MeV gamma-ray Compton camera using a gaseous electron tracker for background-suppressed observation

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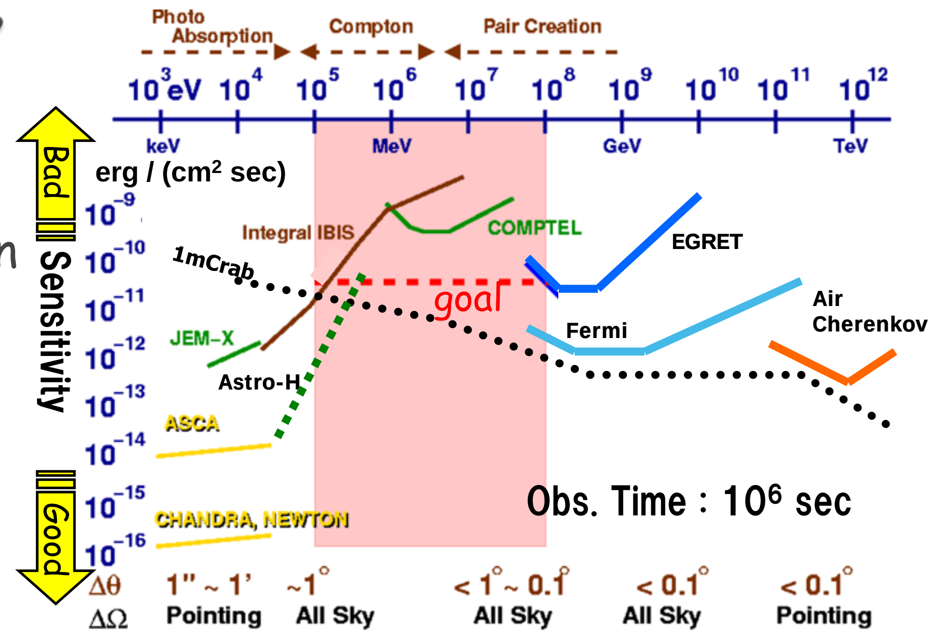
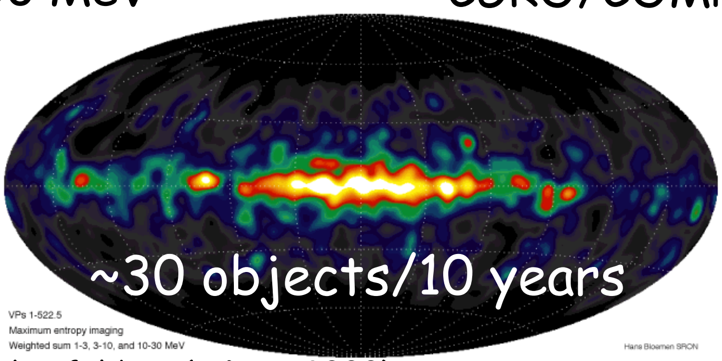
MeV Astronomy

- Nucleosynthesis
  - SNR : Radio-isotopes
  - Galactic plane : ^{26}Al • Annihilation
- Particle acceleration
  - Jet (AGN) : Synchrotron + Inverse Compton
- Strong gravitational potential
  - Black hole : accretion disk, π^0
- Etc.
  - Gamma-ray Pulsar, solar flare



MeV sky map

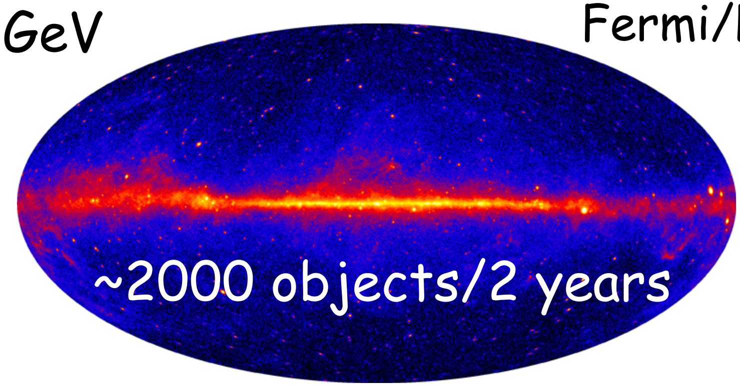
1-30 MeV CGRO/COMPTEL



V. Schönfelder+ (A&AS, 2000)

GeV sky map

> 1 GeV Fermi/LAT

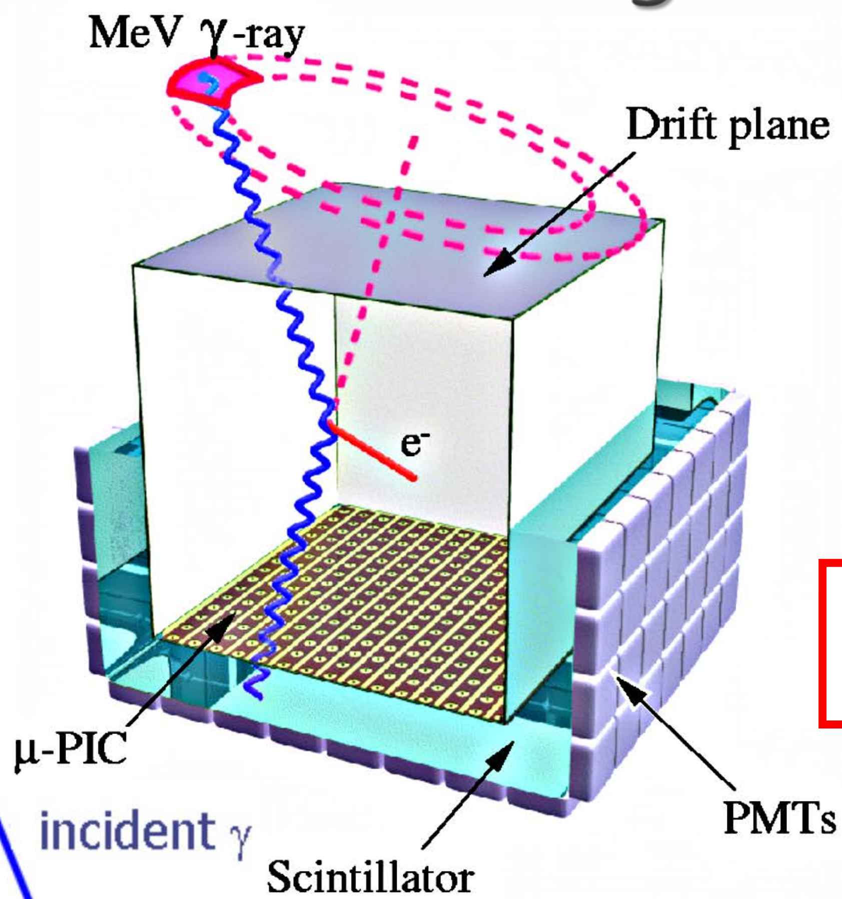


P. L. Nolan+ (ApJS, 2012)

Requirements for the next-generation detectors are …

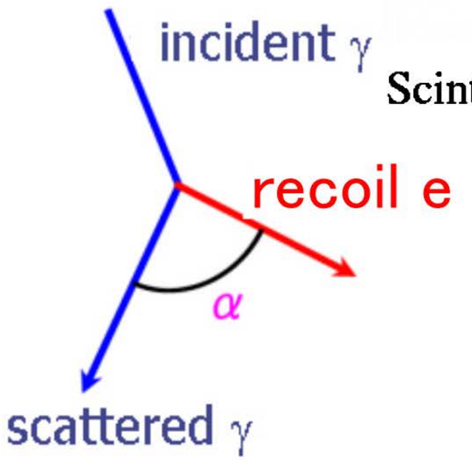
- Wide-band detection
- Large Field of View
- High quality image

Electron-Tracking Compton Camera (ETCC)



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

Reconstruct Compton scattering event by event

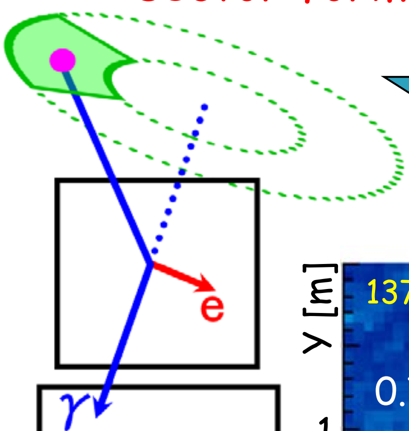


- 1 photon ⇒ direction + energy
- Large FOV (~3str)
- Compton Kinematical test with angle α
- Particle identify with dE/dx
- No VETO & shield around ETCC

Comparison with the usual Compton method

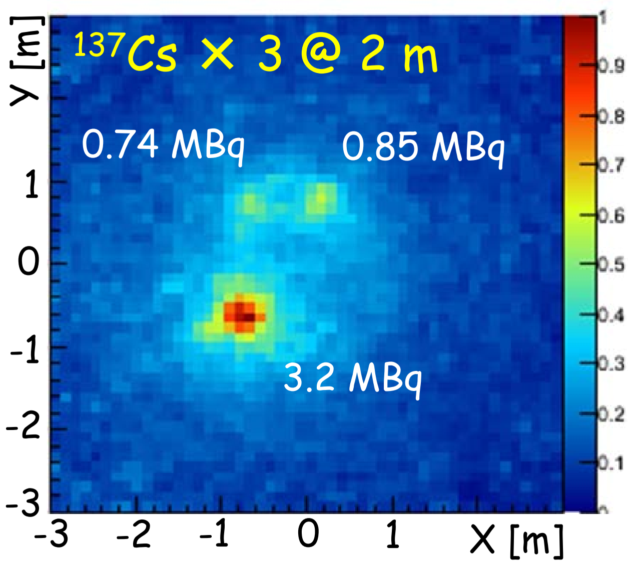
Electron-Tracking Compton (ETCC)

Using the electron tracks
complete direction within
sector form error region



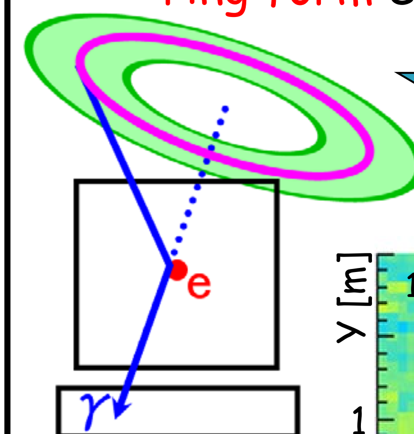
Simply overlay

- High S/N
- No fakes



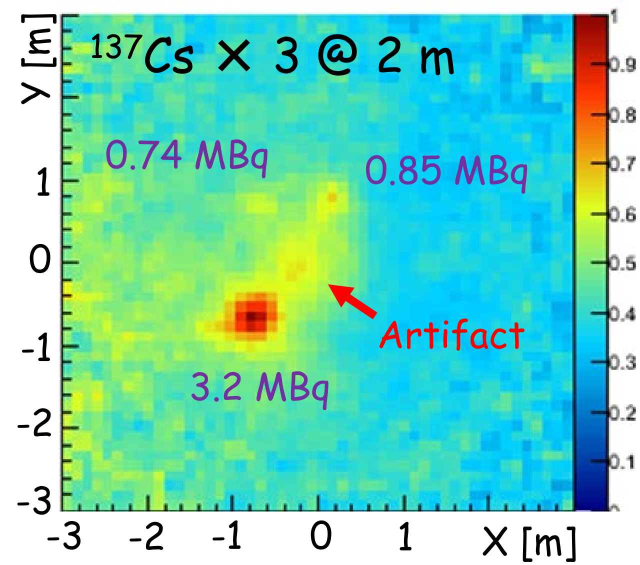
Usual Compton Imaging (COMPTEL)

Not using the electron tracks
only event circle within
ring form error region



Simply overlay

- Low S/N
- Artifacts appear



Electron tracks provide 4 times better S/N than usual Compton imaging !

ETCC for 2nd balloon experiment

SMILE-II

Target: Crab nebula

5σ detection (40 km, several hours)

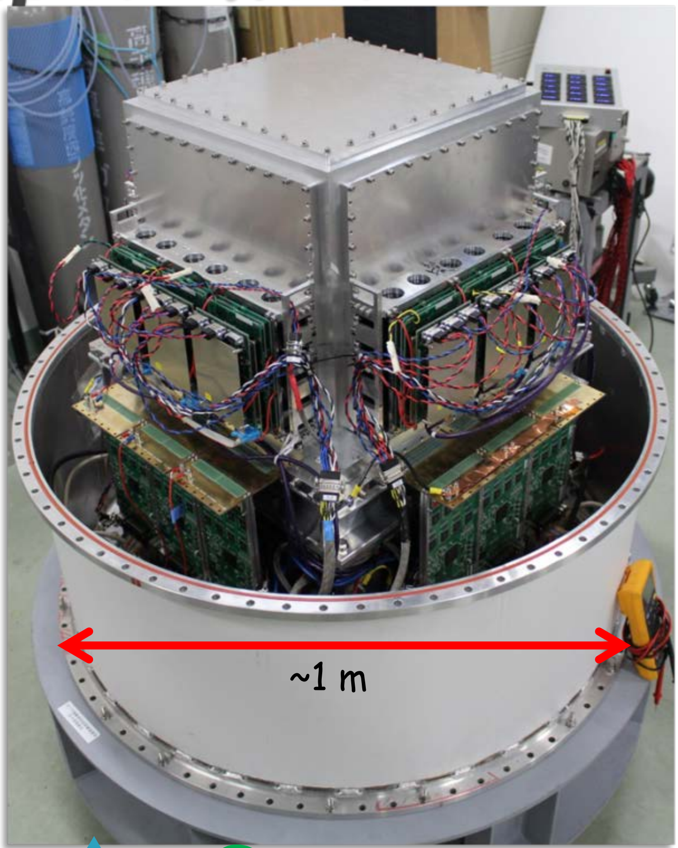
Requirements

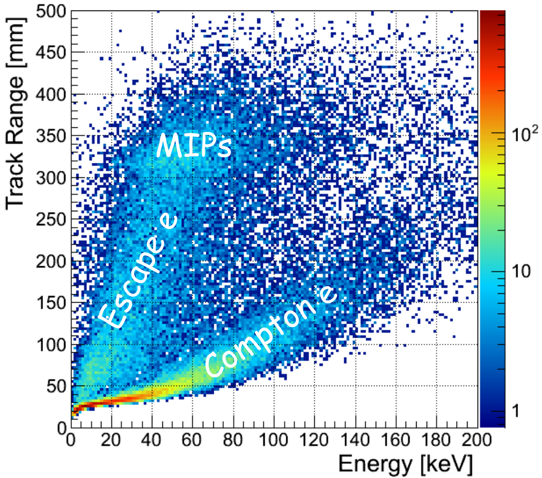
Effective area	:	> 0.5 cm² (300 keV)
Angular resolution	:	< 10° (600 keV)
Sensitivity	:	×100 SMILE-I

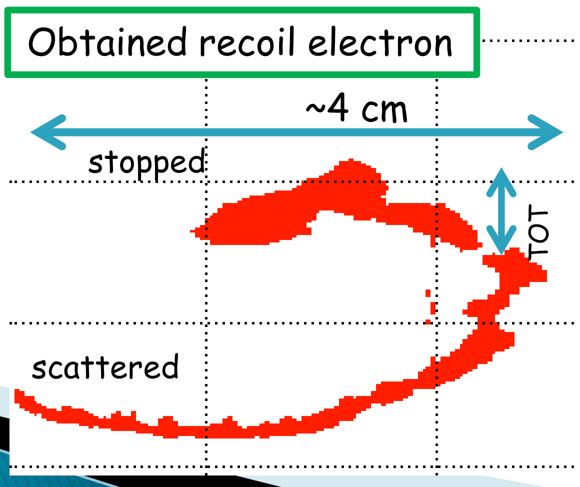
Improvements for SMILE-II

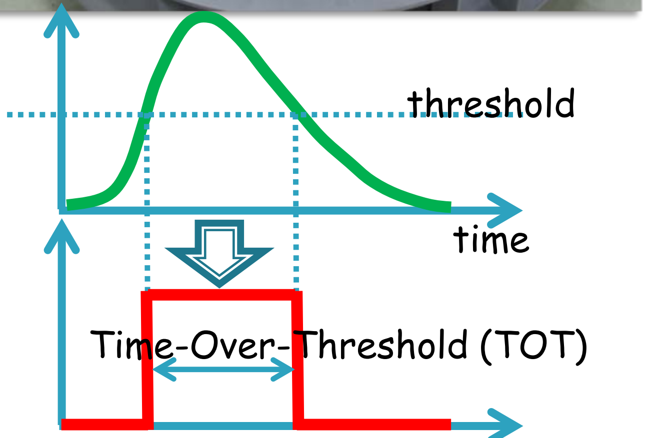
- 30 cm cube tracker ×√10
- Updating of data acquisition system ×√10
- Improvement of imaging ability ×10

Sensitivity will reach to (×100 SMILE-I) !

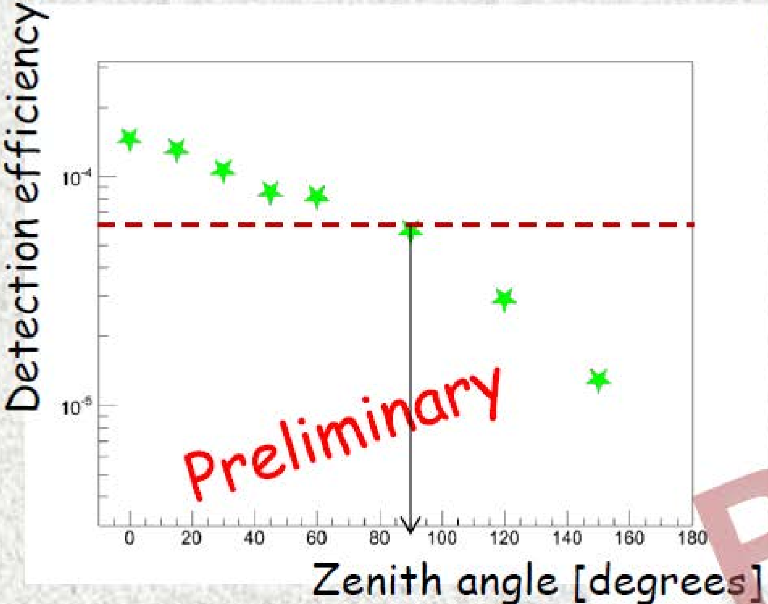






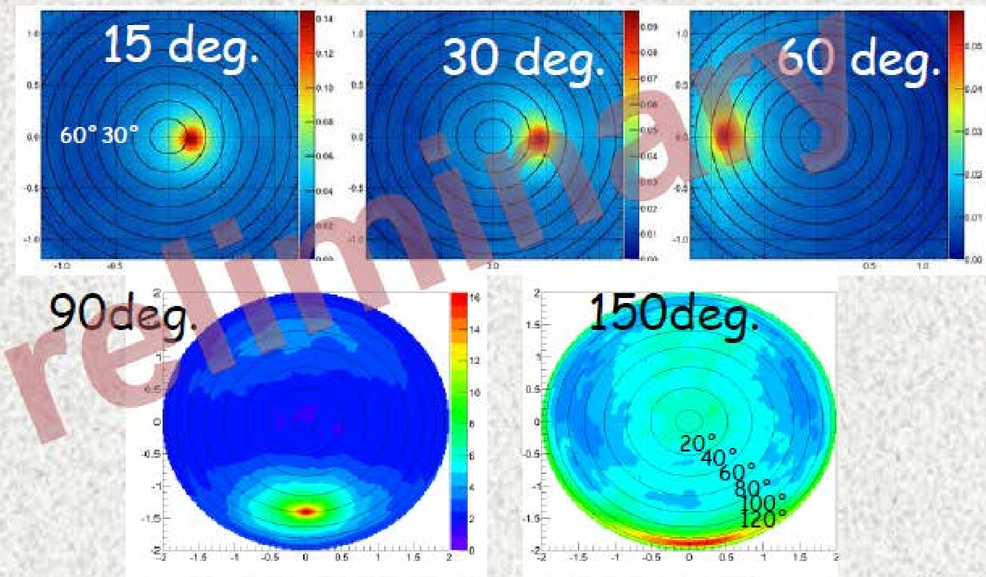


Performance in 30cm-cube ETCC

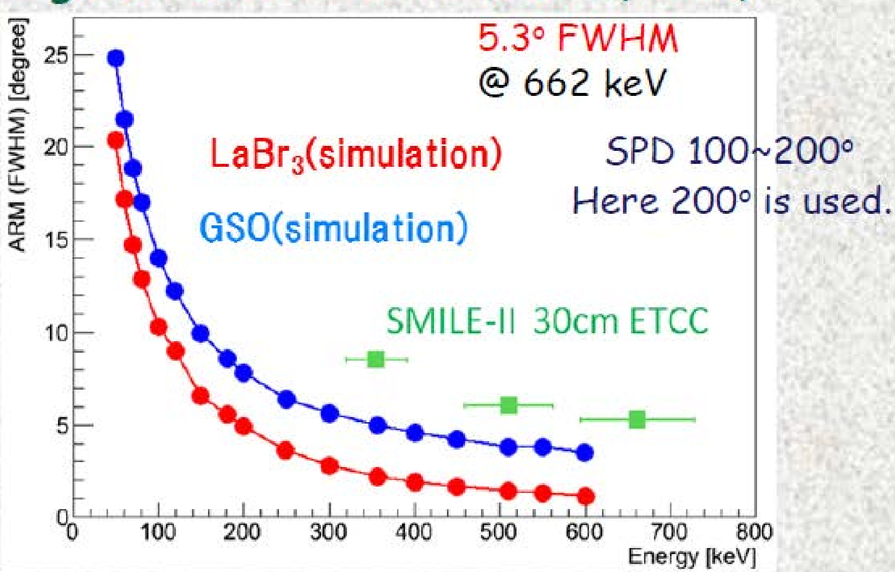


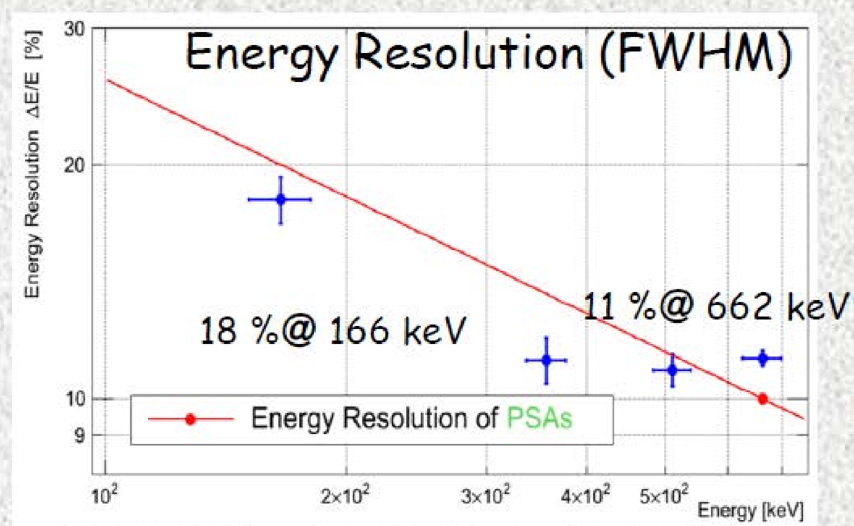
Wide Field of View (~6 sr) at a half effi.

^{137}Cs (662 keV) 0.7MBq 2m

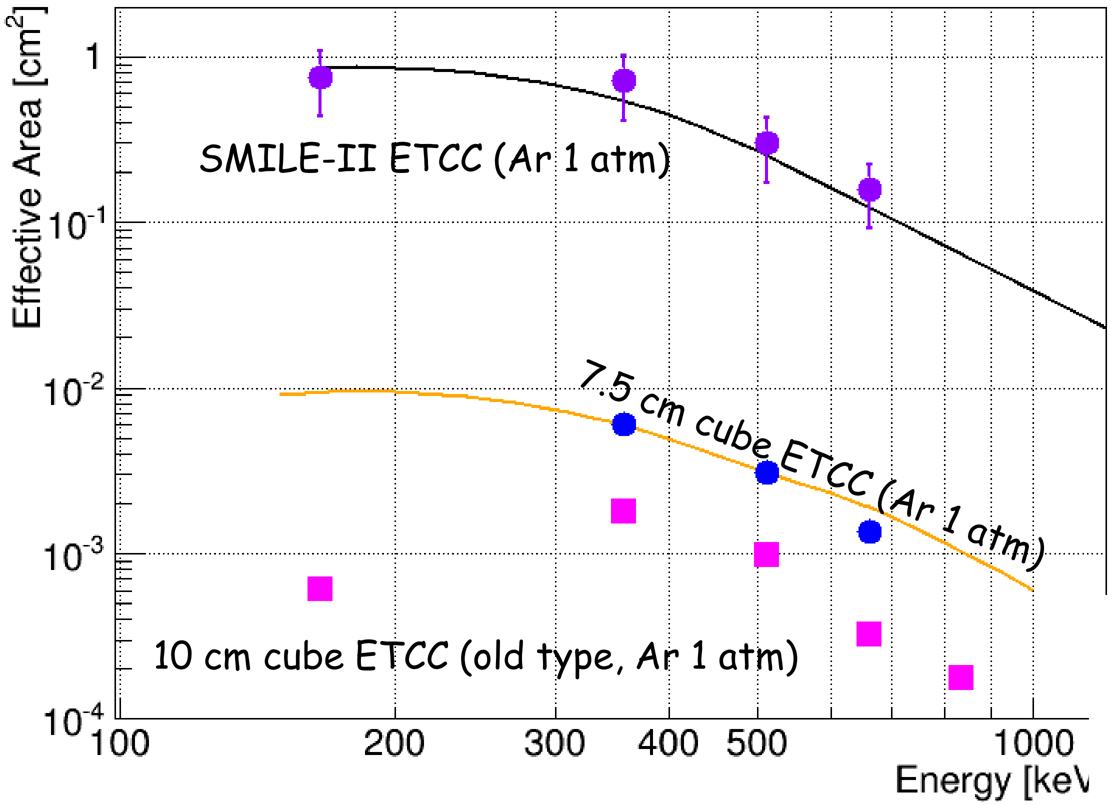


Angular Resolution Measure(ARM)





Effective area



Improvement of DAQ system
-> efficiency ×10
Large size tracker
-> effective area ×10

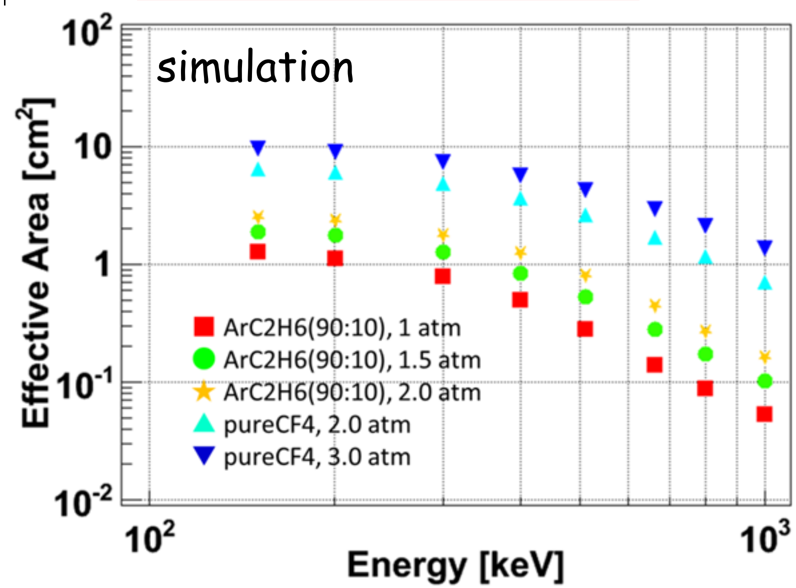
×100

SMILE-II ETCC
~1 cm^2 (< 300 keV)

Requirement : > 0.5 cm^2 @ 300 keV

Experiment ≈ Simulation

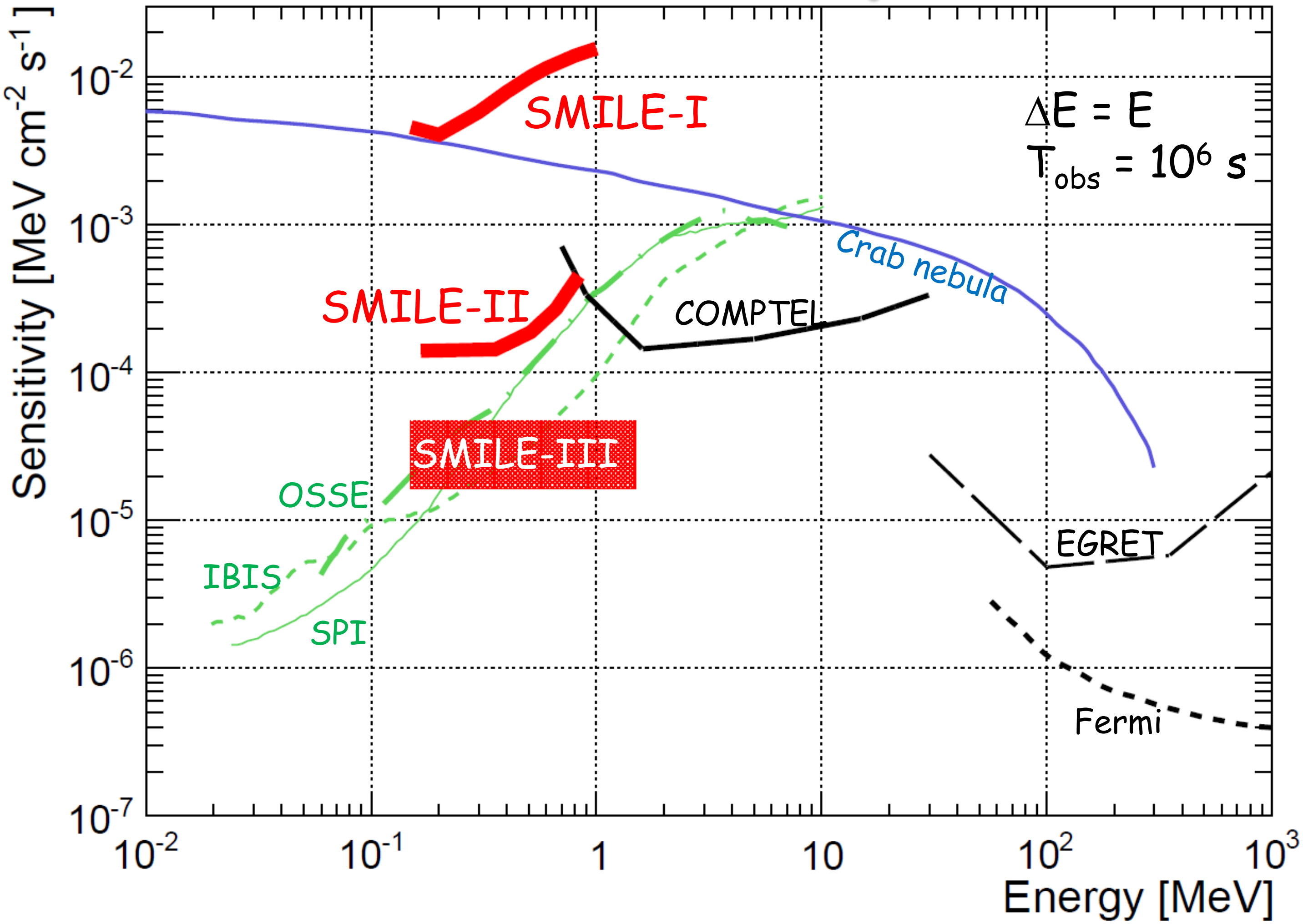
ETCC obtains ~100% of Compton events



If we use CF_4 gas (3 atm) …

Effective area :
~10 cm^2 (< 300 keV)

Detection sensitivity

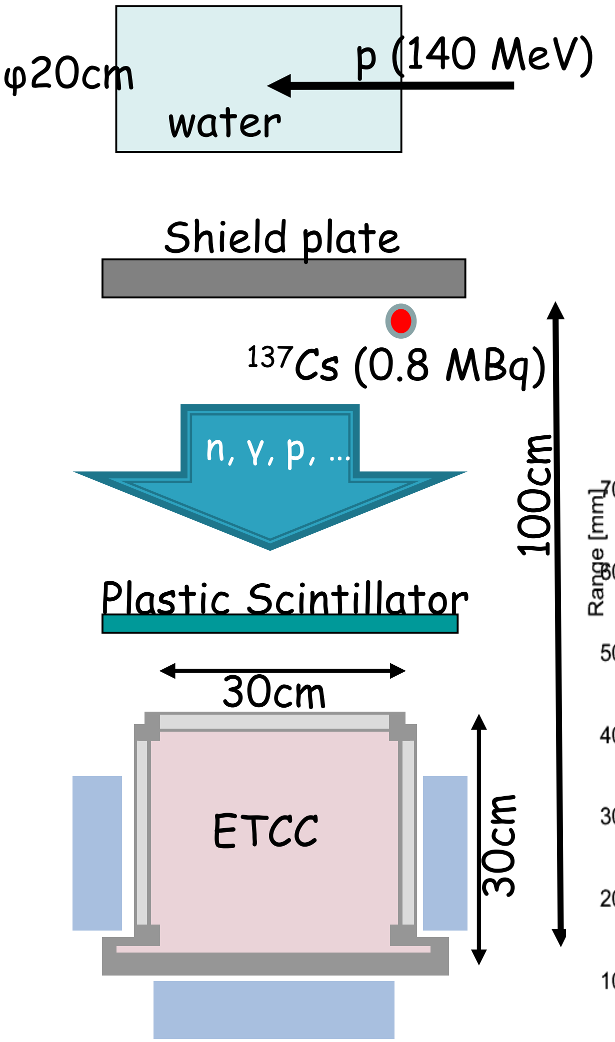


SMILE-II : detectable Crab nebula with 3 h at 40 km

SMILE-III : CF_4, 3 atm and 2-3 Radiation length GSO

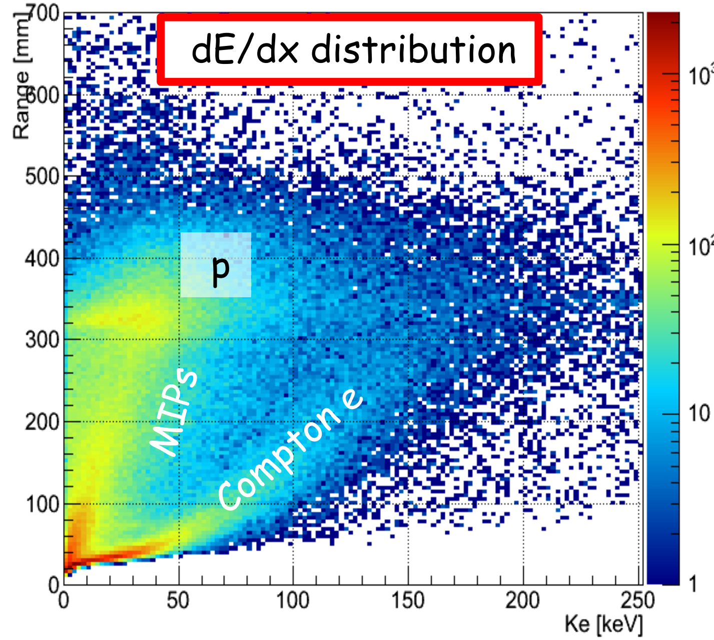
-> 10 times better sensitivity

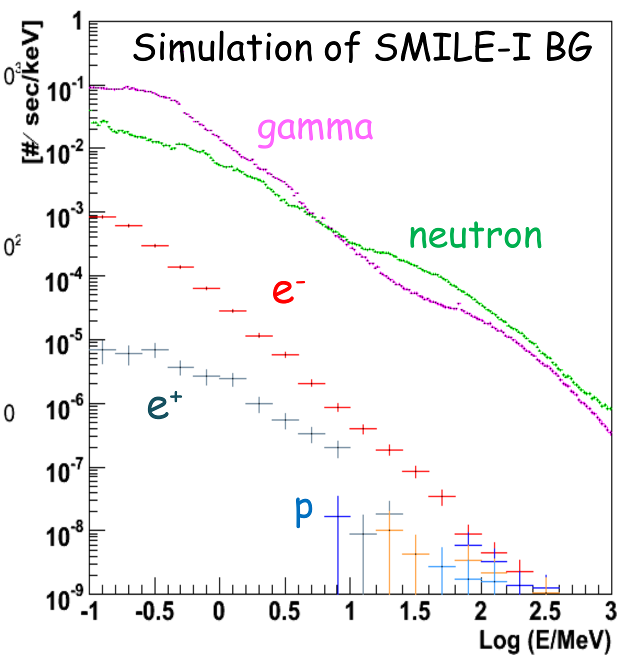
Experiment 1:
Confirmation of background rejection power



Can our ETCC detect gamma-ray source in strong radiation field?

- Irradiation proton beam to water target
  -> produced gamma, neutrons, protons, …
- gamma : neutron = 3 : 1
  -> similar to background at balloon altitudes
- Observation ^{137}Cs under this situation

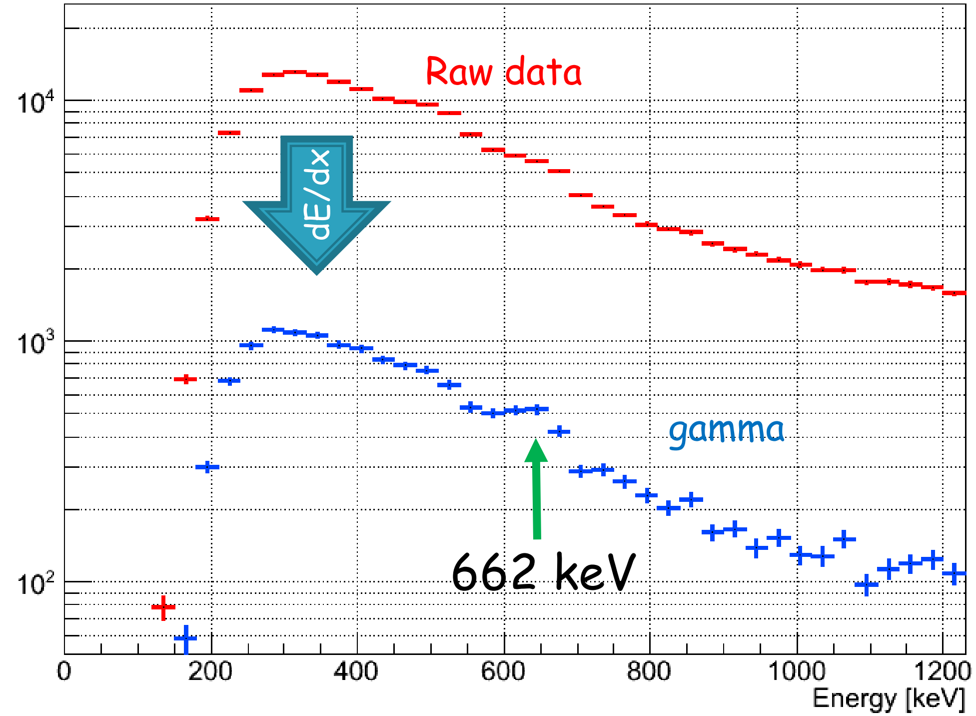




Experiment 1:
Confirmation of background rejection power

With dE/dx selection, background events are rejected.

Spectrum:
excess @ 511, 662 keV



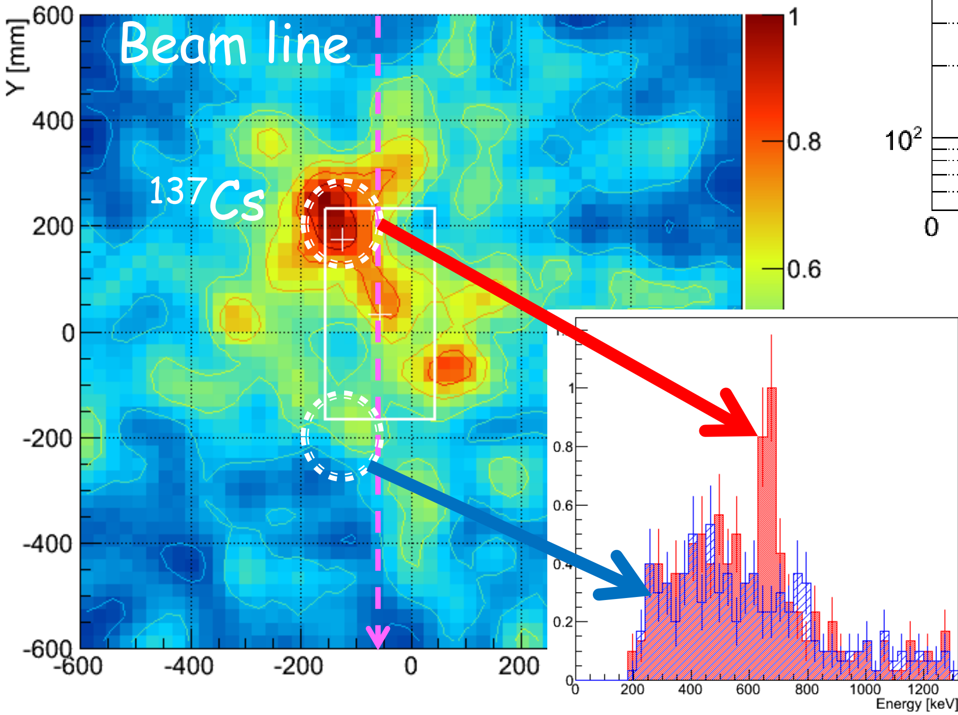


Image:
compact excess @ ^{137}Cs
excess @ 662 keV in ON-region
no excess in OFF-region

ETCC detected gamma ray correctly.

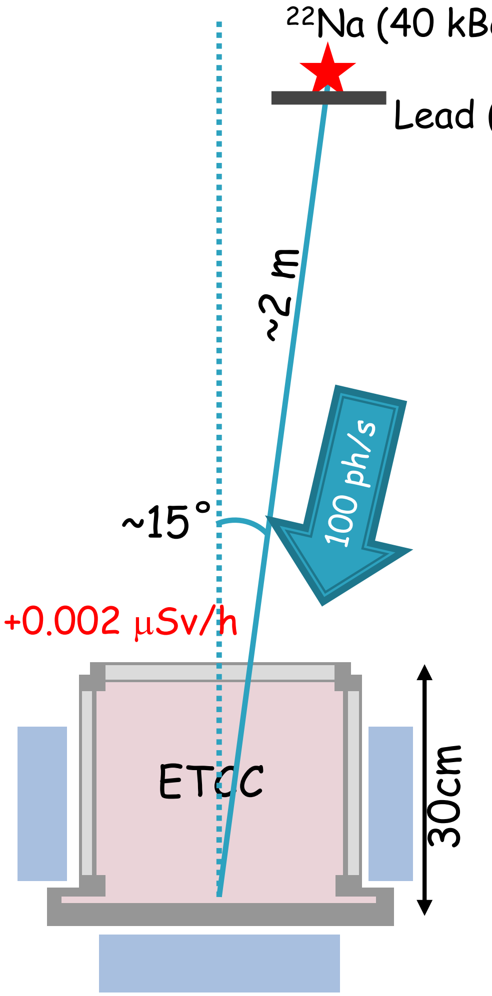
Experiment 2: Observation of a week source

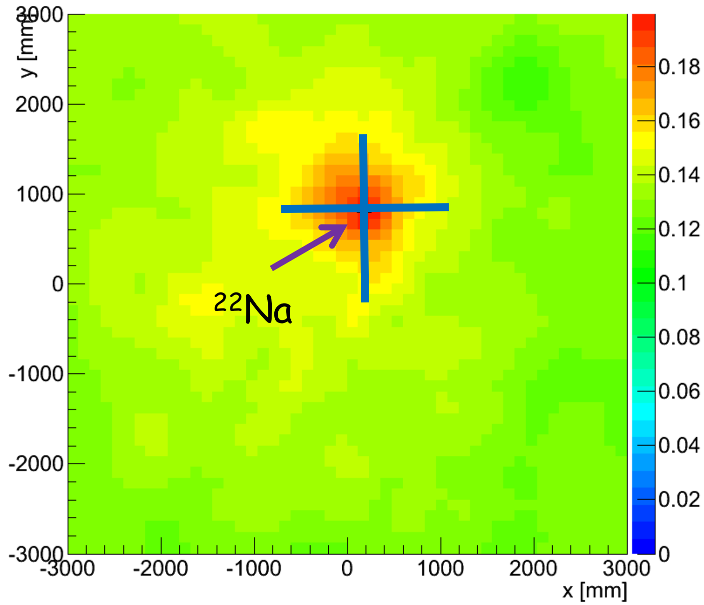
Can ETCC detect gamma-ray source with low S/N?

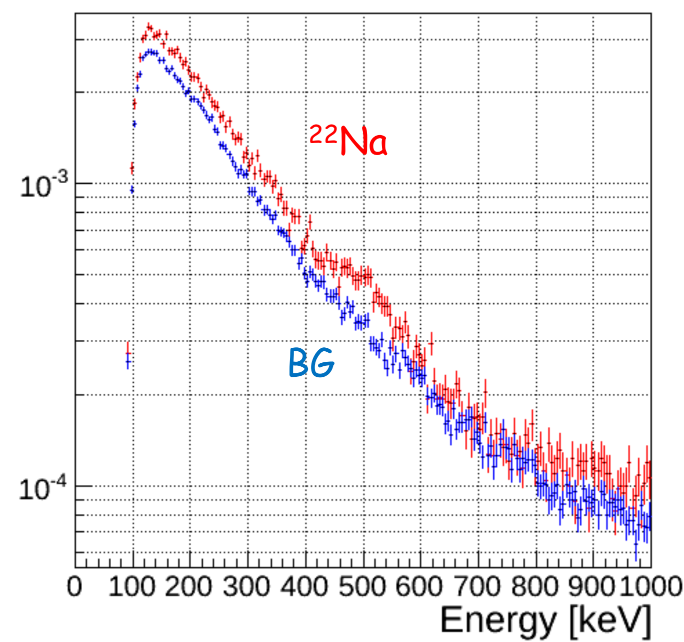
Crab nebula : BG-gamma ≈ 0.01 : 1

Weak ^{22}Na -> ~100 ph/s come into ETCC
511 keV : BG = 0.02 : 1

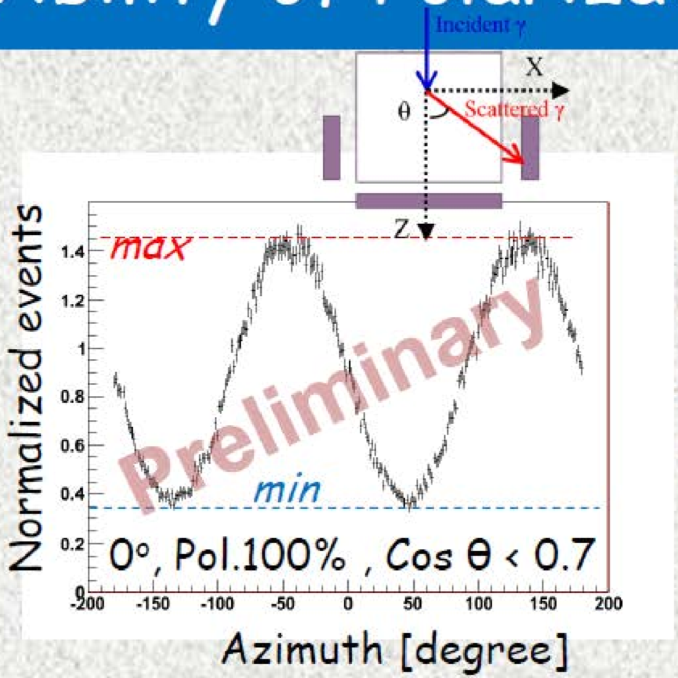
Gamma-ray image has a clear excess.
Significance of excess @ 511 keV is about 11σ during 5.5 h.

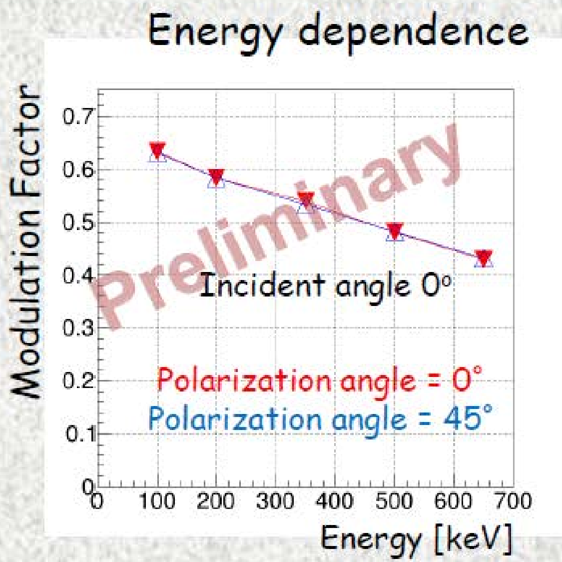


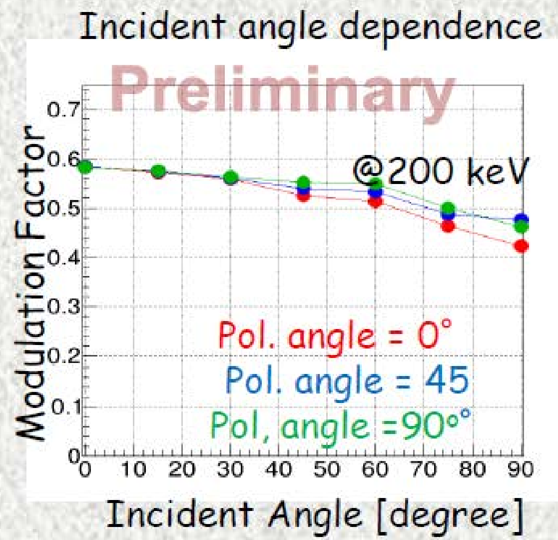




Ability of Polarization Measurement (Simulation)







$$\text{Modulation Factor(MF)} = \frac{max - min}{max + min}$$

Good MF >0.5 from 100 ~300keV with =6str !

Possible Detection of GRB polarization in 1 month Balloon flight

Reported 6GRB Pol. >30%

- **SMILE-III** : M>0.6 FoV 3str, Eff. Area 20cm2@200 keV
- GRB 10^{-6} erg/cm^{2}s MDP = 5/M % (3σ) (M>0.6) 8% pol.
  GRB 10^{-7} erg/cm^{2}s- 30% pol.

a few GRBs (10^{-6} erg/cm^{2}s) ~10 (10^{-7} erg/cm^{2}s) with one-month

Summary

- We are developing an Electron-Tracking Compton Camera using a gaseous tracker.
- SMILE-II ETCC:
  - Effective area : ~1 cm^2 (< 300 keV)
  - Angular resolution : 5.3° (662 keV)
    - -> Crab nebula with 3σ level with 3 h at 40 km
- ETCC has redundancies of background rejection
  - complete reconstruction using electron track
  - particles identify using dE/dx
  - Compton kinematic test using angle α
- Confirmation experiments:
  - detected gamma-ray source in high radiation field
  - detected a low S/N source
    - 511 keV, S/N = 0.02, live time = 2.0×10^4 s -> 10.5σ