The Si/CdTe semiconductor Compton camera of the ASTRO-H Soft Gamma-ray Detector

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Hiroshima, Japan

ASTRO-H SGD

SGD: Soft Gamma-ray Detector

ASTRO-H observational capabilities

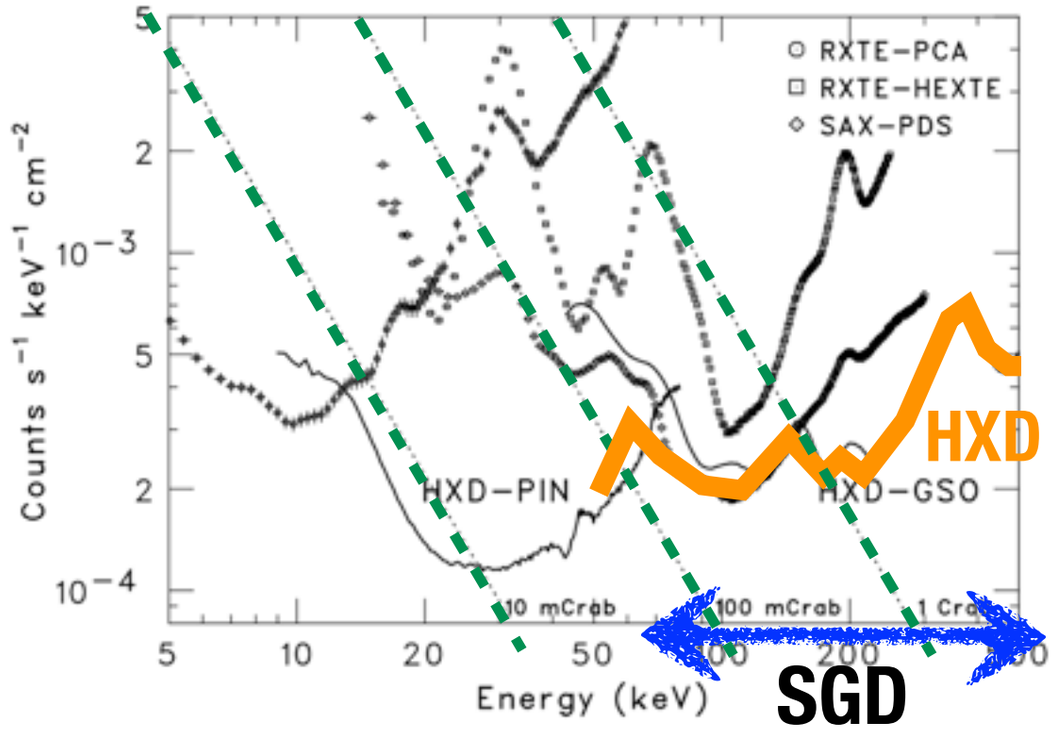
1. ---Hard X-ray imaging spectroscopy---
2. ---The micro-calorimeter observation---
3. **The most sensitive wide-band observation over an energy range from 0.3 to 600 keV.**

60--600 keV sensitive observation

Soft gamma-ray observations: struggles against the high background

0.01 Crab 0.1 Crab 1 Crab

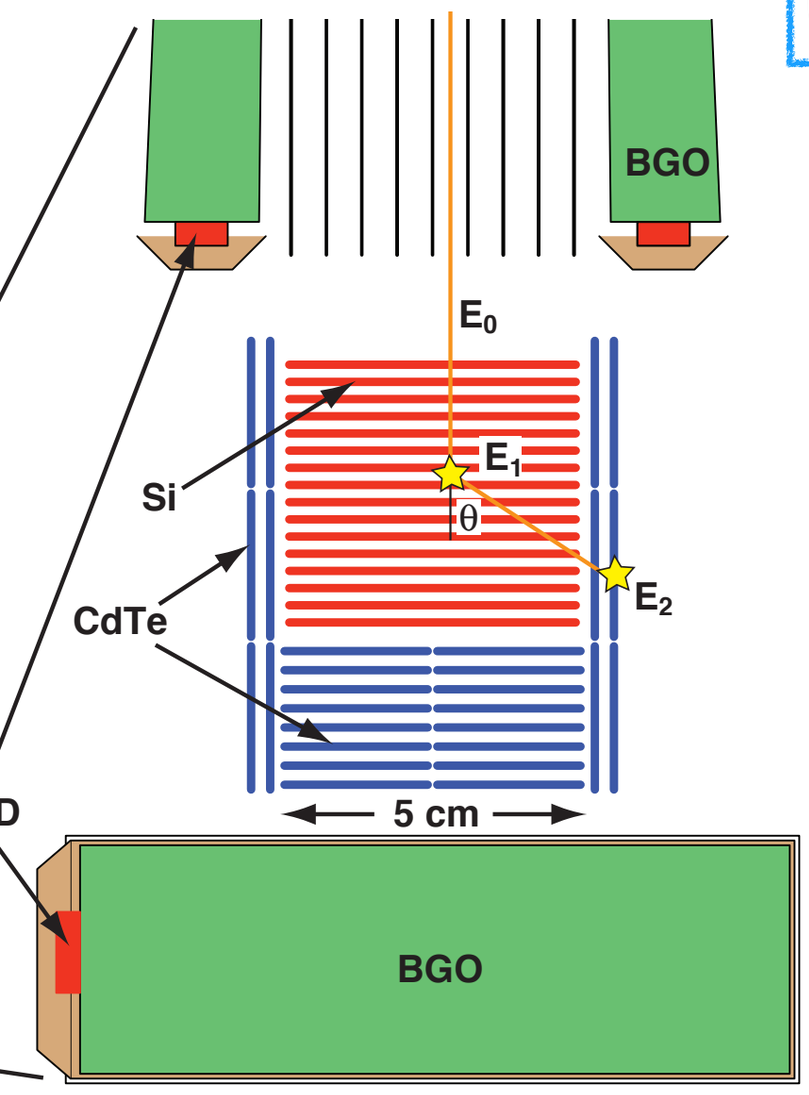
Background levels of past/current missions



ASTRO-H Thermal Test Model

SGD concept & Si-CdTe semiconductor Compton camera

SGD: Compton camera + narrow FOV active shield(Suzaku HXD)



T. Takahashi et al, SPIE 2002

Compton camera: inside well-type BGO active shield

record interaction information (energy, position)

Compton Scattering: gamma-ray specific interaction

select only gamma-ray-induced events

$$\cos\theta = 1 + \frac{m_e c^2}{E_1 + E_2} - \frac{m_e c^2}{E_2}$$

determine Compton scattering angle

-> constraint of incident gamma-ray direction

reject the gamma-ray events not coming from opening angle

azimuth angle distribution -> polarization information

precise "gamma-ray tracker"

Si-CdTe semiconductor Compton camera (Si scatter detector and CdTe detectors)

SGD Compton camera requirements

Requirements for the SGD observation performance

- Effective Area: > 20 cm^2@ 100 keV
- Energy Resolution: < 2 keV (FWHM) @ 60 keV or < 2% (FWHM)
- Energy Range: 60—600 keV

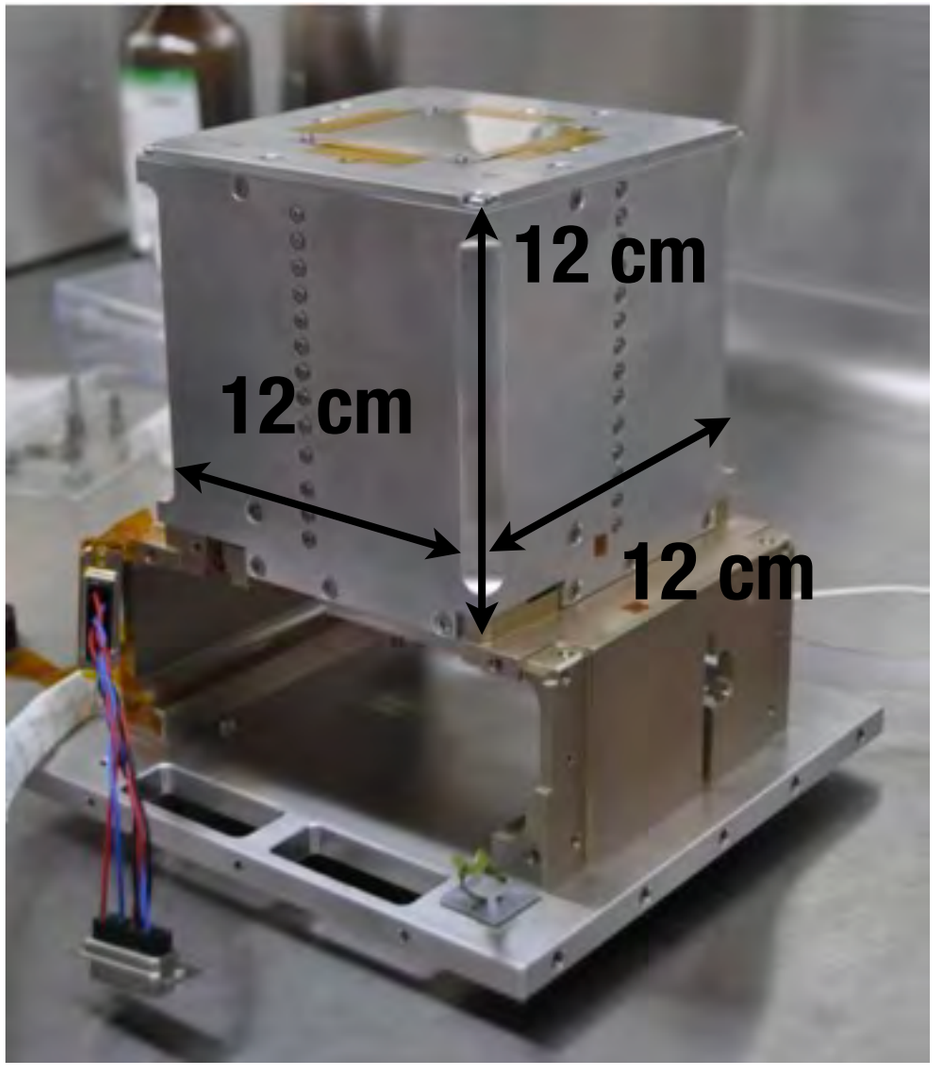
Si-CdTe Compton camera constraint
size: ~10 x 10 x 10 cm^3 (detection area ~5 x 5 cm^2)
number: 6 (in total ASTRO-H)
power: < 5-6 W/Camera

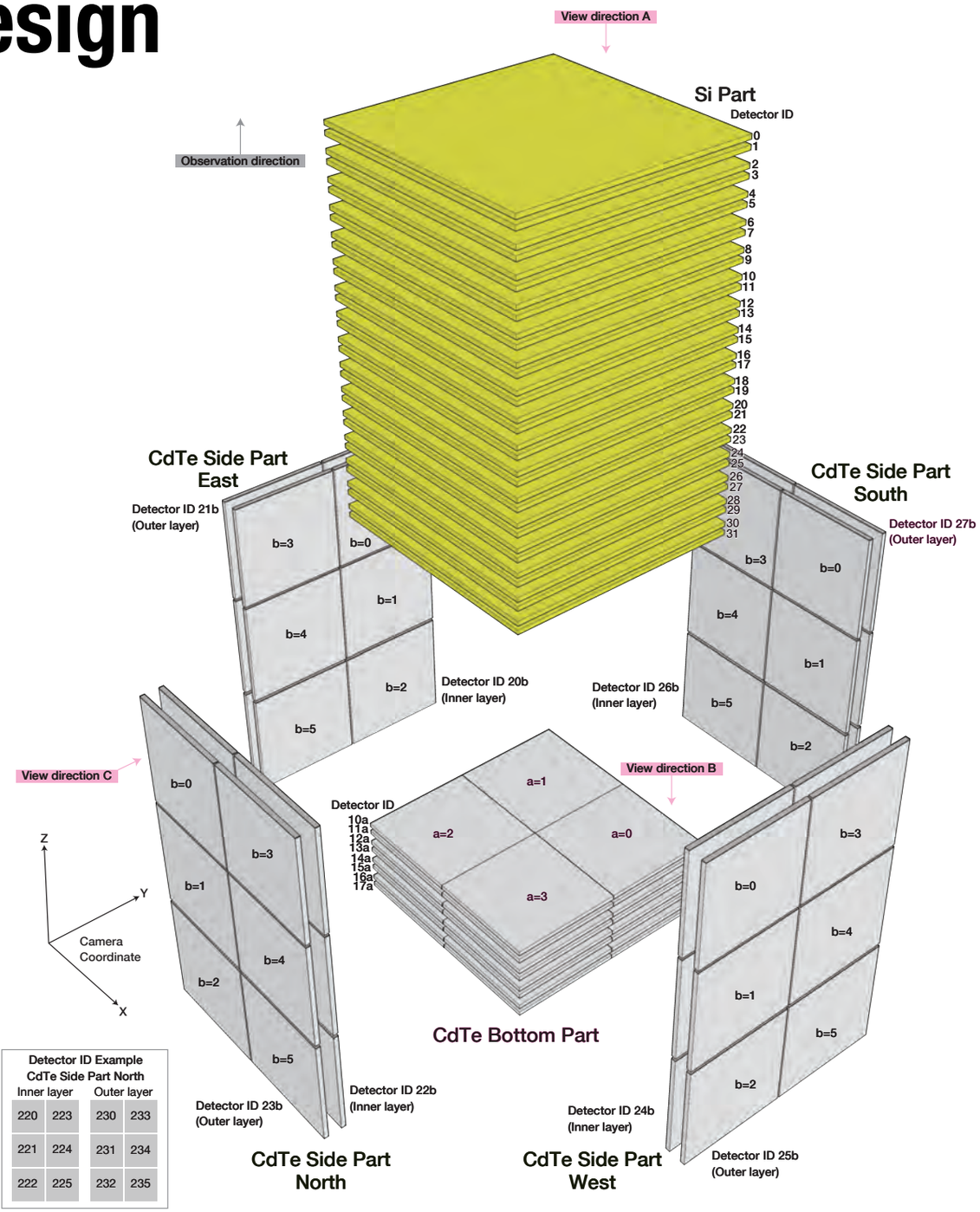
Si:
detection area > 5 x 5 cm^2
total thickness ~2 cm (50% interaction efficiency @100 keV)
32 layers (0.6 mm thick devices)

CdTe:
covering 50% solid angle of Si part

ASIC: readout
only digital I/O (inc. internal ADC)
low power (>10000ch -> < 0.5mW/ch)
noise performance 100--200e-(ENC) (with a capacitance of several pF)

Camera Design





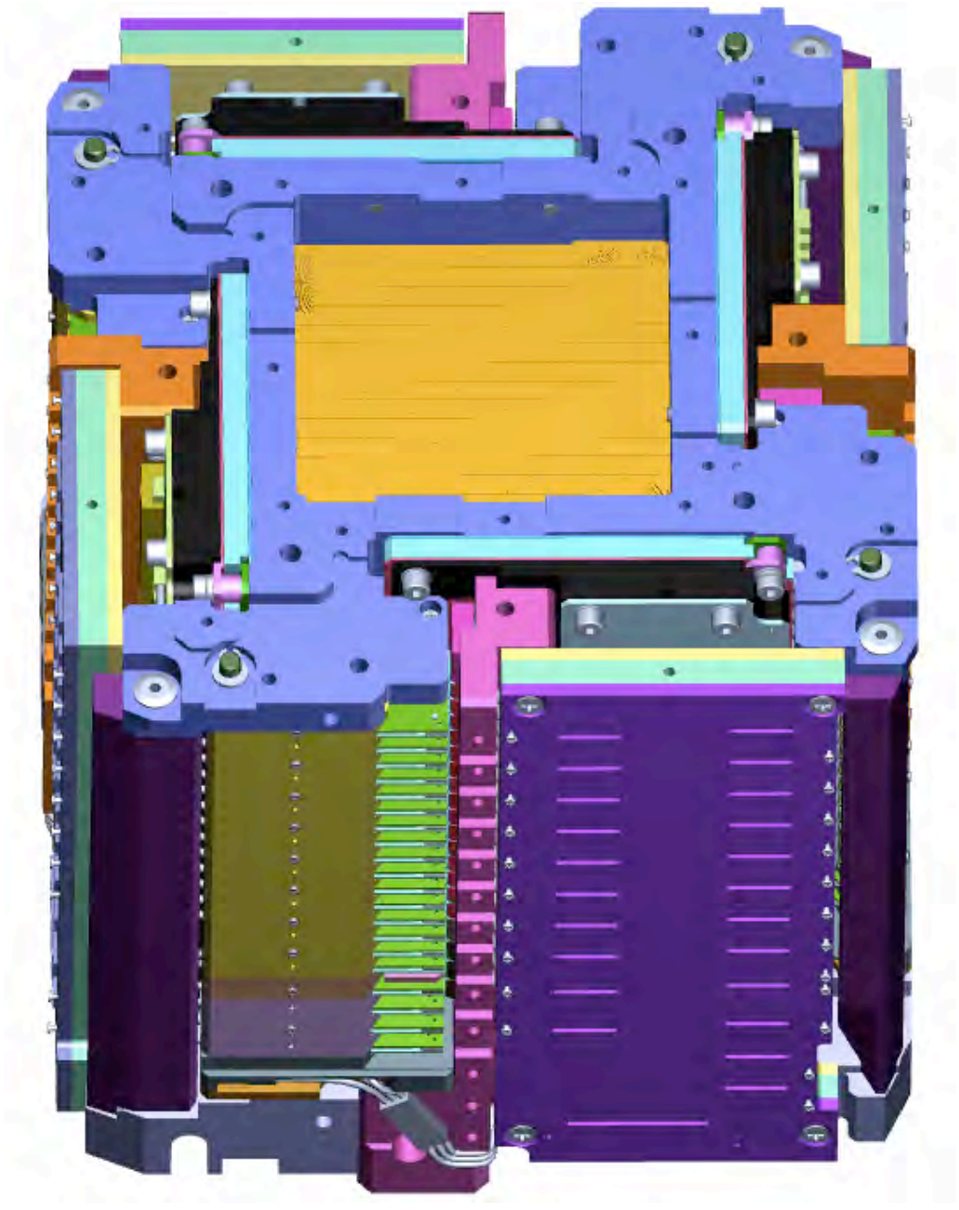
Detector ID Example
CdTe Side Part North

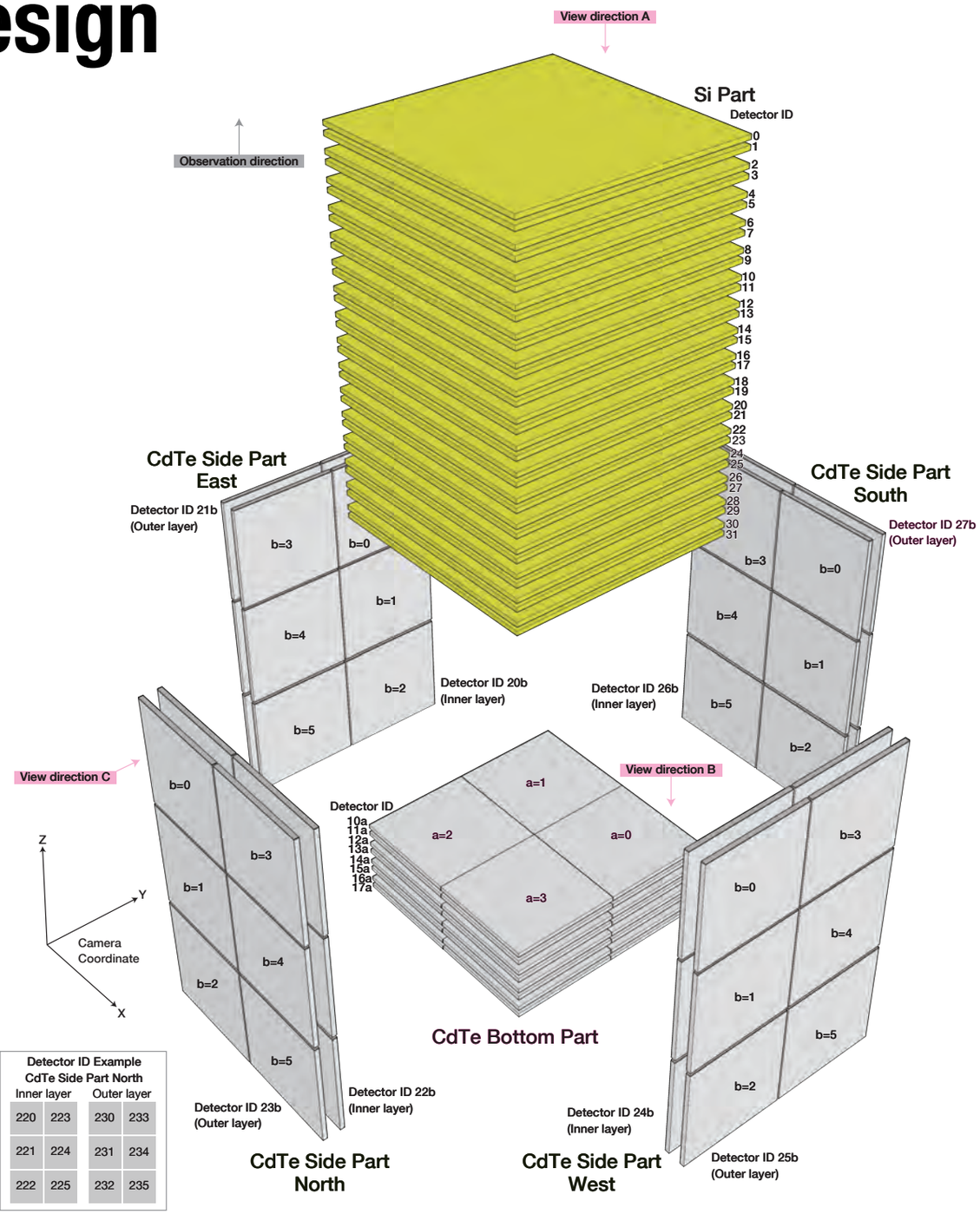
Inner layer		Outer layer	
220	223	230	233
221	224	231	234
222	225	232	235

- 32 layers of 0.6 mm thick Si Pad
- 8 layers of 0.75 mm thick bottom-CdTe Pad
- 2 layers of 0.75 mm thick side-CdTe Pad
- 3.2 mm pitch pads for Si and CdTe
- Readout channels: 13312 ch / 1 Compton Camera

$50cm^3$ Si
$40cm^3$ CdTe

Camera Design





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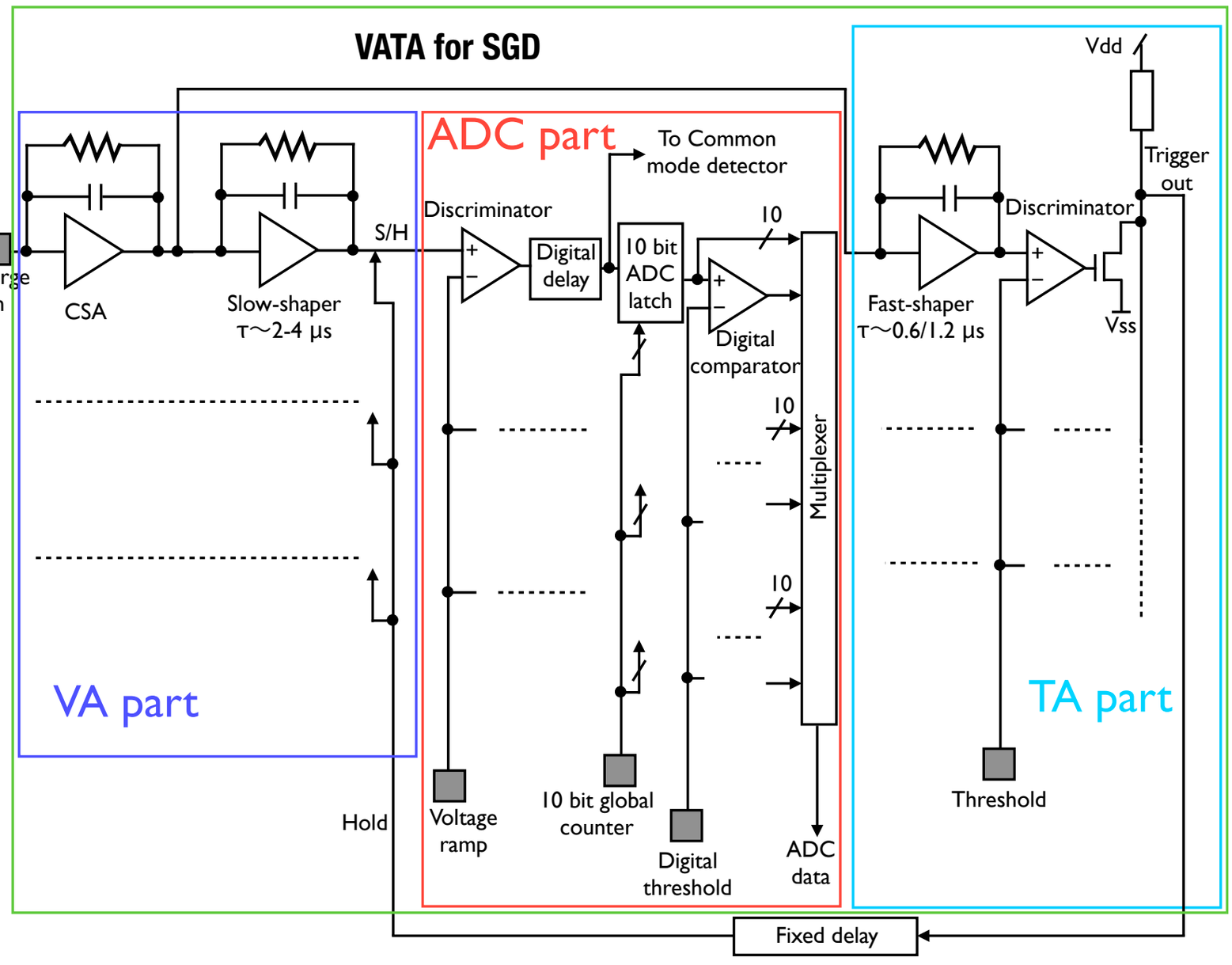
ASIC(VATA for SGD)

developed with IDEAS(Norway)

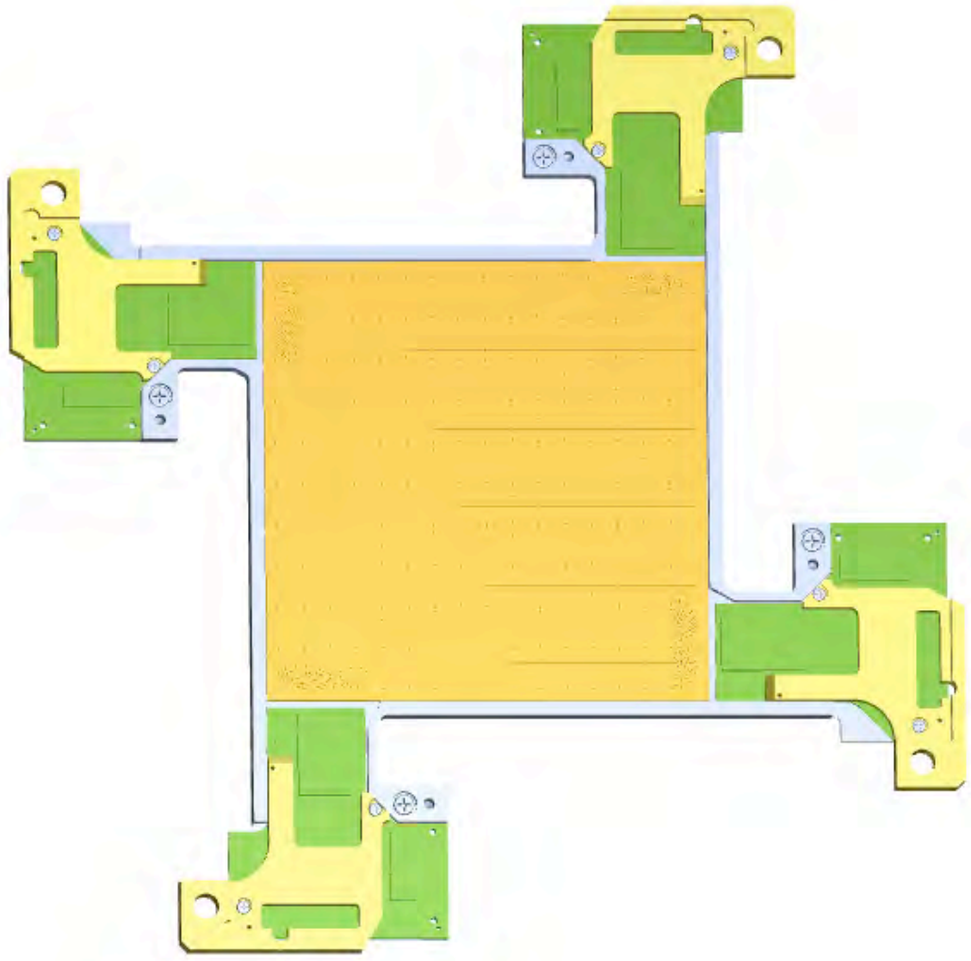


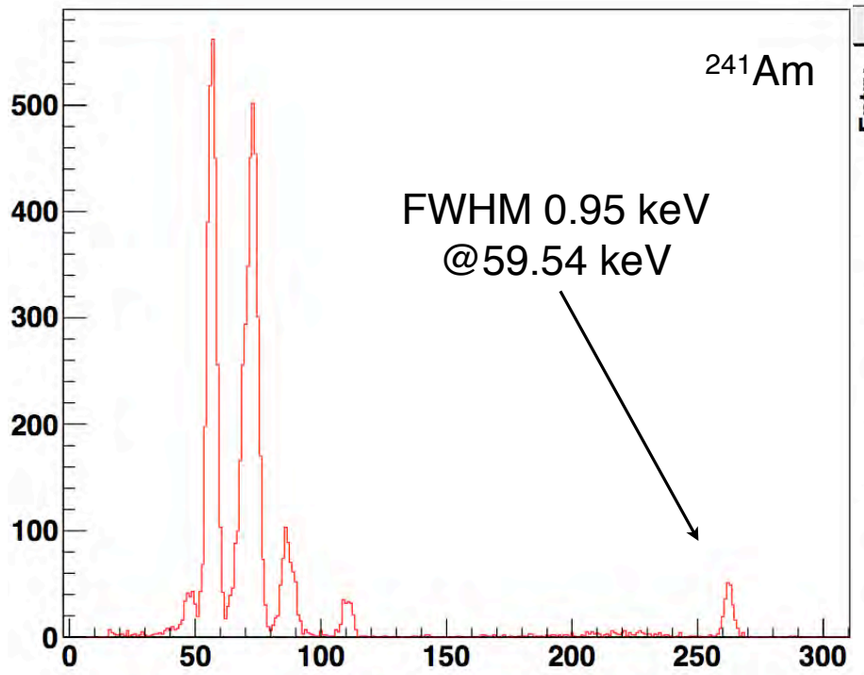
- 64ch signal processing
- CSA and two Shapers (Spectroscopy & Trigger)
- Internal ADC (Wilkinson type)
- Inside Common mode Noise Calculation (during AD conversion)
- Data suppression(only hit ch data are output)
- only Digital I/O

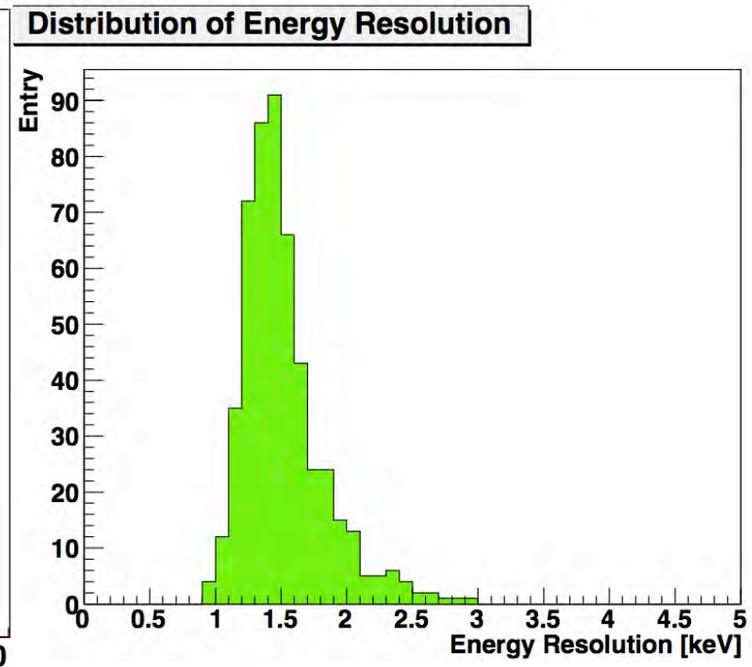
Low Power Consumption: 0.3 mW/ch

Good Noise Performance: 65 e- (0 pF), 180 e- (6 pF, 10 pA) [designed]

Si Pad detector







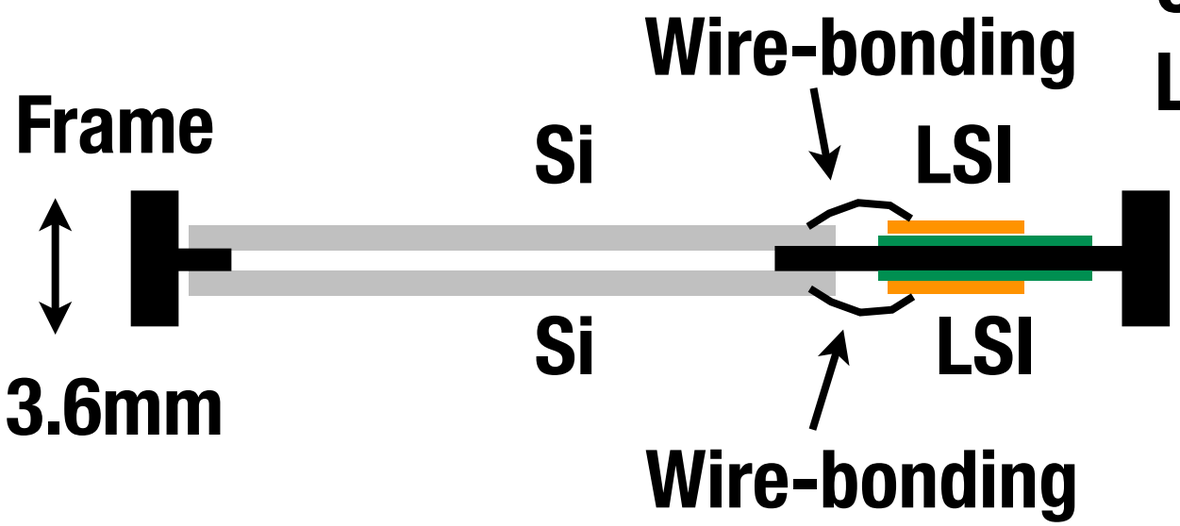
Si Pad device (HPK)

Area: 51.2 x 51.2 mm^2, Thickness: 0.6 mm

Operating bias voltage: 230V

Capacitance: 4--15 pF/pad(inc. the traces)

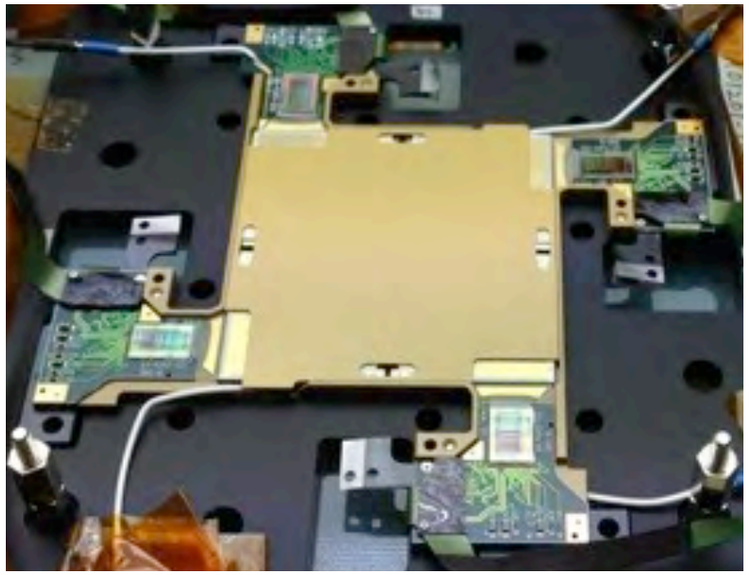
Leakage current: ~2 nA/device @–20ºC

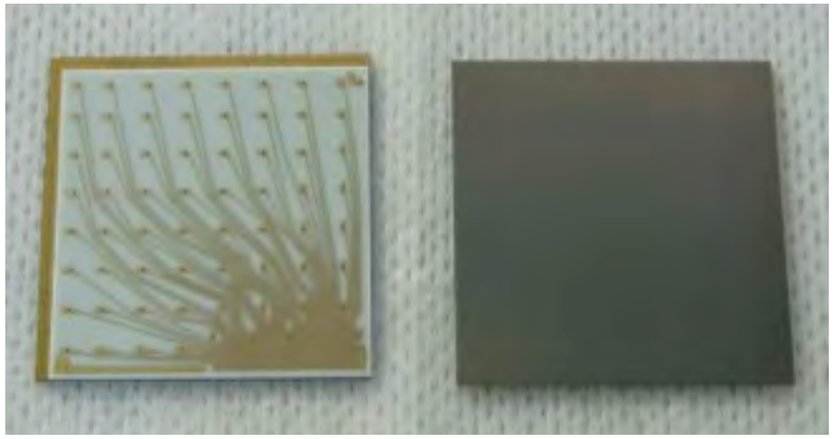


One tray consists of 2 Si detectors and 8 FECs(ASICs).

16 Si trays are stacked in one CC

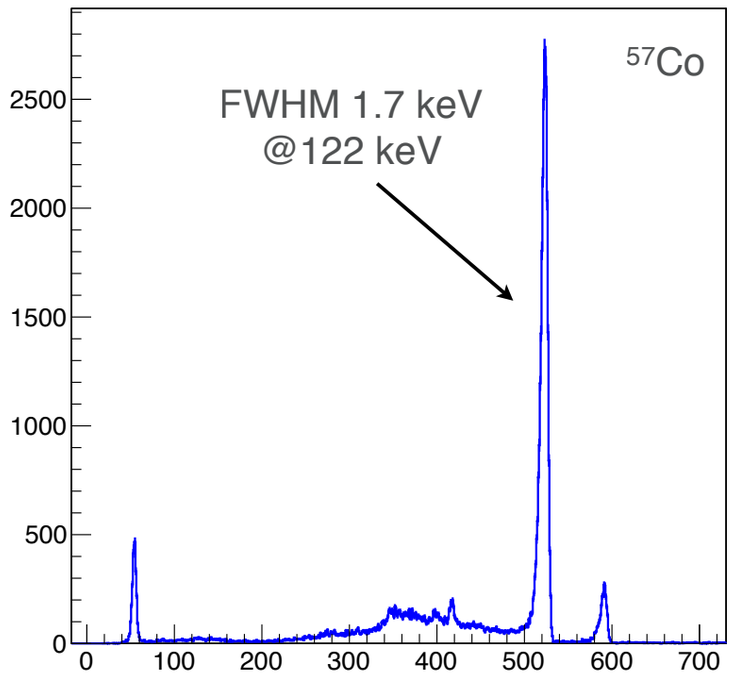
CdTe stack tray





CdTe (ACRORAD)
26.75 x 26.75mm^2
0.75mm thick
3.2 mm pitch pad

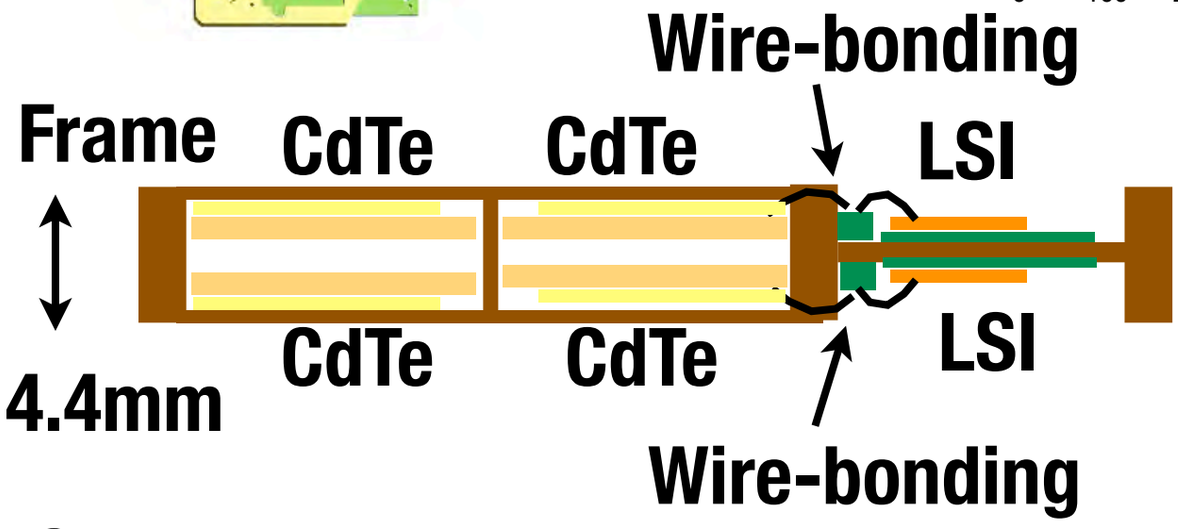
CdTe device with the ceramic fanout board



Bias Voltage: 1000V
capacitance: 3-6pF/pad

Energy resolution(FWHM):

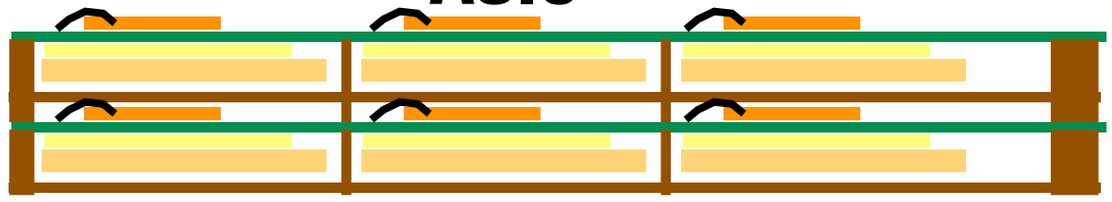
$$\Delta E \approx \sqrt{(1.0\text{--}1.8\text{keV})^2 + ((0.013\text{--}0.015) \times E)^2}$$

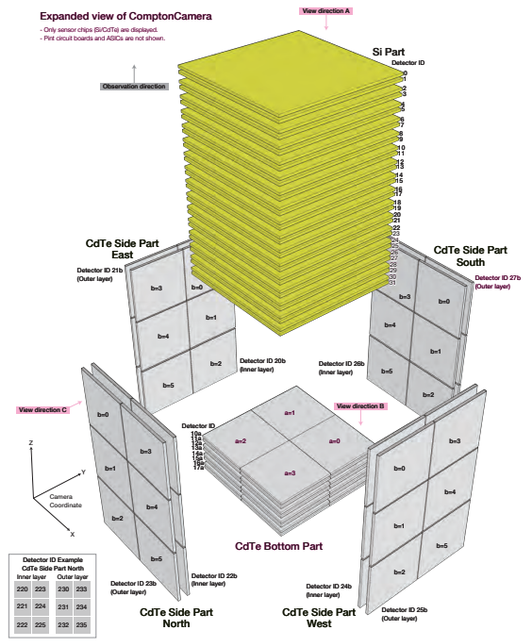


2 x 2 x 2 layers
4 trays are stacked in the CC

CdTe side tray

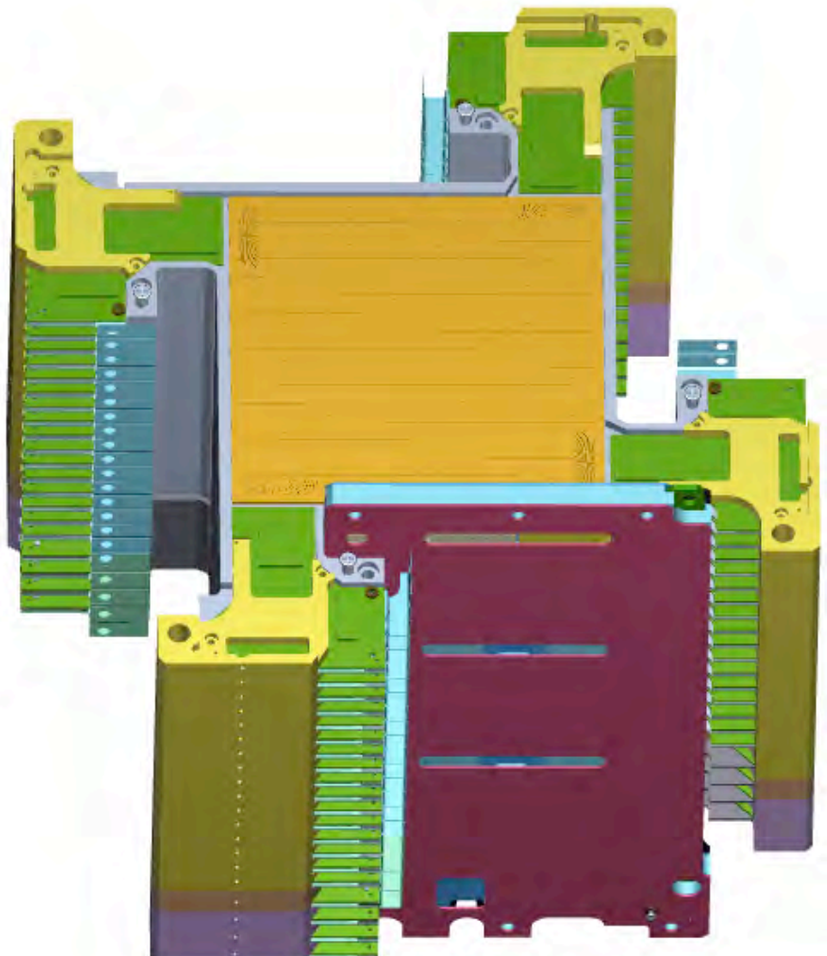
tall Si stack part, low energy (<200 keV)
-> CdTe side part: important roles
(polarization measurement)





6 CdTe in 1 layer

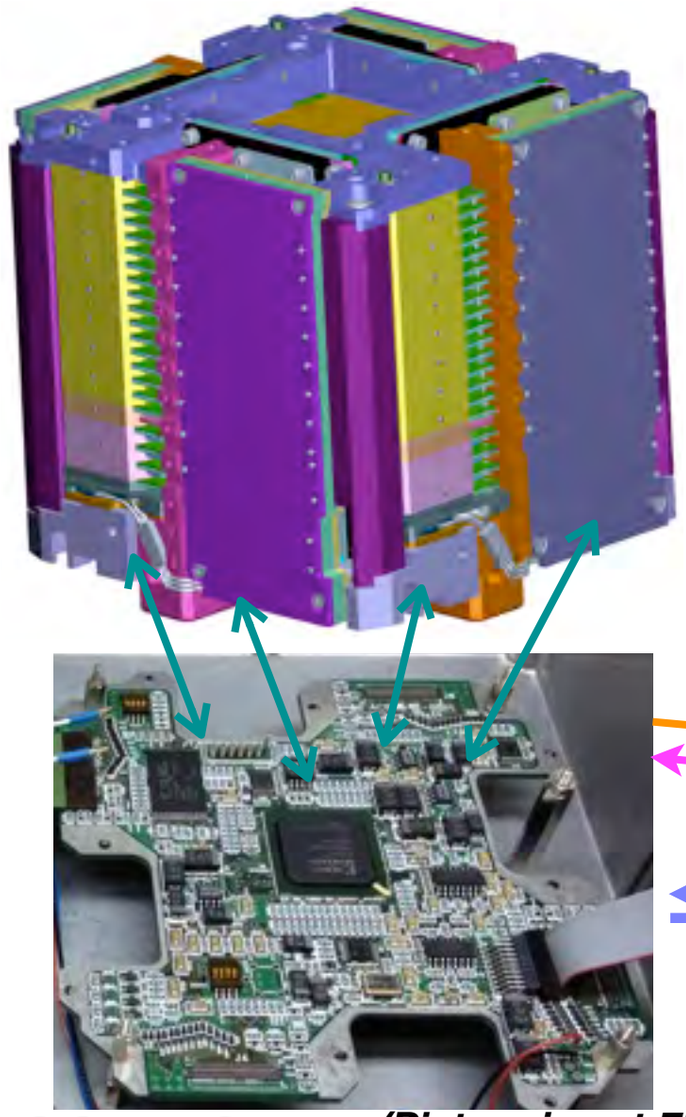
2 layers on each side



maximized the covering solid angle

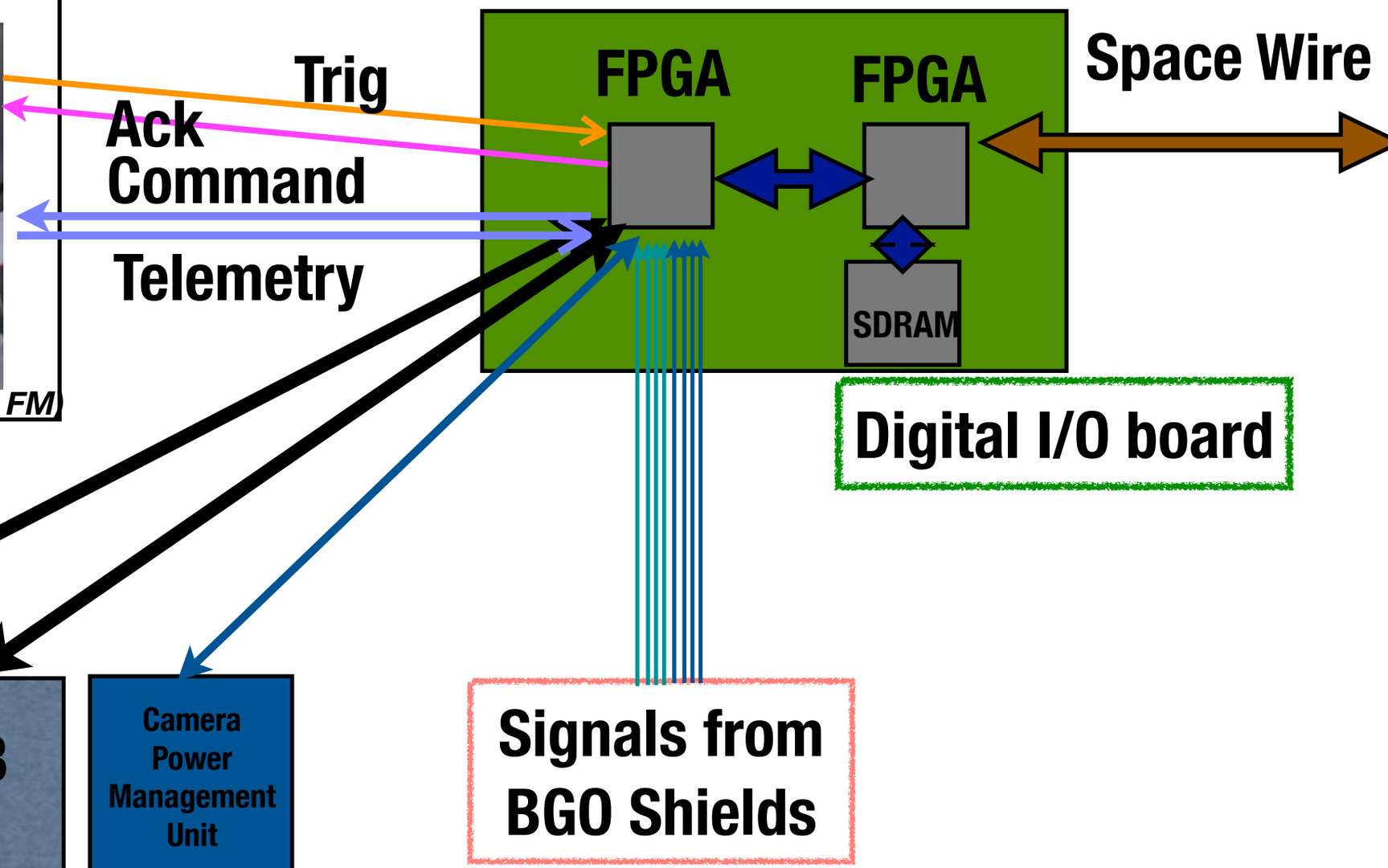
Readout system

208 ASICs are controlled/readout in 28 daisy chains by the CC FPGA.

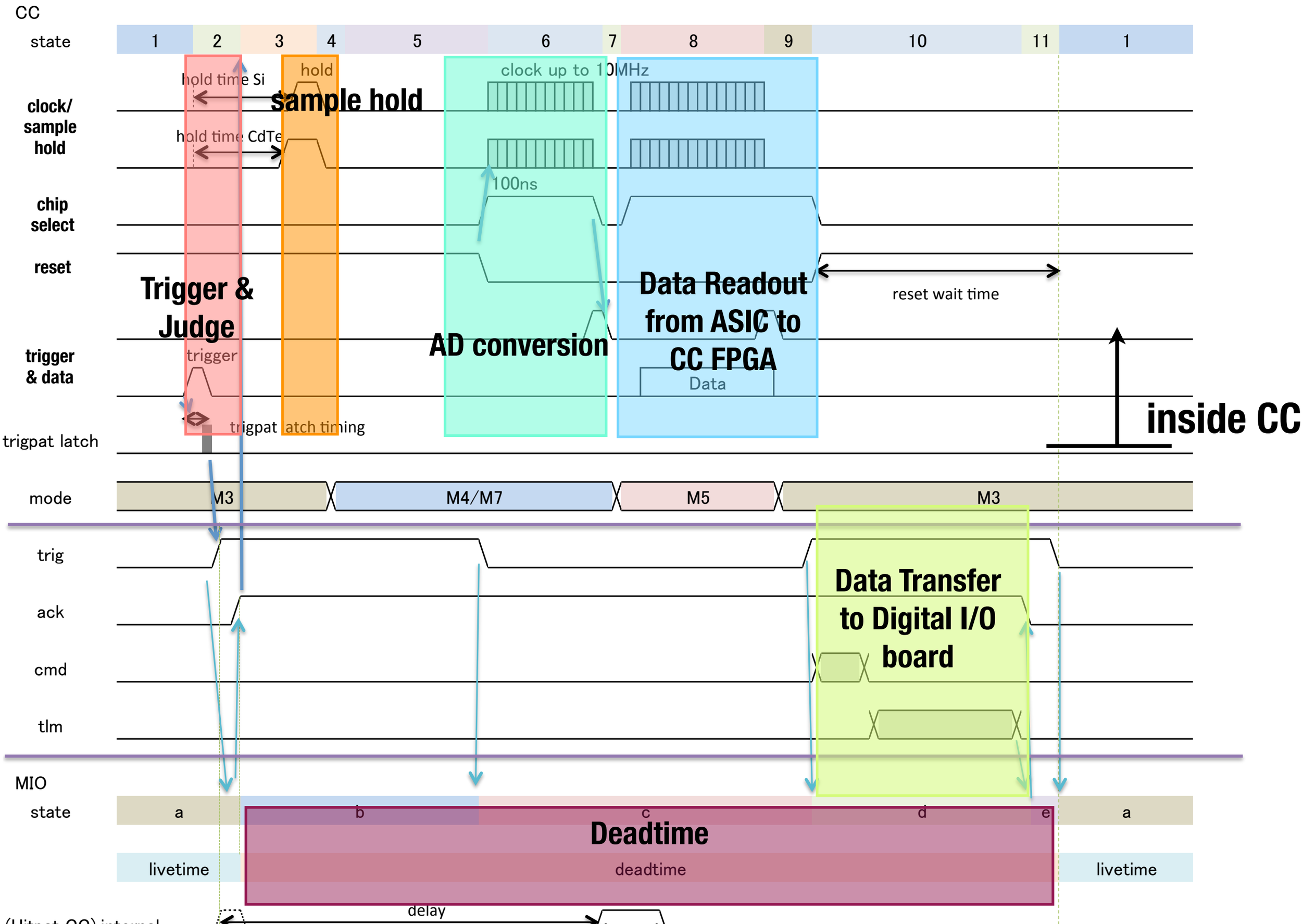


CC FPGA (Picture is not FM)

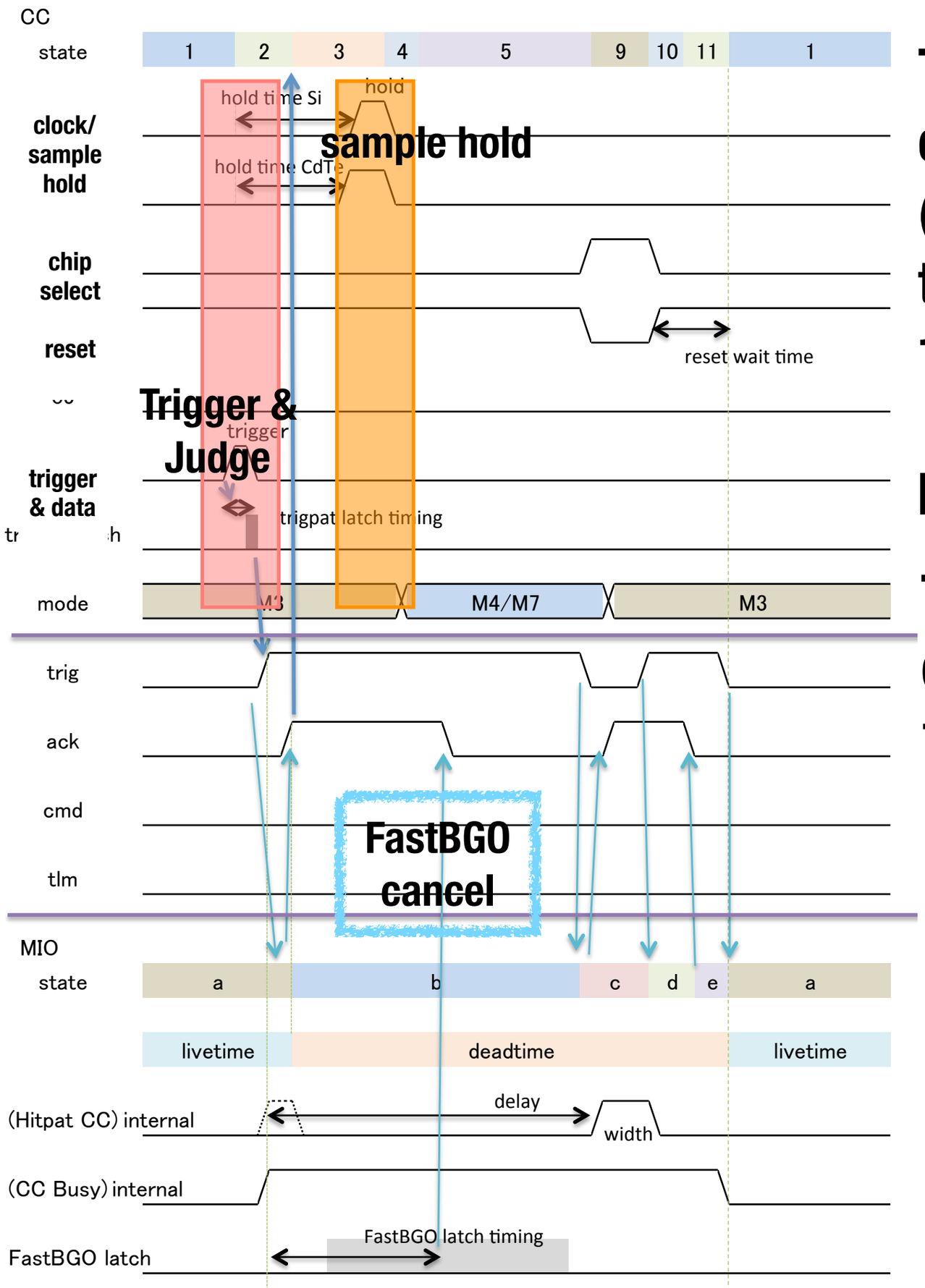
Command/Telemetry:
3 line serial LVDS interface(10MHz)
Ack, Trig: realtime LVDS lines



Readout Sequence



Suppression of Dead Time



The dead time associated with the event data acquisition is not short. (AD conversion, Data readout/ transfer, Wait time after SH reset) 100 μs ~ several 100 μs / event.

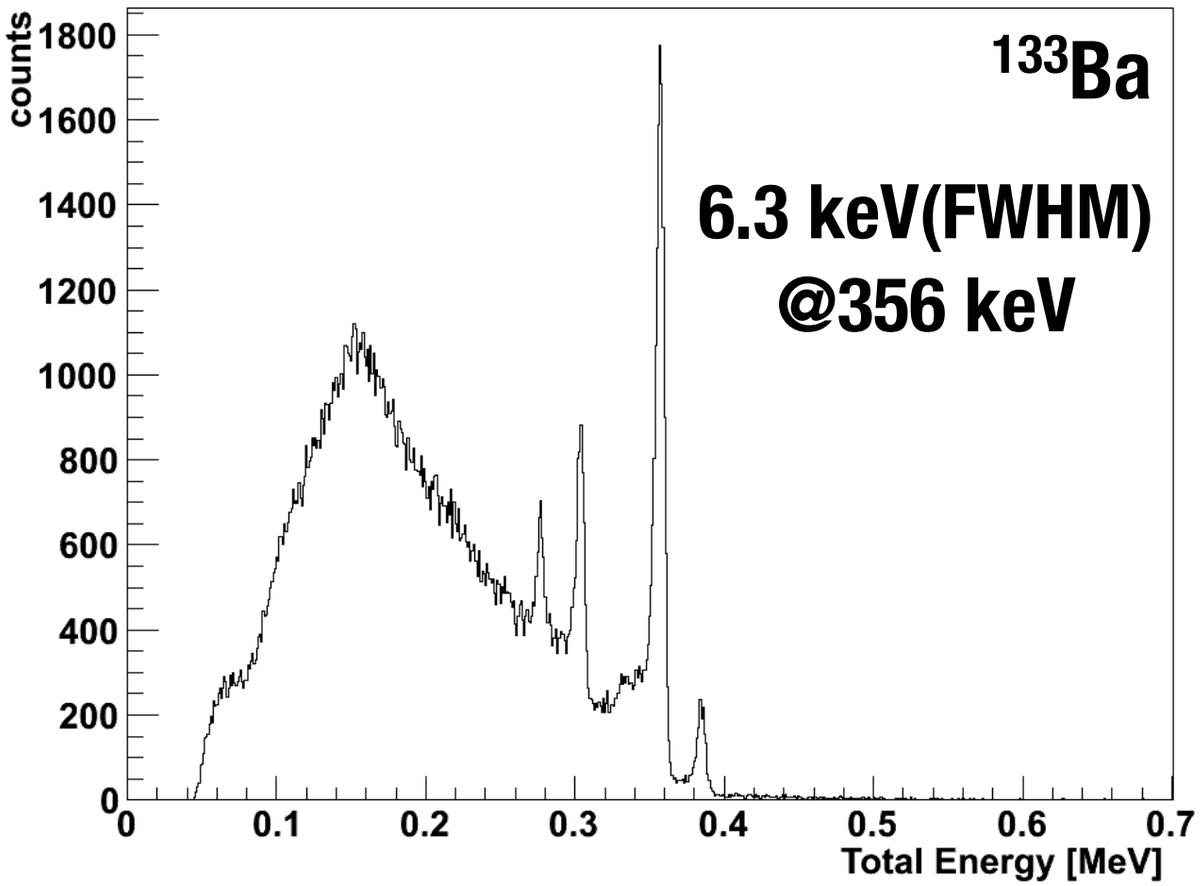
Functions for effective event DAQ

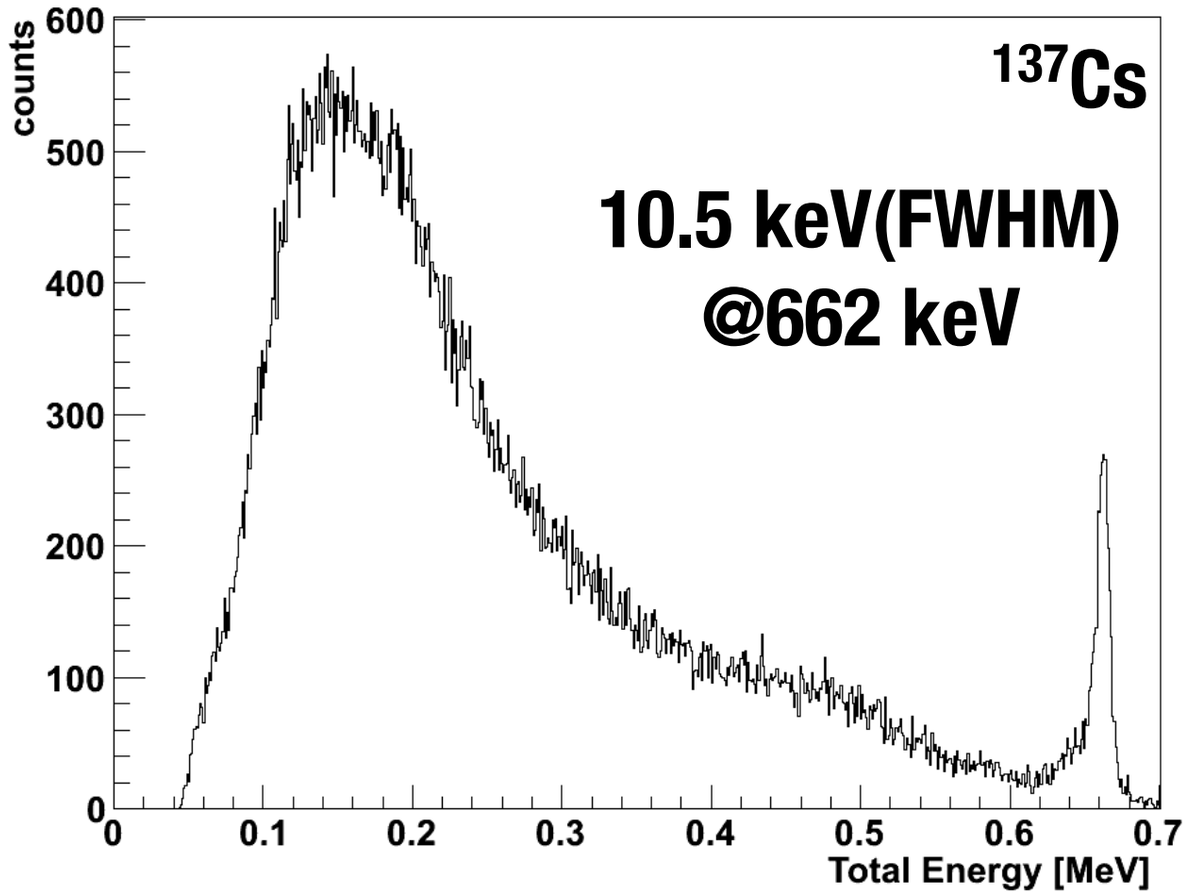
Trigpat judge: trigger patterns of 28 daisy chains are categorized into 16 groups. Selectable in each group

FastBGO cancel: cancel the event data acquisition before AD conversion by using FastBGO signals. FastBGO: relative large signal in one of BGO shields

Spectral performance

Total energy spectra (Si-CdTe 2 signal)





- Energy resolution: 1.6%@662keV
- Satisfy the requirement of the spectral performance (< 2%)

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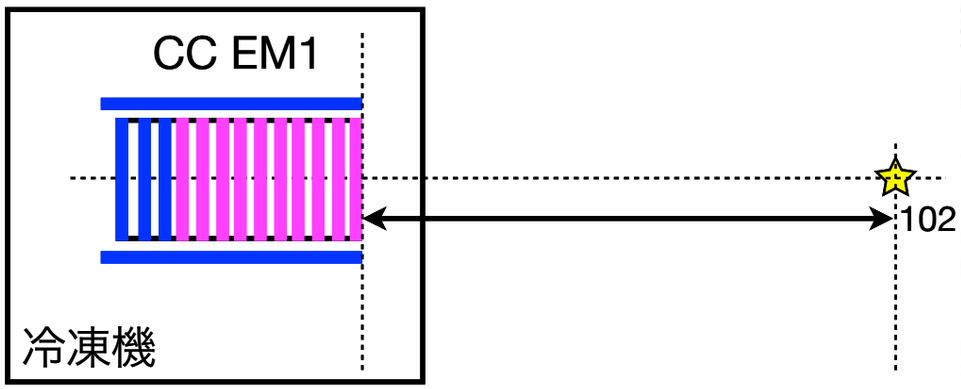
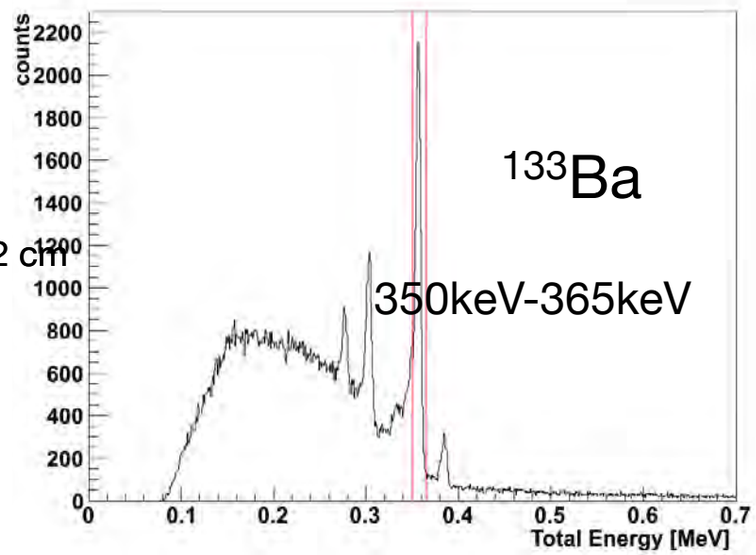
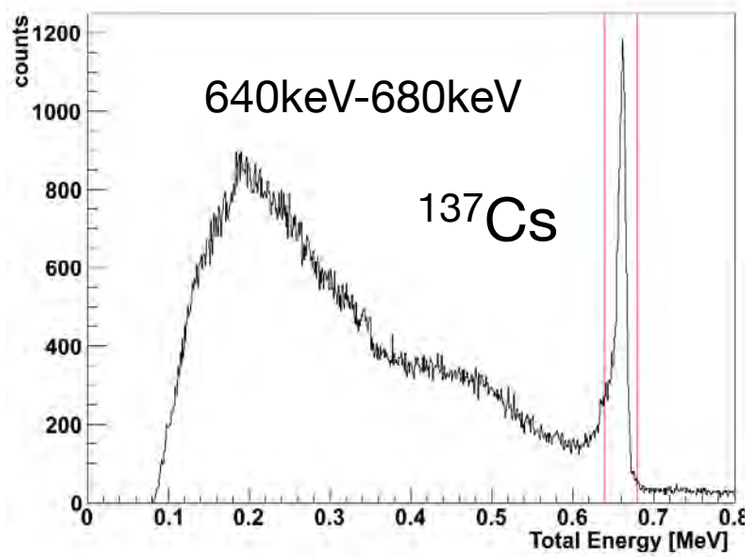
Prototype Performance

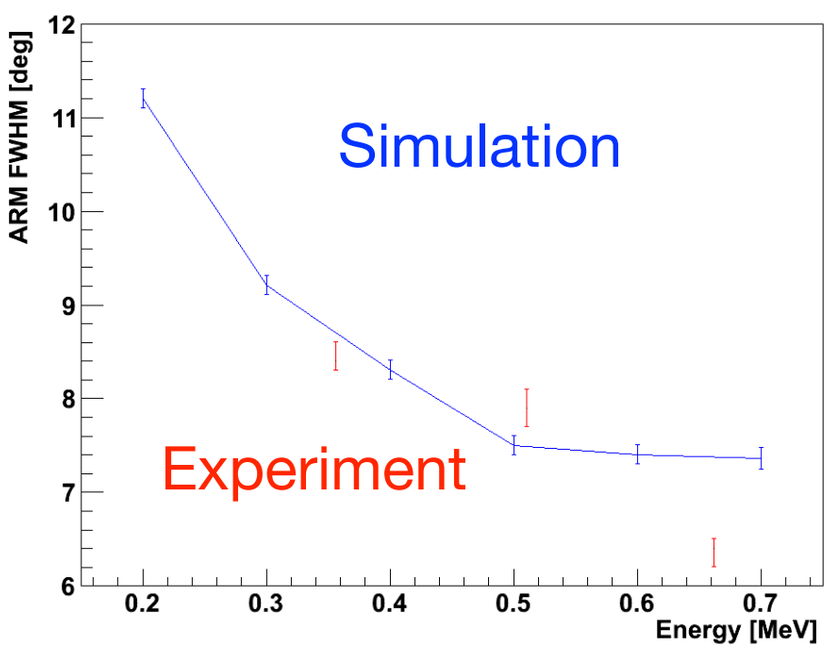
- **102cm, ^{133}Ba,^{137}Cs**
- **Compton Imaging using the 356 keV peak and 662 keV peak**

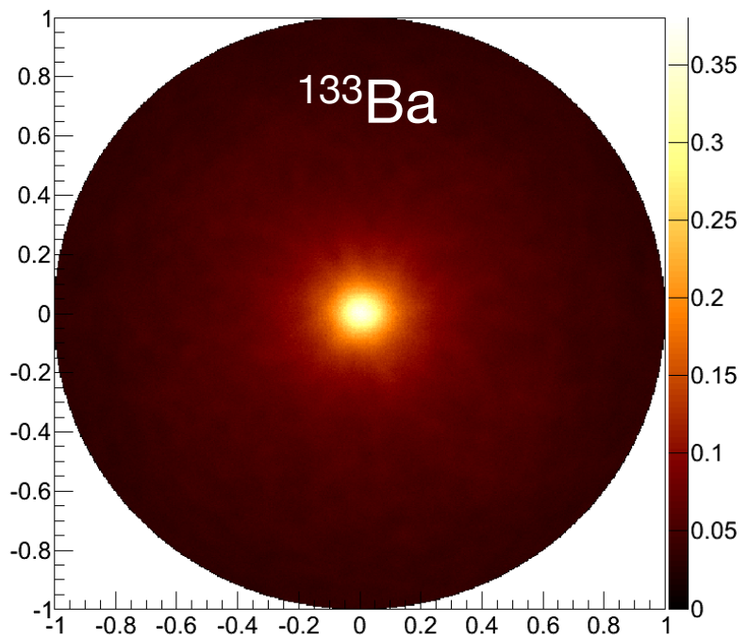


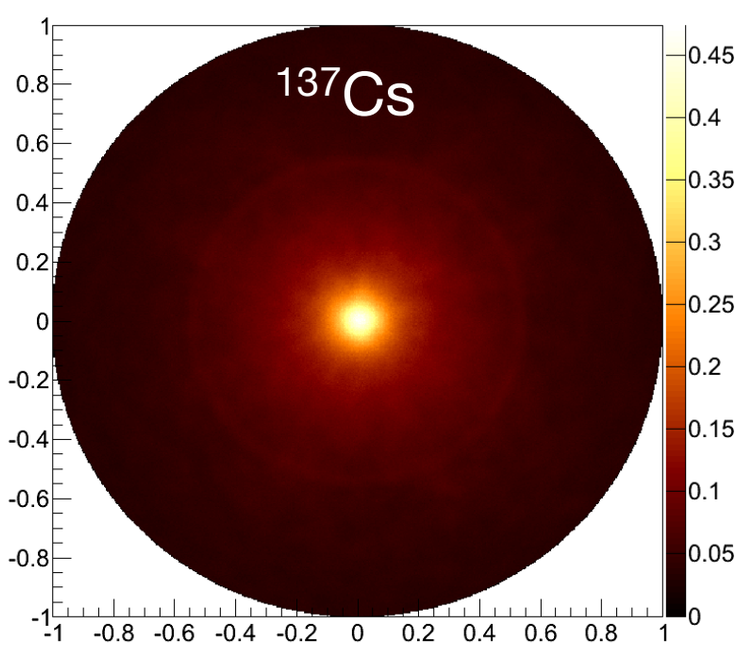




Angular Resolution







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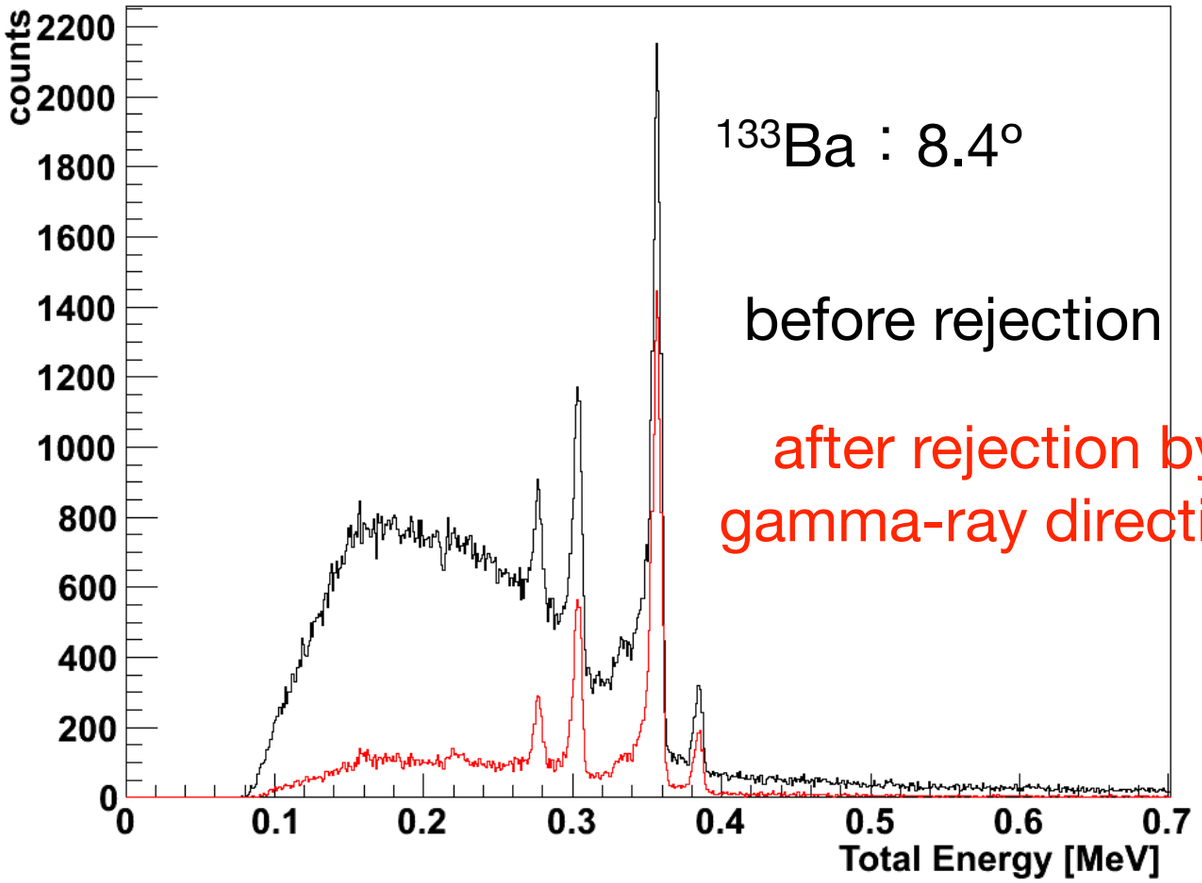
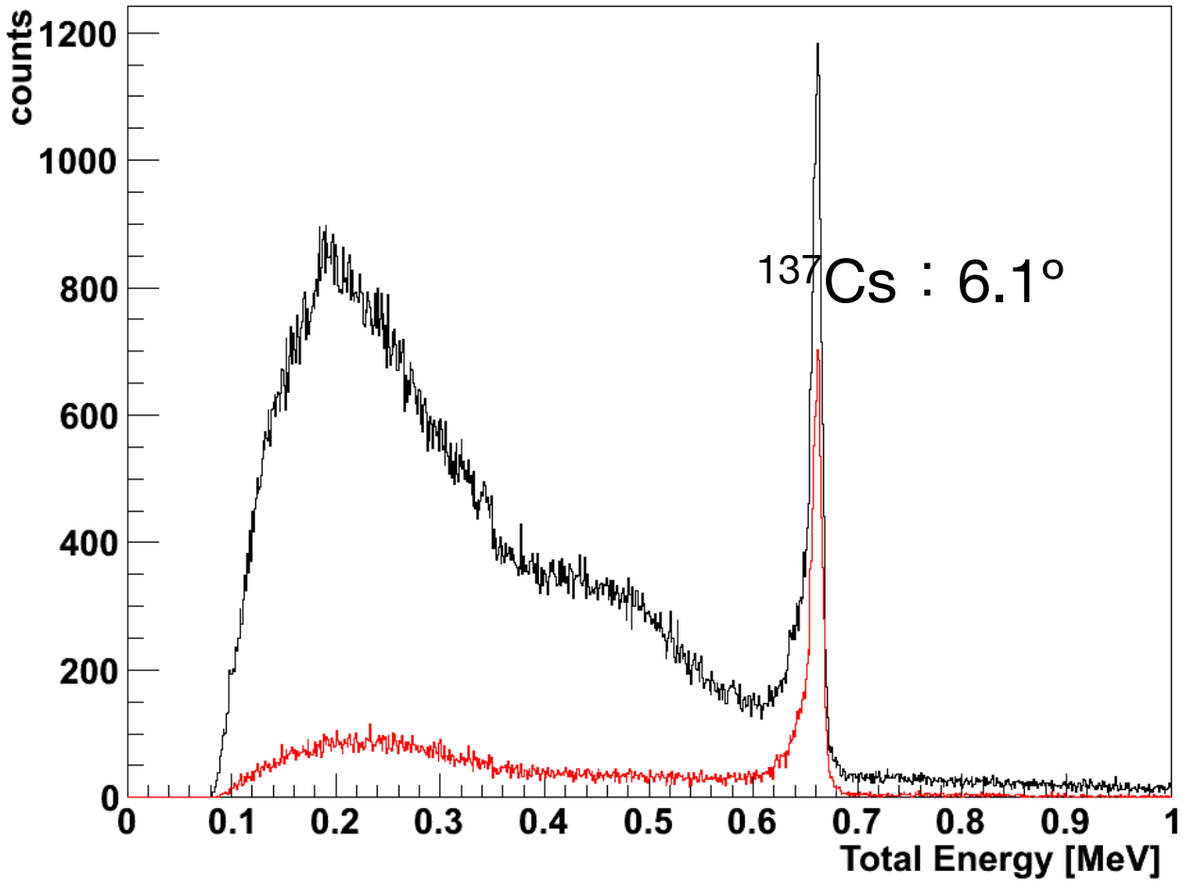
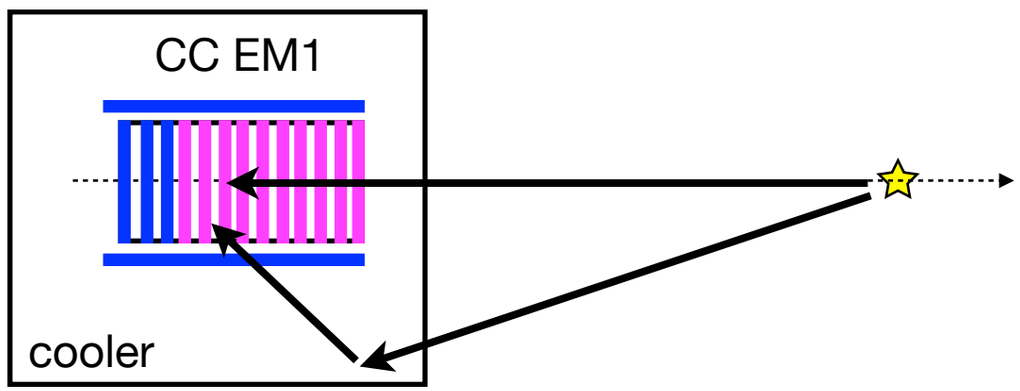
Prototype Performance





- regarding the direction of the RI source as the line of sight
- continuum level is suppressed to 1/10
- peak count is not suppressed so much

-> verification of the concept of the background rejection with narrow FOV CC



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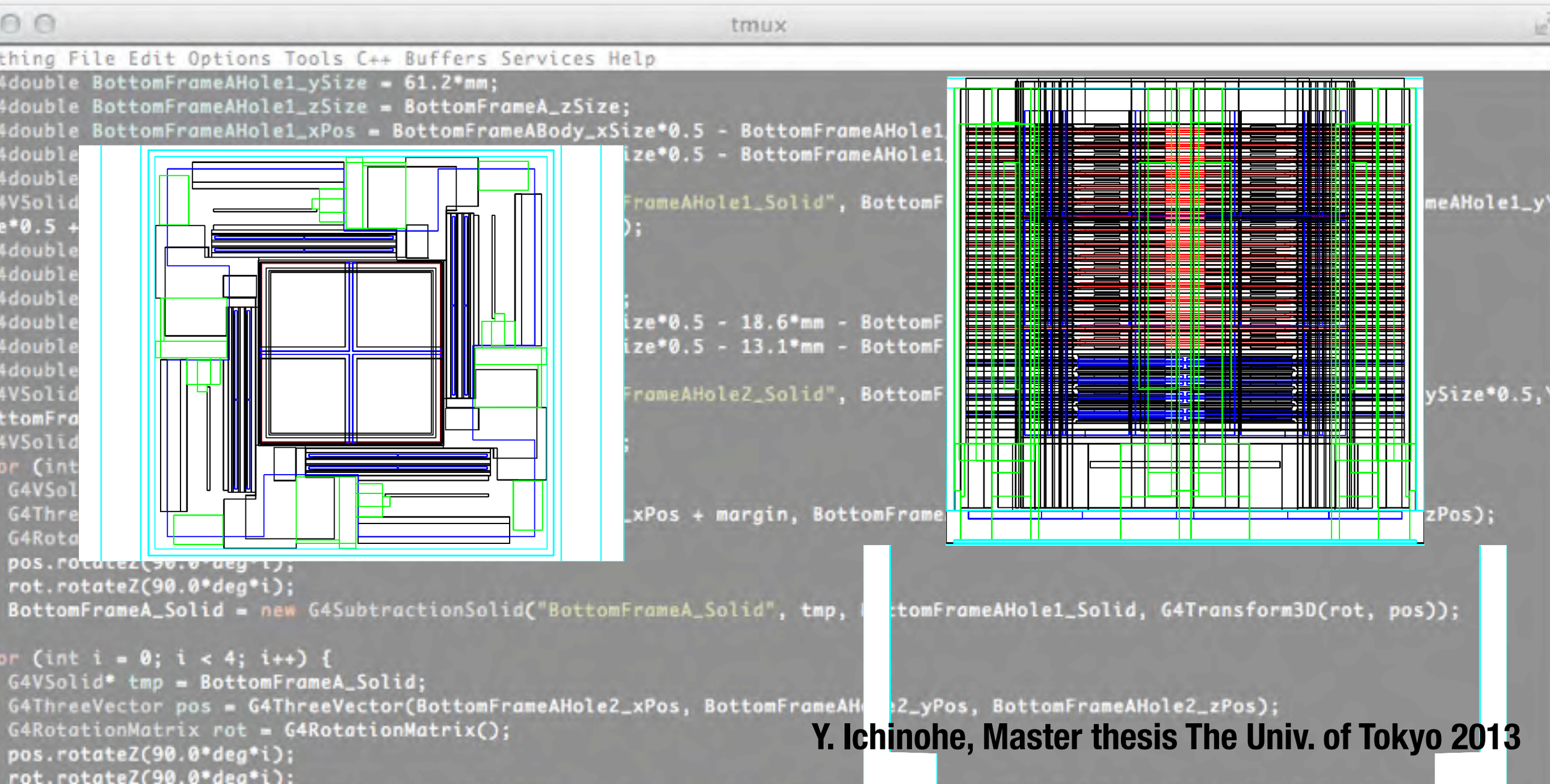
Monte-Carlo Simulator

- Geant4 base
- implement the experimental results and the latest design
- precise implementation of the detectors, circuit boards etc...



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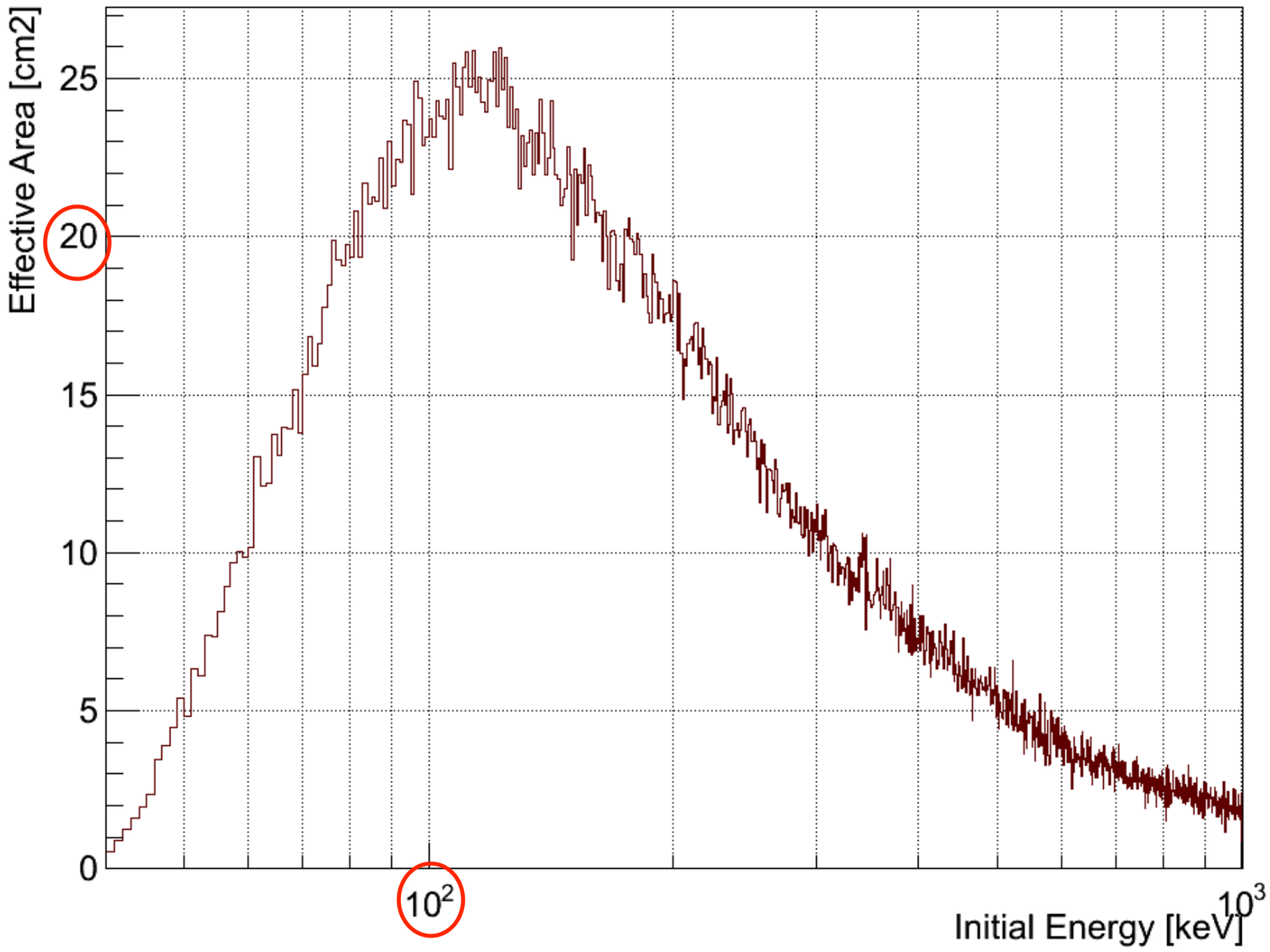
Effective Area

Effective area for 6 SGD Compton cameras (calculated from the Monte Carlo simulation)



- satisfy the requirement of the effective area (>20cm^2@100keV)
- further tunings of the event reconstruction algorithms underway

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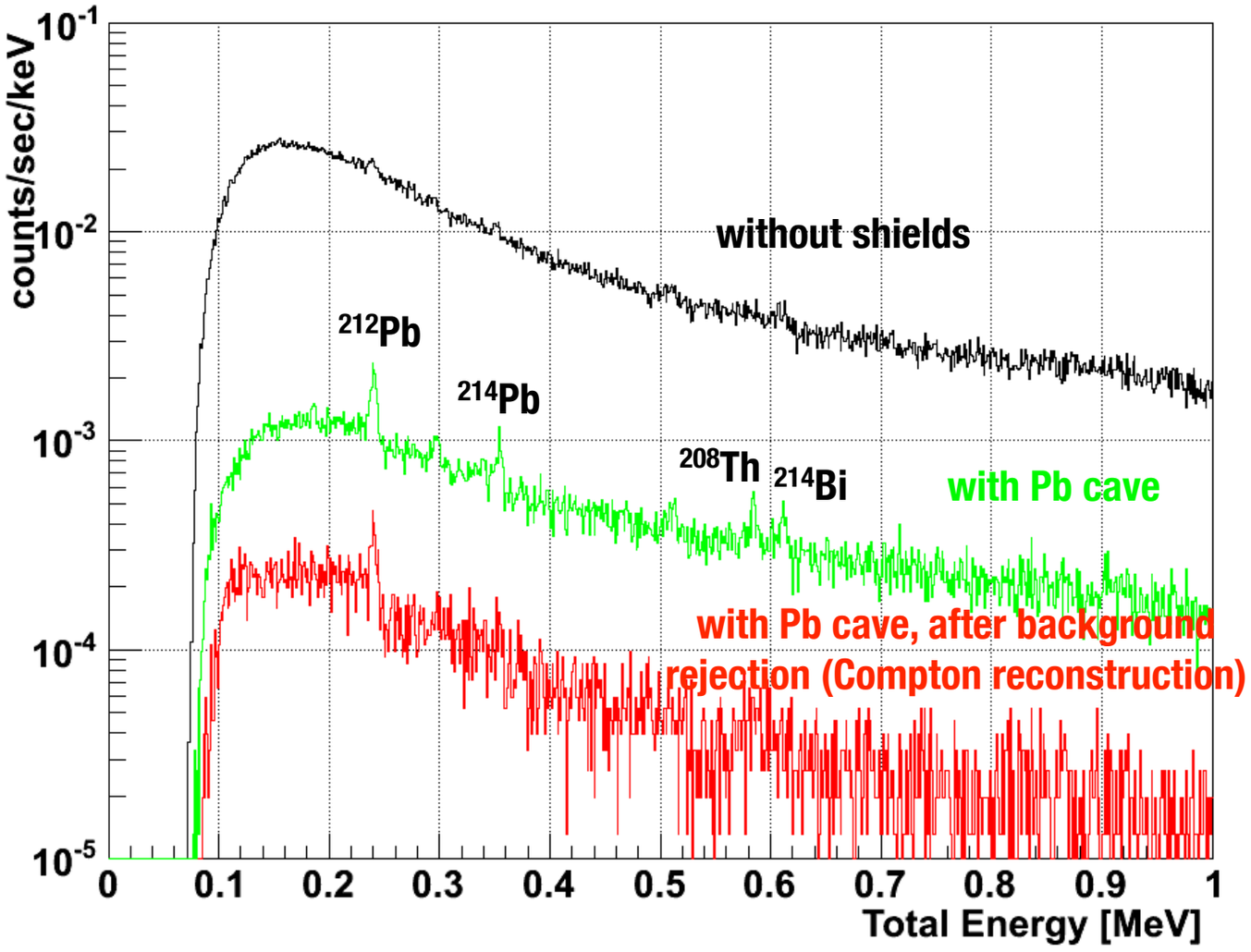
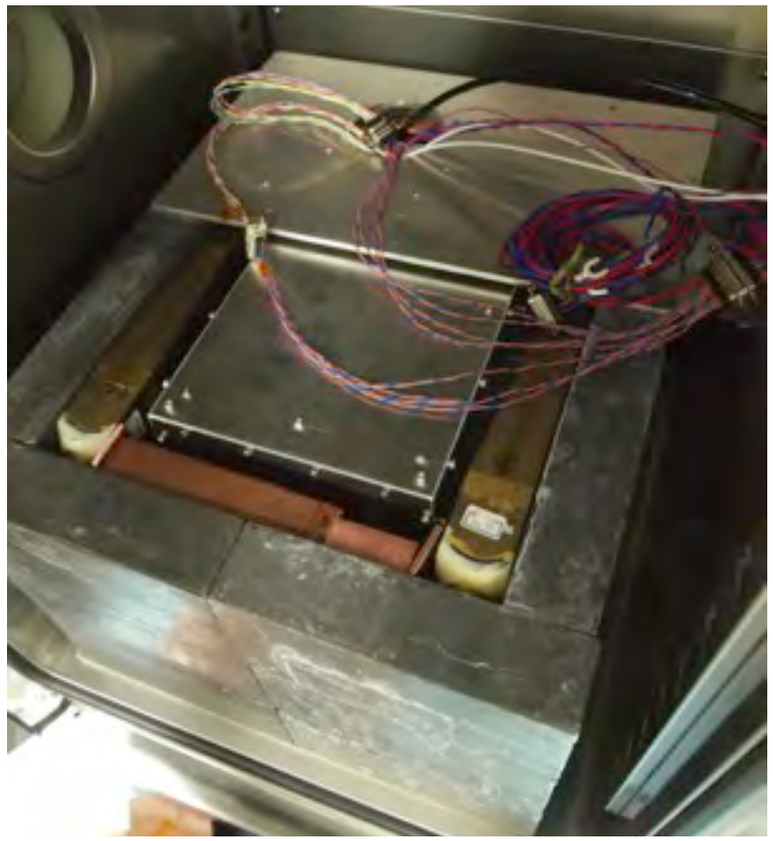
Intrinsic Background





lead shield (5cm thick)、copper/brass shield (1cm-5cm thick)、aluminum case(several mm thick)

- performed a continuos measurement for 44 hours
- evaluation using BGO active shields

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Summary

- Developed Si/CdTe semiconductor Compton cameras for SGD
  - Si detector, CdTe detector, ASIC, ...
- Designed the flight model of the SGD Compton camera
- Evaluations using the final prototype Compton camera
  - Spectral performance, Low background, Thermal vacuum environment, and so on.
  - Designed/Expected performances are being confirmed.
  - Flight model production is being performed.
- Spin-off product (ASTROCAM 7000HS by MHI) is commercially available now.