Gamma-Ray Induced Photocurrent and Readout Noise for BTL LYSO+SiPM

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Introduction

A Question from the Fermilab Director's Review

"Effect on time resolution related to the instantaneous TID (rad/hour). From your 25 kGy after 10 years, we can derive 2.5 kGy per year i.e., 0.5 Gy/hour (50 rad/hour). Measurement of assembled BTL with MIP during irradiation should be performed before going to further. The noise induced from the scintillating tile can deteriorate the timing resolution."

Plan: Experiments of Two Types

- Measurements for BTL sensors from selected vendors under the expected dose rate and the expected hadron flux: Radiation induced photocurrent and readout noise (RIN) measurements, following R. Mao *et al.*, Paper N32-4 and N32-5, *IEEE NSS Conference Record* (2009). Coincidence timing resolution (CTR) will also be measured.
- One total ionization dose (TID:ɣ) and two total neutron/proton fluence (TF:n/p) experiments.

Reported today is the RIN:ɣ data

Results for RIN:n, CTR:ɣ and CTR:n will follow soon

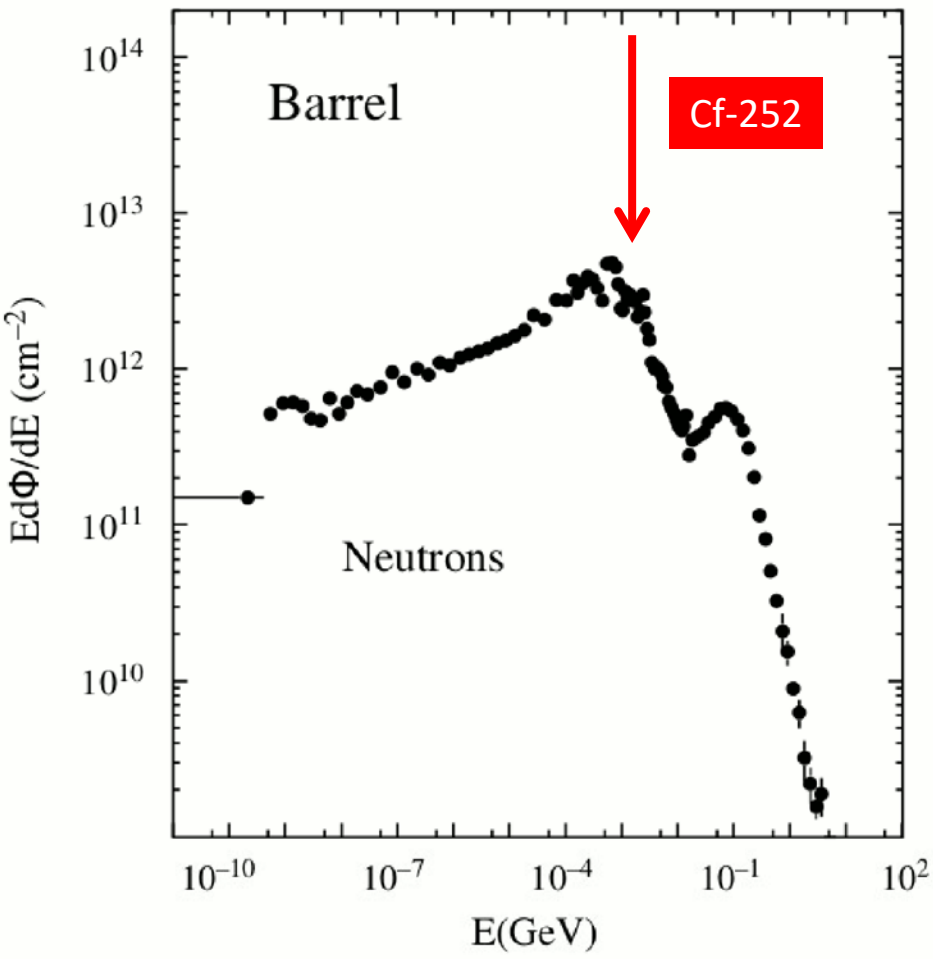
Radiation Expected by CMS BTL

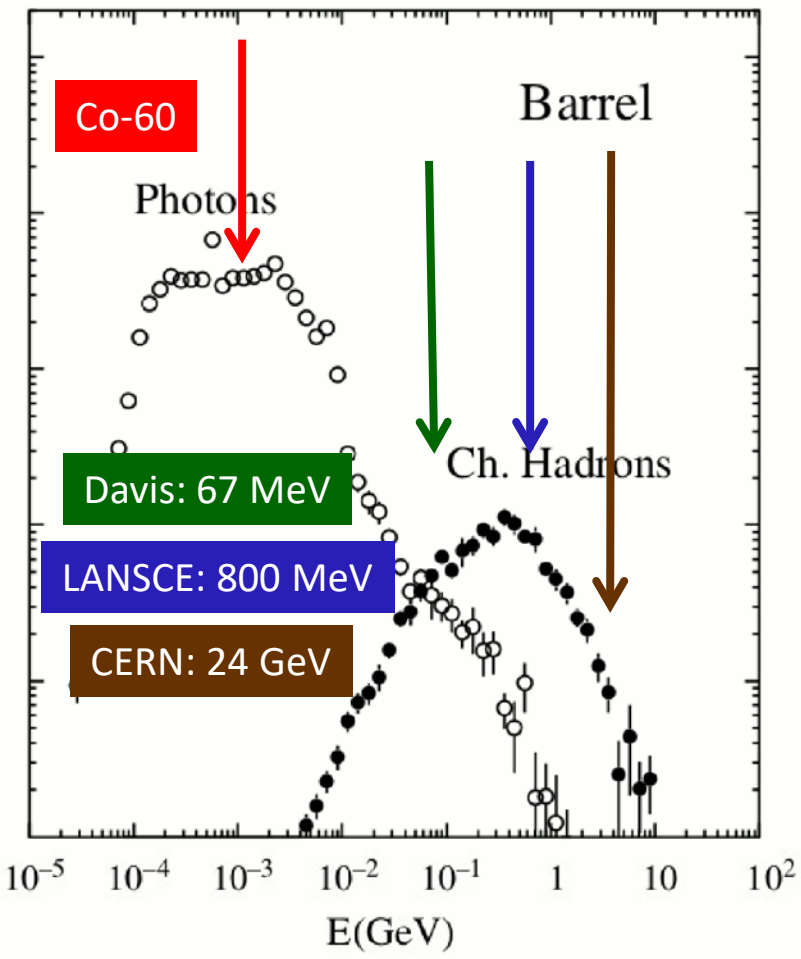
MTD TDR: assuming 5×10^{34} $cm^{-2}s^{-1}$, 3,000 fb^{-1} & a safety factor of 1.5
Radiation spec: λ_{in}<3 m^{-1} for 4.8 Mrad, 2.5 x 10^{13} p/cm^2 & 2.9 x 10^{14} n_{eq}/cm^2

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

Particle Energy Spectra at LHC

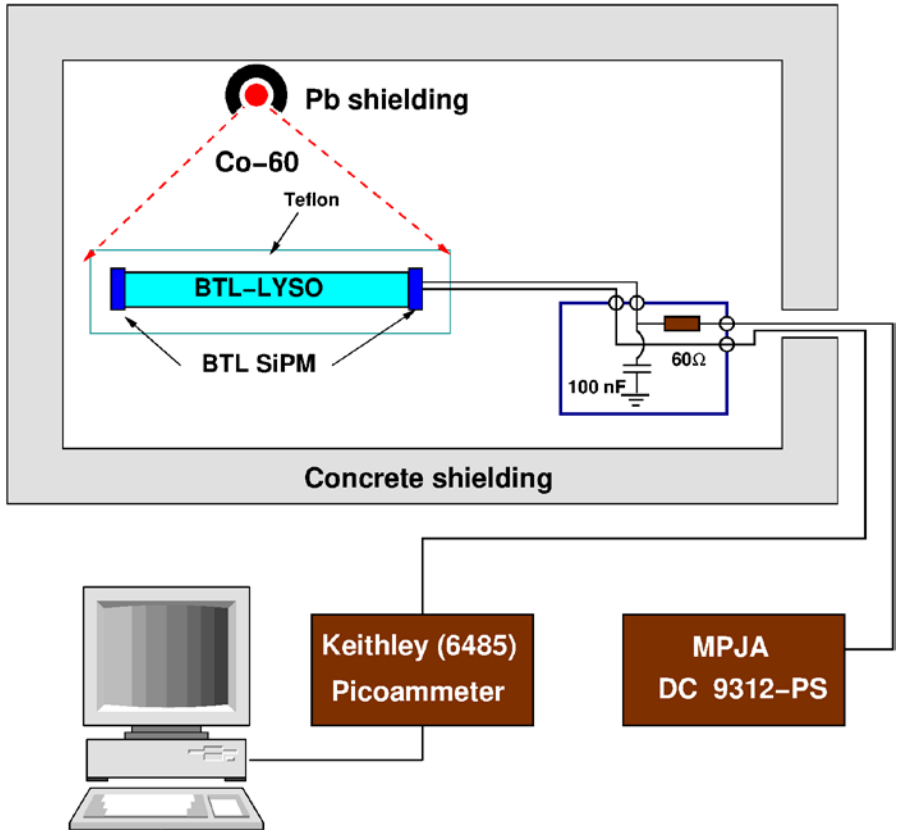
FLUKA simulations: ɣ/n and charged hadrons peaked at MeV and several hundreds MeV respectively. RIN:ɣ and RIN:n, as well as CTR:ɣ and CTR:n are investigated at Caltech.





γ-Ray Induced Photocurrent

Hamamatsu SiPM s14160-3015ps @ -40 V, LYSO surrounded by a Teflon block with an air gap coupling were irradiated at three positions



F is defined as the radiation induced photoelectron number per second, determined from the photocurrent in the SiPM at different γ-ray dose rate.

Hamamatsu SiPM operated with 2 V over voltage has a gain of 2×10^5.

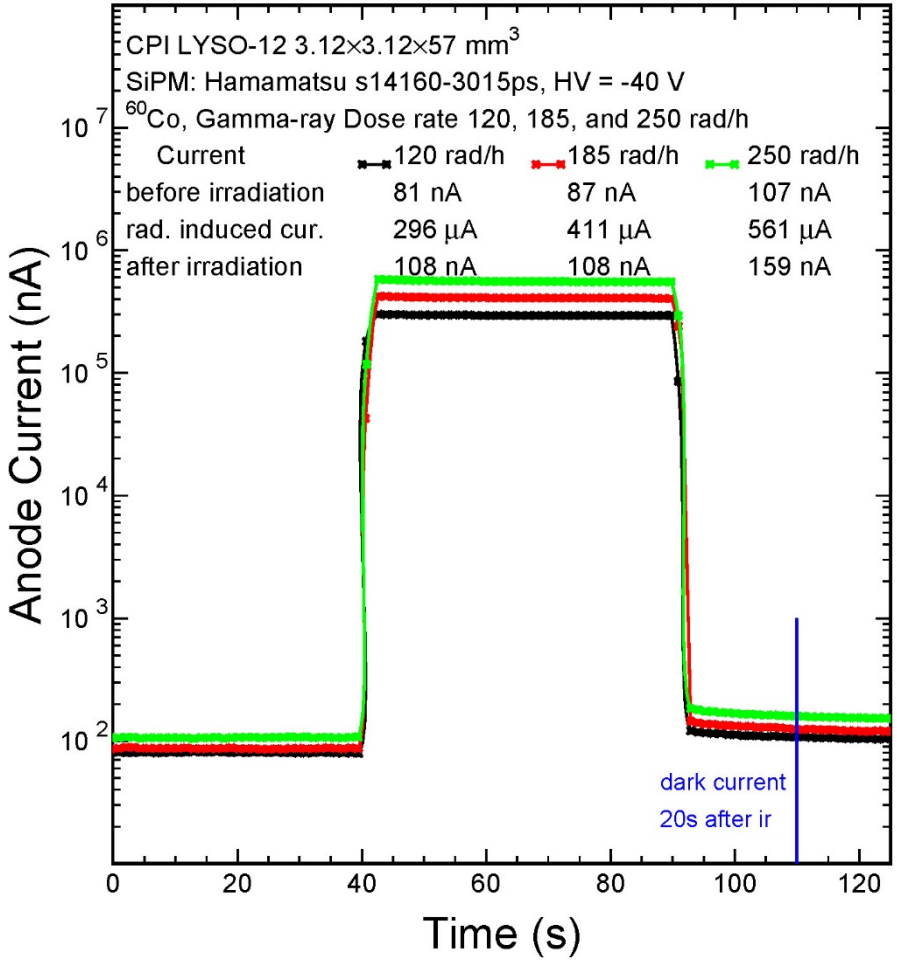
Four typical LYSO samples from CPI, SIC, Tinle-1 and Tinle-2 were tested

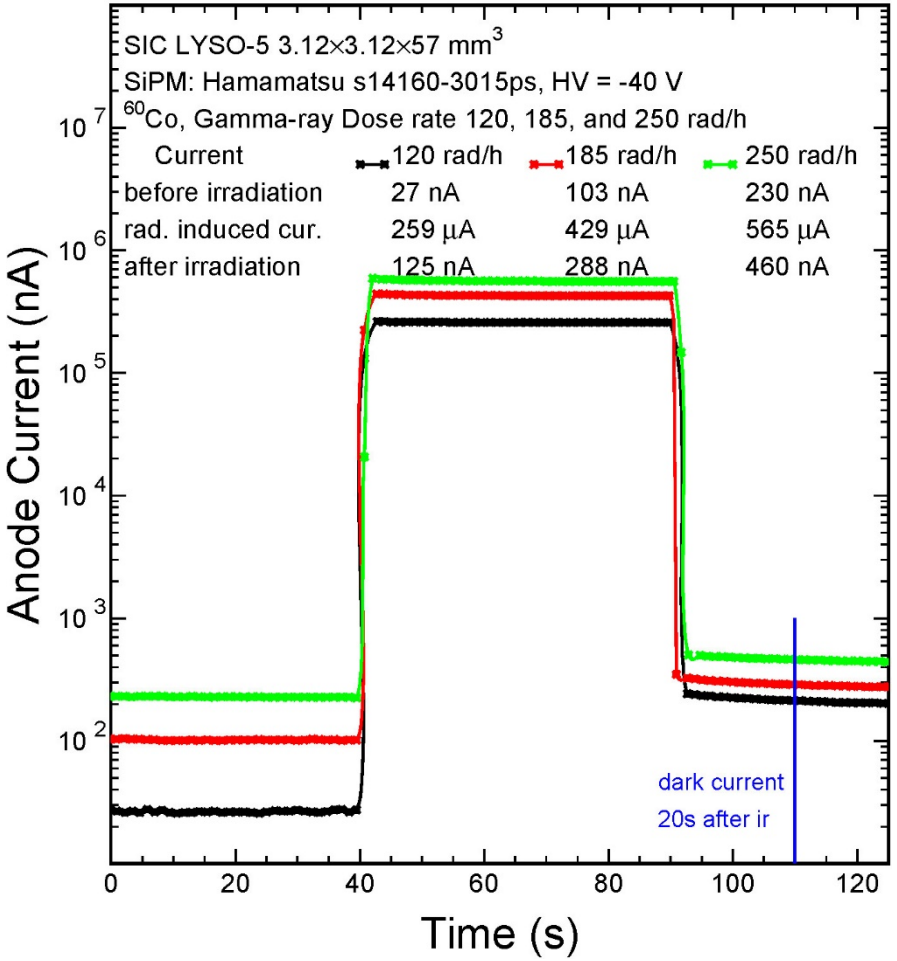
$$F = \frac{Photocurrent}{Charge_{electron} \times Gain_{SiPM}} \Big/ Dose\ rate_{\gamma-ray}\ or\ Flux_{neutron}$$

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

Photocurrent: CPI and SIC

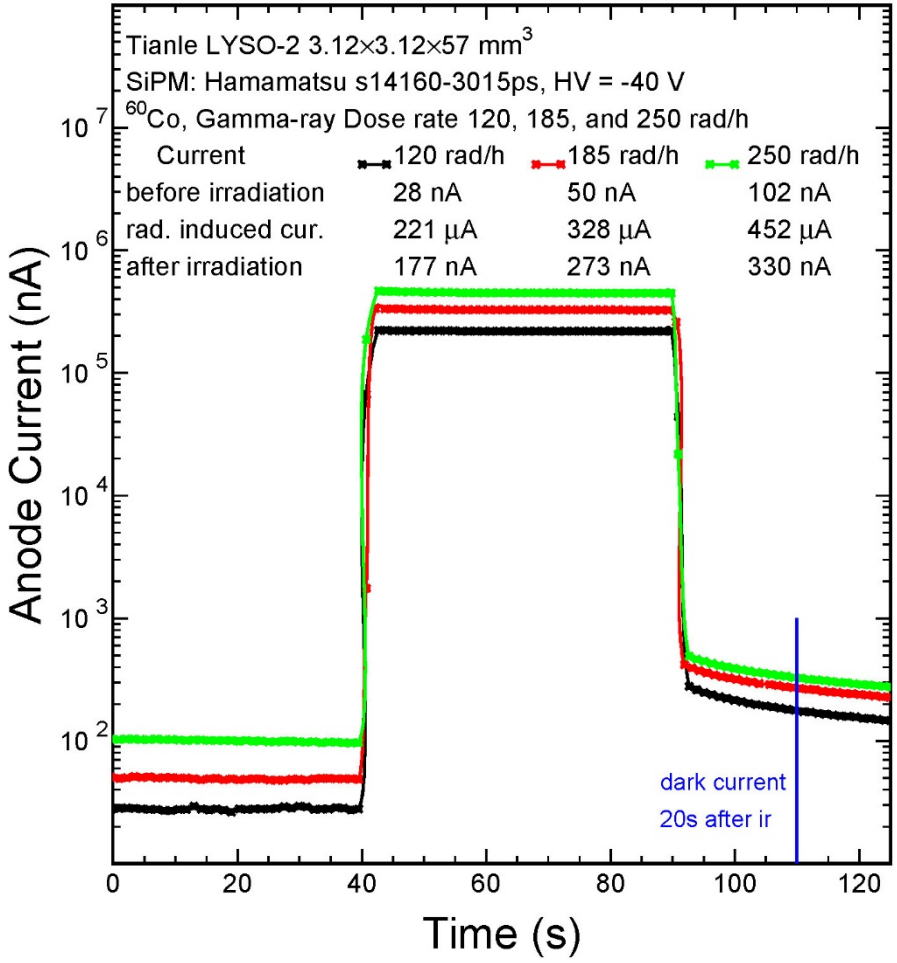
Consist photocurrent and after glow observed

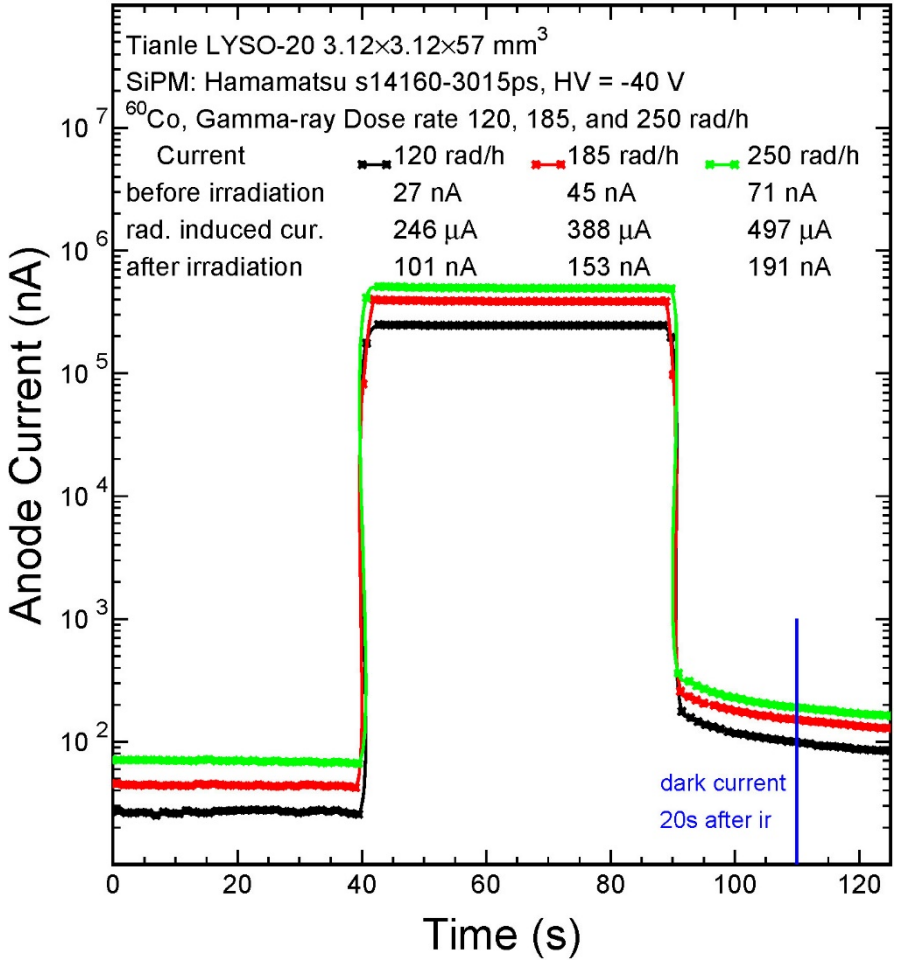




Photocurrent: Tinle-1 & -2

Consist photocurrent and after glow observed



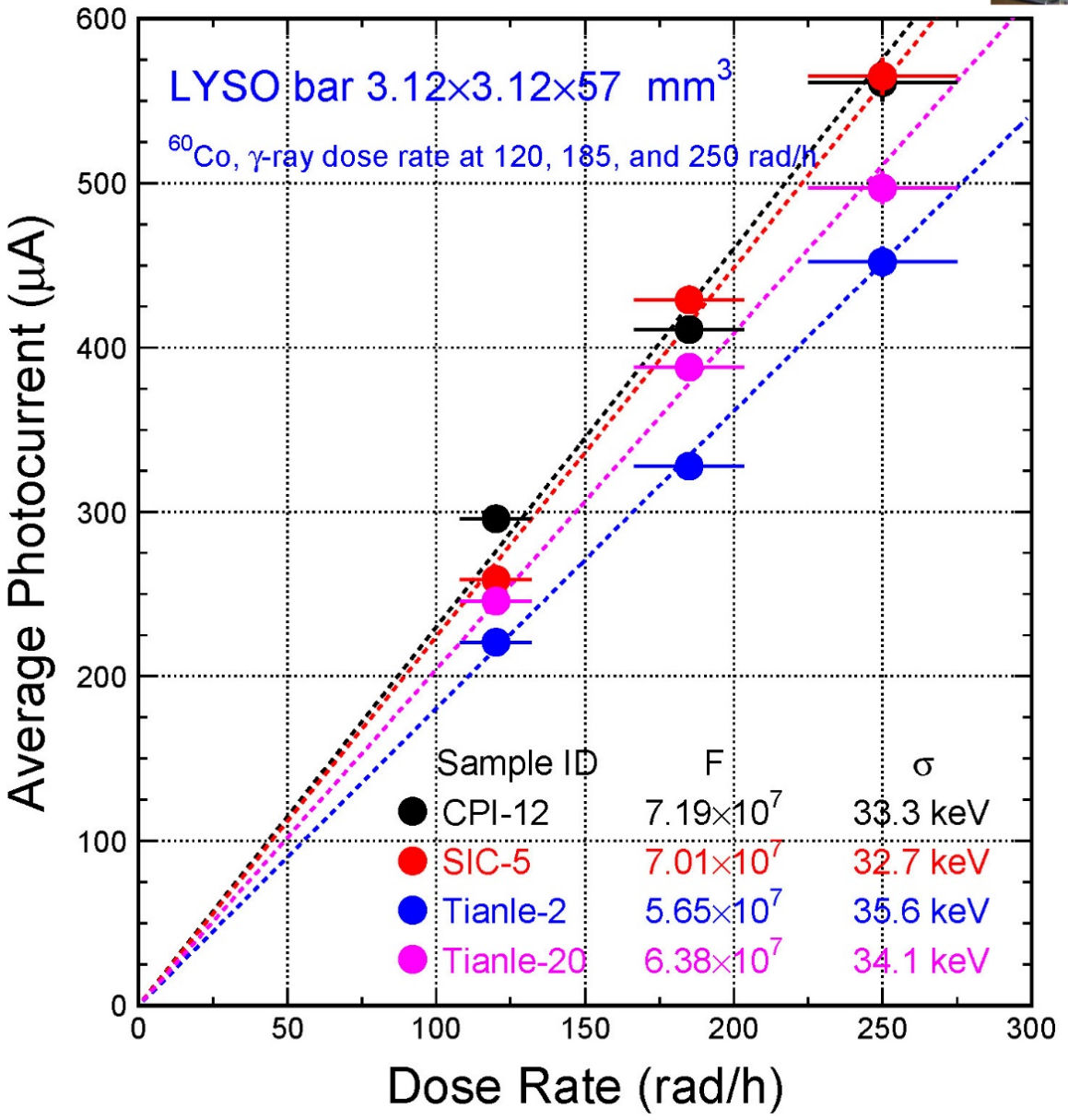


Gamma-Ray Induced Noise

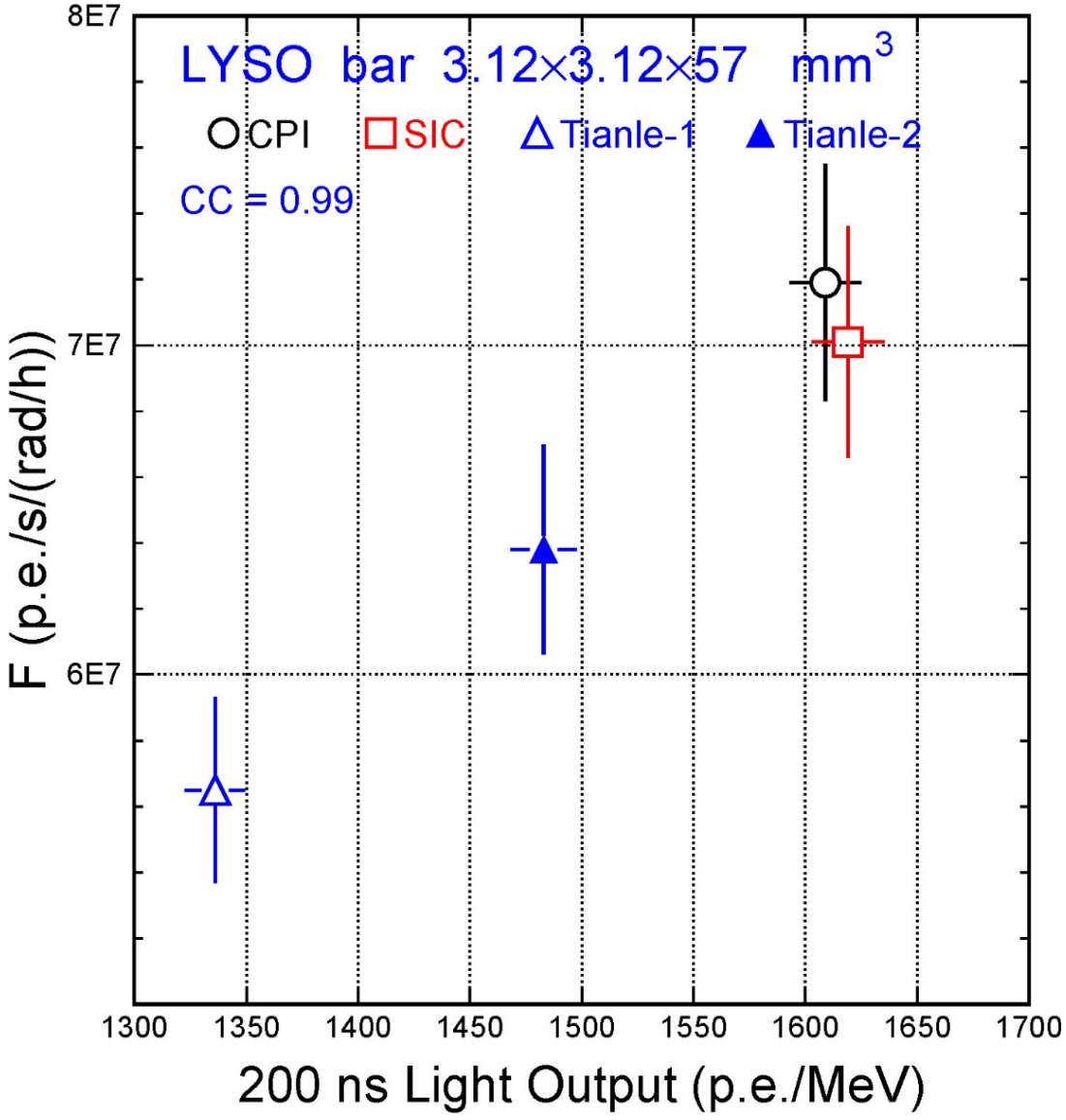
Dose rates at each position determined from a combined fit.

Good linearity observed for all samples.

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



Correlations: F values vs. LO



Excellent correlation shows that the observed photocurrent is entirely due to scintillation light

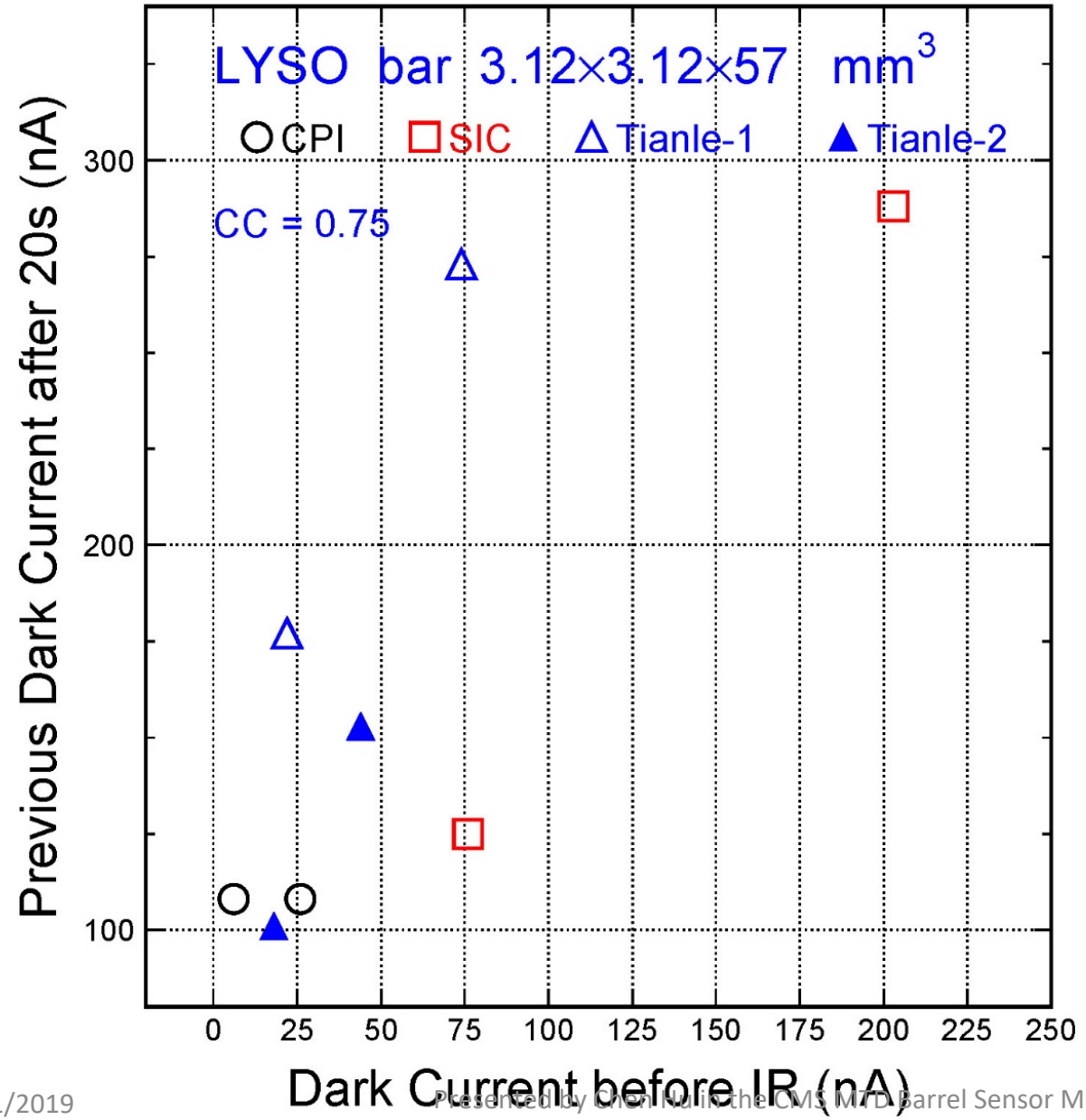
Gamma-Ray Induced Noise

- 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. LO in 200 ns gate.
- Negligible readout noise at 35 keV as compared to 4.2 MeV MIP signal.

Crystal ID	Corrected SiPM L.O. (p.e./MeV)*	Dose rate (rad/h)	Dark cur. before irrad. (nA)	Photo cur. (μA)	Dark cur. 20s after irrad. (nA)	F (p.e./s/rad/hr)	σ (keV)
CPI-12	1609	120	81	296	108	7.19×10^{7}	33.3
		185	87	411	108		
		250	107	561	159		
SIC-5	1619	120	27	259	125	7.01×10^{7}	32.7
		185	103	429	288		
		250	230	565	460		
Tianle-2	1336	120	28	221	177	5.65×10^{7}	35.6
		185	50	328	273		
		250	102	452	330		
Tianle-20	1483	120	27	246	101	6.38×10^{7}	34.1
		185	45	388	153		
		250	71	497	191		

* Corrected by PDE/QE, wrapping and geometry

Correlation: Dark Currents before vs. after



Good correlation shows that the dark current is affected by the afterglow after irradiation

Summary

An RIN:ɣ experiment was carried out for LYSO samples surrounded by a Teflon block and coupled to SiPMs with an air gap. Four LYSO samples from three vendors were tested under three dose rates. While these LYSO samples are not identical, the RIN:ɣ values show a consistent noise level at about thirtyish keV, which is negligible as compared to the 4.2 MeV MIP signal.

A new pair of Cf-252 sources is being added to the existing two pairs. An RIN:n experiment will be carried out in October.

CTR:ɣ and CTR:n experiments will be carried out in Fall.

A TID:ɣ experiment is also planned in Fall.

Depending on a crane reparation, a TF:n experiment may start at LANSCE in Fall, 2019.