Fermilab-CZ (LM2015068)

Day with Particle and Astroparticle Research Infrastructures

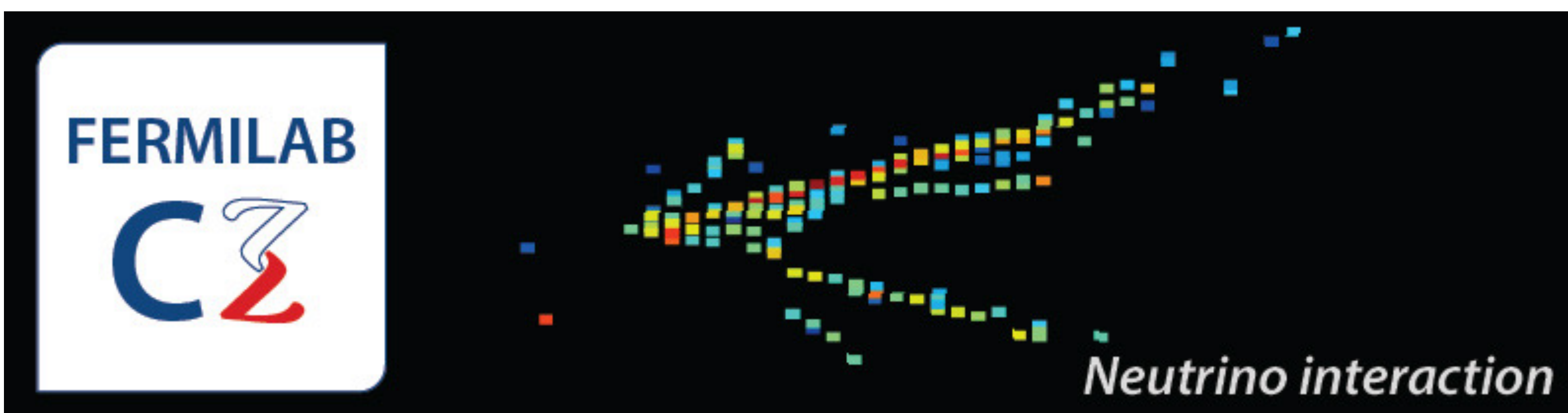
ICRI'2022 satellite event

Jaroslav Zálešák

Institute of Physics, Czech Academy of Sciences

Oct 17, 2022

FZU
Institute of Physics of the Czech Academy of Sciences



Fermilab-CZ Large Research Infrastructure

❑ Four Czech institutions

- ❑ Institute of Physics, CAS (FZU)
- ❑ Charles University (UK)
- ❑ Czech Technical University in Prague (CTU)
- ❑ Institute of Computer Science, CAS (ICS)

❑ Four pillars of infrastructure

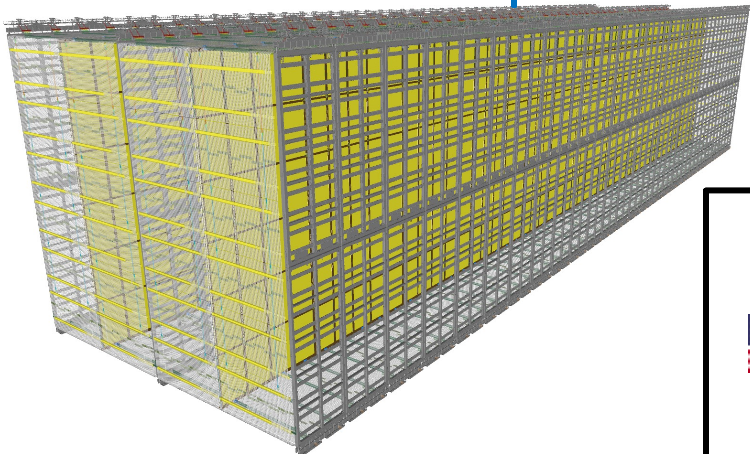
- ❑ Fermilab experimental infrastructure (NOvA, DUNE, ...DØ)
- ❑ Computing Centre (FZU & UK)
- ❑ Support for new statistical and artificial intelligence methods, dedicated computing clusters (CTU & ICS)
- ❑ Photodetector laboratory @ FZU

❑ Services provided

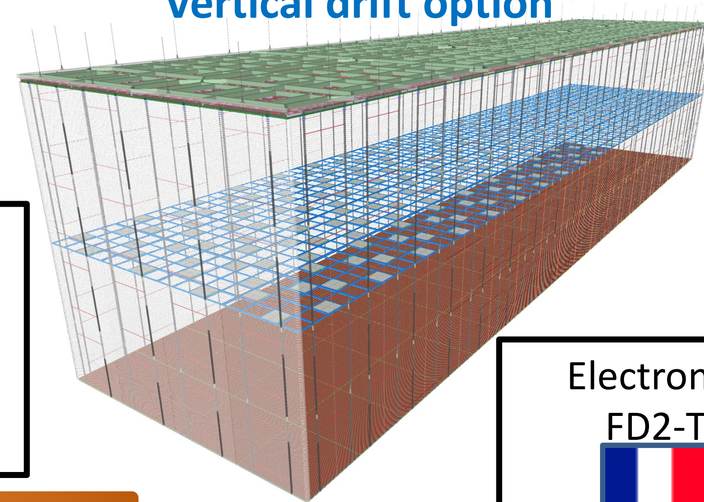
- ❑ Operation, maintenance and upgrade of detectors
- ❑ Supply of computing and storage capacity for simulations and data analysis
- ❑ Implementation of advanced methods within the analysis teams
- ❑ Supply of small components, Participation in design, Prototypes, Measurement of silicon detectors (SiPM) at cryogenic and room temperatures

DUNE Far Detector Partners – FD Consortia

Horizontal drift option



Vertical drift option



High Voltage
FD1, FD2

Electronics
FD2-T

Anode Plane Assemblies - FD1

Photon Detection
FD1, FD2

Charge Readout Planes - FD2

TPC Electronics
FD1, FD2-B

Data Acquisition
FD1, FD2, ND

CALCI
FD1, FD2

Single-Phase/HD Photon Detection Consortium

is responsible for the Light Collection System

We are an *INTERNATIONAL CONSORTIUM:*

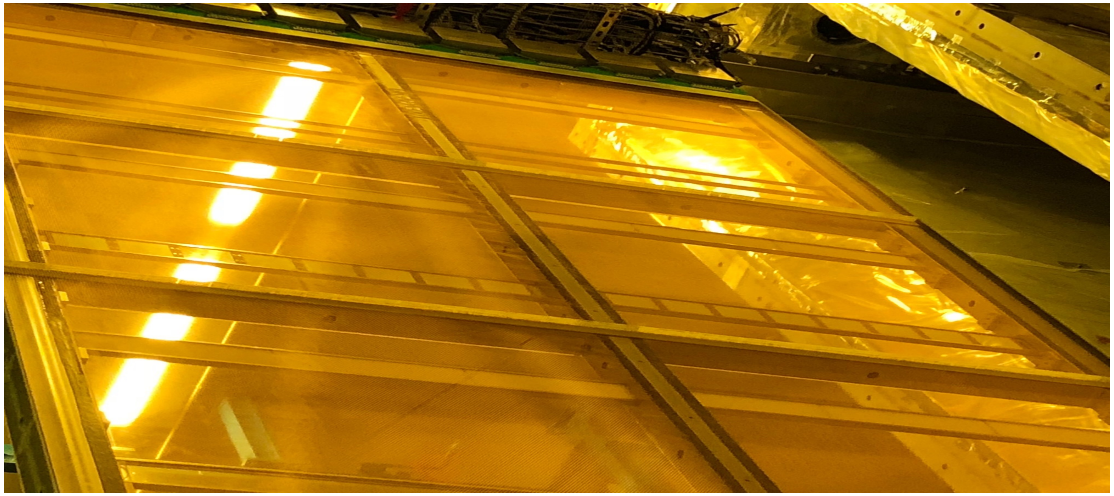
47 Participating Institutions

distributed among Latin America (17) , North America (12) and Europe (17)

Project Management Board: Czech inst. Representative – Jaroslav Zalesak

<u>Working groups:</u>

- Physics/Simulation
- Light Collector
- Photosensors
- Electronics
- Integration
- Calibration
- ProtoDUNE



Why do we need a PD system?

- **Photon Detection System** is an important part of the experimental technique and is used for different purposes:

- **Determining** the **exact time** when an event happens inside the TPC (T0).
  - This is critical to understand how far an event occurred from the wire planes
  - Especially critical for non-beam events (Supernovae, nucleon decay)

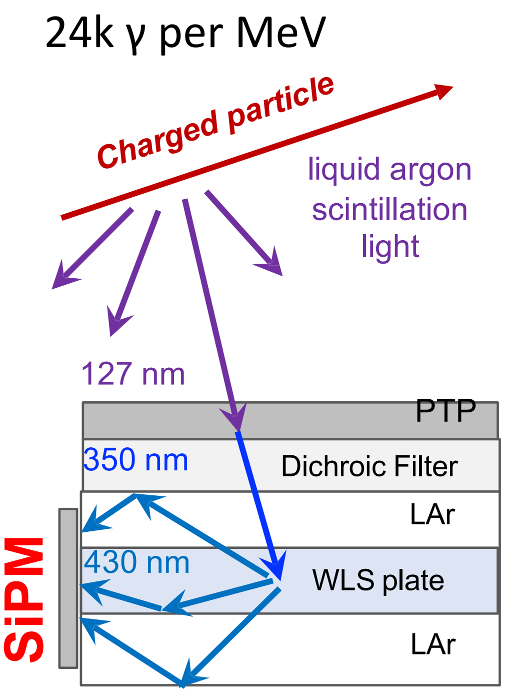
- **Triggering** the detector
  - Separating interesting events from background
  - Especially critical for non-beam events (Supernovae, nucleon decay)

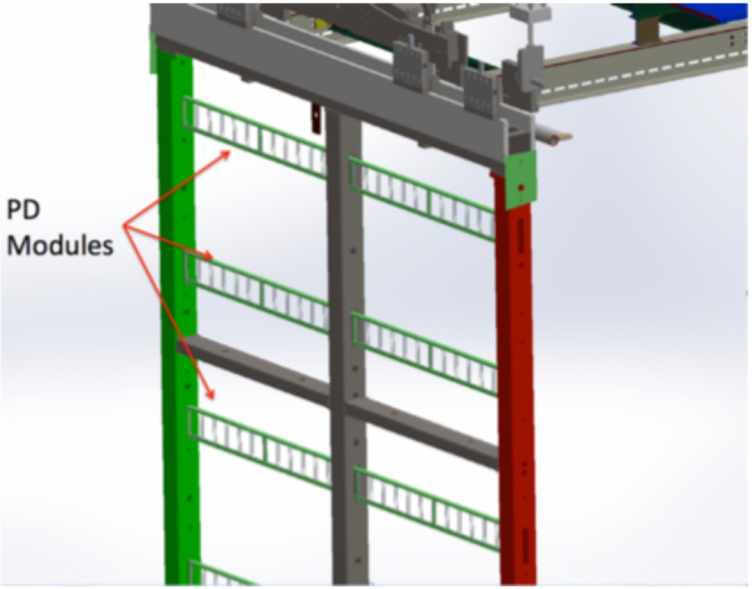
- **Assisting** us to measure the energy of the events

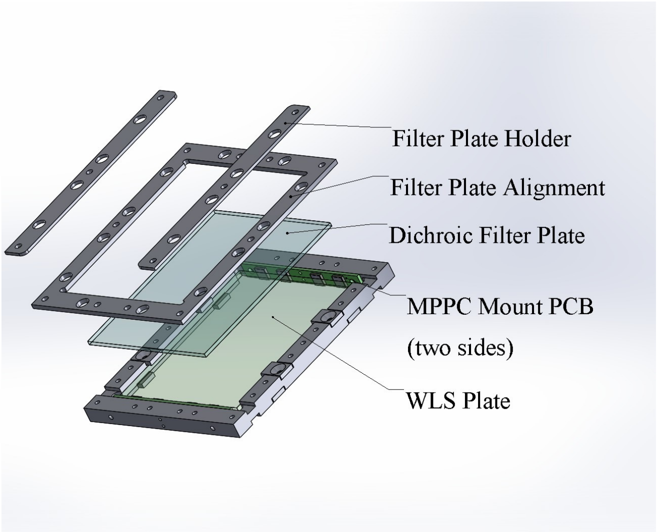
Single Phase Photon Detection system

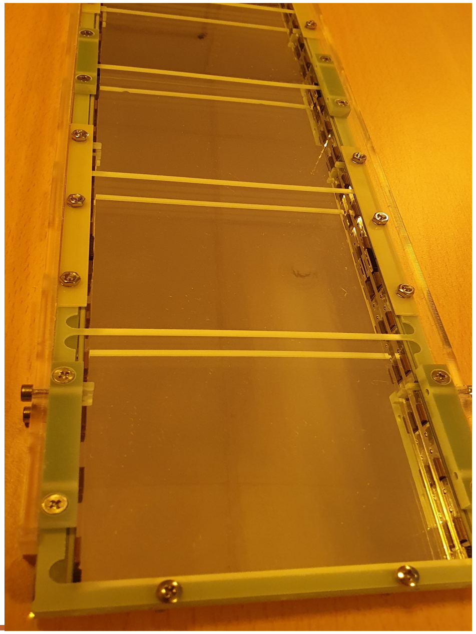
Provides T_0 for each event, fiducializing nucleon-decay, SNB resolution

- X-ARAPUCA "light trap"
  - Increase active area of SiPM
  - Dichroic filter + wavelength shifter
  - Highly reflective interior
  - Acrylic guides shifted light to SiPMs
- 6000 supercells of 48.8 cm x 10 cm x 0.8 cm
- Inserted in APA frames

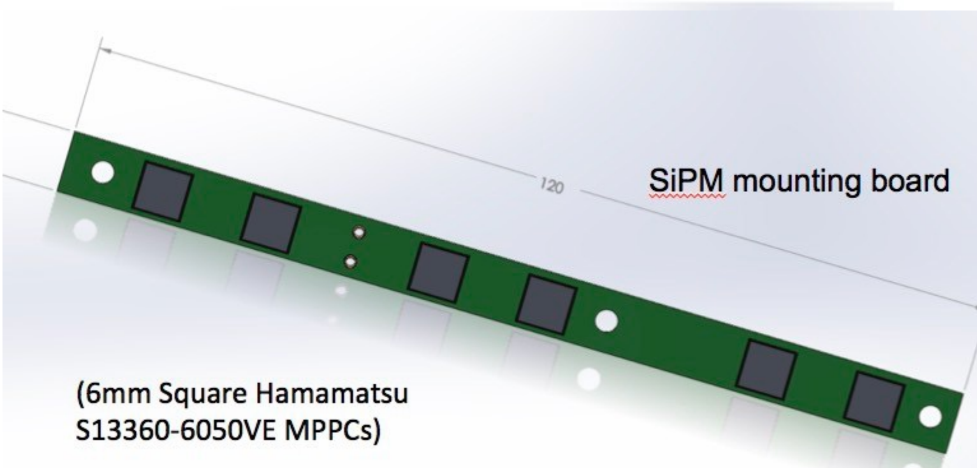






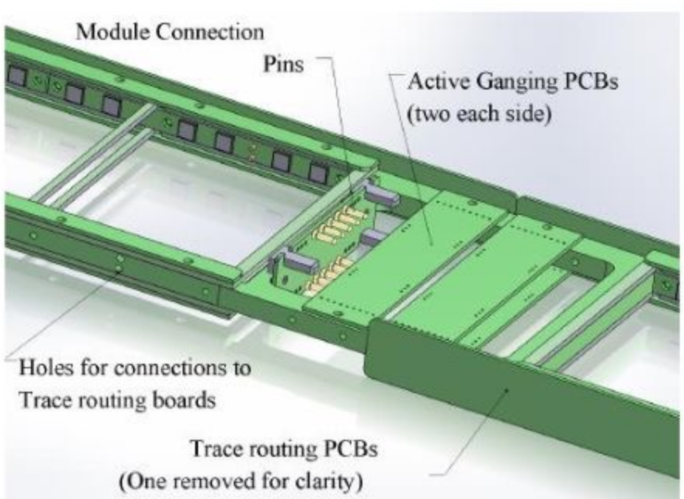


SiPMs in the Photodetection System



"super-cell": 50 cm x 11.8 cm define a "channel"

(up to) 48 SiPMs actively ganged per channel



Quantity
10 modules per APA; 1500 total (1000 single-sided; 500 double-sided)
192 SiPM per module; 288,000 total
4 circuits per module; 6000 total
4 channels/module; 6000 total
45 diffusers/CPA side; 135 diffusers for 3 CPA sides

Strategy for SiPMs

- DUNE is pursuing a «**two vendor scheme**» for the procurement of the SiPMs for FD1-HD (288,000+spares) because of:
- **Risk mitigation** (retirement/disappearance of a vendor, as it happened with SensL a few years ago)
- **Cost reduction** (multiple bids)
- We call it a «two vendor» scheme because in the preparatory phase we identified two vendors able to produce such an **amount** of cryogenic SiPMs and **certify them at 87 K**

Hamamatsu Photonics (HPK)
A Japanese company with satellite distribution companies in US and EU

Fondazione Bruno Kessler (FBK)
An Italian company serving particle and astroparticle experiments (CTA, CMS, DarkSide, LHCb, etc.)

Specifications

- Test 6 types of SiPMs 6x6 mm^2 developed specifically for DUNE "splits": 4 from Hamamatsu (HPK) and 2 from FBK
- 25 SiPMs per type fully characterized at single SiPM level
- 250 SiPMs per type in the DUNE SiPM board, tested in ganging

- High level requirements
  - **Sensitivity to single p.e.** at the level of one electronic channel and **dynamic range** for 48 SiPM **> 2000 p.e.**
  - **Dark count rate** contribution negligible compared with **background of 39A**

- Low level Requirements
  - Breakdown voltage < 50 V and uniformity 0.1 V per channel
  - **X-talk & After pulses < 35% @ nominal OV**
  - Gain ~ 10^6
  - **Dark count rate < 100 mHz/mm^2**
  - **Thermal cycles > 20 times**
  - **S/N ratio for 1 p.e. with the PDS cryogenic amplifier > 4 sigma**

Sharing of the splits of 25/250

A reference for all labs involved:
Standard DUNE splits from FBK and HPK

Vendor	Split	Cell pitch	τ at 87 K
FBK	Standard	30 μm	400 ns
FBK	Triple Trench	50 μm	600 ns
HPK	6050HS-LRQ	50 μm	30 ns
HPK	6075HS-LRQ	75 μm	63.5 ns
HPK	6050HS-HRQ	50 μm	117 ns
HPK	6075HS-HRQ	75 μm	254 ns

Table 1: The DUNE pre-production splits

<u>Sharing:</u>
SiPMs were sent to Italy (**Bologna**, **Ferrara** and **Milano**), Spain (**Madrid** and **Valencia, Granada**), **NIU** and **<u>Prague</u>**.
The single splits sent to at least 2 laboratories to be independently measured

Lab setup & measurement procedure

Device	Specifications
Scope	1 GHz bandwidth, 5 Gs/s, 8 bit vertical scale, **10 Msample memory**
Source meter	0-100 V voltage range, **few pA precision**
Source meter cable	less than few pA loss
Signal cable	RG174 with SMA connector
Preamp power cables	coaxial RG174
SiPM bias cable	coaxial RG174

Table 4: Relevant specifications of instrumentation

Planning for the SiPM tests in the DUNE pre-production phase

Alessandro Montanari[1] and Francesco Terranova[2]

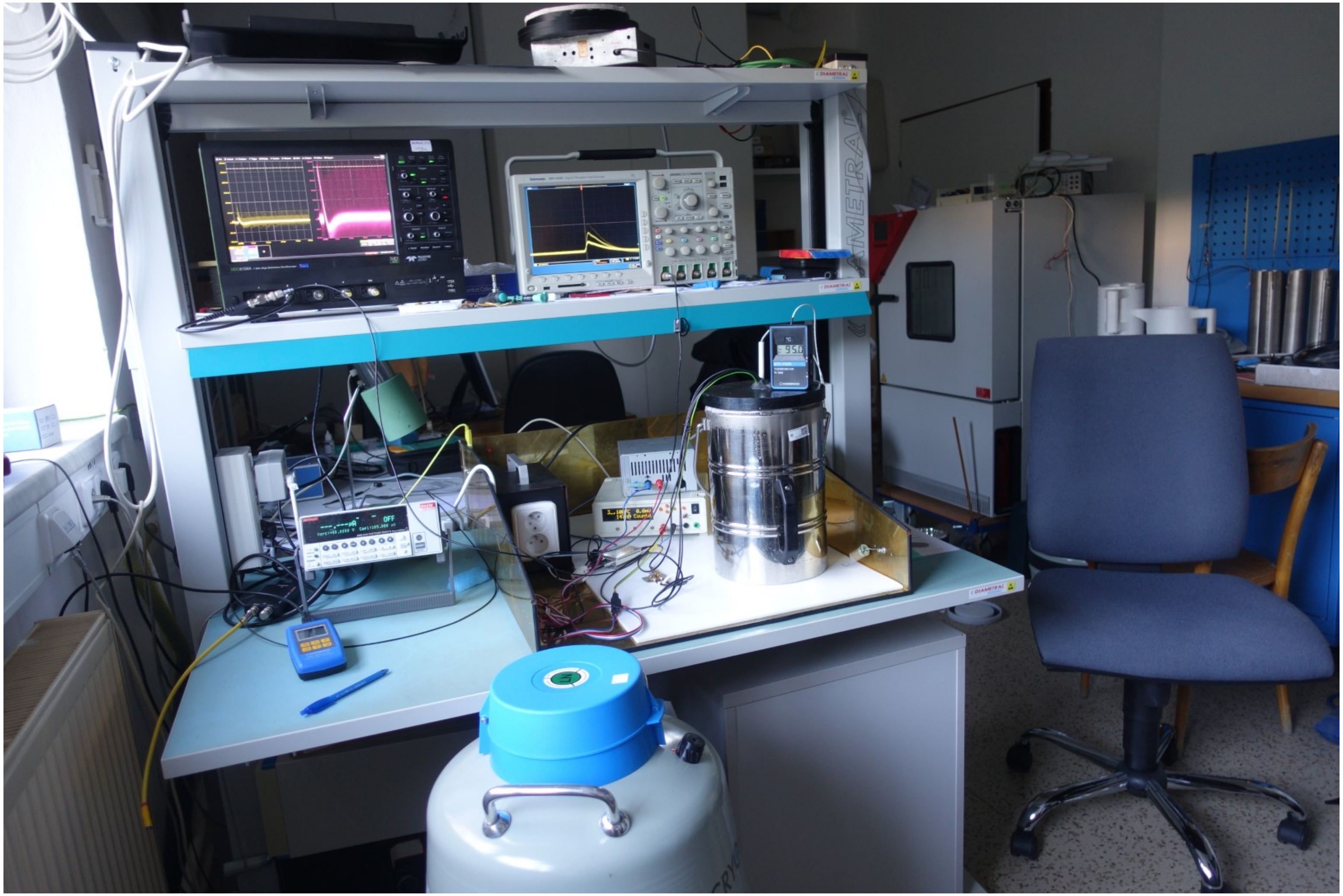
[1]INFN Sez. di Bologna
[2]Dep. of Physics, Univ. di Milano Bicocca and INFN

Version 4, 10 March 2020

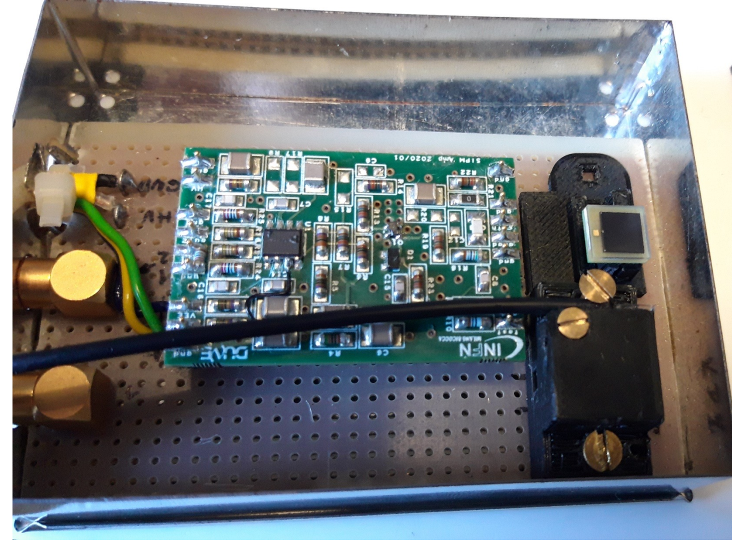
List of tasks:

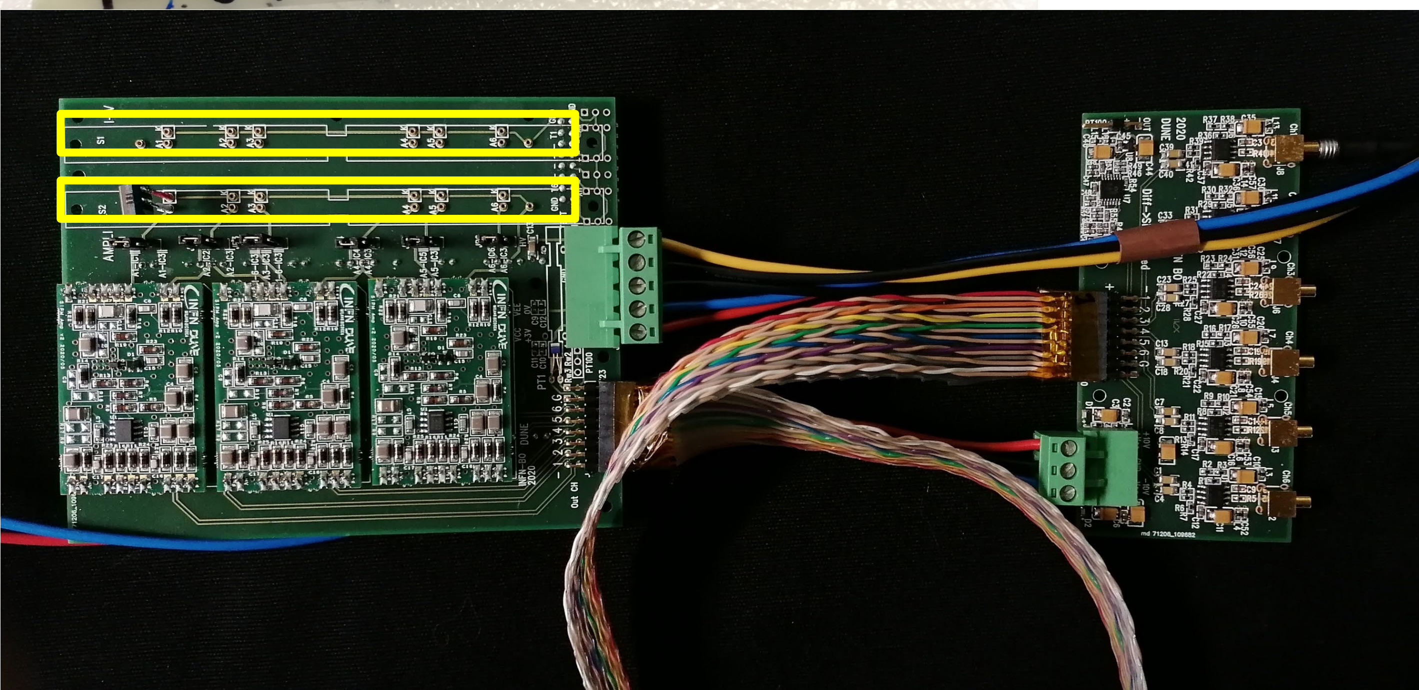
- ❑ **Reliability at cryo temperatures LN2**
- ❑ **I-V curve in forward bias – Rq**
- ❑ **I-V curve in reverse bias – Vbr**
- ❑ **P. E. response – gain & S/N ration**
- ❑ **Dark count rate – intrinsic noise**
- ❑ **Correlated noise – X-talk & After-pulse**

Photosensor laboratory in Prague @ FZU
SiPM measurement @ cryogenic (LN2) temp



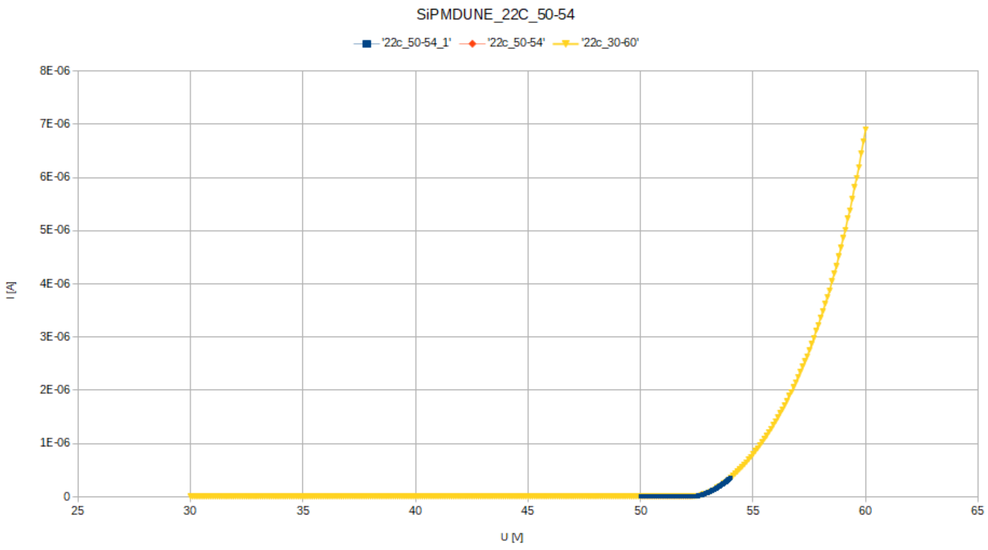
Single (25) chip setup

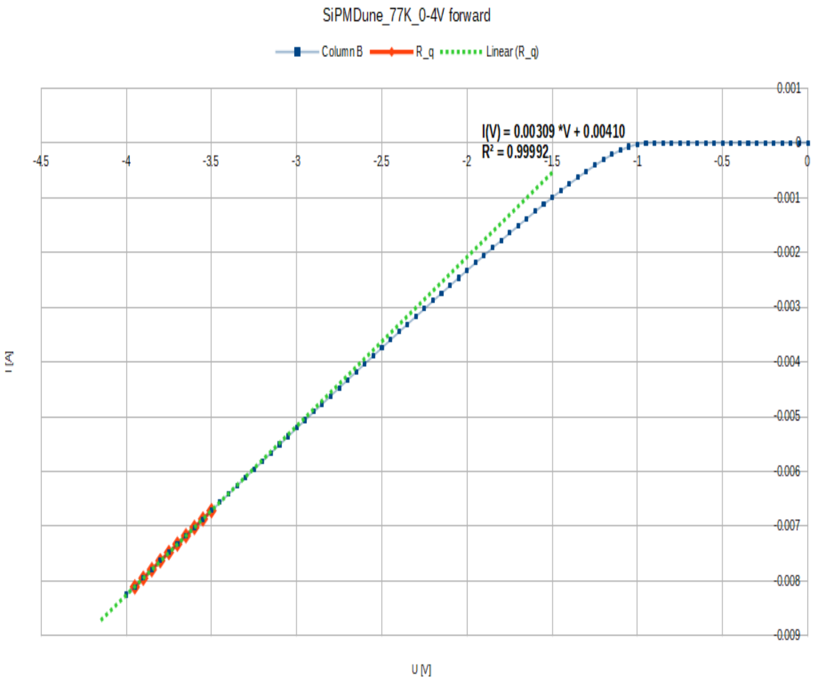


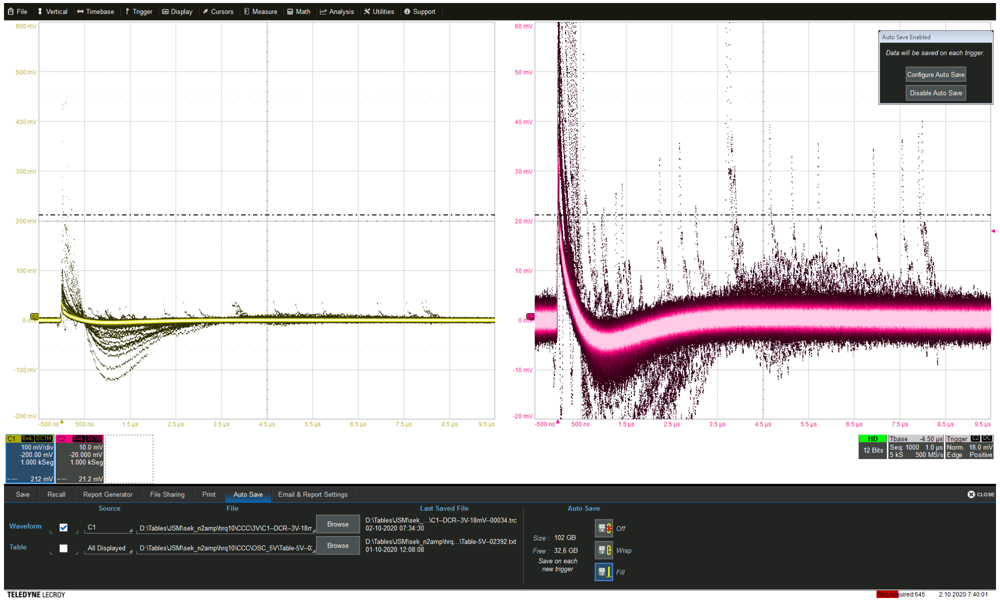


Tool for 6-SiPM board test (250)

Breakdown voltage V_br
Quenching resistor (Rq)
DCR & coherent noise
(no light, full dark)

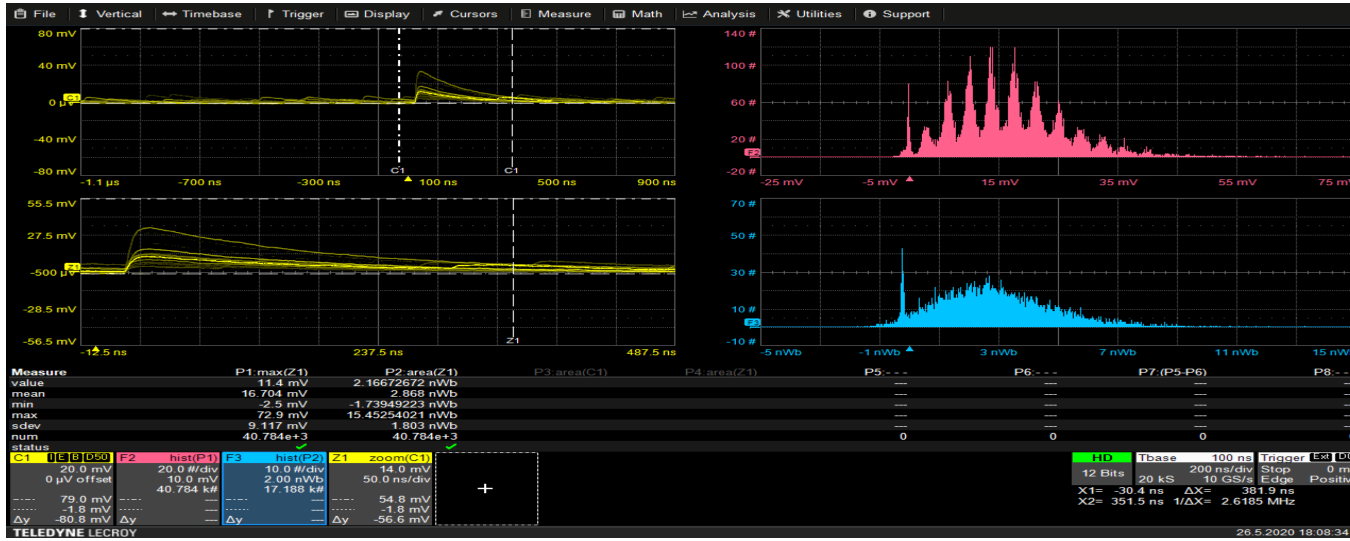




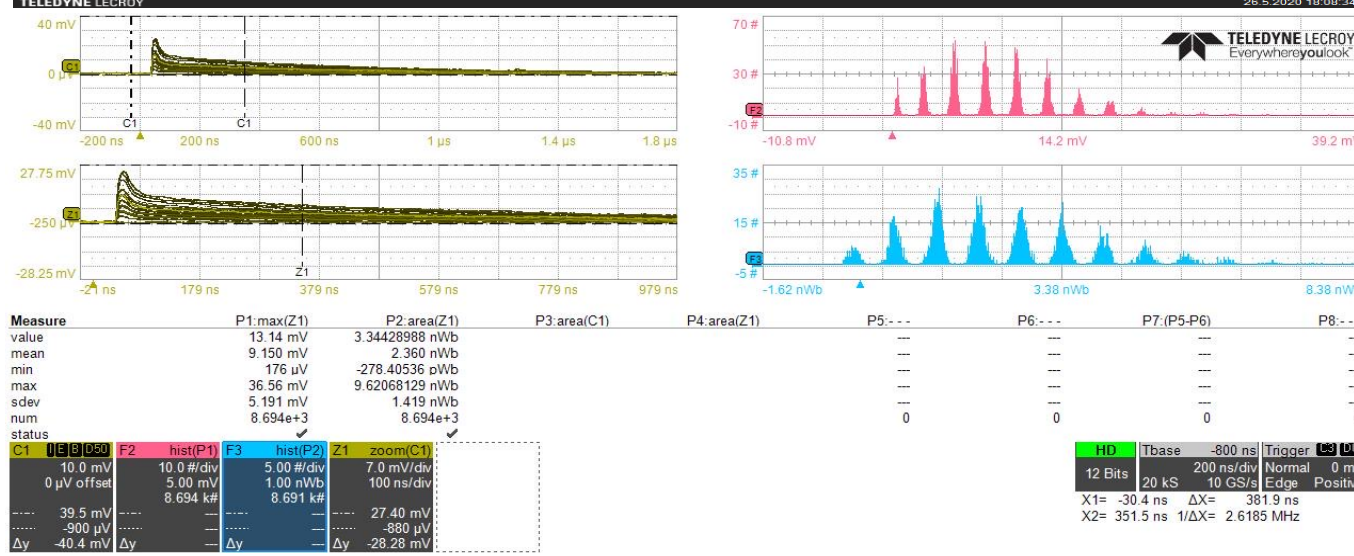


Oscillography & Thermo-cycling

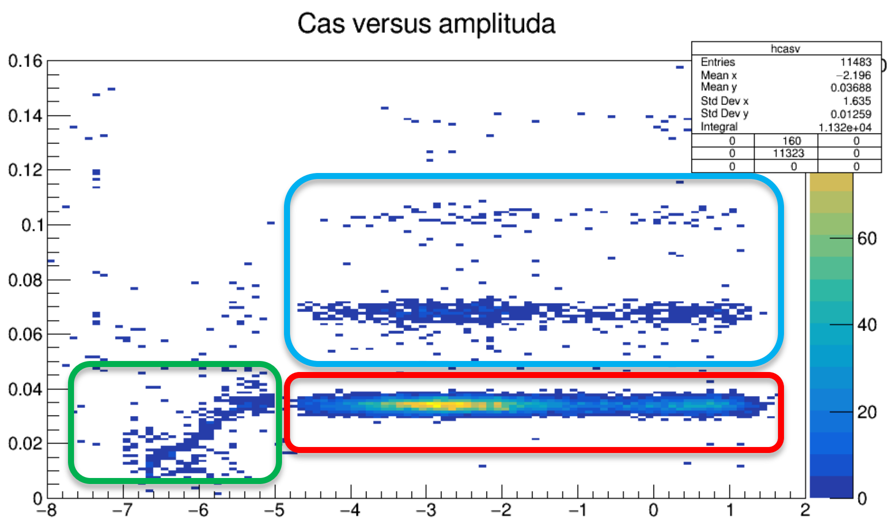
Room temp.

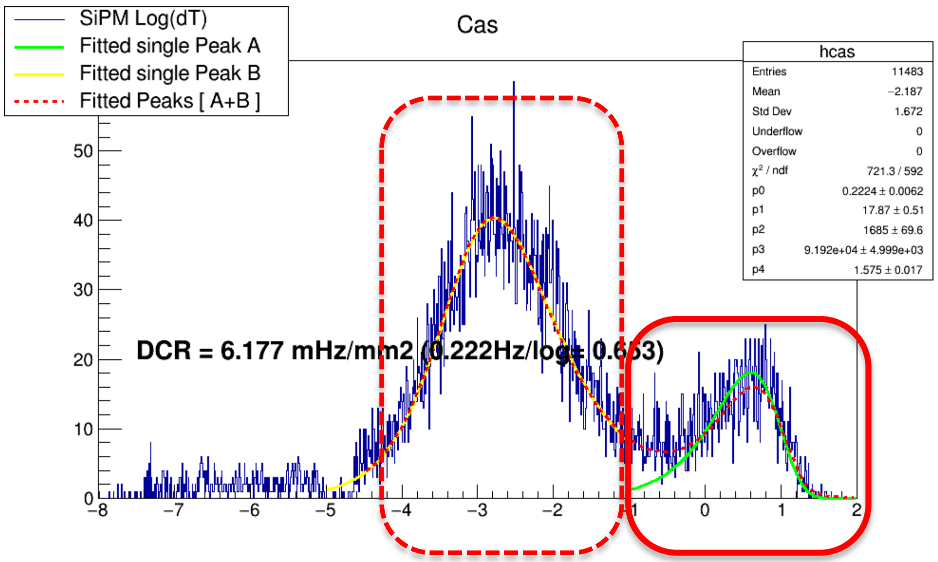


LN2 temp



Dark count rate (bursts contamination) Coherent noise Xt + AP





1 p.e. Dark Count rate

Cross-talk – rate above 1.5 p.e. in different trigger

After pulse – pulses piled up within waveform

Bursts in DCR events – induced by high amplitude real environmental signal, echoes with many fast train signals 1kHz for a minute.

Results

LABS INVOLVED			Gain		DCR+B (mHz/mm²)		DCR-B (mHz/mm²)		Xtalk (%)		Afterpulses(%)	
	Model	PDE (%)	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev
Valencia Prague Madrid Ferrara Bicocca Bologna	50_LQR	40	2,38E+06	6,60E+03	54,08	0,96	12,79	0,67	9,96	0,47	2,15	0,15
		45	3,10E+06	8,97E+03	60,29	1,06	13,70	0,70	11,23	0,39	2,62	0,17
		50	3,84E+06	8,57E+03	71,92	1,01	16,62	0,85	13,38	0,37	5,13	0,21
Valencia Madrid Bicocca	50_HQR	40	2,25E+06	6,65E+03	38,74	0,98	7,36	0,83	7,15	0,34	2,06	0,16
		45	2,99E+06	6,79E+03	81,57	1,68	8,73	0,68	8,71	0,34	3,50	0,19
		50	3,78E+06	8,04E+03	53,25	0,92	9,65	0,46	10,92	0,36	3,95	0,21
Ferrara Valencia Bologna Madrid	75_LQR	40	3,49E+06	6,72E+03	42,14	0,65	6,10	0,32	9,47	0,32	1,41	0,15
		45	4,33E+06	6,26E+03	50,70	0,75	6,58	0,34	10,18	0,35	1,83	0,16
		50	5,16E+06	7,61E+03	50,88	0,68	9,07	0,41	11,84	0,34	2,06	0,18
Bicocca Prague NIU	75_HQR	40	3,94E+06	2,02E+05	26,40	2,12	4,60	0,24	6,16	0,05	1,63	0,44
		45	5,43E+06	2,34E+05	31,32	0,65	5,57	0,17	7,03	0,30	2,35	0,66
		50	5,81E+06	2,73E+05	32,53	4,68	6,46	0,73	9,85	0,14	2,78	0,23

- We down-selected:

S13360 75μm High Quenching Resistance from Hamamatsu
NUV-HD-CRYO 50μm with Triple Trenches from FBK

ProtoDUNE-SP II – FD-HD prototype

- 4 APAs each 10 PD modules with 4 X-Arapuca supercells
- We are moving fast towards the ProtoDUNE Run II at CERN:
  - Installation started in Q1 2022
  - Capital importance for the SP PDS to demonstrate:
    - the X-ARAPUCA technology,
    - the cold summing strategy,
    - the DAPHNE read-out system,
    - the optimized calibration system, …

- Several steps in process
  - Fabricated, measured, selected and assembled: FBK+HPK: 4000 sensors/each
  - Installation (2022)
  - Commissioning/Initial operation (2022/23)? **Issue with LAr supplies**!!

- **DUNE FD PD-HD module construction 2023/24**
- Mass QC/QA SiPMs tests → Prague Lab @ FZU

Mass SiPMs tests

- Mounting & board identification: 30min;
- IV curve at room 120 SiPM in parallel: 20min;
- 1st diving phase: 20min;
- IV curve at LN2T 120 SiPM in parallel: 20min;
- thermal cycles 15x15min: 225min;
- IV curve at LN2T: 20min;
- global DCR at LN2T: 30min.
  For a sub sample of SiPM DCR before cycles

120 SiPM per day

LN2 refilling system

Cold board holder

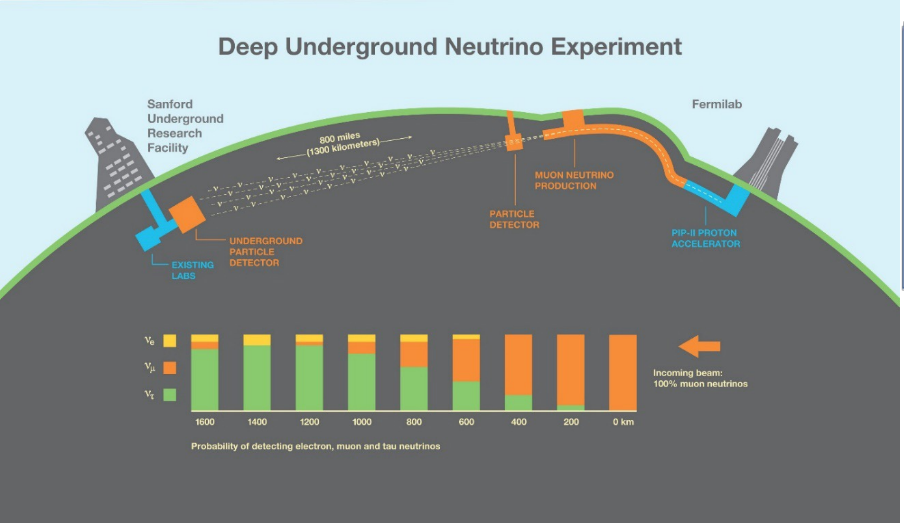
LN2 dewar

Translator stage

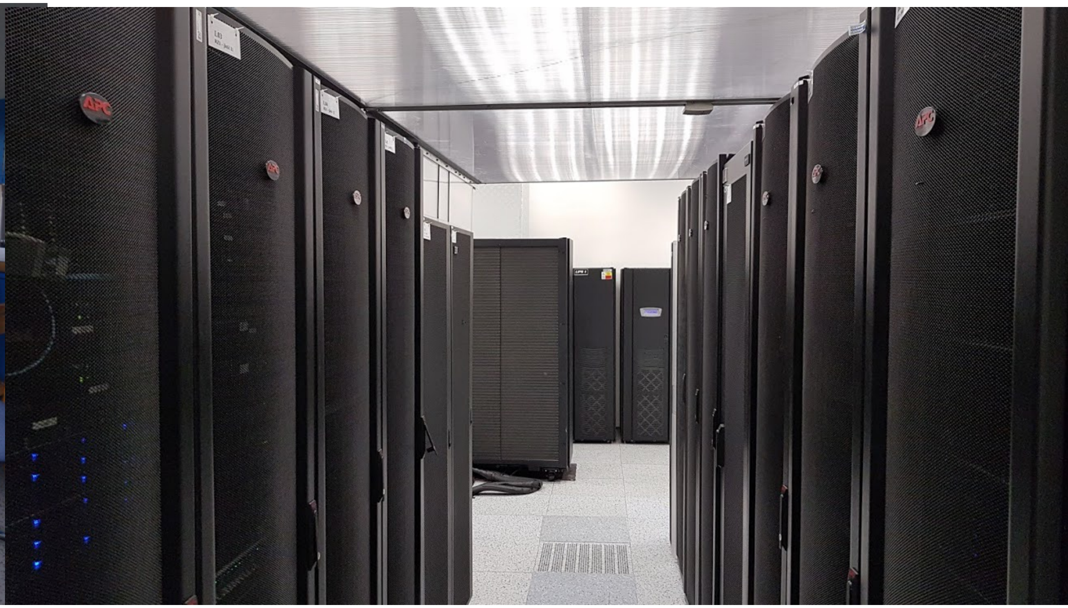
Fermilab – CZ - Conclusion

- RI successfully operates for 20 years
- Our reliable services sought after and consumed by our users
- We keep the equipment and services on the highest available level
- Steady highly qualified force (physicists, engineers, technicians)
- New postdoc coming to the team – detector calibration
- Students supporting services
- Ready to be visible in DUNE detector construction

Thank You



FERMILAB CZ



Backup

Fermilab-CZ LM2018113

Finance

	2020	2021	2022	Celkem	
	Dotace MŠMT	Dotace MŠMT	Dotace MŠMT	Uznané náklady	Dotace MŠMT
Osobní náklady	3 130	2 807	2 854	8 791	8 791
Investice	0	0	0	0	0
Členské poplatky	1 430	1 430	1 430	4 290	4 290
Provozní náklady	8 287	7 681	7 405	24 753	23 373
Celkem	12 847	11 918	11 689	36 454	36 454

Nový OP VVV efektivně jen investice, bez osobních a cestovních nákladů.
Navýšení osobních nákladů na úkor provozních – FZÚ 2020 500 kKč, 2021 a 2022 350 kKč
ČVUT 2020 180 kKč

*Working position:	32 people / 12 FTE
senior researcher	13
junior researcher	2
Ph.D. student	4
student	0
technical staff	12
administrator	1
other	3

Czech institutions at NOvA

- ~240 collaborators
- 50 institututions
- 7 countries

NOvA operations

- Former NOvA Run Coordinator – leading experiment operation role
- Test Beam commissioning
- HV source for NOvA test beam delivery

- **Czech Republic – 4 institutions: FZU, CTU/FNSPE, UK/MFF and ICS**

Computing capacities delivery

- MC production for NOvA (25% offsite capacity delivered by FZU)
- NOvA remote control room Prague

Statistical methods – mathematicians

- Reconstruction methods for machine learning
- CNN networks for NOvA calibration

DAQ software

- Dashboard online alarm watcher and Downtime Logger tools

NOvA data analysis

- Multi-muons seasonal variation analysis
- Systematic study for electron neutrino group
- Sterile neutrino data analysis

DUNE – Collaboration

1347 collaborators from 204 institutions in 33 countries (+CERN)

Armenia, Brazil, Bulgaria, Canada, CERN, Chile, China, Colombia, **Czech Republic (11)**, Spain, Finland, France, Germany, Greece, India, Iran, Israel, Italy, Japan, Madagascar, Mexico, The Netherlands, Paraguay, Peru, Poland, Portugal, Romania, Russia, South Korea, Serbia, Sweden, Switzerland, Turkey, UK, Ukraine, USA

- **Czech Republic – 3 institutions (FZU, CTU, UK)**
  - **Members of Single Phase Photon Detection Consortium**
  - **Measurement SiPMs for the (first) Far Detector module light system.**
  - **Installation, commissioning, operation and data analysis of Single ProtoDUNE prototype at CERN Neutrino Platform (second round starts 2021)**
  - **Data acquisition system development**
  - **Computing capacity**
  - **Data analysis starting with ProtoDUNE beam & cosmics data**

Specifications

- Test 6 types of SiPMs 6x6 mm^2 developed specifically for DUNE "splits": 4 from Hamamatsu (HPK) and 2 from FBK
- 25 SiPMs per type fully characterized at single SiPM level
- 250 SiPMs per type in the DUNE SiPM board, tested at single SiPM level and in ganging

Parameter	value	note
Breakdown Voltage	<50 V	All splits
PDE at 430 nm	>35 % at nominal overvoltage	Achieved 45% for downselected splits
x-talk and afterpulse	<35% at nominal OV	Updated after the reanalysis of throughput
Rise time	<100 ns	not critical
Recovery time	a few μs	Not critical
Thermal cycles	>20	**Achieved by all splits!!**

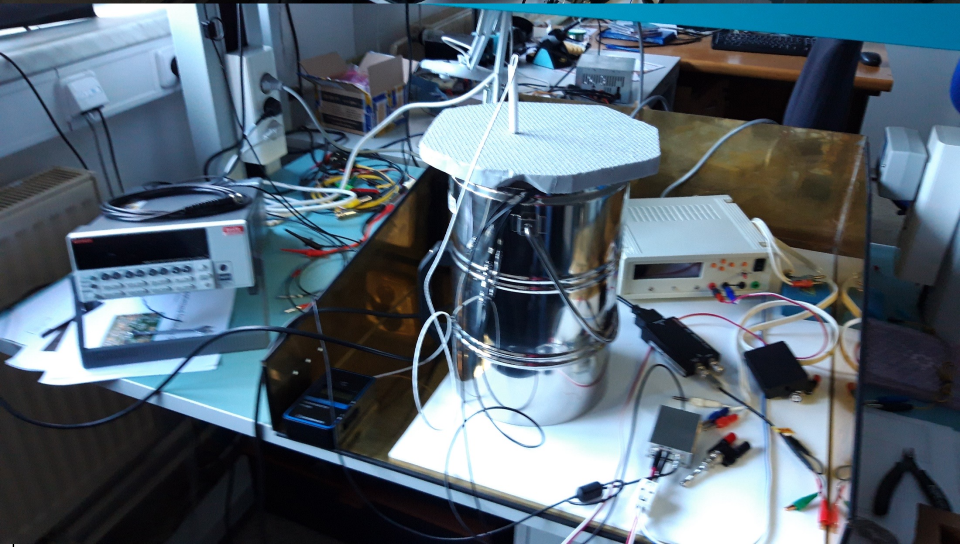
High level specifications

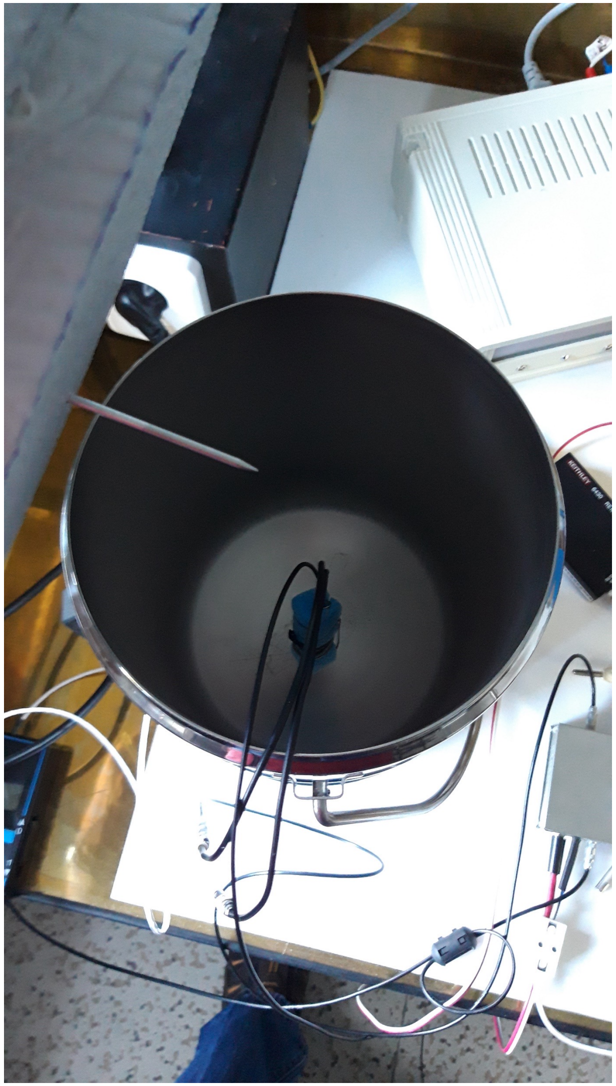
- Sensitivity to single p.e. at the level of one electronic channel and dynamic range for 48 SiPM > 2000 p.e.
- Dark count rate contribution negligible compared with background of ^{39}Ar

Low level specs generated by the high-level specs

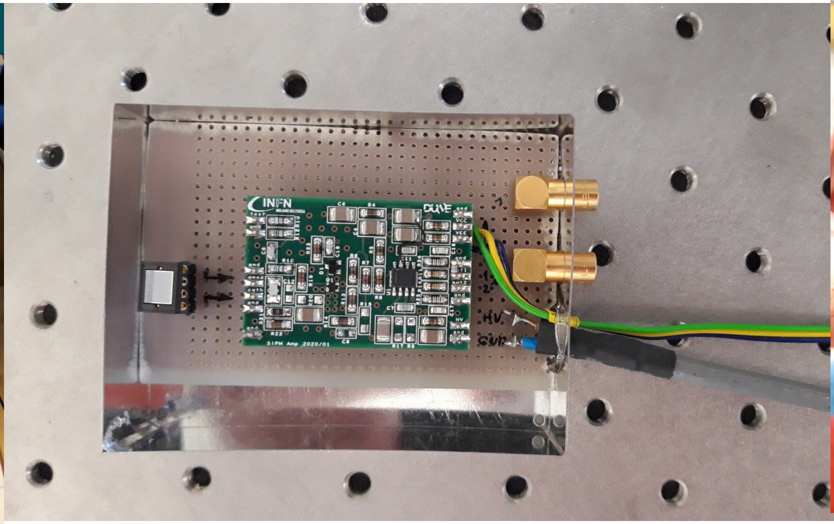
Parameter	value	note
Uniformity of V_{bk}	0.1 V per channel	Achieved by both vendors Agreed on 200pcs lots for mass production
Gain at nominal OV	10^6	Cell pitch of the downselected SiPMs: 75µm (HPK) and 50µm (FBK)
S/N ratio for 1 p.e. with the PDS cryogenic amplifier	**> 4 sigma**	**OK for downselected SiPMs**
Dark Count rate	<60 mHz/mm^2 (<200 mHz/mm^2)	OK for all splits. Can be relaxed because of the 1.5 p.e. trigger
Terminal capacitance	<0.060 nF/mm^2	Updated after the release of the PDS cryogenic amplifier

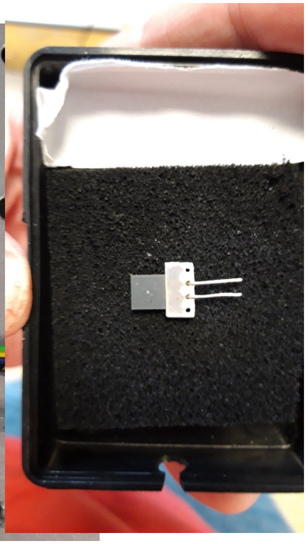

DIAMETRAL

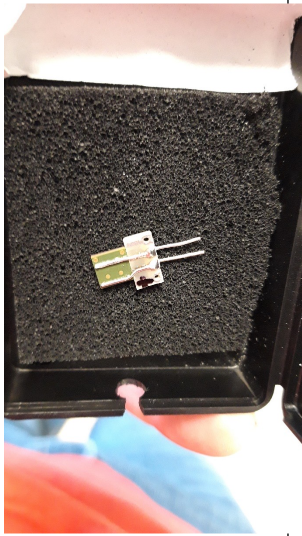




Lab setup improvement this week

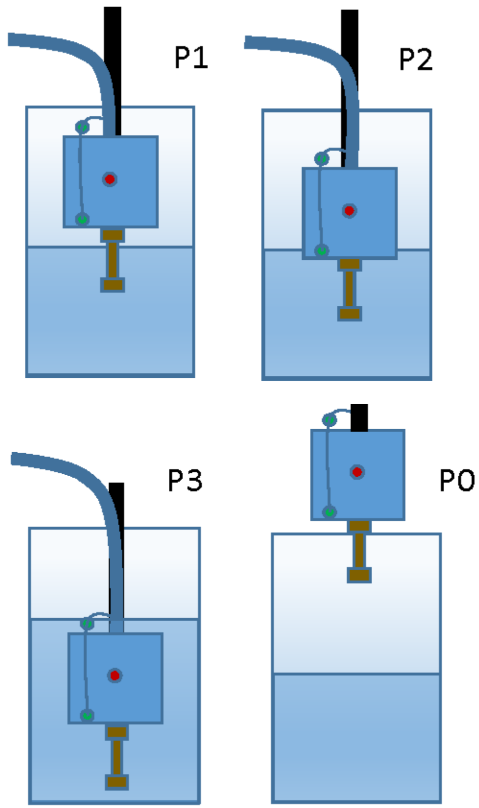


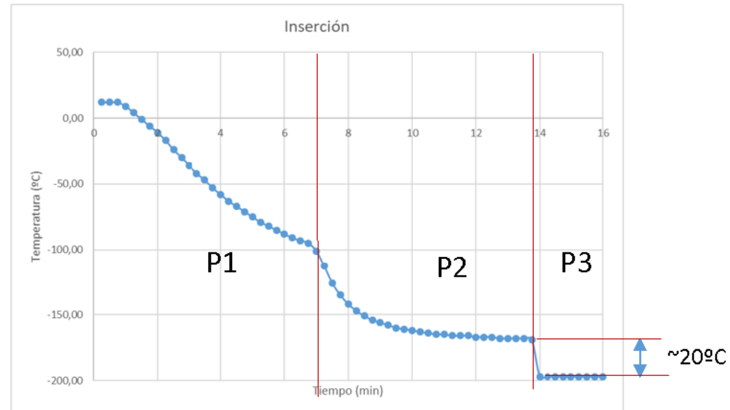


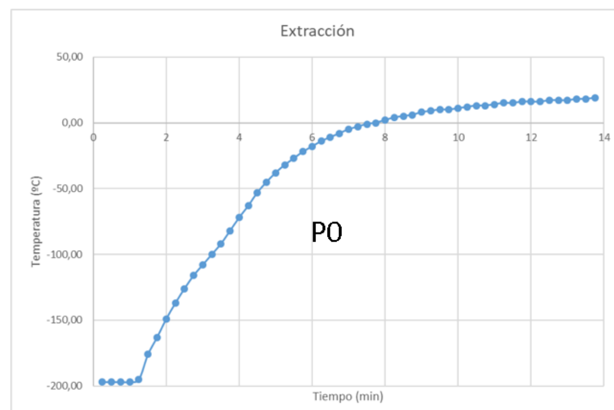


However challenging with DCR versus
CT & AP measurement with scope
And fast data format readout and
decoding

IV box thermal cycle







CZ – Prague
SiPM measurement

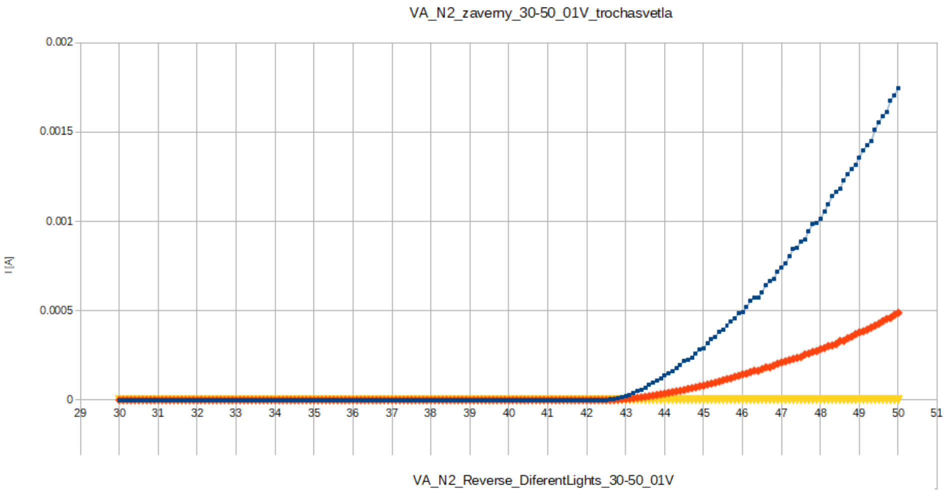
2020/10/27

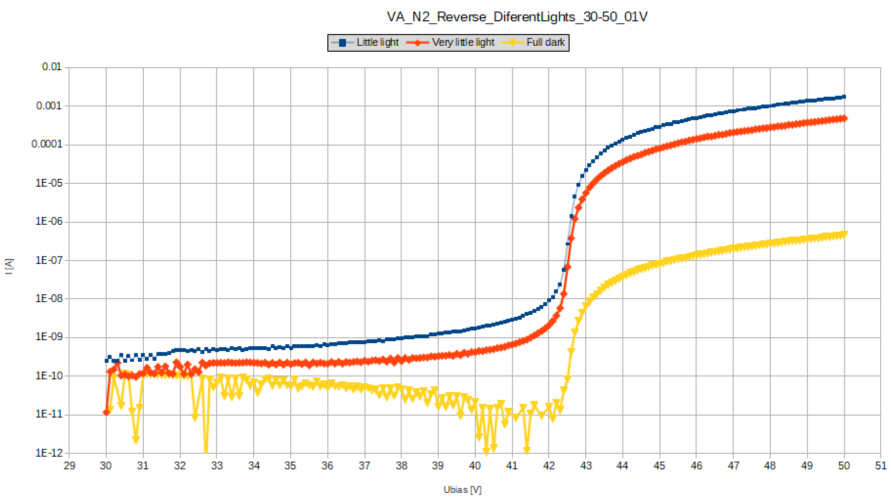
Jaroslav Zalesak, Jan Smolik, Josef Zuklin, Michal Kovalcuk, Peter Filip, Milos Lokajicek, Ivo Polak

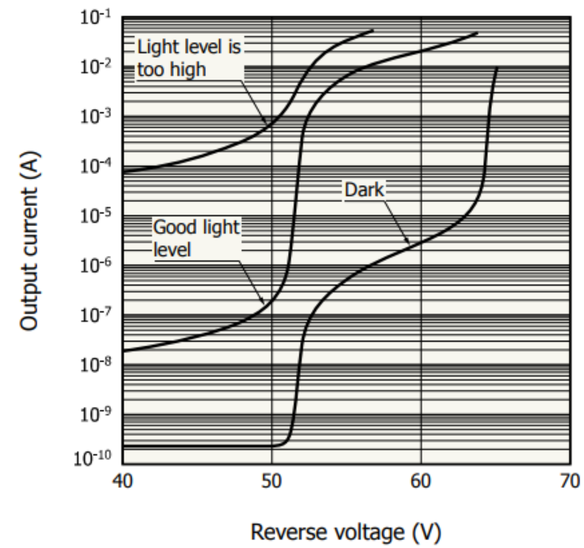
FZU
Fyzikální ústav Akademie věd České republiky
Institute of Physics of the Czech Academy of Sciences

Reverse bias LN2 -

VA_N2_Reverse_DiferentLights_30-50_01V



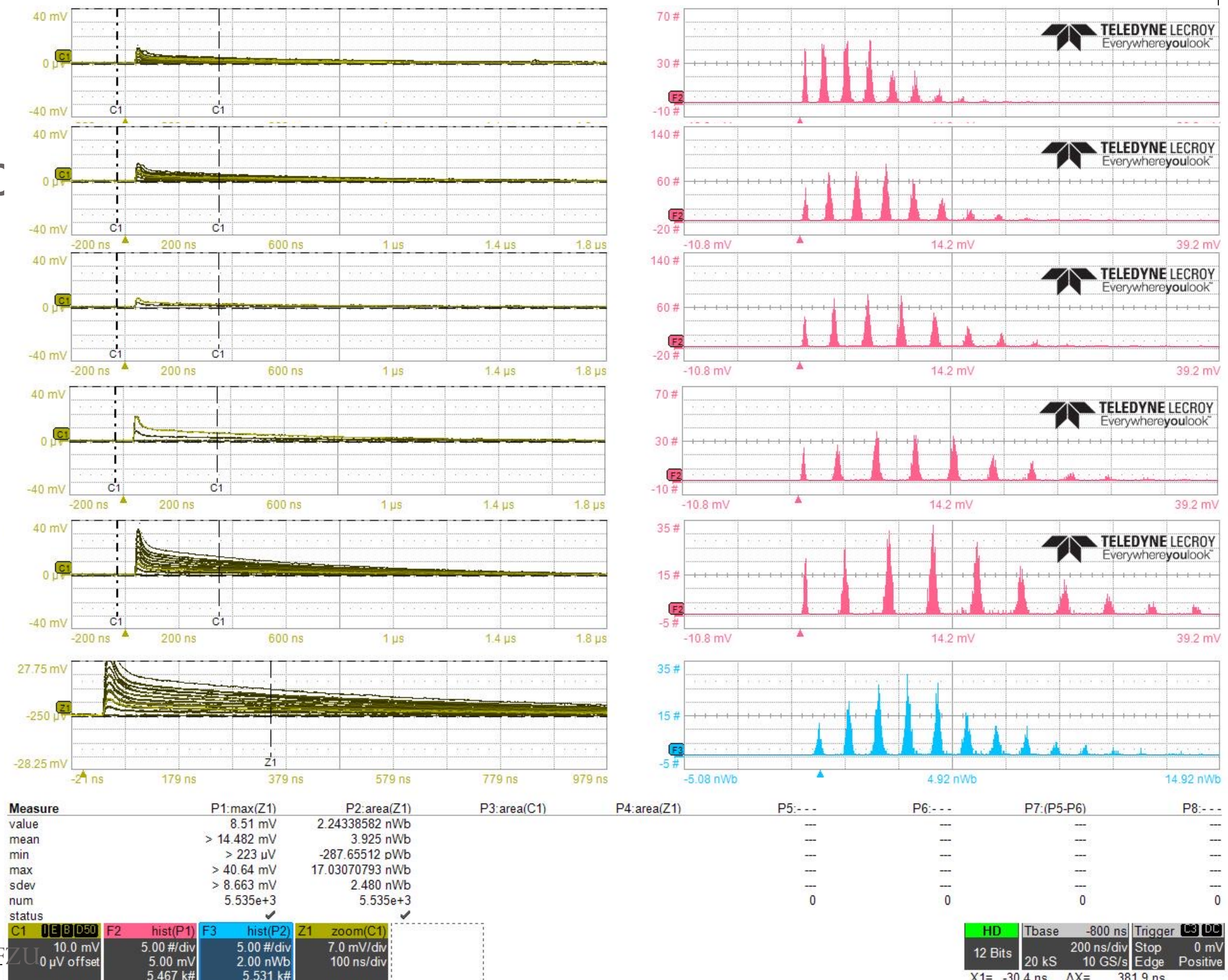




- Light intensity ad-hoc, enters through black certain into the dewar (cable holes, cap tightening), not fully controllable.
- (full) dark means very low currents and noisy before breakdown voltage, affected by environment.
- Also depending on voltage start point, stability in time/routine before measurement start, frequency of (automatic) range/filter changes of the source-meter

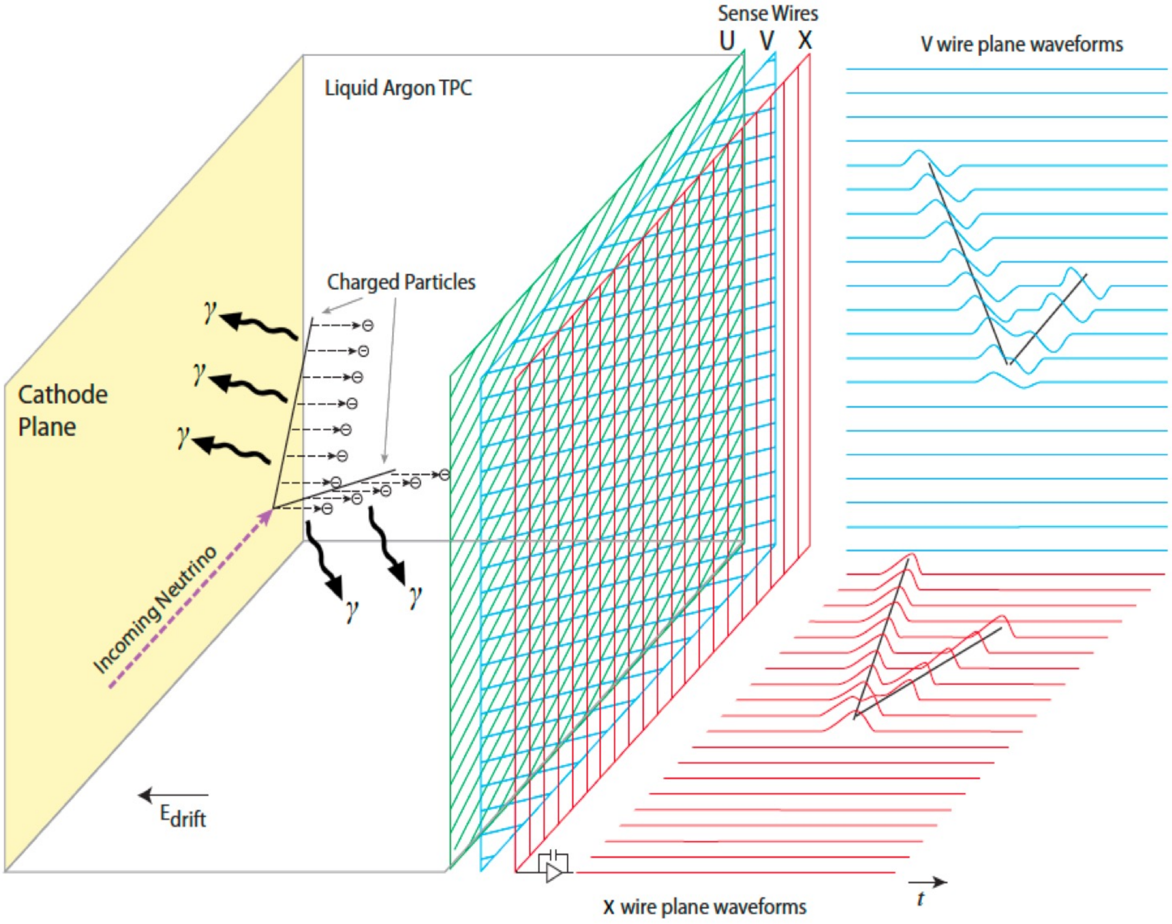
Oscillogr. LN2 temp

44.5V
45.0V
45.5V
46.0V
46.5V
47.0V

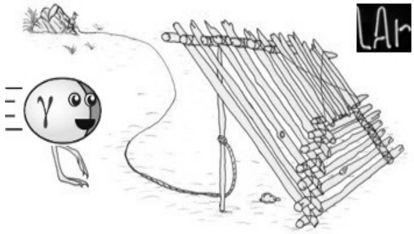


DUNE Far Detectors – Single-Phase LarTPC Option

- Liquid Argon Time Projection Chamber
- Charged particles produce ionization charge and scintillation light
- Electric field across TPC volume
- 2 out of 4 detector modules confirmed to use this technology, including the first one

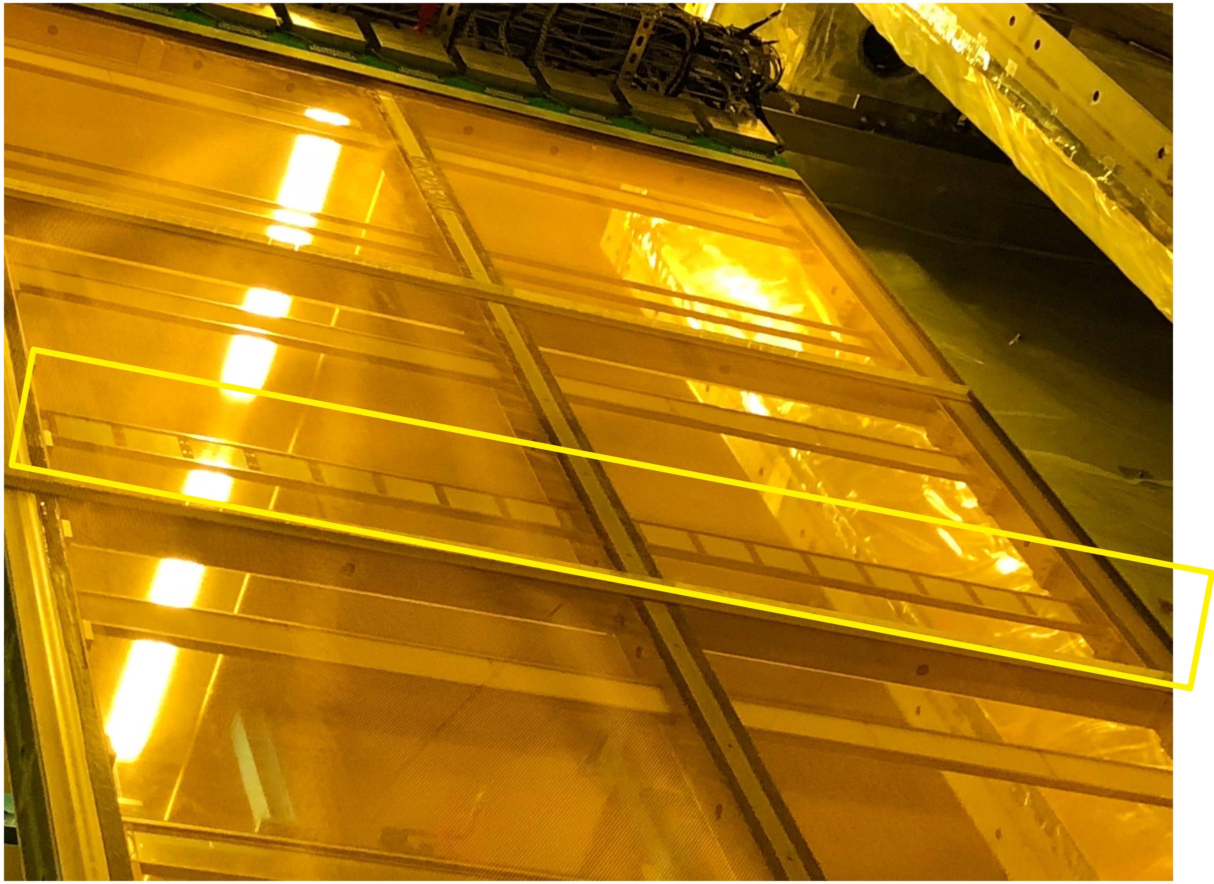


ARAPUCA Concept



- **ARAPUCA** in the language of *native Brazilian* means ***trap*** for birds
- The idea is to **trap photons** inside a **box with highly reflective internal surfaces**, so that the detection efficiency of trapped photons is high even with a limited active coverage of its internal surface → Allows to reduce the number of active device and electronic channels.
- Detection efficiency can be tuned by varying the number of SiPMs (ratio between acceptance window and SiPM areas).
- Initial LAr tests performed at ***Fermilab*** and in ***Brazil*** demonstrated a detection efficiency at the 1% level. ProtoDUNE ARAPUCA modules have demonstrated detection efficiency in the range of 2%.

ARAPUCA modules in protoDUNE



Each array *16 ARAPUCA cells* (10 cm x 8 cm) and each cell is *read-out by 12* (*6*) Hamamatsu MPPCs passively ganged together.

PD Components (Scope)

Component	Description	Quantity (per 10 kT)	Primary Responsibility
Detector support	Support rails, electrical connectors, cables	10 per APA. 1,500 total	US/DOE
Light collector modules	X-ARAPUCA modules (frames, filters, assembly)	10 per APA. 1,500 total	Brazil
Photosensors	$6X6mm^2$ SiPMs	192 per module. 288,000 total	Italy, Spain, Czech Rep.
Cold electronics	Photosensor ganging (6X SiPM passive, 8X active)	1 per module 1,500 total	Italy, Spain
Warm electronics	DAPHNE system. Based on Mu2e ultrasound ADC	1 unit per APA 1,500 total	Colombia, Peru, Brazil
Calibration and monitoring	Pulsed UV flasher with CPA mounted diffusers	180	US/DOE
Installation and integration	Module insertion, installation in cryostat		US/DOE, Brazil, Italy

Active ganging

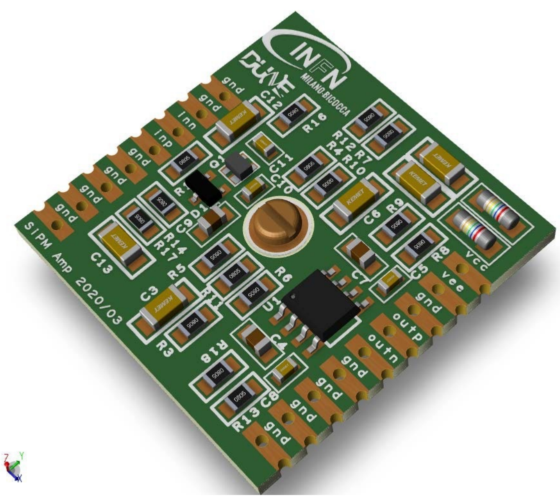
In parallel with photo-sensor testing

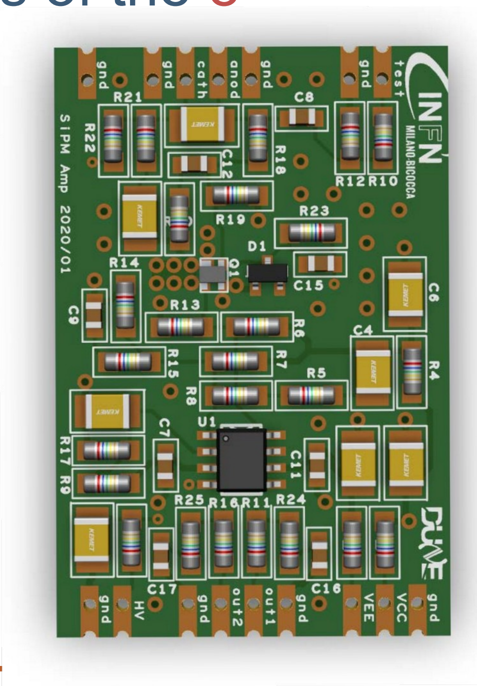
- ❑ Design the cold amplifier, the SiPM board and the signal lead board
- ❑ Test the X-ARAPUCA supercell and half-module with the new photosensors

- ❑ Cold ganging board which actively sums the signals of the 8 arrays of 6 SiPM (48 SiPM).

- ❑ Validation:
  - ❑ System tests in Iceberg
  - ❑ Cold testing in Italy, Spain

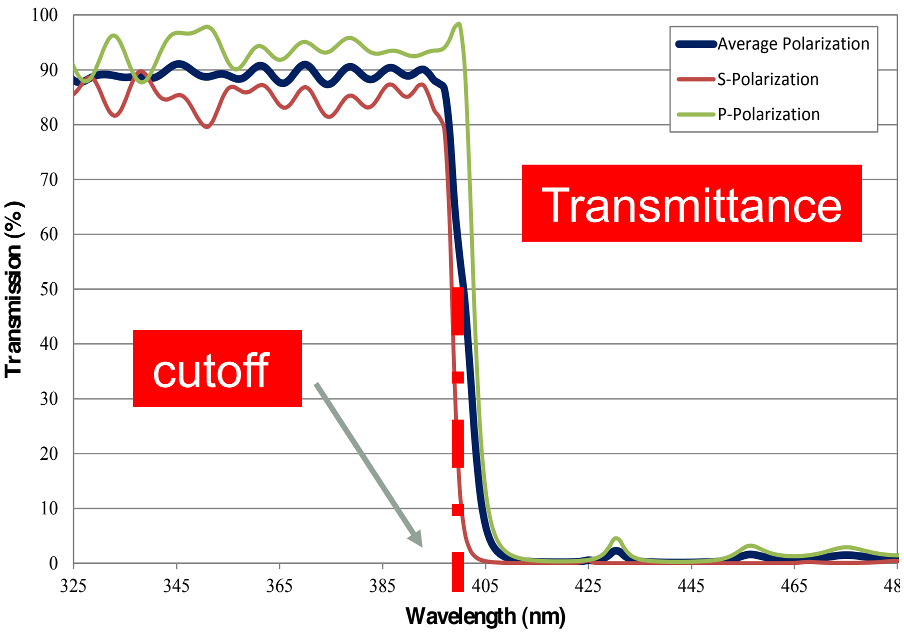
- ❑ Production:
  - ❑ Fabricated in Italy and Spain
  - ❑ DOE engineering support

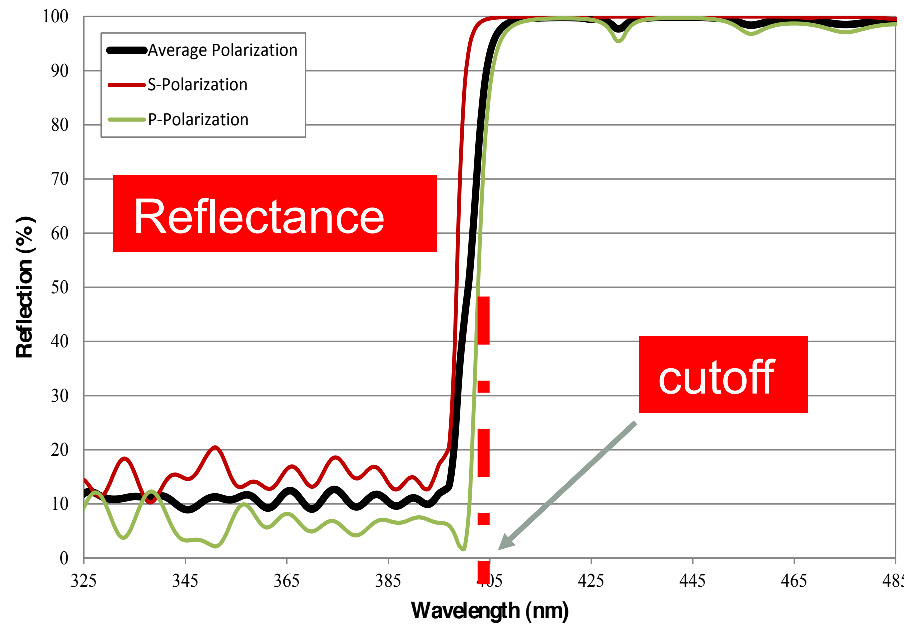




Dichroic filter

- The core of the device is a **dichroic filter**. It is a dielectric interference **film** deposited on a fused silica substrate.
- It has the property of being **highly transparent** for wavelengths **below a cutoff** and **highly reflective above it**.





Photon Detector Module Glossary

- MODULE (AKA Bar): A single photon detector element
  - 10 modules per APA
  - 4 readout channels per module
  - ~2.1m long, 12cm wide
  - 192 SiPMs per module
- Supercell: A single readout channel in a module
  - 4 Supercells per PD module
  - Each read out be a single twisted pair
  - 6 (or 12 for double-sided readout supercell) Dichroic filter windows (“Cells”)
  - Single optical element (no optical separation between supercells)
  - Single wavelength shifting (WLS) bar
  - 112 X 21 X 491.5mm
  - 48 SiPMs per Supercell
- SiPM Mounting PCB
  - Single PCB with 6 passively-ganged SiPMs per side
  - 8 per Supercell (4 per side)
  - Read out along side-mounted PCBs in module
- Active Ganging Circuit
  - Cold summing amplifier summing 8 SiPM mounting PCB channels to a single readout channel
  - 4 amplifiers mounted to a single PCB
  - Mounted in the center of the PD module

The four HPK spilts:

- All splits will be based on the **S13360 chip** (Vbk = 50 V at 300 K), terminal capacitance 1.28 nF per sensor, 61.4 nF per 48 sensors.
- All splits will be based on the **HWB technology**
- Packaging: we asked HPK to perform a thermomecanical study on epoxy versus silicon resin (see below). Results indicate that silicon resin is slightly better. We chose **silicon resin**.
- Cell pitch: **50 and 75 μm** [already fixed in July]
- Quenching resistance: **HQR= 4 LQR**.

Vendor	Split	Cell pitch	τ at 87 K
FBK	Standard	30 μm	400 ns
FBK	Triple Trench	50 μm	600 ns
HPK	6050HS-LRQ	50 μm	30 ns
HPK	6075HS-LRQ	75 μm	63.5 ns
HPK	6050HS-HRQ	50 μm	117 ns
HPK	6075HS-LRQ	75 μm	254 ns

Table 1: The DUNE pre-production splits