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# Report on Radiation Damage in Twelve Mu2e CsI Crystals

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# A Brief Summary

- Four additional CsI samples (three S-G and one SIC) were irradiated in two steps to 10 and 100 krad. All meet CsI RH specification after 100 krad.
- The average light output is 136 and 110 p.e./MeV after 10 and 100 krad for nine SIC crystals and 115 and 102 p.e./MeV for three S-G crystals with losses of 20% and 35% for SIC and 19% and 28% for S-G.
- Slightly degraded energy resolution, F/T ratio and light response uniformity meet Mu2e spec. All, except 3, show light output of  $>100$  p.e./MeV after 100 krad.
- No recovery observed up to 836 and 451 days after 100 krad irradiation in two samples each from S-G and SIC, respectively, indicating a stable calorimeter.

# Summary: Nine SIC Csl Crystals

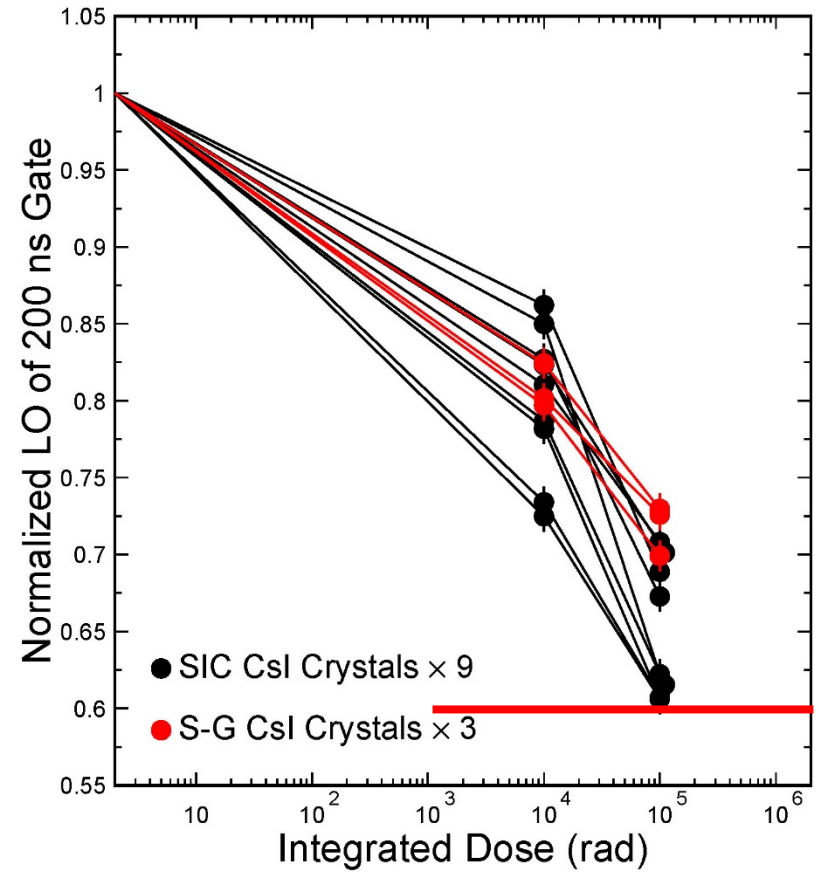
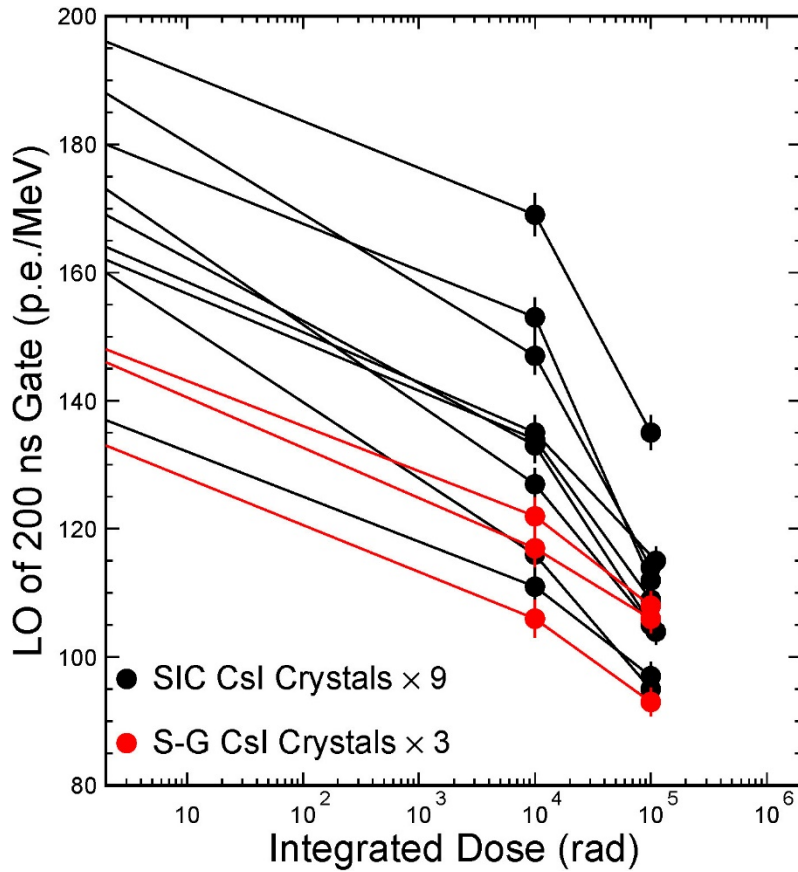
Crystal ID	Dose	L.O. (p.e./MeV)	E.R. (%)	F/T (%)	LRU (%)
SIC-C0002	Before IR	164	34	91	2.2
	10 krad	<b>135 (82%)</b>	35	90	0.83
	110 krad	115 (70%)	36	92	1.9
SIC-C0012	Before IR	169	33	89	2.7
	10 krad	<b>133 (79%)</b>	35	89	1.2
	110 krad	104 (62%)	37	90	1.5
SIC-C0202	Before IR	180	32	82	2.9
	10 krad	153 (85%)	33	86	1.0
	100 krad	112 (62%)	36	90	2.8
SIC-C0276	Before IR	196	32	86	2.9
	10 krad	169 (87%)	33	86	1.1
	100 krad	135 (69%)	35	85	1.5
SIC-C0326	Before IR	188	32	85	1.4
	10 krad	<b>147 (78%)</b>	34	85	1.7
	100 krad	114 (61%)	36	86	2.6
SIC-C0351	Before IR	173	33	90	2.2
	10 krad	<b>127 (73%)</b>	35	88	2.1
	100 krad	105 (61%)	37	91	3.5
SIC-C0438	Before IR	160	34	95	1.5
	10 krad	<b>116 (73%)</b>	36	92	2.6
	100 krad	95 (60%)	37	93	4.6
SIC-C0667	Before IR	137	35	80	1.4
	10 krad	<b>111 (81%)</b>	36	80	3.6
	100 krad	97 (71%)	37	79	4.9
<b>SIC-C0906</b>	Before IR	162	34	90	2.7
	10 krad	<b>134 (83%)</b>	35	90	5.0
	100 krad	109 (67%)	36	89	4.9
Average (RMS)	Before IR	<b>170 (10%)</b>	<b>33 (1.1)</b>	<b>88 (5.4%)</b>	<b>2.2 (0.64)</b>
	10 krad	<b>136 (13%)</b>	<b>35 (1.1)</b>	<b>87 (4.1%)</b>	<b>2.1 (1.40)</b>
	100 krad	<b>110 (11%)</b>	<b>36 (0.71)</b>	<b>88 (4.9%)</b>	<b>3.1 (1.40)</b>

# Summary: Three S-G CsI Crystals

Crystal ID	Dose	L.O. (p.e./MeV)	E.R. (%)	F/T (%)	LRU (%)
SG-C0770	Before IR	133	35	91	0.8
	10 krad	<b>106 (80%)</b>	36	92	1.3
	100 krad	93 (70%)	37	90	2.8
SG-C0950	Before IR	148	31	96	2.0
	10 krad	<b>122 (82%)</b>	34	97	3.0
	100 krad	108 (73%)	36	96	2.7
SG-C1063	Before IR	146	31	98	1.1
	10 krad	<b>117 (80%)</b>	34	96	2.4
	100 krad	106 (73%)	36	97	3.0
Average (RMS)	Before IR	<b>142 (8.1%)</b>	<b>32 (3.3)</b>	<b>95 (5.4%)</b>	<b>1.3 (0.88)</b>
	10 krad	<b>115 (10%)</b>	<b>35 (1.6)</b>	<b>95 (3.9%)</b>	<b>2.2 (1.22)</b>
	100 krad	<b>102 (11%)</b>	<b>36 (0.8)</b>	<b>94 (5.7%)</b>	<b>2.8 (0.22)</b>

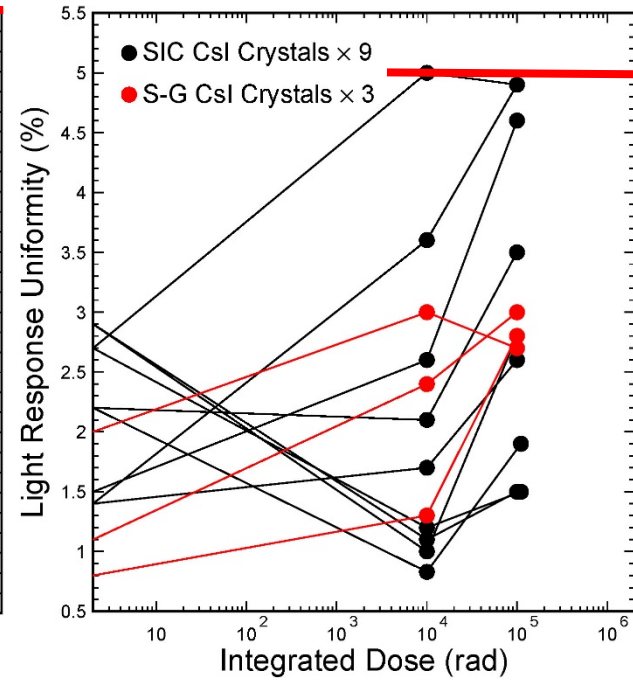
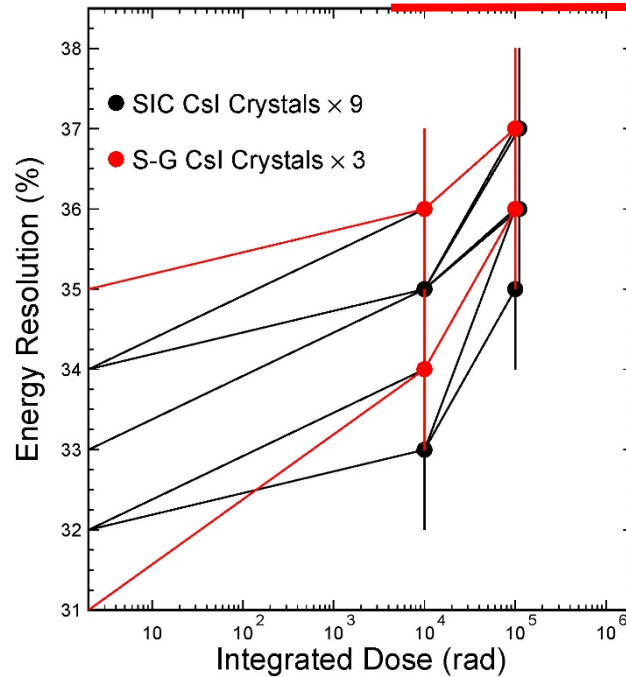
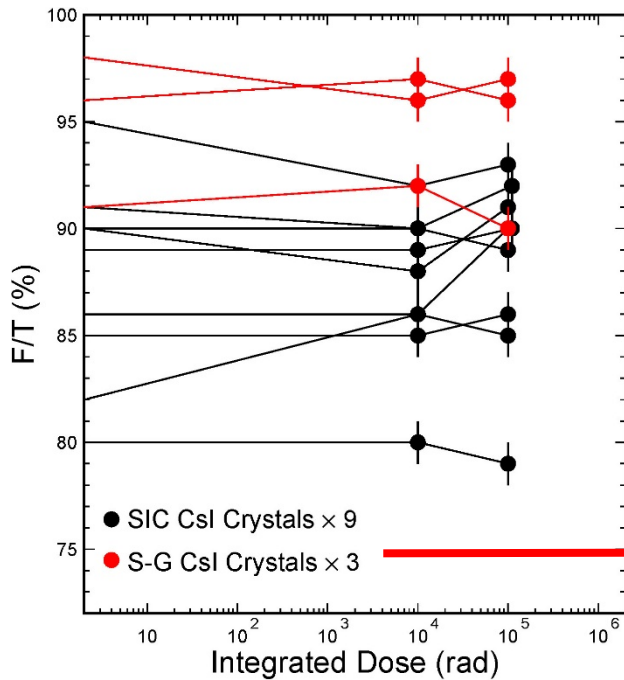
# Light Output vs Integrated Dose

All, except three, show  $> 100$  p.e./MeV after 100 krad  
All meet Mu2e RH spec:  $> 60\%$  after 100 krad



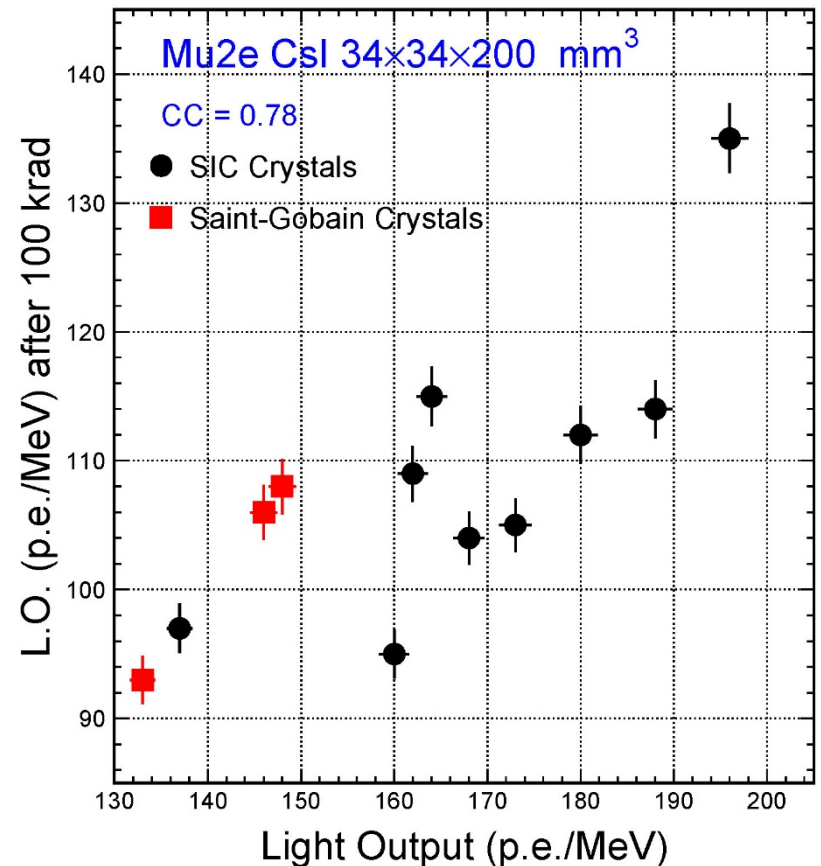
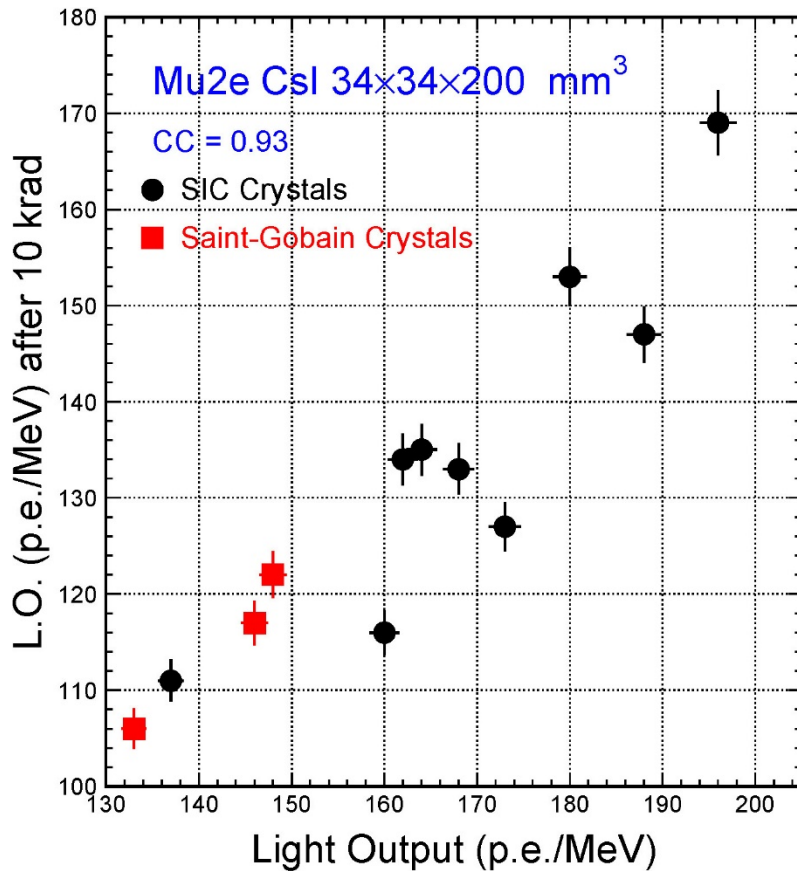
# F/T, Resolution and LRU vs Integrated Dose

All meet Mu2e spec in F/T, resolution and uniformity

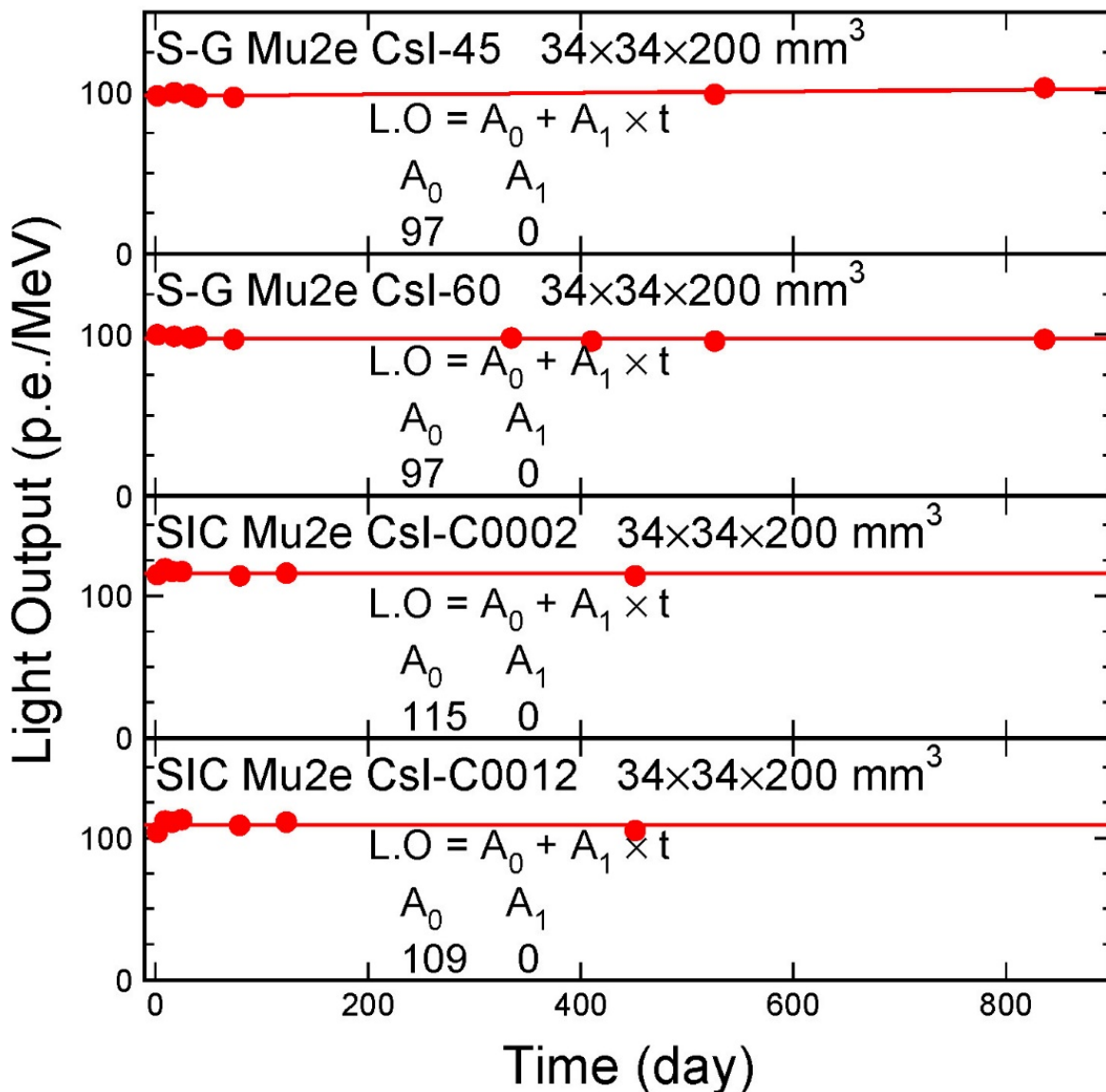


# Correlations: $LO_{\text{before}}$ vs $LO_{\text{after}}$

Correlations observed, indicating consistency in RH



# LO Recovery: S-G and SIC Csl



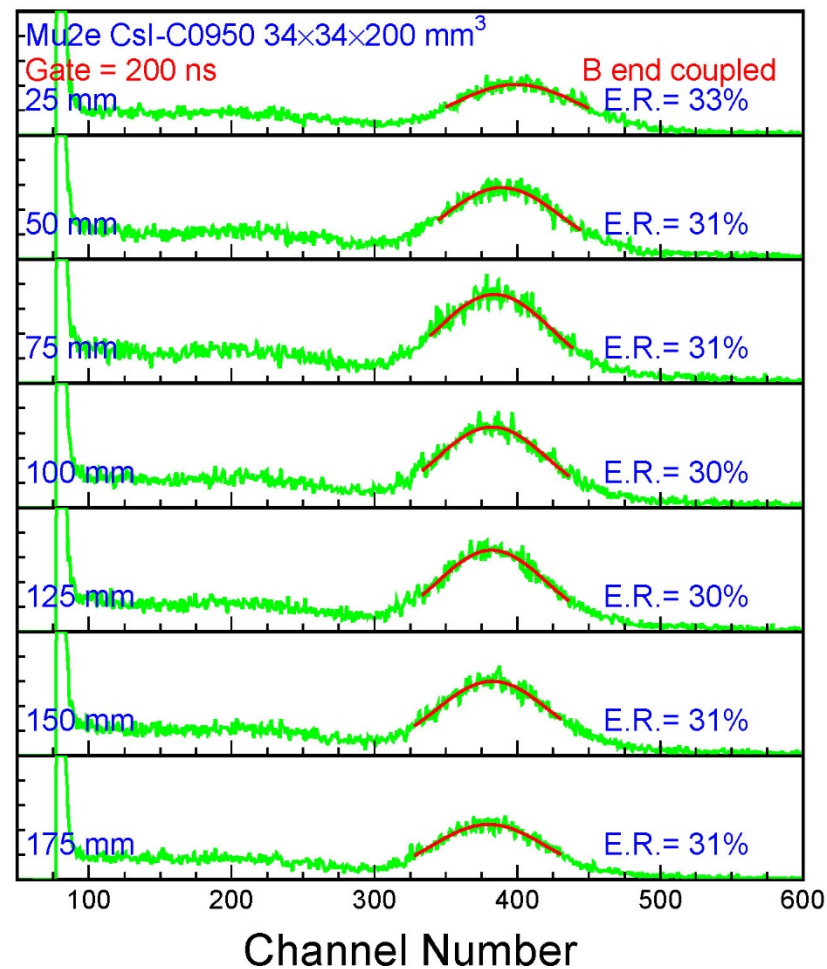
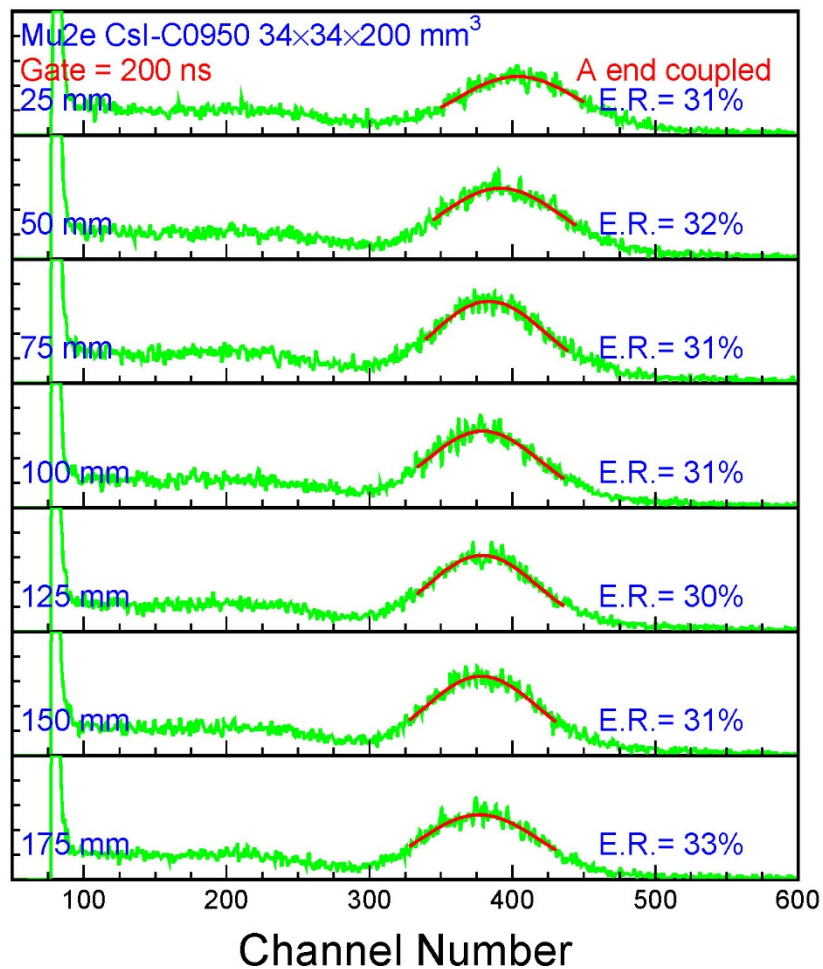
No recovery observed up to 836 & 451 days for two CsI crystals each from S-G and SIC, respectively, indicating a stable calorimeter



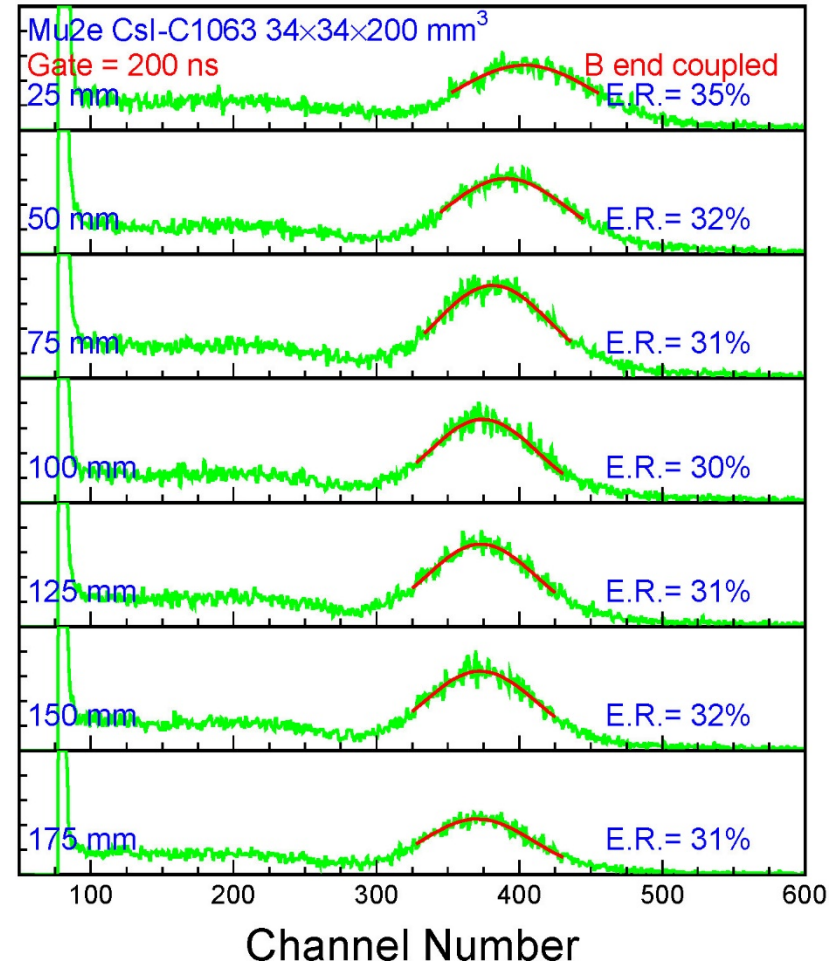
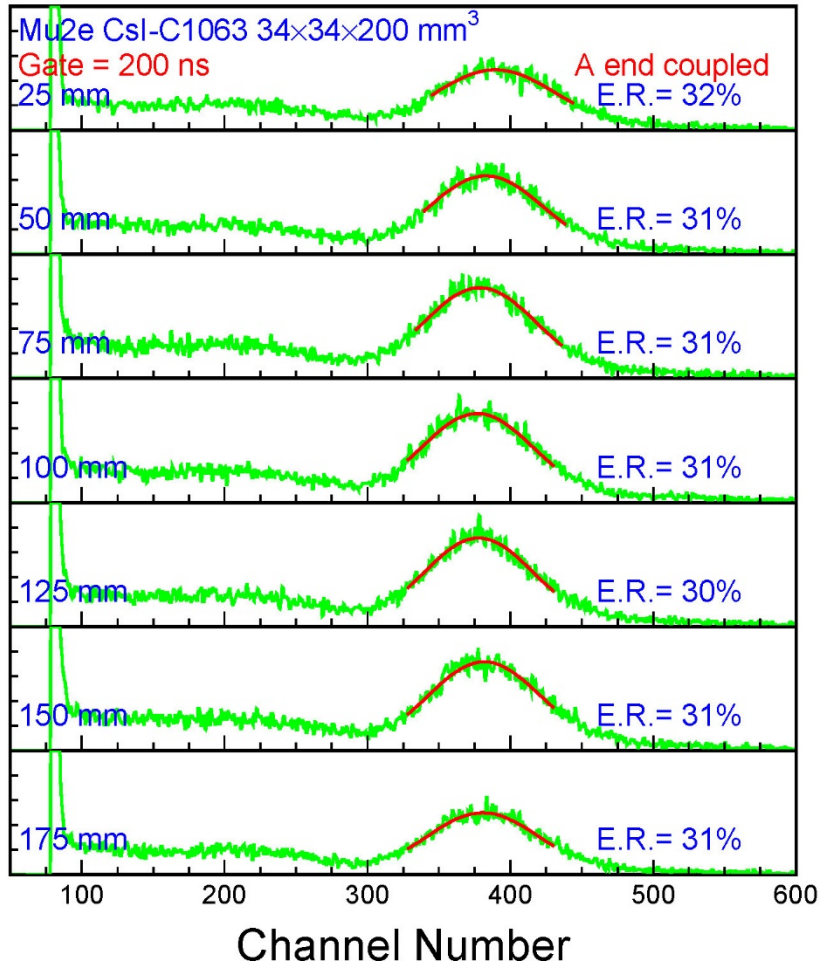
# Summary of Four CsI Samples

Crystal ID	Coupling end	IR dose	L.O. (p.e./MeV)	E.R. (%)	F/T (%)	LRU (%)	Date
C0770 (S-G)	B	Before IR	133	35	91	0.8	2/26/19
		10 krad	106 (80%)	36	92	1.3	3/4/19
		100 krad	93 (70%)	37	90	2.8	3/8/19
C0906 (SIC)	B	Before IR	162	34	90	2.7	2/26/19
		10 krad	134 (83%)	35	90	5.0	3/4/19
		100 krad	109 (67%)	36	89	4.9	3/8/19
C0950 (S-G)	B	Before IR	148	31	96	2.0	4/22/19
		10 krad	122 (82%)	34	97	3.0	4/26/19
		100 krad	108 (73%)	36	96	2.7	4/29/19
C1063 (S-G)	A	Before IR	146	31	98	1.1	4/22/19
		10 krad	117 (80%)	34	96	2.4	4/26/19
		100 krad	106 (73%)	36	97	3.0	4/29/19

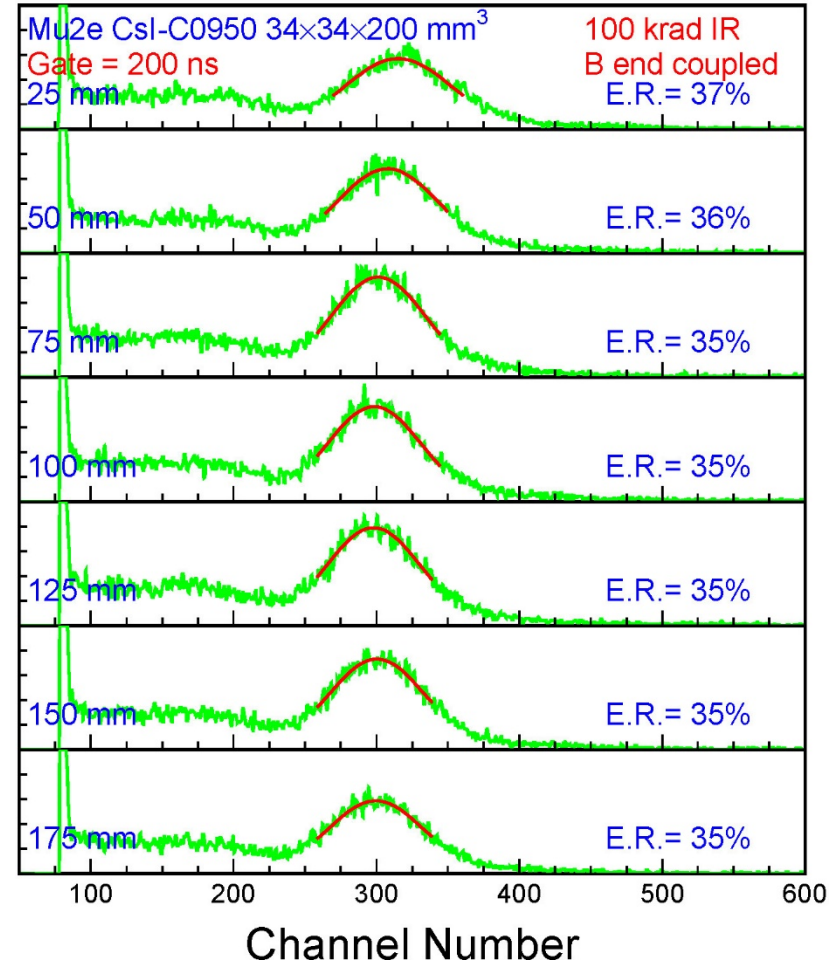
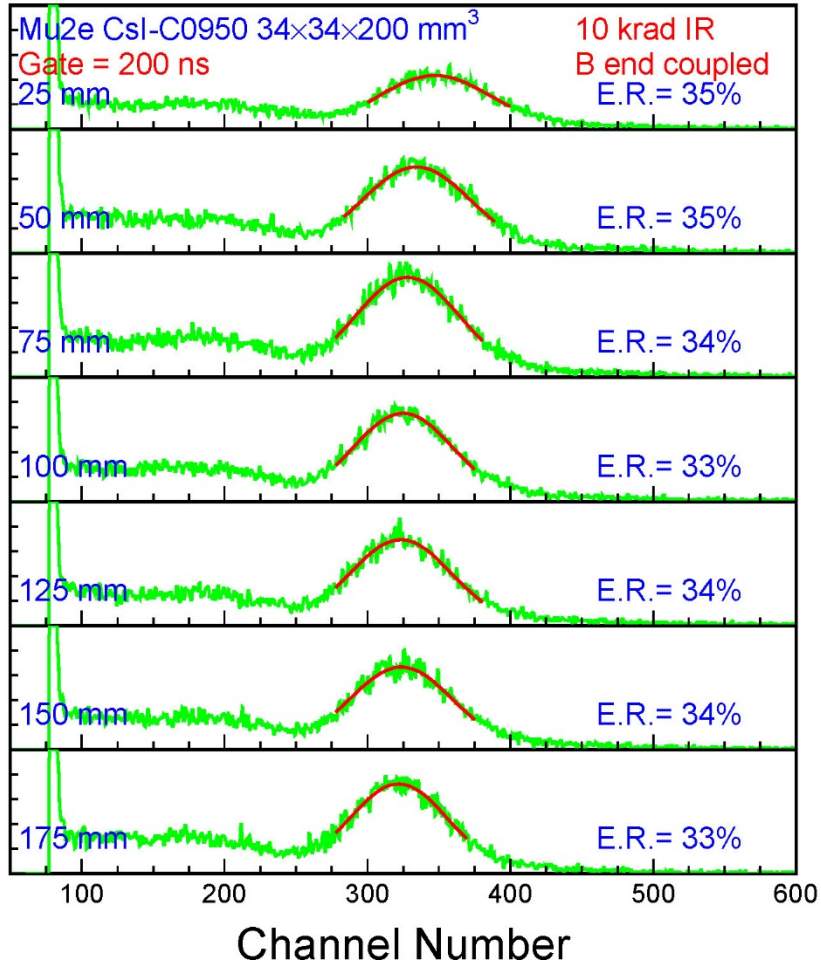
# Mu2e Pure CsI Crystal C0950 (before IR)



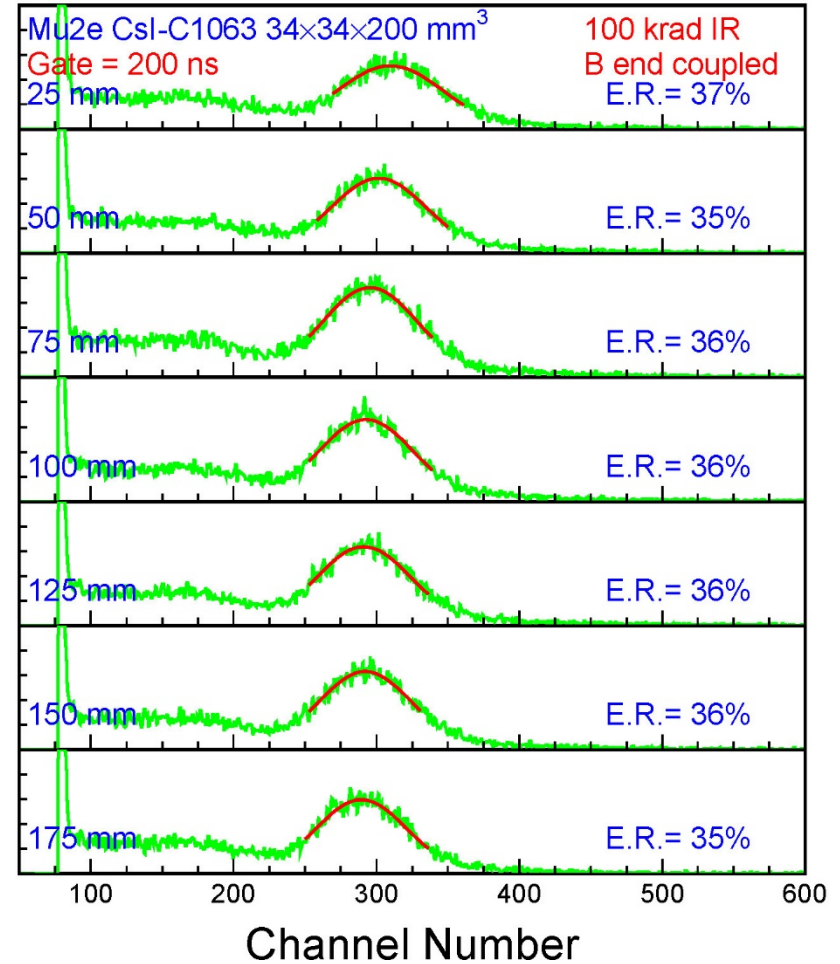
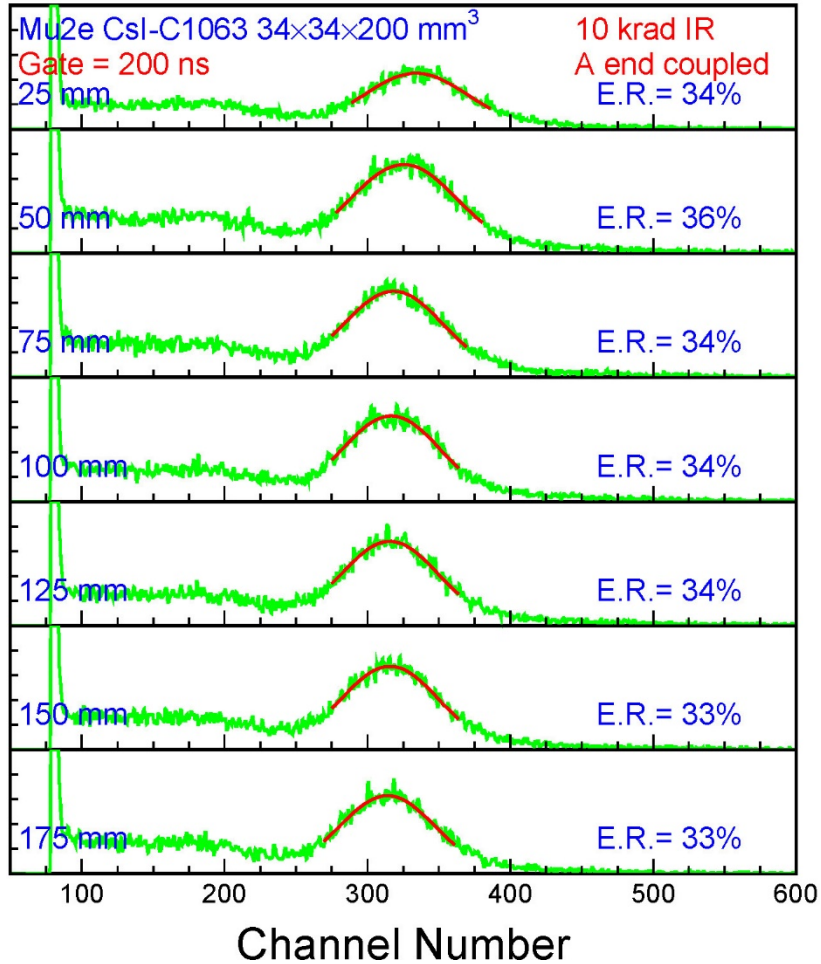
# Mu2e Pure CsI Crystal C1063 (before IR)



# Mu2e Pure CsI Crystal C0950 (after IR)



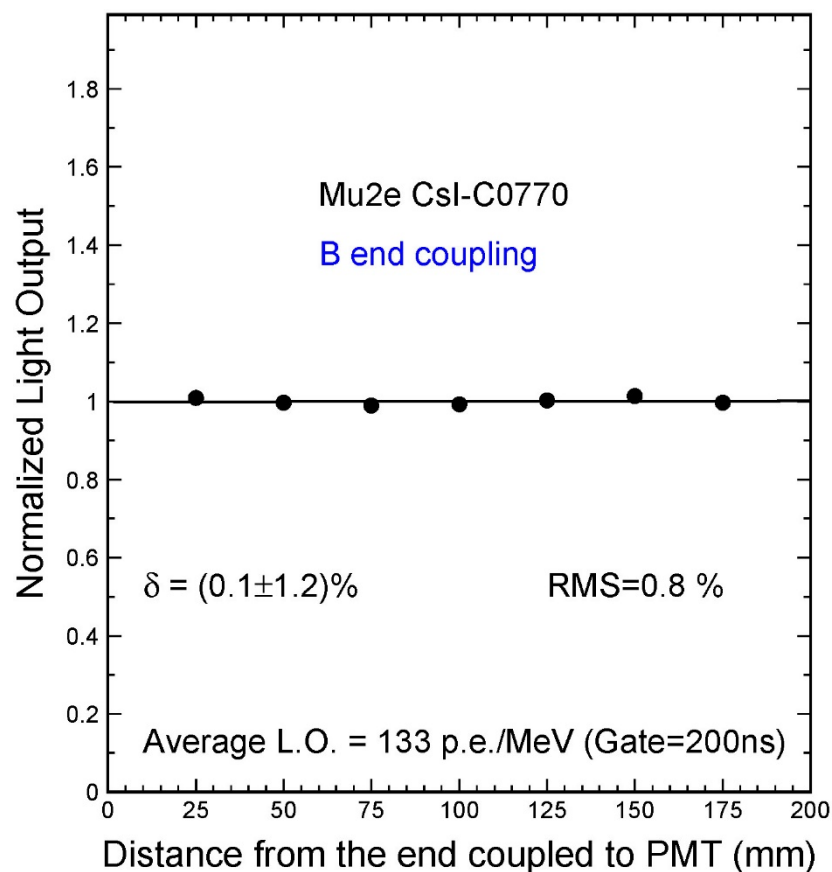
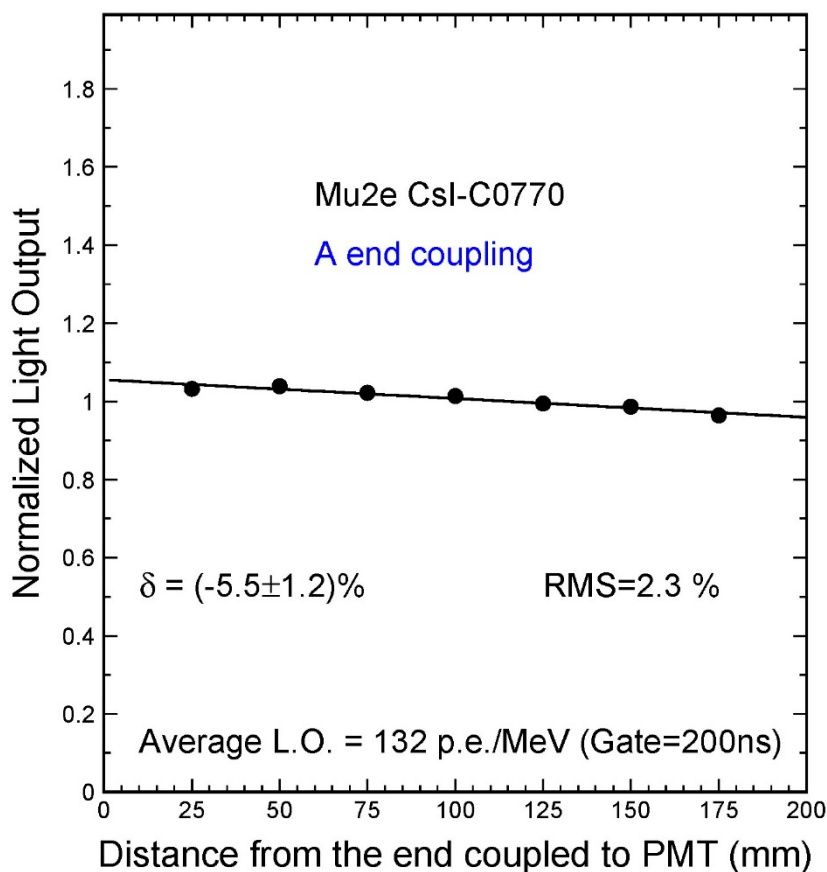
# Mu2e Pure CsI Crystal C1063 (after IR)



# Mu2e Pure CsI Crystal C0770 (Before IR)

Crystal ID	Coupling end	L.O. (p.e./MeV)	E.R. (%)	F/T (%)	LRU (%)
C0770	A	132	35	90	2.3
	<b>B</b>	<b>133</b>	<b>35</b>	<b>91</b>	<b>0.8</b>

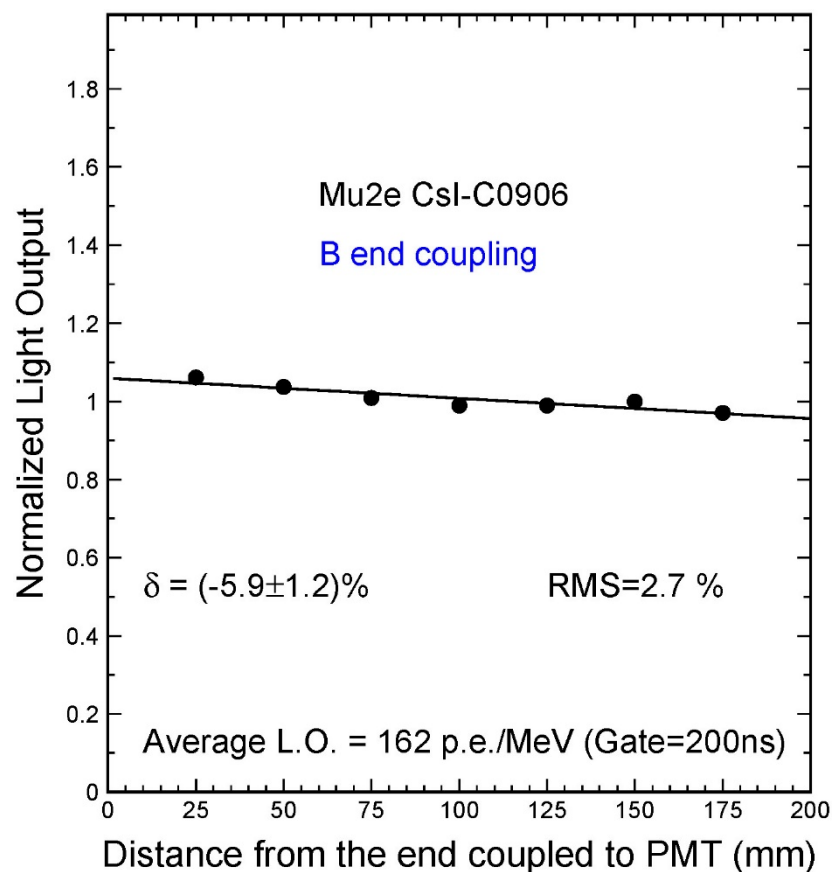
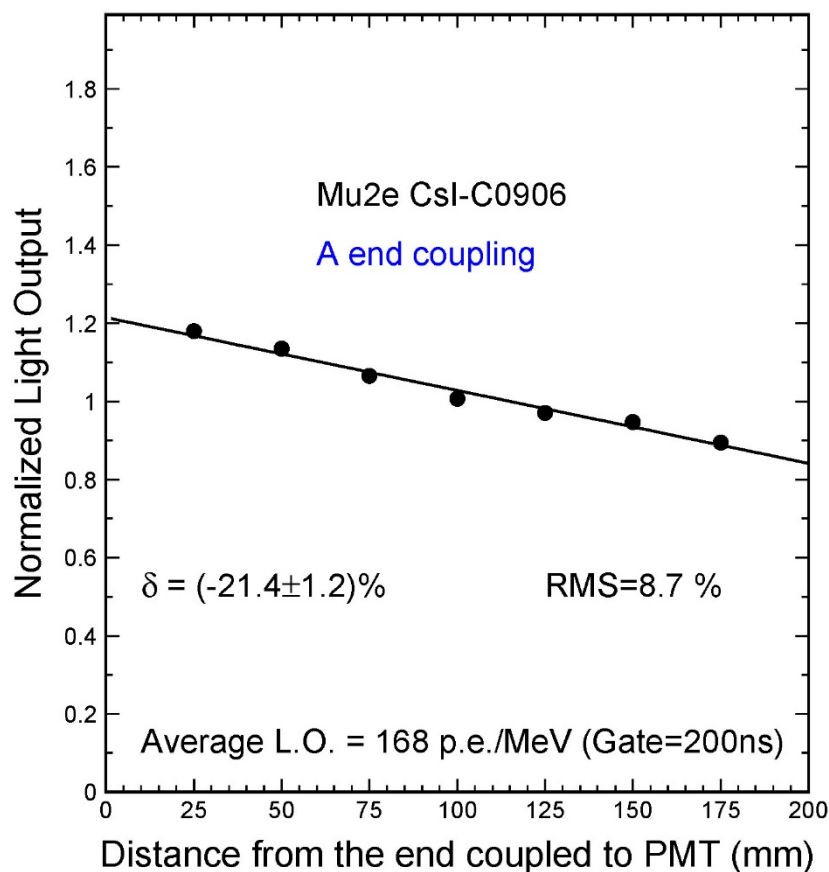
B end chosen



# Mu2e Pure CsI Crystal C0906 (Before IR)

Crystal ID	Coupling end	L.O. (p.e./MeV)	E.R. (%)	F/T (%)	LRU (%)
C0906	A	168	34	91	8.7
	<b>B</b>	<b>162</b>	<b>34</b>	<b>90</b>	<b>2.7</b>

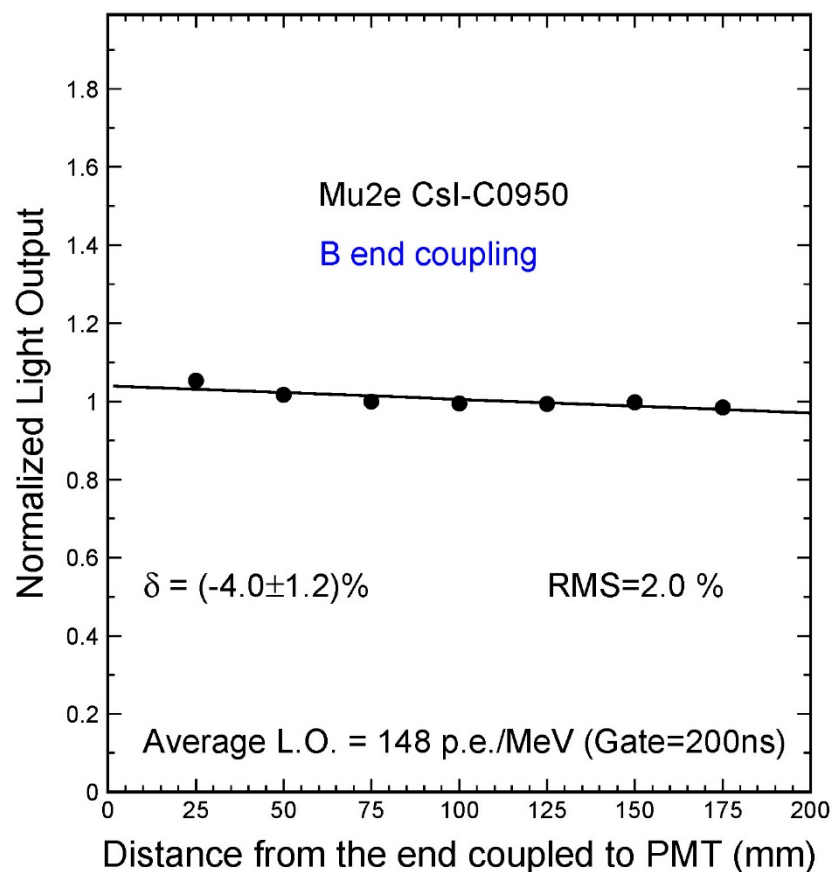
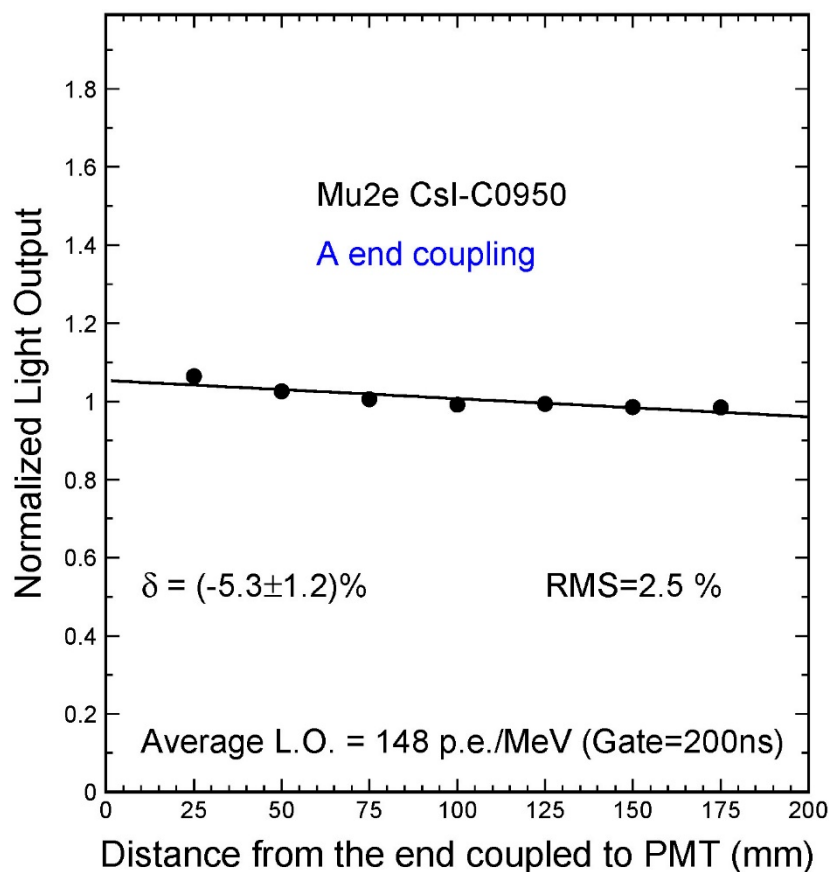
B end chosen



# Mu2e Pure Csl Crystal C0950 (Before IR)

Crystal ID	Coupling end	L.O. (p.e./MeV)	E.R. (%)	F/T (%)	LRU (%)
C0950	A	148	31	96	2.5
	<b>B</b>	<b>148</b>	<b>31</b>	<b>96</b>	<b>2.0</b>

B end chosen

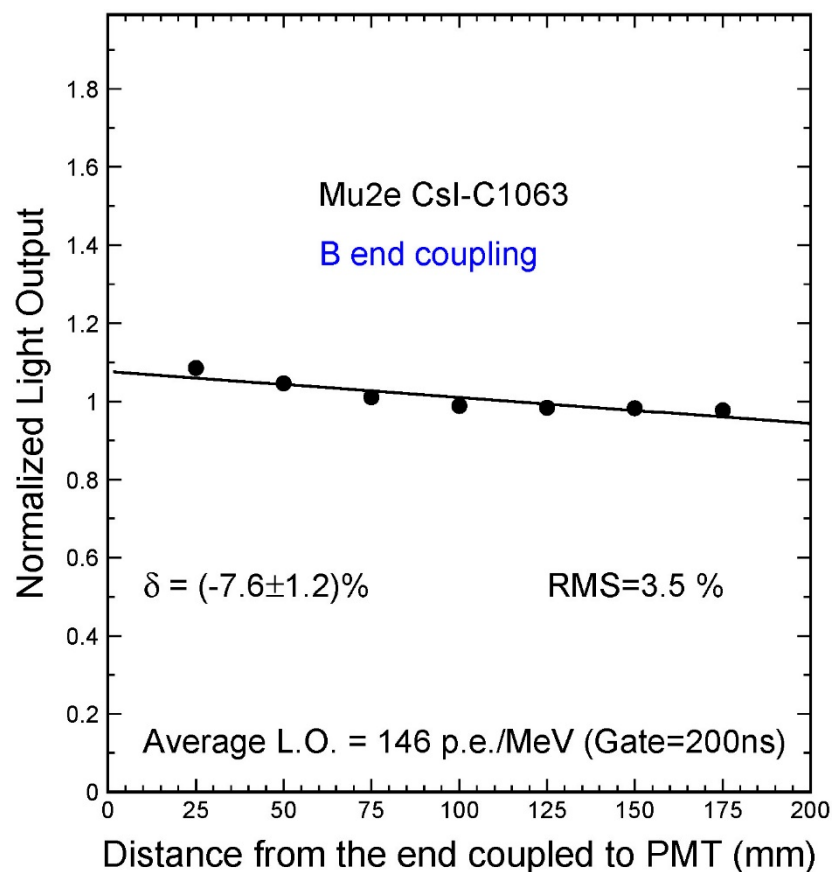
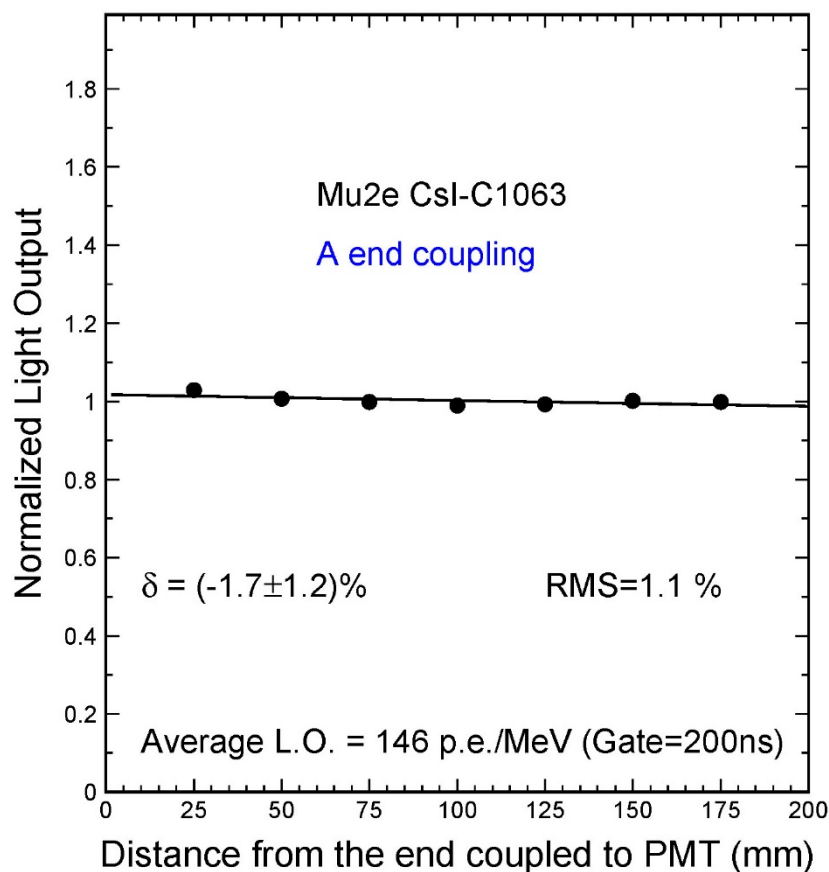




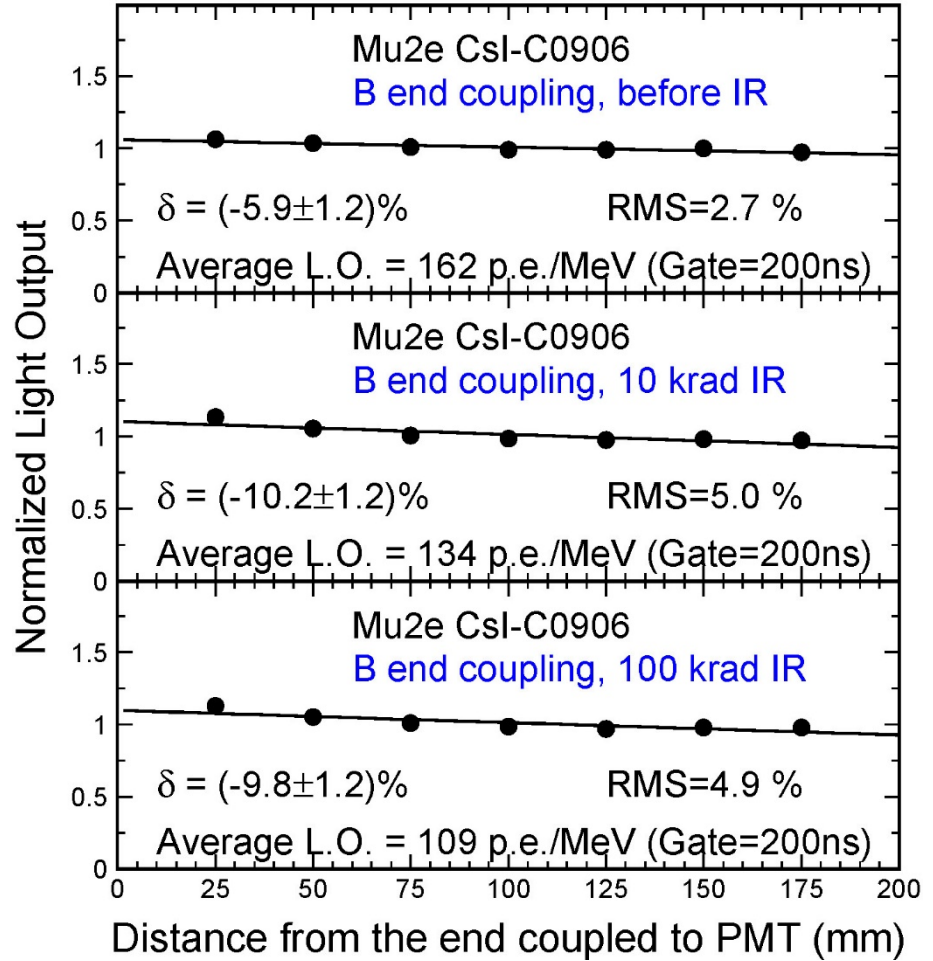
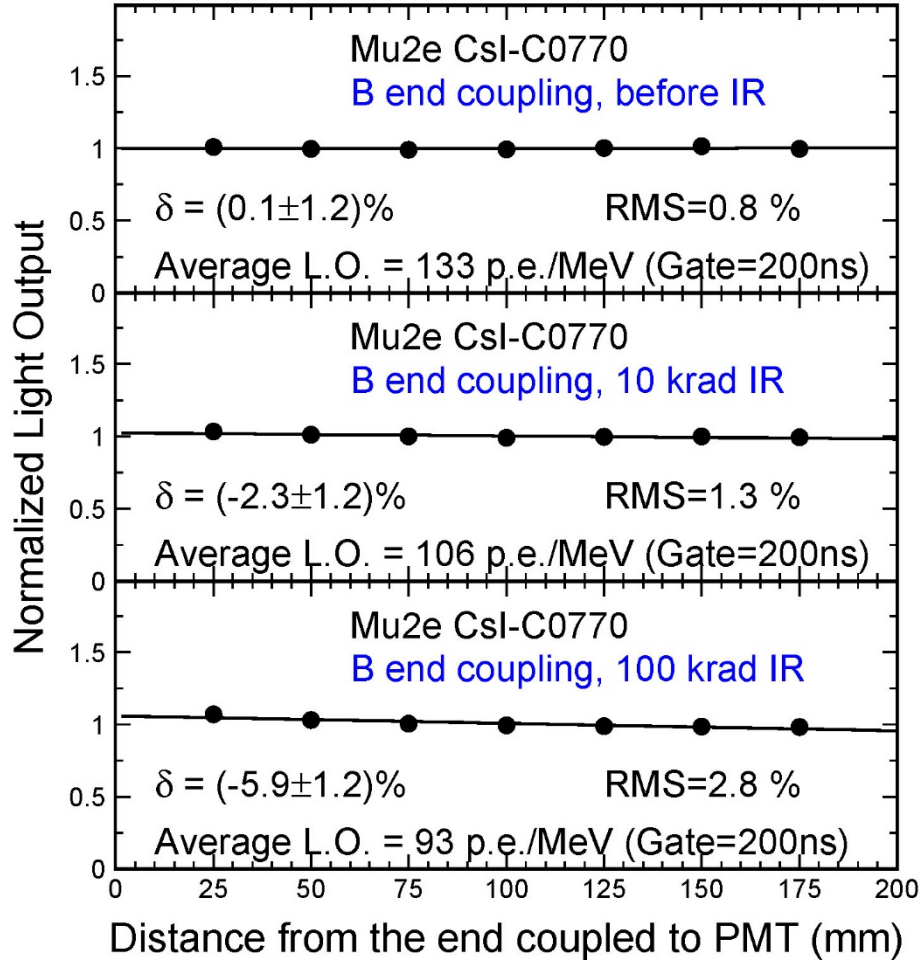
# Mu2e Pure CsI Crystal C1063 (Before IR)

Crystal ID	Coupling end	L.O. (p.e./MeV)	E.R. (%)	F/T (%)	LRU (%)
C1063	A	146	31	98	1.1
	B	146	32	95	3.5

A end chosen



# LO & LRU after $\gamma$ -ray IR of 10 and 100 krad



# LO & LRU after $\gamma$ -ray IR of 10 and 100 krad

