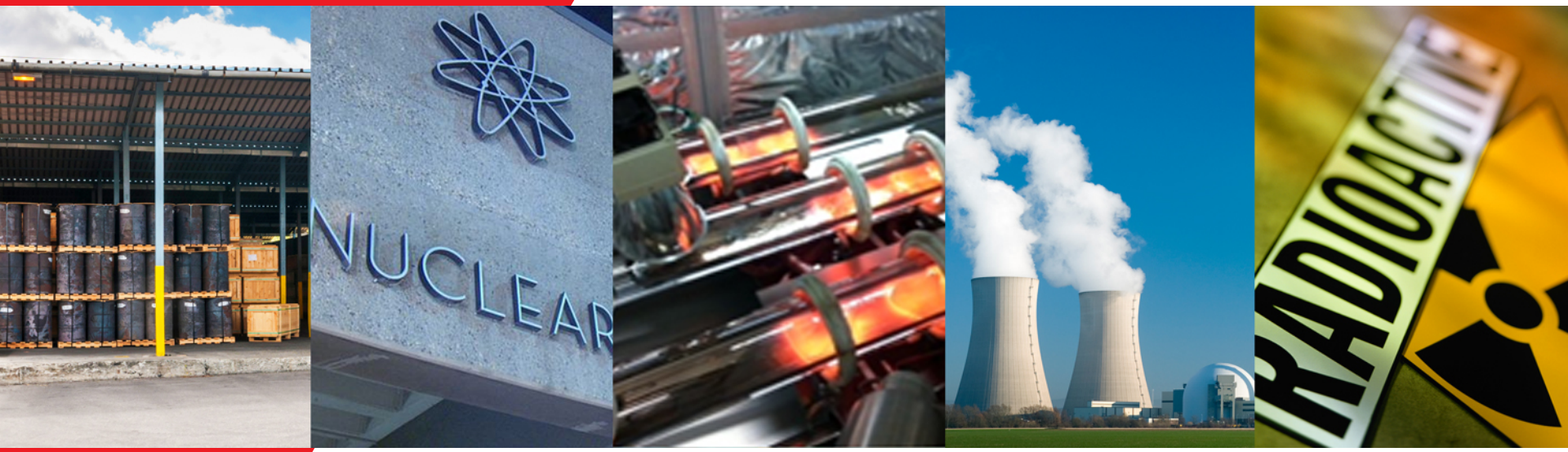
ORTEC®

AMETEK®



12 September 2017
Milan, Italy

Advanced and Special Detector Programs from ORTEC – Historical and Next Step Perspective

Elaine G. Roth

ORTEC Overview

ORTEC®

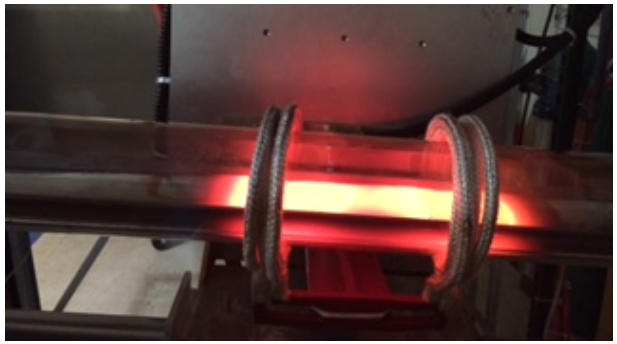
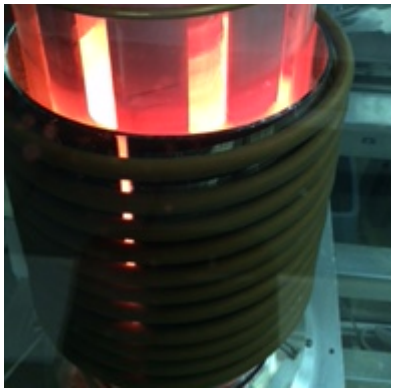
ORTEC was founded in 1960 by researchers from Oak Ridge National Labs to commercialize charged particle detectors

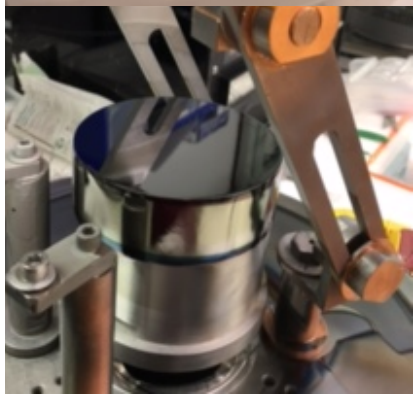
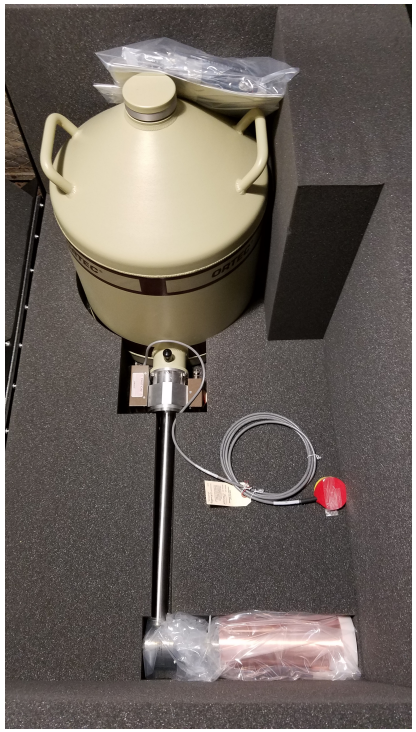
- **Headquarters:** Oak Ridge, TN with global sales and service offices
- **Employees:** 300+ worldwide
- **Core focus:** Ionizing radiation detection, identification and analysis instruments and systems
- **Ownership:** AMETEK, Inc., a leading global manufacturer of electronic instruments and electromechanical devices with 2015 sales of $4.0 billion

ORTEC's Detector Manufacturing

ORTEC®

- Vertically integrated
  - *High purity germanium crystal growth*
  - *HPGe shaping*
  - *HPGe fabrication*
  - *Detector assembly and testing*
- Special and advanced detector systems – design and fabrication
- Technology advancement – detector development with 70 + years of experience with radiation detection and cryostat design and cooling

HP Germanium detector production

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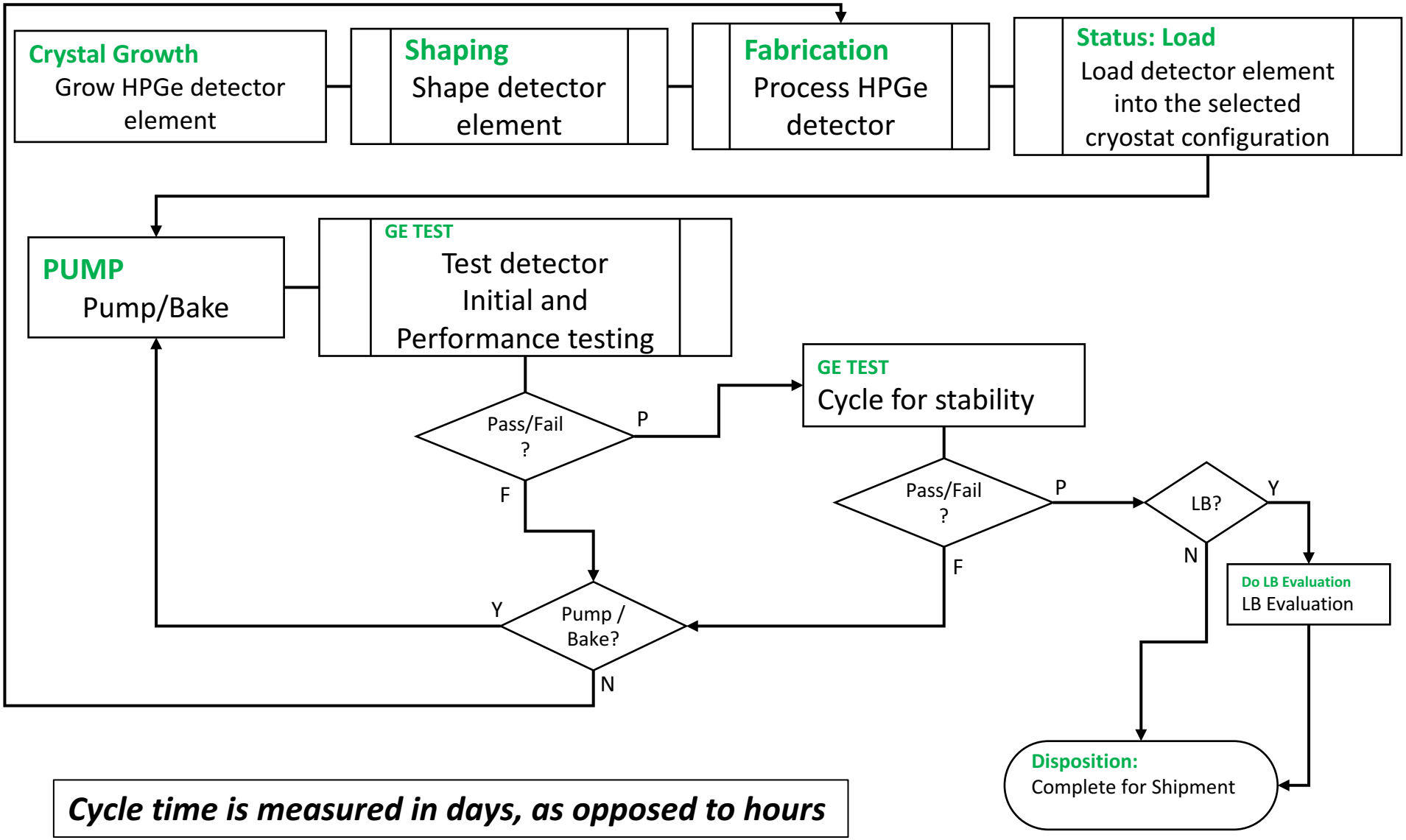

Cycle time is measured in days, as opposed to hours

Overview

ORTEC®

- **ORTEC's special detectors history**
  - *Gamma Sphere*
  - *First generation clovers*
  - *Double sided Ge strip detectors*
  - *Discrete element Array detectors*
  - *Segmented*

- **Current capabilities**
  - *Next generation clovers*
  - *Special point contact technology*
  - *PopTop/Encapsulated*
  - *Low background and very low background applications*
  - *Double sided Ge strip detectors*
  - *Advanced complex detector systems*

Advance Special Detector History

ORTEC®

Advance Detector	First Unit built	Number of Units built	Application Examples
Gamma Sphere	Early 1990s	110+	Nuclear Physics, beamlines
Clover Detectors	Mid 1990s	20+	Nuclear Physics, Health Physics
Point Contact (coaxial, semi-planar)	2009	50+	Neutrino and Dark Matter, High Resolution Spectrometry, Safeguards
PopTop/Encapsulated	Mid 1980s	Hundreds	Multi-detector (limited space) or multi-orientation, electro-mechanical coolers
Double Sided Strip Detectors	Early 2000	Several	Nuclear physics, Beamlines, Imaging, Medical
Shields, Low Background Hardware	1970s	Hundreds	Low count rate, Underground low background studies
Segmented	2000	Several	Spin Spectroscopy, Tracking, Doppler Shift
Arrays	Early 1990s	Several	Synchrotrons and beamlines, EXAFs

Gamma Sphere History

ORTEC®

Key Feature	Application Benefit
70% rel. eff. HPGe	Good efficiency at higher energies
N-type coaxial	Minimize resolution degradation due to neutron damage, annealing capability
Small, multi-orientation dewar	Spherical, compact count geometry
Detector neck	Positioning of “guard” detector to reject Compton scatter

- 24 years of operation
- Currently resides at Argonne National Lab (ANL), USA
- Custom cryostat:
  - 3L dewar
  - Remote preamp
  - Detector neck for BGO detector
  - Remote temperature readout - PRTD100 (special option)
  - Annealing capable (special option)
- On average 100-105 detectors are operation out of 110 (10 spares)
  - Exceeded original lifetime (low return/service rate)
  - Annealing and vacuum service performed on-site
  - Detectors annealed every 1-2 years (depending on position to the center)

Gamma Sphere Pictures

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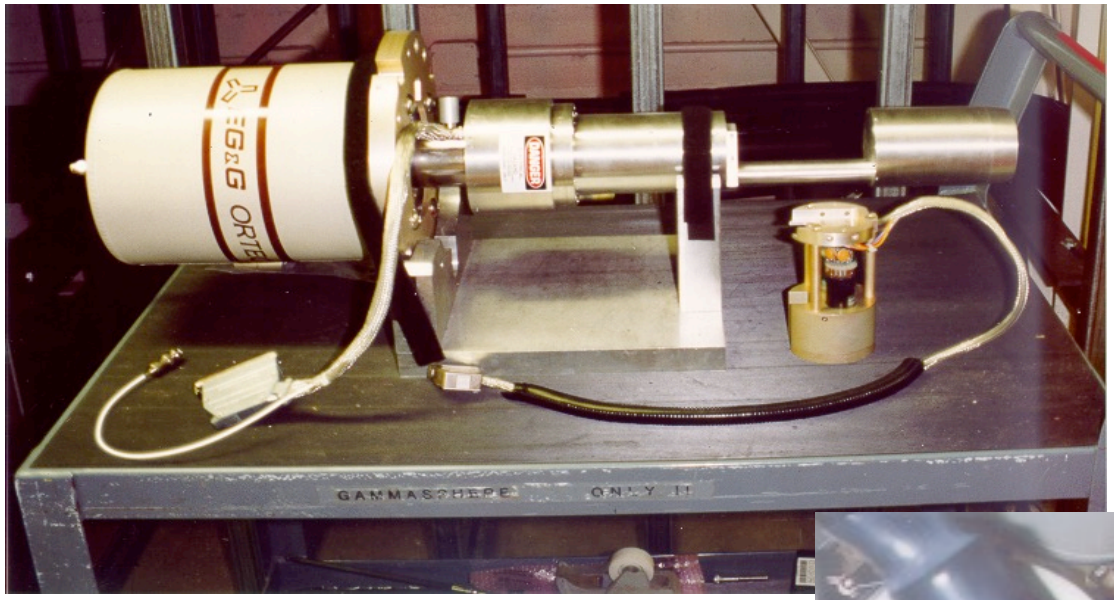
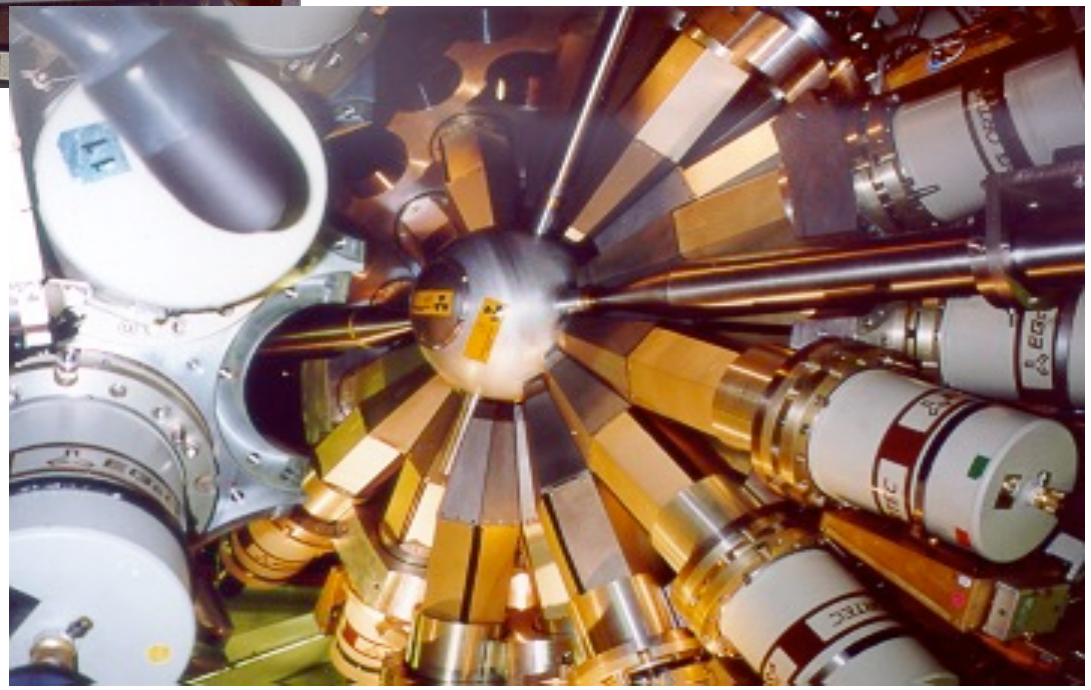
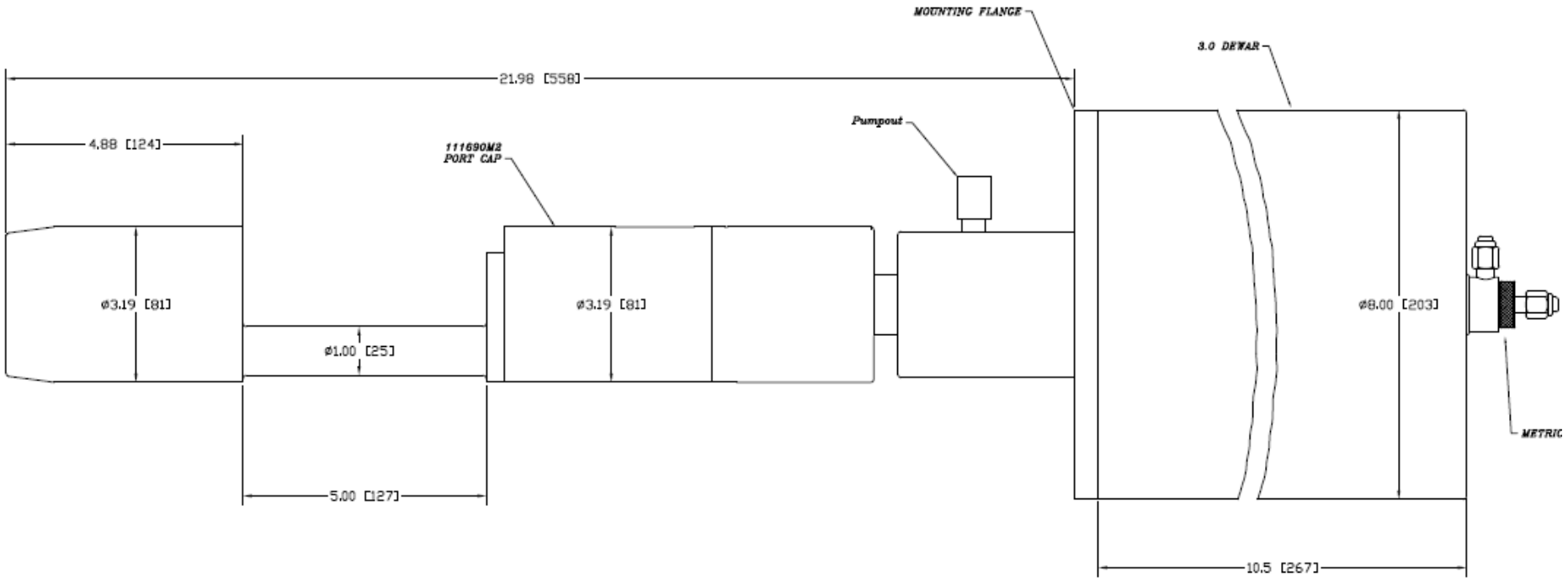




GammaSphere at Argonne National Lab
Featured in the movie Incredible Hulk

Gamma Sphere Drawing



Gamma Sphere outline drawing

ORTEC First Generation Clover History

ORTEC®

Key Feature	Application Benefit
20 to 35+% rel. eff. HPGe	Good resolution compared to a single large detector Good medium to higher energy efficiency 120-150% total rel. eff. per clover in Add-Back mode
4 HPGe detectors in Clover geometry	Close packing to minimize dead space to allow: - Scattering information - Higher throughput
N-type coaxial	Minimize resolution degradation due to neutron damage, annealing capability
Small, multi-orientation dewar Or Larger fixed orientation dewar	Spherical, compact count geometry 180 degree annihilation count geometry
Detector neck (optional)	Positioning of “guard” detector to reject Compton scatter

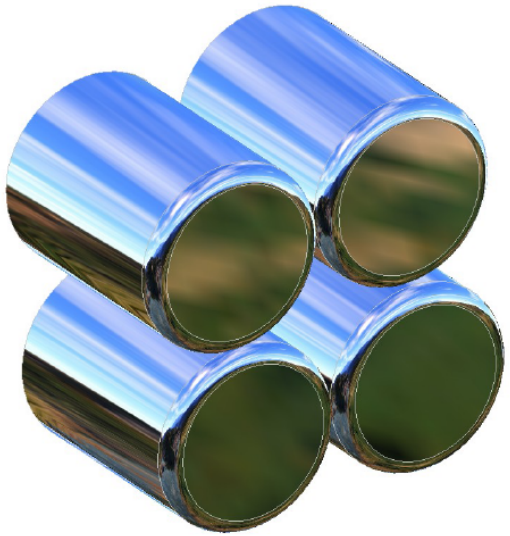
- 20+ years of experience with 20+ functional units in the field.
- A few units with segmented technology
- Multiple references available upon request

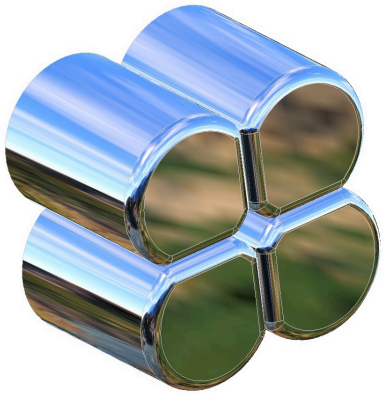
What is a CLOVER detector?

ORTEC®

- Arrangement of a group of discrete detectors that are stacked in close proximity to each other
  - *Typically a small spacing is desired between these discrete detector elements*

- Enclosed by a single endcap
- Share a common vacuum environment





*If these same discrete detector elements are shaped by slicing off the tangent edges, they may be arranged to achieve closer packing, achieving a smaller footprint

Clover detector endcap

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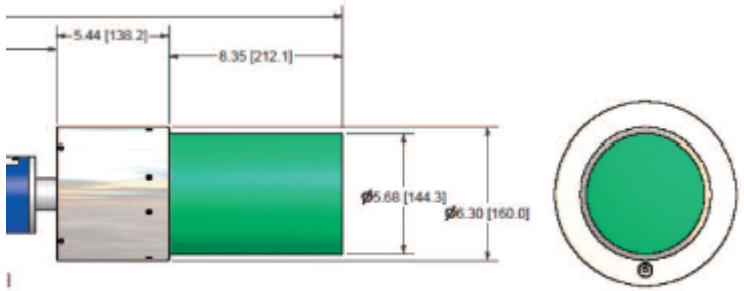
CLOVER detector may have:

1) Square endcap without a taper

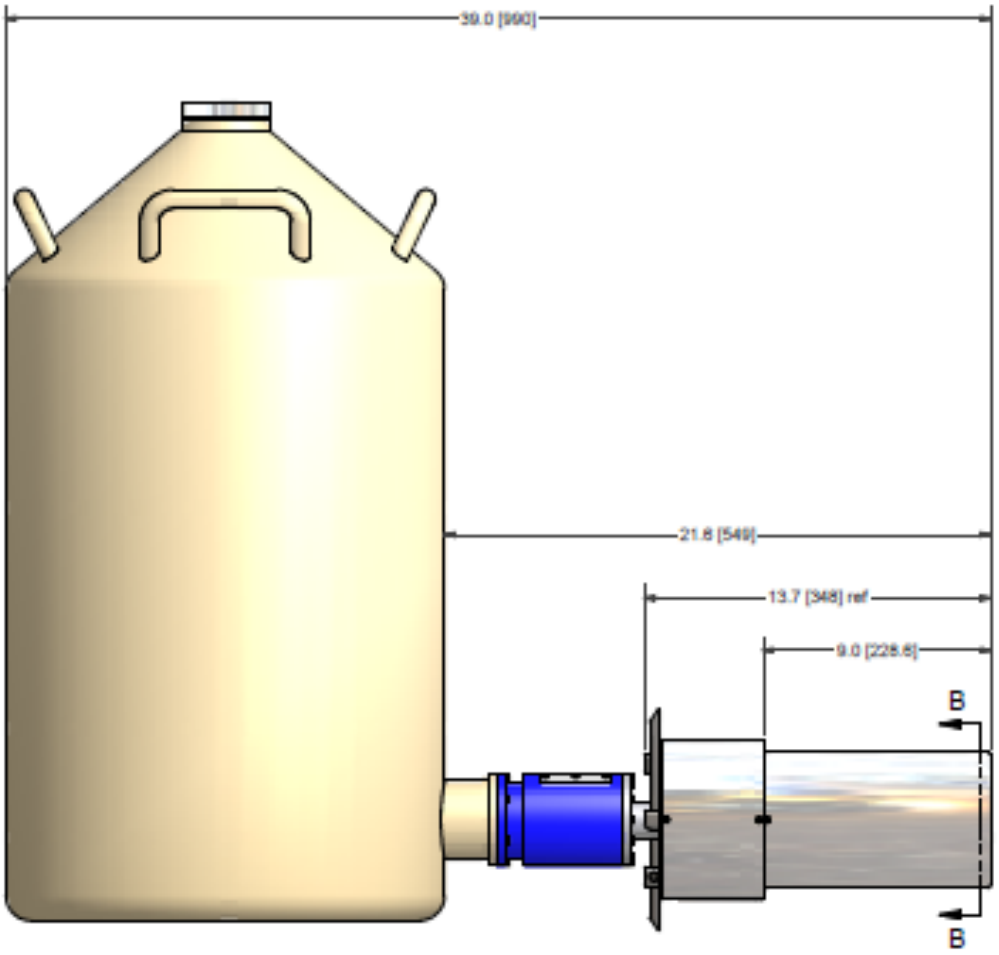
2) Square endcap with tapered ends (typically used with BGO shields)

3) Round endap without a taper
**featured in the next slide*



Isometric view of an ORTEC clover

ORTEC®



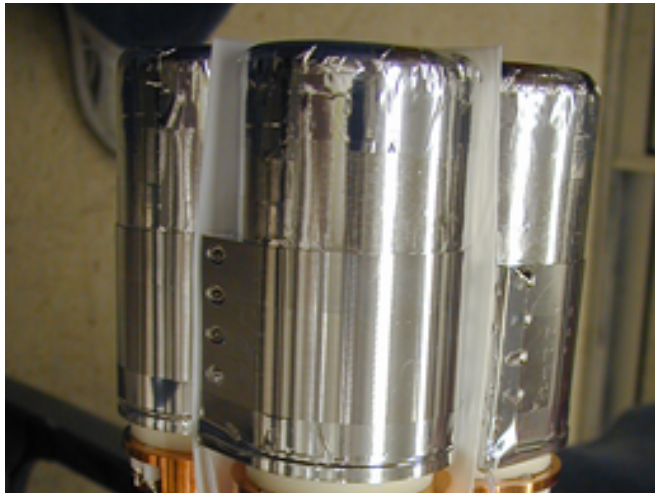
ORTEC advantages in clover detectors

ORTEC®

- #1 – Easy replacement of Molecular Sieves
  - *Customer can perform field vacuum service*

- #2 – ORTEC design allows easy Dewar replacement
  - *replacement of leaking dewar in the field*
  - *upgrade to a larger LN_2 or a mechanical dewar in the future at the factory*

- #3 – ORTEC CLOVER is designed with a modular mount
  - *promotes serviceability at the factory for detector repair/replacement*



Next Generation Clover Specifications

ORTEC®

Clover Detector	Four N-type HPGe detectors.
Efficiency	Relative efficiency of four detectors can be customized between 20% and 80% (for each detector element).
Resolution	Dependent upon detector efficiency and cryostat configuration. For example, four 25% relative efficiency HPGe detectors are warranted to have: FWHM ≤2.15 keV @ 1.33 MeV per detector (typical performance is under 2.00 keV) FWHM ≤1.05 keV @ 122 keV per detector (typical performance is under 1.00 keV)
Energy Range	20 keV up to 10 MeV (larger coaxial detectors are recommended for better high energy efficiency).
Peak to Compton	Dependent upon detector efficiency. For example, four 25% relative efficiency HPGe detectors are warranted to have: 45:1
Cooler	Liquid nitrogen. Minimum capacity 3L (24 hour holding time). For other LN_2 dewar configurations and orientations, or for mechanical cooling options, consult factory.
Preamplifiers	4 in remote configuration (resolution above based on 6 µs shaping time).
Detector Spacing	<1 mm between detector elements. Endcap to detector spacing depends on the endcap angle and size of the detector elements. Typical distances 5–30 mm.
Endcap Material	Aluminum. To maximize low energy efficiency, other customized endcap window options are available.
Low-Background Option	Available (optional)
Warranty	1 year standard warranty. Optional extended warranty is available.

ORTEC Double sided Strip Ge History

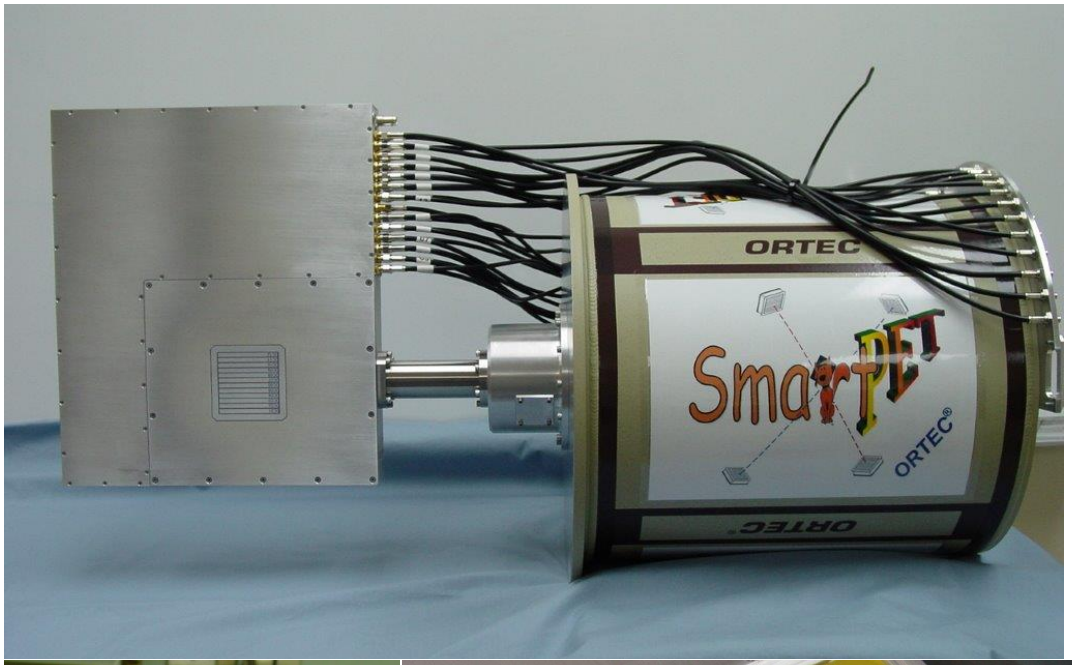
ORTEC®

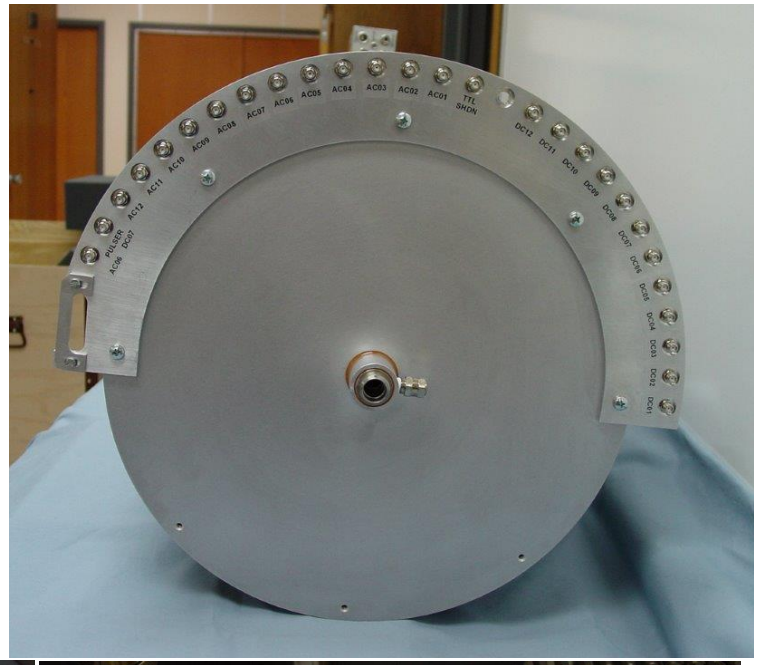
Key Feature	Application Benefit
Double sided orthogonal Ge Strip layers	Allows tracking and positioning information High count rate throughput Better efficiency than Si for hard X-rays (80-200keV)
Large surface area	Very good coverage for large targets or wide scattering angles
Minimized cross-talk	To avoid false signal or double-counting
Small, multi-orientation dewar Or Advance electro-mechanical cooling	Compact count geometry 180 degree annihilation count geometry

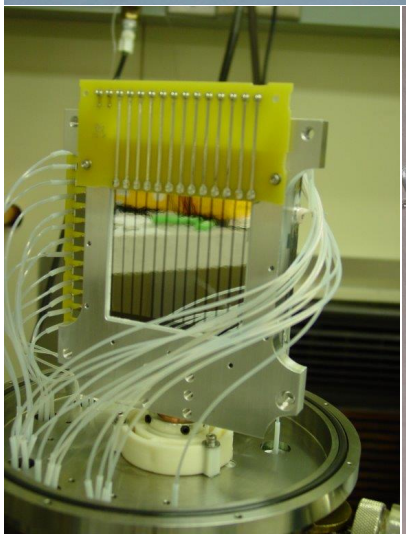
- 15+ years of experience with several functional units in the field
- Multiple references available upon request

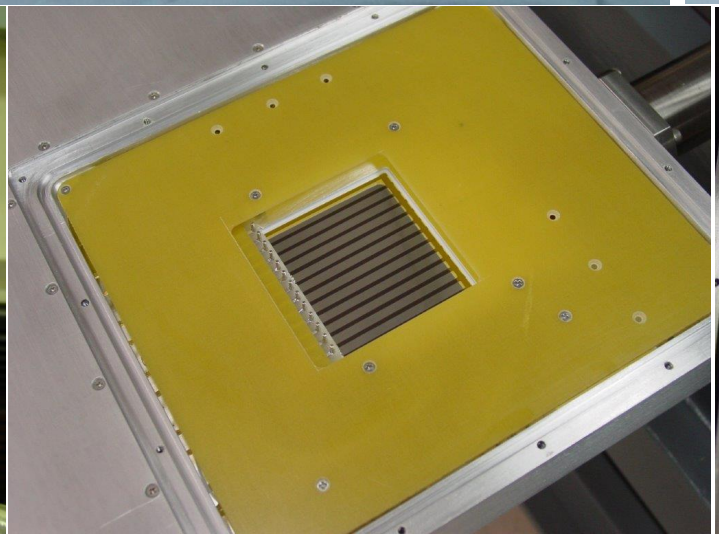
Double Sided Ge Strip Detector

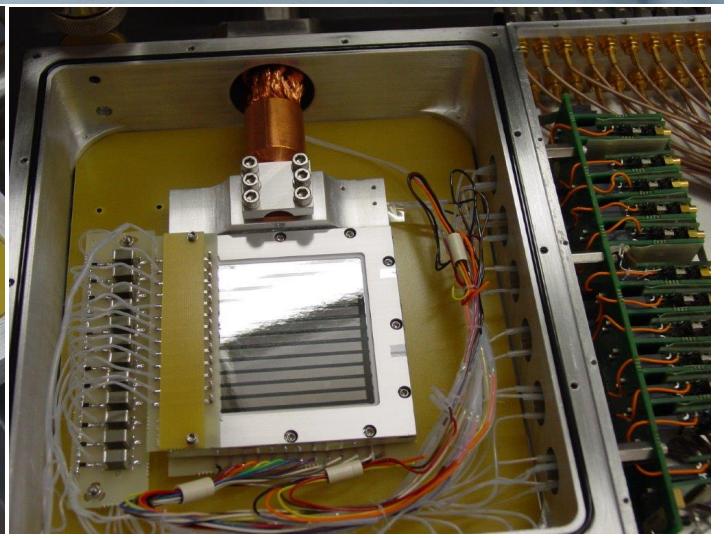
ORTEC®









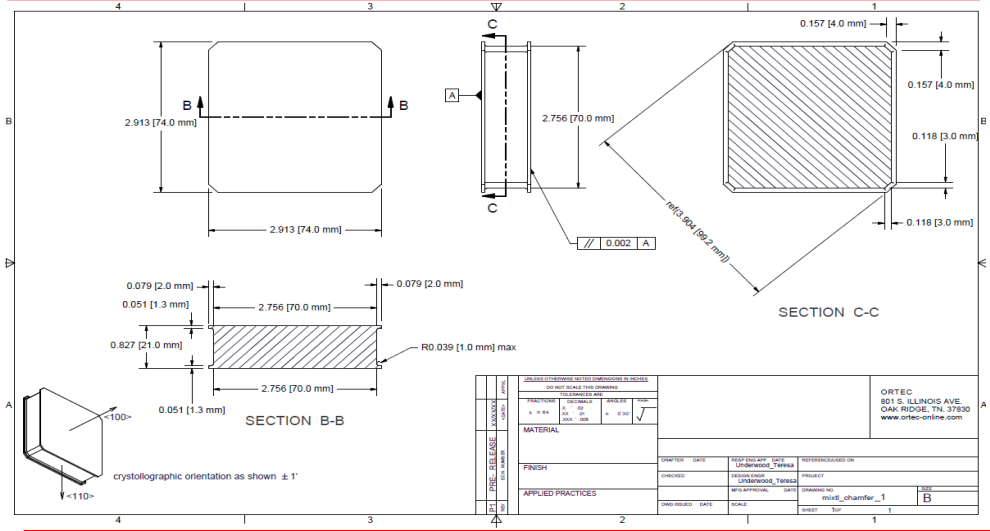


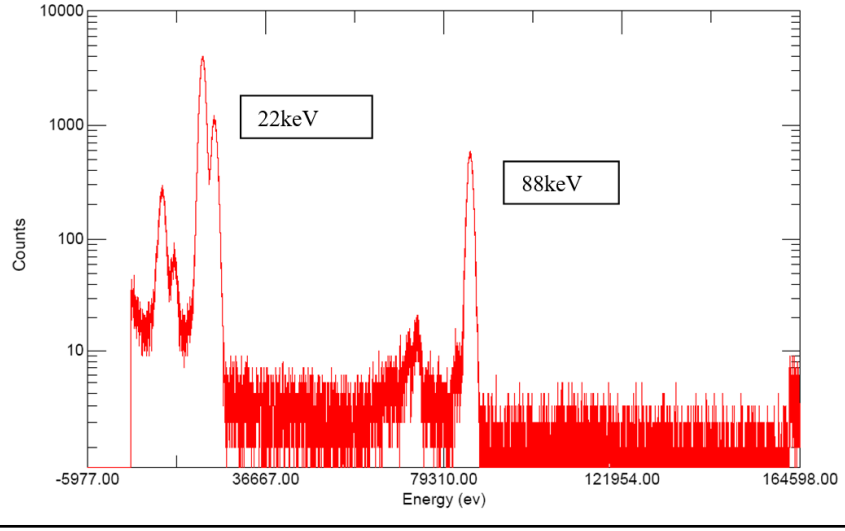
Double Sided Ge Strip Specifications

ORTEC®

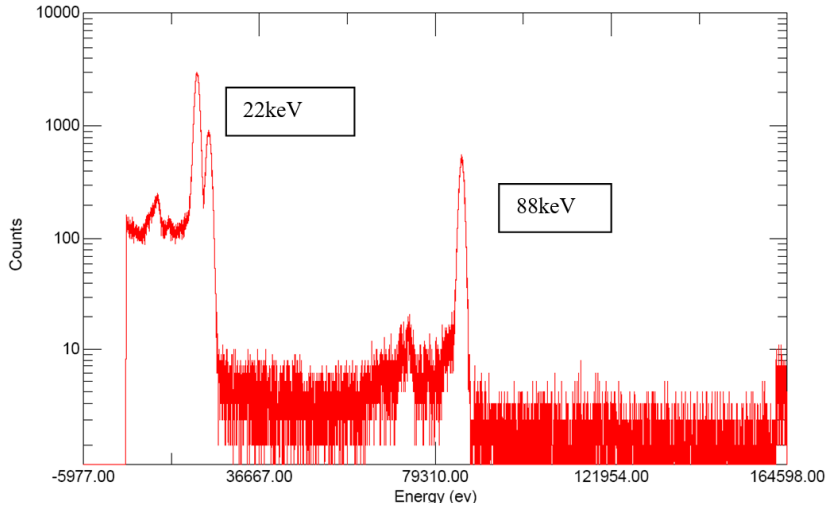
Specifications:

- Average FWHM </= 1.7keV @ 122 keV
- ALL channels FWHM </= 2.3keV @ 122 keV
- No more than 2 strip per side >1.8 keV @ 122 keV
- FWHM </= 2 x FWHM @ 122 keV
- No guard ring operation specified





Cd-109 Spect - photons entering through AC (0.3 µ contact) side



Cd-109 Spect - photons entering through DC (50 µ contact) side

ORTEC Array and Segmented History

ORTEC®

Key Feature	Application Benefit
Small discrete detector elements (one endcap) Large discrete detector elements (one endcap)	Excellent resolution compared and very high count rates for small elements Good resolution and high efficiency for large elements
Multiple detector elements - 3 to 30 (small) - 4+ (large)	Close packing and minimize dead space within endcap to allow: - Scattering information - Higher throughput (less deadtime than single large detector)
P- or N-type HPGe	Annealing option is available with N-types
Segmented	Tracking information, angular scattering, pulse shape analysis for the location of interactions within crystal

- 20+ years of experience
- Consult factory for your array or segmented detector application needs

Point contact detector project – ORTEC GEM-SP

ORTEC®

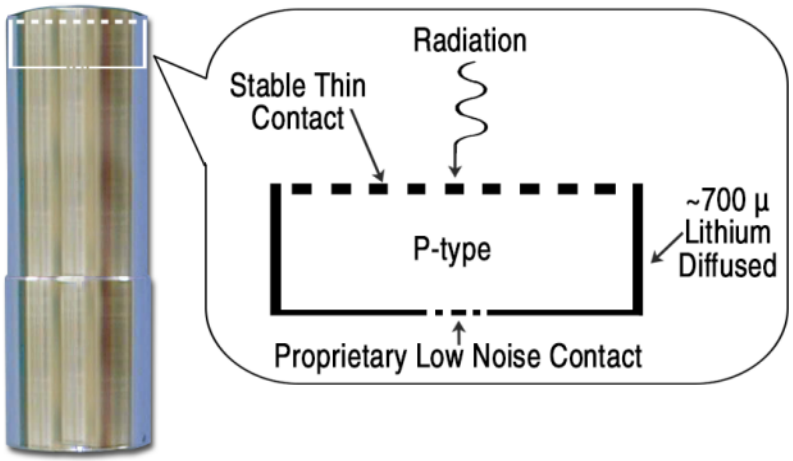
Key Feature	Application Benefit
Low Noise Back Contact (LNBC)	Superior resolution performance at low to medium energies (3-700 keV) – minimize false positives or separates double peaking Excellent resolution in a wide range of energies (3keV to several MeV)
Stable Thin Front Contact (STFC)	No “dead layer growth”, lower handling and storage cost with no loss of detector efficiency Improved efficiency at lower energies

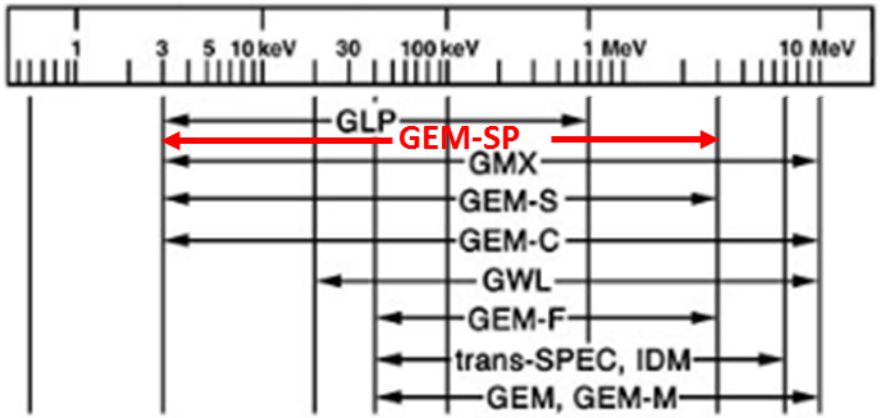
Key Feature (commercial grade)	Application Benefit
Crystal diameter maximized within endcap	Maximized efficiency, minimized “dead space”
Largest surface area available	94+ mm sizes available (unmatched) in the market
Custom designs available (optional)	Customization for application requirements
Compatible with any ORTEC’s LN_2 or electro-mechanical coolers	Versatility to be used in any counting geometry

Point contact detector project – ORTEC GEM-SP

ORTEC®

- First ORTEC semi-planar p-type, point contact (PPC) detector built in 2009
- Commercial versions introduced in 2015
- 50+ units special and commercial grade designs manufactured
- Unmatched commercial guaranteed performance





Resolution Factors

ORTEC®

System resolution $R_T = \sqrt{R_d{}^2 + R_E{}^2 + R_V{}^2}$

where

- R_d is the detector resolution
- R_E is the electronic resolution
- R_V is the vibration resolution

- To a very good approximation Fano Noise[2] R_d (in keV) = $1.35\sqrt{E(in\ MeV)}$
- R_E depends on the capacitance of the detector, in turn capacitance depends on the surface area of the contact
- R_V is zero in LN_2 cryostats or "some" new generation mechanical coolers.

[2] "*(1947). "Ionization Yield of Radiations. II. The Fluctuations of the Number of Ions". Physical Review.* ***72*** *(1): 26. Bibcode:1947PhRv...72...26F. doi:10.1103/PhysRev.72.26.*"

GEM-SP detector design

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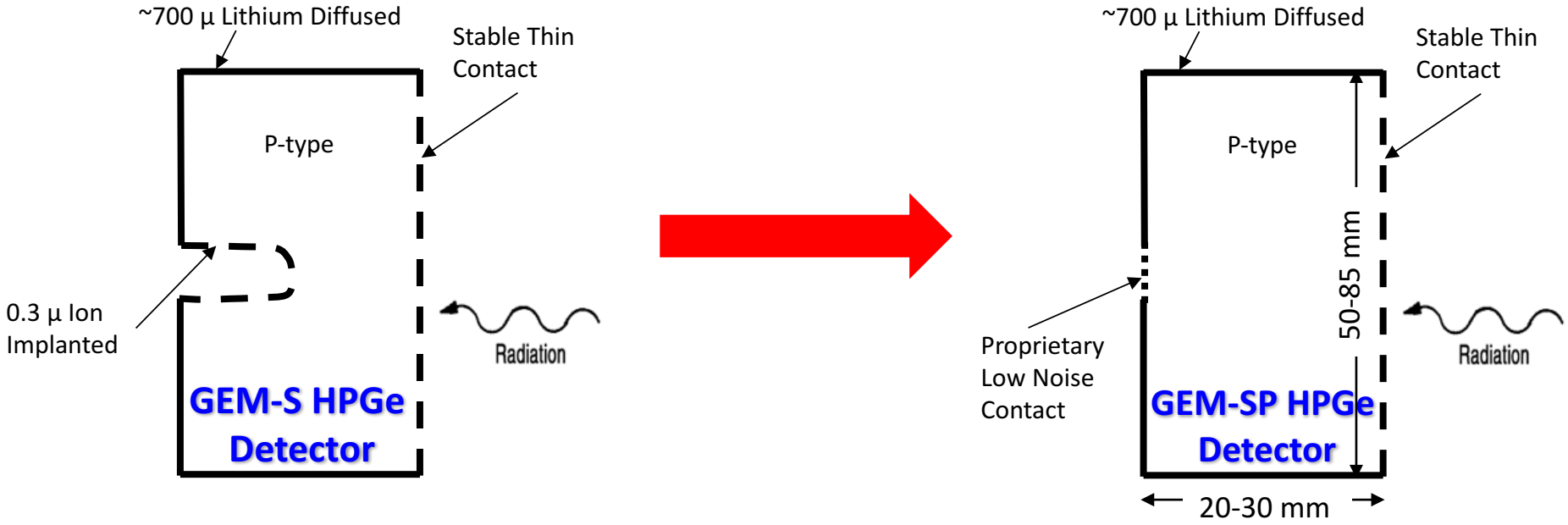

ADVANCED CONTACT FEATURES FOR GEM-SP DETECTORS

- Thin front contact
- Enhance contact stability
- Low noise back contact (reduced detector capacitance)

- *Stable front contact presented at the IEEE NSS/MIC, November 2014 in Seattle, Washington – Kyle T. Schmitt, Gregor Geurkov, Member IEEE, E. G. Roth, Timothy R. Twomey, and Teresa Underwood, Member IEEE, "Improved Efficiency at Low Energies with P-Type High Purity Germanium Detectors", presented at IEEE, November 2014.*

GEM-SP detector performance

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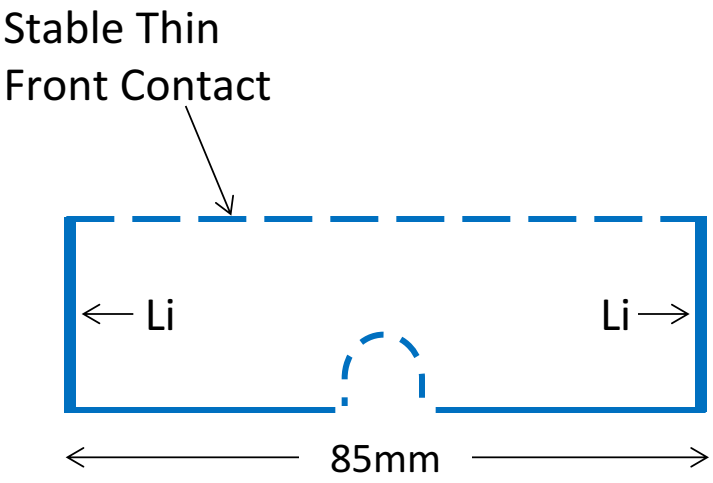
DETECTOR SUMMARY							
New GEM-SP DETECTOR	Shaping time (µs)	5.9 keV Measured	5.9 keV Warranted	122 keV Measured	122 keV Warranted	1.33 MeV Measured	1.33 MeV Warranted
GEM-SP5020	6	**216**	300	**479**	585	**1.6**	1.8
GEM-SP5825	6	**277**	340	**514**	585	**1.7**	1.8
GEM-SP7025	6	**296**	380	**496**	585	**1.6**	1.8
GEM-SP8530	6	**302**	425	**533**	630	**1.9**	1.9

DETECTOR	VOLUME (cm^3)	Nominal Relative Efficiency (%)	5.9 keV	122 keV	1332 keV
			Percentage Improvement in Detector Resolution		
GEM-SP5020	39	7	15%	10%	0% / no degradation
GEM-SP5825	66	15	15%	10%	0% / no degradation
GEM-SP7025	96	20	15%	10%	0% / no degradation
GEM-SP8530	170	50	15%	10%	0% / no degradation

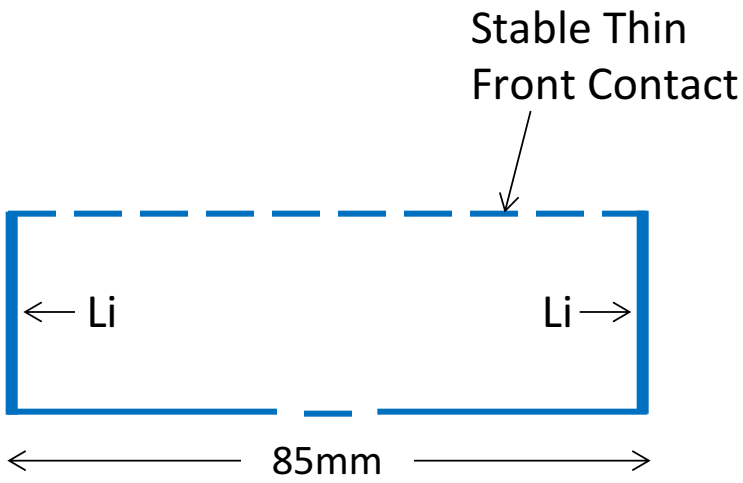
Resolution tests - Setup 1

Two semi-planar P-type detectors Profile S8530 vs SP8530. Both detectors are:

- 50% rel. eff.
- 85mm diameter
- 30mm thickness



Profile S8530



Profile SP8530

PROFILE "SP": SP8530 AT 122 keV and 5.9 keV

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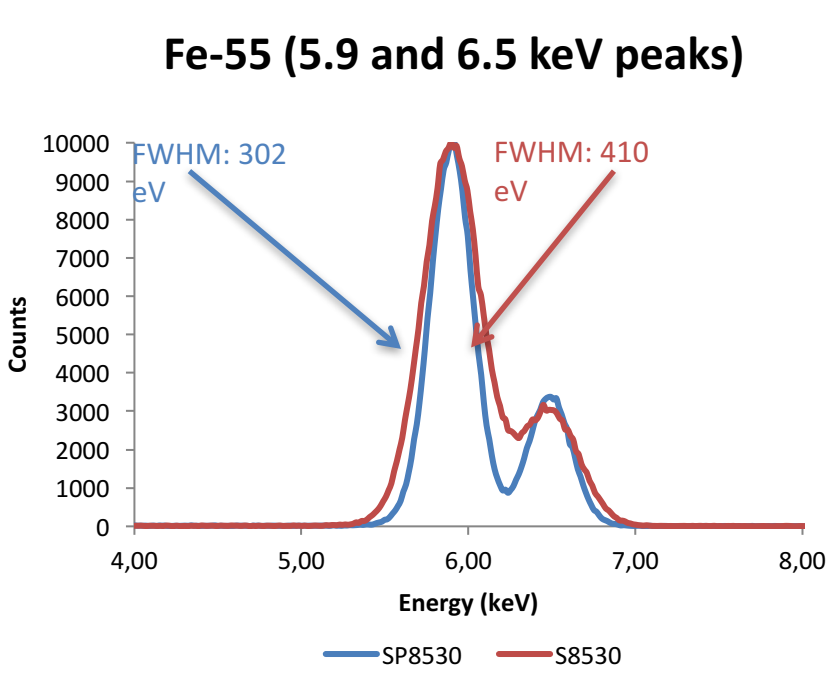
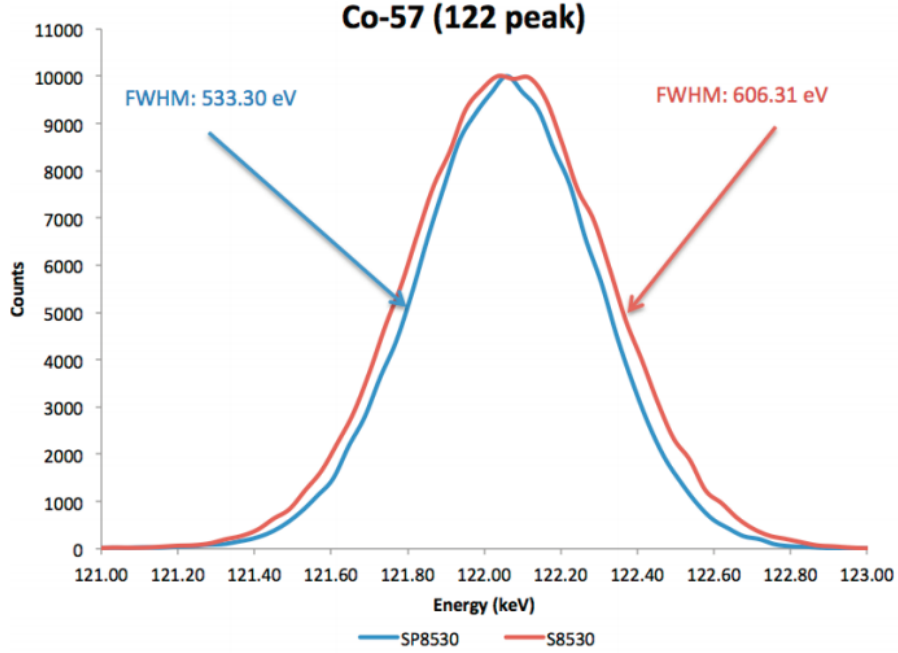




- **FWHM measurement at 5.9 keV energy with**
  - ***GEM-SP8530 is 302eV (spec is 425)***
  - ***GEM-S8530 is 410eV (spec is 500)***
- **25% improvement in measured resolution**
- **15% improvement in specified guaranteed resolution**
- **Better peak differentiation between 5.9 and 6.5 keV peaks**

- **Resolution for GEM-SP8530 is 10% better at 122 keV than a standard GEM-S8530**

*****^{55}*Fe and* ^{57}*Co source positioned 25 cm away from the front of the endcap*

Resolution tests - Setup 2

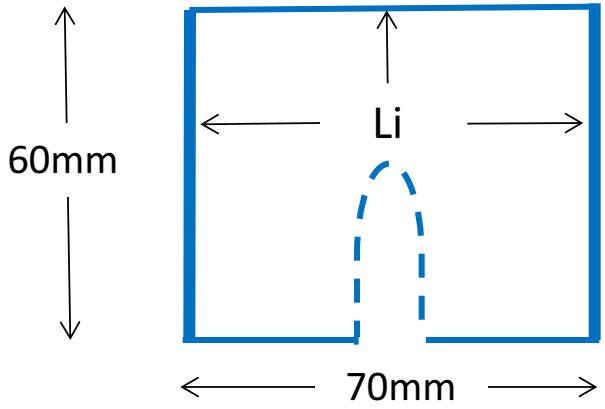
Coaxial P-type GEM50 vs Semi-planar P-type Profile SP8530. Both detectors are:

- 50% rel. eff.

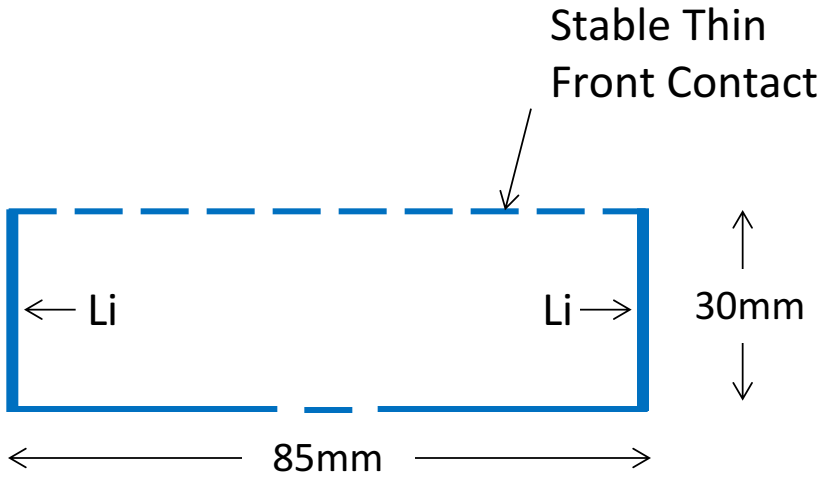
But different crystal geometry:

- SP8530 has diameter greater than thickness (d:l is ~3:1) 85mm by 30mm
- GEM50 has diameter the same as thickness (d:l is ~1:1) 70mm by 60mm

Note: spectra collected with both detectors has the same counting statistics (offset is done for visual differentiation)



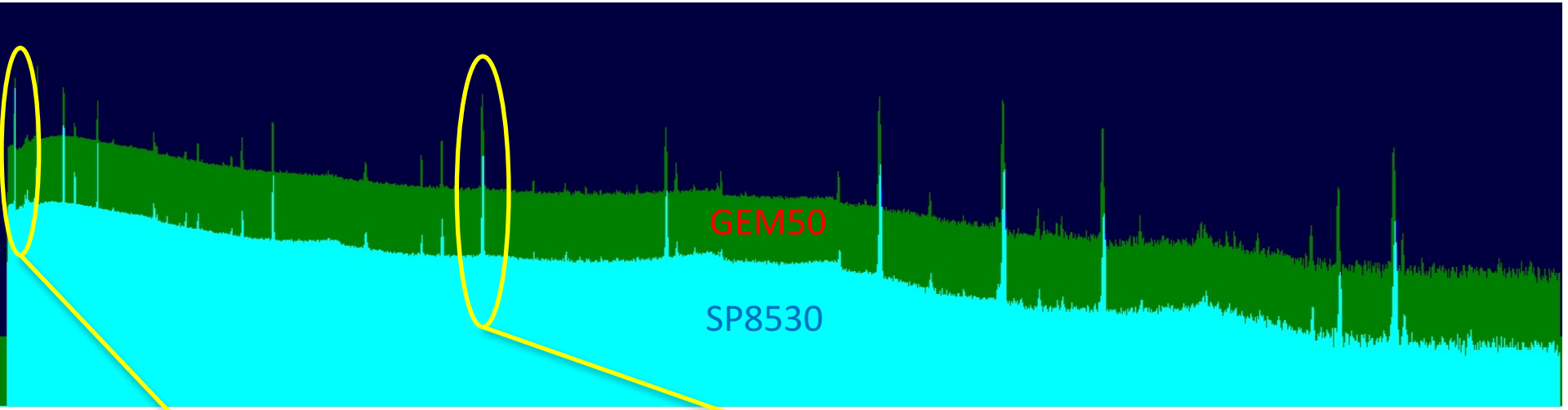
GEM50



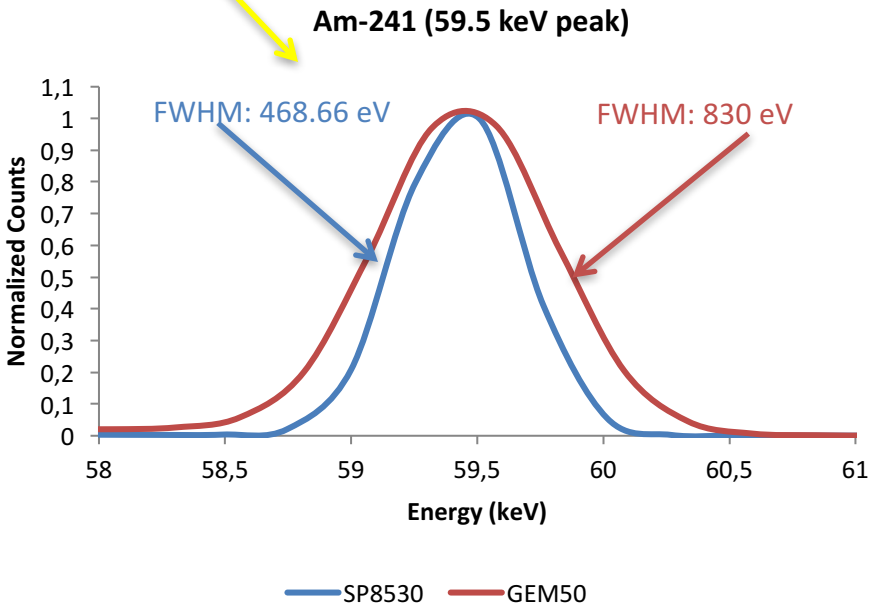
Profile SP8530

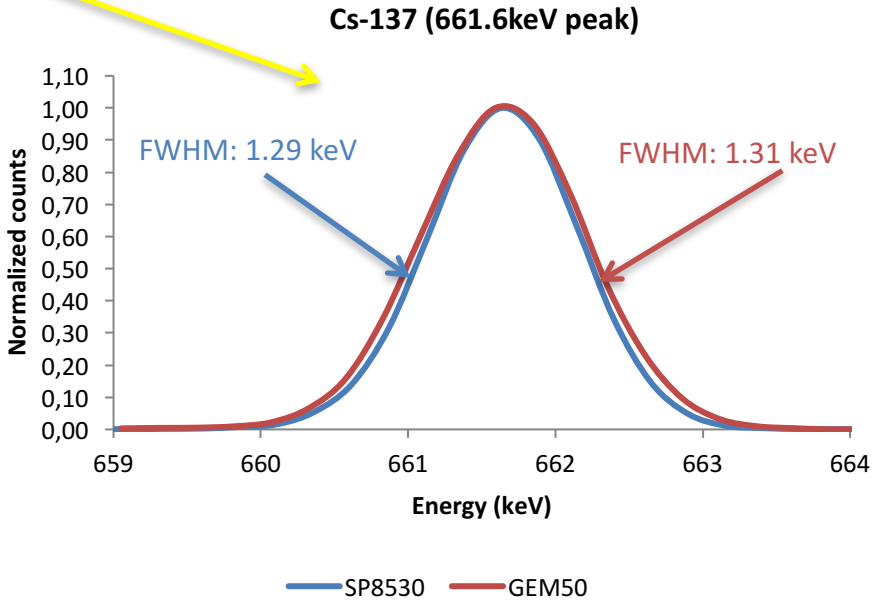
Setup 2 resolution with mixed gamma

ORTEC®

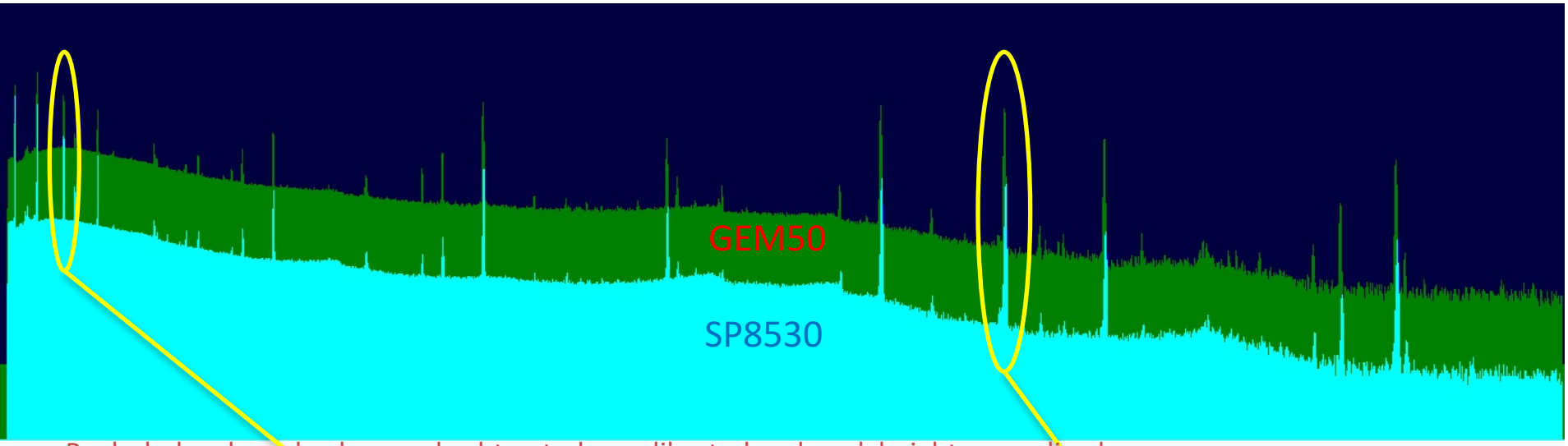


Peaks below have background subtracted, recalibrated and peak height normalized



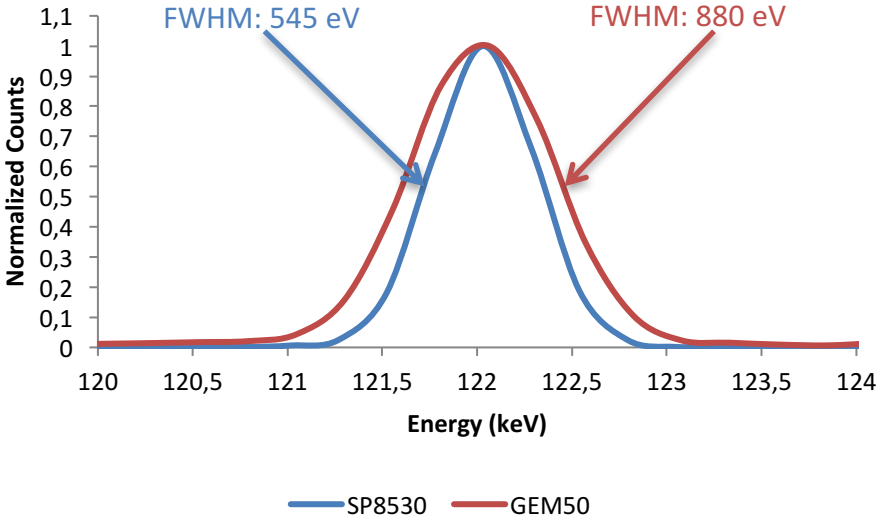


Setup 2 resolution (cont.)

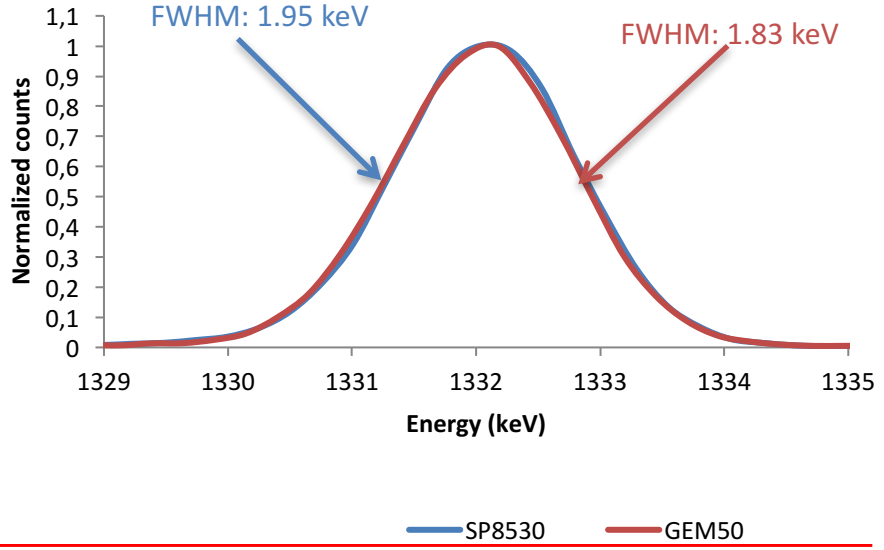


Peaks below have background subtracted, recalibrated and peak height normalized

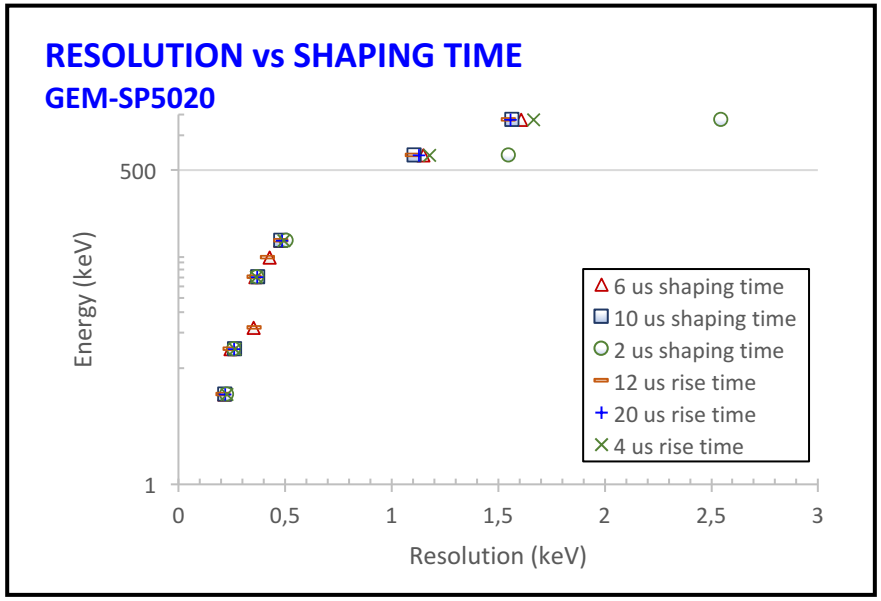
Co-57 (122keV peak)

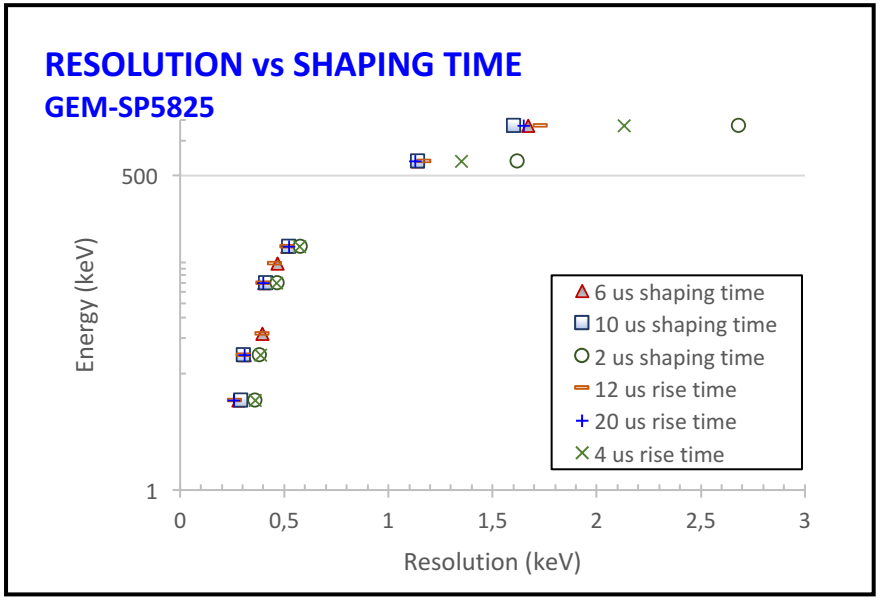


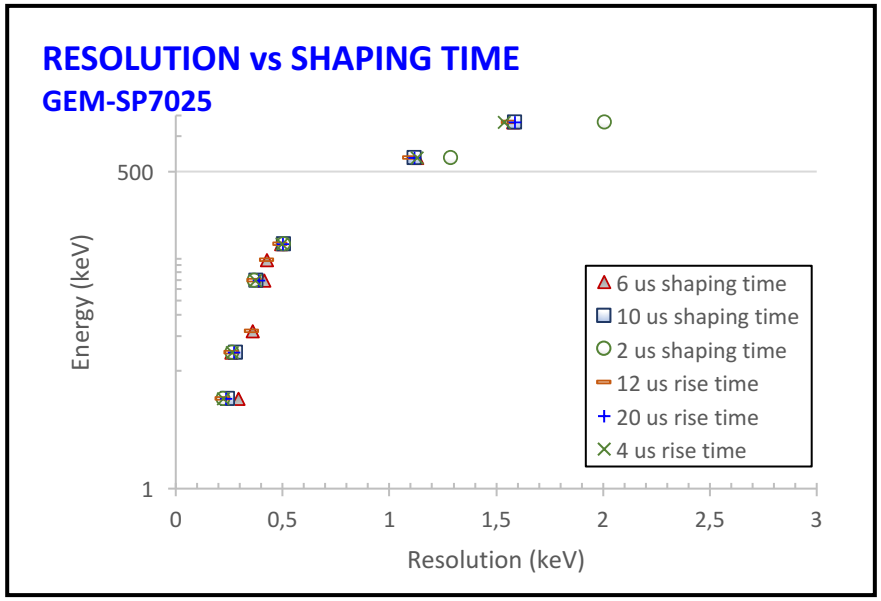
Co-60 (1332keV peak)

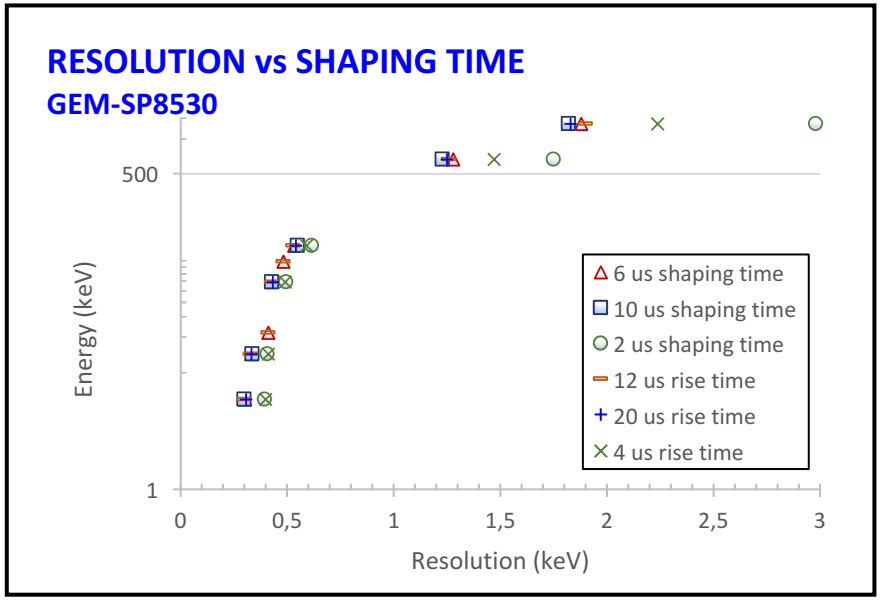


RESOLUTION (FWHM) VS Shaping/Rise time ORTEC®









Point Contact Summary

ORTEC®

- Premium resolution achieved for the GEM-SP detector incorporating several design features:
  - *Detector element design*
  - *Previously developed barrier, stable thin front contact*
  - *Low noise back contact*

- LNBC is a new proprietary contact for p-type detectors employed to improve low to medium energy (<700keV) resolution performance
  - *15% improvement at 5.9 keV*
  - *10% improvement at 122 keV*
  - *Comparable performance at 1332 keV*

- Ideal detector for applications in the energy range of 3 to 3000 keV

- May be used for energy ranges 3 to 10000 keV if premium resolution is required for large distributed sources

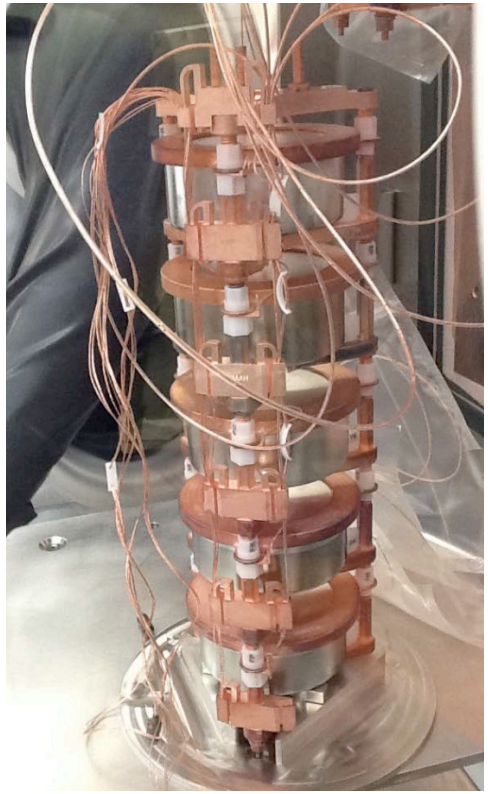
- LN2 performance achieved for a variety of mechanical cooling options: Mobius and X-COOLER-III

Point Contact (Majorana Demonstrator)

ORTEC®

- 30+ Ge-76 detectors built
  - Manufacturing scheduled
  - Advantageous crystal growth and fabrication yield
- Pulser < 400 eV on average
- FWHM @ 1.33 MeV nominally 1.90 keV on average
- Exposure rate far below calculated acceptance value

Considerations:
- Background exposure
- High yield of high-cost Ge-76 material

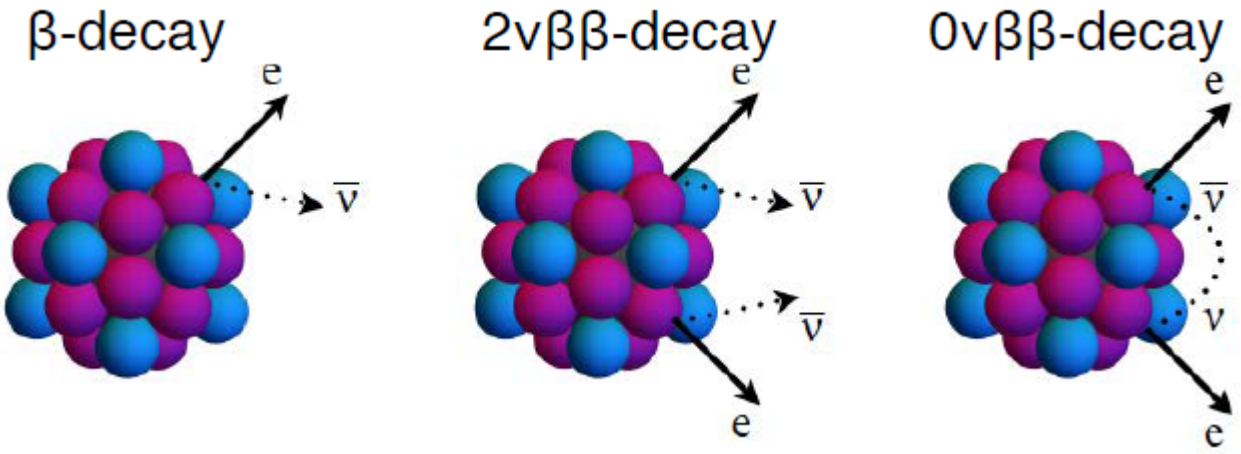


*Picture from Alan Poon of LBL

ORTEC Factory Advantages
Vertical manufacturing facility – maintain control in the exposure of material through growth and manufacturing process
Superior resolution
Control of cosmic exposure

Coaxial Point Contact (Dark Matter)

ORTEC®



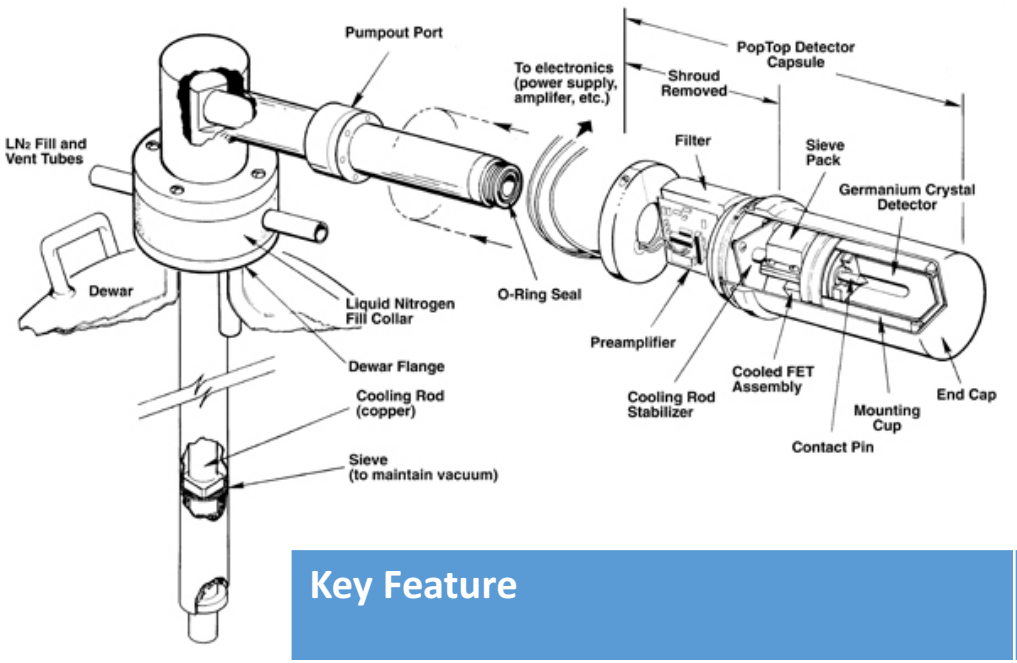
Considerations:

- Background exposure

Dark Matter experiments require coaxial (larger) crystal geometry and have
  - lower energy (<5keV detection) requirements than Majorana experiment (few MeV)
  - Lower FWHM (pulse) requirement <100eV (Majorana's requirement was FWHM ~400eV for pulser)
  - Consult factory for your needs

PopTop detector capsule

ORTEC®



- PopTop detector capsule was introduced in mid 1980s. It provides cryogenic enclosure for HPGe detector.
  - Various sizes for any HPGe type or size

Key Feature	Application Benefit
Single capsule design	Field upgradable/replaceable Quicker deliver times
Same vacuum Integrity as conventional cryostat, but 20-30% higher LN_2 consumption rate	Very good coverage for large targets or wide scattering angles
Compatible with single or multi-orientation LN_2 cryostats or advanced electro-mechanical cooling	Compatible with any counting geometry Field upgradable

Encapsulated

ORTEC®

- ORTEC offers Encapsulated HPGe detectors as a special version of the PopTop capsule with a:
  - standard Harsh Environment (-HE) option.
  - minimized "dead space" within the endcap (similar to Profiles).
  - Comes with 1 HPGe detector per capsule.

Note: for several HPGe per capsule
or tapered
or high magnetic field options
consult factory

- Encapsulated cryostat are used in a range of applications where space is limited or extreme environmental conditions are present:
  - Closely packed multi-detector arrays used nuclear structure studies
  - Space studies using HPGe's
  - Environmental field measurements or waste management (harsh environment and quick upgrades/replacement)

ORTEC Low Background History

ORTEC®

Key Feature	Application Benefit
Largest P- (up to 200% rel. eff.) or N-type (120+ rel. eff.) HPGe sizes	Decreases count times and increases MDA due to higher efficiency
Low background shielding with low Pb210 content	Minimizes cosmogenic and ambient background
Low background detector hardware (OFHC cupper, High Purity Aluminum, CF endcap)	Minimizes MDA emanating from detector subcomponents
Remote preamplifier	Minimizes background from electronics components

- Low background hardware has been available since 1970
- In 2015 ORTEC started marketing campaign to show low background performance capabilities to be in par or better than competition
- Partnerships with low background or underground labs are desired to continue to build premium performance database

Material assay of LB materials

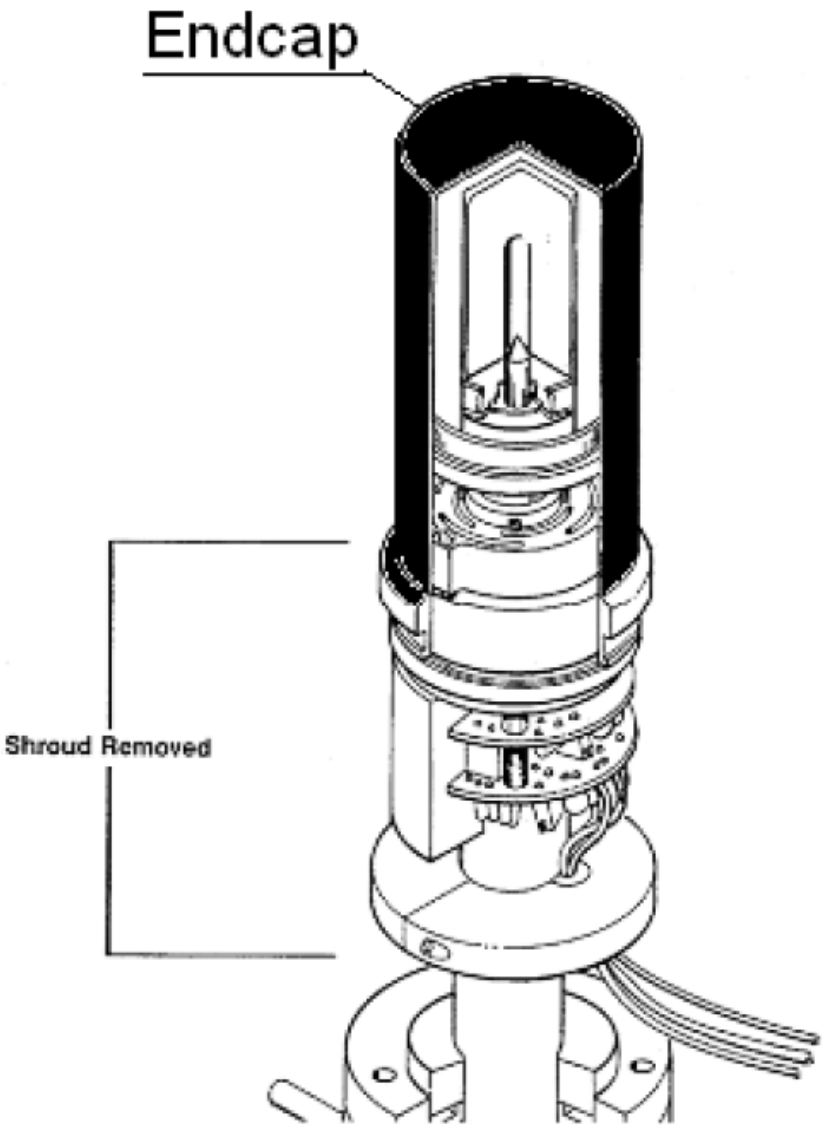
ORTEC®

- Receipt of material samples – Al, SS

Material samples

- Background evaluation performed on samples in dedicated material cave
  - *Material cave is > 35 years old*
  - *Includes a GMX25 LB detector*

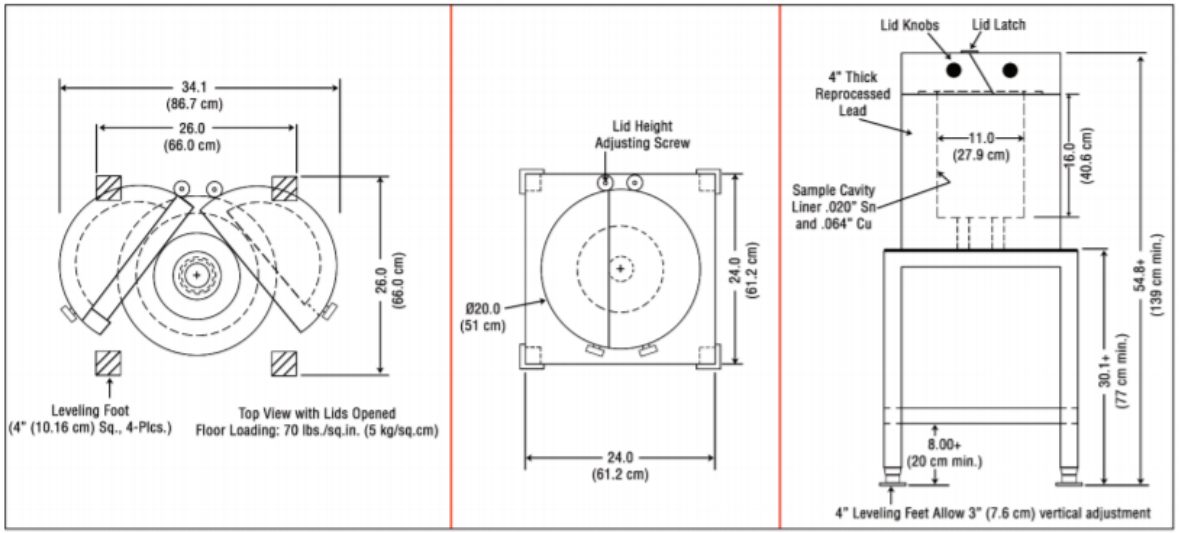
- Material is approved/rejected
  - *Approved:*
    - Material is isolated
    - Components made only from approved material
  - *Rejected:*
    - Supplier provide new material sample



Evaluation of recycled versus virgin lead

Ordered…

- ORTEC top loading shield made from recycled lead
- ORTEC top loading shield made from virgin lead



Background spectrum obtained with a GMX25 LB detector

Magnesium endcap

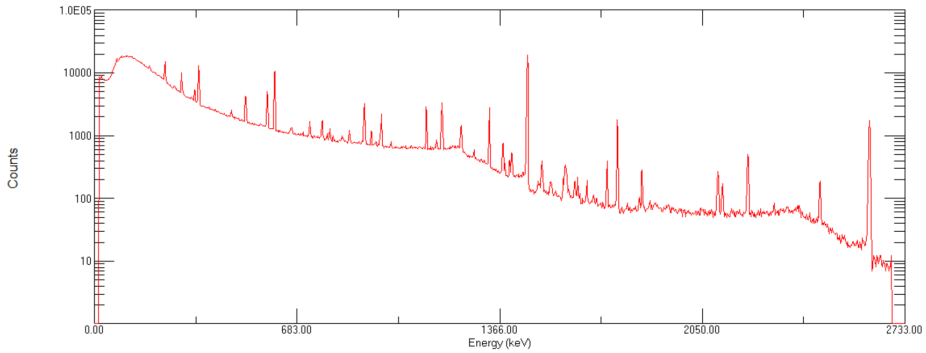
Beryllium window

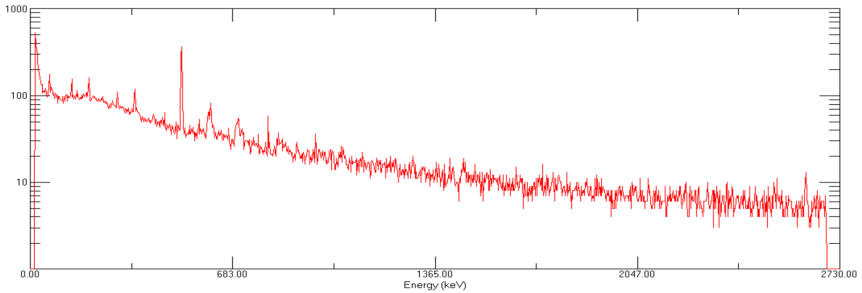
Evaluation of ORTEC 6” lead shield

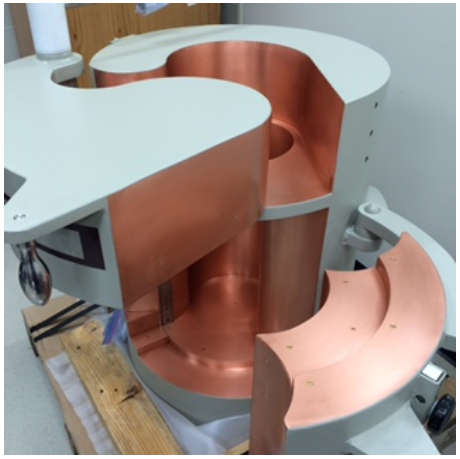
ORTEC®

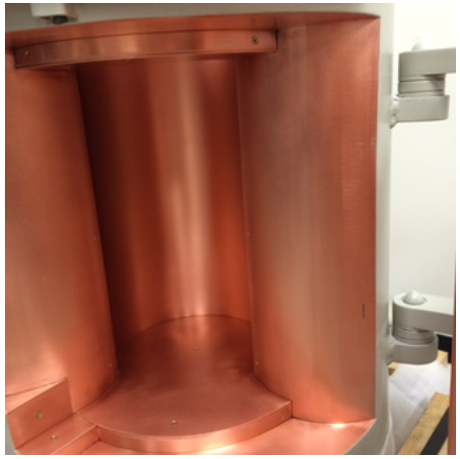
- Background evaluation performed using a 6-inch lead shield
  - *GEM-S8530-LB-C-HJ*
  - *CFG-HJ-LB-108*

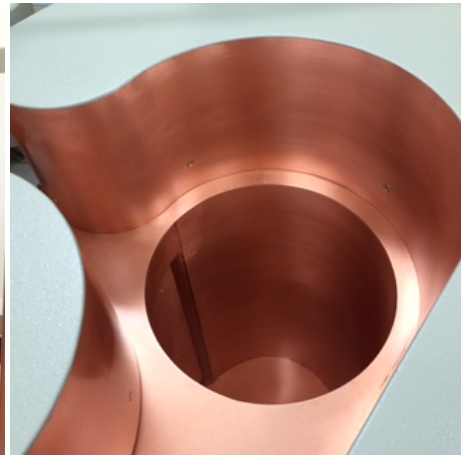
Range of keV (counts)				
Sample ID	3-40	40-350	350 +	Total
6" shield	16621	72063	87421	176235
Unshielded	624833	9393360	3706880	13733900











Summary of Low Background Assay and Materials

ORTEC®

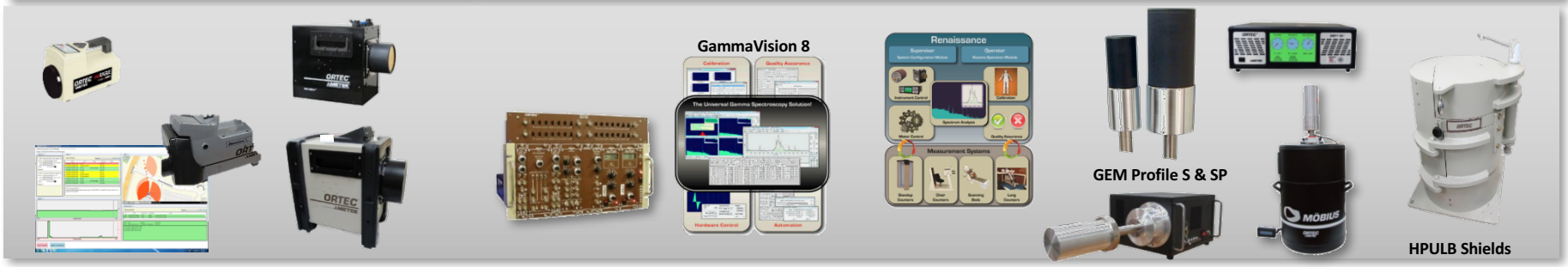
- Background assay of material samples performed prior to use in production of components for LB systems
- Lead shield made from recycled lead not sufficient for customers requiring lowest MDA possible below 400 keV
- Lead shield made from 3” recycled + 1” virgin liner is viable alternative for production of lead shields compared to virgin shields
- Shields made from virgin lead are still fabricated if the application requires lower background than may be achieved with shields constructed from recycled or 3+1 lead
  - *ORTEC may also produce special LB shields less than 10 Bq/kg*
  - *In addition, ORTEC may supply designs with anti-cosmic reduction or cosmic suppression systems*
- ***Future work*** –
  - *Full characterization of different LB cryostat configurations in various shield configuration*
  - *Further characterization of the ORTEC 6” shield offering*
  - *Assembly and supply of advance special low background systems for complex applications*

Thank You

ORTEC®

- In recent years ORTEC showed a Renaissance in core applications –

Nuclear Security & Safeguards	Radiochemistry, Health Physics, Nuclear Power, Research and Education, Waste Management



Advance Detector	Application Examples
Clover Detectors	Nuclear studies Physics, Health Physics
Point Contact (coaxial, semi-planar)	Neutrino and Dark Matter, High Resolution Spectrometry
Encapsulation	Multi-detector (limited space) or multi-orientation
Double Sided Strip Detectors	Nuclear physics, Beamlines, Imaging, Medical
Shields, Low Background Hardware	Low count rate, Underground low background studies
Segmentation, Arrays	Synchrotrons and beamlines, EXAFs, tracking, Doppler Shift

Contact –

- *Local sales agent / distributor*
- *Product Manager – Gregor Geurkov (Gregor.Geurkov@ametek.com)*
- *Detector Director – Elaine Roth (Elaine.Roth@ametek.com)*