Si/CdTe Compton Telescope for the NeXT mission and beyond

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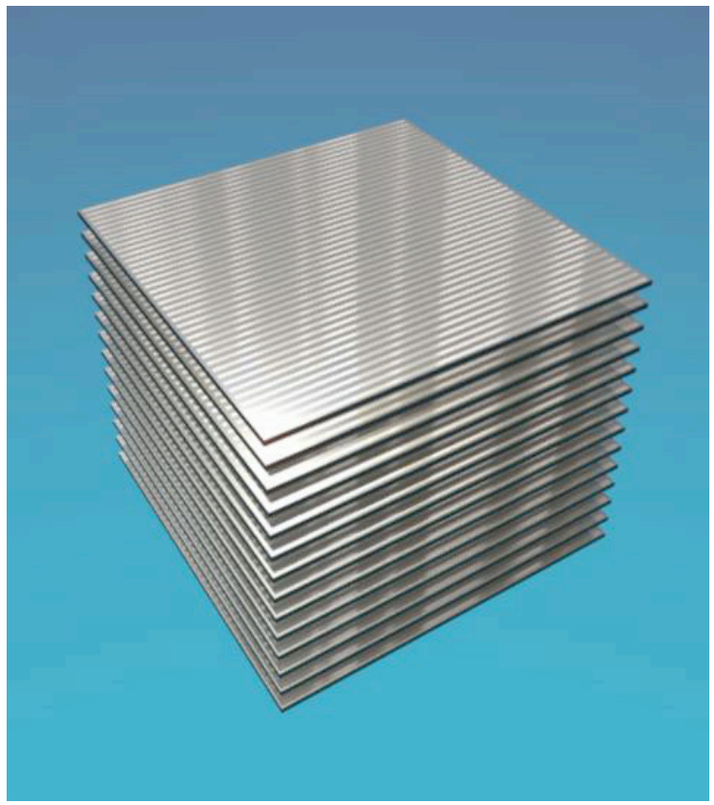
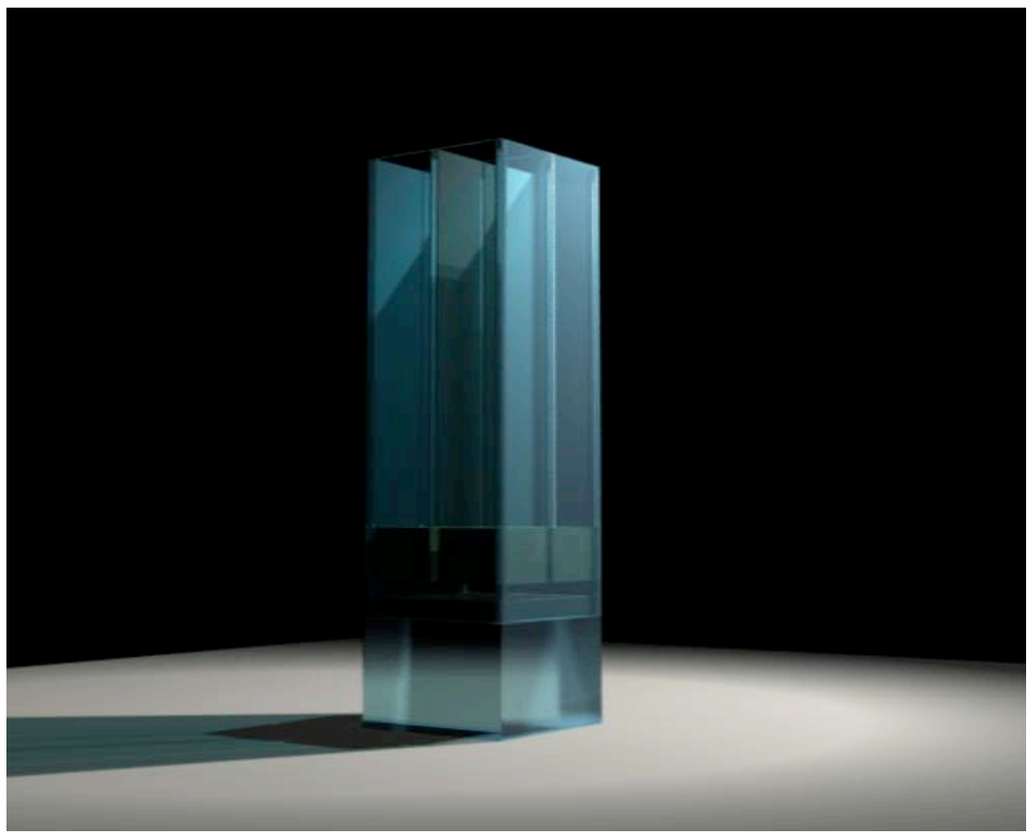




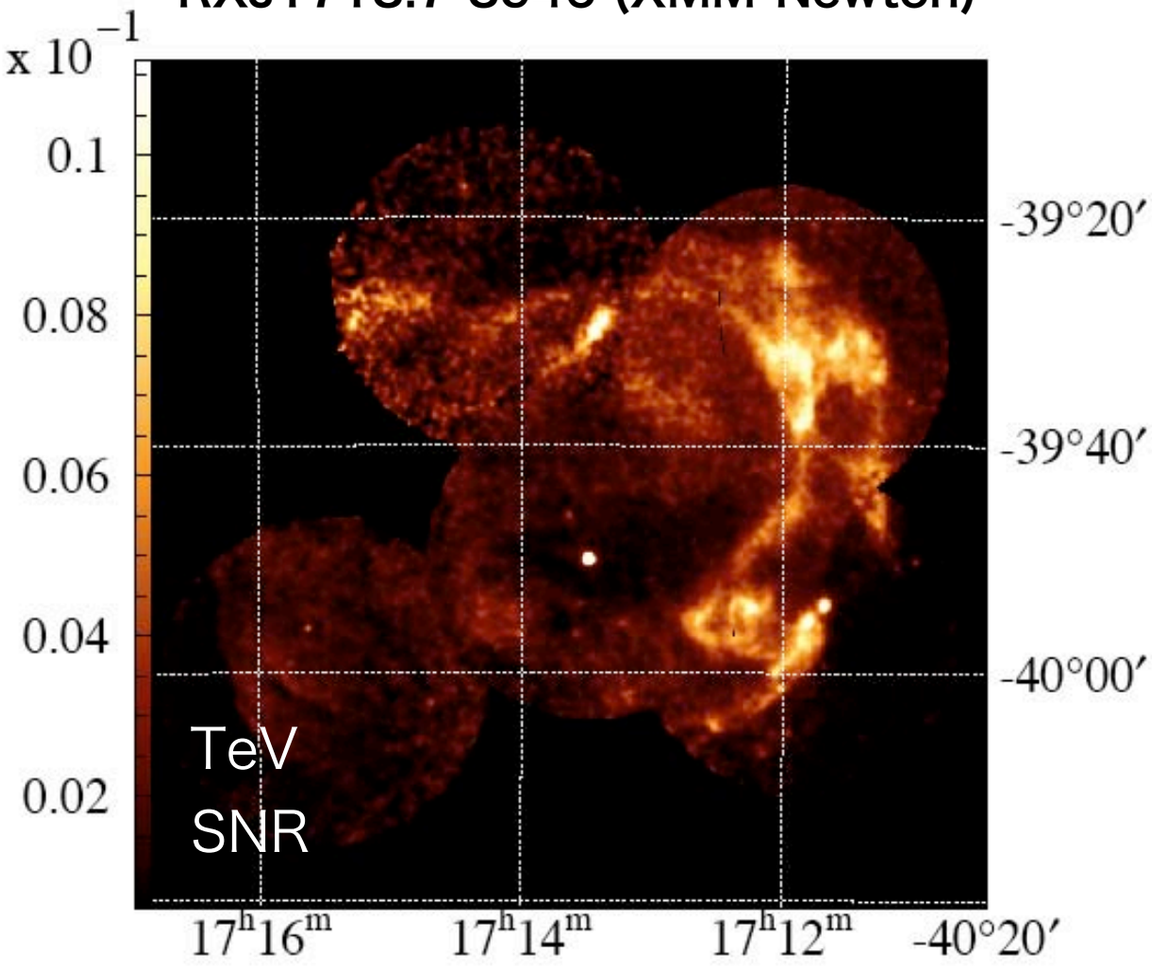
Outline

- Introduction
- From Suzaku (AstroE2) to NeXT
- Key Component - High Res. CdTe pixel
- CdTe Compton Telescope
- Si/CdTe Compton Telescope
- Polarization measurment (demonstration)
- A focal plane detector for gamma-ray lens
- Summary

Long term vision

Gamma-ray mapping of accelerators in the universe

X-ray Image (E<7 keV) of
TeV SNR
RXJ1713.7-3946 (XMM-Newton)



Uchiiyama, Aharonian, TT 2003
Hiraga, Uchiyama, TT, Aharonian 2003

Filaments (width 0.1pc) & Voids
Filled with X-ray synchrotron emission

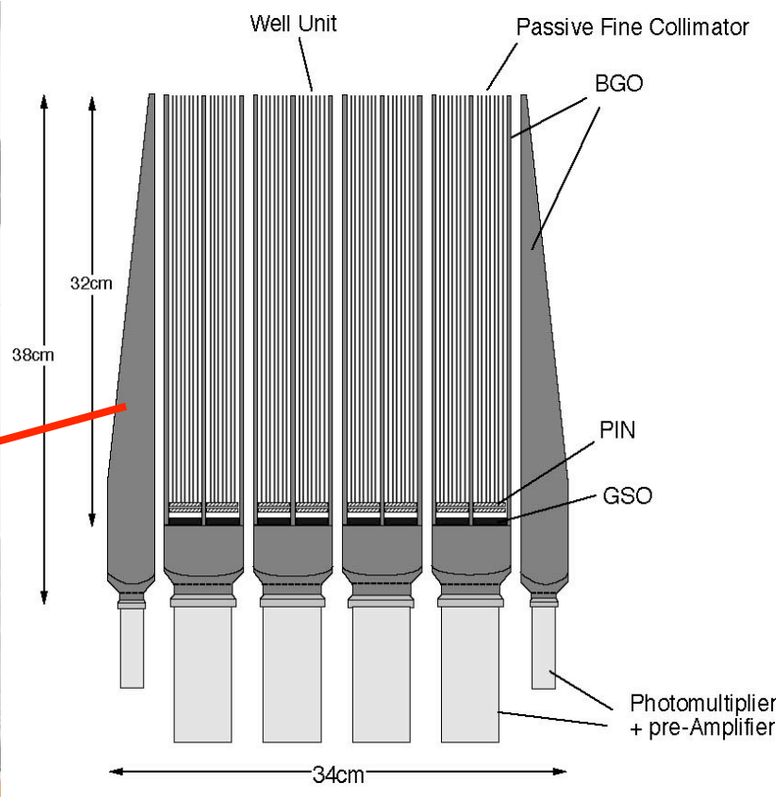
-> E>100 TeV electrons

- X-ray --- DONE
- Hard X-ray -- 50 arcsec
  NeXT/NuStar mission
- Gamma-ray -- Lens?

With an angular resolution of 15 arc sec

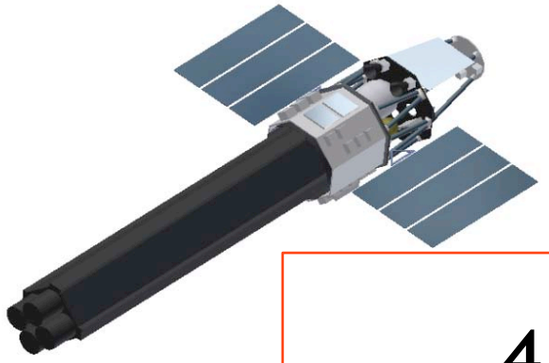
From Suzaku (Astro-E2)

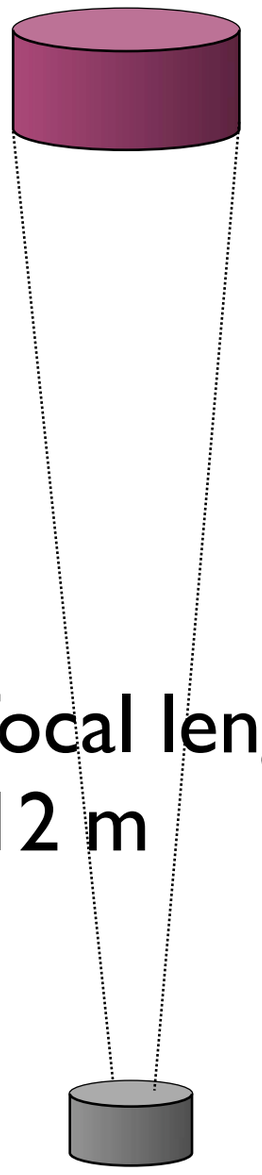
- Launch 2005 July 10th
- Calorimeter (stop operation)
- X-ray CCD/ Hard X-ray Detector



NeXT Satellite (2012...) 0.3 keV - 600 keV

-- to study the non-thermal universe --

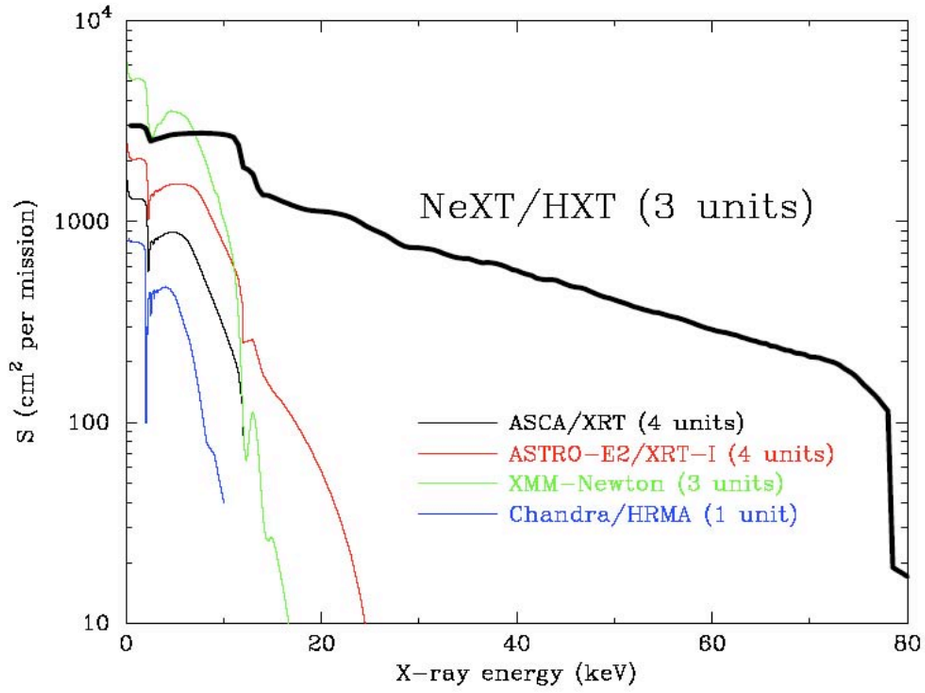




Super Mirror (0.5-80 keV)

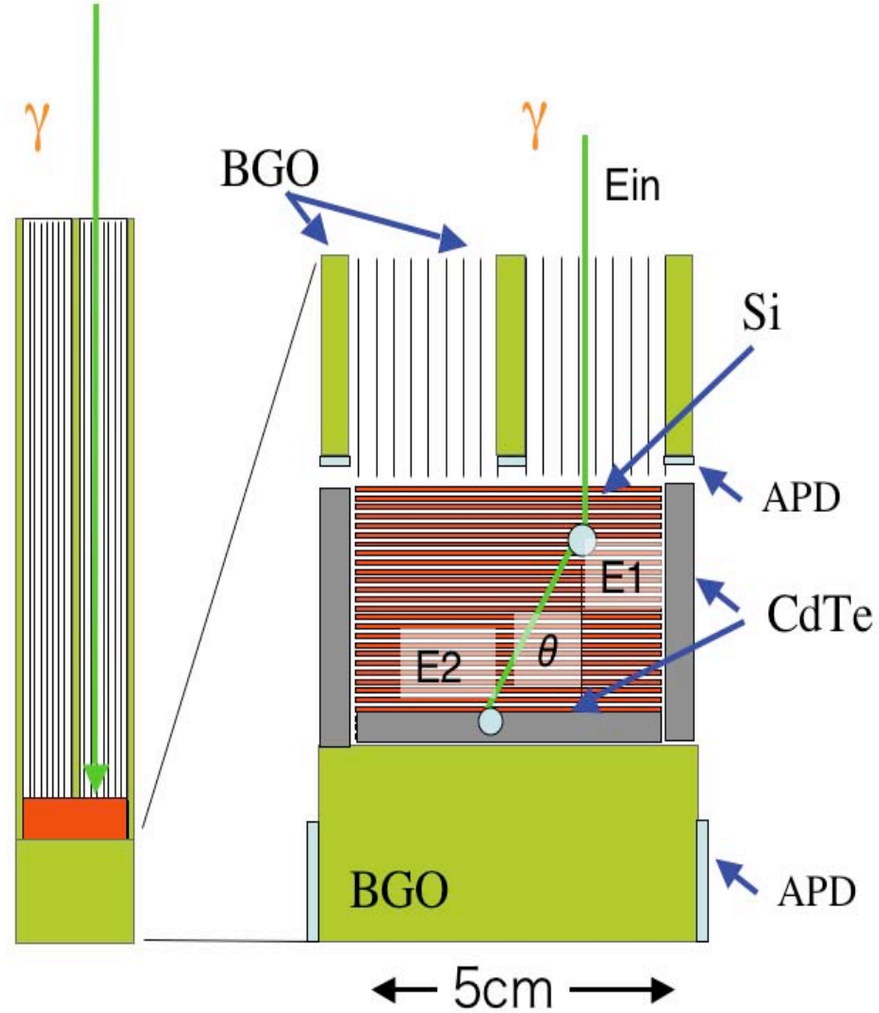
30”
HPD

focal length
12 m



1. Hard X-ray CdTe pixels
2. Soft X-ray CCD
3. X-ray Calorimeter

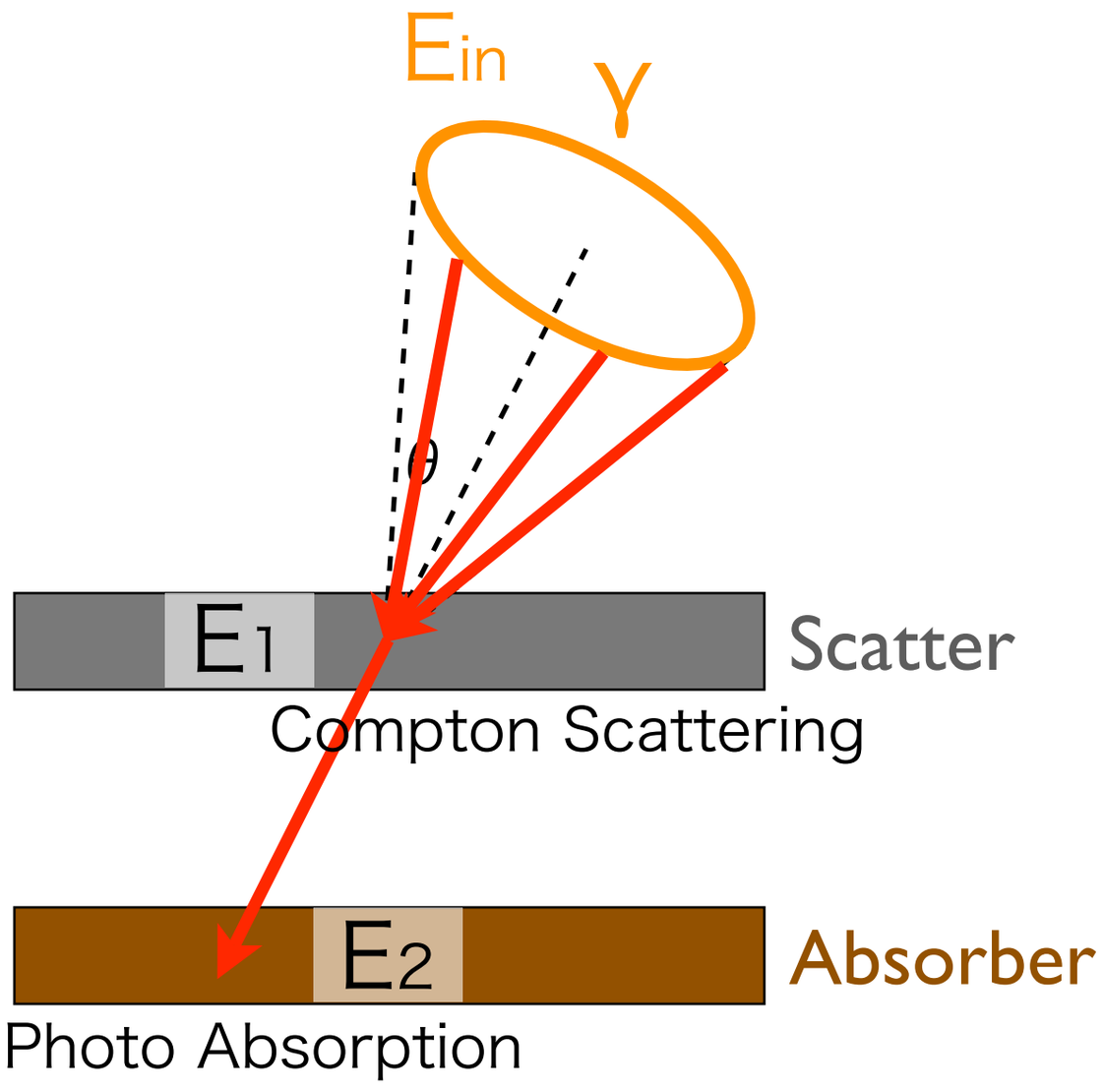
4. Narrow FOV Compton Camera



Compton Telescope

Compton Telescope

- Reduction of Background by Compton Reconstruction (Incident Direction of gamma-ray can be solved)
- In principle, high angular resolution is acheived, if the detector has
  - High Energy Res.
  - High Position Res.



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

$$E_{\mathrm{in}} = E_1 + E_2$$

Key Component (1) : CdTe

High Energy Resolution CdTe Diode Detector (ISAS-JAXA/ACRORAD)

- Thin device (0.3-1.0 mm)
- Schottky Diode (In/CdTe/Pt)
- Guard Ring

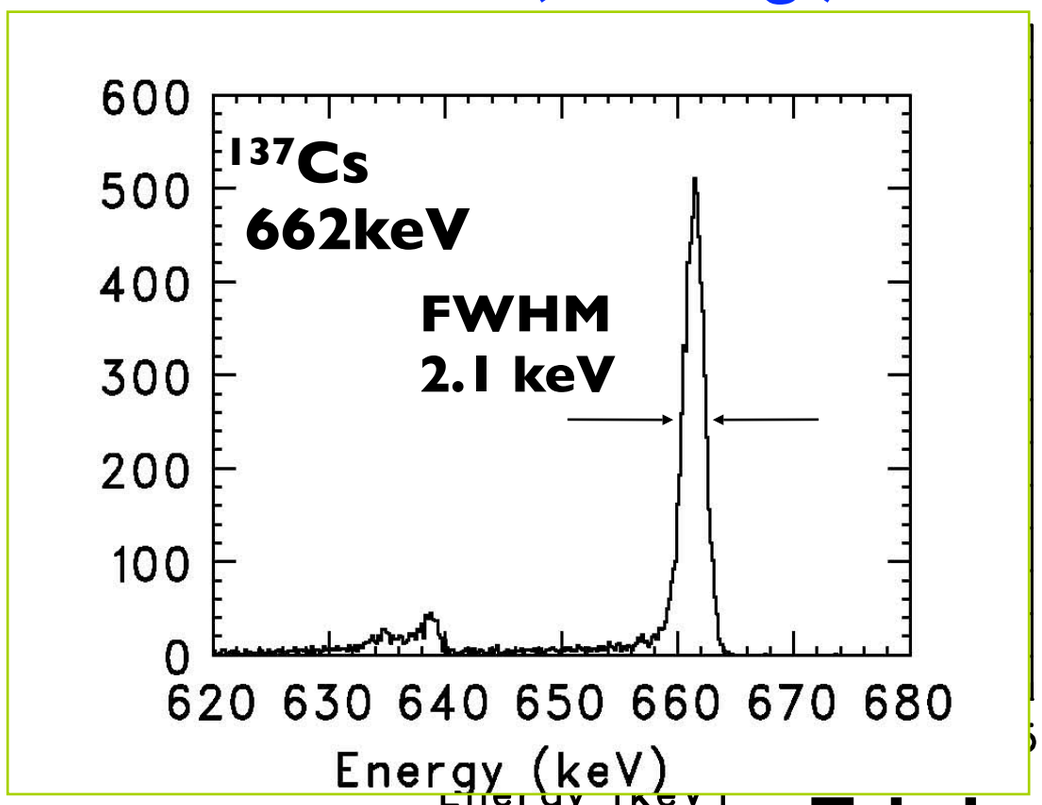
→

- Extremely low leakage
- High bias voltage

→

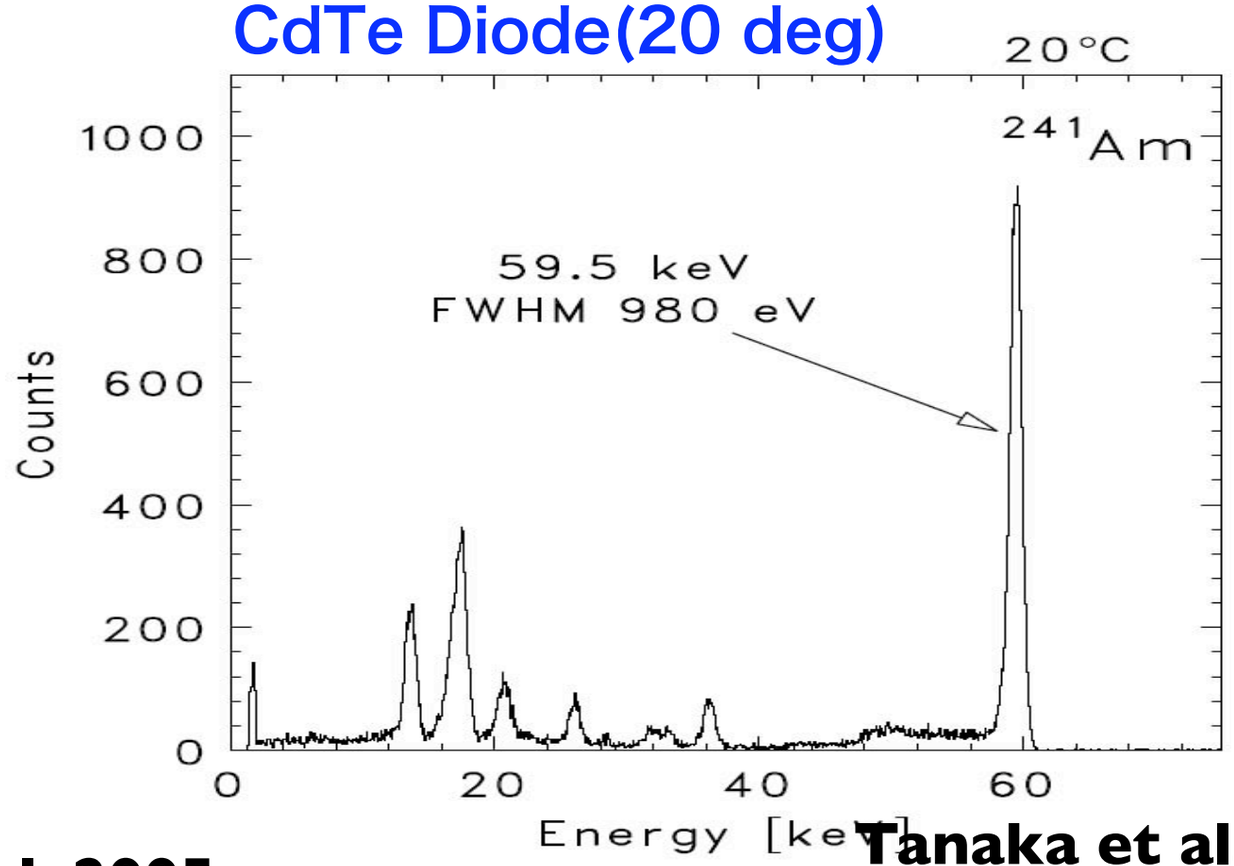
- Full Charge Collection

CdTe Diode(-40 deg.)



Takahashi et al. 2005

CdTe Diode(20 deg)

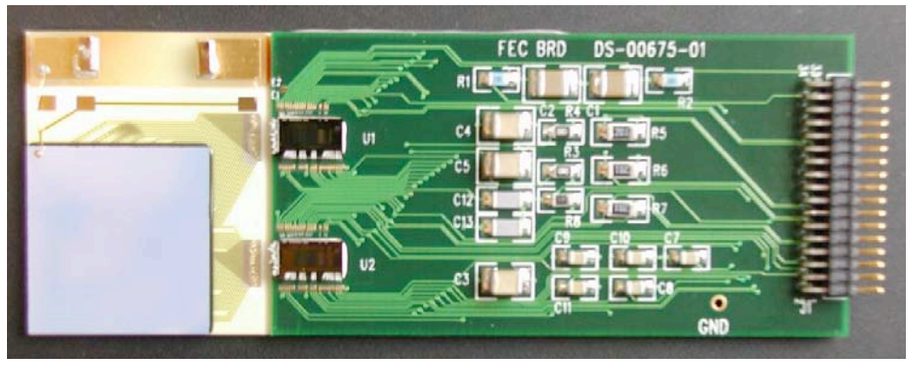


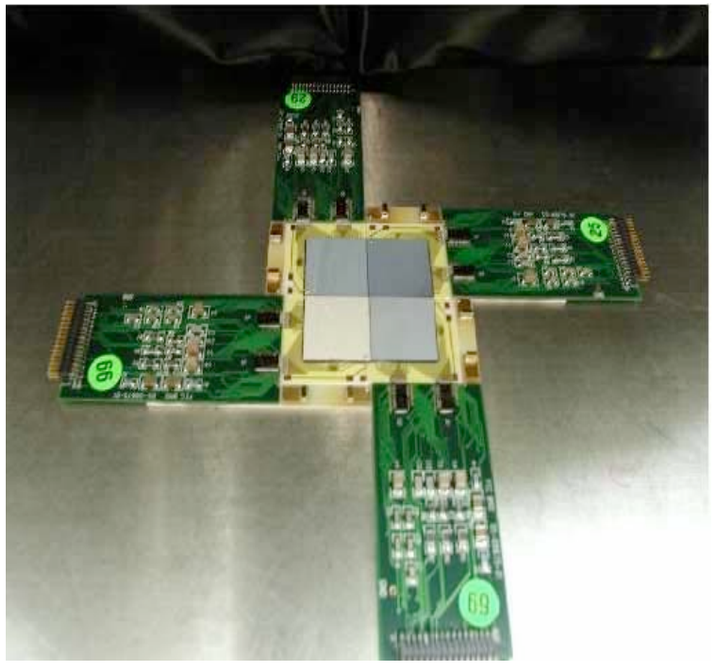
Tanaka et al. 2003

CdTe Pixel Detecter

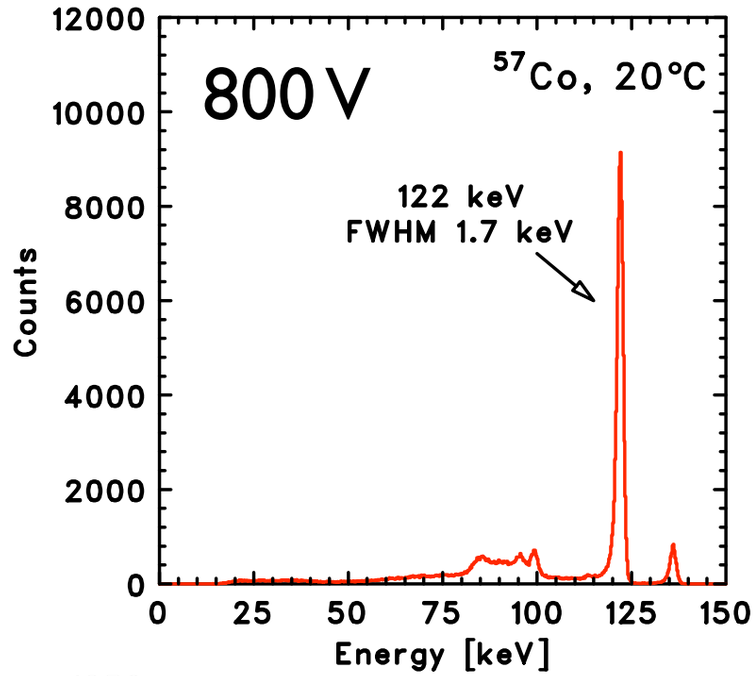
8x8 CdTe Pixel Detector

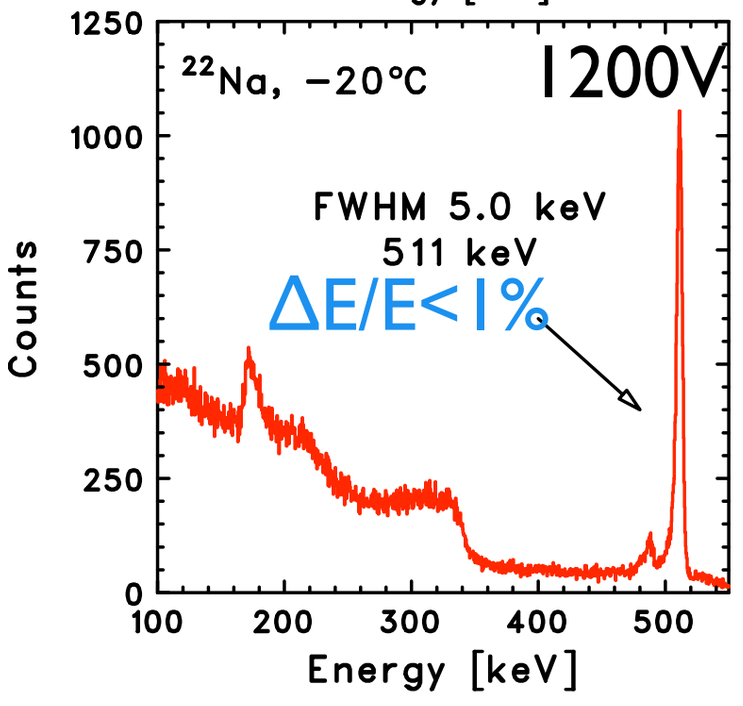
area: 18 x 18 mm^2, thickness: 0.5 - 1.0 mm
pixel size: 2 x 2 mm^2, channel: 64ch





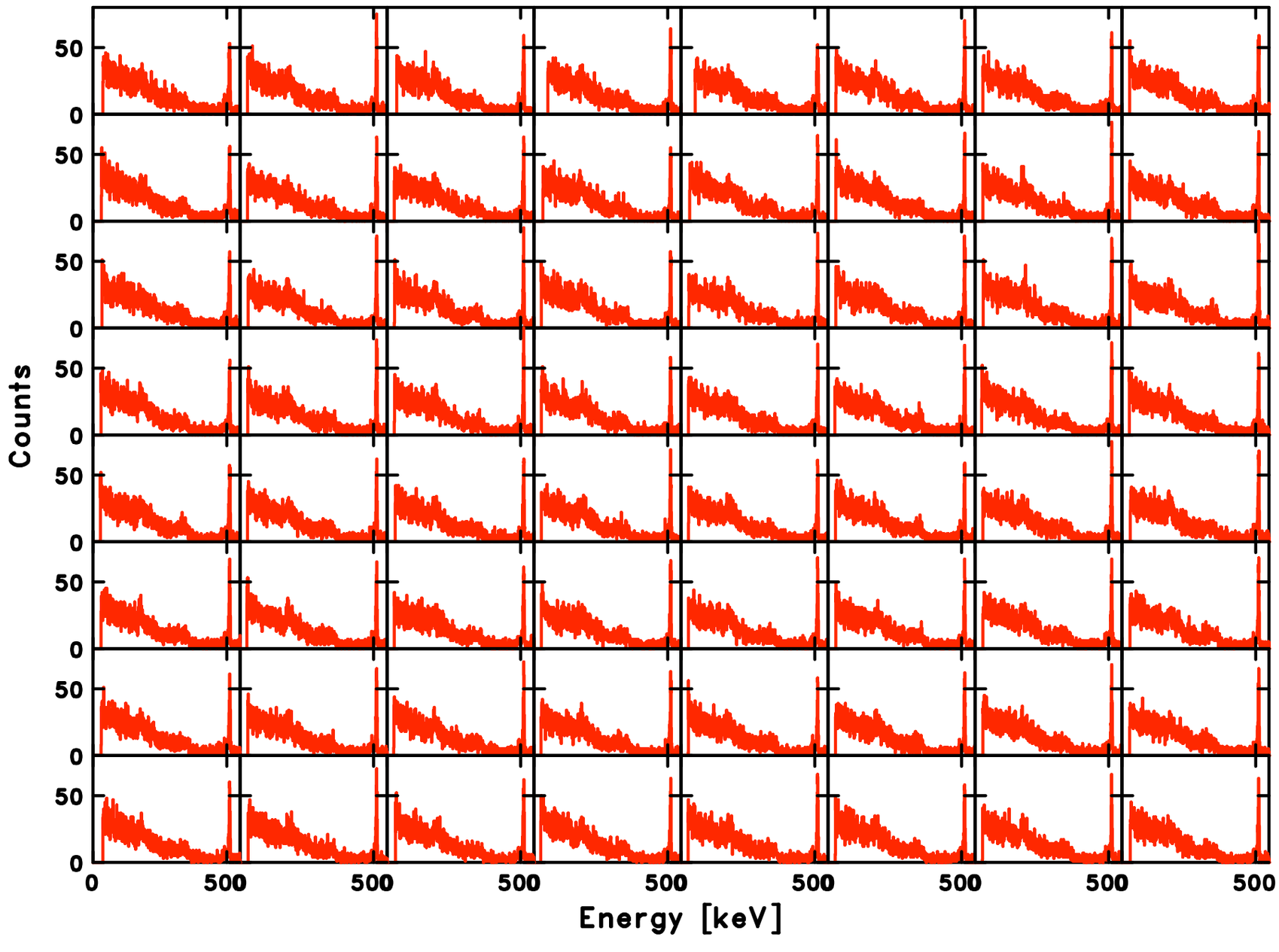
64ch sum-spectrum





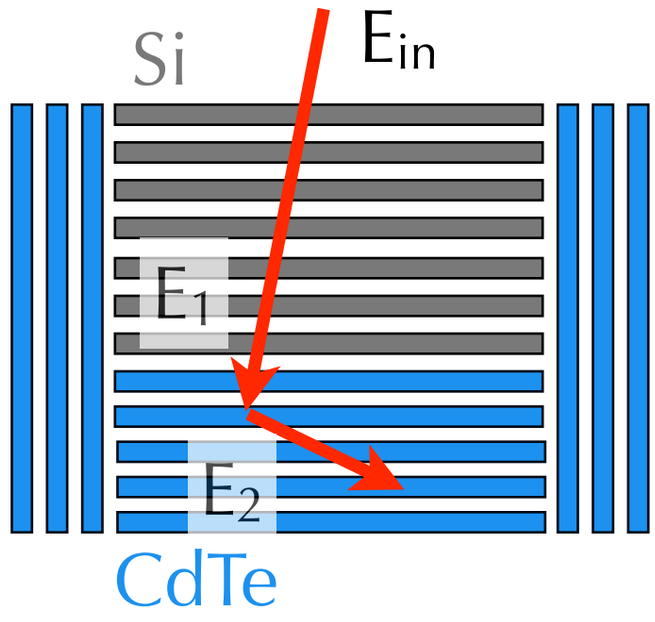
Performance of the CdTe Pixel

^{22}Na spectra from each channel / very high uniformity



New generation Compton Telescope

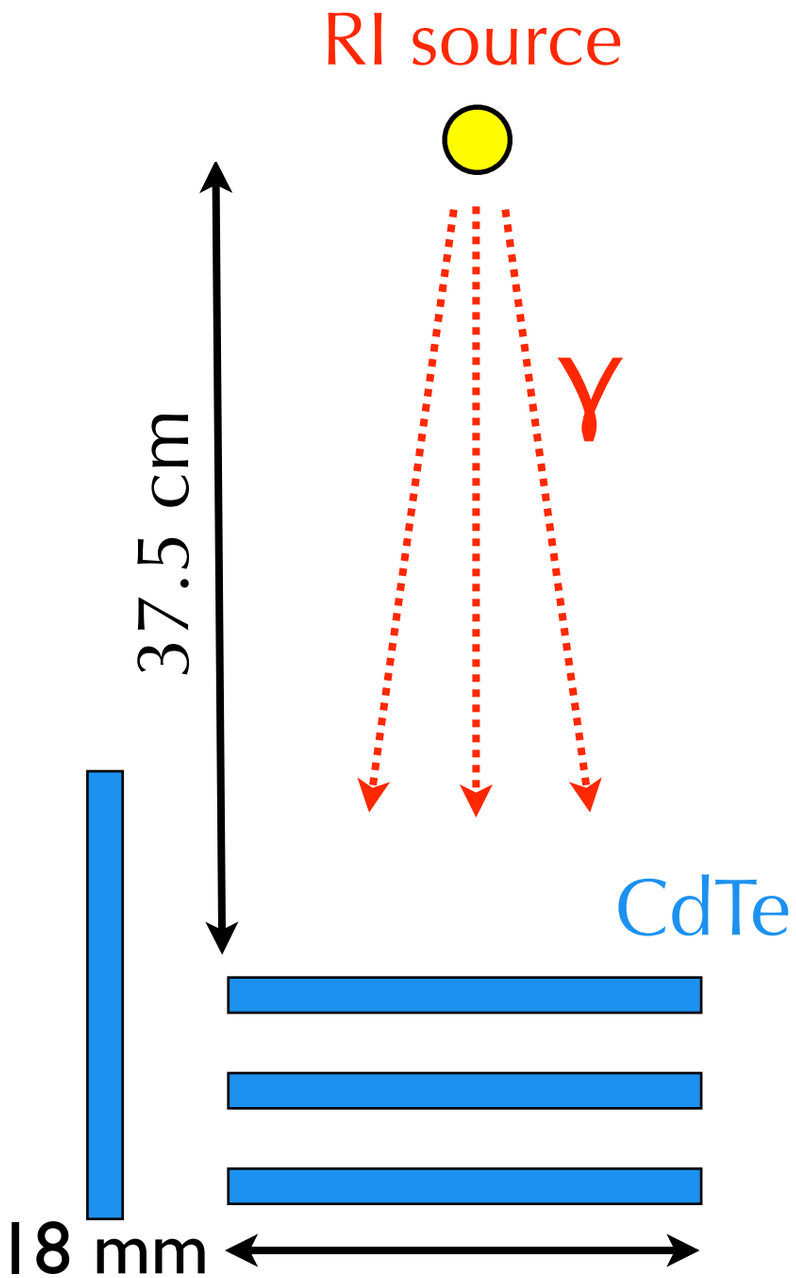
Semiconductor Compton-Stack



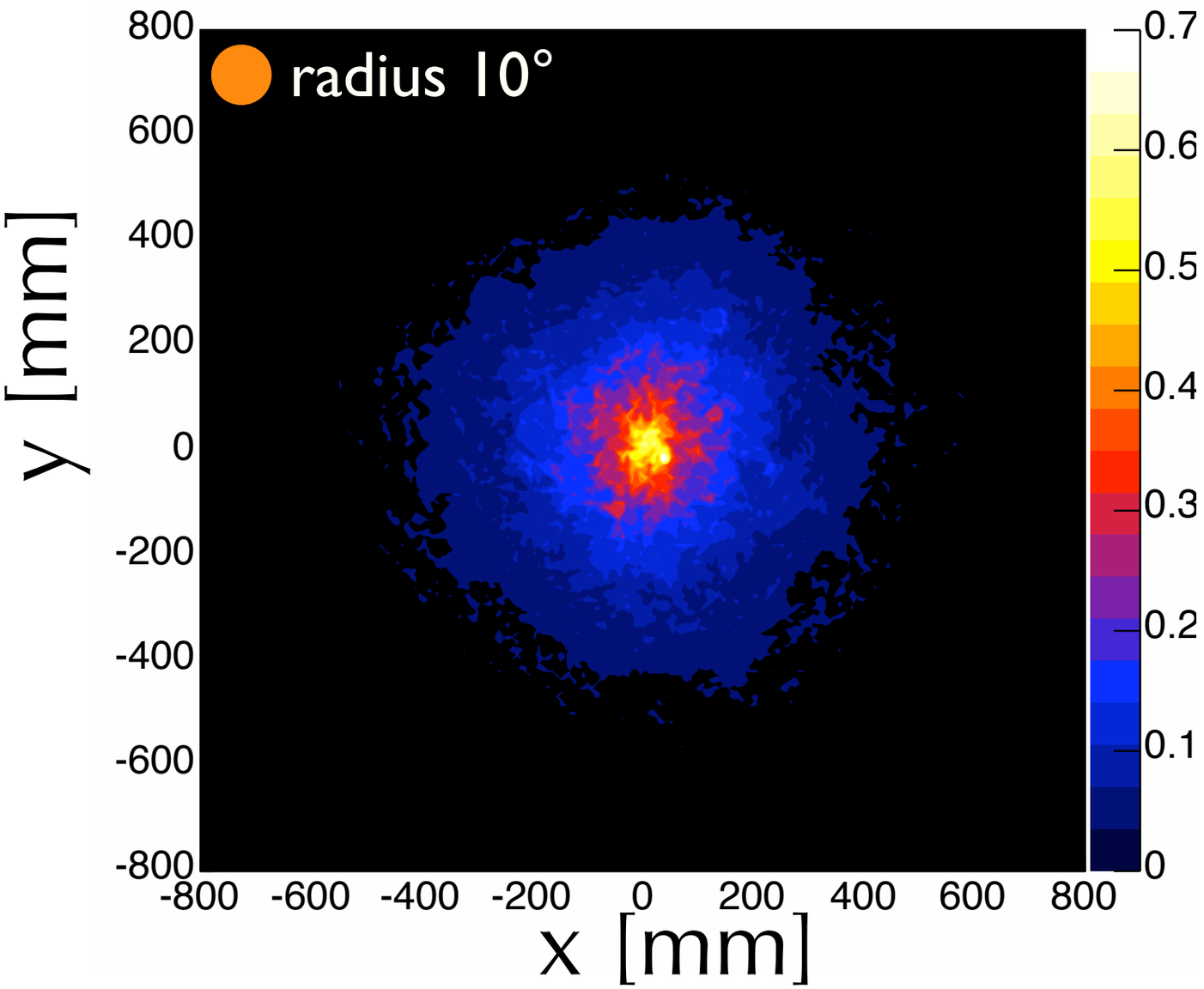
Based on high resolution
Si and CdTe imaging device
(moderate cooling)

(Takahashi et al. SPIE 2003; NIM A 2005)
(Mitani et al. 2004, Tanaka et al. 2004,. Watanabe et al. 2005, Oonuki et al. 2005.)

Prototype (1) - CdTe Compton -



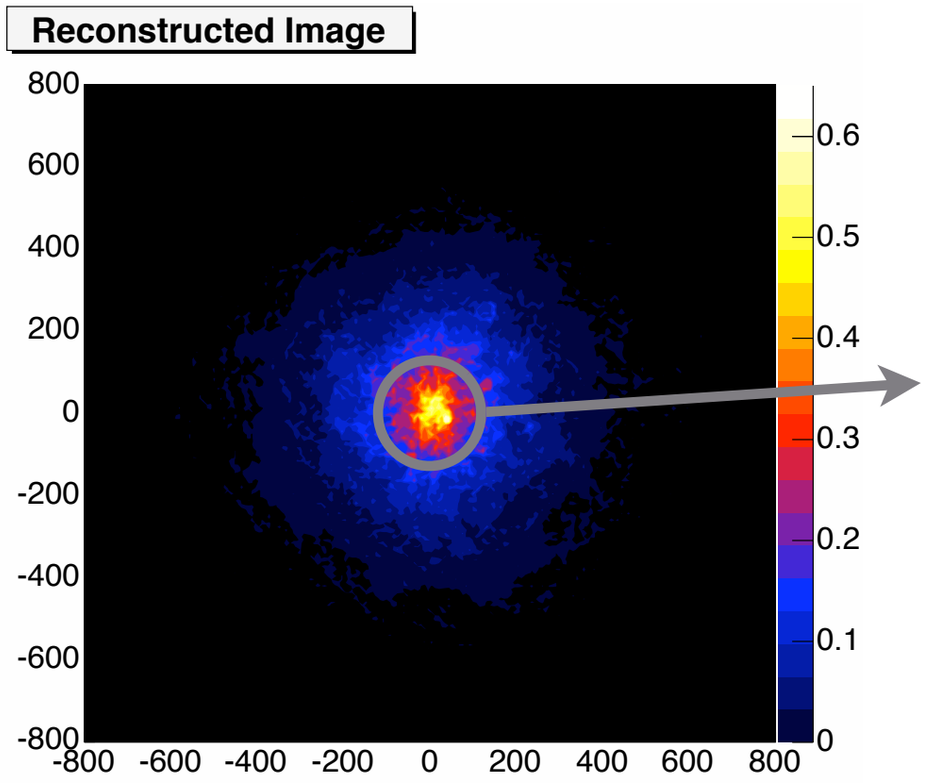
^{22}Na: 511 keV +/– 10 keV

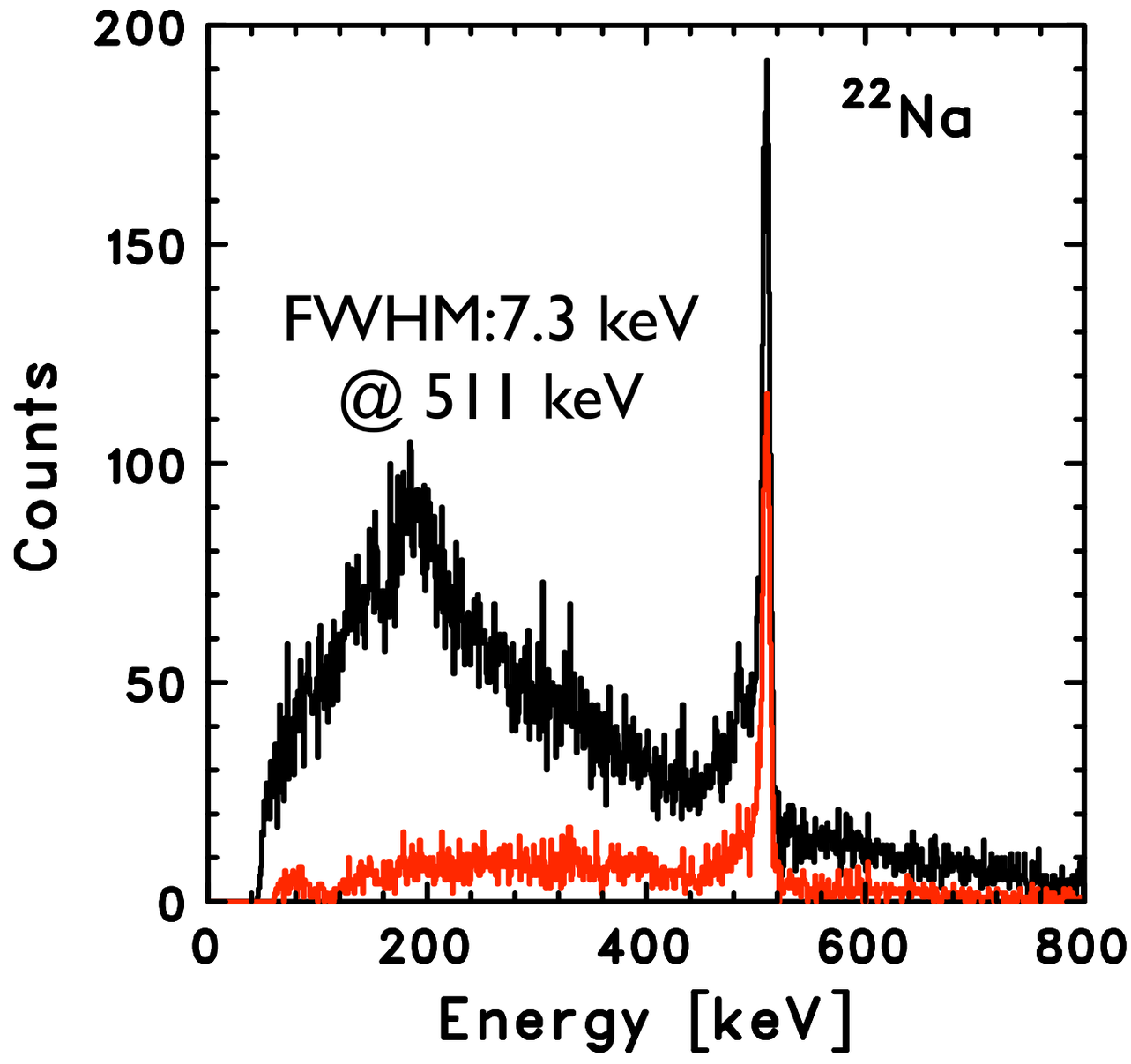


Tanaka et al. 2005

Spectrum Reconstruction

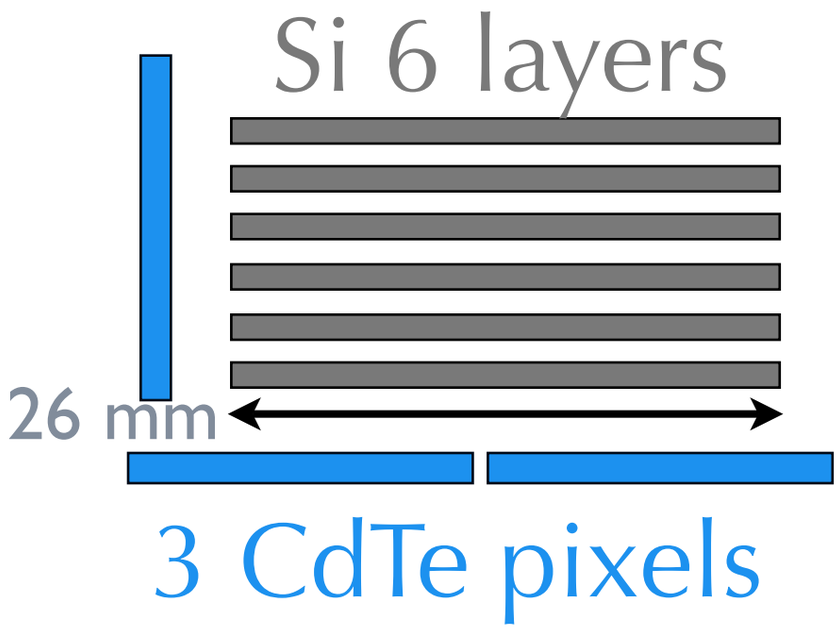
511 keV image



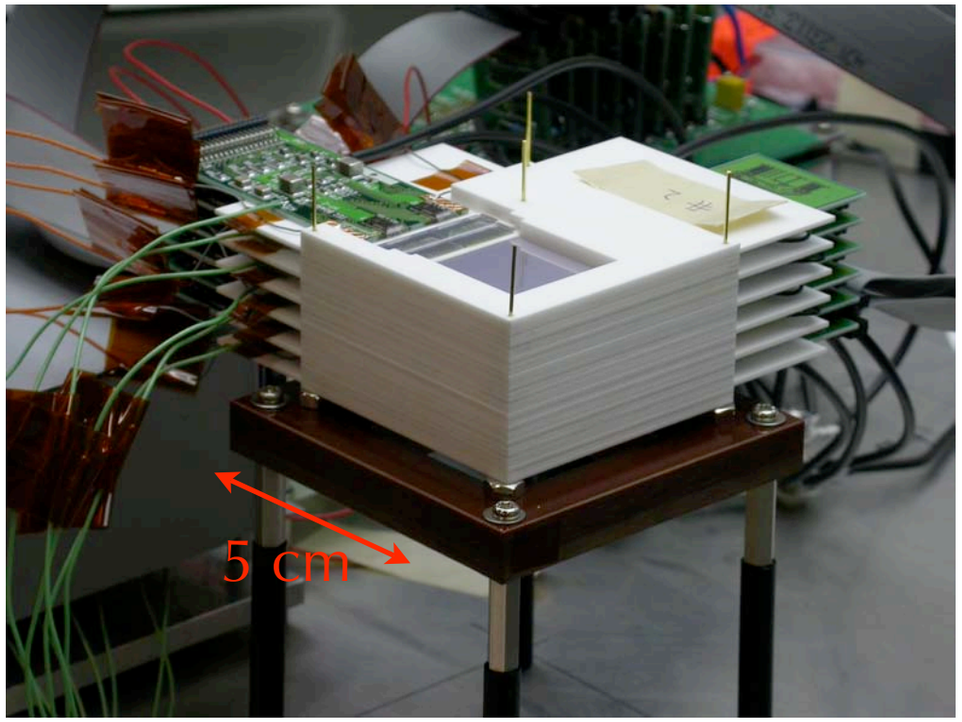


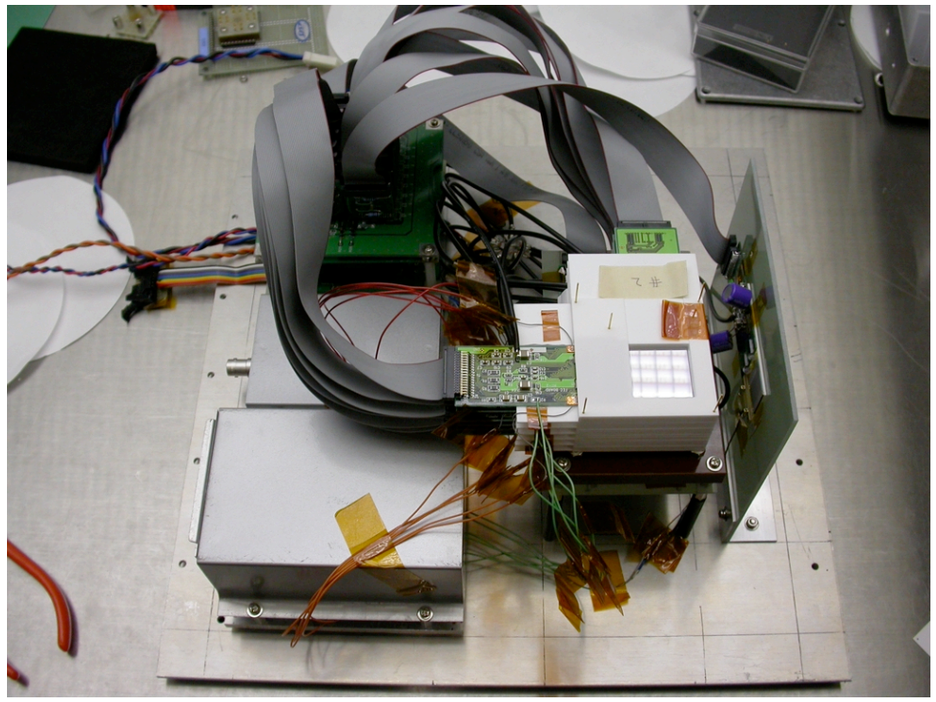
Oonuki et al. 2005

Prototype (2) - Si / CdTe --



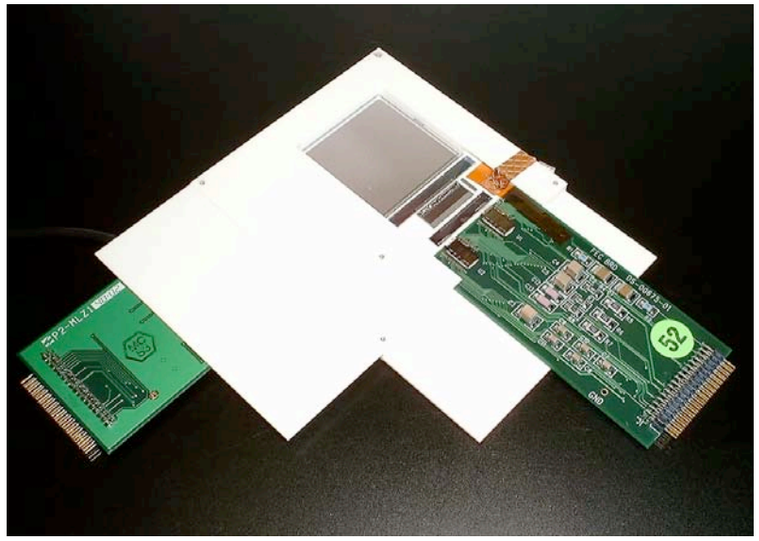
- Si (Z=14) is much suitable as a scatterer.
- CdTe (Z=48,52) works better as an absorber



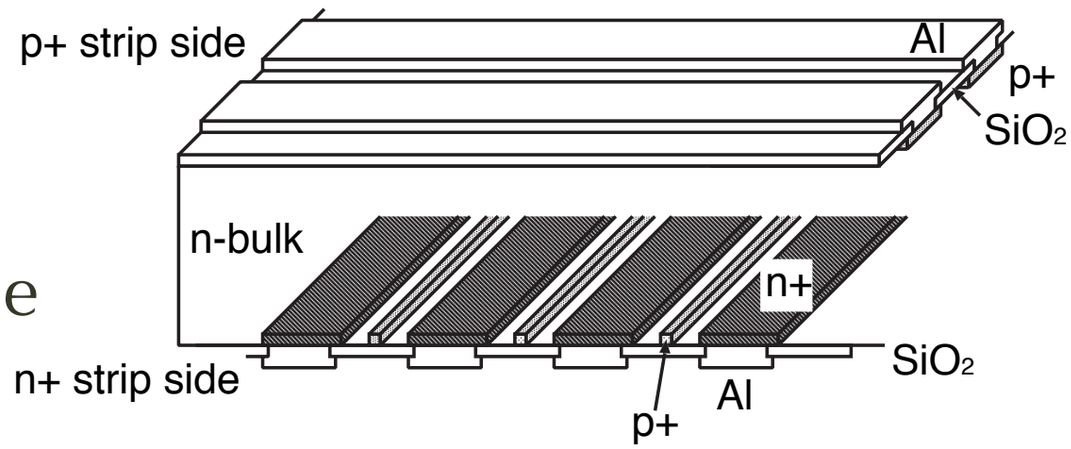


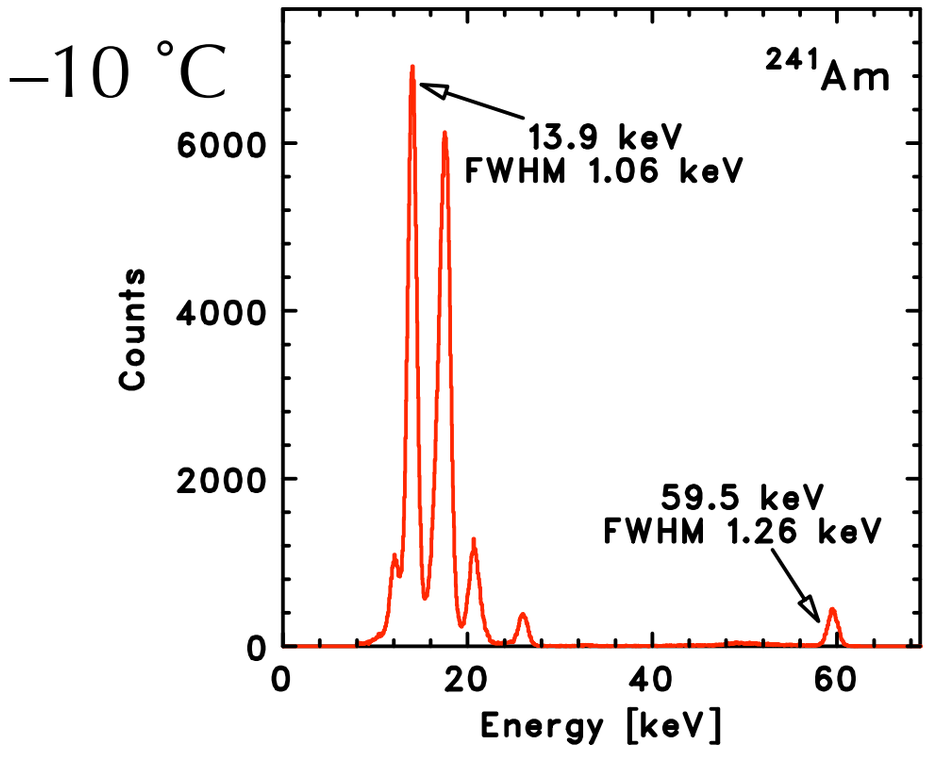
Key Components

- High Resolution Double Sided Silicon Strips

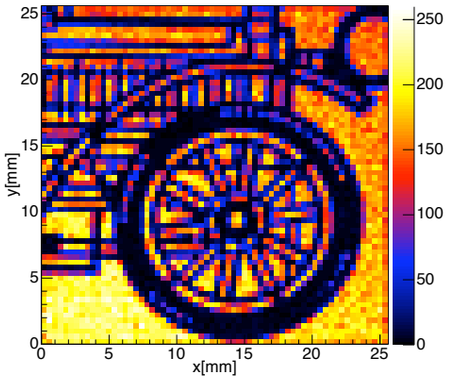


area: 26×26 mm²
thickness: 300 μm
pitch: 400 μm
64 strips on each side

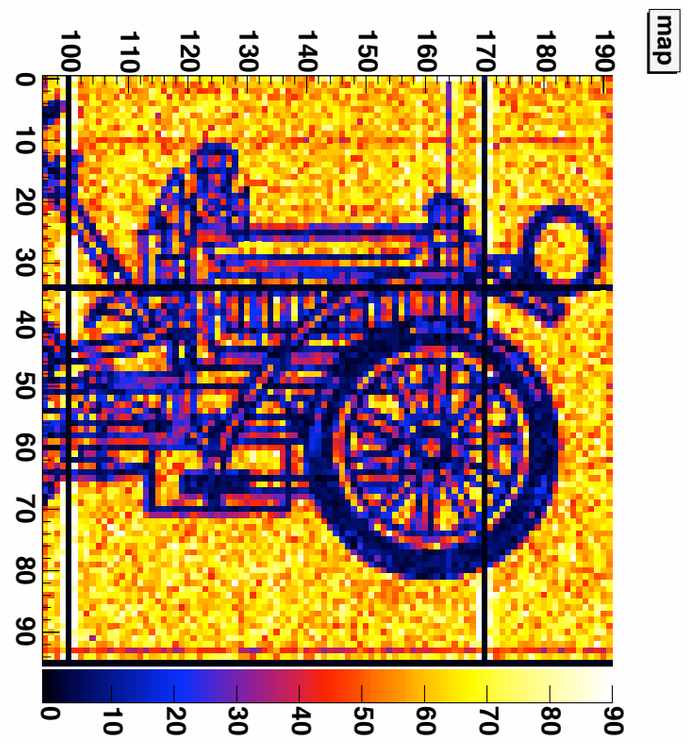




22 keV Shadow Image

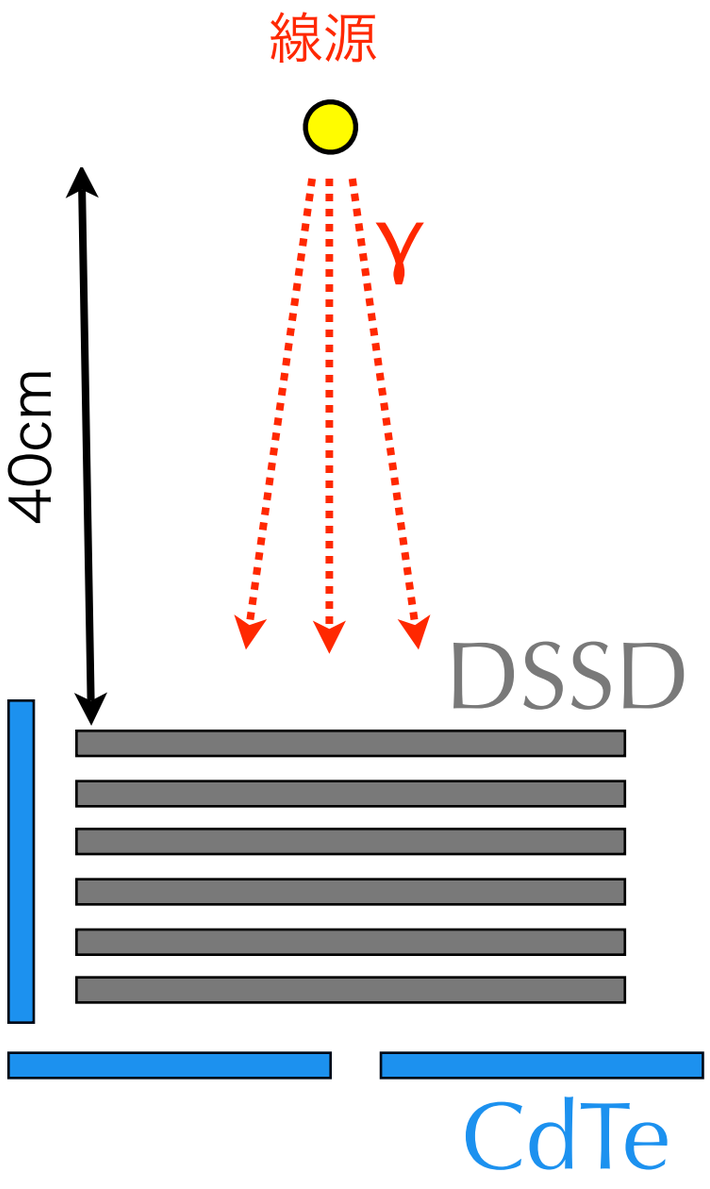


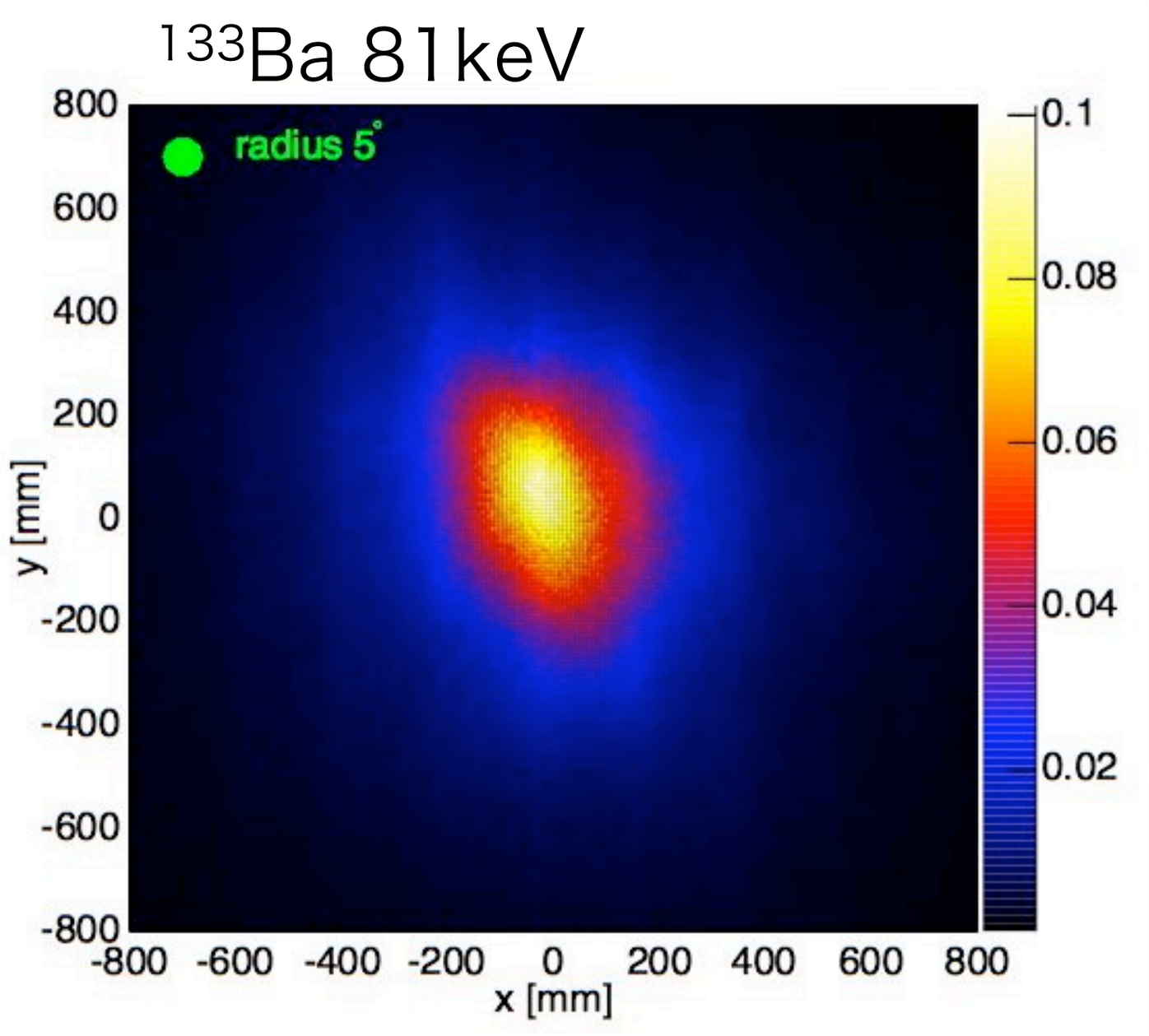
26×26 mm²



40×40 mm²

Si/CdTe Compton Telescope

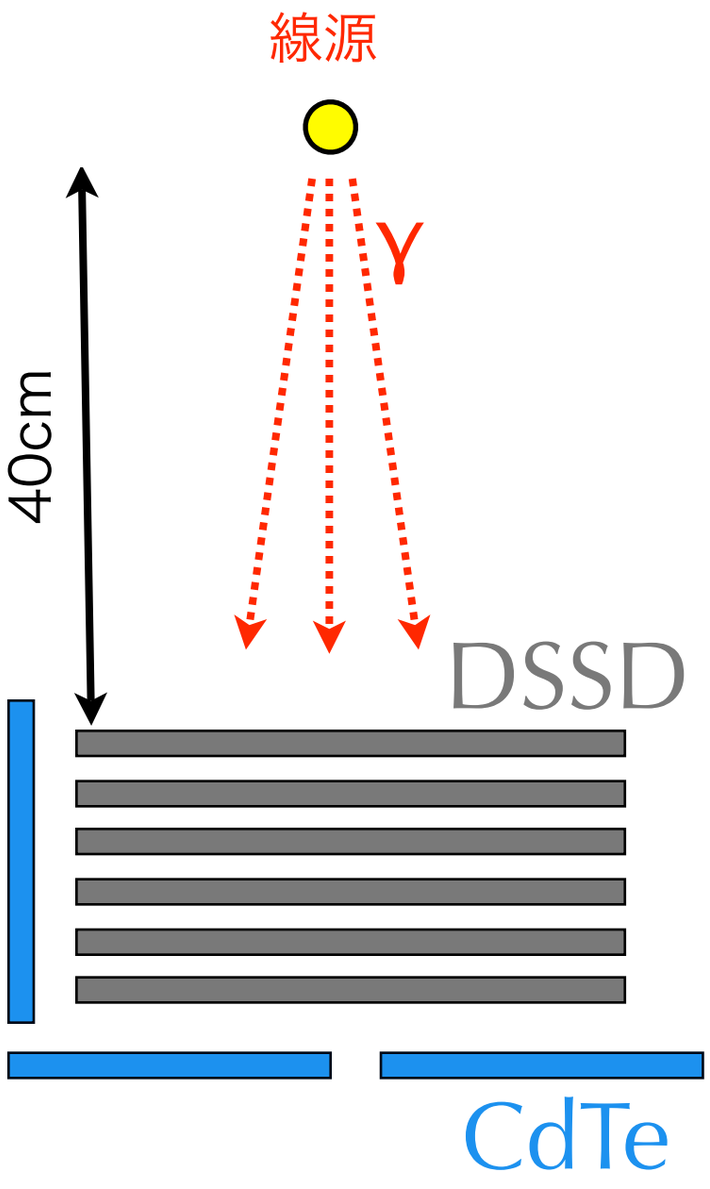


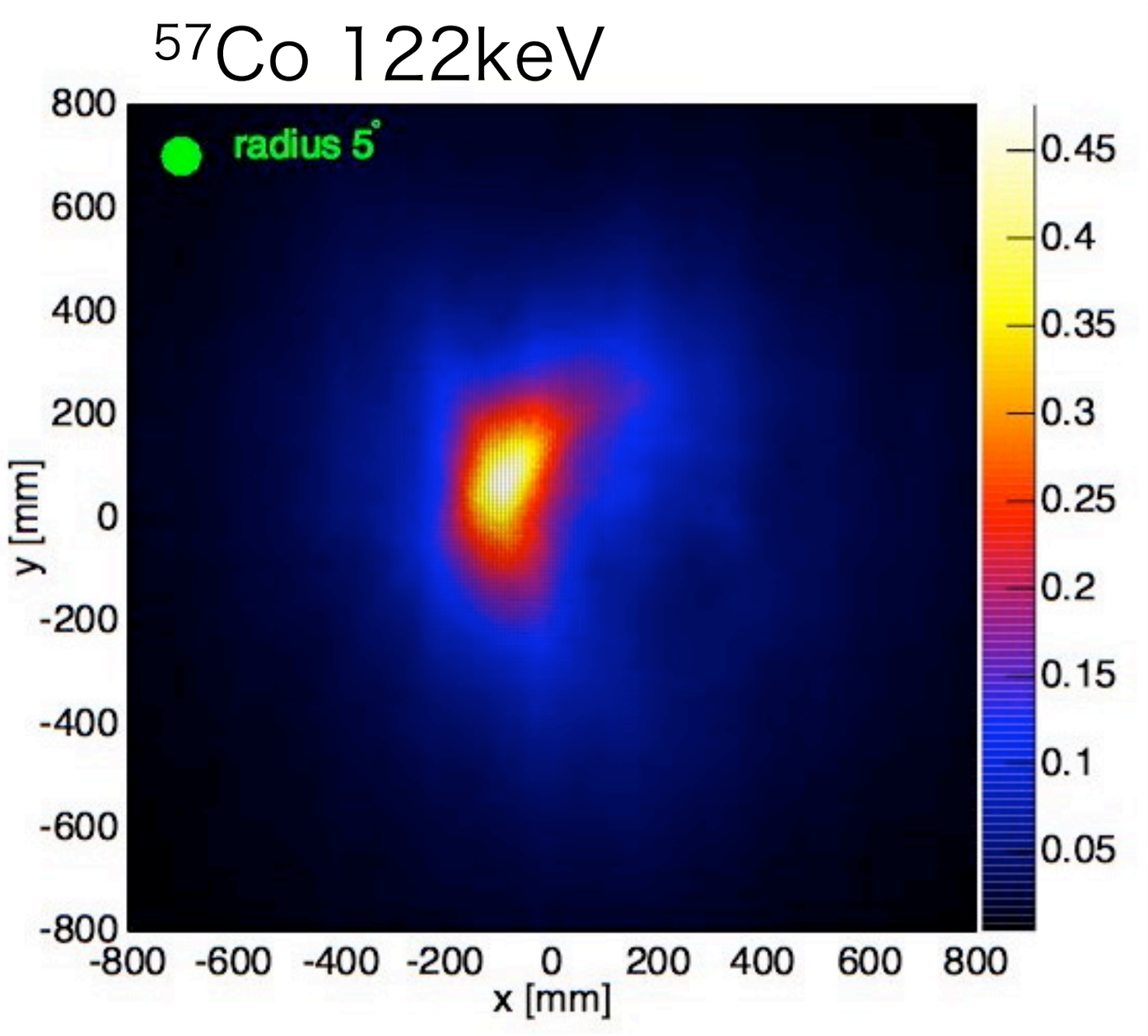


successful reconstruction in 81 — 662 keV

Tanaka et al. 2004, Watanabe et al. 2005

Si/CdTe Compton Telescope





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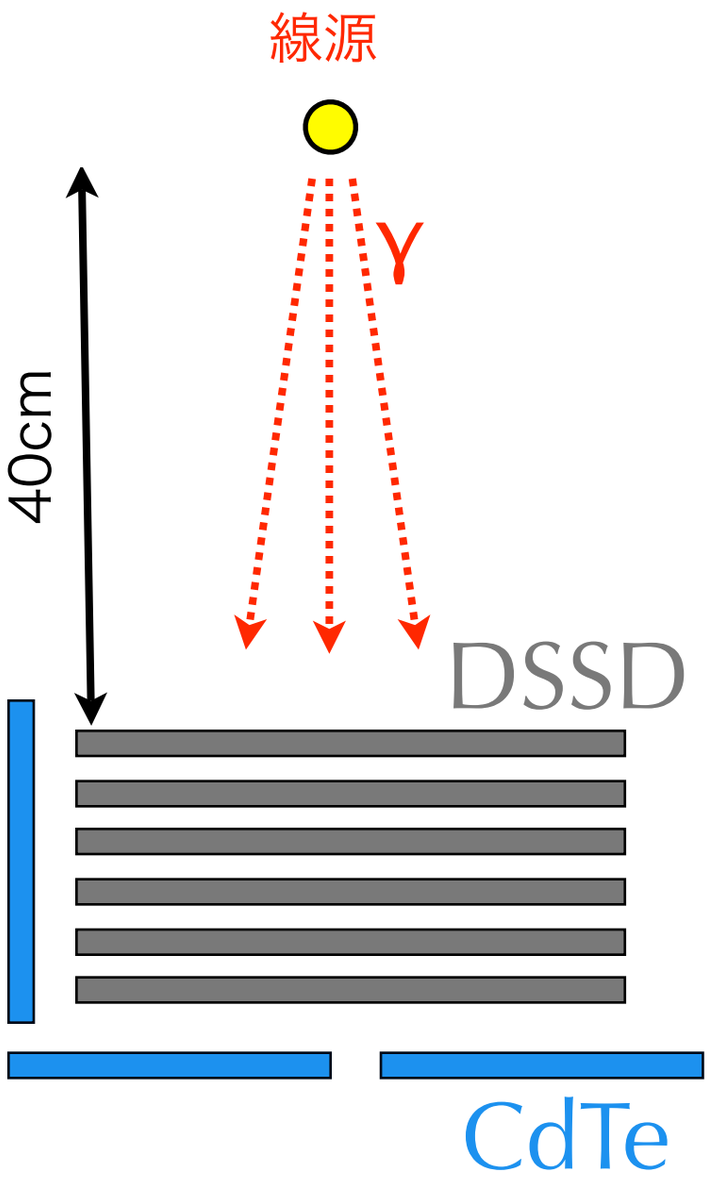
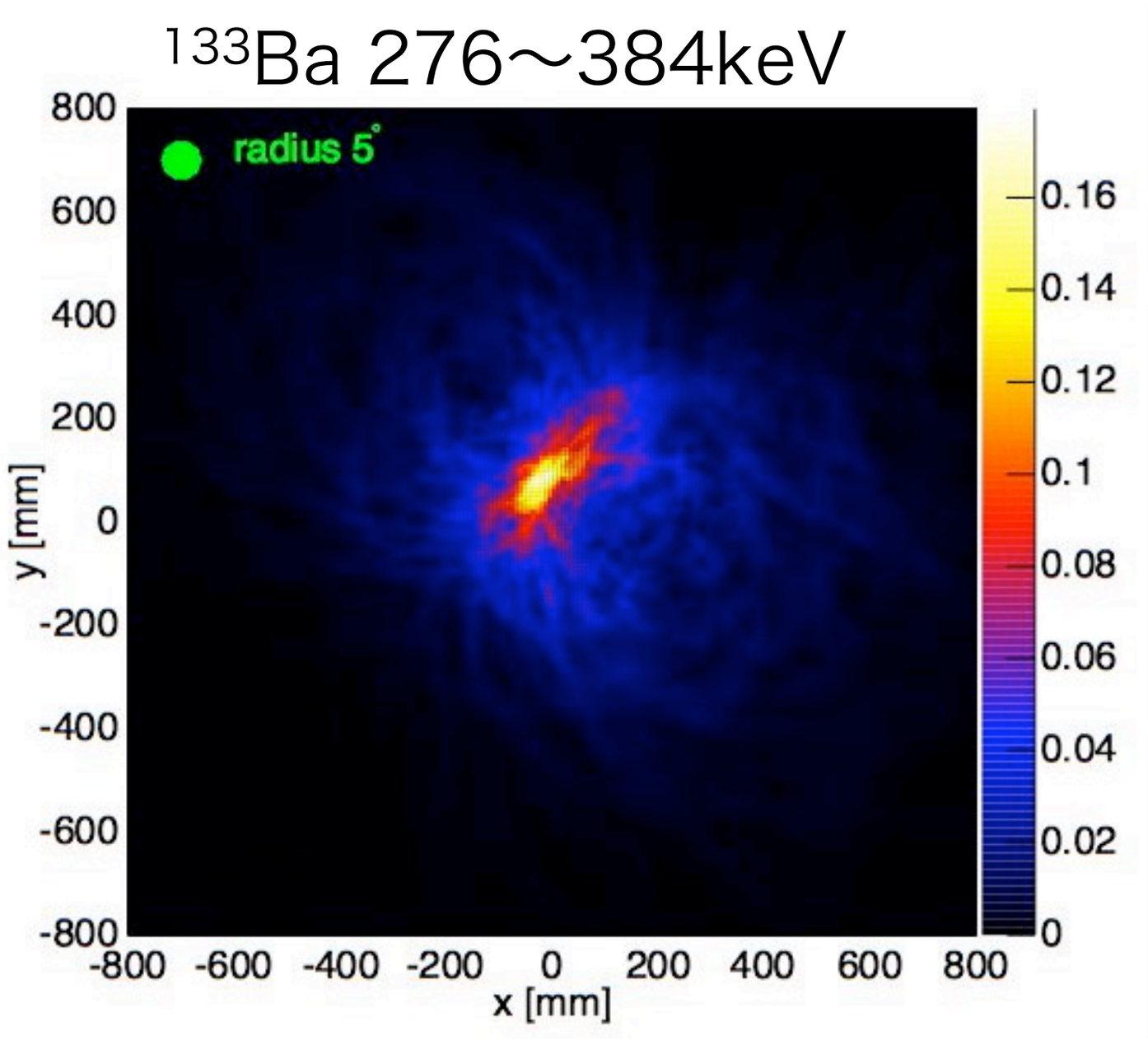
Si/CdTe Compton Telescope

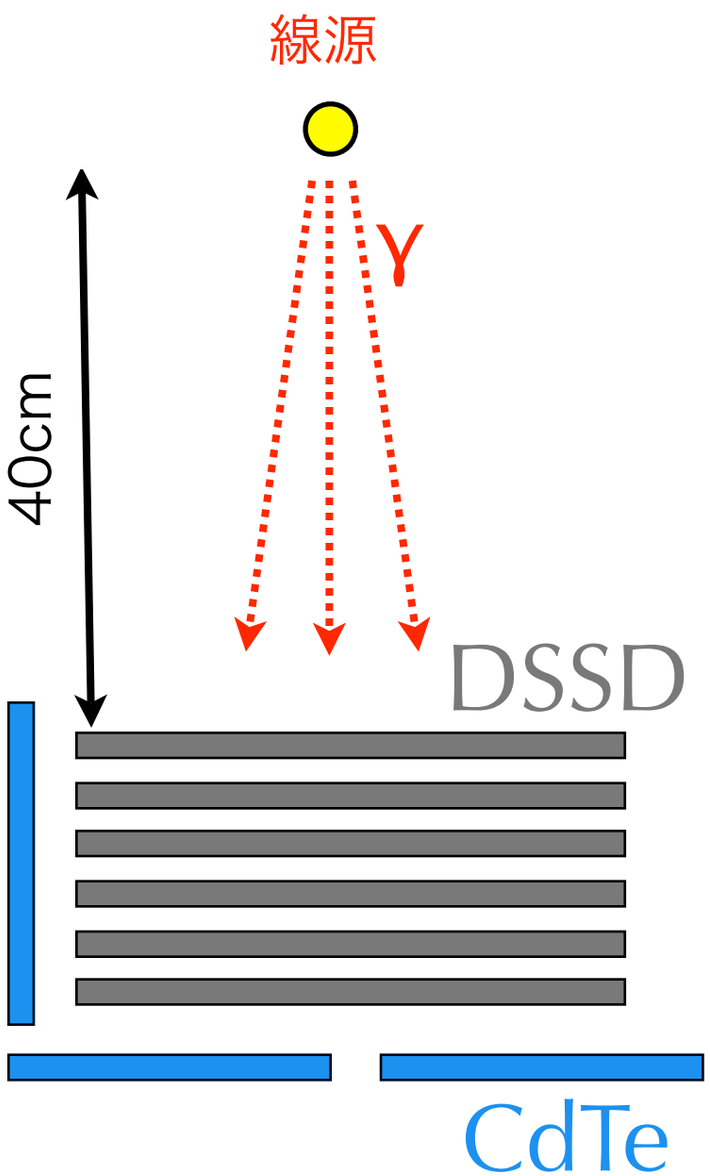


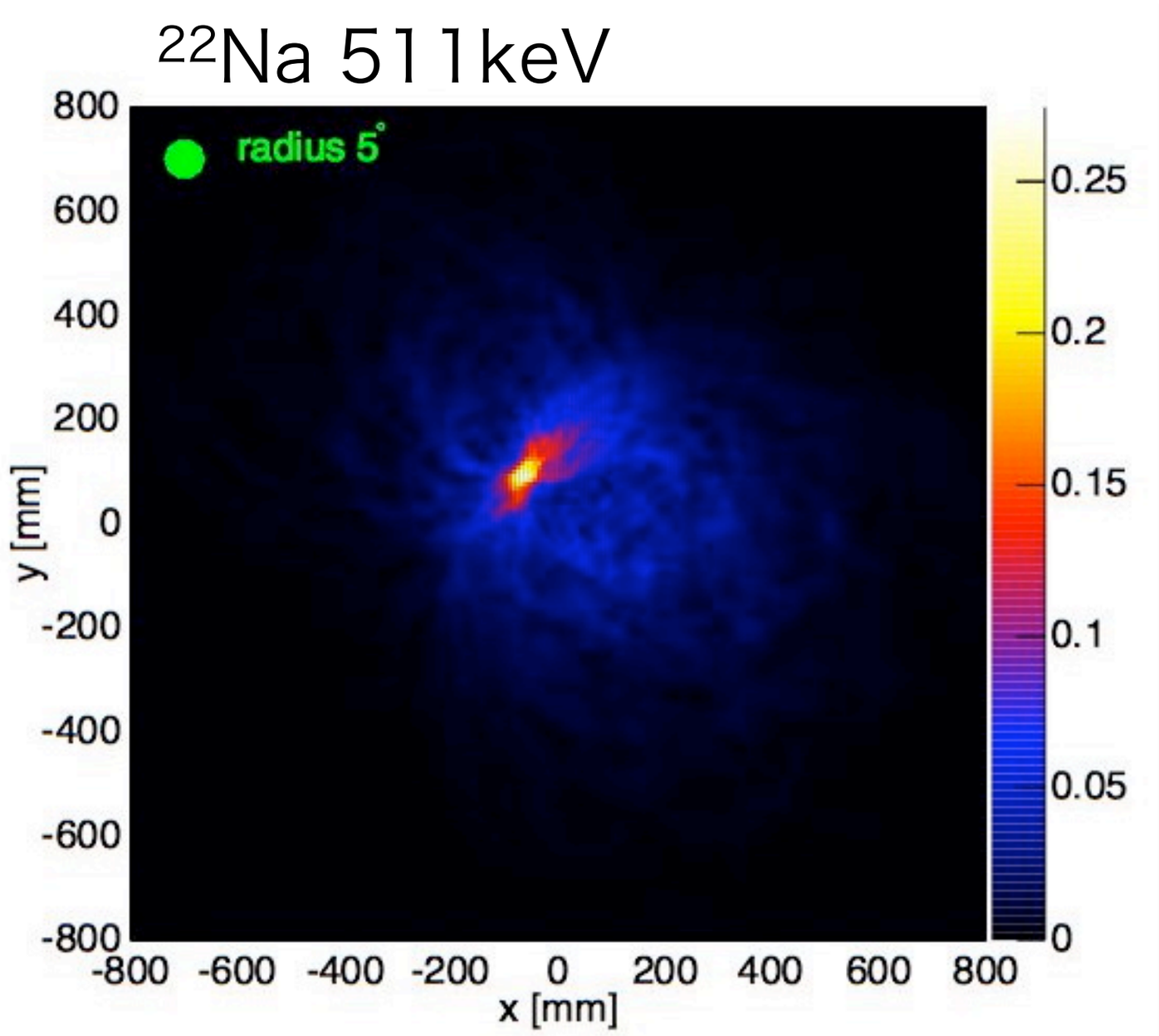


successful reconstruction in 81 — 662 keV

Tanaka et al. 2004, Watanabe et al. 2005

Si/CdTe Compton Telescope

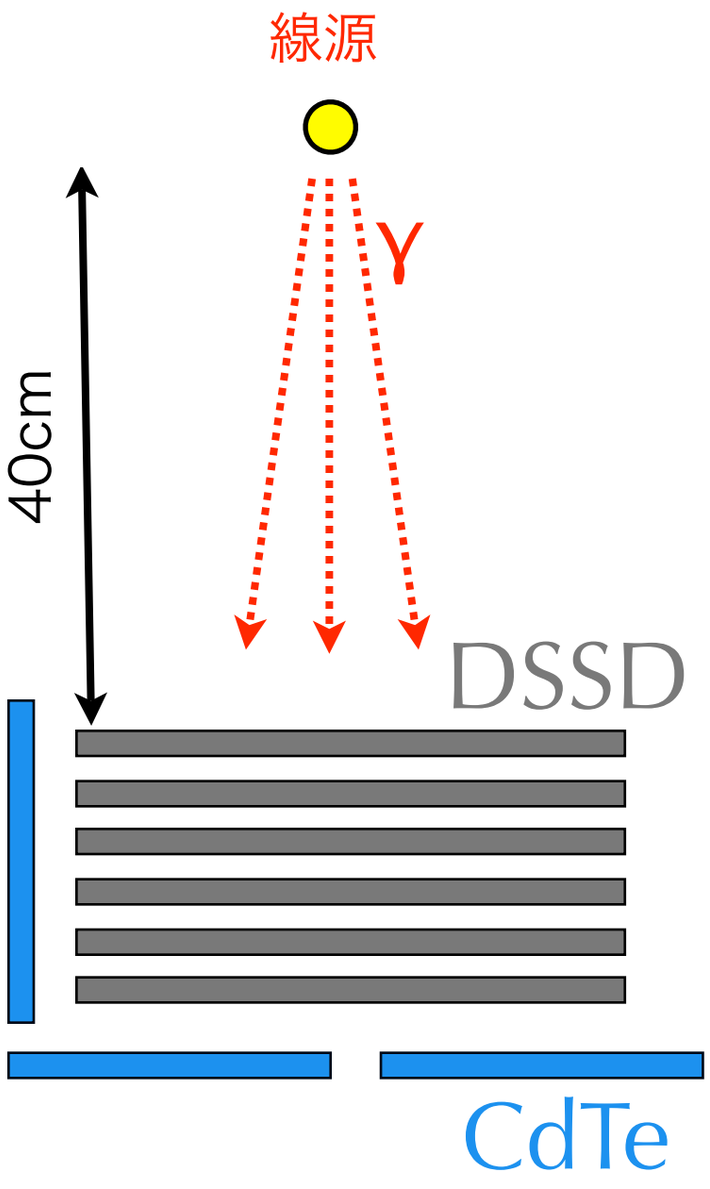


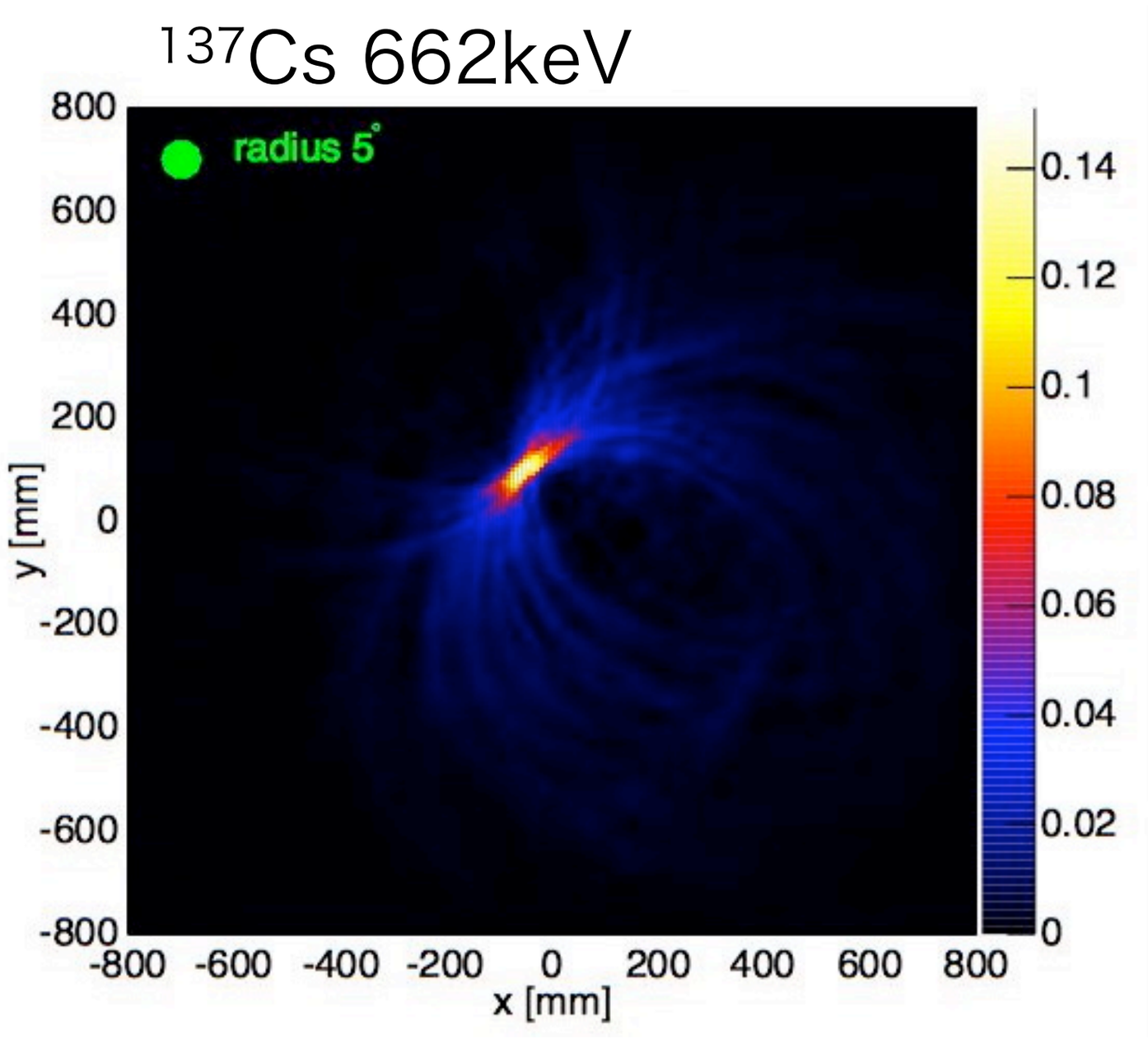


successful reconstruction in 81 — 662 keV

Tanaka et al. 2004, Watanabe et al. 2005

Si/CdTe Compton Telescope



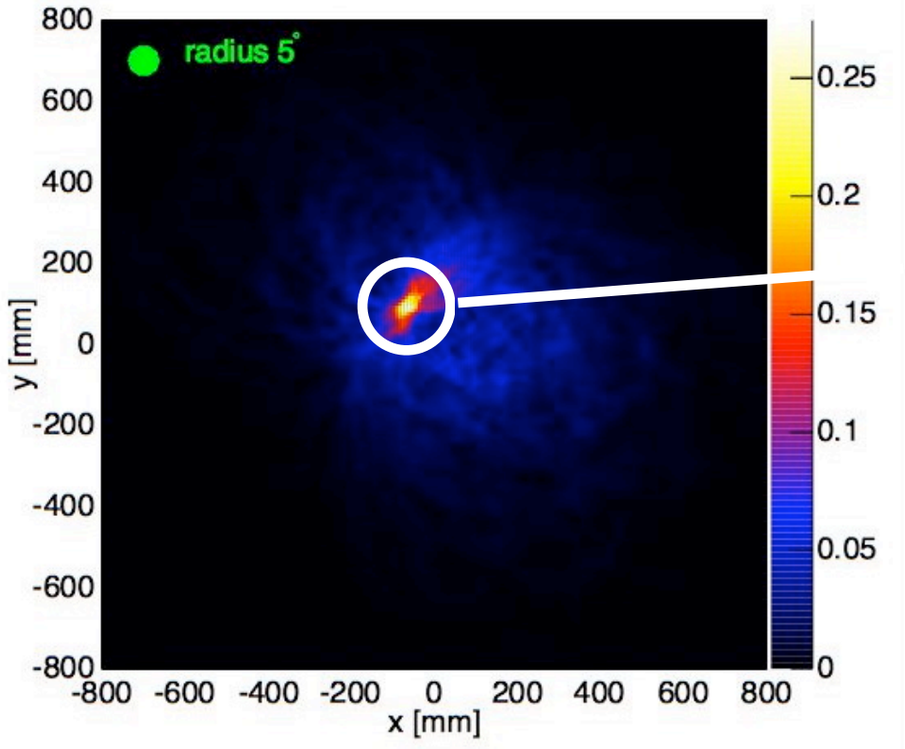


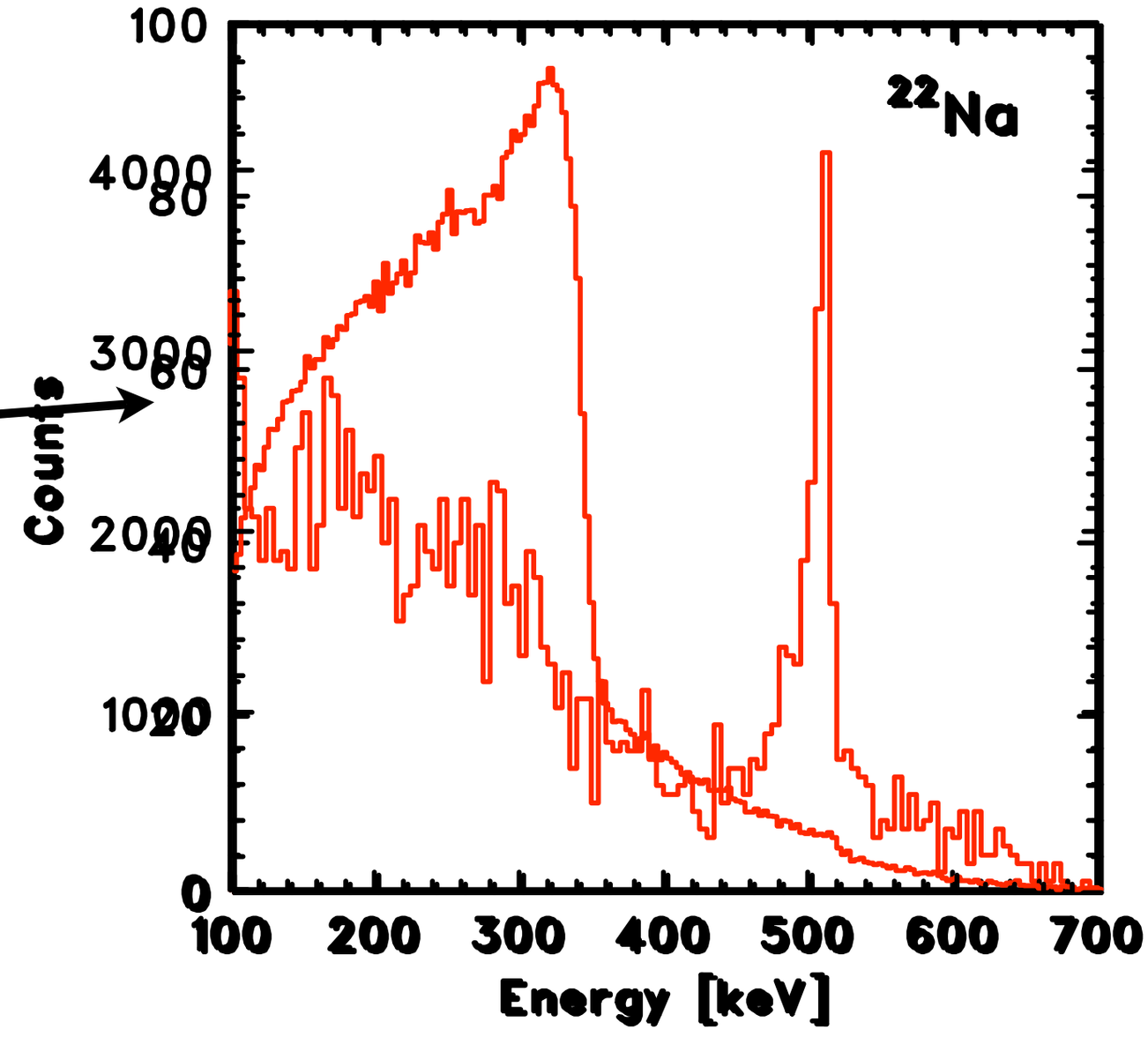
successful reconstruction in 81 — 662 keV

Tanaka et al. 2004, Watanabe et al. 2005

Reconstructed Spectra

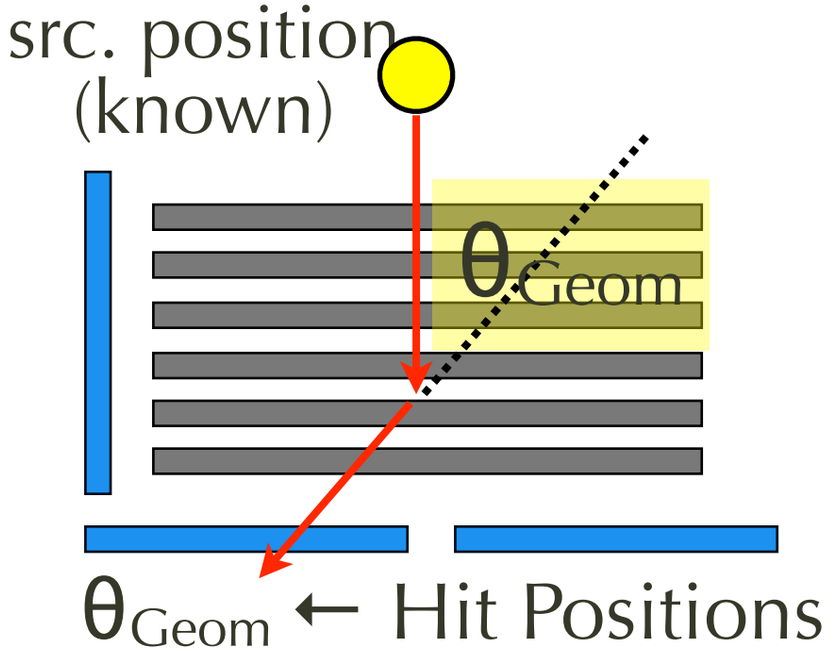
Image of ^{22}Na



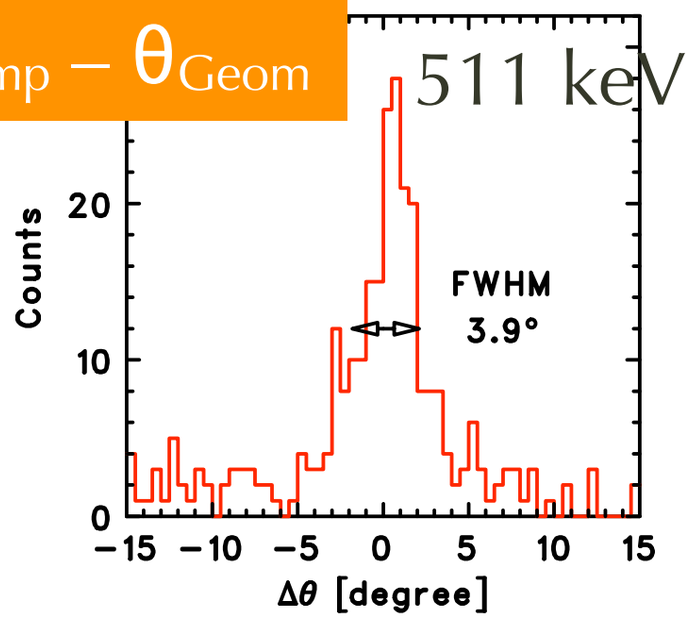


E = 14 keV (FWHM) @ 511 keV

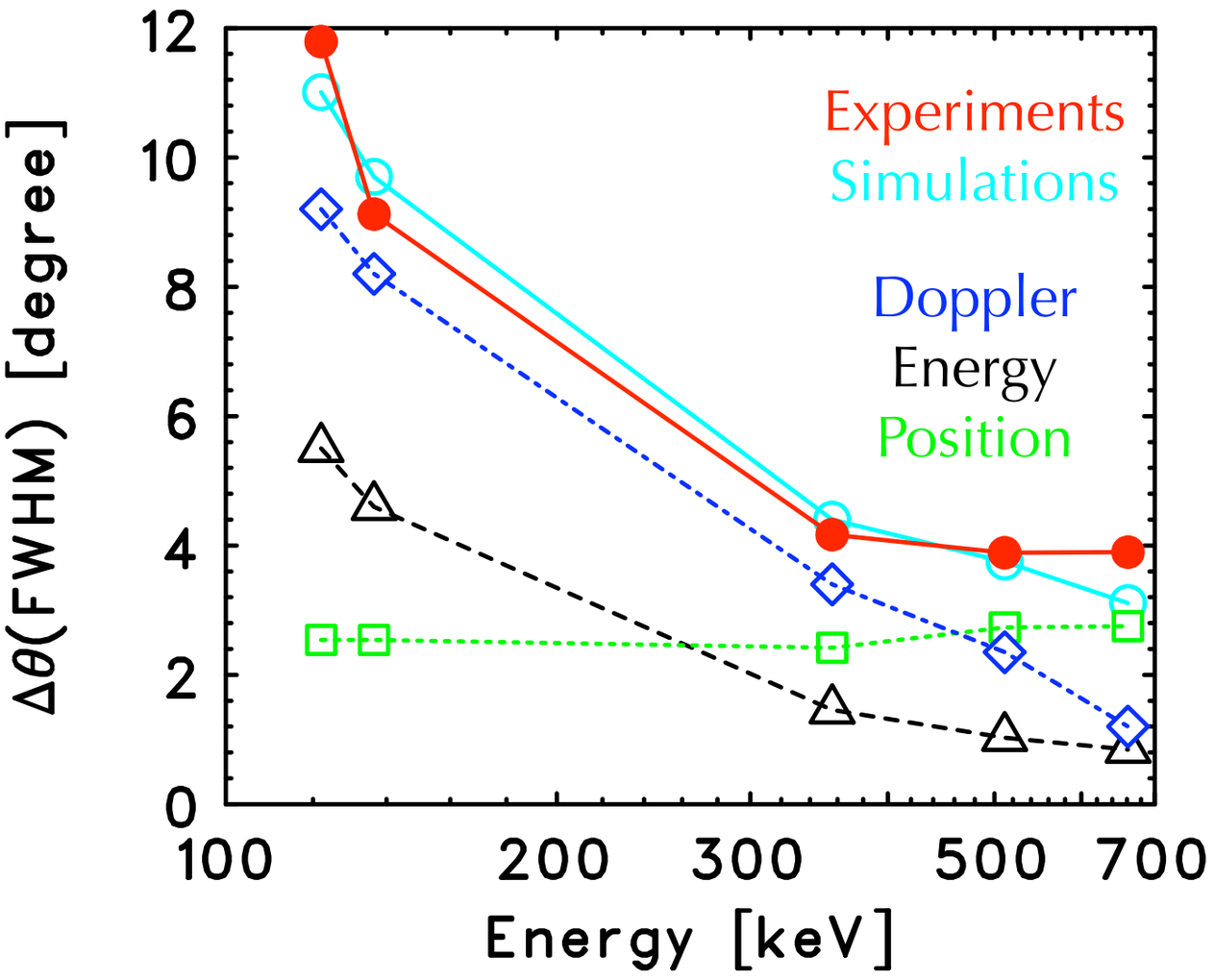
Angular Resolution



θComp − θGeom



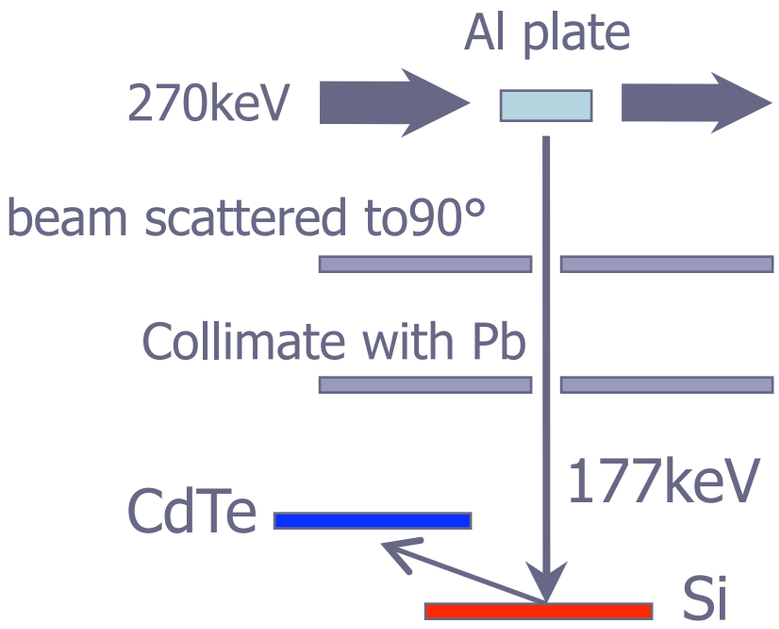
Si/CdTe Compton



CdTe-only Compton

12 degree at 511 keV
(Doppler Limited)
same situation for Ge

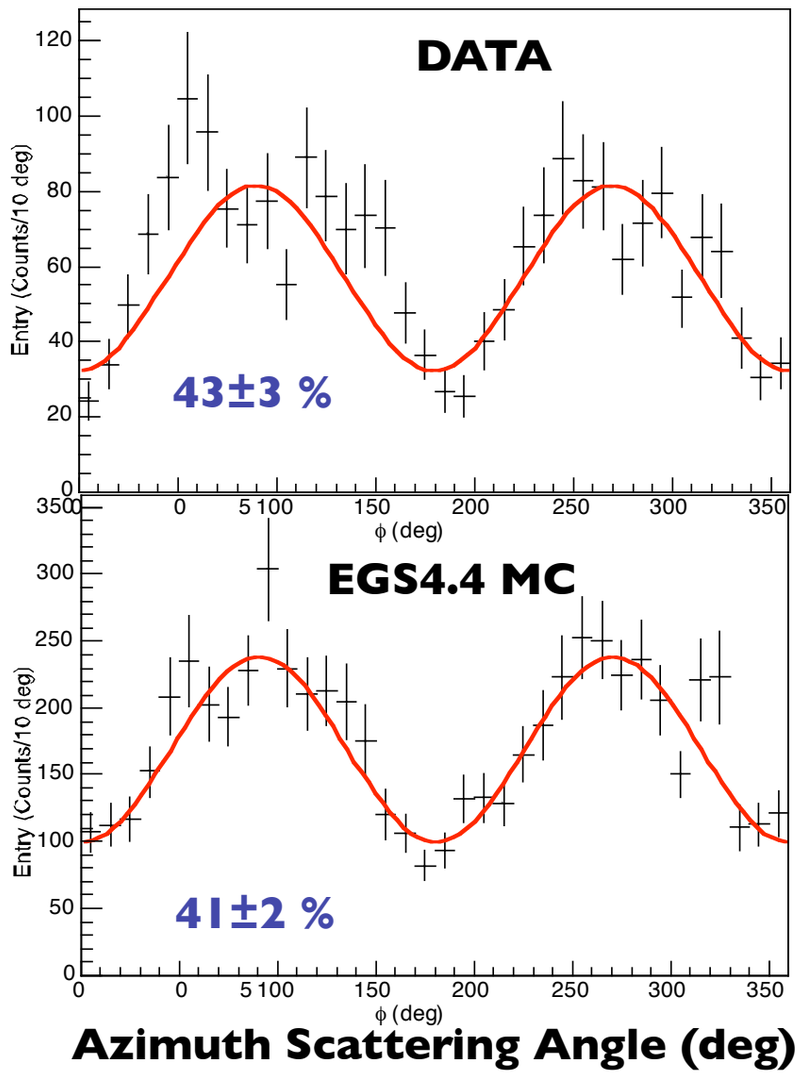
Polarization Measurements by a prototype Si/CdTe Compton Camera



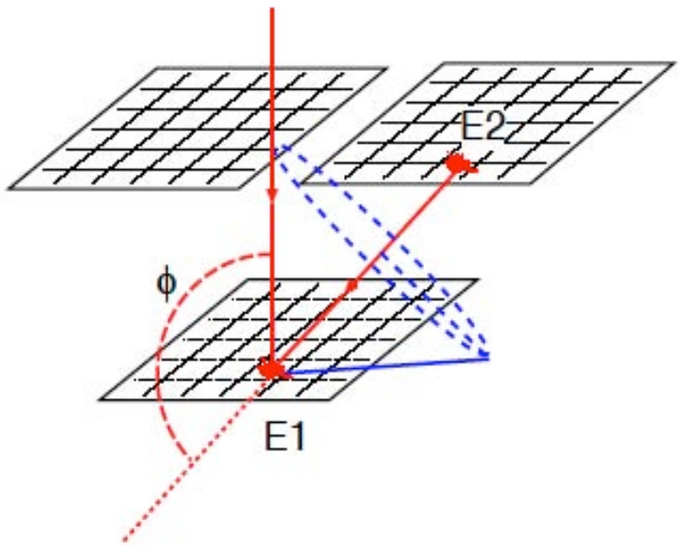
- Spring 8
- 100 % polarized 177 keV gamma-ray line

Modulation Factor =

$$\frac{N_{max} - N_{min}}{N_{max} + N_{min}} = 43 \pm 3\%$$

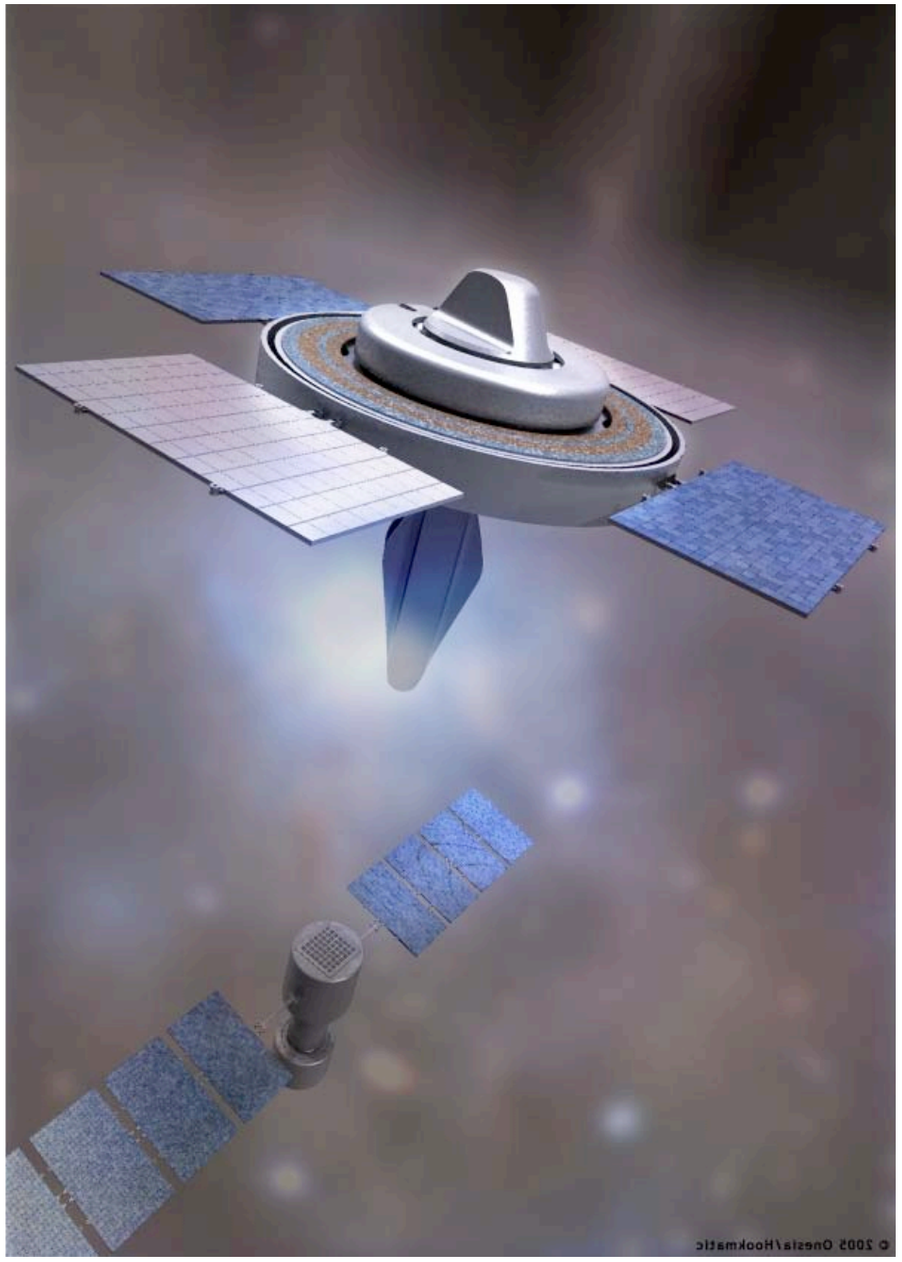


Mitani et al. 2004, Tajima et al. 2005



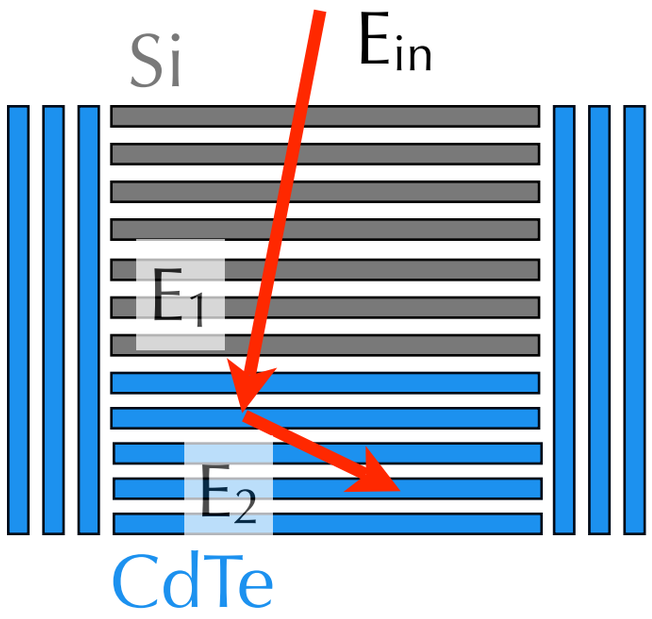
More difficult for higher energy since forward scattering dominate

Focusing Gamma-ray Mission



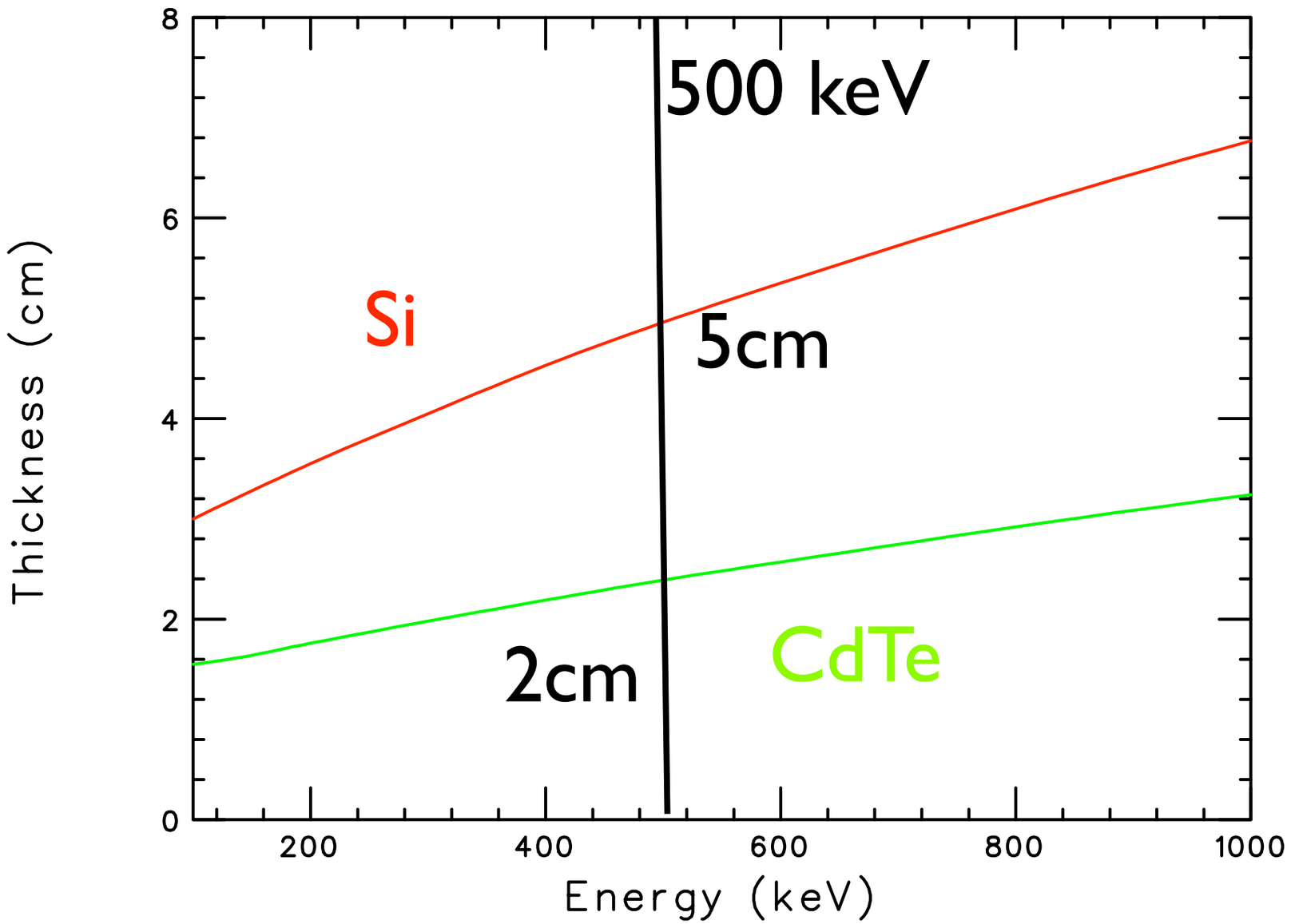
- Good Energy Resolution
- Good Efficiency
- Low Background
  - 511 keV lines come from everywhere (interactions in satellites!)
  - Diffuse Cosmic X/Gamma Background
- Capability to measure polarization
- Minimize Satellite Resource :
  - Cooling System (Cool at -20 deg is relatively easy with passive radiator)

Compton Thick Detector



For 511 keV,
40 - 80 layers

Thickness of tau=1 for Compton Scattering

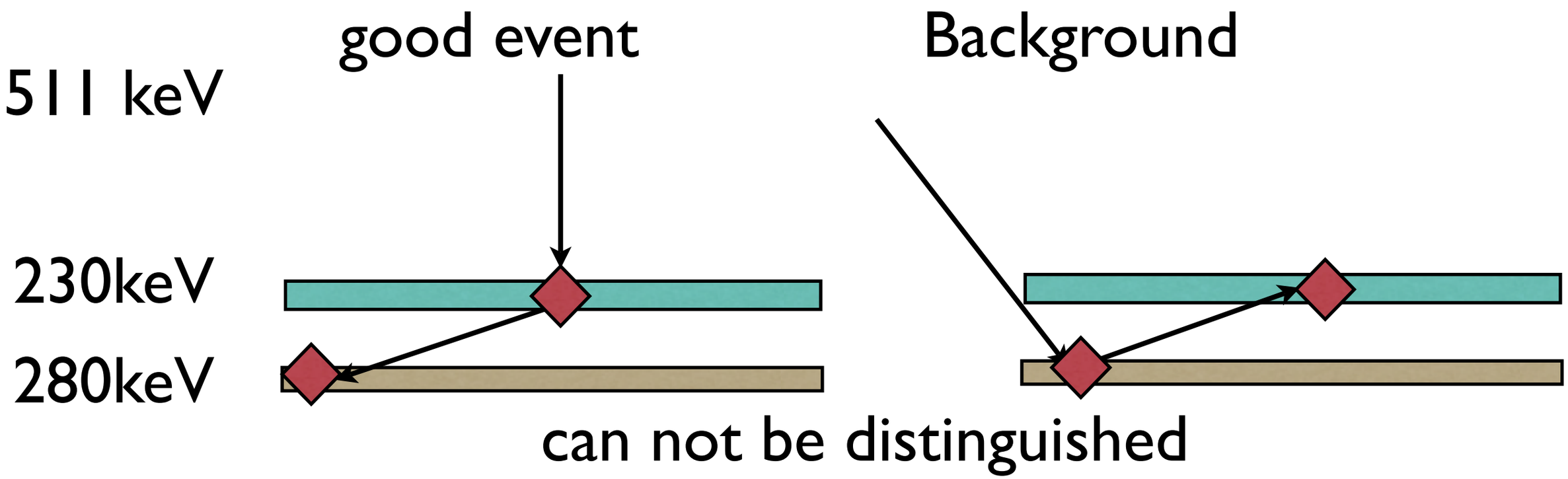


Background

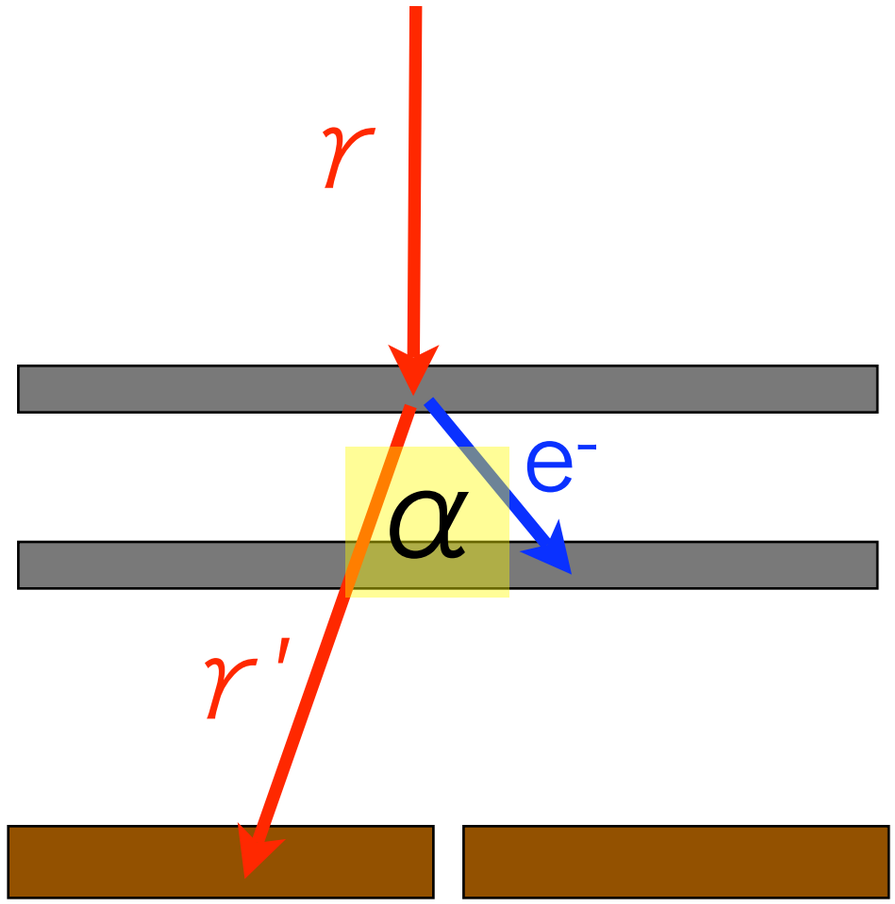
- Nearby Bright Source (Compton Ring overlaps)
- Cosmic Diffuse
- Activation
- Miss Reconstruction

• For 511 keV, angular resolution by Compton reconstruction is ~ 4 degrre for Si/CdTe combination,

~12 degree for CdTe ONLY.

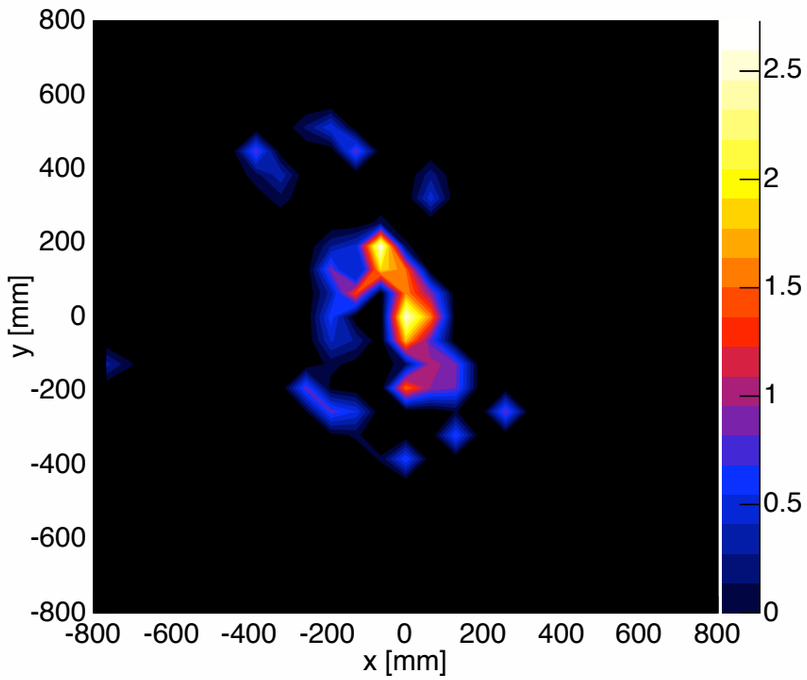


Electron Tracking



α kinematics $\approx \alpha$ geometry

Only unique solution
(NO BACKGROUND)



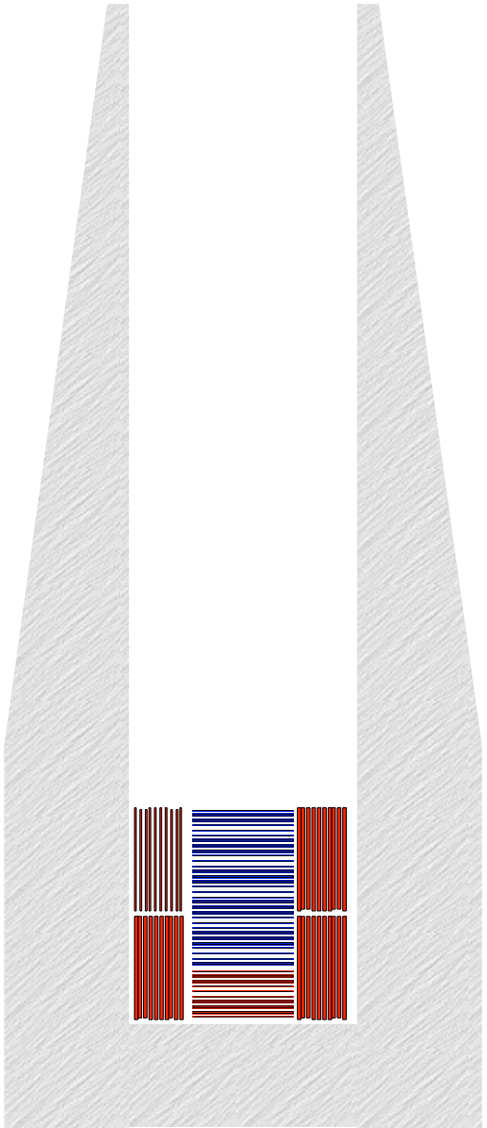
^{137}Cs 662keV

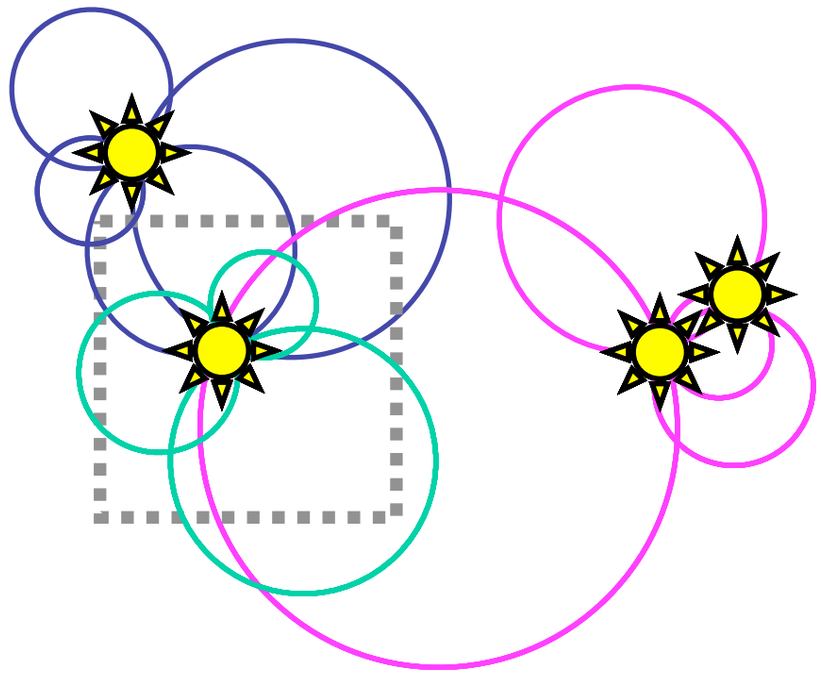
NO ring
(two isotopes)

Efficiency for electron going
through 2 layers is low at ~511keV
(10 % of Compton events)

Narrow FOV Compton Telescope for NeXT (and also MAXA?)

5 degree FOV



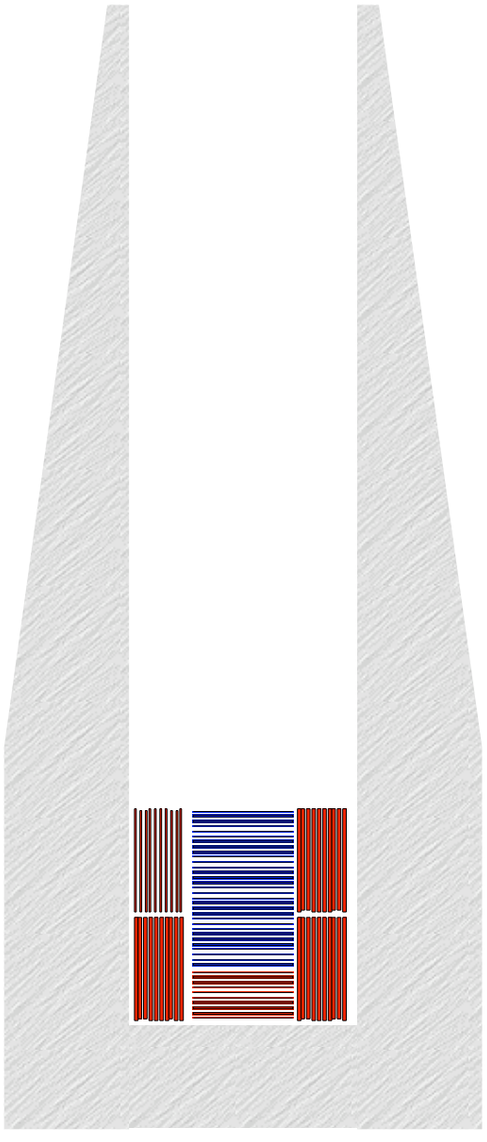


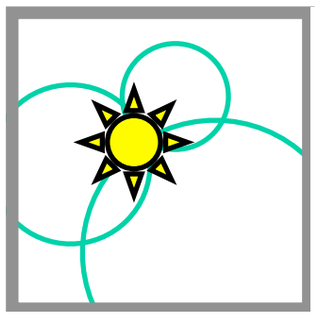
A new concept, Narrow FOV Compton Telescope, reduces all background except for gamma-rays coming from the lens

(see Takahashi et al. SPIE 2001,2003; New Astronomy Rev. 2004, NIM A 2005)

Narrow FOV Compton Telescope for NeXT (and also MAXA?)

5 degree FOV

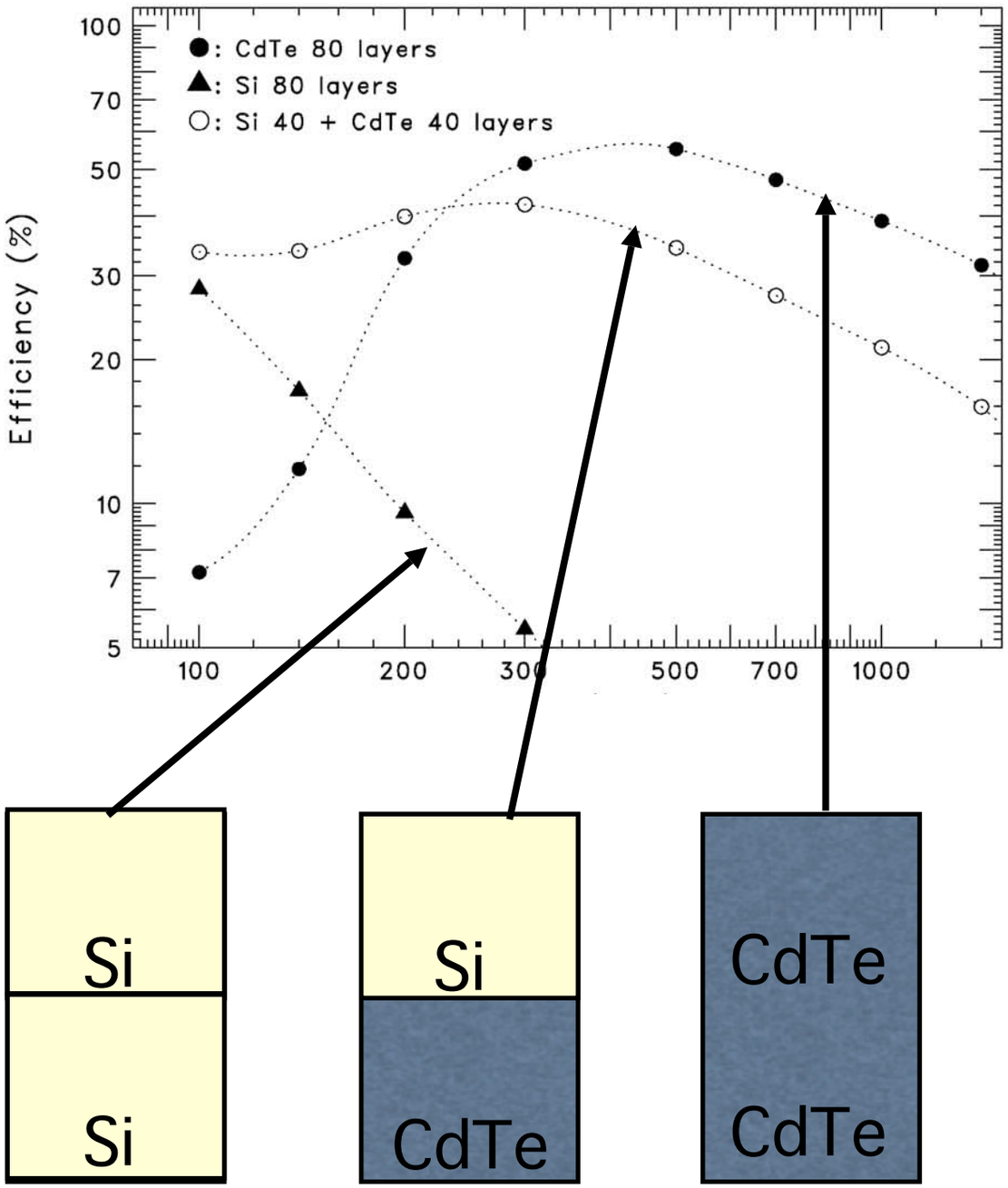




A new concept, Narrow FOV Compton Telescope, reduces all background except for gamma-rays coming from the lens

(see Takahashi et al. SPIE 2001,2003; New Astronomy Rev. 2004, NIM A 2005)

Eff. of Single and MultiCompton events (incl. last photo-absorption)



Note: Angular resolution will be limited by Doppler effect.

- CdTe is effective for energy above 300 keV (50 % at 0.5 MeV for 80 layers, in total 4 cm thick)
- Use of Si for upper layers improves Compton efficiency below 200 keV.

Takahashi et al.
SPIE 4851, pp. 1228-1235, 2003

Summary

- Significant improvements for CdTe detector
- Successful operation of prototype Compton Telescope based on Si and CdTe

(www.astro.isas.jaxa.jp/~takahasi)

- Si/CdTe Compton Telescope provides
  - High Angular Resolution (Important to reduce the background)
  - Good Efficiency/Good Energy Resolution
- Propose a Narrow FOV Compton Telescope for MAX, featuring
  - Low Background
  - Compact/ Moderate Cooling