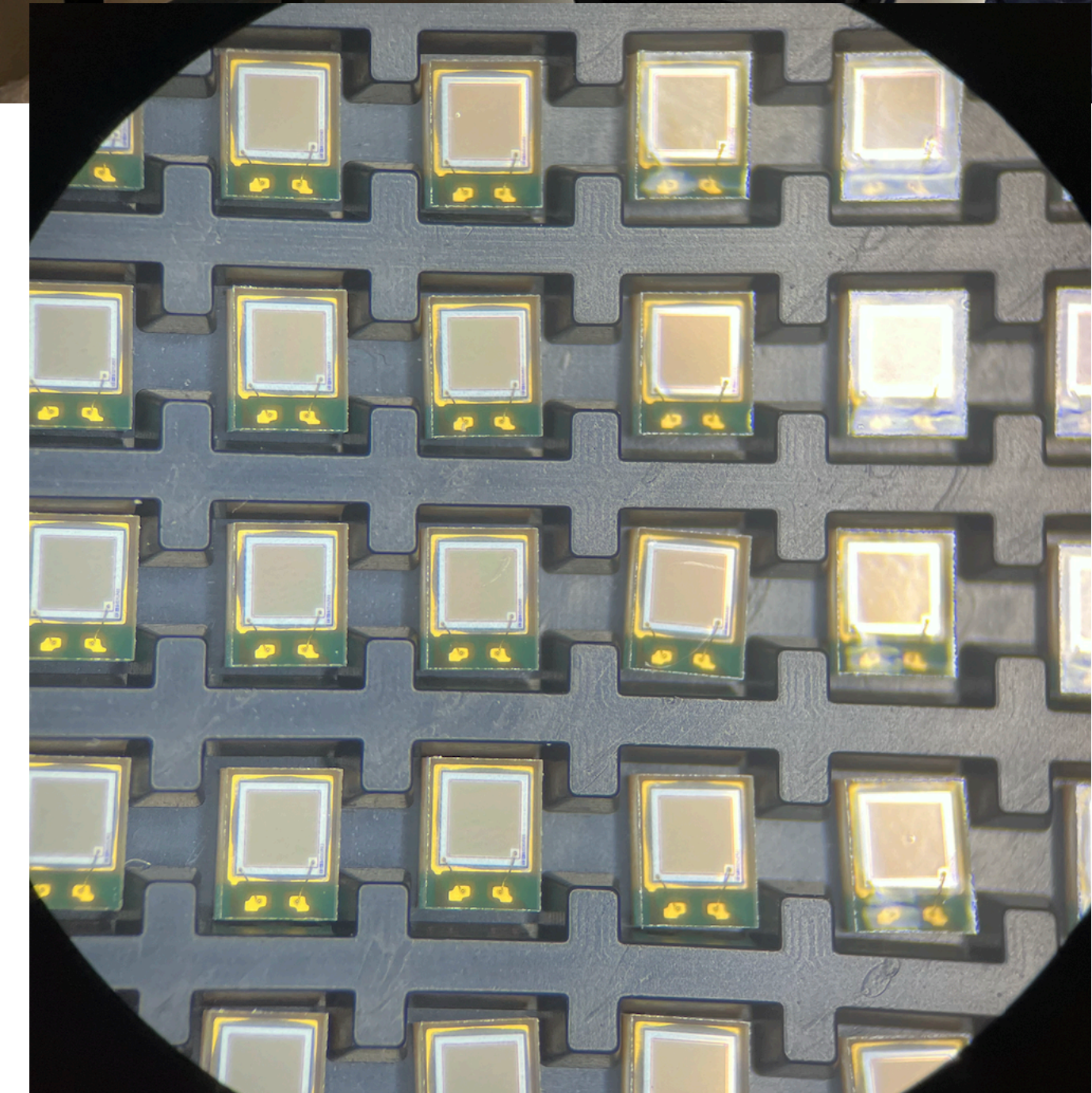


LFHCaI SiPM QC

Yale Update

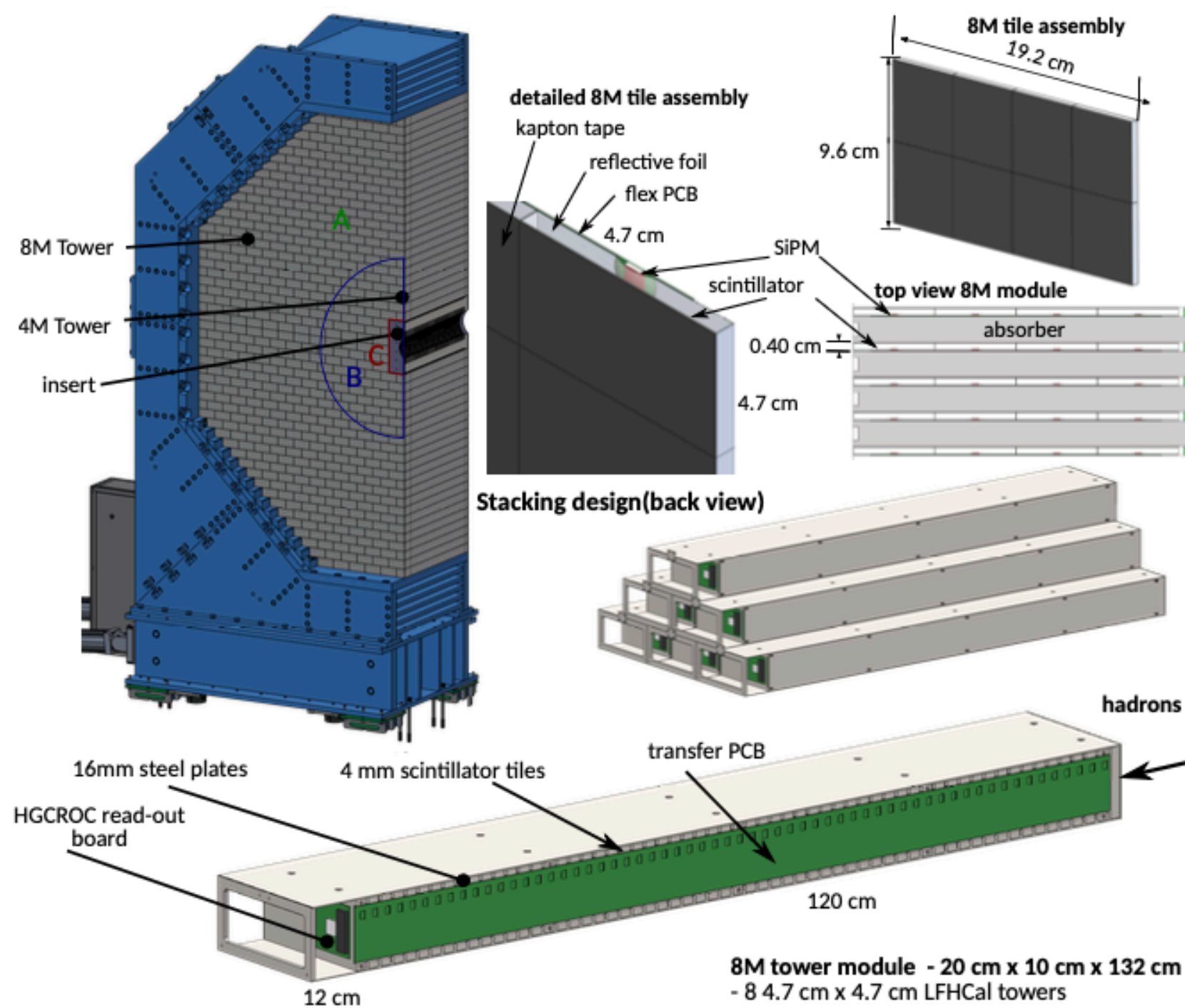
PI	Helen Caines, Laura Havener
Research Scientist	Prakhar Garg
Postdoc	Isaac Mooney
Grad Students	Emily Pottebaum, Ryan Hamilton
Undergrads	Langan Zhu, Emma Wilmott, Michael Nguyen
Visiting Students	Levente Pirent, Jesse Lior



LFHCal details

Slide from I. Mooney TIC 11/3/25

Currently participating institutes: ORNL, BNL, FNAL, Yale, ISU, GSU, UCR, UTK, Valpo, Indiana, UCLA, MSU
Detector subsystem leader: Friederike Bock, ORNL
 (fbock@cern.ch)



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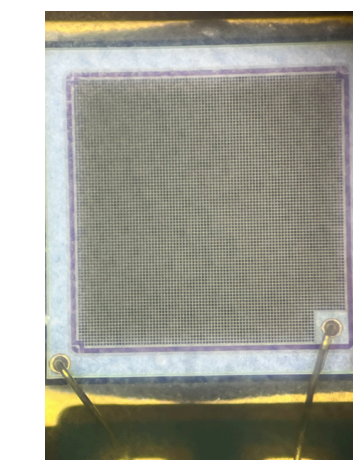
parameter	LFHCal 8M & 4M modules
inner x,y (R)	$-20 \text{ cm} > x > 40 \text{ cm}$, $-30 \text{ cm} > y > 30 \text{ cm}$
outer R (x,y)	$R < 270 \text{ cm}$
η acceptance	$1.2 < \eta < 3.5$
tower information	
x, y	5 cm
z (active depth)	120 cm
z read-out	$\approx 8.4 \text{ cm}$
# scintillator plates	60 (0.4 cm each)
# absorber plates	60 (1.52 cm)
interaction lengths	$5.8-6.5 \lambda / \lambda_0$
# towers	8752
# modules	
8M	1058
4M	72
# read-out channels	$7 \times 8752 = 61264$

ult

One scintillating tile, wrapped in ESR foil:

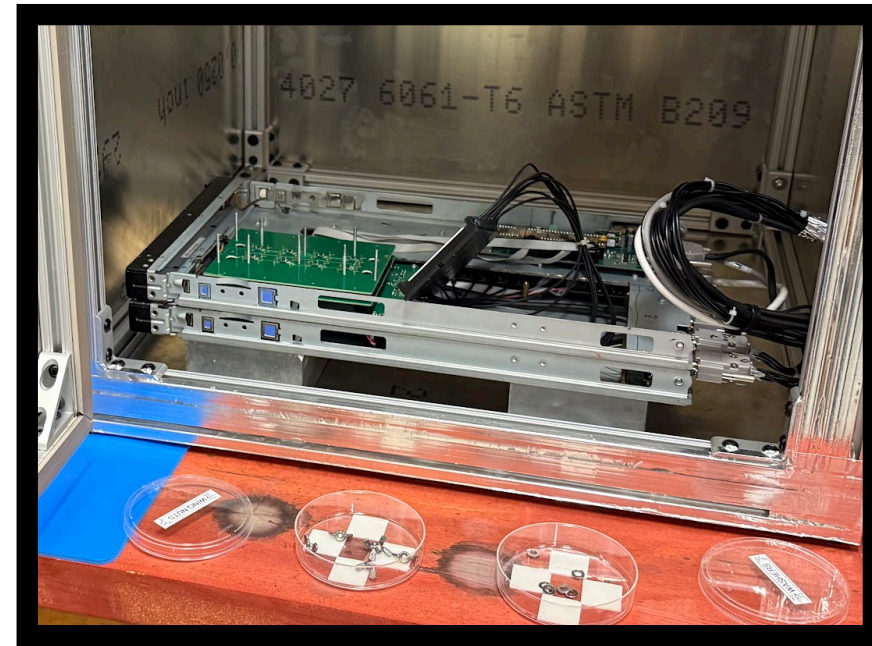


SiPM, on flex PCB, sits inside dimple

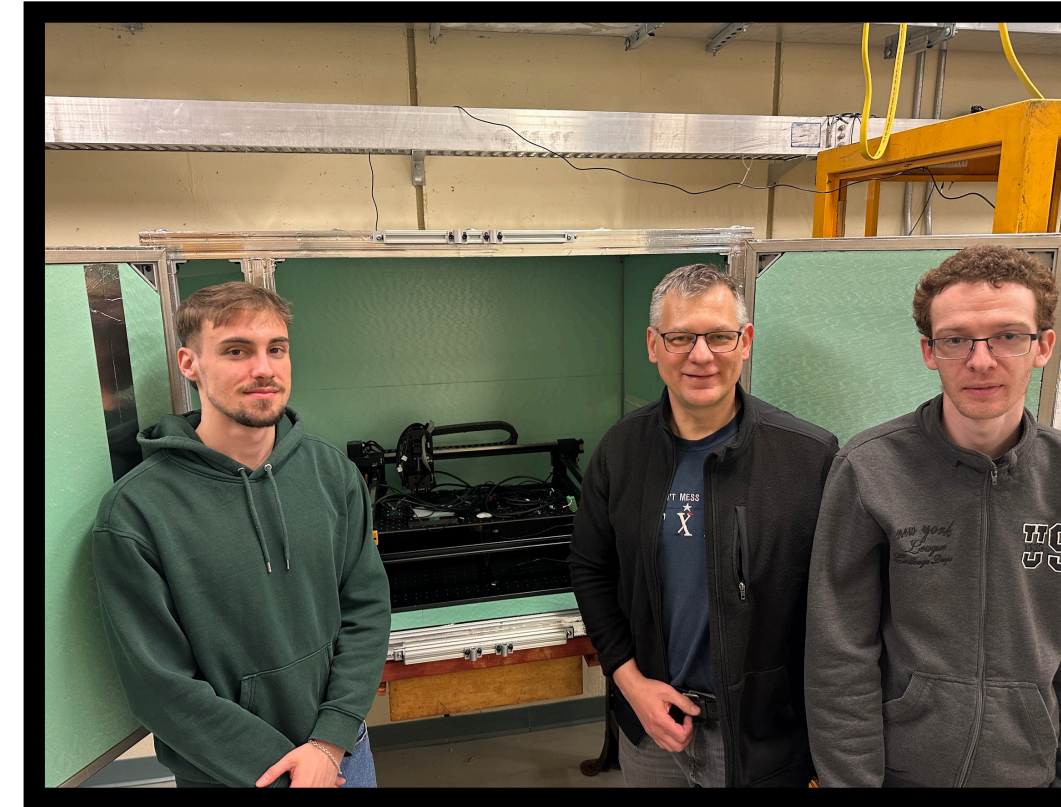


Hamamatsu S14160-1315PS SiPM

Timeline



December 2025
Debrecen finalizes robotic tester, Yale builds extended dark box. Testing complete for 13,000 SiPMs.

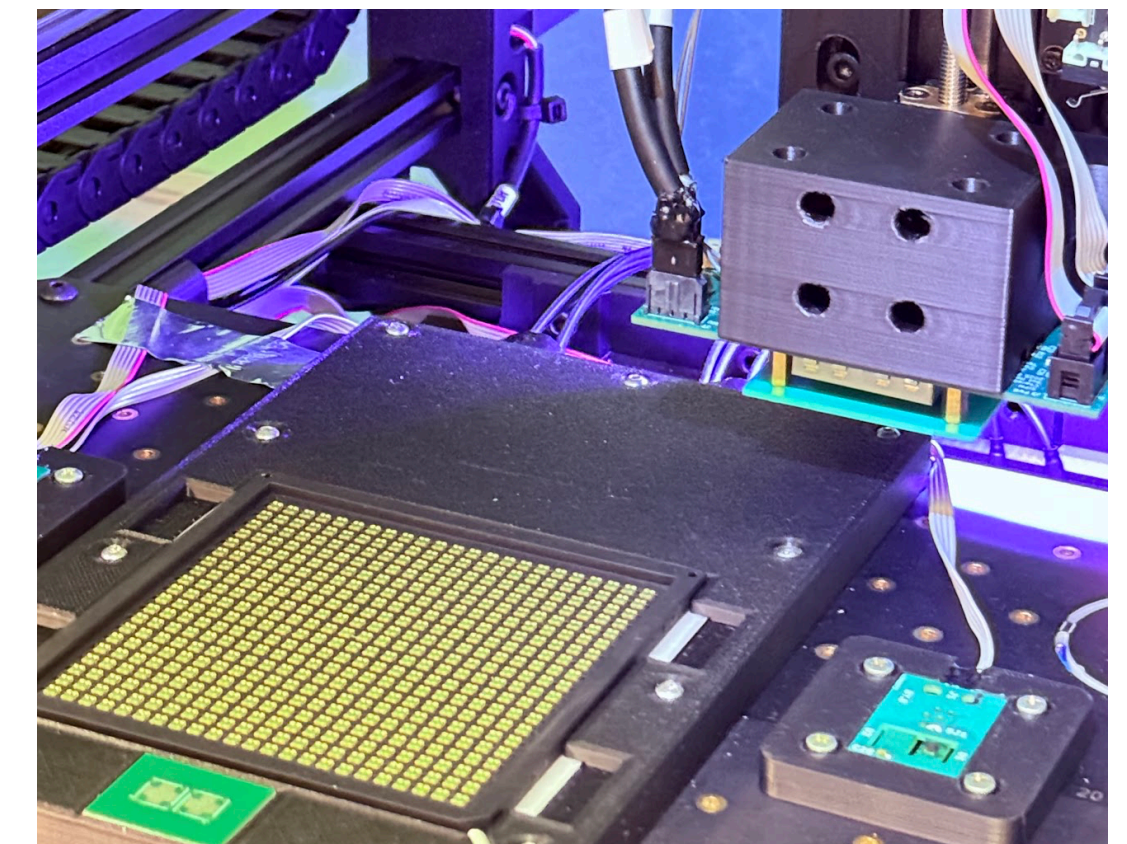


May 2026
All received SiPMs (~20,000) tested.

September 2025
Debrecen Cassette Test stand arrives at Yale



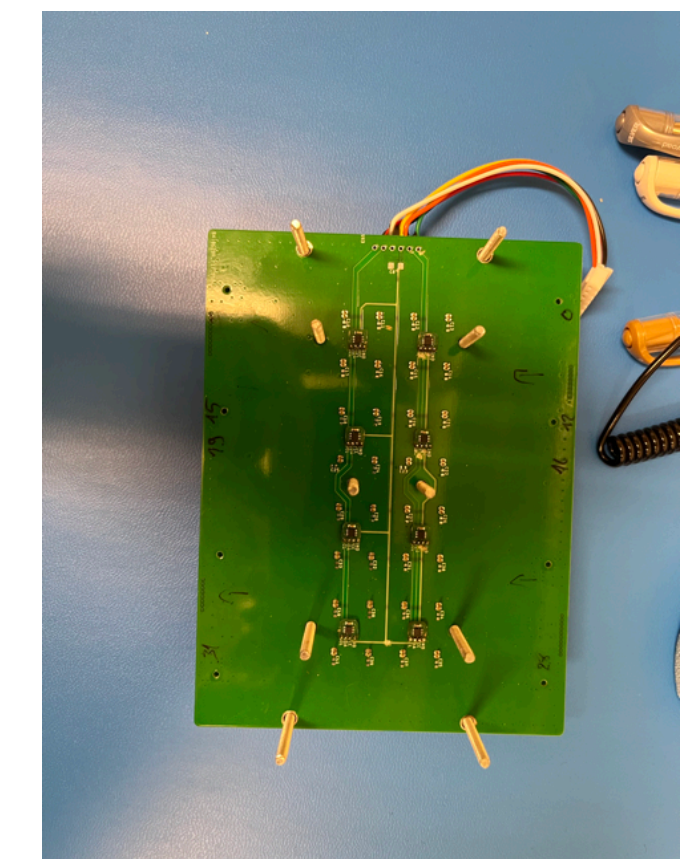
March 2026
Debrecen robot arrives at Yale, testing resumes



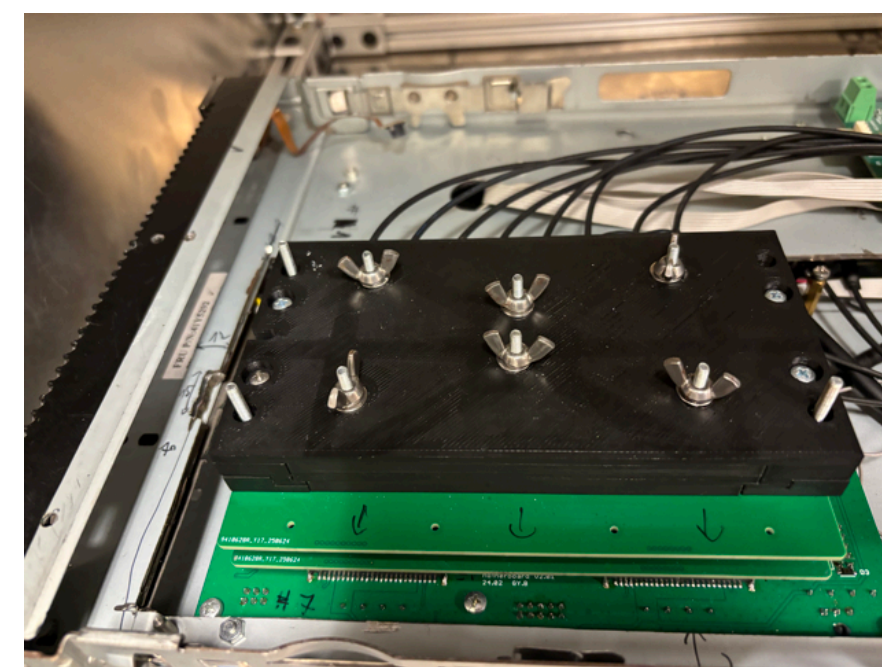
First Batches: Cassette Setup

SiPM quality control

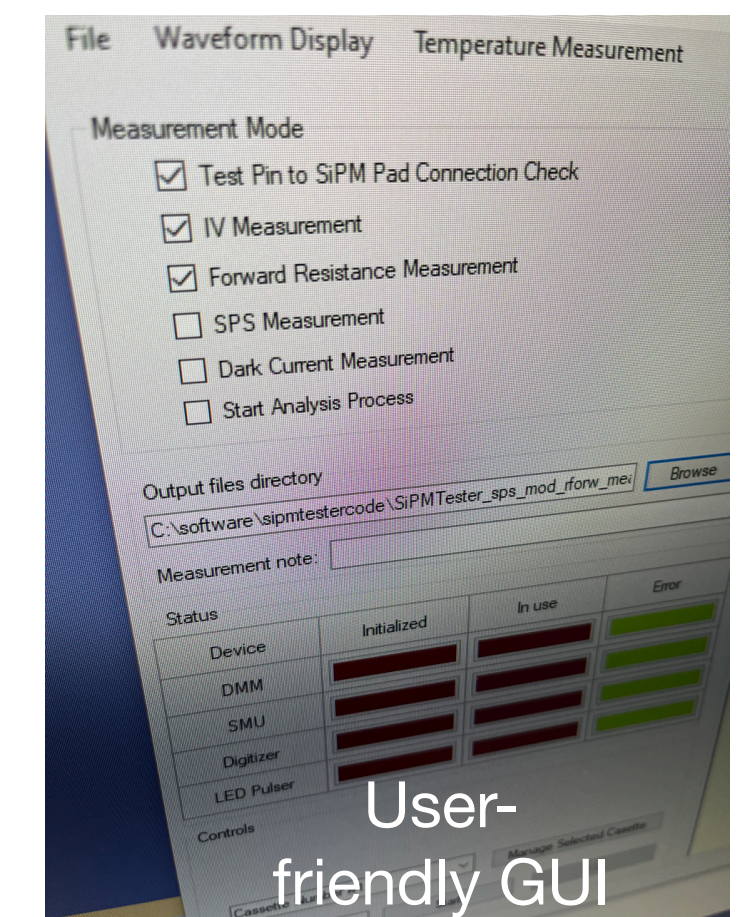
Slide from I. Mooney TIC 11/3/25



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



Ryan Hamilton (Yale)

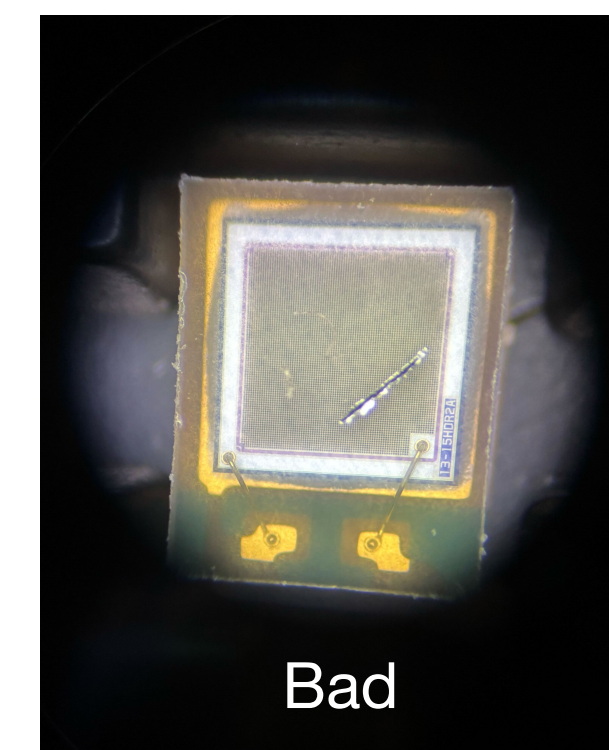
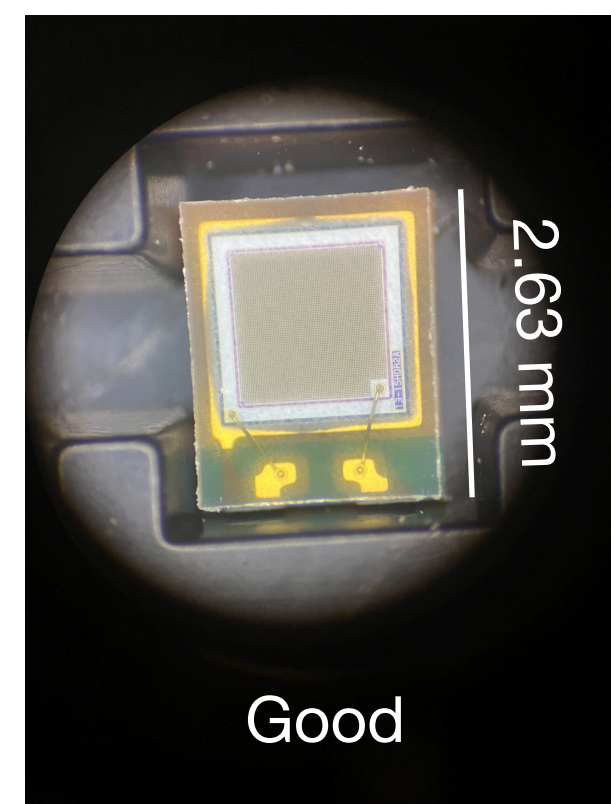
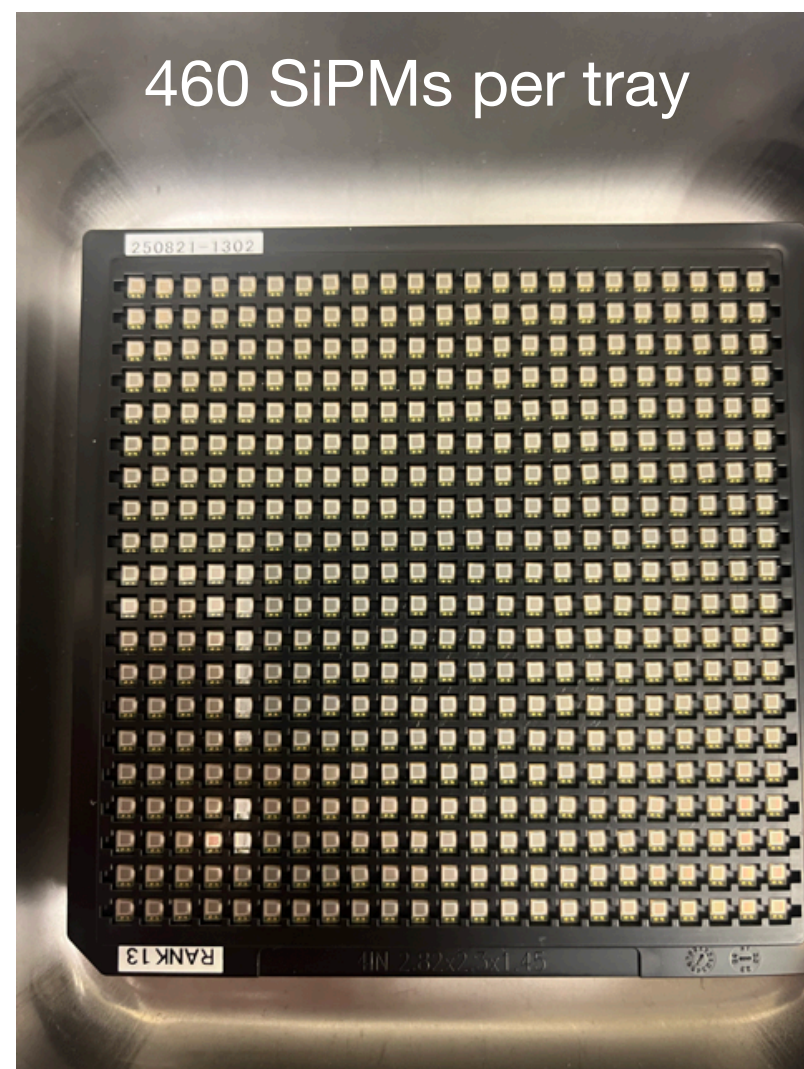


SiPM Quality Control

Slide from I. Mooney TIC 11/3/25



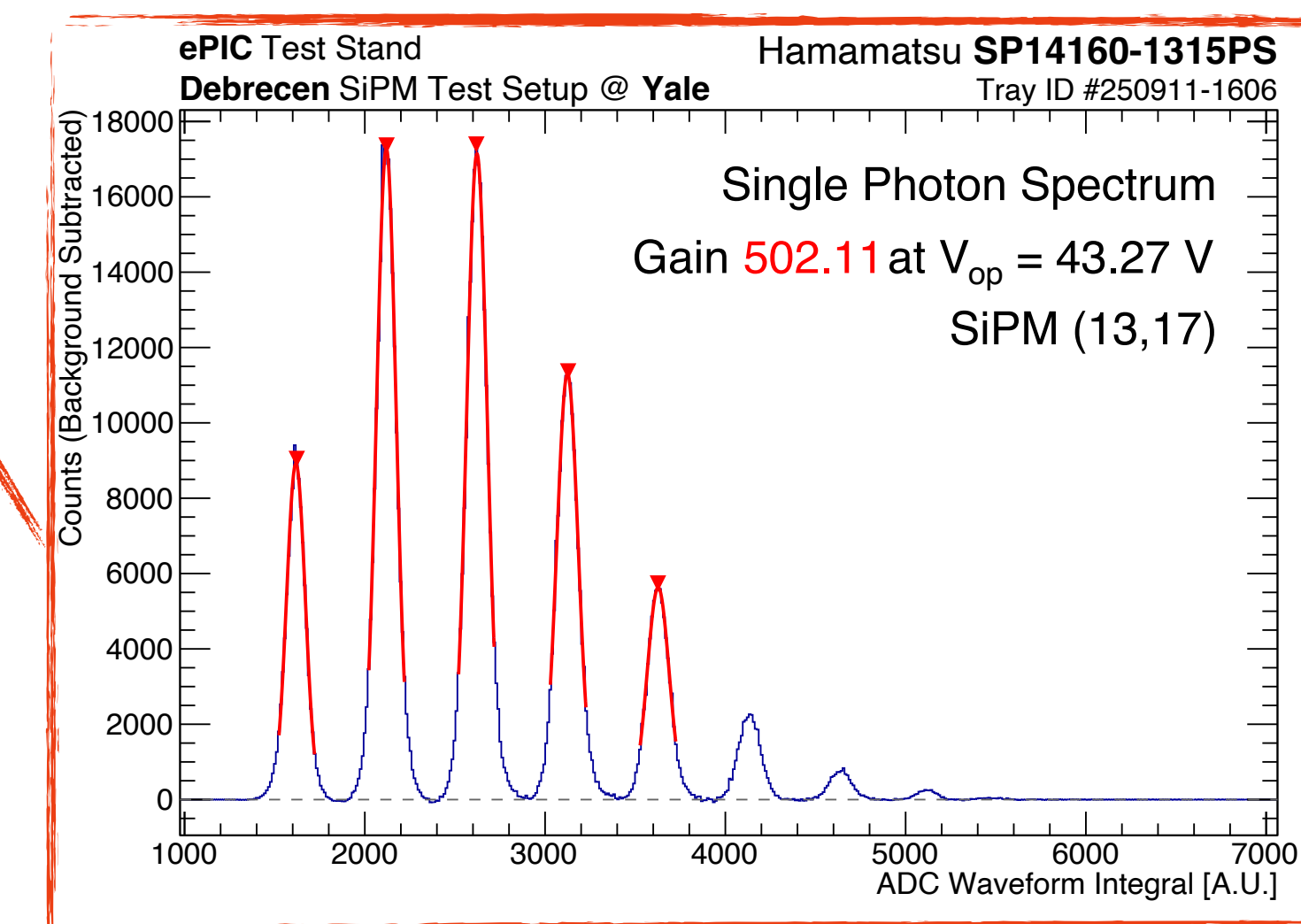
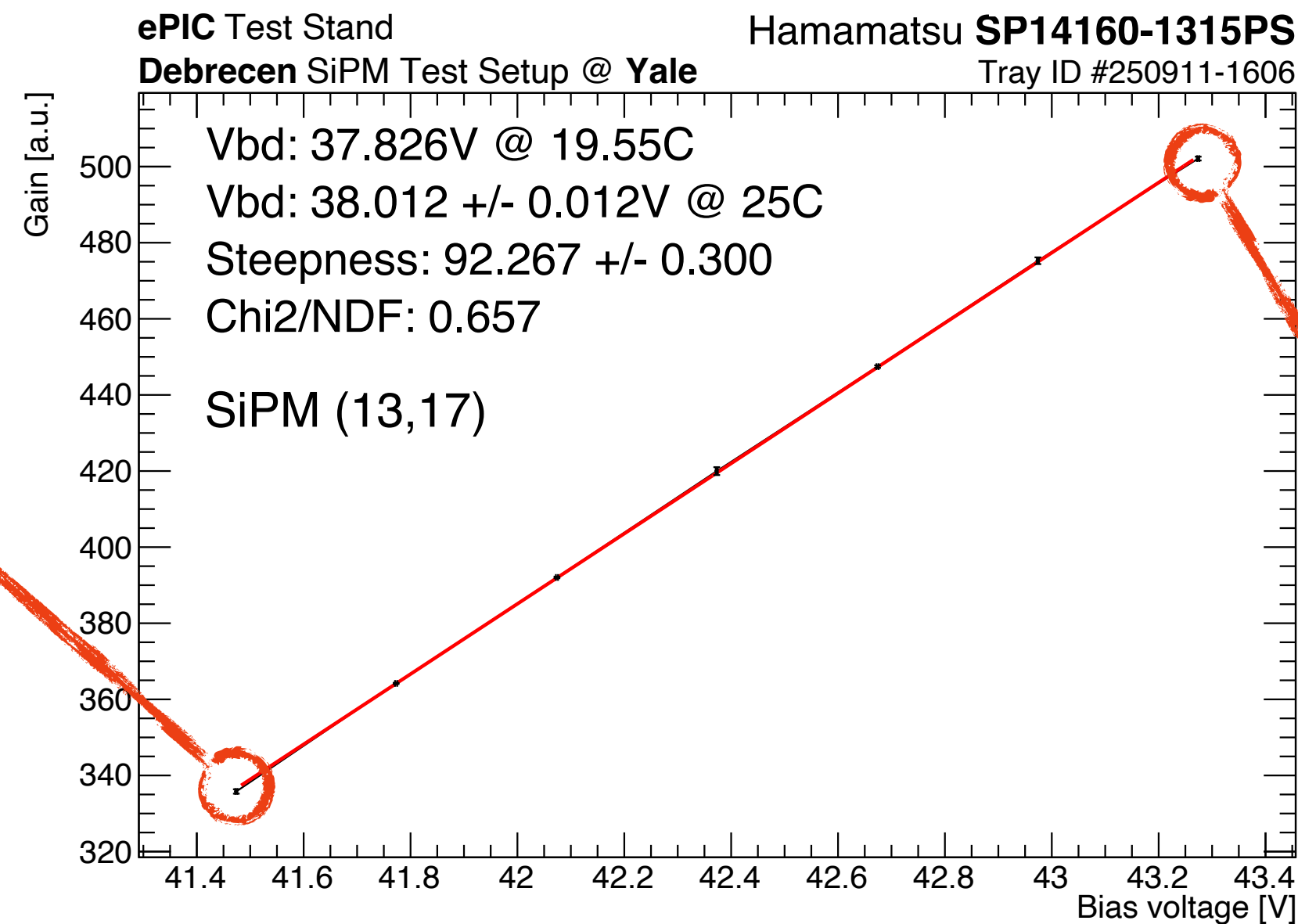
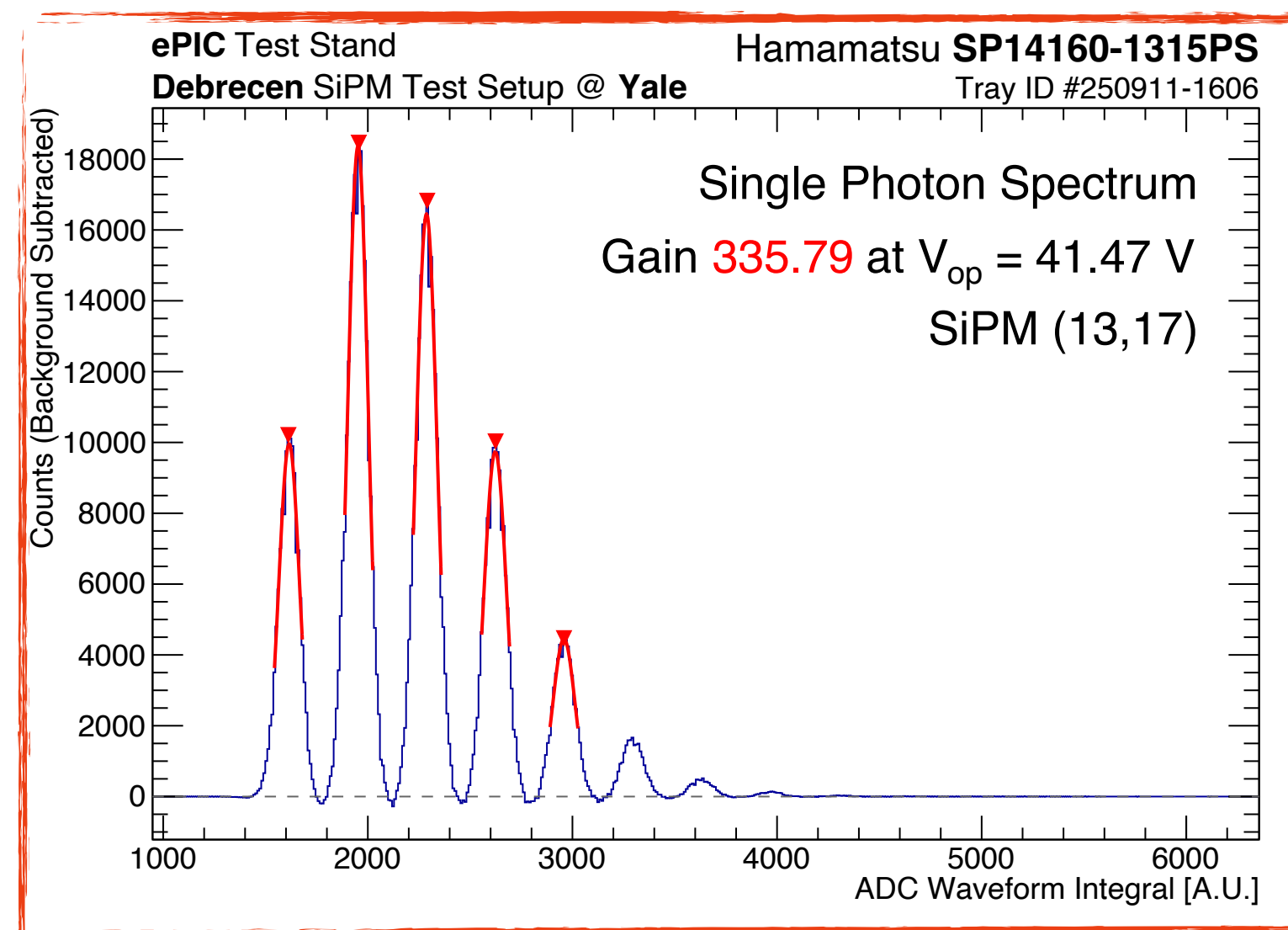
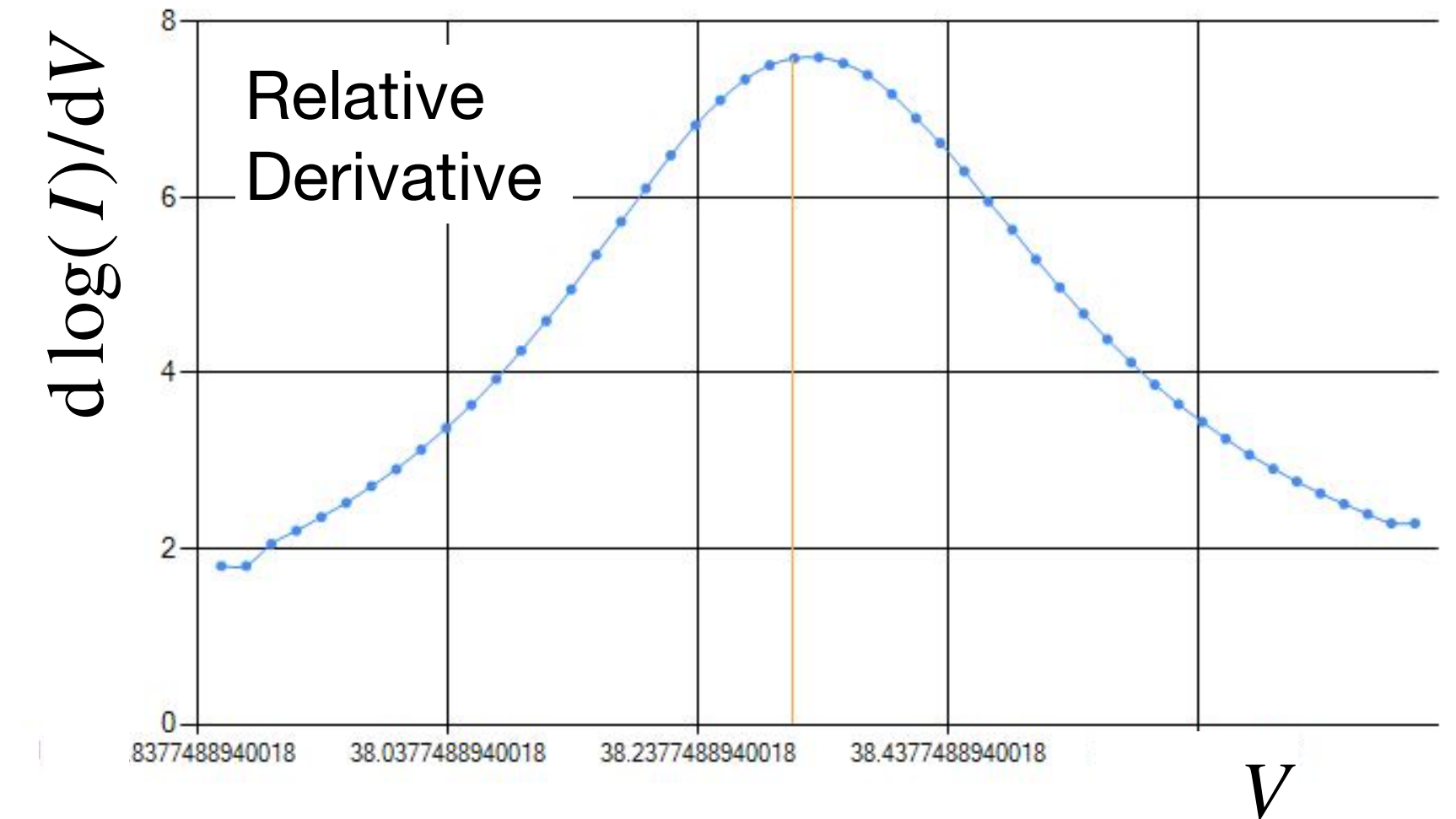
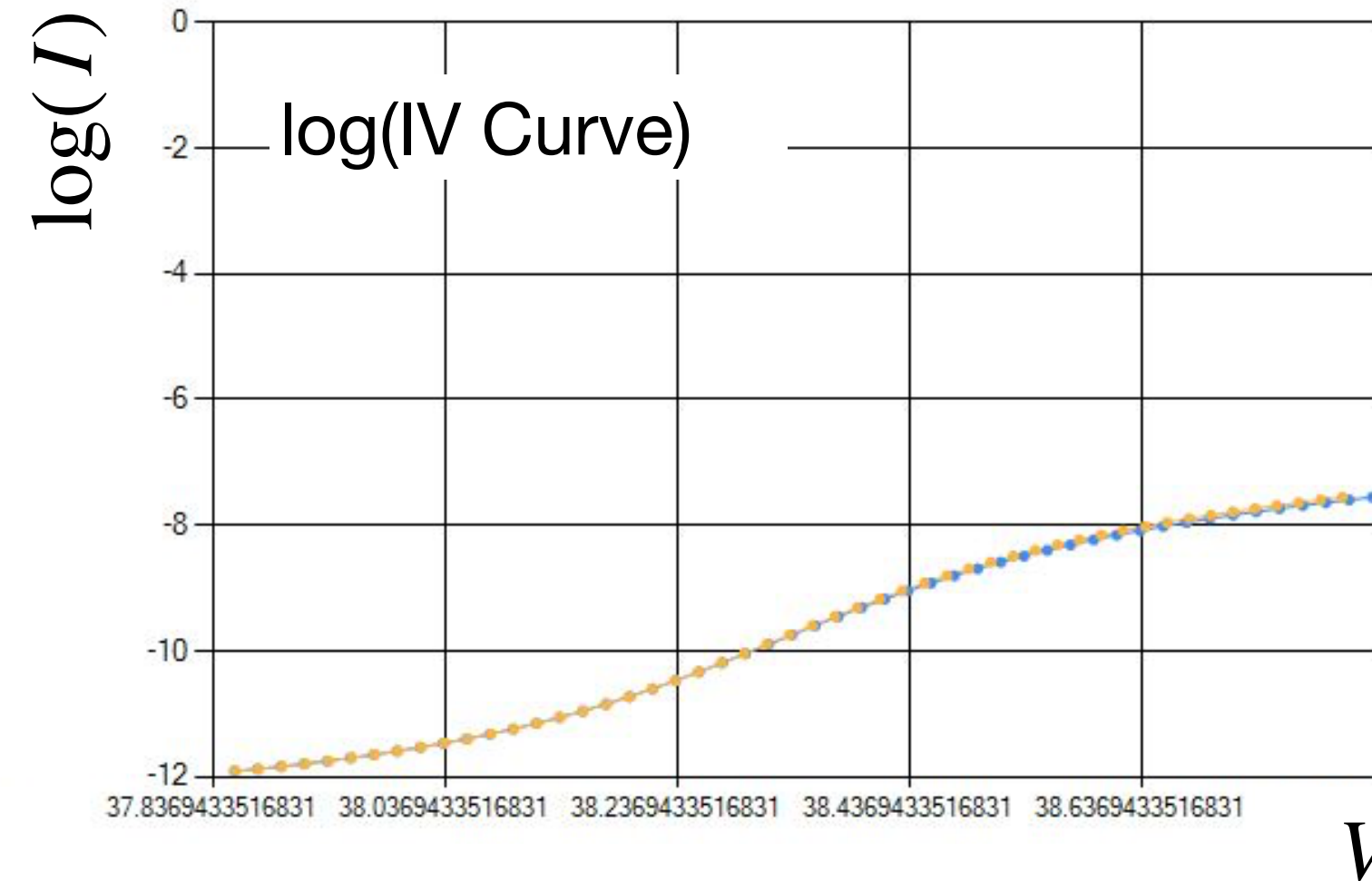
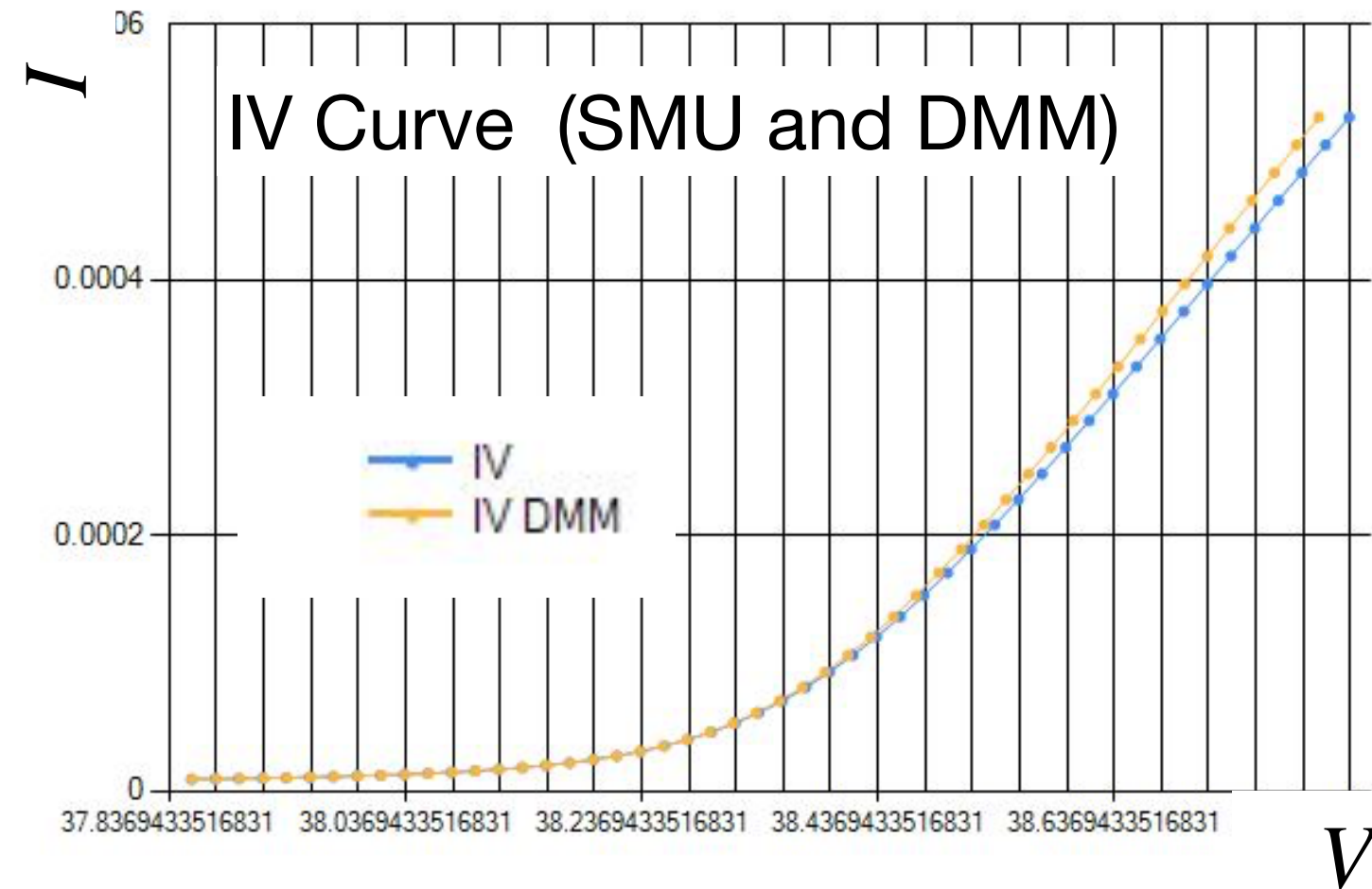
- Debrecen team contributed hardware and software for testing 32 SiPMs at once, ~45 mins
- Yale received a first batch of 2.3k Hamamatsu S14160-1315PS SiPMs out of BNL's 50k
- Started testing 9/26/25; finished first 4 trays (1.84k) 10/19/25



Cassette Measurements

We measure:

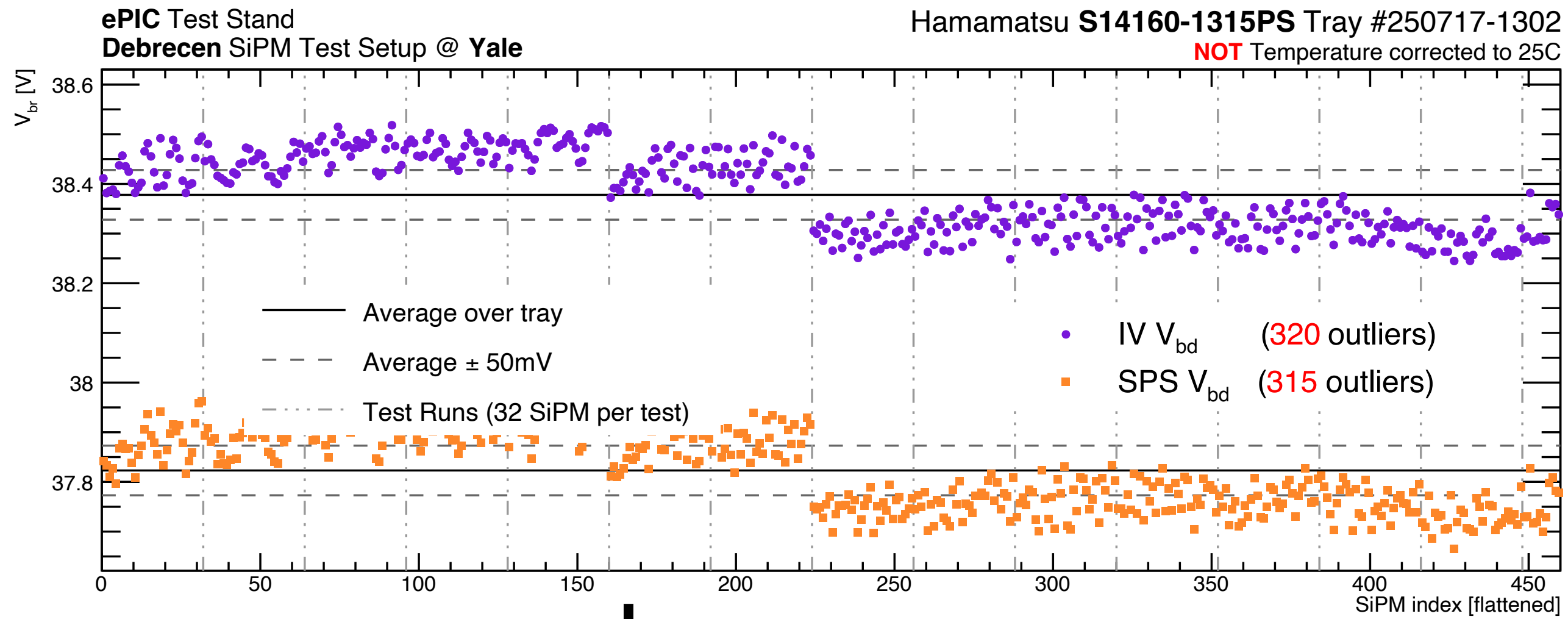
- IV, SPS Breakdown Voltage



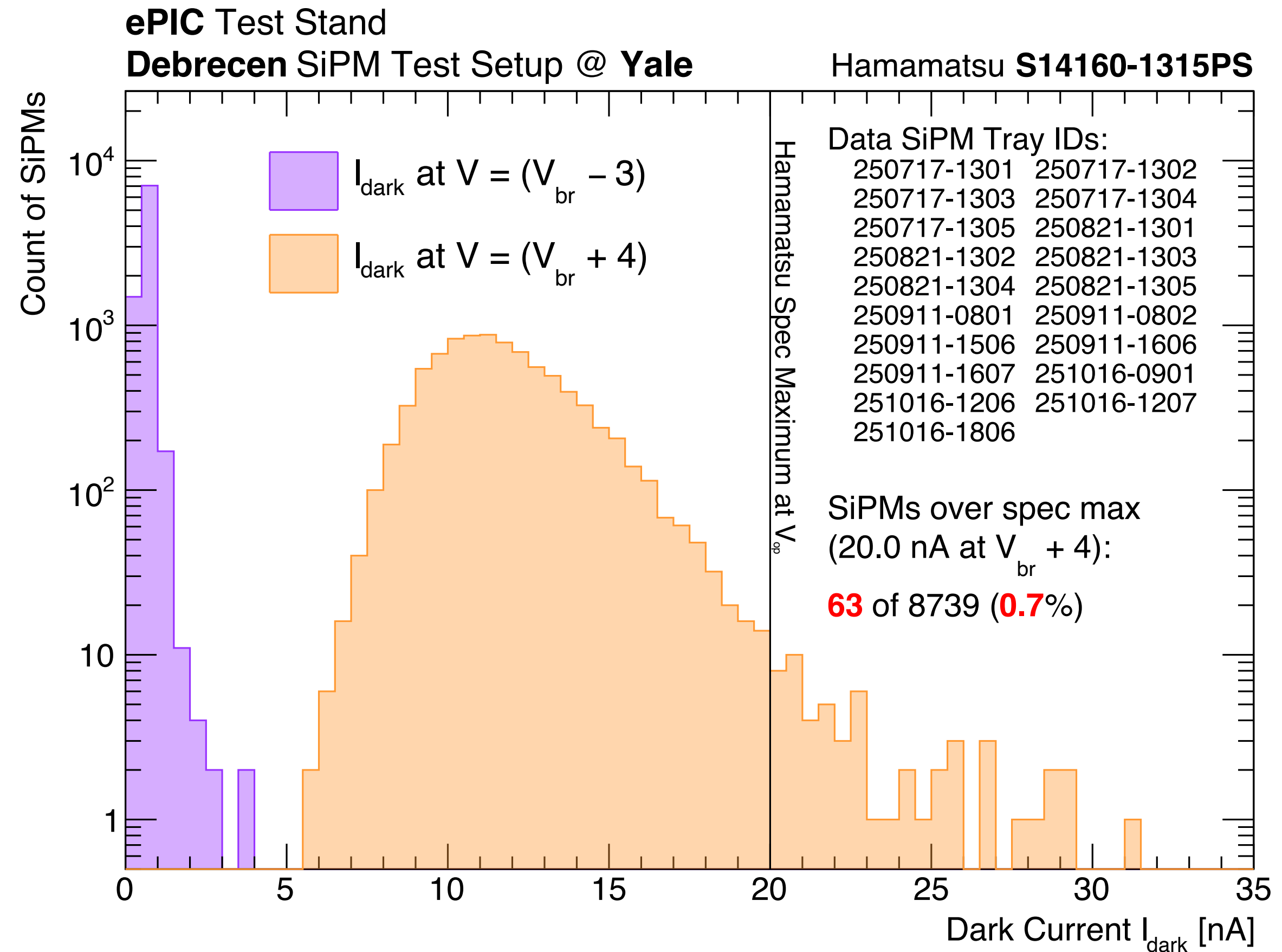
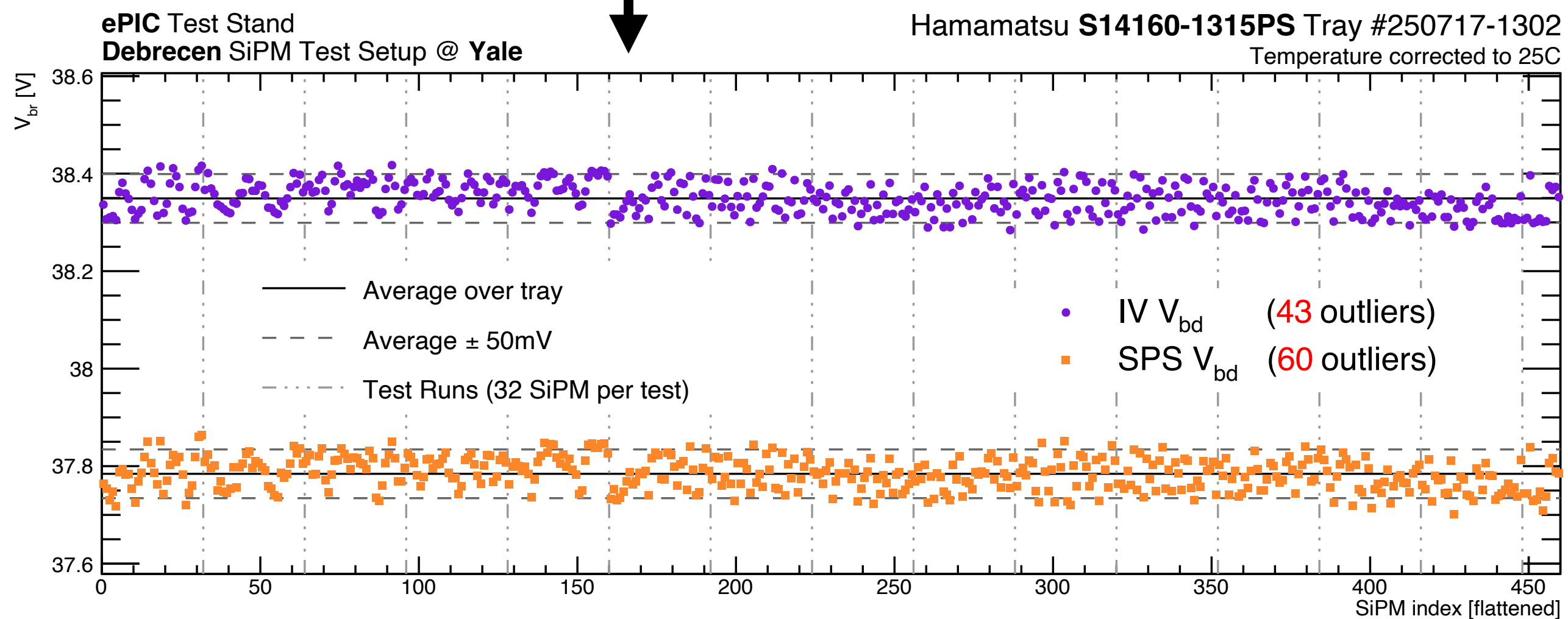
Cassette Measurements

We measure:

- IV, SPS Breakdown Voltage
- Dark Current
- Temperature Correction

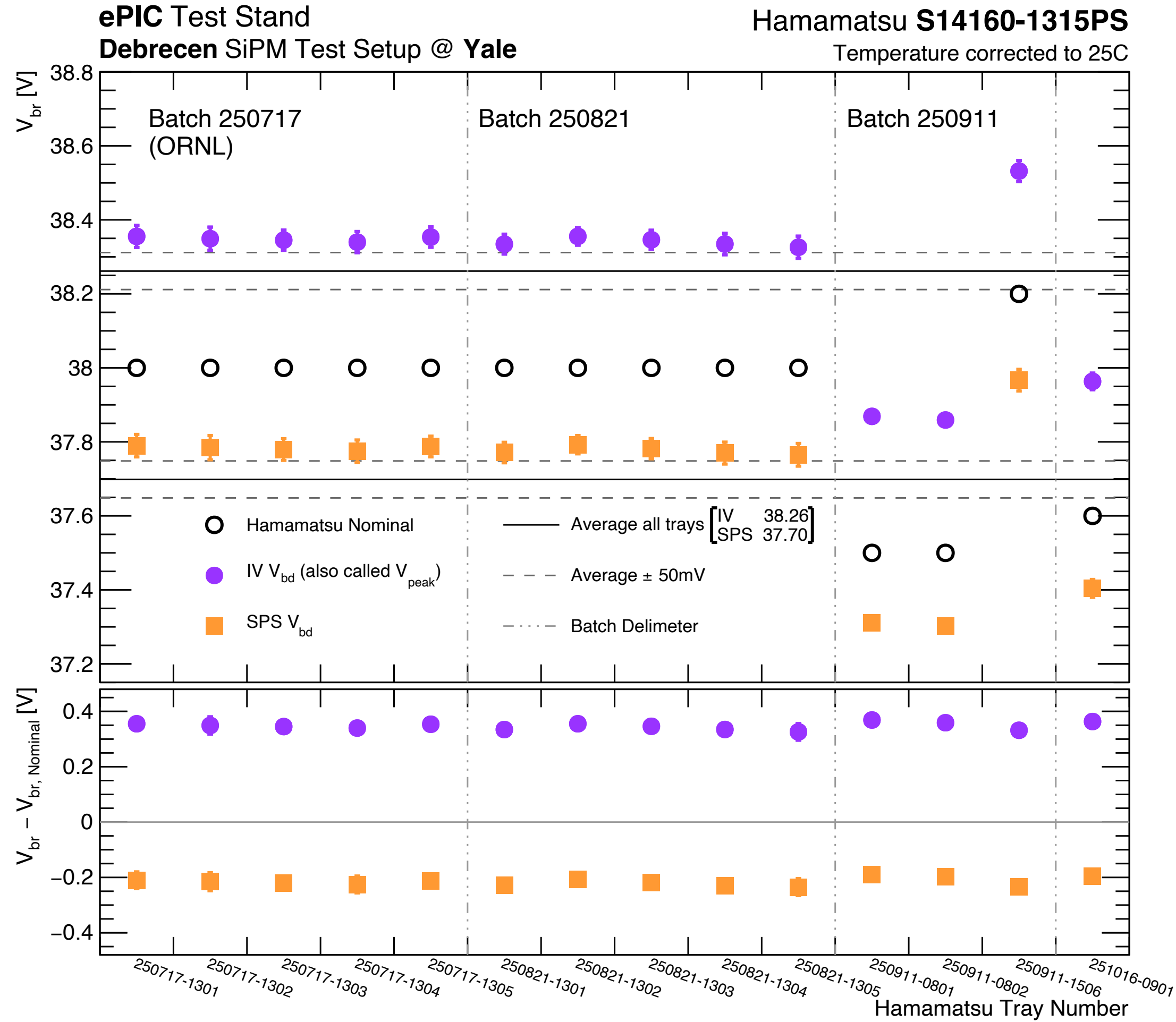


Temperature Correct to 25C

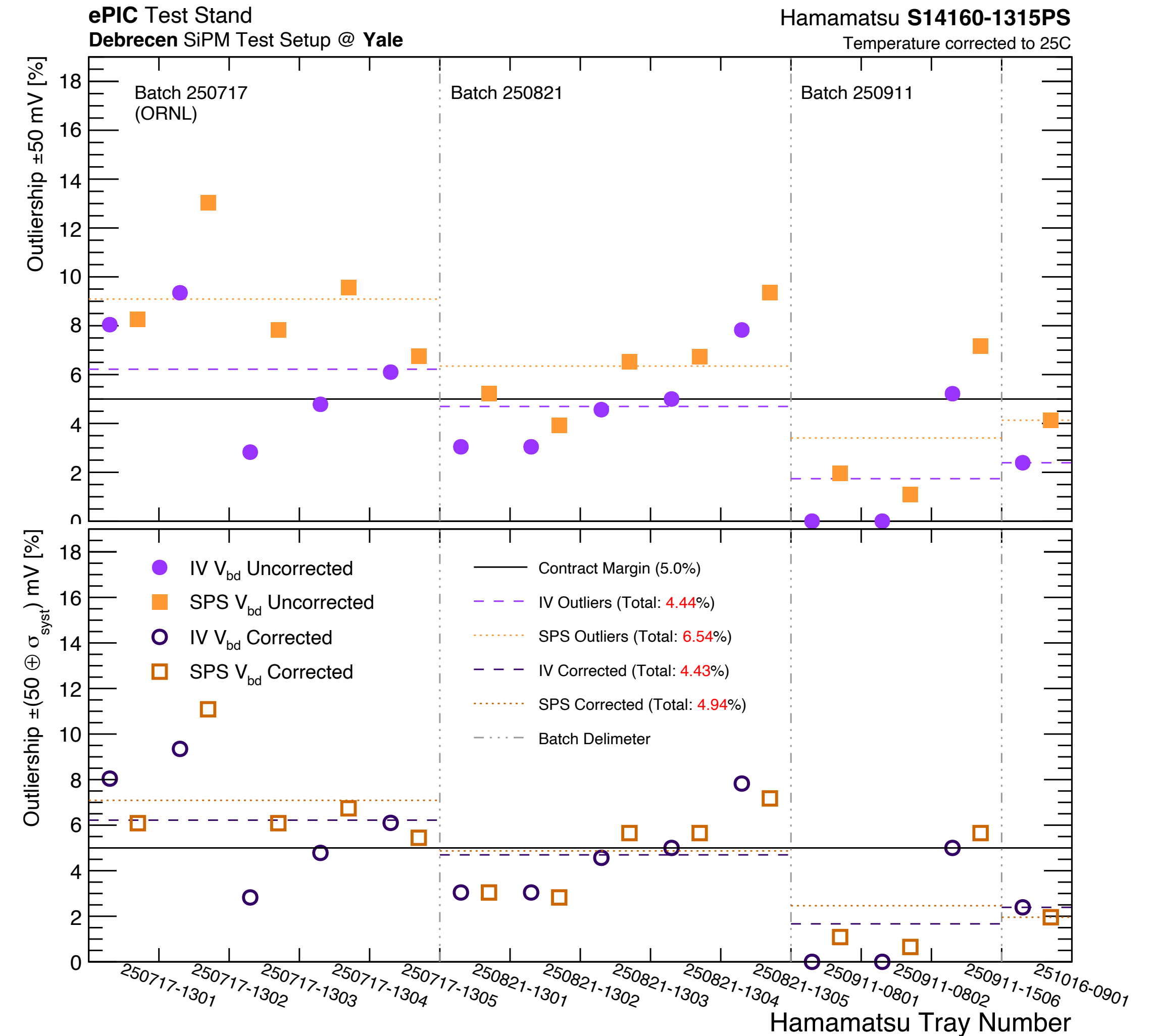


Results for First Batches

Breakdown Voltage



Outlier Counts



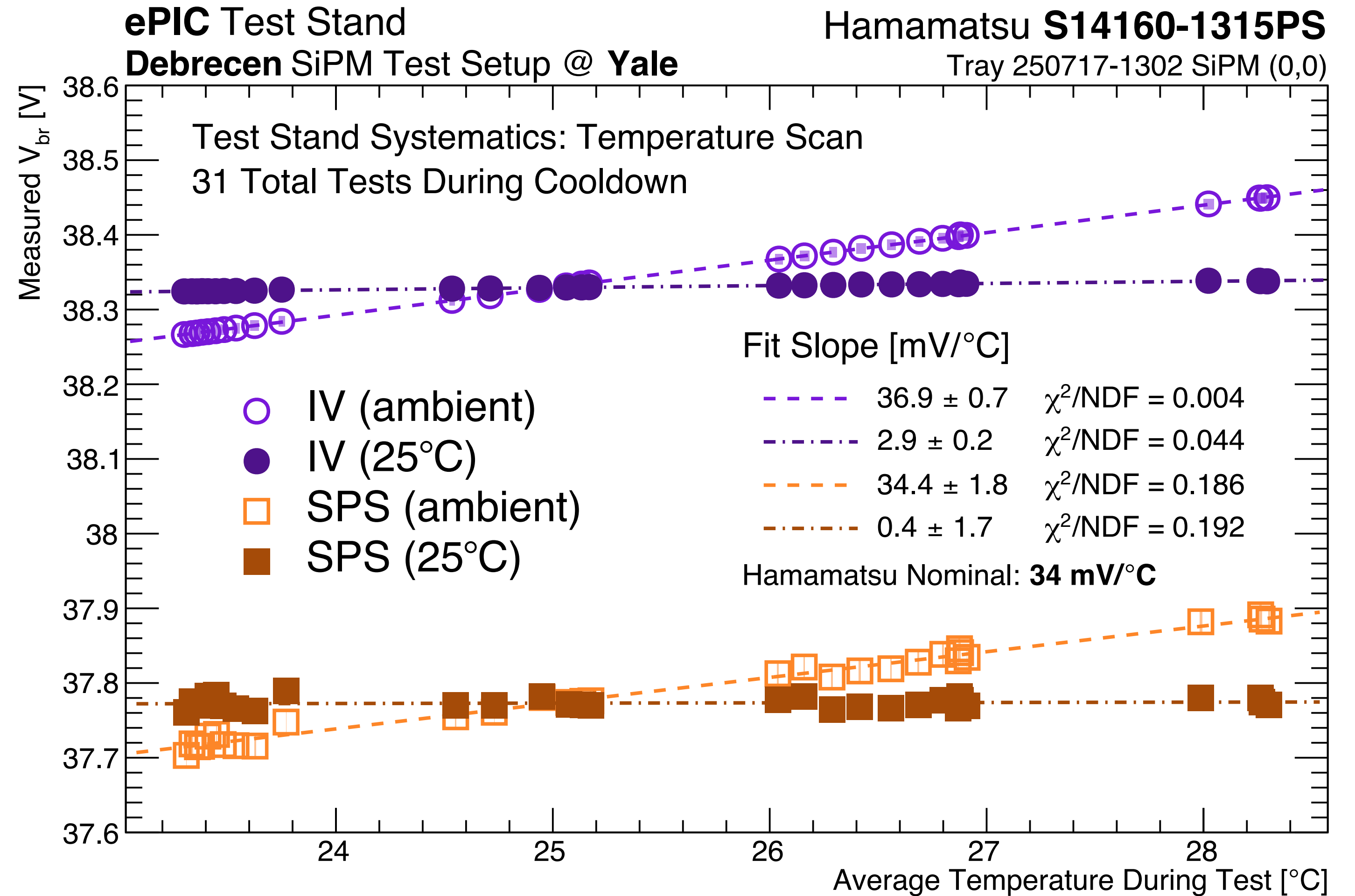
Systematics and Other Considerations

Temperature Correction

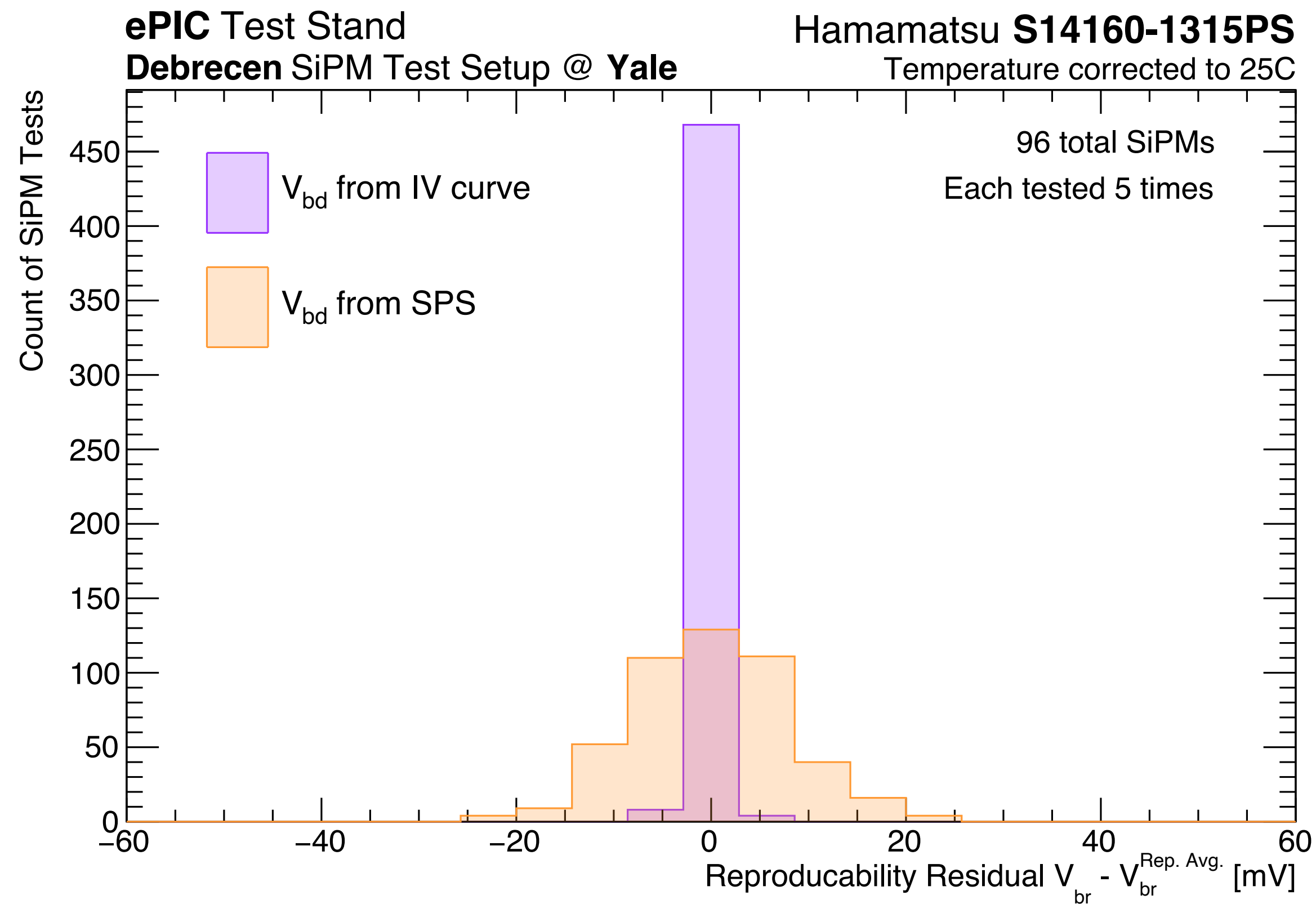
SiPM Breakdown voltage changes roughly linearly on the temperature around room temperatures.

All values are corrected to 25C, as agreed with Hamamatsu.

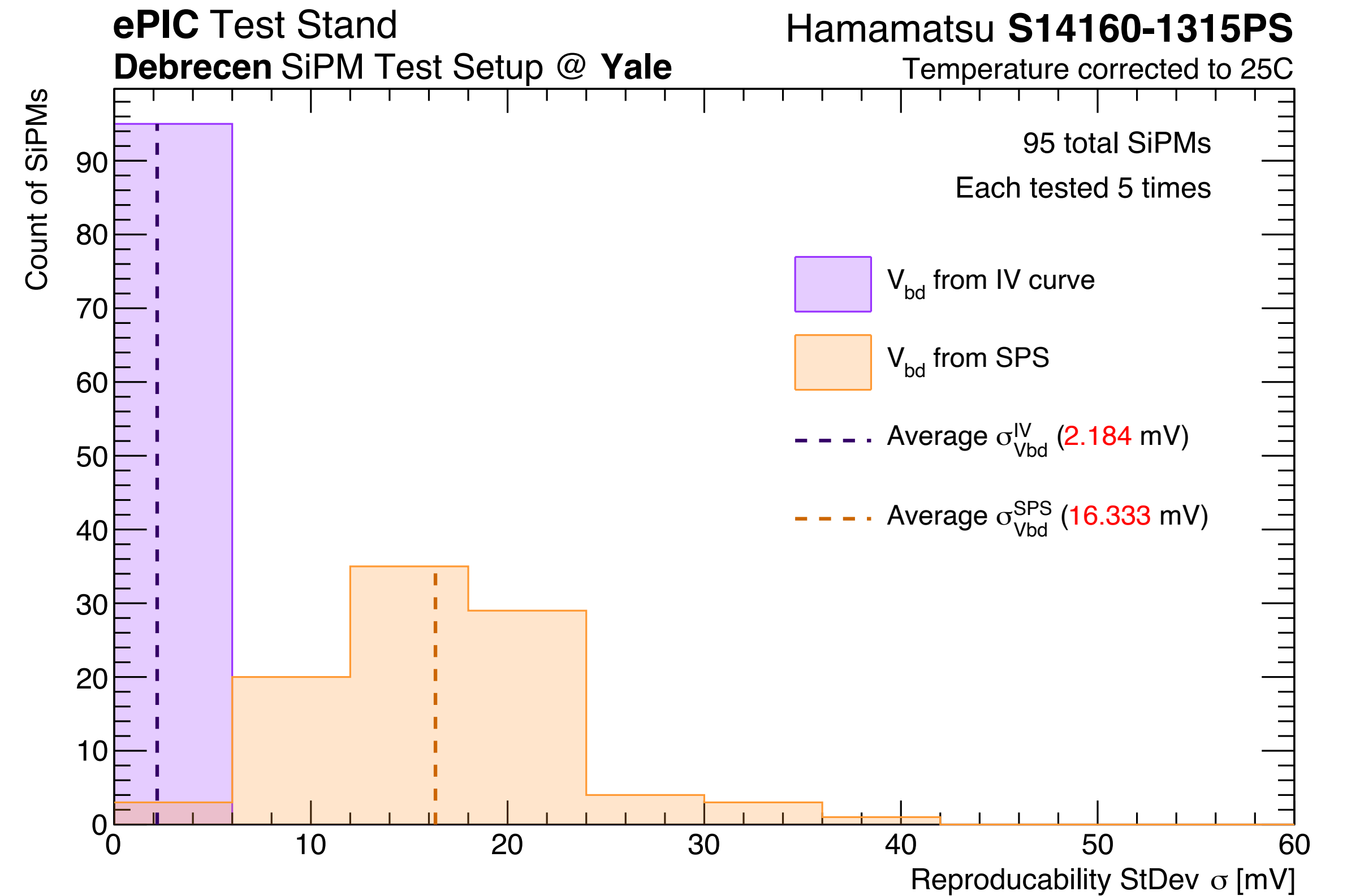
Spec. sheet says 34 mV / C but we do see some variation here.



Reproducibility Test



(Previous SiPM distributions aligned around their average over 5 tests)



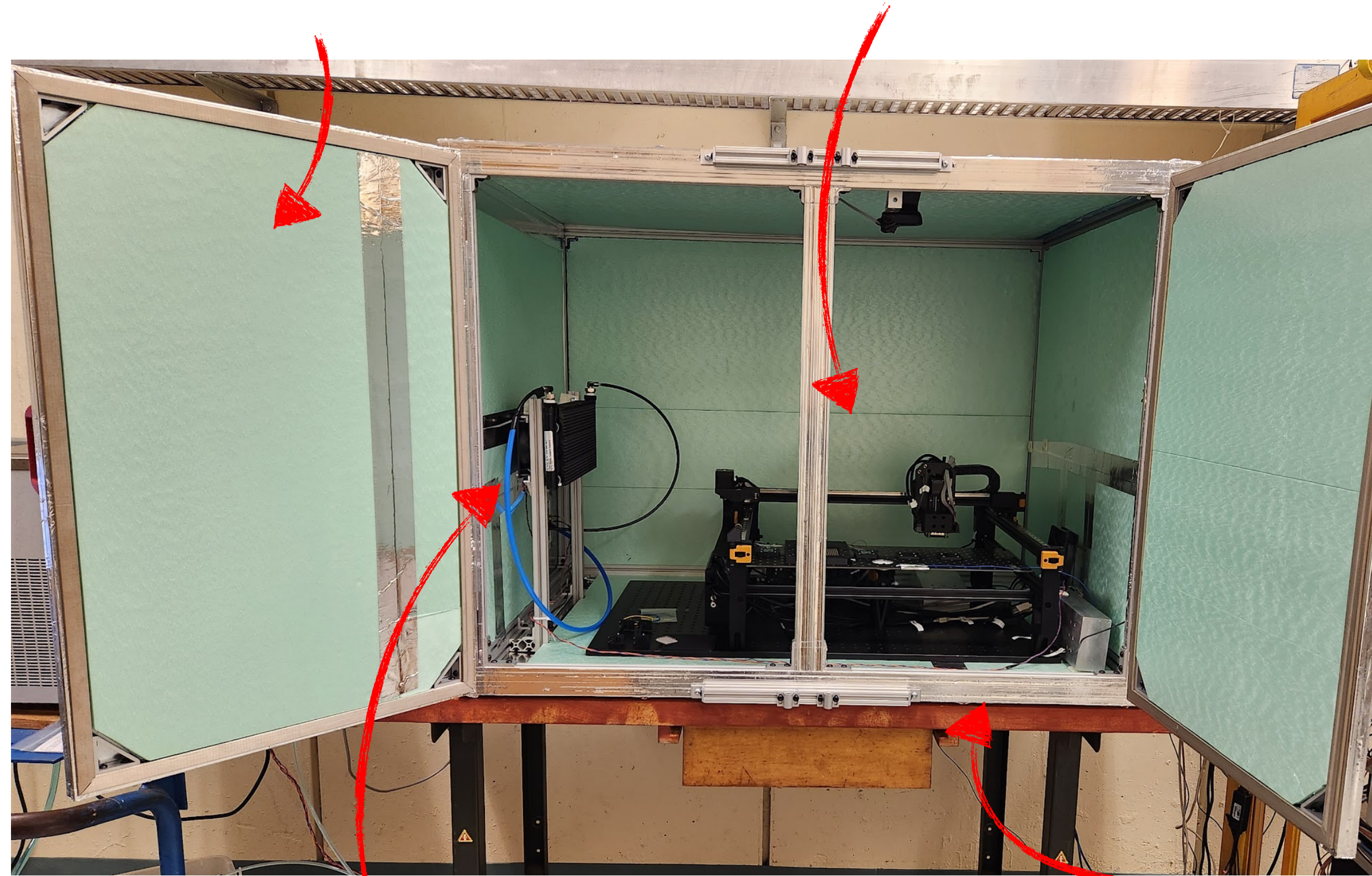
Distribution of sigma from the per-SiPM distributions

Recent Batches: Automated Setup

Automated Setup!

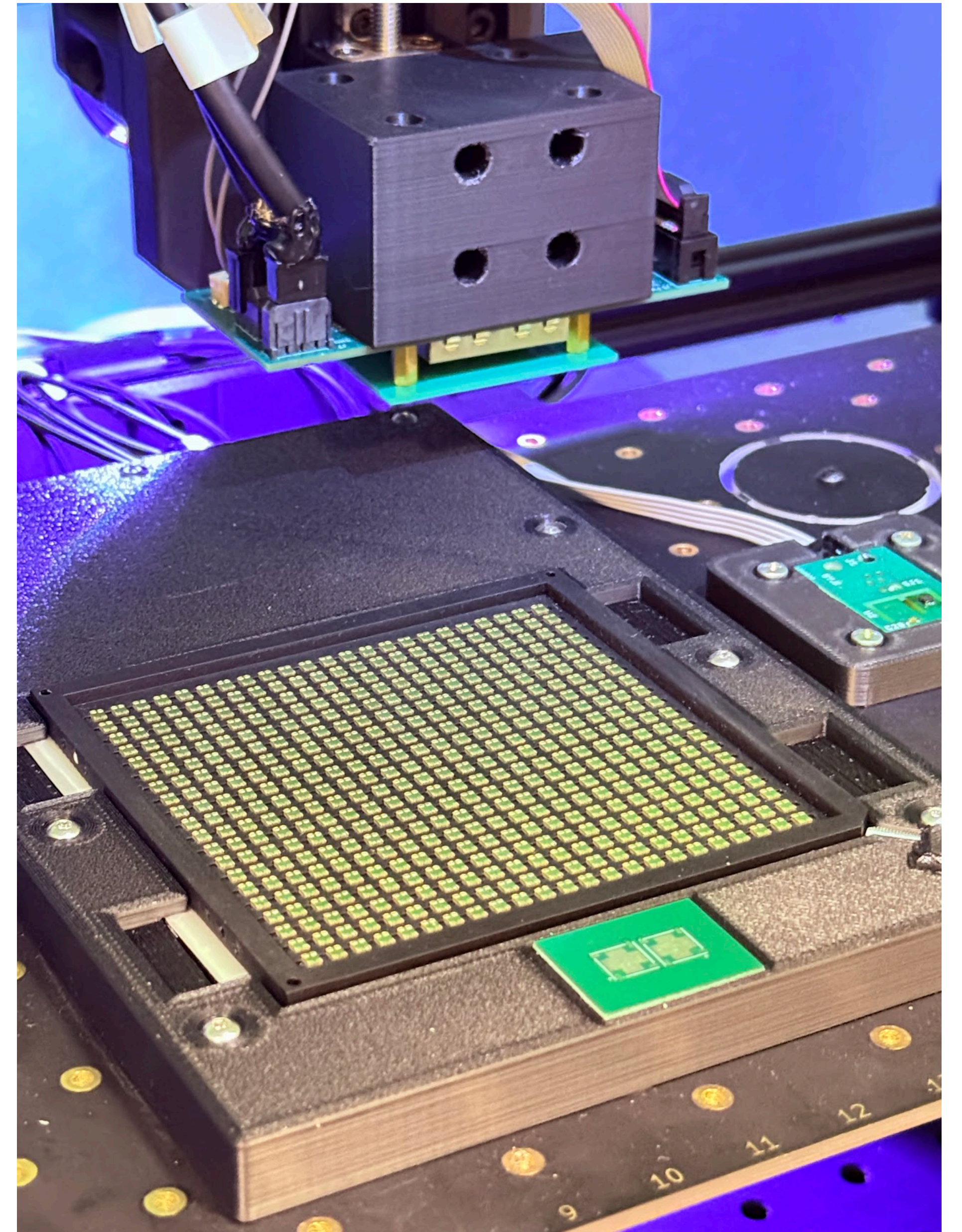
Thermal Insulation

SiPM Testing Robot



Ethylene Glycol Cooling

3' x 4' Dark Box



Components of the Robotic Tester

3' x 4' Dark Box



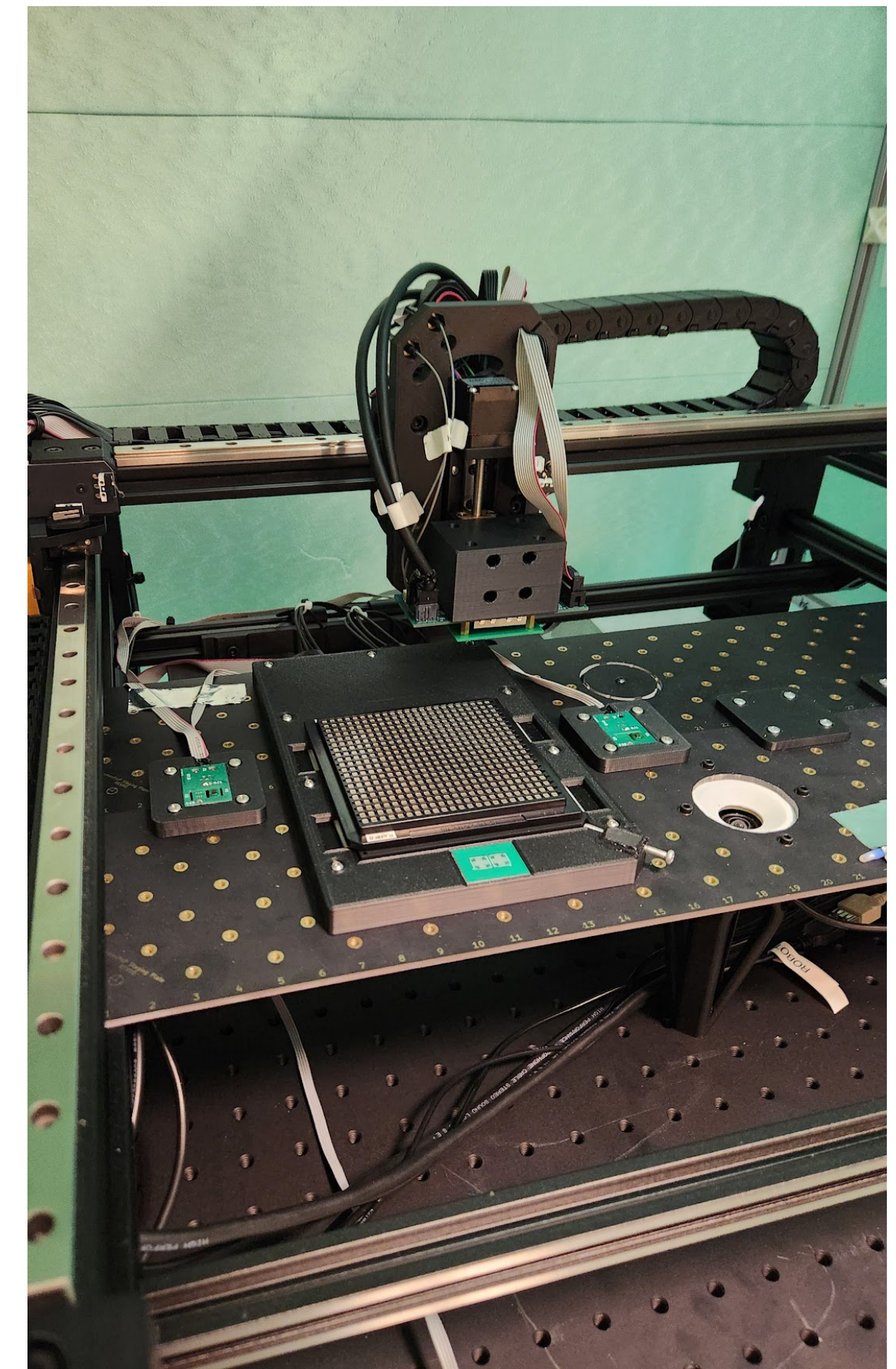
Ethylene Glycol Cooling



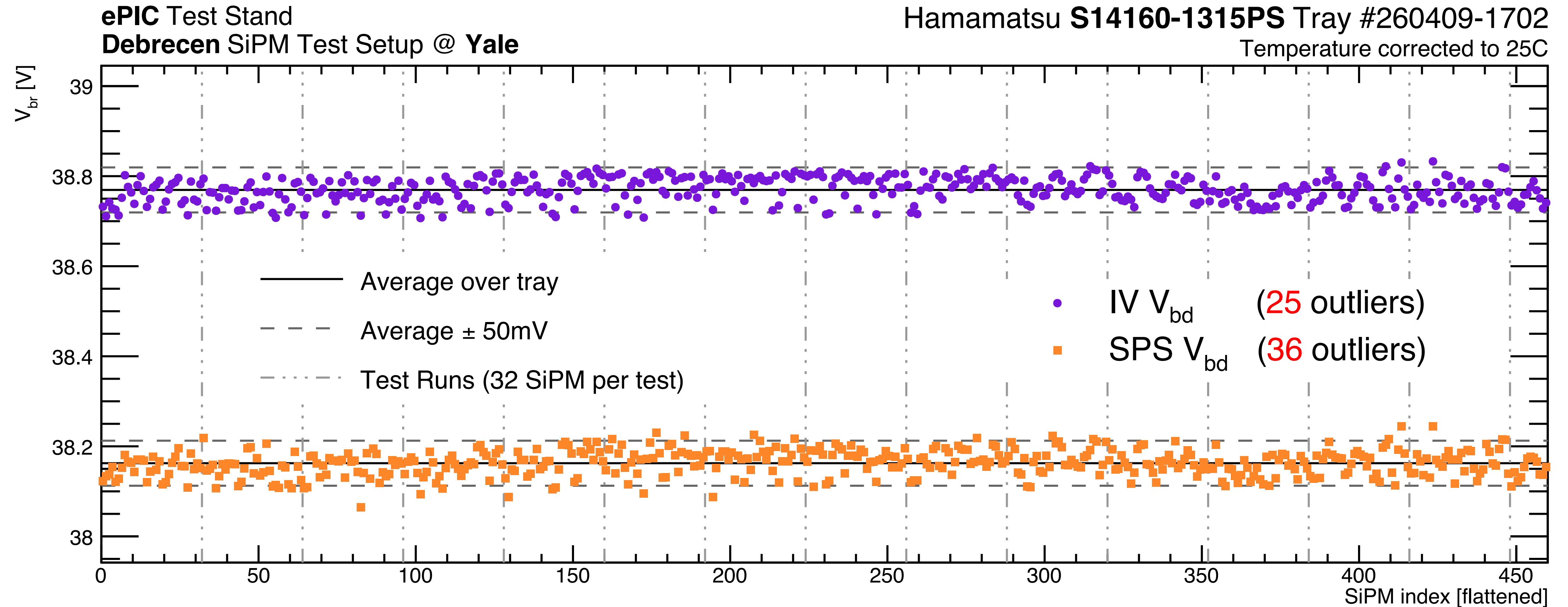
Thermal Insulation



SiPM Testing Robot



First Robot Tray (260409-1702)

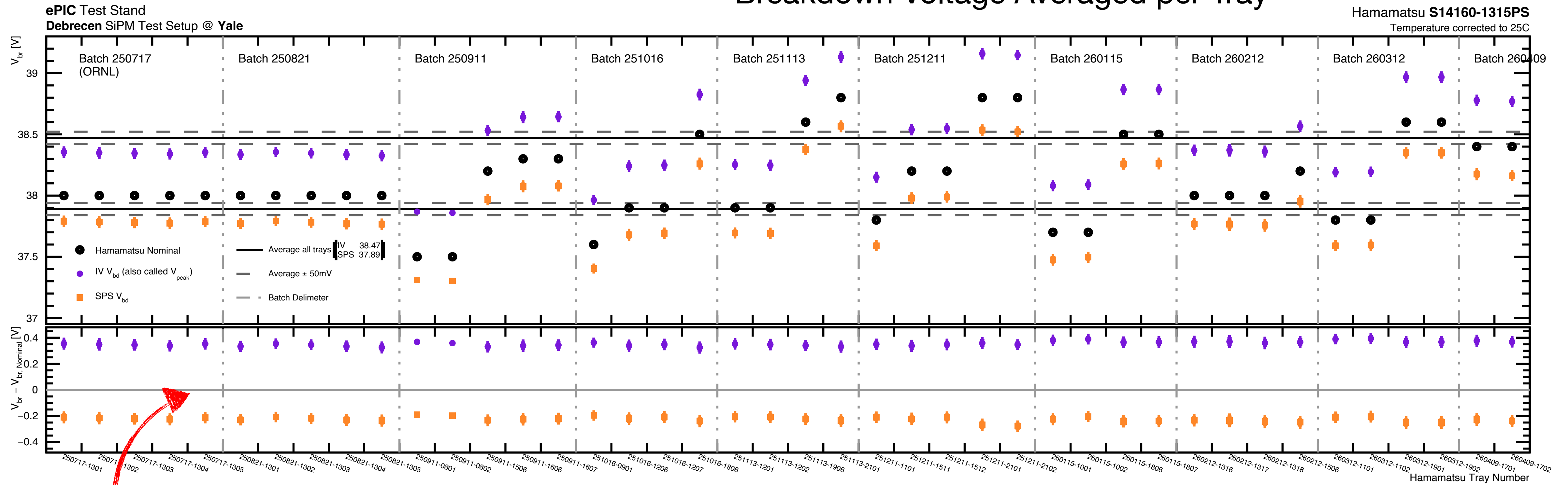


Consistent with previous observations!

All Results

Almost 20,000 SiPMs Tested!

Breakdown Voltage Averaged per Tray

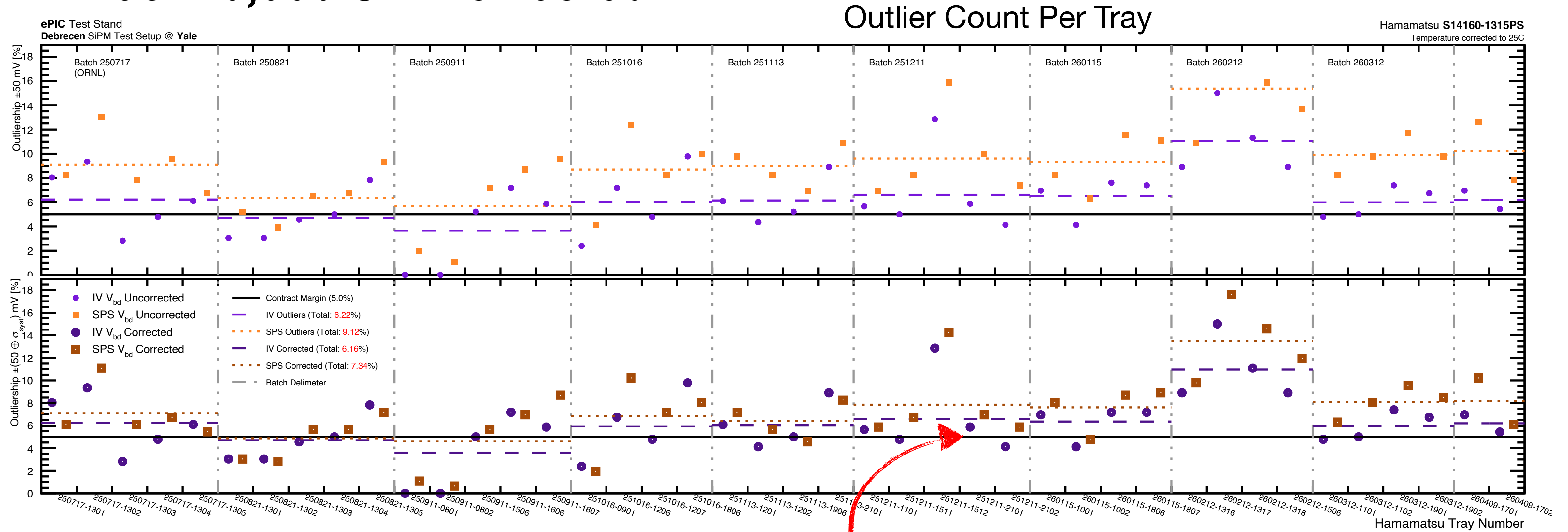


All data consistent with Hamamatsu reported V_{op} (with constant offset)

Tested with Robot!

All Results

Almost 20,000 SiPMs Tested!

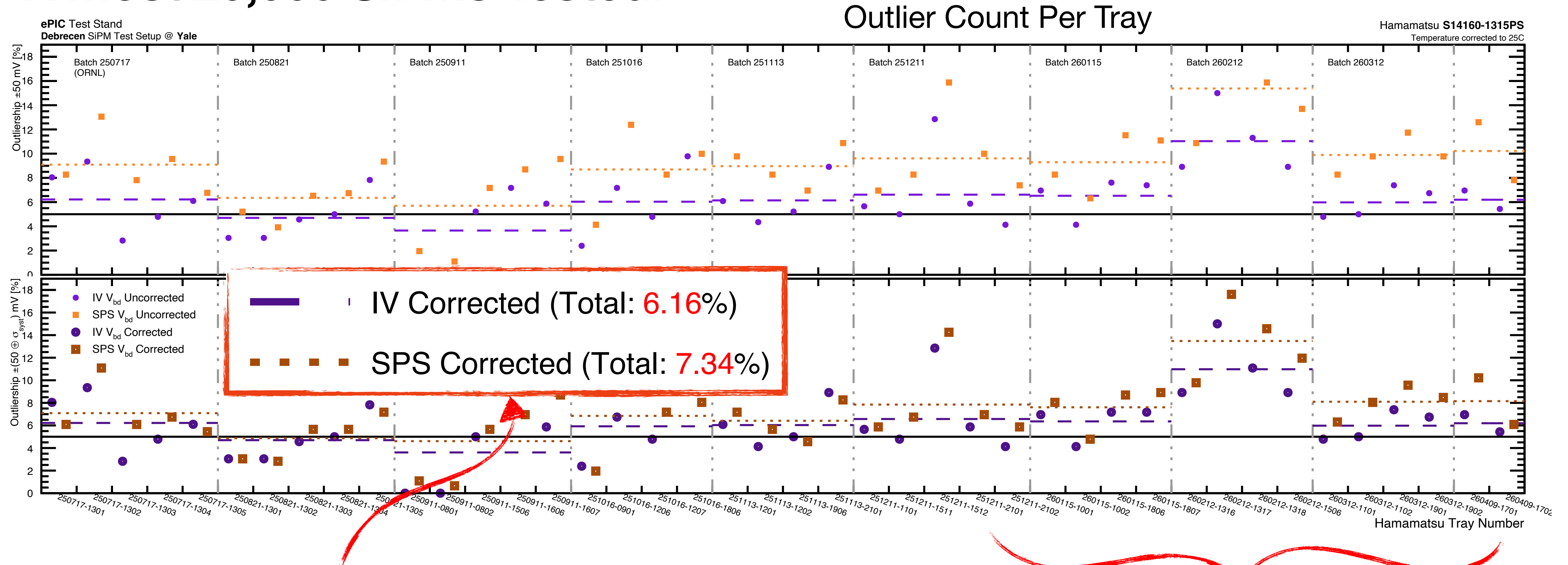


More outliers in new data:
Caused by Robot or SiPMs?

Tested with Robot!

All Results

Almost 20,000 SiPMs Tested!



Corrected outliers are further than $\sqrt{50^2 + \sigma_{\text{syst}}^2}$ mV from tray average.

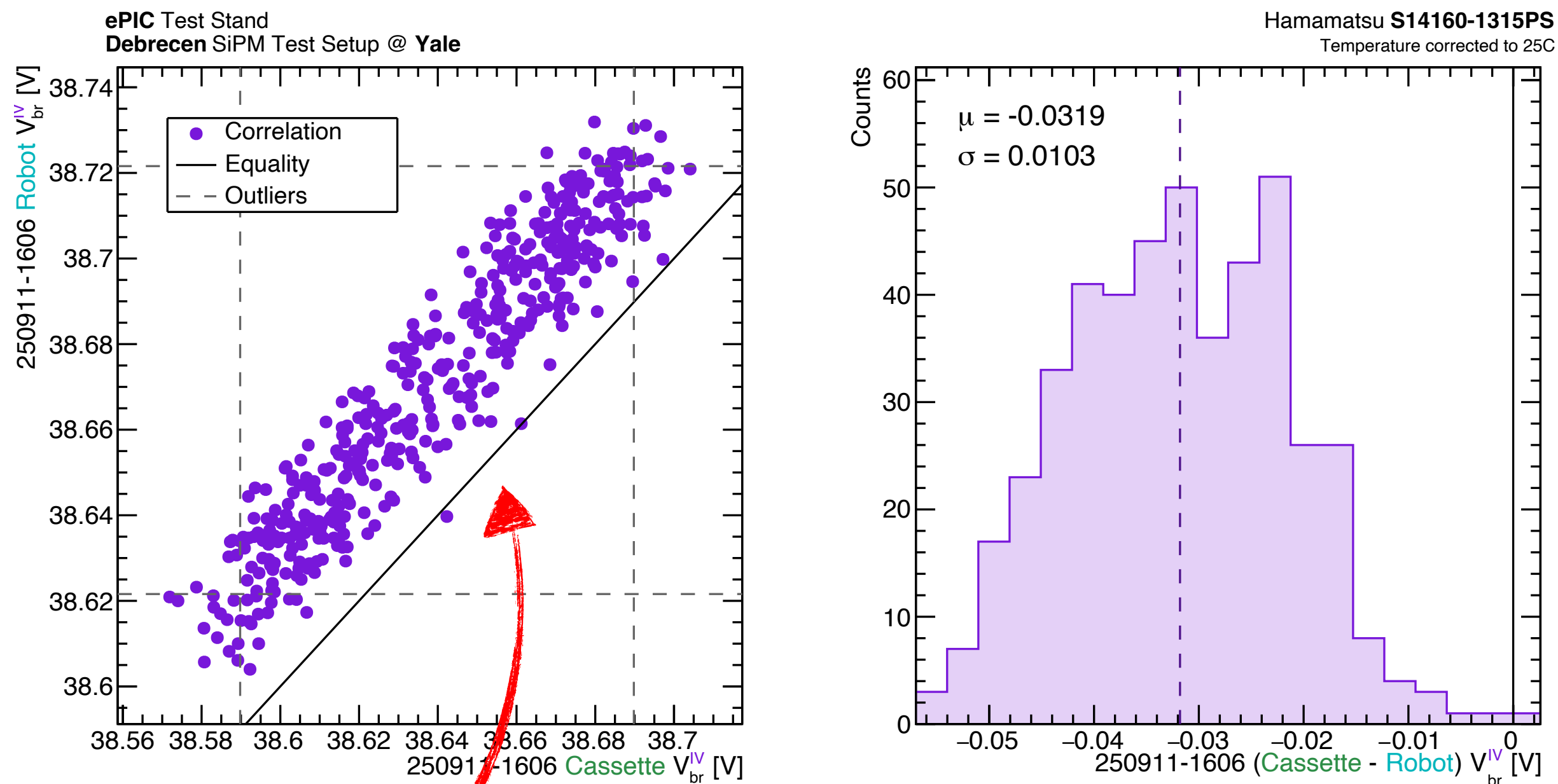
Tested with Robot!

Robot Systematics

Verifying Consistency

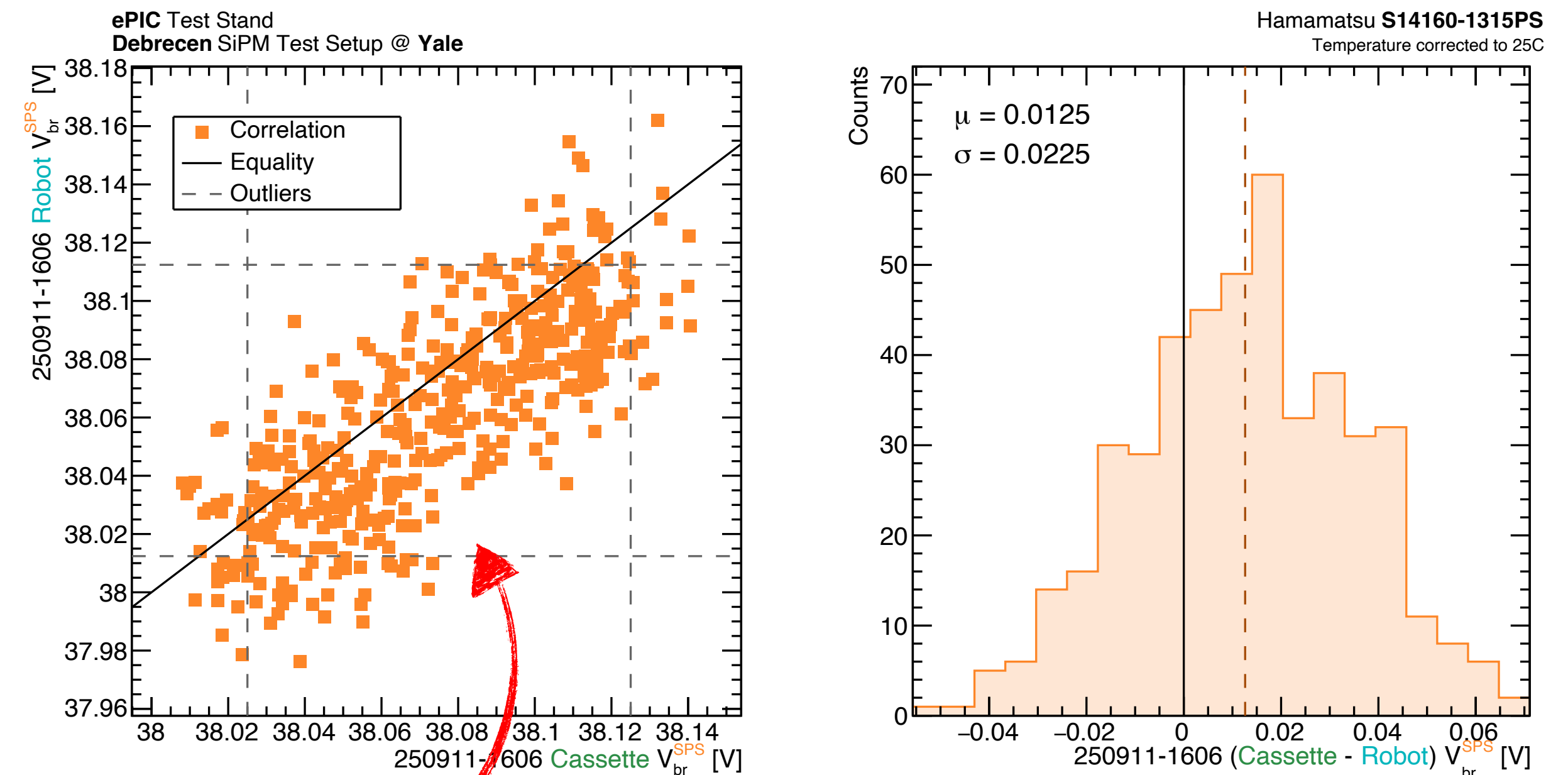
Correlating New (Robot) Results Against Old (Cassette)

IV Breakdown Voltage



Clear small offset!

SPS Breakdown Voltage



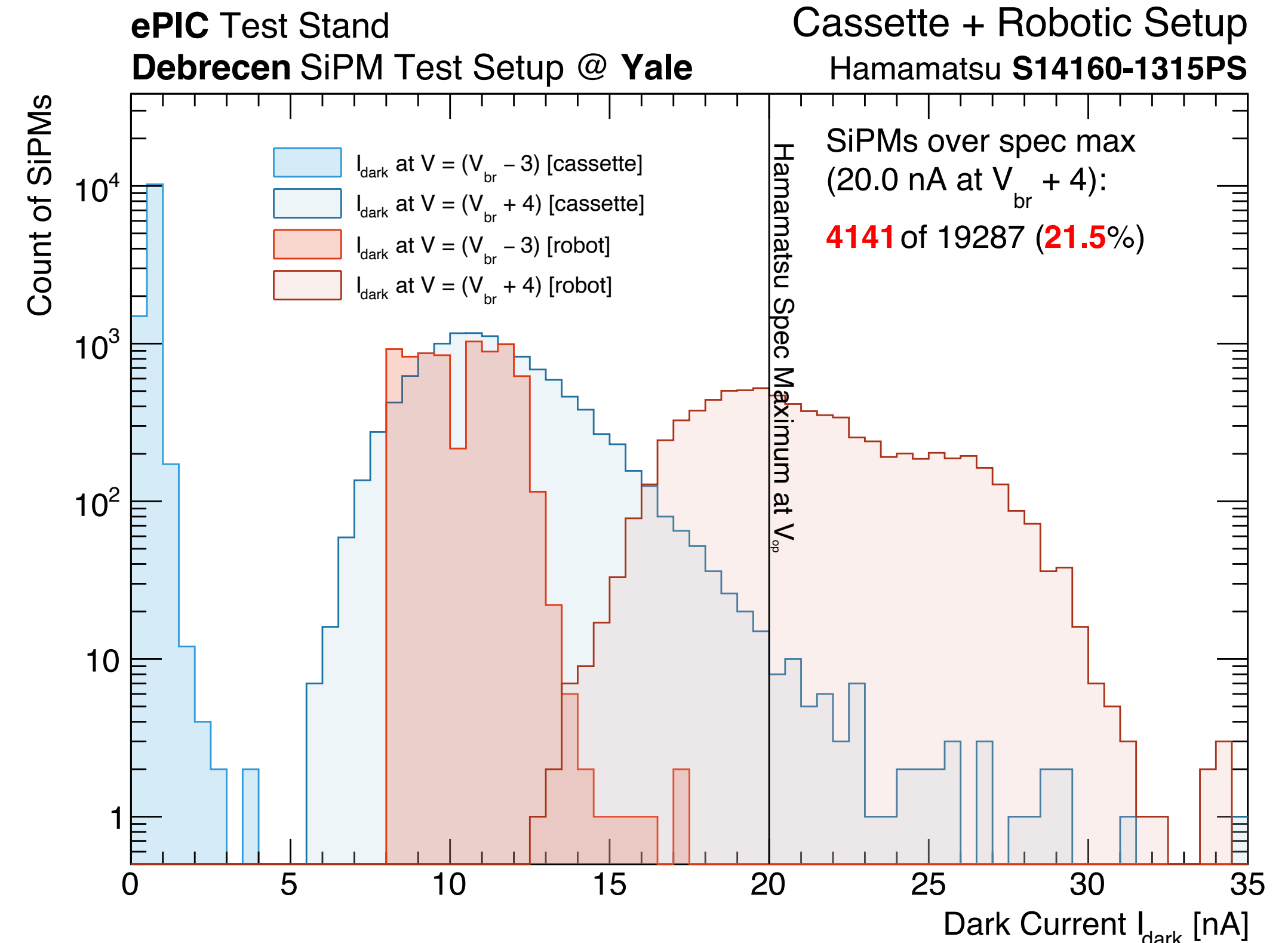
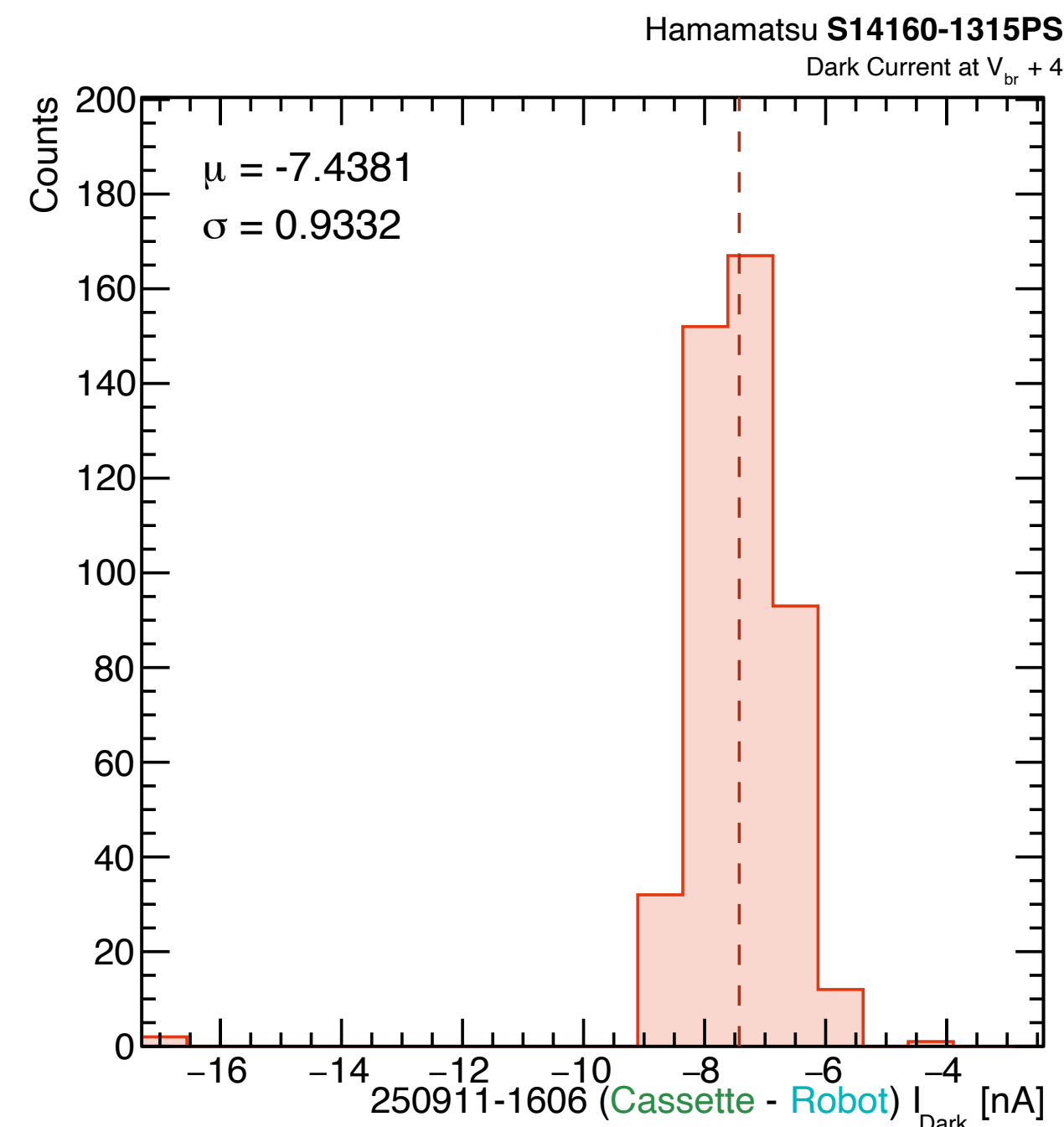
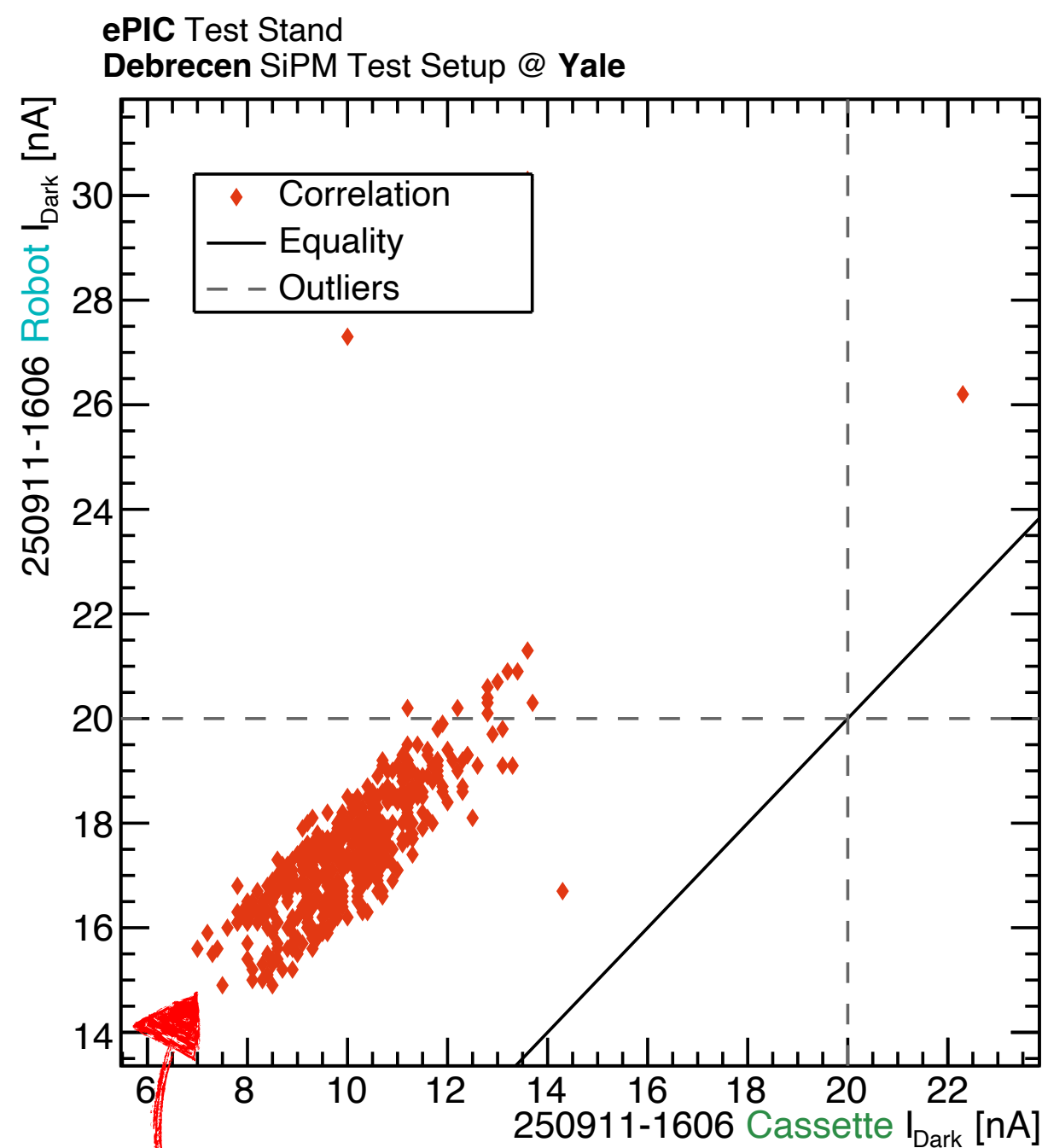
Roughly Consistent within uncertainties

Due to Dark Current?

Correlating New (Robot) Results Against Old (Cassette)

Correlated Dark Current Above Breakdown

Dark Current All Trays

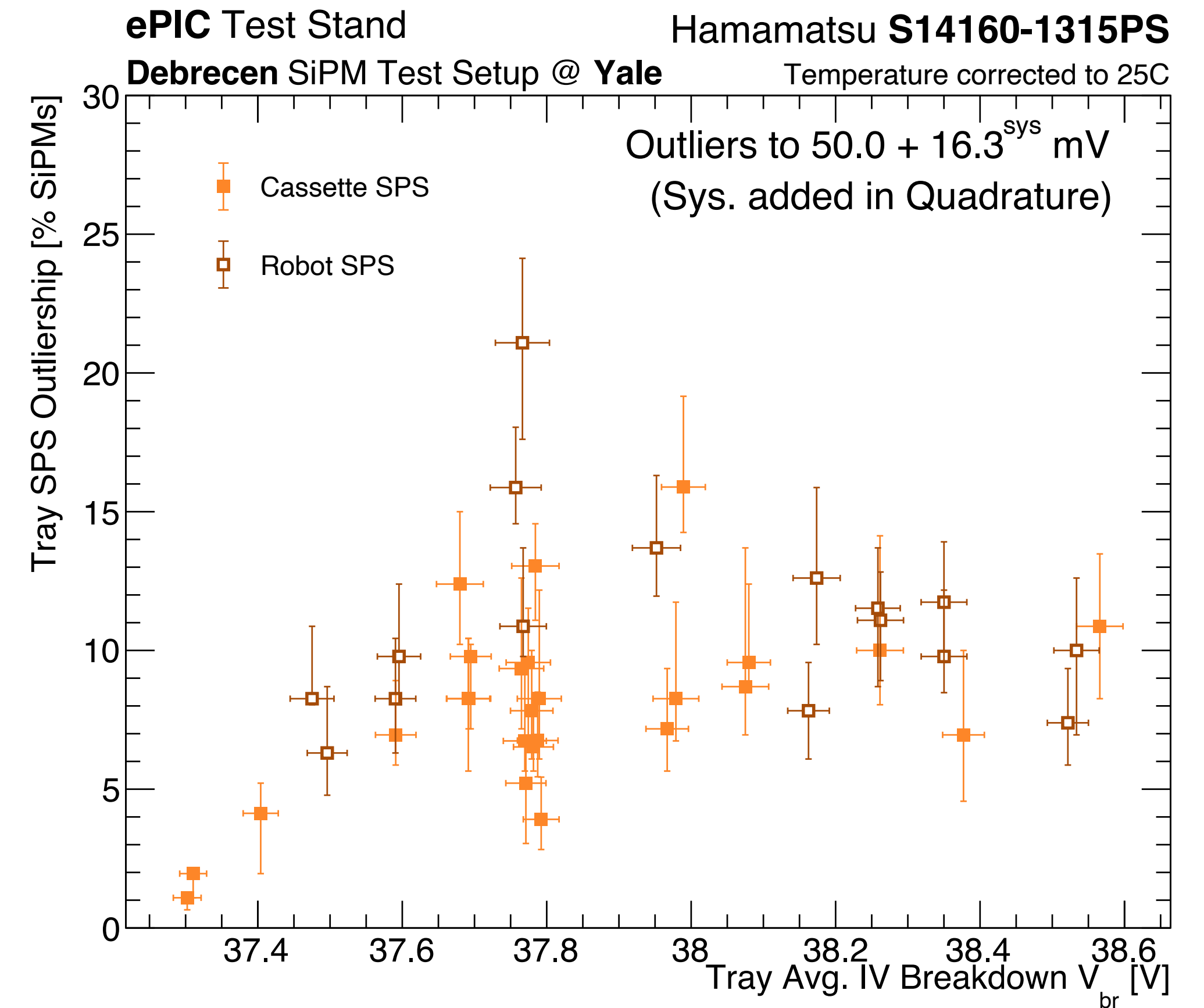
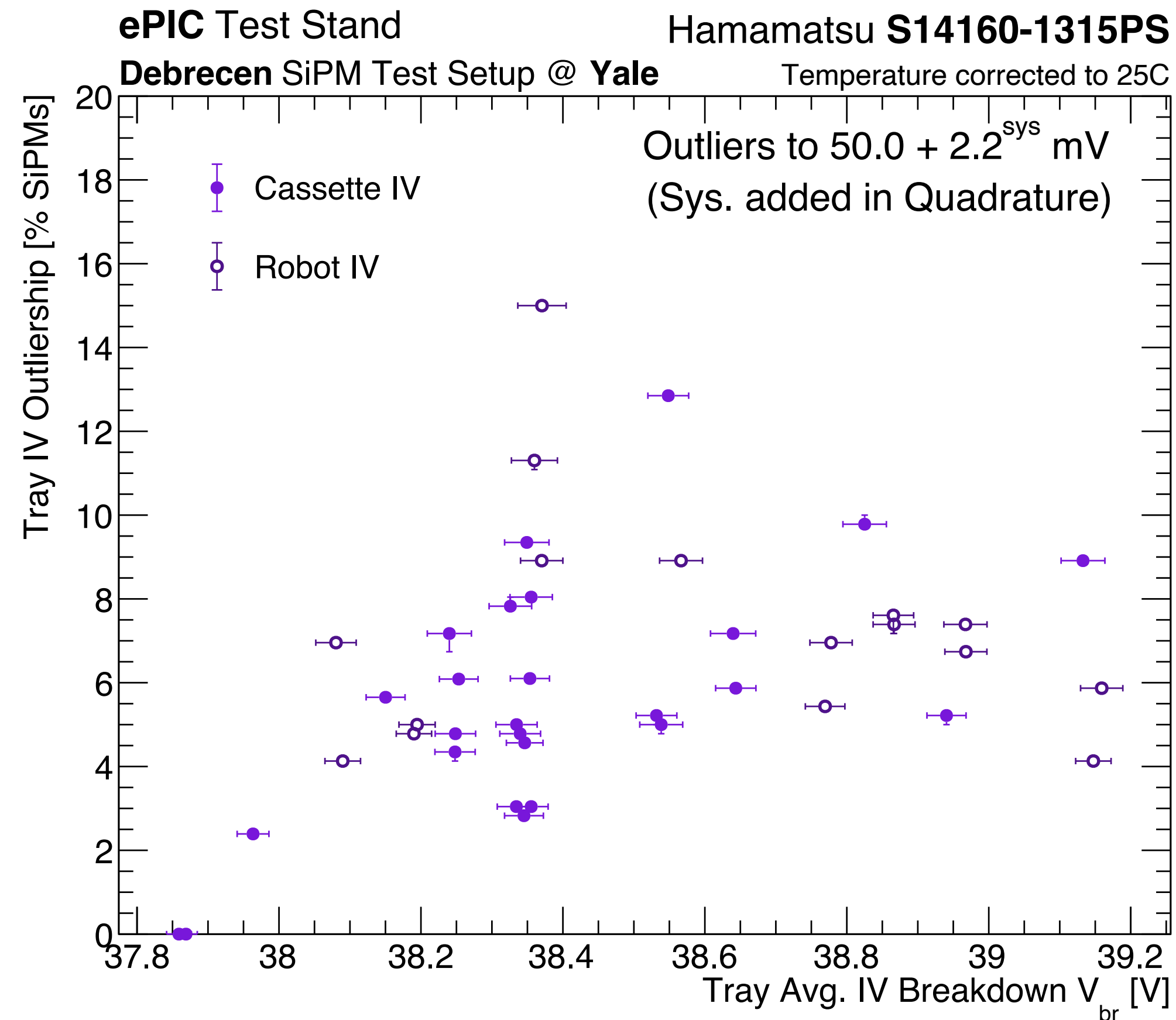


Clear Large offset!

Robot consistently higher: additional current source in the system.

Comparing Outliership

No strong evidence for correlation of outliership with breakdown voltage, more outliers for robot/cassette test stands

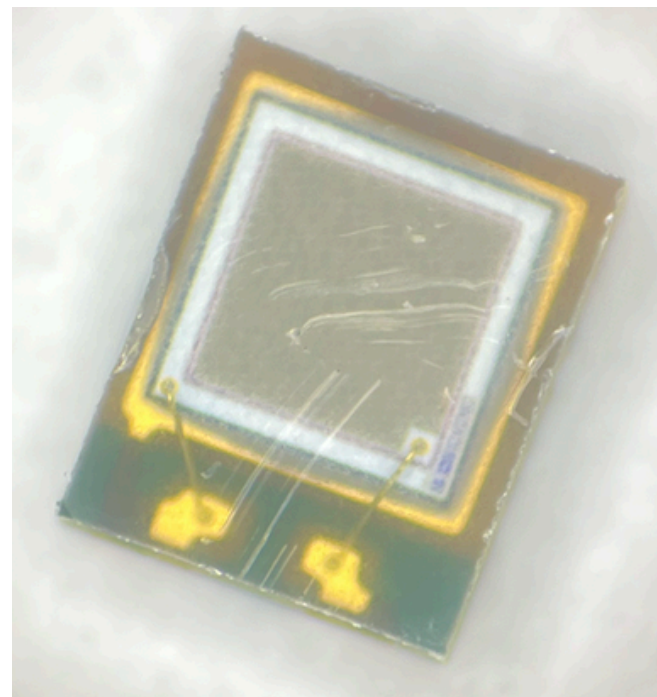


Future Studies

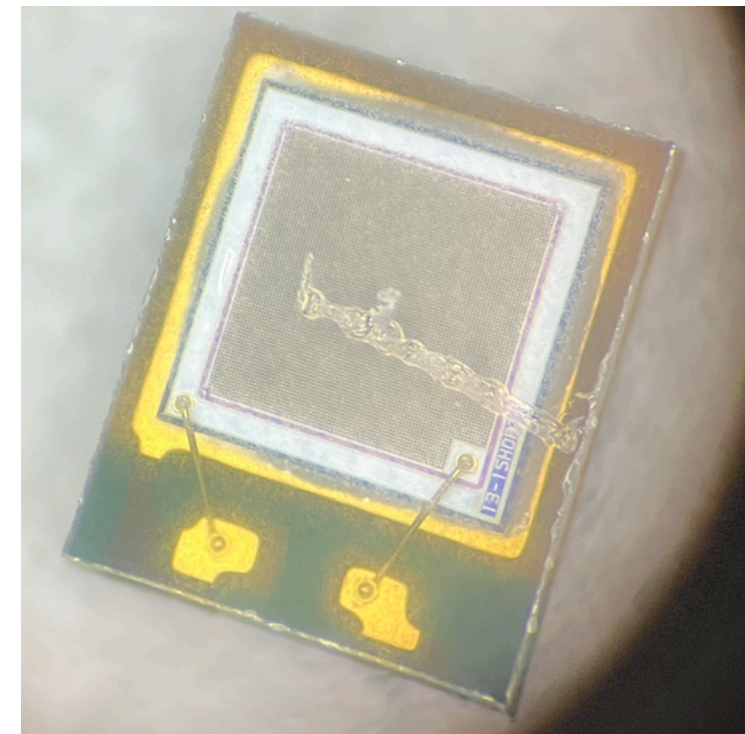
Surface Imperfections

In addition, we inspect each SiPM under a microscope to check for surface defects

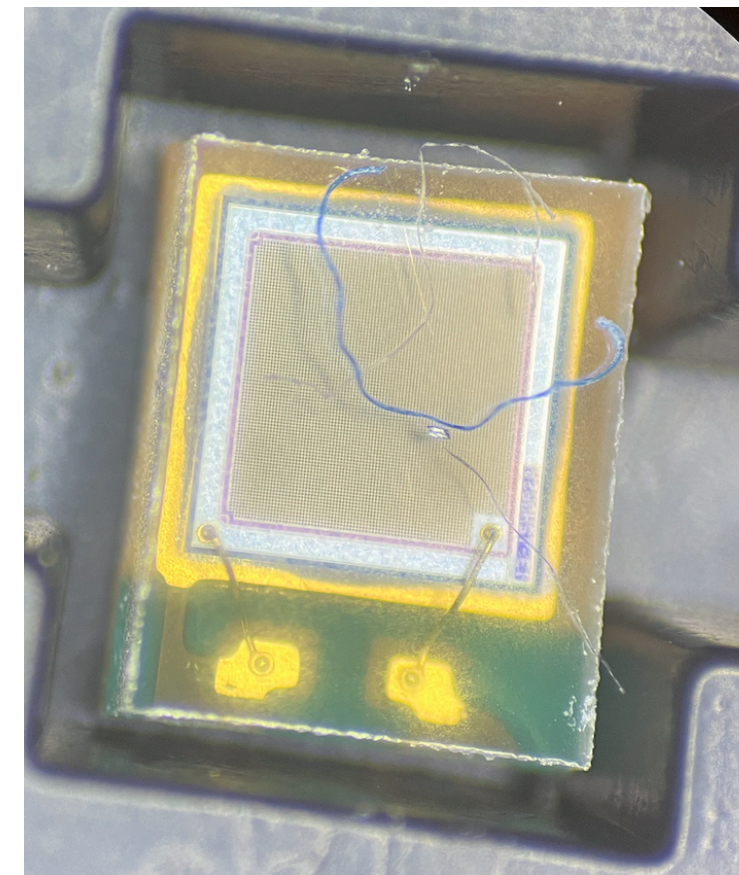
Surface Scratch



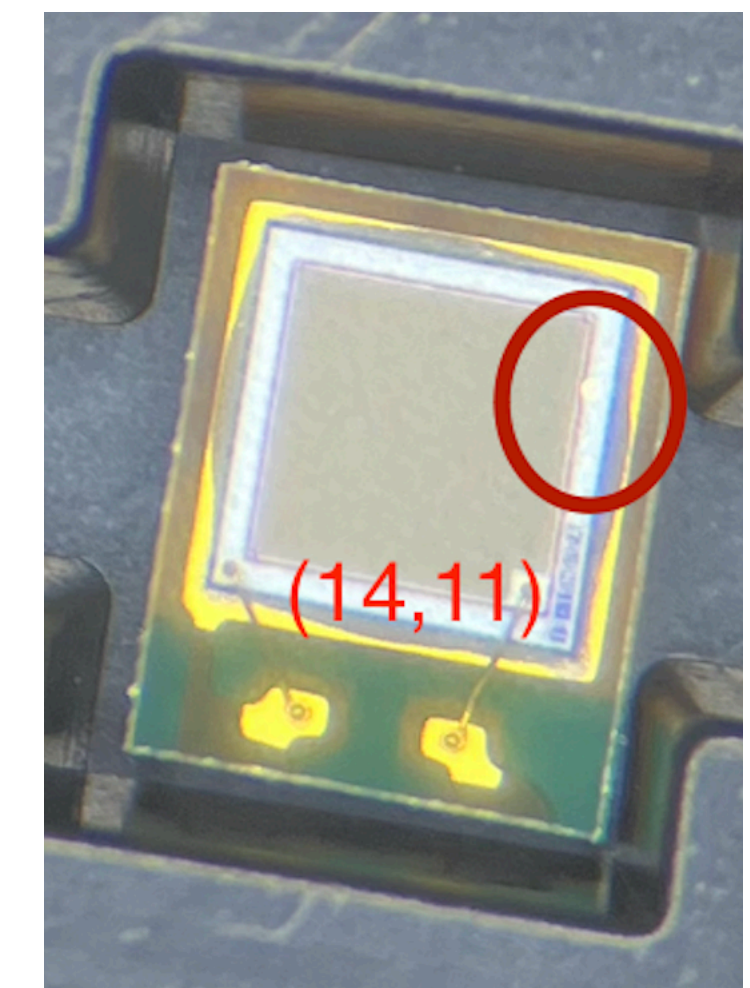
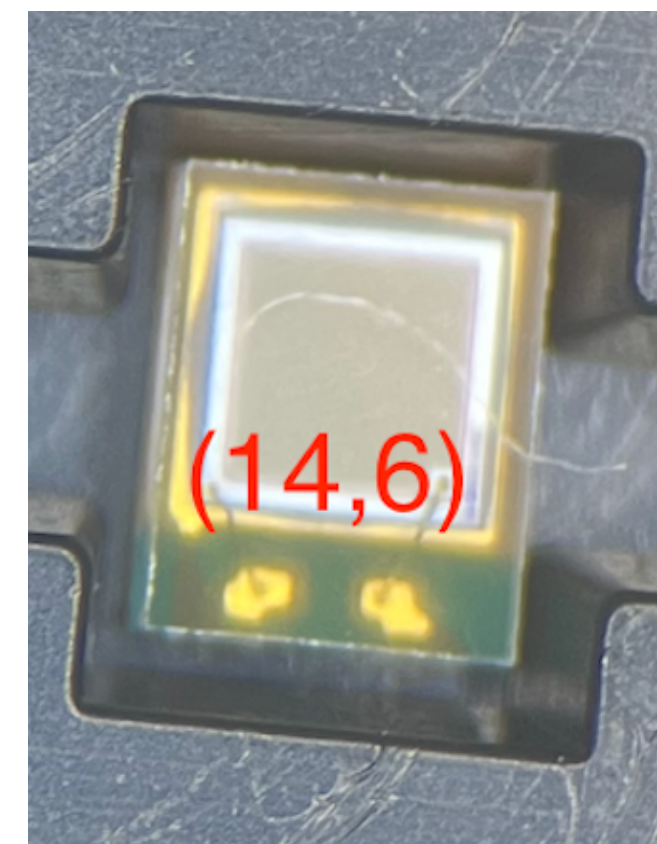
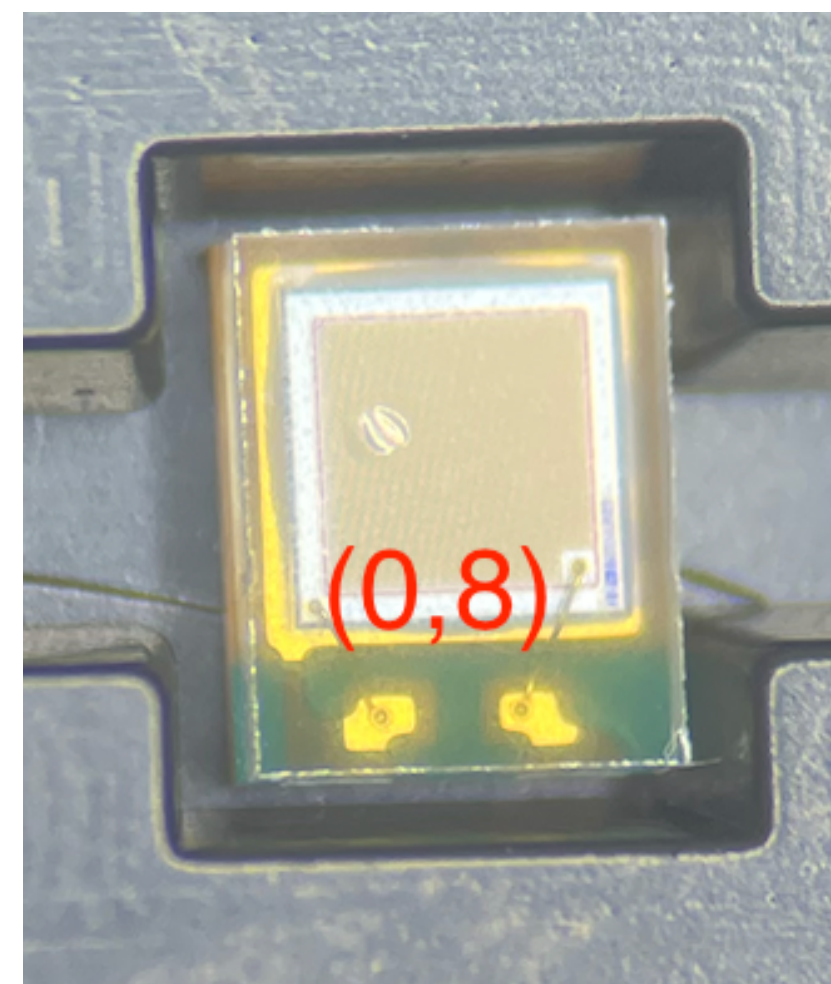
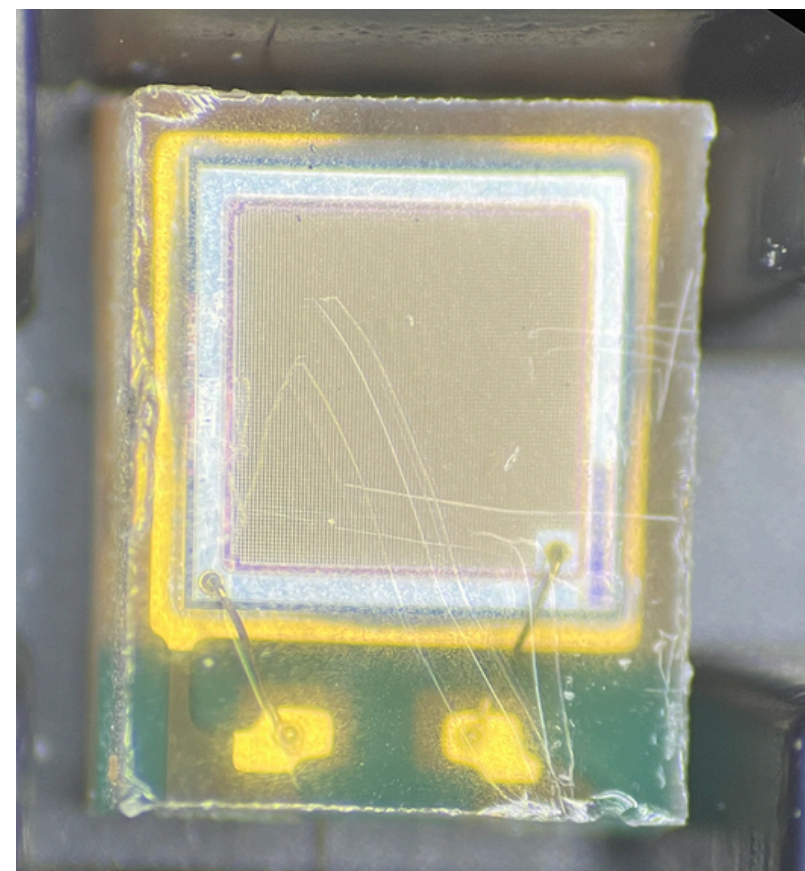
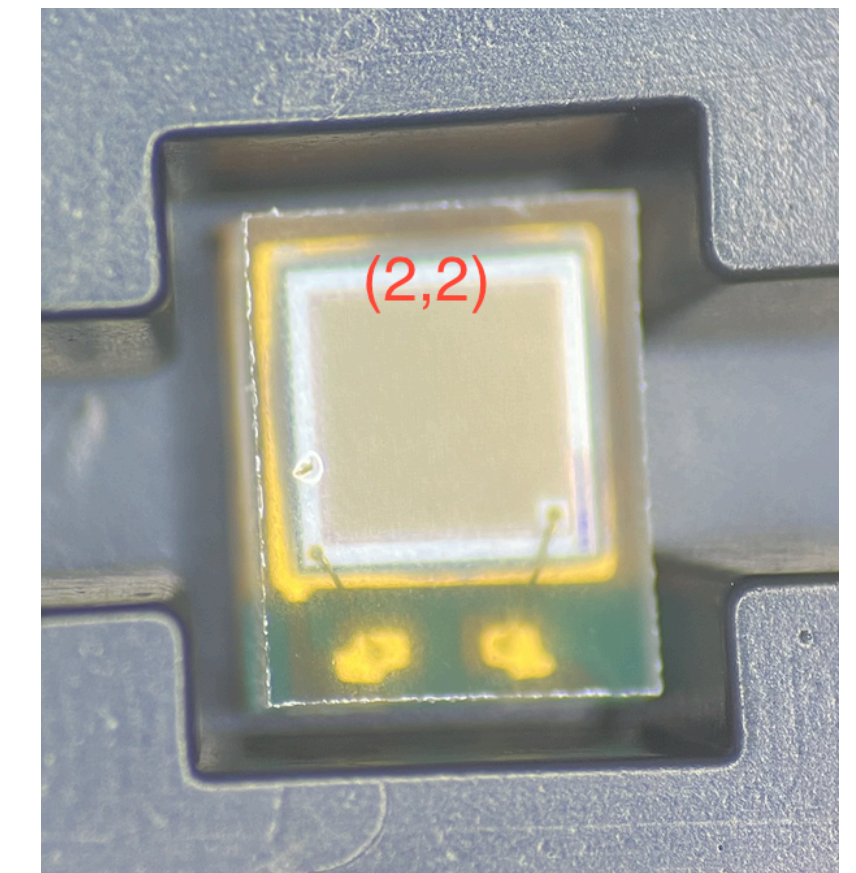
Surface Bubble



Obstructing Debris



Control—Not On Pixels

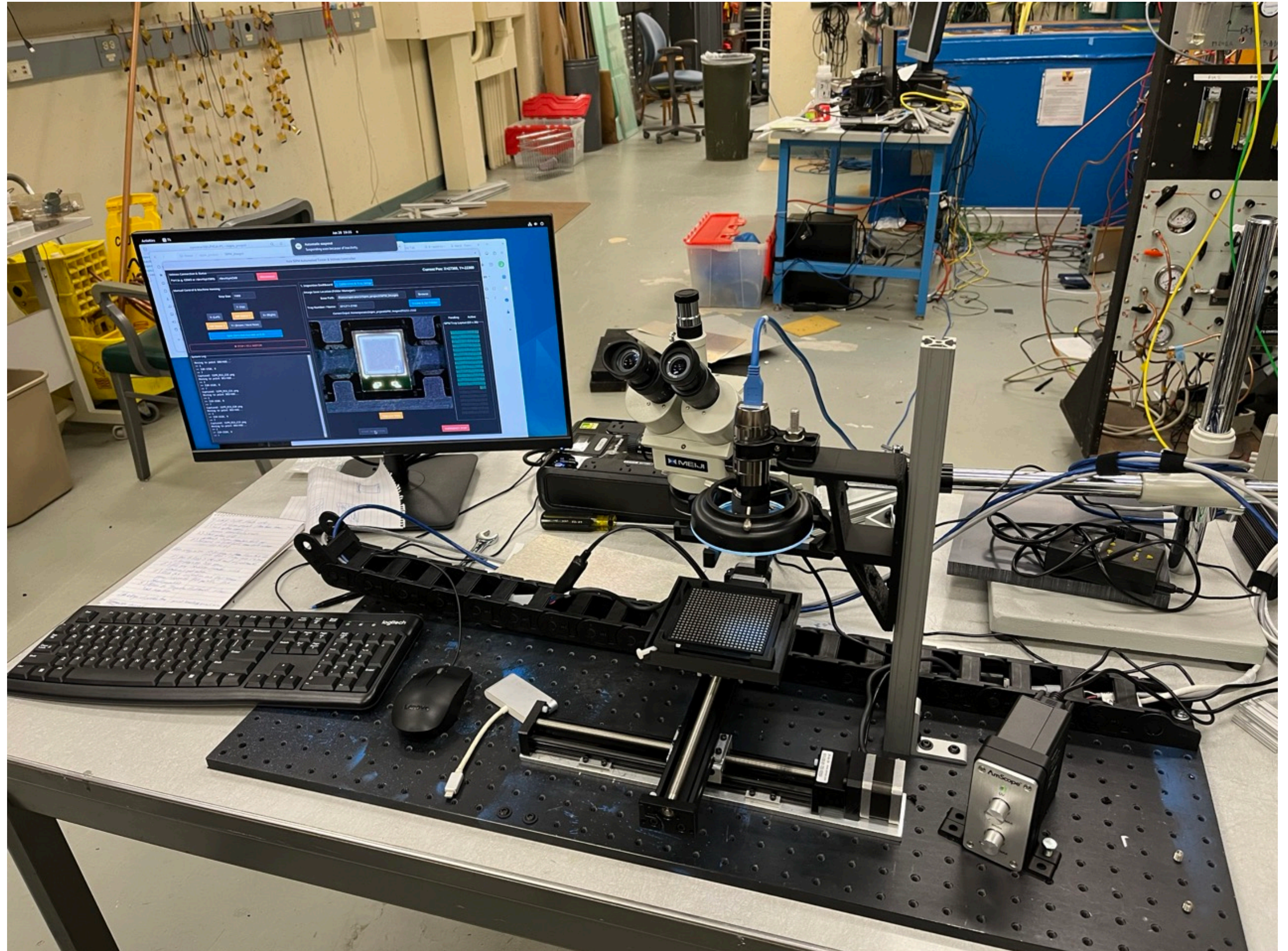


Surface Imperfections

Automated setup

- Design and inspector code by Levente Pirint
- Structural supports designed by Jesse Lior

Jesse also Looking into CNN for damage classification on SiPM surface, after success in LFHCaI tile studies

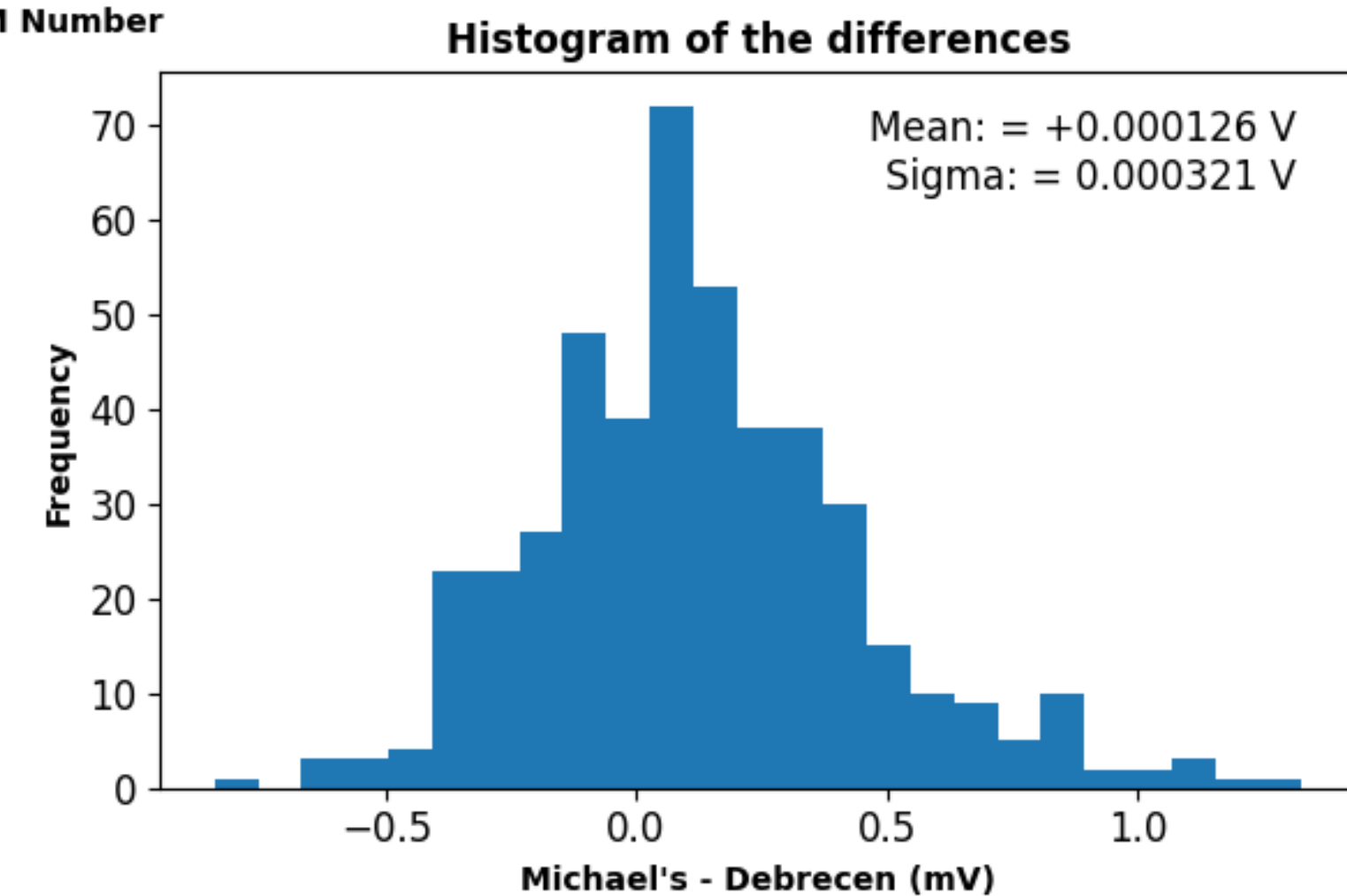
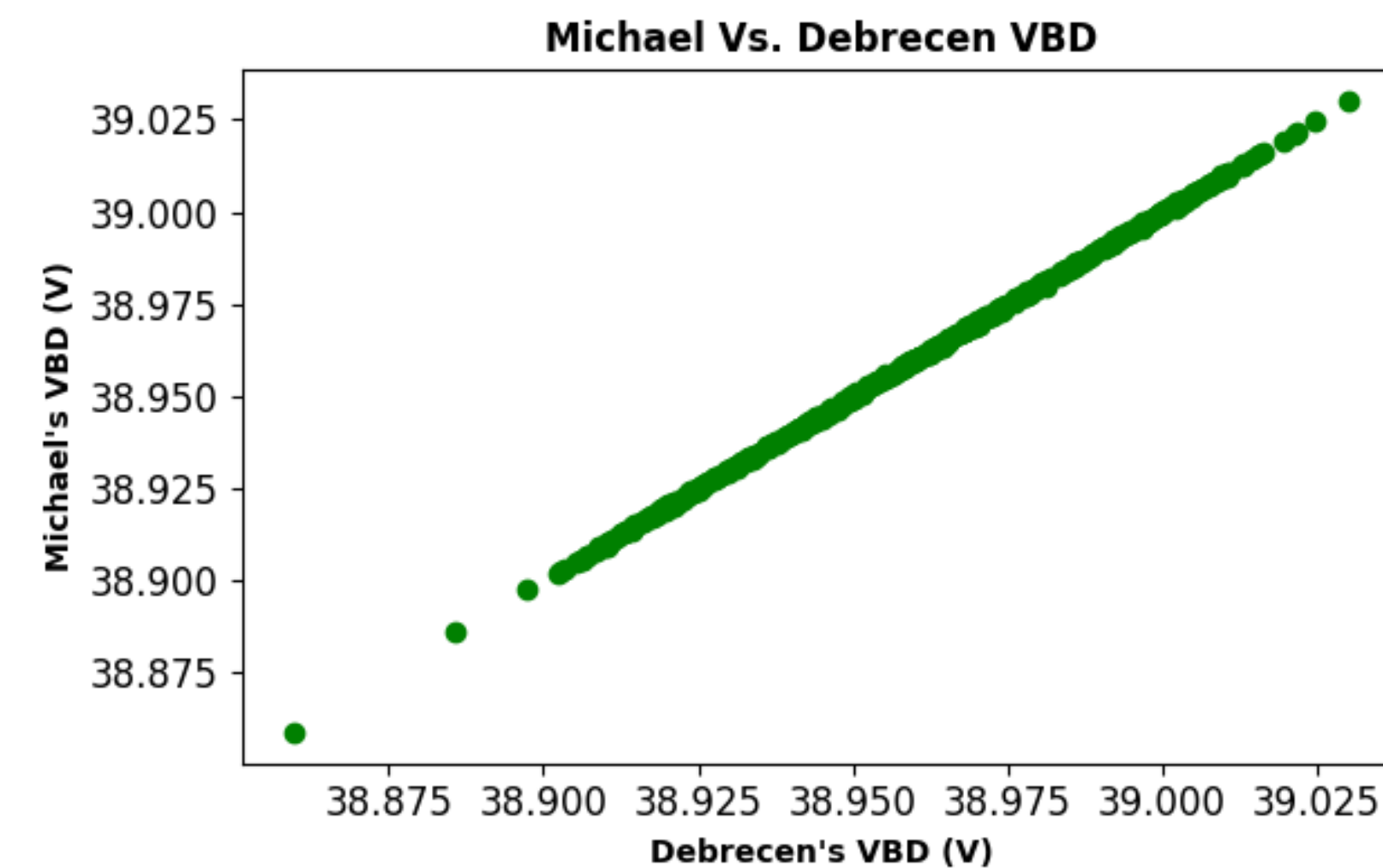
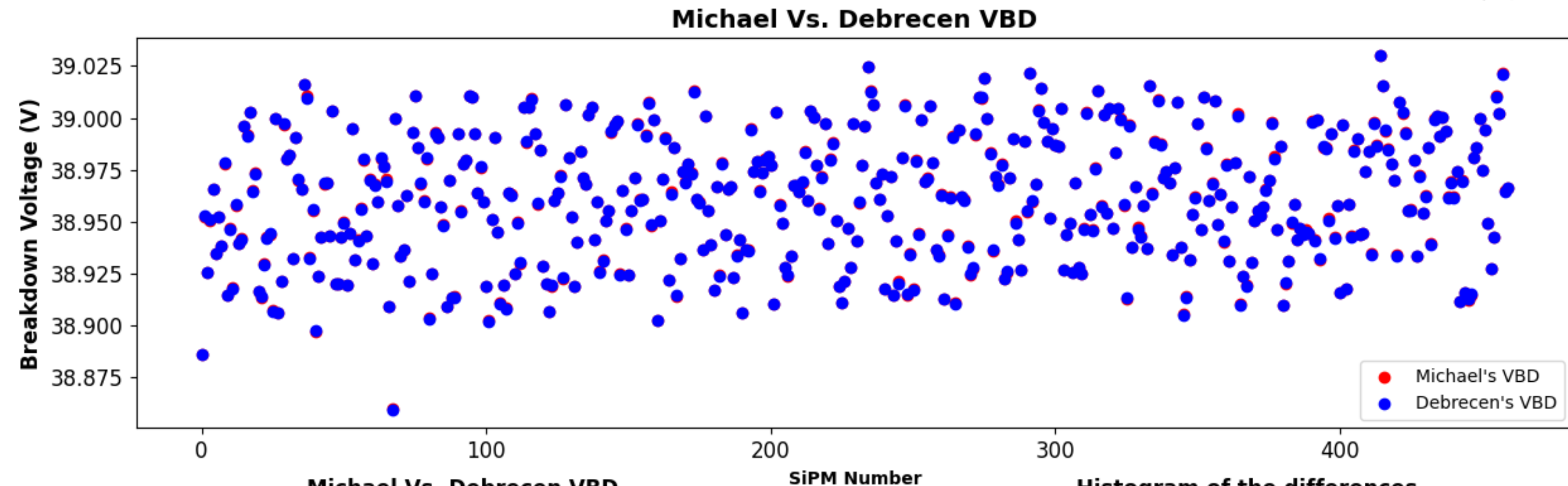


IV Breakdown Methods

Hamamatsu SP14160-1315PS
Tray 251211-2101
Debrecen SiPM Setup @ Yale

Michal Nguyen exploring alternative methods of extracting V_{Br} from IV curve, following NIM-A 849 (2017) 55–59.

First results consistent with Debrecen extraction using Python code.



IV Breakdown Methods

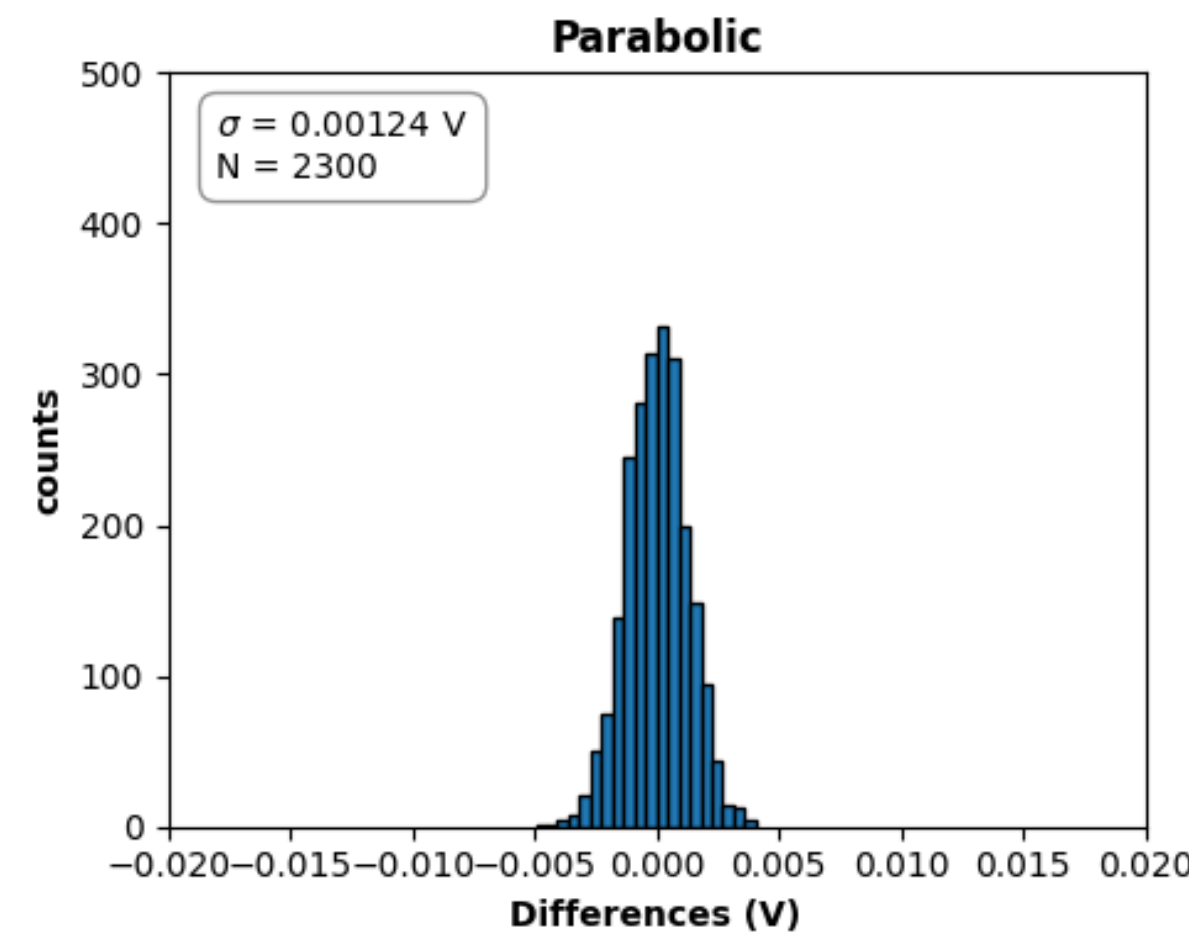
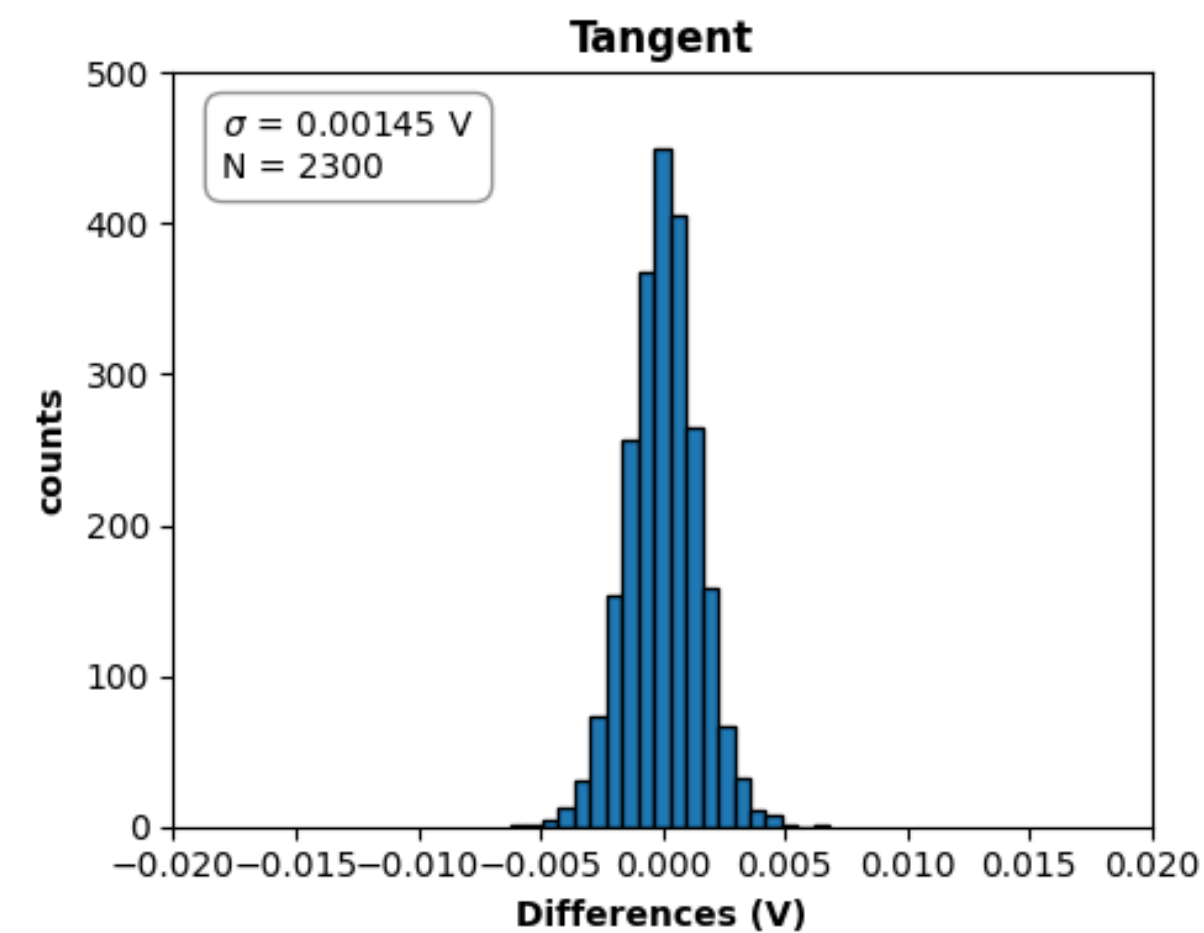
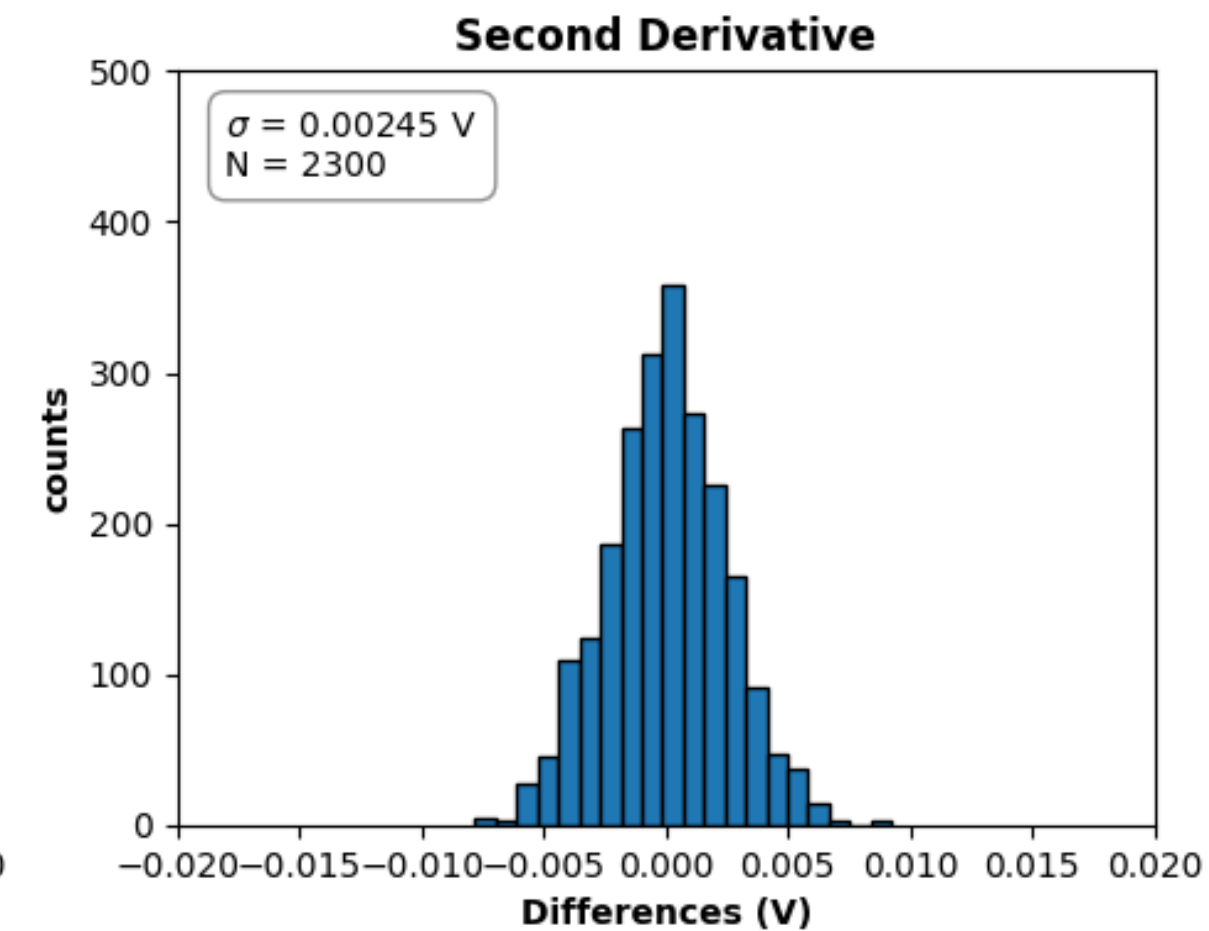
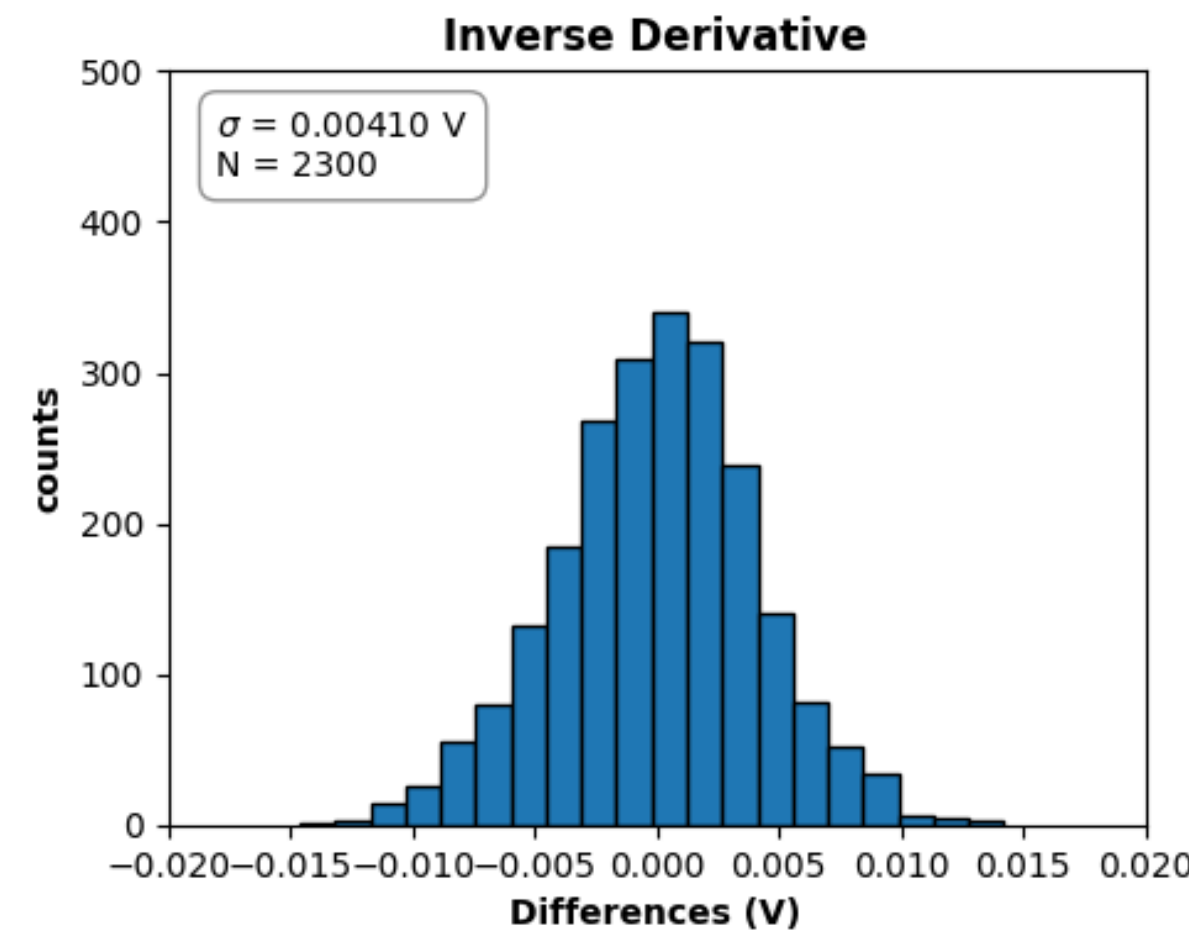
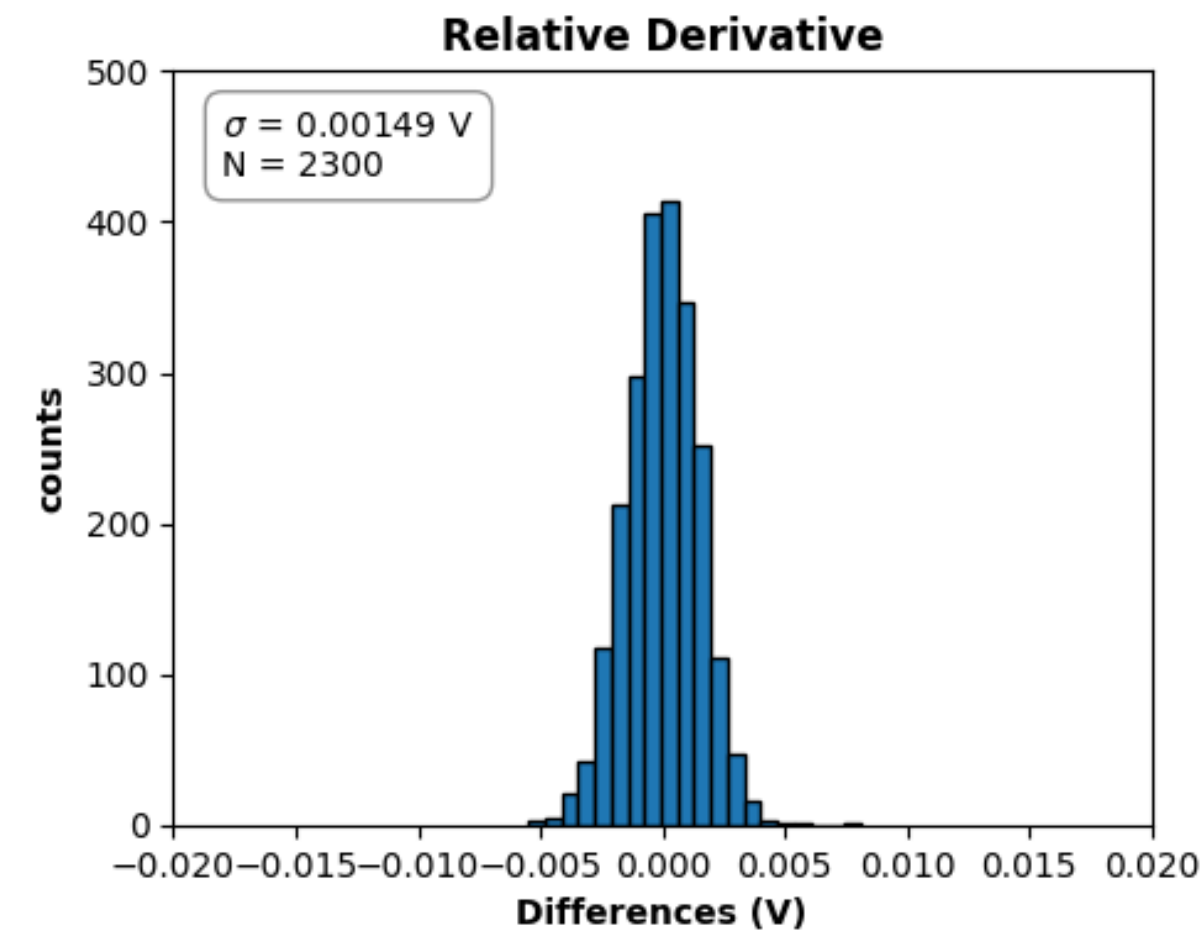
Michal Nguyen exploring alternative methods of extracting V_{Br} from IV curve, following NIM-A 849 (2017) 55–59.

First results consistent with Debrecen extraction using Python code.

4 alternate methods showing promise, but more study must be done to confirm this.

Method Stability Across Repeated Measurements

Tray 250821-1302
Hamamatsu SP14160-1315PS



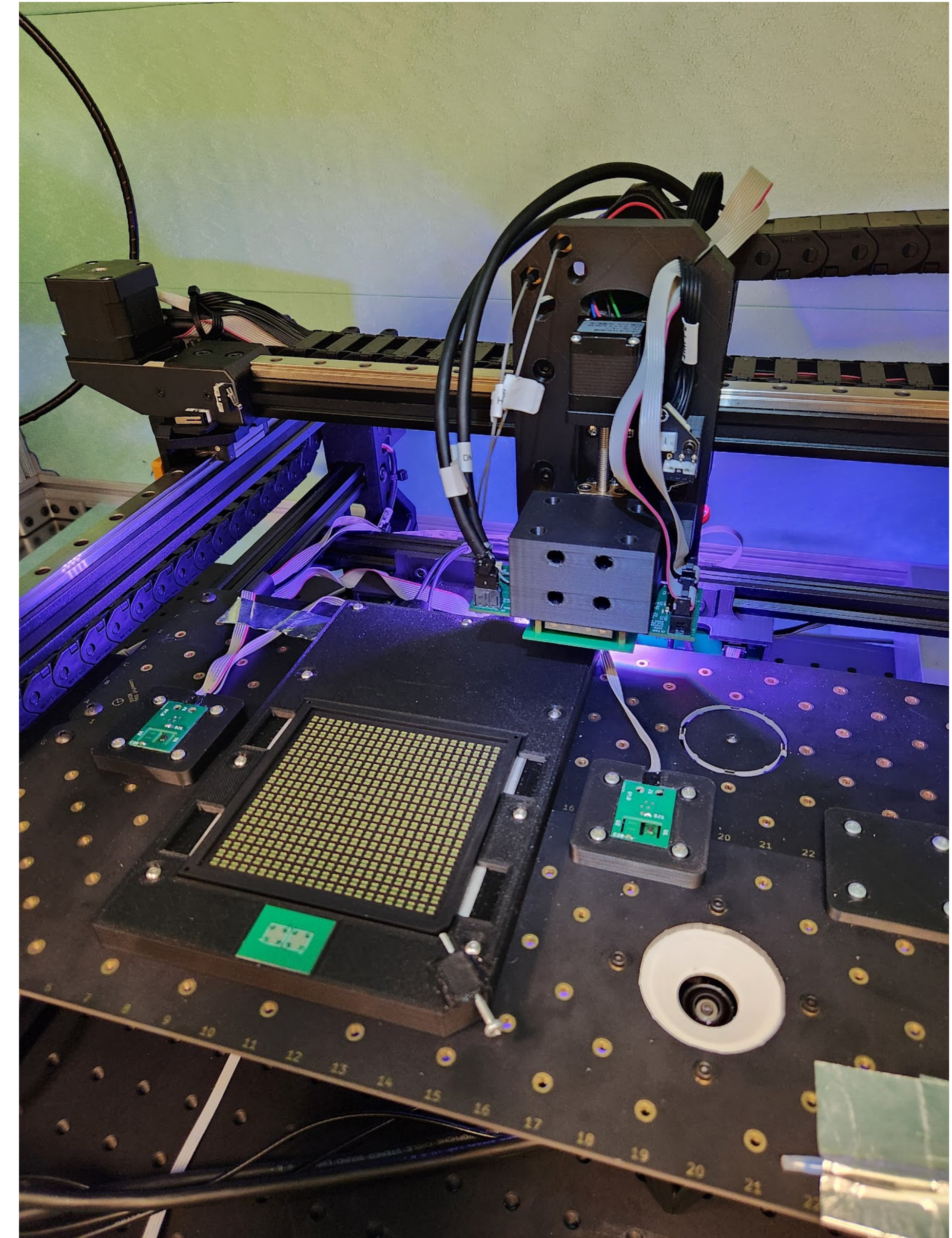
Summary and Status

SiPM Contract Margins

- Robotic setup capable of testing 500 SiPMs/day.
- We see around **6-8%** outliership among 20,000 tested SiPMs after correcting for systematic errors.
- **One bad SiPM** was found ($\mathcal{O}(\text{mA})$ dark current), and several have had very large surface defects.
- Dark current well below spec., but not computed correctly in new robotic setup (additional relay).

Points of Interest

- Outliership may be somewhat correlated with operating voltage, but more data needed to verify.
- Exploring CNN to classify SiPM surface damage.
- Large statistics sample offers detailed study of alternate IV breakdown determination methods.



Robot in Action

