Cadmium Zinc Telluride (CZT) Detectors

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(Presenter: Walter Reviol)

Oak Ridge, March 2003

CZT

WHY: **Small portable/mateable device primarily for "fast-beam" spectrosc.**

1) **Effective Z ~ 50**

PE(dominates < 250 keV) ~ Z^5 ==> Compton (dominates > 300 keV) ~ ρ_e

Need for tracking much less

2) **1.5 eV band gap, no need to cool.**

PROBLEM: **Hole trapping and mobility.**

1) Work only with e- (induced) signals => position dependent signals

2) Use small anodes to induce most of signal very close to anode itself,

"small anode effect" => pseudo Frisch grid.

3) Nevertheless still need DoI corrections from:

a) Cathode/Anode amplitudes, b) rise-time of steering strip, or c) An/Cat amplitudes.

RESULTS:

Single Pixels - with orthogonal coincidence - get ~ 1% at 662 keV.

Dominated by electronics! If one could get the entire detector volume to be this good, VA's would not be good enough. An external FET would be needed to get much better. HOWEVER, this is **not** the issue as …..

Beware of efficiency and data selection! Coin, C/A, and T_r gates greatly reduce eff !

True strip or orthogonal coplanar detectors get 2-3% at 662!

BEST PROSPECT: (Collaborating with space science group, NASA+DOE)

TECHNOLOGY IMPROVEMENTS: Belly **and** coplanar/collinear focusing electrodes.

EXIST plans to use $8m^2$ of CdZnTe - **Launch date 2010**

Problem from the "get-go" from Basic Materials Physics

Two component semiconductors (such as 2-6) have an (excess) free energy associated with lattice (atom placement) errors. This excess free energy is sufficiently small that in any reversible (finite time) crystal growing process imperfections are created. The excess free energy can be increased (promoting better Xtal growth) by enhancing the influence of the difference in atom sizes by growing the crystal at high pressure or by adding a small fraction of a smaller atom (from one of the groups) so that the size difference is enhanced.

High Pressure Bridgman (HPB) crystal growth produces the crystals with the lowest defect rate (highest resistivity). However the cost, ~ 2000$/cc, makes large devices prohibitively expensive. Replacing some Cd with the smaller Zn reduces large scale imperfections (increases resistivity). Hole traps remain.

CdTe is a lost cause. (INTEGRAL is flying however.)

Lets talk about CdZnTe but be wary of HPB crystals as large arrays of them cannot be afforded.

There is some hope that the bulk material properties will improve, from efforts to pin the defects in the middle of the gap, but don't hold your breath.

Improvements are more likely to some from improved weighting functions and use of low work function electrodes.

a) belly field cage electrodes (to heal field faster)

b) adding a dielectric under anode ==> increased anode/steering potential difference.

c) In (low work function) contacts for e- injection

Two communities are working on CZT

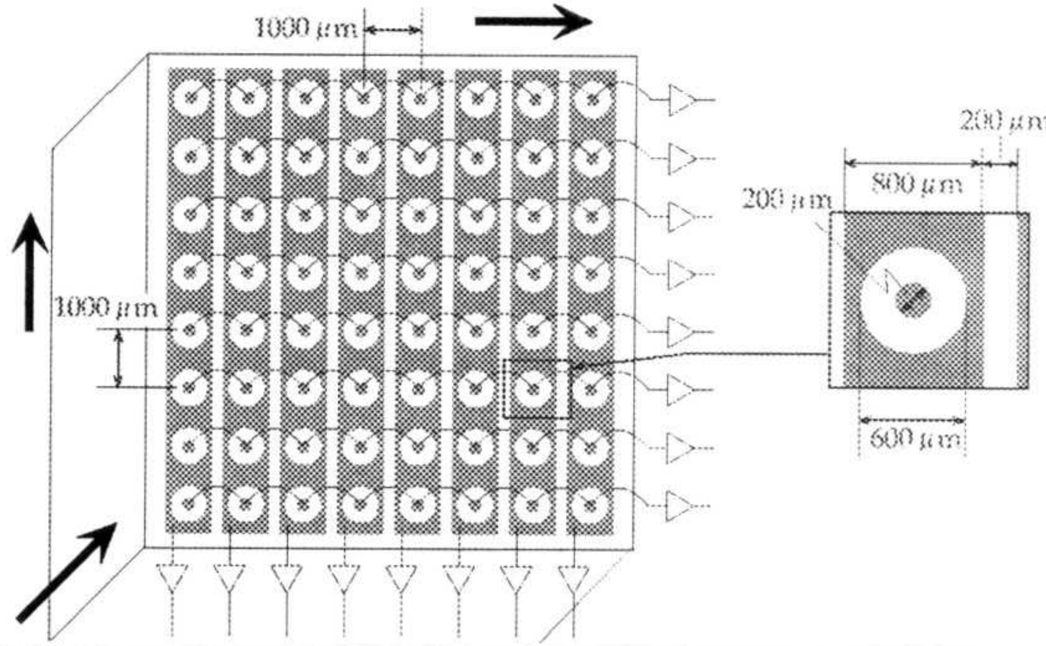
1) Medicine – radiology

Source location via Compton tracking

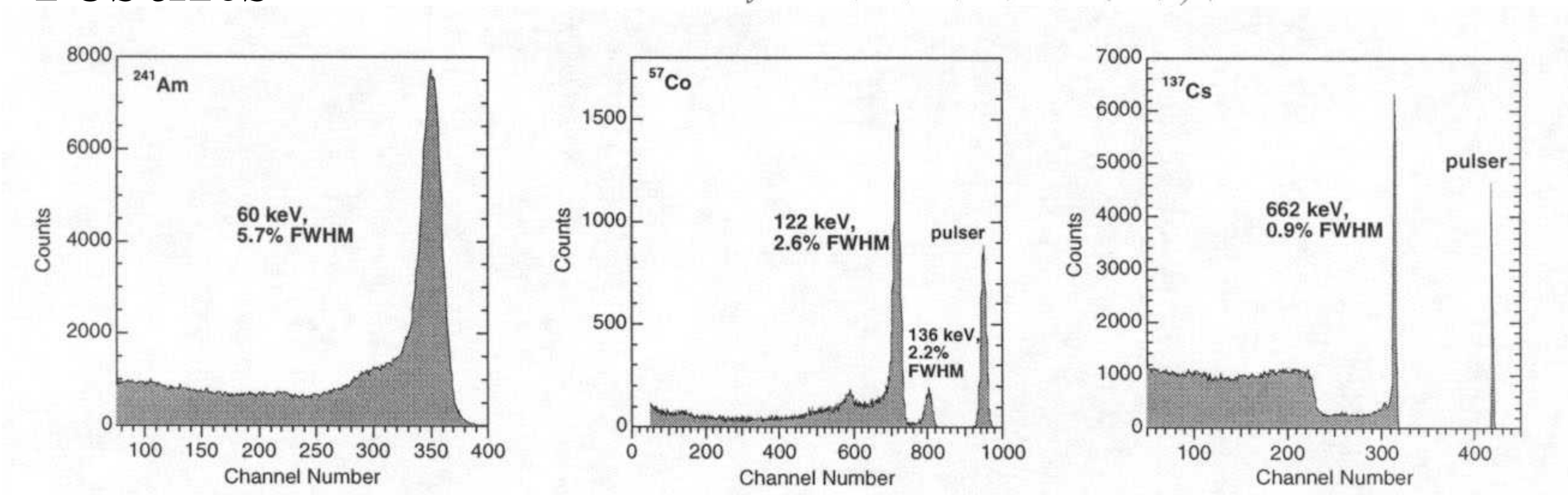
2) Space science (X-ray astronomy) funded by NASA/DOE

Source location and spectral quantification. ("grape-vine" says EXIST is a "go"!)

McConnell et al.
2002 UNH

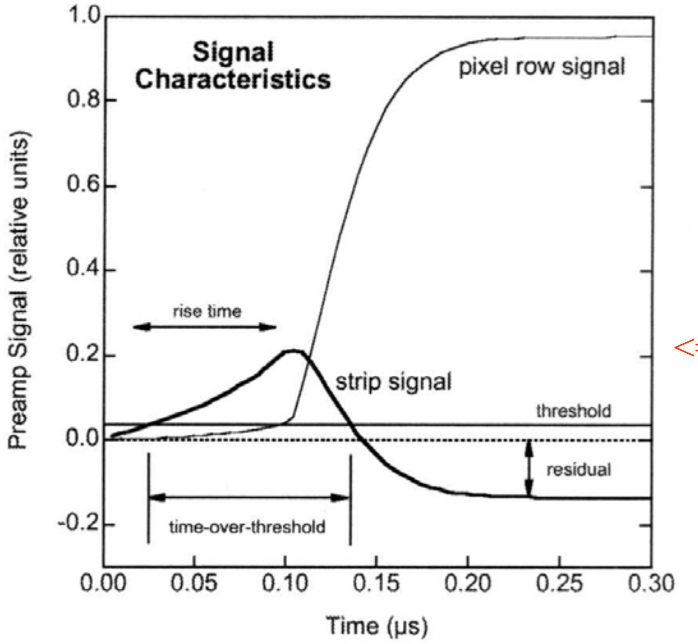


Single Pixel results

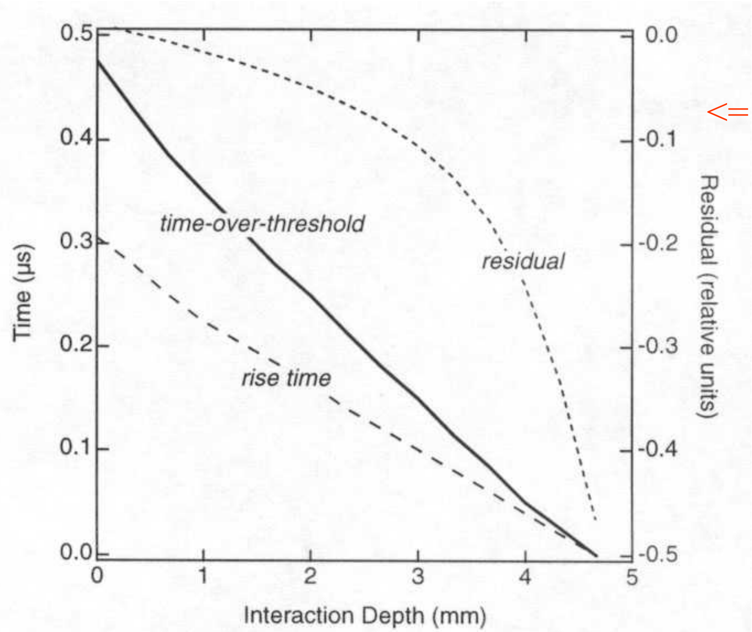


However, orthogonal coin USED! ==> Data selection => reduced eff. not reported!
When pixels added together (no coin) ==> 2.5% @ 662
The single pixel res. is dominated by ele! BEWARE OF SINGLE PIXEL DATA!

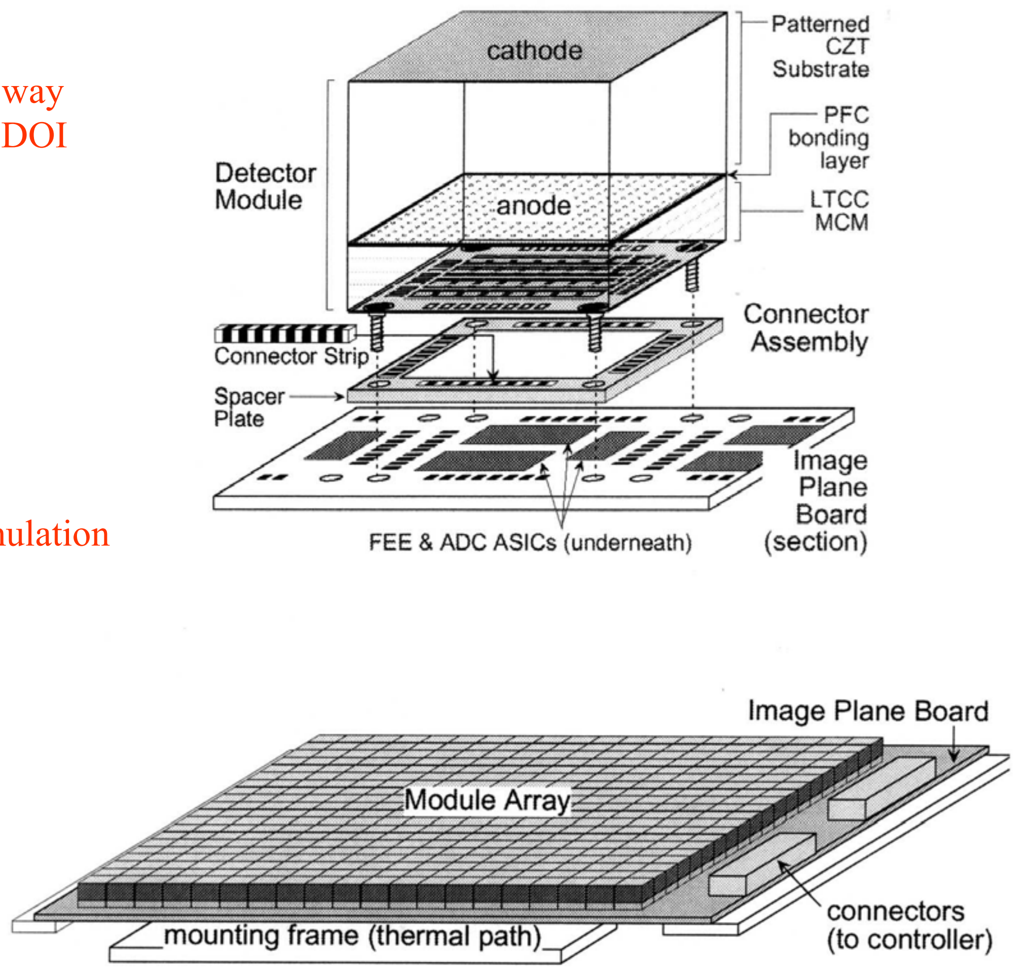
More from McConnell et al.



<= One way
to do DOI

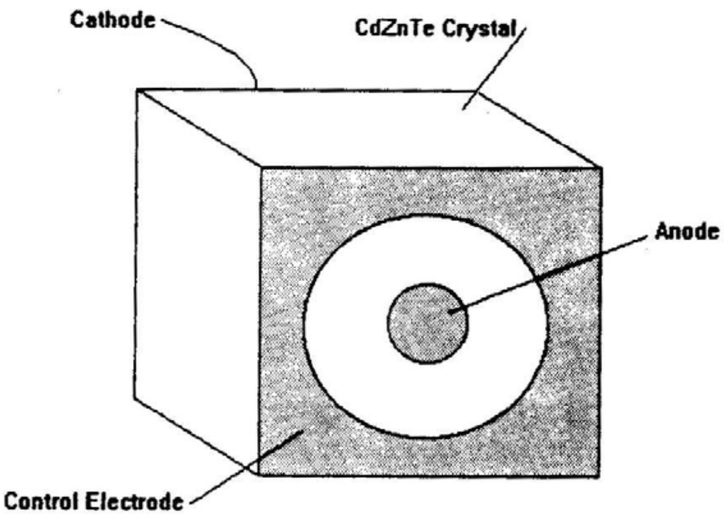


<= Simulation

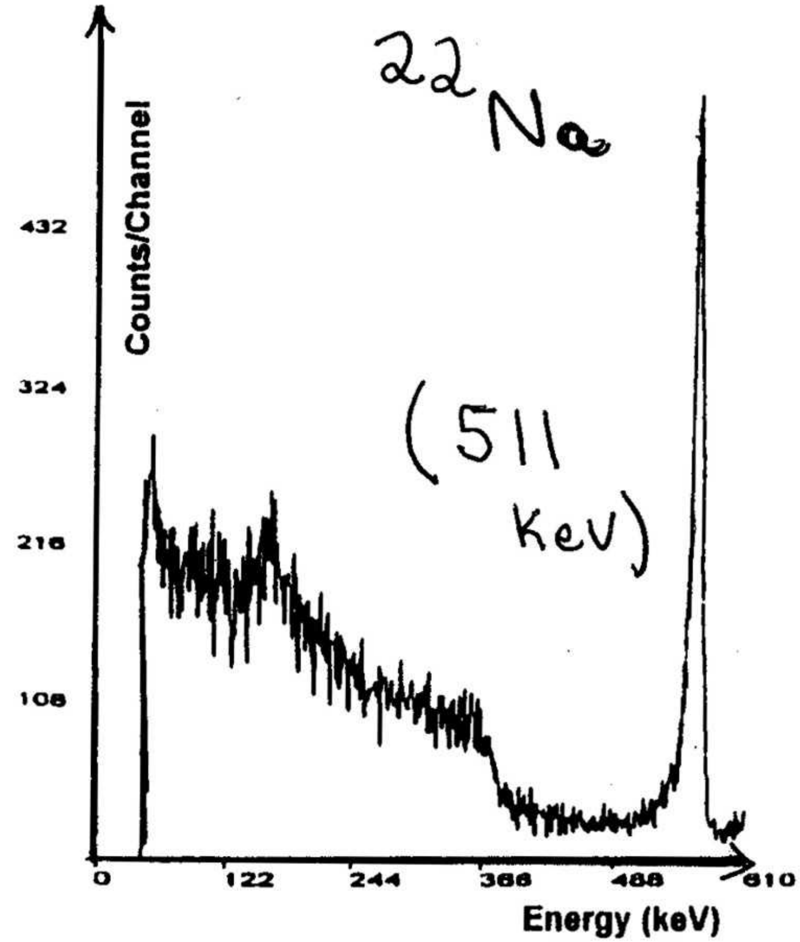


20 X 20 array (1024 cm^2 active area)

Others* have achieved ~ the same with **Pixel** detectors.



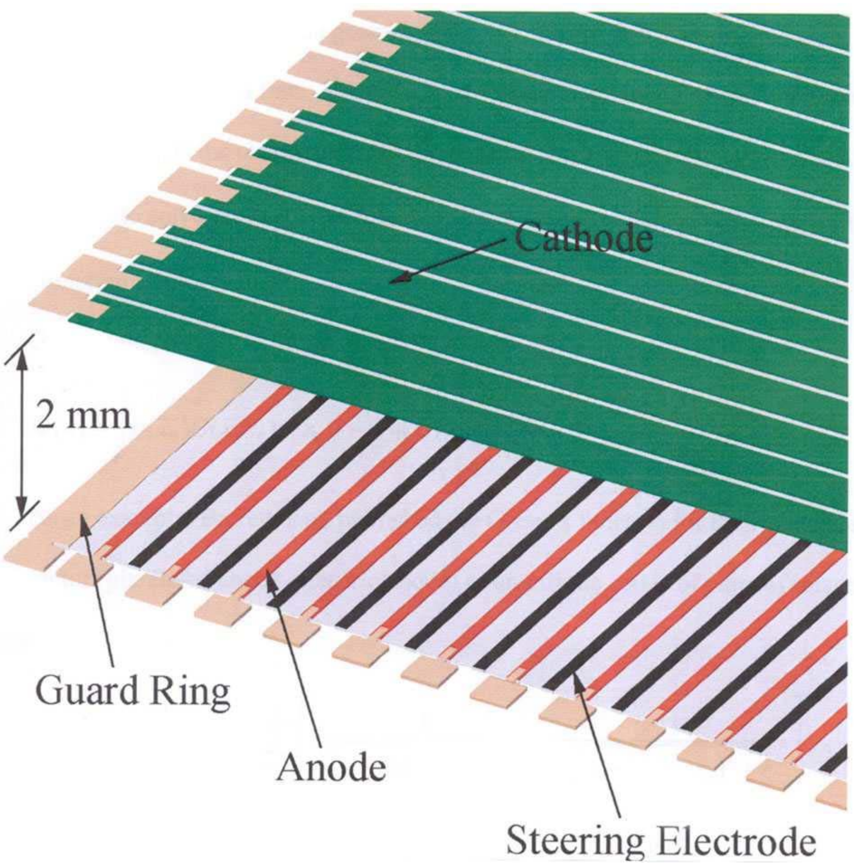
~ 1 % with a pixel detector.
HOWEVER,
A lot of data is rejected!!!

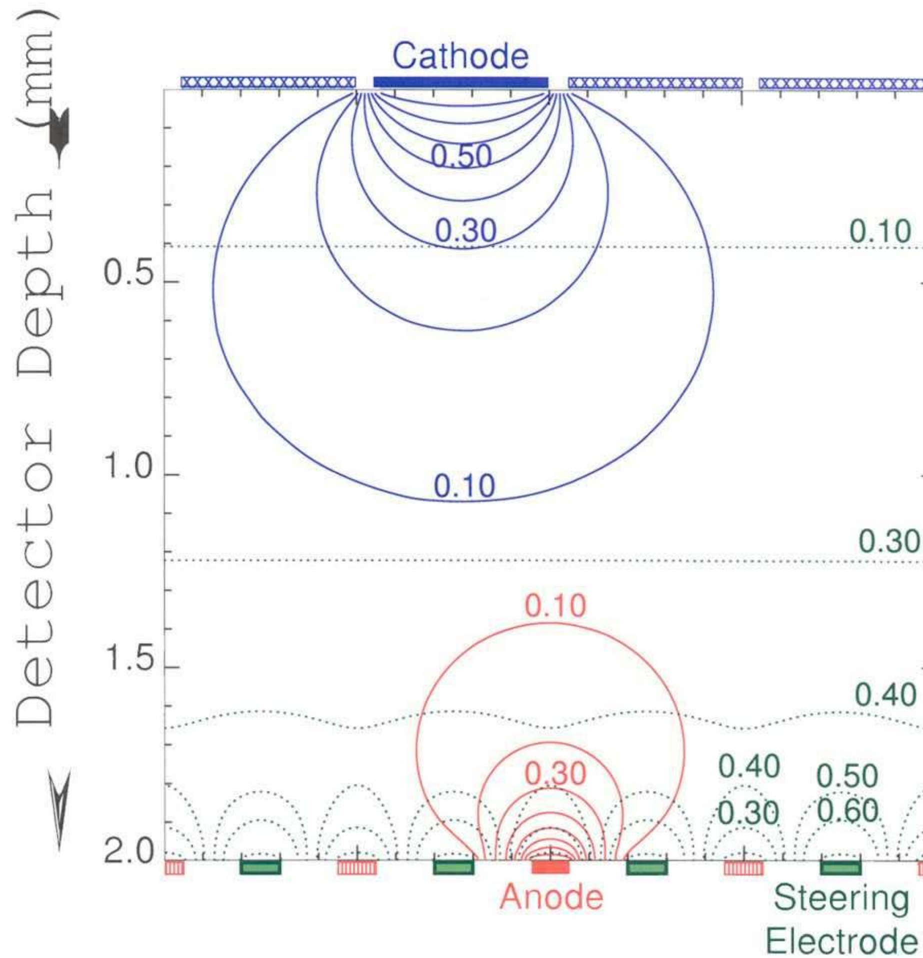


* DIGIRAD

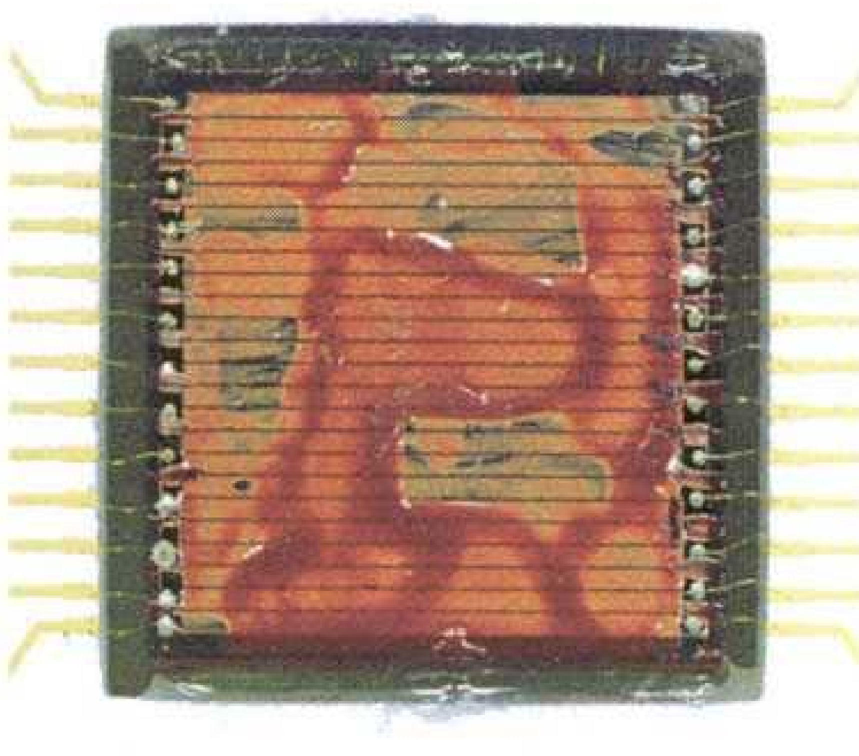
Some old history (with **no** rejection) - WU made a real **strip** detector and flew it in a balloon in 1998.

Anode + Steering Electrode + Guard rings + Cathode

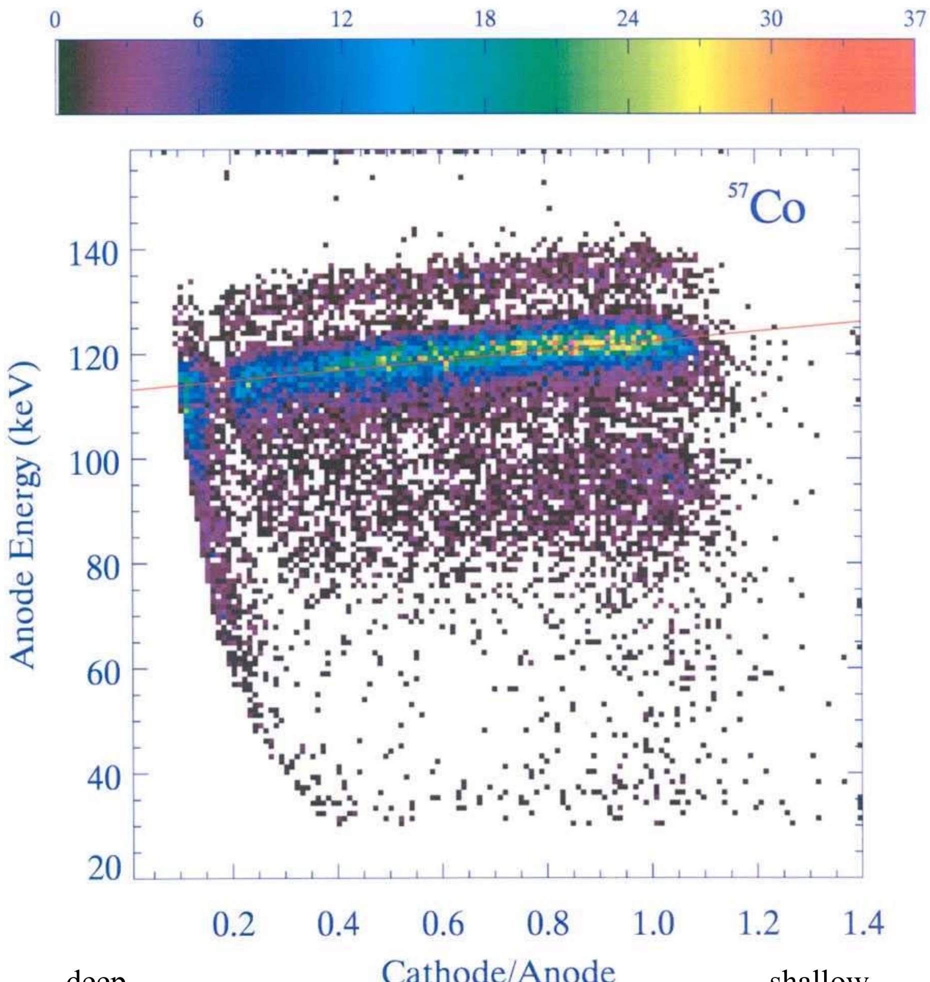




Real **Strip** Device WITH DOI correction



Steering Anodes

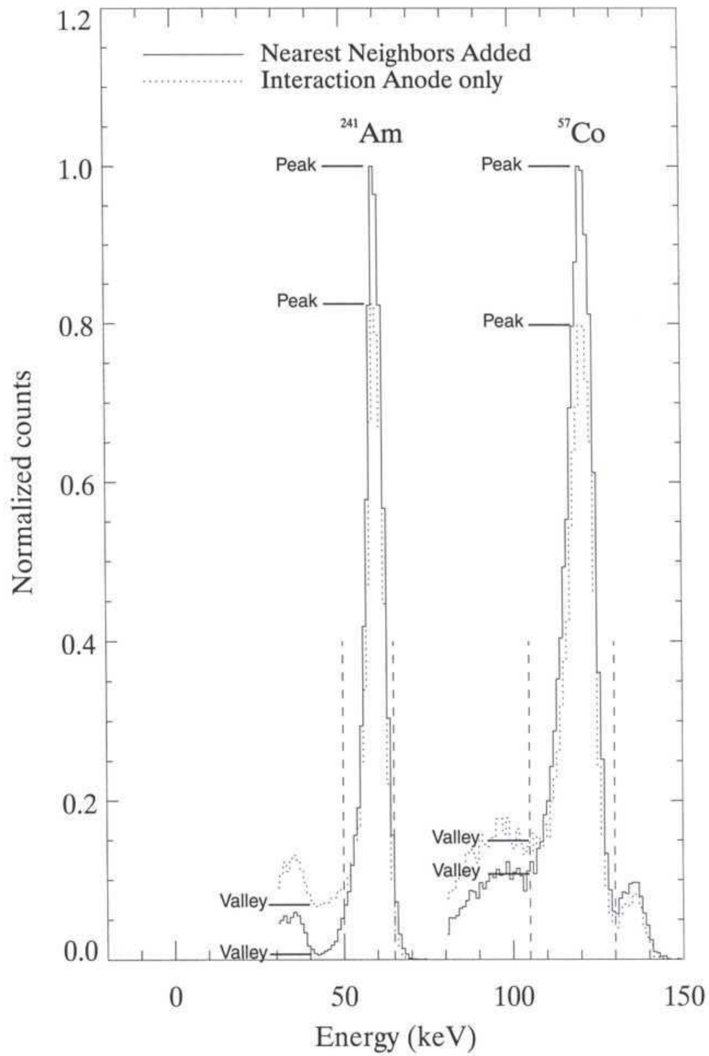


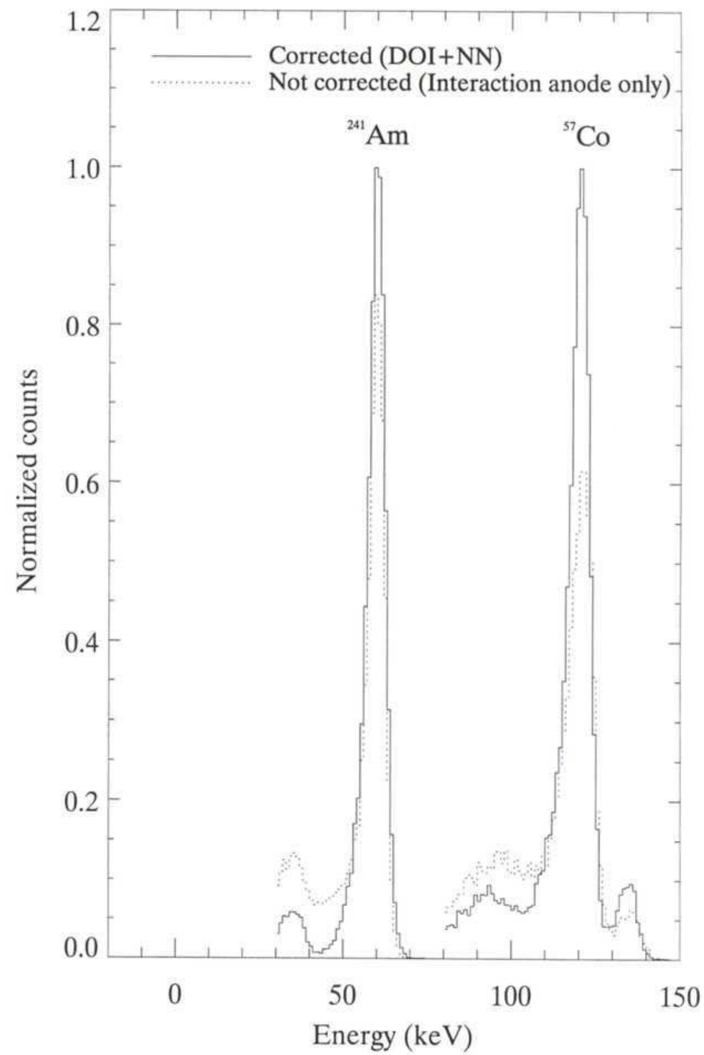
deep interaction

shallow interaction

Two corrections

Neighbors added in & **DOI**





Resolution for this true strip detector

No data rejection

9.3% @ 60 keV
5.3% @ 122 keV

extrapolate assuming sqrt(E) dep.
2.6% @511 keV
2.2%@ 662 keV

This extrapolation is not that different from the summed anode result of McConnell.

Summary of Results

1) Can get 1% (@ 662) from (data rejected) pixel configurations

2) One should be able to get < 1% single pixel events with better electronics.
However, it is not clear this can be done with an ASIC (TA is not good enough.) Can do with external FET or completely external CSA. We have looked at the external FET and it is ugly (too many connections to chip). The external CSA will give optimum performance, but bulky. (Our existing chip allows for this!) However at the very minimum the steering electrodes need PSD info. We are planning to design such a chip.

3) Linked small anodes with coplanar and co-linear (rather than orthogonal) steering electrodes should yield high eff. and ~ 2%.

4) Improvements (WU space science effort)

a) Presently testing with focusing electrodes around belly of CZT - presently on IMARAD detectors.

b) enhancing "small anode effect" by changing material properties under coplanar steering electrodes. (Polished off electrodes adding dielectric and new contacts.)

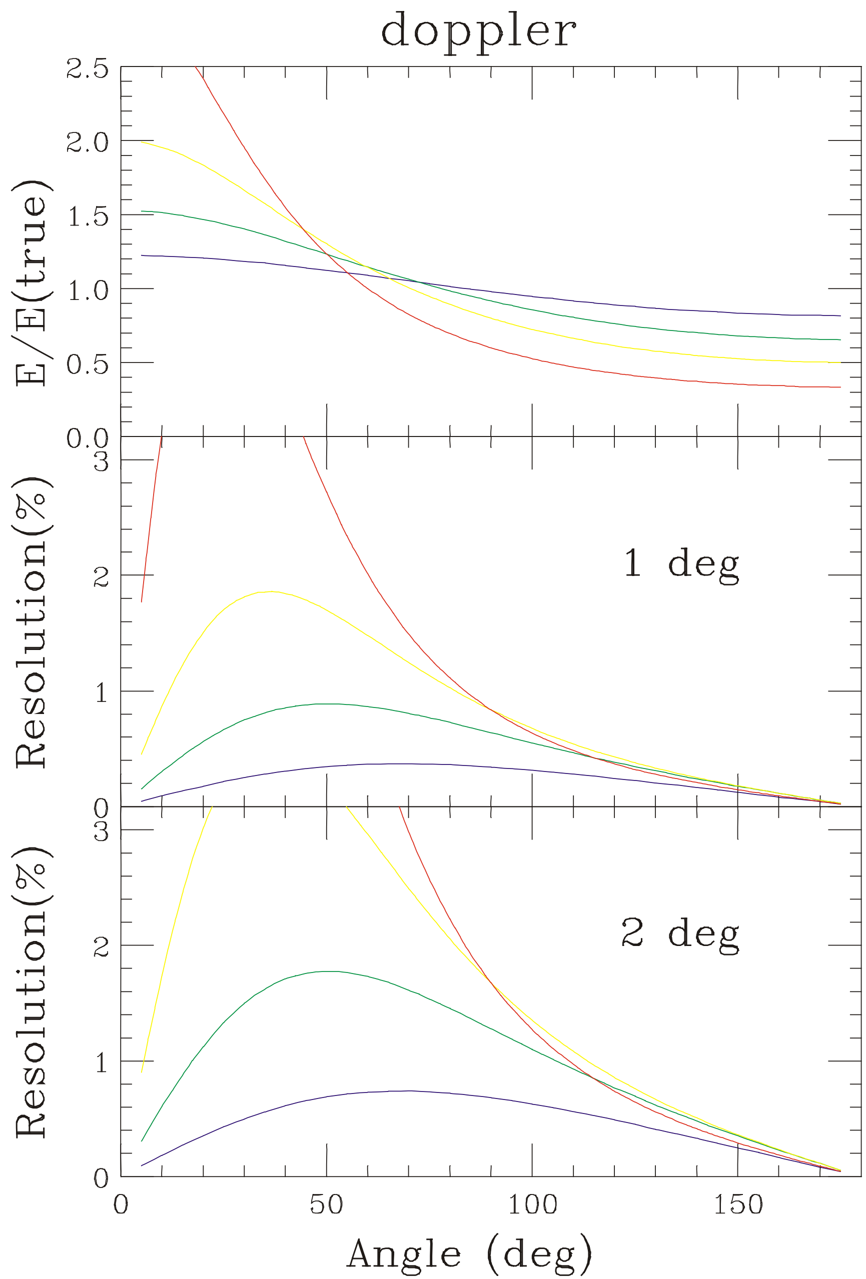
c) Investigation of ohmic contacts (Sn) to counteract hole trapping at the cost of more leakage.

A reminder

Doppler width as a function of β (**0.2**,**0.4**,**0.6**,**0.8**), angle and angular resolution

For example, 1° angular resolution gets you
< 2.0 % for β = **0.6**
< 1.0 % for β = **0.4**
< 0.5 % for β = **0.2**

As a bench mark shoot for ~1° (better: 30-60° if possible).
By the way this means we are talking about "tracked beam."



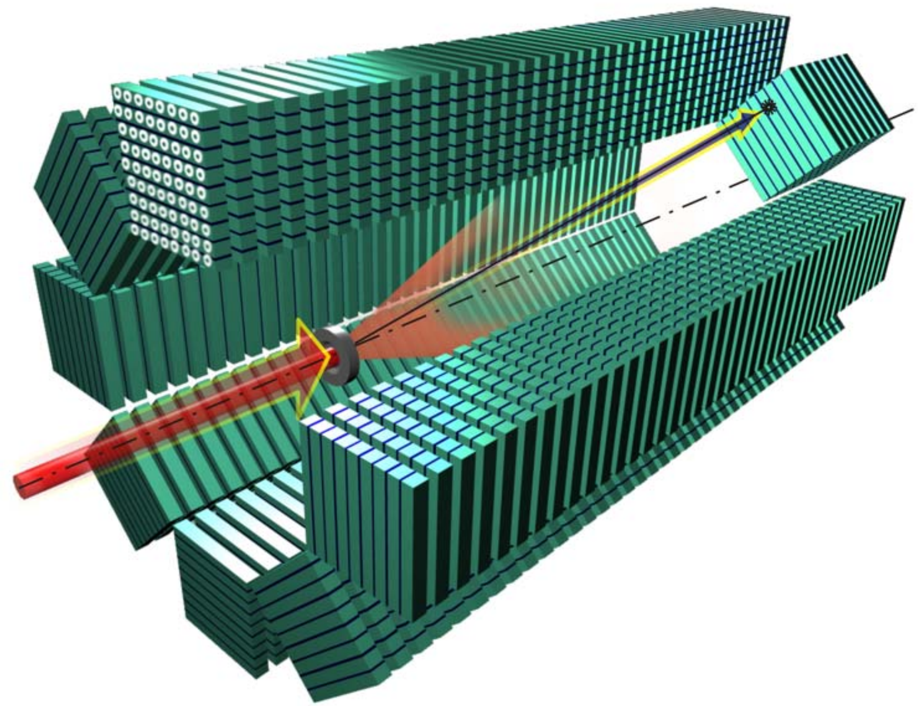
Schematic design **for the sake of discussion**

Consider a **very** small tube:
diameter = 5 cm
length = 15 cm (10 cm CZT)
Volume = 320 cc
# chips = 160
# ch ~ 5120 x 2 (anode+strip)
(1.25 mm pitch)

CZT cost ~ $100,000
If use IMARAD material
(~ $300/cc est.) and construct
electrode structures yourself.

Electronics cost ~ $150,000
Ideally MS chip
Anode string + strip + cath readout
CSA on/off chip option
great way to go!

Need Accurate beam tracking



This is probably too small but, it can be enlarged by just adding more sides.

REALITY: Project makes NO damn sense unless …

1) We can achieve < 1.5 % @ 662 keV (over full volume) WITH an anode composed of linked pixels. A true pixel detector is unrealistic.

2) Focusing (field shaping) **strips** should be read out with a MS (Multi-Sampling) chip (simple PSD characterization required.)

On the other hand, it DOES make sense to make improved pseudo-strip CZT's and do tests with with various electronics schemes.

The x-ray astronomy community is making a significant effort here. NP should have joint development proposals. WU lead the first space science CZT efforts. (Long duration balloon flight in 1998.) They dropped it and now are coming back. **They have built a clean room and are setting up to create there own anode structures.** They have developed the codes for refining the field shaping (Poisson eq. solutions in 3-D). Fairly standard stuff, but it has to be done.

This is a development project for both NASA and DOE

A possible NASA-DoE collaboration

Development of High-Performance Low-Cost Thick CZT Detectors

H. Krawczynski, D.J. Leopold, J. Perkins, L.G. Sobotka, J. Matteson, and R. Thomas Skelton

Although Cadmium Zinc Telluride (CZT) hard X-ray and gamma-ray detectors with excellent spatial and energy resolution have been developed, the high costs of conventionally grown CZT crystals (horizonthal and vertical high pressure Bridgeman CZT) prohibit their application for missions like EXIST (**Energetic X-Ray Imaging Survey Telescope**) and ACT (**Advanced Compton Telescope**) that require active detector areas of several square meters. **We propose the development of a new 0.5 cm thick CZT detector based on low-cost CZT**. The new detector will achieve high detection and photopeak efficiencies as well as excellent energy resolution over the broad energy range from 20 keV to 600 keV at one order of magnitude lower price compared to detectors made from HPB grown CZT. Extensive use of state of the art surface processing techniques will allow us to explore detector designs that are qualitatively different from the ones presently studied elsewhere. **We will complement our experimental program by the development of acomprehensive detector model that will substantially enhance our understanding of CZT detectors.** [H. Krawczynski, Phys. Dept. Washington University in St. Louis (MO) Email: krawcz@wuphys.wustl.edu, Tel: 314 935 8553, Fax: 314 935 6219]

Krawczynski = x-ray astronomer

Leopold = solid-state physicist

LGS = NP

Points of Concern

- Incomplete charge collection ("volume effect")
- Electronic noise ("area effect")
- Lack of material uniformity
- Poor reproducibility

- Limits detector thickness: eff. and energy range (< 1 MeV)
- Limits active area and sensitivity for low-energy γ's
- Limits charge collection (see above) and useful detector size
- Limits yield of good detectors and increases costs