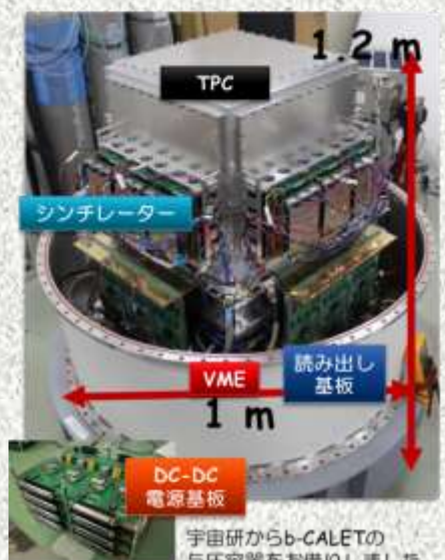
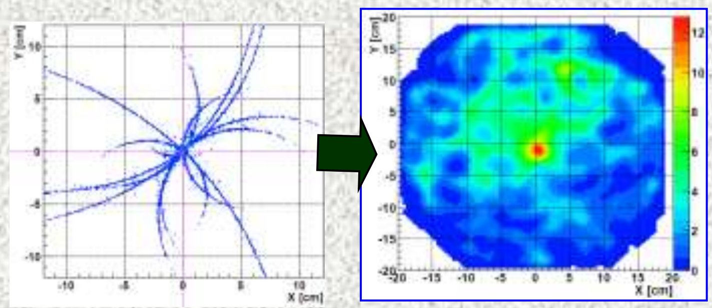
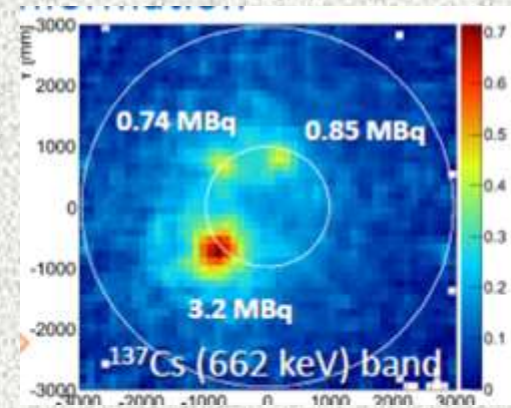
Possibility of Electron tracking Compton camera for seeking deep universe in MeV gamma-ray band







CONTENS

1. MeV Gamma-ray Astronomy
2. Problem of MeV gamma ray observation
3. Electron Tracking Compton Camera
4. Performance of SMILE-II (+Polarization measure)
5. Expected Astrophysics in SMILE-II and III balloon experments.
6. Summary

T.Tanimori, H.Kubo, K.Miuchi[2], J.D.Parker, S.Komura, S.Iwaki, T.Sawano, K.Nakamura1, S.Nakamura, Y.Matsuoka, T.Mizumoto[3], Y.Mizumura, M.Oda. S.Sonoda, A.Takada, D.Tomono,

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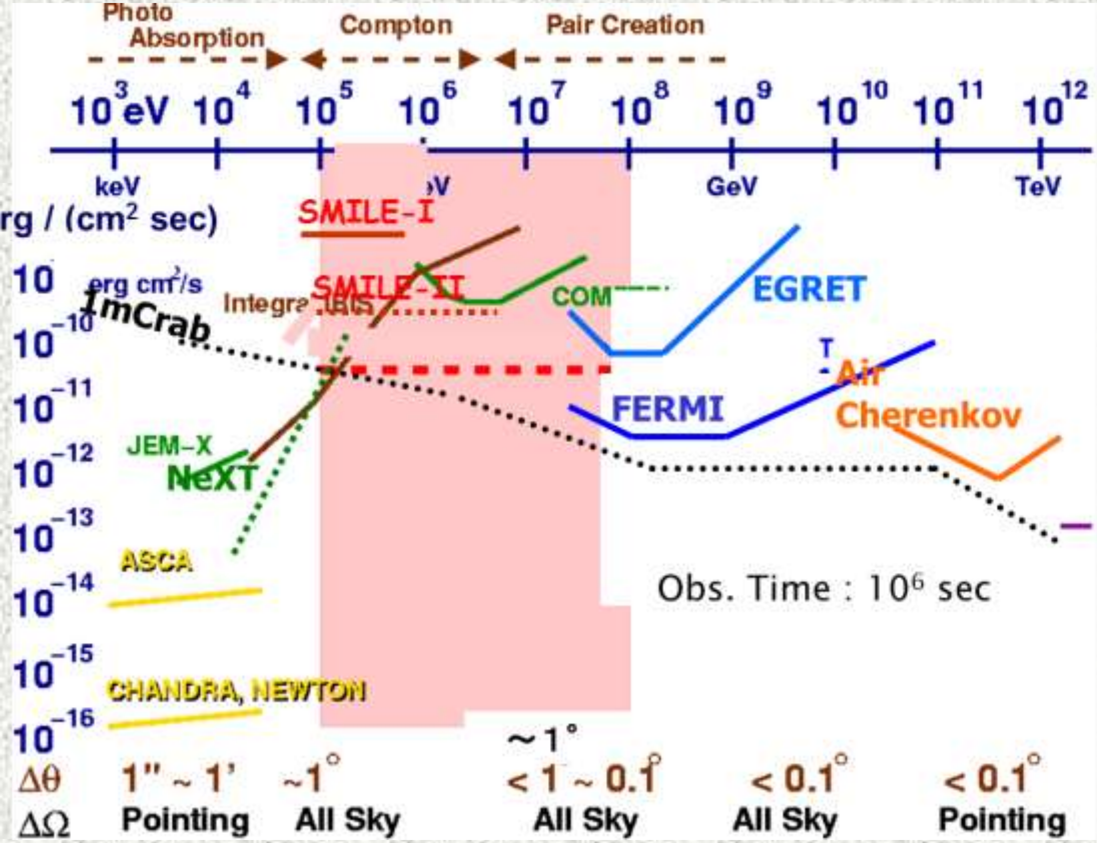
2) Department of Physics, Kobe University, Japan,
3)Research Instit. for Sustainable Humanosphere, Kyoto Univ.

07/10/2013 GRB Meeting @ Ext Univ.Lab.

MeV Astronomy

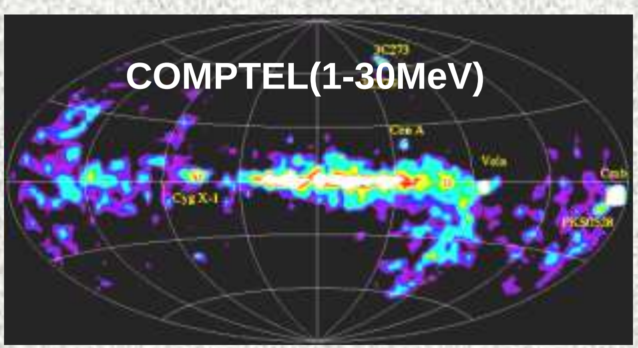


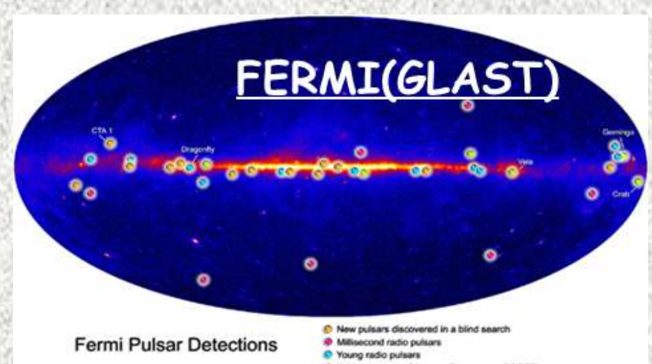
Line γ

- Nucleosynthesis
  SNR : Galactic plane :
  $^{26}Al \cdot {}^{60}Fe$, 511 keV

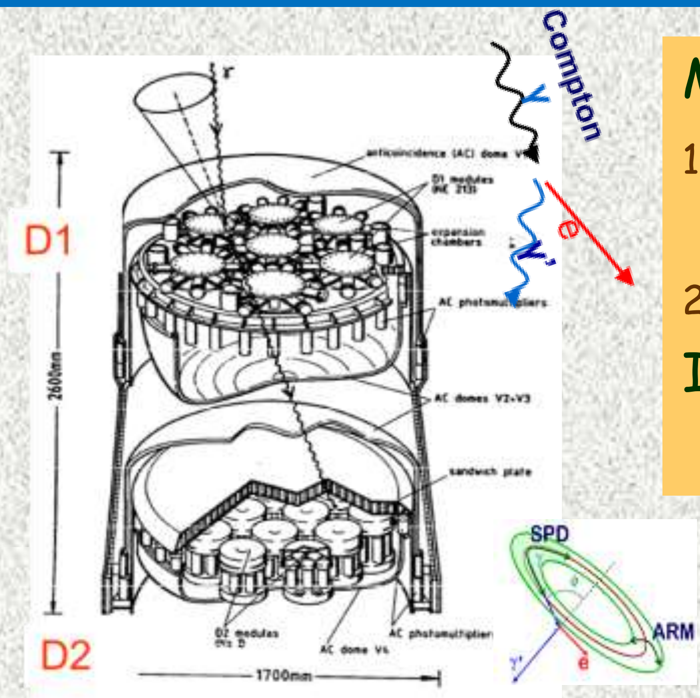
Continuum γ

- Strong Gravitational Potential
- Cosmic ray Acceleration
- Early **GRB**
- Terrestrial Gamma-ray bursts

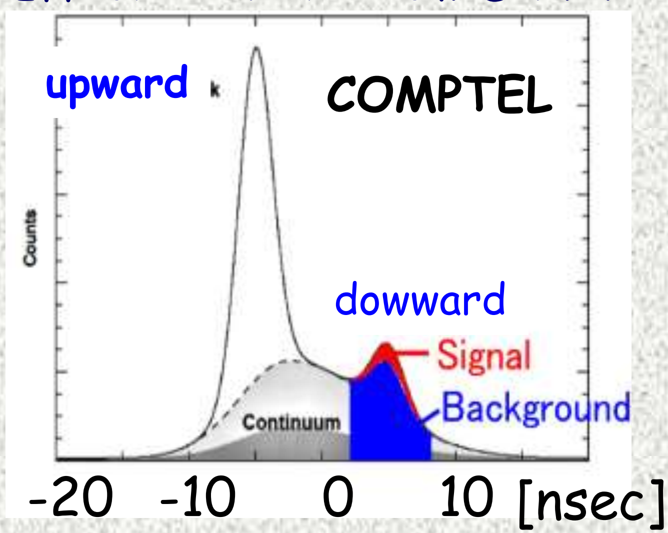




Difficulty of MeV gamma-ray Observation



Effective Area ~20cm^2@1MeV



G.Weidenspointner, et.al. (2001)

Main reasons of Difficulty

1. Huge BG from gammas from Albedo and satellite and fast neutrons
2. Obscurity of imaging by circular direction

If no background, a fewx10cm^2 effective area

=> a few mCrab@10^{6}sec

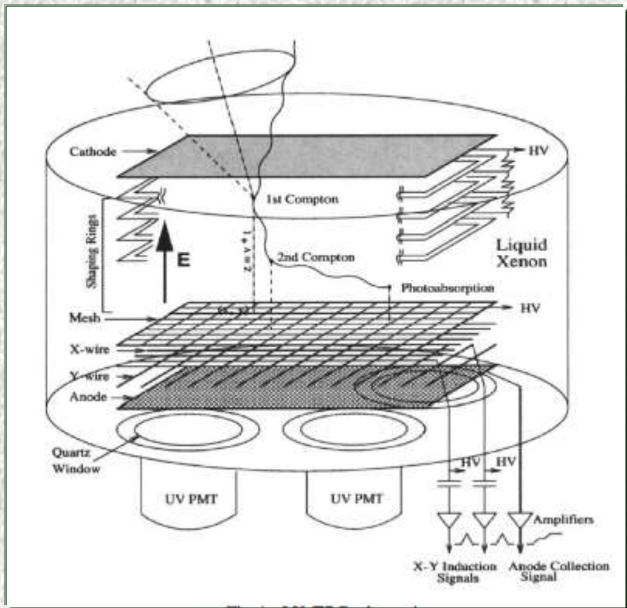
V.Schönfelder (2004) Suggestion

Low background is most important for next MeV detector

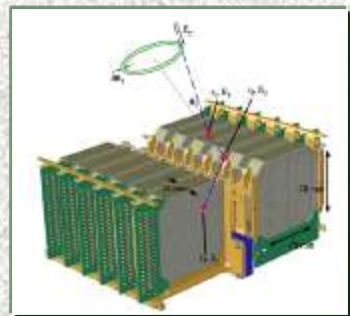
1. Good angular res.(ARM) = good Energy res.
2. Redundancies (TOF, Kinematics, dE/dx)
3. Measurement of electron direction (SPD)!
4. Low-z material and light weight
5. Short timing gate

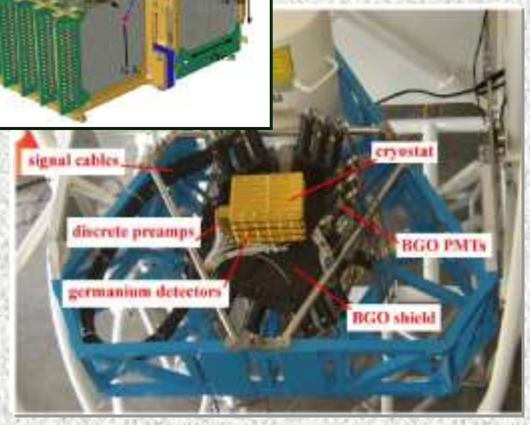
Advanced Compton Camera

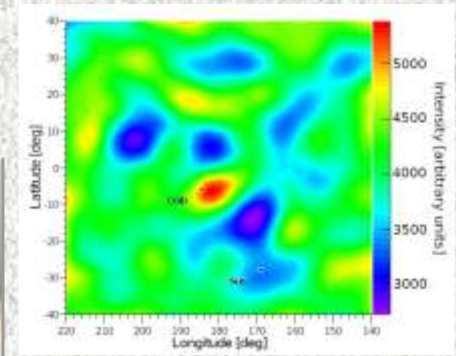
. Aprile et al(2004)



M. S. Bandstra et al. ApJ 2011







Le Xe TPC　　2000

- No VETO
- 0.1-10MeV Expected eff.A～20cm^2
- Obs. 1－10MeV　～2cm2

  expected gamma from Crab ~50ph.

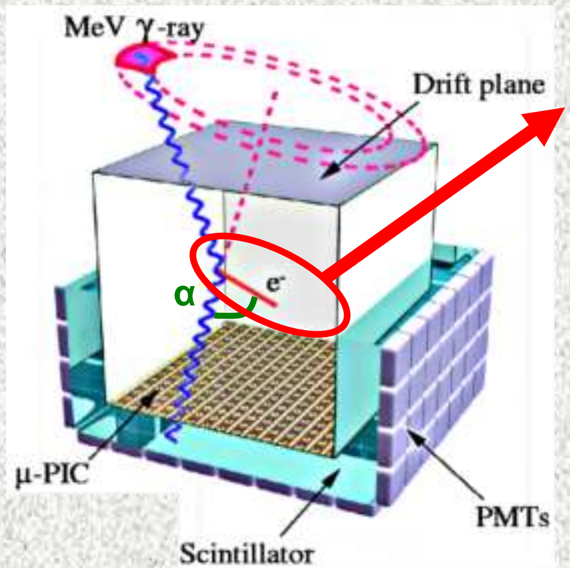
  No. detection

  priority: **Large effective Area large**

- Crab 4σ (8hrs) with NLEM meth.
- Ge strio with BGO VETO
- FoV 3str （BGO 8str)
- 0.3-1.5MeV Eff.A 6cm^2
- Simulation 3800 γ detection 667 γ
- B.G. in Crab view~29000(S/N~0.02)

Priority: good energy res.

Electron Tracking Compton Camera(ETCC)

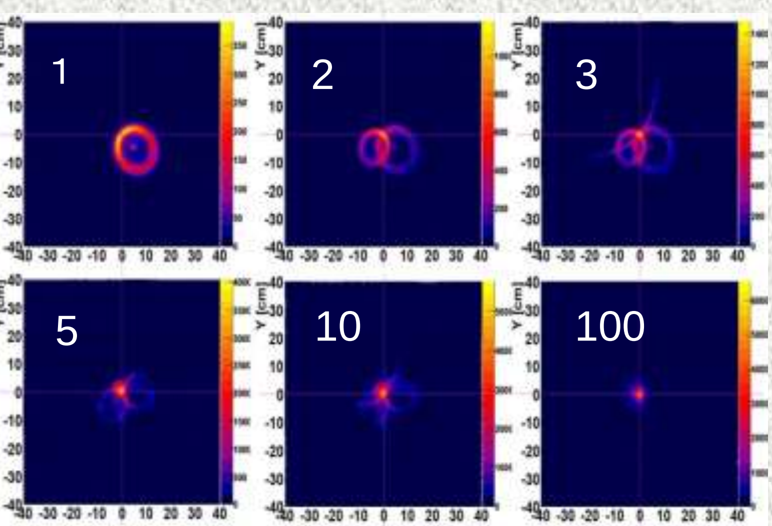


Goal: High sensitivity for Continuum gammas with > 10~50 better than COMPTEL

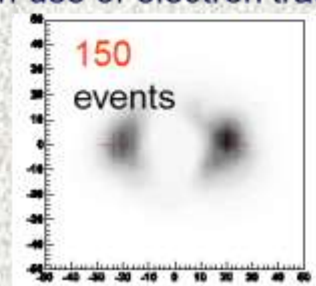
Strong BG rejection & clear imaging are needed

1. Electron tracking for imaging, Kinematics(α)+dE/dx (multi redundancies)
2. Large FoV. ~3str
3. No Veto counters & light weight

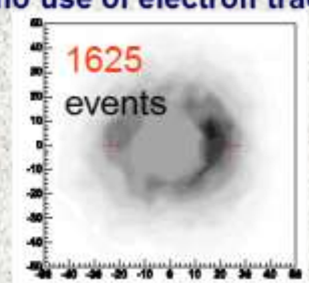
50cm-cubic 3atm CF4 gas ~110cm^2@1MeV

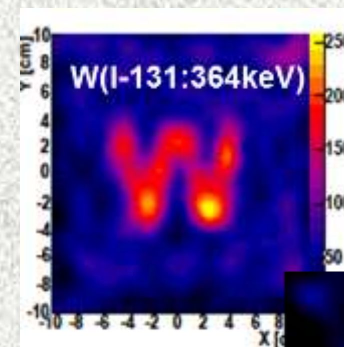


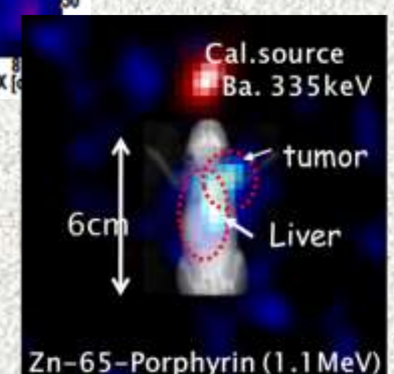
In use of electron track



no use of electron track

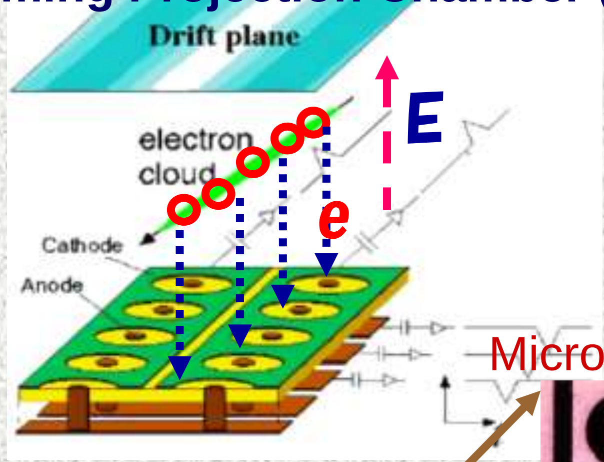




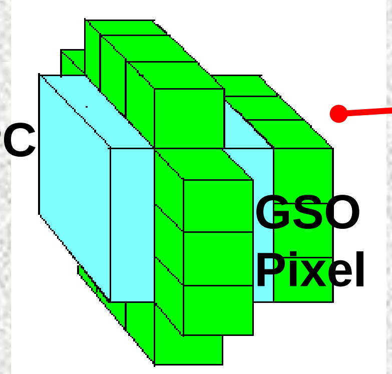


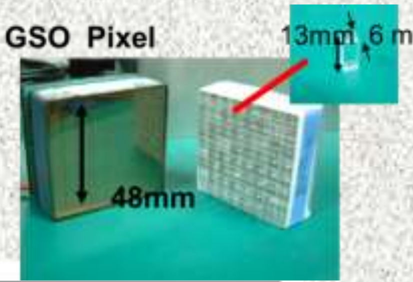
10cm-cube μ-TPC & ETCC

Timing Projection Chamber (TPC)

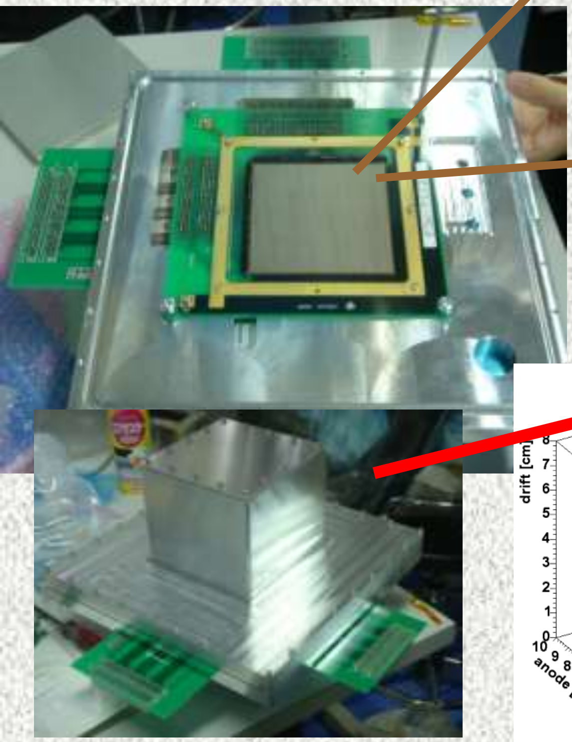


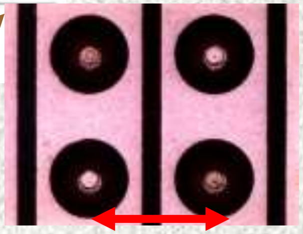
GSO:Crystal



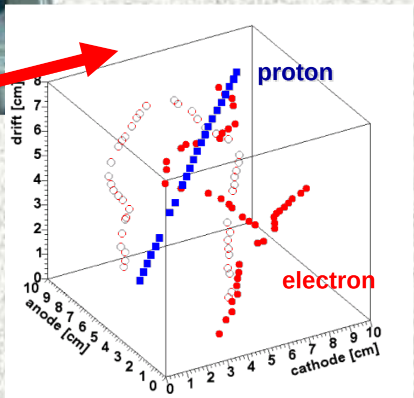


μ-PIC
Micro Pixel Chamber

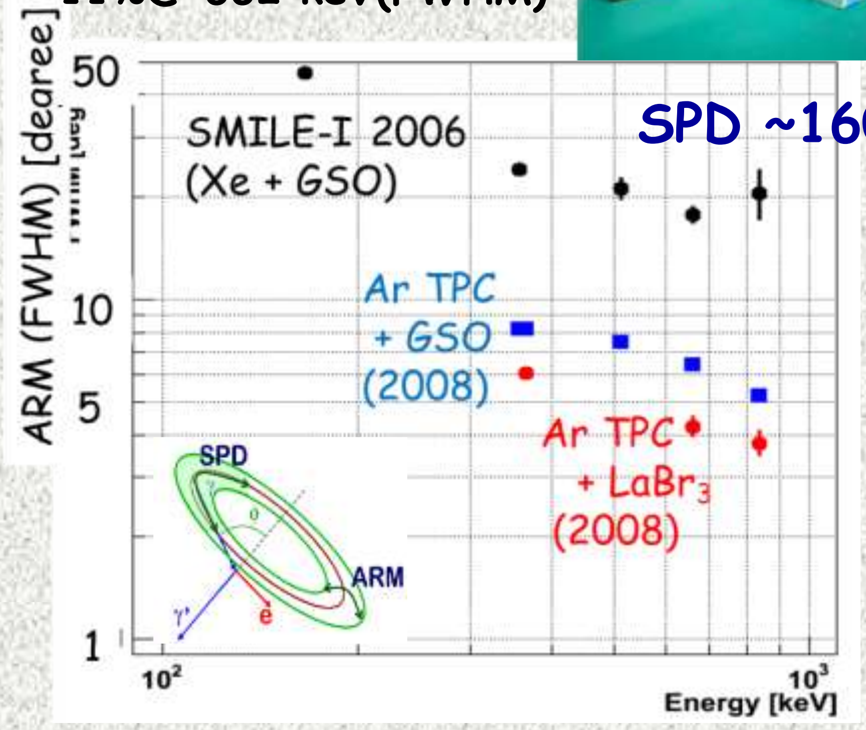




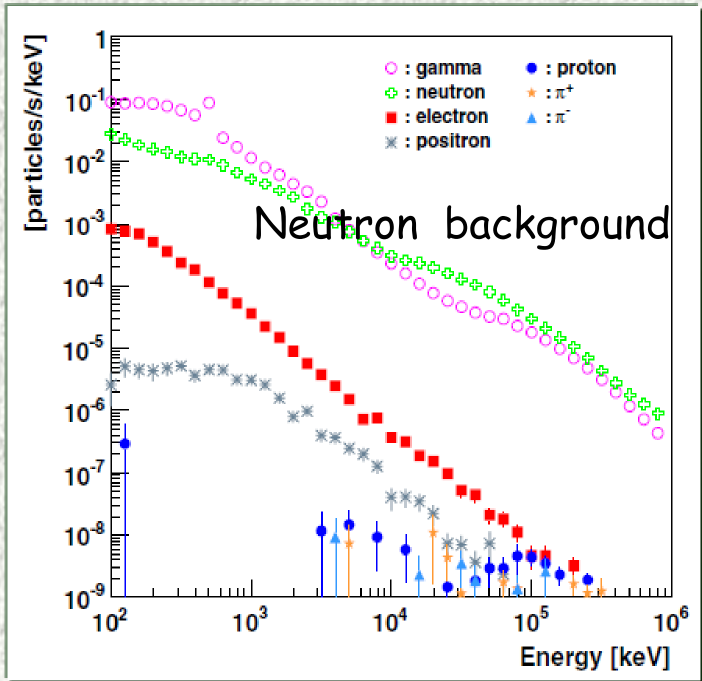
400μm



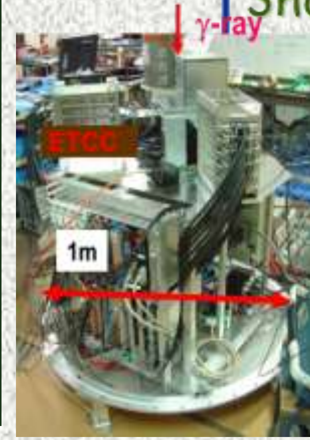
11%@ 662 keV(FWHM)



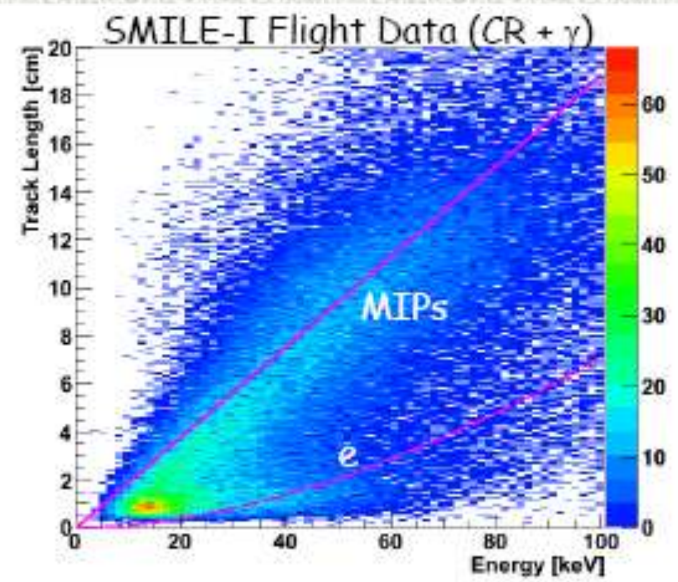
Sub-MeV γ-ray Imaging Loaded-on-balloon Exp. (SMILE-I)

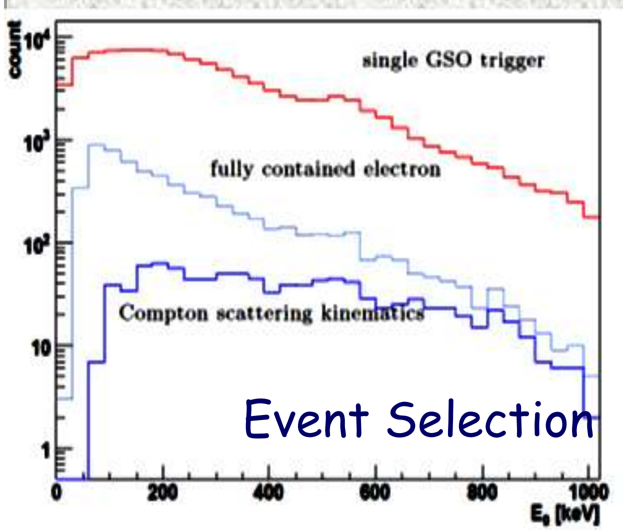


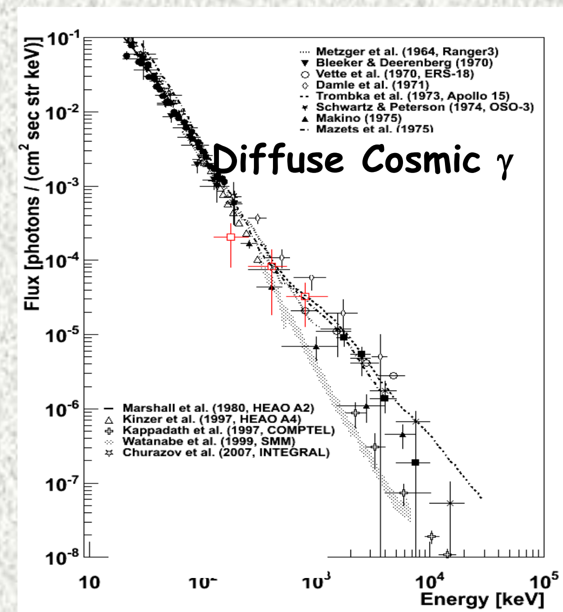
Test flight using 10cm cube ETCC to measure
Diffuse Cosmic and Atmospheric gamma rays in 0.1-1MeV
3hours observation @35km



All Trigger # 2.3×10^5 (3hours)
Signal ⇒ ~420(down going) +500(up)
Simulation ⇒ ~400 (diffuse cosmic)

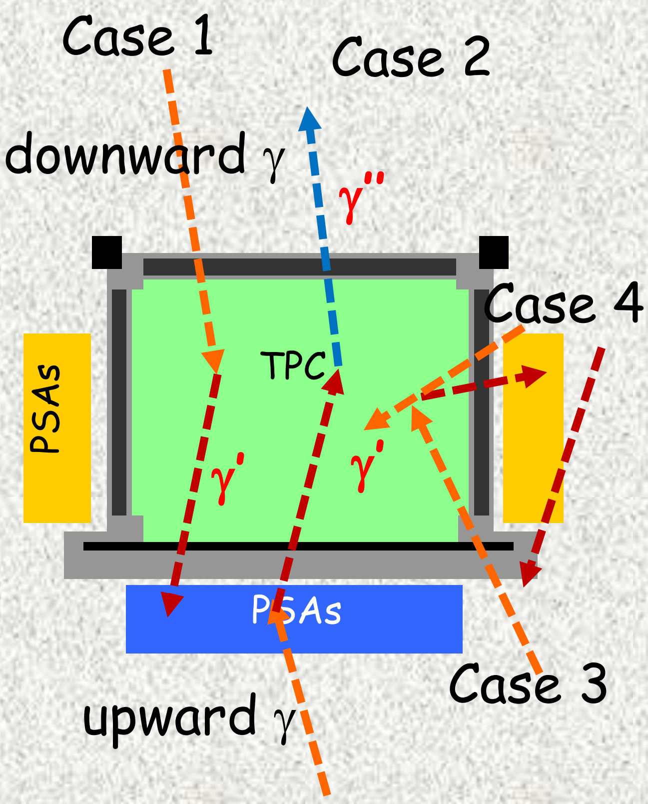






Takda et al. ApJ (2011)

Noise Rejection of ETCC for BG gamma



Case 1: downward gammas (signal)

Compton in TPC x Absorption in Sciniti.(high Z)

Case2 upward gammas (dominant in BG)

Absorption in Scinti (high-Z) >> Compton in Scinti

Scinti (1 Radiation Length) 1/8 (SMILE-I)

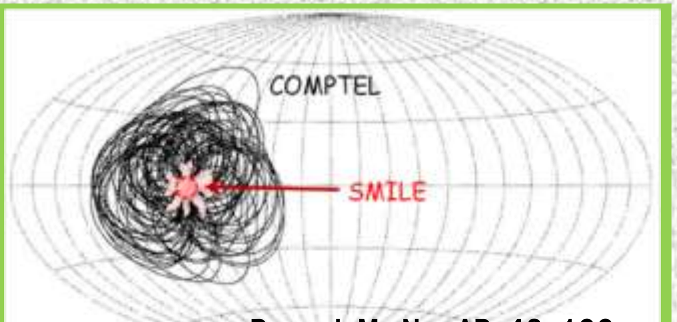
Scinti (2 RL) ~1/50

Self Veto System !

Case 3 & **Case 4 (two gammas)**

Rejection by geometrical and kinematical cuts !

Leakage BG Suppress by SPD



Ryan, J. M., NewAR, 48, 199 (2004).

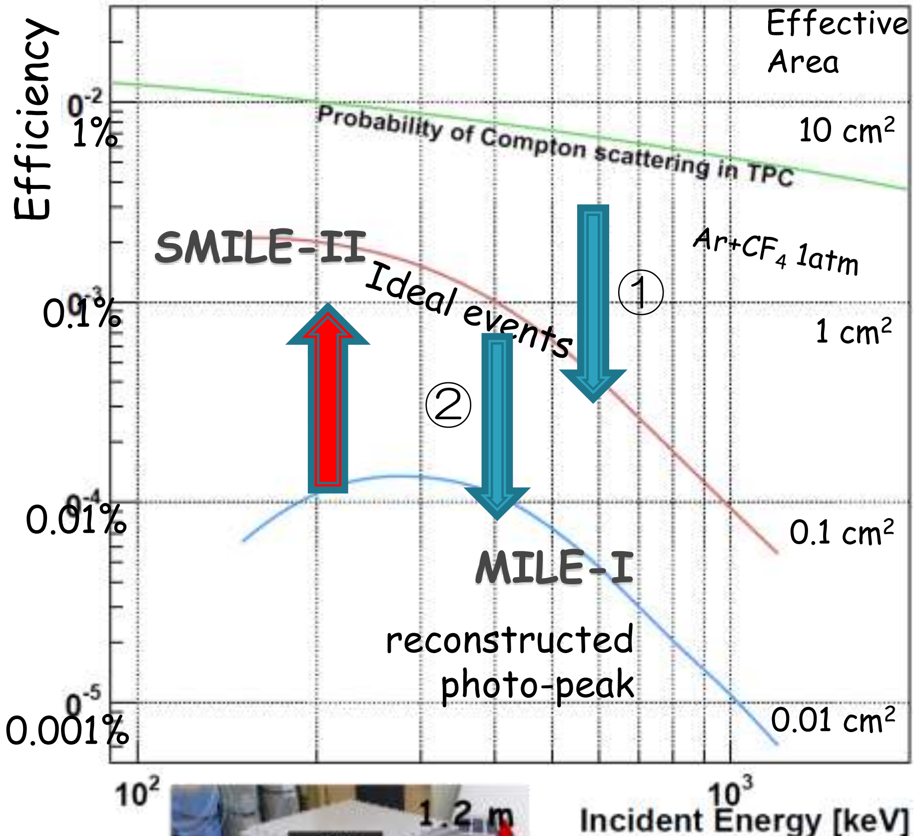
Remained BG in SMILE-1 20% of real signal (Diffuse Cosmic-gamma)

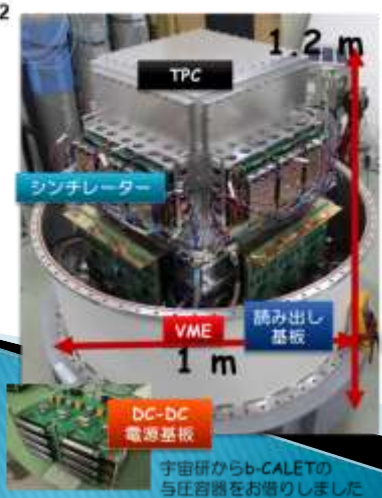
Expected remained BG in SMILE-II only a few % of Diffuse Cosmic-gamma

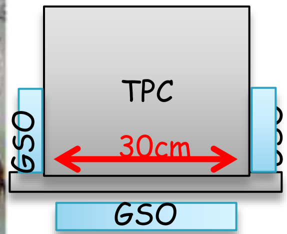
Due to improved SPD, ARM and dE/dx

Improvement of SMILE-II

Diffuse gamma ⇒ point sources







Crab Observation
: ~10^4s observation
5σ detection

⇒ Effective area :
1 cm²
ΔARM 10°

But SMILE-I= : 1~2 mm²

X100times Improvement

① Physical process
- Recoil e stopping in TPC
- Scattered gamma absorbing

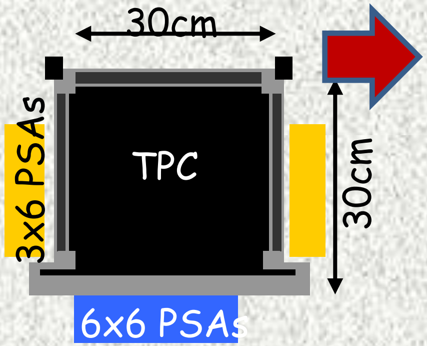
②Reconstruction Inefficiency
~10% in SMILE-I TPC

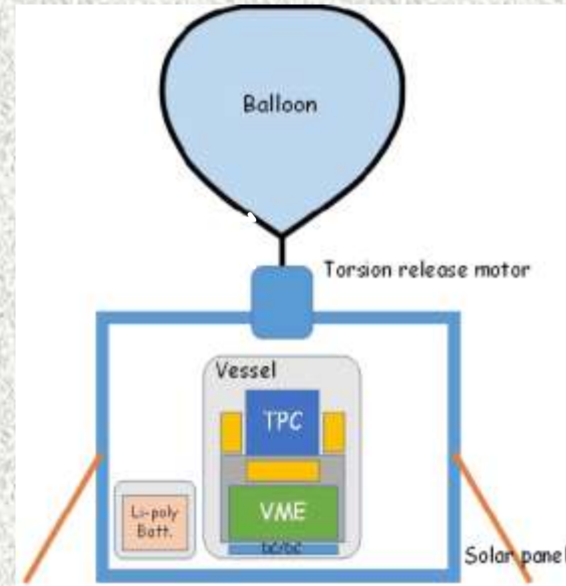
If Recont. Eff. -> 100%

SMILE-II

(30 cm)³ TPC x 20 times of SMILE-I
Reconst. Eff. ⇒ X 10
Angular Res. 16°=>5.3°

SMILE-II Flight Model

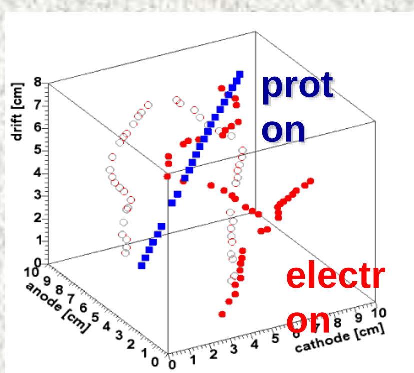


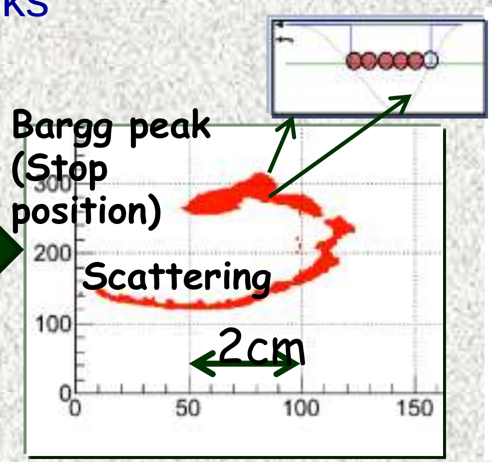


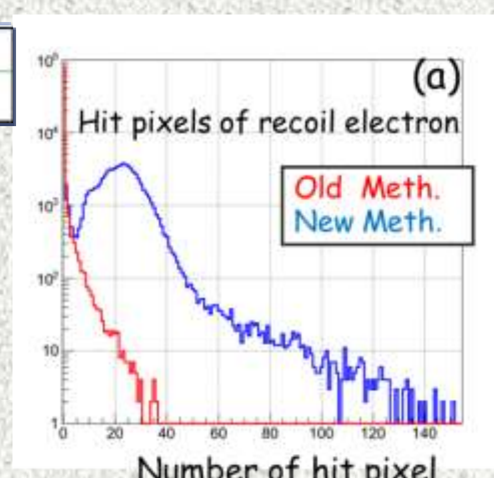
Total weight 300kg Power ~350W

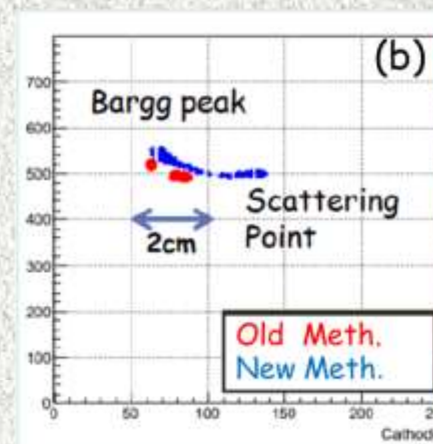
Improvement of Tracking in SMILE-II

Imaging of 3D tracks

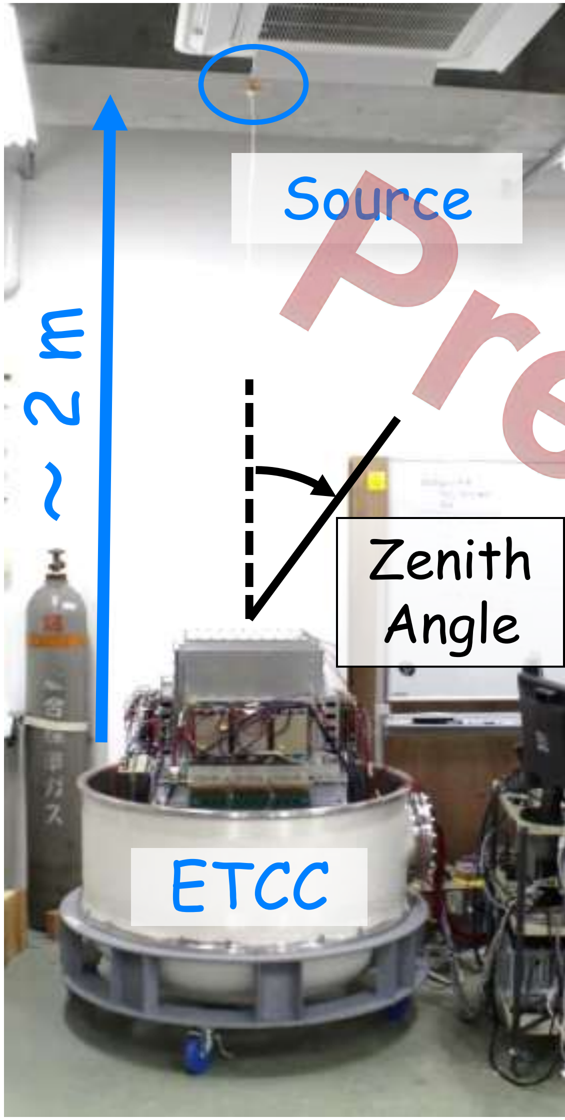


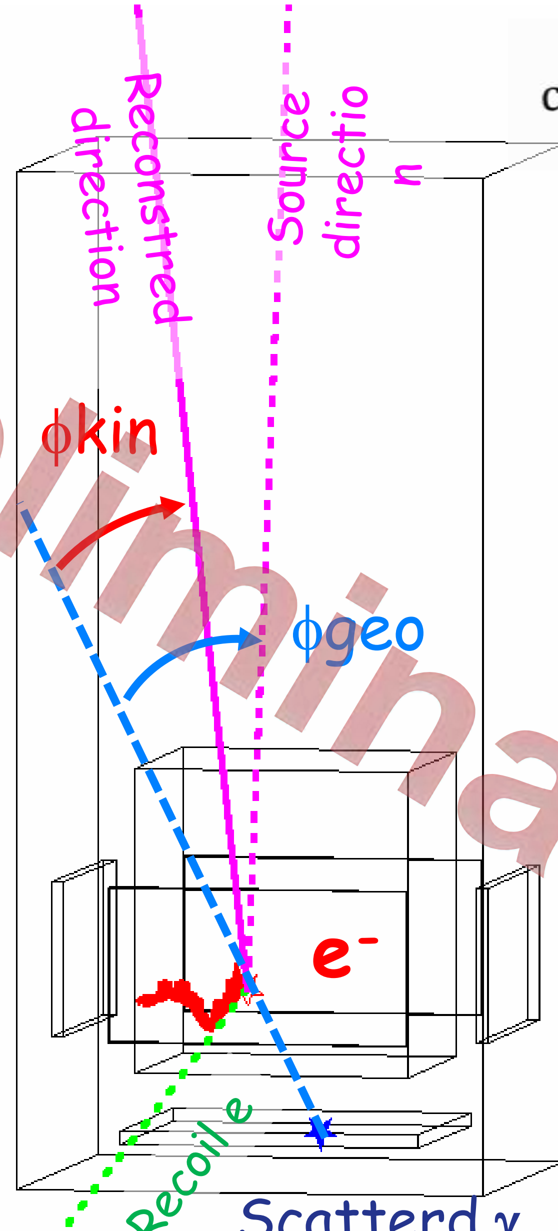






Imaging in 30cm ETCC

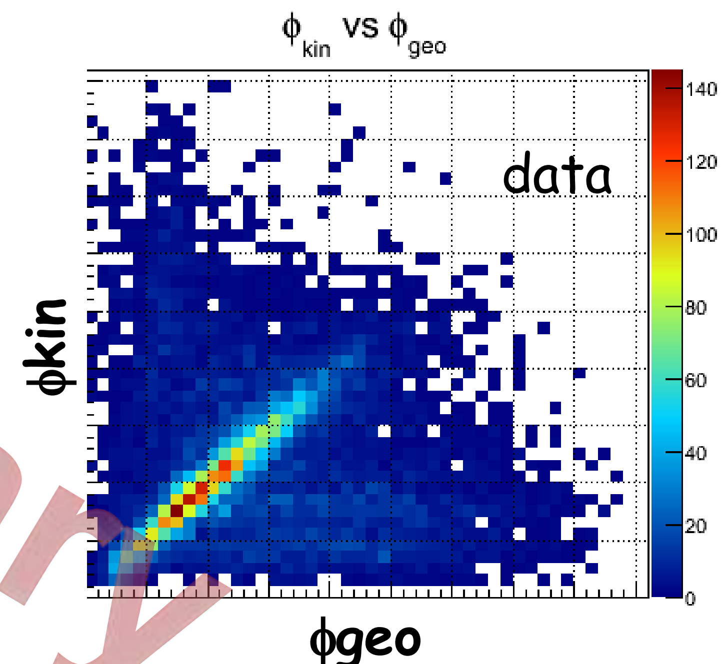




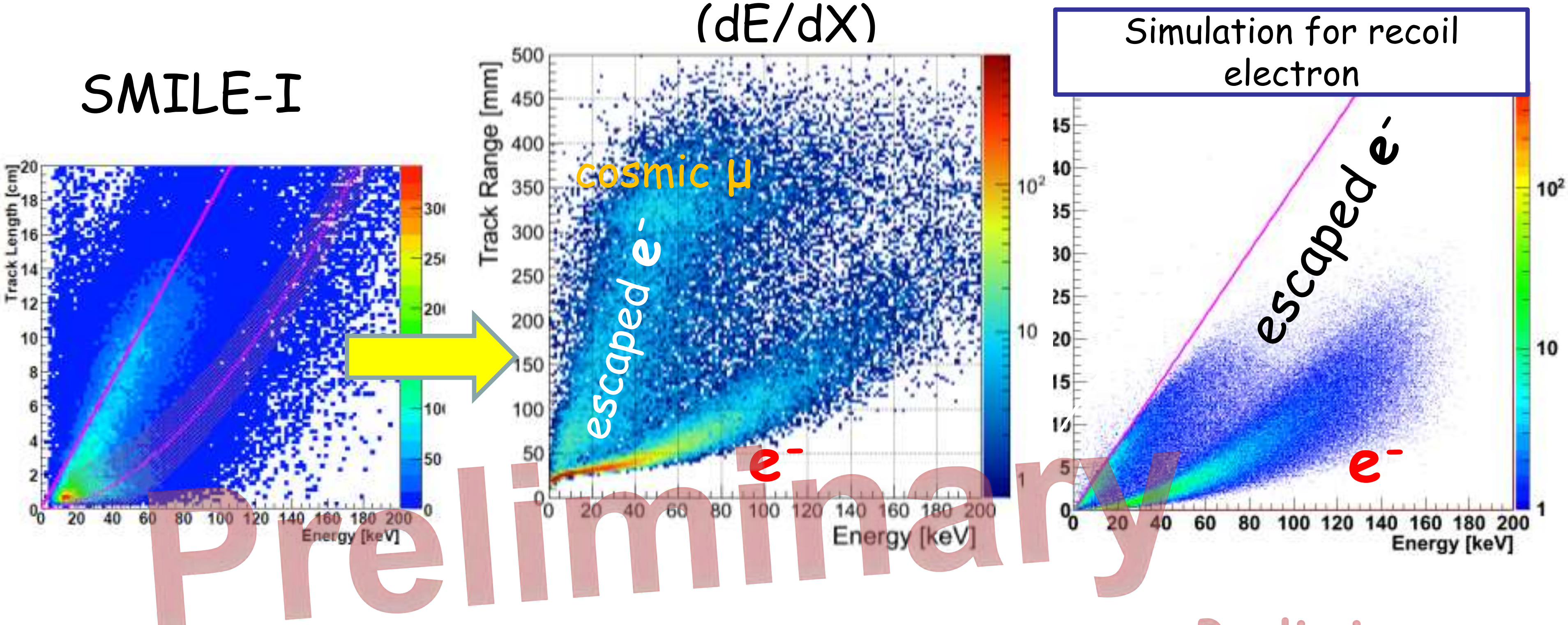
Scattering Angle φ

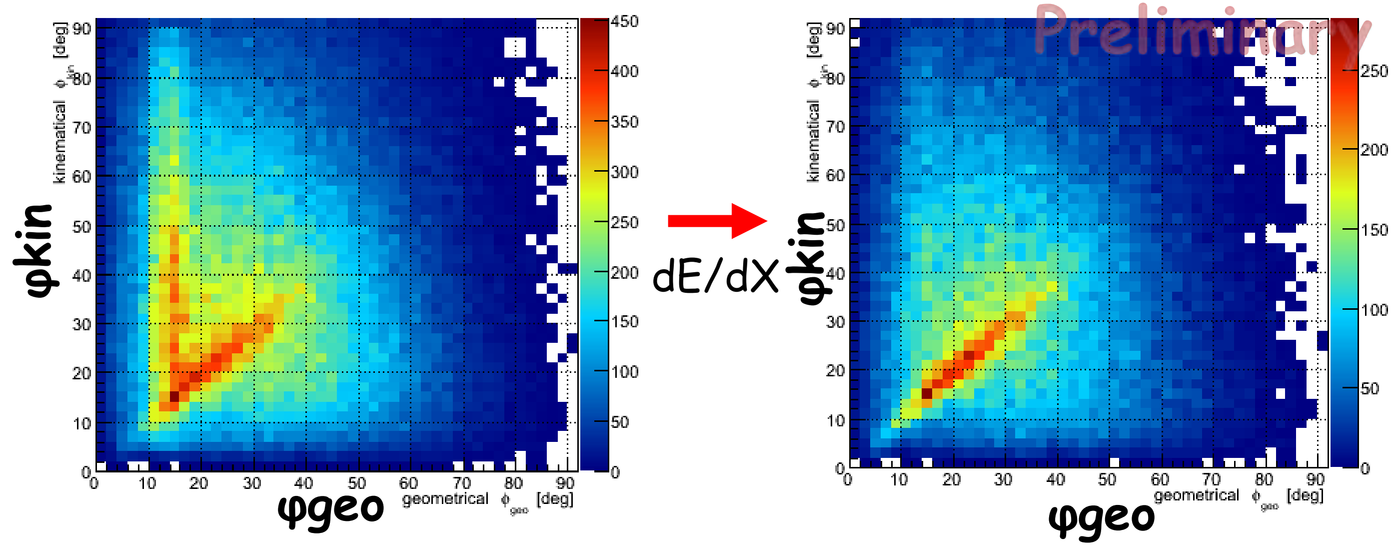
$$\cos\phi_{kin} = 1 - m_e c^2\left(\frac{1}{E_\gamma} - \frac{1}{E_\gamma + E_e}\right)$$

φgeo : calculated φ

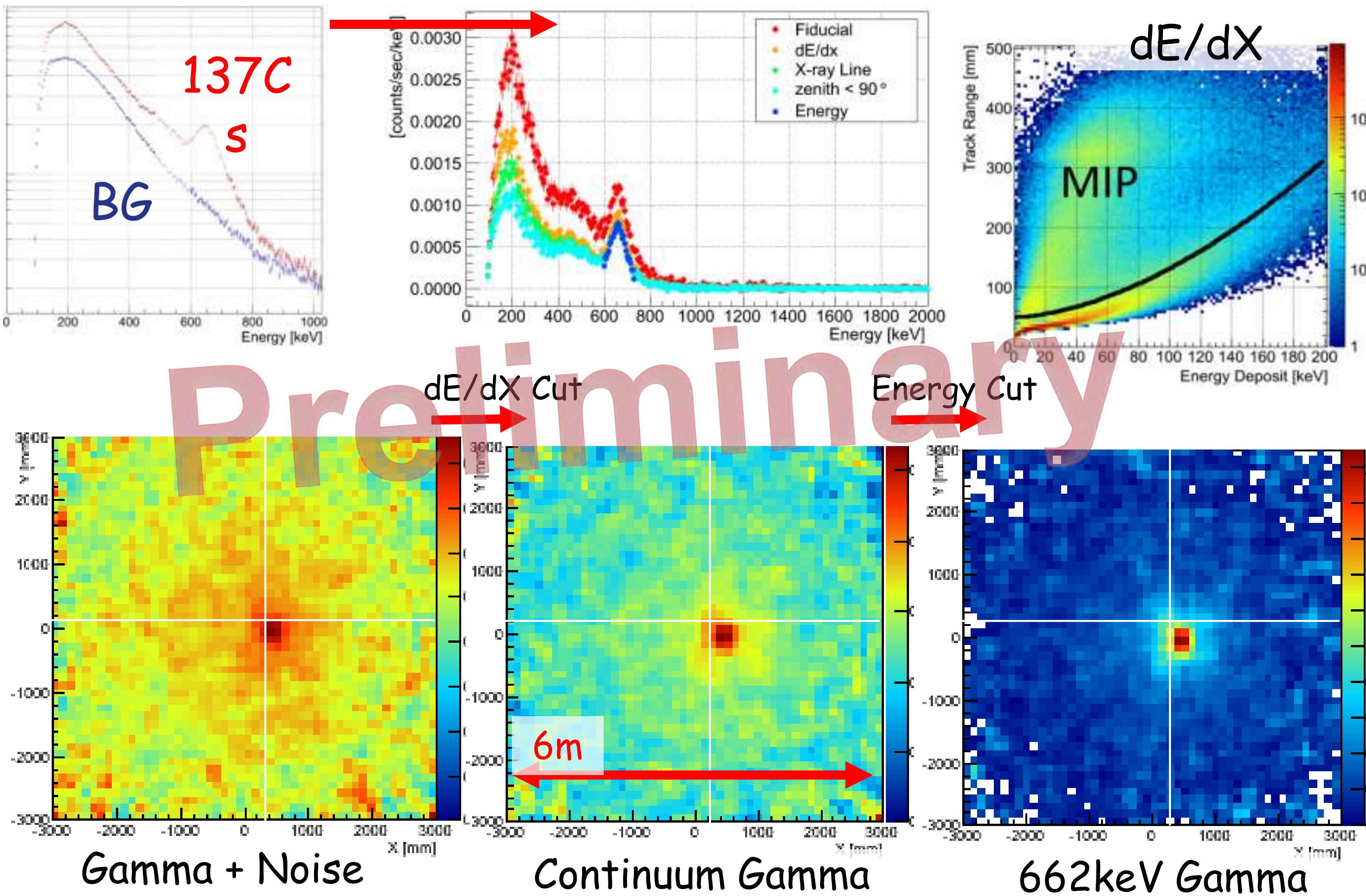


_Noise reduction by Energy loss rate dE/dx



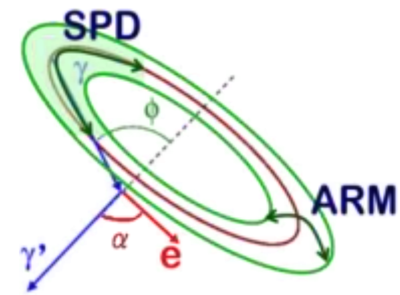


Gamma ray Event selection in ETCC

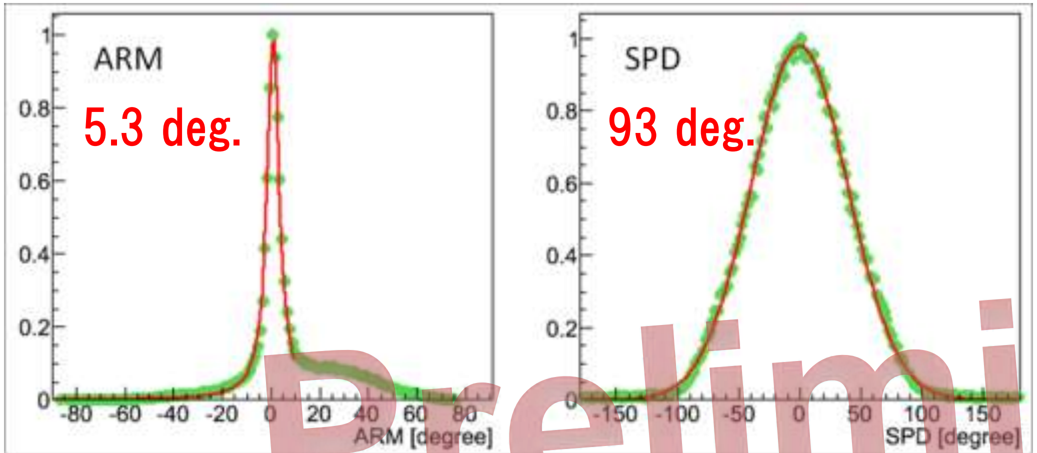


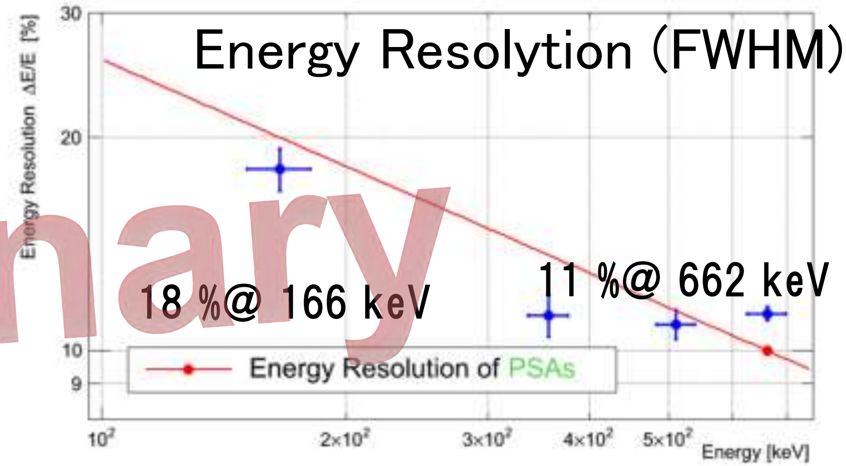
⇒ Continuum fully gamma events selected by dE/dx cut

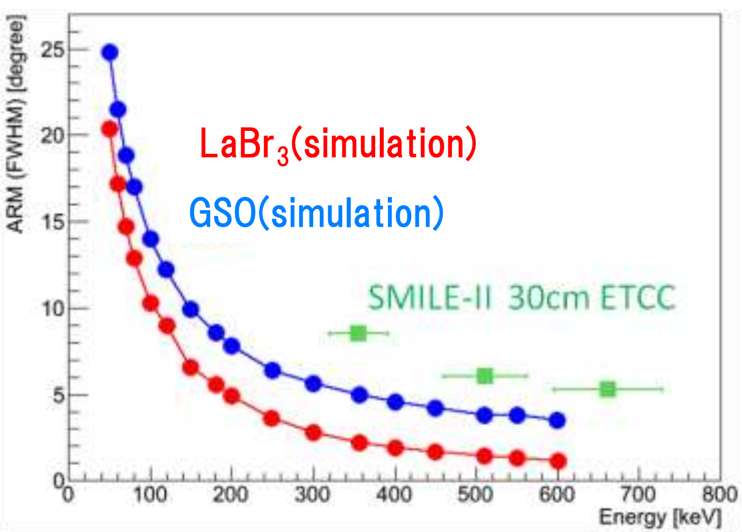
Angular Resolution in 30cm cubicETCC



Angular Resolution(FWHM)@662keV



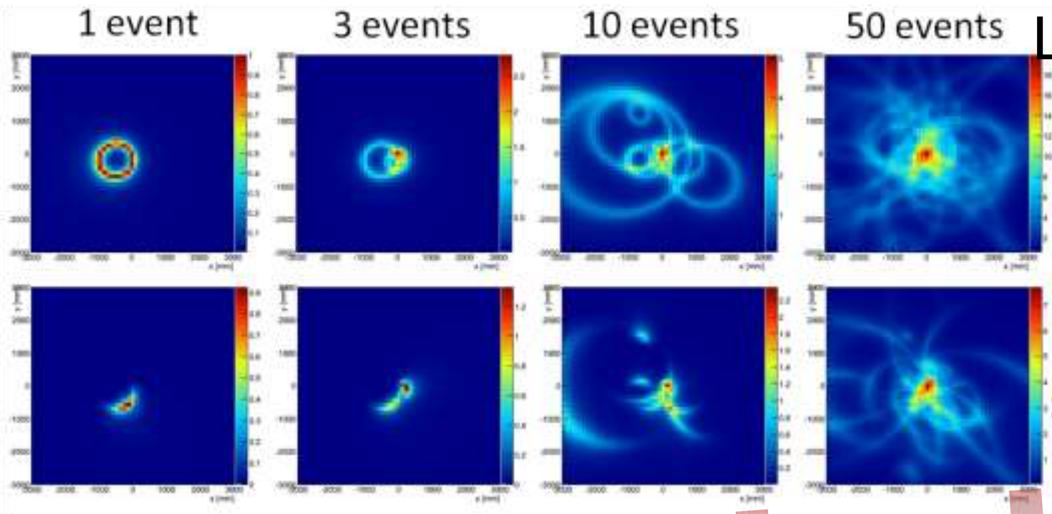




□ SPD = 93o <doube of multiple scattering
(UC group using 10um pixel CCD
SPD ˜200o <100keV electron

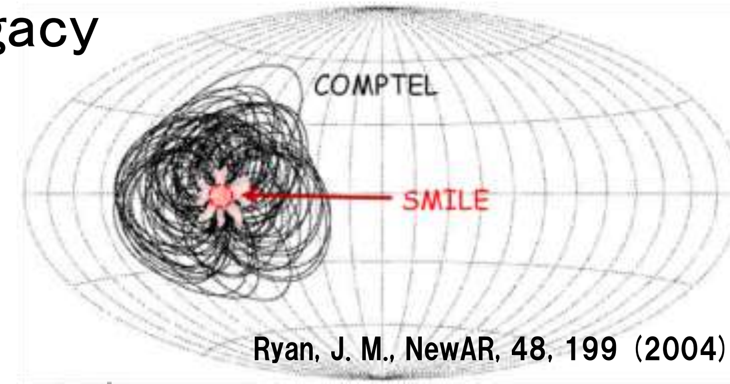
(D.H.Chivers et al.,2010 IEEE)

Imaging Improvement by SPD

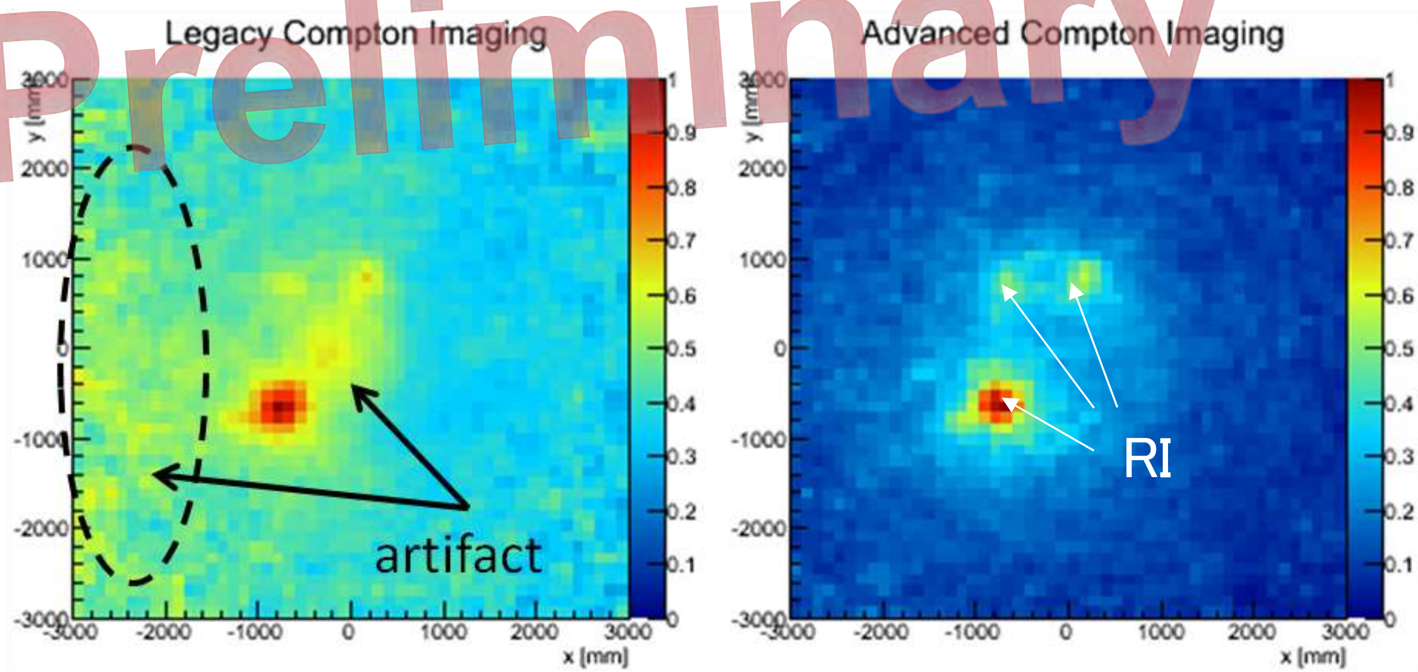


Legacy

:Advanced
（SPD=200°）



Ryan, J. M., NewAR, 48, 199 (2004).



$^{137}Cs \times 3$
3.2MBq
0.85MBq
0.74MBq

⇒（～4times better contrast image

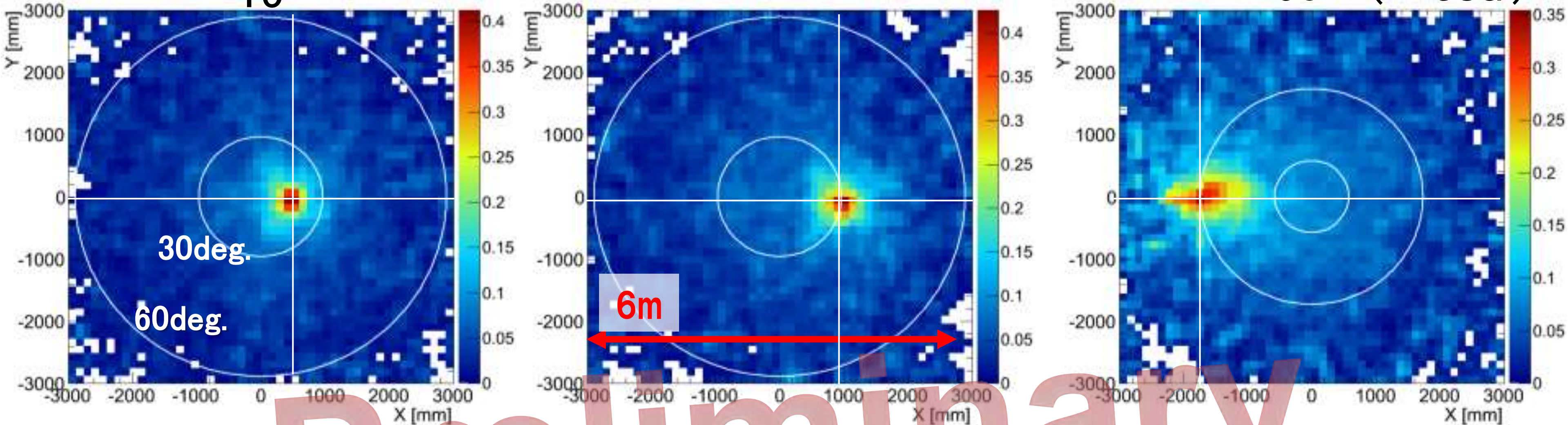
Some Back Projection Image

Preliminary

- ☐ Field of View

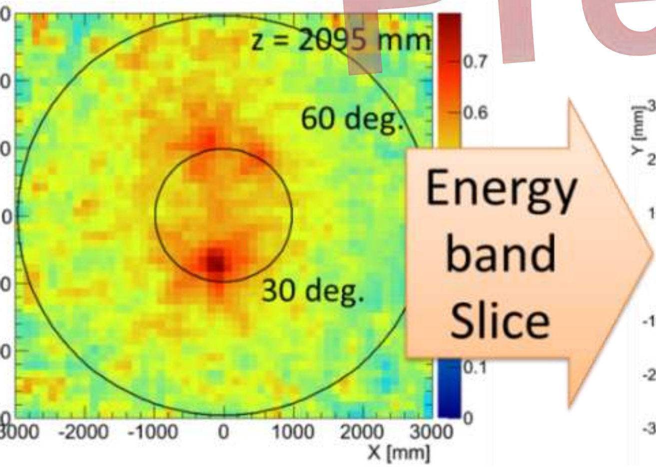
^{137}Cs(～0.85MBq)

15°　　30°　　60°（～3str）

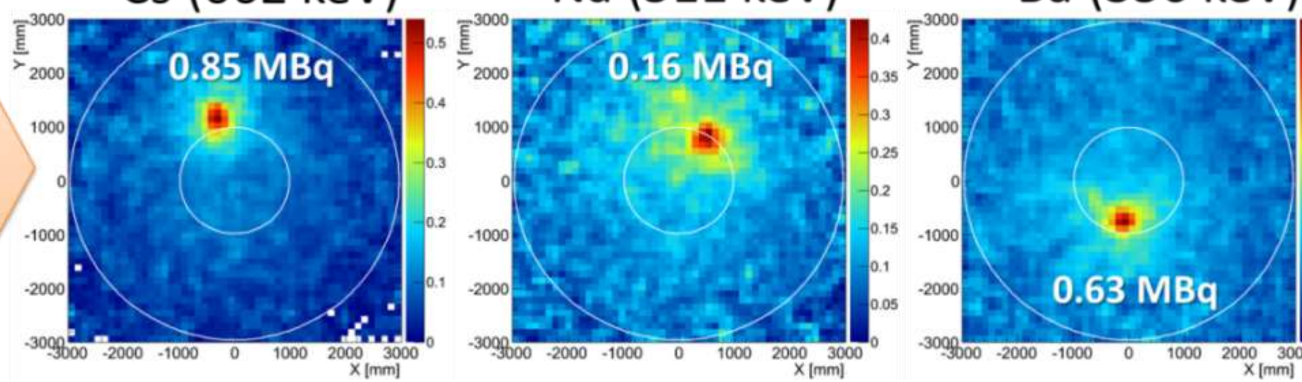


Preliminary

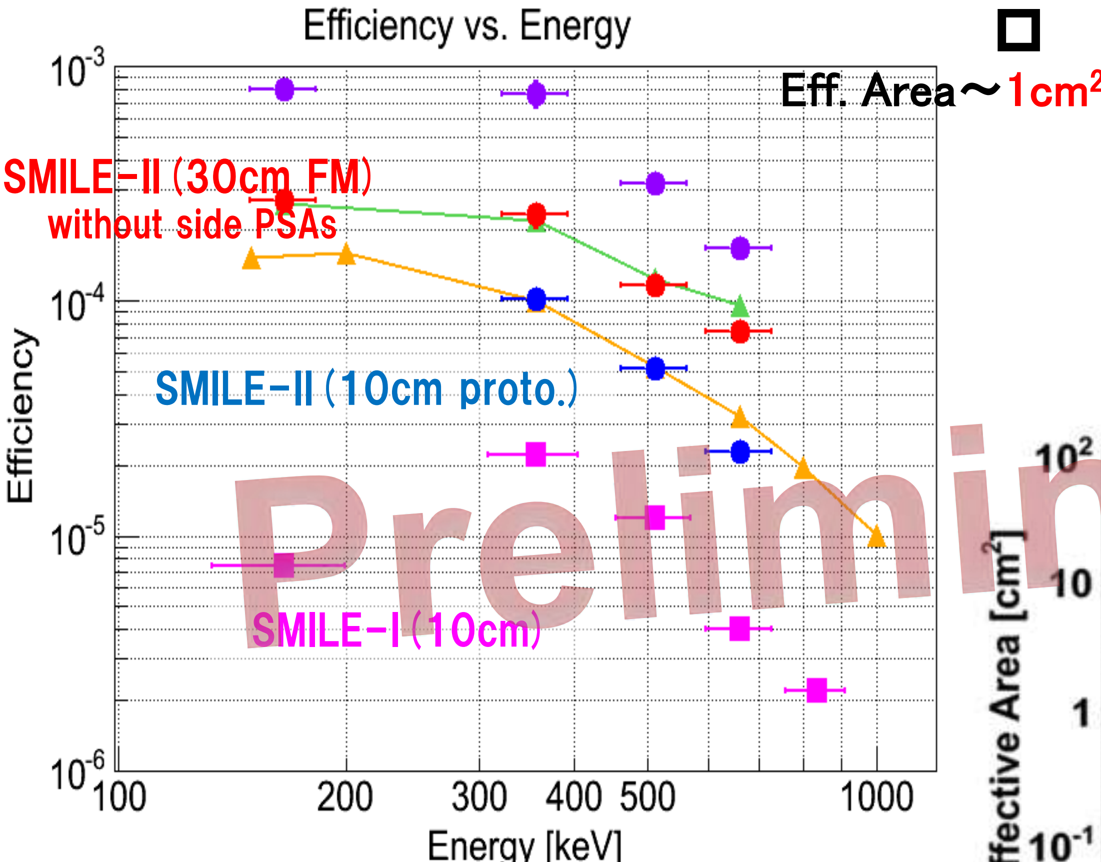
- ☐ Multi energy souces　　⇒ FoV ～3str



^{137}Cs (662 keV)　　^{22}Na (511 keV)　　^{133}Ba (356 keV)



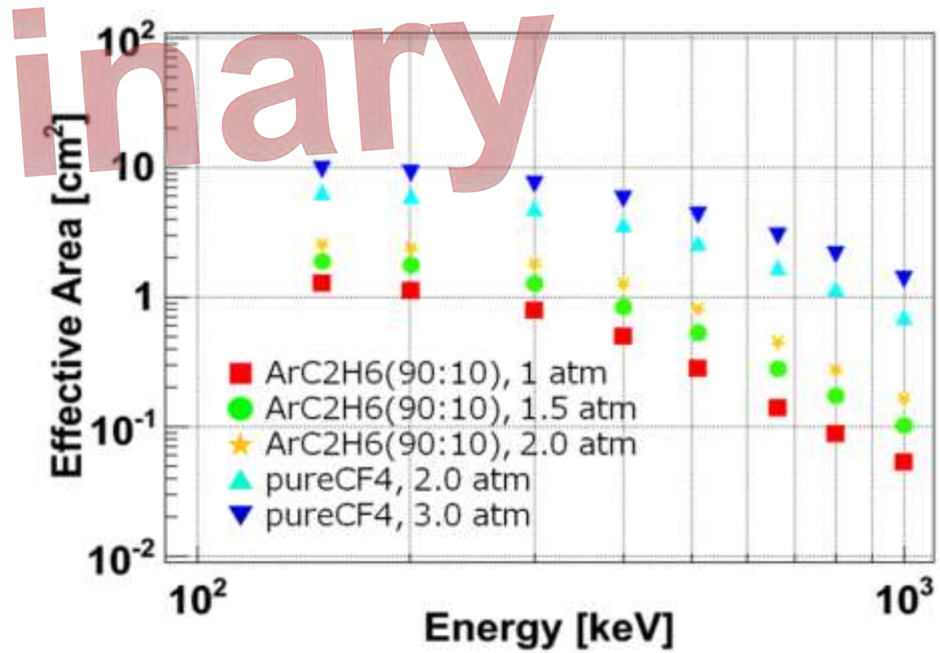
Detection Efficiency & Effective Area



- Present Eff. Area～1cm²

Compton electrons in TPC
->100% detection

Simulated Effective Area



Further improvement

⇒CF_4 + 3atm Eff. Area ～10cm²

+ double of Scintillator ->

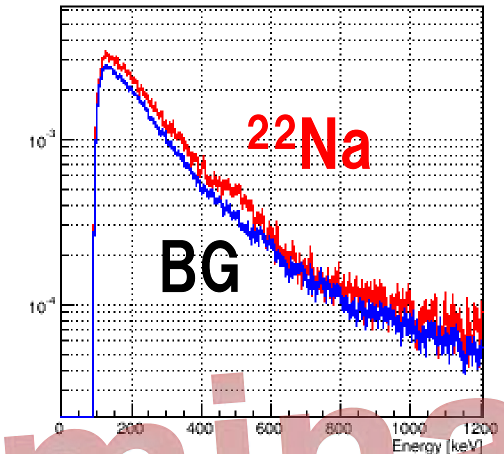
Total ~20 cm² @ SMILE-II

Similar effective area to COMPTEL

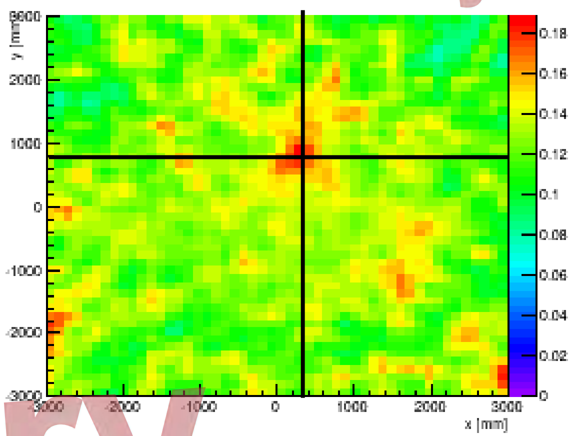
But 3str FoV, Low background, Clear Imaging in SMILE-II

Weak source detection such as Crab

- RI : ^{22}Na
  - Zenith = 26 deg.
  - z = 2095[mm]
  - 31 kBq
- 511 keV ± 10%
  - # Event= 1.2x10^3 (26h)
- S/N = 0.019
  - a few times stronger source than crab for SMILE-II

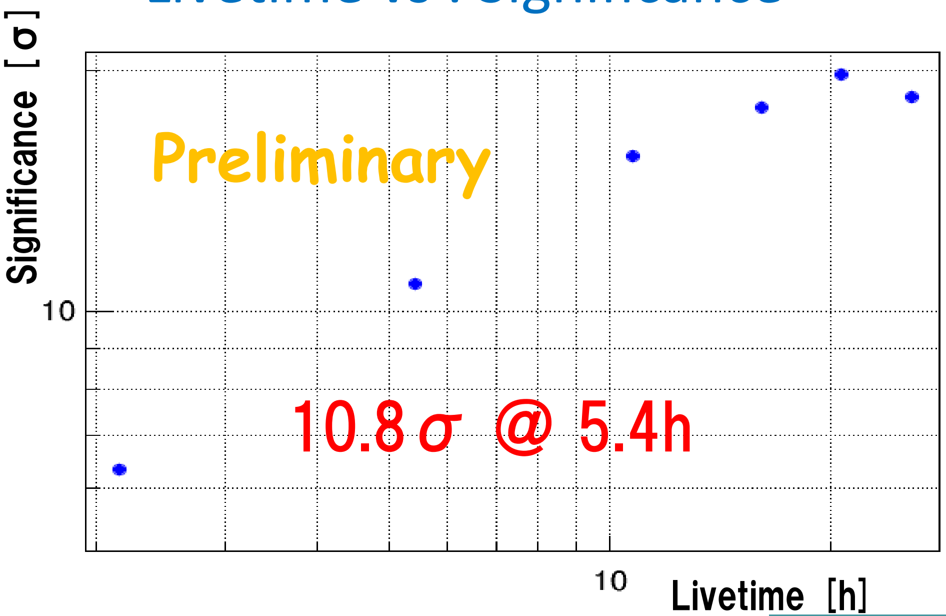


Spectrum after dE/dx



Advanced Compton Image

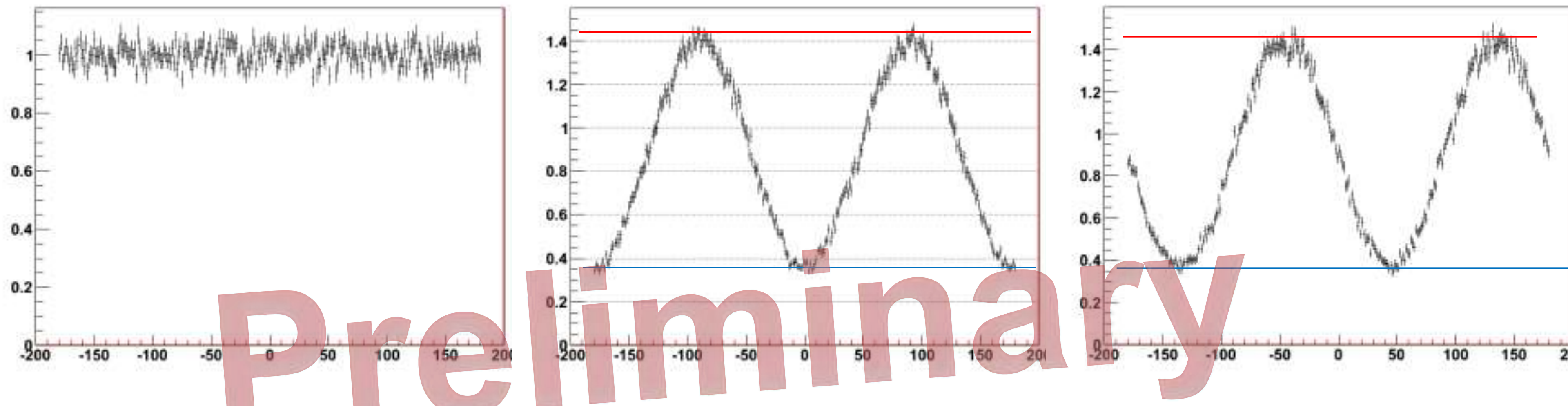
Livetime vs . Significance



Preliminary

Modulation Factor in SMILE-II in Simulation

Preliminary

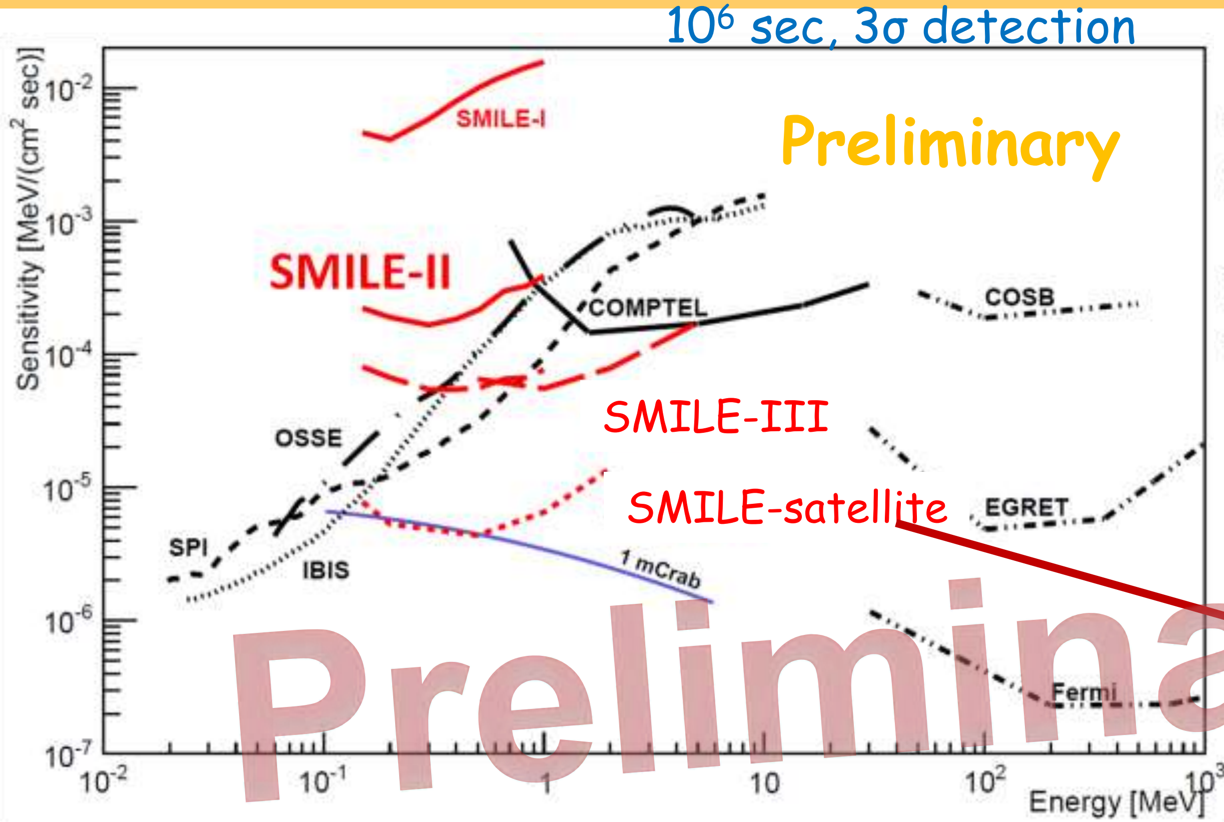


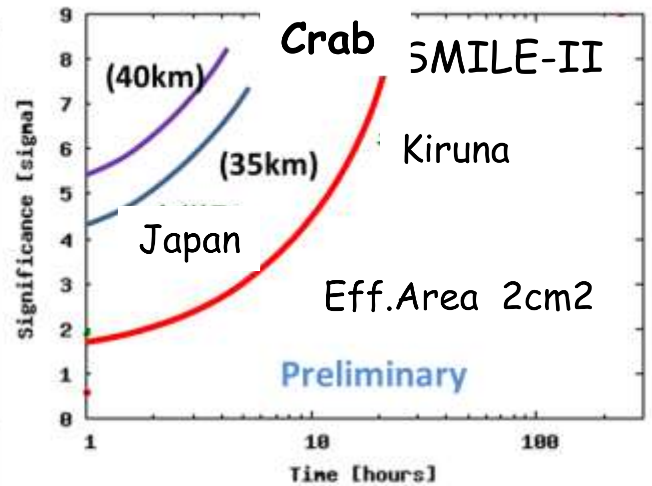
Un-polarized, Cos θ < 0.7   0°, 100%, Cos θ < 0.7   45°, 100%, Cos θ < 0.7

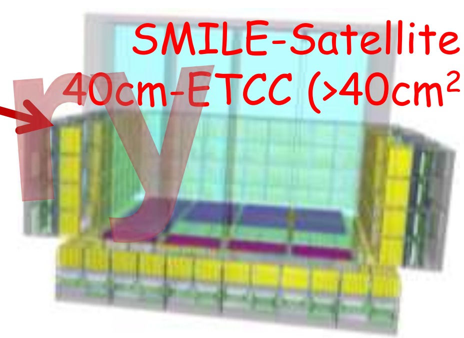
	#Event	Max	Min	MF
Un polarized	5.33e5			
0°, 100%	4.69e5	1.4	0.35	0.60
45°, 100%	4.83e5	1.45	0.35	0.61

MF = (max-min)/(max+min)

New Balloon Exp. (SMILE-II & III)







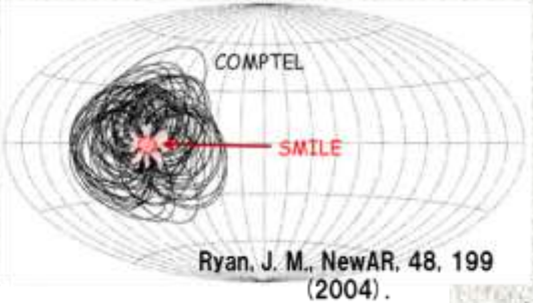
■ SMILE-II (in USA)

- ◆ Collaboration with Goddard
- ◆ 30cmETCC with 1~4cm2
- ◆ Detection Crab ,CygX-1 at >5s
- ◆ Polarization

■ SMILE-Ⅲ (Polar region)

- ➢ upgrade to 10-20cm²
- ➢ Deep Survey for galactic plane

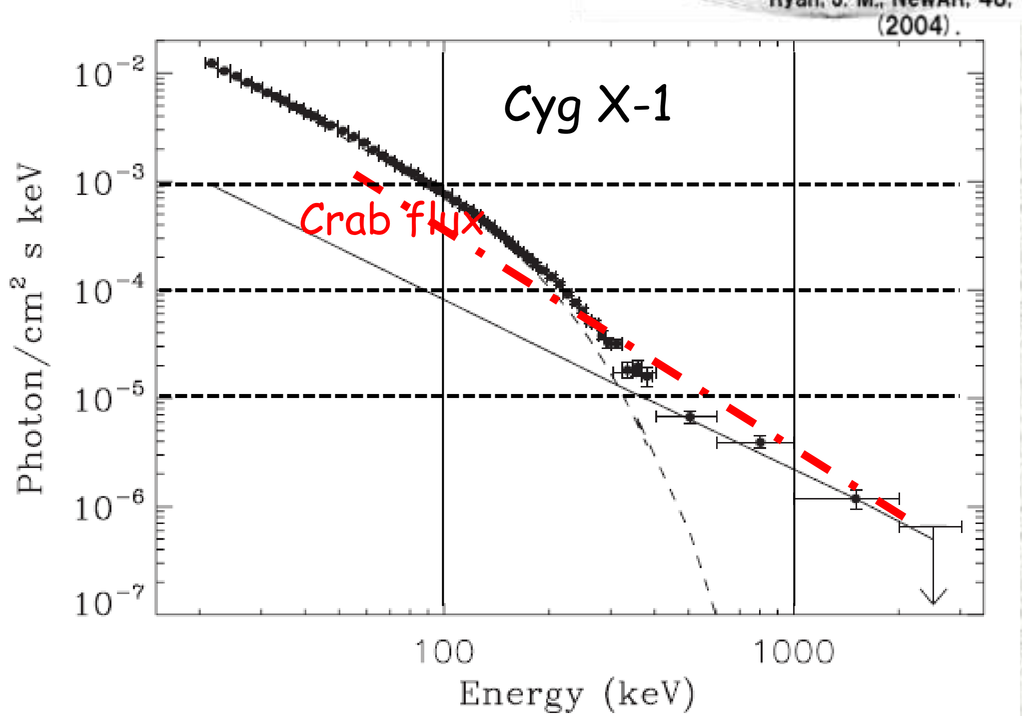
Crab & CygX-1 fluxes (SMILE-II)



Crab polarization above 200keV
(Integral/IBIS)
P=0.46+0.3-0.19
(Integral/SPD)
P=0.4+10-10%

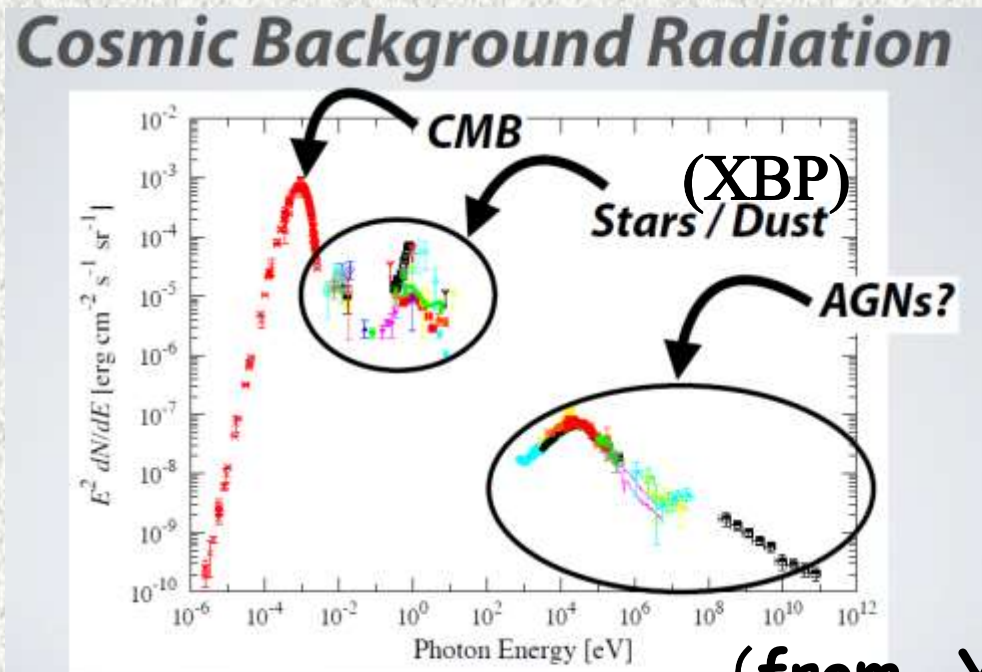
Cyg X-1 above 400keV
P=67+30-30%

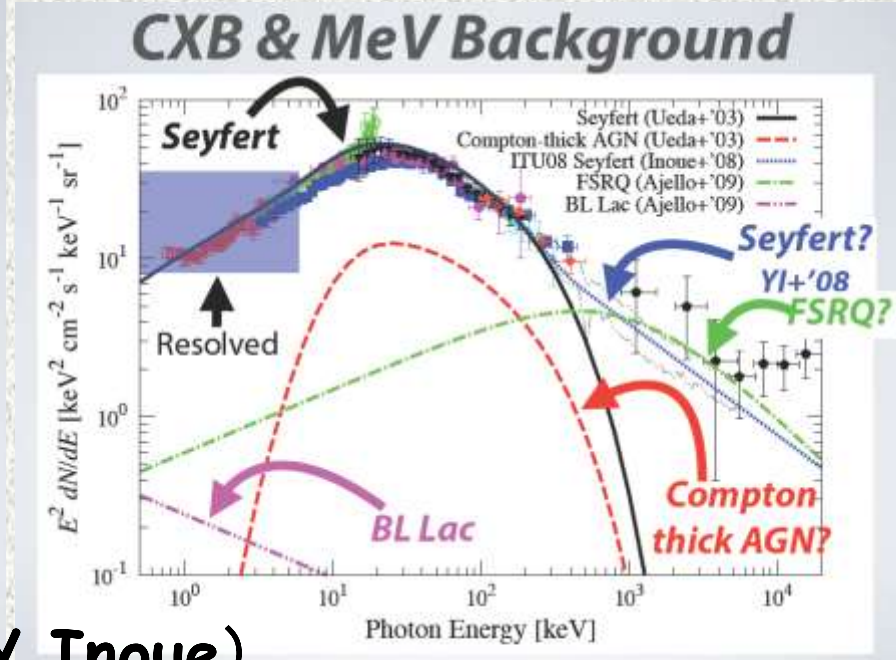
IBIS M=0.3 SPI were not calibrated on the ground as a polarimeter.



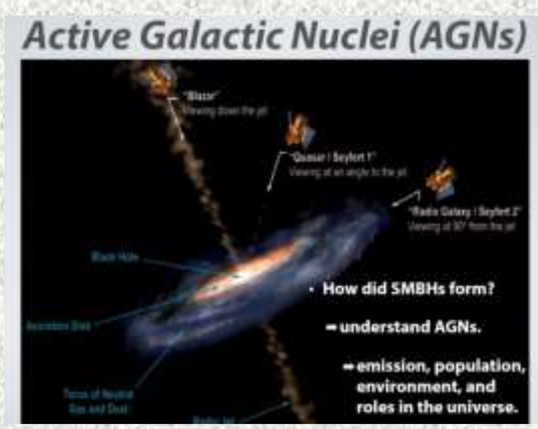
E>100keV, 1cm^2 ETCC 1300 gamma /10hrs from Crab
BG 6500 gamma /10hrs MPD＝28/M % 4cm2 MPD=12/M
10cm^2 28/3.3=8.5/M %
M:modulation factor M > 0.6 expected for ETCC (Low background compared to IBIS due to real imaging)

SMILE-III Test for AGN Evolution





(from Y.Inoue)

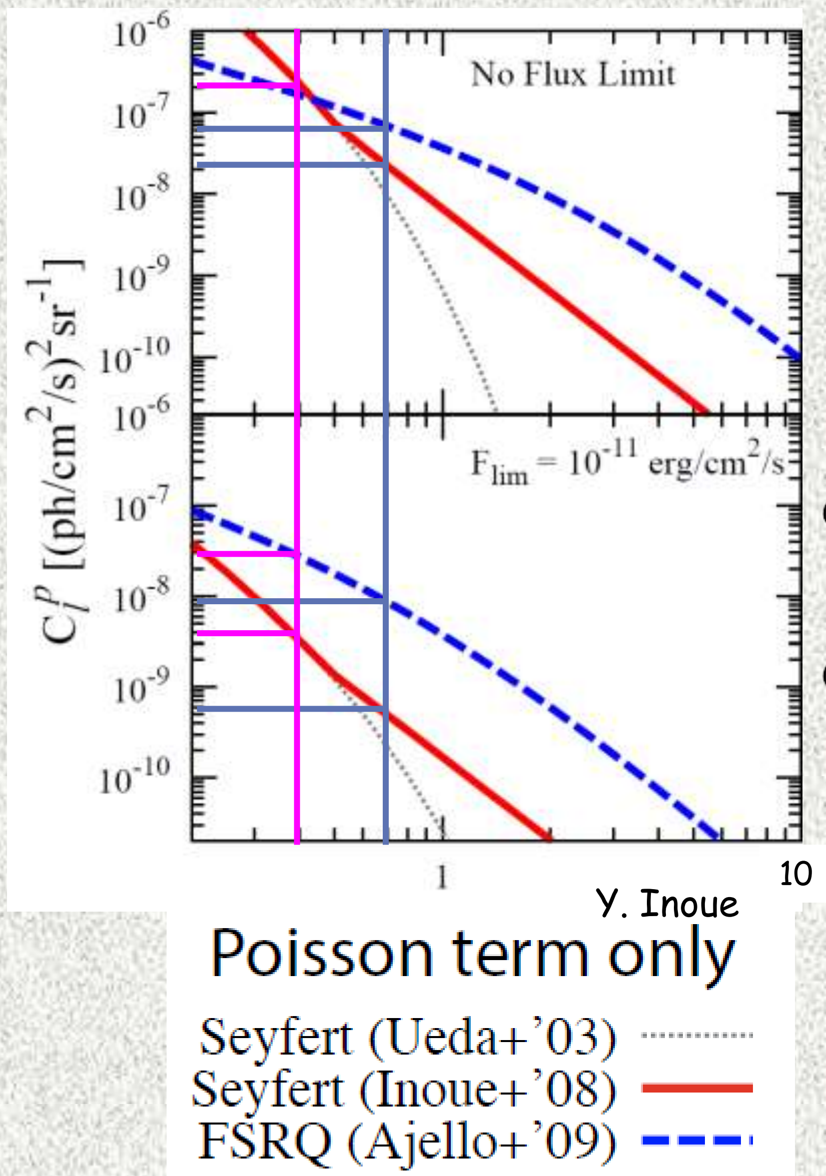


(Ψ.Ιvoυε氏の資料より)

Precise measurement of MeV CMB

- 0.1-10MeV Dominant contribution is unclear
  Seyfert or FSRQ?
- SMILE-II Polar flight
- Due to its large FoV (4str) , background rejection, and point-like gamma-ray direction measure, precise measurement of the map of MeV CMB will be possible.

Main Topics of SMILE-II



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

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

For >3σ detection of Anistoropy

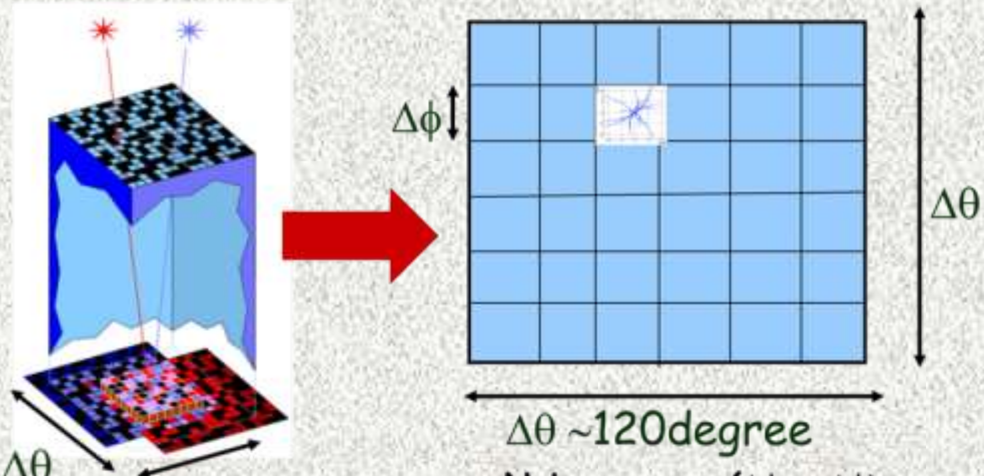
$$\frac{C_l{}^S}{\langle I\rangle^2} > \frac{3\alpha}{1-3\alpha}\frac{4\pi f}{N\,W_l{}^2} \equiv \frac{Q_l}{N}$$

@400±50keV
$\langle I\rangle = 5\times10^{-3}$ ph/cm^2/s/sr
$C_P = 10^{-8}$ (ph/cm^2/s)^2/sr
⇒ $N > 2\times10^{4\sim5}$

@700±50keV
$\langle I\rangle = 10^{-3}$ ph/cm^2/s/sr
$C_P = 10^{-9\sim-8}$ (ph/cm^2/s)^2/sr
⇒ $N > 10^{4\sim5}$

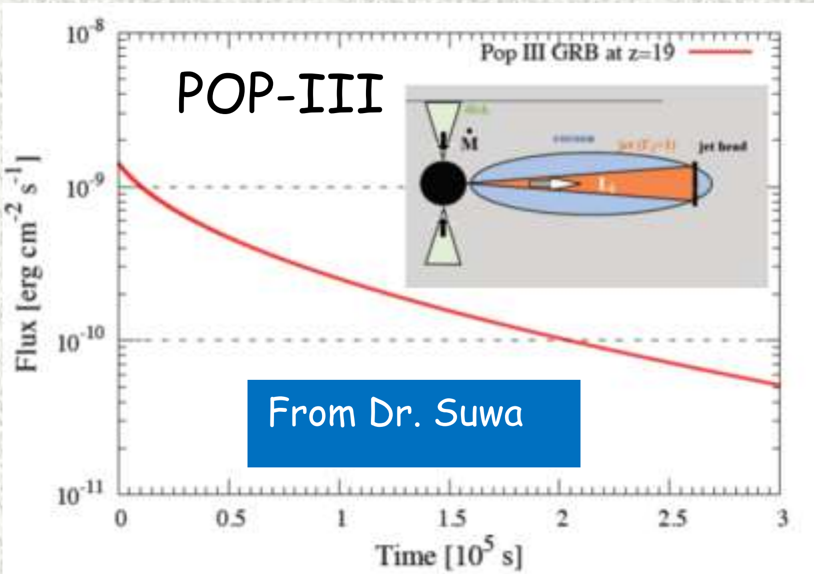
Polar Flight (~10^6 sec) ⇒ >10^6 events
⇒ precise spectrum of CMB Anisotropy
⇒ >10^5 events is enough for separation of Seyfert and FSRQ with 5σ

GRB Cosmology

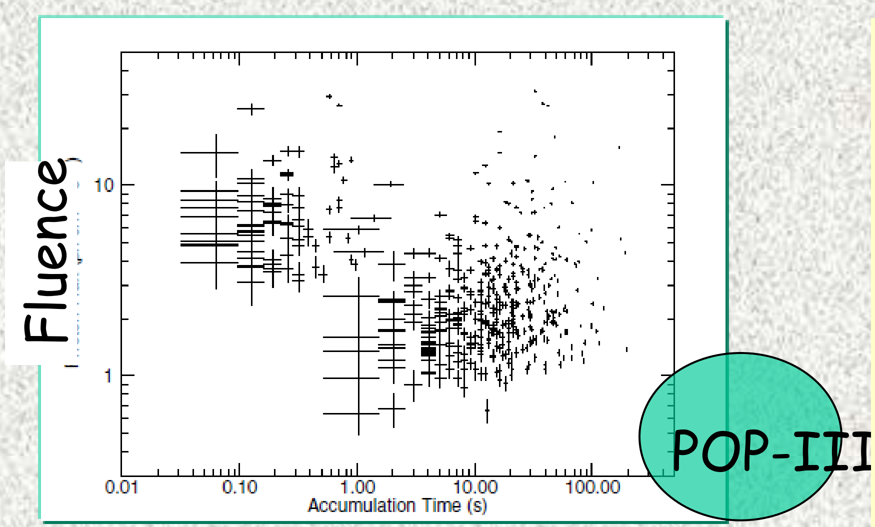


Noise area = Δθ x Δθ

Noise area = (Δφ x Δφ)
Δφ/Δθ=10 Noise reduction -> 1/100



Expected γ in S-ETCC for GRB @z=20 & $E_{iso}=10^{52}$ erg -> **>several x100 ph**.



40cm-cube ETCC

- 10^{-8}erg/cm^{2}s 1γ(>100keV)@10cm^2
  for GRB of 10^{-9}erg/cm^{2}s ($900M_{solar}$)
  Eff.Area 50cm^2
- 10^3s 500γ B.G. 40γ in 4x4° S/N ~20σ
- 10^5s 5×10^4γ B.G> 4×10^3γ S/N =680σ
- 5σ detection during 10^5s -> ~300γ
  <100Msolar Super long bursts OK!

GRB Polarization observational Situation

1. GRB 021206: 80+-20% (Coburn & Boggs 03)
   but, claim from Rutledge & Fox 2004; Wigger et al. 04;)
2. . GRB 930131, GRB 960924: > 30% (Willis et al. 05)
3. GRB 041219a: 96+-40% (Kalemci et al. 07; McGlynn et al. 07)]
4. GAPS

Yonetoku et al.

GRB	Polarization Degree (%)	Duration T90 (sec)	Incident Angle (deg)	E_p (keV)	fluence (erg cm^{-2})	flux (photon cm^{-2} s^{-1})
100826	27 ± 11	100	20	606^{+134}_{-109}	2.94×10^{-4}	9.03
110721	84^{+16}_{-28}	11	30	$375.5^{+26.5}_{-23.6}$	3.43×10^{-5}	6.71
110301	70 ± 22	7	48	$106.80^{+1.85}_{-1.75}$	3.35×10^{-5}	75.59
110825	< 47	12	29	$233.6^{+21.9}_{-19.9}$	5.06×10^{-5}	6.16
110625	< 56	27	41	190^{+17}_{-14}	6.09×10^{-5}	8.21
100715	< 83	30	19	-	-	-
101014	< 71	30	54	$181.40^{+5.66}_{-5.44}$	1.88×10^{-4}	3.74

GRB detection in SMILE-III

- ETCC M＞0.6 GRB signal >>BG FoV 3str
- SMILE- 30cmETCC Eff. Area $20cm^2$@200 keV

GRB 10^{-6}erg/cm^2s ~160 photon/s T^{90}=40s 160x40s ~6000

MDP = 5.5/M % (3σ) (M>0.6) 10% polarization OK !

For, 30% polarization -> 10^{-5}erg/cm^2s^- GRB

a few GRBs (10^{-6}erg/cm^2s) ~10 (10^{-5}erg/cm^2s) with one-month

- **Satellite ETCC~100cm^2 (Sensitivity~1mCrab@10^6sec)**

10^{-7}erg/cm^2s GRB MDP =5.5/M % (>100 GRB/year)

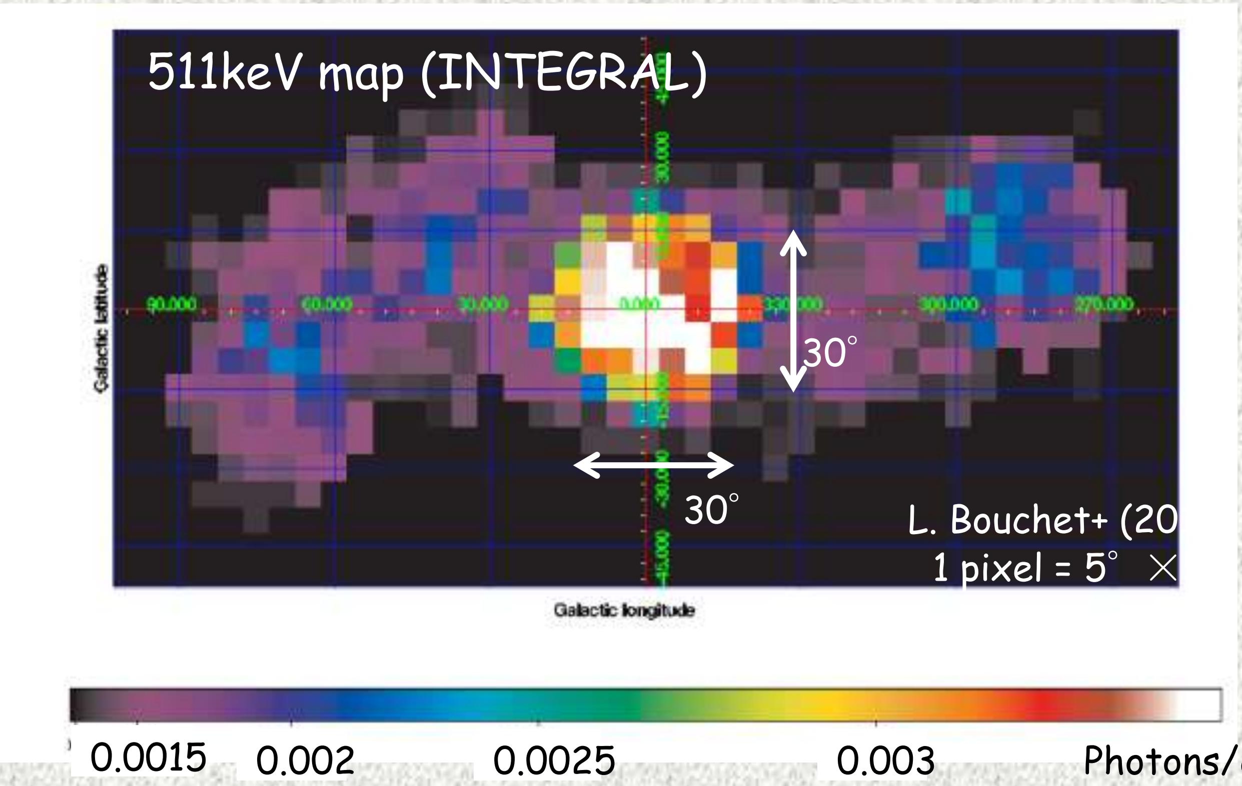
10^{-6}erg/cm^2s GRB MPD= 3/M % (several 10 GRB/year)

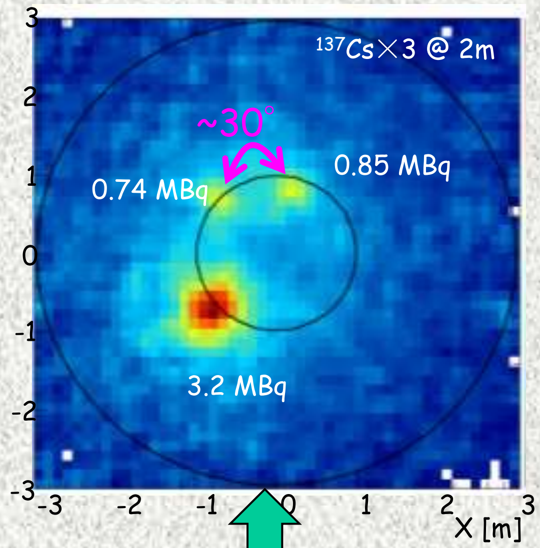
GRBs detected with *Fermi*-GBM Nava et al. (2011) ($10cm^2$) of SMILE-II expected

GRB	z	T90 [s]	Epeak [keV]	-α	-β	Fluence (8-1000 keV) [erg/cm2]	detects (0.15-1 MeV) [ph.]	bg. [ph.]	sigma
GRB090618	0.54	155	155.5	1.26	2.5	2.7×10^{-4}	4.3×10^{3}	7	~70
GRB090717A	-	70	120	0.88	2.33	4.5×10^{-7}	8	3	~2
GRB090528	-	102	172	1.1	2.3	4.65×10^{-5}	9.4×10^{2}	4	~30
090117640	-	21	25	0.4	2.5	1.8×10^{-6}	6	0.9	~2

Galactic lines of SMILE-III

511keV, 1804keV(Al-26), 4MeV (C-12)



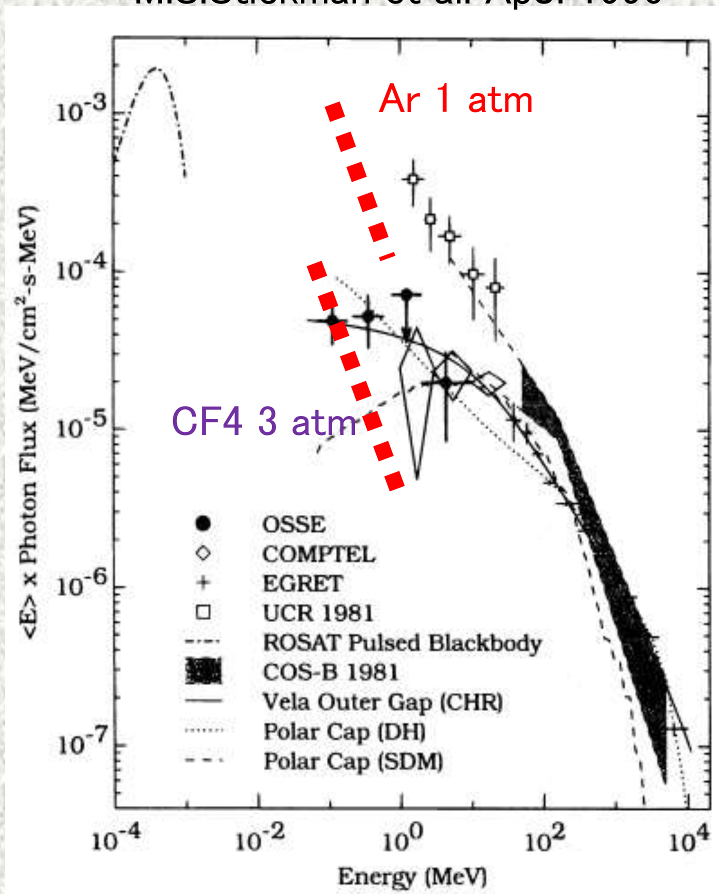


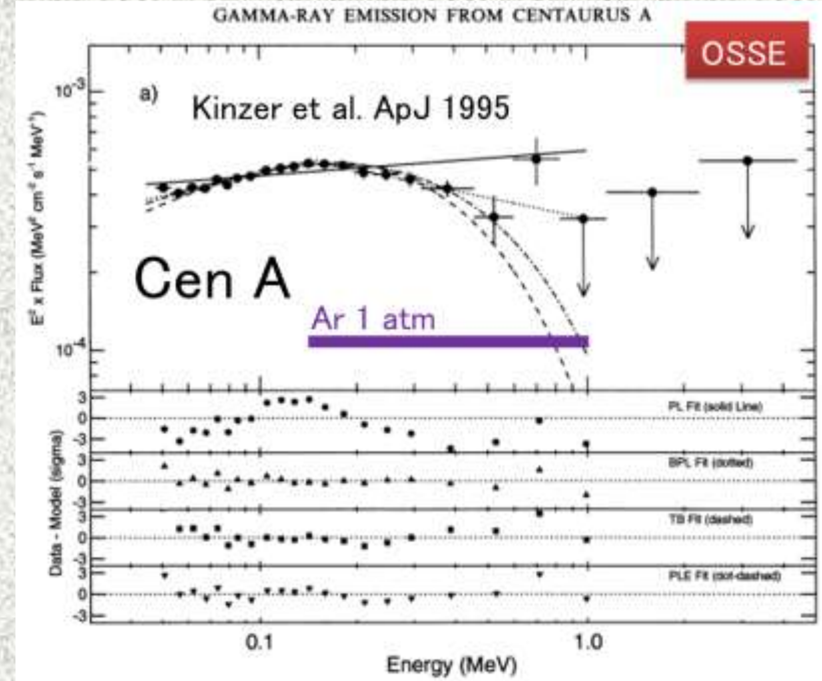
Simple back projection image
More fine imaging is obtained by using MLEM

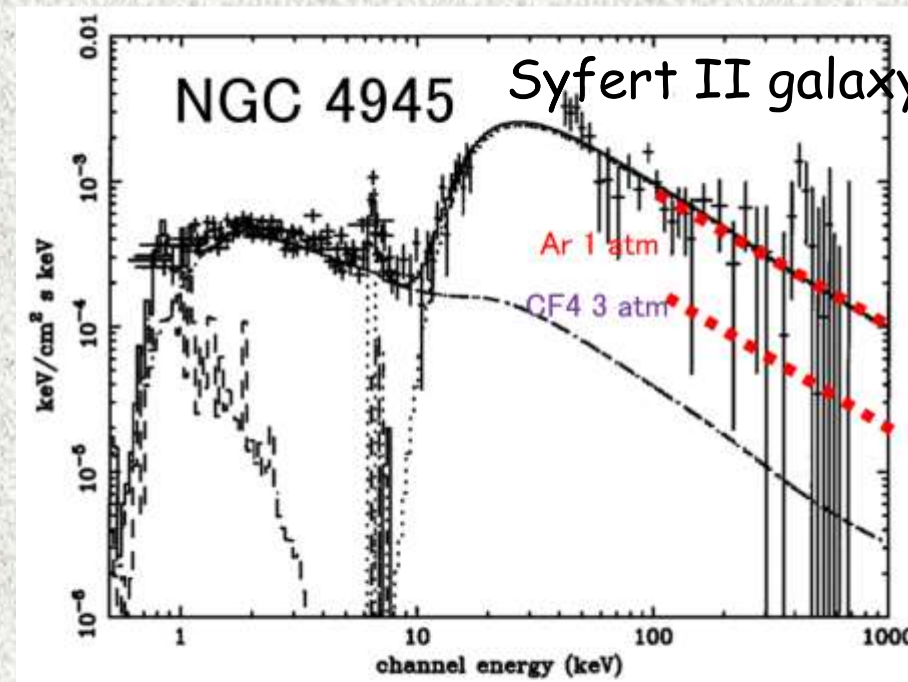
Polar Flight (SMILE-II 10 cm^2, 10^6 sec) ⇒ > 10^3~10^4 event/pixel
More detailed map of 511keV due to point-like direction of gamma rays
In addition, survey for galactic plane ⇒ possible detection of new sources due to low background and point-like directional imaging of ETCC

Vela Pulsar

M.S.Stickman et al. ApJ. 1996







Summary

- ETCC have obtained both strong background rejection abilities and high contrast imaging by direction of recoil electron.
- ETCC has nearly one order better sensitivity than usual CC with similar effective area.
- ETCC also is a good polarimeter with MF>0.6 in sub-MeV region.
- SMILE-II having 1-4cm^2 @0.3MeV effective area will be planned in USA in 2014, 15 for the observation of Crab and Cyg.X-1 with one-day flight. (>5shigma detection, and Polarization)
- SMILE-II will be improved to SMIEL-III having > 10cm^2 (several times better sensitivity of COMPTEL) in 2016.
- In the long duration flight around the Polar cap, SMILE-III will measure ~10 Celestial objects, MeV-Cosmic Background and several GRBs with polarization.