# SMILE project: all-sky MeV gamma-ray observation and dark matter survey

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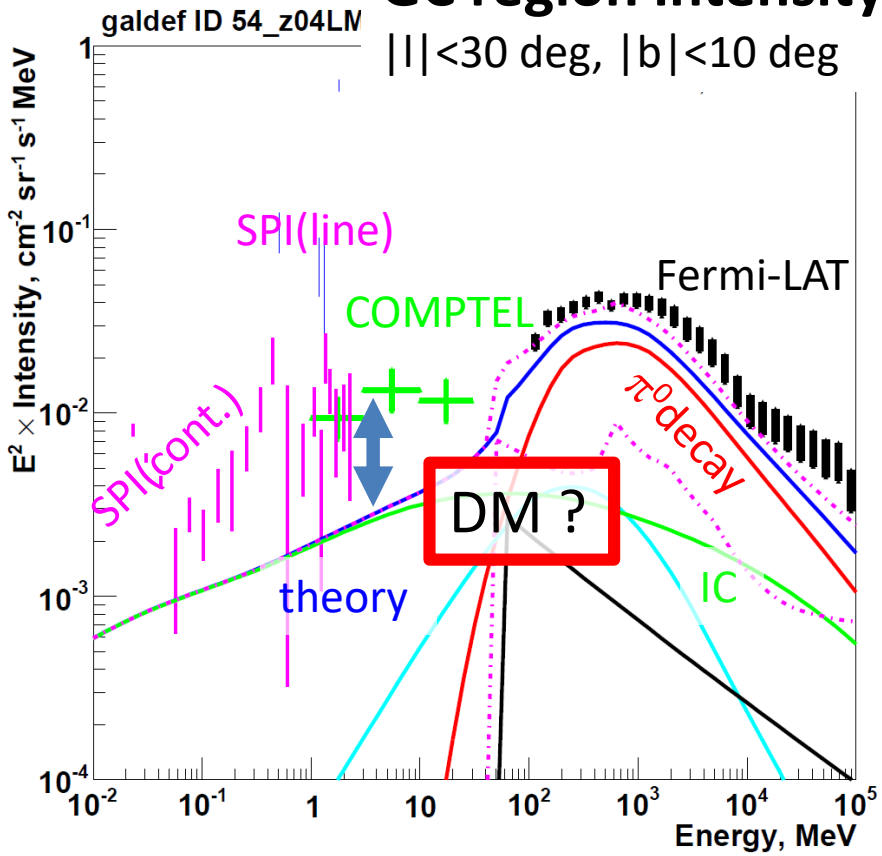
# MeV gamma-ray excess problem

A.W.Strong+ (2011)

**GC region intensity**

|l|<30 deg, |b|<10 deg



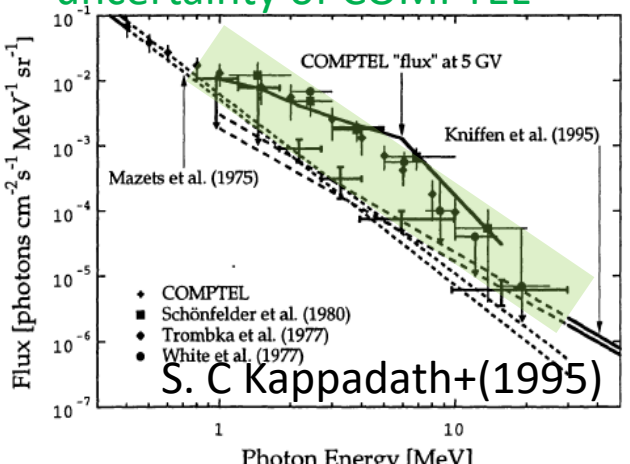

*SPI and Fermi were published data but COMPTEL was not published

MeV band is the good windows of the indirect light dark matter search because this band is outside of the $\pi^0$ bump. PBH as the dark matter is also in this band.

There is **a large gap between the theory and the observations** in the GC MeV gamma-ray intensity.

**But the observation data has the large uncertainty due to the incomplete imaging method and the huge BG.**

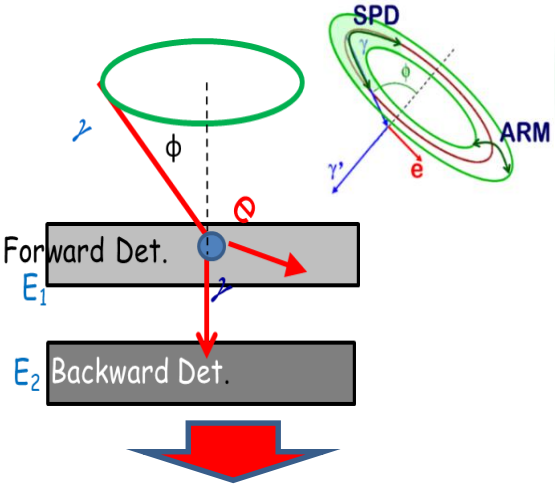
extra galactic diffuse gamma-ray uncertainty of COMPTEL

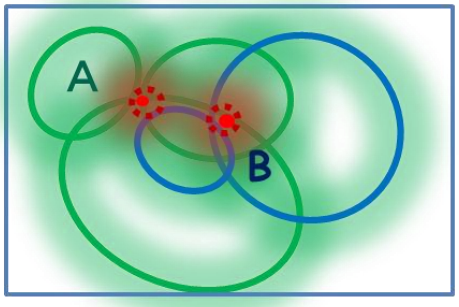



S. C Kappadath+(1995)

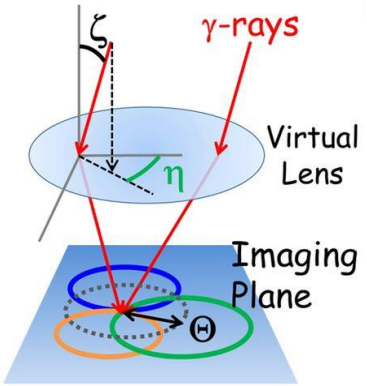
# Importance of the 2 angles imaging

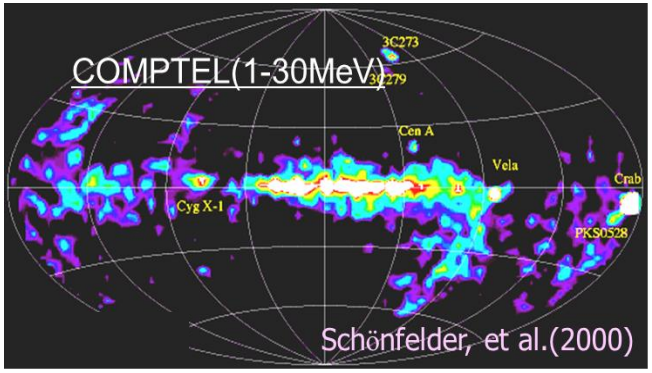
Compton Cameras (CCs) cannot get the recoil direction of the electron.
So, the one event image of CC is a just circle(radius=scattering angle)

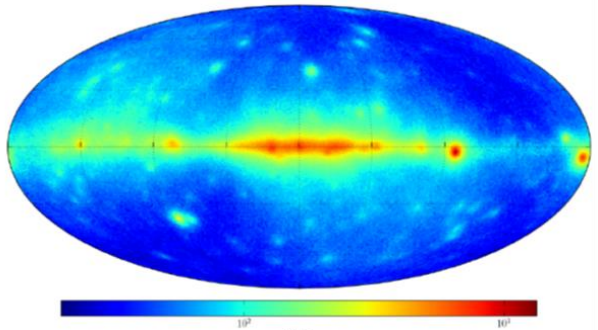



gamma-rays from the different directions A and B are mixed.



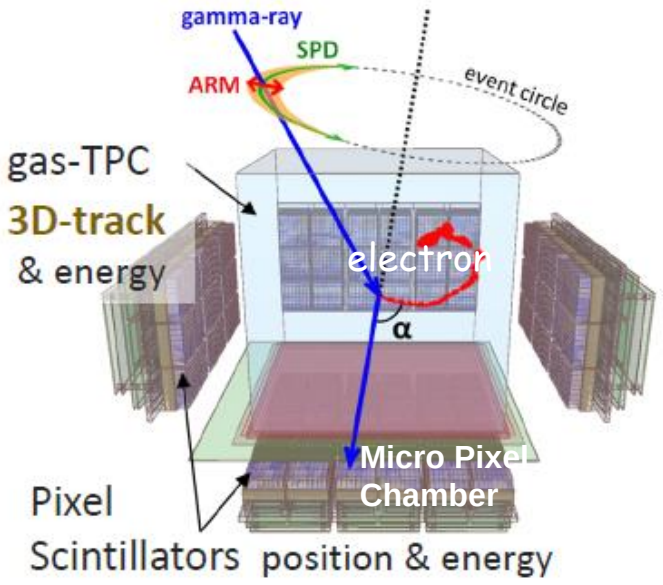



G. Principe et al. (2018)

COMPTEL(1-30 MeV)
32 sources detected 9yrs
**1D-anguler resolution: 1.5 deg(RMS)**

Fermi (low energy band:30-100 MeV)
198 sources detected 9yrs
**2D-PSF 3-12 deg(68% include)**

# Electron Tracking Compton Camera (ETCC)




30cm-cubic Gas Time Projection Chamber
+ Scintillator Array for scattered γ
--- tracking of recoil electron ---

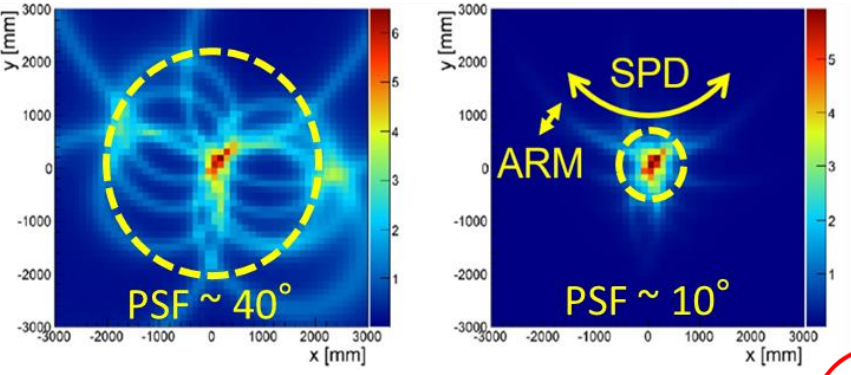
Measuring all parameters of Compton process

1. 2D-PSF ( 8 ~15° @HPR)

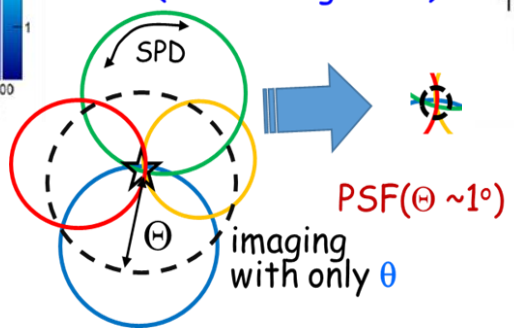
=> Realization of proper imaging spectroscopy

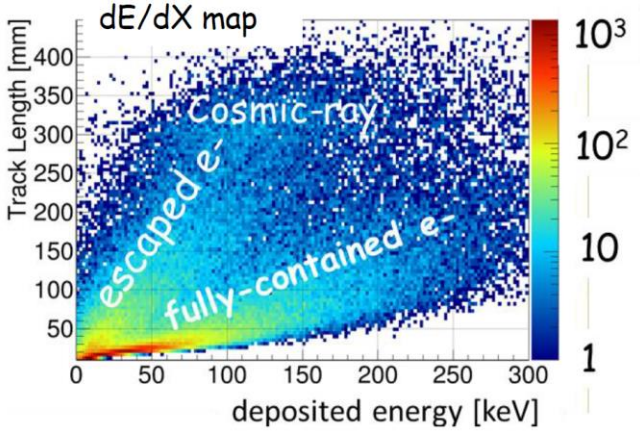
2. dE/dx + kinematical test using α
3. large Field of View (>4str)
4. Ar 2atm in TPC dE/E ~20%@30keV
5. GSO scinti. used dE/E ~11%@662keV

CC imaging (662keV) ETCC imaging



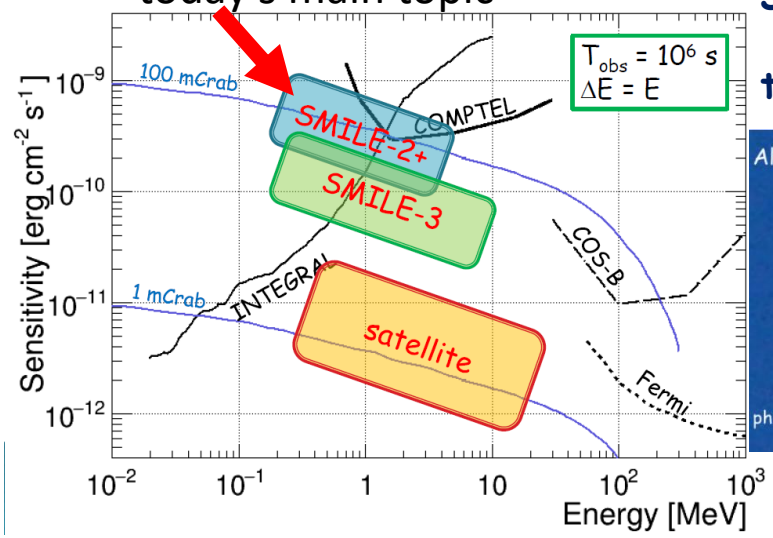

Θ is a Half Power Radius (HPR)



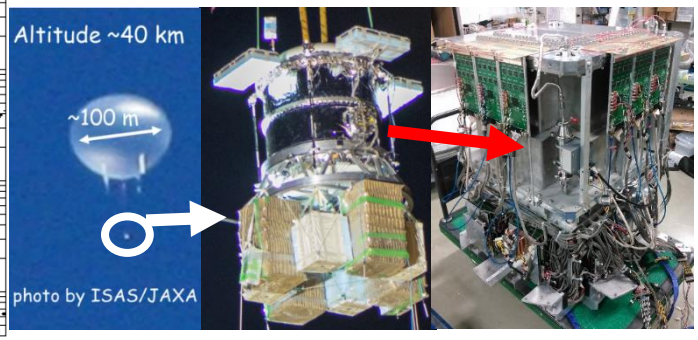



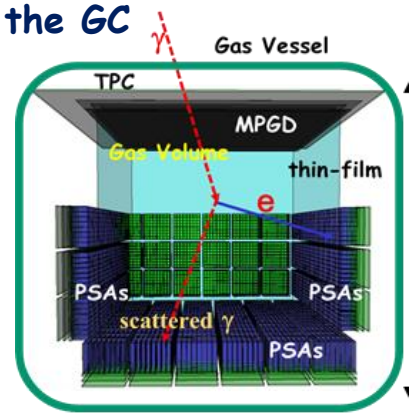
# Sub-MeV and MeV gamma-ray Imaging Loaded-on-balloon Experiment (SMILE-project)

today's main topic




**SMILE-2+ (April 2018 in Australia. 1day flight)**
**30cm cubic ETCC (Ar 2atm)**
**target: Crab nebura & 511 keV from the GC**



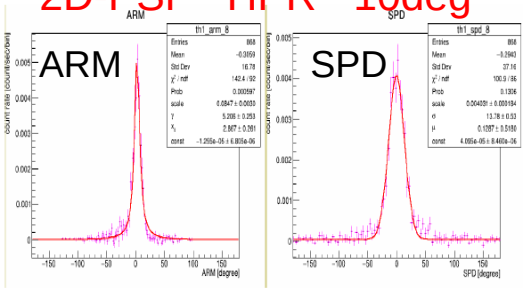



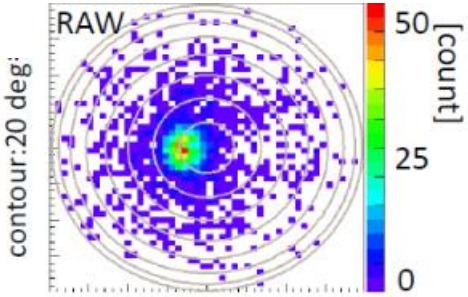

The biggest improvement in SMILE-2+ is
that the electron escaped events get analyzable!
The energy range: 0.2-1 MeV -> 0.2-5 MeV

ARM< SPD & 2D-PSF at present analysis

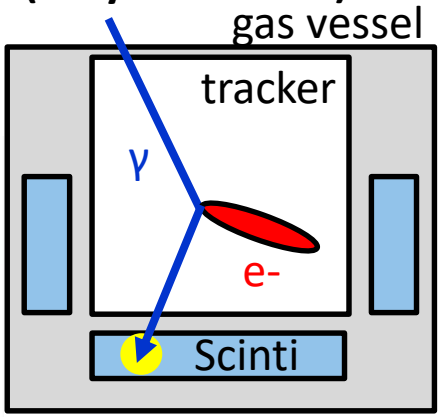
low energy event Cs137 0.66MeV
ARM:9 deg(FWHM), SPD: 70 deg(FWHM)
2D-PSF: Half Power Rad. ~15deg

high energy event Na22 1.27MeV
ARM:10.4 deg(FWHM), SPD: 32.4 deg(FWHM),
2D-PSF HPR ~10deg

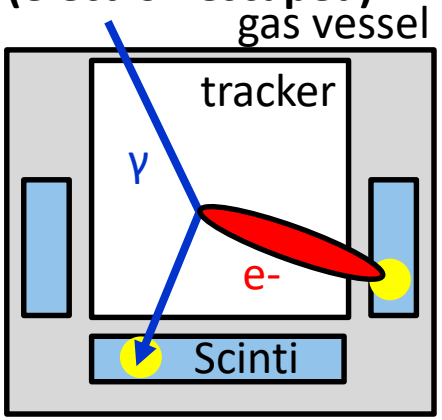



**low energy event**
**(fully contained)**



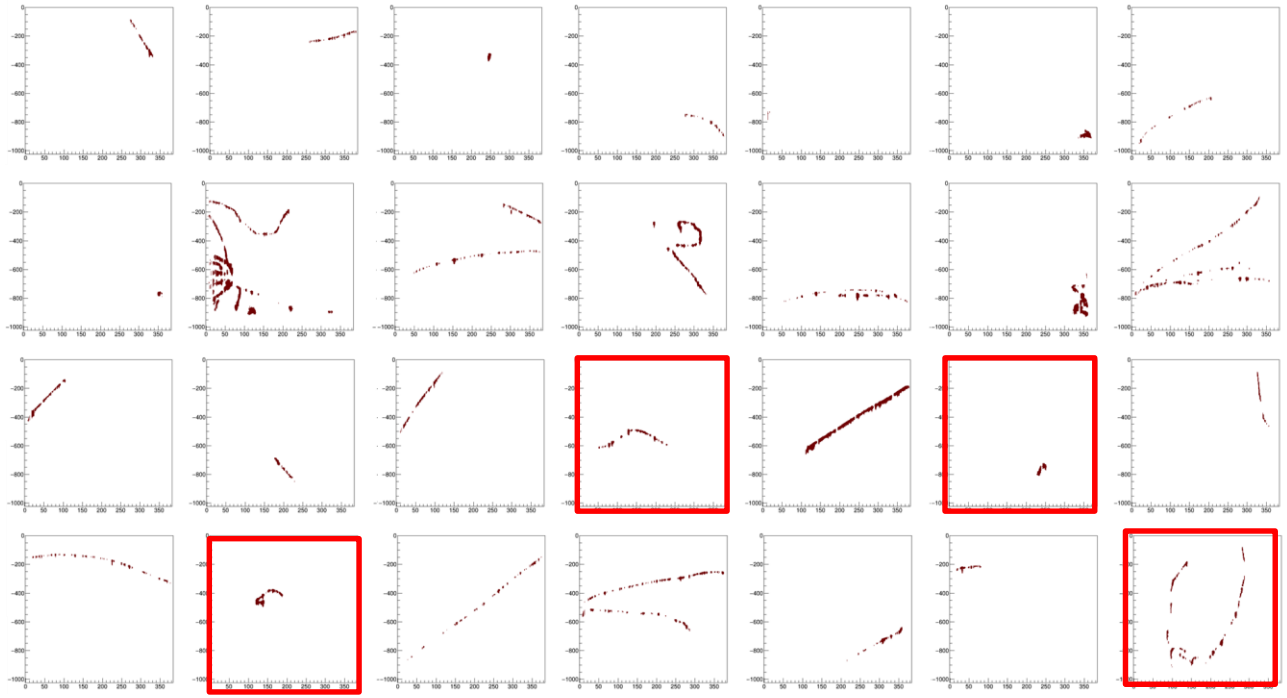

**high energy event**
**(electron escaped)**



# gas tracking detector is essential for our powerful noise reduction

continual 28 events in the flight data

red box: signal-like track



2 atm Ar 30 cm~ 200 um SSD

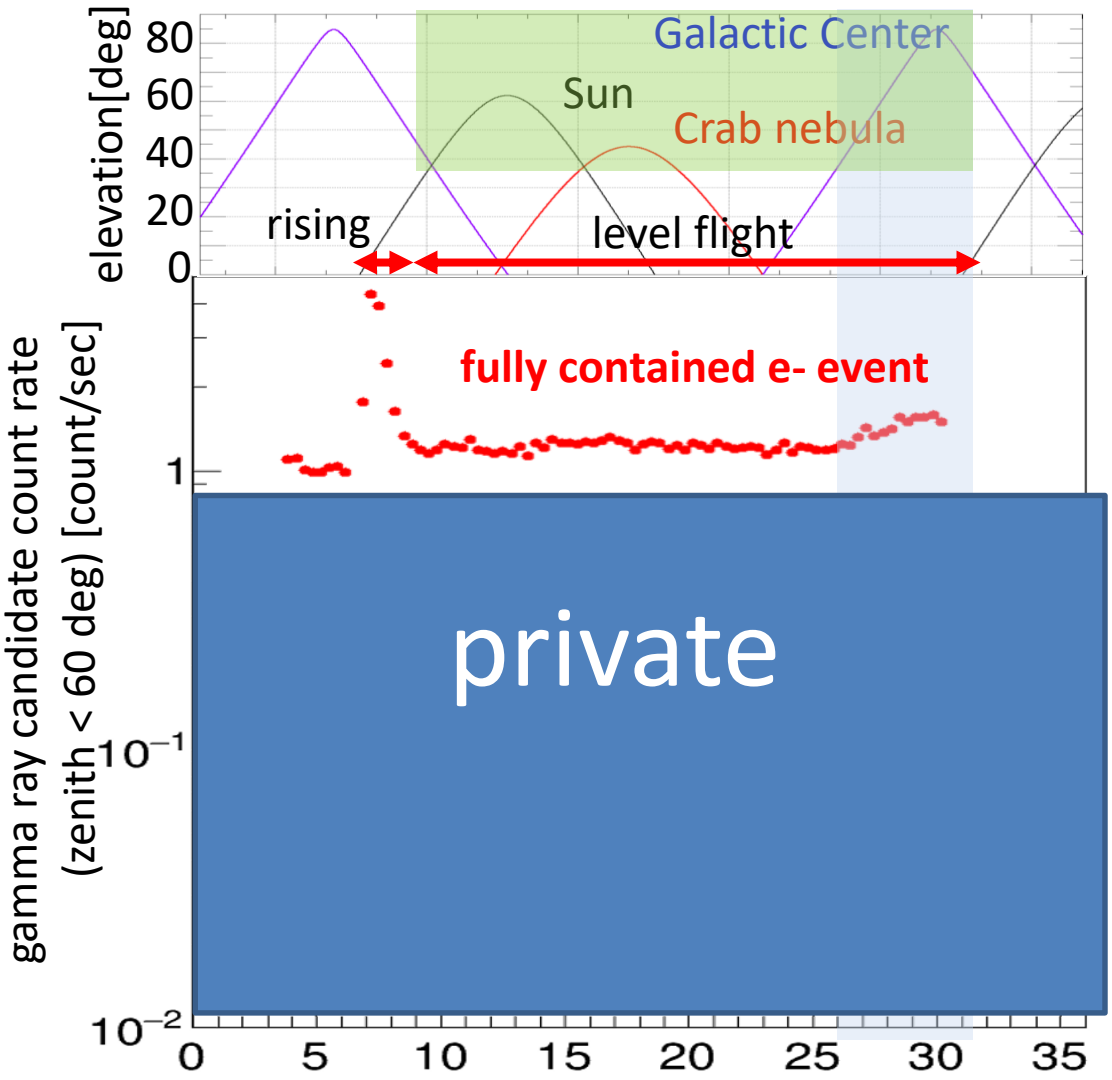
-> solid-state tracker get only 2 point from these tracks

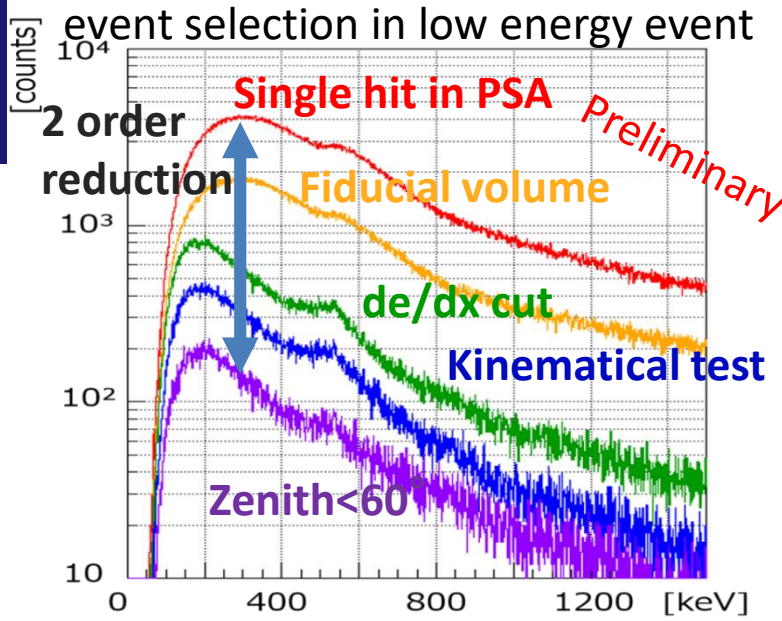
Almost noise events are easily cut by the track topology.

But solid-state trackers cannot get enough these topology.

**Gas-state tracker is essential for the powerful noise reduction.**

# SMILE 2+ count rate




There is the GC excess in the both analysis. **This means that Our Instrumental BG level is equivalent to the cosmic gamma-ray.**
(**<u>this is the first in the world</u>**)

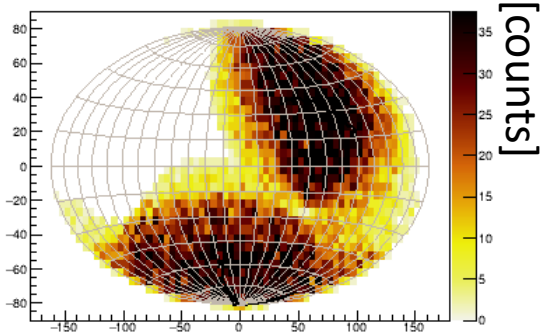
Because of the difference in the ratio between the level flight and the GC between the two analyses, the spectrum of the galactic diffuse gamma-ray is harder than the extra-galactic diffuse gamma-ray.

# sky map of SMILE-2+

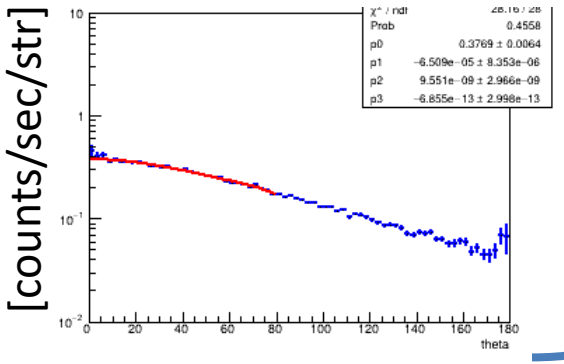
We analyze the flux from The Galaxy by the ON-OFF method. In conventional CC, ON-OFF method is illegal, because the signals from large area (~3 str) are coupled.

**This method is valid only in ETCC.**

sample region

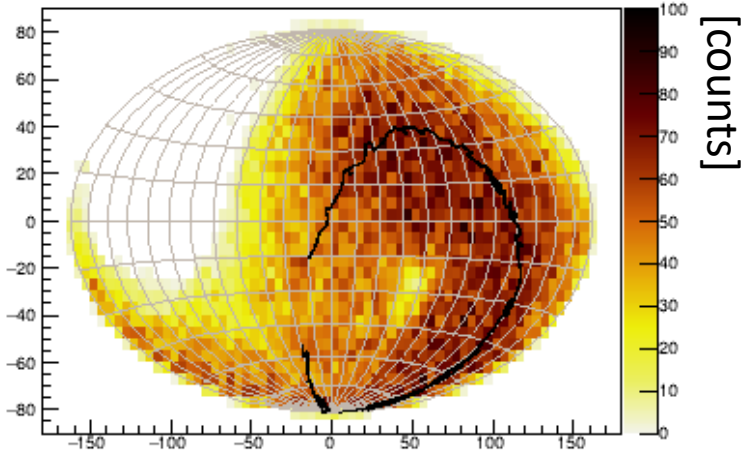



zenith profile




## A:ON count map data

simple count map of the fully contained events

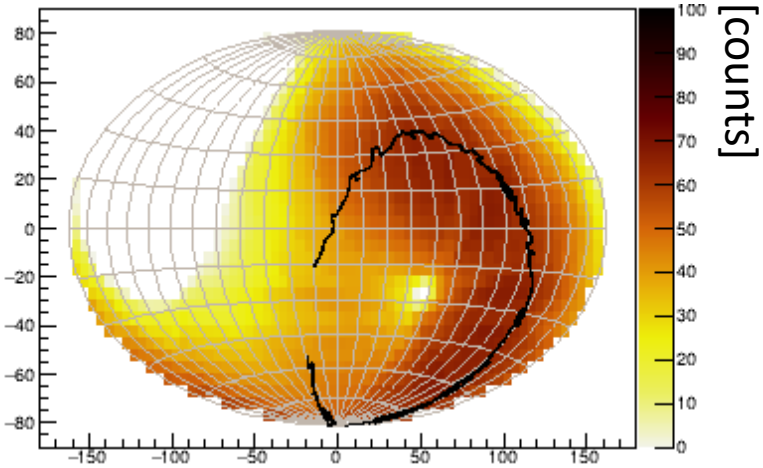



subtracting

A-B

## B:OFF count map model

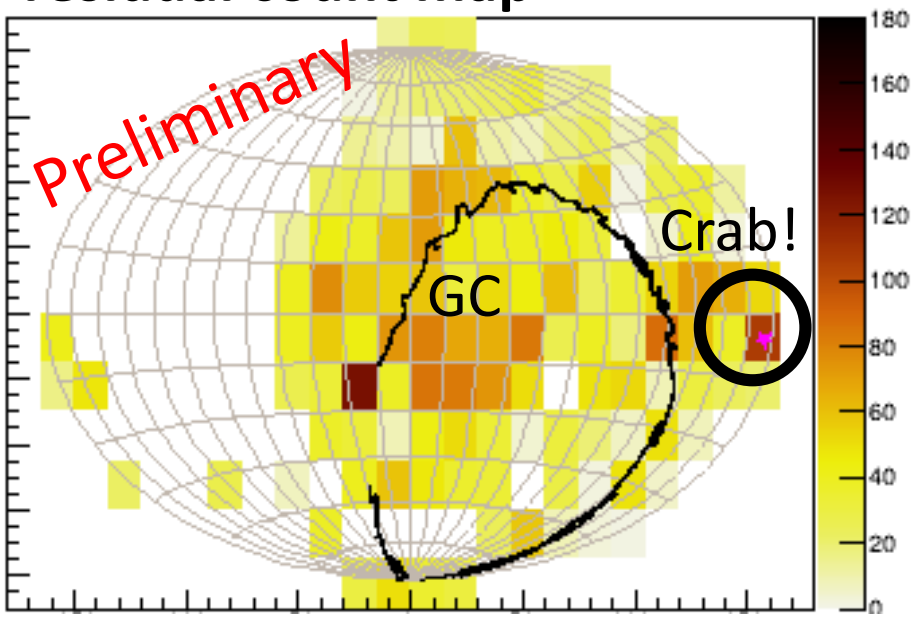
(=CGB + atmospheric + instrumental)




*galactic coordinate

# sky map of SMILE-2+

**residual count map** [counts]



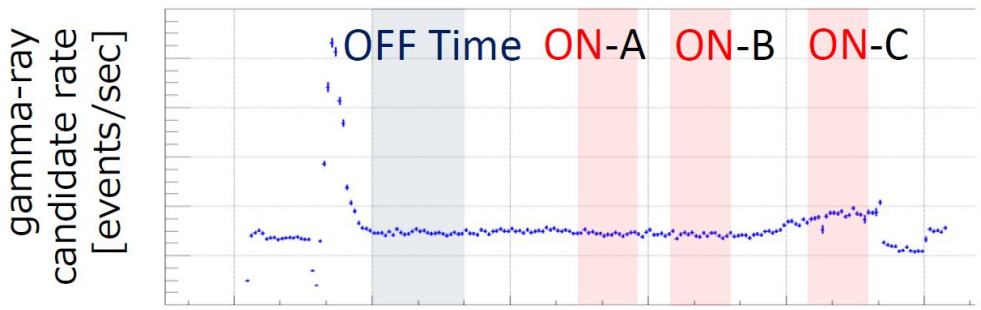

**significance map** [σ]

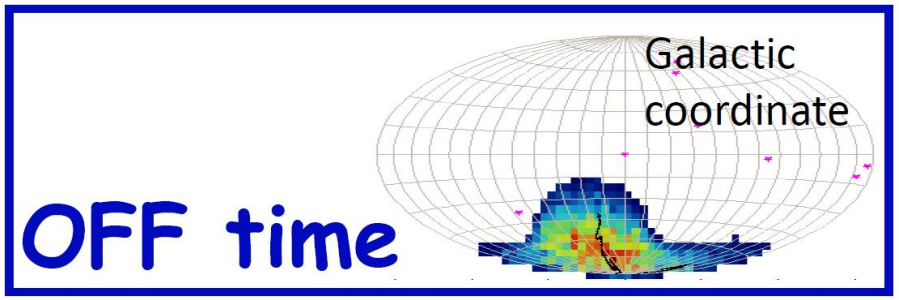
private

Crab nebula was successfully detected (~5σ) by the imaging!
Also this significance is same as the proposal!
This is the first time that the observed significance matches the proposal in the Compton camera.

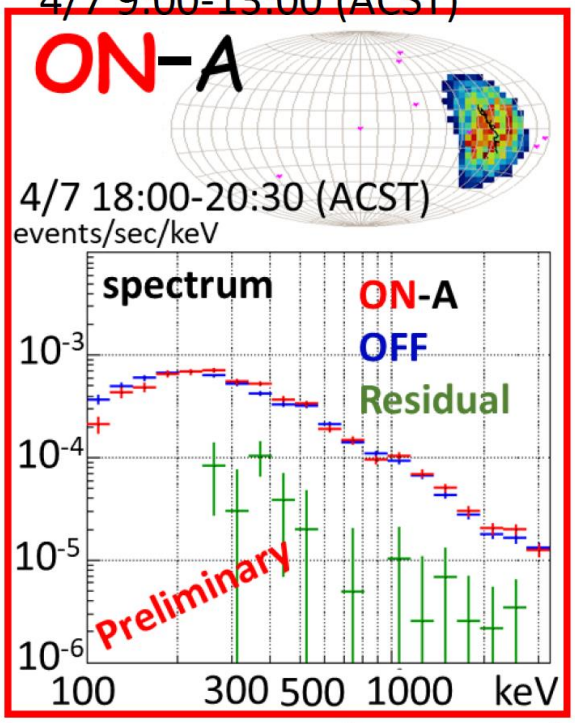
Our preliminary result indicates the radiation from GC is spread ~30 deg in each direction.

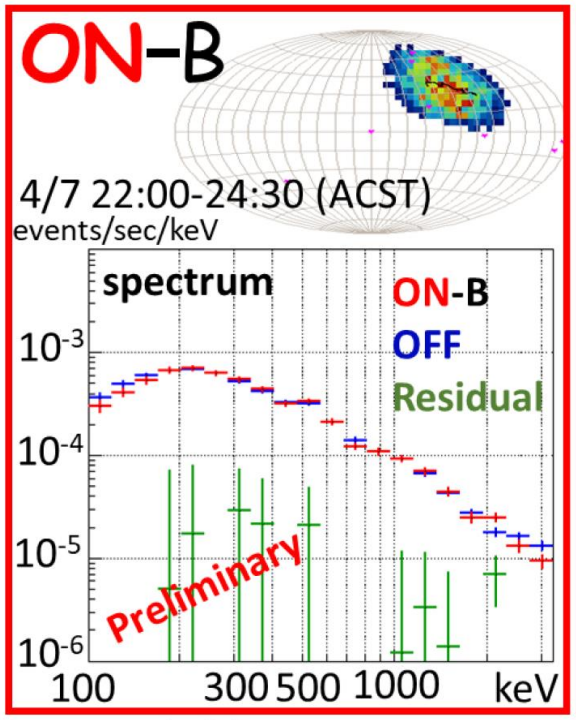
# the spectrum of the low energy event

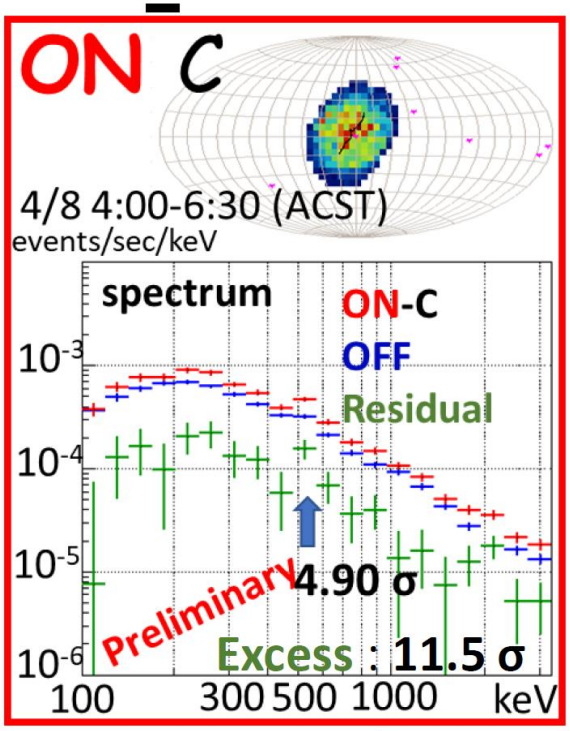



4/7 9:00-13:00 (ACST)



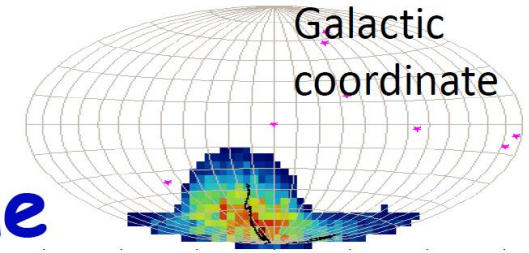



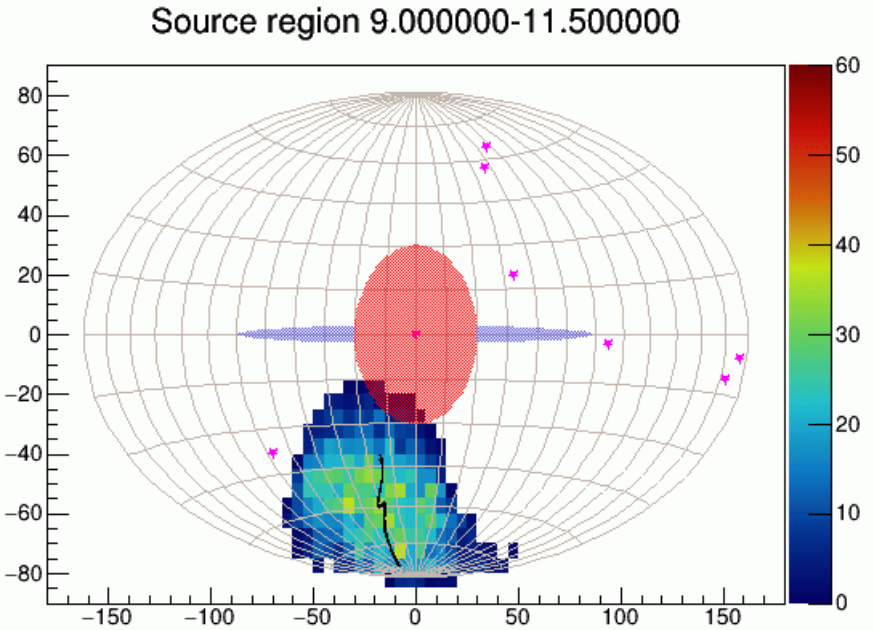



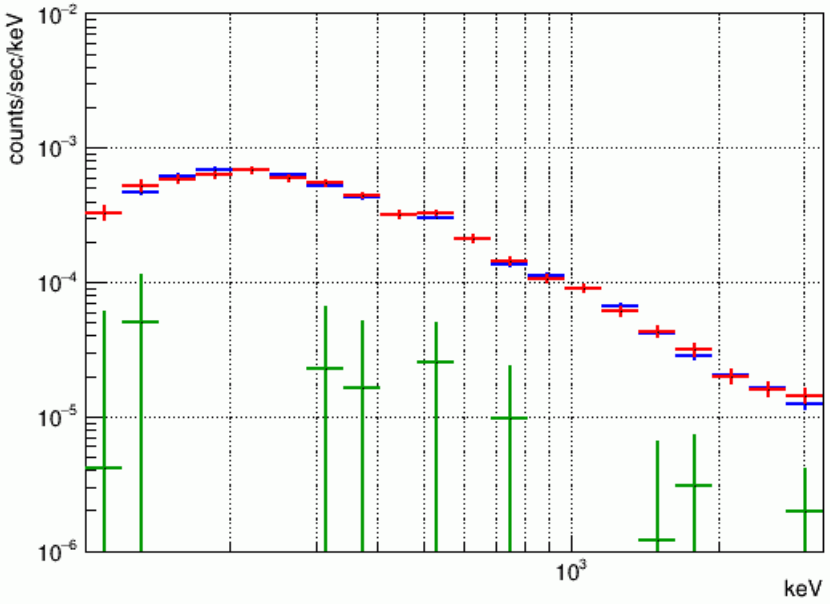

**An excess of ~ 511 keV & diffuse components in G.C. is observed**

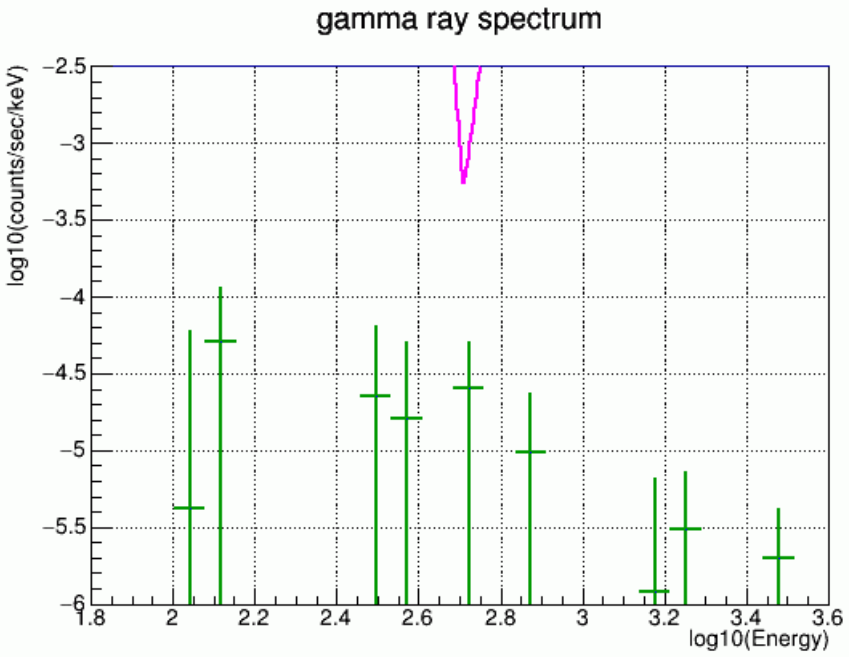
fully contained event analysis
zenith < 30 deg
OFF data: 4/7 11:00 - 13:00

**OFF time**



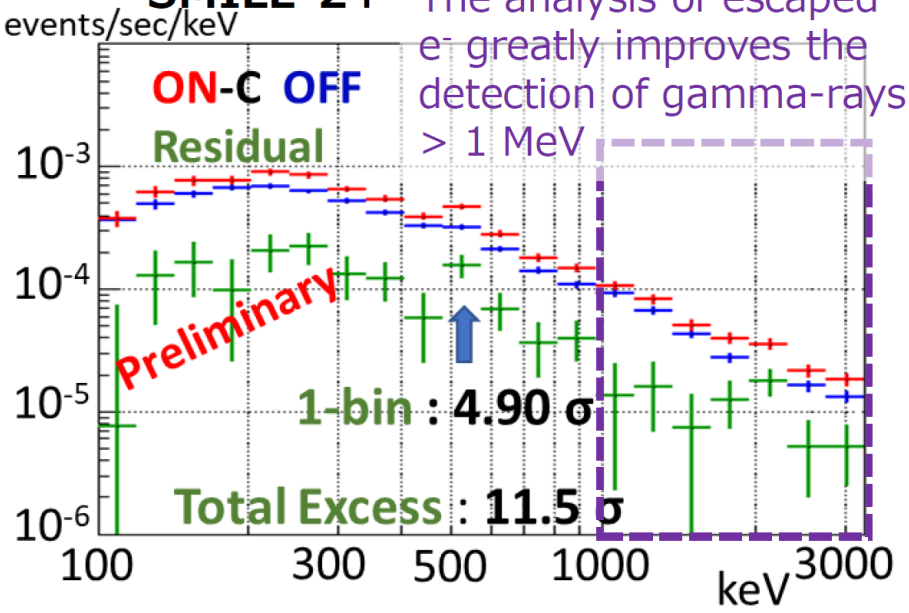



# Comparison with COSI

· **SMILE-2+** The analysis of escaped $e^-$ greatly improves the detection of gamma-rays > 1 MeV



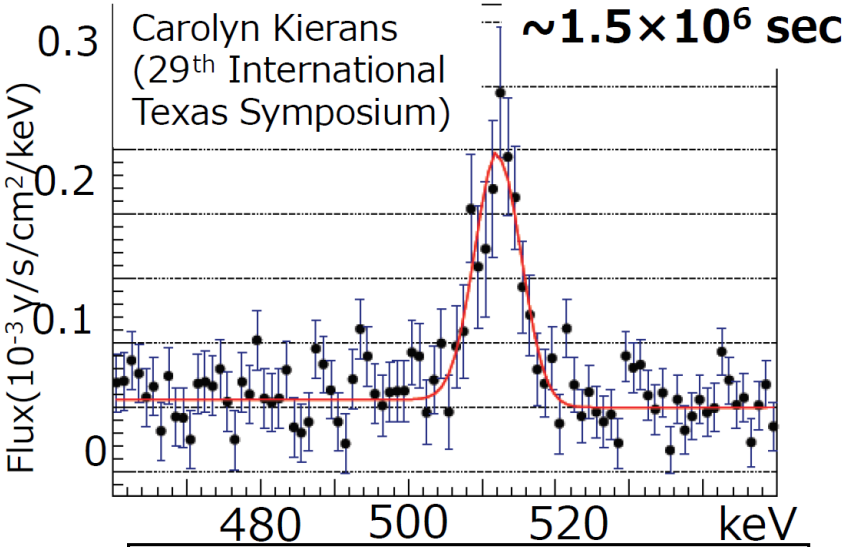

Quick check :
$10^{-3}$ - $10^{-2}$ events/cm²/sec
3σ-5σ @ 460 – 560 keV

Assuming the ETCC has the same observation time of COSI:

$$3\sigma\text{-}5\sigma \times \sqrt{\frac{1.5\times10^{6}\ \mathrm{sec}}{6.4\times10^{3}\mathrm{sec}}} = 45\sigma - 77\sigma$$

ETCC can improve the significance dramatically.

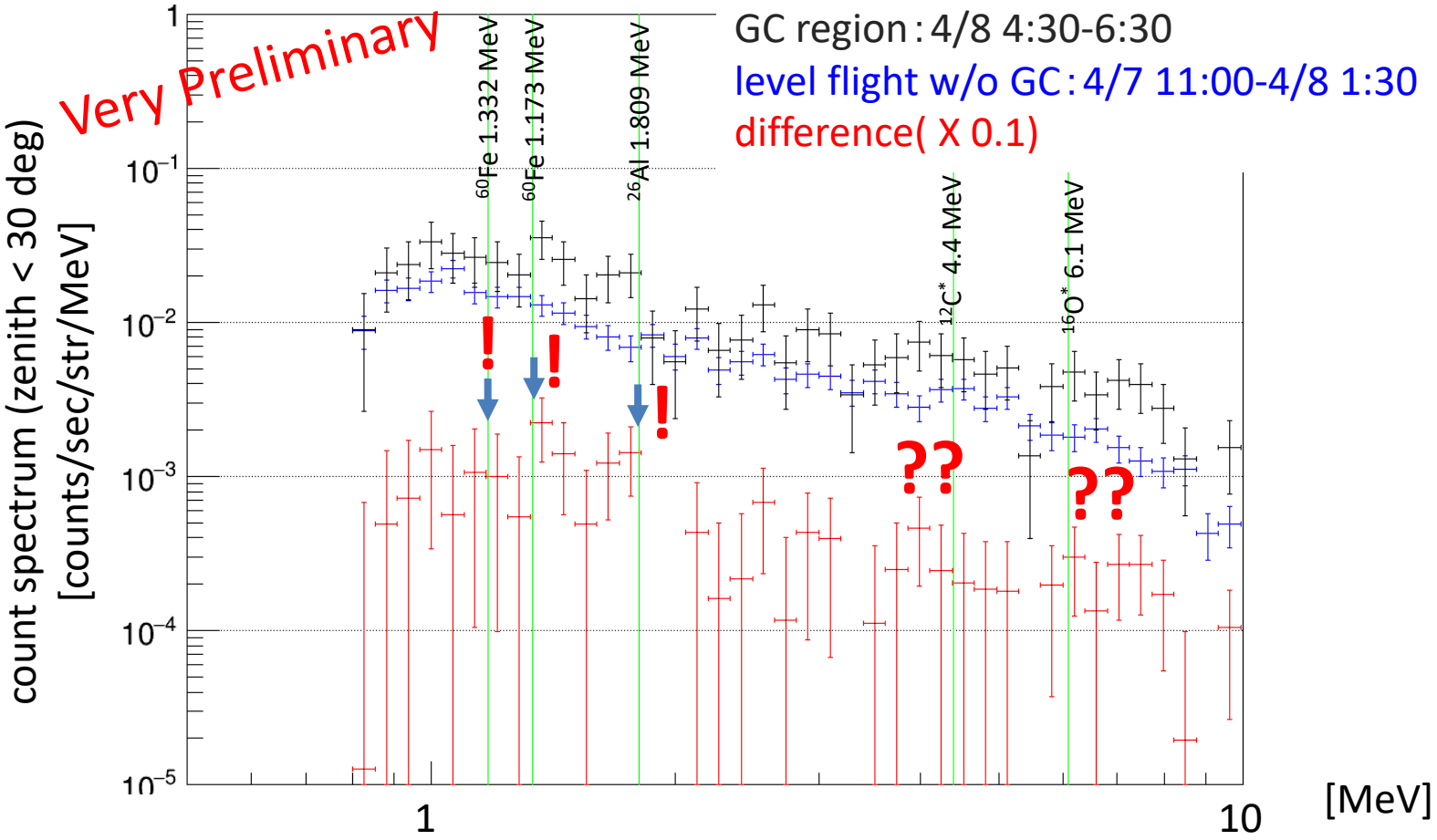
· **COSI** 2016 balloon experiment with telescope in this energy band




~$1.4\times10^{-3}$ ph/cm²/sec
9σ (the same energy range)

| | SMILE-2+ | COSI |
|---|---|---|
| Eff. Area (511 keV) | ~1.5 cm² | ~10 cm² |
| △E/E | 12 % | 0.5 % |
| VETO | nothing | exit |
| **Sig/BG** | **~ 1/1** | **~ 1/60** |

# the spectrum of the high energy events




High energy event analysis of SMILE-2+ indicate the existence of some lines detected by the previous observations. **The level flight spectrum is free from the instrumental BG peaks same as the low energy event analysis.**

In this analysis, the cut is set to be tight. There is a possibility that the statistics can be increased to about twice.

# Galactic diffuse gamma-ray spectrum

private

# Summary

- the MeV gamma-ray is the best window for the GeV-MeV dark matter search.

- Electron Tracking Compton Camera (ETCC), which has the 2D-PSF and the powerful noise reduction, is the best MeV gamma-ray telescope.

- SMILE-2+(2018), the balloon experiment,
  - **The significance of 511 keV(5σ) in the GC region and the Crab nebula(5σ) is same as the proposal.** (This consistency is the first in the Compton methods)
  - **very low instrumental BG < the extra galactic BG** (the first in the Compton methods)
  - the symptom of 60Fe and 26Al lines are simultaneously detected.
  - private