Development and Characterization of CdZnTe Detectors for Neutrino Physics Research

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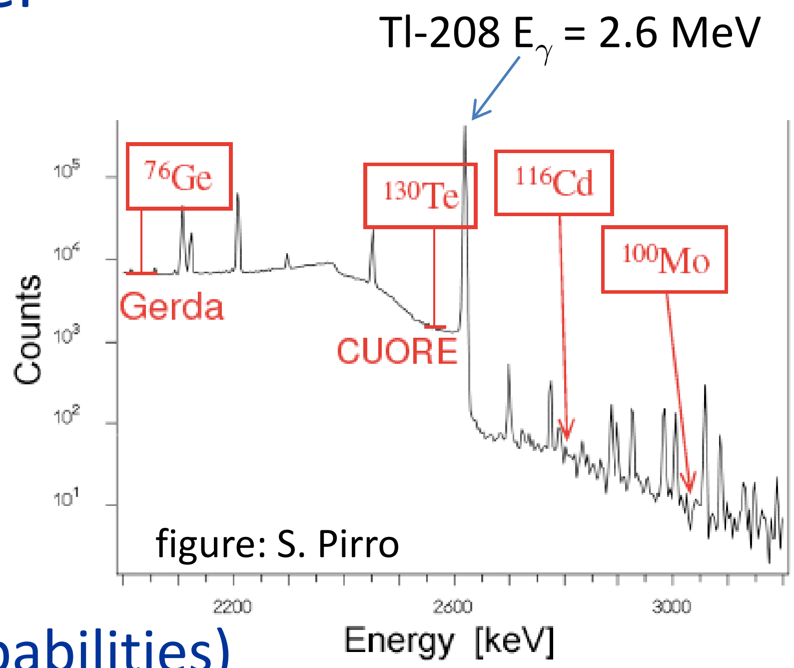
Outline

- Introduction
  - Physics motivation
  - Why CdZnTe ?
- Performance of
  - Coplanar detector
  - Pixelated detector
- Summary + Outlook

Physics Motivation

- Search for neutrino-less double beta decay
  - Physics beyond 'standard model'
  - Nature of neutrino
- Requirement:
  - Excellent energy resolution
  - Efficient background rejection
    - High Q-value (choice of source)
    - Shielding
    - tracking, particle ID (detector capabilities)
  - Multiple isotopes



Why CdZnTe detectors ?

- CdZnTe crystals contain 9 double beta decay isotopes

isotope	Natural abundance [%]	Q value [keV]	Decay mode
Cd – 116	7.5	2805	$\beta^-\beta^-$
Te – 130	33.8	2529	$\beta^-\beta^-$
Cd – 106	1.21	2771	$\beta^+\beta^+$

Above all U and Th chain gamma lines (2614 keV from Tl- 208)

- Source = detector
- Good energy resolution
- Room temperature operation
- Modular design (coincidence studies, scalability)
- Potential for tracking (solid state TPC)
  → background reduction
- Industrial development of (clean) CdZnTe crystals

K. Zuber, Phys. Lett. B 519, 1 (2001)

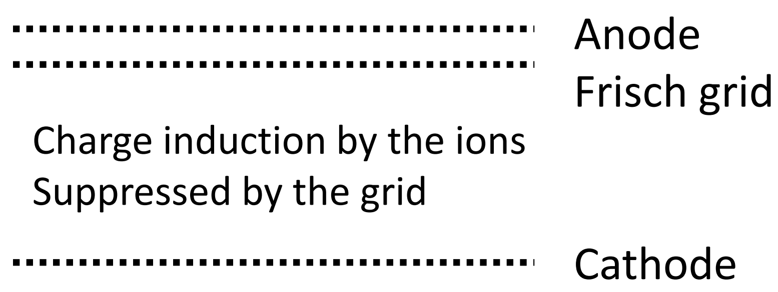
Co-Planar Detectors

- Idea based on gas ionization chambers : electrons and ions have different drift speeds (few orders of magnitudes)
- In large volume, depending on the location of ionization, a combined induced charge by electrons and ions varies greatly

  → worse energy resolution.

  →Frisch Grid is used to suppress charge induction from ions

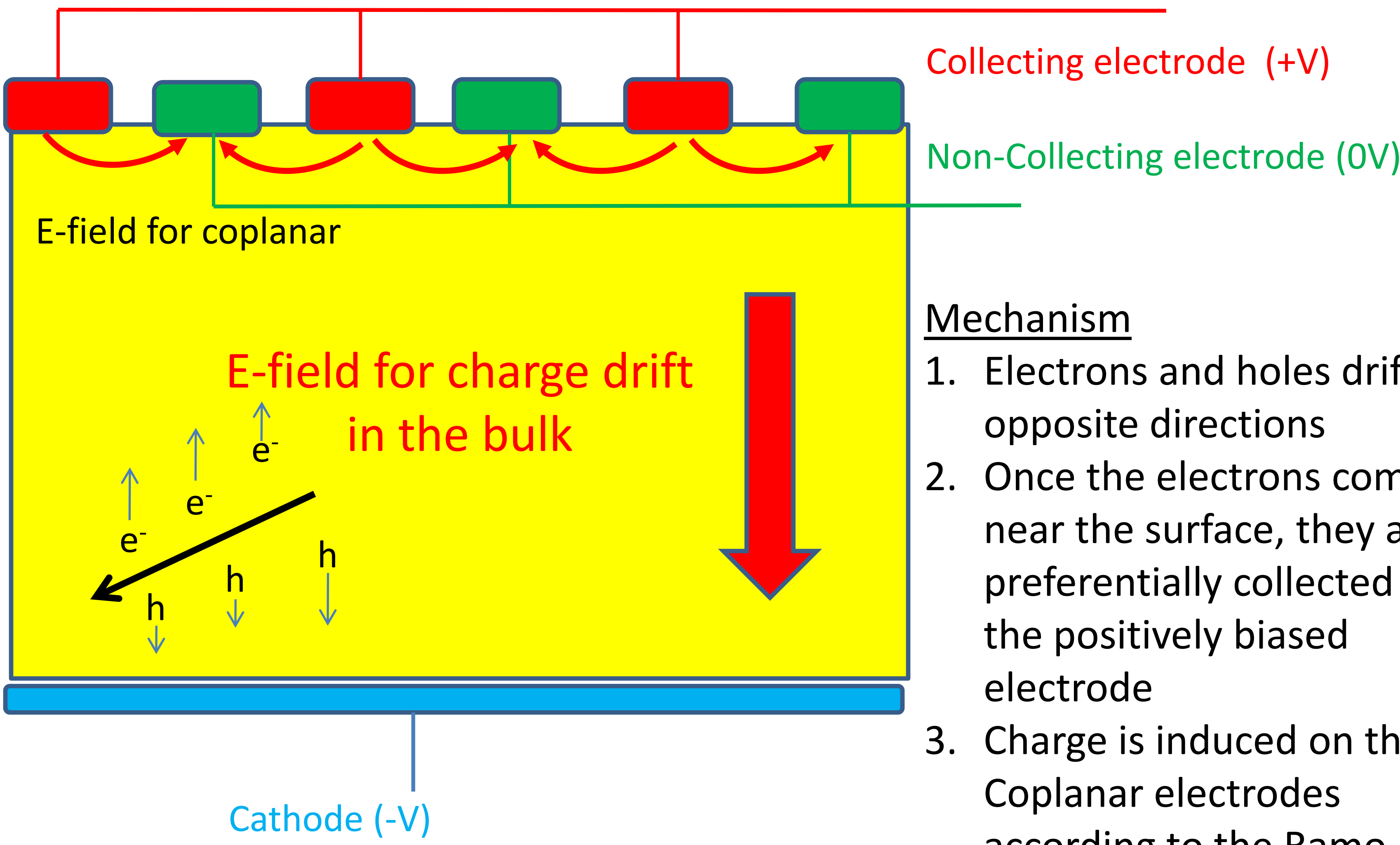
  → single carrier detector



- In CdZnTe: remove the hole contribution to the signal
  – by alternating collecting/non-collecting electrodes biased at different potentials

P. N. Luke, Appl. Phys. Lett. 65 (1994) 2884

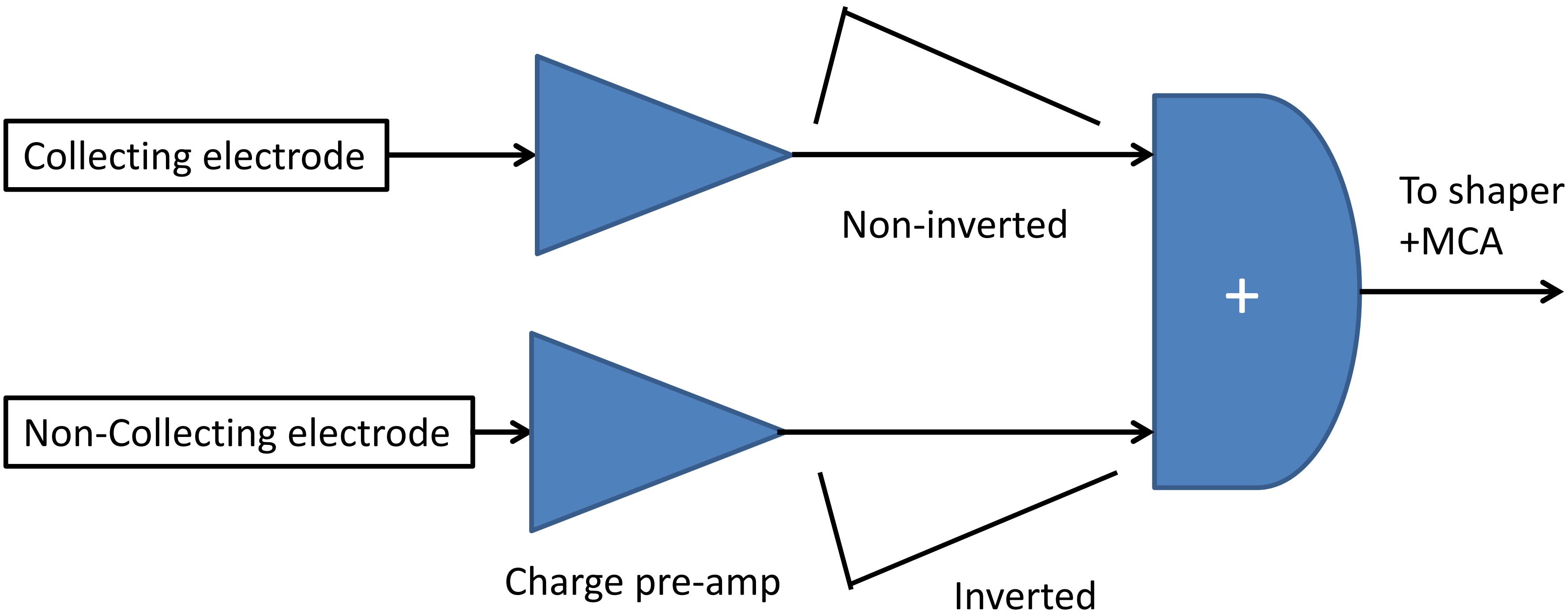
E-field in a coplanar CZT



<u>Mechanism</u>

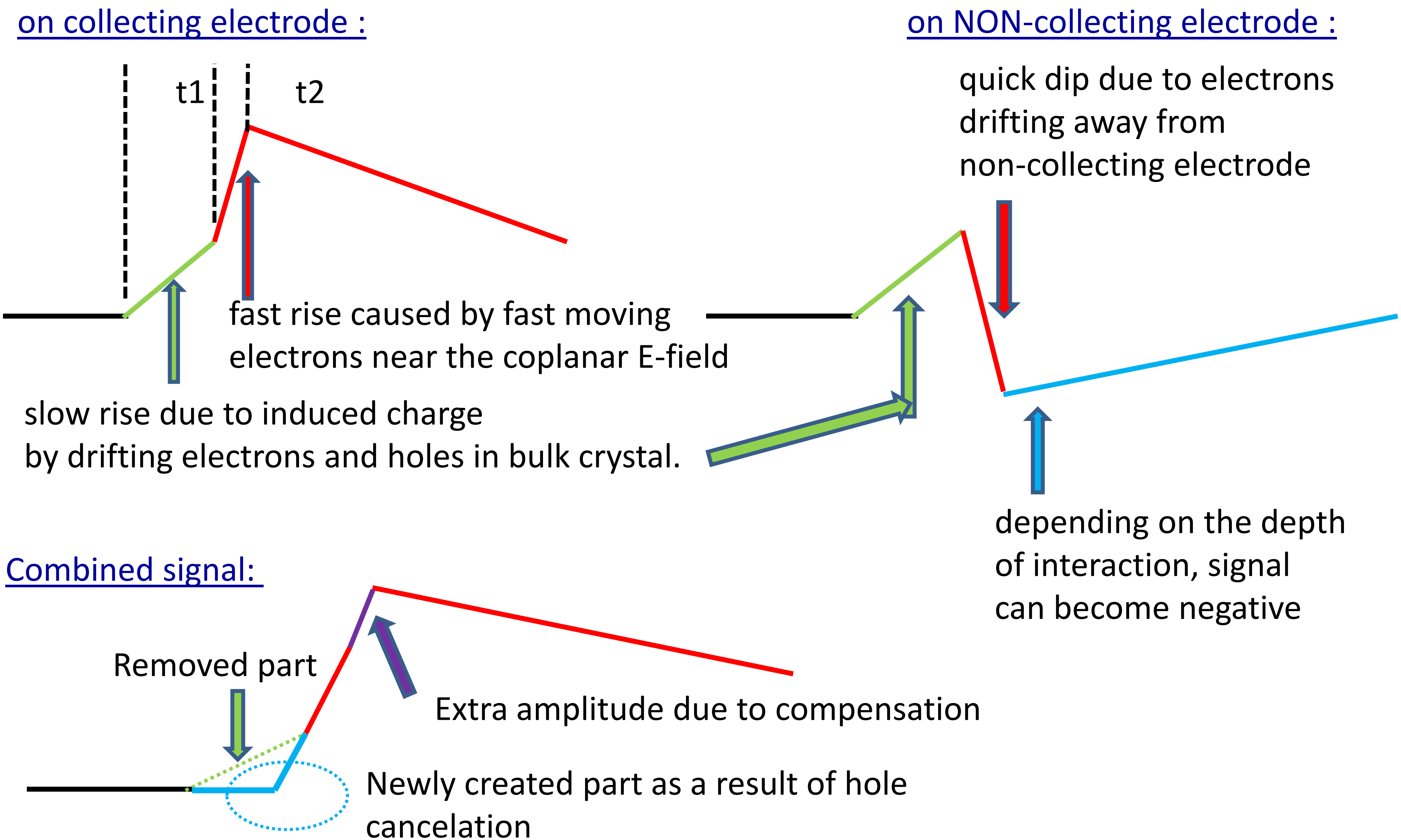
1. Electrons and holes drift in opposite directions
2. Once the electrons come near the surface, they are preferentially collected by the positively biased electrode
3. Charge is induced on the two Coplanar electrodes according to the Ramo theorem in different ways

Schematic of the coplanar subtraction



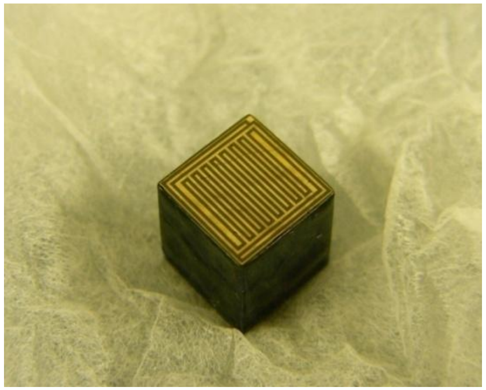
1. Inversion and addition are done in the analog stage of the pre-amp
2. Shaping is done after the two signals are added: equivalent to subtracting two signals from coplanar electrodes.

Charge Induction

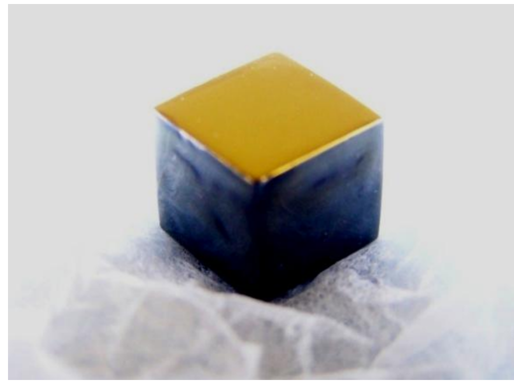


➔ Coplanar electrodes can correct for severe amplitude loss due to hole trapping

Experimental setup at LSU

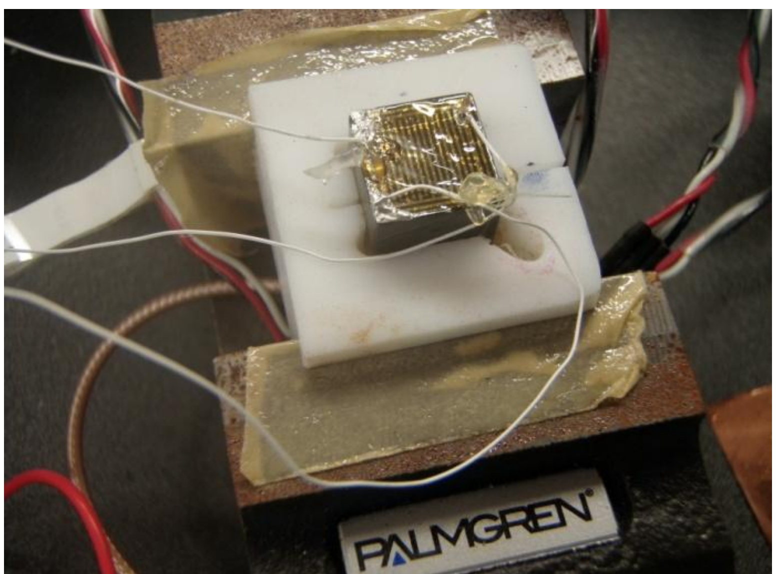


Anode side



Cathode side

$Cd_{0.9}\, Zn_{0.1} Te_{1.0}$ crystal:
weight: ~5.9 g
Dimension: 10 x 10 x 10 mm^3
clear passivation coating

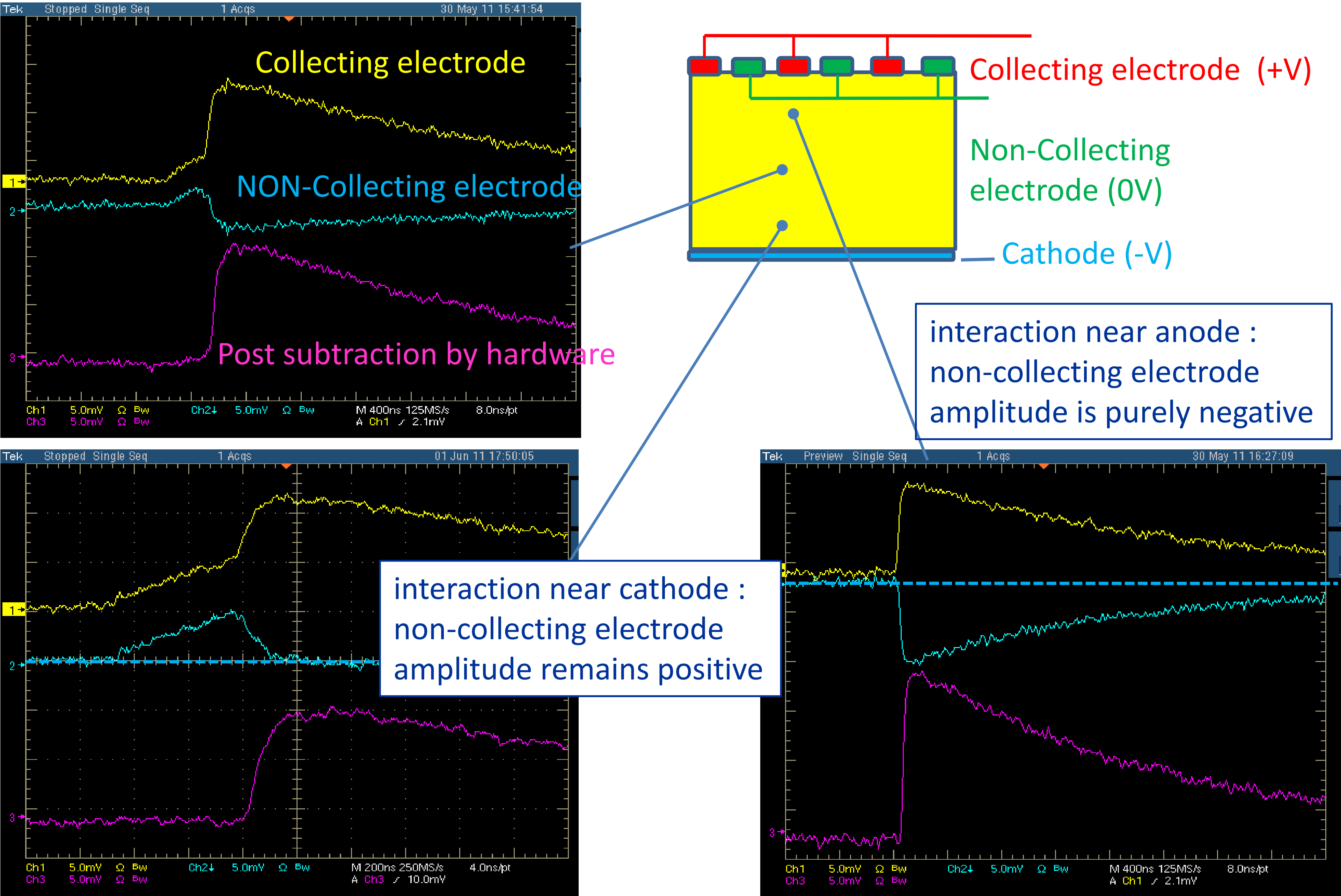


Anode side with wires attached

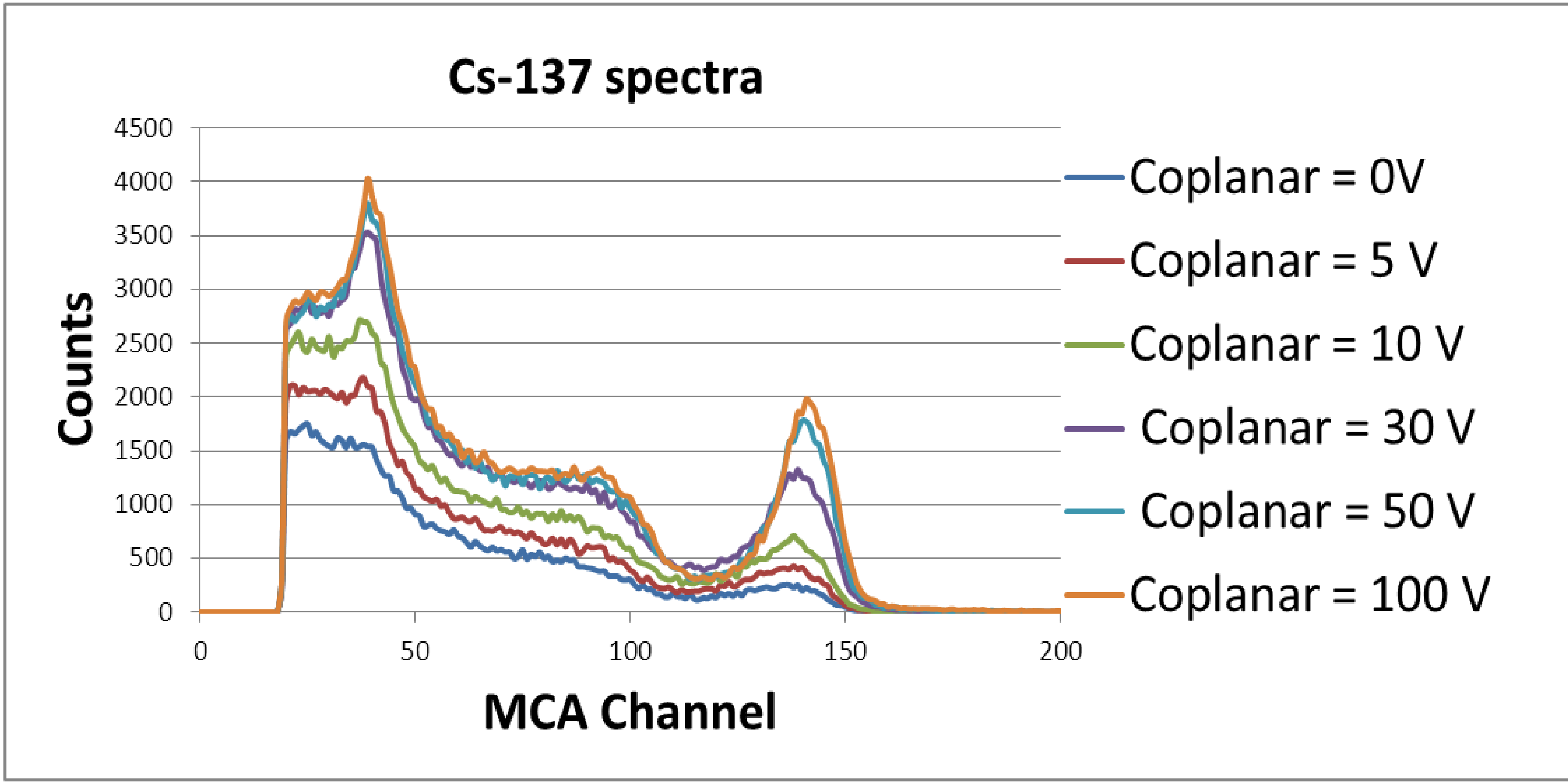
<u>Coplanar grid dimensions:</u>
Width: 200 micron
gap: 300 micron

<u>Guard ring:</u>
guard ring to edge: 250 micron
active area to edge: 600 micron.

Observed signals (Cs-137 source)



Optimization of Coplanar Operation

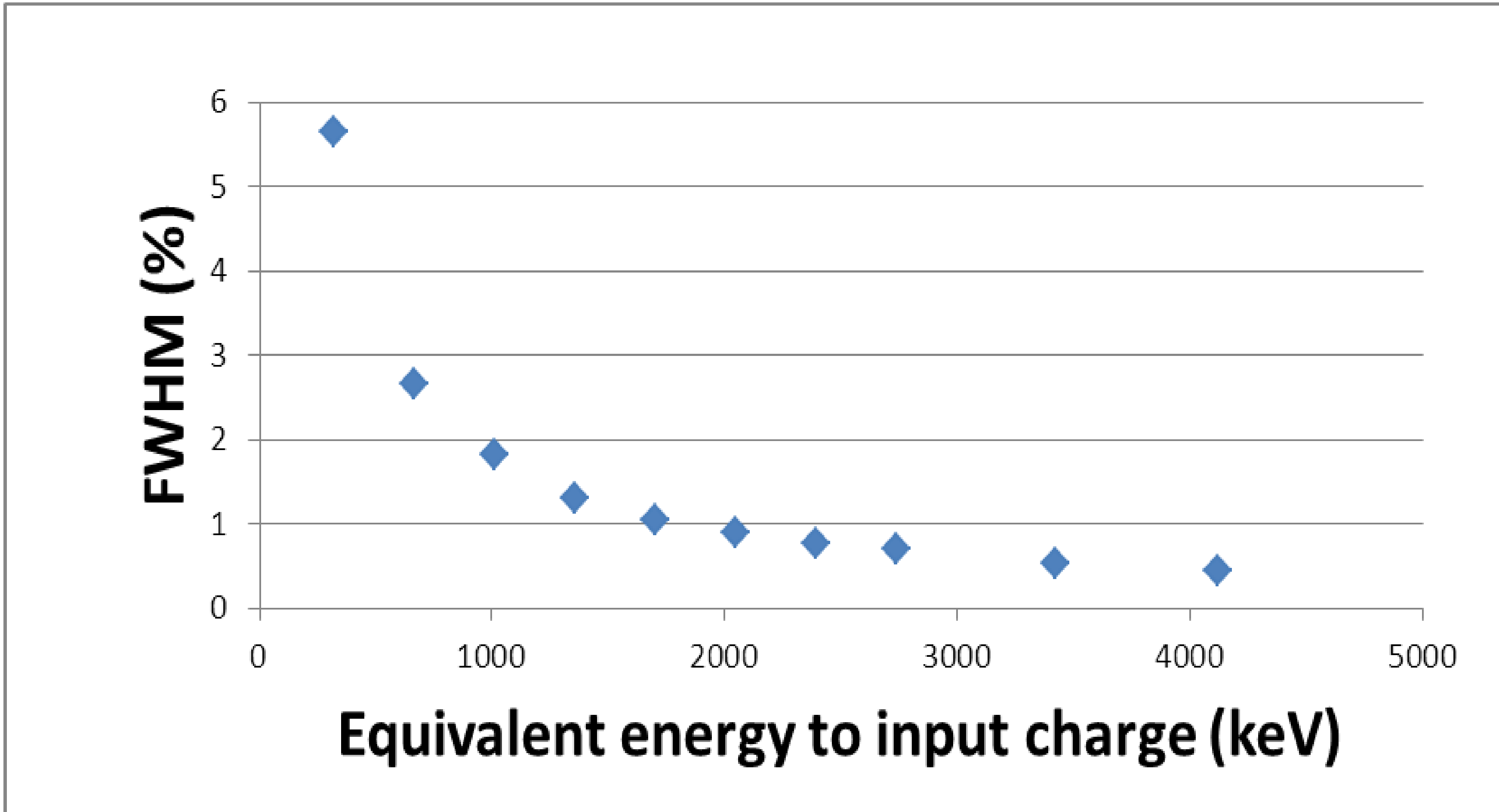


- Because of the small gap (≈300 μm), even a small bias voltage of 30 V (or more) is sufficient to make the coplanar field effective
- Cathode biased at ~ - 2000 V

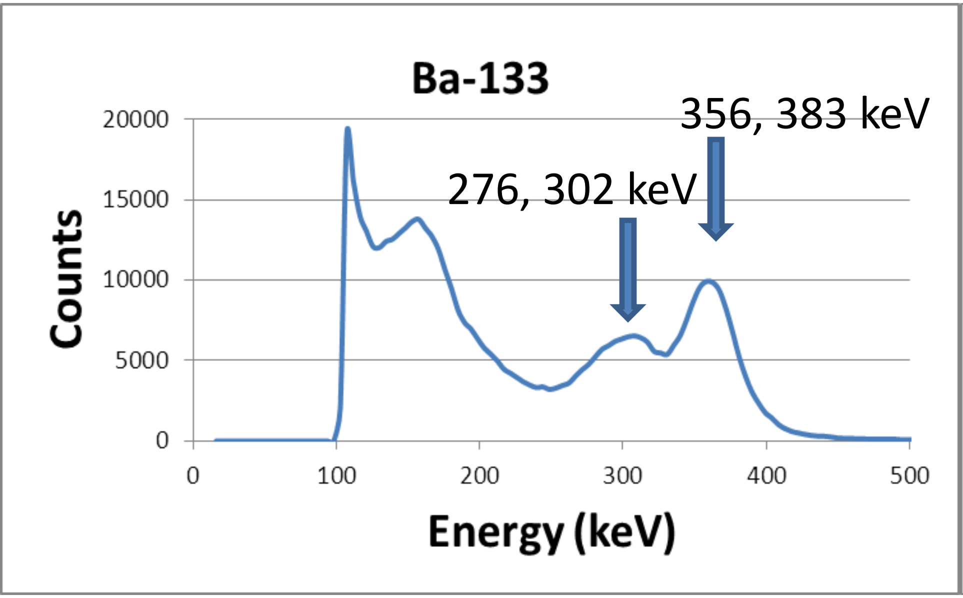
Inherent electronics noise

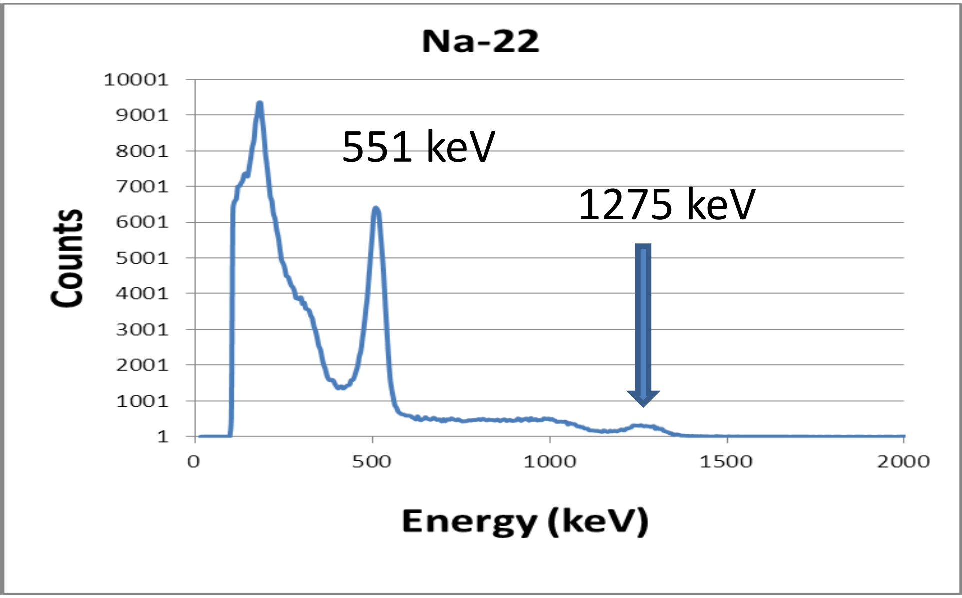
Tests with pulse generator:

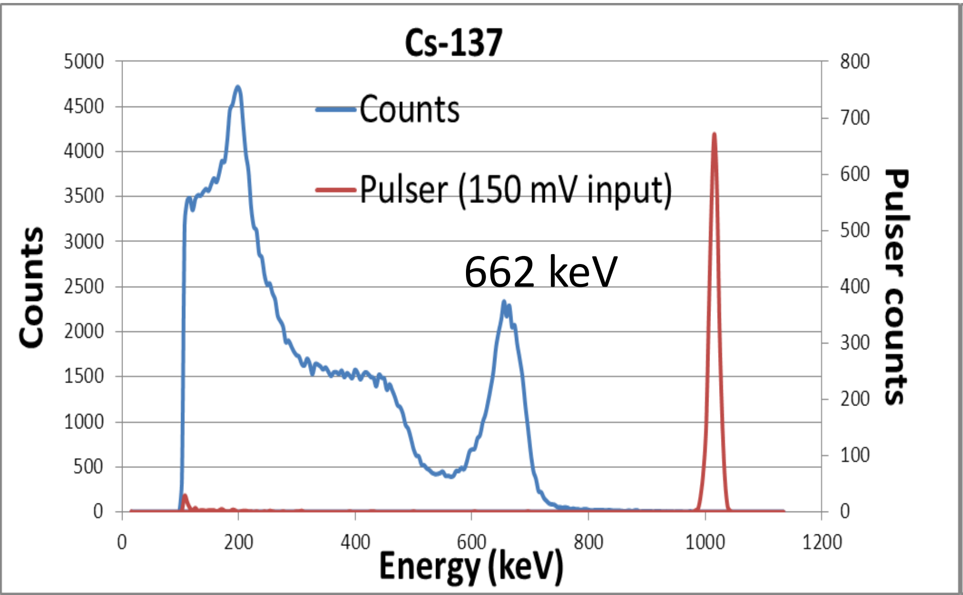
1. Used shaping time of 2 μsec
2. Width due to electronic noise remains constant
3. FWHM/Centroid (%) approaches sub percent levels

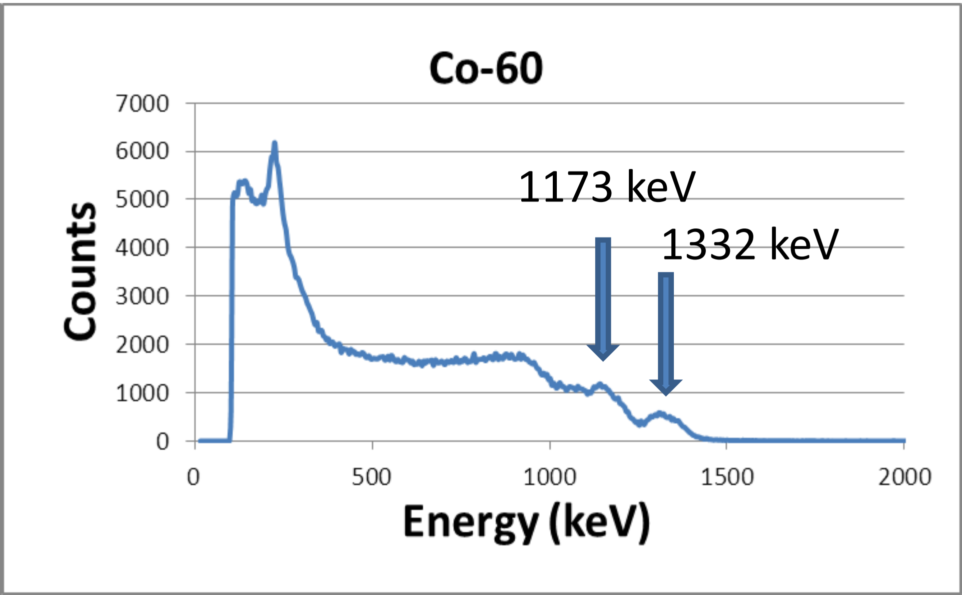


Gamma Source Spectra



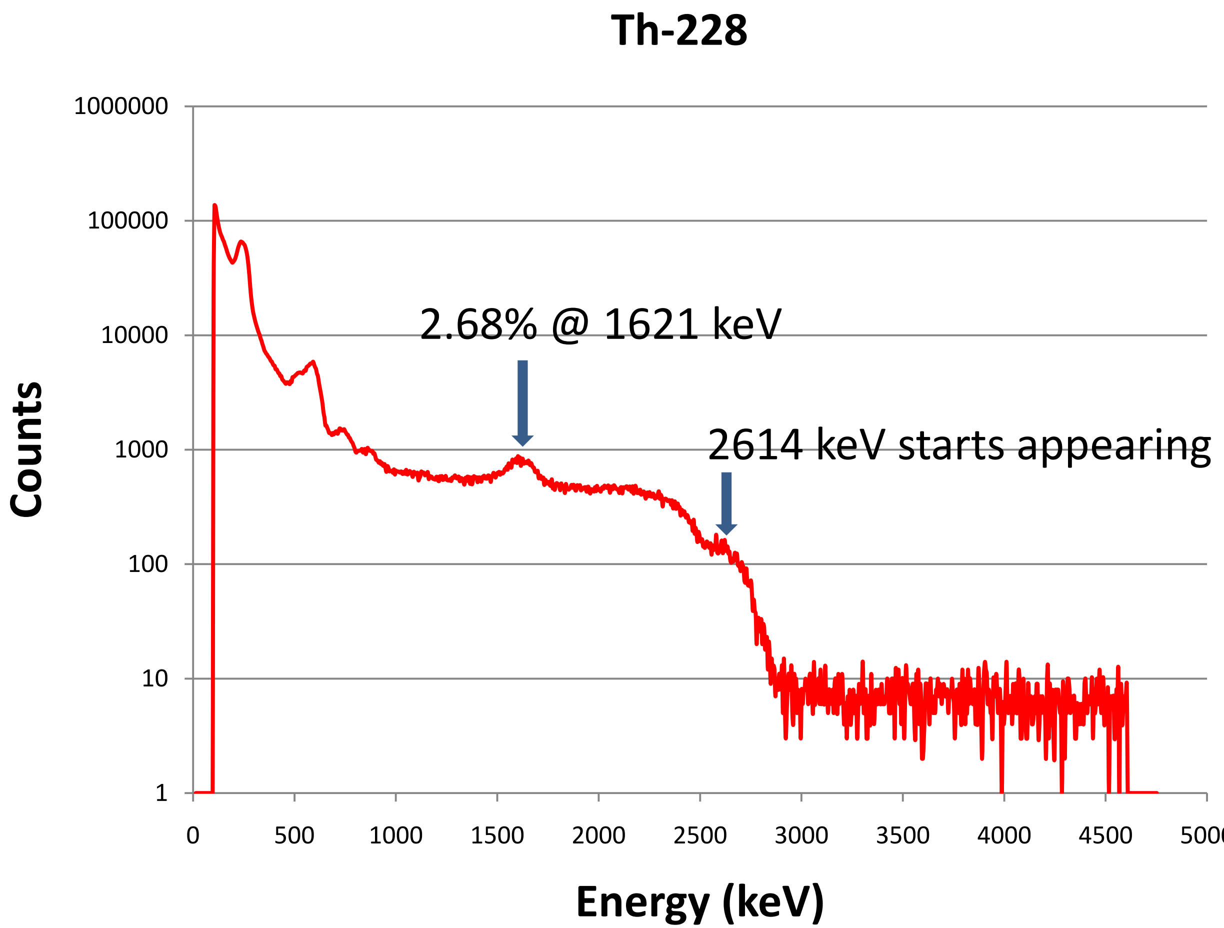




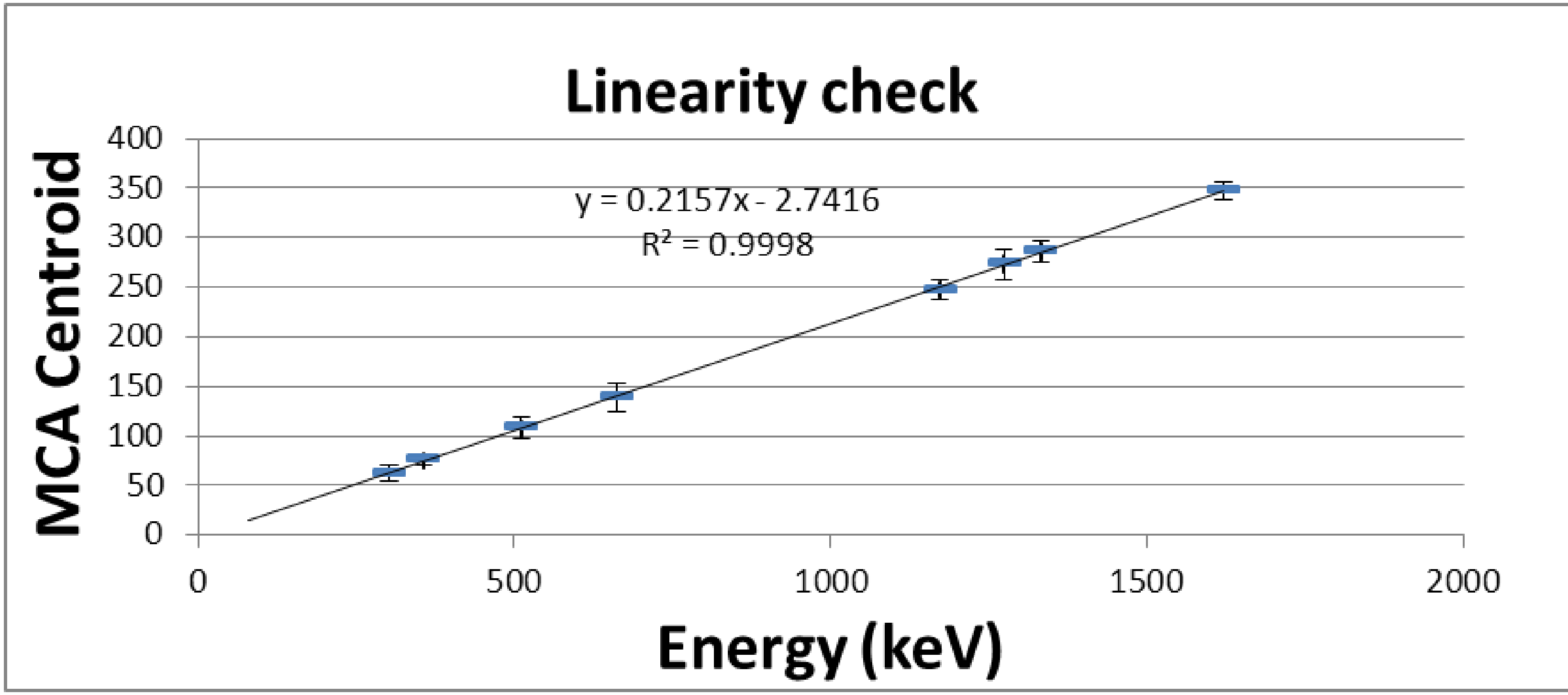


Th-228

120 hr, Total counts=3,259,487

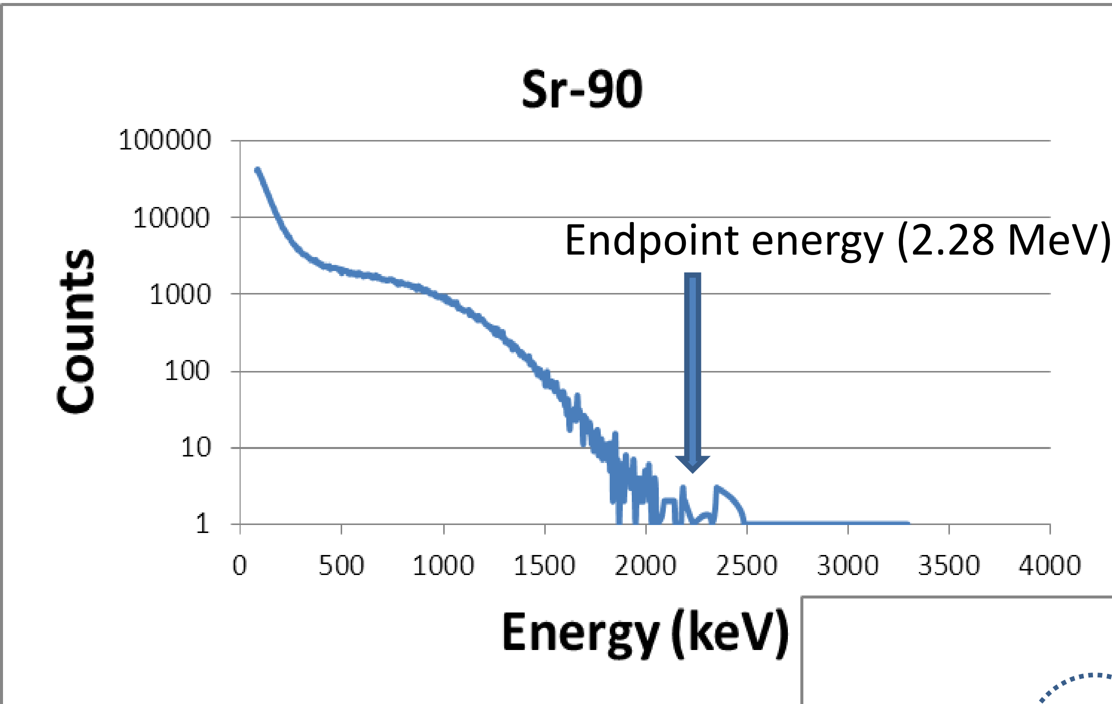


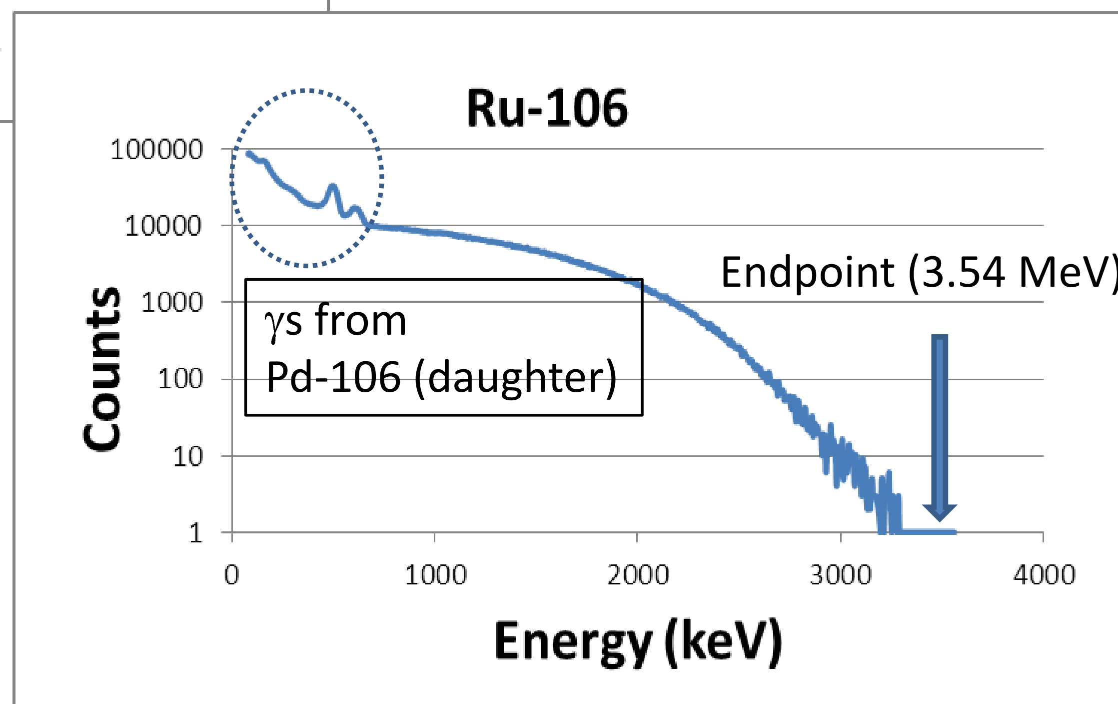
Energy Resolution Summary



Isotope	E_γ [keV]	$\Delta E_{FWHM}/E$ [%]	Isotope	E_γ [keV]	$\Delta E_{FWHM}/E$ [%]
Ba-133	276, 302	12.97	Na-22	511	8.8
	355, 383	7.02		1274	5.9
Cs-137	662	7.0	Co-60	1173.2	3.95
Th-228	1621	2.68		1332.5	3.89

Beta Source Spectra





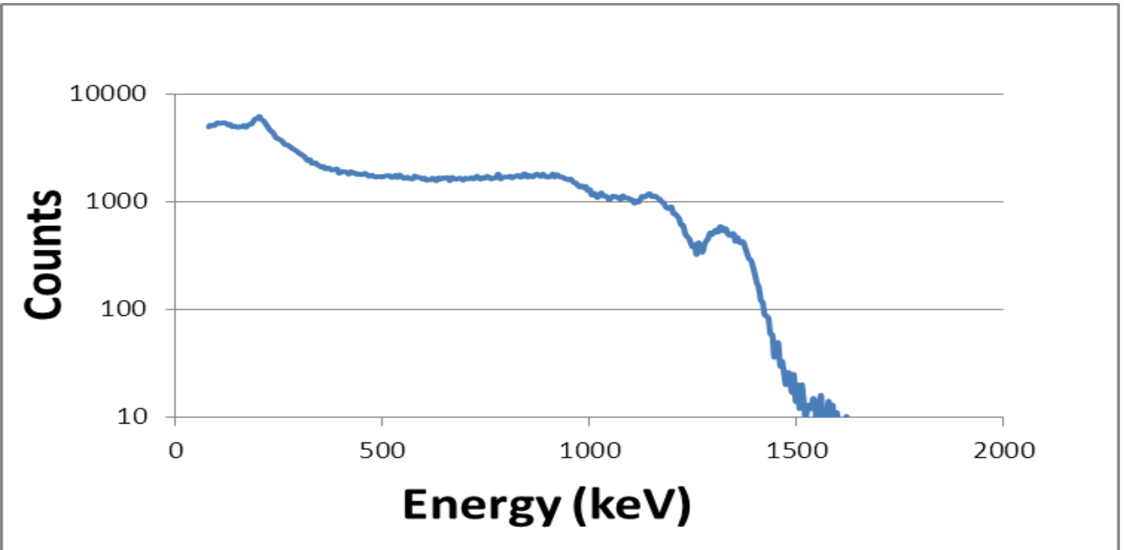
Counts near endpoint energies

Sr-90 : 2.28 MeV
Ru-106 : 3.54 MeV

→Detector shows good dynamic range

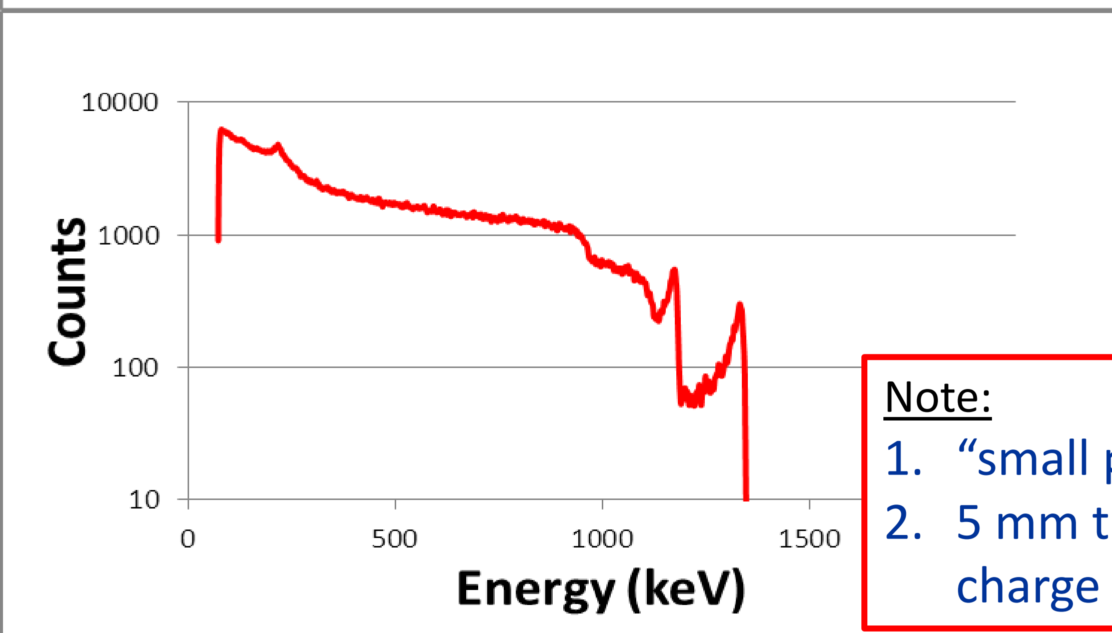
Coplanar and Pixel Detector

Co – 60 source spectra



Coplanar detector: 10 x 10 x 10 mm^3

ΔE/E ~ 3.89 % FWHM@ 1332 keV



Pixel detector: 11 x 11 x 5 mm^3
4 x 4 pixels size: 2.0 x 2.0 mm
pitch: 2.1 mm
ΔE/E (FWHM) ~ 1.5% @ 1332 keV

Note:

1. "small pixel" → superior energy resolution.
2. 5 mm thickness → reduced effect from charge trapping

Summary and Outlook

- Motivated CdZnTe detector R&D
- Demonstrated signal cancelation from hole contribution
- Presented results for energy resolution of coplanar and pixilated detector
- Linearity and dynamic range of detector response

<u>Outlook:</u>

- Study correlation between DOI and energy resolution
- Continue to develop sub millimeter pixel size detectors:
  - Study charge sharing effects
  - Possibility of particle tracking