Re[incontri] di Fisica Partenopea

The DarkSide-20k experiment

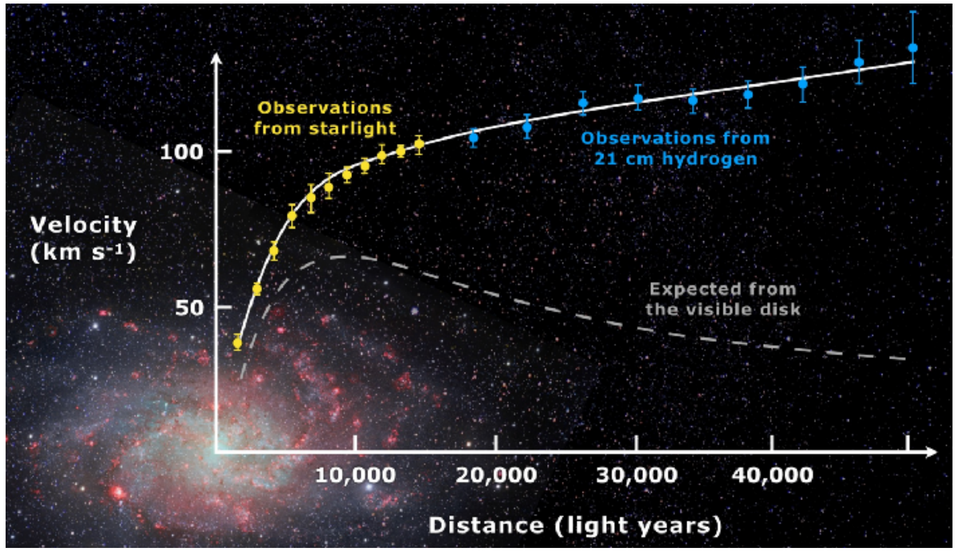
Yury Suvorov on behalf of Naples Group of Giuliana Fiorillo

19-21 December 2023, Dipartimento di Fisica "Ettore Pancini"

Direct dark matter search

The presence of the dark matter comes from different observations:

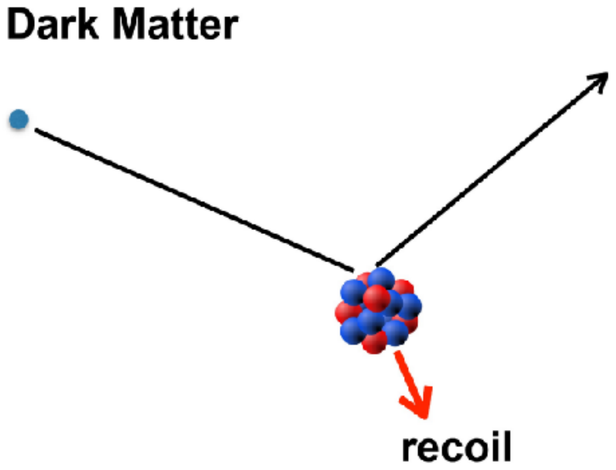
- ☆ Galactic rotation curves.
- ☆ Gravitational lensing.
- ☆ Anisotropy in relict radiation (Cosmic Microwave Background).



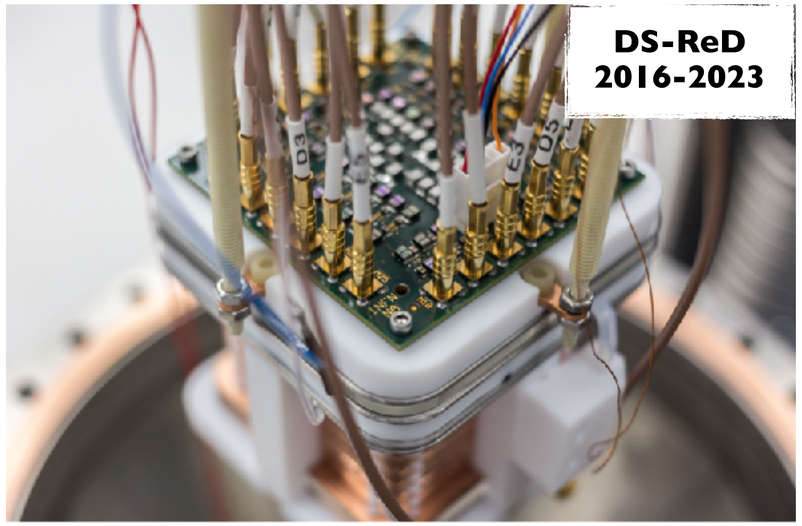
There is more mass in the Galaxies than the luminous matter (atoms).
It also has a different distribution: Dark Matter halo.

WIMP hypotheses: Weakly Interactive Massive Particle,

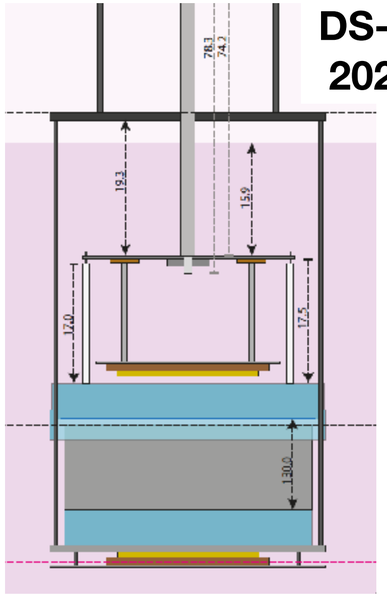
- ☆ Elastic scattering off target nucleus,
- ☆ Nuclear recoils 1-100 keV,
- ☆ Great target volume (t scale), ultra-low background (<1 event).

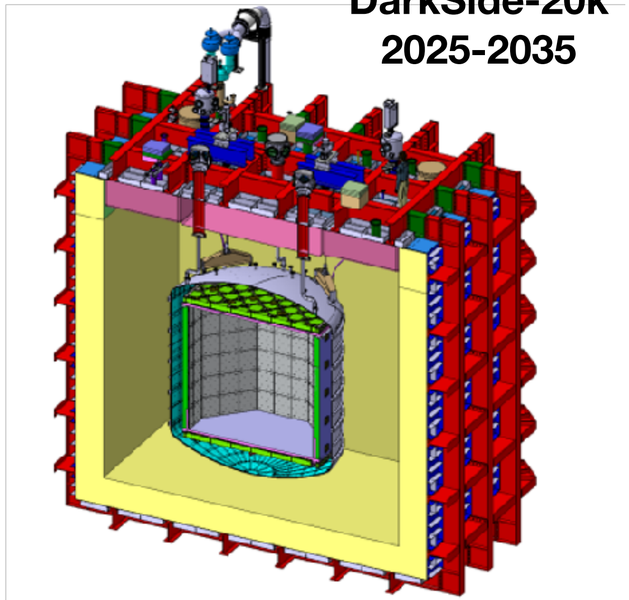


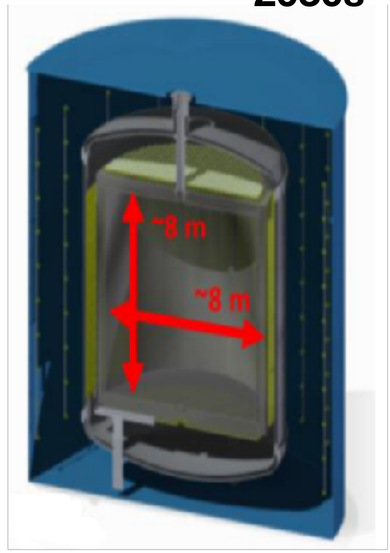
DarkSide project. 2010-2023 and beyond



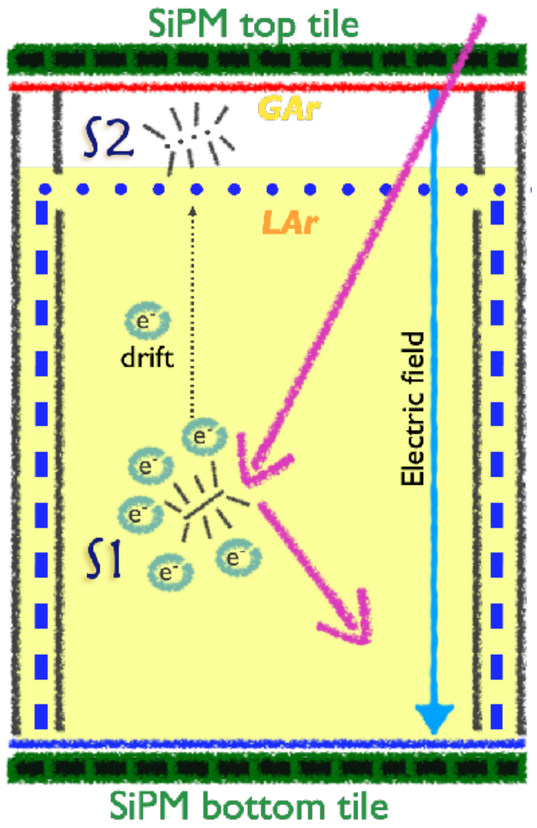
2017 - Global Argon Dark Matter Collaboration (GADMC) >400 scientists, >100 institutions distributed across 13 countries

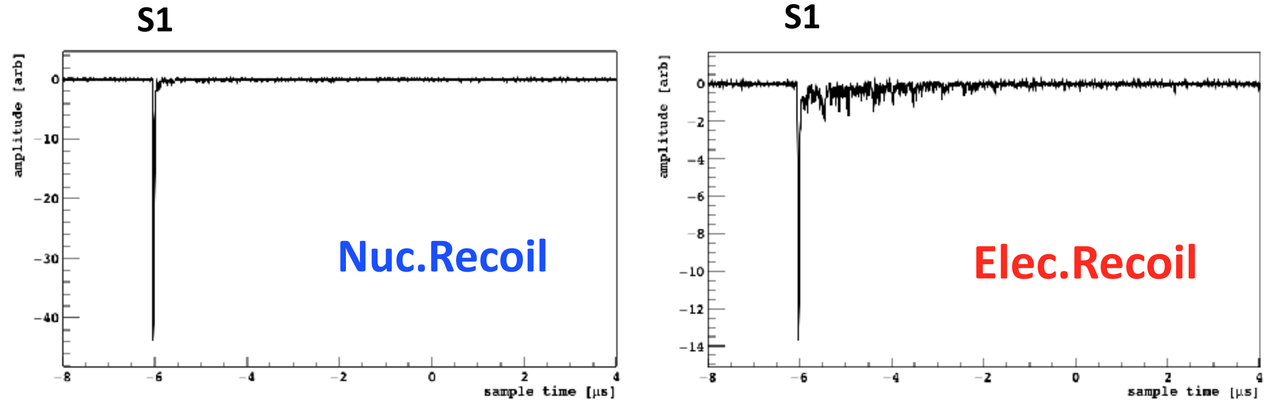




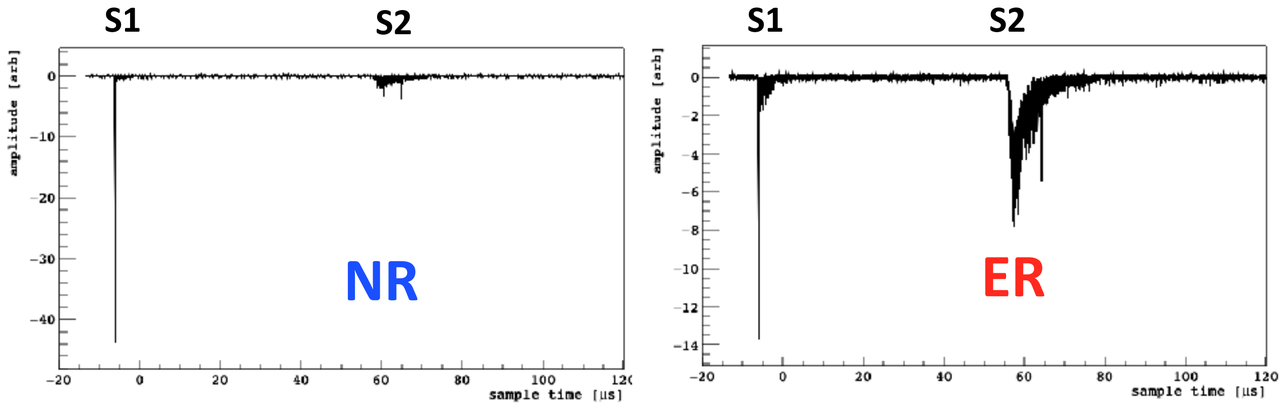


Detection Principle. Two phase TPC

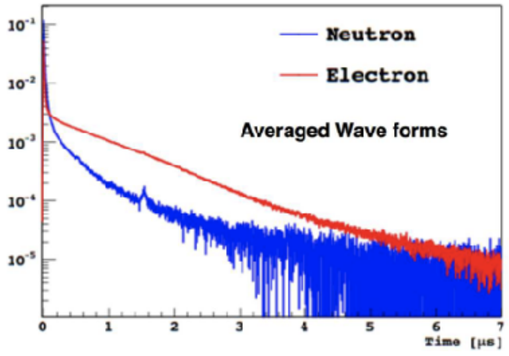




- X-Y position is determined by the top PMTs (*SiPM*) array with S2.



- Z position from drift time (*DS-50 max. drift time is 376 μs @ 200V/cm*).



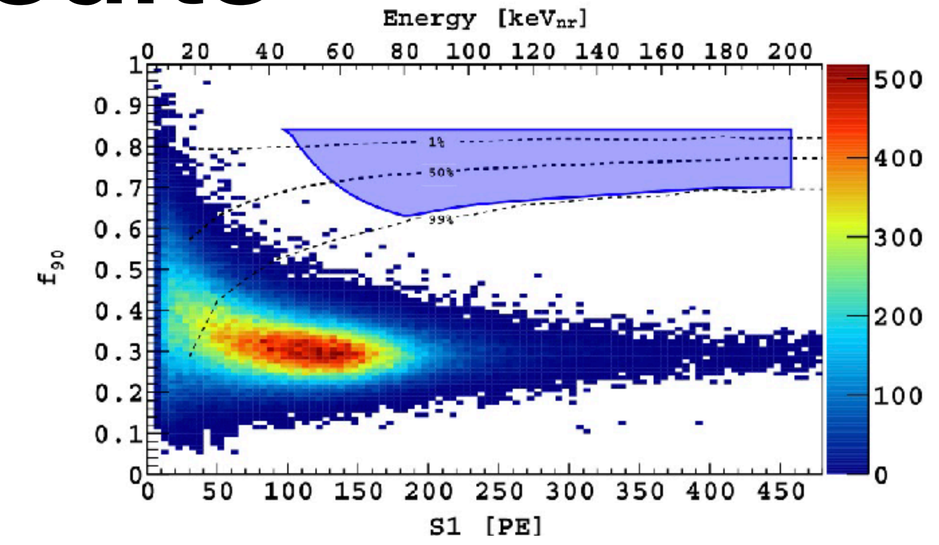
Pulse Shape Discrimination in LAr

Two time constants: 7 ns singlet & 1600 ns triplet. Temporal pulse shape of S1 (first 90 ns - f_{90}) provides powerful discrimination between NR & ER.

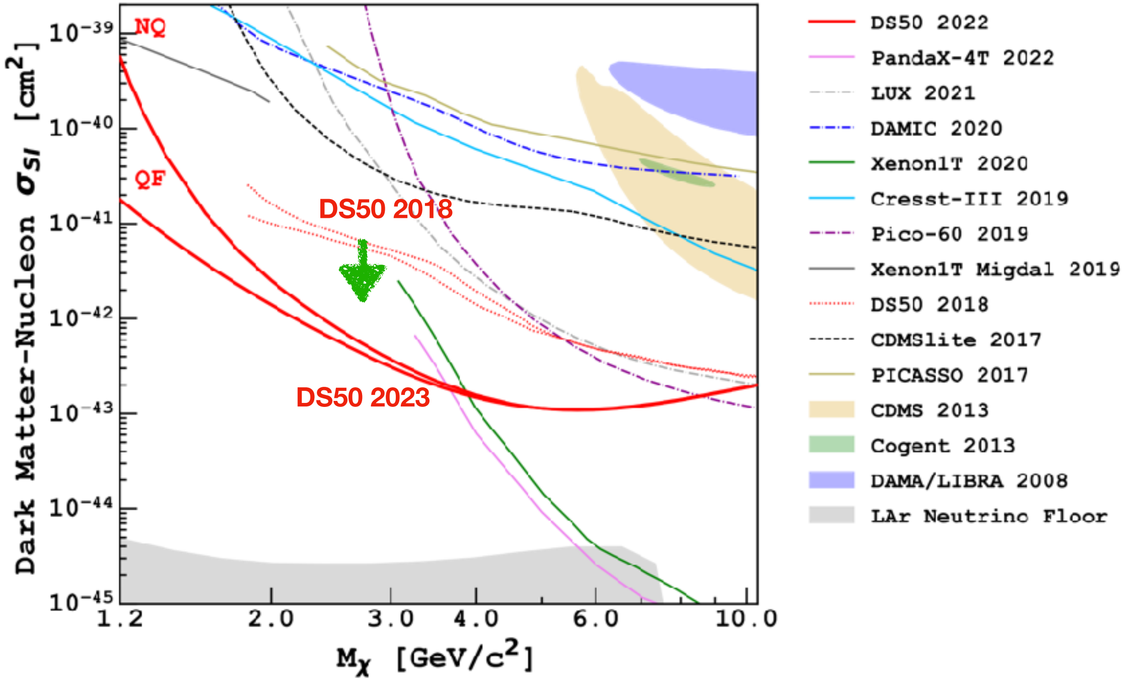
DarkSide-50 results

2015-2019

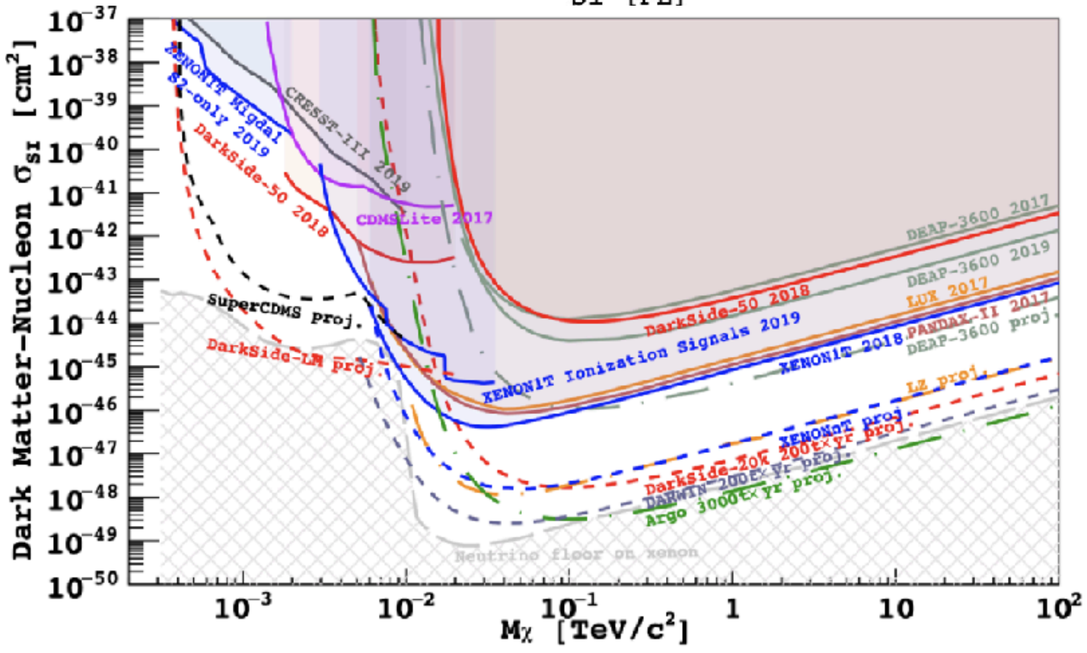
- Inner Detector: fiducial volume = (46.4 ± 0.7) kg
- Two veto detectors: LSV and WCD
- 532 live days x 46kg = (16660 ± 270)kg d exposure with UAr
- L.Y. ~ 8 p.e./keV based on zero field ^{83}Kr source data
- Background level < 0.1 in ROI for the full exposure
- 1.14 x 10^{-44} cm^2 90% CL limit on DM-Nucleon cross-section for 100 GeV/c^2 DM



2023: **New**, improved results for the mass rage < 10 GeV/c^2



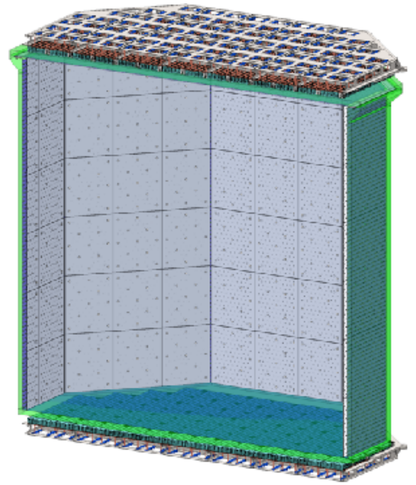
Physical Review D.107.063001 (2023)

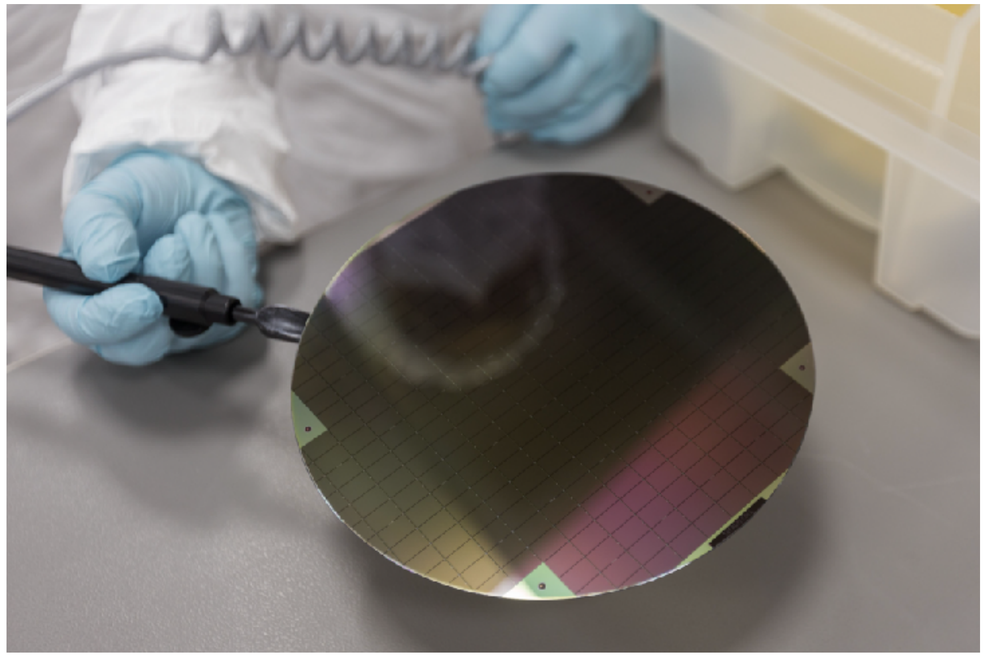


Physical Review D 98 (10), 102006 (2018)
Physical Review Letters 121 (8), 081307 (2018)

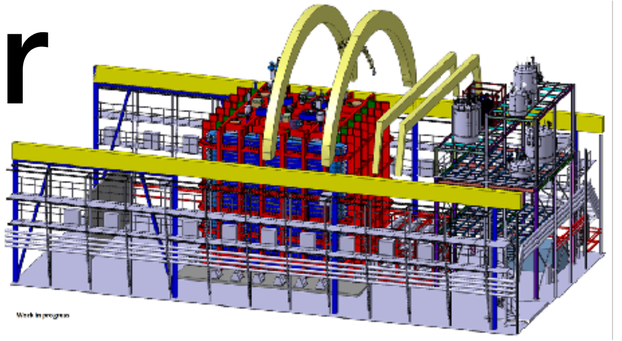
DarkSide-20k. New ingredients

- **Deep Underground Location ▹ INFN-LNGS (3800 m.w.e.) Italy**.
- **TPC** ▹ Two phase Time Projection Chamber (scintillation S1 + ionization S2).
- **PDU** ▹ SiPM array 20x20 cm^2 coupled with TPB coated PMMA panels.
- **Active n-veto** ▹ LAr (UAr) + Gd loaded acrylic + 128 PDUs.
- **Active μ-veto** ▹ LAr (AAr) + 32 PDUs.
- **UAr** ▹ Argon from underground sources, depleted in ^{39}Ar.

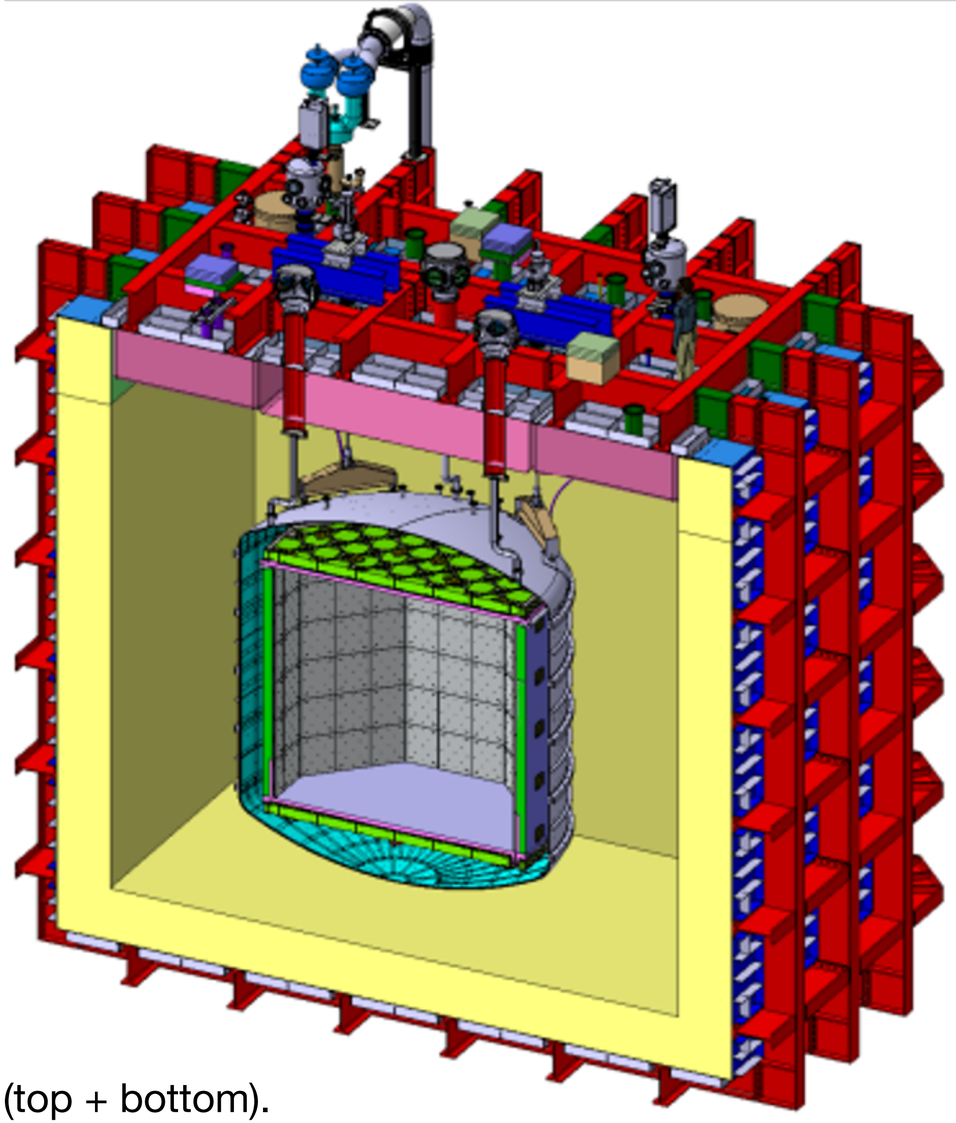


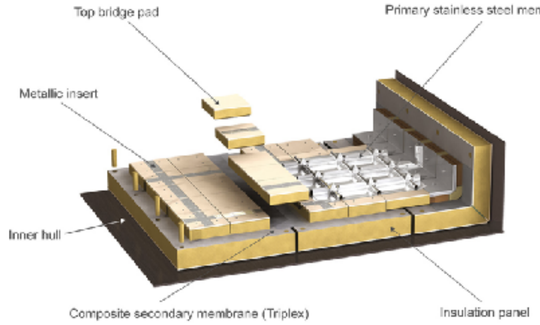


DarkSide-20k detector

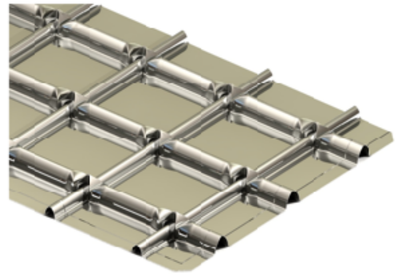


External cryostat: 8.5 x 8.5 x 8 m^3 vessel
Multilayer assembly (proto Dune like membrane)
Filled with 700 t of liquid AAr.
Active muon veto detector, equipped with SiPMs.





Stainless steel vessel: H:5.8 m & ID:4.7 m
Filled with 99 t of depleted in ^{39}Ar Argon (UAr)
Divided in two volumes:
- **Neutron Veto** (outside TPC).
- **TPC** inner volume.



Neutron veto detector:
Gd-loaded PMMA panels,
Equipped with 5 m^2 of SiPMs (vPDU).
Filled with 44 t of depleted in ^{39}Ar Argon (UAr).

TPC: 3 x 3 x 3 m octagonal vessel
Filled with 55.4 t of depleted in ^{39}Ar Argon (UAr)
Two optical planes, total SiPM coverage of **<u>21m²</u>** (top + bottom).

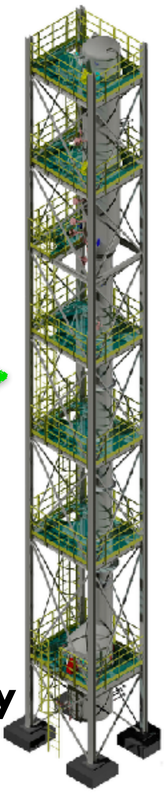
Low-radioactivity Argon. DS50- DS20k

- The ^{39}Ar gives 1Bq/kg of bkg events. Ar from the deep underground CO_2 sources. Exploration of wells in Cortez, **Colorado** USA (from 2009). First in situ extraction and enrichment plant, from **400ppm** to **5%**.
- **Colorado** ▻ **Fermilab** further purification in 3.2m tall cryogenic Distillation Column. The CO_2, O_2, N_2 and He all <100ppm. Final UAr purity **~99,96%**.
- UAr was shipped to LNGS, **Italy**. DS-50 fill with Zr getter, further recirculation with SAES hot getter.

Six Years Effort! 155 kg produced
The $(1.4\pm0.2)\times10^3$ less ^{39}Ar with respect to atmospheric Argon

Extraction - URANIA

110t of **UAr in needed**, same location of extraction (Cortez, Colorado, USA). A new industrial scale extraction plant with a production rate of 330 kg/day (90 ton/y) has already been built and is ready to be delivered to the site. Direct contribution from Naples group!



Purification - ARIA

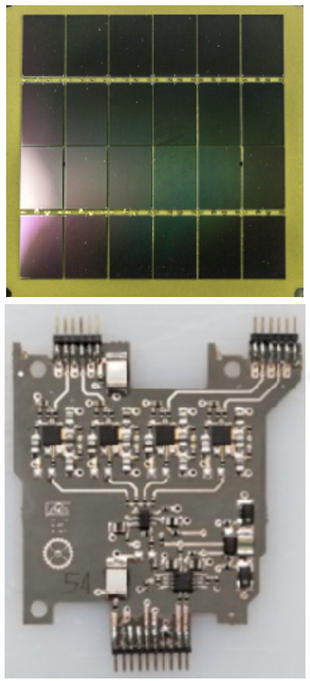
The **350m** tall (0.32 m inner diameter) distillation column to be installed in the coal mine well in Sardinia (ITALY).

Demonstrator column **Seruci-0** (**25m**) made of three modules (reboiler, condenser and middle module) was successfully tested in July-Oct 2019 with LN_2. Separation factor of 1.3 between Top and Bottom for the molecules ^{15}N-^{14}N & ^{14}N-^{14}N(***https://arxiv.org/pdf/2101.08686.pdf***).

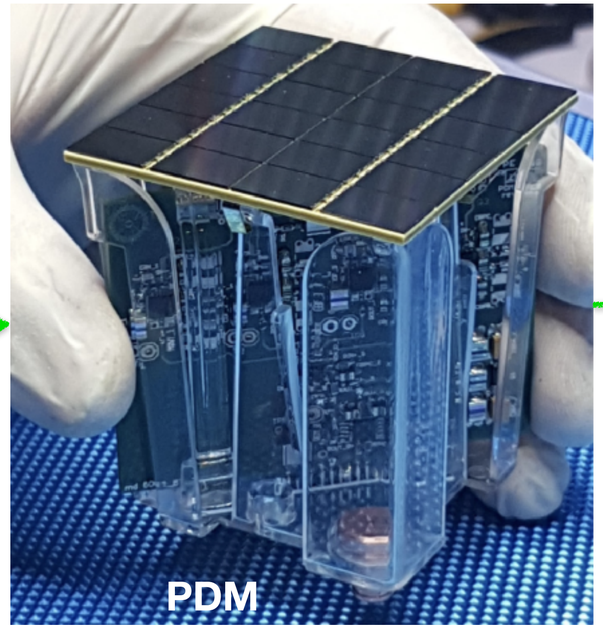
DS-20k. From PMT to SiPM

From PMTs to SiPMs. The customised NUV-HD-Cryo SPMs developed for LAr in collaboration with **F**ondazione **B**runo **K**essler. Overall size is 25x25 cm^2, weight ~5 kg, hight of 6 cm. Steering Module to distribute power and proved the communication with PDUs. Front-end cryogenic pre-amplifier with differential output.

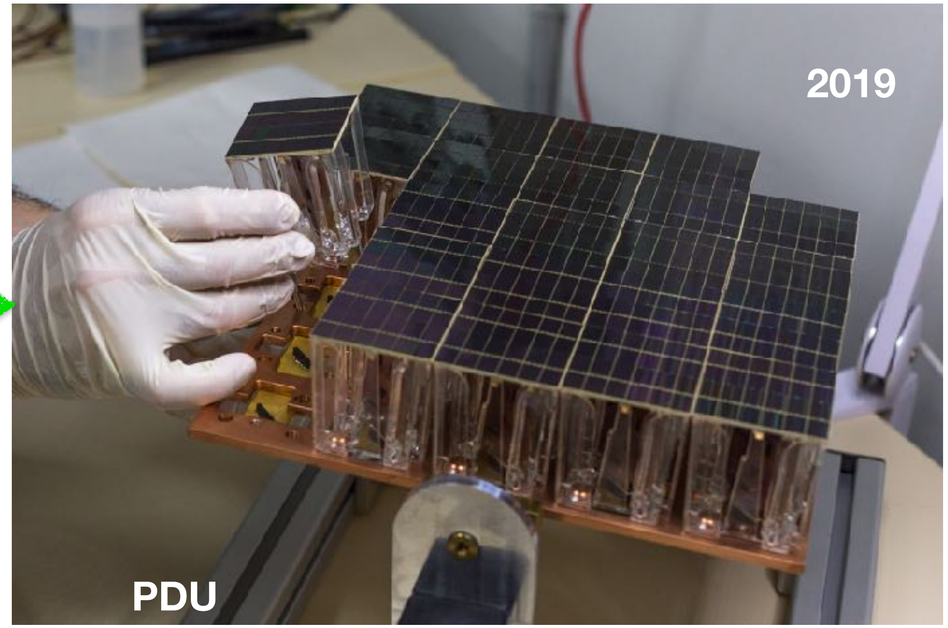
Room for improvement: *Three produced prototypes, tested @ LNGS (**2019**, LN), CERN (**2019**, LAr) and Naples **Cryolab** (**2021**, LN).*



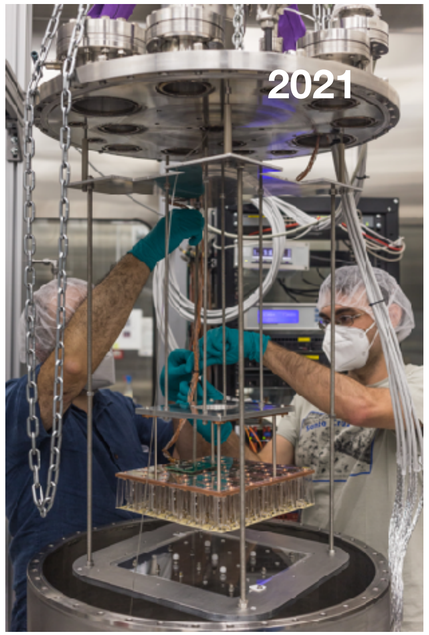
5x5cm SiPMs tile+FEB makes one PDM



25 PDMs make one Photo Detecting Unite (PDU)

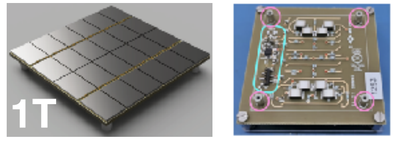


PDU LN test in Naples



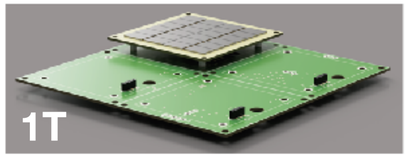
Wafer cryo-testing, cutting & assembly of the 5x5cm^2 tiles, wire-bonding, final assembly of SiPM arrays in a dedicated ISO6 clean room NOA (LNGS).

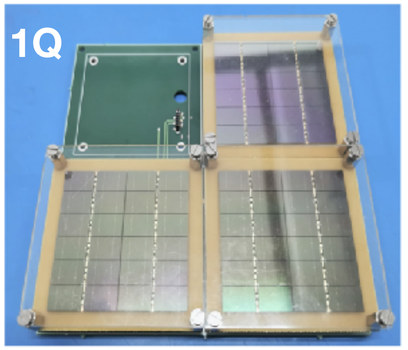
DS-20k SiPM, PDU II



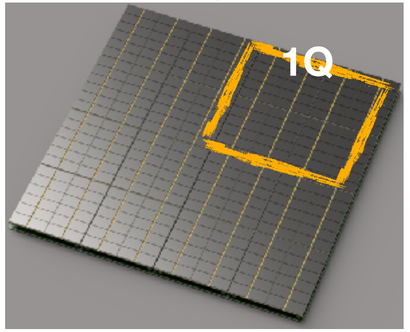
Optimised version of PDM and PDU was designed, fabricated and tested in 2021-2022:

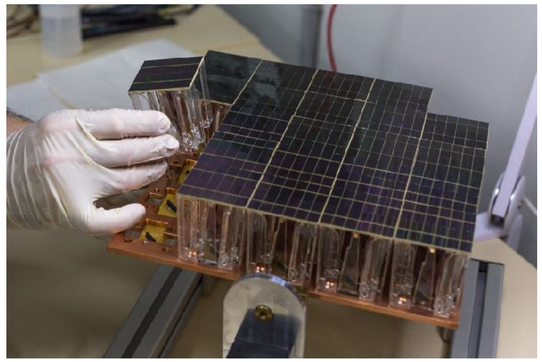
- Reduced PDMs number 25 → 20. Smaller size 20x20 cm^2 instead of 25x25 cm^2.
- No single PDM readout. Four tiles are summed in one channel (100 cm^2). New PDU has 4 channels (not 16).
- Great reduction of overall weight: from 5 kg to ~ 0.4 kg.
- Simplified assembly: tile + Mother Board (no plastic cage).
- Reduced hight: 1.5 cm.
- Acrylic protection for the SiPMs surface and wire bondings + metal support plate for secure transportation.

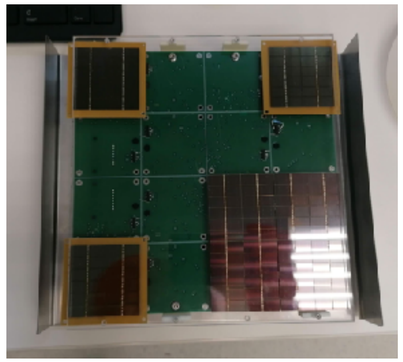


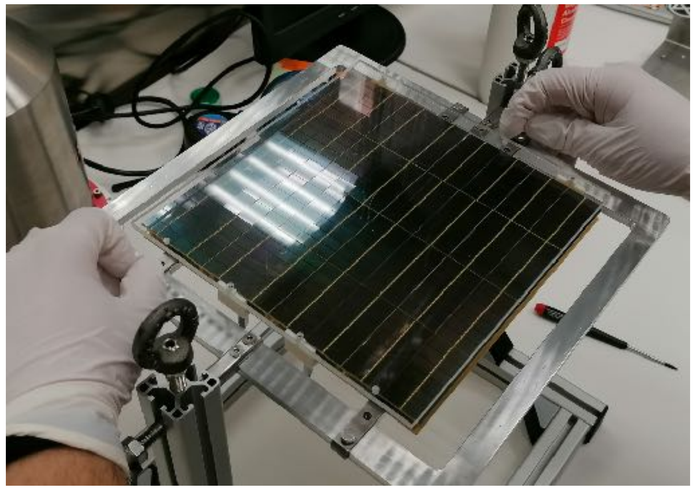


4 tiles = 1 channel





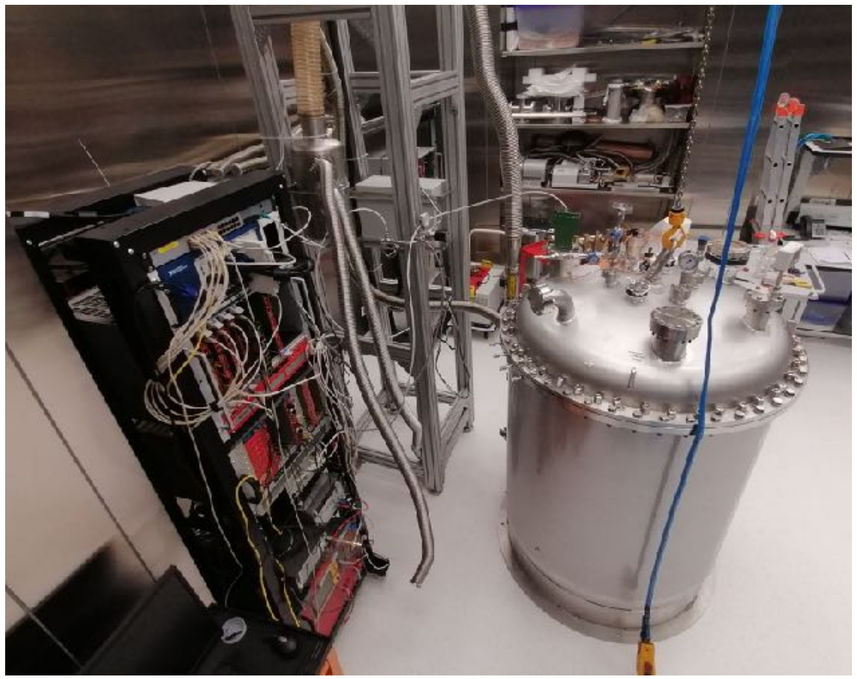
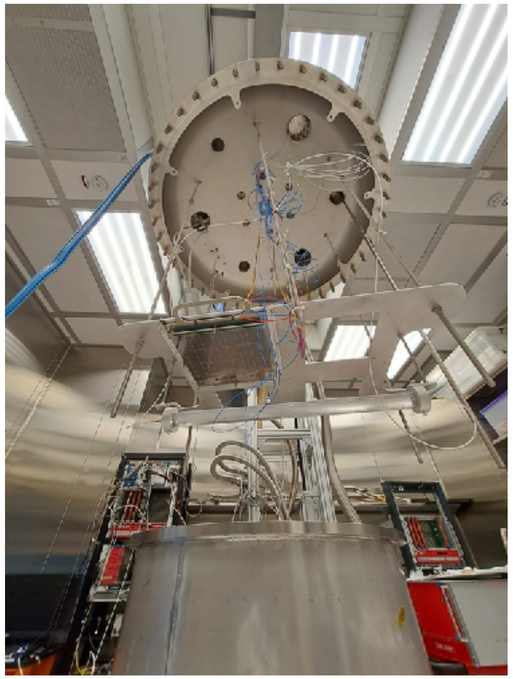




Tests in Naples facility are ongoing since fall of 2021

Naples PDU Test Facility

The Naples PDU Test facility (PTF) is composed of ~800L double wall cryostat with domed top flange, coupled with custom cryogenic system. Double wall vacuum insulated inlet and outlet lines for LN and cold vent of N2. Custom Cold Box. External LN storage plant with 3000L tank. **Designed, fabricated, assembled, commissioned and is active since summer 2021.**

ISO6 50m^2 clean room of **CRYOLAB** for PDU handling and LN characterization. Fully automated process of FILL, DRAIN and constant level maintenance over the period of testing (*evaporation rate of 0.2 cm/h*).

Mechanical structure composed of four floors to host 4 PDUs each (16 in total). Full integration with light distribution system.

Electronic rack with Caen mainframe for the Power Supplies board, VME crate for VX2740 ADCs, NIM crate with trigger logic formation unite and laser unite.

Dedicated software (online and offline tools) integrated in the MIDAS framework. DAQ system: daq server, analyses and storage server 40Tb.

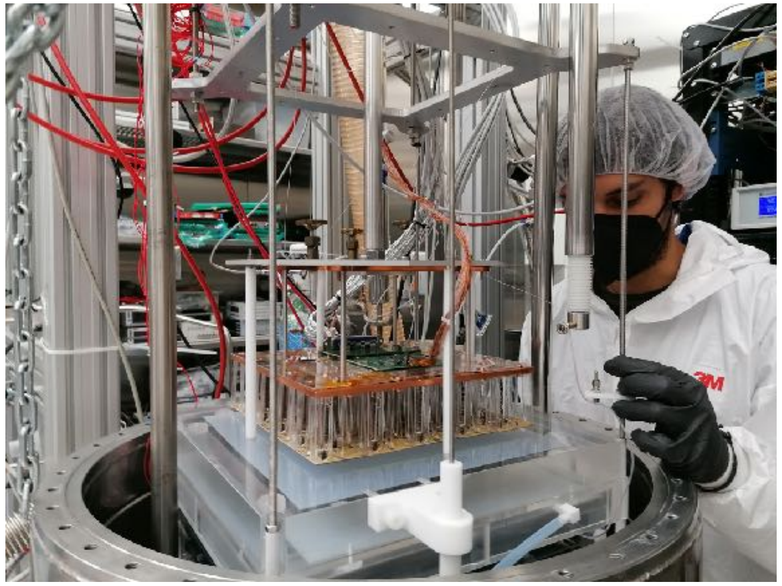
Proto-0

Our group is also conducting the DarkSide-20k prototype test (Proto-0), real experiment of DarkSide-50 scale.
Dedicated cryogenic system: 300L dewar, custom Argon condenser, Hot Seas getter for Gas purification, gas recirculation pump.

Determination of the key information for the experiment:

- ✦ Performance of the PDUs in LAr with real TPC (measurement of S1, S2 signals),
- ✦ Robustness of the TPC design (choice of Clevios, Acrylic, wire grid)
- ✦ Electric field uniformity,
- ✦ Study of the gas pocket thickness.

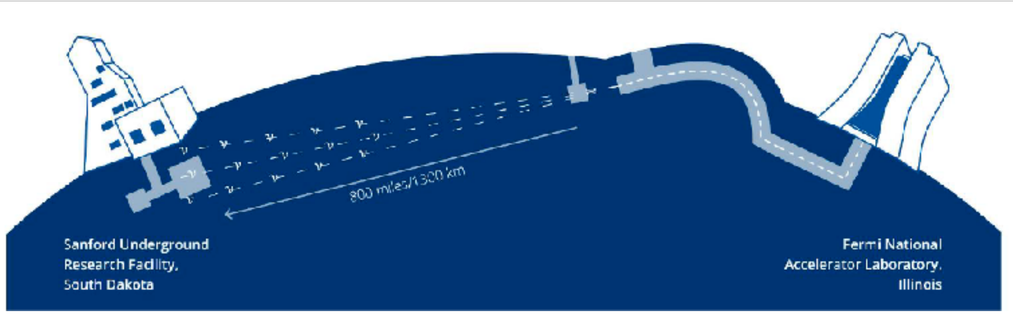
New run with TPC and 1-2 PDU is foreseen in March 2024.



Liquid Argon for neutrino physics

Liquid Argon & TPC technology. Deep-Underground-Neutrino-Experiment. Single phase LAr TPC.

New generation of long-baseline neutrino oscillation experiment. Long distance 1300 km. High power wide-band neutrino (ν_μ / $\tilde{\nu}_\mu$) beam from the Fermilab accelerator complex. Near Detector at production site and 4 modules of Far Detector (17 (10 FD) x 4 kton of LAr).

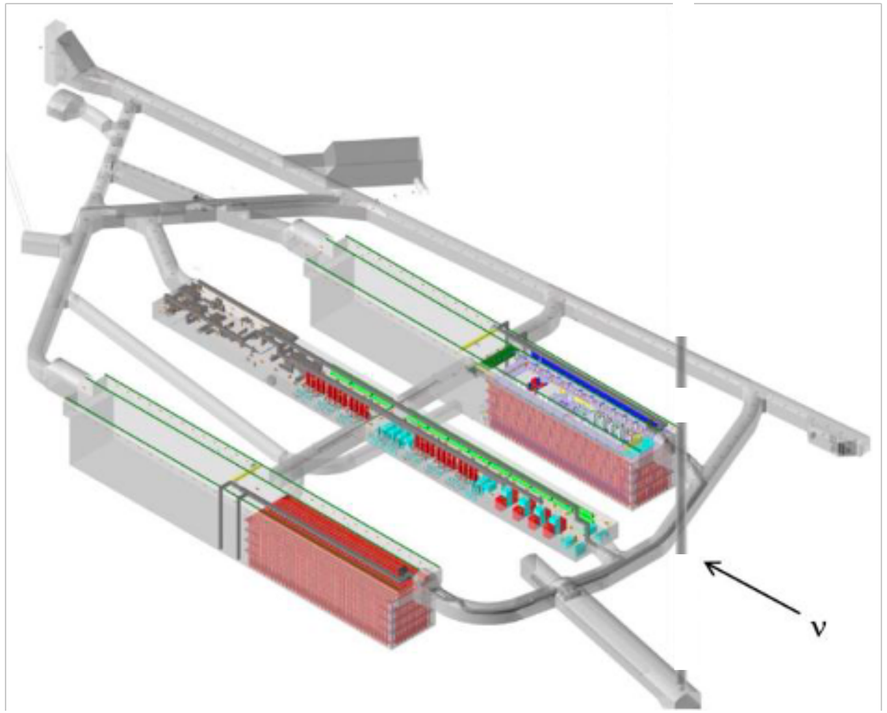


Beam Physics (FD1 & 2)

- Discovery of CP violation phase CP
- Determine neutrino mass hierarchy
- Precise measurement of neutrino oscillation parameters($\theta_{23}, \Delta m_{13}^2$)

Astroparticle Physics (FD3 & 4)

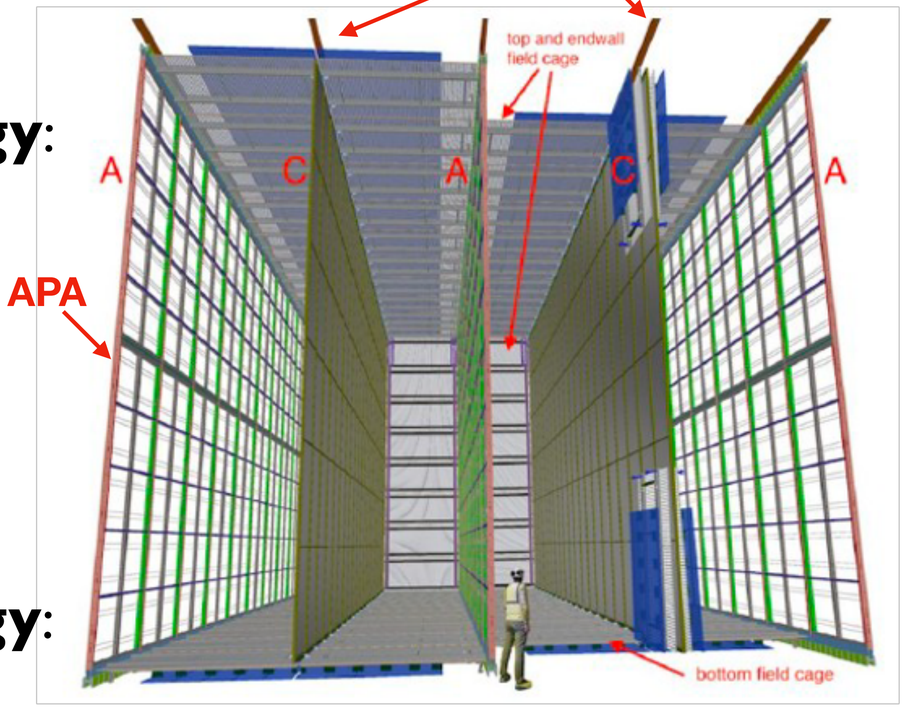
- Detection of low energy neutrinos bursts from galactic supernova
- Detect solar neutrinos (first possible observation of hep-neutrinos, best measurement of .12)
- BSM physics:proton decay…
- Dark matter



DUNE far detector

First Far Detector module will use **Horizontal Drift technology**:

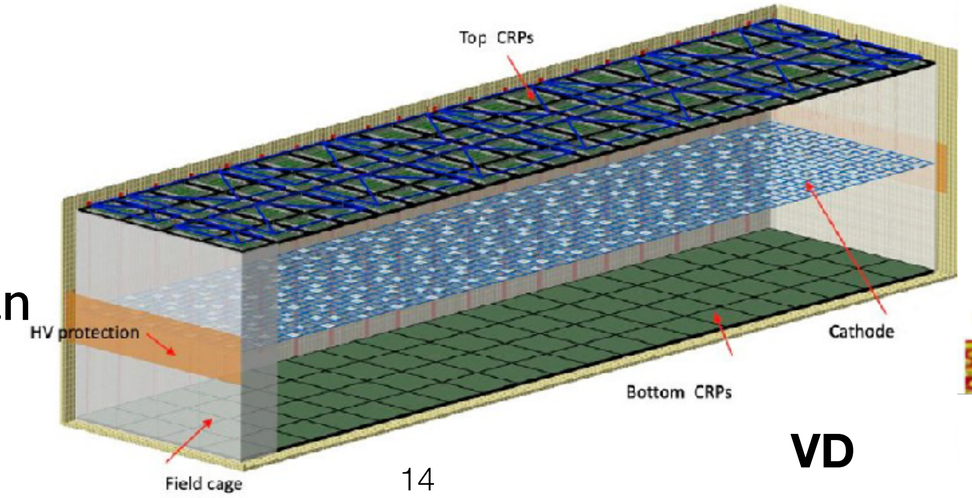
- 4 drift regions (3.5m each),
- charge readout with wires in **A**node **P**lanes **A**ssembly (APA). Similar to ICARUS, MicrobooNE, SBND.



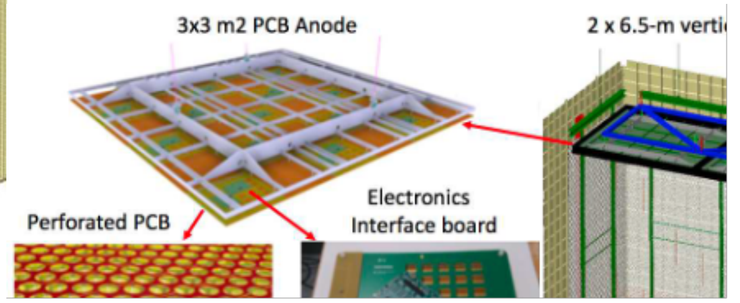
Second Far Detector module will use **Vertical Drift technology**:

- 2 volumes 13.5m x 6.5m drift x 6.0m,
- readout with strips (perforated PCB).

Larger active volume, cheaper than FD-1 and similar performance



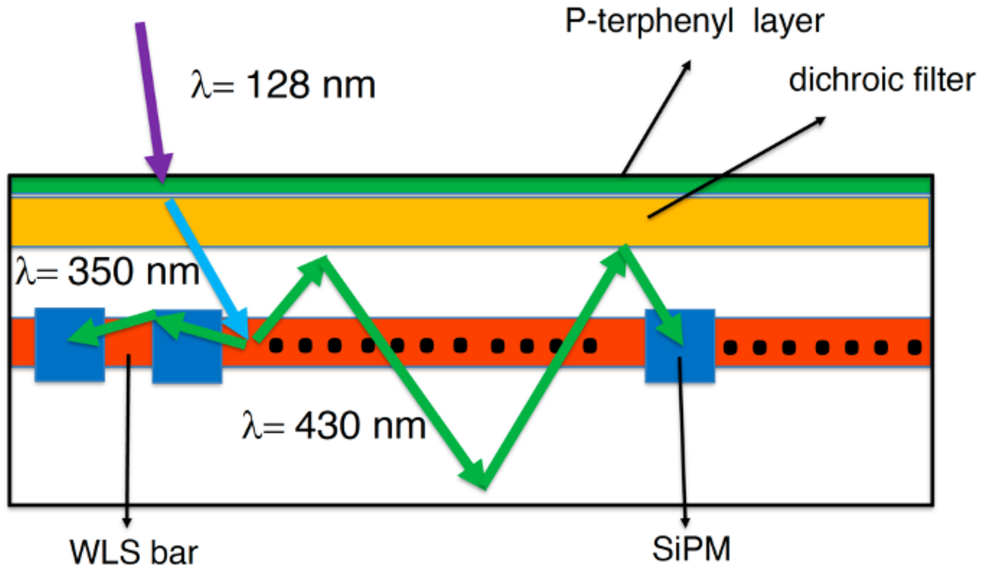
VD

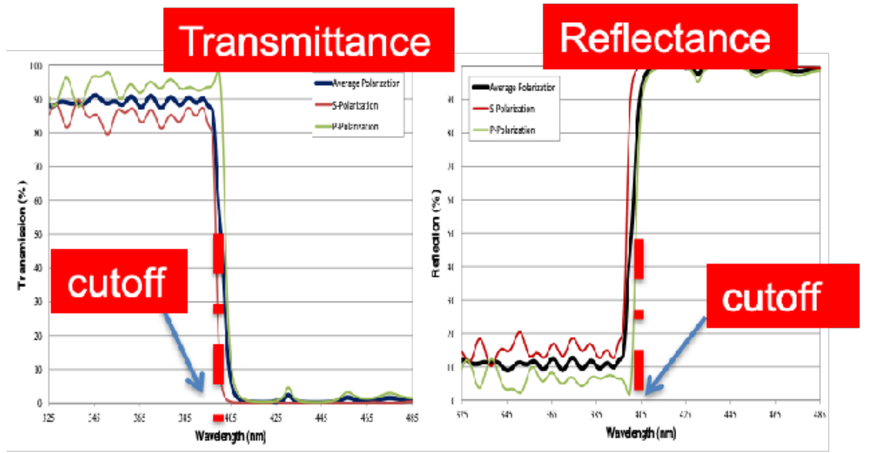


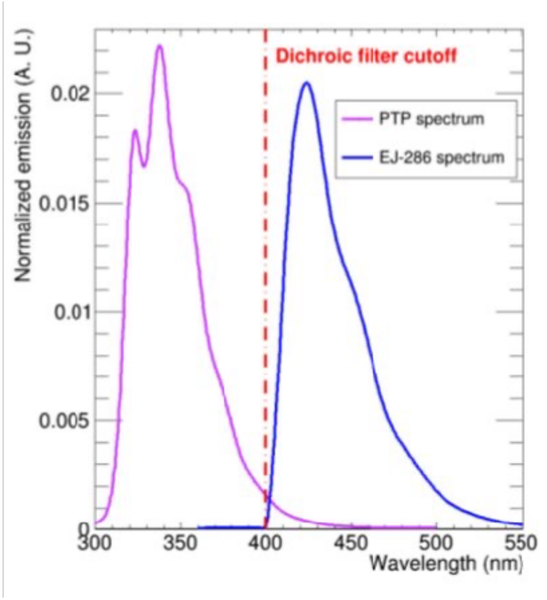
Charge Readout Planes (CRP)

Photon Detection System: the X-ARAPUCA concept

- VUV (128 nm) scintillation light produced in LAr
- PTP shifter deposited on the dichroic external side converts VUV light to a wavelenght (350 nm) - *dichroic cutoff* (light is transmitted)
- The internal WLS bar converts the primary shifted photons to a wavelenght (430 nm) - *dichroic cutoff* (light is trapped)
- After reflections the photons get detected by SiPM positioned laterally with respect to the WLS plane





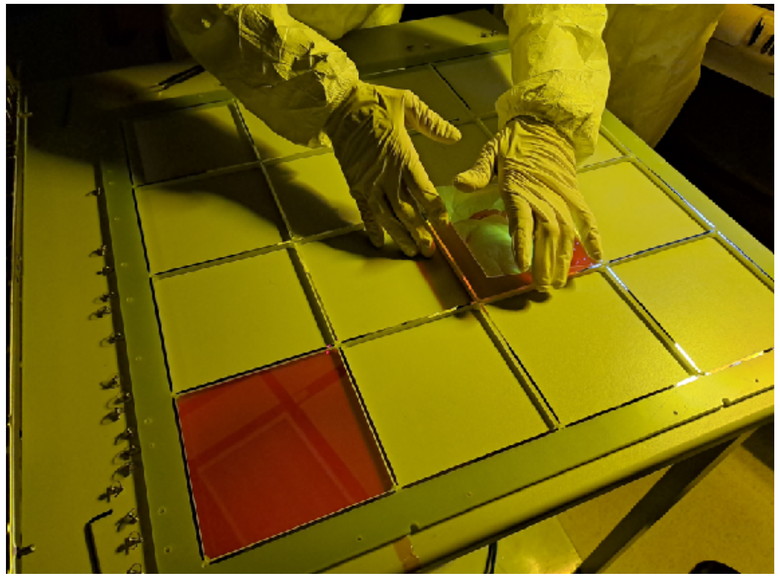


PDE Test. Megacell

Long term test in liquid Nitrogen, or Argon. Fundamental for a number of experiments and projects.

- XArapuca (14x27 cm2) and Megacell (60x60 cm2) tests fo DUNE experiment.

Test is in progress.



LAr Technology Hub

Cryogenics, Detector, Electronics, DAQ, Computing & Analysis

Ita
- Marco Rescigno, Maria Adriana Sabia (Roma1)
- Mauro Caravati (Cagliari)
- Bianca Bottino, Paolo Musico (Genova)
- George Korga, Davide Sablone (LNGS)
- Simone Sanfilippo (Roma3)
- Luciano Pandola, Marisa Gulino (LNS)
- Eugenio Paoloni, Simone Stracka (Pisa)
- Luca Meazza, Alessandro Minotti (Milano)

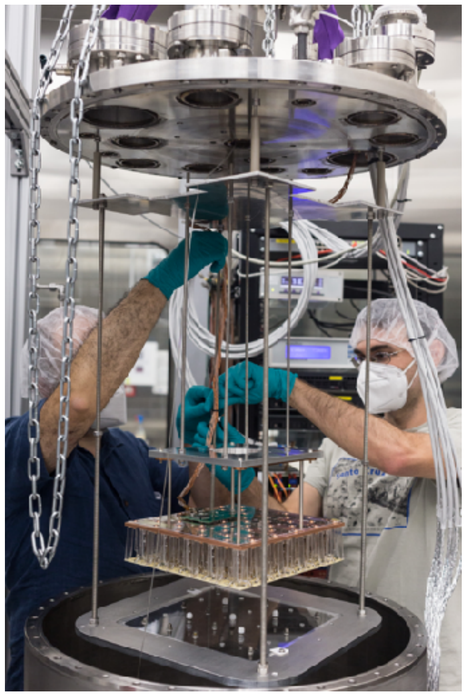
Rus
- Grigory Dolganov (NRC Kurchatov)
- Vladislav Oleynikov (Budker Institute of Nuclear Physics)

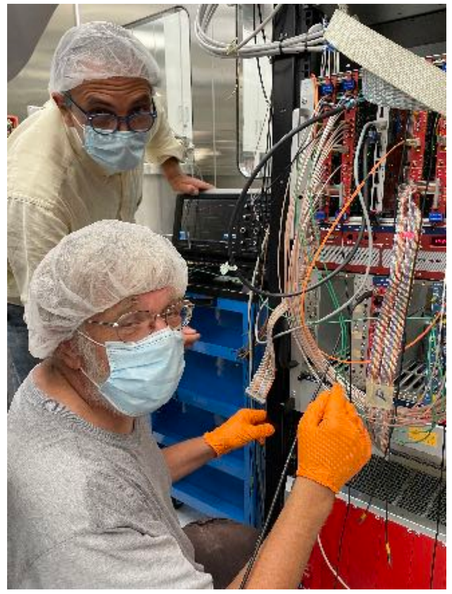
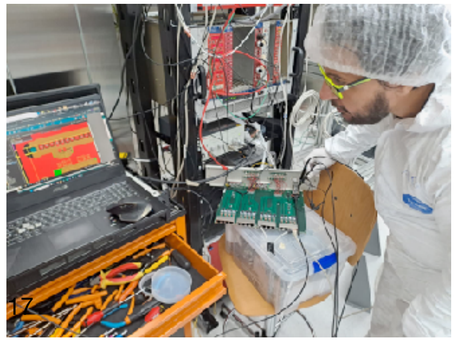
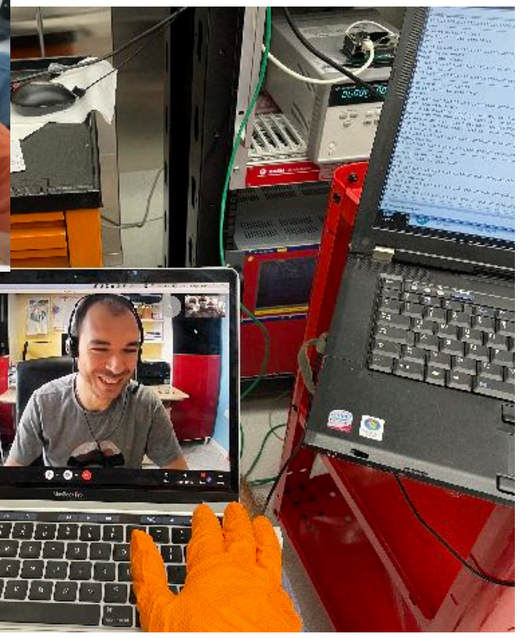
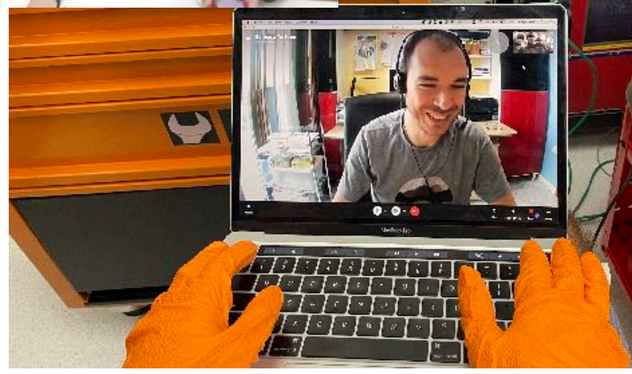
Can
- Ben Smith, Pierre Amaudruz, Andrea Capra (TRIUMF)
- Peter Skensved (Queen's U.)

UK
- Ashlea Kemp, Zoe Balmforth (RHUL)
- Ellen Sandford, Conner Roberts, Cara Barltrop (Manchester)

Bra
- Ettore Segreto, Ana Machado (Campinas U.)
- Vinicius do Lago Pimentel (CTI Renato Archer)

US
- Bob Wilson, David Warner, John Harton (Colorado State U.)
- Flavio Cavanna, Peter Shanahan (FNAL)

Backup slides

DarkSide-20k TPC

Octagonal vessel: 3.5m H x 3.5m W barrel, made of radiopure acrylic Gd loaded 15 cm thick panels bonded together.

Anode & Cathode: pure acrylic (*no Gd*) 6 cm thick panels bonded together.

Clevios conductive polymer film spray coated on top and bottom acrylic windows to make transpired electrodes (Anode and Cathode) and on the walls to provide shaping rings (to shape the drift field).

TPB coated 3M ESR foils on the inner side of the TPC walls to to shift the 128 nm to 420 nm and improve light collection.

Optical planes: 21 m^2 in total, populated 528 PDUs (top 264 + bottom 264).

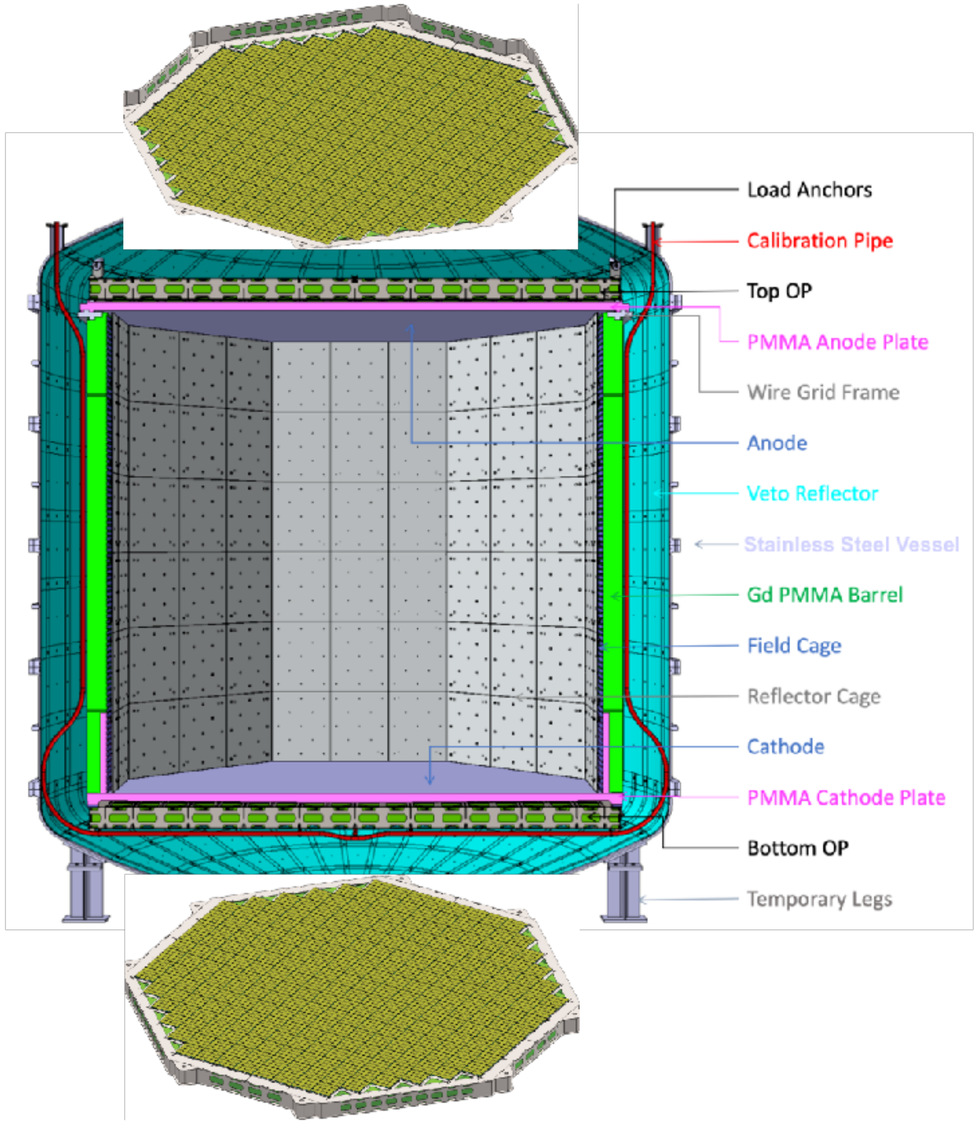
Grid: The SS frame with wires.

Drift: 348 cm.

Target: 55.4 tonnes of Underground Argon (UAr).

Calibration system: motorised system to map the detector energy response with radioactive sources.

Top Optical plane, 264 PDUs



Bottom Optical plane, 264 PDUs

CryoLab Team (2023/2024)

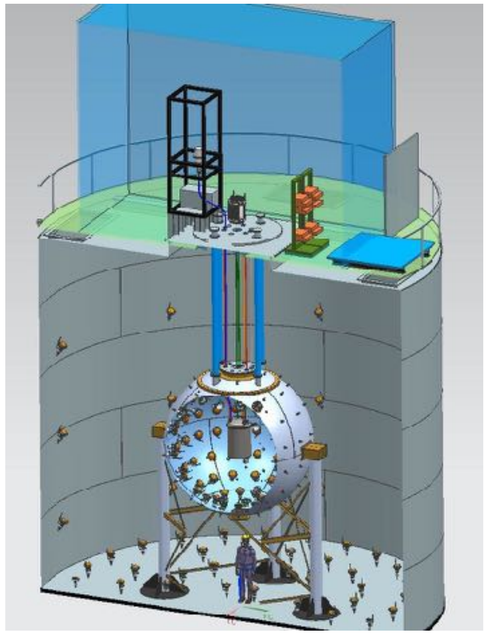
	Cognome	Nome	Qualifica
Staff	Fiorillo	Giuliana	**PO**
	Di Capua	Francesco	**PA**
	Suvorov	Yury	**RTDb**
	Canci	Nicola	**INFN-TI**
	Grauso	Gianfrancesco	**INFN-TD**
Training	Rudik	Dmitry	**AdR UNINA**
	Calabrese	Roberta	**AdR INFN**
	Matteucci	Giuseppe	**PhD**
	Botogoske	Gabriel	**PhD**
New	New	New	**RTDa - concorso in atto**
	Segreto	Ettore	**PA - chiamata diretta in corso**
Totale		**11 ricercatori**	

DarkSide-50

TPC: 46 kg of active LAr viewed by the 38 3” PMTs (top + bottom) enclosed inside the SS double wall custom made Cryostat.

LSV: The 4 m Stainless Steel Sphere filled with 30 ton of boron-loaded liquid scintillator. 110 8” PMTs. Lumirror reflective foil.

WCD: The 11m x 10m SS cylinder. The 1 kton of high purity water, 80 8“ PMTs. Tyvek reflector.

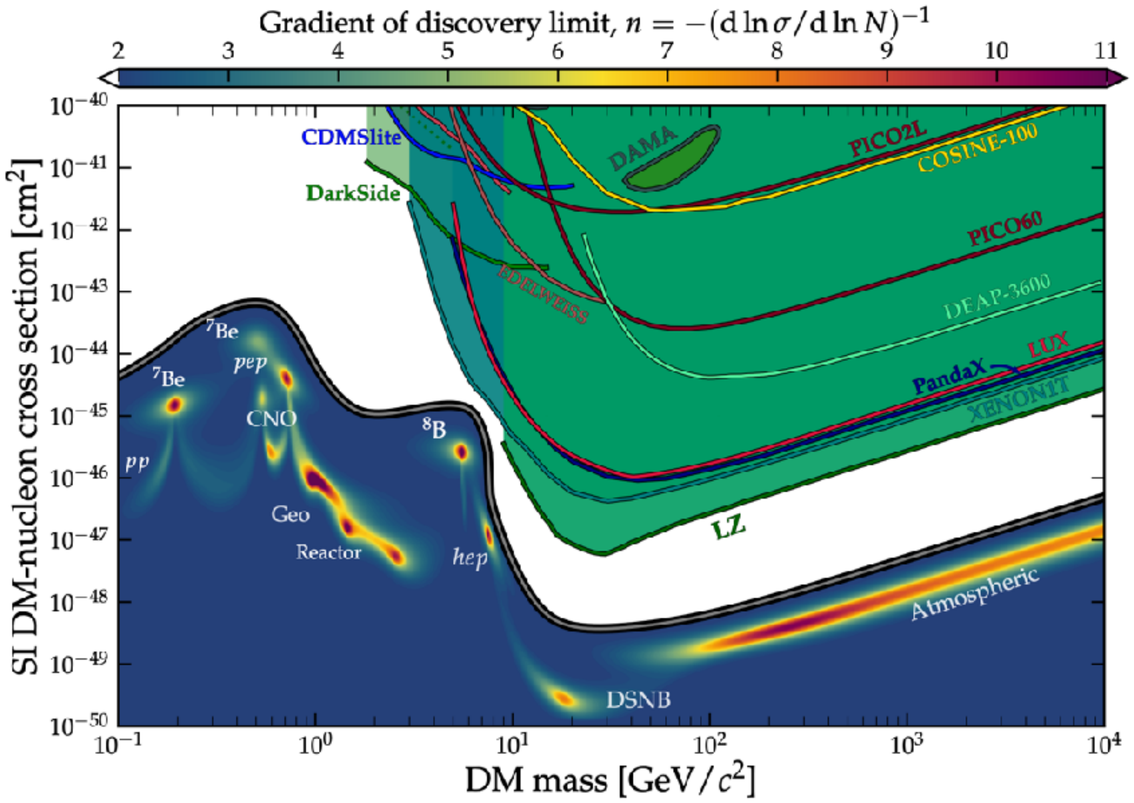


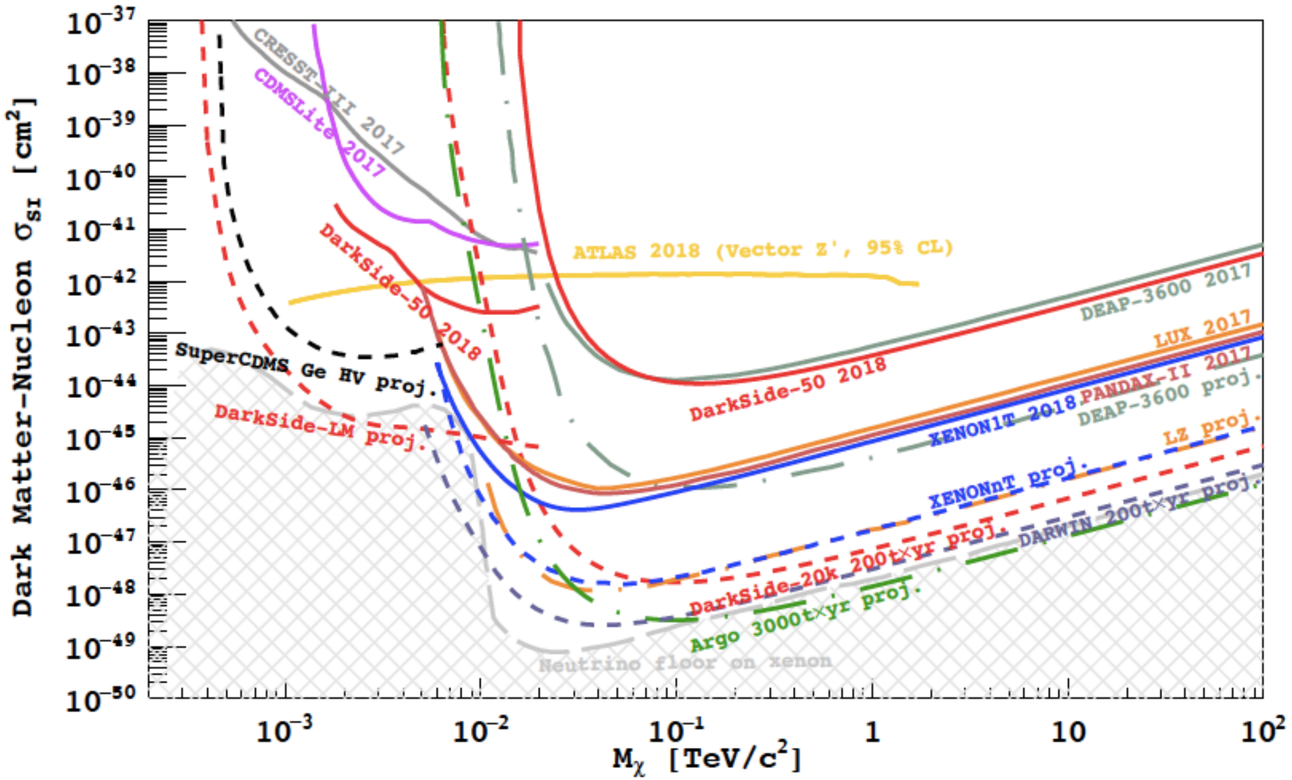
DarkSide-50 TPC

- **2.5 cm thick PTFE cylinder**: (36 x 36) cm → **46 kg active mass** (37 kg fiducial).
- **38 3" PMT**: Hamamatsu R11065. 19(top) + 19(bottom). Coupled with specially designed at LNGS **cold amplifiers** in order to work under the nominal HV value (otherwise cause instabilities and unwilling photon reemission);
- **Fields**: Copper field shaping rings for uniforme drift field formation & hexagonal mashed grid. Standard field configuration: E_{drift} = 200V/cm, E_{extrac} =~ 2.8kV/cm, $E_{mult.}$ = 4.2 kV/cm.
- **Cathode & Anode windows**: Indium Tin Oxide (ITO), 15 nm thin conductive transparent layer on the fused silica windows. The f. s. diving bell for 1 cm gas pocket.
- **WaveLength Shifter**: All inner surfaces are coated with WLS Tetra-phenyl butadiene (TPB), to shift the Argon scintillation from 128 nm to 420 nm.

Neutrino floor (fog) & DarkSide

Theoretical limit on the WIMP-like dark matter searches. Coherent scattering of neutrino off target nuclei will give nuclear recoils indistinguishable from WIMPs induced events. Not a hard limit.



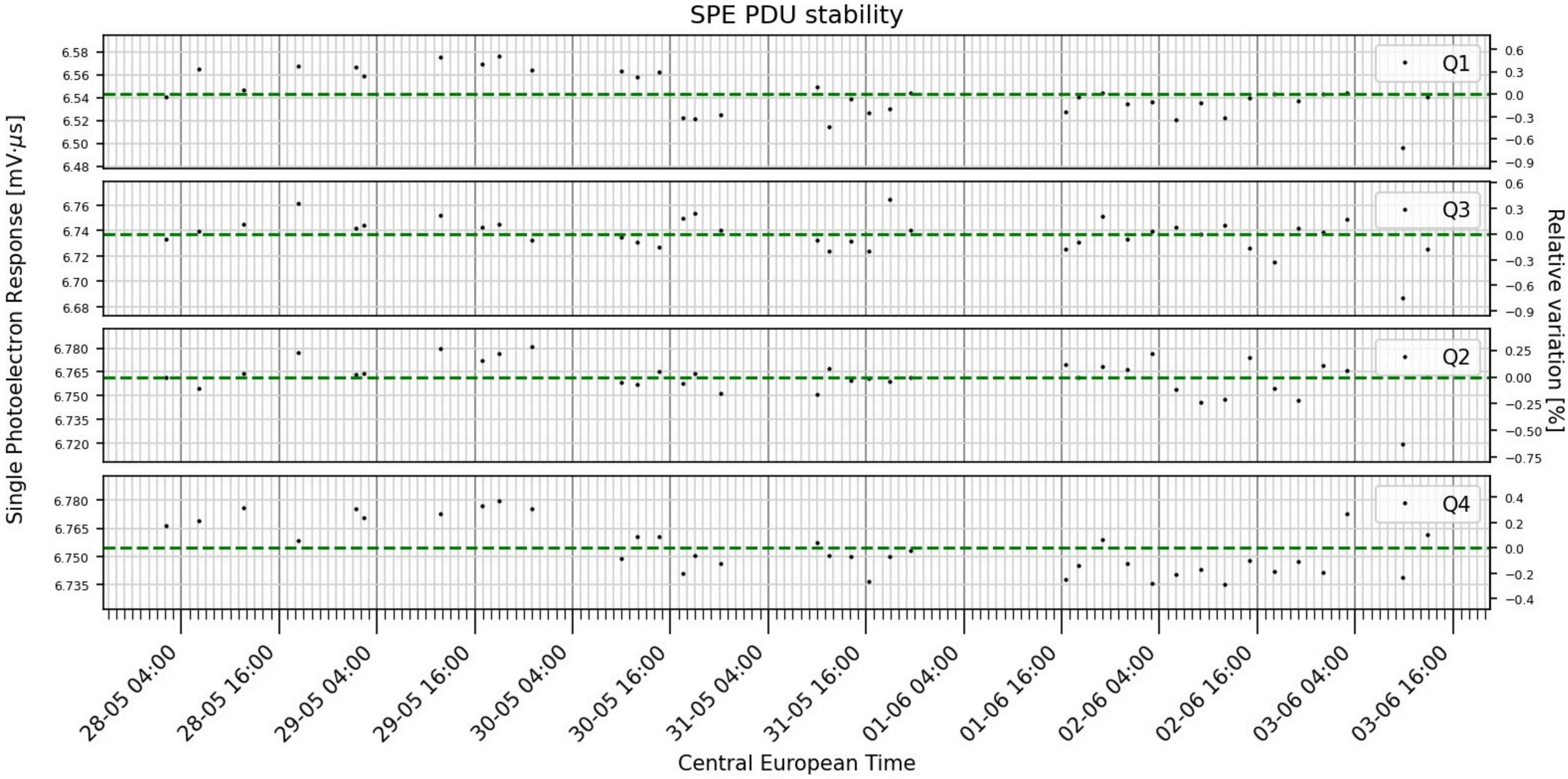


DarkSide-20k should touch neutrino fog limit at 200 x yr exposure.

https://arxiv.org/pdf/2109.03116.pdf

https://indico.cern.ch/event/922783/contributions/4892502/attachments/2481150/4259329/nufog.pdf

1st PDU. Test results

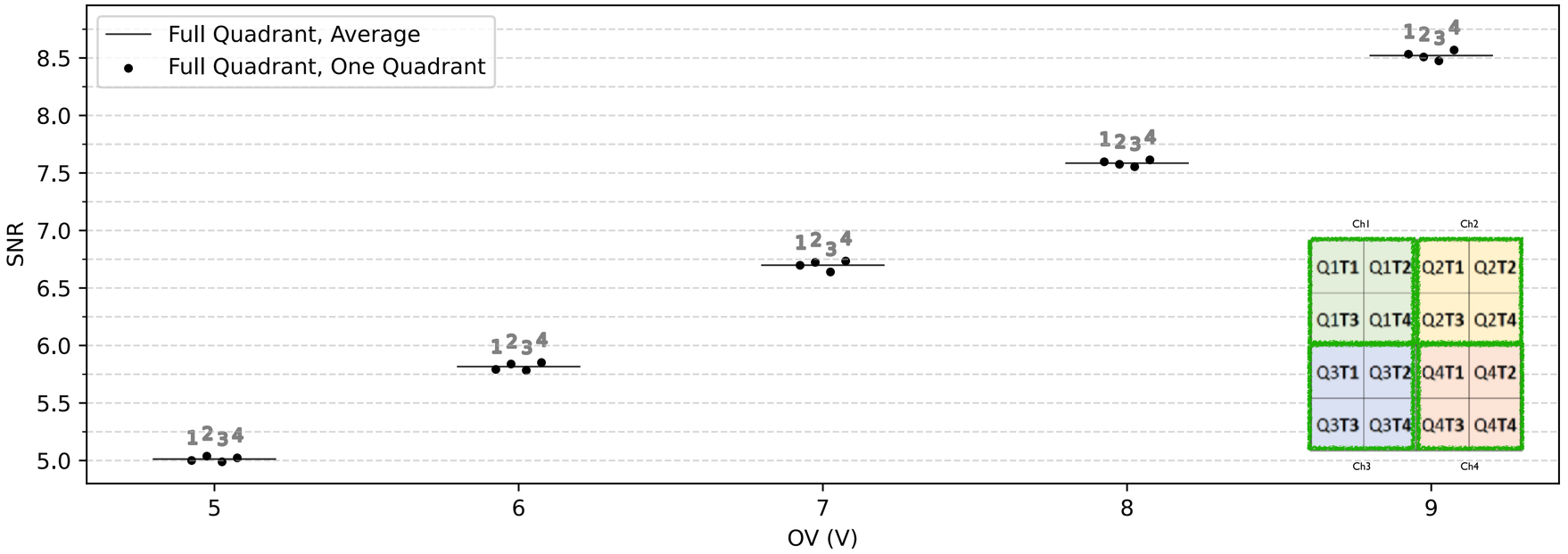


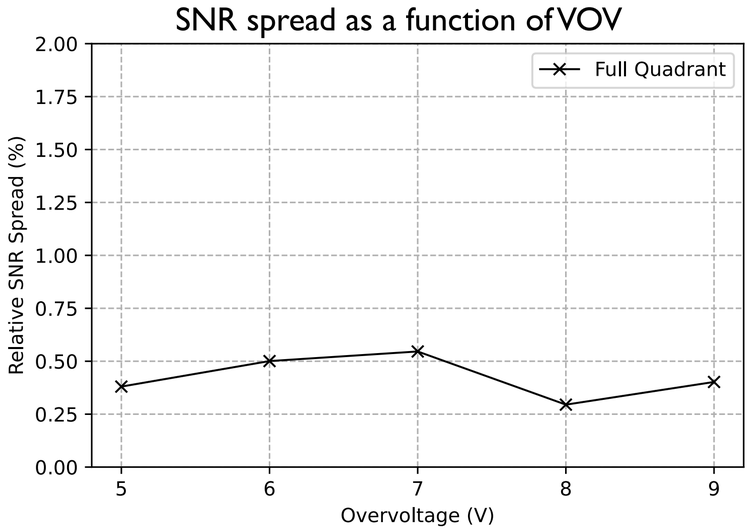
1st PDU. Test results

Raw SNR for all quadrants, in range from 5 (@5V VOV) to 8.5 (@9V VOV).

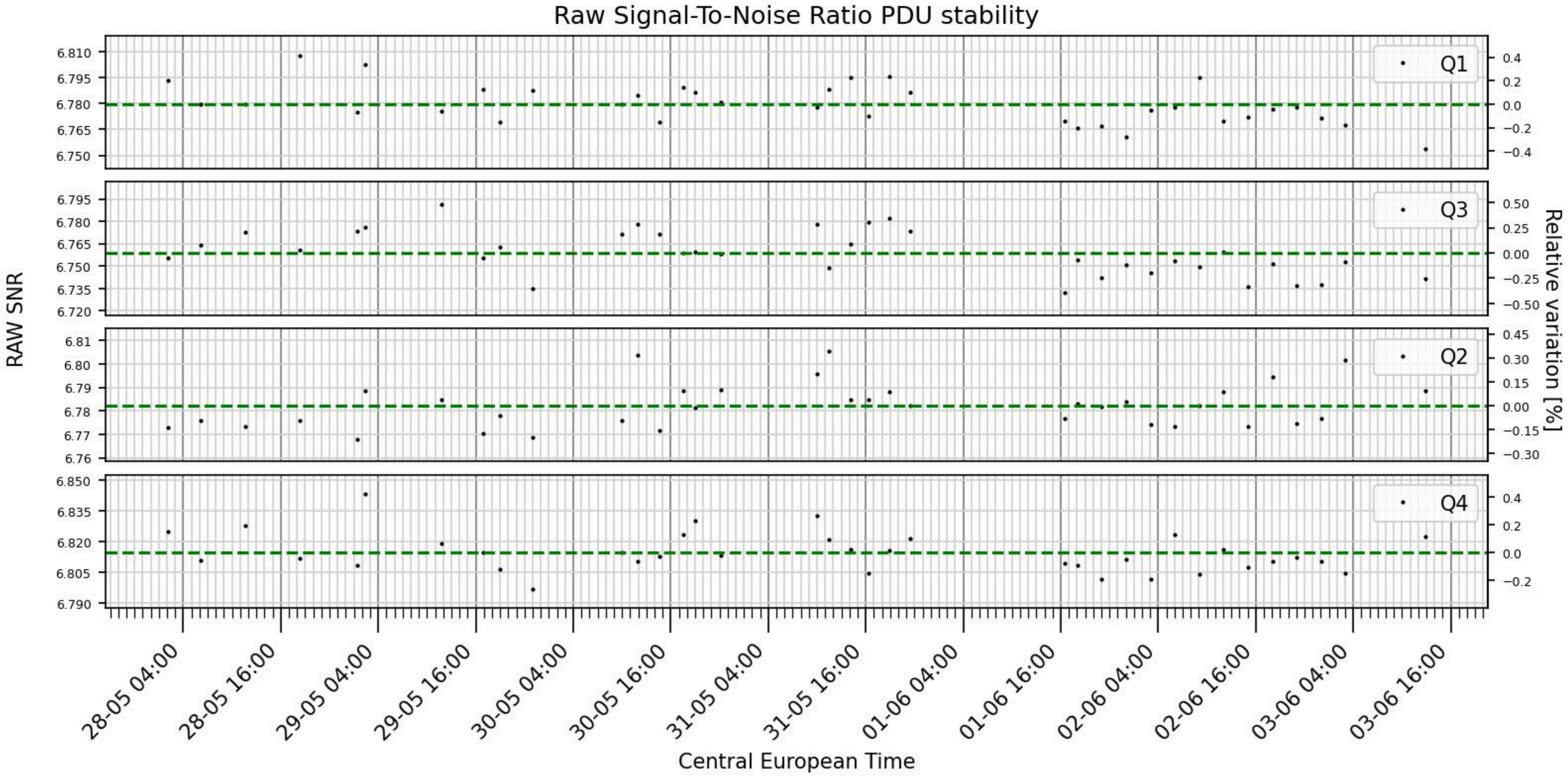
Raw SNR: A_{1PE} / RMS_{BL}: ~7.
Resolution: σ_{1PE} / A_{1PE} : ~14 %.

Naples, November Data Campaign (SiPM Bias 34 V)						
	Tile			SUM x4		
	K&K	CAEN Filtered	CAEN No Filter	K&K	CAEN Filtered	CAEN No Filter
Raw SNR	13.1	12.9	12.8	6.7	6.6	6.7
Raw Resolution	7.3 %	7.5 %	7.5 %	14.3%	14.1%	14.3%

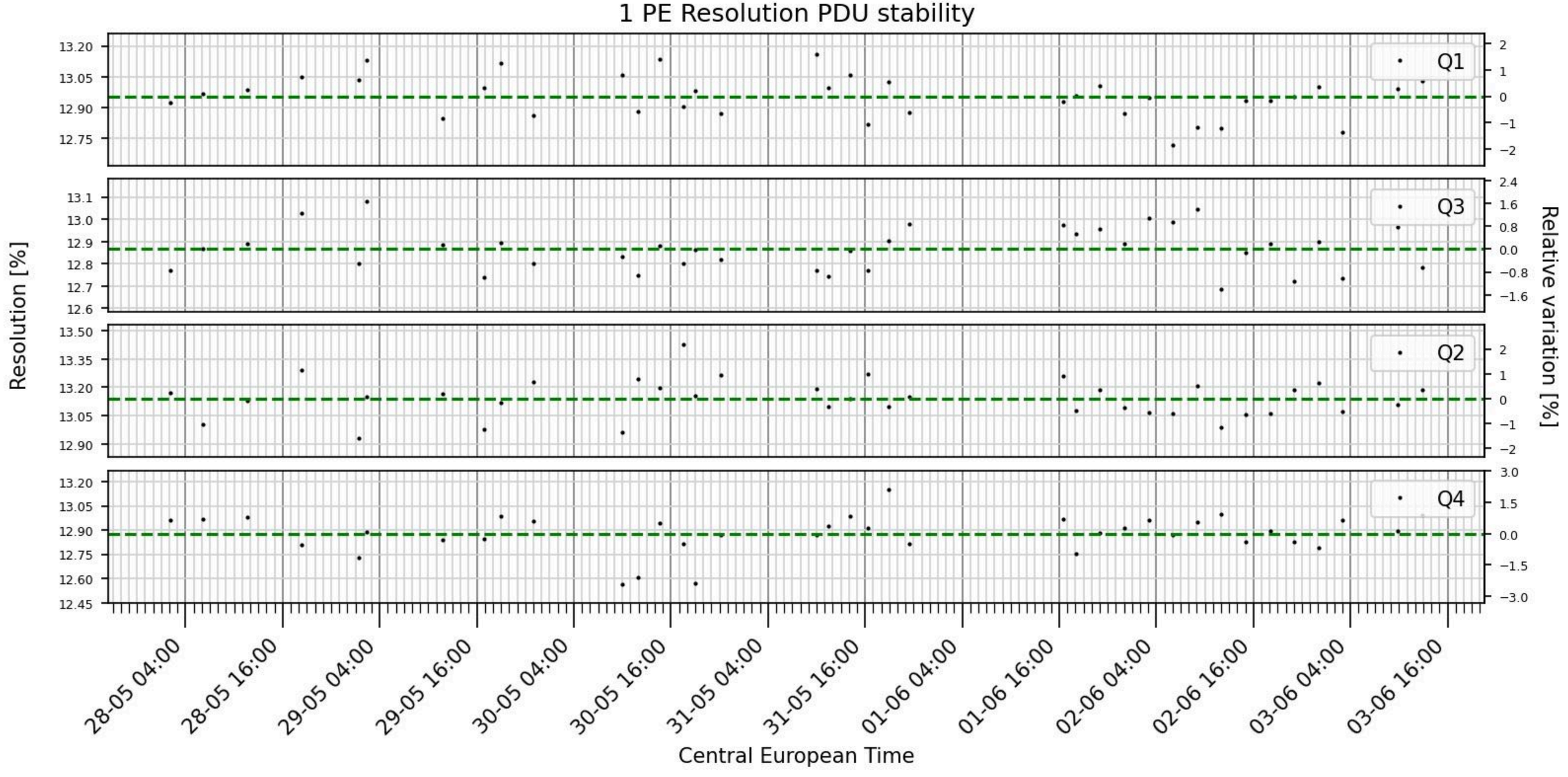




PDU. Test results



PDU. Test results



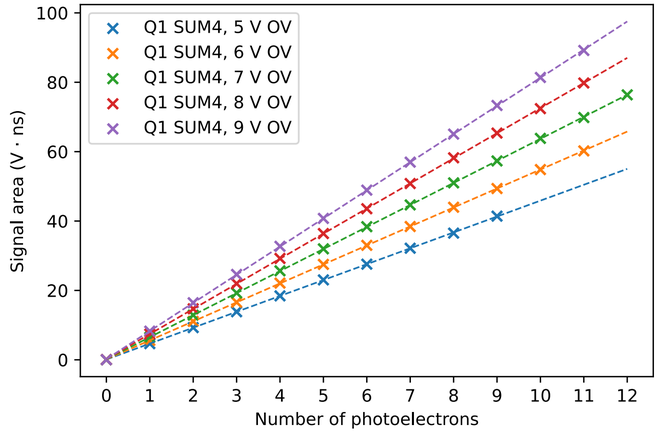
PDU. Test results

Gain evaluation based on voltage variation associated with 1PE signal (result of the conversion of the current produced by the SiPM in response to the trapped photoelectron, done by the cold TransImpedance cold Amplifier TIA); feedback resistance and the elementary charge.

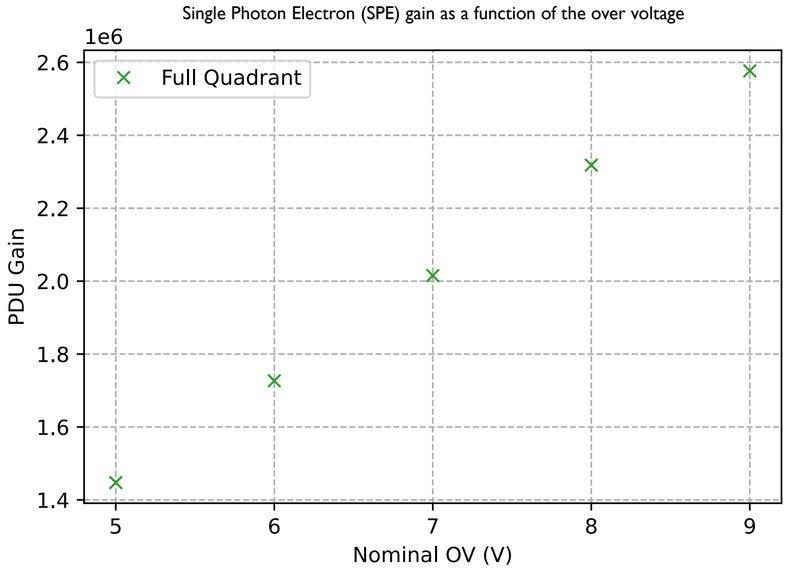
$$G_{\mathrm{PDU}} = \frac{1}{R_{\mathrm{TIA}}}\frac{1}{e}\int_{1\ \mathrm{PE}} v(t)\,dt \qquad G_{\mathrm{PDU}} = A\cdot\frac{1}{e}\int_{1\ \mathrm{PE}} i(t) = A\cdot G$$

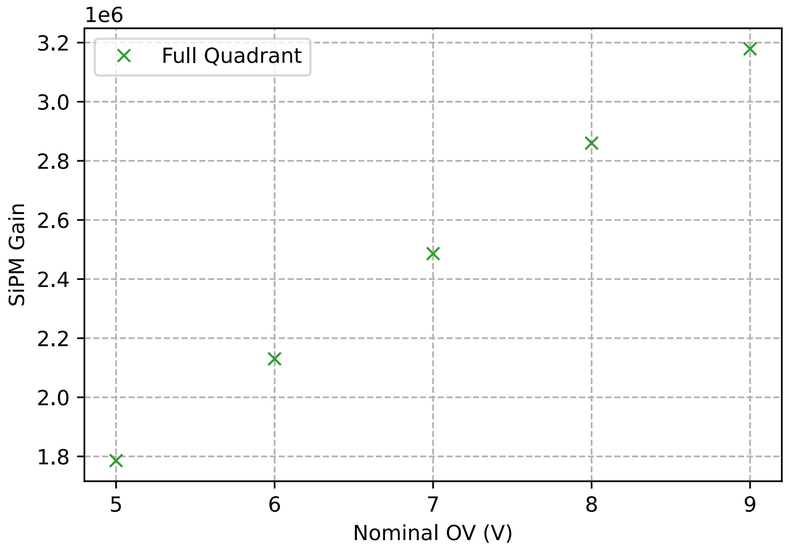
$$G_{PDU} = 2.0\times 10^{6}$$

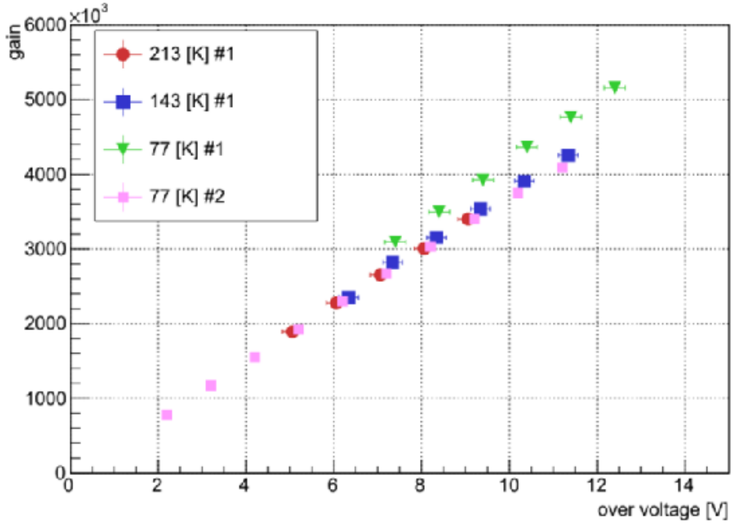
$$G = 2.6\times 10^{6}$$



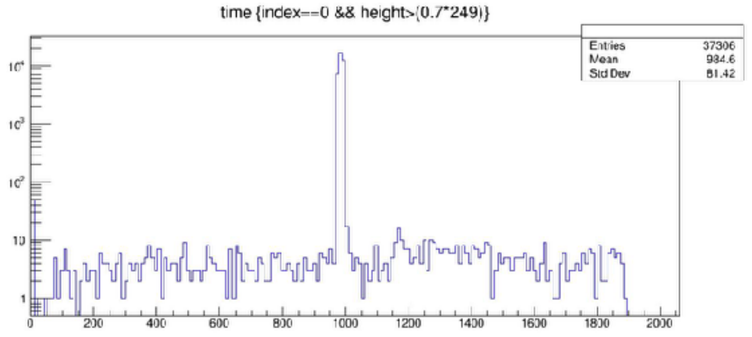
Estimation of the absolute gain considering value of a constant A of ~0.81. Obtained value for 7VOV is in good agreement with previous measurements performed with single SiPM by colleagues from TRIUMF and LNGS.

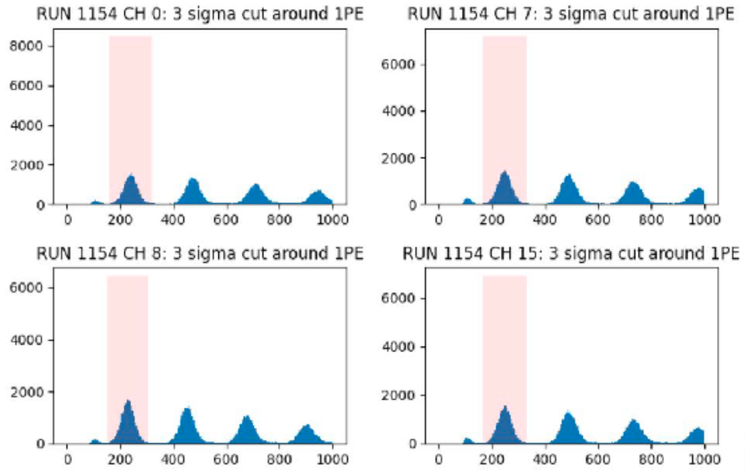






PDU. Test results





Rate in Hz, tile by tile

464 ± 31	368 ± 27	395 ± 28	366 ± 27
508 ± 32	368 ± 27	462 ± 31	435 ± 30
437 ± 30	441 ± 30	445 ± 30	422 ± 29
391 ± 28	337 ± 26	422 ± 29	499 ± 32

The DCR evaluation based on Laser run (16μs window) and on the periodic trigger data (5000μs window).

Only 1PE events are considered.

Calculated rate from both types of runs give the average value of ~1200 Hz per quadrant (4 tiles together), in LN, @ sea level.