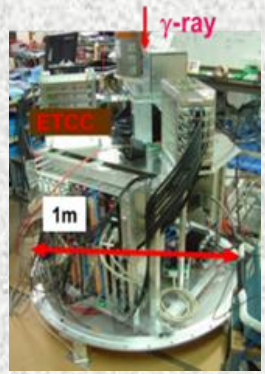
SMILE (Sub-meV & MeV gamma-ray Imaging Loaded-on-balloon Experiment) & ETCC-Satellite

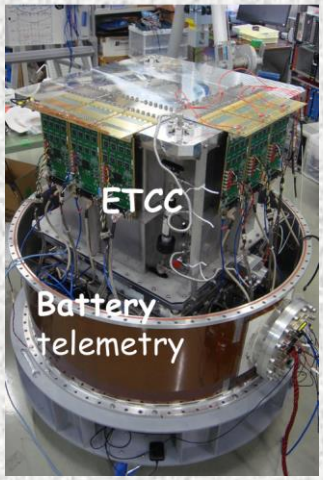
SMILE Project

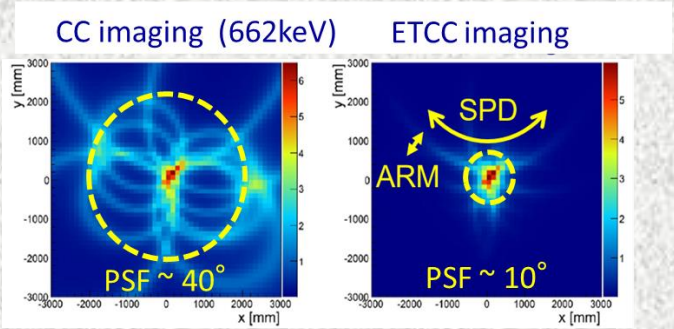
Electron Tracking Compton Camera(ETCC)

2006 SMILE-I
10cm cubic ETCC



SM2+ 2018
30cm ETCC





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- What is ETCC?
- SIMLE2+ balloon Exp.
- Results
- Next and future perspectives
- Summary

8th/Jan./2020@AAS 2020 Honolulu

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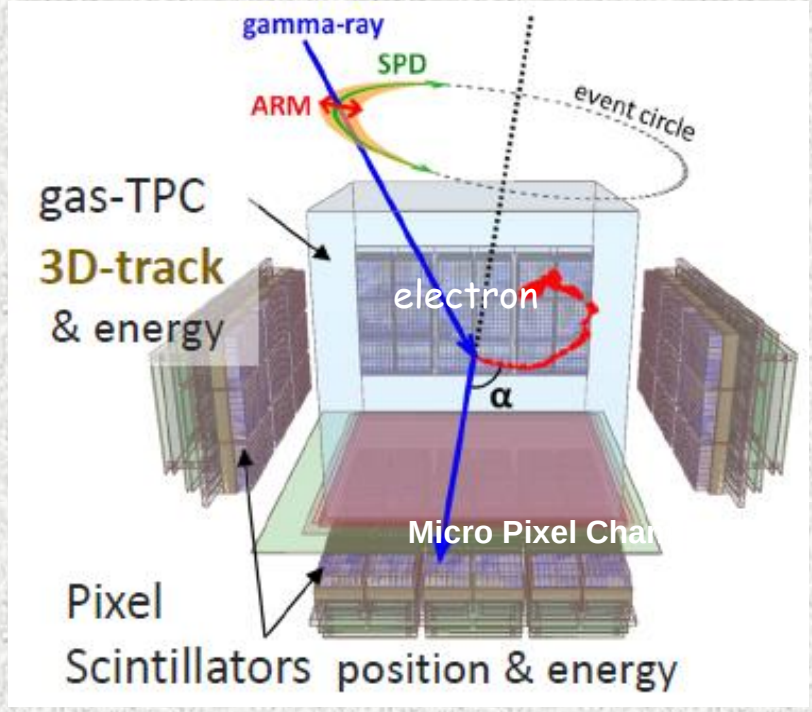
Cosmic-ray group, Physics Division, Kyoto University, Japan

Electron Tracking Compton Camera

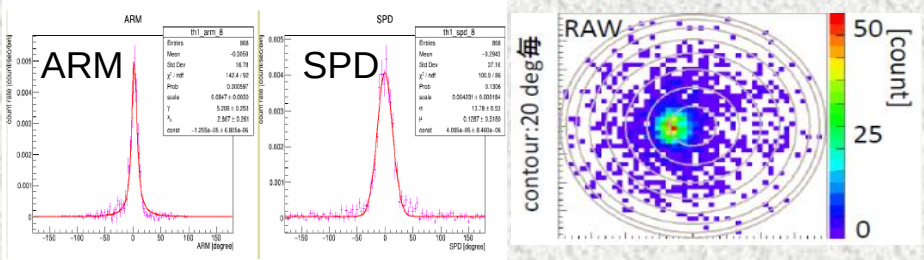


--- tracking of recoil electron ---

Measuring all parameters of Compton process

1. true2D-PSF (8~15° @Half Power Radius)
   => Realization of proper imaging spectroscopy
2. dE/dx + kinematics using α (particle-ID)
3. FoV of .4sr ,Energy 0.1~10MeV, No Veto !

2D- PSF (12°, 1.27MeV)

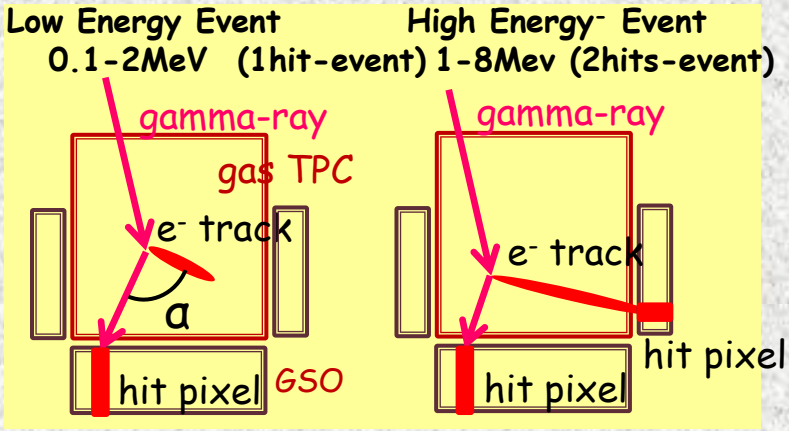


30cm-cubic Gas Time Projection Chamber(TPC)

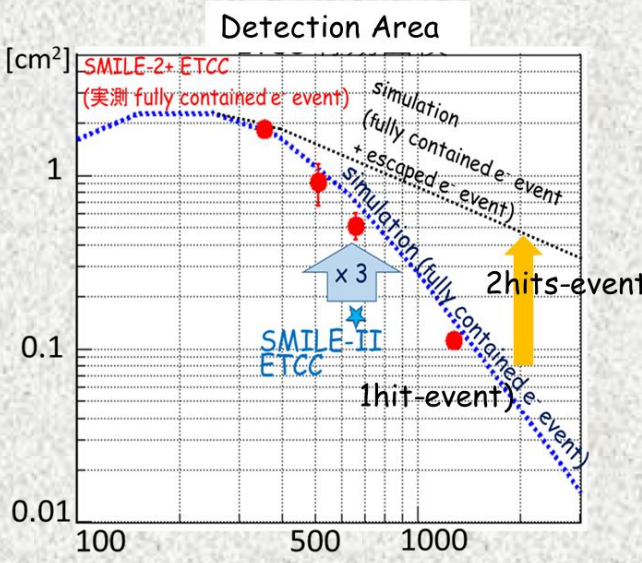
\+ Scintillator Array for scattered γ

. Ar 2atm in TPC
dE/E ~20%@30keV

GSO
dE/E ~12%@662keV
future
GSO;MPPC 8%
HR-GAGG 5%
CzT+HR-GAGG 3%



Detection Area



SMILE-2+ Balloon flight at Alice Springs (JAXA)

Proposed Targets :511keV line, Crab (~5sigma), Cosmic Diffuse gamma (CDG)

by
A

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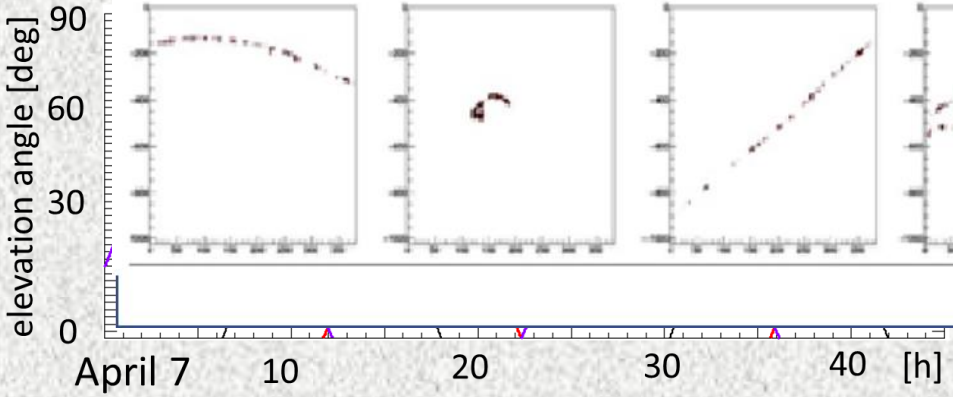
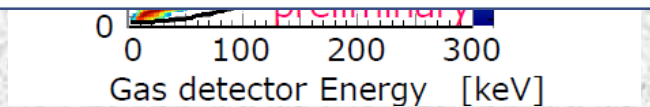
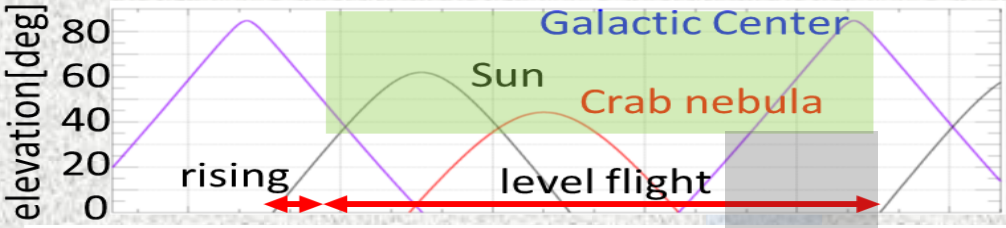
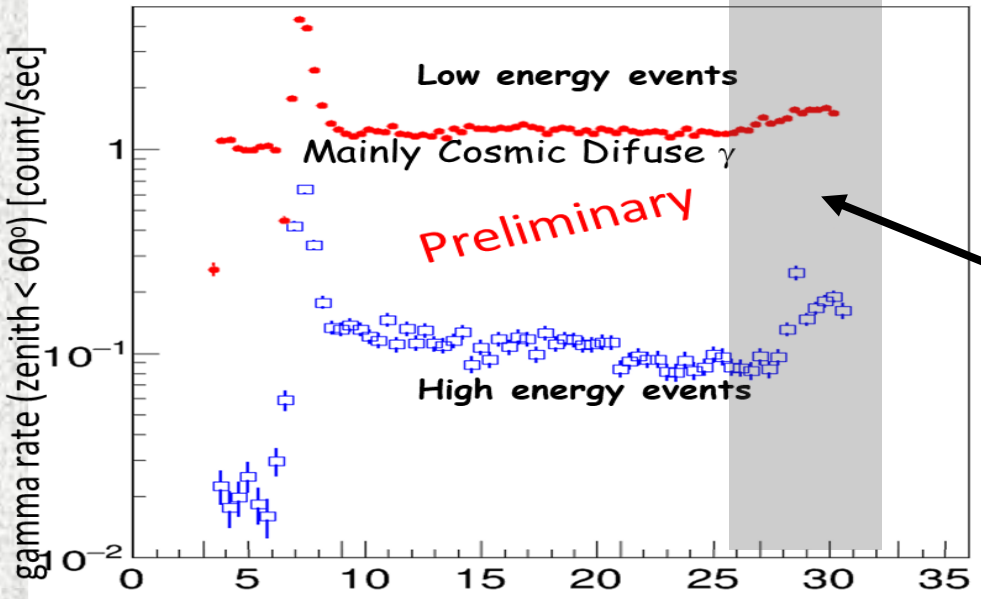
Observed Tracks in space
2arm Ar 30cm ~ 200μm thick SSD x3





Light Curve & Cosmic Diffuse gamma (CDG)

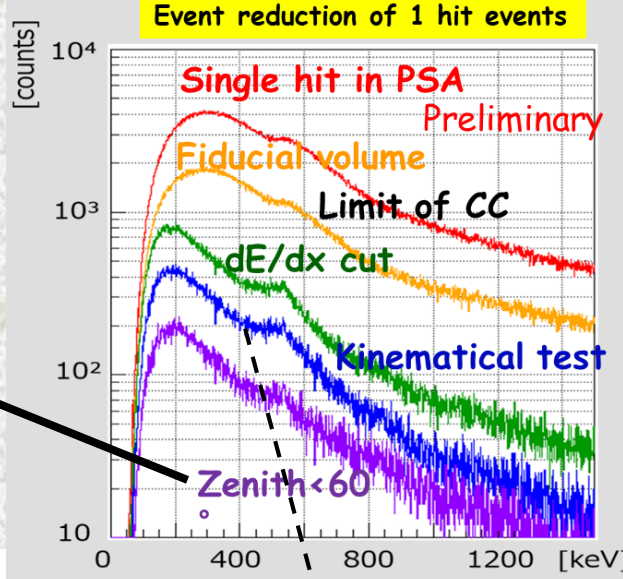


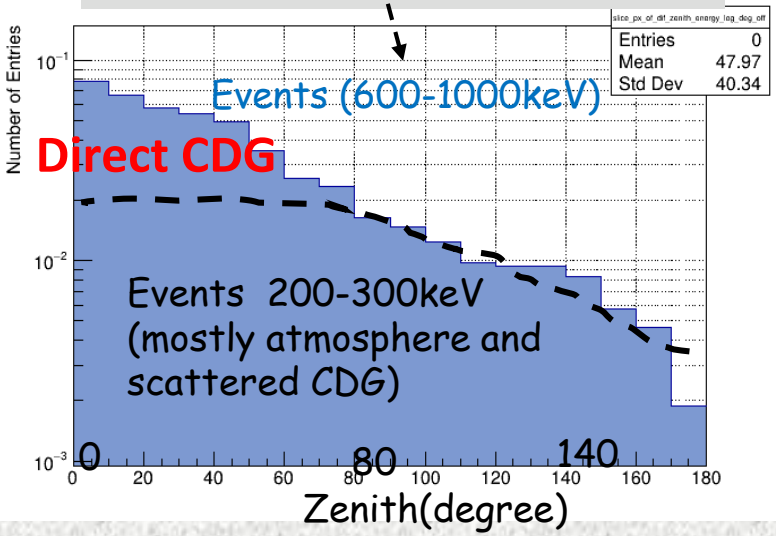


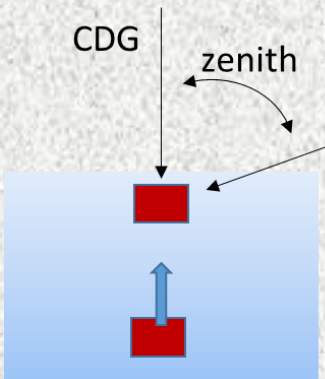
Simple Event selection

- Fiducial cut in TPC
- dE/dx cut

Event reduction of 1 hit events



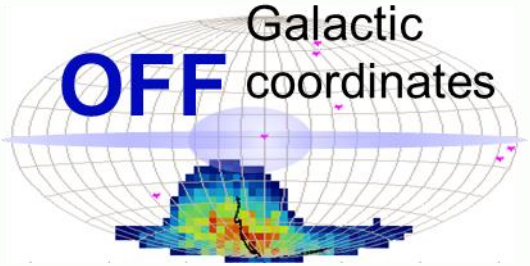




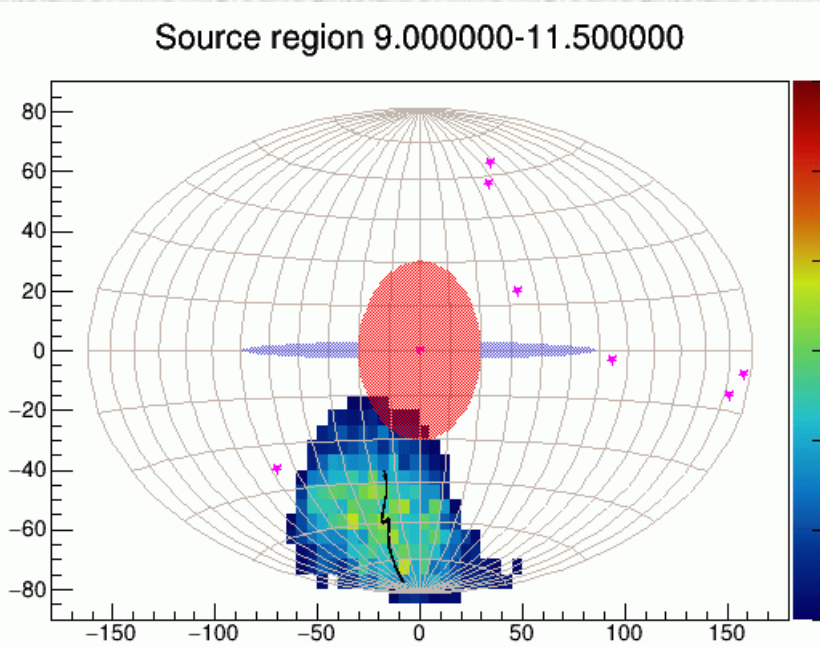
2/3 of events (<zenith 30°
are Cosmic Diffuse γ
1/3 are Atmospheric γ
Growth Curve gives same result.

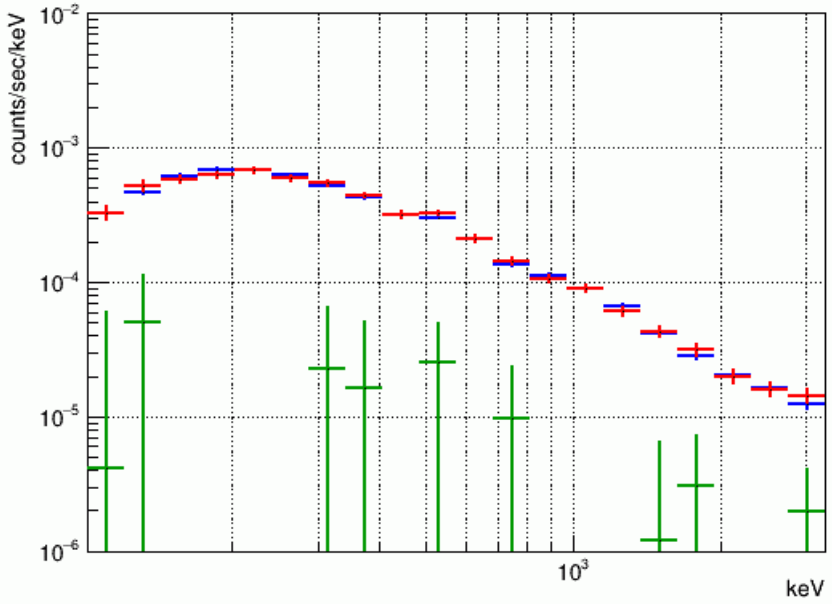
We have ~10^5 events of CDG

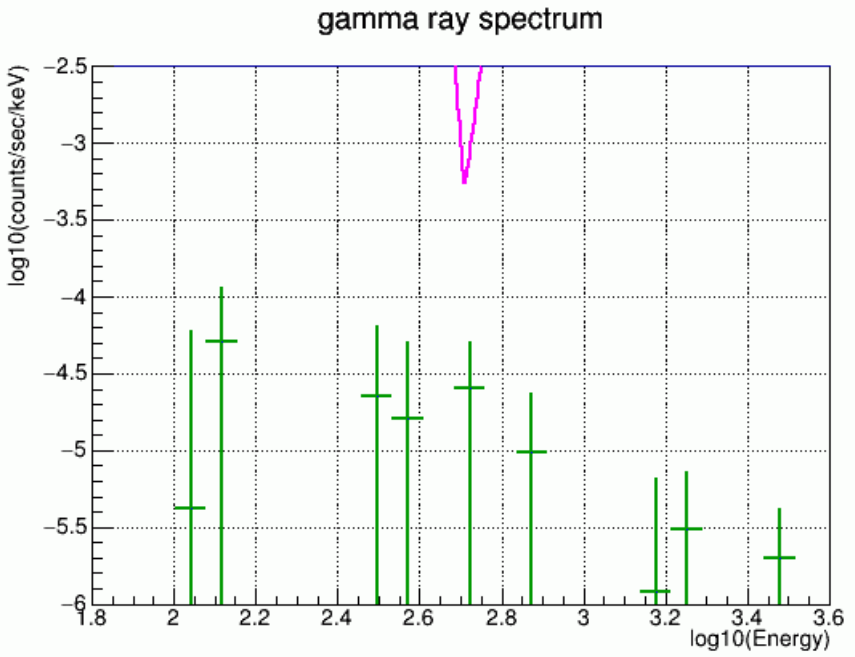
Detection of Galactic Diffuse Gamma (GDG) around Galactic Center



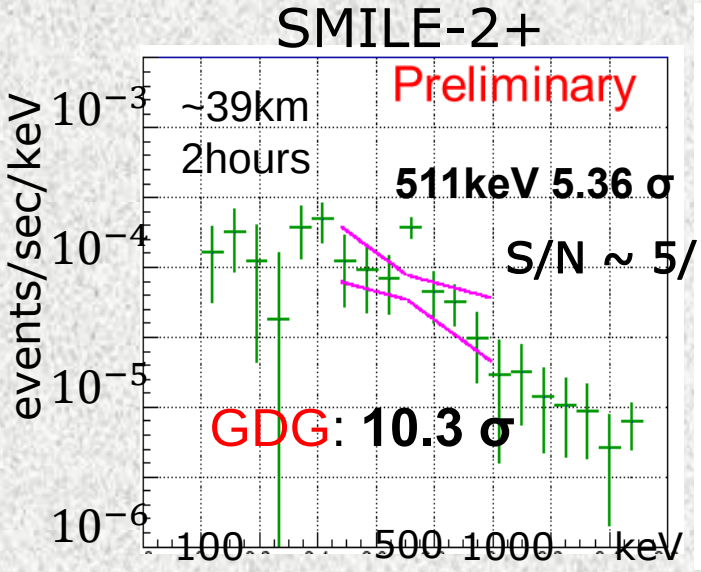
ON
OFF
Residual(ON-OFF)

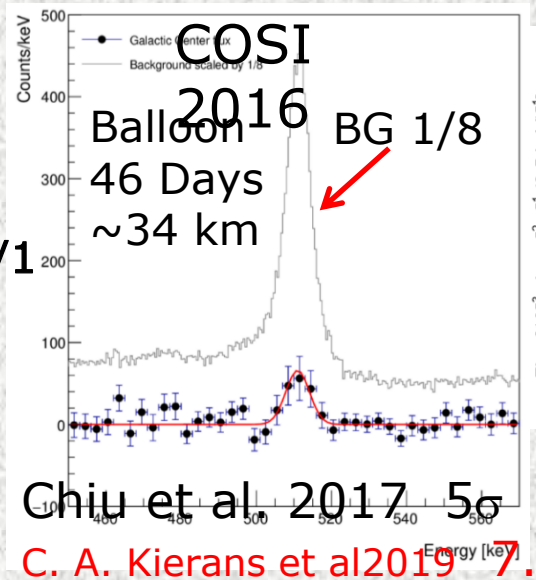


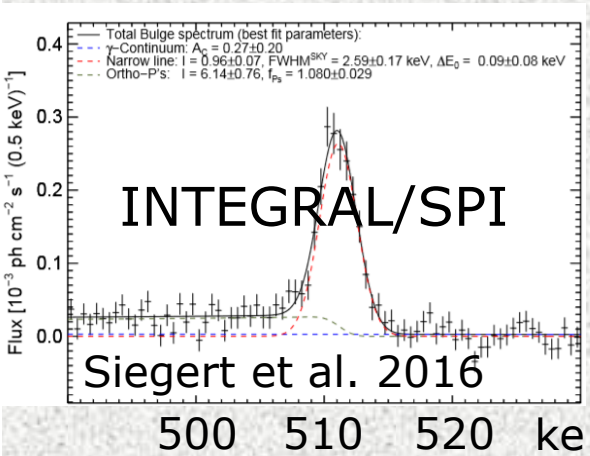




Comparison of significance with other observations







Chiu et al. 2017 5σ

C. A. Kierans et al2019 7.2σ

- 511 keV line 58 σ
- 3-gammas 29 σ
- combined 65 σ

SMILE-2+ 511 keV bin ~5 σ

511 keV bin over diffuse ~3σ

Same time with COSI : $3\sim5\ \sigma \times \sqrt{\frac{3\times10^{6}\,\mathrm{sec}}{2\mathrm{x}6.4\times10^{3}\,\mathrm{sec}}} =$

$30\sim50\sigma$

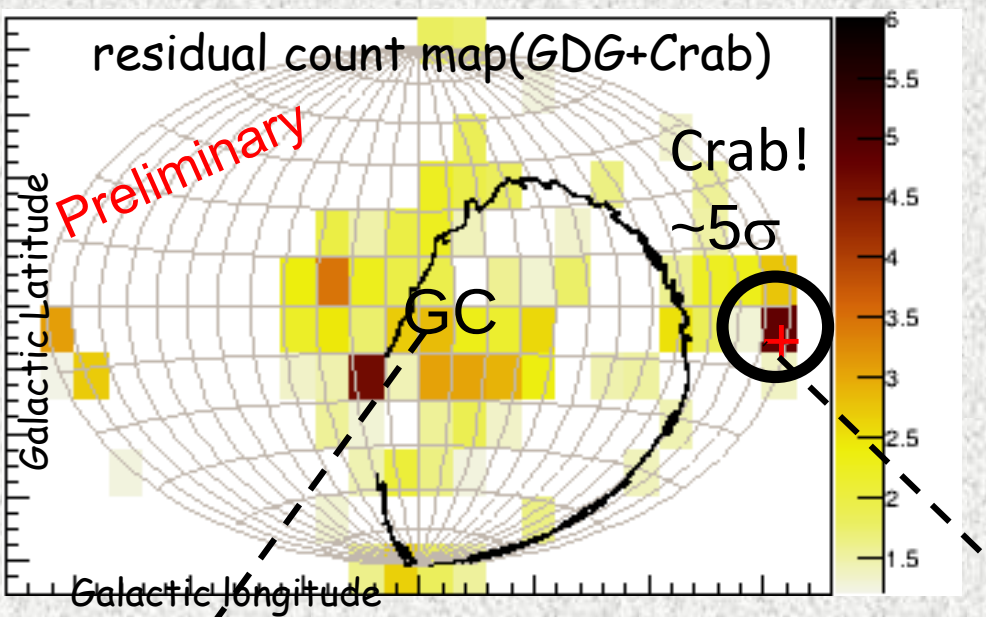
INTEGRAL/SPI same time: $\sim5\sigma \times \sqrt{\frac{1.6\times10^{9}\ \mathrm{cm^2\ sec}\ /75\mathrm{cm^2}}{6.4\times10^{3}\,\mathrm{sec}}} = 170\sim295\sigma$

Instum.	Eff. Area	ΔE/E	Normalized Sensitivity to SPI
SPI	75cm^2	<1%	1 Coded Mask with Veto
SM2+	1cm^2	13%	100—200 x ETCC with no-veto

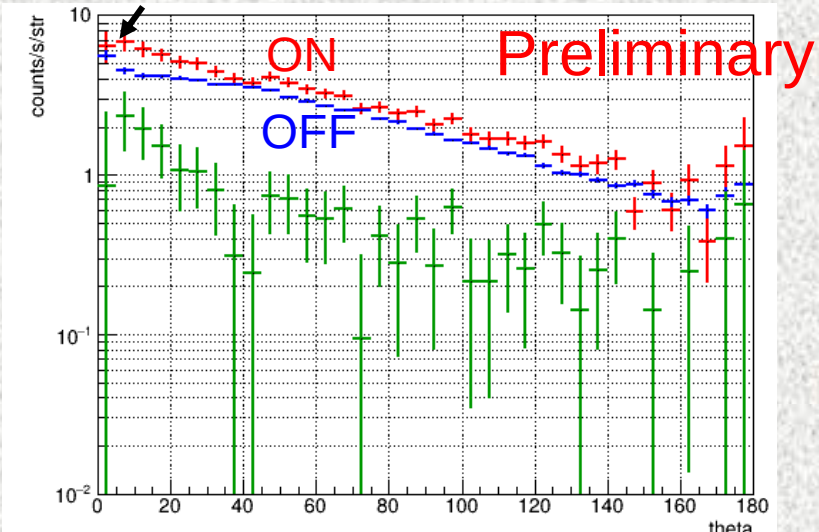
First real MeV γ sky map <1MeV

ON data: simple count map <1MeV

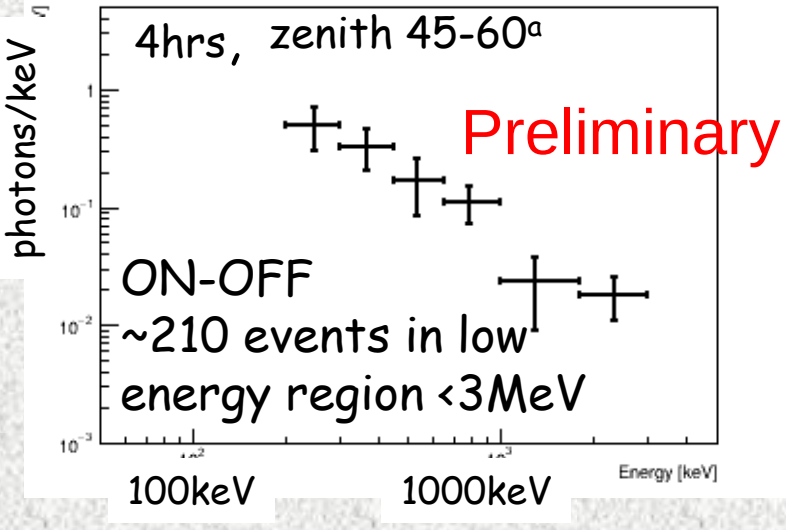
OFF sky model(=CGB + atmospheric+instrumental)



- Simple Detection of Crab by ON-OFF with >5σ (4hrs, zenith 45-60ᵅ) as expected in proposal
- Halo-like emission around GC over 30° radius

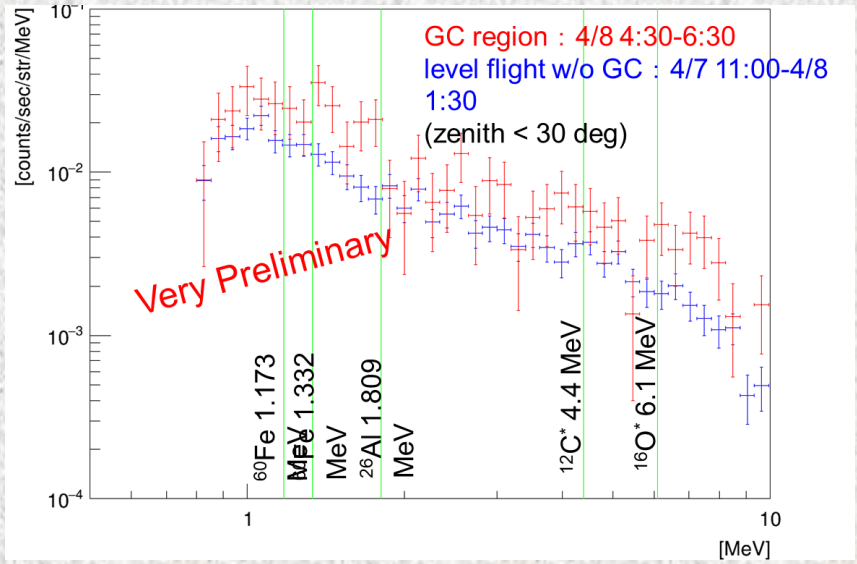


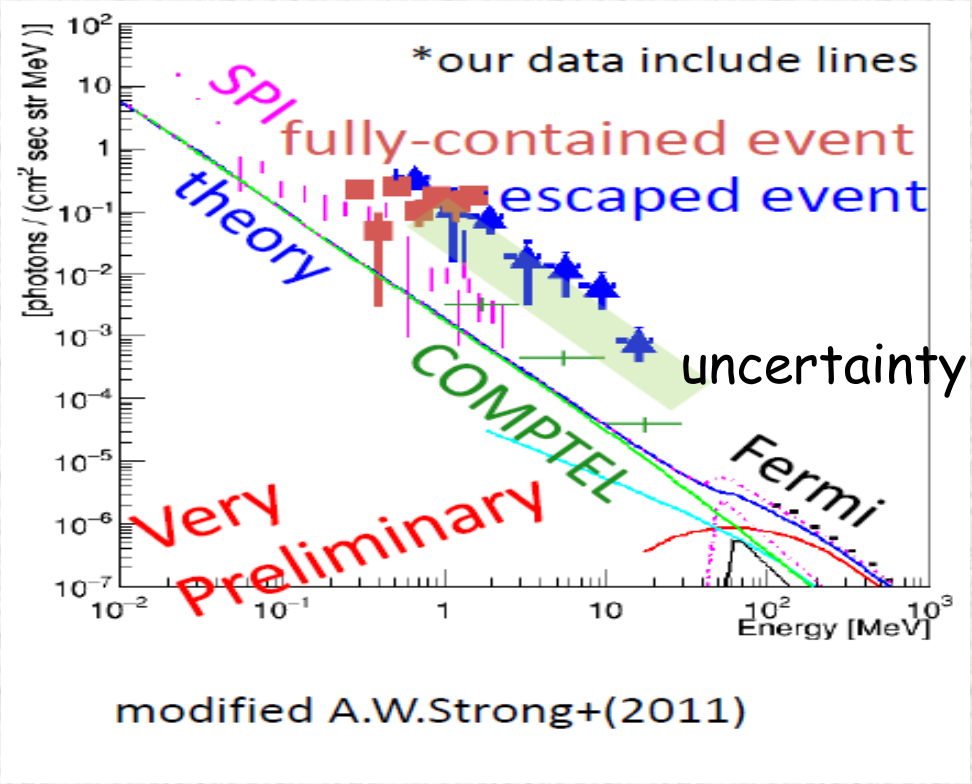
Raw Photon Flux of Crab <Radius20°



Spectrum of Galactic diffuse γ in 0.2-10MeV

High energy event count spectrum (Raw)



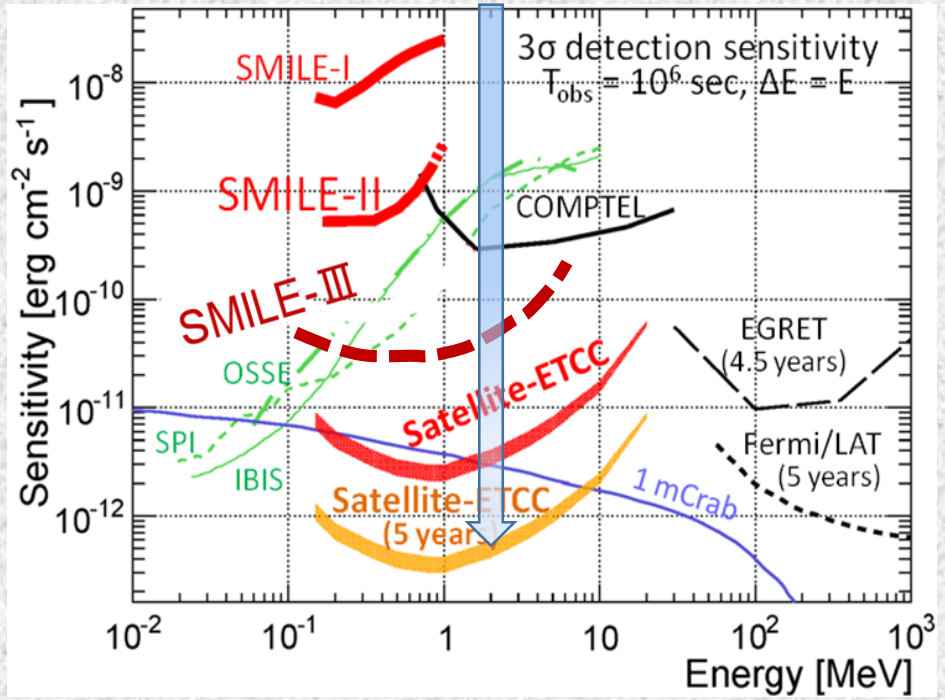


- Obtained spectra may still include the effects of scattering (of several 10 %) => uncertainty of ~50% for Photon fluxes
- **Anyway GC is very bright from the enhancement in Light-curve, and simultaneously observed with 511keV and Crab**

How to reach to sub-m Crab

S: signal EA: Effective Area BG; Backgrounds
θ:; Half Power Radius (HPR) as PSF

$$\text{Significance} \propto \frac{EA \bullet S}{\theta\sqrt{(EA \bullet BG)}}$$



- Effective Area ~200 cm^2 @1MeV: gas (3atm CF_4) and Si in <1m^3 cub.
- Minimum Back Ground =>
  Same as Cosmic MeV background
  => We achieved !
- PSF θ(HPR)= 1~2° is needed !!

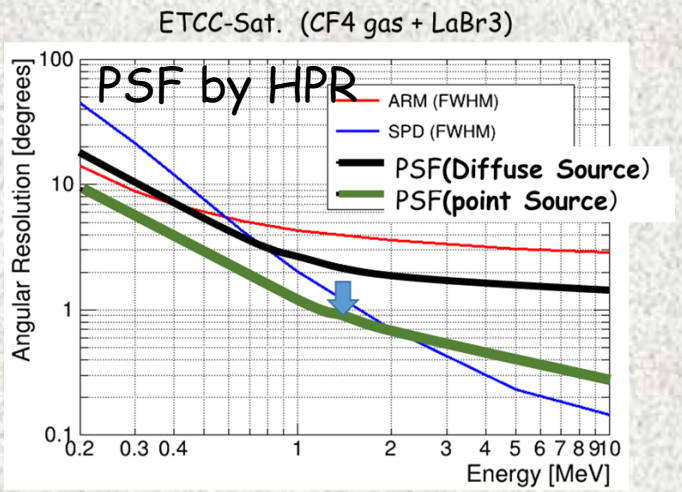
=> fine 3D-tracking of a reoile electron is inevitable
(mm sampling in gas sub-μm sampling in Si) Key technology

Celestial MeV gamma is essentially rich; ~1000 times of GeV gammas, Then, if proper 2D-PSF of <~2° and complete BG rejection were realized, we need a relatively small detector to go beyond 1m Crab

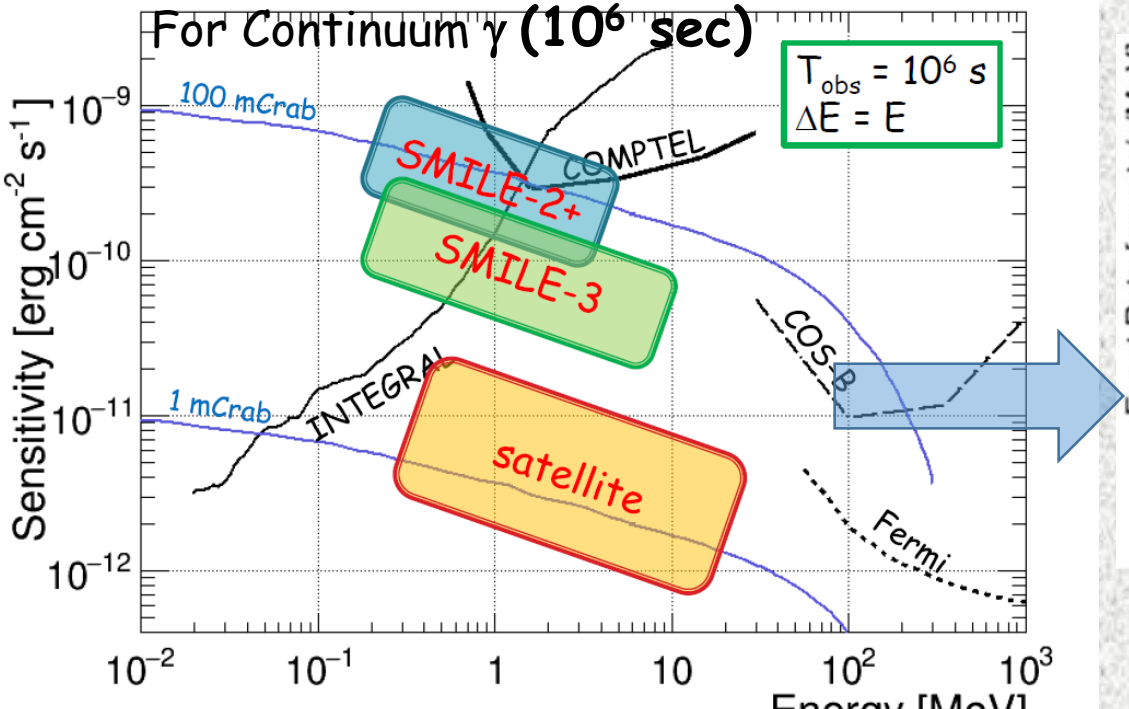
Expected Sensitivity based on well-defined PSF

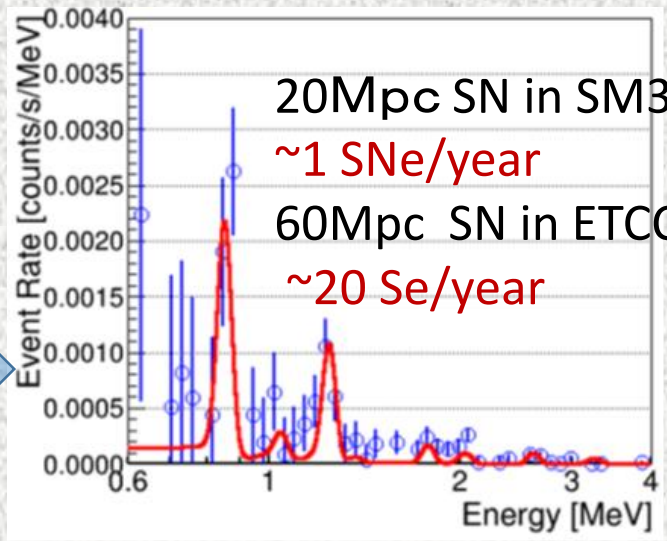
SMILE3: long duration balloon (more one month) within 4~5years
30cm cubic ETCC, CF4 3atm,
Effective Area 10~20cm^2 PSF <5°
Expected data 1000 times of SM2+

ETCC-Satellite 50cm-cubic ETCC (CF_4 3atm)
with >5RL Scinti. x 4 modules
Effective Area ~200cm^2@1MeV and PSF:HPR-2°



Next & Future Plans





New MeV gamma Astronomy beyond 1mCrab

Summary

- ETCC provides true Imaging Spectroscopic Observation same as general astronomical telescopes, and reveals the reliable way to reach to sub mCrab
- Background is reduced less than CDG as proposed.
- Crab and 511keV line were detected with ~5σ as proposed with no use of optimization methods like MLEM
- Galactic Center region (>10σ) is unexpectedly bright !!
- CDG spectrum with high statistics will be soon opened.
- Next Balloon SMILE-3 ＝＞10times better sensitivity than COMPTEL : ~x1000 data (10^8 γ) of SM2 within ~5years
- ETCC-Satellite will surely reach to the sub-mCrab sky.

MeV γ sky will be most **clean and rich** (1000 times of GeV gamma sky.) in near future !!

Collaborators are very welcome!

Members of SMILE Projects

SMILE2+ Project

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ETCC-Satellite (Astro 2020 APC White Paper)

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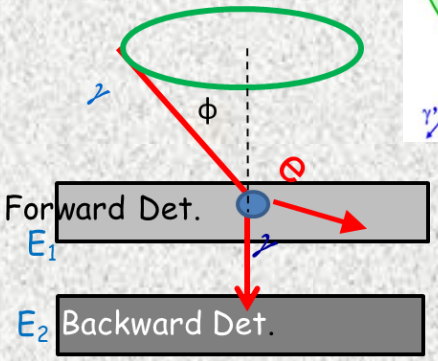
Thank you for your attention!

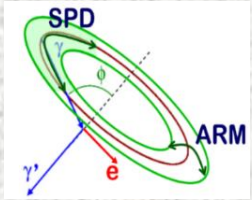
Difficulty of MeV γ imaging in space

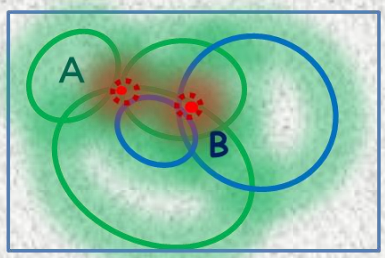
MeV γ astronomy suffers from two major problems

1. Incomplete imaging method (Conventional Compton; CC)
   Imaging spectroscopy is impossible
2. Huge background by collision of cosmic-ray and instruments

⇒ No instruments of CC measured celestial source flux quantitatively after COMPTEL

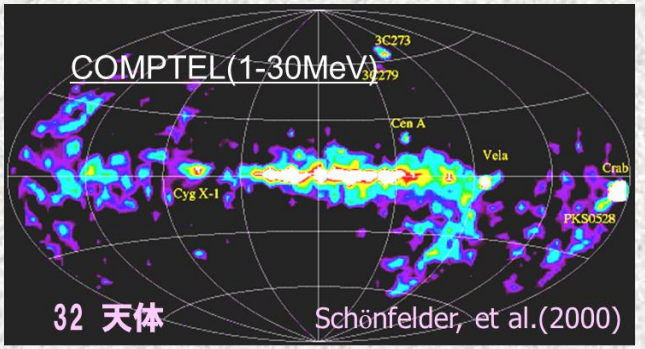






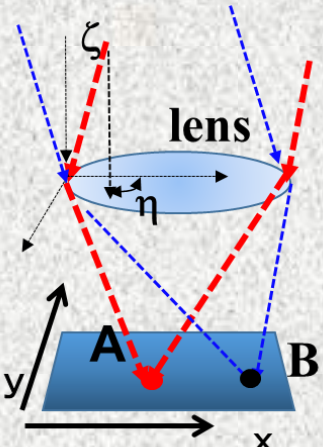
γs from different directions A and B are mixed

Intensity is not conserved!!

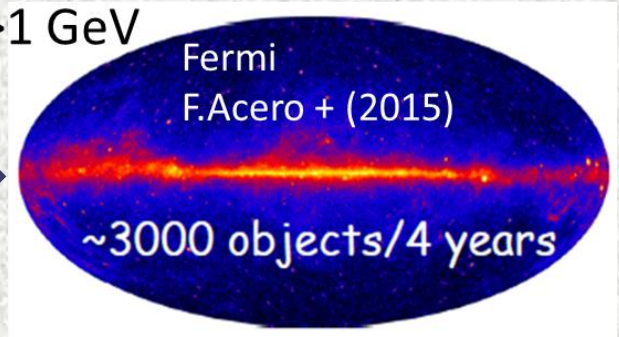


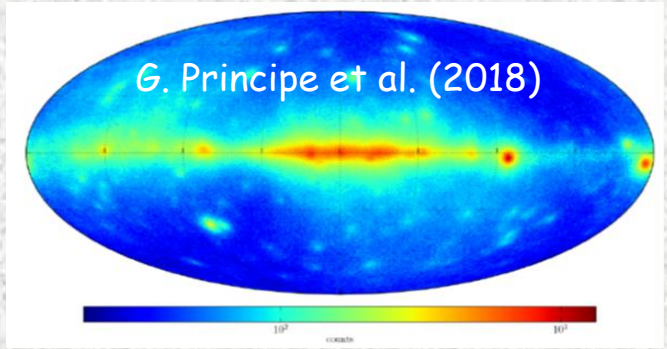
COMPTEL 1d-auglar resolution(RMS) ~1.5° 32sources (9yrs)

Deconvolution image !!



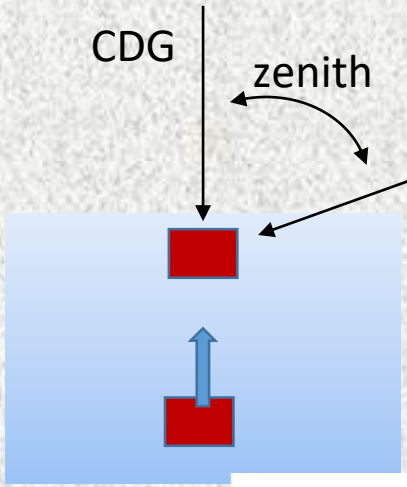
Fine Tracking is inevitable



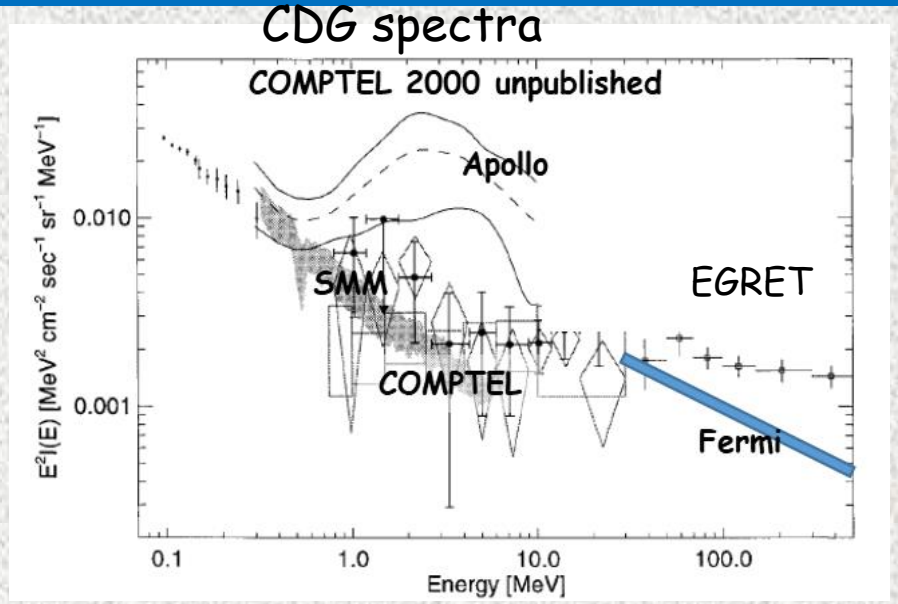


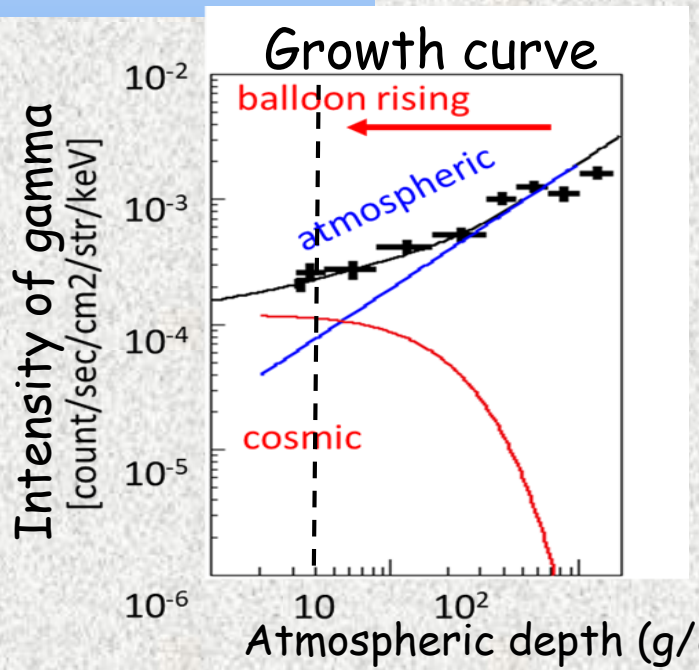
Fermi low energy (30-100MeV) 198sources 2D-PSF (3°-12°) 9yrs.

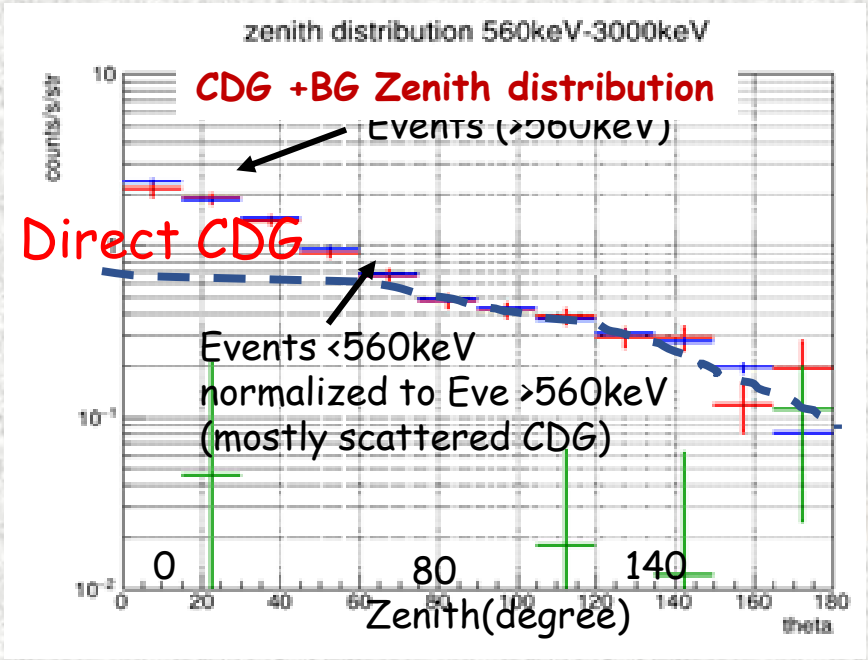
Estimation of BG & Cosmic Diffuse Gamma (CDG)



Atmospheric gamma
~1/3 <zenith 30°
2/3 of events are
Cosmic Diffuse γ







- Minimum Back Ground was acheuved !!
- We have clean several 10^4 DDG =>