Balloon-borne experiment for deep sky survey of MeV gamma rays using an Electron-Tracking Compton Camera

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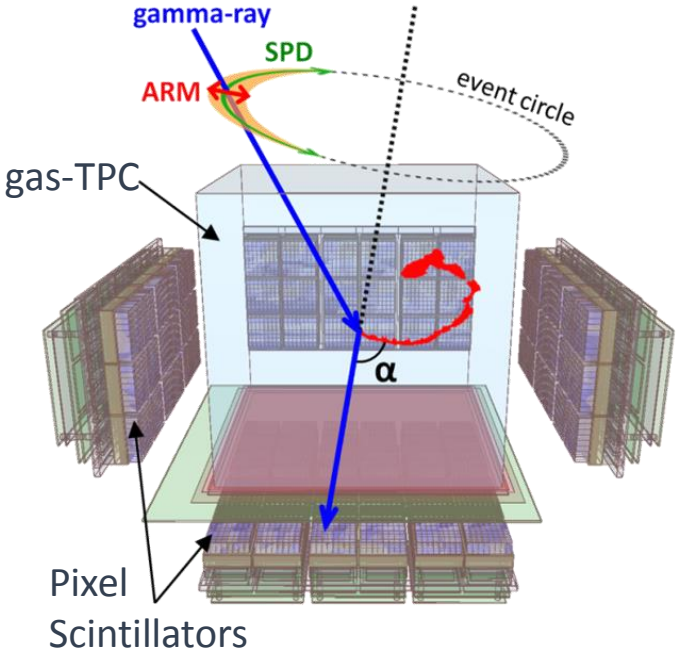


Sub-**M**eV gamma-ray **I**maging

Loaded-on-balloon **E**xperiment

SMILE-I
(Sep., 2006)

Now planning

SMILE-II (1 day flight)

Crab Nebula, Cygnus X-1

SMILE-III (1 month flight)

- more faint sources
- polarization measurements

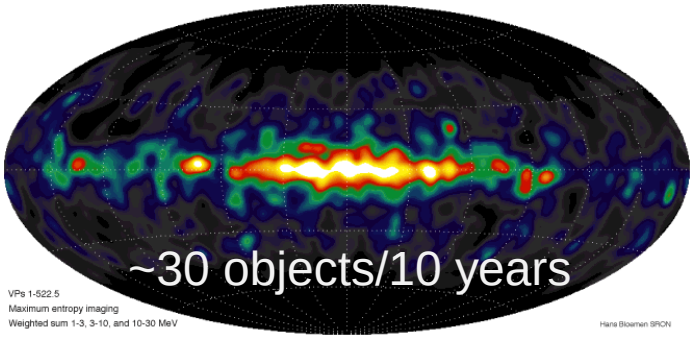
Contents

1. Status and problems in MeV gamma-ray astronomy
2. How to challenge by using ETCC
3. Current and near-future ETCC
   - ✓ Performances
   - ✓ Polarization measurement

◆ Summary

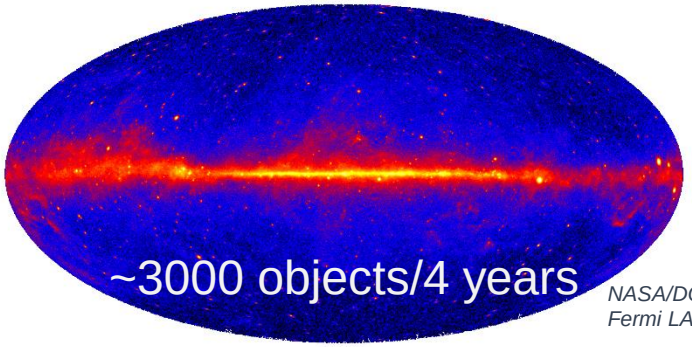
Status of MeV gamma-ray astronomy

COMPTEL 1-30 MeV map



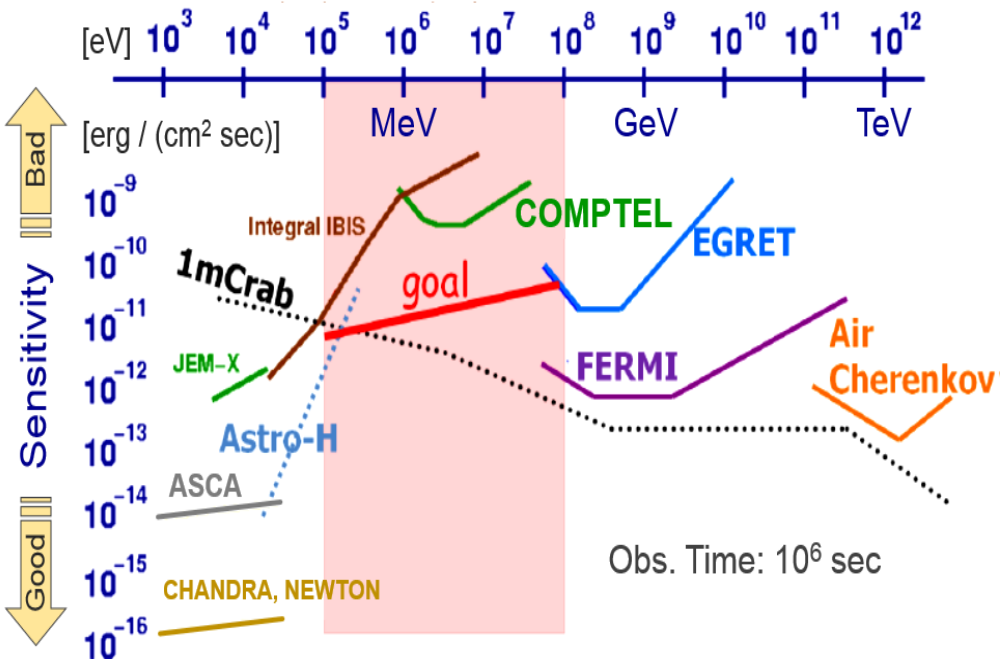
V. Schönfelder+ (A&AS, 2000)

Fermi > 1 GeV map



NASA/DOE/
Fermi LAT Collaboration

F. Acero+ (ApJS, 2015)



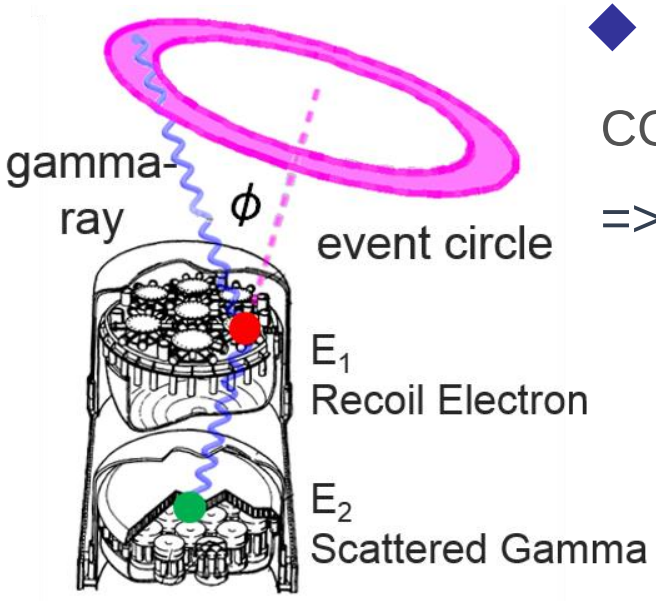
Interesting science

- ❏ Nucleosynthesis in SNR
- ❏ Particle acceleration in AGN
- ❏ Early universe probe with GRB

etc.

MeV gamma-ray region is unexplored frontier!

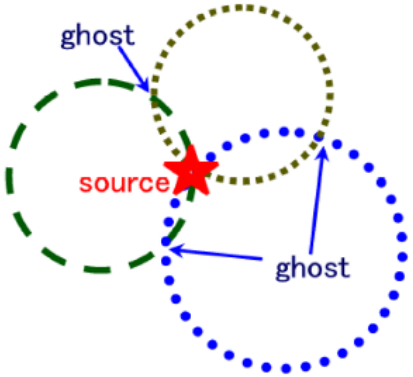
Problems



◆ Unclearness of Imaging

COMPTEL did not measure direction of recoil electron.

=> Imaging by superposition of event circles

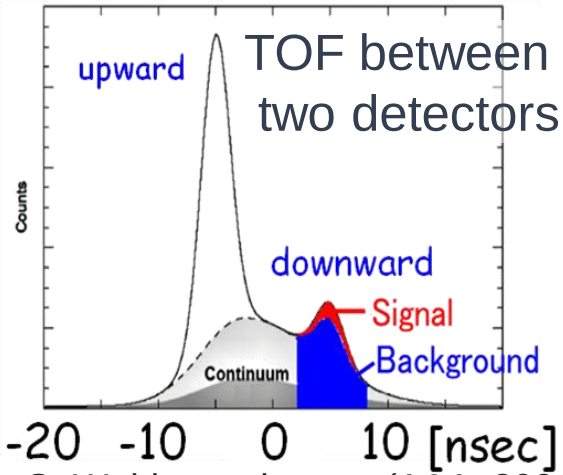


wide-spread

Point Spread Function (PSF)

needs of optimization algorithm

as like ML-EM



G. Weidenspointner+ (A&A, 2001)

◆ Huge backgrounds in space

Radioactivation of detectors by cosmic rays

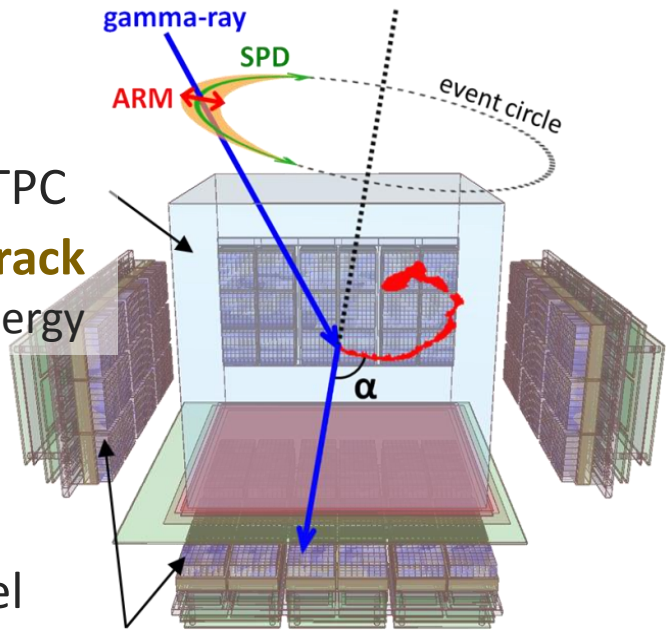
BG rejection in COMPTEL was not sufficient.

=> ~ 1/3 of the expected sensitivity

Reliable PSF and

Powerful BG rejection are needed.

Electron-Tracking Compton Camera (ETCC)

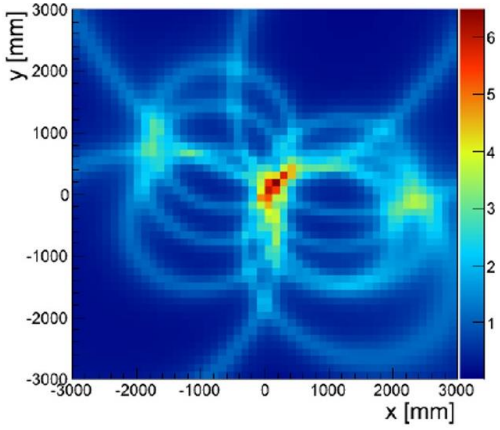


By measuring electron tracks, ETCC overcome the problems !

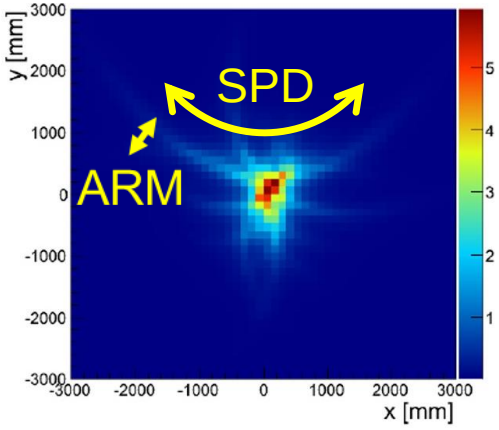
- **Well-defined PSF** without ML-EM
- **Powerful BG rejection** using dE/dx
  - No shield => Wide field of view ~ 6sr

T.Tanimori et al., *ApJ* (2015) accepted,
arXiv: 1507.03850 [astro-ph.IM]

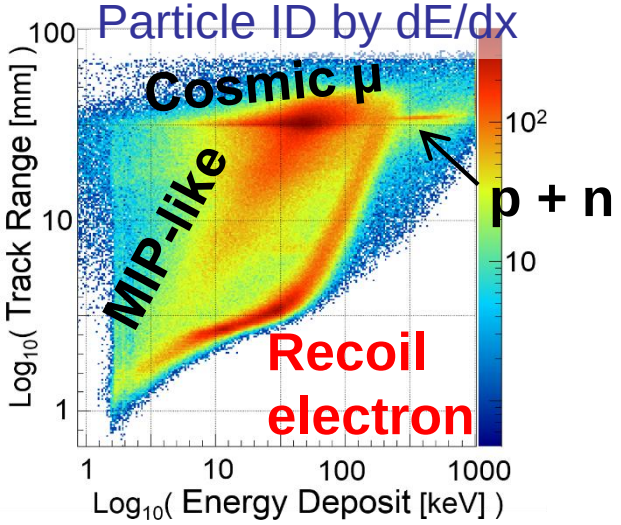
Conventional method



Electron Tracking method

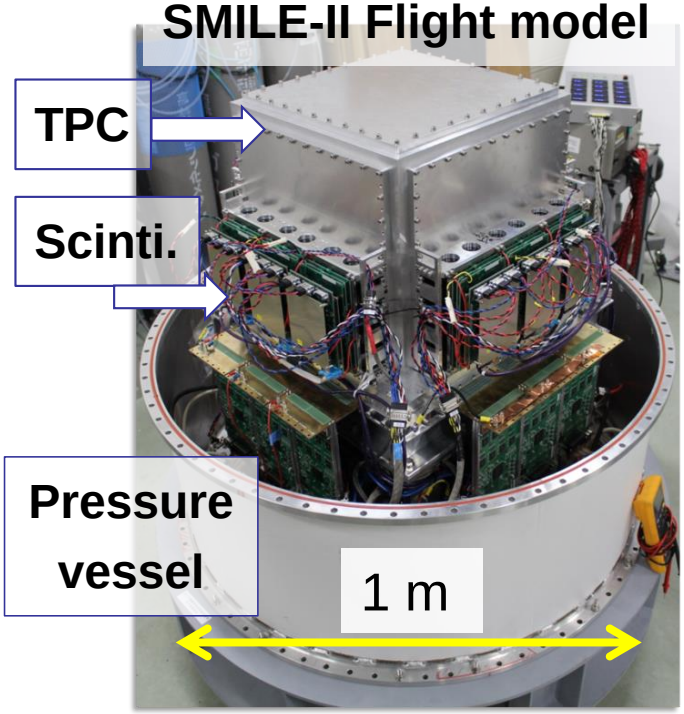


Particle ID by dE/dx



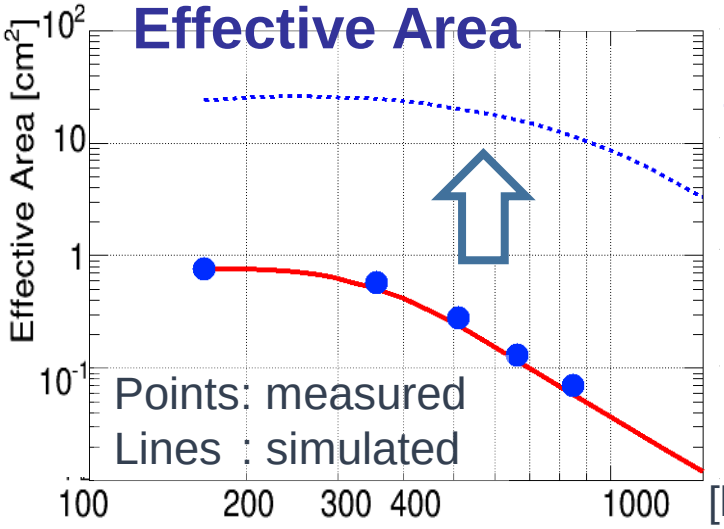
Current and near-future performance

SMILE-II Flight model



Gas	Ar-based @1atm
Gas volume	30 cm-cubic
Track sampling	800 μm
Scintillator	GSO:Ce 1 Radiation length
Energy resolution	10%@662 keV (FWHM)
Field of View	~ 6 sr

Effective Area

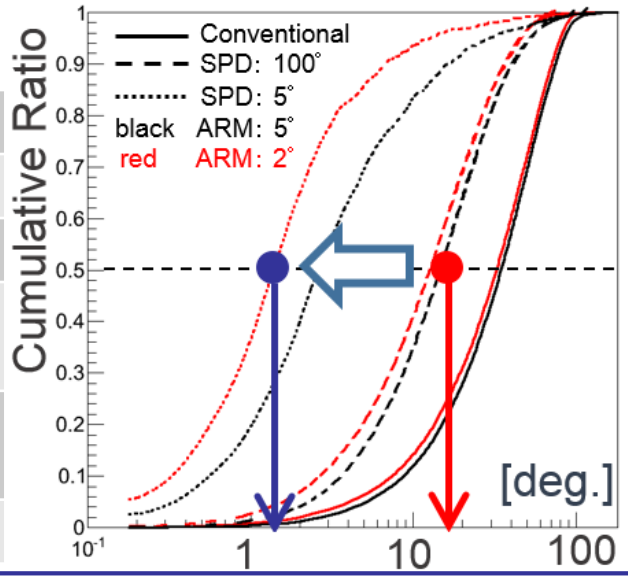


SMILE-III

- ✓ 40 cm-cubic
- ✓ CF_4 gas @3atm
- ✓ 3 R.L. scintillator

SMILE-II

PSF: angle containing half of all photons



SMILE-II, III 7-15º

SPD 30-100º

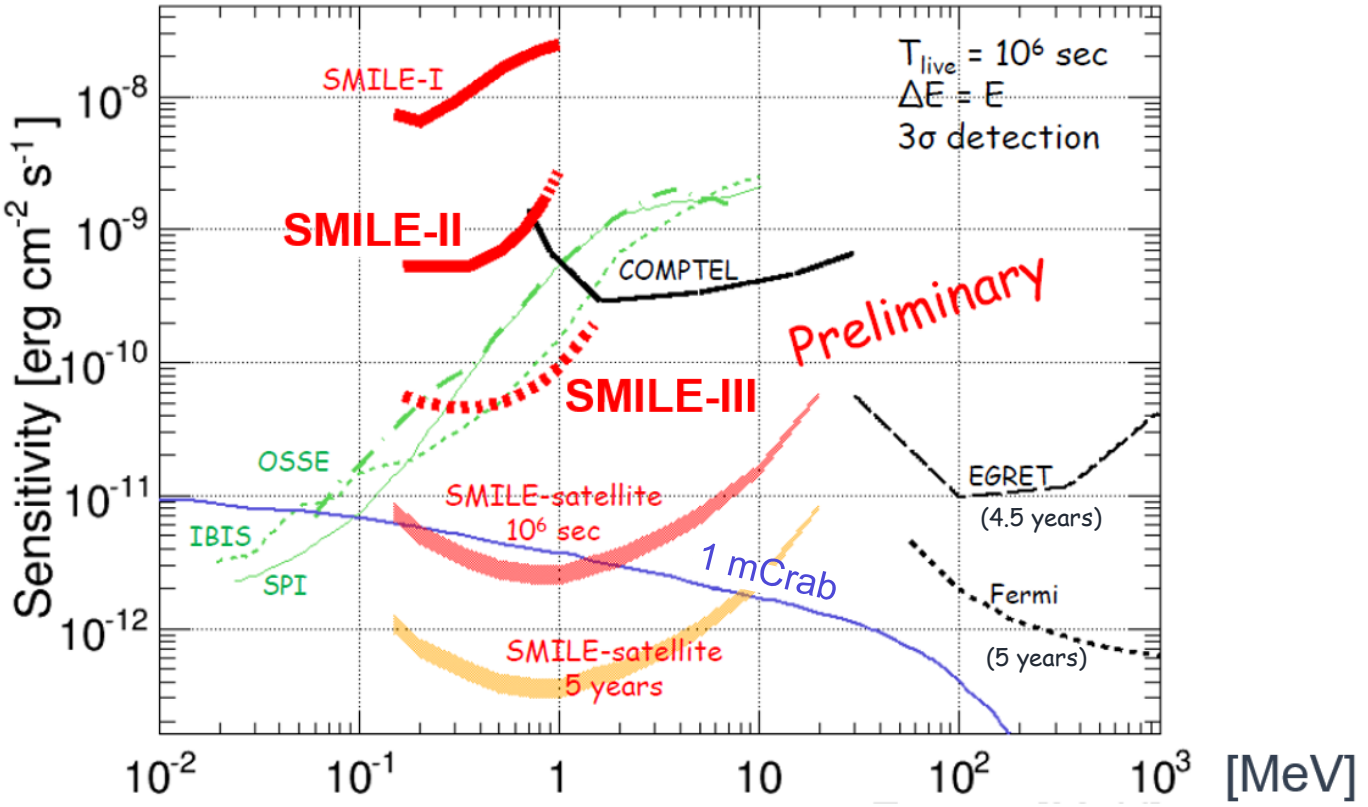
(energy dependence)

Near future ~ 1º

SPD < 10º

- ✓ more precise track sampling

Detection sensitivity

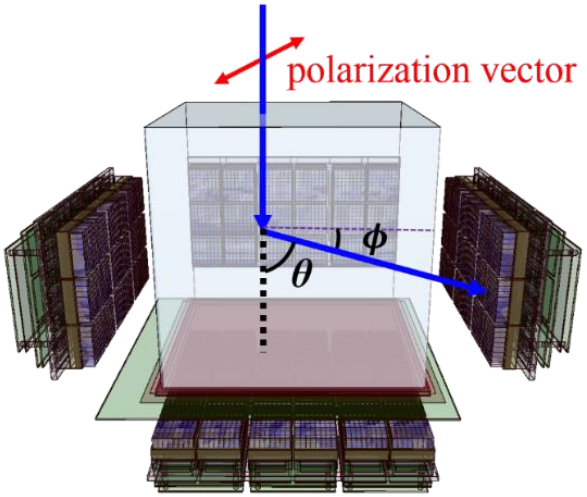


- SMILE-II : **Crab nebula > 5σ** (middle latitude, @ 40 km, 4 hours)
- SMILE-III : **10 times better sensitivity** (polar region, @ 40 km, 1 month)

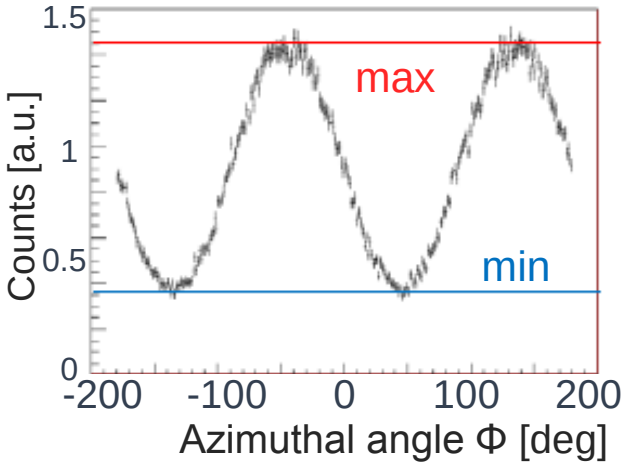
  ~10 celestial objects, extragalactic and galactic plane survey
- Satellite : **reach 1 mCrab sensitivity**（50 cm-cubic ETCC x 4）

as a Polarimeter

linearly polarized γ-ray



Asymmetric distribution of the scattered photons



Modulation Factor $= \frac{max-min}{max+min}$

~ 0.6@200 keV,

~ 0.5@500 keV

(Geant4 simulation)

Minimum detectable polarization (MDP)

$$MDP_{[\%]} = \frac{429}{ASM}\sqrt{\frac{AS+B}{T}} \quad 99\%\ \mathrm{CL}$$

$$B \gg AS \Rightarrow MDP \propto \frac{\sqrt{B}}{AS}$$

A	Effective area [cm^2]
M	Modulation Factor
T	Observation time [sec]

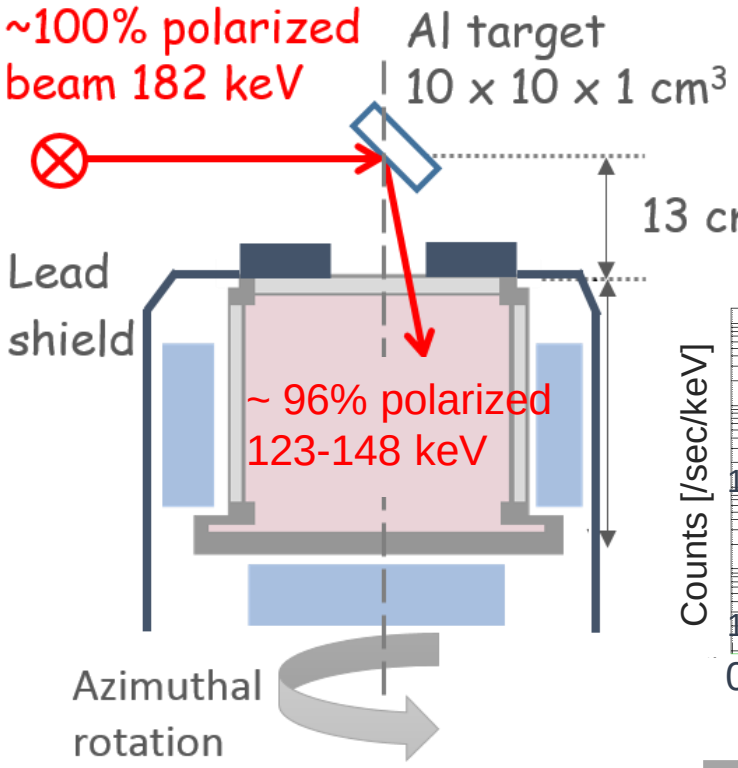
S	Signal [cm^{-2} sec^{-1}]
B	Background [sec^{-1}]

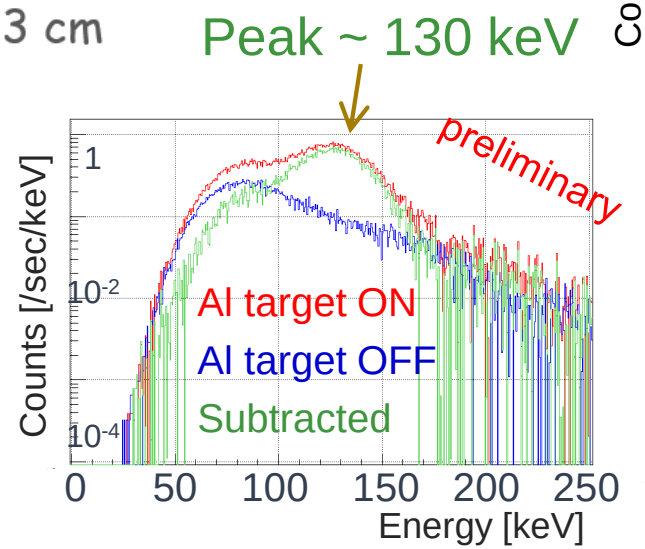
Sensitivity is limited by the background rate.

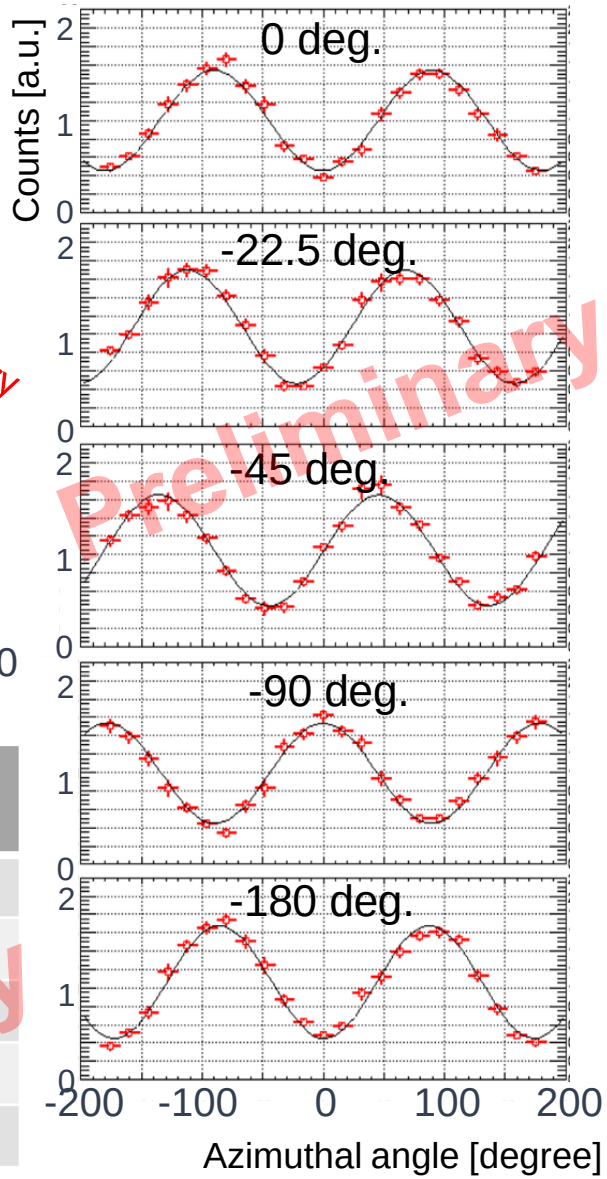
ETCC has a large advantage

- ✓ Powerful background rejection
- ✓ Imaging with wide FOV ~ 6sr

Beam test







- ✓ M ~ 0.6@130 keV
- ✓ Polarization angle
  ≒ Rotation angle

rotation [deg.]	M	Polarization angle [deg.]
0	0.57	0.3±1.3
-22.5	0.59	-22±1.0
-45	0.60	-44±0.7
-90	0.57	-90±1.1
-180	0.60	-2.3±1.1

Preliminary

Modulation Factor is consistent with the simulation results.

Summary

ETCC has the potential to overcome the problems in MeV band.

- ❑ Well-defined PSF without ML-EM
- ❑ Powerful background rejection by dE/dx

- ➢ SMILE-II ETCC ~ 1 cm^2 @ 200 keV
  - ✓ **detectable Crab nebula with > 5σ level**
    (middle latitude, 4 hours at 40 km)

- ➢ Future Plan: SMILE-III ETCC (~10 times better sensitivity)
  - ✓ **~ 10 celestial objects** (polar region, 1 month at 40 km)
  - ✓ Polarization sensitivity : 3σ MDP
    Crab nebula ~ 15 %, Cyg X-1 ~ 20 % (half-day flight)
    GRBs ~ 6% for 10^{-6} erg/cm^2 s (2-3 GRBs/month)
    ~ 20% for 10^{-7} erg/cm^2 s (~10 GRBs/month)

- ➢ Future Plan: SMILE-satellite (~ 1mCrab sensitivity in 10^6 sec)

Thank you for your attention!

Details are discussed in T.Tanimori+2015 accepted for publication in ApJ.

[arXiv: 1507.03850]

Report of polarization measurement will be submitted within the year.