Development of the Balloon-Borne sub-MeV Gamma-ray Compton Camera Using an Electron-Tracking Gaseous TPC and a Scintillation Camera

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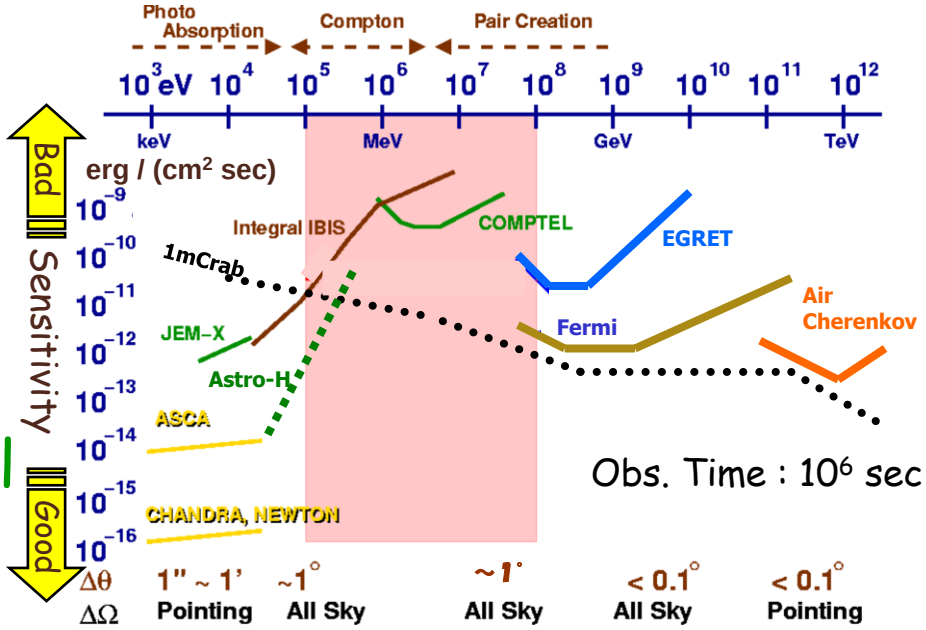
contents

- About SMILE experiment and the Electron Tracking Compton Camera (ETCC)
- $(30\ \mathrm{cm})^3$ prototype ETCC
- New readout circuit of the scintillation camera for SMILE-II

Motivation (sub-MeV/MeV gamma-ray astronomy)

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

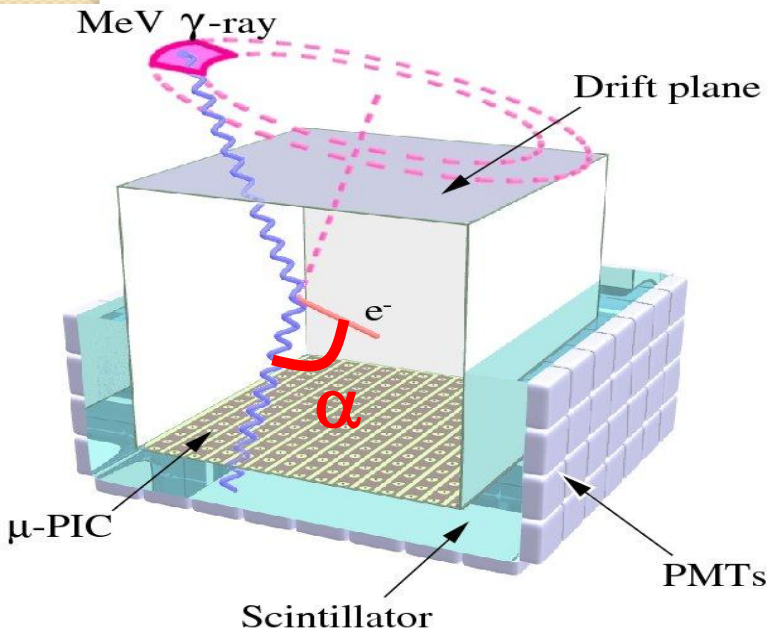


- The observation of continuum component is also important.
- Where are MeV gamma-ray objects?
- There are many background events which obstruct the observations.

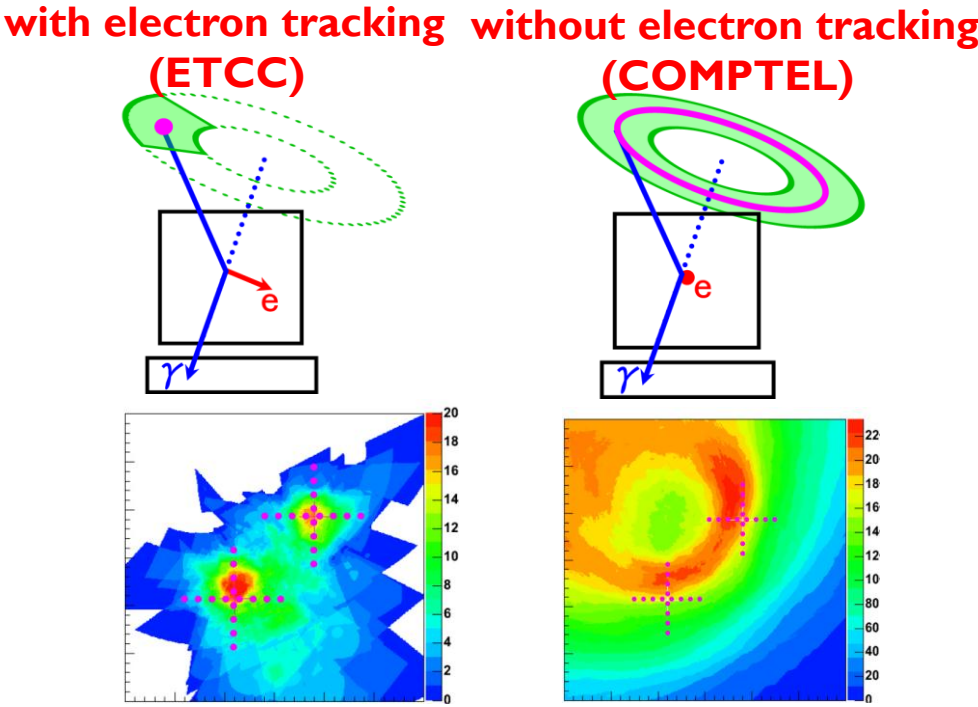
Requirements for the next-generation detectors are …

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

Electron-Tracking Compton Camera (ETCC)



Schematic view of 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 fielf of view (~3str)**
- **Kinematical noise rejection (α)**

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

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)

SMILE-I

30cm cube camera

- Checking the imaging performance
  by observing gamma rays from Crab/Cyg X-1

SMILE-II

40cm cube camera

Sub-MeV ~ MeV

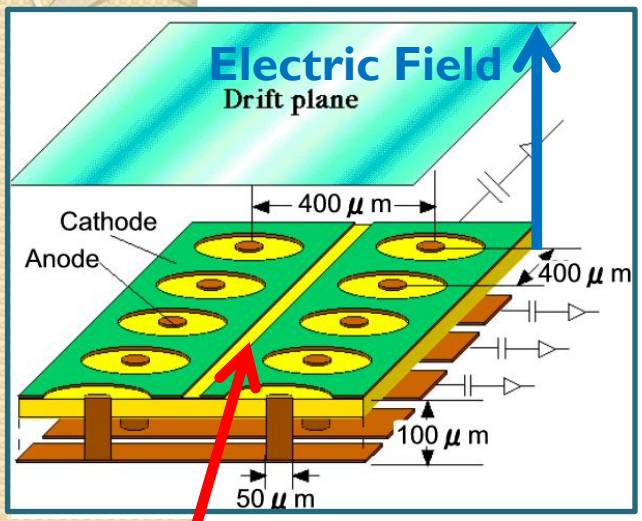
- Long duration observation with super pressure balloon
- Adding pair-creation mode

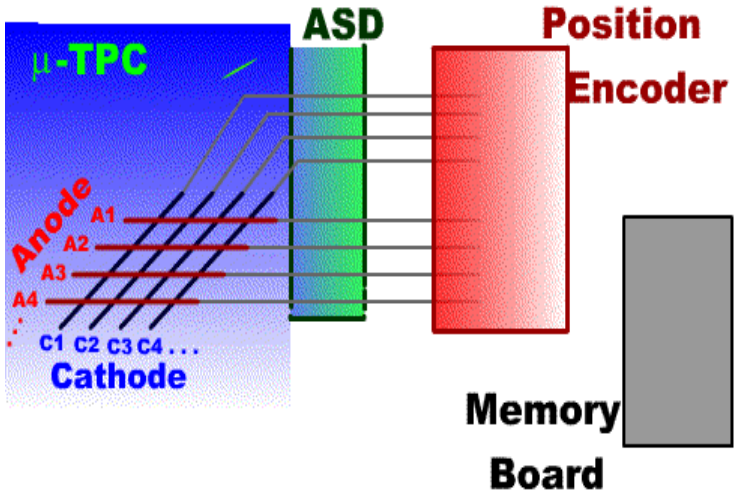
50cm cube camera

- All sky survey (load on a satellite)

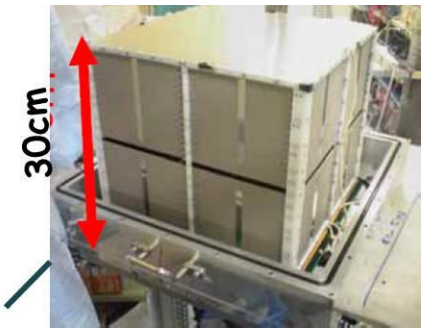
Gaseous TPC (micro-TPC)

- Gas : Ar 90% + C_2H_6 10% 1atm, sealed
- Gain : ~10^6
- Drift velocity (4 cm/μsec)
- position resolution: 400μm





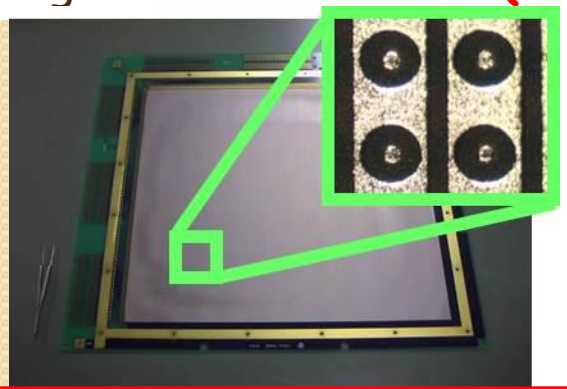
Pressure Vessel

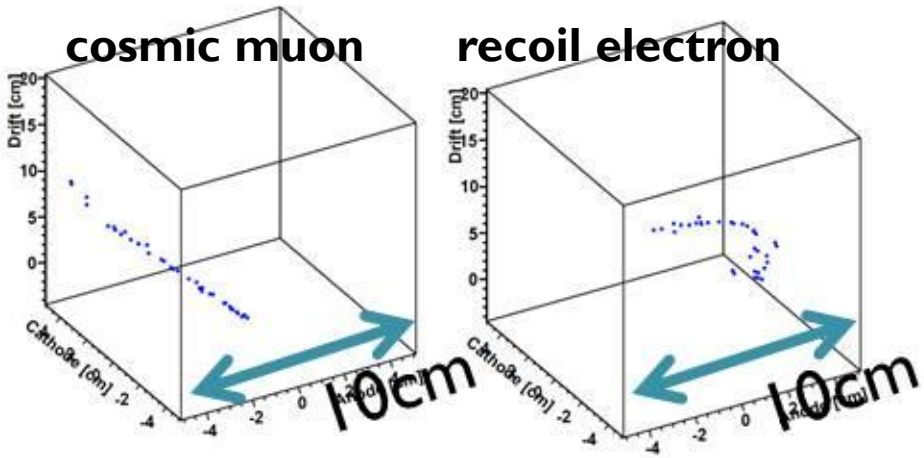


Drift Cage

micro PIxel Chamber(μ-PIC)

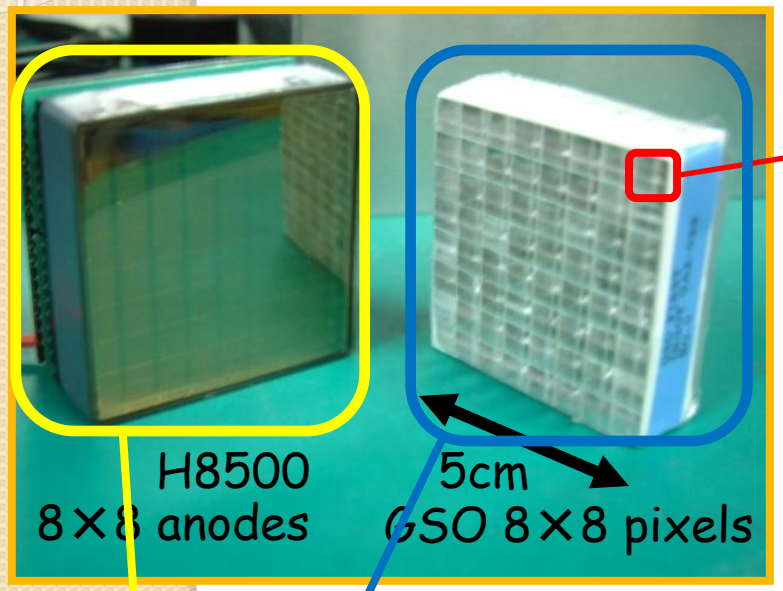
- sliced proportional chambers
- 2D readout (400 μm pitch)
- Large detection area : $(30cm)^2$

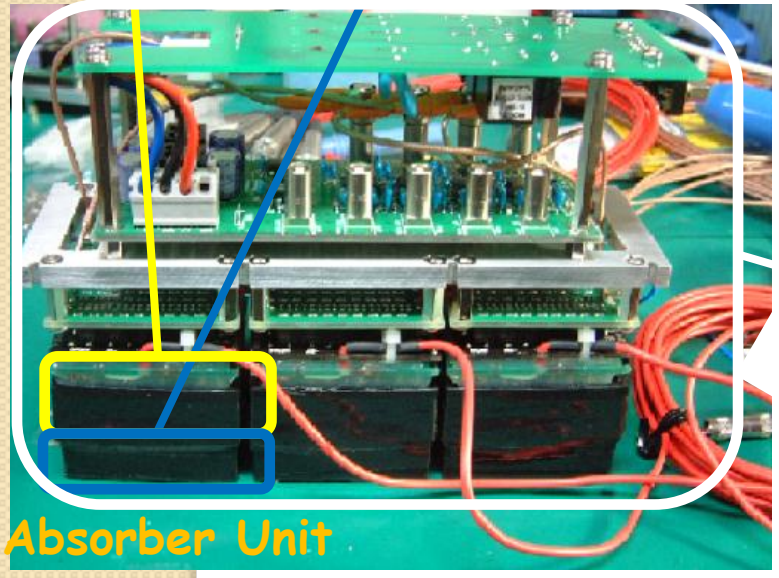




Data of $(10\ cm)^3$ ETCC

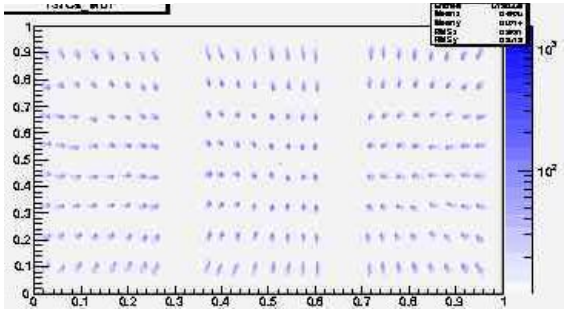
Scintillation Camera

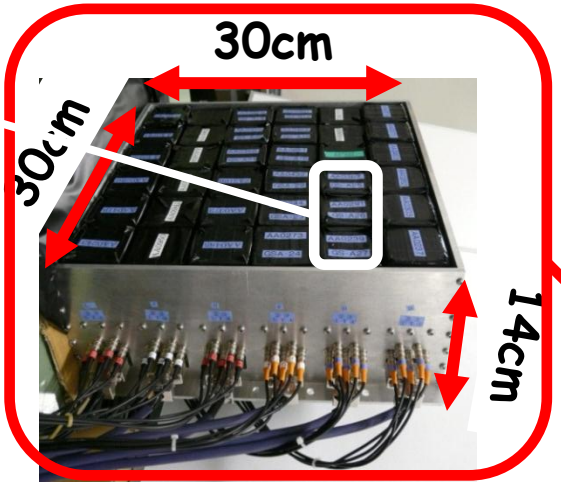


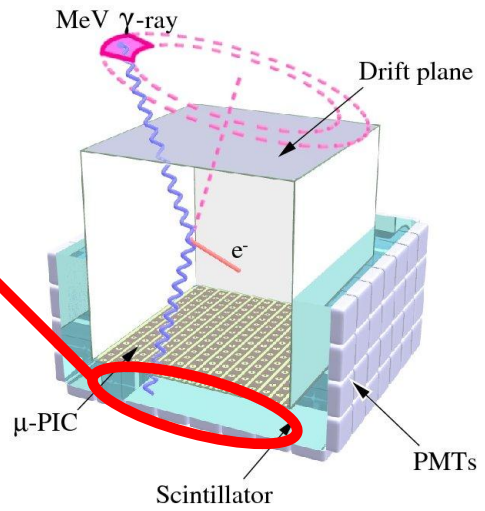


- Scintillator : GSO(Ce)
- Pixel size : 6x6x13 mm^3
- Photo readout : multi anode PMT H8500 (Hamamatsu Photonics)
- 4 channels readout with resistor chain

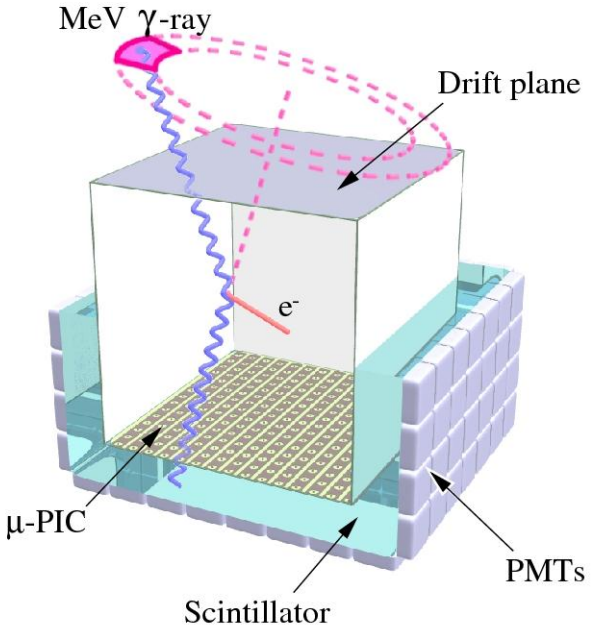
^{137}Cs Position imaging map







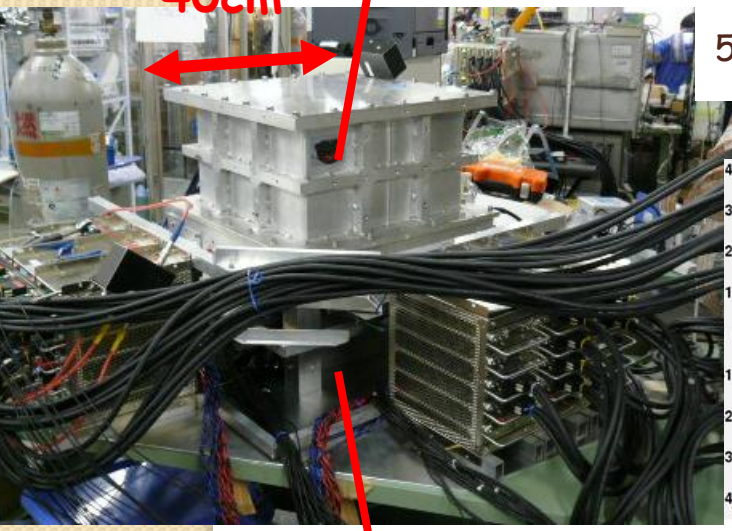
$(30\ \mathrm{cm})^3$ prototype ETCC



Imaging performance

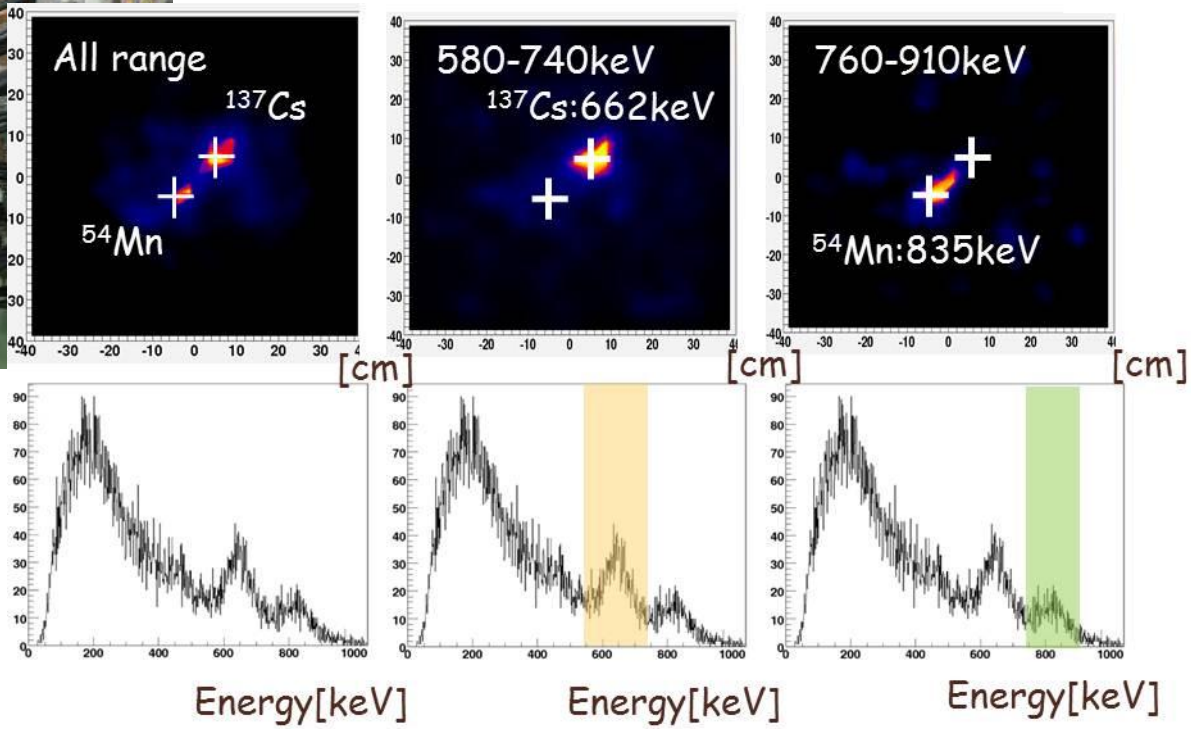
$(30cm)^3$ Gaseous TPC

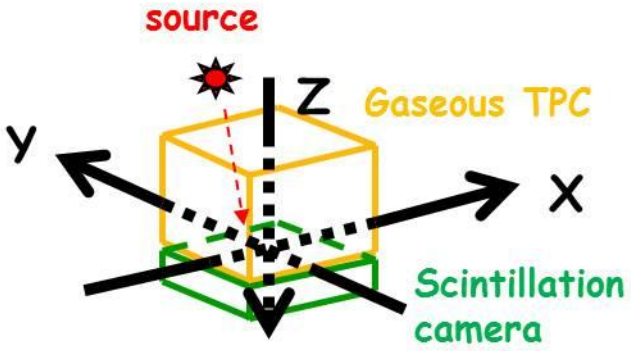
40cm



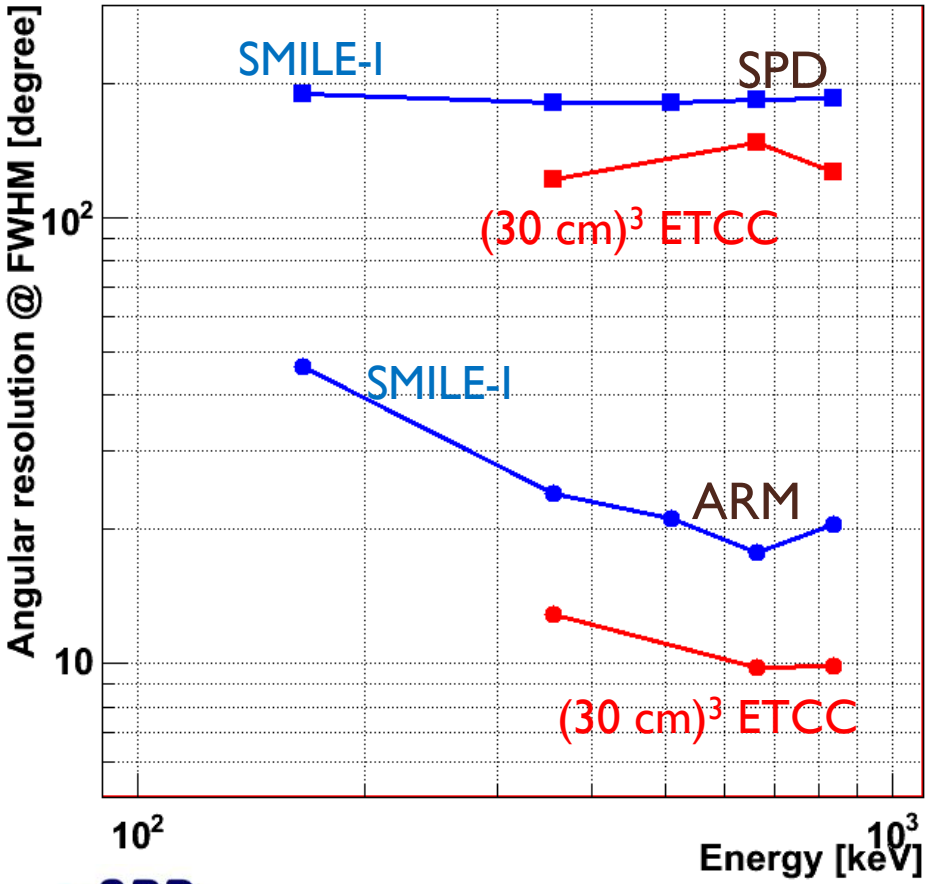
Scintillation Camera
(6×6 absorber units)

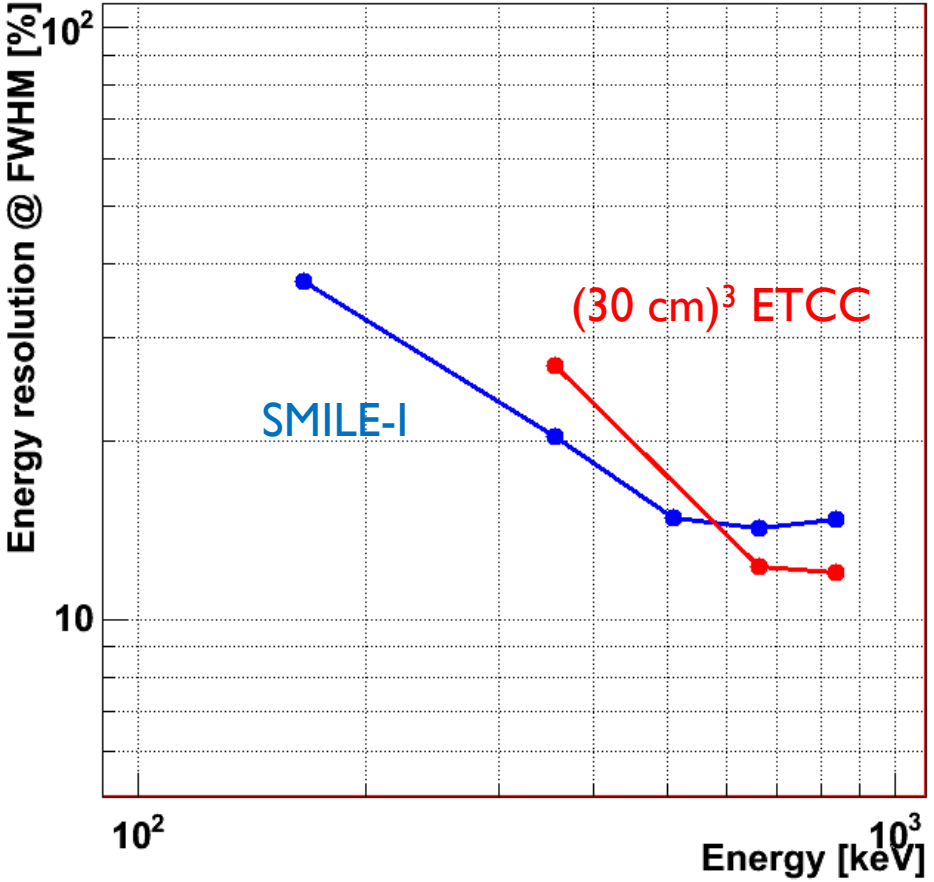
^{137}Cs : 662keV, 1MBq (X,Y,Z) = (5, 5, -52) [cm]
^{54}Mn : 835keV, 1MBq (X,Y,Z) = (-5, -5, -52) [cm]

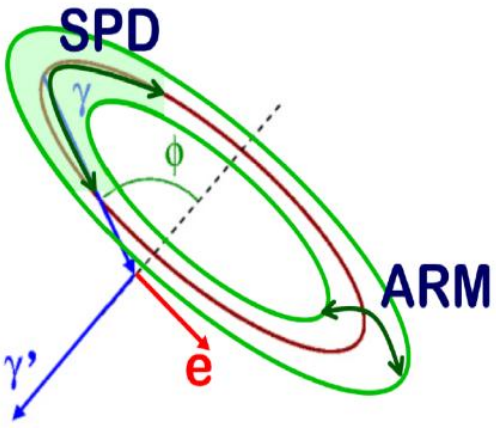




Angular and energy resolutions







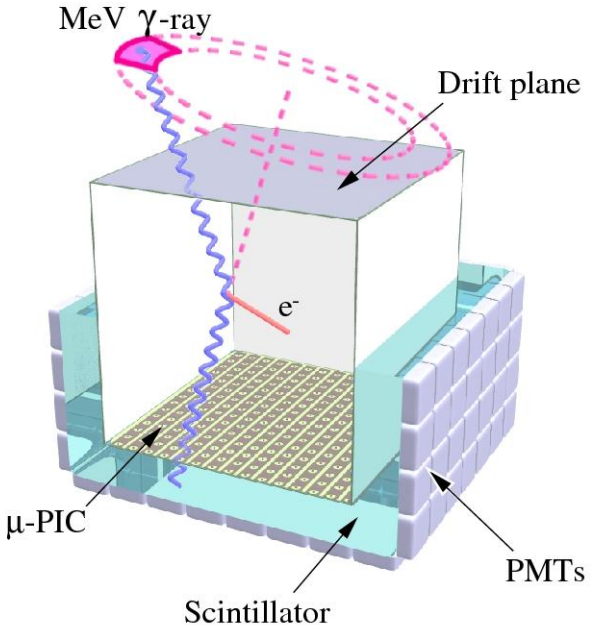
SPD: 147[deg]
ARM: 9.8[deg]
DE/E: 12.3%
(FWHM) @662keV

⟺

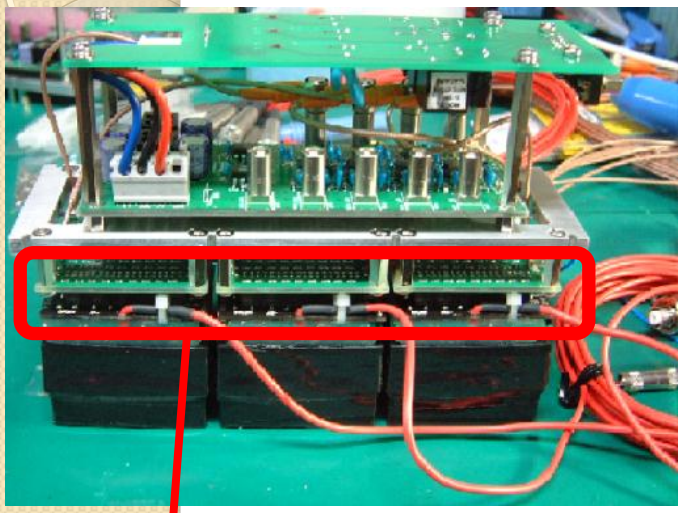
183[deg]
17.7[deg]
14.3%
SMILE-I

ARM : Angular Resolution Measure
SPD : Scatter Plane Deviation

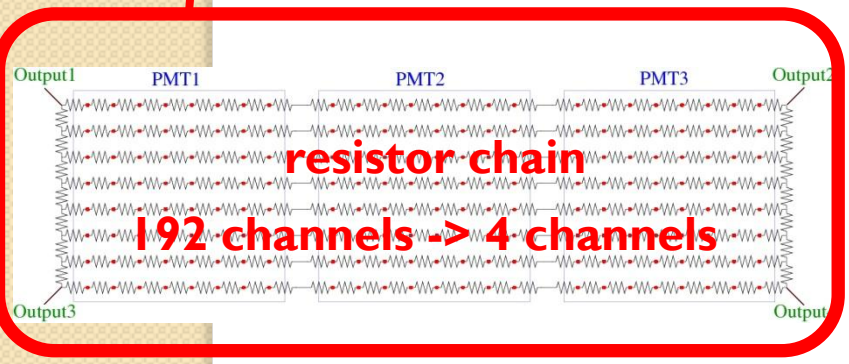
New readout circuit of the scintillation camera for SMILE-II



Readout System of Scintillation Cameras for SMILE-I



readout circuit for SMILE-I.



- Use resistor chain to reduce the power consumption.
  - **192 anode outputs -> 4channel**
- Power consumption of the readout system
  - **1.71 W/channel**
- Energy resolution :
  - **11% (FWHM, at 662 keV)**
- Typical dynamic range :
  - **80keV – 800keV**

↓ for SMILE-II, we need

- Wider dynamic range

192anodes/4ch -> 64anodes/4ch

- Saving the power consumption

Use recent power saving electrical components

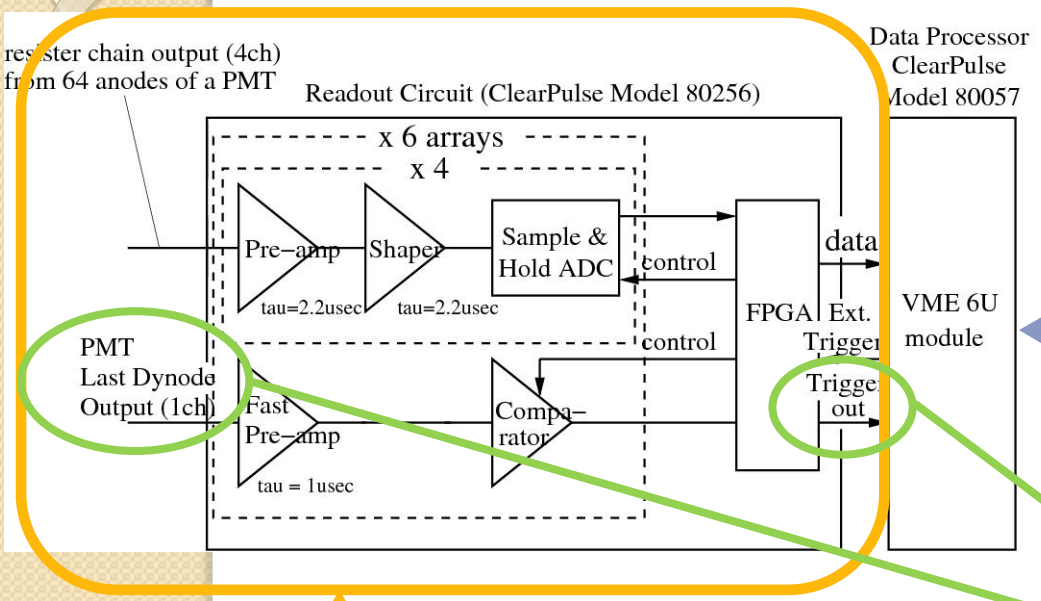
- The same or higher energy resolution.

To meet these requirements,

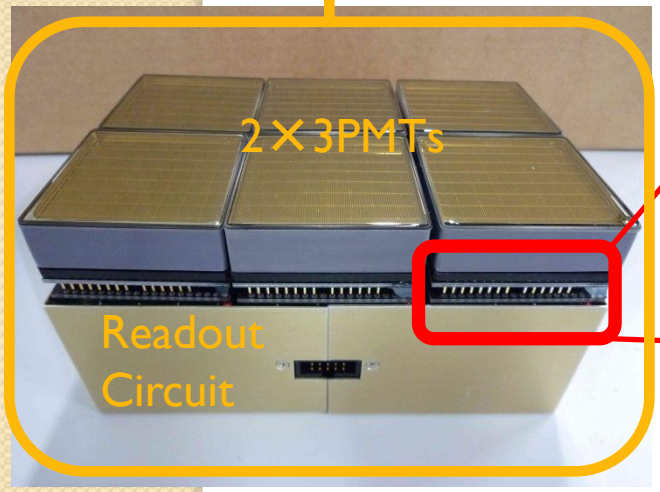
we developed the new readout system.

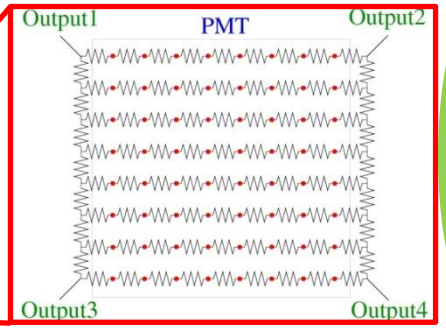
New Readout System of Scintillation Cameras for SMILE-II

We developed the new readout circuit of scintillation cameras with ClearPulse Co. Ltd.



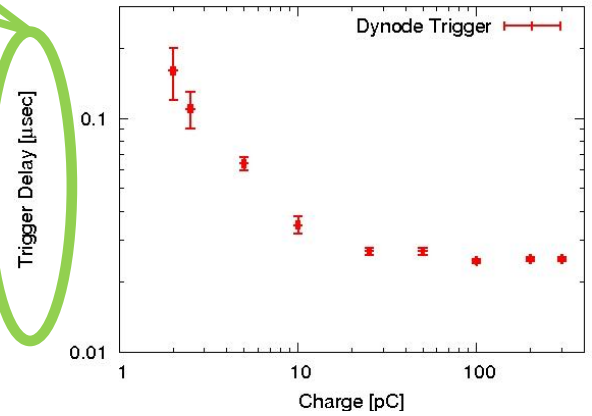
- Use the resistor chain (64 anodes /4 channels)
- Power consumption 0.41 W/channel
- 2×3 PMTs can be attached to one readout circuit.
- Use the output of the last dynode for the generation of the trigger of DAQ.





resistor chain

64 anodes -> 4 channels



The trigger delay and its change are small enough for SMILE-II

Performances of the new readout circuit

We checked the performance of the new readout circuit with a PMT (HV = -900V) by using several irradiation sources.

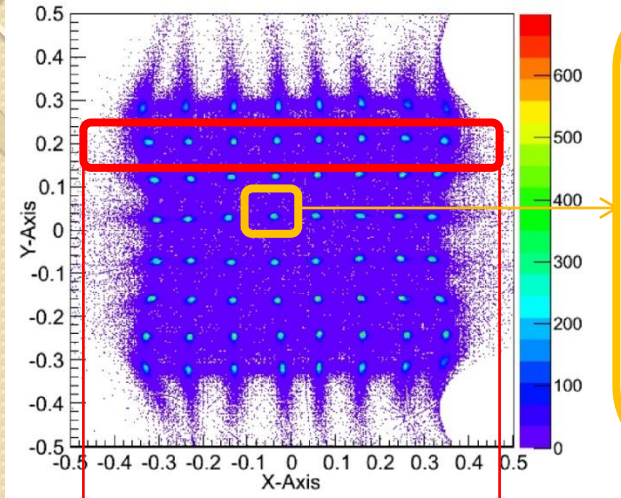


Fig.1 : reconstructed 2-dimensional histogram (^{137}Cs)

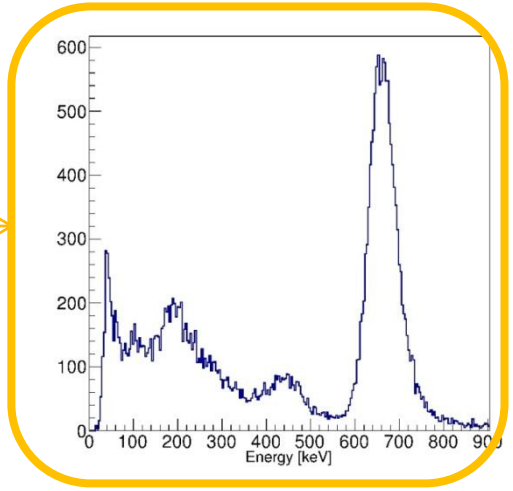


Fig.3 : typical energy spectrum of one pixel (^{137}Cs)

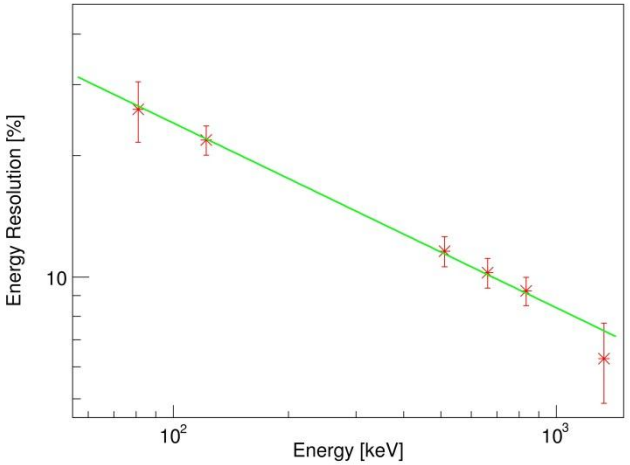


Fig.4 : Energy Resolution (**10.3±0.9% at 662keV**)

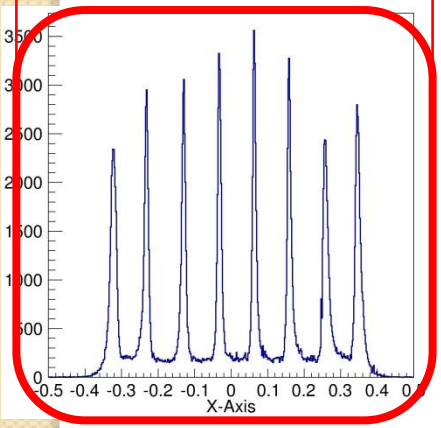


Fig.2 : x-projection of a row (red circle) in Fig.1

- Reconstructed Image of absorption points is good.
- Peak-to-valley ratio **10:1** ← **well separated**
- Energy Resolution : **10.3±0.9% at 662keV**.

It's enough for SMILE-II.

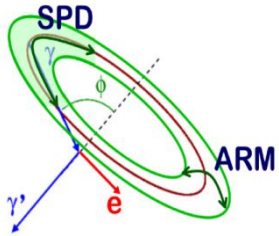
- Energy dynamic range : **81 keV – 1332keV**.

(SMILE-I dynamic range : 80 keV-800 keV).

conclusion

- Developing the ETCC for MeV gamma ray astronomy.
- Used a $(10\ cm)^3$ ETCC in SMILE-I (2006).
- As the next step, we have been developing the $(30\ cm)^3$ ETCC for SMILE-II.
- Constructed a prototype $(30\ cm)^3$ ETCC, and checked its performanc

SPD: 147[deg]
ARM: 9.8[deg] @662keV
DE/E: 12.3% (FWHM)



- Developed a new low-power readout system of scintillation cameras for SMILE-II, and checked its performance.

Power consumption ••• 0.41 W/channel
Dynamic range ••• 81keV - 1333 keV
Energy Resolution ••• 10.3 ± 0.9 % at 662 keV

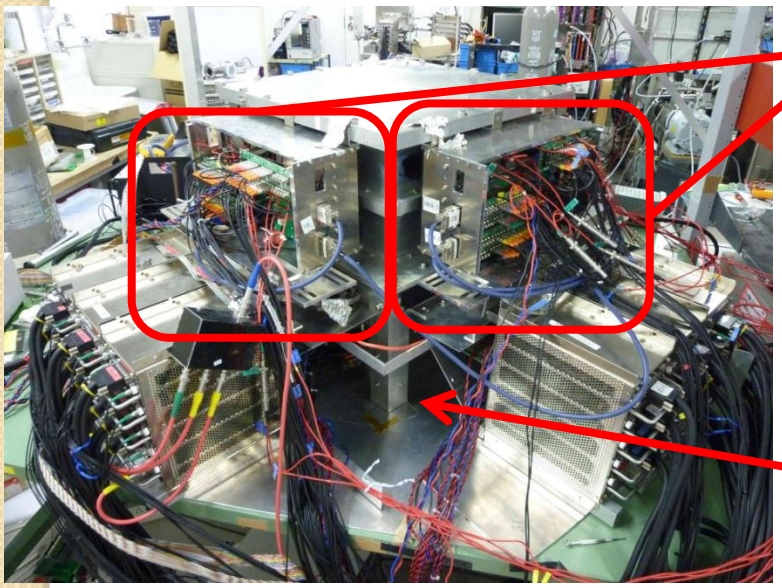
Available for SMILE-II

And the future work is …

Future work

- Development and performance study of the (30 cm)^3 prototype ETCC with bottom **and side scintillation cameras (108 absorber units).**

We will begin changing to the new readout system for the scintillation camera.



Side scintillation cameras
(3 × 6 absorber units per one face)

Bottom scintillation cameras
(6 × 6 absorber units)

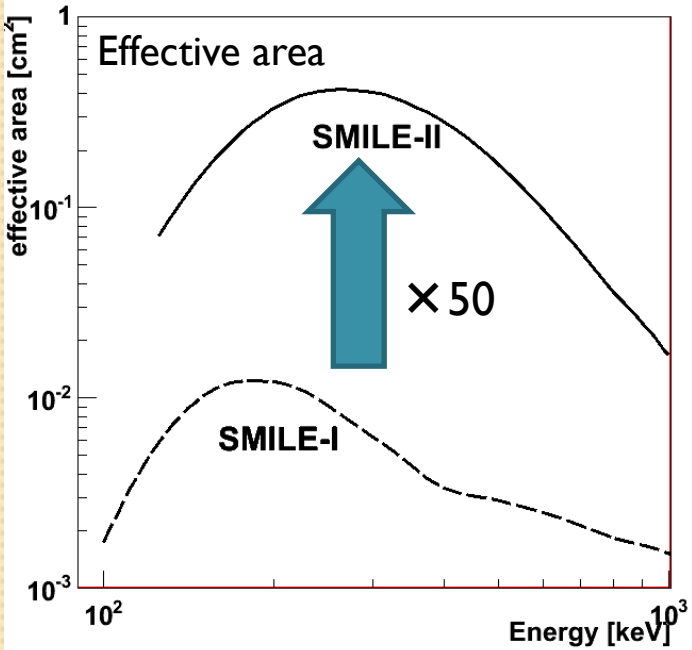
- Development of the (30 cm)^3 flight-model ETCC for SMILE-II experiment.

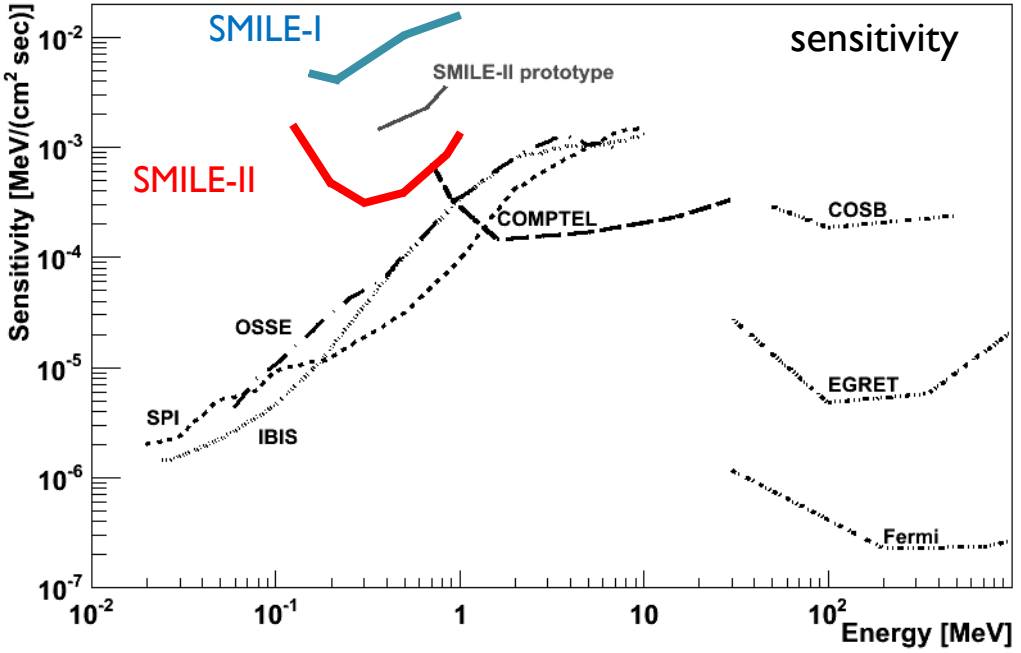
Future work

In SMILE-II, we will use 216 absorber units for the $(30\ \mathrm{cm})^3$ ETCC .

→ estimated effective area : $0.5\mathrm{cm}^2$.

(50 times larger than that of $(10\ \mathrm{cm})^3$ ETCC for SMILE-I)





To observe gamma rays from the Crab nebula at a 5 sigma confidence level in the 5 hour SMILE-II measurement, we are developing the $(30\mathrm{cm})^3$ flight-model ETCC using the result of the prototype ETCC.

End