A Large Facility for Photosensors Test at Cryogenic Temperature

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On behalf of the **DarkSide** Collaboration

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Summary

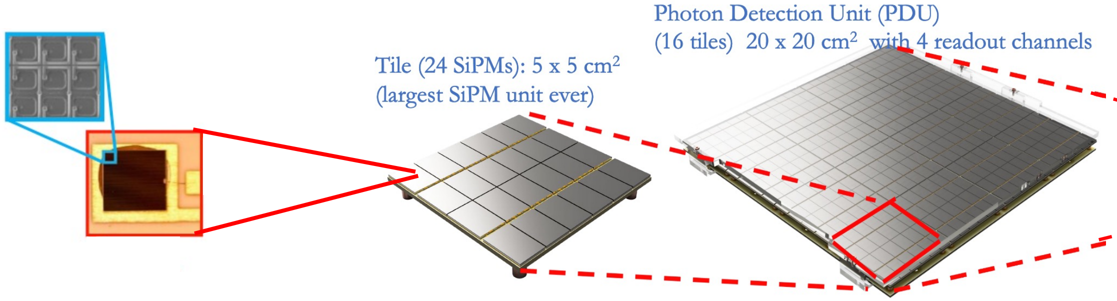
- General overview
- Purpose of the photosensors test facility
- Facility description: cryogenics, mechanics, DAQ and electronics
- Test of photosensors
- Characterization of PDUs
- Photosensors main parameters
- Stabilities
- Conclusions

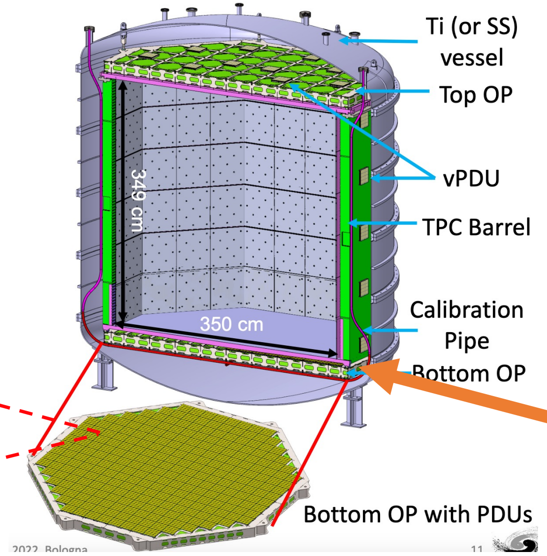
General Overview

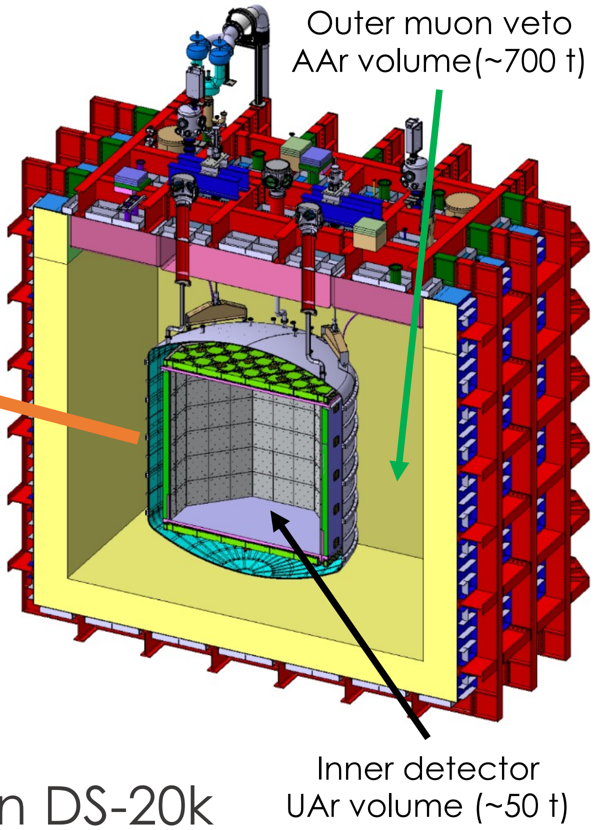
- Photosensors play a crucial role in astroparticle physics experiments
- Silicon based photo-detectors are innovative light collecting devices employed in low temperature environment
- SiPM phototosensors represent a successful technology in the field of direct dark matter search and neutrino detectors based on liquified noble gases
- Next generation of large scale noble liquid experiments need a remarkable amount of Silicon photodevices

Purpose of the Photosensors Test Facility

- The DarkSide collaboration started a dedicated development and customization of SiPM technology for its specific needs

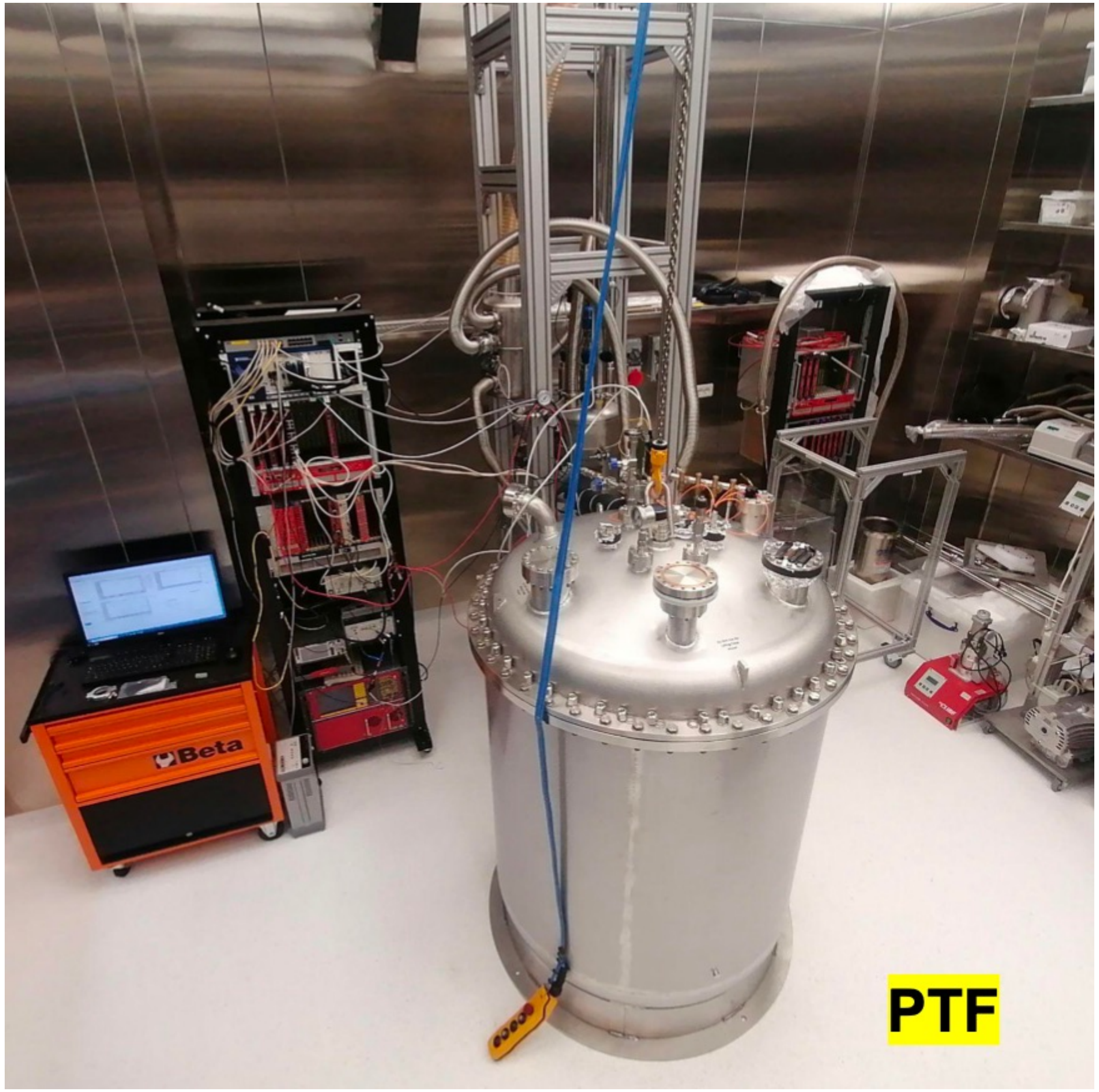






- Design, production and assembly of a large surface module of 20x20 cm^2 to be used as PhotoDetectionUnit (PDU) in the DarkSide-20k experiment have been made
- Production of a large number of such devices (15 m^2 of active surface in DS-20k detector) requires robust testing and validation process
- A dedicated test facility (PTF) for the PDU tests was designed, integrated and commissioned at INFN Naples laboratory
- Some testing campaigns were alredy performed

Facility Description: Overview

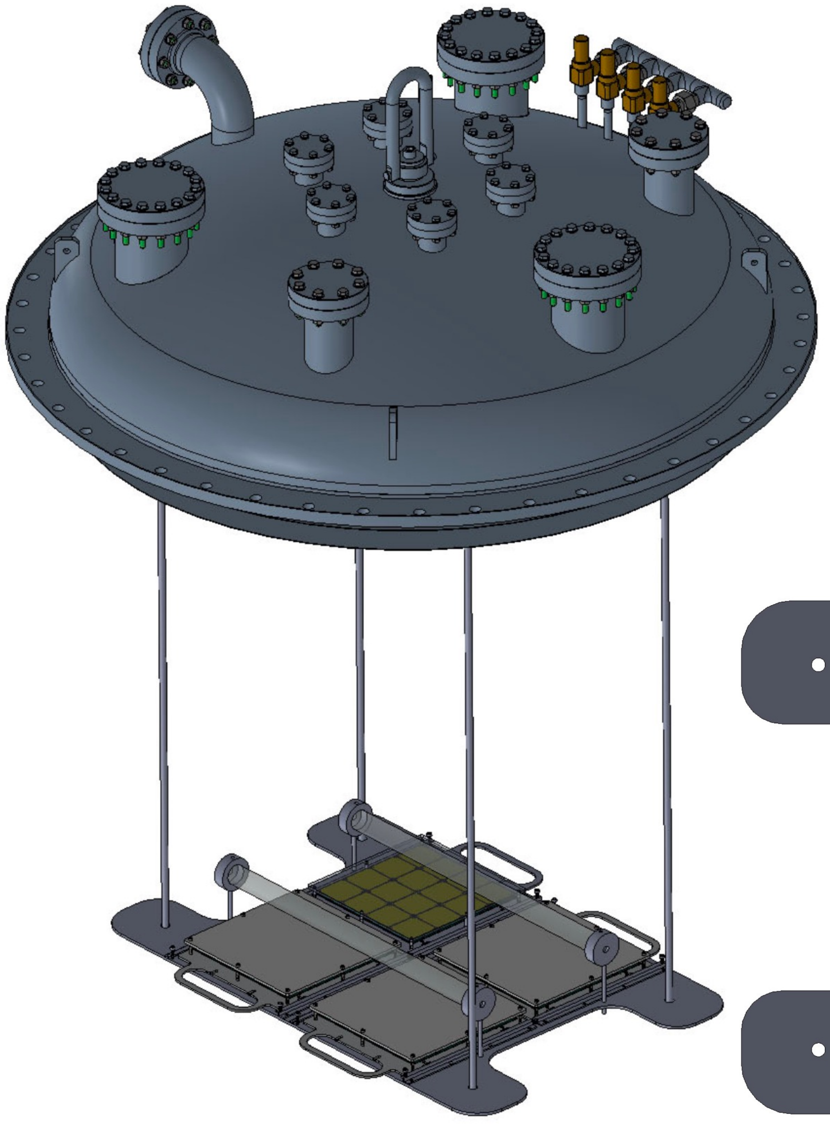


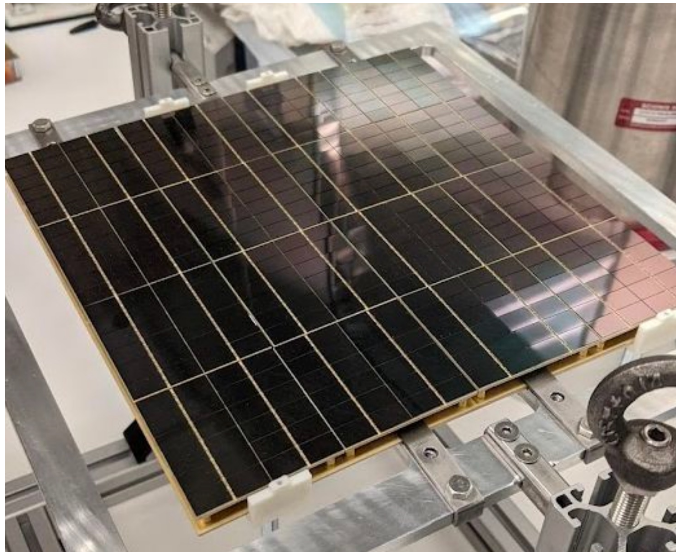
- Custom made cryostat located inside the Naples Cryolab cleanroom
- System composed of open double wall vacuum insulated vessel (1.15 m diameter – 1.57 m height) coupled with a single wall domed flange
- Equipped with PT100 temperature/level meter sensors, pressure transducer and analog pressure indicator
- Top flange with CF flanges for electrical and optical feedthroughs
- Double wall vessel with two ports for liquid nitrogen inlet and cold gas venting
- Maximum allowed absolute pressure in the cryostat of 3 bar
- DAQ and electronics close to the setup

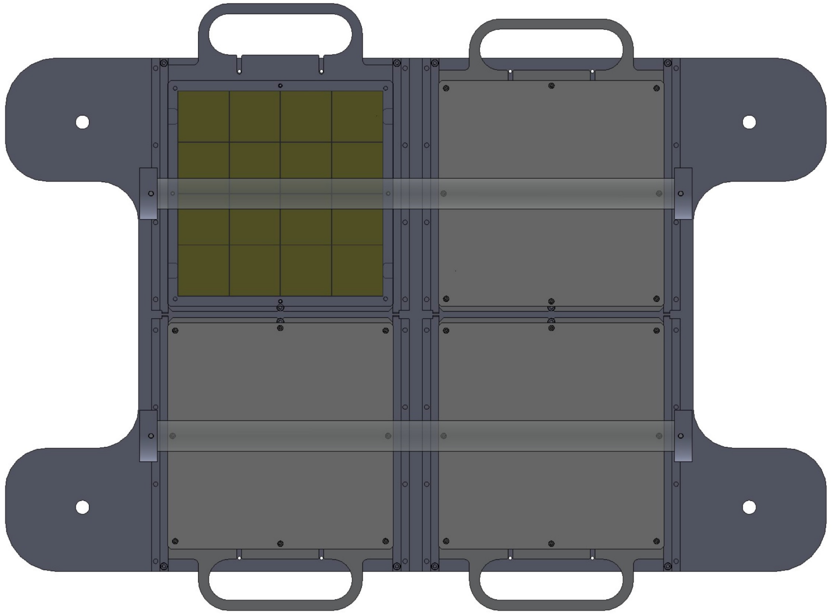
Facility Description: Cryogenics

- Facility cryostat directly connected to an external 3000 l LN storage tank (operation pressure of 2.5 bar)
- System controls (proportional and automatic valves) and operating parameters (pressure, temperatues, nitrogen level, etc.) controlled and monitored by a National Instruments PXI computer and LabView-based slow control program
- Pressure in the cryostat (after filling) maintained at a constant value of 1100 mbar by the inline relief valve
- Controlled LN filling (about 7 hrs) and draining (about 15 hrs)

Facility Description: Mechanics

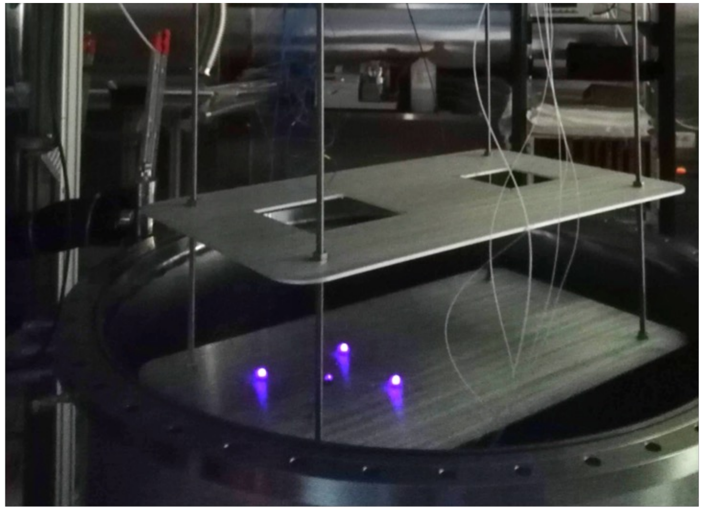


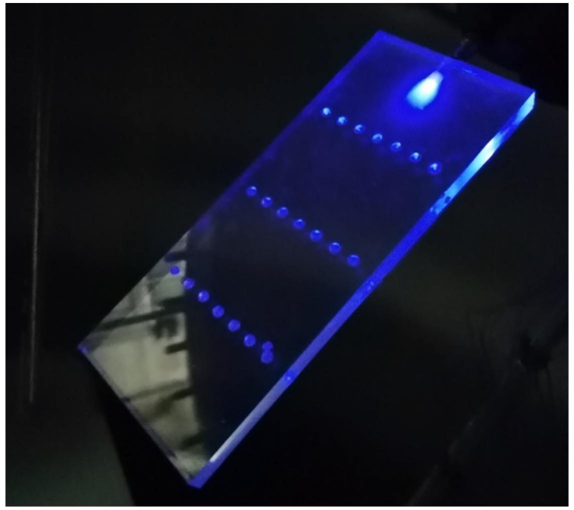




- Dedicated mechanical structure hanged to the domed flange to host PDUs
- Thermal insulating adapters for the hanging structure
- Three horizontal planes allocating 4 PDUs each
- Illumination system for laser light distribution
- PDUs mounted on the proper support plates
- «Fast and safe» removable PDUs structures
- Adjustable distance among planes and illuminating system

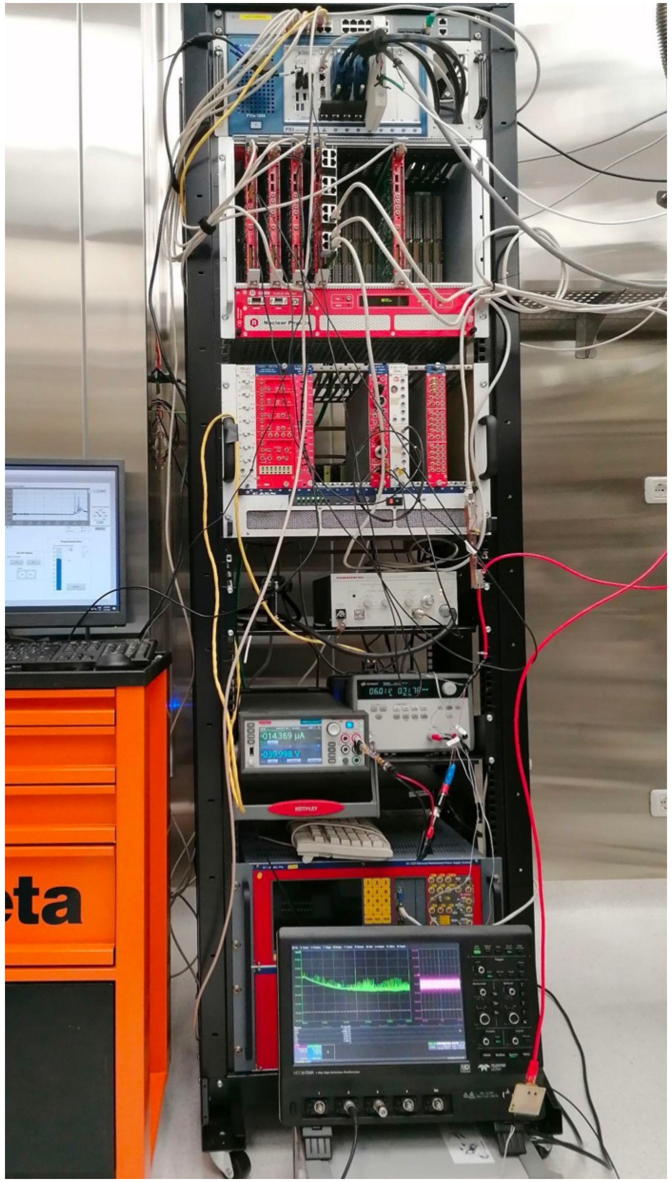
Facility Description: Light Distribution





- Hamamatsu PLP Laser 407 nm light emission, fiber splitter (inside the cryostat), 4 diffusor channels to cover the PDU
- Optical feedthrough with two ports each
- Explored configurations: 16 ports optical feedthrough to deliver 16 individual fibers coupled with scintillating plates/rods (test are going on) and diffusers
- Optimize the unifomity for the laser light to be used in calibration runs

Facility Description: DAQ & Electronics



- **Electronics**: 12 channels of L&H voltage (CAEN A2518, A1619) Signal readout**:** CAEN VX2740 digitizers (48 readout channels)
- **Computing**: DAQ server, analysis and storage server (40 TB), regular transfer of data to CNAF
- **Software**: MIDAS framework, fully integrated controls for Power Supplies, DAQ, Elog, data summaries, slow control history and online monitoring
- Remotely and automated data acquisition runs
- Monitoring of DAQ rate and individual control of channels Dedicated software (*dsanana*) allowing online monitoring of the data used for the majority of the offline reconstruction
- Reconstruction software tool (*PyReco*) used offline

Test of Photosensors: Overview

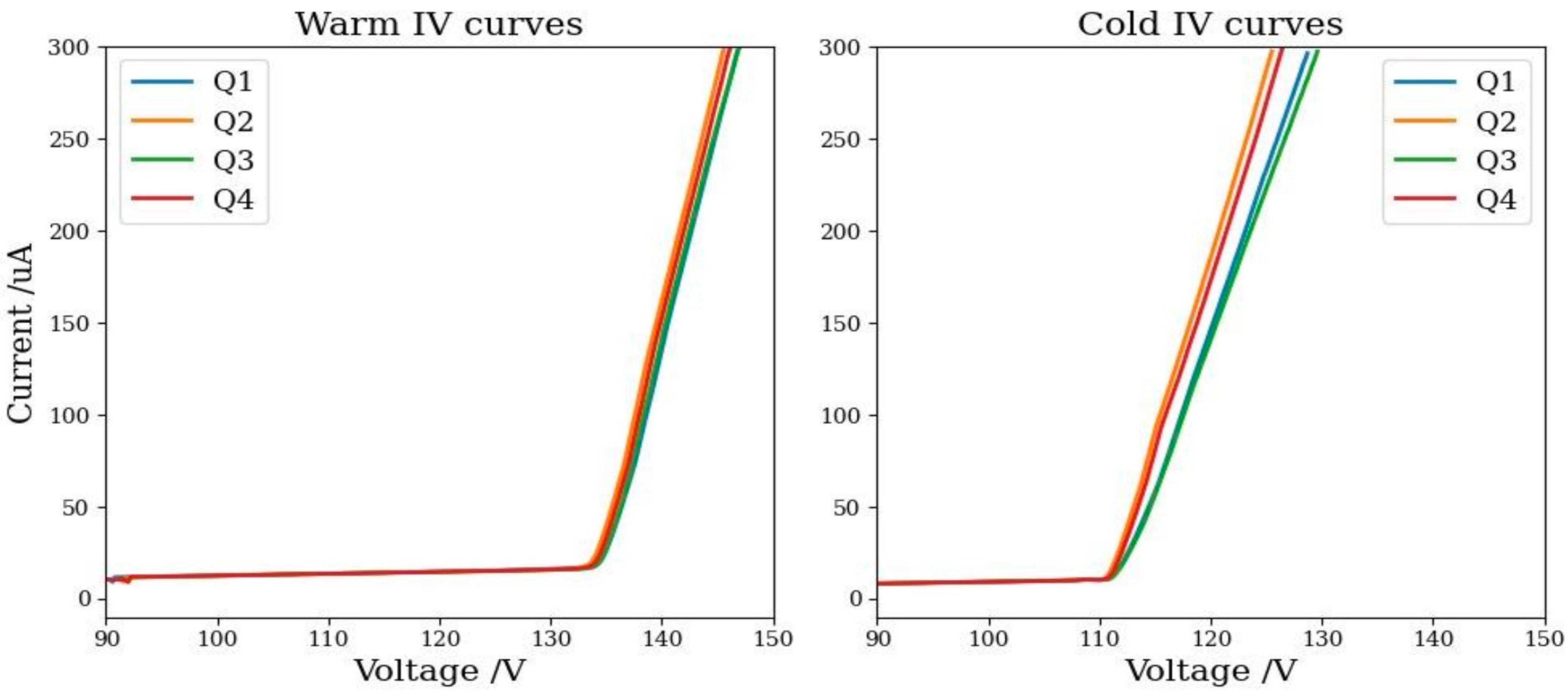
- PDUs production in NOA and transportation to Naples INFN Cryolab
- Installation of the PDUs in the test facility
- Measurement of IV curves at room and LN temperatures
- Laser calibration runs at different overvoltages for one selected laser intensity
- Check the stabilities with periodic runs
- Measured values of BD voltages, PE positions, S/N ratio, Gain, noise spectra, etc.
- Controlled drain, warm up, cryostat opening at room temperature
- PDUs unmounting, preparing for delivery to INFN-LNGS, storage
- Loading of a new batch

Characterization of PDUs: Overview

PDU scheme of MB4/4
with 16 photodevices and 4 quadrants

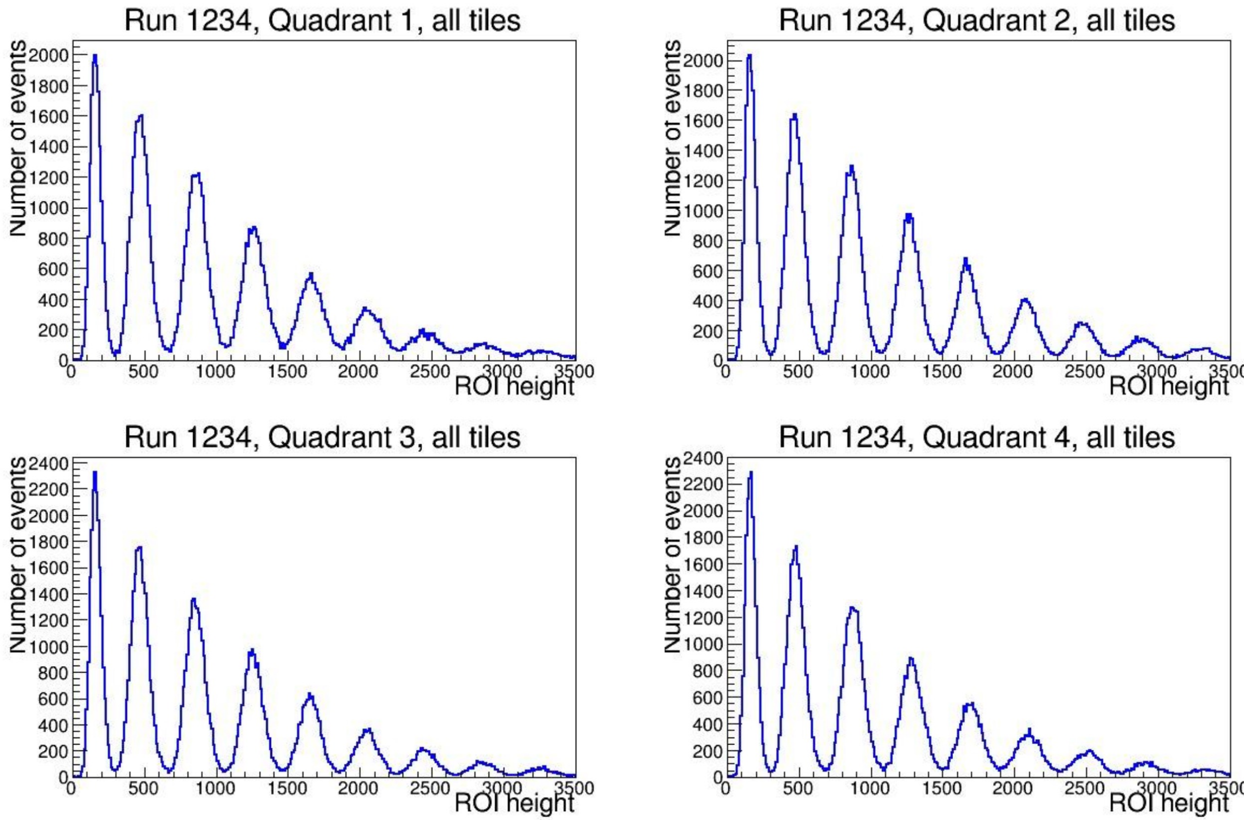
- 16 PDMs grouped into 4 readout channels
- LV: Keysight E3649A dual PS - no remote control or history
- HV: Keithley 2450 SMU - remote control but no history
- Laser: Hamamatsu PLP-10 pulsed diode laser
- MB4/4 illuminated with 4 laser diffusers from an optical plane below the MB.
- Data taken with both periodic and laser trigger and reconstructed with *dsanana*
- Different overvoltages of 5-9 VOV (32V - 36V) considered
- Four tiles per quadrant powered individually
- Each quadrant read out as a single channel

Characterization of PDUs: IV Curves

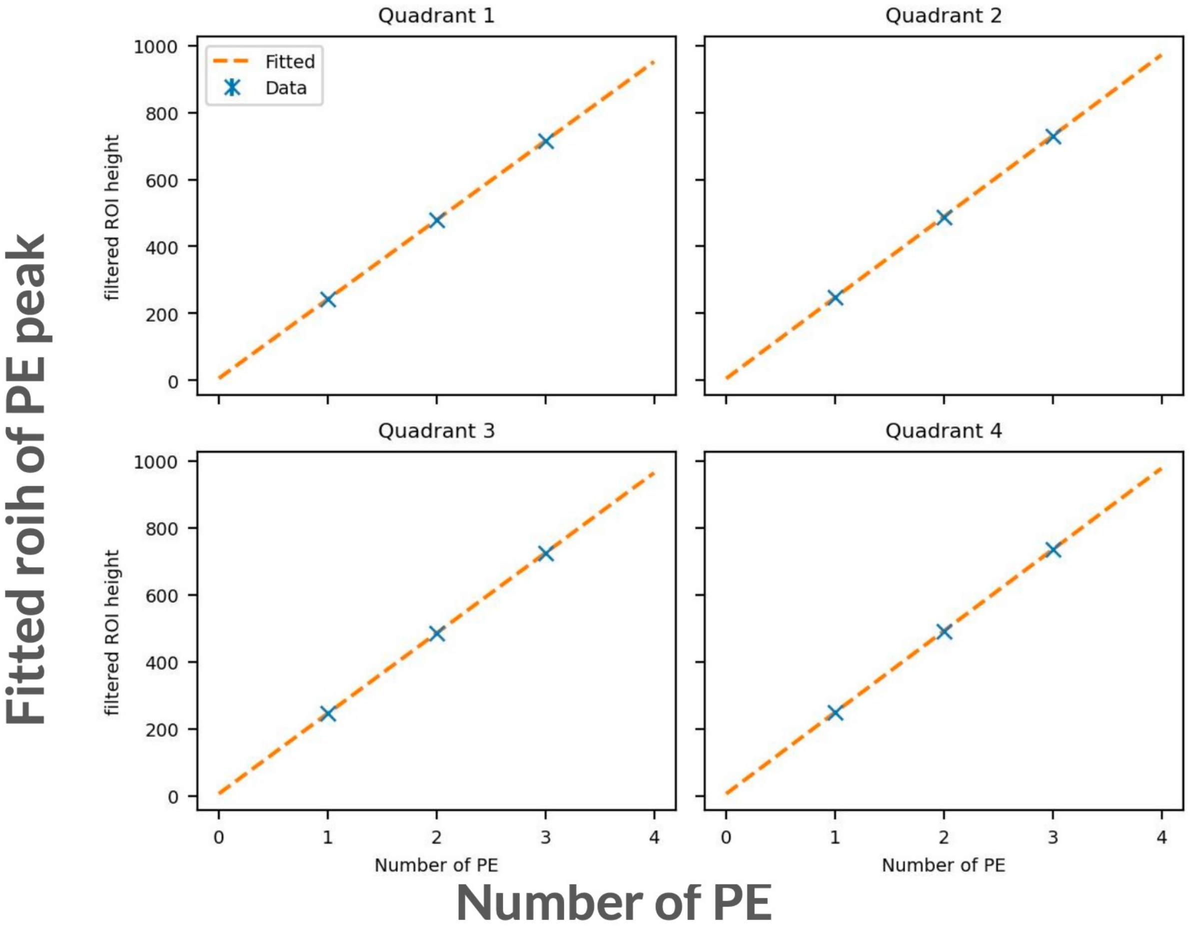


- Change in the breakdown voltage as function of temperatures expected for all the quadrants
- Slight discrepancy of the IV curves at higher voltages at LN temperature (111.1-111.7 V)

Characterization of PDUs: Gain

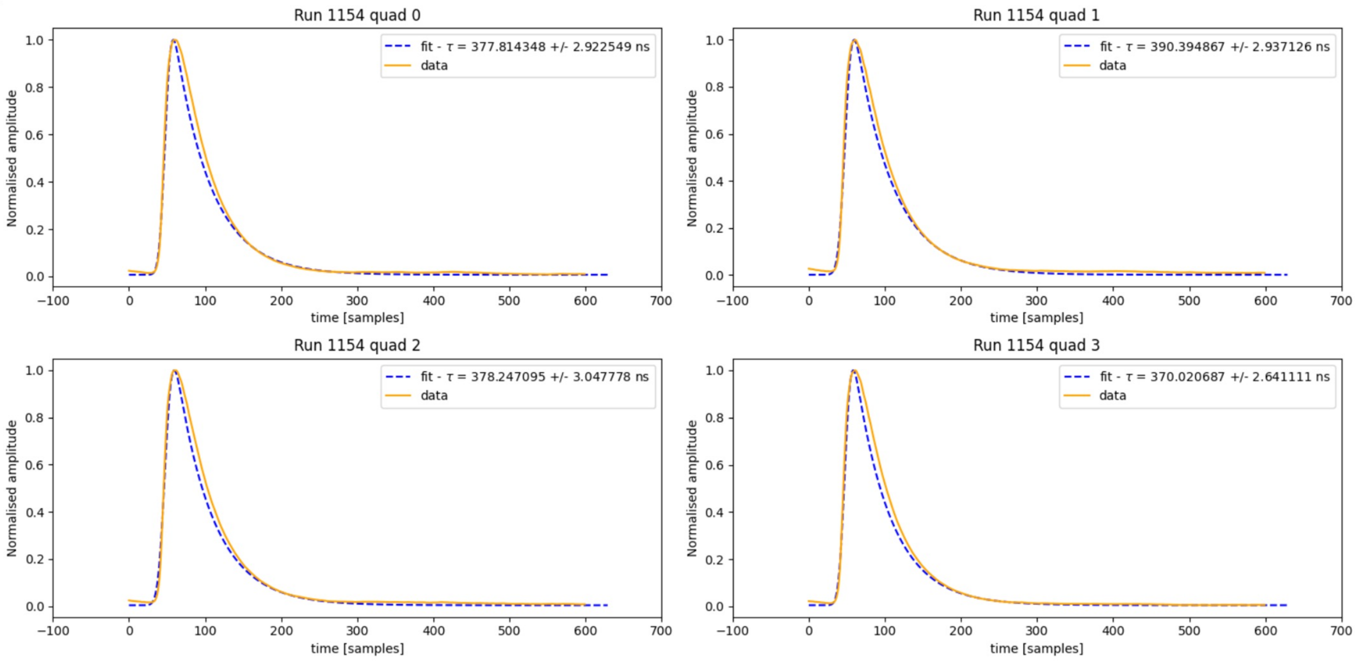


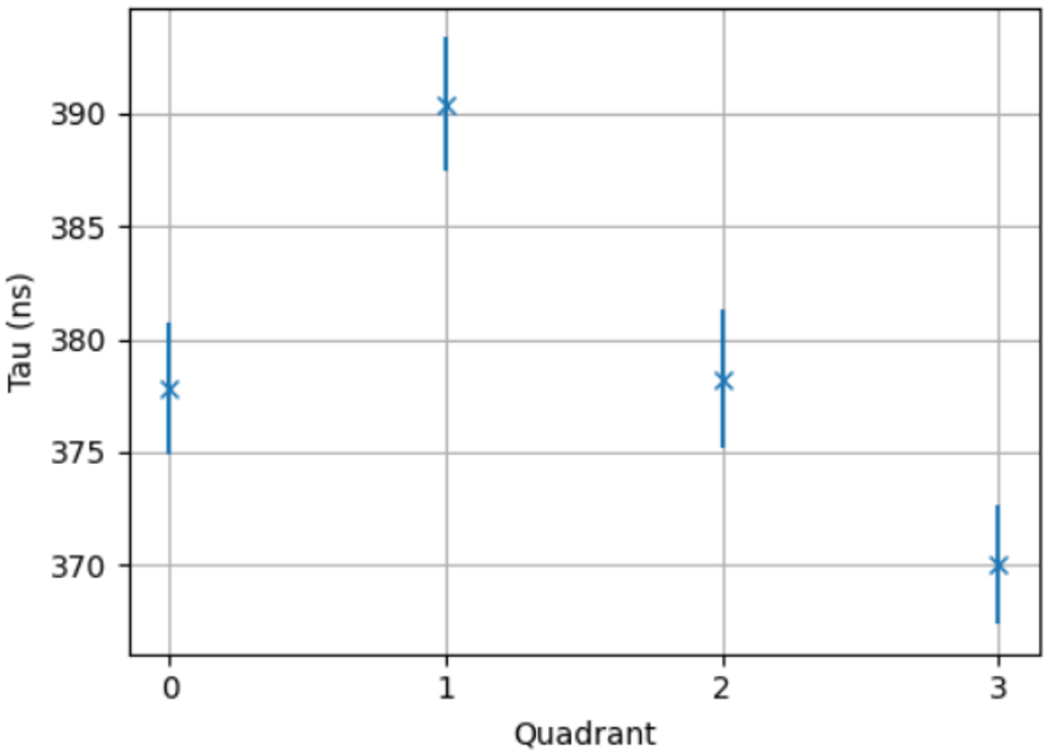
Several photoelectron peaks clearly visible in the distribution for each quadrant



Gain at 34 V supplying voltage:
Mean = 240.4 - Std = 2.4

Characterization of PDUs: Pulse Shape



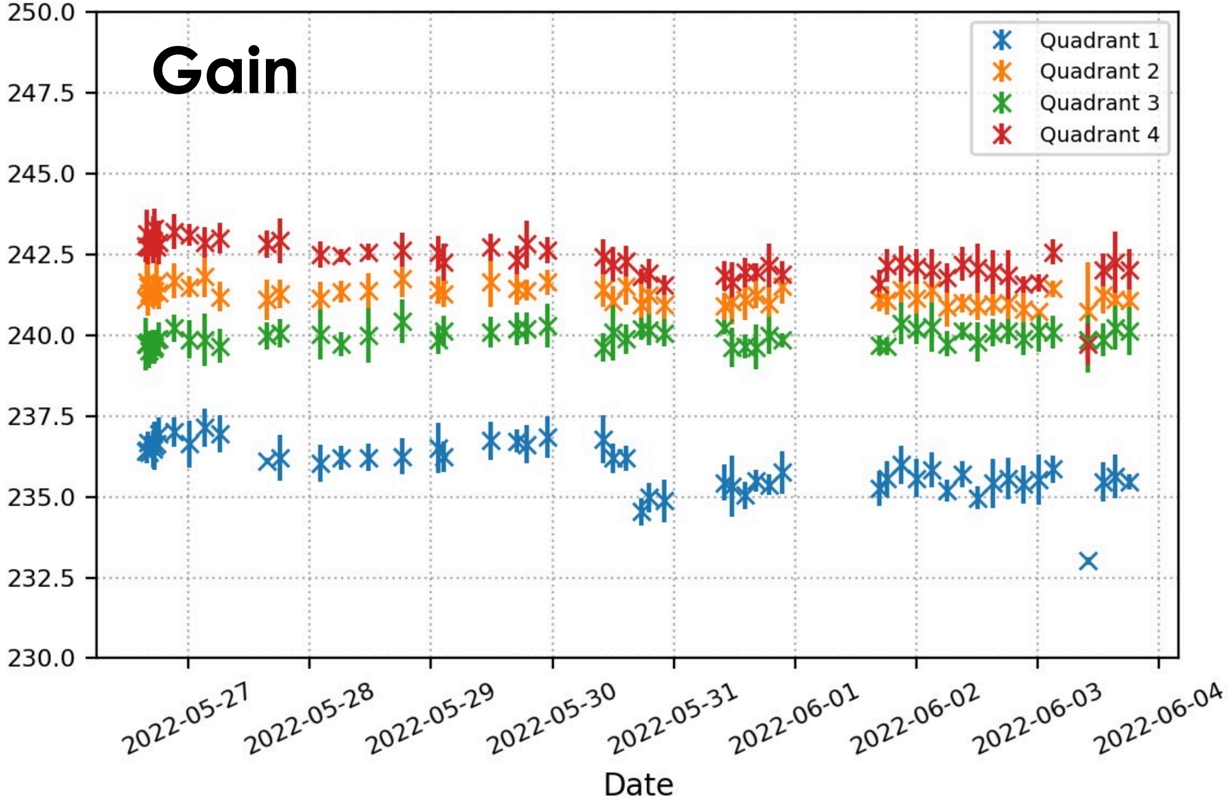


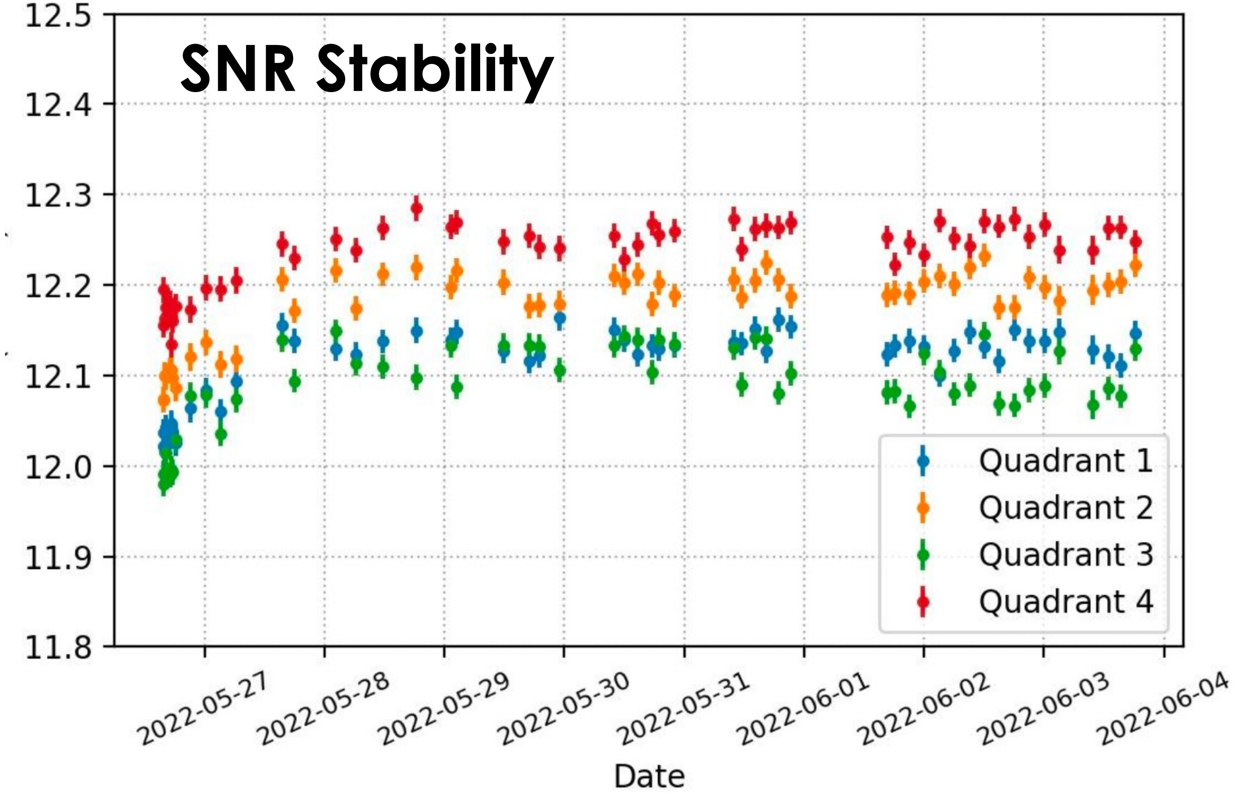
$$\text{fast} = \frac{1}{\sqrt{2\pi}\sigma} e^{-\frac{(x-x_0)^2}{2\sigma^2}}$$

$$\text{slow} = \frac{1}{2\tau} e^{-\frac{1}{\tau}\left(x-x_0-\frac{\sigma^2}{2\tau}\right)} \left(1 + erf\left(\frac{x-x_0-\frac{\sigma^2}{2\tau}}{\sqrt{2}\sigma}\right)\right)$$

- Identified waveform pulses with 1PE - 2σ < height < 1PE + 2σ
- Fit average pulse shape with convolution functions

Characterization of PDUs: Gain & SNR Stabilities

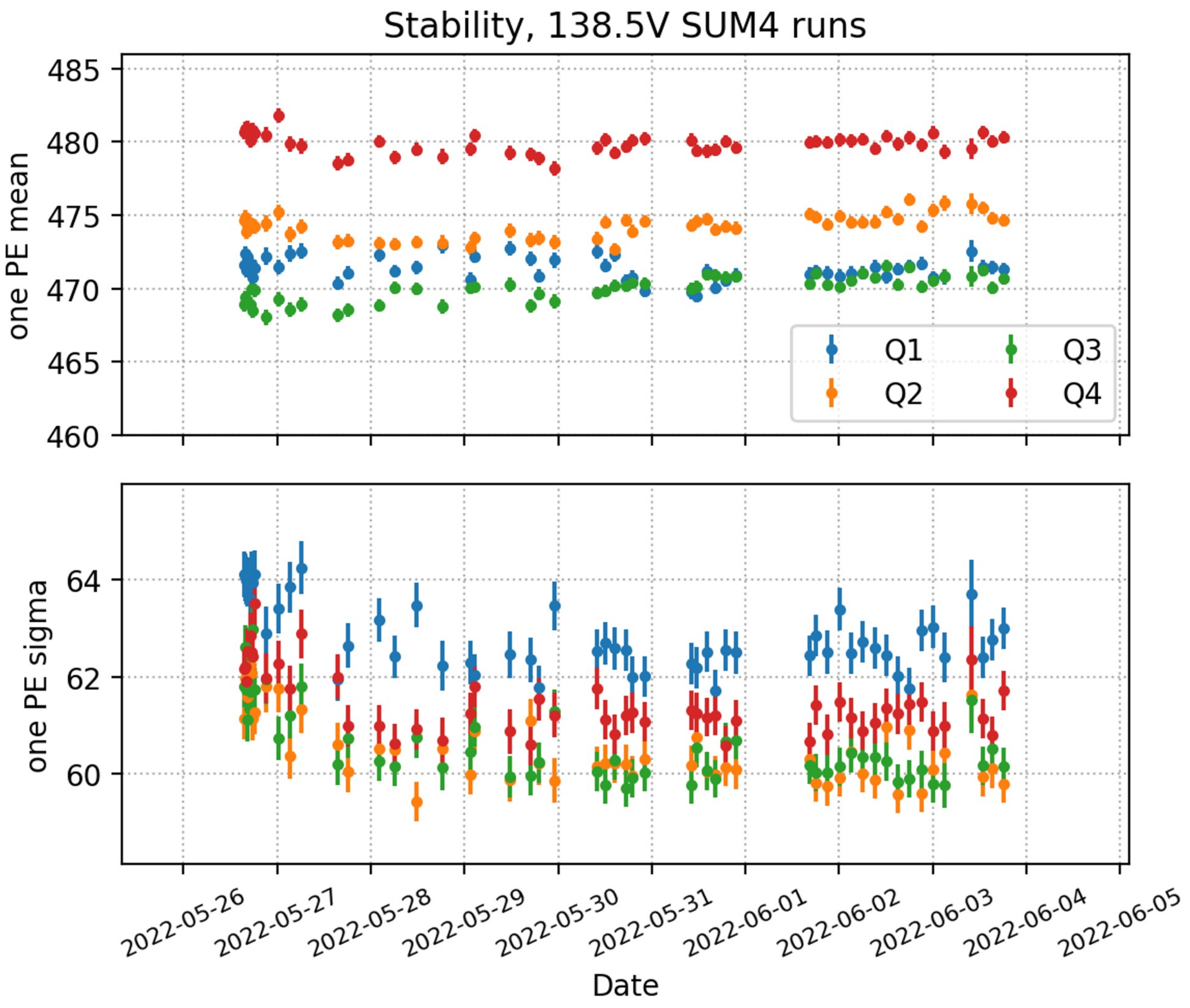


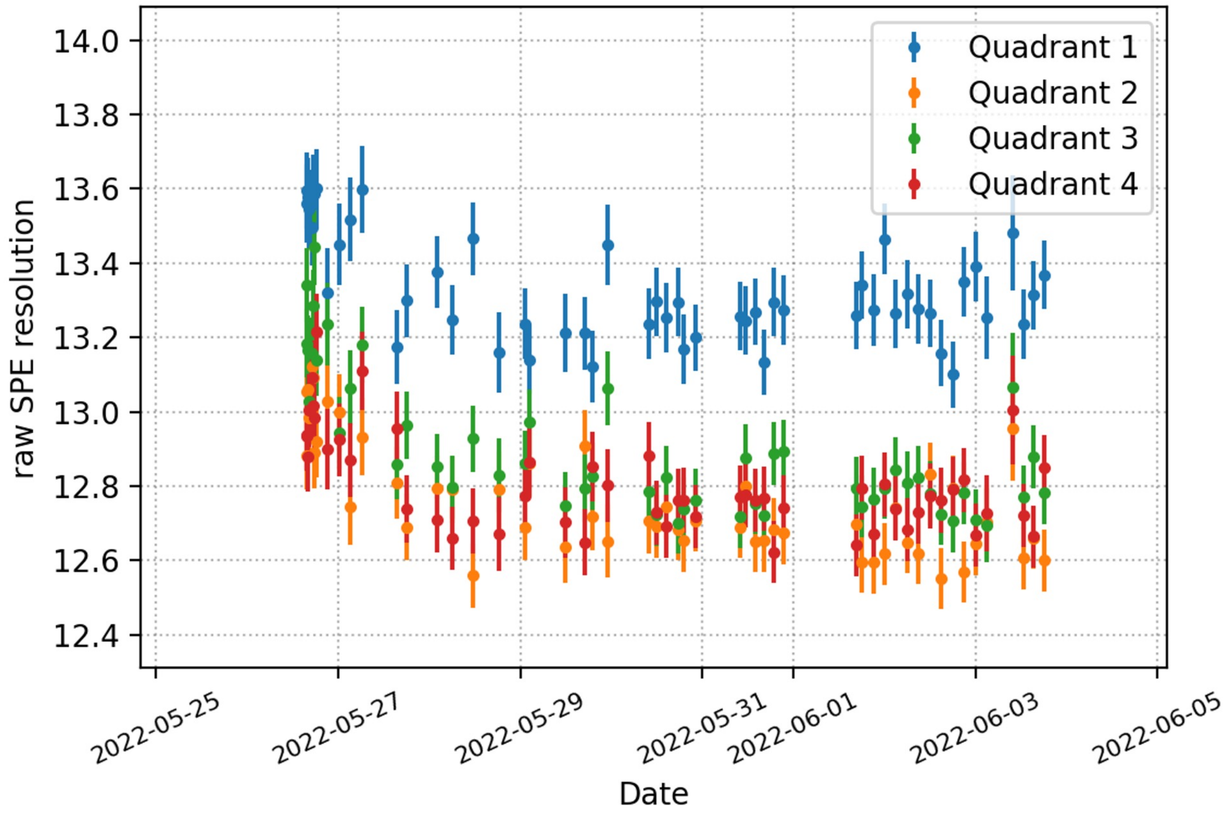


- Quadrants supplied with 7 VoV average
- Gain plotted for each of the four quadrants

- Stability over a period of about 10 days
- Discrepancies in the SNR of the order of the 2% (peak to peak) for the same quadrant

Characterization of PDUs: SPE Resolution Stability

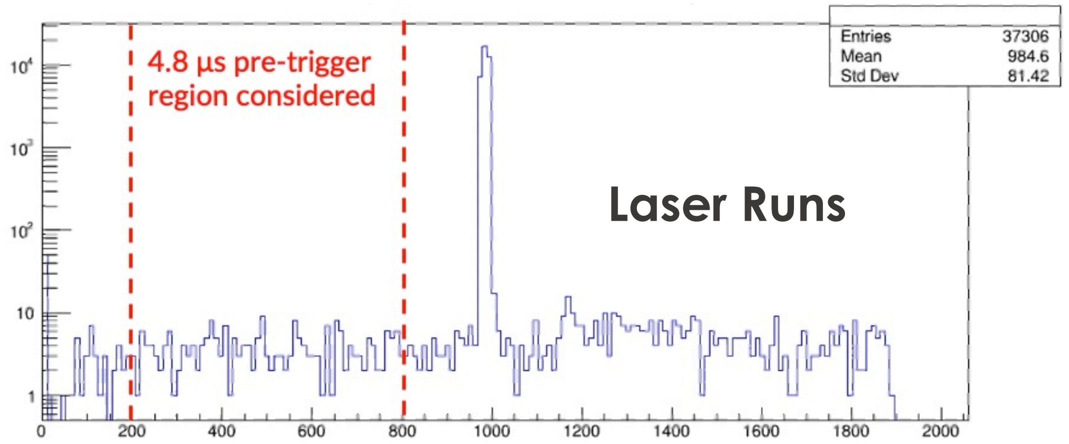


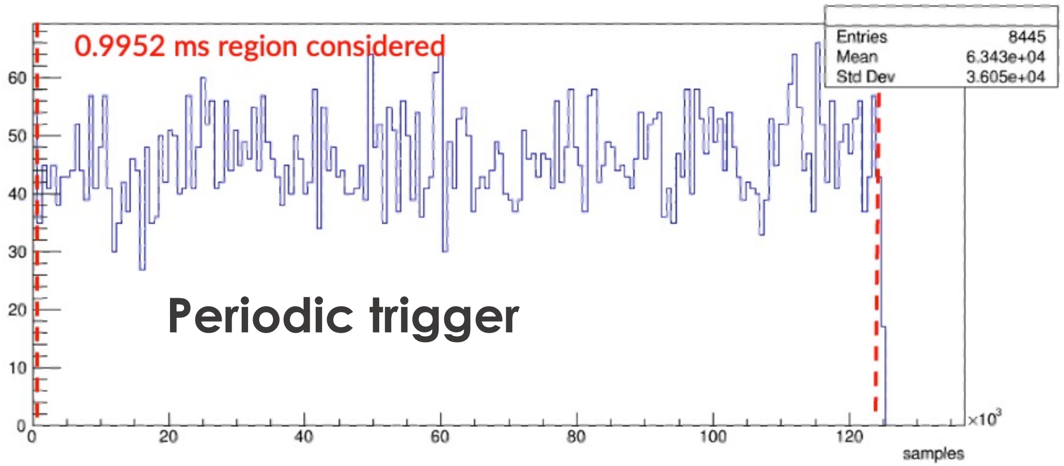


- SPE resolution = sigma/mean of the fitted 1 PE peak in ROI height
- Behaviors of the different quadrants and ratios

Characterization of PDUs: DCR Evaluation

- Dark Count Rates estimated through 2 different methods: pretrigger in the laser runs and dedicated runs with random trigger
- DCR = #pulses/(#total entries*time window)

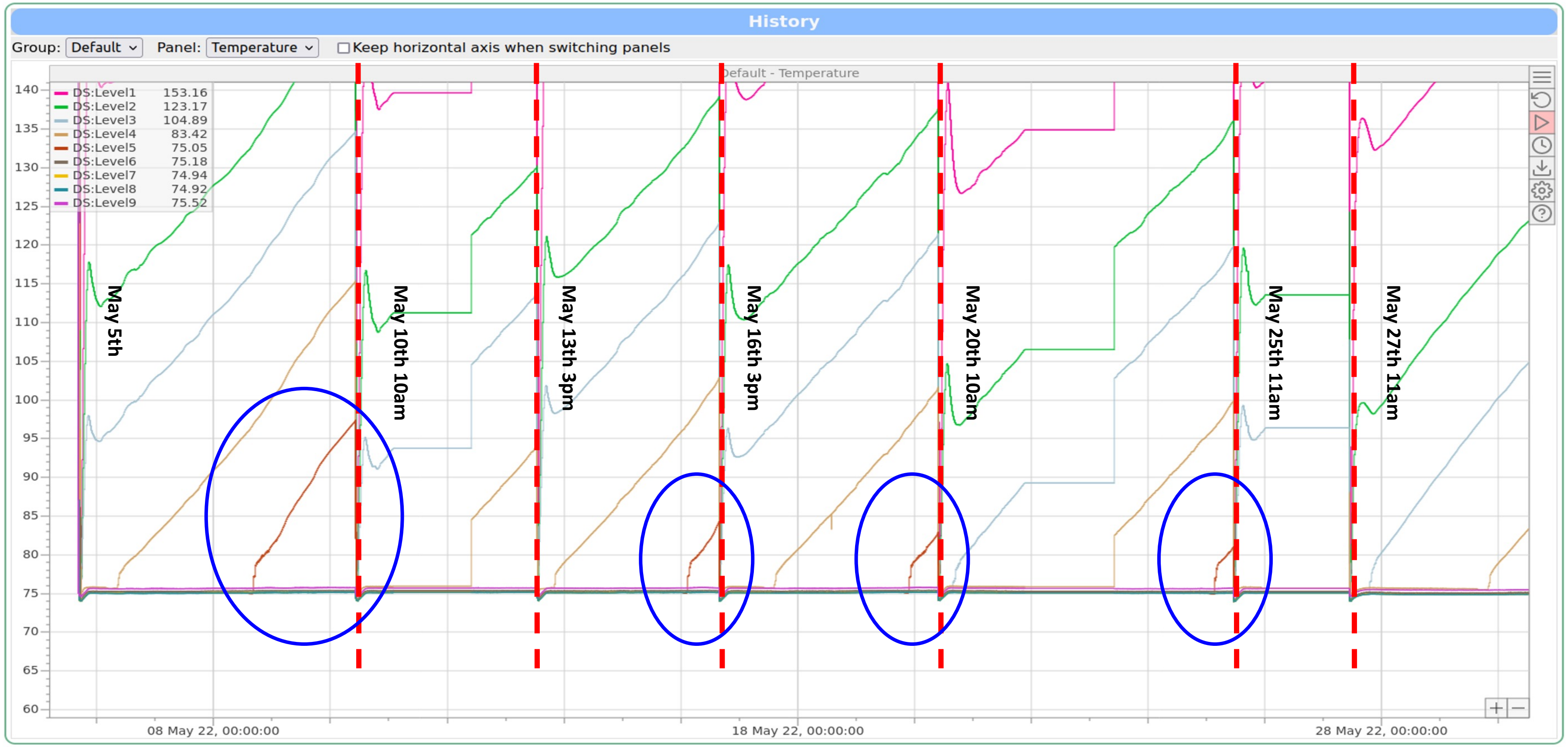




DCR (Hz) @ 34 V	Laser Quad1	Periodic Quad1	Laser Quad2	Periodic Quad2	Laser Quad3	Periodic Quad3	Laser Quad4	Periodic Quad4	Laser MB4/4 average	Periodic MB4/4 average
	1229 ± 50	1218 ± 7	1239 ± 50	1194 ± 7	1352 ± 53	1224 ± 7	1241 ± 50	1191 ± 7	**1265 ± 87**	**1206 ± 14**

- All runs taken with lab lights off, over the weekend/in evenings so no people in the lab
- DCR calculated from both laser and periodic data with an average rate of ~1.2 kHz per quadrant – 0.12 Hz/mm^2

Characterization of PDUs: Temperature Monitoring



- Temperature monitored throughout the MB4/4 data taking
- Liquid nitrogen (re)filling clearly visible
- No significant effects found with the LN level and refilling

Conclusions

- A dedicated Photosensor Test Facility PTF for testing large area and number of photodevices has been assembled, commissioned and ready for tests since Summer 2021
- Testing campaigns of individual PDUs since Fall 2021 has been carried out
- Upgrade of the Facility performed in July 2022 with LN Fill and Drain in full “Auto-mode” new transfer lines (liquid and cold gas) double wall vacuum insulated, cold gas from all systems collected and warmed up before venting
- New holding structure for hosting 12 PDUs is ready for production
- Improvement of light distribution with optical feedthroughs able to (quite) uniformly cover the whole of the PDUs
- Tests in May-June 2022 have been performed with the aim of characterizing PDUs MB4/4 in terms of the main paramters (BD voltage, Gain, SNR, DCR, Stabilities, etc.)
- Test of PDUs from preproduction phase of NOA starting from Fall/Winter 2022
- Versatile system able to host other type photosensors (large area PMTs, ARAPUCAs, MegaCells, etc.) to be characterized and used in low temperature environment

Extra Slides

DARKSIDE

Characterization of PDUs: Test Protocol

- Aperture of the case and visual inspection of the PDUs
- Mounting of the PDUs on the NTF holding structure and cabling
- Connections check and verification of the SM communication (tile by tile)
- Warm IV curves
- Closure of the cryostat and filling with liquid nitrogen
- New measurement of the IV curves at LN temperature
- Laser runs: at 6-7-8-9 of VoV for one selected laser intensity
- Check the stability setting (~10 min - 200 Hz frequency) and periodic (1/ hrs) runs up to 72 hrs
- Main parameters to be stored in DB: BD voltage, PE positions, S/N ratio, Gain, etc
- Define a PDU passport with all accetable parameters
- Test duration of the order of ~1 week

Characterization of PDUs: DCR Evaluation

Laser Runs

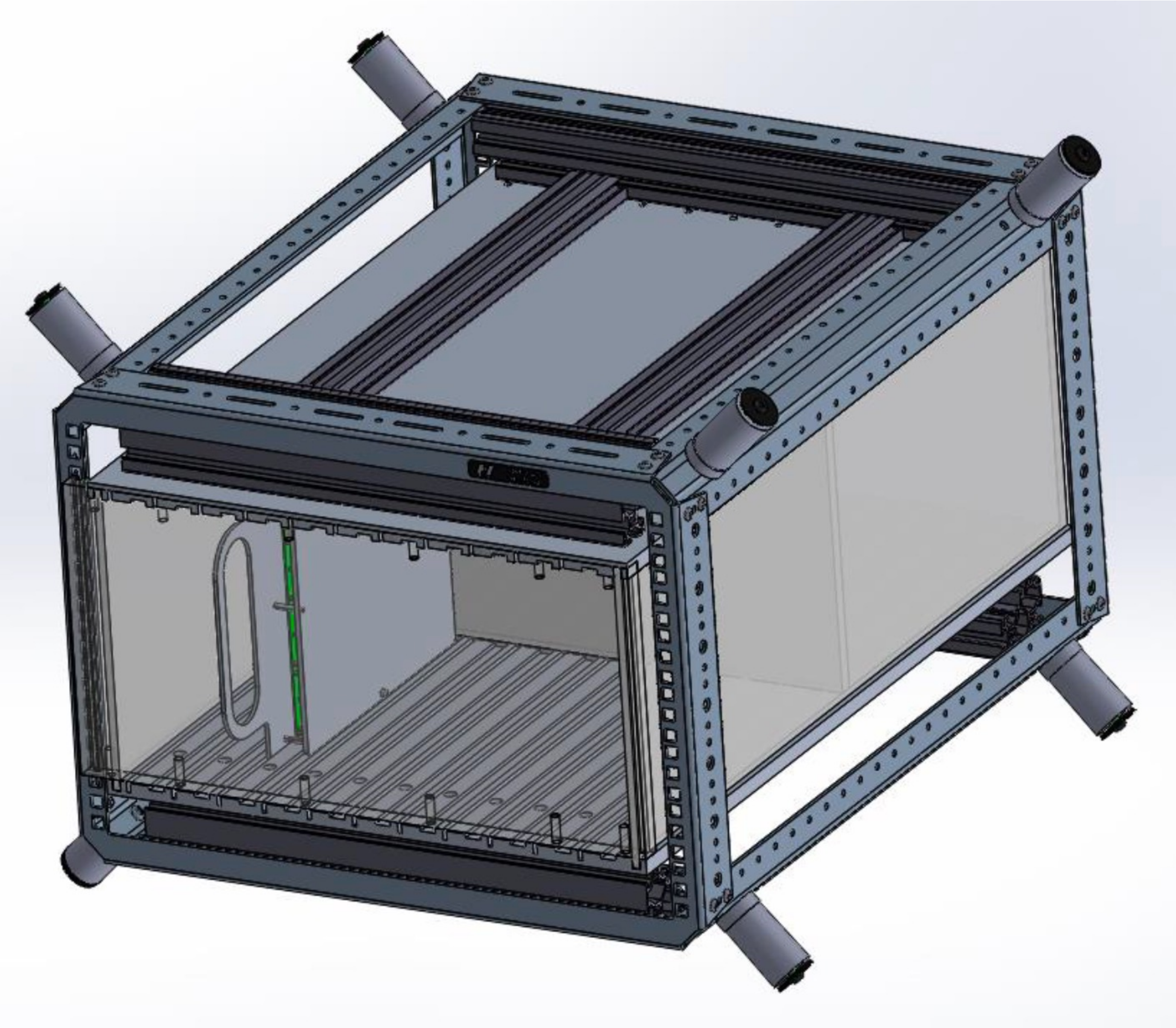
- Acquisition window of 16 μs, with a laser trigger at 8 μs (100k events acquired)
- Plot height of pulses found throughout entire waveform (not only in ROI around laser) and fit 1 PE peak
- Using 200 - 800 samples (4.8 μs) in the pretrigger region
- Pulses over 0.7*1 PE peak mean height counted

DCR = #pulses/(#total entries * time window)

Periodic trigger

- Acquisition window of 1 ms with 10 Hz frequency and no laser (20k events acquired)
- Plot height of pulses found throughout entire waveform and fit 1 PE peak
- Using 500 - 124900 samples (0.9952 ms)
- Pulses over 0.7*1 PE peak mean height counted

Test of Photosensors: Logistics



- Three Peli super-v 7 U case for 10+10 PDU to transport modules between NOA and PTF
- Service is needed for PDUs periodic deliveries
- Peli boxes can be also used as the temporary storage in Naples clean room
- PTF holding structure to be fully compatible with the transportation plates
- PDU plate removed from the case and directly inserted into the PTF holding structure