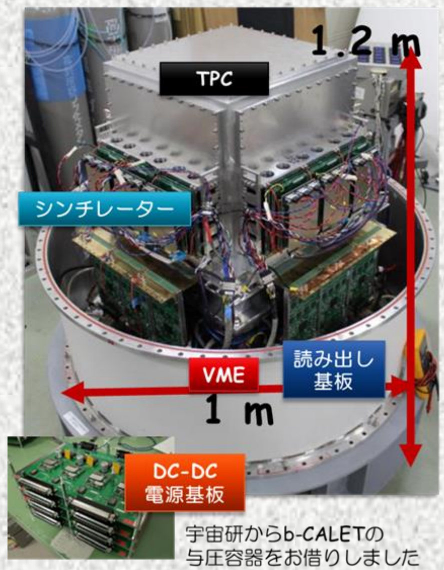
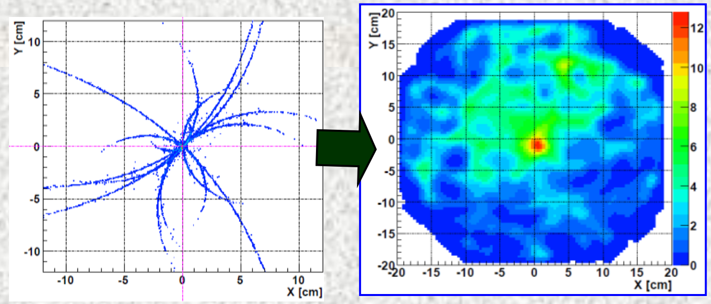
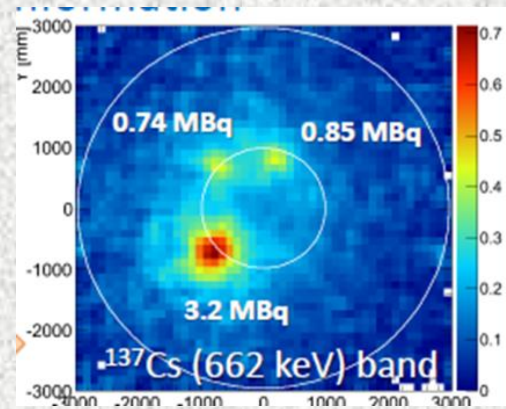
Imaging detection for GRBs & SNe with high sensitivity and good polarimetry by Electron Tracking Compton camera



SMILE-II





CONTENS

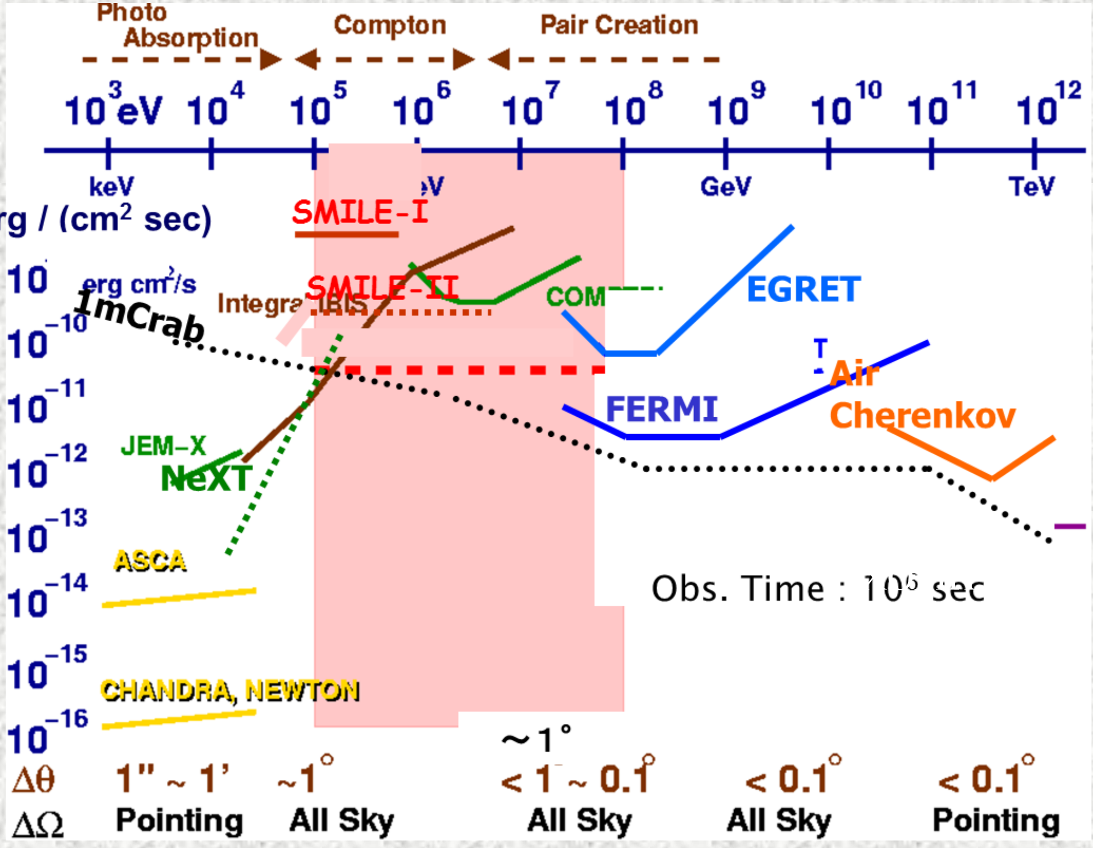
1. Problem of MeV gamma ray observation
2. Electron Tracking Compton Camera
3. Performance of SMILE (+Polarization measure)
4. Expected MeV Astrophysics in GRB, SNe & AGNs
5. Summary

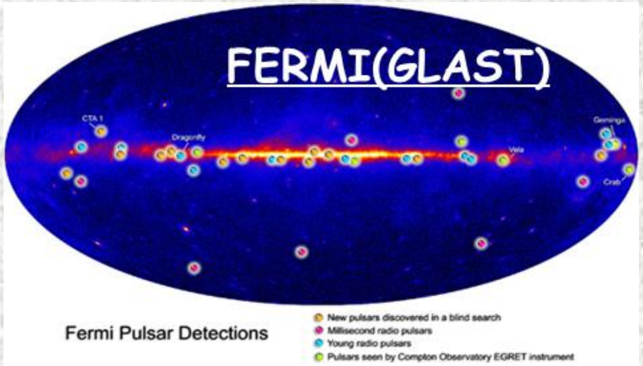
T.Tanimori, H.Kubo, K.Miuchi[2], J.D.Parker, S.Komura, S.Iwaki, T.Sawano, K.Nakamura1, S.Nakamura, Y.Matsuoka, T.Mizumoto[3], Y.Mizumura, M.Oda. S.Sonoda, A.Takada, D.Tomono,

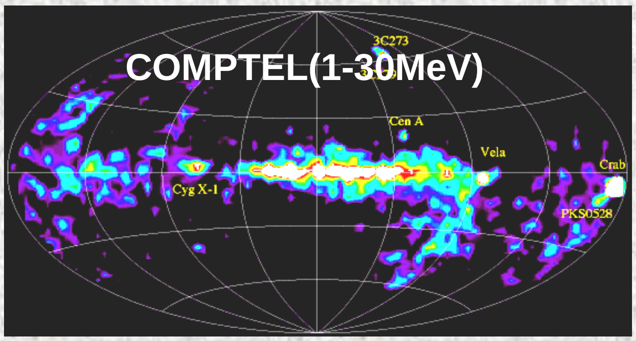
1) Department of Physics, Kyoto University, Kyoto, Japan,
2) Department of Physics, Kobe University, Japan,
3)Research Instit. for Sustainable Humanosphere, Kyoto Univ.

08/11/2013 SN-GRB Workshop

MeV Astronomy Sky survey



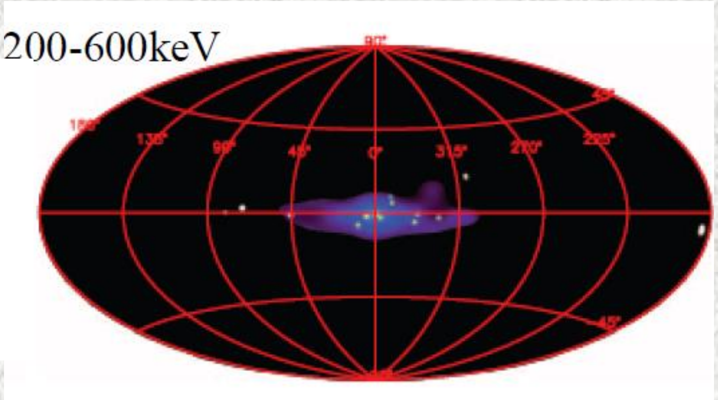




SN, GRB-> 1-150keV

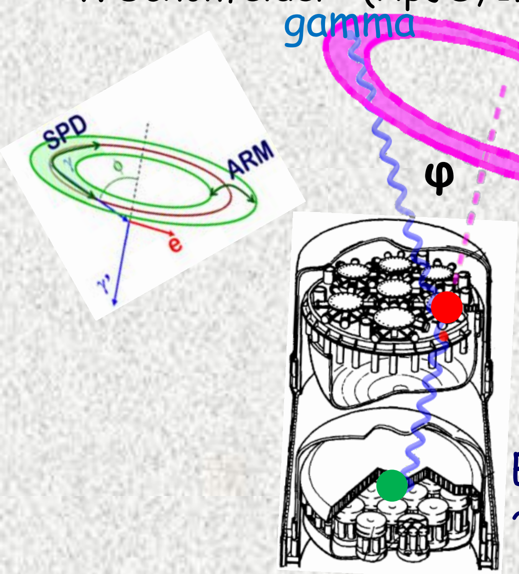
INTEGRAL

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

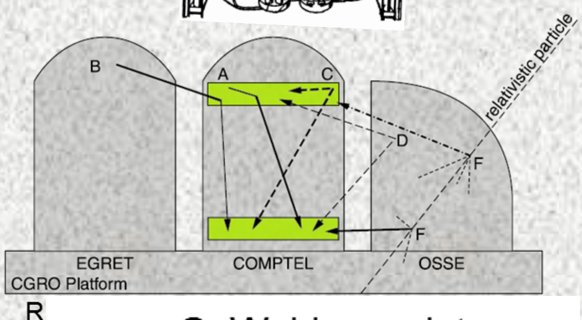


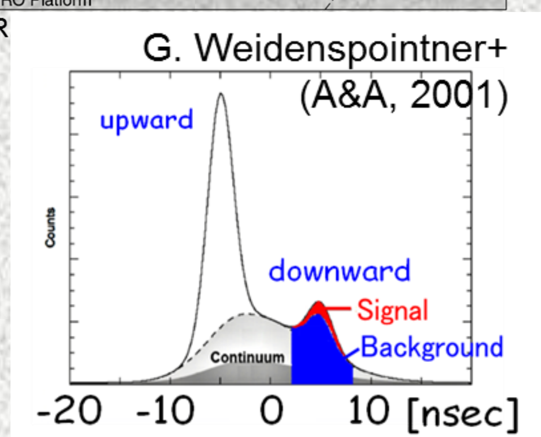
Difficulty of MeV gamma-ray Observation

V. Schönfelder+ (ApJS, 1993)



Effective Area ~13cm^2@1MeV

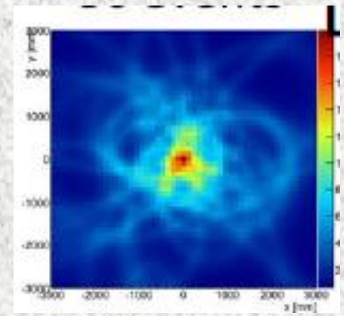


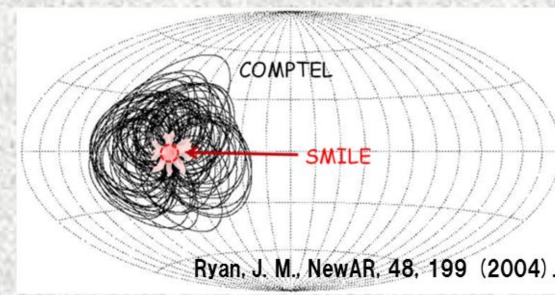


Main reasons of Difficulty

1. Huge BG of gammas & fast neutrons
2. Obscurity of imaging by circular direction

If no BG, severalx10cm^2 => a few mCrab@10^{6}sec





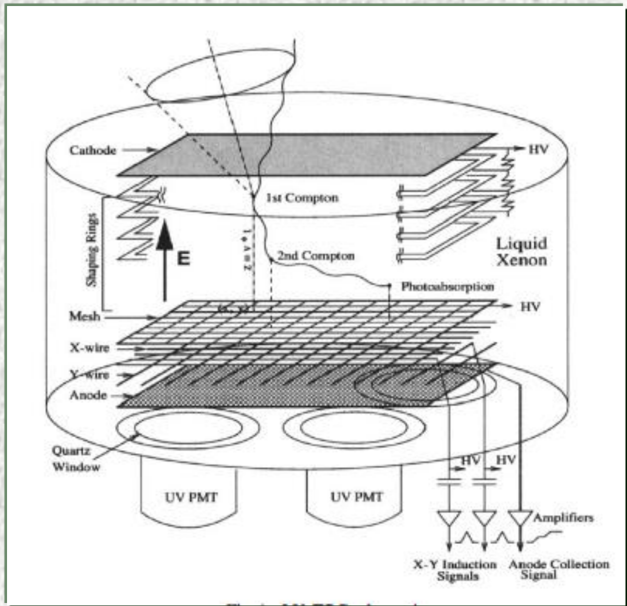
V.Schönfelder (2004) Suggestion

Low background is most important for next MeV detector

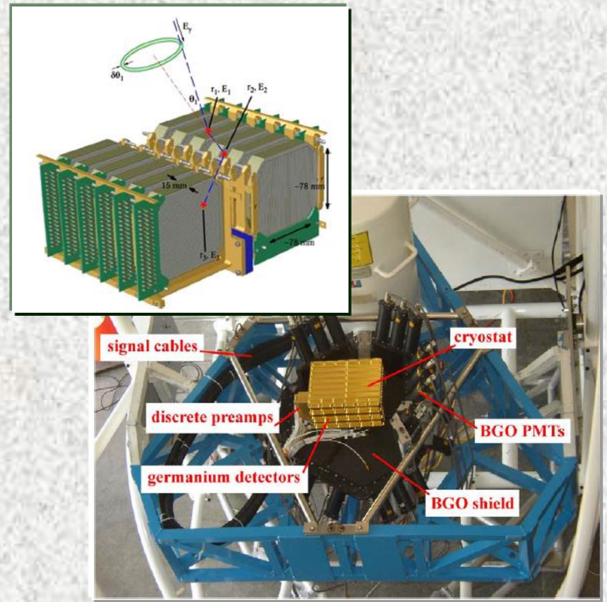
1. Good angular res.(ARM) = good Energy res.
2. Redundancies (TOF, Kinematics, dE/dx)
3. Measurement of electron direction (SPD)!
4. Low-z material and light weight
5. Short timing gate

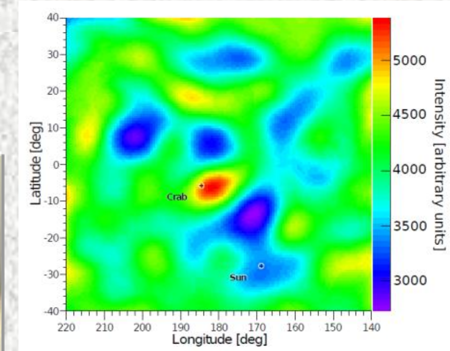
Advanced Compton Camera

. Aprile et al(2004)



M. S. Bandstra et al. ApJ 2011





Liquid Xe TPC 2000

- No VETO
- 0.1-10MeV Expected eff.A～20cm^2
- No. detection for Crab

priority: **Large effective Area large**

- Crab 4σ (8hrs) with MLEM meth.
- Ge detector with BGO VETO
- FoV 3str ,ΔARM 7.3^o (FWHM)
- 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.

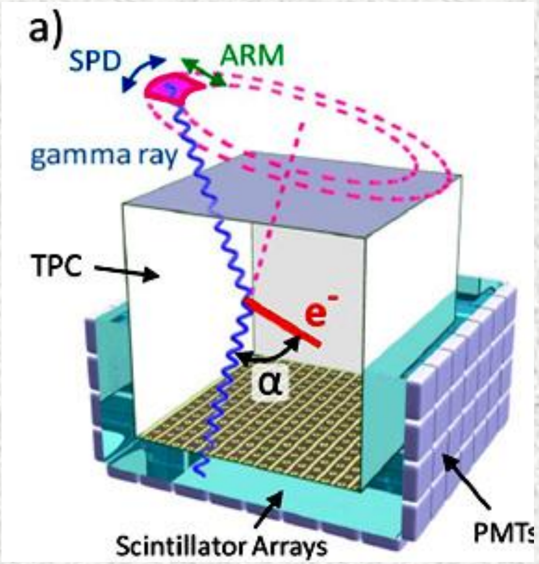
Electron Tracking Compton Camera(ETCC)

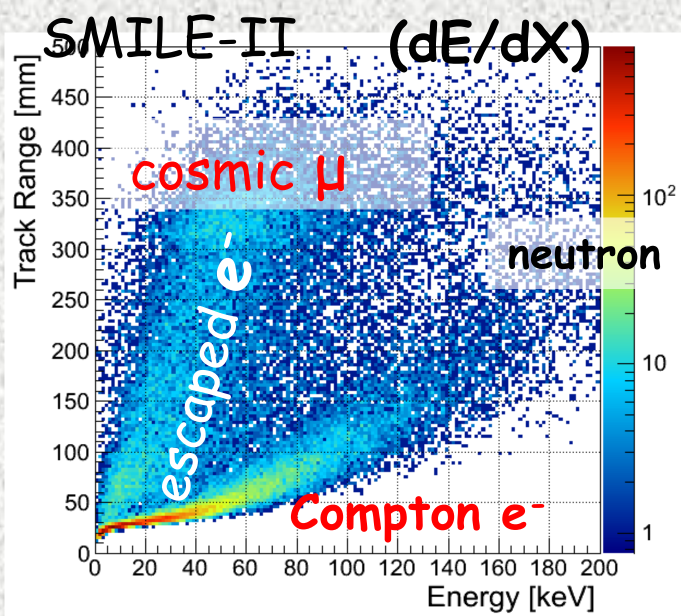
Goal: High sensitivity for Continuum gammas
with > ~50 better than COMPTEL

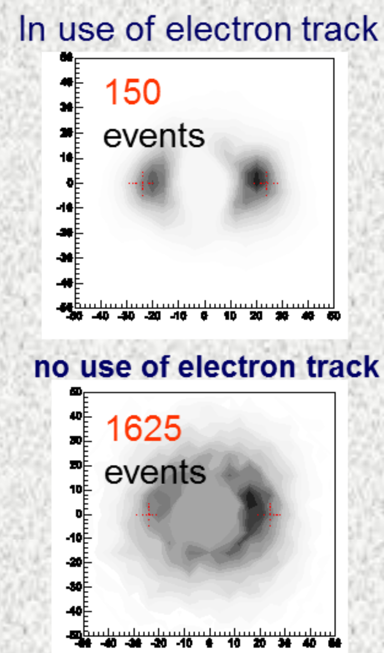
Strong BG rejection & clear imaging are needed

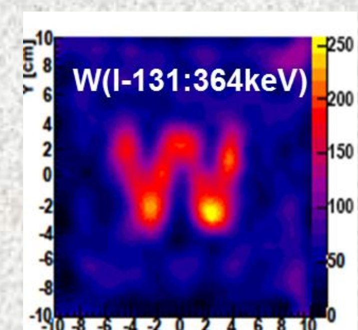
1. Electron tracking for imaging,
   Kinematics(α)+dE/dx (multi redundancies)
2. Large FoV. ~3str & No Veto counter

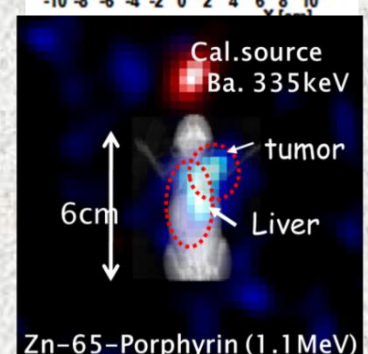
! 50cm-cubic 3atm CF4 gas ~110cm^2@1MeV





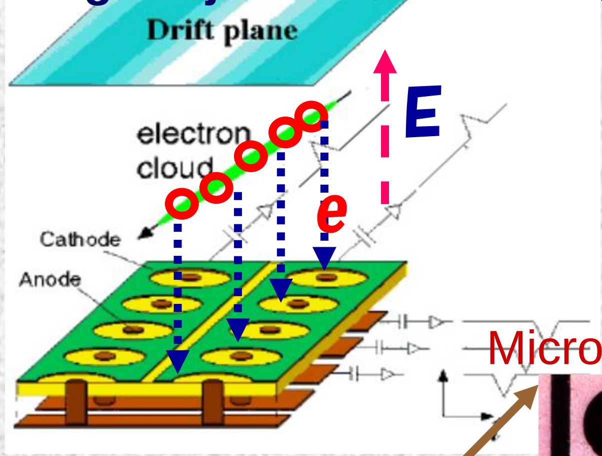




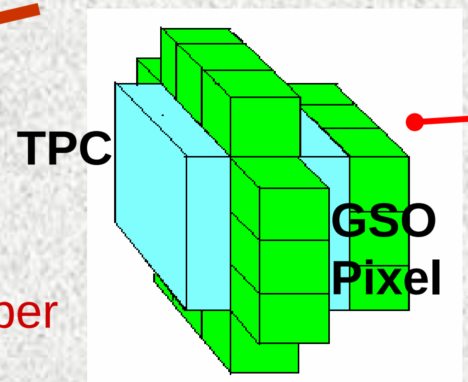


10cm-cube μ-TPC & ETCC

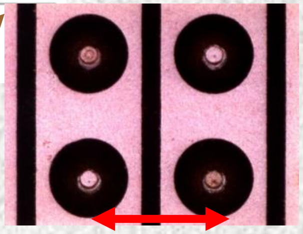
Timing Projection Chamber (TPC)



GSO:Crystal

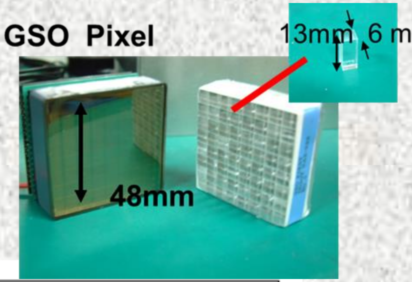


μ−PIC
Micro Pixel Chamber

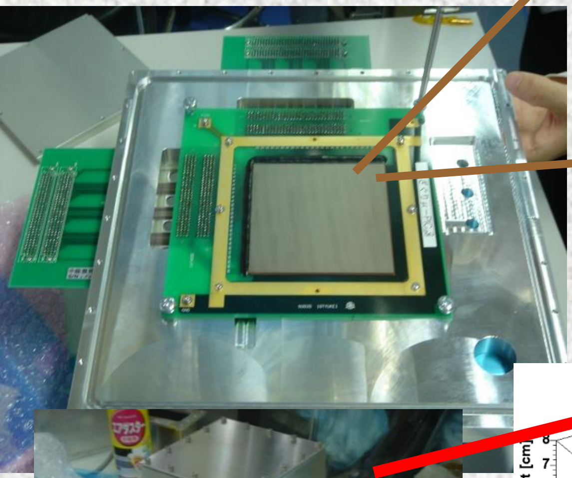


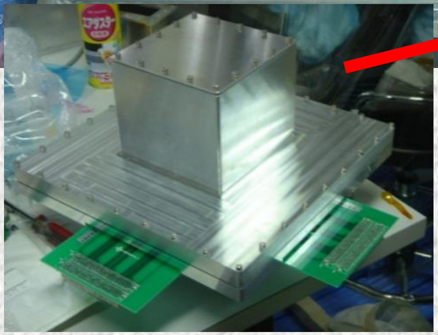
400μm

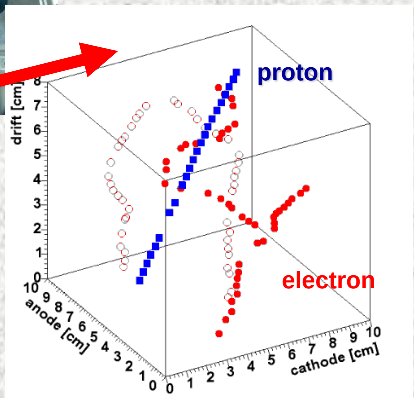
GSO Pixel

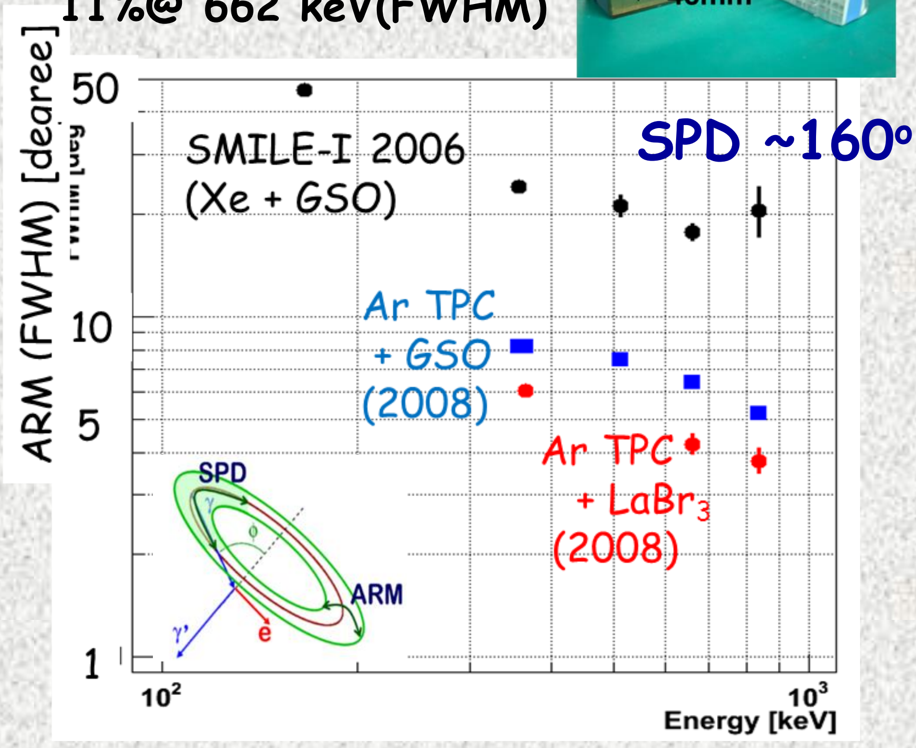


11%@ 662 keV(FWHM)

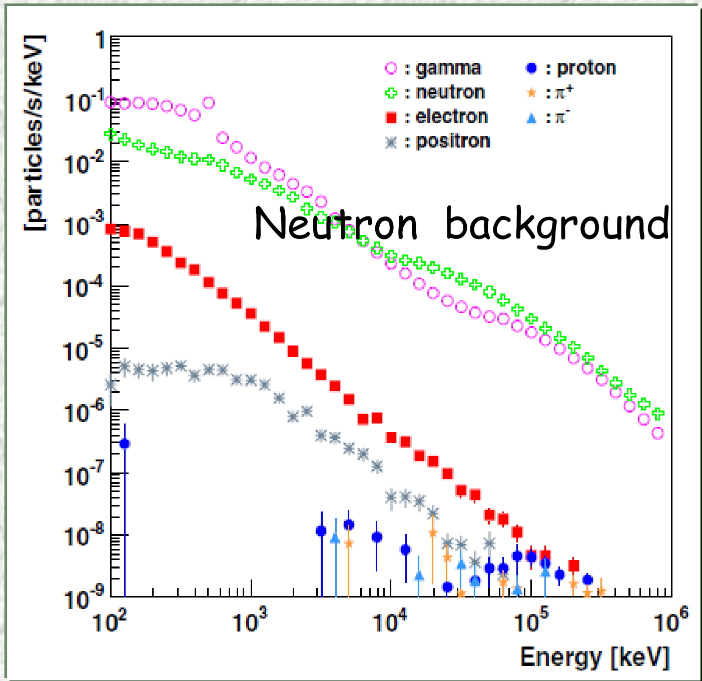




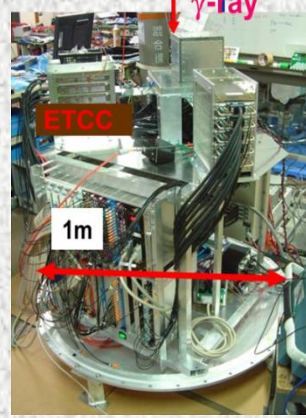




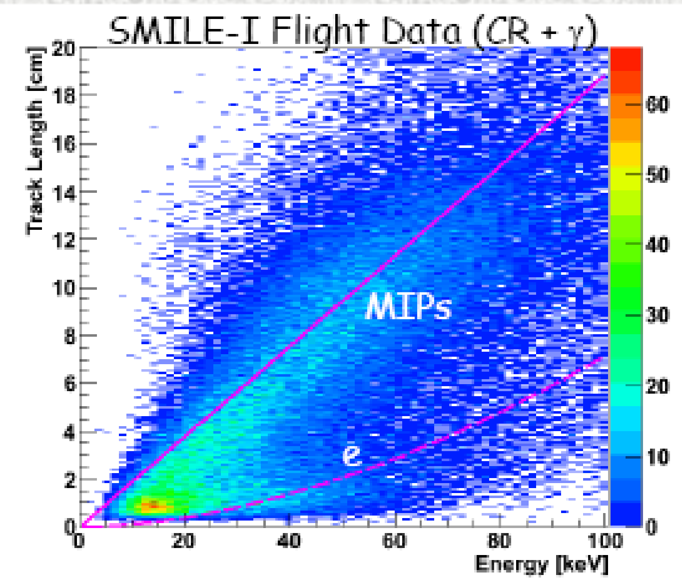
Sub-MeV γ-ray Imaging Loaded-on-balloon Exp. (SMILE-I)

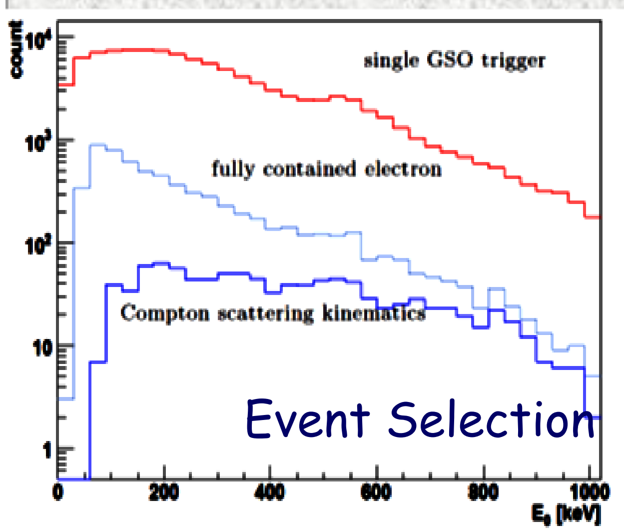


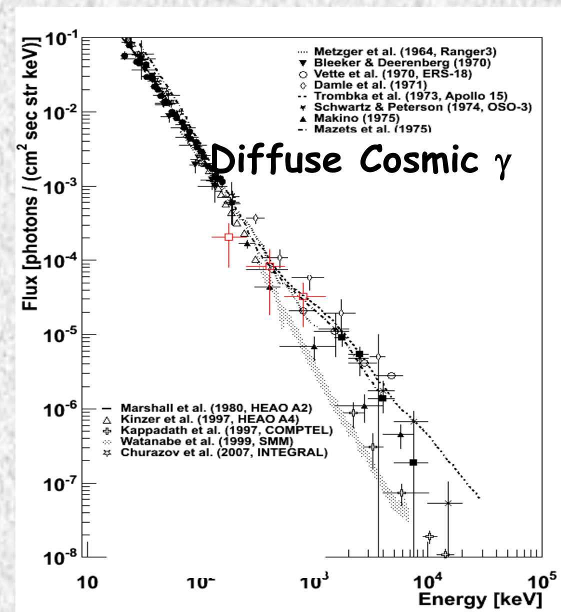
Test flight using 10cm cube ETCC to measure
Diffuse Cosmic and
Atmospheric gamma rays in 0.1-1MeV
3hours observation @35km



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

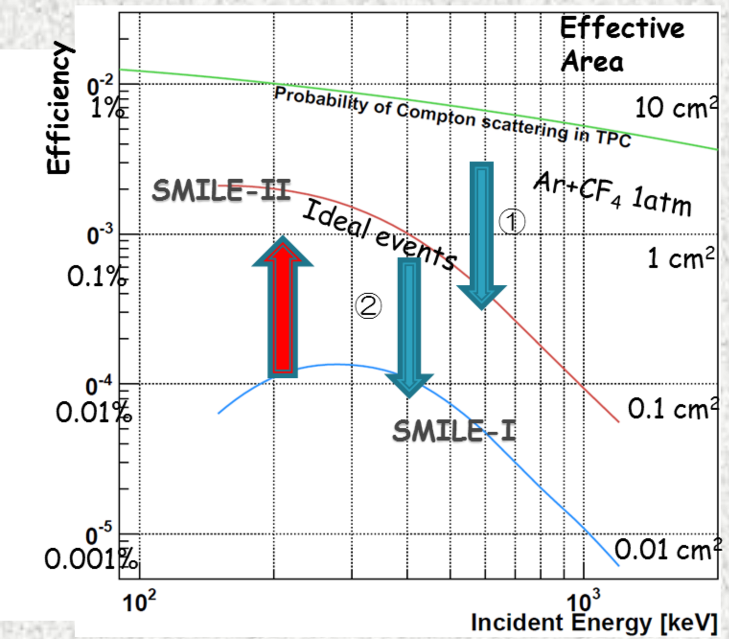






Takda et al.ApJ (2011)

Improvement of SMILE-II



Crab Observation for 10^4s with 5σ detection

From SMILE-I,
Effective area 1 cm^2 ΔARM 10°

But SMILE-I= : 1mm^2 ->x100 Improvement

① Physical process

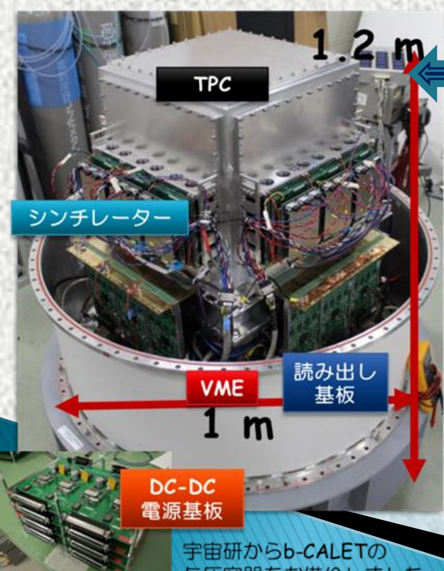
- Recoil e stopping in TPC
- Scattered gamma absorbing

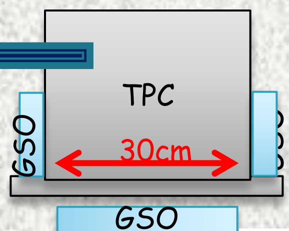
②Reconstruction Inefficiency; ~10% in SMILE-I

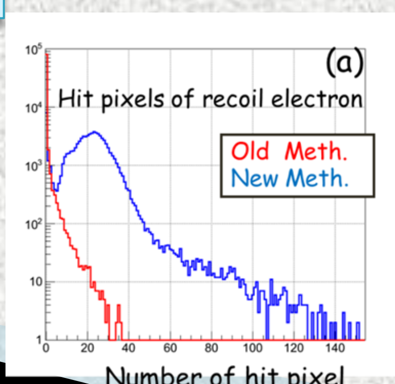
If Recont. Eff. -> 100% SMILE-II

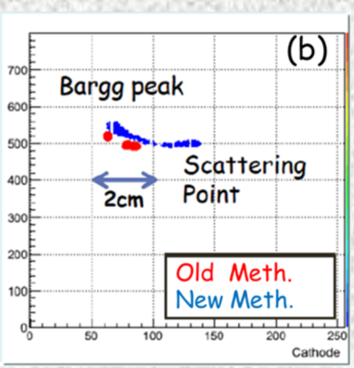
(30 cm)^3 TPC x 20 times of SMILE-I

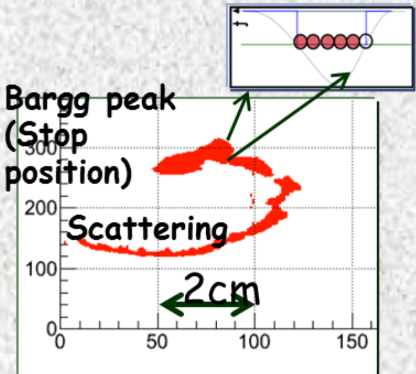
Reconst. Eff. ⇒ X 10 Angular Res. 20°=>5.3°



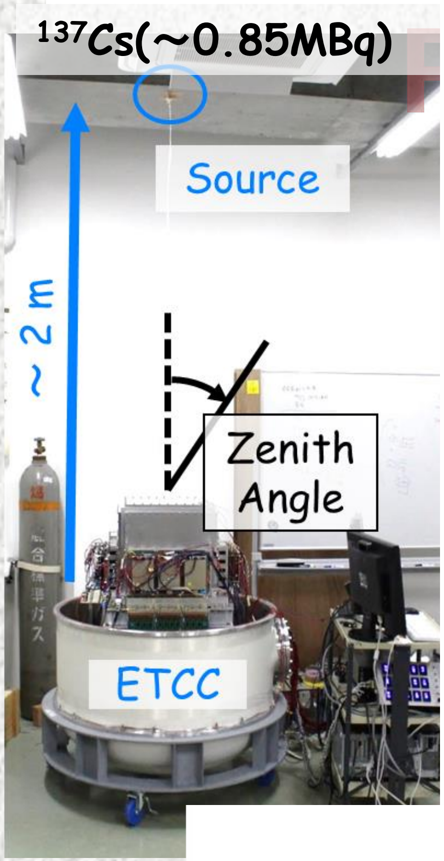


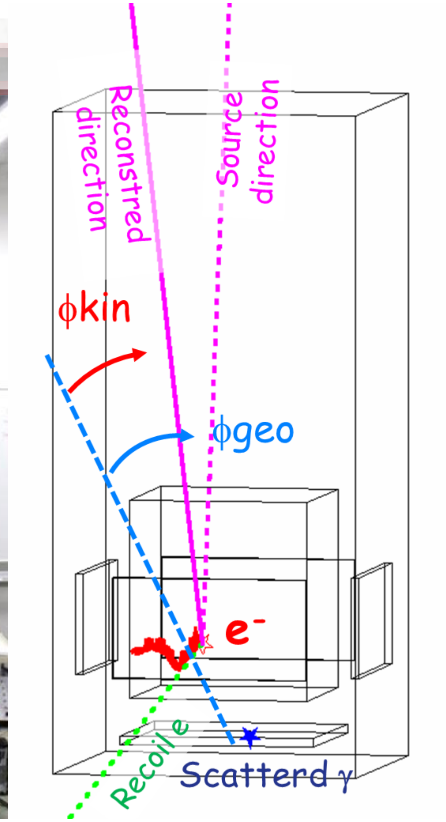




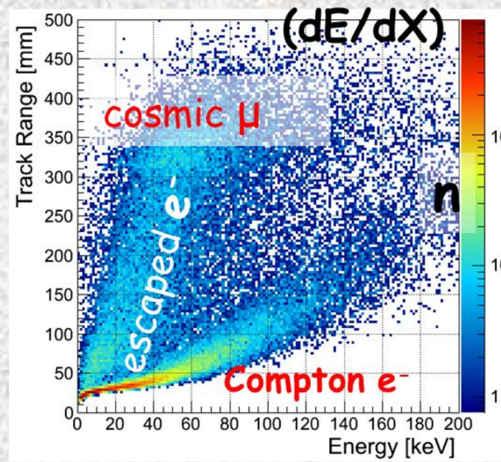


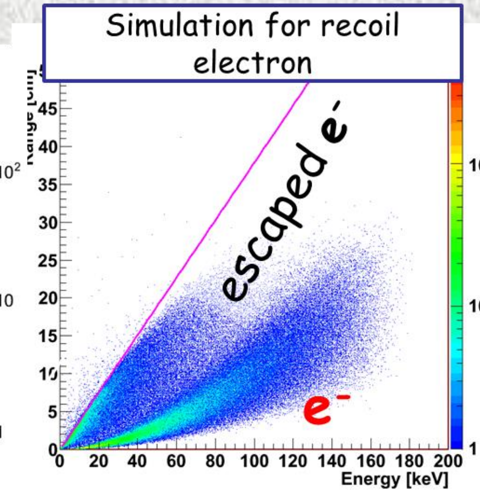
Imaging Test in 30cm ETCC



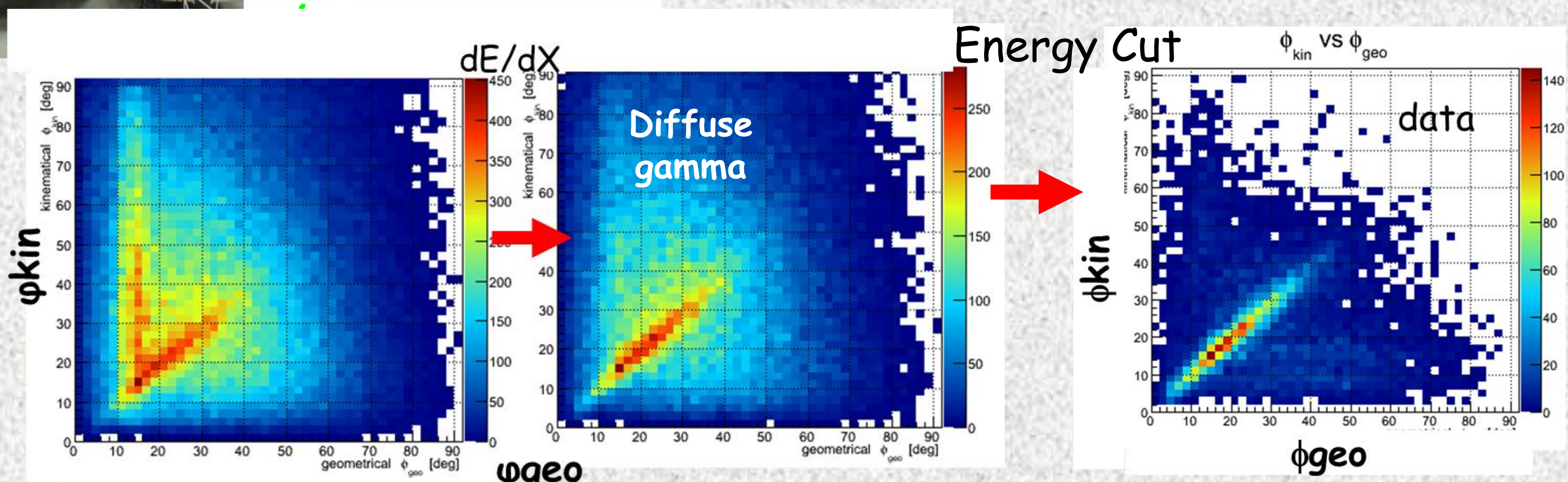


Noise reduction by Energy loss rate dE/dx



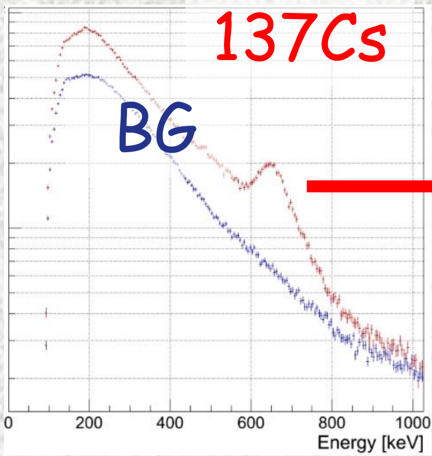


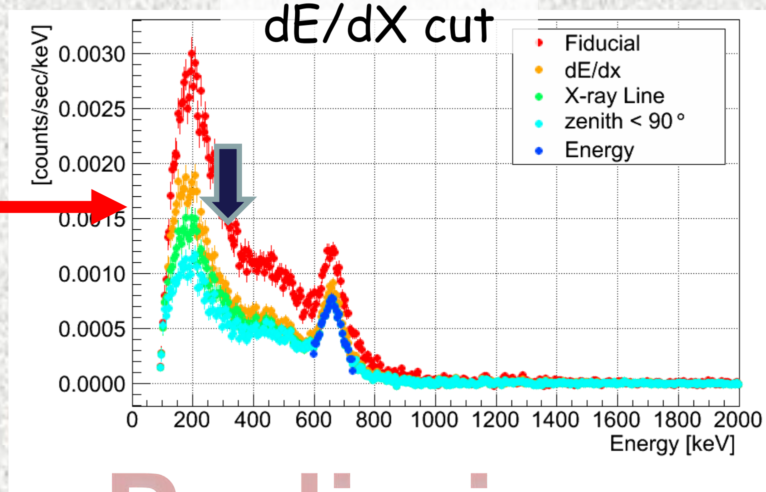
⇒ Continuum fully gamma events selected by dE/dx cut



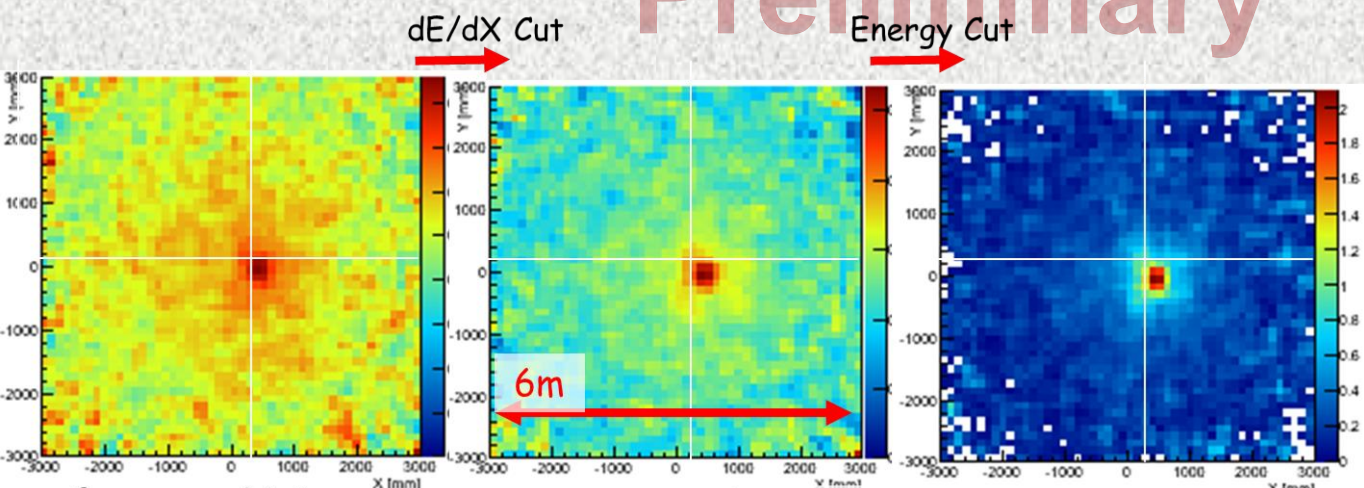
Performance in 30cm-cube ETCC

^{137}Cs(~0.85MBq) 2m





Preliminary

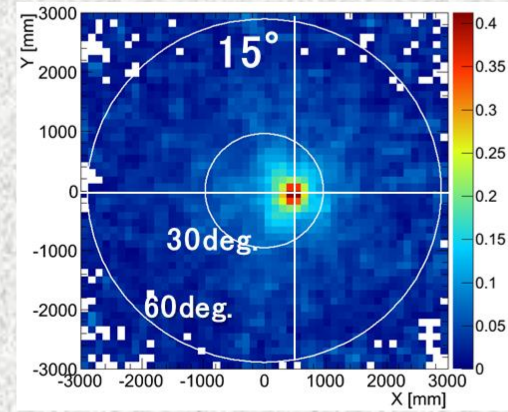


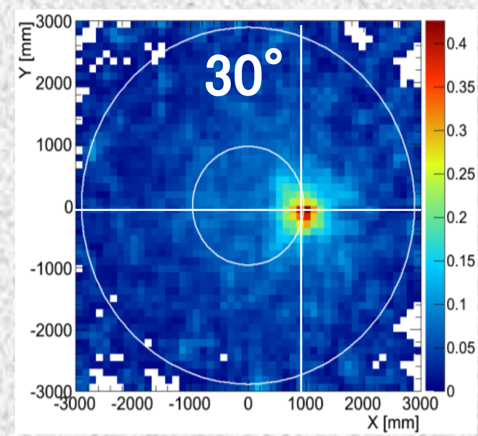
Gamma + Noise

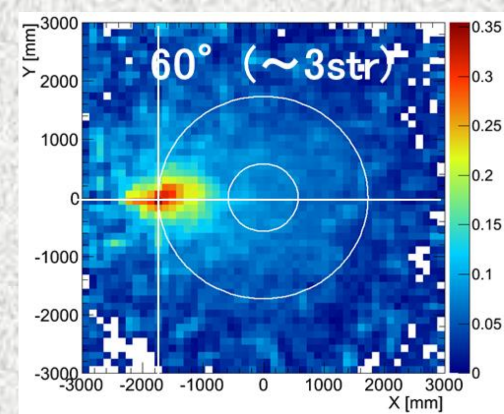
Continuum Gamma

662keV Gamma

□ Field of View (3str)



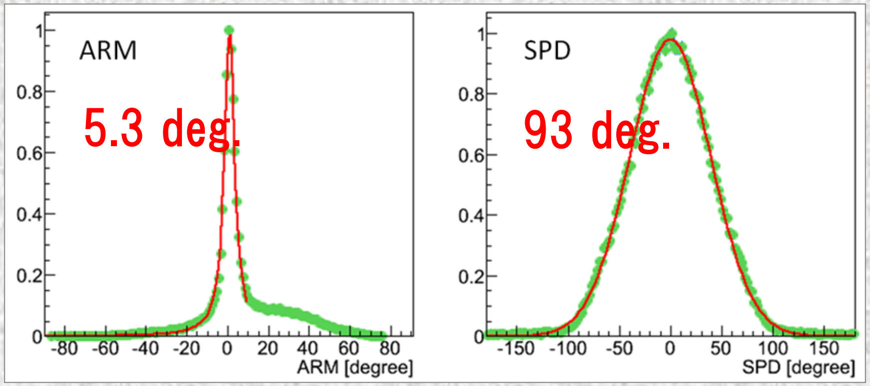


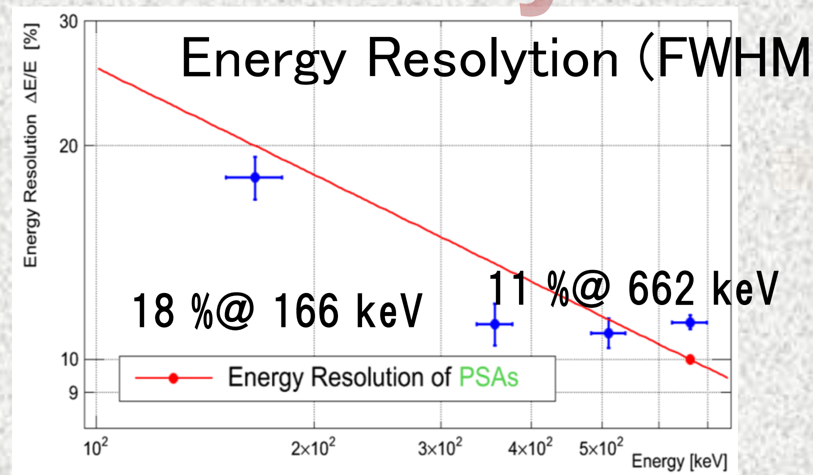


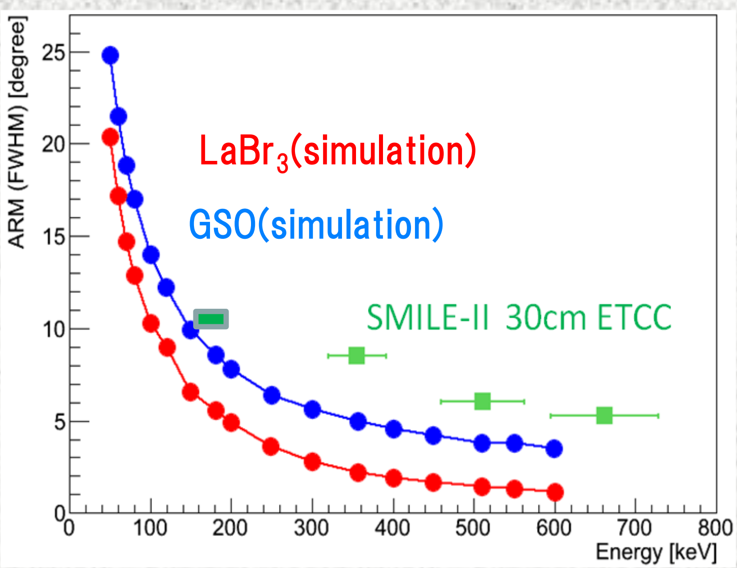
Angular Resolution & Energy band in 30cm-cube ETCC

Preliminary

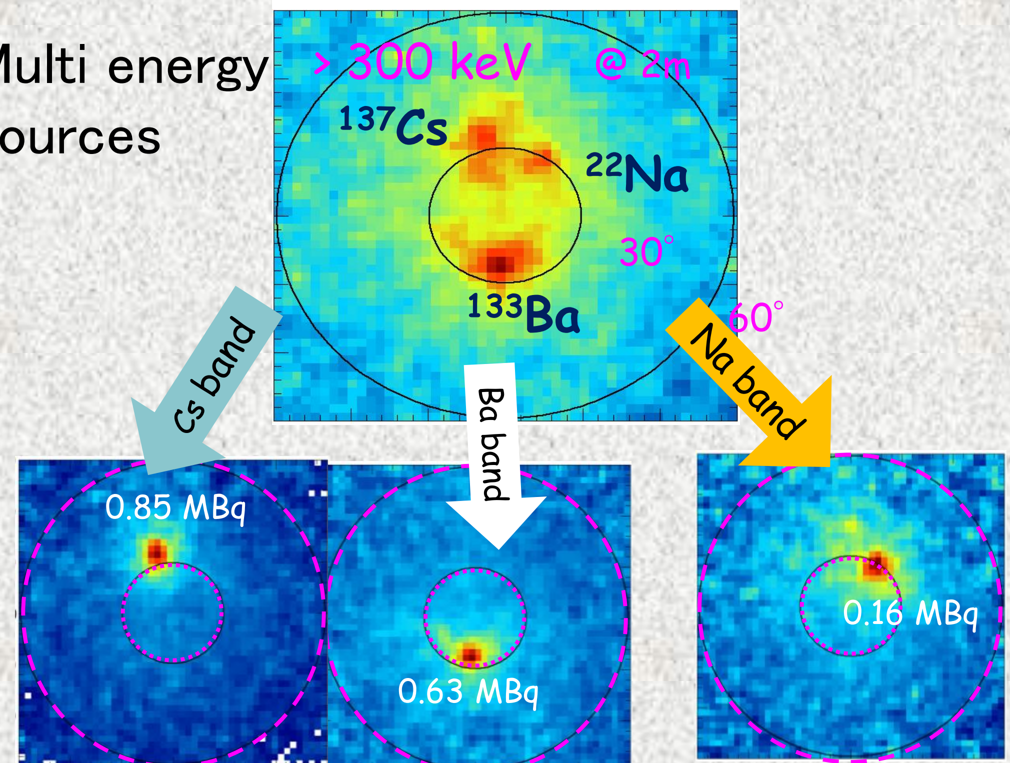
Angular Resolution（FWHM）@662keV





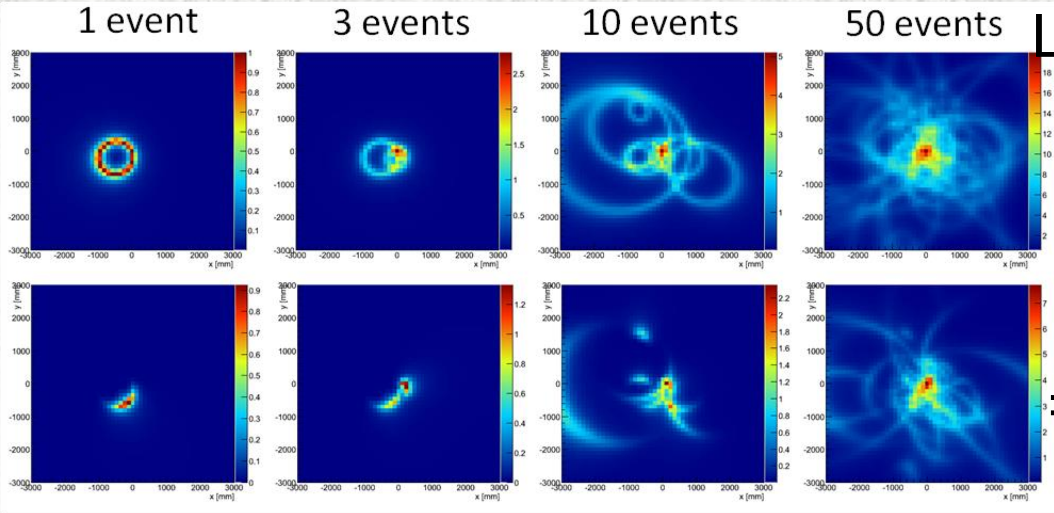


☐ Multi energy sources

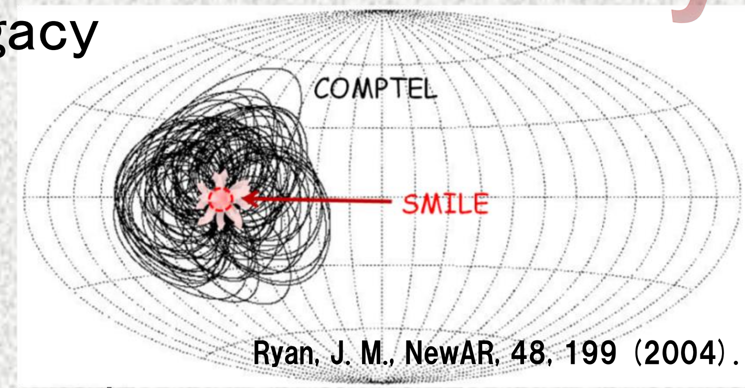


Imaging Improvement by SPD

Preliminary

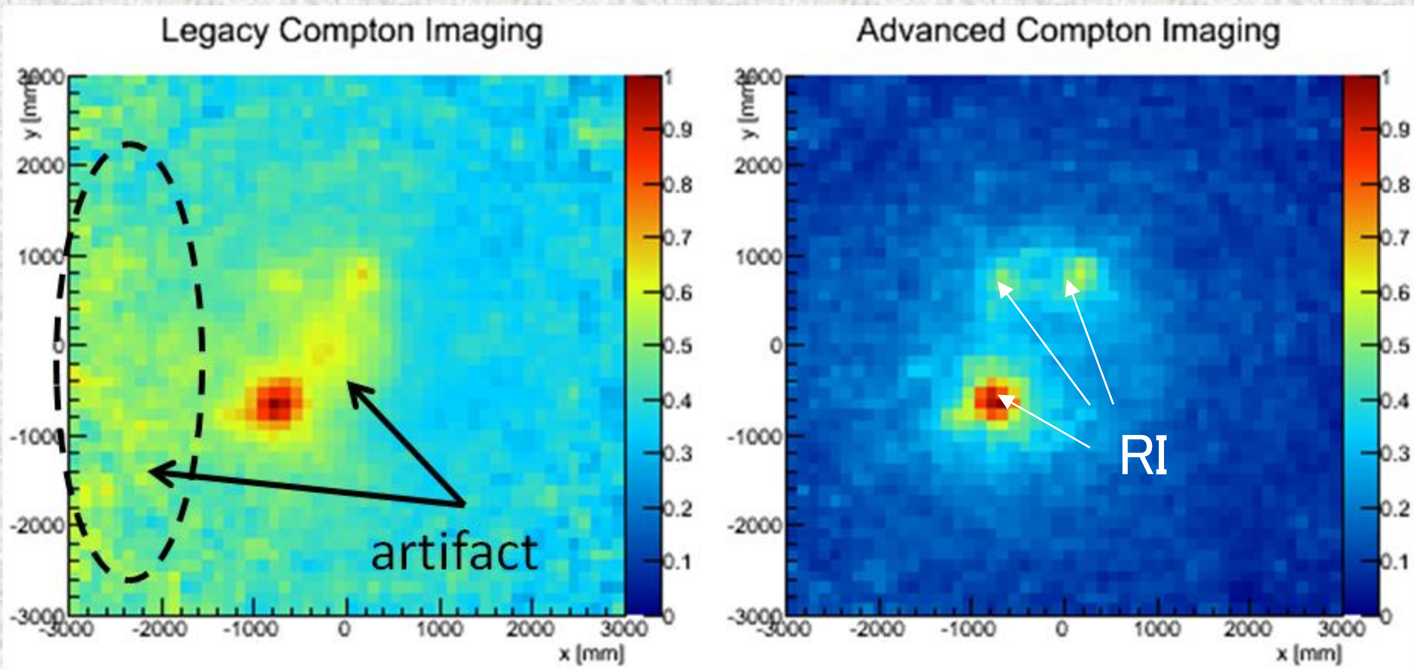


Legacy



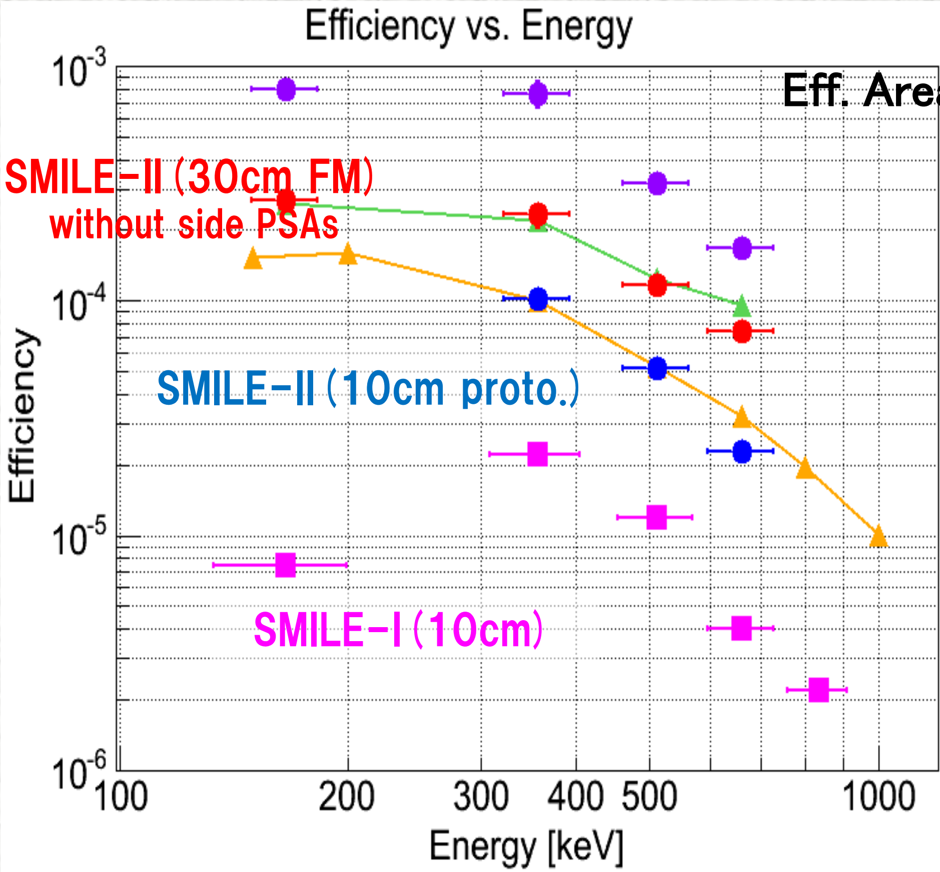
:Advanced
(SPD=200°)

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



⇒（～4times better contrast image

Detection Efficiency & Effective Area

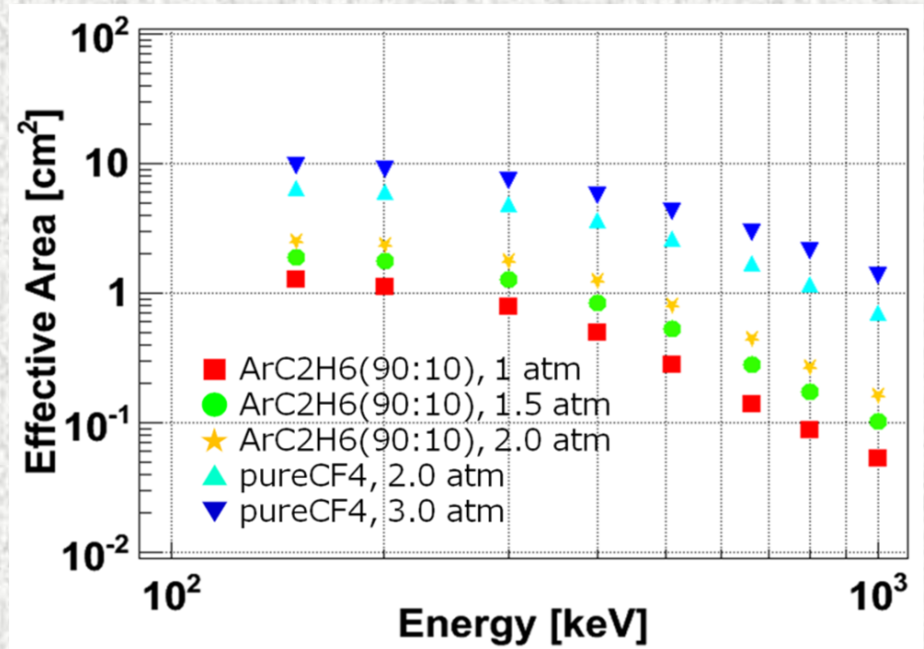


- Present Eff. Area～1cm²

Compton electrons in TPC
->100% detection

Preliminary

Simulated Effective Area



Further improvement

⇒CF_4 + 3atm Eff. Area ～$10cm^2$

+ double of Scintillator ->

Total ~20 cm^2 @ SMILE-II

Similar effective area to COMPTEL

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

Weak source detection such as Crab

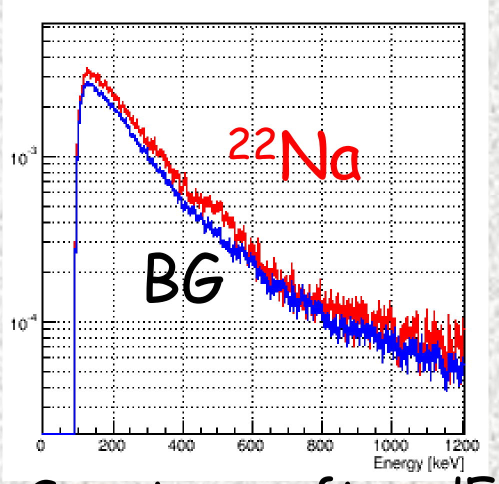
Preliminary

- RI : ^{22}Na

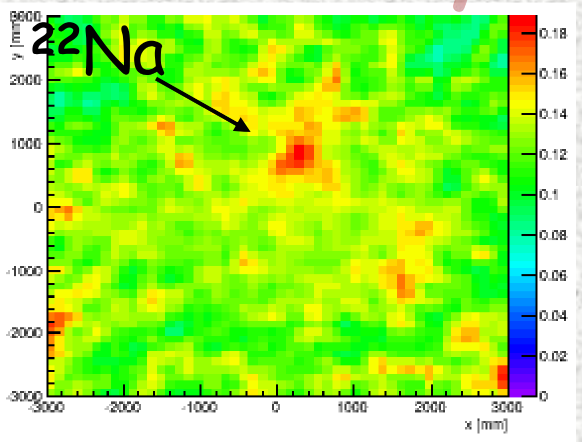
Zenith = 26°.

z = 2m, 31 kBq

1/4 of total system Operation



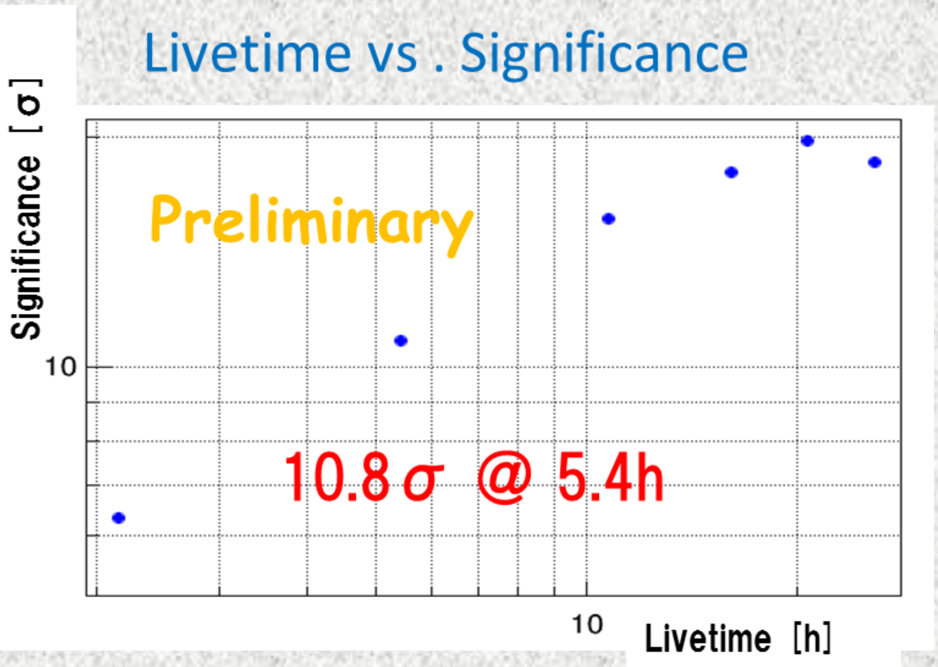
Spectrum after dE/dx



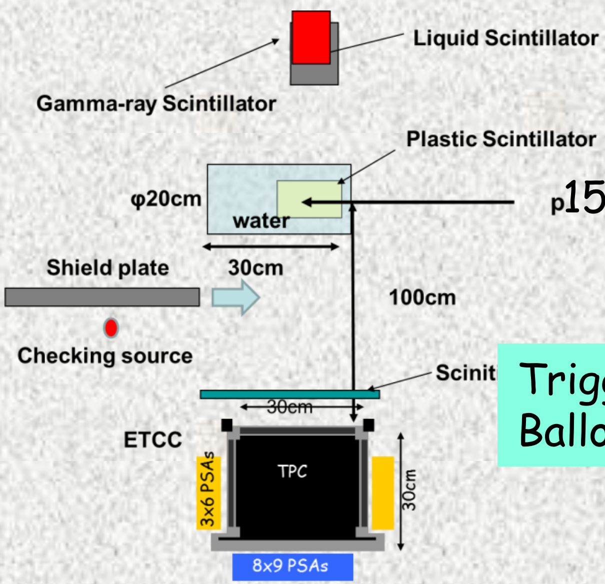
Advanced Compton Image

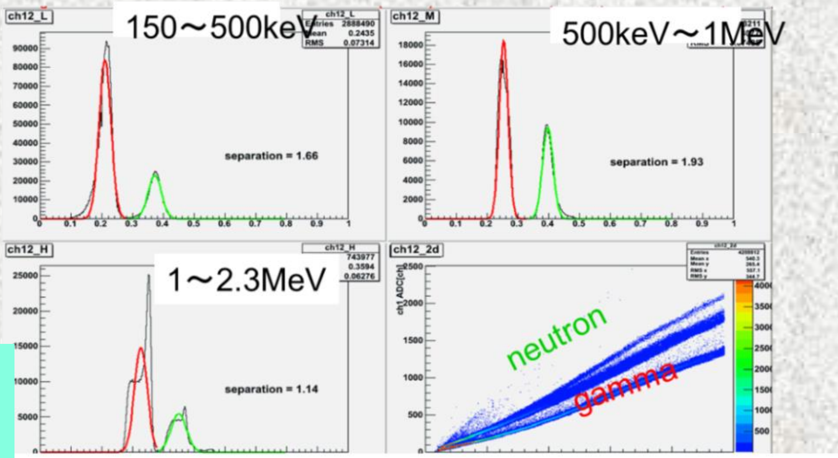
- S/N = 0.019

a few times stronger source than crab for SMILE-II



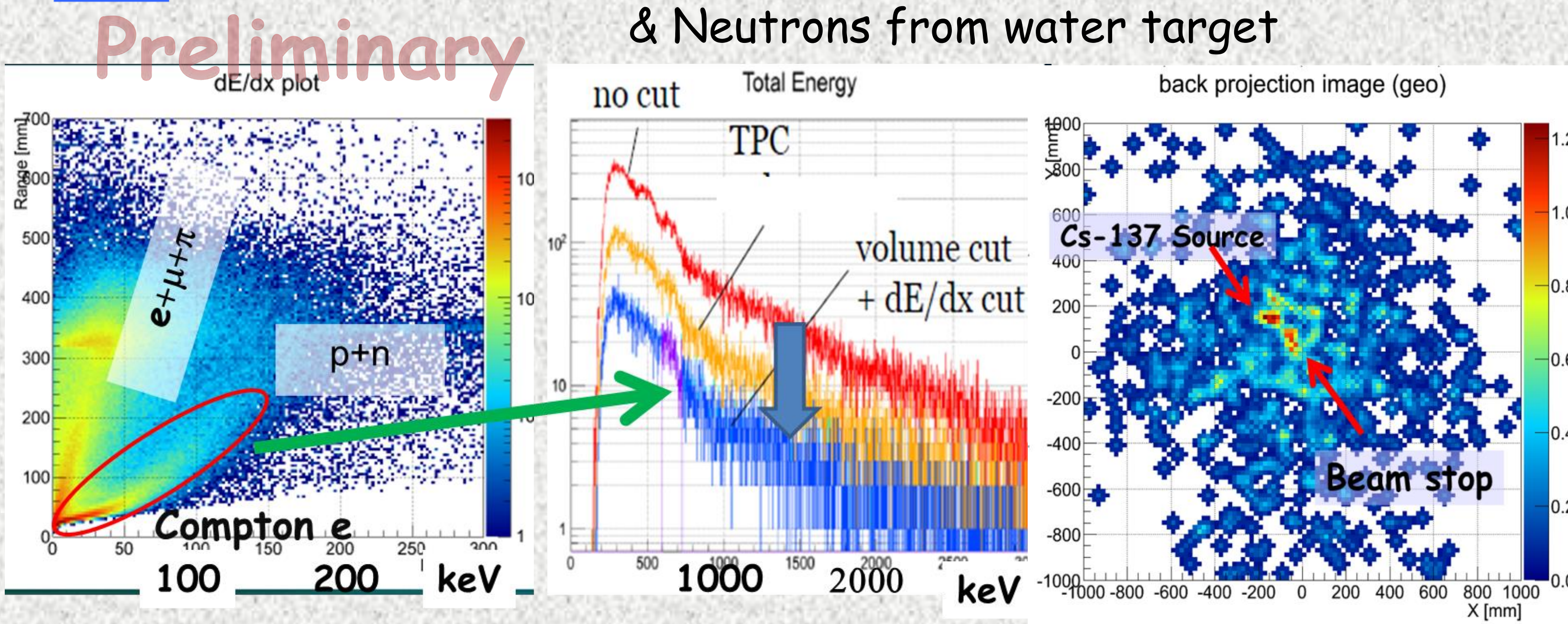
Performance Test under intense radiation condition using 140MeV proton beam 2013 -Oct.





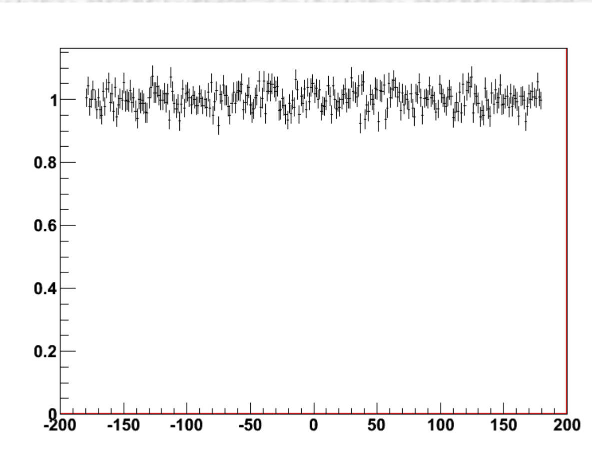
Trigger rate 300-500Hz
Balloon trigger rate 60Hz

ETCC operation under intense MeV Gammas & Neutrons from water target

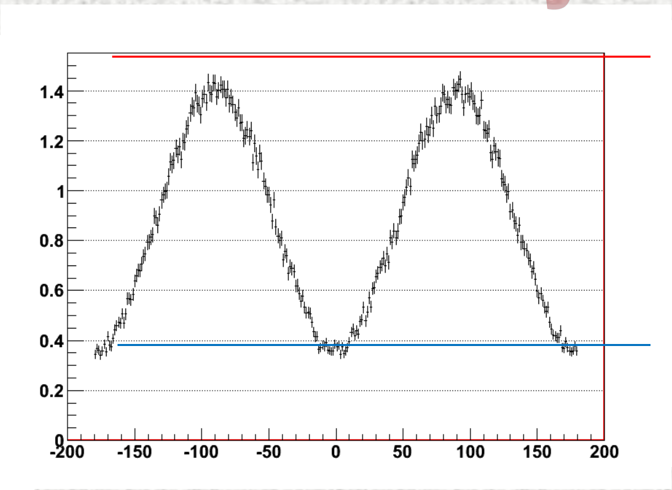


Modulation Factor in SMILE-II in Simulation

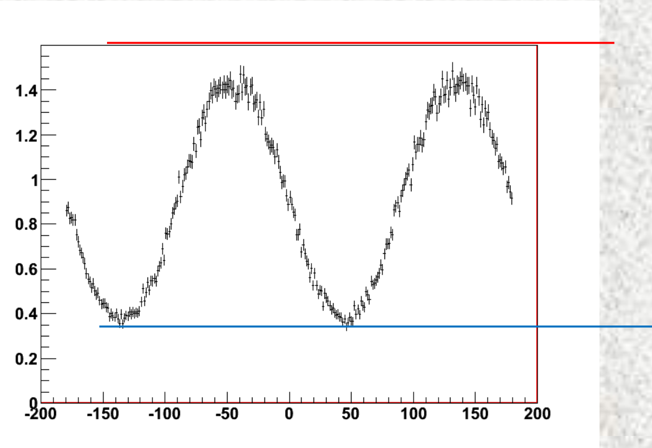
Preliminary



Un-polarized, Cos θ < 0.7



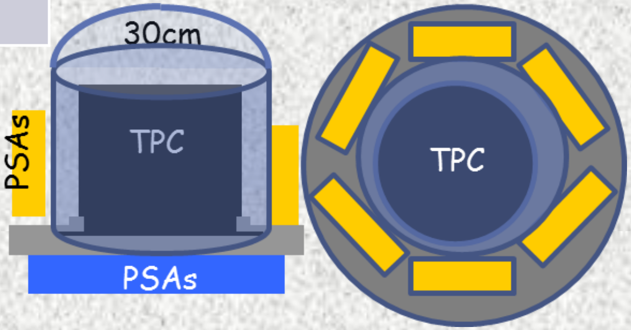
0º, 100%, Cos θ < 0.7



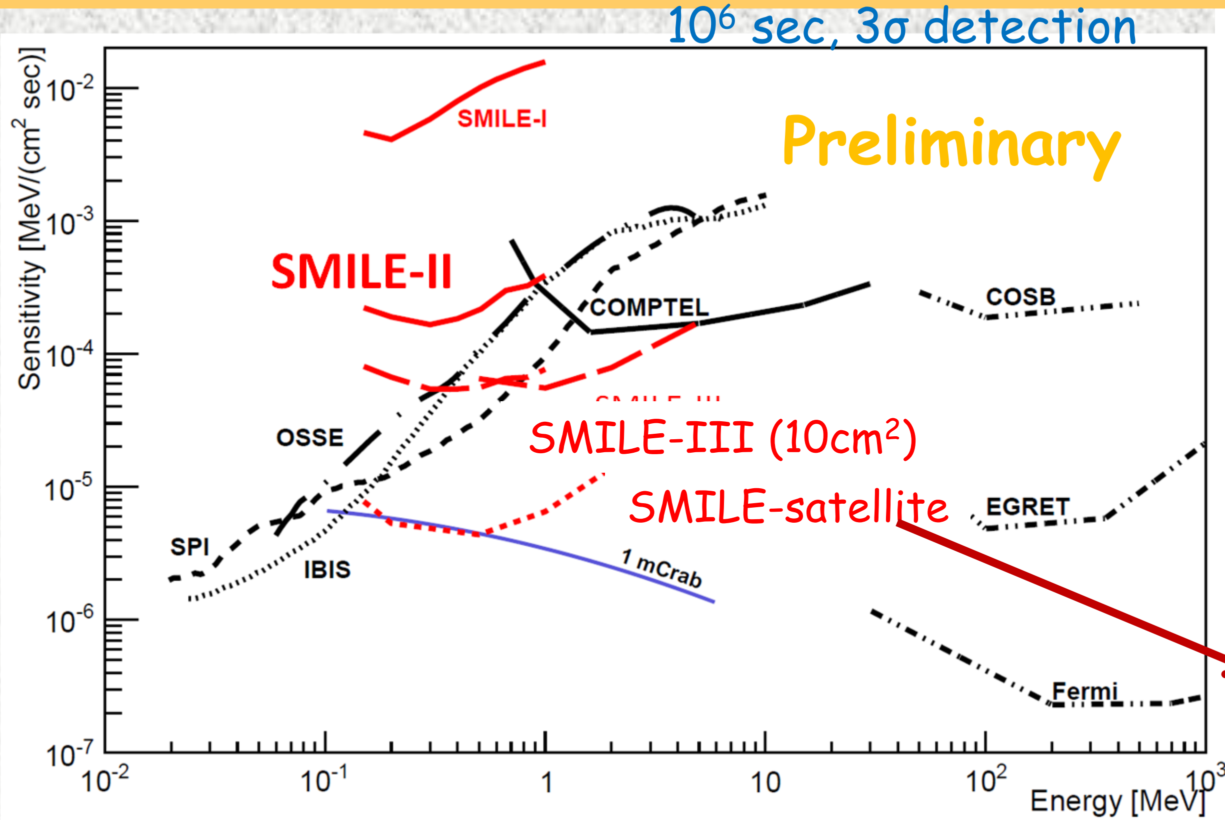
45º, 100%, Cos θ < 0.7

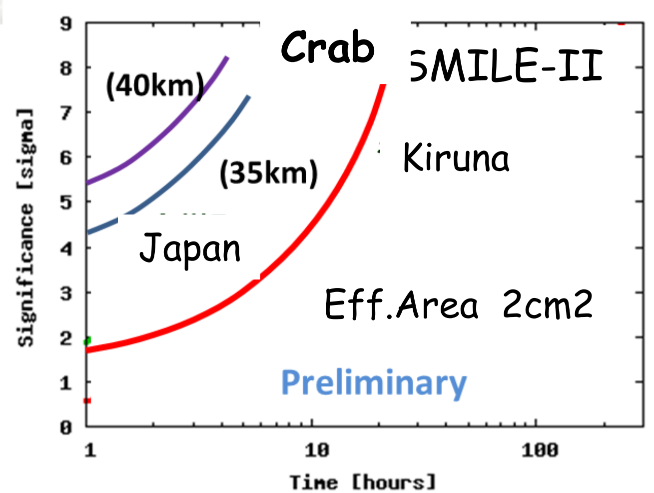
	#Event	Max	Min	MF
Un polarized	5.33e5			
0º, 100%	4.69e5	1.4	0.35	0.60
45º, 100%	4.83e5	1.45	0.35	0.61

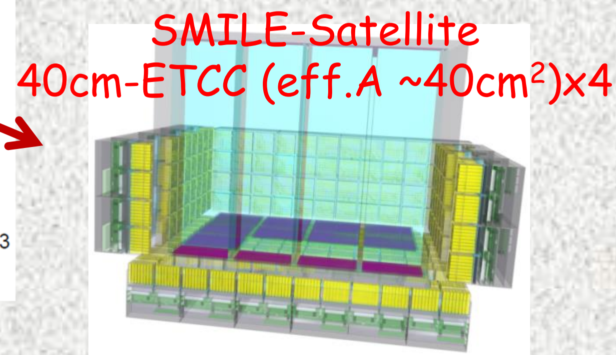
MF = (max-min)/(max+min)



New Balloon Exp. (SMILE-II & III)







■ SMILE-II (in USA)

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

■ SMILE-Ⅲ (Polar region)

- ➢ upgrade to ~15cm² X2 ETCCs
- ➢ Deep Survey for galactic plane

MEV Survey type Gamma Satellite plan

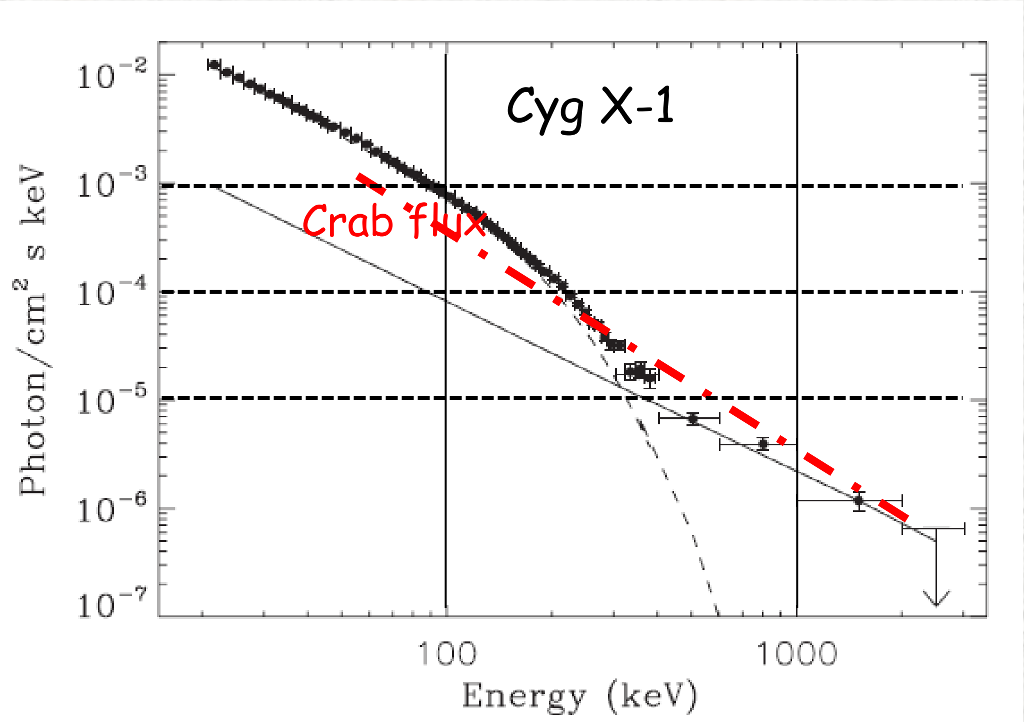
	S-ETCC(4unit)	ACT	GRIPS	CAST	Terminated MEGA
Scatt, material	gas	Si	Si	Si	Si
Absorber	GSO/$LaBr_3$	Ge	$LaBr_3$	CdTe	CsI
γVETO	nothing	BGO/CsI	nothing	BGO	nothing
Tracking	○	×	△	×	△
Eff. Area	40x4 cm^2	~10^3 cm^2	190m^2	10-30 cm^2	20 cm^2
ARM	2.3° @ 1 MeV	1.2° @ 1 MeV	1.8° @ 1 MeV	2.5° @ 1 MeV	2.0° /5.5° @ 1 MeV
FoV	3 str	3 str			
Sensitivity MeV/cm^2/s	4.4e-6 @ 0.5 MeV 6.5e-6 @ 1 MeV 4.7e-5 @ 5 MeV	1e-5 @ 1 MeV	3e-5 @ 1 MeV 7e-4 @ 5 MeV		6e-5 @ 1 MeV

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%

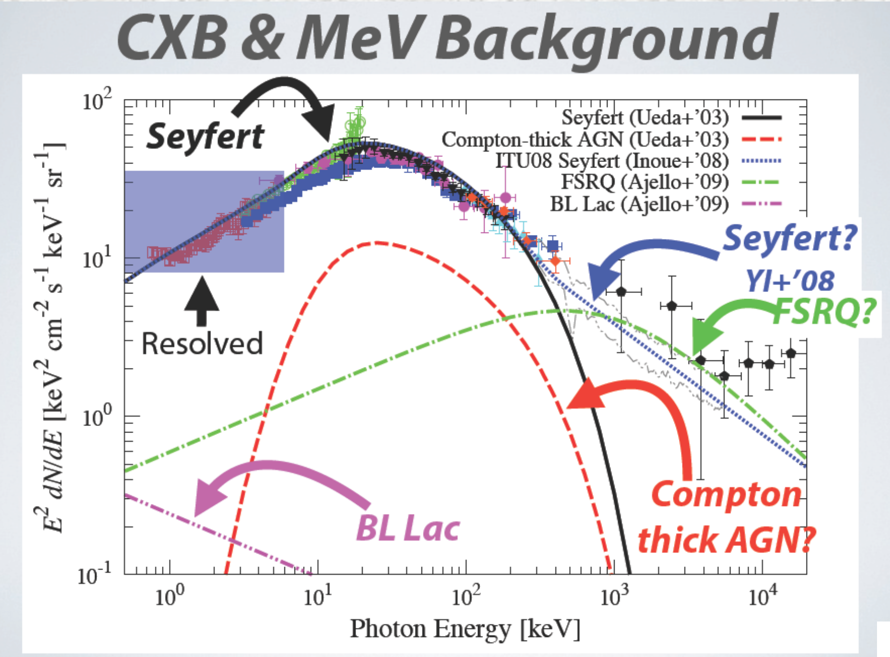
IBIS M=0.3 SPI were not calibrated on the ground as a polarimeter.



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 %

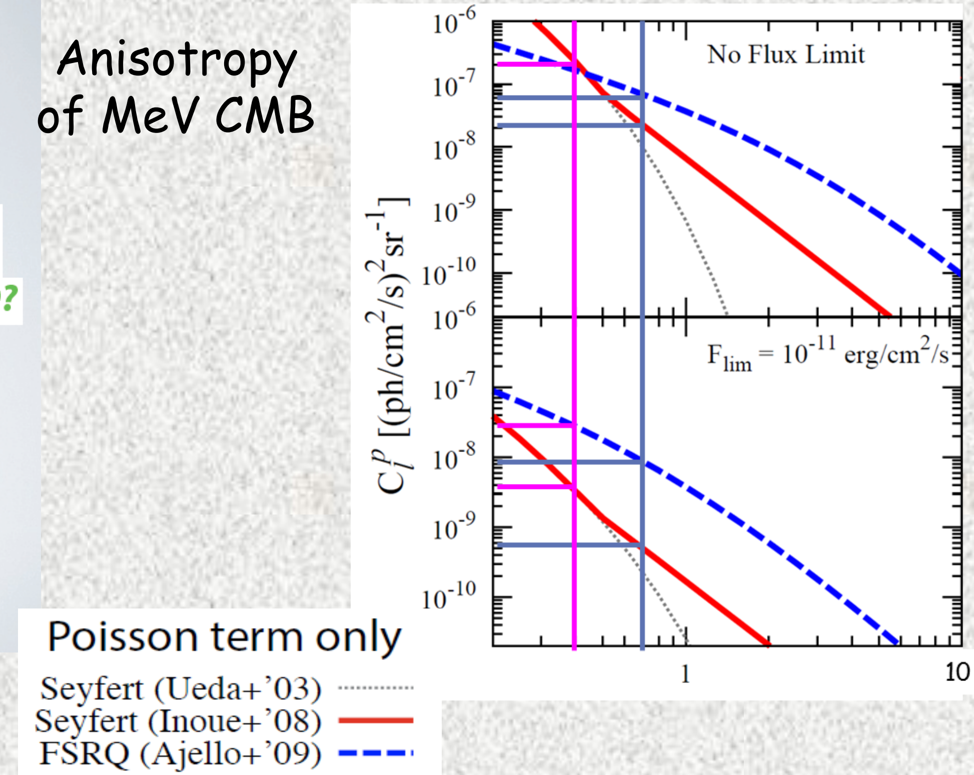
M:modulation factor M > 0.6 expected for ETCC (Low background compared to IBIS due to real imaging)

SMILE-III Test for AGN Evolution



(from Y.Inoue)

Anisotropy of MeV CMB



Precise measurement of MeV CMB

- 0.1-10MeV Dominant contribution is unclear

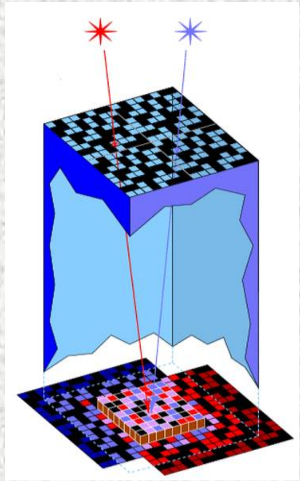
  Seyfert or FSRQ?

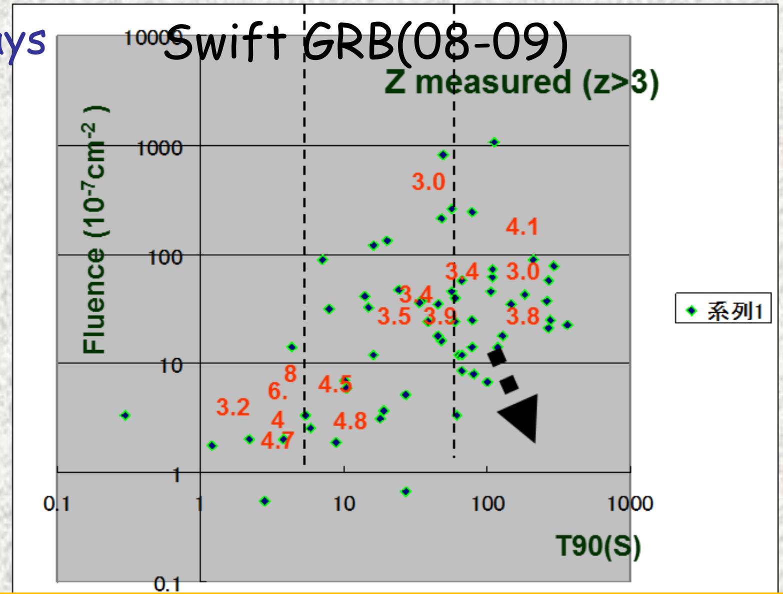
- SMILE-III Polar flight

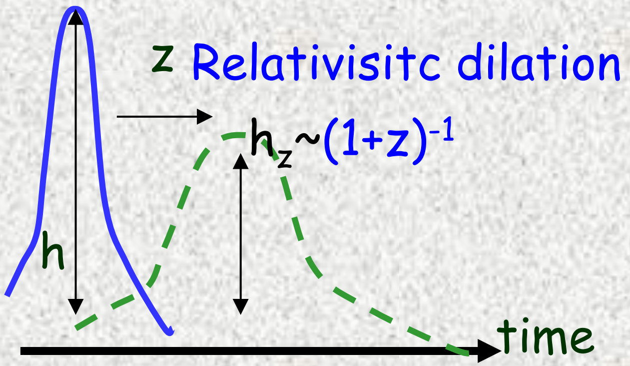
Polar Flight (~10^6 sec) ⇒ >10^6 events
⇒ precise spectrum of CMB
Anisotropy
⇒ >10^5 events is enough for separation of
Seyfert and FSRQ with 5σ

GRB Detection with Swift

BAT 15-100keV X-rays





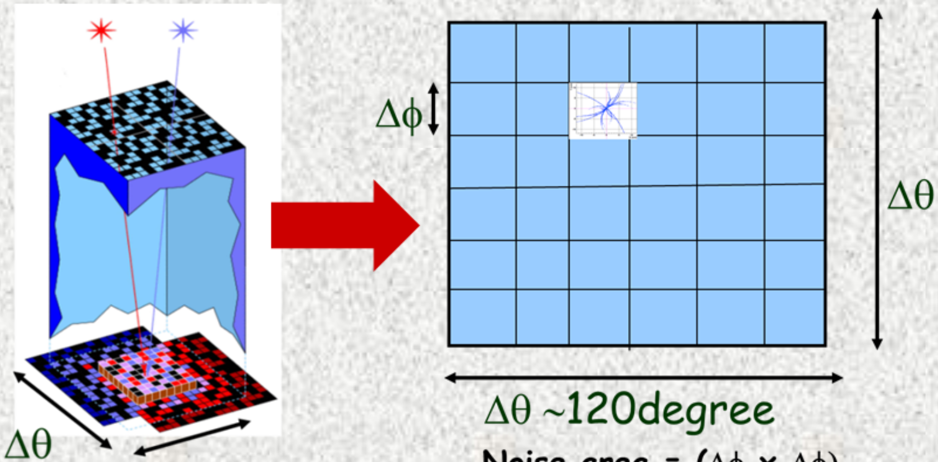


Trigger bias looks to appear above for long GRB with z>4

Salvaterra et al. 2008

Instrument	Band (keV)	Field of view (sr)	P_{lim} (photon s^{-1} cm^{-2})	z_{max}	GRBs per year at $z \geqslant 6$	GRBs per year at $z \geqslant 10$
Swift	15–150	1.4	0.4	6.3–7.5	1.3–4	0.09–0.1
			0.25	7.0–8.3	2–7	0.16–0.25
			0.1	7.5–9.9	3-16	0.3–0.9
INTEGRAL/IBIS	20–200	0.1	0.2	3.8–5.2	0.1-0.5	<0.01
GLAST/GBM (on-board)	50–300	9	0.7	6.2–6.3	1.2–1.5	<0.1
GLAST/GBM (ground)			0.47	6.8–6.9	1.8–2.4	0.05–0.12
SVOM	4–50	2	1.0	6.7–7.4	2–4	0.1–0.13
EDGE	8–200	2.5	0.6	6.9–8	2–6	0.18–0.23
EXIST	10–600	5	0.16	9.7–11.3	11–56	0.9–2.8

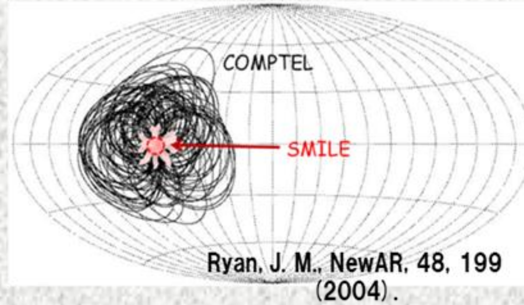
Imaging GRB Trigger in Sub-MeV



Noise area = Δθ x Δθ

Noise area = (Δφ x Δφ)

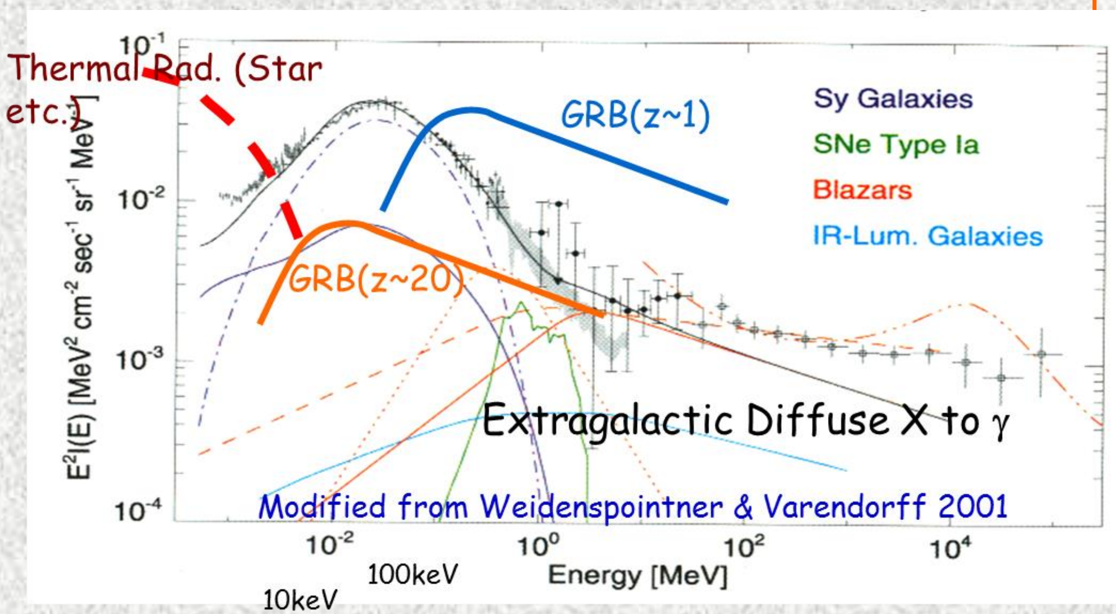
Δφ/Δθ=10 Noise reduction -> 1/100



Imaging ability for each photon

Even 10° x10° -> 1/100 B.G. of 1 str Detector

->Imaging Trigger photon by photon in ETCC



GRB detection limit

~70 ph. >100keV in 4°x4° @~100cm² in 10^3 sec (8σ)

Point Accuracy for GRBs

<0.2° for 300γ, 0.5° for 30γ

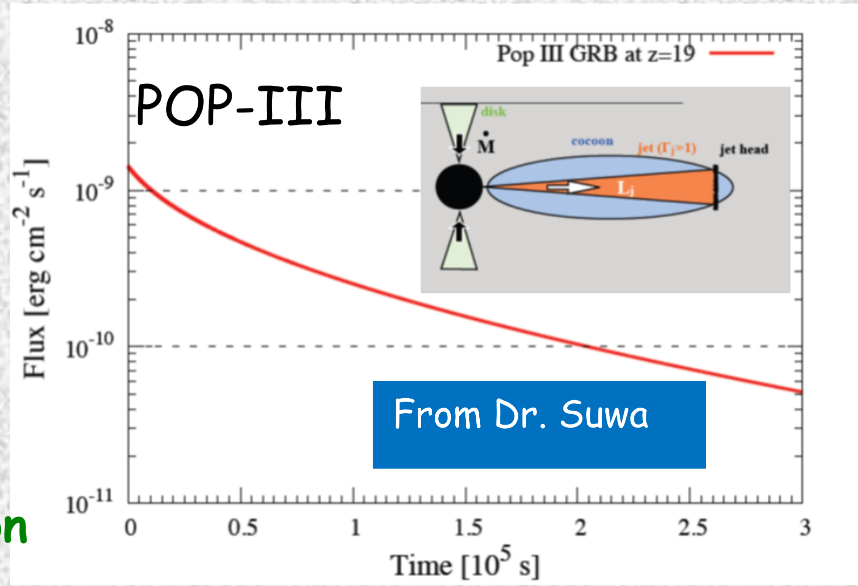
GRB Cosmology

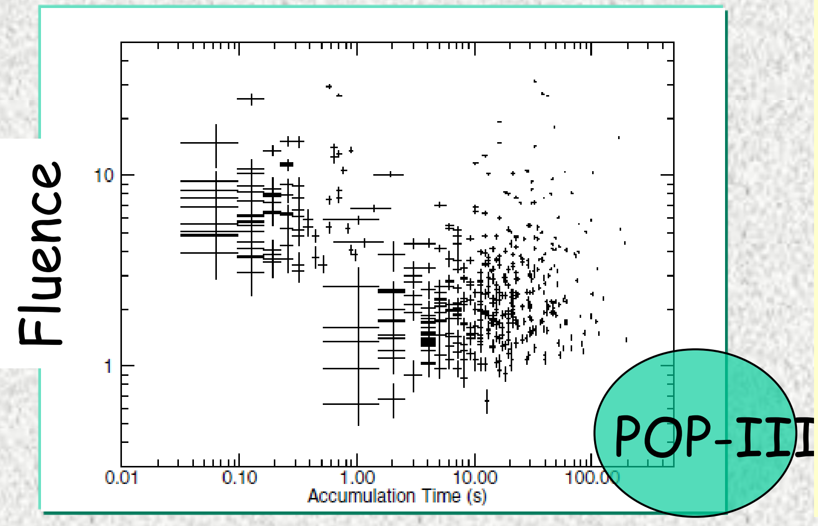
- ~650 GRBs/one year & 10 with z>10 /10years from GRIPS proposal

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

ETCC could detect weak flux long duration GRB efficiently

At least relativistic dilation effect (x~10)





40cm-cube ETCC

GRB of 10-2x10^{-10}erg/cm^{2}s ($900M_{solar}$)

Eff.Area 40cm^2

- **10^3s 200γ B.G. 35γ in 4x4° S/N ~18σ**
- **10^5s 2x10^4γ B.G> 3.5x10^3γ S/N =330σ**
- **5σ detection during 10^5s -> ~300γ**

a few 10 M_{solar} Super long bursts OK!

GRB detection in SMILE-III

Observations

1. GRB 021206: 80+-20% (Coburn & Boggs 03)
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 27+- 11%, 84+16-28%, 70+-22% Yonetoku et al.2011

- **SMILE-III** GRB~ No background **Calibration by Crab!**
- ETCC M>0.6 FoV 3str, Eff. Area 30cm^2@200 keV

GRB 10^{-6}erg/cm^{2}s ~250 photon/s T_{90}=40s 250x40s ~10^4

MDP = 4.3/M % (3σ) (M>0.6) 7% polarization OK !

GRB 10^{-7}erg/cm^{2}s$^-$ 24% polarization

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

& low fluence and long duration GRB

- **Satellite ETCC~160cm^2 (Sensitivity~1mCrab@10^6sec)**

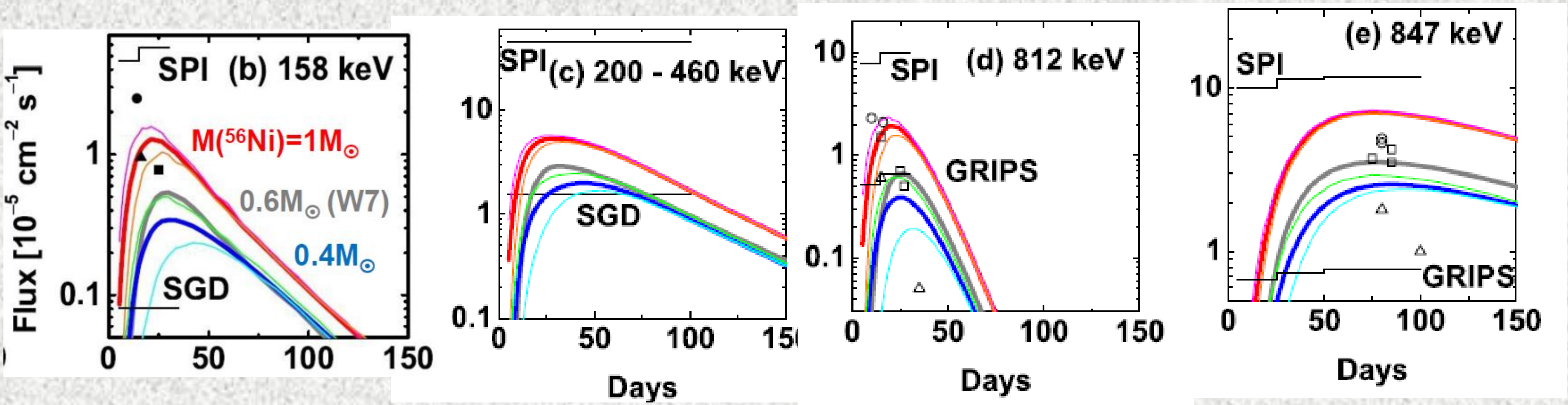
10^{-7}erg/cm^{2}s GRB MDP =5/M % (>100 GRB/year)

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

MeV Gammas from SNe

- SMILE with $laBr_3$ dE/E ~3%@900keV(FWHM)
- Sensitivity for line γ ~5x10^{-6} γ/cm^{2}s (SMILE=III Eff.Area 30cm^2)

  ~5x10^{-7} γ/cm^{2}s (Satellite-ETCC: Eff. Area ~160cm^2)



From Maeda et al ApJ (2012)

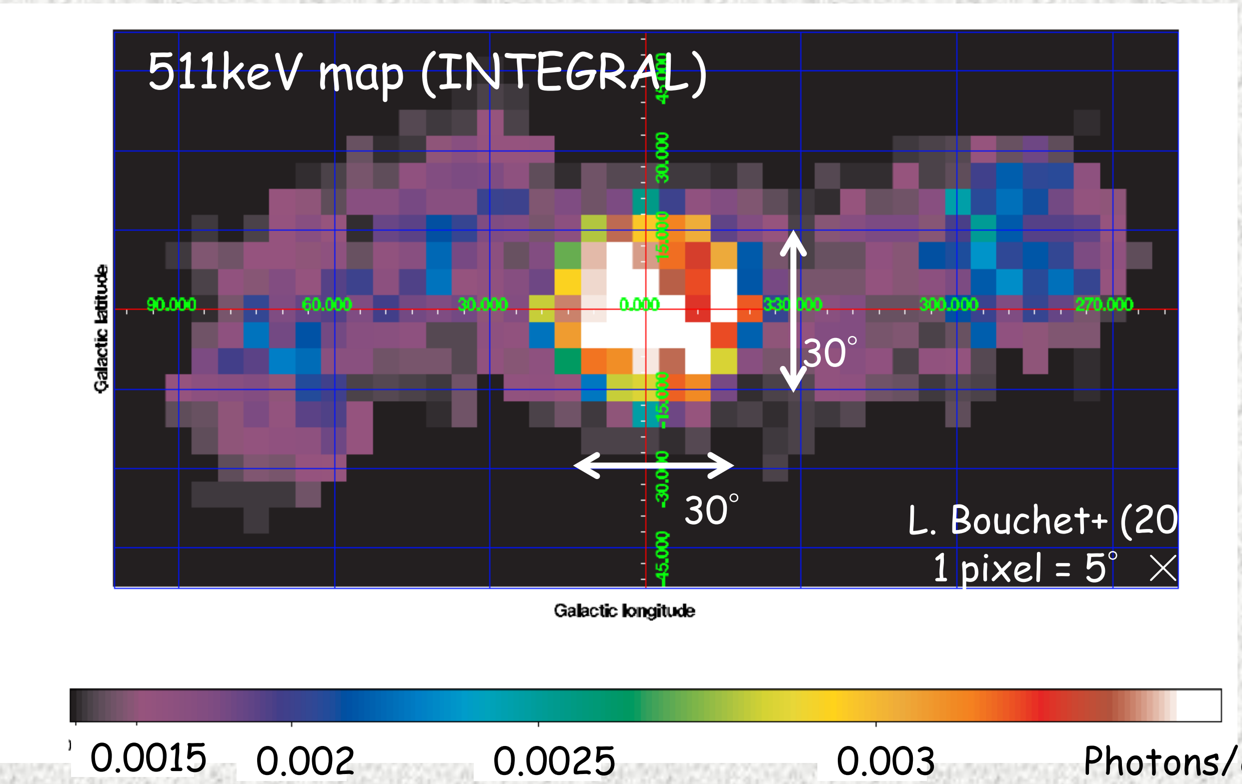
1 M sec @ 10 Mpc

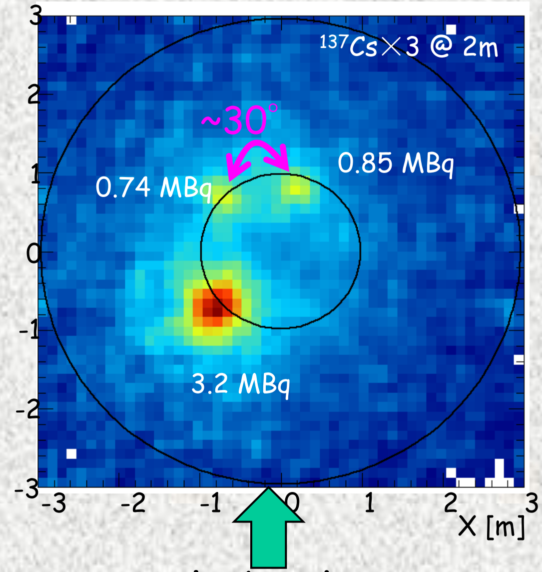
SN 1a ~20 /several years observation within 20Mpc

Collapse type SNe ~5 from GRIPS proposal

Galactic lines of SMILE-III

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



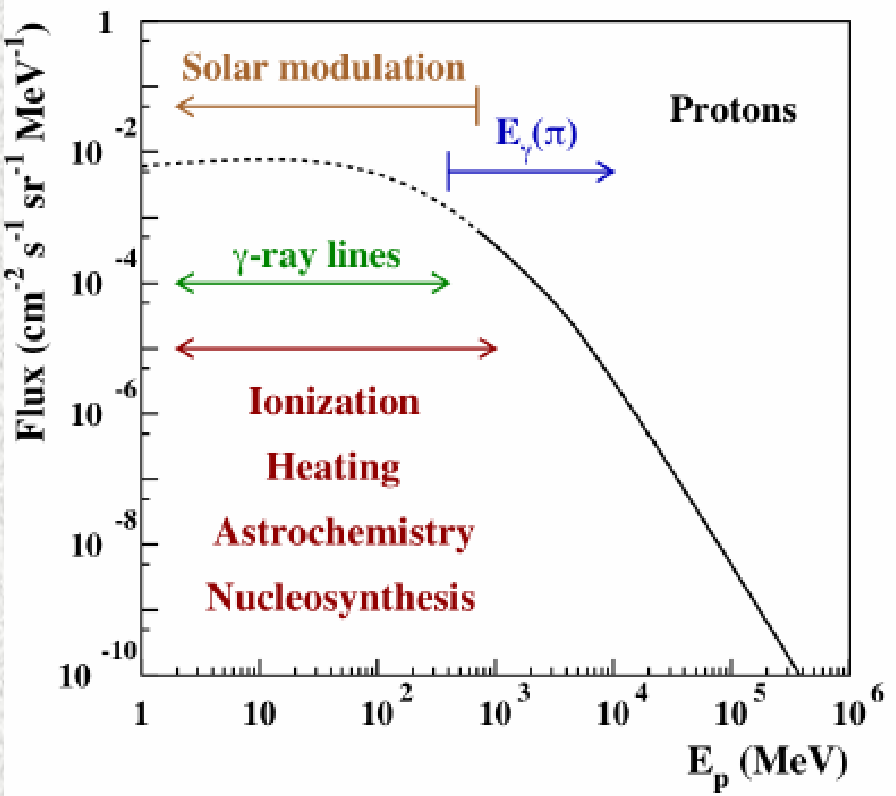


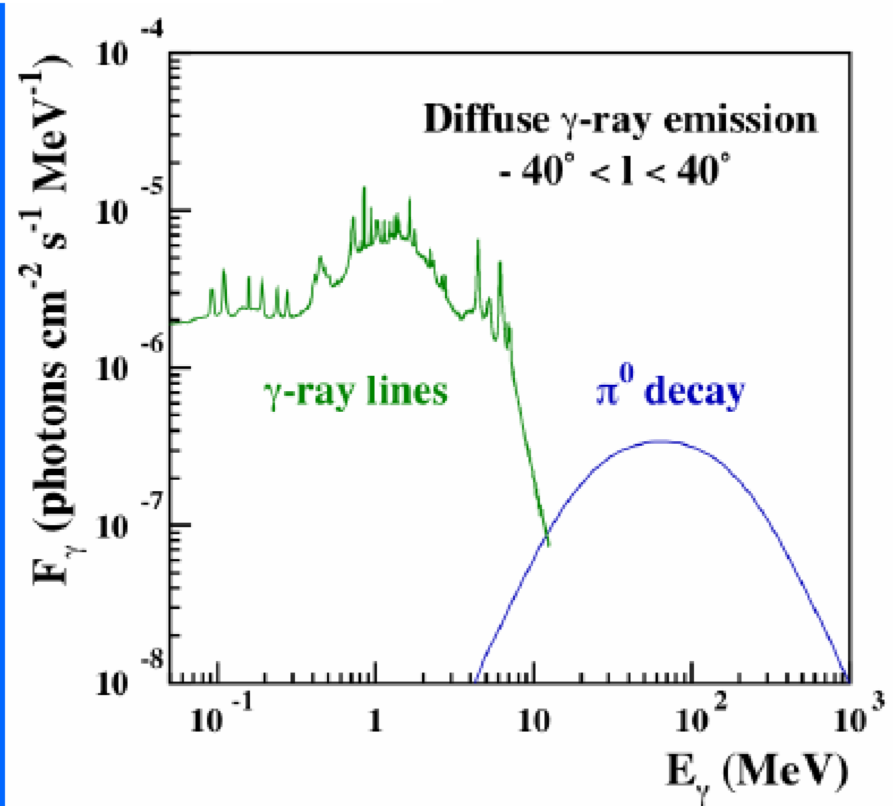
Simple back projection image
More fine imaging is obtained by using MLEM

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

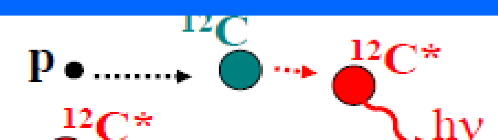
The effects of cosmic rays on the ISM

Vincent Tatischeff, MPE, Oct. 20-21, 2009

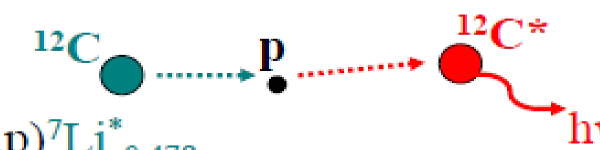




- Narrow lines: e.g. $^{12}C(p,p')^{12}C^*_{4,439}$, $^{12}C(p,2pn)^{10}B^*_{0,718}$



- Broad lines: e.g. $^{1}H(^{12}C,{}^{12}C^*_{4,439})^{1}H$



- α–α line: $^{4}He(\alpha,n)^{7}Be^*_{0,429}$ and $^{4}He(\alpha,p)^{7}Li^*_{0,478}$

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.