PHS with SiPM Readout and RIN for Six Preproduction CsI Crystals

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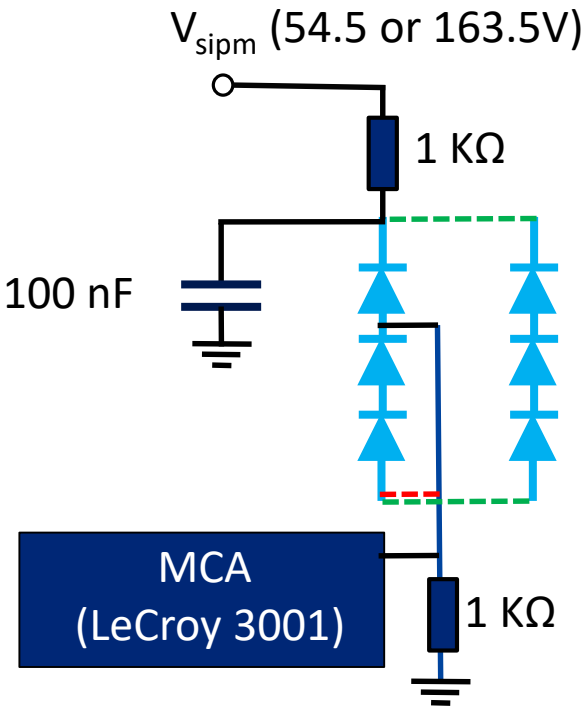
Introduction

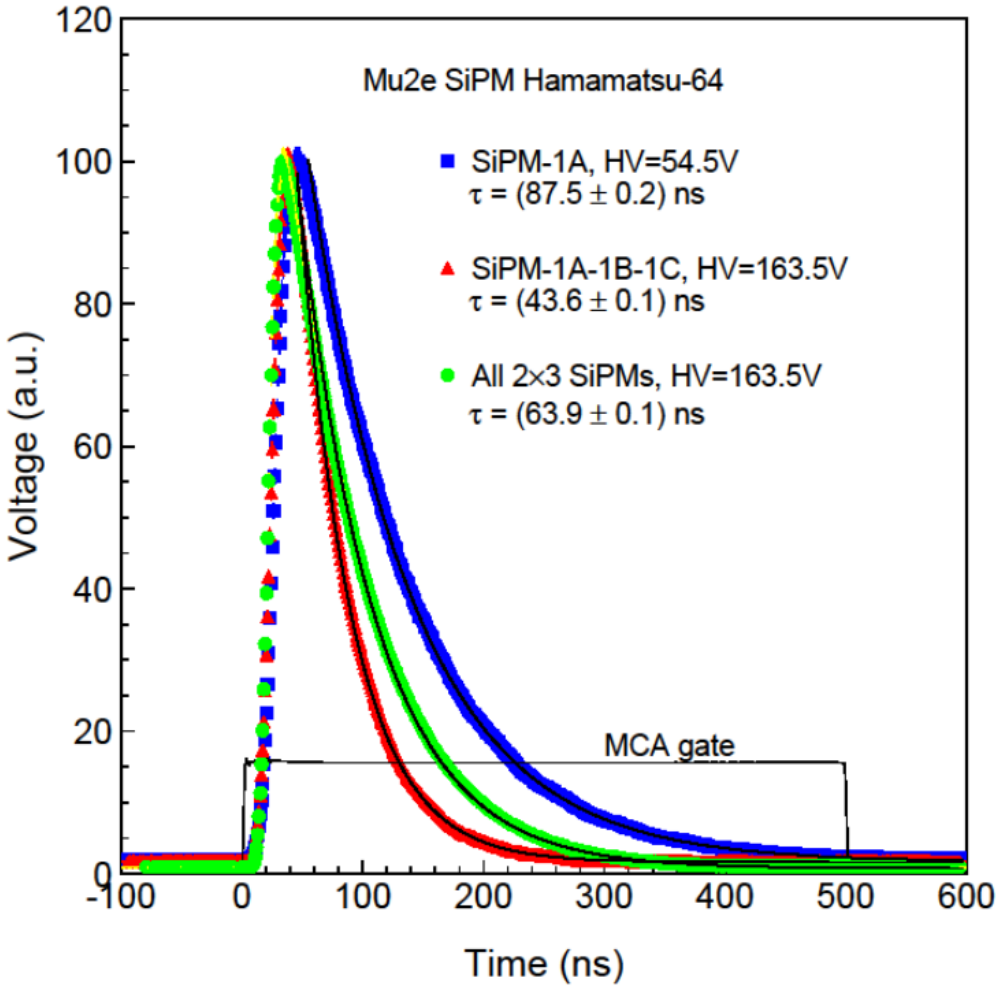
- A Mu2e SiPM Hamamatsu-64 in the 2 x 3 configuration is used to measure pulse height spectrum of a LYSO crystal sample for various ɣ-ray sources.

- The Hamamatsu-64 SiPM in the 1 x 1, 1 x 3 and 2 x 3 configurations is also used to measure the radiation induced photocurrent for six preproduction CsI crystals at 2 rad/h, which are used to extract the corresponding RIN assuming that the PDE of the SiPM is the same as the QE of the PMT.

Response of 1, 3 & 6 SiPM to 10 ns LED Pulse

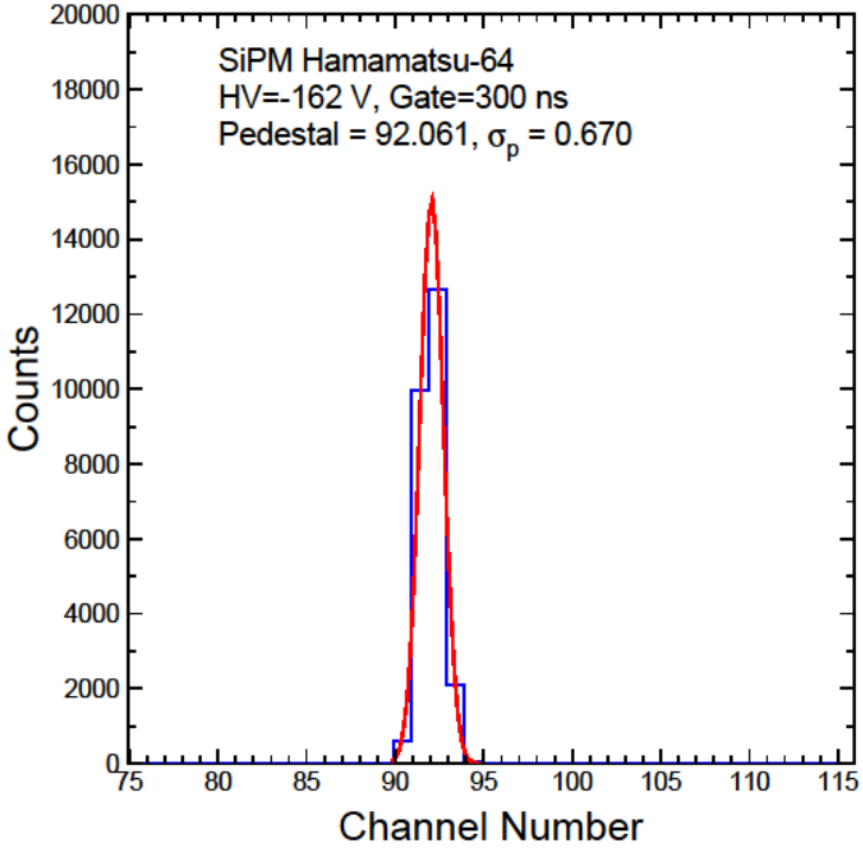
Decay time of 1, 3 and 6 SiPM is 87.5, 43.6 and 63.9 ns respectively

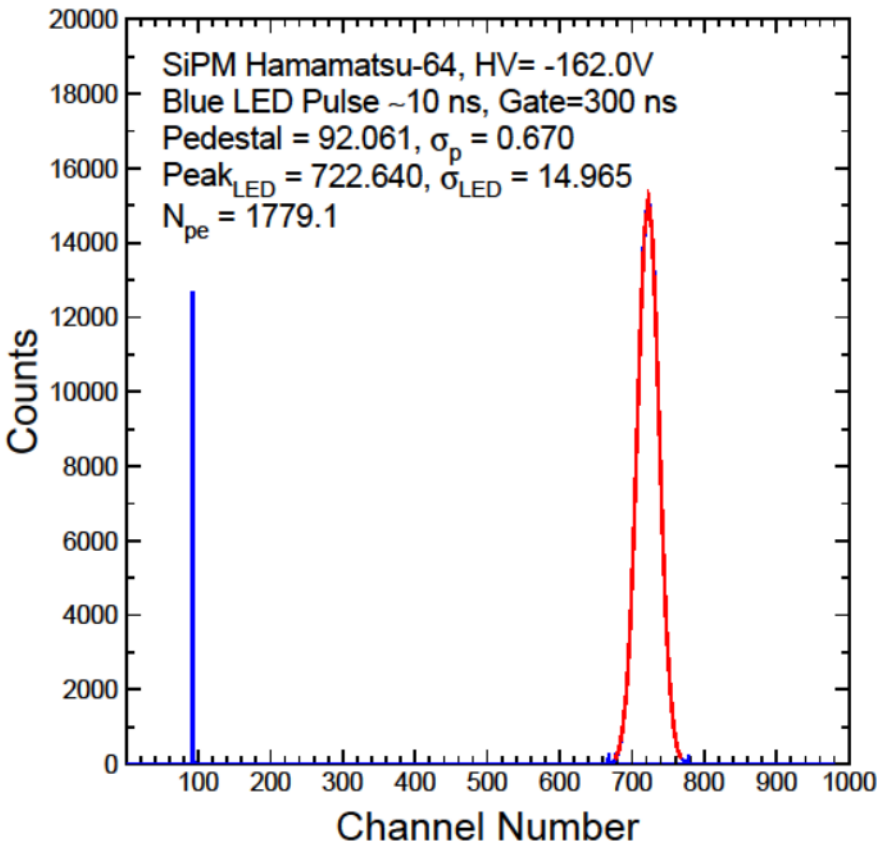




ADC Calibration for Ham-64 Readout

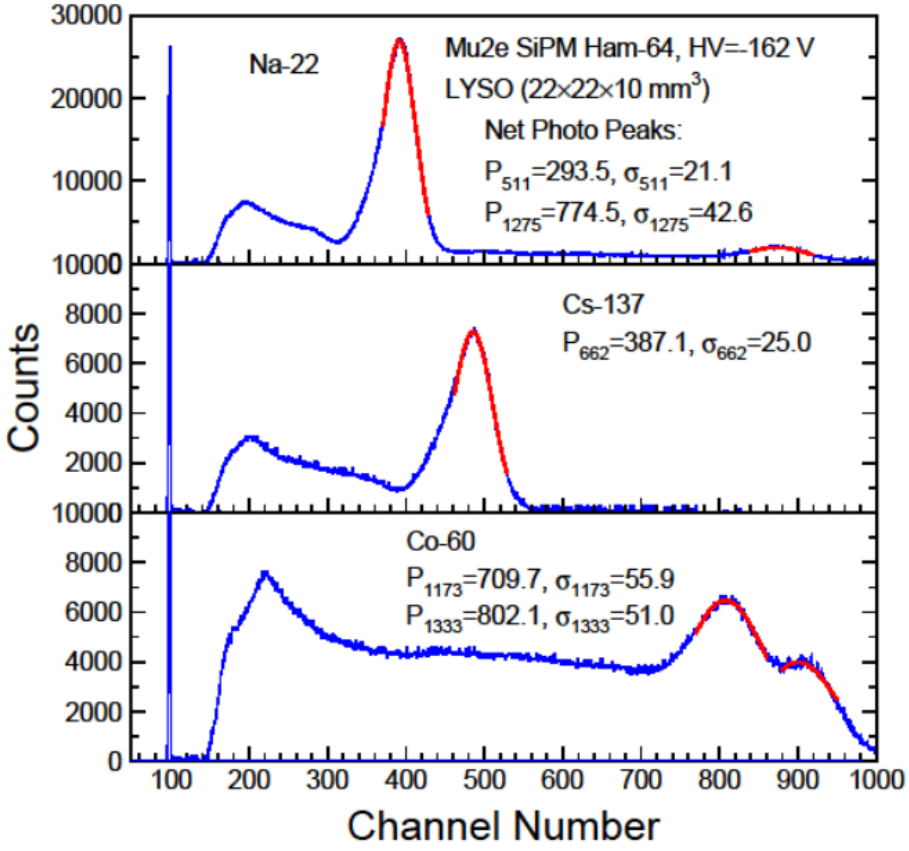
Ham-64 (2×3) SiPM calibrated at 162 V by 10 ns pulse with 300 ns gate: $N_{P.E.}$/ADC = 2.821, σ_{noise}= 1.89 electrons

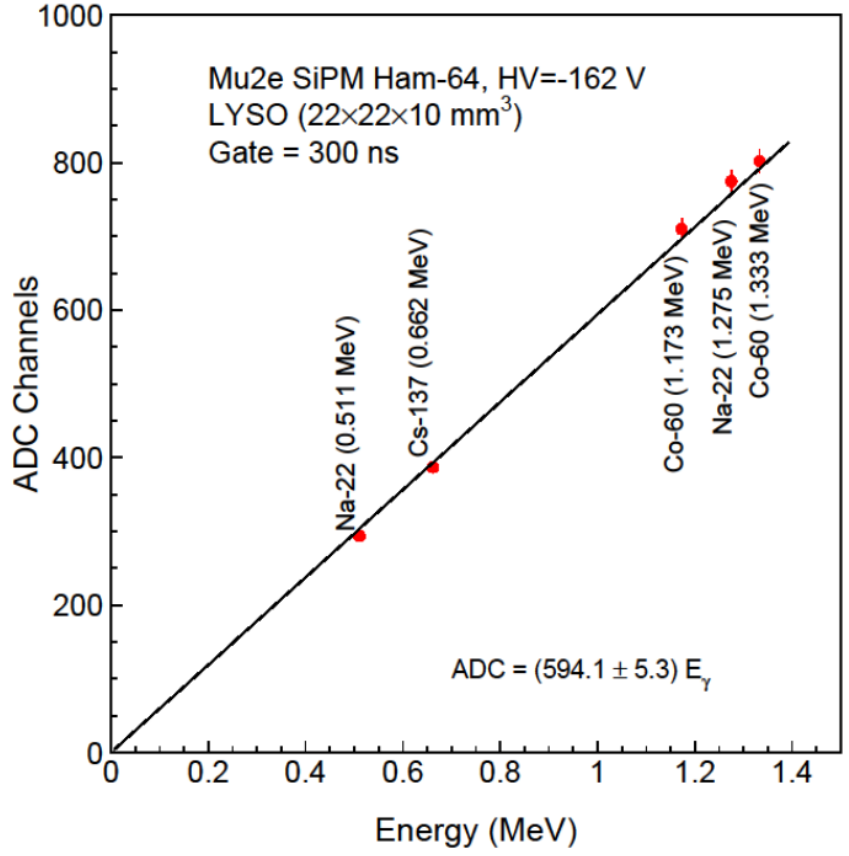




PHS by SiPM Ham-64 for LYSO

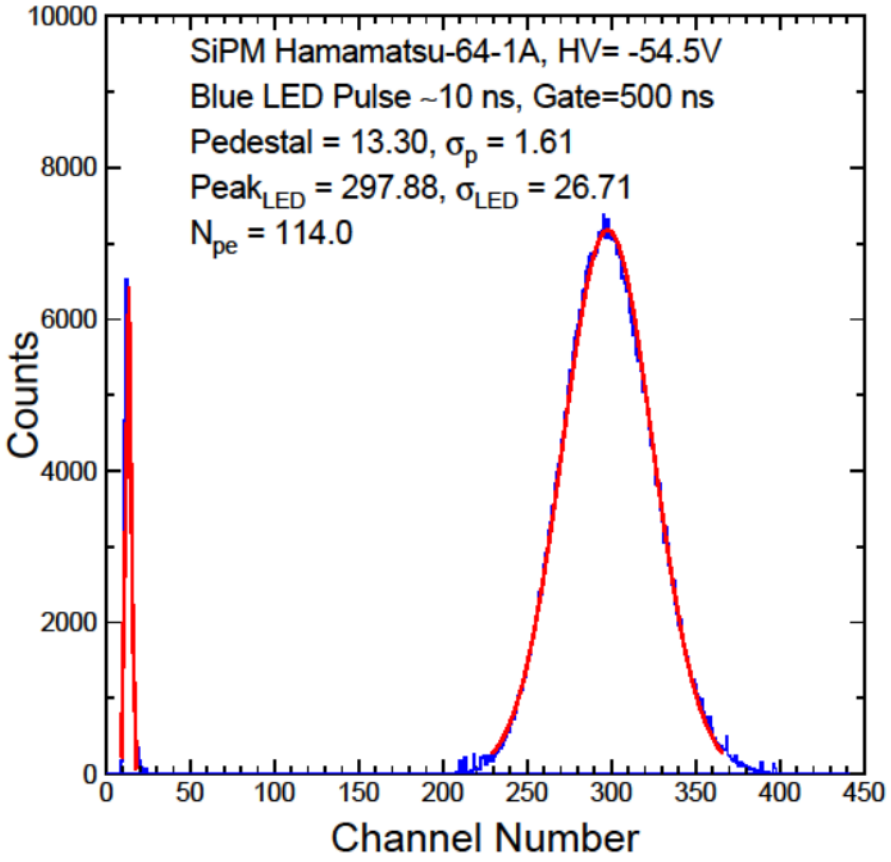
Good linearity from 0.511 to 1.3 MeV observed for a LYSO sample with light output of 1,676 p.e./MeV, indicating a PDE/QE ratio of 87% compared to the PMT data of 4,327p.e./MeV.

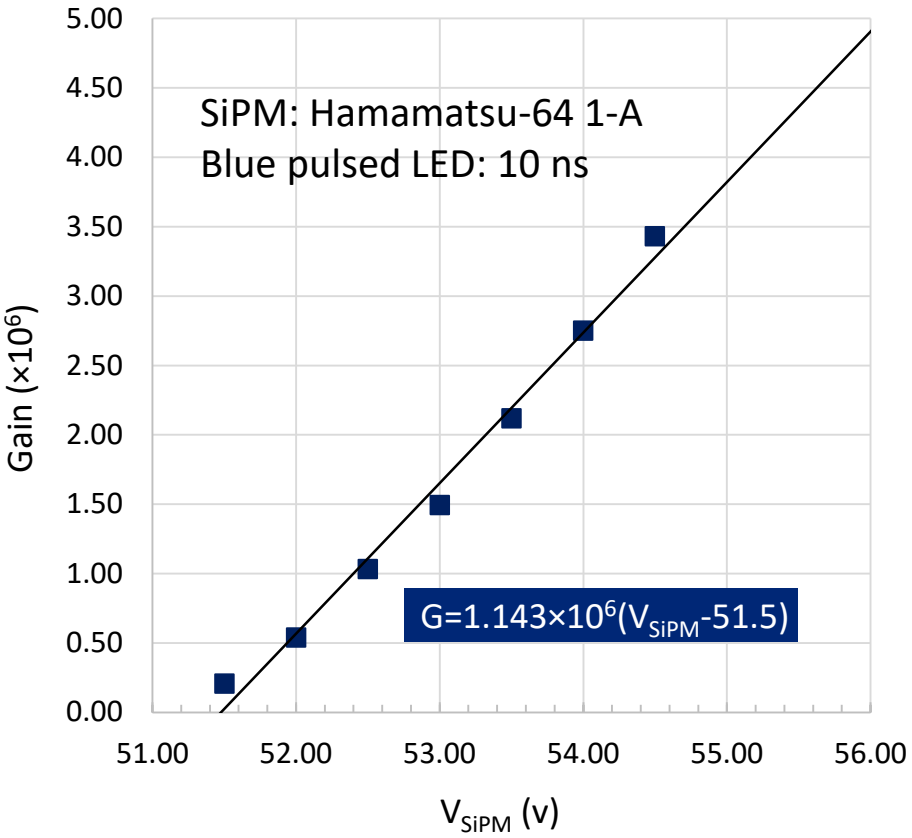




Calibration for One SiPM

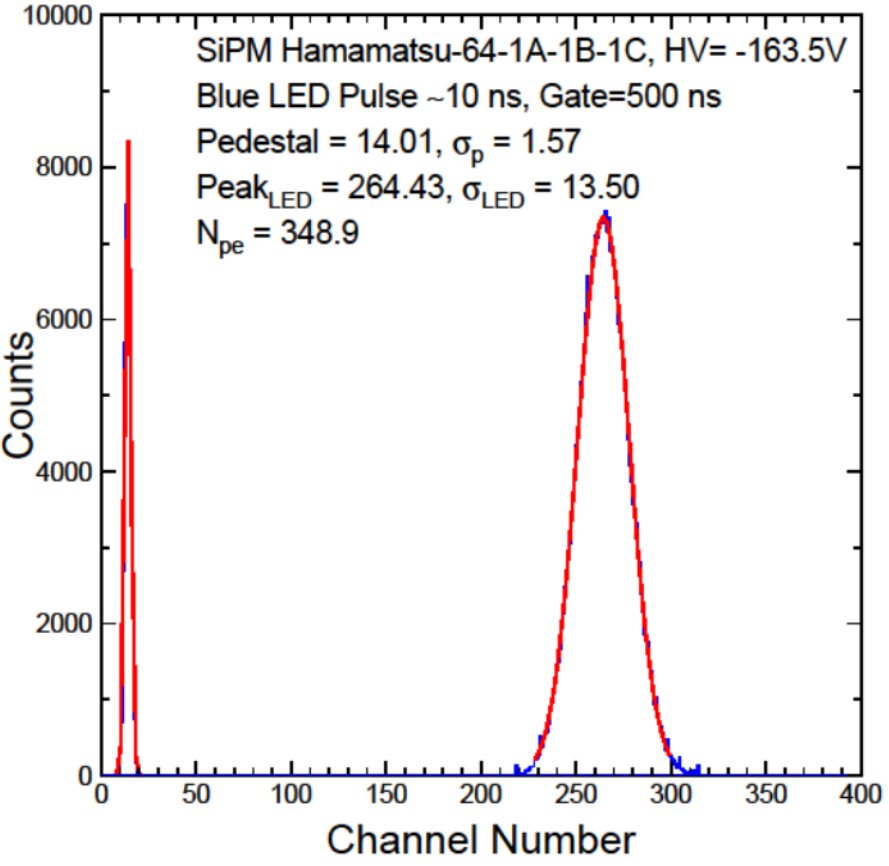
N_{pe}/ADC = 0.401 for one SiPM @ 54.5 V, 500 ns gate
Gain = 1.143 x 10^6 x overvoltage

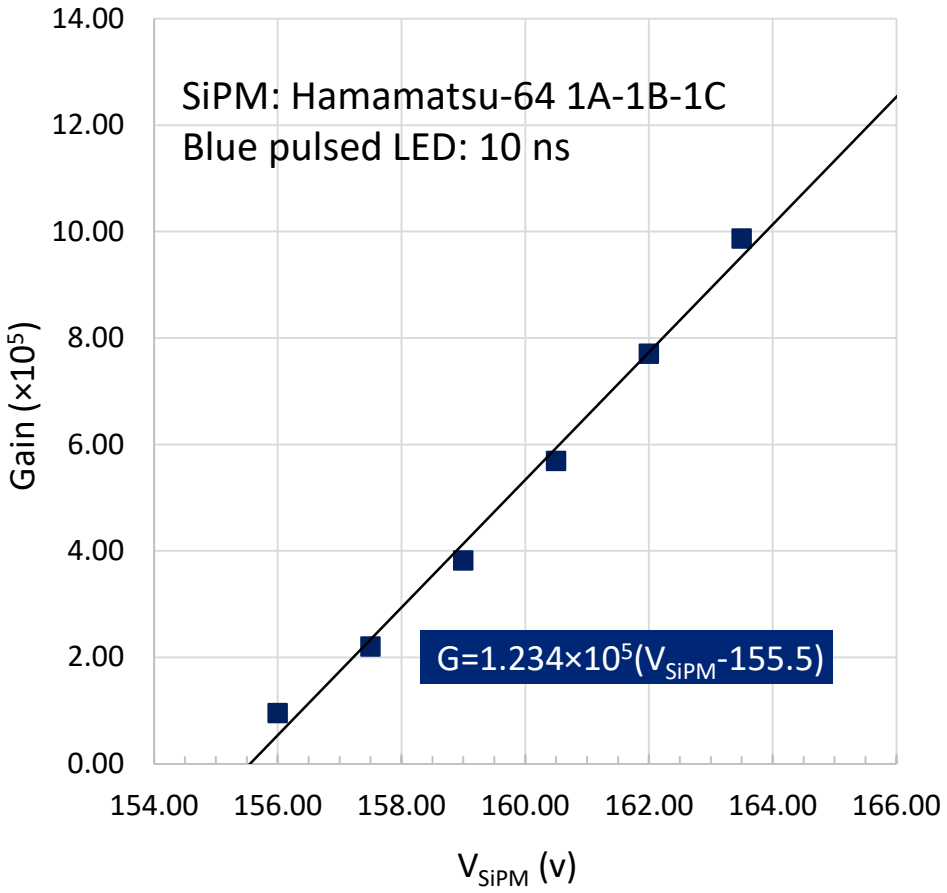




Calibration for Three SiPMs

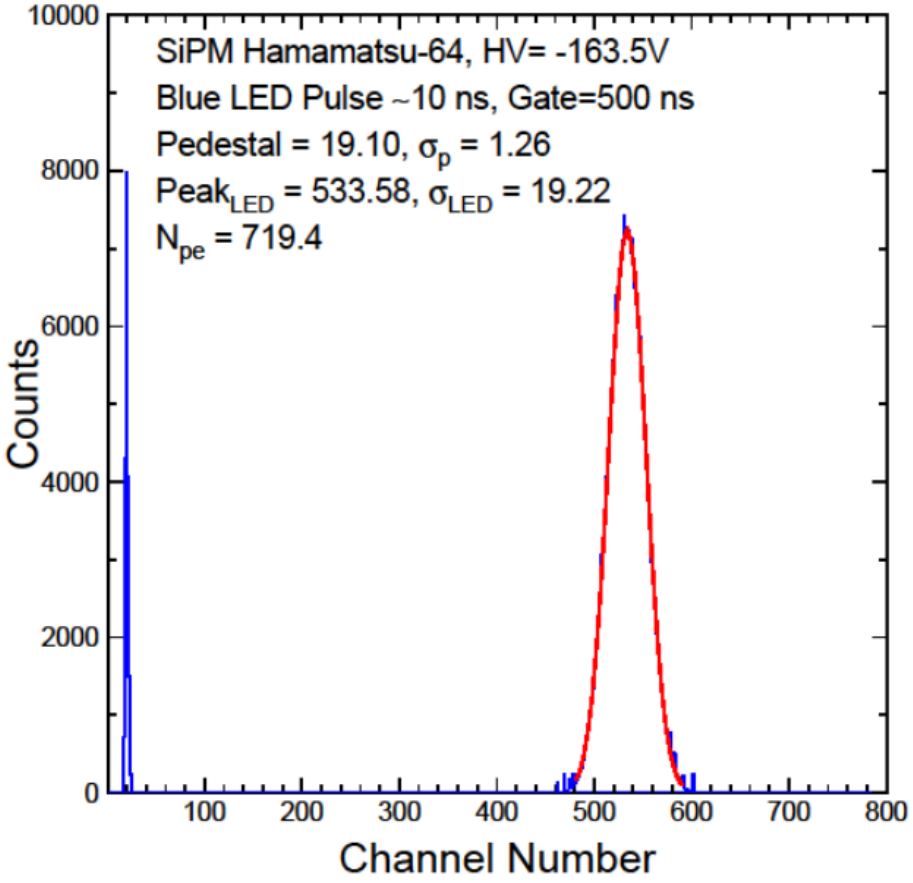
N_{pe}/ADC = 1.397 for 1 x 3 SiPM @ 163.5 V, 500 ns gate
Gain = 3.702 x 10^5 x overvoltage, a factor of 3.1 smaller

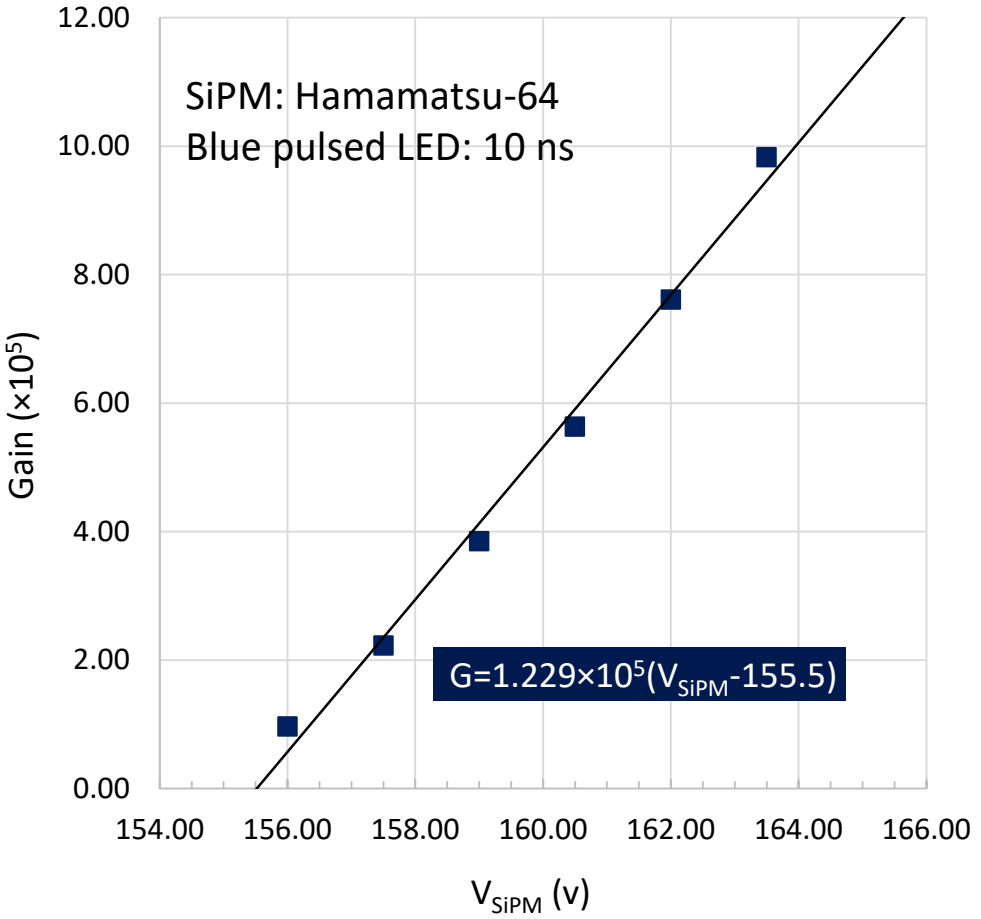




Calibration for Six SiPMs

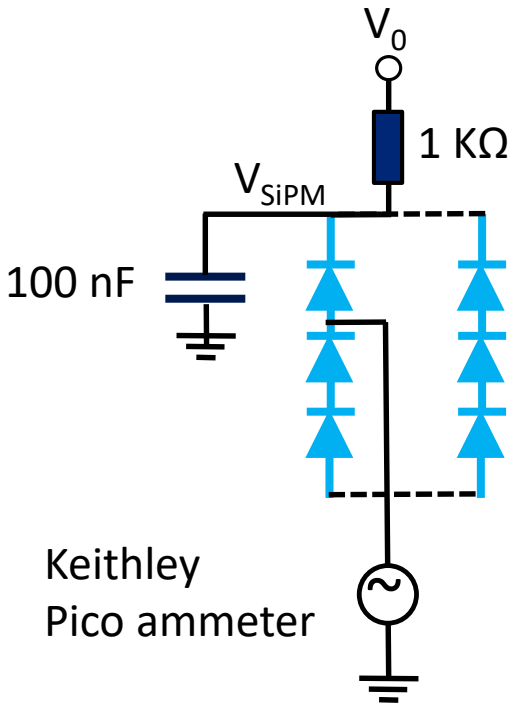
N_{pe}/ADC = 1.398 for 2 x 3 SiPM @ 163.5 V, 500 ns gate
Gain = 3.687 x 10^5 x overvoltage, a factor of 3.1 smaller

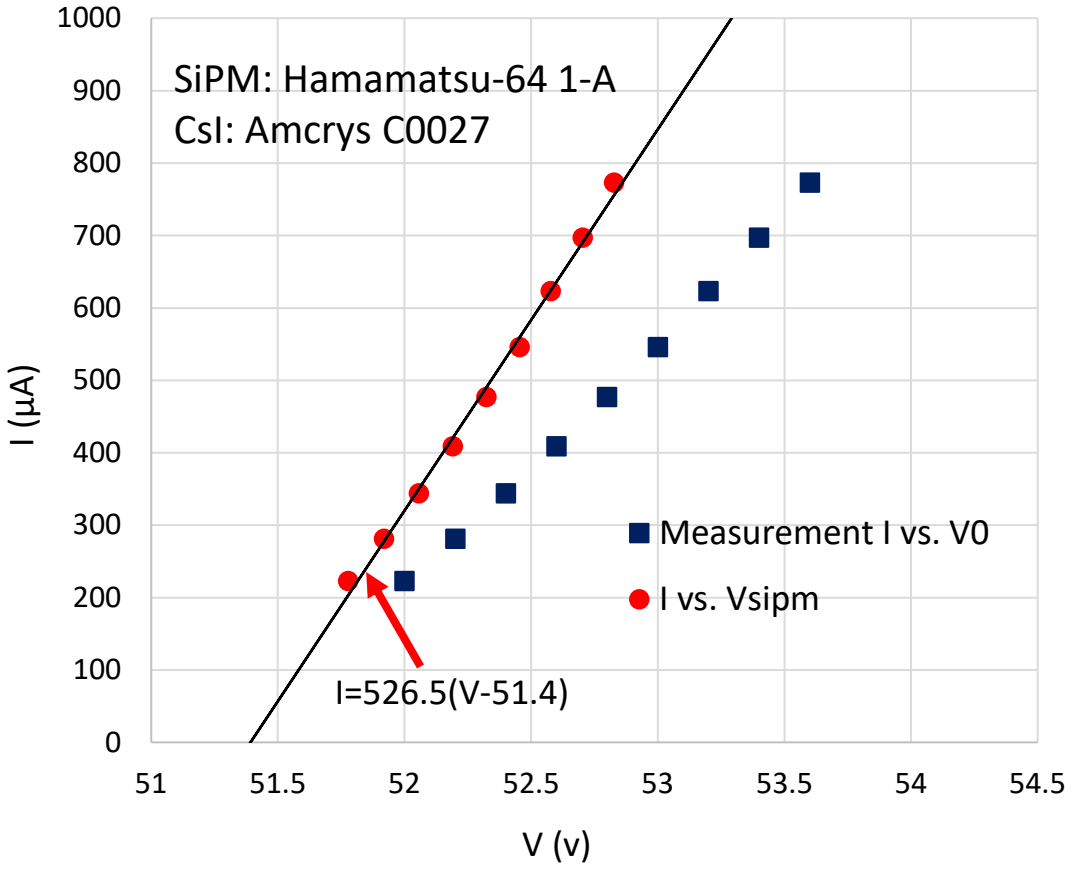




Radiation Induced Photocurrent in SiPM

CsI samples are coupled to the Hamamatsu-64 in 1, 3 and 6 conf. with an air gap
Radiation induced photo current measured for six CsI crystals under 2 rad/h
V_0 = 54.5, 163.5 and 163.5V for 1, 3 and 6 SiPM, $V_{SiPM} = V_0 - I_{SiPM} \times 1\ k\Omega$ for gain





Gamma-Ray Induced Noise: Amcrys

Hamamatsu-64 SiPM @ 54.5V & 163.5 V for 1 & 3/6 SiPM with air gap to CsI @ 1.8 rad/h and LO_{PMT} in 200 ns scaled to SiPM area

Crystal ID		C0019	C0036	Average	RMS
Batch No.		015	019		
LO (p.e./MeV)		125	134	130	3.5%
1 SiPM	I (μA)	1068	576	822	29.9%
	Gain (10^5)	22.08	27.71	24.90	11.3%
	F (p.e./s/rad/hr)	1.51×10^9	6.49×10^8	1.08×10^9	39.9%
	σ_1 (MeV)	5.992	3.663	4.827	24.1%
	$\sigma_6 = \sigma_1/\sqrt{6}$ (MeV)	**2.446**	**1.496**	**1.971**	**0.475**
3 SiPM	I (μA)	1252	553	903	38.7%
	Gain (10^5)	8.33	9.19	8.76	4.9%
	F (p.e./s/rad/hr)	4.70×10^9	1.88×10^9	3.29×10^9	42.8%
	σ_3 (MeV)	3.521	2.079	2.800	25.8%
	$\sigma_6 = \sigma_3/\sqrt{2}$ (MeV)	**2.490**	**1.470**	**1.980**	**0.510**
6 SiPM	I (μA)	2085	1058	1571	32.7%
	Gain (10^5)	7.27	8.53	7.90	8.0%
	F (p.e./s/rad/hr)	8.96×10^9	3.87×10^9	6.42×10^9	39.6%
	σ_6 (MeV)	**2.432**	**1.492**	**1.962**	**0.470**
RMS for 3 σ_6		**2.5%**	**1.1%**	**0.7%**	

Gamma-Ray Induced Noise: S-G

Hamamatsu-64 SiPM @ 54.5V & 163.5 V for 1 & 3/6 SiPM with air gap to CsI with Tyvek @ 1.8 rad/h and LO_{PMT} in 200 ns scaled to SiPM area

Crystal ID		C0048	C0049	Average	RMS
Batch No.		A11823	A11819		
LO (p.e./MeV)		135	142	139	2.5%
1 SiPM	I (μA)	105	111	108	2.6%
	Gain (10^5)	33.09	33.02	33.06	0.1%
	F (p.e./s/rad/hr)	9.92×10^7	1.05×10^8	1.02×10^8	2.7%
	σ_1 (MeV)	1.422	1.389	1.405	1.2%
	$\sigma_6 = \sigma_1/\sqrt{6}$ (MeV)	**0.580**	**0.567**	**0.574**	**0.007**
3 SiPM	I (μA)	94	98	96	2.1%
	Gain (10^5)	9.76	9.75	9.75	0.0%
	F (p.e./s/rad/hr)	3.00×10^8	3.13×10^8	3.06×10^8	2.2%
	σ_3 (MeV)	0.823	0.800	0.812	1.4%
	$\sigma_6 = \sigma_3/\sqrt{2}$ (MeV)	**0.582**	**0.566**	**0.574**	**0.008**
6 SiPM	I (μA)	189	194	191	1.3%
	Gain (10^5)	9.60	9.59	9.60	0.0%
	F (p.e./s/rad/hr)	6.15×10^8	6.32×10^8	6.23×10^8	1.3%
	σ_6 (MeV)	**0.590**	**0.568**	**0.579**	**0.011**
RMS for 3 σ_6		**0.4%**	**0.1%**	**0.3%**	

Gamma-Ray Induced Noise: SIC

Hamamatsu-64 SiPM @ 54.5V & 163.5 V for 1 & 3/6 SiPM with air gap to CsI with Tyvek @ 1.8 rad/h and LO_{PMT} in 200 ns scaled to SiPM area

Crystal ID		C0072	C0073	Average	RMS
Batch No.		2016 a22	2016 a21		
LO (p.e./MeV)		174	176	175	0.6%
1 SiPM	I (μA)	203	205	204	0.4%
	Gain (10^5)	31.97	31.95	31.96	0.0%
	F (p.e./s/rad/hr)	1.98×10^8	2.00×10^8	1.99×10^8	0.4%
	σ_1 (MeV)	1.559	1.548	1.554	0.4%
	$\sigma_6 = \sigma_1/\sqrt{6}$ (MeV)	**0.637**	**0.632**	**0.634**	**0.002**
3 SiPM	I (μA)	191	185	188	1.8%
	Gain (10^5)	9.64	9.64	9.64	0.0%
	F (p.e./s/rad/hr)	6.20×10^8	5.98×10^8	6.09×10^8	1.8%
	σ_3 (MeV)	0.919	0.892	0.906	1.5%
	$\sigma_6 = \sigma_3/\sqrt{2}$ (MeV)	**0.650**	**0.631**	**0.640**	**0.009**
6 SiPM	I (μA)	363	364	364	0.2%
	Gain (10^5)	9.39	9.38	9.39	0.0%
	F (p.e./s/rad/hr)	1.21×10^9	1.21×10^9	1.21×10^9	0.2%
	σ_6 (MeV)	**0.641**	**0.635**	**0.638**	**0.003**
RMS for 3 σ_6		**0.5%**	**0.2%**	**0.3%**	

Summary

- Pulse height spectra measured by a LYSO crystal air coupled to a Mu2e SiPM Hamamatsu-64 in the 2 x 3 configuration shows a good linearity for various ɣ-rays sources and a PDE/QE ratio of ~87%.
- The gain of the Hamamatsu-64 SiPM in the 1 x 3 and 2 x 3 configurations is roughly a factor of three smaller that that of the 1 x 1 configuration with the same overvoltage since the former need 3 times p.e. number to generate the same signal.
- Radiation induced photocurrent was measured by the Hamamatsu-64 SiPM in the 1 x 1, 1 x 3 and 2 x 3 configurations for six Mu2e CsI crystals, and was converted to the RIN assuming that the light output of CsI measured by SiPM is scaled by the PMT data according to the area coverage. The RIN data measured by 2 x 3 SiPMs are consistent with the 1 x 1 and 1 x 3 data scaled down by a factor of √6 or √2 respectively according to the area coverage.
- To be investigated:
  - Light output of CsI with SiPM readout by ɣ-rays: need a wide band amplifier;
  - QE and PDE response of the PMT and SiPM for the CsI fast and slow scintillation light.