



QA on Radiation Induced Noise for 36 Preproduction CsI Crystals

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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. A report of QA on scintillation properties was given on January 11, 2017, following which discussions with vendors started.
- Reported today is the summary of QA on radiation induced noise for 36 preproduction CsI crystals.



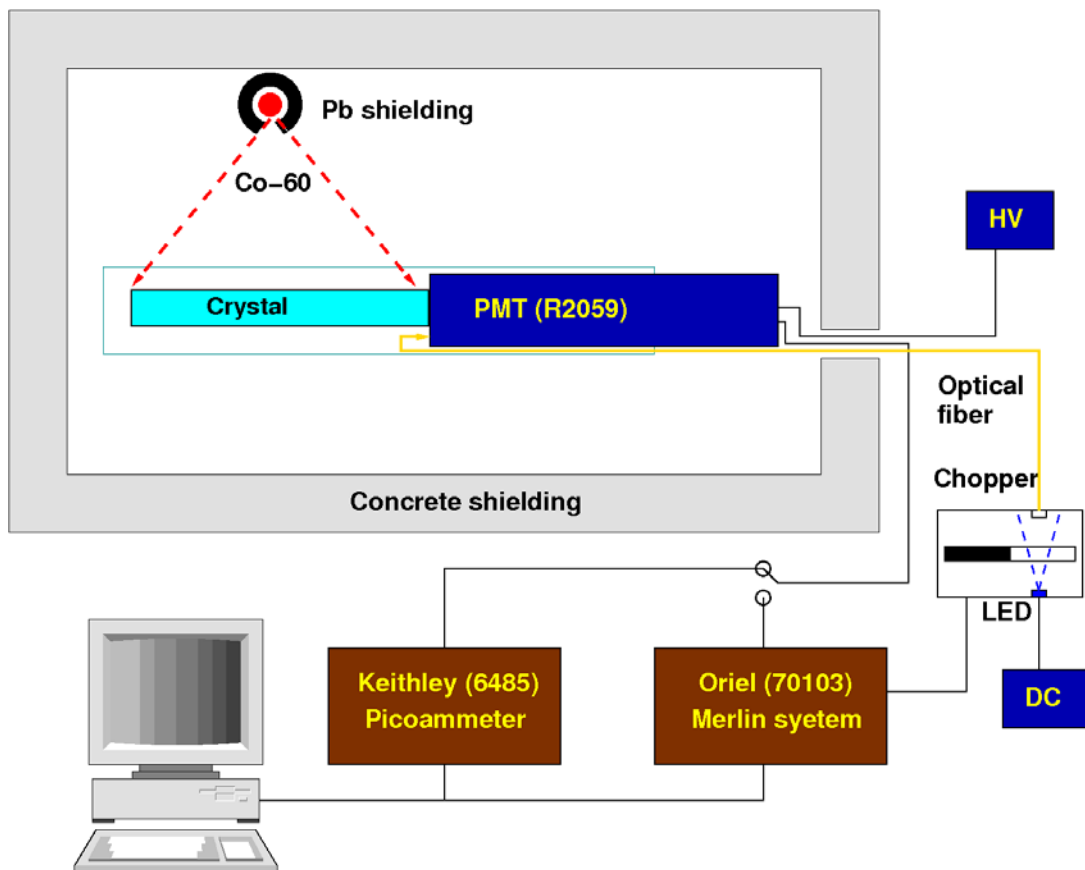
Specifications for Undoped CsI



- ❑ Crystal lateral dimension: $\pm 100 \mu$, length: $\pm 100 \mu$.
- ❑ Scintillation properties at seven points along the crystal wrapped by two layers of Tyvek paper of $150 \mu\text{m}$ for alternative end coupled to a bi-alkali PMT with an air gap. Light output and FWHM resolution are the average of seven points with 200 ns integration time. The light response uniformity is the rms of seven points. F/T is measured at the point of 2.5 cm to the PMT.
 - ❑ Light output (LO): **> 100 p.e./MeV with 200 ns gate, will be compared to reference for cross-calibration;**
 - ❑ FWHM Energy resolution: **< 45% for Na-22 peak;**
 - ❑ Light response uniformity (LRU, rms of seven points): **< 5%;**
 - ❑ Fast (200 ns)/Total (3000 ns) Ratio: **> 75%.**
- ❑ Radiation hardness:
 - ❑ Radiation Induced noise @ 1.8 rad/h: **< 0.6 MeV;** 
 - ❑ Normalized LO after 10/100 krad: **> 85/60%.**



Radiation Induced Photocurrent



F is radiation induced photoelectron numbers per second, determined by the measured anode current in the PMT @ 2rad/h

Photocurrent

$$F = \frac{\text{Charge}_{\text{electron}} \times \text{Gain}_{\text{PMT}}}{\text{Dose rate}_{\gamma\text{-ray}} \text{ or } \text{Flux}_{\text{neutron}}}$$

$$\sigma = \frac{\sqrt{Q}}{LO} \quad (\text{MeV})$$



AMCRYS (Chosen End)



R2059 PMT @-700 V (Gain 263) with air gap to CsI crystals with Tyvek @ 2 rad/h and 200 ns

Crystal ID	Batch Number	Coupling end	L.O. (p.e./MeV)	Dark cur. before irradi. (nA)	Photo cur. @ 2 rad/h (nA)	F (p.e./s/rad/hr)	σ (MeV)
€0013	011	a	148	0.070	1974	2.35×10^{10}	0.621
€0015	007	a	113	0.069	1913	2.27×10^{10}	0.801
€0016	013	b	134	0.069	1938	2.30×10^{10}	0.679
€0019	015	a	125	0.068	1947	2.31×10^{10}	0.730
€0023	024	a	117	0.067	1945	2.31×10^{10}	0.780
C0025	022	b	145	0.063	1764	2.10×10^{10}	0.599
C0026	020	b	132	0.037	936	1.11×10^{10}	0.479
€0027	006	b	139	0.066	1895	2.25×10^{10}	0.648
€0030	001	a	105	0.063	1767	2.10×10^{10}	0.828
C0032	004	b	122	0.037	923	1.10×10^{10}	0.515
€0034	012	a	127	0.068	1913	2.27×10^{10}	0.712
C0036	019	b	134	0.027	526	6.24×10^9	0.354
Average			128	0.059	1620	1.92	0.645
RMS			9.6%	25.3%	30.2%	30.2%	0.136



Saint-Gobain (Chosen End)

R2059 PMT @ -700 V (Gain 263) with air gap to CsI crystals with Tyvek @ 2 rad/h and 200 ns

Crystal ID	Batch Number	Coupling end	L.O. (p.e./MeV)	Dark cur. before irradi. (nA)	Photo cur. @ 2 rad/h (nA)	F (p.e./s/rad/hr)	σ (MeV)
C0045	A11827	a	141	0.016	166	1.97×10^9	0.189
C0046	A11825	b	142	0.015	165	1.97×10^9	0.187
C0048	A11823	b	135	0.015	163	1.94×10^9	0.196
C0049	A11819	b	142	0.017	165	1.96×10^9	0.187
C0051	A11826	a	138	0.015	157	1.86×10^9	0.188
C0057	A11812	a	137	0.015	164	1.95×10^9	0.194
C0058	A11805	b	134	0.016	157	1.87×10^9	0.194
C0060	A11804	a	136	0.016	166	1.97×10^9	0.196
C0062	A11811	b	138	0.015	165	1.96×10^9	0.192
C0063	A11807	a	136	0.013	162	1.92×10^9	0.193
C0065	A11815	a	134	0.027	160	1.90×10^9	0.195
C0066	A11808	a	136	0.017	160	1.90×10^9	0.192
Average			137	0.016	162	1.93	0.192
RMS			2.1%	20.0%	2.0%	2.0%	0.003



SICCAS (Chosen End)



R2059 PMT @-700 V (Gain 263) with air gap to CsI crystals with Tyvek @ 2 rad/h and 200 ns

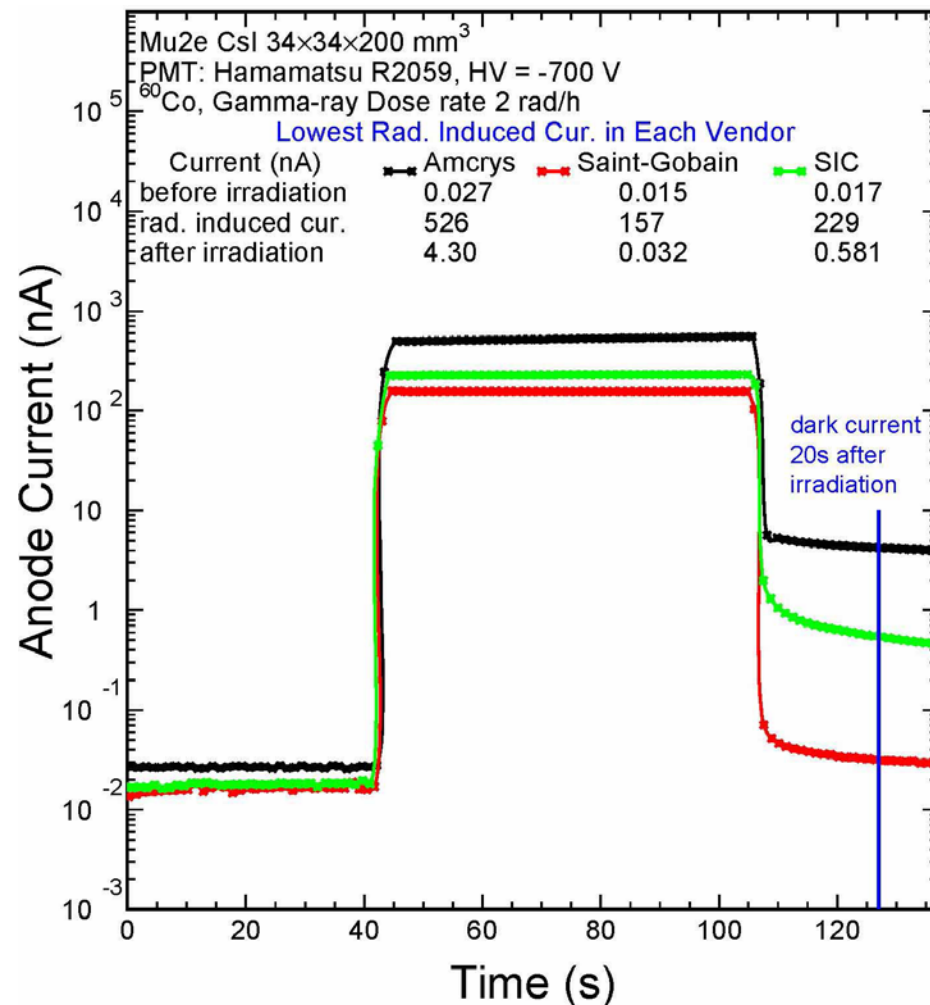
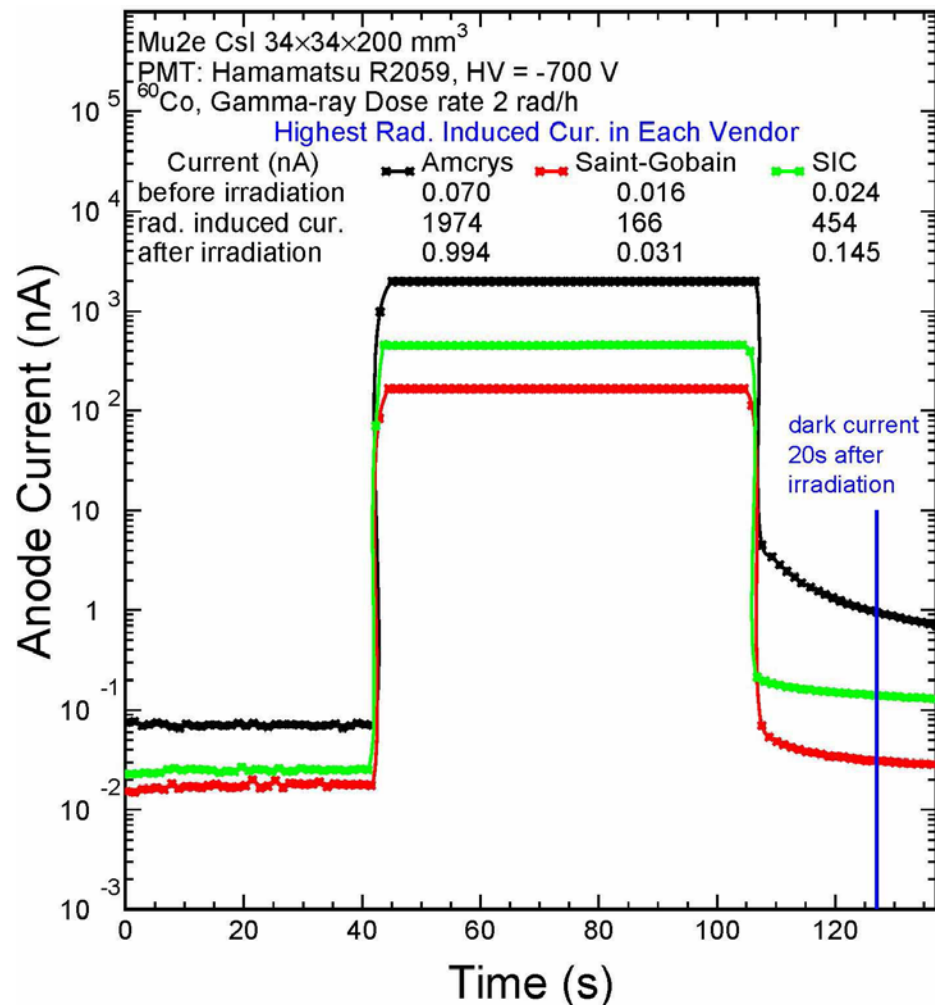
Crystal ID	Batch Number	Coupling end	L.O. (p.e./MeV)	Dark cur. before irradi. (nA)	Photo cur. @ 2 rad/h (nA)	F (p.e./s/rad/hr)	σ (MeV)
C0037	2016 A13	a	150	0.019	233	2.77×10^9	0.211
C0038	2016 A14	b	154	0.018	239	2.85×10^9	0.208
C0039	2016 A15	b	153	0.018	239	2.84×10^9	0.209
C0040	2016 A16	a	152	0.019	234	2.78×10^9	0.208
C0041	2016 A17	a	163	0.022	241	2.87×10^9	0.197
C0042	2016 A18	b	154	0.017	237	2.82×10^9	0.207
C0043	2016 A19	a	136	0.024	454	5.40×10^9	0.324
C0068	2016 A24	b	172	0.020	295	3.51×10^9	0.207
C0070	2016 A20	a	153	0.017	229	2.72×10^9	0.205
C0071	2016 A23	a	183	0.025	417	4.95×10^9	0.231
C0072	2016 A22	a	174	0.018	245	2.92×10^9	0.186
C0073	2016 A21	a	176	0.023	257	3.05×10^9	0.188
Average			160	0.020	277	3.29	0.215
RMS			8.2%	13.1%	26.5%	26.5%	0.035



History of Photocurrent



Crystals with the highest (left) and lowest (right) current

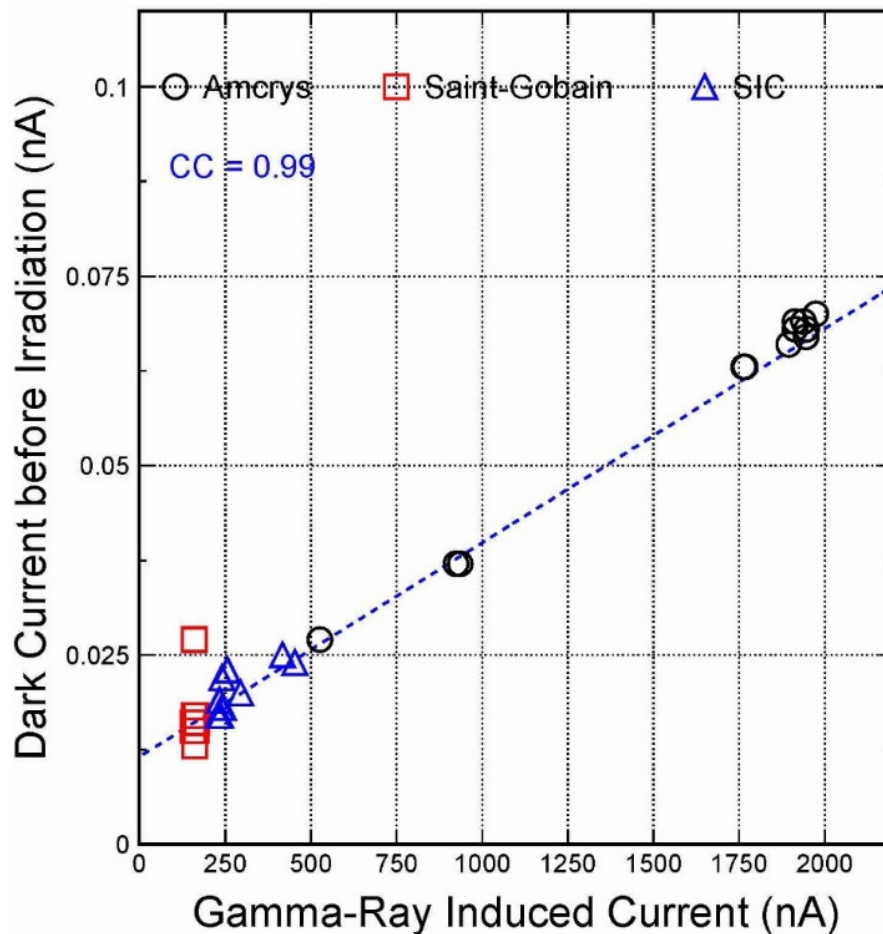
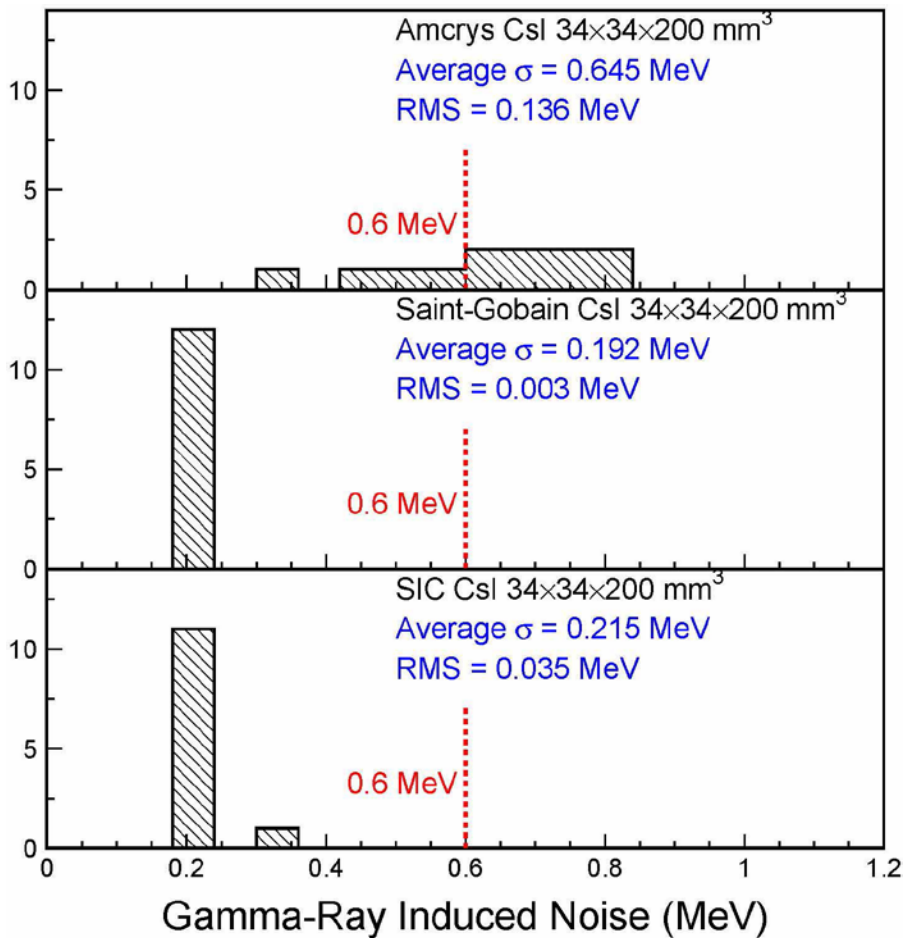




γ -Ray Induced Readout Noise



Rank of RIN: SG, SIC, AMCRYS; Highly correlated currents

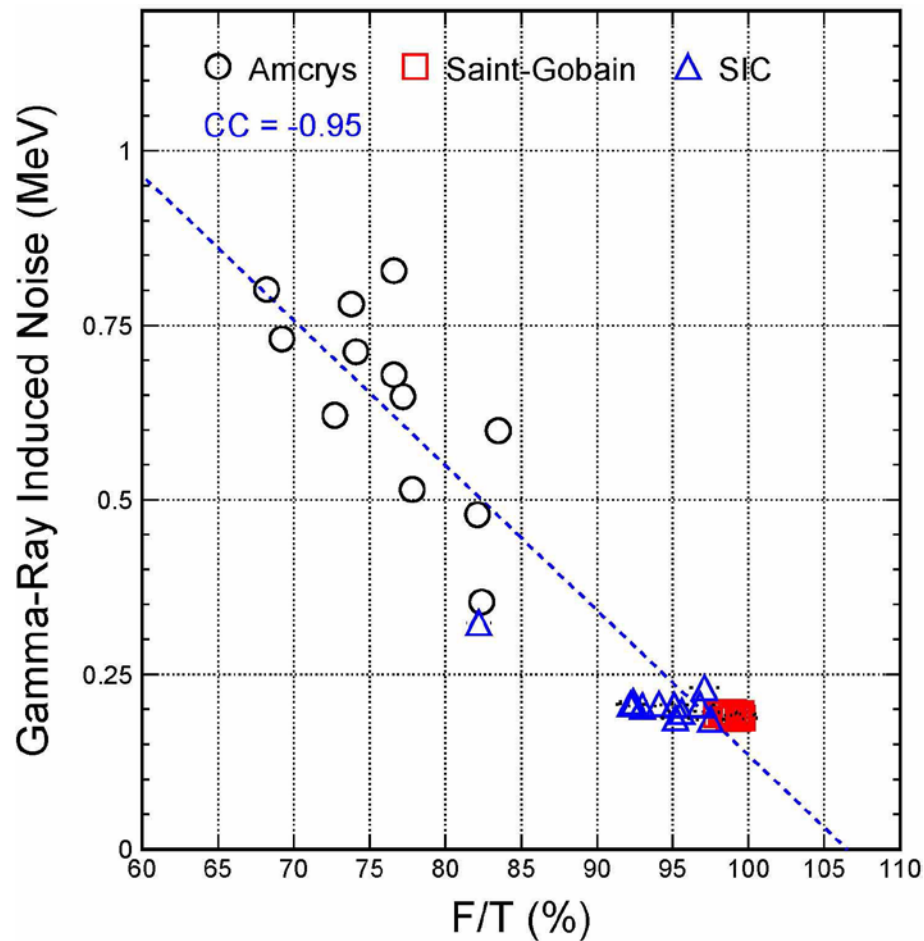
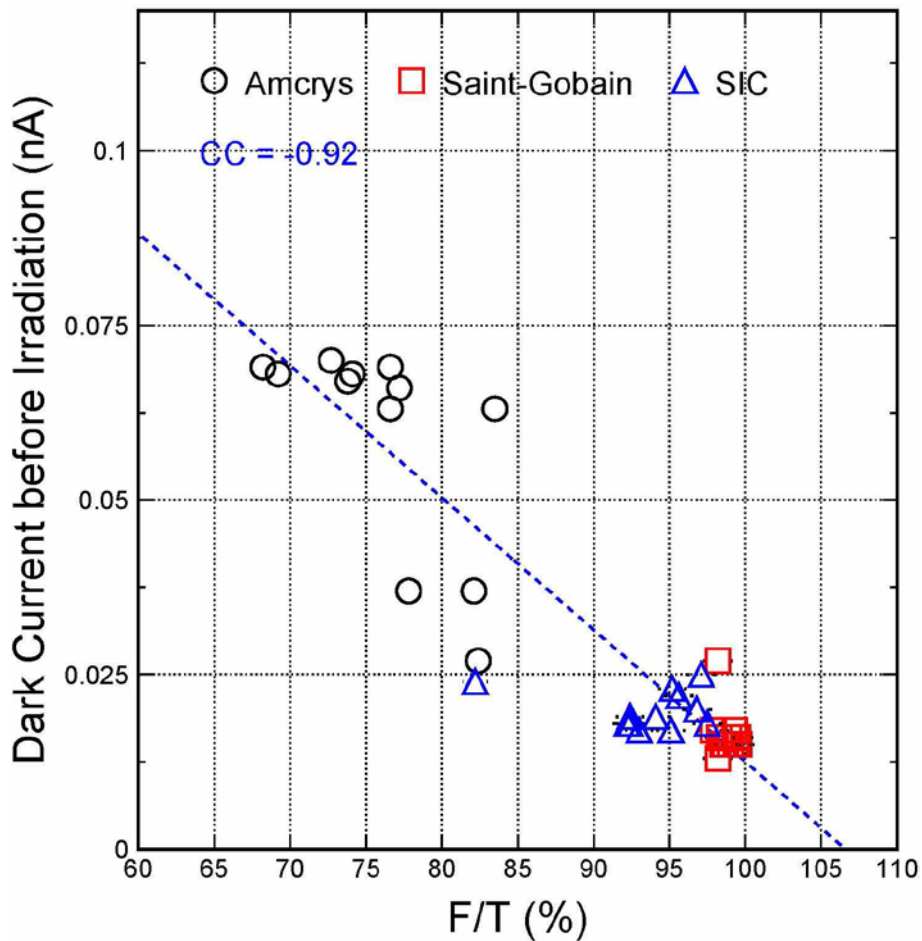




Correlation with F/T Ratio



Dark current and RIN are highly correlated with F/T





Summary



- Radiation induced readout noise are measured for 36 Mu2e preproduction CsI crystals. All crystals from Saint-Gobain and SICCAS meet the Mu2e spec. Eight crystals from AMCRYS do not.
- Excellent correlations between the dark current and radiation induced current/noise versus the F/T ratio are confirmed, which is in addition to that between the F/T ratio to light output and resolution, enhancing the importance of reducing or eliminating slow component.
- Mu2e uses SiPM with different QE response from bi-alkali PMT. Radiation induced photocurrent would fire pixels and thus reduce dynamic range. Will check RIN for the Mu2e SiPM readout.
- QA on radiation induced damage will be started after samples are selected. Plan to irradiate two samples from each vendor to 100 krad. Since these samples will be wasted, our plan is to use crystals failing mechanical spec.