

# A Balloon-Borne sub-MeV/MeV Gamma-ray Compton Camera Using an Electron-Tracking Gaseous TPC and a Scintillation Camera (SMILE)

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## Abstract

We have been developing an Electron-Tracking Compton Camera (ETCC) to open up a window for MeV gamma-ray astronomy. We successfully performed the first balloon experiment in 2006 to detect diffuse cosmic and atmospheric gamma rays (SMILE-I). To build on the success of SMILE-I, we plan to launch a large ETCC to observe celestial objects to test its imaging properties (SMILE-II). To attain this, we are developing a large ETCC using a (30 cm)<sup>3</sup> TPC and low power consumption readout modules for the flight model.

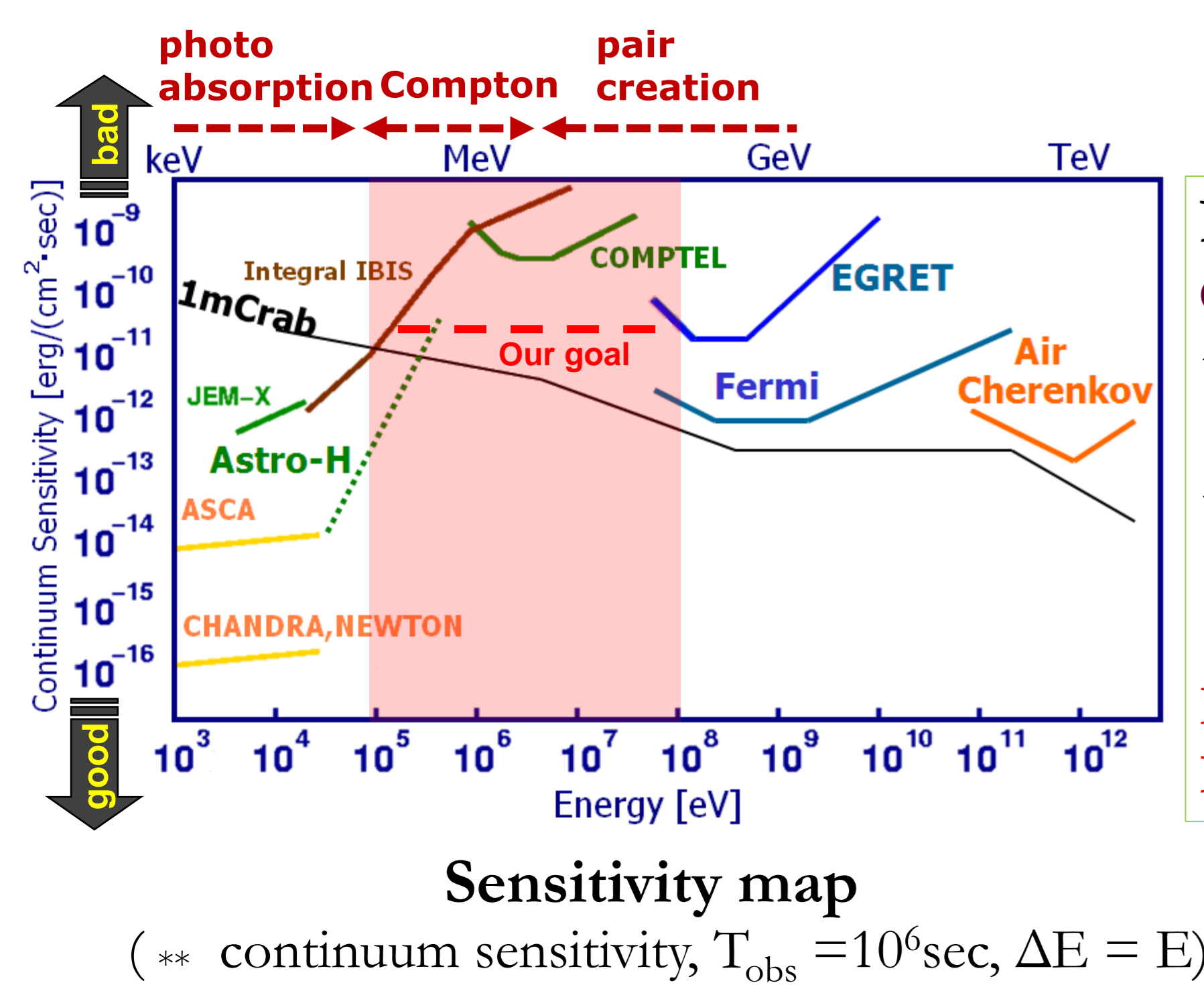
## 1. MeV Gamma-ray Astronomy

### Line gamma rays

- ✓ Nucleosynthesis products : <sup>26</sup>Al, <sup>44</sup>Ti, <sup>57</sup>Co, <sup>56</sup>Co, <sup>56</sup>Ni
- ✓ Electron-positron annihilation in Galactic center

### Continuous radiation from candidates of cosmic-ray origin

- ✓ leptonic: Synchrotron + Inverse Compton scattering
- ✓ hadronic:  $\pi^0$  decay with characteristic cut off at  $\sim 70$  MeV



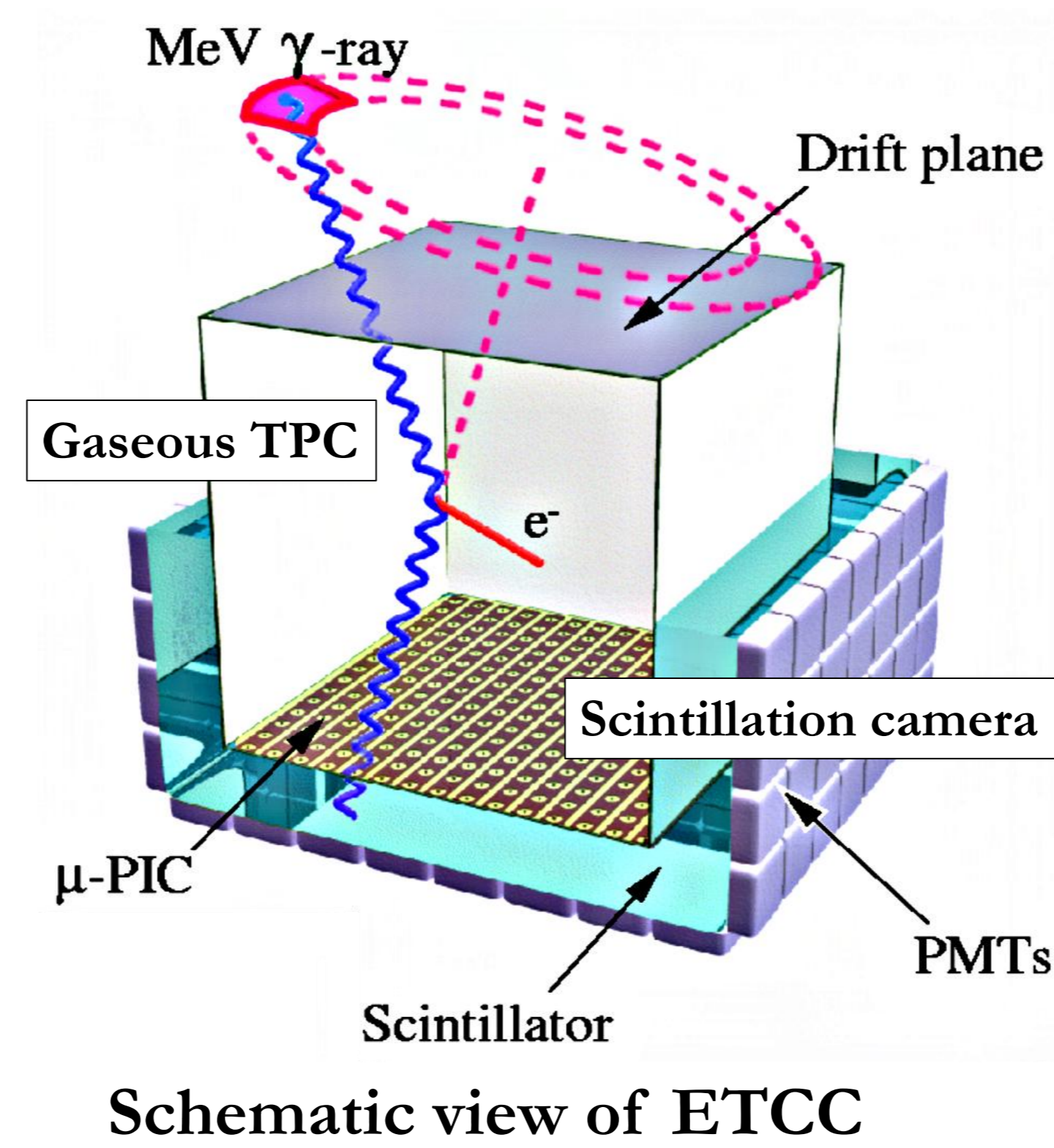
### Previous Observations

- COMPTEL (CGRO)[1]
- ✓ Classical Compton Imaging IBIS, SPI (INTEGRAL)[2]
- ✓ Coded Aperture Imaging  $\Rightarrow$  high background  $\Rightarrow$  low sensitivity
- Reduction of background is IMPORTANT in MeV band.**

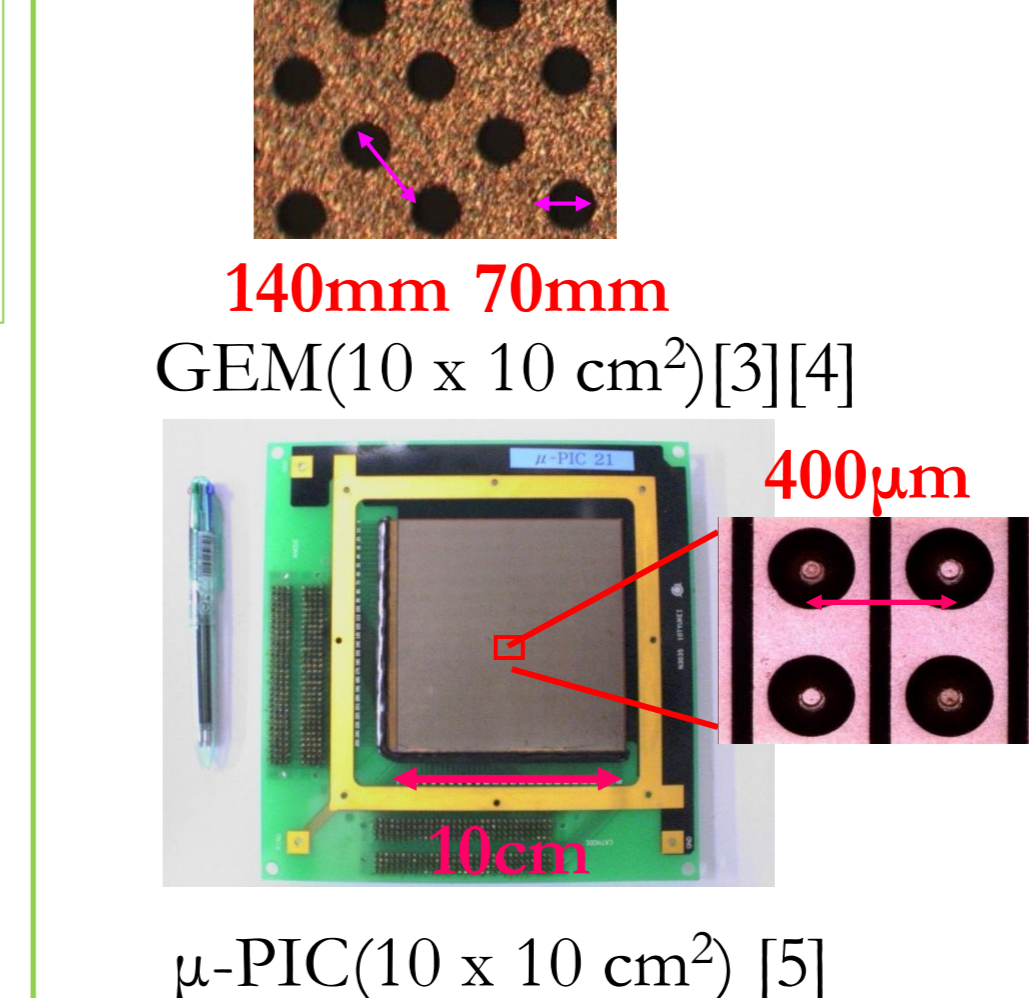
## 2. Electron-Tracking Compton Camera (ETCC) Using a Gaseous TPC and a Scintillation Camera

### Compton Method + Electron Tracking

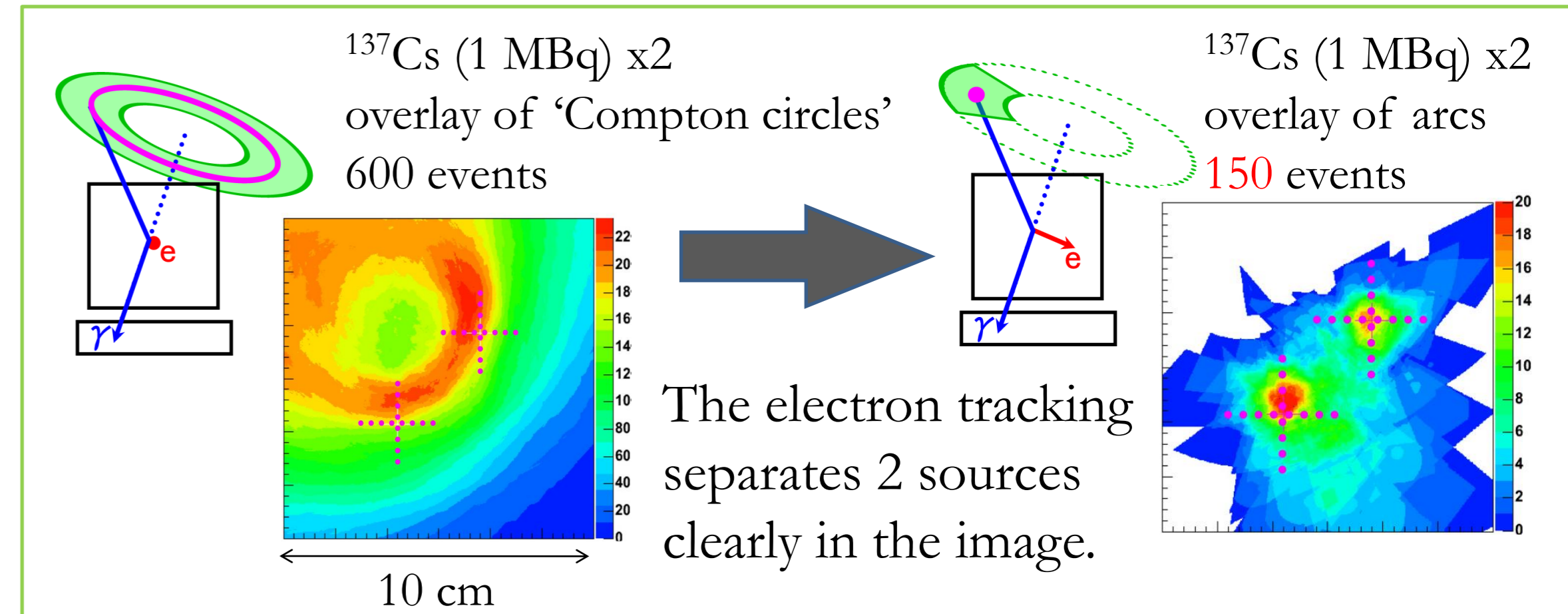
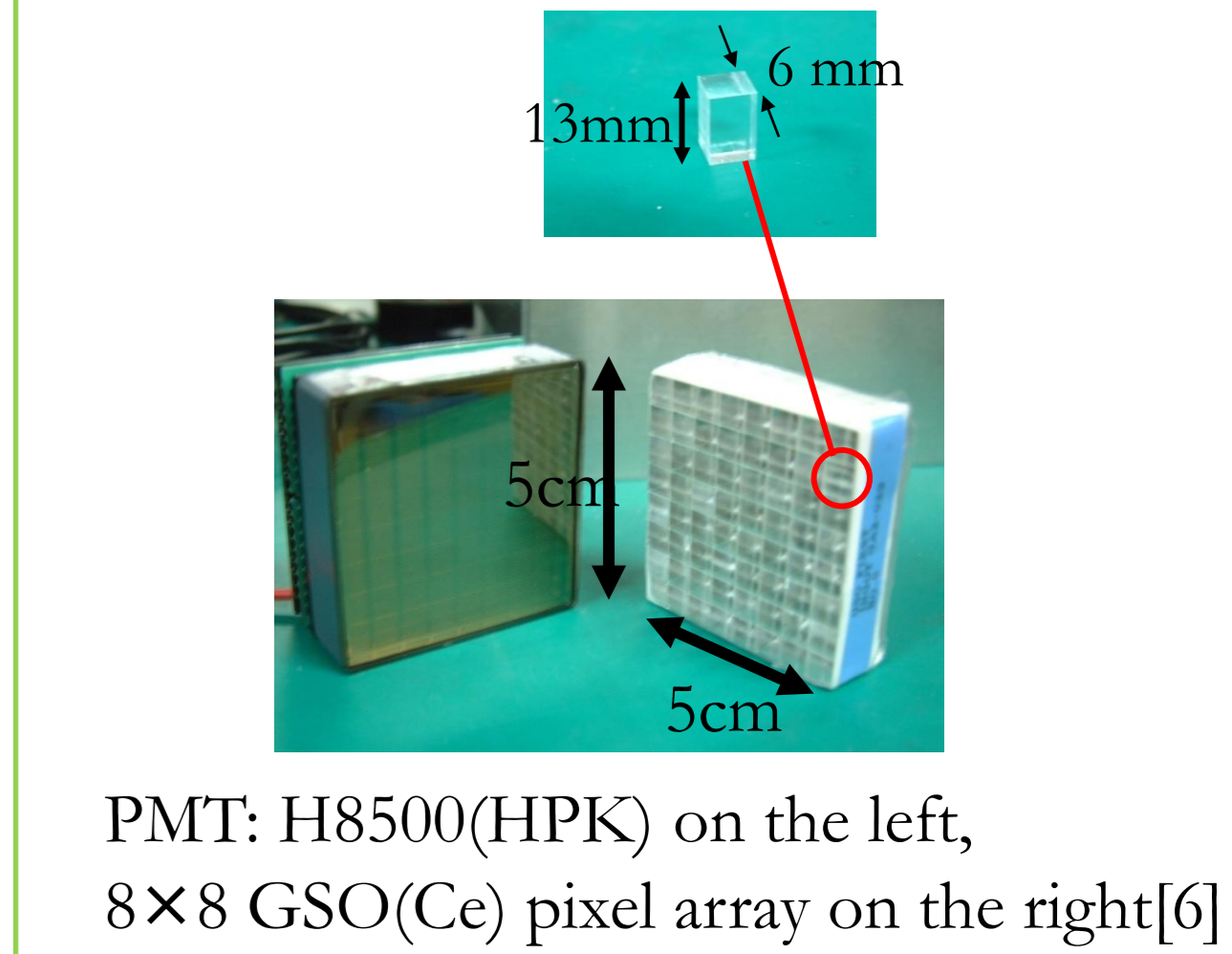
- ✓ Full reconstruction for each photon
- ✓ Kinematical background rejection
- ✓ Wide FOV:  $\sim 3$  str



### Gaseous TPC



### Scintillation camera



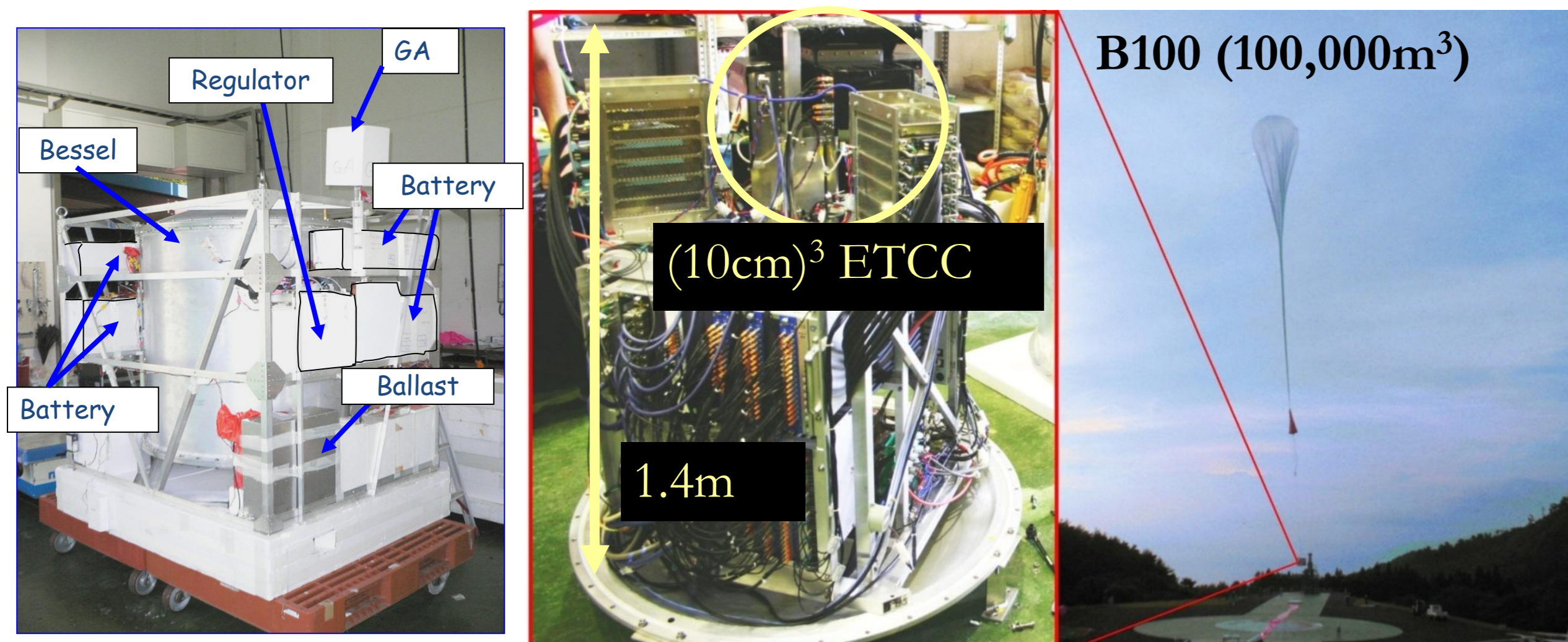
## 3. SMILE Project

### (Sub-MeV gamma-ray Imaging Loaded-on-balloon Experiment)

### Road map of SMILE

#### SMILE-I: 10cm cube camera in Sanriku, Japan (Sep. 1<sup>st</sup> 2006) [7]

- ✎ Operation test at balloon altitude
- ✎ Observation of diffuse cosmic/atmospheric gamma rays  $\sim 400$  photons during 3 hours (100 keV $\sim$ 1MeV)



Gondola, ETCC and balloon at SMILE-I

#### SMILE-II: 30cm cube camera (2012 ~)

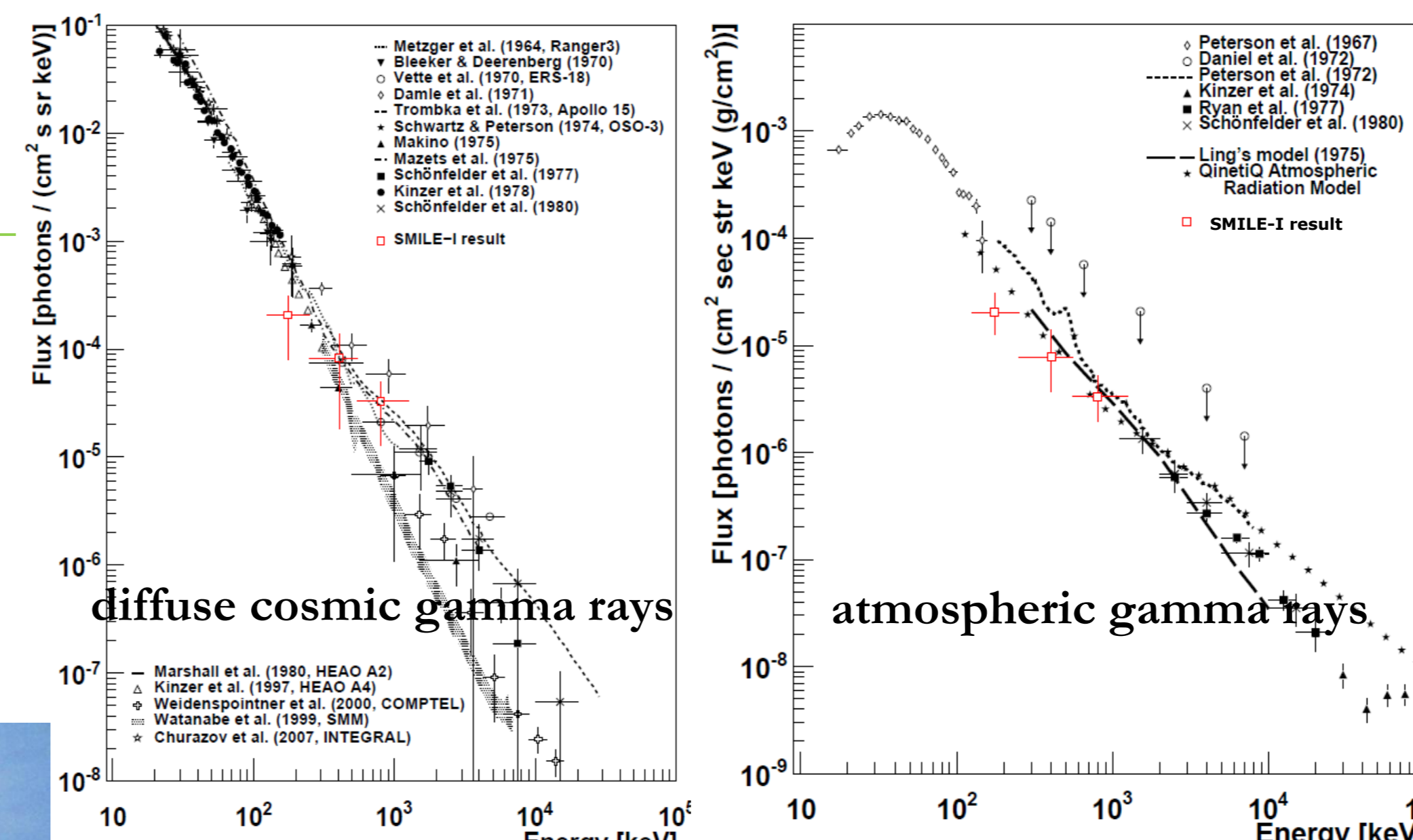
- ✎ Large system test in Taiki, Japan (2012)
- ✎ Observation of Crab/Cyg X-1 in Kiruna, Sweden (2013)

#### SMILE-III: 40cm cube camera (2014~)

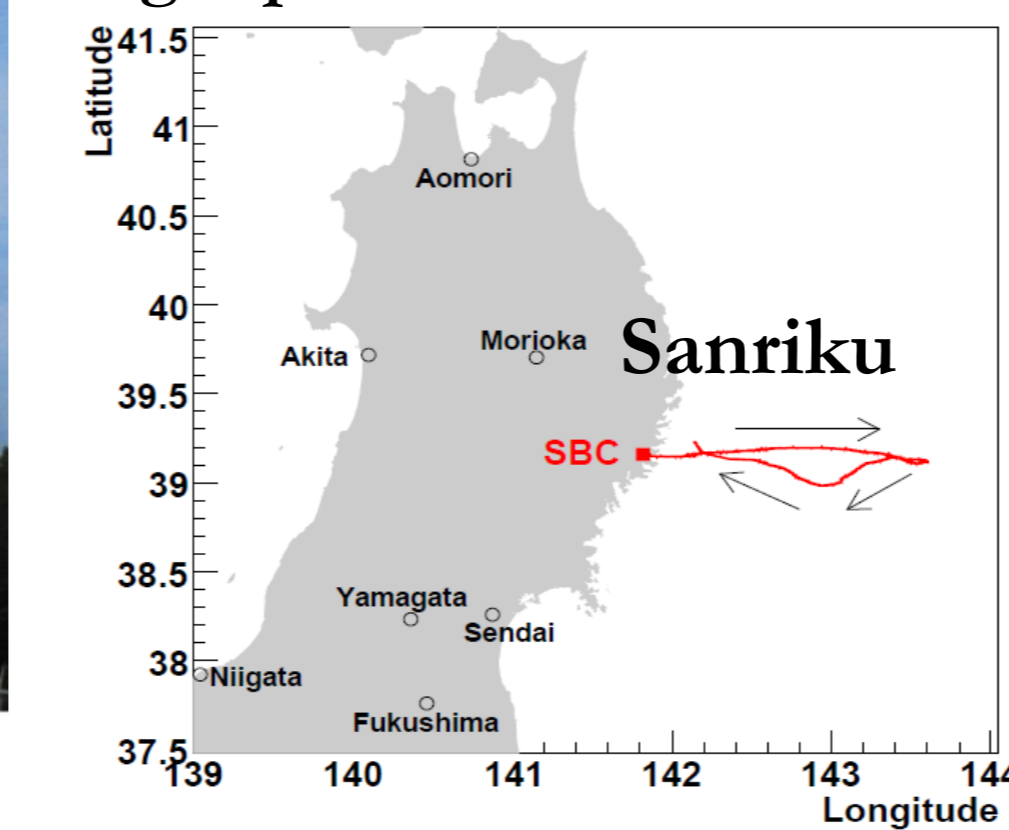
- ✎ Adding pair-creation mode

#### SMILE-IV: 50cm cube camera

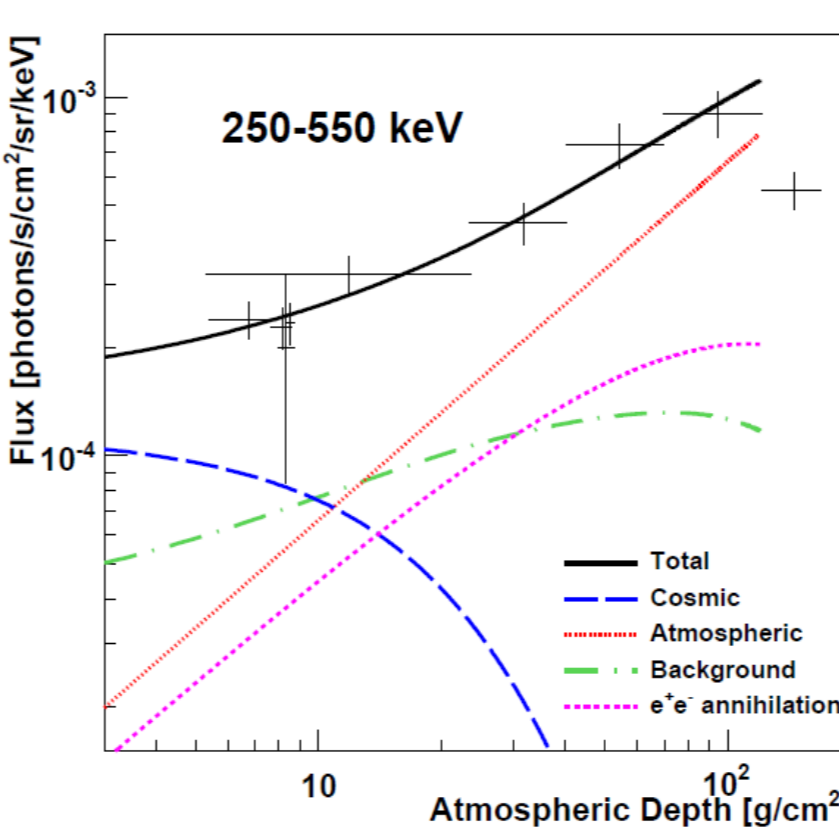
- ✎ All sky survey (loaded on a satellite)



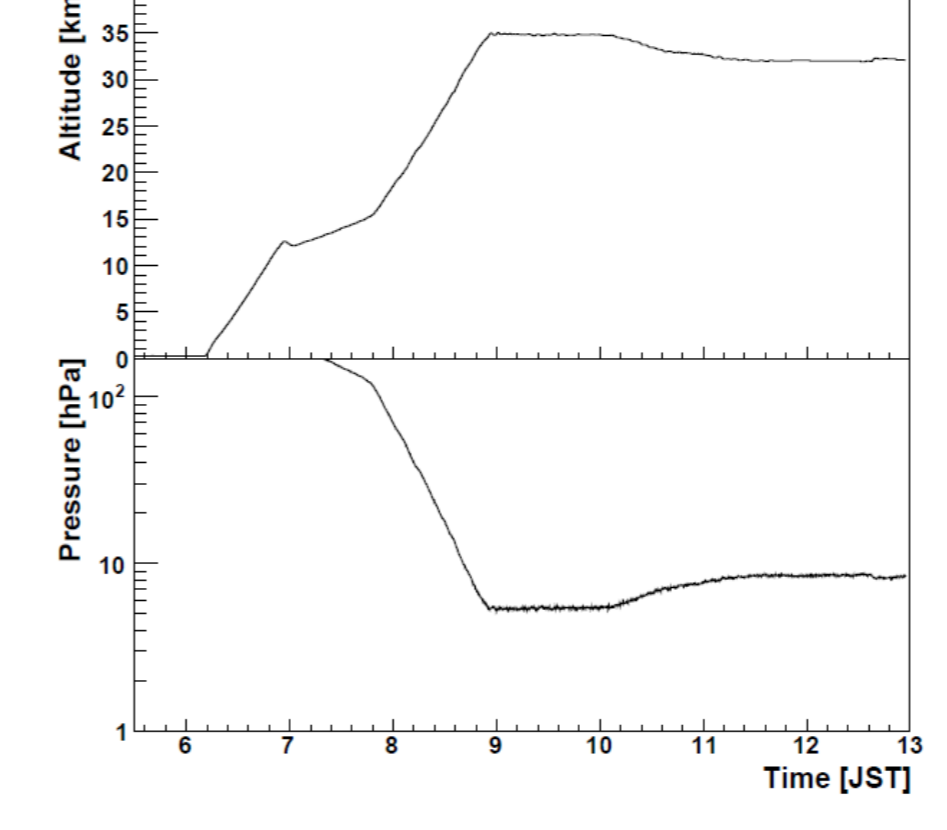
### Flight path



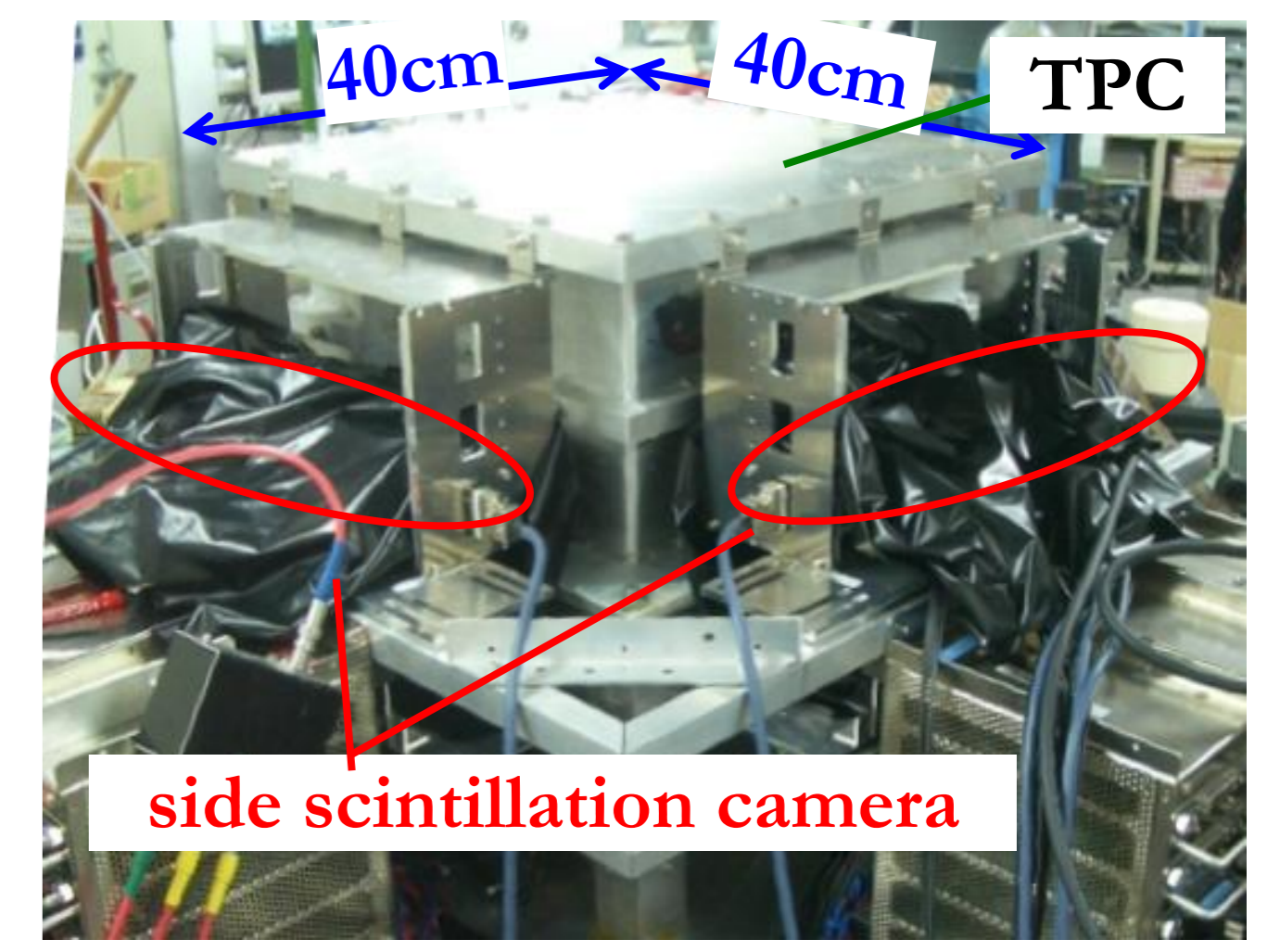
### Growth curves



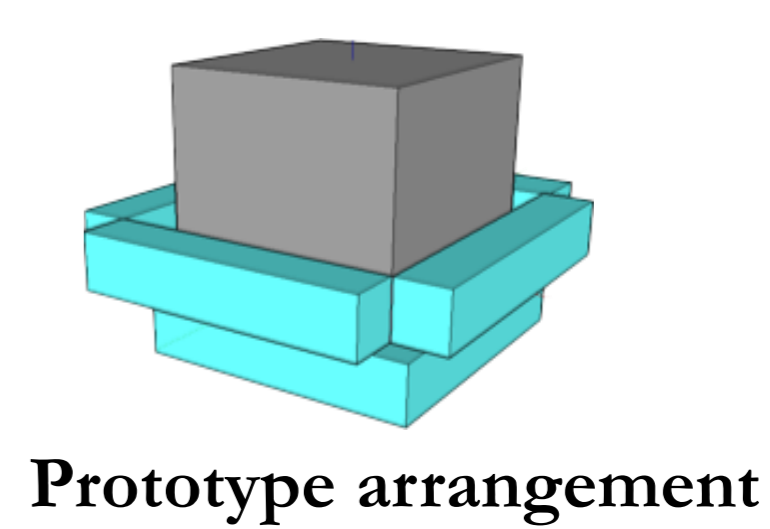
### Balloon altitude at SMILE-I



## 4. Development for Larger ETCC

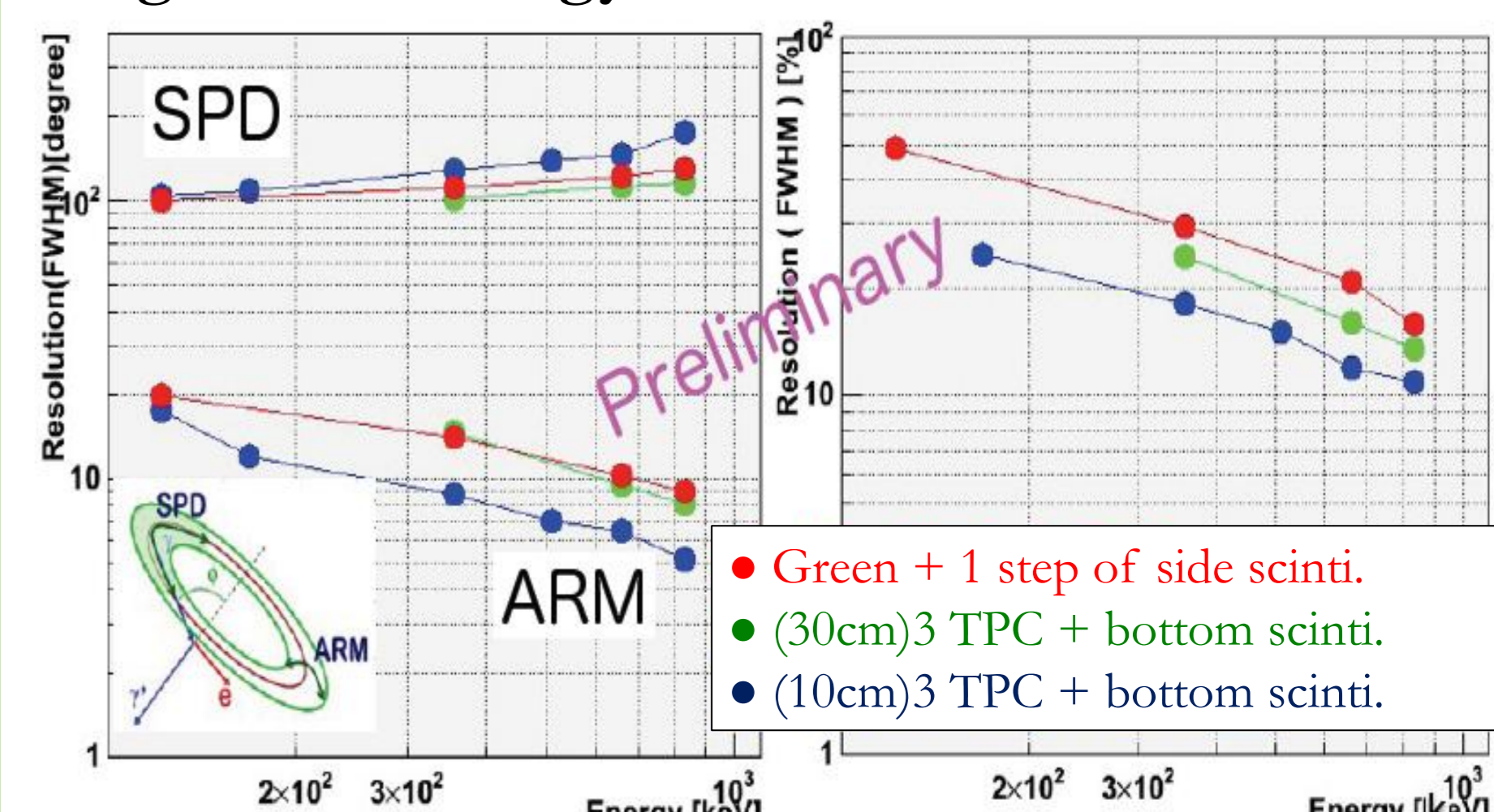


Prototype (30cm)<sup>3</sup> ETCC [8]



- Bottom  $\checkmark$  36 PMTs
- Side  $\checkmark$  4 x 6 PMTs

### Angular and energy resolutions



## 5. Readout Circuit for Lower Power Consumption

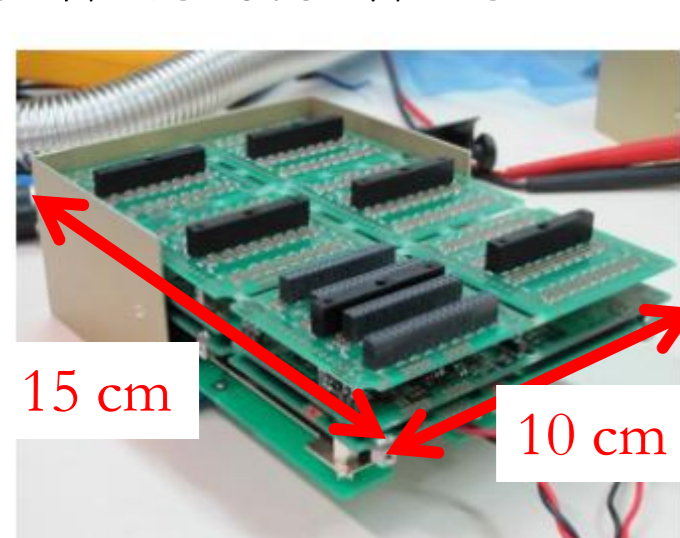
### Read-out board based on ASIC "FE2009bal" chips for TPC

240 W to 80 W for a (30cm)<sup>3</sup> ETCC



### Read-out module for Scintillation camera

2.6 W to 0.6 W for 1 PMT



## 6. Revision of Track Data Read Logic

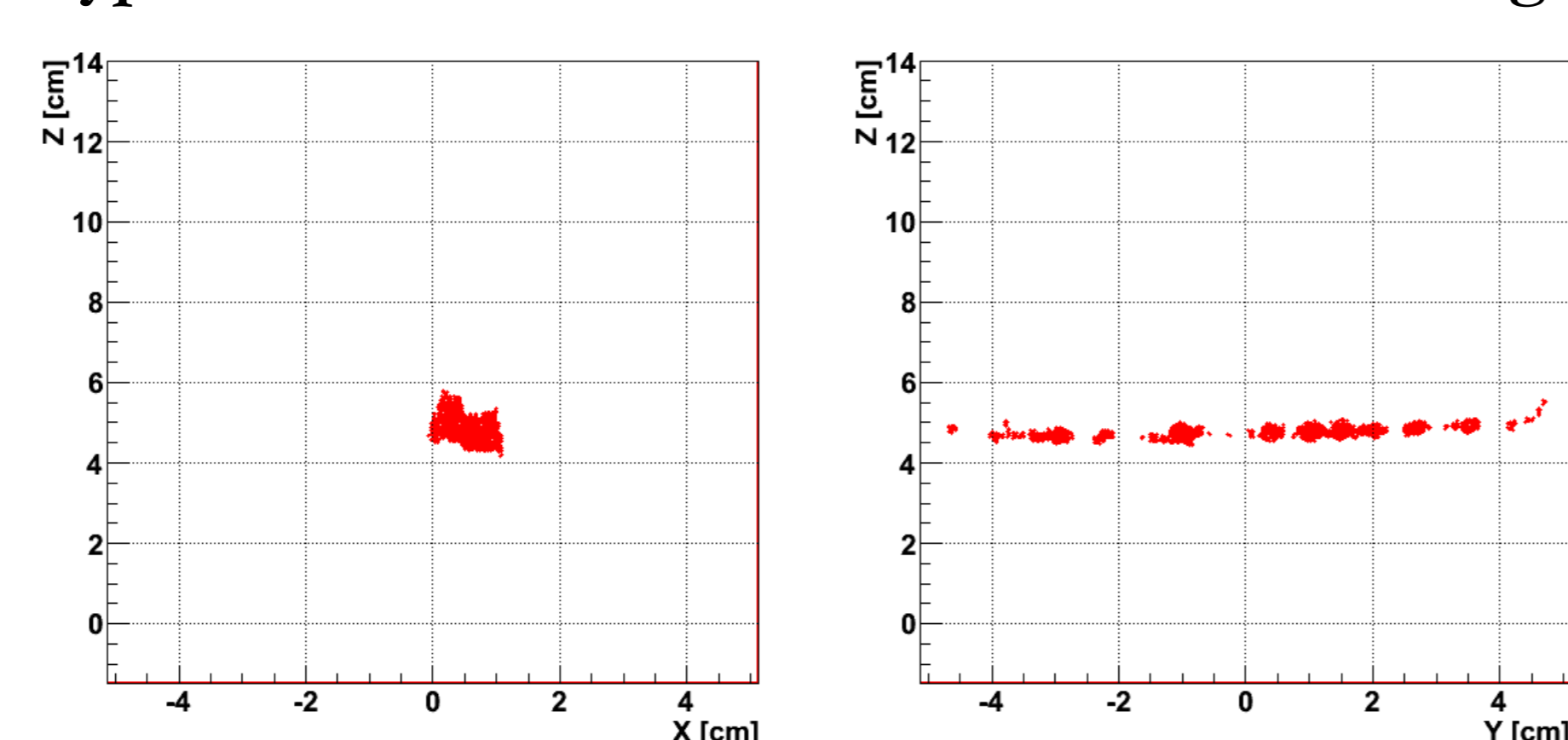
### Previous logic

- ✓ Only rising time of signals at each clock
- ✓ Mean of the two edge positions among hit data

### New logic

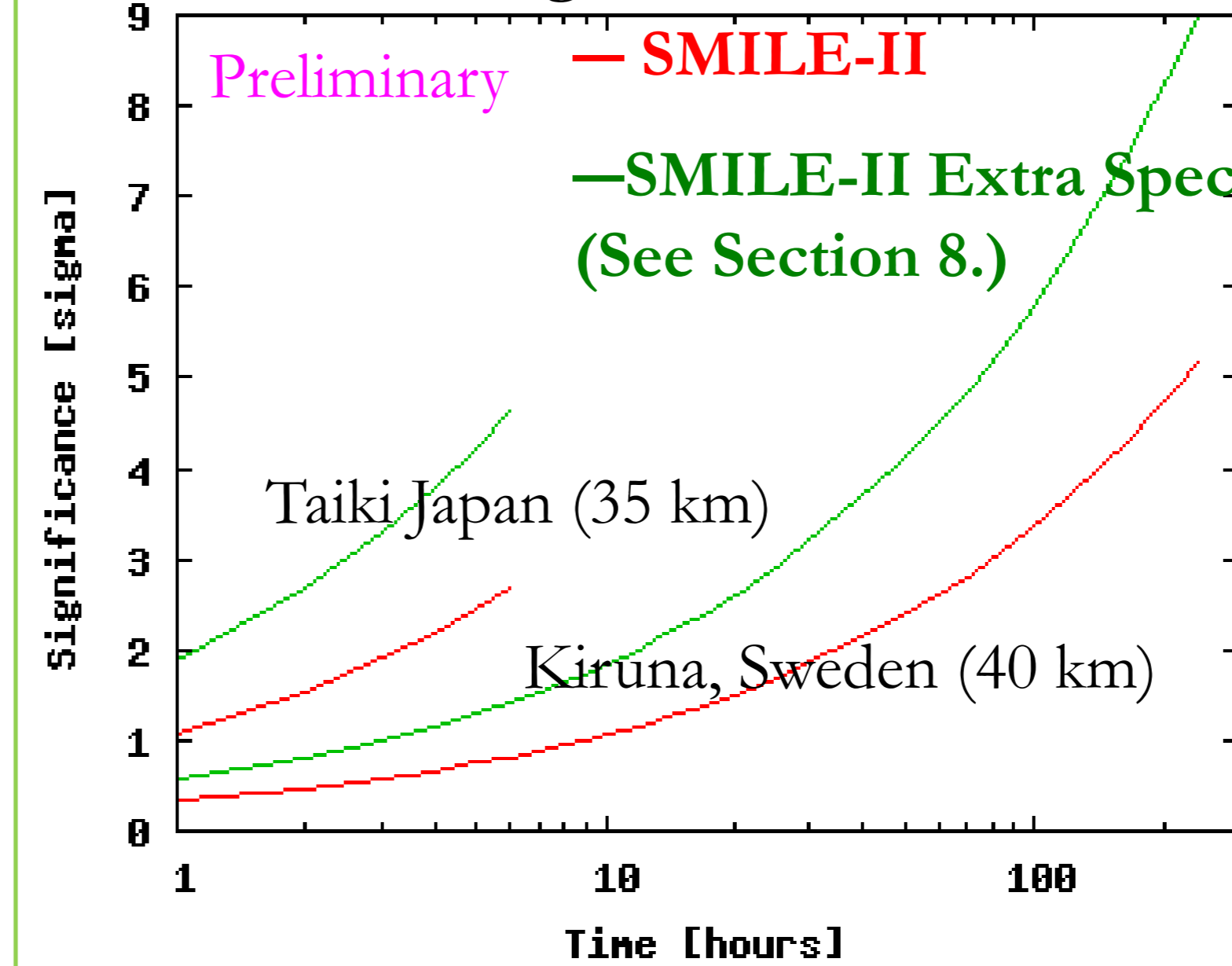
- ✓ Not only rising but also falling time
  - ✓ All of the hit position
- The vertex and the direction of Compton-recoil electron are expected to be measured more precisely.

### Typical cosmic muon track took with the new logic



## 7. SMILE-II Flight Model

### Calculated significance for Crab



- ✓ Extrapolated Ling's model[9] for flux of Crab
- ✓ Background intensity in Kiruna is assumed to be 5 times higher than that in Taiki.
- ✓ Using the method of Maximum Likelihood - Expectation Maximization

## 8. Future prospect

- 24-hour power supply system using solar cell and rechargeable batteries.
- Light TPC based on a vessel made of PET. (Extra item)
- filling gas of CF<sub>4</sub>-mixed gas at 1.5 atm. (Extra item)
- Attitude control system to orient celestial objects. (Extra item)

## 9. Reference

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- [2] C. Winkler *et al.* *A & A* **411** (2003) 1
- [3] F. Sauli, *NIM A* **386** (1997) 531
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- [7] A. Takada *et al.* *ApJ* **733** (2011) 13
- [8] K. Ueno *et al.*, *IEEE Conf. Rec.* (2008) N65-8
- [9] L.M. Bartlett *et al.* *AIP conf. Proc.* **304** (1994) 67
- [10] J. Ling, *J. Geophys. Res.* **80** (1975)