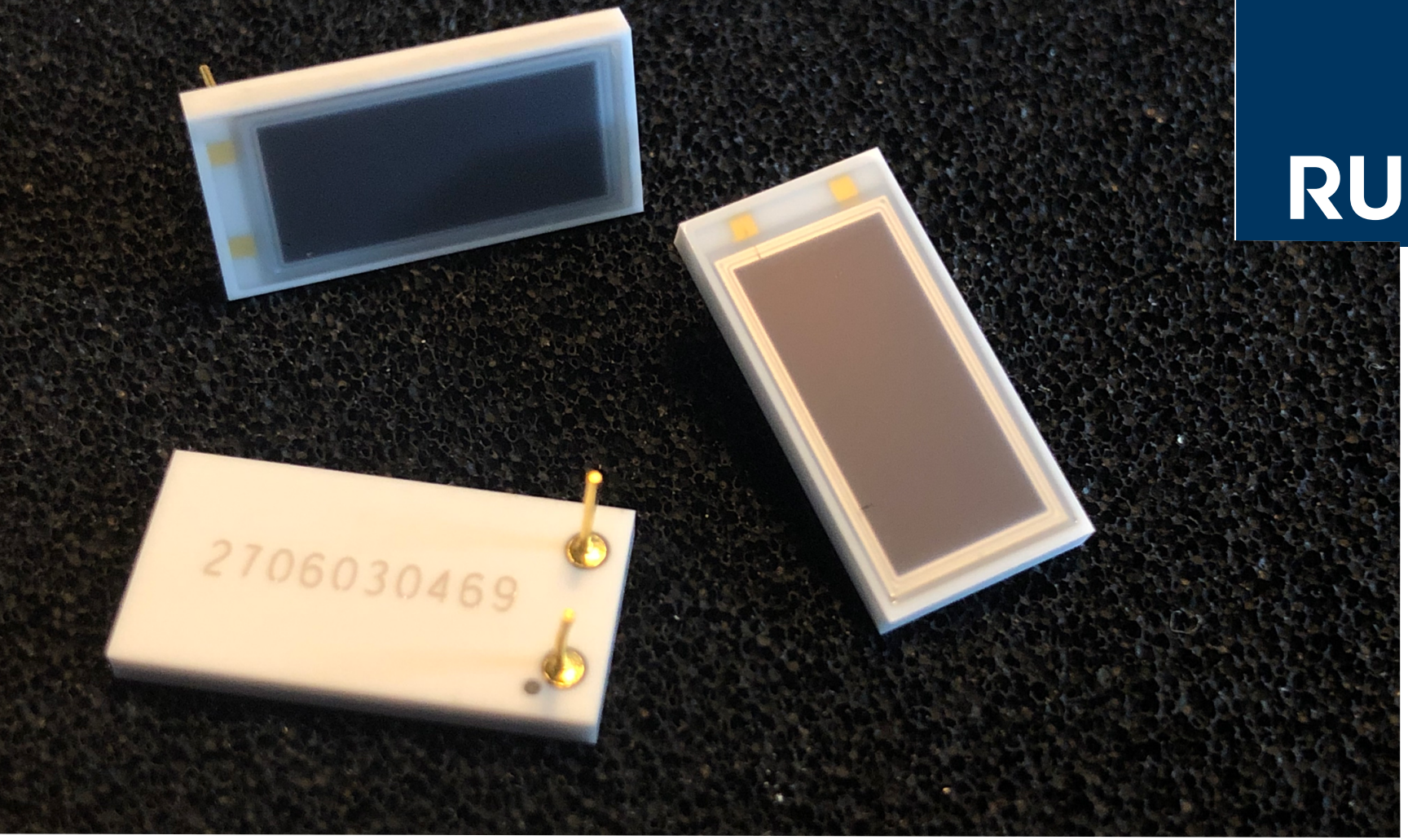


RUB

RUHR-UNIVERSITÄT BOCHUM

APD SCREENING

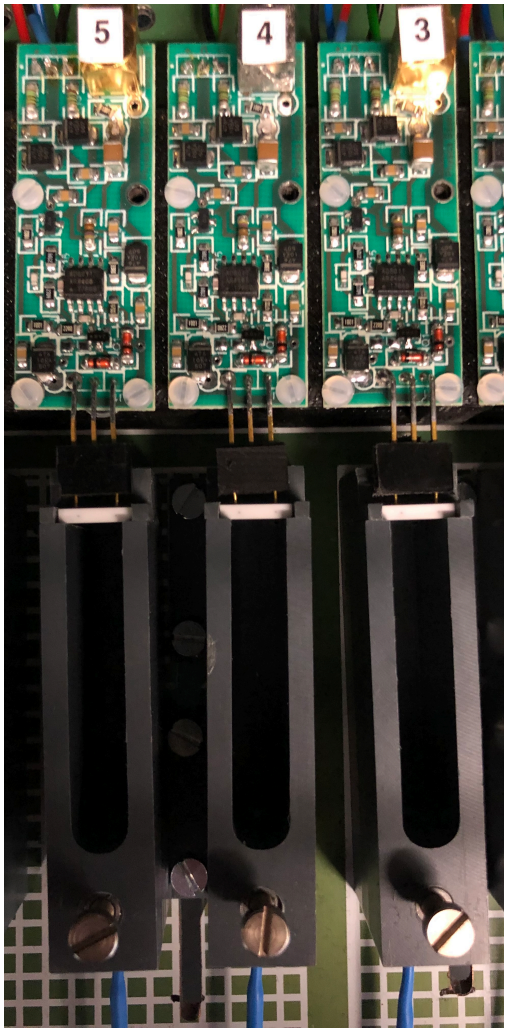
Execution and Results of Screening in Bochum

Jan Reher | 05.11.2019

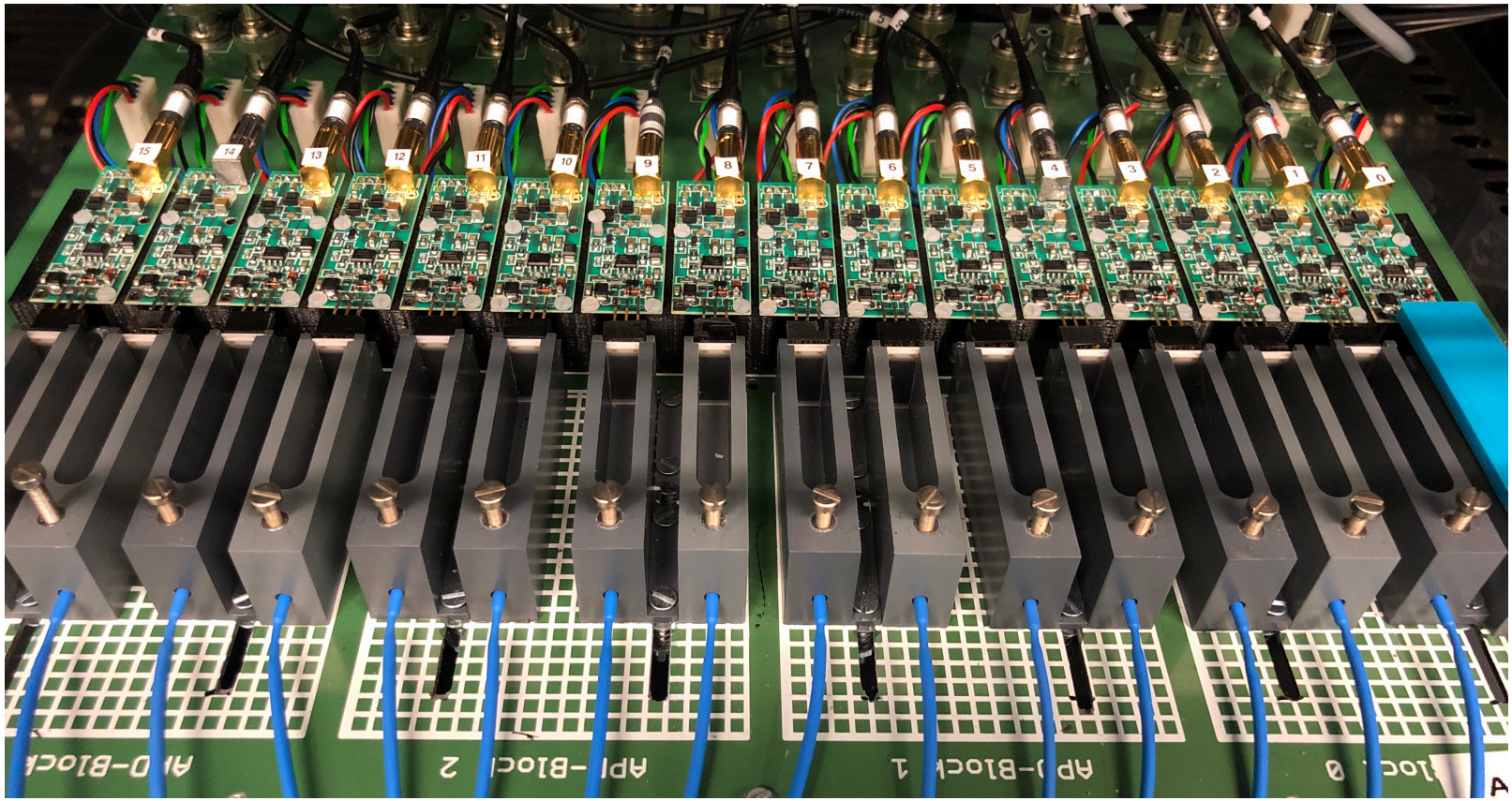
Part 1: Logistics and Screening Process

Screening Setup

- **Illumination with modified light pulser**
  - Pulsed light resembles lead-tungsten signals
  - Additional DC-LED to measure light currents
- **Readout using original PANDA Preamplifiers and SADCs during pulsed measurements**
- **Power supply using iseg-HV modules and Wiener LV modules**
  - Current measurement for each individual channel within HV modules
- **Includes Reference APDs to compensate fluctuations in pulser intensity**

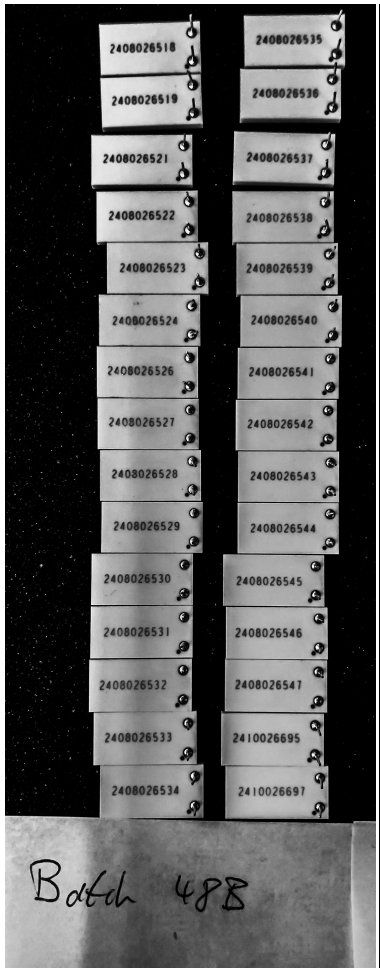


Full screening setup



- 15 APDs (+1 Reference) on each Board, two boards in each climate chamber
- Two climate chambers used for screening

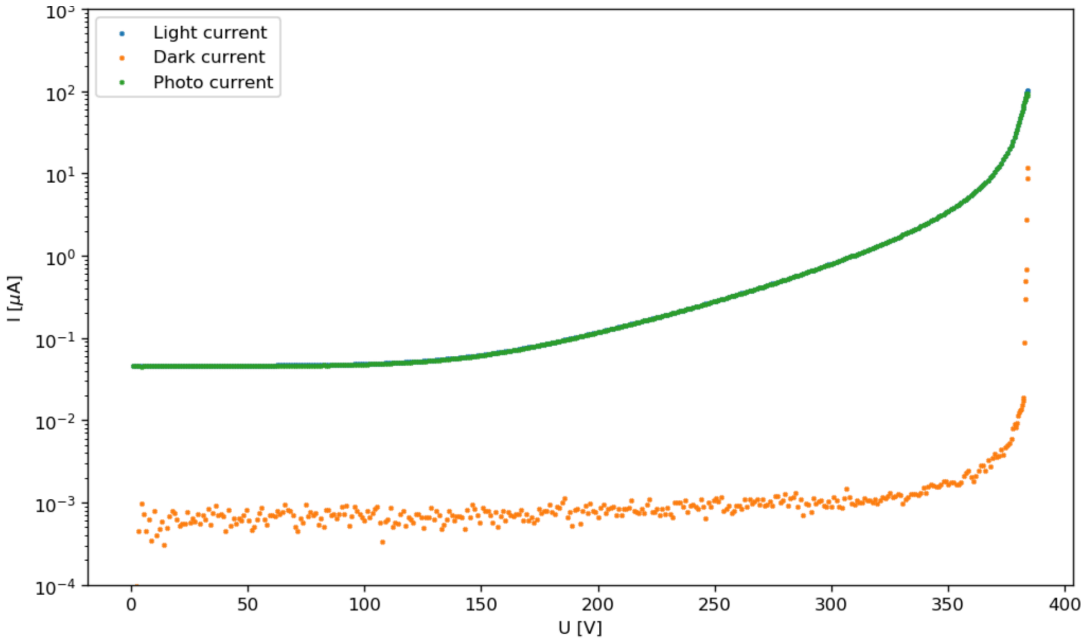
Batches



1 3701038232
2 3701038233
3 3701038234
4 3701038236
5 3701038237
6 3701038238
7 3701038239
8 3701038240
9 3701038241
10 3702038251
11 3702038252
12 3702038254
13 3702038255
14 3703038272
15 3703038273
16 3703038275
17 3703038277
18 3703038278
19 3703038284
20 3703038285
21 3704038293
22 3704038294
23 3704038295
24 3704038296
25 3704038298
26 3704038299
27 3704038300
28 3704038301
29 3704038302
30 3704038303

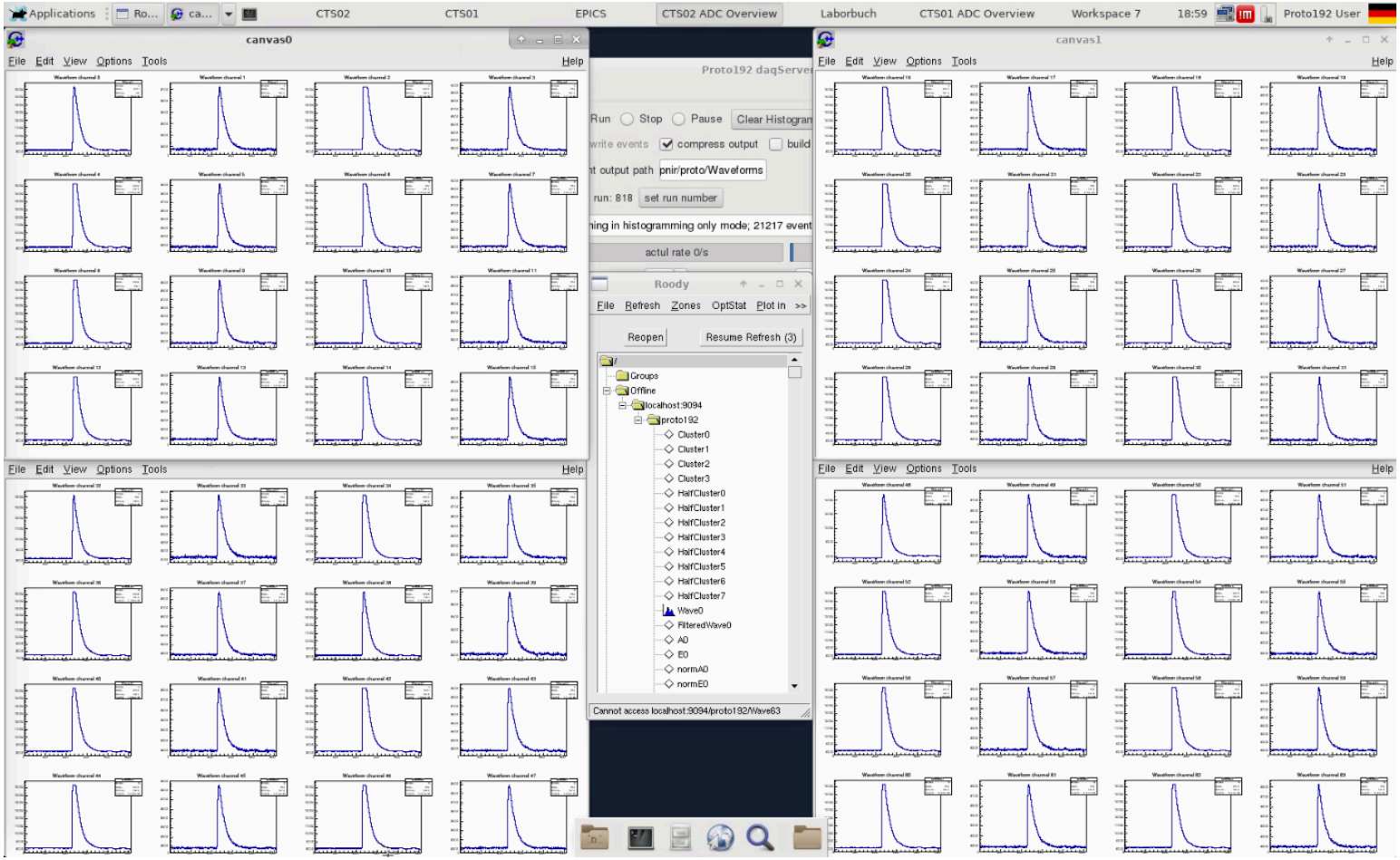
- **APDs sorted to Batches of 30 for screening**
- **Serial numbers of APDs are registered digitally:**
  - ASCII-File containing serial numbers
  - Software enters information into production database
- **Measures to ensure correctness**

Measurement Process



- **Four measurements per screening cycle:**
  - Light current (APDs illuminated by DC LED in modified pulser)
  - Pulsed + Dark (Illumination with light pulses similar to lead-tungsten at 60 Hz)
  - Both at $20℃$ and $-25℃$
- **Total duration (incl. cooling and warmup times): Approx. 10 Hours**

Screen to verify signal shapes



panda

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Shift Plan

KW 30			Montag	Dienstag	Mittwoch	Donnerstag	Freitag	Samstag	Sonntag
	Möglich ab	Spätestens bis	05.08.2019	06.08.2019	07.08.2019	08.08.2019	09.08.2019	10.08.2019	11.08.2019
Morgens	04:00-08:00	9:00	Tom	Tom	Tom	Miriam	Malte	Malte	Jan
Abends	18:00-19:00	22:00	Jan	Jan	Jan	Jan	Matthias		

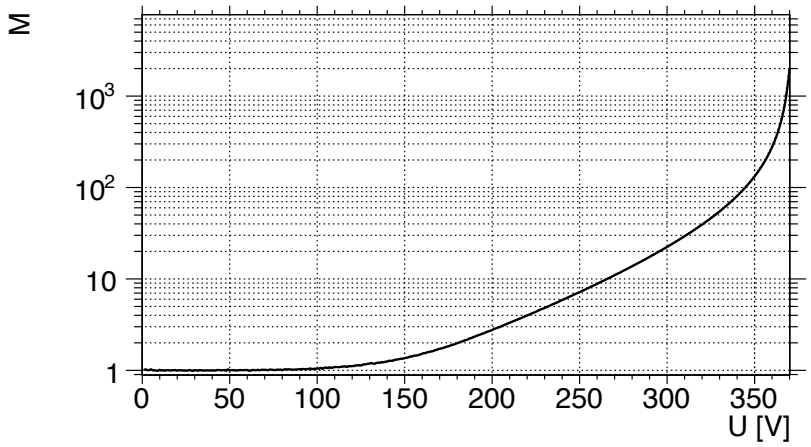
KW 31			Montag	Dienstag	Mittwoch	Donnerstag	Freitag	Samstag	Sonntag
	Möglich ab	Spätestens bis	12.08.2019	13.08.2019	14.08.2019	15.08.2019	16.08.2019	17.08.2019	18.08.2019
Morgens	04:00-08:00	9:00	Tom	Tom	Tom	Tom	Miriam	Matthias	Miriam
Abends	18:00-19:00	22:00	Jan	Jan	Jan	Jan	Miriam		

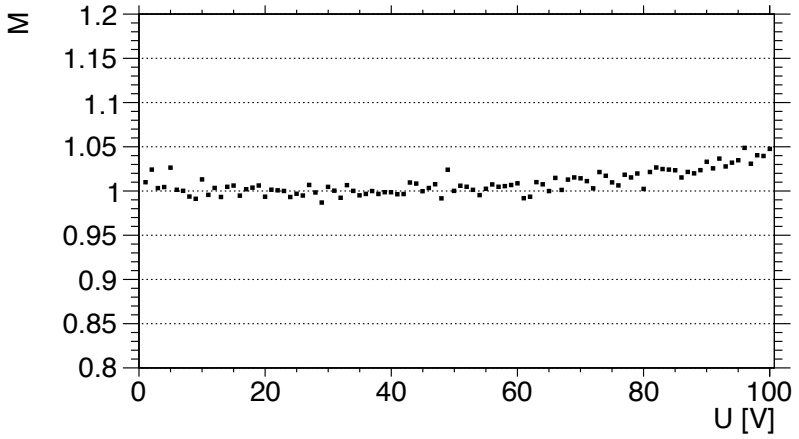
KW 32			Montag	Dienstag	Mittwoch	Donnerstag	Freitag	Samstag	Sonntag
	Möglich ab	Spätestens bis	19.08.2019	20.08.2019	21.08.2019	22.08.2019	23.08.2019	24.08.2019	25.08.2019
Morgens	04:00-08:00	9:00	Tom	Tom	Tom	Miriam	Miriam	Jan	Matthias
Abends	18:00-19:00	22:00	Jan	Jan	Jan	Jan	Jan		

KW 33			Montag	Dienstag	Mittwoch	Donnerstag	Freitag	Samstag	Sonntag
	Möglich ab	Spätestens bis	26.08.2019	27.08.2019	28.08.2019	29.08.2019	30.08.2019	31.08.2019	01.09.2019
Morgens	04:00-08:00	9:00	Tom	Tom	Tom	Tom	Tom		Matthias
Abends	18:00-19:00	22:00	Matthias	Jan	Jan	Miriam	Jan		

- **Two shifts per day possible (morning and evening shift) → 120 APDs per day**
- **Normal shift work 5 days a week, one shift per day on the weekend → 720 APDs / week**
- **Average of 580 APDs screened per week so far**

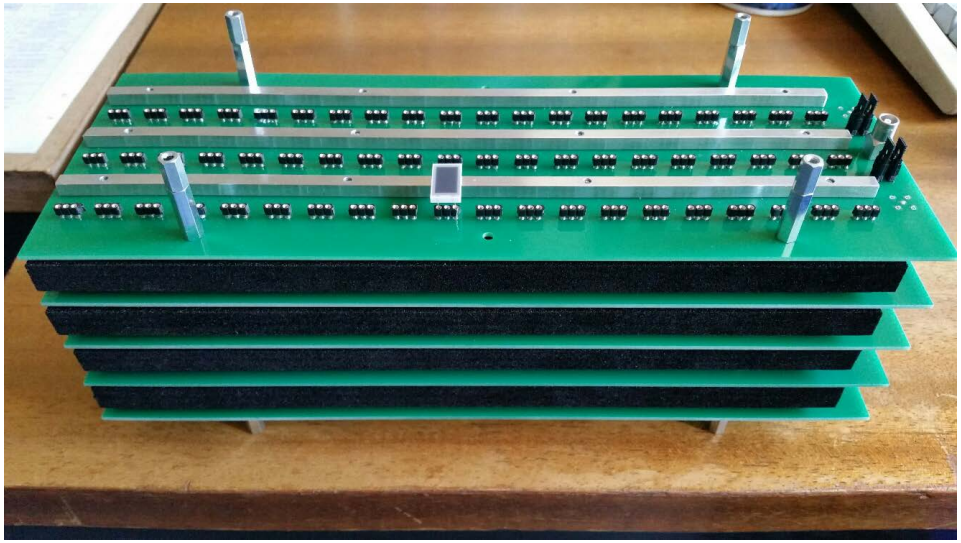
Data evaluation:





- **Determine Yield corresponding to M = 1 and normalize**
  - Use average from 10V to 35V
  - Low currents at M = 1 lead to relatively big errors
  - Normalization of the gain curve causes error on the entire gain curve
- **Interpolate Voltages corresponding to M = 100, M = 150, M = 200 and M = 300**

Irradiation and Annealing



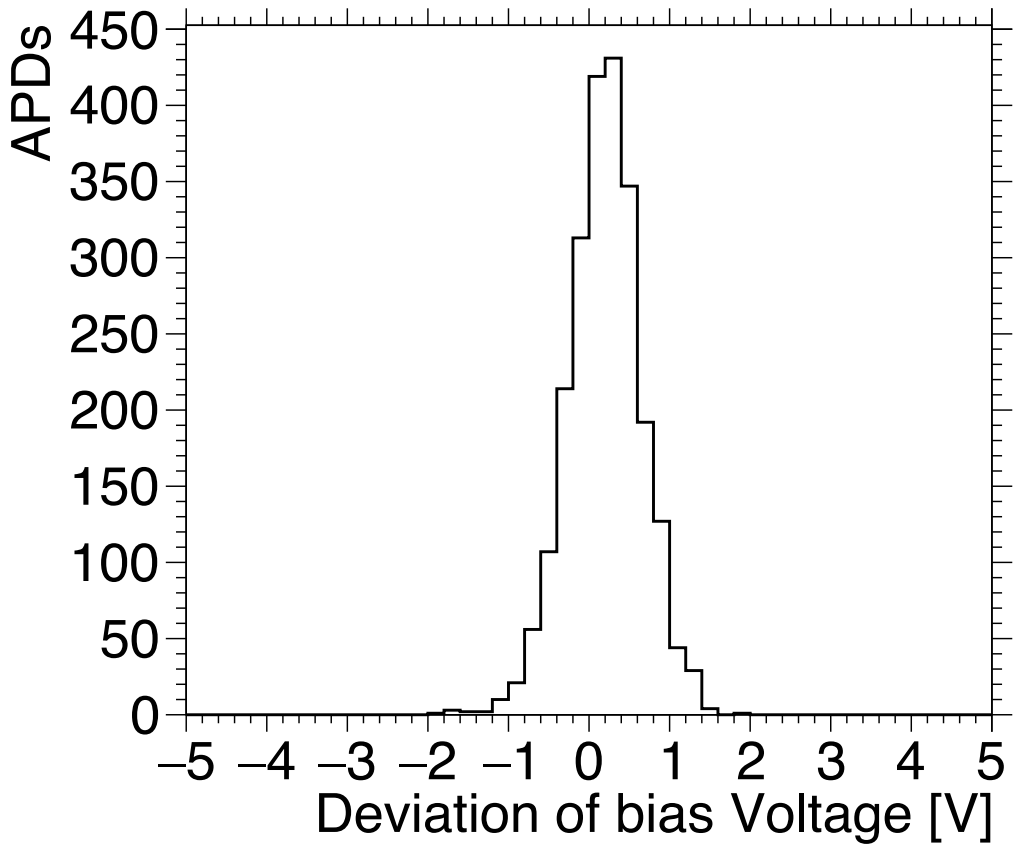
- **Irradiation with gamma radiation at JLU Giessen (37 Gy)**
- **Annealing for 48 hours**
- **Boards for irradiation and transport developed in Giessen**
  - 60 APDs per board
  - Irradiation, annealing and shipment without removing APDs from boards
  - Sandwich design of screening boards makes safe shipment possible
  - 15 Boards currently in use

Current Progress:

- **Progress so far:**
  - Screened 6180 APDs before irradiation
  - Screened 6600 APDs after irradiation (pool for matching)
    - ~2300 APDs were screened in Bochum before and after irradiation
    - ~4300 remaining irradiated APDs were screened before irradiation at GSI
- **Estimated Weekly Capacity of 720 APDs can be met**
- **All APDs stored in Bochum have been screened**
- **JLU Giessen working on additional screening boards**
  - Currently working in sync with screening in Bochum (same throughput)
  - Rebuild a buffer in Bochum (independence from access to gamma source)
- **First two 16-crystal alveoles and first 8-crystal alveole assembled with matched APDs**

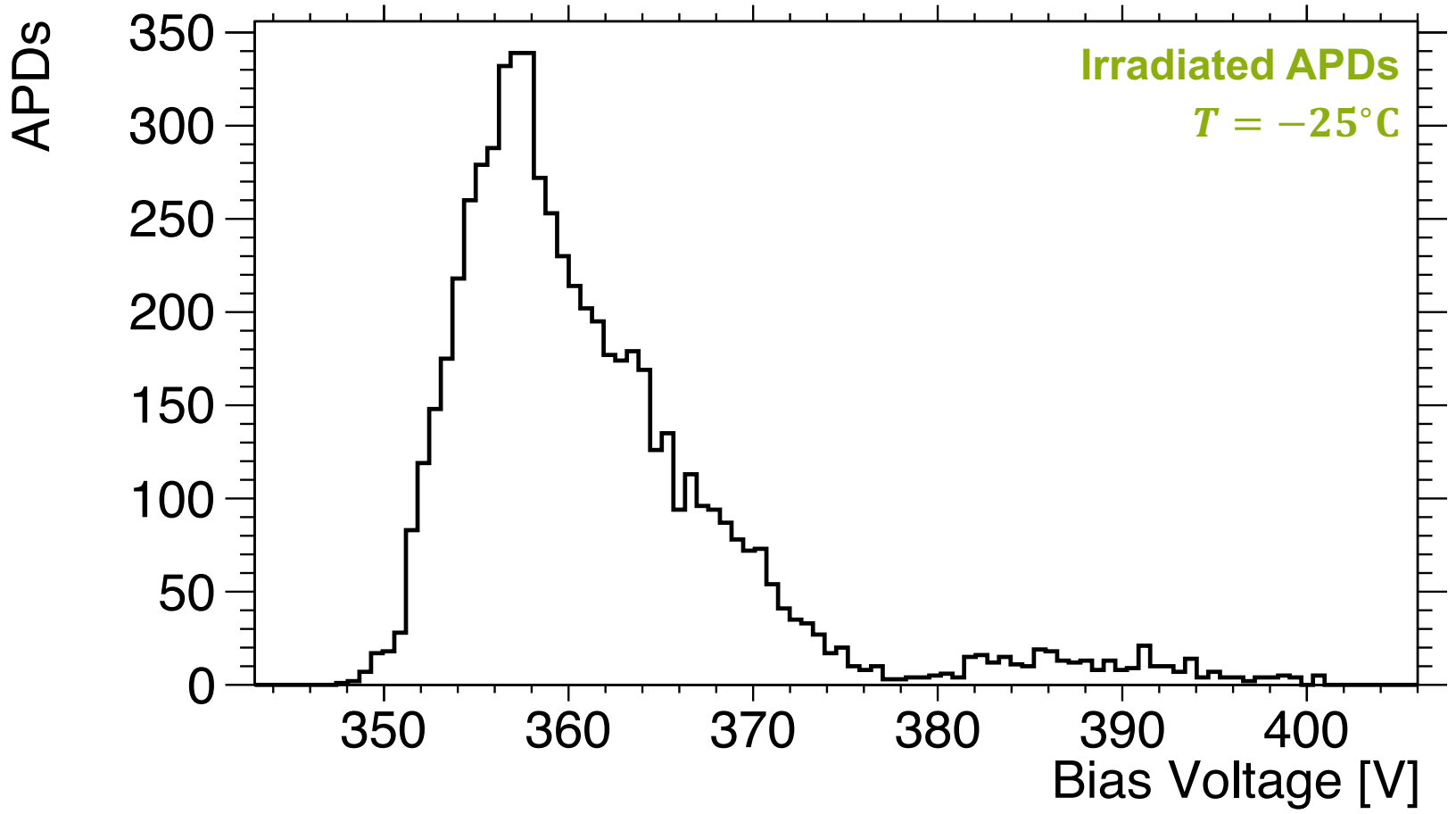
Part 2: Results of Screening

Comparing to Values from vendor

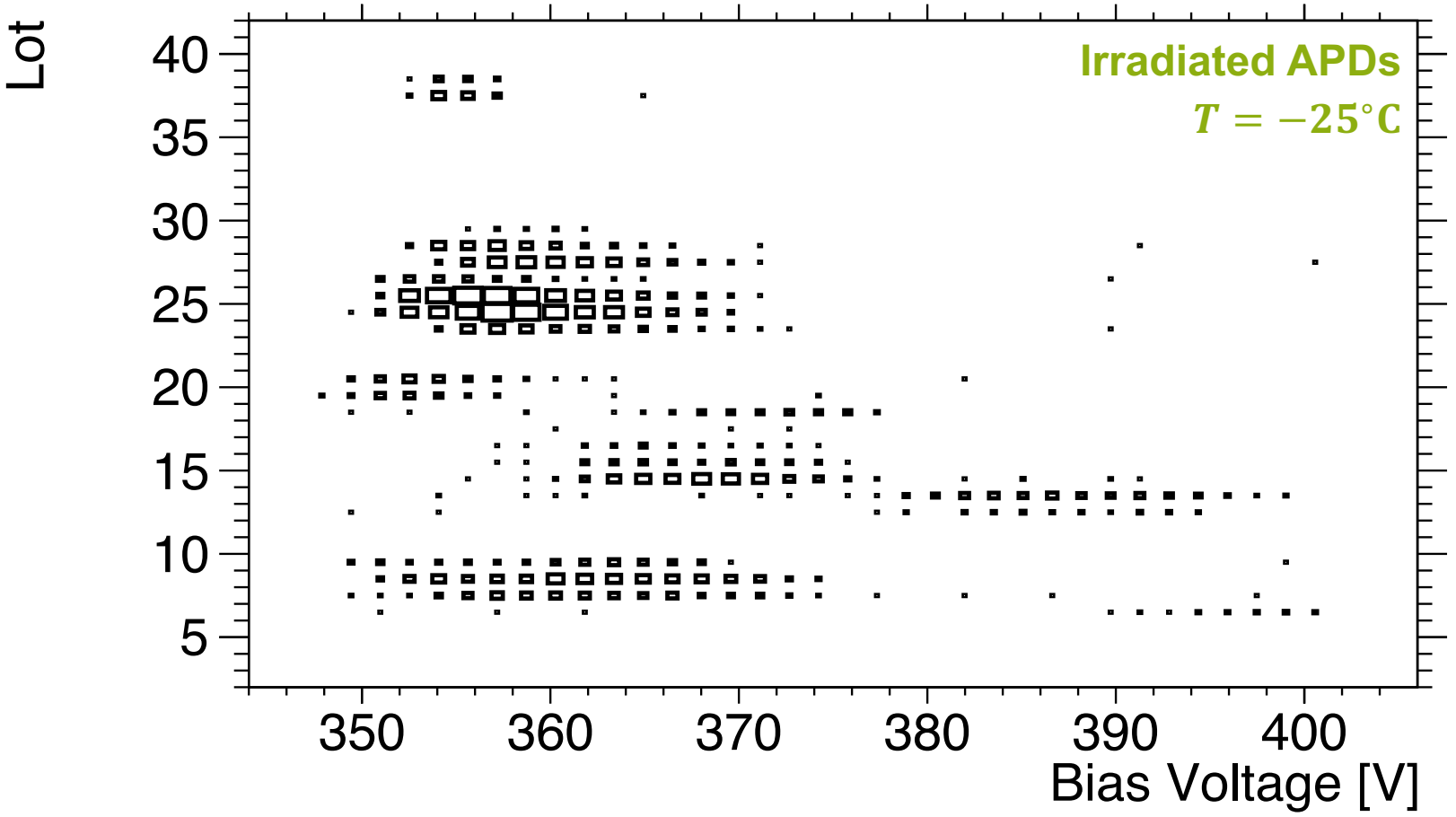


- **Values provided by Hamamatsu:**
  - Bias voltage at gain 100
  - Measured at ~20°C
- **Only small deviations between measured bias voltage and manufacturer value**
- **Deviations in agreement with temperature uncertainty at Hamamatsu**

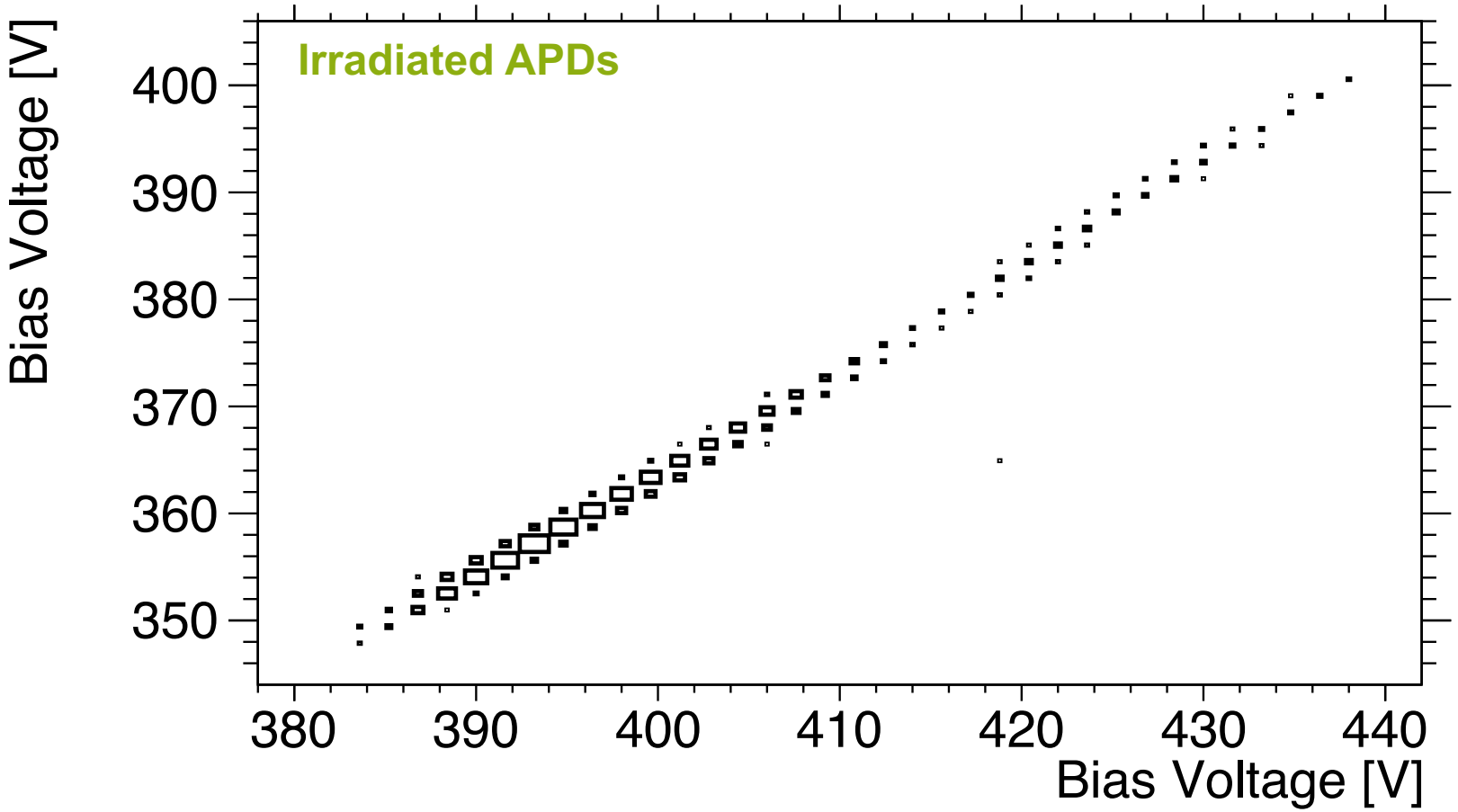
Bias Voltage for M = 200



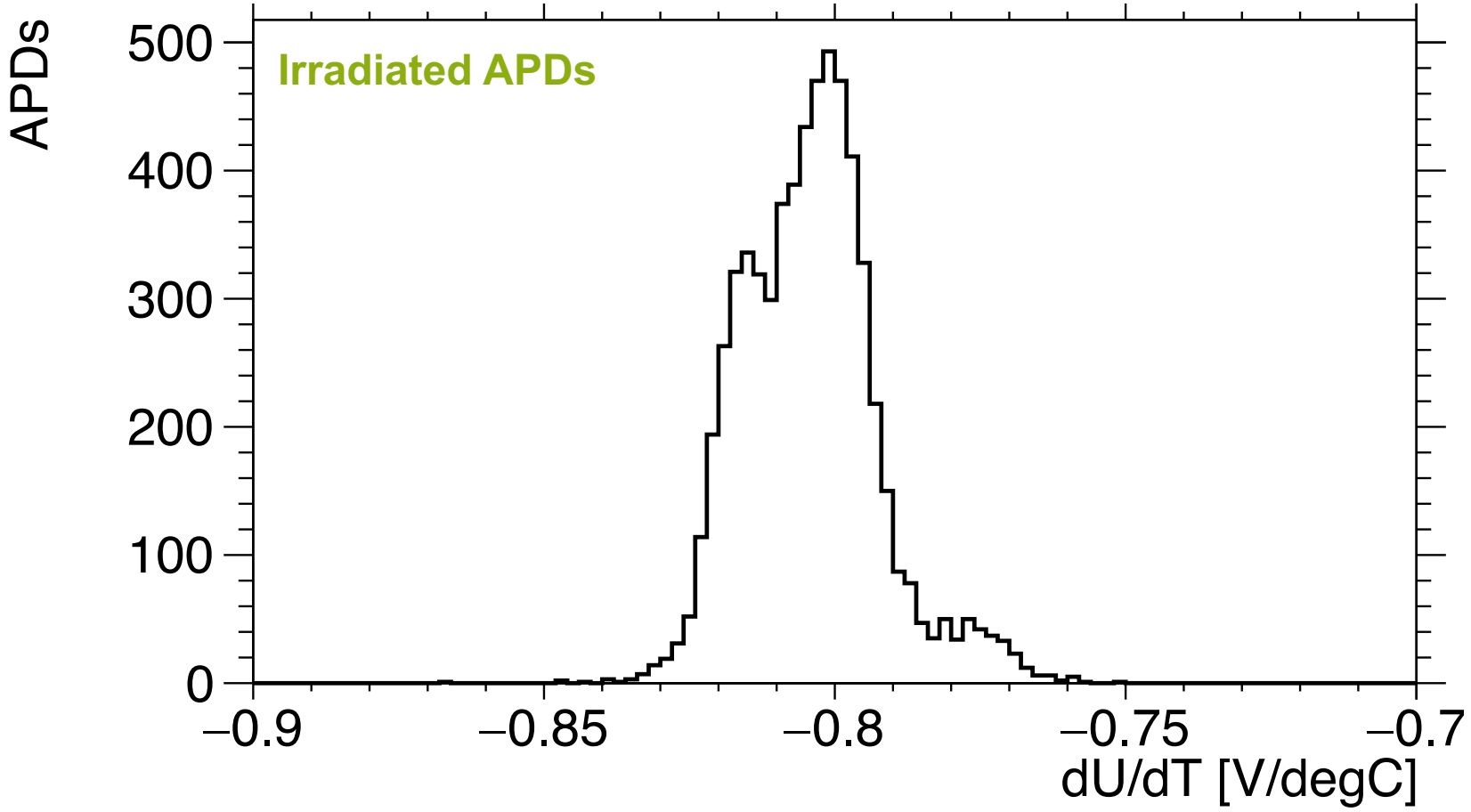
Bias Voltage for M = 200



Comparison of $20°C$ and $-25°C$

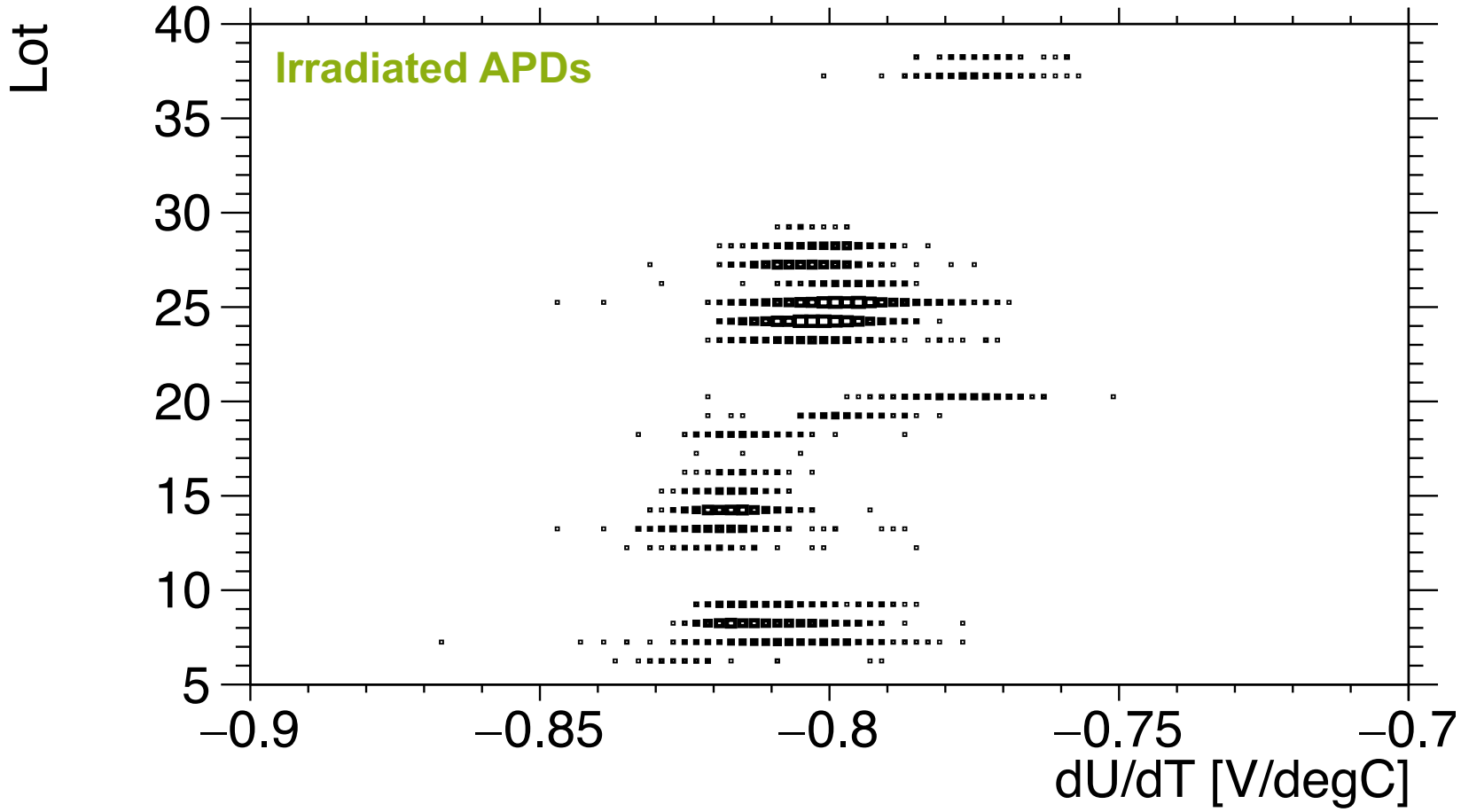


Comparison of $20°C$ and $-25°C$



- $dU/dT = -0.8\ \mathrm{V}/°\mathrm{C}$ corresponds to $dM/dT = 12.5/°\mathrm{C}$

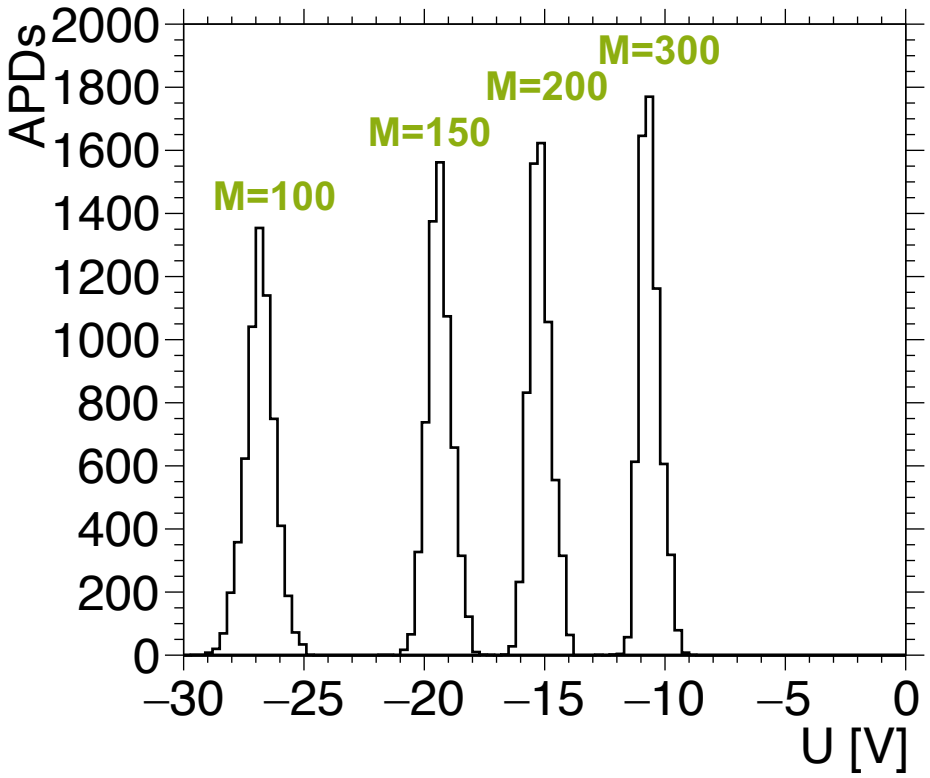
Comparison of $20°C$ and $-25°C$



- $dU/dT = -0.8\ \mathrm{V}/°\mathrm{C}$ corresponds to $dM/dT = 12.5/°\mathrm{C}$

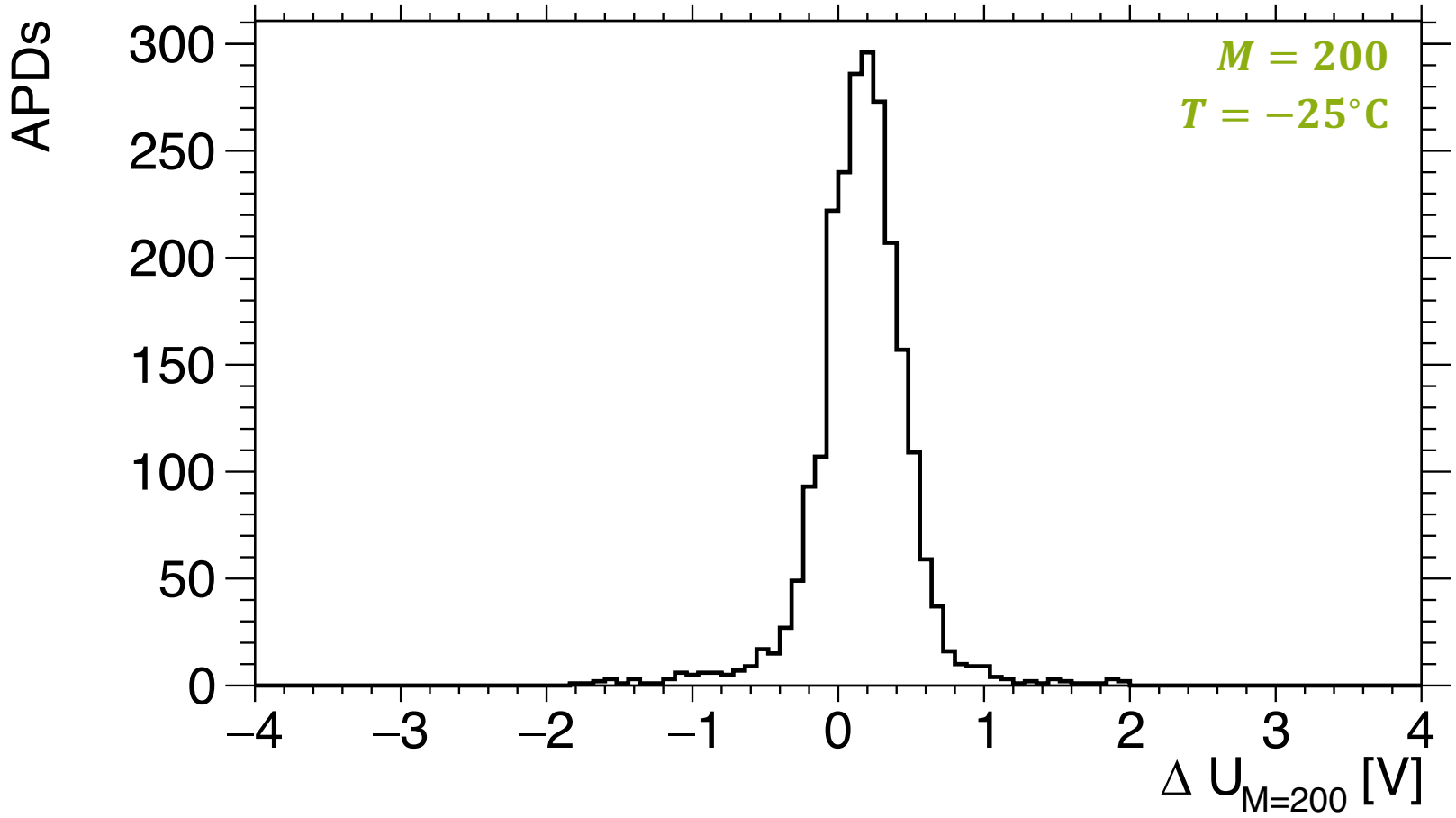
Small enough dark current

- Gain may have to be increased to compensate for radiation damage in crystals
- Dark current must not get too big during operation
- Figure of Merit: Distance from current threshold
  - $I_{dark} \leq 10\mu A$
- $M = 300$: At least 8 V remain

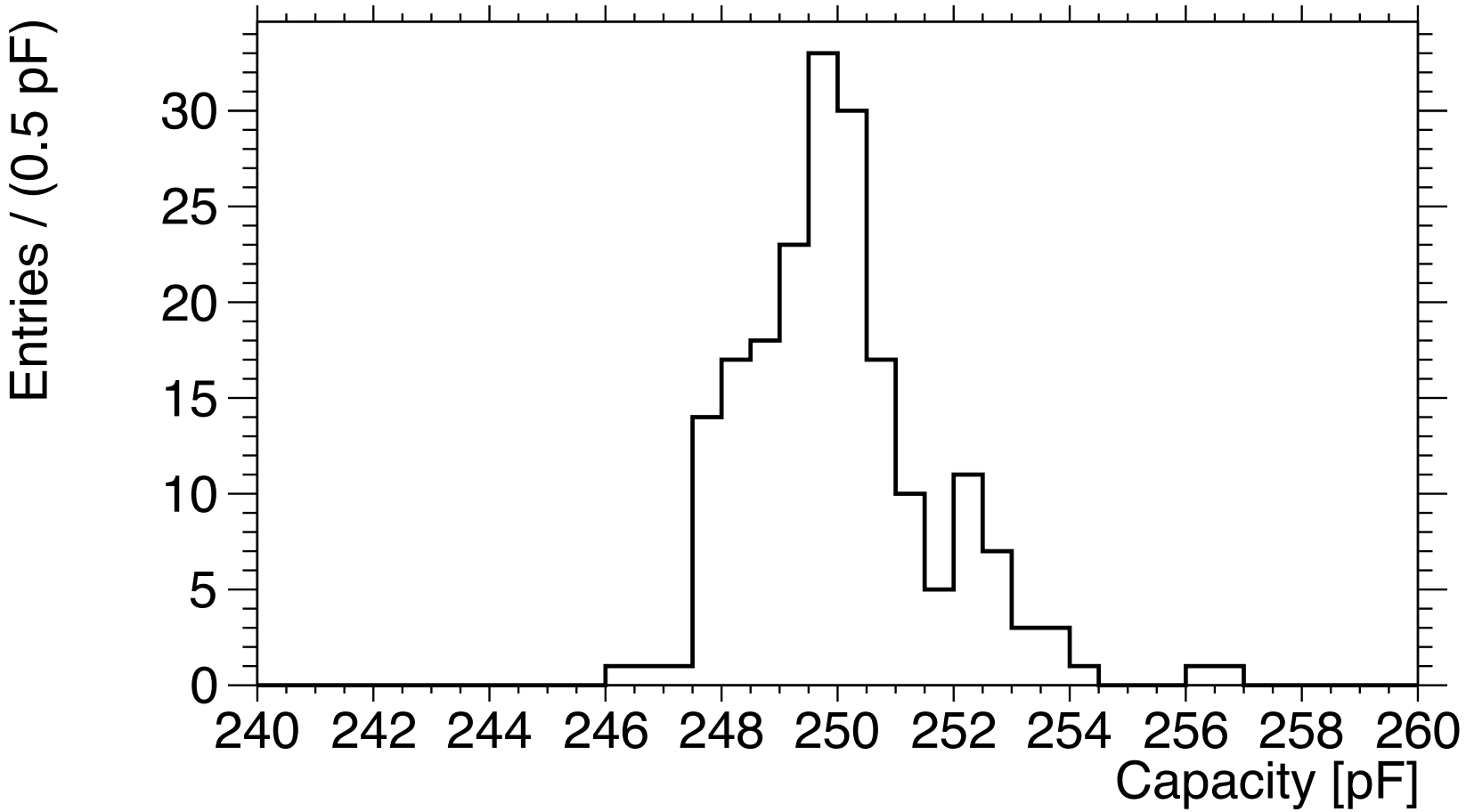


Irradiated APDs, $T = -25°C$

APDs before and after irradiation



Capacity Measurements at GSI



Matching for Forward Endcap EMC:

- **8 APDs supplied by a common voltage supply**
  - APDs need similar bias voltages to reach at operating gain
  - Similar shape of gain curve even at higher gain (to compensate radiation damage)
  - Voltage adjustment boards allow some variation within groups

- **Only use APDs with $U_{10\mu A} - U_{M=200} > 14$ V for forward endcap**

- **Spread: Squared difference in bias voltages for M=200 and M=300**
  - $\mathbf{S} = \frac{1}{n-1} \sum_{i,j=0;i<j}^{n-1} \left(\left(U_{i,200} - U_{j,200} \right)^2 + \left(U_{i,300} - U_{j,300} \right)^2 \right)$

Matching for Forward Endcap EMC:

- **Create groups of APDs by pairing APDs, then pairing pairs, …**
  - Average bias voltage and spread calculated for every pair
  - Repeat procedure to make groups of four from two pairs, repeat for groups of eight
  - Calculate spread using average voltage of pair

- **Sort list of groups by Spread**
- **Use first groups in List for production**
  - Later groups will improve as more APDs are screened
  - Global optimization not feasible without full sample

Summary:

- **Screening at Bochum running smoothly**
  - Screened 6180 APDs before irradiation
  - Screened 6600 APDs after irradiation (pool for matching)
    - ~2300 APDs were screened in Bochum before and after irradiation
    - ~4300 remaining irradiated APDs were screened before irradiation at GSI
  - 580 APDs / week on average
- **Characteristics of APDs match expected values**
- **No APDs rejected after irradiation**
- **Continuous Matching is ready**
  - Successfully matched APDs for first submodules
  - APDs for further production can be supplied