Observation of sub-MeV gamma rays with an Electron Tracking Compton Telescope using a gaseous TPC at balloon altitude

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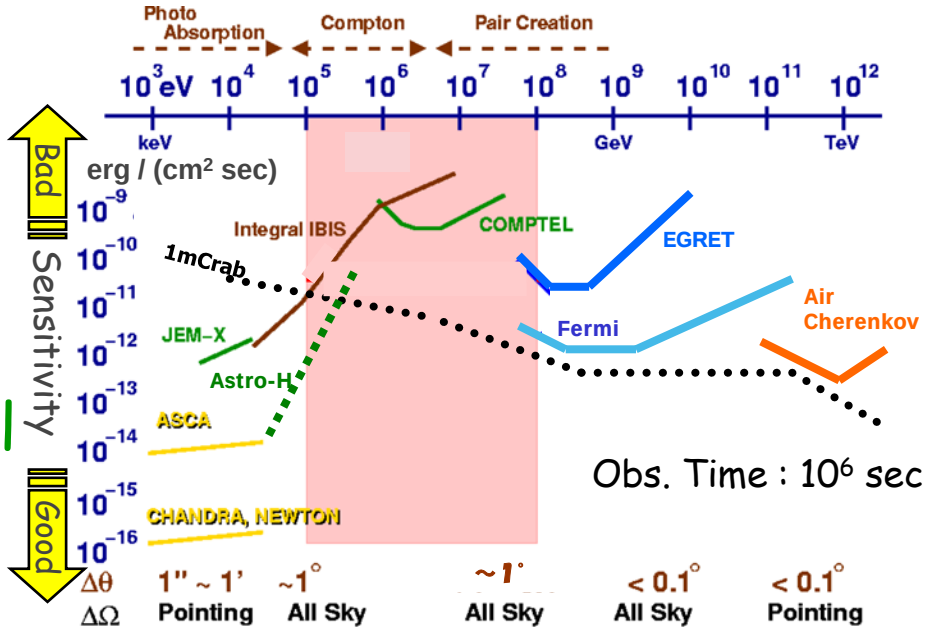
(Kyoto Univ.)

- Motivation
- Electron-Tracking Compton Telescope
- 1st Flight of SMILE
- Preparation for next step
- summary

Motivation

Observation of MeV gamma-ray will provide us…

- **Nucleosynthesis**
  - SNR : Radio-isotopes
  - Galactic plane : ^{26}Al • ^{60}Fe
  - Annihilation
- **Acceleration**
  - Jet (AGN) : Synchrotron
    + Inverse Compton
- **Strong Gravitational Potential**
  - Black Hole : accretion disk, π^0
- **Etc.**
  - Gamma-ray Pulsar, solar flare

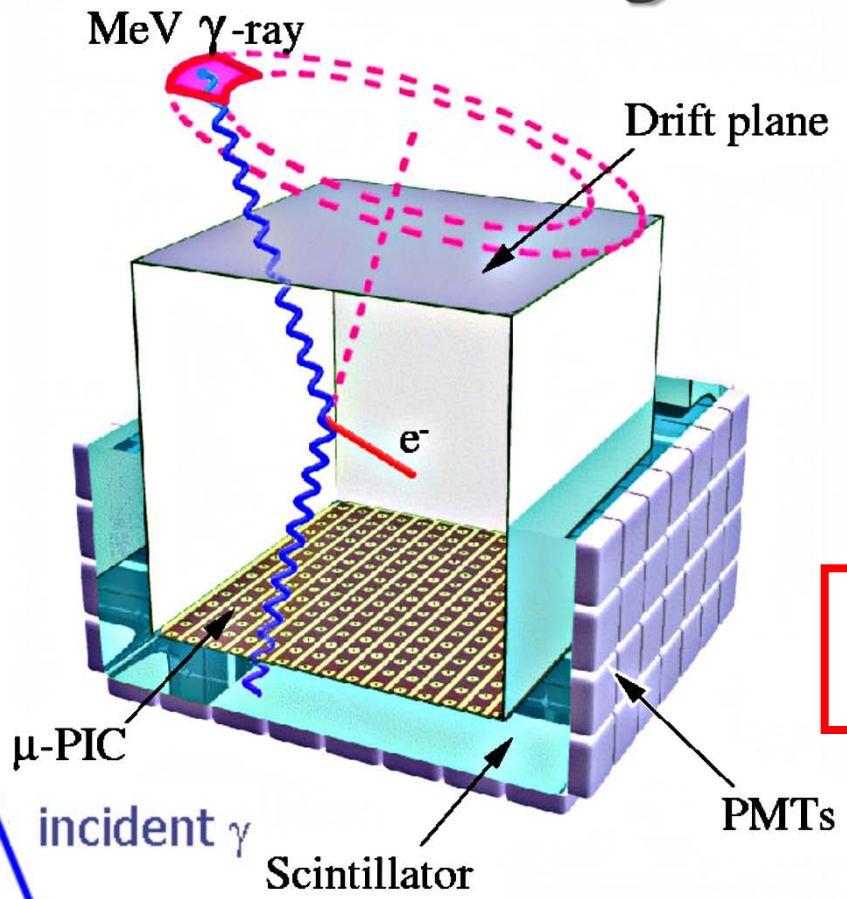


- The observation of continuum component is also important.
- Where are MeV gamma-ray objects?
- There are many background events which obstruct the observations.

Requirements for the next-generation detectors are …

- Wide-band detection
- Large Field of View
- Background rejection

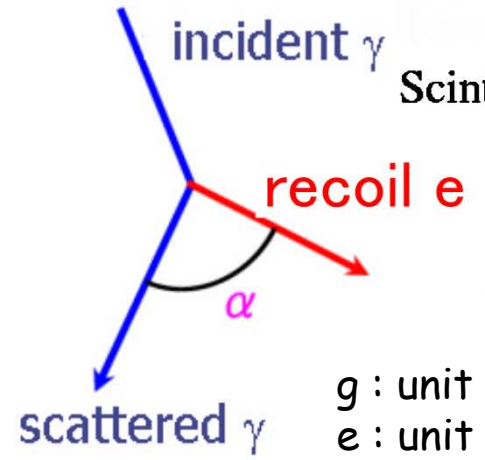
Electron-Tracking Compton Camera (ETCC)



- Gaseous TPC : Tracker
  track and energy of recoil electron
- Scintillator : Absorber
  position and energy of scattered gamma

Reconstruct Compton scattering event by event

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



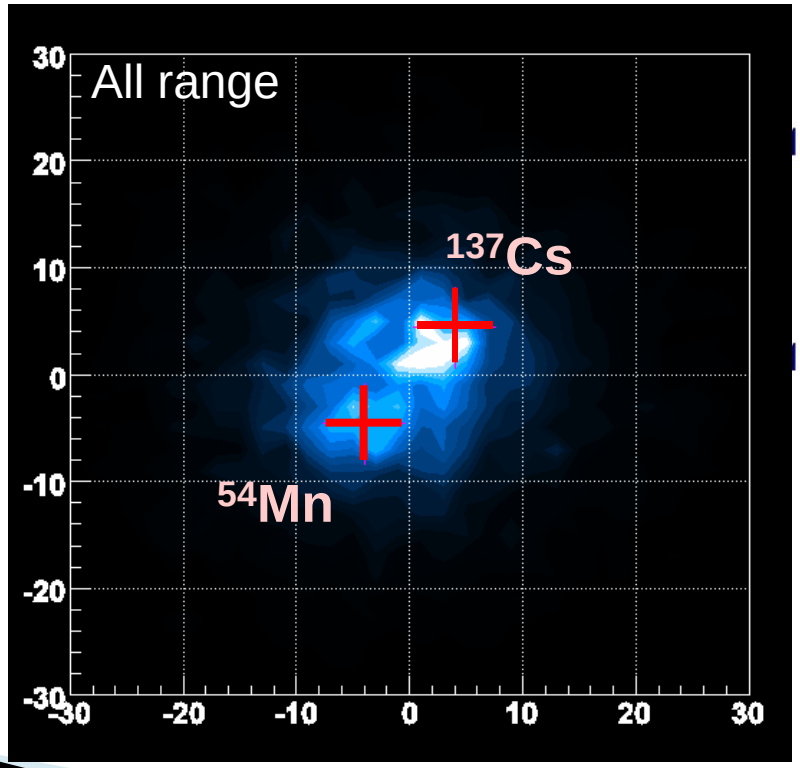
$$\cos\alpha_{\mathrm{geo}} = \vec{g}\cdot\vec{e} \quad \Leftrightarrow \quad \cos\alpha_{\mathrm{kin}} = \left(1-\frac{m_e c^2}{E_\gamma}\right)\sqrt{\frac{K_e}{K_e+2m_e c^2}}$$

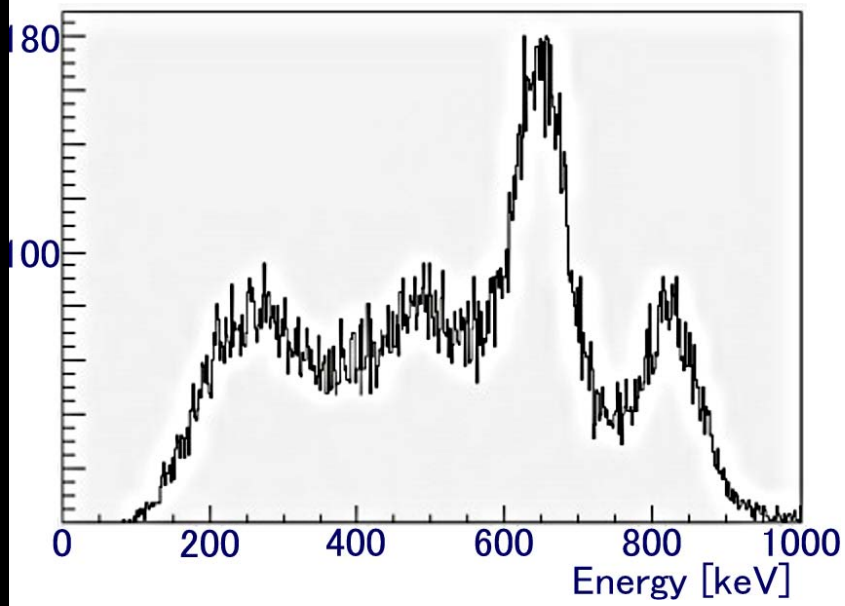
g : unit vector of scattering direction
e : unit vector of recoil direction

E_γ : Energy of scattered gamma-ray
K_e : Kinematic energy of recoil electron
$m_e c^2$: Rest mass of electron

MeV-γ imaging

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





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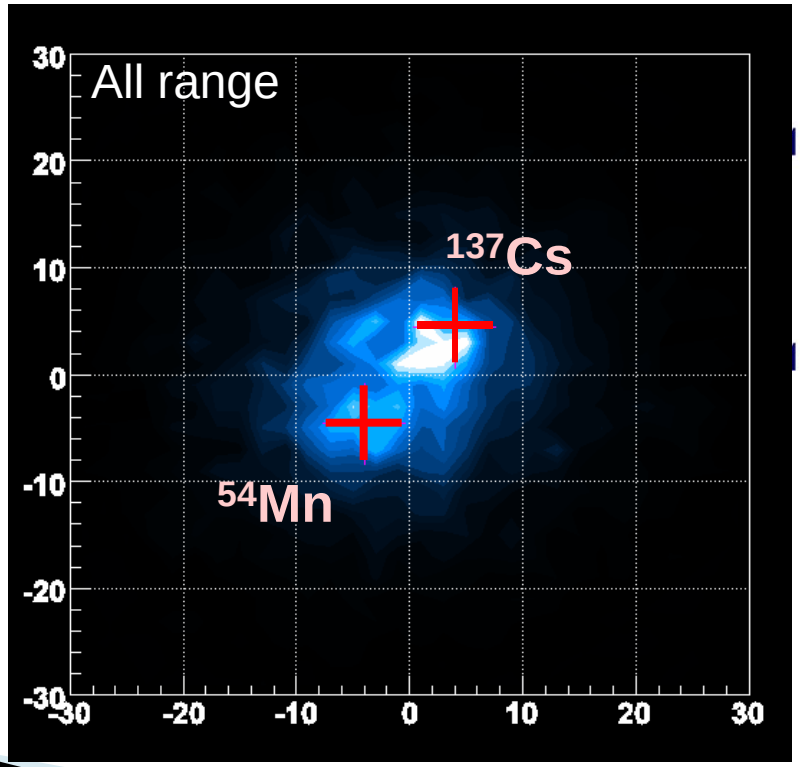
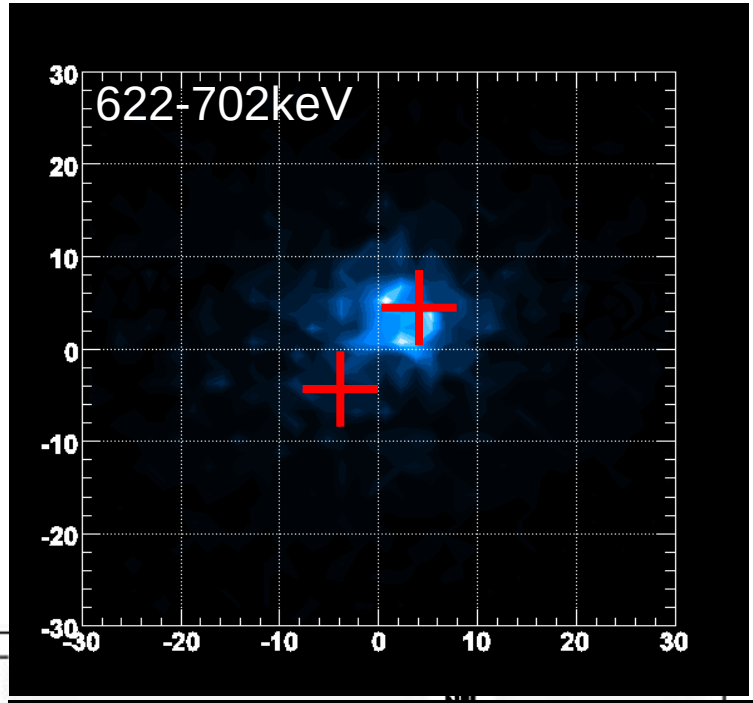
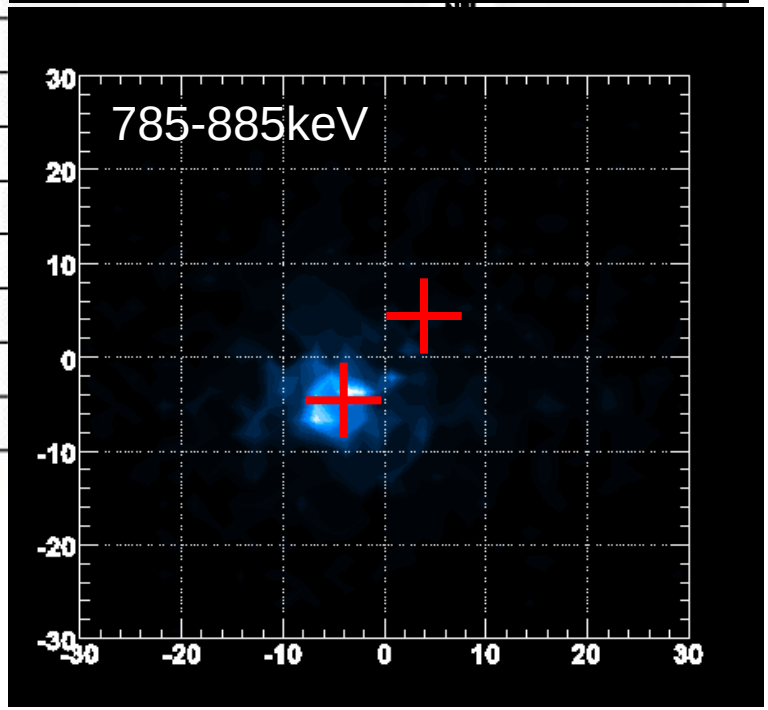




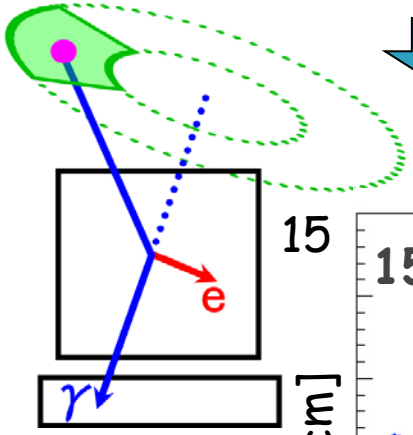


Comparison with the classical Compton method

Electron-Tracking Compton (ETCC)

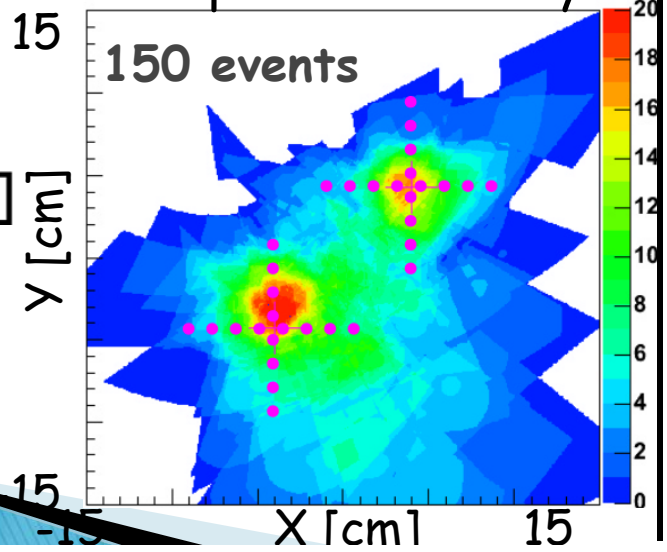
Using the electron tracks

- complete direction within sector form error region



Simply overlay

2 sources were separated clearly

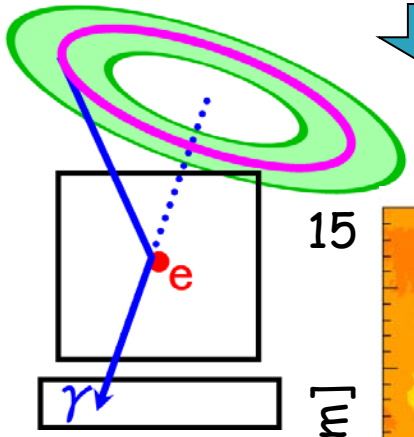


^{137}Cs(1MBq)×2, Advanced Compton

Classical Compton Imaging (COMPTEL)

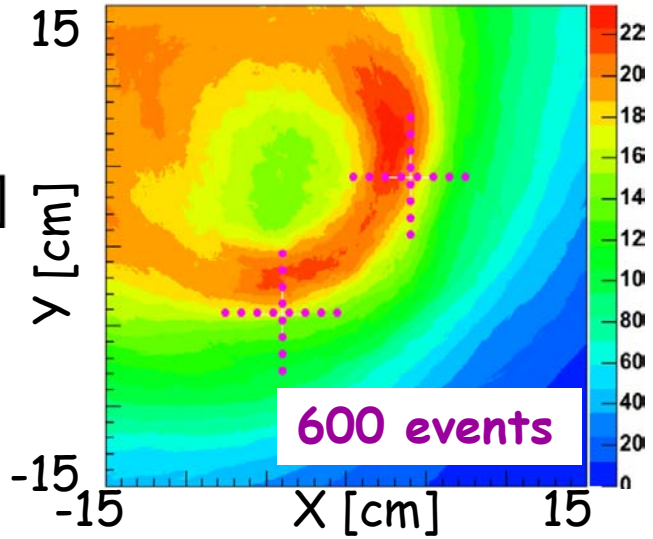
Not using the electron tracks

- only event circle within ring form error region



Simply overlay

Hard to separate 2 sources



^{137}Cs(1MBq)×2, Classical Compton

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

10cm cube camera @ Sanriku (Sep. 1st 2006)

- Operation test @ balloon altitude
- Observation of
  diffuse cosmic/atmospheric gamma
  ~400 photons during 3 hours
  (100 keV~1MeV)

30cm cube camera

- Observation of Crab/Cyg X-1

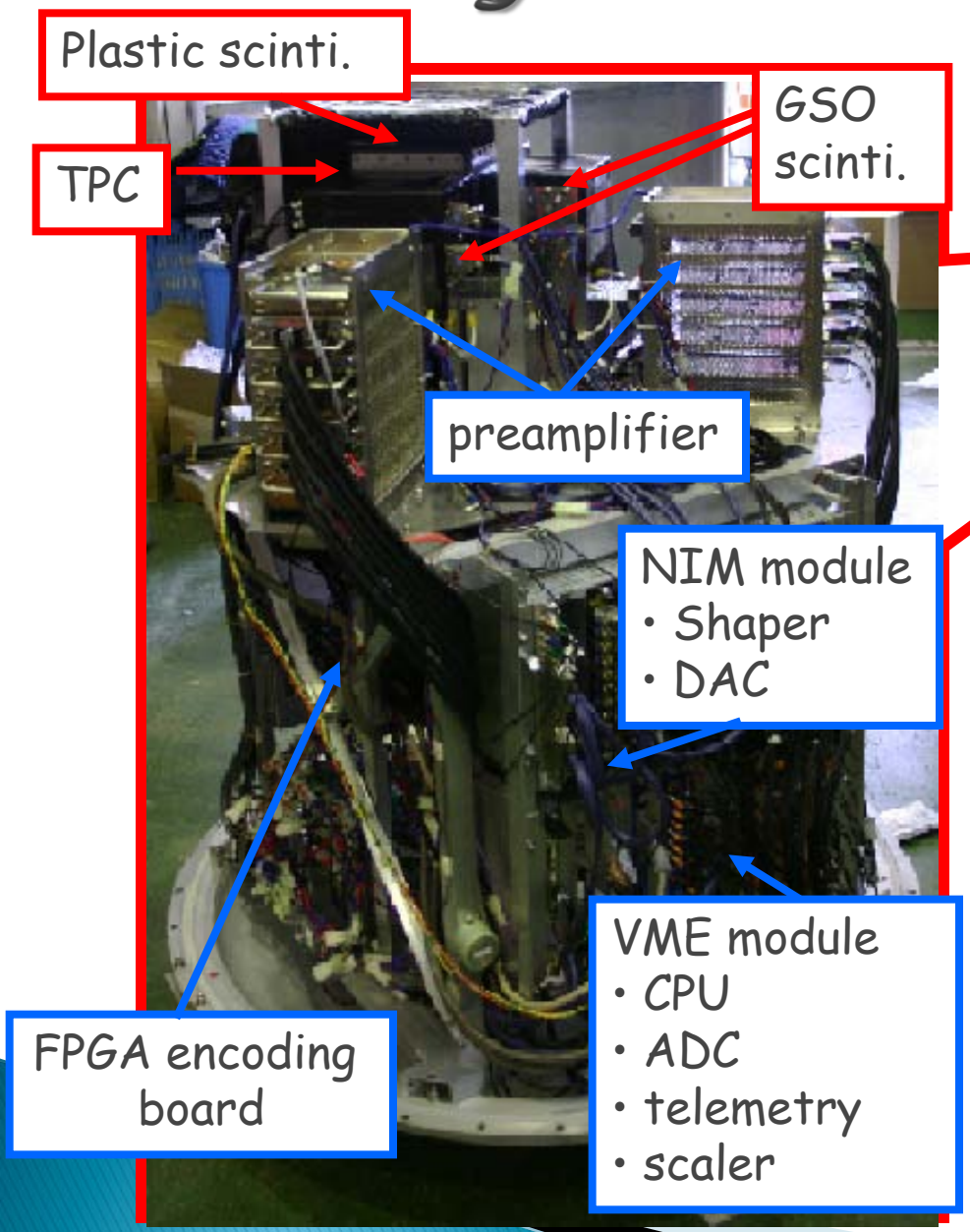
40cm cube camra Sub-MeV ~ MeV

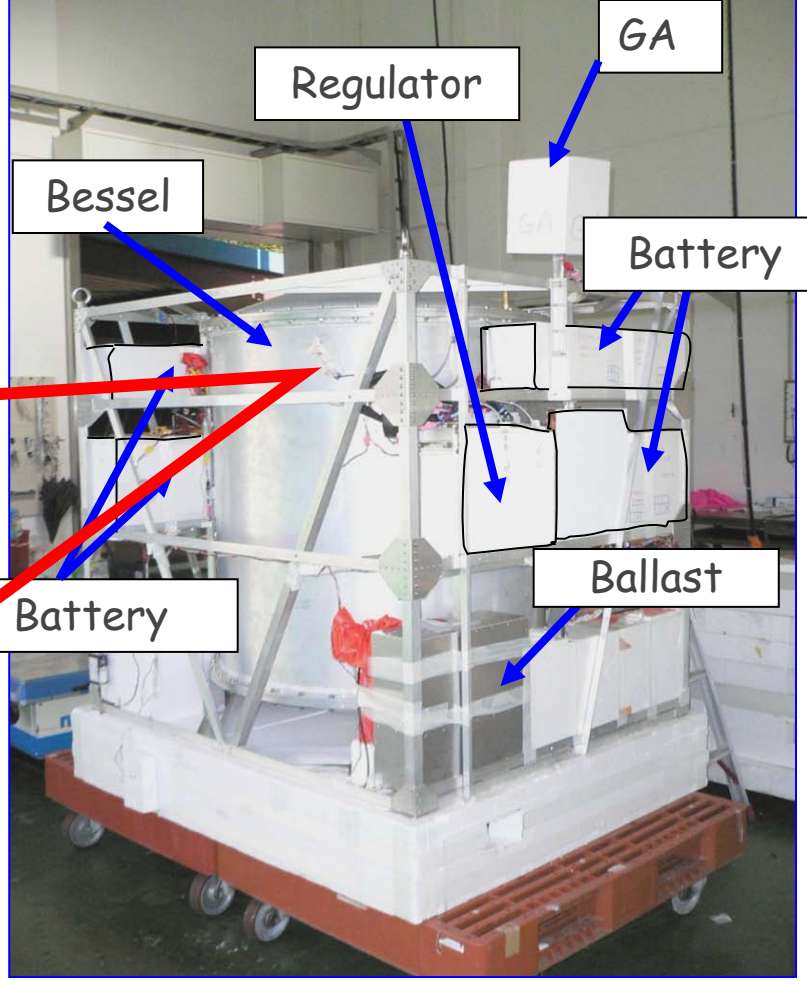
- Long duration observation with super pressure balloon
- Adding pair-creation mode

50cm cube camera

- All sky survey (load on a satellite)

SMILE-I gondola

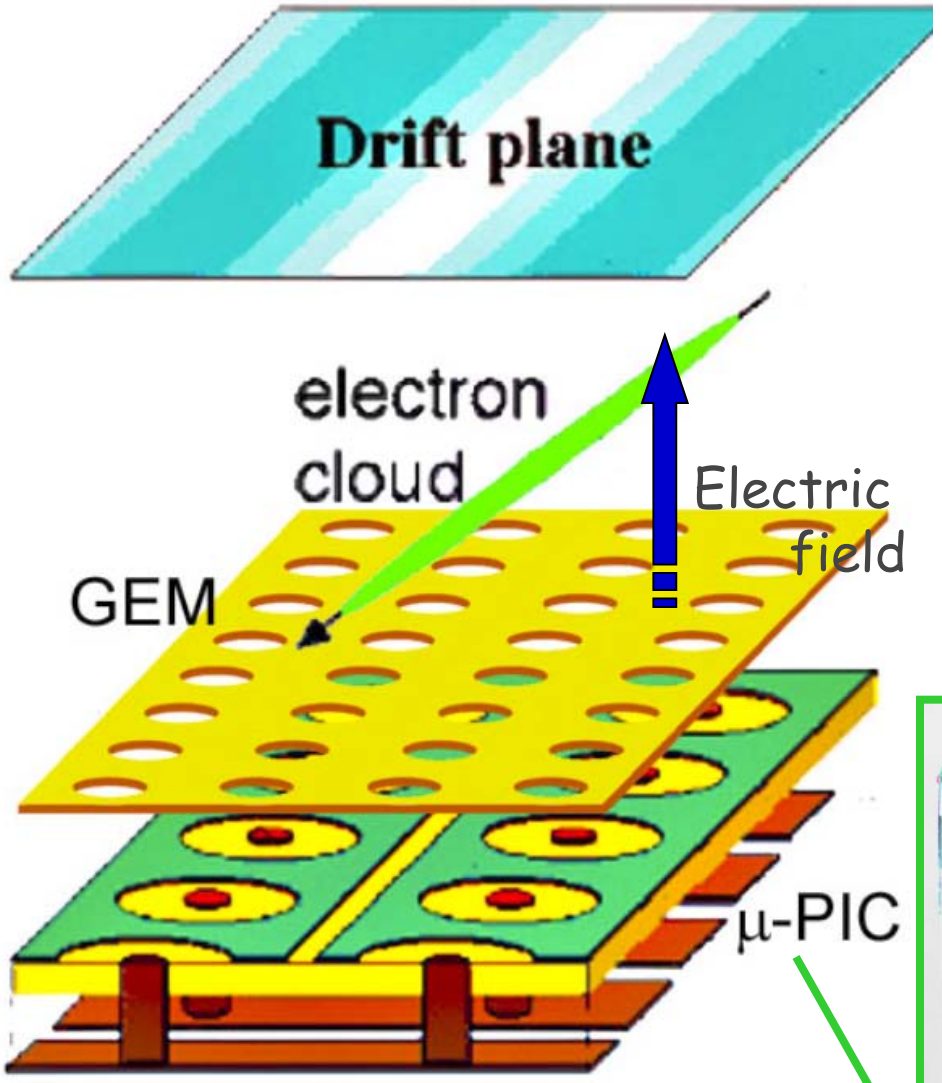




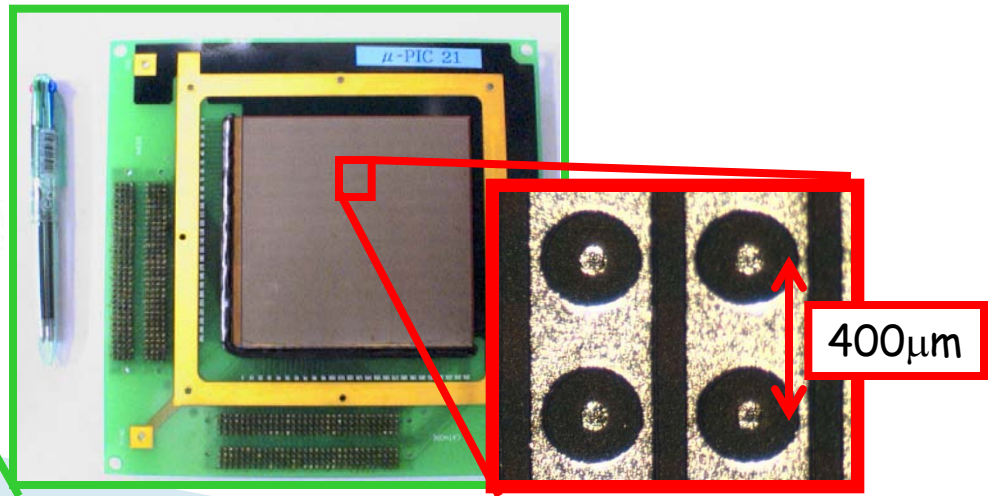
Size : 1.45×1.2×1.55m^3
Weight : 397 kg
Power : ~250 W
No posture control !!

Gaseous electron tracker

2D readout (400μm pitch) + Drift time (100MHz)



- Gas : Xe 80% + Ar 18% + C_2H_6 2%
  1atm, sealed
- Gain : ~35000
- Drift velocity (V_d=400V/cm) :
  measured 2.5cm/μsec
  simulation 2.48cm/μsec
- Volume : 10×10×14 cm^3
- Energy resolution :
  ~45% (22.2keV, FWHM)
- Position resolution : ~500μm



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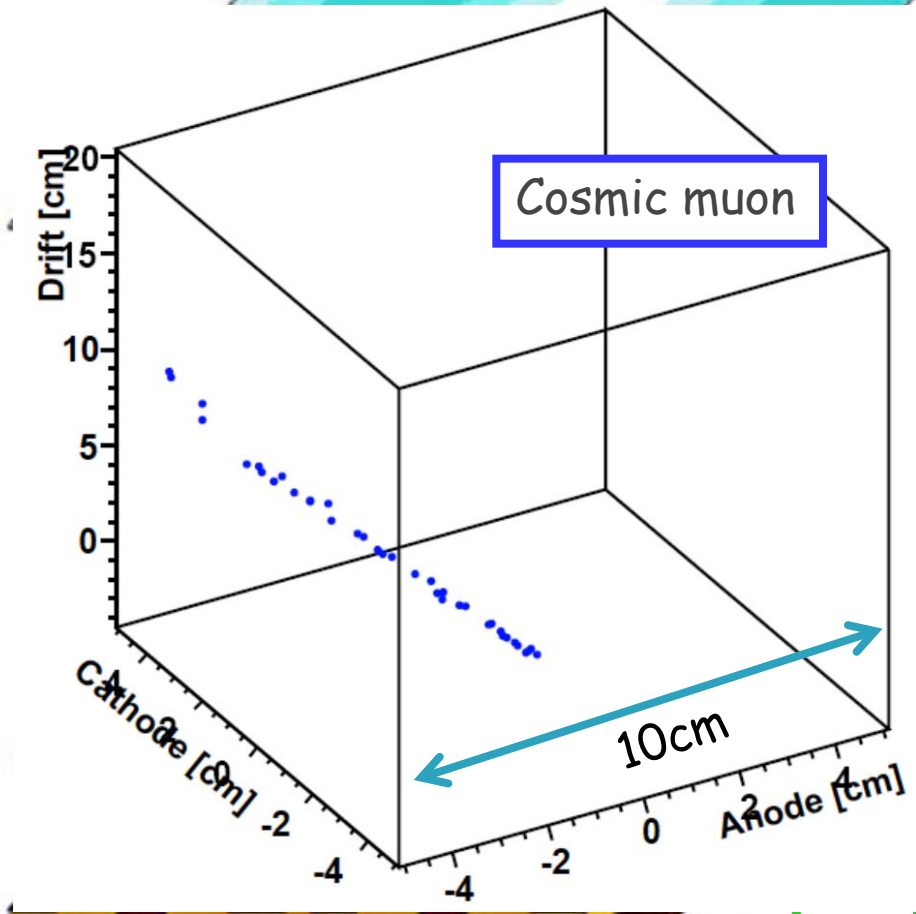
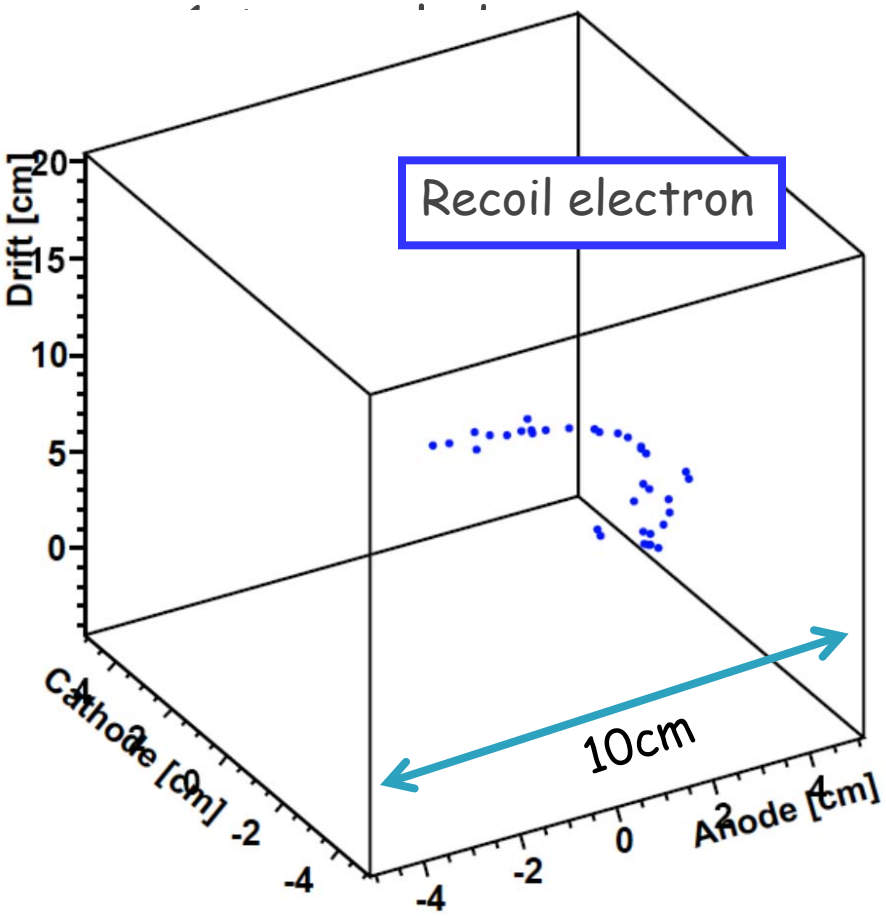
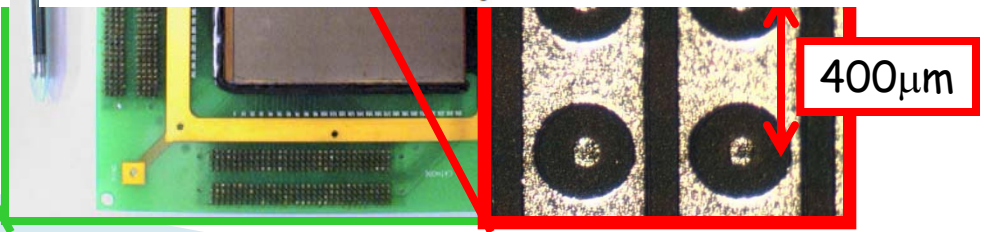
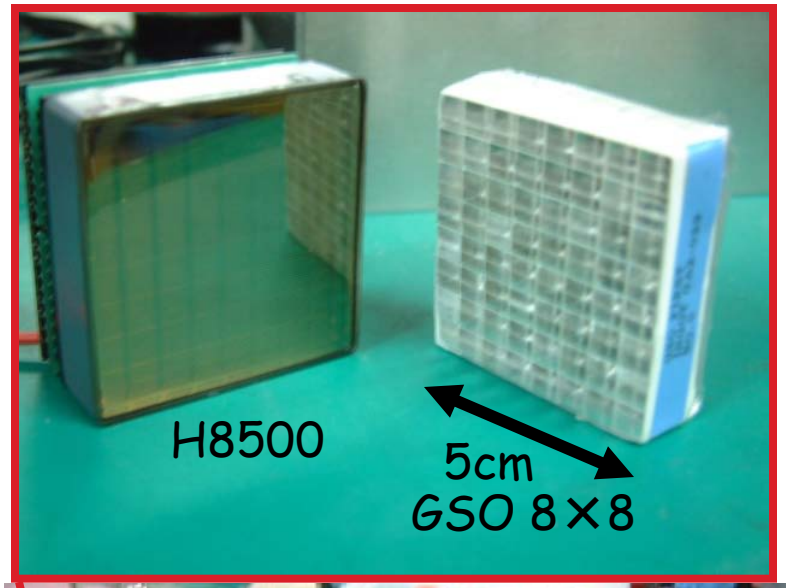
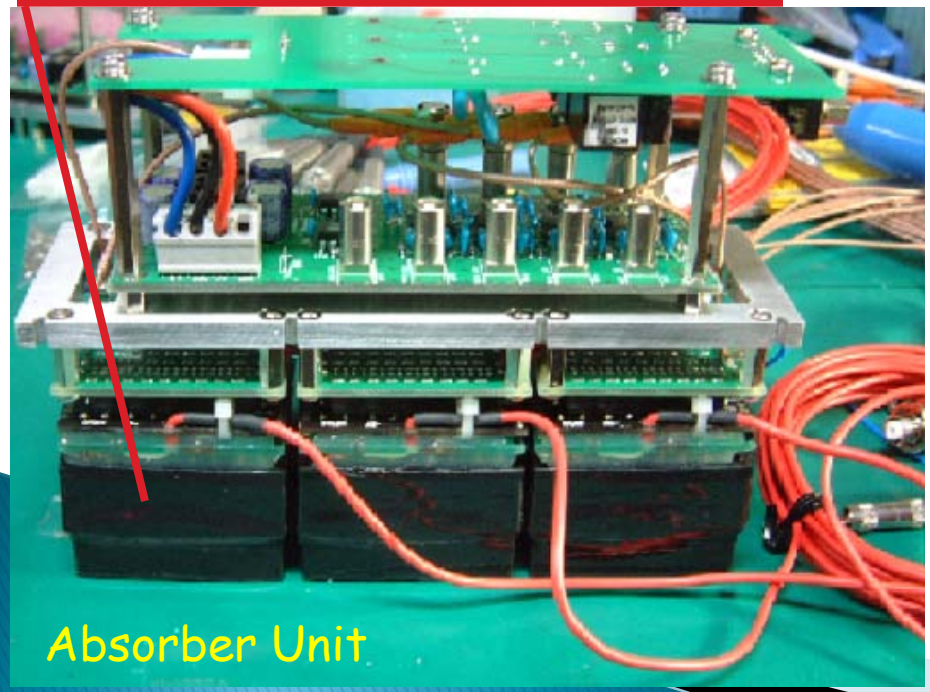






Scintillation Camera



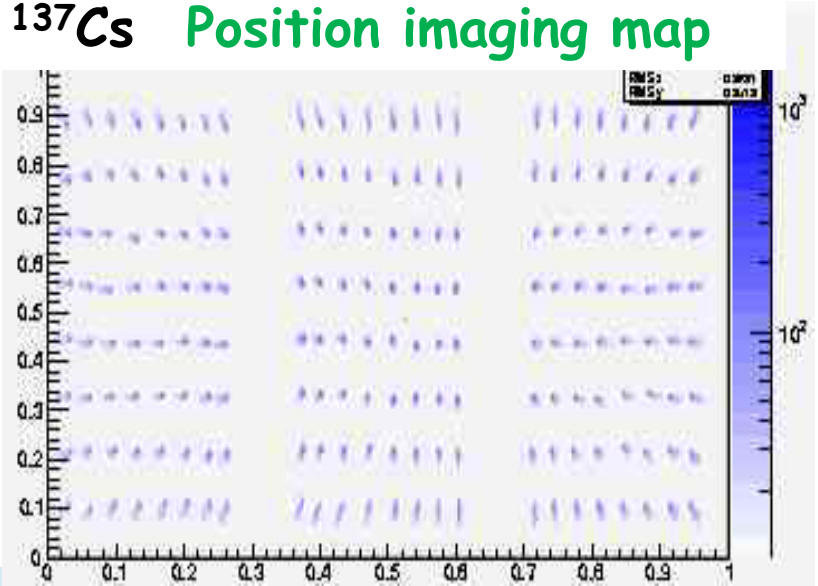


- Scintillator : GSO(Ce)
- Pixel size : 6x6x13 mm^3
- Photo readout : H8500 (HPK)
- DC/HV : EMCO Q12N-5
- A unit consists of 192 pixels, 3 PMTs, 3 DC/HV and 4 preamplifier
- 4 channels readout with resistive chain
- Bottom : 3×3 PMTs
- Side : 3×2 PMTs × 4

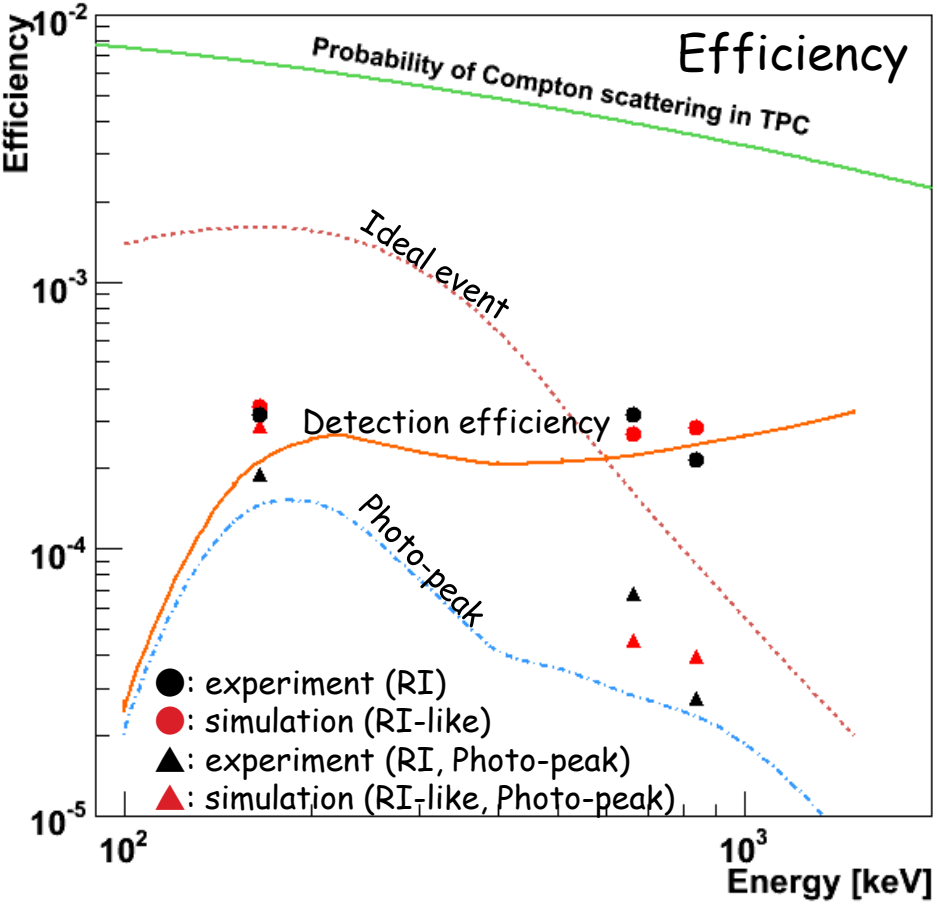
} 2112 pixels

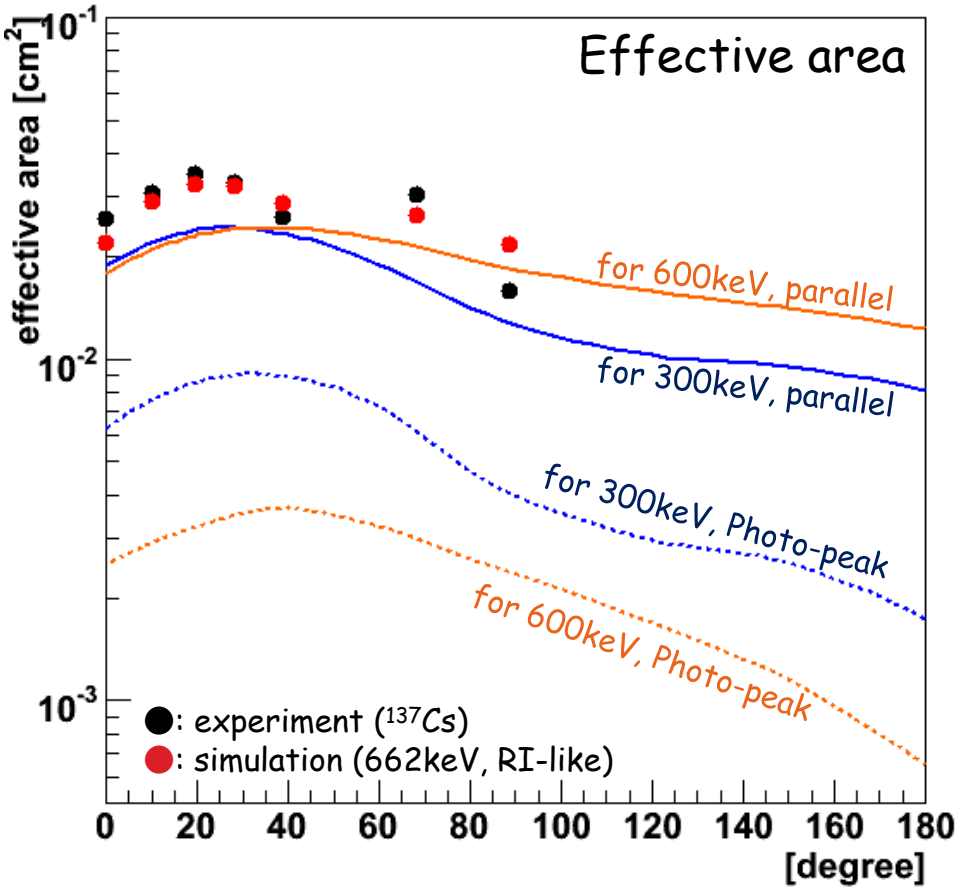
- Energy resolution : ~11% (662keV, FWHM)

^{137}Cs Position imaging map



Efficiency & Effective area

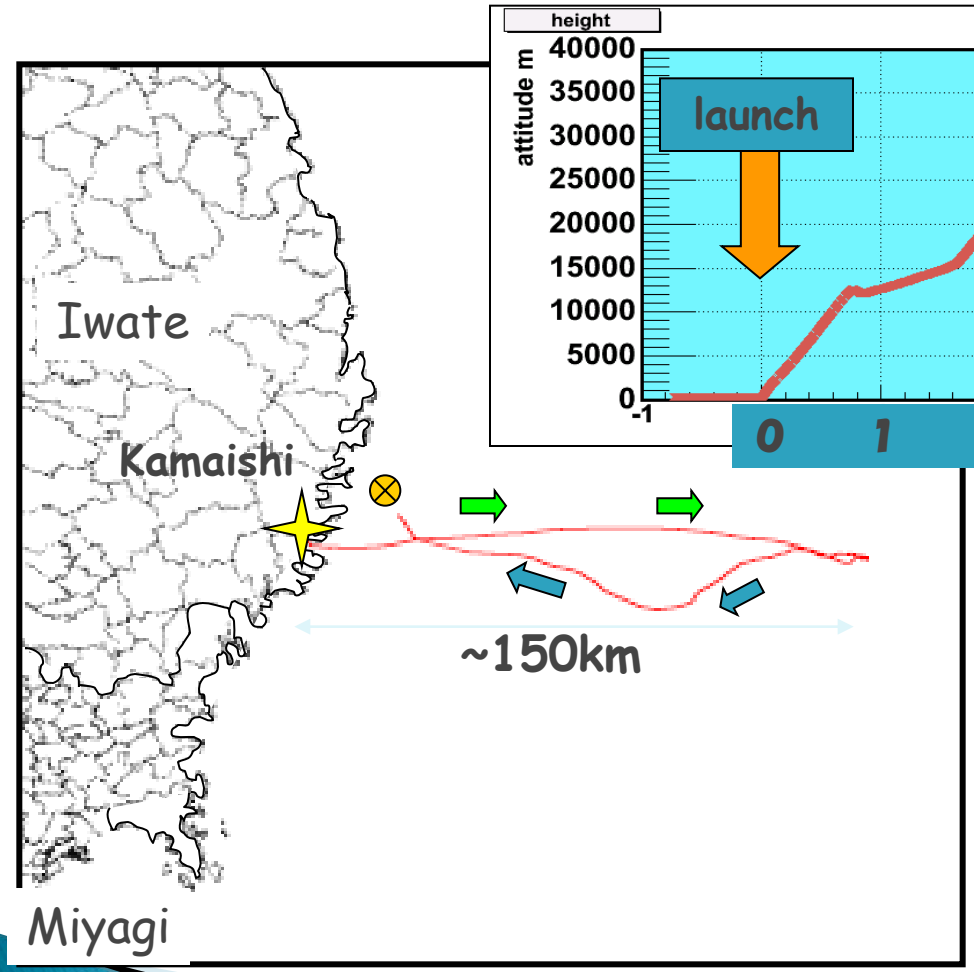


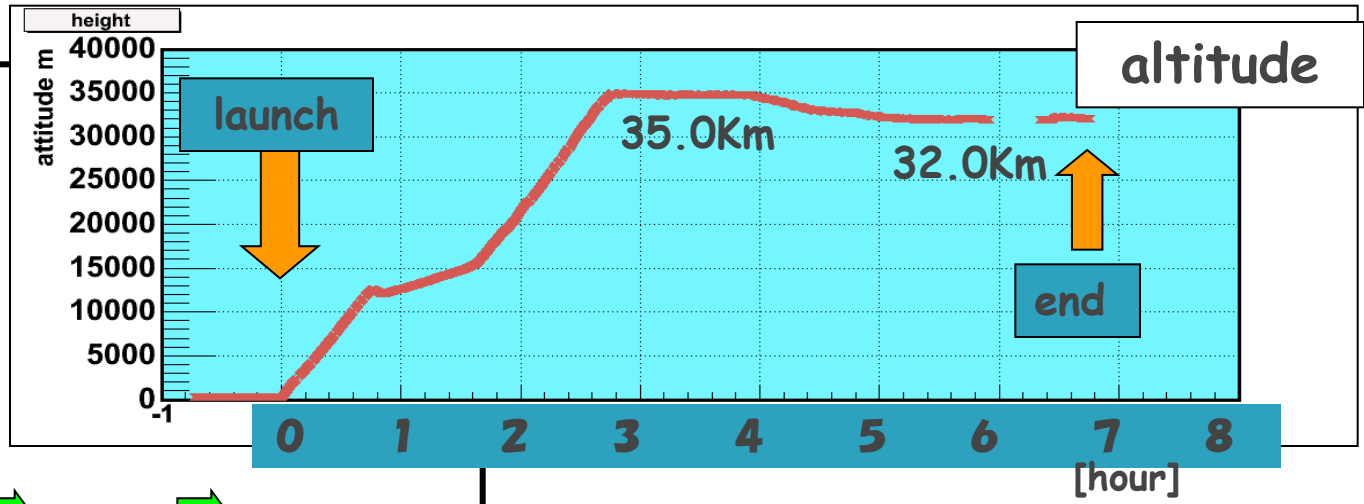


- Detection Efficiency : 3×10^{-4} for 150-1500keV
- Effective area : 2×10^{-2} cm^2 for 150-1500keV, 0-60°
- The simulated effective area was roughly consistent with that obtained by experiments.
- Effective area has a maximum at ~25° <- caused by the geometry

1st Flight

- Sanriku Balloon Center (JAXA)
- Launch at Sep. 1st 2006





[JST]
05:26 turn on
06:11 launch
08:56 level-flight start
12:59 turn off
13:20 cut off
13:45 landing
14:32 recovery

There was no serious trouble during this flight !

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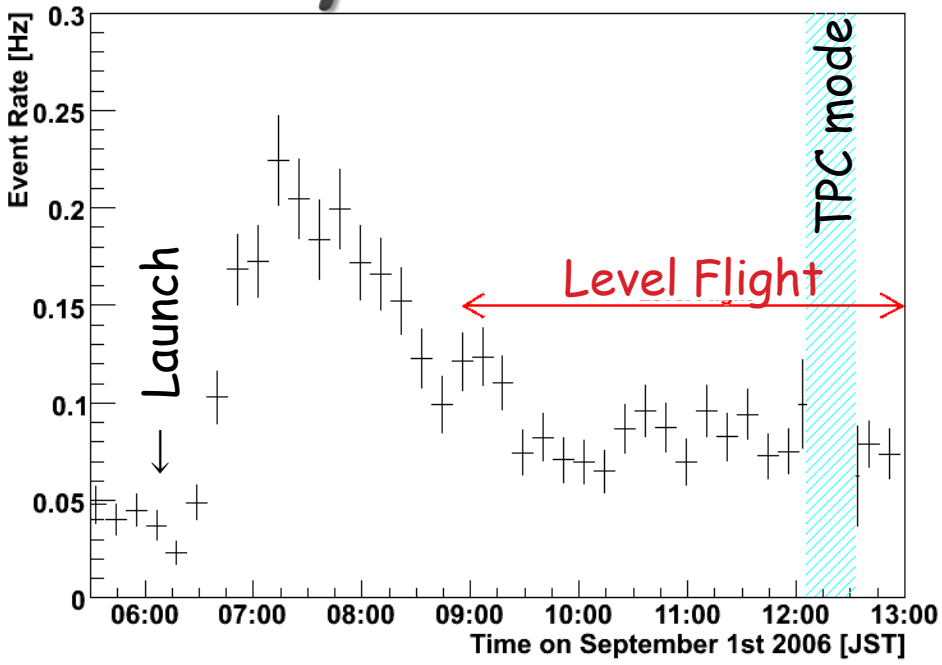
Compton event rate & spectrum



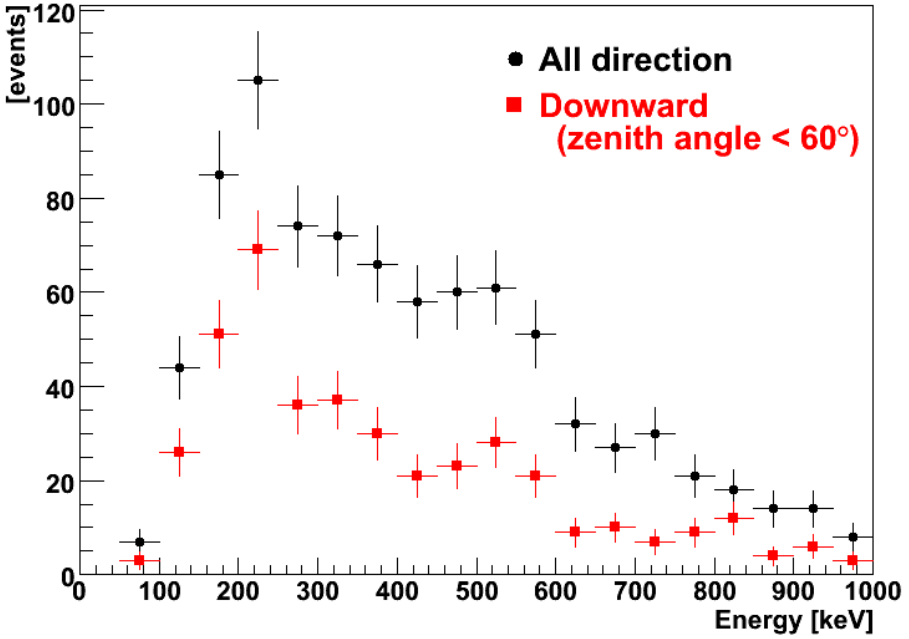
Rate of Compton event

- 100~900 keV
- All direction ~2000
- in FOV (3 str) ~940

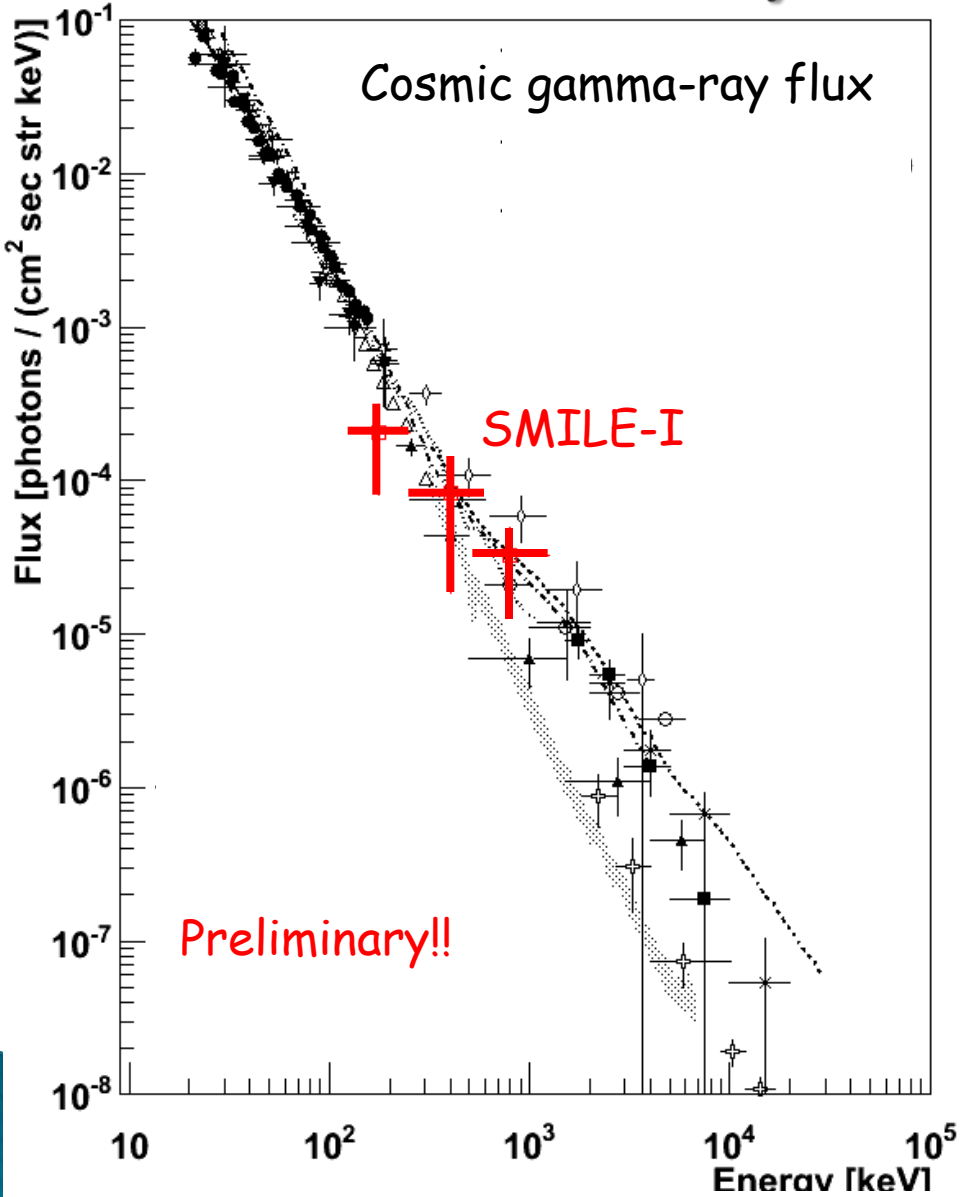
Energy Spectrum

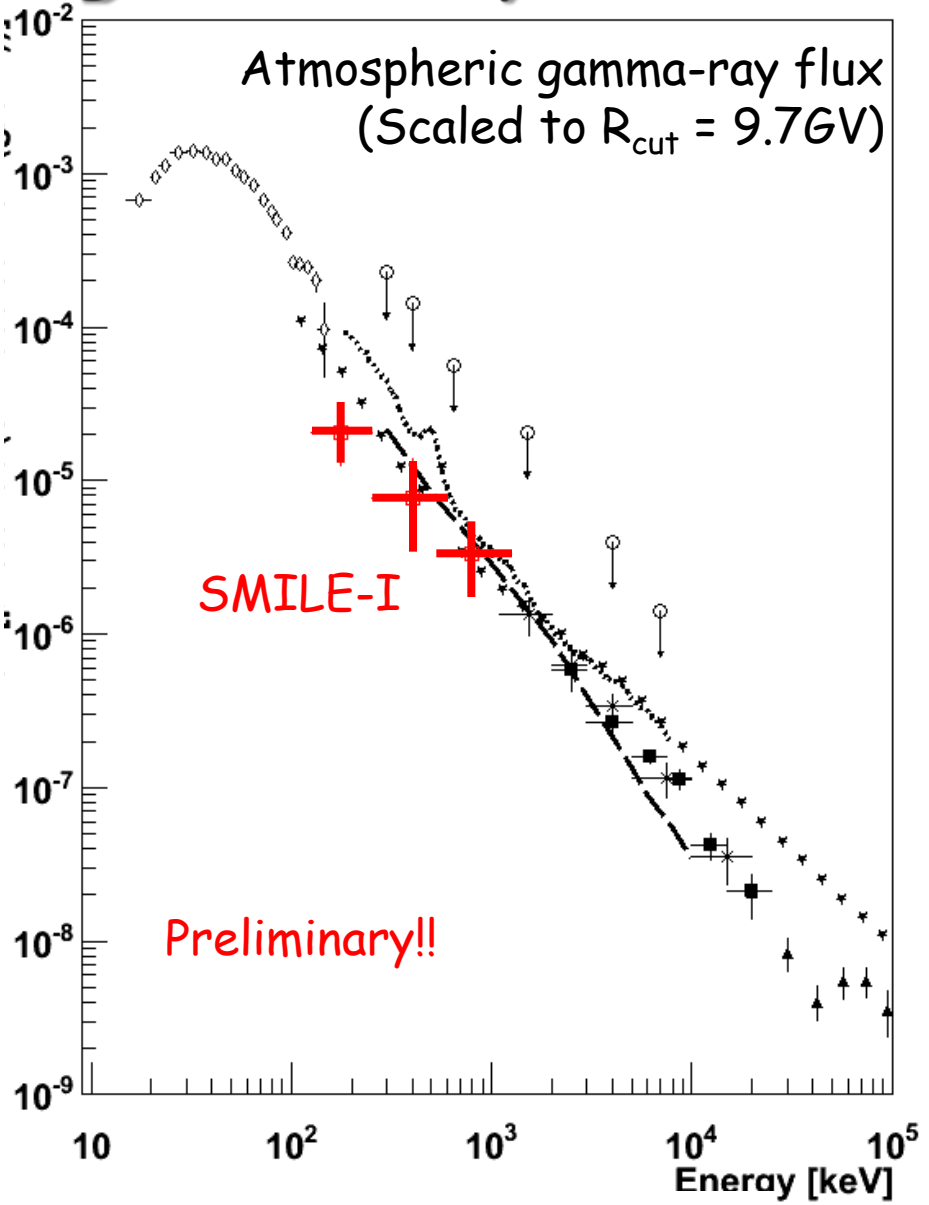
- 32~35 km level flight
- 3.5 hours (live ~3h)
- in FOV event
  ~420 events

GEANT4 ⇒ ~400events



Cosmic & Atmospheric gamma-ray flux





Our results were consistent with those of past observations!!!

Toward Next Step

- SMILE-I : 1st Sep. 2006 launched
  - Observation of diffuse cosmic/atmospheric gamma-rays
    -> detection by integration in a large FOV
  - Electron Tracker : 10x10x15 cm^3 , Xe+Ar 1atm
  - Absorber : 15x15x1.3 cm^3 @ Bottom
    15x10x1.3 cm^3 x4 @ Side

  ⇒ Effective area : ~2×10^{-2} cm^2

- SMILE-II
  - Observation of a Bright object (Crab nebula or Cyg X-1)
    3.0 hours, 40 km

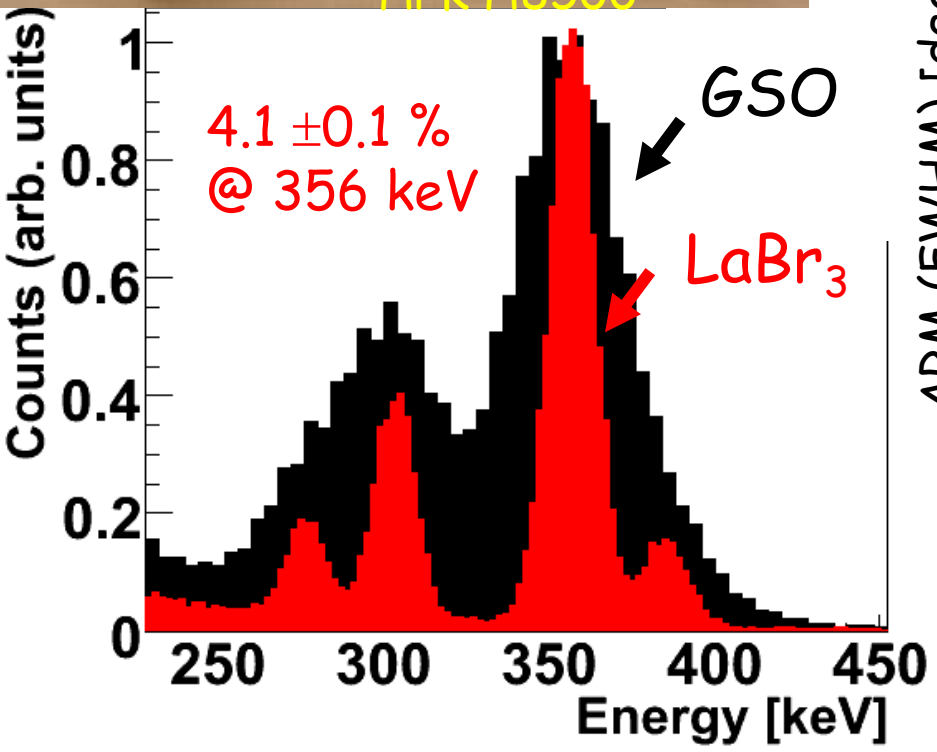
  ⇒ Requirement : ~1 cm^2

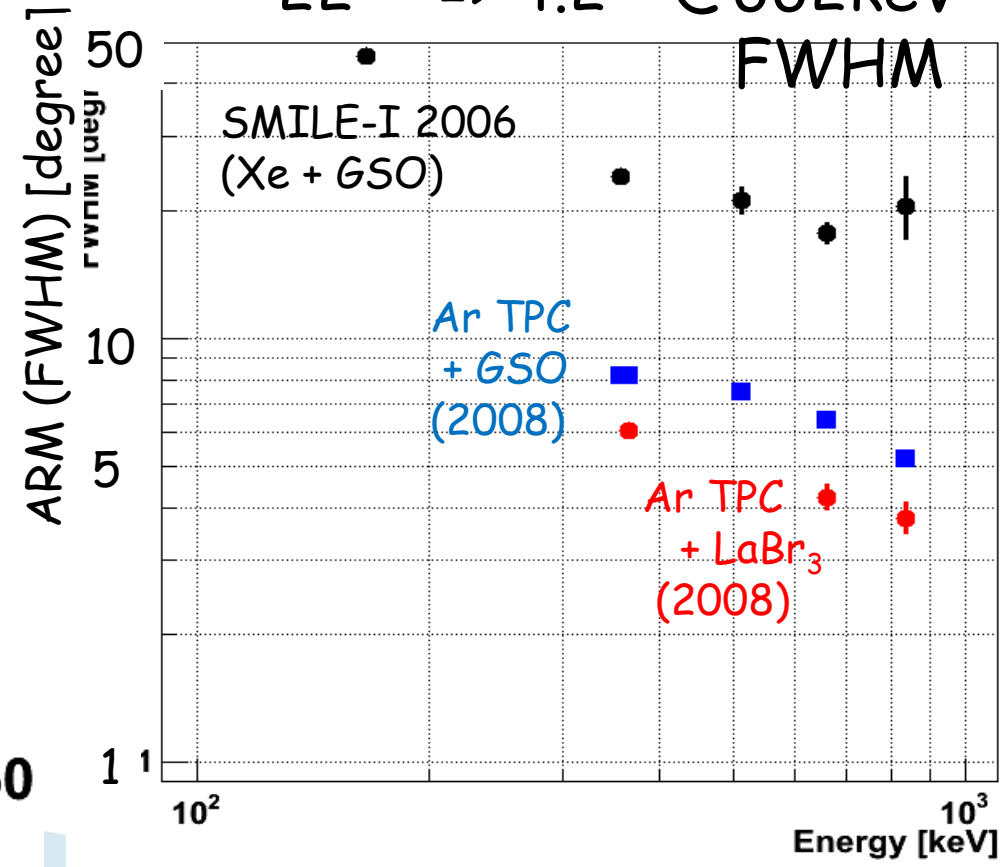
  - Electron Tracker : 30x30x30 cm^3 , Ar/CF_4 2atm
  - Absorber : 30x30x1.3 cm^3 @ Bottom
    30x15x1.3 cm^3 x4 @ Side
  - Improvement of Angular resolution

Improvement of Angular resolution

ARM :
limited by energy resolution of absorber
and the accuracy of Compton point

Xe + GSO(Ce) => Ar + $LaBr_3$
22° => 4.2° @662keV





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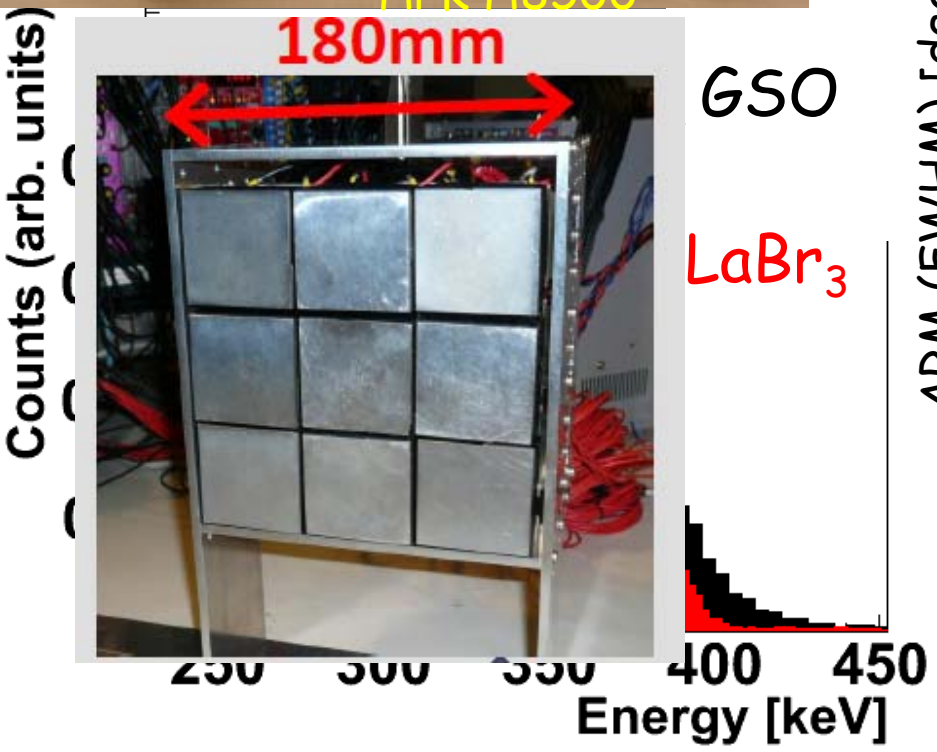
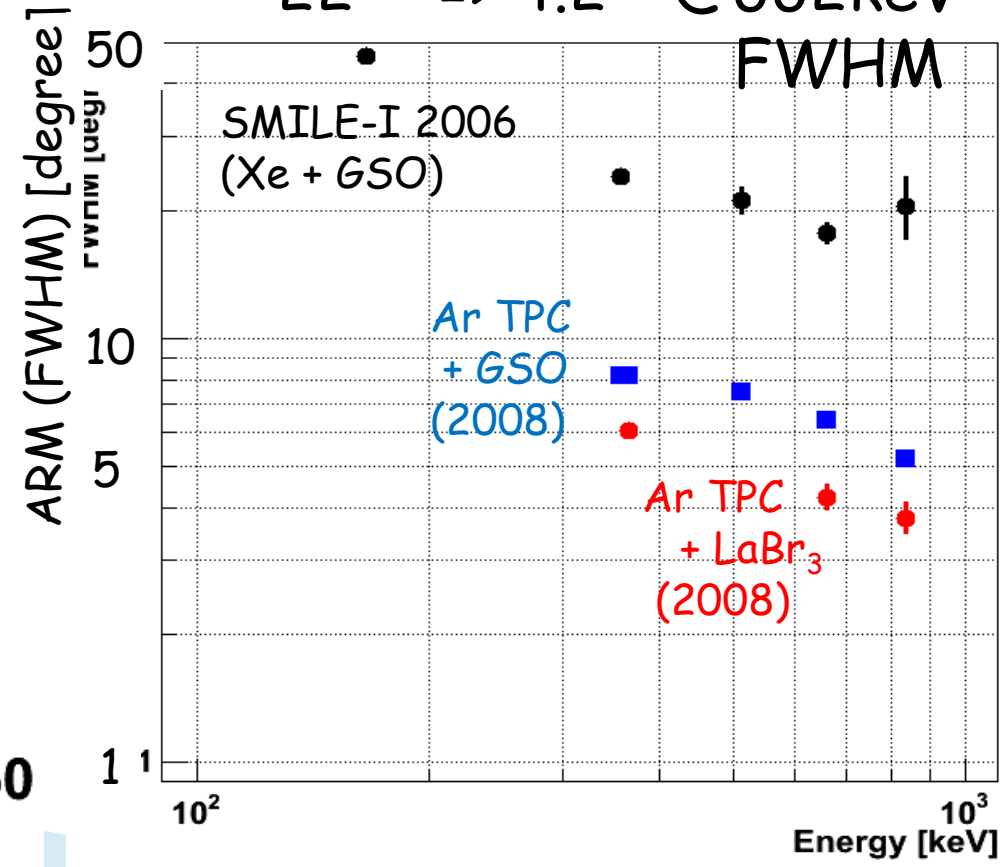


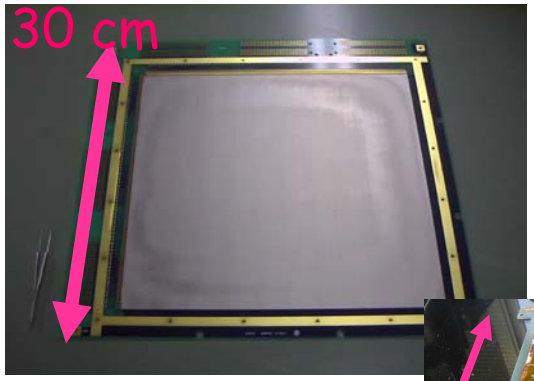


30×30×30cm³ ETCC current status

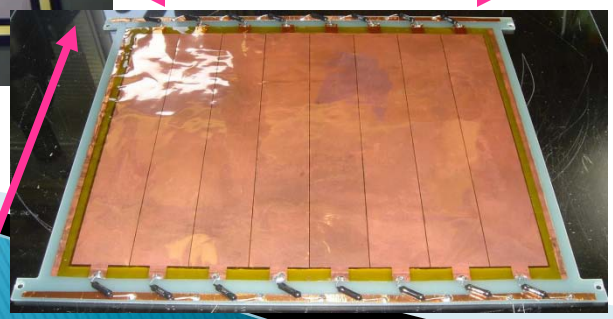
We are developing a larger ETCC based on the 30cm ×30cm×30cm TPC and 6 x 6 scintillation cameras.

➢ Gaseous TPC

- volume : 30×30×30 cm^3
- gas : Ar 90% + $C_2H_6$10% (1atm)
- drift velocity : 4 cm/μsec
- gain : ～30000
- energy resolution : 46%@32keV
- position resolution: 400μm

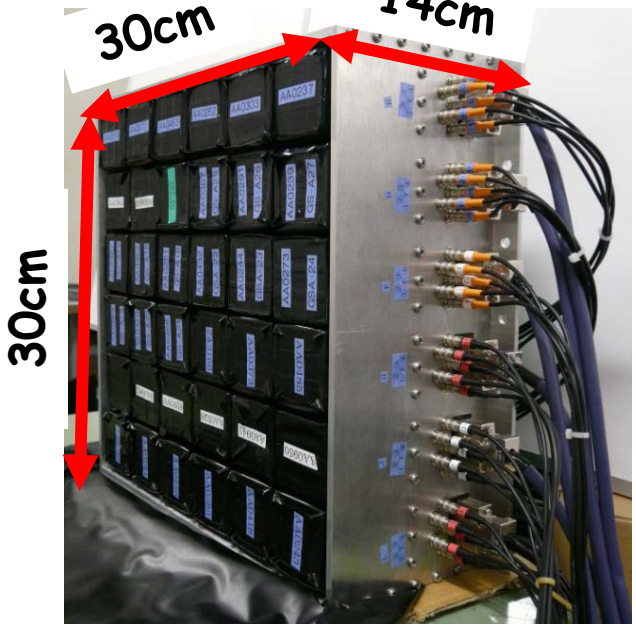


30cm x 30cm μPIC



➢ Scintillation Camera

- number of pixels : 2304 pixels
- Crystal : GSO(Ce)
- pixel size : 6×6×13mm^3
- energy resolution : 10.9% (@662keV, FWHM)
- position resolution : 6mm



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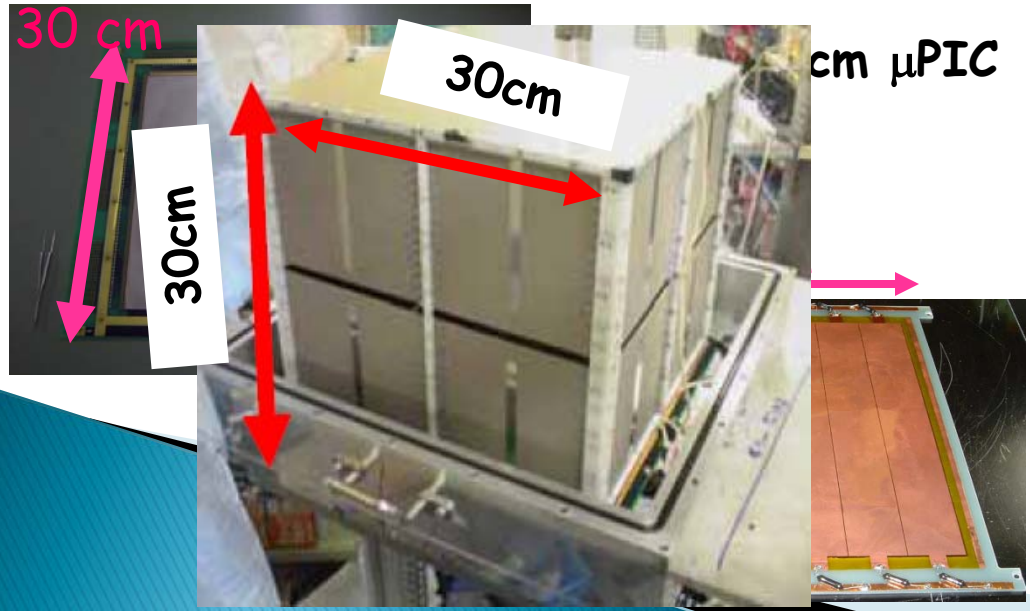
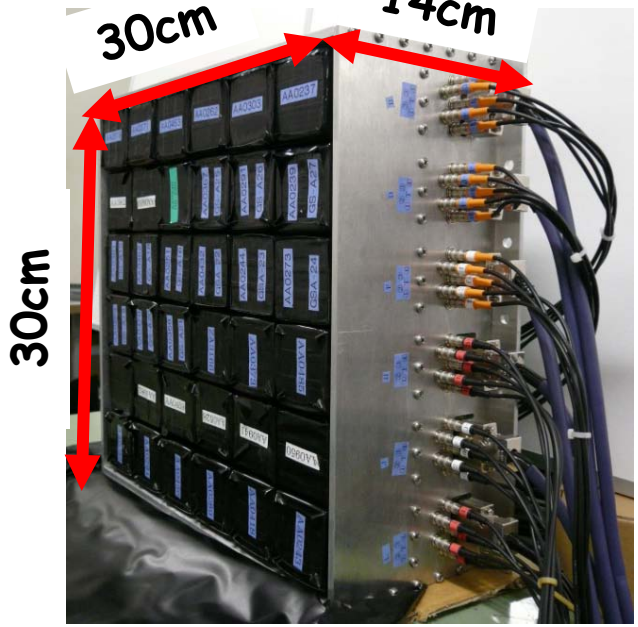
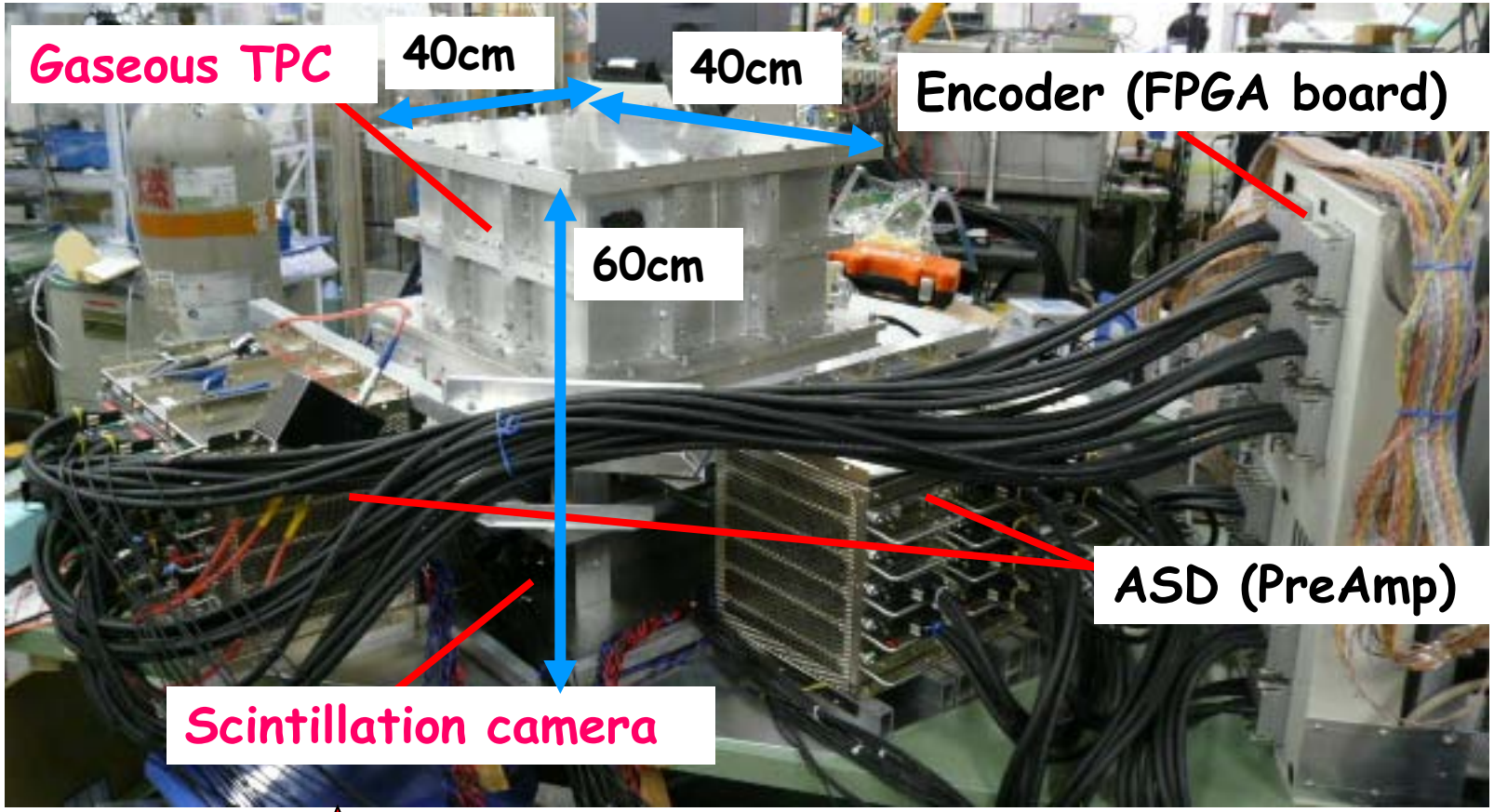
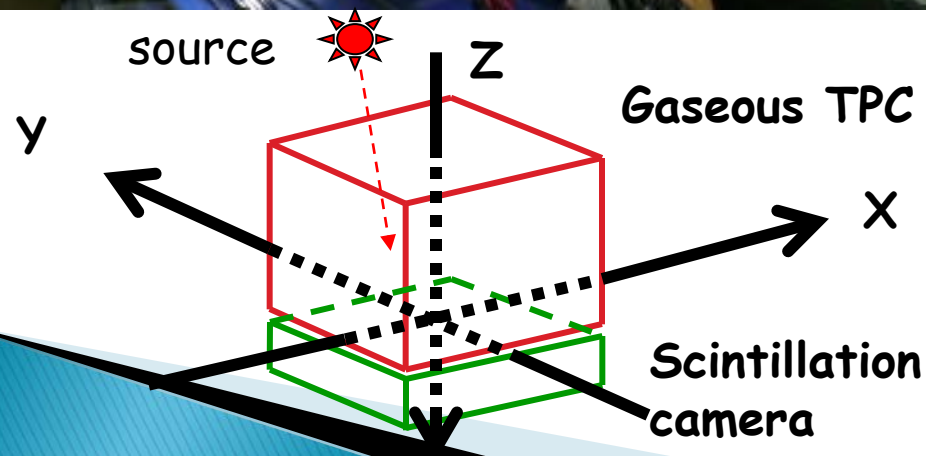






Setup



Center of μPIC :(0,0,0)

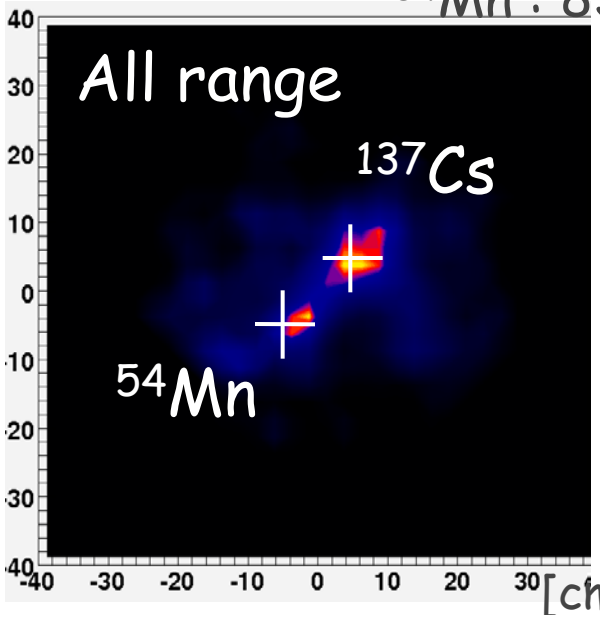
Center of Scinti.

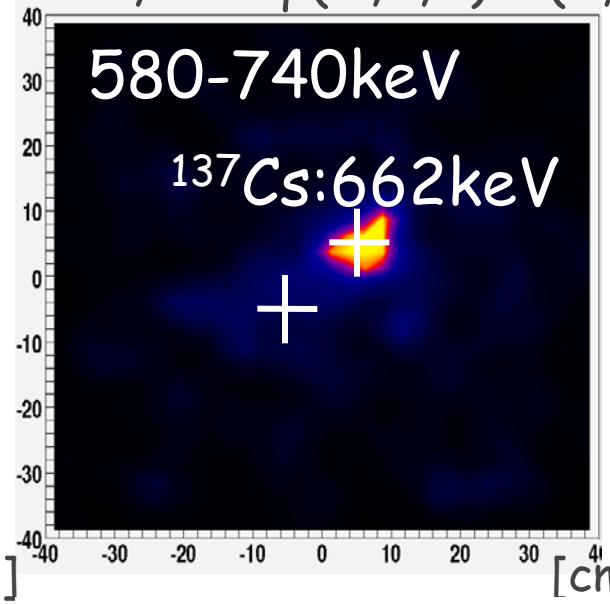
:(-3.3, 0.2, 5.7)

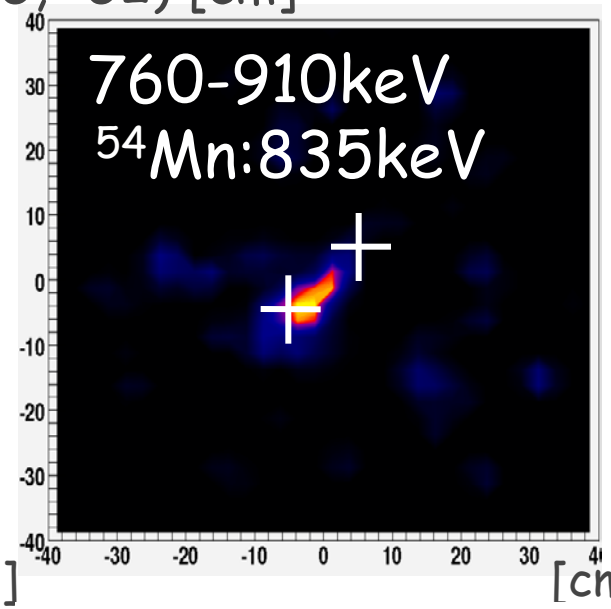
simultaneous imaging (preliminary)

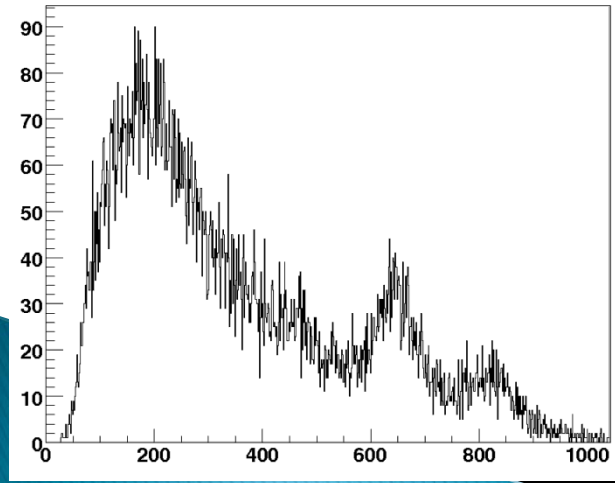
^{137}Cs : 662keV, 1MBq (X,Y,Z) = (5, -5, -52) [cm]

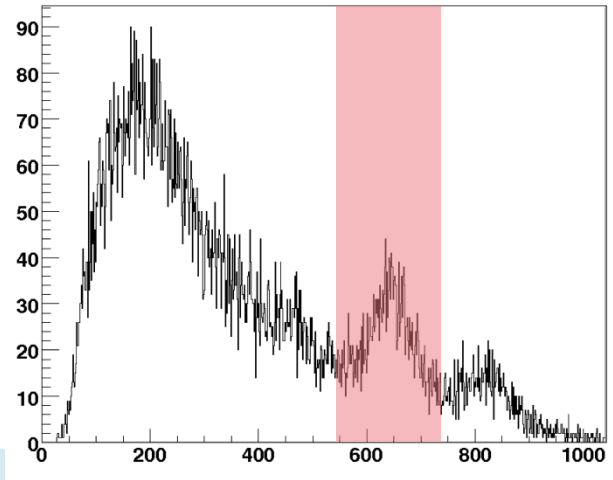
^{54}Mn : 835keV, 1MBq (X,Y,Z) = (5, 5, -52) [cm]

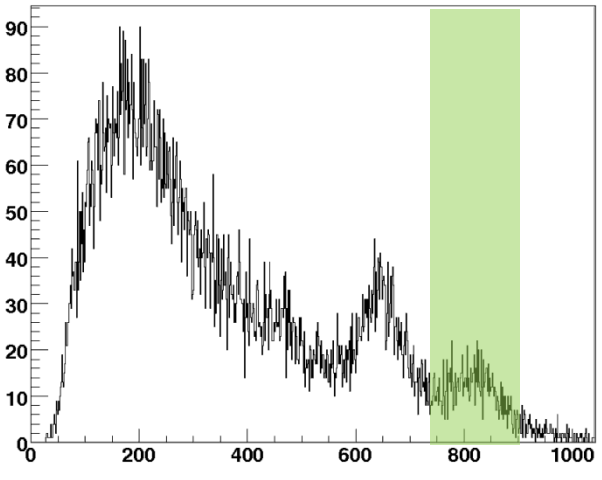




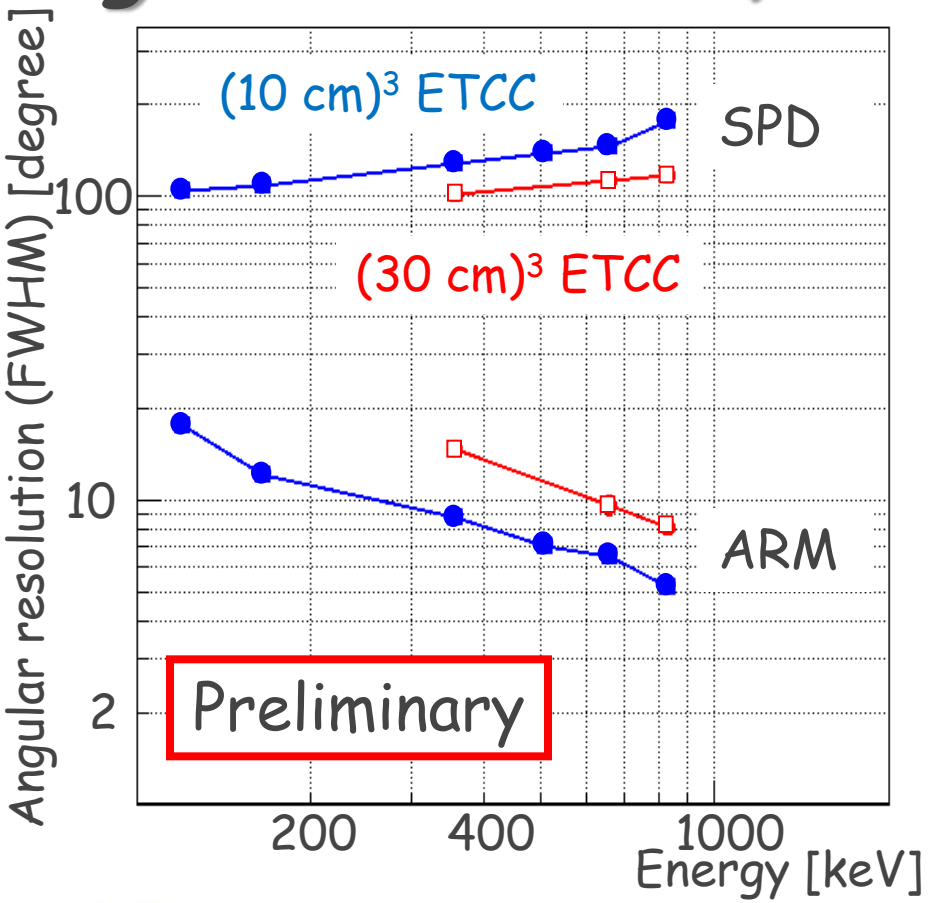


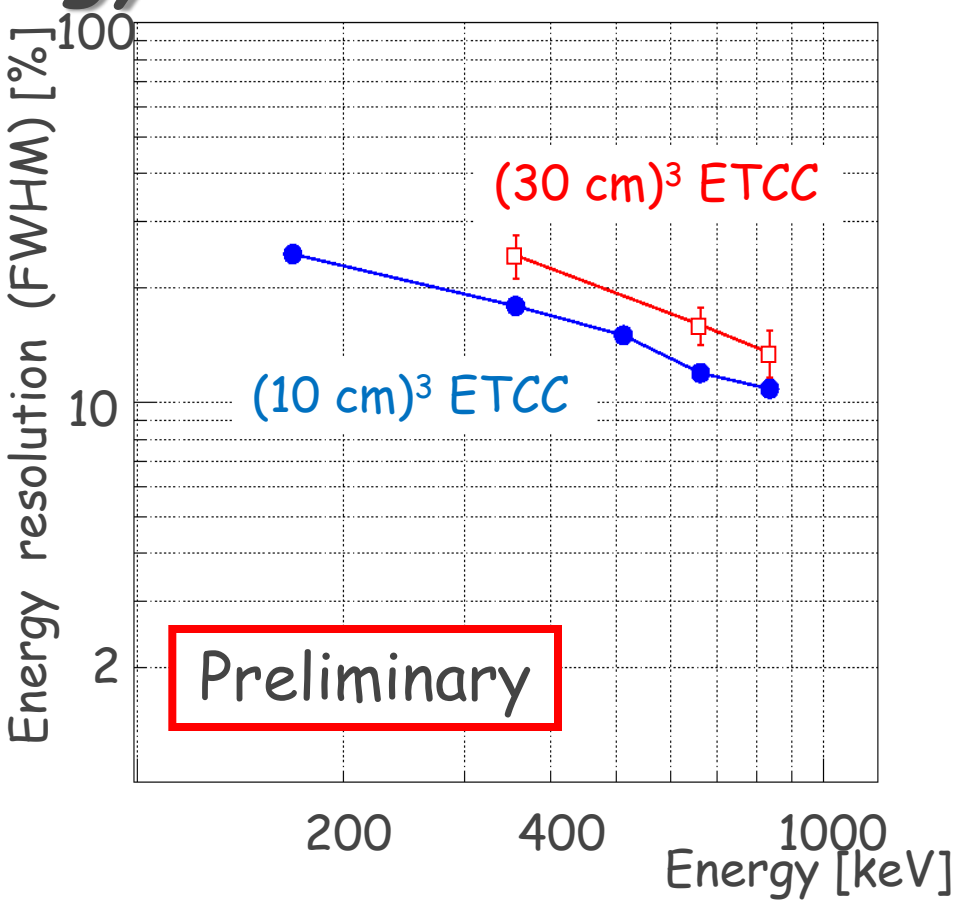


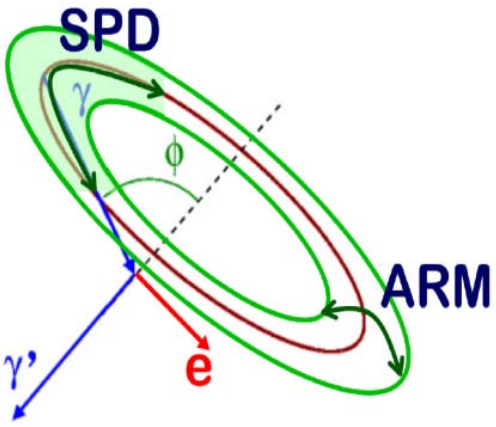




Angular resolution, Energy resolution







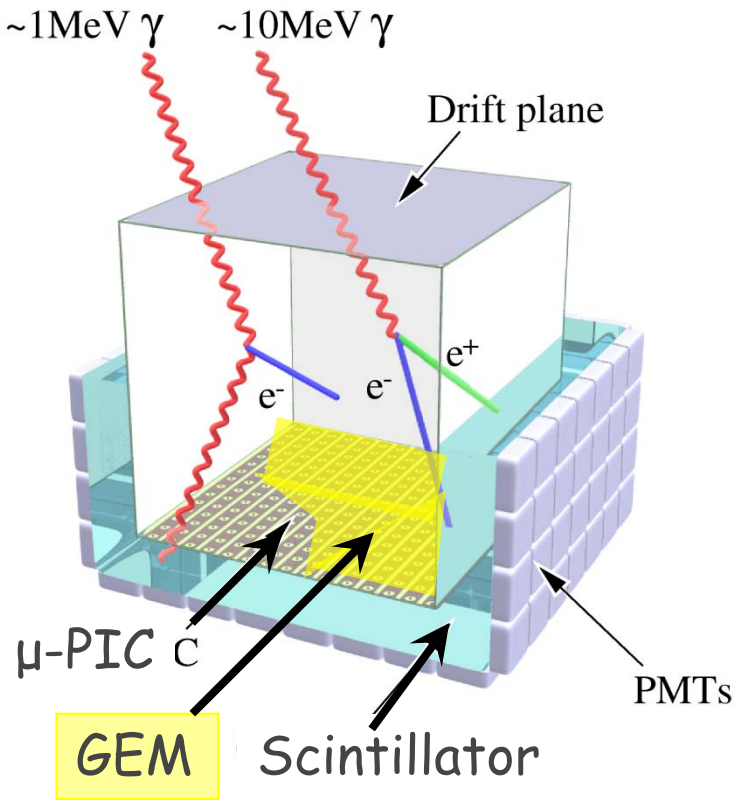
SPD: 113[deg]
ARM: 9.6[deg]
DE/E: 16.0%
(FWHM) @662keV

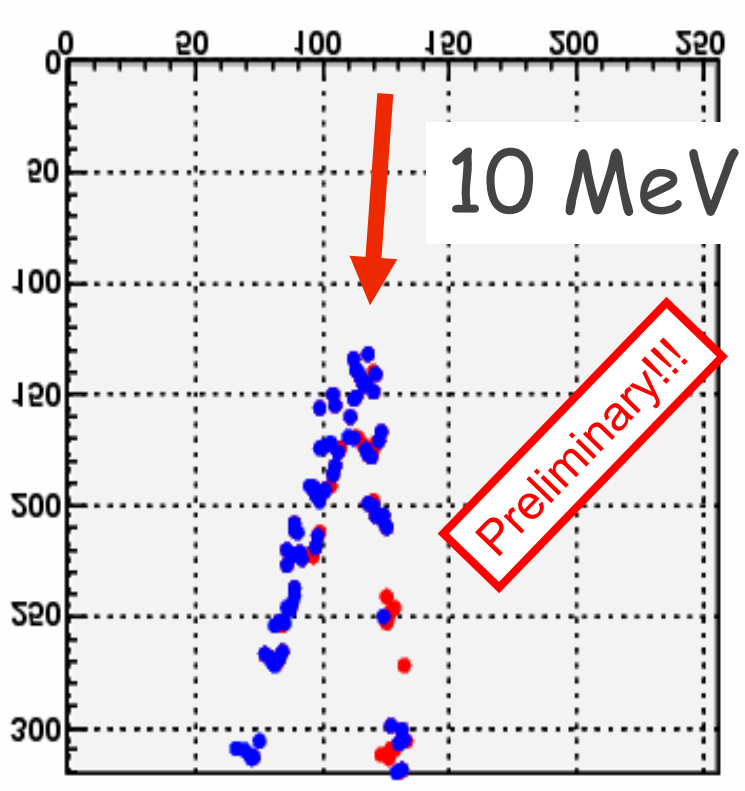
⟺

130[deg]
6.6[deg]
12.0%

(10cm)³ETCC

Imaging of Pair-Creation Process





We detected 10 MeV gamma rays with our camera as pair creation detector using AIST laser-Compton gamma-ray beam

Collaborator: H.Toyokawa (Advanced Industrial Science and Technology: AIST, Japan)

Summary

- We develop an Electron-Tracking Compton Camera.
- The flight model detector for SMILE-I
  - Energy resolution : ~12% for 662keV @ FWHM
  - Detection efficiency : ~2×10^{-4} for 356 keV
  - Field Of View : ~3str
- The first balloon was launched on September 1st, 2006 from Sanriku-Balloon-Center (ISAS/JAXA).
- The balloon flight lasted 7 hours, and the level flight continued during 4 hours at the altitude of 32-35 km.
- Our detector was stable at the balloon altitude.
- The experiment is the first observation using ETCC at the balloon altitude.
- There were ~2000 gamma-ray events in this flight, and ~420 gamma-ray events in FOV during the level flight.
- We confirmed the past observations of the fluxes of diffuse cosmic and atmospheric gamma-rays.
- Our detector realized a large FOV and a high S/N at the balloon altitude.
- Now, we are developing a larger volume detector for the next step.

Sensitivity of X/Gamma-ray observations