Fermilab

DUNE ND-LAr
2x2 Demonstrator Tests

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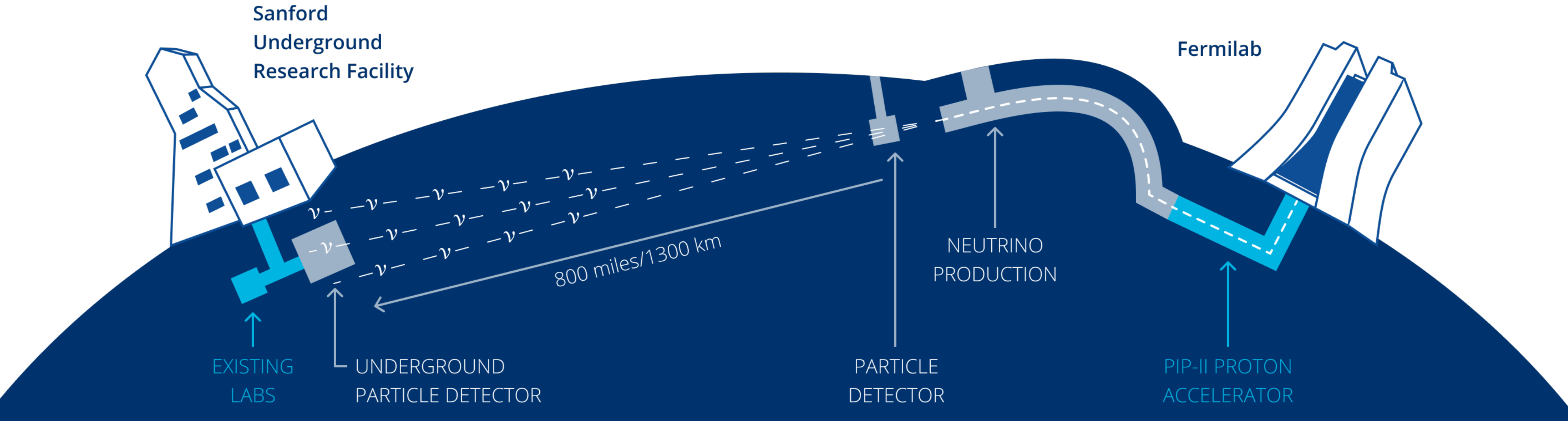
Italian Summer Student Program 2022
Final Term Review

DEEP UNDERGROUND NEUTRINO EXPERIMENT

ArgonCube

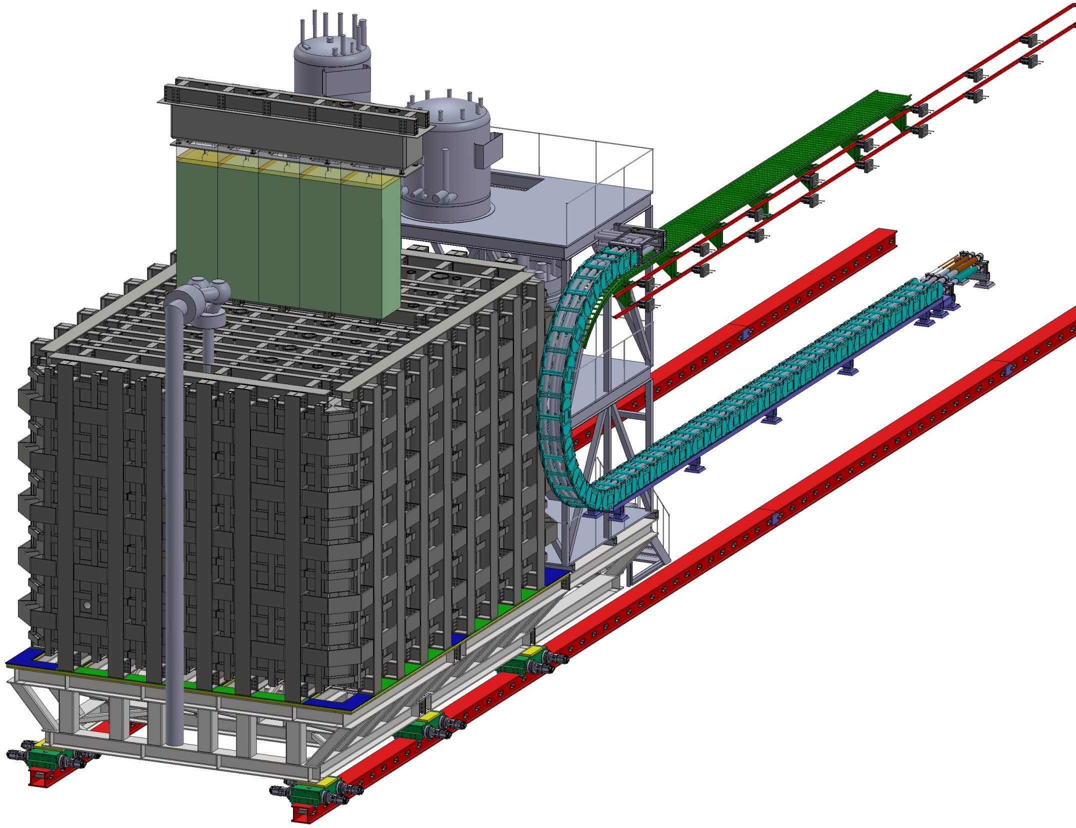
The DUNE experiment

- Leading-edge, international neutrino experiment [1]
- **Far Detector (FD)**: ≈ 1.5 km underground at the Sanford Underground Research Facility (SURF) in South Dakota, 1300 km from Fermilab
- **Near Detector (ND)**: 574 m from the target, at Fermilab



Liquid Argon TPC - ND-LAr

- **ArgonCube** technology [2]
- 35 LAr TPC modules in a common bath of liquid argon
- Active mass ≈ 150 t, 50 t fiducial
- Detector **modularization**
  - Improved drift field stability
  - Reduced high voltage and LAr purity requirements
- **Pixelated charge readout**:
  - 3D imaging of particles interactions
- **Large area dielectric photon detection system:**
  - Fast timing information from scintillation light



ND-LAr detector

ArgonCube 2x2 Demonstrator

- Ton-scale LAr TPC detector → verify technical readiness of the ND-LAr TPC module design
- Four LAr TPC modules in a 2 x 2 grid and a shared high-purity LAr bath
- To be operated in the NuMI beamline → **First DUNE detector to take neutrino events**

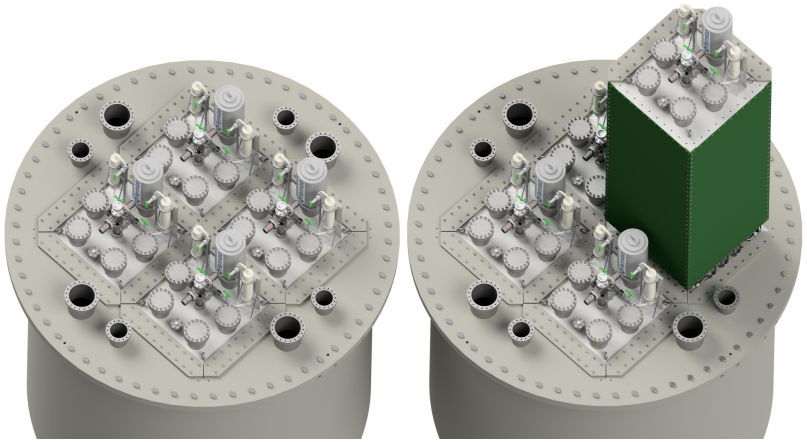
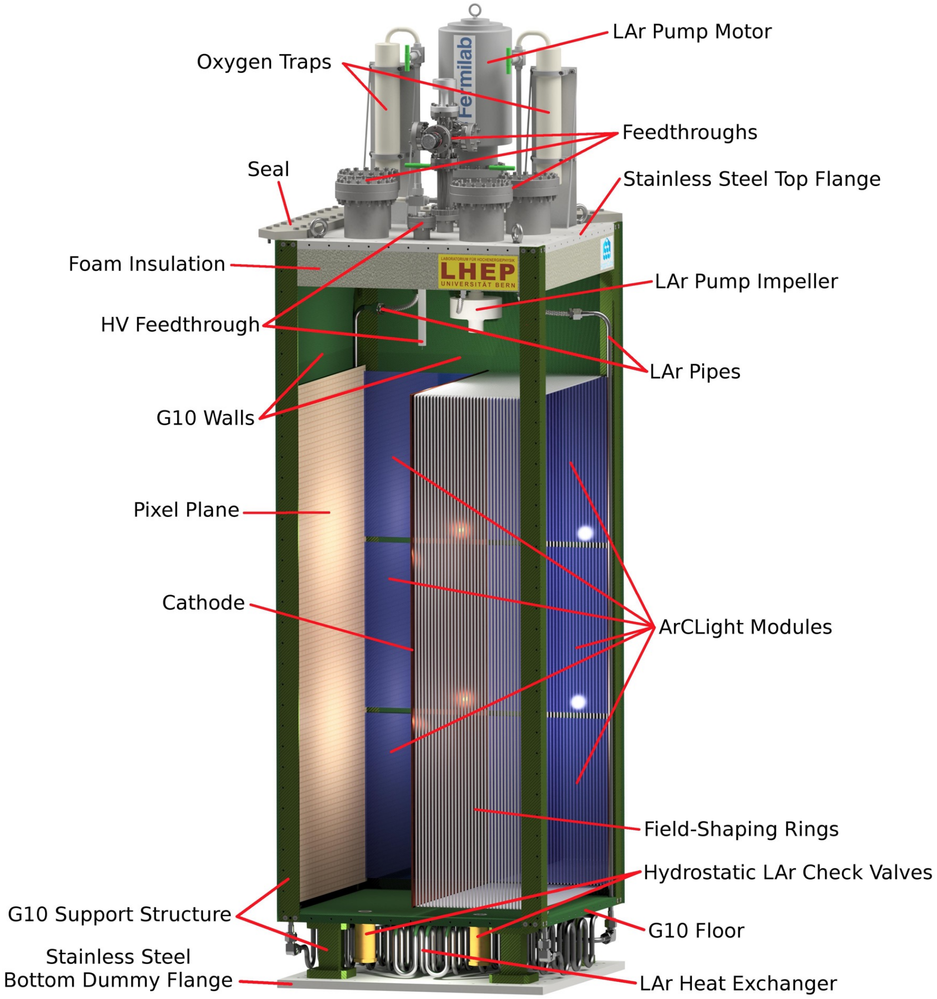


Illustration of the ArgonCube 2x2 Demonstrator module

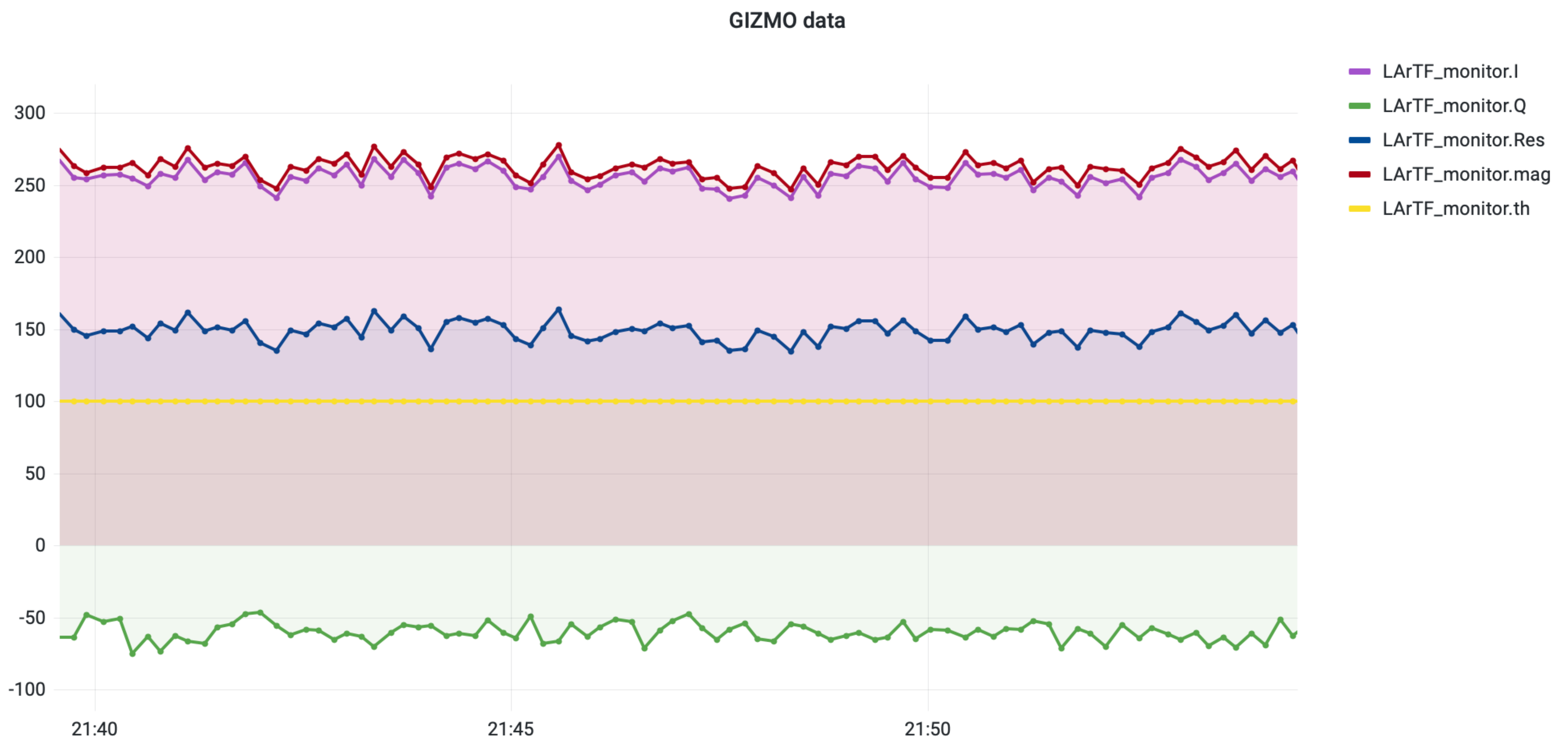


Cutaway drawing of ArgonCube module for the 2x2 Demonstrator

Project tasks I

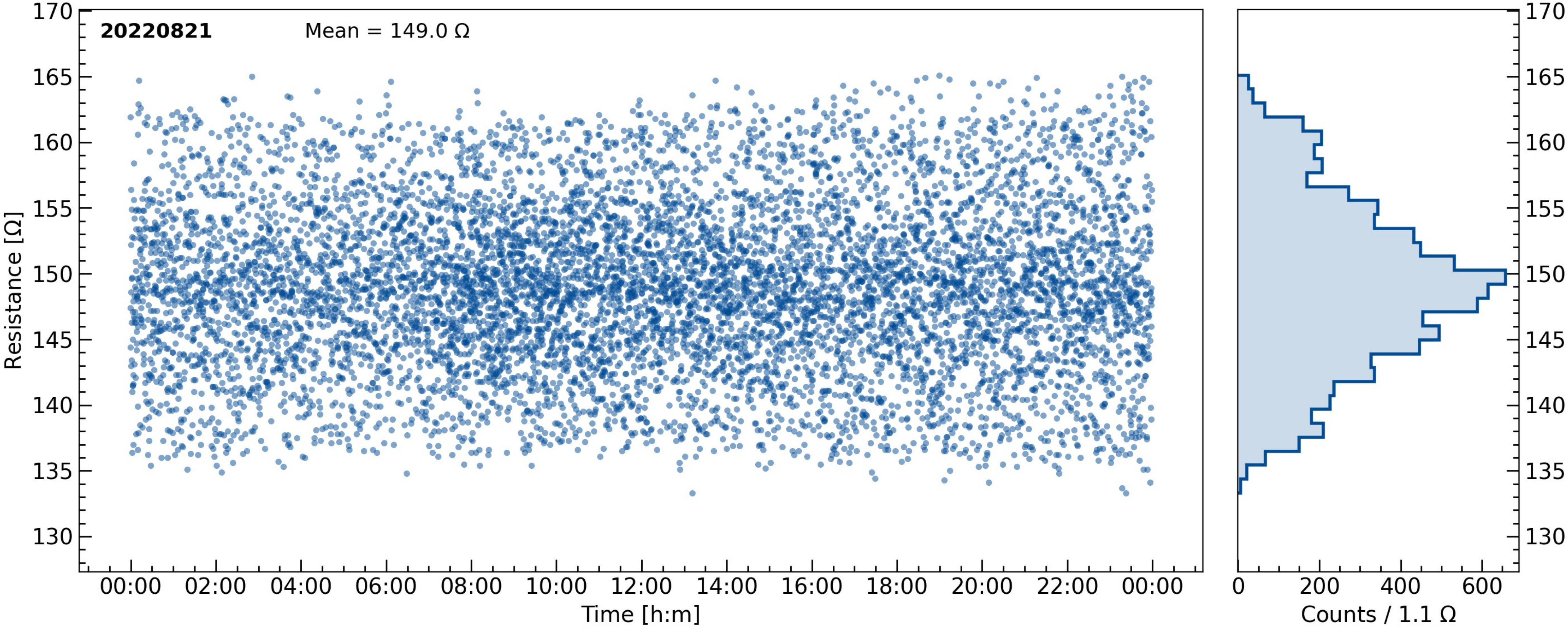
- ArgonCube 2x2 modules tested in the Liquid Argon Test Facility (LArTF)
- Characterization measurement of the Ground Current Impedance Monitor (GIZMO)
- GIZMO slow control:
  - Read GIZMO and save data on database **InfluxDB**
  - Live monitoring through **Grafana**

Impedance Monitor Control



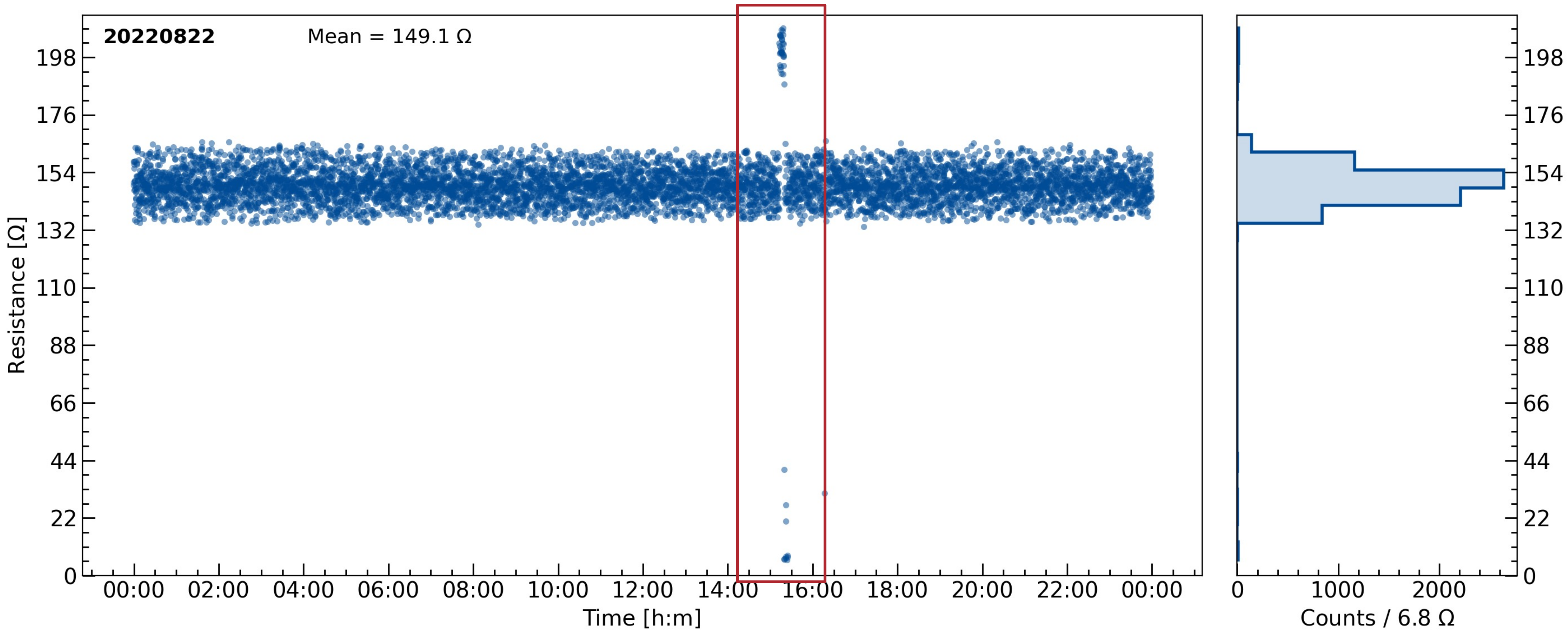
Impedance Monitor Control

Python script reading data from InfluxDB: 24 hours summary plot of the measured impedance.



Impedance Monitor Control

24 hours summary plot of the measured impedance → **identify potential ground shorts.**



Project tasks II

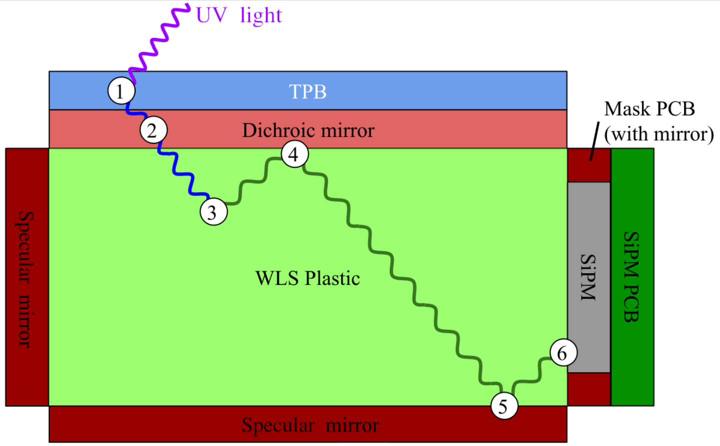
- ArgonCube 2x2 modules tested in the Liquid Argon Test Facility (LArTF)
- Characterization measurement of the Ground Current Impedance Monitor (GIZMO)
- GIZMO slow control:
  - Read GIZMO and save data on database **InfluxDB**
  - Live monitoring through **Grafana**

- Light Readout System (LRS) QA/QC tests
- LED calibration run analysis

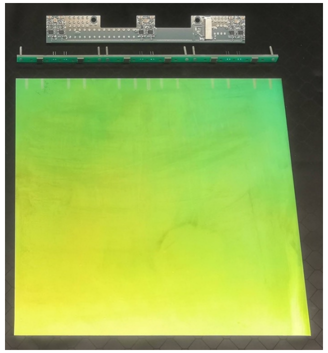
2x2 Light Readout System (LRS)

Two comparable Silicon Photomultiplier (SiPM)-based systems sharing the same readout electronics:

- **ArgonCube Light detector** (ACL)

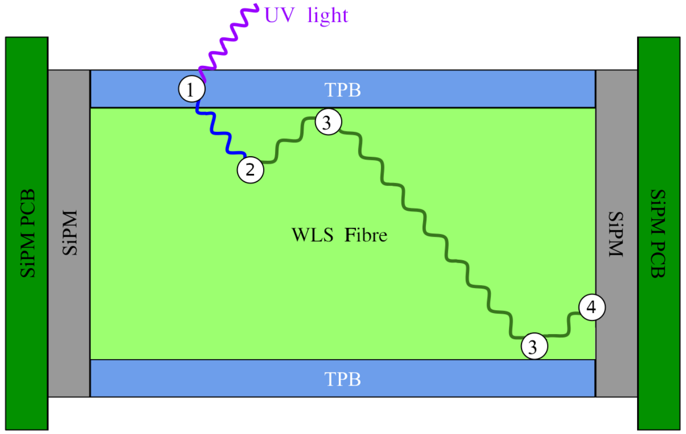


Schematics illustrating the working principle of an ACL module [3]



ArCLight

- **Light Collection Module** (LCM)



Schematics illustrating the working principle of an LCM module (only one fiber) [3]

LCM

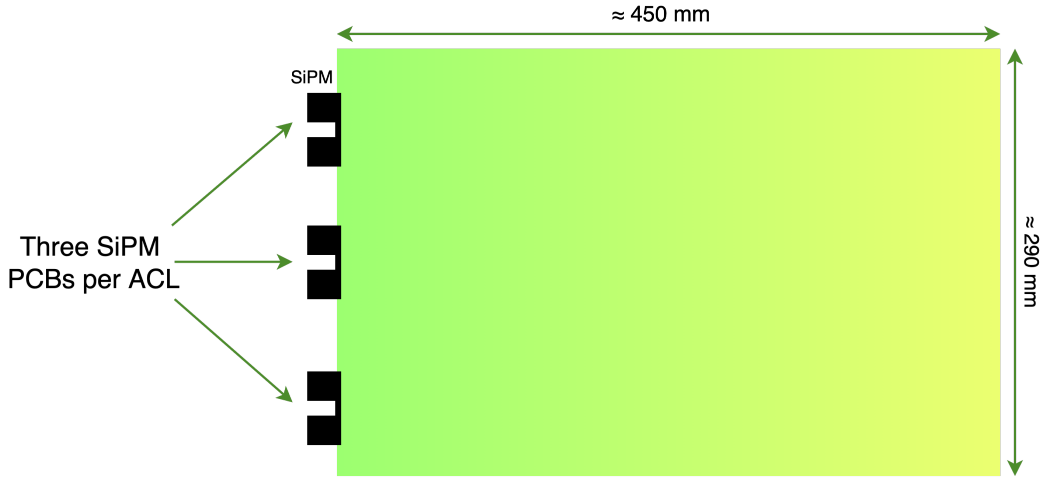
- Dielectric light trap: bar
- Accurate scintillation **position reconstruction**

- Dielectric light trap: fibers
- High **collection efficiency**

2x2 Light Readout System (LRS)

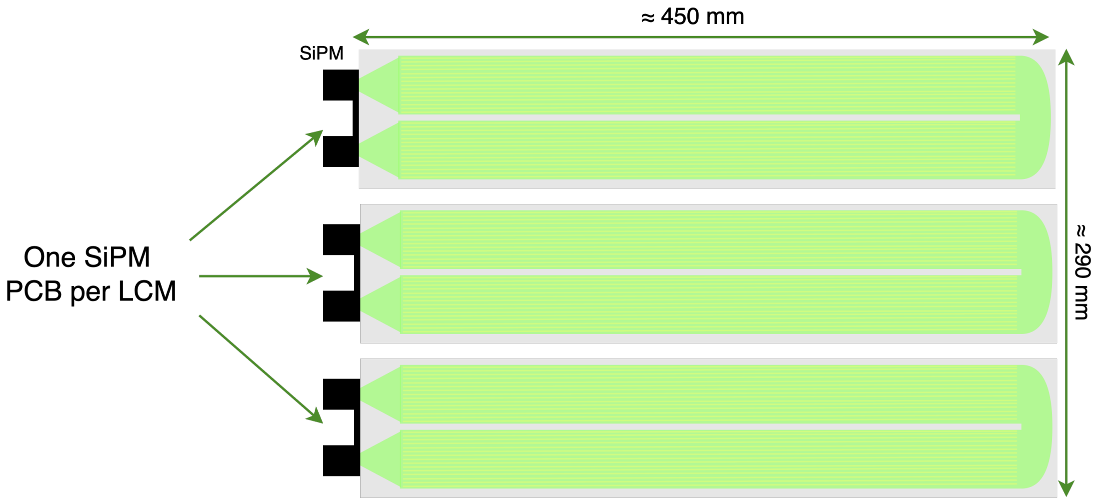
Each 2x2 demonstrator module hosts:

- **8 ArCLight tiles**



- Two SiPMs per Printed Circuit Board (PCB)
- Six SiPMs per ArCLight

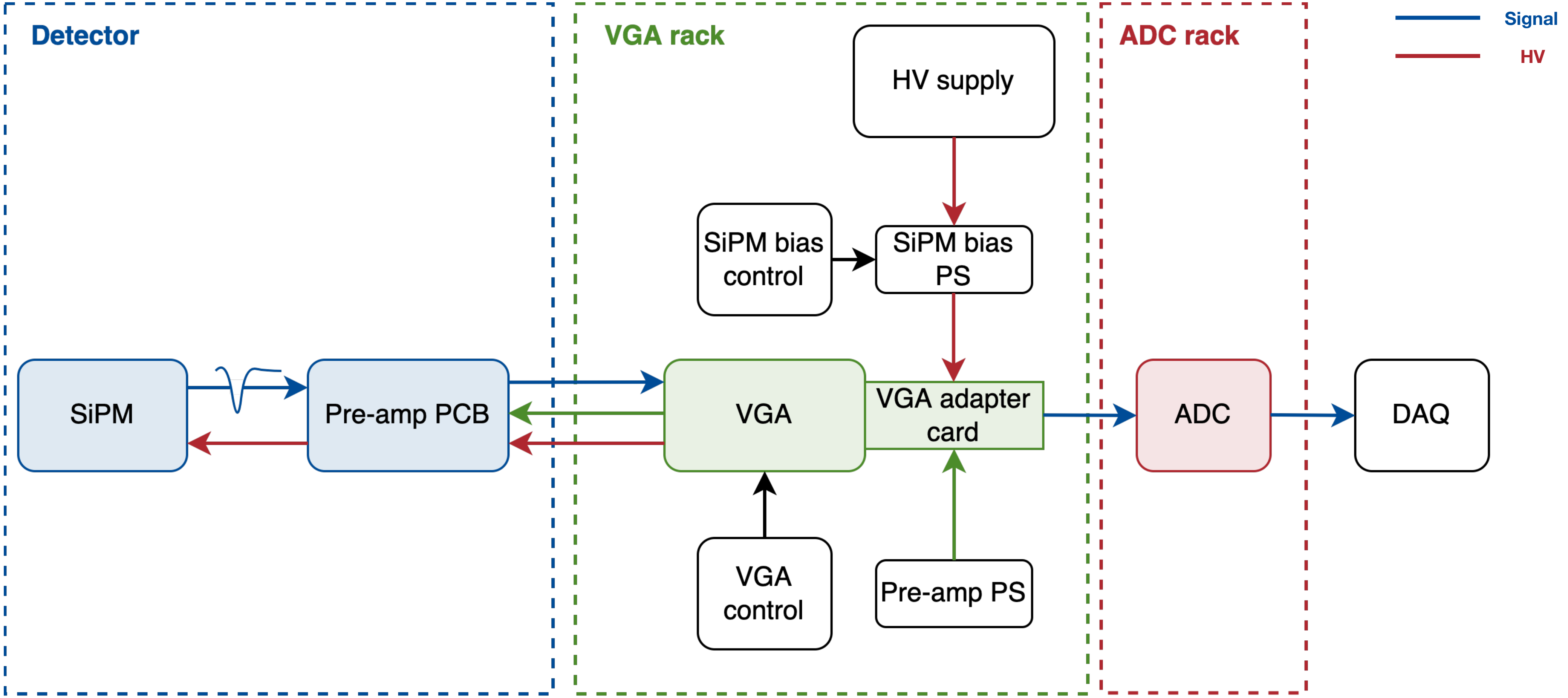
- **24 LCM tiles**



- Three LCM tiles per array
- Six SiPMs per LCM array

LRS electronics overview

1 module : 96 SiPMs : 16 E-boards : 4 Variable Gain Amplifiers (VGAs) : 2 Analog-to-Digital-Converters (ADCs)



Current setup at LArTF

QA/QC procedure

- **Pre-test**:
  - Measure current draw of pre-amplifier boards (E-boards) and test connections between readout (R/O) and detector electronics
  - Power up VME crates with VGAs, ADCs, control boards and verify communication with all R/O electronics devices
- **Full chain test**:
  - Test of full readout chain from SiPM to DAQ server
  - All devices (VGA, ADC, SiPM bias supply) powered up and configured
  - Check single photo electron (p.e.) noise on the ADC oscilloscope
- **LED calibration run**
  - Calibration LEDs: test the response of each single SiPM channel
  - Measure SiPM gain by running at single photon regime

Pre-tests

- Measure pre-amp current draw for each (set of) E-boards
- +5 V and -5 V provided by PS module
- Expected ≈ 68 mA per E-board channel
  - → 4 x 68 mA = 272 mA per adapter card
  - → 16 x 68 mA = 1.088 A for all E-boards
- Sum current not as expected → test individual E-boards
- Verify integrity of cable connections between VGA adapter and single E-boards
- Power up VME crates with VGAs, ADCs, control boards

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- Sum current not as expected → test individual E-boards
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- Power up VME crates with VGAs, ADCs, control boards

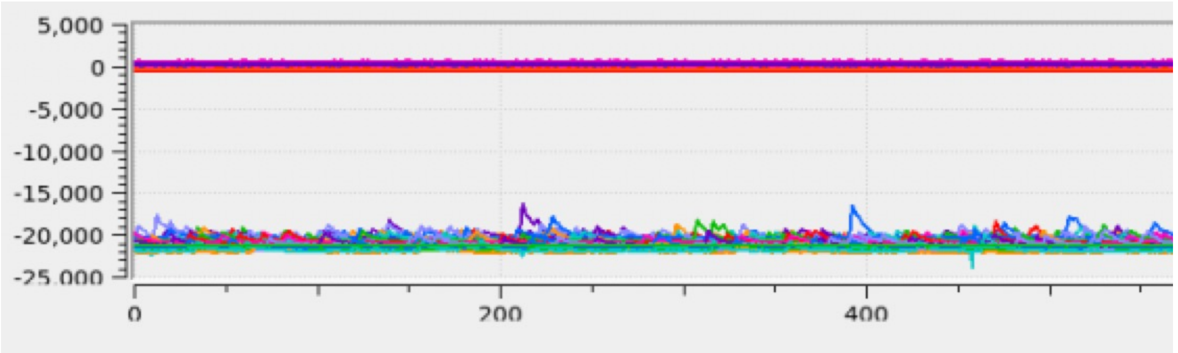
Module 1 results:

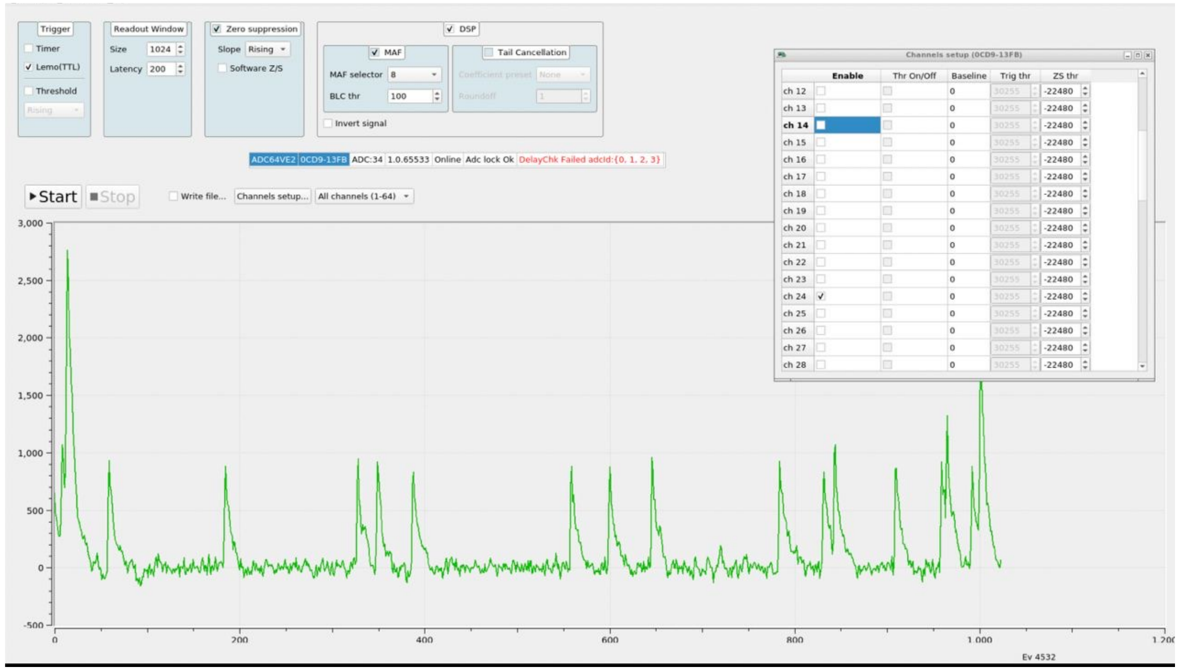
All current draw measurements **consistent with expectations**

Integrity of cable connections is verified

Full chain tests

- Test of full readout chain from SiPM to DAQ server
- Establish communication and configure VGAs, ADCs and SiPM bias control board
- Ramp up SiPMs bias voltage to 90-100 V
- Trigger via pulse generator
- Output voltage on SiPM bias board (~ 57V in warm / ~ 46V in cold)
- Check each channel for **single p.e. noise**





Full chain tests

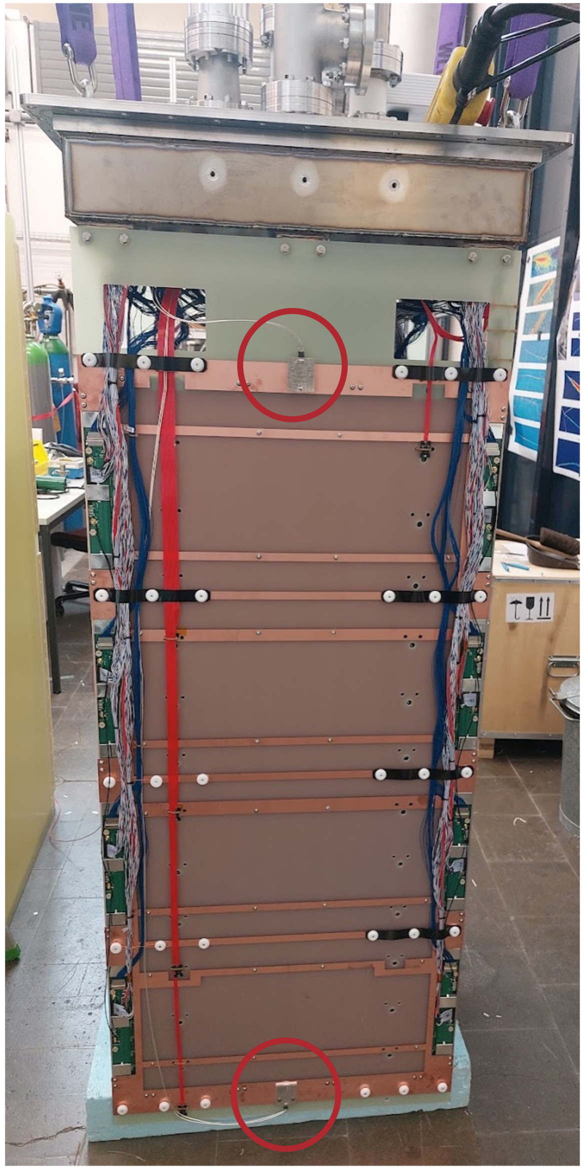
- Test of full readout chain from SiPM to DAQ server
- Establish communication and configure VGAs, ADCs and SiPM bias control board
- Ramp up SiPMs bias voltage to 90-100 V
- Trigger via pulse generator
- Output voltage on SiPM bias board (~ 57V in warm / ~ 46V in cold)
- Check each channel for **single p.e. noise**

Module 1 results:
LRS system successfully tested

No more dead channels compared to the Bern runs were found

LED calibration run

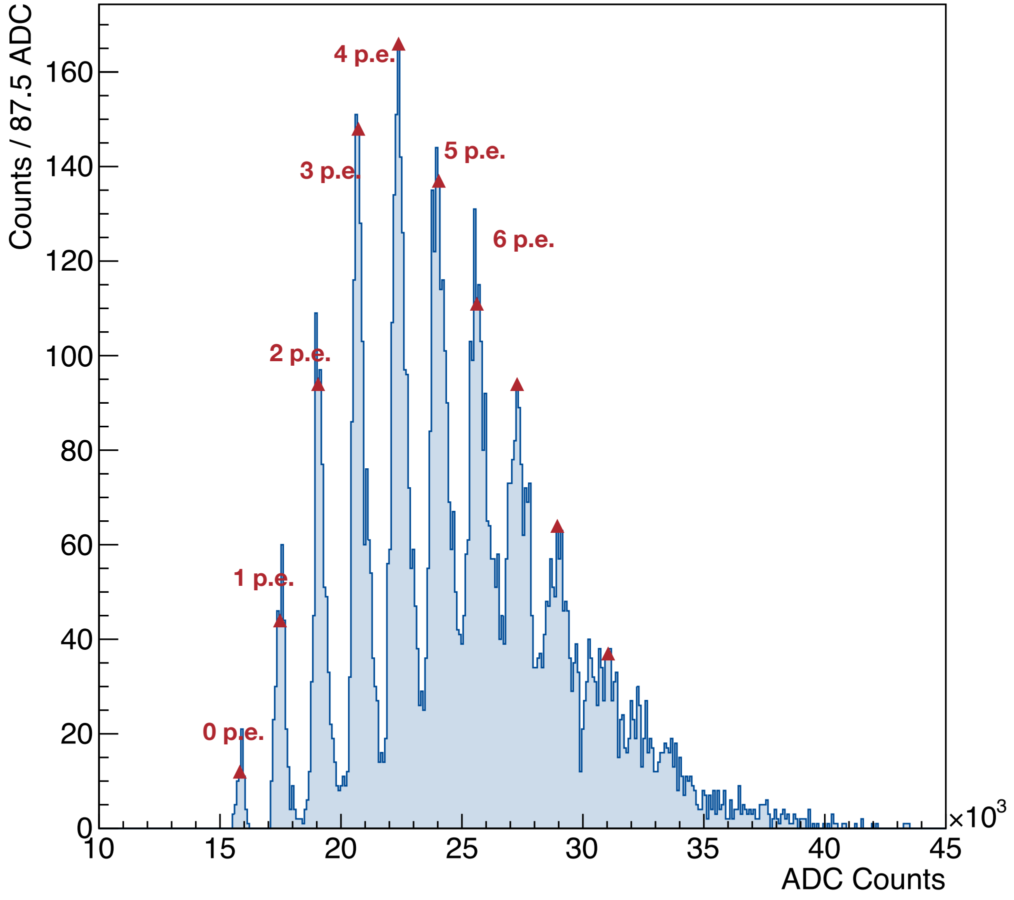
- **For final QA/QC tests**
- Two blue LEDs on top and bottom of each TPC
- DAQ runs for each LED position with different amplitude settings → choose which LED to trigger
- Extract gain factor by studying single p.e. spectrum for each SiPM
- Tool to quickly perform this analysis during QA/QC tests → verify the proper operation of all ADC channels



SiPM charge spectrum

Find peaks

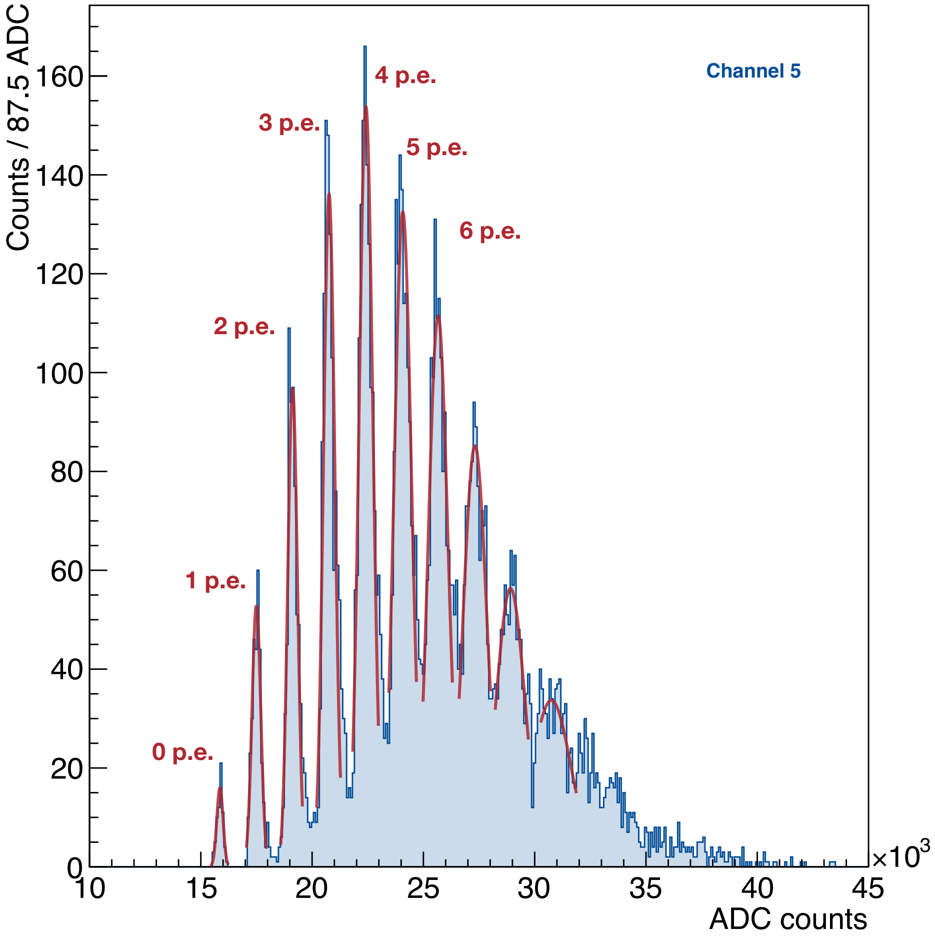
- ROOT TSpectrum to search for peaks
- Define threshold ($\gtrsim$ 0.05 × highest peak)
- Get peaks x-axis position
  - Input parameter



SiPM charge spectrum

Fit peaks

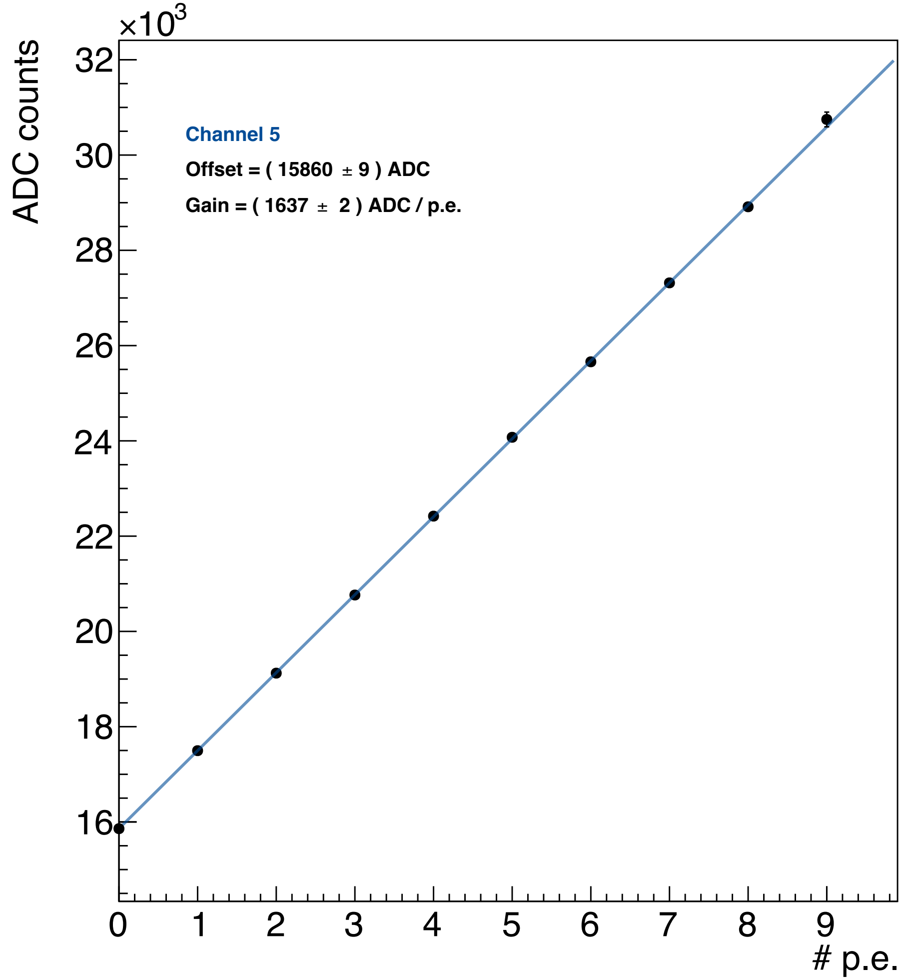
- ROOT TSpectrum to search for peaks
- Define threshold ($\gtrsim$ 0.05 × highest peak)
- Get peaks x-axis position
  - Input parameter
- Perform **Gaussian fit**
  - Extrapolate mean and standard deviation

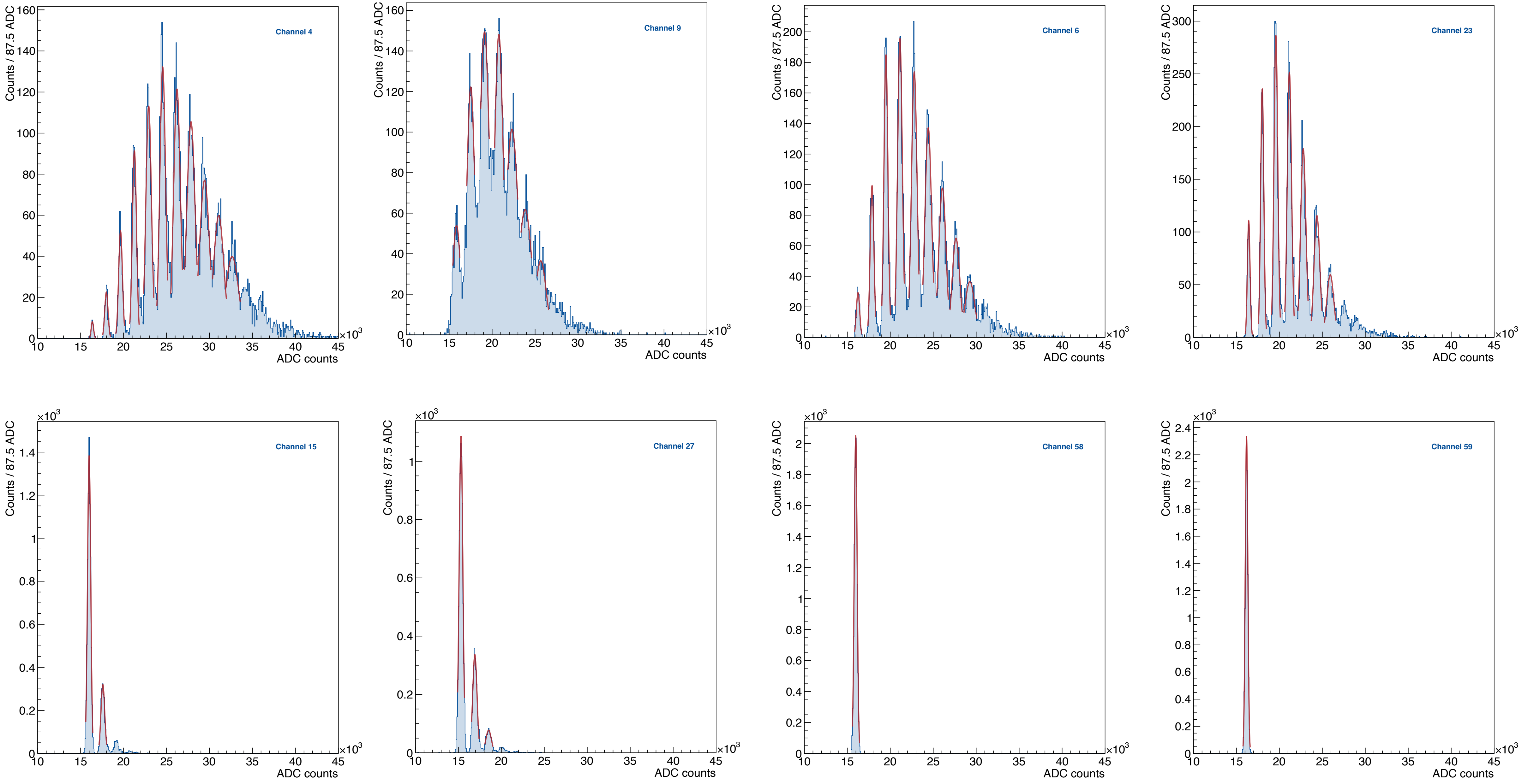


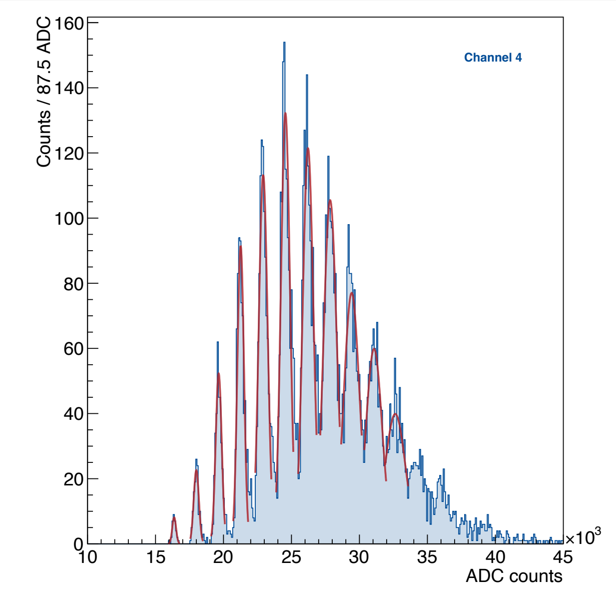
SiPM charge spectrum

Gain factor

- ROOT TSpectrum to search for peaks
- Define threshold ($\gtrsim$ 0.05 $\times$ highest peak)
- Get peaks x-axis position
  - Input parameter
- Perform **Gaussian fit**
  - Extrapolate mean and standard deviation
- Linear fit: slope → single channel **gain** factor



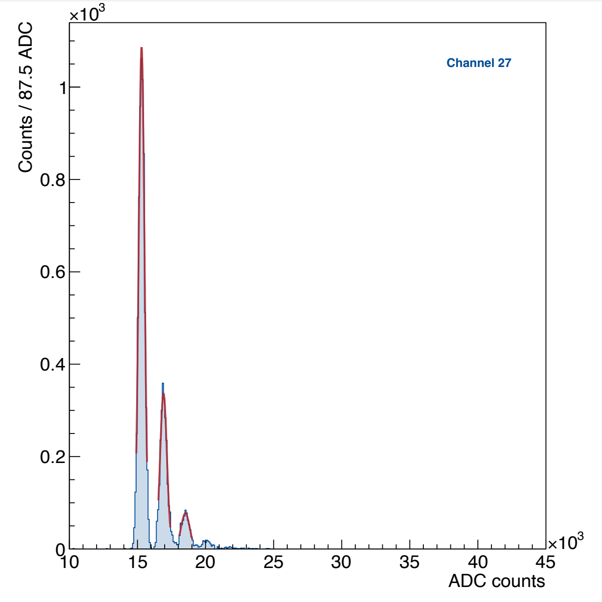

Channel 4
Channel 9
Channel 6
Channel 23
Channel 15
Channel 27
Channel 58
Channel 59
Counts / 87.5 ADC
ADC counts
×10³



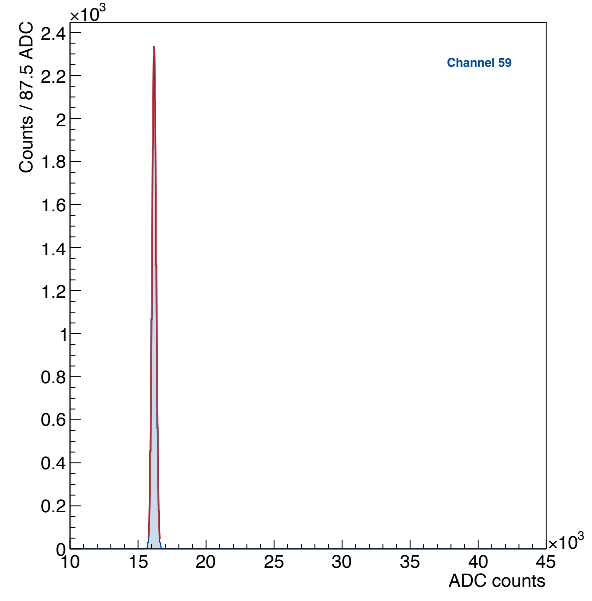
Modules close to LED → Clean spectrum with several p.e. peaks

Note: some channels are inactive → empty histograms

Modules far from LED → Small number of p.e. peaks

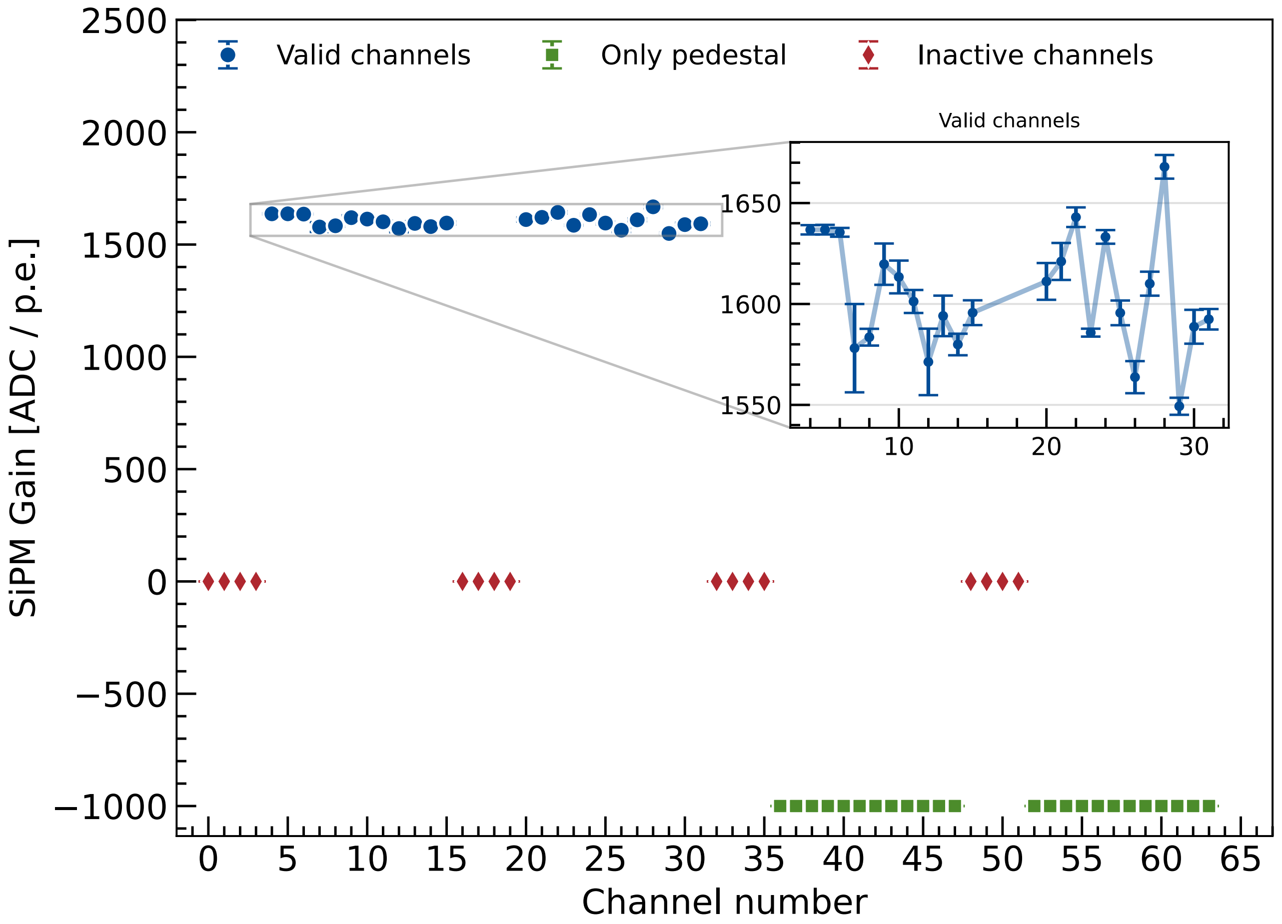


Modules in the other TPC → Only pedestal (no LED is triggered)



SiPM gain distribution

- Output csv file:
  - Channel number, number of p.e. peaks found, fit parameters
  - Inactive channels gain set to 0
  - Only pedestal gain set to -1000
- SiPM gain vs channel number
  - Highlight possible dead channels
  - Check if gain is in expected range (depends on individual run settings)



LRS cabling scheme

VIEW FROM INSIDE TPC

ADC channel numbering here starts from 1 as in adc-64 program

In the data and adc-64-system numbering starts from 0!

NORTH TPC 1 | negZ

DAC ch	ADC chan	sum	ADC chan glob	Cable	E-Board	LED: UV A3, BLUE A4		E-Board	Cable	ADC chan glob	sum	ADC chan	DAC ch	DAC ch	AD
18,19	15,16		79,80			LCM-118	LCM-106			95,96		31,32	30,31	122,123	4
16,17	13,14	175 / 47	77,78	NL4	EL-106	LCM-117	LCM-105	ER-106	NR8	93,94	173 / 45	29,30	28,29	120,121	4
14,15	11,12		75,76			LCM-116	LCM-104			91,92		27,28	26,27	118,119	4
18,19	15,16		15,16							31,32		31,32	30,31	58,59	4
16,17	13,14	143 / 15	13,14	NL3	EL-102	ACL-103	ACL-104	ER-102	NR7	29,30	141 / 13	29,30	28,29	56,57	4
14,15	11,12		11,12							27,28		27,28	26,27	54,55	4
12,13	9,10		73,74			LCM-115	LCM-103			89,90		25,26	24,25	116,117	4
10,11	7,8	176 / 48	71,72	NL2	EL-105	LCM-114	LCM-102	ER-105	NR6	87,88	174 / 46	23,24	22,23	114,115	3
8,9	5,6		69,70			LCM-113	LCM-101			85,86		21,22	20,21	112,113	3
12,13	9,10		9,10							25,26		25,26	24,25	52,53	4
10,11	7,8	144 / 16	7,8	NL1	EL-101	ACL-101	ACL-102	ER-101	NR5	23,24	142 / 14	23,24	22,23	50,51	3
8,9	5,6		5,6							21,22		21,22	20,21	48,49	3
						LED: UV A2, BLUE A1									

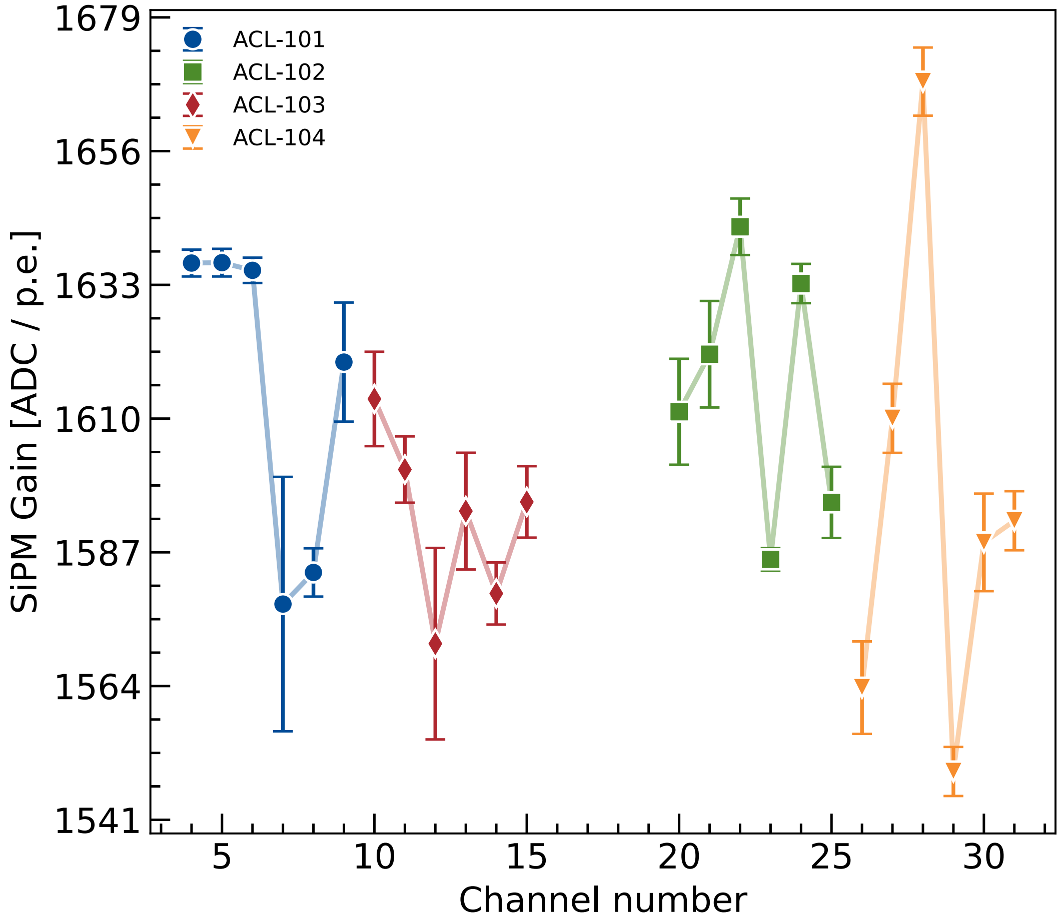
han glob	sum	ADC chan	DAC ch
7,128		63,64	70,71
5,126	189 / 61	61,62	68,69
3,124		59,60	66,67
3,64		63,64	6,7
1,62	157 / 29	61,62	4,5
9,60		59,60	2,3
1,122		57,58	64,65
9,120	190 / 62	55,56	126,127
7,118		53,54	124,125
7,58		57,58	0,1
5,56	158 / 30	55,56	62,63
3,54		53,54	60,61

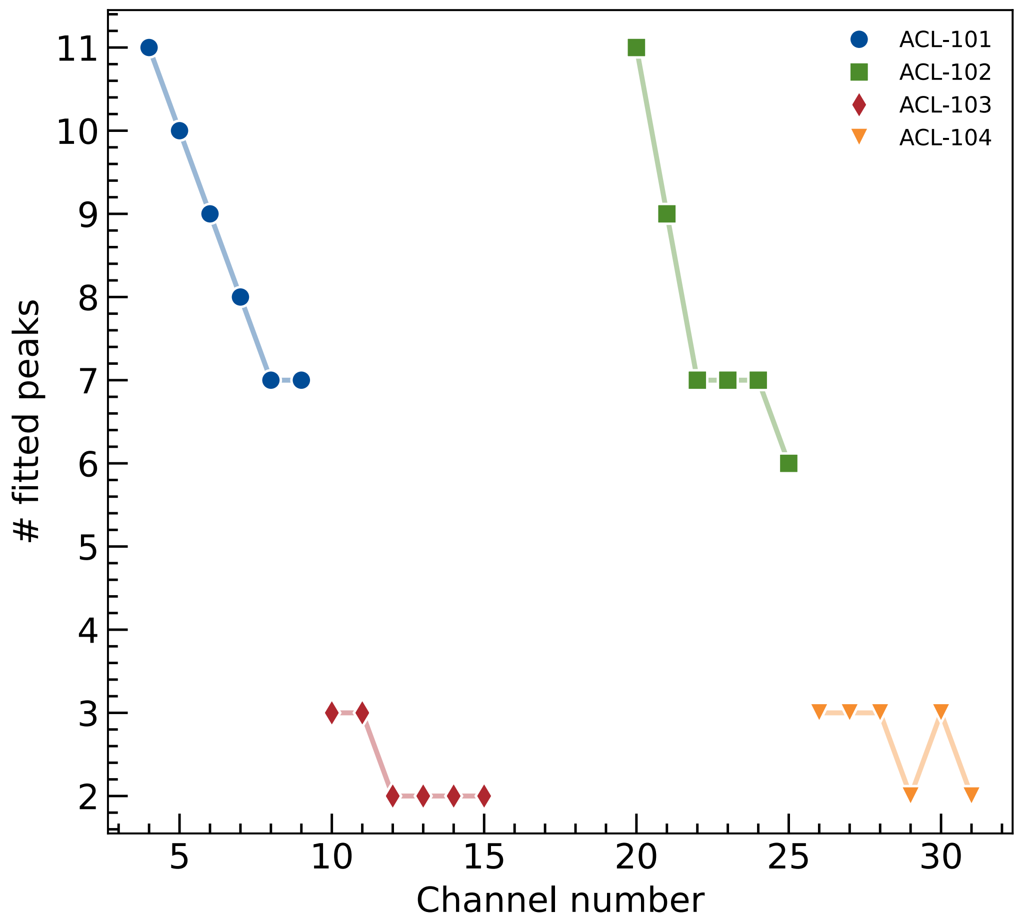
ADC chan	LED: UV A3, BLUE A4		ADC chan
15,16	LCM-118	LCM-106	31,32
13,14	LCM-117	LCM-105	29,30
11,12	LCM-116	LCM-104	27,28
15,16			31,32
13,14	ACL-103	ACL-104	29,30
11,12			27,28
9,10	LCM-115	LCM-103	25,26
7,8	LCM-114	LCM-102	23,24
5,6	LCM-113	LCM-101	21,22
9,10			25,26
7,8	ACL-101	ACL-102	23,24
5,6			21,22
	LED: UV A2, BLUE A1		

- Check connections ADC channel – LRS modules
- In this case: **LED A1** used

SiPM gain distribution

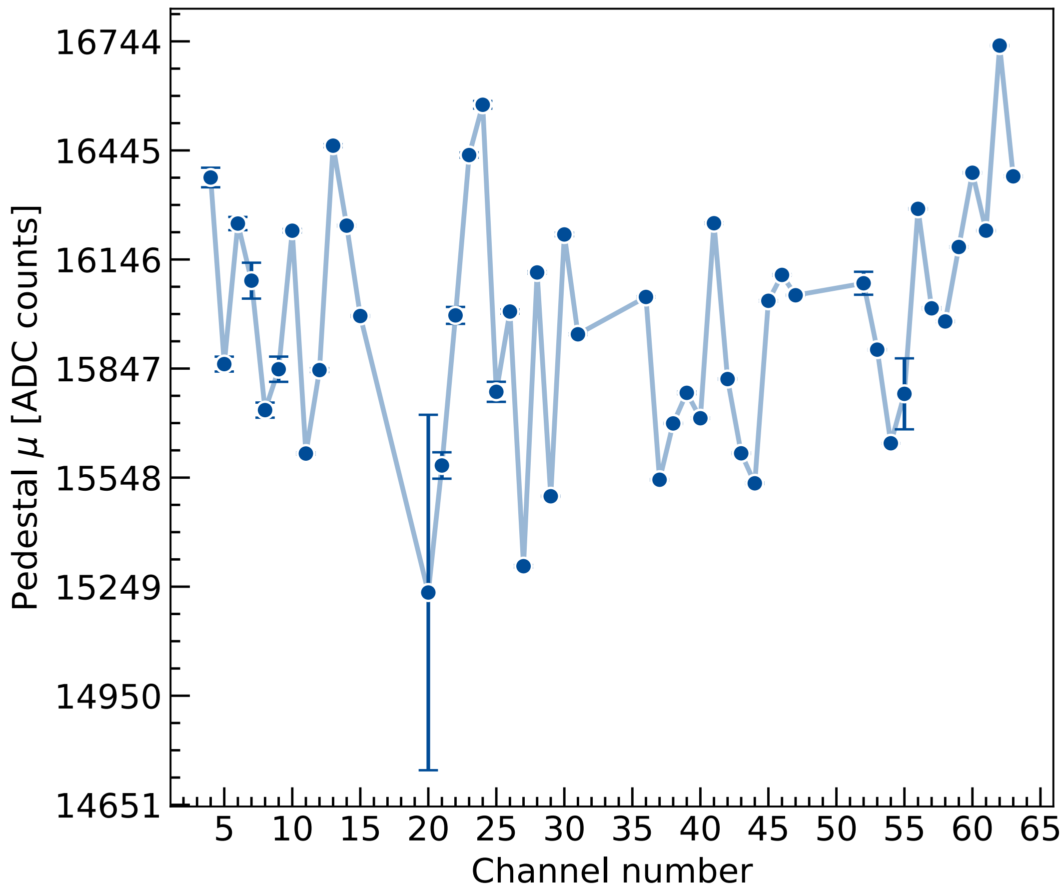
- ACL101 and ACL102 show the highest light yield → consistent with expectations

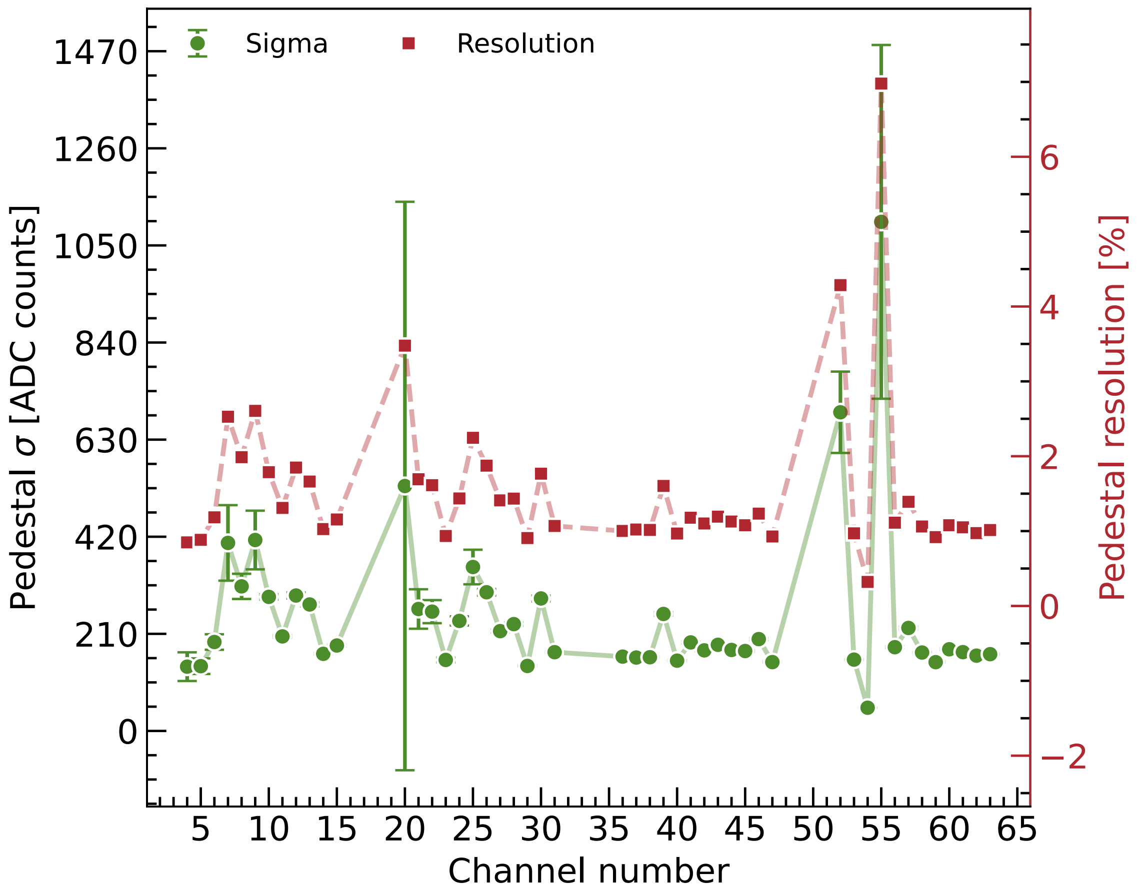




Pedestal analysis

- Compare **pedestal** centroid and sigma to highlight outliers or strange behaviors.





Summary

- Characterization of the Ground Current Impedance Monitor (GIZMO)
- Real-time monitoring of the impedance Detector/Building grounds

- Light Readout System QA/QC tests
- Developed a tool to perform the LED calibration analysis:
  - Extract SiPM gain
  - Identify possible malfunctioning channels

THANK YOU!

References

[1] “Deep Underground Neutrino Experiment (DUNE) Near Detector Conceptual Design Report”, arXiv 2103:13910

[2] ArgonCube Collaboration, C. Amsler et al., “ArgonCube: a novel, fully-modular approach for the realization of large-mass liquid argon TPC neutrino detectors”, Tech. Rep. CERN-SPSC-2015-009

[3] Berner, Roman Matthias (2021), ArgonCube – A Novel Concept for Liquid Argon Time Projection Chambers

[4] ArgonCube collaboration website, https://www.argoncube.org

[5] M. Auger, Y. Chen, A. Ereditato, D. Goeldi, I. Kreslo, D. Lorca et al., ArCLight – A Compact Dielectric Large-Area Photon Detector, Instruments 2 (2018) 3 [arXiv:1711.11409].

BACKUP

SiPM gain distribution

- LCM and ACL modules have different light yields
  - In each run the VGA gain and the LED amplitude are adjusted in order to be optimal for one of the two systems
  - Define different fit ranges and/or parameters

Same gain settings:
LCM has a higher light yield than ACL