QE/PDE of UV Photodetectors for Barium Fluoride Readout

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Introduction

Because of its ultrafast scintillation peaked at 220 nm with less than 0.6 ns decay time, barium fluoride (BaF_2) crystals have attracted a broad interest in the communities pursuing ultrafast calorimetry for future high energy physics and nuclear physics experiments and GHz hard x-ray imaging for future x-ray free electron laser facilities.

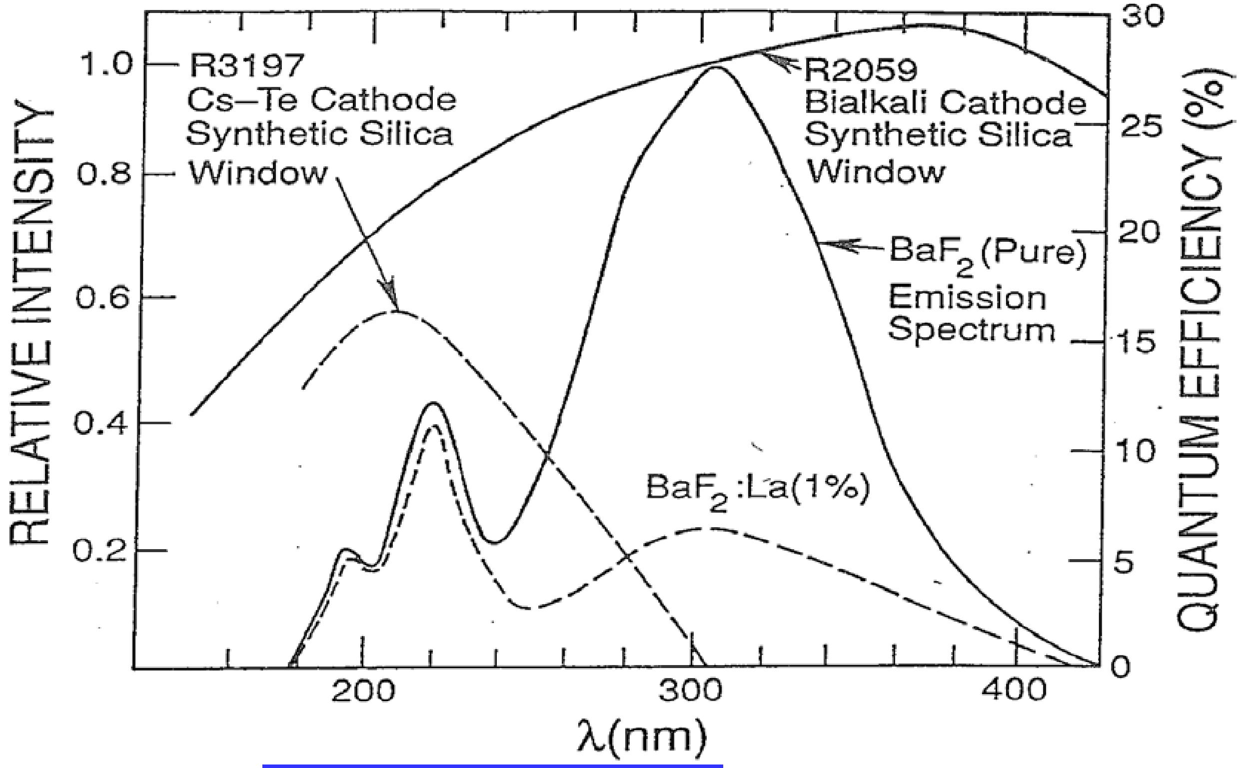
One crucial issue of BaF_2 is its slow scintillation peaked at 300 nm with a 600 ns decay time and an intensity of much higher than the fast component, which causes pileup noise in a high rate environment.

R&D has been carried out along two approaches to suppress the slow component: 1) selective doping in BaF_2, and 2) development of solar-blind UV photodetectors sensitive to the fast component but not the slow component.

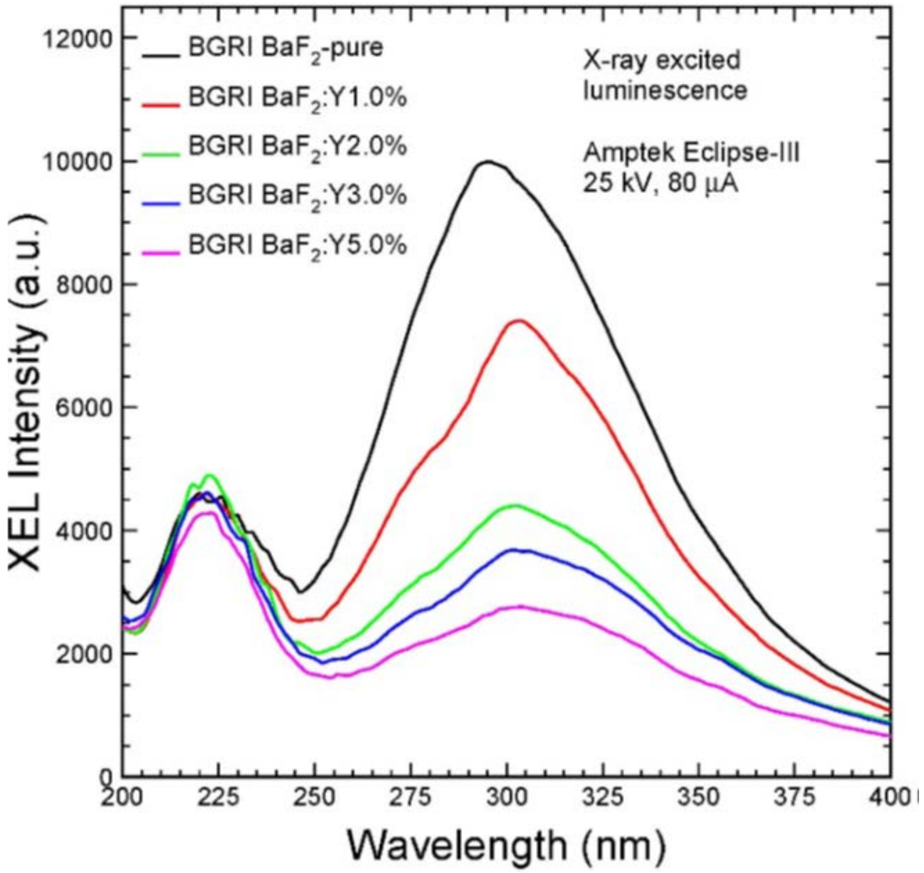
We report results of quantum efficiency (QE) and photon detection efficiency (PDE) measurements for several photodetectors down to 200 nm and their corresponding figures of merit for detecting the BaF_2 ultrafast component.

Emission Spectra of BaF_2 and BaF_2:Y

Yttrium doping was found recently to suppress the slow component while maintaining the ultrafast component. Selective readout of BaF_2 ultrafast scintillation light with UV detectors was investigated.



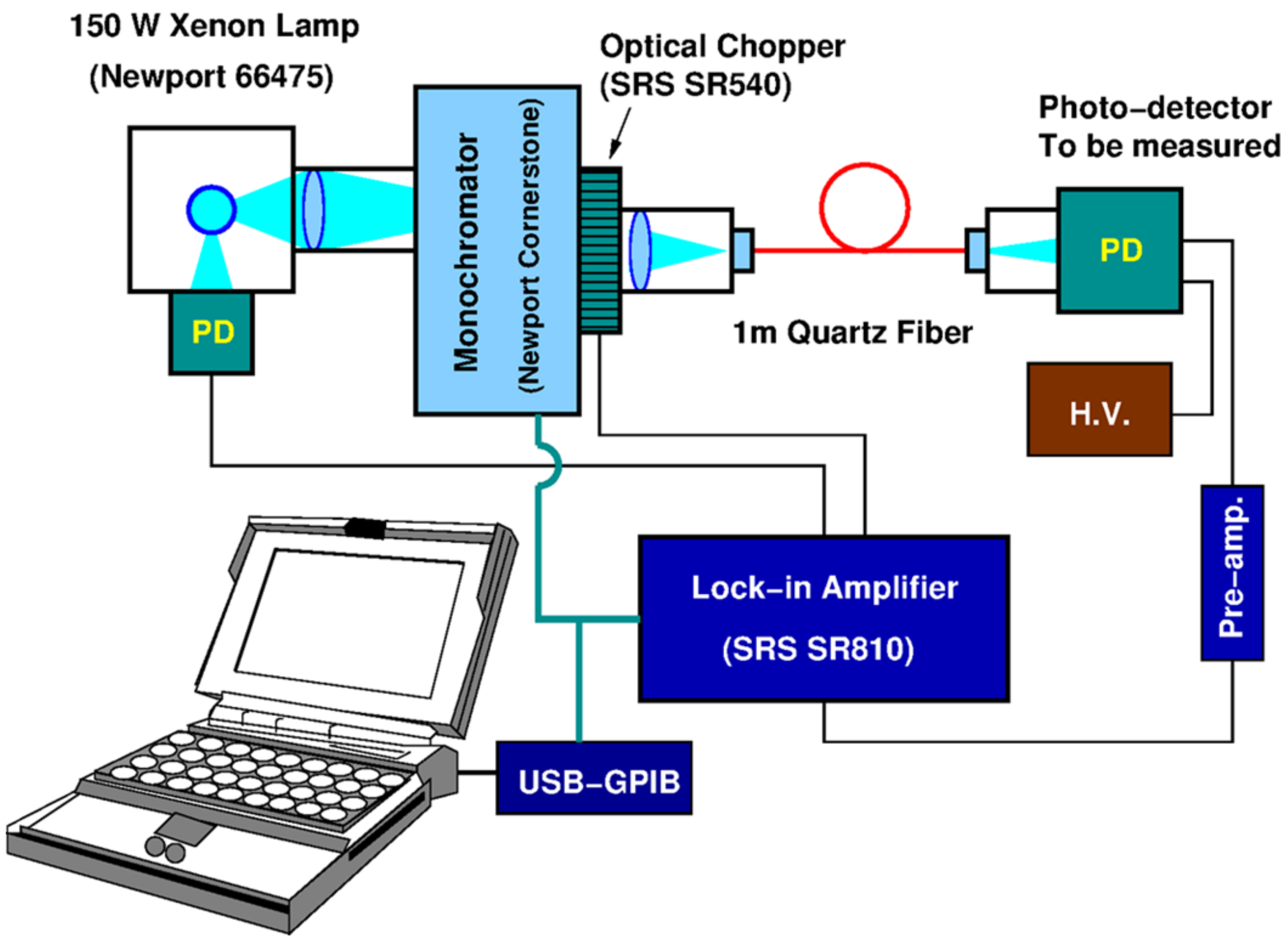
NIM B61, 61-66, 1991

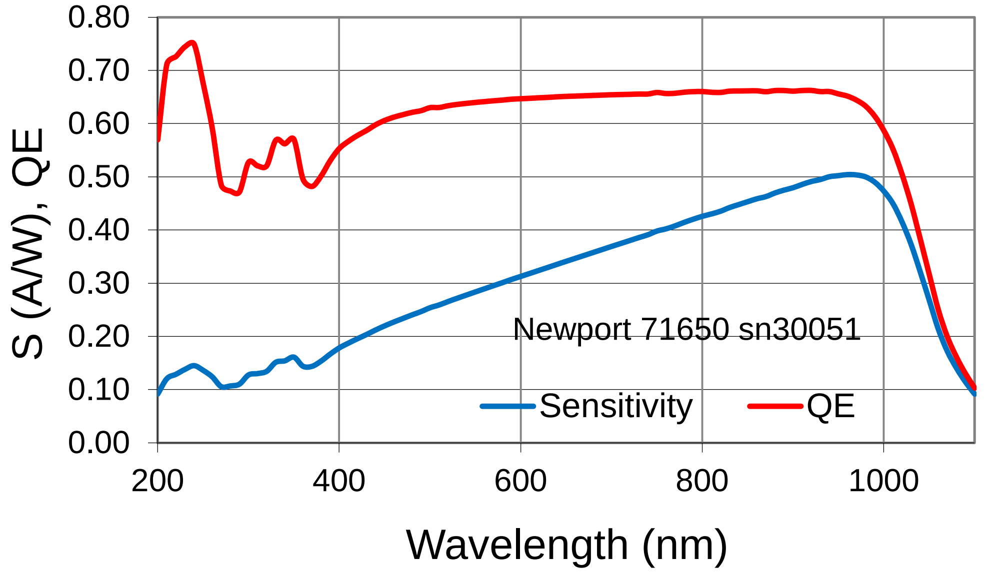


UV Photodetectors Investigated

Company	Photodetector	Model	Qty	Product
Hamamatsu	PMT	R2059	4	Commercial
Hamamatsu	VUV3 MPPC	S13371-6621	4	Commercial
Photek	MCP-PMT	Solar-blind photocathode	1	R&D
FBK	SiPM	612 A1 with UV Filter-I	3	R&D
FBK	SiPM	615-A1 with UV Filter-II	3	R&D

QE(λ) and PDE(λ) Scan (200-1100 nm)





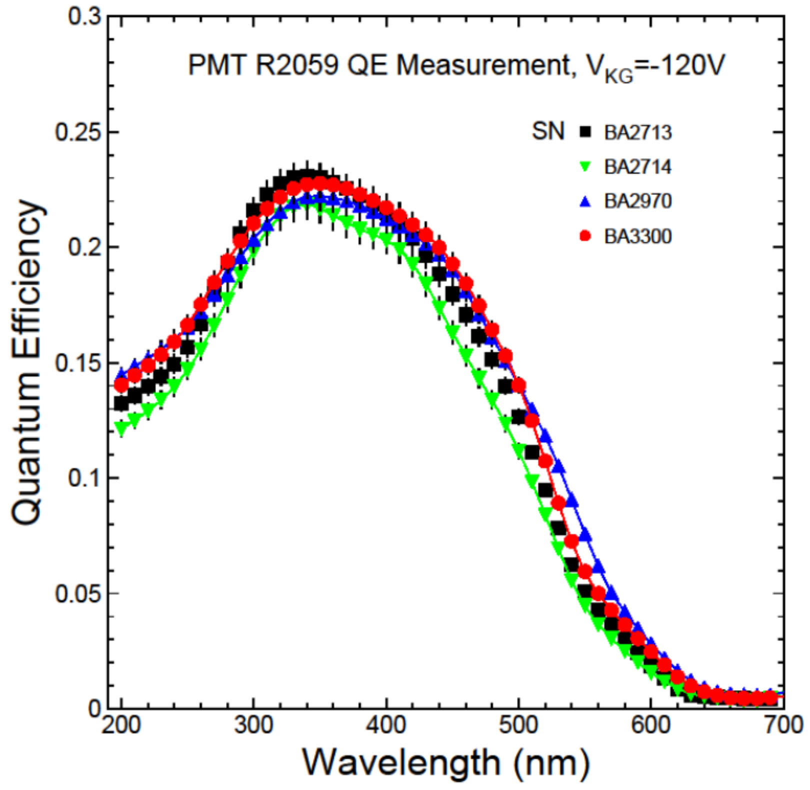
- QE of PMT and Photocathode (G=1):

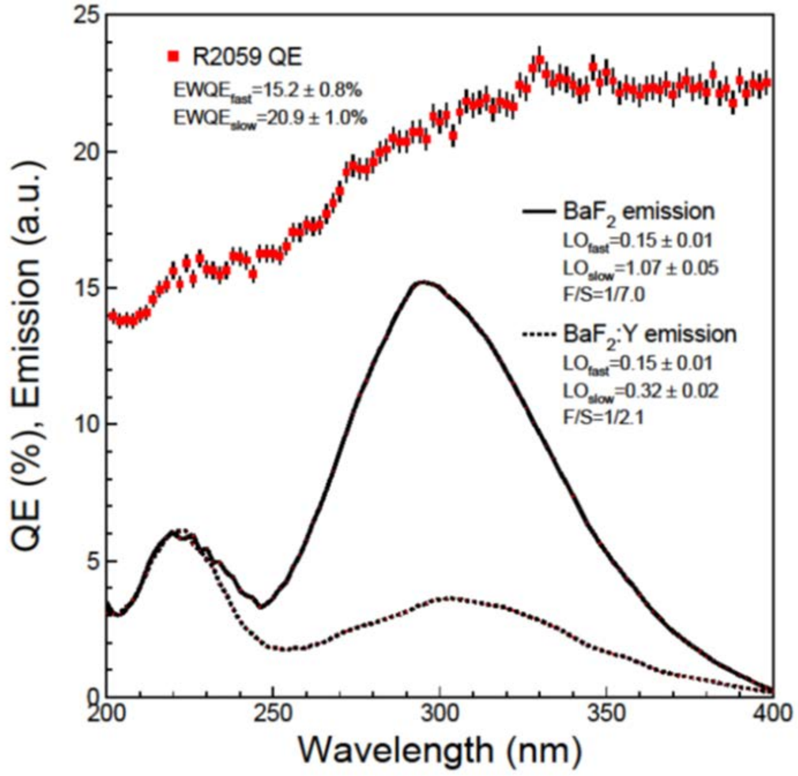
$$QE(\lambda) = \frac{R(\lambda)}{R_{PD}(\lambda)} QE_{PD}(\lambda)$$

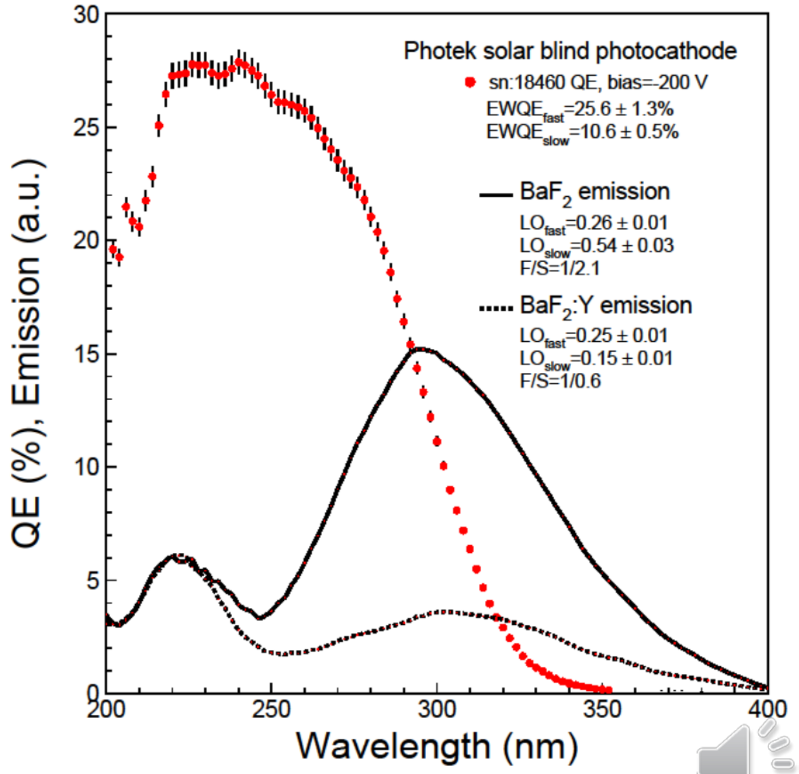
- PDE of SiPM (MPPC) (G>1): relative wavelength scan combined with a calibration by a pulsed LED

Bialkali and Solar-blind Cathodes

QE response to the ultrafast and slow component (LO) and the F/S ratio for BaF_2 and BaF_2:Y emissions were determined for four Hamamatsu R2059 PMTs and a Photek solar-blind photocathode

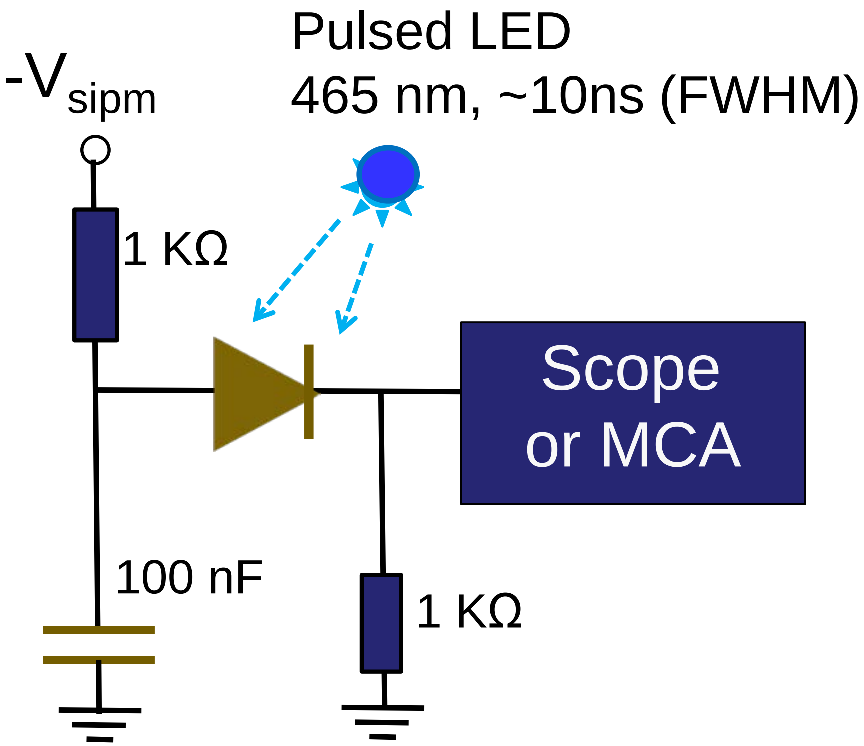


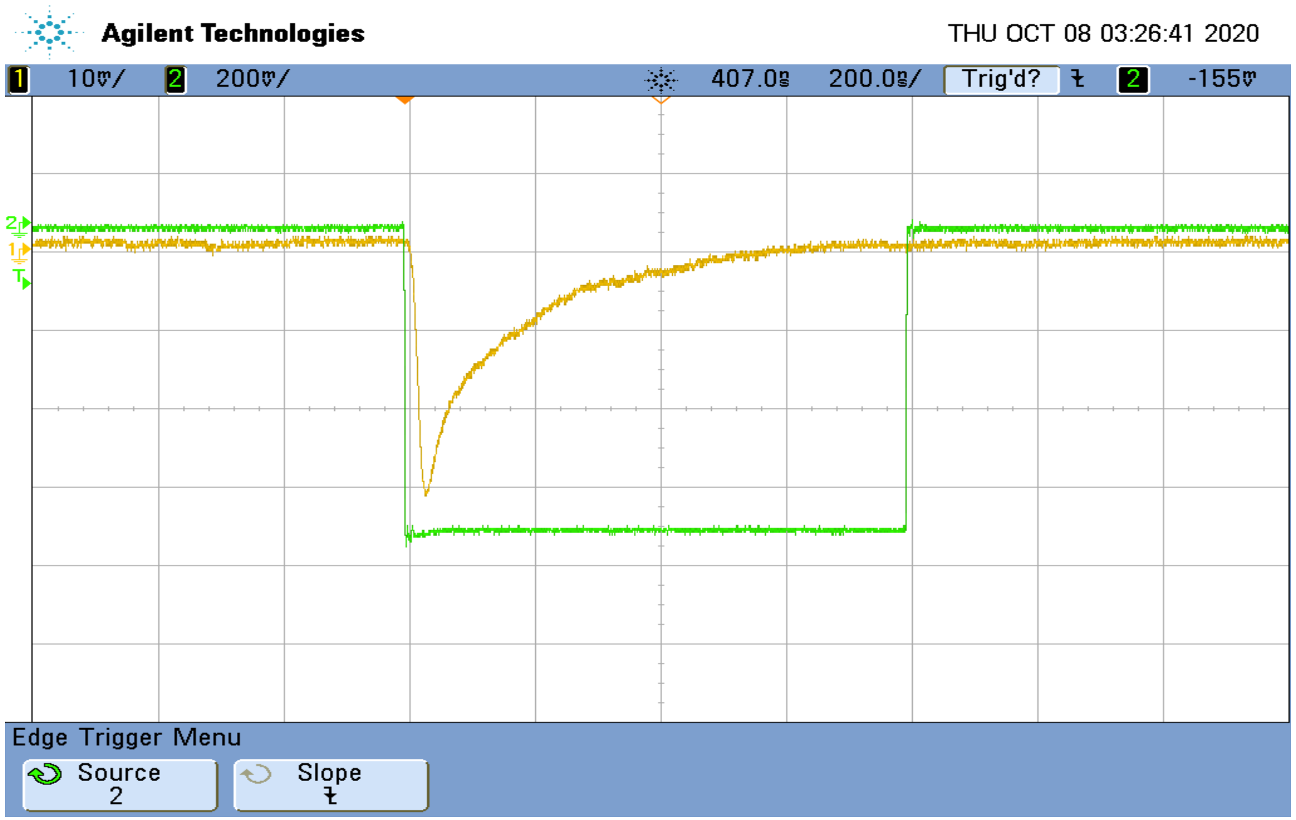




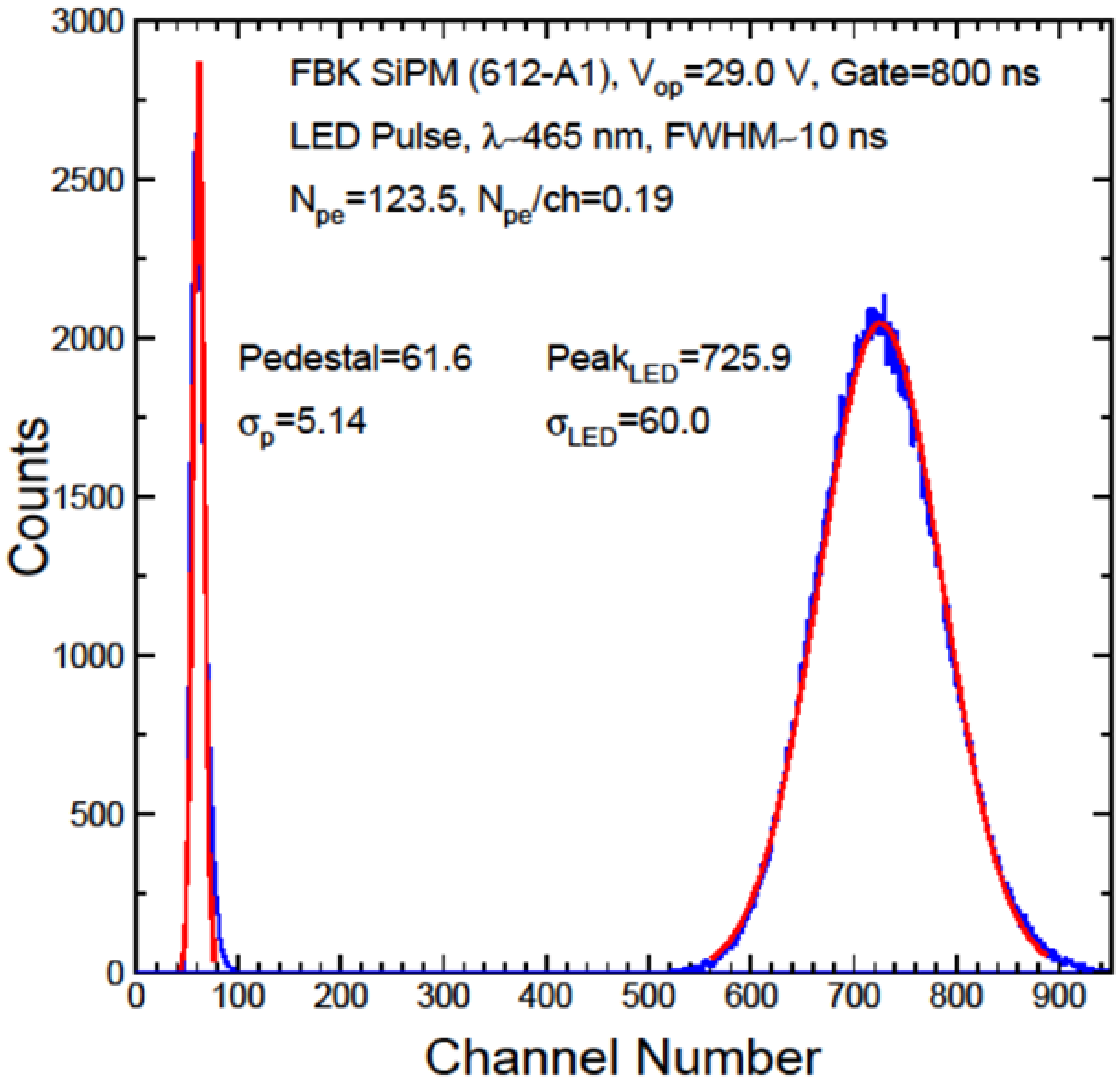
PDE Calibration Setup

Input photon #s were measured by a calibrated PD (Newport 71650). Response to 10 ns pulses from a 465 nm LED was digitized by a LeCroy 3001 qvt with photoelectron #s determined by fitting the photopeak, taking into account the excess noise factor (ENF).





PDE Calibration with a Pulsed LED



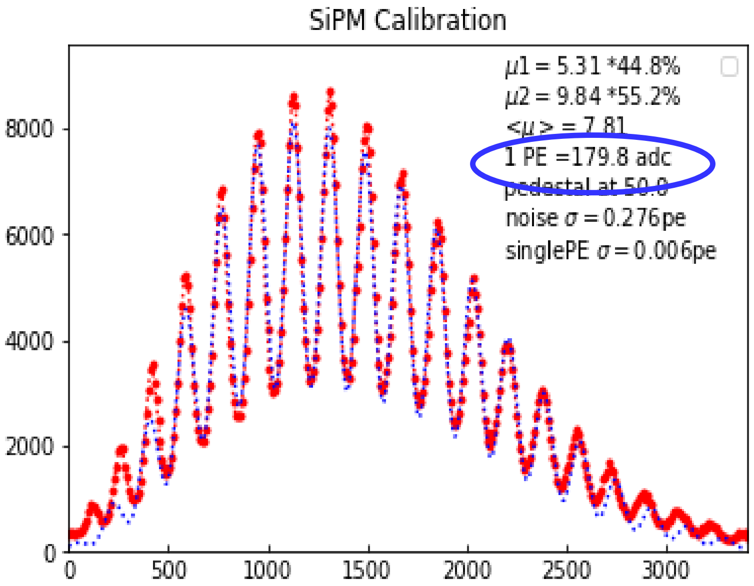
$$N_{ph} = \frac{I_{LED}/S}{h\nu_{LED} \times f_{LED}}$$

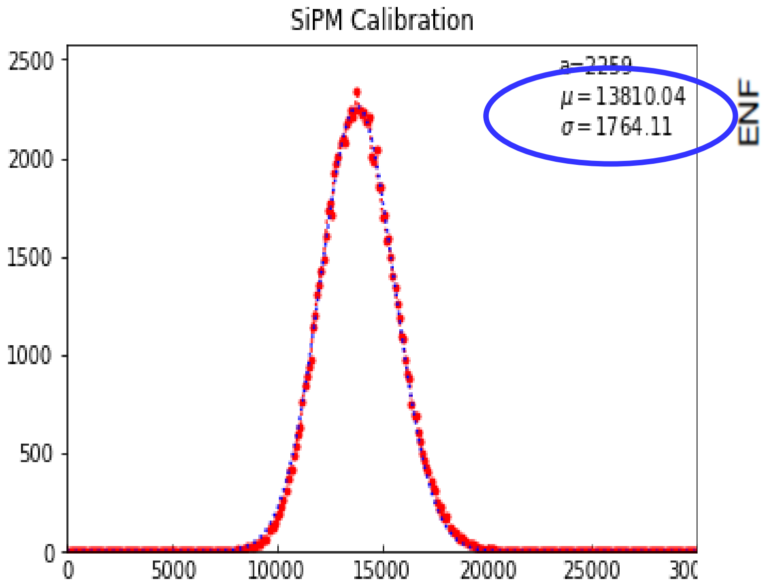
I_{LED}: led photocurrent measured by PD, S: PD sensitivity
$h\nu_{LED}$ and f_{LED}: LED photon energy and pulse rate

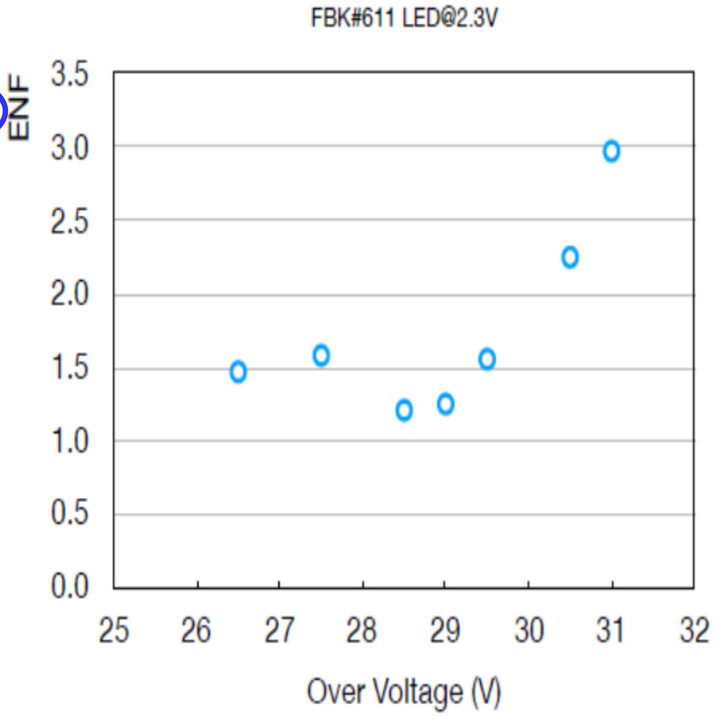
$$N_{pe} = \frac{P_{LED}^2}{\sigma^2} = \frac{P_{LED}^2}{\sigma_{LED}^2 - \sigma_P^2}$$

P_{LED} and σ_{LED}: LED photo-peak and width
P_P and σ_p: Pedestal peak and width

SiPM Excess Noise Factor Measurement

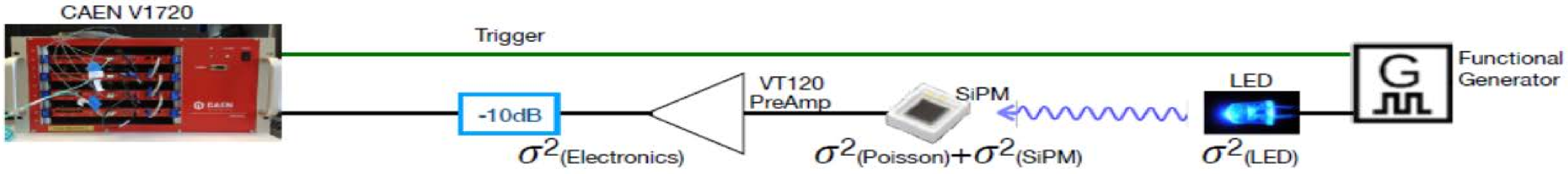






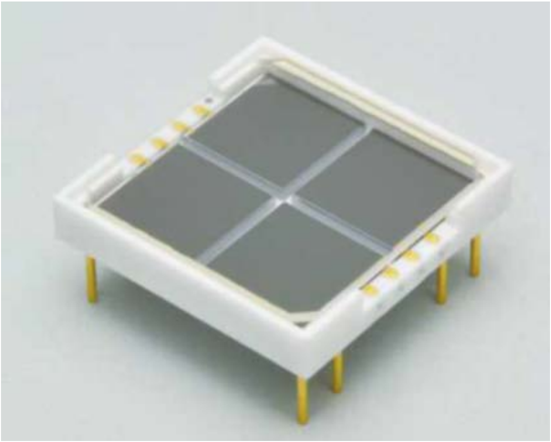
$$\sigma^2_{(observed)} = \sigma^2_{(Poisson)} + \sigma^2_{(SiPM)} + \sigma^2_{(Electronics)} + \sigma^2_{(LED)}$$
$$= N_{pe\,(Poisson)} + N_{pe} \times \sigma^2_{(pe)} + \sigma^2_{(Pedstal)} + \sigma^2_{(LED)}$$
$$= N_{pe\,(Poisson)} \times (1 + \sigma^2_{(pe)} + \sigma^2_{(Pedstal)}/N_{pe} + \sigma^2_{(LED)}/N_{pe})$$

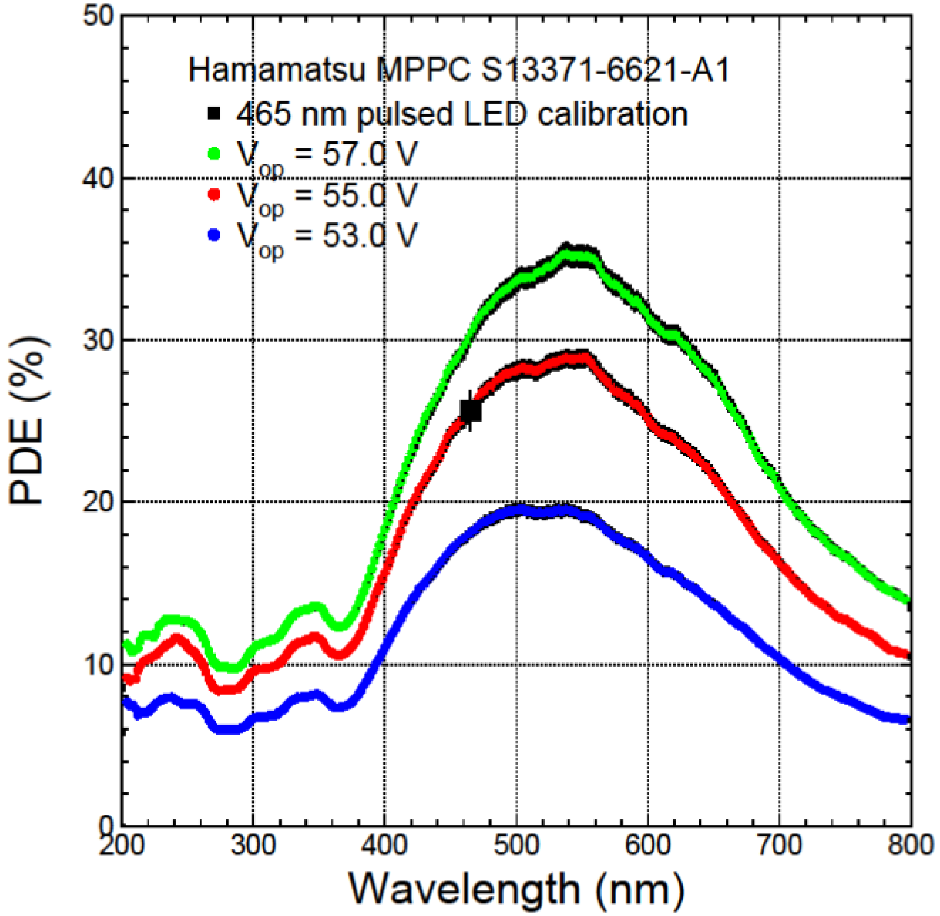
$$ENF = \sigma^2_{(observed)} / N_{pe(Poisson)} = N_{pe(Poisson)} / (\mu_{(observed)}/\sigma_{(observed)})^2 \quad \because \mu_{(observed)} = N_{pe(Poisson)}$$

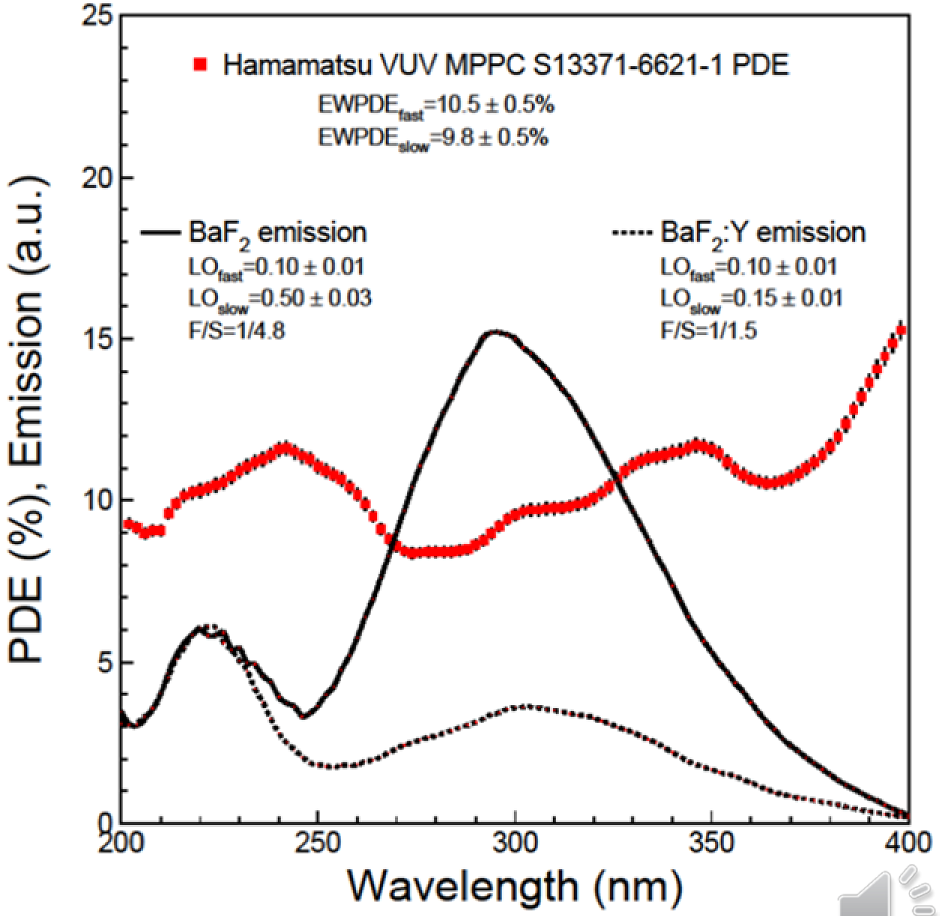


Hamamatsu VUV3 MPPC

Over-voltage dependent PDE measured for a Hamamatsu 13371-6621 MPPC (VUV3), and its response to BaF_2 and BaF_2:Y emissions with V_{op} = 55.0 V

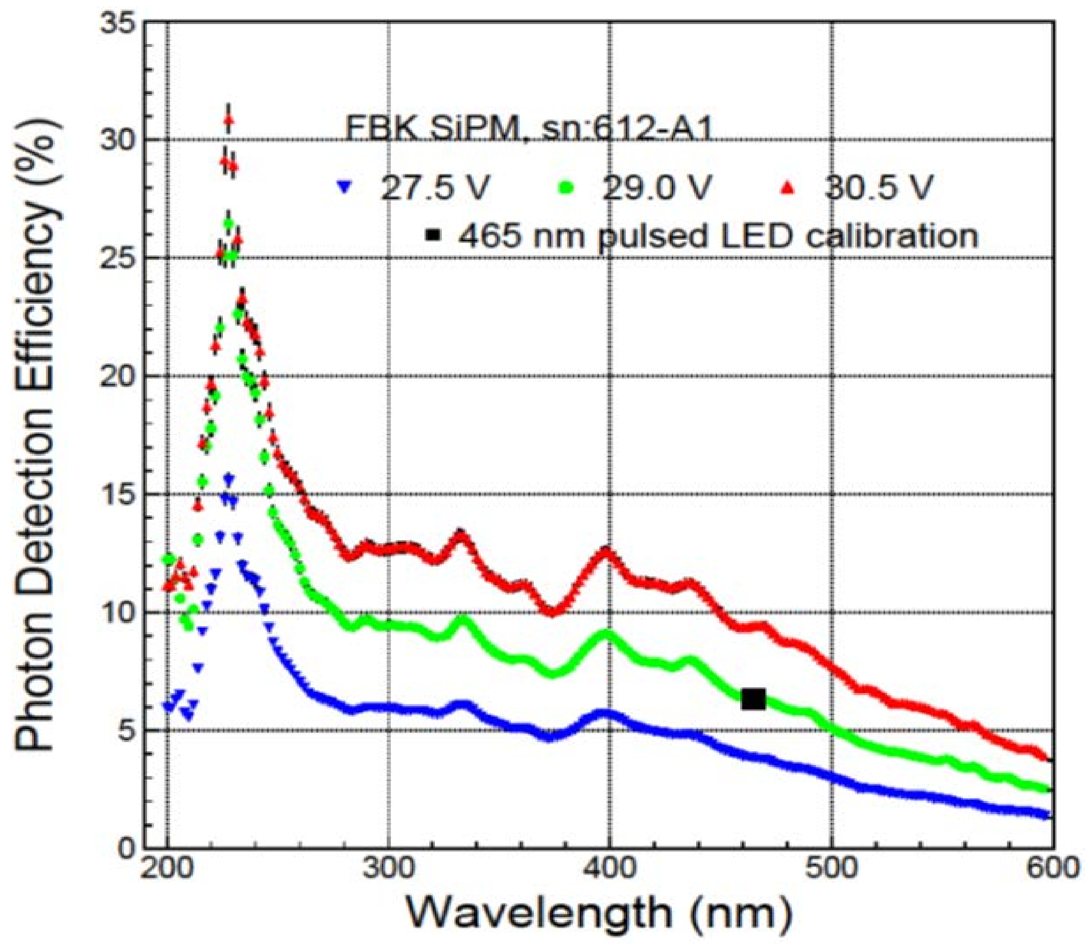


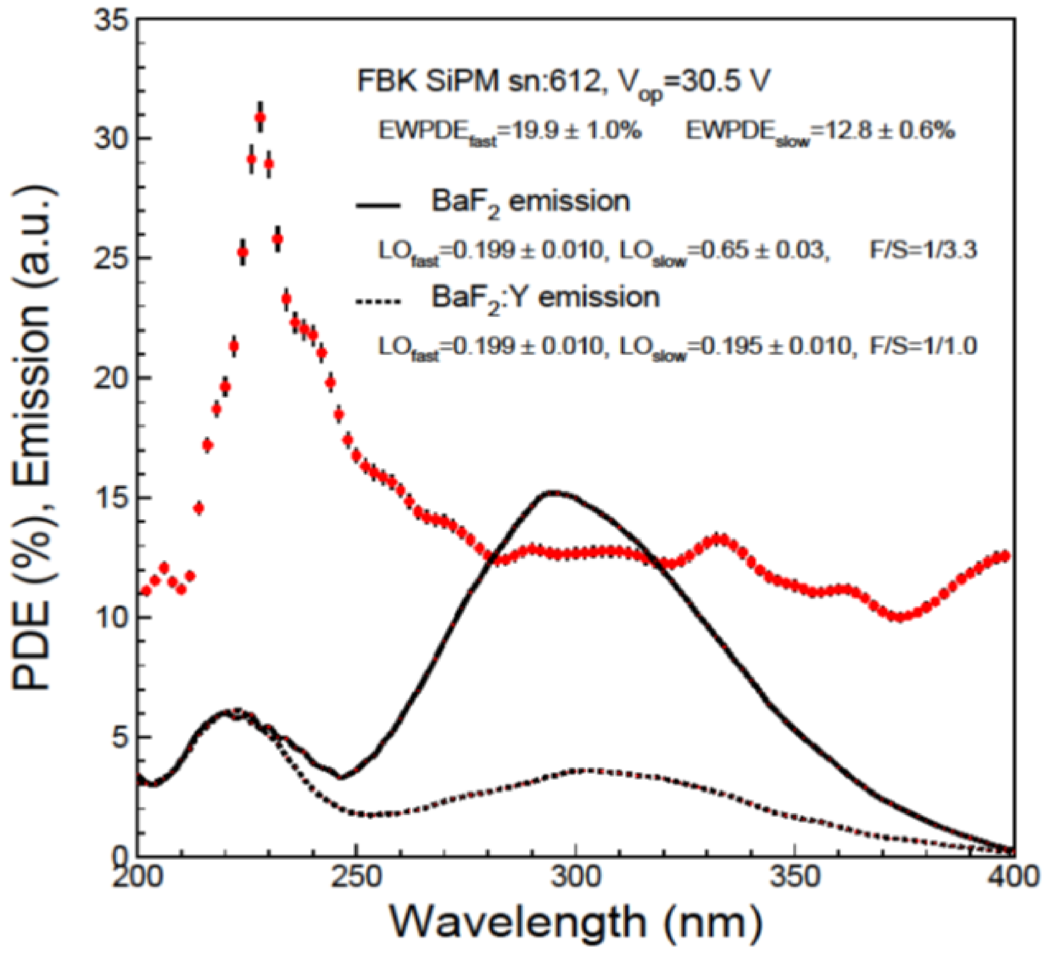




FBK SiPM 612-A1 with UV Filter-I

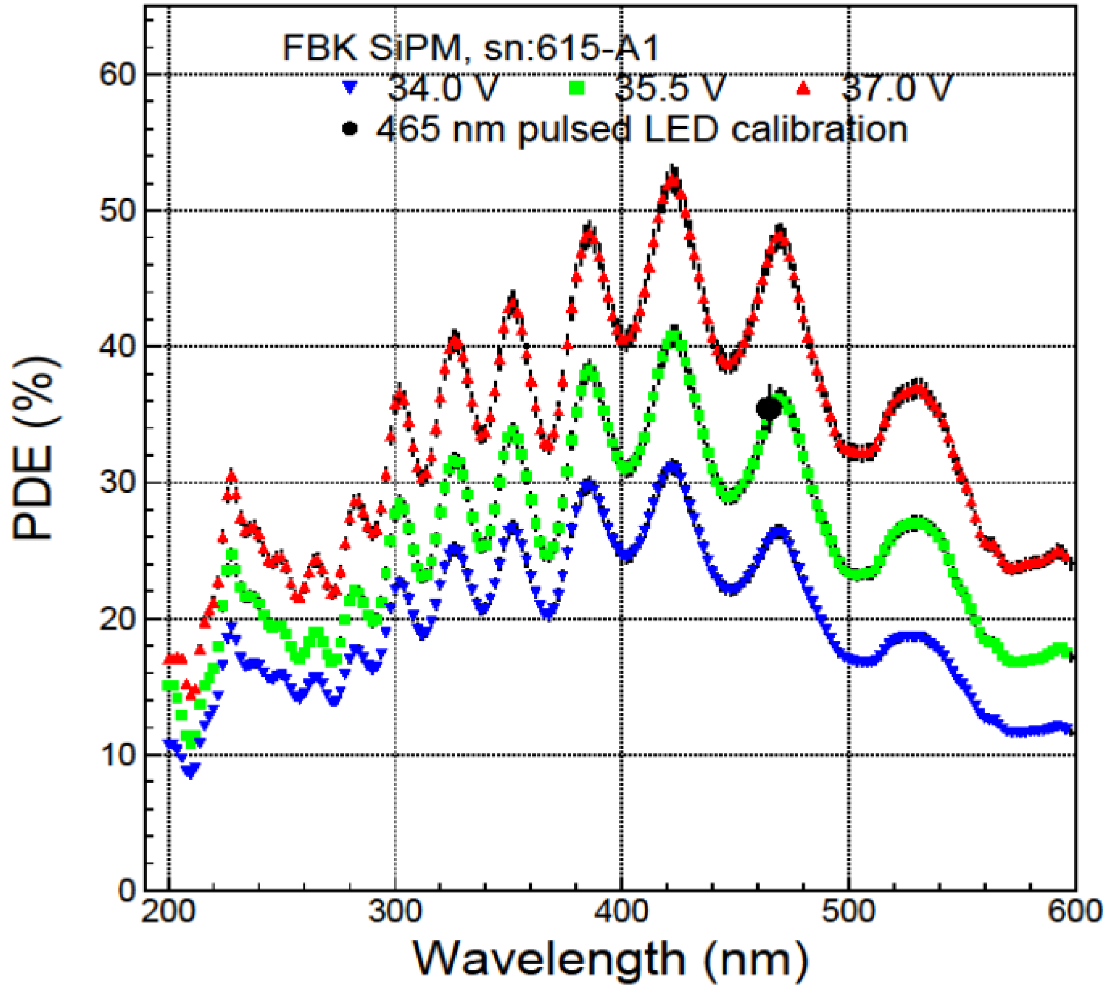
Over-voltage dependent PDE measured for a FBK SiPM 612-A1, and its response to BaF_2 and BaF_2:Y emissions with V_{op} = 30.5 V

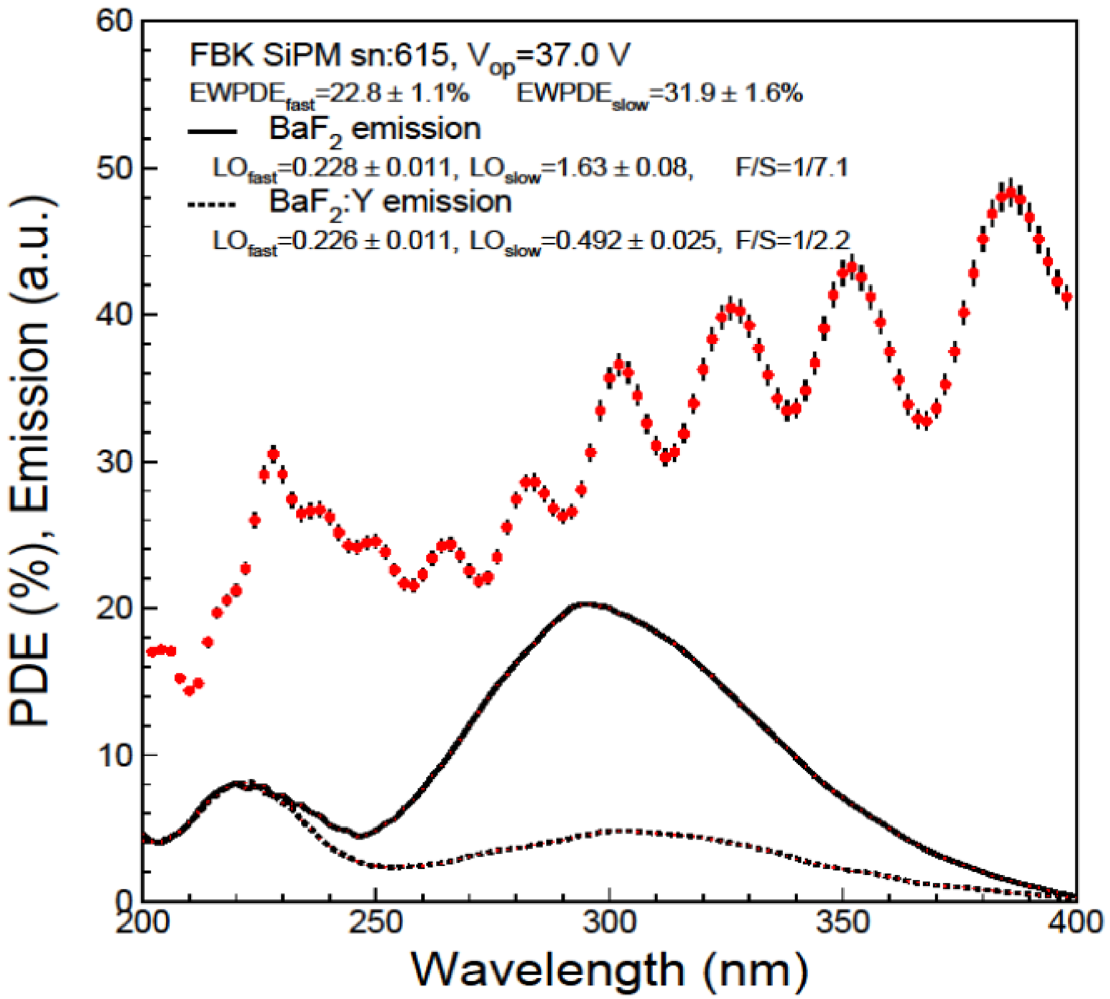




FBK SiPM 615-A1 with UV Filter-II

Over-voltage dependent PDE measured for a FBK SiPM 615-A1, and its response to BaF_2 and BaF_2:Y emissions with V_{op} = 37.0 V





Photodetector Response to BaF_2 and BaF_2:Y

Photodetectors	$EWQE_{fast}$ (%)	$EWQE_{slow}$ (%)	*BaF_2 LO_{fast}	*BaF_2 LO_{slow}	BaF_2 F/S	*BaF_2:Y LO_{fast}	*BaF_2:Y LO_{slow}	BaF_2:Y F/S
Hamamatsu R2059	15.2	20.9	0.15	1.07	1/7.0	0.15	0.32	1/2.1
Hamamatsu VUV MPPC, S13371	10.5	9.8	0.10	0.50	1/4.8	0.10	0.15	1/1.5
Photek PMT solar blind	**25.6**	**10.6**	**0.26**	**0.54**	**1/2.1**	**0.25**	**0.15**	**1/0.6**
FBK SiPM w/UV filter -I	**19.9**	**12.8**	**0.20**	**0.65**	**1/3.3**	**0.20**	**0.20**	**1/1**
FBK SiPM w/UV filter-II	22.8	31.9	0.23	1.63	1/7.1	0.23	0.49	1/2.2

* LO is normalized to ultrafast photons from BaF_2.

Summary

While yttrium doping in BaF_2 crystals increases its F/S ratio significantly a solar-blind photodetector is necessary to minimize the pileup for a BaF_2 crystal based ultrafast calorimeter for future experiments, such as Mu2e-II.

Progress has been made in solar-blind photo-cathode and SiPMs with integrated UV band-pass filters. R&D is on-going to further optimize the LO_{fast} and the F/S ratio for BaF_2 crystal readout.

We plan to extend the QE/PDE test bench to 175 nm with N_2 purging.

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