



Radiation Induced Photocurrent and Noise with SiPM Readout for 30 Preproduction CsI Crystals

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March 1, 2017

Talk given in the Mu2e Calorimeter Group Meeting



Introduction

- Mu2e specifications for CsI crystals were defined in early August. A total of 72 crystals from three vendors were delivered to Fermilab early December.
- After QA on visual and dimension by a CMM machine at Fermilab, 36 CsI crystals arrived Caltech late December. Reports of QA on scintillation properties, radiation induced noise with PMT and Gamma-ray induced damage were given on January 11, 17 and February 9, 2017.
- Two reports today:
 - Radiation induced photocurrent with one SiPM readout and the expected RIN with six SIPM readout for 30 preproduction CsI crystals.
 - A Kharkov reference crystal as compared to other two references.

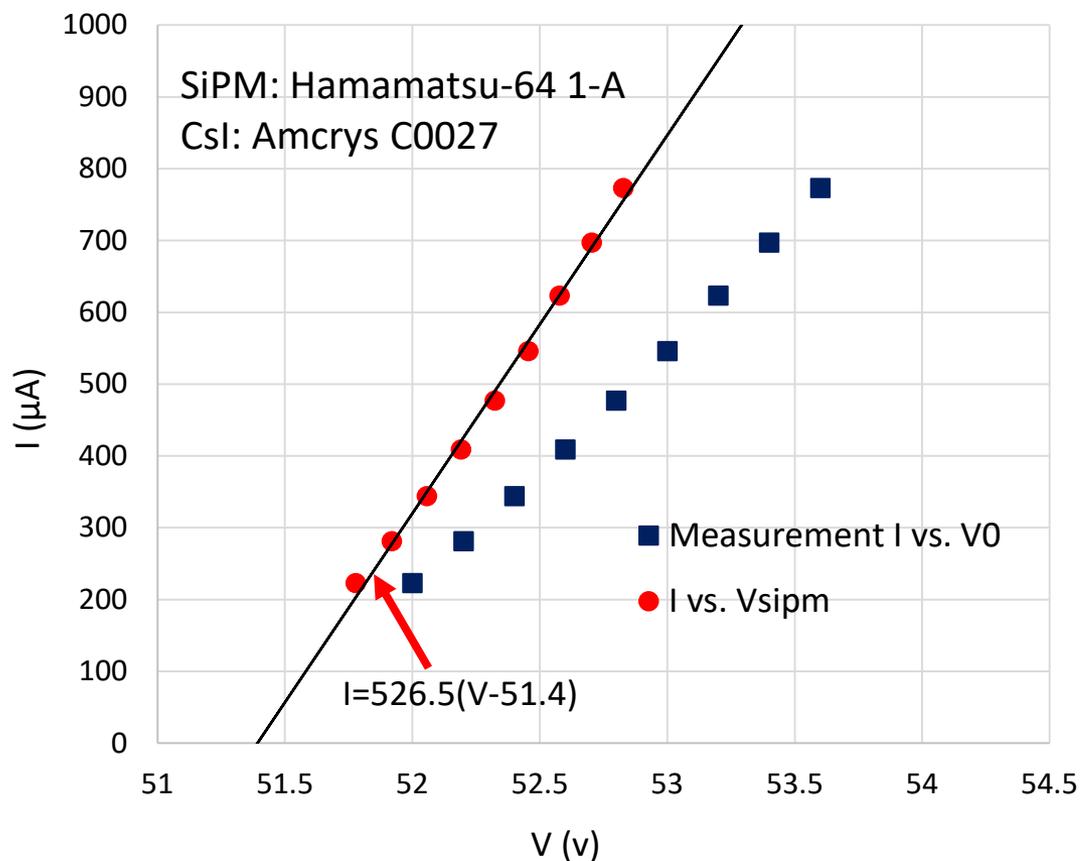
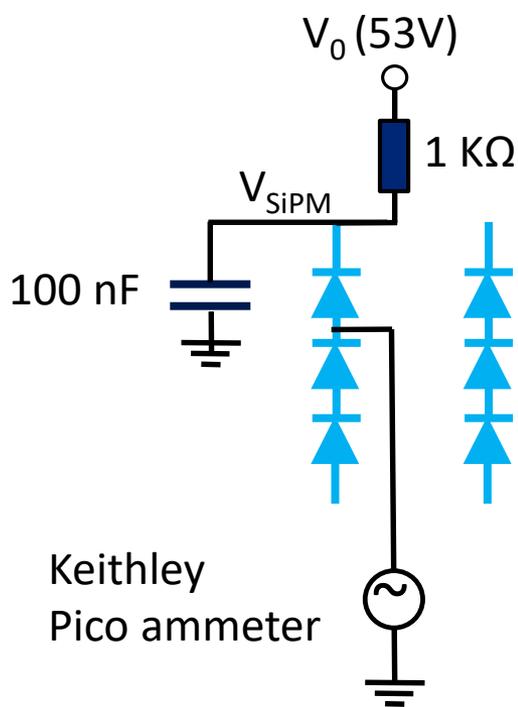


Radiation Induced Photocurrent in SiPM



CsI samples are coupled with an air gap to one of the six SiPMs in Hamamatsu-64
Radiation induced photo current measured for CsI crystals under 2 rad/h (Co-60)

$$V_{SiPM} = V_0 - I_{SiPM} \times 1 \text{ k}\Omega, \text{ which is used to extract SiPM gain}$$

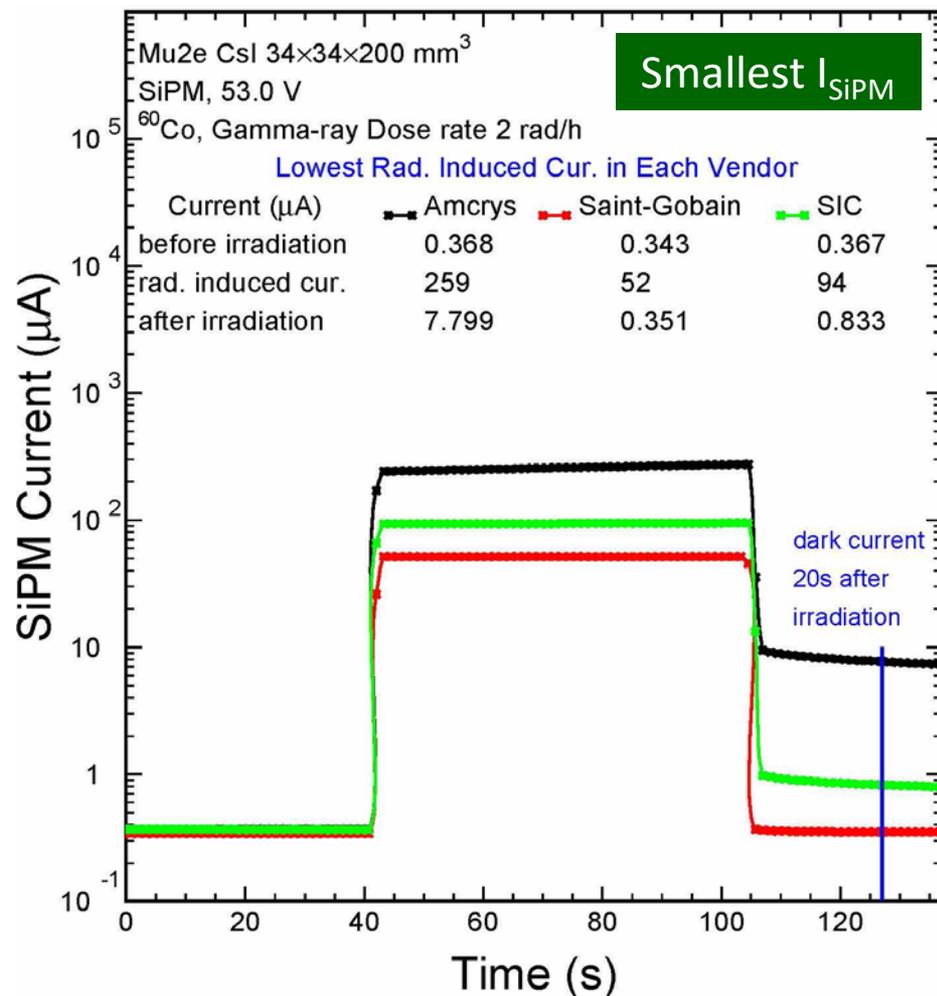
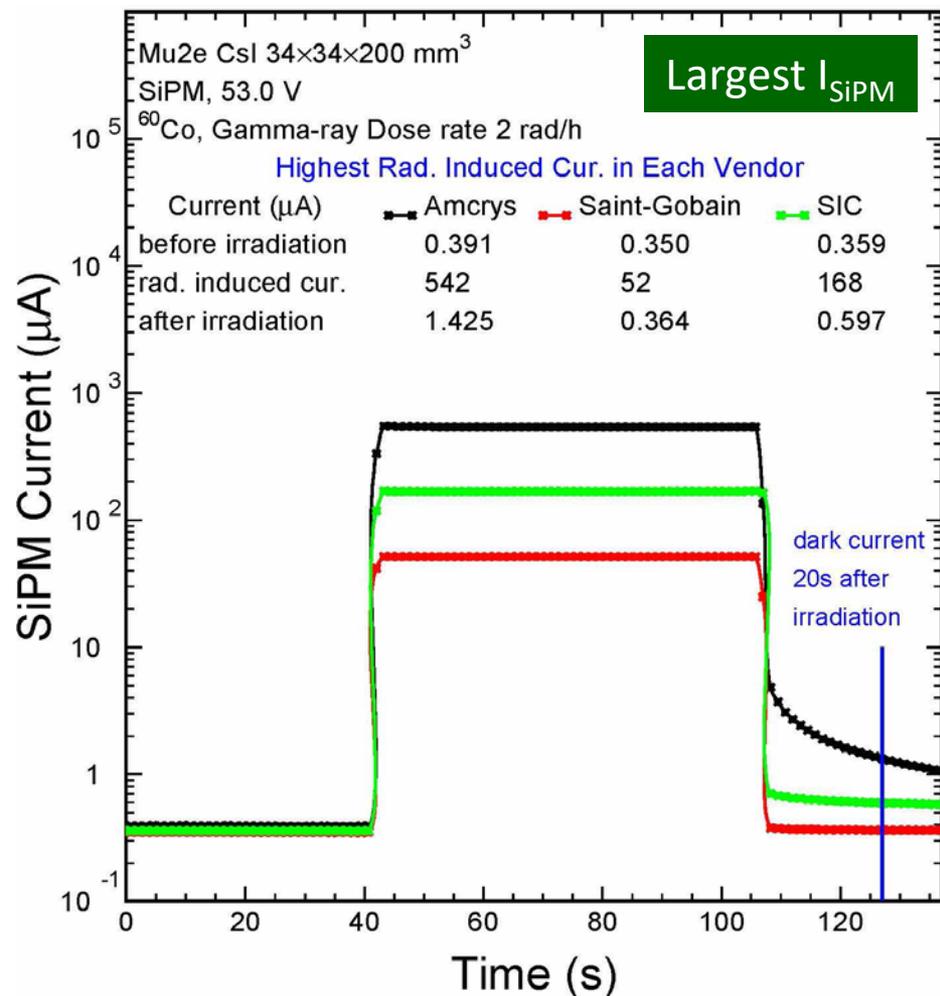




History of Current in SiPM



Consistent results following the same procedure as the RIC measurement with PMT

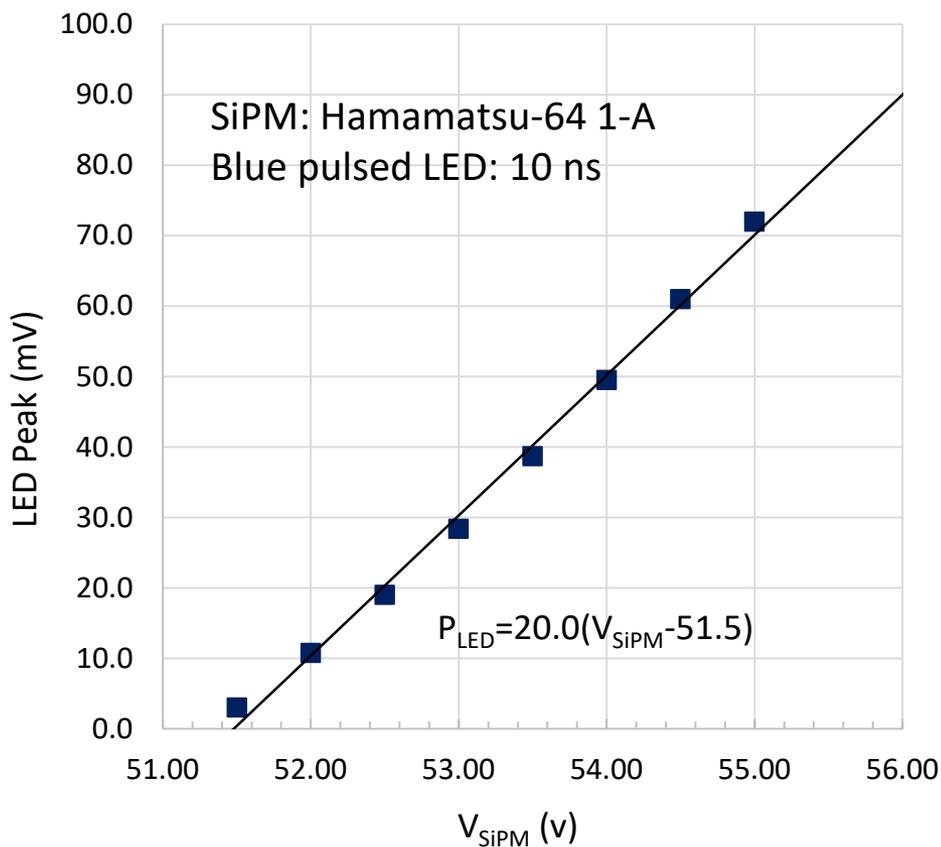
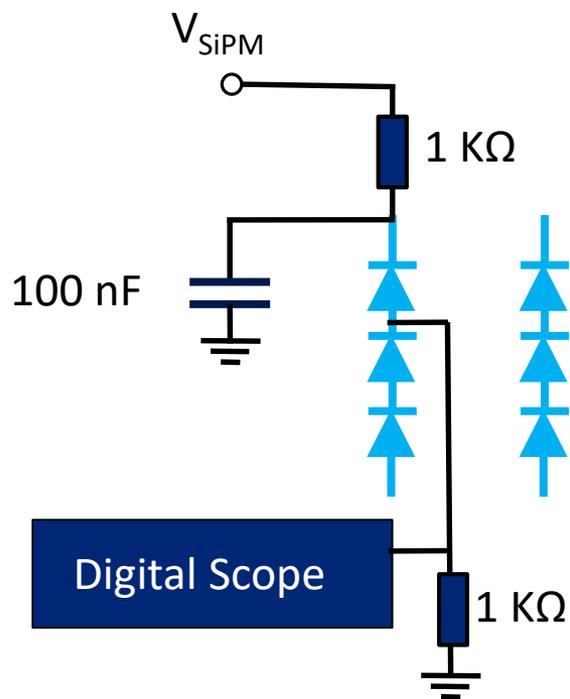




Linearity of SiPM Gain



SiPM gain is linear up to $V_{br} + 3.5$ V tested with 10 ns blue LED pulses

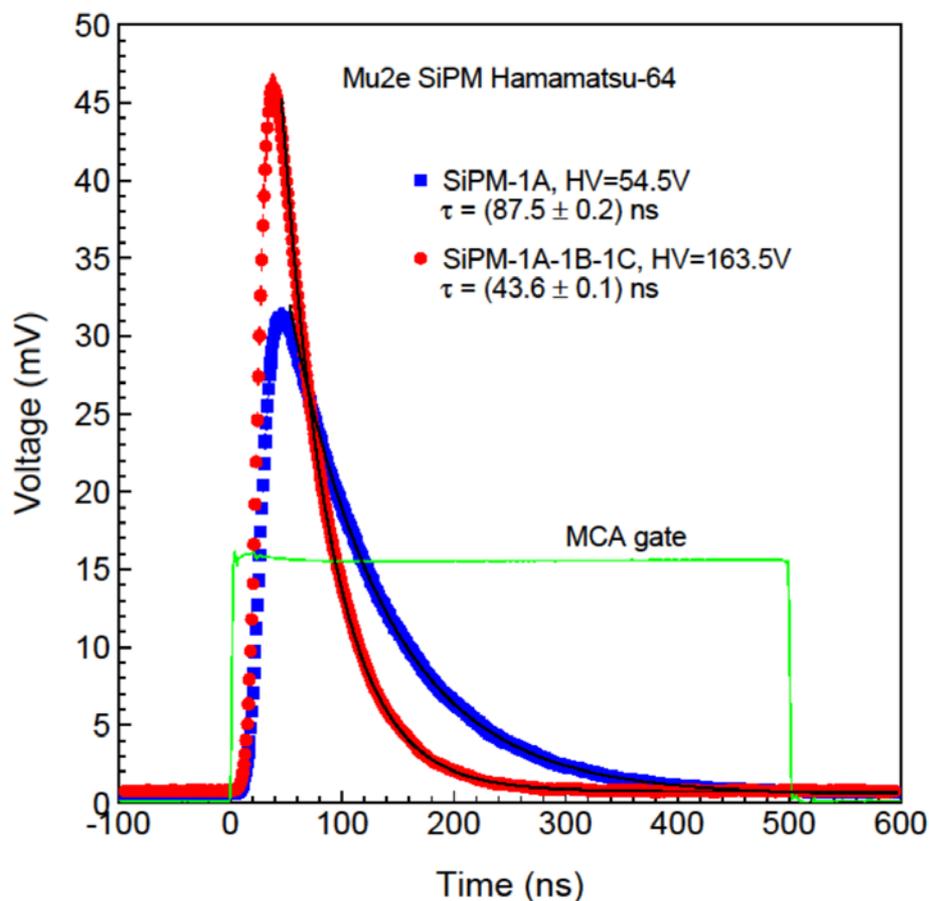
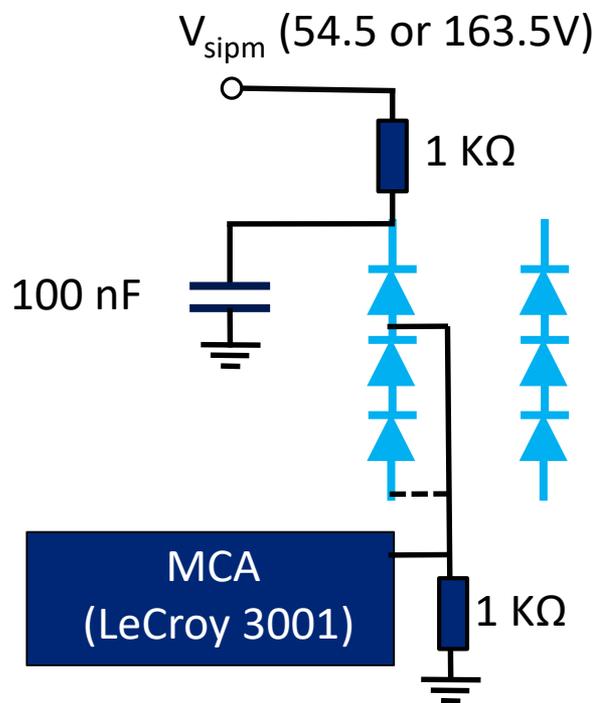




Response of 1- and 3-SiPM to 10 ns LED Pulses



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

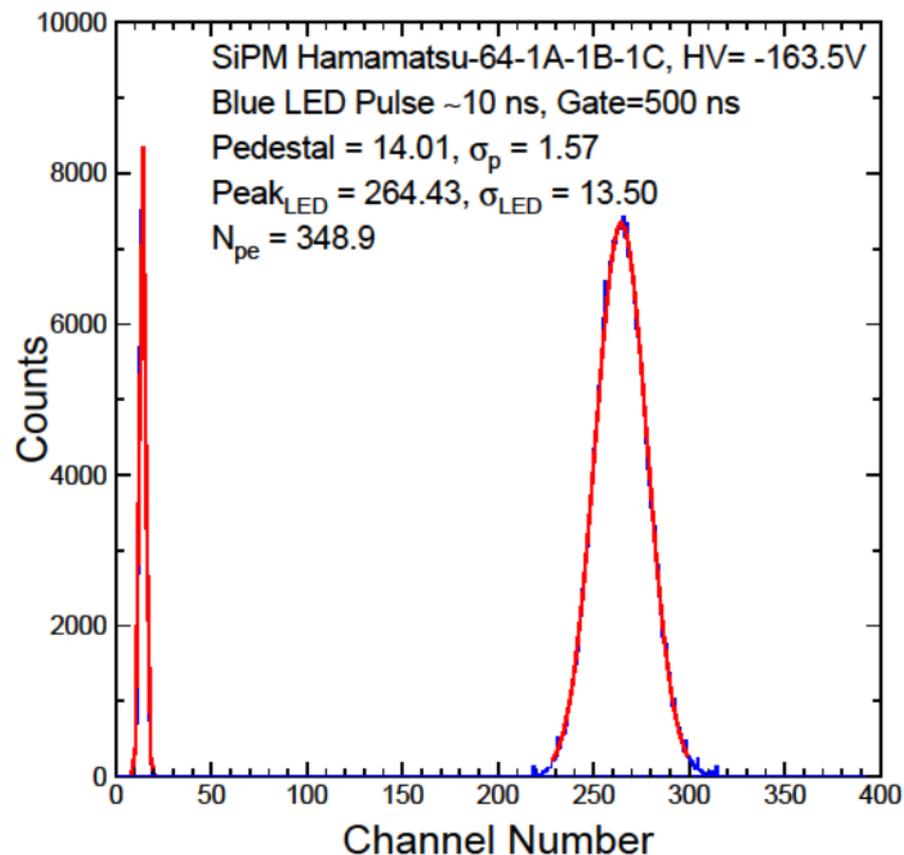
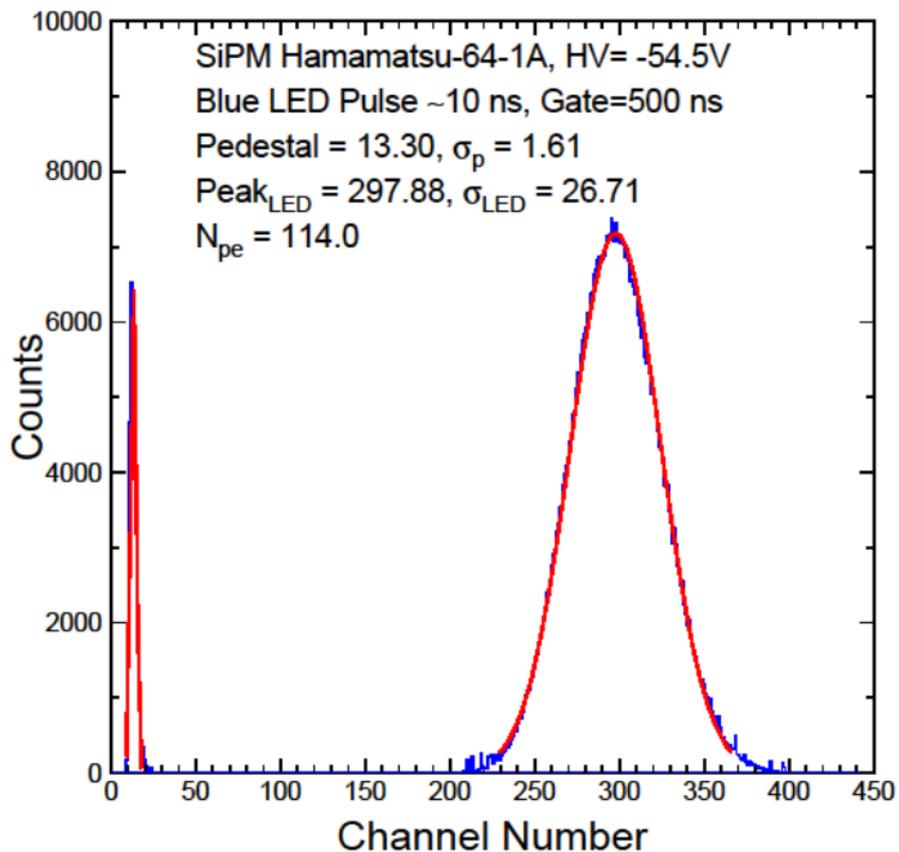




Calibration of N_{pe}



$N_{pe}/\text{channel}$ is 0.401 and 1.39 for 1 and 3 SiPM respectively

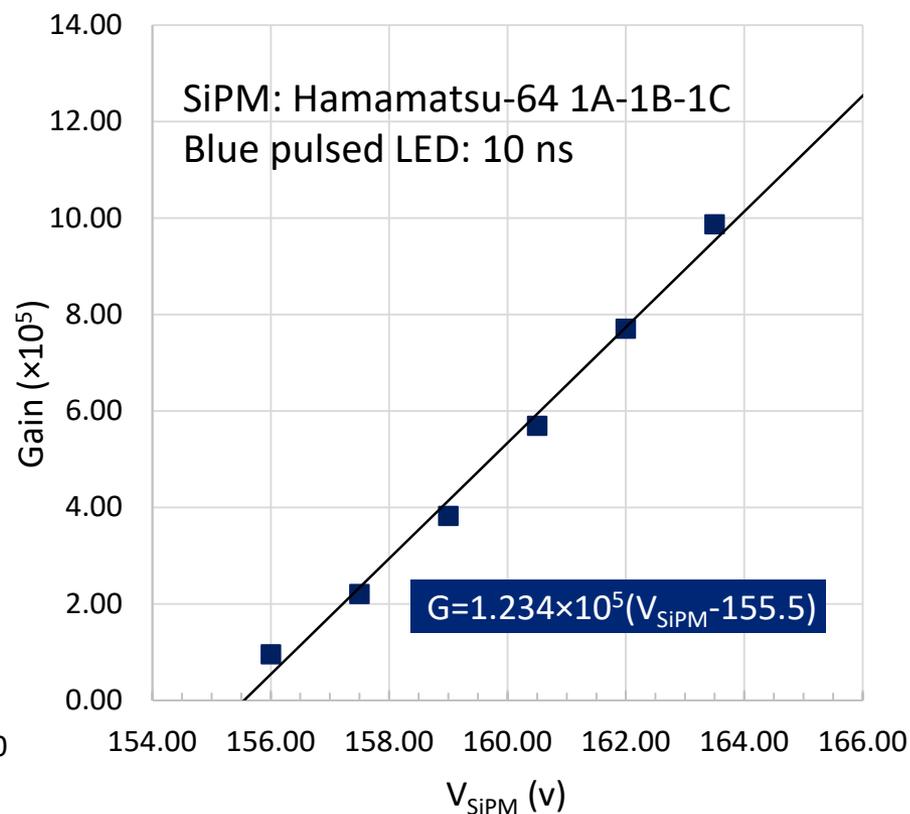
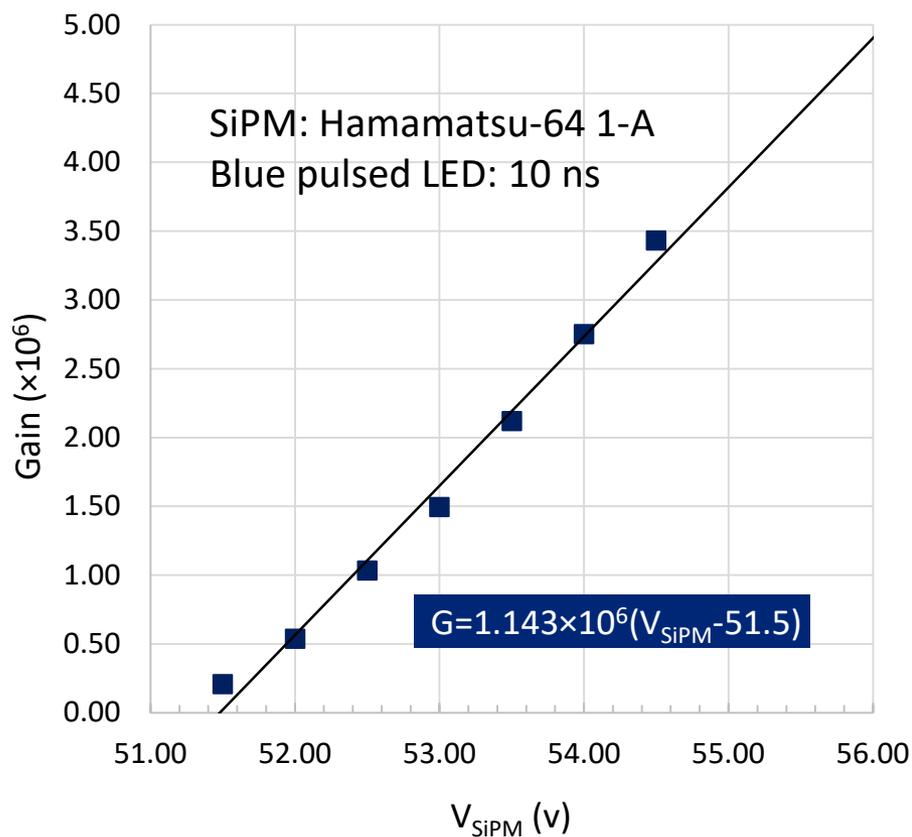




Calibration of SiPM Gain



ADC was calibrated to be 0.22 pC/channel by electrical pulses
SiPM gain was calculated by net Peak_{LED} × 0.22pC / (N_{pe} × e)





Gamma-Ray Induced Noise: Amcryst



Hamamatsu-64 SiPM @ 53 V (Gain $\sim 1.2 \times 10^6$) with an air gap to CsI crystals with Tyvek @ 1.8 rad/h and LO_{PMT} in 200 ns scaled with the area of six SiPM

Crystal ID	Batch No.	LO_{PMT} (p.e./MeV)	Dark cur. before irradiat. (μA)	Photo cur. @ 2 rad/h (μA)	Dark cur. 20s after irradiat. (μA)	Gain for σ_1 (10^5)	F (p.e./s/rad/hr)	σ_1 (MeV)	Cal. σ_6 (MeV) from σ_1
C0013	011	148	0.387	541	1.079	10.96	1.54×10^9	5.111	2.087
C0016	013	134	0.407	534	1.446	11.04	1.51×10^9	5.589	2.282
C0019	015	125	0.388	537	1.130	11.00	1.53×10^9	6.022	2.458
C0023	024	117	0.391	542	1.425	11.18	1.55×10^9	6.475	2.643
C0025	022	145	0.412	522	4.816	11.18	1.46×10^9	5.073	2.071
C0026	020	132	0.369	317	1.082	13.52	7.32×10^8	3.949	1.612
C0027	006	139	0.388	544	1.471	10.93	1.56×10^9	5.468	2.232
C0032	004	122	0.368	316	0.937	13.53	7.30×10^8	4.267	1.742
C0034	012	127	0.392	540	1.440	10.98	1.54×10^9	5.947	2.428
C0036	019	134	0.368	259	7.799	14.19	5.70×10^8	3.432	1.401
Average		132	0.387	465	2.263	11.83	1.27×10^9	5.133	2.096
RMS		7.1%	3.8%	23.9%	94.5%	10.7%	30.8%	18.1%	0.379



Gamma-Ray Induced Noise: S-G



Hamamatsu-64 SiPM @ 53 V (Gain $\sim 1.7 \times 10^6$) with an air gap to CsI crystals with Tyvek 1.8 rad/h and LO_{PMT} in 200 ns scaled with the area of six SiPM

Crystal ID	Batch No.	LO_{PMT} (p.e./MeV)	Dark cur. before irradiat. (μA)	Photo cur. @ 2 rad/h (μA)	Dark cur. 20s after irradiat. (μA)	Gain for σ_1 (10^5)	F (p.e./s/rad/hr)	σ_1 (MeV)	Cal. σ_6 (MeV) from σ_1
C0046	A11825	142	0.342	52	0.351	16.56	9.72×10^7	1.338	0.546
C0048	A11823	135	0.350	52	0.364	16.55	9.74×10^7	1.409	0.575
C0049	A11819	142	0.353	52	0.364	16.55	9.75×10^7	1.340	0.547
C0051	A11826	138	0.350	50	0.363	16.57	9.42×10^7	1.355	0.553
C0057	A11812	137	0.356	51	0.365	16.56	9.67×10^7	1.383	0.565
C0058	A11805	134	0.362	49	0.374	16.58	9.32×10^7	1.388	0.567
C0062	A11811	138	0.351	51	0.360	16.56	9.66×10^7	1.372	0.560
C0063	A11807	136	0.357	49	0.368	16.58	9.28×10^7	1.365	0.557
C0065	A11815	134	0.349	51	0.358	16.57	9.56×10^7	1.406	0.574
C0066	A11808	136	0.348	51	0.362	16.56	9.60×10^7	1.388	0.567
Average		137	0.352	51	0.363	16.56	9.57×10^7	1.374	0.561
RMS		2.0%	1.5%	1.7%	1.6%	0.1%	1.8%	1.7%	0.010



Gamma-Ray Induced Noise: SiC

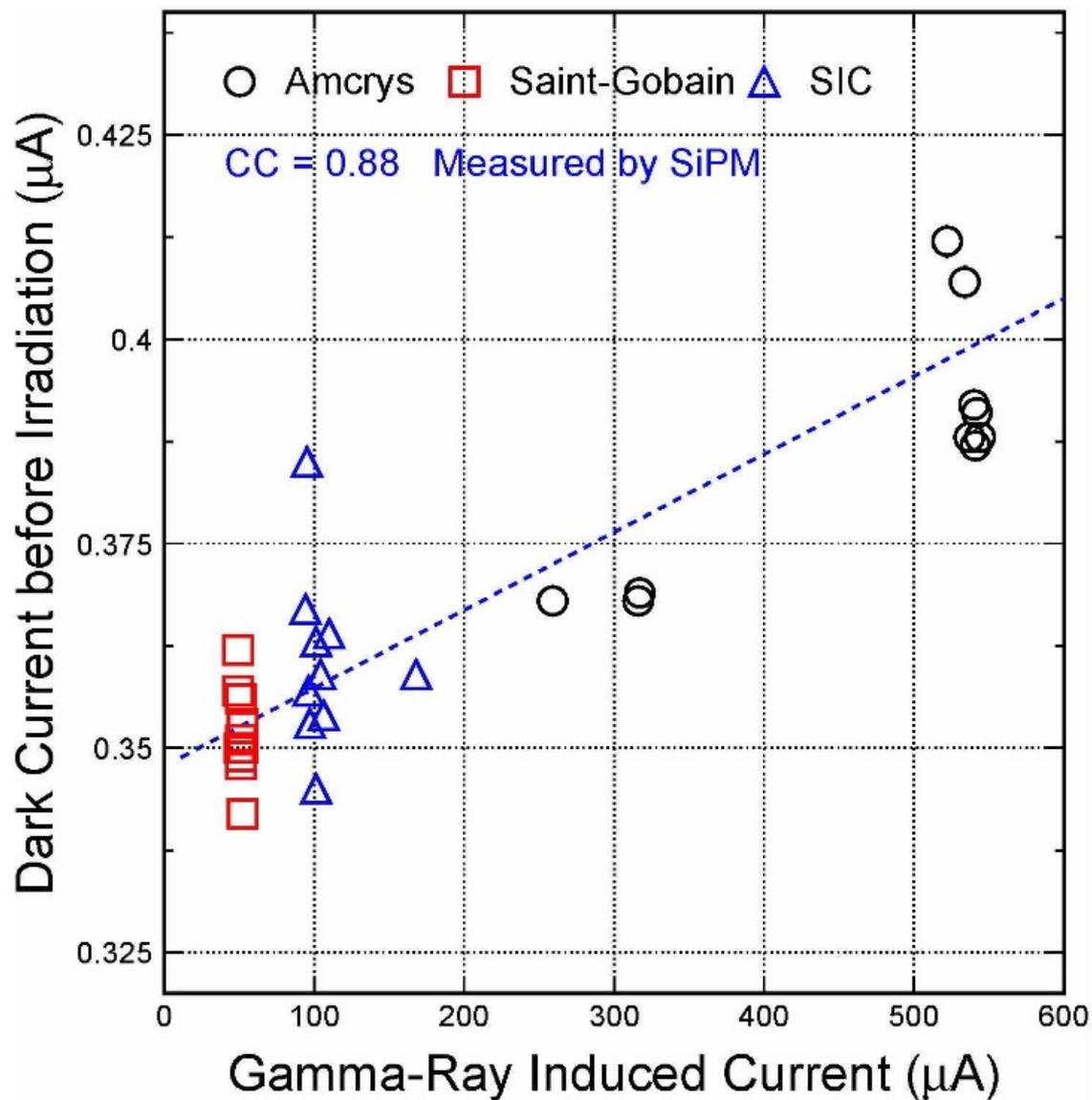


Hamamatsu-64 SiPM @ 53 V (Gain $\sim 1.6 \times 10^6$) with an air gap to CsI crystals with Tyvek @ 1.8 rad/h and LO_{PMT} in 200 ns scaled with the area of six SiPM

Crystal ID	Batch No.	LO_{PMT} (p.e./MeV)	Dark cur. before irradi. (μA)	Photo cur. @ 2 rad/h (μA)	Dark cur. 20s after irradi. (μA)	Gain For σ_1 (10^5)	F (p.e./s/rad/hr)	σ_1 (MeV)	Cal. σ_6 (MeV) from σ_1
C0037	A13	150	0.353	97	1.140	16.04	1.89×10^8	1.764	0.720
C0038	A14	154	0.363	101	0.716	15.99	1.97×10^8	1.757	0.717
C0039	A15	153	0.345	101	1.171	15.99	1.98×10^8	1.772	0.723
C0040	A16	152	0.357	96	1.066	16.04	1.88×10^8	1.736	0.709
C0041	A17	163	0.354	106	1.507	15.93	2.09×10^8	1.707	0.697
C0042	A18	154	0.359	104	1.311	15.96	2.03×10^8	1.782	0.727
C0043	A19	136	0.359	168	0.597	15.23	3.44×10^8	2.629	1.073
C0068	A24	172	0.364	110	0.541	15.88	2.17×10^8	1.650	0.674
C0072	A22	174	0.385	95	1.077	16.06	1.85×10^8	1.506	0.615
C0073	A21	176	0.367	94	0.833	16.07	1.83×10^8	1.481	0.605
Average		158	0.361	107	0.996	15.92	2.11×10^8	1.778	0.726
RMS		7.6%	2.8%	19.4%	30.0%	1.5%	21.6%	17.0%	0.123



Correlation: Dark Current vs. RIC



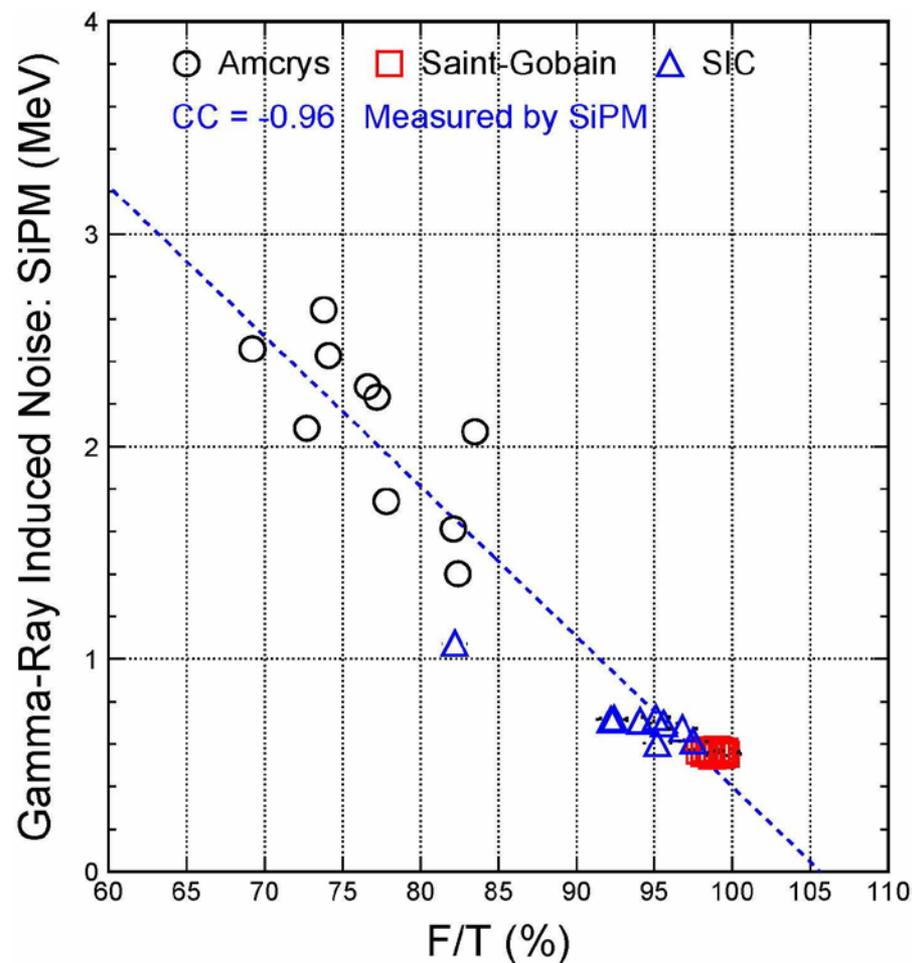
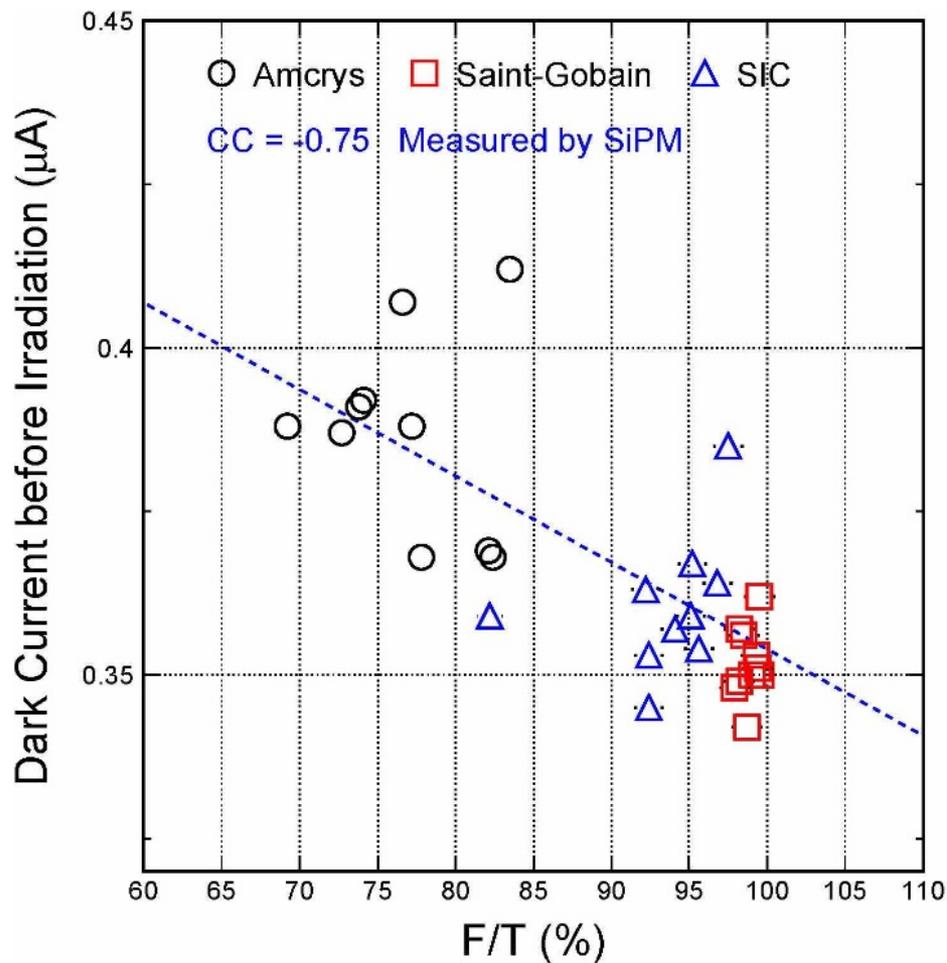
Correlation observed between the dark current and the Gamma-ray induced photocurrent



Correlation with F/T ratio



Both dark currents and RIN are correlated with the F/T

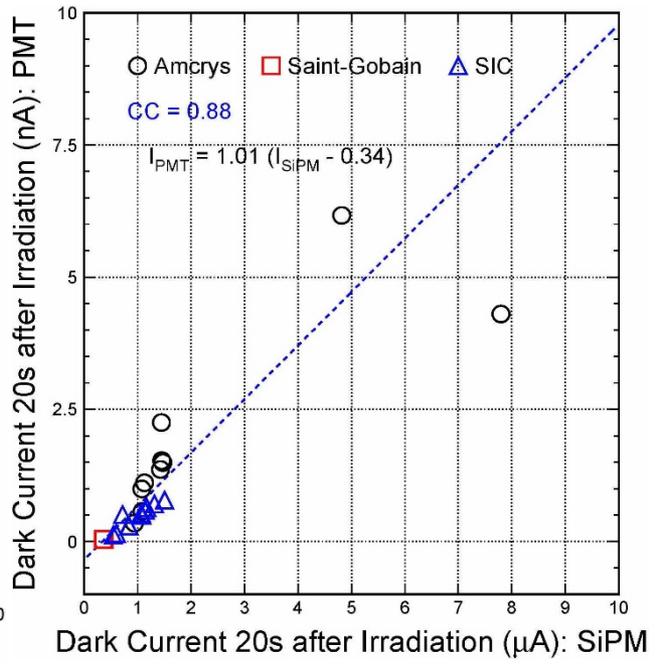
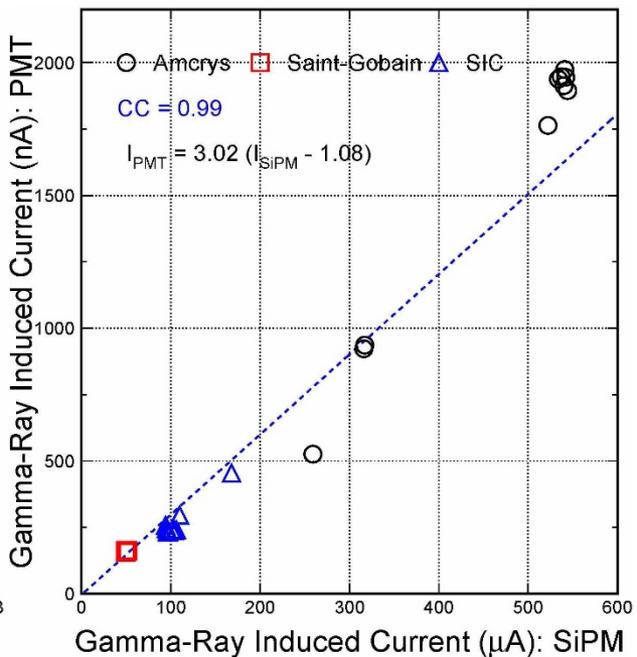
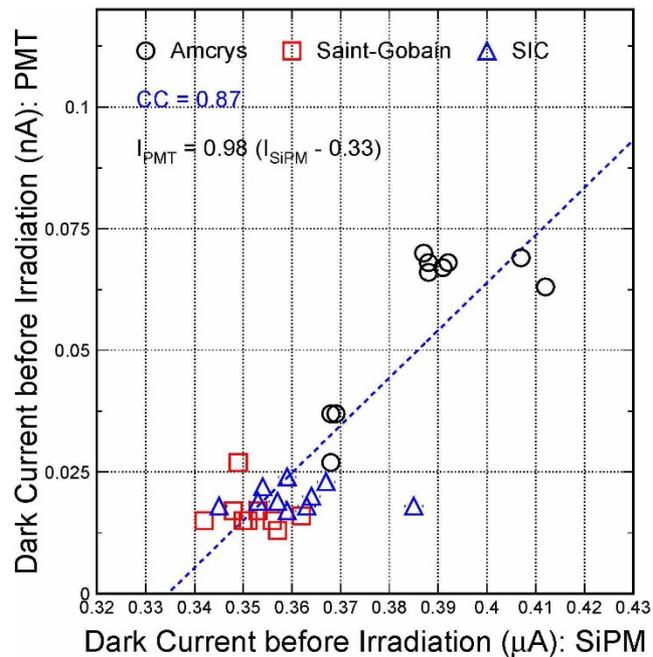




Correlation between Photocurrents Measured by SiPM & PMT



Excellent correlations observed between currents measured by Hamamatsu-64 SiPM and R2059 PMT



Consistent fit for both dark currents in ratio and offset
Different ratio and offset for RIC is due to different emission



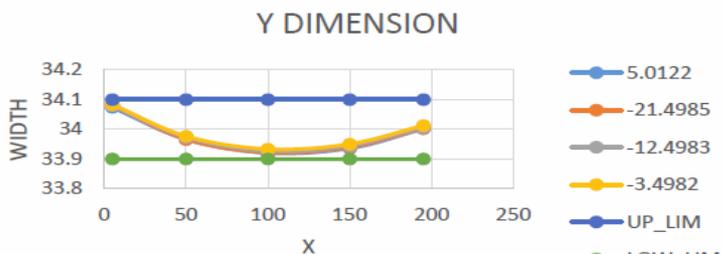
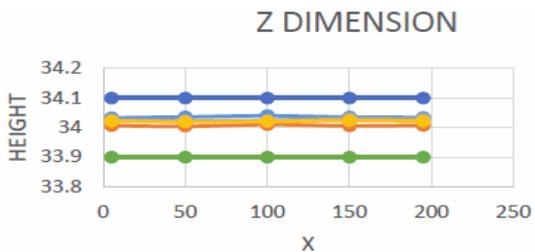
Summary



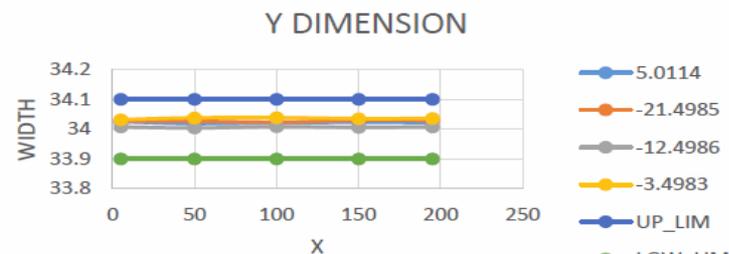
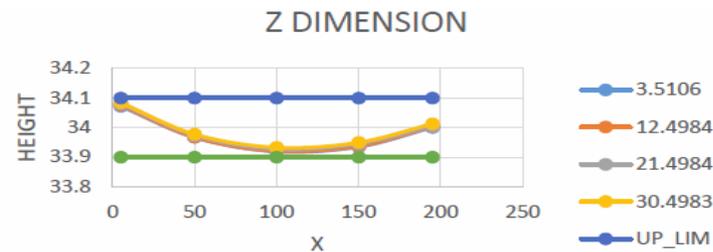
- Radiation induced photocurrent was measured by a single Hamamatsu-64 SiPM for 30 Mu2e preproduction CsI crystals, and is converted to RIN for SiPM readout assuming that light output of CsI measured by a single SiPM is scaled from that by PMT according to the area coverage, i.e. the QE of PMT is the same of the SiPM PDE.
- SiPM gain was determined by using 10 ns blue LED pulses.
- RIN for six SiPMs is scaled down by a factor of $\sqrt{6}$.
- To be investigated: Absolute light output of SiPM readout with source and QE/PDE response of the PMT/SiPM for the CsI fast and slow scintillation.
- 24 preproduction CsI crystals were shipped to Frascati for module zero construction.
- A Kharkov reference CsI has been characterized, and is on the way to Kharkov: see report about 3 reference CsI.



Mike's Data on a Dummy



1a 1b



1c 1d

