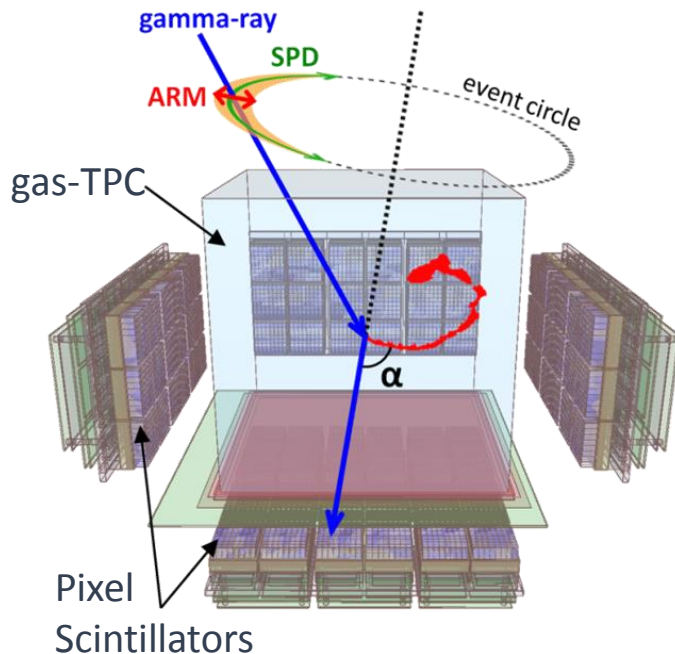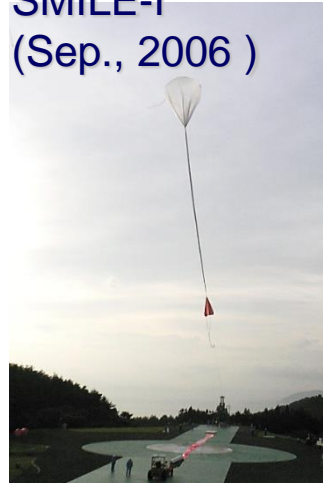# SMILE24：電子飛跡検出型コンプトンカメラが持つ偏光撮像性能の評価試験

古村翔太郎

谷森達, 窪秀利, 高田淳史, Parker Joseph,水村好貴,水本哲矢, 園田真也, 友野大,中村輝石, 松岡佳大, 中村祥吾,岸本哲郎, 小田真, 竹村泰斗, 宮本奨平,中増勇真,吉川慶 (京都大学) 身内賢太朗(神戸大学), 黒澤俊介（東北大学）, 澤野達哉（金沢大学）

Sub-**M**eV gamma-ray **I**maging

Loaded-on-balloon **E**xperiment

SMILE-I
(Sep., 2006)

Now planning

SMILE-II (1 day flight)
　Crab Nebula, Cygnus X-1

SMILE-III (1 month flight)
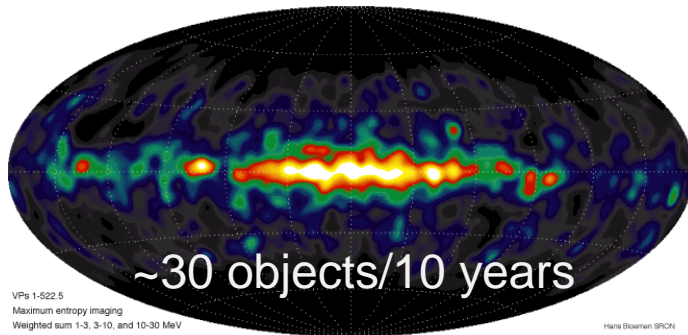・ more faint sources
・ polarization measurements

Contents

1. MeVガンマ線天文学の現状・課題

2. ETCCのコンセプト

3. Current and near-future ETCC

4. 偏光検出器としての応用

5. 偏光ビーム試験＠SPring-8　2015年1月
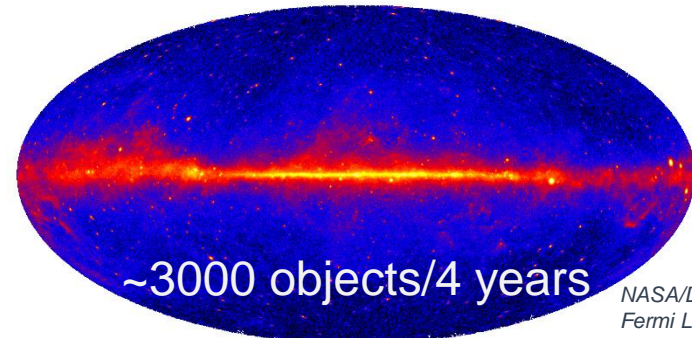
◆　Summary

Problems in MeV gamma-ray astronomy

COMPTEL 1-30 MeV map

~30 objects/10 years

VPs 1-522.5
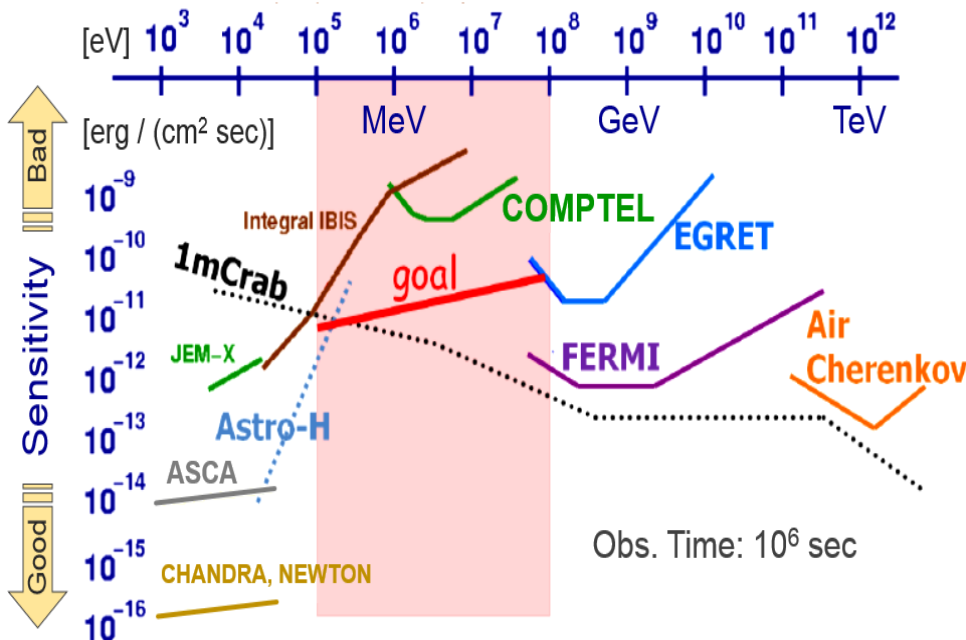Maximum entropy imaging
Weighted sum 1-3, 3-10, and 10-30 MeV

Hans Bloemen SRON

V. Schönfelder+ (A&AS, 2000)

Fermi > 1 GeV map

~3000 objects/4 years

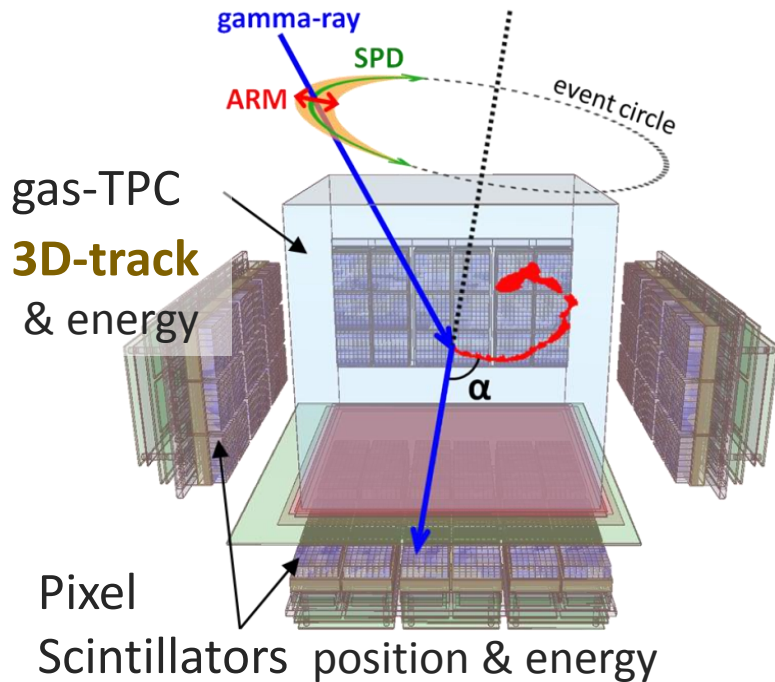*NASA/DOE/
Fermi LAT Collaboration*

F. Acero+ (ApJS, 2015)

Obs. Time: 10^6 sec

Unexplored frontier!

gamma-ray

ϕ

event circle

E_1 Recoil Electron

E_2 Scattered Gamma

ghost

source

ghost
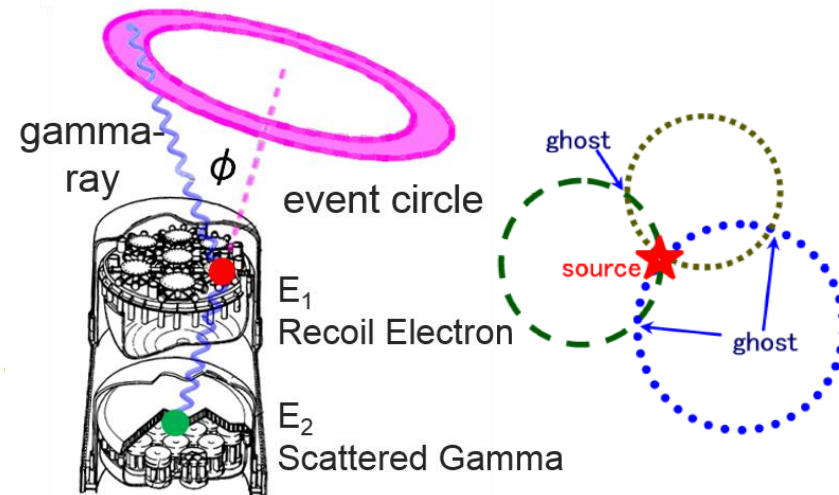
◆ **Wide-spread PSF**

◆ **Huge backgrounds in space**

3

Electron-Tracking Compton Camera (ETCC)

gas-TPC
3D-track
& energy

Pixel
Scintillators position & energy

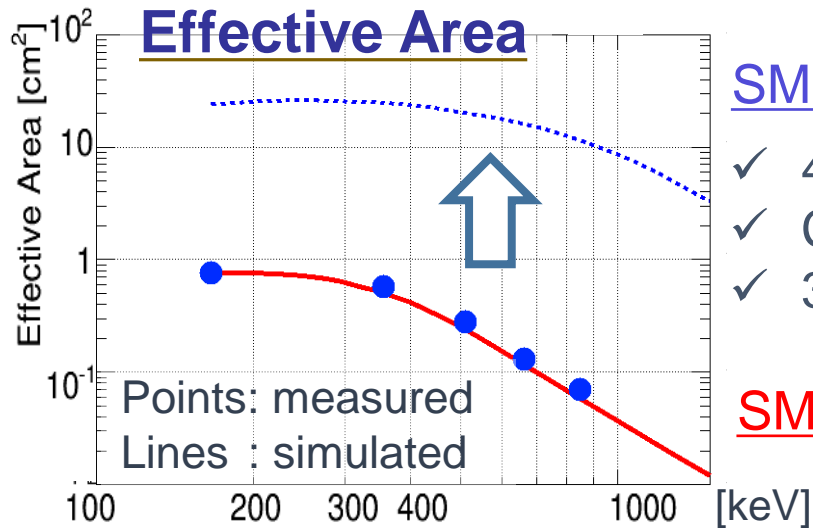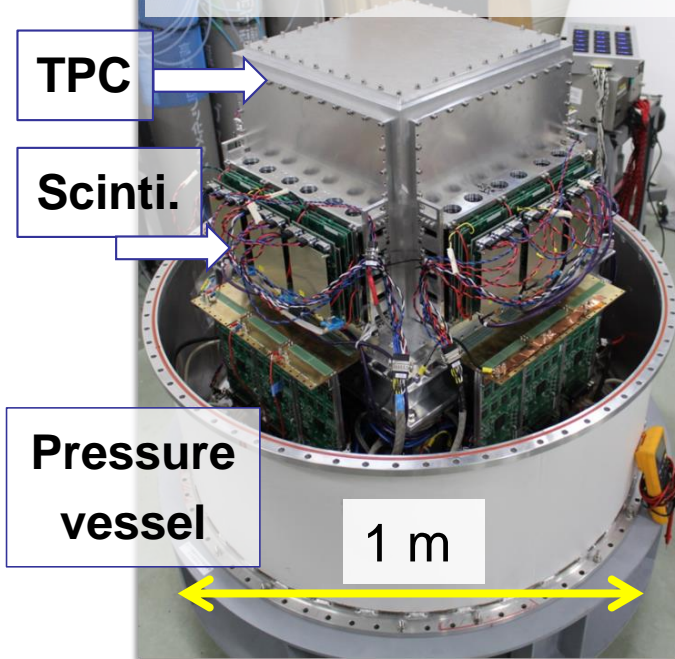**By measuring electron tracks, ETCC overcome the problems !**

➢ **Well-defined PSF** without ML-EM

➢ **Powerful BG rejection** using dE/dx

  ➢ No shield => Wide field of view ~ 6sr

T.Tanimori et al., *ApJ* (2015) accepted, arXiv: 1507.03850 [astro-ph.IM]

Conventional method

Electron Tracking method

Particle ID by dE/dx

4
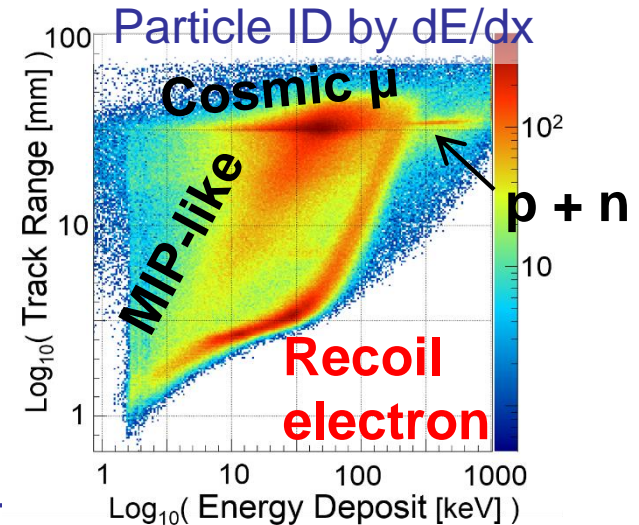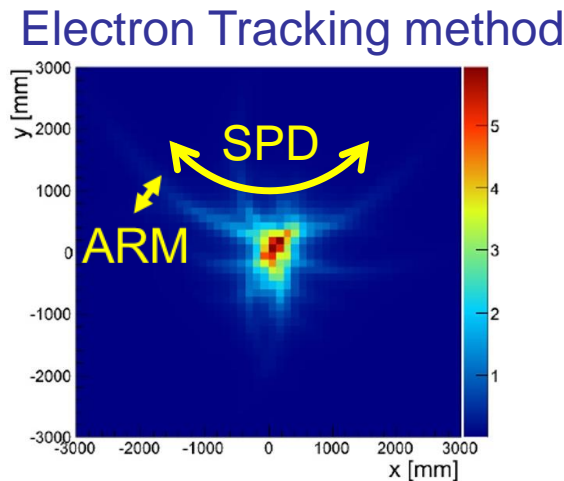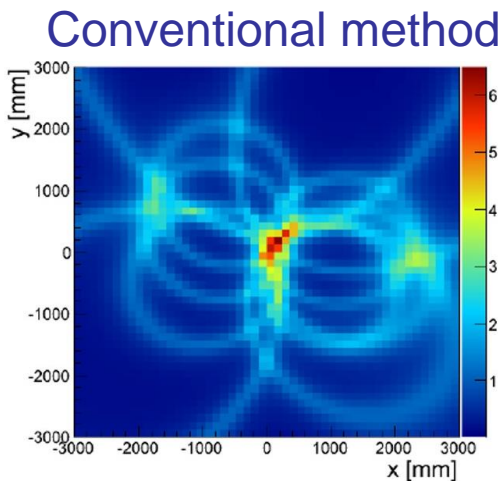
Current and near-future performance

SMILE-II Flight model

TPC

Scinti.

Pressure vessel

1 m

Gas	Ar-based @1atm
Gas volume	30 cm-cubic
Track sampling	800 μm
Scintillator	pixel GSO:Ce (6 x 6 x 13 mm^3) 1 Radiation length
Energy resolution	10% @662 keV (FWHM)

Effective Area

Effective Area [cm^2]

10^2

10

1

10^{-1}

100   200   300 400   1000   [keV]

Points: measured
Lines : simulated

SMILE-III

✓ 40 cm-cubic
✓ CF$_4$ gas @3atm
✓ 3 R.L. scintillator

SMILE-II

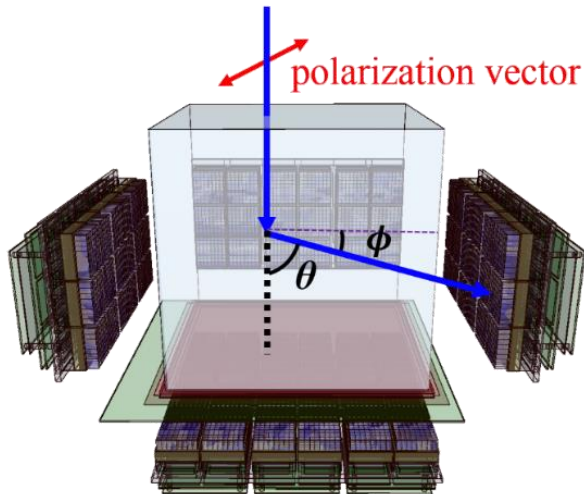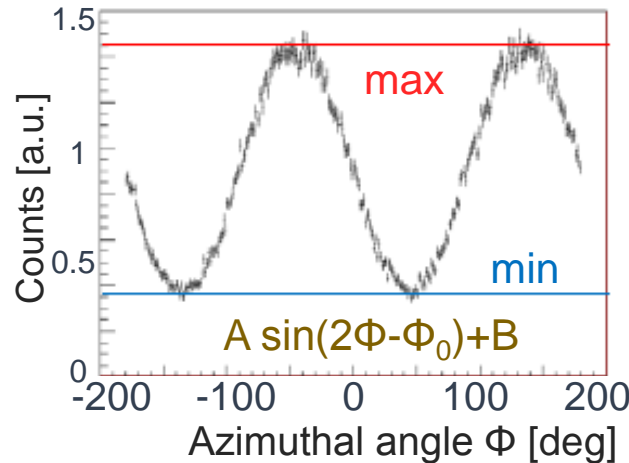## Point Spread Function

SMILE-II, III： ARM 5° SPD 30-100° => **8-15°**

Near future： ARM 2° SPD < 10° => **~ 1°**

➢ SPDの改善策   25aSJ-11 宮本

➢ PSFの導入, 予想感度 25aSJ-12 高田

as a Polarimeter

linearly polarized γ-ray

polarization vector

ϕ

θ

Asymmetric distribution of the scattered photons

max

min

$A \sin(2\Phi - \Phi_0) + B$

Counts [a.u.]

Azimuthal angle Φ [deg]

$$\text{Modulation Factor} = \frac{max - min}{max + min}$$

~ 0.6@200 keV,

~ 0.5@500 keV

(simulation)

Minimum detectable polarization (MDP)
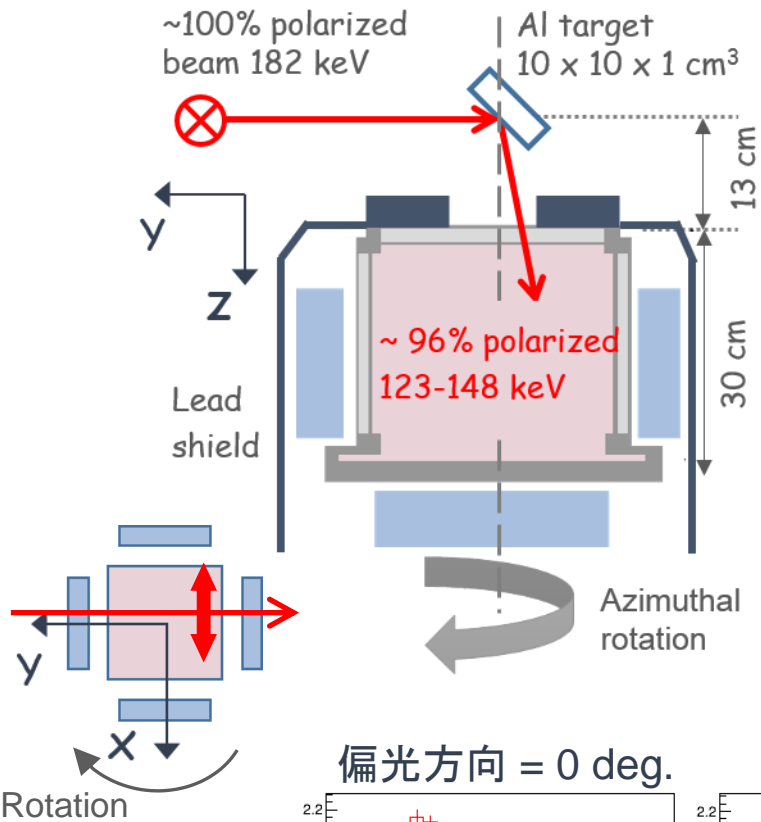
$$MDP = \frac{429}{ASM} \sqrt{\frac{AS + B}{T}} \quad \begin{array}{c} 99\% \\ CL \end{array}$$

[%]

$$B \gg AS \implies MDP \propto \frac{\sqrt{B}}{AS}$$

A	Effective area [cm^2]	S	Signal [cm^{-2} sec^{-1}]
M	Modulation Factor	B	Background [sec^{-1}]
T	Observation time [sec]		

Sensitivity is limited by the background rate.

Large advantage
- ✓ Powerful background rejection
- ✓ Imaging with wide FOV ~ 6sr

faint sources,
transient objects (GRBs)

Beam test@ SPring-8 BL08W

~100% polarized beam 182 keV

Al target 10 × 10 × 1 cm³

13 cm

30 cm

Lead shield

~ 96% polarized 123-148 keV

Azimuthal rotation

Rotation

再構成スペクトル＆イメージ (Al散乱事象)

— Al あり
— Al なし
— 差分

[/sec/keV]

90°散乱 134 keV

Beam 180 keV

[keV]

Al あり

Al なし

y [cm]
x [cm]

散乱ガンマ線 方位角分布

空気による 前方散乱

偏光方向 = 0 deg.

-22.5 deg.

-45 deg.

-90 deg.

[deg.]

Preliminary

7
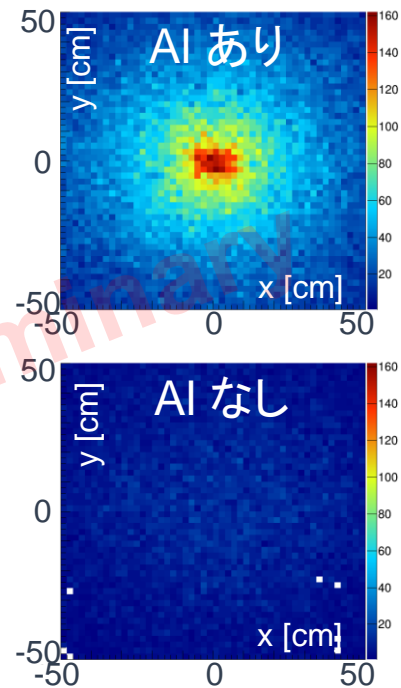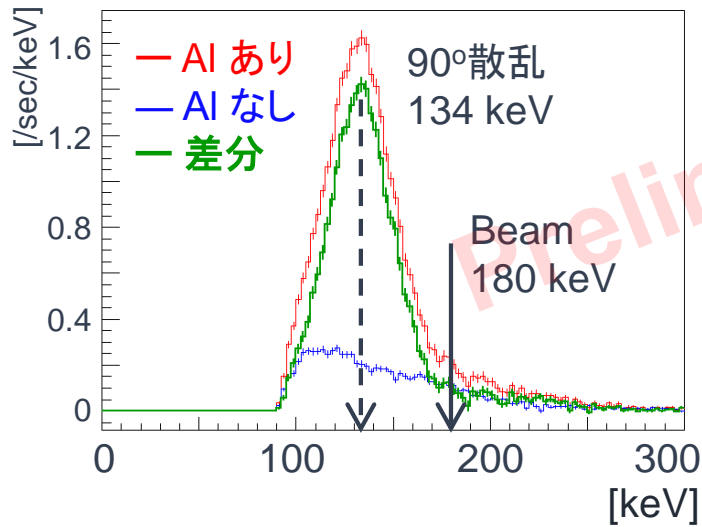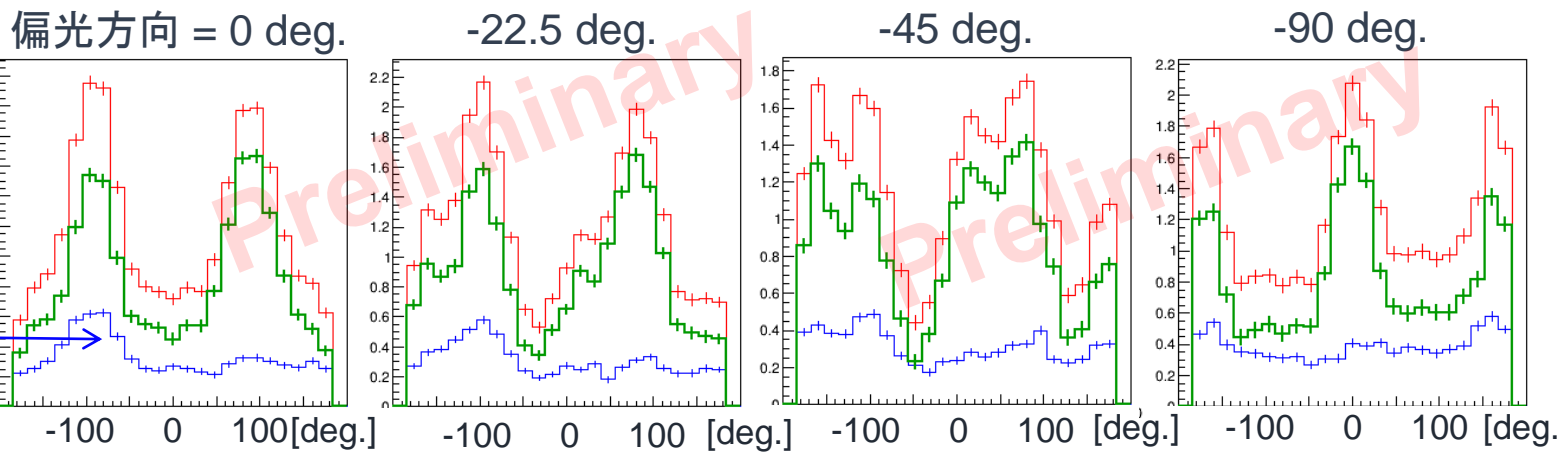
Geant4 Simulation

Geant4	Geant4 10.1 Patch-02
物理モデル	G4EmLivermorePolarizedPhysics (Fixed G4UrbanMscModel)
ジオメトリ	SMILE-II フライトモデル準拠
位置分解能	Scinti.のpixel sizeのみ
エネルギー分解能	TPC　22%＠22 keV, Scinti. 10%＠662 keV のガウス分布
その他	回路応答、解析特性は未考慮

再構成スペクトル
(AI散乱事象)

― 差分
▼ G4 sim.
最大値で規格化
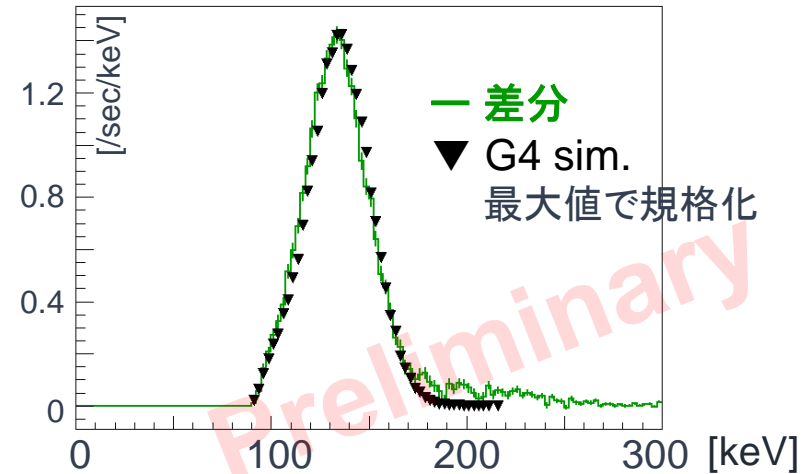
散乱ガンマ線
方位角分布

▼ G4 sim.
面積で規格化

偏光方向 = 0 deg.　　　-22.5 deg.　　　-45 deg.　　　-90 deg.
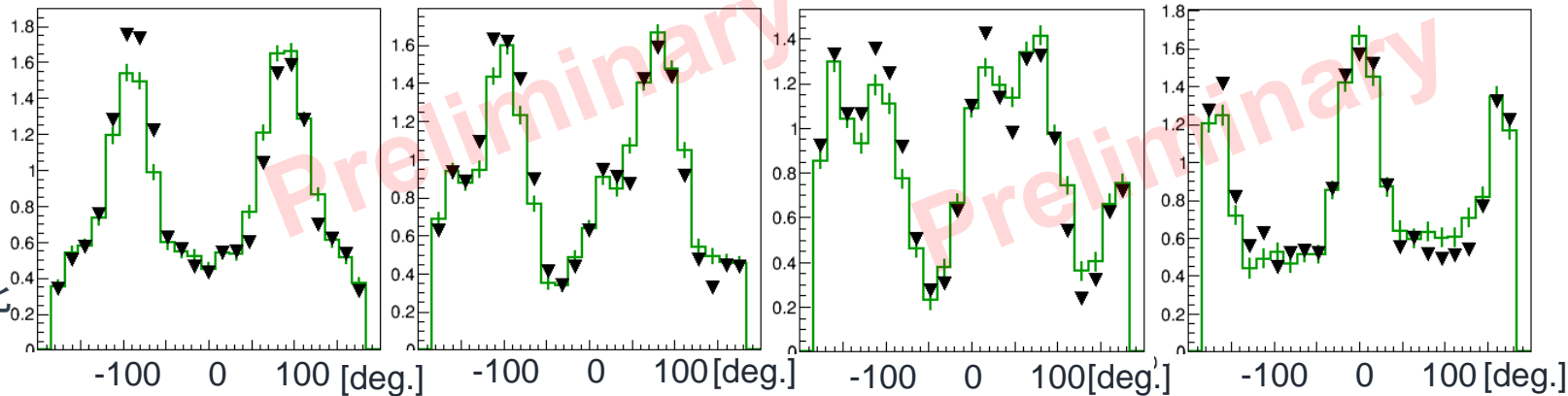
Results
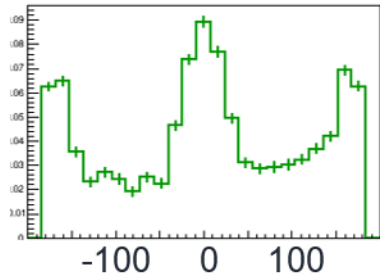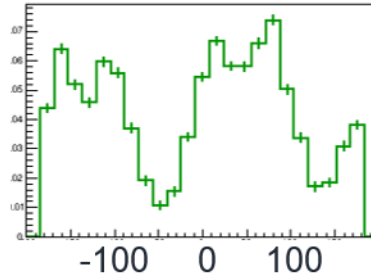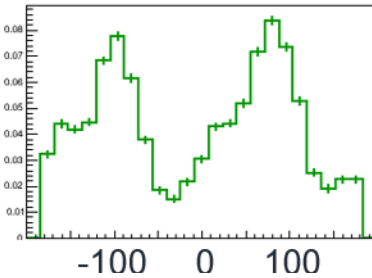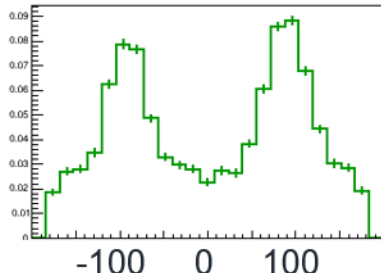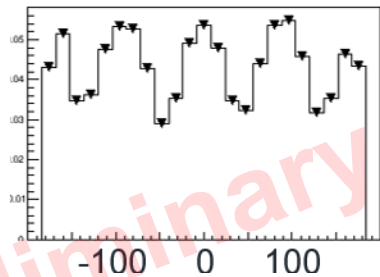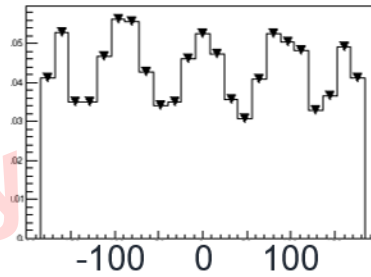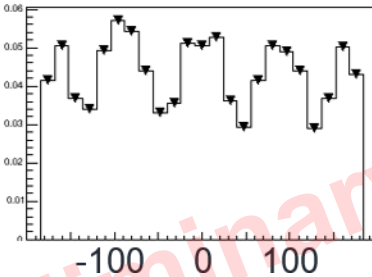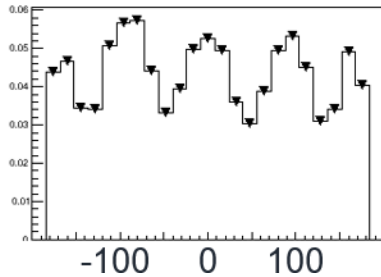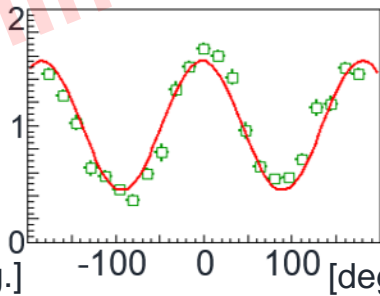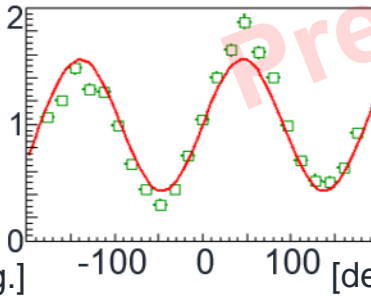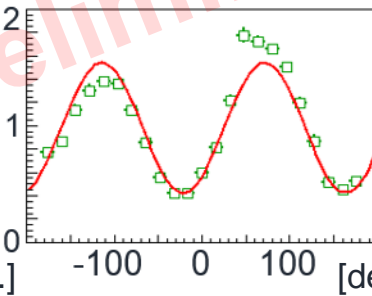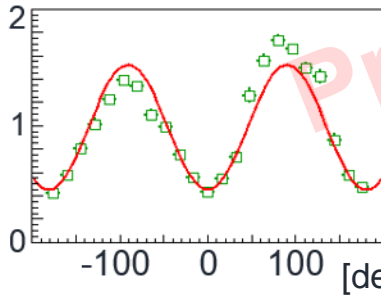
	偏光方向 = 0 deg.	-22.5 deg.	-45 deg.	-90 deg.
偏光方向 [deg.]	0.19±1.03	-18.8±0.9	-44.4±0.7	-92.1±0.9
Modulation Factor	0.57±0.01	0.59±0.01	0.59±0.02	0.58±0.02

◆ 偏光方向は設定値と誤差の範囲内で一致　◆ M〜 0.6@130 keV

Summary

❏ Well-defined PSF without ML-EM

❏ Powerful background rejection by dE/dx

❏ Polarization Measurement

➢ M ~ 0.6@200 keV, ~0.5@500 keV (simulation)

➢ Future Plan: SMILE-III ETCC (~20 cm^2 @200 keV)
   ✓ Polarization sensitivity : 3σ MDP
      Crab nebula ~ 15 %, Cyg X-1 ~ 20 % (half-day flight)
      GRBs ~   6% for 10^{-6} erg/cm^2 s (2-3 GRBs/month)
               ~ 20% for 10^{-7} erg/cm^2 s (~10 GRBs/month)

➢ Beam test @SPring-8
   ✓ 撮像・分光・偏光の同時測定
   ✓ シミュレーションによる幾何学補正
   ✓ 検出偏光方向はセットアップと一致
   ✓ M ~ 0.6@130 keV

~100% polarized
beam 182 keV

Al target
10 x 10 x 1 cm^3

SMILE-II
ETCC

y

z

Al あり

y [cm]
x [cm]