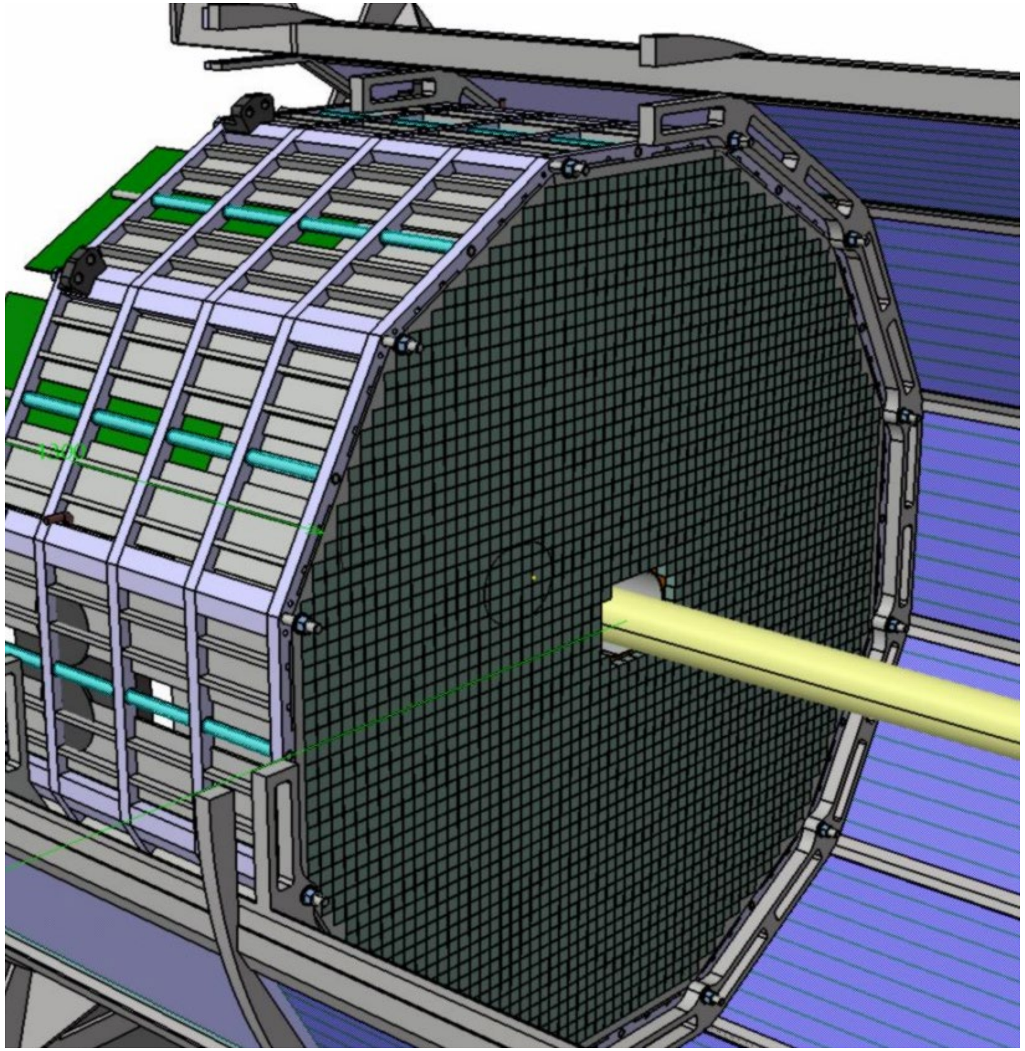


SiPM Specs Backward ECAL

Tanja Horn

THE CATHOLIC UNIVERSITY OF AMERICA

Jefferson Lab
Thomas Jefferson National Accelerator Facility

Performance requirements for backward ECAL

Charge Qn 1

Goals:

- Electron/pion separation
- Improve electron resolution at large $|\eta|$
- Measure photons with good resolution
- Separate 2-γ from π^0 at high energy

Detector requirements established and documented during the Yellow Report exercise

Requirements:

- Energy resolution: 2-3%/$\sqrt{E}$ + (1-2)%
- Pion suppression: 1:10^4 (together with other PID detectors)
- Minimum detection energy: > 100 MeV

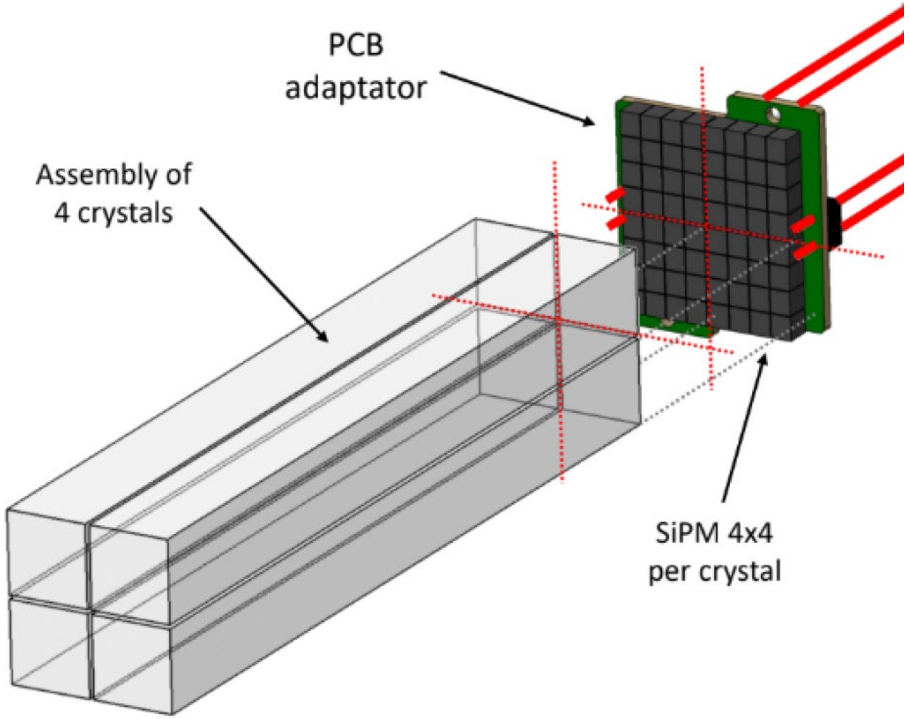
PERFORMANCE REQUIREMENTS		
Backward EMCAL		
P-DET-ECAL-BCK.1	System shall cover pseudo rapidity down to -3.5.	F-DET.2 F-DET-ECAL-BCK.1
P-DET-ECAL-BCK.2	Energy resolution in the most backward region shall be s(E)/E ~ (2-3)%/sqrt(E) + (1-2)%; in less backward region shall be <7%/sqrt(E) + (1-2)%.	F-DET.2 F-DET-ECAL-BCK.3
P-DET-ECAL-BCK.3	System shall have high power for e/pi separation down to 1 GeV/c.	F-DET-ECAL-BCK.3
P-DET-ECAL-BCK.4	System shall have high granularity and be capable of distinguishing two showers with opening angle down to 0.015 (=>tower size).	F-DET-ECAL-BCK.5
P-DET-ECAL-BCK.6	System shall have low material budget on the way from the vertex: <5%X0 in the 1st half a way, or <10%X0 on the second half a way, or <30%X0 just in front of EMCal (within 10cm).	F-DET-ECAL-BCK.6
P-DET-ECAL-BCK.7	A cooling system shall be provided if PWO crystals are used.	F-DET-ECAL-BCK.7

Requirements documented by the EIC project

Context for SiPM Specifications

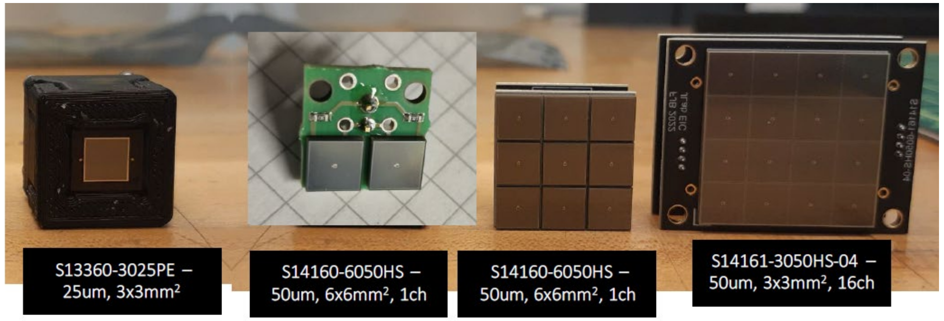
In general, for high-precision electromagnetic calorimetry, the following are of relevance for readout selection:

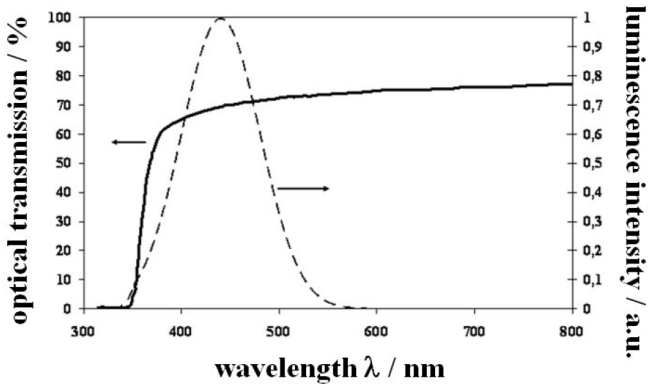
- Operational in the expected magnetic field
- Large dynamic range to detect particles from 50 MeV to 15 GeV and good linearity
- Low dark current to trigger signals close to the single p.e. amplitude of the radiator
- Compatible with streaming readout data acquisition method
- Photosensor curve should be in agreement with crystal transmittance spectrum



SiPM readout and monitoring system

Silicon Photomultipliers (SiPMs) meet the requirements for the backward EMCal





Crystal transmittance spectrum

Anticipated SiPM model for backward ECAL

Charge Qn 3

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PRELIMINARY

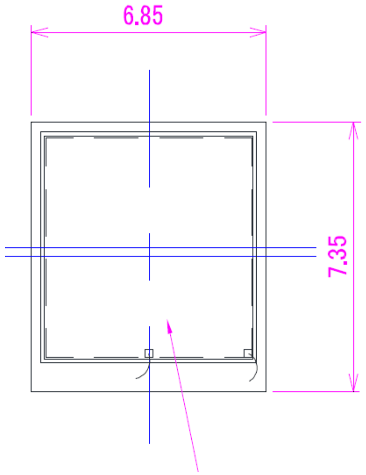
MPPC

Feb. 3, 2022

SPECIFICATION SHEET S14160-6010PS/6015PS

■ Structure

Parameters	S14160-6010PS	S14160-6015PS	Unit
Effective photosensitive area	6.0 × 6.0		mm^2
Pixel pitch	10	15	µm
Number of pixels	359011	159565	-
Window	Silicone resin		-
Window refractive index	1.57		-
Package	Surface mount type		-

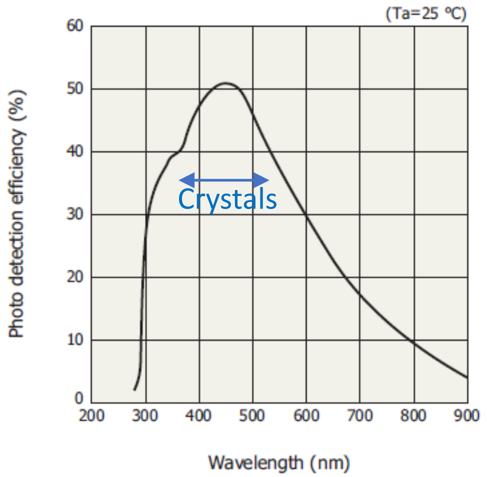


■ Electrical and optical characteristics (Typical value, Ta = 25 deg C, Vr = Vop unless otherwise noted)

Parameters	Symbol	S14160-6010PS	S14160-6015PS	Unit
Spectral response range	λ	290 to 900		nm
Peak sensitivity wavelength	λp	460		nm
Photon detection efficiency at λp *2	PDE	18	32	%
Breakdown voltage	Vbr	38 +/- 3		V
Recommended operating voltage *3	Vop	Vbr + 5.0	Vbr + 4.0	V
Dark count rate	DCR	Typ. 3.0 / Max. 10		Mcps
Terminal capacitance at Vop	Ct	2500		pF
Gain	M	1.8×10^5	3.6×10^5	-
Temperature coefficient of Vop	ΔTVop	34		mV/°C

Backward ECAL readout :

- 4 SiPM per crystal (S14160-6010PS)
- A total of 1.4M pixels per crystal: sufficiently large dynamic range
- Photon detection curve in agreement with crystal transmittance



EEEMCAL SiPM Specifications

Charge Qn 3

SiPM

SiPM Size	6x6 mm2
Voltage	40-46 V
Array of SiPM (summing)	2x2
Capacitance/ channel	2.5 nF
Pixel/channel	160-360k
Dynamic range	10-10,000pC

SiPM stability

Overvoltage	+5 V
Stability required [mV]	*For FE design, not an individual SiPM specification*
Bias voltage accuracy	*For FE design, not an individual SiPM specification*
Bias voltage current	*For FE design, not an individual SiPM specification*
Temperature compensation	Bias voltage temperature compensation would be preferred

Pre-amp

Linearity	< 0.5 %
Gain stability	< 0.5 %
Peak time	20 ns
Charge resolution	14-bit
Time-hit resolution	(TBD) 5 ns
Double pulse resolving	10 ns(?)

FEB, RDO

SiPM bias monitoring	Yes
Temperature monitoring	Yes
FEB on detector	Yes
FEB accessibility	Between runs
FEB-RDO distance	3-5m
RDO on detector	No
RDO location	TBD

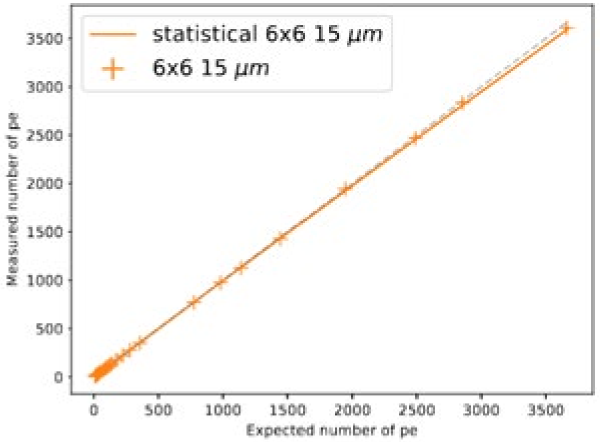
See Calorimetry WG discussion on July 12:
https://indico.bnl.gov/event/20029/contributions/78495/attachments/48567/82578/20230712CaloMeeting.pdf

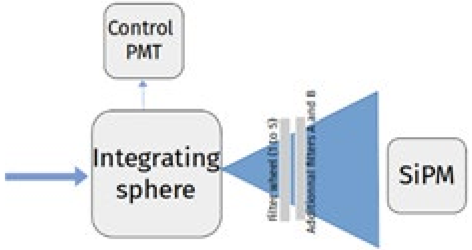
For high-precision calorimetry one needs to pay a lot of attention that all pieces works together even after the SiPMs are in hand

SiPM tests at Universities

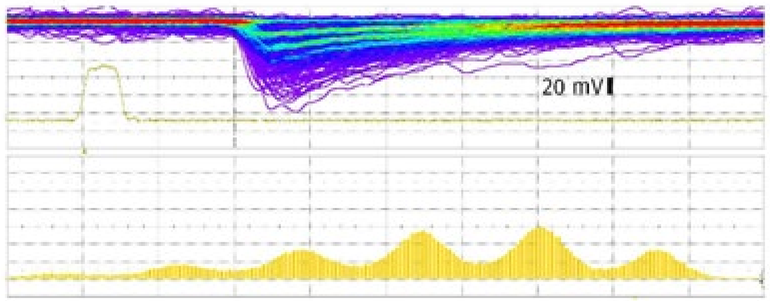
Charge Qn 3

- ❑ **Calorimeters at EIC require photo-sensors with a very large dynamic range expanding more than 3 orders of magnitude.**
  - Both the Hamamatsu S14160-6015 and S14160-6010, high density, large array SiPMs were tested at IJCLab-Orsay and were shown to have linearity within 2% over 3 orders of magnitude and were within statistical expectations





- ❑ **The SiPM must also detect at low energies**
  - Requires low dark current in order to trigger signals close to the single p.e. amplitude
  - These SiPM waveforms were measured using a low intensity LED and show a clear separation between the individual p.e. signals allowing for valid small signal identification



Waveform (top) and integrated signal (below) showing single p.e. signals in Hamamatsu S14160-6015, produced with a low-intensity LED.

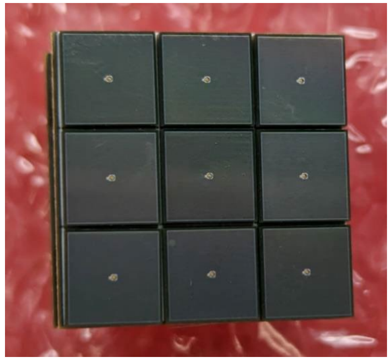
JLab SiPM tests and prototype

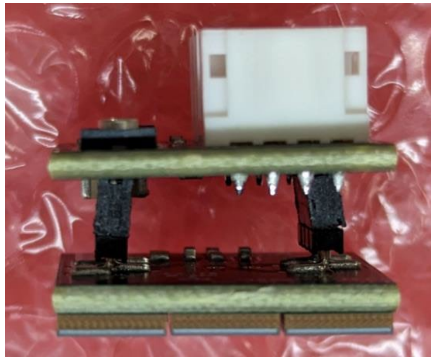
THE CATHOLIC UNIVERSITY OF AMERICA

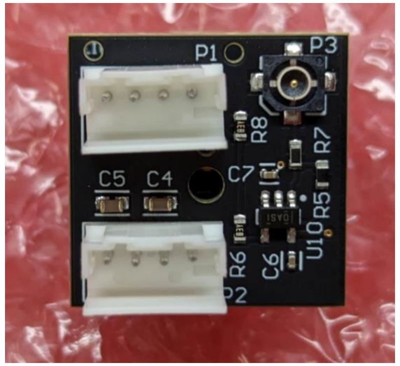
Charge Qn 2

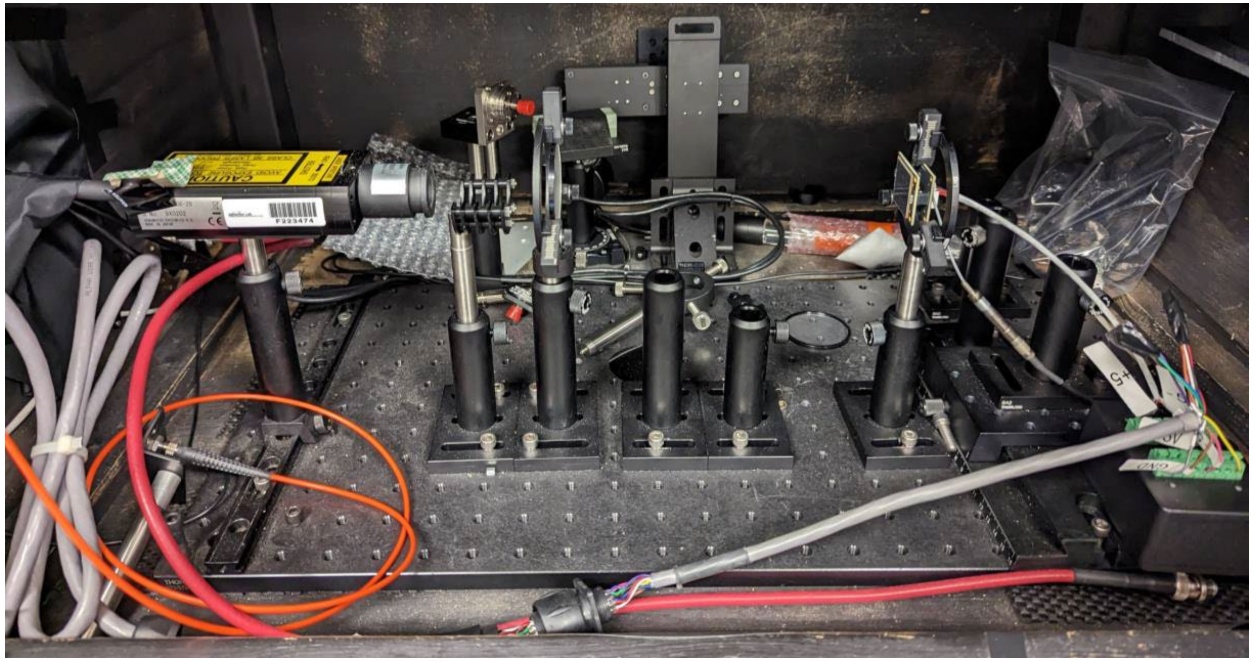
Jefferson Lab
Thomas Jefferson National Accelerator Facility

- ❑ SiPM matrices have been characterized on the test bench
  - ➢ PCBA with SiPMs, thermal correction circuit, pre-amp circuit, coax and connectors for LV and SiPM bias
  - ➢ Test setup to measure laser pulse response, signal linearity, PCB dynamic range, scaling of the PCB output with multiple SiPMs
- ❑ Beam test facility with tagged photon beam up to 4-5 GeV
  - ➢ Technique demonstrated successfully with eRD105 (studies concluded) can be adapted for EEEMCAL prototype tests









Prototype Beam Test Campaigns at JLab

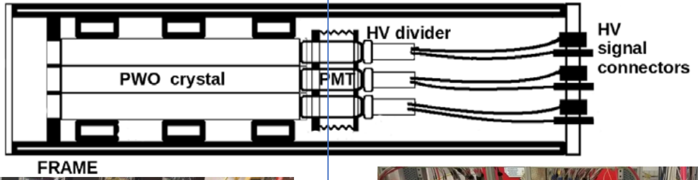
Charge Qn 2

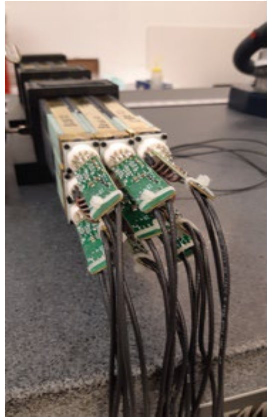
With SiPM coupled to homogeneous radiators

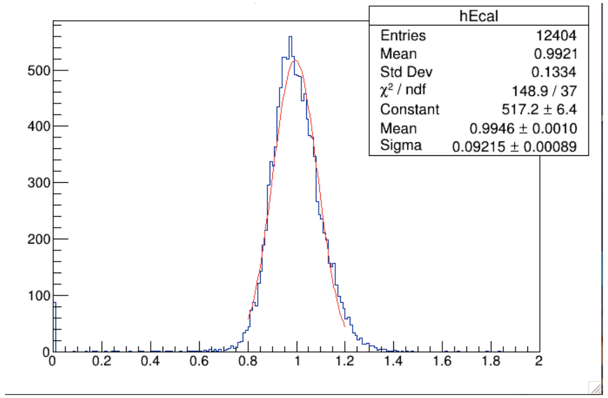
3x3 prototypes (2022) eRD105

9 scintillating glass blocks

1 x PMT (Hamamatsu R4125) baseline



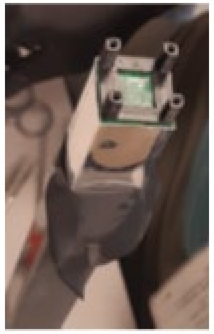


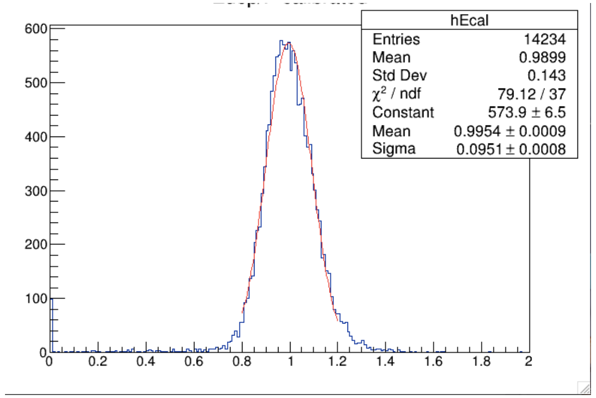


3x3 prototypes (2022) eRD105

9 scintillating glass blocks

1 x 6x6mm 50um Hamamatsu

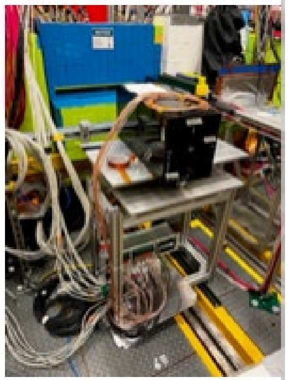


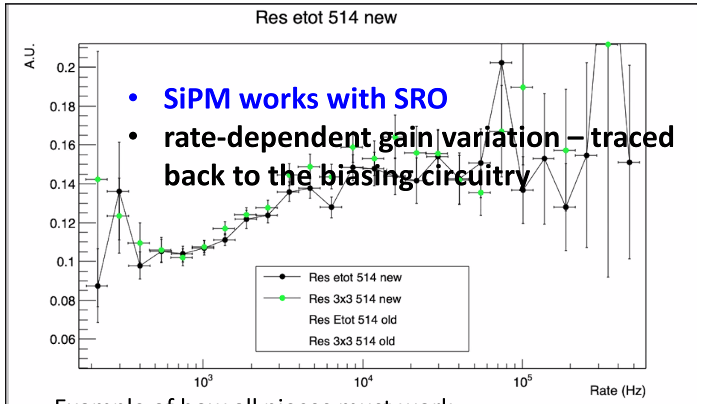


5x5 prototypes (2023) eRD105

25 scintillating glass blocks

2 x 6x6mm2 50um Hamamatsu mounted on a PCB





- **SiPM works with SRO**
- **rate-dependent gain variation – traced back to the biasing circuitry**

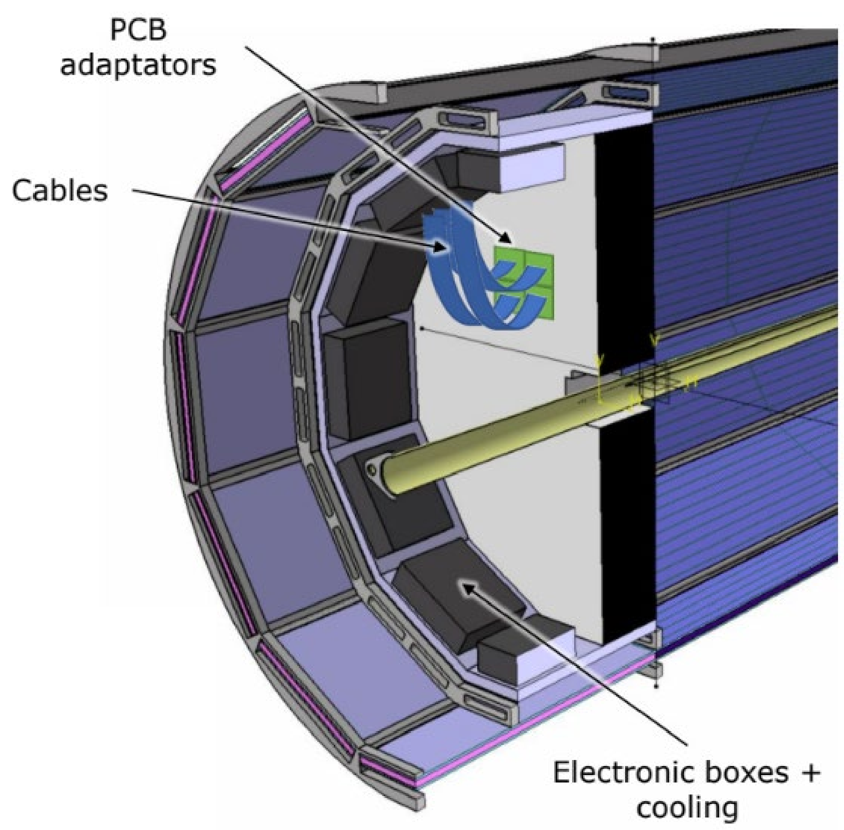
Example of how all pieces must work together even when SiPMs are in hand

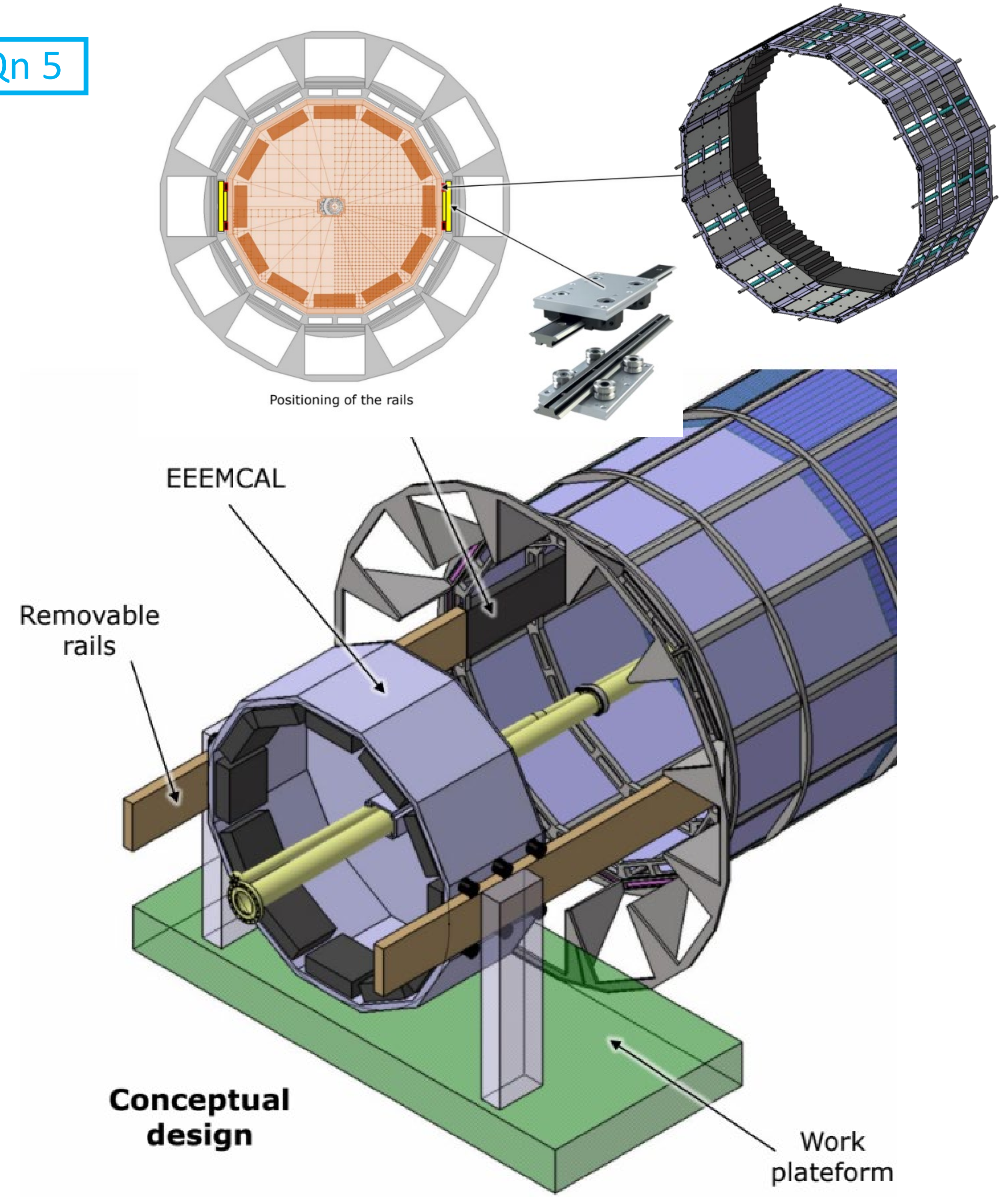
Mechanical design

Charge Qn 5

- Advanced preliminary design of mechanical assembly and installation procedure

- SiPM readout using short cables to electronics sitting behind the crystals (inside cooled boxes)





Installation into the DIRC frame using rails

SiPM Quality Assurance Protocol

Charge Qn 7

- Quality assurance on the SiPM and SiPM assemblies builds on the process developed for previous prototype tests
  - Linearity
  - Dark noise variation
  - PCBA testing (signal response, linearity, dynamic range)
- No special requirements on the vendor beyond providing the characteristics that were provided with purchases for previous prototype tests

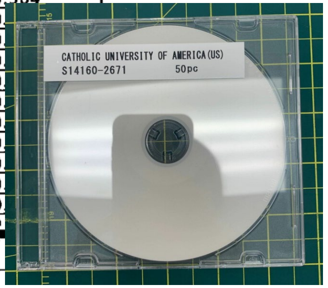
SiPM characteristics provided by vendor

2, Data in each tray

Type No.	S14160-2671
Shipping date	6/1/2023
Ta[degC]	25

Tray No.	Position No.	Serial No.	Vop[V] Vop=Vbr+4V	Id at Vop[μA]
230601-01	1	1	41.87	0.302
	2	2	41.78	0.305
	3	3	42.14	0.279
	4	4	41.99	0.277
	5	5	41.66	0.339
	6	6	41.71	0.342
	7	7	41.78	0.342
	8	8	42.48	0.290
	9	9	42.24	0.361
	10	10	42.02	0.287
	11	11	42.31	0.290
	12	12	42.26	0.294
	13	13	41.73	0.322
	14	14	42.05	0.274
	15	15	41.83	0.319
	16	16	41.79	0.327
	17	17	41.77	0.373
	18	18	42.51	0.262
	19	19	42.04	0.293
	20	20	41.89	0.320
	21	21	42.37	0.285
	22	22	42.28	0.301
	23	23	41.89	0.329
	24	24	41.73	0.305
	25	25	42.02	0.291
	26	26	42.16	0.282
	27	27	41.81	0.324
	28	28	41.83	0.348
	29	29	41.78	0.361
	30	30	42.44	0.281
	31	31	41.95	0.288
	32	32	41.86	0.296
	33	33	42.47	0.263
	34	34	42.35	0.286
	35	35	41.78	0.360
	36	36	41.96	0.341
	37	37	42.22	0.302
	38	38	41.88	0.304
	39	39	41.81	0[illegible]
	40	40	41.74	0[illegible]
	41	41	42.13	0[illegible]
	42	42	41.94	0[illegible]
	43	43	42.43	0[illegible]
	44	44	42.39	0[illegible]
	45	45	42.11	0[illegible]
	46	46	41.95	0[illegible]
	47	47	41.87	0[illegible]
	48	48	42.21	0[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]

Tray | datasheet



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Ship To:

Physics Department
Hannan Hall RM 212
620 Michigan Ave NE
Washington, DC 20064
USA

CERTIFICATE OF COMPLIANCE

Customer PO Number	009936-031423
Customer Part No.	
Customer Part Description	
Hamamatsu Part Number	S14160-2671
Number of Pieces Shipped	50.00
Packing Slip No.	SOPS-235245

We hereby certify that all articles, materials, products, equipment's and services listed above furnished pursuant to this purchase order have been produced and assembled, inspected and tested in full accordance with all applicable specifications. It is also certified that all devices in this shipment are part of the shipment covered by manufacturer's documentation.

Customer Part No.

Date: 2023/06/09

Matt Matsumoto
Hamamatsu Corporation
Quality Assurance Manager

Hamamatsu Corporation
360 Foothill Road, Bridgewater, NJ 08807 Phone: 908.231.0960 Fax: 908.231.1218 http://www.hamamatsu.com
Production Facility & Shipping/Receiving: 250 Wood Avenue, Middlesex, NJ 08846 Phone: 732.356.1203 Fax: 732.356.6153

FCD-0159 Rev 8

Certificate of compliance

SiPM Quality Assurance Documentation

Charge Qn 7

A1 fx

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
1		PCB parameters							SiPM characterization					Reference for cosmics			fADC parameters		
2	Glass number	ID PCB	V bias *	I dark	Position inside detector	Bias setting	Power supply char	Amplifier	Amplitude (mV)	Area (pWb)	RMS	LY (phe/MeV)	Measured baseline	Amplitude	Rise time	Signal width*	Baseline	TET	Slot
3	10*	Pann 1 PCB 10	40,34	1,45/1,54	1	40,34	3J2	A1	0.11	24.5							155,521	20	
4	16*	Pann 1 PCB 18	40,41	1,65/1,55	2	40,41	3J3	A2	0.10	24.4							160,578	20	
5	17*	Pann 1 PCB 17	40,42/40,41	1,47/1,53	3	40,41	3J4	A3	0.12	20.2							131,529	20	
6	13	Pann 1 PCB 6	41,29/41,27	1,13/1,05	4	41,29	3J5	A4	0.11 !	19.5		3.76(-0.3, +0.5)	100uV	5 mV	50ns	700ns	148,13	20	
7	7**	Pann 1 PCB 8	40,35	1,5/1,47	5	40,35	5J2	A5	0.12	23.3							195,22	20	
8	18	Pann 2 PCB 2	40,4	1,54/1,45	6	40,4	5J3	A6	0.10	24.1		3.28(-0.3, +0.3)	100 uV	3.3 mV	50 ns	700 ns	183,816	20	
9	6	Pann 1 PCB 4	41,36/41,37		7	41,3	5J4	A7	0.09	21.7		3.46(-0.3, +0.408)	100uV	3 mV	50 ns	600ns	183,137	20	
10	4	Pann 1 PCB 3	41,26	1,13/1,16	8	41,28	5J5	A8	0.14	21.4		3.6(-0.3, +0.446)	100uV	3 mV	60 ns	700 ns	188,672	20	
11	5	Pann 2 PCB 1	40,4	1,70/1,62	9	40,4	7J2	A9	0.10	19.7		3.92(-0.4, +0.47)	100uV	4 mV	50ns	700ns	184,657	20	
12	11	Pann 1 PCB 2	41,38	1,00/1,30	10	41,4	7J3	A10	0.10 !	18.1		4.34(-0.4, +0.5)	100uV	3.8mV	50ns	700ns	177,158	20	
13	13*	Pann 1 PCB 7	42,25/40,23	1,07/4,54	11	41,31	7J4	A11	0.10	20							188,448	20	
14	2	Pann 1 PCB 11	40,34	1,65/1,64	12	40,34	7J5	A12	0.11	17.05 !		4.29(-0.3, +0.425)	100uV	5 mV	60 ns	700 ns	184,569	20	
15	10	Pann 2 PCB 7	40,37	1,59/1,63	13	40,36	8J2	A13	0.02 ?	21.6		4.32(-0.8, +1)	100 uV	4 mV	50 ns	700 ns	162,937	20	
16	3	Pann 1 PCB 1	41,27	1,07/1,14	14	41,27	8J3	A14	0.12	18.6		4.07(-0.3, +0.447)	100uV	3 mV	60 ns	700 ns	180,454	20	
17	12*	Pann 1 PCB 9	40,34/40,35	1,52/1,70	15	40,35	8J4	A15	0.08	23.9							180,808	20	
18	14	Pann 1 PCB 14	40,35	1,53/1,54	16	40,35	8J5	A16	0.09	25.2		3.41(-0.4, +0.5)	100 uV	3.8 mV	50 ns	700 ns	180,749	20	
19	7	Pann 2 PCB 6	40,38	1,52/1,52	17	40,38	21J2	A17	0.09	19.5		4.05(-0.4, +0.534)	100uV	4 mV	50ns	700ns	203,777	20	
20	9	Pann 1 PCB 5	41,31/41,29	1,13/1,09	18	41,3	21J3	A18	0.12	20.1		4.25(-0.5, +0.7)	100 uV	4 mV	60 ns	700 ns	211,174	20	
21	8	Pann 2 PCB 4	40,39	1,70/1,68	19	40,39	21J4	A19	0.11	20.5		3.64(-0.3, +0.403)	100uV	4 mV	50ns	700ns	191,734	20	
22	14*	Pann 1 PCB 12	40,20/40,17	1.04/1.05	20	40,19	21J5	A20	0.10	20							187,46	20	
23	15	Pann 2 PCB 3	40,39	1,41/1,52	21	40,39	23J2	A21	0.08	23.2		xxx	100 uV	3 mV	50 ns	700 ns	218,991	20	
24	16	Pann 1 PCB 15	40,35/40,36	1,55/1,64	22	40,35	23J3	A22	0.08	19.2 !		4.19(-0.3, +0.4)	100 uV	3.6 mV	50 ns	600 ns	234,888	20	
25	11*	Pann 1 PCB 13	40,2	4,31/4,29	23	40,2	23J4	A23	0.10	20							176,001	20	
26	19	Pann 1 PCB 16	40,36	1,46/1,39	24	40,36	23J5	A24	0.10	24.5		3.13(-0.3, +0.3)	100 uV	3.3 mV	60 ns	700 ns	203,348	20	
27	15*	Pann 2 PCB 5	40,38	1,39/1,52	25	40,39	44J2	A25	0.08	23.6							218,576	20	
			* Bias voltage set																

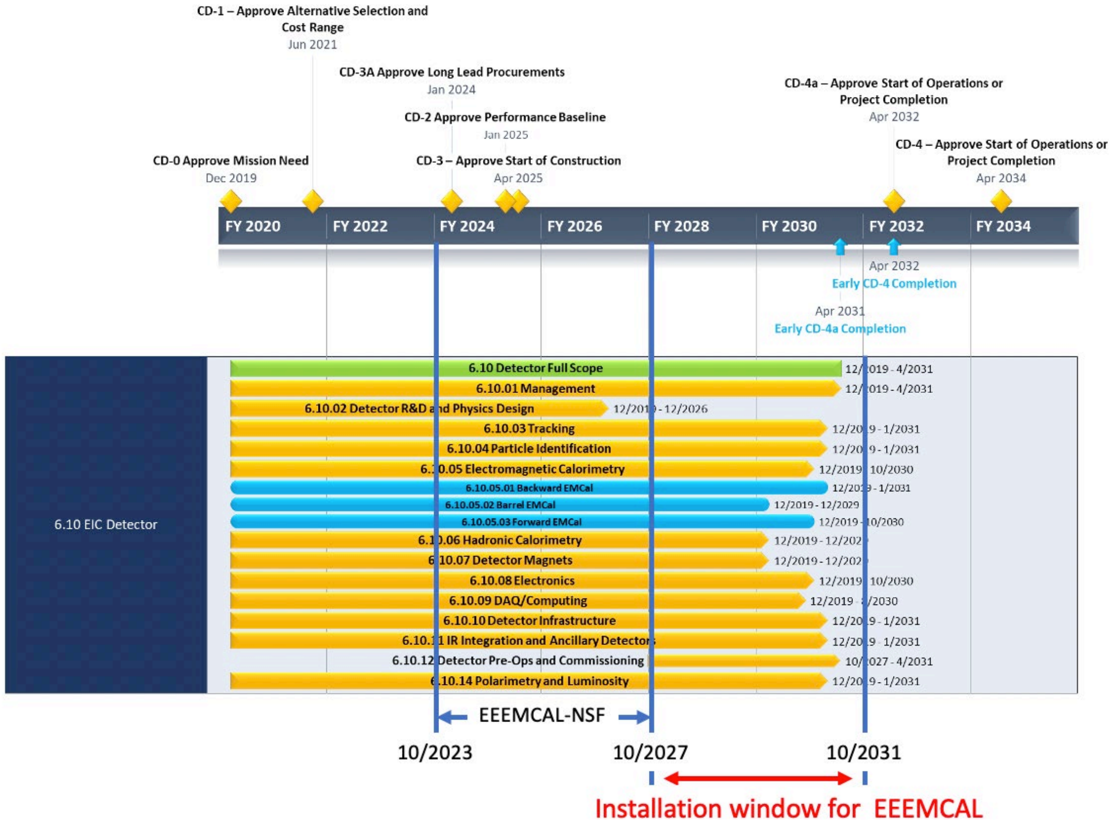
- SiPM quality assurance results will be documented in a central location, e.g., a master spreadsheet or Wiki
  - SiPM assemblies may be tracked by ID

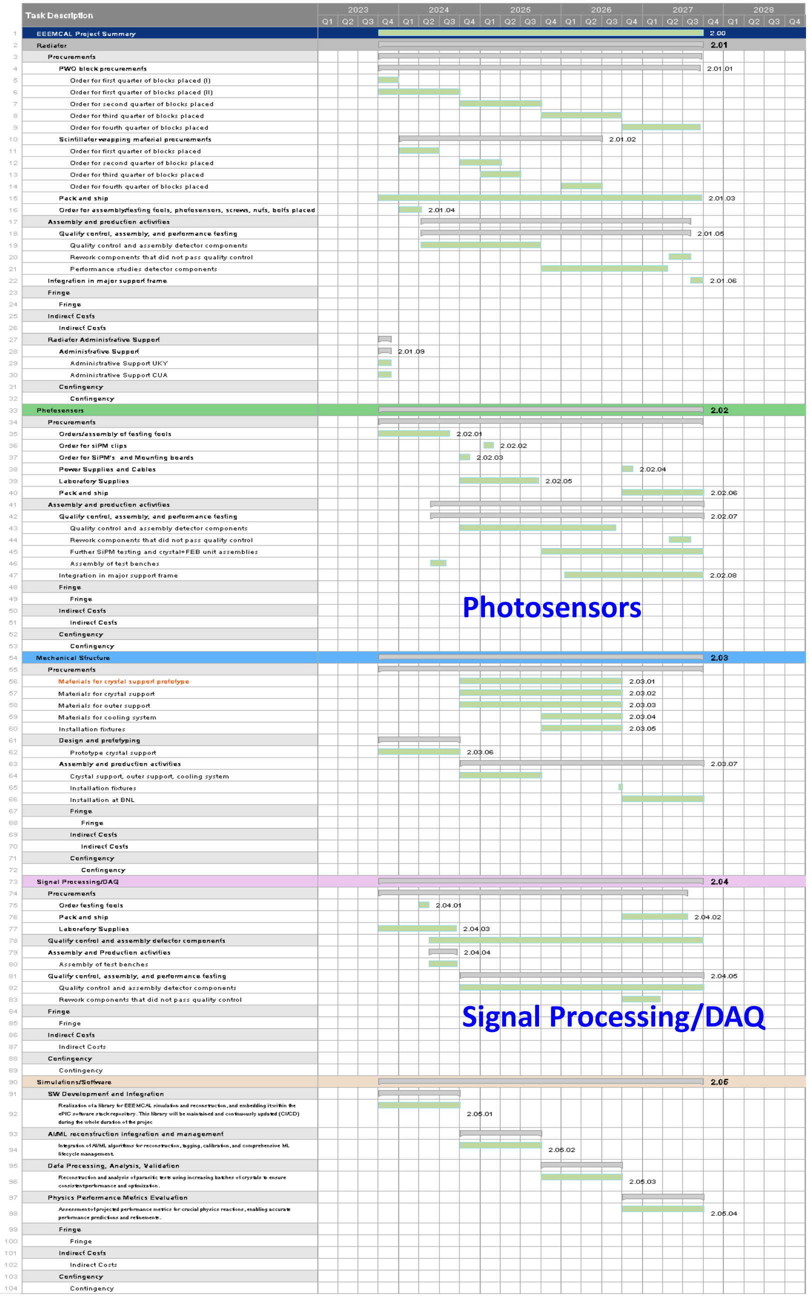
		Sample										
		S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	Sample Avg.
Transmittance	ND Filter (OD)	Vpp	Vpp	Vpp	Vpp	Vpp	Vpp	Vpp	Vpp	Vpp	Vpp	Avg V
100%	0	0.52	0.528	0.6	0.536	0.592	0.544	0.56	0.568	0.52	0.448	0.542
79%	0.1	0.44	0.456	0.408	0.424	0.472	0.368	0.44	0.584	0.504	0.496	0.459
63%	0.2	0.392	0.416	0.384	0.432	0.392	0.384	0.44	0.472	0.392	0.392	0.410
50%	0.3	0.272	0.234	0.26	0.288	0.24	0.204	0.276	0.214	0.264	0.294	0.255
40%	0.4	0.248	0.228	0.202	0.22	0.262	0.264	0.236	0.22	0.208	0.226	0.231
32%	0.5	0.198	0.204	0.216	0.226	0.288	0.19	0.27	0.222	0.202	0.256	0.227

SiPM Timeline in the EEEMCAL

Charge Qn 4

- ❑ Backward ECAL installation window integrated into the overall schedule
- ❑ Photosensor procurement and signal processing DAQ tasks are aligned with this overall schedule





EEEMCAL in Smartsheets

Summary Backward ECAL

- The Backward ECAL technical performance requirements are complete and understood
- Plans for achieving Backward ECAL detector performance and construction are in place.
- The Backward ECAL design and resulting SiPM specifications meet the performance requirements for high precision calorimetry with scintillating crystals
- The fabrication and assembly plans for the Backward ECAL system are consistent with the overall project and detector schedule
- Advanced preliminary design of mechanical assembly and installation procedure in place
- QA considerations have been incorporated in Backward ECAL procurement planning
- A procurement approach and schedule have been developed