The Quality Assurance test setup for DUNE SiPMs characterization

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TIPP conference 2023

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Università degli Studi di Ferrara

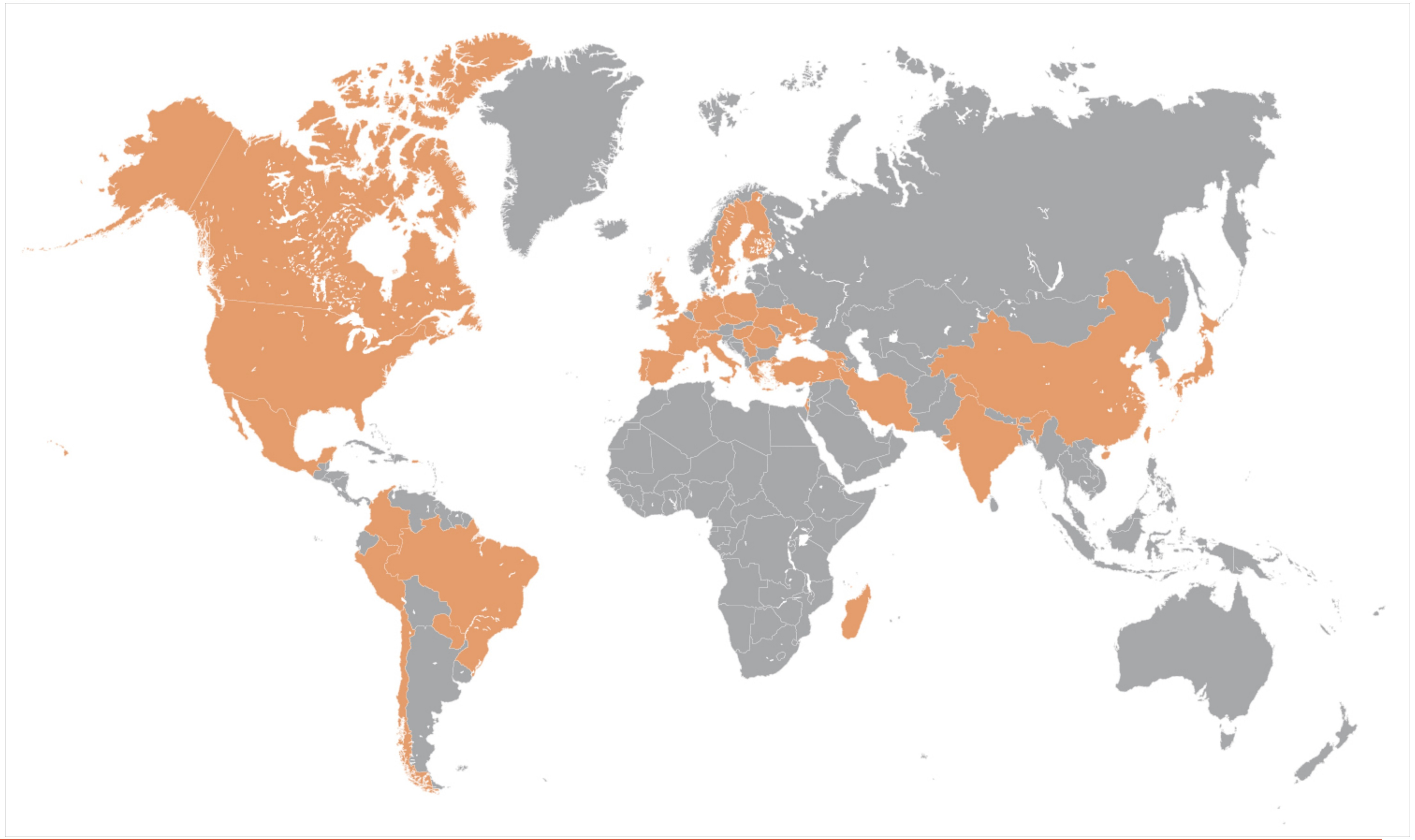
INFN Istituto Nazionale di Fisica Nucleare

Contents

The DUNE Collaboration

- 1440 collaborators
- 37 countries
- 208 institutions including CERN

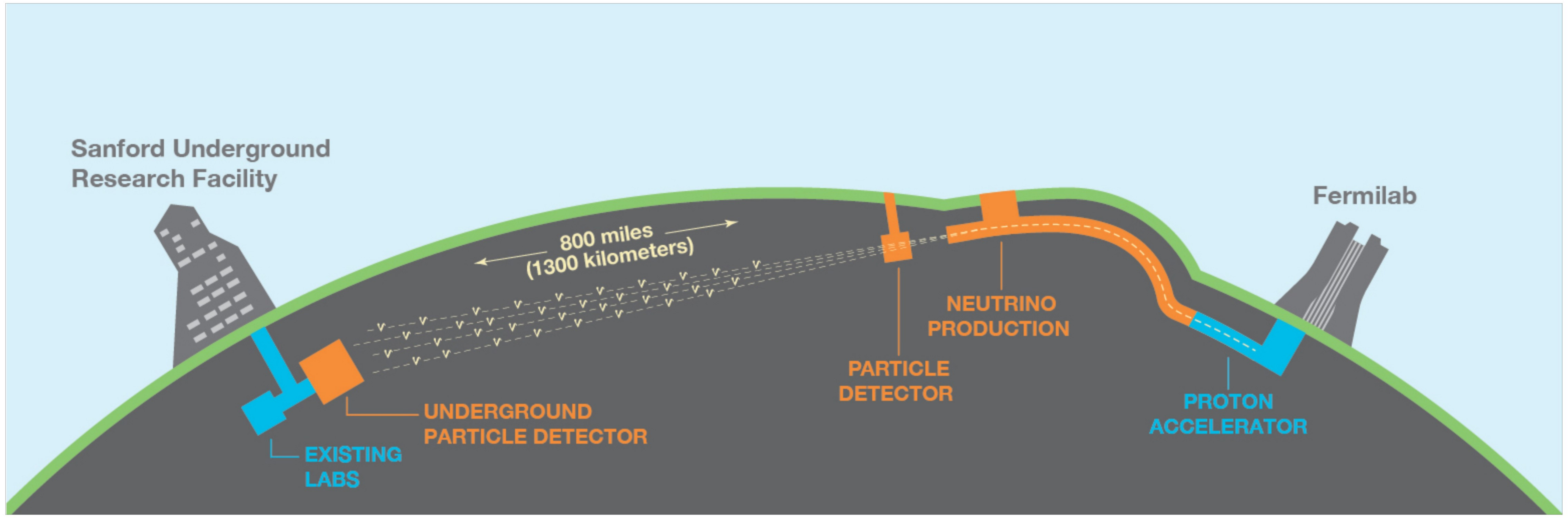
DUNE Collaboration meeting
FNAL May 2023



Deep Underground Neutrino Experiment (DUNE)

DUNE, main physics goals:

- Precise measurement of neutrino oscillation parameters (mass ordering and δ_{CP}) *EPJC 80 (2020) 978*
- Study supernova low energy neutrino *EPJC 81 (2021) 322*
- Physics beyond SM *EPJC 801(2021) 423*



- New neutrino **beam facility** @ FNAL (LBNF)
- **Near detectors** @ FNAL→ measure unoscillated neutrino spectrum & flux constraints
- **Far detectors** @SURF→oscillated neutrino studies

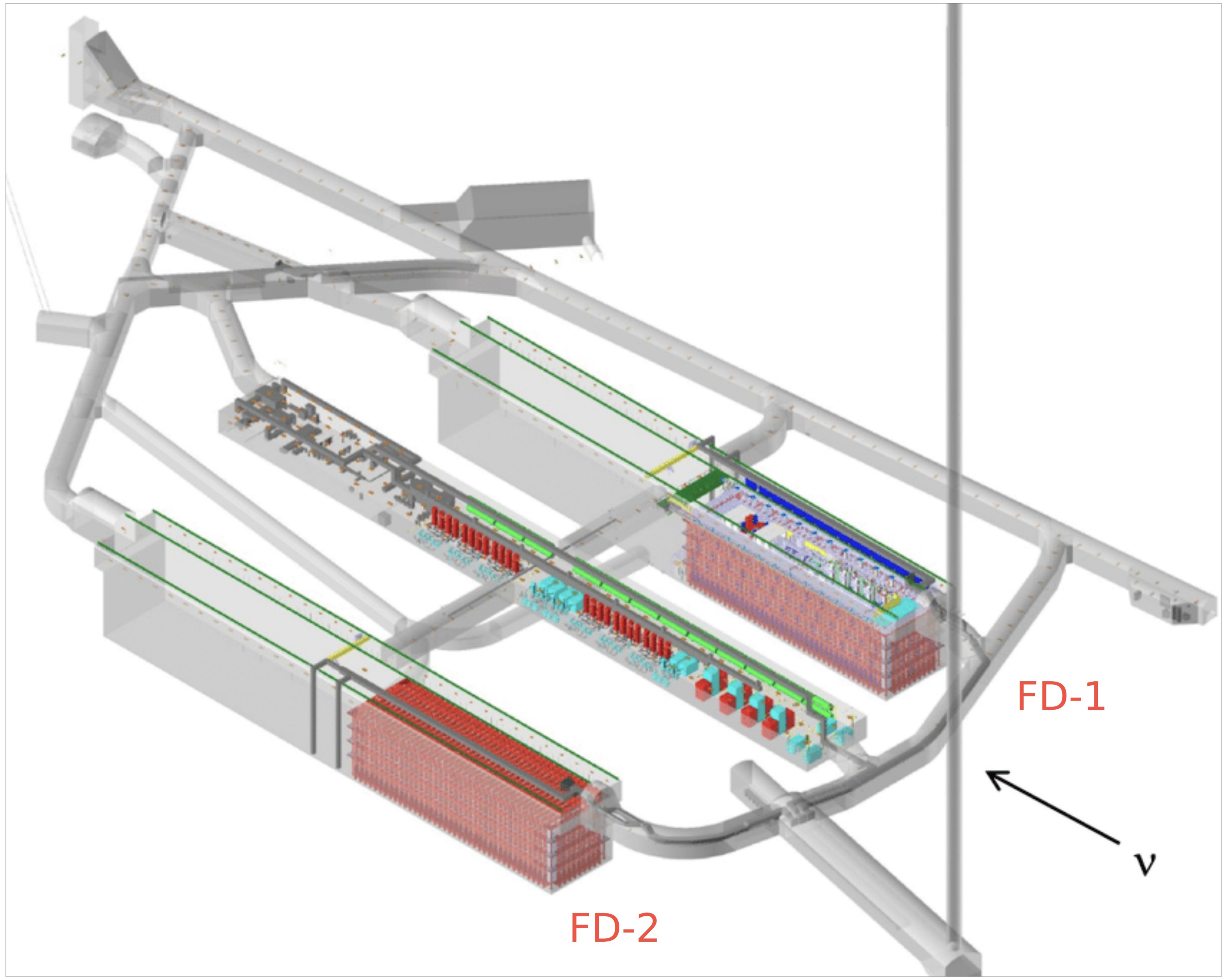
Instrum 5 (2021) 31
JINST 15 (2020) T08008
JINST 15 (2020) T08010

DUNE Far Detector

- Located ~1300km from the production site ~1.48 km underground @ Sanford Underground Research Facility in Lead, South Dakota (USA)

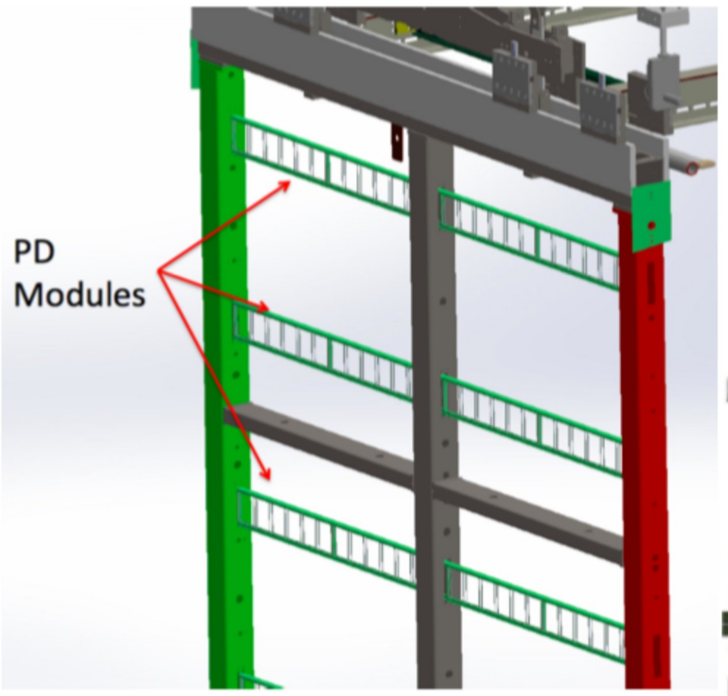
- Four 17-kt LAr TPC modules
- Phase I:
  - **FD-1 horizontal drift (HD)**
  - FD-2 vertical drift (VD)

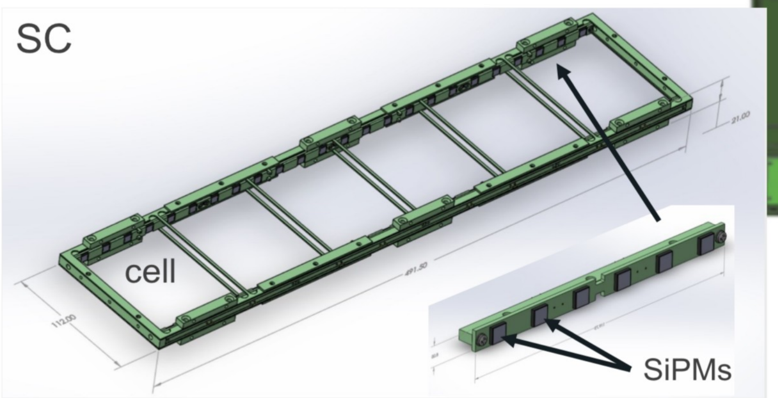
- ProtoDUNEs
  - Construction and operation of 1 kton-scale prototypes at CERN, critical to demonstrate viability of technology

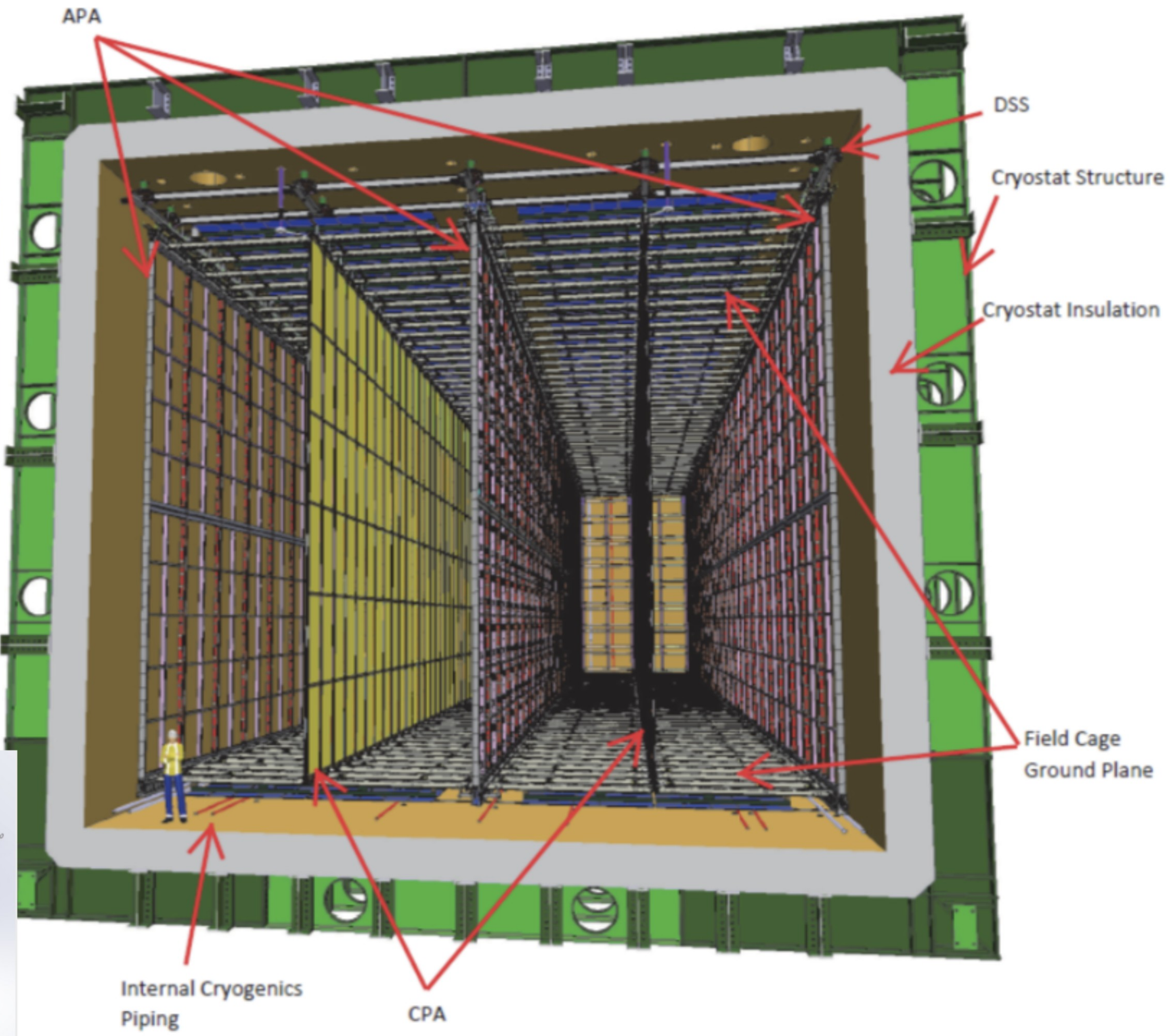


FD-1 HD

- 4 drift volumes. Anode-cathode drift distance 3.5 m with E = 500 V/cm.
- 150 Anode Plane Assemblies (APAs).
  Each APA consists of three wire planes for charge collection and
  10 Photon Detection modules.
- 10 (2m x 12cm) PD modules/APA
  each composed by 4 X-ARAPUCA supercells.
- A supercell consists of
  six 10×10 cm^2 pTP-coated dichroic filters,
  a 60 cm WLS bar and 48 SiPMs.
- ~300k SiPMs in total.







See Optimization of the Efficiency of the DUNE FD1 and FD2 photon detection system (C. Cattadori)

The DUNE photosensors

- SiPMs
  - A matrix of single-photon avalanche photodiodes operating in reverse bias above breakdown voltage V_{bd}
  - Robust, w/ high sensitivity and dynamic range, immune to B field, w/ reduced cost/size

- Specifications for DUNE:
  - Quantum efficiency > 35% for 430 nm light @ 87 K
  - Dimensions compatible w/ ARAPUCA design
  - SiPM + FEE w/ dynamic range 1-2000 photons, even for events far from the ARAPUCA
  - Dark count Rate (DCR) subdominant wrt noise from ^{39}Ar
  - Cross-talk (CT) and after-pulse (AP) < 15%
  - Durability (> 10 y) and cryoreliability (resistant to multiple cool-downs)
  - Few µs recovery time

See Photon Detection System in the far detector module of the DUNE experiment talk (F. Di Capua)

The DUNE photosensors

- **SiPMs:**

-Several models tested from two vendors: HPK, FBK; ~50% of FD-1 SIPMs each

-models of choice HPK S16517 (6x6mm^2, 75um pitch) & FBK NUV-HD-CryoTT (6x6mm^2, 33um pitch)

-Mounted in arrays with 6 SiPMs each in common cathode configuration w/ independent anode

See Cryogenic SiPMs for the DUNE experiment talk (A. Falcone)

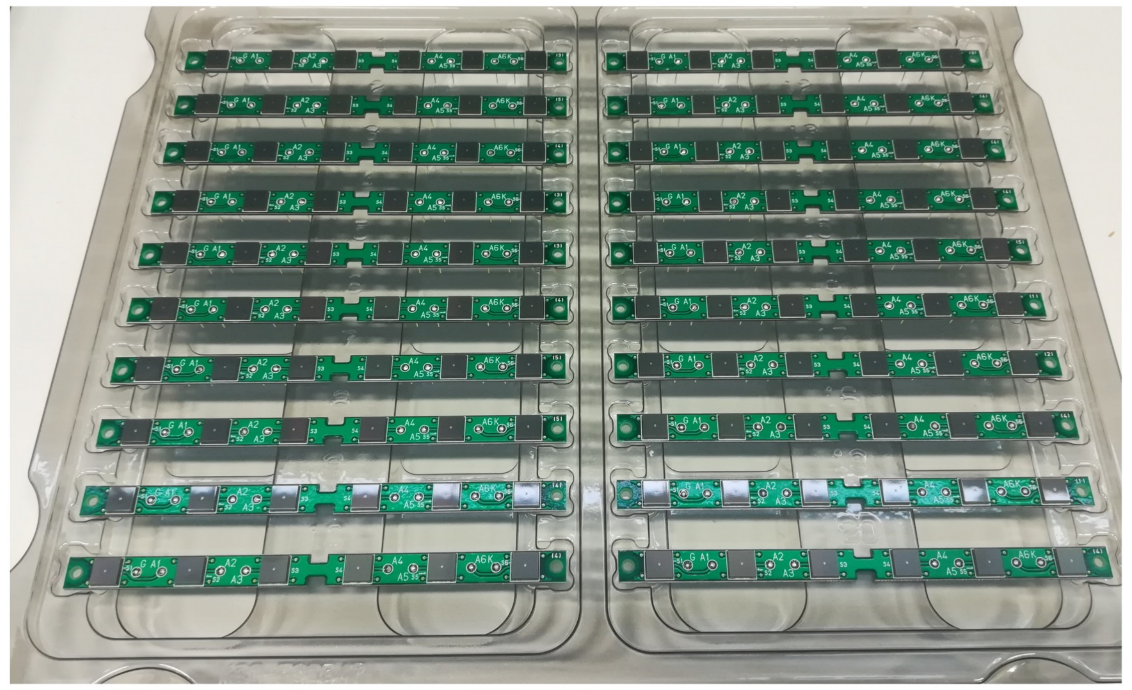
- ~100 SiPMs during selection process
- ~8k SiPM for ProtoDUNE-HD tested in 2022
- ~300k SiPM for DUNE FD-1 under test (2023 – …)

- **Measurements to be performed:**

-IV curves in FWD and REV bias @ room temperature and LN2 temperature

-Thermal stresses resilience

-DCR @ LN2 temperature



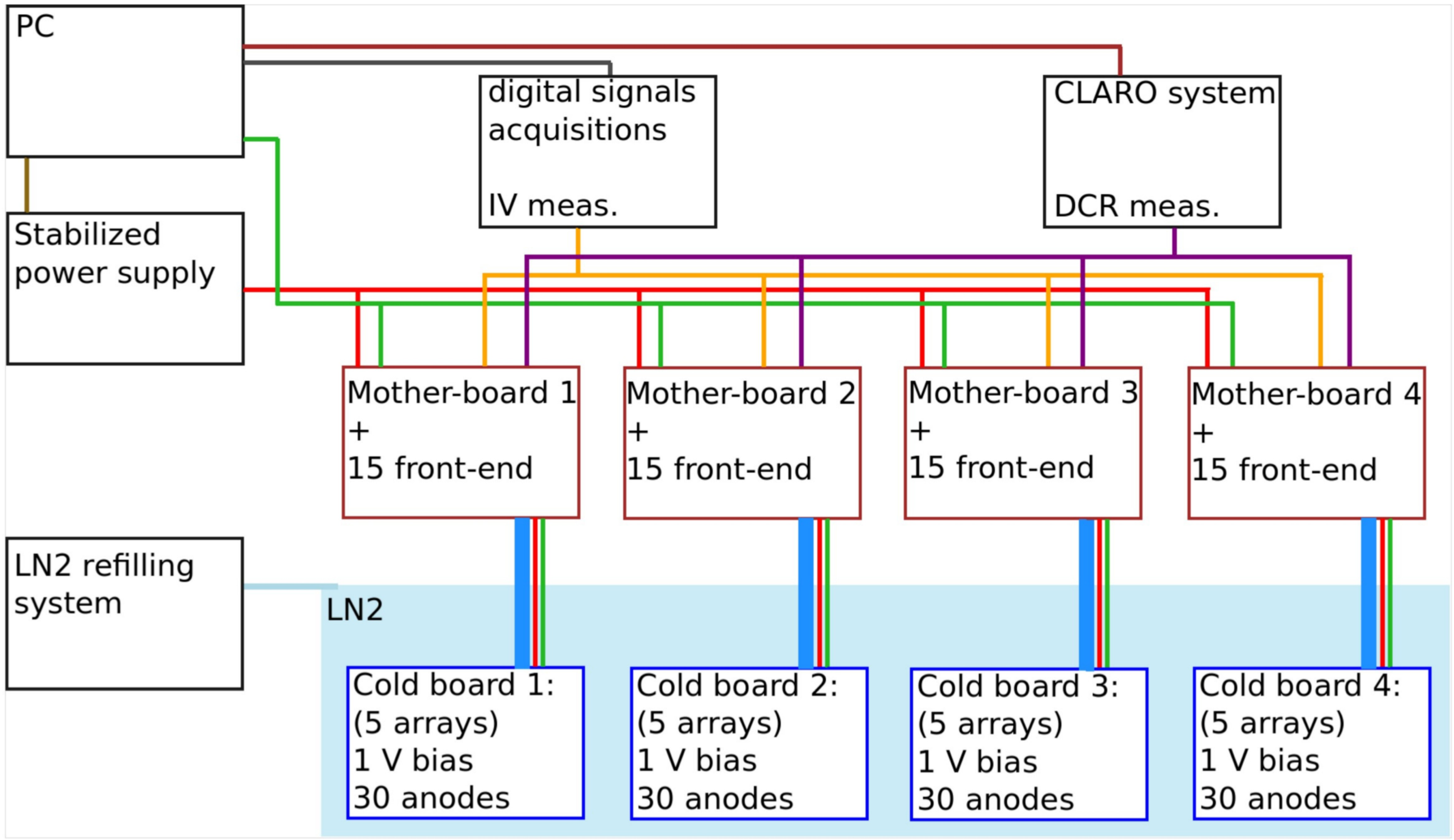
HPK tray example

The Quality Assurance Test Setup

- Cryogenic Apparatus for Continuous Tests Upon SiPM (CACTUS)
  - Custom setup developed by INFN and Universities of Ferrara and Bologna
  - Massive tests on the entire FD-1 SiPMs production to assess:
    - SiPM identity
    - Failure/mortality rate
    - Quality assurance
  - Custom electronics developed by Ferrara & Bologna
  - Capability: test 120 SiPM (20 arrays) in a single session of complete characterization (lasting < 6 h)
  - 5 different test sites: Bologna, Ferrara, Granada, Milano Bicocca (operating), Prague (from October)
    - Test rate ≥ 2400 SiPM/month @ each site

The Quality Assurance Test Setup

- Scheme of the setup, featuring modularity, automation, easy replication



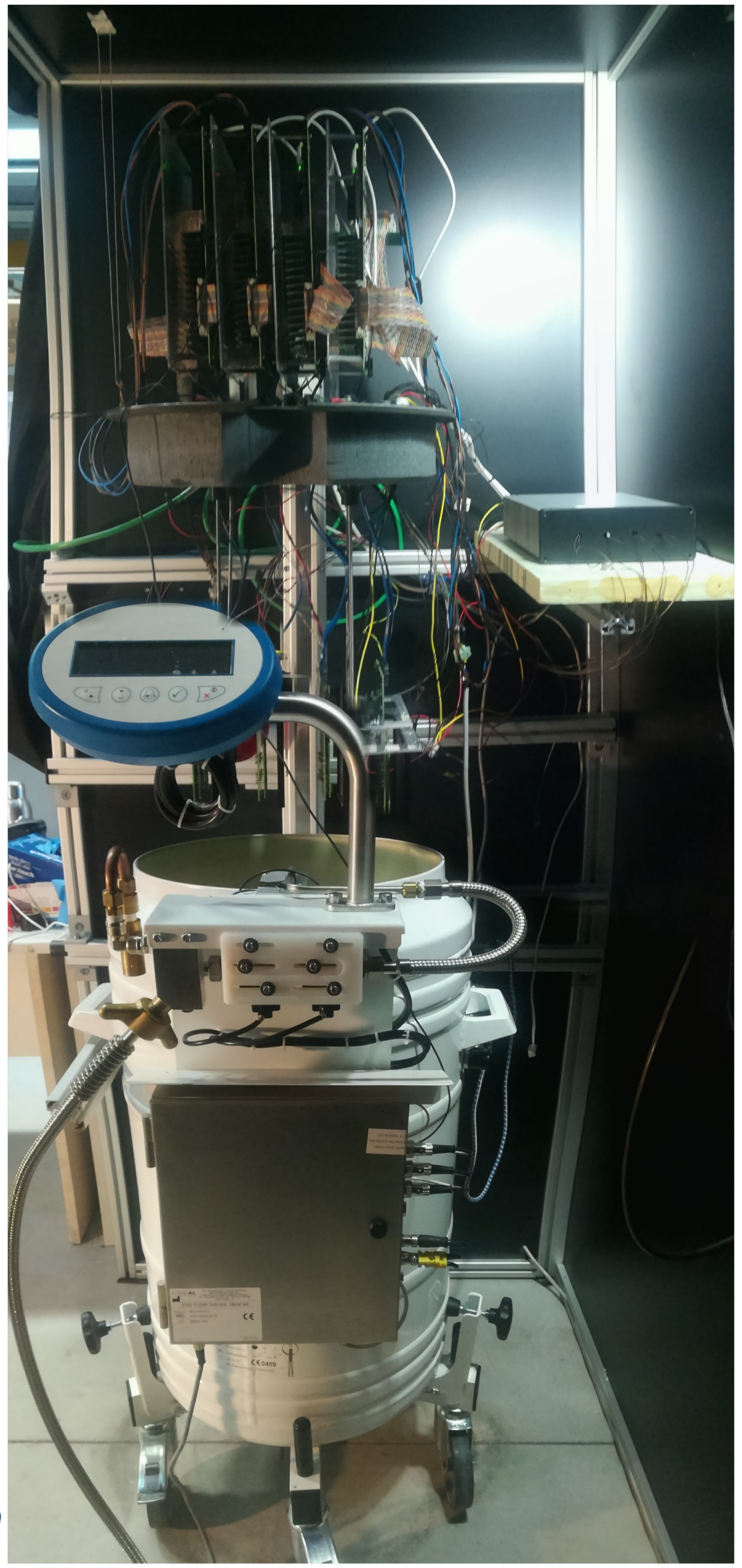
Features:

- 55 liters liquid Nitrogen auto refilling system;
- 120 parallel channels;
- Voltage range [-210;210]V;
- Voltage precision 10mV;
- DC acquisition mode;
- Measured current range 10nA-3mA;
- AC acquisition mode;
- Programmable threshold DCR from 30ke e to 16Me;
- 60cm long translator stage.

The Quality Assurance Test Setup

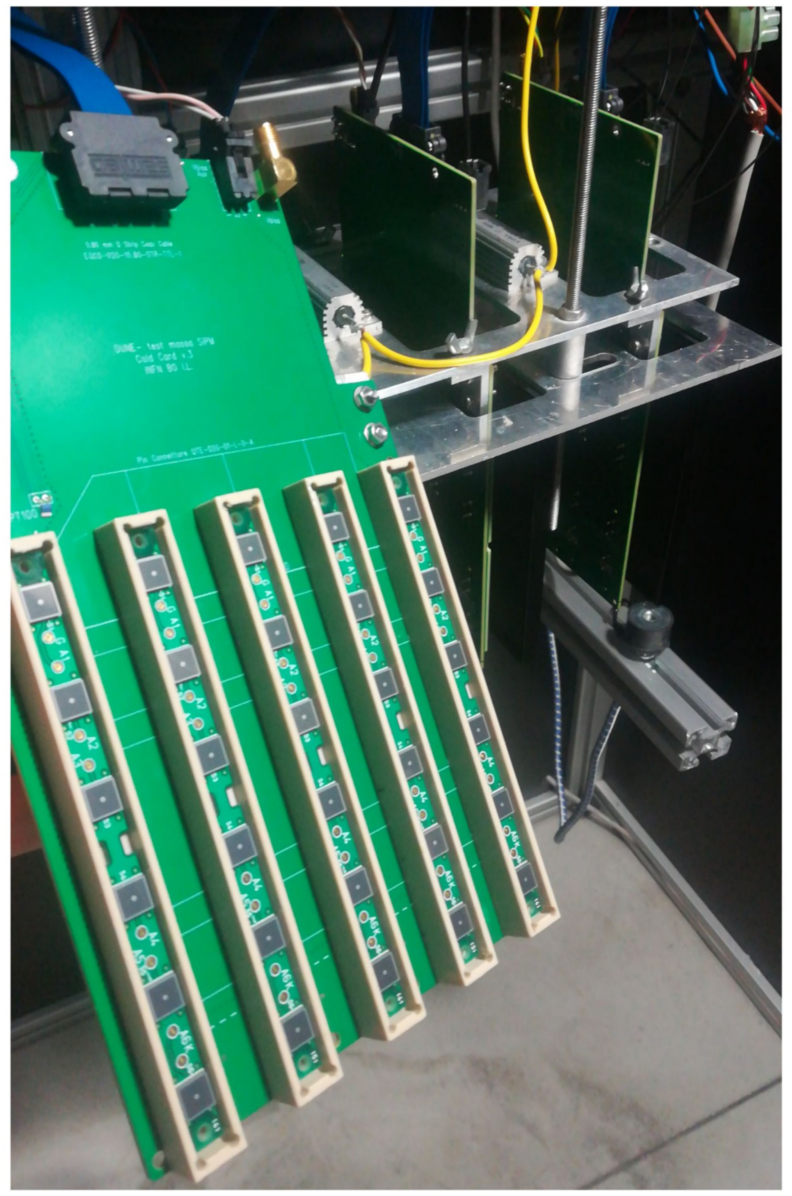
- **Motherboards + front-end cards (@ warm):**
  - 4 motherboards/system
  - 15 front-end cards/motherboard
  - 120 independent channels
  - Current measure/digitalization
  - Signals acquisition

Motherboards + front-end



Ferrara system

- **Cold boards (@LN2)**
  - 4 boards/system
  - 5 arrays/board
  - 120 SiPM
  - Temperature monitor
  - Bias voltage



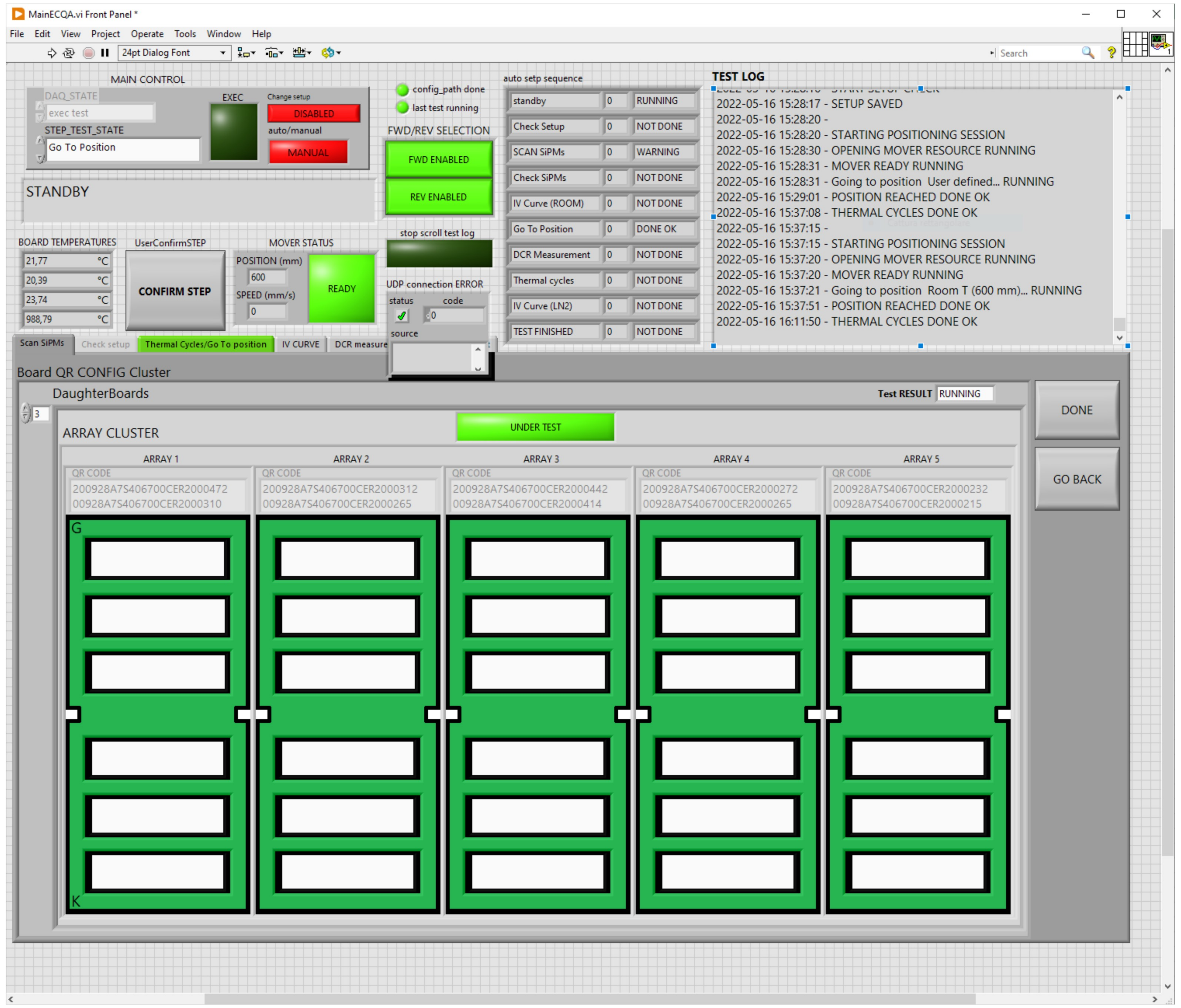
Cold boards

- **Python software** for run-time acquisition and analysis:

Quality assurance procedure

Unique Labview interface → perform each step of the QA tests

A panel shows the final report and if the SiPMs are in specs



Labview interface

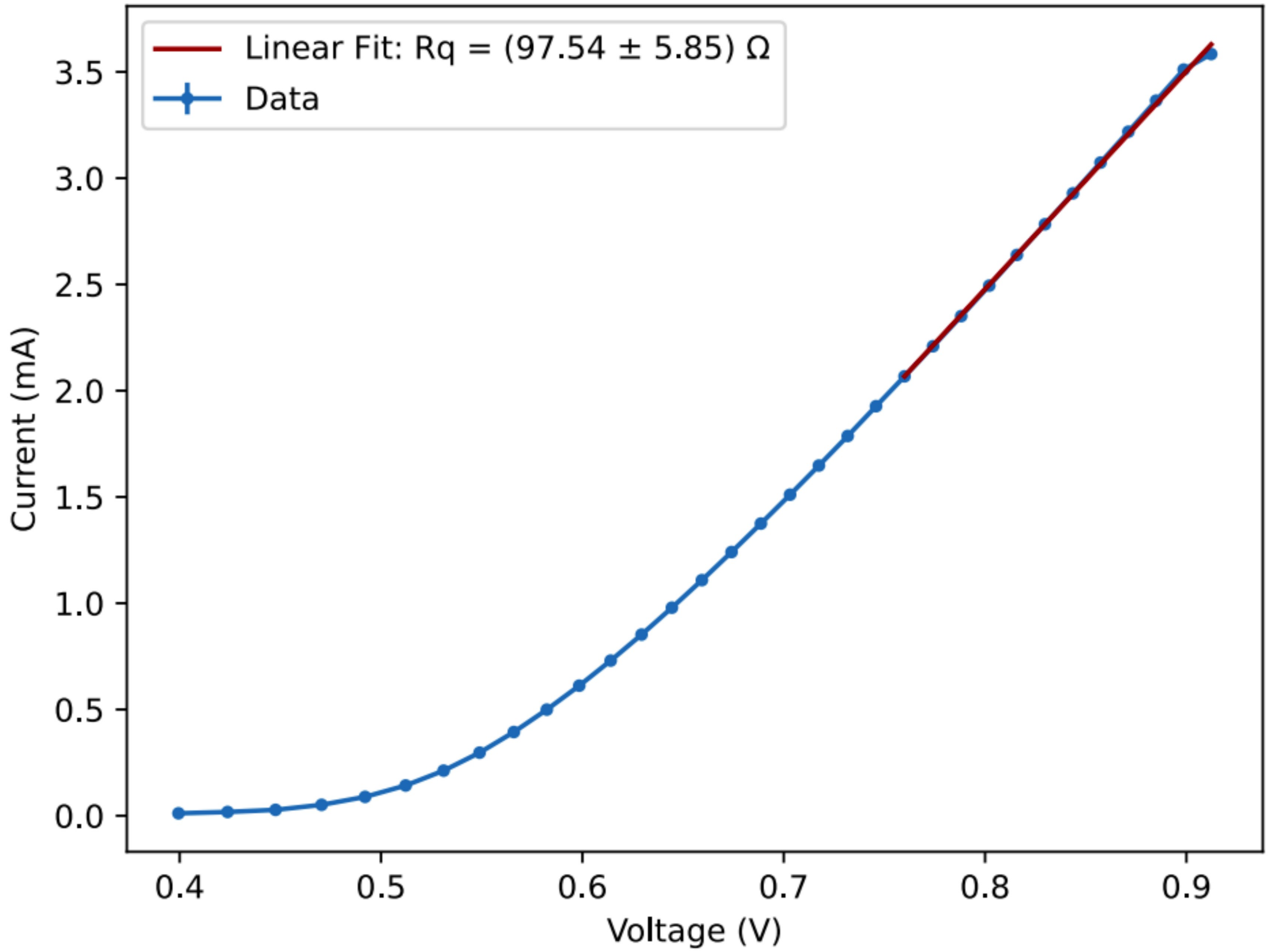
Steps & parameters:

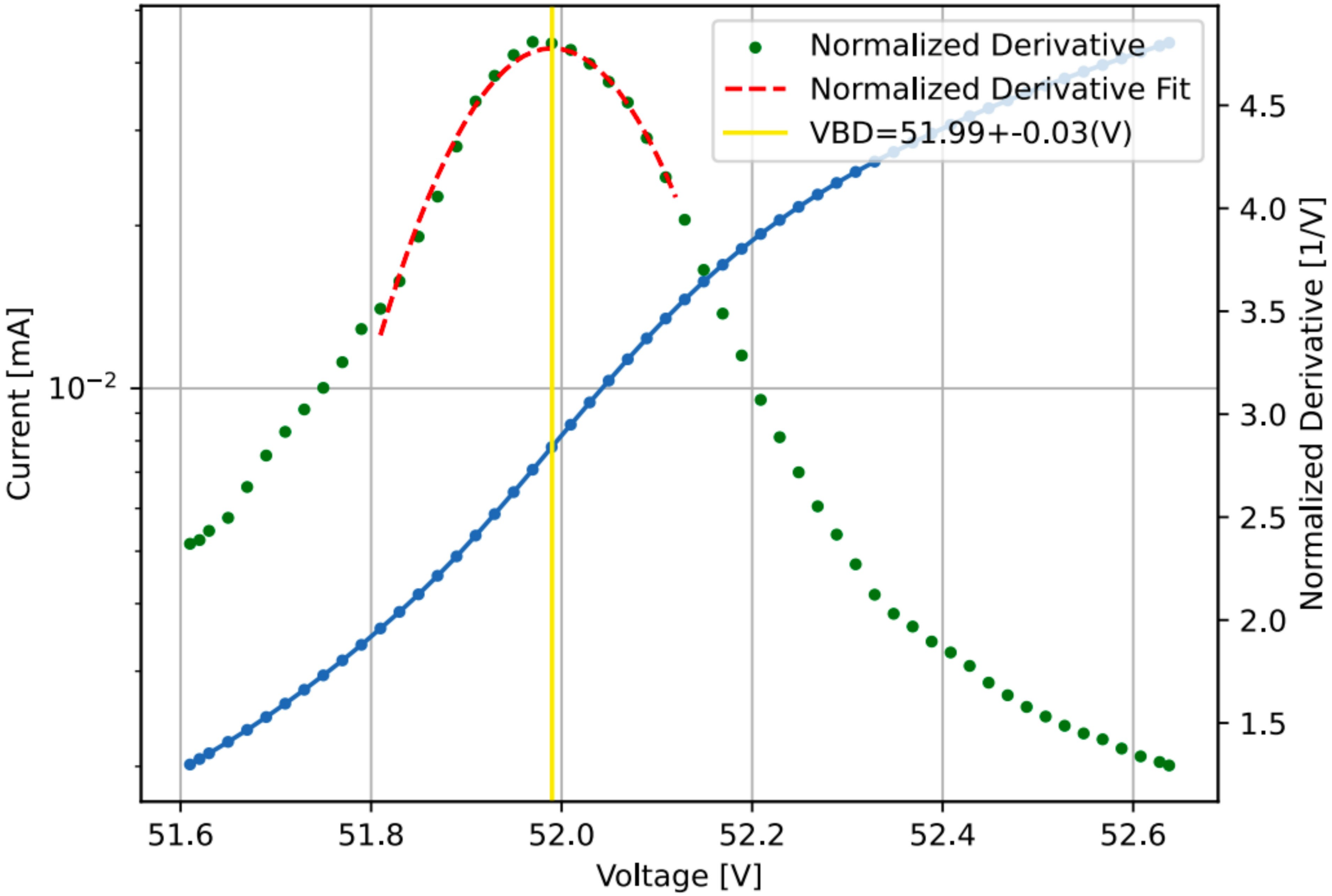
- IV@roomT (10min)→(FW) R_q^{RT} + (REV) V_{bd}^{RT};
- First LN2 immersion (20min);
- IV@LN2T (10min)→(FW) $R_q^{LN2T\_pre}$ + (REV) $V_{bd}^{LN2T\_pre}$;
- 2 thermal cycles (1.5h);
- IV@LN2T (10min)→(FW) $R_q^{LN2T\_post}$ +(REV) $V_{bd}^{LN2T\_post}$;
- Extended IV@LN2T (10min)→ dark current
- DCR@LN2 T (5min)→global-DCR total dark signals, AP, CT + bursts;

Single measurements examples

- Room temperature IV:

	Voltage range (V)	Current range	Step (mV)	Fit
Forward curve	0-1	[0.1-3.5]mA	20	linear
Reverse curve	51-53	[10-500]nA	15	parabolic

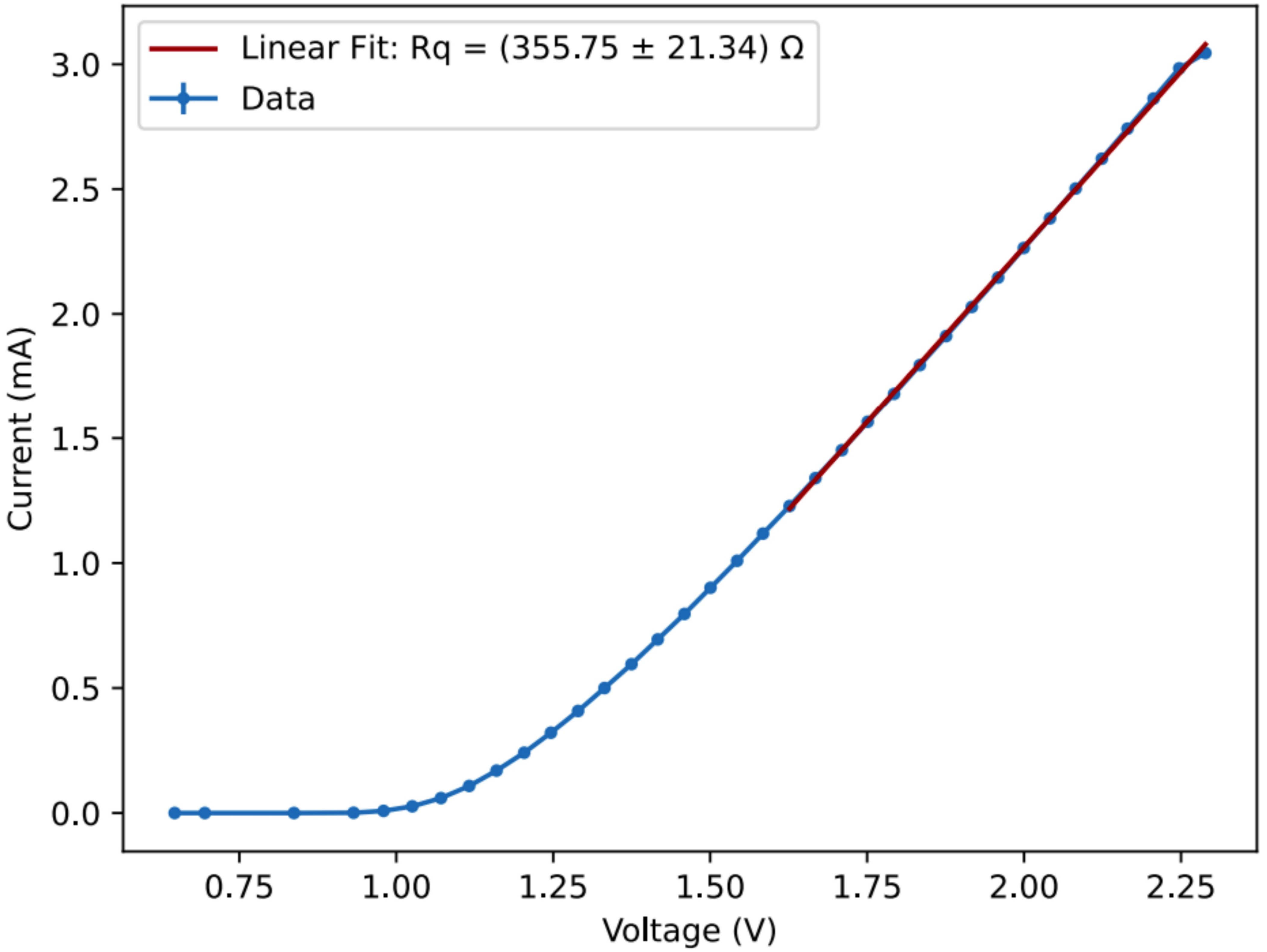


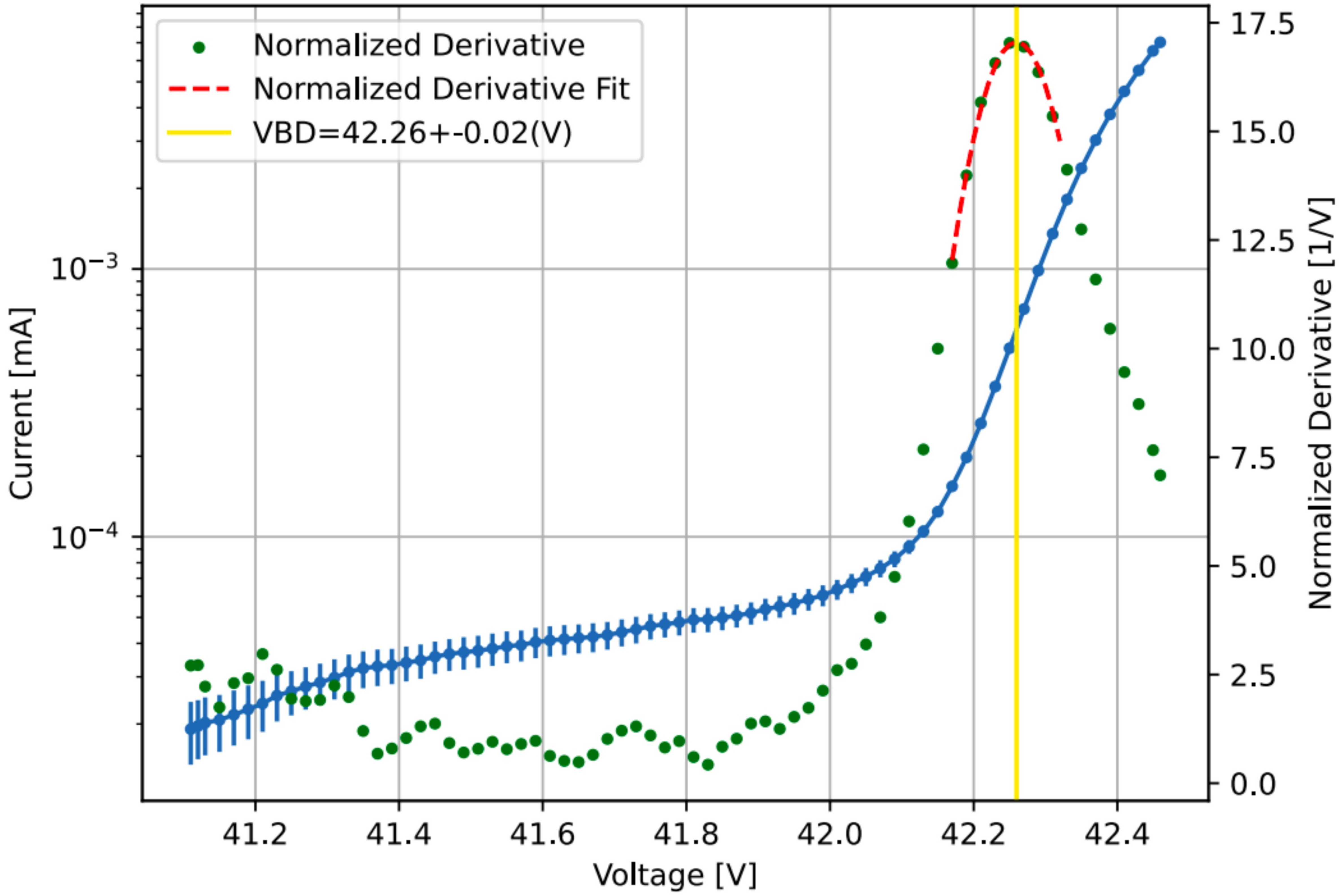


Single measurements examples

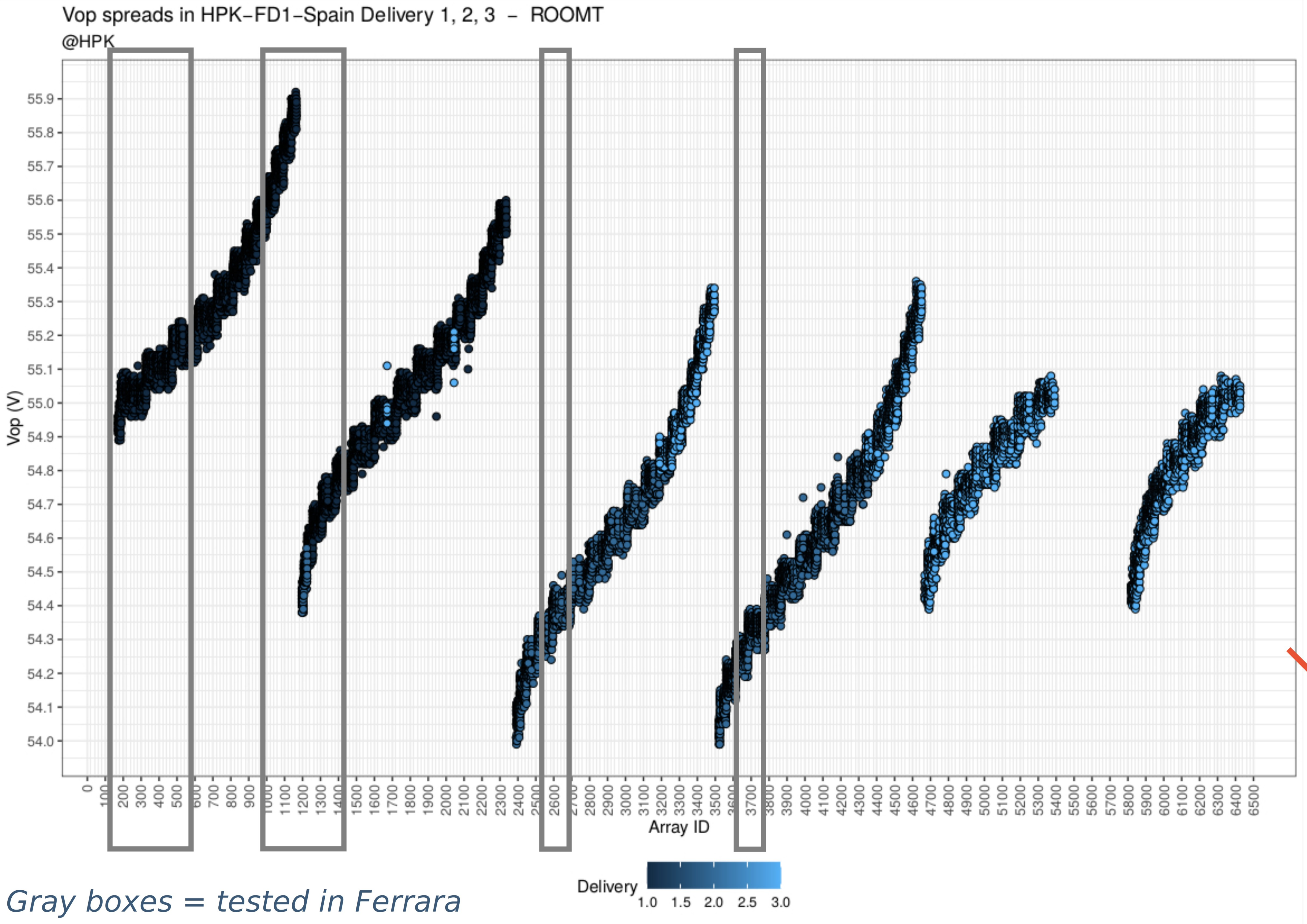
- LN2 temperature IV:

	Voltage range (V)	Current range	Step (mV)	Fit
Forward curve	0-2.3	[0.1-3.5]mA	20	linear
Reverse curve	41-43	[10-500]nA	15	parabolic





Results: data from HPK

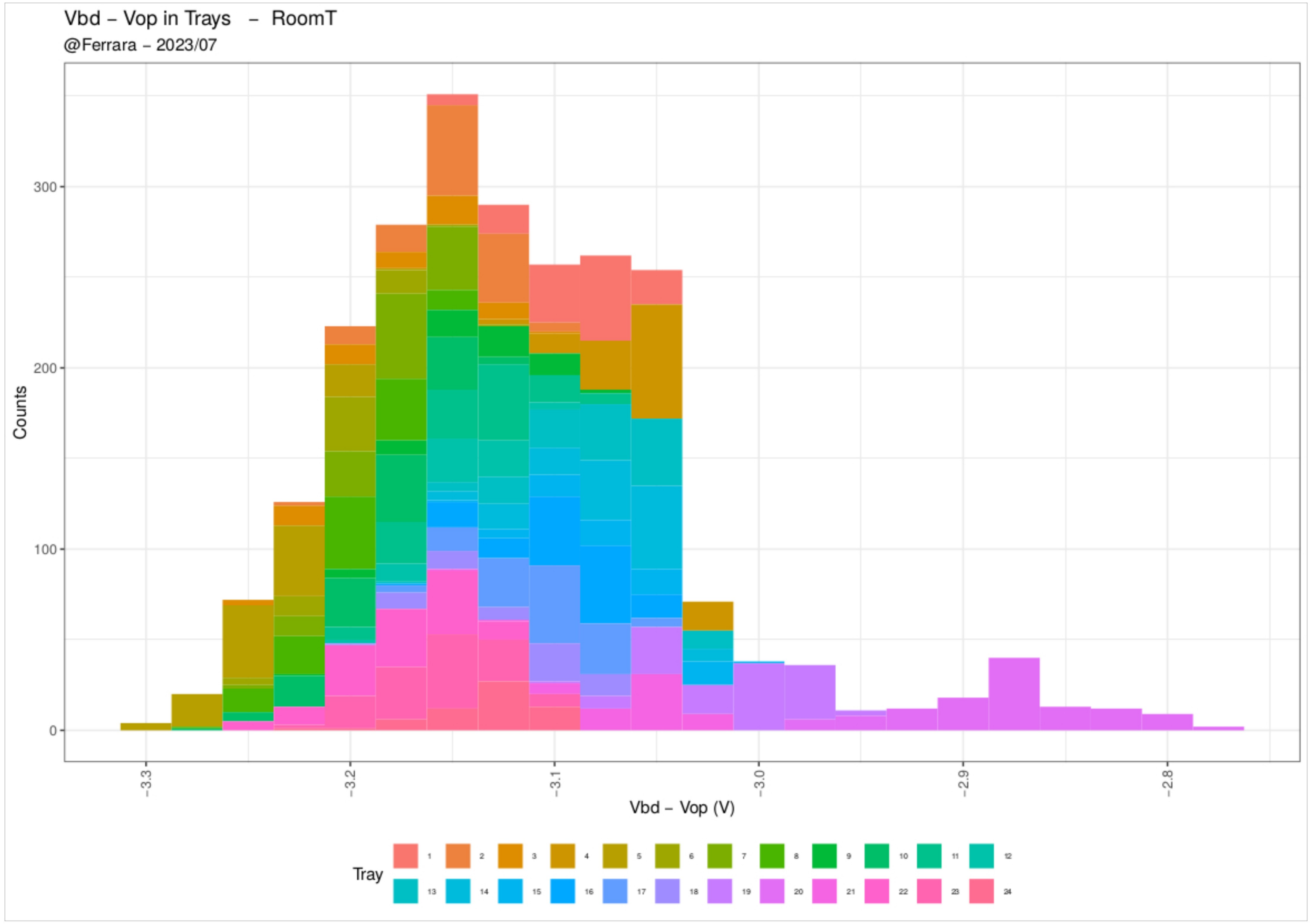


Gray boxes = tested in Ferrara

- HPK provided us Voltage of operation (V_{op}) for each sensor
- $V_{op} = V_{bd} + 3V$
- Behaviour related to manufacturing processes
- Batches shared among test sit es

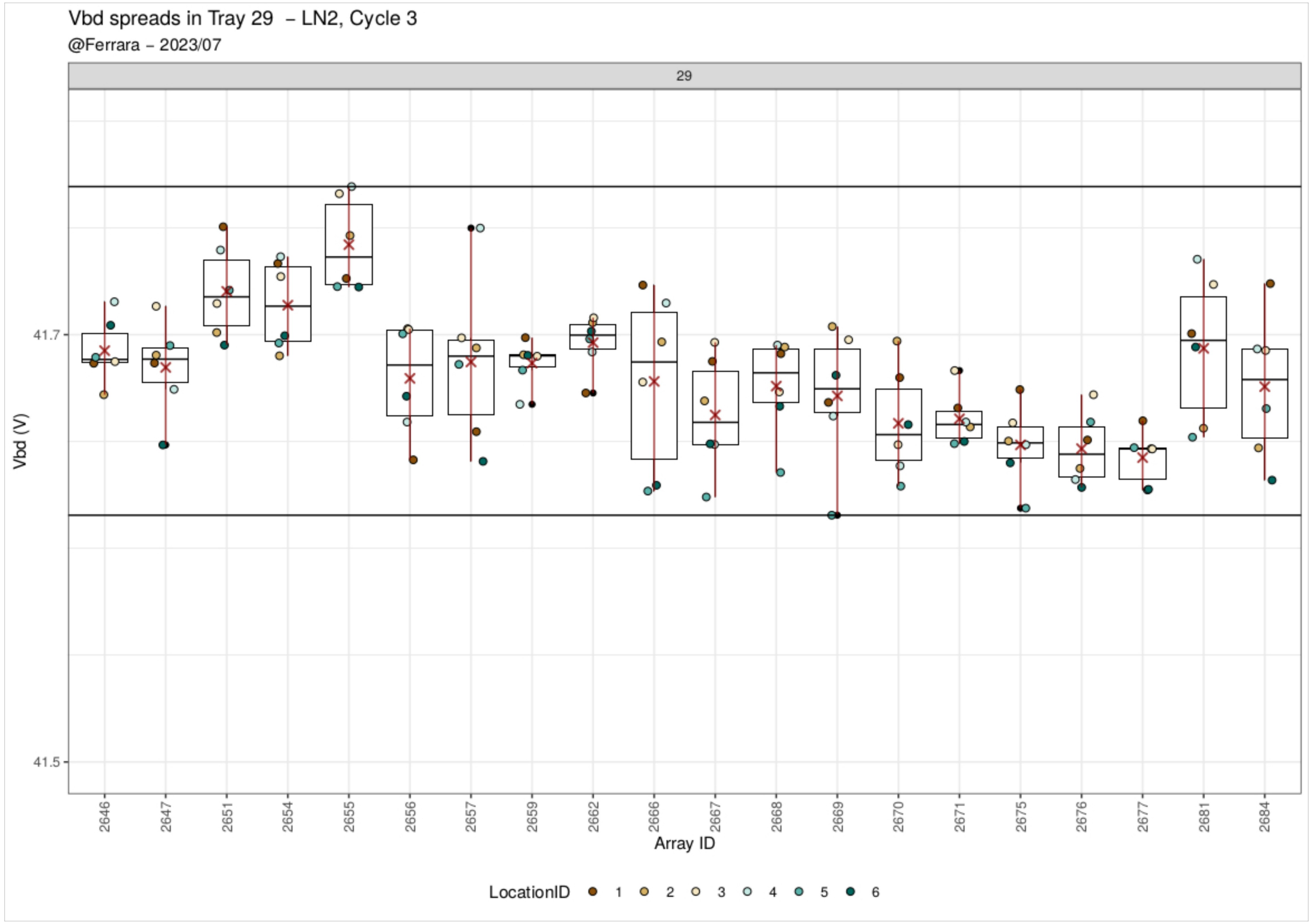
Corresponds to the first 3 delivery ~40k SiPMs ~1.4m²

Results: SiPM check



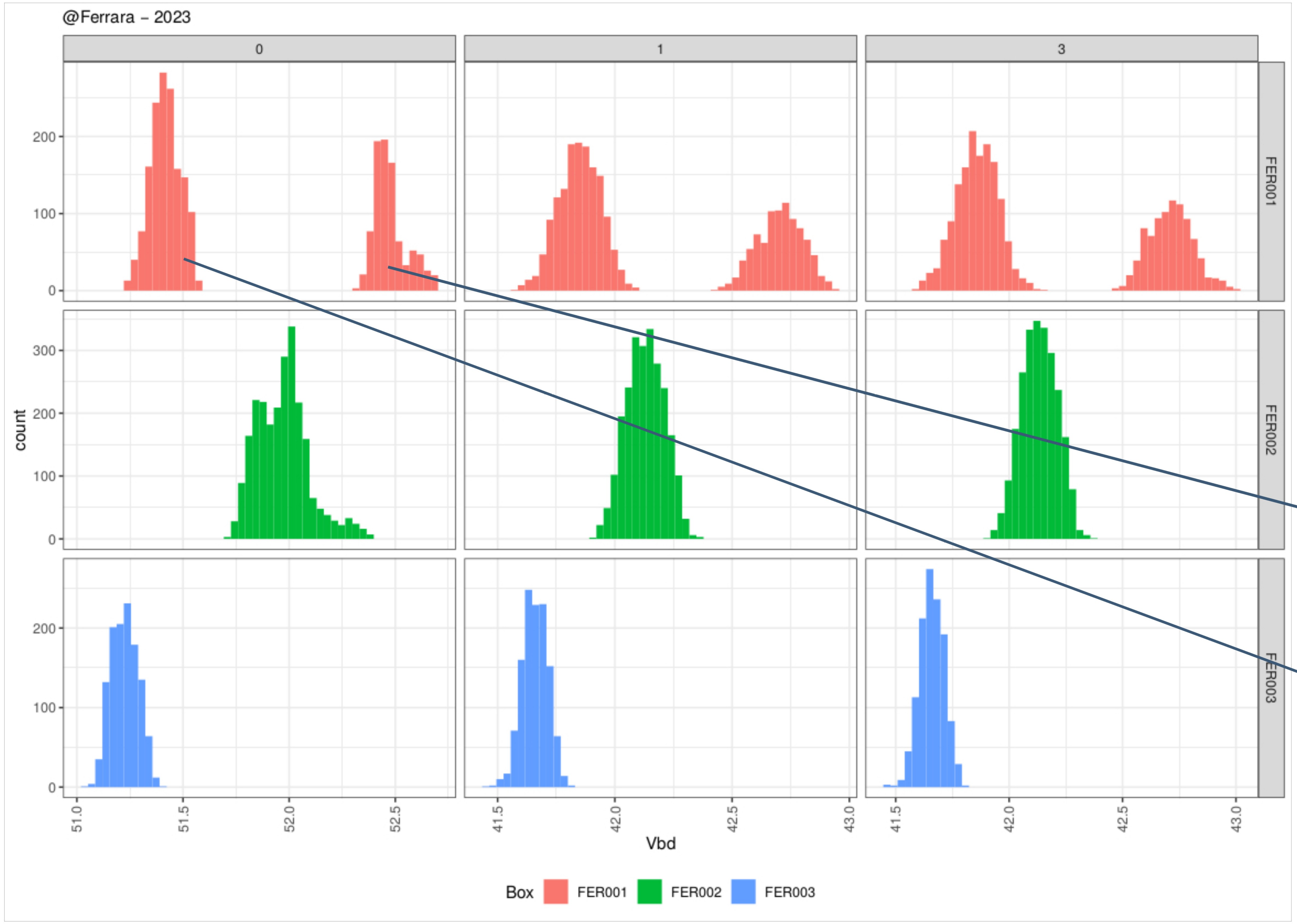
- Compatibility with vendor data has been check at room temperature
- More than 3V because of the difference in temperature from HPK values and our data (thermal coefficient breakdown voltage is ~40mV/K)

Results: V_{bd} @LN2

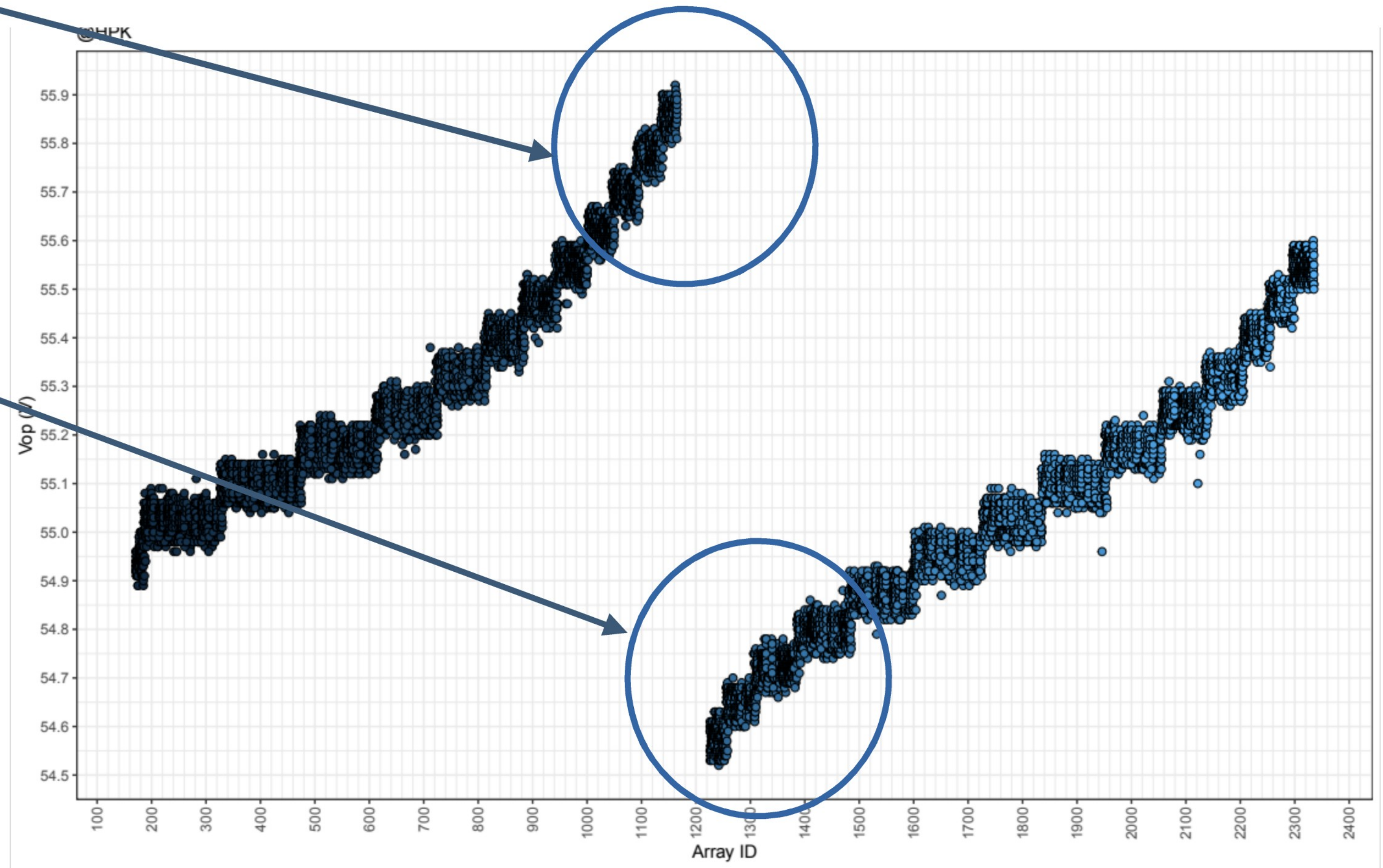


- Example of data for a tray (20 arrays of 6 SiPMs each) @LN2
- Pre-grouped by HPK
- Min-Max<200mV

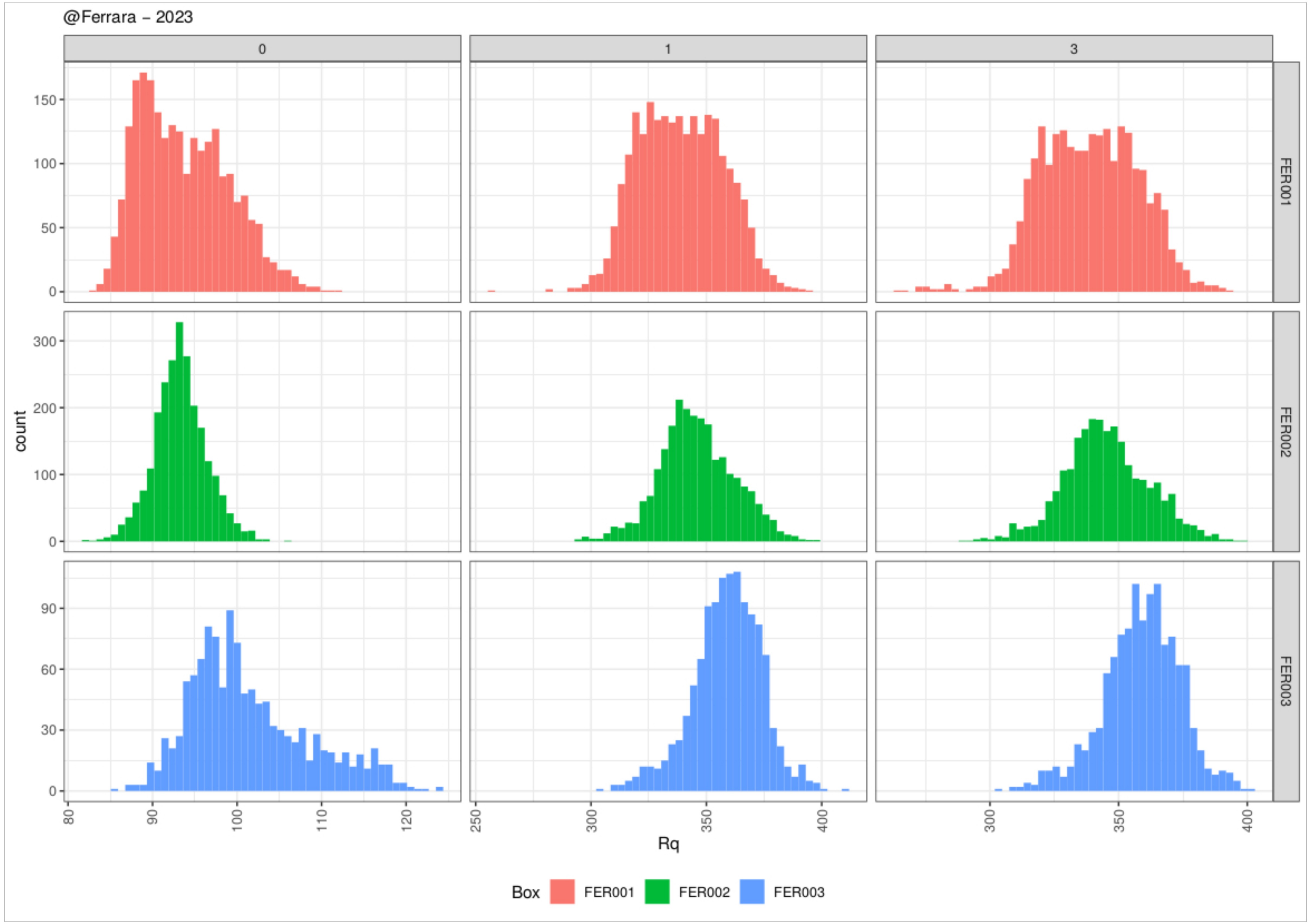
Results: V_{bd}



- Breakdown voltage distribution for batches tested in Ferrara divided by boxes
- SiPMs in specs
- Accordance with thermal coefficient (40mV/K)
- Width of distribution @LN2<200mV for a box
- Behaviour as expected

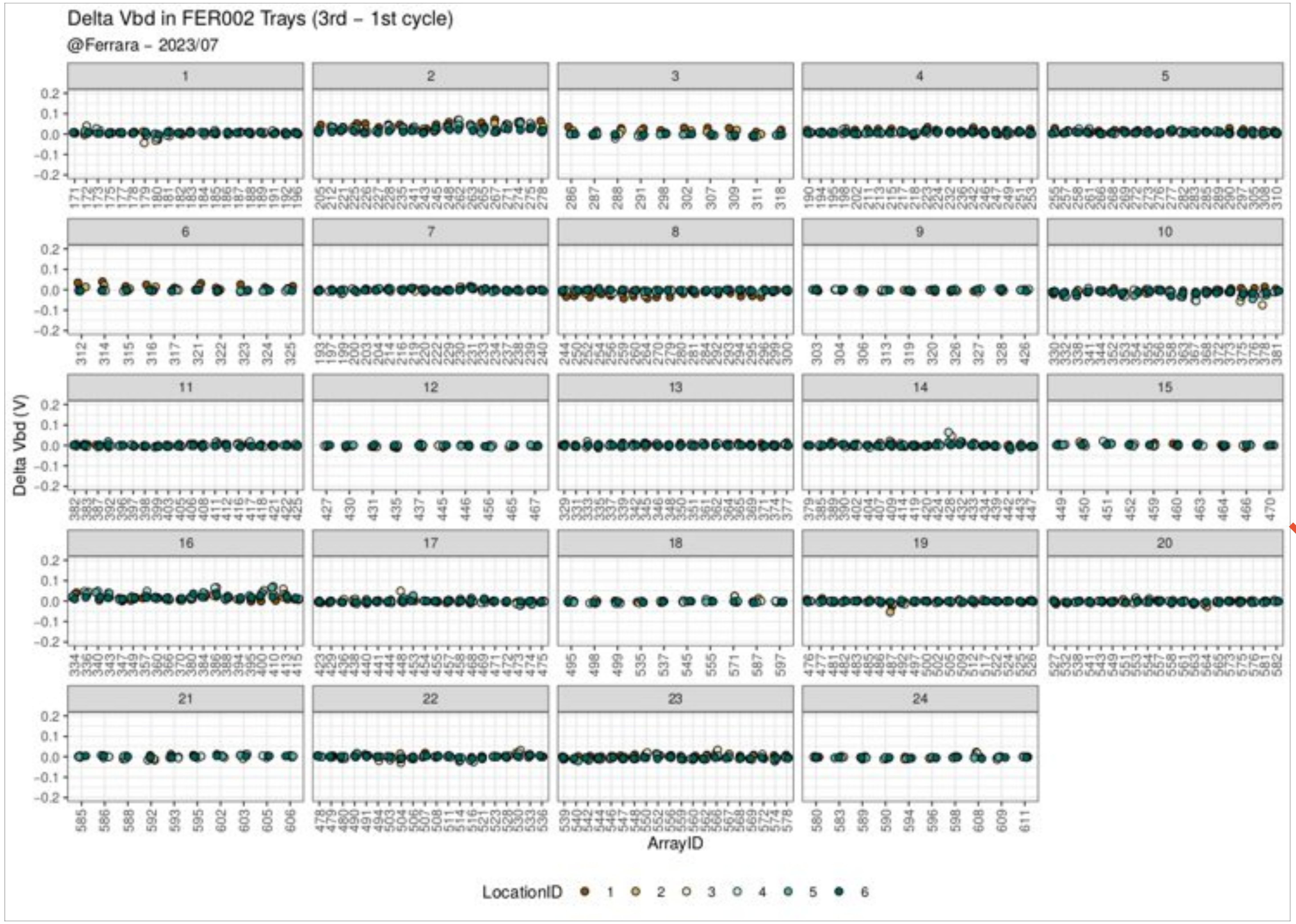


Results: R_q

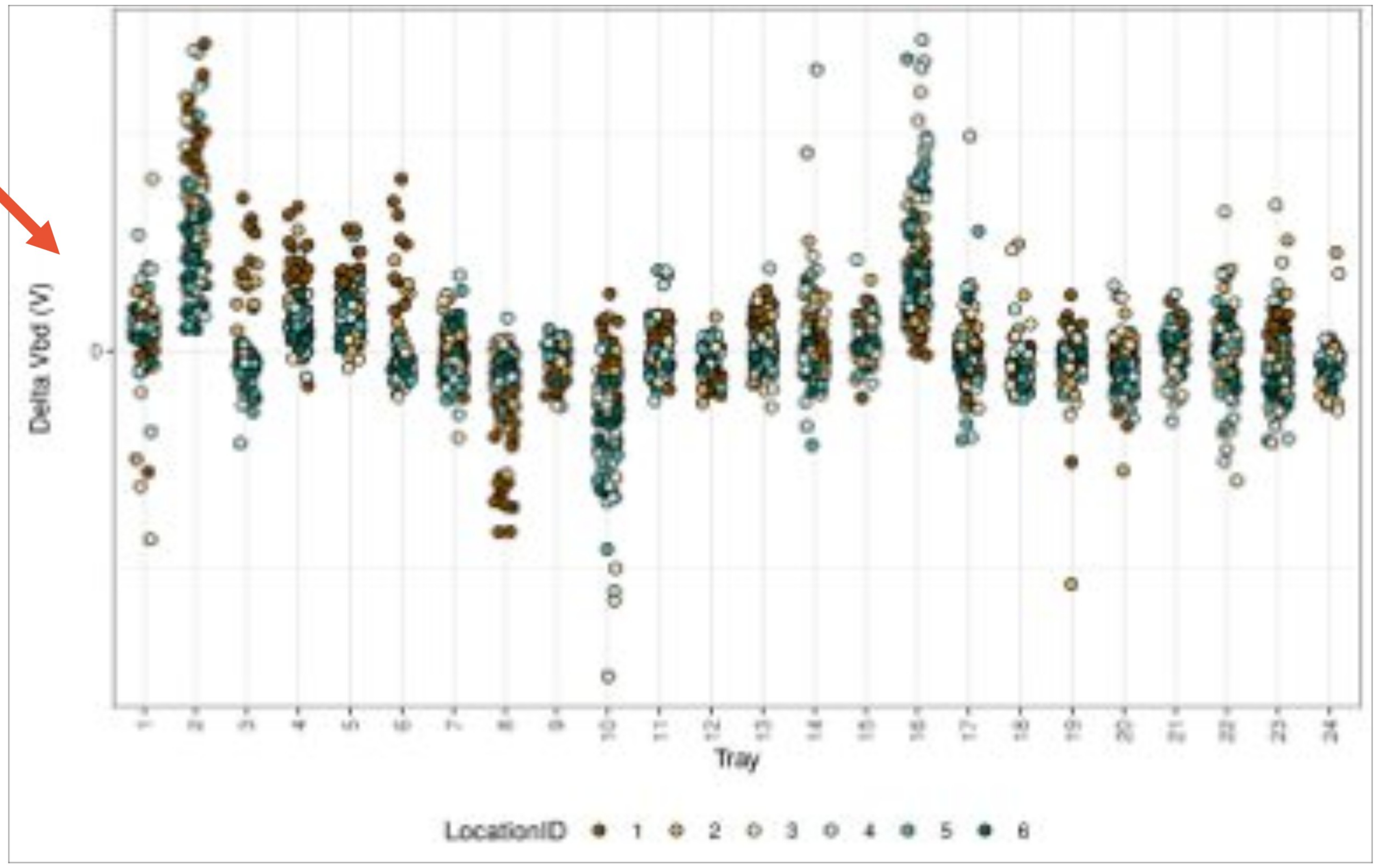


- Quenching resistor distribution for batches tested in Ferrara divided by boxes
- Behaviour as expected from vendor
- SiPMs in specs
- Mean value @ room T:~100Ω
- Mean value @LN2:350Ω
- Accordance with thermal coefficient (~1Ω/K)
- Width of distribution @LN2<50Ω

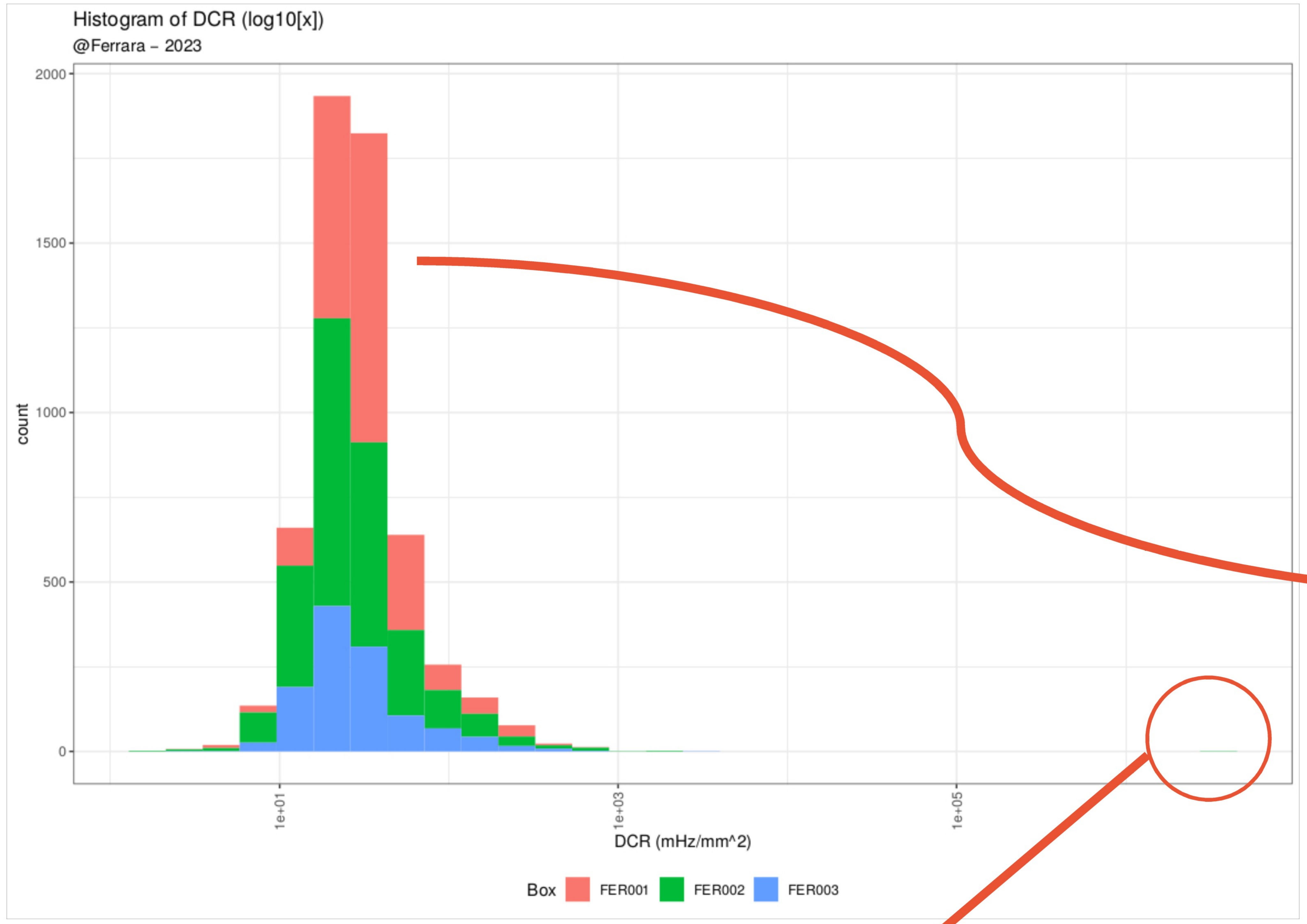
Results:thermal cycles



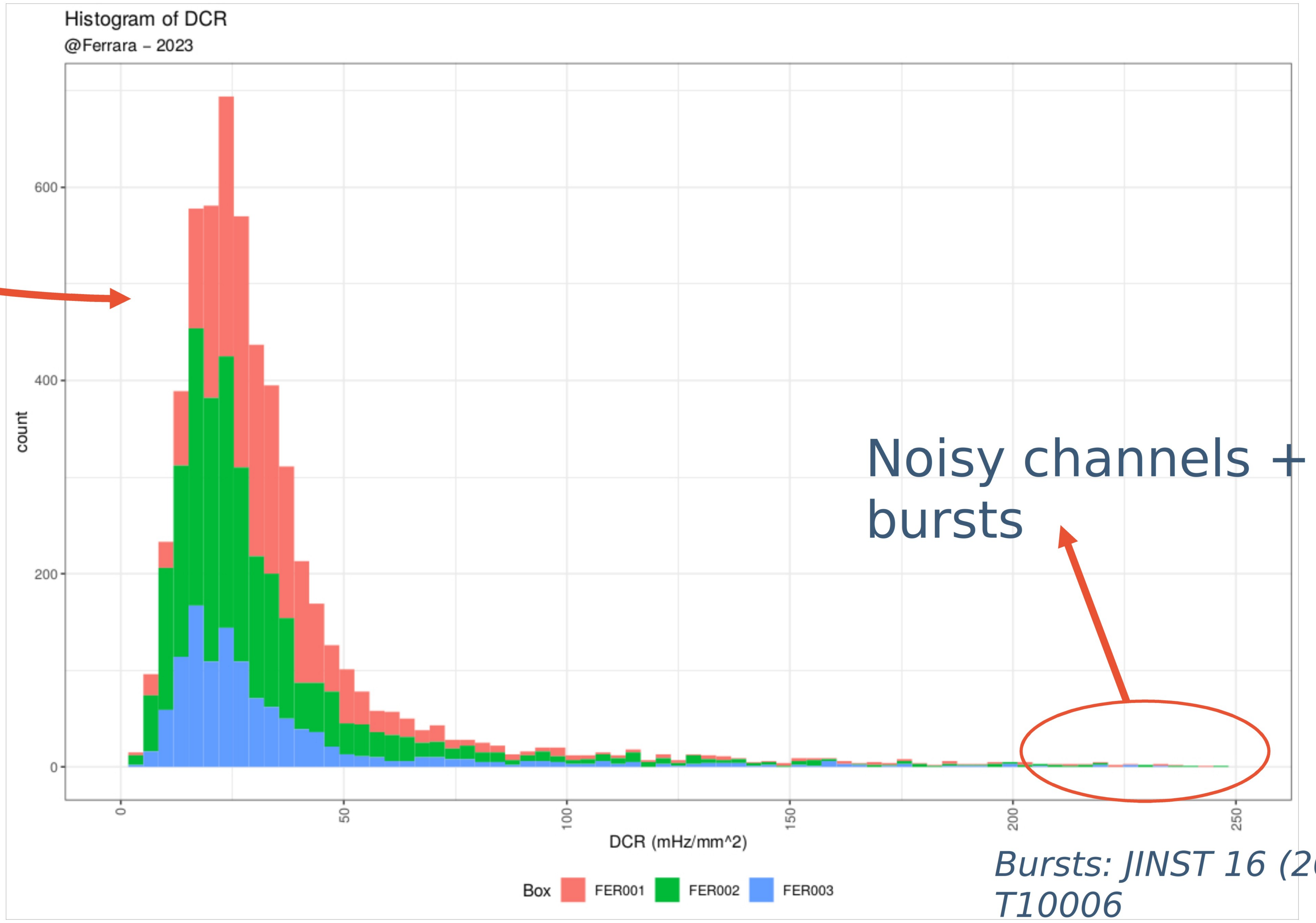
- Resilience to thermal stresses has been checked
- No discrepancies between 3rd and 1st thermal cycle
- Example of data from box n. 2 tested in Ferrara
- V_{bd} Data within errors (50mV)



Results: DCR



DCR in specs for almost all SiPM (<200mHz/mm²)



Noisy channels + bursts

1 SiPM with a high DCR @LN2 (>10^5Hz)

Bursts: JINST 16 (2021) T10006

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Conclusions

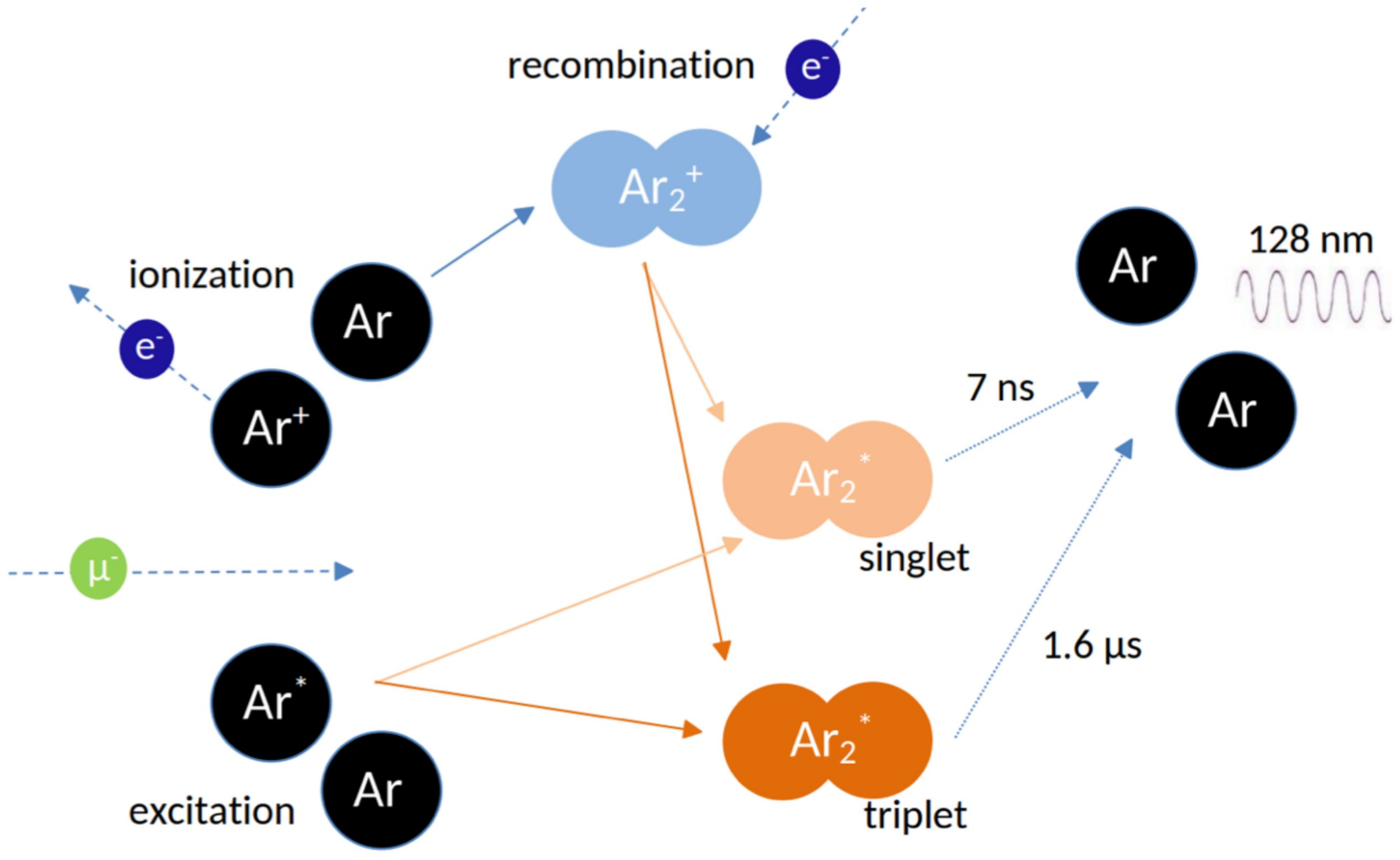
- Dune SiPMs 300k sensors FD1 (+ProtoDUNE HD ~10k sensors)
- Cactus: quality assurance and massive tests
- System capability: 120SiPM per single run
- Tests:
  - IV forward + reverse @ Room Temp
  - IV forward + reverse @ LN2 Temp before and after thermal stresses
  - Global DCR
- Sites: Ferrara, Bologna, Granada, Milano Bicocca, Prague ~2400SiPM/month
- Failure rate untill now ~0.1%
- In this presentation data from Ferrara, but other site similar results
- Tested so far ~10k SiPM ProtoDUNE & ~15k SiPM FD1

Thank You

Backup slides

LAr VUV Light Detection

- Excited argon interacts creating excited molecules in singlet and triplet states
- LAr VUV scintillation light (λ = 128 nm) is
  - Abundant (25k photons/MeV @ 500 V/cm)
    → enhance calorimetry, especially at low E
  - Fast (fast component has τ = 7ns)
    → provides event t_0, crucial for triggering non-beam event
  - Topological
    → Slow/Fast component relative contribution has PID and
    capabilities



- Detection of light in DUNE LArTPC
  - VUV photons converted to longer wavelength by photofluorecent compounds (WLS)
  - Visible light is trapped inside a module and a fraction of it is conveyed to photosensors (SiPMs)