CdTe and CdZnTe Array Detectors

For Space Experiment

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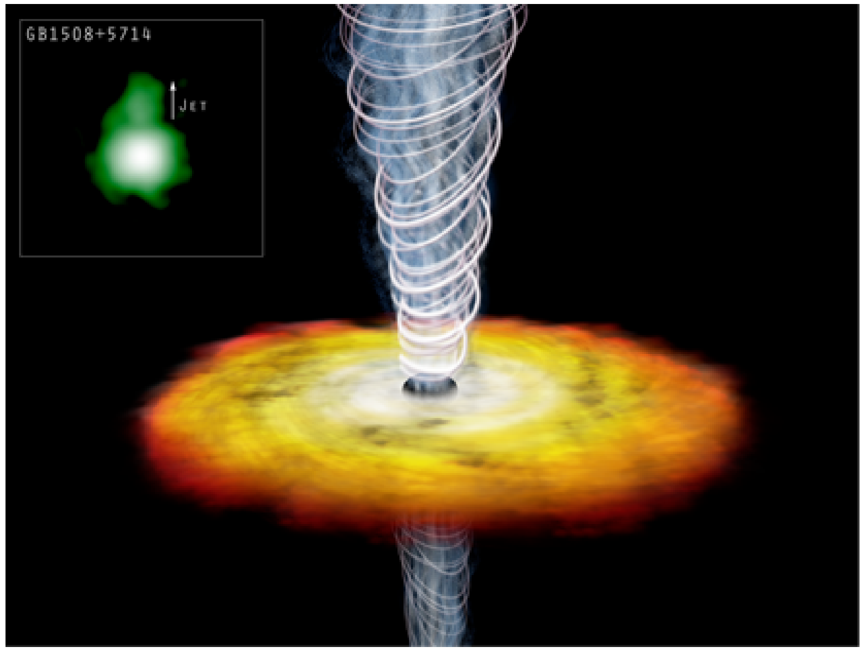
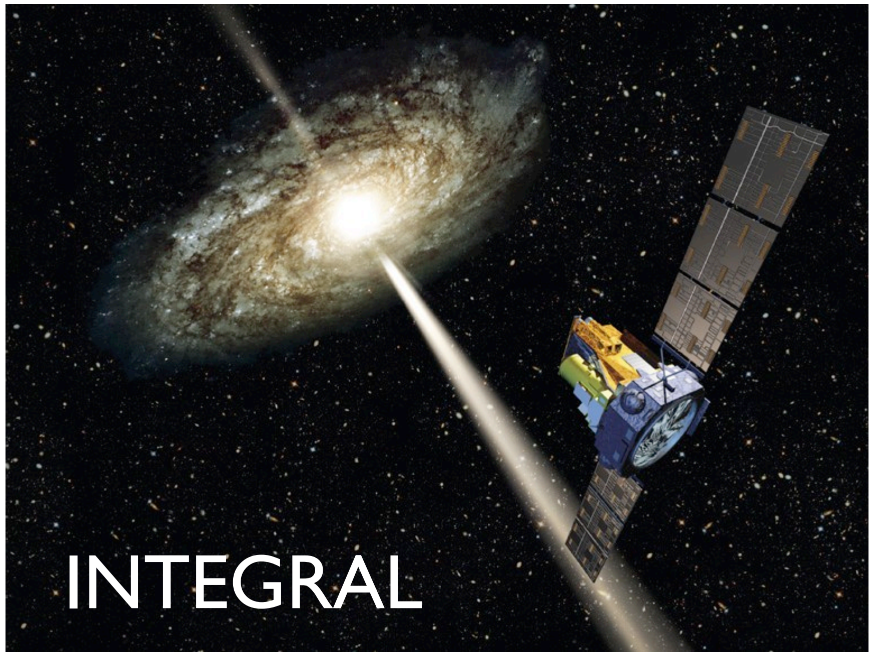
JAXA

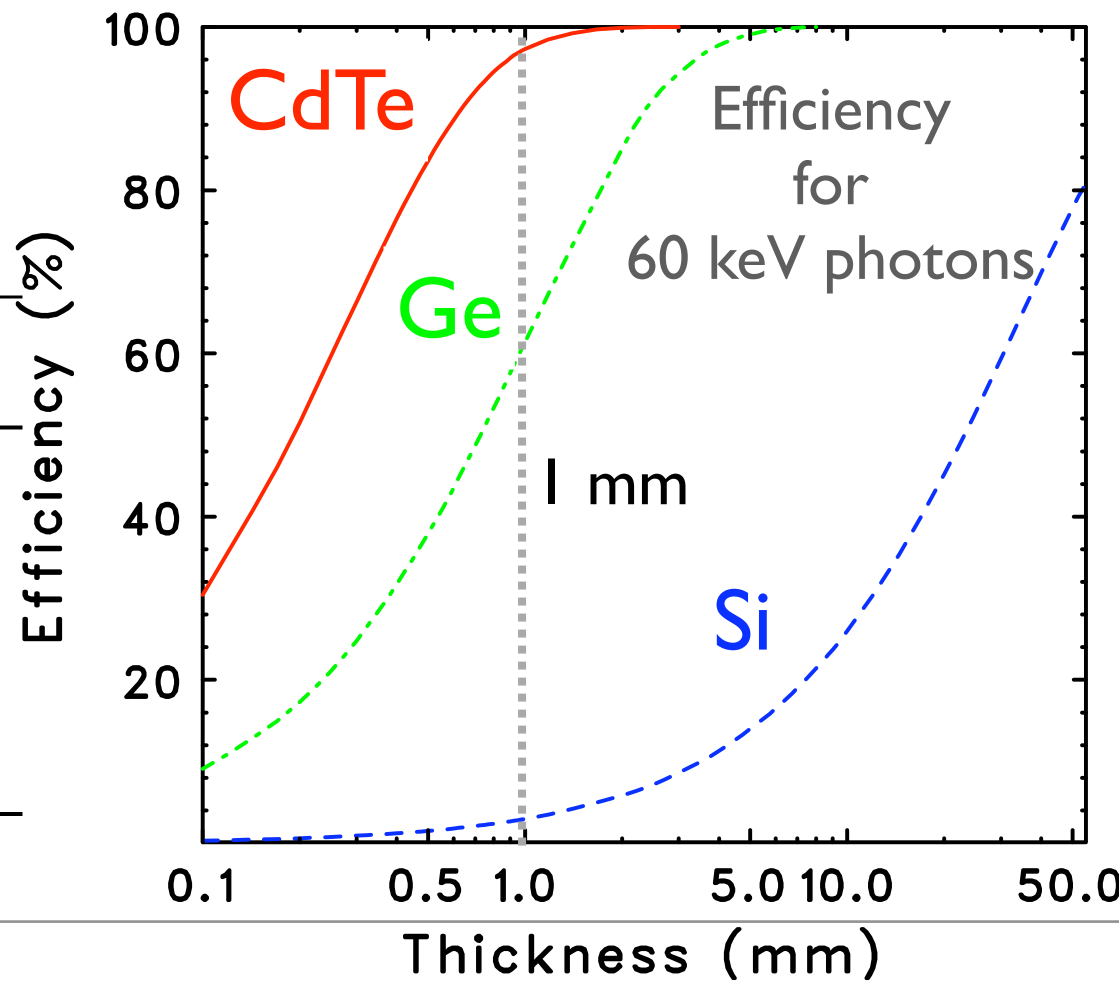




CdTe & CdZnTe

- High Z semiconductor
(Z_{Cd} = 48, Z_{Te} = 52), ρ =5.9 g/cm^3

semi-conductor	density [g/cm^3]	Z	E_{gap} [eV]	ϵ [eV]	X_0 [cm]
Si	2.33	14	1.12	3.6	9.37
Ge	5.33	32	0.67	2.9	2.30
CdTe	5.85	48,52	1.44	4.43	1.52
CdZnTe	5.81		1.6	4.6	
HgI_2	6.40	80,53	2.13	4.2	1.16
GaAs	5.32	31, 33	1.42	4.3	2.29



- Wide band gap (Eg:1.5 eV, e:4.4 eV)

⇒ Allows room temperature operation or
the operation under moderate cooling (> - 20 ℃)

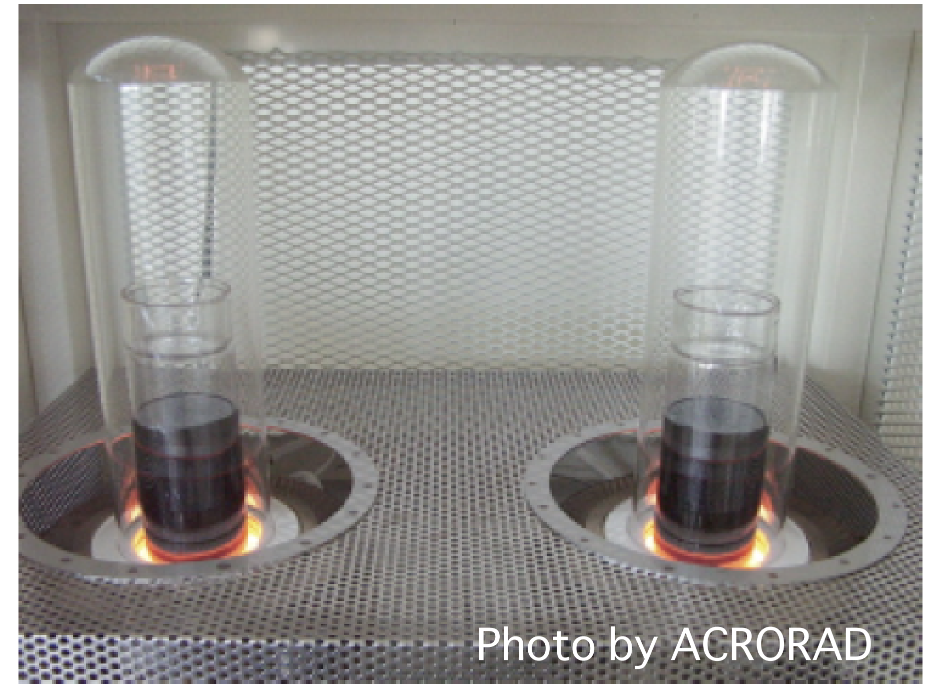
- High resistivity ~ 10^9 Ωcm for CdTe ~ 10^{10-11} Ωcm for HPB-CdZnTe

- With "ohmic" contacts, the detector can be operated as a simple "solid ionization chamber". In principle, it has no polarity
- 10ns timing resolution possible

Recent Achievements of Crystal Growth

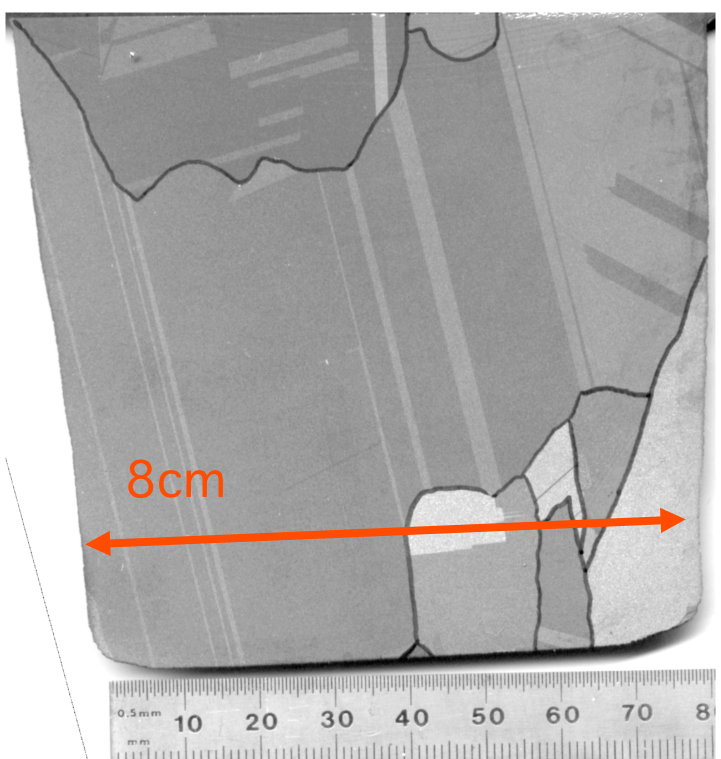
←HPB-CdZnTe
(eV Products)

THM-CdTe→
(ACRORAD)

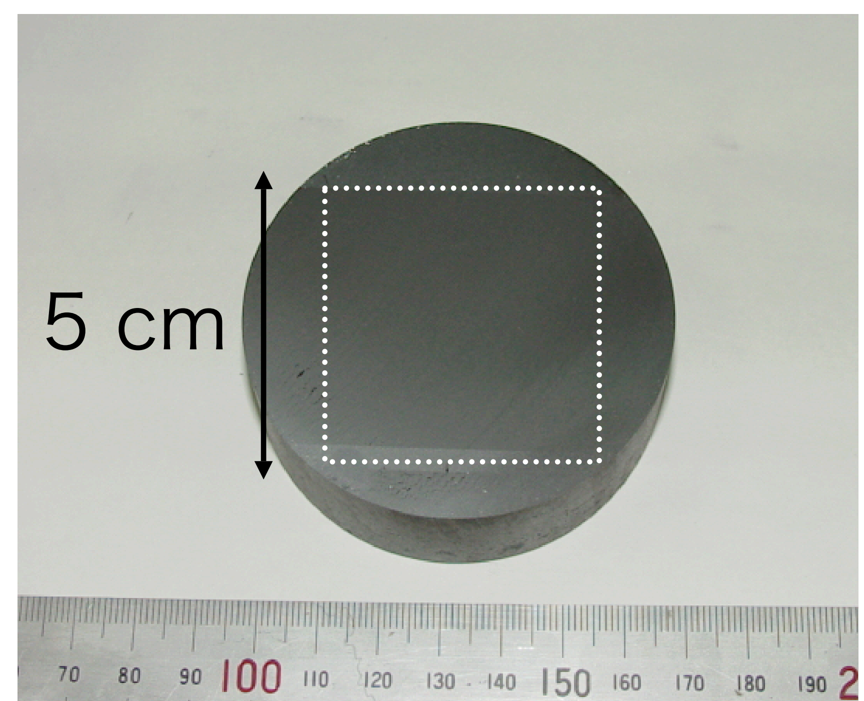


High-Pressure Bridgman (HPB)

CdTe single crystal
Travel Heater Method (THM)



←Large Volume
(as poly crystal)
High Resistivity



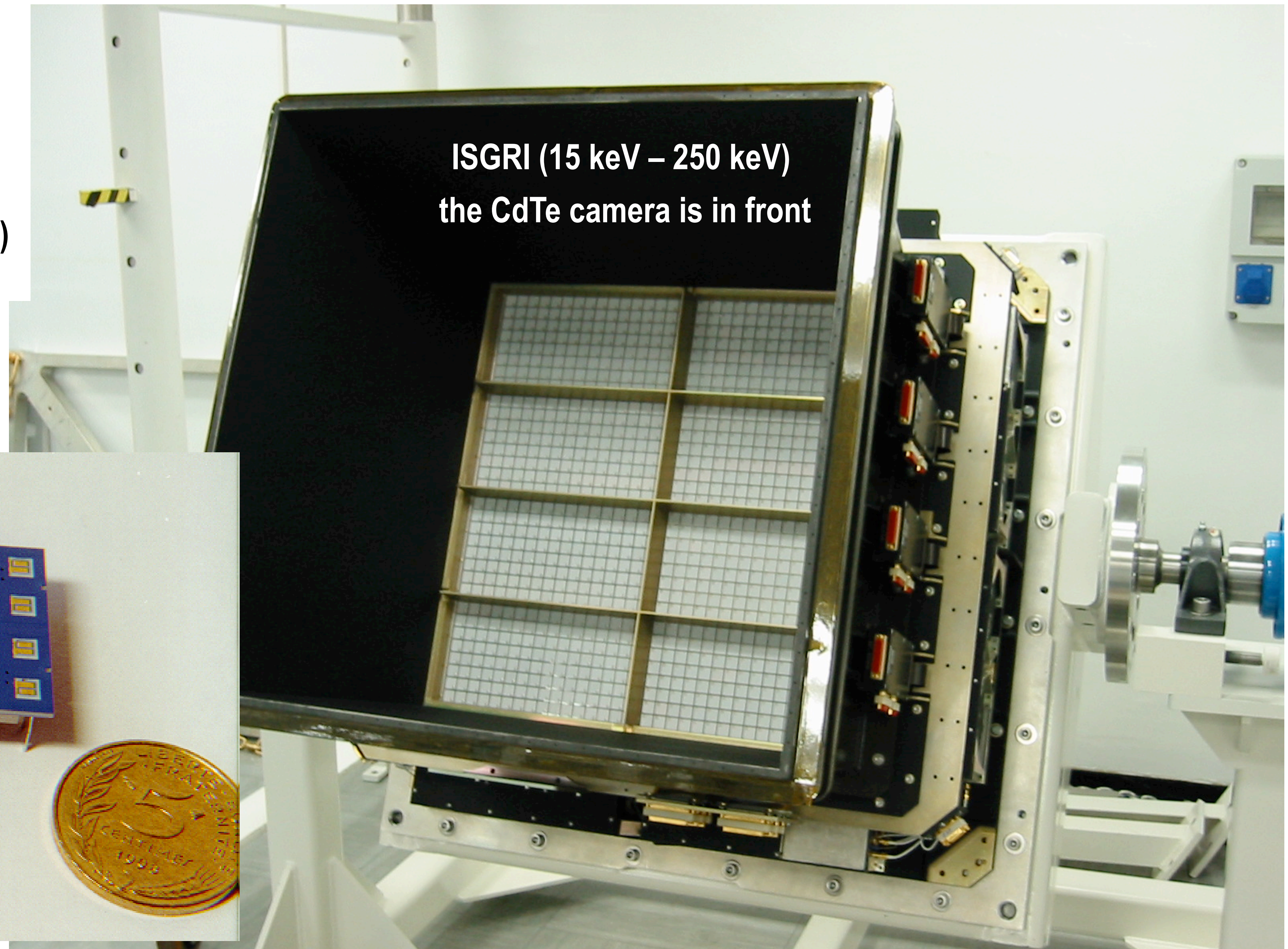
Large Wafer
of single crystal→
High Uniformity

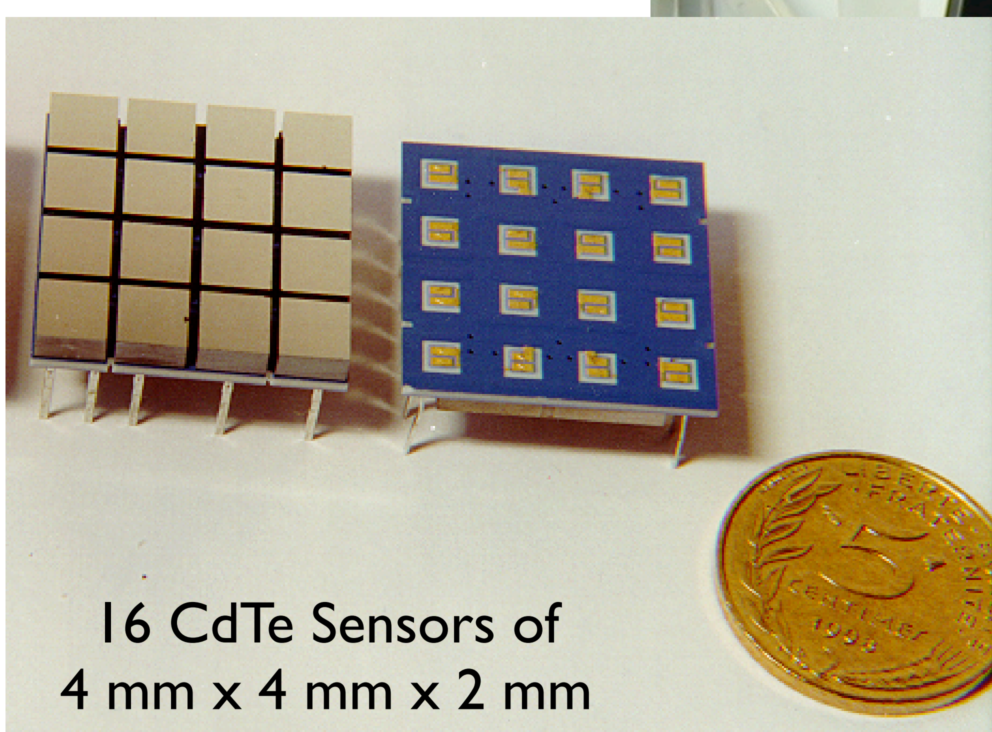
Large Scale CdTe/CZT Experiment in Space (1)

INTEGRAL IBIS
(Launched in 2004)

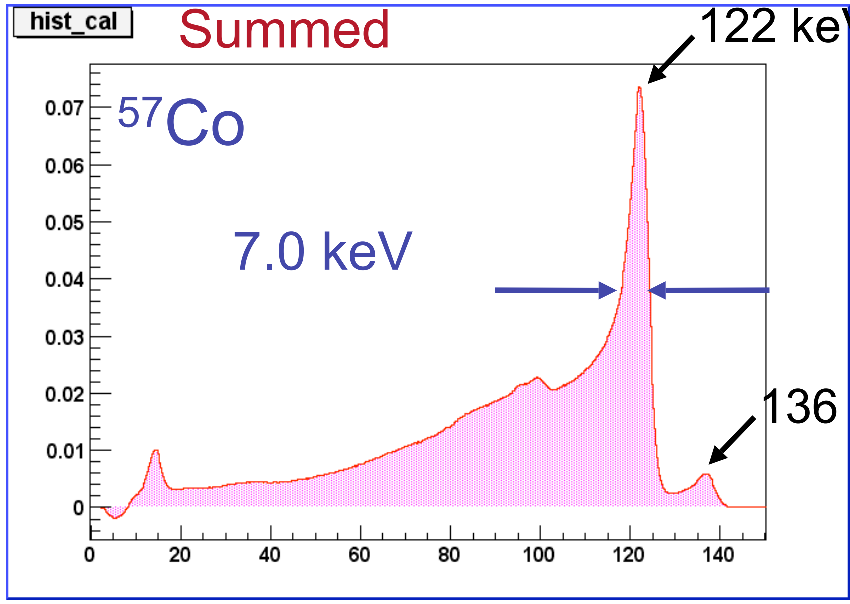
First large (60x60 cm) CdTe gamma camera
(16384 planar CdTe THM detectors 4x4x2 mm)

- Field of view : 19° FWHM
- Angular resolution : 12'
- Energy range : 15 keV- 250 keV
- Energy resolution : 9 % (60 keV)
- Time resolution : 100 microsec





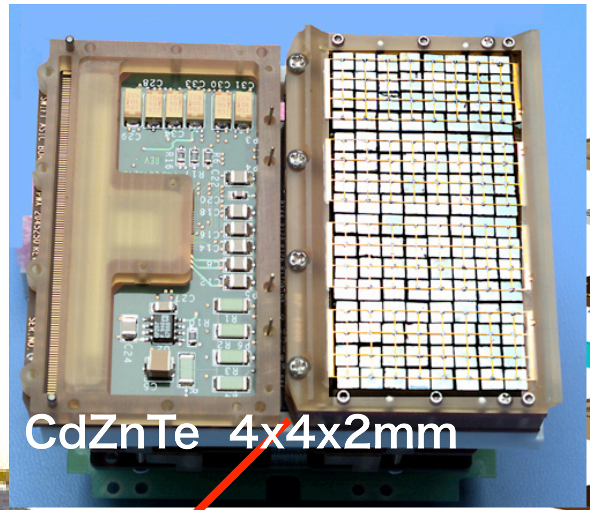
Large Scale CdTe/CZT Experiment in Space (2)

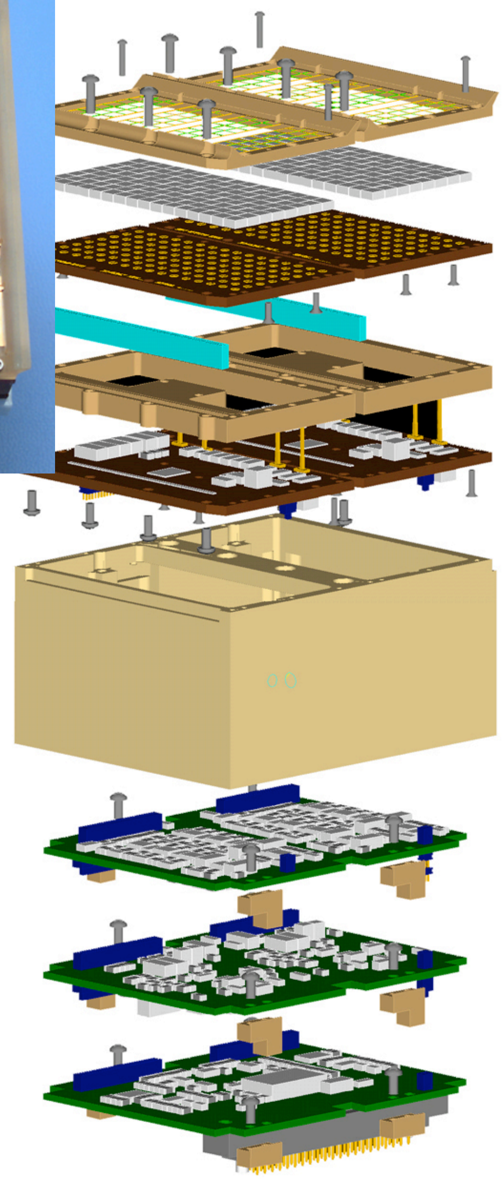


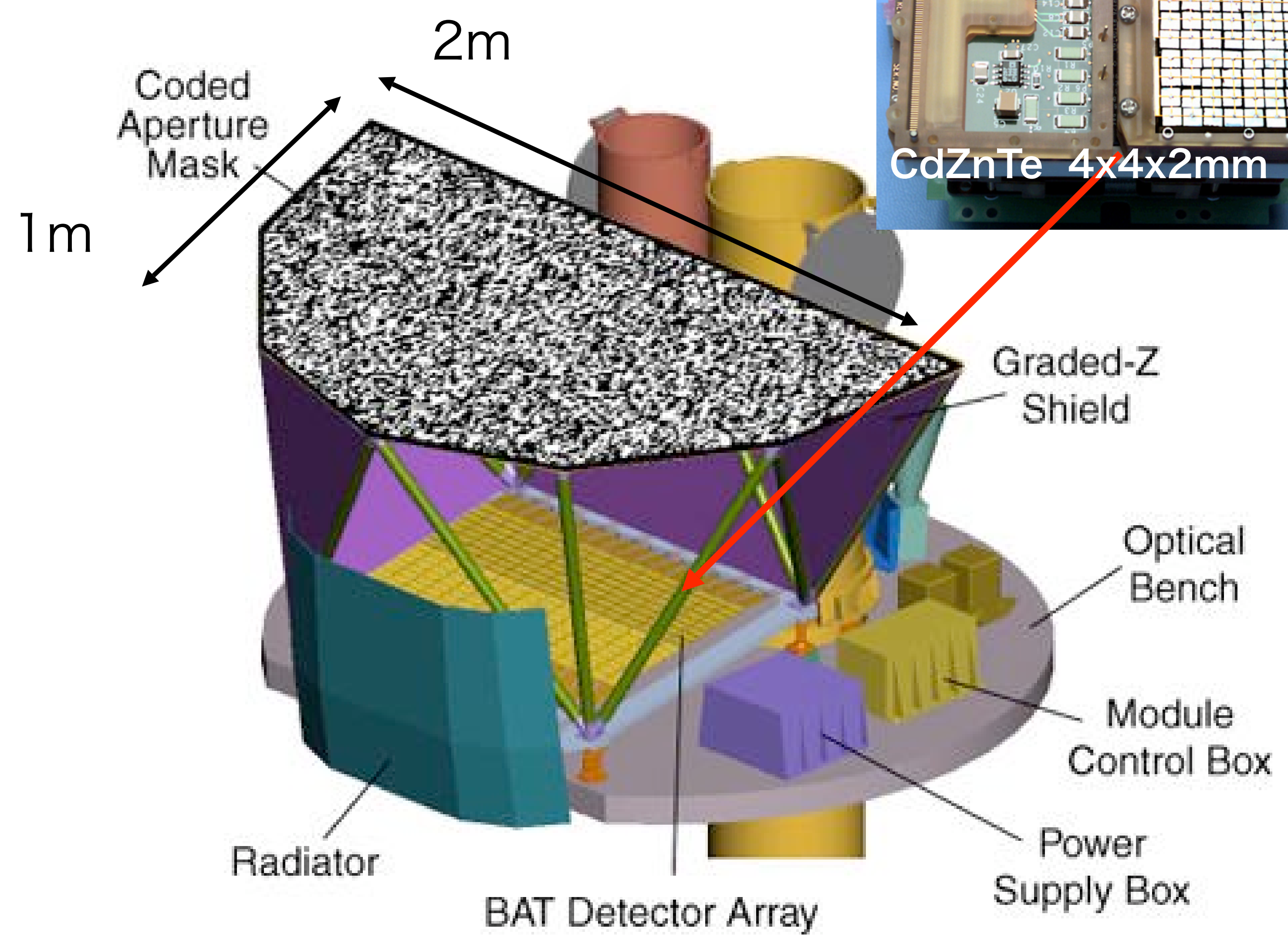
Burst Alert Telescope (BAT) on Swift
(Launched in 2004)

XA Chip (IDEAS)

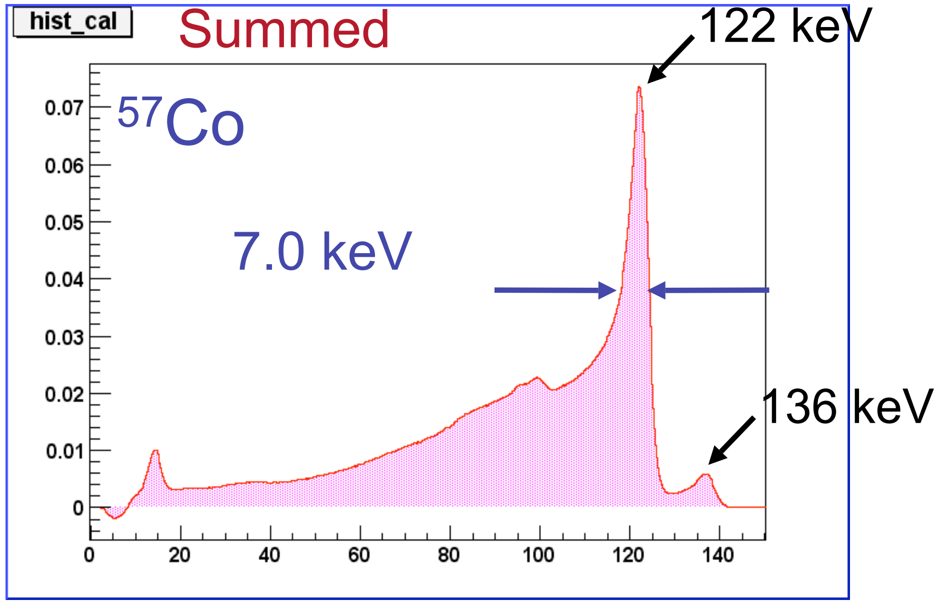
32,768 CZT







Large Scale CdTe/CZT Experiment in Space (2)



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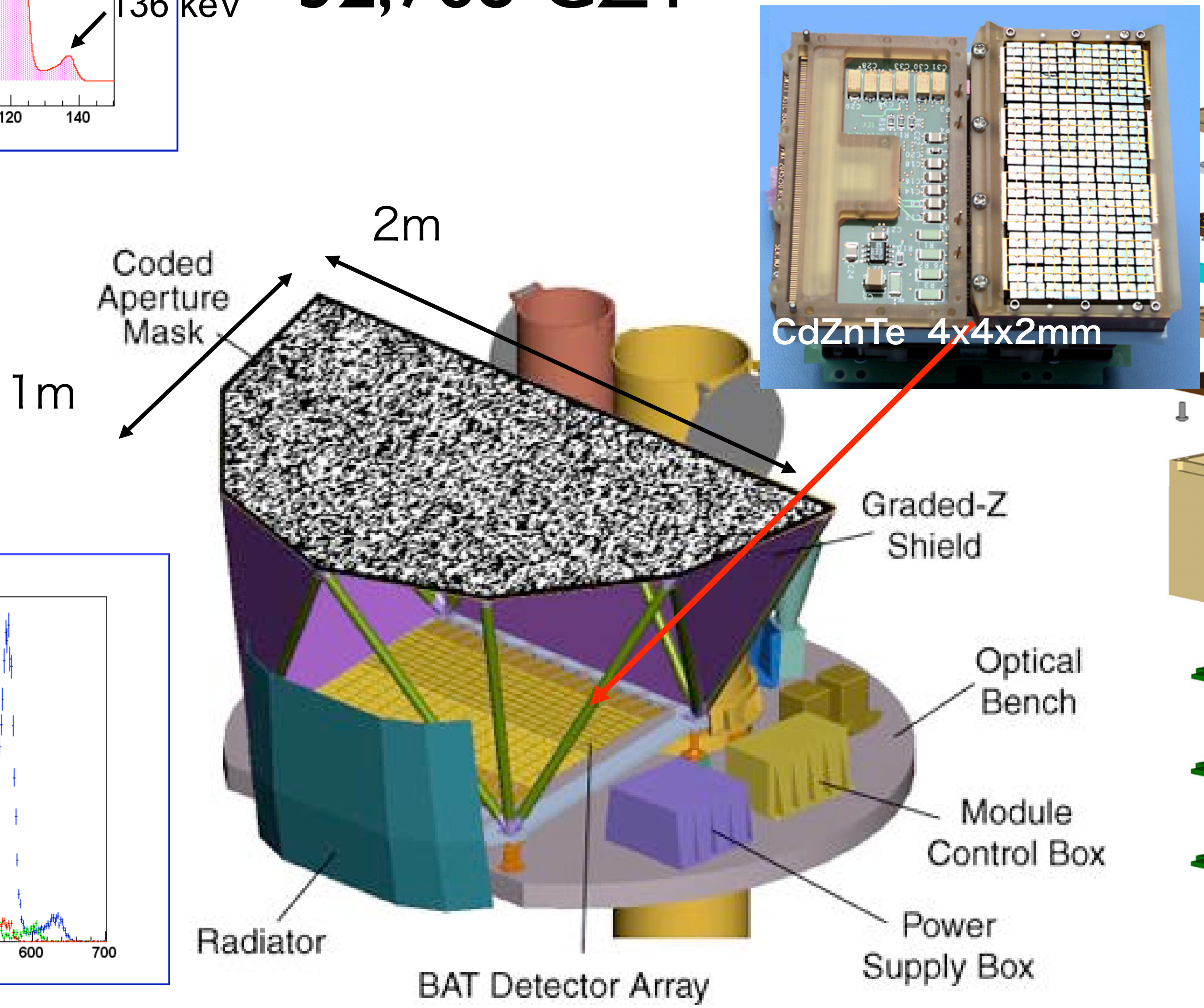
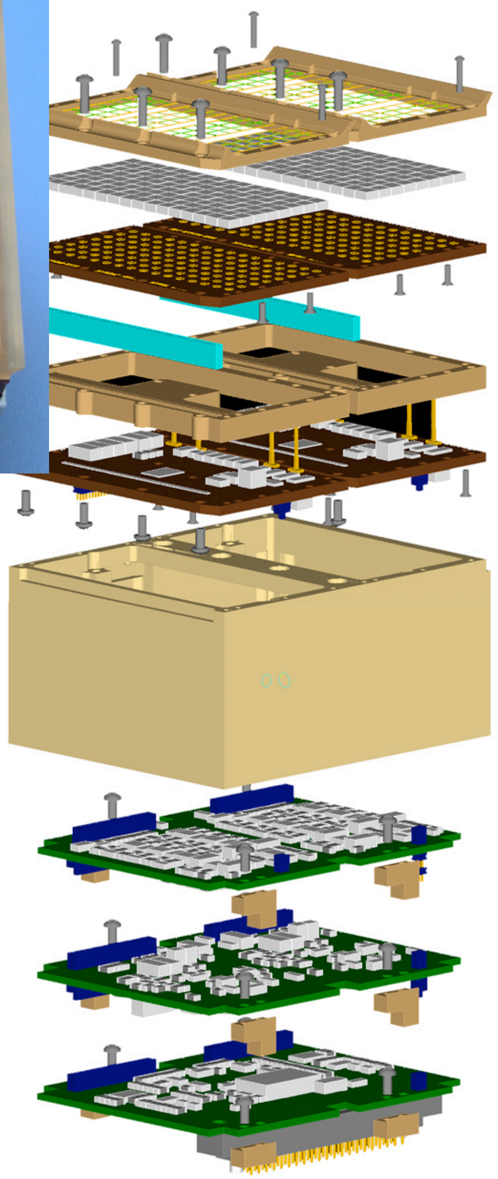
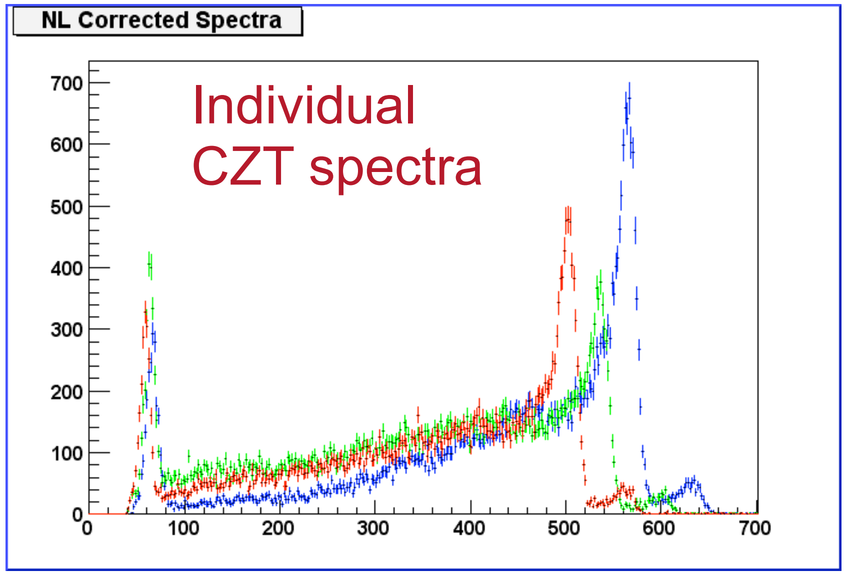






Poor charge-carriers transport properties

μτ products

electron :3x10^-3 cm²/V   Si : 0.42

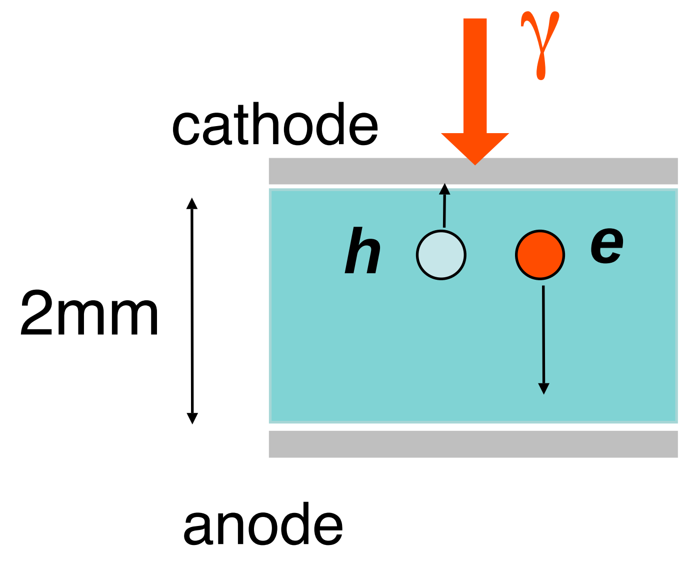
hole

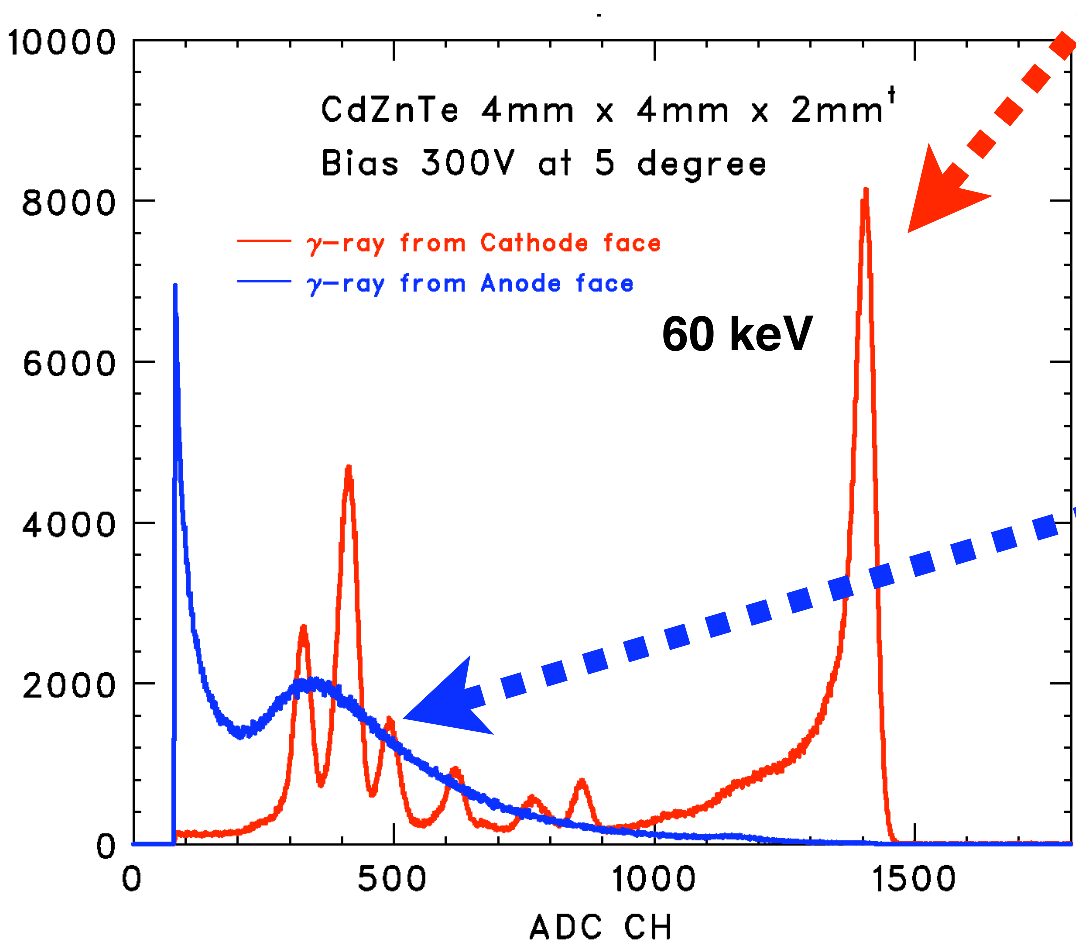
THM-CdTe : 3x10^-4 cm²/V   Si : 0.22

HPB-CdZnTe: ~0.5x10^-4 cm²/V

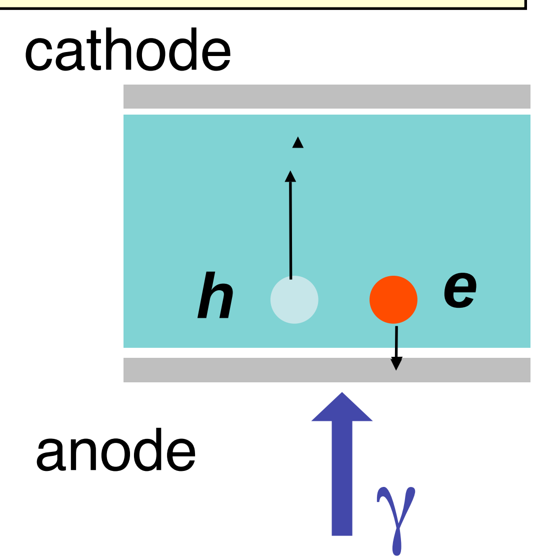
Even with the thickness of 2mm effect of charge trap is significant

Case I : signal is mostly due to the movement of electrons





Case II : signal is mostly due to the movement of holes



High Resolution CdTe Diode

(ISAS-JAXA / ACRORAD)

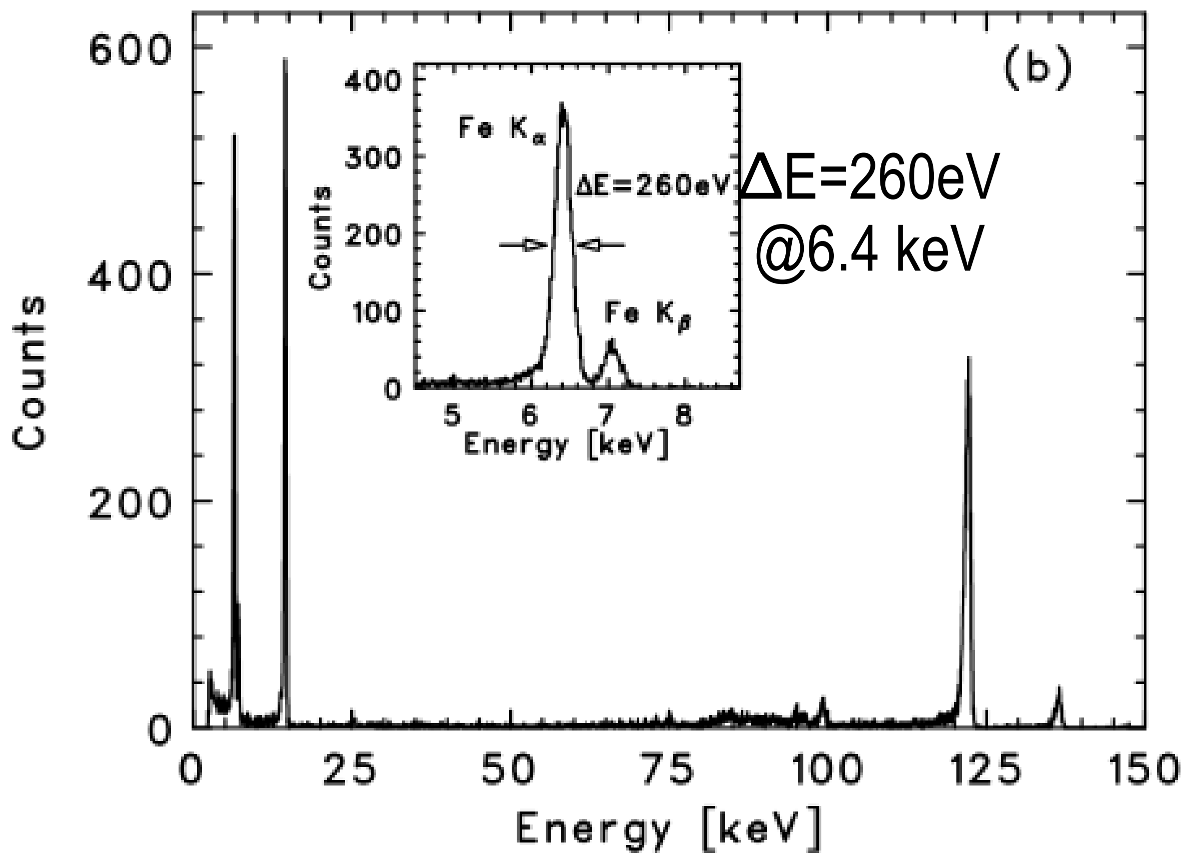
1. Thin device （0.3-1.0 mm)
2. Schottky Diode （In/CdTe/Pt)
3. Guard Ring

- Extremely low leakage
  10 pA for 2x2x0.5mm2 at 20℃ at 500 V
- High bias voltage

- Full Charge Collection (NO-TAIL)

Takahashi et al. IEEE NS 49, 1297, 2002

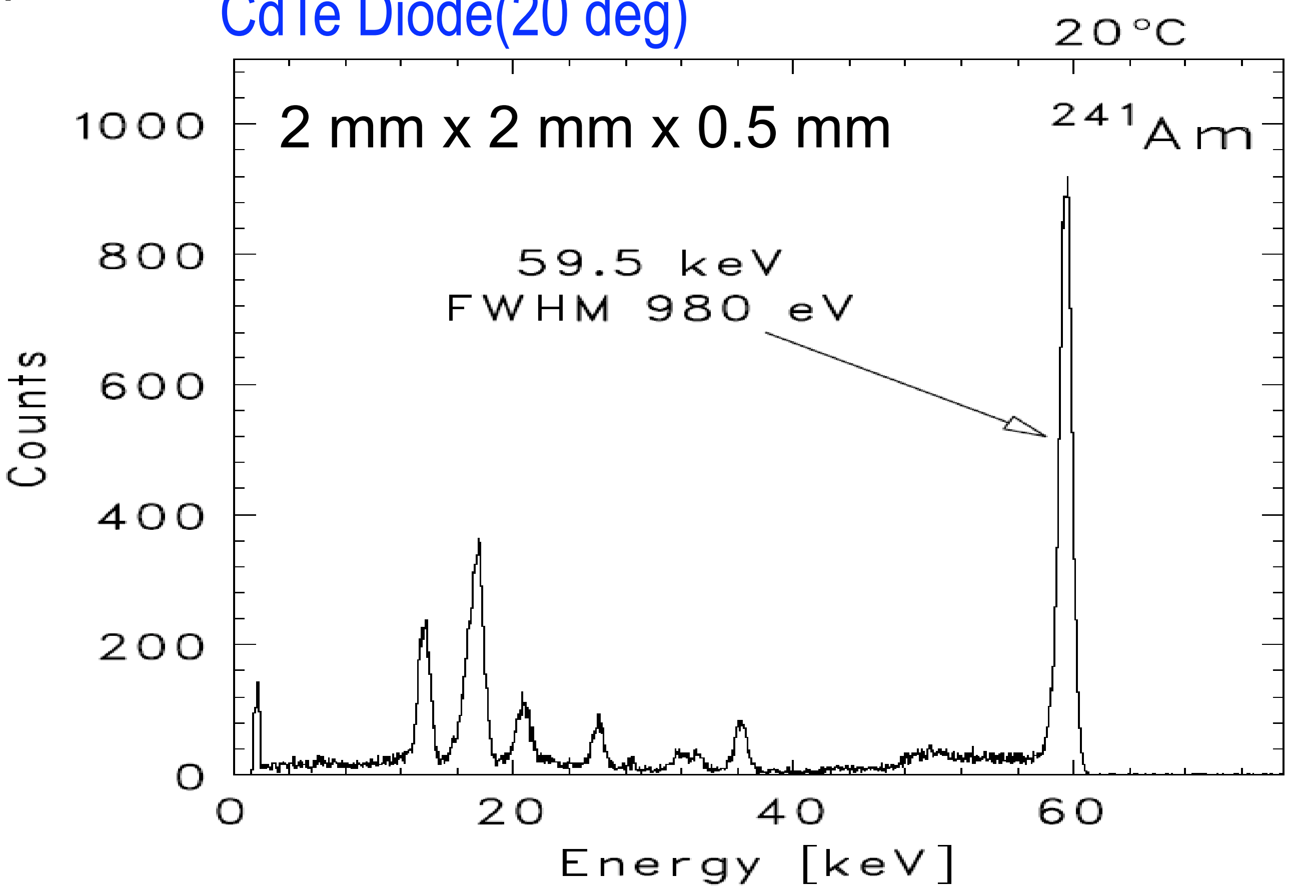
CdTe Diode(-40 deg.) 3 mm x 3 mm x 1.0 mm



Taken with Amptek system

Takahashi et al. 2005

CdTe Diode(20 deg)



Tanaka et al. 2003

Improvements

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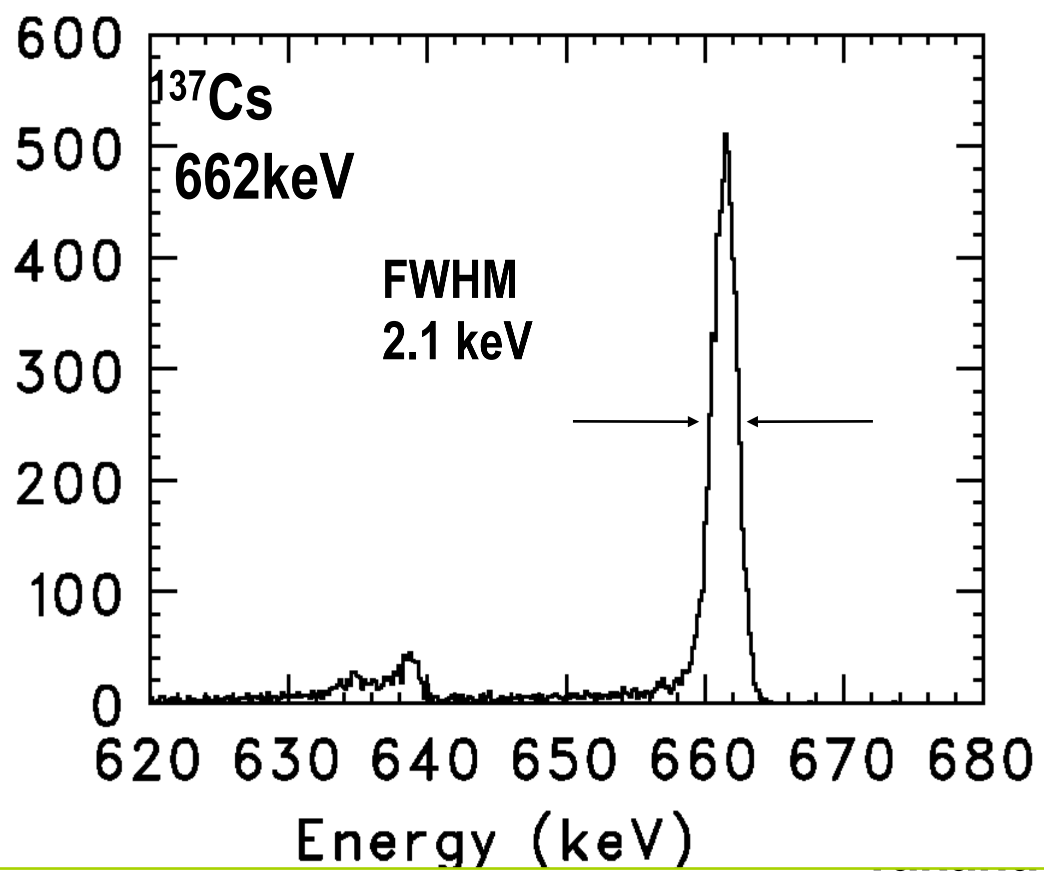
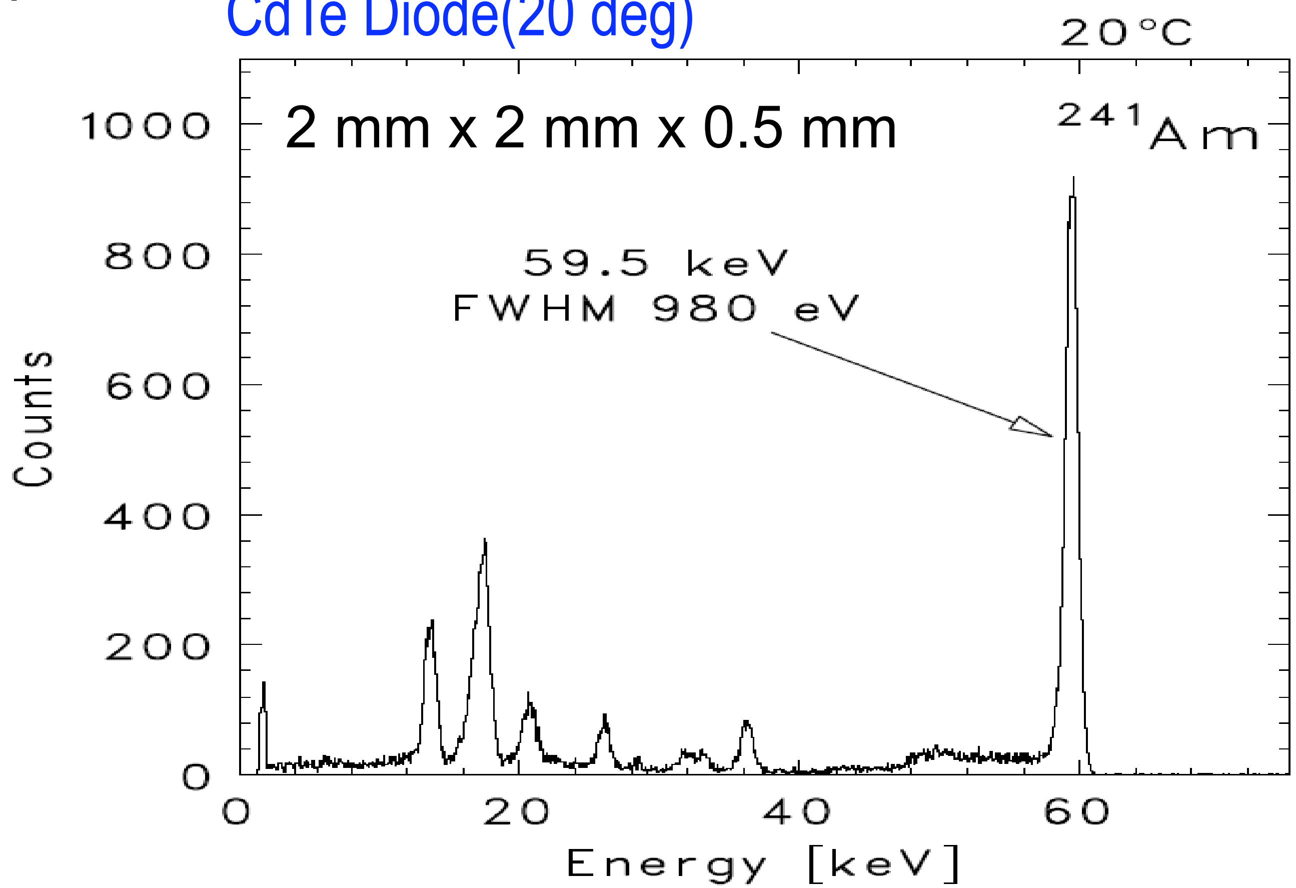


et al. 2005

CdTe Diode(20 deg)



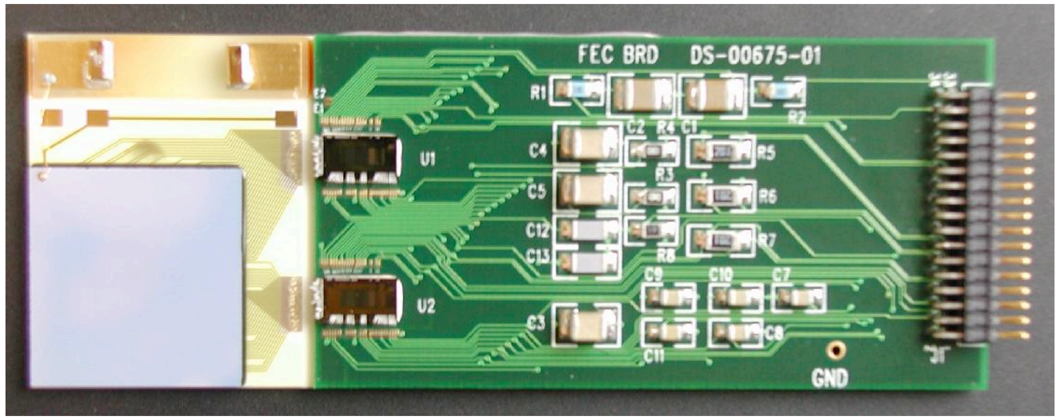
Tanaka et al. 2003

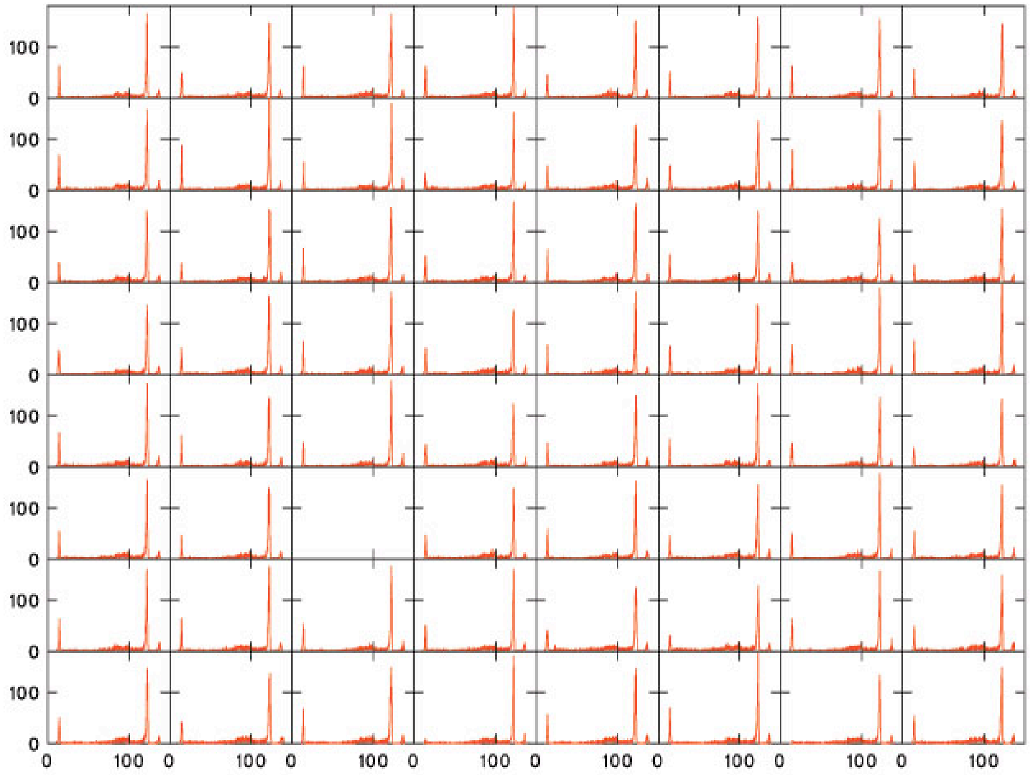
CdTe Pixel “Gamma-ray Module”

8x8 module

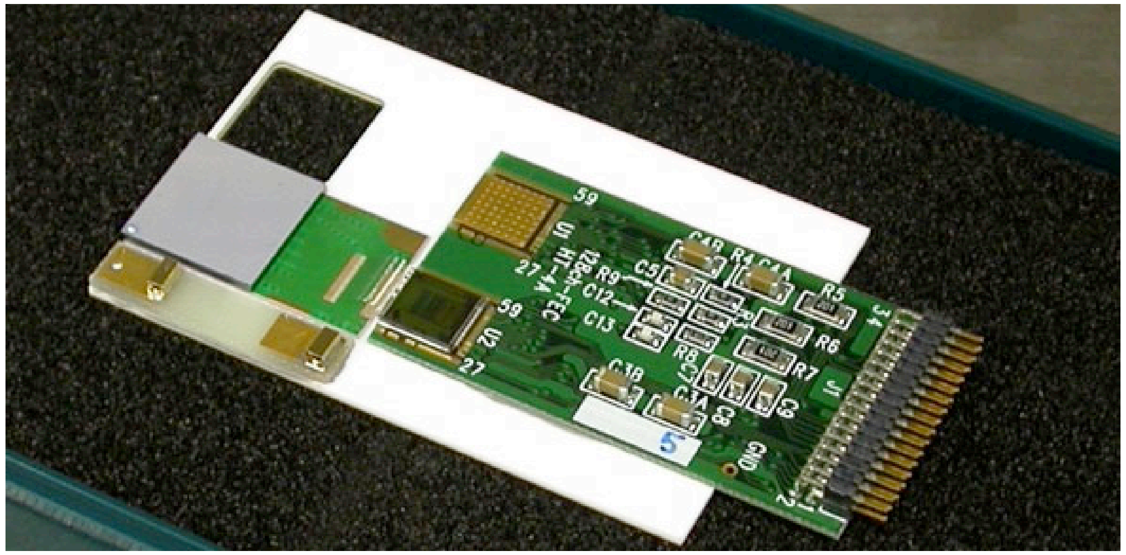
ISAS/JAXA

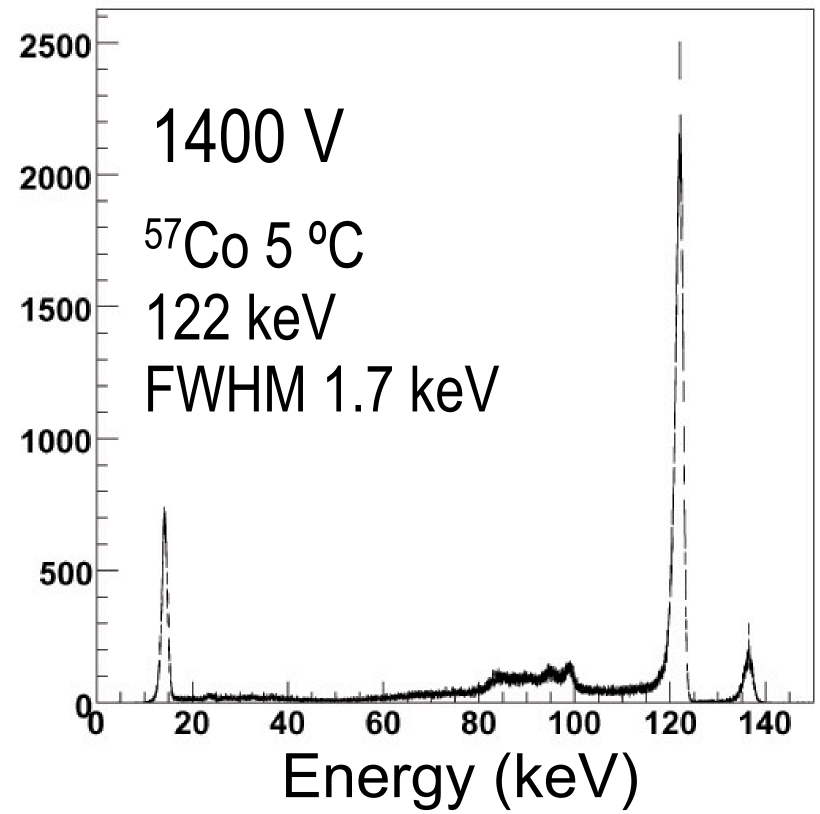
area: 18 x 18 mm^2, thickness: 0.5 mm
pixel size: 2 x 2 mm^2, 64ch, cathode side
guard ring : 1 mm width
backing : 200 micron thick Al_2O_3





area: 11.2 x 11.2 mm^2, thickness: 0.75 mm
pixel size: 1.35 x 1.35 mm^2, 64 ch



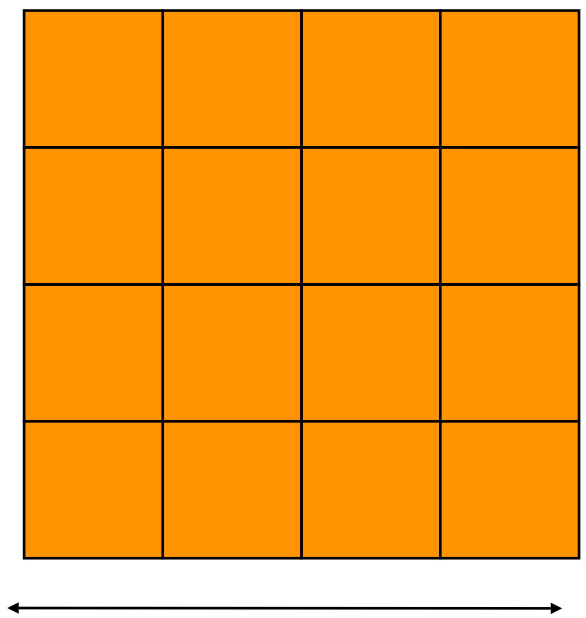


New ASIC (VA32TA/VA64TA) by ISAS/SLAC/IDEAS

Application of Gamma-ray Module

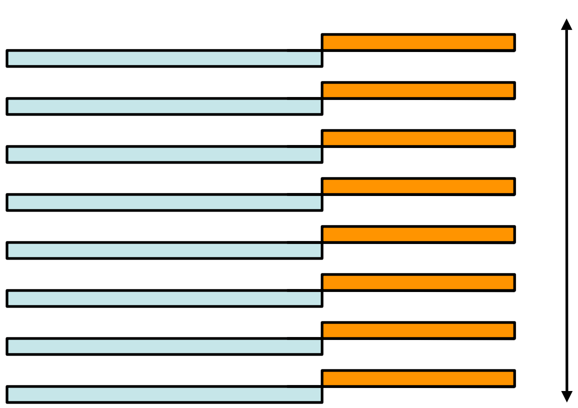
Once we establish the module, we can expand it to... ISAS/JAXA

- Large Area Detector



4 ~ 8 cm

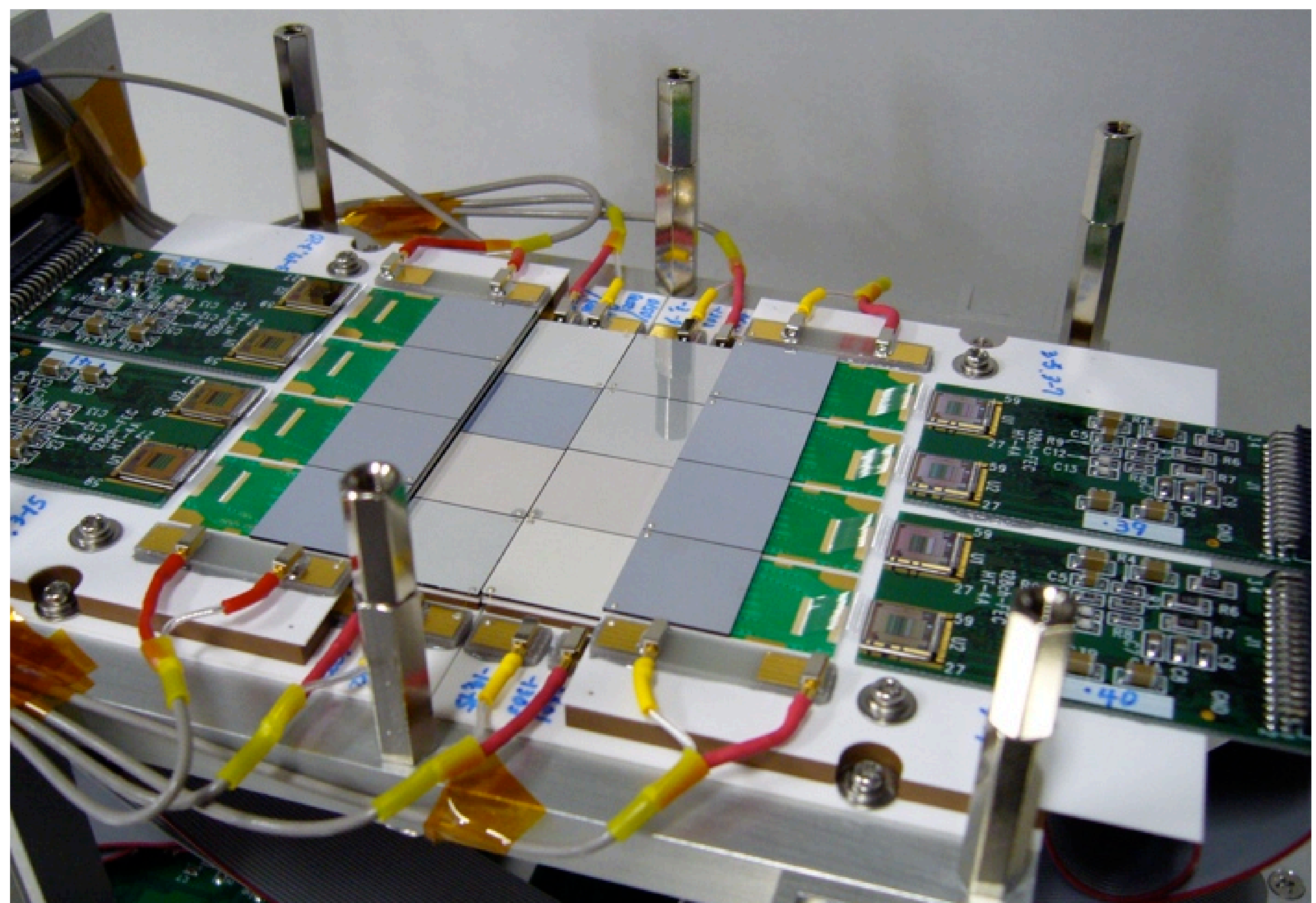
- Stacked Detector



5 ~ 10 mm

Large Area 1024 pixel CdTe Array

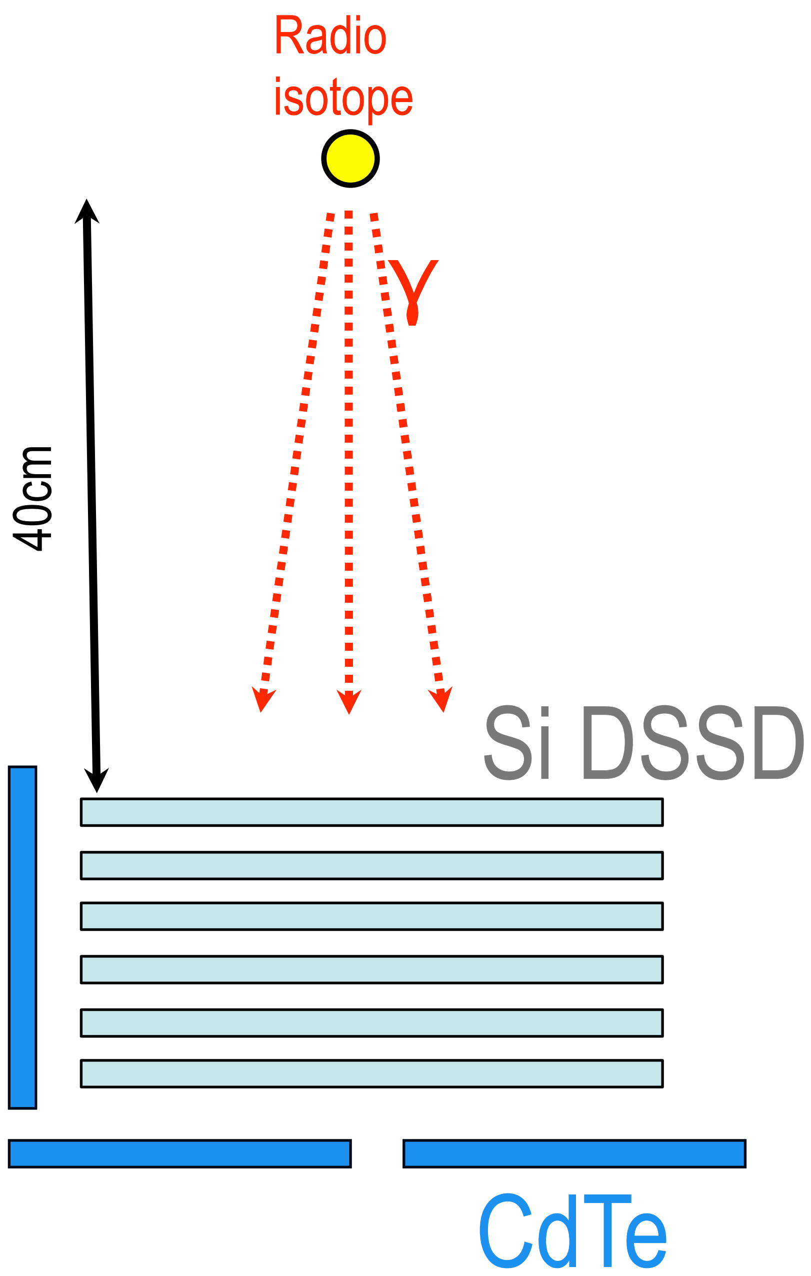
(pixel size 1.4 x 1.4 mm^2)



Si/CdTe Compton Telescope

High Energy Resolution of CdTe pixel is the KEY
for BOTH Angular Resolution and Energy Resolution

ISAS/JAXA
w H. Tajima in SLAC



Watanabe et al. IEEE 2005

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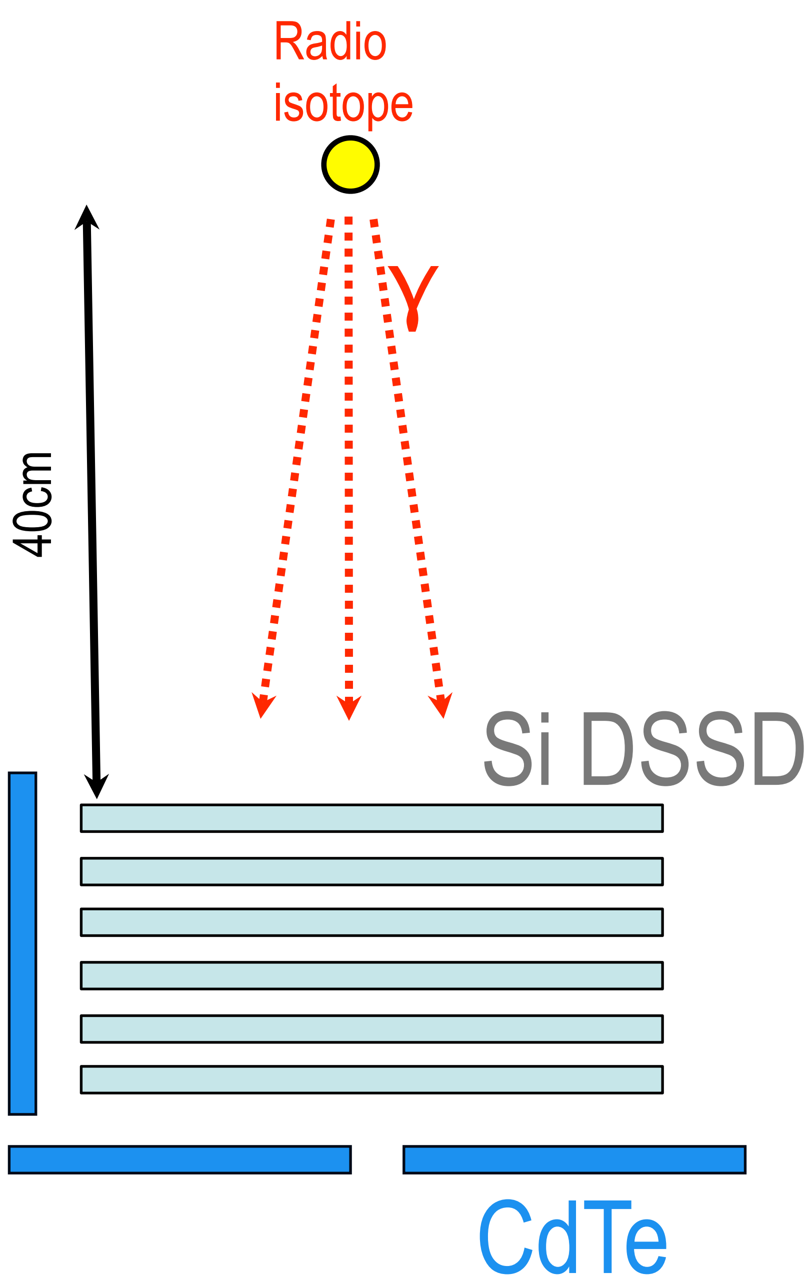

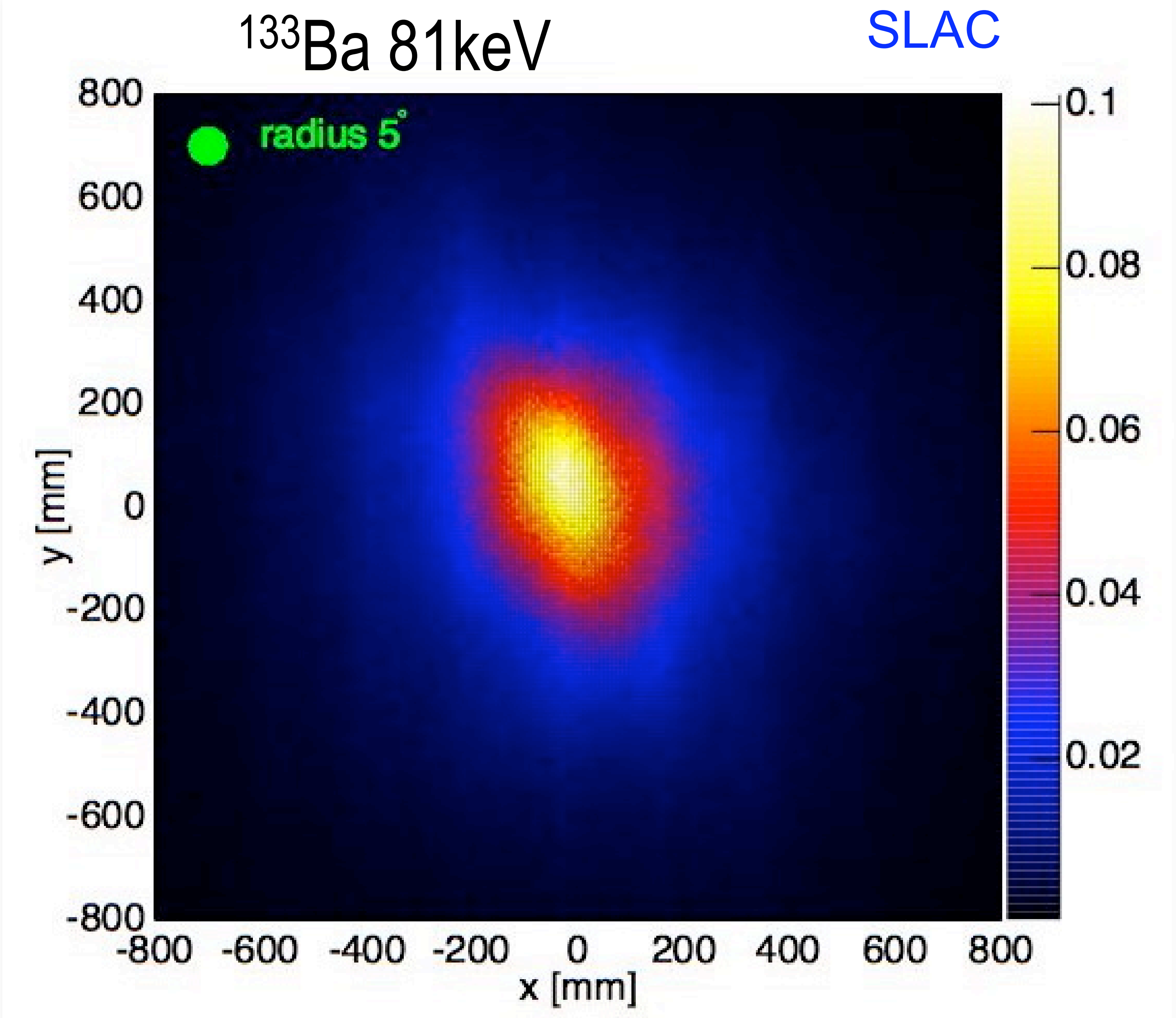

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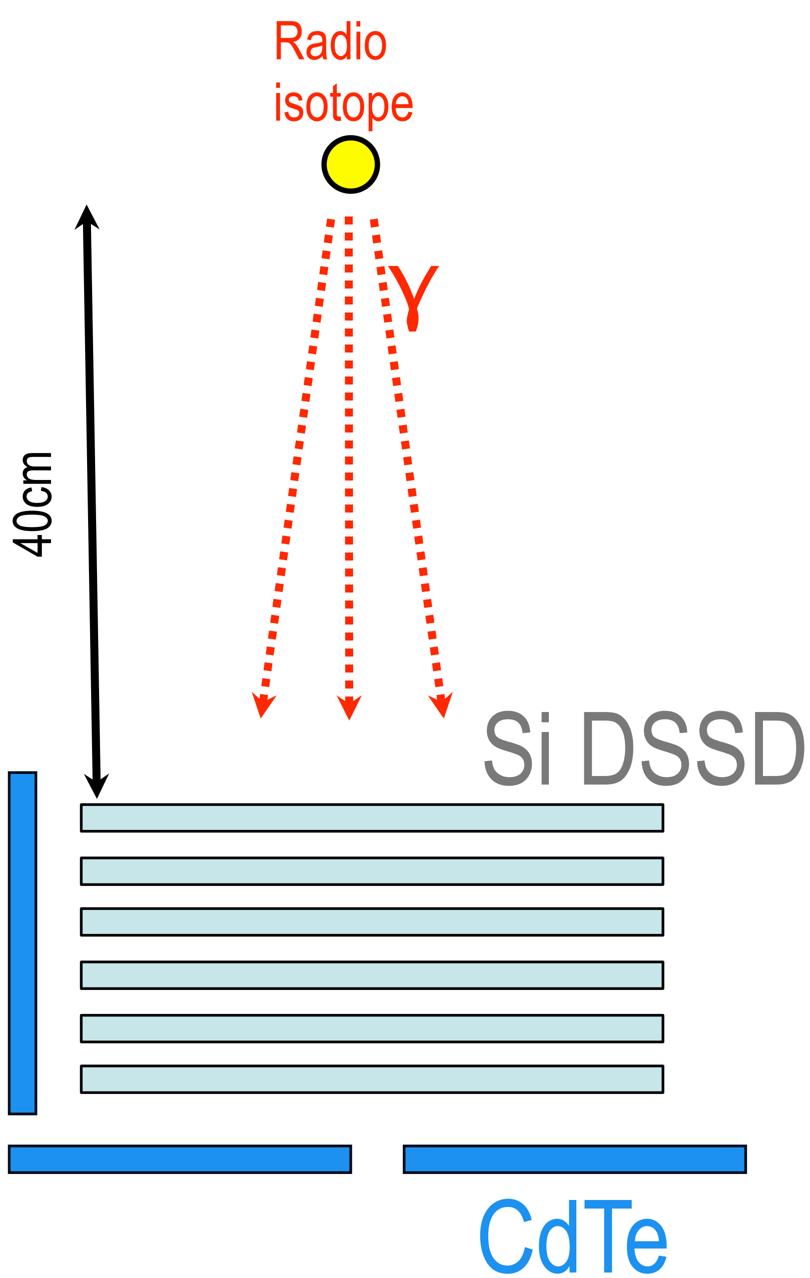

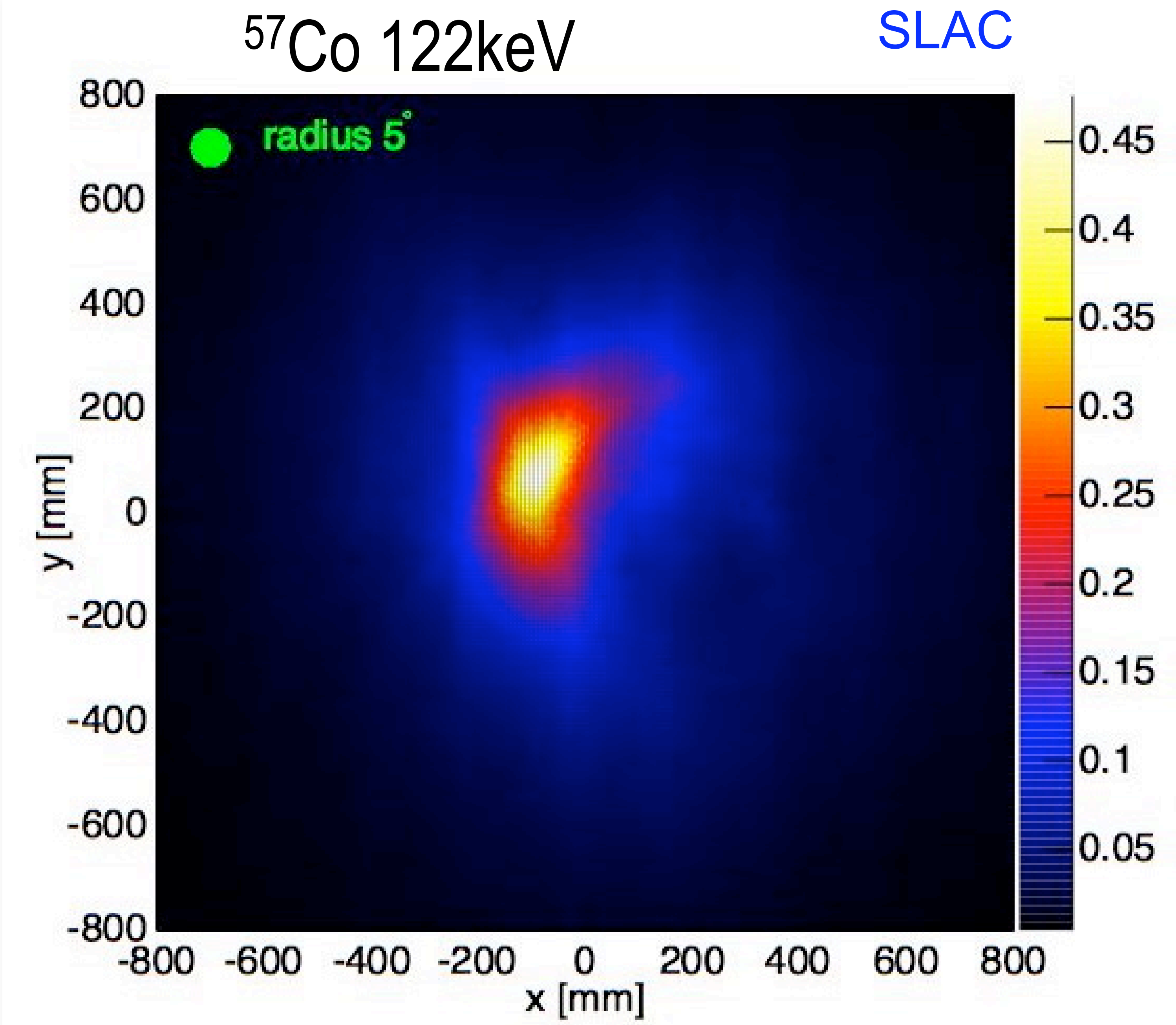

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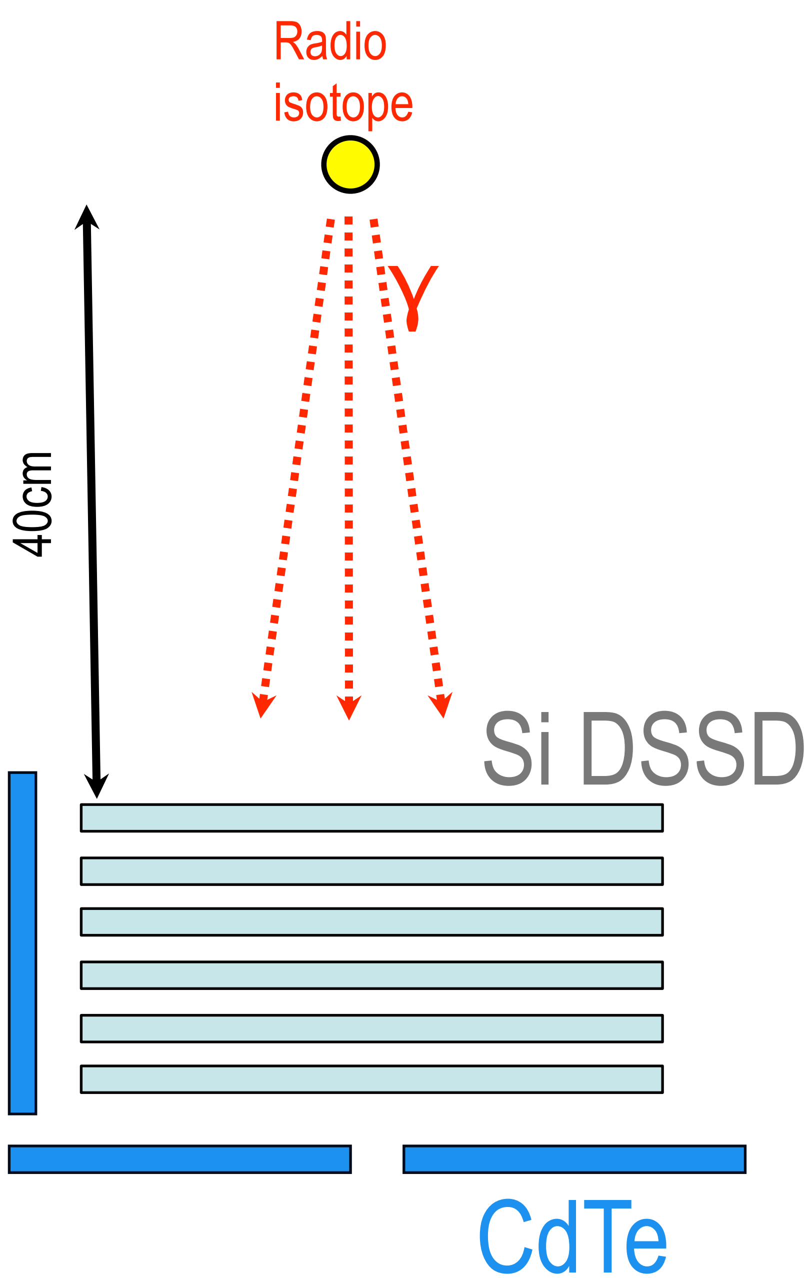

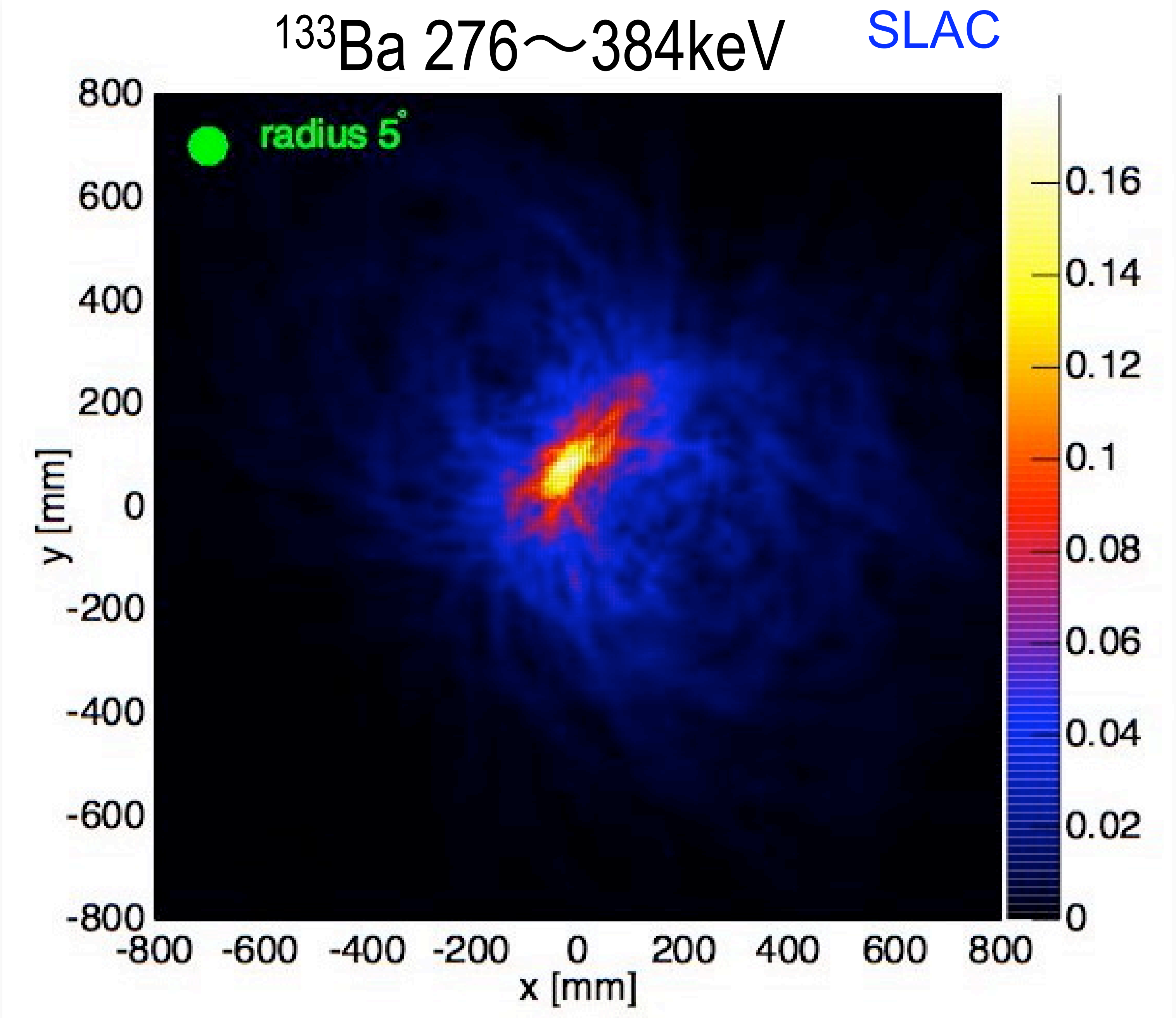

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Si/CdTe Compton Telescope

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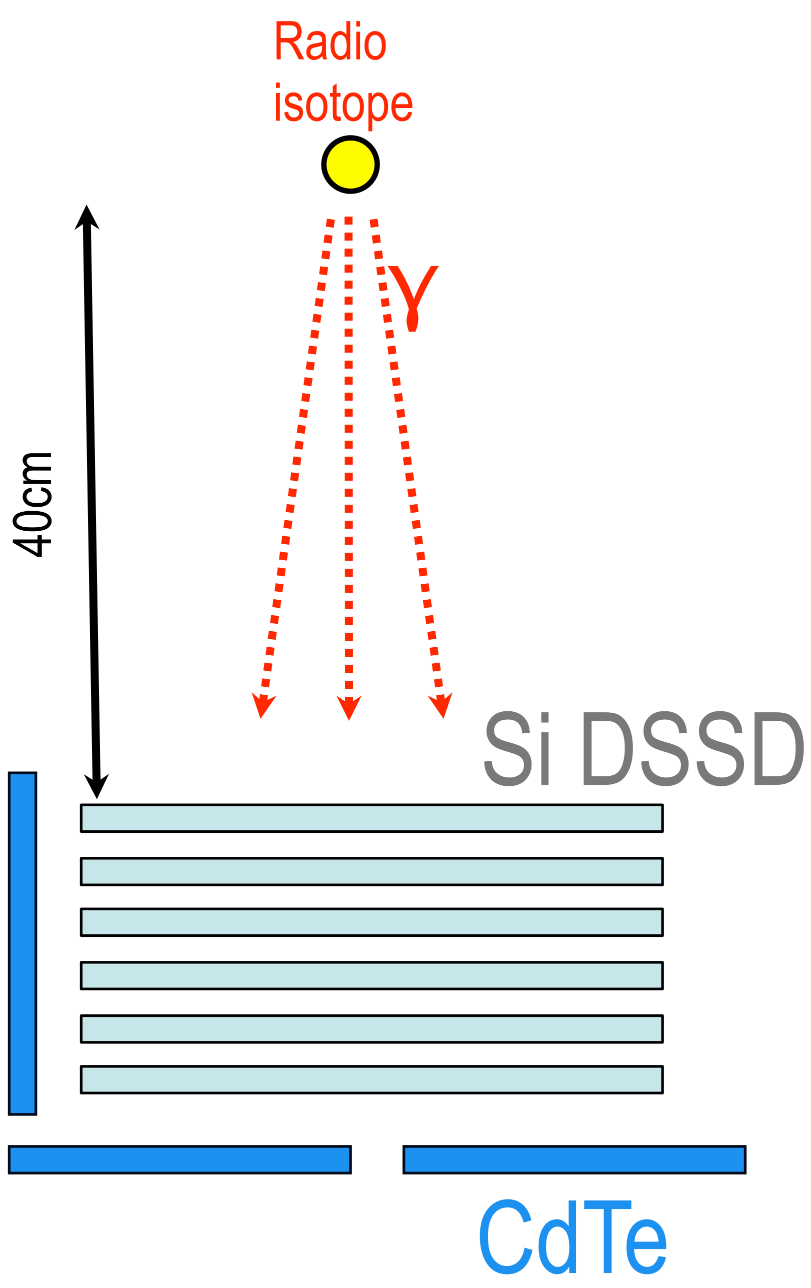

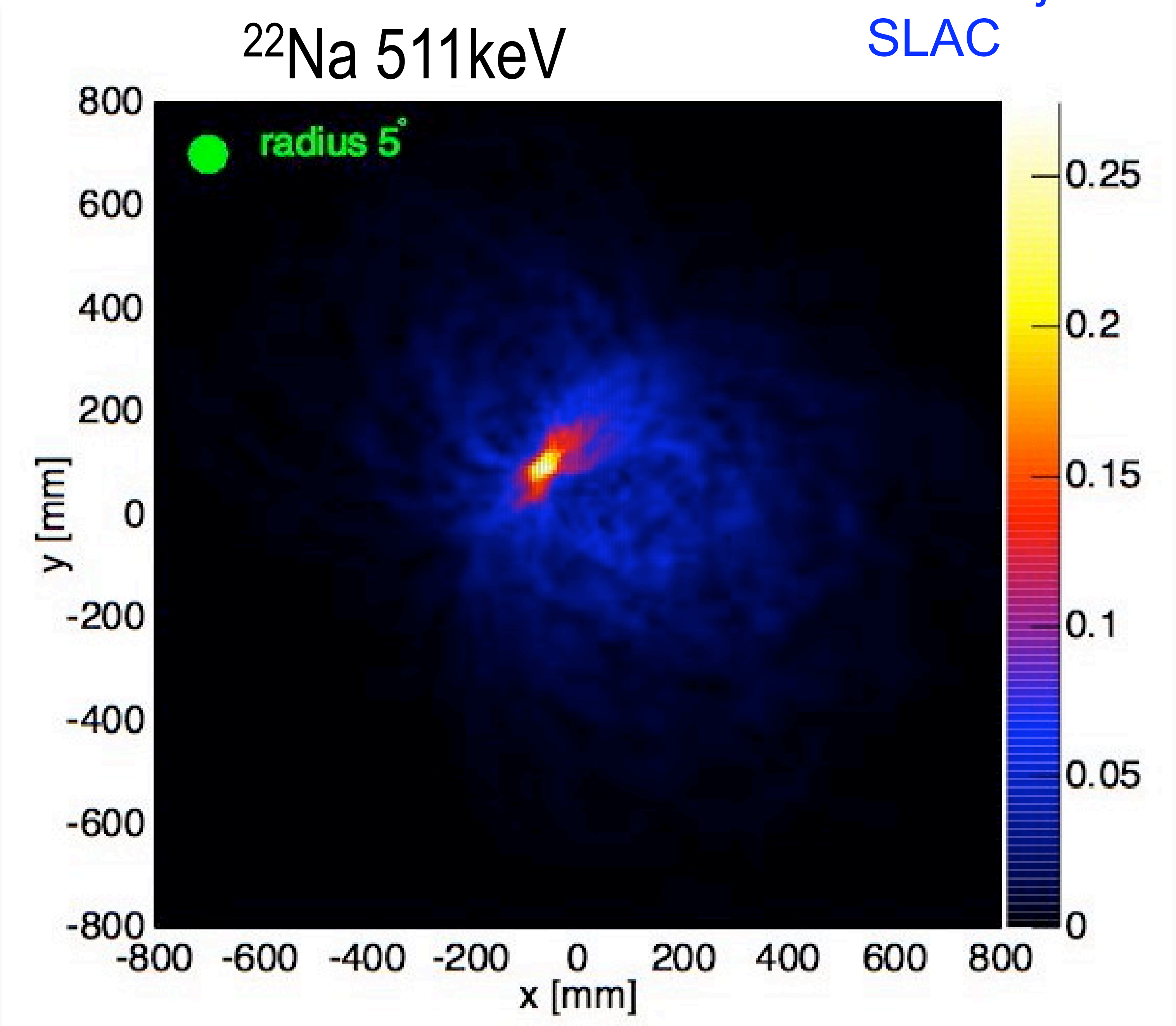

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Si/CdTe Compton Telescope

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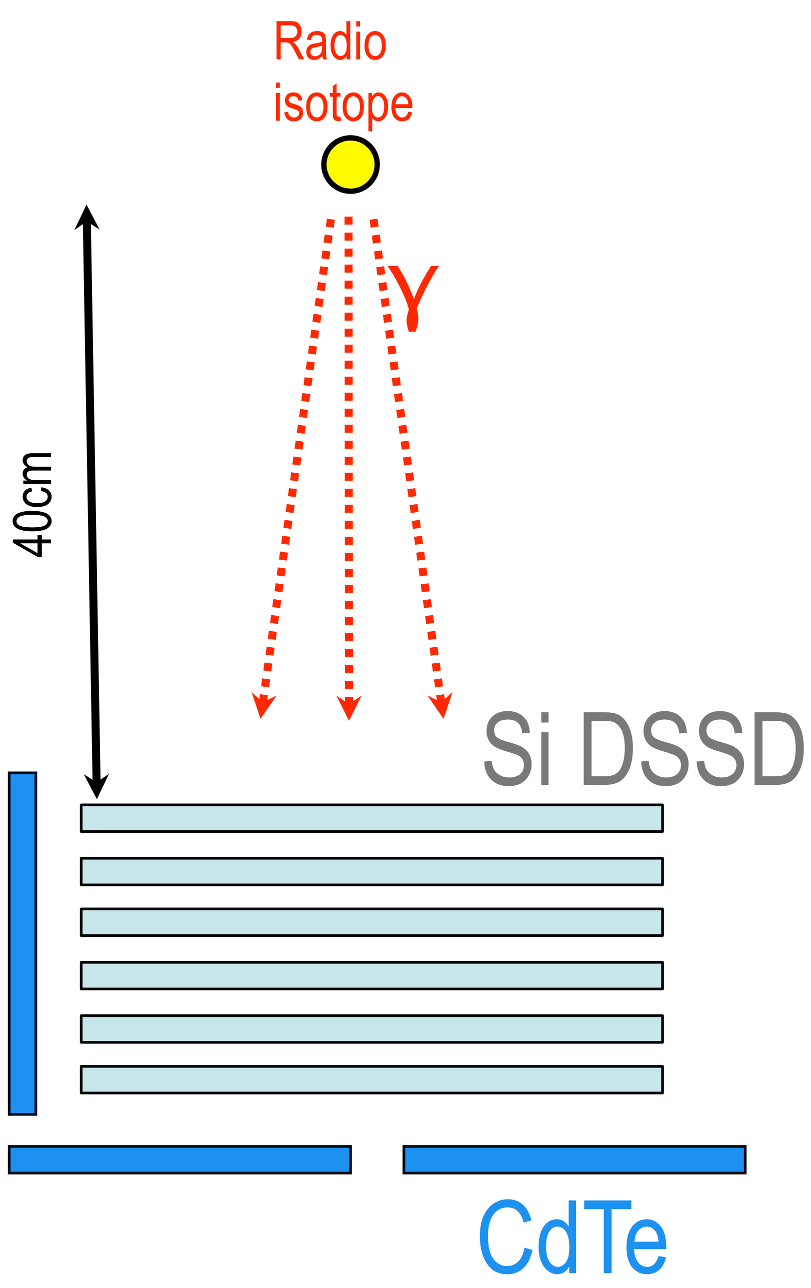
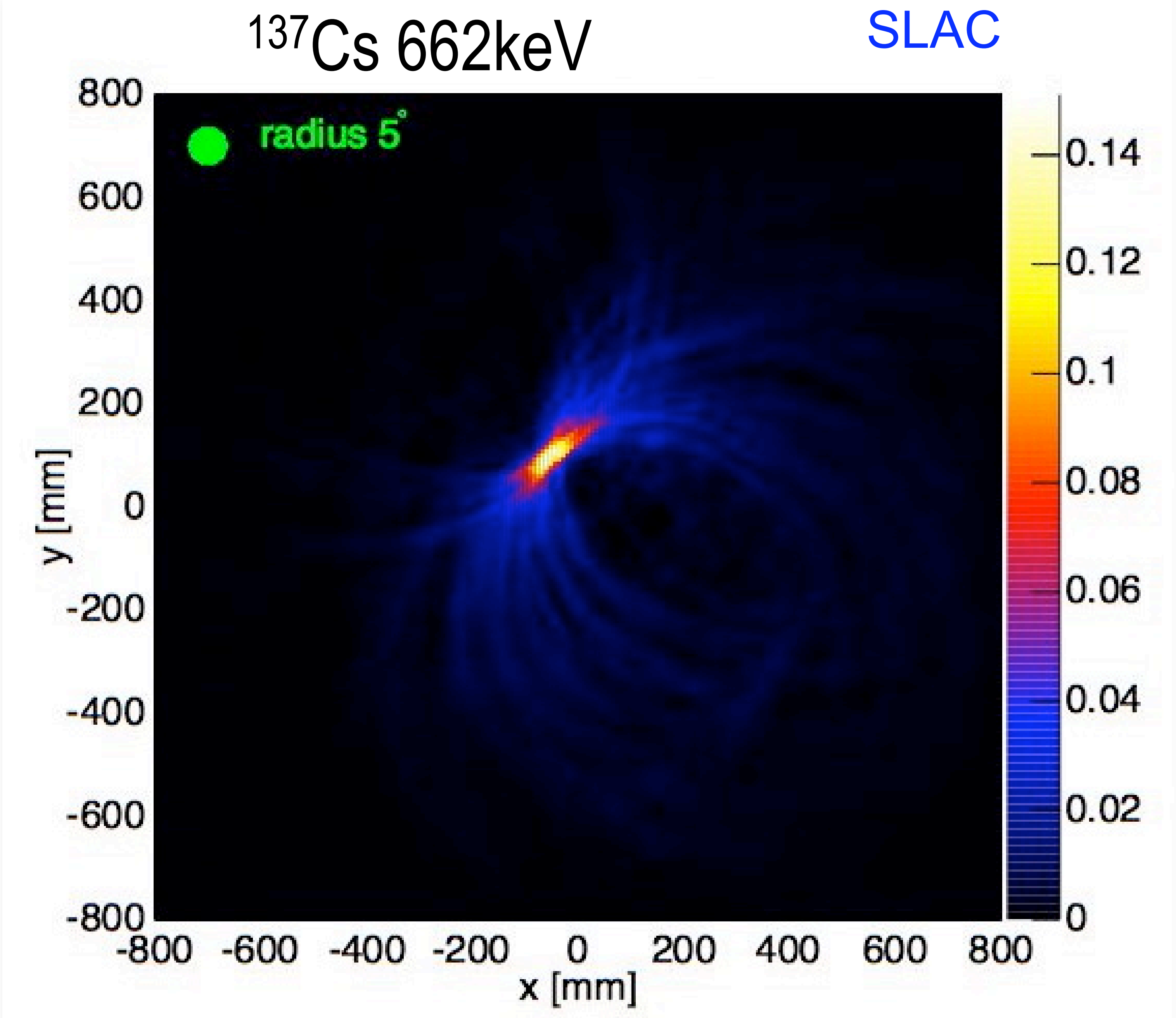
SLAC





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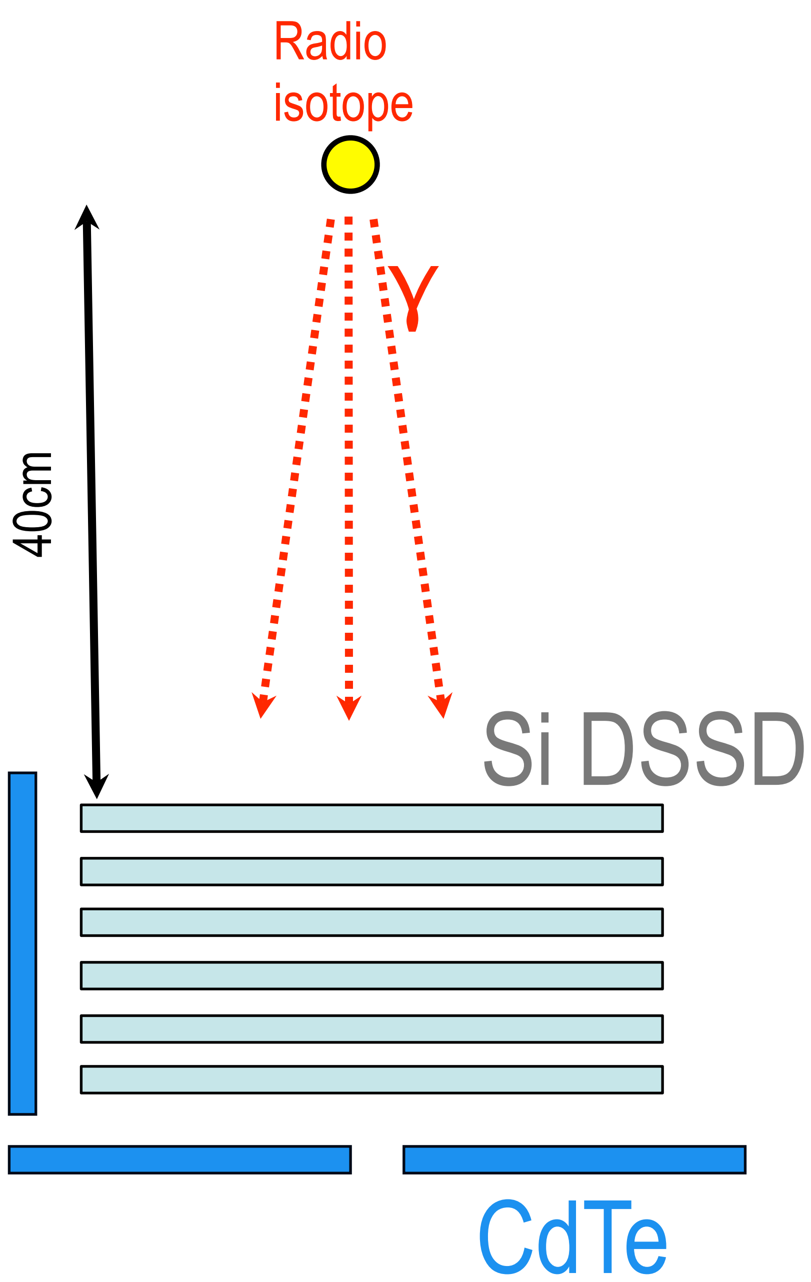
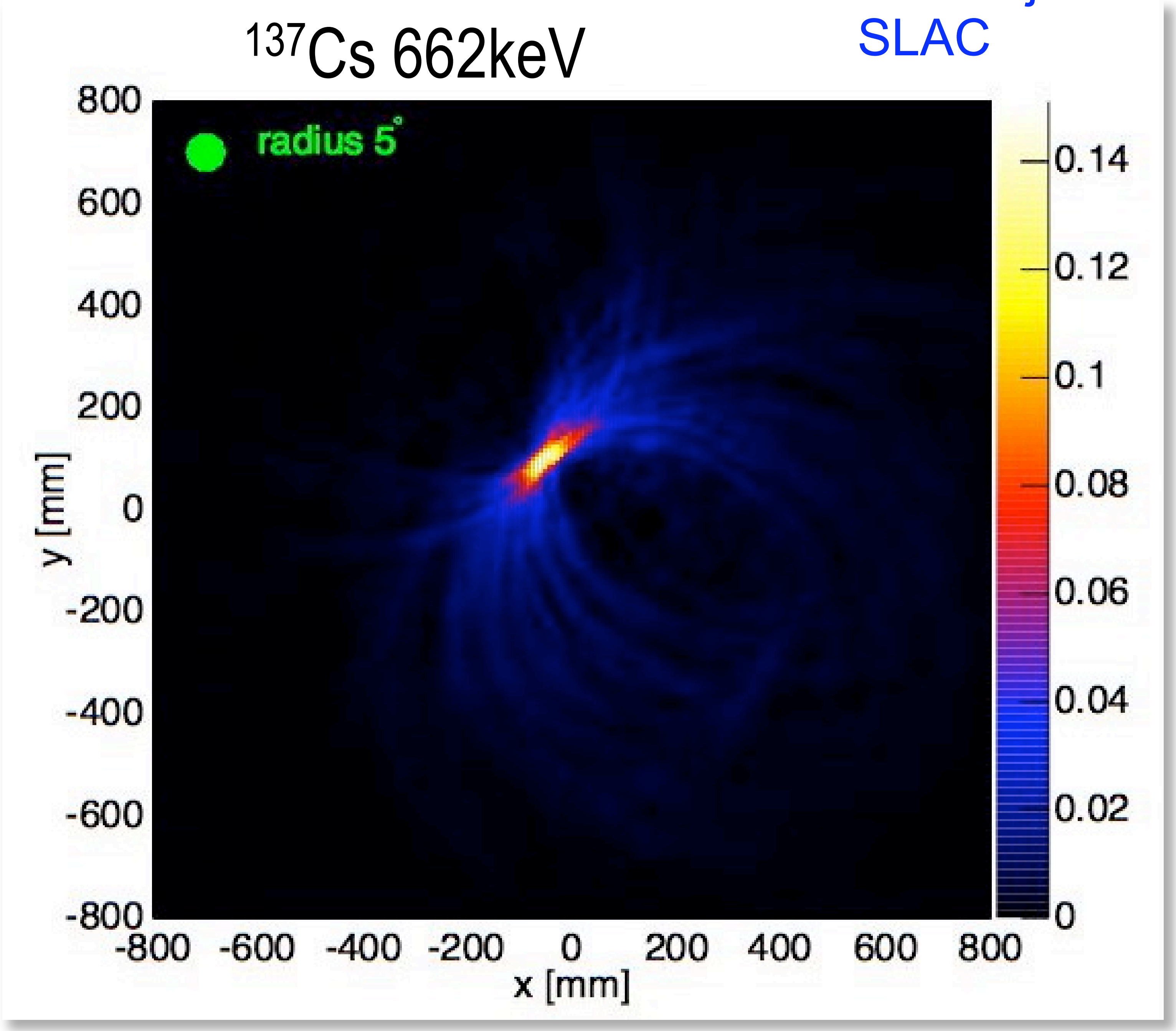




successful reconstruction in 81 — 662 keV

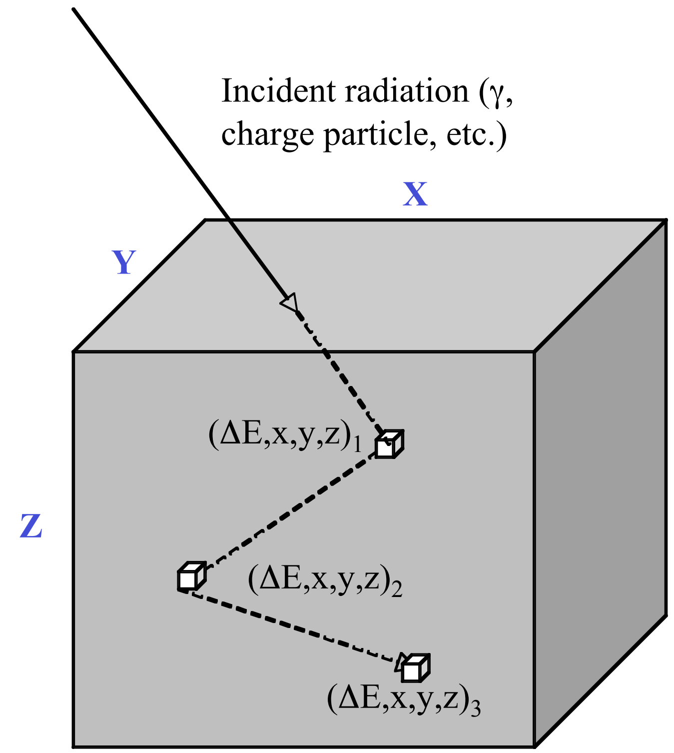
Watanabe et al. IEEE 2005

Improvements

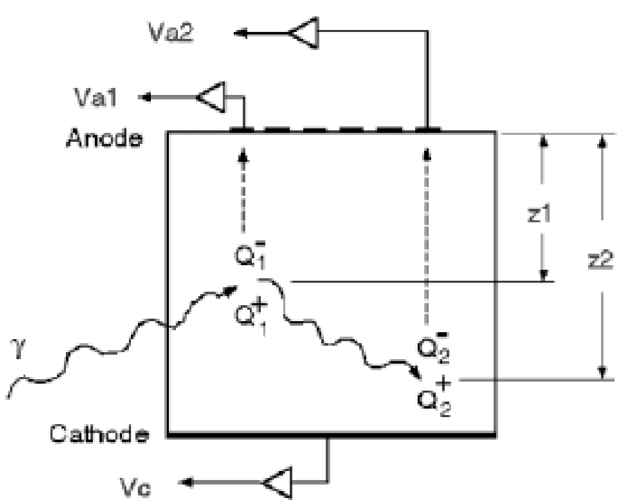
3D CdZnTe Detector

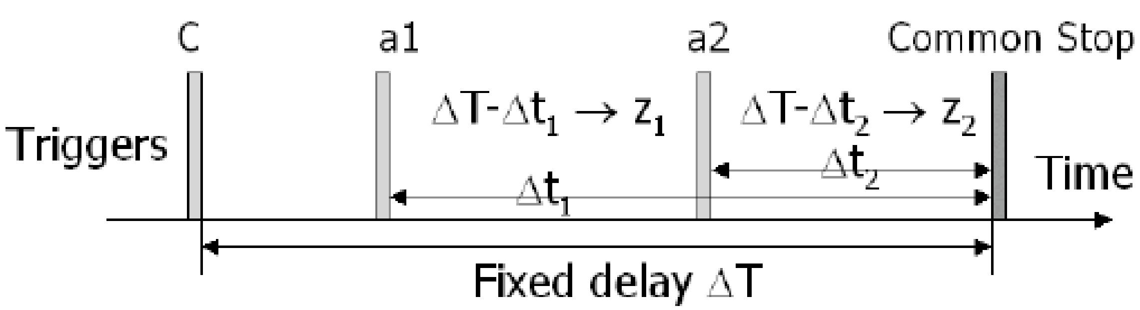
Z. He et al. Michigan U.

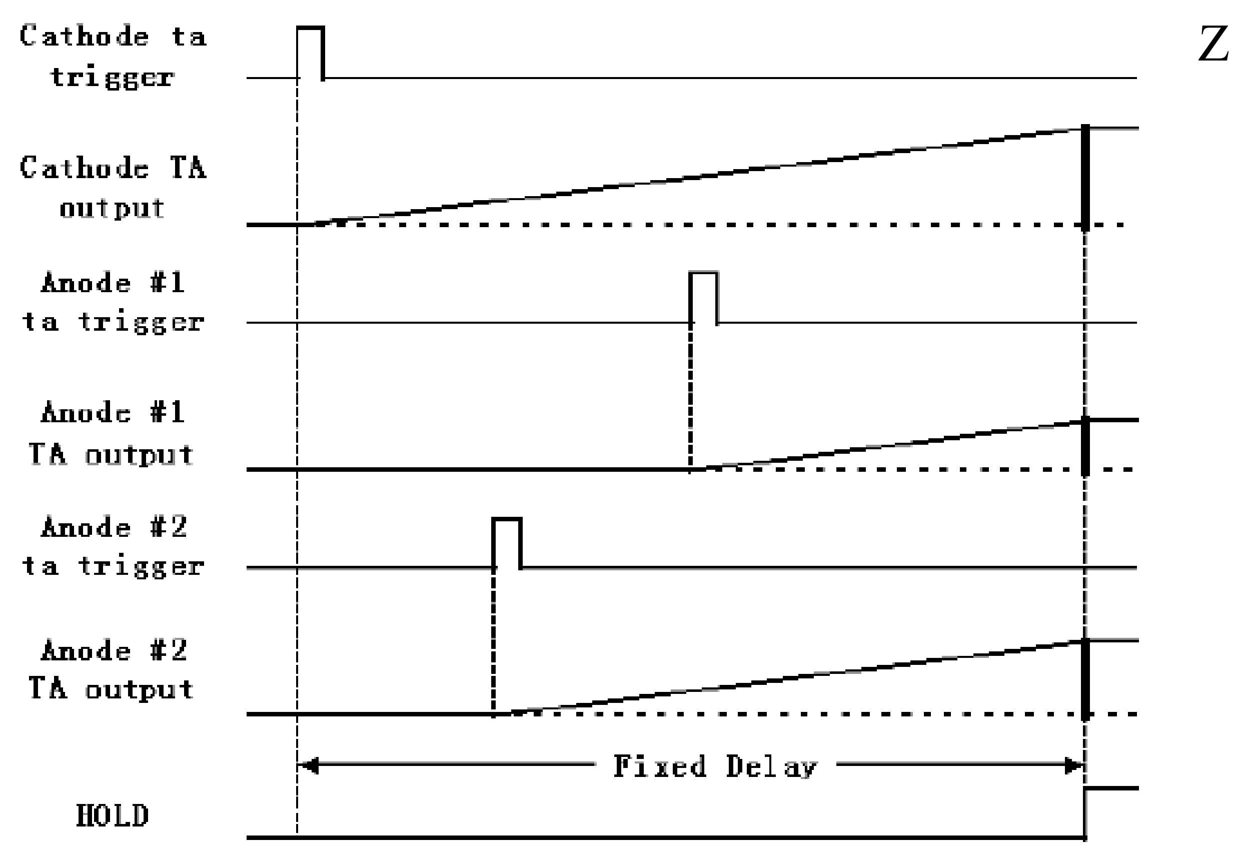
- Small Pixel Effect
- Cathode/Anode Ratio (Depth Info)
- Timing Measurement
  (Multiple Interaction/ Depth Info)



Position/Energy



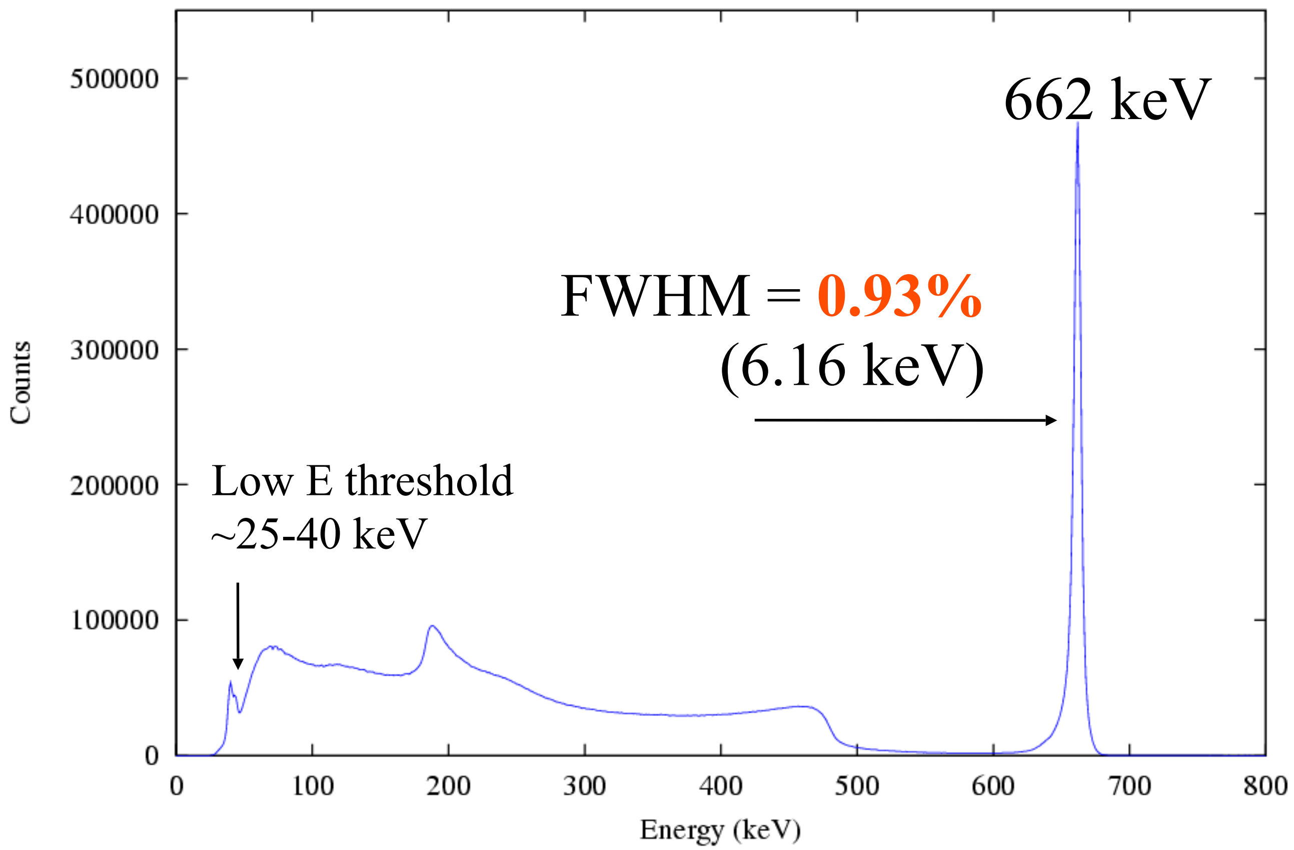




3D CdZnTe Detector

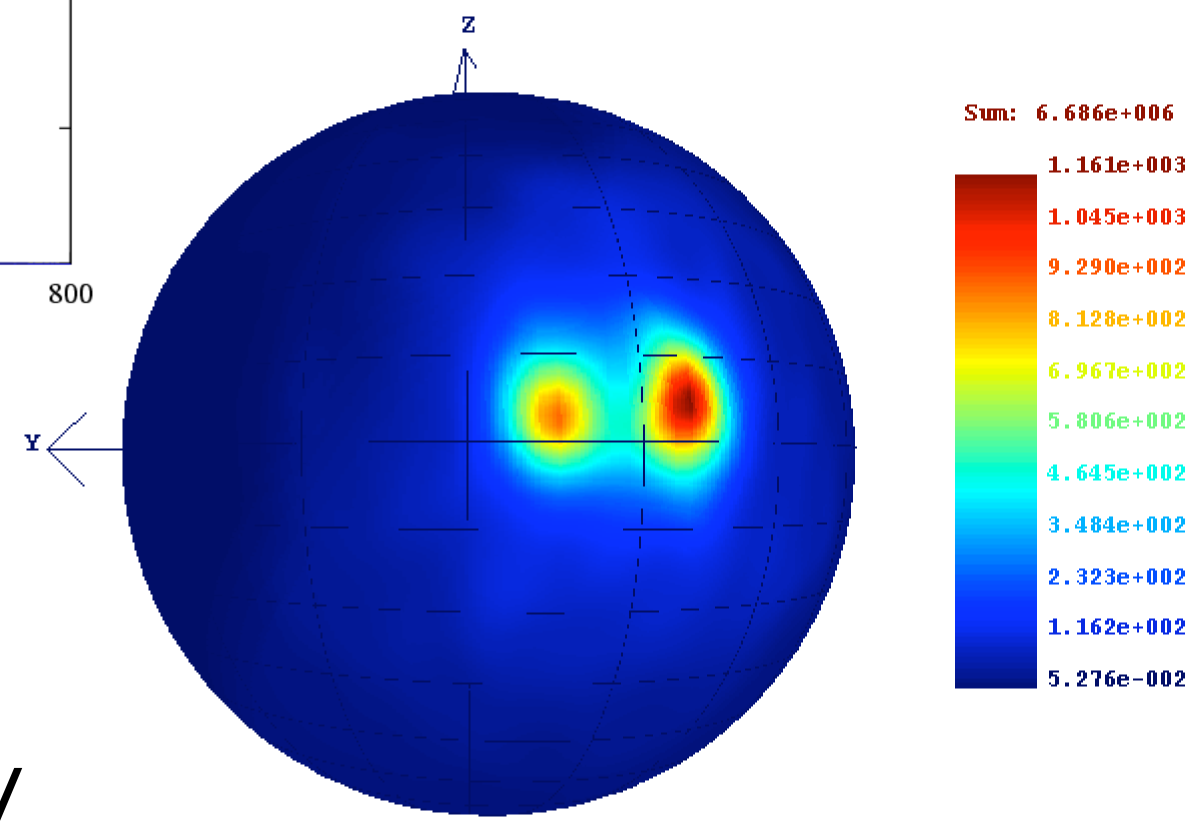
Spectrum of **all** 1, 2 and 3-pixel events

(Detector #2.3; 1.5 × 1.5 × 1.0 cm^3; V_C = -1400 V; V_G = -45 V)



Material non-uniformity can be correcting by using Cathode/Anode pulse height ratio

Compton Image Reconstruction

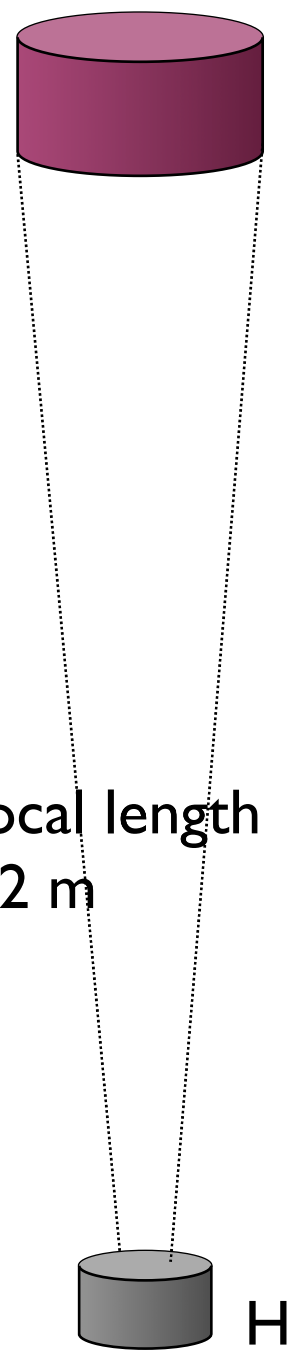


Angular resolution
10-14 deg. for 662 keV

Angular resolution: **14.4°** in polar angle and **10.1°** in azimuthal direction

CdTe/CZT pixels for future missions

NeXT (Japan), NuStar/Con-X (US), Simbol X (Eu)



Super Mirror (0.5-80 keV)

30” HPD

focal length
12 m

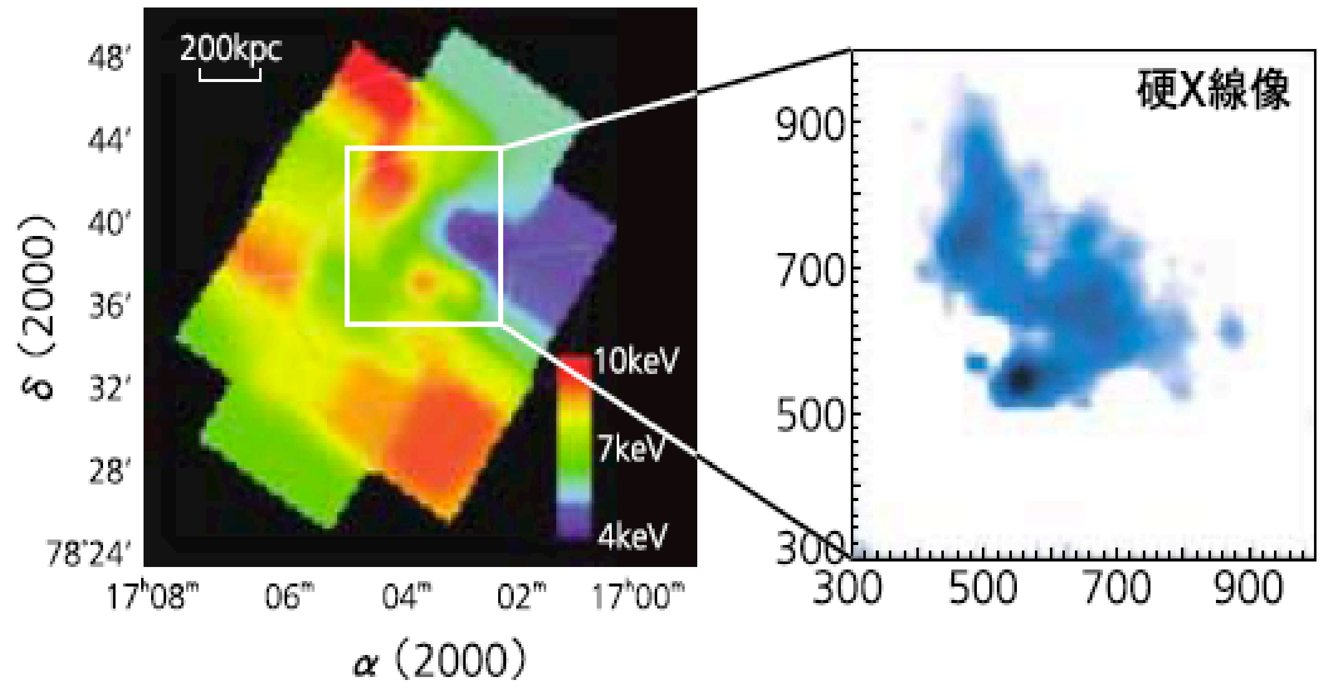
Hard X-ray
Imager

0.25 arc min = 0.8 mm

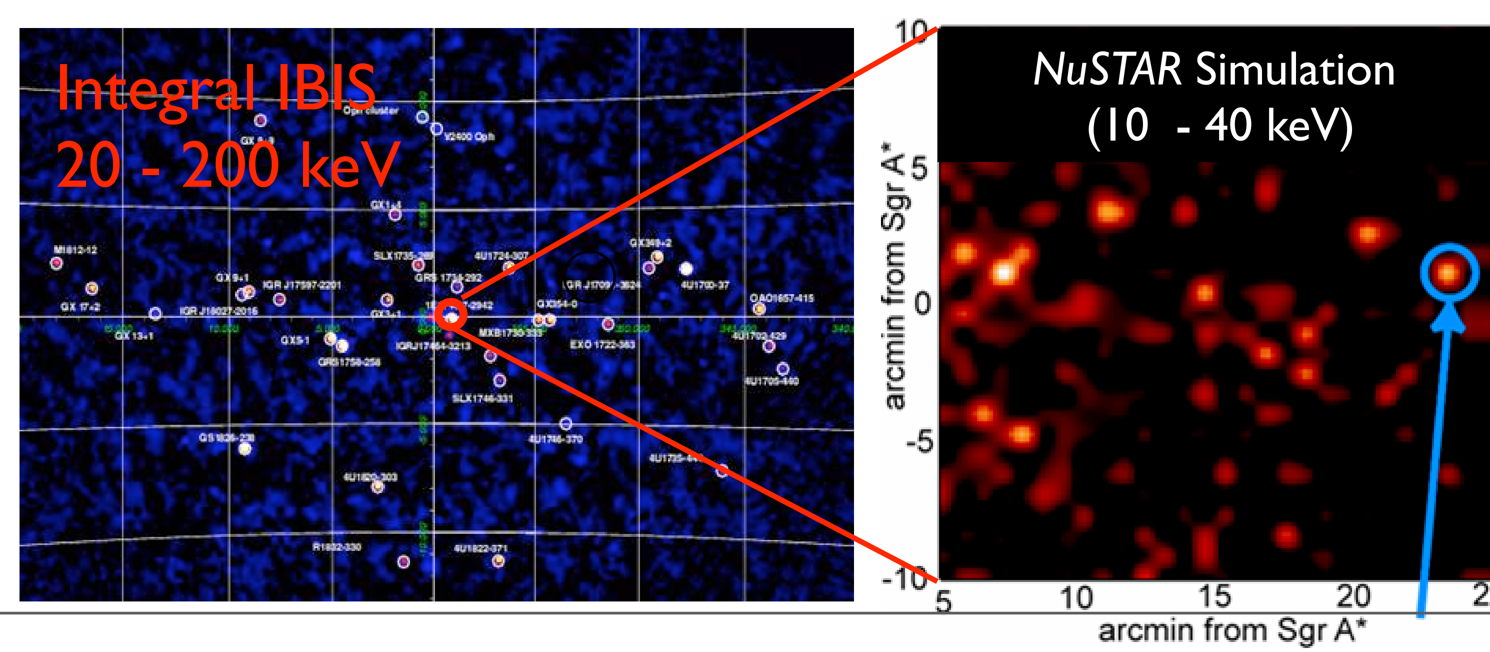
NeXT simulation : Merging Clusters

Soft X-rays
sensitive to the heating

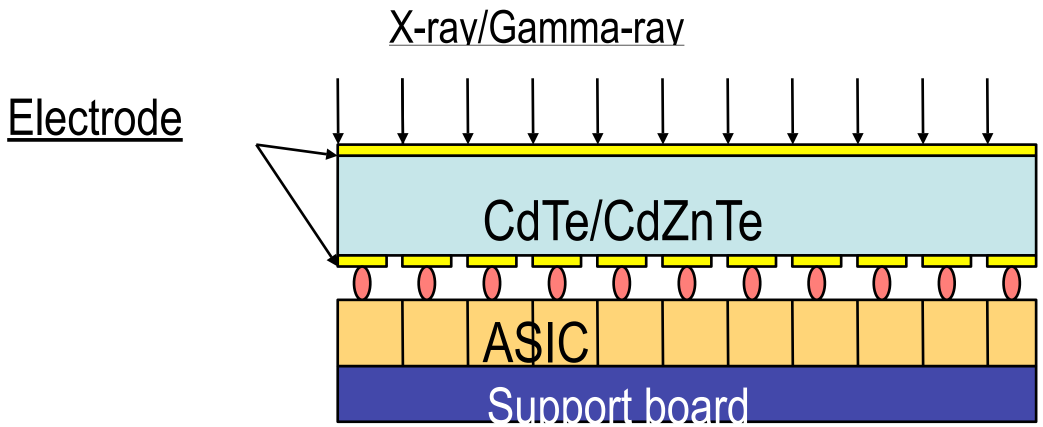
Hard X-rays (E>10 keV)
sensitive to non-thermal emission



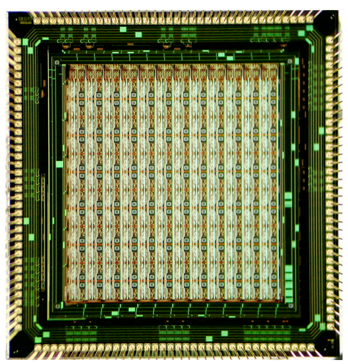
NuStar simulation : Galactic Center Regiom

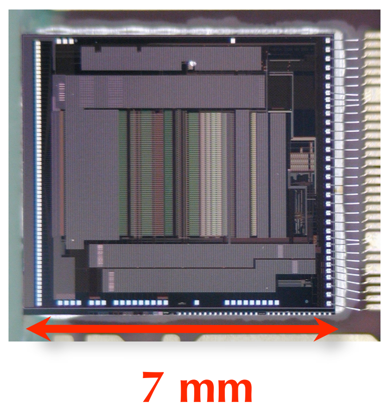


Key tech. for pixels and array



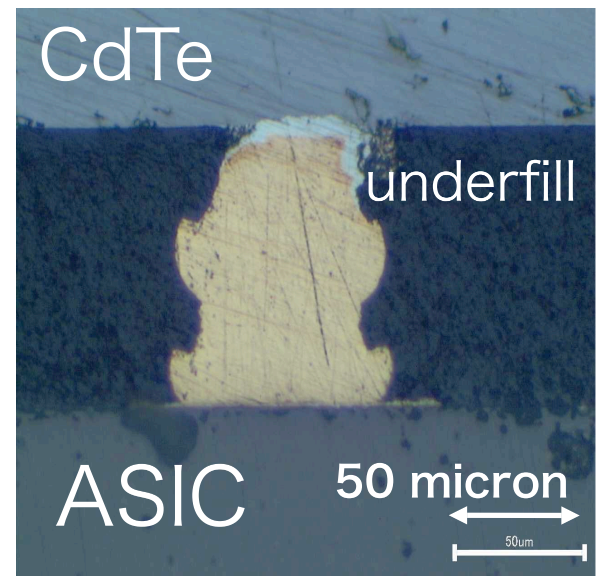
ASICs

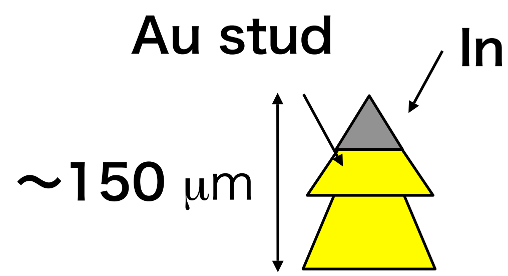




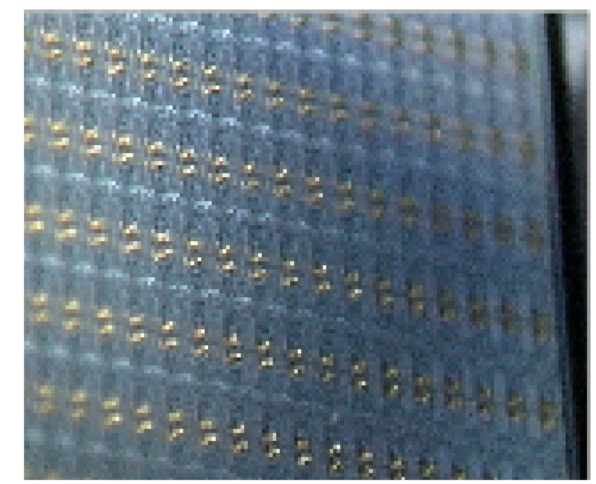
Relatively Large Capacitance
(1pF - 10 pF)
Self Trigger Capability (discri/pixel)
Goal : ENC ~50 e- RMS at 0pF
(ΔE < 1 keV at 60 keV)
100-200 microW/pixel

Bump Bonding





Example:
In/Au Stud

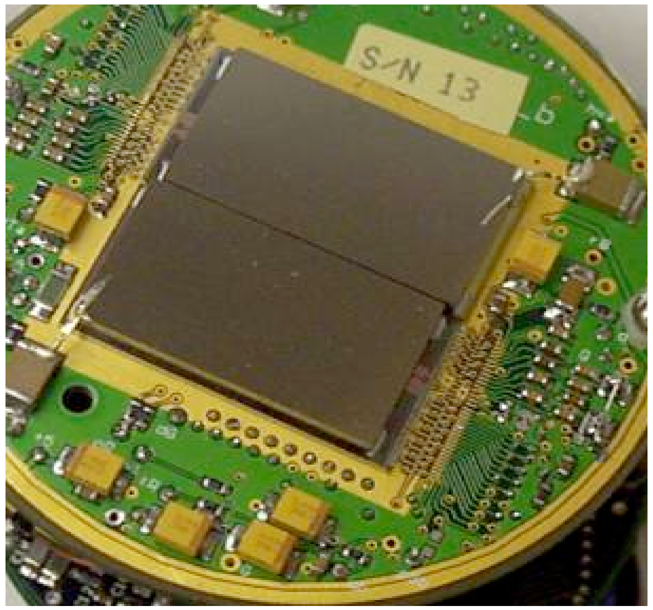


US 6,992, 292 B2
(Kuroda and Takahashi)

Similar to the efforts for Si pixels but CdTe/CZT need special care for the process Stress/Temperature

Toward Fine Pitch CdTe/CdZnTe pixels with spectroscopic capabilities (1)

F.A. Harrison et al. (Caltech)

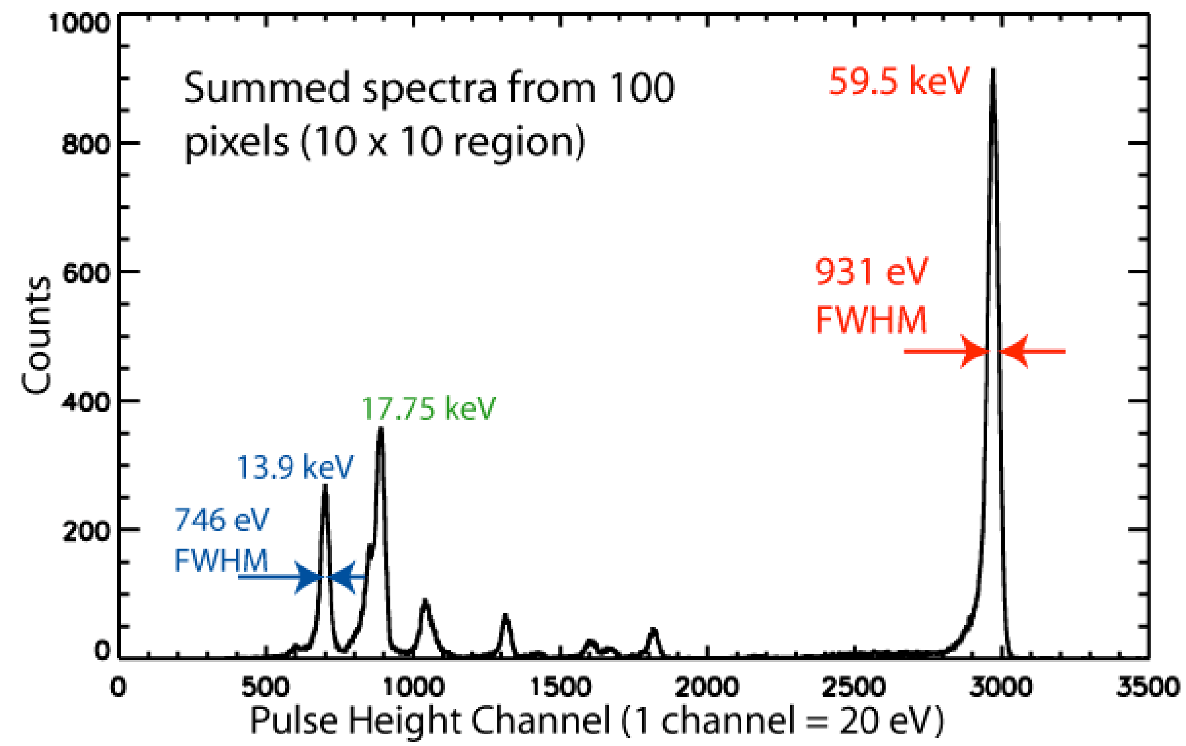


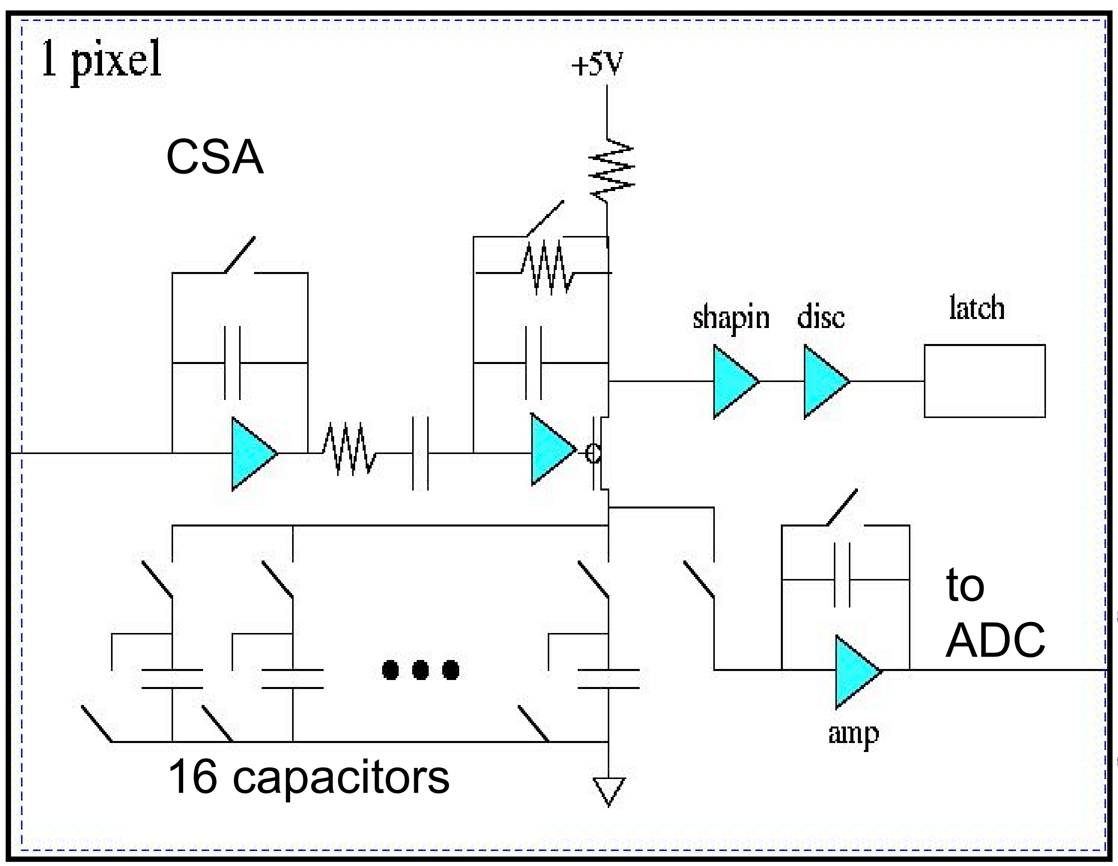
Two hybrid CdZnTe/ASIC side by side

500 micron pixels
1056 ch

Spectrum taken with CdZnTe

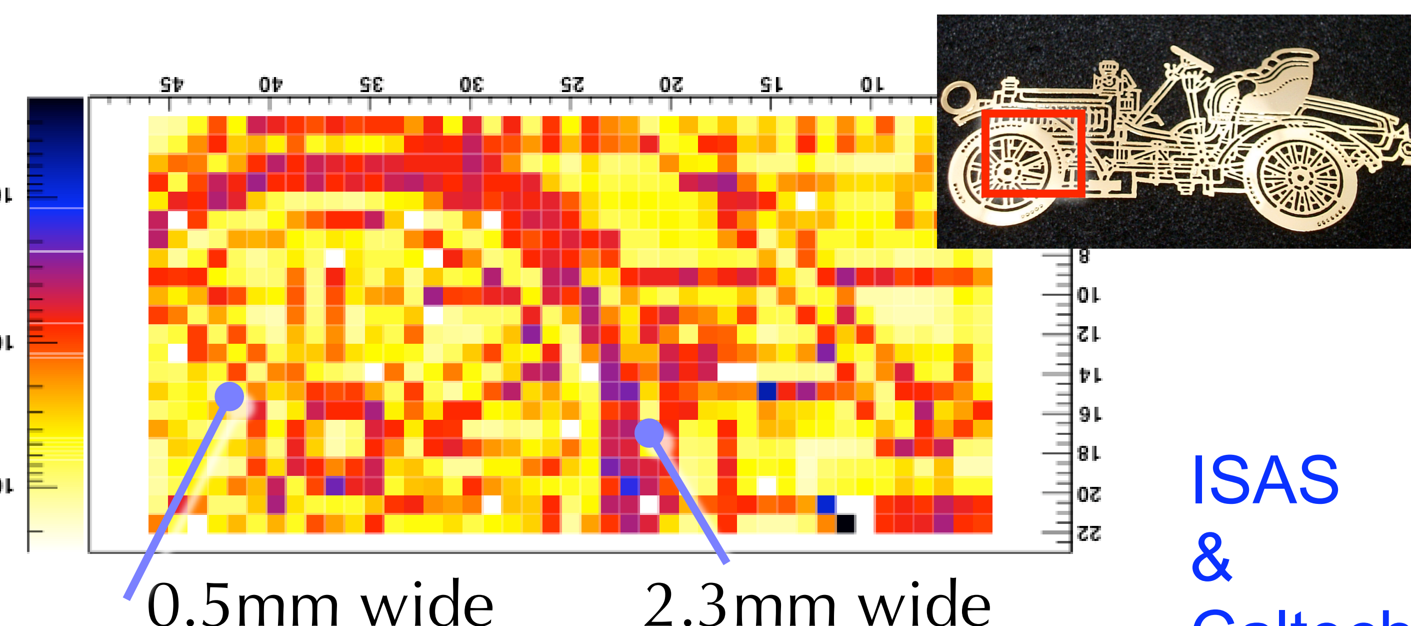
Caltech





F. A. Harrison, et al. SPIE 2003

Image taken with CdTe (shows better uniformity)



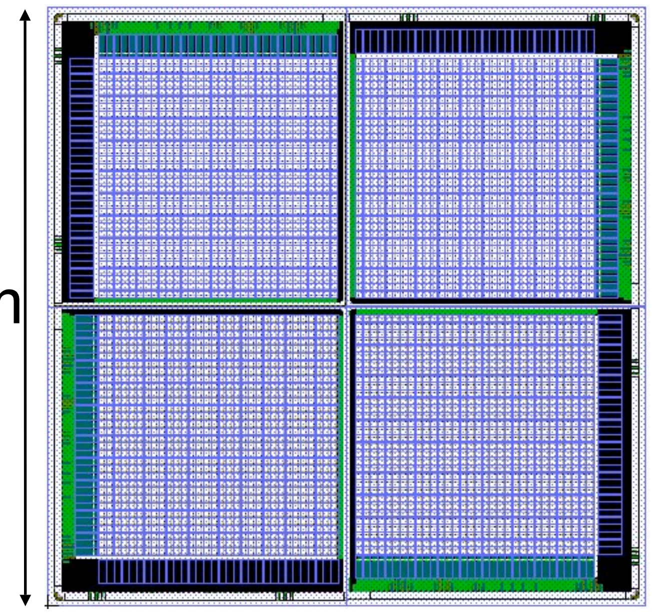
ISAS & Caltech

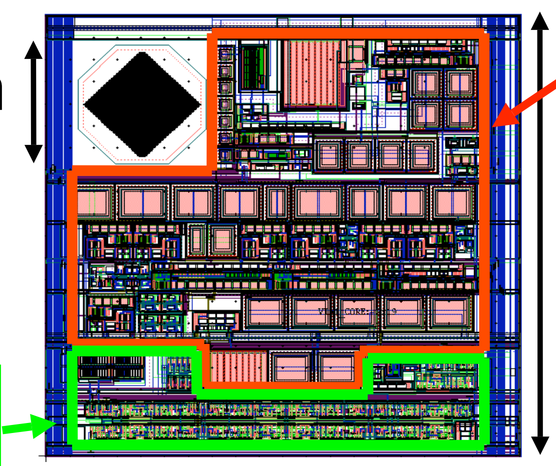
Toward Fine Pitch CdTe/CdZnTe pixels
with spectroscopic capabilities (2)

H. Ikeda et al. (ISAS/JAXA)

64 x 64 pixel analog VLSI "H02"

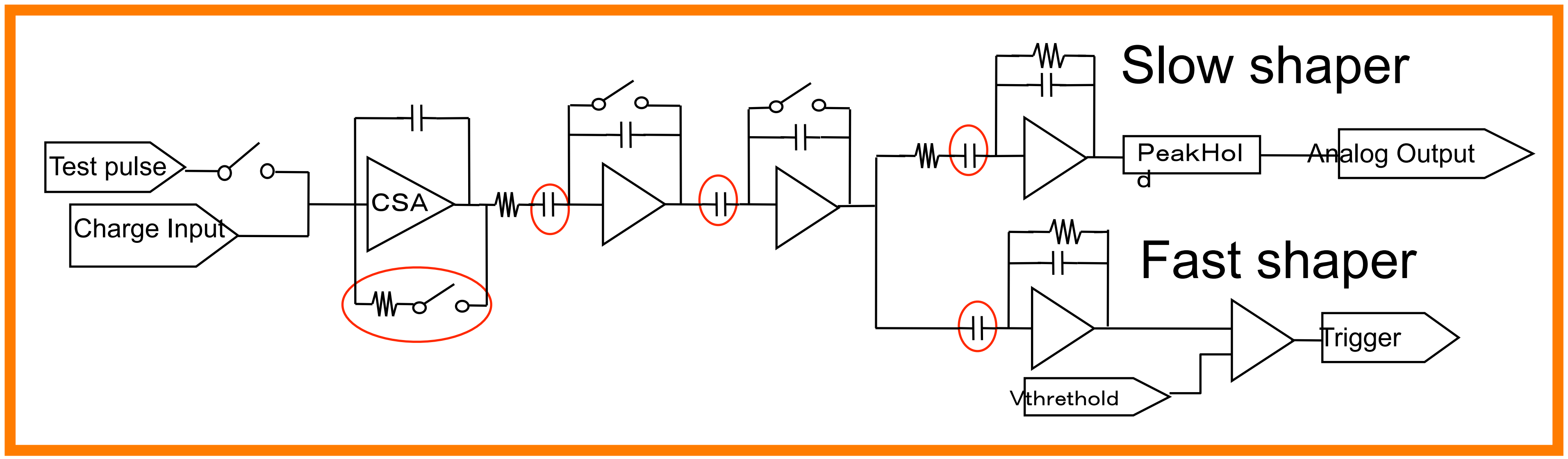
Process : TSMC 0.25μm CMOS
Pixel size : 200 μm





a pixel layout

Schematic diagram



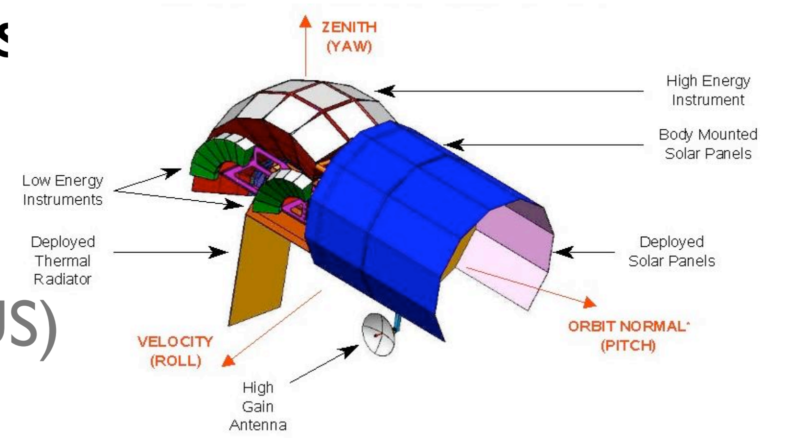
To make an ASIC with this complex circuit is not an easy task.

SPICE tells
Noise (RMS)
55 + 34 e- / pF

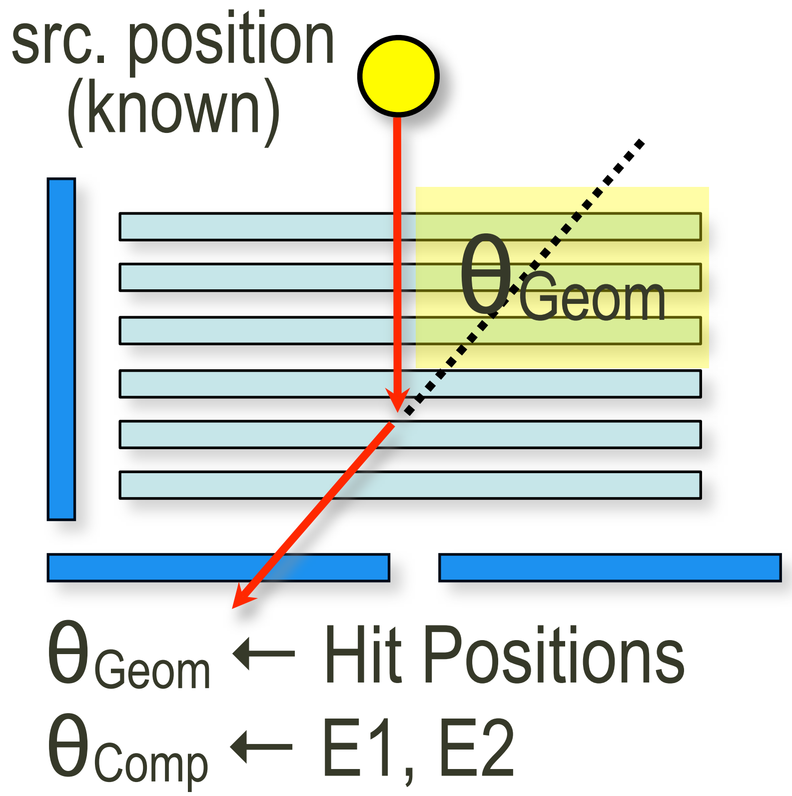
Summary

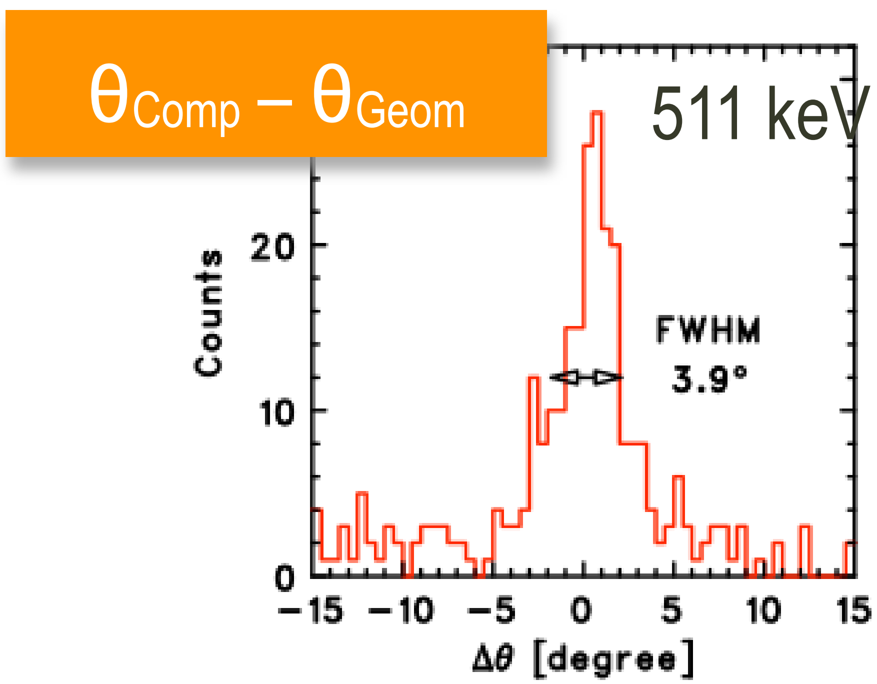
- CdTe/CdZnTe : attractive material for gamma-ray imaging
  - Now widely available in the market
    - (after 10 years of efforts in industries)
  - Big Market in Space (INTEGRAL/Swift/NeXT/Simbol-X/Con-X...)
- Possible solution for Charge Trapping : Thin CdTe diode and Single Polarity Charge Sensing
- Requirements range from "m^2 large array" with cm resolution to "cm^2 pixel detector" with sevral 10 micron resolution.
- Photo-counting chip with the pixel size of 50 micron x 50 micron already exits (Medipix2). Efforts to make ASICs for spectroscopy are on-going for CdTe/CdZnTe pixels.
- Photo-response uniformity becomes very important issue, when we plan to make array detectors with many elements
- Strong demands for lower prices of wafers
  →mass production

ex. EXITE Mission (US)
5.64 m^2 CdZnTe

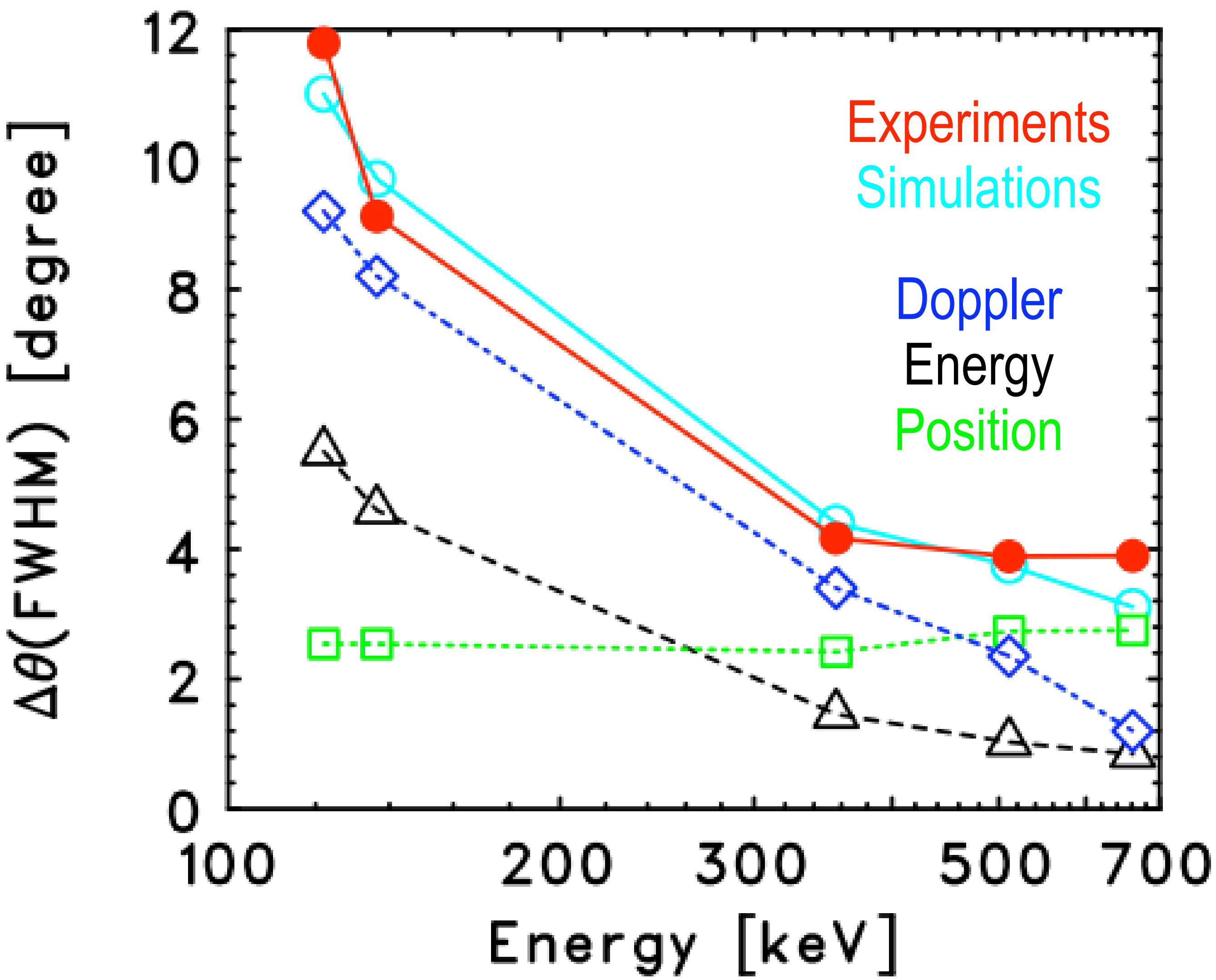


Angular Resolution





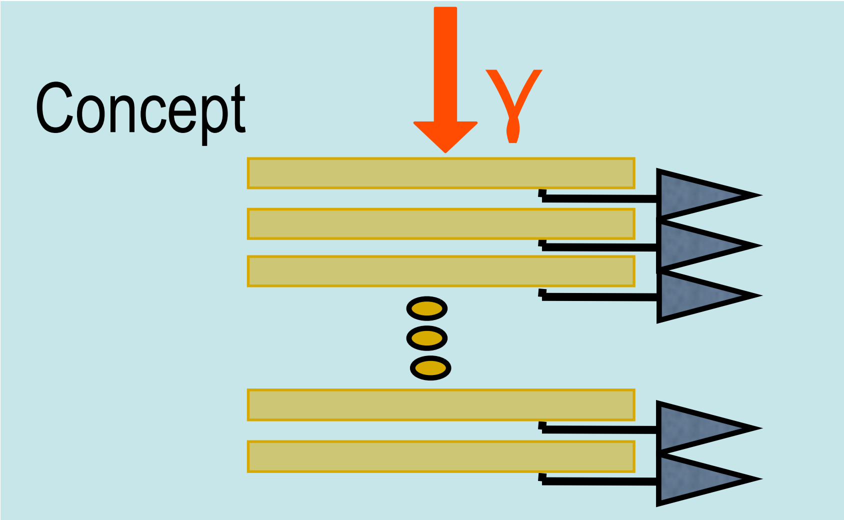
Si/CdTe Compton

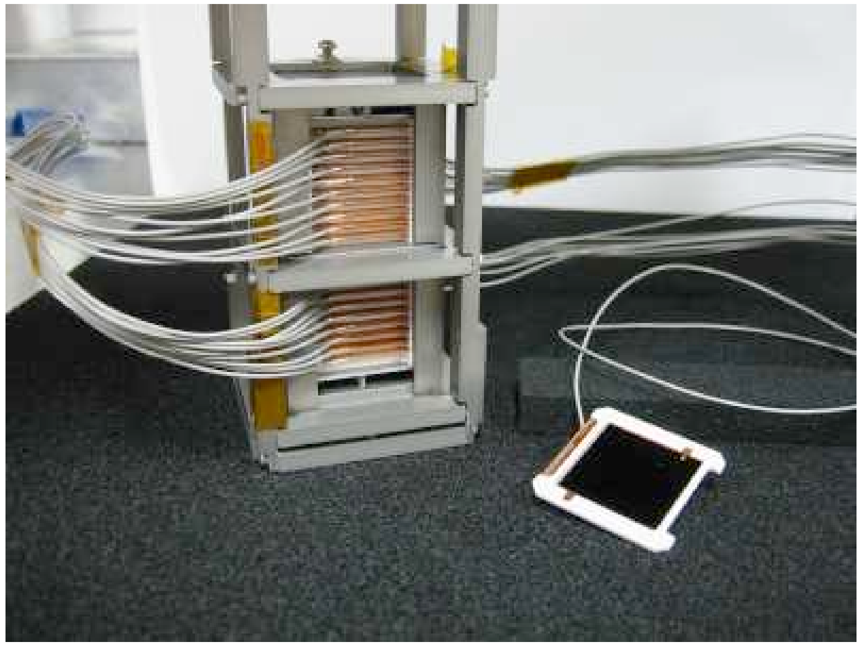


CdTe-only Compton
12 degree at 511 keV
(Doppler Limited)

Stacked Detector for E > 1 MeV

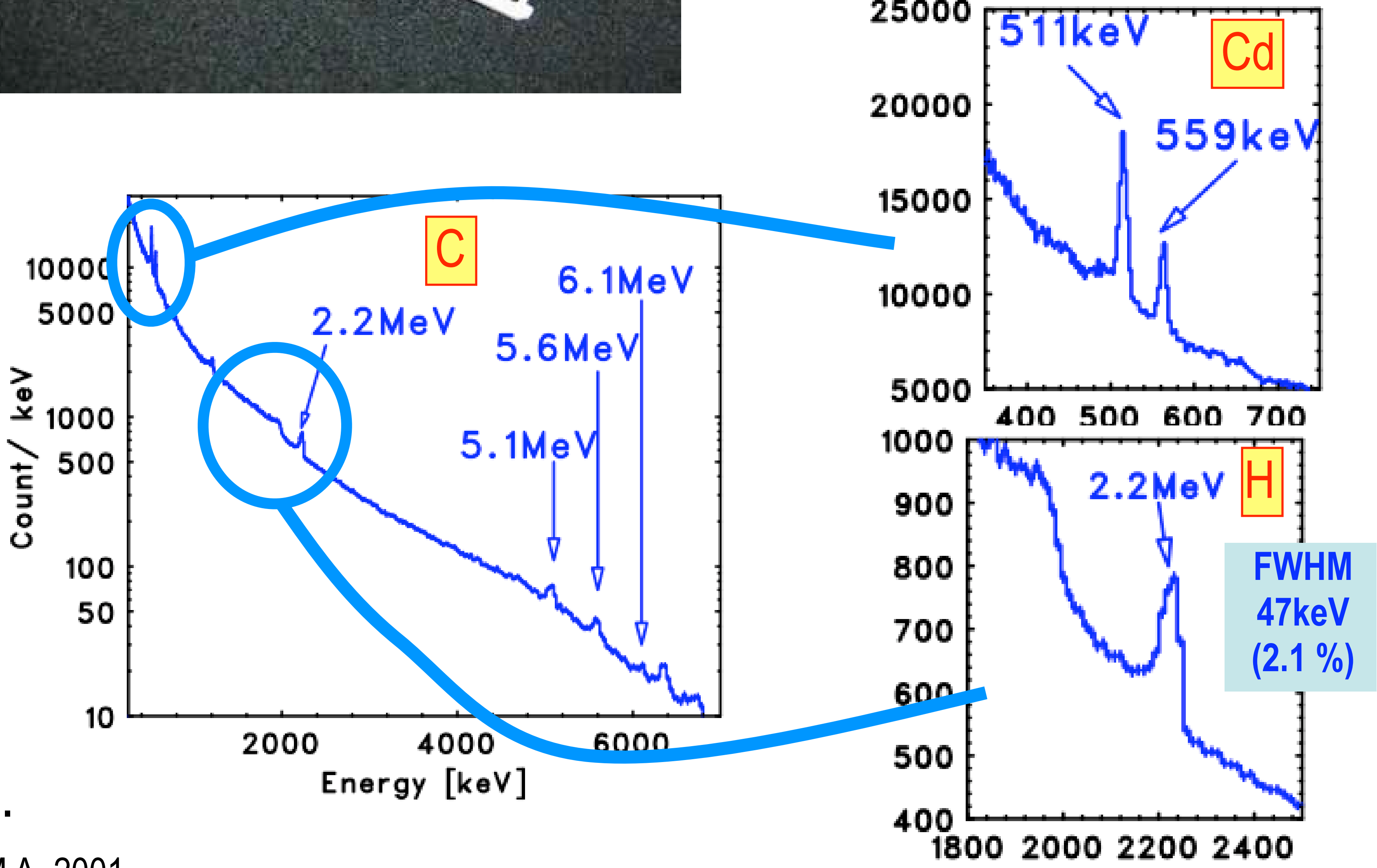
Stacked CdTe





2cm x 2cm:
Planar (no pixel)
40 layer = 20 mm

Approach:
Stack of thin CdTe detectors
1. to get high efficiency for high energy photons.
2. still keeping high energy resolution at low energy



Only possible,
if the detector is fully active.

Takahashi et al. NIM A436,2000, Watanabe et al. NIM A, 2001