

Balloon-borne sub-MeV/MeV gamma-ray observation using a Compton camera with a gaseous TPC and a scintillation camera

SPIE @ Town and Country Resort and Convention Center
San Diego, California, USA (2010.7.2)

Shunsuke KUROSAWA

Hidetoshi Kubo, Atsushi Takada^a, Kazuki Ueno^b, Yuji
Kishimoto, Satoru Iwaki, Michiaki Takahashi, Naoki Higashi,
Tatsuya Sawano, Kojiro Taniue, Kaori Hattori, Chihiro Ida,
Shigeto Kabuki, Kentaro Miuchi, Kiseki Nakamura, Hironobu
Nishimura, Joseph D. Parker, Toru Tanimori

Dept. of Physics, Graduate school of Science, Kyoto University, Kyoto, Japan

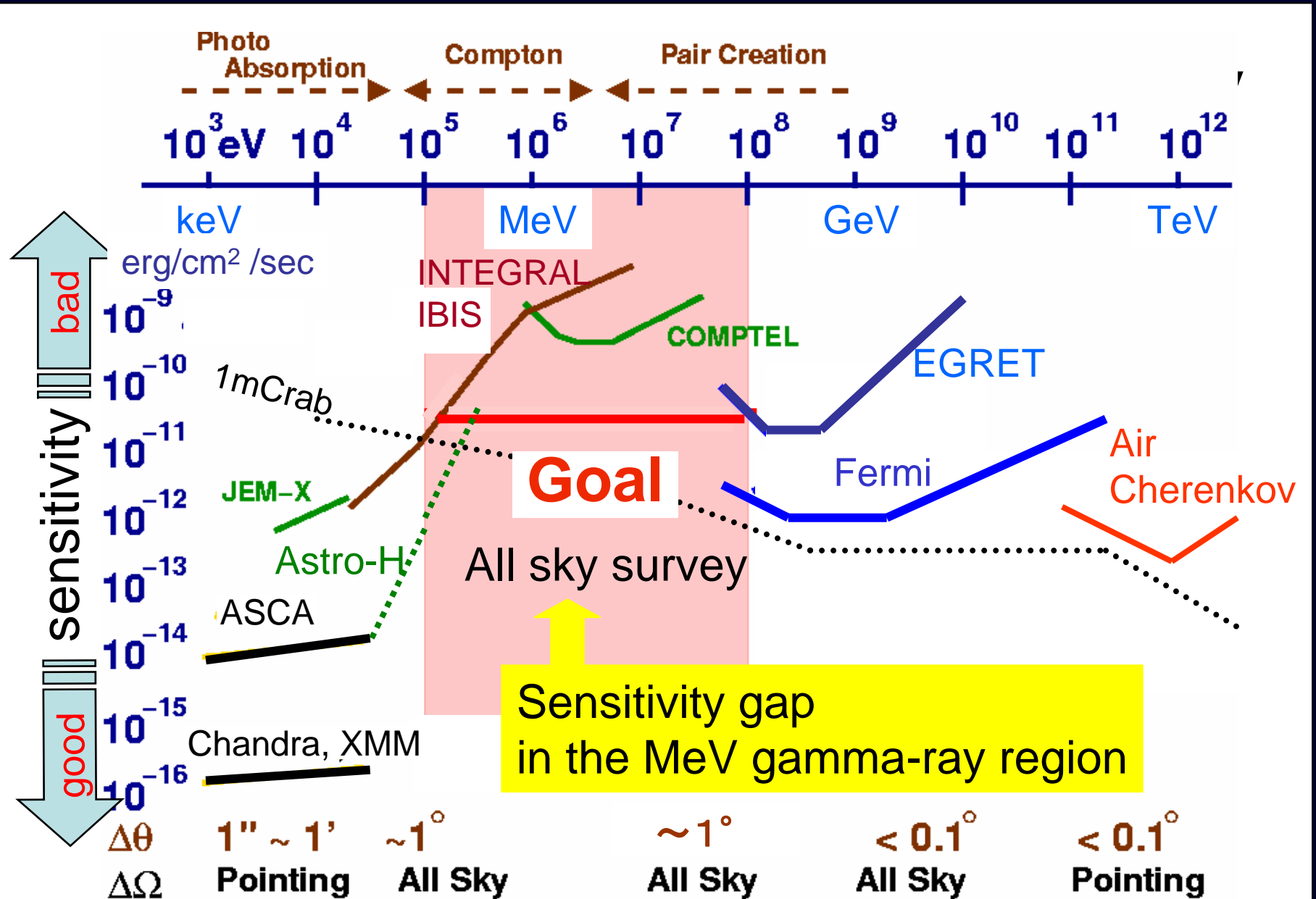
a) ISAS / JAXA, Kanagawa, Japan

b) RIKEN, Saitama, Japan

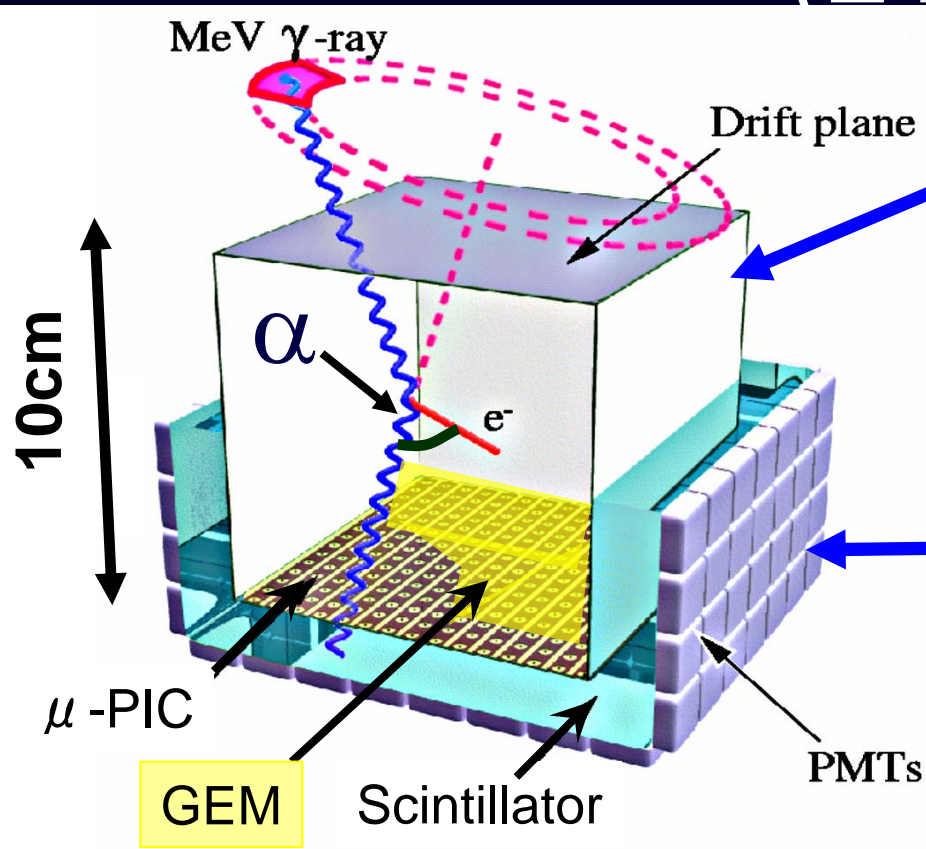
Contents

- Electron Tracking Compton gamma-ray Camera (ETCC)
- SMILE project
- SMILE-II
 - Large ETCC
 - New readout system
 - Gas study
- SMILE-III
- Summary

Sensitivity in X / Gamma-ray Astronomy



Electron-Tracking Compton Camera (ETCC)



gaseous TPC

(time projection chamber) :

[containing μ -PIC(MPGD),
GEM (Sauli (1997), Inuzuka *et al.* (2004))]

--- **energy** and **3-D track** of
Compton-recoil electron

Scintillation camera:

[Pixel array Scintillator]

--- **energy** and **position** of
scattered gamma ray

- Large FOV (~ 3 str)
- Kinematical background rejection by comparison of two α angles

Reconstruct incident gamma ray event by event

Energy dynamic range: from 0.1 to ~ 10 MeV

Vs. Conventional Compton Camera

Advanced

Our ETCC

Conventional

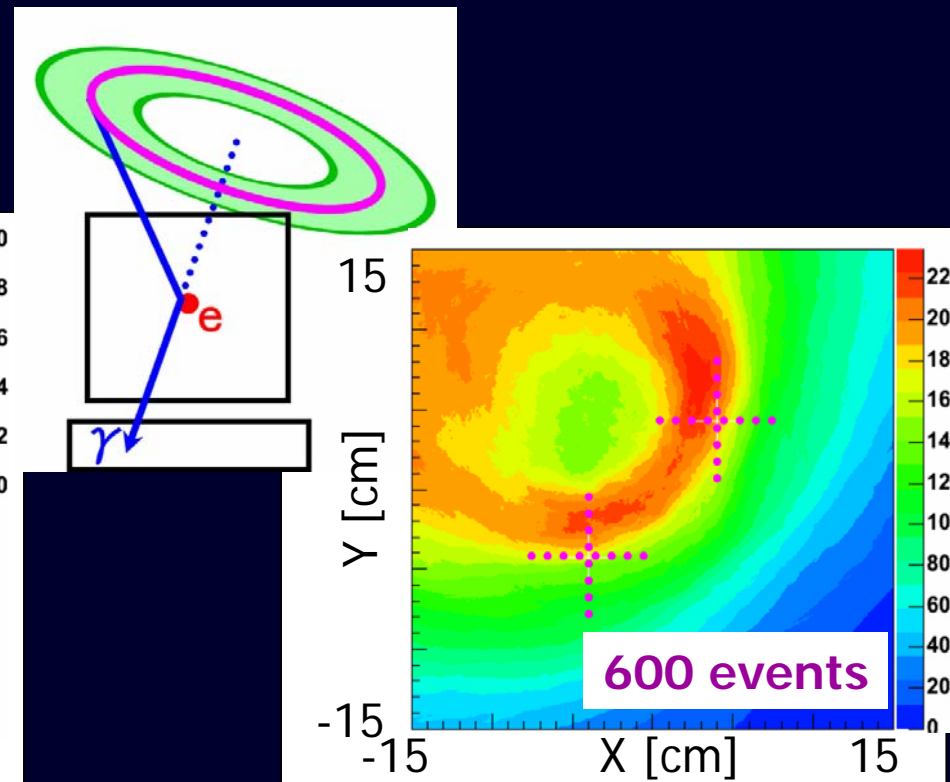
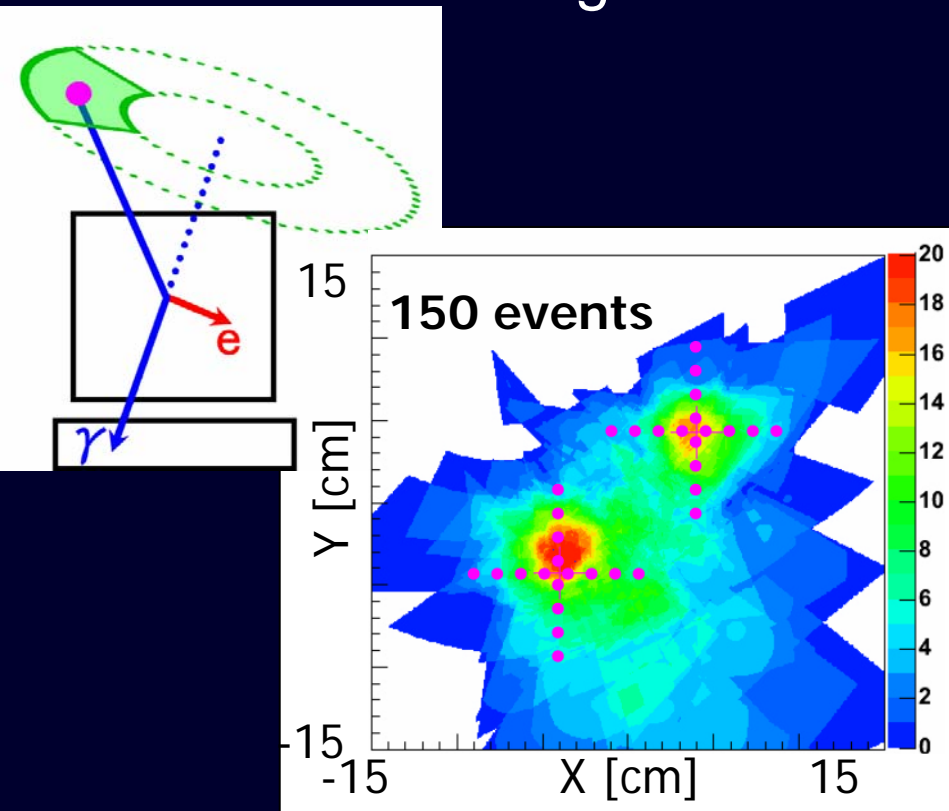
COMPTEL

Measure
the 3-D track of a Recoil electron

- Reconstruction : point
- Direction error region: arc

DO NOT measure
the track of a Recoil electron

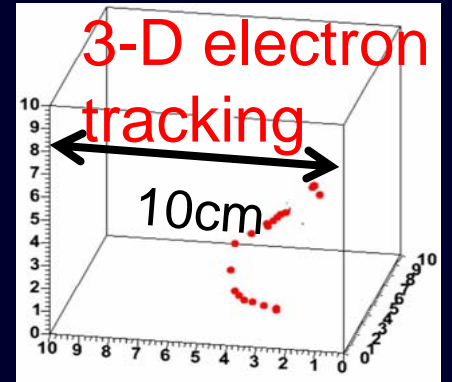
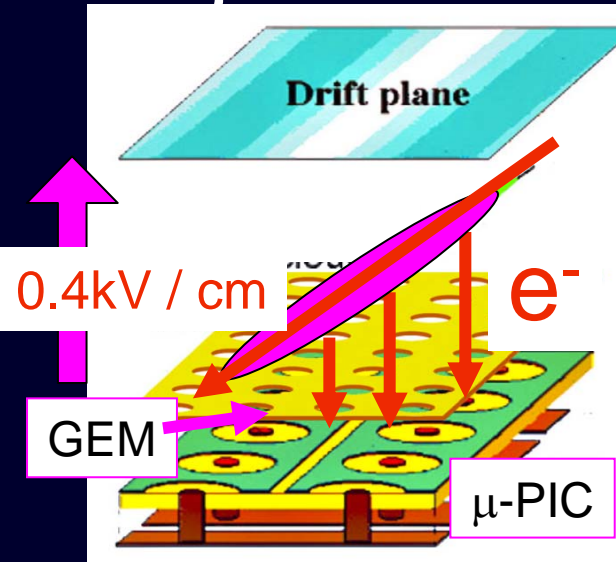
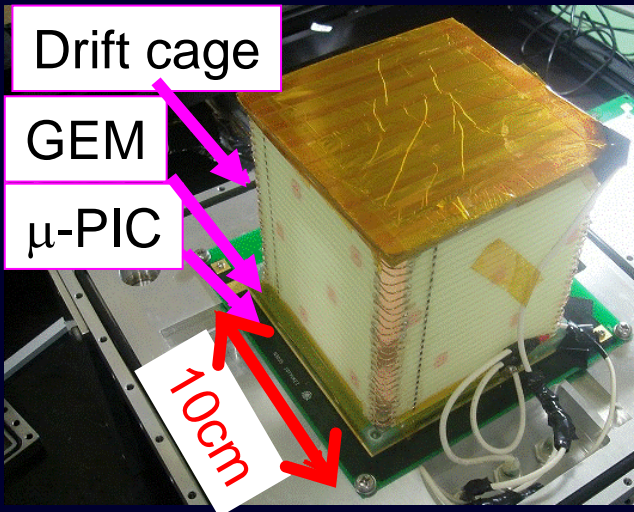
- Reconstruction : circle
- Direction error region : donut



$^{137}\text{Cs}(1\text{MBq})\times 2$, Advanced Compton

$^{137}\text{Cs}(1\text{MBq})\times 2$, Classical Compton

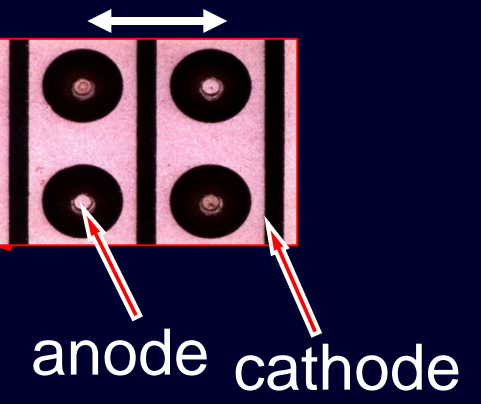
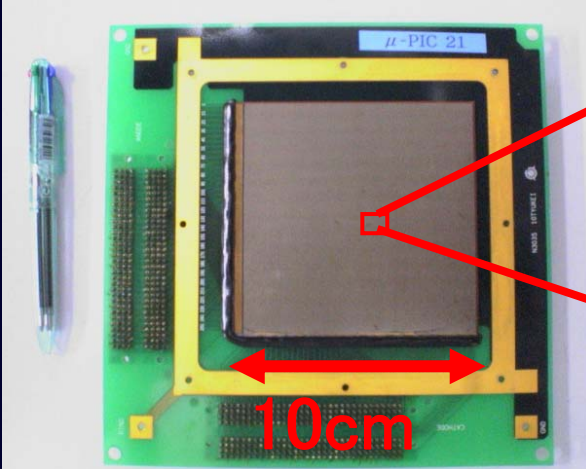
Gaseous Time Projection Chamber (TPC)



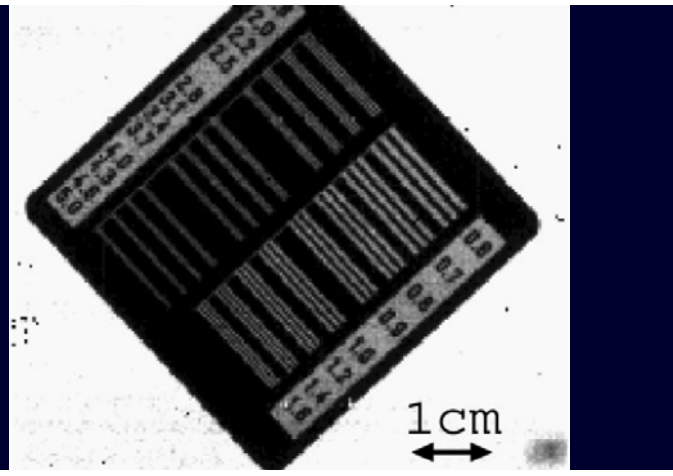
Gas gain: $\sim 30,000$
Position Resolution (FWHM): ~ 0.4 mm (3-D)

μ -PIC (micro pixel chamber)

➤ 2-D gaseous detector: $\sim 65,000$ pixels
400 μ m pitch



X-ray image with μ -PIC



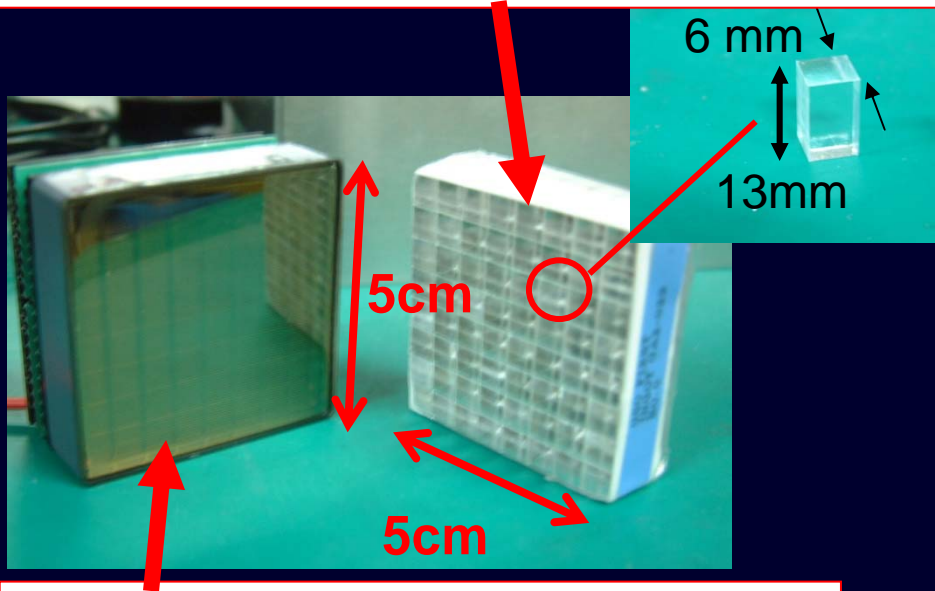
Position resolution: 120 μ m

Position-Sensitive Scintillation Camera

GSO(Ce) 8x8 pixels

Pixel size: 6x6x13mm³

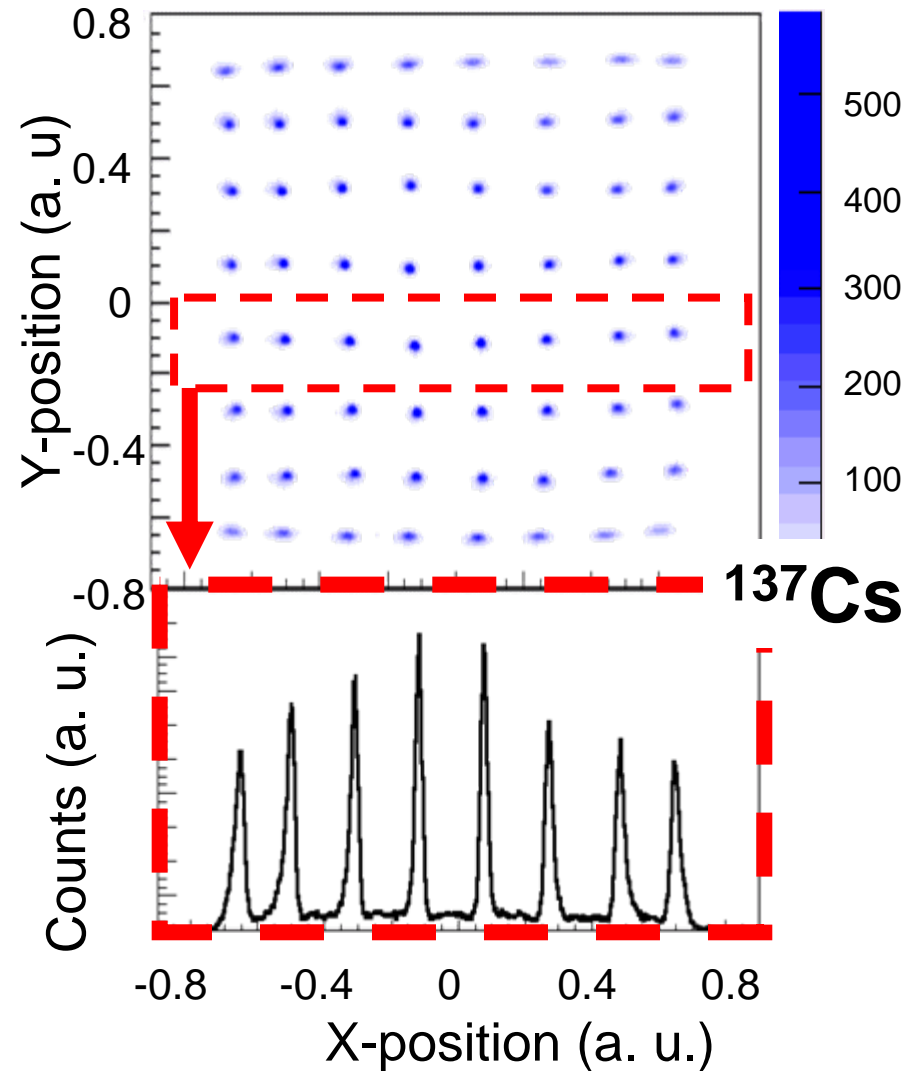
Reflector: ESR™ (3M) 65μm thickness



Multi-anode
Photo Multiplier Tube (PMT)
HPK H8500 8x8 anodes

Dynamic energy range: 0.08 -1 MeV

Eng. Resolution: 10.5 % @662 keV




2-D image in flood-field irradiation

SMILE Roadmap

SMILE Project *Sub-MeV gamma-ray Imaging Loaded-on-balloon Experiment*

(10cm)³ ETCC (2006) **SMILE-I**

- 
- Operation test of ETCC @ 35km
 - Measurement of Diffuse cosmic and atmospheric gamma rays ~ 3hours (live time)

(30cm)³ ETCC (2012) **SMILE-II**

Observation of Crab or Cyg X-1 ~ 3hours

(40cm)³ ETCC

long duration balloon ~ 10days

(50cm)³ ETCC All sky survey

Orbiting balloon (~30days) or satellite

SMILE-I Flight Model

GSO scintillator

3x3PMTs@bottom
4x(3x2)PMTs@side

(10cm)³-
size TPC

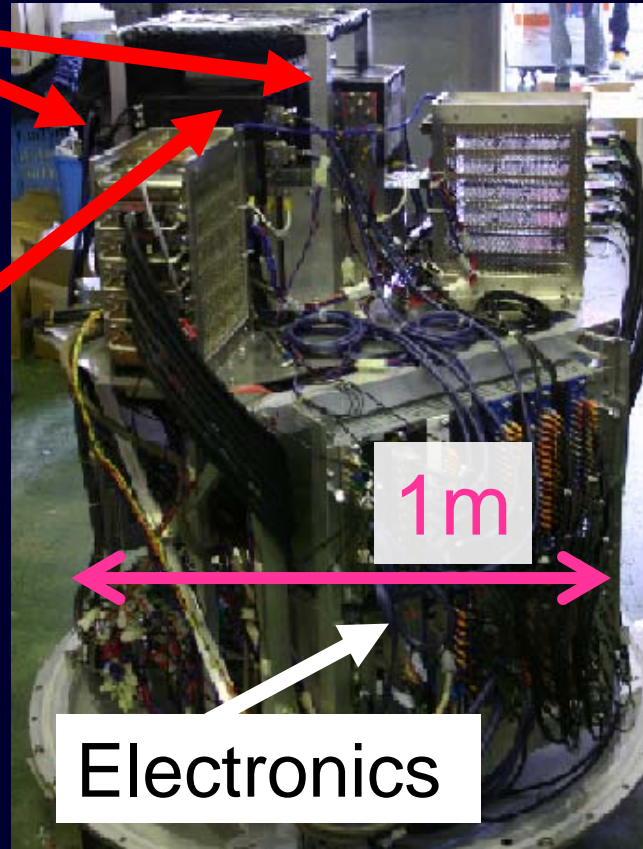
gas:

Xe(80%)+

Ar(18%)+

C₂H₆(2%)

1atm, sealed



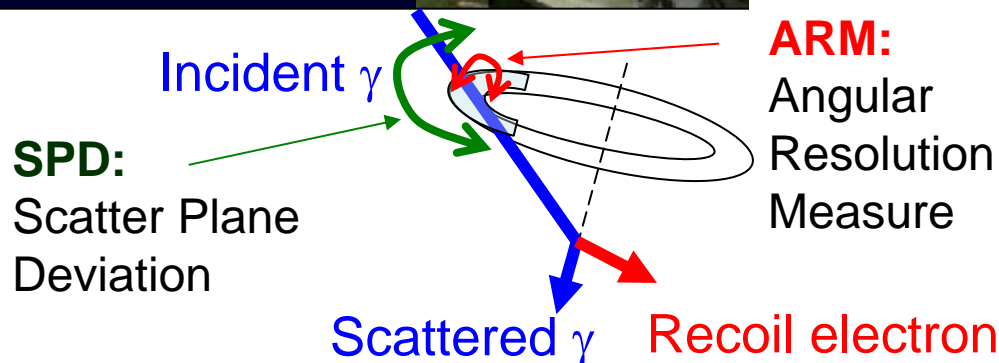
❖ Dynamic energy
Range: 0.15 – 1 MeV

❖ Field of view (FOV):
3 str (FWHM)
(0.15 - 1 MeV)

❖ Efficiency:
 $\sim 10^{-4}$ @ 0.15 – 1 MeV

❖ Energy resolution
(ETCC): $\sim 12\%$
@ 662 keV, FWHM

❖ Angular resolution
ARM: 22 deg.
SPD: 165 deg.
@ 662 keV, FWHM



SMILE-I Flight Model

GSO scintillat

3x3PMTs@bottom
4x(3x2)PMTs@side

(10cm)³-
size TPC

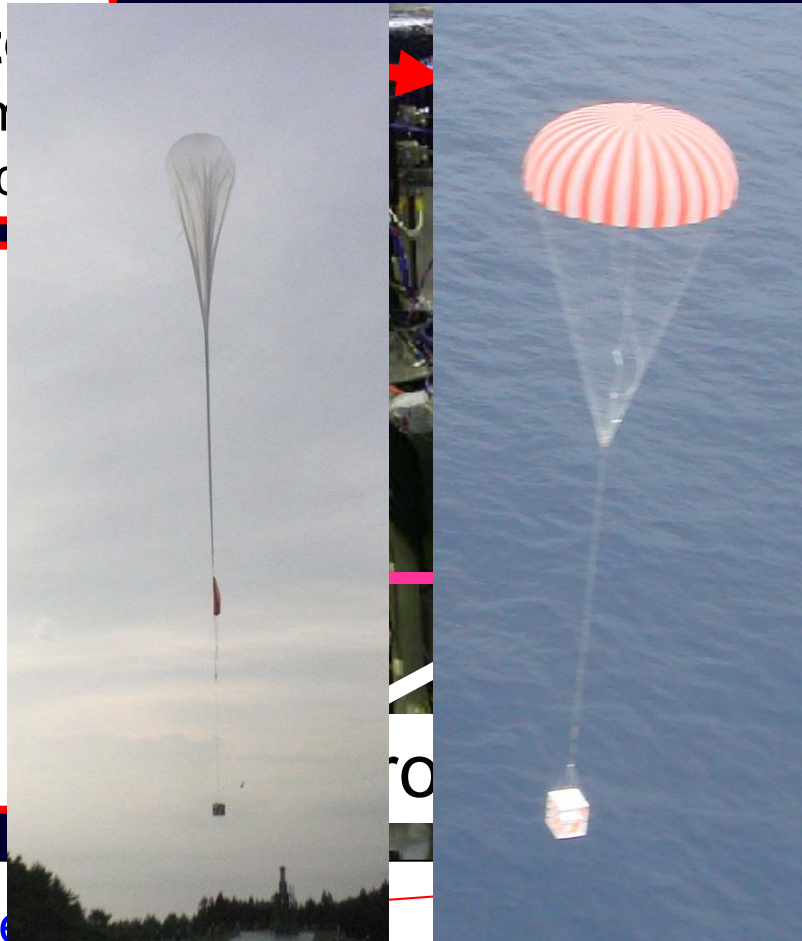
gas:

Xe(80%)+

Ar(18%)+

C₂H₆(2%)

1atm, sealed



❖ **Dynamic energy**
Range: 0.15 – 1 MeV

❖ **Field of view (FOV):**
3 str (FWHM)
(0.15 - 1 MeV)

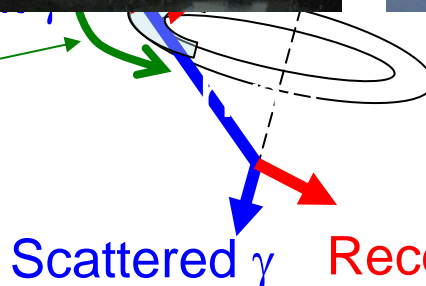
❖ **Efficiency:**
~10⁻⁴ @ 0.15 – 1 MeV

❖ **Energy resolution**
(ETCC): ~12%
@ 662 keV, FWHM

❖ **Angular resolution**
ARM: 22 deg.
SPD: 165 deg.
@ 662 keV, FWHM

SPD:
Scatter Plane
Deviation

Incident γ

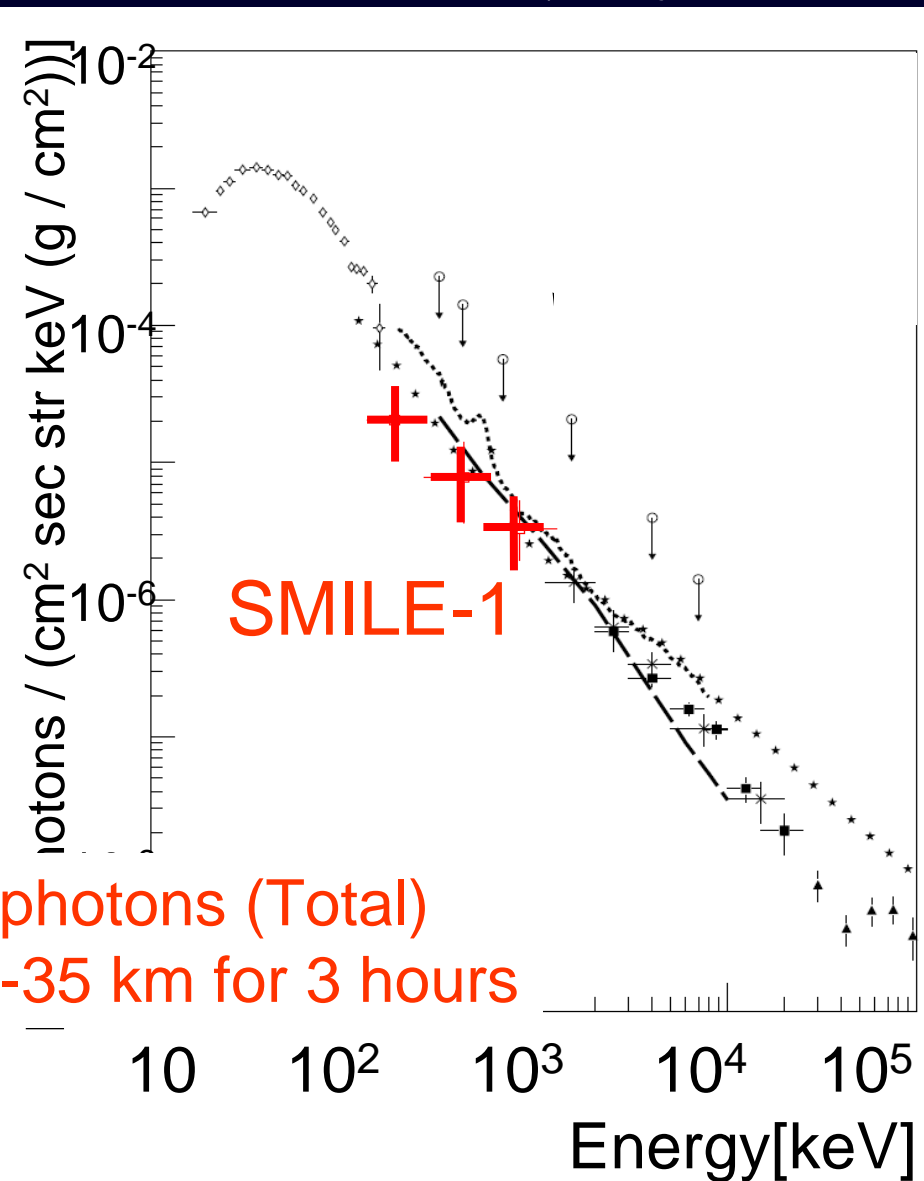
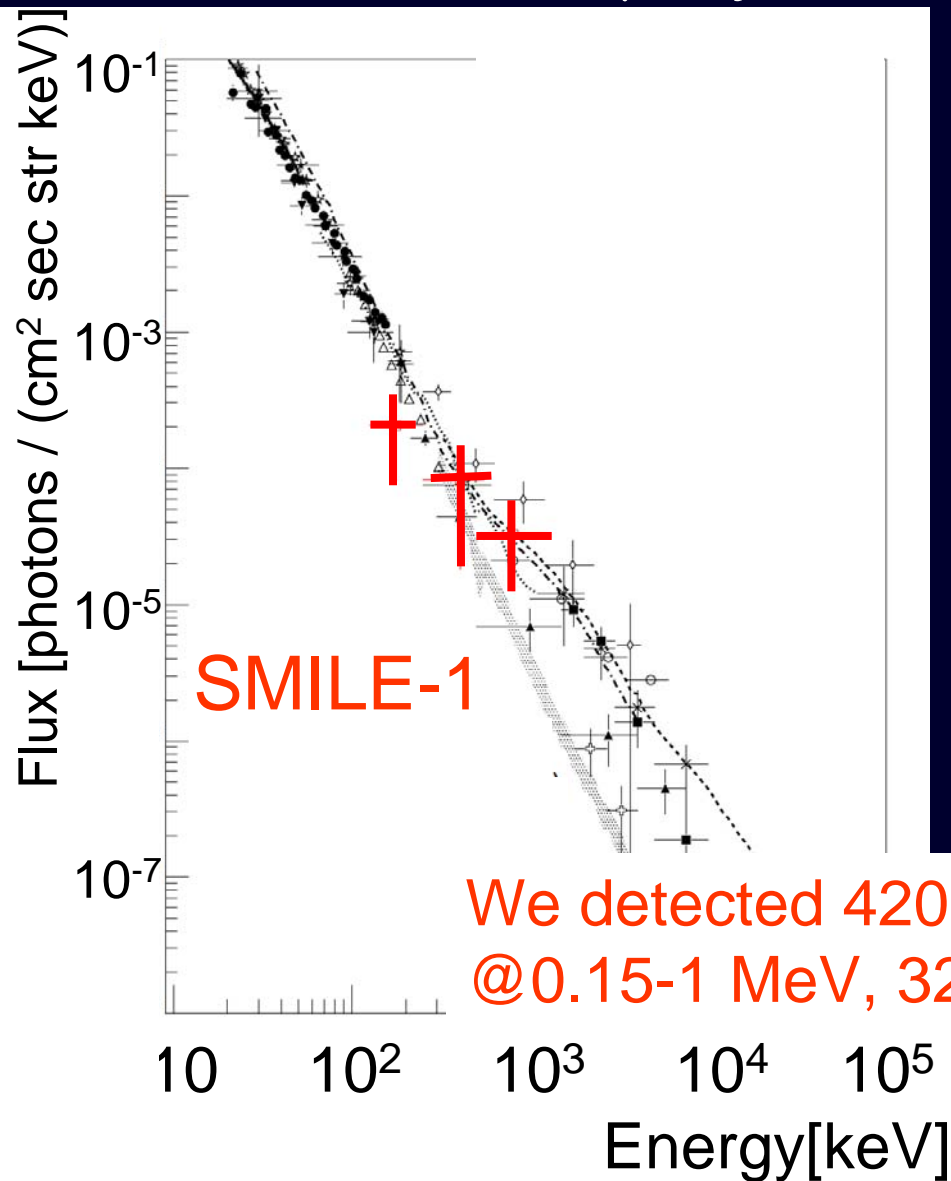


Angular
Resolution
Measure

Energy spectrum

diffuse cosmic γ rays

atmospheric γ rays



We detected 420 photons (Total)
@0.15-1 MeV, 32-35 km for 3 hours

$(30\text{ cm})^3$ ETCC for SMILE-II

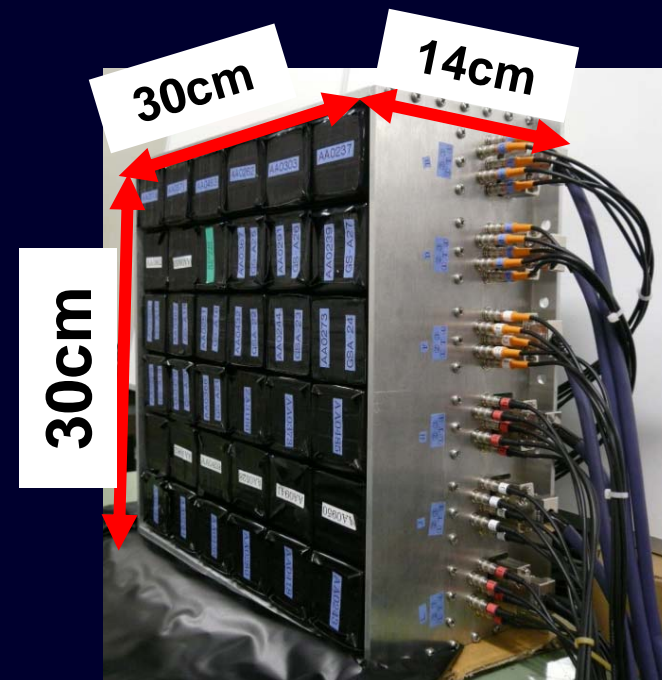
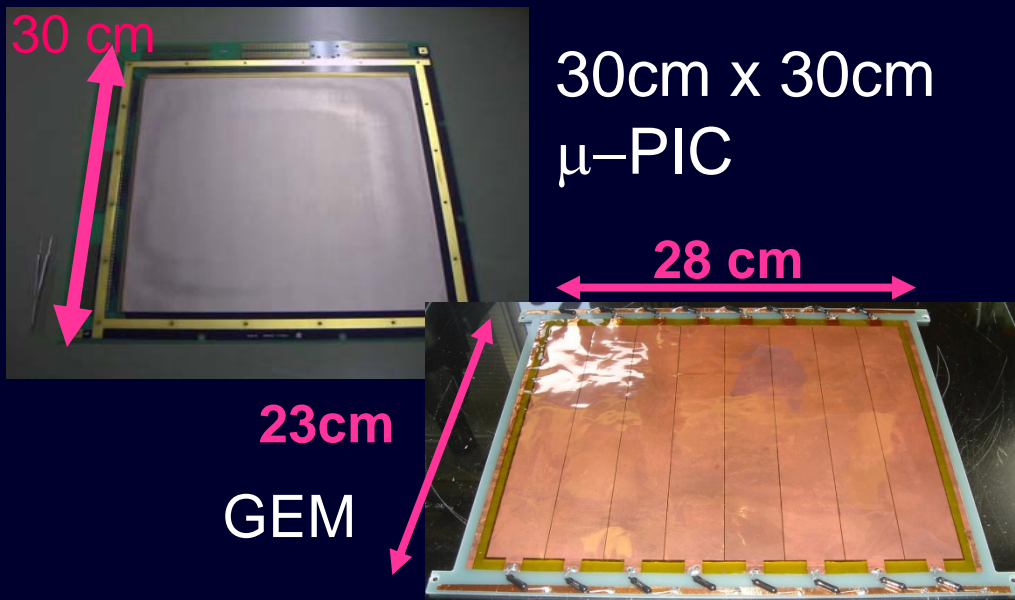
Test model of $(30\text{ cm})^3$ ETCC

gaseous TPC

- volume : $30 \times 30 \times 30\text{ cm}^3$
- gas : Ar 90% + C_2H_6 10%
1atm
- energy resolution : 46% @ 32keV
- position resolution: $400\ \mu\text{m}$

scintillation camera

- crystal : GSO(Ce)
- number of pixels : 2304
- pixel size : $6 \times 6 \times 13\text{mm}^3$
- energy resolution : 10.9%
(@662keV, FWHM)
- position resolution : 6mm



$(30\text{ cm})^3$ ETCC for SMILE-II

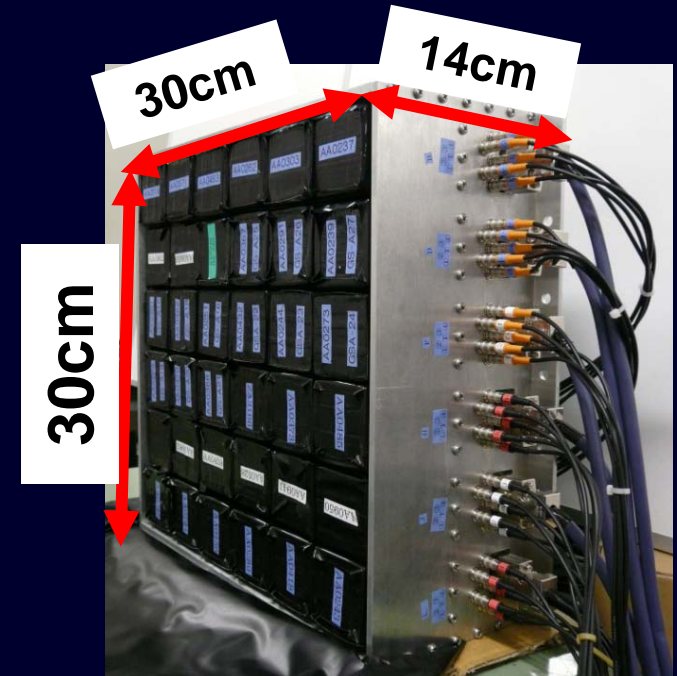
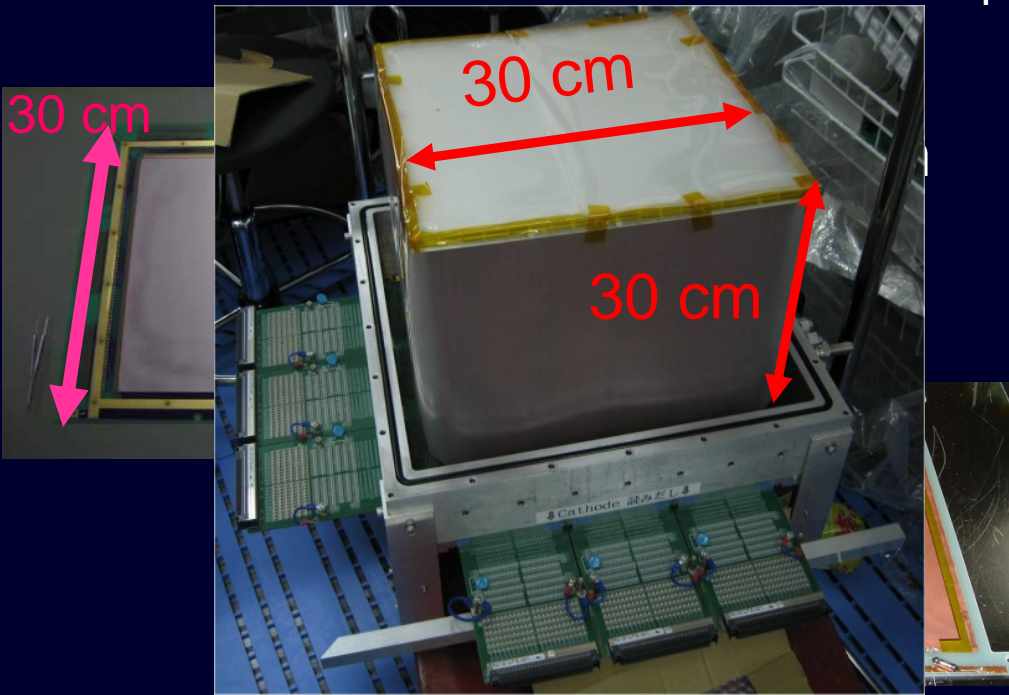
Test model of $(30\text{ cm})^3$ ETCC

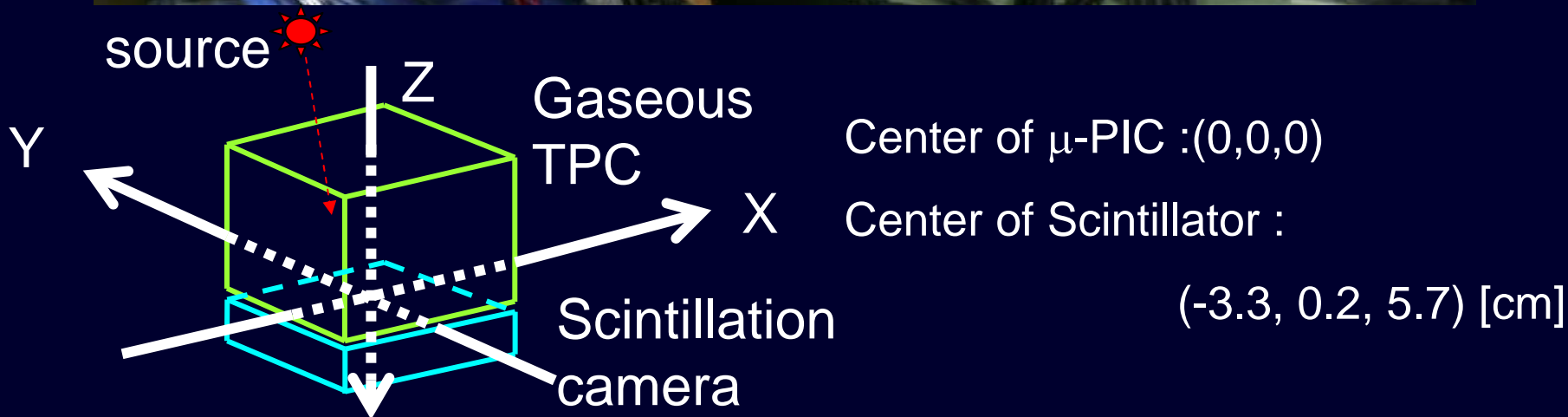
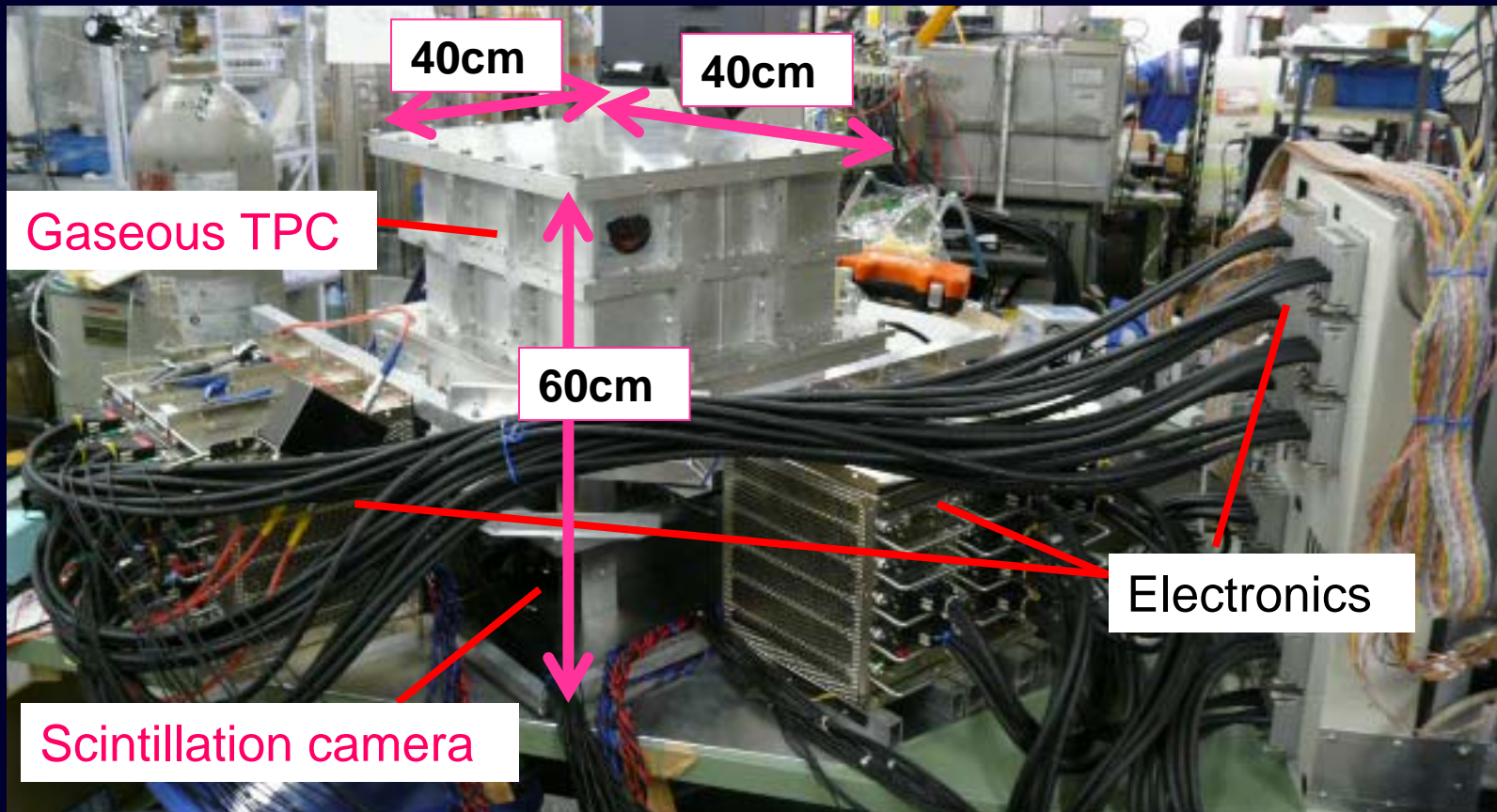
gaseous TPC

- volume : $30 \times 30 \times 30\text{ cm}^3$
- gas : Ar 90% + C_2H_6 10%
1atm
- energy resolution : 46% @ 32keV
- position resolution: $400\ \mu\text{m}$

scintillation camera

- crystal : GSO(Ce)
- number of pixels : 2304
- pixel size : $6 \times 6 \times 13\text{mm}^3$
- energy resolution : 10.9%
(@662keV, FWHM)
- position resolution : 6mm





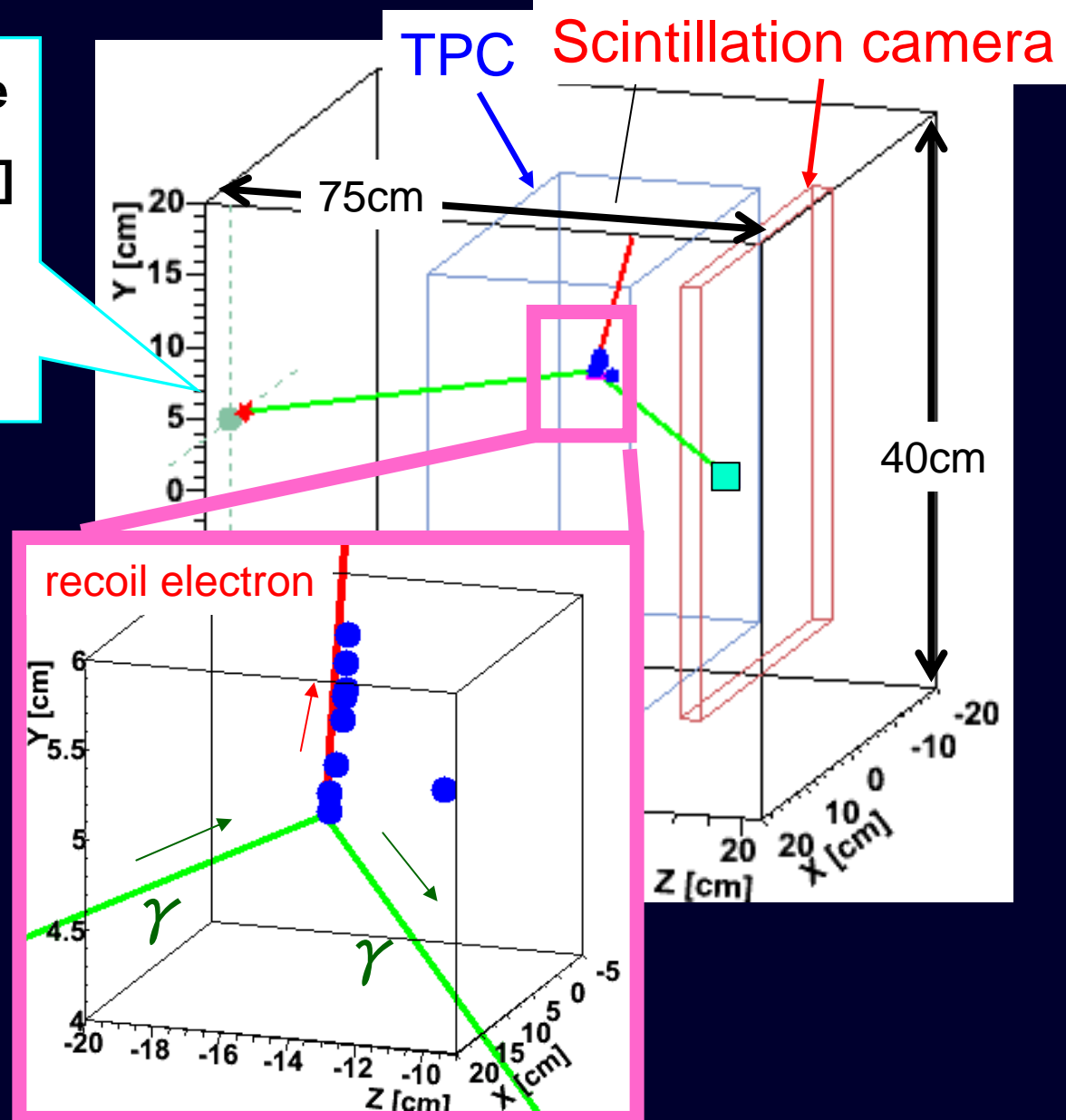
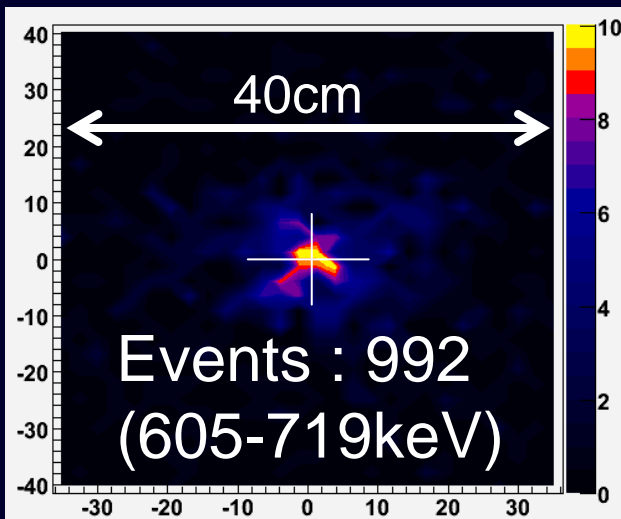
Point source Imaging (preliminary)

^{137}Cs (662keV) source
(X,Y,Z) = (0,0,-52) [cm]

★ reconstructed position

● : electron hit

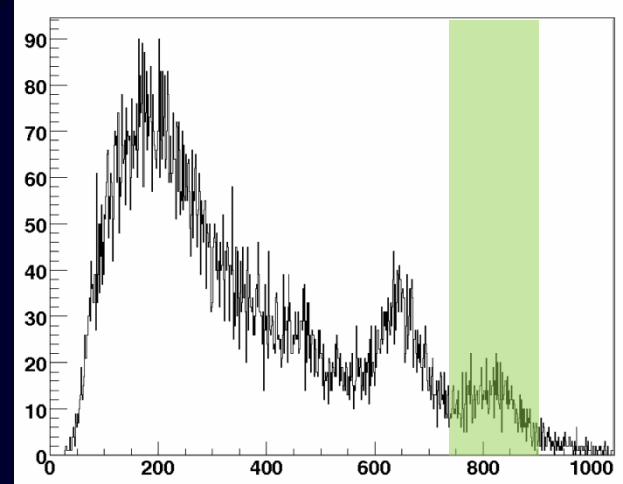
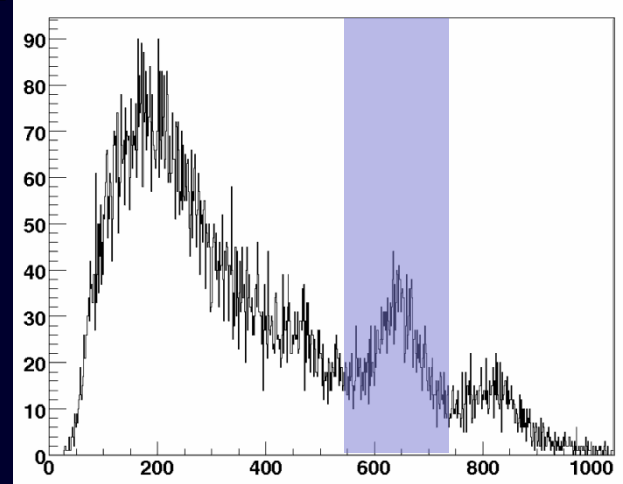
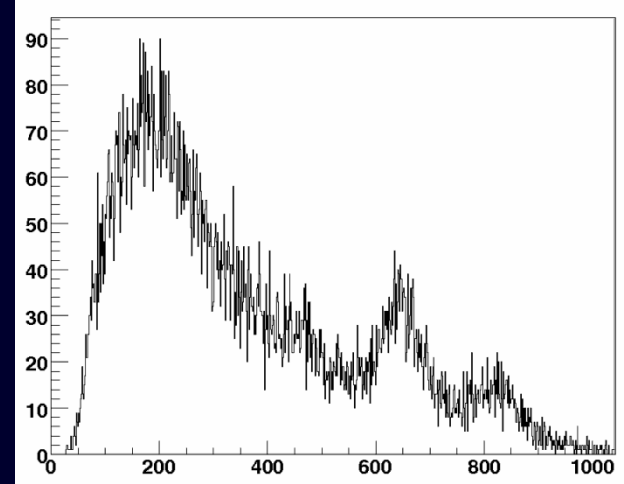
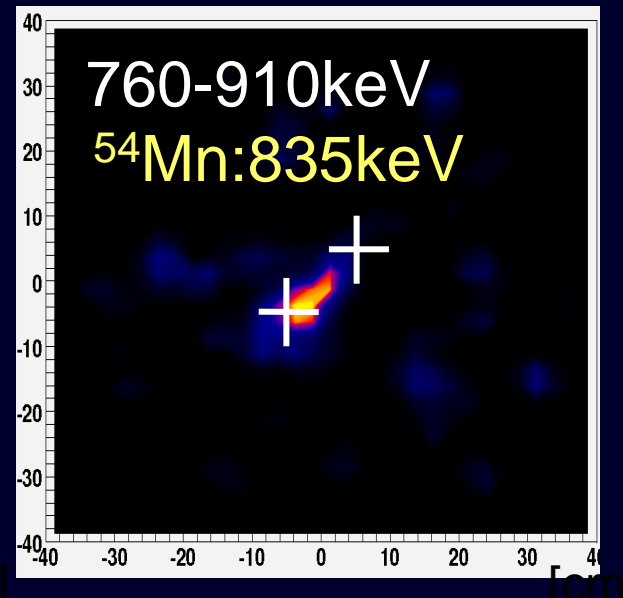
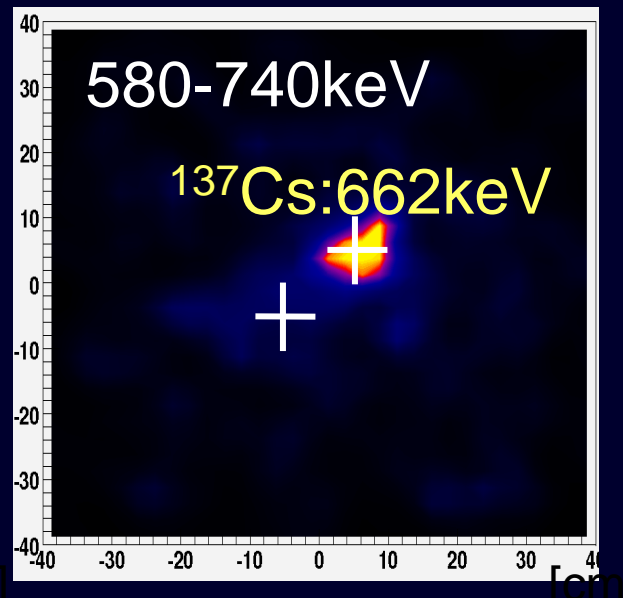
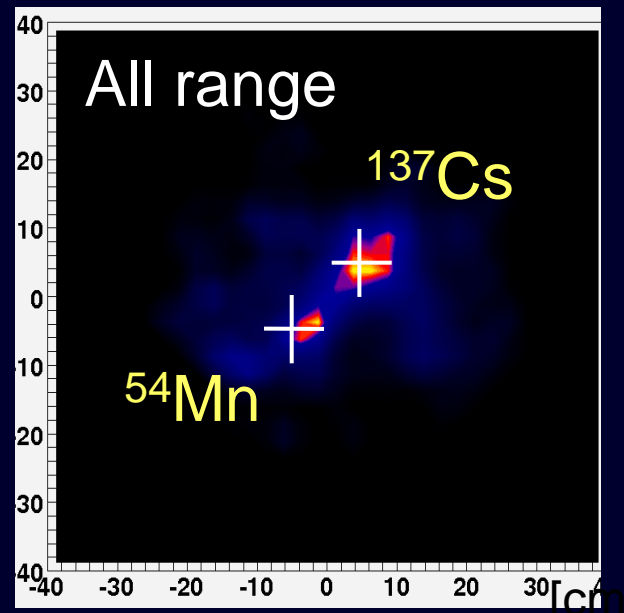
■ : scintillator hit



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]

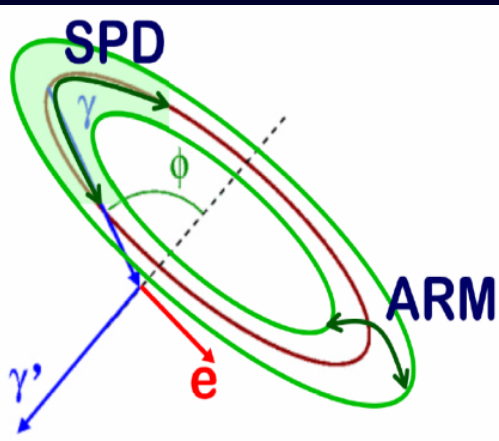
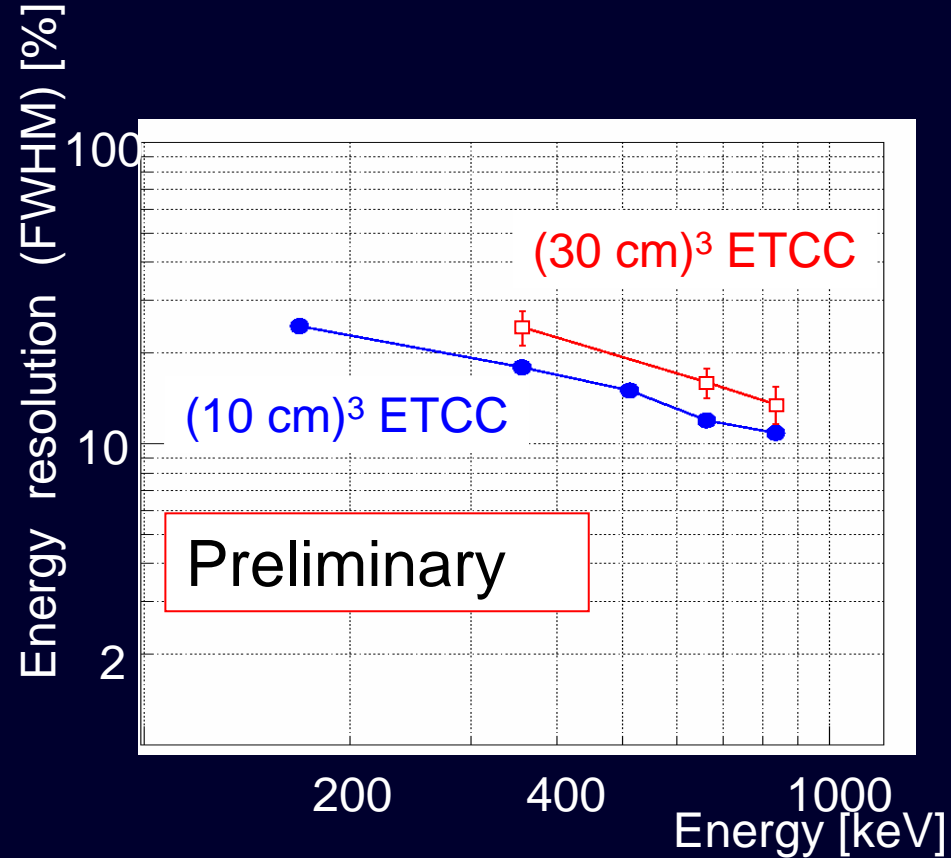
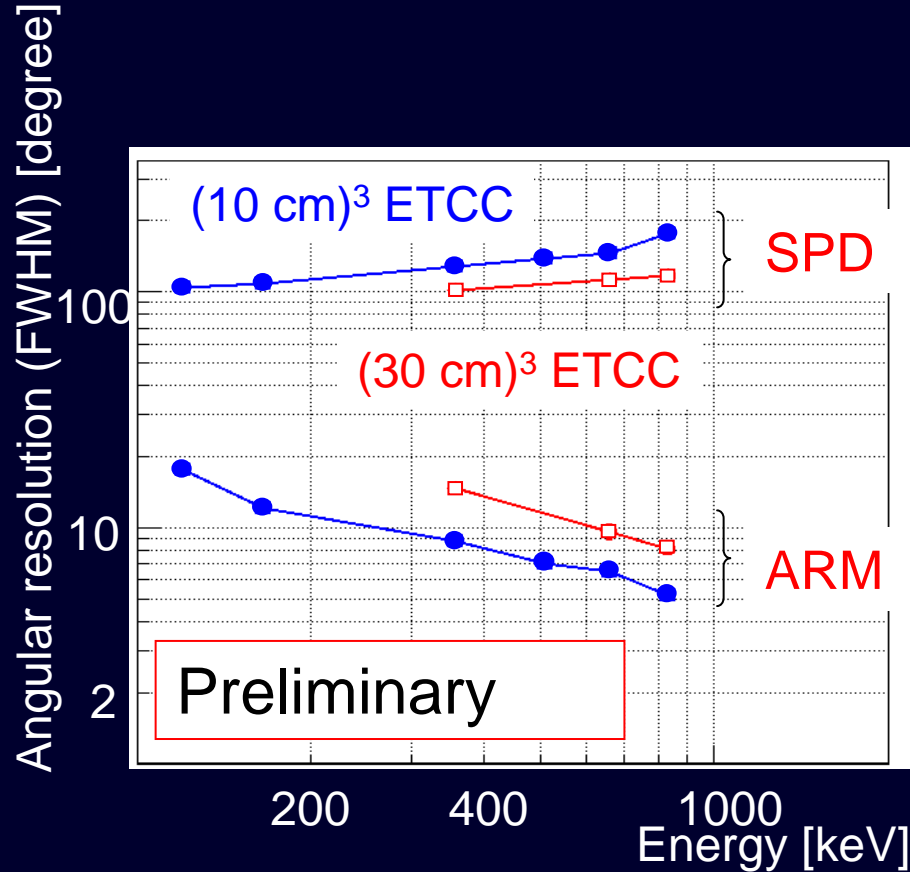


Energy [keV]

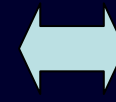
Energy [keV]

Energy [keV]

Angular and Energy resolutions



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



130[deg]
 6.6[deg]
 12.0%

(10cm)³ETCC

Saving power consumption of the readout

SMILE-I The power of readout system

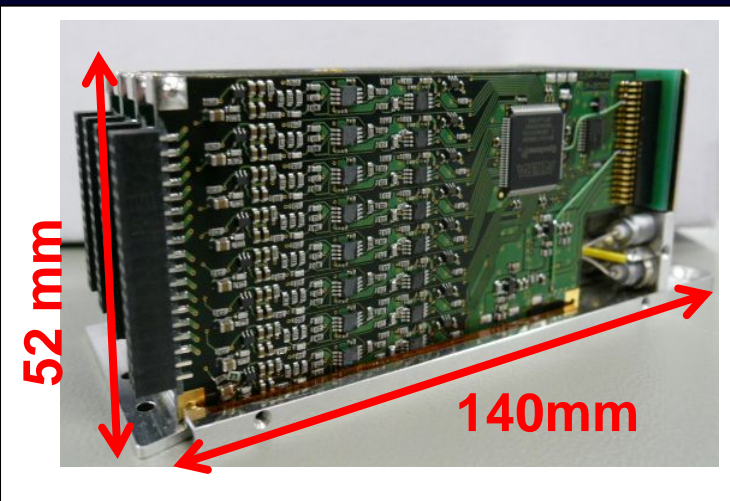
SMILE-II

33 PMTs : ~80 W (~30 % of all system)
 (10 cm)³ μ -PIC (1024ch) : ~70 W



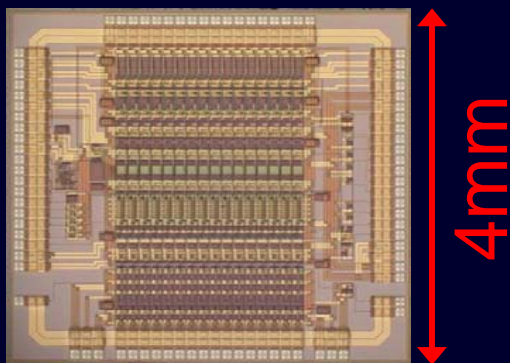
~200 PMTs
 (30 cm)³ μ -PIC (1536ch)

➤ For scintillation camera (CP80190 Clear Pulse)



	GSO array $\Delta E / E$ (FWHM @ 662 keV)	Power (/PMT)
SMILE-I system	11 %	2700 mW
New system (SMILE-II)	10.5 %	100 mW

➤ ASIC for gaseous TPC with a 0.5 μ m-CMOS Collaborator: M. Tanaka, and Y. Fujita (KEK)



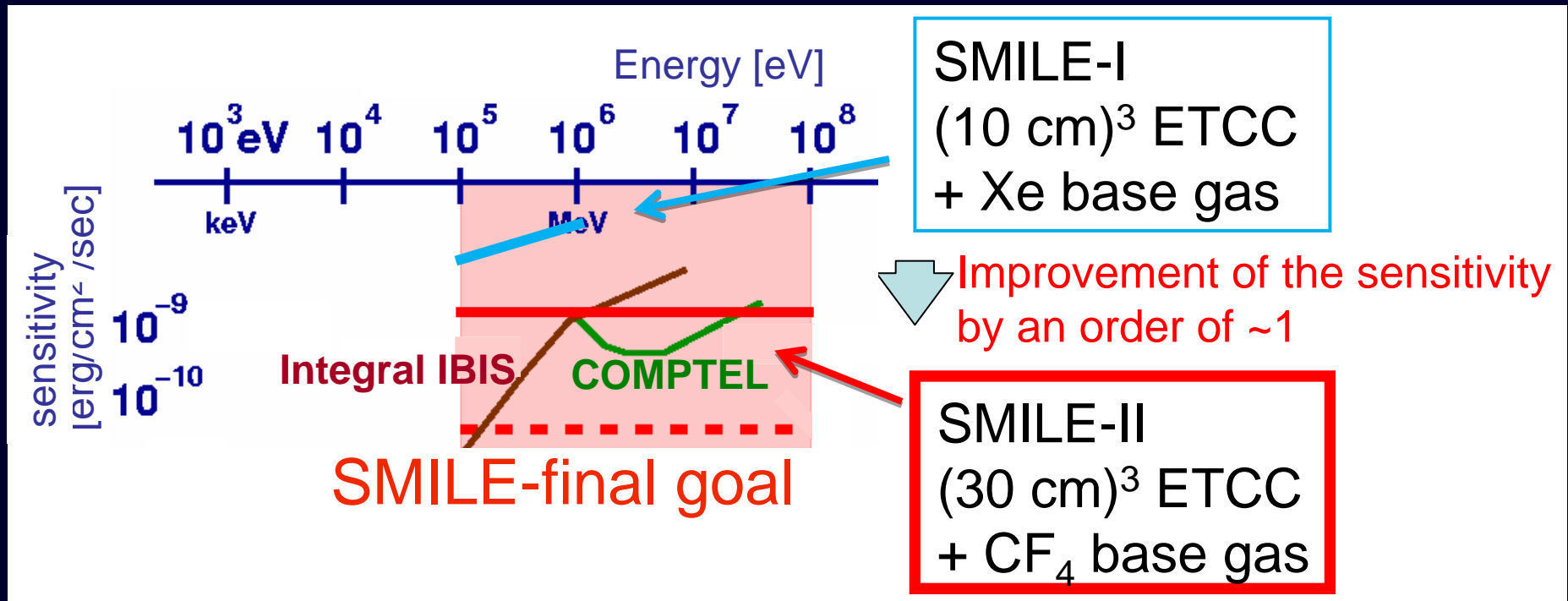
	TPC $\Delta E / E$ (FWHM @ 22 keV)	Power (/ch)	ch # (/chip)
SMILE-I	~ 20 %	59 mW	4
New	~ 20 %	18 mW	16

Gas study & Sensitivity

Gas	Pressure	ARM (FWHM) @356keV *	Efficiency @356 keV**
SMILE-I Xe/Ar/C ₂ H ₆ (80:18:2)	1 atm	24.1 ± 1.0°	1.0
Ar/CF ₄ /isoC ₄ H ₁₀ (54:40:6)	1.4 atm	11.2 ± 0.3°	1.0

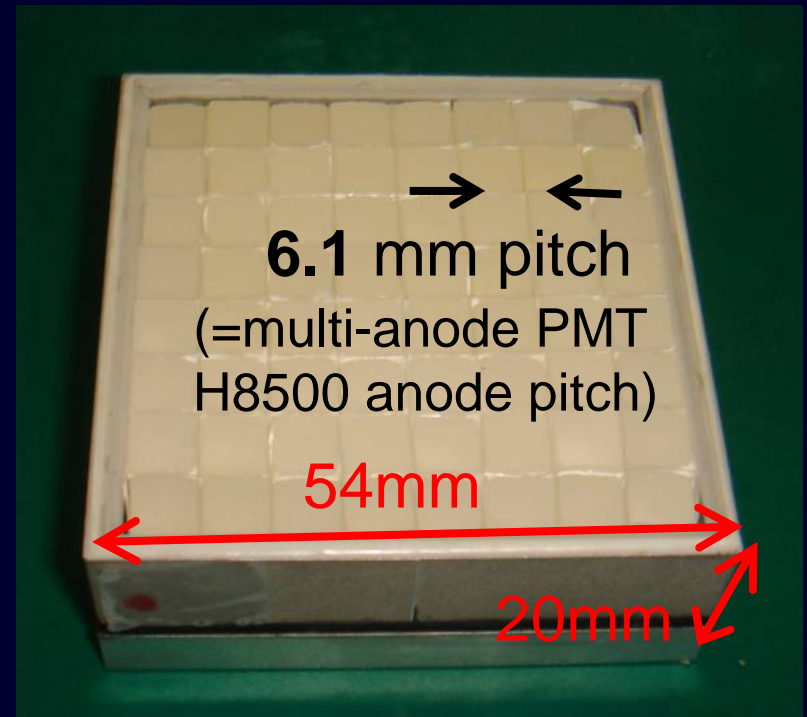
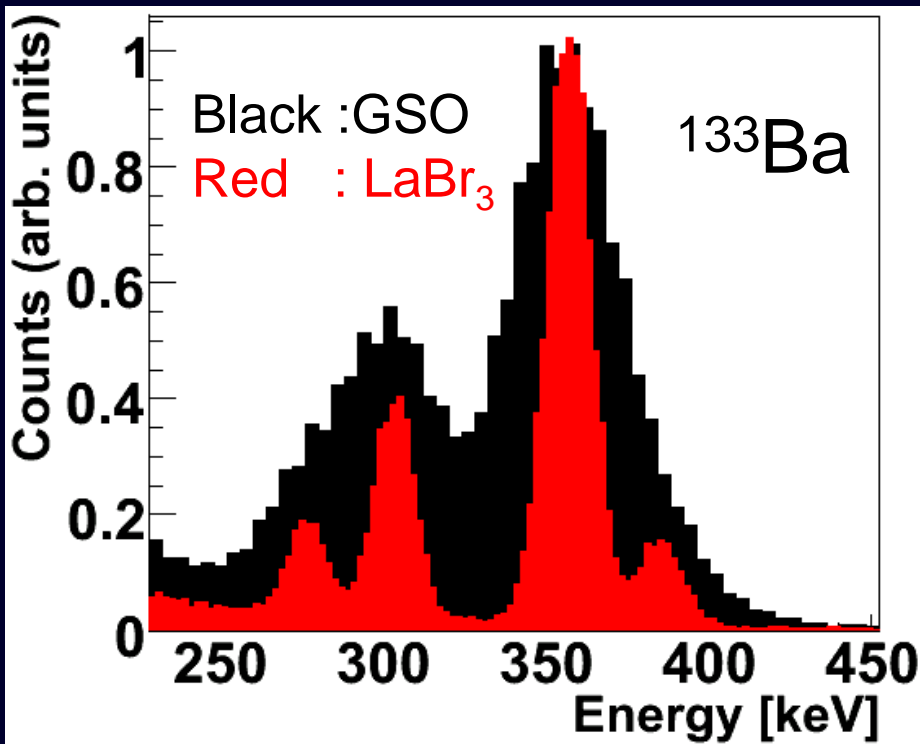
*Measured with (10 cm)³ ETCC

**simulated results, normalized to SMILE-I



Post SMILE-II (SMILE-III)

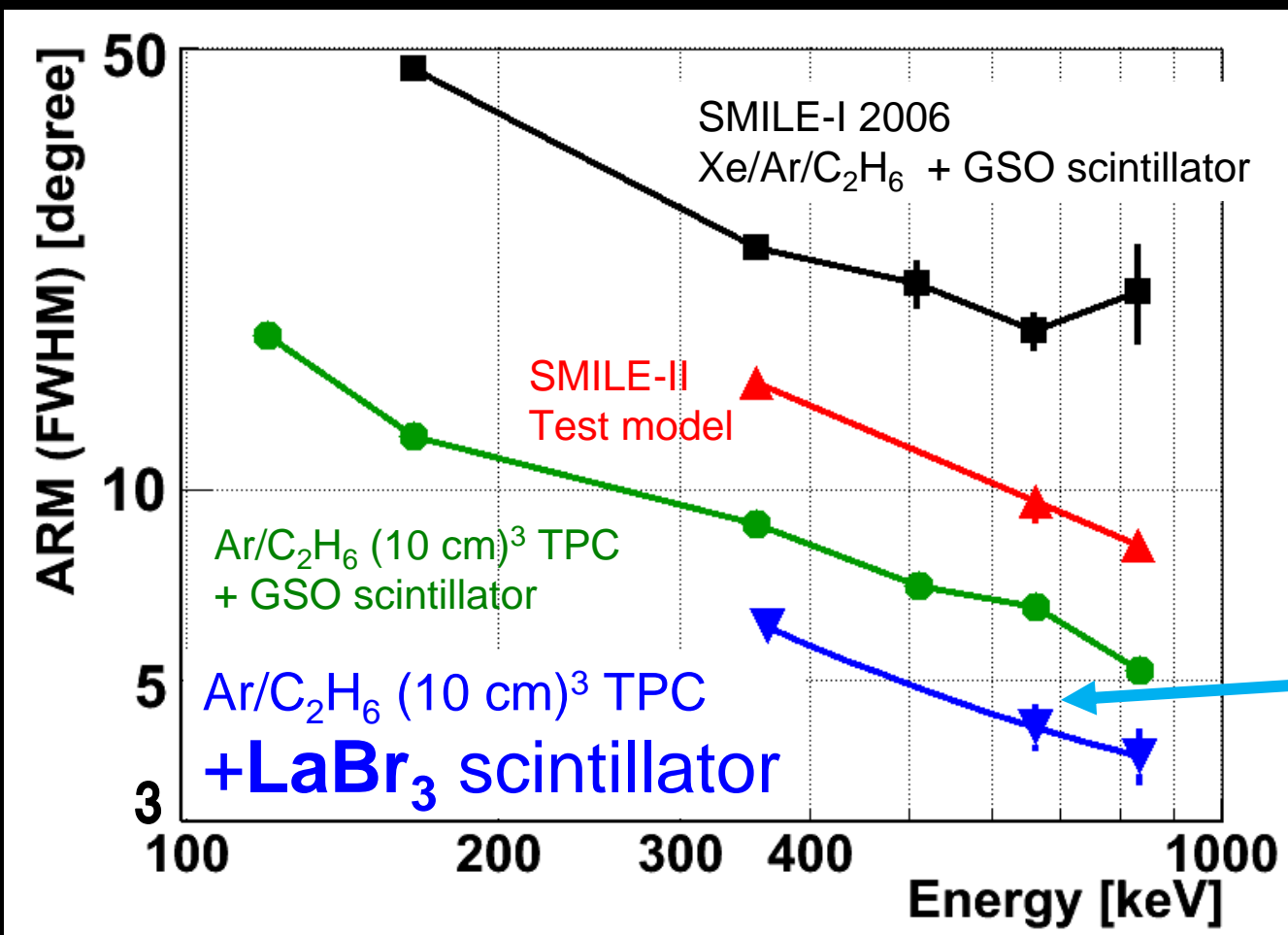
To obtain a higher angular resolution
Angular resolution of the Compton camera
depends on the energy resolution of scintillator



Energy spectrum of monolithic crystal
using a single anode PMT R6231 (Hamamatsu)

To obtain a higher angular resolution

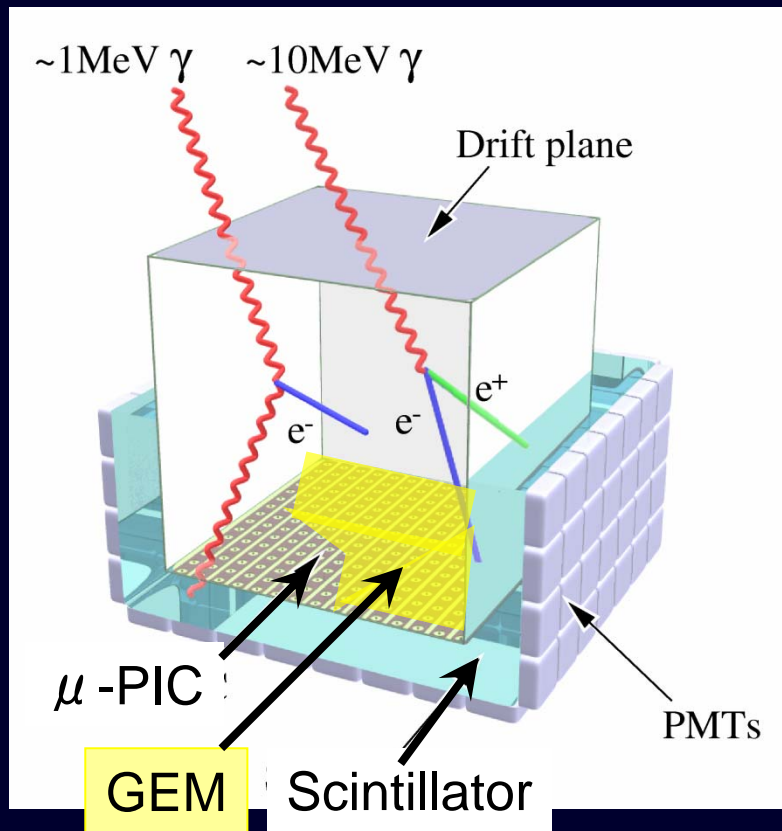
Angular resolution of the Compton camera depends on the energy resolution of scintillator



ARM (FWHM)
@662 keV

4.2 ± 0.3 deg.
(w/ LaBr₃)

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.To yokawa (Advanced Industrial Science and Technology: AIST, Japan)

Summary

- SMILE-II with $(30\text{ cm})^3$ Electron-Tracking Compton Camera
 - $(30\text{ cm})^3$ ETCC : test model
 - Angular resolutions (FWHM @ 662 keV)
ARM : 9.6 deg. SPD : 113 deg.
 - Energy resolution (FWHM @ 662 keV) 16.0 %
 - New readout system to save power consumption
 - Scintillation camera : 2700 \rightarrow 100 mW/PMT
 - Gaseous TPC : 59 \rightarrow 18 mW/ch
 - Gas study using $(10\text{ cm})^3$ ETCC
 - Ar/CF₄/isoC₄H₁₀ (54:40:6) 1.4 atm + GSO
Improvement of ARM (@ 356 keV) by $\sim 1/2$ than SMILE-I.
- We are developing the Flight model of SMILE-II
- For SMILE-III
- LaBr₃ scintillator installed $(10\text{ cm})^3$ ETCC,
ARM (FWHM @ 662 keV) : 4.2 ± 0.3 deg.
 - pair-creation mode
 - $(40\text{ cm})^3$ size detector etc.