CsI Light Output with SiPM Readout

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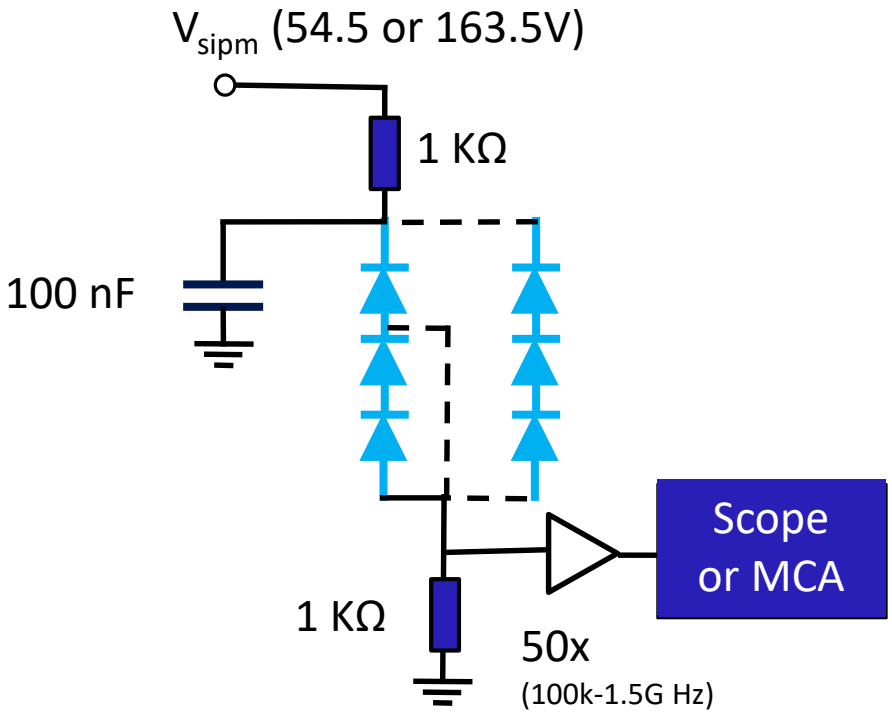
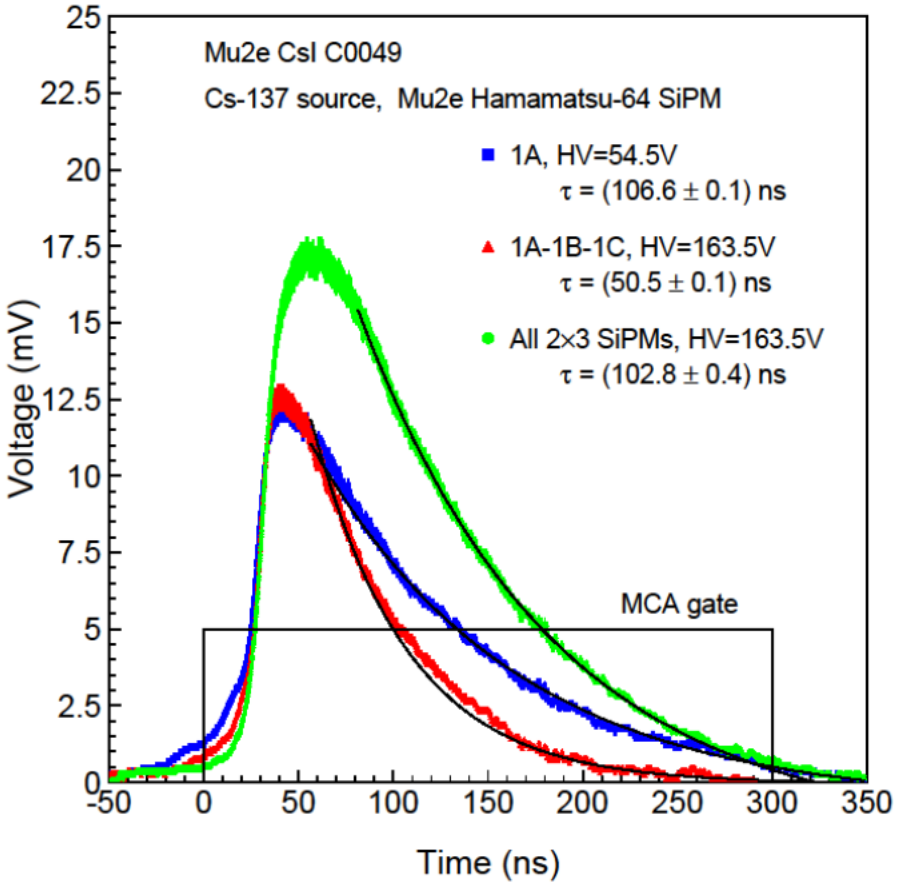
Introduction

- The PHS measured for a LYSO sample by a Mu2e Hamamatsu-64 SiPM in the 2 x 3 configuration at 162 V bias was reported on April 12, following which a 50 x wideband amplifier (Phillips Scientific) was added in the readout chain to increase gain.
- The entire readout chain, including x 50 amplifier, was calibrated by using (1) LED pulses for the 2x3 configuration at 163.5 V bias and (2) individual photoelectron peaks for 1 x 1 configuration at 54.5V bias.
- Light output and ration induced readout noise were measured for six CsI crystals, and were compared to the PMT data.

Setup: SiPM + 50 x Amplifier

Decay of Ham-64 in 1/3/2×3 is 107/50.5/103 ns respectively for CsI light

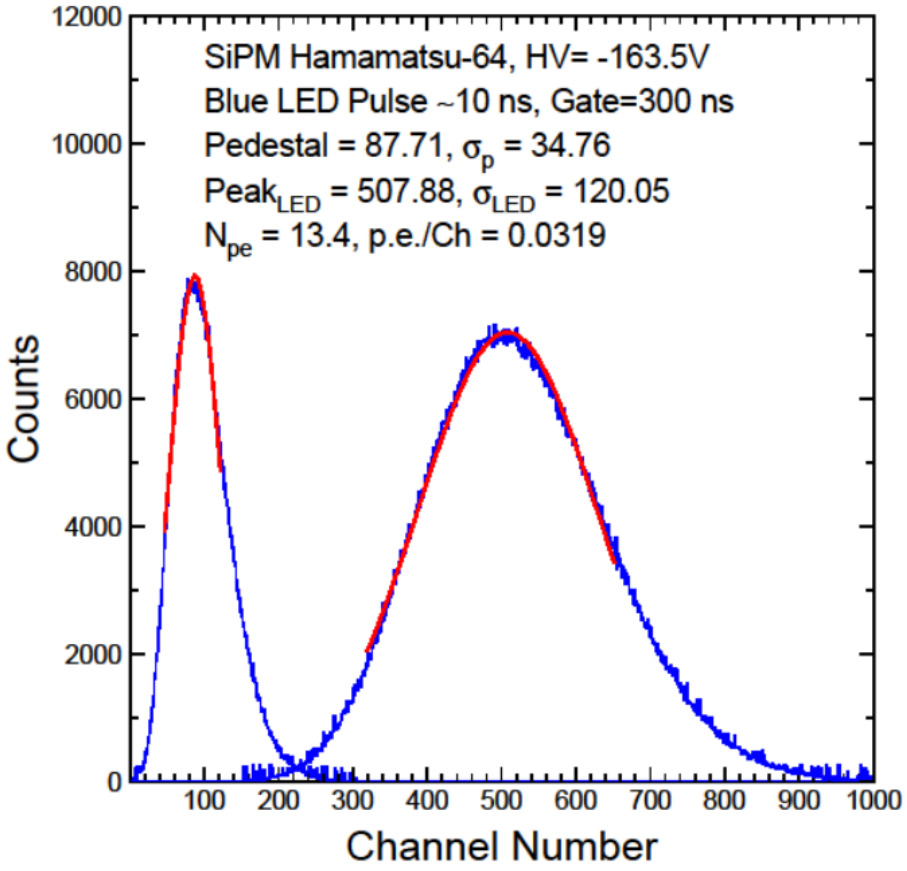


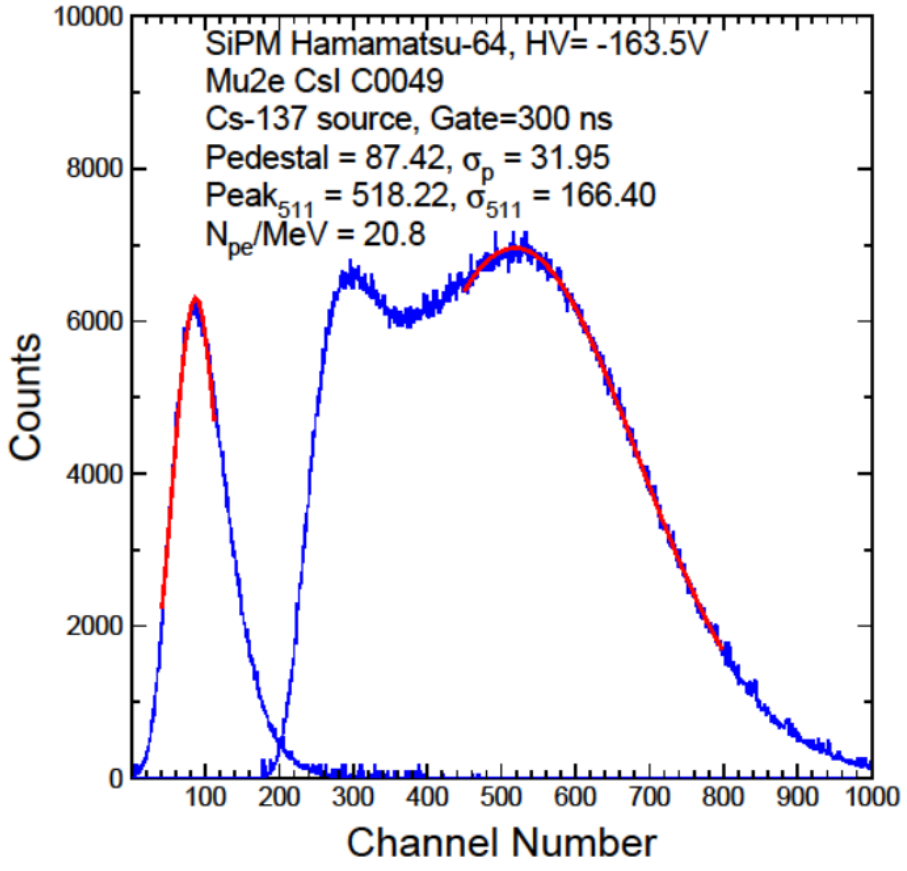


Improvement in decay time is less compared to 87.5/43.6/63.9 ns for 10 ns pulse

SiPM 2x3: Calibration by LED & CsI PHS

Calibration @ 163.5 V: $N_{P.E.}$/ADC = 0.0319, σ_{noise} = 1 electron
S-G CsI C0049: Light output = 20.8 p.e./MeV, σ_{noise} = 48 keV

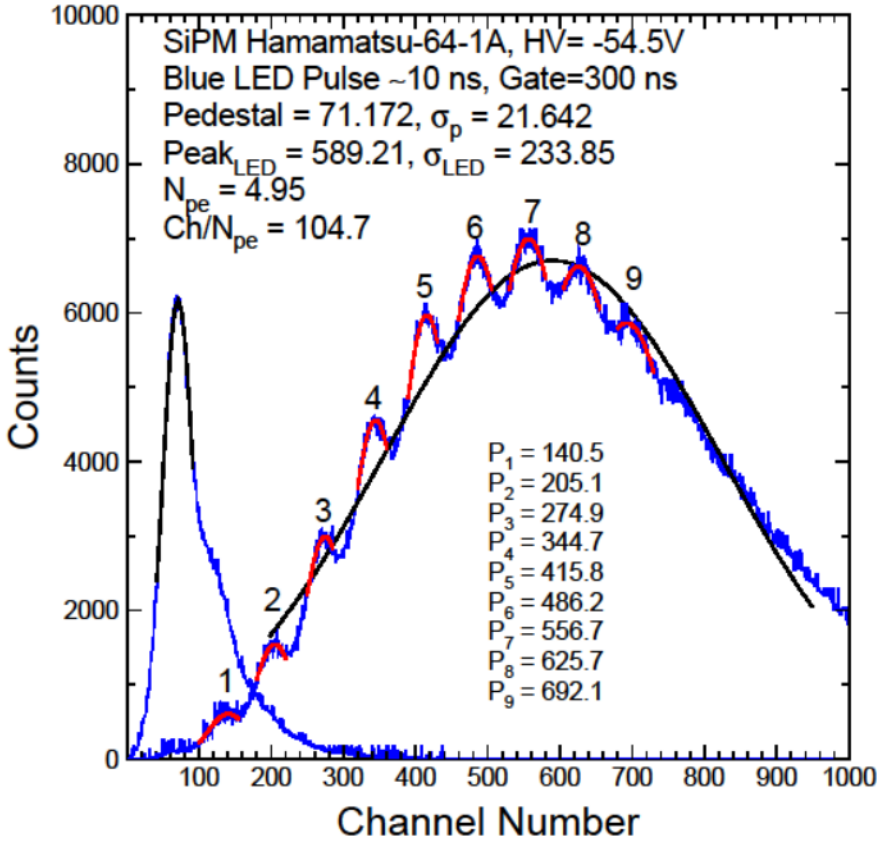


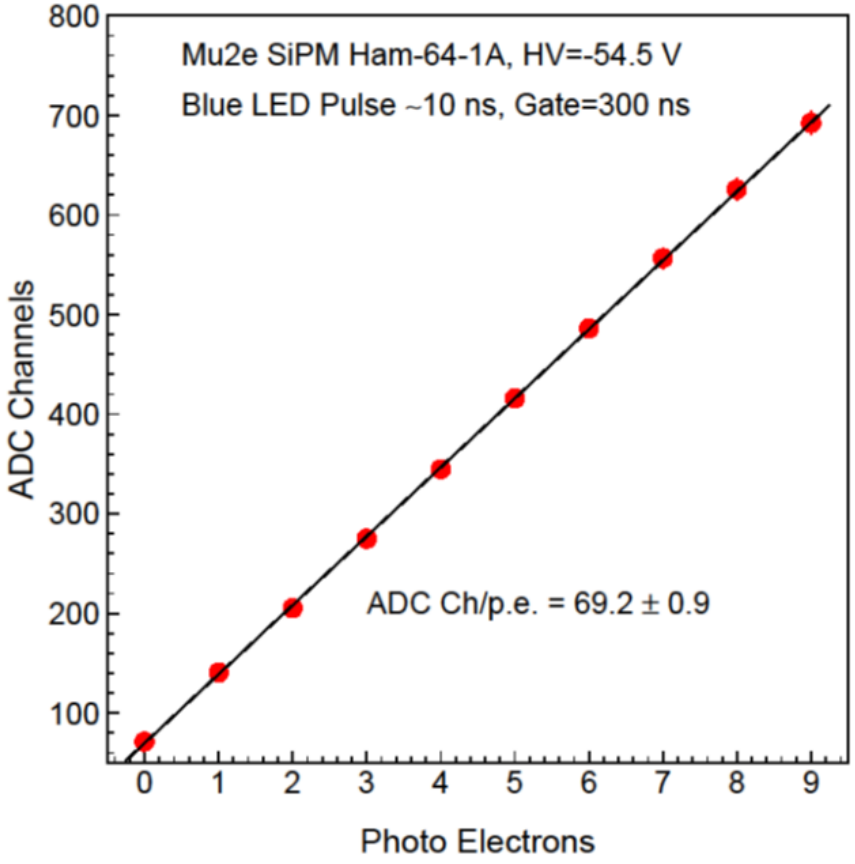


This calibration shows the low limit because of the excess noise in SiPM readout

SiPM 1 x 1: Calibration by p.e. Peaks

Calibration is ADC/p.e. = 69.2 by individual p.e. peaks, and is 104.7 by LED pulse width, indicating an excess noise factor (ENF) of 1.5, which is higher than 1.2 of PMT
This result is consistent with http://dx.doi.org/10.1088/1748-0221/8/02/P02017.

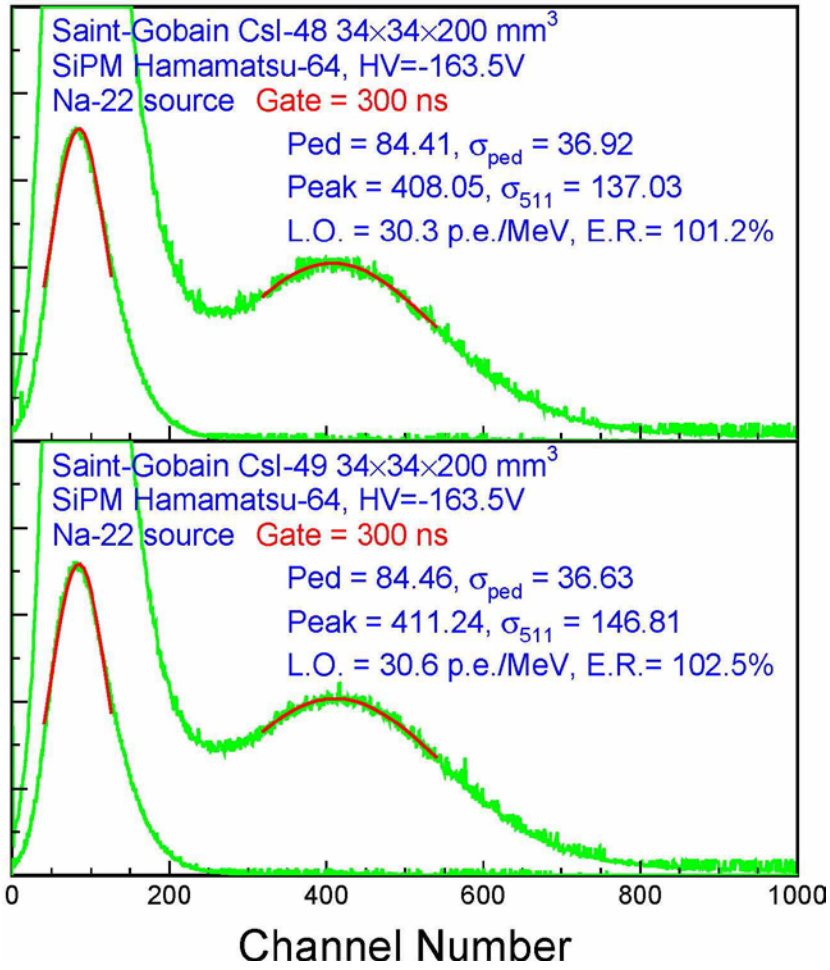


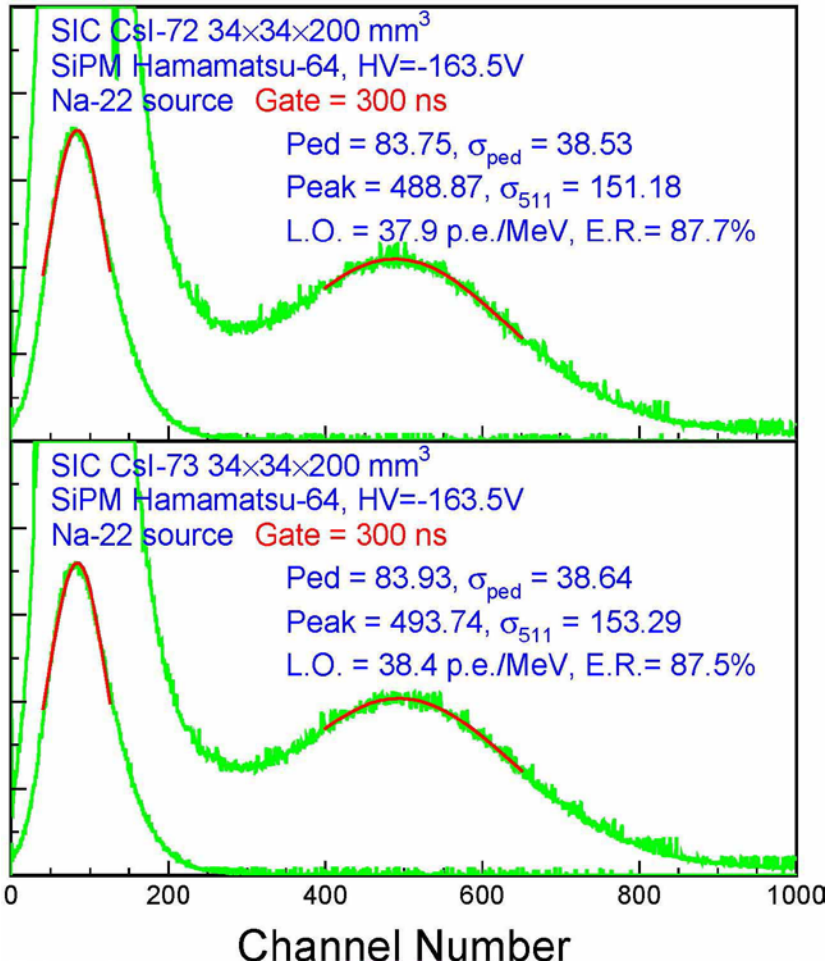


Individual p.e. peaks were not observed in the 2 x 3 configuration
This ENF of 1.5 applied to LED calibration shows the up limit of LO

CsI PHS with SiPM: S-G and SIC

Light output: 30 to 38 p.e./MeV σ_{noise} = 60 to 50 keV

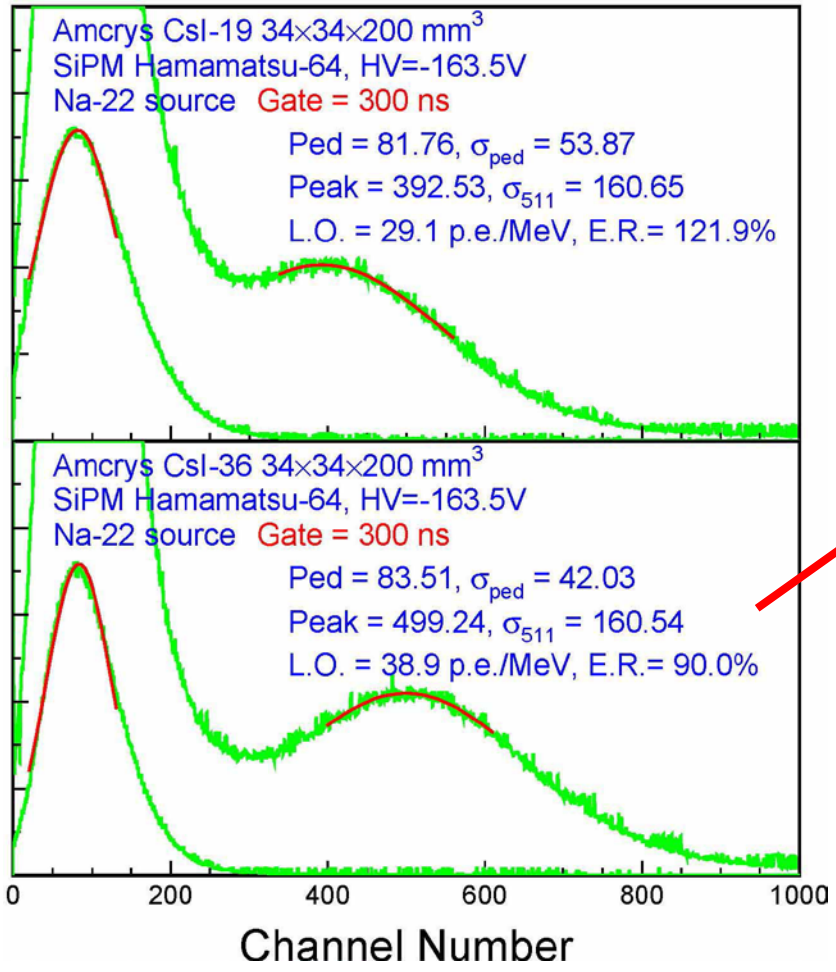


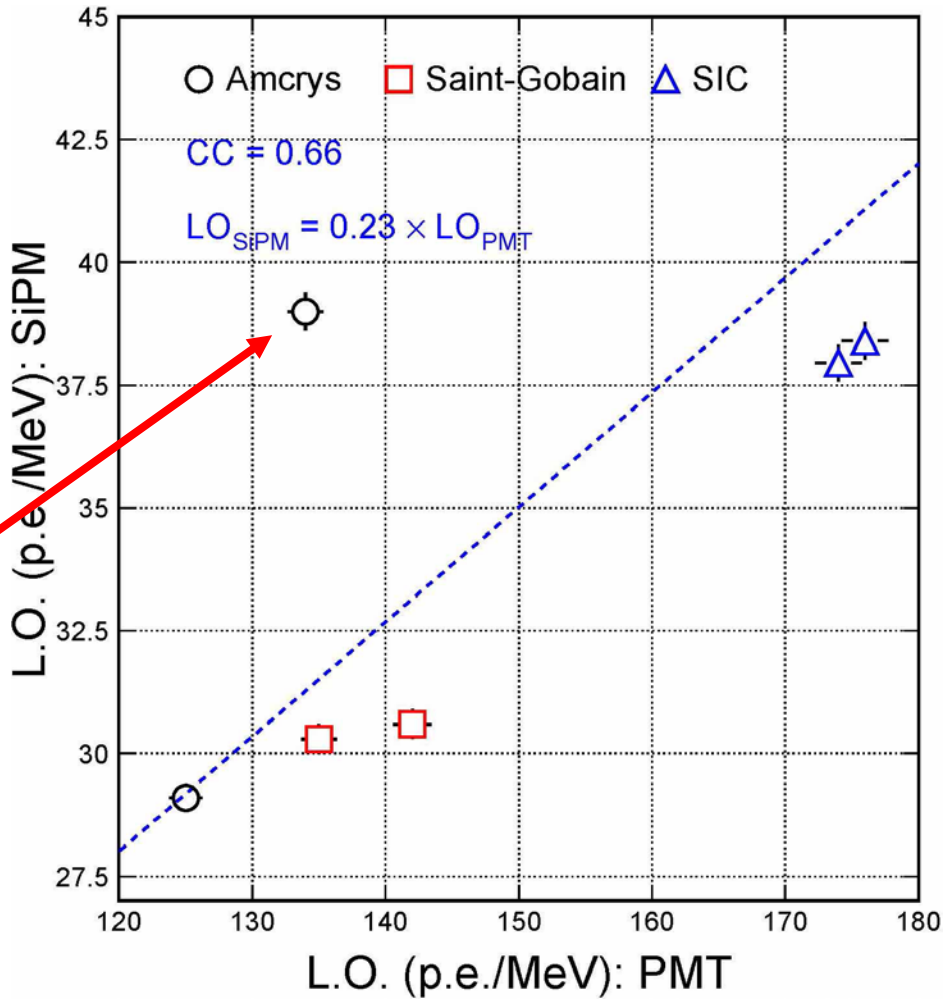


CsI PHS: Amcrys & Correlation

Light output: 29 to 39 p.e./MeV
σ_{noise} = 88 to 52 keV

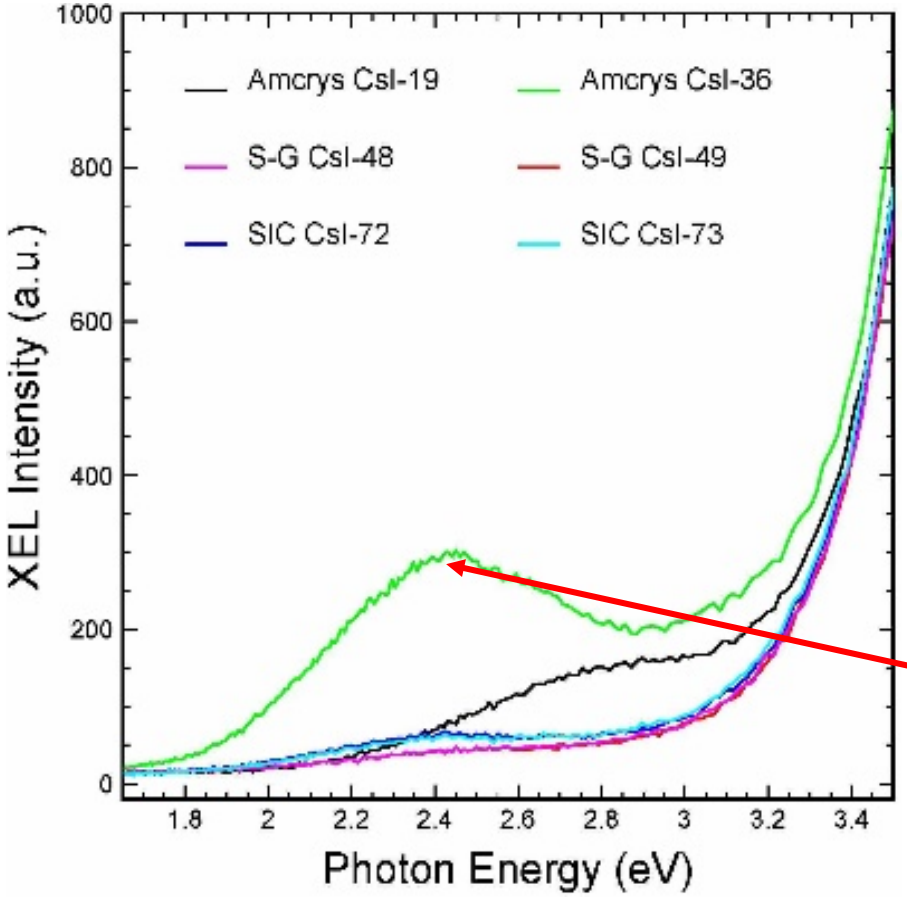
Good correlation versus PMT data, excluding Amcrys-36

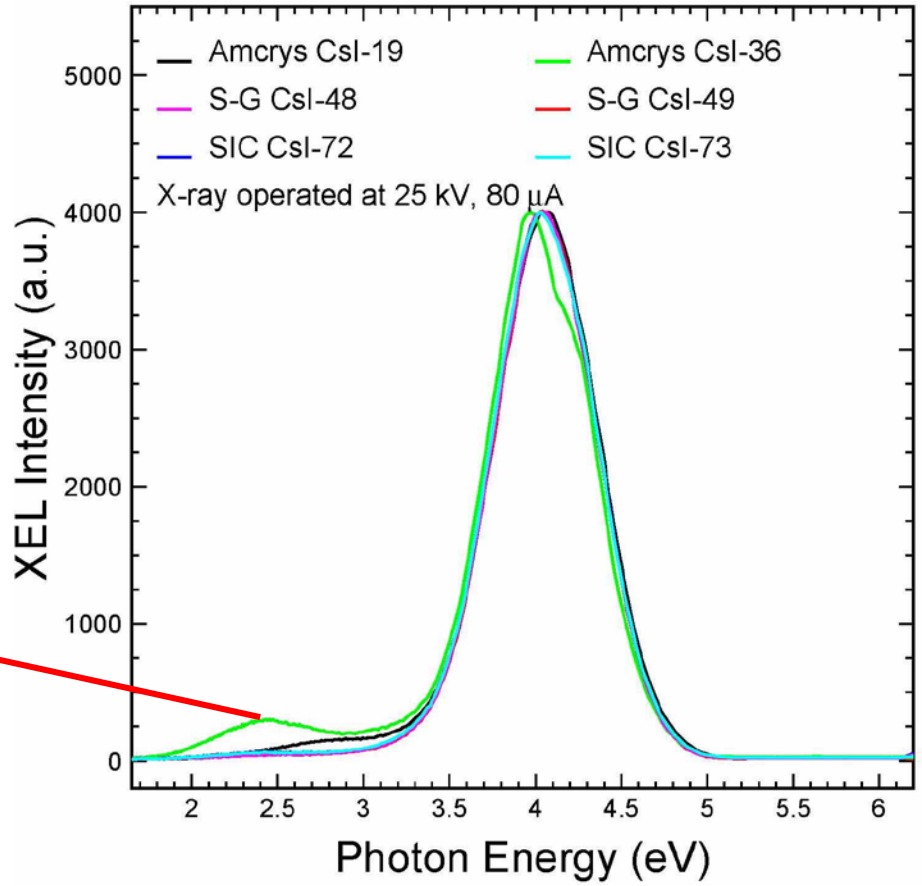




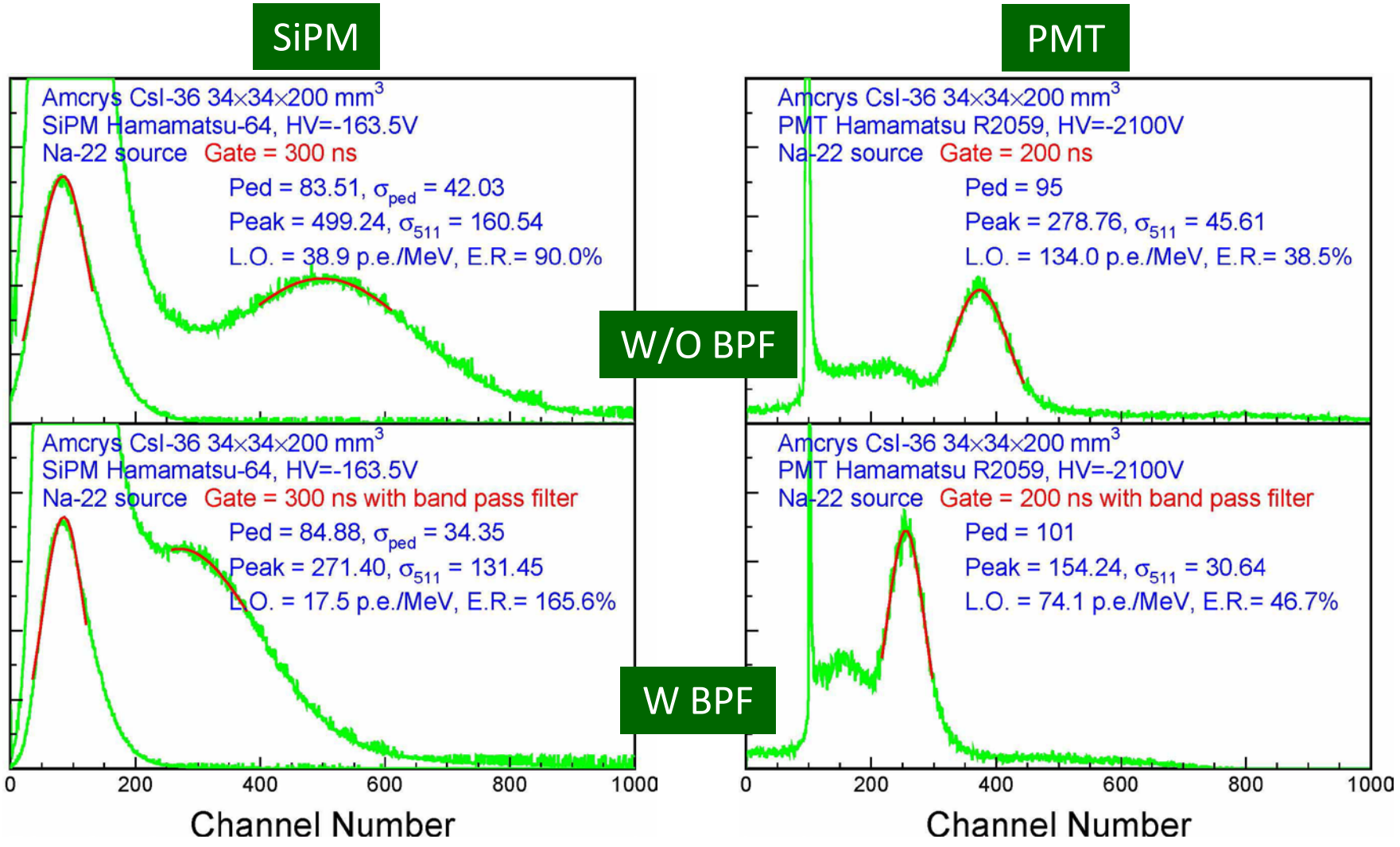
XEL of CsI Crystals

Amcrys-36 has a large emission peak at 500 nm



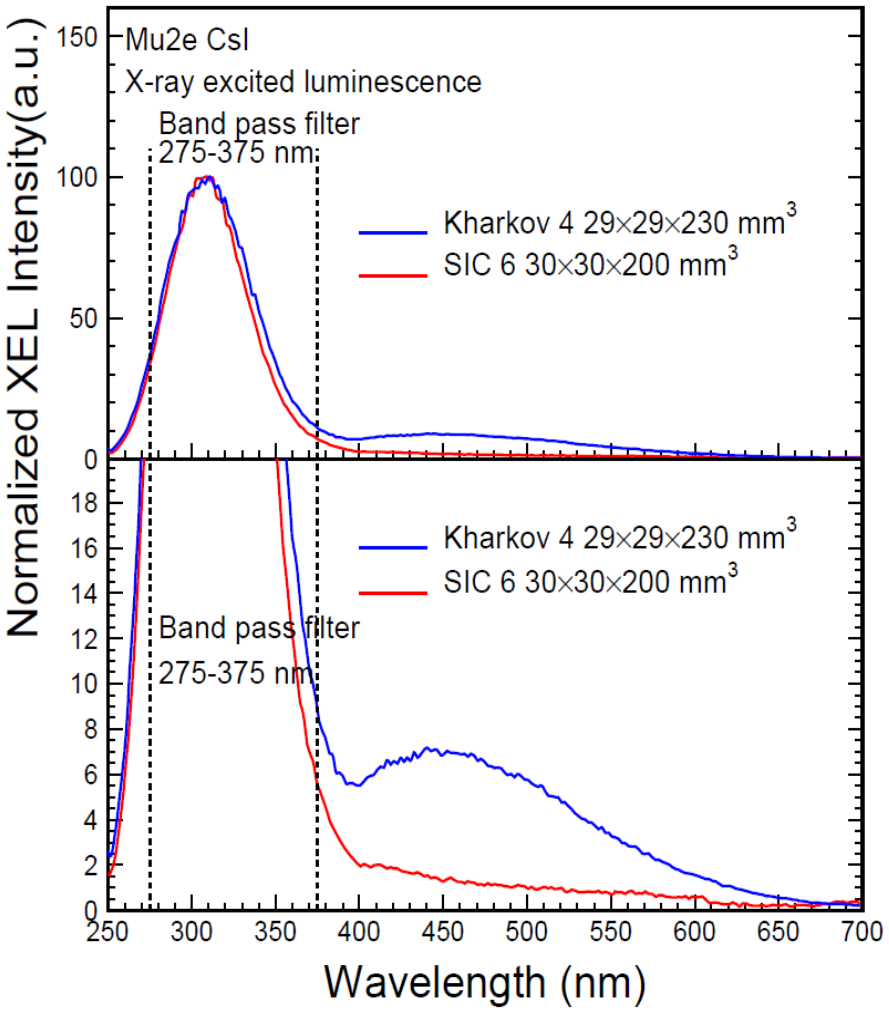


Amcrys-36 PHS with & without BPF (275 nm-375nm) by SiPM and PMT

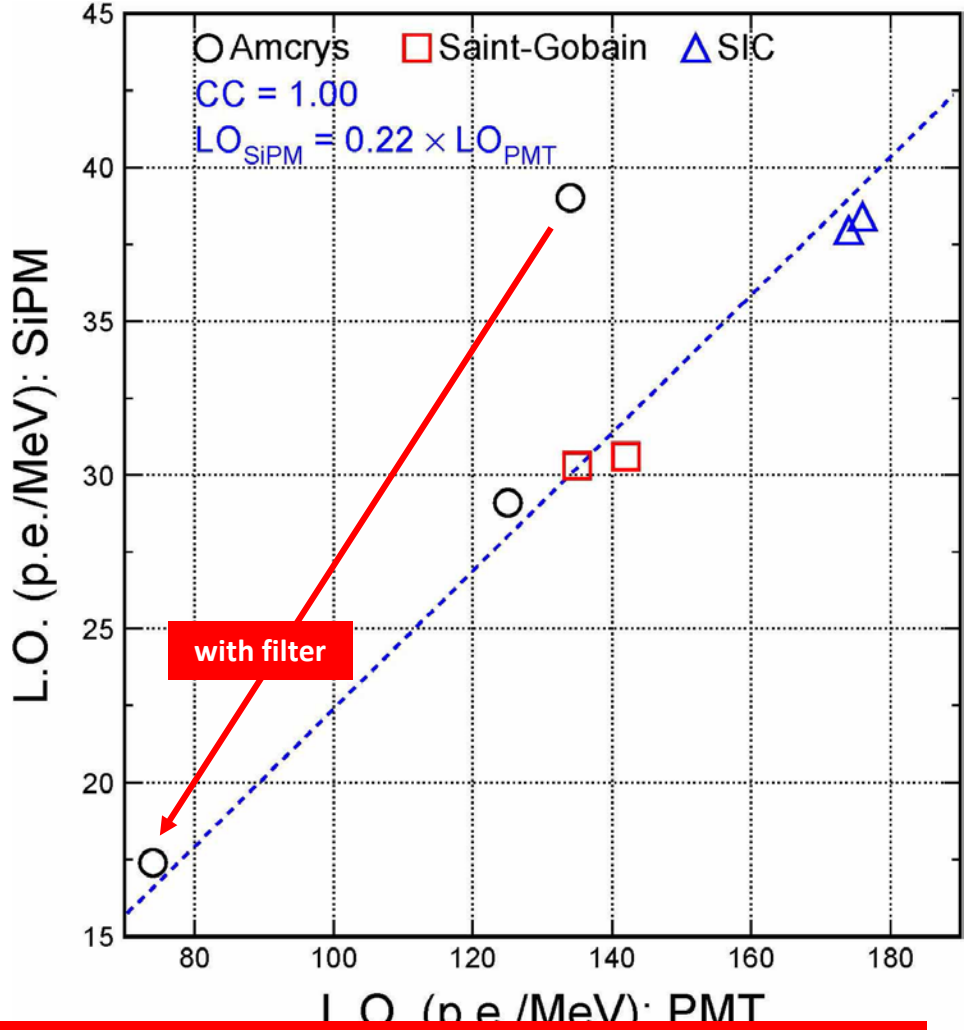


BPF and Correlation: SiPM vs. PMT

Paper N07-9 in NSS16 Conf. Rec.



Perfect correlations: SiPM vs. PMT



18.6% of CsI end face covered by SiPM indicates SiPM PDE/PMT QE = 0.8 to 1.2

Summary: CsI LO with SiPM Readout

Amcrys

Crystal ID	Batch Number	Coupling end	LO_{SiPM} (p.e./MeV)	LO_{PMT} (p.e./MeV)	LO_{SiPM}/LO_{PMT}
C0019	015	a	29.1	125	23.3%

Saint-Gobain

Crystal ID	Batch Number	Coupling end	LO_{SiPM} (p.e./MeV)	LO_{PMT} (p.e./MeV)	LO_{SiPM}/LO_{PMT}
C0048	A11823	b	30.3	135	22.4%
C0049	A11819	b	30.6	142	21.5%
Average			**30.5**	**139**	**22.0%**
RMS			**0.5%**	**2.5%**	**2.0%**

SIC

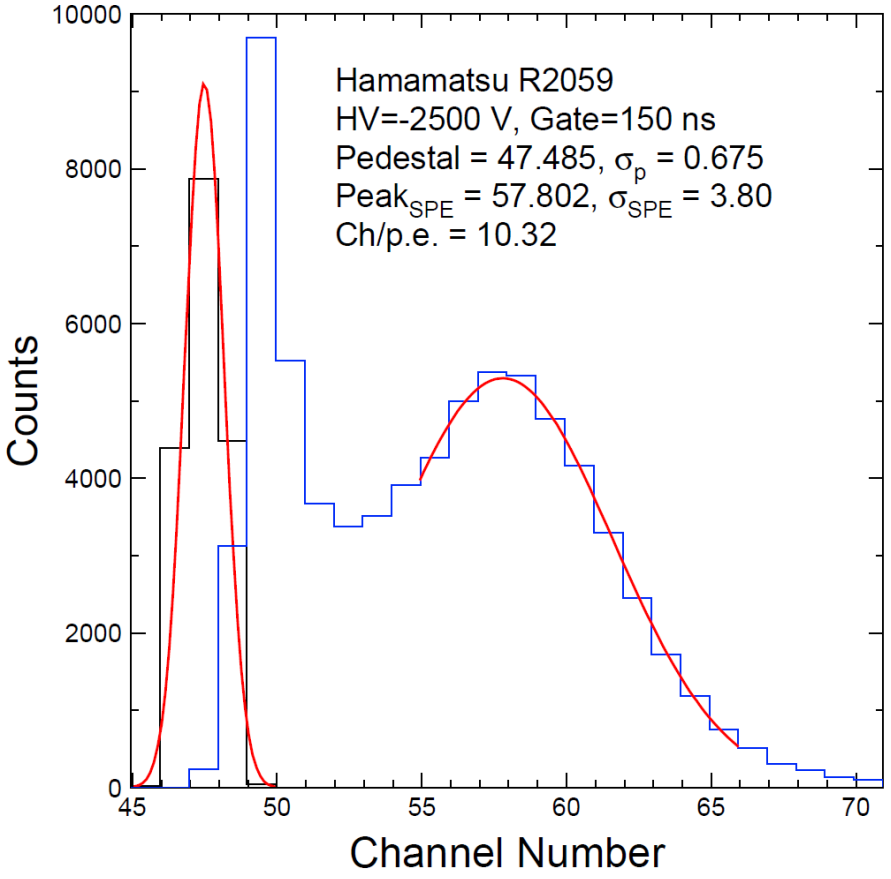
Crystal ID	Batch Number	Coupling end	LO_{SiPM} (p.e./MeV)	LO_{PMT} (p.e./MeV)	LO_{SiPM}/LO_{PMT}
C0072	2016 a22	a	37.9	174	21.8%
C0073	2016 a21	a	38.4	176	21.8%
Average			**38.2**	**175**	**21.8%**
RMS			**0.7%**	**0.6%**	**0.1%**

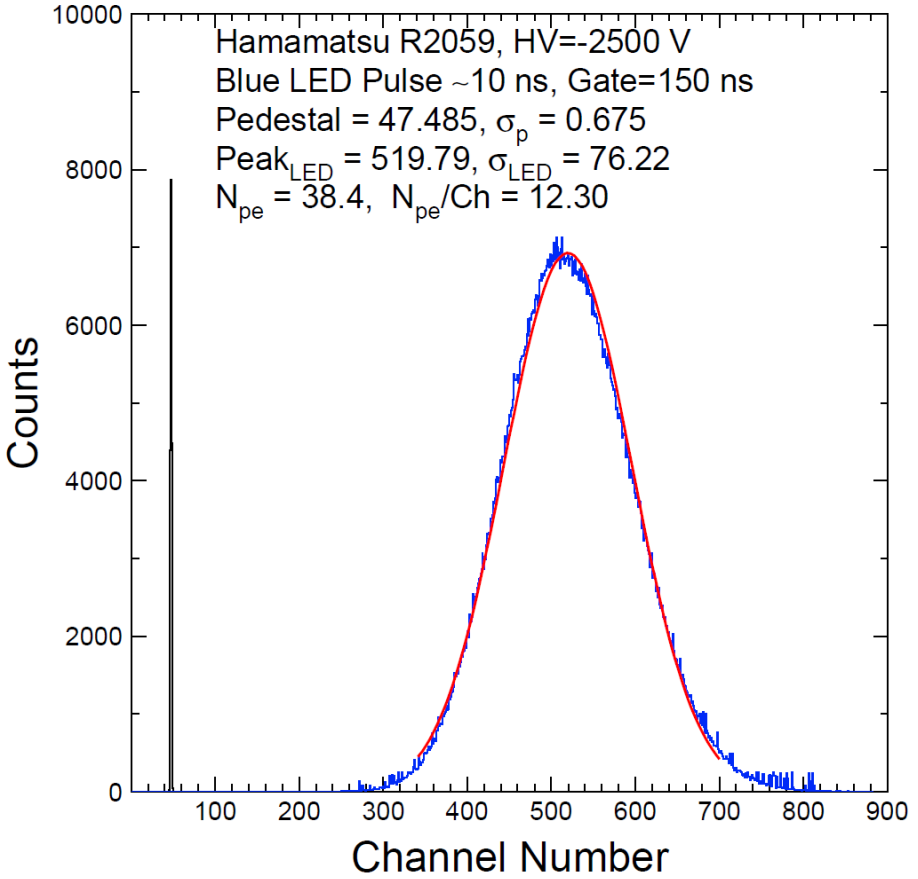
Summary

- PHS are measured by a Mu2e SiPM Hamamatsu-64 in 2 x 3 at 163.5 V bias for six CsI crystals. The results show a light output of 20 to 25 p.e./MeV by using calibration of the LED pulse width, or 30 to 38 p.e./MeV after taking into account the ENF of 1.5 determined for the 1 x 1 SiPM configuration with individual p.e. peaks. The readout noise is 60 to 50 keV.
- The light output measured by SiPM has a perfect correlation with the PMT data after excluding a CsI with significant slow component peaked at 500 nm. Inserting a BPF brought back the correlation for that particular crystal.
- Taking into account 18.7% area coverage by SiPM, the ratio between SiPM PDE and PMT QE is between 0.8 and 1.2.
- To be investigated:
  - QE and PDE response of the PMT and SiPM for the CsI fast and slow scintillation light.

Single P.E. Calibration: R2059 PMT

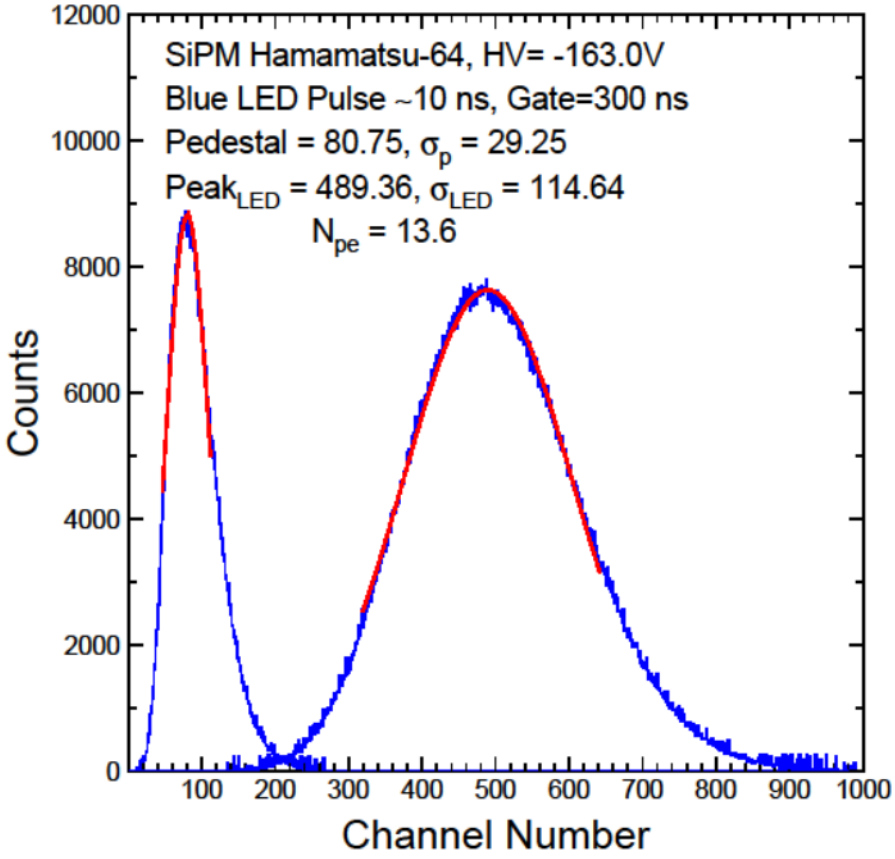
An ENF of 1.2 found between SPE and light pulse width calibrations for R2059 PMT, which is consistent with the Hamamatsu data sheet

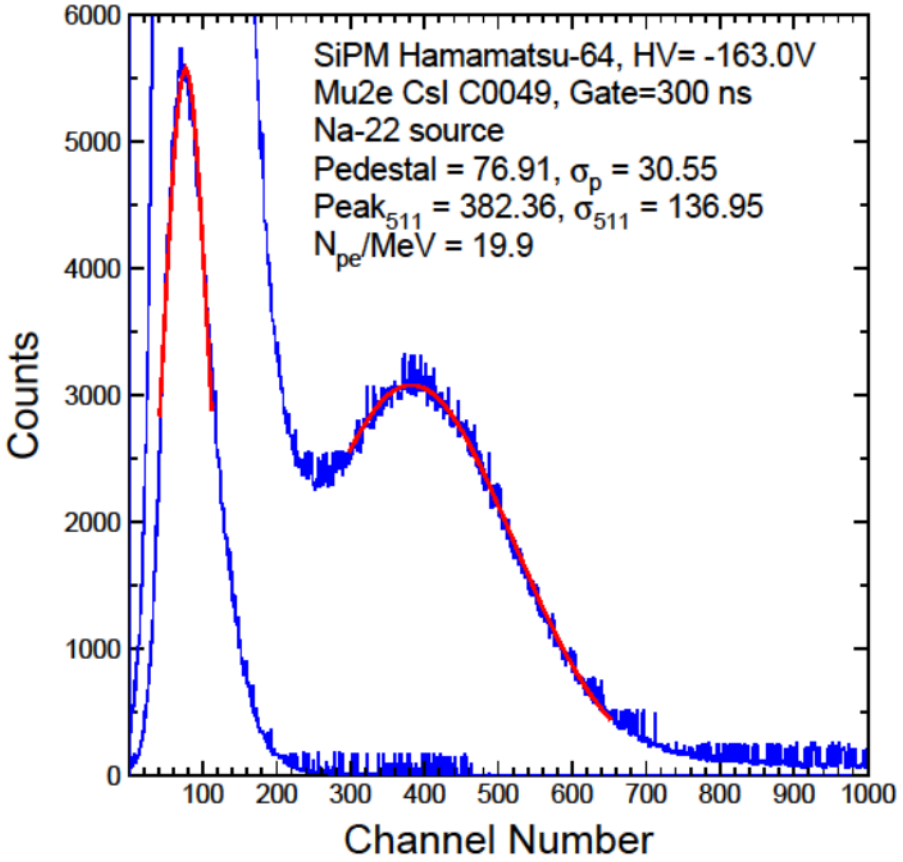




Readout Calibration (163 V) & CsI PHS

Calibration @ 163 V: $N_{p.e.}$/ADC = 0.0333, σ_{noise} = 0.97 electrons
S-G CsI C0049: light output = 19.9 p.e./MeV and σ_{noise} = 49 keV





LO: 19.9 & 20.6 p.e./MeV at 163 & 163.5 V maybe due to different PDE