A portable Si/CdTe Compton camera and its applications to visualization of radioactive substances

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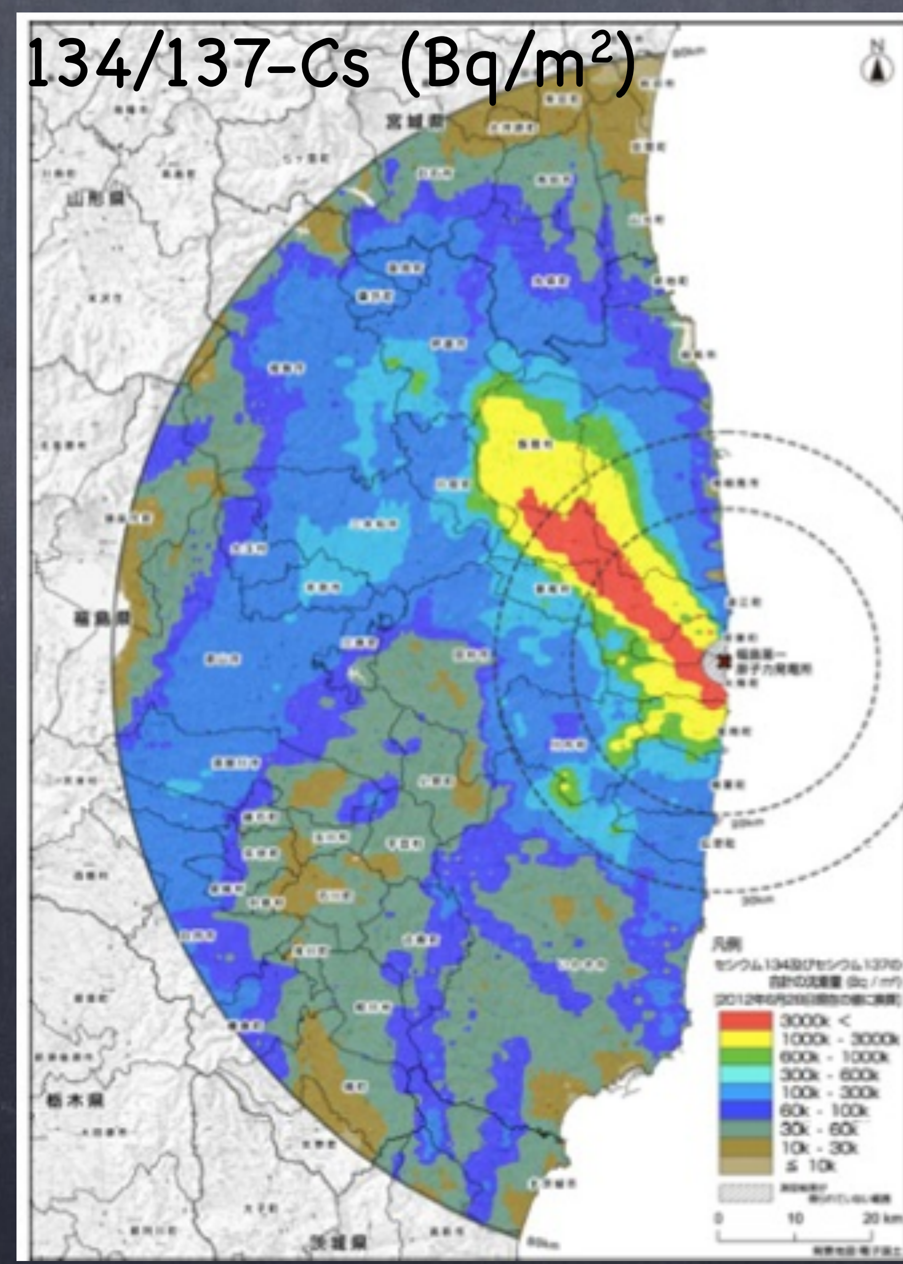
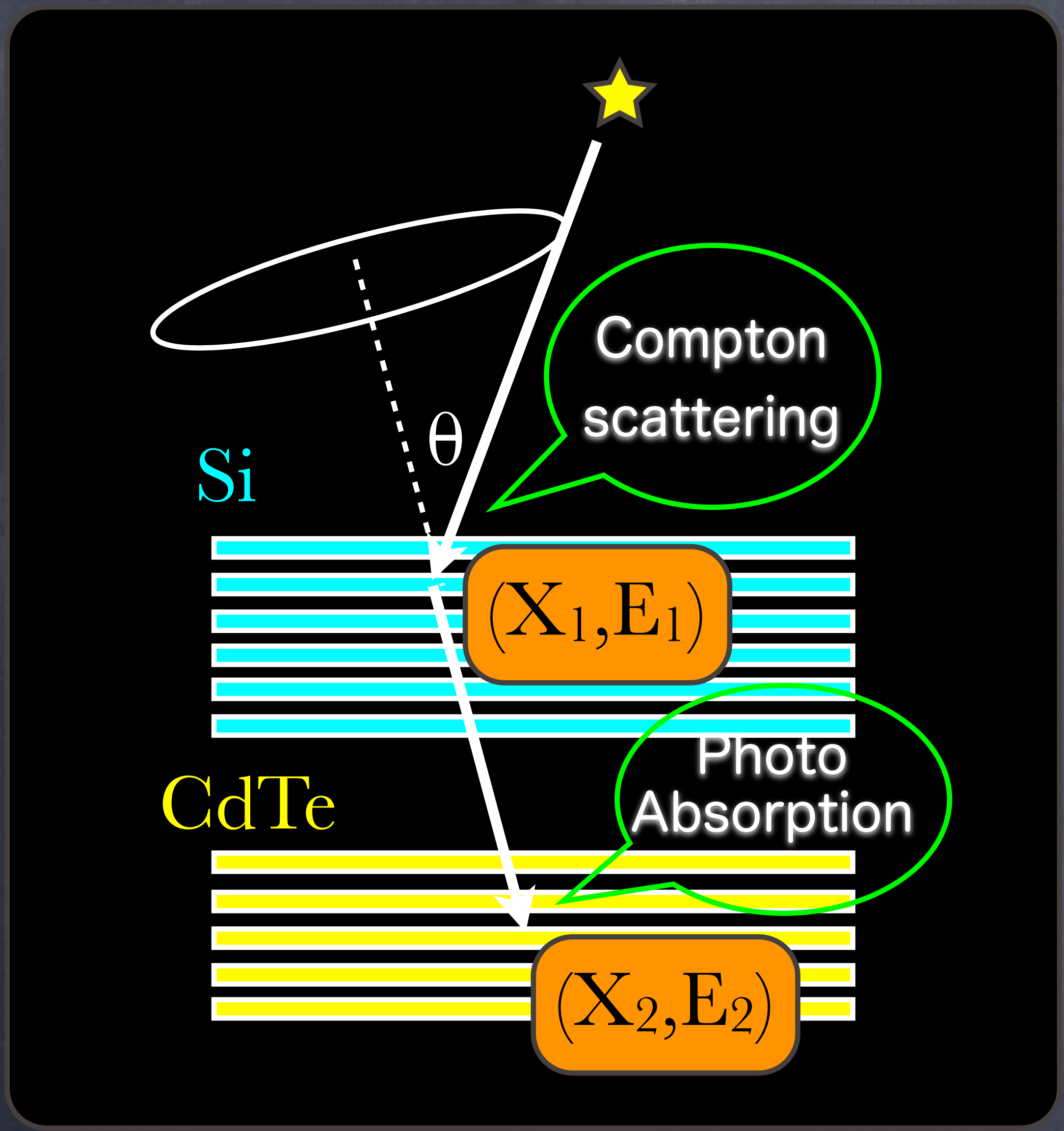


Approach

Si/CdTe Compton camera



(Takahashi et al. 2003)

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

Advantage ;

- Semiconductor detectors

  Precise gamma tracking (high ΔX, ΔE)

- Low-Z (Si) & High-Z (CdTe)

  Si : small doppler broadening effect

  Good angular resolution (〜1°@500 keV)

  Si : $\sigma_{comp} / \sigma_{photo} >> 1$

  Correct sequence reconstruction (>85%) without Time of Flight

  CdTe : High stopping power

  (Z=48(Cd), 52(Te), ρ =5.83g/cm3)

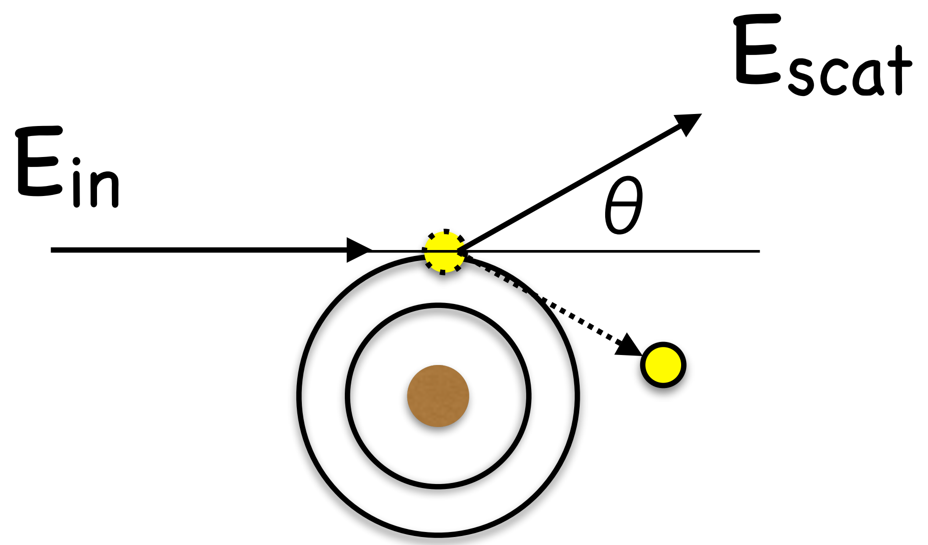
- Collimator-less imaging

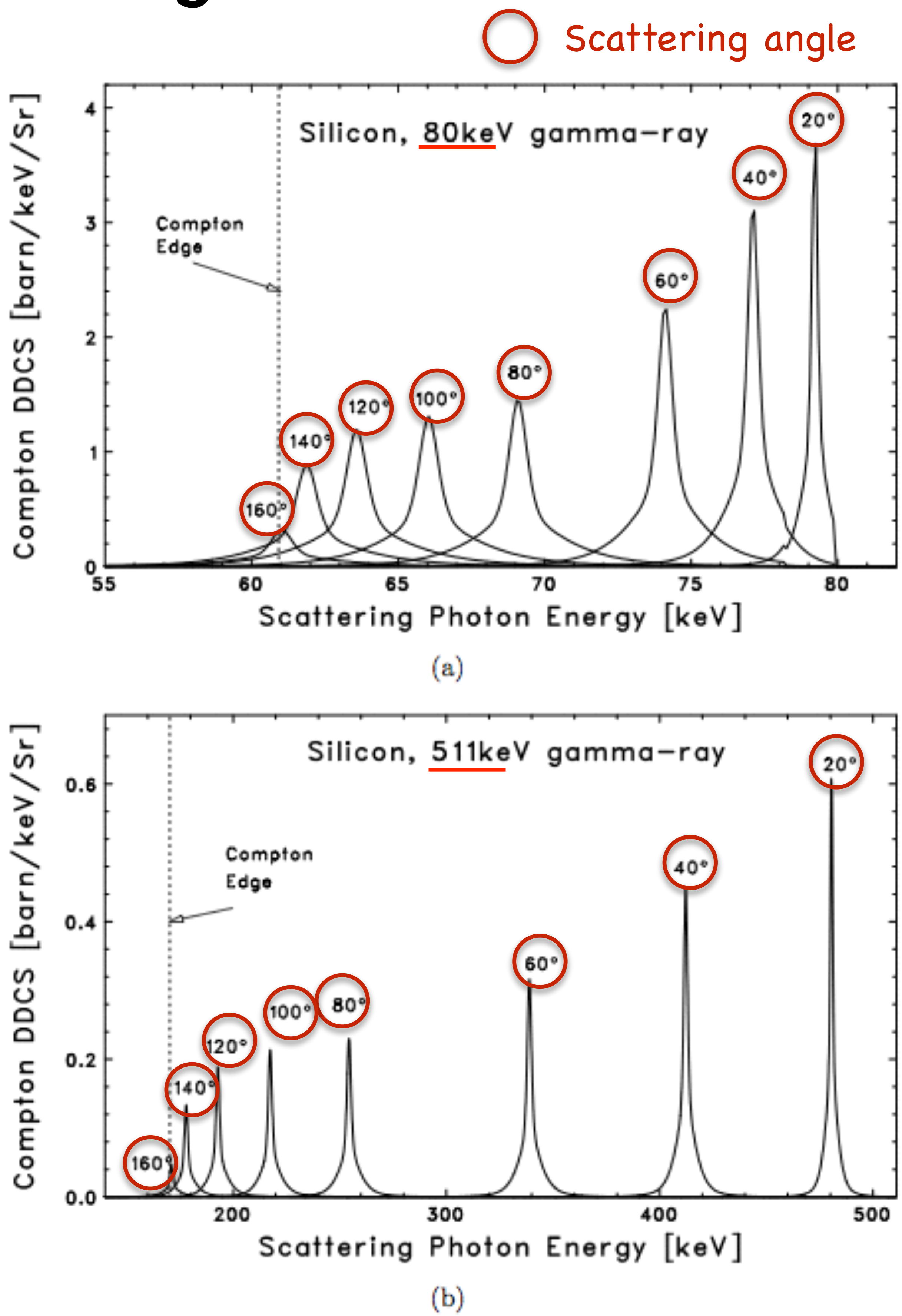
  High efficiency, Large field of view

  Wide energy band, Light weight

What's a Compton camera ?

Doppler broadening Effect





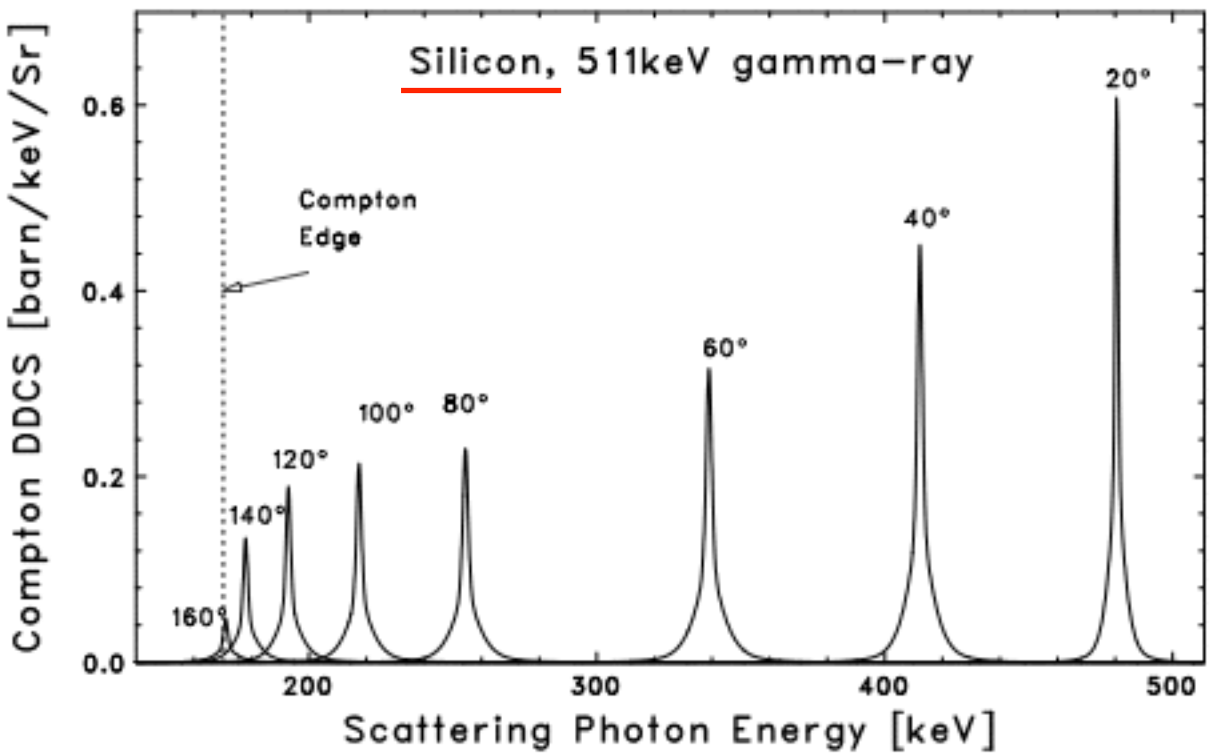
Calculation based on

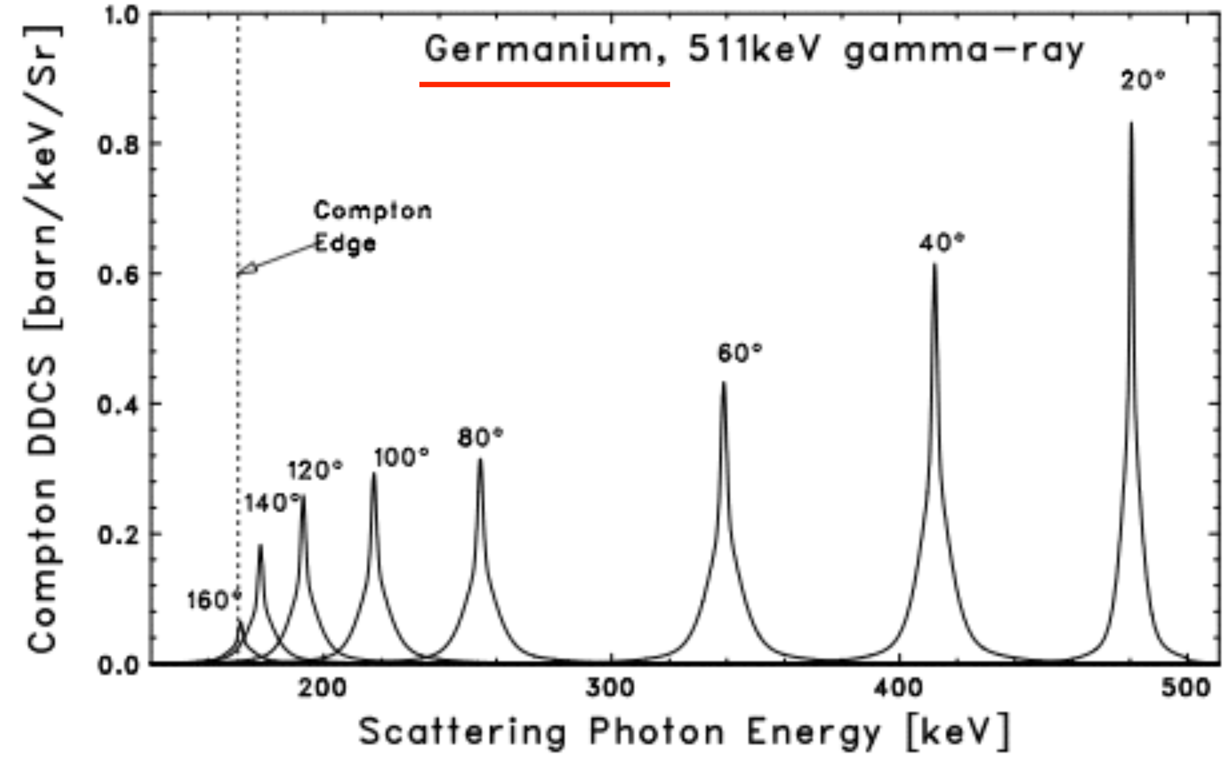
Numerical Hartree-Fock profile :
F. Biggs et al. (1975)

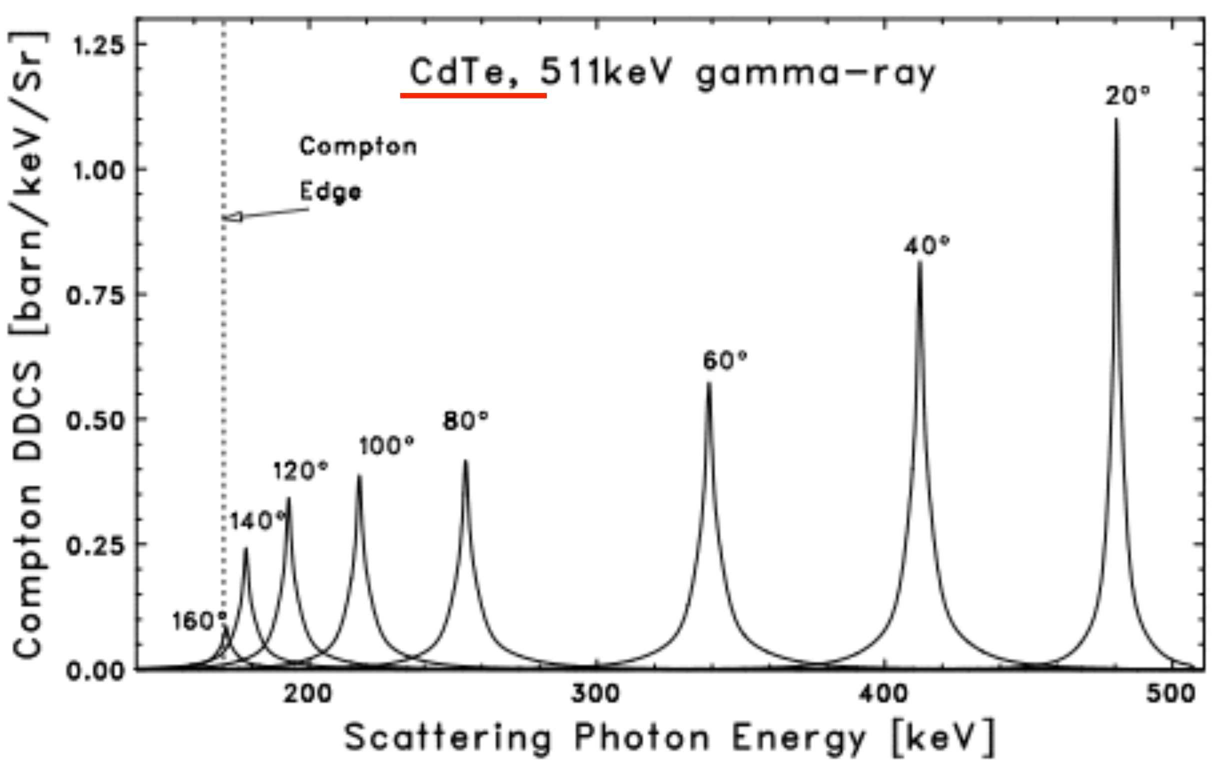
Simplified analytical equation :
D. Brusa et al. (1996)

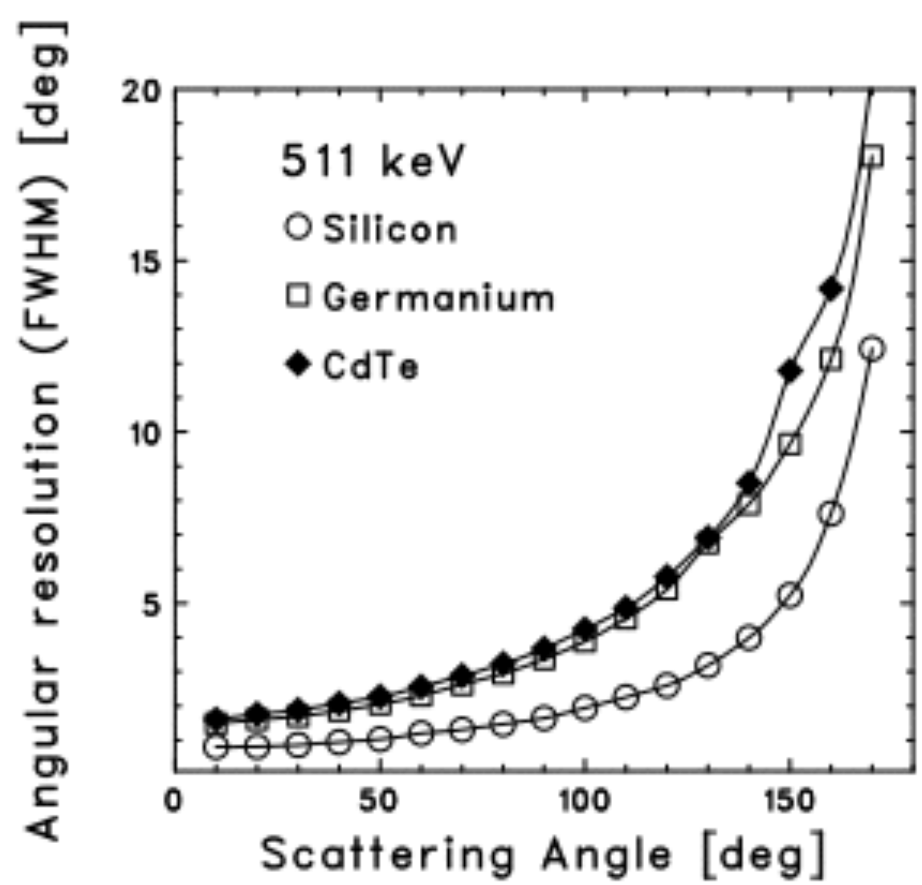
What's a Compton camera ?

Doppler broadening Effect



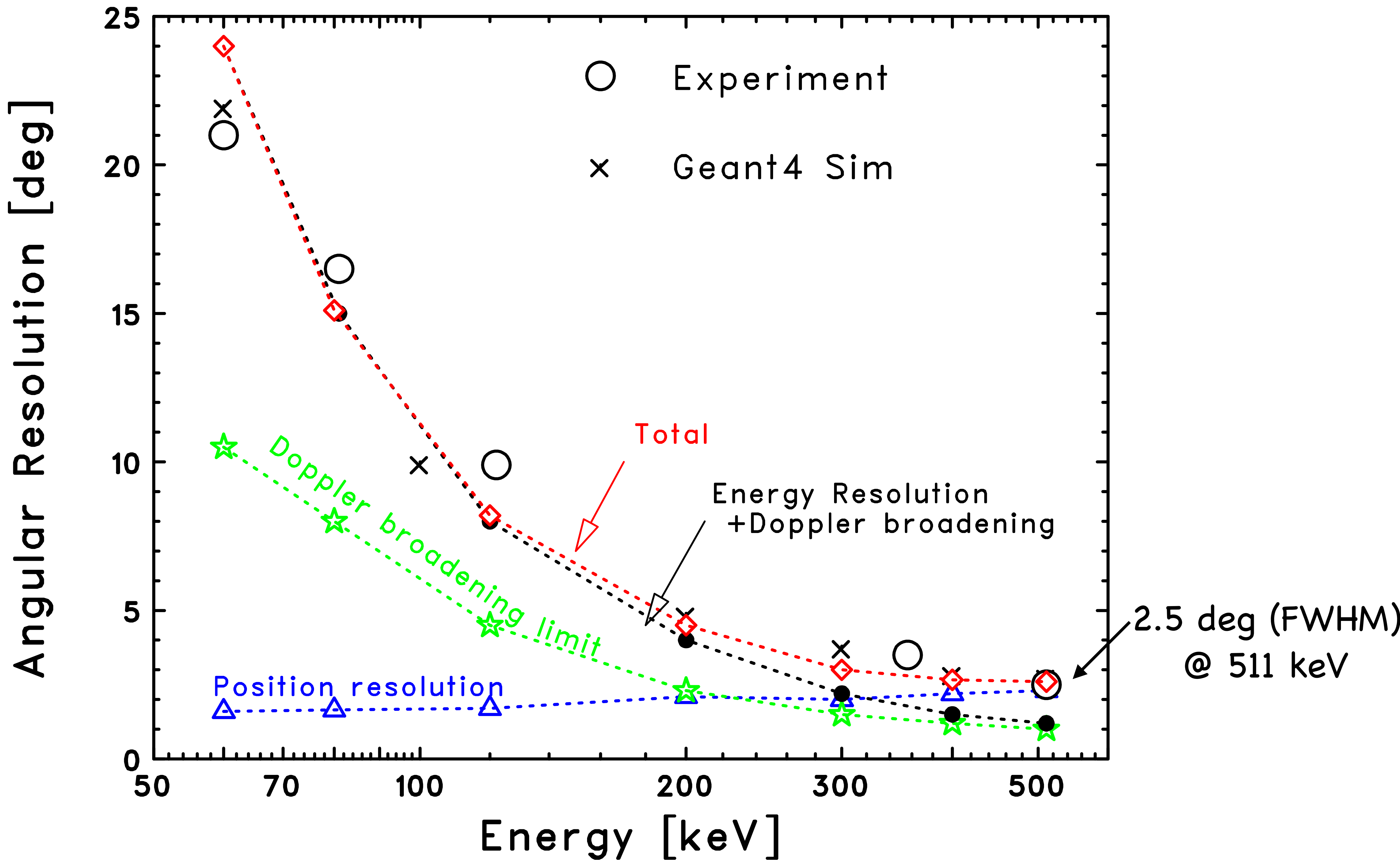






What's a Compton camera ?

Angular resolution achieved by a Si/CdTe Compton camera

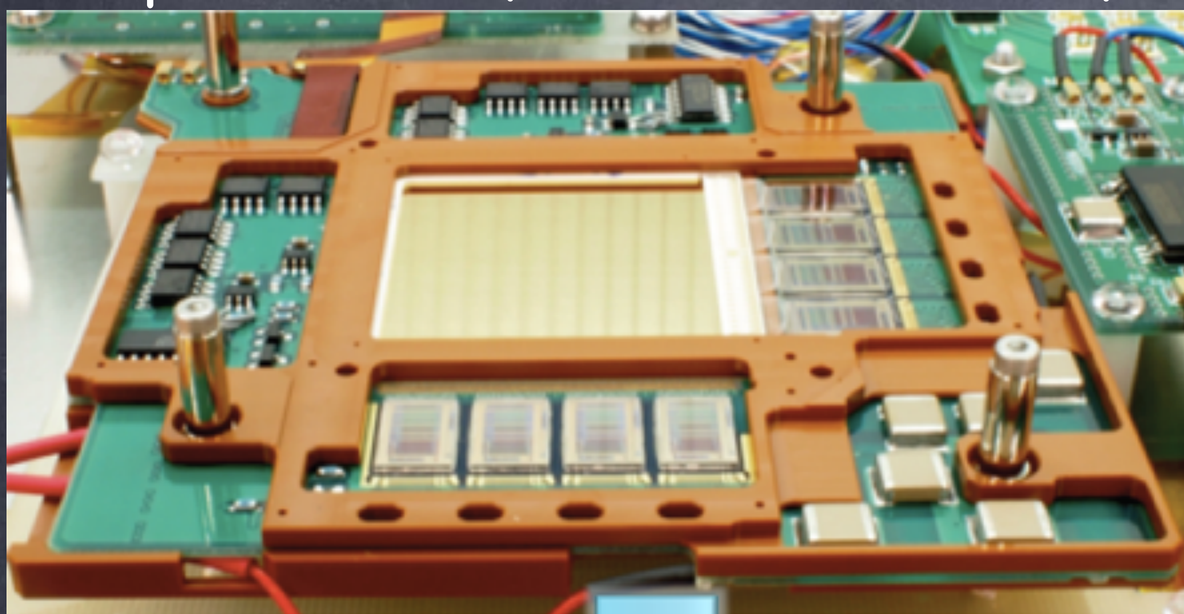


Practice

A prototype camera (2012)

Test system for visualization of radioisotopes in Fukushima

250 μm pitch CdTe Double-sided strip detector (watanabe et al. 2011)

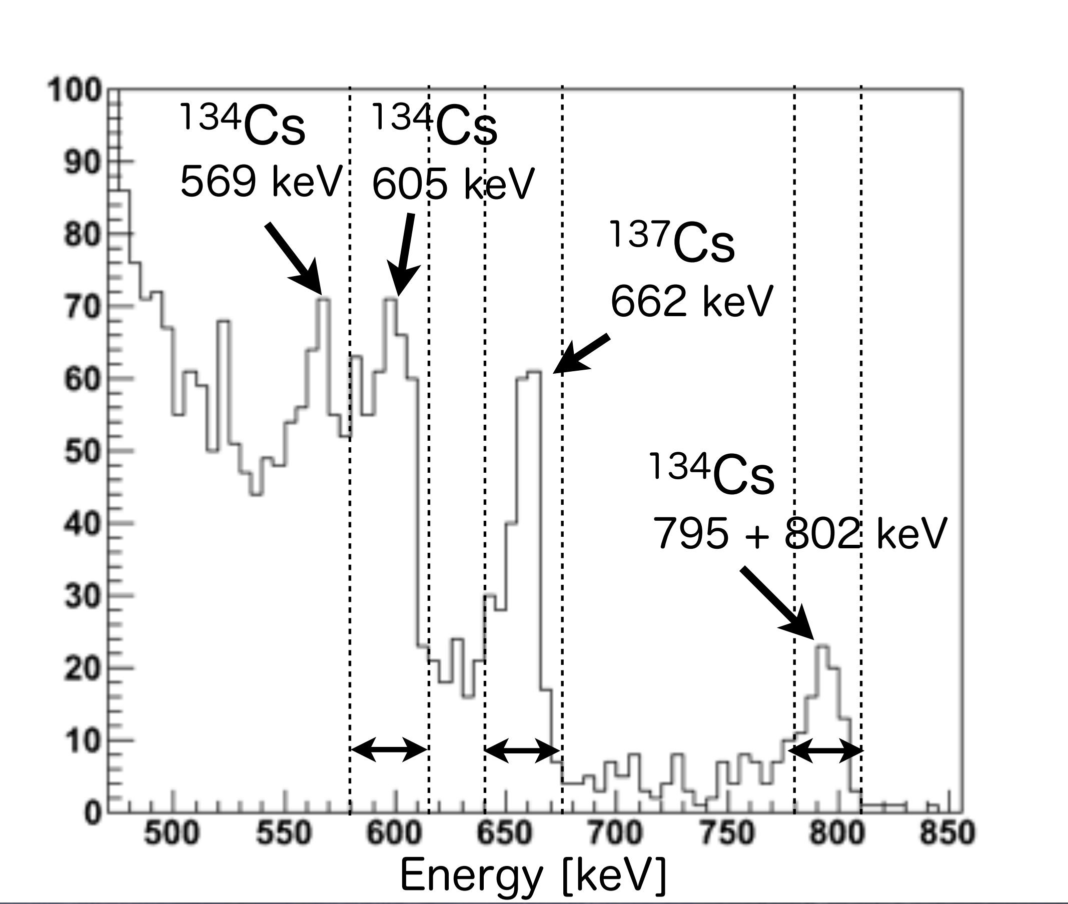


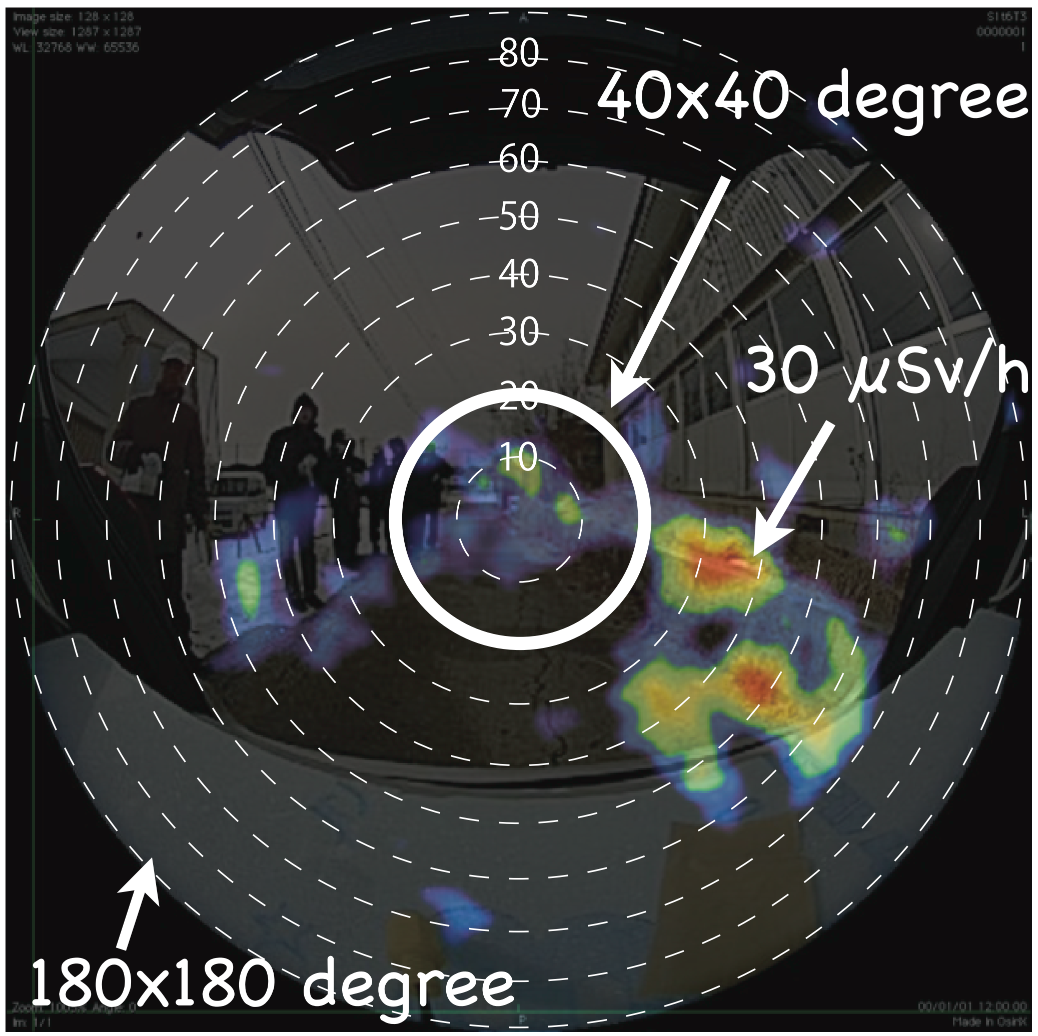
- 250 μm pitch Si-DSSD & CdTe-DSSD
- Thickness : 0.5 mm (Si), 0.75 mm (CdTe)
- ADC implemented VATA ASIC

First demonstration in Fukushima

Env. radiation level ~ 3 μSv/h

After 60 min exposure

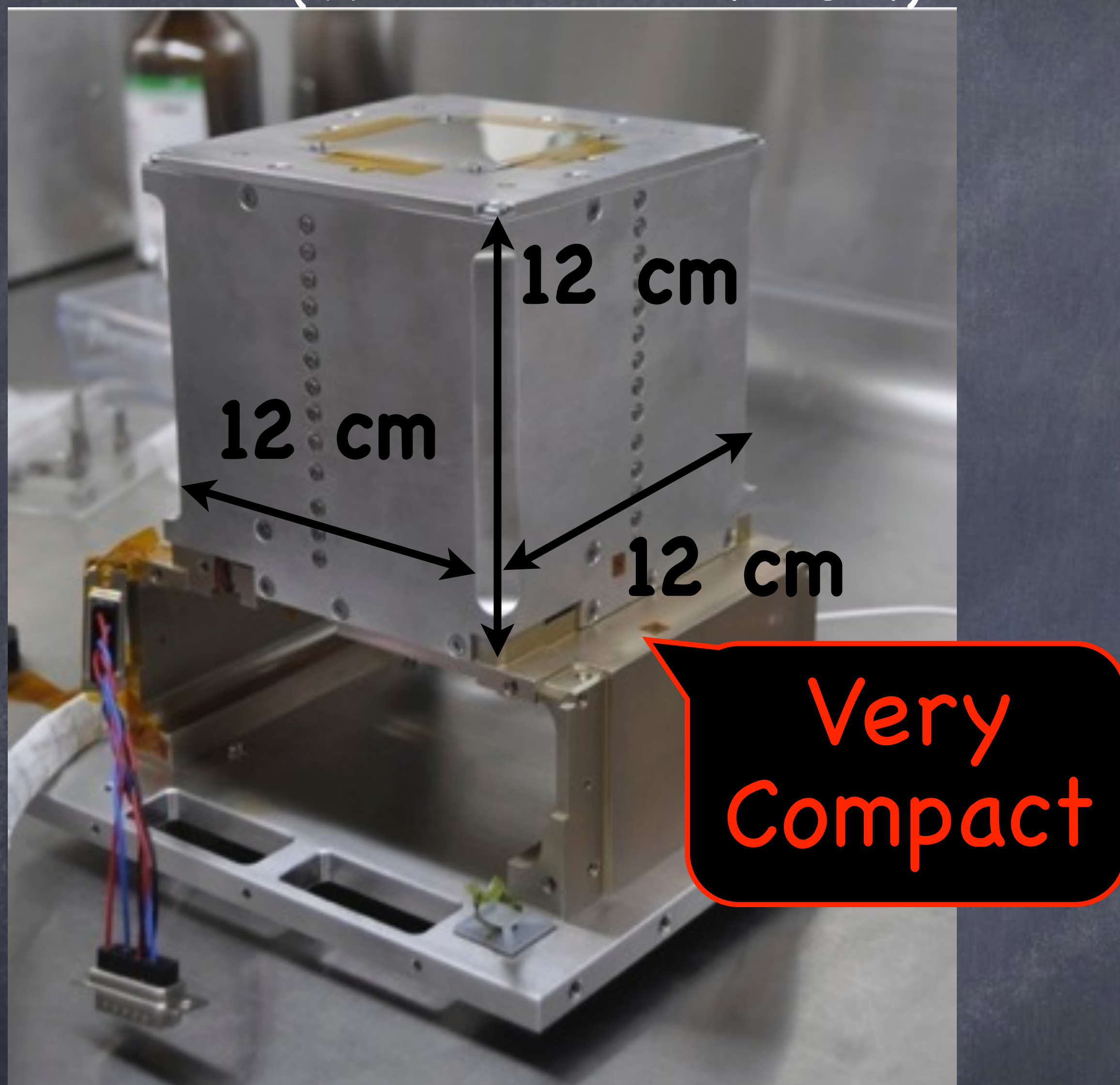


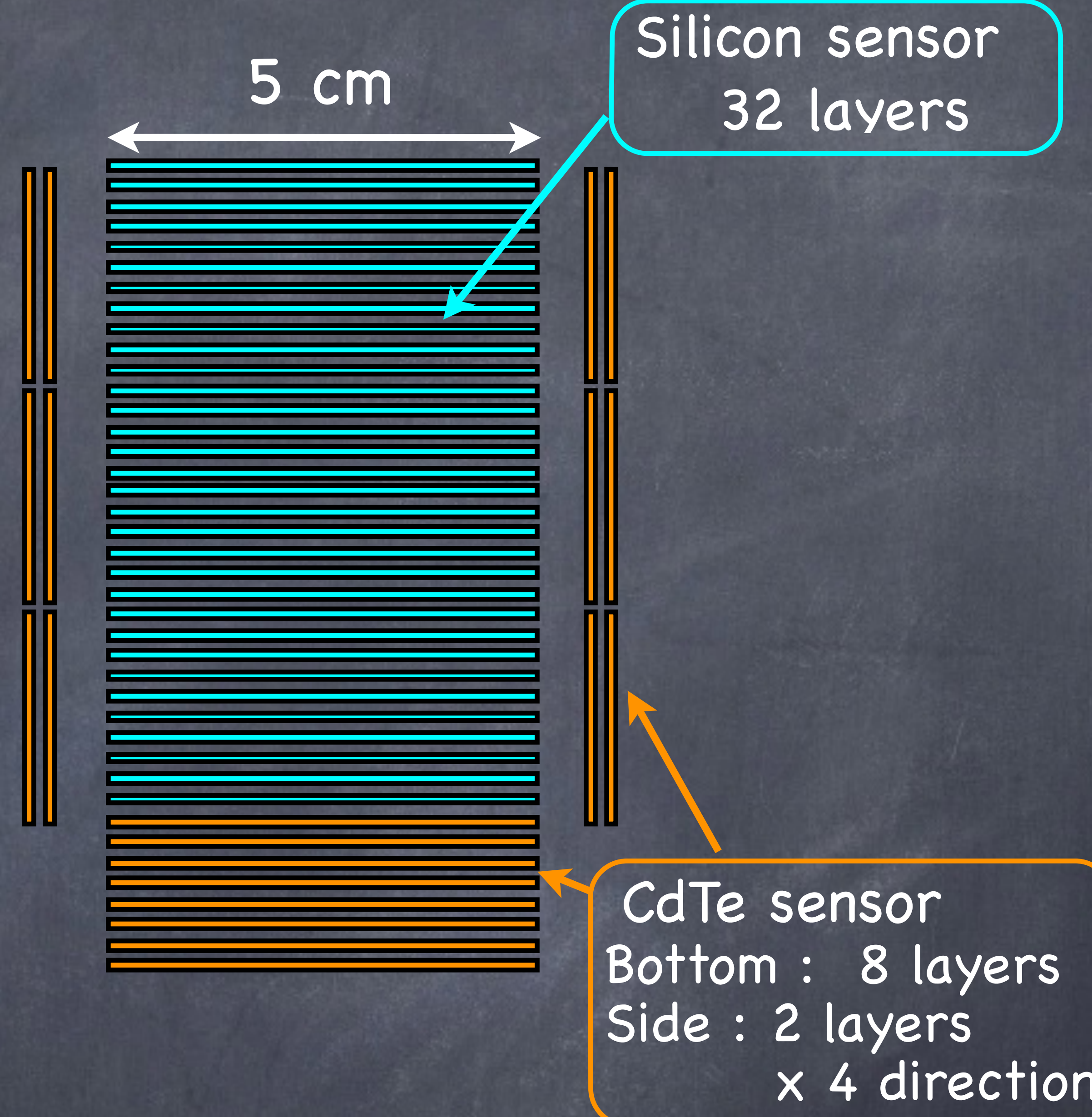


Upgrade High sensitivity Compton camera (2013)

ASTRO-H SGD module

(Watanabe et al. 2014)





- 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

Prototype

(Takeda et al 2012)

Upgrade

Imaging algorithms

Two important topics in data analysis :

1 Reconstruction of multiple hits event

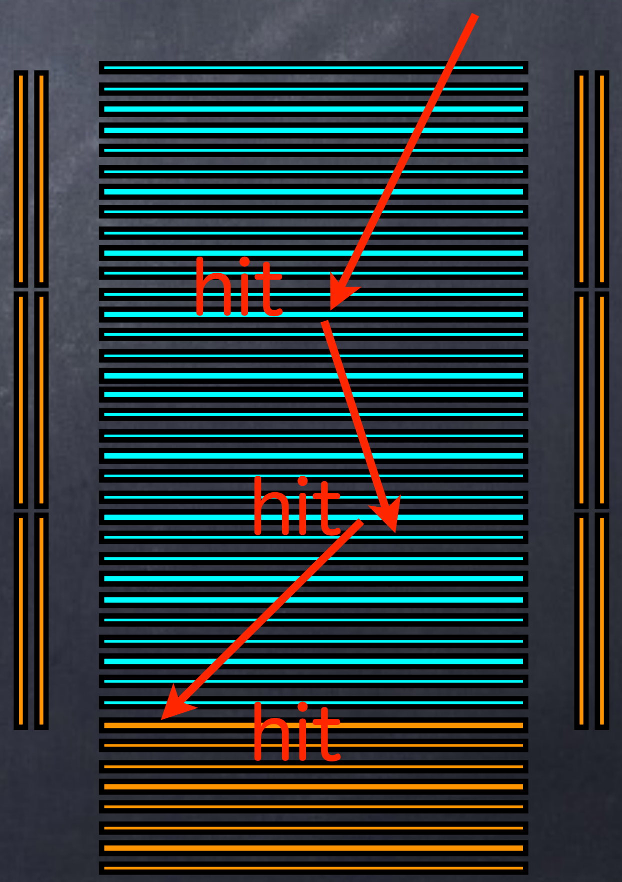
Gamma-ray energy ↑, Multiple scattering ↑

- Si (1 hit) + CdTe (1 hit) : Only 35 % @ 662 keV
- Requirement : Analysis of num. of total hits ≤ 5

2 Significance of hotspots

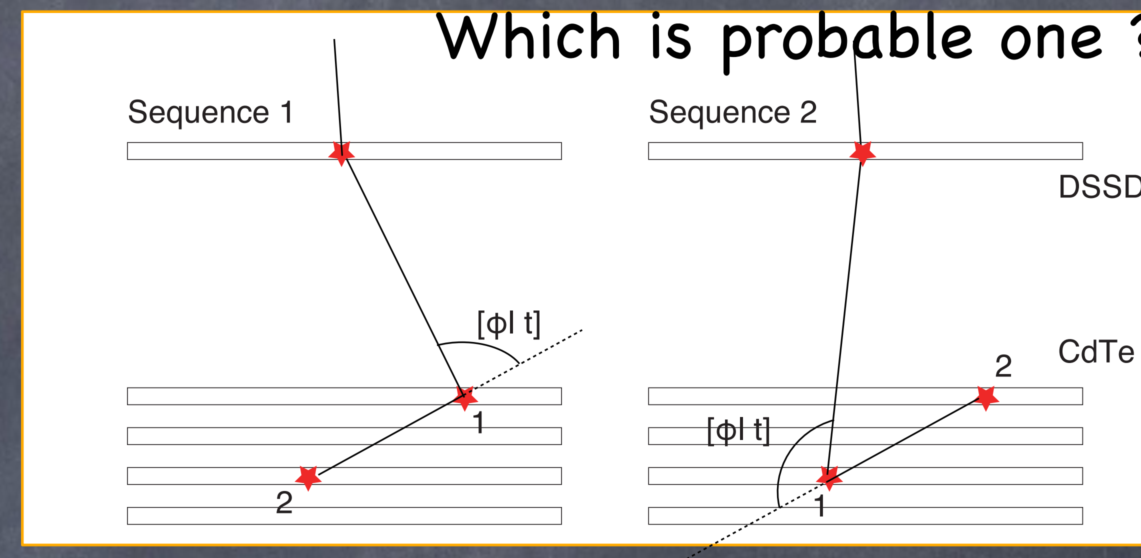
to distinguish hotspots from image noises

Why you can say this is hotspots ….



1 Reconstruction of multiple hits event

Correct order is unknown (no ToF) !!
How to select the most probable sequence.



KEY : MC simulator (Odaka et al. 2010)

KEY : Figure of Merits (FoM) in hits' ordering

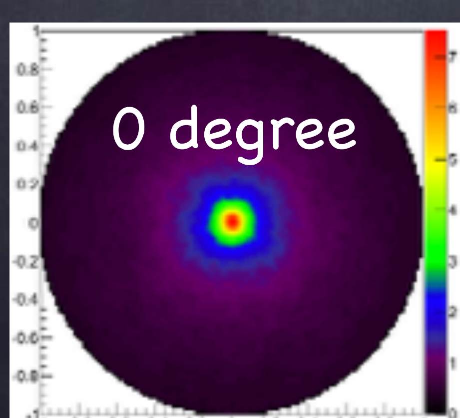
(Ichinohe et al. 2014)

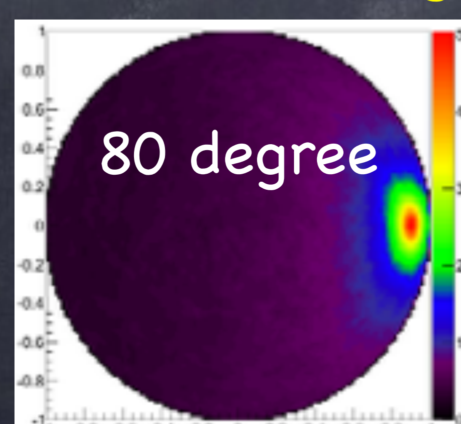
Results :

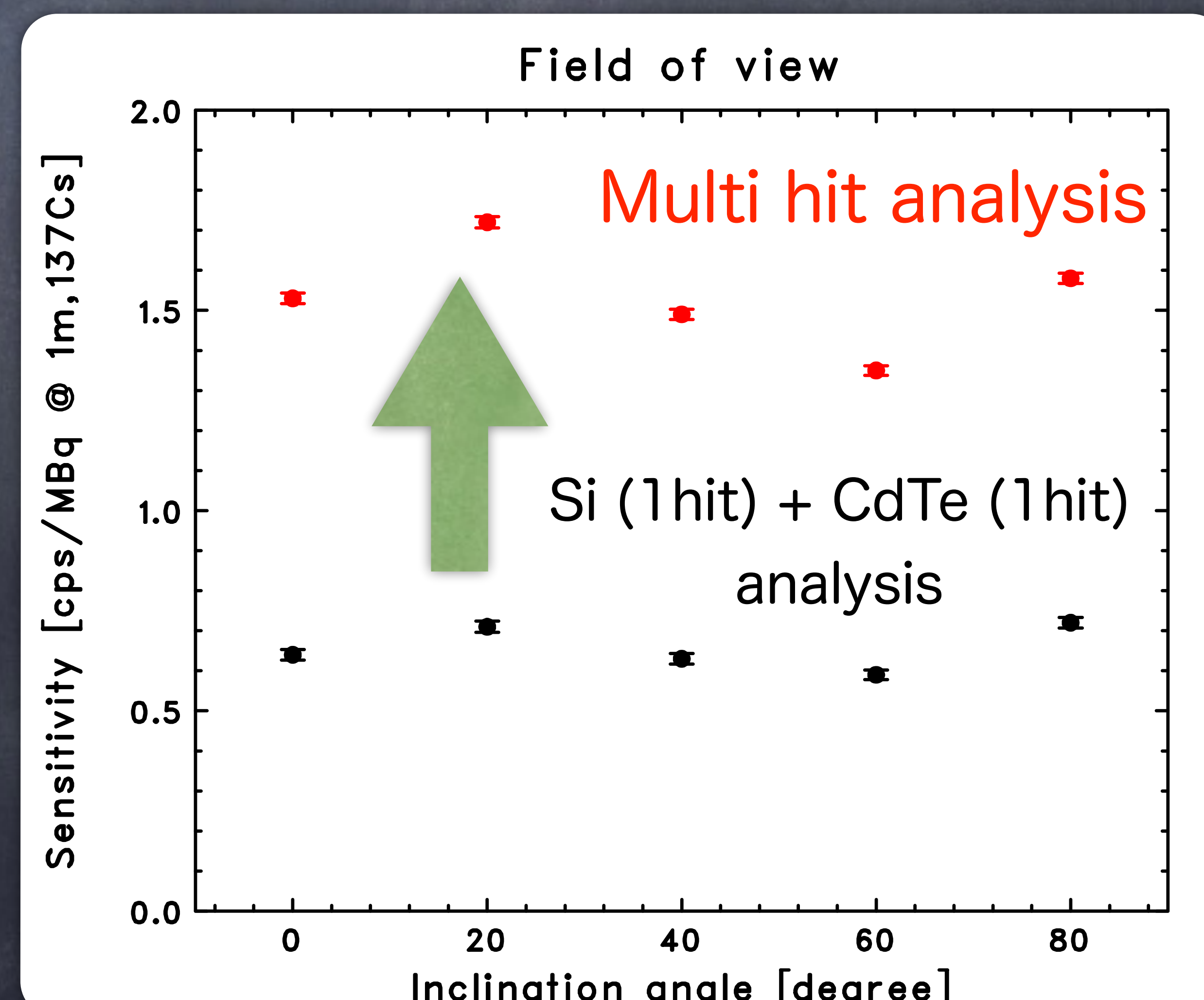
Efficiency : 2.5 times better

Acceptable reconstruction :

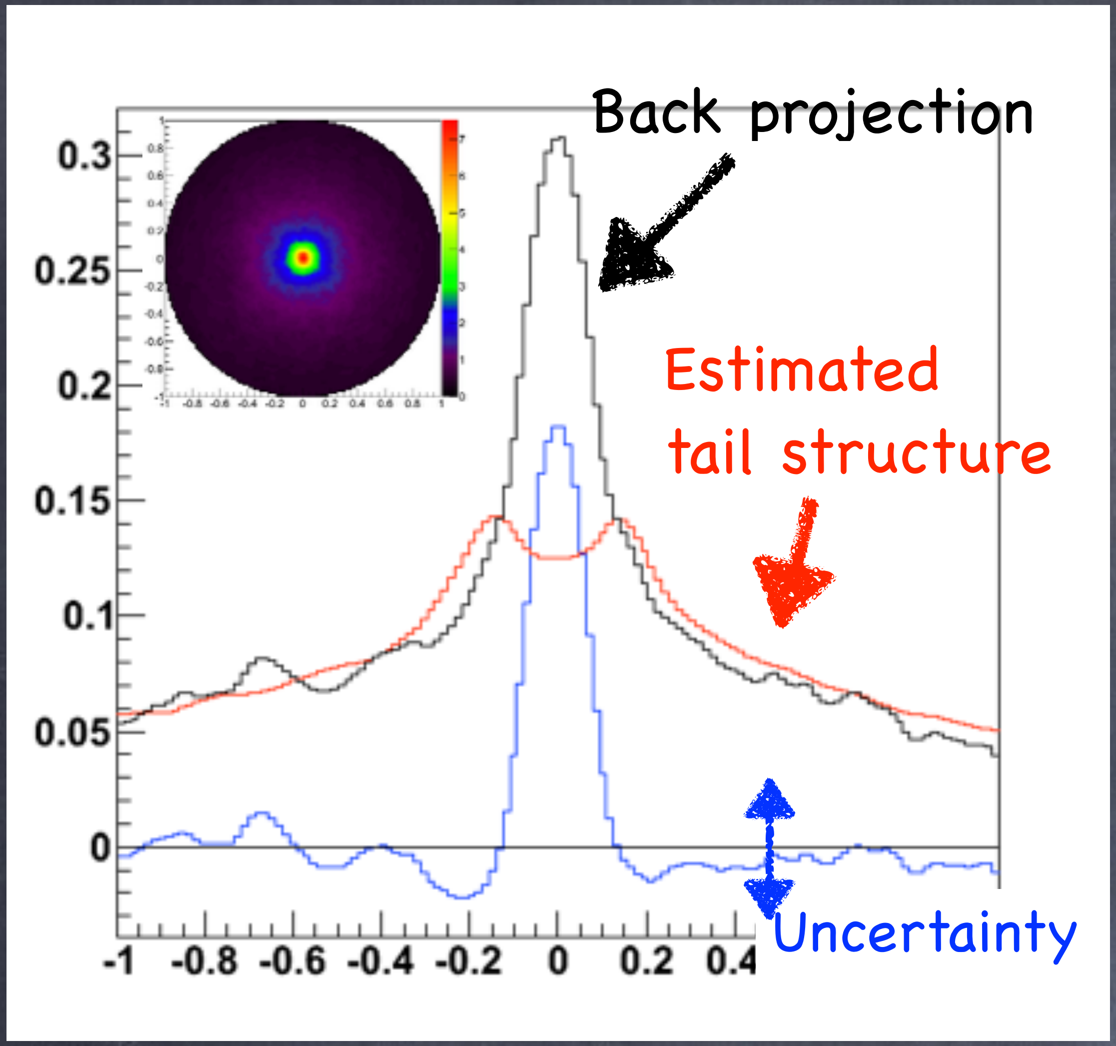
87 % (0 degree), 84 % (80 degree)







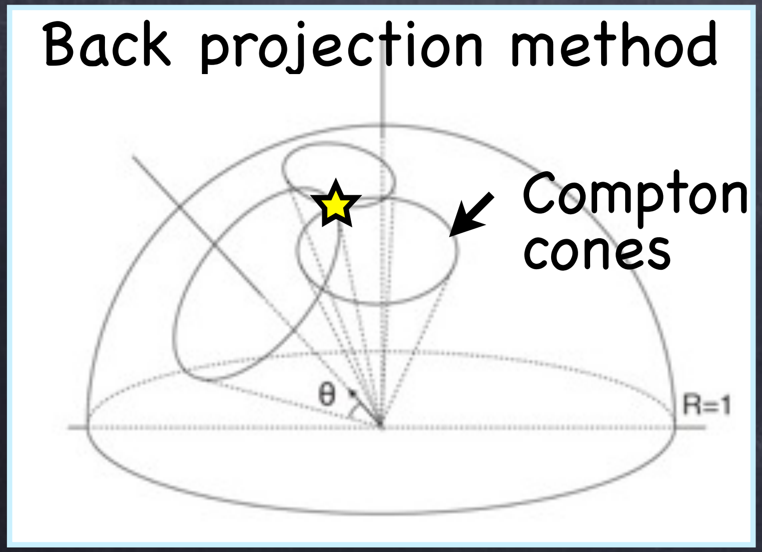
2 Significance of hotspots

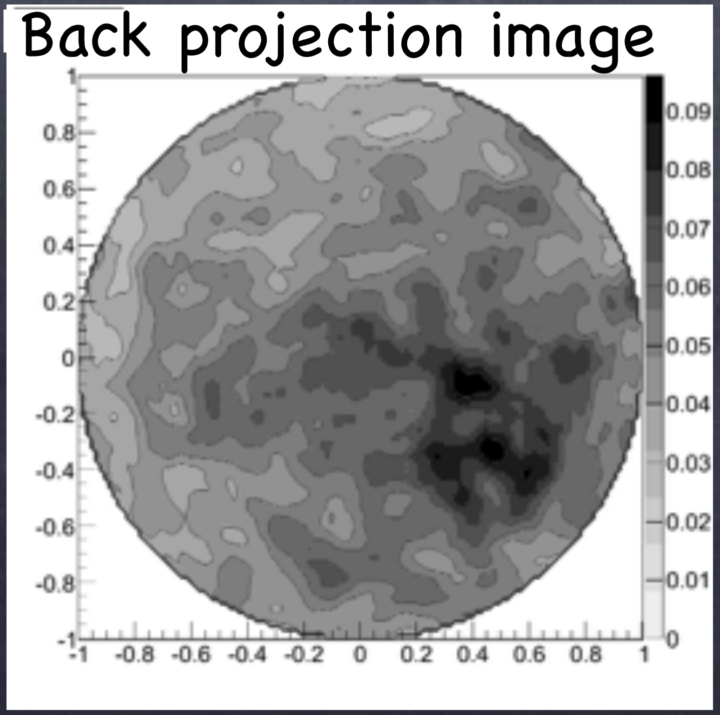


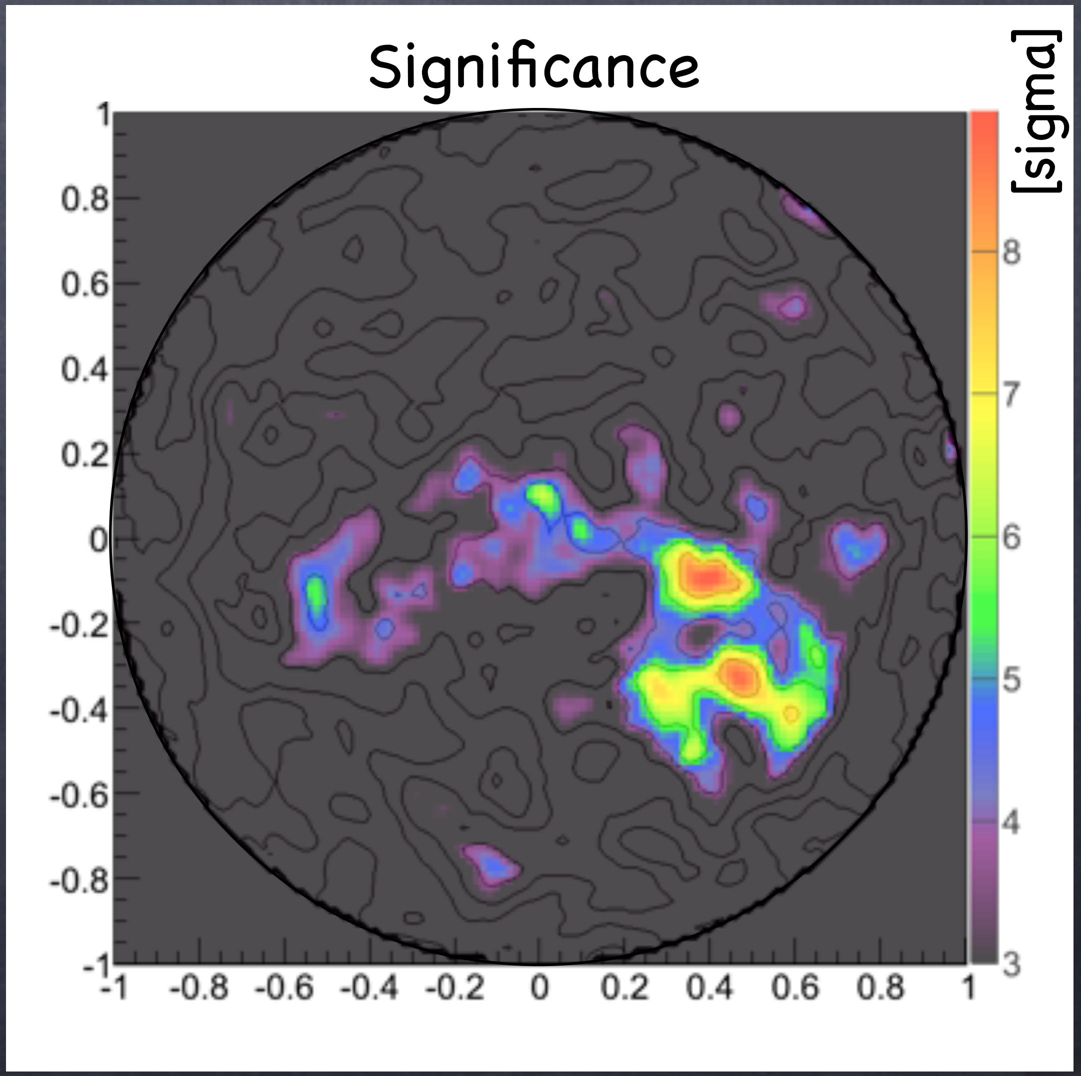
Our approach :

Step 1 : Making image with low systematic error and artifacts. Back projection image is suitable to meet this requirement.

Step 2 : Modeling of tail structure, then calculating uncertainty.



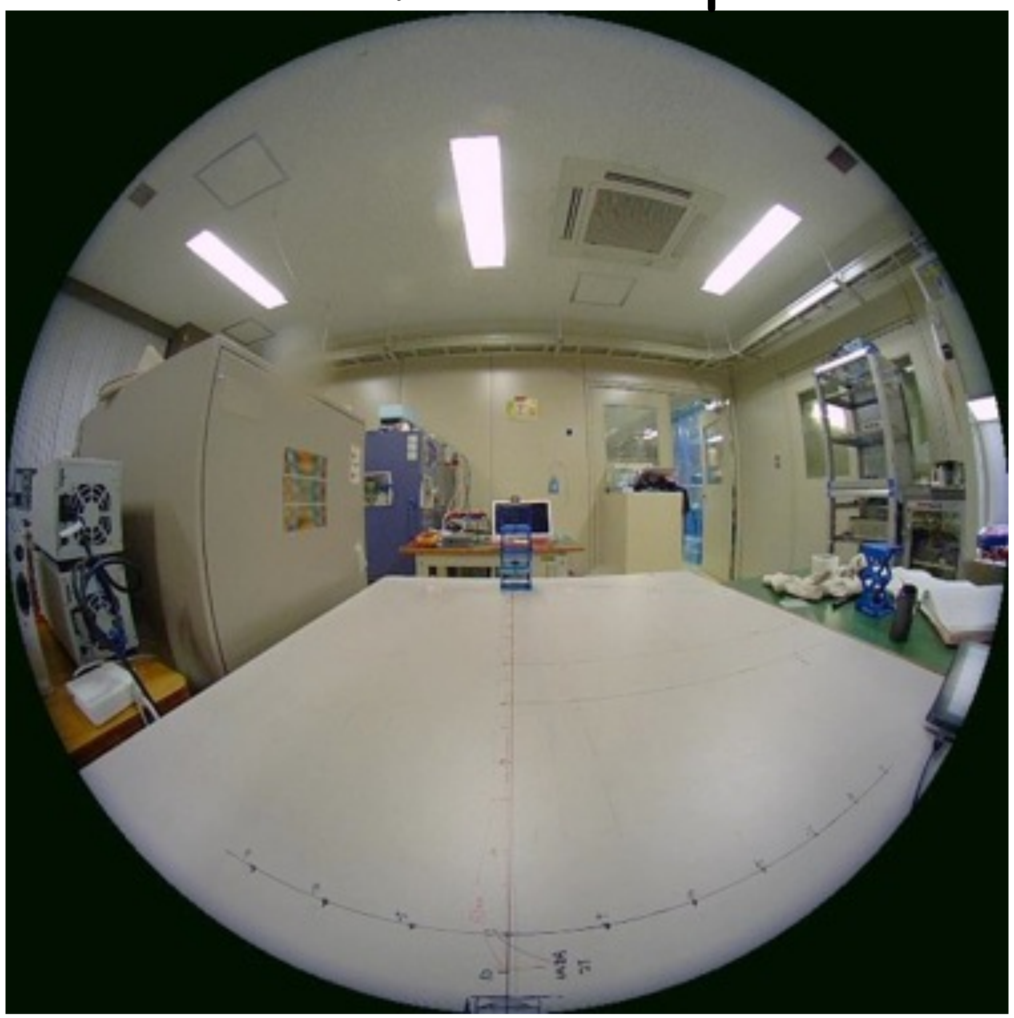


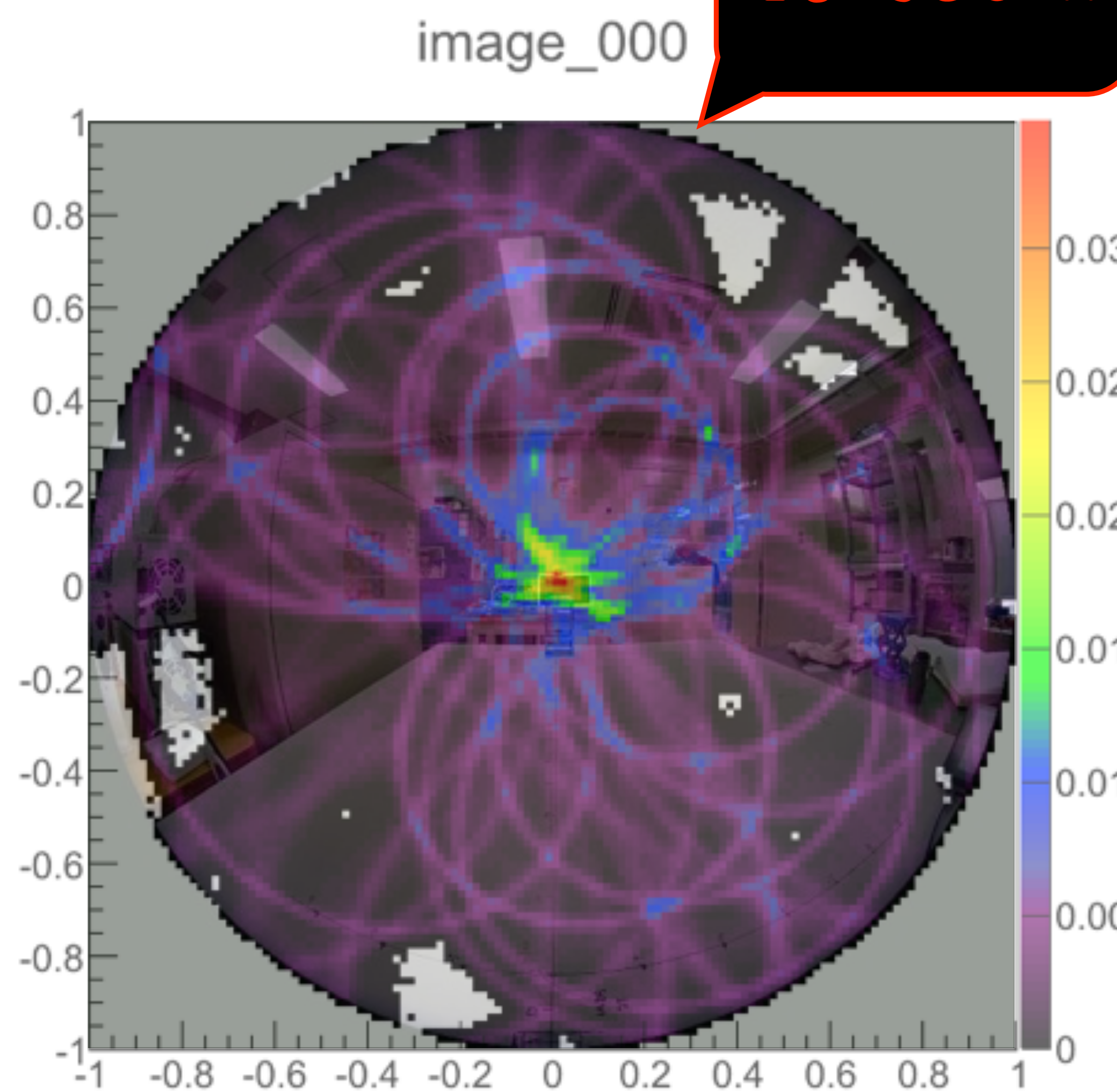


The prototype took 5 minutes

10 sec !!

137-Cs, 2.7MBq @ 1m





40 times better efficiency than the prototype

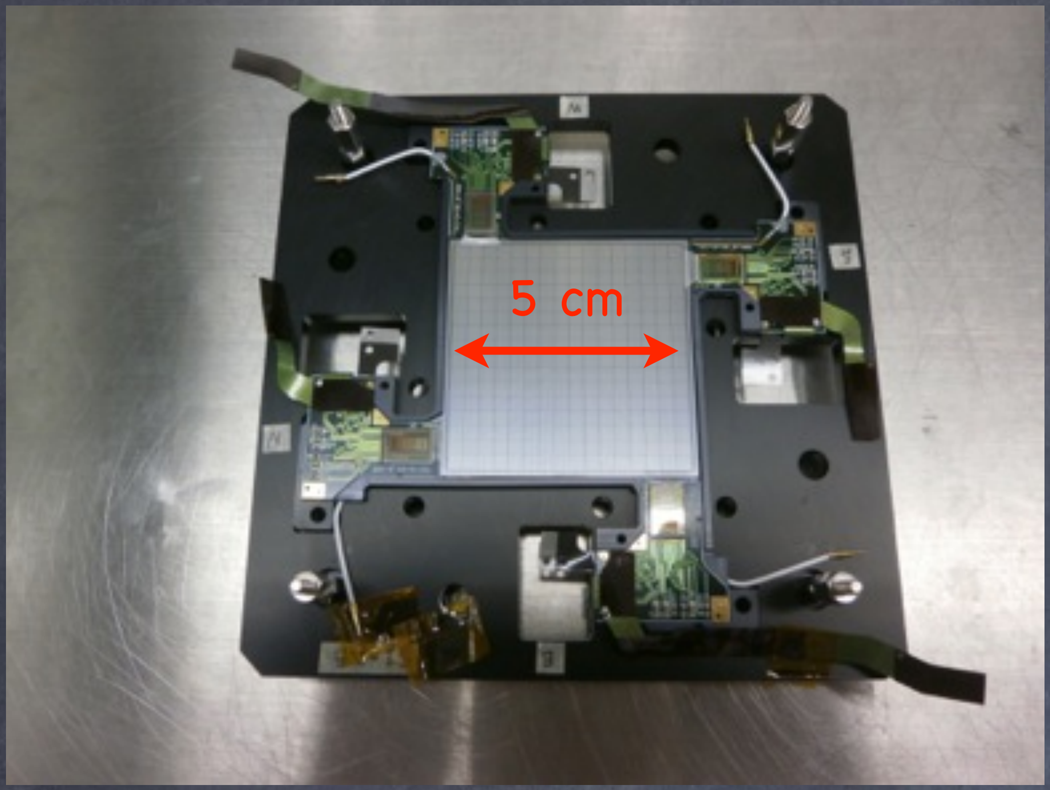
2.8 cps/MBq, 137-Cs 662 ke @ 1m

Release First commercial camera (2013)

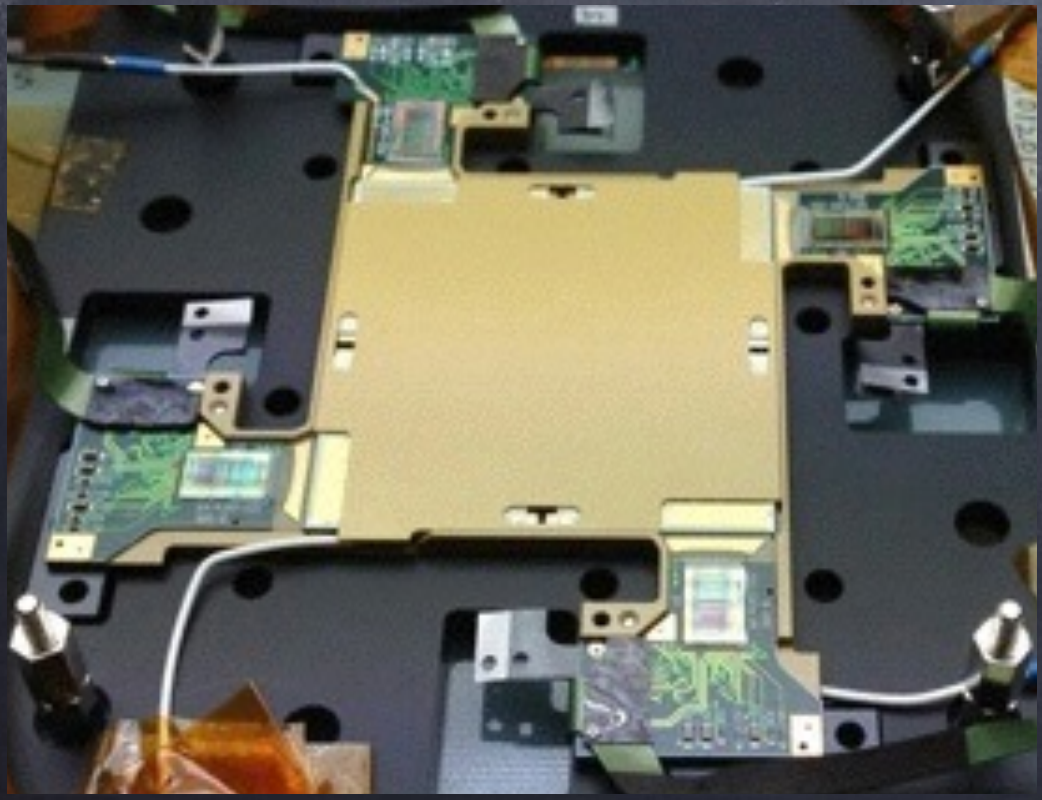
Radiation Visualization Camera

MITSUBISHI HEAVY INDUSTRIES, LTD.
Our Technologies, Your Tomorrow

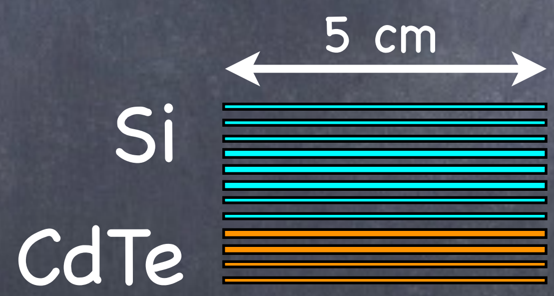
Si Pixel detector



CdTe Pixel detector

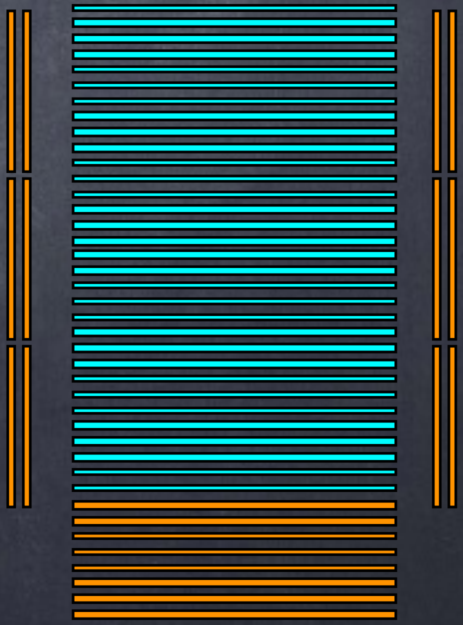


Standard Configuration



0.16 cps/MBq
@1m, 137-Cs

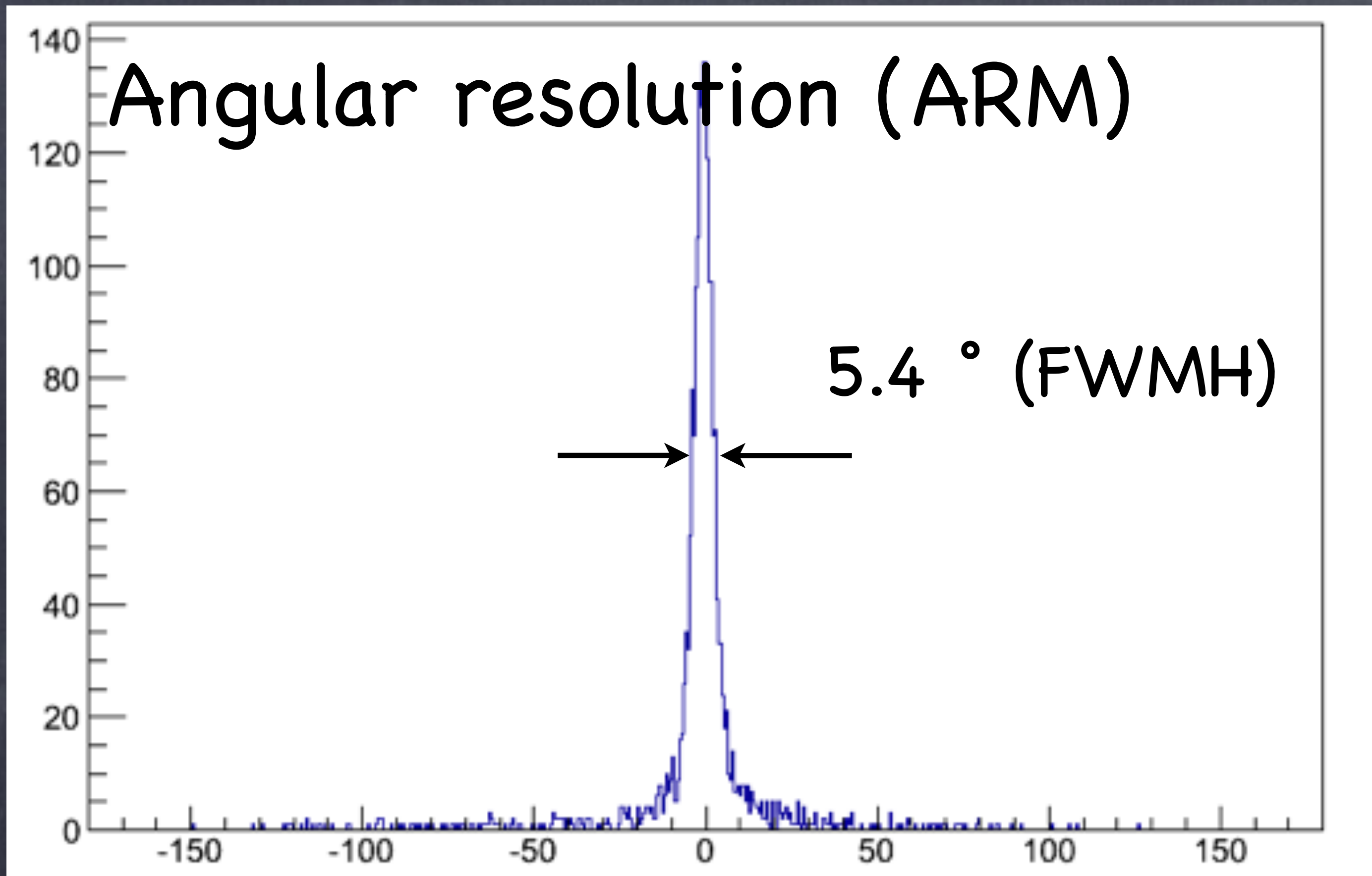
Enhanced Configuration

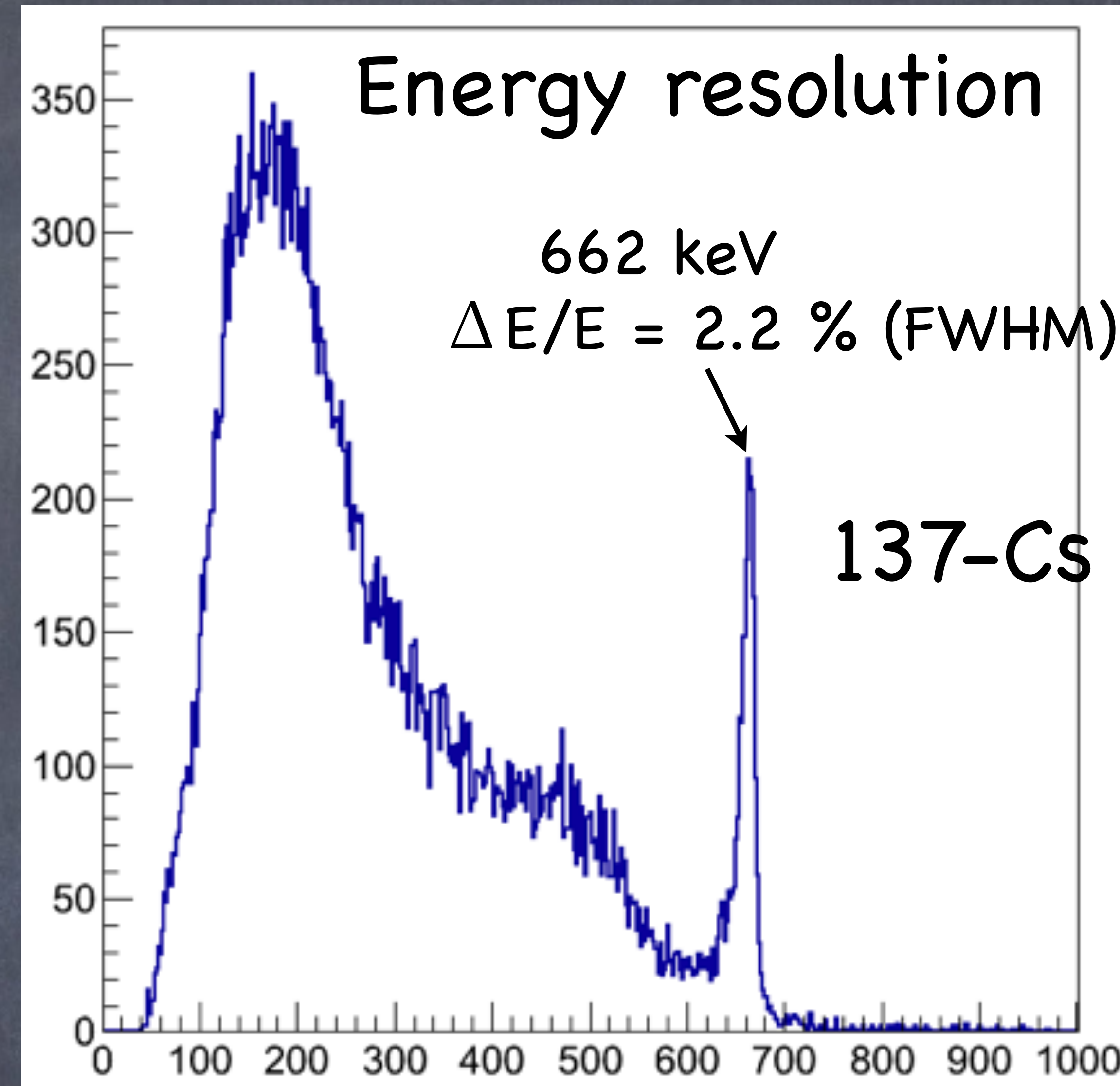


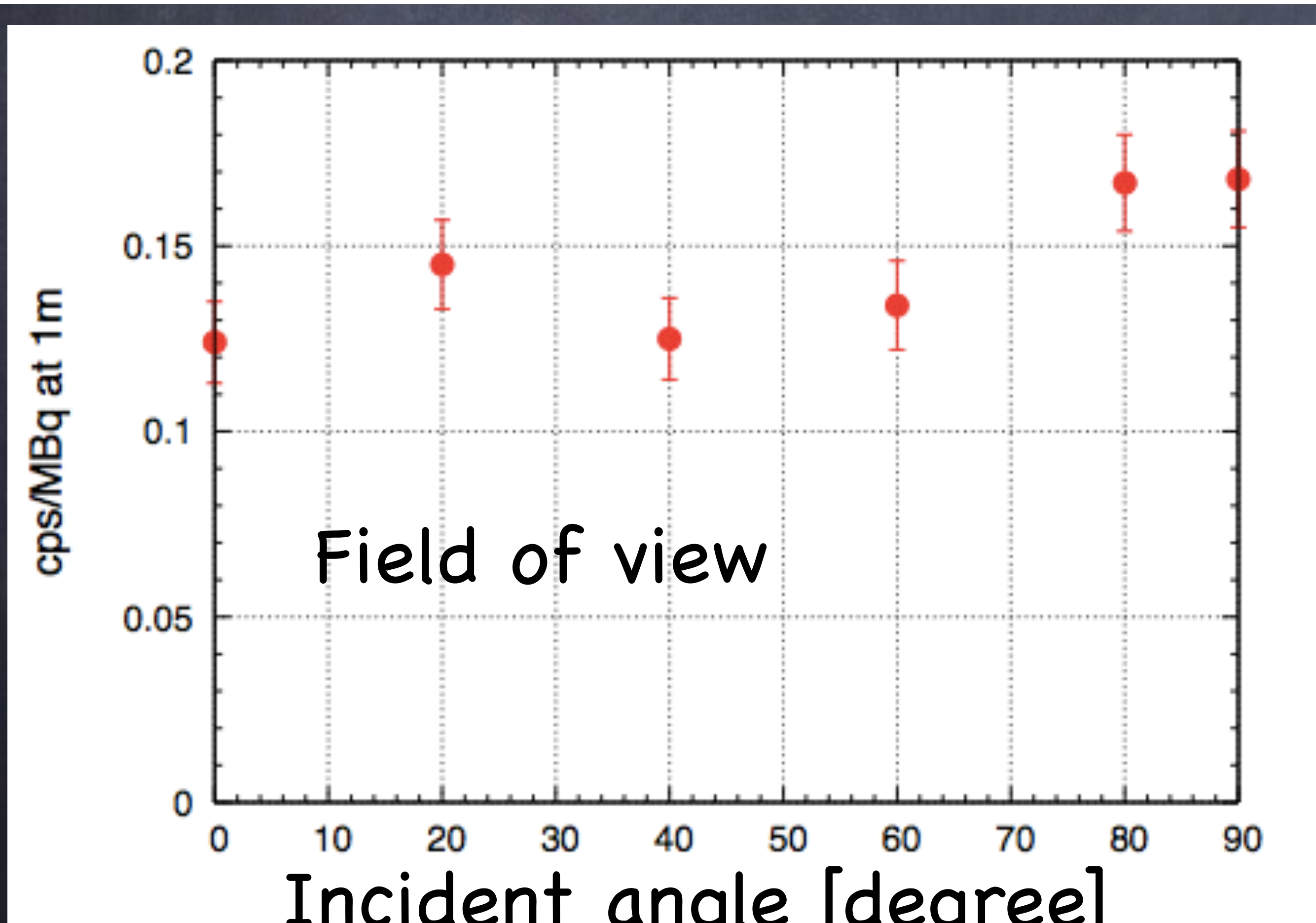
2.8 cps/MBq
@1m, 137-Cs

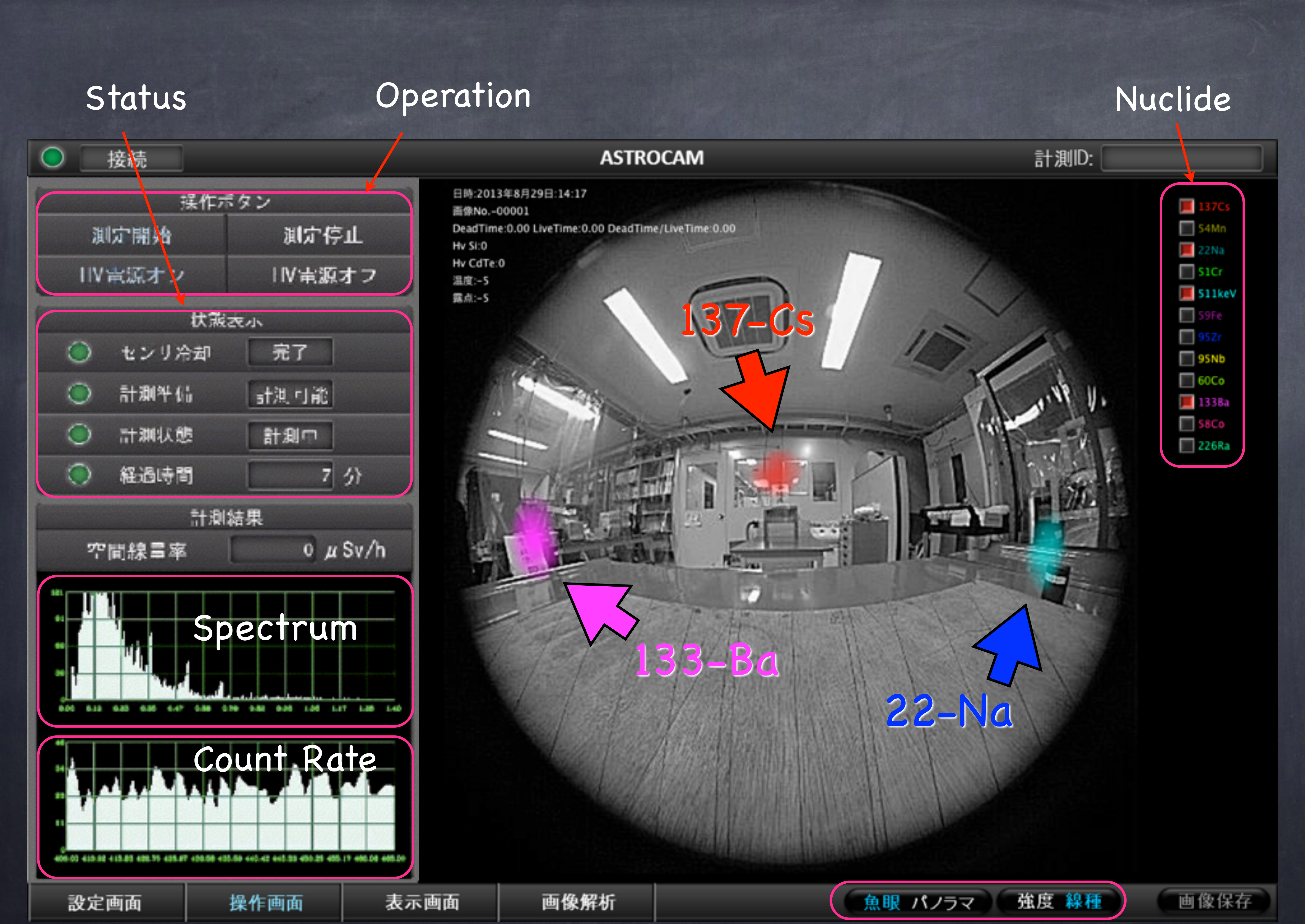
(cf. Prototype)

0.035 cps/MBq
@1m, 137-Cs


Angular resolution (ARM)
5.4 ° (FWMH)
140
120
100
80
60
40
20
0
-150
-100
-50
0
50
100
150


Energy resolution
662 keV
ΔE/E = 2.2 % (FWHM)
137-Cs
350
300
250
200
150
100
50
0
0
100
200
300
400
500
600
700
800
900
1000

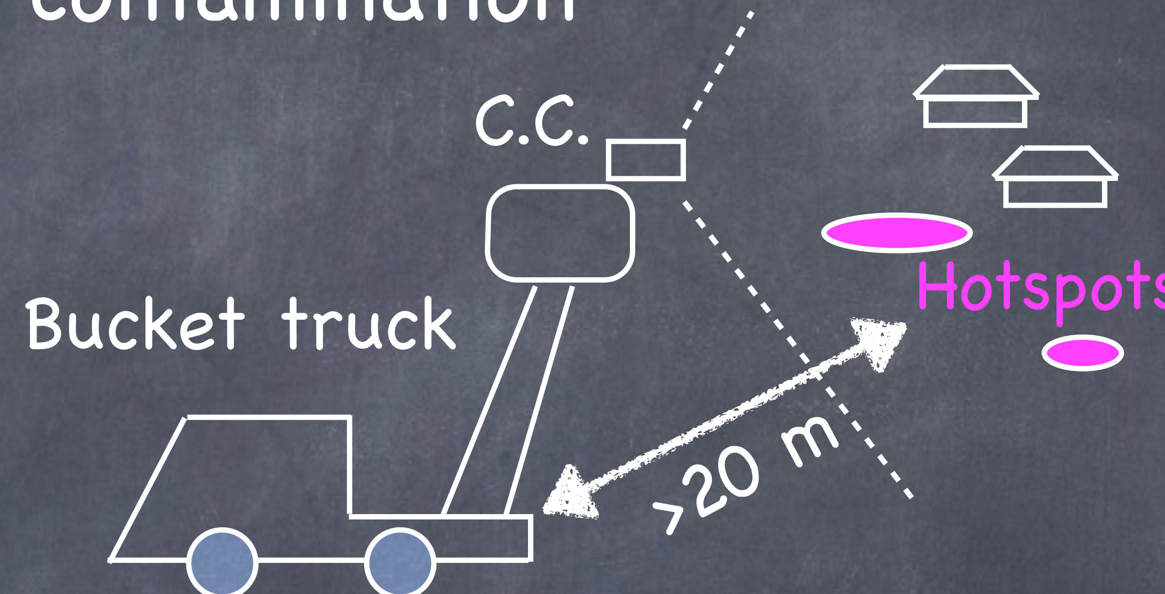

cps/MBq at 1m
Field of view
Incident angle [degree]
0.2
0.15
0.1
0.05
0
0
10
20
30
40
50
60
70
80
90



Status
Operation
Nuclide
接続
ASTROCAM
計測ID:
操作ボタン
測定開始
測定停止
HV電源オン
HV電源オフ
状態表示
センサ冷却
完了
計測準備
計測可能
計測状態
計測中
経過時間
7
分
計測結果
空間線量率
0
μSv/h
Spectrum
Count Rate
日時:2013年8月29日:14:17
画像No.-00001
DeadTime:0.00 LiveTime:0.00 DeadTime/LiveTime:0.00
Hv Si:0
Hv CdTe:0
温度:-5
露点:-5
137-Cs
133-Ba
22-Na
137Cs
54Mn
22Na
51Cr
511keV
59Fe
95Zr
95Nb
60Co
133Ba
58Co
226Ra
設定画面
操作画面
表示画面
画像解析
魚眼
パノラマ
強度
線種
画像保存
Mode

Demonstration in Fukushima

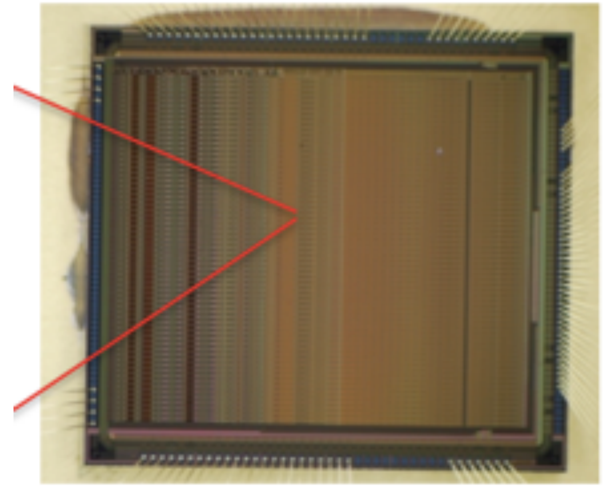
Tests to visualize a vast expanse of contamination



C.C. altitude ↑ imaging area ↑

Enhancing the merit of Compton imaging
(large field of view)

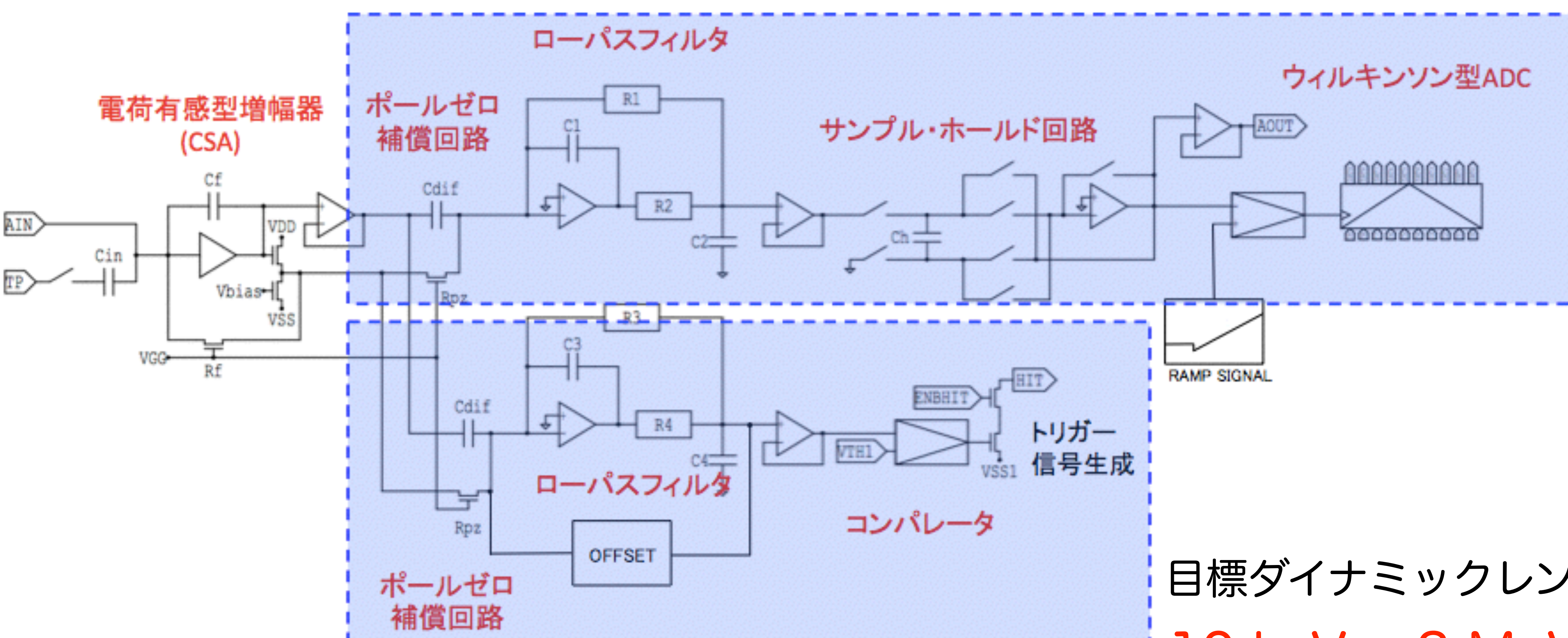
Low-noise 64ch IKEDA ASIC



独自開発した　64ch front-end ASIC
（KW04D64）

- Chip Size:　7.8 mm x 7.1 mm
- XFAB 0.35 um CMOS
- Strip pitch: 91.2 um
- Pad area: 64 x 90um
- Power rail +1.65 V, -1.65V

➤ 1 channel 当りの信号処理回路

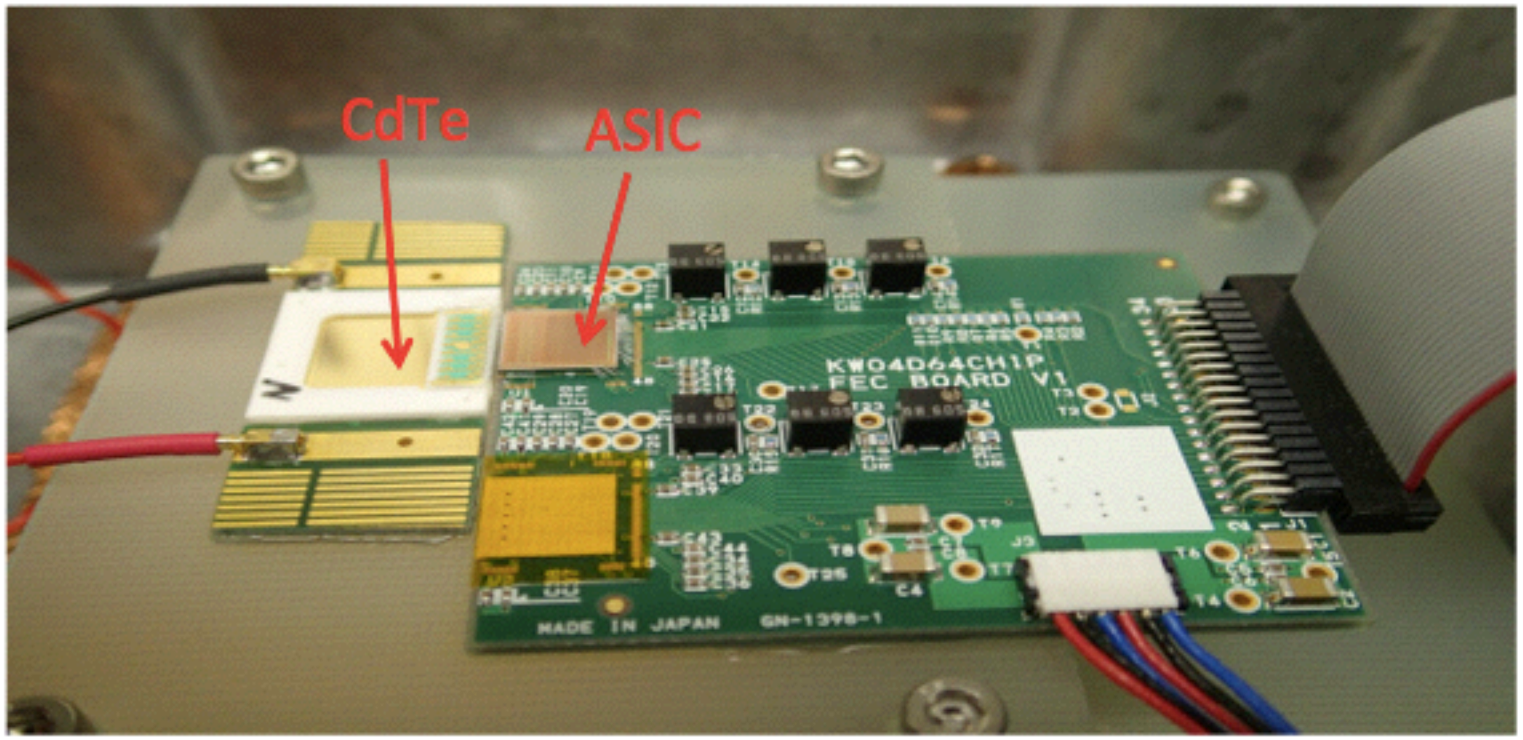


目標ダイナミックレンジ

10 keV ~ 2 MeV !!

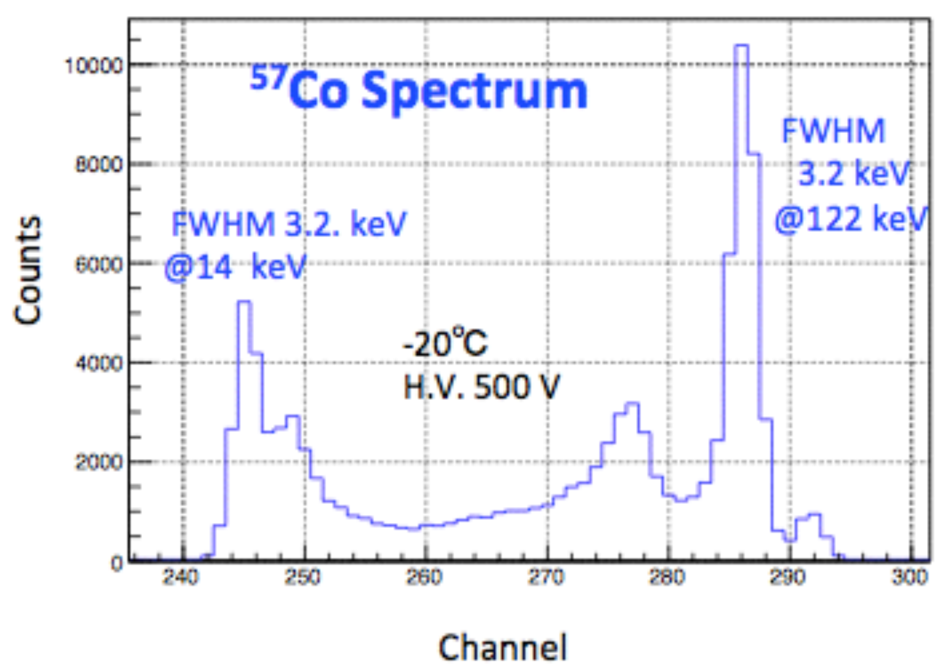
Low-noise 64ch IKEDA ASIC

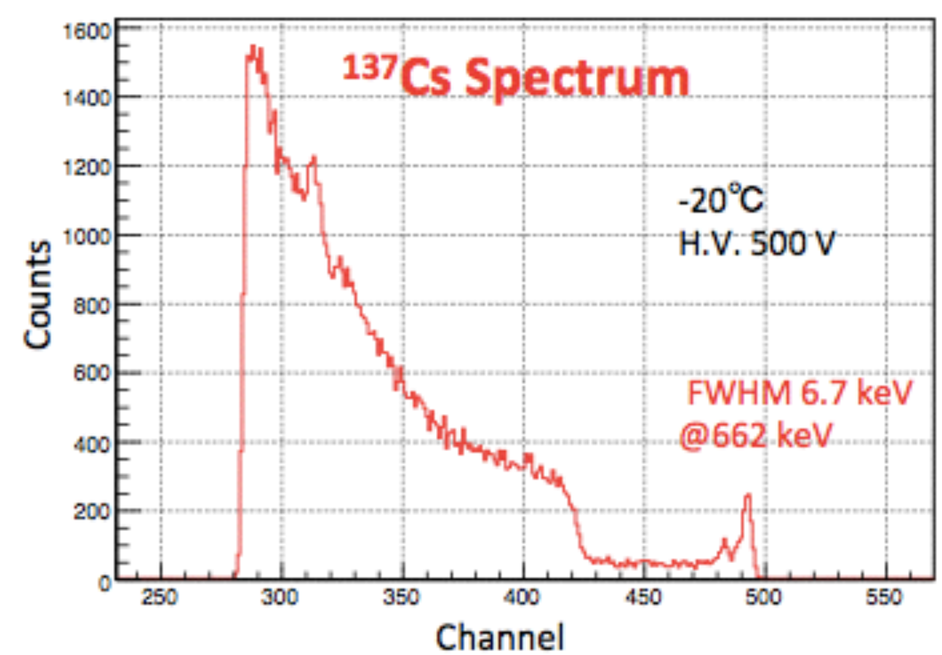
(KW04D64)



CdTeストリップ検出器(Al/CdTe/Pt)との接続

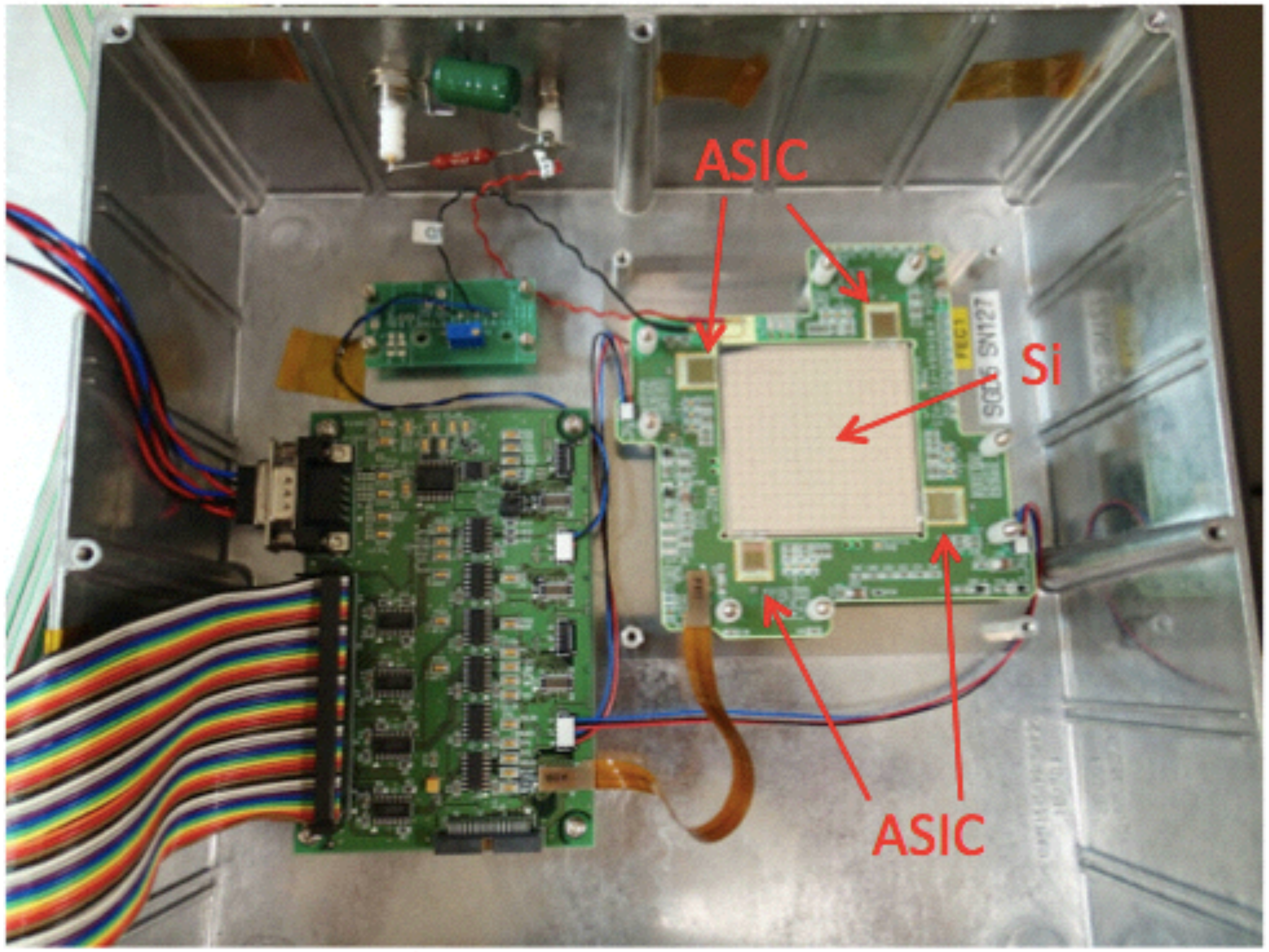
- 検出器サイズ: 10 mm x 10 mm
- 厚み: 0.75 mm
- ストリップ数: 32 strips
- ストリップ間隔: 250 um (50 um gap)





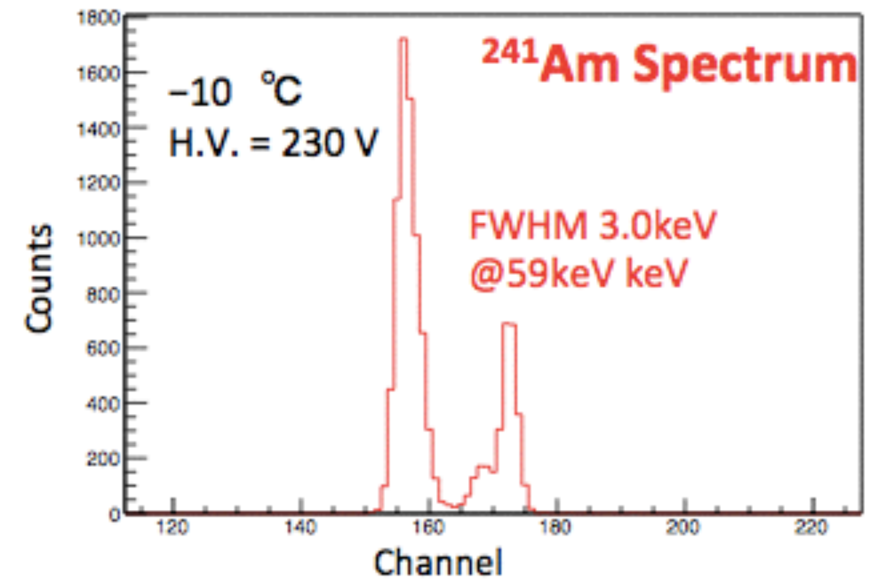
Low-noise 64ch IKEDA ASIC

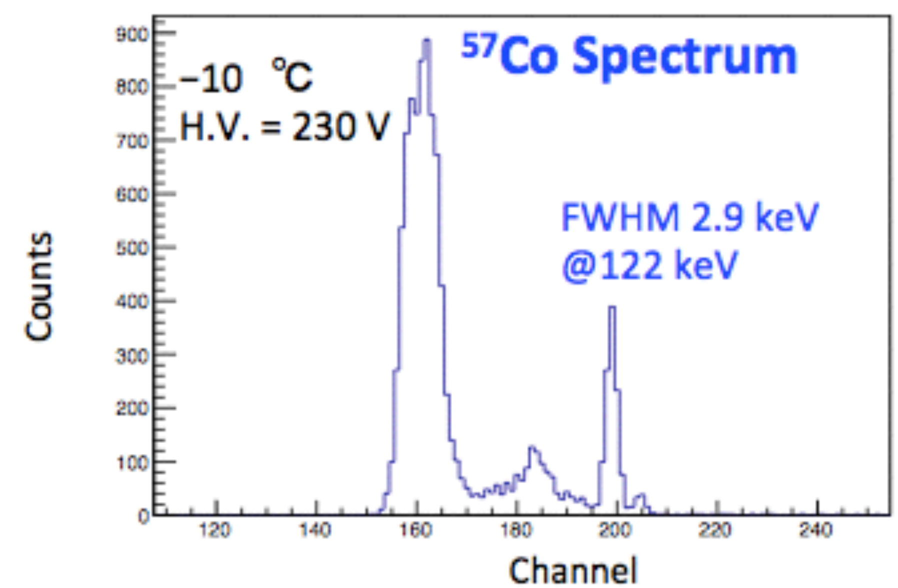
(KW04D64)



Si ピクセル検出器との接続

- 検出器サイズ:　54 mm x 54 mm
- 厚み:　Si 0.6 mm
- ピクセル数:　256 pixel
- ピクセルサイズ:　3.2 mm x 3.2 mm

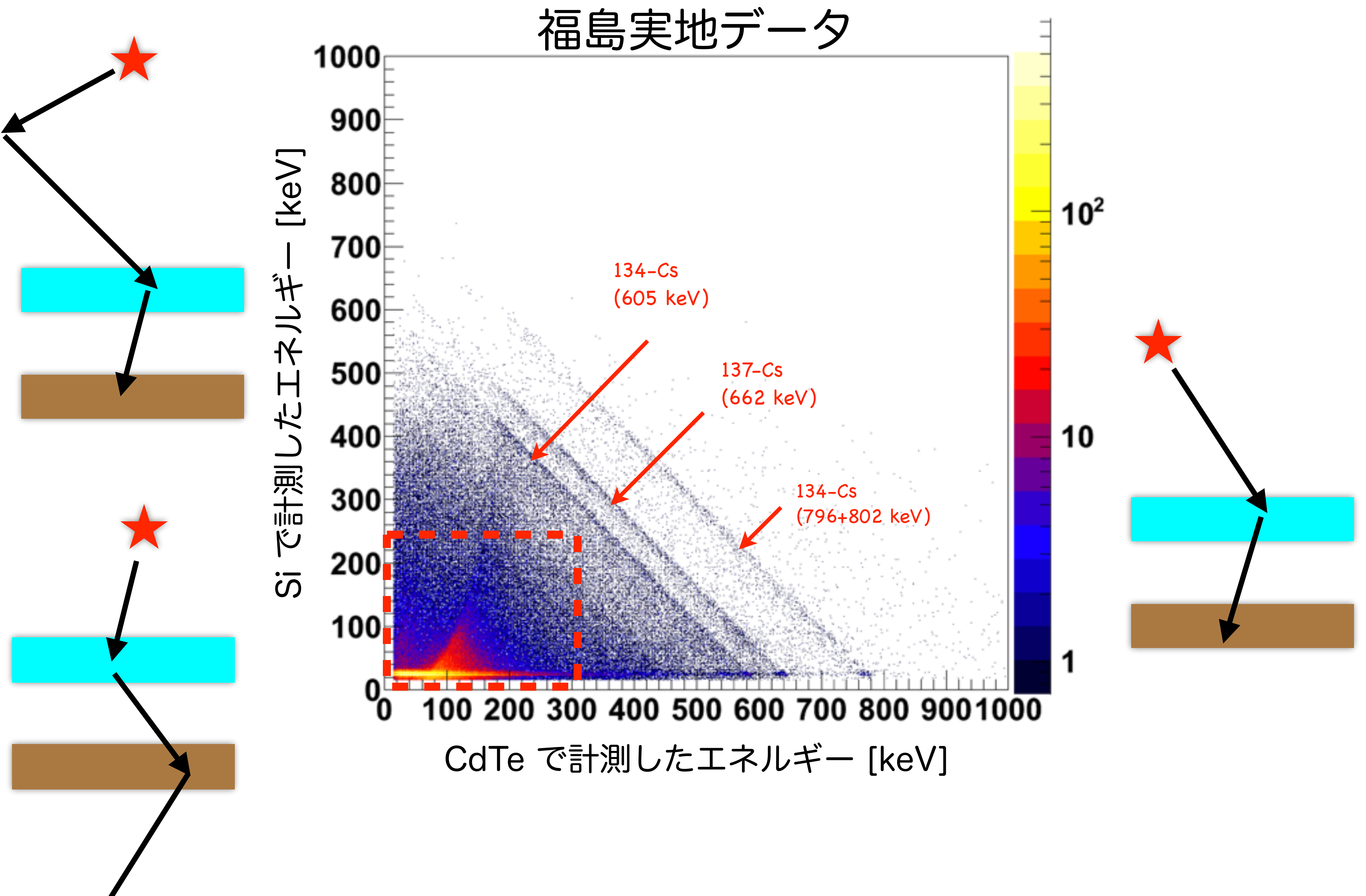




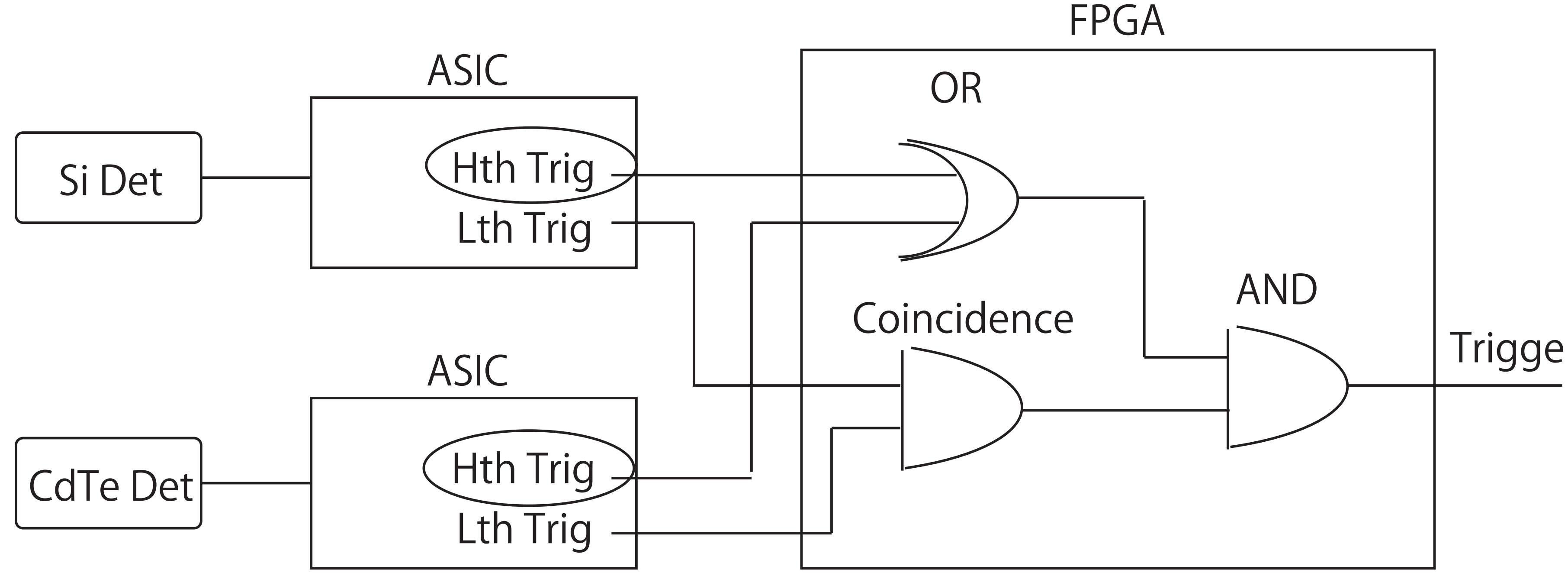
✓ ^{241}Am: ~3.0 keV(FWHM)@ 59 keV

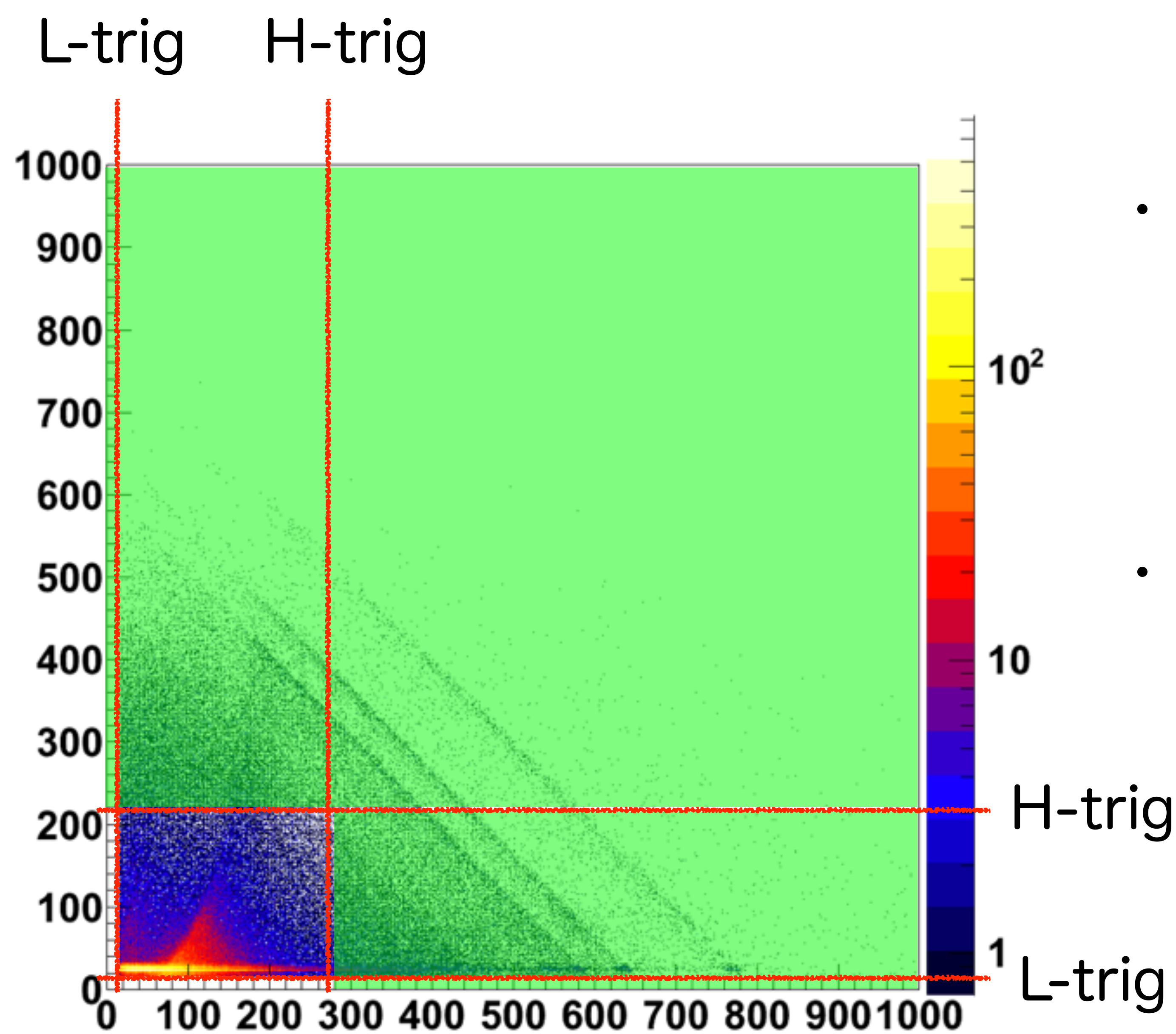
✓ ^{57}Co : ~2.9 keV (FWHM)@ 122 keV

Compton camera Oriented Trigger system



Compton camera Oriented Trigger system





- 緑の領域だけ　DAQ (サンプルホールド, AD変換,データ転送) をおこなう。
- Dead Time を劇的に低減させる。