

SiPM vs PMT Readout for Scintillators

A systematic comparison of silicon photomultiplier and photomultiplier tube readout: gain, form factor, ruggedness, magnetic immunity, temperature behavior, operating voltage, and cost. Guidance on which technology fits which measurement environment, with reference to the ScintIQ SiPM Readout module and the 2-inch SiPM Detector assembly.

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TECHNICAL NOTE · SCINTIQ CUSTOM SCINTILLATION DETECTORS

1 The Photon-to-Electron Problem

Every scintillation detector rests on the same principle: ionizing radiation deposits energy in a luminescent crystal, and the crystal re-emits that energy as visible or near-UV photons. The downstream challenge is converting those photons into a measurable electrical signal with as little added noise as possible. Two technologies dominate that conversion stage today: the photomultiplier tube (PMT) and the silicon photomultiplier (SiPM). They accomplish similar things by very different means, and understanding the differences is essential for choosing the right detector configuration.

This note works through the principal tradeoffs systematically. The goal is not to declare a winner but to give engineers and scientists a clear framework for making the right choice given their specific measurement environment, budget, and physical constraints.

2 How Each Device Works

The Photomultiplier Tube

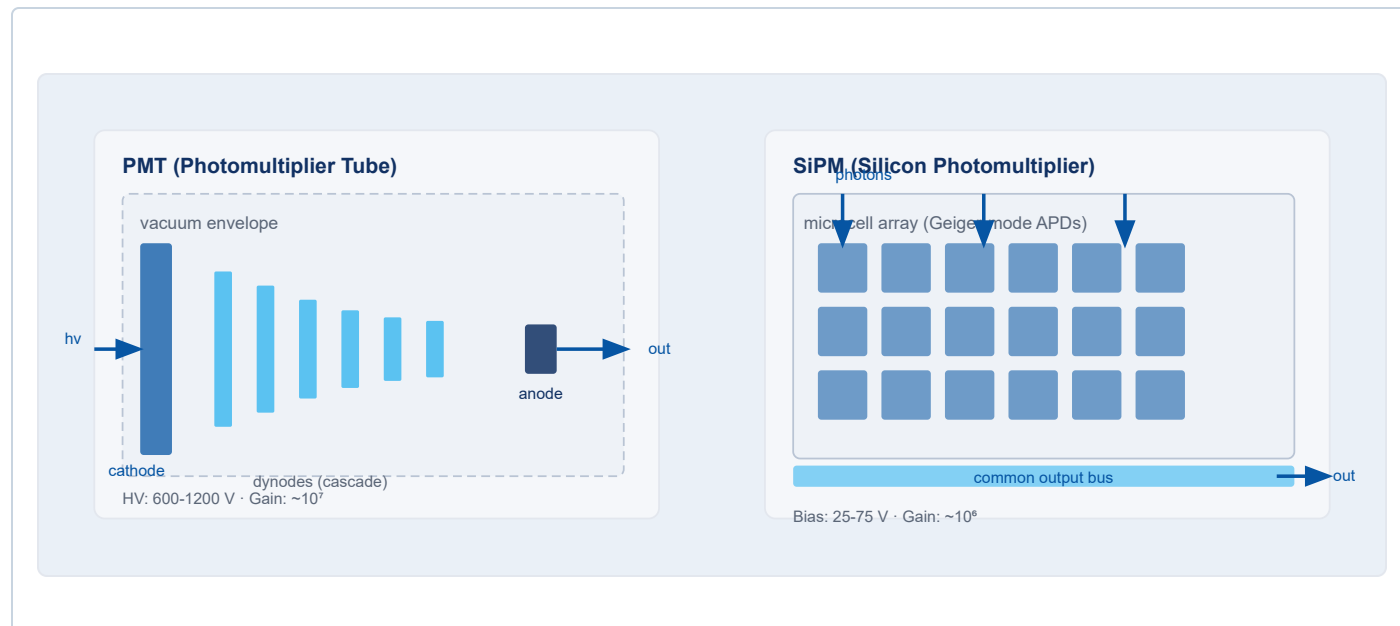
A PMT is a vacuum device. Photons strike a photocathode and eject photoelectrons through the photoelectric effect. A series of dynodes, each held at a successively higher potential, multiplies the electron current at each stage: a typical 10-stage tube achieves gain on the order of 10^6 to 10^7 . The final electron current at the anode is collected and amplified by the readout electronics. The photocathode spectral response peaks in the blue-to-near-UV range, which pairs naturally with the emission spectra of NaI(Tl) at 415 nm, LaBr₃(Ce) and CeBr₃ at 370 nm, and most other common scintillators.

The PMT requires a high-voltage supply, typically 600 to 1200 V depending on the tube type and gain setting. That voltage must be stable and low-noise; ripple and drift translate directly into gain instability and baseline shifts in the spectrum. Conventional voltage divider chains consume current continuously, which matters for battery-operated or thermally constrained systems.

The Silicon Photomultiplier

A SiPM is a solid-state device: an array of avalanche photodiodes (microcells) operated above their reverse-breakdown voltage in Geiger mode. Each microcell fires as a binary event when struck by a photon, producing a standard charge packet. The total output of the SiPM is the sum of all firing microcells in a given time window, providing an analog signal proportional to photon flux so long as the photon count per pulse does not saturate the available microcells. Gains in the range of 10^5 to 10^6 are typical, comparable to a PMT, achieved at bias voltages of only 25 to 75 V.

SiPMs respond well to longer wavelengths than traditional bi-alkali photocathodes, covering green emission efficiently. This makes them an excellent match for CsI(Tl) at 550 nm, GAGG(Ce) at 520 nm, and BGO at 480 nm, materials whose emission is poorly suited to a standard bi-alkali PMT. A green-extended or multi-alkali PMT can partially bridge that gap, but the SiPM does so inherently and efficiently.



■ **SCHEMATIC** **Figure 1.** Schematic comparison of PMT dynode cascade (left) and SiPM Geiger-mode microcell array (right). The PMT achieves gain through successive electron multiplication in a high-vacuum envelope; the SiPM achieves comparable gain through parallel avalanche events in a compact solid-state die. Diagram is illustrative.

3 Tradeoff Analysis

Physical Size and Integration

This is one of the clearest wins for SiPM technology. A standard 2-inch PMT adds roughly 50 to 80 mm of length to a detector assembly, and its glass envelope demands careful mechanical protection. A SiPM die for the same active area is a few millimeters thick and can be mounted directly against the crystal exit face with optical coupling compound. The result is a detector package that can be 30 to 50 percent shorter than an equivalent PMT-coupled assembly. For handheld instruments, wearable dosimeters, and downhole logging tools where every centimeter of length and every gram of mass matter, that compactness is decisive.

The ScintIQ 2-inch NaI(Tl) SiPM Detector illustrates this directly: a 2-inch diameter by 2-inch length NaI(Tl) crystal coupled to an integrated SiPM readout board. The complete module is substantially more compact than the same crystal coupled to a conventional PMT with its dynode voltage divider.

Ruggedness: Shock and Vibration Resistance

A PMT is a glass vacuum tube. Mechanical shock, vibration, or even a sharp pressure transient can fracture the envelope, destroy the photocathode, or dislodge a dynode. Standard PMT assemblies are rated for modest shock levels that depend on the tube family, and they require protective housing and careful mounting. Field instruments built around PMTs must absorb most of the shock load through the detector housing.

A SiPM is a solid-state device with no evacuated envelope. Its shock and vibration tolerance is orders of magnitude higher. The limiting mechanical factor in a SiPM-based detector becomes the crystal itself (hygroscopic materials like NaI(Tl) need sealed housing regardless of readout) and the solder joints on the readout board. For vehicle-mounted survey systems,

backpack-carried RIID instruments, and any application subject to regular handling impact, the SiPM-based detector is far more robust by design.

Magnetic Field Immunity

Electron trajectories inside a PMT are bent by magnetic fields. Even the Earth's field, about half a gauss, produces a measurable gain shift if the PMT is not shielded with mu-metal, and a field of a few gauss costs a substantial fraction of the gain. Near MRI magnets, accelerator beam lines or high-current switching equipment, an unshielded PMT stops working.

A SiPM contains no free electron trajectories. Carriers travel through silicon lattice, not vacuum, and the Lorentz deflection is negligible at all field levels encountered in practical detector work. SiPM-based detectors operate normally inside MRI scanners and adjacent to superconducting magnets. This makes SiPM readout the practical choice for PET/MRI, in-bore radiation monitoring, and any detector system that must coexist with strong magnetic fields.

Gain

Both technologies deliver gain in the 10^5 to 10^7 range, which is adequate for single-photon detection and for the light pulses produced by typical scintillators. In absolute gain terms, a high-quality PMT can reach 10^7 to 10^8 with 12 or more dynode stages, slightly ahead of typical SiPMs. However, for scintillation spectroscopy the gain does not need to be maximized independently: what matters is the signal-to-noise ratio at the shaping amplifier input, which depends on gain uniformity, dark current, and excess noise factor together. Well-designed SiPM readout circuits match or exceed PMT-based systems in terms of achievable energy resolution for most scintillator types.

One caveat: SiPMs generate significant dark current from thermally triggered Geiger events (dark count rate). At room temperature, dark counts run of order 100,000 per second per square millimeter, so a 6 mm x 6 mm die fires a few million times per second, device dependent. These are small, single-photoelectron pulses, and they are largely invisible when a scintillator produces a multi-photon burst; the coincidence requirement inherent in pulse-height analysis rejects them efficiently. But in very low light flux measurements or when integrating over long time windows, dark counts add noise. Cooling the SiPM suppresses dark counts aggressively, roughly halving the rate for every 10 degrees Celsius of temperature reduction.

Temperature Behavior

Temperature is the most significant practical challenge for SiPMs in field use. The breakdown voltage of a SiPM shifts with temperature, typically around 20 to 60 mV per degree Celsius depending on the device. Because the SiPM is biased at a fixed overvoltage above breakdown, a temperature change shifts the effective operating point, which shifts gain and photon detection efficiency. In a laboratory with temperature-controlled electronics, this is easily managed with a temperature compensation circuit that adjusts bias voltage as temperature drifts. In a field instrument operating from -10 to +50 degrees Celsius, the compensation must be active, accurate, and responsive.

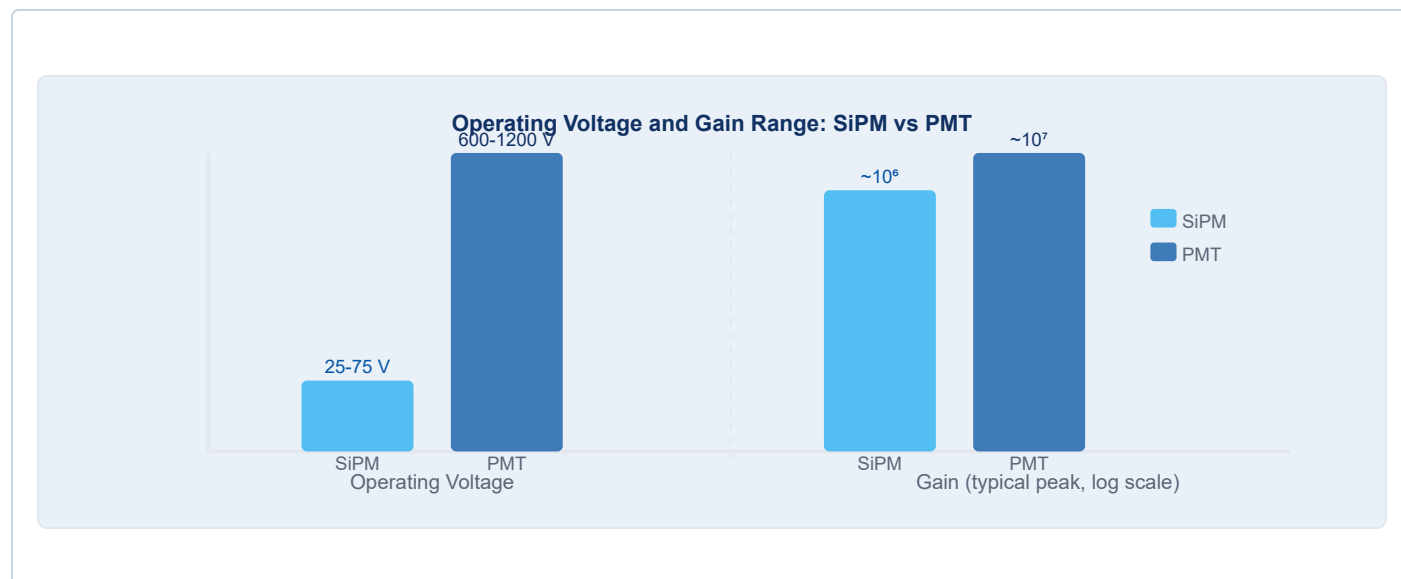
The ScintIQ SiPM Readout module addresses this directly: the design includes bias temperature compensation to maintain stable gain across the operating temperature range. Instruments that do not implement compensation will see spectral peaks broaden and shift as ambient temperature changes, degrading energy resolution in the field.

PMTs are not immune to temperature effects, but they need no active bias control. The gain temperature coefficient of a PMT is typically a few tenths of a percent per degree, so a 50-degree swing moves the gain by tens of percent, which a gain-stabilization routine or a calibration corrects. For applications in thermally extreme environments without active compensation, PMT readout often requires less circuit complexity to stabilize.

Operating Voltage

This is a stark difference. A PMT requires a high-voltage supply in the range of 600 to 1200 V, with stability better than 0.1 percent to avoid gain drift. Generating that supply from a battery or from a 5 V system bus requires a DC-DC boost converter with careful filtering. The supply chain for high-voltage components carries cost and regulatory complexity. In portable instruments, the high-voltage converter is a significant fraction of the power budget and a known reliability concern.

A SiPM operates at 25 to 75 V, a range that is easily generated from a standard low-voltage rail with a small boost stage or directly from available instrument voltages. The lower supply voltage is safer for personnel, simpler to regulate, and reduces electromagnetic emission in sensitive measurement environments. For battery-powered handheld instruments and embedded systems, this is a meaningful practical advantage.



■ **SCHEMATIC Figure 2.** Comparative ranges for operating voltage (left pair) and typical peak gain (right pair, log scale) for SiPM and PMT readout. The SiPM's low bias voltage is a major system integration advantage. Gain values are approximate and device-dependent; see manufacturer datasheets for precise figures.

Cost

PMT pricing varies with size, sensitivity and manufacturer, and the high-voltage power supply and voltage divider add to it. Specialized tubes (low-background glass, fast timing, large area) cost considerably more than a standard alkali tube.

SiPM pricing has fallen as the technology has matured, and the supporting electronics (low-voltage bias supply, temperature compensation, charge amplifier) are generally less expensive than a PMT high-voltage chain. Covering a 2-inch face takes an array of dies, which adds device count and capacitance. For high-volume production instruments such as handheld survey meters or portal monitors, the cost argument favors SiPM; for low-volume research systems where a specialized PMT provides a unique characteristic (very low dark current at room temperature, for example), the difference narrows.

4 Summary Comparison

Table 1.

Parameter	SiPM	PMT (standard bialkali)
Operating voltage	25-75 V (low voltage)	600-1200 V (high voltage)
Typical gain	10^5 to 10^6	10^6 to 10^8
Physical size	Very compact (mm-scale die)	Large (50-100 mm body length)
Ruggedness (shock and vibration)	High (solid-state)	Fragile (glass vacuum envelope)
Magnetic field immunity	Full immunity	Sensitive; mu-metal shielding required
Temperature sensitivity	Moderate; bias compensation required	Low; simpler temperature management
Dark current / noise	Higher dark count rate (temperature-dependent)	Lower dark current at room temperature
Spectral range	Wide; good green/red response	Blue-optimized (bialkali); extended options at cost
Photodetection efficiency	35-50% peak (PDE)	25-35% peak quantum efficiency
Unit cost (2-inch equivalent)	Lower in volume	Higher; plus HV supply overhead
Preferred scintillators	CsI(Tl), GAGG(Ce), BGO, CdWO ₄ , all blue emitters	NaI(Tl), LaBr ₃ (Ce), CeBr ₃ , BaF ₂

5 When SiPM Readout Is the Right Choice

The SiPM wins decisively in several common scenarios.

Portable and handheld instruments. Lower operating voltage simplifies the power supply design, reduces weight, and improves battery run time. Solid-state ruggedness eliminates the largest single fragility concern in field instruments. The ScintiQ SiPM Readout module and the 2-inch NaI(Tl) SiPM Detector are designed around this use case: compact assemblies that integrate crystal, SiPM array, and readout electronics into a single unit that tolerates field handling conditions.

Magnetic field environments. Any detector that must operate inside or near an MRI scanner, a cyclotron vault, a beam line, or a power switching installation needs SiPM readout. There is no practical way to shield a PMT adequately in a high-field environment without adding substantial mass and volume.

Green-emitting scintillators. Materials like CsI(Tl) at 550 nm and GAGG(Ce) at 520 nm are poorly matched to standard bialkali PMTs. A SiPM covers this range efficiently. The same SiPM that reads CsI(Tl) in a portal monitor will also read NaI(Tl) or CeBr₃ if the application changes, because SiPM spectral response is broad. This flexibility simplifies inventory and detector platform design.

High-volume and cost-sensitive production. For instruments manufactured in large quantities, the combination of lower device cost, simplified power supply, and reduced mechanical housing requirements makes SiPM the economically dominant choice. The savings compound across the full bill of materials.

Embedded and custom form factors. SiPMs can be tiled, arrayed, and positioned on curved or angled surfaces in ways that a round PMT cannot. Multi-pixel arrays reading a single large crystal, position-sensitive detector concepts, and edge-on crystal configurations all become practical with SiPM readout.

6 When PMT Readout Remains the Better Choice

The PMT is not obsolete. It retains real advantages in specific applications.

Very low background counting. At room temperature, a SiPM's dark count rate generates a baseline noise floor that, while manageable for spectroscopy, can obscure very weak signals in ultra-low-background applications. A selected low-noise PMT can achieve lower room-temperature dark current, which matters for long-integration counting experiments where the detector sits idle between rare events.

Large-area detectors. Covering a 3-inch or 4-inch crystal face uniformly with SiPMs requires an array of multiple dies wired in parallel, which increases capacitance and complicates the readout circuit. A single large-area PMT of equivalent diameter is simpler, produces a single anode output, and can be optimized for the crystal's emission wavelength. For large-volume NaI(Tl) assay systems, traditional PMT readout remains common.

Fast-timing experiments. Select PMTs, particularly those with metal channel dynodes or microchannel plate (MCP) designs, achieve single-photoelectron transit time spreads below 200 picoseconds. These tubes are used in coincidence counting and positron lifetime spectroscopy. Production time-of-flight PET is SiPM based today, and SiPMs with fast front-end electronics are competitive in laboratory timing, but the most demanding timing experiments may still specify a specialized tube.

Simplified temperature management. In applications where electronics must operate over a very wide temperature range without active thermal management, a PMT's relative insensitivity to temperature simplifies the system design. A SiPM-based system can match PMT stability over temperature with bias compensation, but that requires additional circuit complexity and calibration.

Choose SiPM when:

- Portable or handheld operation
- Strong magnetic fields present
- Green-emitting scintillator (CsI(Tl), GAGG, BGO)
- High-volume, cost-sensitive production
- Compact or custom detector geometry
- Low supply voltage required
- MRI-compatible application

Choose PMT when:

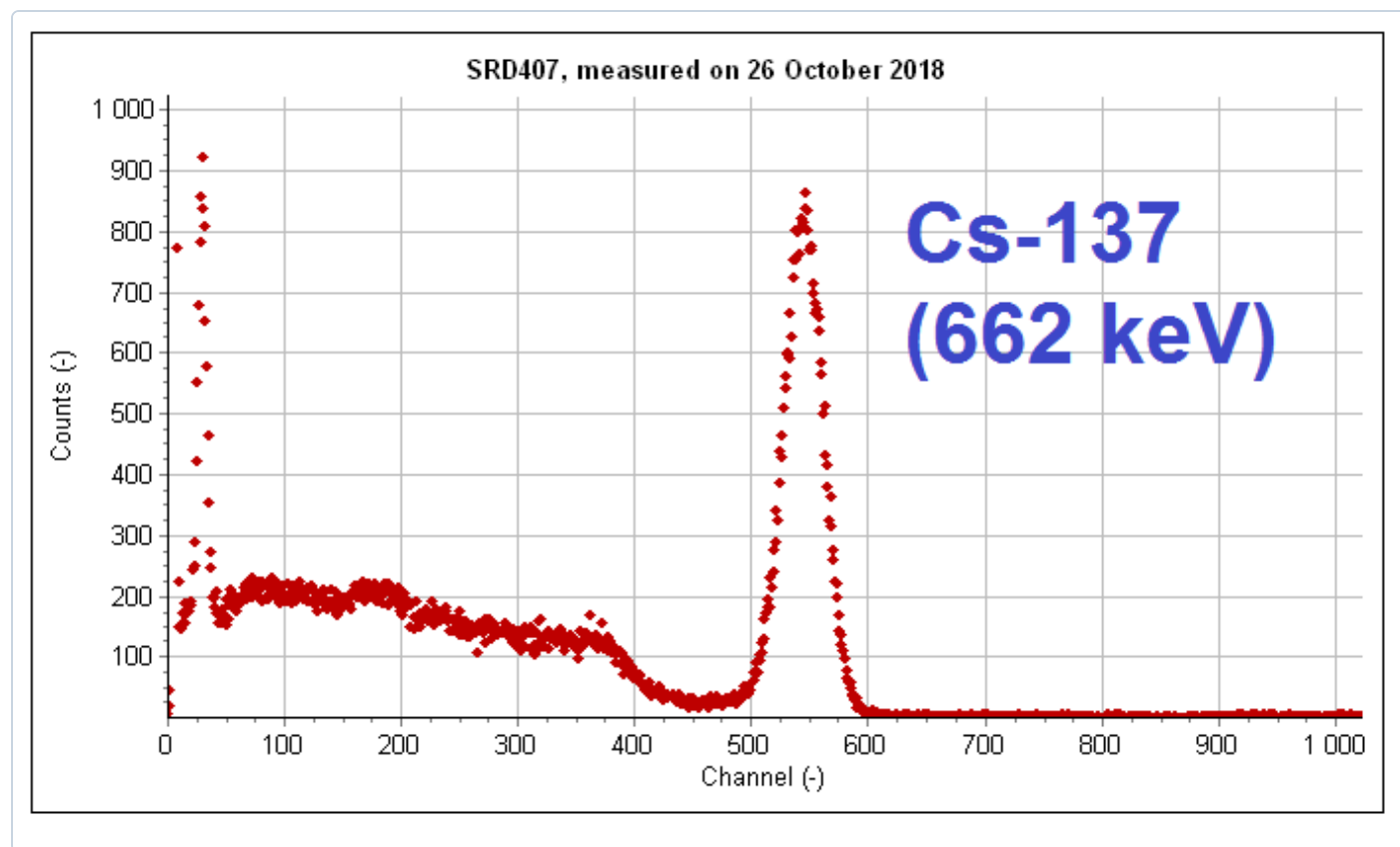
- Ultra-low-background counting at room temperature
- Large-area crystal face (3-inch or 4-inch)
- Sub-200 ps timing resolution required
- Wide temperature range without active bias compensation
- Existing validated instrument design
- Low-volume research where tube cost is secondary

7 ScintIQ Readout Options

Berkeley Nucleonics offers both readout technologies within the ScintIQ line, allowing the appropriate choice for each application.

The **ScintIQ SiPM Readout Module** is a compact, self-contained board that integrates the SiPM array, a low-voltage bias generator with internal temperature compensation, and a preamplifier. The SiPM bias is 25 to 30 V at a gain of 10^6 ; the module runs from a single 5.2 to 16 V supply at under 30 mW, operates to 60 C, uses 3 x 3 mm or 6 x 6 mm elements tiled to the crystal face, and offers 1 M Ω or 50 Ω termination to suit a direct digitizer or a shaping amplifier. It requires no high-voltage components and is designed for portable instrument integration.

The **ScintIQ 2-inch NaI(Tl) SiPM Detector** is a fully integrated assembly: a hermetically sealed 2-inch by 2-inch NaI(Tl) crystal coupled to the SiPM readout board, ready for installation into a handheld or bench instrument chassis. It delivers better than 7.5 percent resolution at 662 keV from a single 5 to 16 V supply at 3 mA, in a 59.2 mm by 75.3 mm aluminum housing, and is ready 30 seconds after power-on. This detector demonstrates the compactness and ruggedness advantages of SiPM readout while pairing it with the workhorse scintillator for general gamma spectroscopy and survey applications. Specifications are available on the 2-inch NaI(Tl) SiPM Detector data sheet.



■ **MEASURED** **Figure 3.** Cs-137 spectrum from the 2 x 2 inch NaI(Tl) SiPM detector, the 662 keV photopeak resolved at better than 7.5 percent FWHM (detector datasheet).

For applications where a traditional PMT-coupled assembly is preferred, the **V102AR406 PMT and voltage divider assembly** provides a validated high-voltage readout option for standard 2-inch detector configurations. Its specifications are documented on the V102AR406 data sheet.

The PMT path pairs with the bMCA-Ethernet or bMCA-USB multichannel analyzer, a digital MCA with its own 0 to 1500 V supply that mounts on the 14-pin tube base; the SiPM module's preamplifier output feeds a standard MCA or digitizer.

8 Conclusion

The choice between SiPM and PMT readout is rarely absolute. Both technologies convert scintillation photons into measurable electrical signals with adequate gain for practical spectroscopy. The decision turns on form factor, operating environment, temperature management capability, cost target, and the specific scintillator being read.

For new instrument designs, particularly those aimed at portable operation, magnetic field environments, or green-emitting crystals, SiPM readout is the natural starting point. The lower operating voltage, solid-state ruggedness, and competitive photon detection efficiency make SiPM the forward-looking default. For large-area detectors, ultra-low-background laboratory setups, and sub-nanosecond timing experiments, the PMT retains a clear role.

Berkeley Nucleonics engineers are available to review your application and recommend the configuration that best fits your requirements. Contact us at info@berkeleynucleonics.com or call **800-234-7858** to discuss detector selection, readout integration, or custom ScintIQ assemblies.

Further reading

For a comprehensive treatment of scintillation detector principles, light yield, energy resolution, and readout electronics, see the Berkeley Nucleonics technical reference: *Nuts & Bolts of Scintillation Detectors* ([external link, opens in new window](#)).

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Technical Note

ScintIQ Custom Scintillation Detectors