First Look on Radiation Induced Photocurrent in LYSO+SiPM Package

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Introduction

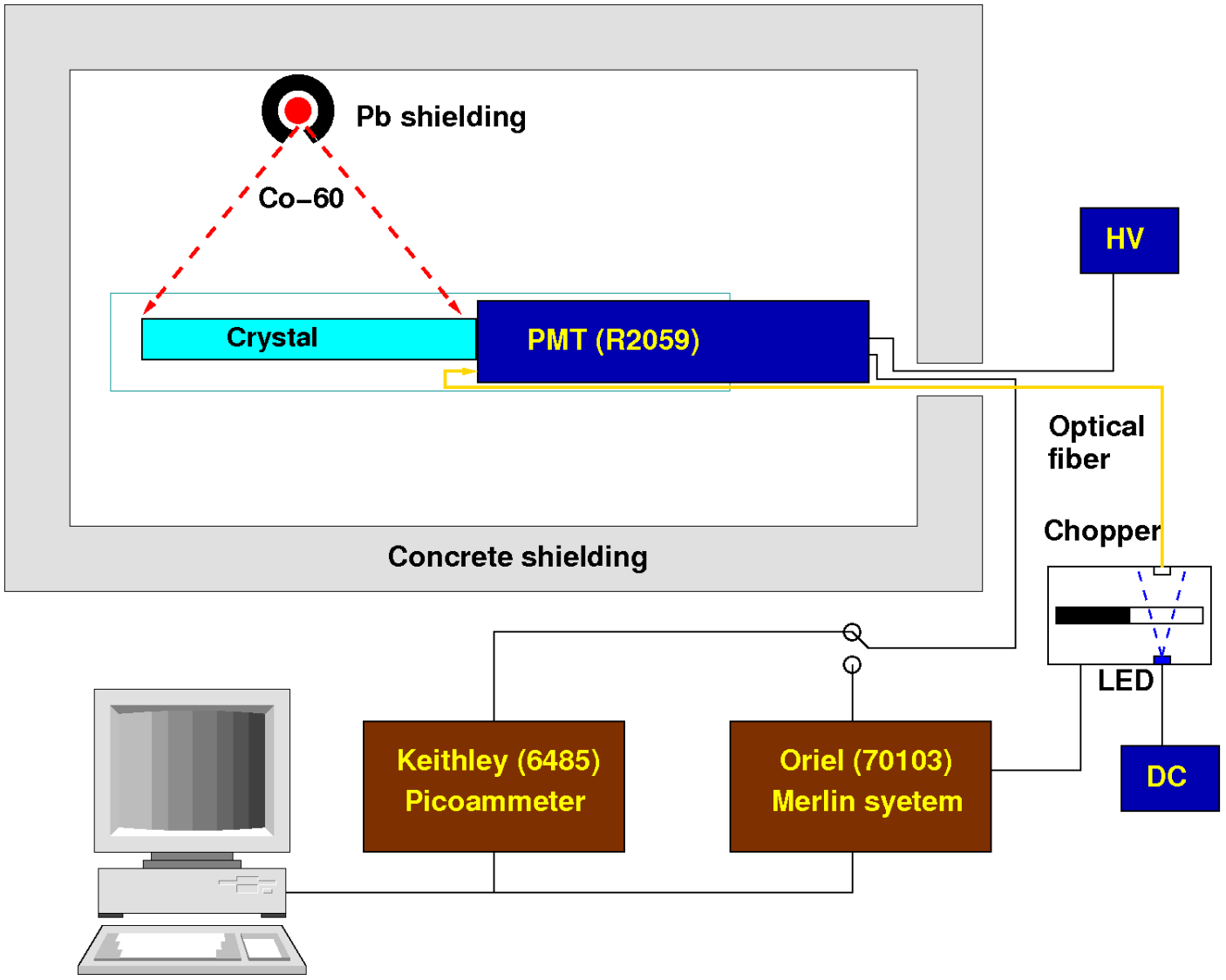
- A LYSO + SiPM layer will provide precision timing for MIPs as well as photons.
- While radiation induced absorption and light output loss are under control it is important to look radiation induced photocurrent in SiPM and its consequence to readout noise.
- Gamma-ray and neutron induced photocurrent were measured for LSO/LYSO crystals of 25 x 25 x 200 mm, and is used to calculate radiation induced photo-electron number for SiPMs in 10 ns readout gate as well as the corresponding readout noise.

CMS Radiation Environment

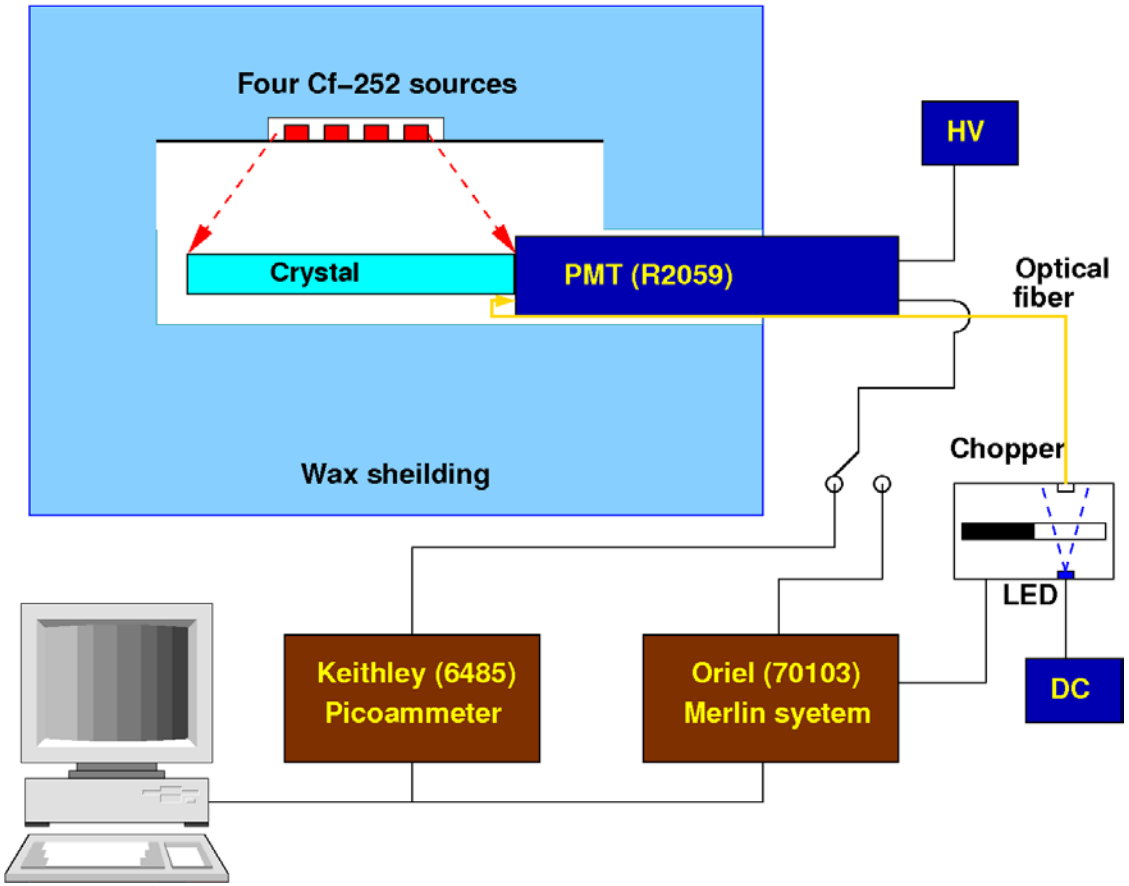
BRIL simulation: https://cms-project-fluka-flux-map.web.cern.ch/cms-project-fluka-flux-map/, which are consistent with the CMS note CMS DP-2013/028.

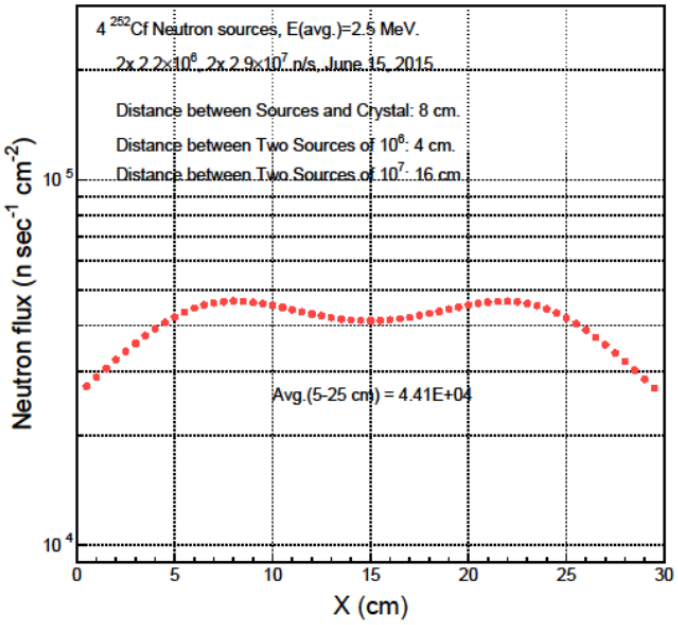
CMS ECAL Environment	LHC (10^{34} $cm^{-2}s^{-1}$, 500 fb^{-1})		HL-LHC (7 TeV, 5×10^{34} $cm^{-2}s^{-1}$, 3000 fb^{-1})			
	Barrel (max)	Endcap (max)	Barrel (η=0)	Barrel (η=1.479)	Endcap (η=1.479)	Endcap (η=3)
Absorbed dose (rad)	**3.50E+05**	**2.10E+07**	**1.20E+06**	**2.25E+06**	**6.03E+05**	**5.66E+07**
Dose rate (rad/h)	21	1260	72	135	36	3394
Fast neutrons fluence (cm^{-2})	**3.00E+13**	**8.00E+14**	**3.63E+14**	**5.24E+14**	**3.35E+14**	**2.94E+15**
Fast neutrons flux ($cm^{-2}s^{-1}$)	5.00E+05	1.33E+07	6.05E+06	8.73E+06	5.58E+06	4.90E+07
Charged hadrons fluence (cm^{-2})	**4.00E+11**	**5.00E+13**	**6.68E+12**	**8.65E+12**	**2.71E+12**	**5.82E+14**
Charged hadrons flux ($cm^{-2}s^{-1}$)	6.67E+03	8.33E+05	1.11E+05	1.44E+05	4.52E+04	9.69E+06

Gamma-Ray Induced Photocurrent



Neutron Induced Photocurrent





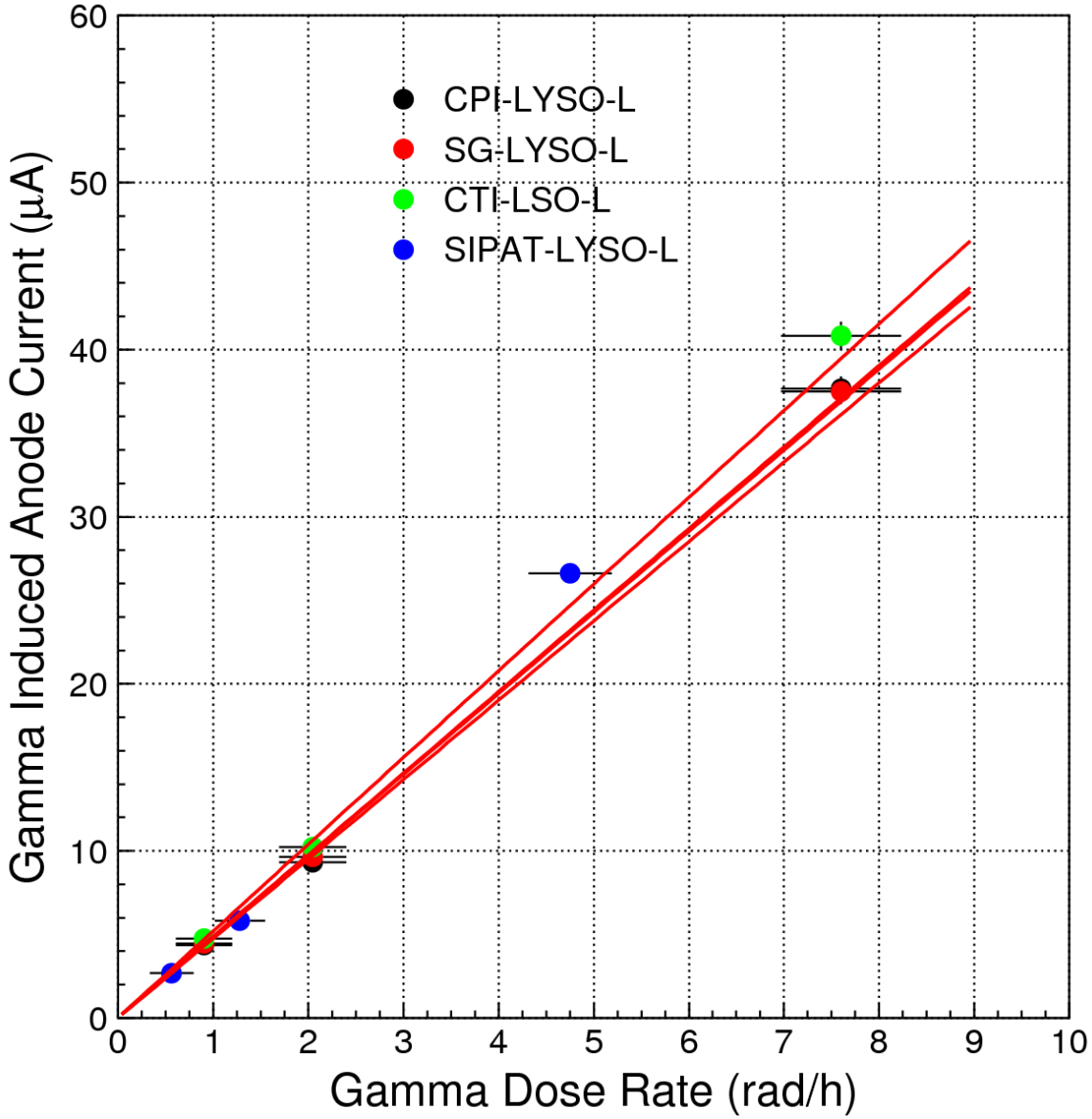
Radiation Induced Photoelectron Coefficient

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

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

Energy equivalent noise is derived as the standard deviation of photoelectron number in the readout gate normalized to the light output

γ-ray Induced Photocurrent



γ-ray induced anode current was measured for four LSO/LYSO samples at different dose rate

Gamma Induced Photocurrent in Four LSO/LYSO Crystals

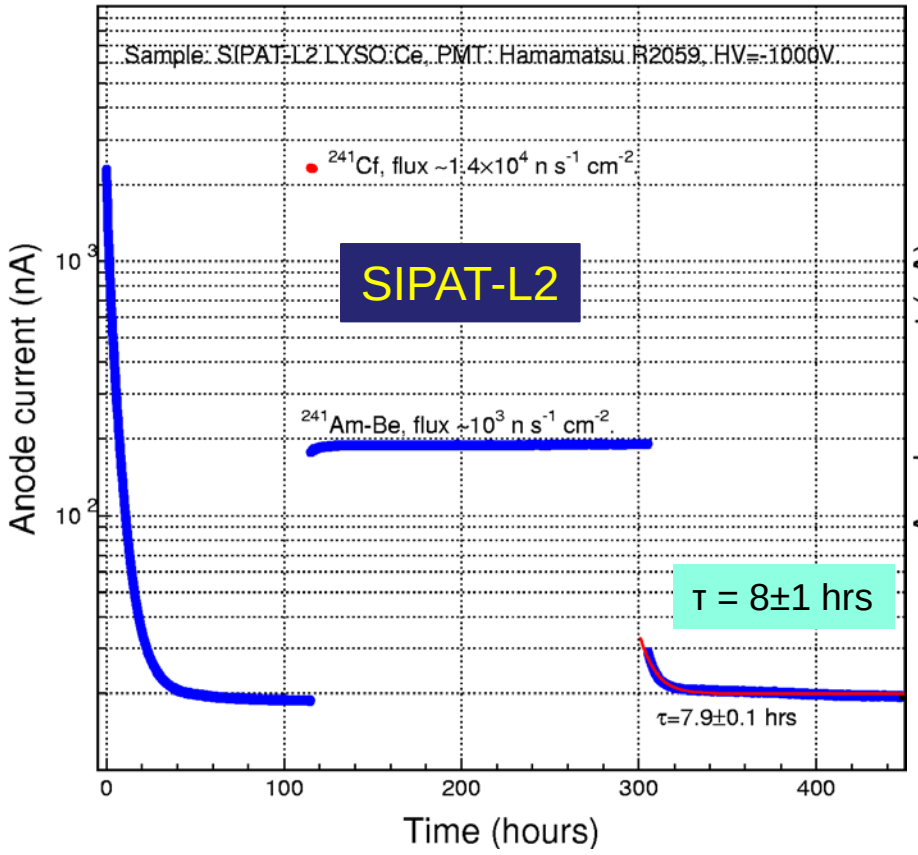
Gamma-ray induced photo-electron coefficient averaged for four LSO/LYSO crystals of 25×25×200 mm^3: 4.86E10 p.e. s^{-1} $(rad/h)^{-1}$

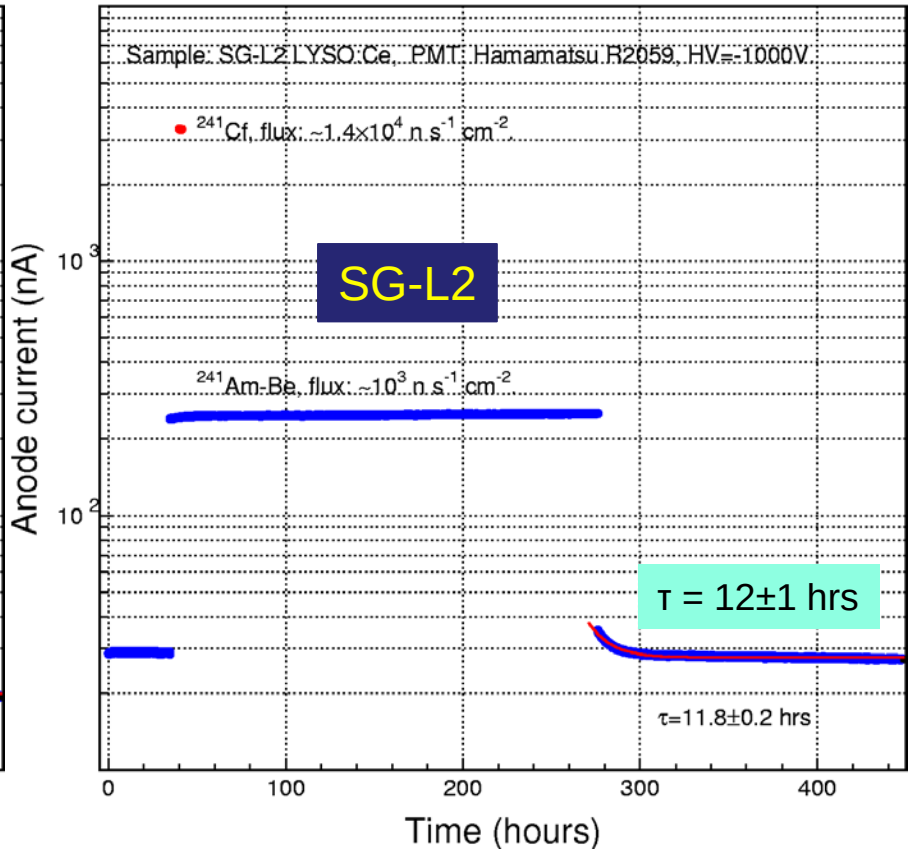
www.hep.caltech.edu/~zhu/papers/09_NSSCR_gamma.pdf

TABLE I
SUMMARY OF GAMMA INDUCED COEFFICIENT AND READOUT NOISE IN PWO AND LSO/LYSO

Sample ID	L.Y. p.e./MeV	F^a p.e.s^{-1}(rad/h)$^{-1}$	Q_{bar} p.e.	Q_{end} p.e.	σ_{bar} MeV	σ_{end} MeV
SIC-S392 PWO	7.1	1.94E +08	290	9680	2.4	13.8
SIC-S411 PWO	6.7	1.76E +08	265	8820	2.4	14.0
BTCP-2133 PWO	5.8	1.52E +08	244	8120	2.7	15.6
BTCP-2162 PWO	7.1	1.89E +08	284	9460	2.4	13.7
CPI-LYSO-L	2060	4.74E +10	1.41E +05	4.71E +06	0.2	1.1
SG-LYSO-L	2270	4.80E +10	1.44E +05	4.80E +06	0.2	1.0
CTI-LSO-L	2020	5.10E +10	1.53E +05	5.10E +06	0.2	1.1
SIPAT-LYSO-L	2155	4.80E +10	1.44E +05	4.80E +06	0.2	1.0

Neutron Induced Photocurrent in Two LYSO Crystals





Neutron Induced Photocurrent in Two LYSO Samples

Neutron induced photo current factor averaged for two LYSO samples of 25 x 25 x 200 mm: 2.75E3 p.e. n^{-1} cm^2

www.hep.caltech.edu/~zhu/papers/09_NSSCR_neutron.pdf

TABLE I
SUMMARY OF THE NEUTRON INDUCED READOUT NOISE

Sample ID	Dimension cm^3	L.Y. p.e./MeV	F^a p.e.$n^{-1}cm^2$	F^c p.e.$n^{-1}cm^2$	σ^a_{bar} MeV	σ^c_{bar} MeV	σ^a_{end} MeV	σ^c_{end} MeV
SIC-2781 PWO	$2.8 \times 22. \times 3.0$	14.2	1.7×10^3	1.6×10^3	3.0	2.9	16.9	16.4
BTCP-2376 PWO	$2.8 \times 22. \times 3.0$	7.5	1.0×10^3	1.2×10^3	4.3	4.8	24.6	26.9
SIPAT-L2 LYSO	$2.5 \times 20. \times 2.5$	1940	2.6×10^5	2.3×10^3	0.4	0.4	2.2	2.0
SG-L2 LYSO	$2.5 \times 20. \times 2.5$	2480	3.4×10^3	3.2×10^3	0.3	0.3	1.9	1.9
SIC BGO	$2.5 \times 20. \times 2.5$	340	2.0×10^4	4.1×10^4	1.4	1.9	7.7	11.0
SIC CeF_3	$3.0 \times 14. \times 3.0$	60	2.6×10^3	3.0×10^3	1.2	1.3	7.0	7.5

Radiation Induced Photocurrent and Readout Noise in LYSO+SiPM

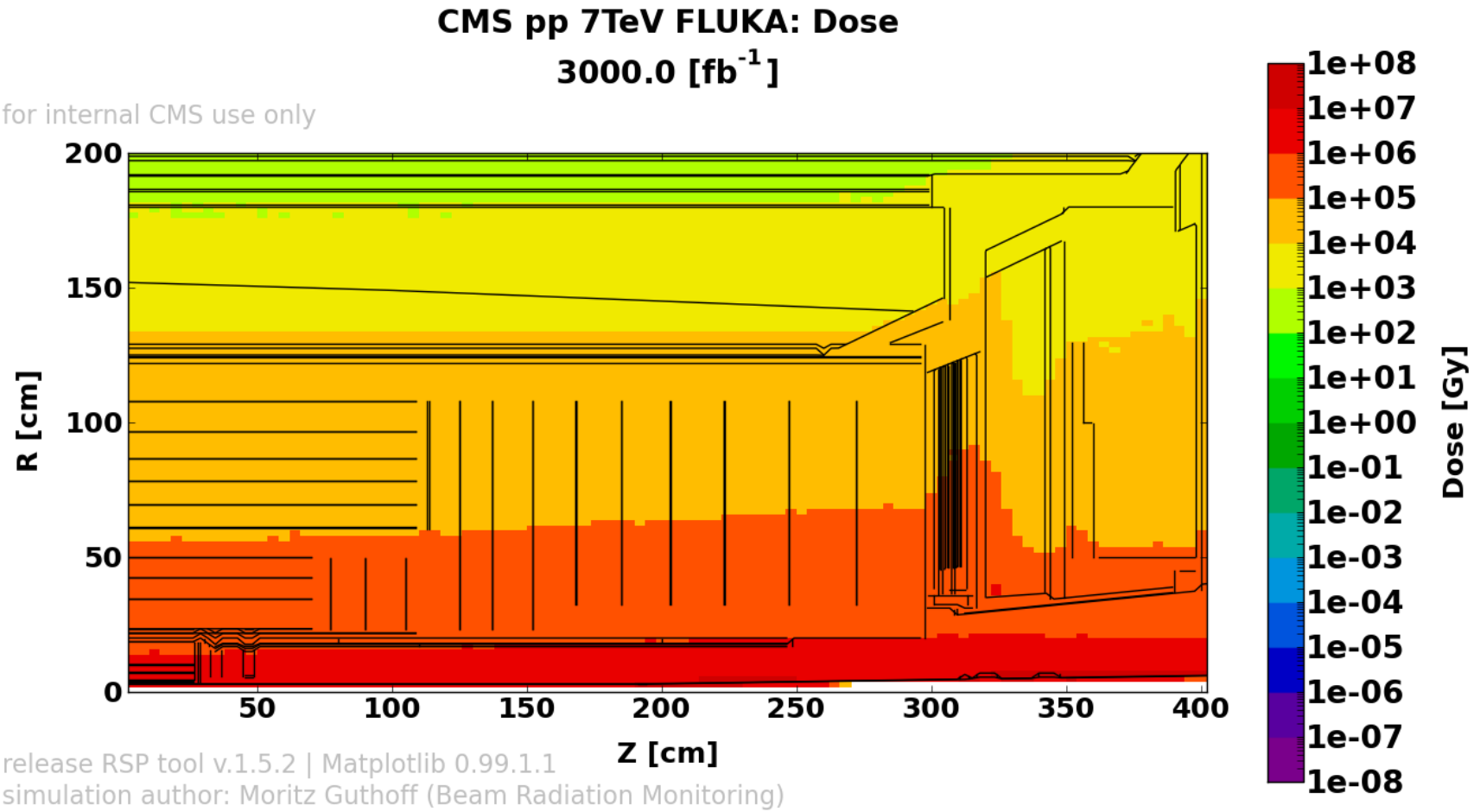
With SiPM area of 5×5 mm^2, both readout gate and recovery time of 10 ns, radiation induced photo electrons (r.i.p.e.) and noise (σ) are calculated within the readout gate, assuming light output of LYSO plate of 3000 p.e./MeV

No	LYSO Plates	Vol. Corrected F	HL-LHC (7 TeV, 5×10^{34} cm^{-2}s^{-1}, 3000 fb^{-1})***							
	(mm^3)		EB, η=0		EB, η=1.479		EE, η=1.479		EE, η=3	
γ induced p.c.		(p.e. s^{-1}(rad/h)$^{-1}$)	r.i.p.e.	σ (keV)	r.i.p.e.	σ (keV)	r.i.p.e.	σ (keV)	r.i.p.e.	σ (keV)
1	10×10×1.5	8.23E+07	2.96E+01	5.13E+00	5.55E+01	7.03E+00	1.49E+01	3.64E+00	1.40E+03	3.52E+01
2	10×10×3	1.65E+08	5.93E+01	7.26E+00	1.11E+02	9.94E+00	2.98E+01	5.14E+00	2.79E+03	4.98E+01
3	10×10×5	2.74E+08	9.88E+01	9.37E+00	1.85E+02	1.28E+01	4.96E+01	6.64E+00	4.66E+03	6.43E+01
n induced p.c.		(p.e. n^{-1}cm^2)	r.i.p.e.	σ (keV)	r.i.p.e.	σ (keV)	r.i.p.e.	σ (keV)	r.i.p.e.	σ (keV)
1	10×10×1.5	4.48E+00	1.36E-01	3.47E-01	1.95E-01	4.17E-01	1.25E-01	3.33E-01	1.10E+00	9.88E-01
2	10×10×3	8.96E+00	2.71E-01	4.91E-01	3.91E-01	5.90E-01	2.50E-01	4.71E-01	2.19E+00	1.40E+00
3	10×10×5	1.49E+01	4.52E-01	6.34E-01	6.52E-01	7.61E-01	4.17E-01	6.09E-01	3.66E+00	1.80E+00

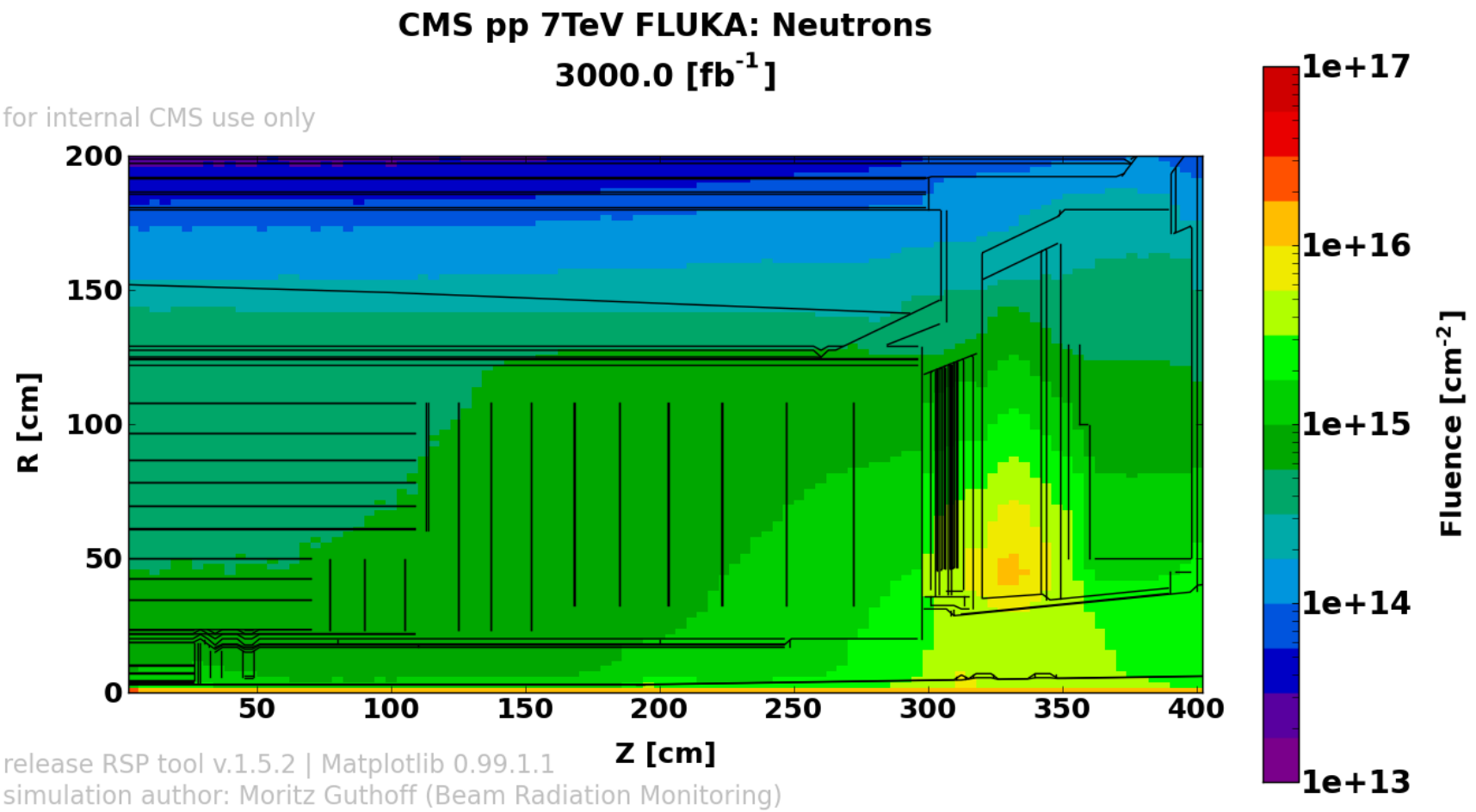
Summary

- Gamma-ray and neutron induced photocurrent was measured for long LYSO crystals and used to extract radiation induced photoelectron number in the readout gate for LYSO+SiPM package. Its variation is used to extract radiation induced readout noise.
- While radiation induced readout noise is negligible because of high light output of LYSO crystals, the number of SiPM pixels fired by radiation is found to be less than 200 at the barrel and several thousands at the endcaps. Further investigation with LYSO+SiPM under radiation is needed.
- At HL-LHC, the dominant contribution to radiation induced photocurrent is from gamma-rays, not neutrons.

Ionization Dose for HL-LHC



Neutron Fluence for HL-LHC



Charged Hadron Fluence for HL-LHC