Slow Scintillation Component and Radiation Induced Photocurrent and Readout Noise in Pure CsI Crystals for the Mu2e Experiment

Fan Yang, Liyuan Zhang and Ren-Yuan Zhu

Crystal Laboratory, HEP, California Institute of Technology, Pasadena, CA 91125, USA

1. Introduction

Because of its fast decay time and low cost, pure CsI crystals are used in HEP experiments for fast crystal calorimetry, especially in the intensity frontier. CsI crystal samples from three vendors were characterized for the Mu2e experiment at Fermilab with data used to define crystal specifications. In addition to the fast scintillation component peaked at 310 nm, a slow scintillation component peak at 450 nm was found, which may be reduced spectroscopically by inserting an optical filter. It was also found that the slow scintillation component and the radiation induced photocurrent in CsI crystals are highly correlated, which are believed to be defects and/or impurity related.

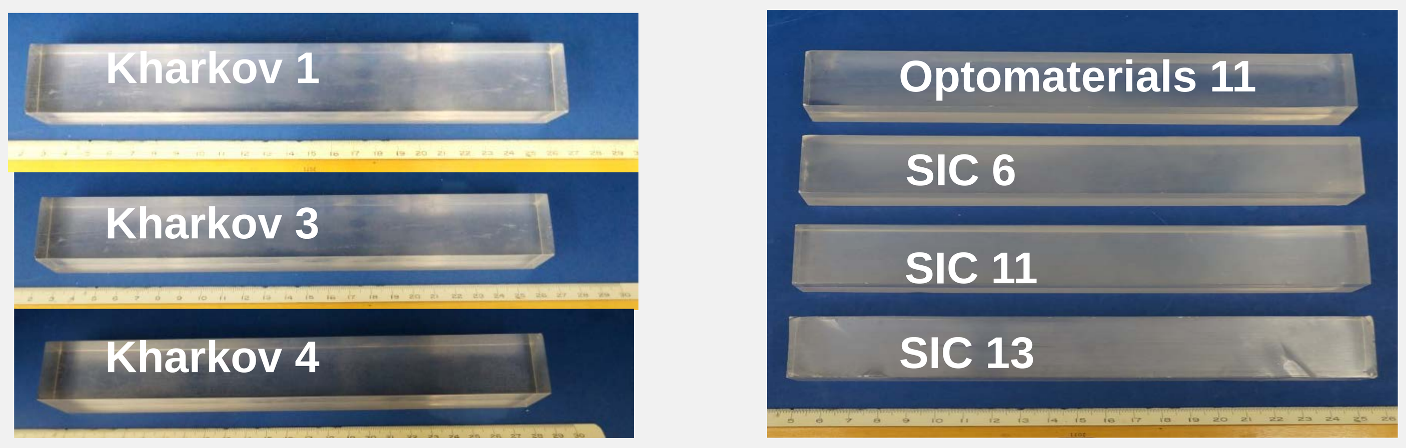

Fig. 1 20 cm Long CsI samples from Kharkov, Optomaterials and SICCAS

2. Initial Performances

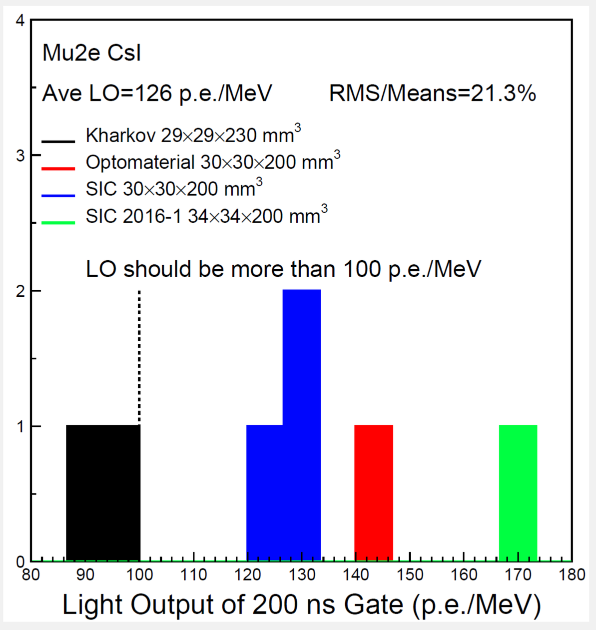

Fig. 2 Light Output with 200 ns gate

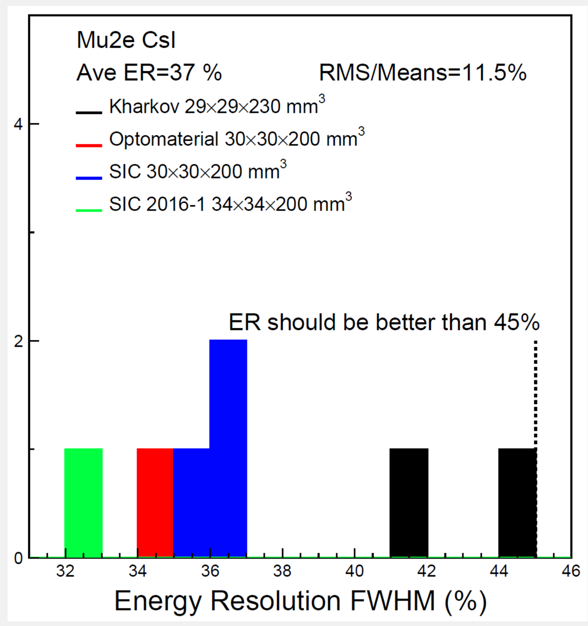

Fig.3 FWHM energy resolution of Cs-137 peak in 200 ns gate

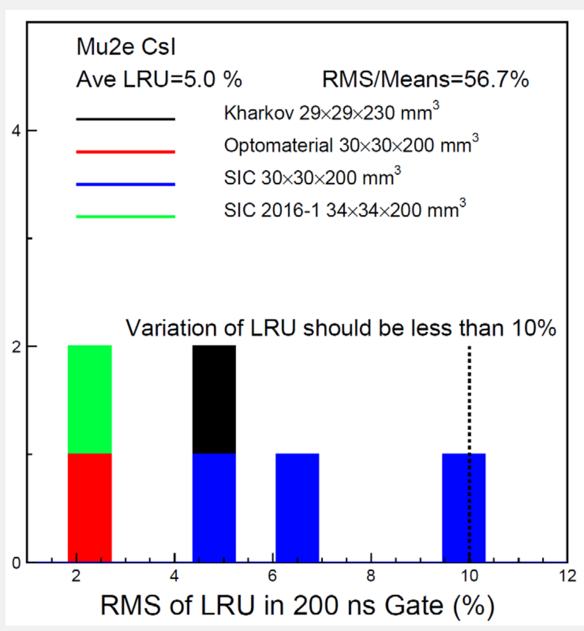

Fig. 4 RMS of light response uniformity with 200 ns gate

Fig. 2, 3 and 4 summarize the light output, FWHM resolution for Na^{22} peak and rms of the light response respectively. Also shown in the figures are the Mu2e specifications defined based upon Mu2e requirements.

3. Slow Scintillation Component

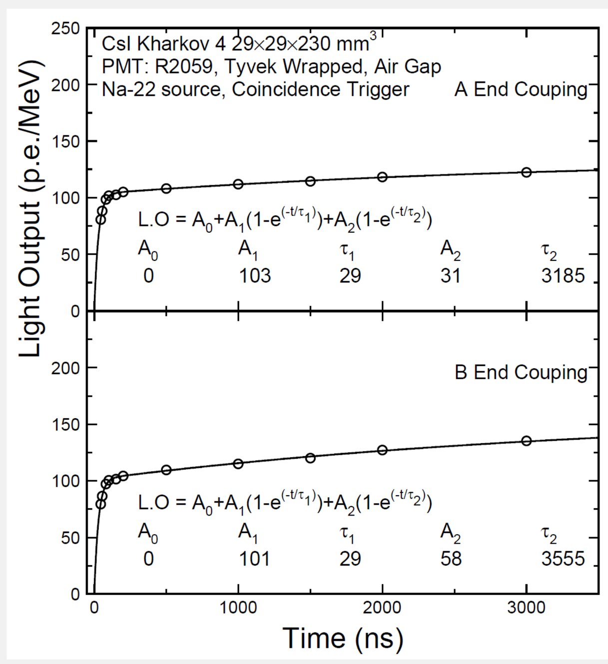

Fig. 5 Decay Kinetics of Kharkov 4 measured at the point closest to PMT for one of two ends coupled to PMT.

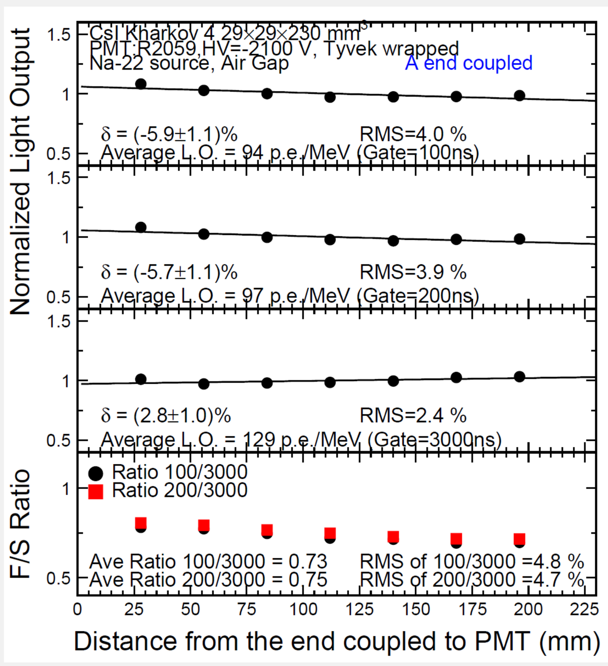

Fig. 6 Light response uniformity of seven points along the crystal with 100, 200 and 3000 ns gate.

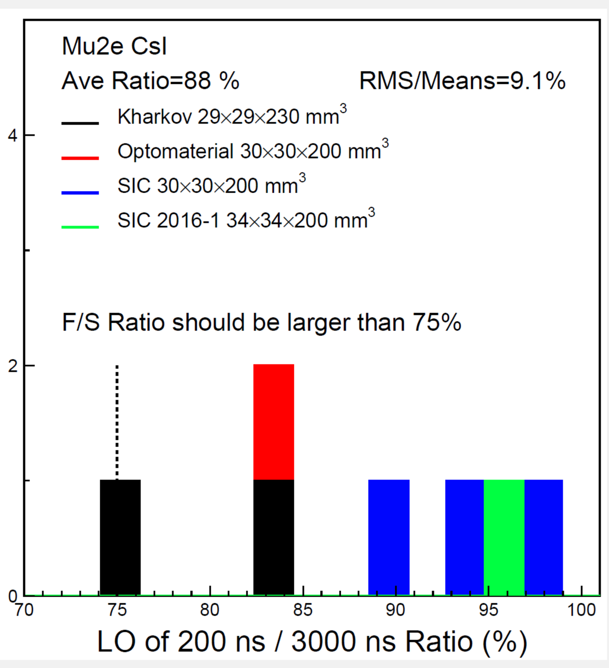

Fig. 7 Summary of the F/T radio (200 ns vs. 3000 ns) for all samples.

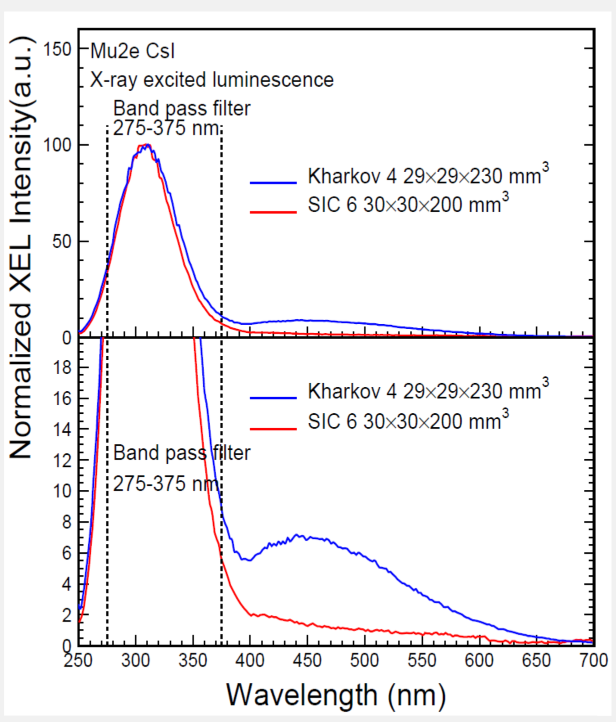

Fig. 8 XEL spectra are shown for Kharkov 4 and SIC 6 with very different levels of slow scintillation component

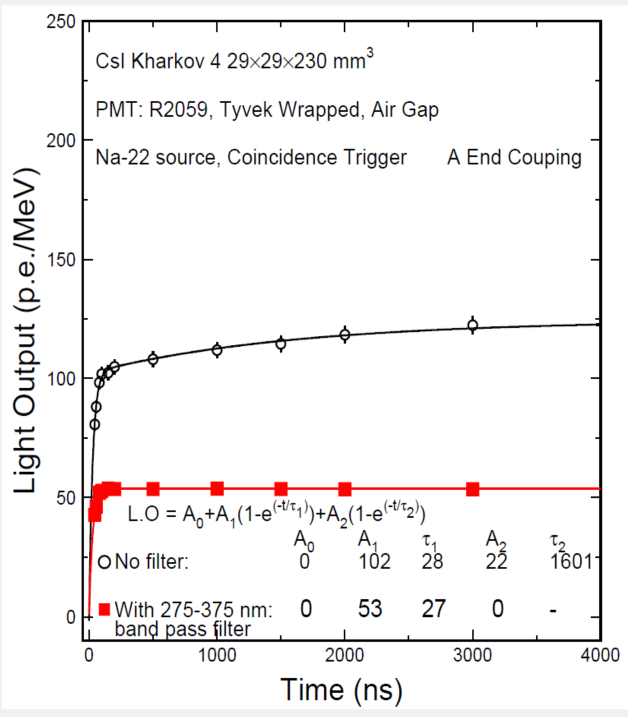

Fig. 9 A comparison of decay kinetics measured with and without filter between sample and PMT for Kharkov 4

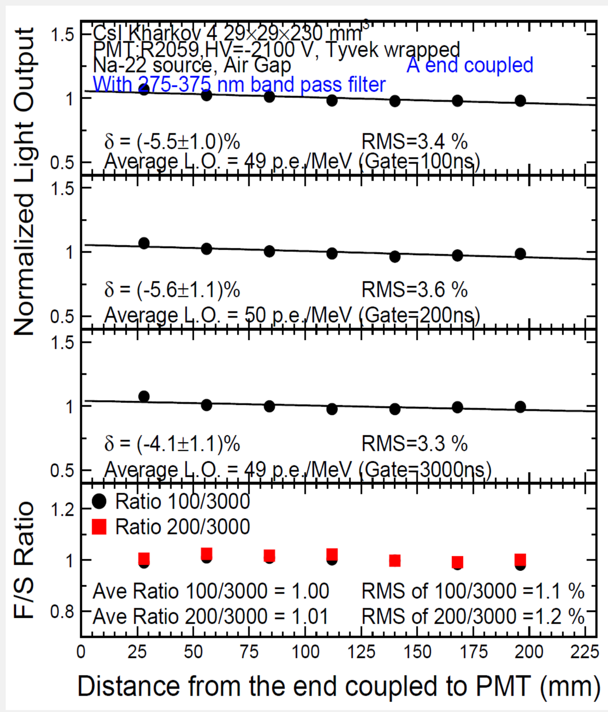

Fig. 10 The same as Fig. 6 for Kharkov 4 with a filter inserted between the sample and PMT

A sample-dependent slow scintillation component with decay time of a few thousands ns was observed (Fig. 5, 6 and 7). Fig. 8 shows an emission peak at 450 nm in X-ray excited luminescence (XEL) with intensity related to the slow scintillation component. Inserting a FGUV-11 filter between the sample and PMT eliminated the slow scintillation component (Fig. 9 and 10), confirming that the slow scintillation component is peaked at 450 nm.

4. Radiation Induced Photocurrent and Readout Noise

F is defined as radiation induced photoelectron numbers per second, determined by using the measured anode current in the PMT.

$$F = \frac{\frac{Photocurrent}{Charge_{electron} \times Gain_{PMT}}}{Dose\ rate_{\gamma-ray}\ or\ Flux_{neutron}}$$

The energy equivalent noise (σ) is derived as the standard deviation of photoelectron number (Q) in the readout gate: $\sigma = \frac{\sqrt{Q}}{LO}$ MeV

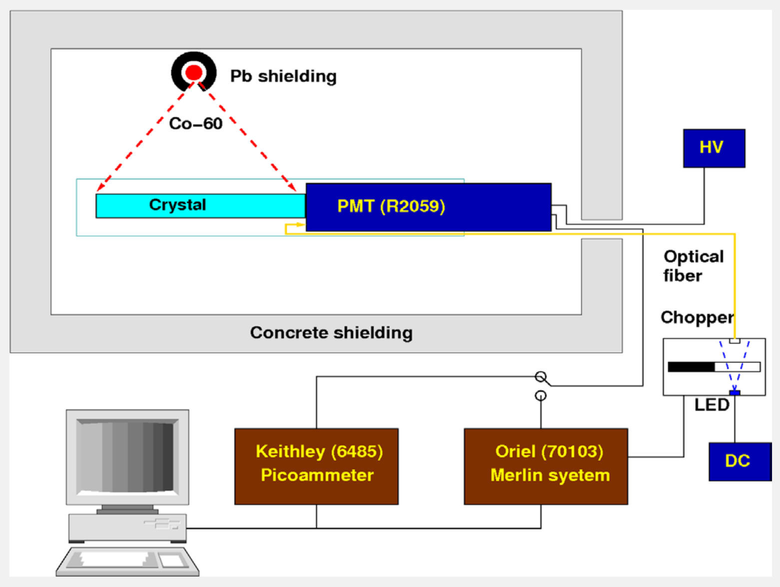

Fig. 11 ɣ-ray induced photocurrent

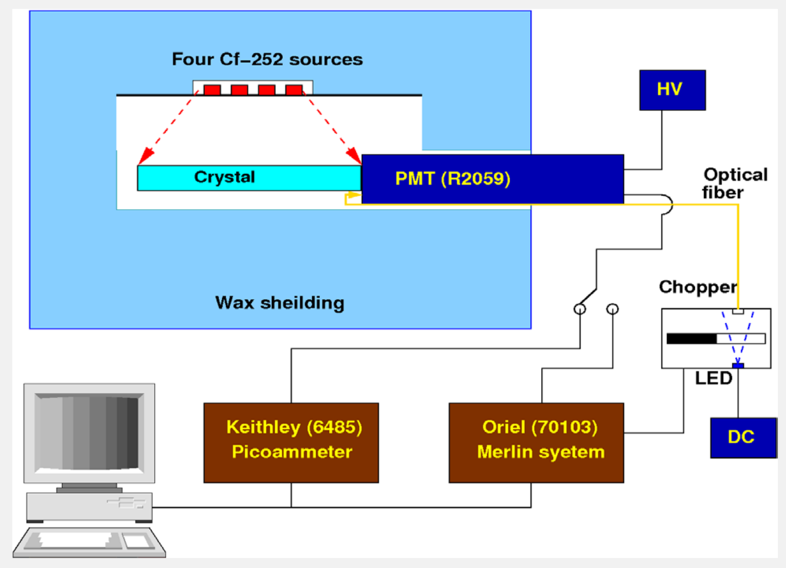

Fig. 12 Neutron induced photocurrent

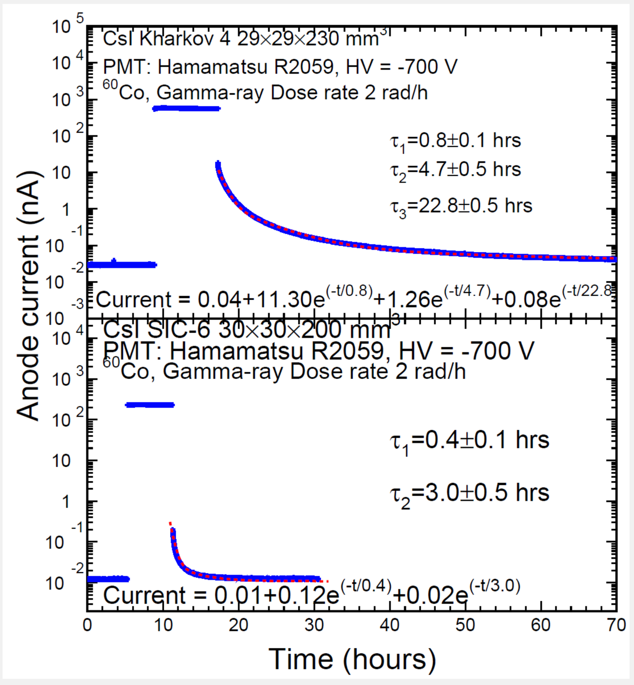

Fig. 13 History of photocurrent measured before, during and after ɣ-ray irradiation

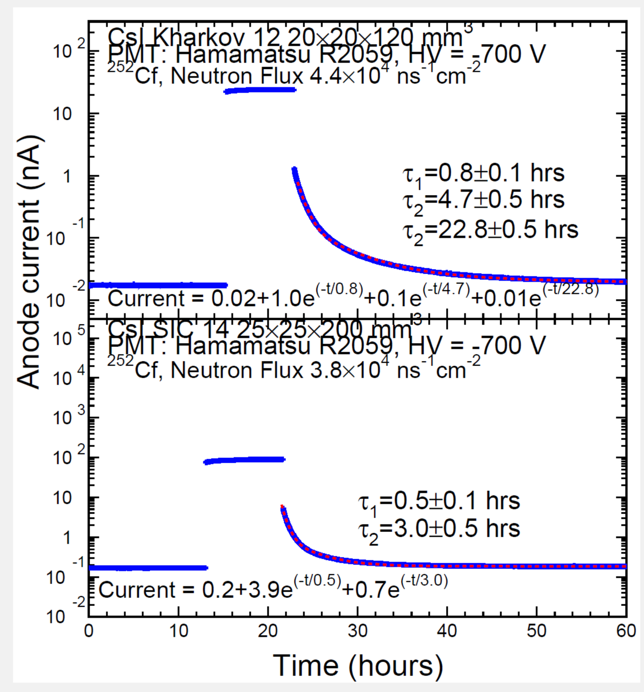

Fig. 14 History of photocurrent measured before, during and after neutron irradiation

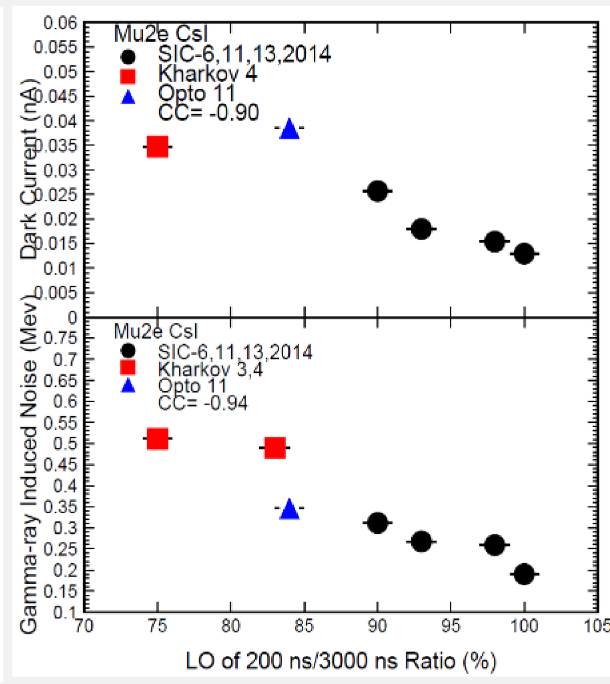

Fig. 15 Correlations of the dark current and the ɣ-ray induced noise versus the F/T ratio defined in Fig. 7

Fig. 11 and 12 show respectively setups used for ɣ-ray and neutron induced photocurrent measurements. Fig. 13 and 14 show typical photocurrent histories respectively. Table I summarizes result of six CsI samples for the dose rate and neutron flux expected *in situ* by Mu2e. Fig. 15 shows that the dark current and the ɣ-ray induced readout noise are highly correlated to the F/T ratio defined in Fig. 7.

Table I Volume Normalized ɣ-ray Induced Readout Noise for six CsI Samples

Sample	Dimensions (cm^3)	LO of 200 ns Gate (p.e./MeV)	Dark Current (nA)*	Photo current @ 2 rad/h (nA)*	F (p.e./s/rad/hr)*	σ (MeV)*
Kharkov 4	2.9x2.9x23	96	0.035	679	6.68E+09	5.11E-01
Optomaterials 11	3x3x20	140	0.039	663	6.53E+09	3.46E-01
SIC 6	3x3x20	125	0.015	296	2.91E+09	2.59E-01
SIC 11	3x3x20	128	0.018	330	3.25E+09	2.67E-01
SIC 13	3x3x20	130	0.026	461	4.54E+09	3.11E-01
SIC 2014	2.5x2.5x20	140	0.013	200	1.97E+09	1.90E-01

Volume Normalized Neutron Induced Readout Noise for two CsI Samples

Sample	Dimensions (cm^3)	LO of 200 ns Gate (p.e./MeV)	Dark Current (nA)*	Photo current (nA)*	F (p.e./n/s/cm^2)*	σ (MeV)*
Kharkov 3	2.9x2.9x23	97	1.1	650	2.91E+05	2.6E-01
SIC 2014	2.5x2.5x20	140	0.31	165	8.56E+04	1.0E-01

*** Dark current, photocurrent, F and σ are corrected to the volume 3.4×3.4×20 cm^3.**

5. Summary

- **Pure CsI crystals are chosen by the Mu2e experiment. Its fast emission peaked at 310 nm with 30 ns decay time requires photodetector with UV extended response.**
- **A slow scintillation component is observed in most CsI samples at different levels. Peaked at 450 nm with μs decay time, the slow component may be reduced or eliminated spectroscopically by inserting an optical filter. It is also believed to be defects or impurity related.**
- **ɣ-ray and neutron induced photocurrent in pure CsI crystals were measured, and were used to extract induced readout noise in defined integration gate for the ionization dose rate and neutron flux expected by Mu2e.**
- **Excellent correlations are observed between the dark current and the ɣ-ray induced readout noise versus the F/T ratio (LO in 200 ns/LO in 3000 ns).**

Acknowledgments: This work is supported by the U.S. Department of Energy, Office of High Energy Physics program under Award Number DE-SC0011925.

Contact : zhu@hep.caltech.edu