Modular Planar Germanium (MPGe) Detector Systems for High Resolution Gamma-ray Spectroscopy and Tracking Arrays

DE-SC0009639

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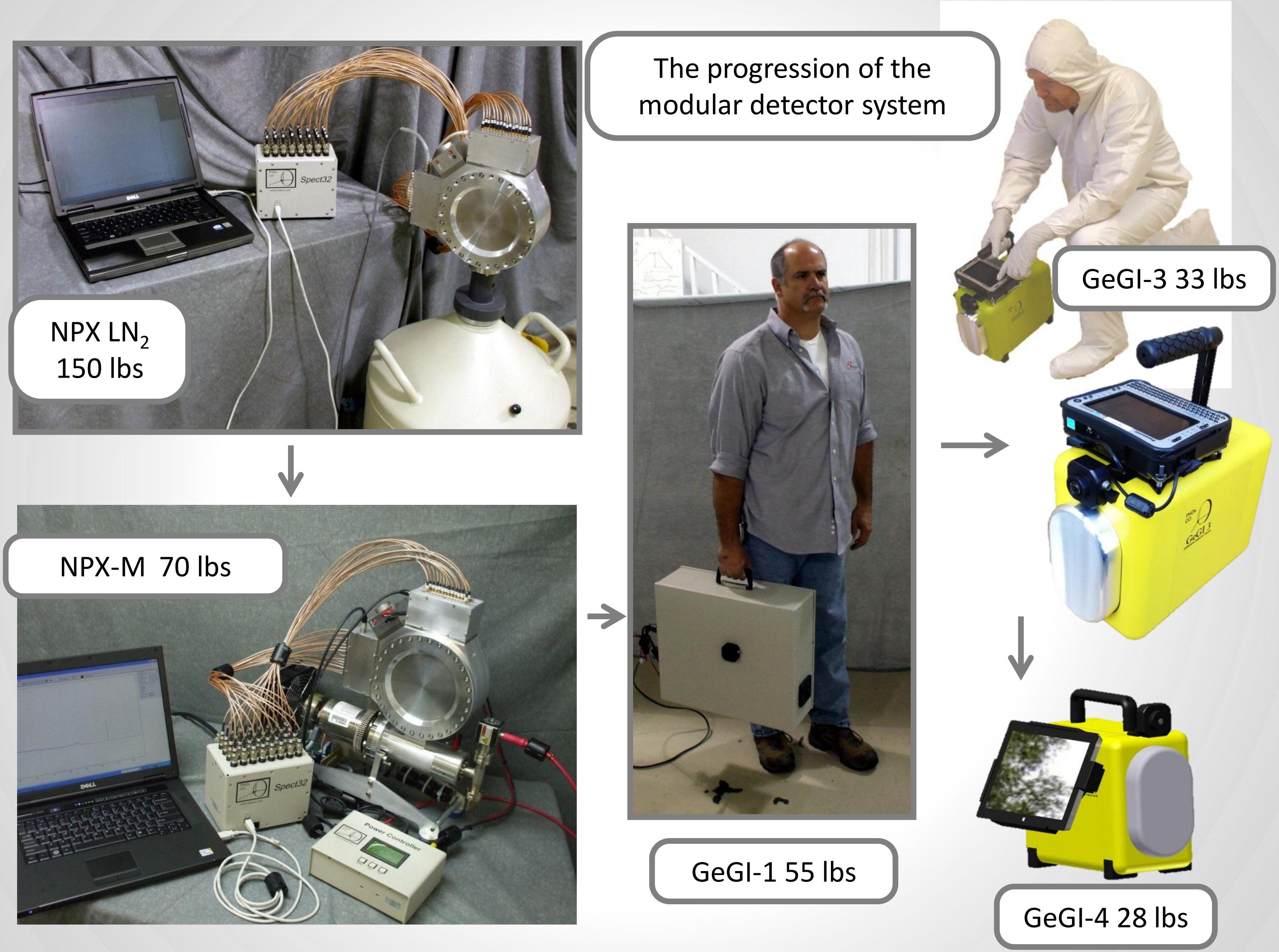
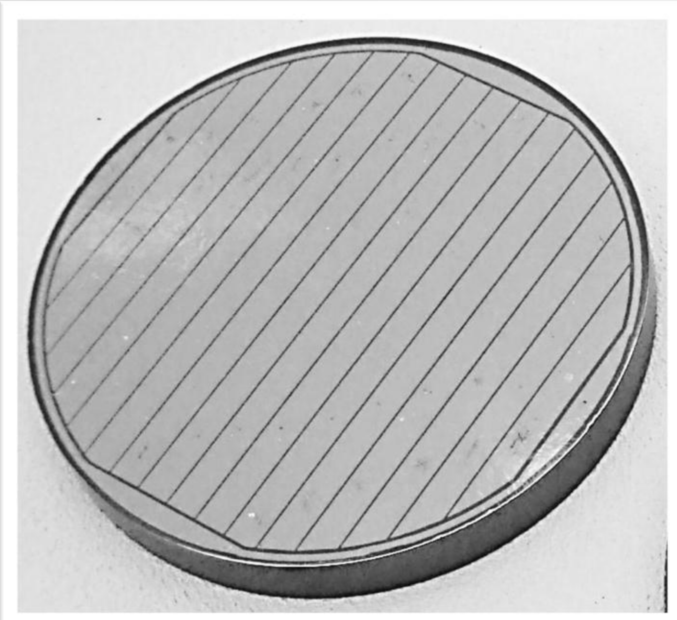
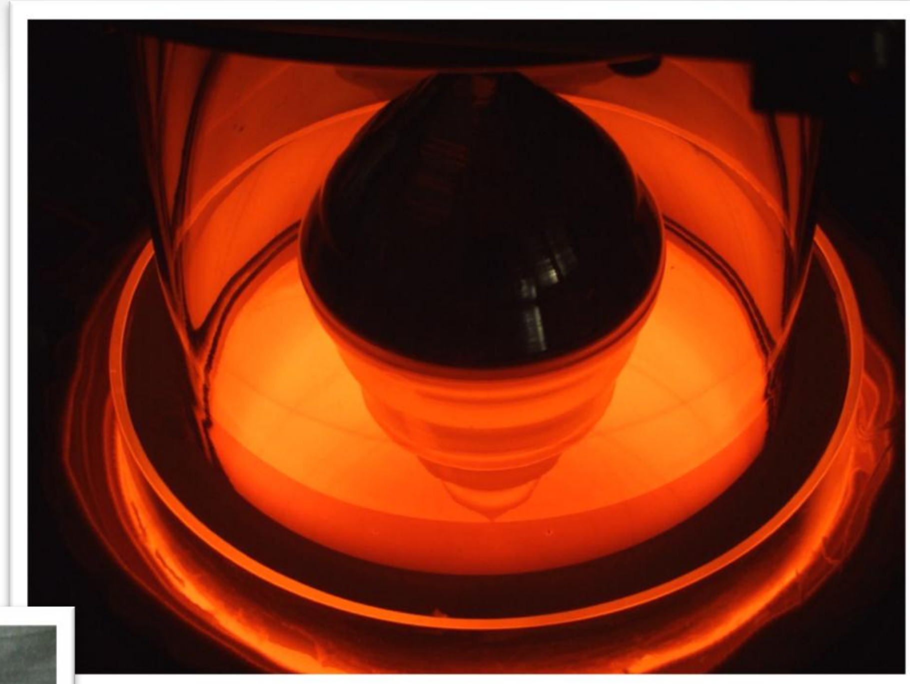
2/19/2013-4/14/2015

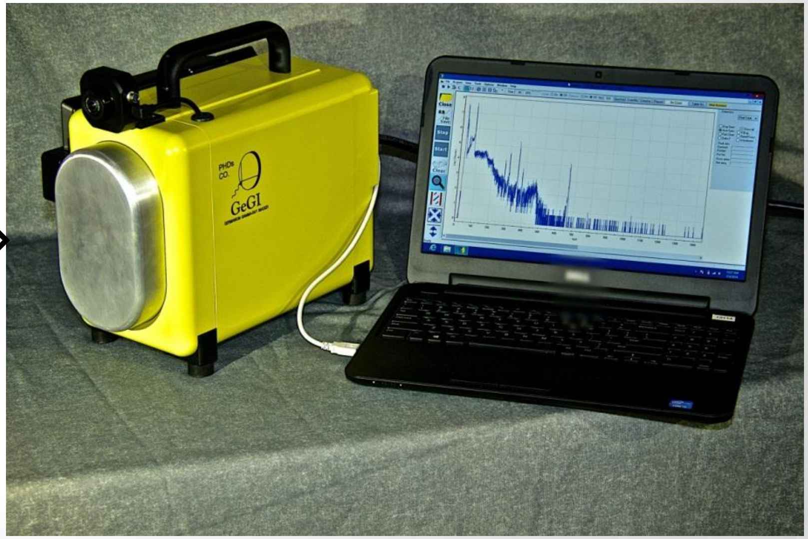
Collaboration with C.J. Lister at U. Mass Lowell

- Modular System Concept: A Complete System Solution
  - NPX-M → GeGI + GGC → MPGe next generation array concepts
  - Radiation damage
    - Charge-trap correction
    - Lower temperature from mechanical cooler
- Trap correction technique
  - Crystallography
  - Radiation damage
- MPGe System design challenges


The progression of the modular detector system
NPX LN_2 150 lbs
NPX-M 70 lbs
GeGI-1 55 lbs
GeGI-3 33 lbs
GeGI-4 28 lbs
Spect32
Power Controller







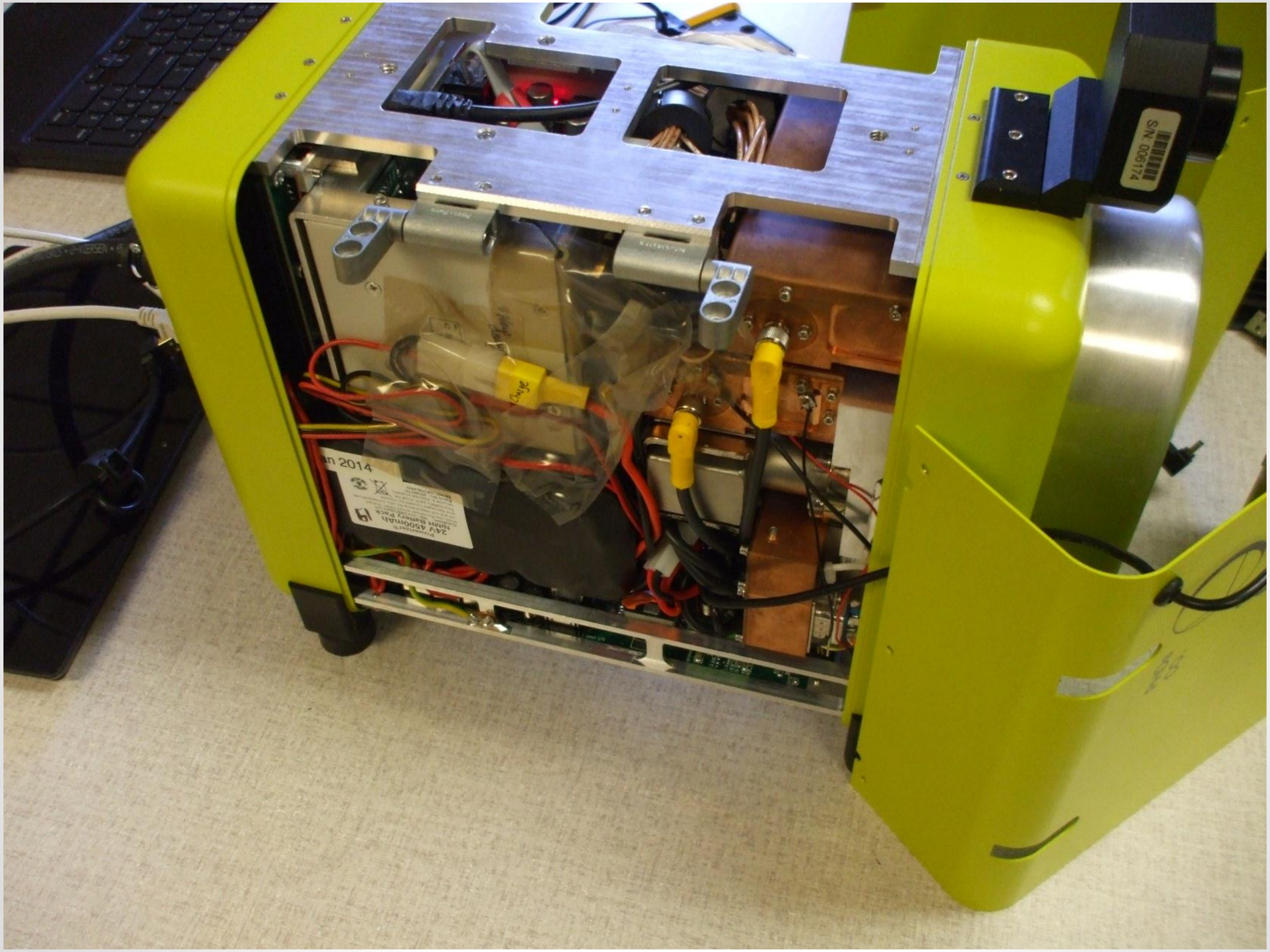
DOE Nuclear Physics supported the enabling technologies

- Segmented Detector Fabrication
- Mechanically cooled systems
- Large diameter crystal growth

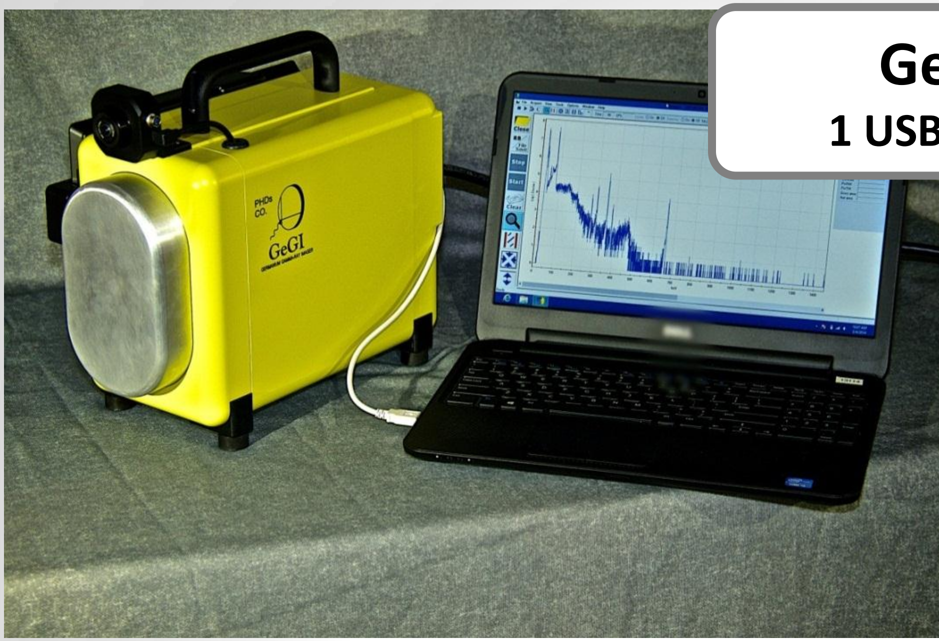
Detector Fabrication

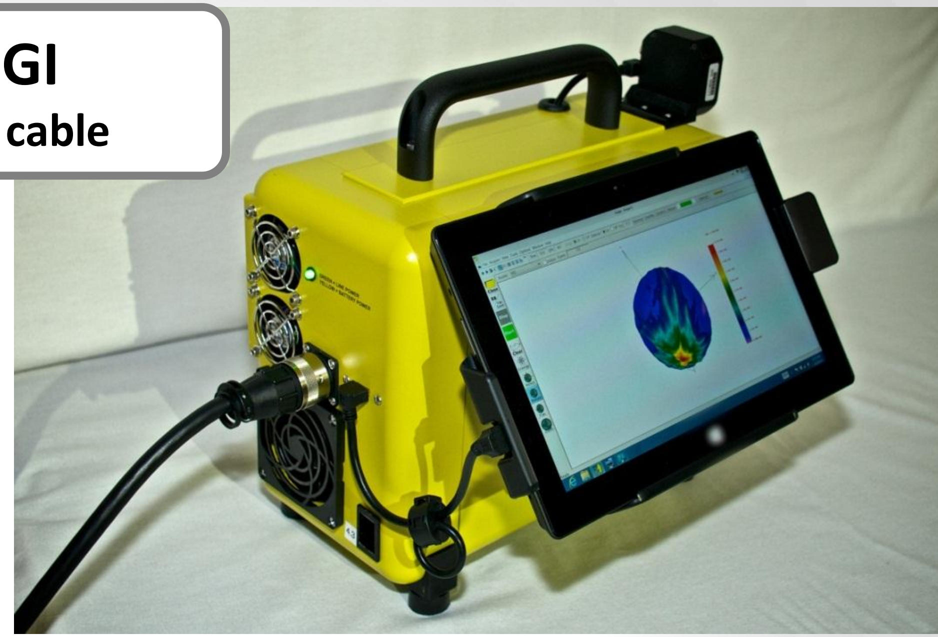
GeGI Detector

16x16 Orthogonal strips, 5 mm pitch, 0.25 mm gaps, 10-mm thick, 90-mm diameter

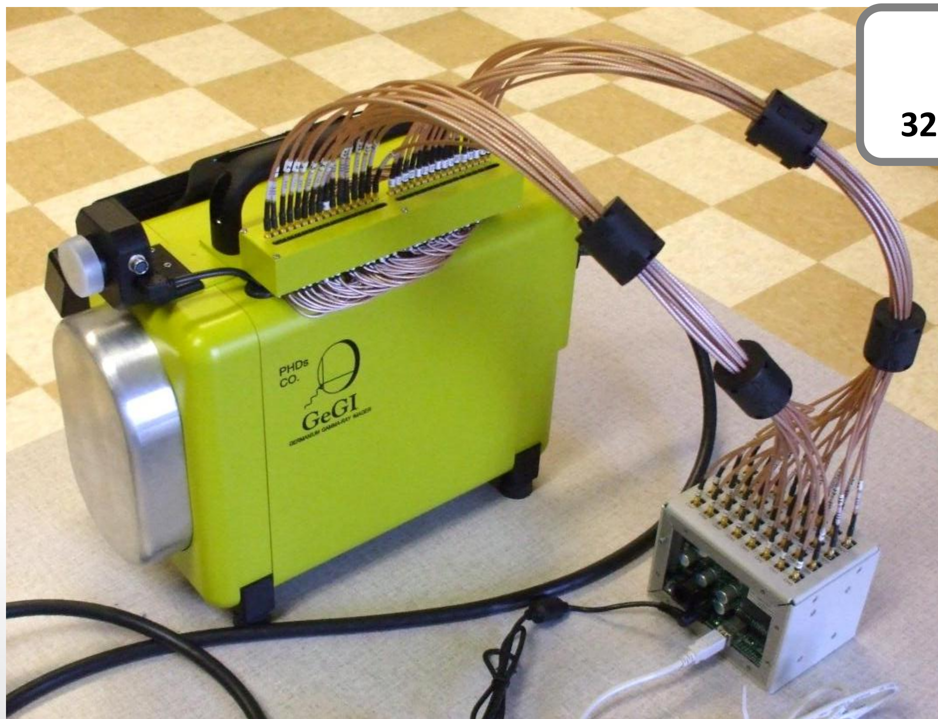

an 2014
S/N: 006174

GeGI
1 USB cable

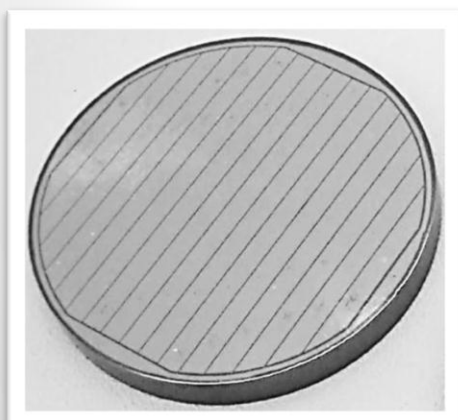




GeGI
32 preamplifier outputs

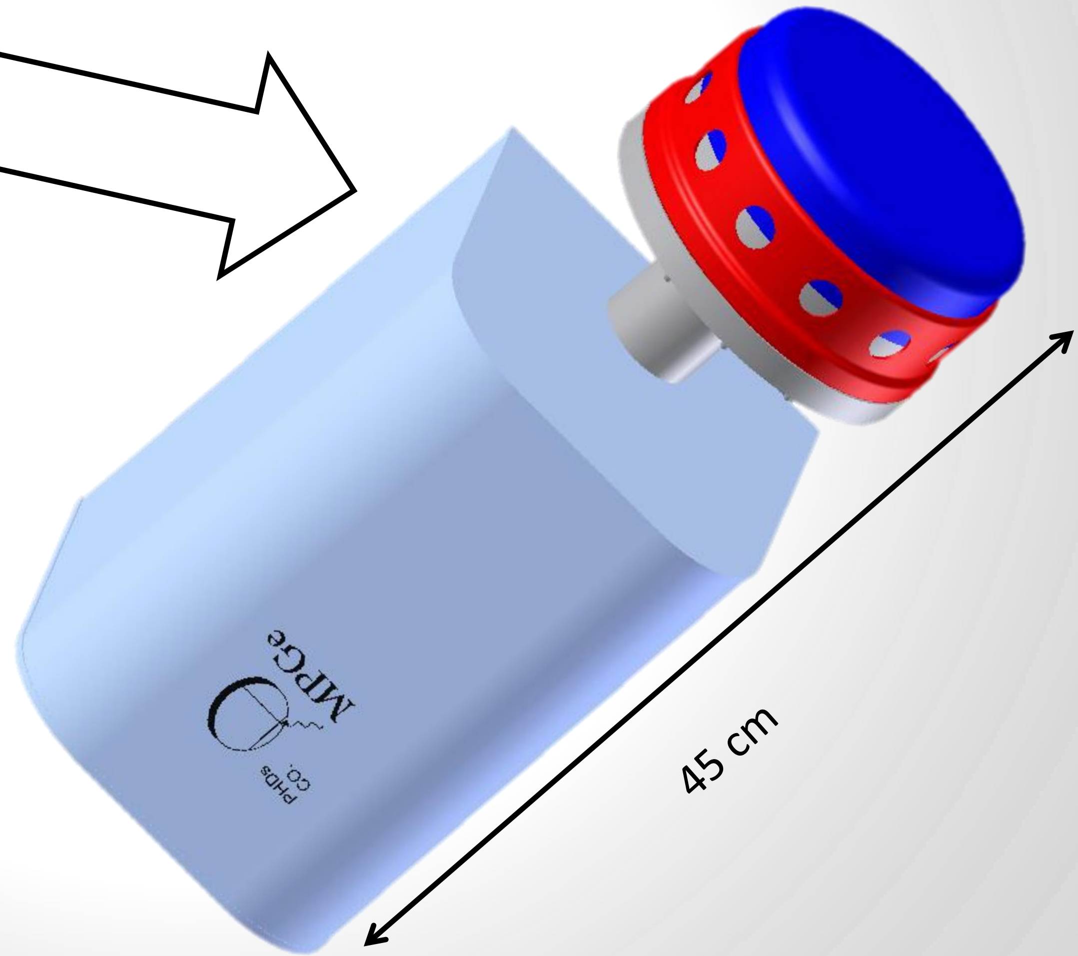


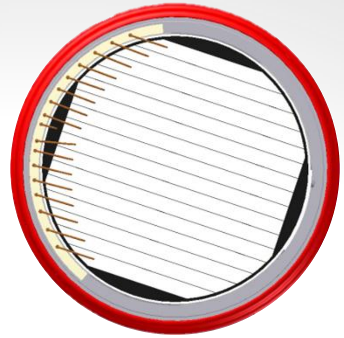
GeGI (2014)



(x, y, z, Energy)

MPGe System for Nuclear Physics





MPGe

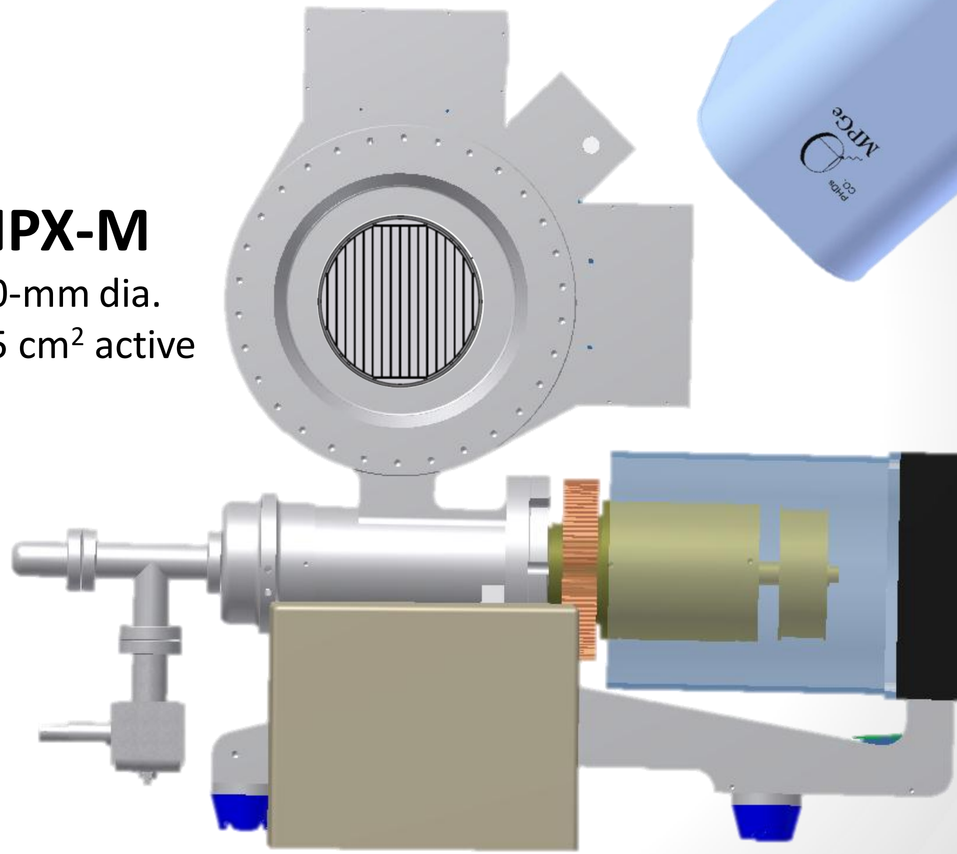
140-mm dia.

133 cm^2 active
(x2.4)

NPX-M

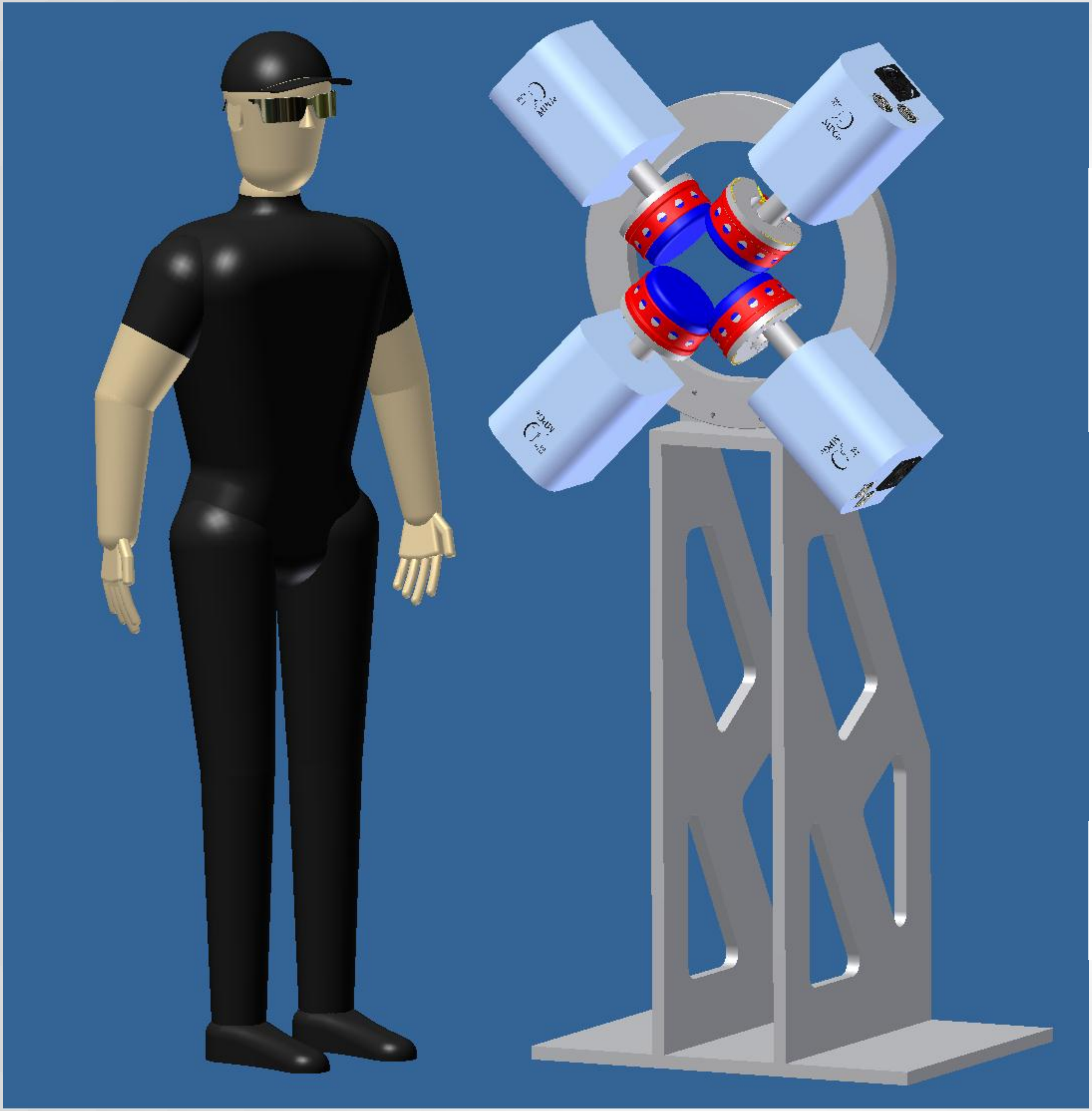
90-mm dia.

55 cm^2 active



Less hardware around the detector

Greater detector area



MPGe
4-Detector Array

14.7 cm face to face
2π solid angle coverage
6 ft. tall

Close proximity
Higher luminosity
→ More radiation damage!

Radiation damage and rate considerations: Next generation heavy ion array

From 10 particle*nA → I particle*μA (x100)

Detector is ~ 10 cm from a 1 mg/cm^2 Pb target

X- and gamma-ray count rate ~ 40 kcps/strip

Advantage of smaller strip segments

Fast fission neutrons ~ $4x10^3$ $n/cm^2/sec$ x 2 weeks = $5x10^9$ n/cm^2

~ 2 week runs offers reasonable physics measurements stats

Resolution degradation becomes visible at ~10^8 n/cm^2 level.
Resolution degradation can be severe at ~10^9 n/cm^2 level.

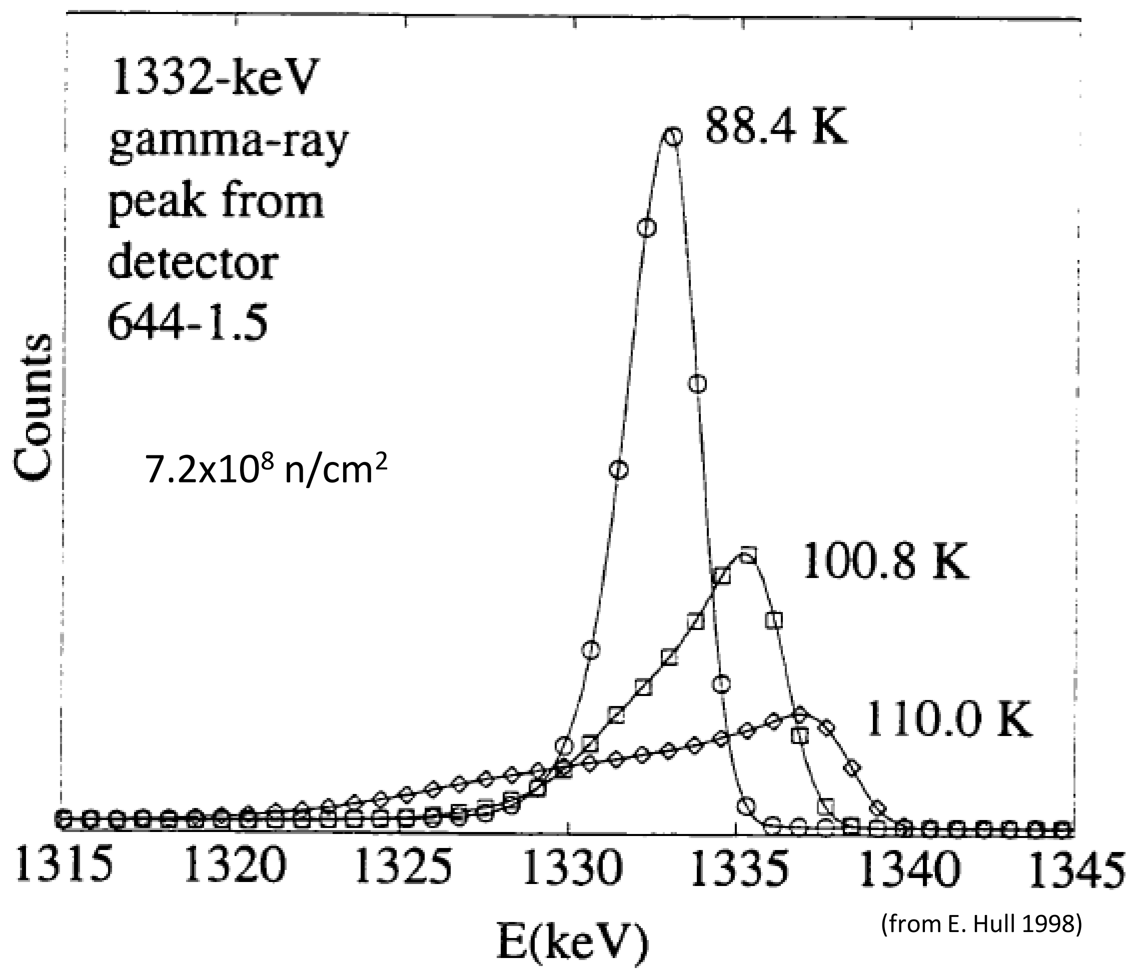
Two unique tools we have with MPGe planar detector concept

1. Temperature
2. Charge collection physics

Temperature sensitivity of radiation damage …

1. Temperature. Higher temperature → more hole trapping

Mechanical cooler affords operation at temperature below 77 K



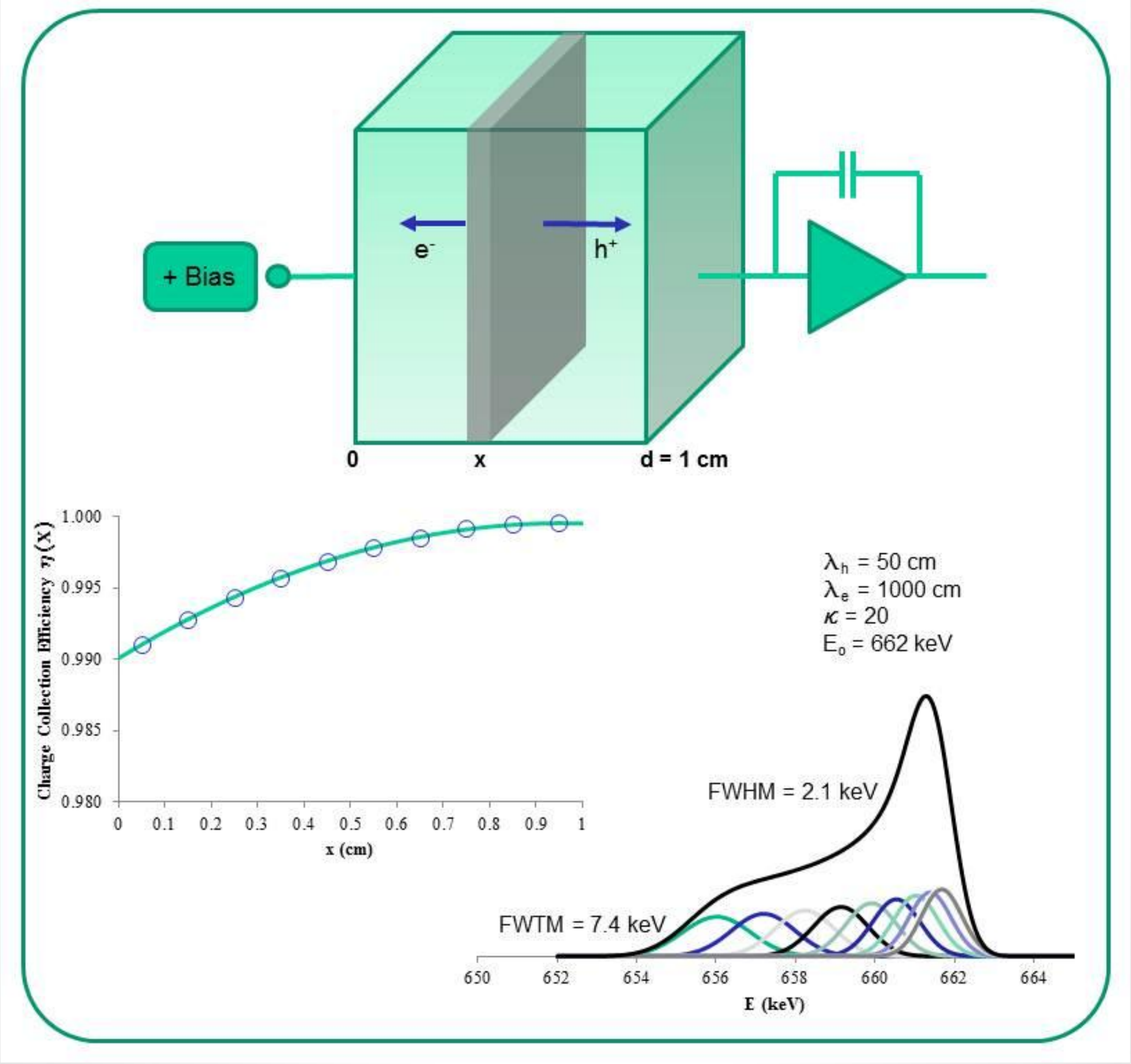
(from E. Hull 1998)

And geometry is the reason trapping degrades the resolution ….

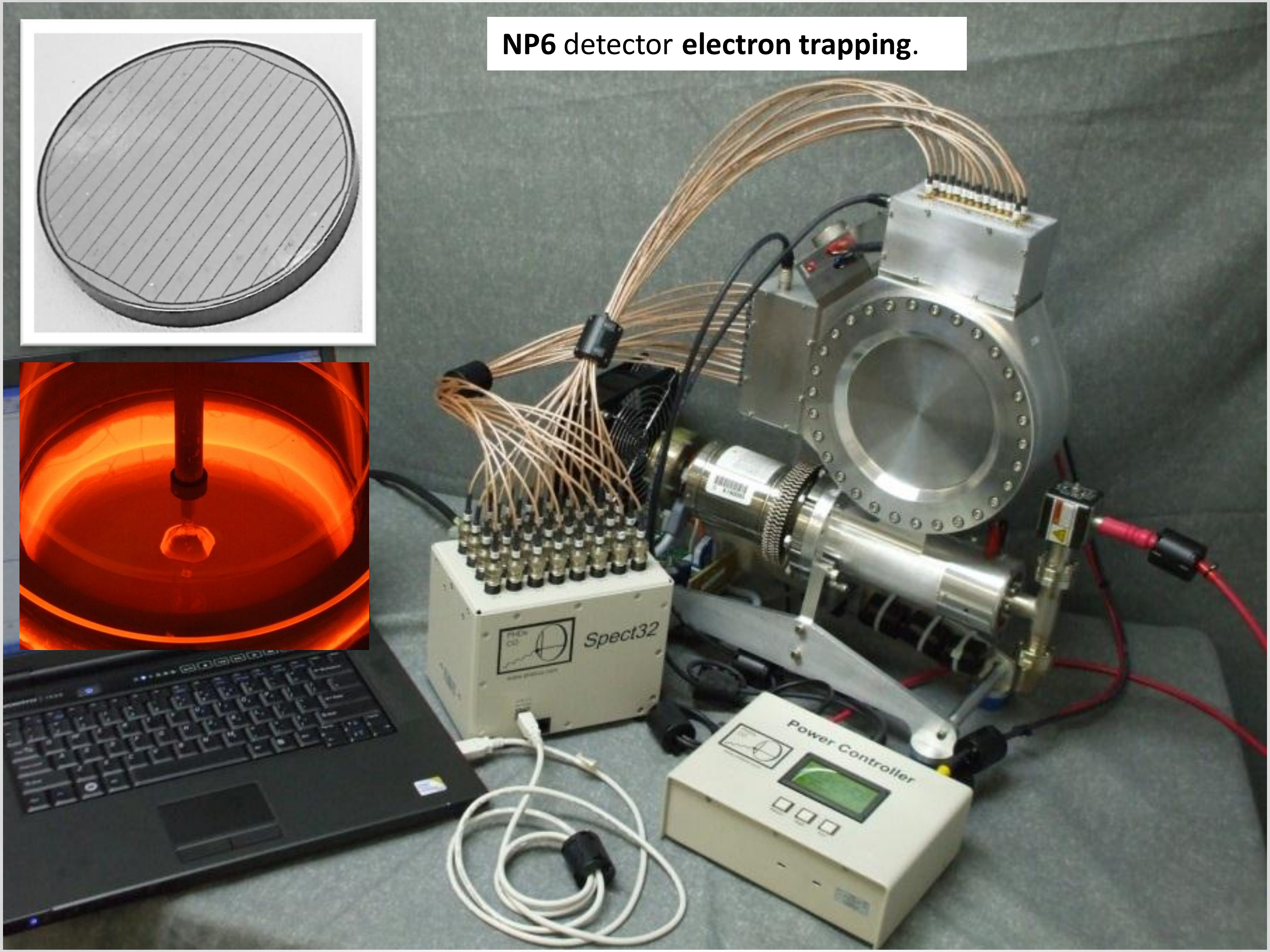
2. Charge collection physics

Gamma-ray energy resolution degradation is caused by depth variation

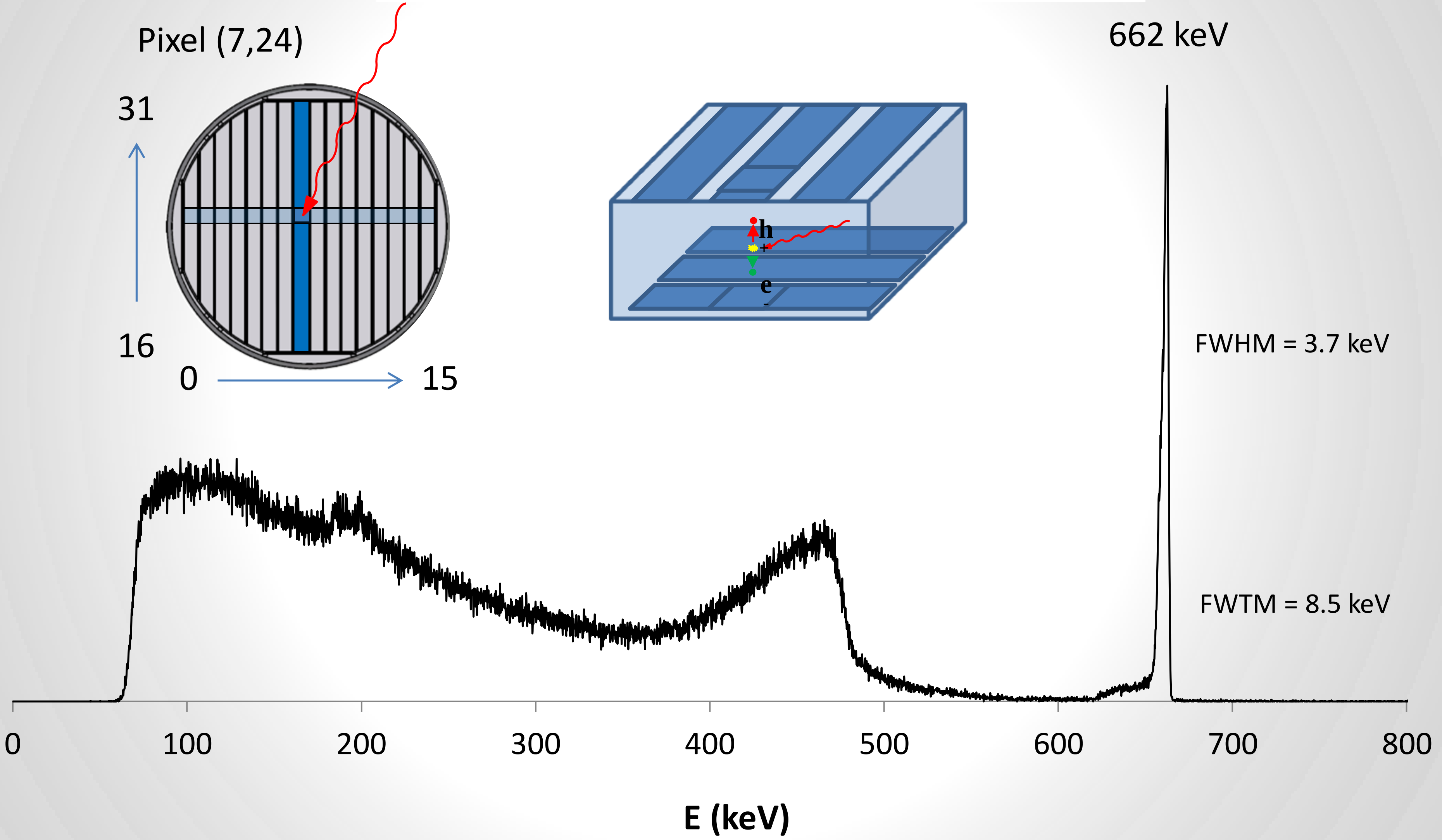
Strip detector CFD Timing of electrons vs. holes (depth) → Trap corrector



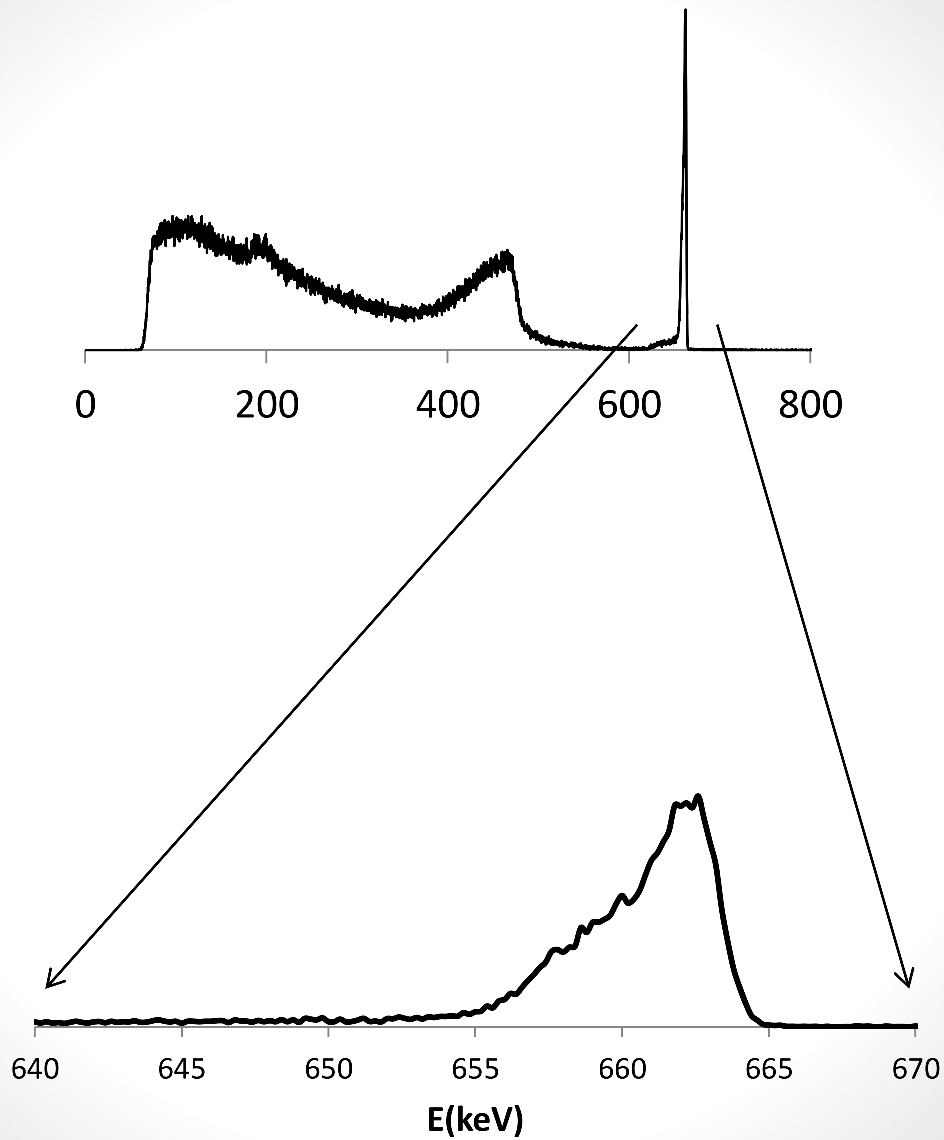
NP6 detector **electron trapping**.



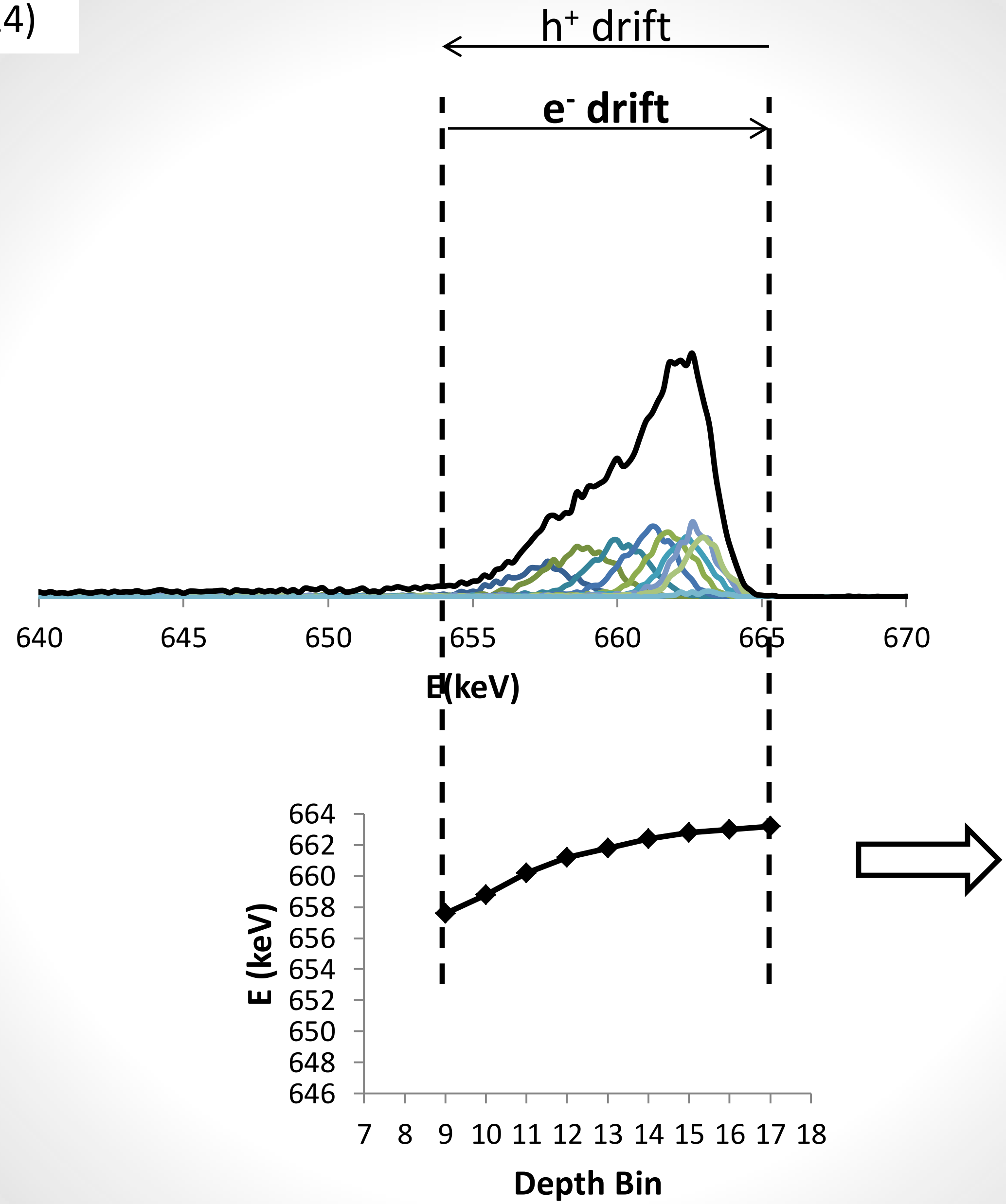
NP6 Pixel (7,24) Energy spectrum.
Pixel is a timing coincidence between 7 and 24.
Electron trapping.



NP6 Pixel (7,24)

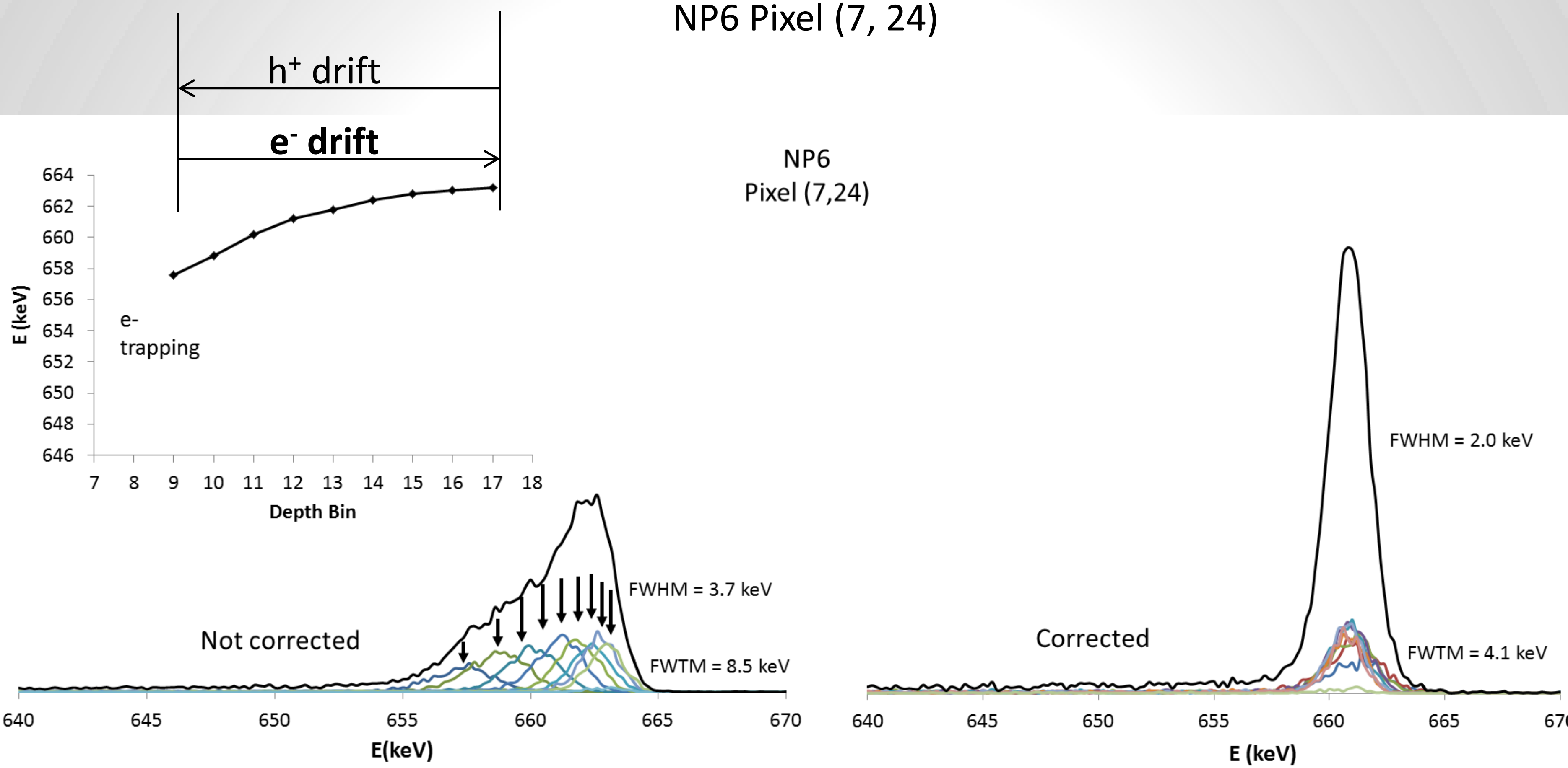


NP6 Pixel (7,24)



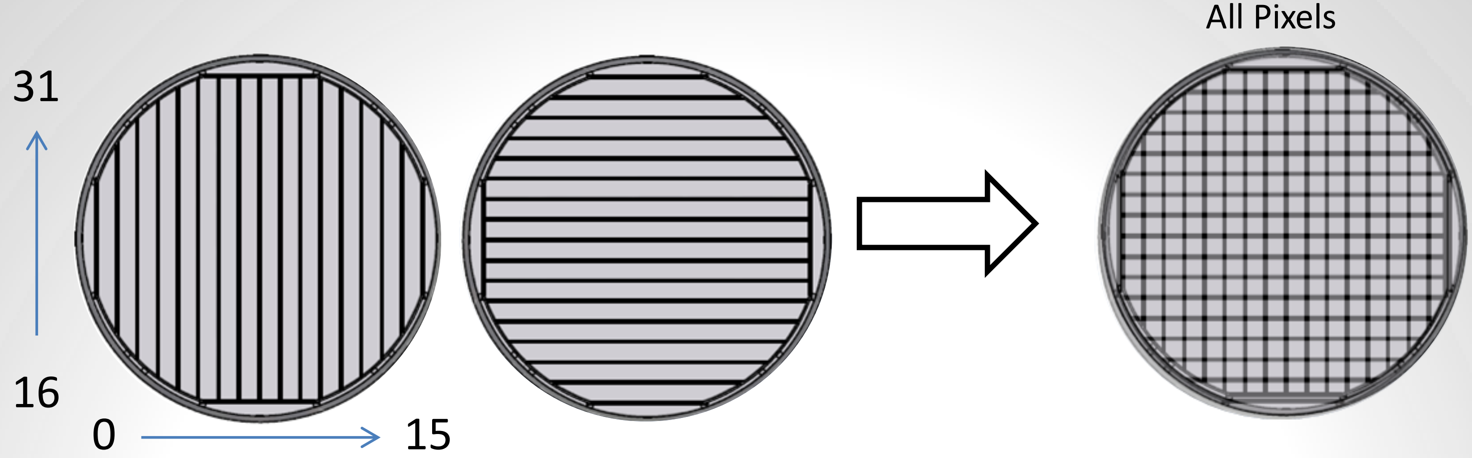
A correction factor for each depth of Pixel (7,24)

Measurement and application of the charge trap corrector
NP6 Pixel (7, 24)

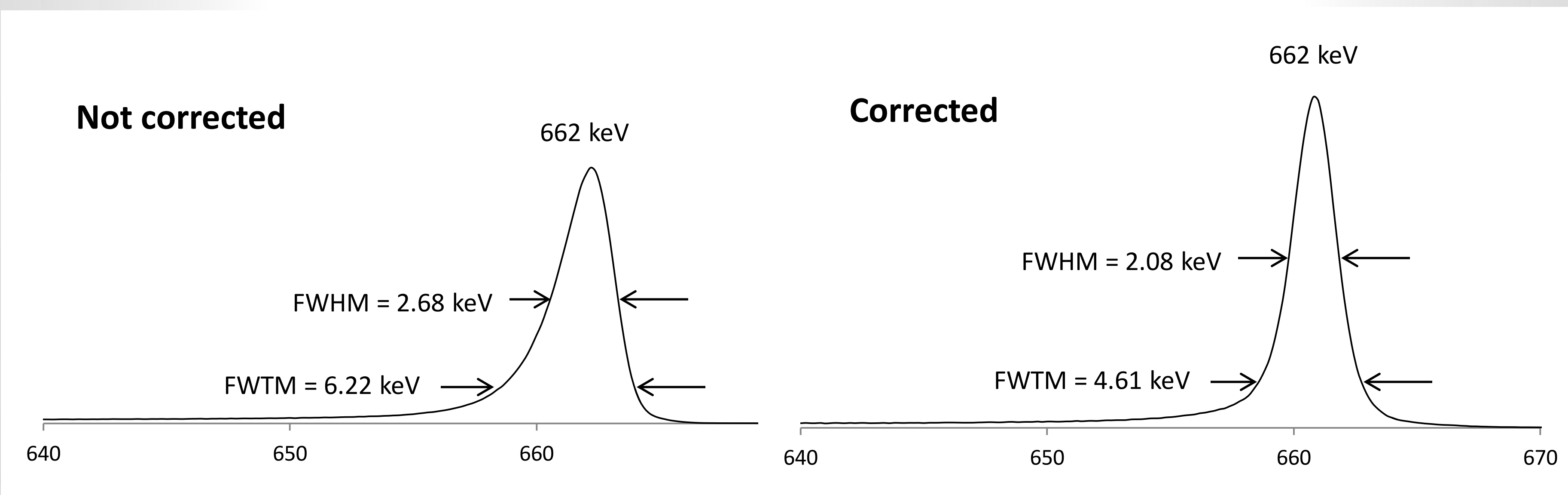


Event by event correction

and the rest of the pixels…

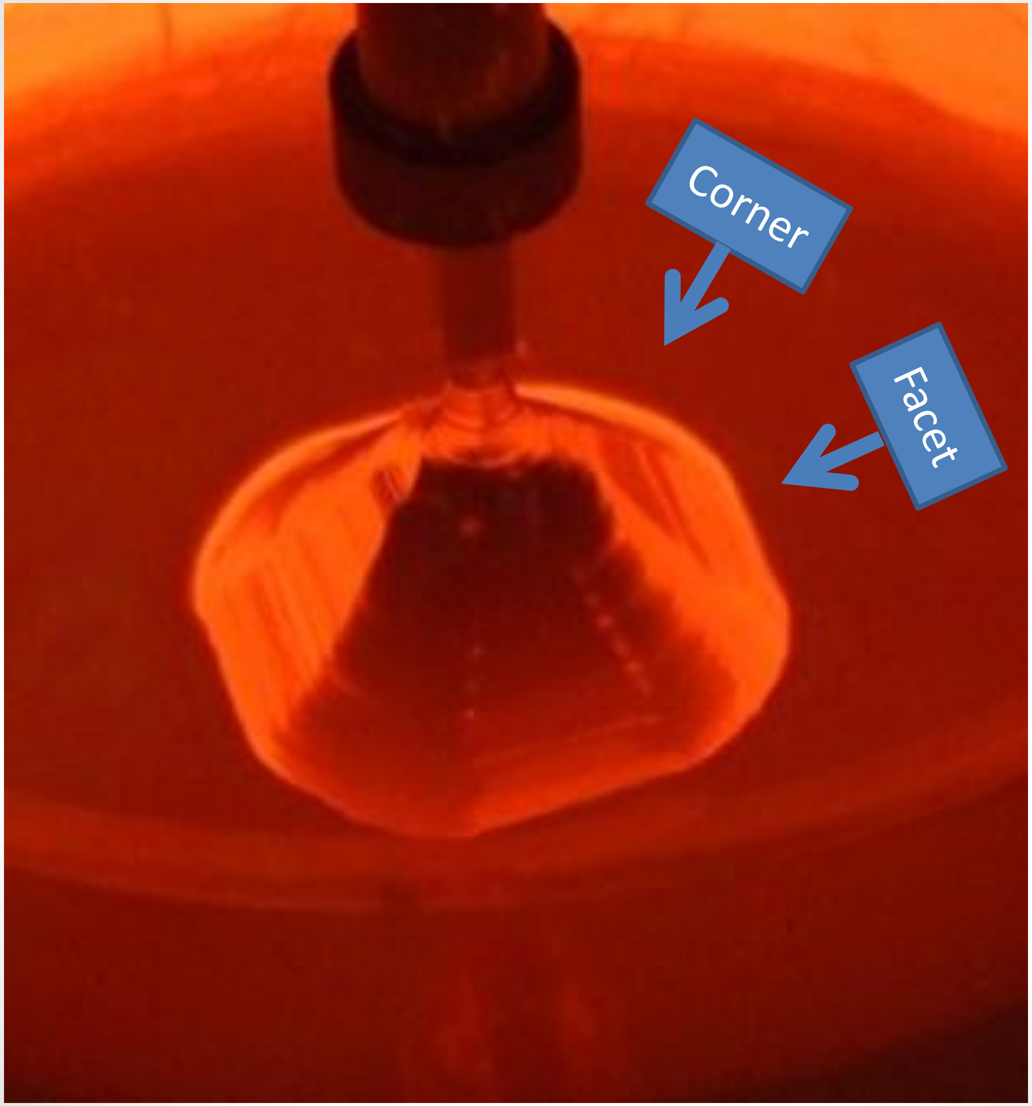


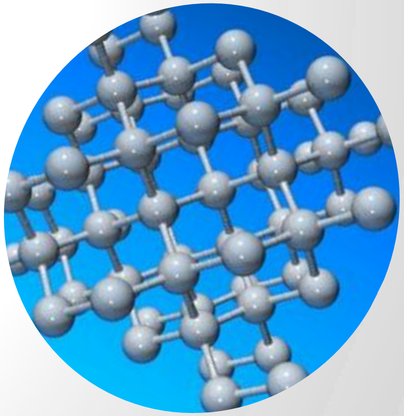
Sum of all Pixels (Pixel Total)
Energy spectrum from the whole detector



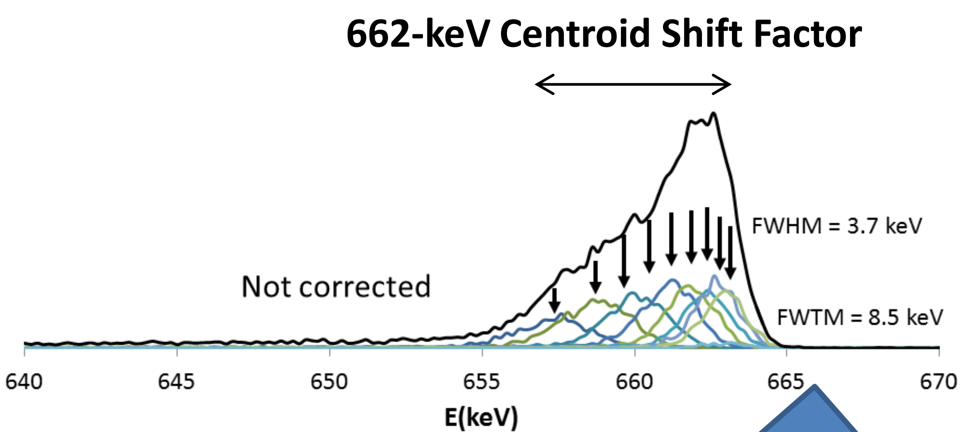
This is electron trapping from a Ge crystal **as grown** ….

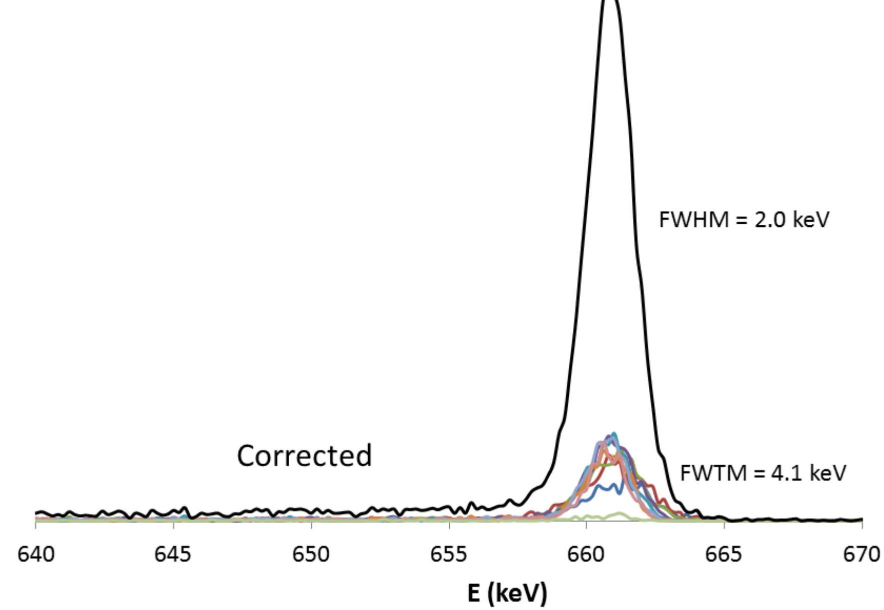
Electron trapping in a (1 0 0) HPGe crystal

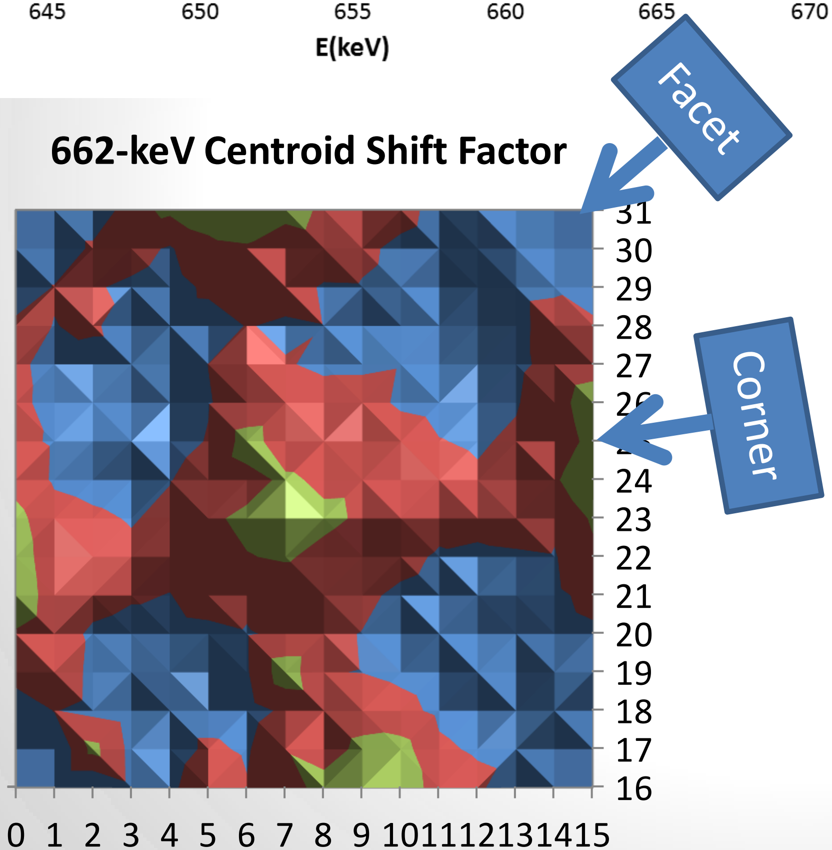


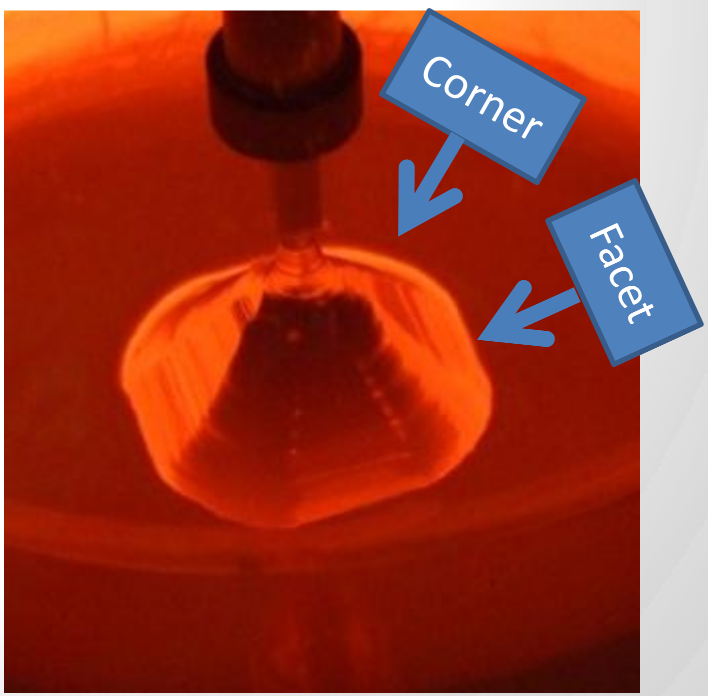


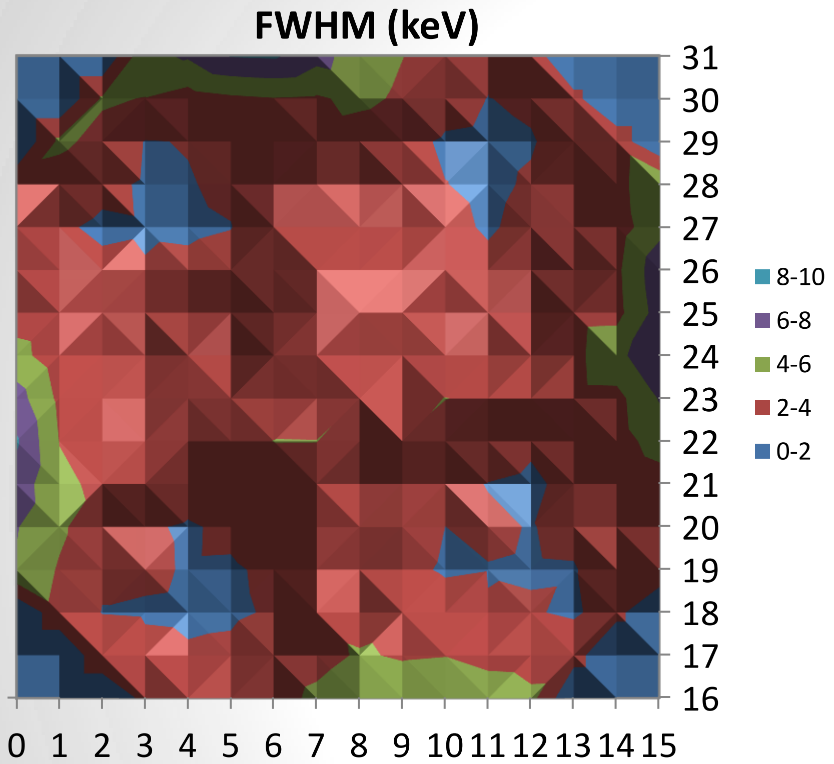
Four-fold “square” symmetry of (1 0 0) axis

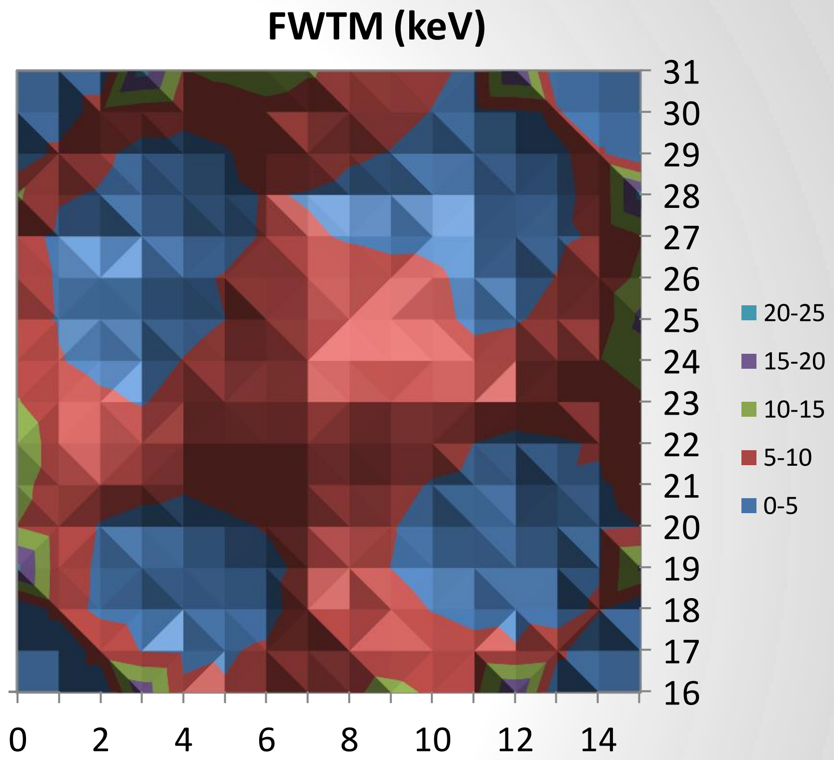

662-keV Centroid Shift Factor
Not corrected
FWHM = 3.7 keV
FWTM = 8.5 keV
640 645 650 655 660 665 670
E(keV)


FWHM = 2.0 keV
Corrected
FWTM = 4.1 keV
640 645 650 655 660 665 670
E (keV)


662-keV Centroid Shift Factor
Facet
Corner
31 30 29 28 27 24 23 22 21 20 19 18 17 16
0 1 2 3 4 5 6 7 8 9 101112131415

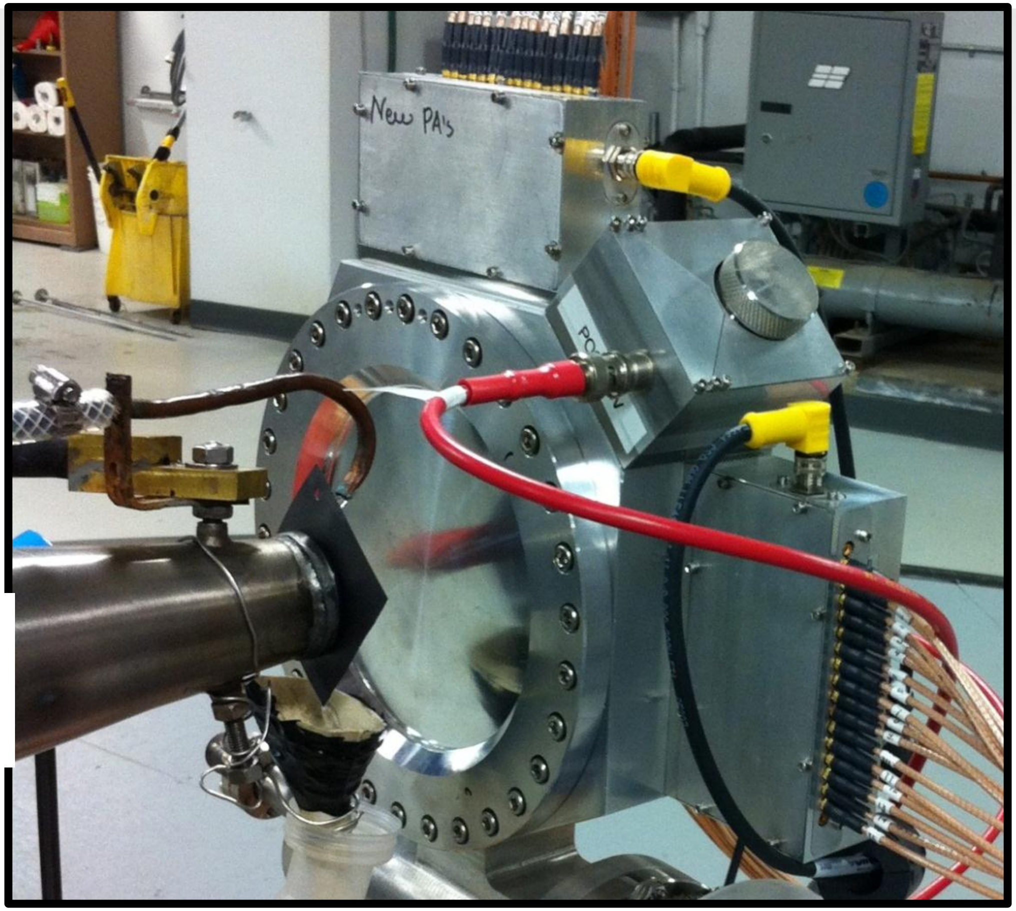

Corner
Facet





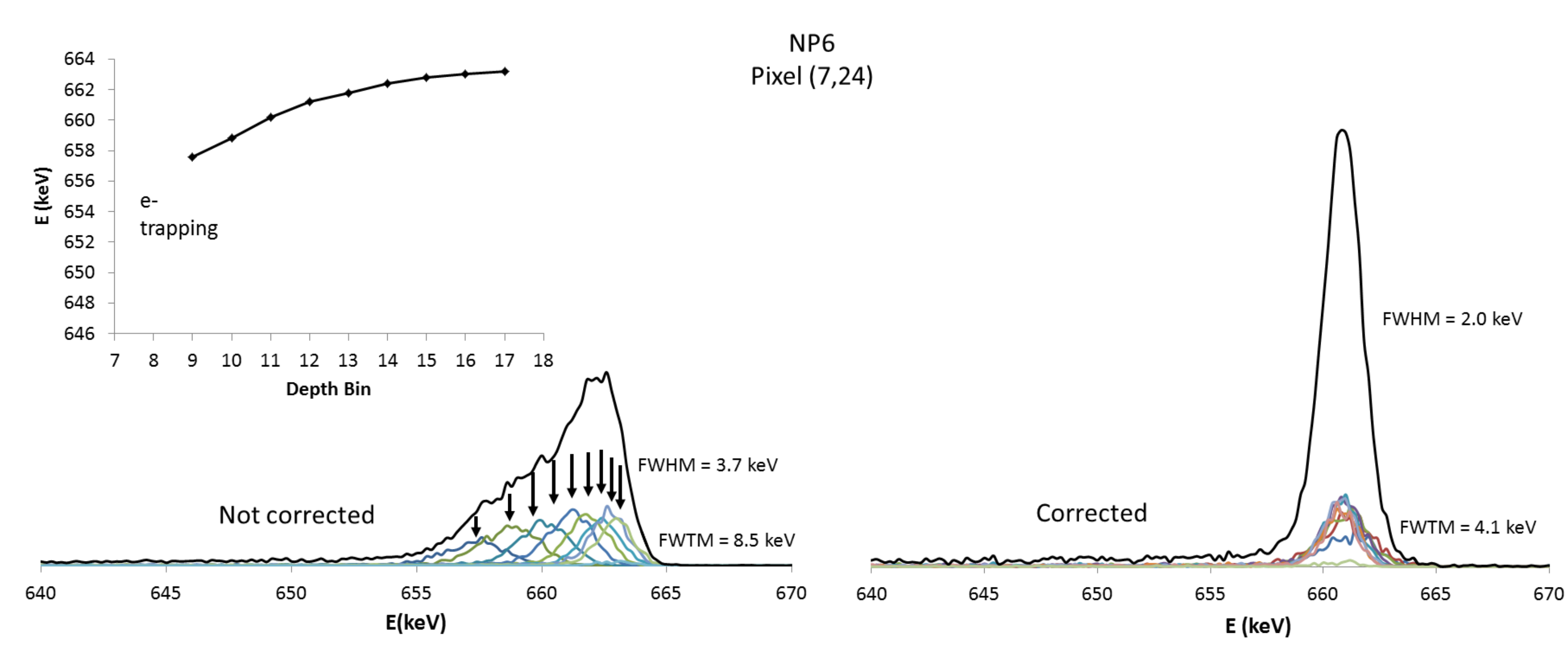
1. Trap correction
2. A map or image of charge collection properties !!

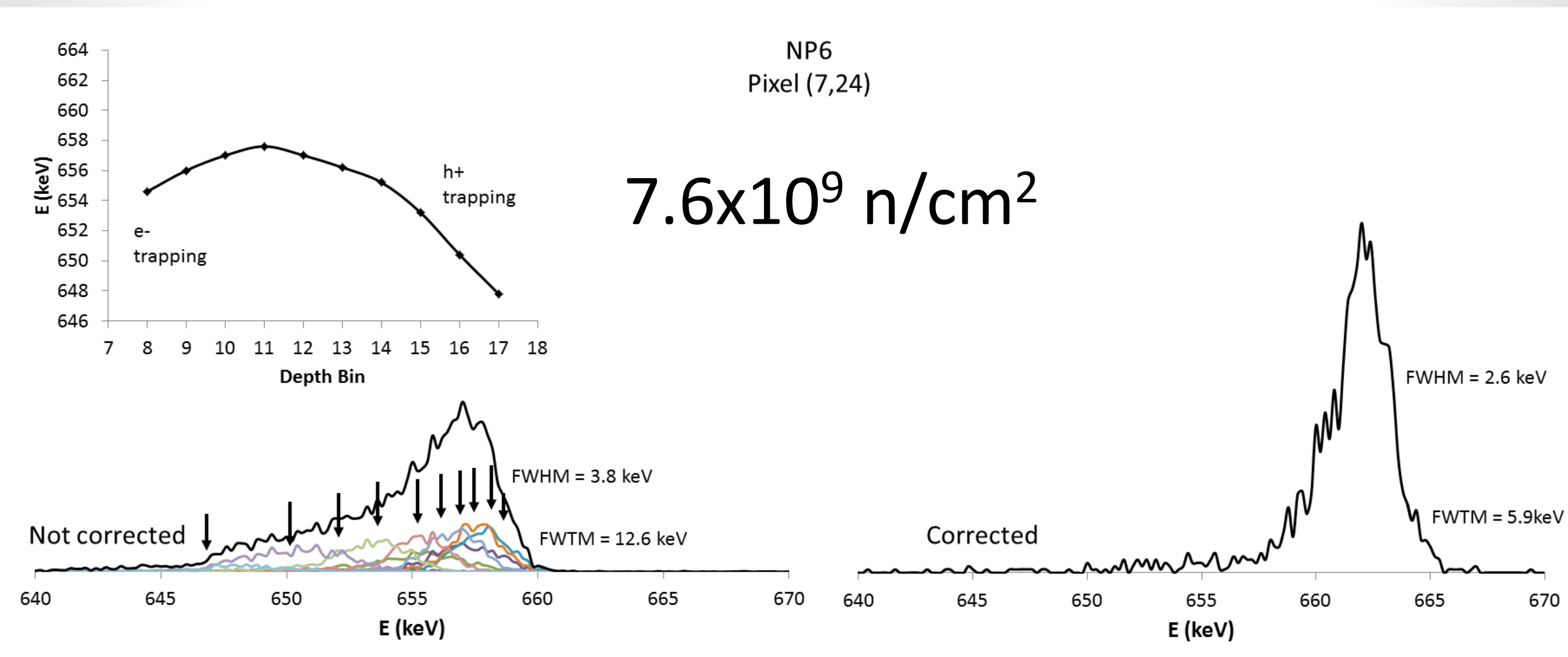
Radiation Damage experiment at UMass Lowell (Kim Lister)



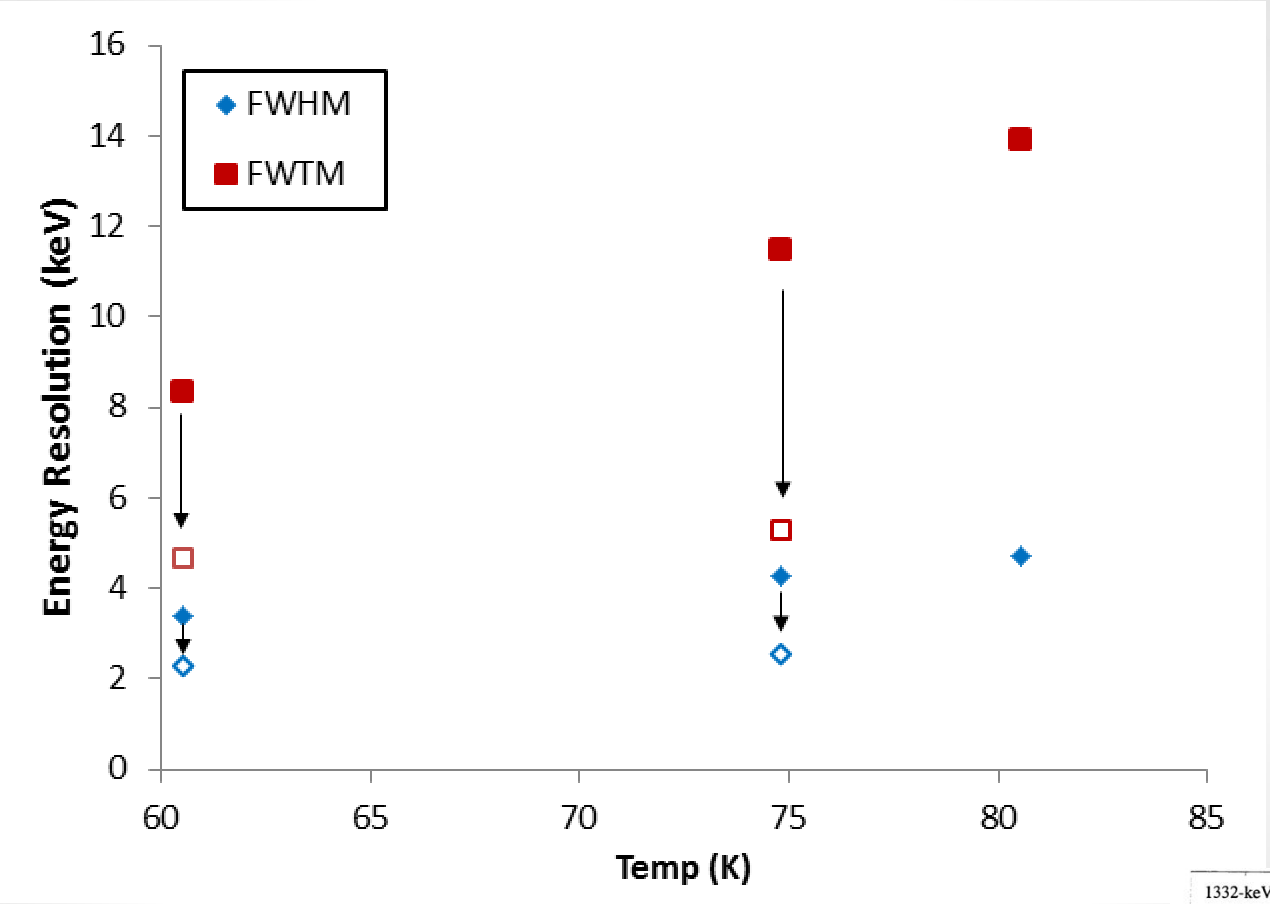
3.7 MeV protons →
$^{7}Li(p,n)^{7}Be$
→ 2.0 MeV neutrons

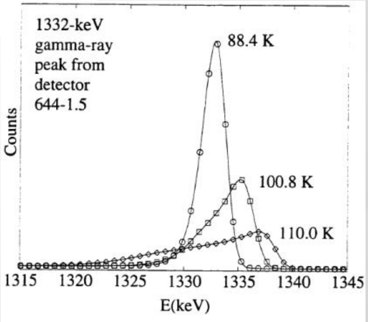
Detector	Neutron Fluence (n/cm^2)	No Correction		Correction		T (K)
		FWHM (keV)	FWTM (keV)	FWHM (keV)	FWTM (keV)	
NP3	0	1.88	3.81	1.85	3.51	75.0
NP6	0	2.68	6.22	2.07	4.60	77.0
NP3	**9.0x10^9**	4.31	11.68	2.52	5.08	75.0
NP6	**7.6x10^9**	5.02	12.72	3.12	6.08	77.0


NP6
Pixel (7,24)
E (keV)
Depth Bin
e-
trapping
Not corrected
FWHM = 3.7 keV
FWTM = 8.5 keV
E(keV)
Corrected
FWHM = 2.0 keV
FWTM = 4.1 keV
E (keV)


NP6
Pixel (7,24)
E (keV)
Depth Bin
e-
trapping
h+
trapping
$7.6x10^9$ n/cm^2
Not corrected
FWHM = 3.8 keV
FWTM = 12.6 keV
E (keV)
Corrected
FWHM = 2.6 keV
FWTM = 5.9keV
E (keV)

NP3 9.0×10^9 n/cm^2





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Charge-trap correction and radiation damage in orthogonal-strip planar germanium detectors

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ABSTRACT

A charge-carrier trap correction technique was developed for orthogonal strip planar germanium gamma-ray detectors. The trap corrector significantly improves the gamma-ray energy resolution of detectors with charge-carrier trapping from crystal-growth defects and radiation damage. Two orthogonal-strip planar germanium detectors were radiation damaged with 2-MeV neutron fluences of $\sim 8 \times 10^9$ n/cm^2. The radiation-damaged detectors were studied in the 60–80 K temperature range.

1. Introduction

Germanium detectors have been the best gamma-ray energy spectrometers for five decades. Their excellent energy resolution is due to good charge-carrier mobility and efficient charge-carrier collection at the detector contacts. Charge-carrier trapping causes position-dependent pulse-height deficits that degrade the gamma-ray energy resolution. In germanium, trapping sites can be formed during crystal growth both thermally and through contamination [1–3]. Nuclear collisions between energetic massive particles, such as protons and neutrons, and germanium nuclei create giant disordered regions in the germanium crystal [4,5]. In the depleted detector, these giant disordered regions develop a negative charge state making them preferential hole-trapping sites [6]. Radiation damage considerations are important in accelerator environments,

of Green's reciprocation theorem [7]. The relevance of Green's theorem to semiconductor-detector signal induction is often described as the "weighting field" effect, the "near-field" effect, or "Ramo's theorem" [8–13]. The gamma-ray peak shape depends on multiple factors including Compton scattering, the electrostatics of charge induction, and the degree of charge-carrier trapping [14–16]. Charge-induction electrostatics have been recognized and used to correct some level of hole trapping in radiation-damaged coaxial germanium and segmented coaxial detectors resulting in improved gamma-ray peak shapes [17–20]. Building on this earlier work, we have developed a charge-carrier trap correction technique or "trap corrector" specifically for orthogonal-strip planar germanium detectors. A planar trap corrector provides a unique view of charge-carrier trapping because charge carriers drift in a single crystallographic direction, unlike a coaxial

MPGe

Radiation damage
- Temperature
- Trap corrector

Modular Design + larger crystals
- Low-overhead arrays
- Greater solid angle coverage
- Lower cost