

Understanding Energy Resolution

A technical note on how scintillation detectors separate gamma-ray peaks: the physics of light yield, FWHM, statistical broadening, and crystal non-proportionality that together determine why some materials resolve closely spaced photopeak pairs that others cannot.

Berkeley Nucleonics · ScintiQ™ Custom Scintillation Detectors · Rev. B · October 2026 · dc-62022201

TECHNICAL NOTE · SCINTIQ CUSTOM SCINTILLATION DETECTORS

1 What Energy Resolution Means

Every gamma spectrometer produces a photopeak at the energy of the incident photon. In a perfect detector, that peak would be a delta function: a single, infinitely sharp line. Real detectors spread the peak into a Gaussian shape because the signal-generation process introduces statistical scatter at every stage. The width of that Gaussian is the energy resolution.

Resolution is conventionally quoted as the full width at half maximum (FWHM) of the photopeak, expressed as a percentage of the peak centroid energy:

$$R (\%) = \text{FWHM} / E_0 \times 100$$

A smaller number is better. A detector with 3% resolution at 662 keV (the Cs-137 reference photopeak) can distinguish two gamma lines that differ by roughly 20 keV near that energy. One with 7% resolution at the same energy needs lines to be roughly 46 keV apart before they show as separate peaks. For isotope identification work, environmental monitoring, or low-background counting, those differences are decisive.

2 Where Peak Broadening Comes From

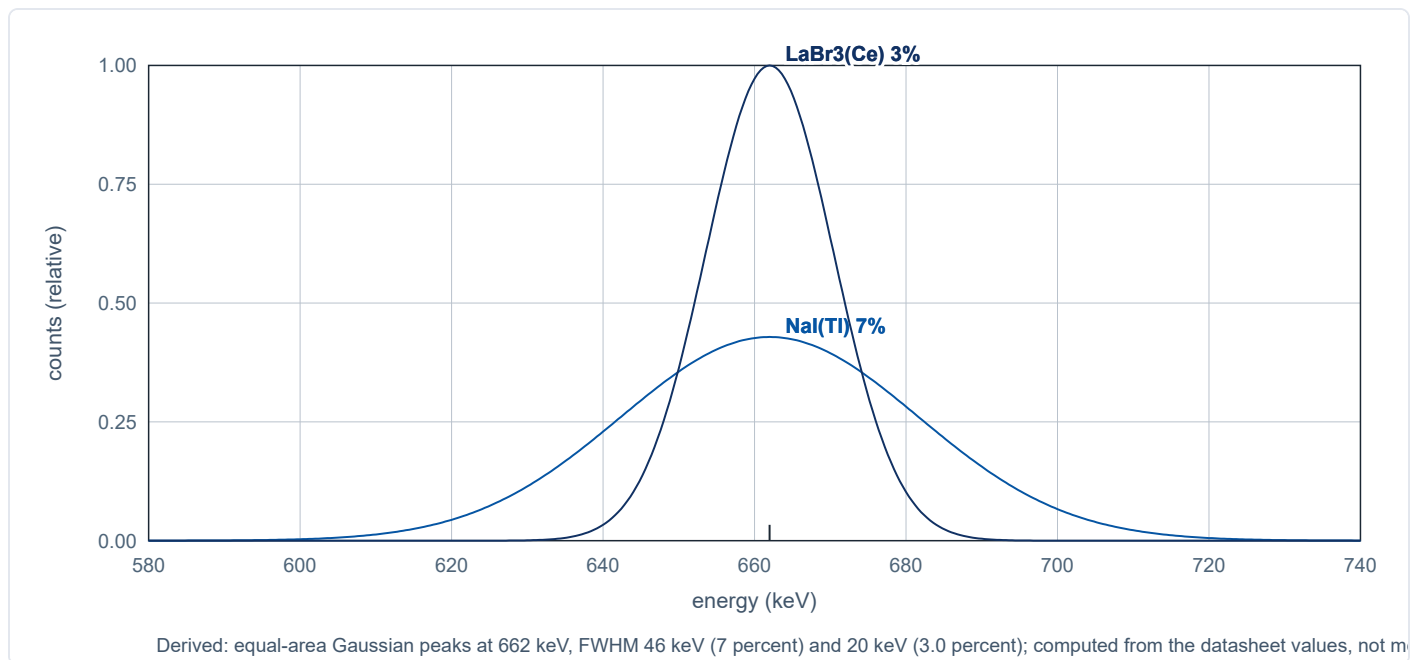


Figure 1. Derived: two Gaussian photopeaks at 662 keV for a wide-FWHM material (NaI(Tl), 7%) and a high-resolution material (LaBr₃(Ce), 3.0%), plotted at the same centroid. The narrower peak separates closely spaced gamma lines that overlap in the broader spectrum.

Three independent physical processes add in quadrature to produce the observed FWHM. Each originates at a different stage of the signal chain.

Statistical Variance in Photon and Photoelectron Production

A gamma ray of energy E deposits its energy in the crystal, and the crystal converts that energy into N visible photons. Because photon production is a Poisson process, the RMS spread in N is the square root of N . The photodetector (PMT or SiPM) then converts those photons to photoelectrons with efficiency described by the quantum efficiency. At each conversion step, the variance compounds. The combined statistical contribution to the FWHM scales as $1/\sqrt{N}$: the more photons the crystal produces per unit energy, the narrower the peak. This is why absolute light yield matters so directly to resolution.

Non-Proportionality

An ideal scintillator would emit exactly twice as many photons for twice the deposited energy at every point along the interaction track. Real crystals deviate from this linear ideal, particularly at low energies below a few hundred keV where photoelectric interactions dominate and the secondary electron spectrum cuts off sharply. When the local light yield along the electron track is not strictly proportional to local energy loss, the integrated yield per gamma event varies even for monoenergetic photons. This non-proportionality contributes a floor to the resolution that cannot be reduced by improving the photodetector or increasing the number of photons.

NaI(Tl) shows measurable non-proportionality across the 10 to 1000 keV range, contributing roughly 2 to 3 percentage points to its resolution at 662 keV. LaBr₃(Ce) and CeBr₃ show substantially better proportionality over the same range, which is one reason their intrinsic resolution floors are lower even when light yield differences are accounted for.

Instrumentation and Inhomogeneity

Electronics add noise: preamplifier Johnson noise, PMT dark current, SiPM dark-count rate during the integration window, and ADC quantization. Crystal optical imperfections, internal reflections, surface finish, and index-of-refraction mismatches at the crystal-photodetector interface all produce event-to-event variation in the fraction of scintillation photons that are collected. These terms are largely independent of energy. Their FWHM contribution adds in quadrature with the statistical and non-proportionality terms, so at high photon energies where the statistical term shrinks, instrumentation terms begin to set the practical floor.

Quadrature addition

Because these three contributions are statistically independent, the total variance is their sum:

$$\sigma^2_{\text{total}} = \sigma^2_{\text{stat}} + \sigma^2_{\text{nonprop}} + \sigma^2_{\text{instr}}$$

The observed FWHM is 2.355 times the total standard deviation. Improving one term yields diminishing returns once the others dominate. That is why ultra-high resolution work demands a crystal with both high light yield and excellent proportionality, coupled to a low-noise photodetector.

3 Light Yield and the Photon Statistics Limit

Light yield, quoted in photons per MeV (ph/MeV), is the starting point for the statistical analysis. At the photon statistics limit alone, the intrinsic resolution is:

$$R_{\text{stat}} (\%) = 2.355 \times \text{sqrt}(1 / (\text{LY} \times E \times \text{QE} \times \text{CE})) \times 100$$

where LY is the absolute light yield in ph/MeV, E is the gamma energy in MeV, QE is the photodetector quantum efficiency, and CE is the photon collection efficiency from crystal to photodetector. Every factor under the square root improves resolution. Doubling the light yield narrows the statistical contribution by a factor of sqrt(2), roughly 1.4x.

The table below shows absolute light yield and the resulting resolution at 662 keV for five frequently compared materials. The relative light yield column uses NaI(Tl) = 100 as the reference, the conventional bialkali-PMT scale.

Table 1.

Material	Abs. Light Yield (ph/MeV)	Rel. Yield (NaI=100)	Res. at 662 keV (typical)	Non-proportionality
NaI(Tl)	~38,000	100	~7%	Moderate
LaBr3(Ce)	~66,000	150	3.0%	Very low
CeBr3	~60,000	130	4%	Low
SrI2(Eu)	~80,000	120–140	~3.5%	Very low
CsI(Tl)	not stated on the datasheet	45 (bialkali PMT)	~8–9% (bialkali PMT)	Moderate

CsI(Tl) emits substantial light but its emission is centered near 550 nm, where bialkali photocathodes have poor quantum efficiency. Paired with a silicon photodiode or SiPM its effective yield recovers (the SiPM readout datasheet lists under 7 percent at 662 keV for a 25 x 25 mm CsI(Tl) crystal), demonstrating that the choice of photodetector is part of the system resolution budget, not a fixed property of the crystal alone. The relative yield column is photoelectron yield on a bialkali PMT, which is why CeBr3 at 130 does not equal the ratio of its 60,000 photons per MeV to the NaI(Tl) literature value of about 38,000.

4 How Resolution Changes with Energy

Resolution improves with increasing gamma energy (more photons per event) in the statistical regime. The energy dependence follows approximately:

$$R(E) = \sqrt{a^2 / E + b^2}$$

The first term captures photon statistics and the second captures a floor set by non-proportionality and instrumentation. At low energies (below ~100 keV) the statistical term dominates and resolution degrades rapidly. At high energies (above ~1 MeV) the floor term dominates, and even perfect counting statistics cannot push resolution below a material-specific limit.

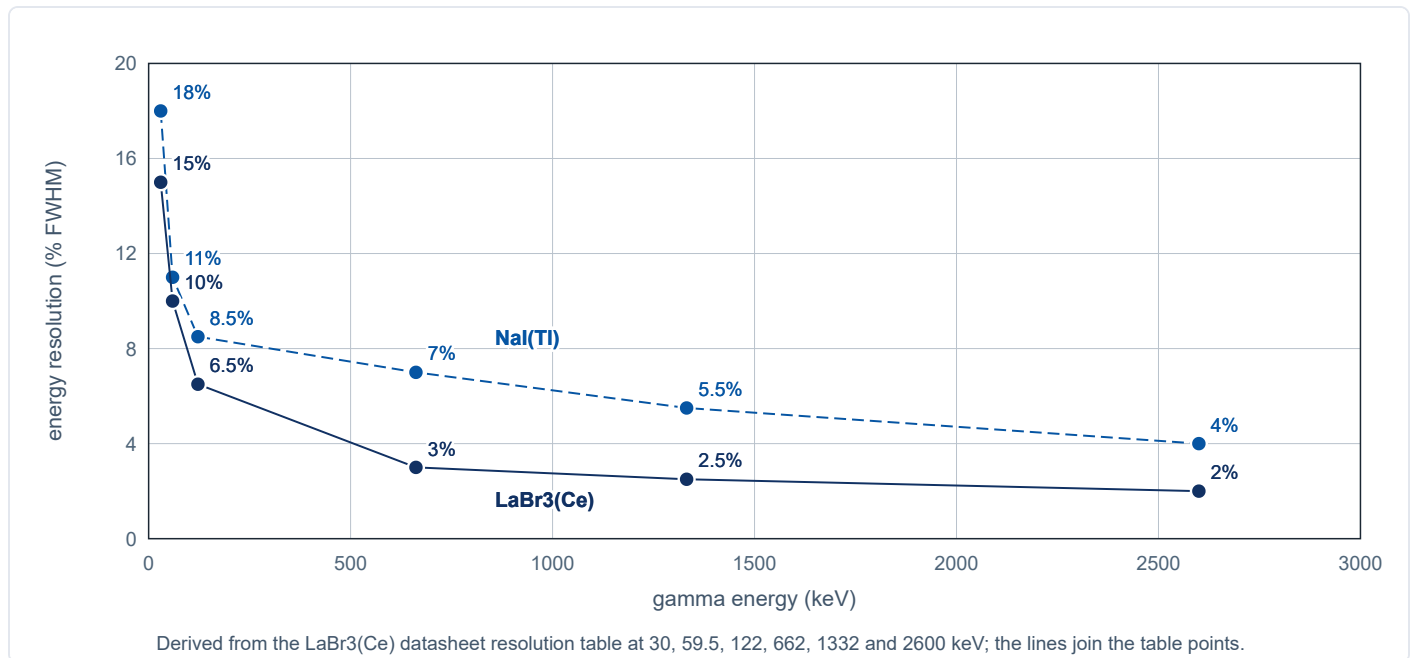


Figure 2. Energy resolution against gamma energy for NaI(Tl) and LaBr3(Ce). The datasheet points are 8.5, 7 and 5.5 percent for NaI(Tl) and 6.5, 3 and 2.5 percent for LaBr3(Ce) at 122, 662 and 1332 keV; resolution improves with energy, and each material approaches a different floor set by its non-proportionality.

The CeBr3 datasheet provides reference points that illustrate the relationship directly. At 662 keV, CeBr3 achieves approximately 4% FWHM against 7% for NaI(Tl) measured in the same conditions. At 1332 keV, CeBr3 reaches approximately 3% against NaI(Tl)'s 5.5%. At 122 keV (Co-57 reference), CeBr3 measures approximately 8%, reflecting the steeper degradation at low energy where statistics are poor and Compton scatter in the crystal raises the background under the photopeak.

5 Resolution at 662 keV: Key Materials Compared

The chips below summarize typical photopeak resolution at 662 keV for the high-performance materials in the ScintIQ line. These figures reflect well-coupled, room-temperature PMT readout unless noted. Values are typical and subject to crystal quality, readout coupling, and shaping time selection. Consult individual datasheets for guaranteed specifications.

NaI(Tl)

CsI(Tl)

CeBr3

SrI2(Eu)

LaBr3(Ce)

~7%Workhorse
reference**~8–9%**Bialkali PMT
readout**~4%**No La-138
background**~3.5%**Highest absolute
yield**3.0%**Best intrinsic
resolution

6 Why LaBr₃(Ce), CeBr₃, and SrI₂(Eu) Outperform NaI(Tl)

NaI(Tl) has served as the gamma spectroscopy workhorse for more than seven decades. Its combination of high light yield, large growth diameter, and low cost still makes it the right answer for general health physics surveys, environmental monitoring, and applications where cost dominates. But three properties combine to cap its resolution at approximately 7% at 662 keV:

- **Non-proportionality:** NaI(Tl) shows a significant dip in light yield per unit energy below ~200 keV. This creates an energy-dependent spread in photon yield even for monoenergetic gammas, adding directly to the measured FWHM.
- **Thallium emission kinetics:** The 0.23 microsecond decay time is not a resolution penalty in itself, but the thallium dopant creates multiple emission centers with slightly different yields depending on where in the crystal the energy is deposited.
- **Moderate absolute yield ceiling:** At roughly 38,000 ph/MeV, the statistical photon-counting floor is manageable but not exceptional. Newer crystals push past 60,000 ph/MeV.

LaBr₃(Ce): The Resolution Leader

Lanthanum bromide activated with cerium sets the practical resolution floor for commercially available scintillators. Its light yield reaches approximately 66,000 ph/MeV, and its non-proportionality is among the lowest measured for any inorganic scintillator. The result is a typical FWHM of 3.0% at 662 keV. In practice that is the difference between separating Cs-134 at 605 keV from Cs-137 at 662 keV, 57 keV apart, which a 46 keV NaI(Tl) peak only begins to do and a 20 keV LaBr₃ peak does cleanly; it is not the difference between resolving U-235 at 185.7 keV from Ra-226 at 186.2 keV, which no scintillator does. The 16 to 20 nanosecond decay time allows short shaping times and high count-rate tolerance. The cost is hygroscopicity (the crystal requires hermetic sealing) and an intrinsic low-level background from La-138, an isotope present at 0.09% natural abundance in natural lanthanum, which produces a 1436 keV line and continuum counts below, plus alpha lines above 2.5 MeV from the Ac-227 chain, about 2.5 counts per second per cubic centimeter in an unshielded 51 x 51 mm crystal.

CeBr₃: High Resolution Without the La-138 Background

Cerium bromide is a self-activated material: Ce serves as both the host lattice element and the luminescence center, eliminating the need for a dopant. This chemistry removes the La-138 background entirely, leaving only a small Ac-227 contribution (0.002 counts per second per cubic centimeter inside a 100 mm lead shield), while retaining most of the resolution advantage. At about 130 relative photoelectron yield (60,000 ph/MeV absolute photon yield) and a decay time of 18 to 25 nanoseconds, CeBr₃ delivers 4% resolution at 662 keV and 3% at 1332 keV. That is a substantial improvement over NaI(Tl) in the same measurement geometry. For low-background counting applications where the La-138 continuum would interfere, CeBr₃ is frequently the preferred material over LaBr₃(Ce).

SrI₂(Eu): The Highest Light Yield Available

Strontium iodide activated with europium holds the record for absolute light yield among commercially produced scintillators, reaching 80,000 ph/MeV. That photon output pushes the statistical limit lower than LaBr₃(Ce) can achieve on yield alone. SrI₂(Eu) also shows very low non-proportionality across its emission range. The result is about 3.5% resolution at 662 keV (3.4% measured on a 38 x 38 mm crystal), 3% at 1332 keV and 2.5% at 2600 keV. The tradeoffs are a slow decay time (1 to 5 microseconds, limiting high count-rate use), strong hygroscopicity, and considerably higher cost than NaI or CsI-based materials. For high-resolution spectroscopy at low to moderate count rates, particularly in isotope identification and environmental measurements, the yield advantage is real and measurable.

7 Practical Implications for Detector and System Design

Resolution does not exist in isolation. Several related factors interact with crystal choice to determine the resolution a complete system achieves in the field.

Photodetector Coupling

The quantum efficiency of the photodetector, the optical coupling quality (grease, direct bonding, or air gap), and the reflector geometry all affect the fraction of scintillation photons converted to signal. A high-yield crystal paired with a poorly matched or poorly coupled photodetector will not realize its intrinsic resolution potential. SiPM photon detection efficiency peaks near 420 to 450 nm, so the 370 nm emission of LaBr₃(Ce), CeBr₃ and CLYC couples at reduced efficiency, and the choice between a SiPM and a bialkali PMT is part of the resolution budget. Modern readout electronics from Berkeley Nucleonics (the bMCA, bPAD, and TOPAZ-HR modules) are designed to extract full resolution from these high-performance crystals.

Temperature Dependence

Light yield is temperature-sensitive in most inorganic scintillators, and the NaI(Tl) datasheet calls for verification at temperature extremes. Gain stabilization algorithms in the readout electronics compensate for yield drift, but the underlying crystal stability still matters for a field deployment where temperature control is not guaranteed.

Count Rate and Pile-Up

A crystal with a long decay constant accumulates pile-up at high count rates. Srl2(Eu) at 1 to 5 microseconds is unsuitable for high-rate applications. LaBr₃(Ce) and CeBr₃ at 16 to 25 nanoseconds tolerate high input count rates with appropriate shaping. NaI(Tl) at 230 nanoseconds lies in between. Resolution quoted in a datasheet assumes low dead-time conditions; at high count rates the effective FWHM degrades unless the shaping time is reduced, which in turn increases the electronic noise contribution.

Crystal Size and Surface Area

Larger crystals collect more counts per unit time but also accumulate more optical path length from the far end of the crystal to the photodetector. Non-uniform light collection degrades resolution in crystals where the reflector geometry is not well optimized. Resolution specifications should always be tied to the crystal size: a 3 x 3 inch LaBr₃ crystal will not match the resolution of a 1 x 1 inch unit at the same energy in the same measurement time, though the larger crystal recovers efficiency gains that compensate for many applications.

8 Summary: Selecting for Resolution

The table below condenses the key resolution trade-offs for common ScintlQ materials. All resolution values are typical at 662 keV with PMT readout at room temperature unless otherwise noted.

Table 2.

Material	Res. @662 keV	Res. @1332 keV	Key Resolution Driver	Primary Limitation
NaI(Tl)	~7%	~5.5%	High yield, low cost	Non-proportionality
CeBr ₃	~4%	~3%	High yield, low non-prop., no La-138	Cost, hygroscopic
Srl2(Eu)	~3.5%	~3%	Highest absolute yield	Slow decay, high cost
LaBr ₃ (Ce)	3.0%	~2.5%	Highest yield + lowest non-prop.	La-138 intrinsic background
LBC (LaBr _{2.85} Cl _{0.15} :Ce)	~3%	Not listed	Bright, mixed halide, robust	La-138 background (present)

Material	Res. @662 keV	Res. @1332 keV	Key Resolution Driver	Primary Limitation
CLLBC	<3.5%	~2.3%	High res + neutron/gamma PSD	Complex crystal growth, cost

When resolution is the primary selection criterion and background purity matters, CeBr₃ offers the clearest operating advantage: near-LaBr₃ resolution, no La-138 background and only a small Ac-227 contribution, and a well-established supply chain. When resolution must be maximized at any cost and the La-138 background is acceptable (or can be subtracted), LaBr₃(Ce) remains the benchmark. Srl₂(Eu) is the right choice when yield must be maximized for a low-rate, high-sensitivity application and the slower shaping time is acceptable.

9 Further Reading and Contact

Berkeley Nucleonics offers the full ScintIQ range from standard hermetically sealed NaI(Tl) assemblies to custom LaBr₃(Ce), CeBr₃, and Srl₂(Eu) detectors with PMT or SiPM readout and matched electronics including the TOPAZ-HR and bMCA modules. The engineering team can work from a resolution requirement to a complete detector system specification.

For questions about energy resolution measurements, crystal selection for a specific isotope identification problem, or custom detector configurations, contact the ScintIQ applications team:

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For a broader treatment of scintillation physics, detection efficiency, timing, and readout electronics, the Berkeley Nucleonics web book covers these topics in depth. *Nuts & Bolts of Scintillation Detectors* ([opens in a new window](#))

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Technical Note

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