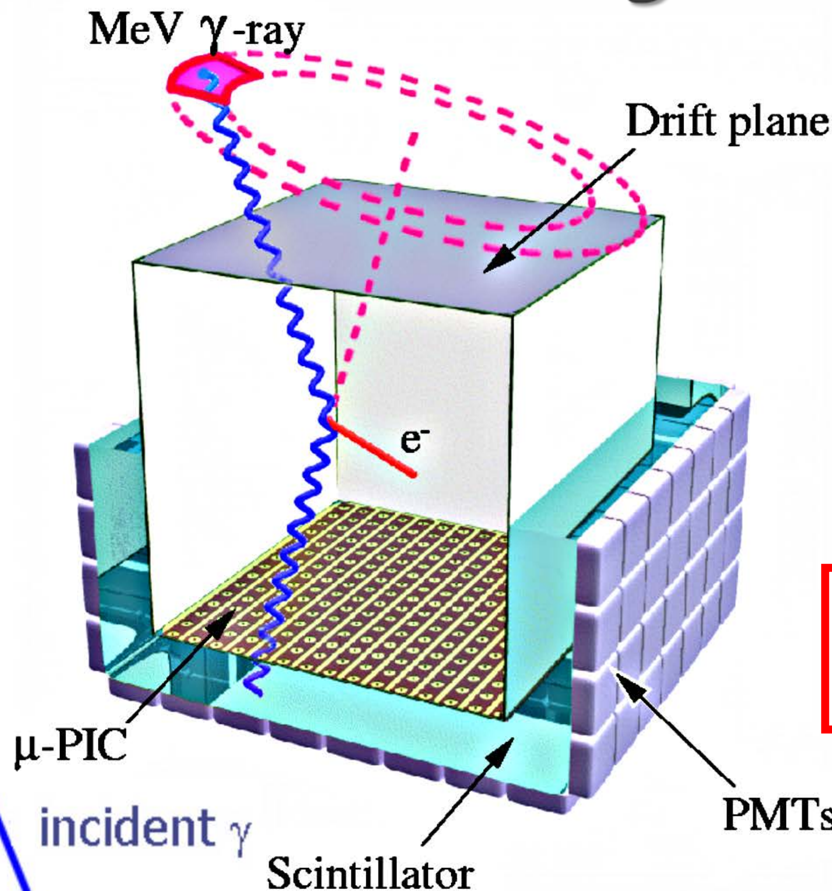
電子飛跡検出型 コンプトンカメラによる 長時間GRB検出の可能性

京都大学 生存圏研究所
高田淳史

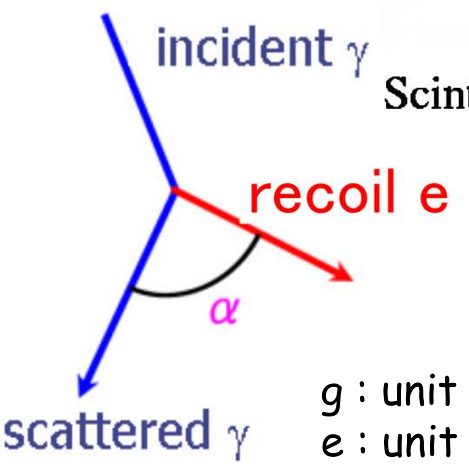
Electron-Tracking Compton Camera (ETCC)



- Gaseous TPC : Tracker
  track and energy of recoil electron
- Scintillator : Absorber
  position and energy of scattered gamma

Reconstruct Compton scattering event by event

- 1 photon ⇒ direction + energy
- Large FOV (~3str)
- Kinematical background rejection



$$\cos\alpha_{\rm geo} = \vec{g}\cdot\vec{e} \quad \Leftrightarrow \quad \cos\alpha_{\rm kin} = \left(1 - \frac{m_e c^2}{E_\gamma}\right)\sqrt{\frac{K_e}{K_e + 2m_e c^2}}$$

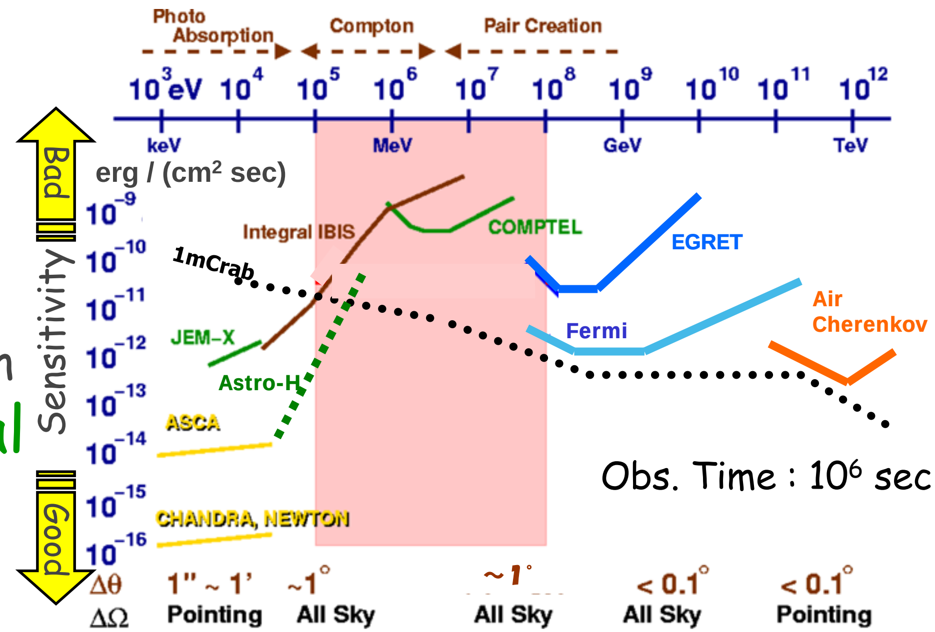
g : unit vector of scattering direction
e : unit vector of recoil direction

E_γ : Energy of scattered gamma-ray
K_e : Kinematic energy of recoil electron
$m_e c^2$: Rest mass of electron

Motivation

Observation of MeV gamma-ray will provide us…

- **Nucleosynthesis**
  - SNR : Radio-isotopes
  - Galactic plane : ^{26}Al • ^{60}Fe
  - Annihilation
- **Acceleration**
  - Jet (AGN), GRB
  - : Synchrotron + Inverse Compton
- **Strong Gravitational Potential**
  - Black Hole : accretion disk, π^0
- **Etc.**
  - Gamma-ray Pulsar, solar flare

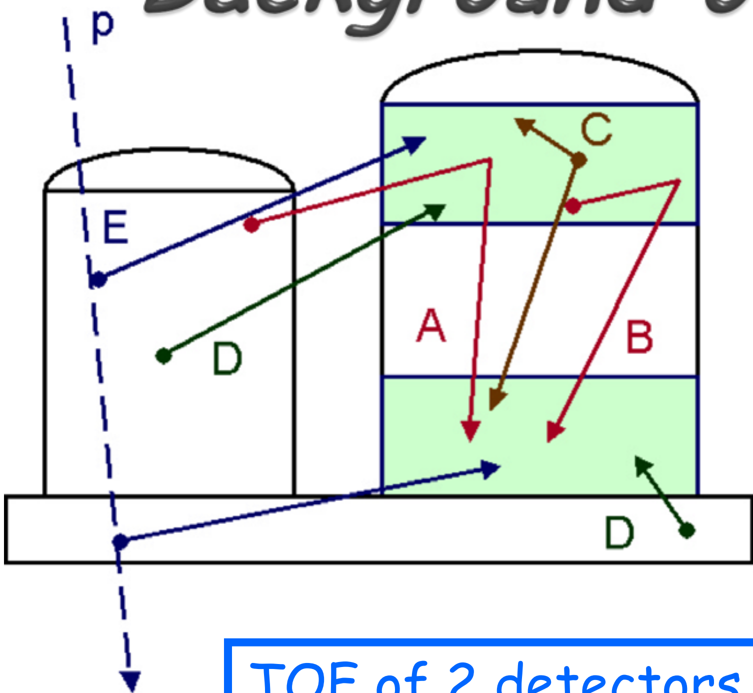


- The observation of continuum component is also important.
- Where are MeV gamma-ray objects?
- There are many background events which obstruct the observations.

Requirements for the next-generation detectors are …

- Wide-band detection
- Large Field of View
- Background rejection

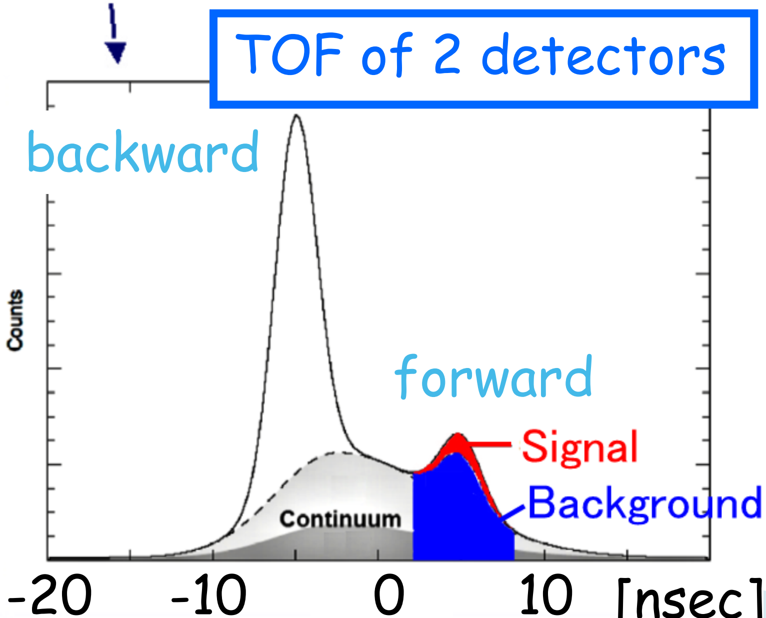
Background of COMPTEL



G.Weidenspointner, et.al. (A&A, 2001)

A : external γ
B : internal γ
} Intrinsic background
C : two γ
D : random coincidence
E: proton-induced γ

Other background
neutron
electron
gamma from atmosphere



COMPTEL has rejected such background by the measurement of the Time Of Flight between 2 detectors.

Background rejection was not complete
Bad S/N

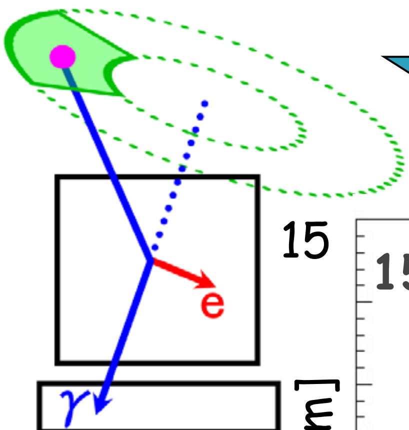
Comparison with the usual Compton method

Electron-Tracking Compton

(ETCC)

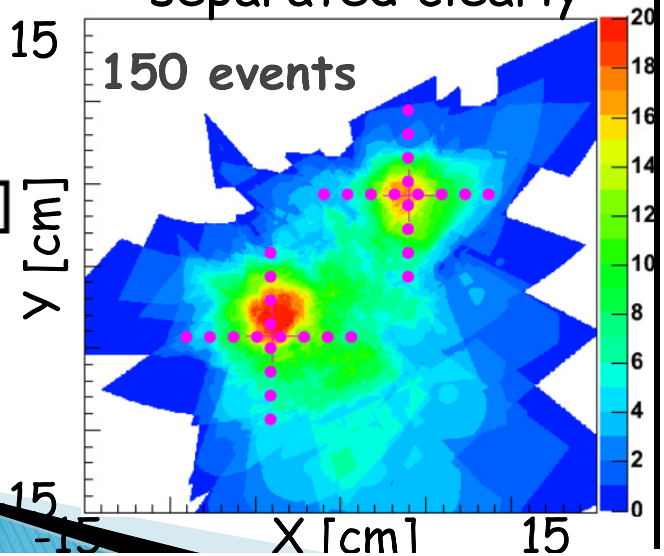
Using the electron tracks

- complete direction within sector form error region



Simply overlay

2 sources were separated clearly



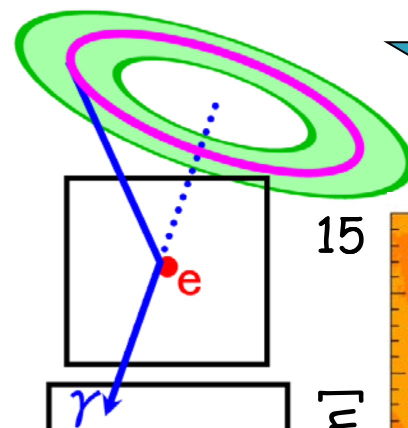
^{137}Cs(1MBq)×2, Advanced Compton

Usual Compton Imaging

(COMPTEL)

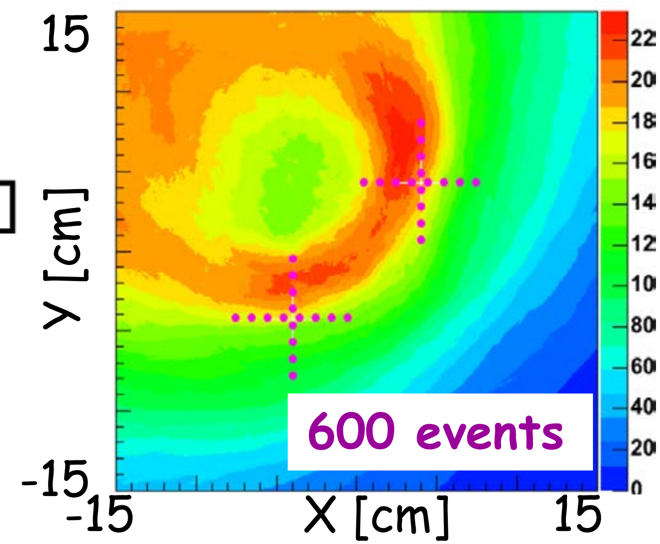
Not using the electron tracks

- only event circle within ring form error region



Simply overlay

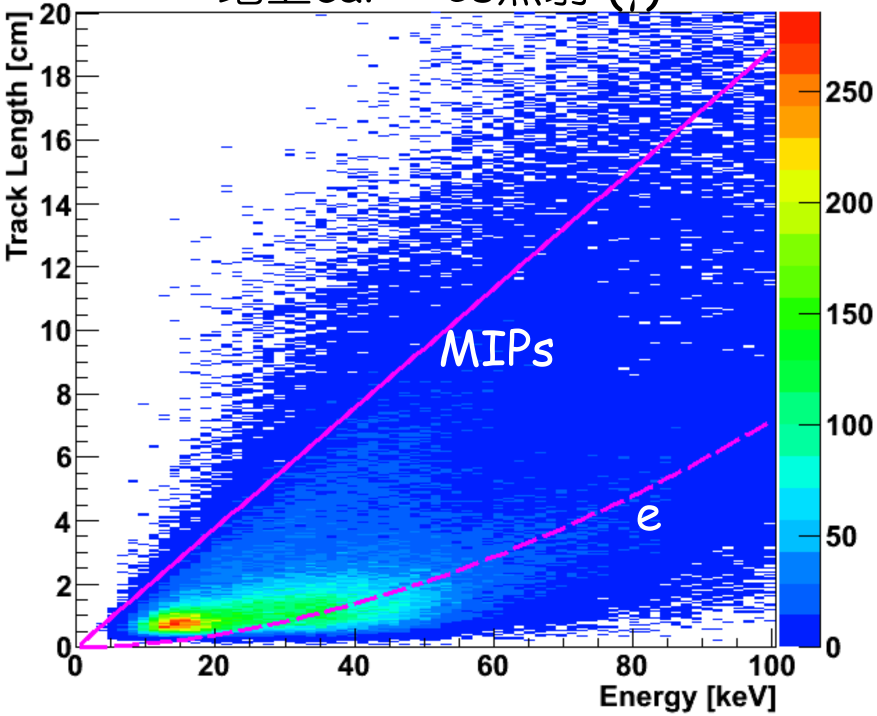
Hard to separate 2 sources



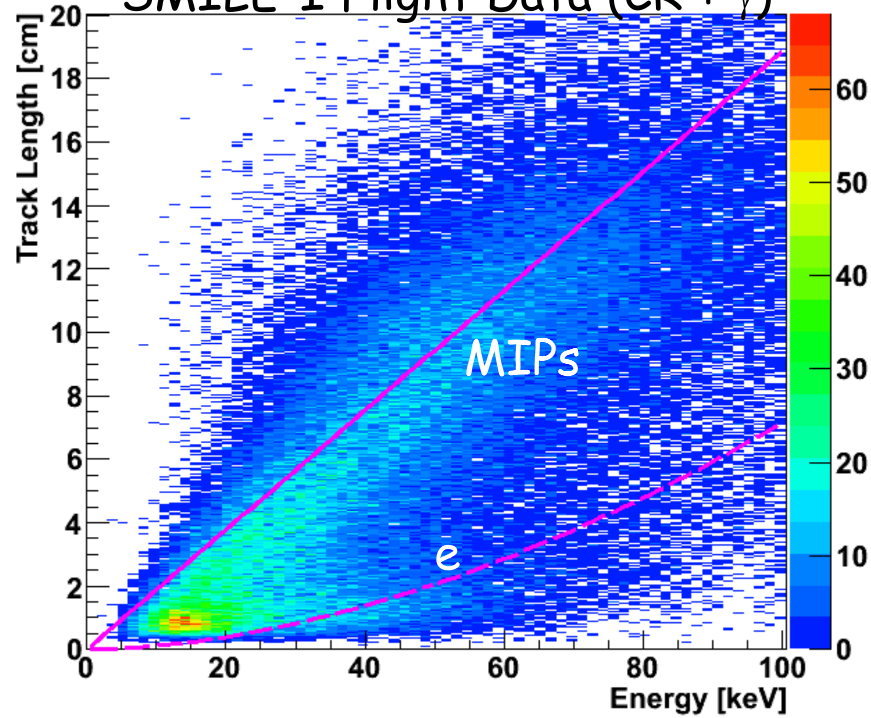
^{137}Cs(1MBq)×2, usual Compton

Background rejection by TPC

地上cal ^{137}Cs照射 (γ)



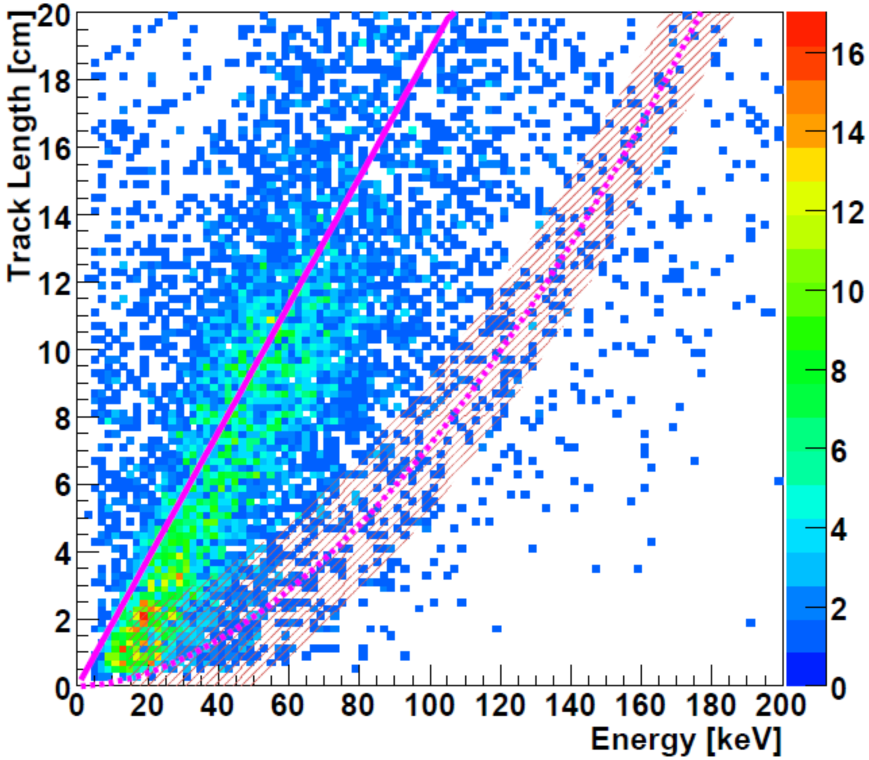
SMILE-I Flight Data (CR + γ)



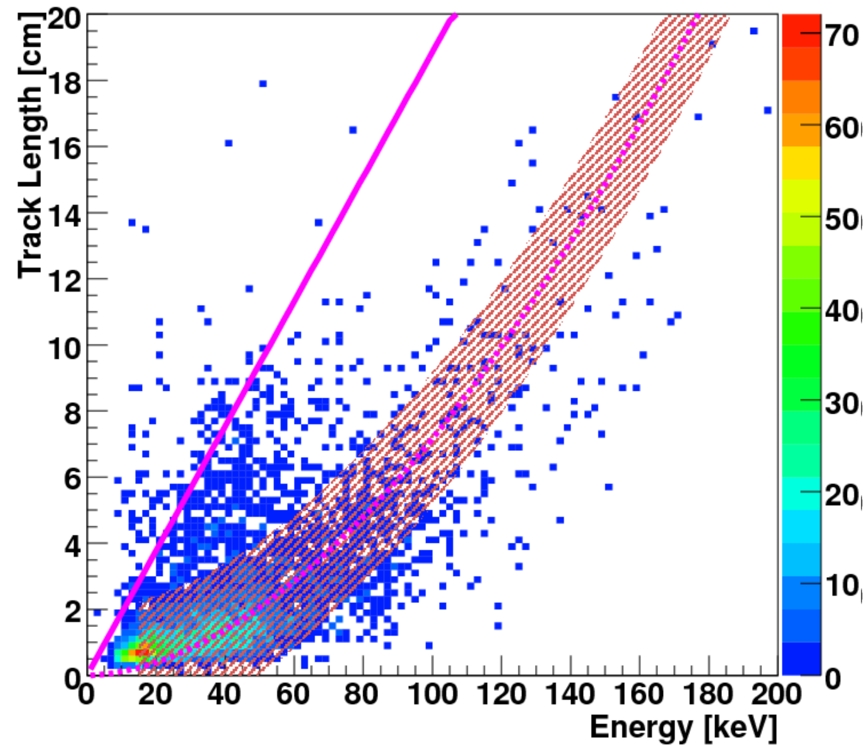
- TPCへのenergy depositとtrack lengthからparticle IDが可
- 電子と陽子の飛程の違い

⇒　ガンマ線Compton散乱と中性子の弾性散乱の区別が容易

Background rejection by TPC



Charged particle mode

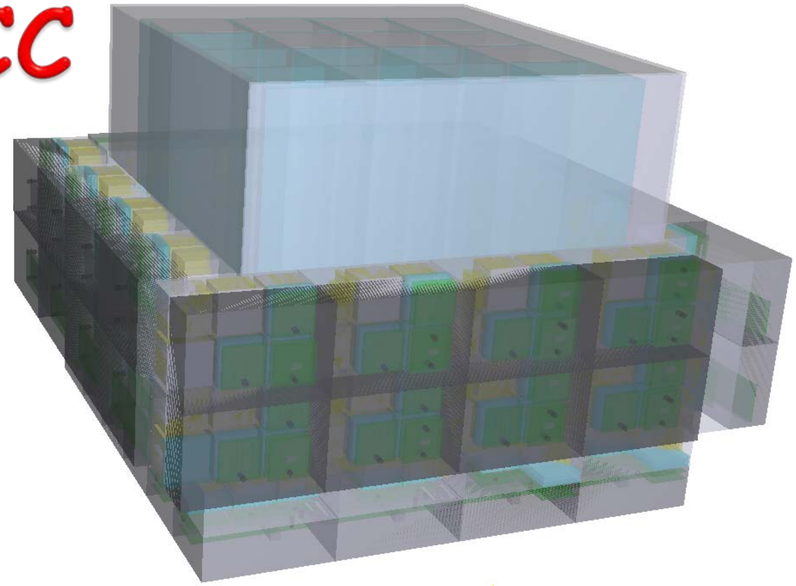


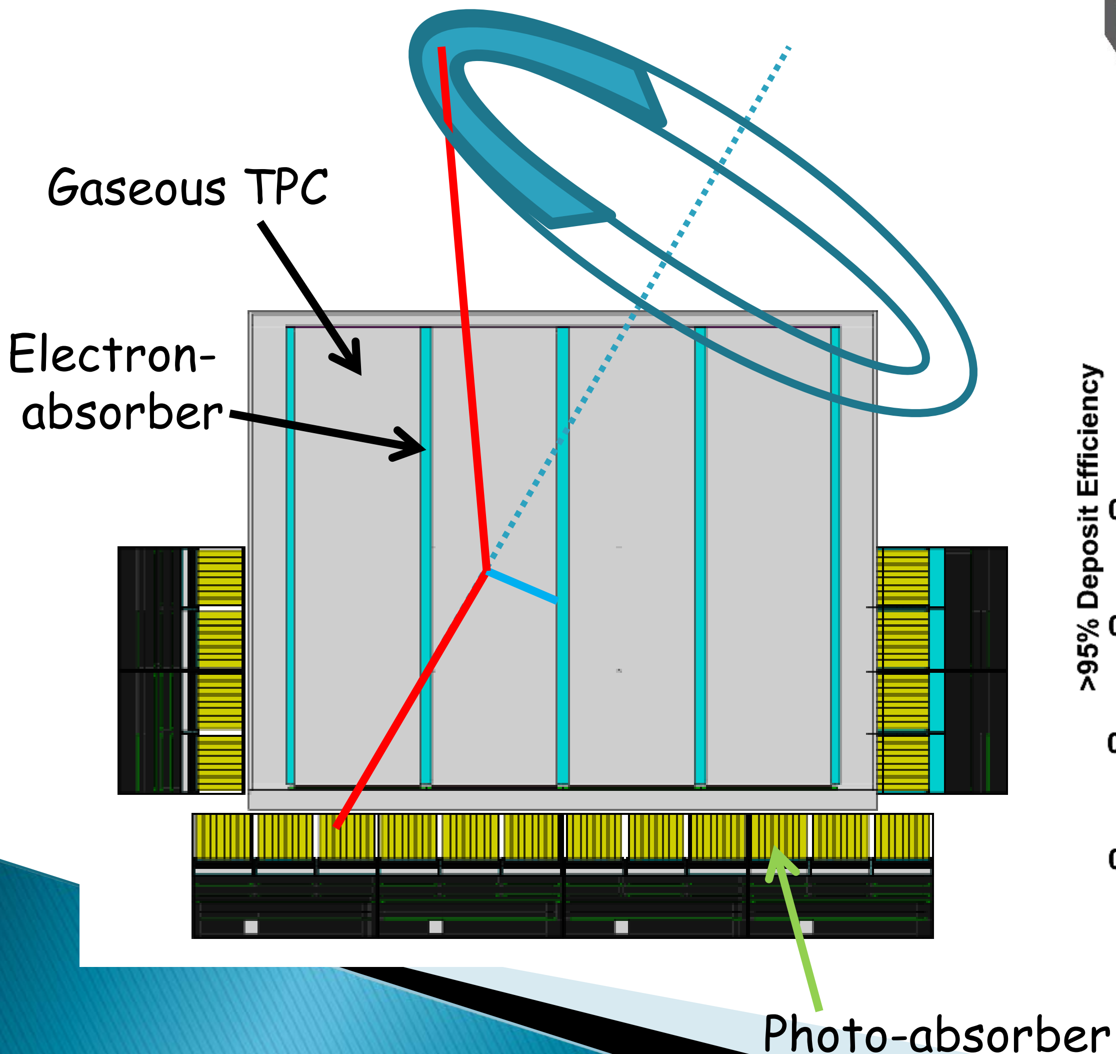
Compton mode
fiducial vol. = $7 \times 7 \times 7 cm^3$

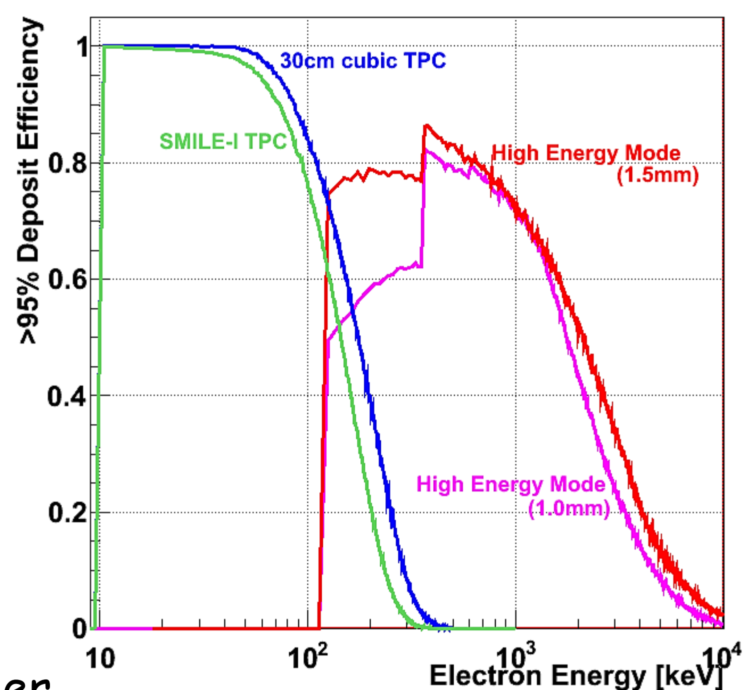
- TPCへのenergy depositとtrack lengthからparticle IDが可
- 電子と陽子の飛程の違い
  ⇒ ガンマ線Compton散乱と中性子の弾性散乱の区別が容易

High Energy mode ETCC

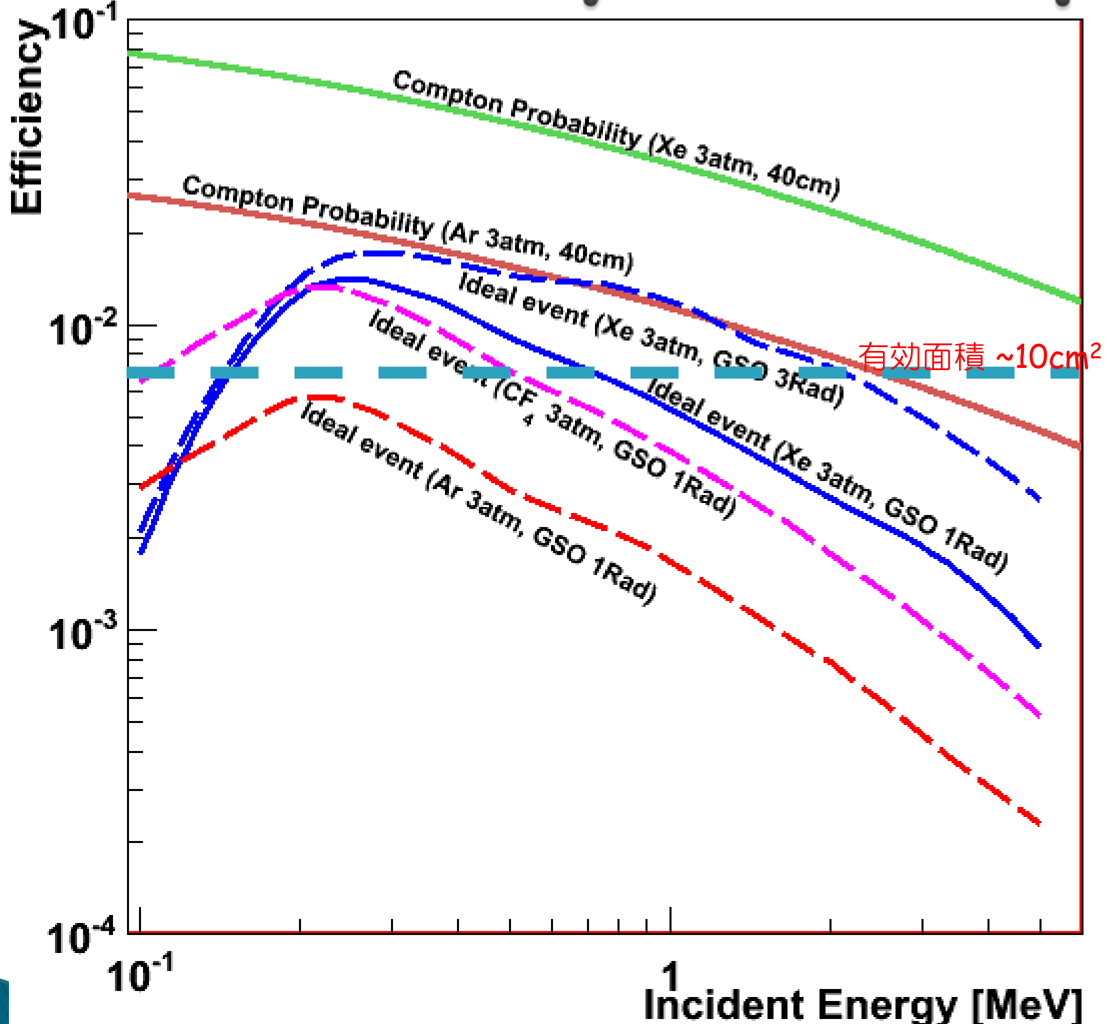
電子吸収体をTPC中に導入することで
より高エネルギー側に感度を持たせる







Efficiency of Compton event



Gas : Xe 3atm
TPC size : ($10 \times 10 \times 40$ cm^3) x (4×4)
Electron-absorber:
plastic scinti. (1.02 g/cm^3)
GSO pixel : 6x6x(13 or 40)mm^3
Bottom : 96x96 pixel
Side : (96x32 pixel) x 4

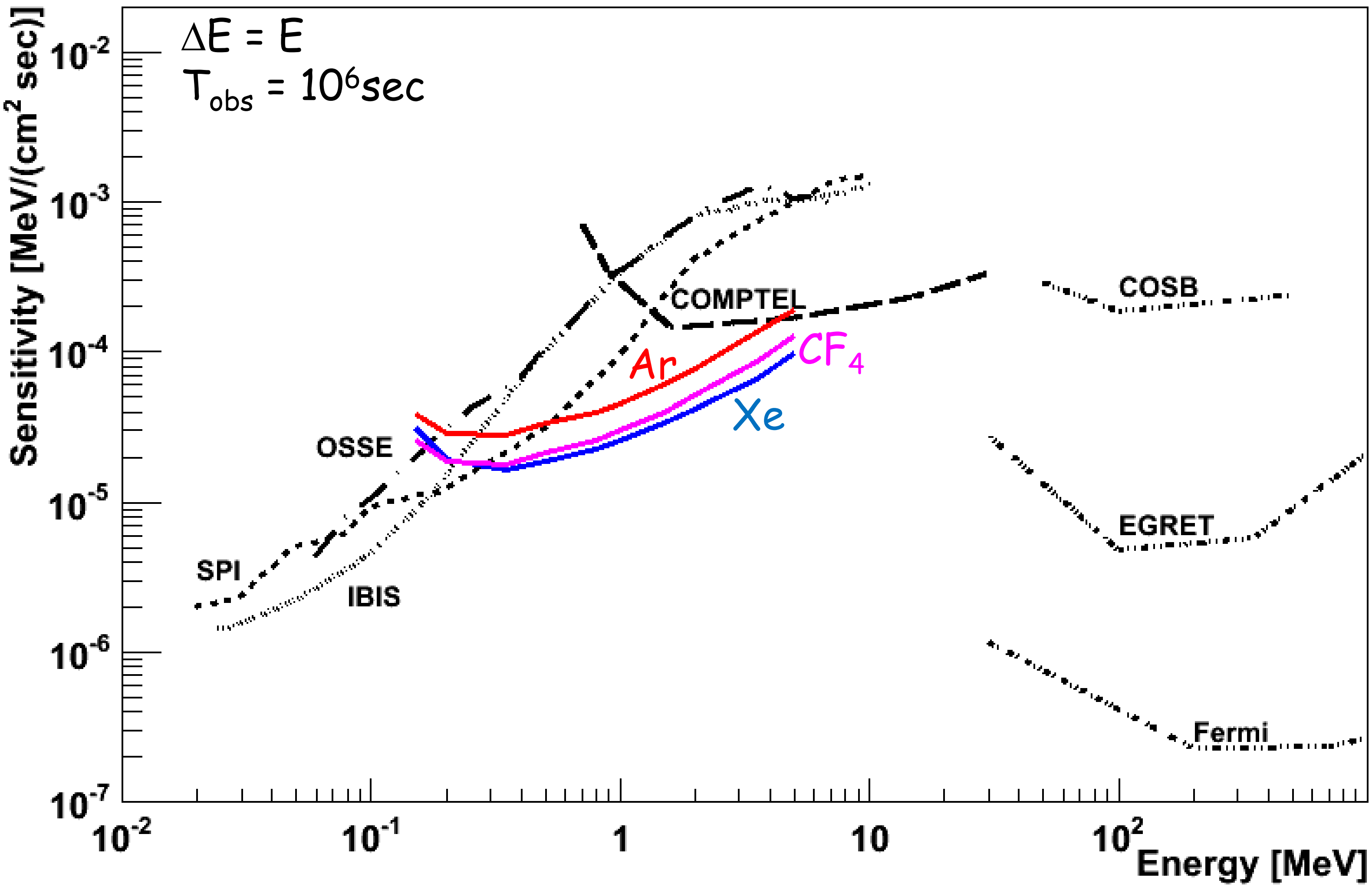
Detector responseは考慮せず

Xe 3atm + GSO 40mm
⇒ 検出器重量 ~250kg
結晶 200kg,
TPC他 50kg

Xe 3atm + GSO 13mm
⇒ 検出器重量 ~120kg
結晶 70kg
TPC他 50kg

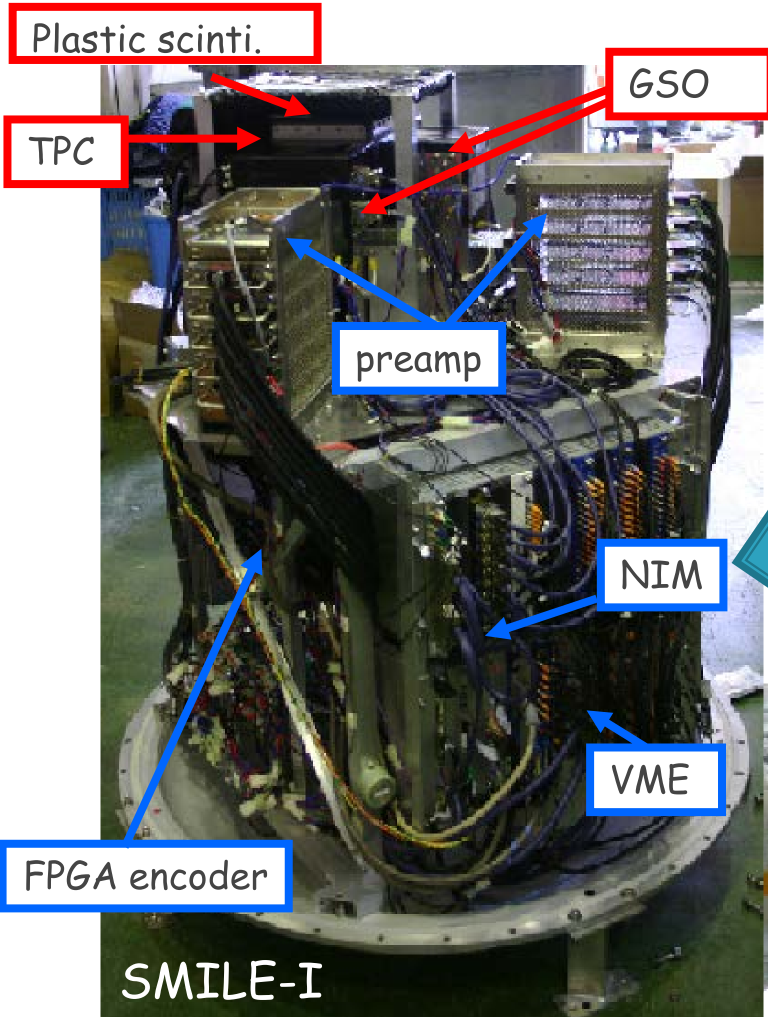
sensitivity

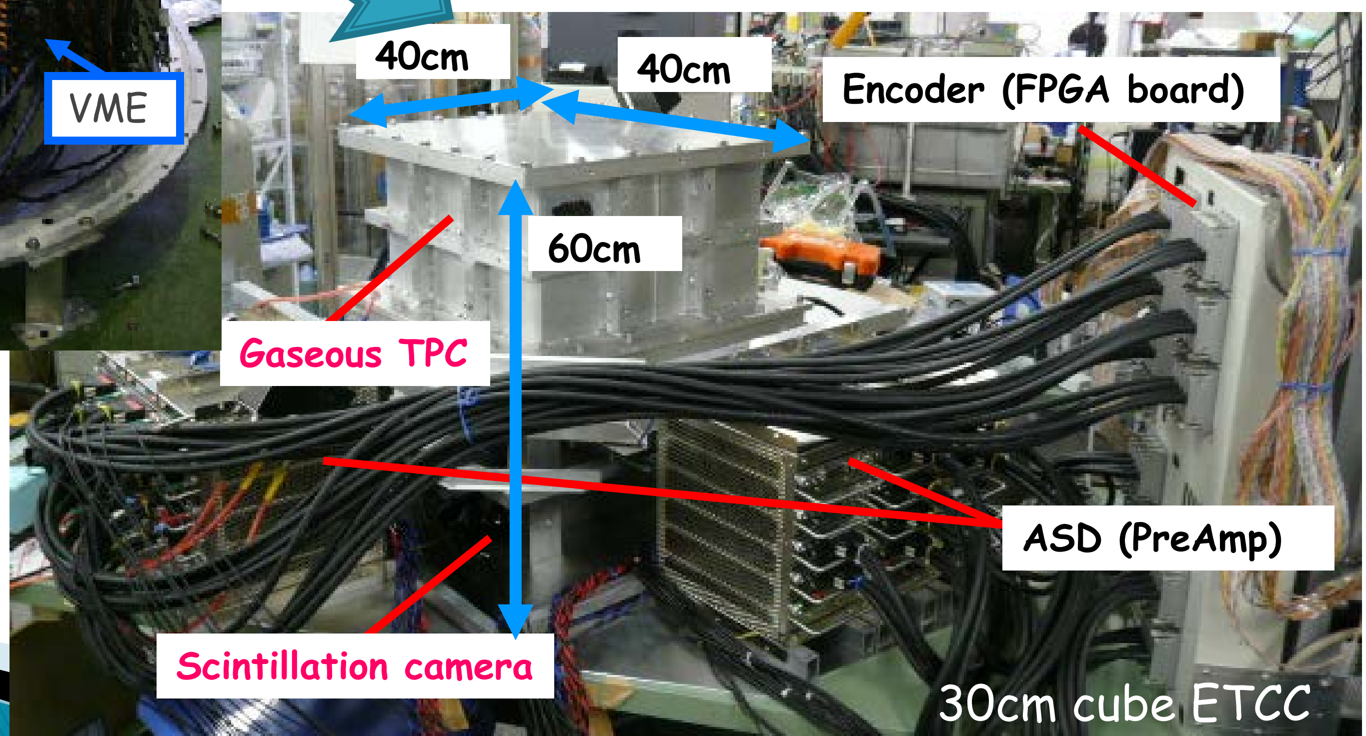
TPC : 10% @ 22keV
Scinti. : 3% @ 662keV
Detect of recoil dir. @ 5mm
Scattering angle < 90 deg



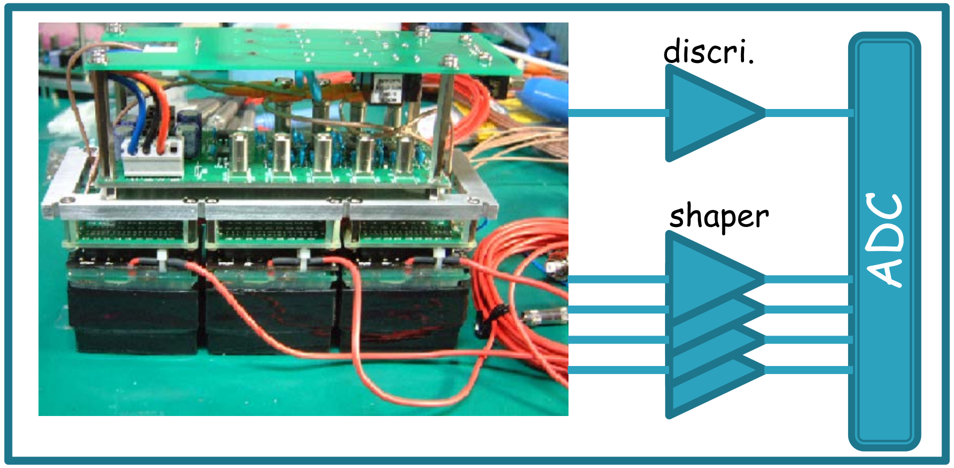
開発現状

- 飛翔体観測に向け
  省電力・省スペースなシステムの開発
- 電子飛跡の改善
- 有効面積の拡大
- ２回目の気球実験へ向けた準備



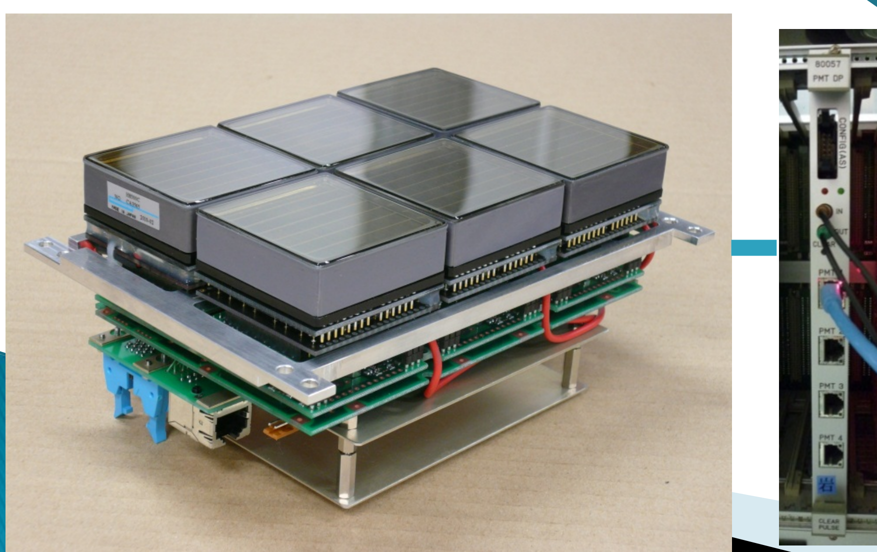


GSO readout system



SMILE-I GSO-PSA readout system

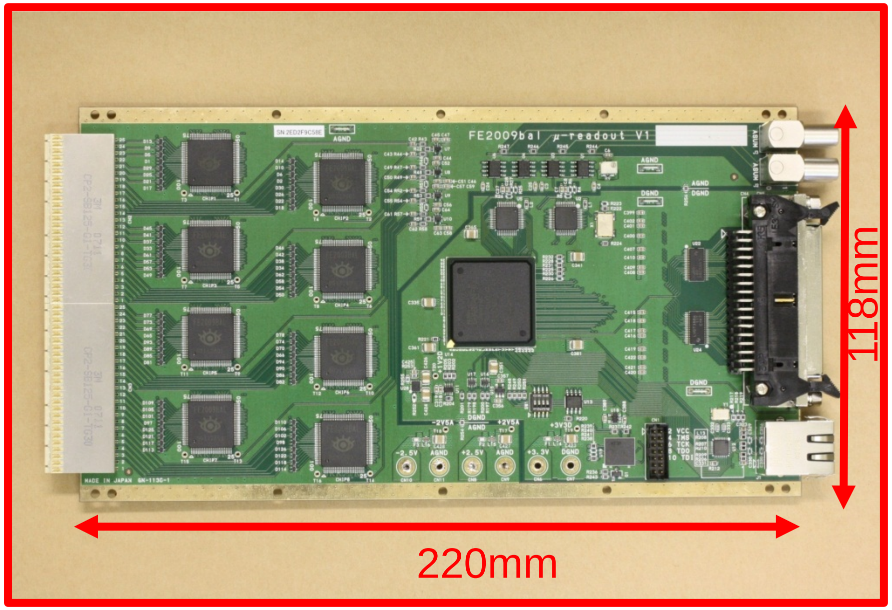
- 抵抗分割による読み出し
  192 pixels/4 ch
- 消費電力：1.7 W/ch
- Energy分解能：11% @ 662keV
- Dynamic range：80-800 keV
- NIM shaper + VME PHADC



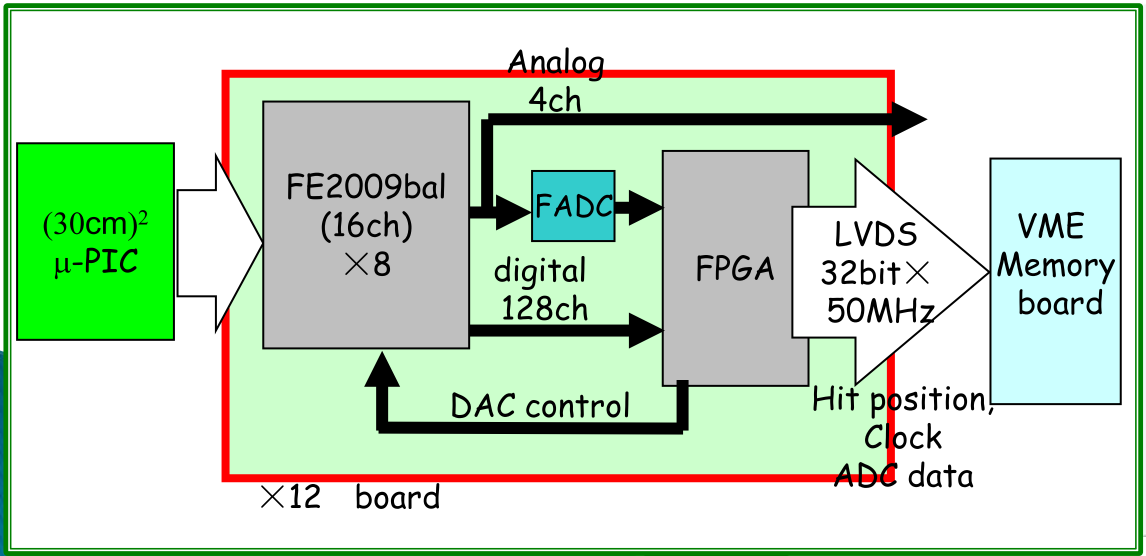
SMILE-II Headamp unit system

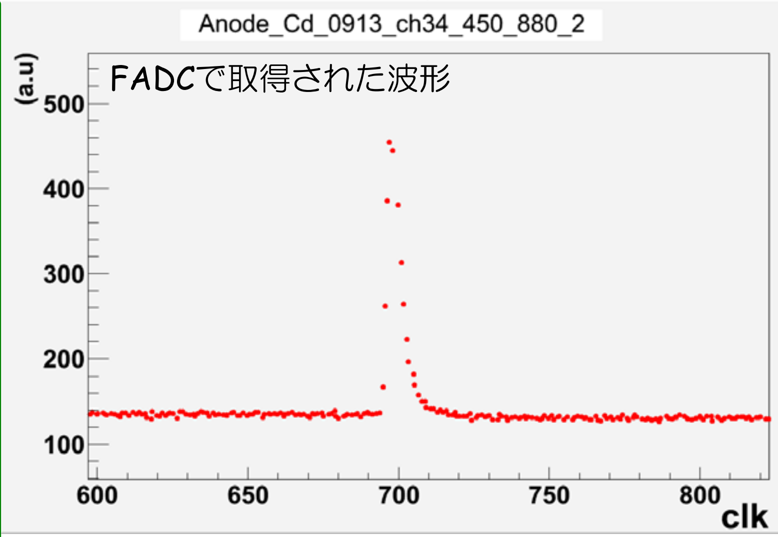
- 抵抗分割による読み出し
  64 pixels/4 ch
- 消費電力：0.4 W/ch
- Energy分解能：10.3% @ 662keV
- Dynamic range：80-1300 keV
- VME buffer board

TPC readout

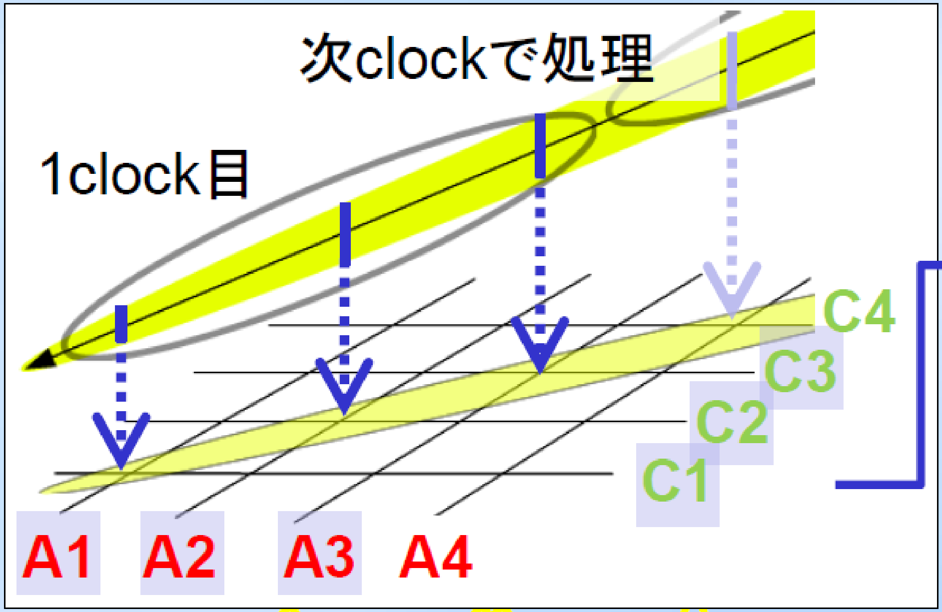


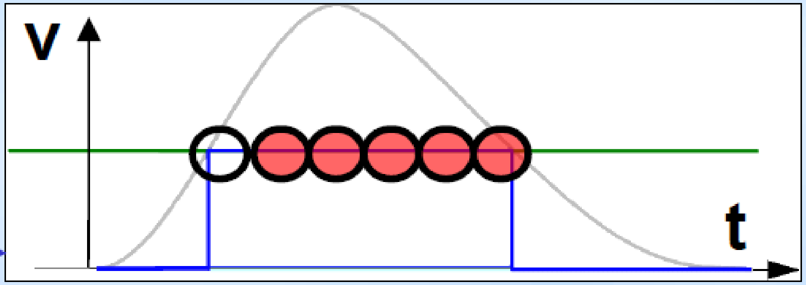
Specification of Readout Board
- 8 FE2009bal chips (128ch).
- 32ch sum analog signal output.
- 10bit 100MHz ADC ×4.
- FPGA : Xilinx Spartan6
  (XC6SLX100-2FGG676C) .
- Parallel LVDS output
  50MHz, 32bit (1.6Gbps).
- ±2.5V and +3.3V are required.
- Power Consumption : ~5.5W/board.





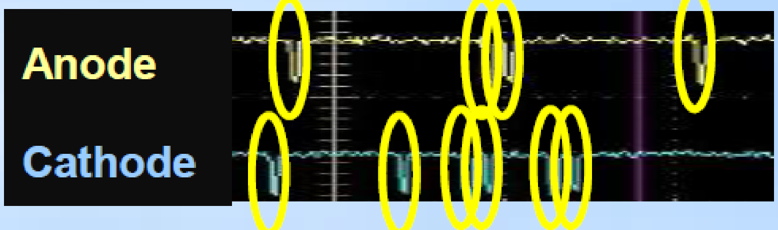
改良した飛跡取得アルゴリズム





1、信号の立ち上がりを検出

2、10ナノ秒幅でHit したストリップ番号の最大値と最小値を記録



3、10ナノ秒幅でAnode,Cathode Hitのコインシデンスをとる

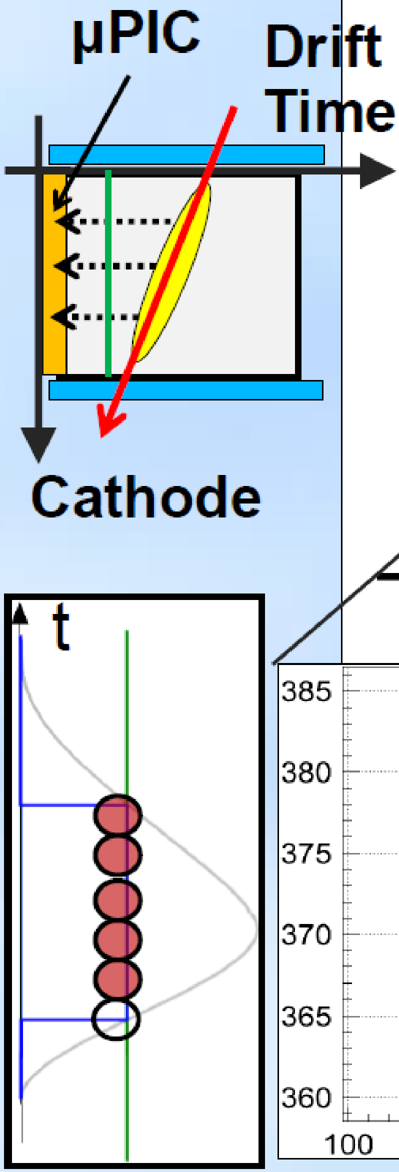
ハードウェア（FPGA）のプログラムを全面改訂した

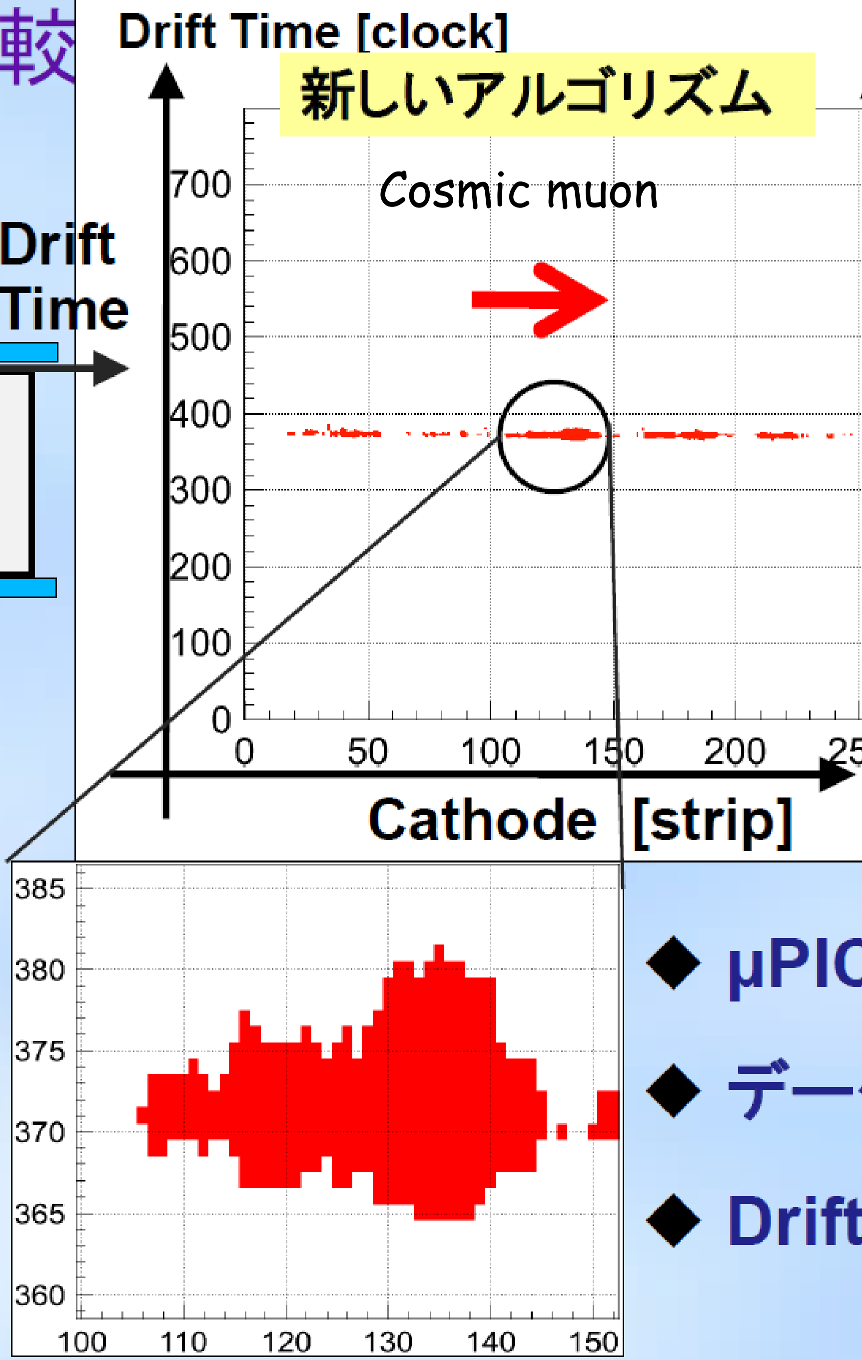
1、スレッショルドを超えている間、検出を続ける

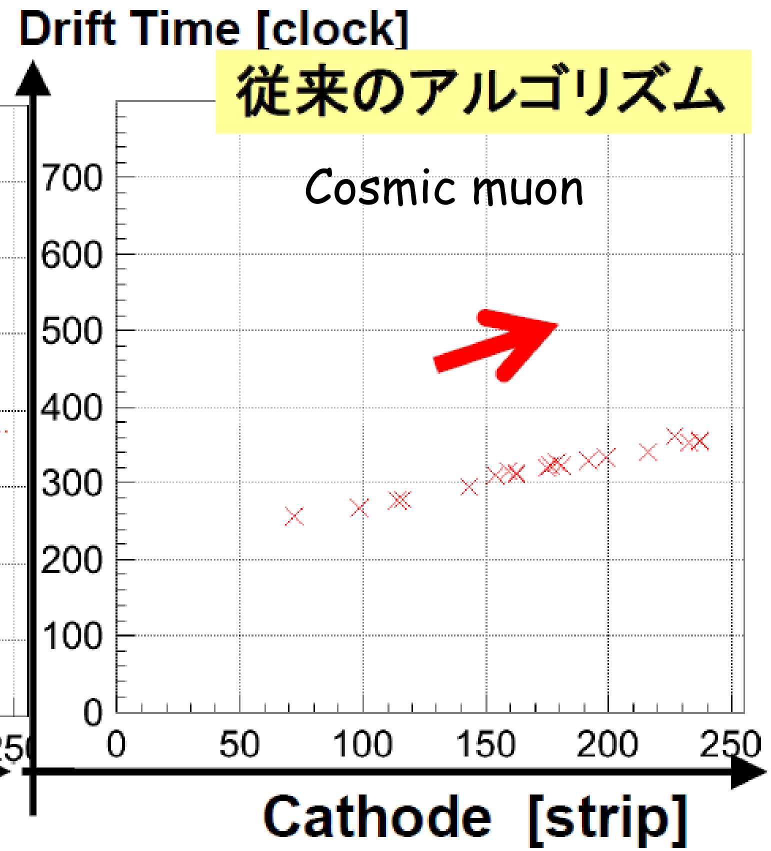
2、10ナノ秒幅でHit したストリップ番号の**すべて**を記録

3、Anode,Cathode Hitの**コインシデンスをとらず**別々に記録

飛跡比較



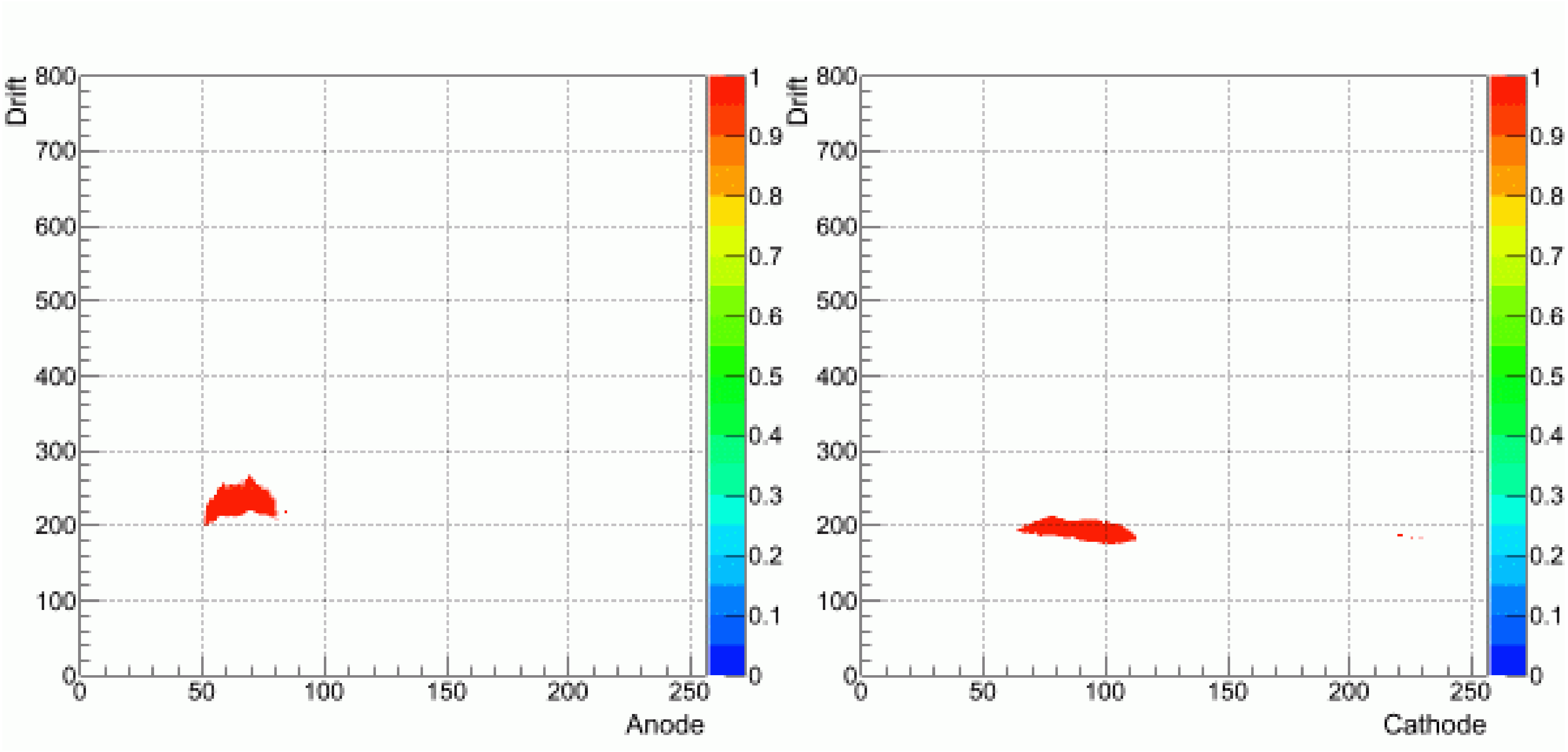




- μPICに対して平行に近い飛跡
- データ点が密である
- Drift方向に幅 をもつ

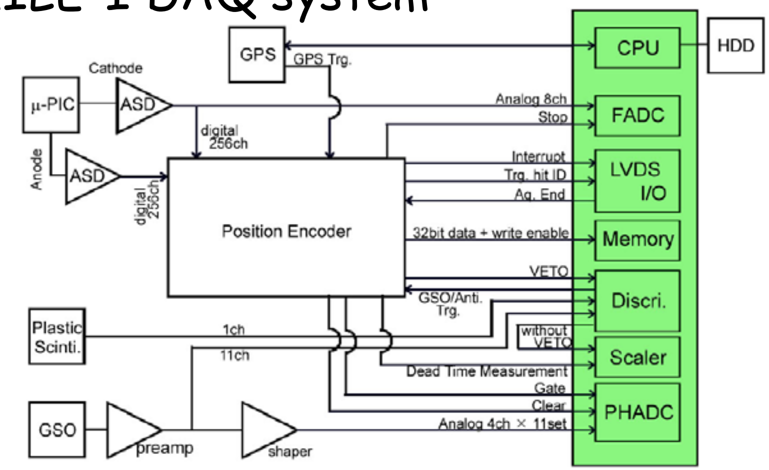
〜信号のパルス幅

新しい手法で得られた電子飛跡

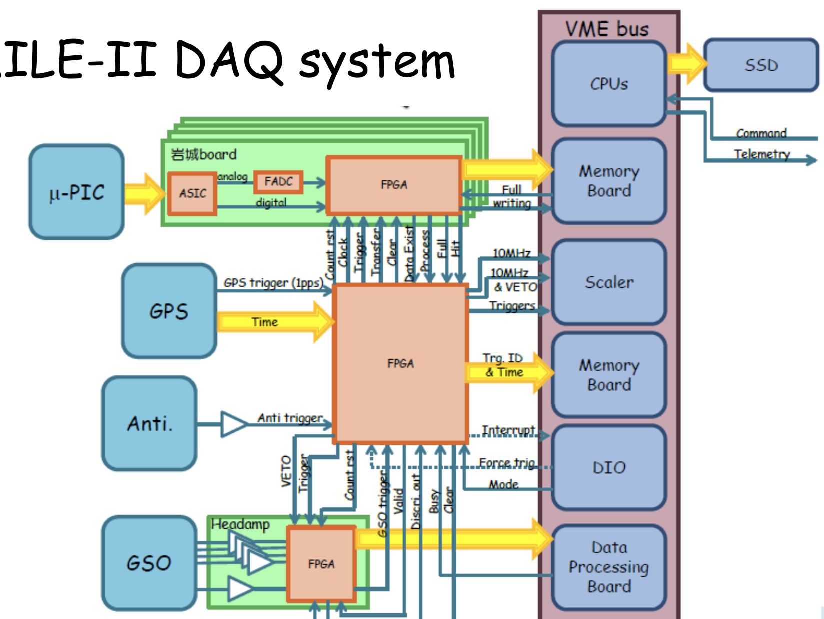


SMILE-II DAQ

SMILE-I DAQ system



SMILE-II DAQ system



SMILE-I DAQ

- Trigger後、CPUが全てのdataを取得
- CPUが取得中、ずっとVETO

SMILE-II DAQ

- Trigger後、dataはbufferへ貯める
- Dataがbufferに移動したらVETO解除
- CPUはDAQに関係なくbufferのdataをstorageに保存するのみ

さらに将来のDAQ

- Trigger後、dataはnetwork上のstorageへ
- CPUは不要に

まとめ

- 電子飛跡検出型コンプトンカメラを開発中
- MeVガンマ線天文学の開拓を目的、
  GRB探索にも可能性
- 飛翔体観測に向け、システム更新中
- 有効面積・角度分解能向上を狙った開発も進行中