SMILE project and the current status

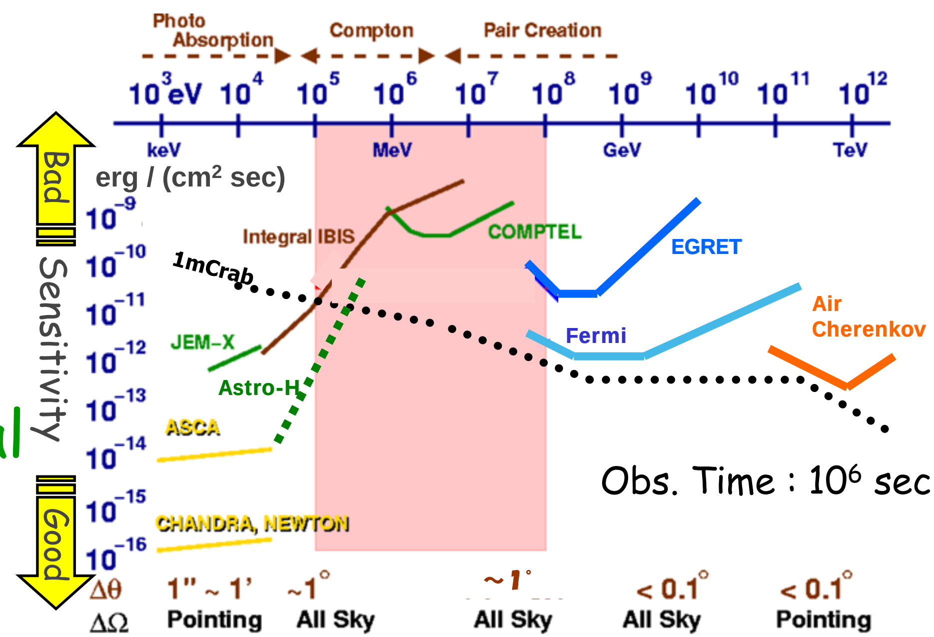
A. Takada (Kyoto Univ.)

1. MeV gamma ray Imaging & ETCC
2. Results of SMILE-I
3. Preparations of SMILE-II

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 …

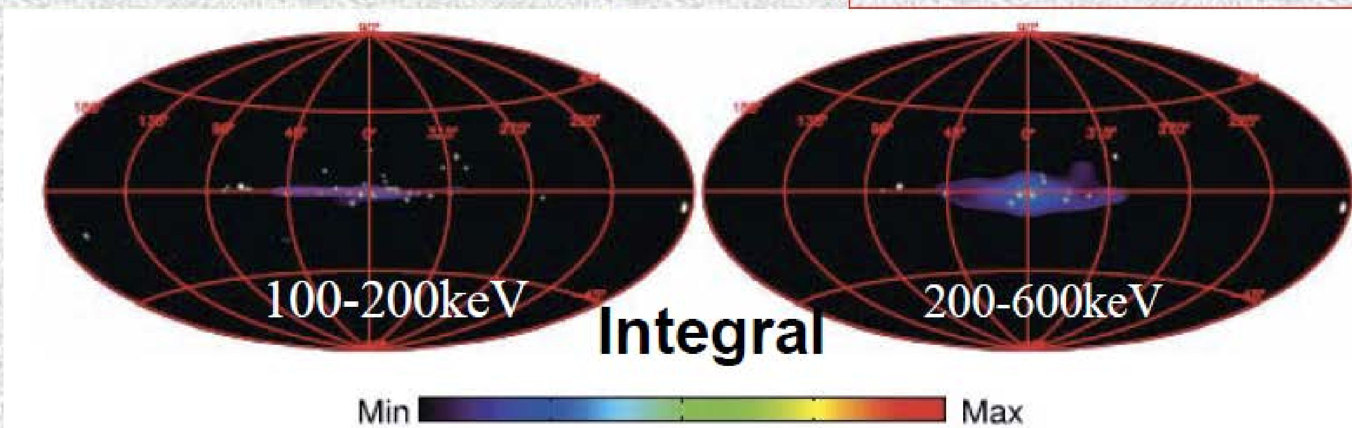
- Wide-band detection
- Large Field of View
- Background rejection

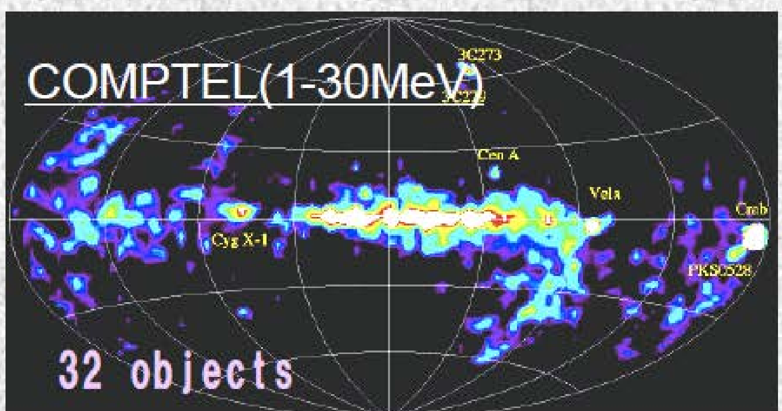
Sky Map of MeV Gamma rays

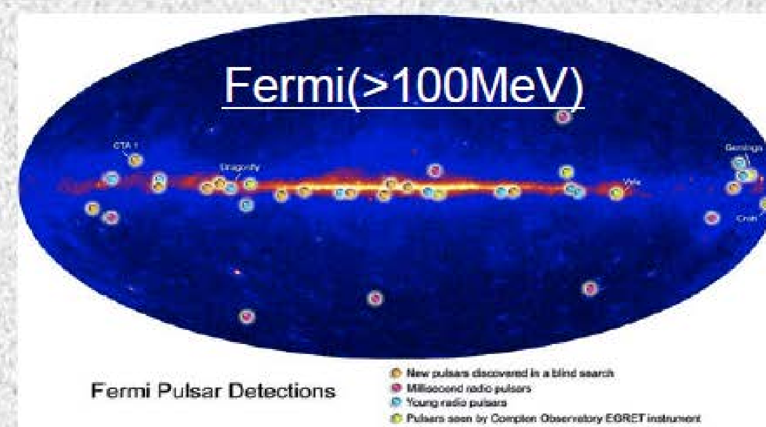
COMPTEL(1-30MeV) 32 objects

AGN 10
Line Emissions from SNR 7
Crab 1 γ-Pulsar 3
B.H.Candidates 2,
UnID 9

Integral Point Sources
25-50keV 173
50-100keV 79 (>3.5σ)
100-200keV 30(>2.5σ)
200-600keV 12
>600keV 4

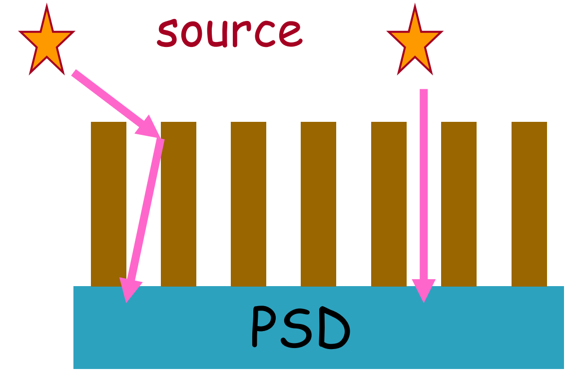




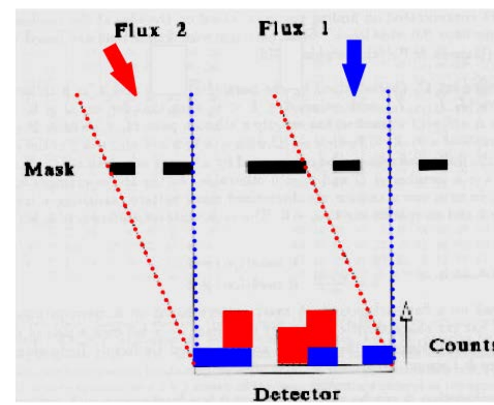


MeV gamma-ray imaging

- Collimator + position-sensitive detector
  - ⇒ OSSE (*CGRO*)
  - narrow FOV
  - background from collimator
  - Energy < 1MeV

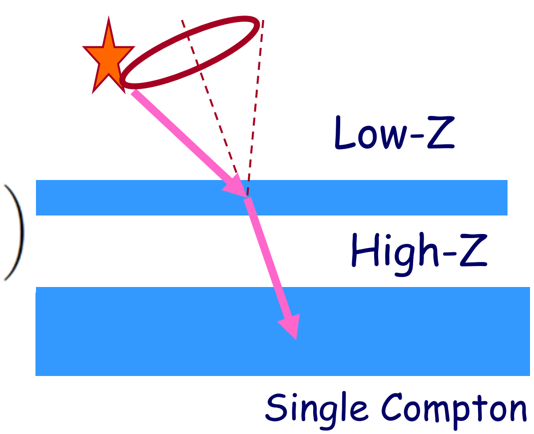


- Coded Aperture Imaging
  - ⇒ BAT (*SWIFT*), SPI (*INTEGRAL*)
  - wide FOV & good angular resolution
  - photons from outside of mask are background
  - imaging of the spread sources is difficult
  - Energy < 1MeV



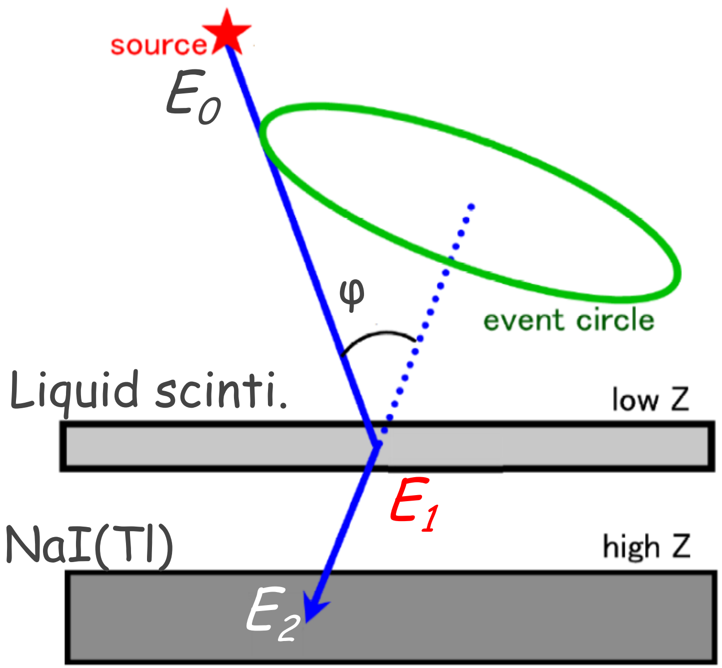
- Laue Lens
  - narrow FOV & good angular resolution
  - mono-energy
- Compton imaging
  - ⇒ COMPTEL (*CGRO*)
  - wide Energy band
  - only event circle
  - no background rejection

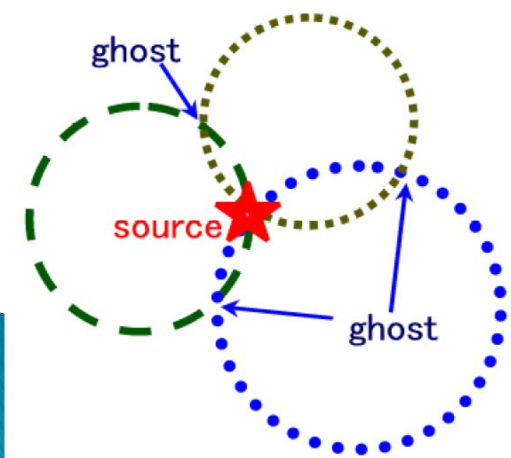
$$\cos\phi = 1 - m_e c^2 \left(\frac{1}{E_2} - \frac{1}{E_1 + E_2} \right)$$



⇨ A new method with satisfying requirements

COMPTEL (CGRO:1991～2000)





Using Compton Scattering

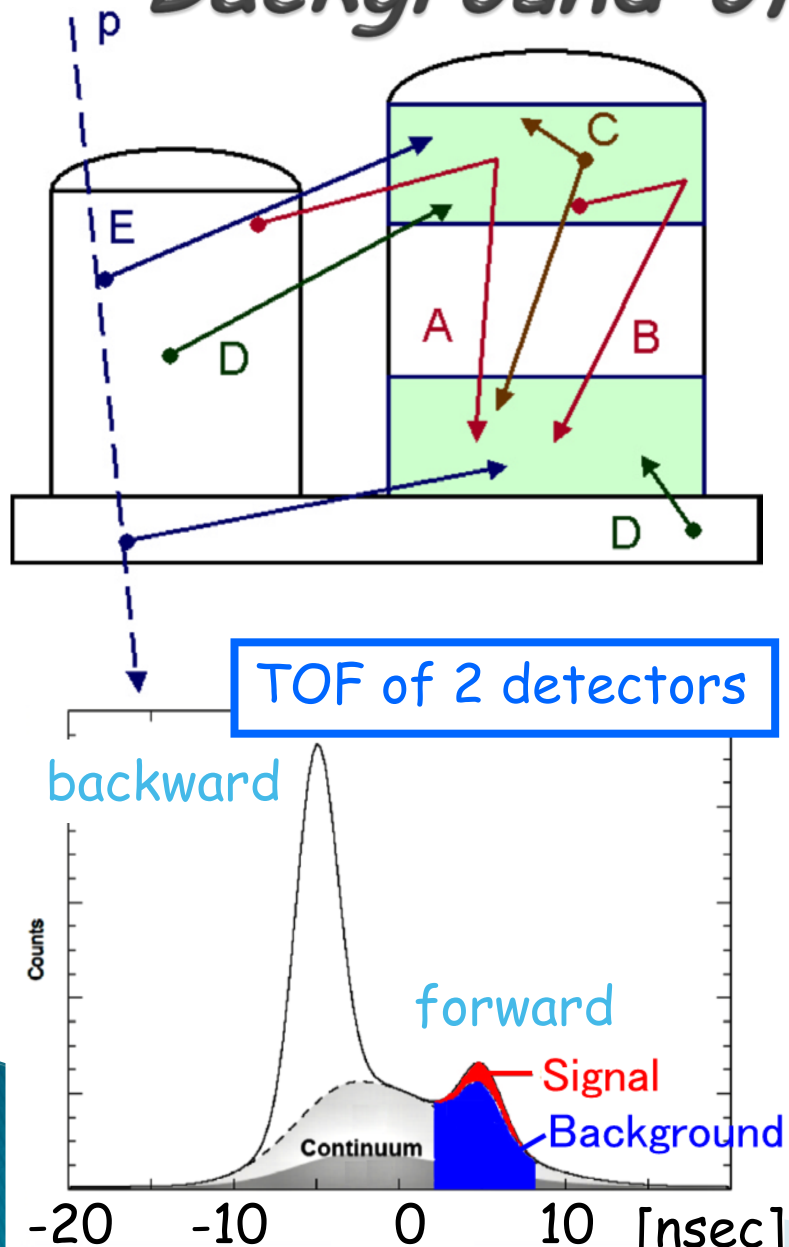
- energies of scattered gamma and recoil electron
  → Energy of incident gamma
  Scattering angle

$$\cos\phi = 1 - m_e c^2 \left(\frac{1}{E_2} - \frac{1}{E_1 + E_2} \right)$$

- Compton scattering point & Absorption point
  → Direction of scattered gamma
- ignore the direction of recoil electron

➢ Restrict the direction of incident gamma-ray to a circle
➢ The source position is determined fully by piling up circles
  → require 3 γ at least

Background of COMPTEL



G.Weidenspointner, et.al. (A&A, 2001)

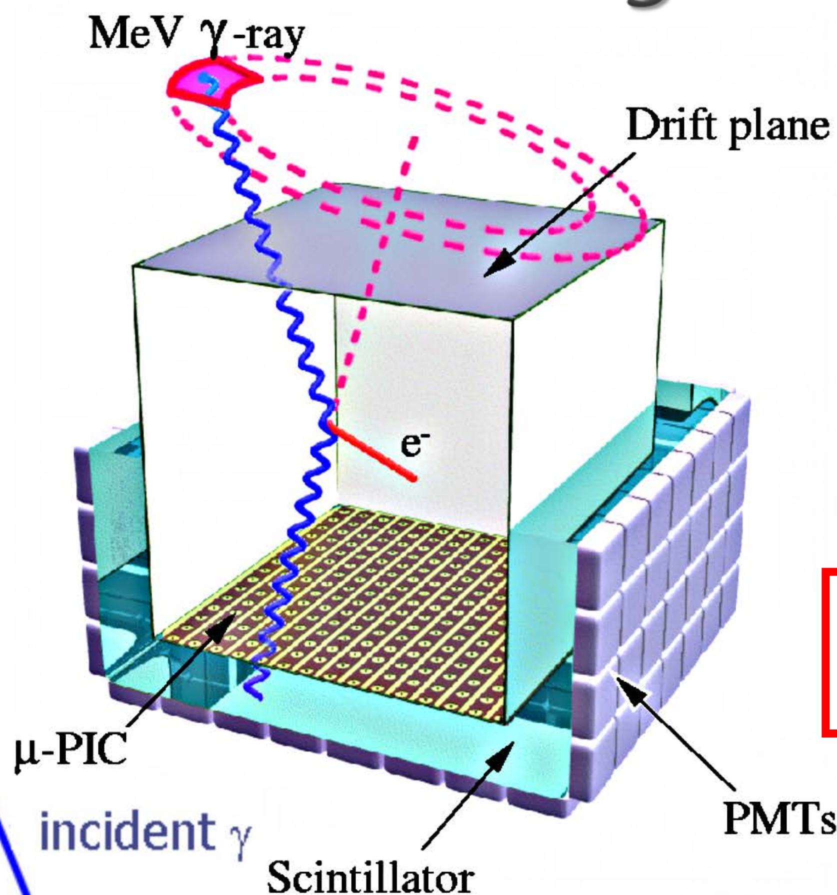
A : external γ
B : internal γ
} Intrinsic background
C : two γ
D : random coincidence
E: proton-induced γ

Other background
- neutron
- electron
- gamma from atmosphere

COMPTEL has rejected such background by the measurement of the Time Of Flight between 2 detectors.

Background rejection was not complete
Bad S/N

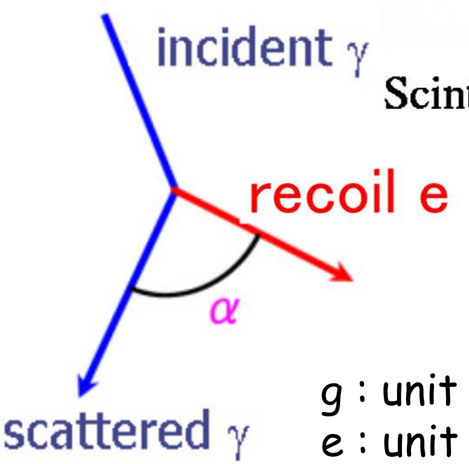
Electron-Tracking Compton Camera (ETCC)



- 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



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

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

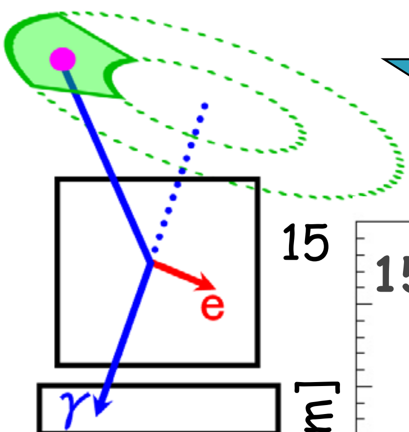
E_γ : Energy of scattered gamma-ray
K_e : Kinematic energy of recoil electron
$m_e c^2$: Rest mass of electron

Comparison with the usual Compton method

Electron-Tracking Compton (ETCC)

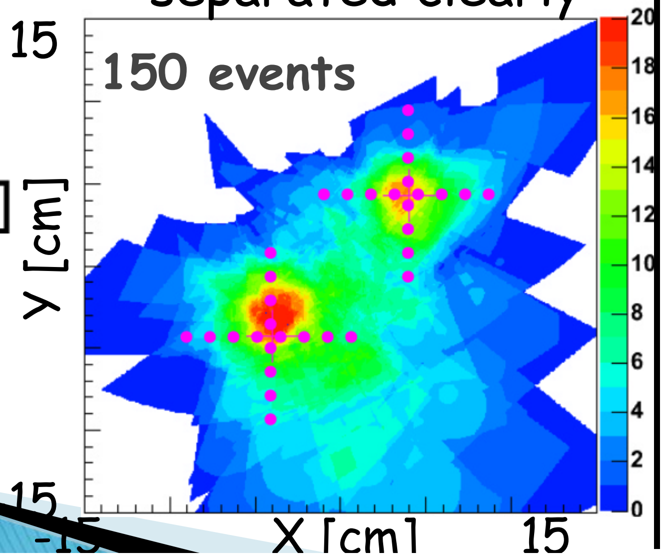
Using the electron tracks

- complete direction within sector form error region



Simply overlay

2 sources were separated clearly

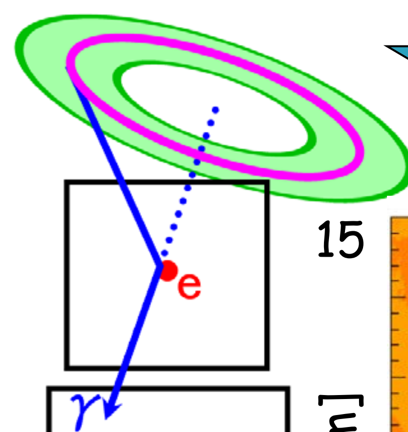


^{137}Cs(1MBq)×2, Advanced Compton

Usual Compton Imaging (COMPTEL)

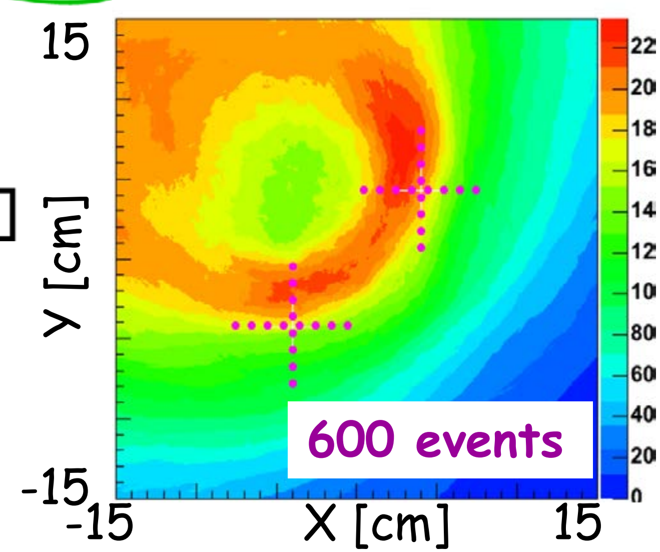
Not using the electron tracks

- only event circle within ring form error region



Simply overlay

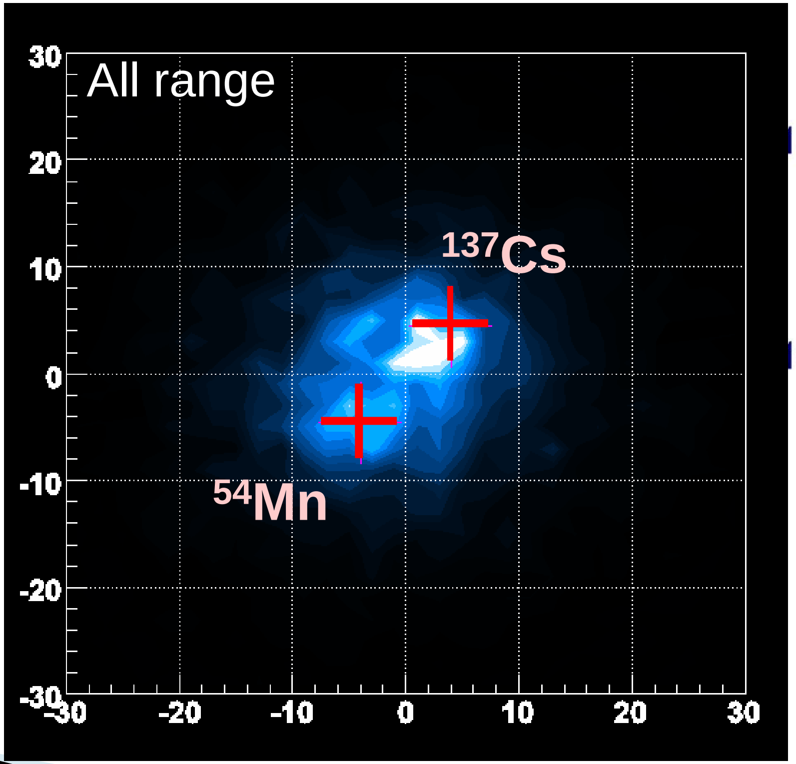
Hard to separate 2 sources

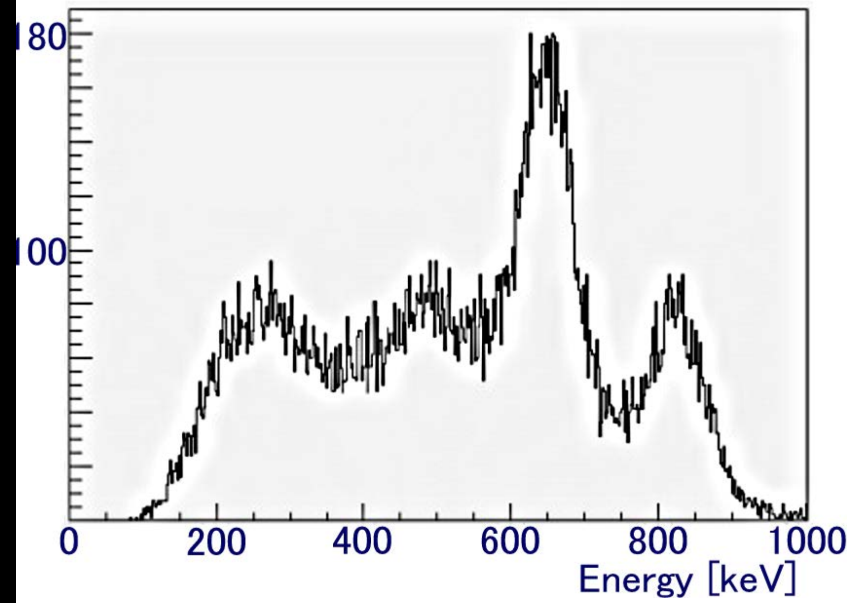


^{137}Cs(1MBq)×2, usual Compton

MeV-γ imaging

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





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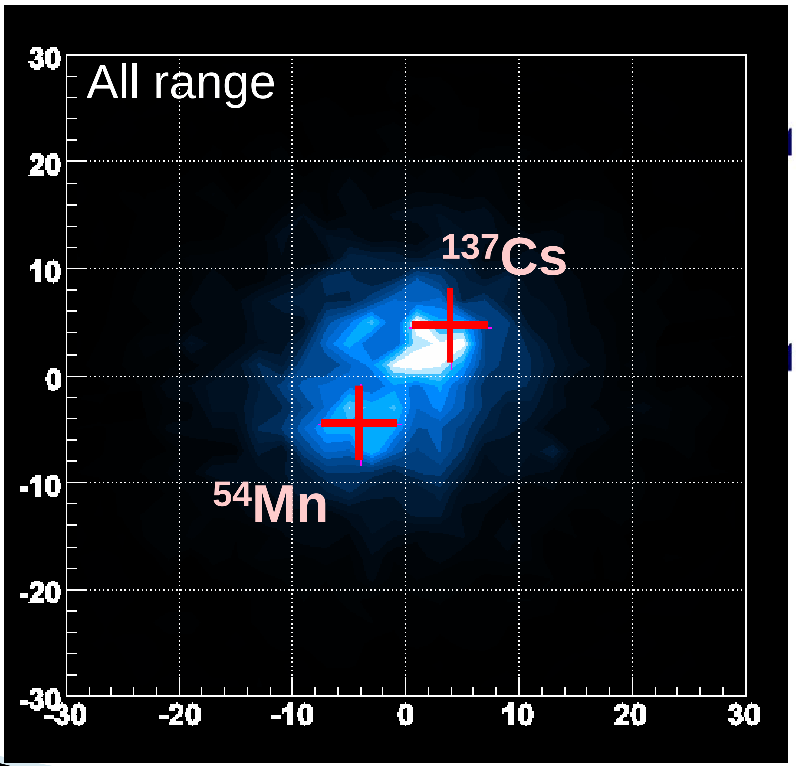
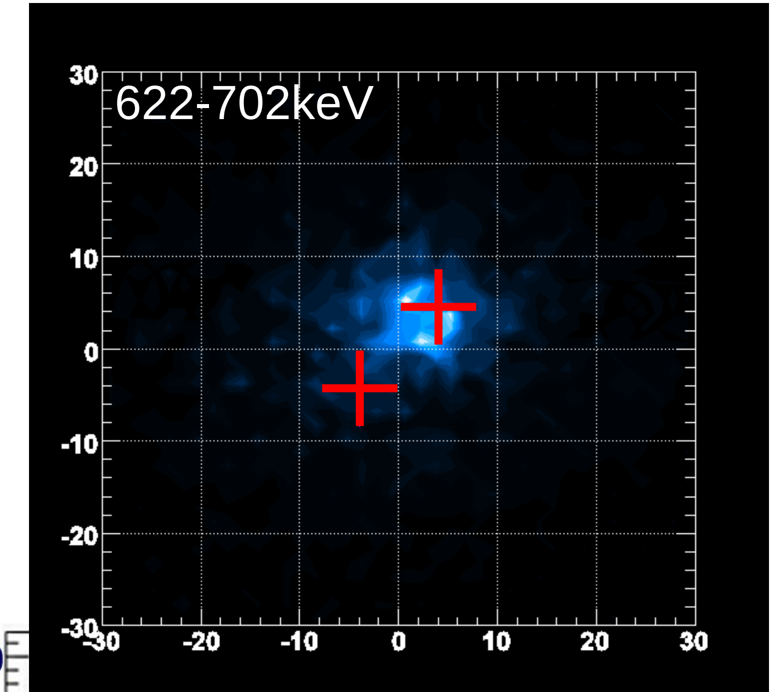
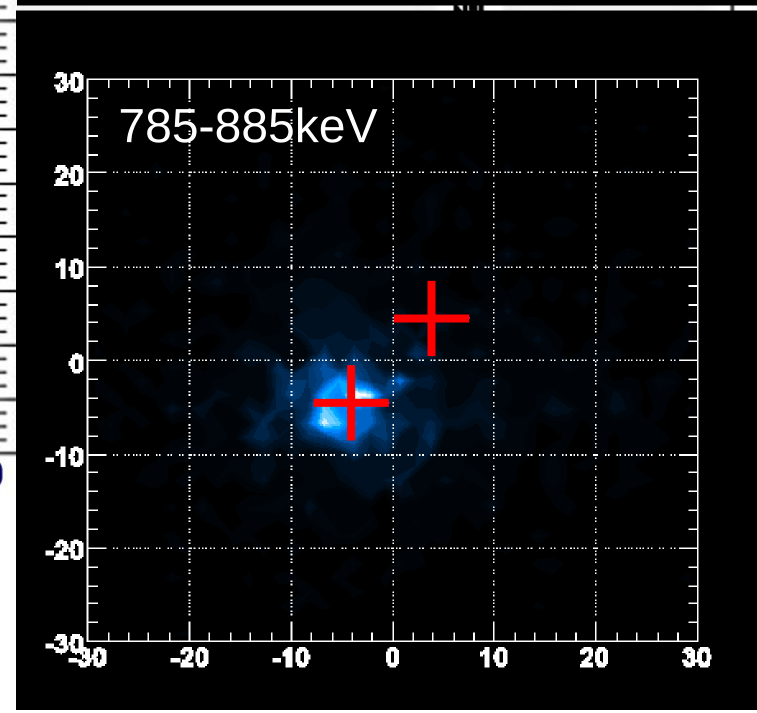






Sub-MeV gamma-ray Imaging Loaded-on-balloon Experiment

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

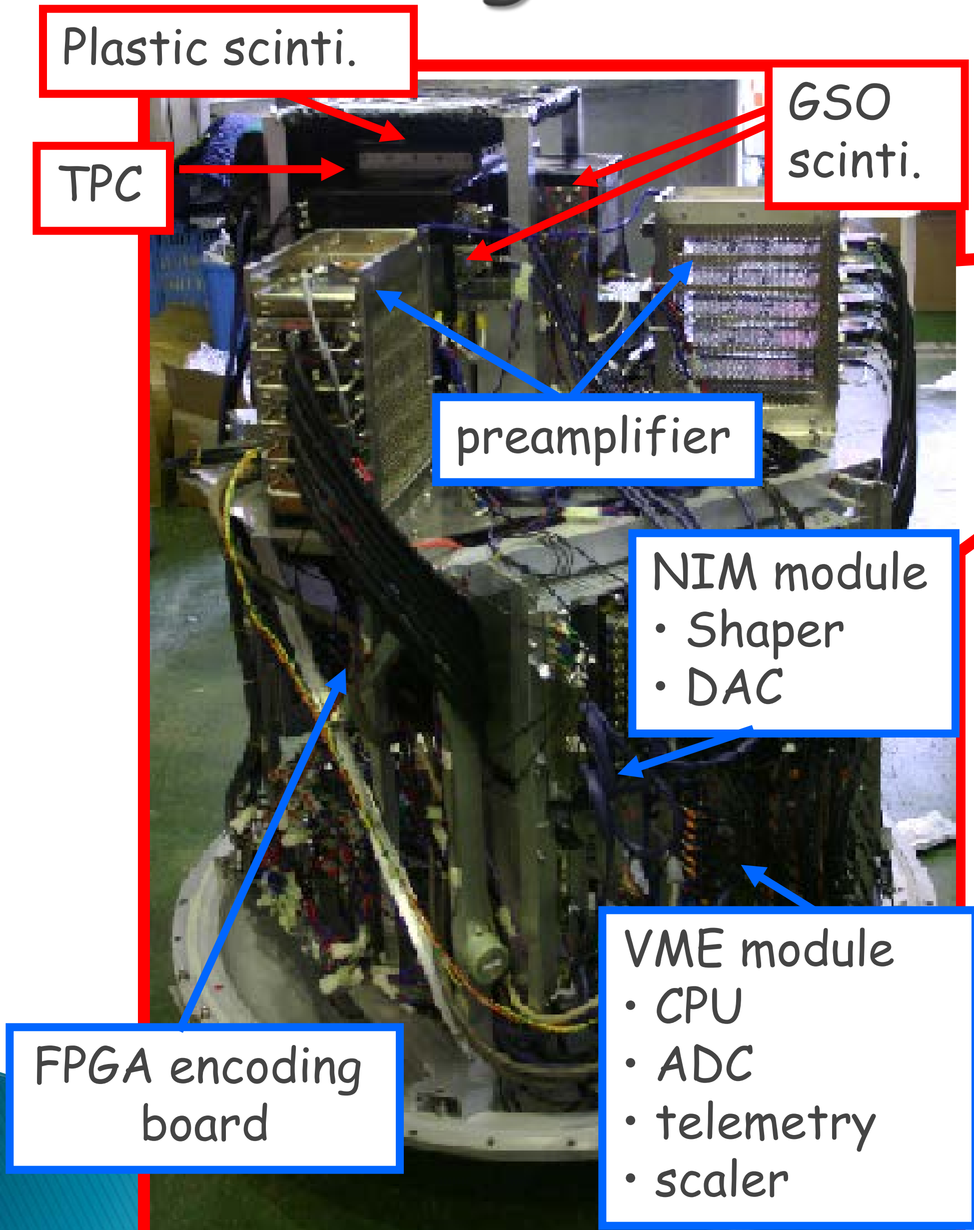
40cm cube camra Sub-MeV ~ MeV

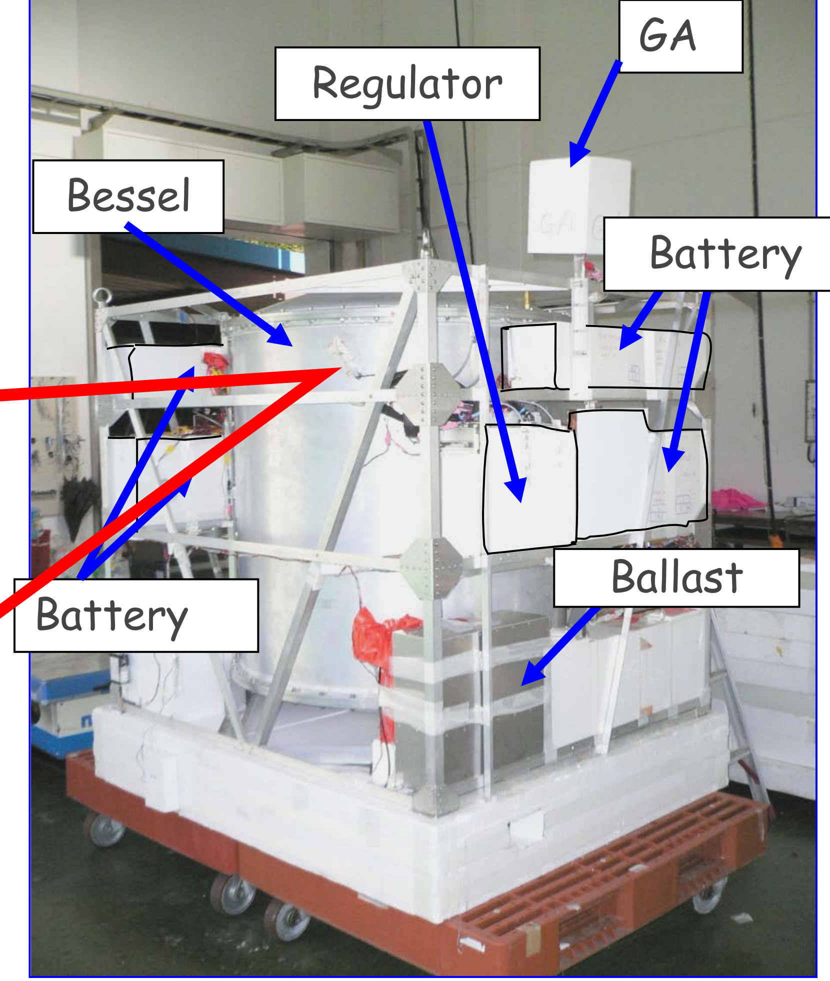
- Long duration observation with super pressure balloon
- Adding pair-creation mode

50cm cube camera

- All sky survey (load on a satellite)

SMILE-I gondola

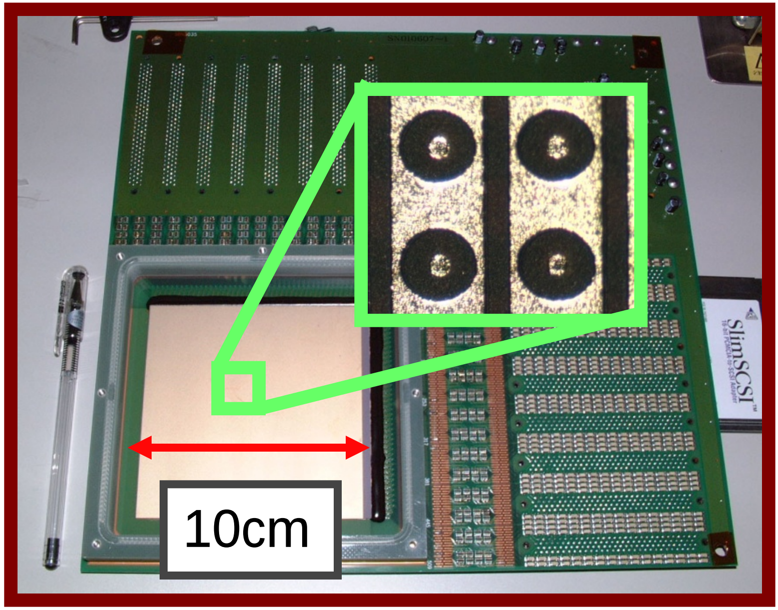


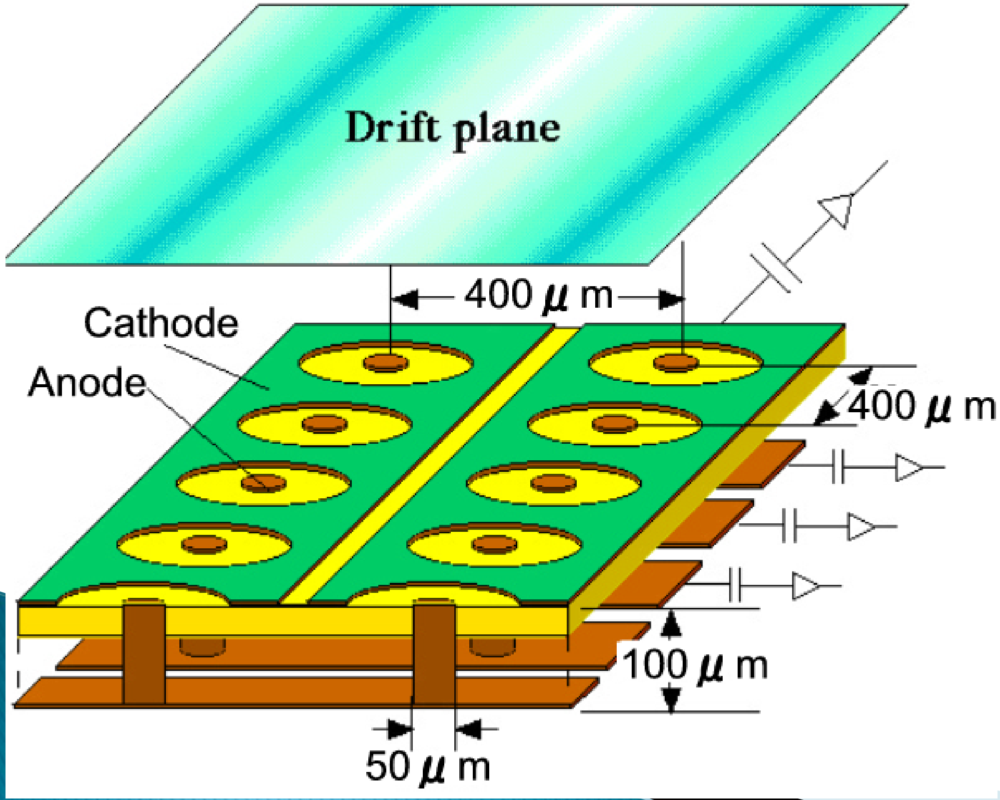


Size : $1.45 \times 1.2 \times 1.55 m^3$
Weight : 397 kg
Power : ~250 W
No posture control !!

The character and structure of μ-PIC

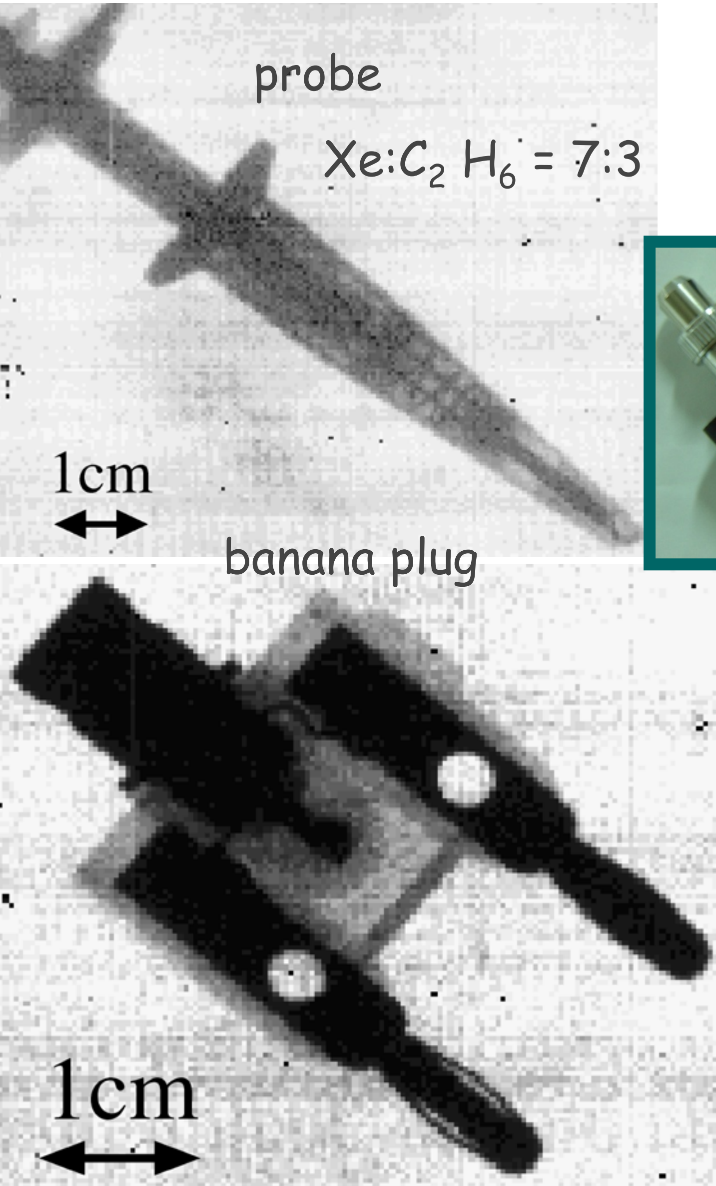
- 2D readout (~65000pixels)
- Large detection area (10cm×10cm)
- Print Circuit Board technology

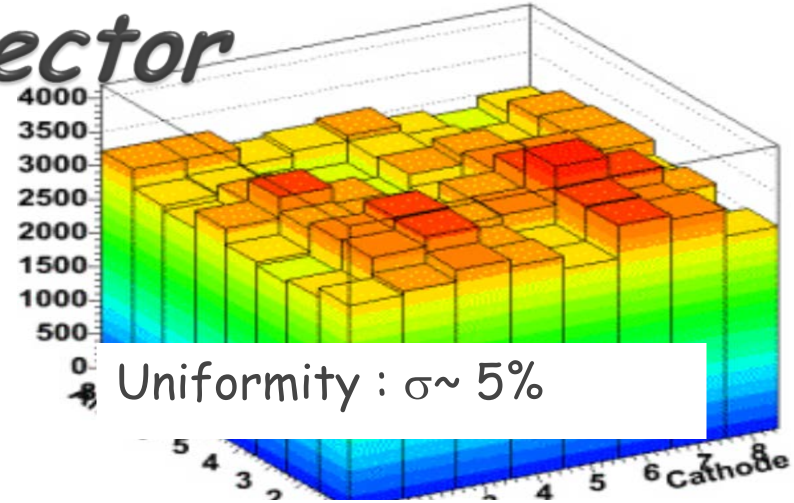


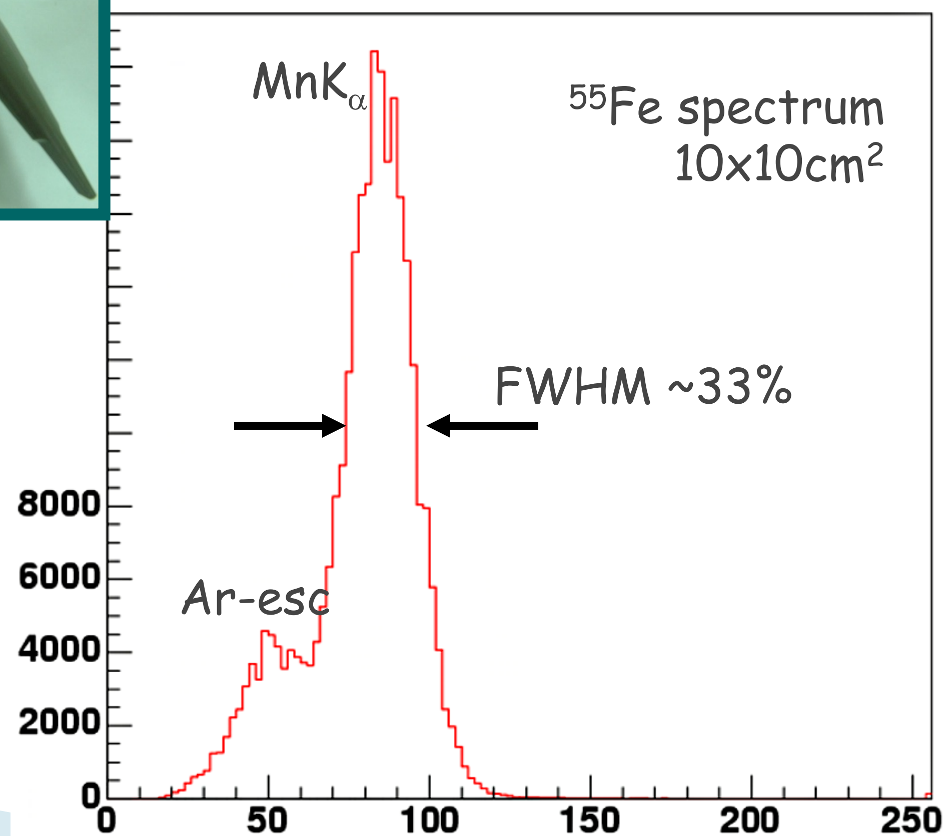


- max gas gain ~16000
- energy resolution
  30% @ 5.9keV (100cm^2)
- stable operation for 1000h
  @ gas gain ~6000
- good gas gain uniformity
  4.5% @ 100cm^2
- fine position resolution
  (~120mm)

μ-PIC as a X-ray Detector

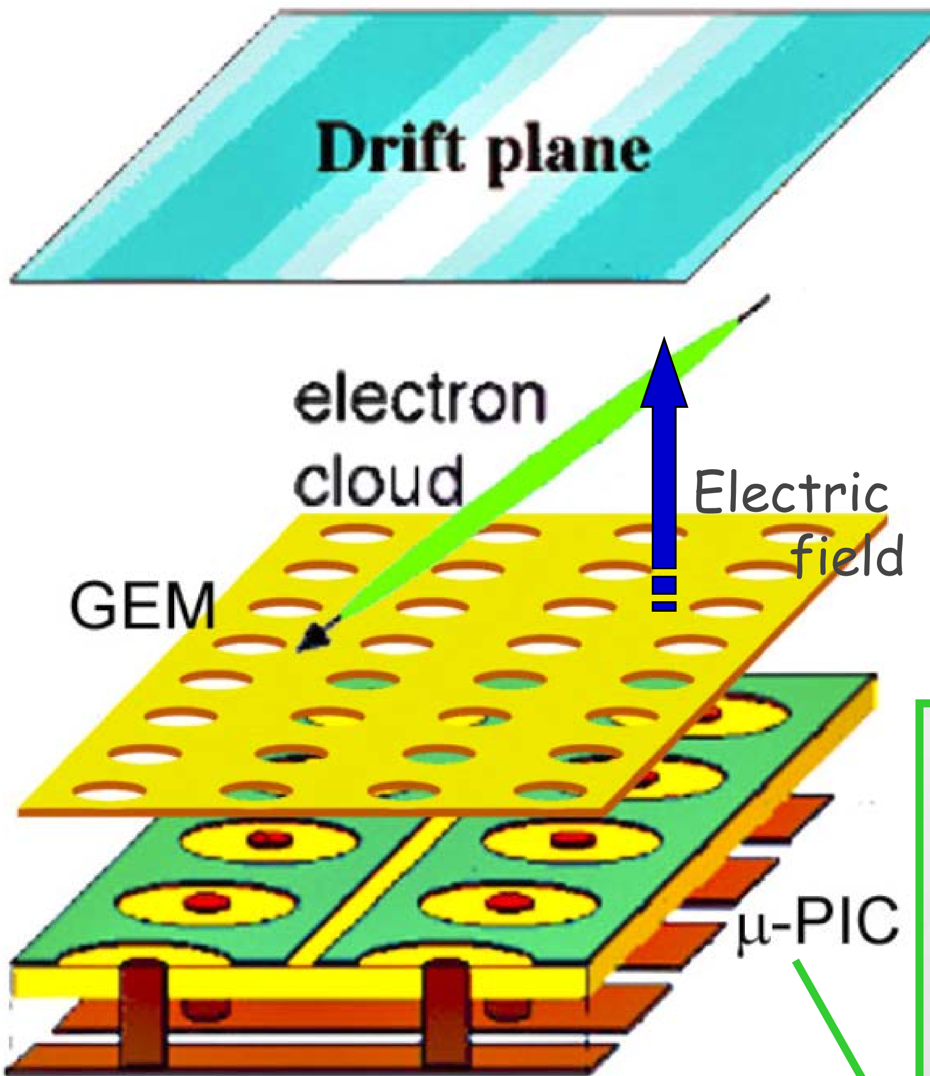




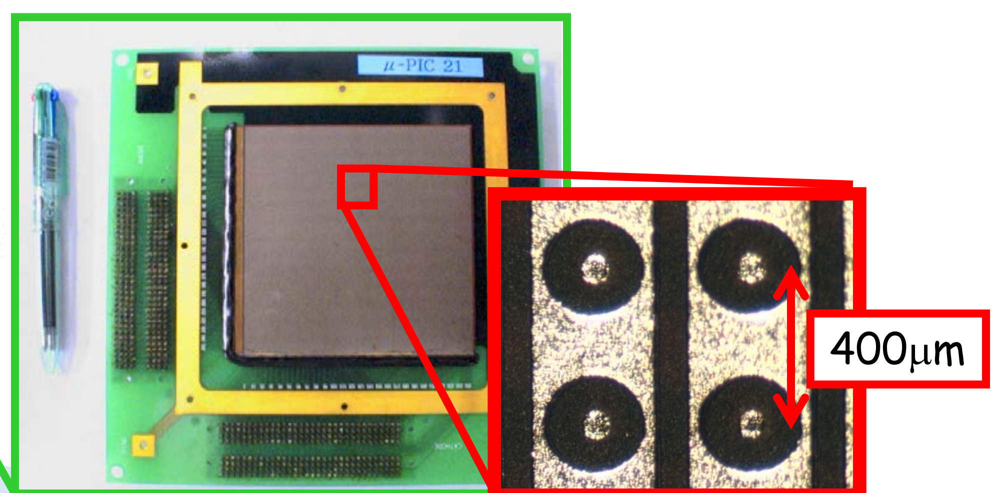


Gaseous electron tracker

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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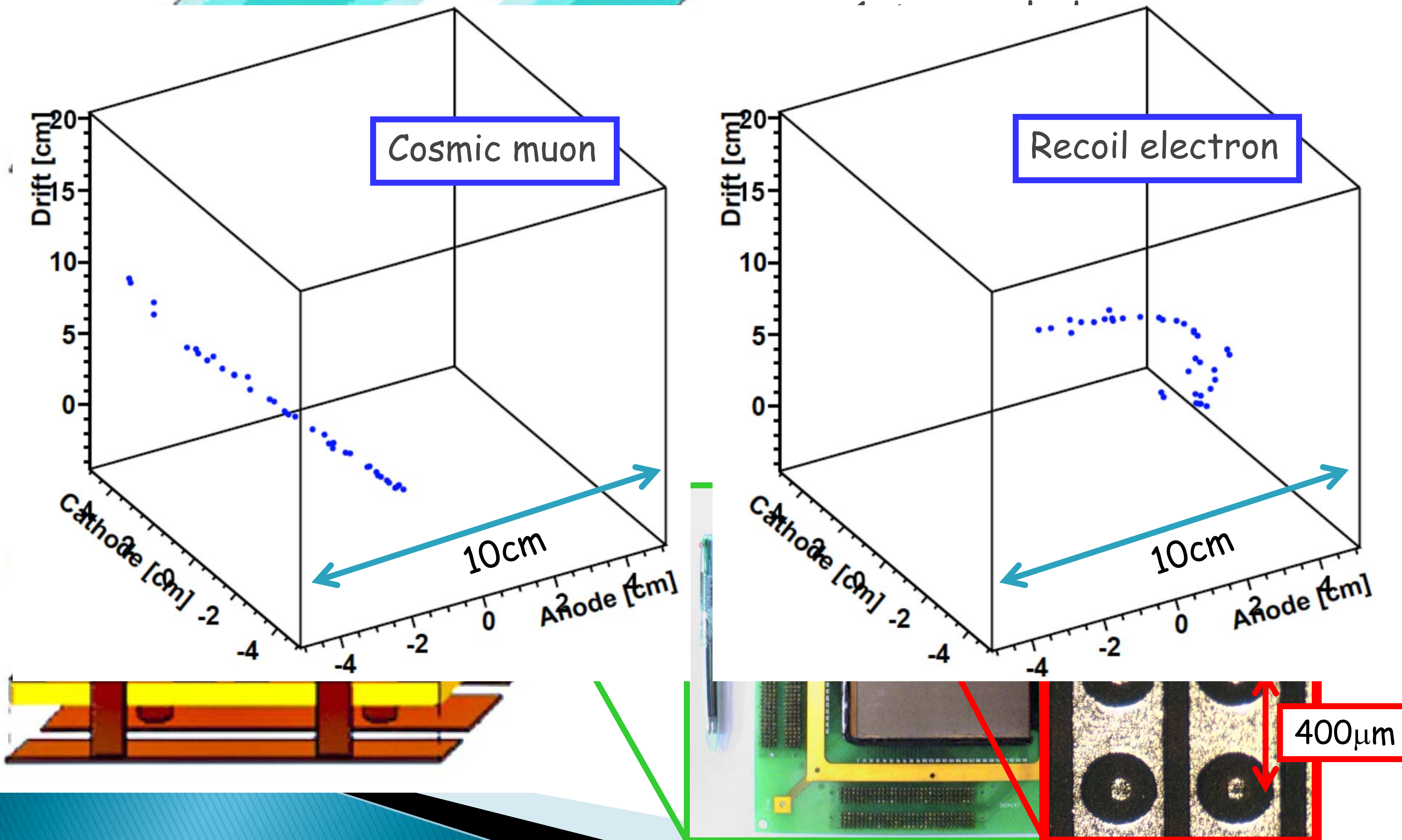
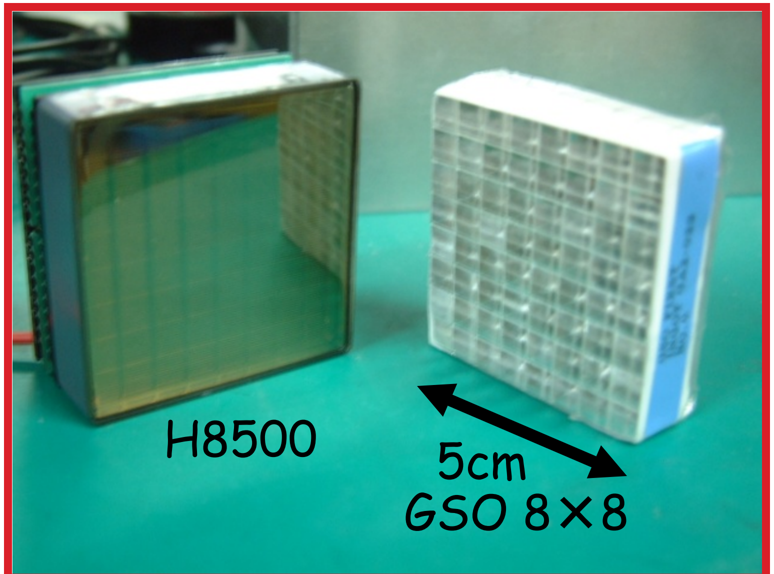
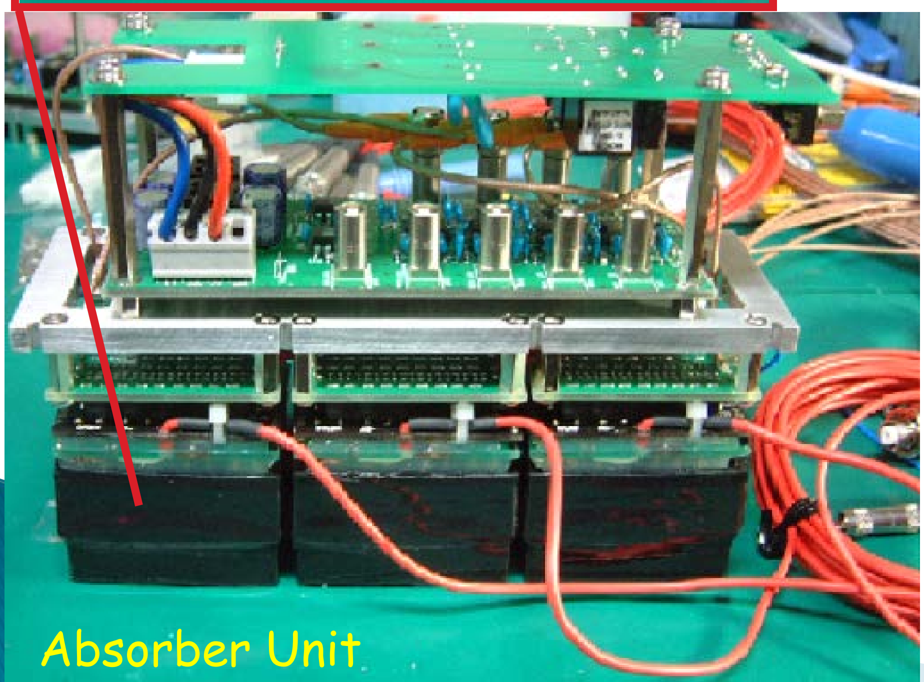


Scintillation Camera



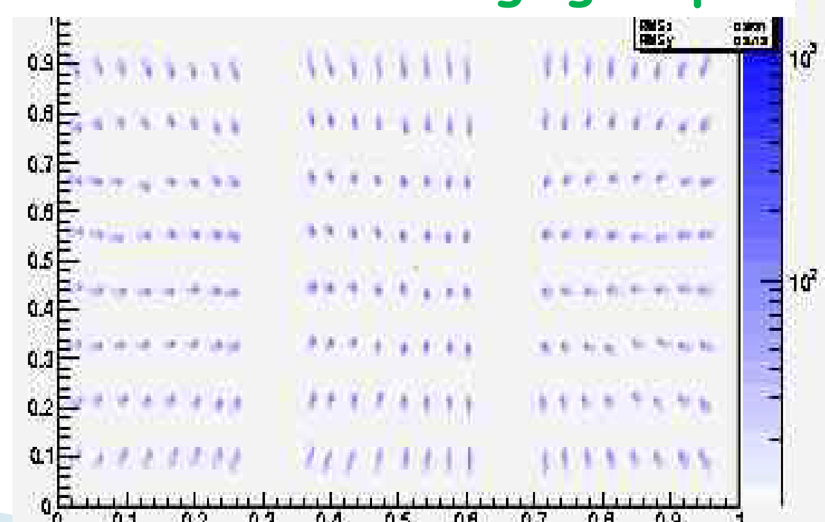


- Scintillator : GSO(Ce)
- Pixel size : 6x6x13 mm^3
- Photo readout : H8500 (HPK)
- DC/HV : EMCO Q12N-5
- A unit consists of 192 pixels, 3 PMTs, 3 DC/HV and 4 preamplifier
- 4 channels readout with resistive chain
- Bottom : 3×3 PMTs
- Side : 3×2 PMTs × 4

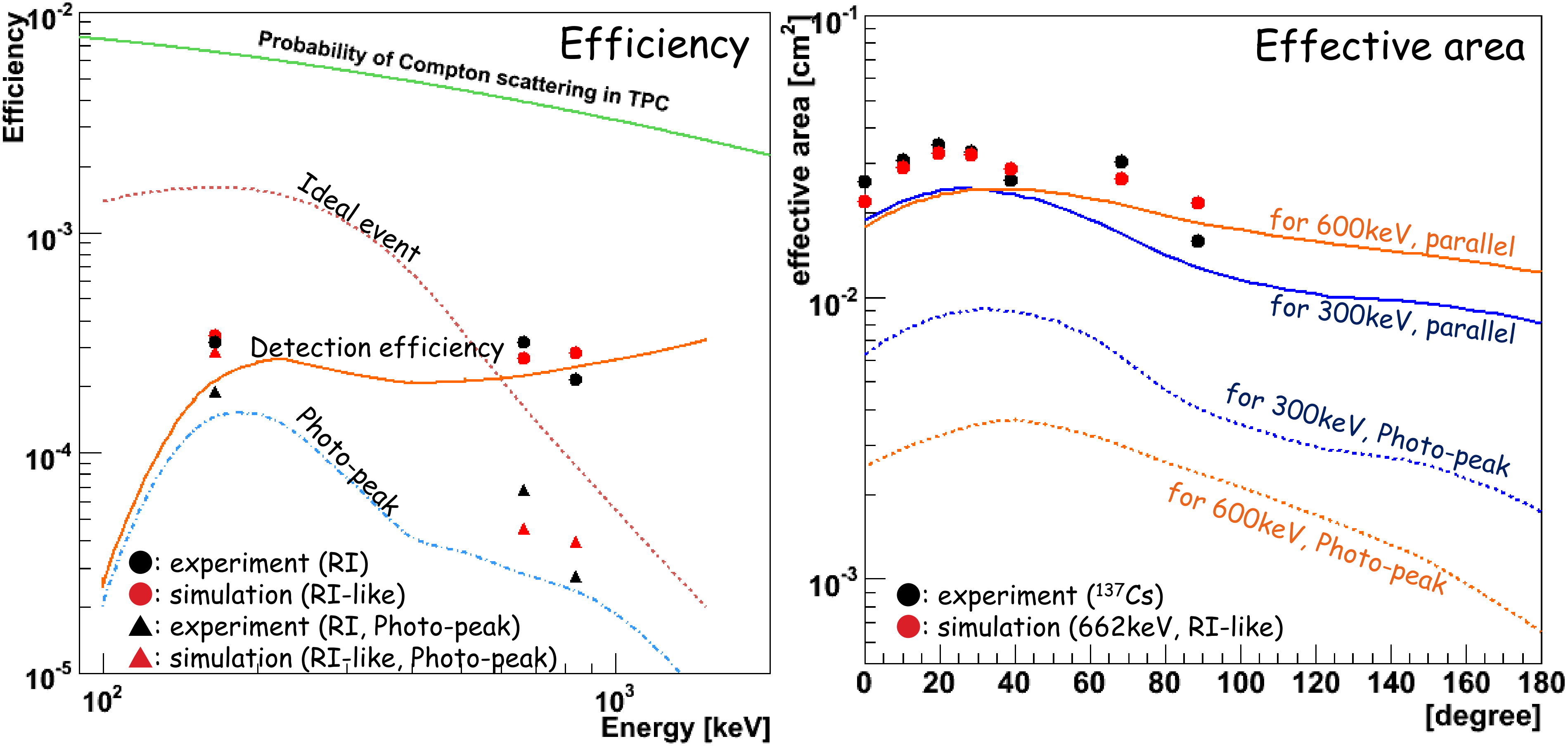
} 2112 pixels

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

^{137}Cs Position imaging map



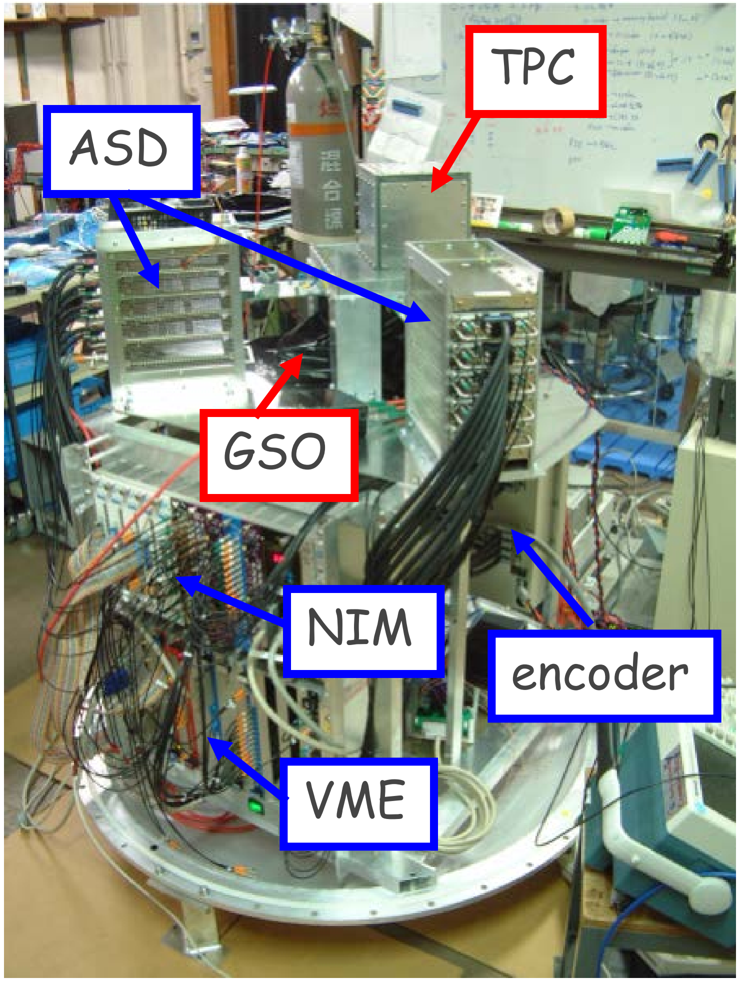
Efficiency & Effective area



- 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 SMILE

- Gondola size: 1.45×1.2×1.55m^3
- Gondola weight: 397kg
- Bessel: ϕ1×1.4m^3
- Power: ~350W
  in Bessel : 220W



In Bessel (1 atm)

Detector, DAQ system, Storage, Thermometer, Pressure gauge, GPS, Clinometer

Flight Control

Telemetry, Transponder, Buoy, Radiosonde, GPS, Thermometer, Pressure gauge, etc.

Out of Bessel

Battery & Regulator, Thermometer, Pressure gauge, GPS antenna, Geomagnetic aspectmeter

Balloon

B100 (100,000m^3)

Weight 816kg

Buoyancy 888.2kg

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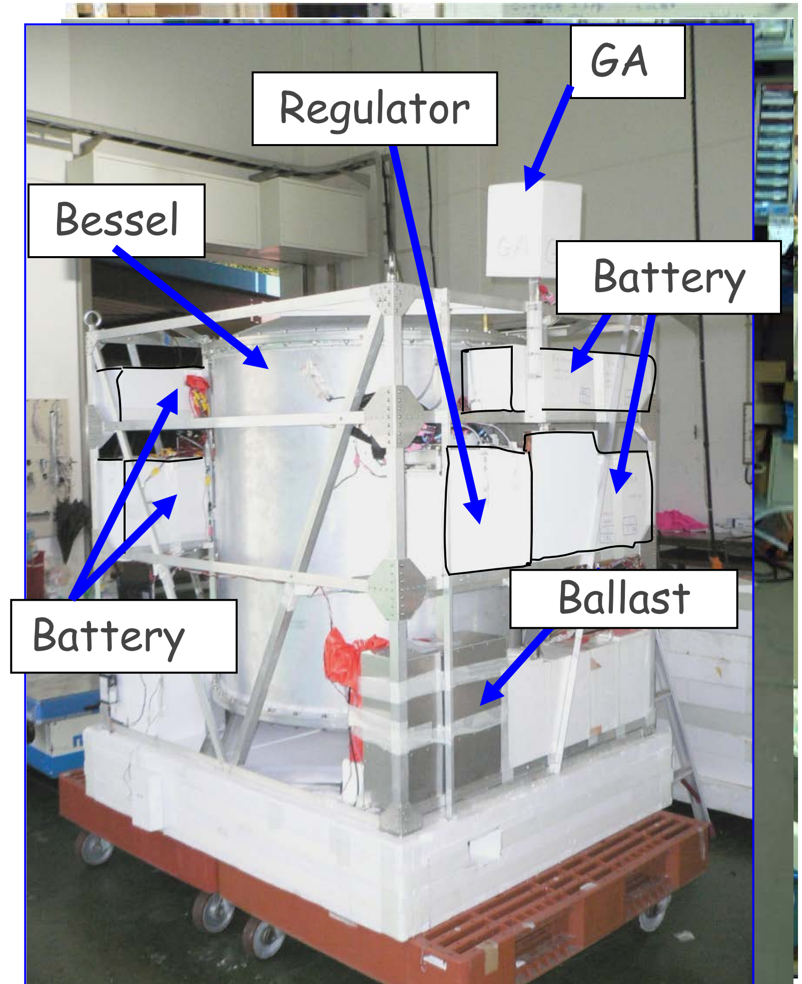

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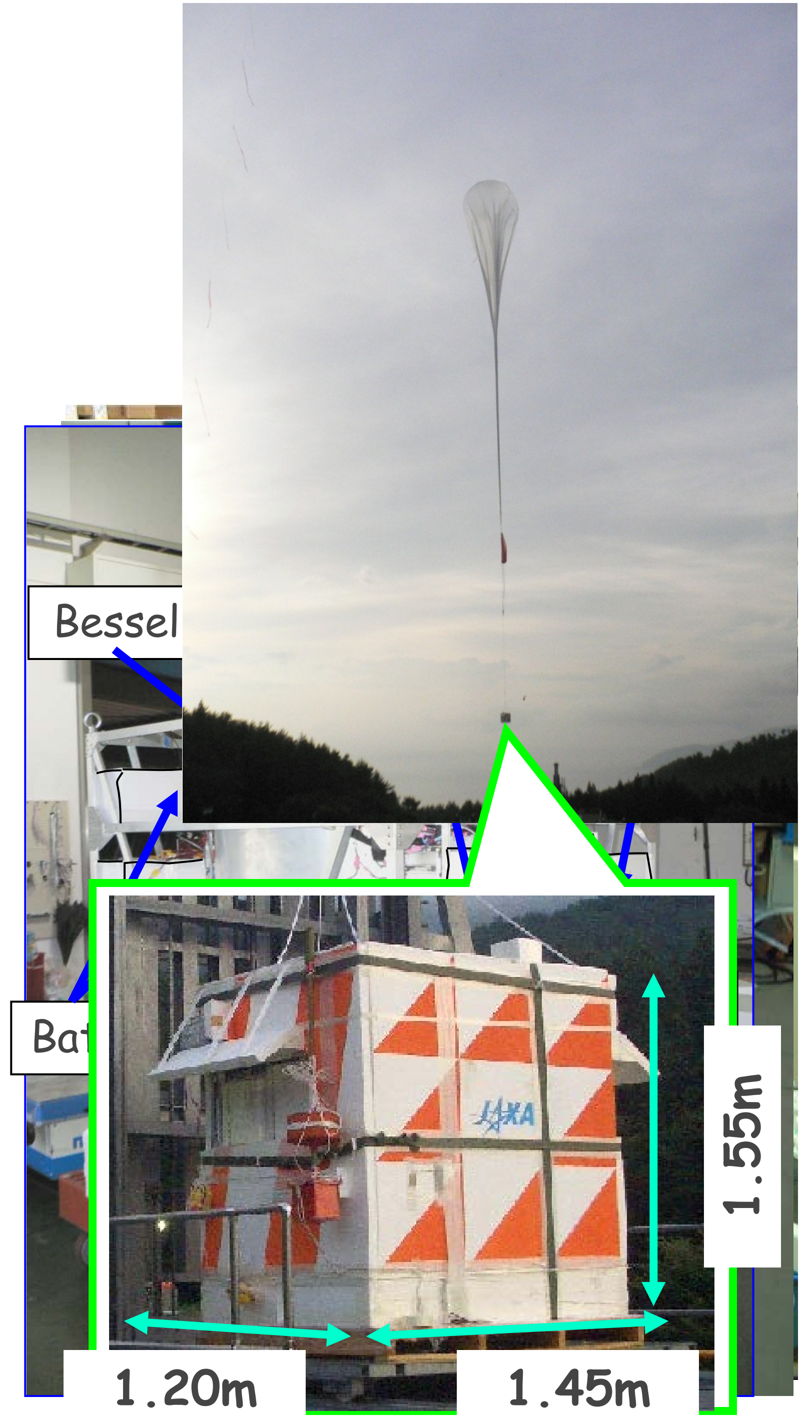

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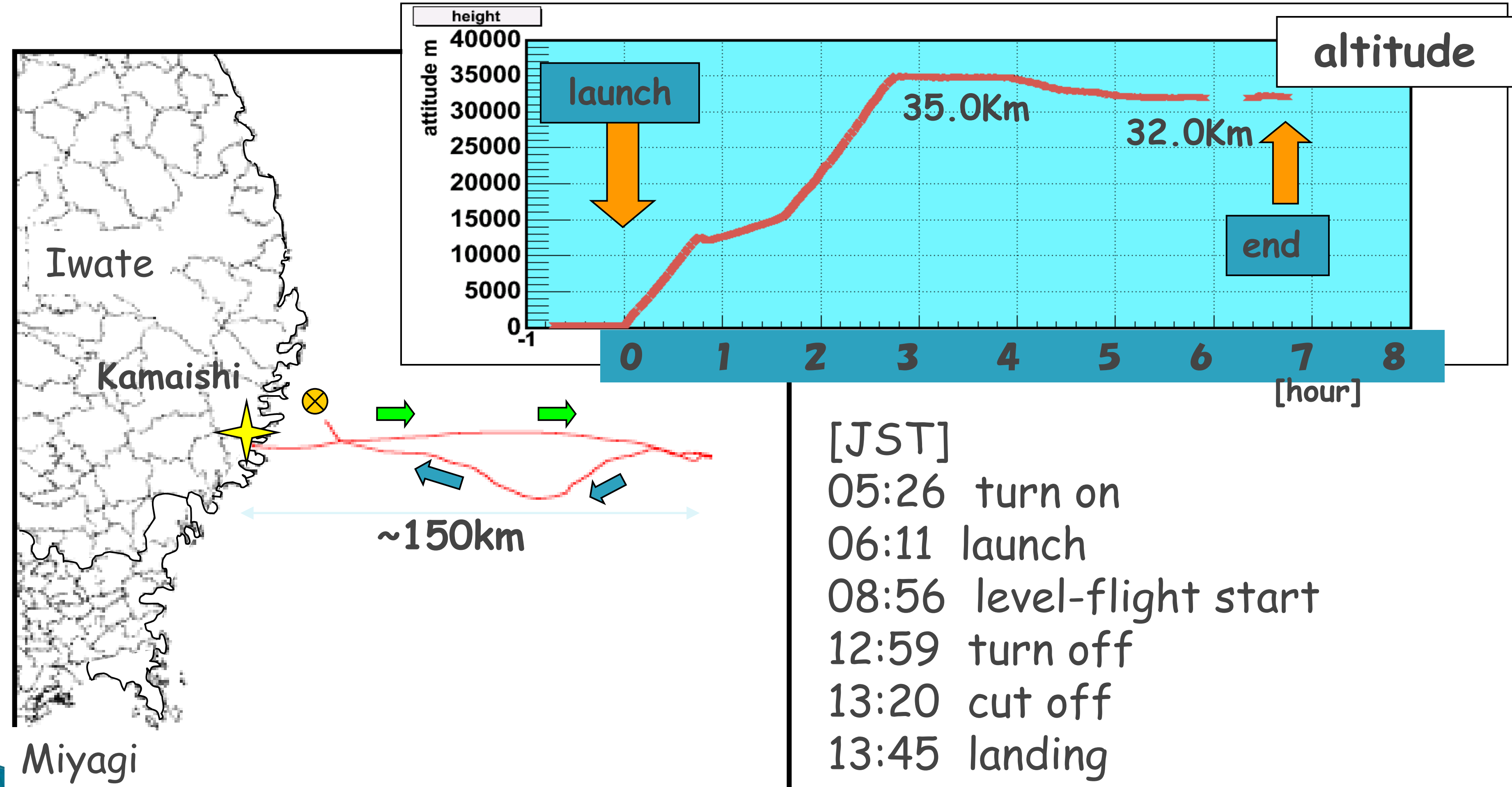
Balloon
B100 (100,000m^3)
Weight 816kg
Buoyancy 888.2kg

1st Flight

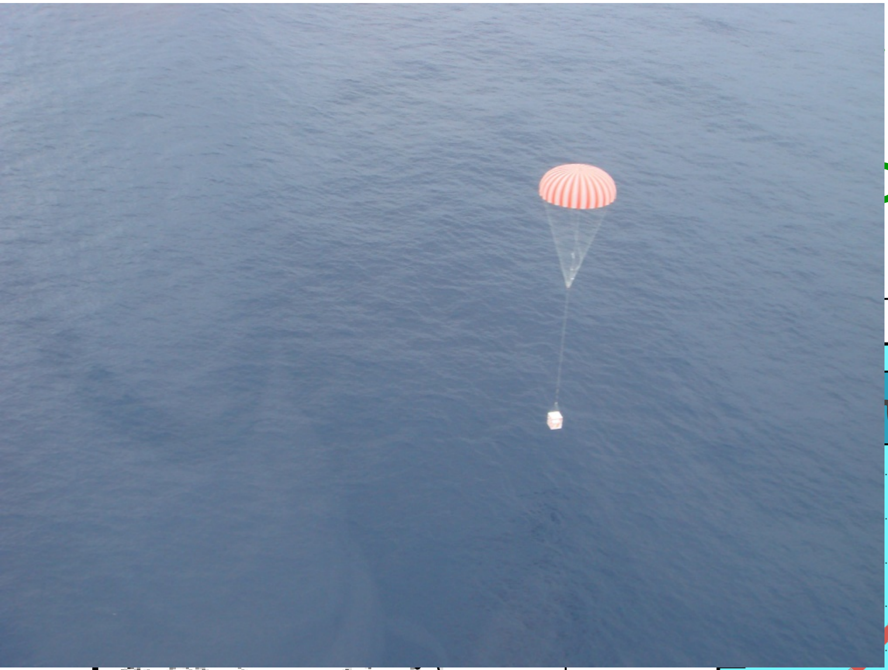
- Sanriku Balloon Center (JAXA)
- Launch at Sep. 1st 2006

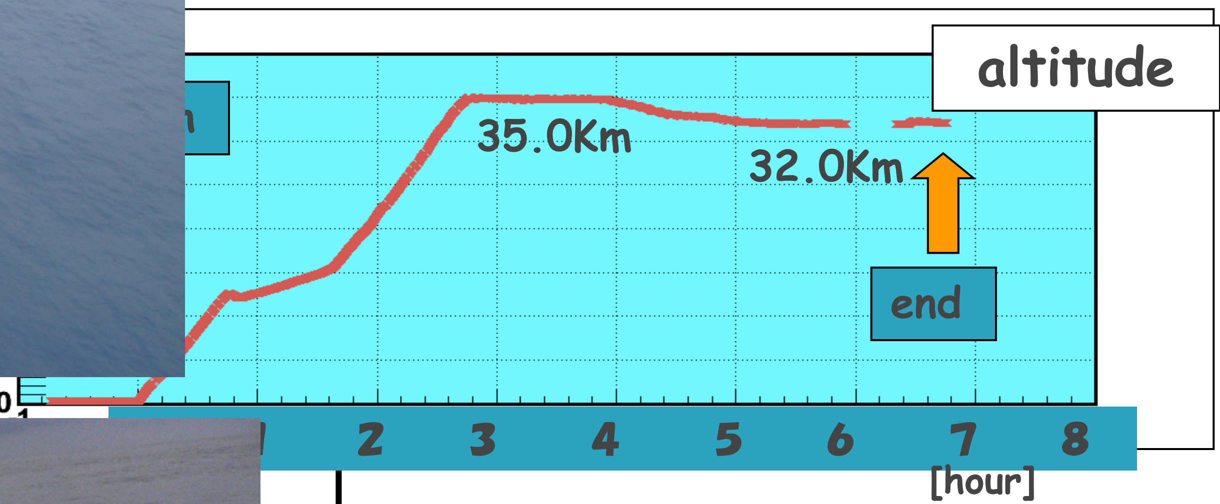


[JST]
05:26 turn on
06:11 launch
08:56 level-flight start
12:59 turn off
13:20 cut off
13:45 landing
14:32 recovery

There was no serious trouble during this flight !

ku Balloon Center (JAXA)
ch at Sep. 1st 2006





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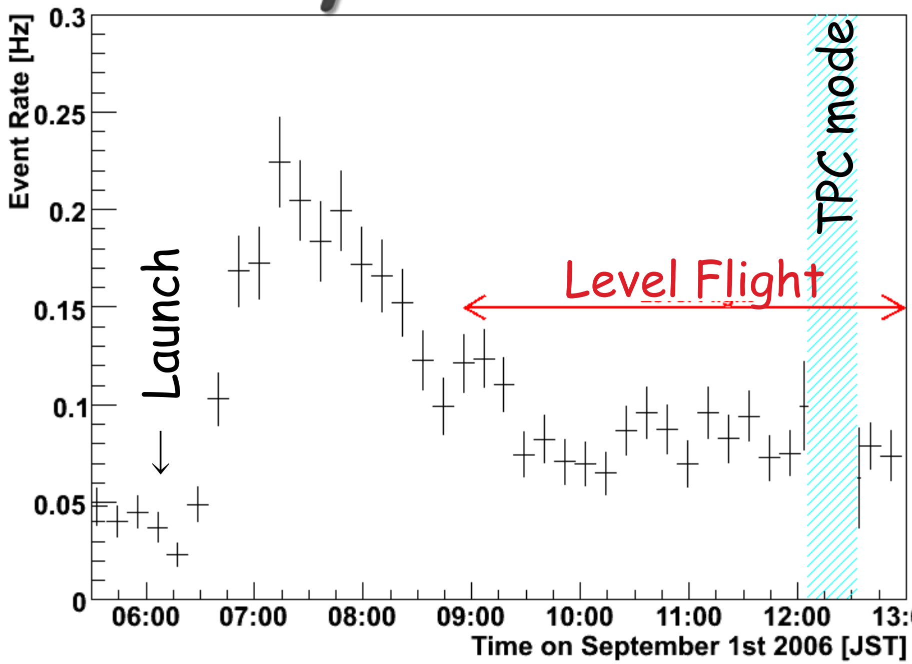
Compton event rate & spectrum



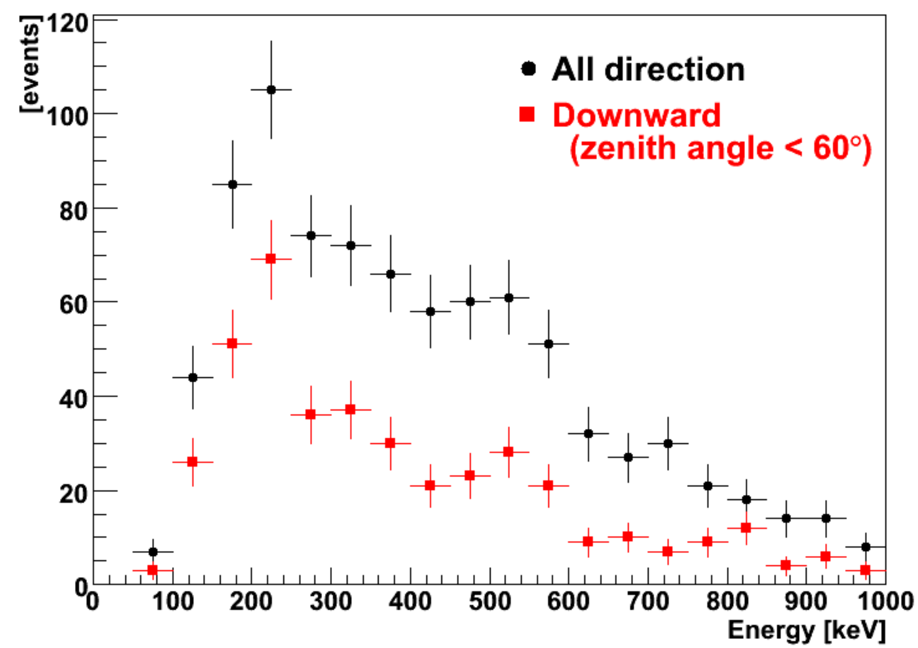
Rate of Compton event

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

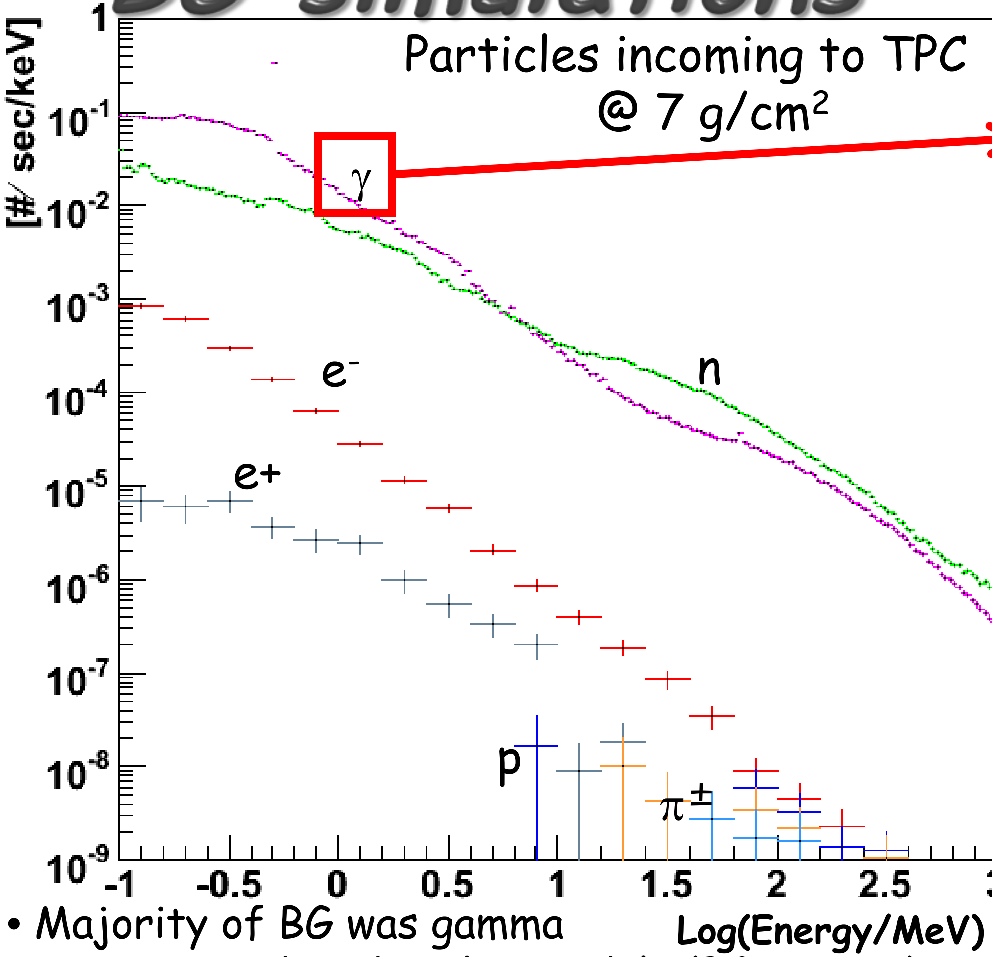
Energy Spectrum

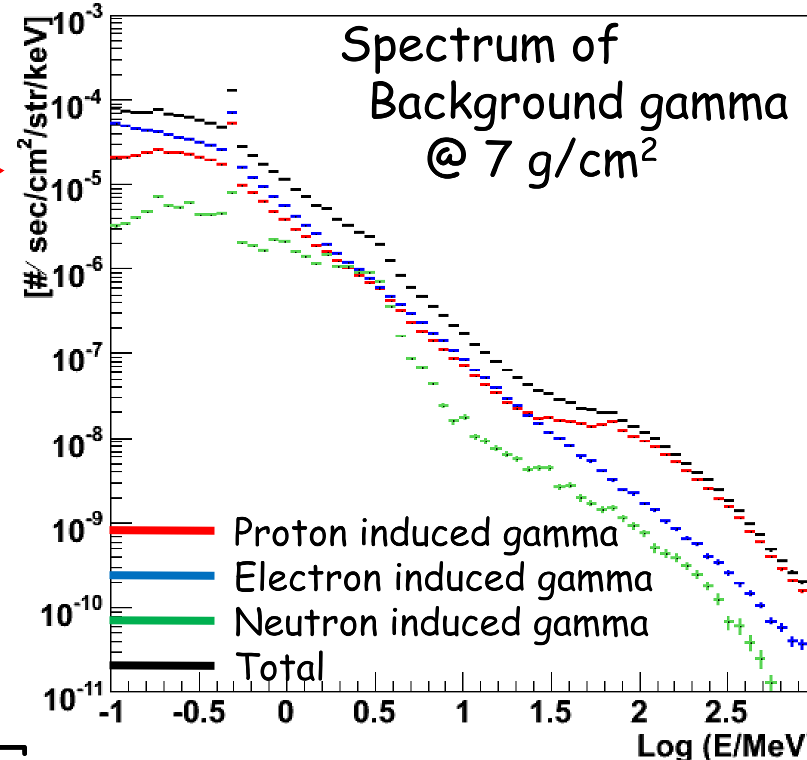
- 32~35 km level flight
- 3.5 hours (live 〜3h)
- in FOV event
  ~420 events

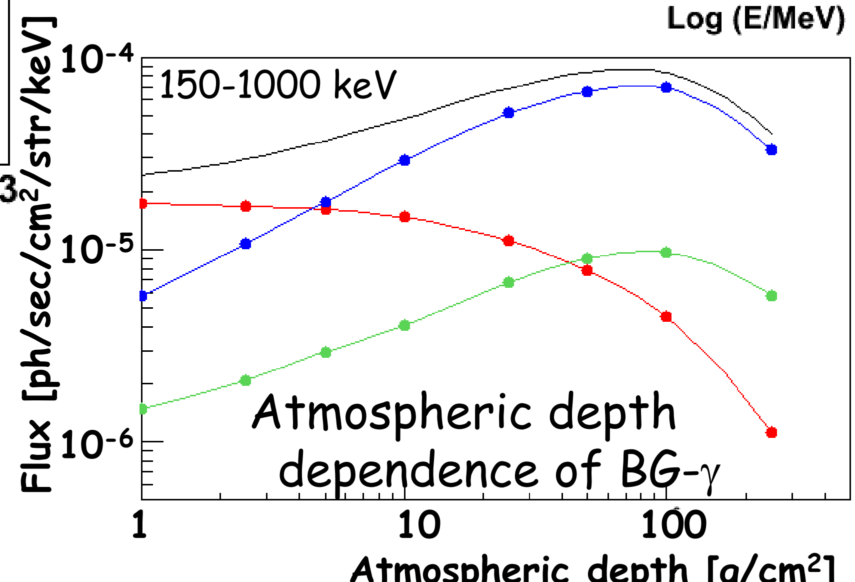
GEANT4 ⇒ ~400events



BG simulations



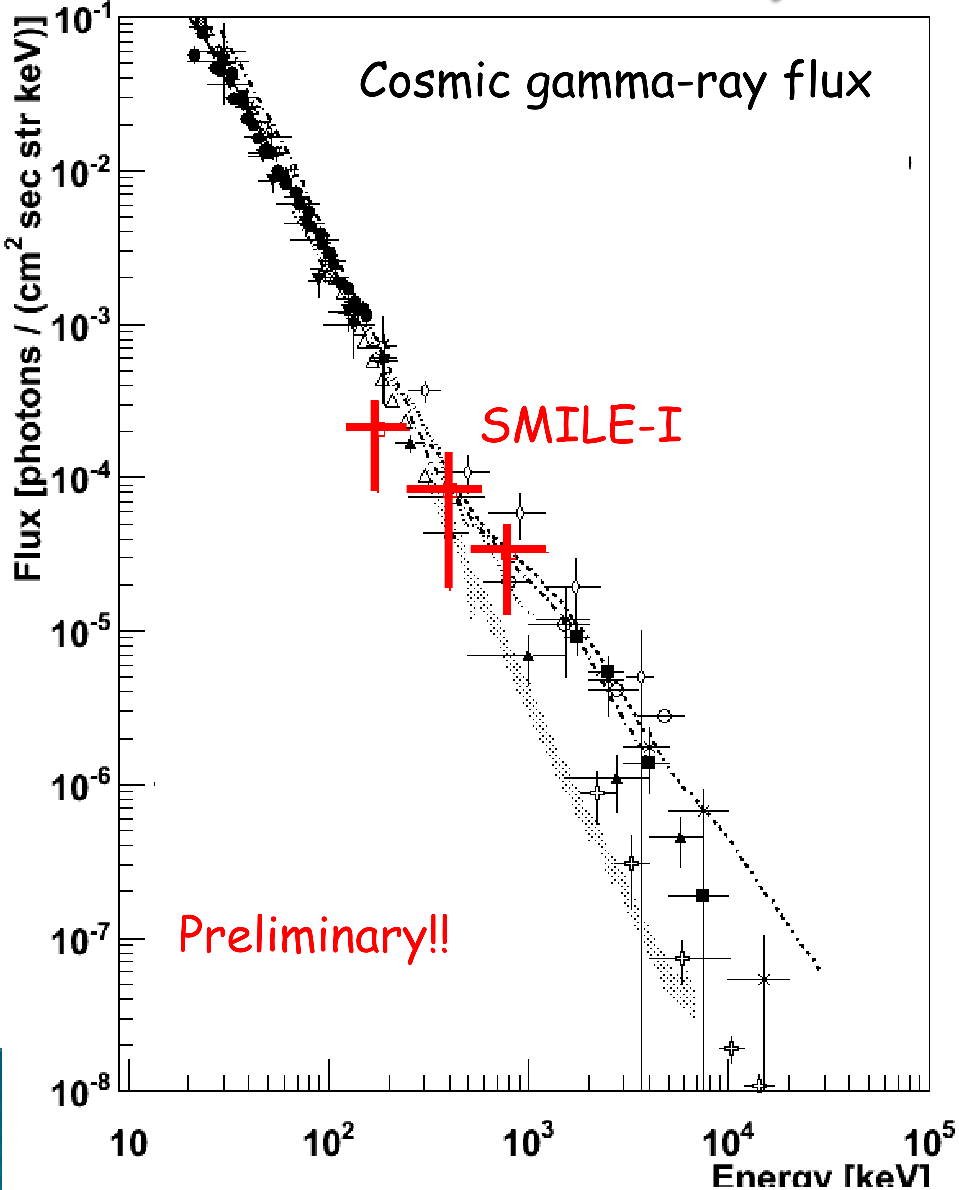


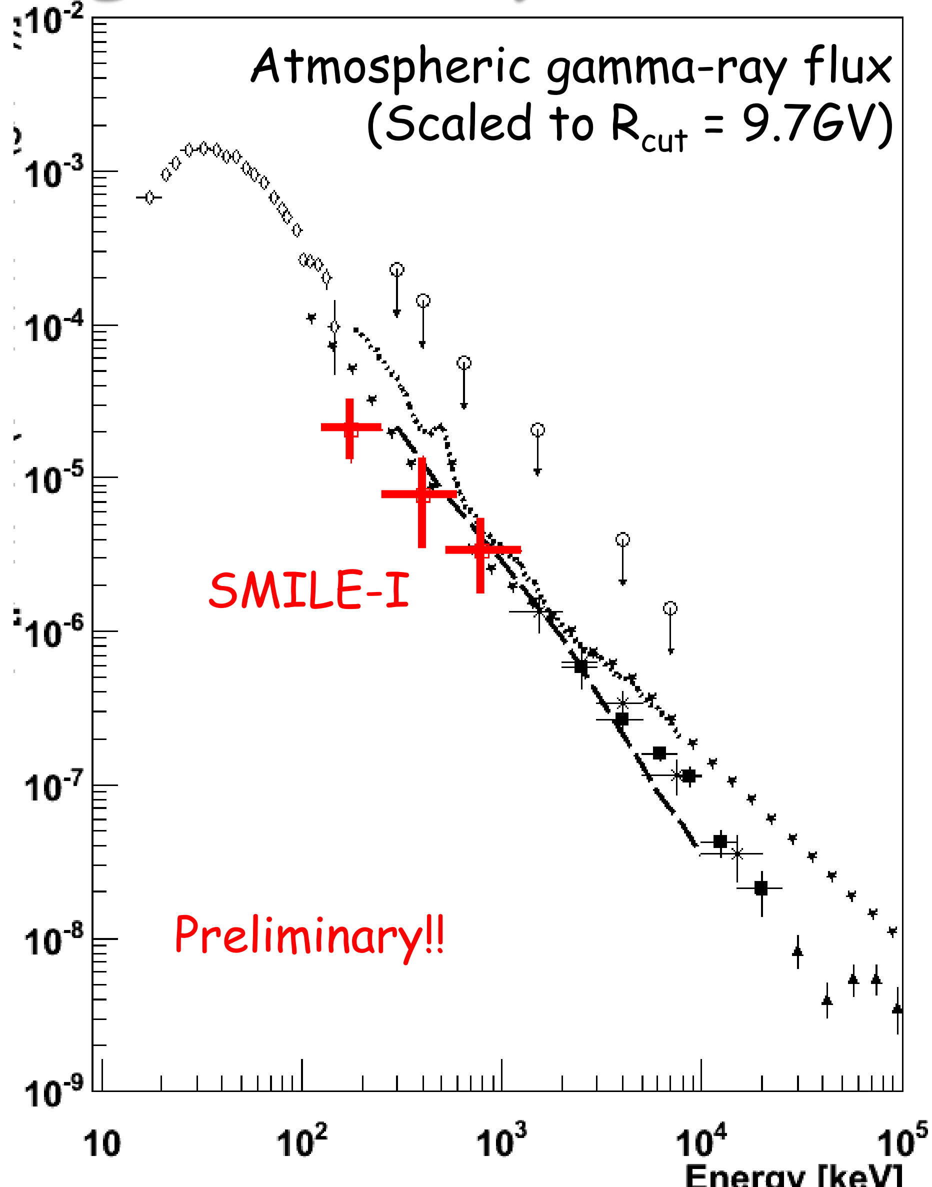


- Majority of BG was gamma produced in the gondola (BG-gamma).
- Simulator expected : obtained Compton events at level flight

gamma-ray	~78%
BG-gamma	~20 %,
neutron	1.5%
charged particle	< 0.25%

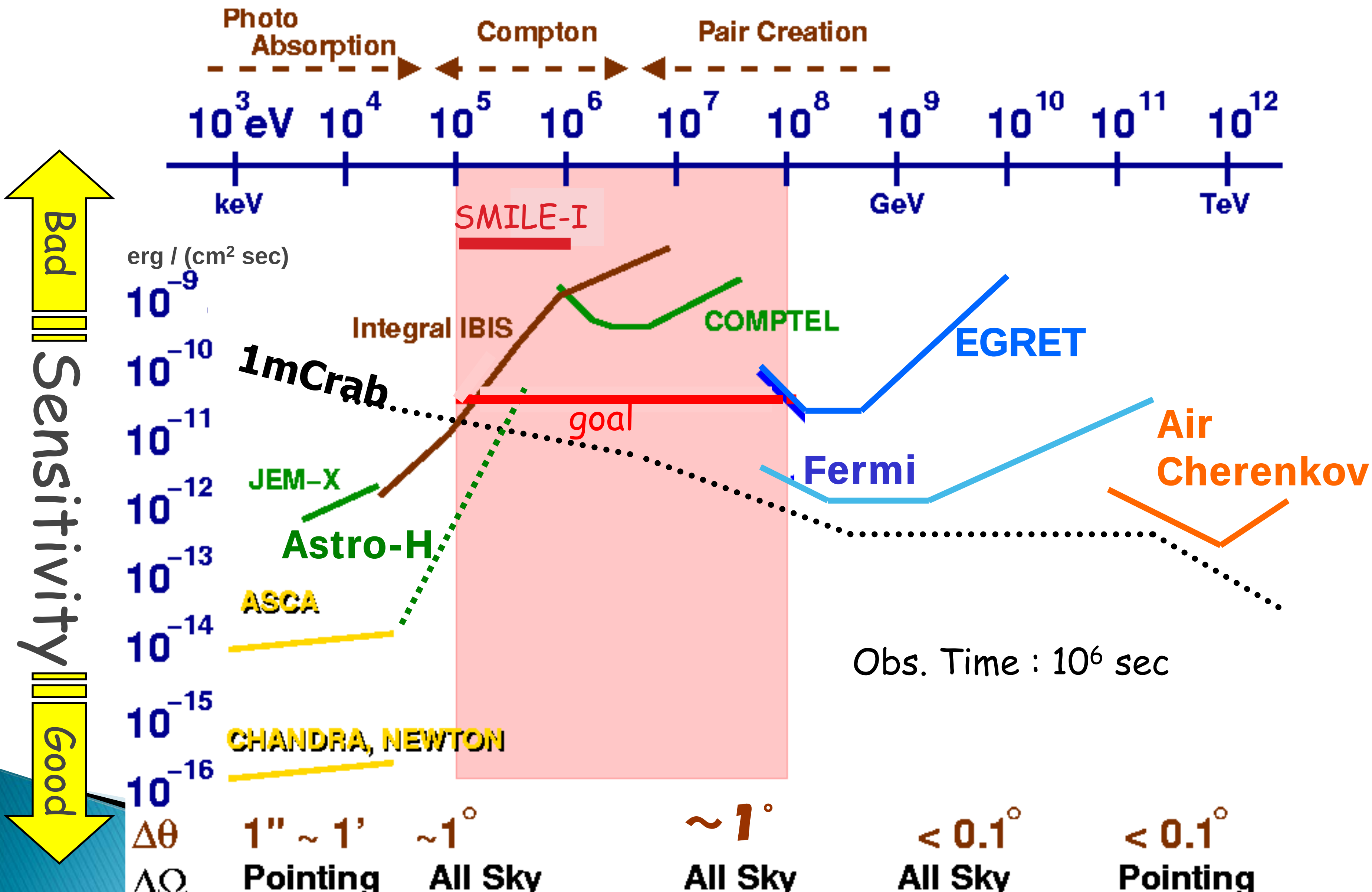
Cosmic & Atmospheric gamma-ray flux





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

Sensitivity of X/Gamma-ray observations



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)

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

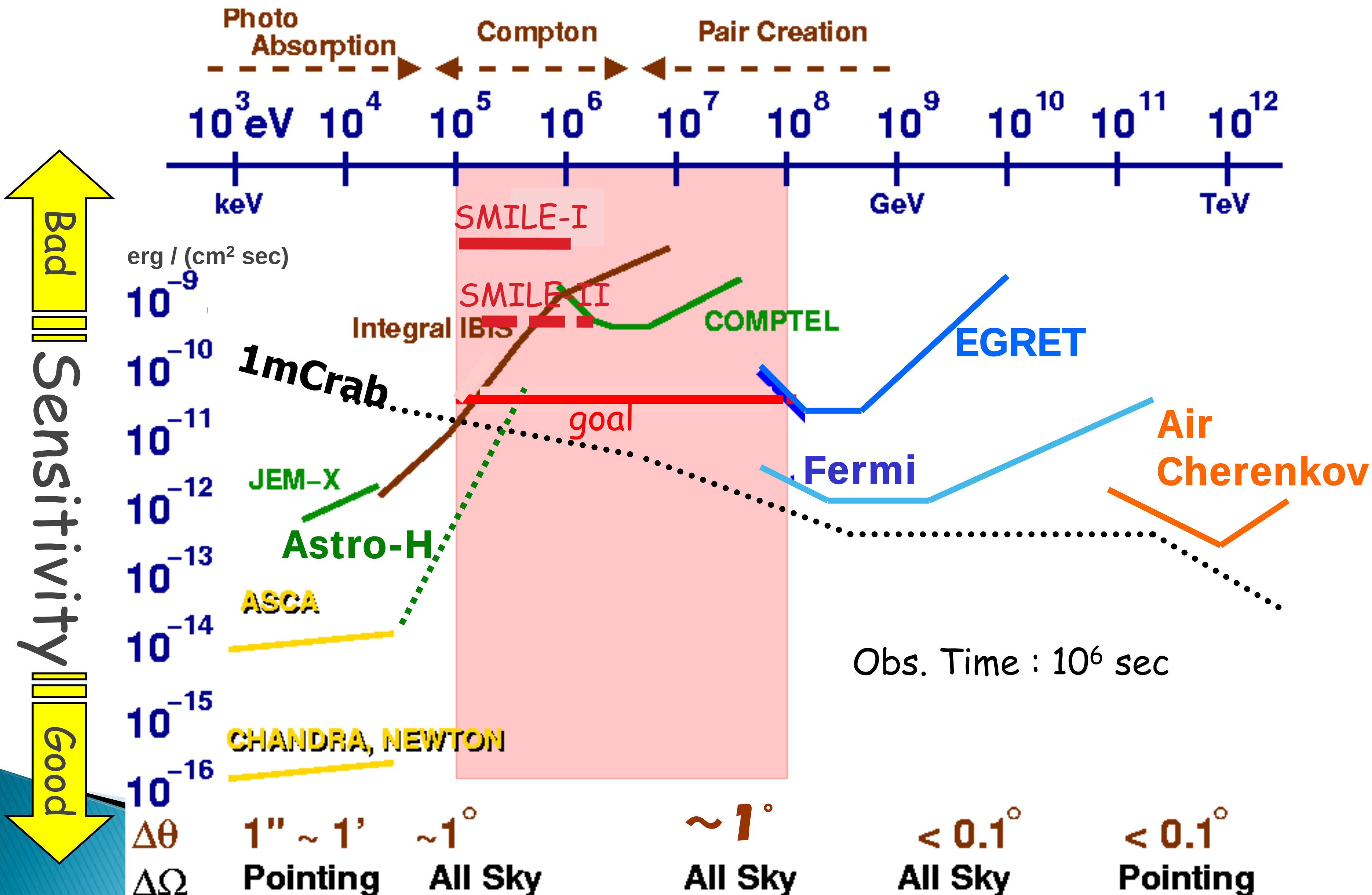
→ Effective area : ~2×10^{-2} cm^2

- SMILE-II
  - Observation of a Bright object (Crab nebula or Cyg X-1)

→ Requirement : ~1 cm^2

- Electron Tracker : 30x30x30 cm^3 , Ar/CF_4 1.5atm
- Absorber : 30x30x1.3 cm^3 @ Bottom
  30x15x1.3 cm^3 x4 @ Side
- Improvement of Angular resolution

Sensitivity of X/Gamma-ray observations



γ-ray burst due to Relativistic Electron Precipitation in 1996 @Kiruna for SMILE-II

K.R.Lorentzen et al.,(2000)

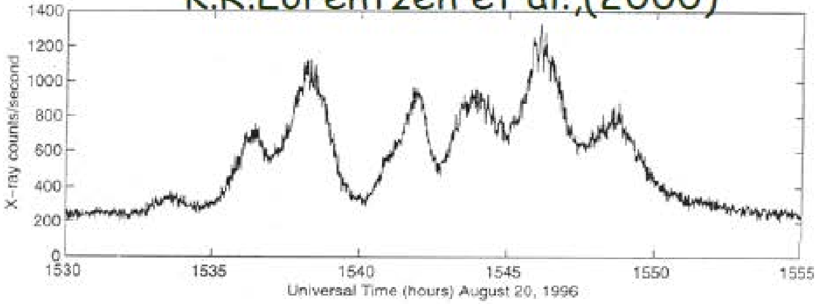
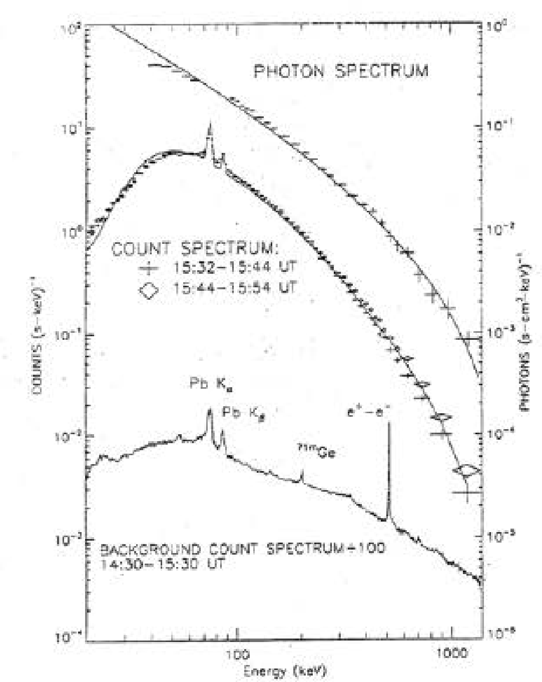


Figure 1. X-ray imager data taken during the relativistic electron precipitation event of August 20, 1996. The X-ray count rate between 20 and 120 keV is averaged over 1 s. The 10–20 s modulation is most clearly visible superposed on the peak starting near 1545 UT.

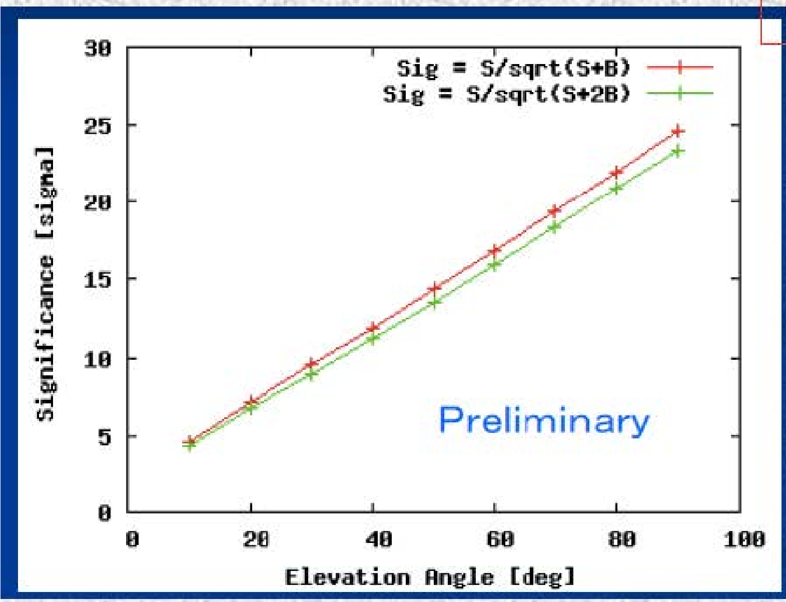


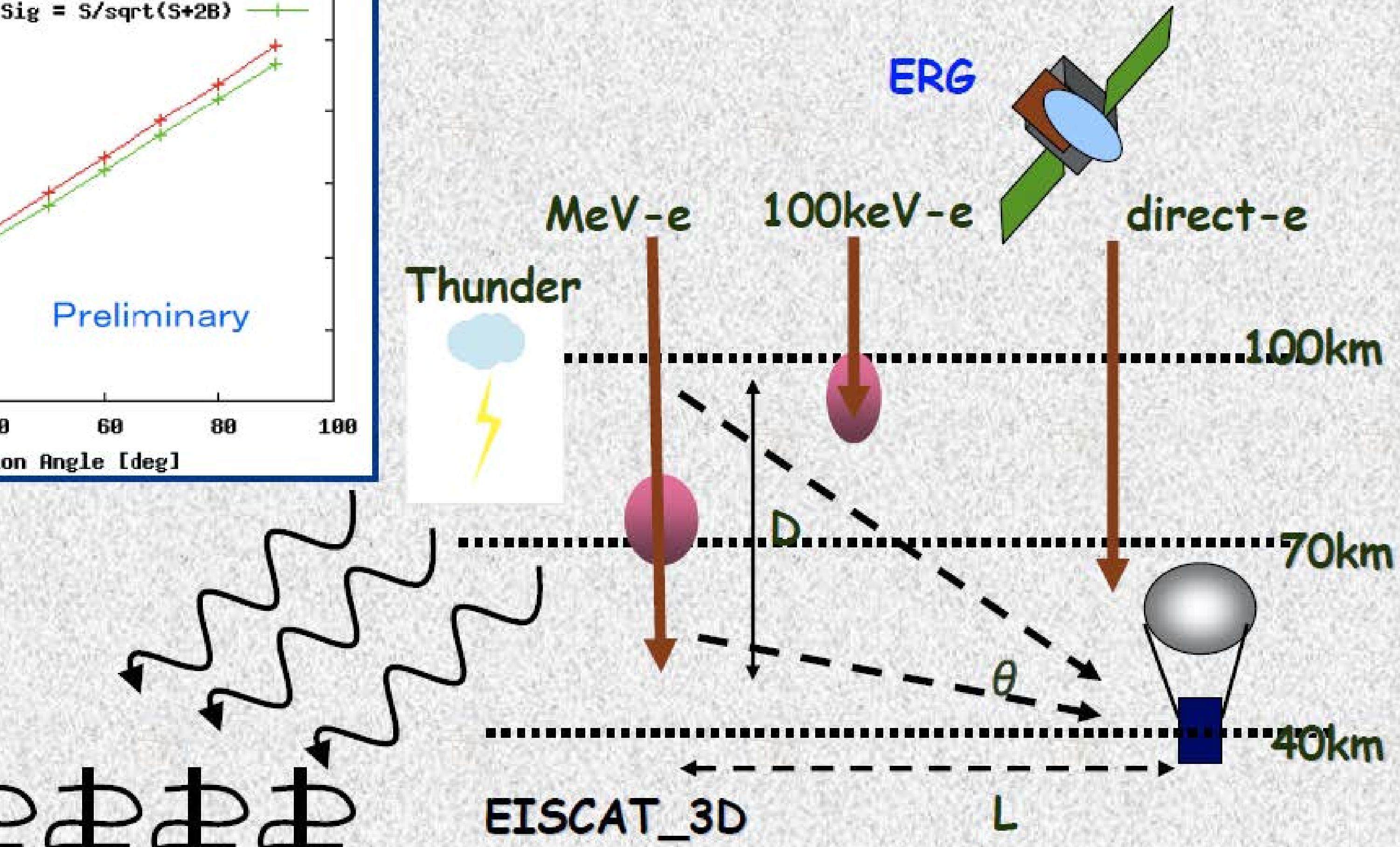
- Similar scale burst
  SIMILE-II(30x30x30cm ETCC)
  100kev-2MeV
  ~20σ detection for imaging Δθ 10°
  Good Spectroscopy from large crystal arrays.
  Wide field of View with ~3str
- Fixed point observation
  - -> spatial or temporal
- Direct Measurements of high energy electrons, proton, neutron and nucleus

Rep-burst observation

Wide FoV imaging-> Direction, Position
Spectroscopy, Light Curve,

γ-ray spectrum—>Depth of burst
D & θ -> L (Distance)





30×30×30cm^3 ETCC current status

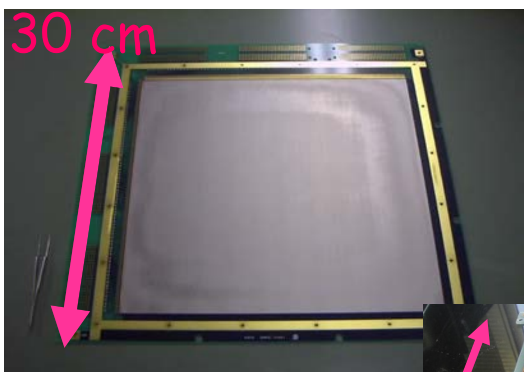
We are developing a larger ETCC based on the 30cm ×30cm×30cm TPC and 6 x 6 scintillation cameras.

➢ Gaseous TPC

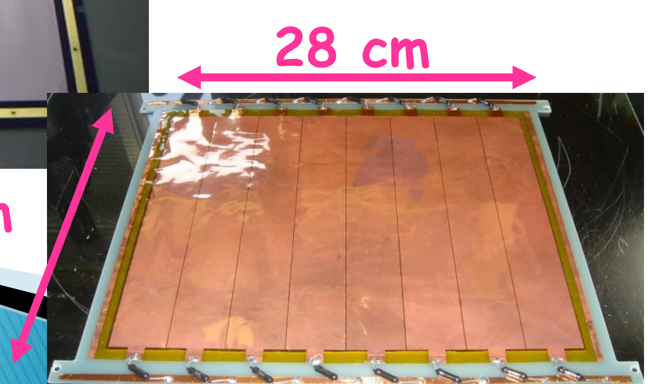
- volume : 30×30×30 cm^3
- gas : Ar 90% + $C_2H_6$10% (1atm)
- drift velocity : 4 cm/μsec
- gain : ～30000
- energy resolution : 46%@32keV
- position resolution: 400μm

➢ Scintillation Camera

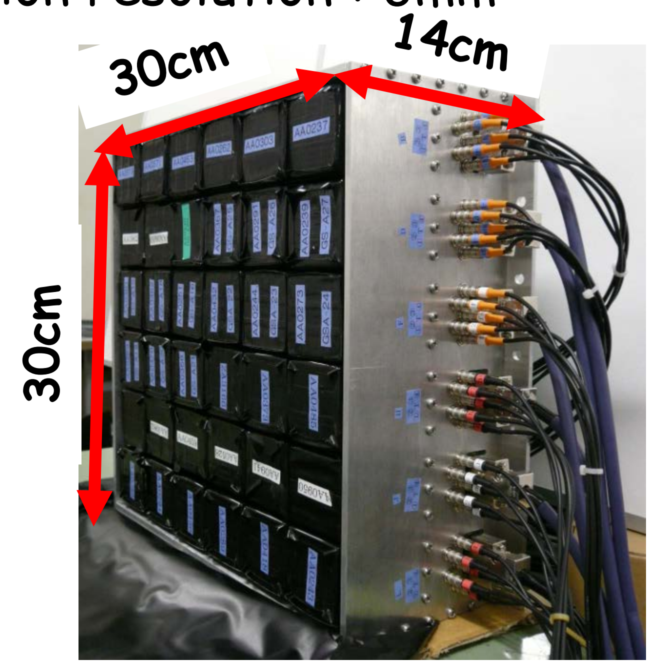
- number of pixels : 2304 pixels
- Crystal : GSO(Ce)
- pixel size : 6×6×13mm^3
- energy resolution : 10.9% (@662keV, FWHM)
- position resolution : 6mm



30cm x 30cm μPIC



GEM



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

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- gas : Ar 90% + $C_2H_6$10% (1atm)
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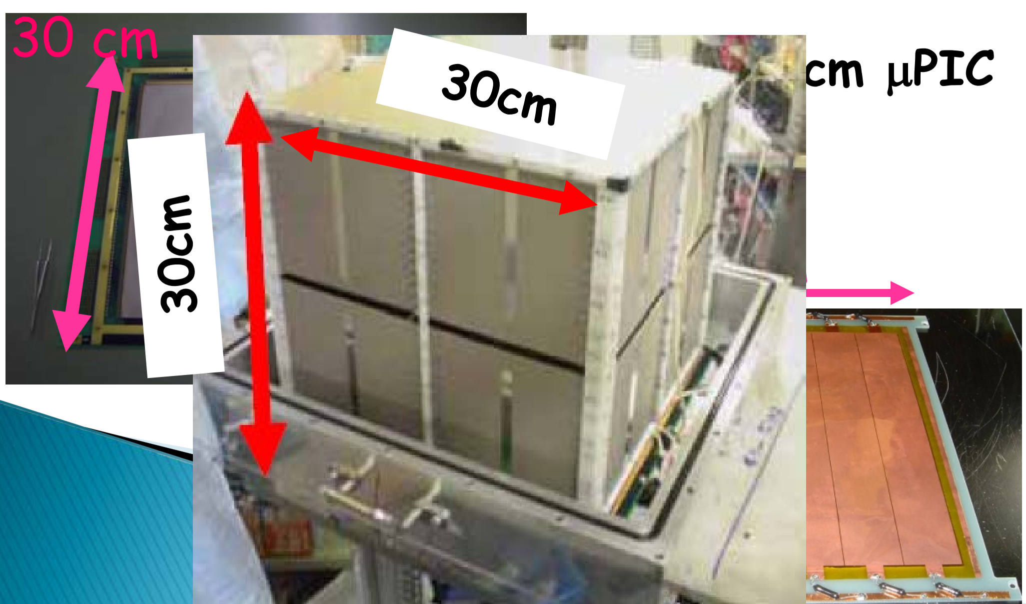
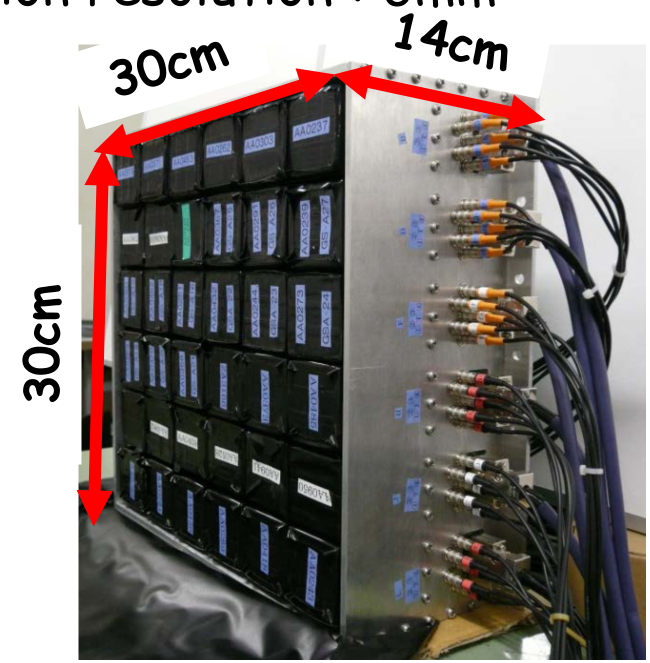
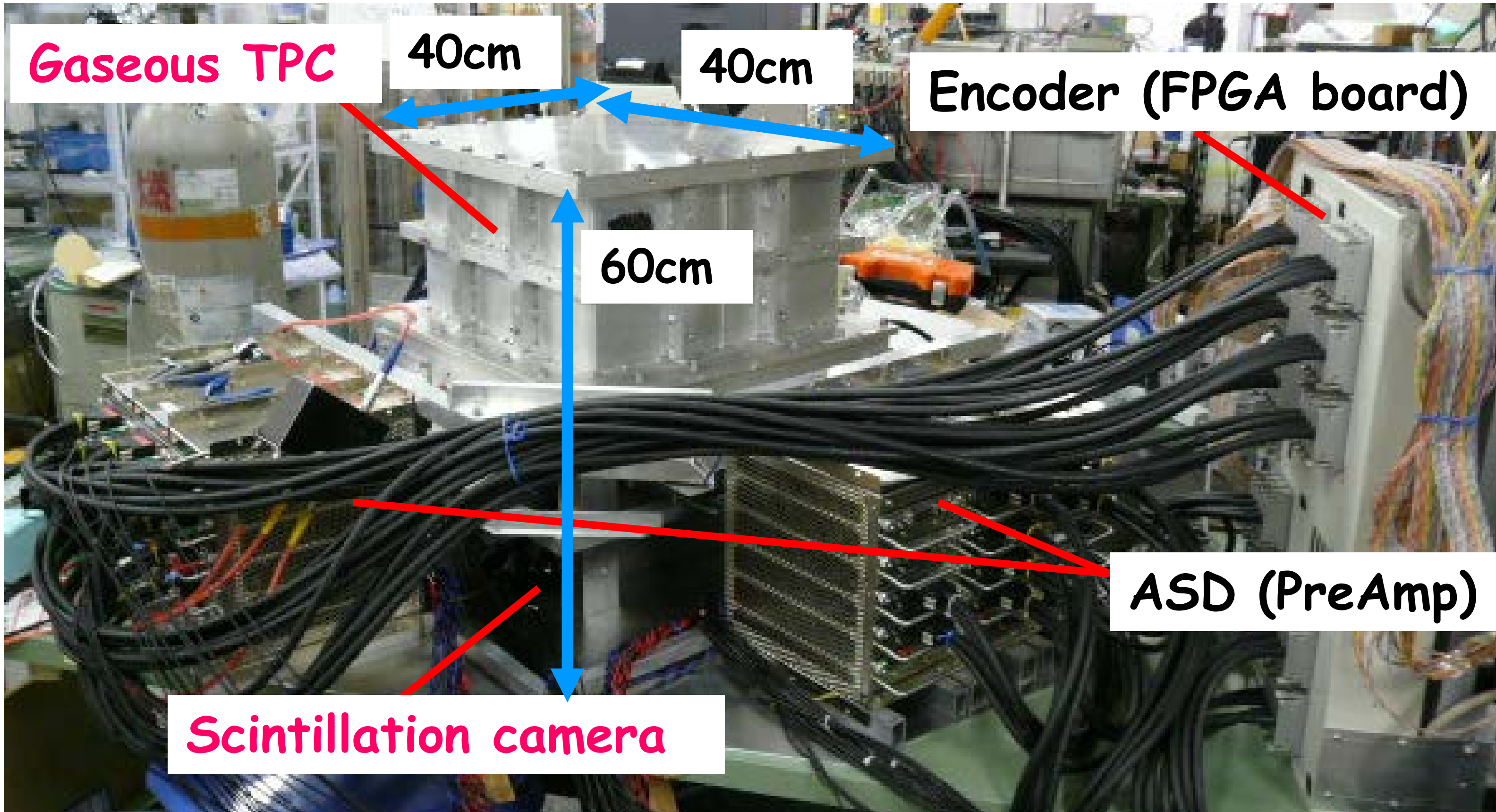
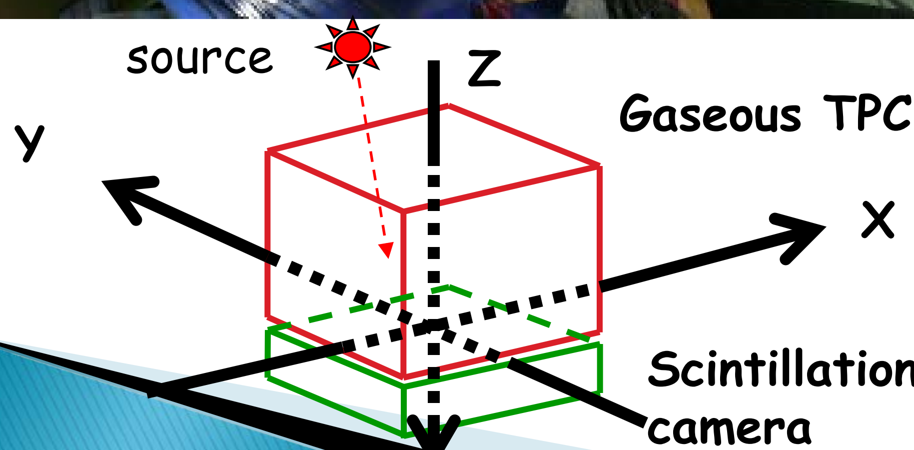






Setup



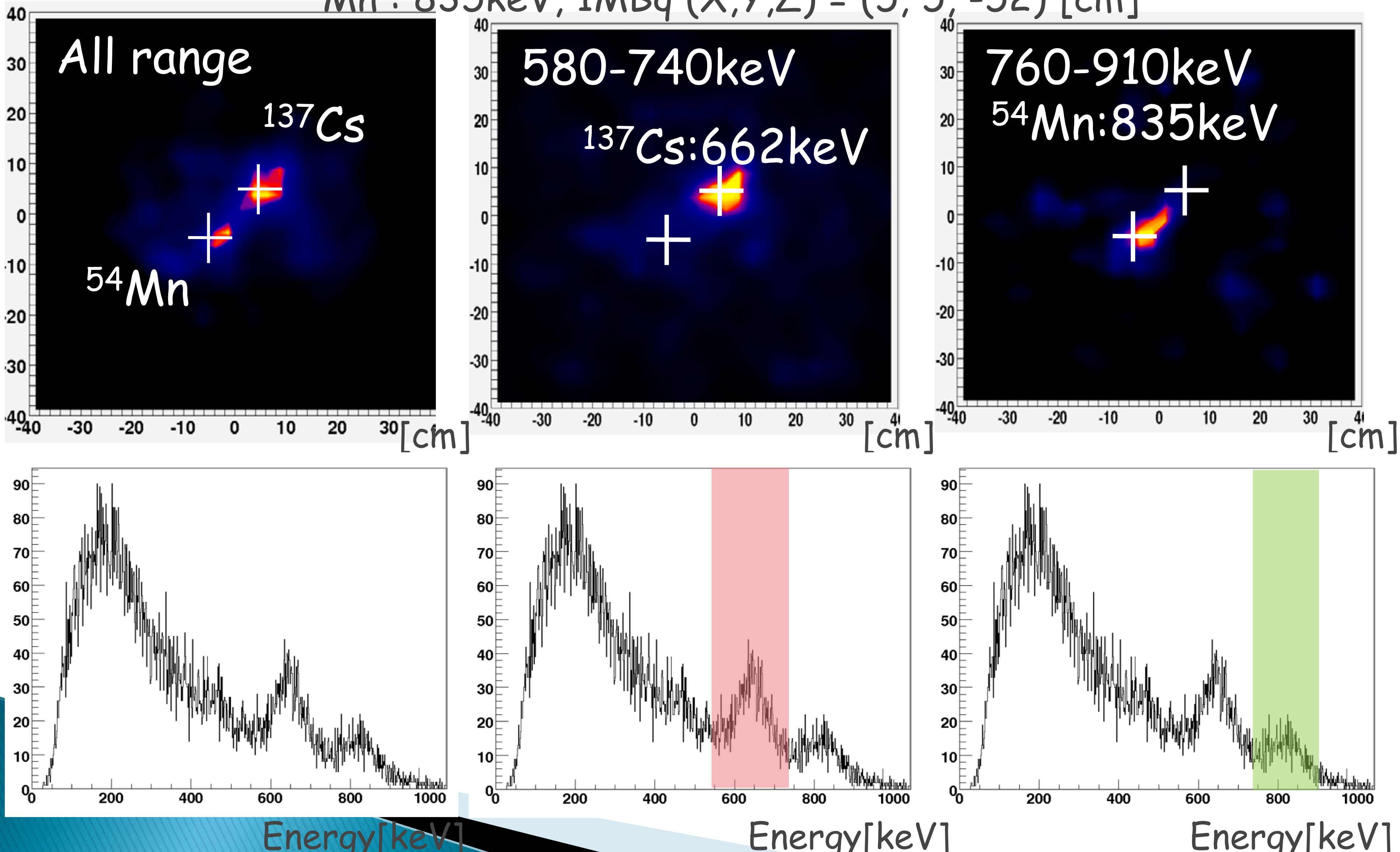
Center of μPIC :(0,0,0)

Center of Scinti.

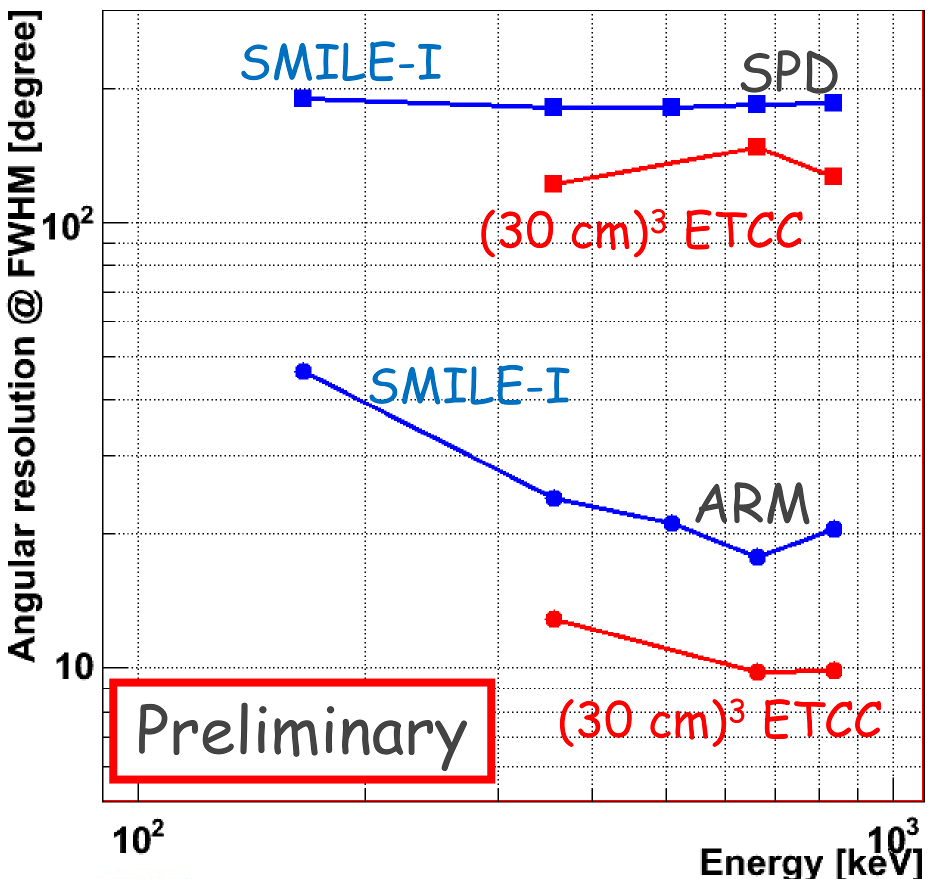
:(-3.3, 0.2, 5.7)

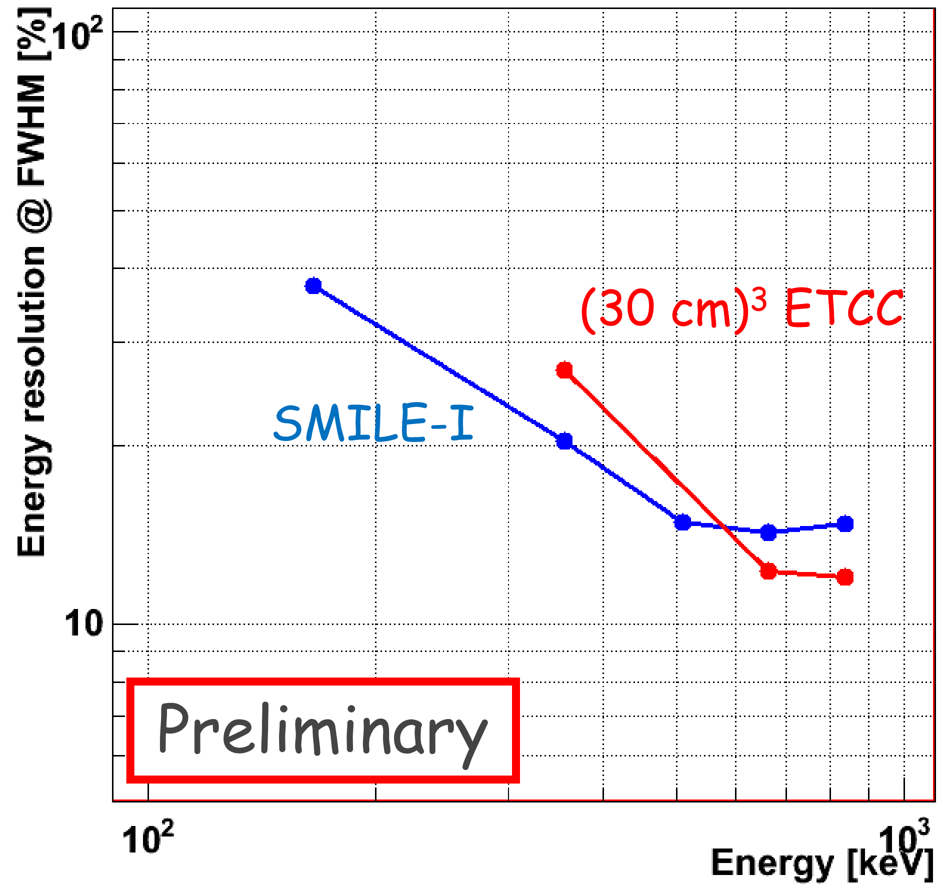
simultaneous imaging (preliminary)

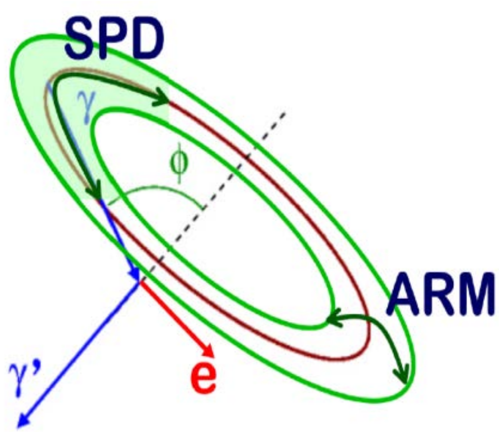
^{137}Cs : 662keV, 1MBq (X,Y,Z) = (5, -5, -52) [cm]
^{54}Mn : 835keV, 1MBq (X,Y,Z) = (5, 5, -52) [cm]



Angular resolution, Energy resolution







SPD: 147[deg] ⟺ 183[deg]
ARM: 9.8[deg] ⟺ 17.7[deg]
DE/E: 12.3% ⟺ 14.3%
(FWHM) @662keV — SMILE-I

ARM : Angular Resolution Measure
SPD : Scatter Plane Deviation

Saving power consumption of the readout

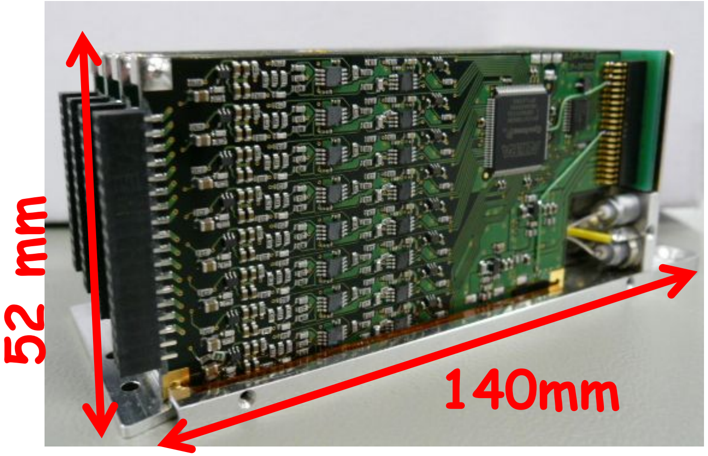
SMILE-I The power of readout system

33 PMTs : ~80 W
(10 cm)^3 μ-PIC (1024ch) : ~70 W

SMILE-II

~200 PMTs
(30 cm)^3 μ-PIC (1536ch)

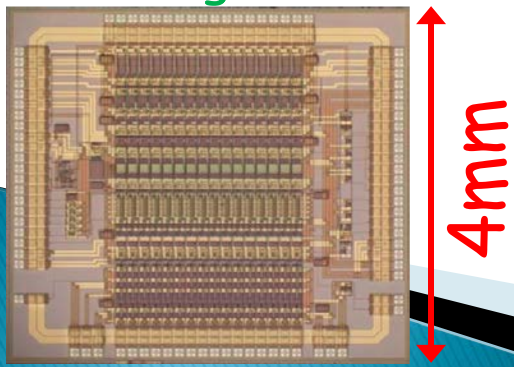
- For scintillation camera (CP80190 Clear Pulse)



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

Collaborator: M. Tanaka, and Y. Fujita (KEK)

- ASIC for gaseous TPC with a 0.5 μm-CMOS



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

Developments around detector

- Batteries
  - solar panel and Li-ion batteries for long duration balloon
- Attitude control
  - azimuthal control for tracking of celestial object and solar
  - sensors for knowledge of gondola attitude
- Design of structure
  - Design of gondola
    - for mechanical stability during balloon flight
    - for minimal damage of detector and sensors at the landing
- Thermal design
  - calculation of thermal balance
- Telemetry and Command
  - monitoring and control of all systems at anytime

Batteries

SMILE-I

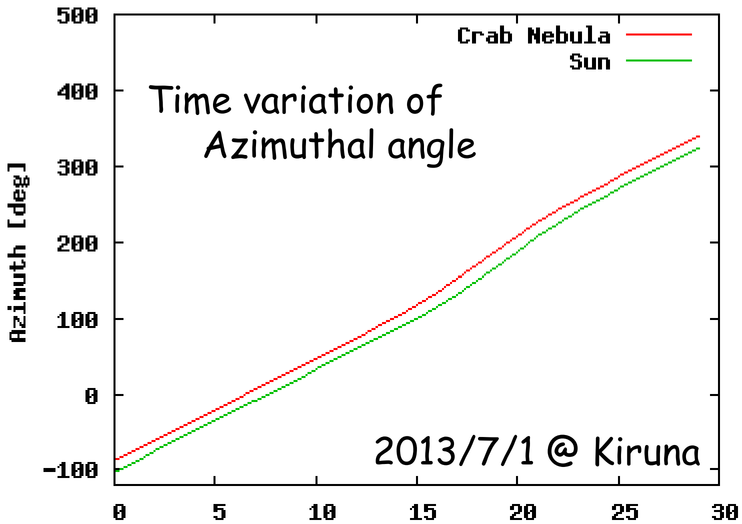
- only Li batteries (primary chemistry)
- Batteries capacity: 350W, 30h (flight + dressed rehearsal)
- Weight of batteries: 40kg (10% of gondola weight)
- All system power were generated by the regulators. (loss: 100W)

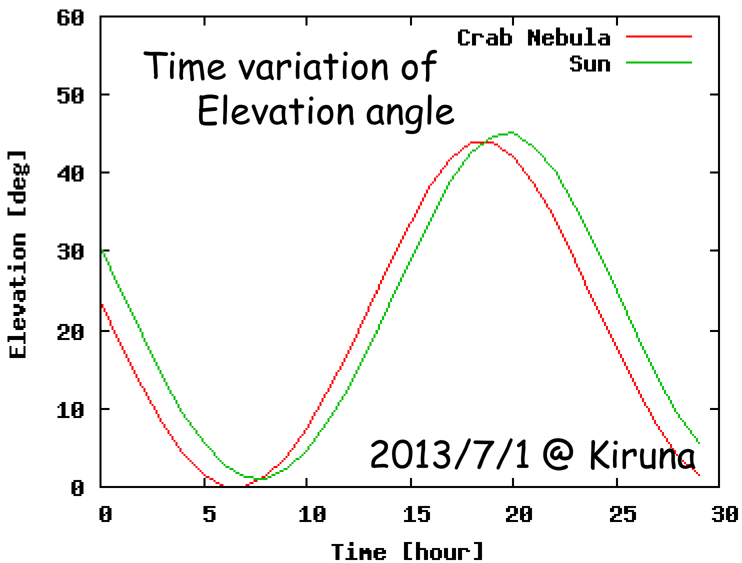
SMILE-II

- Long duration balloon (~2 weeks)
- System will require the power (batteries output) of ~400W.
- The elevation angle of sun depends on the local time.

➢ Solar panel and Li-ion batteries system
➢ Charge/Discharge control system
➢ System power will be generated by the DC to DC converters.
  (candidate of DC/DC: COSEL SFS series)

Attitude control





- The observation target of SMILE-II will be Crab nebula.
- The azimuthal and elevation angle of celestial objects are changing by time and position.
- Thus, we need to trace the target.

SMILE-II

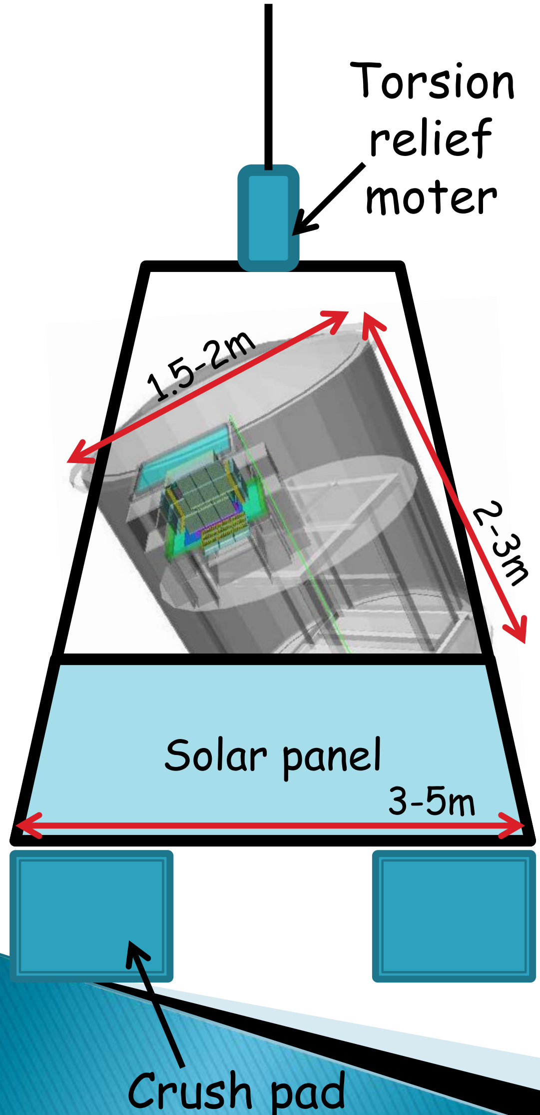
Field of View : ~3 sr

Angular resolution : 5-10°

Requirements

- The resolution of the attitude knowledge will be ~0.1°.
  GPS compass, clinometer,
  geomagnetic aspectmeters
- The accuracy of the attitude control is ~10°.
  only azimuthal control
  by the torsion relief motor

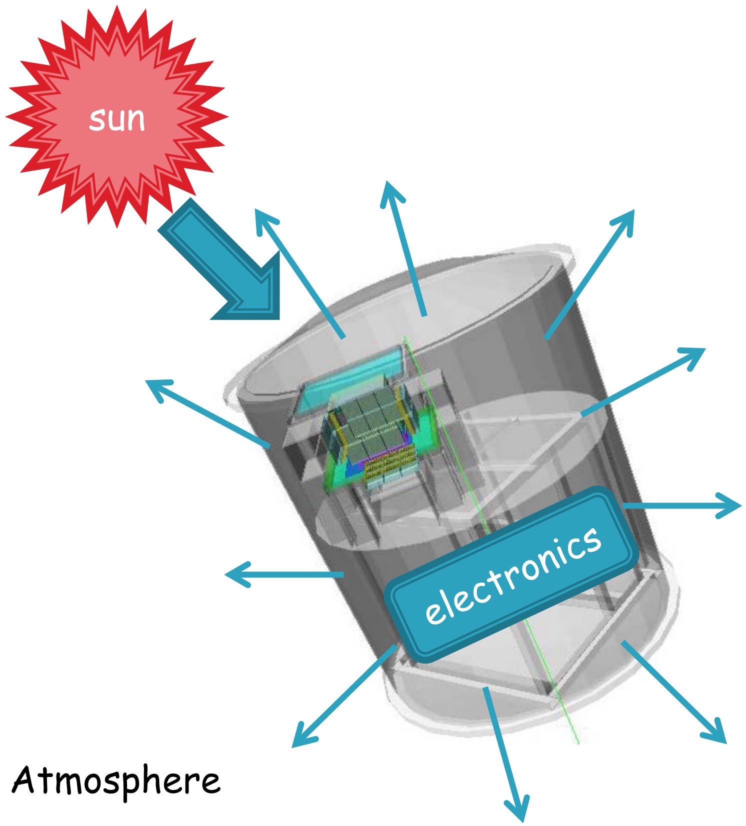
Design of structure



- The weight of gondola will be 500-700 kg.
- The elevation angle of the pressured vessel will be 60-70 degrees.
- The impact of the landing will be >30 G.

- All components must be fixed on the gondola frame rigidly.
- At the landing, the gondola frame and the crush pad must absorb the impact, for the minimal damage to the systems.

Thermal design



Sources :

- Pressured vessel
  electronics (power < 400W)
- Sun (daytime)
- Atmosphere

	40km	15km
pressure	3hPa	120hPa
density	4g/cm^3	195g/cm^3
temperature	-27°C	-60°C

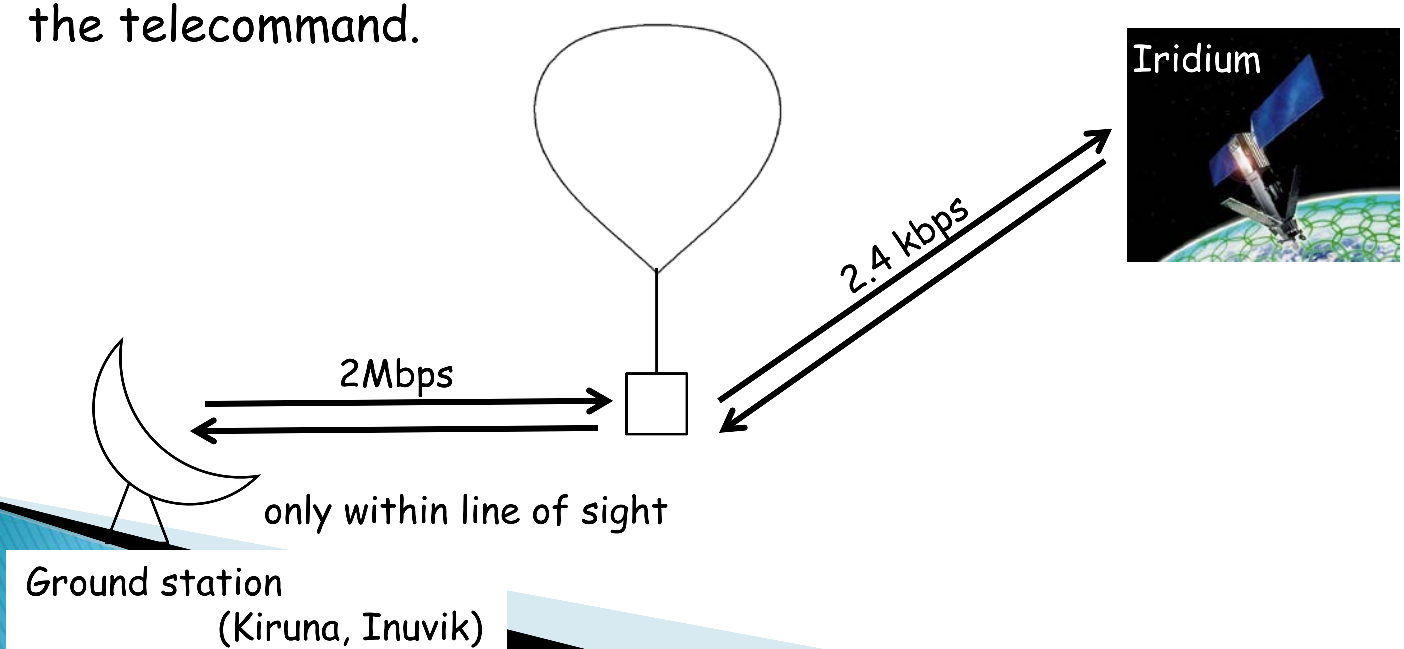
(at Taiki, Japan)

- ➢ There is a big difference of thermal input between noon and midnight.
- ➢ The electronics must be kept in the range of the operation temperature.
- ➢ The solar panel and the Li-ion batteries have a dependence on temperature.

Calculation of thermal balance is very important!

Telemetry & Command

- We must control and monitor the system at anytime.
- Our hands can not reach at the altitude of 40km, of course, we thus use telemetry and telecommand.
- Because we can not see the balloon over the horizon, we use Iridium satellite connection (2.4 kbps/channel).
- In the circumpolar balloon flight launched from Kiruna, we can use also 1Mbps downlink in Kiruna launch pad and Canada downlink station.
- We need to develop the encoder of the telemetry and decoder of the telecommand.



Thank you!

If you have any question,
please send e-mail to cr-bal@cr.scphys.kyoto-u.ac.jp

http://www-cr.scphys.kyoto-u.ac.jp/research/MeV-gamma/en/index.html