Radiation Induced Noise of LYSO Crystals from Eight Vendors

Adi Bornheim, Chen Hu, Nan Lu, Maria Spiropulu, Jason Trevor, Liyuan Zhang and Ren-Yuan Zhu

California Institute of Technology

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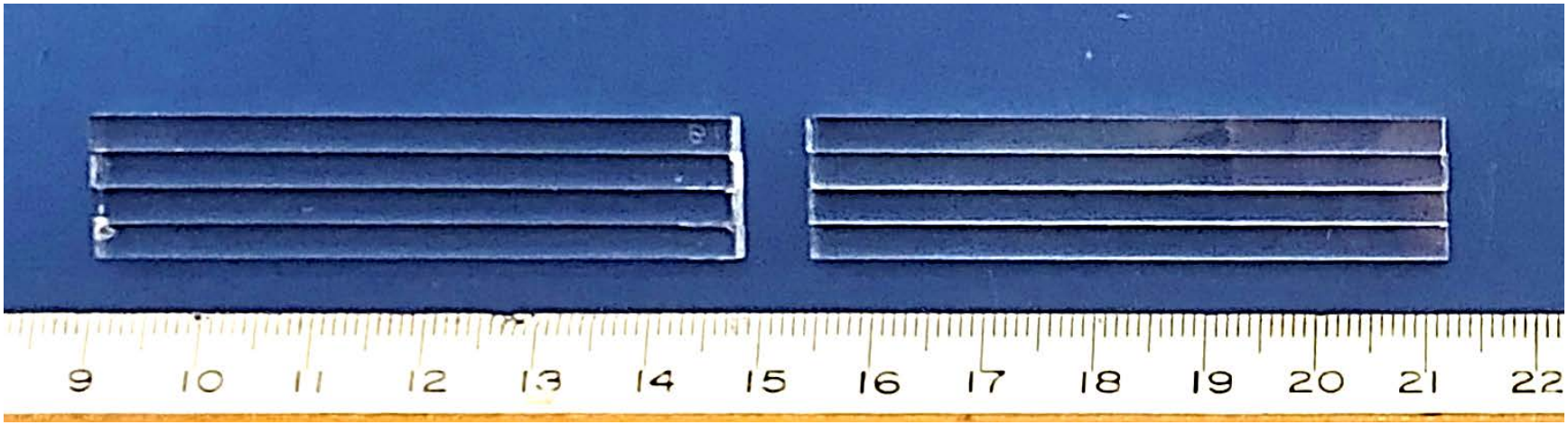
LYSO Bars from Eight Vendors



ID	Dimension (mm^3)	#	Polishing
BTL LYSO bar-1,8	3.12x3.75x57	8	All faces
Received on Dec 4th, 2019. Poor surface quality observed for some samples			

Experiments

- Properties measured at room temperature : LT, PHS, LO, ER, Decay time, CTR, **and RIN:ɣ & RIN:n**

LT/LO/τ/CTR @ 1/20/20

Light output measured with Teflon block wrapping and an air gap coupling to a PMT R1306 with triggers provided by a Na-22 source at the crystal center

ID	EWLT (%)	T% @ 420 nm	200ns E.R. (%)	200ns L.O. (p.e./MeV)	2000ns L.O. (p.e./MeV)	LO(200) /LO(2000)	Decay Time (ns)	τ/LO(200)	Corrected CTR (ps)
1	62.0	78.6	13.9	1100	1134	97.0%	44.5	0.040	43.5
2	63.7	80.2	14.0	1207	1240	97.3%	45.0	0.037	42.3
3	73.3	84.5	13.6	1118	1135	98.5%	41.1	0.037	43.1
4	60.6	76.5	16.4	983	1029	95.5%	46.2	0.047	47.7
5	70.8	81.4	13.7	1141	1160	98.4%	41.3	0.036	43.1
6	65.0	78.0	14.9	1145	1177	97.3%	45.1	0.039	43.5
7	68.9	82.8	14.2	1137	1163	97.8%	42.9	0.038	44.2
8	60.8	75.6	15.6	1057	1076	98.2%	39.0	0.037	42.2
Ave	65.6	79.7	14.5	1111	1139	97.5%	43.1	0.039	43.7
RMS	6.9%	3.6%	6.5%	5.6%	5.3%	0.9%	5.4%	8.5%	3.7%
Systematic Uncertainty	0.5%	0.5%	1.7%	0.7%	1.0%	1.0%	3%	3%	1.4%

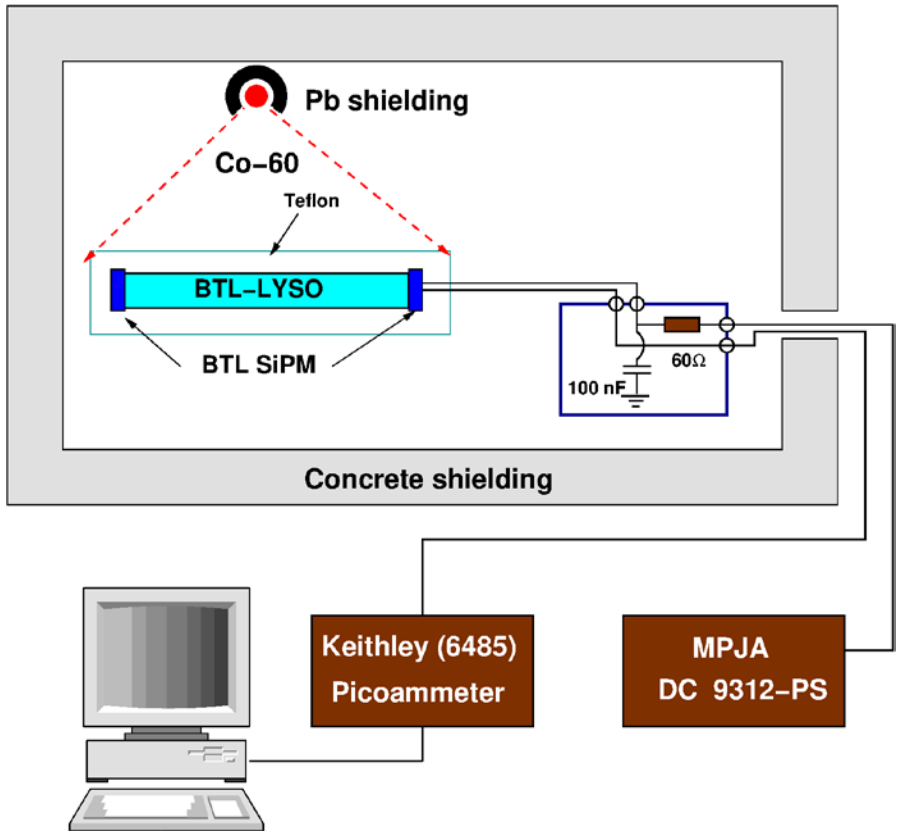
Radiation Expected by CMS BTL

MTD TDR: assuming 5×10^{34} $cm^{-2}s^{-1}$, 3,000 fb^{-1} & a safety factor of 1.5
Radiation spec: λ_{in}<3 m^{-1} for 4.8 Mrad, 2.5 x 10^{13} p/cm^2 & 2.9 x 10^{14} n_{eq}/cm^2

CMS MTD	η	n_{eq}/cm^2	n_{eq} Flux ($cm^{-2}s^{-1}$)	Proton* /cm^2	p Flux ($cm^{-2}s^{-1}$)	Dose (Mrad)	Dose rate (rad/h)
Barrel	0.00	2.48E+14	2.75E+06	2.2E+13	2.4E+05	2.7	108
Barrel	1.15	2.70E+14	3.00E+06	2.4E+13	2.6E+05	3.8	150
Barrel	**1.45**	**2.85E+14**	**3.17E+06**	**2.5E+13**	**2.8E+05**	**4.8**	**192**
Endcap	1.60	2.3E+14	2.50E+06	2.0E+13	2.2E+05	2.9	114
Endcap	2.00	4.5E+14	5.00E+06	3.9E+13	4.4E+05	7.5	300
Endcap	2.50	1.1E+15	1.25E+07	9.9E+13	1.1E+06	25.5	1020
Endcap	3.00	2.4E+15	2.67E+07	2.1E+14	2.3E+06	67.5	2700

RIN:ɣ Photocurrent

LYSO+SiPM @ dose rates of 120, 185, and 250 rad/hr



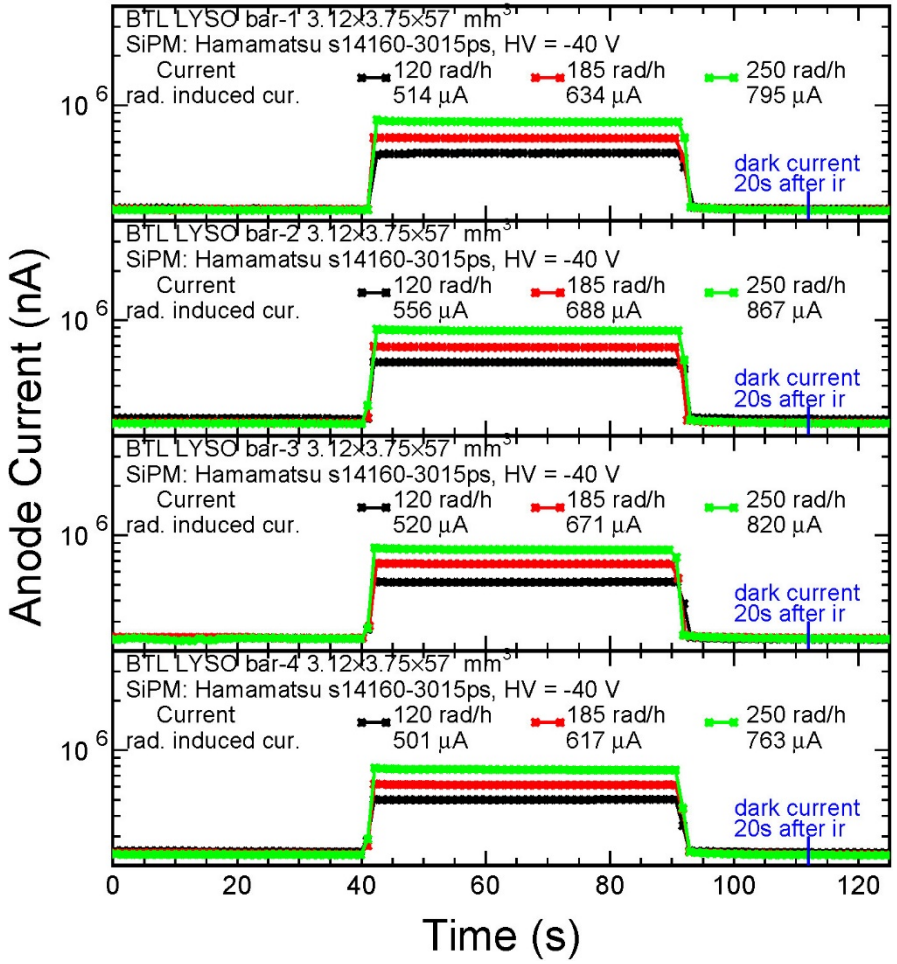
F is defined as the radiation-induced photoelectron number per second, calculated by using the photocurrent in the LYSO+SiPM normalized to the ɣ-ray dose rate.

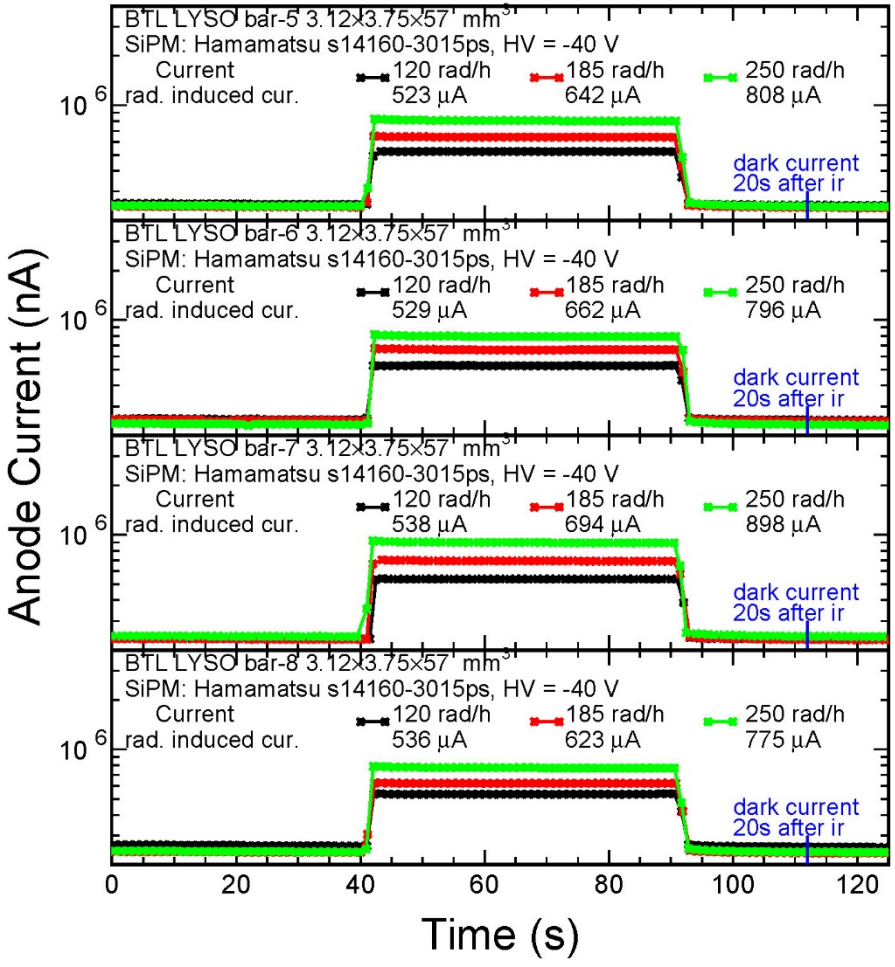
$$F = \frac{Photocurrent}{Charge_{electron} \times Gain_{SiPM}} \Big/ Dose\ rate_{\gamma-ray}\ or\ Flux_{neutron}$$

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

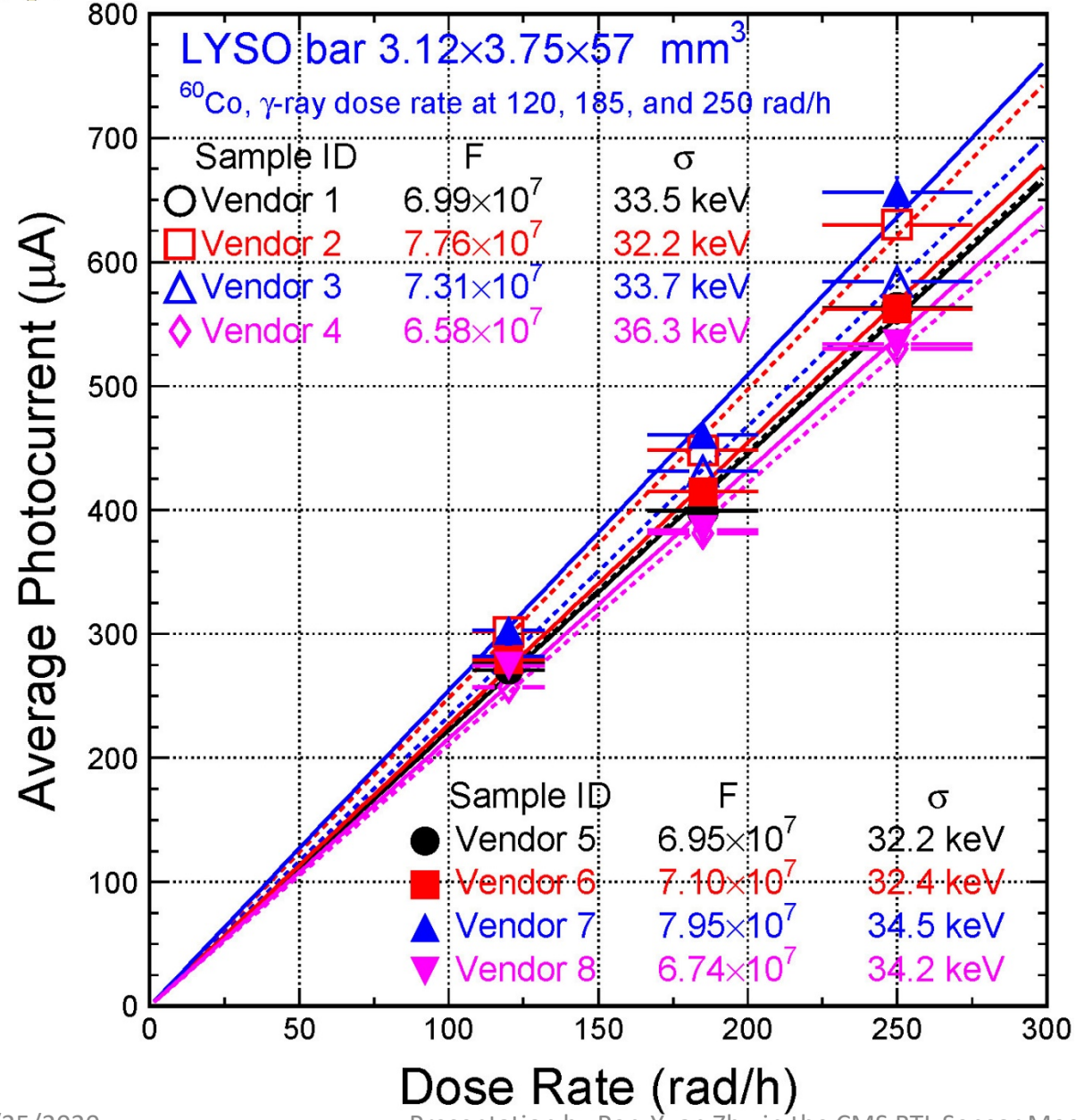
History of Photocurrent

Consist photocurrent and after glow observed





Photocurrent vs. Dose Rate



Good linearity observed for all samples.

F values obtained from linear fit are larger for LYSO with higher LO.

RIN obtained @ 200 rad/h with LO in 200 ns gate.

Gamma-Ray Induced Noise

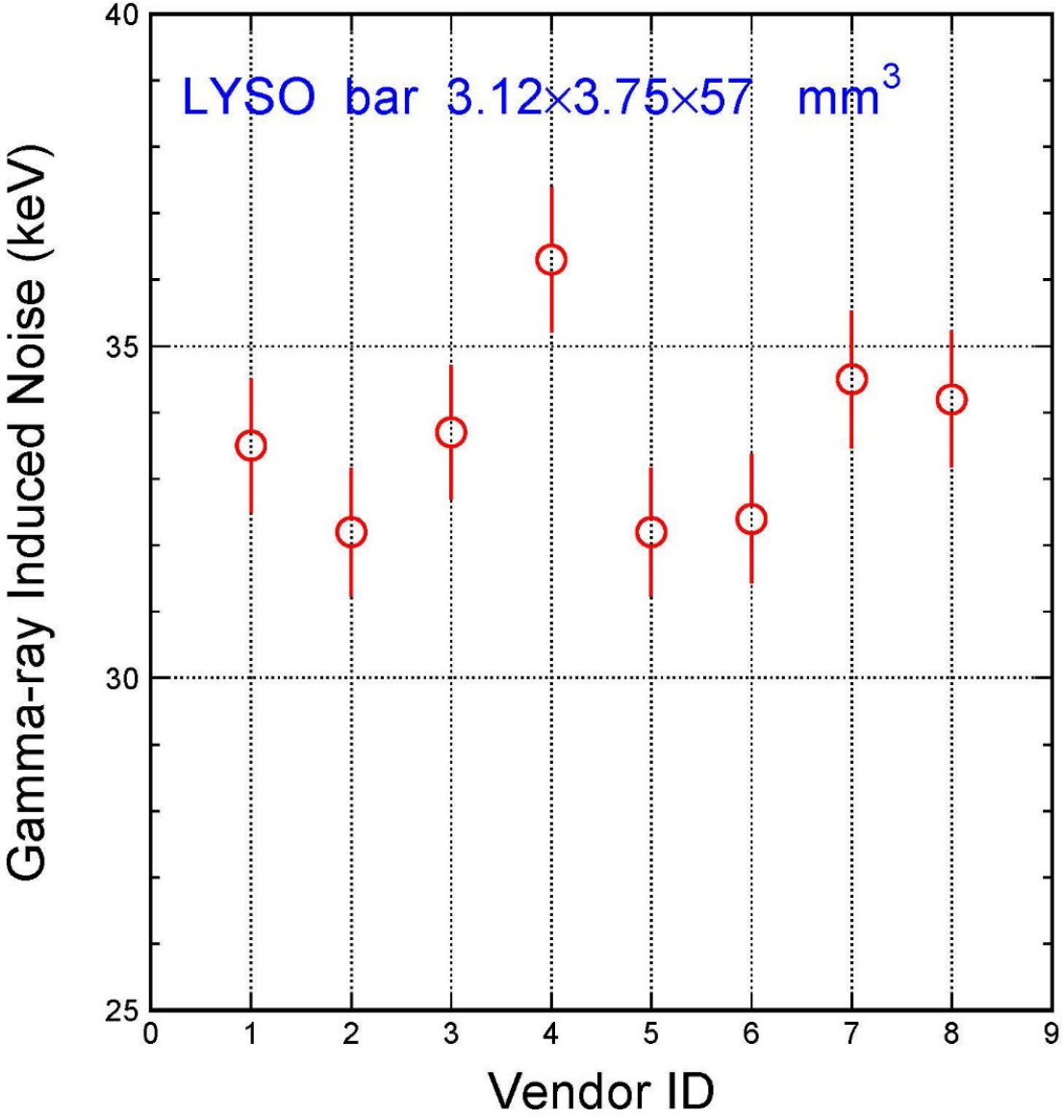
- Hamamatsu SiPM s14160-3015ps @ -40 V with a gain of 2×10^{5}. LYSO surrounded by a Teflon block and coupled to SiPM with an air gap was Irradiation @ 120, 185 and 250 rad/h. RIN obtained @ 200 rad/h with LO in 200 ns after dark current subtraction.
- Negligible readout noise at 35 keV as compared to 4.2 MeV MIP signal.

Vendor ID	Corrected SiPM L.O. (p.e./MeV)*	Dose rate (rad/h)	Dark cur. before irrad. (nA)	Photo cur. @ 120 rad/h (μA)	Dark cur. 20s after irrad. (nA)	F (p.e./s/rad/hr)	σ (keV)
1	1580	120	237	514	236	6.99×10^{7}	33.5
		185	235	634	235		
		250	232	795	234		
2	1733	120	254	556	253	7.76×10^{7}	32.2
		185	240	688	241		
		250	237	867	240		
3	1606	120	238	520	236	7.31×10^{7}	33.7
		185	240	671	240		
		250	236	820	239		
4	1412	120	244	501	241	6.58×10^{7}	36.3
		185	237	617	235		
		250	233	763	234		
5	1639	120	252	271	249	6.95×10^{7}	32.2
		185	243	642	242		
		250	245	808	247		
6	1644	120	250	529	248	7.10×10^{7}	32.4
		185	247	662	247		
		250	234	796	234		
7	1633	120	235	538	234	7.95×10^{7}	34.5
		185	233	694	233		
		250	242	898	245		
8	1518	120	262	536	258	6.74×10^{7}	34.2
		185	239	623	237		
		250	241	775	241		

* Corrected by PDE/QE, wrapping and geometry

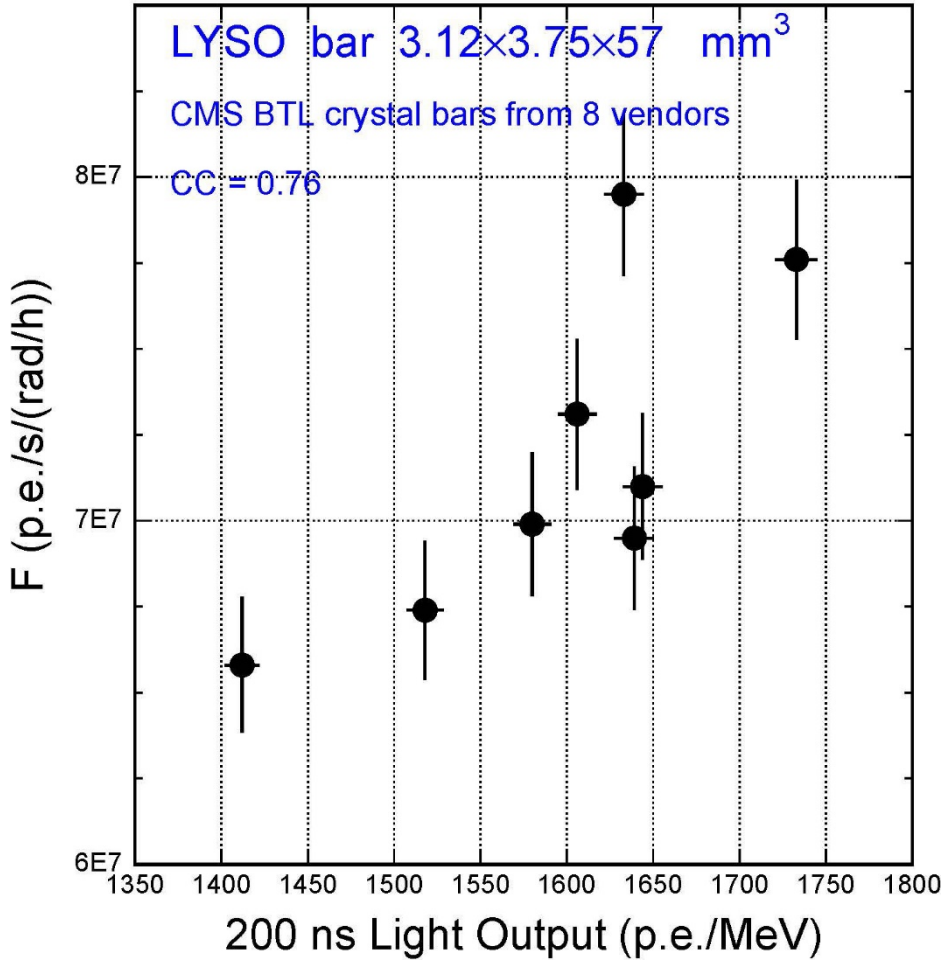
RIN:γ for LYSO from 8 Vendors

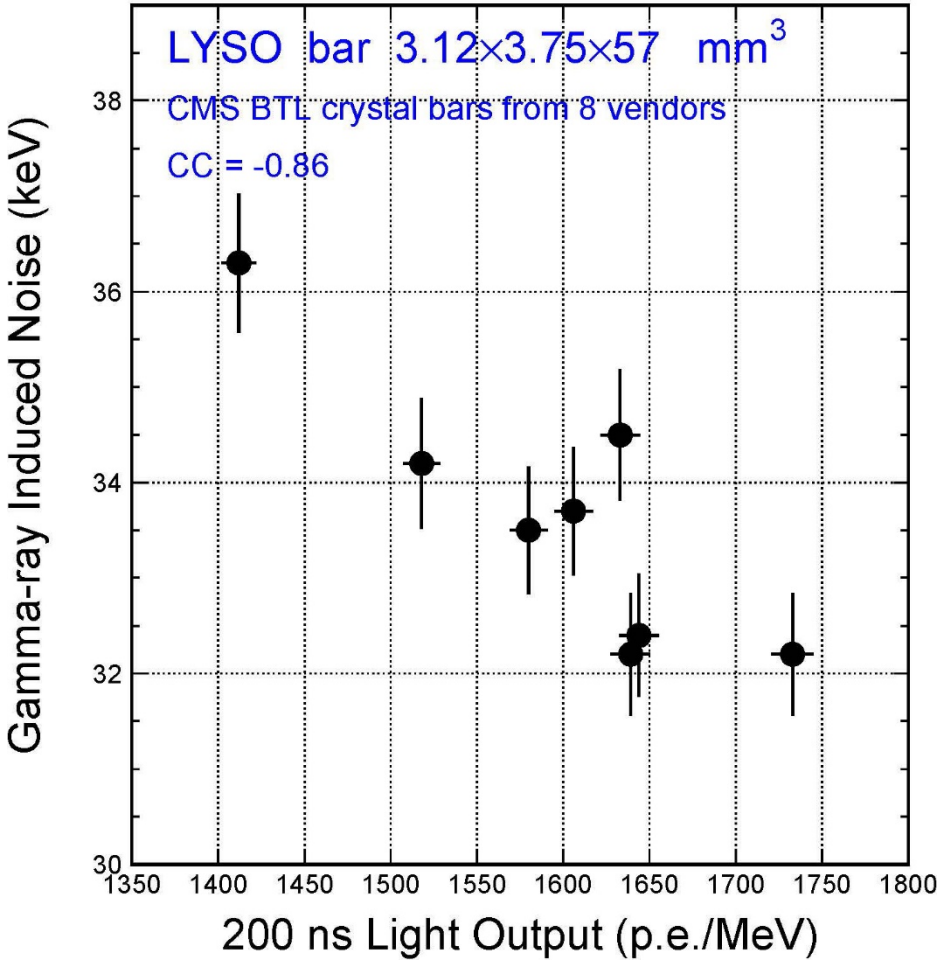
RIN:γ values are consistent at about thirtyish keV, which is negligible as compared to the 4.2 MeV MIP signal



Photocurrent & RIN:γ vs. LO

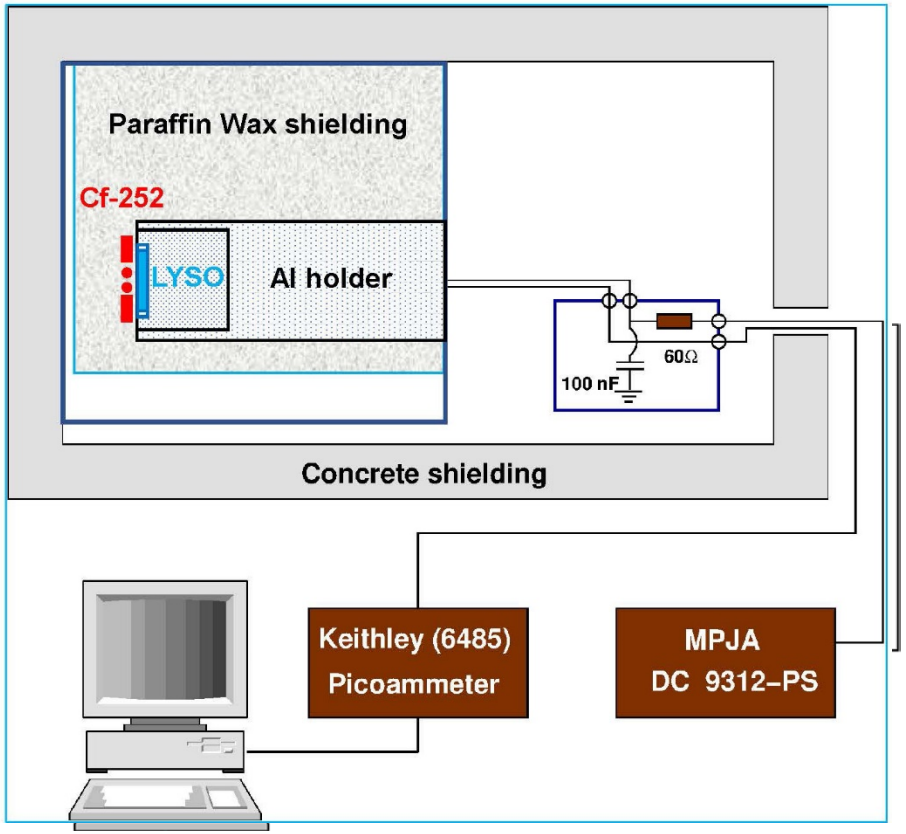
Good correlations observed for LYSO from 8 vendors





RIN:n Photocurrent

LYSO+SiPM @ $n_{eq} = 7.4 \times 10^5\ s^{-1}\ cm^{-2}$



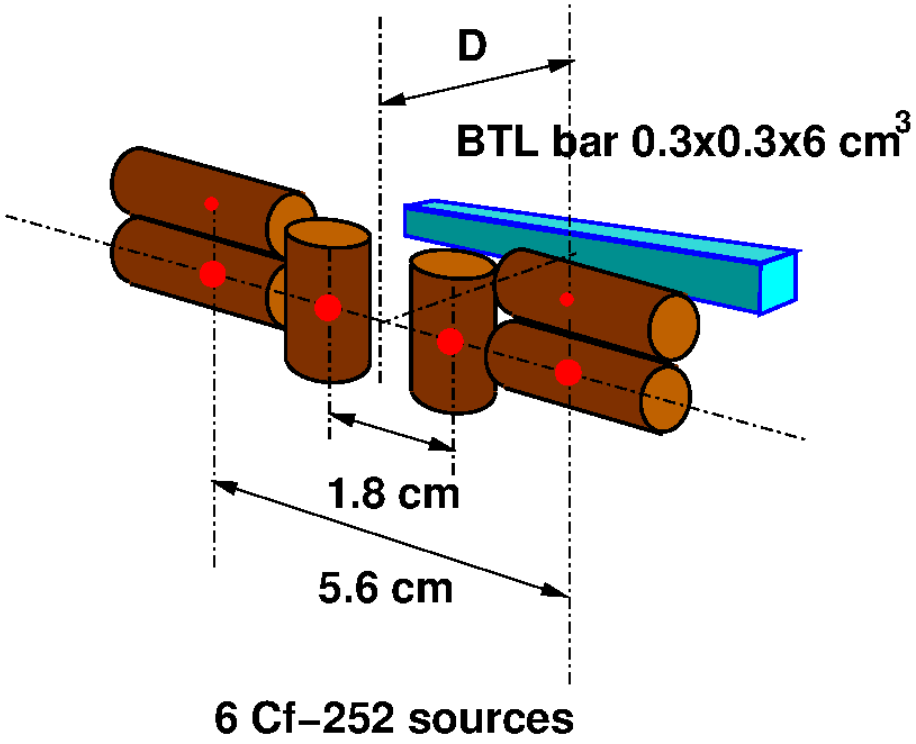
F is defined as the radiation-induced photoelectron number per second, calculated by using the photocurrent in the LYSO+SiPM normalized to 1 MeV equivalent neutron flux.

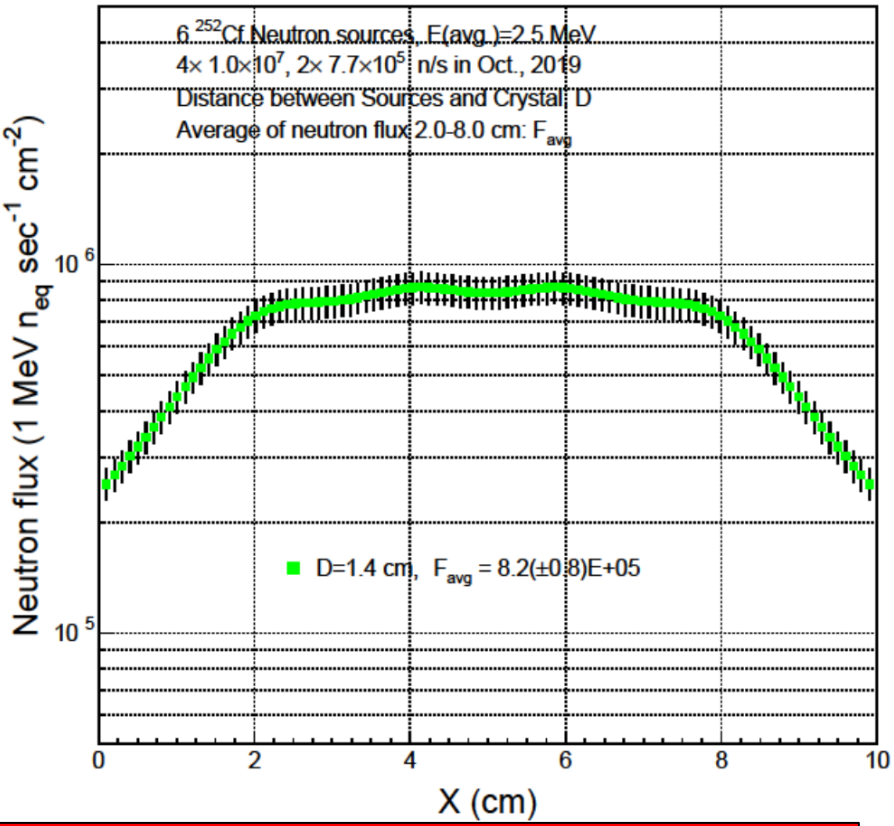
$$F = \frac{Photocurrent}{Charge_{electron} \times Gain_{SiPM}} \Big/ Dose\ rate_{\gamma-ray}\ or\ Flux_{neutron}$$

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

Cf-252 Source Pairs

Three pairs of Cf-252 source of a total of 20 μg at the Isotope Lab with 1 MeV equivalent neutron fluence (n_{eq}) calculated by using RD50 neutron induced displacement damage in Si: https://rd50.web.cern.ch/rd50/NIEL/.





Average flux = 8.2×10^5 n_{eq} $s^{-1}cm^{-2}$ in October, 2019, scaled down to 7.4×10^5 $s^{-1}cm^{-2}$

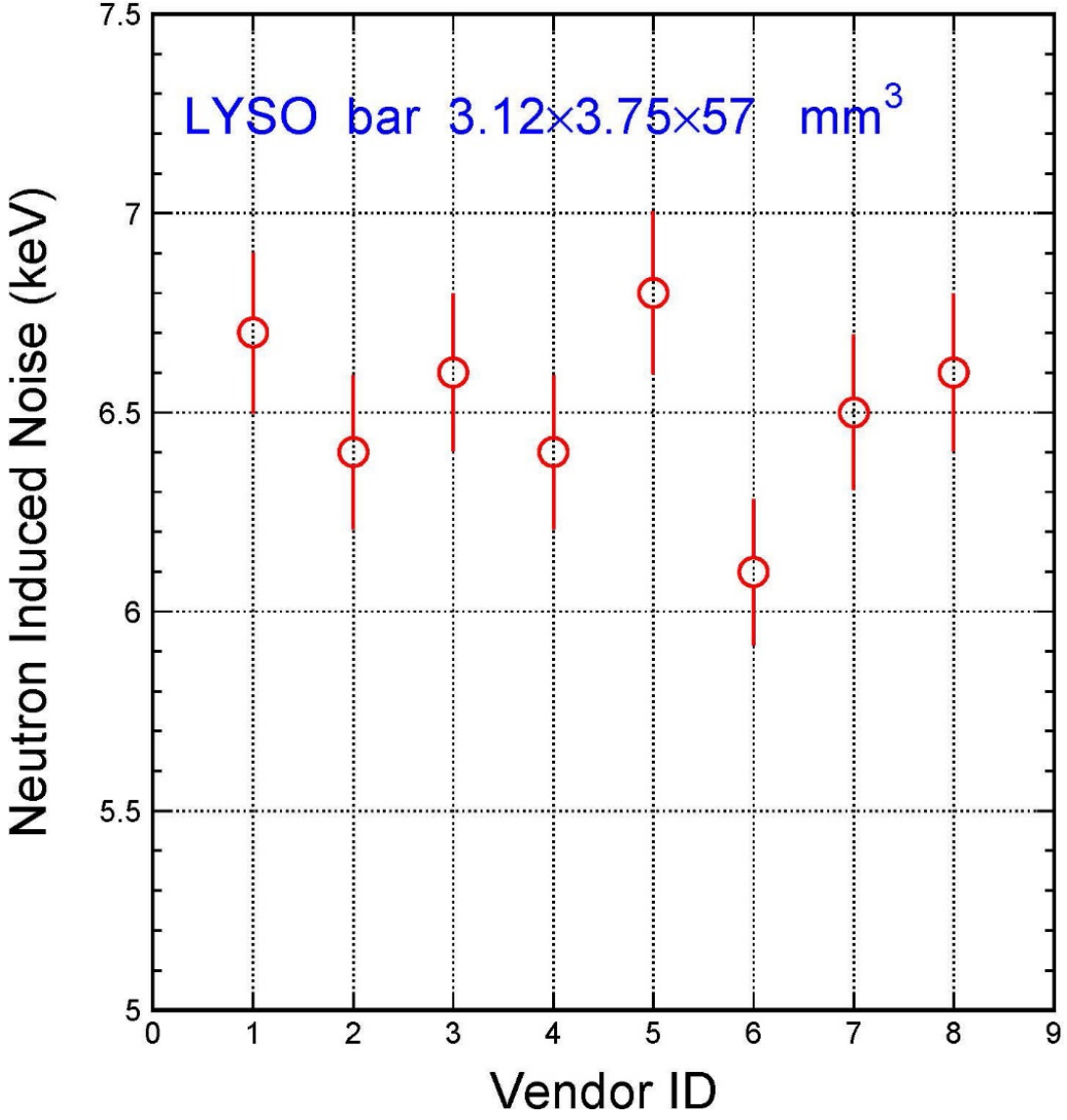
Neutron-Induced Noise

- Hamamatsu SiPM s14160-3015ps @ -40 V with gain of 2×10^{5}. LYSO surrounded by a Teflon block and coupled to SiPM with an air gap. Irradiation @ $n_{eq} = 7.4\times10^{5}$ $cm^{-2}s^{-1}$. RIN scaled to 3.2×10^{6} $cm^{-2}s^{-1}$ with LO in 200 ns after dark current & ɣ-ray background (1.8 rad/h) subtraction.
- Negligible readout noise at 6-7 keV as compared to 4.2 MeV MIP signal.

Vendor ID	Corrected SiPM L.O. (p.e./MeV)*	Flux ($cm^{-2}s^{-1}$)	Dark cur. before irrad. (μA)	Photo cur. (μA)	Dark cur. 20s after irrad. (μA)	Gamma Contribution (μA)	σ (keV)
1	1580	7.4×10^{5}	232	240	230	4.0	6.7
2	1733	7.4×10^{5}	252	260	248	4.5	6.4
3	1606	7.4×10^{5}	244	251	240	4.2	6.6
4	1412	7.4×10^{5}	253	260	252	3.8	6.4
5	1639	7.4×10^{5}	226	234	224	4.0	6.8
6	1644	7.4×10^{5}	245	251	240	4.0	6.1
7	1633	7.4×10^{5}	234	243	233	4.6	6.5
8	1518	7.4×10^{5}	246	251	240	3.9	6.6

* Corrected by PDE/QE, wrapping and geometry

RIN:n for LYSO from 8 Vendors



The RIN:n values show a consistent noise between 6 and 7 keV, which is negligible compared to the MIP signal.

Increased dark current in SiPM is expected to dominate the noise

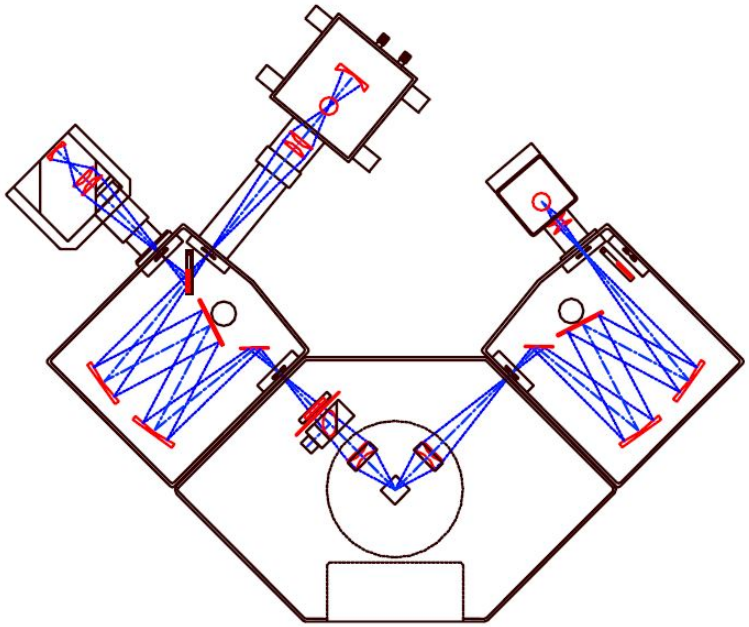
Summary

- RIN:ɣ and RIN:n measured for LYSO samples from 8 vendors, showing a noise level at about thirtyish and 6-7 keV respectively. Such a noise is negligible as compared to the 4.2 MeV MIP signal. No obvious difference observed between vendors.
- Plan to measure variation of decay time and intensity of photo-luminescence for LYSO samples from 8 vendors down to -30°C by using an Edinburgh FLS920 Fluorescence Spectrometer with liquid nitrogen cooling at Caltech.
- Plan also to measure TID:ɣ for these samples by using the 2,000 curie Cs-137 source at Caltech.
- Two proposals submitted to LANSCE for TF:n (8597) and TF:p (8588) to be started in Summer and Fall, 2020. Results will be available in 2021 after samples cooled down.
- An additional set of LYSO samples are needed to carry out both TF:n and TF:p experiments.

PL and Decay of LYSO @ -30°C

Edinburgh FLS920 fluorescence spectrometer

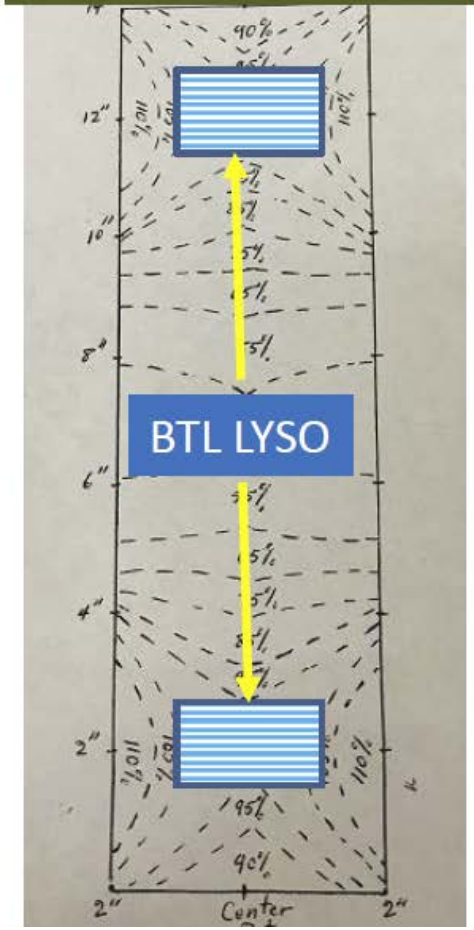
- A Xe900 continuous xenon lamp;
- A nF920 ns flash-lamp;
- Single photon counting PMT and TCSPC;
- Oxford cryostat OptistatDN: 77.2-500K;
- A sample holder made for BTL LYSO;
- PL & decay of LYSO: @ -30°C with LN.



TID:γ at P1 with Cs-137

4.8 Mrad in ~10 days for BTL LYSO samples in P1 @ 20.7 krad/hr

P1: 20.7 krad/hr



P2: 5.2 krad/hr