SMILE
長時間気球による MeVガンマ線天文学の開拓

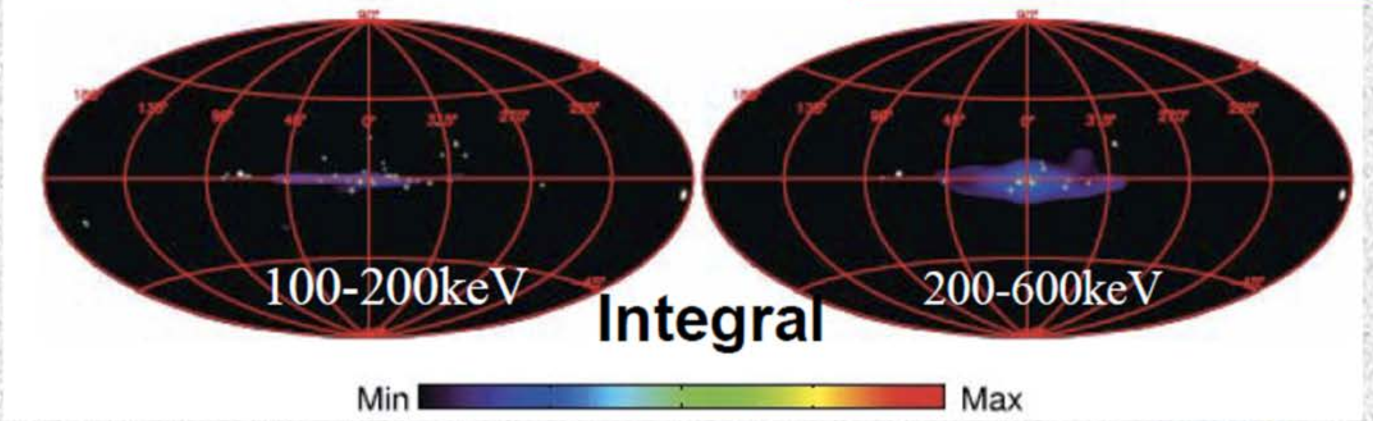
京大理　髙田淳史

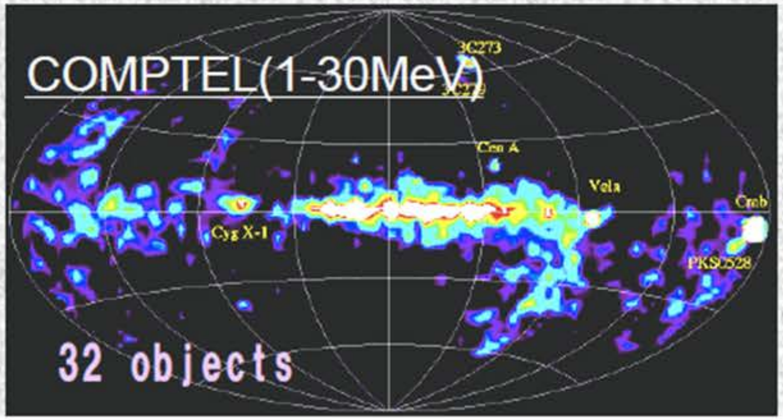
Sky Map of MeV Gamma rays

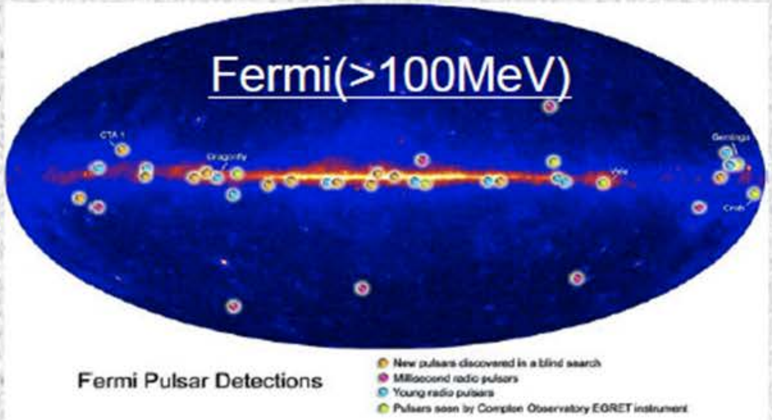
COMPTEL(1-30MeV) 32 objects

AGN 10
Line Emissions from SNR 7
Crab 1 γ-Pulsar 3
B.H.Candidates 2,
UnID 9

Integral Point Sources
25-50keV 173
50-100keV 79 (>3.5σ)
100-200keV 30(>2.5σ)
200-600keV 12
>600keV 4

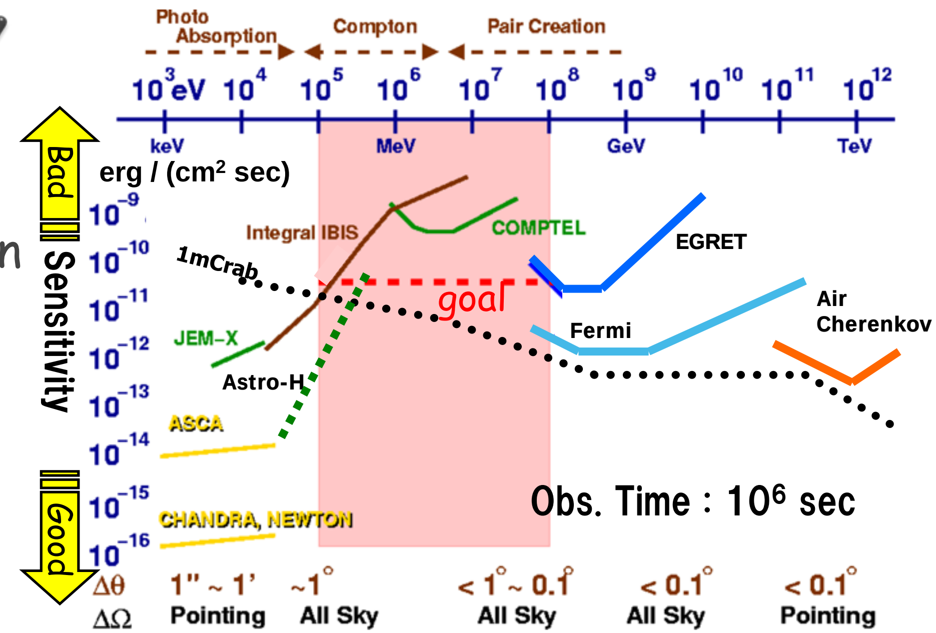






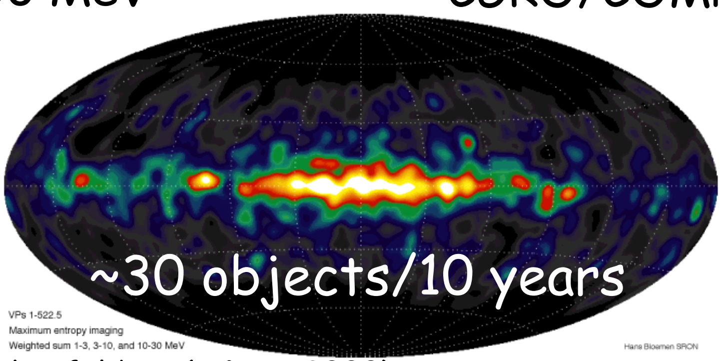
MeV Astronomy

- 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

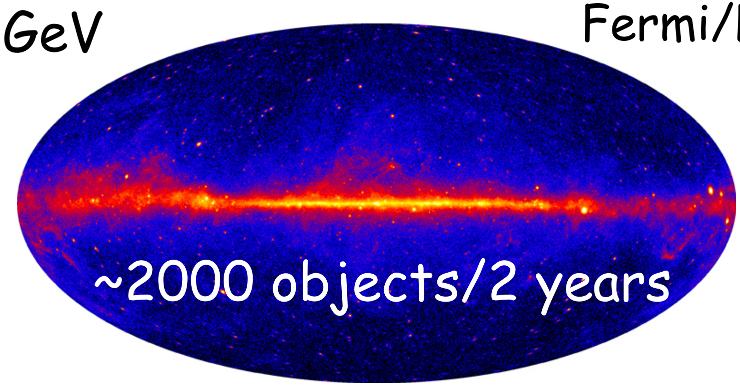
1-30 MeV CGRO/COMPTEL



V. Schönfelder+ (A&AS, 2000)

GeV sky map

> 1 GeV Fermi/LAT



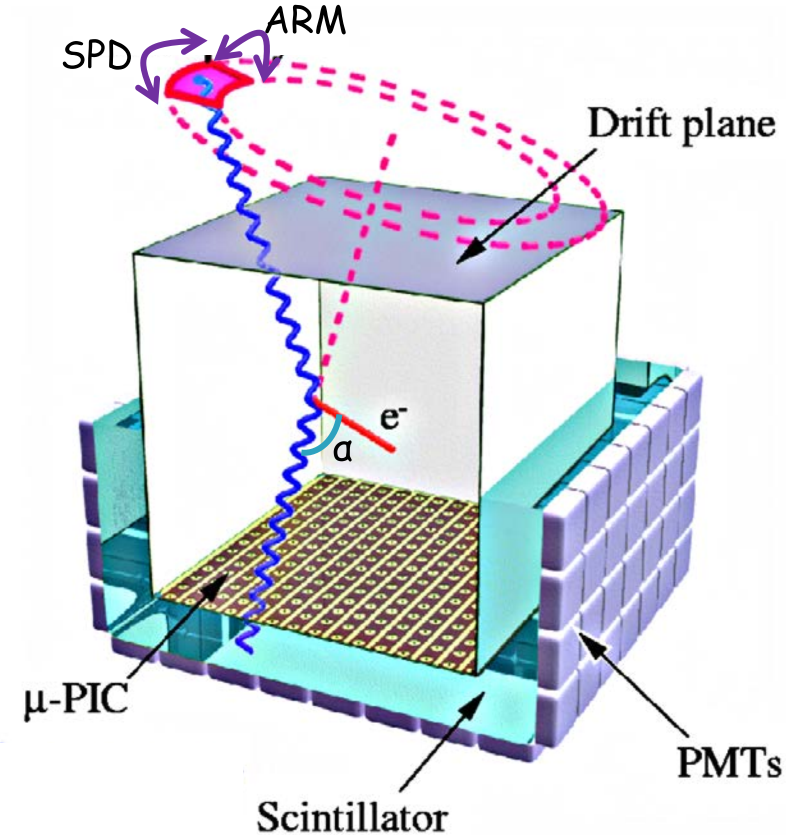
P. L. Nolan+ (ApJS, 2012)

Requirements for the next-generation detectors are …

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

Electron-Tracking Compton Camera (ETCC)

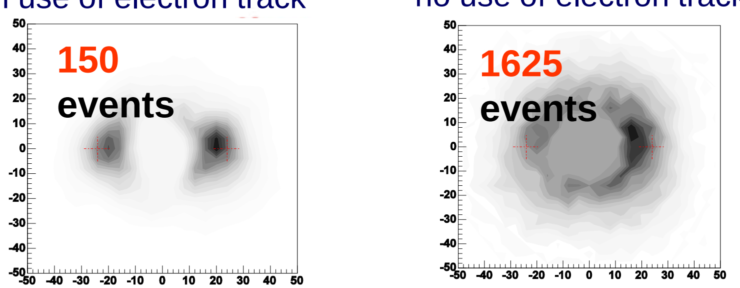
1. 雑音を徹底的に落とす事を方針とした検出器
2. 電子の反跳方向を用いた高品質画像
3. COMPTELの3倍の広い視野

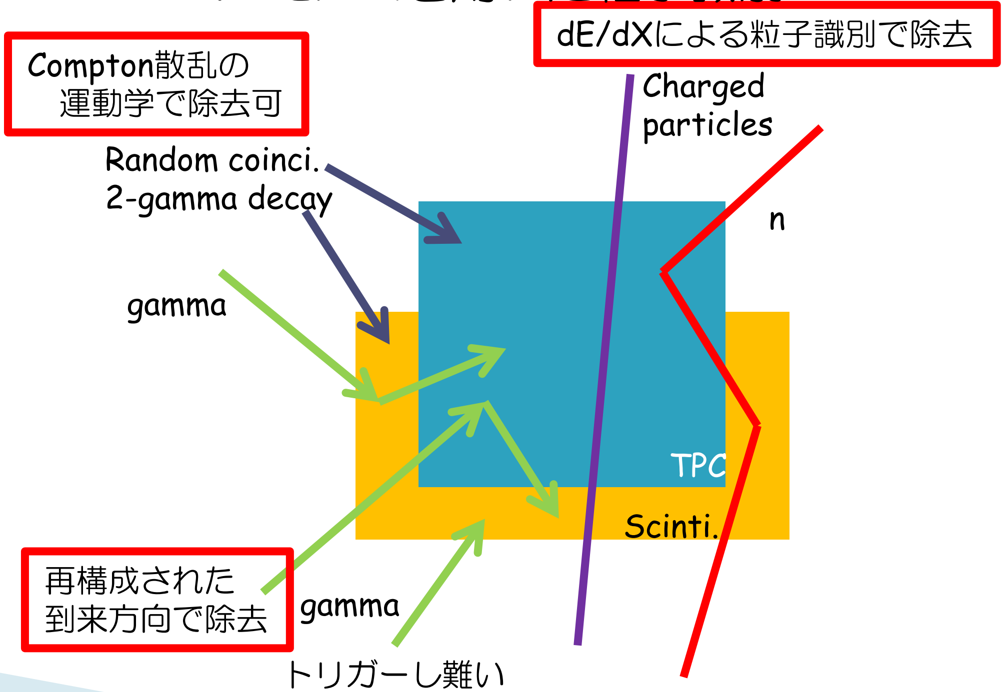


- ガス飛跡検出器 (散乱体)
  反跳方向・電子の飛程・エネルギー
- シンチレータ (吸収体)
  散乱方向とエネルギー

光子毎に到来方向とエネルギーを特定
複数の雑音除去能力をもつ

1. SPDによる到来方向の完全決定
2. α角による運動学チェック
3. dE/dXを用いた粒子識別





Comparison with the usual Compton method

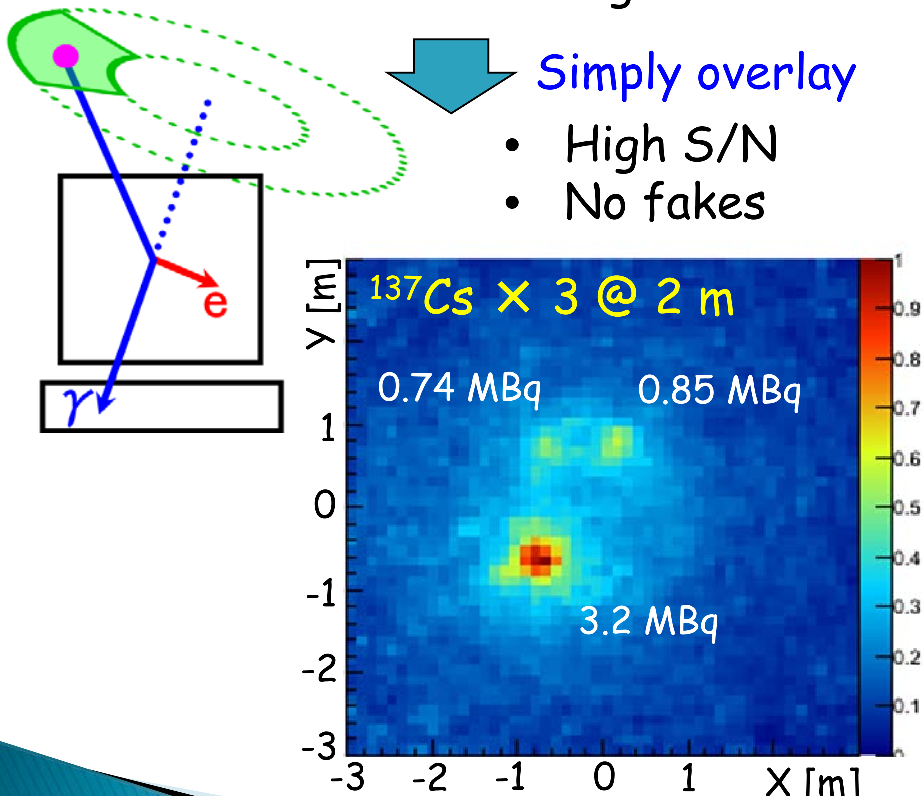
Electron-Tracking Compton (ETCC)

Using the electron tracks

complete direction within **sector form** error region

Simply overlay

- High S/N
- No fakes



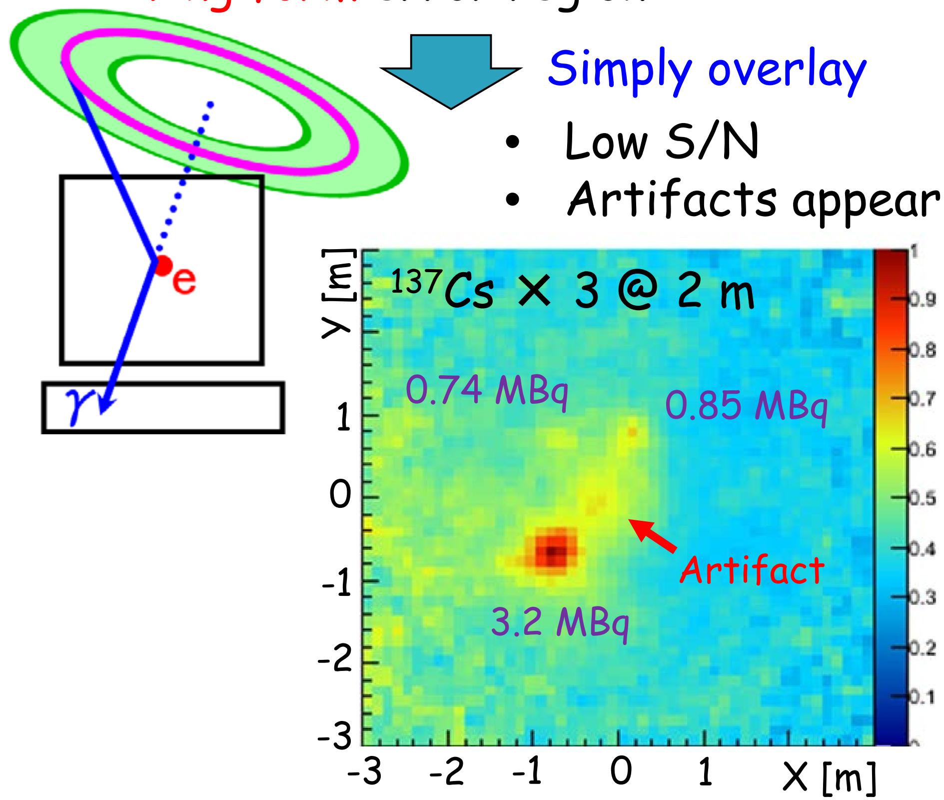
Usual Compton Imaging (COMPTEL)

Not using the electron tracks

only event circle within **ring form** error region

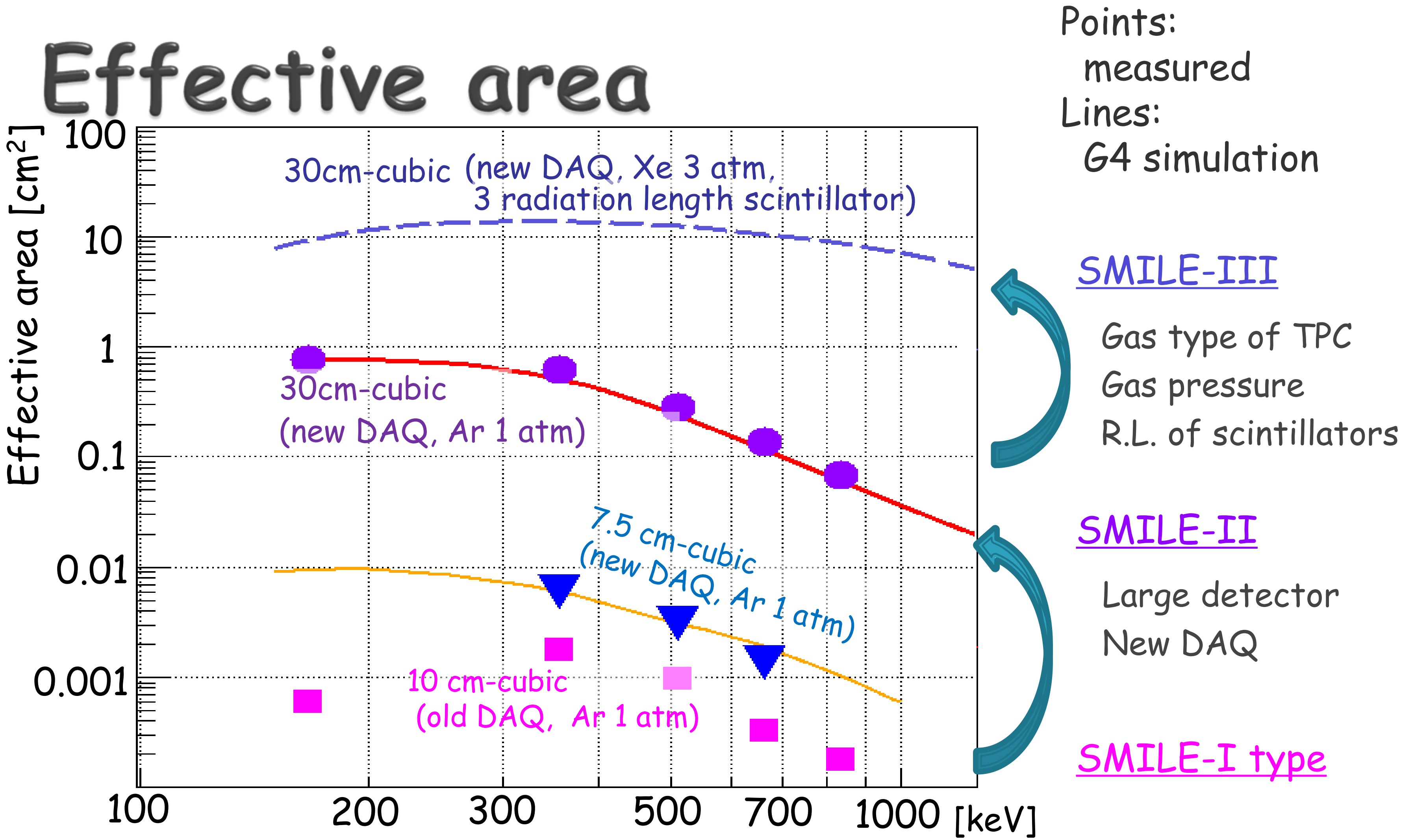
Simply overlay

- Low S/N
- Artifacts appear



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

Effective area



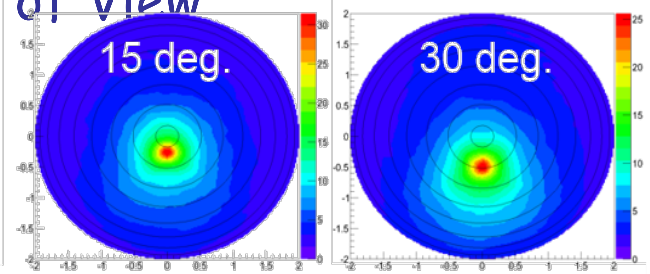
- ✓ SMILE-II ETCC ~1 cm² @ 300 keV (requirement > 0.5 cm²)
- ✓ Experiment ≈ Simulation (not including detector response)

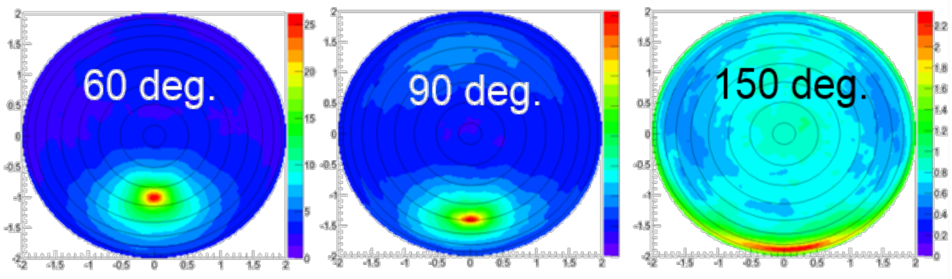
  ETCC obtains ~100 % of Compton events.
- ✓ We will upgrade to SMILE-III ETCC ~10 cm² (in 2016)

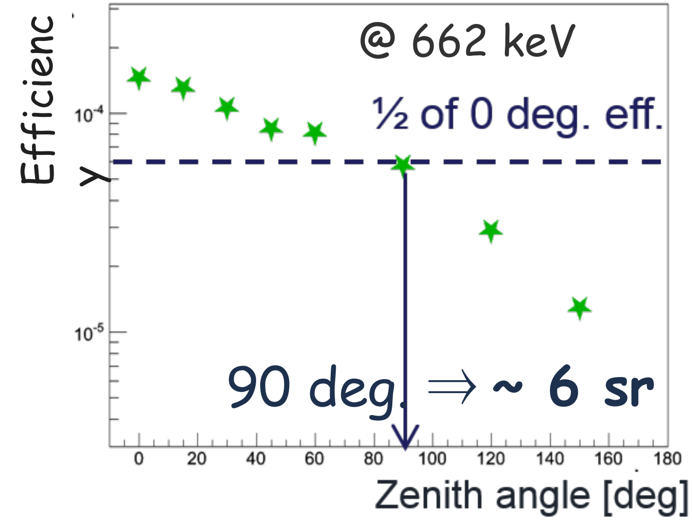
Performance of 30-cube ETCC

◆ Large Field of View

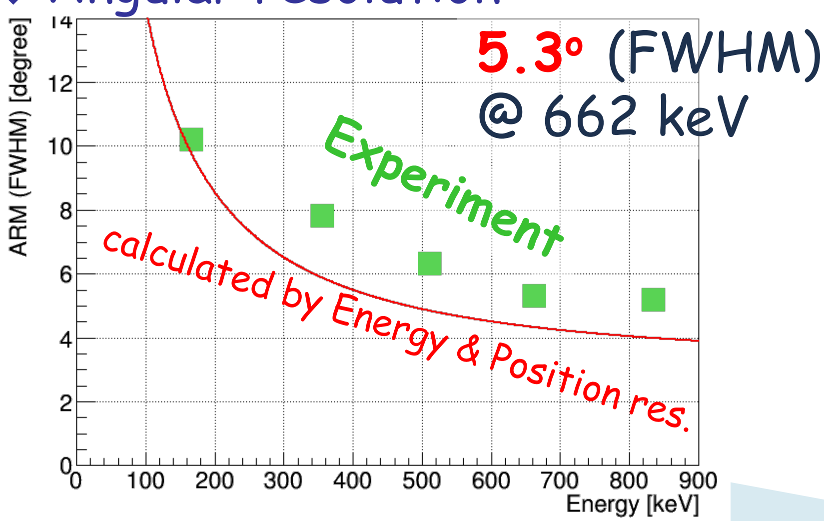
^{137}Cs (662 keV)
0.7 MBq @ 2 m



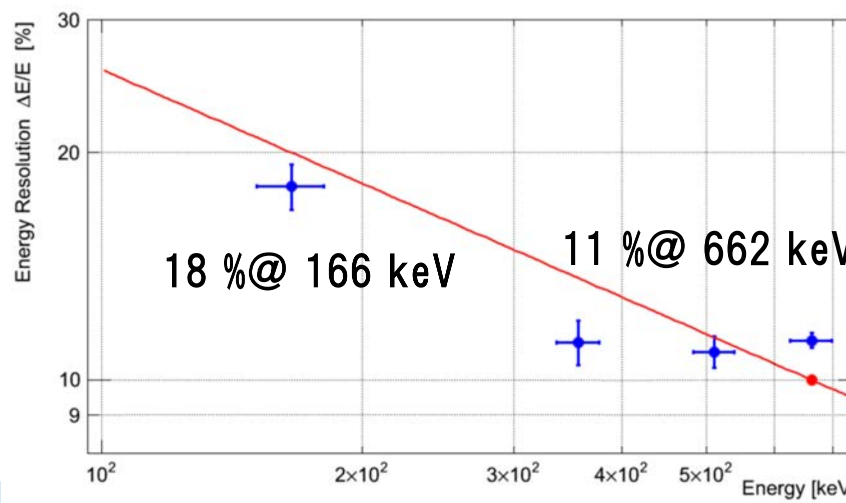




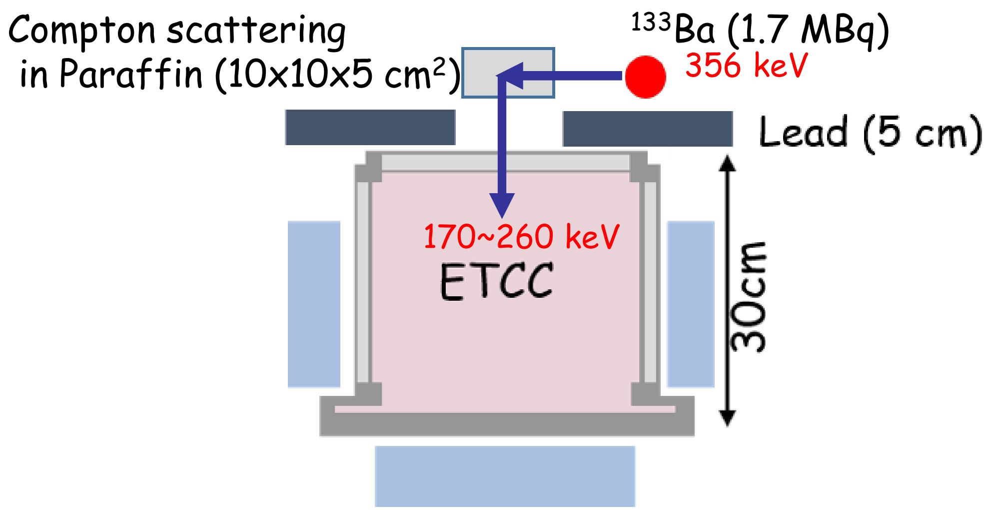
◆ Angular resolution



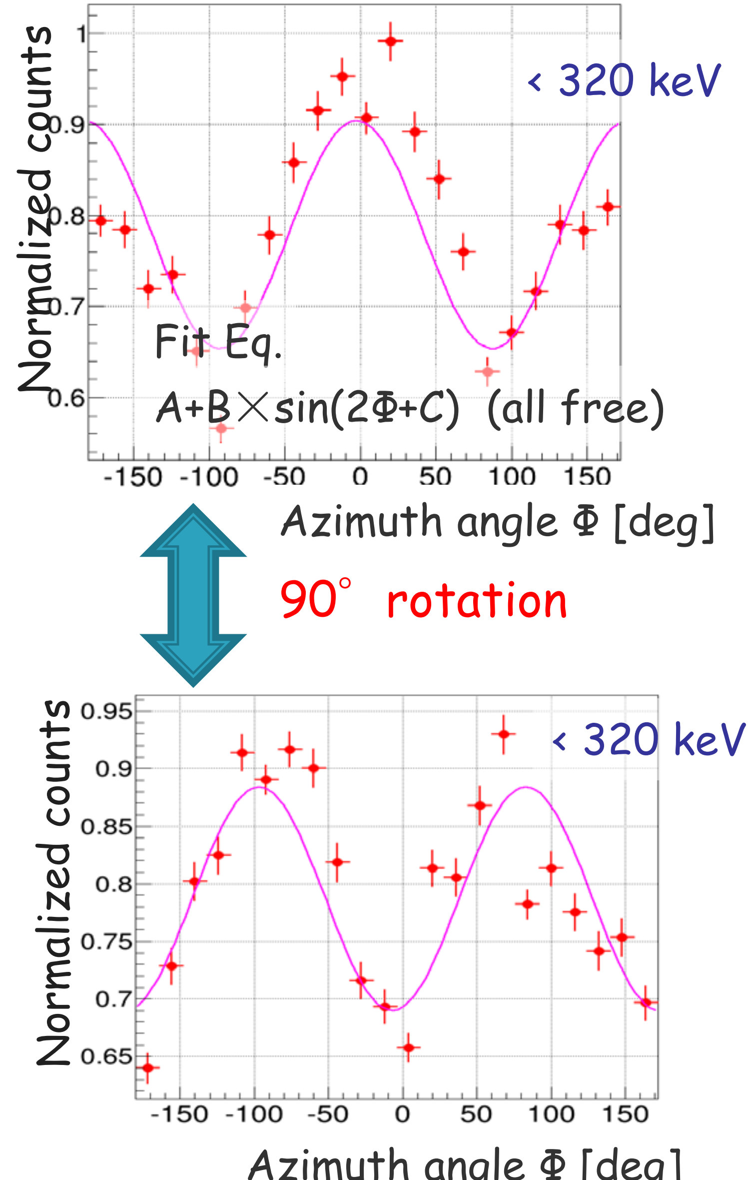
◆ Energy resolution



Ability of polarization measurement



~ 90 deg. scattered gamma on Paraffin is polarized ~ 40 % (calculated by simulation)

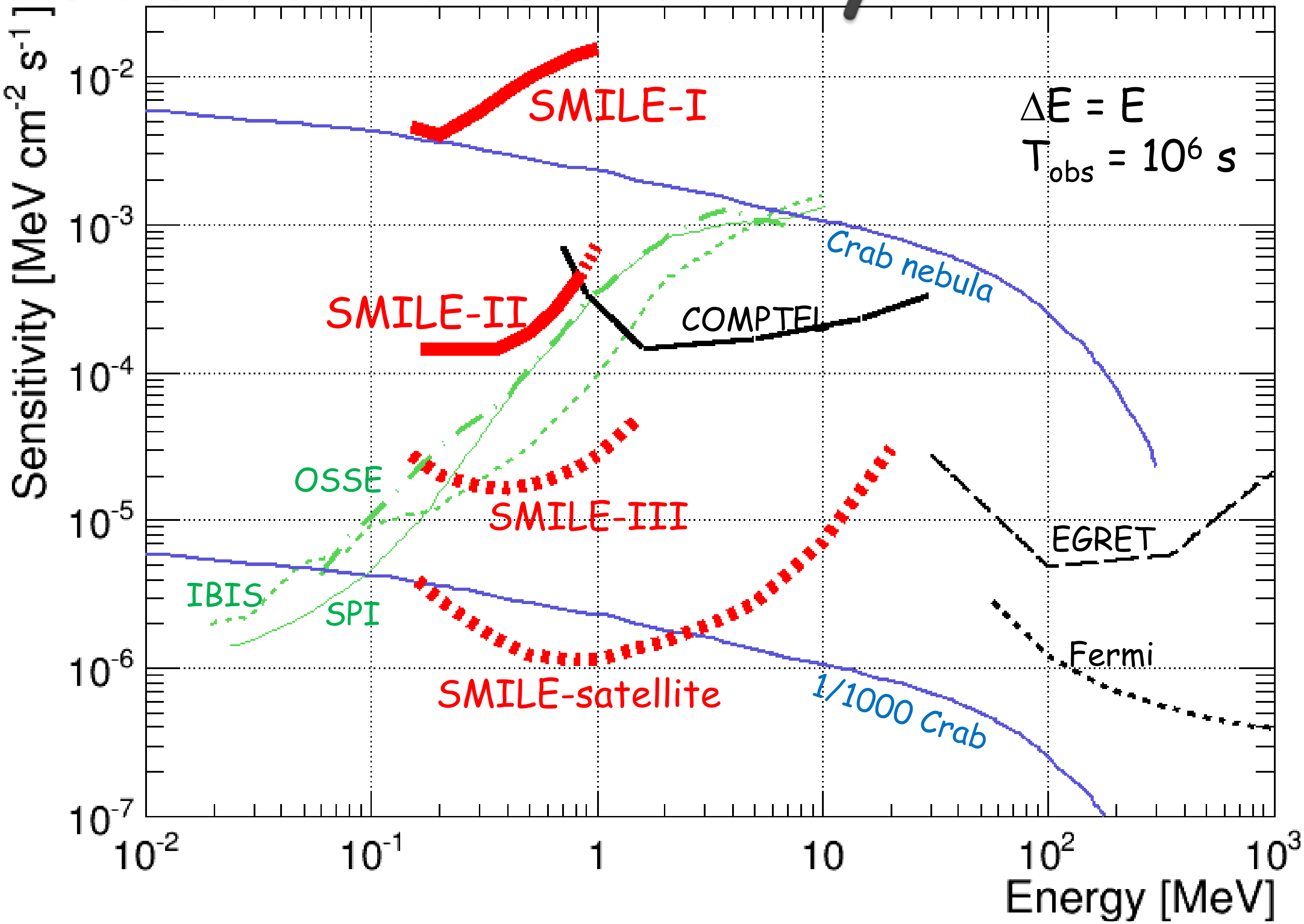


Signal : BG = 0.08 : 1

ETCC succeed to detect
the polarization modulation with low S/N.

SMILE-II ETCC will be tested at Spring-8

Detection sensitivity



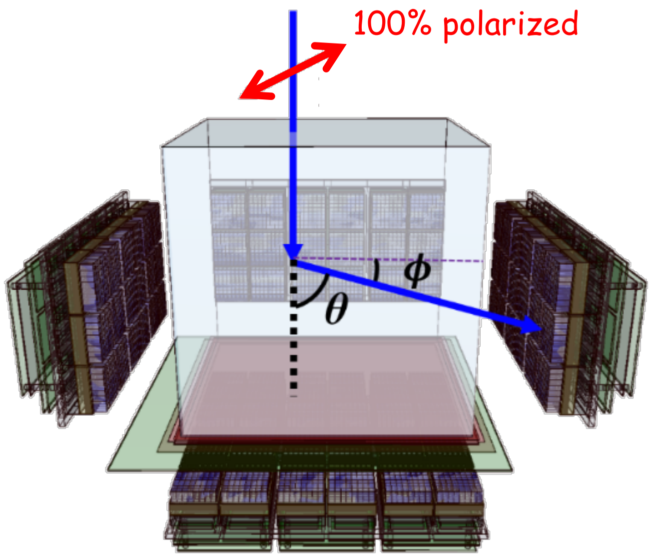
SMILE-II : detectable Crab nebula with 3 h at 40 km

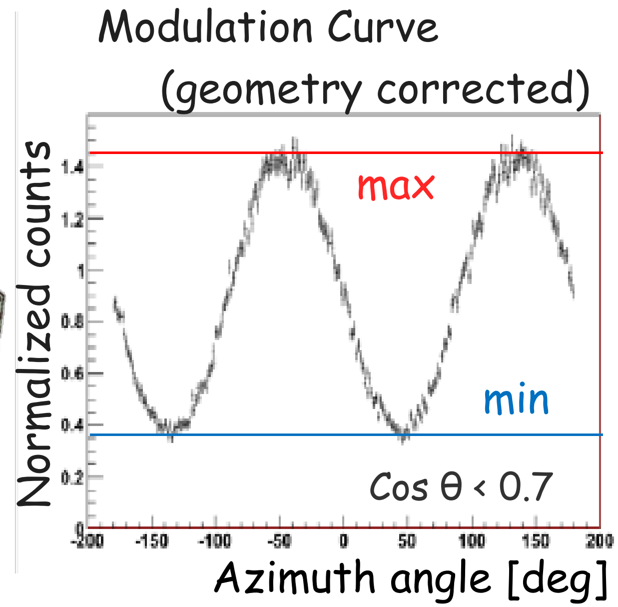
SMILE-III : CF_4, 3 atm and 2-3 Radiation length GSO -> 10 times better sensitivity

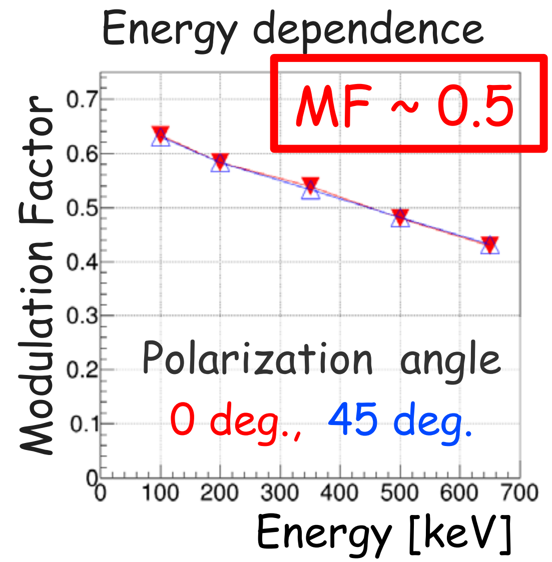
Satellite : (50 cm-cube, Xe 3 atm, 10 Rad. Len. $LaBr_3$)×4 -> reach to 1 mCrab

Geant4 Simulation

Ability of polarization measurement







SMILE-III (effective area ~10 cm^2)

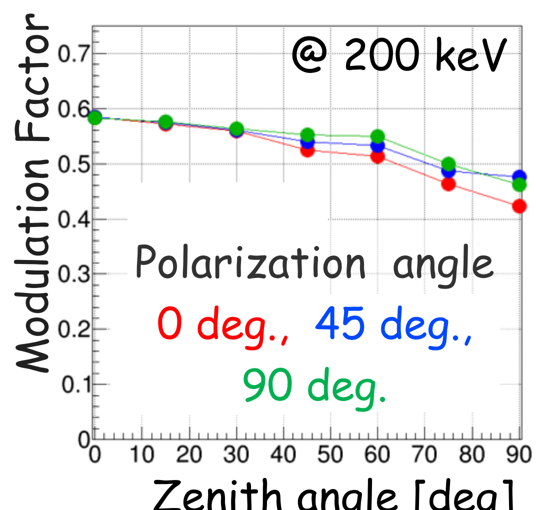
- Crab : 3σ Minimum Detectable Polarization → ~ 20%
- Cyg X-1 : → ~ 30%

  mid-latitude, 40 km, 10hours flights

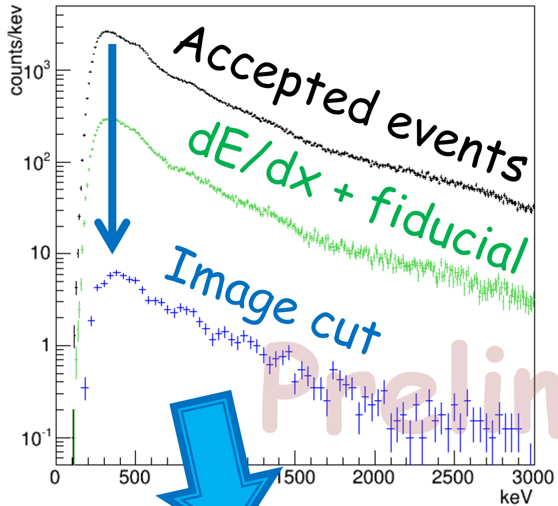
- GRBs : 10^{-6} erg/cm^2/s (2-3 GRBs/month) → ~ 8%

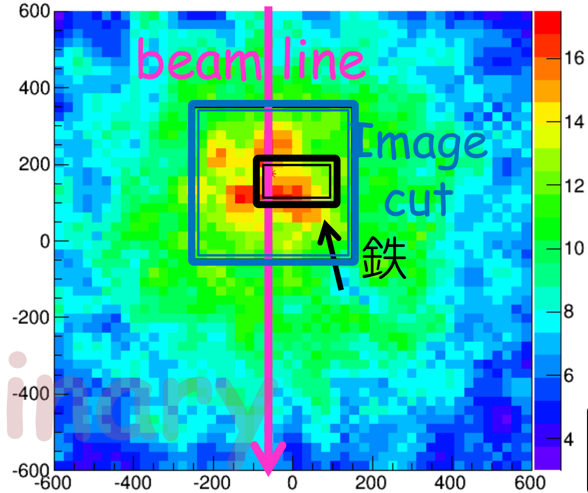
  10^{-7} erg/cm^2/s (~10 GRBs/month) → ~ 30%

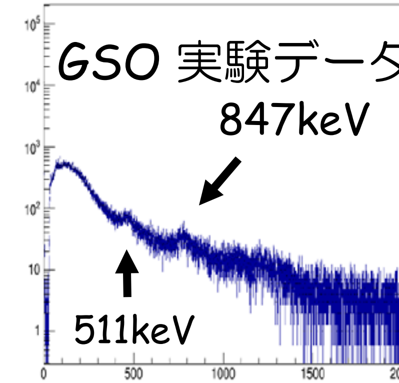
  polar region, 40 km, 1 month flights

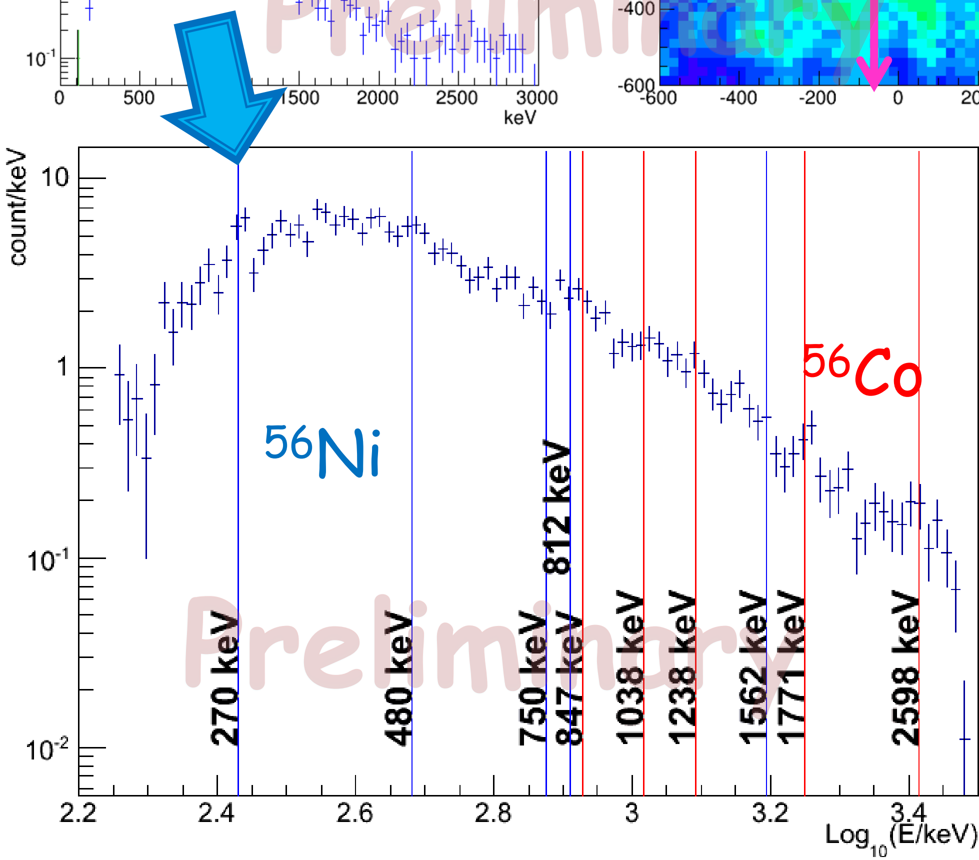


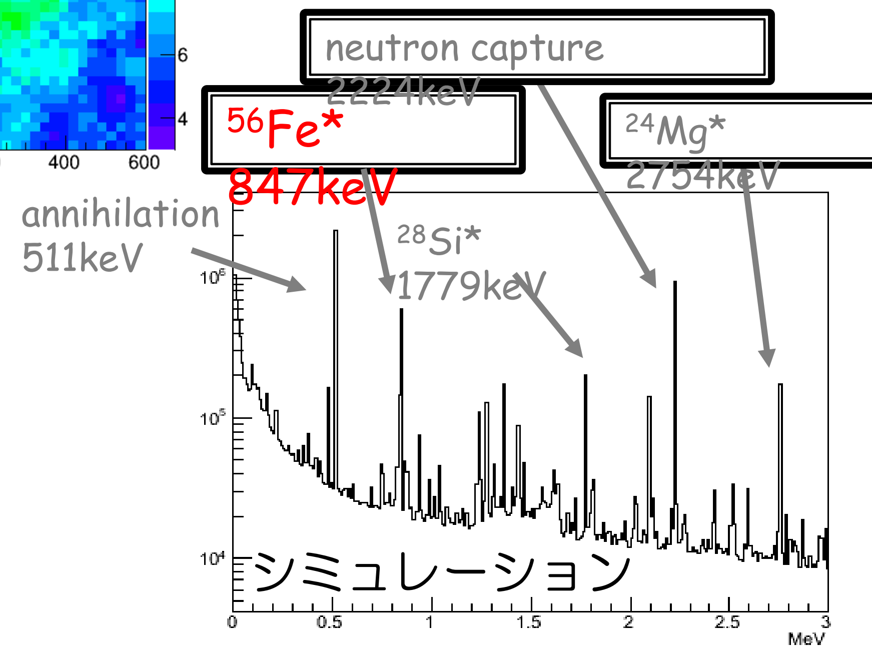
ETCCによる鉄の847keV励起ガンマ線観測







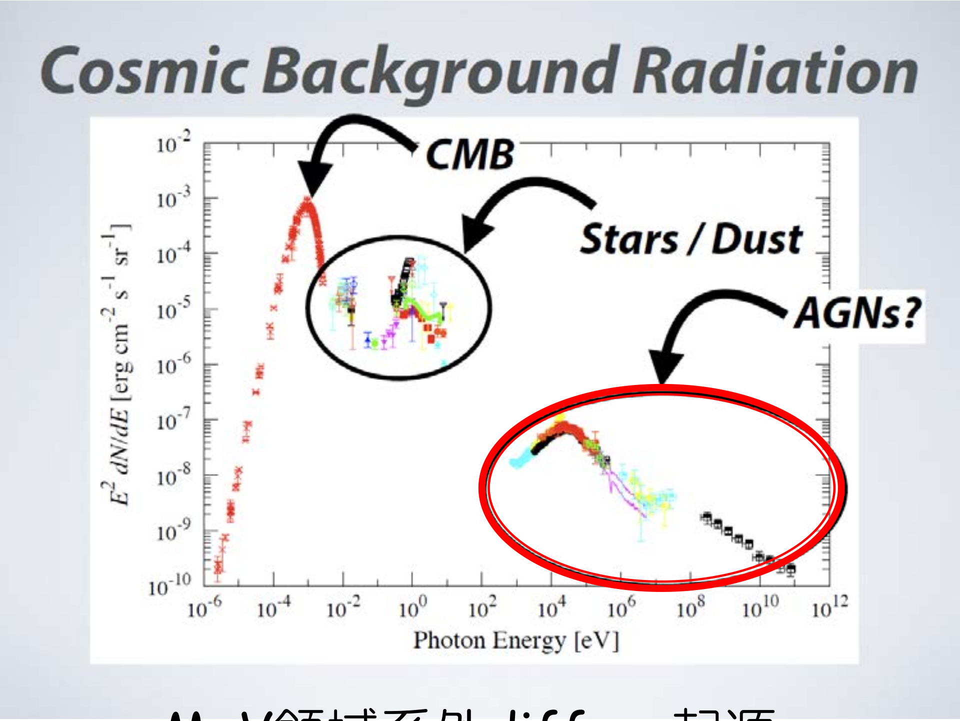


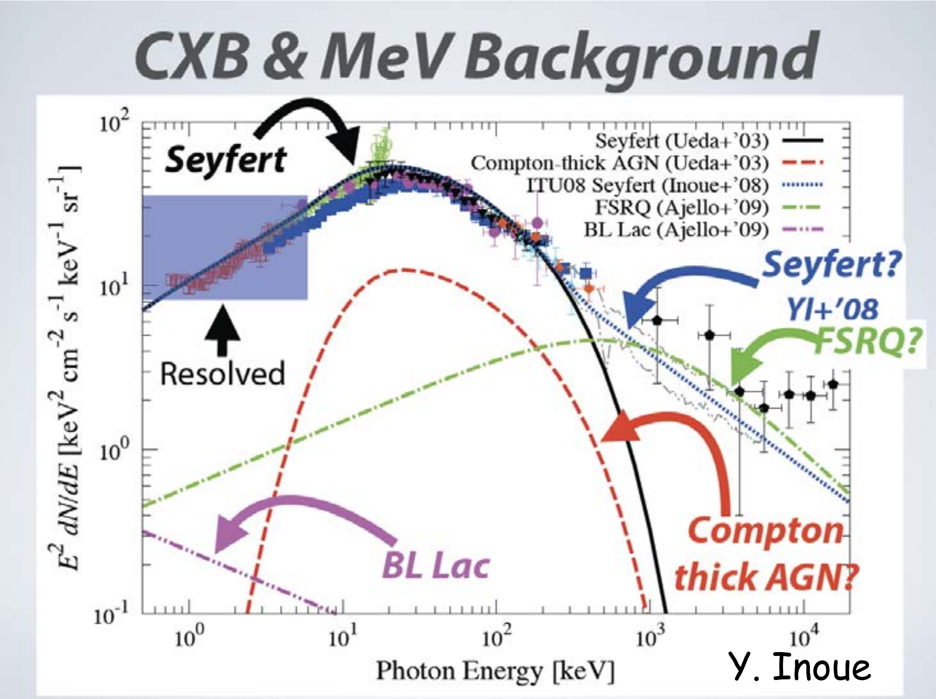


^{56}Niや^{56}Coの
ラインガンマ線を検出？

詳しく解析＆シミュレーション中…

SMILEのtopics

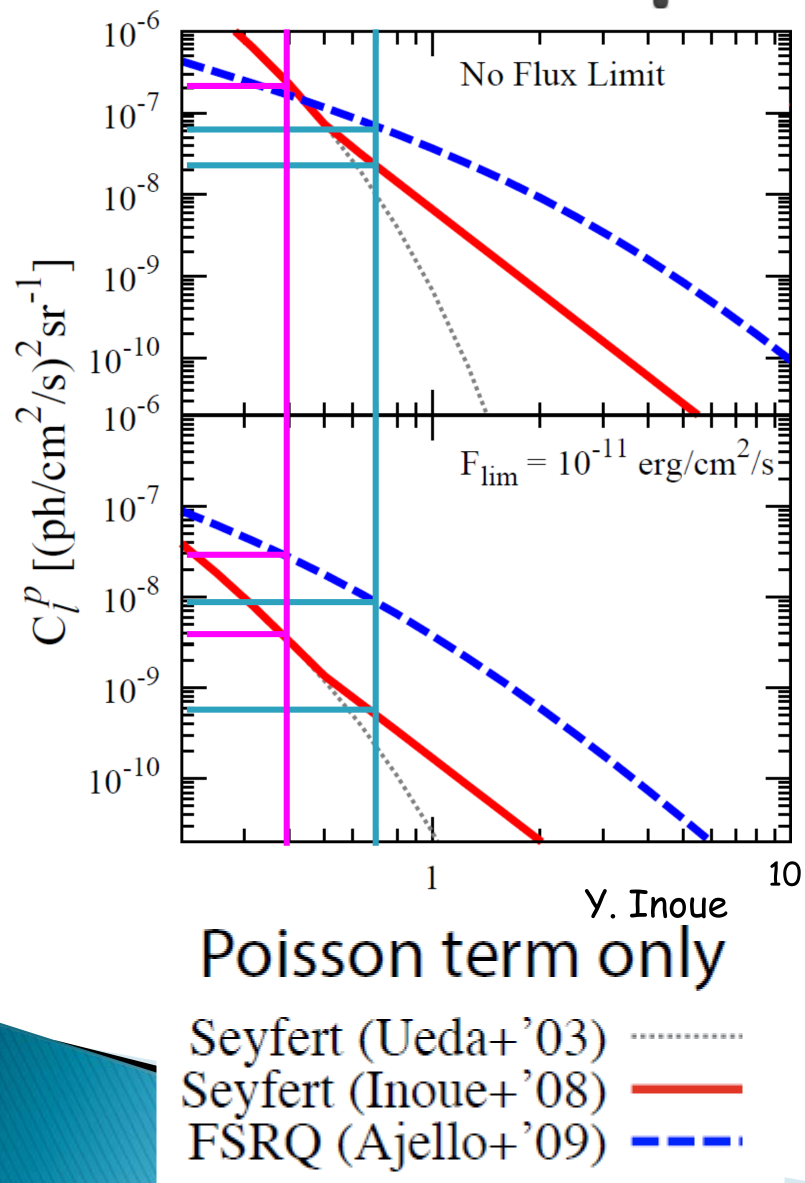




MeV領域系外diffuse起源
- Ia型超新星？
- 少量の明るいFSRQ？
- 暗いSeyfertがたくさん？

個々に分離できなくても
Anisotropyから議論可
銀河の進化に対して新しい知見

SMILEのtopics



$$C_\ell^{\rm signal} = \frac{C_\ell^{\rm raw}/f_{\rm sky} - C_{\rm N}}{(W_\ell^{\rm beam})^2}$$

$$W_\ell^{\rm beam}(E) = 2\pi \int_{-1}^{1} d\cos\theta P_\ell(\cos(\theta)){\rm PSF}(\theta;{\rm E})$$

3σ以上の有意度でC_lを得るには

$$\frac{C_l{}^S}{\langle I\rangle^2} > \frac{3\alpha}{1-3\alpha}\frac{4\pi f}{N\,W_l{}^2} \equiv \frac{Q_l}{N}$$

@400±50keV

$\langle I\rangle$ =5×10^{-3} ph/cm^2/s/sr

C_P =10^{-8} (ph/cm^2/s)^2/sr

⇒ N > 2×10$^{4\sim5}$

@700±50keV

$\langle I\rangle$ =10^{-3} ph/cm^2/s/sr

C_P =10$^{-9\sim-8}$ (ph/cm^2/s)^2/sr

⇒ N > 10$^{4\sim5}$

極周回気球(~10^6 sec)

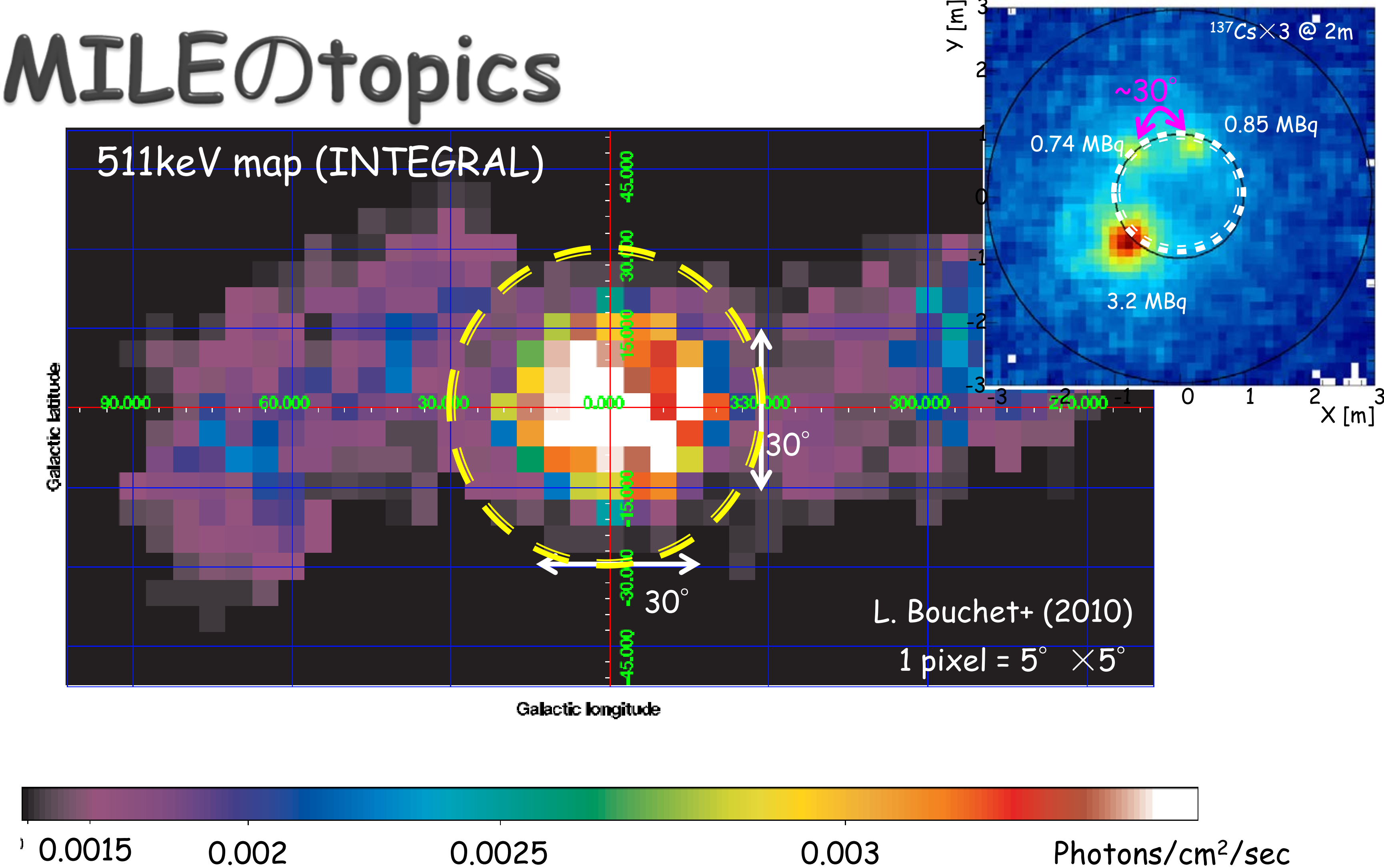
⇒ >10^6 events ⇒ 高精度スペクトル

Anisotropy

⇒ >10^5 eventsから議論可

極周回気球での観測から
背景放射の起源を同定可能

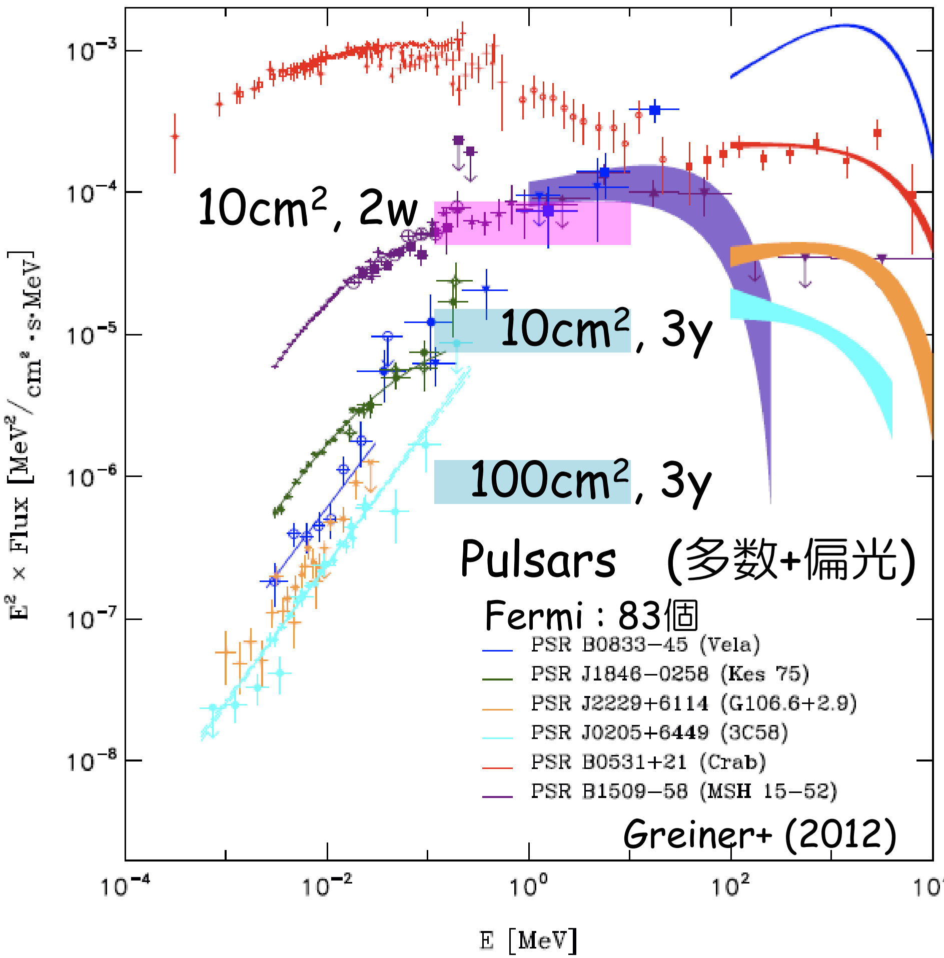
SMILEのtopics

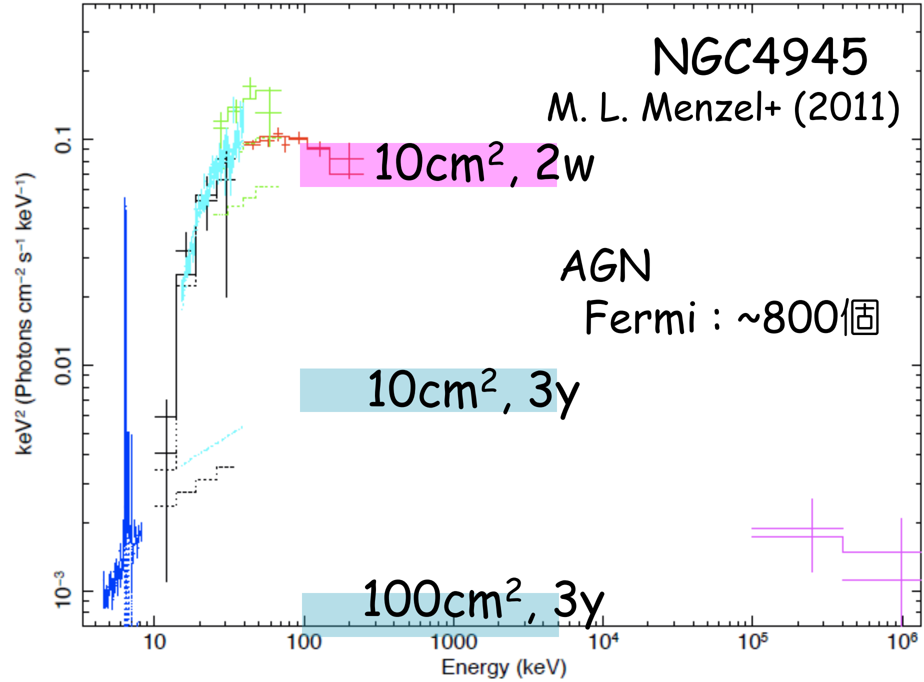


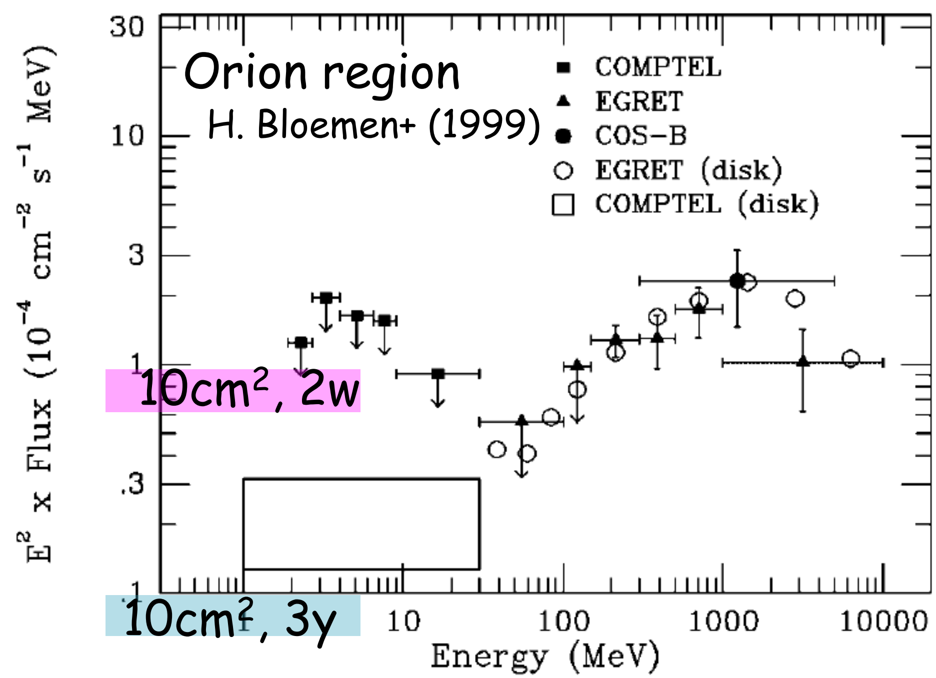
極周回気球 (10 cm^2, 10^6 sec) ⇒ > 10^4 event/pixel

同時に銀河面探査 ⇒ 新しいMeVガンマ線天体の探索

未発見天体探査


10cm², 2w
10cm², 3y
100cm², 3y
Pulsars (多数+偏光)
Fermi : 83個
PSR B0833−45 (Vela)
PSR J1846−0258 (Kes 75)
PSR J2229+6114 (G106.6+2.9)
PSR J0205+6449 (3C58)
PSR B0531+21 (Crab)
PSR B1509−58 (MSH 15−52)
Greiner+ (2012)
E² × Flux [MeV²/cm²·s·MeV]
E [MeV]


NGC4945
M. L. Menzel+ (2011)
10cm², 2w
AGN
Fermi : ~800個
10cm², 3y
100cm², 3y
keV² (Photons cm⁻² s⁻¹ keV⁻¹)
Energy (keV)


Orion region
H. Bloemen+ (1999)
COMPTEL
EGRET
COS-B
EGRET (disk)
COMPTEL (disk)
10cm², 2w
10cm², 3y
E² x Flux (10⁻⁴ cm⁻² s⁻¹ MeV)
Energy (MeV)

γ-ray burst due to Relativistic Electron Precipitation in 1996 @Kiruna for SMILE-II

K.R.Lorentzen et al.,(2000)

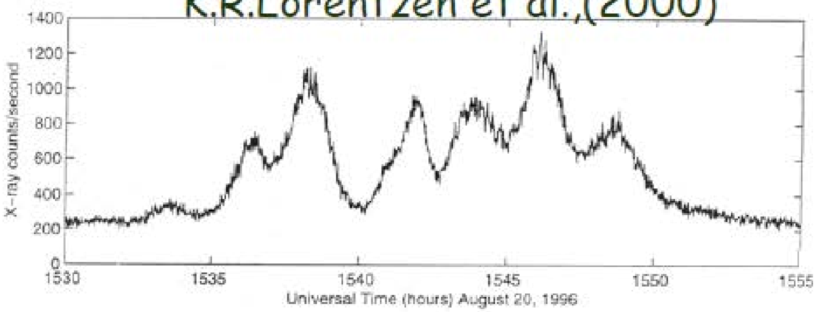
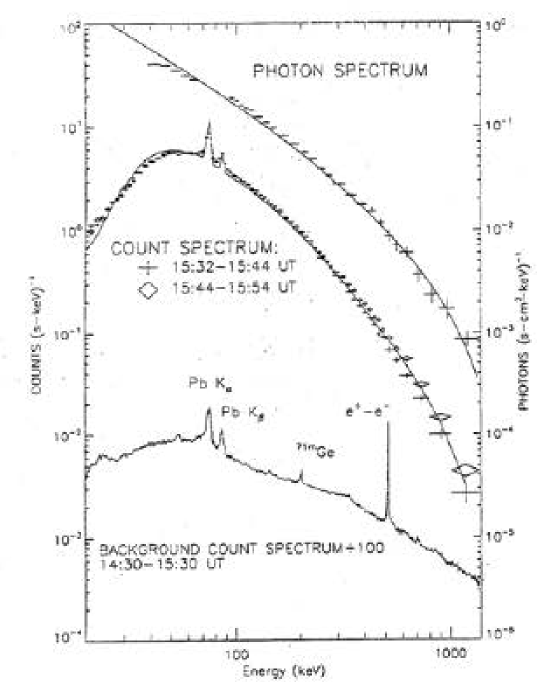


Figure 1. X-ray imager data taken during the relativistic electron precipitation event of August 20, 1996. The X-ray count rate between 20 and 120 keV is averaged over 1 s. The 10–20 s modulation is most clearly visible superposed on the peak starting near 1545 UT.



- Similar scale burst
  SIMILE-II(30x30x30cm ETCC)
  100kev-2MeV
  ~20σ detection for imaging Δθ 10°
  Good Spectroscopy from large crystal arrays.
  Wide field of View with ~3str
- Fixed point observation
  - -> spatial or temporal
- Direct Measurements of high energy electrons, proton, neutron and nucleus

Rep-burst observation

Wide FoV imaging-> Direction, Position
Spectroscopy, Light Curve,

γ-ray spectrum—>Depth of burst
D & θ -> L (Distance)