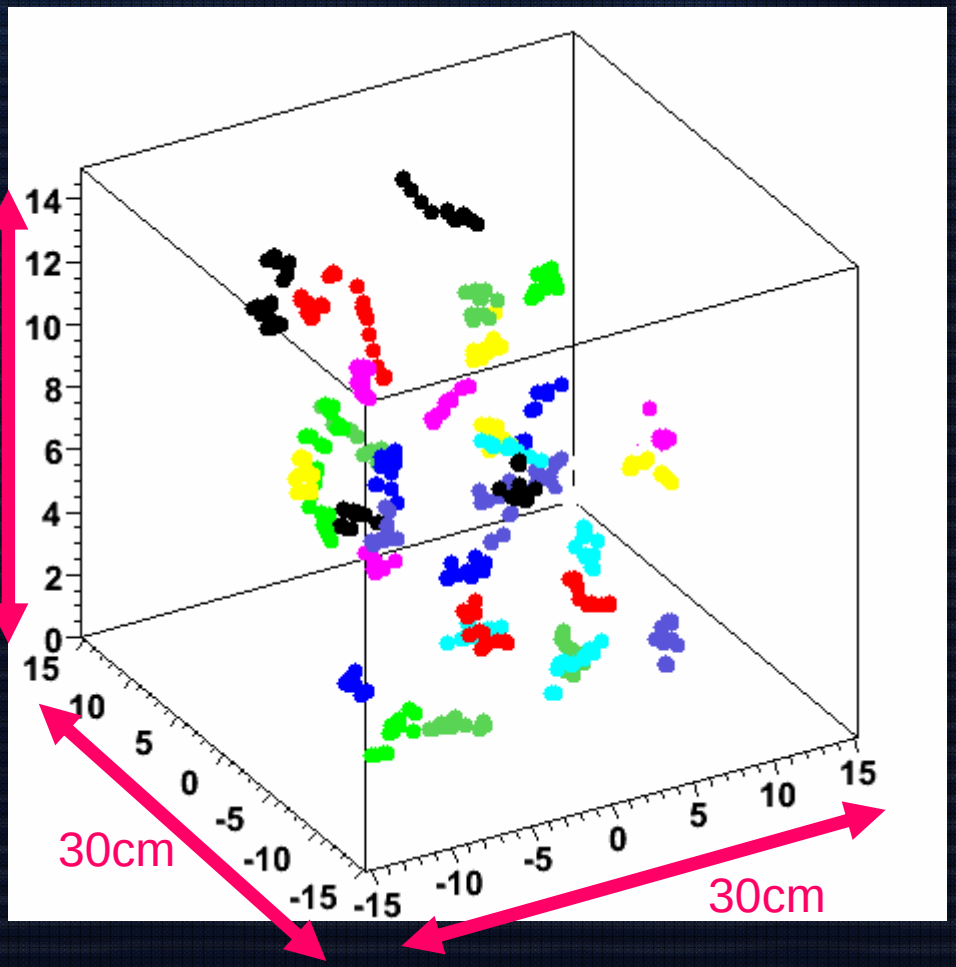
Line source
I-131 (364 keV)



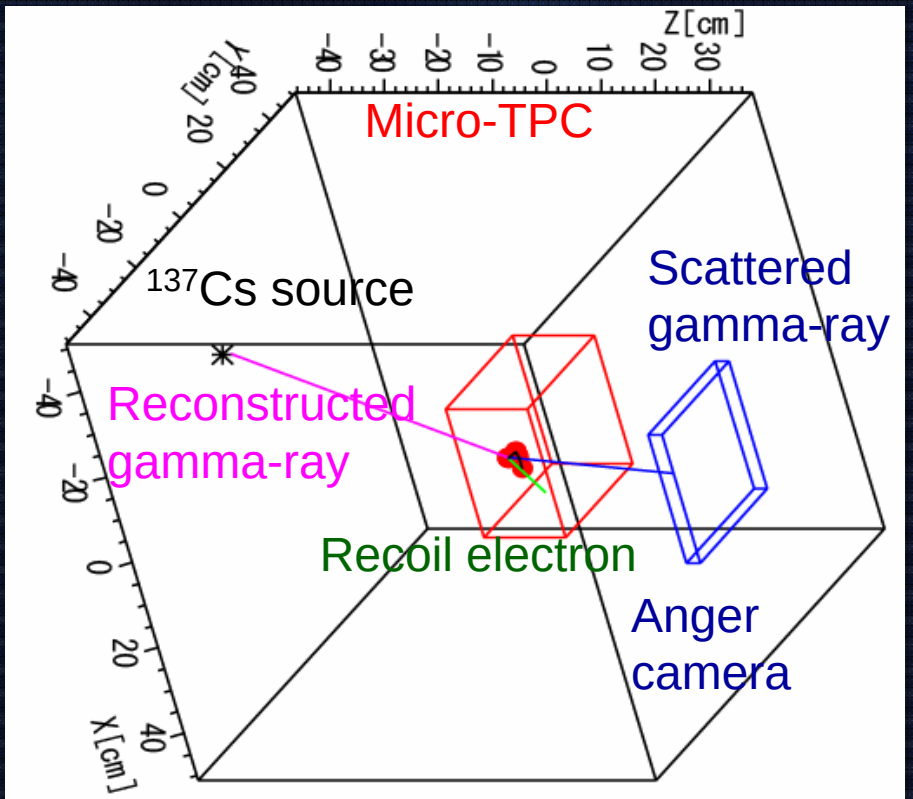
Performance of Compton Camera(1)

based on 23 cm × 28 cm × 15cm micro-TPC

Typical recoil electron tracks
Irradiating ^{137}Cs (662 keV)



Typical Compton event
^{137}Cs (662 keV)

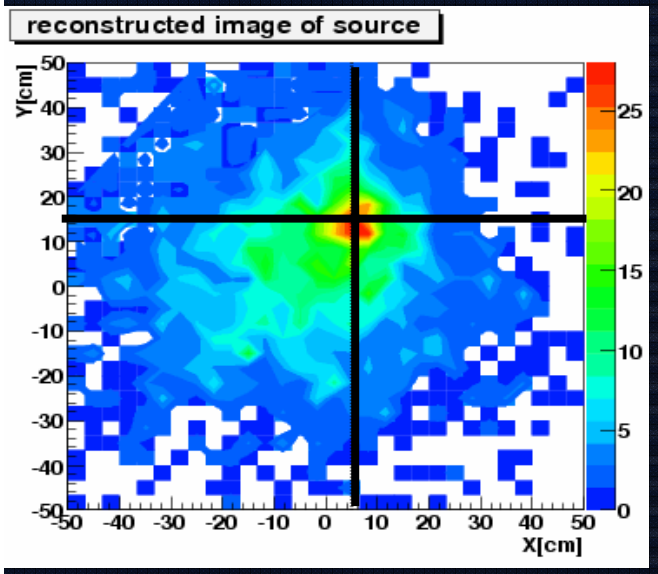


$E_{\mu\text{-PIC}}$: 78.02 keV
E_{scinti} : 615.9 keV

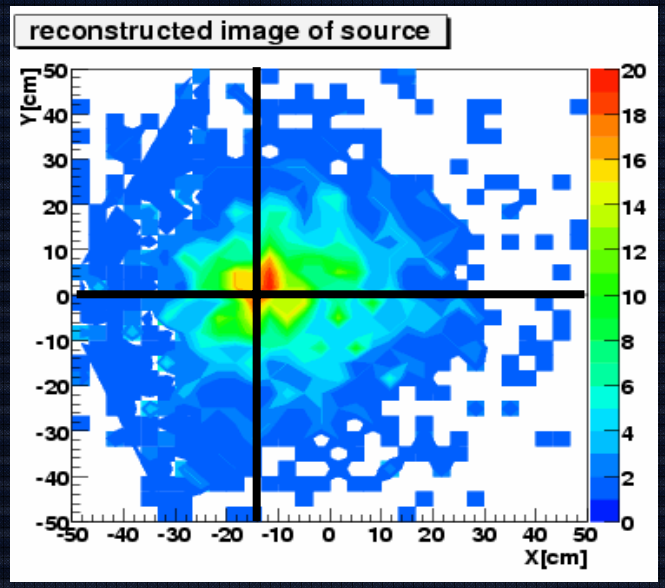
Performance of Compton Camera(2)

^{137}Cs 662 keV using data with reconstructed energy 610 keV ~ 760 keV

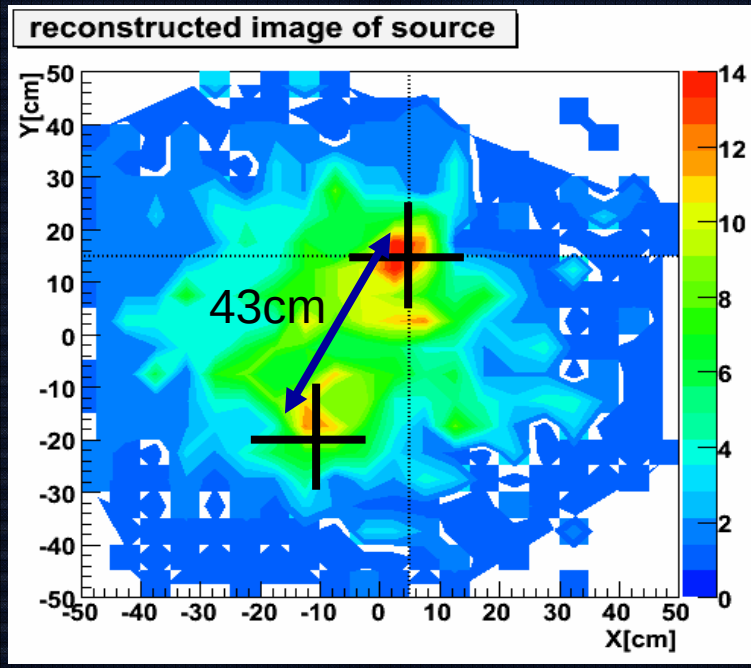
137Cs (1 MBq)



137Cs (1 MBq)



137Cs (1 MBq) ×2

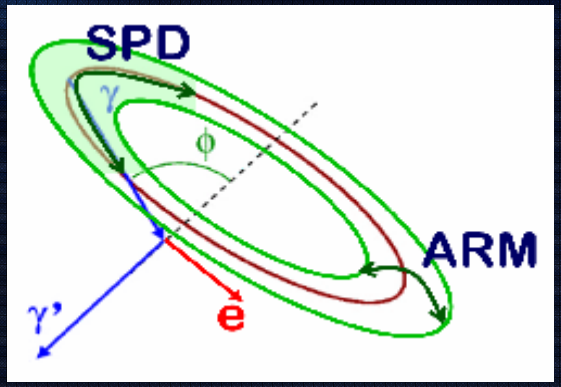


point source ~45 cm from micro-TPC

Performance of Compton Camera(3)

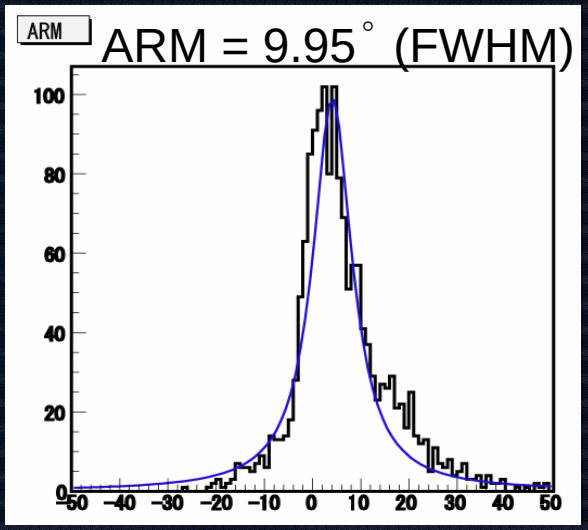
Error concerned with the reconstructed direction of a Incident gamma is determined event by event

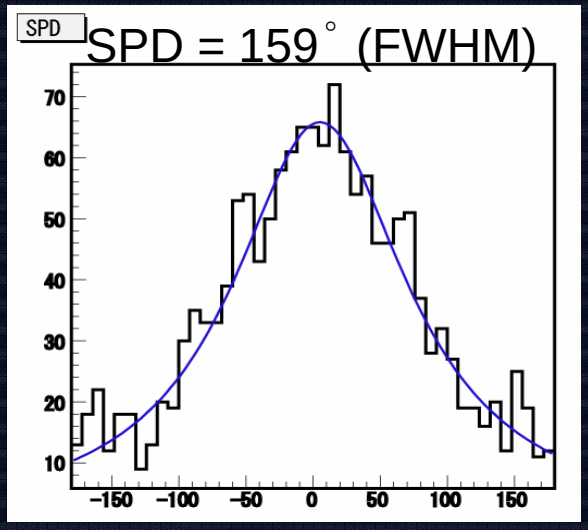
✓ARM (Angular Resolution Measure)
Concerned with the angle between the scattered gamma-ray and the recoil electron

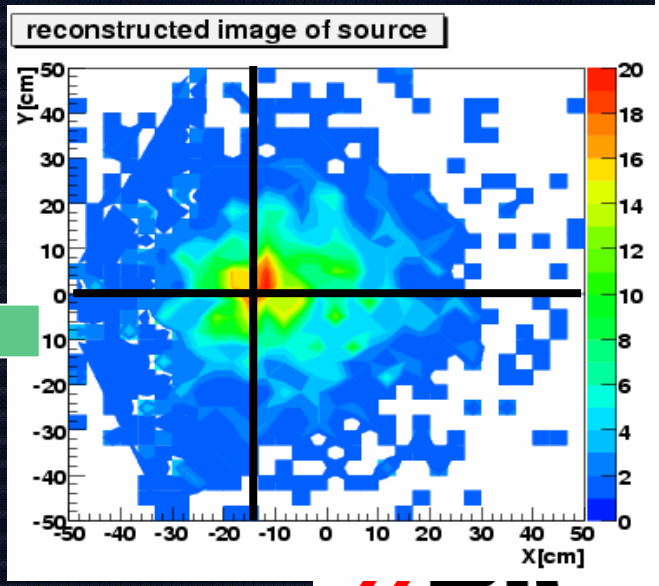


✓SPD (Scatter Plane Deviation)
Determination accuracy of the plane formed
By the scattered gamma-ray and the recoil electron

^{137}Cs (662 keV)



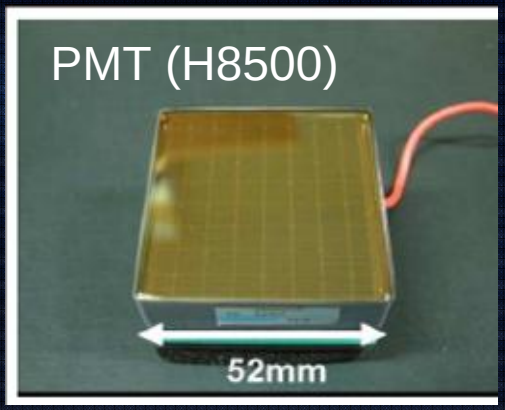


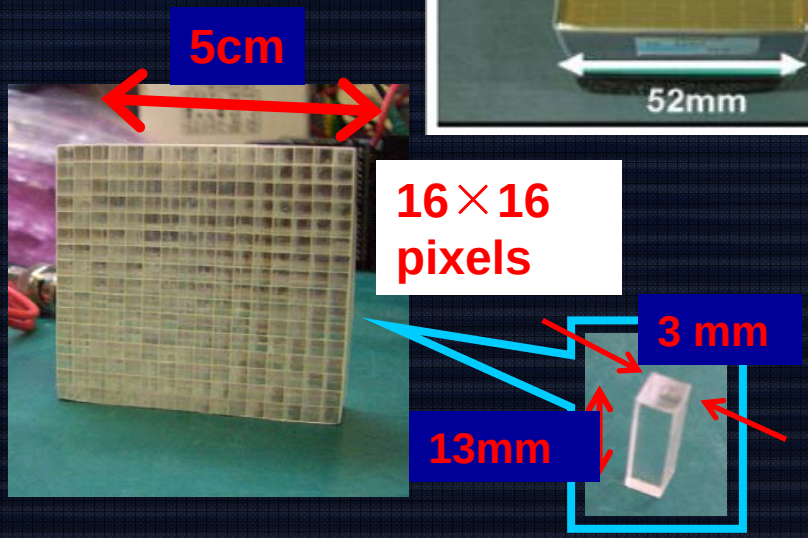


Well fitted by Lorentzian

Summary & Future Works

- **Micro-TPC based on 23cm×28cm GEM and 30cm×30cm μ-PIC**
  effective volume 23cm×28cm×15cm
  Gain uniformity rms 13.9 %
  energy resolution FWHM 37.5% (31.0 keV)





- **Large Compton camera**
  recoil electron tracks were successfully obtained
  point source imaging
  using ^{137}Cs (662 keV)
  ARM 9.96° (FWHM)
  SPD 159° (FWHM)

- Future Works
  Imaging using source with various energy (350 keV ~ a few MeV)
  To obtain better position resolution of scattered gamma-rays…..
  Anger camera (< 11mm FWHM) → Pixel scintillator (< 3mm FWHM)

- Goal FWHM
  500 keV ARM 7° SPD 40°
  1 MeV 5° 20°

MeV gamma-ray Astronomy

- ✓Nucleosynthesis
  - Supernova: nuclear line from radioisotope
  - Galactic disk: long-time decay radioisotope
- ✓Particle Acceleration
  - AGN Jet, Gamma-ray pulsar
  - Gamma-ray burst、Solar flare
- ✓Strong Gravity
  - Black hole:
    - accretion disk・π^0decay・Primordial
- ✓Structure and Evolution of Universe
  - Extragalactic diffuse background
- ✓Origin and Propagation of cosmic-ray
  - Galactic diffuse emission