QA on Scintillation Properties for 36 Preproduction CsI Crystals

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January 11, 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 (AMCRYS, SICCAS and Saint-Gobain, 24 each) were delivered to Fermilab early December.

- After QA on visual inspection and mechanical dimension by a CMM machine at Fermilab, 36 CsI crystals arrived Caltech in three batches on Dec 15 and 19. A report on two additional reference crystals one each from Saint-Gobain and SICCAS was given on Dec 21, 2016.

- Reported today is the summary of QA on scintillation properties for 36 preproduction CsI crystals.

36 CsI Crystals from Three Vendors

Arranged according to crystal ID in the Mu2e database

Specifications for Undoped CsI

- Crystal lateral dimension: ±100 μ, length: ±100 μ.
- Scintillation properties at seven points along the crystal wrapped by two layers of Tyvek paper of 150 μm 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%.**

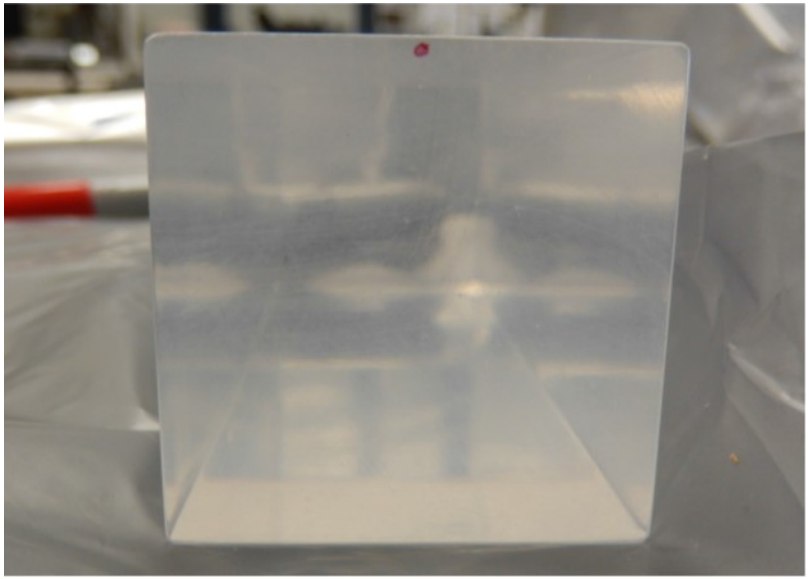
Crystal ID and Coupling End

AMCRYS 012

Saint-Gobain A11815

SIC 2016 A16

Vendor batch IDs are also listed to facilitate sample tracing



The crystal end marked with a red dot is defined as the “A end”. Picture from R. Donghia’s report on 12/21/16.

Mu2e IDs are carved on a side surface close to the chosen coupling end.

The coupling end for each crystal is selected to provide a better LRU.

AMCRYS (Chosen end: blue)

Crystal ID	Batch Number	Coupling end	L.O. (p.e./MeV)	E.R. (%)	F/T (%)	LRU (%)
~~C0013~~	~~011~~	a	148	34	72.7	1.6
		b	149	34	72.2	1.7
~~C0015~~	~~007~~	a	113	39	68.2	1.7
		b	116	38	69.1	2.1
C0016	013	a	130	36	75.9	1.7
		b	134	35	76.6	1.7
~~C0019~~	~~015~~	a	125	37	69.2	1.6
		b	124	37	69.1	1.6
~~C0023~~	~~024~~	a	117	39	73.8	1.9
		b	119	38	73.2	2.6
C0025	022	a	147	35	83.2	2.8
		b	145	34	83.5	2.6
C0026	020	a	130	36	76.5	2.4
		b	132	36	82.1	3.7
C0027	006	a	135	36	76.4	1.4
		b	139	35	77.2	2.1
C0030	001	a	105	41	76.6	2.4
		b	108	40	75.3	1.8
C0032	004	a	122	38	78.0	4.3
		b	122	38	77.8	2.5
~~C0034~~	~~012~~	a	127	37	74.1	1.3
		b	128	36	74.7	1.6
C0036	019	a	138	36	85.4	1.9
		b	134	37	82.4	1.3
Average			**129**	**37**	**76.0**	**2.1**
RMS			**9.3%**	**1.8**	**6.2%**	**0.71**

Saint-Gobain (Chosen end: blue)

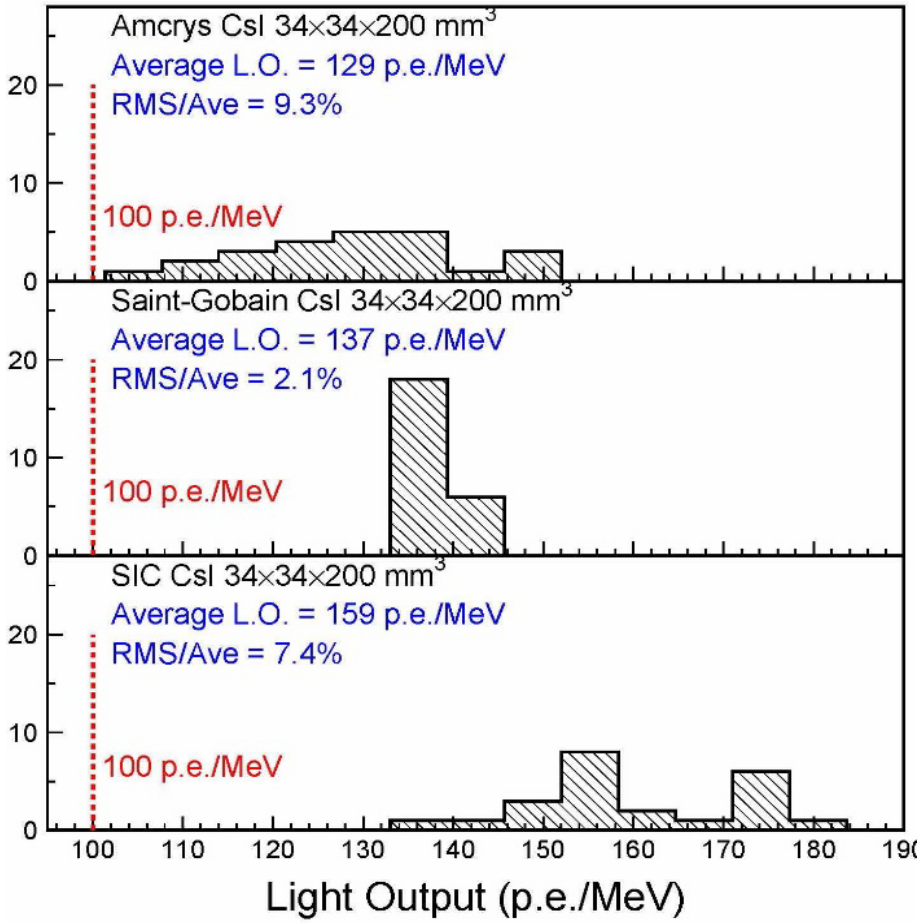
Crystal ID	Batch Number	Coupling end	L.O. (p.e./MeV)	E.R. (%)	F/T (%)	LRU (%)
C0045	A11827	a	141	33	98.9	0.9
		b	140	34	99.7	1.0
C0046	A11825	a	144	34	99.3	2.3
		b	142	34	98.7	1.6
C0048	A11823	a	134	35	98.0	1.9
		b	135	35	99.0	3.9
C0049	A11819	a	141	34	98.9	2.9
		b	142	34	99.3	0.9
C0051	A11826	a	138	34	99.6	3.3
		b	135	35	98.9	3.8
C0057	A11812	a	137	34	98.5	1.3
		b	138	34	98.8	3.2
C0058	A11805	a	134	35	98.9	5.1
		b	134	35	99.5	3.0
C0060	A11804	a	136	35	98.3	2.0
		b	136	35	98.4	3.4
C0062	A11811	a	138	34	100.0	3.2
		b	138	34	99.4	0.9
C0063	A11807	a	136	35	98.2	2.2
		b	136	35	99.0	3.8
C0065	A11815	a	134	35	98.2	2.5
		b	133	35	98.1	2.5
C0066	A11808	a	136	35	97.9	2.5
		b	137	35	99.1	2.8
Average			**137**	**35**	**98.9**	**2.5**
RMS			**2.1%**	**0.58**	**0.58%**	**1.1**

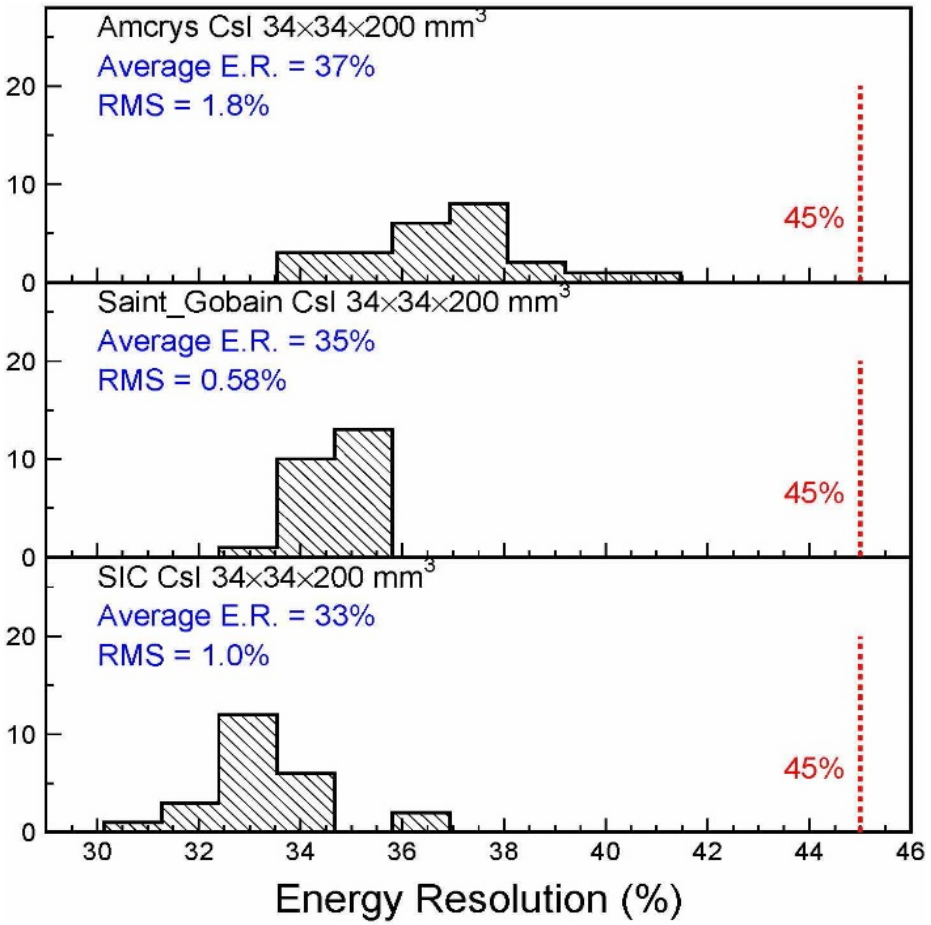
SICCAS (Chosen end: blue)

Crystal ID	Batch Number	Coupling end	L.O. (p.e./MeV)	E.R. (%)	F/T (%)	LRU (%)
C0037	2016 a13	a	150	33	92.4	1.2
		b	149	34	94.7	5.0
C0038	2016 a14	a	148	34	95.2	3.4
		b	154	33	92.2	1.8
C0039	2016 a15	a	154	34	94.4	3.8
		b	153	33	92.4	0.7
C0040	2016 a16	a	152	34	94.1	1.5
		b	154	33	95.0	3.8
C0041	2016 a17	a	163	33	95.6	3.3
		b	161	33	95.3	3.3
C0042	2016 a18	a	152	34	92.7	3.2
		b	154	33	95.1	2.3
C0043	2016 a19	a	136	36	82.2	1.3
		b	143	36	96.9	**9.4**
C0068	2016 a24	a	166	33	86.6	2.8
		b	172	33	96.8	2.9
C0070	2016 a20	a	153	34	93.0	1.4
		b	155	33	95.4	3.5
~~C0071~~	~~2016 a23~~	a	183	32	97.1	**5.6**
		b	172	32	75.7	**5.7**
~~C0072~~	~~2016 a22~~	a	174	33	97.5	**5.3**
		b	172	33	92.6	**6.0**
C0073	2016 a21	a	176	32	95.2	0.7
		b	175	31	95.6	1.0
Average			**159**	**33**	**93.1**	**3.3**
RMS			**7.4%**	**1.0**	**5.2%**	**2.1**

Light Output and Resolution

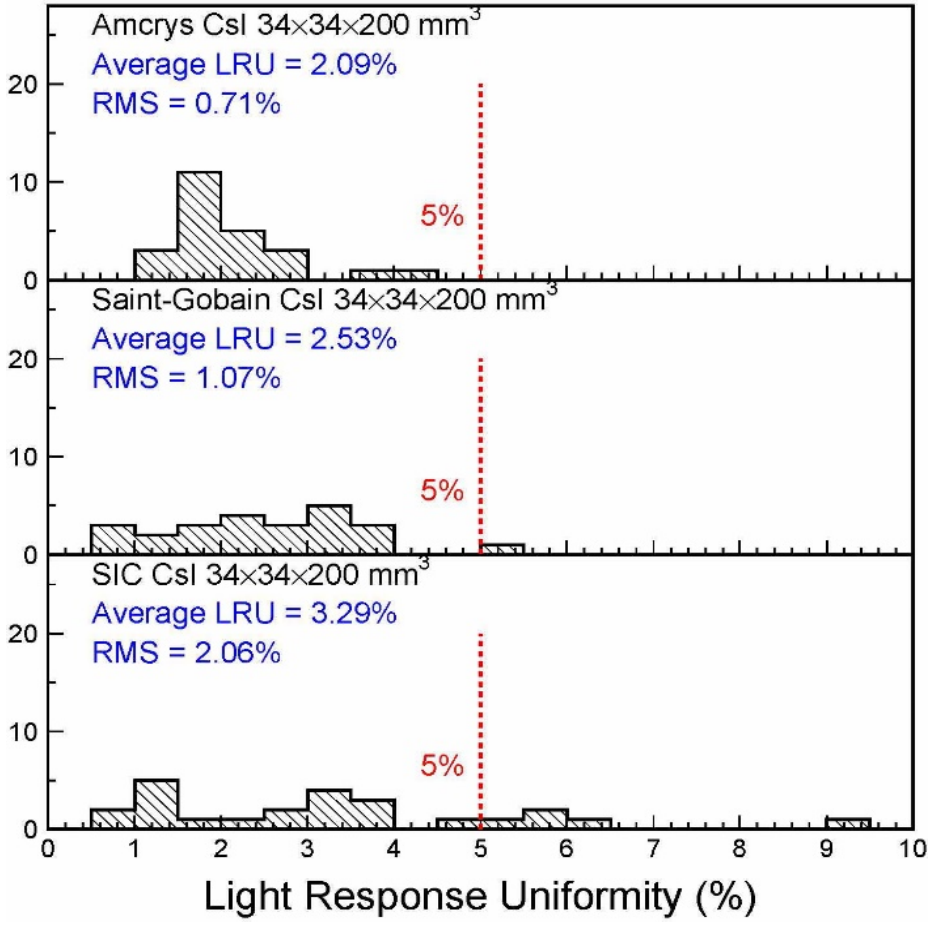
Rank of light output and resolution: SIC, SG, AMCRYS
Rank of consistency: SG, SIC, AMCRYS

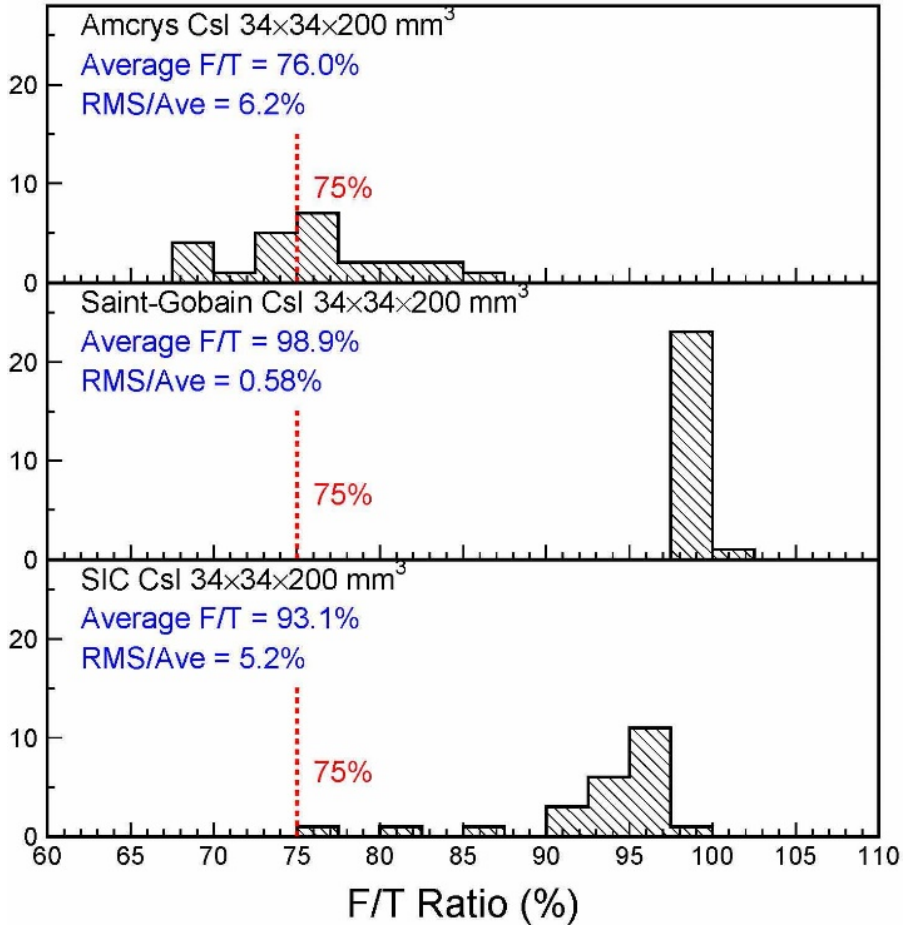




Light Response Uniformity & F/T Ratio

Rank of uniformity and its consistency: AMCRYS, SG, SIC
Rank of F/T and its consistency : SG, SIC, AMCRYS





AMCRYS with the Chosen Coupling End

Five crystals fail to meet the F/T ratio specification

Crystal ID	Batch Number	Coupling end	L.O. (p.e./MeV)	E.R. (%)	F/T (%)	LRU (%)
~~C0013~~	~~011~~	a	148	34	72.7	1.56
~~C0015~~	~~007~~	a	113	39	68.2	1.65
C0016	013	b	134	35	76.6	1.69
~~C0019~~	~~015~~	a	125	37	69.2	1.63
~~C0023~~	~~024~~	a	117	39	73.8	1.93
C0025	022	b	145	34	83.5	2.58
C0026	020	a	130	36	76.5	2.40
C0027	006	a	135	36	76.4	1.35
C0030	001	b	108	40	75.3	1.81
C0032	004	b	122	38	77.8	2.49
~~C0034~~	~~012~~	a	127	37	74.1	1.32
C0036	019	b	134	37	82.4	1.29
Average			**128**	**37**	**75.5**	**1.81**
RMS			**9.0%**	**1.9**	**5.7%**	**0.24**

S-G with the Chosen Coupling End

All 12 crystals meet specifications

Crystal ID	Batch Number	Coupling end	L.O. (p.e./MeV)	E.R. (%)	F/T (%)	LRU (%)
C0045	A11827	a	141	33	98.9	0.92
C0046	A11825	b	142	34	98.7	1.63
C0048	A11823	a	134	35	98.0	1.94
C0049	A11819	b	142	34	99.3	0.85
C0051	A11826	a	138	34	99.6	3.32
C0057	A11812	a	137	34	98.5	1.33
C0058	A11805	b	134	35	99.5	3.02
C0060	A11804	a	136	35	98.3	1.96
C0062	A11811	b	138	34	99.4	0.87
C0063	A11807	a	136	35	98.2	2.18
C0065	A11815	a	134	35	98.2	2.50
C0066	A11808	a	136	35	97.9	2.48
Average			**137**	**34**	**98.7**	**1.92**
RMS			**2.1%**	**0.64**	**0.60%**	**0.41**

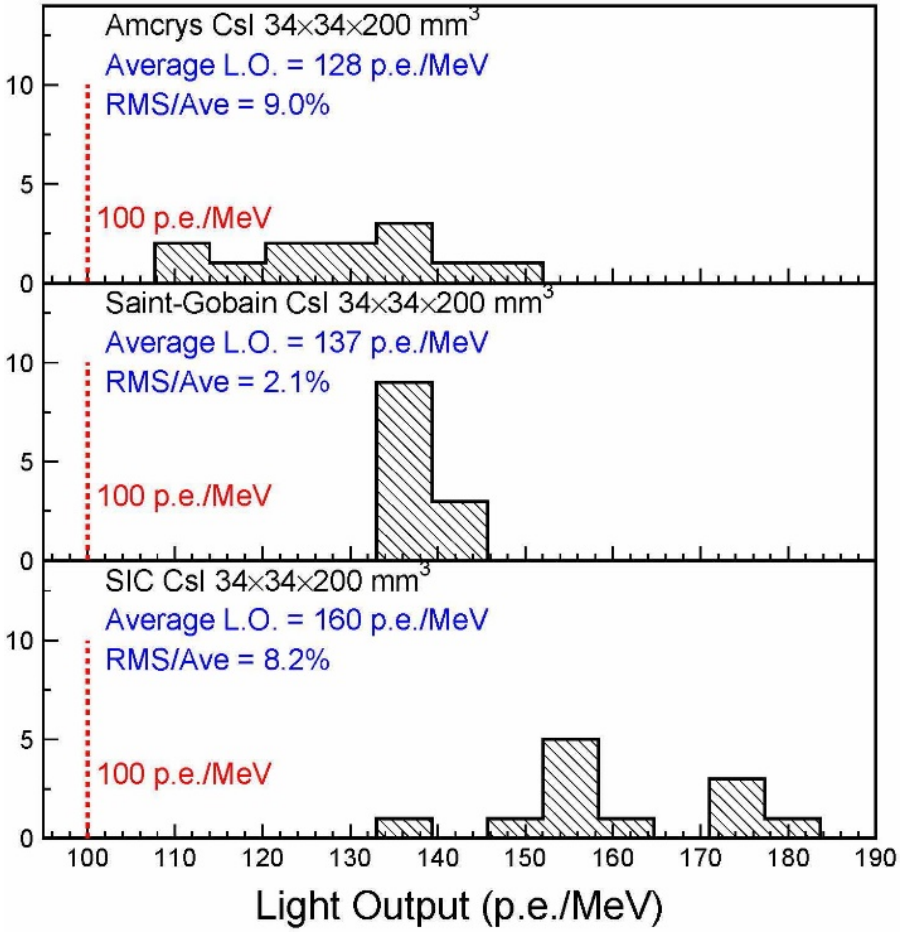
SIC with the Chosen Coupling End

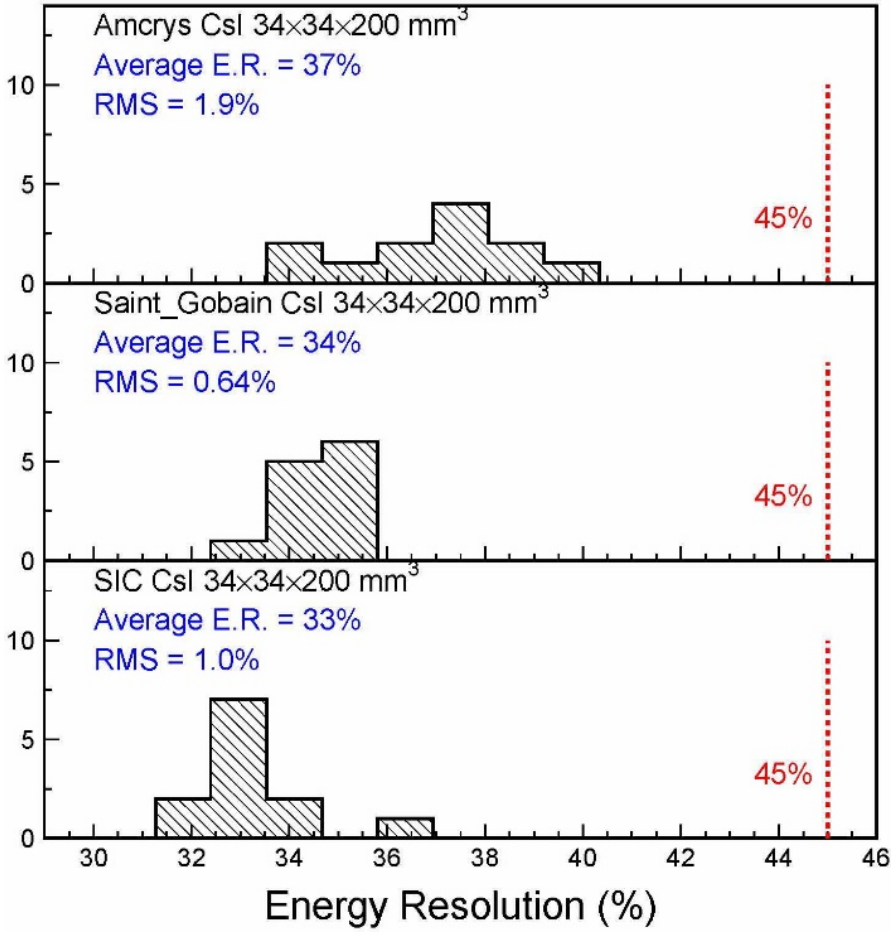
Two crystals fail the uniformity spec

Crystal ID	Batch Number	Coupling end	L.O. (p.e./MeV)	E.R. (%)	F/T (%)	LRU (%)
C0037	2016 A13	a	150	33	92.4	1.16
C0038	2016 A14	b	154	33	92.2	1.82
C0039	2016 A15	b	153	33	92.4	0.70
C0040	2016 A16	a	152	34	94.1	1.46
C0041	2016 A17	a	163	33	95.6	3.33
C0042	2016 A18	b	154	33	95.1	2.28
C0043	2016 A19	a	136	36	82.2	1.28
C0068	2016 A24	b	172	33	96.8	2.85
C0070	2016 A20	a	153	34	93.0	1.39
~~C0071~~	~~2016 A23~~	a	183	32	97.1	**5.63**
~~C0072~~	~~2016 A22~~	a	174	33	97.5	**5.30**
C0073	2016 A21	a	176	32	95.2	0.72
Average			**160**	**33**	**93.6**	**2.33**
RMS			**8.2%**	**1.0**	**4.2%**	**1.60**

LO & Resolution with the Chosen End

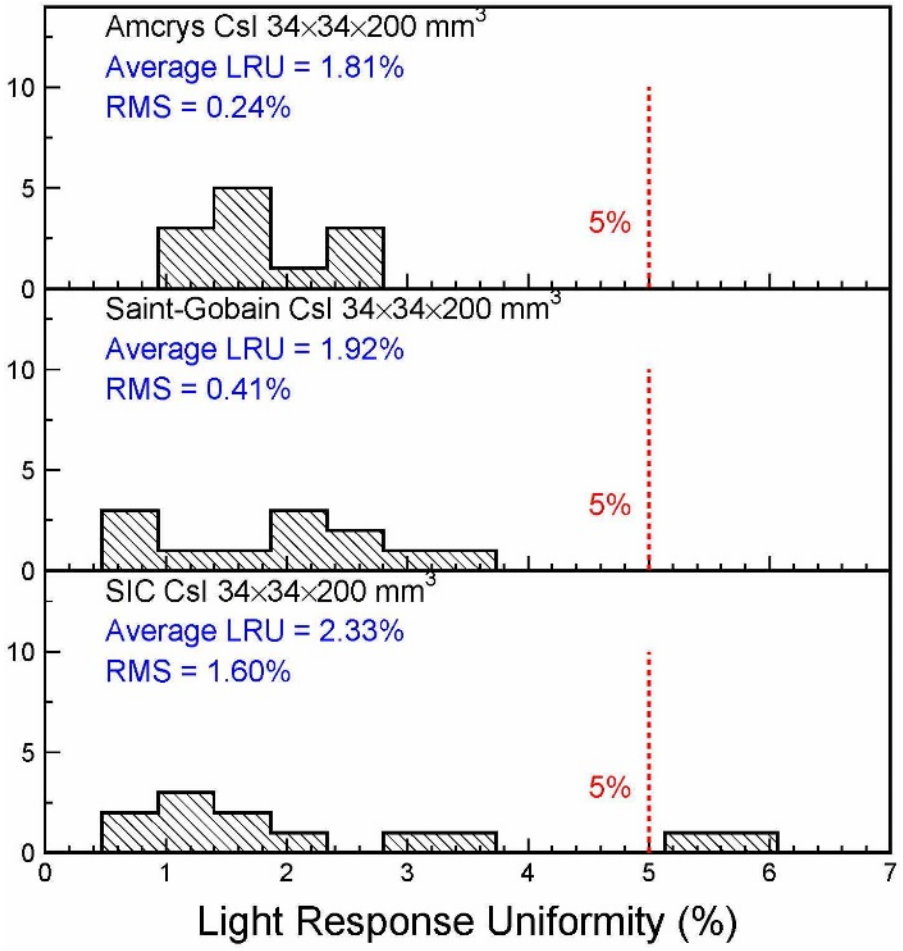
Rank of light output and resolution: SIC, SG, AMCRYS
Rank of consistency: SG, SIC, AMCRYS

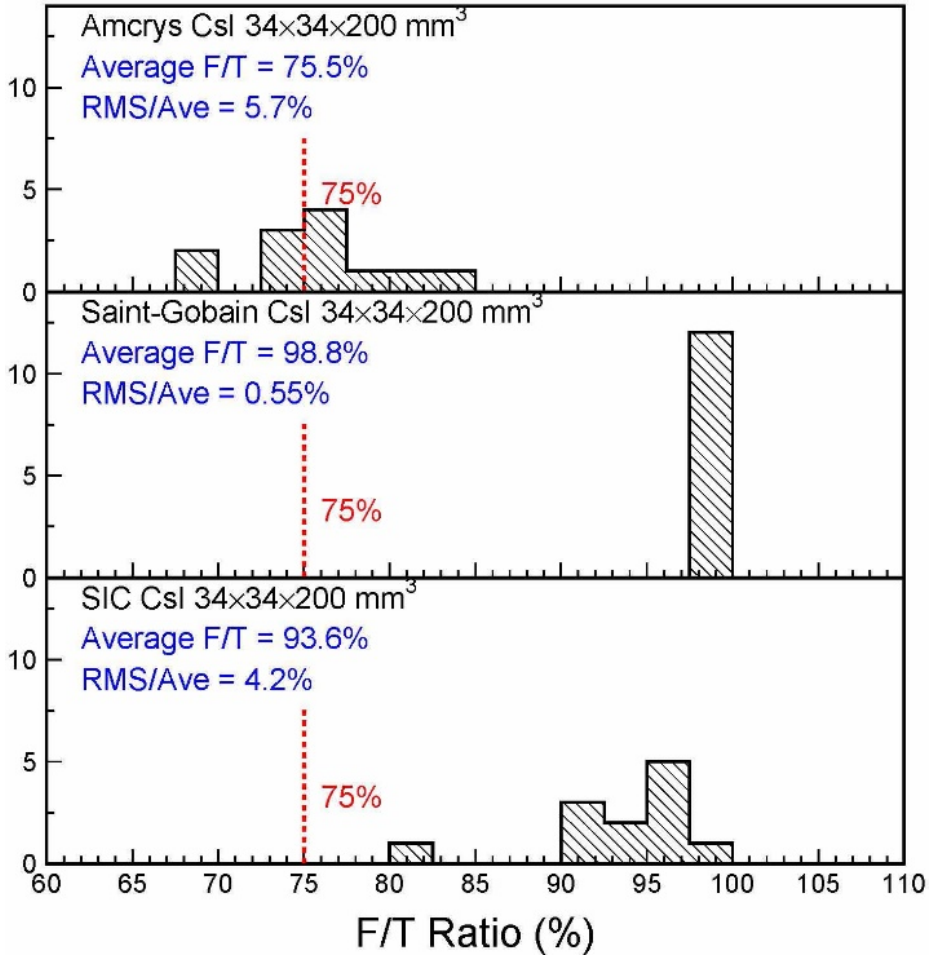




LRU and F/T with the Chosen End

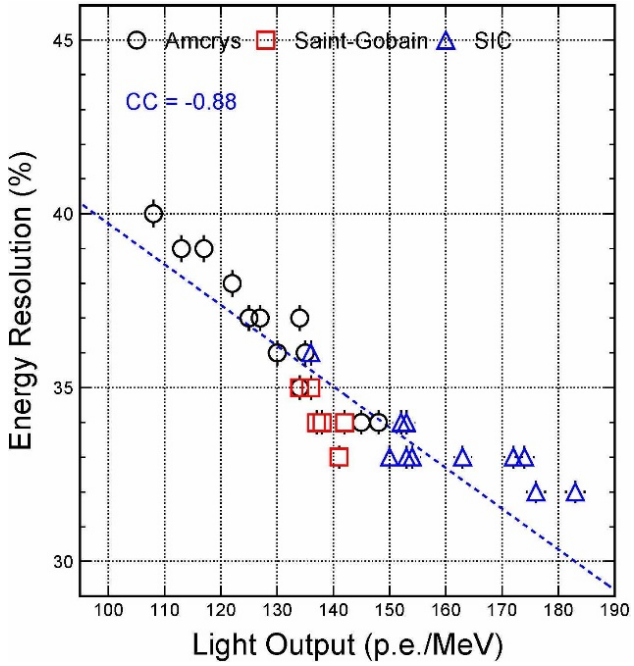
Rank of uniformity and its consistency: AMCRYS, SG, SIC
Rank of F/T and its consistency : SG, SIC and AMCRYS

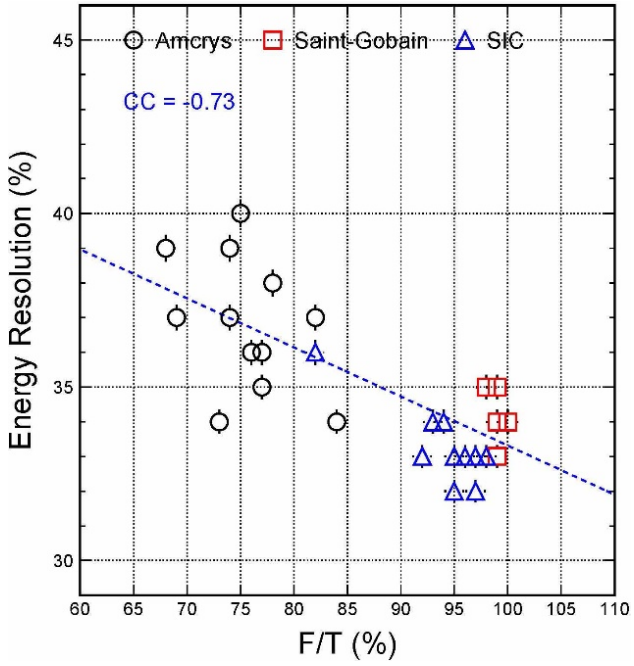


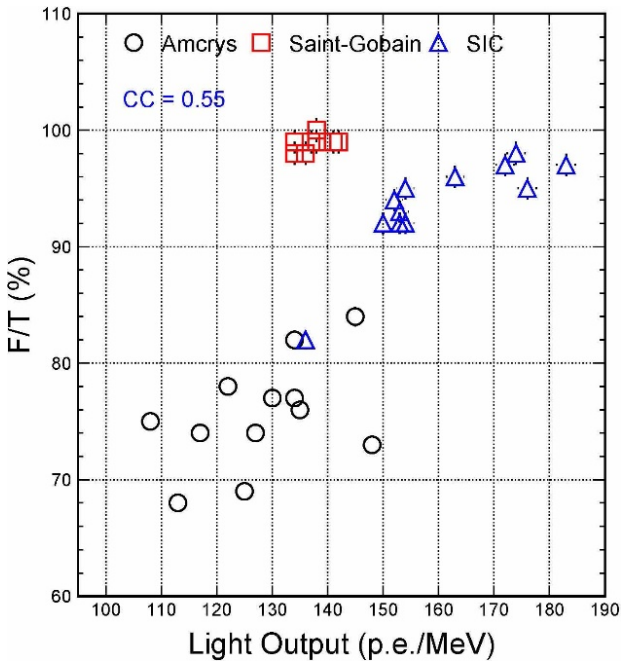


Correlations: LO, Resolution and F/T

Good correlations observed between LO, resolution and F/T, indicating the importance of slow control. Energy resolution seems having a limit at 32%.

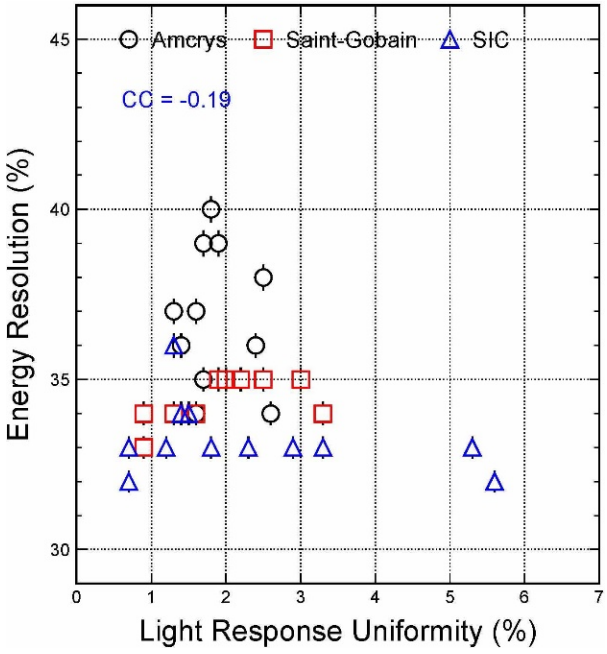


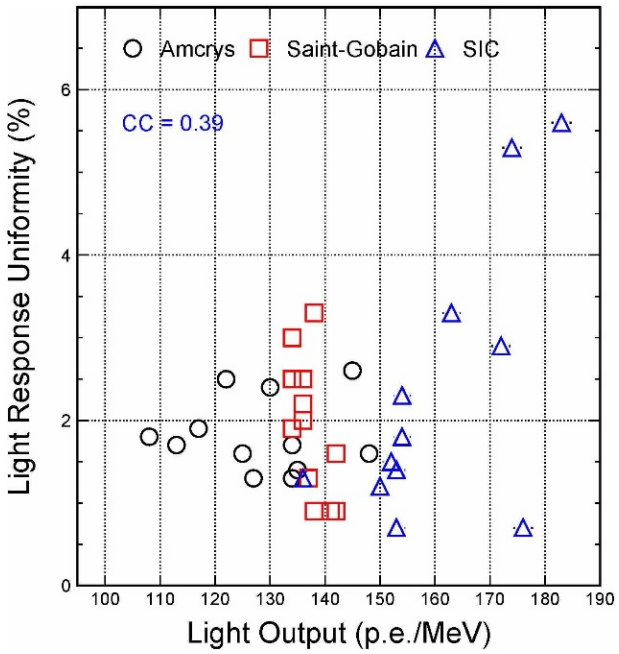


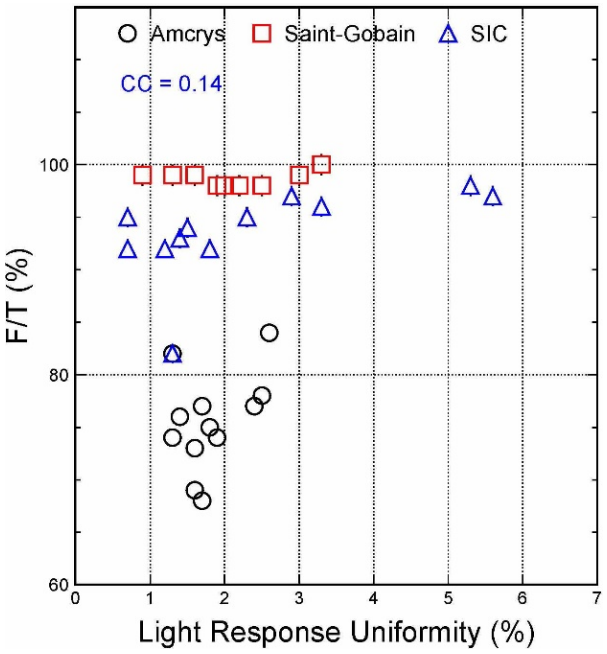


Correlations Related to Uniformity

No overall correlations for crystals from all vendors between uniformity vs. LO, resolution and F/T. For SIC crystals, correlations exist, indicating a possibility to tune uniformity by roughing a part of crystal surfaces and/or painting Tyvek wrapping.







Summary

- Scintillation properties of 36 Mu2e preproduction CsI crystals from AMCRYS, Saint-Gobain and SICCAS are characterized.
  - AMCRYS crystals have the best uniformity, but the poorest light output, energy resolution and F/T ratio. Five crystals do not meet the F/T spec.
  - Saint-Gobain crystals have the best F/T ratio and the best overall consistency. All crystals meet spec.
  - SIC crystals have the best light output and energy resolution, but the poorest uniformity. Two crystals do not meet the uniformity spec.
- Correlations are observed between LO, resolution and F/T ratio, indicating the importance of slow component control, which is related to raw material purity.
- Some correlations exist between LO and uniformity in SIC crystals, indicating a possibility to tune uniformity by roughing a part of crystal surfaces and/or painting Tyvek wrapping.
- QA on radiation induced noise and damage has started. Plan to irradiate two samples from each vendor to 100 krad.