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U.S. DEPARTMENT OF ENERGY | Office of Science
Wright Laboratory
Yale
Center for Frontiers in Nuclear Science

Silicon photomultiplier characterization for the LFHCal

ePIC Technical and Integration Council Meeting

November 3, 2025

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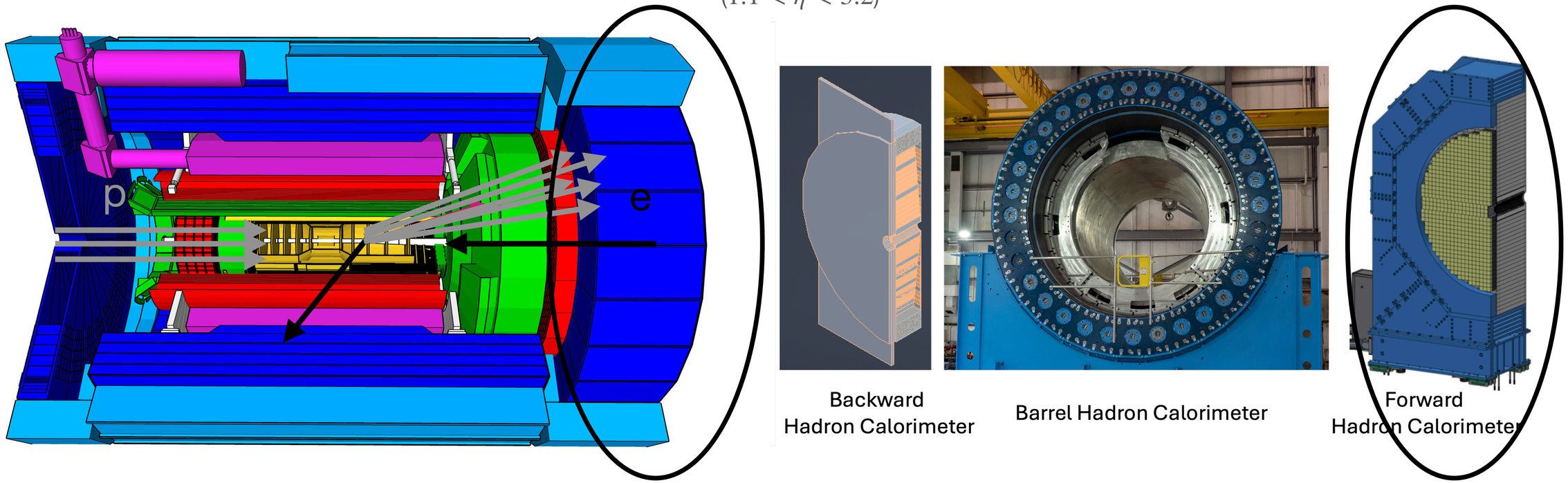
ePIC

ePIC LFHCal

Measuring hadronic jets

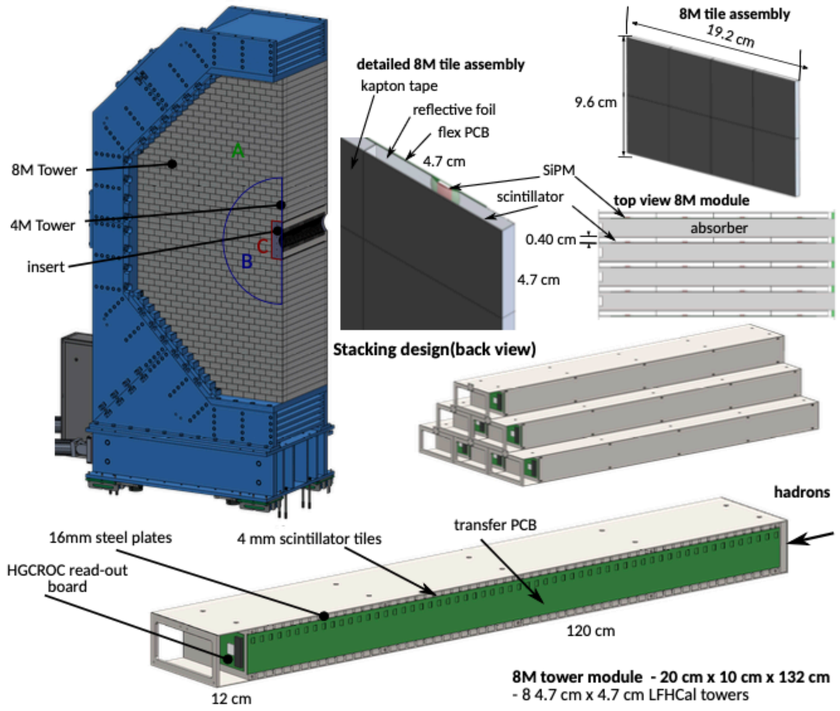
Image

$(1.1 < \eta < 3.2)$



Longitudinally-segmented Forward Hadronic Calorimeter: SiPM-on-tile design with 565,760 steel+plastic scintillator+SiPM components, summed within longitudinal segment of 10 tiles

LFHCal objectives



Goals/requirements:

Good energy resolution (require[1] $\sigma_E/E < 50\,\%/\sqrt{E} \oplus 10\,\%$)

High granularity for good spatial resolution, allows for combination with tracking (“particle-flow”)

Few gaps

Multiple-radiation-length coverage ($\sim 6\lambda_{\mathrm{int}}$)

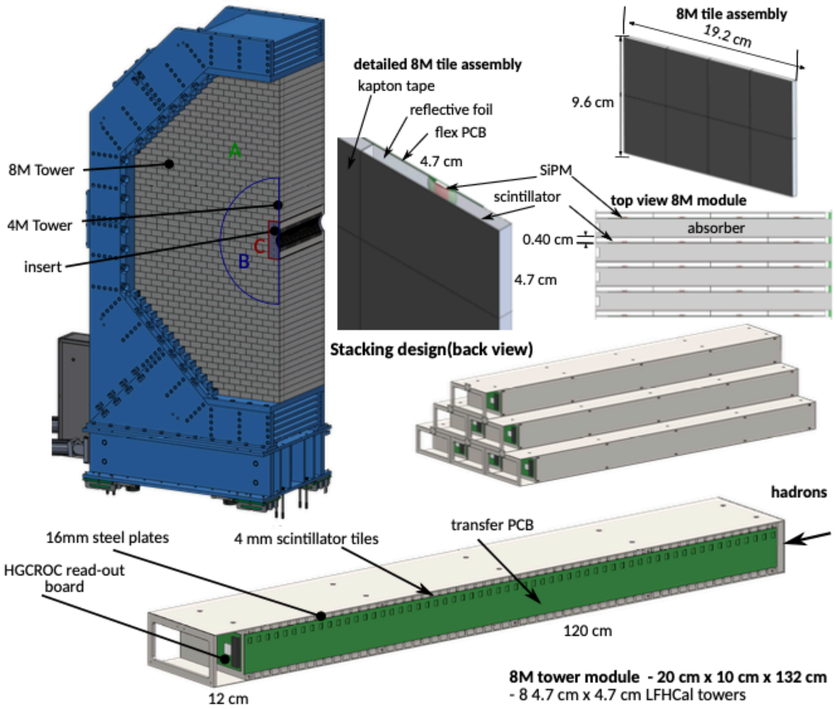
Distinguish shower max

Steel + plastic scintillator + SiPM

LFHCal details

Currently participating institutes: ORNL, BNL, FNAL, Yale, ISU, GSU, UCR, UTK, Valpo, Indiana, UCLA, MSU

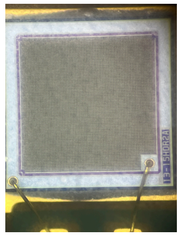
Detector subsystem leader: Friederike Bock, ORNL (fbock@cern.ch)



parameter	LFHCal 8M & 4M modules
inner x,y (R)	-20 cm $> x >$ 40 cm, -30 cm $> y >$ 30 cm
outer R (x,y)	$R <$ 270 cm
η acceptance	$1.2 < \eta < 3.5$
tower information	
x, y	5 cm
z (active depth)	120 cm
z read-out	$\approx$ 8.4 cm
# scintillator plates	60 (0.4 cm each)
# absorber plates	60 (1.52 cm)
interaction lengths	5.8-6.5 λ/λ_0
# towers	8752
# modules	
8M	1058
4M	72
# read-out channels	7 x 8752 = 61264

One scintillating tile, wrapped in ESR foil:

SiPM, on flex PCB, sits inside dimple



Hamamatsu S14160-1315PS SiPM

Yale LFHCal SiPM QC team

Helen Caines

Prakhar Garg

Isaac Mooney

Emily Pottebaum

Ryan Hamilton

Langdan Zhu

Motivation for SiPM quality control

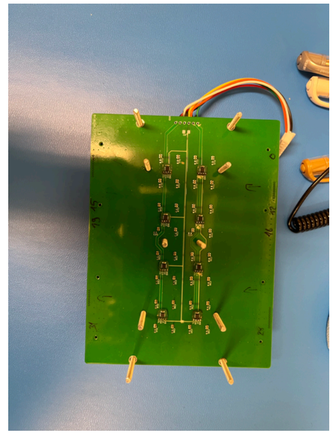
CD-3A procurement shipments of Hamamatsu S14160-1315PS SiPMs arriving, 33k/month starting summer 2025, ending April, 2026 (320k total)

Need to test for consistency of operating characteristics, e.g. breakdown voltage, dark current, etc.

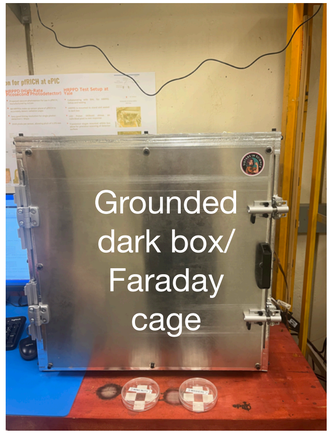
As of September, Yale has a test stand for QC (visual, operational) of 5% of trays for acceptance; expectation of almost all SiPMs within 100 mV spread

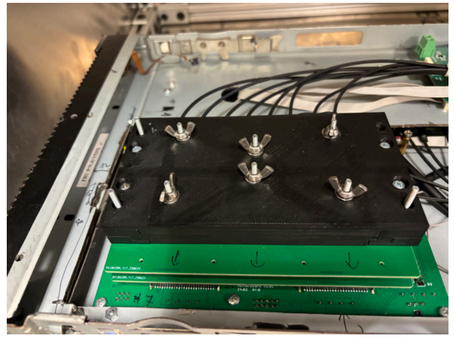
Plan to automate in early 2026 for almost order of magnitude speedup

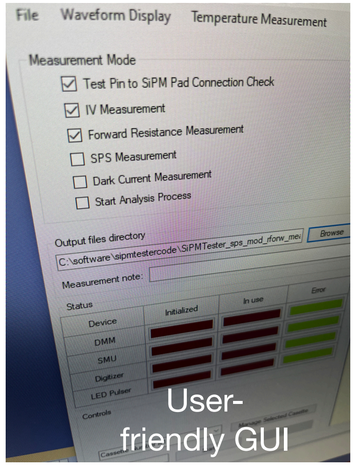
SiPM quality control



- Debrecen team contributed hardware and software for testing 32 SiPMs at once, ~45 mins

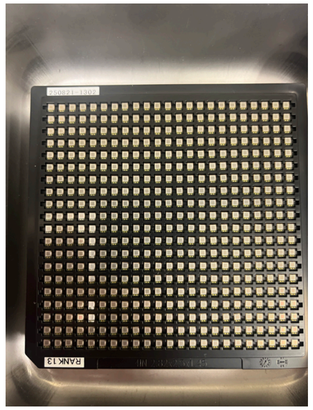


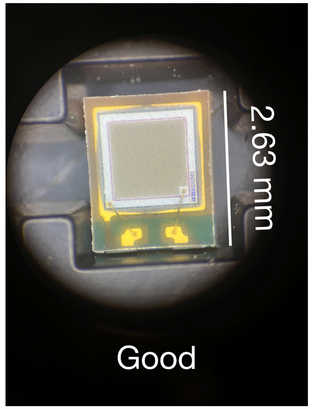


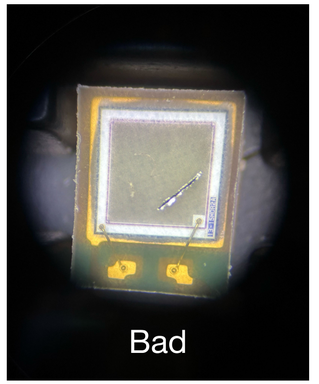


SiPM quality control

- Debrecen team contributed hardware and software for testing 32 SiPMs at once, ~45 mins
- Yale received a first batch of 2.3k Hamamatsu S14160-1315PS SiPMs out of BNL's 50k
- Started testing 9/26/25; finished first 4 trays (1.84k) 10/19/25

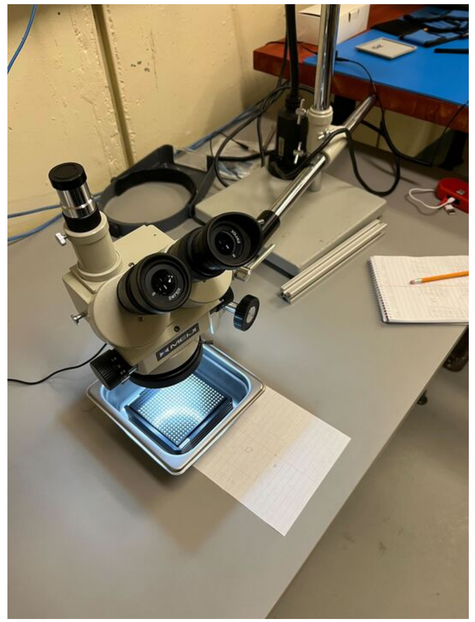






Testing procedure

Step 1: receipt of batch, visual inspection of trays with microscope, entered into spreadsheet (sent to Oleg Eyser, CAM, once values added)



	A	B	C	D	E	F	G	H	I	J	K	L
1	**tray number**	**250821-1301**		**row**	**col**	**row (0)**	**col (0)**	**visual**	**Vop**	**Vbd (SPS)**	**Vbd (IV)**	**Notes**
2	**Vop (V)**	41.80		1	1	0	0	ok	41.7479	37.7479	38.2906	
3	**test start**	10/1/25		1	2	0	1	ok	41.7125	37.7125	38.2712	
4	**test finish**	10/6/2025		1	3	0	2	ok	41.7162	37.7162	38.2773	
5				1	4	0	3	ok	41.6798	37.6798	38.2413	
6	**<Vop> (V)**	**41.72**		1	5	0	4	ok	41.7531	37.7531	38.3192	
7	Count of bad	1		1	6	0	5	ok	41.722	37.722	38.288	
8	Count small defect	12		1	7	0	6	ok	41.6706	37.6706	38.241	
9				1	8	0	7	ok	41.7373	37.7373	38.3145	
10				1	9	0	8	ok	41.7257	37.7257	38.2774	
11				1	10	0	9	ok	41.7462	37.7462	38.2908	
12				1	11	0	10	ok	41.6917	37.6917	38.2422	
13				1	12	0	11	ok	41.7237	37.7237	38.2866	
14				1	13	0	12	ok	41.7432	37.7432	38.3196	
15				1	14	0	13	ok	41.7248	37.7248	38.281	
16				1	15	0	14	ok	41.7269	37.7269	38.2824	
17				1	16	0	15	ok	41.6971	37.6971	38.2589	
18				1	17	0	16	ok	41.7492	37.7492	38.3036	
19				1	18	0	17	ok	41.7011	37.7011	38.2685	
20				1	19	0	18	ok	41.69	37.69	38.2563	
21				1	20	0	19	ok	41.7416	37.7416	38.3179	
22				1	21	0	20	ok	41.7107	37.7107	38.277	

Testing procedure

Step 1: receipt of batch, visual inspection of trays with microscope, entered into spreadsheet (sent to Oleg Eyser, CAM, once values added)

Step 2 (daily): shifter sign-in/out using elog hosted on Yale server

Message ID: **117** Entry time: **Sat Oct 25 21:23:58 2025**

Author:	Ryan
Type:	Hardware
Category:	SiPM test
Subject:	LFHCal SiPM Testing Shift Log: Sign In Sheet 10/25

All fields highlighted in yellow should be filled before and after any SiPM testing shift.

Sign in or sign out?: Sign In

Task of shift (SPS/IV/full, # of tests): Making some headway on new tray 250717-1304

Production, stability, or test run?: production

Current State of Testing Setup:

Cassette States

Current Cassette in dark box:	**Current Cassette in queue (Next to be tested):**
Cassette number (#1 or #2): #1	Cassette number (#1 or #2): #2
Manufactory Tray Code: 250717-1304	Manufactory Tray Code: 250717-1304
SiPM range (row - col): (11,3) to (row- col) (12,11) [set 8]	SiPM range (row - col): (12,12) to (row- col) (13,20) [set 9]

Any special notes about setup state (misplaced parts, special testing information, etc):

Continuing runs after handing off from Prakhar. Setup seems to be in a good state.

(Run summary)

Tray 250717-1304 Set 8 (SiPMs (11,3) to (12,11)) [Completed by Prakhar in last shift]

Tray 250717-1304 Set 9 (SiPMs (12,12) to (13,20))

Tray 250717-1304 Set 10 (SiPMs (13,21) to (15,6)) [x5 overnight]

Testing procedure

Step 1: receipt of batch, visual inspection of trays with microscope, entered into spreadsheet (sent to Oleg Eyser, CAM, once values added)

Step 2 (daily): shifter sign-in/out using elog hosted on Yale server

Step 3 (multiple times per shift): Following written procedures (being formalized in test bench document),

6. After repeating 32 times, the cassette should be empty with the SiPMs restored to their original positions on the manufacturer tray. Check the “Placement is correct” box in the GUI and click “OK”.

Adding SiPMs:

1. Check that label on the cassette corresponds to the Cassette Number in the GUI. If not, click the drop-down arrow and then the other Cassette Number.
2. Click “Manage Selected Cassette” in the GUI.
3. Locate the cassette into which SiPMs from the tray will be placed. Check that the number on the top-left (where notch is bottom-left, for reference) of the tray on top of the stack corresponds to the “Factory tray number” in the top of the pop-up from the GUI.
4. Align the cassette such that the open slot cutout on the side is facing to your right (match the GUI image of the cassette in the pop-up).
5. Remove SiPMs with the tweezers from the tray from top left to bottom right *by row*; place in the cassette from bottom right to top-left *by column*. Check off the space in the GUI corresponding to the SiPM you just removed. Then check off the square in the cassette image in the GUI. Then click “Move >>” which will highlight the tray square in red and the cassette square in green.
6. After doing this 32 times, the cassette should be full, and you can check the “Placement is correct” box and click “OK”.
7. To avoid leaving SiPMs exposed, add the top bracket for this cassette, such that the labels (#1 or #2) match in number and position, and the open slot cutouts line up between the two. You can now secure the top bracket of the cassette with four small screws to hand-tightness.
8. The cassette is now ready to be measured.

Switching Display (Between Linux analysis PC and Windows PXIe):

1. Assure that both computers are on, with flashing lights (take photo for reference).

Testing procedure

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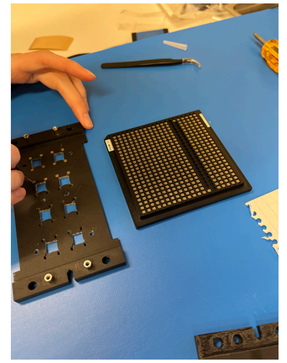
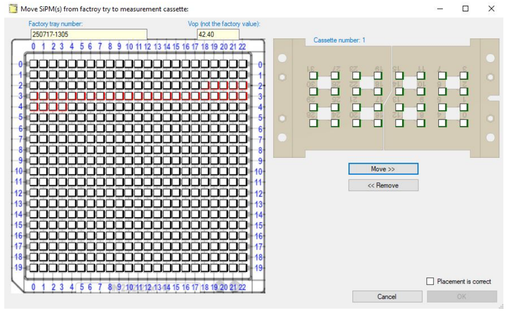


Step 2 (daily): shifter sign-in/out using elog hosted on Yale server

Step 3 (multiple times per shift): Following written procedures (being formalized in test bench document), once grounded with **grounding wrist strap**, fill cassettes with 32 SiPMs from tray of 460 using **ESD-safe tweezers** while recording positions in **user-friendly GUI**, insert into **grounded dark box/Faraday cage** for testing in circuit with LED pulser, 8 temp. sensors



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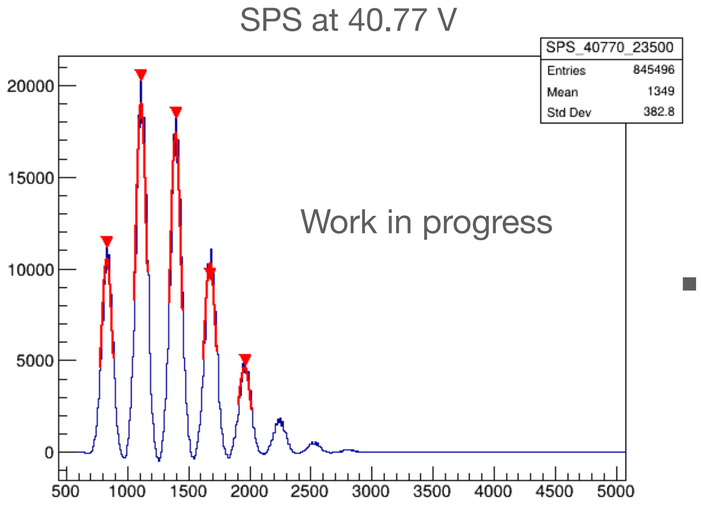
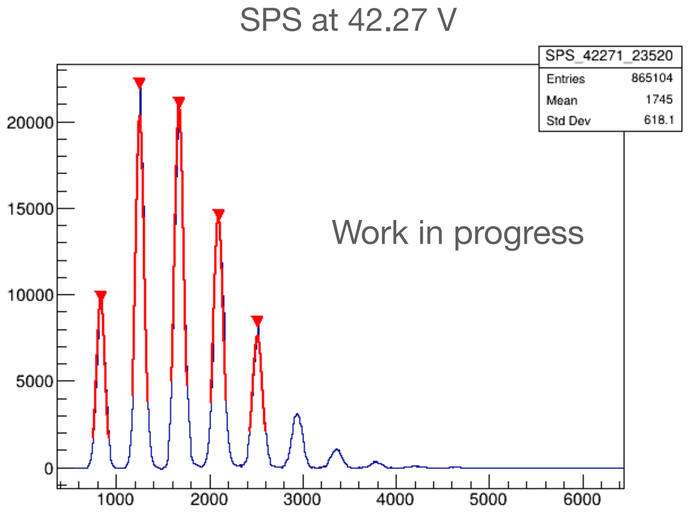
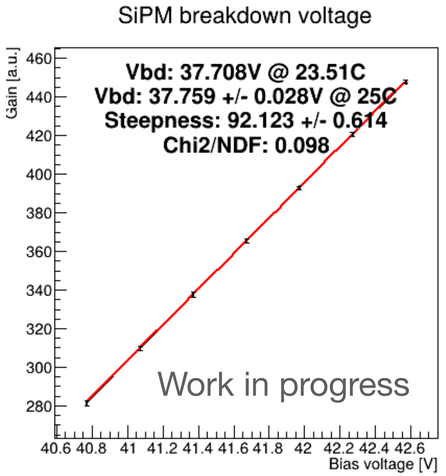
Step 4: Run tests (goal of 5 cassettes per day (160 SiPMs), one hour each). Back data up to external disk frequently.

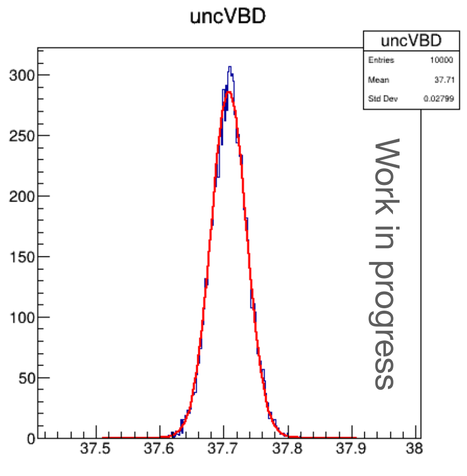
SiPM quality control: early results

$V_{bd} = 37.76 \pm 0.03$ V





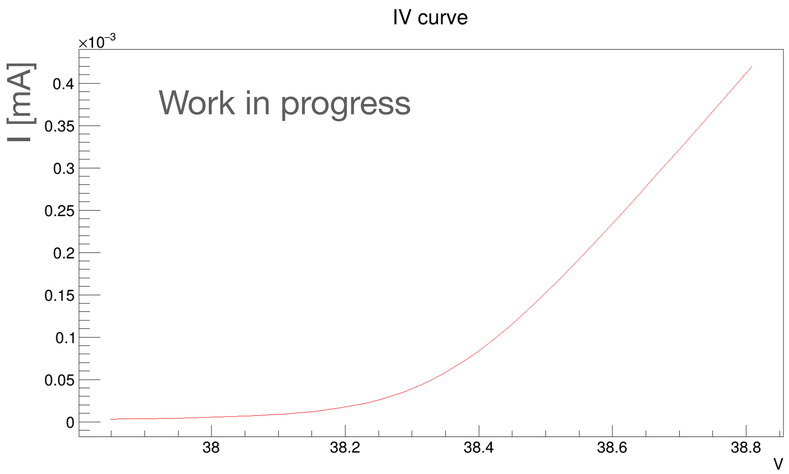


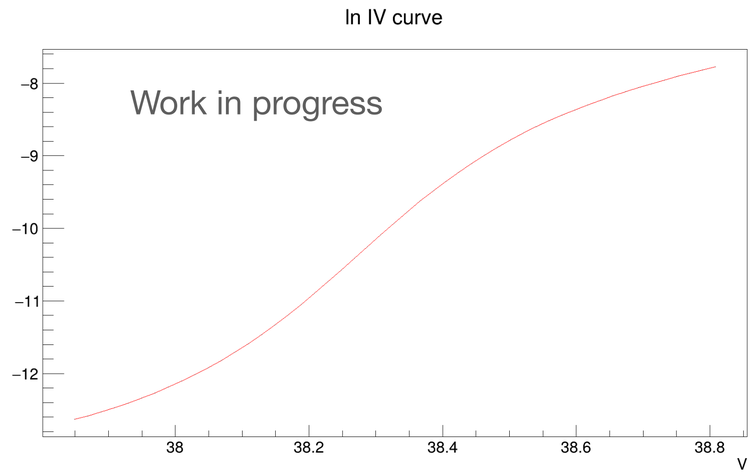


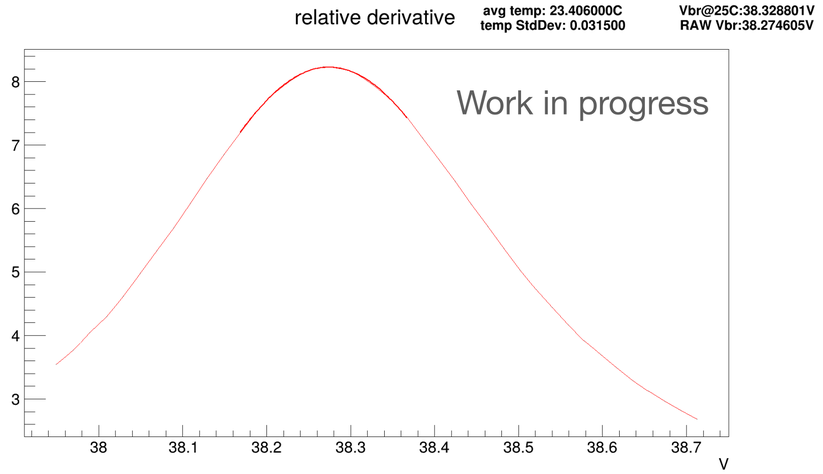
Single photon spectra used to extract the gain and find breakdown voltage extrapolated to zero gain assuming linearity (excellent χ^2/ndf). Also temperature-corrected to 25 C by Debrecen setup.

SiPM quality control: early results

V_{peak} = 38.33 V





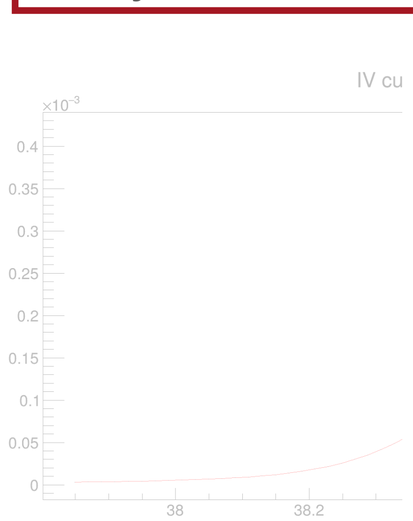


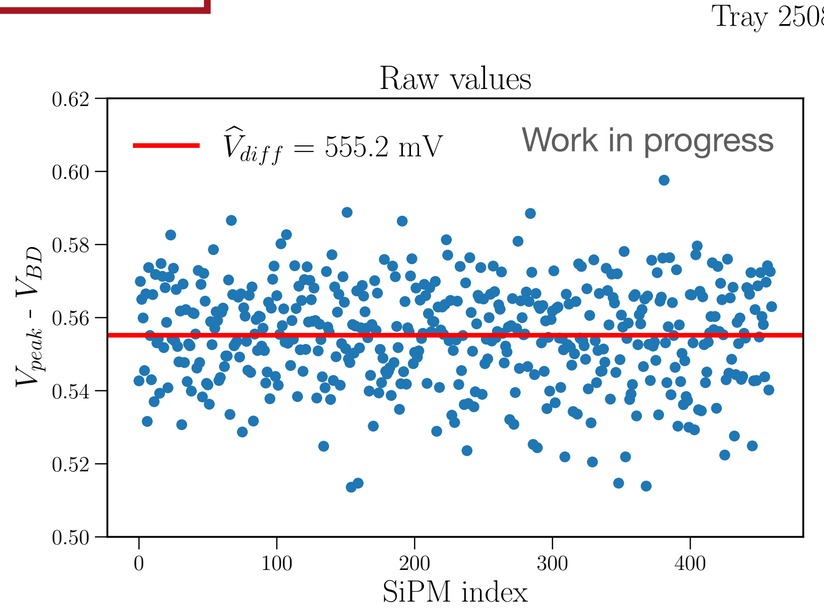
The derivative of the log of the IV curve gives an independent measurement of the breakdown voltage (*not necessary to agree with SPS technique* — differ by ~0.5 V on average)

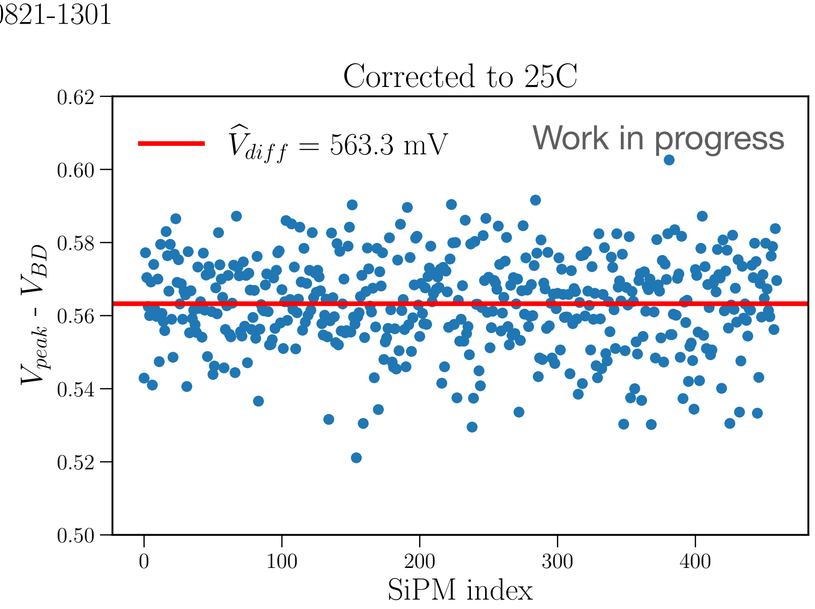
SiPM quality control: early results

V_{peak} = 38.33 V

Analysis code on GitHub

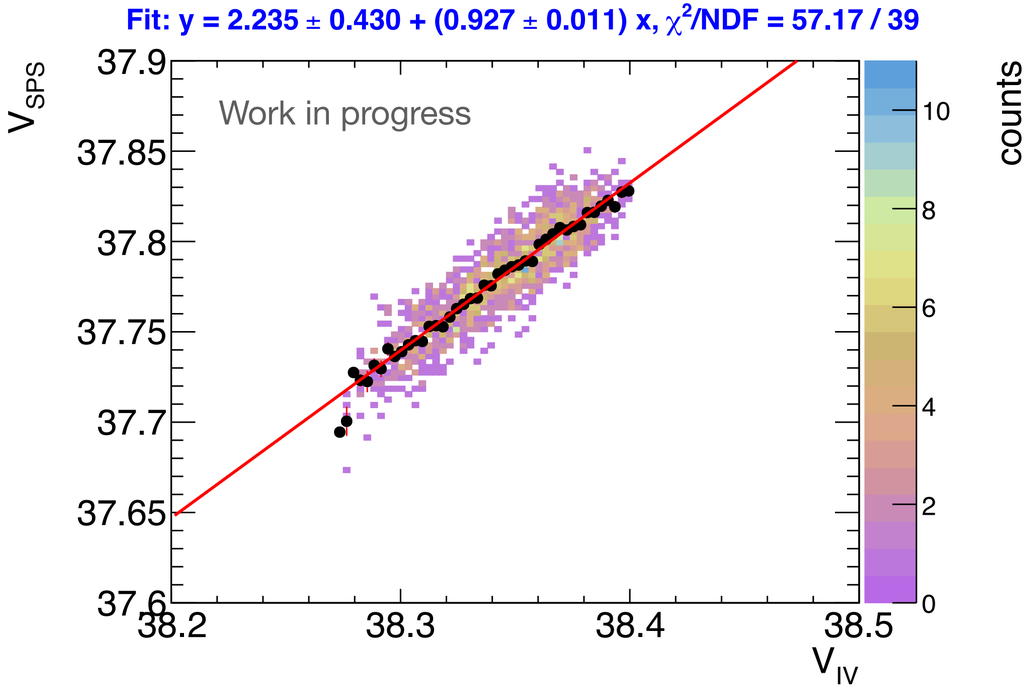


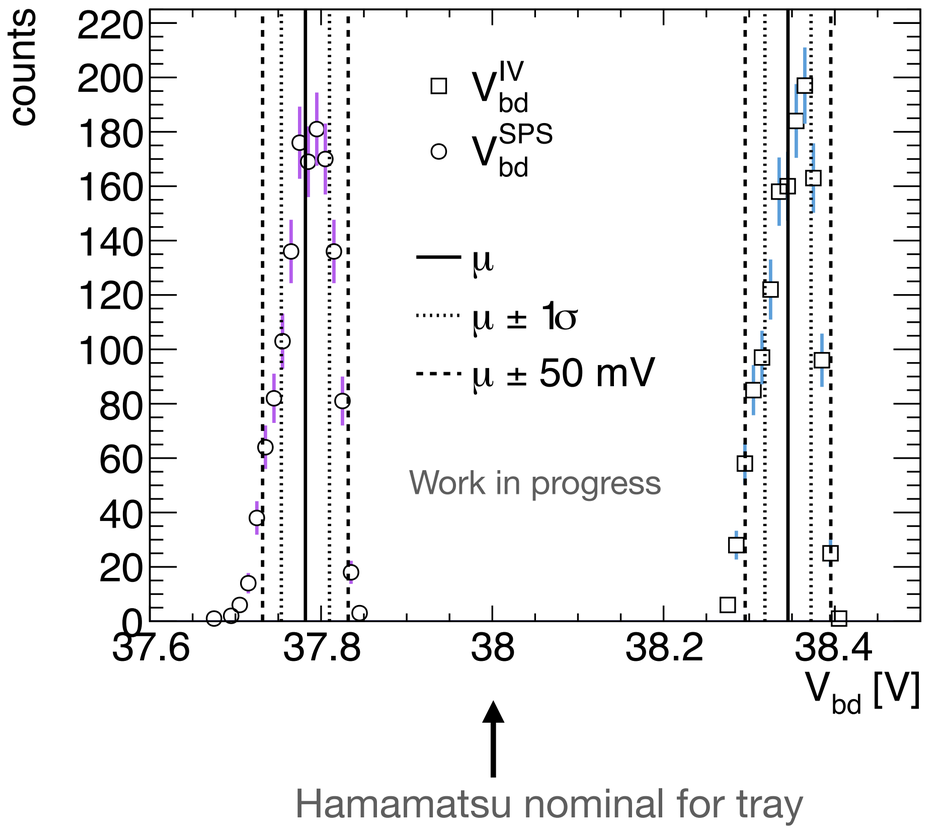




The derivative of the log of the IV curve gives an independent measurement of the breakdown voltage (*not necessary to agree with SPS technique* — differ by ~0.5 V on average — consistent across tiles)

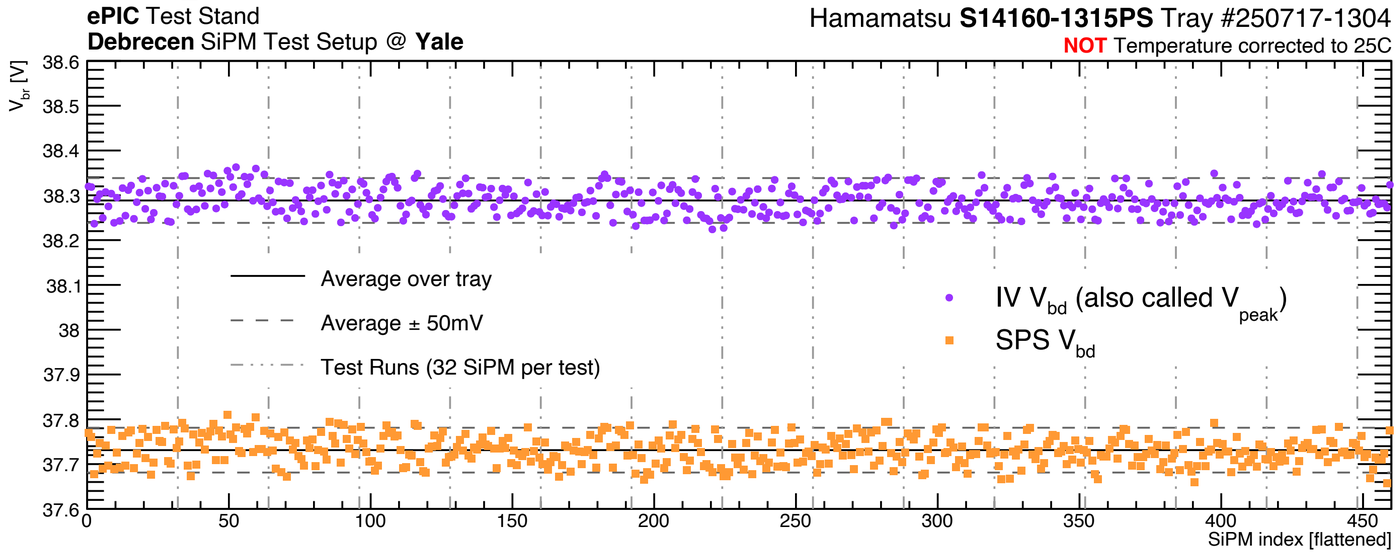
SiPM quality control: early results

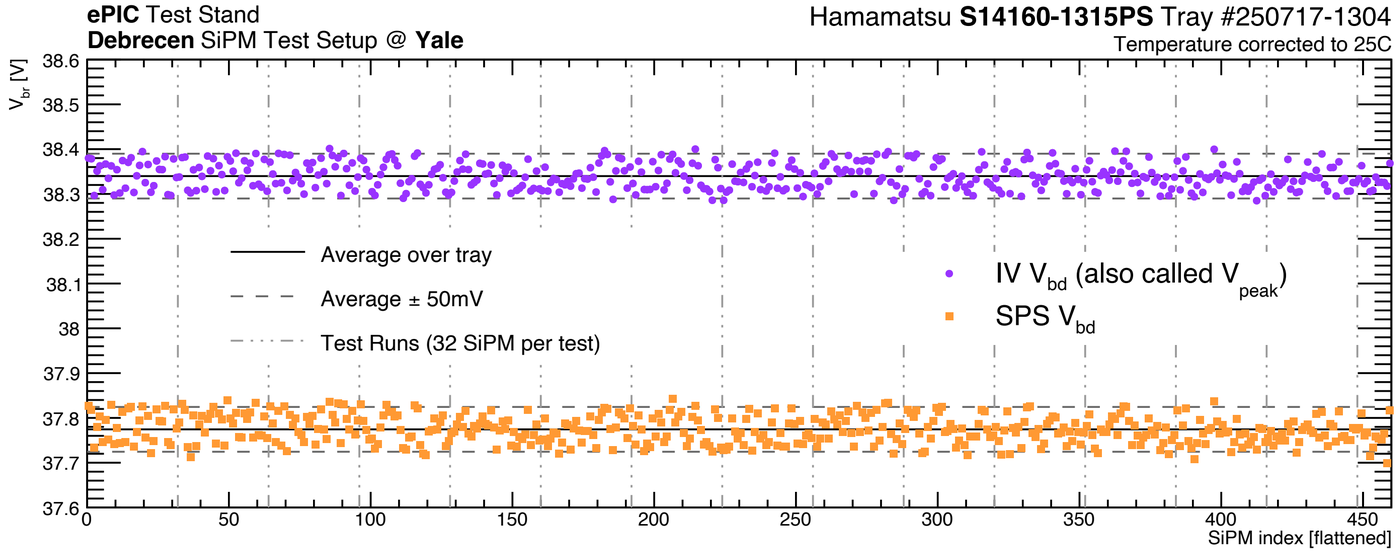




Vast majority of SiPMs within spec (± 50 mV), few (~5%) percent outside. More studies to be done on these outliers.

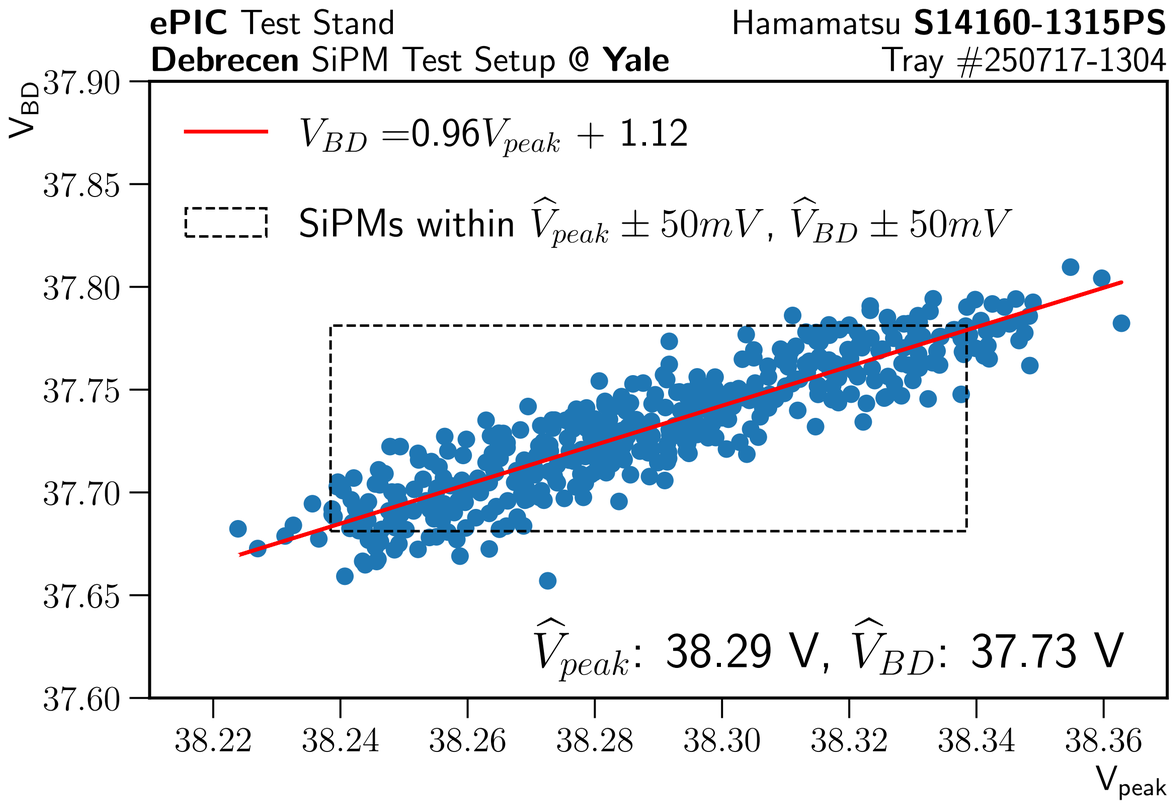
Effect of temperature correction



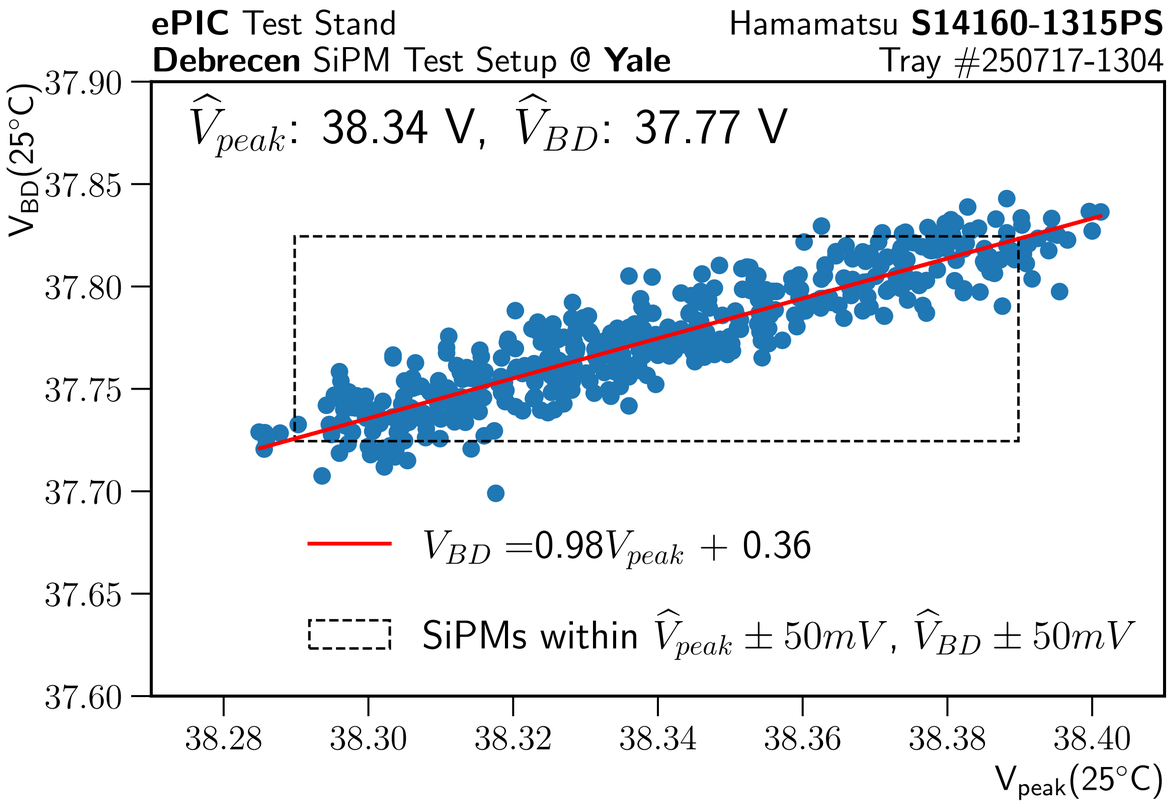


Small effect, as SiPM temperatures are usually ~ 23.5 C with ~ 0.5 C width, and scaling is ~10-40 mV / C

Method comparison



Using the 100mV window centered around the mean,
the "outlier" SiPMs fall outside that window
V_{peak} outliers (IV): 29 (6.3%)
V_{BD} outliers (SPS): 48 (10.4%)



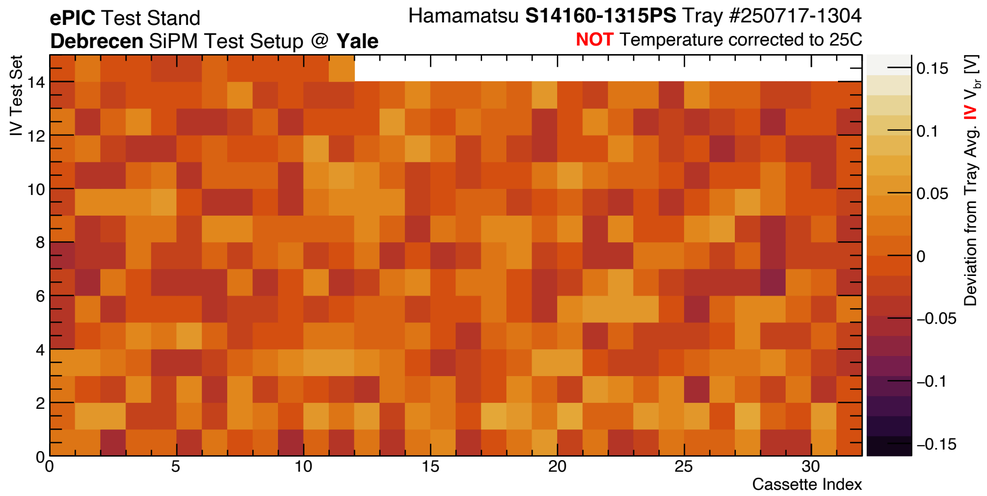
Using the 100mV window centered around the mean,
the "outlier" SiPMs fall outside that window
V_{peak} outliers (IV): 22 (4.8%)
V_{BD} outliers (SPS): 44 (9.6%)

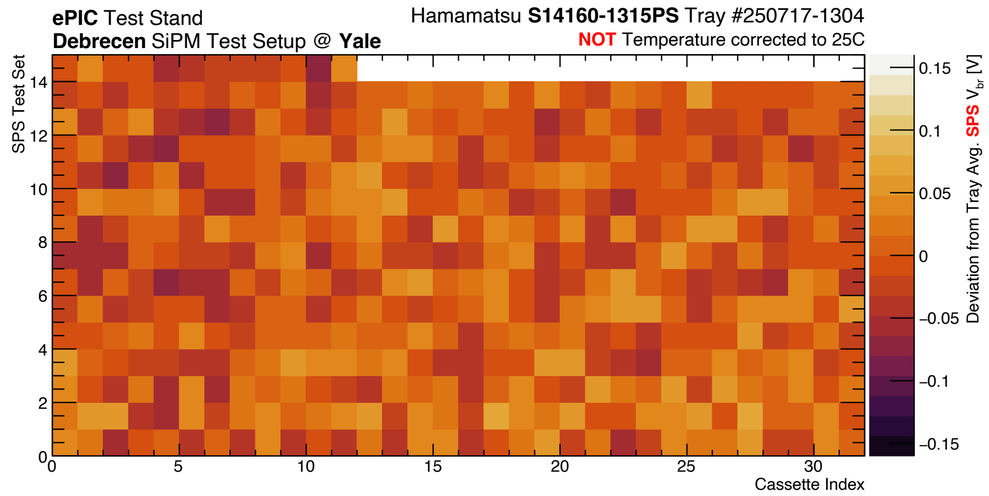
Intra-cassette comparisons

IV

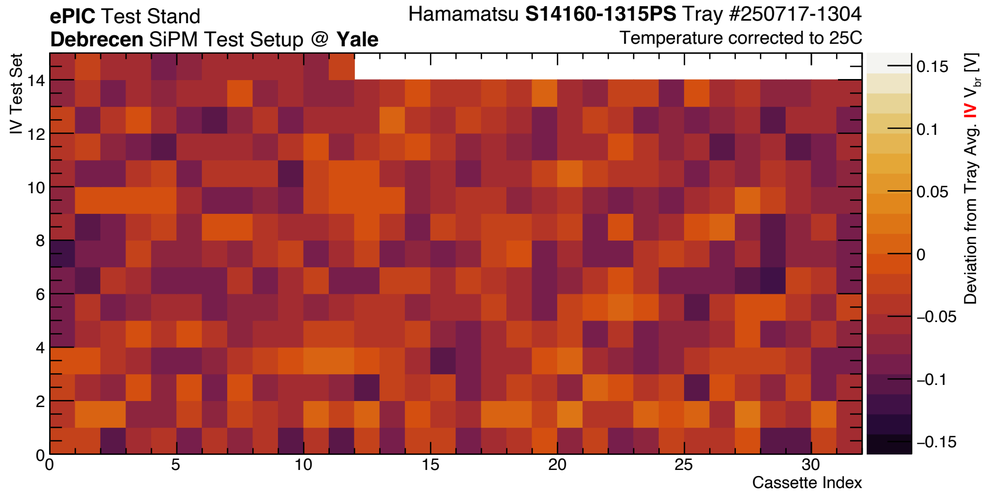
SPS

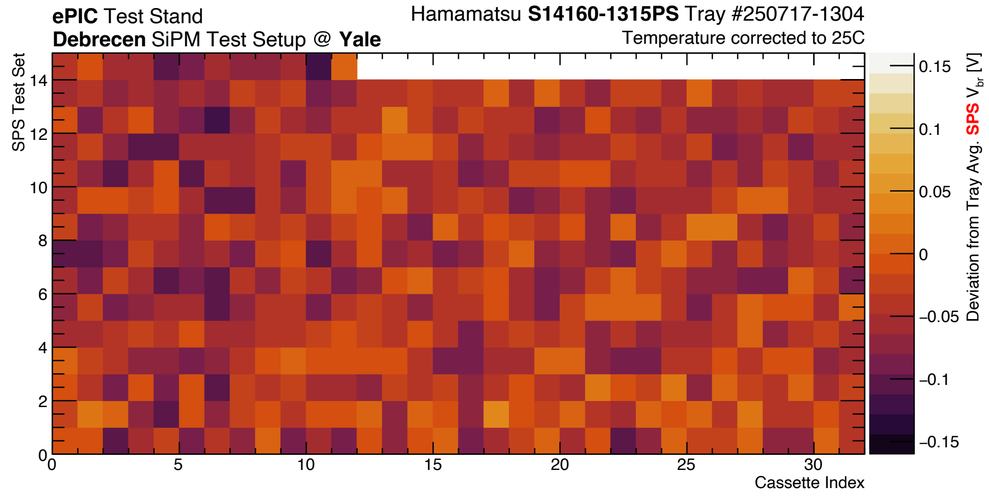
NOT Temp. Corrected





Temp. Corrected





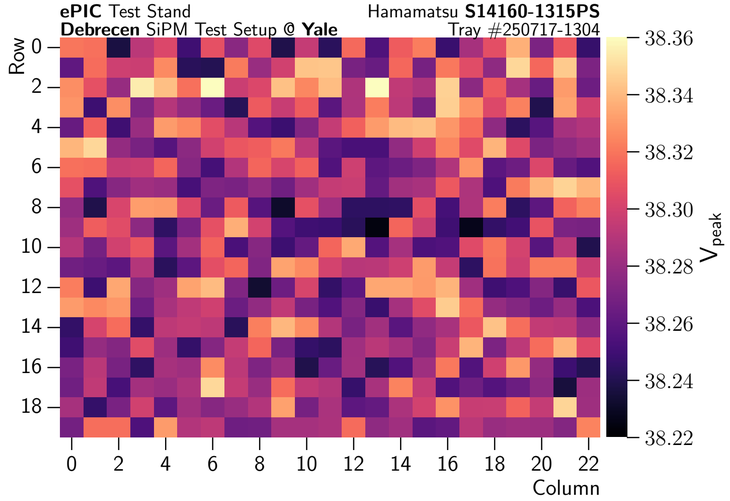
No noticeable effects of SiPM position in cassette

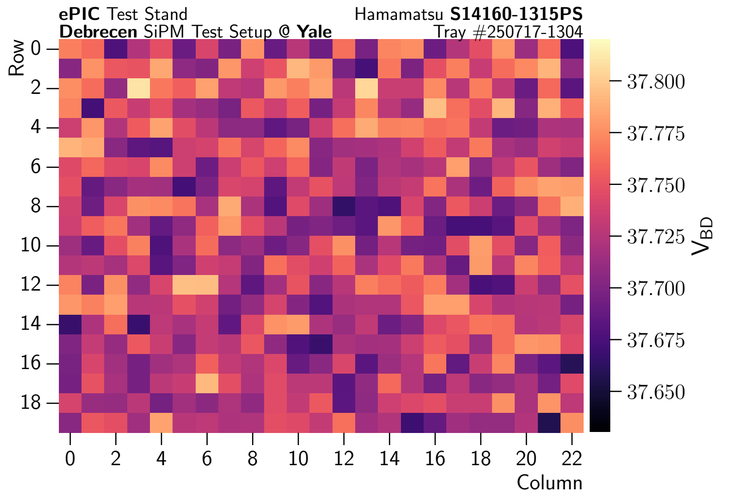
Intra-tray comparisons

IV

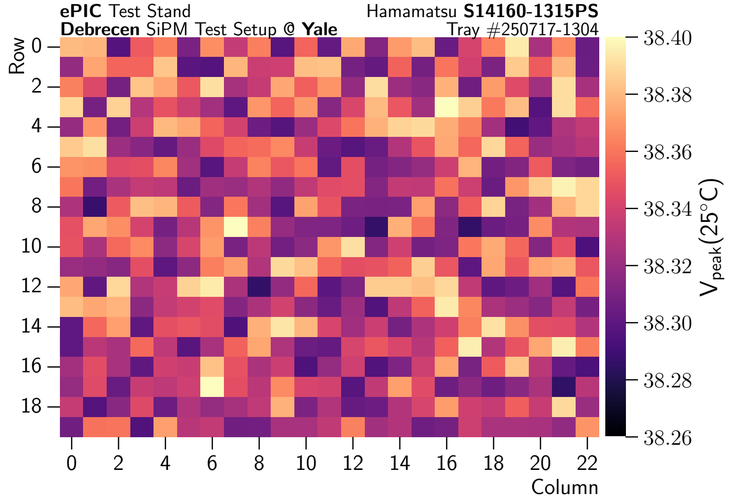
SPS

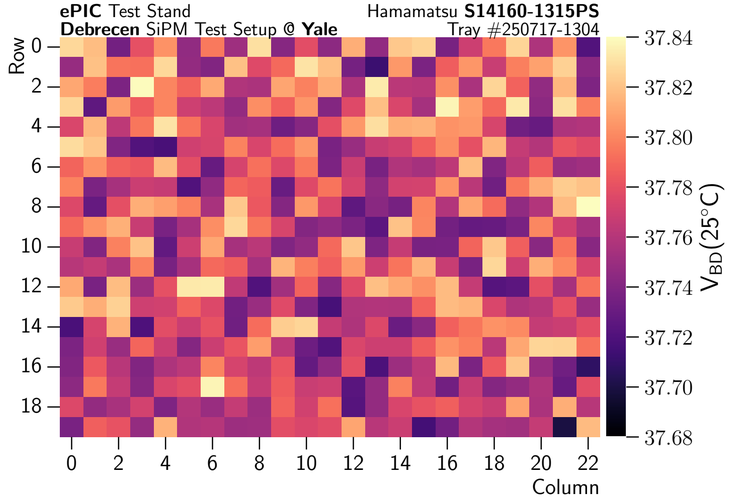
NOT Temp. Corrected





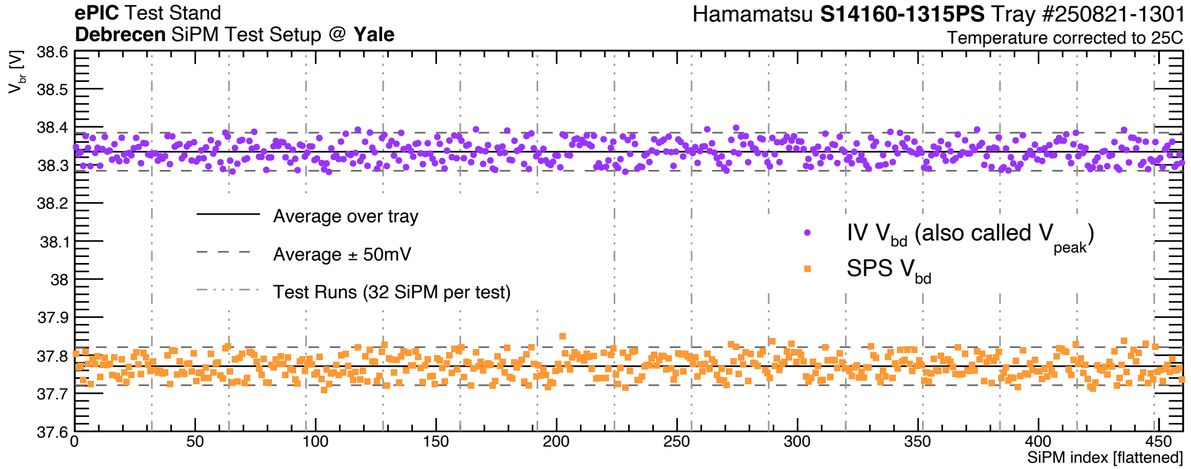
Temp. Corrected

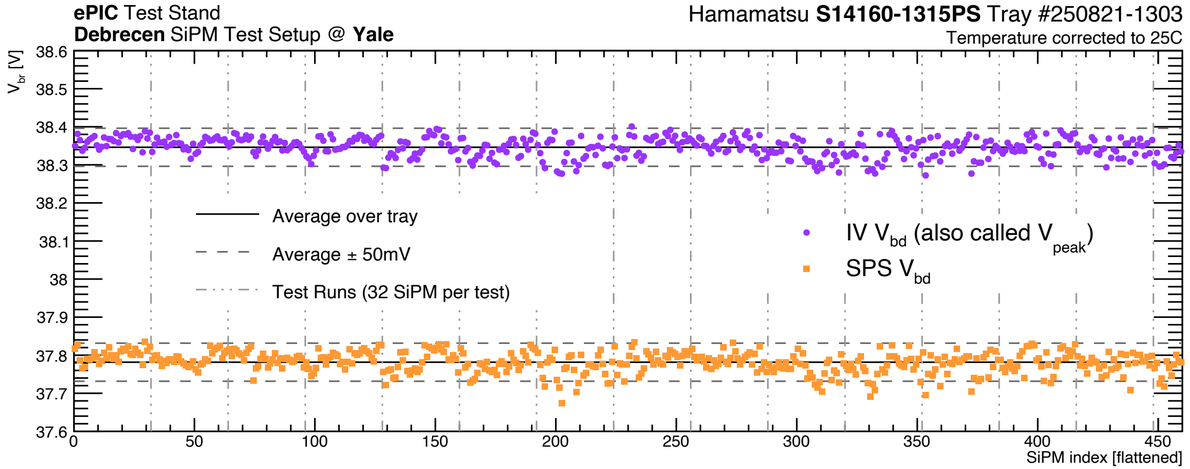


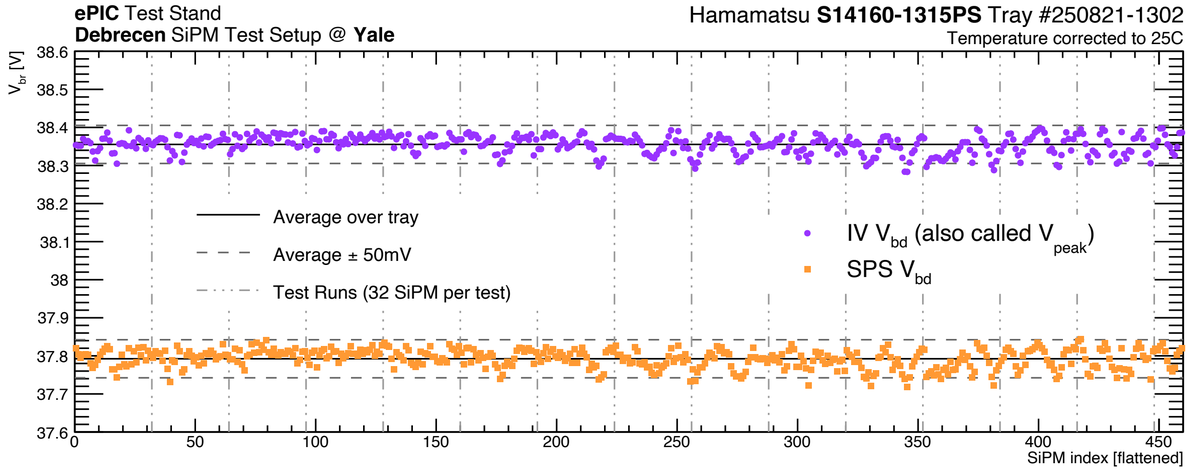


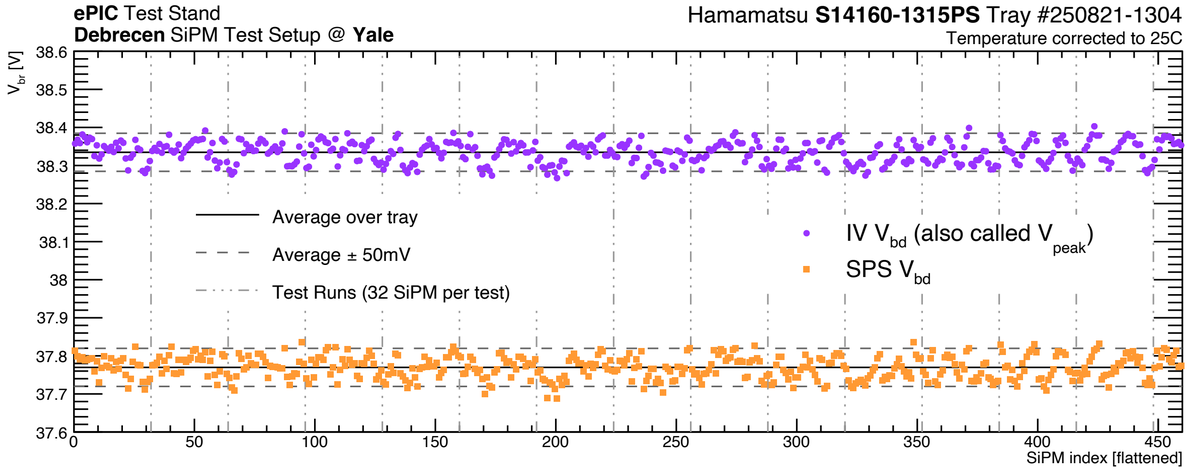
No noticeable effects of SiPM position in tray

Inter-tray comparisons



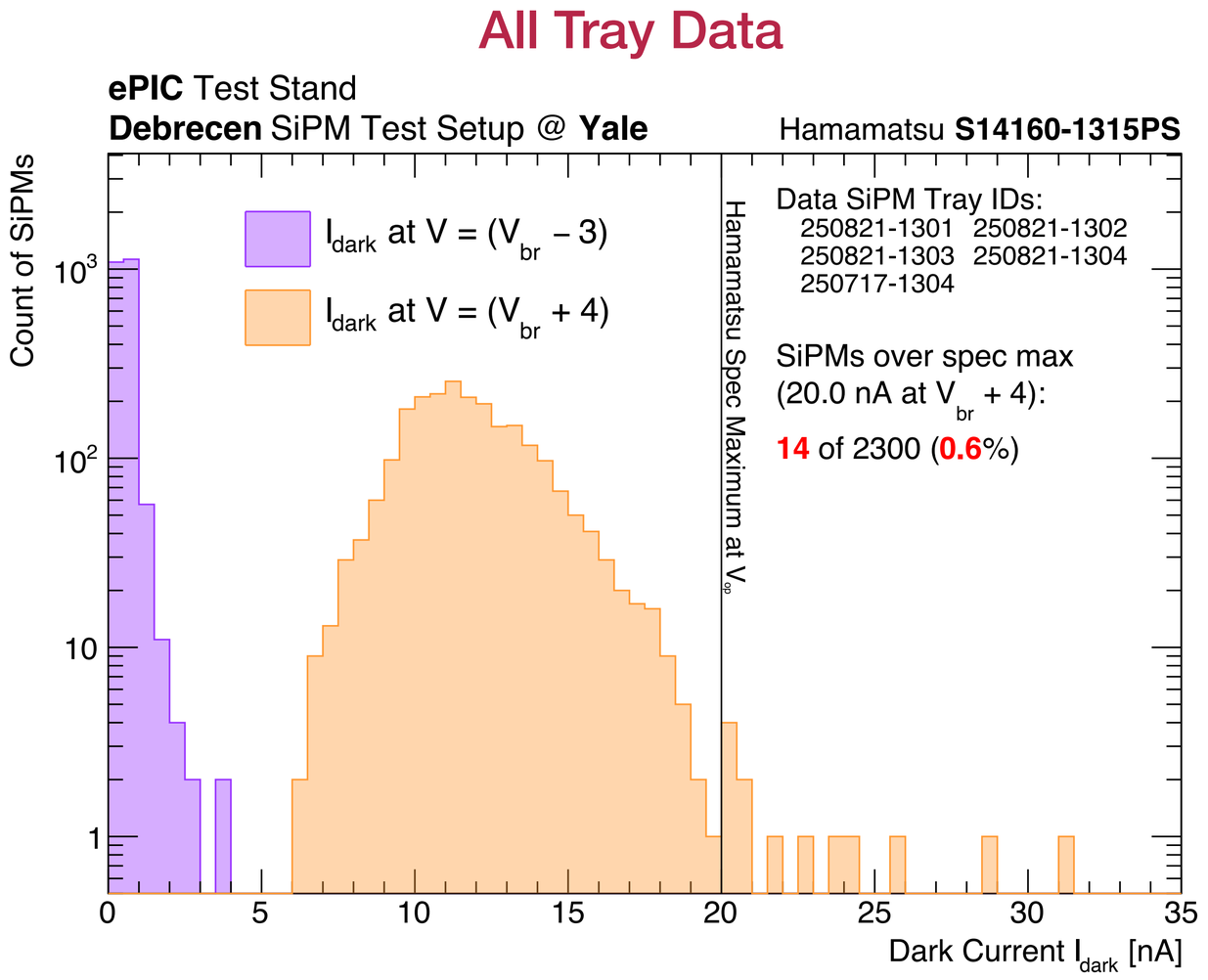






No noticeable effects of tray number

Dark current measurement



Dark current almost entirely within spec

Outlook

The testing method is stable and has a history of use in other detectors (CMS calorimeters)

Finalized Batch 3 Hamamatsu SiPM sample characterization, which was overall consistent within 100 mV with few percent outliers

Server-hosted database for storing per-SiPM properties/plots will be ready in the next few weeks

Vacuum sealing for storage planned

Robot to automate expected from Debrecen
~ Feb. 2026

More to come!