Neutron Induced Photocurrent and Readout Noise for BTL LYSO+SiPM

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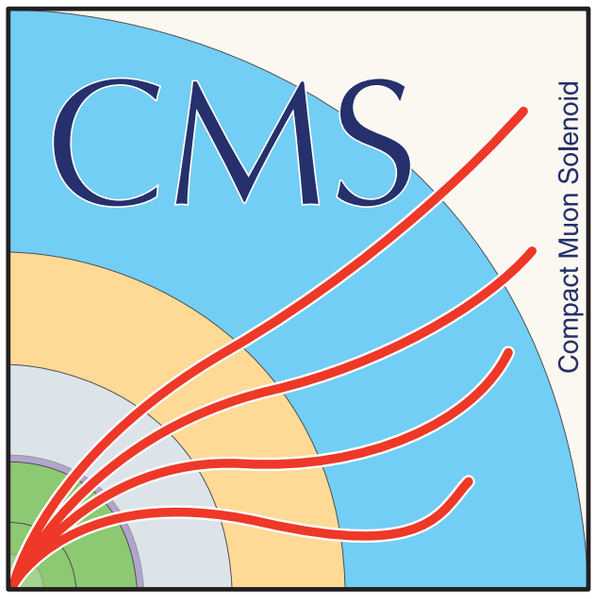


November 13, 2019

BTL sensor meeting

Caltech

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.**

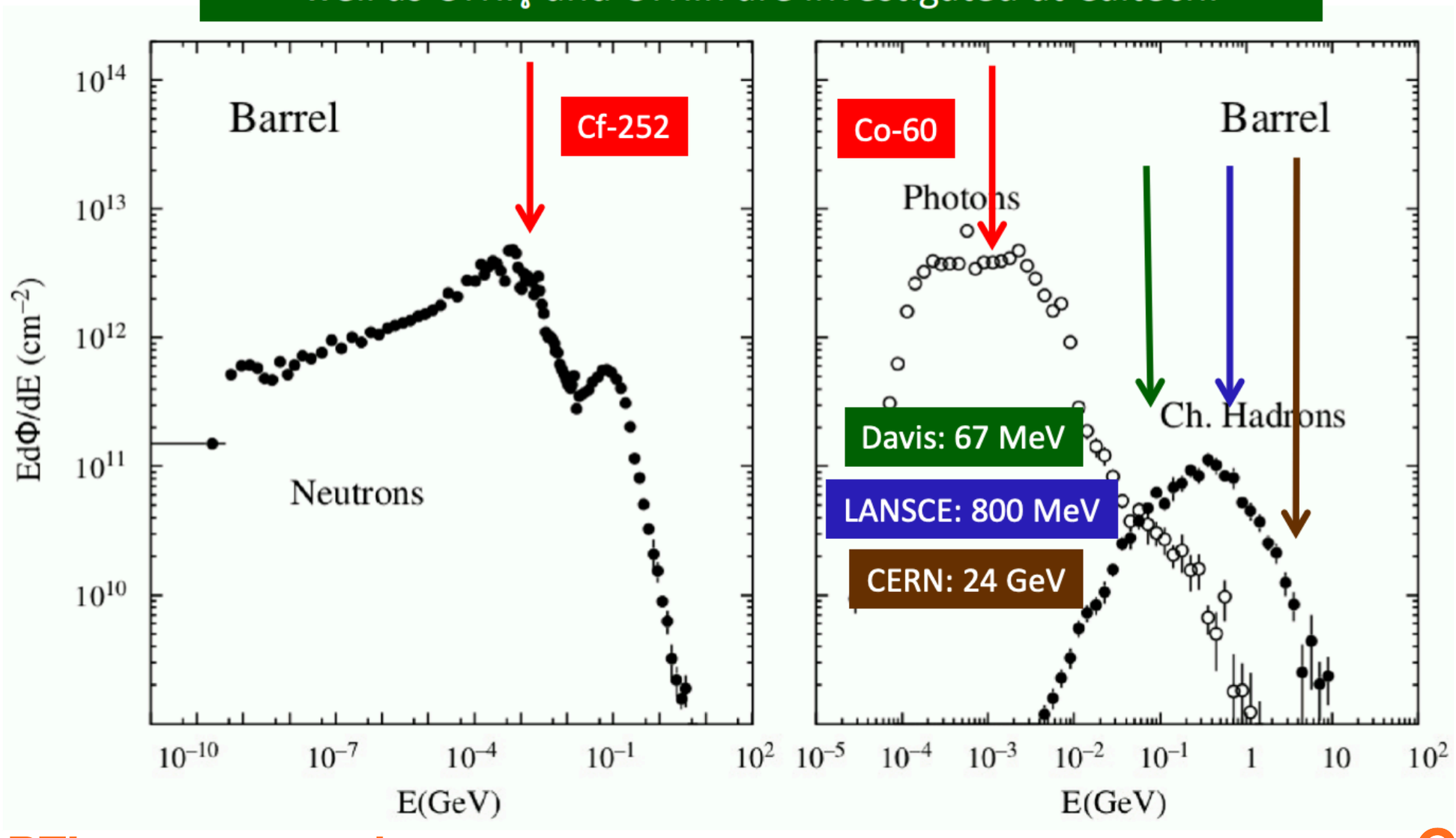
Introduction

- Previous reports:
  - RIN:γ data by Chen Hu on Oct 02 BTL sensor meeting: link :

    RIN:γ values show a consistent noise level at about thirtyish keV, which is negligible as compared to the 4.2 MeV MIP signal.
    - Characterization of 60 LYSO bars from 3 vendors for radiation damage tests by Chen Hu on Oct 16 BTL sensor meeting: link
- Today: Results for RIN:n
- CTR:γ and CTR:n will follow soon

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.

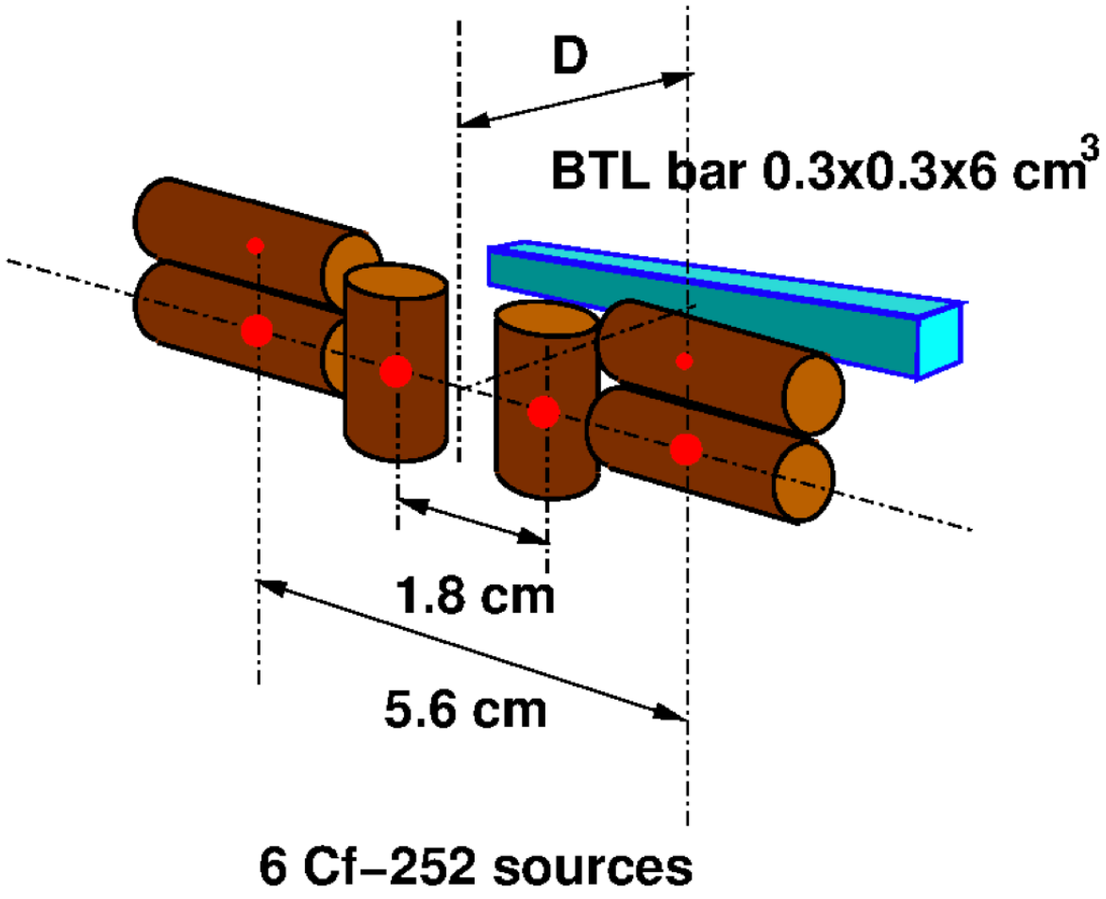


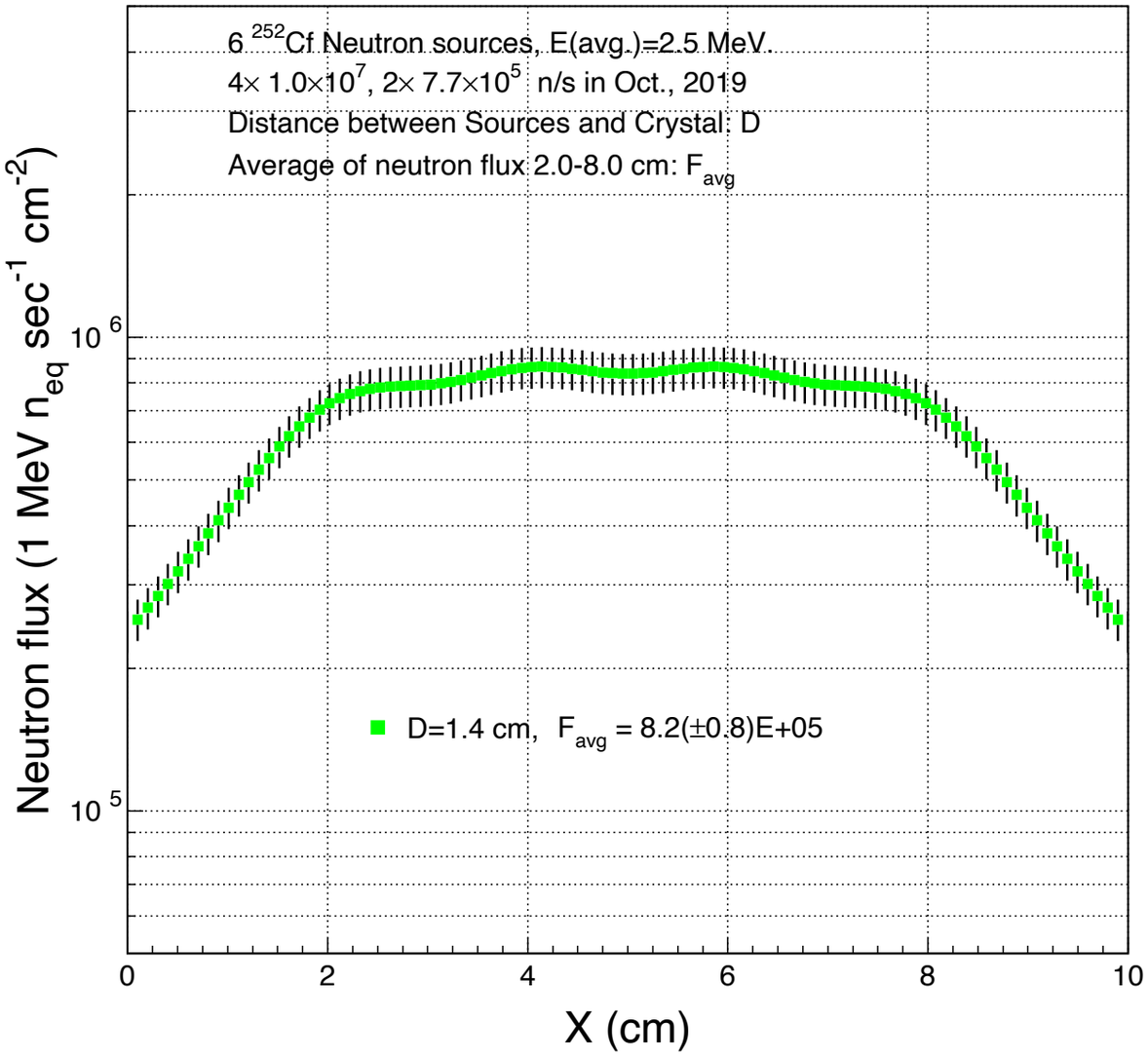
Radiation expected by CMS BTL

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

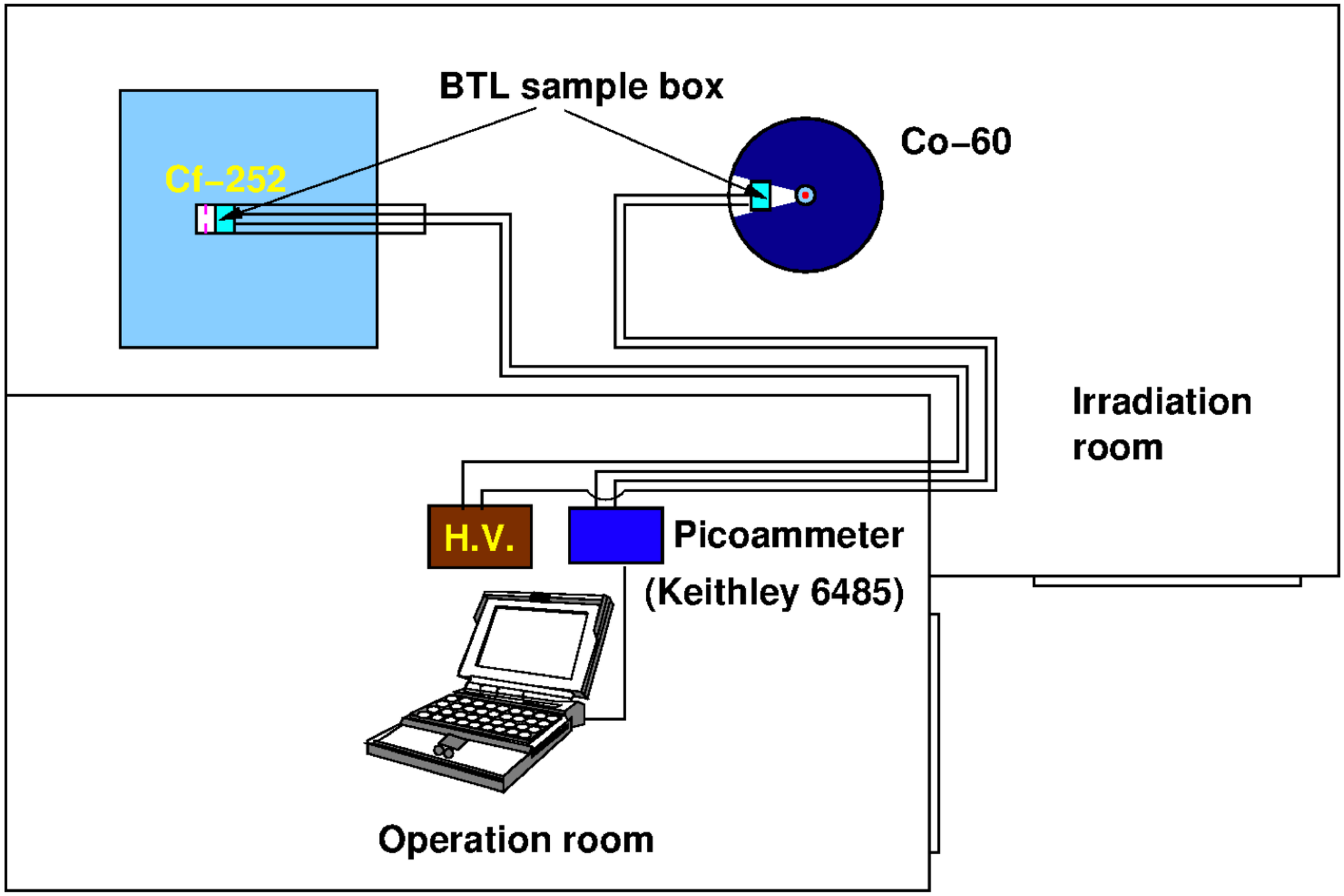
Neutron flux





- Six $^{252}Cf\ neutron\ fluence : 8.2 \pm 0.8 \times 10^5\ [1\ MeV\ n_{eq}\ cm^{-2}s^{-1}]$, 10% uncertainly calculated by estimated position error of 1mm.
- Gamma dose rate is measured to be 2 rad/h , measured using a ionizing chamber

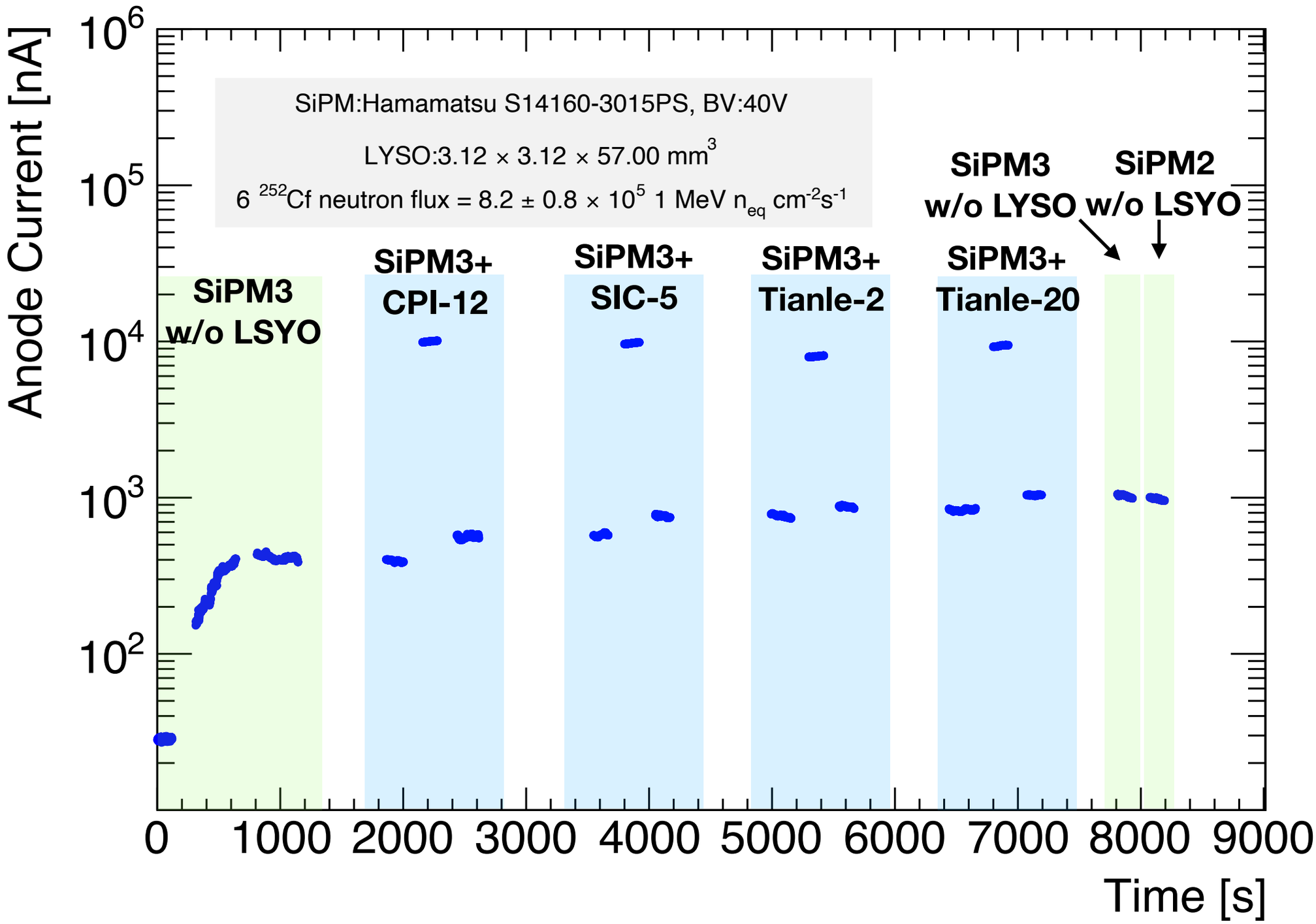
Experiment setup at Caltech



LYSO+SiPM setup and experiment procedures

- SiPM and LYSO:
    - Hamamatsu SiPM s14160-3015ps #3, breakdown voltage about 38 V, operating at 2 V over voltage, a gain of 2×10^5
    - LYSO surrounded by a Teflon block
    - Air gap coupling between to SiPM and LYSO
- Irradiation at room temperature
- Measure the current readout from SiPM before, during and after neutron irradiation
    - SiPM only without LYSO
    - SiPM + LYSO, tested 4 crystals in the order of CPI-12, SIC-5, Tianle-2, Tianle-20
    - Remove LYSO, SiPM only

Current evolution



Summary of measured current readout from SiPM

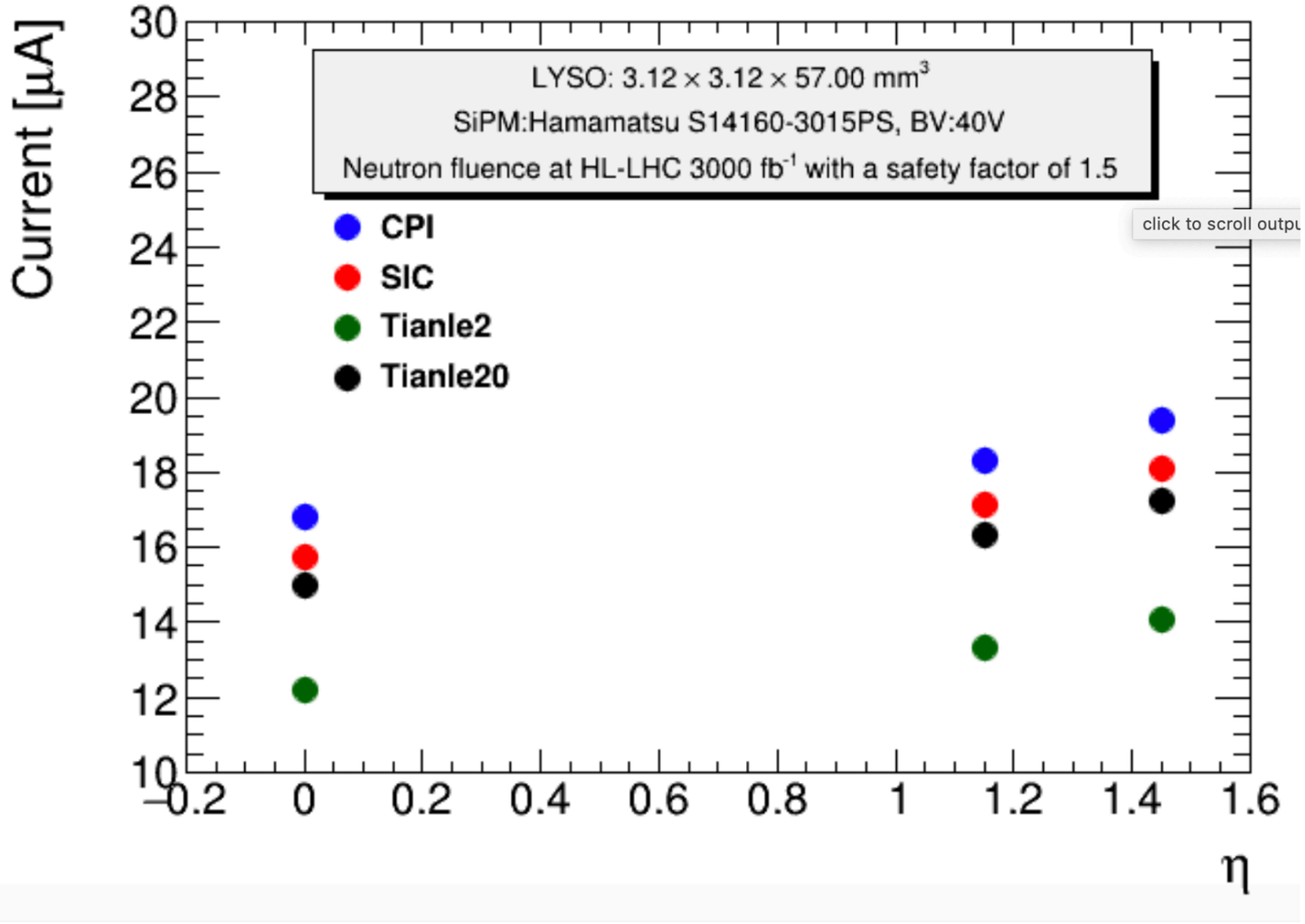
The current is an average of all data points taken (100-170 data points)

Crystal ID	current before irrad. [μA]	current during irrad. [μA]	current after irrad. [μA]
CPI-12	0.39	10.00	0.56
SIC-5	0.58	9.75	0.76
Tianle-2	0.76	8.02	0.88
Tianle-20	0.83	9.38	1.04

- **Clear observation of neutron induced readout noise:** during irradiation, readout current much higher than before/after irradiation
- **Radiation damage effect accumulated on SiPM:** readout out current higher after irradiation than before irradiation.

Expected current readout from SiPM at HL-LHC

- Gamma dose rate measured to be <= 2 rad/h. Subtract radiation induced noise from gamma to get the effect from neutron fluence
- Average current is scaled from the measured neutron-induced readout current (slide 10) to the neutron flux expected at three η regions, assuming the current has a linear dependency on the neutron flux.

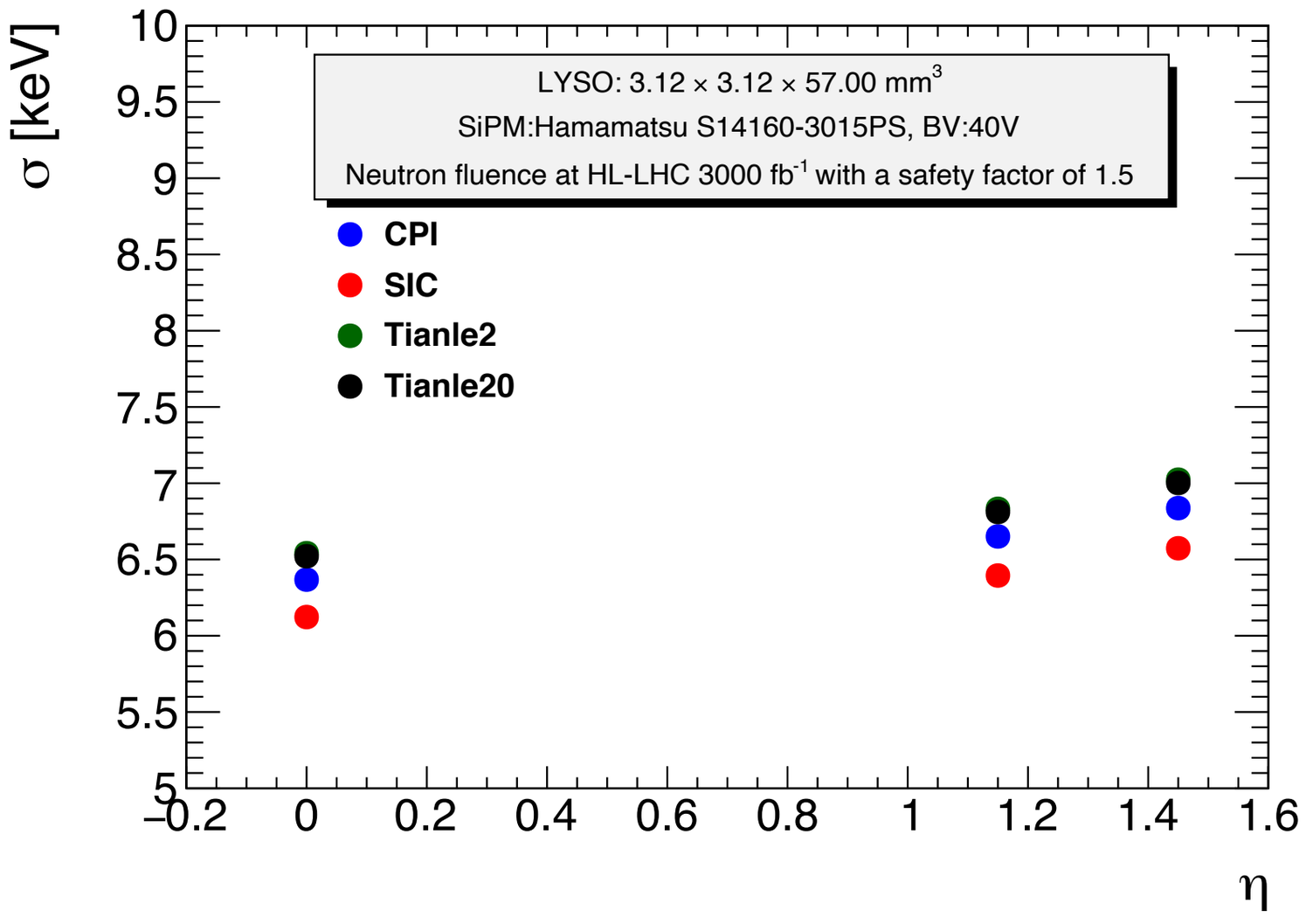


Neutron induced noise at HL-LHC

- **Neutron induced noise σ** estimated: about **7 keV**, using LO measured by Chen Hu, Slide10 of talk
- **Much smaller** than **γ induced noise of about 35 keV**

$$\sigma = \frac{\sqrt{Q}}{LO} = \frac{\sqrt{\frac{I \times time}{Gain_{SiPM} \times e}}}{LO}\ keV,$$

$$time = 200\ ns,\ e = 1.6 \times 10^{-19}\ C$$



LO in 200 ns gate measured with PMT:

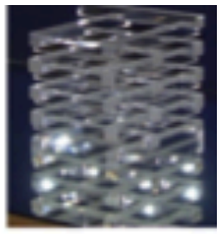
Crystal ID	Corrected SiPM L.O. (p.e./MeV)*
CPI-12	1609
SIC-5	1619
Tianle-2	1336
Tianle-20	1483

Summary

- Neutron induced readout noise:
  - measured to have an upper limit of 7 keV for BTL at HL-LHC
  - much smaller than gamma induced noise
- Both neutron and gamma radiation induced readout noise are negligible compared to a MIP signal of 4.2 MeV.

Backup slides

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

https://indico.cern.ch/event/849043