# Profile SP (P-type) HPGe Detectors – Premium Resolution at Low to Medium Energies

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*Abstract* - The resolution performance of a High Purity Germanium (HPGe) gamma-ray detector is a function of three factors: crystal quality and geometry, electronic noise, and any microphonic contribution. Improving detector resolution solves peak overlapping problems in complicated multi-peak spectra and improves the performance of peak identification algorithms yielding fewer false positive results in spectrometry analysis. A new Low Noise Back Contact (LNBC) has been developed by ORTEC® for p-type semi-planar HPGe detectors. This LNBC minimizes electronic noise, while the semi-planar p-type crystal geometry offers premium efficiency and charge collection performance for the 3 keV to 1 MeV energy region, where the majority of the nuclides reside. Additionally, semi-planar crystal geometry lowers the Compton region created by higher energy gammas, allowing lower Minimum Detectable Activity (MDA) levels. The "Profile SP" with unmatched premium resolution results will be discussed for various energies and shaping times.

*Index Terms* – ORTEC; HPGe; semi-planar detector; low-noise contact

## INTRODUCTION

High purity germanium (HPGe) radiation detectors are often referred to as the gold standard for gamma-ray spectroscopy due to their superior resolution. However, there remains a need for improved resolution below energy range of 1 MeV where most natural radioactive isotopes have prominent energy lines.

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Detectors that provide premium resolution are important when there is a need to separate gamma lines or energies for nuclide identification. Furthermore, low minimum detectable activity (MDA) limits may be achieved if gamma lines can be separated with a high-resolution detector. MDA is referred to as the smallest quantity that may be detected. From Curie's MDA formula [1]:

$$MDA(E) \approx \frac{\sqrt{B(E)}}{t * \varepsilon(E)}$$

where $t$ = time (s)
$B(E)$ = background rate (cts/s)
$\varepsilon(E)$ = efficiency
$E$ = energy in keV,

and $B(E)$ is indirectly proportional to the detector resolution. Therefore, improvement in gamma radiation detectors in this low-energy region is useful. Commercial applications that benefit from premium resolution include health physics, environmental counting, waste management, low background counting, safeguards and field measurements.

ORTEC, a division of Ametek®, Inc., is a leading supplier of gamma radiation detectors made with HPGe. Within the scope of this work, ORTEC has developed an HPGe detector that maximizes counting efficiency and provides premium resolution performance. The target was to improve low-to-medium energy resolution and throughput, while maintaining high-energy performance. This would yield a premium detector that performs over a wide energy range.

## DISCUSSION

There are tradeoffs in the development and production of HPGe gamma ray detectors. A very low capacitance detector that is increased in size for greater counting efficiency will exhibit increased noise, thereby negatively affecting resolution performance. Similarly, there are limitations on how much the capacitance of a detector with a semi-planar, coaxial geometry may be reduced. The detector technology discussed here offers a semi-planar, p-type HPGe detector in which the diameter of the HPGe crystal is maximized inside the detector capsule to maintain good counting efficiency, while reducing the capacitance to achieve improved resolution performance.

The well-known relationship for system resolution is

$$R(system) = \sqrt{R(d)^2 + R(E)^2} \ ,$$

where *R(d)* is the detector resolution component and *R(E)* is the electronic resolution component. Careful assembly of the cryostat and system is required to negate any anomalous mechanical noise contribution. The *R(d)* (in keV) may be approximated using the Fano factor, *F*, using

$$R(d) = 2.35\sqrt{FE\varepsilon} \ ,$$

where *F*=Fano Factor or ~ 0.12, *E* is the photon energy and $\varepsilon$ is the average energy required to produce a hole-electron pair. The Fano factor is a measure of the dispersion of a Fano noise. For germanium at 77°K, *R(d)* in keV is

$$R(d) = 1.35\sqrt{E(MeV)}$$

As energy is reduced, system performance is dominated by the electronic contribution *R(E)*, which is directly related to the capacitance of the detector. The capacitance of a coaxial detector is in turn dependent on the surface area of the contact. Employing this relationship, a detector element was designed to reduce the capacitance. In addition, a detector with over-square geometry where the diameter is greater than the length exhibits improved efficiencies in the low-to-medium energy regime.

This new detector employs a design feature of an earlier detector development of ORTEC's p-type GEM-S semi-planar and GEM-C coaxial profile detectors. This detector R&D program was completed in 2014 in which a stable, thin barrier contact, referred to as the stable thin front contact (STFC), was developed for the front face of the detector. The STFC development was published in the conference proceedings following the IEEE NSS/MIC meeting in Seattle Washington in November 2014. [2] The STFC design enhances the long-term stability of the contact for these detectors preventing any dead layer growth and loss of efficiency at lower energies.

It will be shown in the next section that a premium semi-planar detector, labeled the GEM-SP detector, exhibits superior resolution in the energy range of 3 keV to 3 MeV. The detector includes a STFC, illustrated below in Figure 1A, allowing transmission of energies down to 3 keV. [2] Development focused on the back contact of the detector to attempt to reduce the capacitance, and thus, the electronic resolution component. Within this project, a Low Noise Back Contact (LNBC) was developed. Furthermore, the unique design of the detector element to reduce the detector capacitance and the electronic contribution of the system resolution will be discussed.

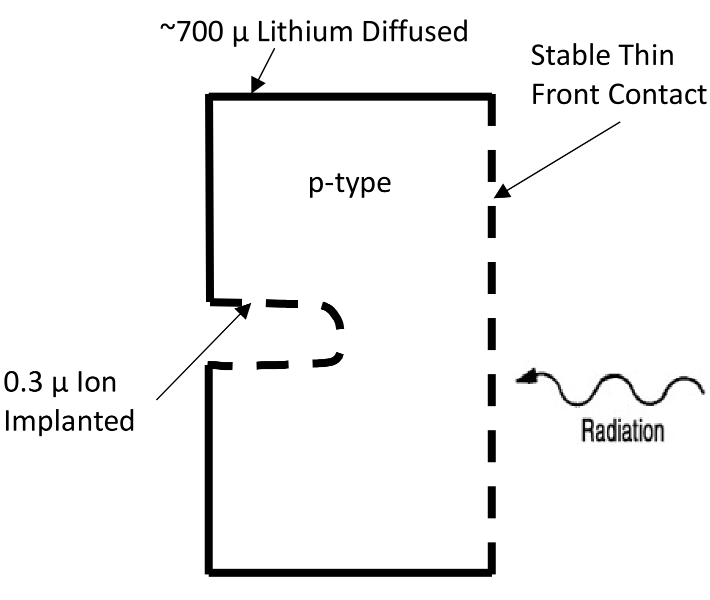


**Figure 1A**. Diagram of the GEM-S HPGe detector. Stable Thin Front Contact on the detector entrance window and standard contacts on remaining surfaces are illustrated.

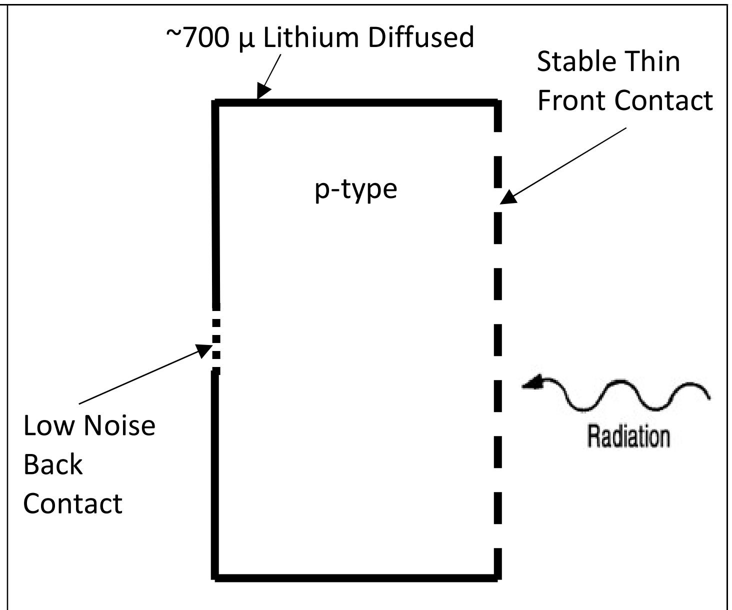


**Figure 1B**. Diagram of the GEM-SP HPGe detector. Proprietary low noise and stable thin contact on the detector are detailed, along with the standard contacts on the remaining surfaces.

## RESULTS

A diagram of this new detector is illustrated in Figure 1B. A novel, LNBC was developed to lower the detector capacitance to achieve improved resolution performance at lower energies. This GEM-SP detector was developed by ORTEC® and exhibited improved resolution performance above other coaxial and semi-planar detector geometries. Four models were developed within the scope of this project: GEM-SP5020, GEM-SP5825, GEM-SP7025 and GEM-SP8530. Table I contains the diameter of the GEM-SP detectors, ranging from 50 to 85 mm and the length, ranging from 20 to 30 mm. The HPGe, GEM-SP detector elements are loaded into a cryostat, placed under vacuum, and cooled to liquid nitrogen temperature. The endcap size associated with each model of GEM-SP detector is also displayed in Table I: 70 mm endcap for both the GEM-SP5020 and GEM-SP5825 models, 83 mm endcap for the GEM-SP7025 model and 108 mm endcap for the largest GEM-SP8530 detector model.

**Table I.** Four sizes of GEM-SP models were developed, ranging in diameter 50-85 mm and length 20-30 mm.

| GEM-SP Model | Diameter | Length (finished) | Endcap Diameter (mm) |
|---|---|---|---|
| GEM-SP5020 | 50 | 20 | 70 |
| GEM-SP5825 | 58 | 25 | 70 |
| GEM-SP7025 | 70 | 25 | 83 |
| GEM-SP8530 | 85 | 30 | 108 |

The semi-planar geometry was selected for this detector application to avoid charge trapping concerns in the detector at higher energies of interest.

The full width half maximum (FWHM) was measured for each size of the GEM-SP models at three different energies: Fe-55 at 5.9 keV, Co-57 at 122 keV and Co-60 at 1332 keV. The resolution performance for the GEM-SP detectors is summarized in Table II. The measured performance for each model is compared to the guaranteed resolution performance. For each GEM-SP detector model at each energy, the measured performance is better or lower than the guaranteed values.

**Table II.** Measured resolution of the GEM-SP detector models.

| 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 |

The GEM-SP (Fig. 1B) detectors show a 15% improvement in resolution over standard semi-planar GEM-S (Fig. 1A) detectors at low energies, 5.9 keV. A 10% improvement is achieved at 122 keV. Finally, there was no degradation of the resolution at higher energies, such as, 1.33 MeV.

The separation of peaks and superior resolution may be seen most clearly from the measurement made with an Fe-55 source. The spectra of the 5.9 and 6.5 keV peaks for both a GEM-SP8530 detector and a standard semi-planar profile GEM-S8530 detector are shown in Figure 2. The Fe-55 point source was positioned 25 cm away from the front of the endcap per IEEE ANSI standards. [3] The FWHM for the GEM-SP8530 measured 302 eV at 5.9 keV and the GEM-S8530 detector measured 410 eV. More importantly, the differentiation between the 5.9 and 6.5 keV peaks is more pronounced in the spectrum from the GEM-SP8530 detector (inner line).

The resolution of the GEM-SP8530 is improved 25% over the standard profile GEM-S8530 detector. The guaranteed resolution is improved 15% over the resolution for the GEM-S detector. Both the GEM-S8530 and the GEM-SP8530 detectors have a comparable geometry, the same nominal relative efficiency, and contain the STFC. The only difference between these two detectors is the LNBC.

Similarly, measurements were made with a Co-57 source with both the GEM-SP8530 and the GEM-S8530. The Co-57 point source was positioned 25 cm from the front of the endcap. The GEM-SP8530 detector resolution @ 122 keV was 533 eV and the resolution for the GEM-S8530 was 606 eV, as seen in Figure 3. The only difference is the addition of the LNBC for the GEM-SP series detectors.

In addition, spectra obtained using a mixed gamma source that includes several nuclides extended 25 cm from the front of the endcap for a GEM-SP8530 detector and a standard, p-type coaxial GEM50 detector were compared. The spectra in Figure 4 have the same number of counts, but they are offset to aid visualization. Two energies were compared: Am-241 and Cs-137. The GEM50 was selected for comparison because the relative efficiency is the same as the GEM-SP8530, nominally 50%. These spectra are shown in Figure 4. The geometry of the detectors is vastly different. The resolution for Am-241 is changed with the GEM-SP detector over a standard GEM50 by 52%, but the resolution performance converges at higher energies. At Cs-137, the FWHM for both the GEM-SP8530 (1.29 keV) detector and the standard coaxial, p-type GEM50 (1.31) is comparable.

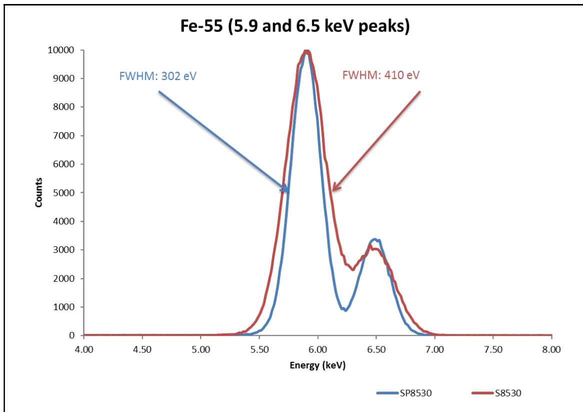


**Figure 2**. FWHM for an ORTEC GEM-SP8530 and GEM-S8530 measured with an Fe-55 point source positioned 25 cm away from the front of the endcap.

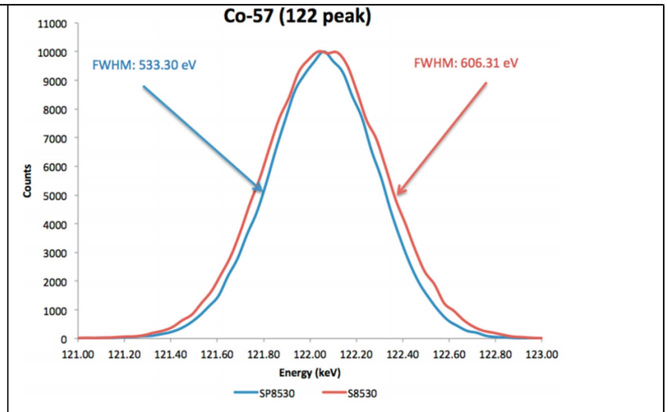


**Figure 3**. FWHM for an ORTEC GEM-SP8530 and GEM-S8530 measured with a Co-57 point source positioned 25 cm away from the front of the endcap.

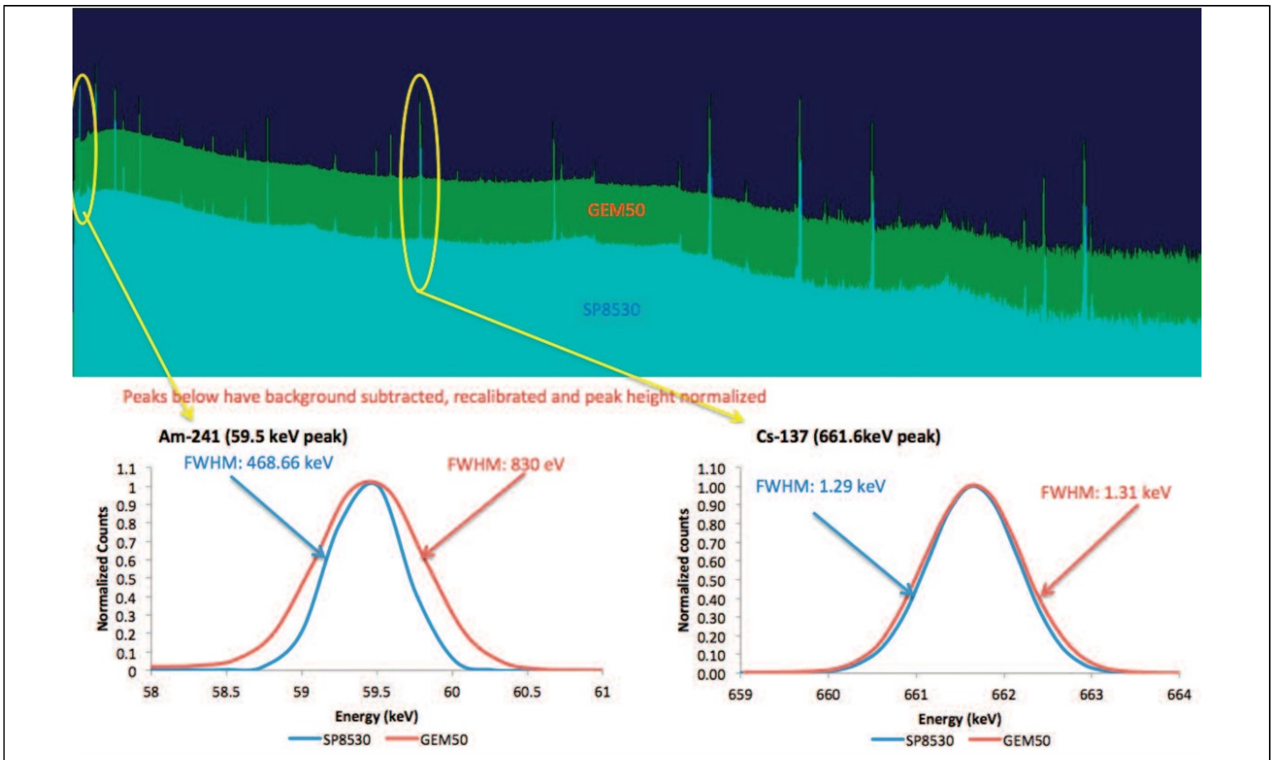


**Figure 4**. Spectra for a semi-planar GEM-SP8530 and a standard coaxial GEM50 measured with a Mixed Gamma Source containing several nuclides positioned 25 cm away from the front of the endcap. The peaks at Am-241 and Cs-137 were compared for the two detectors. Spectra have the same counts, but offset to aid visualization.

Finally, all GEM-SP detector models were measured using an analog multi-channel analyzer (MCA) at different shaping times and with a digital spectrometer at comparable rise times. The flat top was 1.00 for all digital measurements. The plots are collected in Figure 5. Energy (keV) is shown versus FWHM (keV) for each detector model. Figure 5A contains resolutions measurements at 6 µs shaping and 12 µs rise time. Tracking clockwise in each of the Figures 5A, B and C, (1) is GEM-SP5020, (2) is GEM-SP5825, (3) is GEM-SP7025, and (4) shows GEM-SP8530. There is complete agreement between the analog and digital runs for 6 µs shaping/12 µs rise times. The same is found for 10 µs shaping and 20 µs rise time. The resolution measured with an analog amplifier at 2 µs shaping time is degraded ~ 60% when compared to the measured resolution at higher time parameters. This is primarily due to the detector shape. Ballistic deficit is contributing to this poor resolution when using analog electronics. [4] However, the digital runs at 4 µs rise time have better resolution than the 2 µs analog measurements, because the digital spectrometer filters out low-side peak tailing to optimize resolution.

Figure 6 shows all runs at different energies. This figure illustrates more clearly the similarities in resolution at 6 µs and higher shaping times. There is virtually no difference in FWHM for any model at different energies for 6 µs and higher shaping time, however, the resolution is poor for low shaping time measured with an analog MCA.

Finally, the resolution was measured for the GEM-SP5020, GEM-SP5825 and GEM-SP7025 detectors using different cooling mechanisms. The resolution is plotted versus energy. There is complete agreement at the different energies measured: 5.9, 122 and 1332 keV. We find there is near $LN_2$ performance with this detector series with the different cooling methods. The measurements were made with an analog MCA at 6 µs shaping time and 1000 K counts per second (cps).

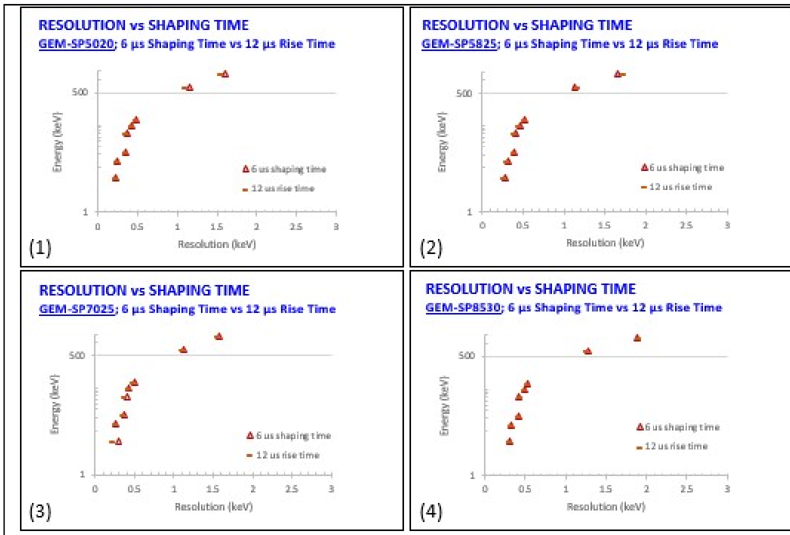


**Figure 5A**. FWHM at various energies for four GEM-SP models at 6 µs analog shaping and 12 µs digital rise time.

(1)GEM-SP5020
(2)GEM-SP5825
(3)GEM-SP7025
(4)GEM-SP8530

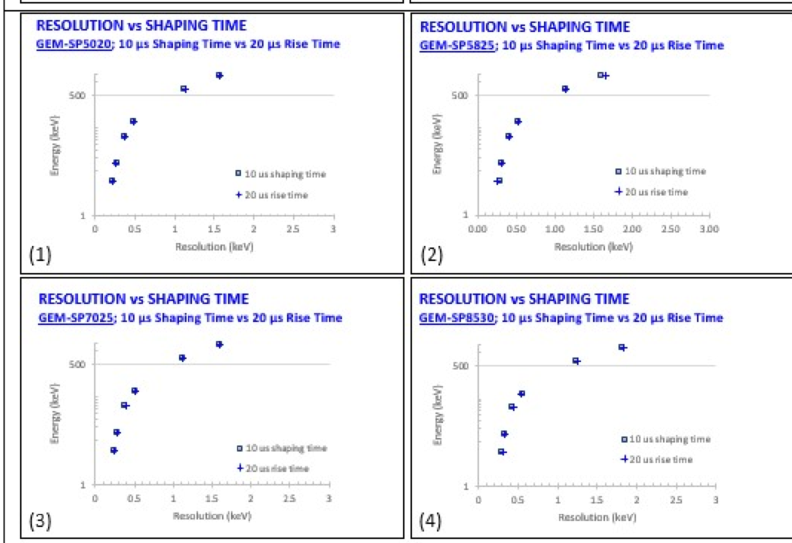


**Figure 5B**. FWHM at various energies for four GEM-SP models at 10 µs analog shaping and 20 µs digital rise time.

(1)GEM-SP5020
(2)GEM-SP5825
(3)GEM-SP7025
(4)GEM-SP8530

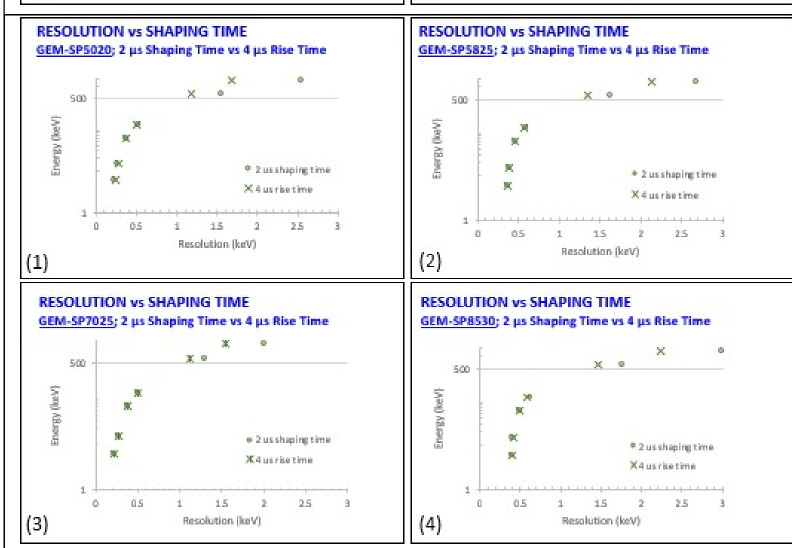


**Figure 5C**. FWHM at various energies for four GEM-SP models at 2 µs analog shaping and 4 µs digital rise time.

(1)GEM-SP5020
(2)GEM-SP5825
(3)GEM-SP7025
(4)GEM-SP8530

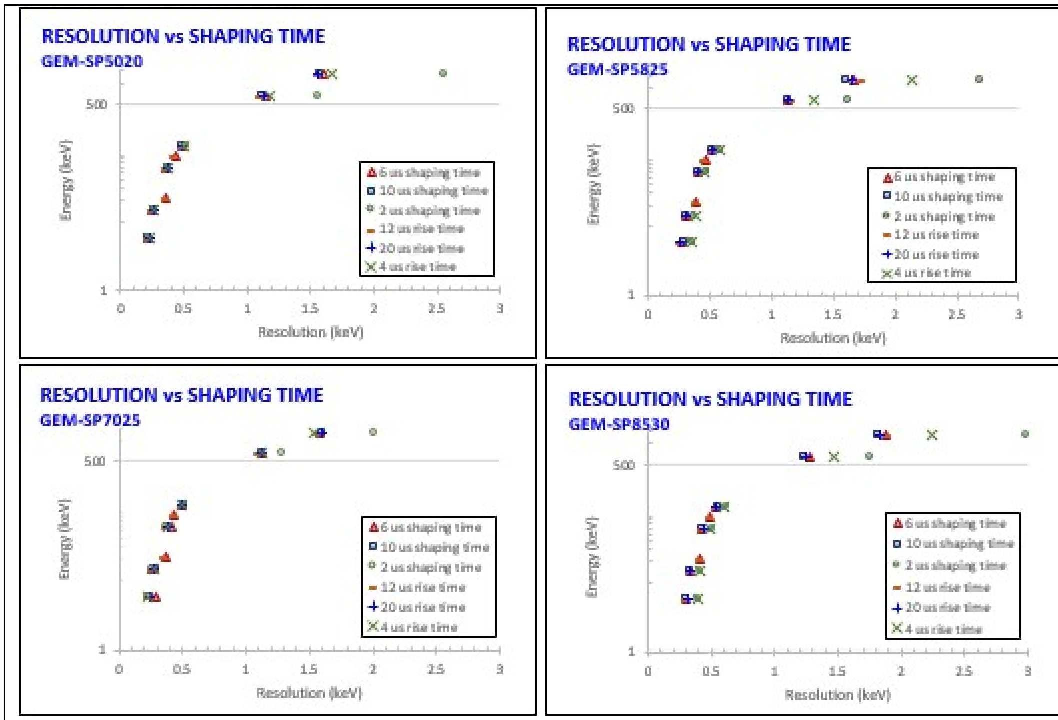


**Figure 6**. Summary FWHM at various energies for four GEM-SP models at 2, 6, and 10 µs analog shaping and 4, 12, 20 µs digital rise time.

CONCLUSION

ORTEC® produced a new GEM-SP detector with optimum resolution and efficiency at lower energies. Employing a stable thin contact and new LNBC, a high-performing detector capable of operating over a wide range of energies was developed. This semi-planar detector exhibited improved, premium detector performance above any other commercially available detector of equal dimensions. Comparable results were observed across several premium semi-planar detectors for various energies and shaping times.

Premium resolution was achieved with the GEM-SP detector series incorporating the STFC developed previously that offers measurability down to 3 keV and a stable contact. The detector may be stored at room temperature for periods at a time with no loss of efficiency at lower to medium energies from the front of the detector upon cooling the detector following being stored. The new LNBC was developed for the semi-planar HPGe detector geometry that generates superior performance at the lower to medium energies. This new GEM-SP detector shows a consistent 15% improvement at 5.9 keV, 10% improvement at 122 keV, and consistent high energy performance at 1332 keV across all sizes of the GEM-SP product line. This is an ideal detector for the 3 to 3000 keV range. This premium detector may be used for higher energies, as well, for large distributed source geometries.

Liquid nitrogen ($LN_2$) performance was achieved on both ORTEC's Mobius and X-COOLER-III cooling mechanisms for GEM-SP5020, GEM-SP5825 and the GEM- SP7025 models. Measured resolution at 5.9, 122 and 1332 keV for models GEM-SP5020, GEM-SP5825 and GEM-SP7025 is shown in Figure 7. There is no degradation in resolution for the mechanical cooler or the cryo-recycler when

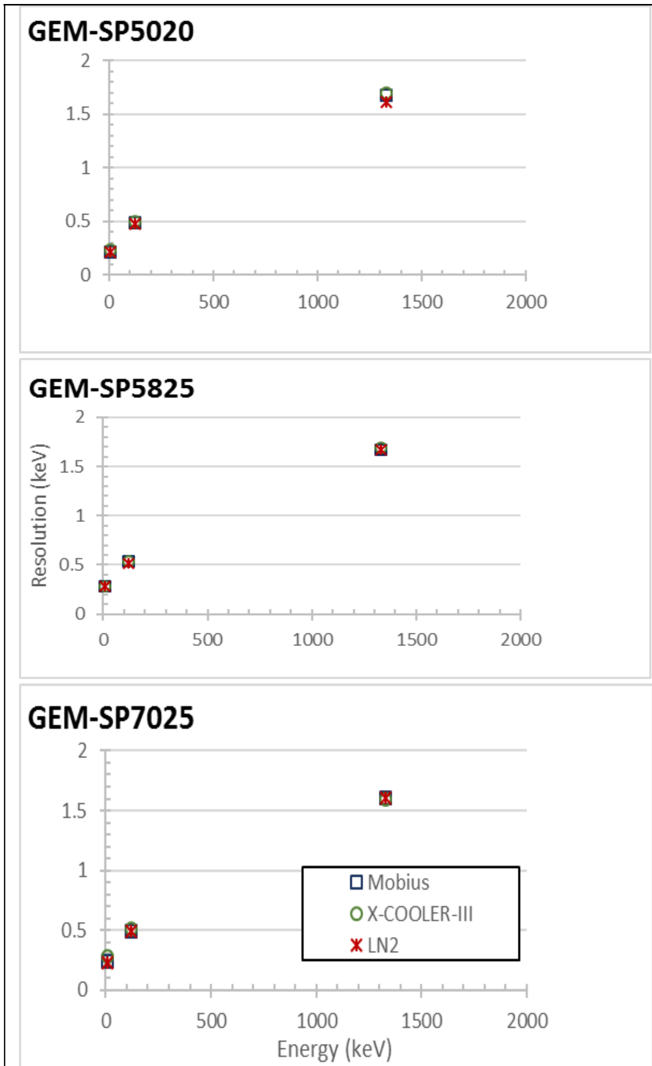


**Figure 7**. Resolution measured at 5.9 keV, 122 keV and 1332 keV for models GEM-SP5020, GEM-SP5825 and GEM-SP7025 with different cooling configurations: Mobius cryo-cooler, mechanical cooler and $LN_2$.

compared to the resolution measured with $LN_2$ cooling. In fact, the range between the resolution measured in $LN_2$ versus the Mobius or X-cooler was just a few eV for each detector. The difference between $LN_2$ resolution and the Mobius and mechanical cooler is 20 eV for the lower energies and 90 eV for Co-60 for the GEM-SP5020 detector. The difference between $LN_2$ and the Mobius and mechanical cooler for the GEM-SP5825 and GEM-SP7025 detectors ranged 6-51 eV.

The p-type semi-planar GEM-SP product is a premium detector for low-to-medium energies in the 3 to 3000 keV range. Table III displays the published specifications for each GEM-SP detector model: GEM-SP5020, GEM-SP5825, GEM-SP7025 and GEM-SP8530. The detectors are warranted at 5.9 keV, 122 keV and 1332 keV. The peak shape, P:C and relative efficiency are additionally specified.

**Table III.** Summary of performance for all ORTEC GEM-SP models.

| Detector Model | Energy Resolution (FWHM) | | | 122 keV | | P:C Warranted | Volume ($cm^3$) | Nominal Relative Efficiency (%) |
|---|---|---|---|---|---|---|---|---|
| | 5.9 keV Warranted (eV) | 122 keV Warranted (eV) | 1.33 MeV Warranted (keV) | FW.1M/ FWHM Typical | FW.02M/ FWHM Typical | | | |
| GEM-SP5020 | 300 | 585 | 1.8 | 1.90 | 2.55 | 35 | 39 | 7 |
| GEM-SP5825 | 340 | 585 | 1.8 | 1.90 | 2.65 | 35 | 66 | 15 |
| GEM-SP7025 | 380 | 585 | 1.8 | 1.95 | 2.75 | 40 | 96 | 20 |
| GEM-SP8530 | 425 | 630 | 1.9 | 2.00 | 2.90 | 55 | 170 | 50 |

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