The CERN Neutrino Platform

FNAL PAC, 8 December 2020, M.Nessi

Some history ……

- 2012 : a CERN project was presented for a neutrino new short baseline at CERN (LOI presented in March 2013).
- At the same time a European long baseline, pointing to Finland from CERN was under discussion.
- In all these proposals, LAr TPCs technologies were among the main options.
- 2013 : the European strategy priorities put CERN neutrino among the 4 CERN priorities : "….. ***pave the way*** *for a substantial European role in future long-baseline experiments. Europe should explore the possibility of major participation in leading long-baseline neutrino projects in the US and Japan."*
- June 2014 Paris APPEC meeting: we announced that CERN would stop any plan for a CERN based Neutrino beam, in favour of an active cooperation with the US and Japan programs.

The CERN Neutrino Platform (NP) mandate (2014)

- Assist the various groups in their R&D phase (detectors and components) in the short and medium term and give coherence to a fragmented European Neutrino Community
- Provide to the ν community a test beam infrastructure (charged particles)
- Bring R&D at the level of technology demonstrators in view of major technical decisions
- Continue R&D on ν beam, as a possible base for further collaborations
- Support the short baseline activities (infrastructure & detectors)
- Support the long baseline activities (infrastructure & detectors)

MOU frame https://edms.cern.ch/document/1353815

Memorandum of Understanding

for providing a framework for developing a Neutrino Program at CERN

between

The EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH, an Intergovernmental Organization having its seat at Geneva, Switzerland, ('CERN,'), as the Host Laboratory,

on the one hand,

and

The FUNDING AGENCIES/INSTITUTIONS PARTICIPATING IN THE NEUTRINO PHYSICS RESEARCH PROJECTS AT CERN ('the Neutrino Institutions'),

on the other hand,

(collectively "the Parties")

Preamble

(a) As endorsed by the CERN Research Board at its meeting of August 28th, 2013 and detailed in Annex 1, CERN has decided to develop a Neutrino Program at CERN ('the Neutrino Program') to pave the way for a substantial European role in future Long-Baseline Experiments and explore the possibility of major participation of Europe in leading Long-baseline Neutrino Projects in the United States and Japan;

(b) The Neutrino Institutions, including possibly CERN, wish to collaborate in the research and development (R&D) and construction of prototypes, equipment and related infrastructure for the Neutrino Program and have obtained the support of their Funding Agencies to enable them to participate in the Neutrino Program;

STEPS:

- Present to the CERN SPSC a LOI or an expression of interest
- When approved by CERN RB prepare an MOU
- Then a CERN experiment is created (NPxx, …), with all privileges and requirements

NP01

Addendum No. 01

to the Memorandum of Understanding for Collaboration in the Neutrino Program

WA104

Overhauling of the ICARUS T600 and R&D on Liquid Argon Time Projection Chamber (LAr TPC)

ANNEXES

Annex 1:	List of the Sub-units (systems) and/or deliverables provided by participating institutes
Annex 2:	Organization and Management structure of the Collaboration and persons currently holding management positions
Annex 3:	List of Institutes, Funding Agencies and Representatives
Annex 4:	Value of deliverables, grouped by Funding Agency and/or sub-units (systems) and payment profile
Annex 5:	Project Milestones

Version_22-11-2014

The European Organization for Nuclear Research (CERN)

and

The INFN, on behalf of the WA104 Collaboration

endorse the Present Addendum to the Memorandum of Understanding with the indicated improvements of ICARUS T600 and with the related R&D on Liquid Argon Time Projection Chamber (LAr TPC).

for CERN 25/11/2014

The Director of Reasearch and Computing

Sergio Bertolucci

For INFN, on behalf of INFN participating Institutes

The President

ISTITUTO NAZIONALE DI FISICA NUCLEARE
IL PRESIDENTE
(Prof. Fernando Ferroni)

Signature

Place and Date

ROMA, 28 NOV. 2014

Page 5

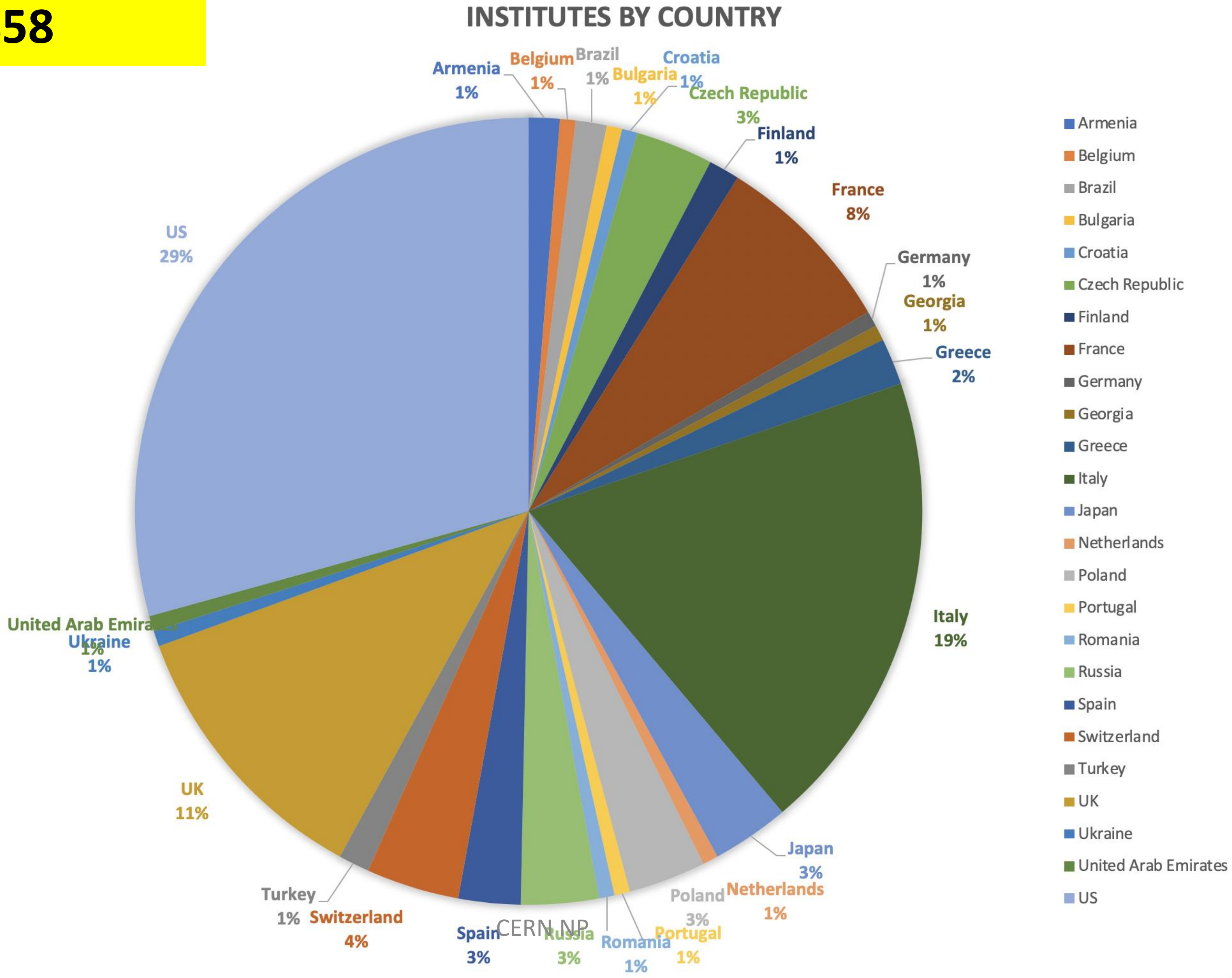
Present status of NP activities

- 7 MOUs signed:
  - ✓NP01: ICARUS overhauling + FNAL activities
  - ✓NP02: R&D on a double phase LAr TPC technology (including protoDUNE DP)
  - ✓NP03: generic R&D on neutrino detectors and facilities
  - ✓NP04: R&D on a single phase LAr TPC technology (protoDUNE SP)
  - ✓NP05: Baby Mind muon spectrometer for a T2K near detector
  - ✓NP06: ENUBET, R&D on a neutrino beta beam
  - ✓NP07: ND280, a new T2K Near Detector
- Cooperation agreements
  - CERN participation in the USA LBNF/DUNE project
  - CERN delivery in kind to USA of the first large LBNF cryostat
  - CERN participation in the FNAL short baseline Neutrino program (ICARUS+SBND)
  - CERN technical participation in the DarkSide project at LNGS
- Other activities
  - NP participation in the CERN FASER project

Institutes 157

Collaborators 858

NP Platform serves the community



NP01 : the ICARUS new detector at the SBN FNAL

CERN & INFN

Steps :

- ✓ Bring the 2 ICARUS active detectors from LNGS to CERN
- ✓ Construct new cryostats (cold and warm)
- ✓ Reshape ICARUS in a new clean room at CERN
- ✓ Insert the 2 ICARUS detectors in their new cold cryostats
- ✓ Bring the two cold cryostats to FNAL
- ✓ Assemble there a new large warm cryostat
- ✓ Insert the two new cold vessels, close the warm structure
- ✓ Procure and install the necessary LAr cryogenics system
- ✓ Provide a large muon tagger
- ✓ Participate in the cool down and filling phase, qualify the cryostat
- ✓ Participate in the commissioning and physics exploitation

ICARUS at FNAL

Leaving CERN 12 June 2017

Warm cryostat construction at FNAL

Positioning of the two ICARUS modules (cold cryostats) in final position in a new building at FNAL

ICARUS filled with LAr and ready

- ✓ Started on Feb 13th, 2020 by breaking the vacuum in the two main cold vessels.
- ✓ Cooldown started on Feb 14th by injecting liquid nitrogen in the cold shields.
- ✓ 4 days duration, maximum temperature gradient on the TPC chambers 35 K.
- ✓ Gas recirculation units activated on Feb 18th for purification of Ar gas before filling.
- ✓ Filling started on Feb 24th, interrupted at around 50% to regenerate the filters, and stopped again when the liquid reached 6 cm below the nominal level to perform the final pressure test of the two cold vessels.
- ✓ Filling completed on April 19th.
- ✓ Liquid recirculation started on April 21st, at 1.85 m3/h in the West cryostat and 2.25 m3/h in the East.
- ✓ Cryogenic stabilization completed around end of May. Steady performance since
- ✓ Cryostat works perfectly and it has been qualified for operation
- ✓ Common effort of **CERN/Fermilab** teams

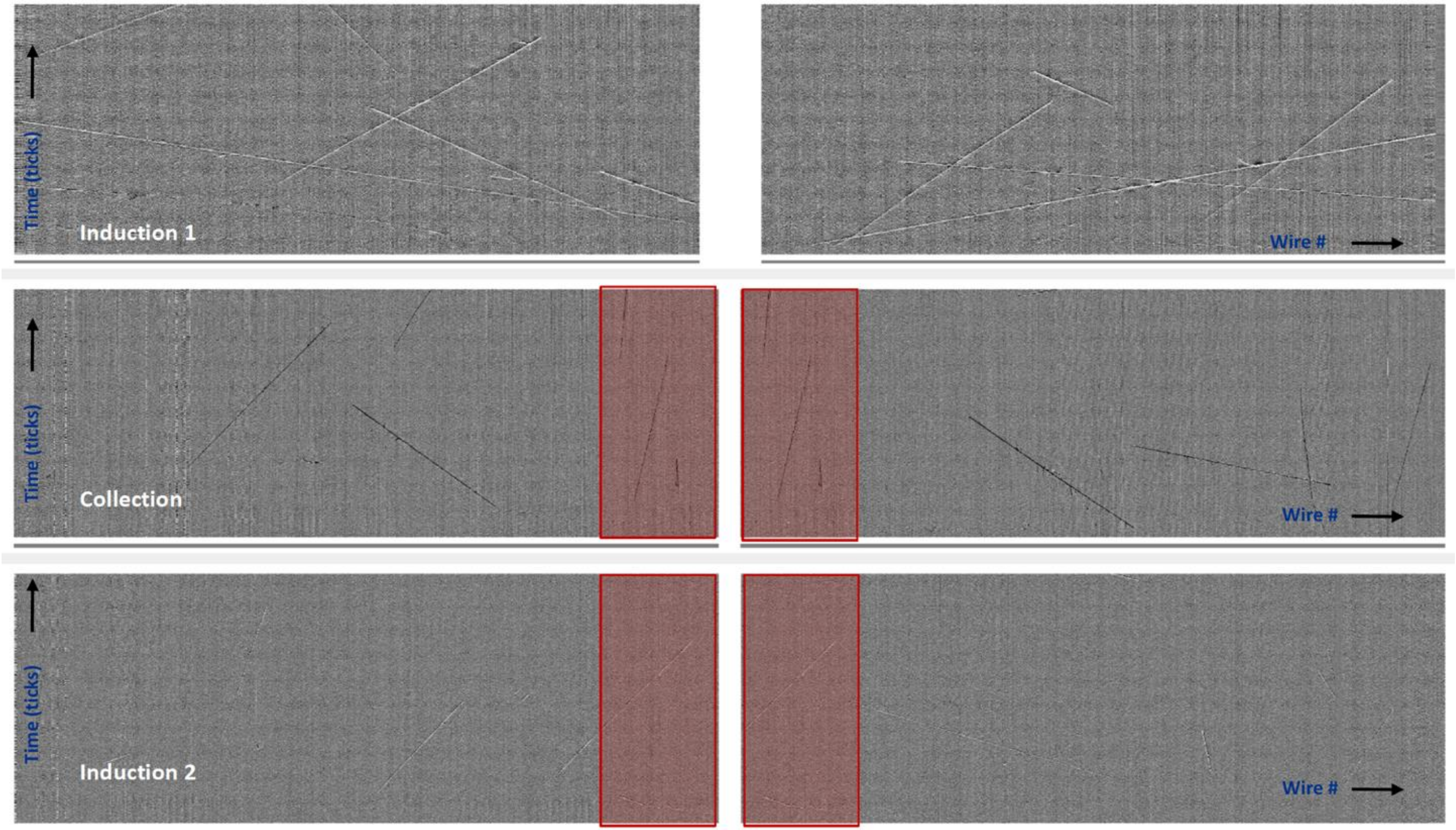
- ✓ See C.Rubbia presentation for the present operation status

ICARUS first cosmic tracks

Sample event EW TPC: Run 2272 Event 4500 (Monday, Sept 7th).

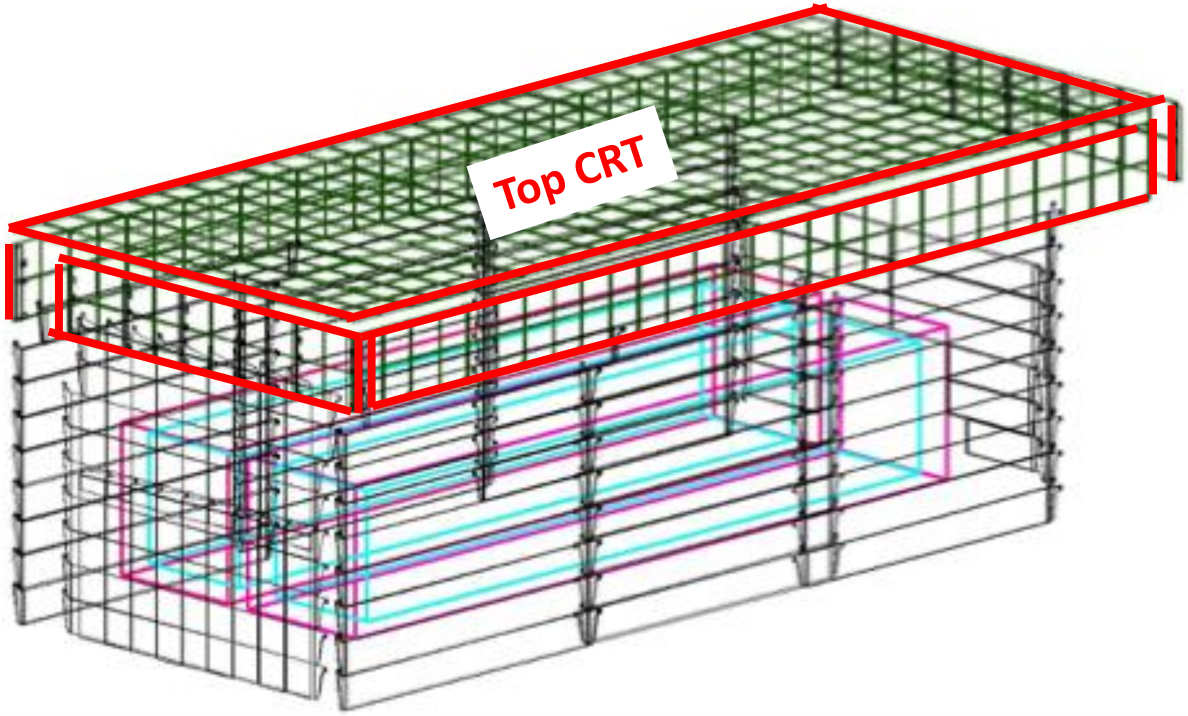
Each box represents half-TPC.

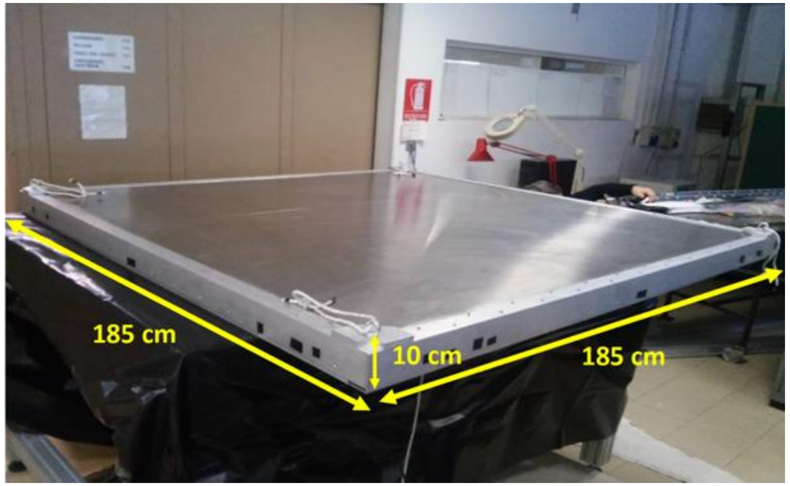
For Collection and Induction there is an overlap region in the middle, highlighted in the red boxes.

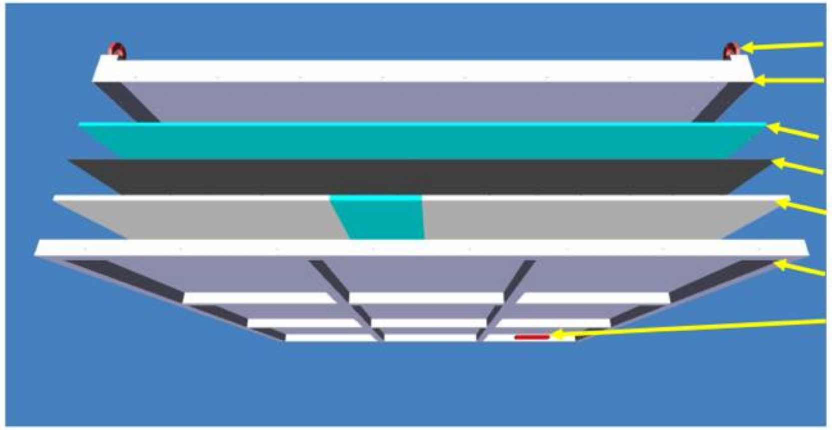


CERN group committed to the physics exploitation phase (shifts, analysis, …)

Cosmic muon tagger





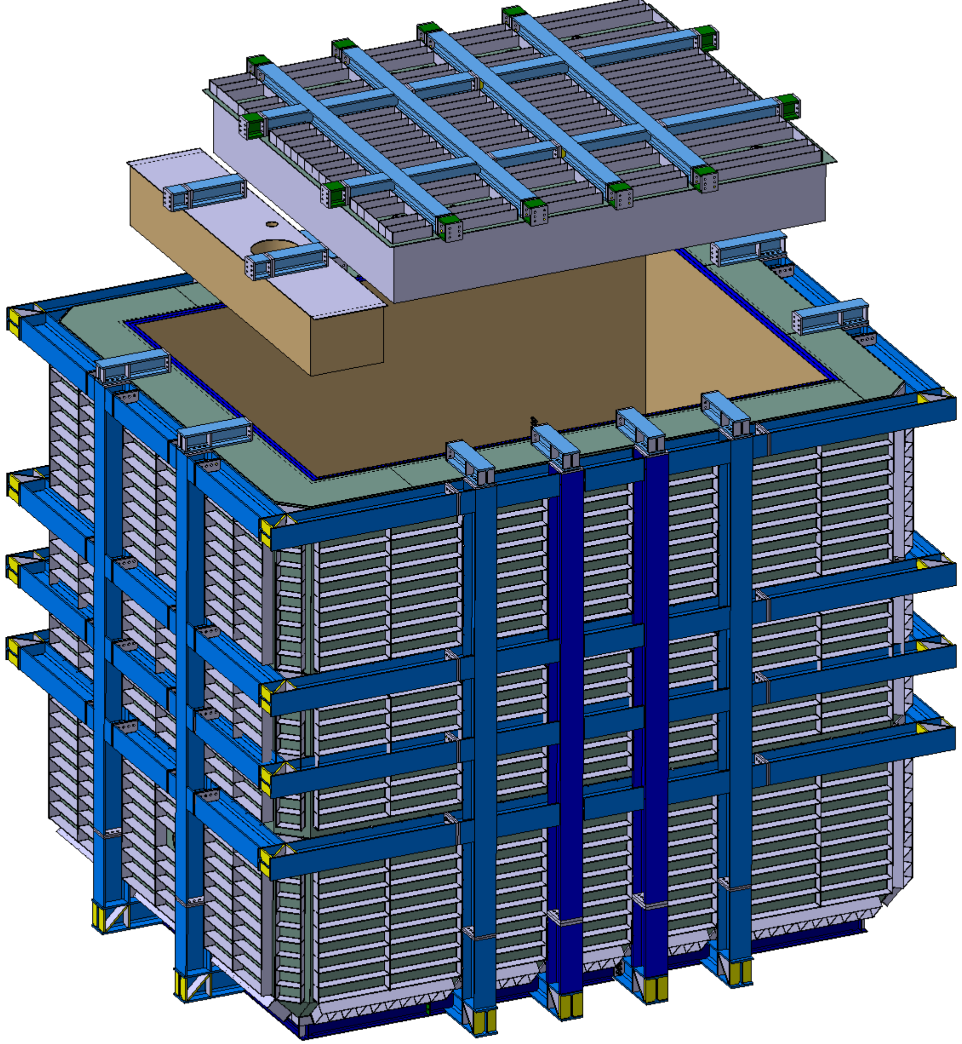


TOP CRT (CERN, INFN):

- ~ 900 m^2 of scintillators produced in CZ and Ukraine
- 125 modules (~2x2 m^2) assembled in Frascati by INFN and CERN
- Ready at CERN, to be delivered to FNAL in early 2021
- Installation in 2021 (Covid19 issue)

SBN: SBND near detector

- Warm cryostat design, procurement and installation at FNAL
- Cold cryostat design, procurement and installation at FNAL
- LAr proximity cryogenics design, procurement and installation at FNAL

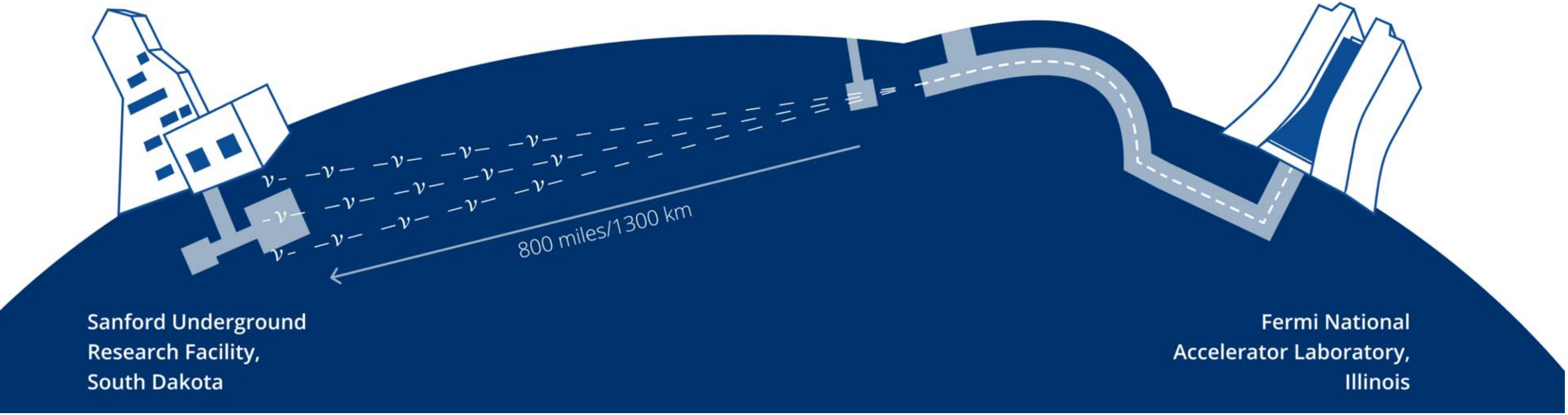


SBND : 200 T LAr membrane cryostat , warm vessel installed at FNAL in 2019, cold vessel will be installed in 2021

LAr cryogenics installed

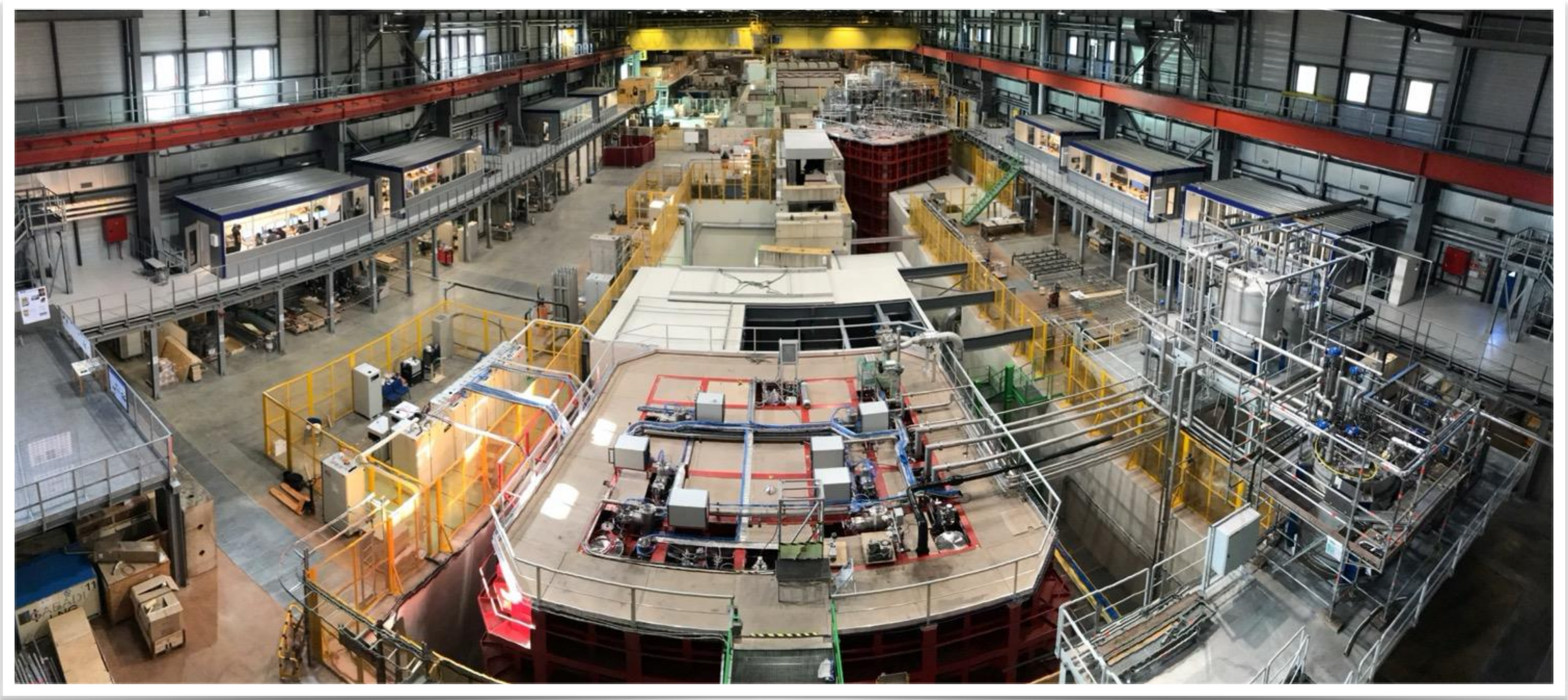
- Seen at the last prototype before LBNF
- Many structural and design changes done form the original protoDUNE experience both in the warm and the cold structures
- Excellent opportunity to prove the new design

LBNF/DUNE neutrino Long baseline



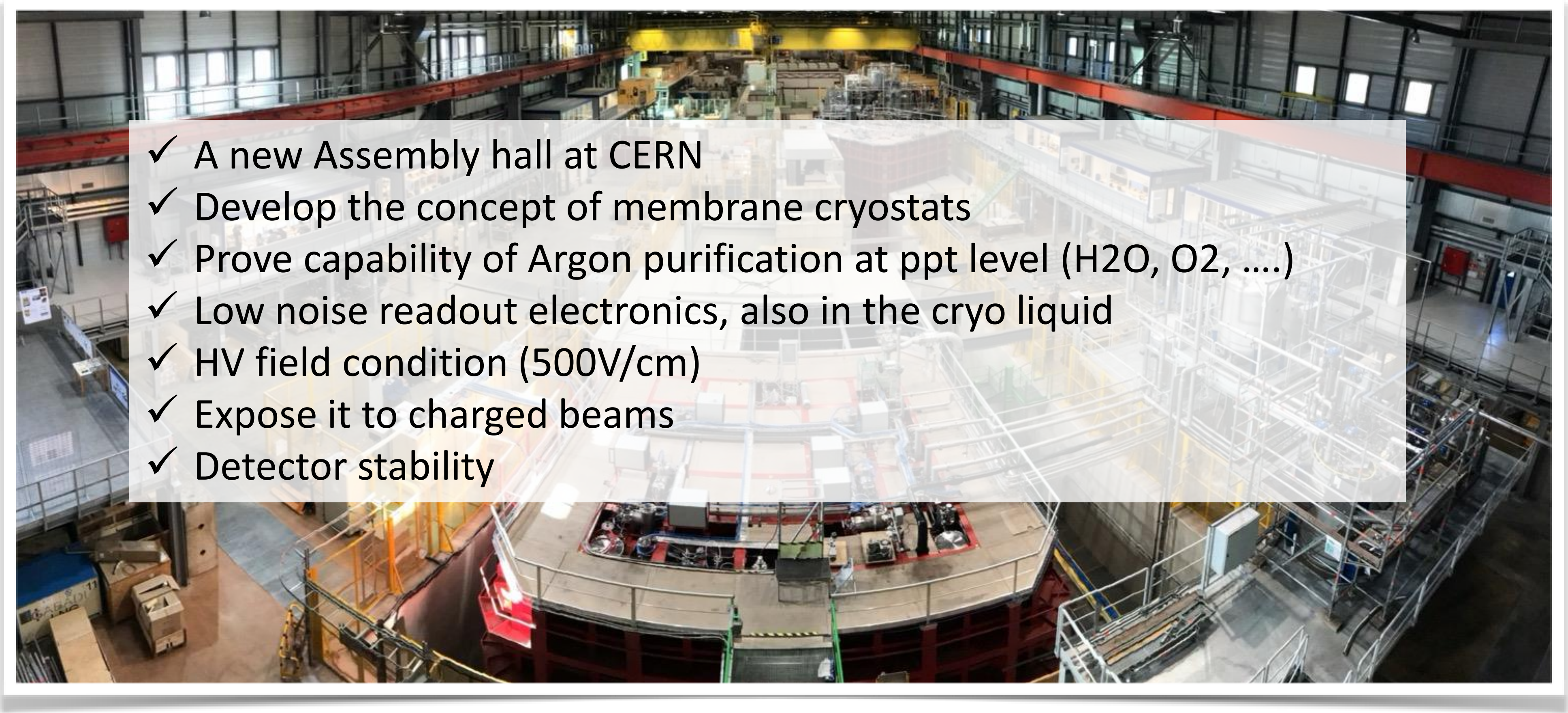
- To search for the origin of matter (CP violation, ν oscillations, …)
- To learn more about neutron stars and black holes
- To shed light on the unification of nature's forces (proton decay?)

ProtoDUNE as the necessary step to demonstrate the feasibility of the LAr technology for large detectors



- Prototypes at the scale 1:20, with modules at the DUNE scale
- Two technologies investigated (LAr single phase, LAr double phase)

ProtoDUNE as the necessary step to demonstrate the feasibility of the LAr technology for large detectors

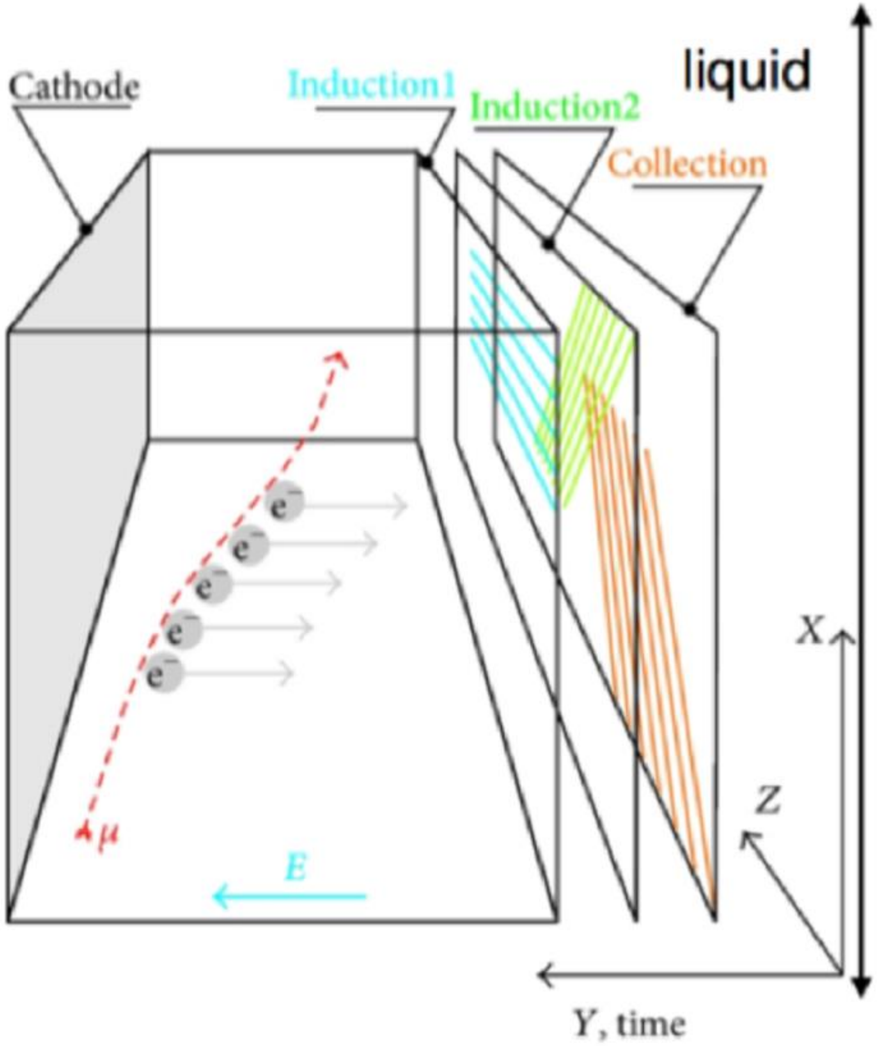


- ✓ A new Assembly hall at CERN
- ✓ Develop the concept of membrane cryostats
- ✓ Prove capability of Argon purification at ppt level (H2O, O2, ….)
- ✓ Low noise readout electronics, also in the cryo liquid
- ✓ HV field condition (500V/cm)
- ✓ Expose it to charged beams
- ✓ Detector stability

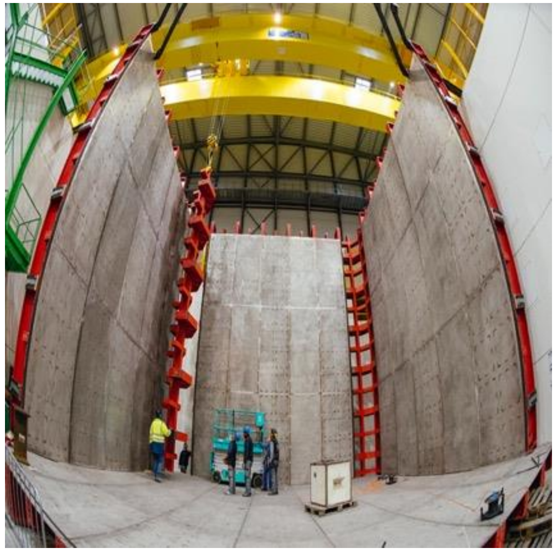
- Prototypes at the scale 1:20, with modules at the DUNE scale

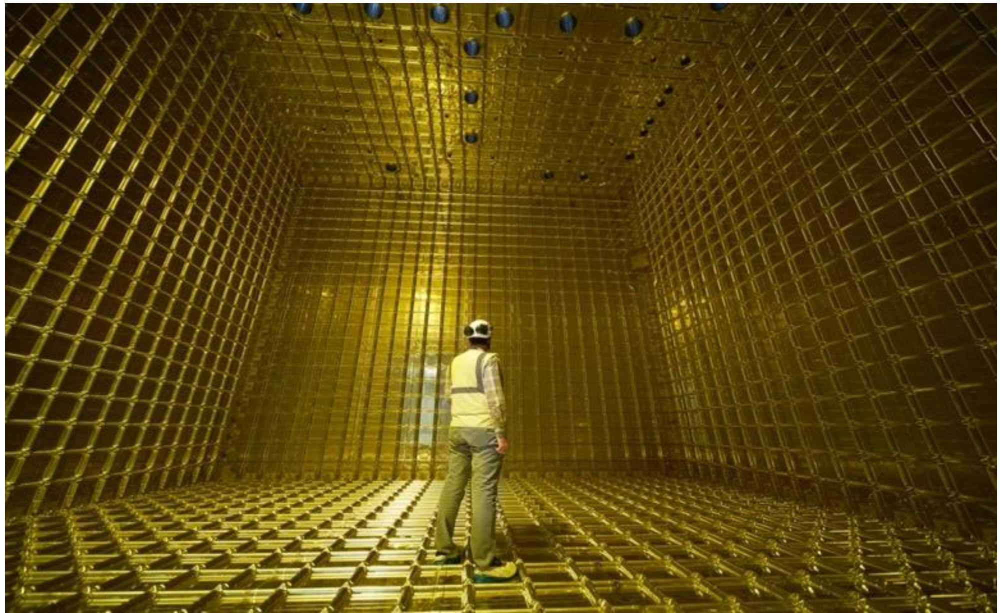
- Two technologies investigated (LAr single phase, LAr double phase)

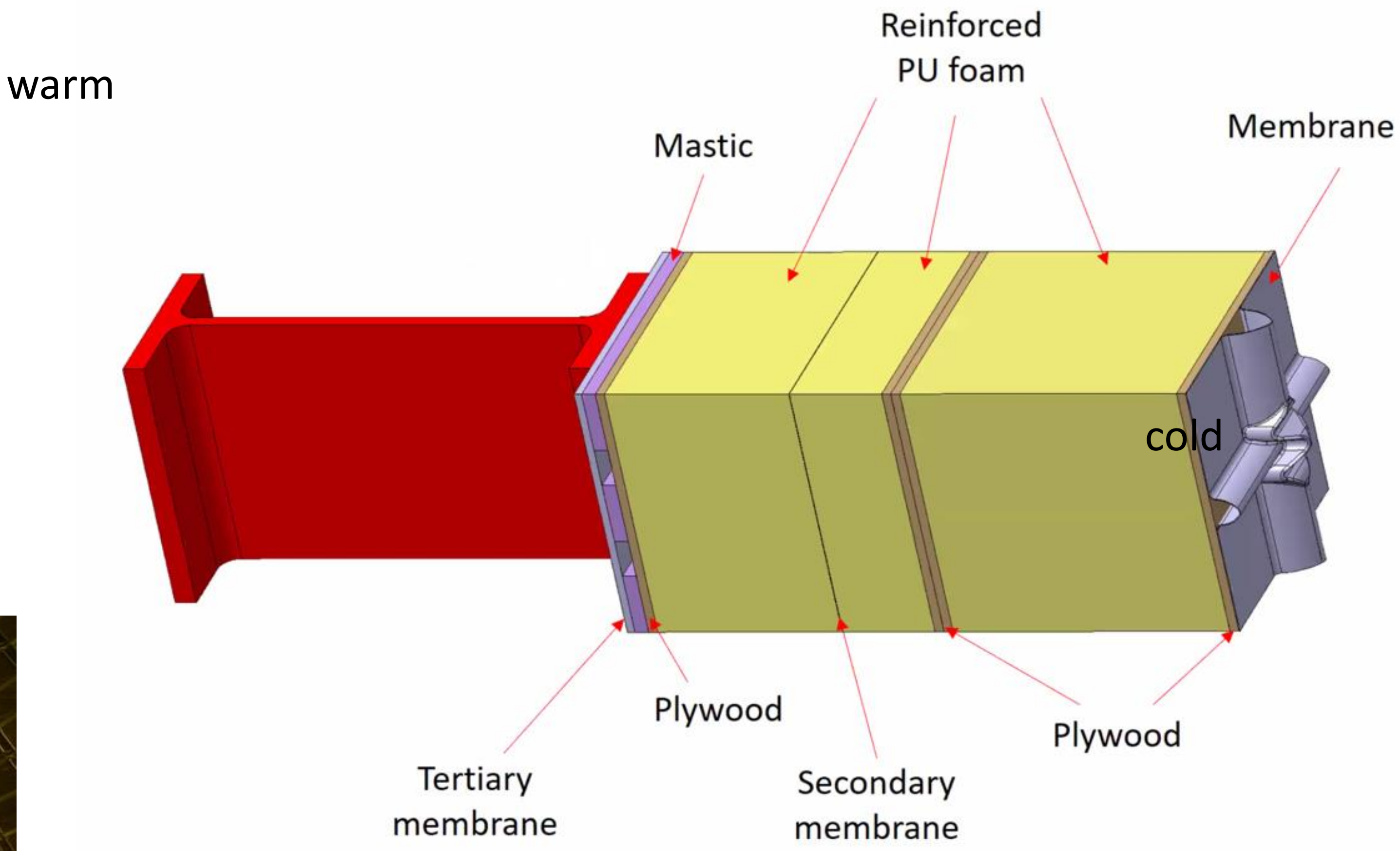
NP04: protoDUNE SP



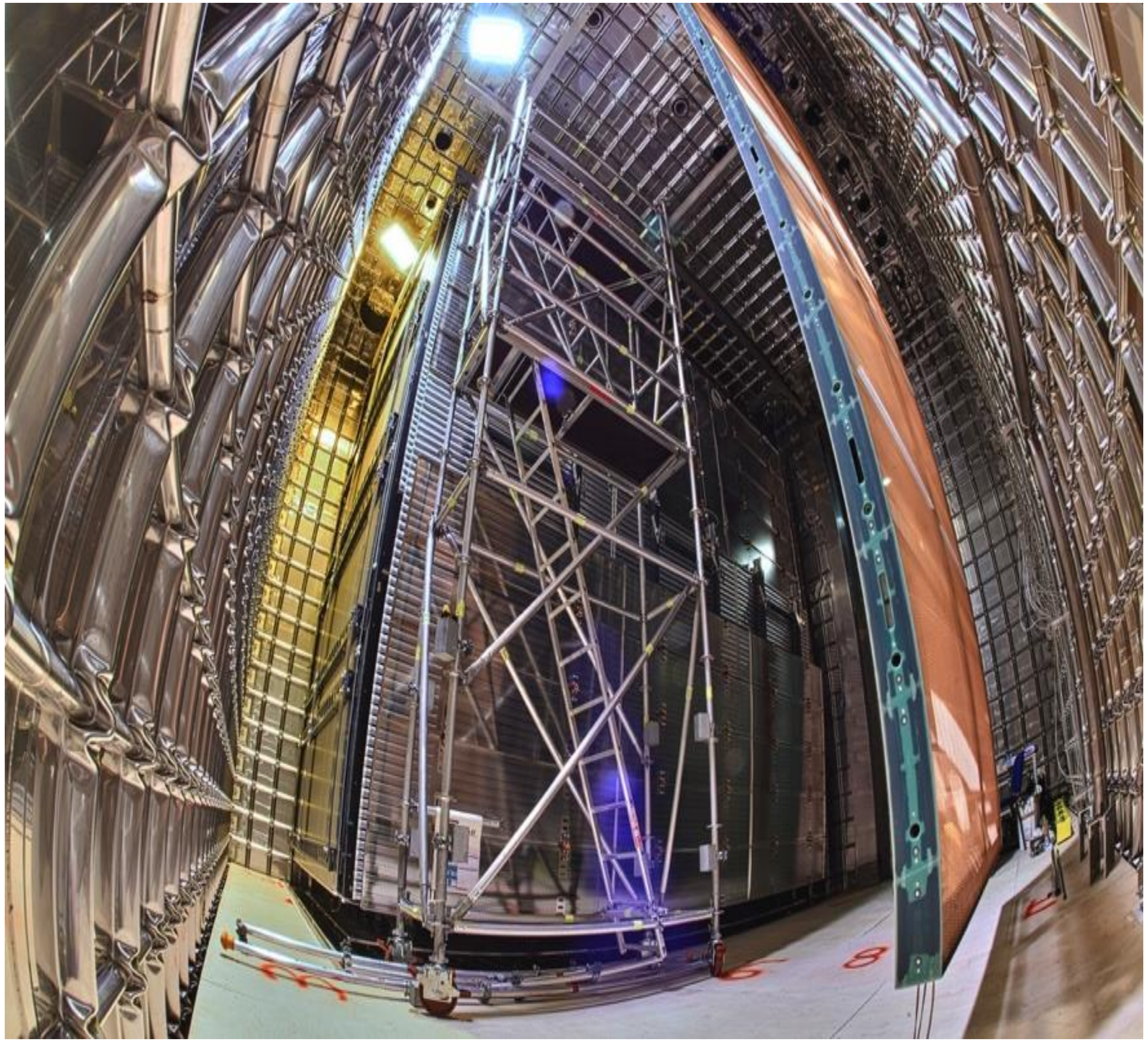
LNG membrane cryostat concept and key ingredients







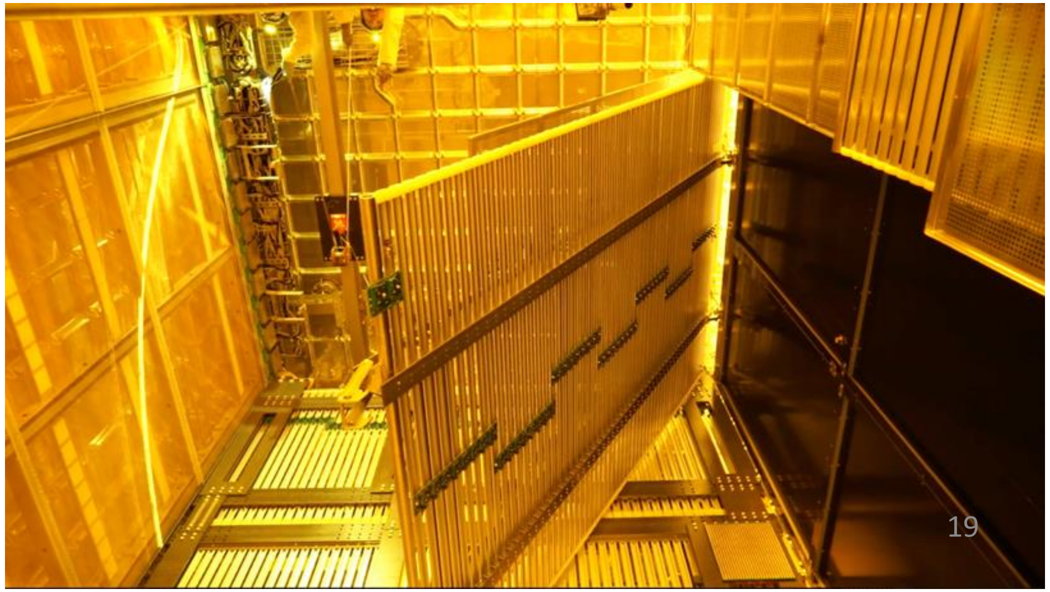
- ✓ EHN1 hall constructed in 2016
- ✓ First cryostat ready in Sep. 2017



✓ New beam line ready in August 2018

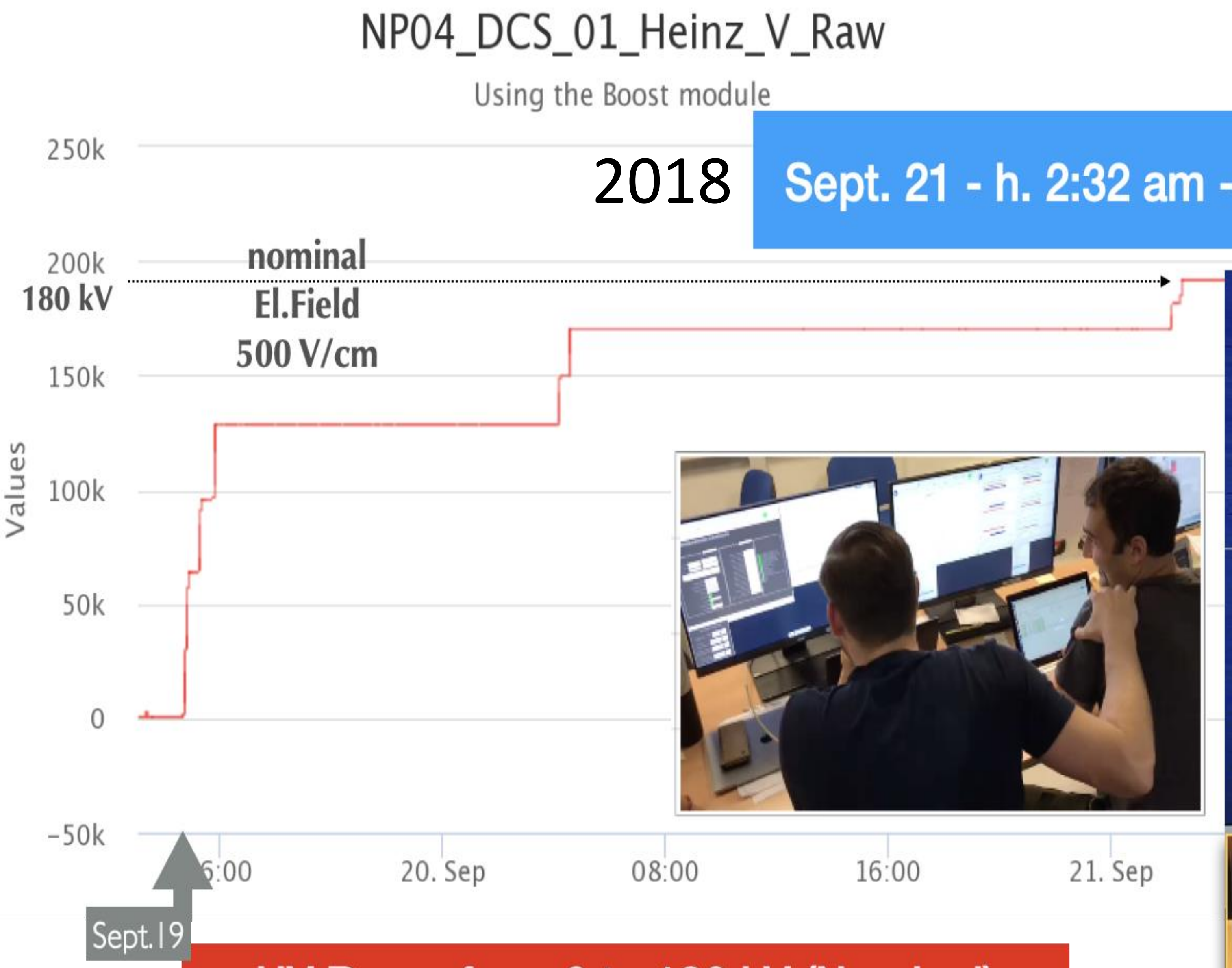
✓ Detector cooled and filled by mid September 2018

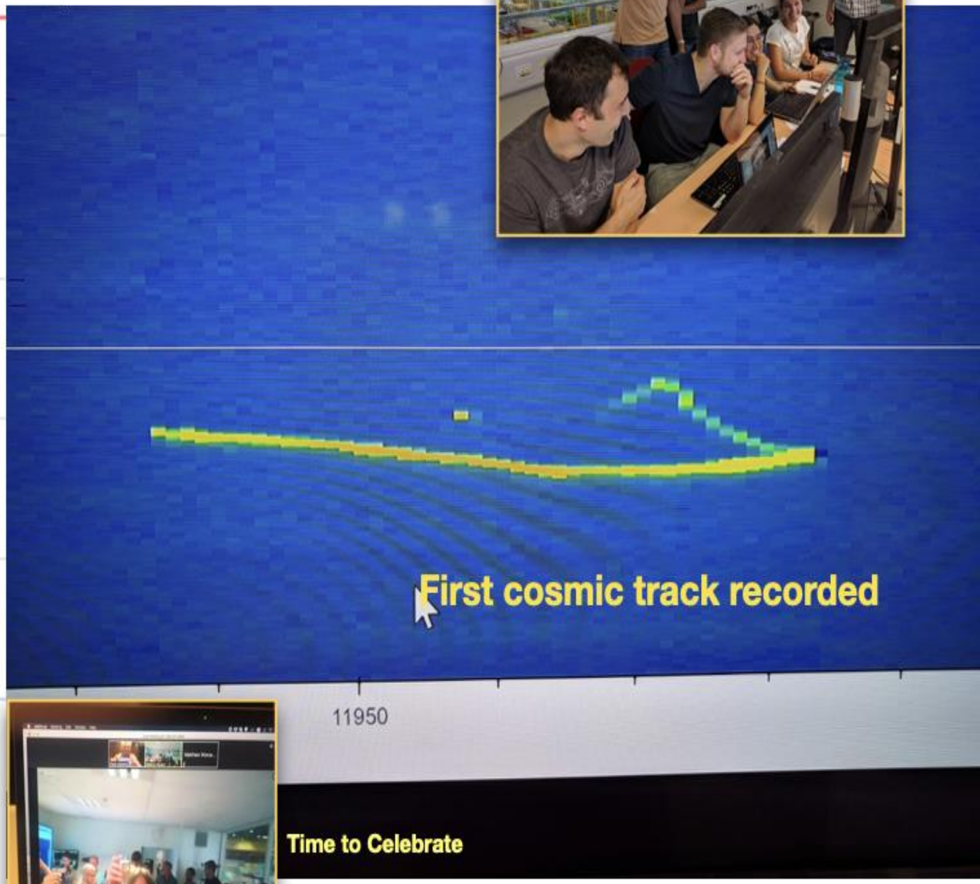
✓ Detector closed in July 2018



few seconds after,
from the On-Line Monitor

2018 Sept. 21 - h. 2:32 am - CDT





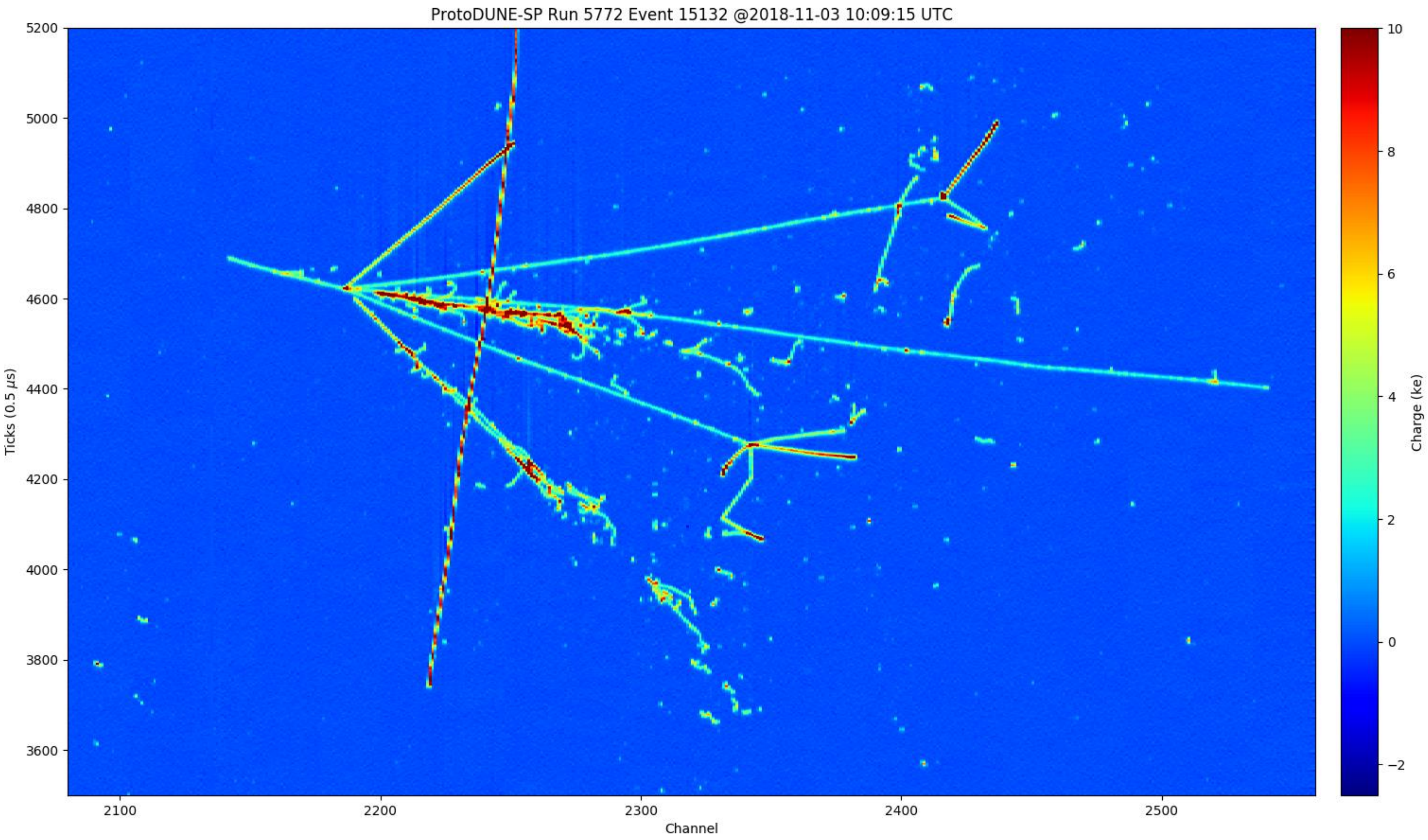
HV Ramp from 0 to 180 kV (Nominal)

A spectacular collection of events with an extensive variety of nuclear and particle processes

~ 3 months of beam before LS2, large statistics collected

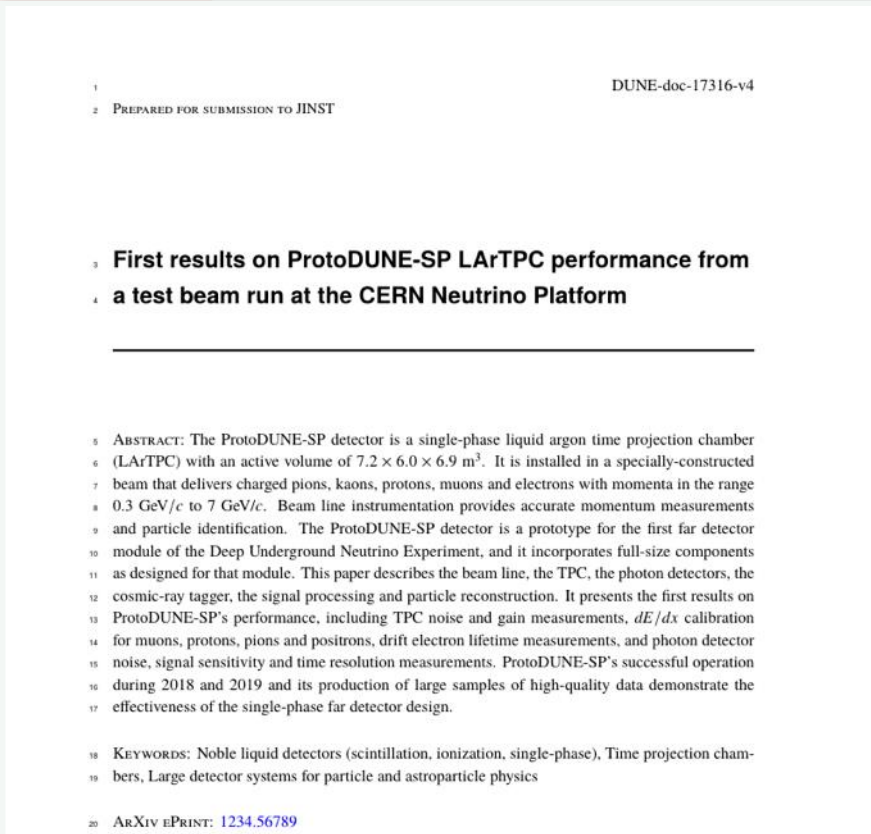
We kept the detector on cosmic events for about 20 months, proving the stability of the system and its reliability

The vessel is now warm and empty



Detector Parameter	Specification for DUNE	Goal for DUNE	ProtoDUNE Performance
Electric Drift Field	> 250 V/cm	500 V/cm	500 V/cm * (tested up to 650 V/cm)
Electron Lifetime *Impurity Concentration*	> 3 ms *(<100 ppt [O_2-equiv])*	10 ms *(<30 ppt [O_2-equiv])*	> ~30 ms in TPC ** *< 10 ppt*
TPC Electronics Noise	< 1000 e ENC	ALARA	550-650 e ENC (raw) 450-560 e ENC (cnr)***
TPC dead channels	< 1%	ALARA	0.2 % (of ~15,360 channels over 1.5 yr operation)
PhotoDetector Light Yield	> 0.5 Ph/MeV (at cathode plane - 3.6 m distance)		1.9 Ph/MeV ++ (at 3.3 m distance)
PhotoDetector Time Resolution	< 1μs	< 100 ns	14 ns ^^

Well beyond expectations


DUNE-doc-17316-v4

Prepared for submission to JINST

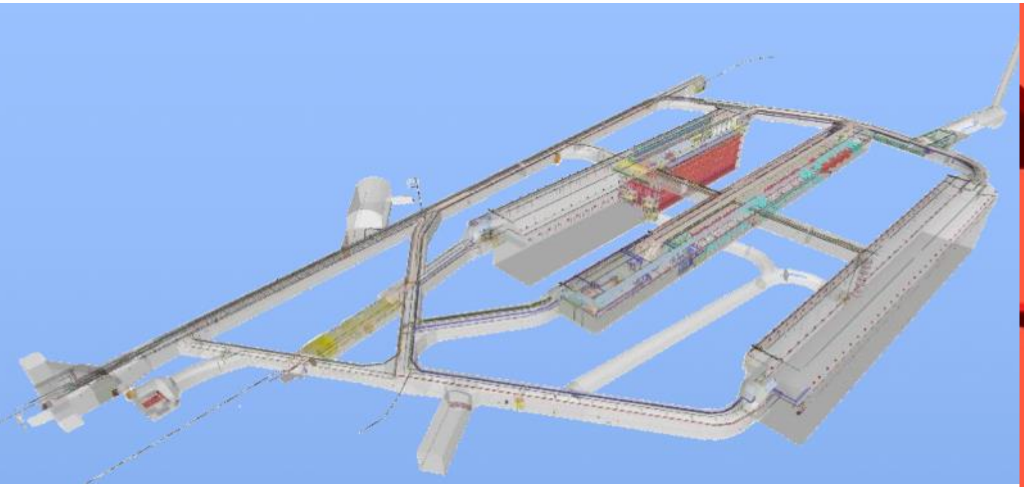
First results on ProtoDUNE-SP LArTPC performance from a test beam run at the CERN Neutrino Platform

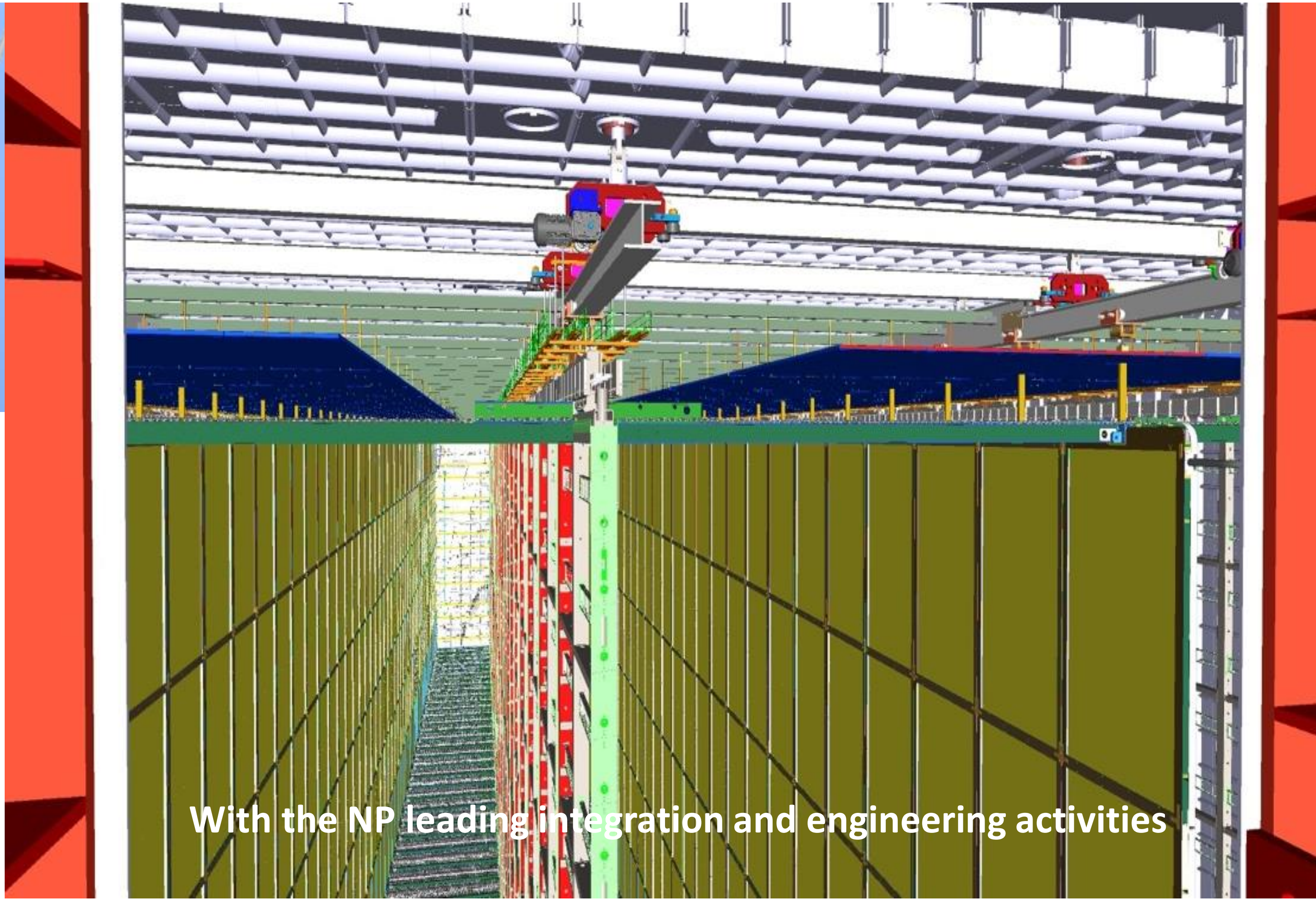
Abstract: The ProtoDUNE-SP detector is a single-phase liquid argon time projection chamber (LArTPC) with an active volume of $7.2 \times 6.0 \times 6.9$ m^3. It is installed in a specially-constructed beam that delivers charged pions, kaons, protons, muons and electrons with momenta in the range 0.3 GeV/c to 7 GeV/c. Beam line instrumentation provides accurate momentum measurements and particle identification. The ProtoDUNE-SP detector is a prototype for the first far detector module of the Deep Underground Neutrino Experiment, and it incorporates full-size components as designed for that module. This paper describes the beam line, the TPC, the photon detectors, the cosmic-ray tagger, the signal processing and particle reconstruction. It presents the first results on ProtoDUNE-SP's performance, including TPC noise and gain measurements, dE/dx calibration for muons, protons, pions and positrons, drift electron lifetime measurements, and photon detector noise, signal sensitivity and time resolution measurements. ProtoDUNE-SP's successful operation during 2018 and 2019 and its production of large samples of high-quality data demonstrate the effectiveness of the single-phase far detector design.

Keywords: Noble liquid detectors (scintillation, ionization, single-phase), Time projection chambers, Large detector systems for particle and astroparticle physics

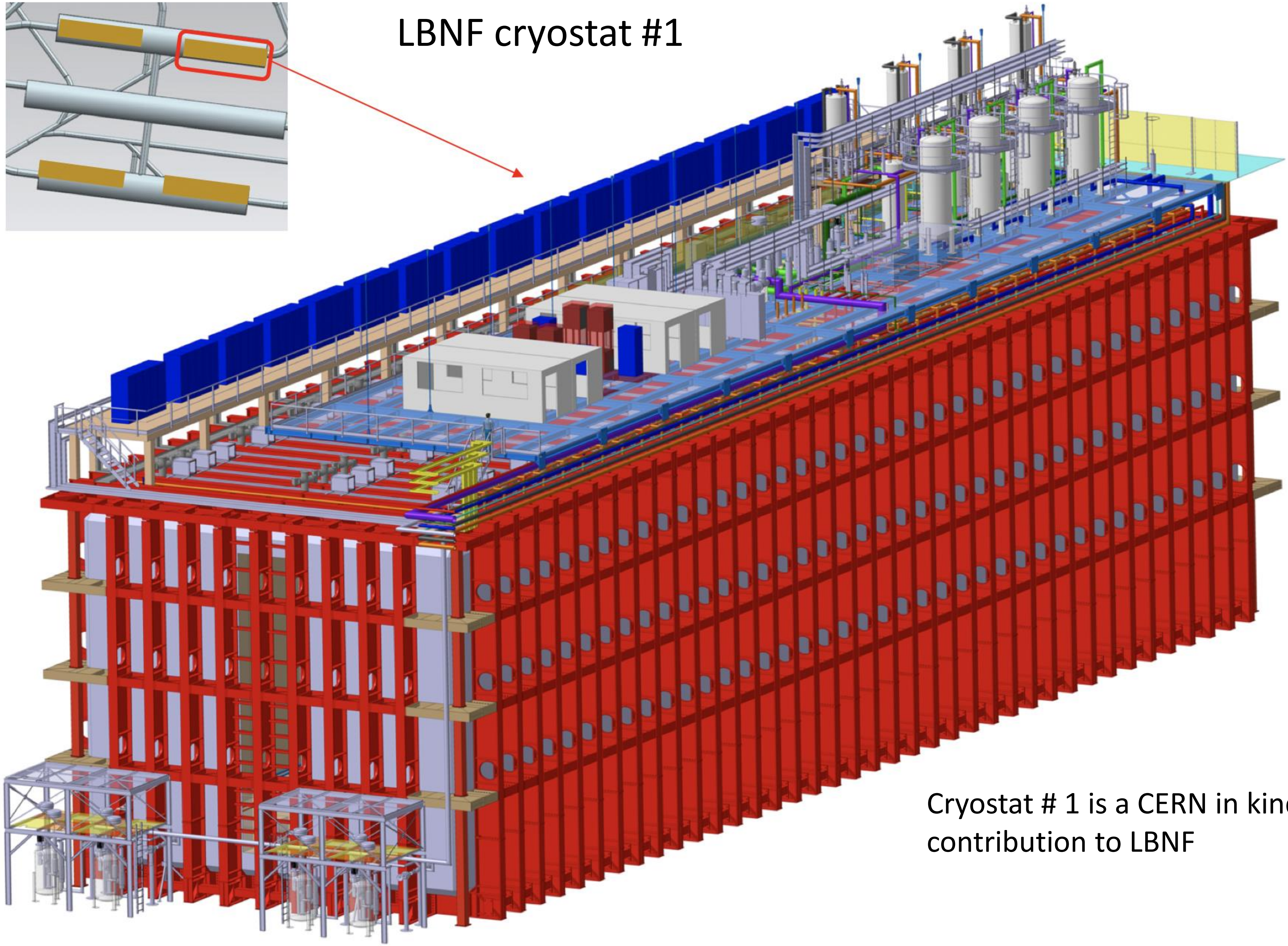
ArXiv ePrint: 1234.56789

NP04 as the baseline for the first DUNE far detector



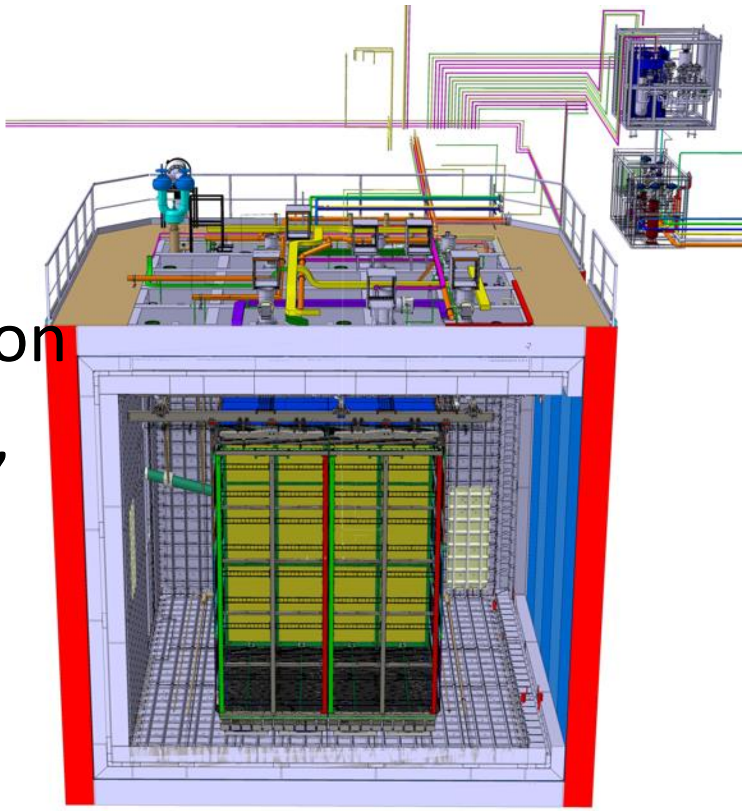


LBNF cryostat #1



Cryostat # 1 is a CERN in kind contribution to LBNF

NEXT : protoDUNE NP04 – phase II



- Insert all final detector components (Module 0 concept)
- Verify that all is fine and ready to move to mass production
- Continue the investigations with beam (different polarity, cross section mesurments)
- Period 2021-2023

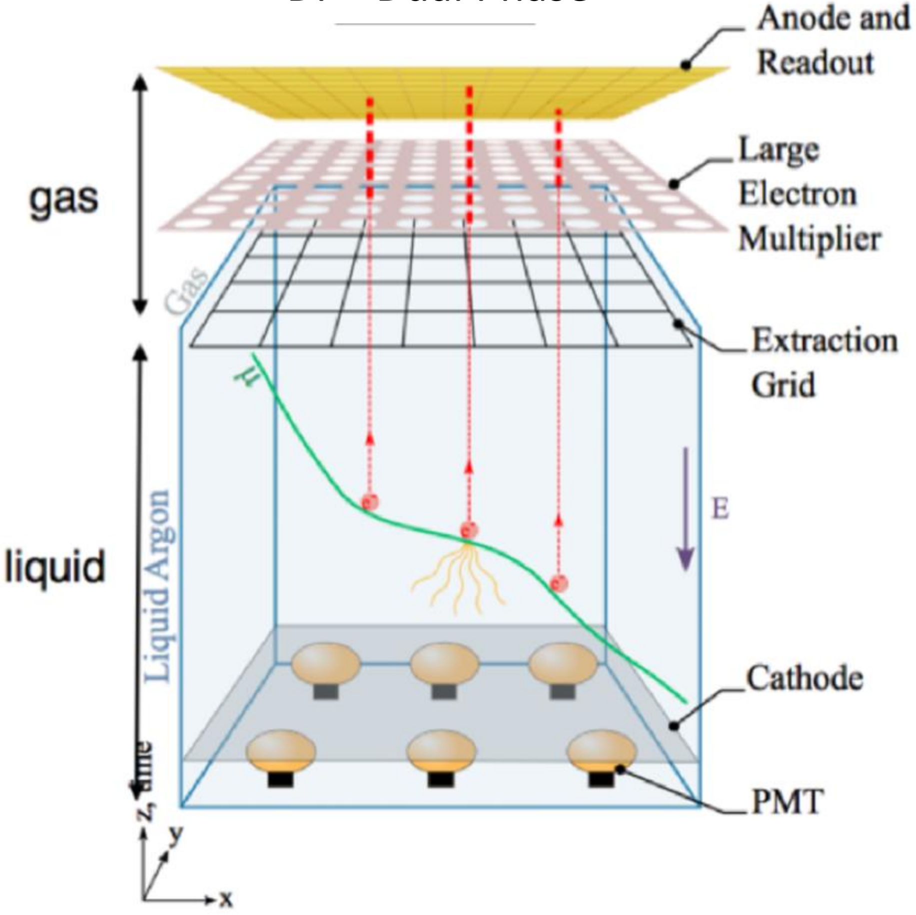
NEXT : LBNF/DUNE schedule

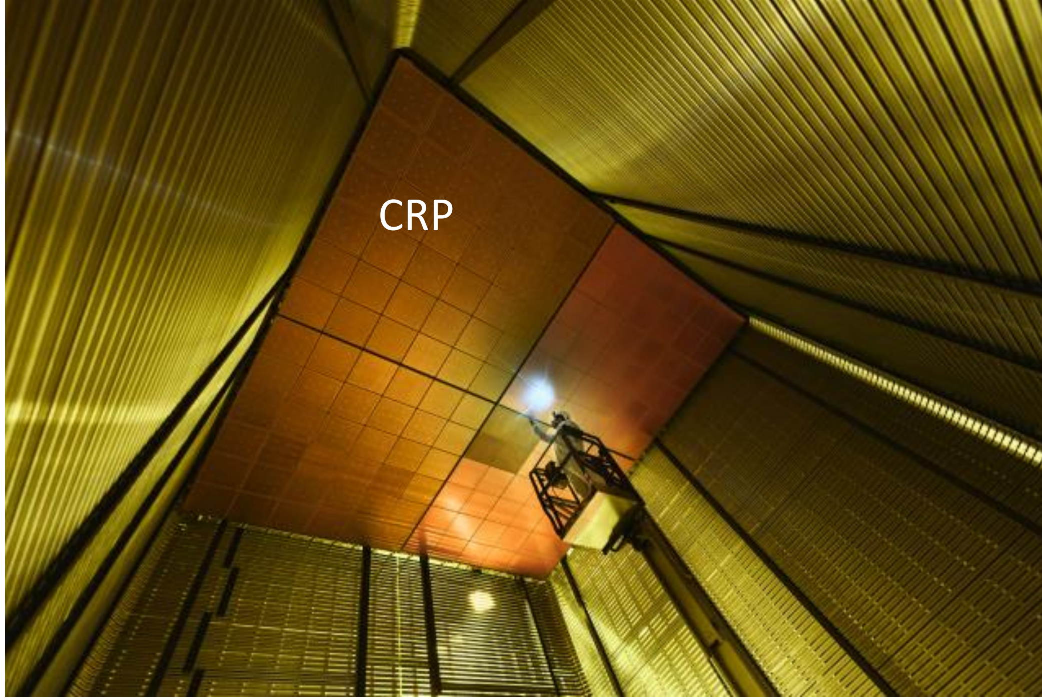
- *LBNF has a new schedule: end of civil engineering for the far detector (caverns ready) March 2024, start Cryostat assembly April 2024*
- *In 2021 we will start the LBNF cryostat procurement project at CERN with all proper consultations and CERN Finance Committee rules*
- *Discussions are now happening in Europe and in the US to secure a second cryostat*

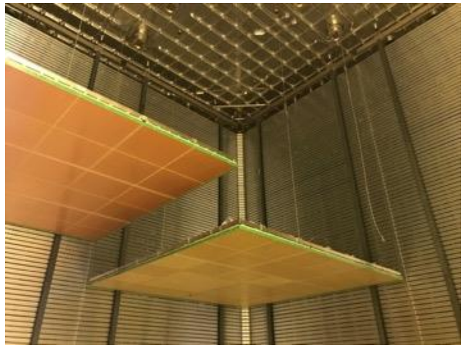
NP02: protoDUNE DP

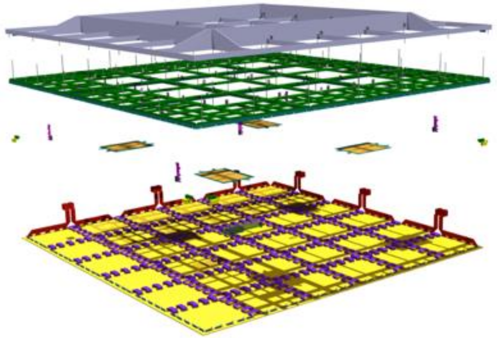
- *Simple layout*
- *No dead material in the drift region*
- *Signal amplification*
- *Electronics not in liquid*

DP= Dual Phase









LEMs + anodes

NP02 : protoDUNE DP

Steps : Double Phase large prototype in EHN1

- ✓ Construct the LAr membrane cryostat (760 T of Argon)
- ✓ Construct a clean room in front of the cryostat
- ✓ Assemble the active readout components (CRP) in the ICARUS (b185) cleanroom (CEA, Lyon, LAPP, CERN)
- ✓ Construct and operate a cold box for testing all CRPs in b182
- ✓ Assemble the cathode (EHN1) and the field cage
- ✓ Bring all components to the EHN1 clean room
- ✓ Assemble and test the field cage
- ✓ Install 4 CRPs
- ✓ Install the bottom PMTs (prepared in Spain)
- ✓ Install the cathode plane
- ✓ Install the LAr cryogenics
- ✓ Clean the inside of the cryostat and detector, close the cryostat
- ✓ Cooldown and fill with LAr
- ✓ Commission and debug the detector

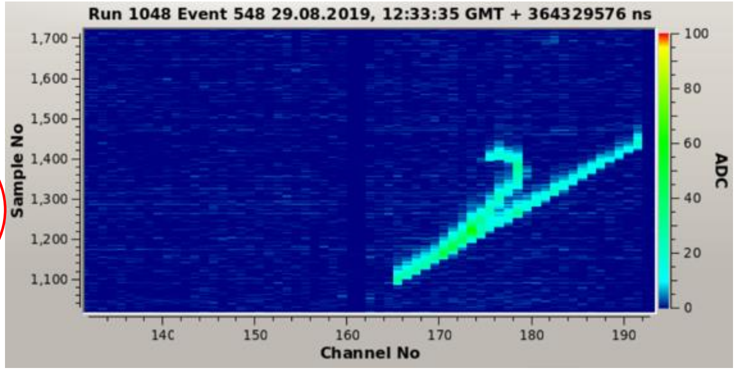
CRPs performance

- ✓ CRPs level meters calibration and alignment activities and HV tests performed → **grids of all 4 CRPs reaching goal of 7kV**

- ✓ **Observation of first short tracks on 29/8** with CRP 1 LEMs brought to **2.9 kV ΔV**, grid voltage 6kV, electrons lifetime 200 μs

- ✓ Since first operation on 29/8, **LEMs of both CRPs working in stable way at 2.9 kV ΔV with negligible LEMs sparking rate. Beyond this value the sparking rate becomes prohibitive. Problems also of planarity of the readout unit (CRP)**

One of the very first tracks

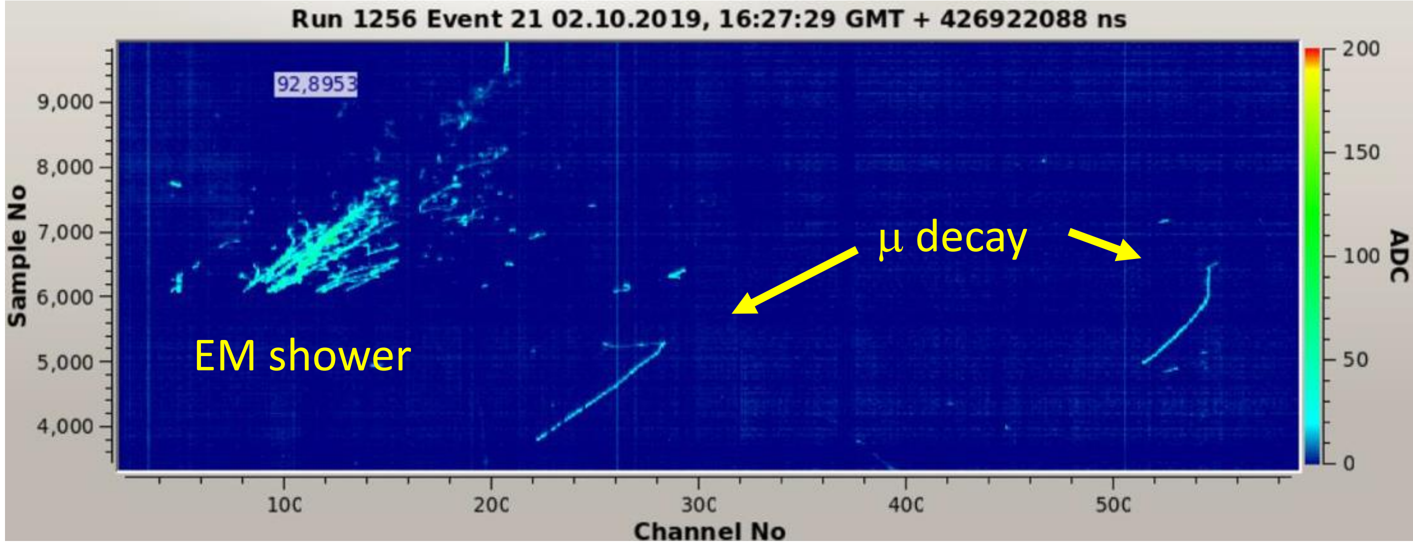


- ✓ **Electronics noise ~1.5 ADC counts, still dominated by coherent noise due to grounding of slow control cabling** which is being improved → goal: bring to intrinsic electronics noise ~<1 ADC count

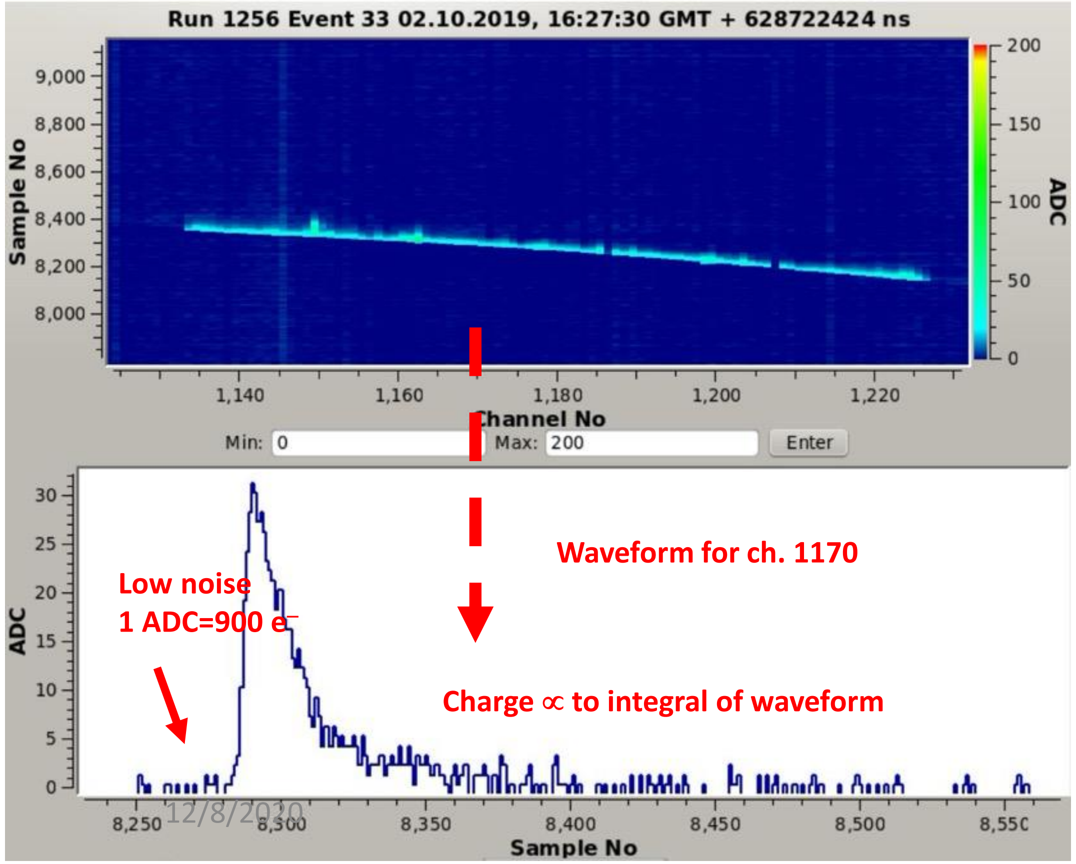
- ✓ Smooth operation of DAQ with random triggers (cosmic trigger counters being set up) **660k events** (4 ms drift) **~70 TB** acquired since 29/8, data transferred to FNAL

Cosmic ray events
in protoDUNE dual-phase
(October 2019)

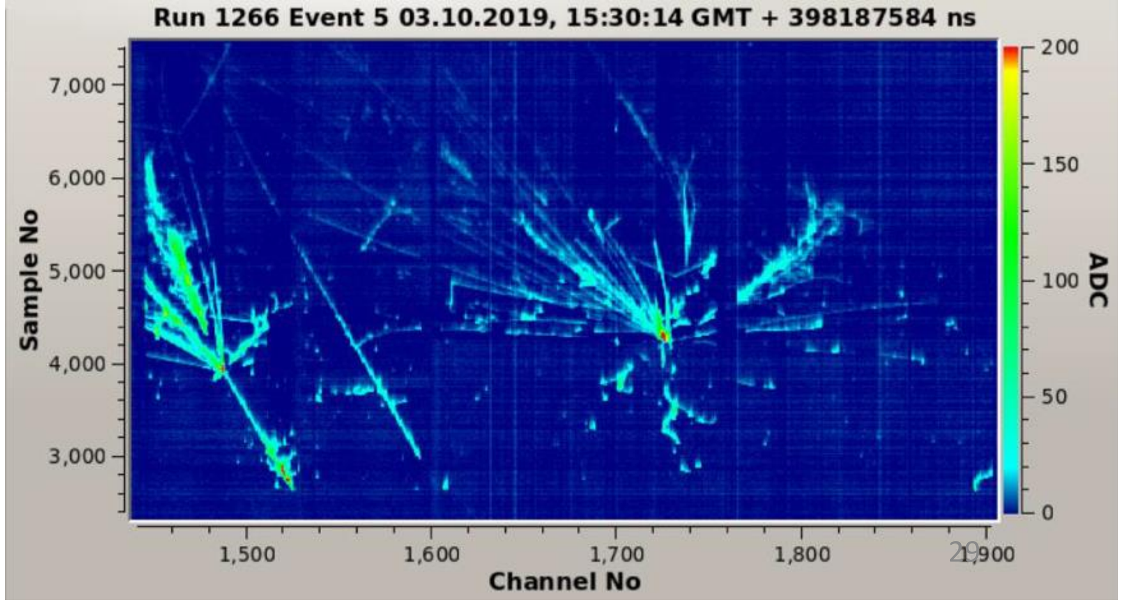
Electromagnetic shower + two muons decay



Horizontal muon track



Multiple hadronic interactions in a shower

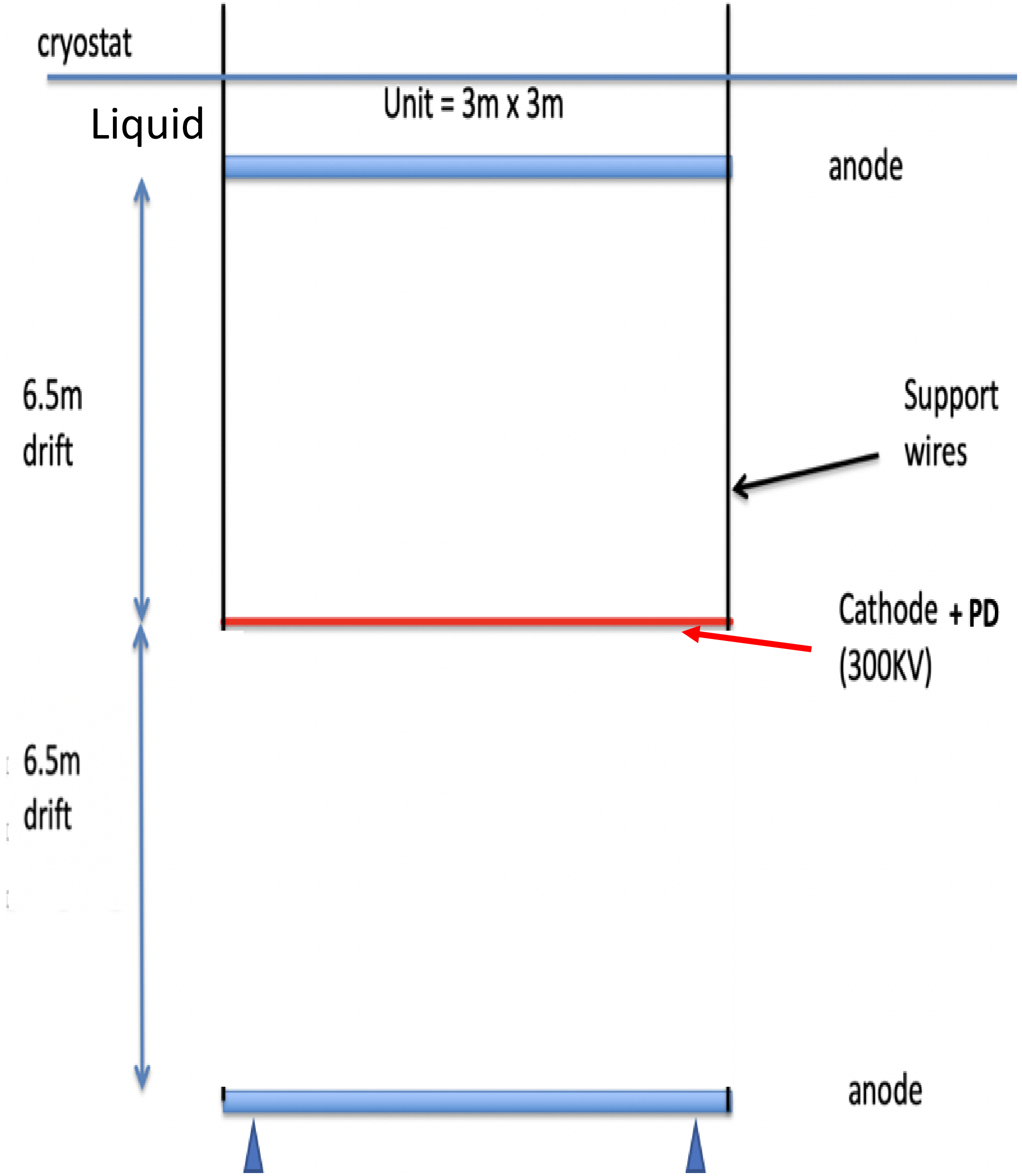


Lessons learned:

1. This DP technology is very complex and very demanding
2. The observed waves in the liquid (amplitude ~0.1mm) are not understood and might represent a problem in a large detector. We are not sure !
3. More R&D is necessary on the HV system. Other solutions need to be explored through R&D. We see problems at 300KV, the final requirement is for 600KV.
4. The main problem is the quality of the CRP (mechanics and material). We never arrived to the situation where the amplification is beneficial. A new R&D phase can be envisaged! The CRP mechanical structure was not as flat as required at cold. The readout package (LEM, Anode and wires) is too complex and demanding on many parameters. The instability and sparks rate are the the major problems. This part of the project has to revisited after considerable basic R&D.
5. The general layout, with an external field cage, an empty drift space with no dead material and all the readouts external to the drift space is very interesting and should be preserved. New ideas (long vertical drift SP TPC) are emerging.

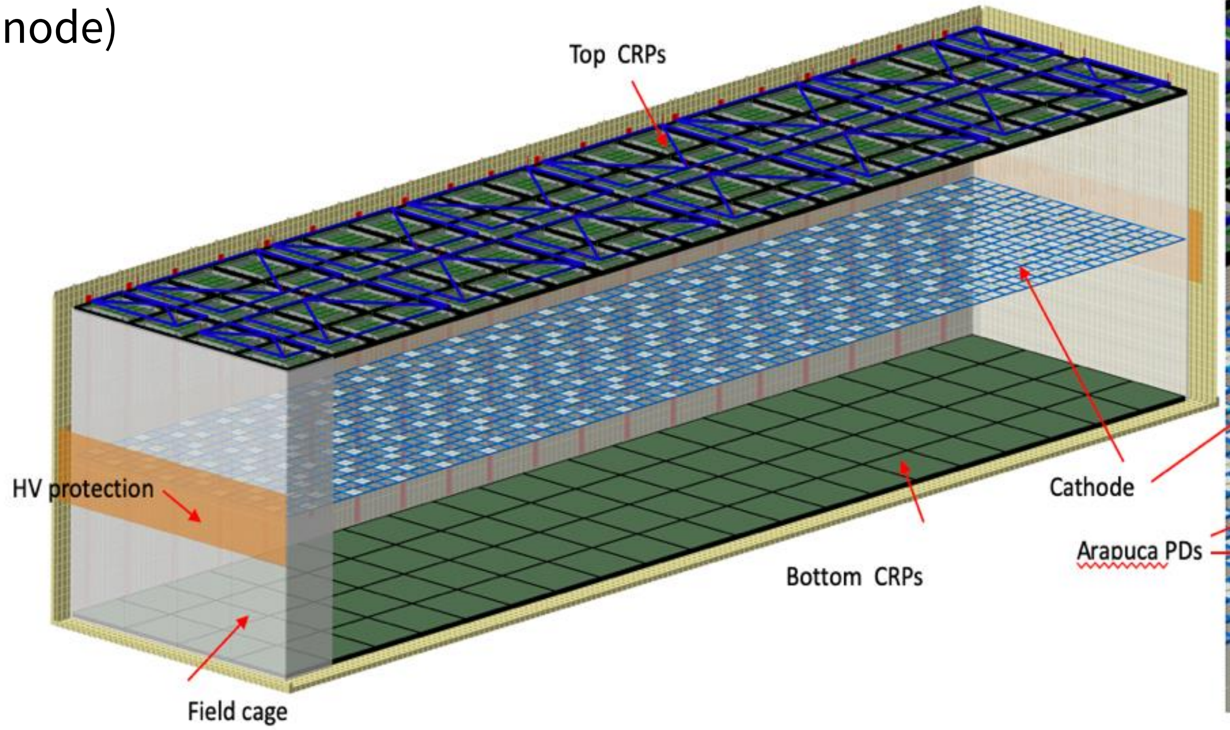
NEXT : Developing a new concept based on DP

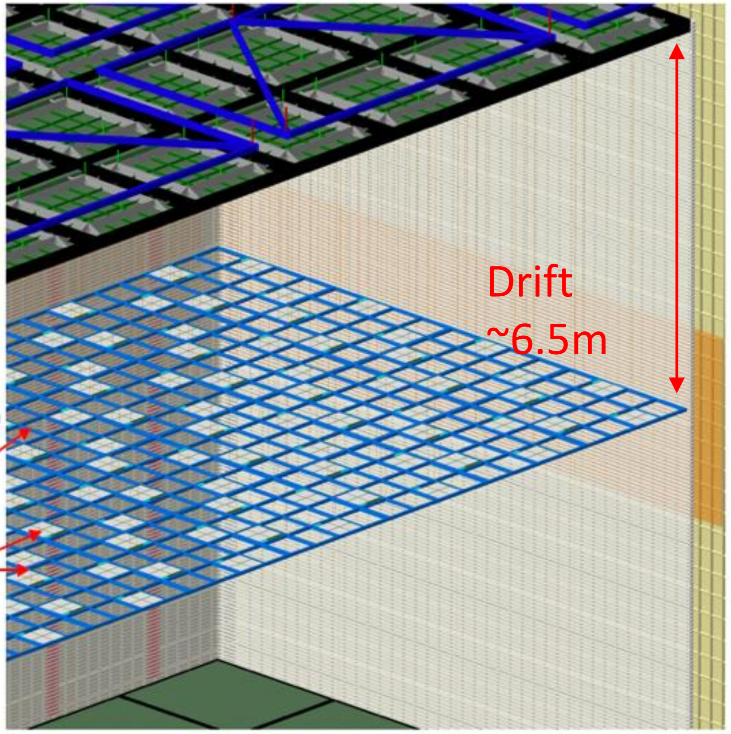
- *Main idea: keep all what was done for NP02, but the LEMs (signal amplification)*
- *Profit from the excellent electronic noise, move to a single phase system, all immersed, to avoid sparks and instabilities*
- *First small scale R&D successfully done, full DUNE detector proposal being prepared*
- *Possibility to have a full demonstrator on the existing cold box very fast (mid 2021)*
- *A ProtoDUNE-II will then be eventually considered as a Module-0*

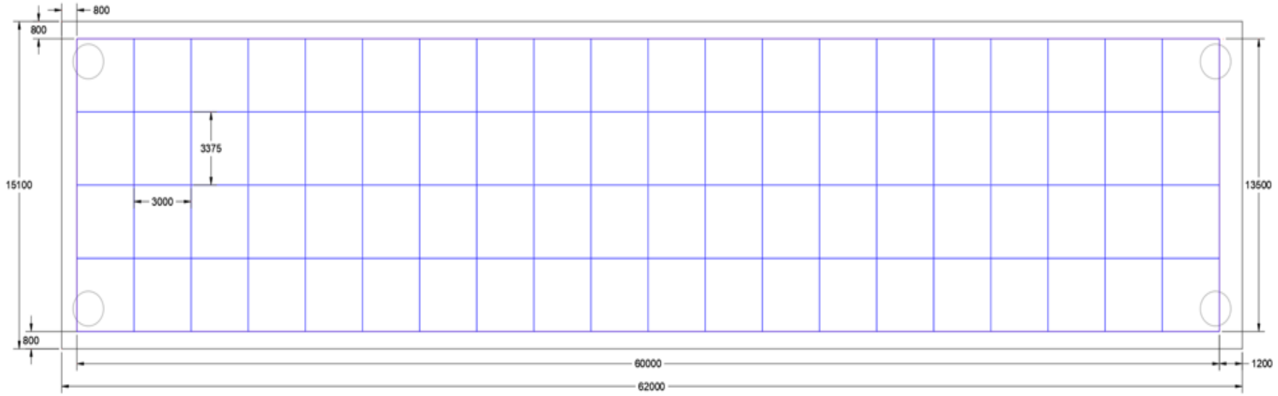


✓We have extensive proposal: https://edms.cern.ch/document/2429382

CRP= 3x3.375 m^2 readout units (anode)



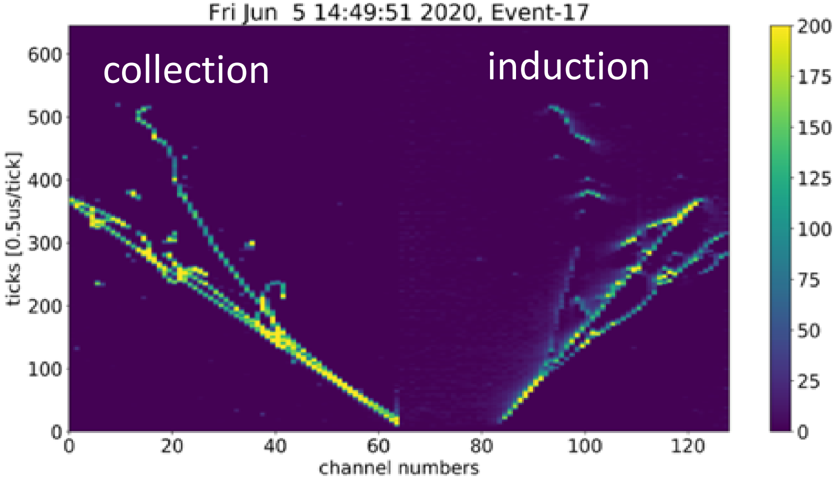


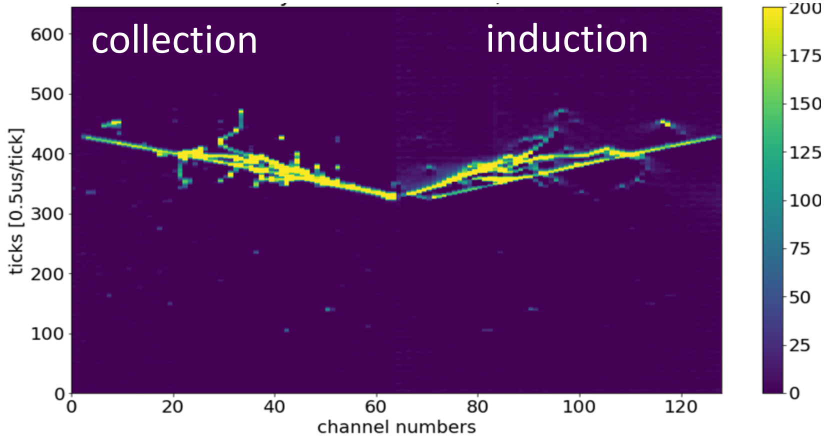


- ✓ 160 CRP units (80 on top, 80 on the bottom)
- ✓ Drift active volumes 2*5'265 m^3 = LAr 14.74 Ktons

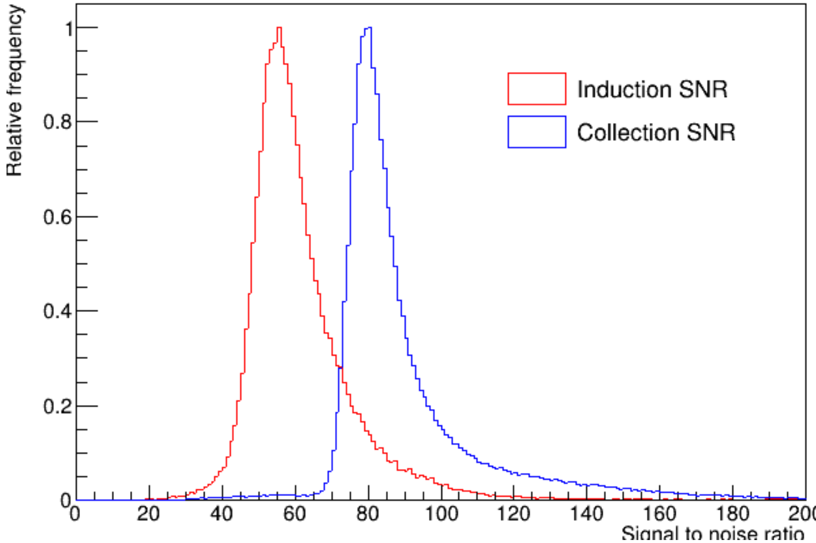
We have done a small TPC prototype in 2020

- We have, during spring 2020, constructed and operated a 50x50 cm^2 TPC, with all the components of the vertical drift detector (PCB perforated anode, readout electronics, field cage, HV system, Photon detectors,..)
- Results are very good





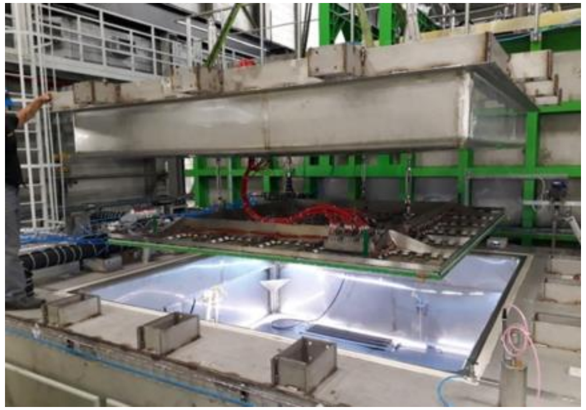
- ENC for small PCB anode at room temperature and inLAr:
  - Collection plane:
    - ~ 900e$^-$ at room temperature
    - ~ 320e$^-$ in LAr.
  - Induction plane:
    - ~800e$^-$ at room temperature
    - ~375e$^-$ in LAr.

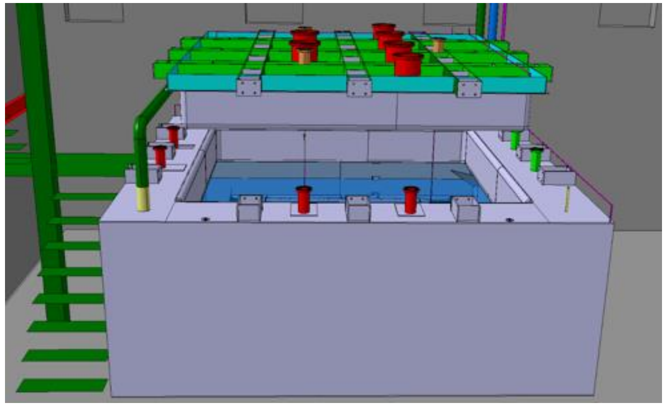


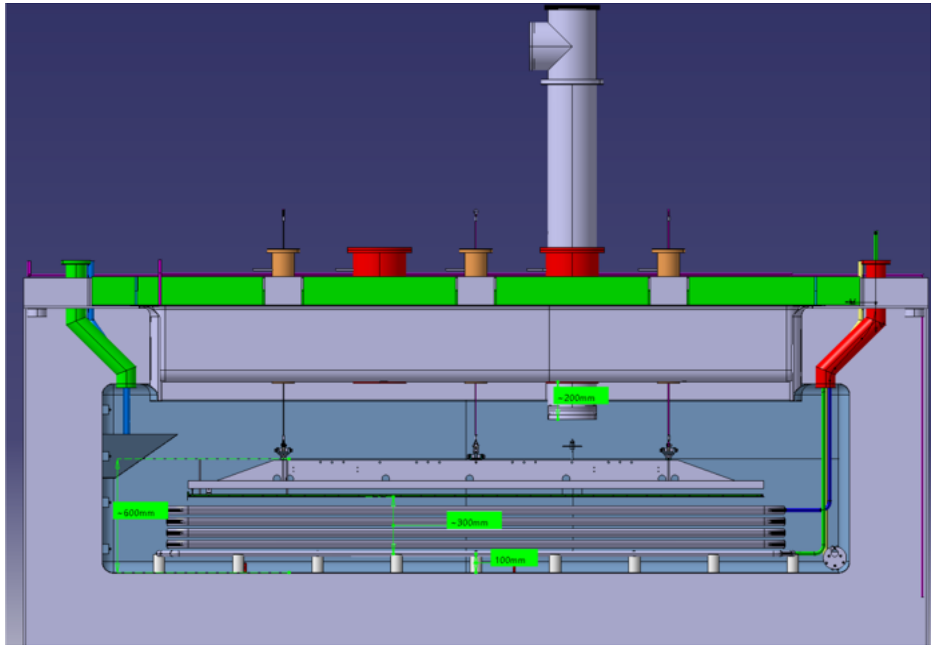
Demonstrator activities in 2021 towards a second DUNE detector

A complete TPC tested in the existing coldbox

- ✓ Full TPC (CRP, perforated anodes, both electronics, HV, Arapuca, …)
- ✓ 25-30 cm drift length as the only difference to the 6.5m
- ✓ Operation in LAr in the existing cold box, several cycles possible

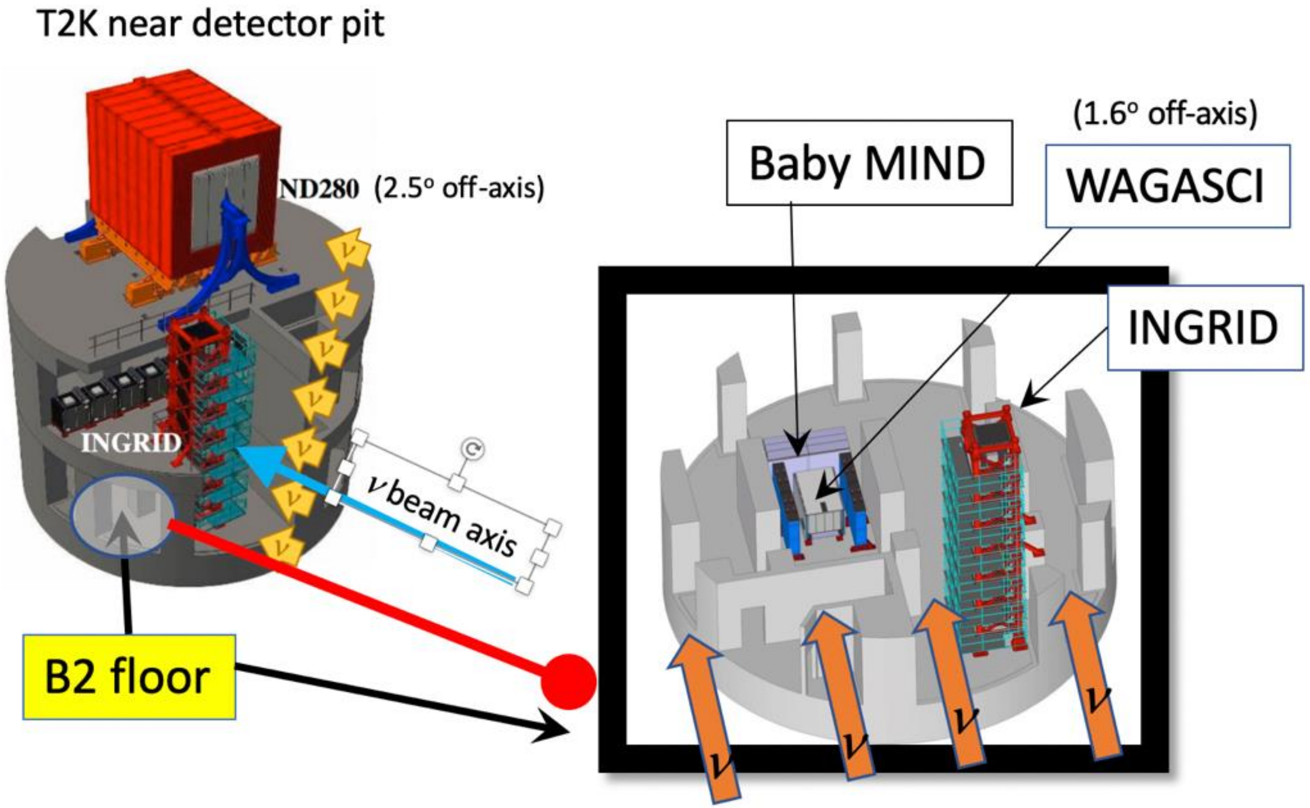




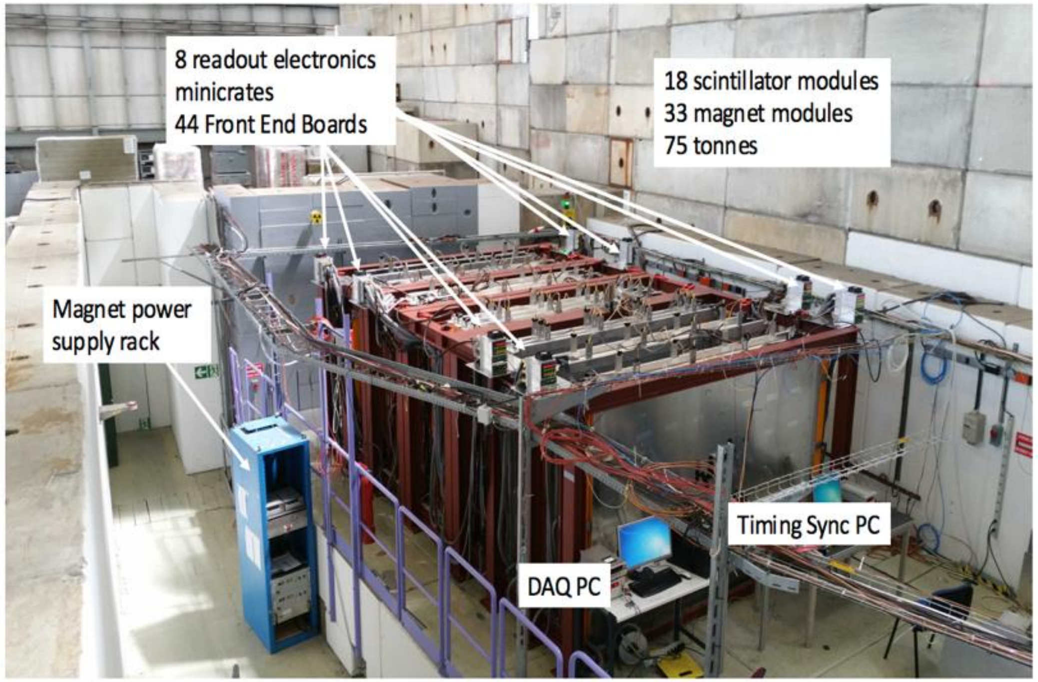


NP05 : Baby Mind
NP07 : ND280

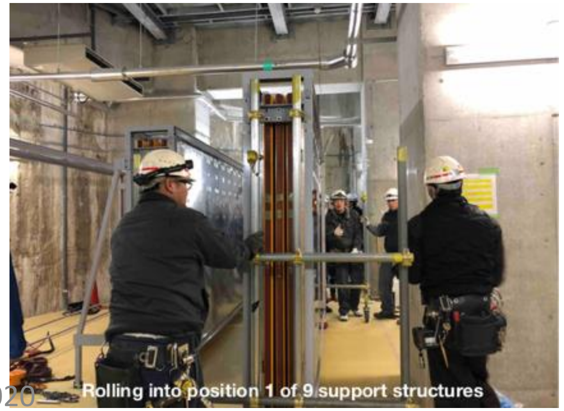
Contribution to the Japanese program: T2K Near detectors



WAGASCI/Baby Mind muon detector



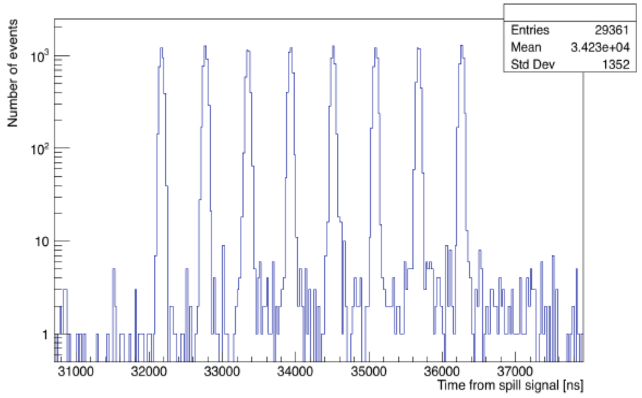
Assembled and tested in the SPS test beam in 2017



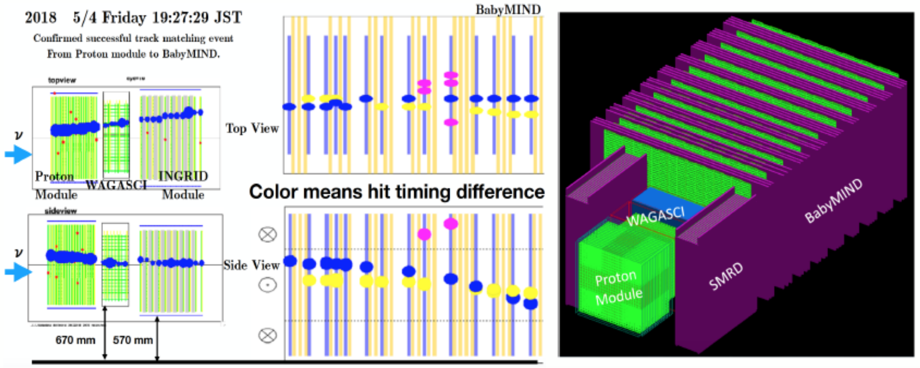
Transported and reassembled at J-Parc in February 2018

Commissioning with beam in anti-neutrino mode at J-PARC: 9 March - 31 May 2018

8-bunch beam structure clearly seen in neutrino interactions recorded by Baby MIND (J-PARC nu beam spill has 8 bunches)



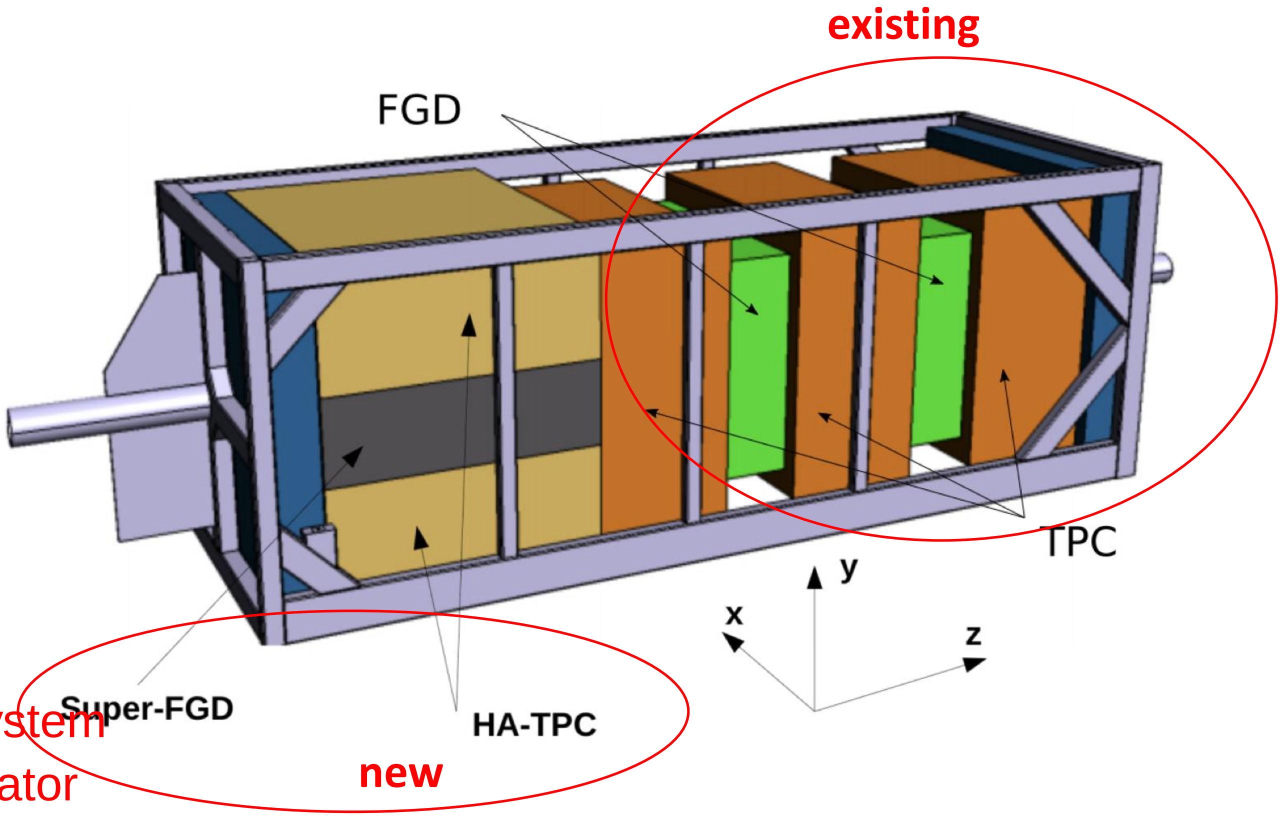
Event rate measured by Baby MIND:
~ 5.246 +/- 0.656 (stat.) 10^4 events/1500 Kg (Fe)/10^{21} P.O.T.



NP07: T2K upgraded near detector

- Support to the test beam activities (TPC with micromegas readout and the SuperFGD tracker) in 2018
- A new laboratory at EHN1 for the assembly and test work, new technical proposal
- MOU under signature for the final detector, it will be operational in 2022

It includes a fiducial mass of a few tons and highly efficient 4π tracking for low energy πs and protons to determine event topology, with proton-pion identification. Furthermore, good timing determination (at the 0.5 ns level) that can be used to distinguish inward going background events from outward going neutrino interactions.



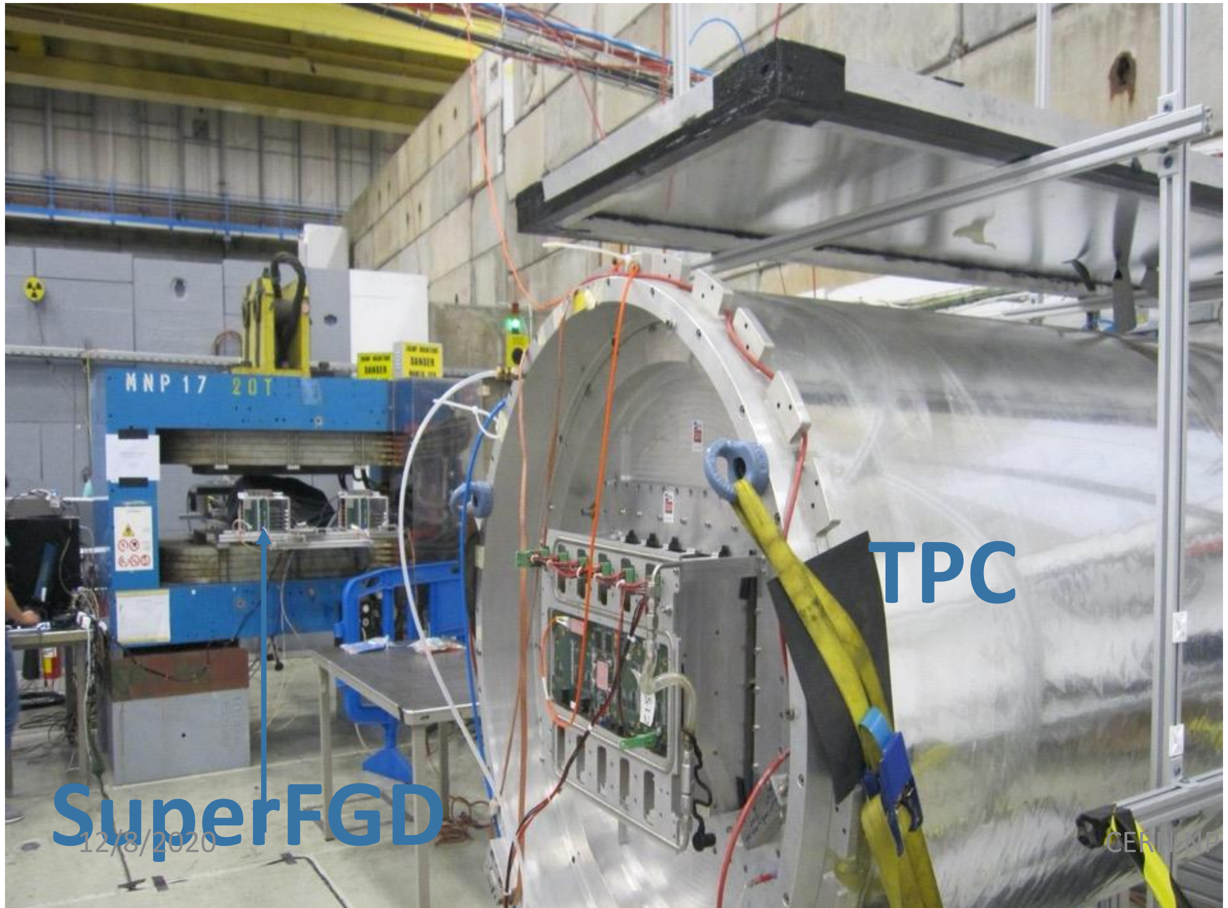
HA-TPC =High Angle TPCs read by a micromegas system
SuperFGD = many optically independent 1 cm scintillator cubes

Near Detector studies, prototypes and test beams

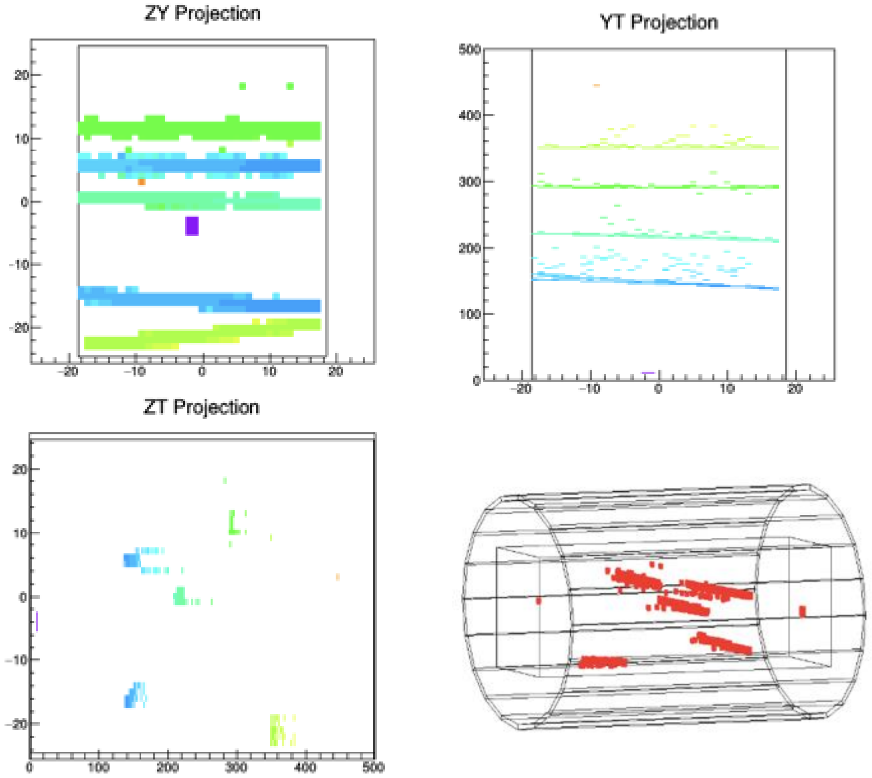
New test beams in T9 area at CERN

Atmospheric gas TPC with resistive MicroMegas

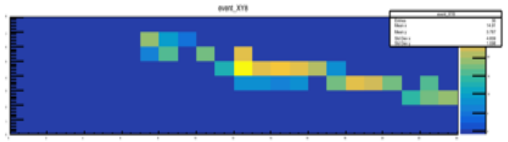
SuperFGD detector in B-field from 0.2T to 0.7T (MNP17 magnet)

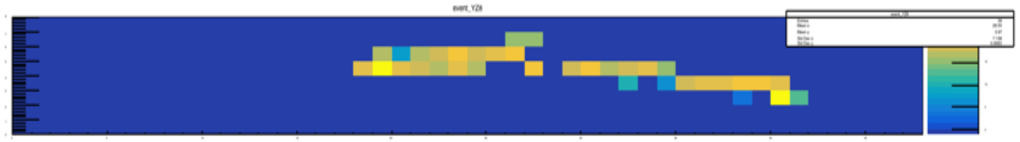


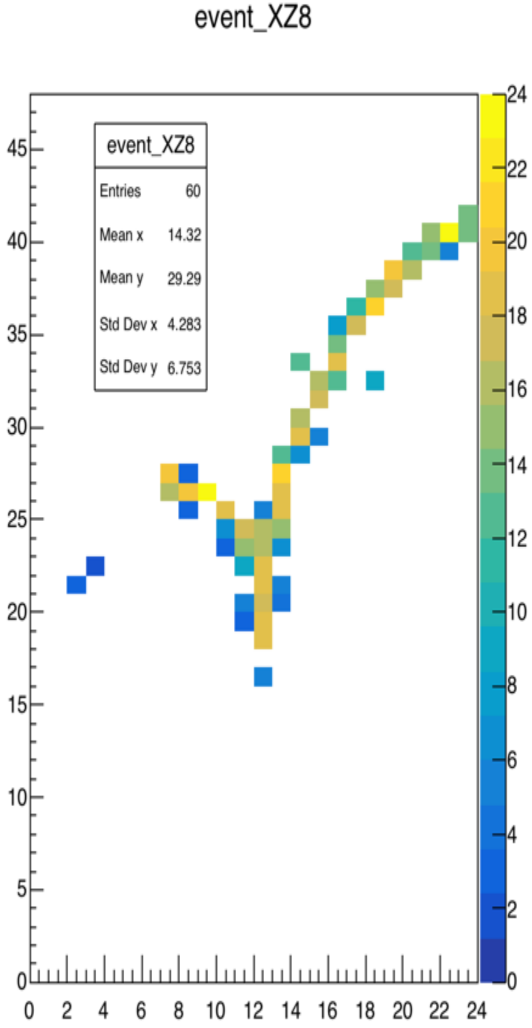
Electrons in the TPC during photon beam



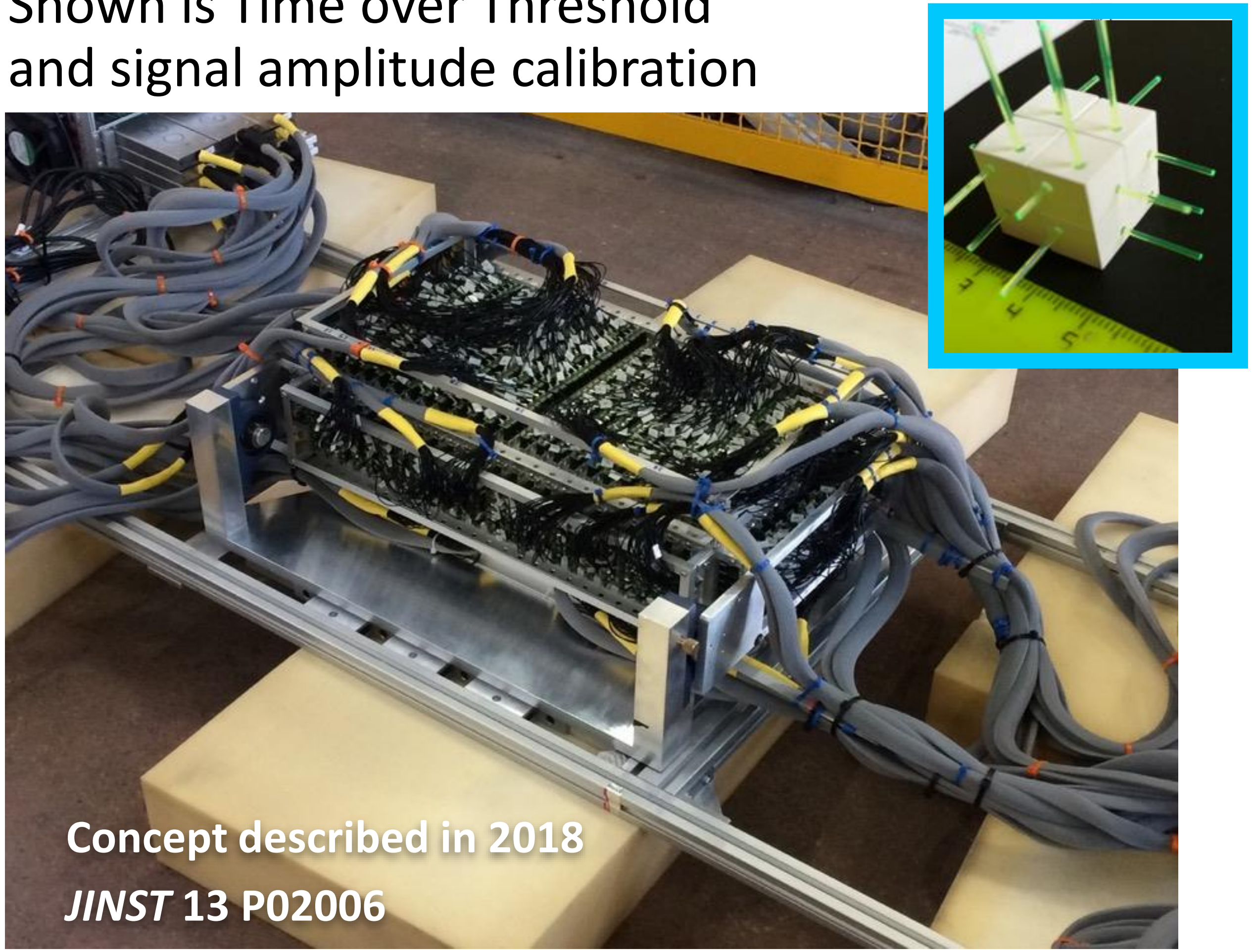
SuperFGD Detector size: 24 cm (width) x 8 cm (height) x 48 cm (length)





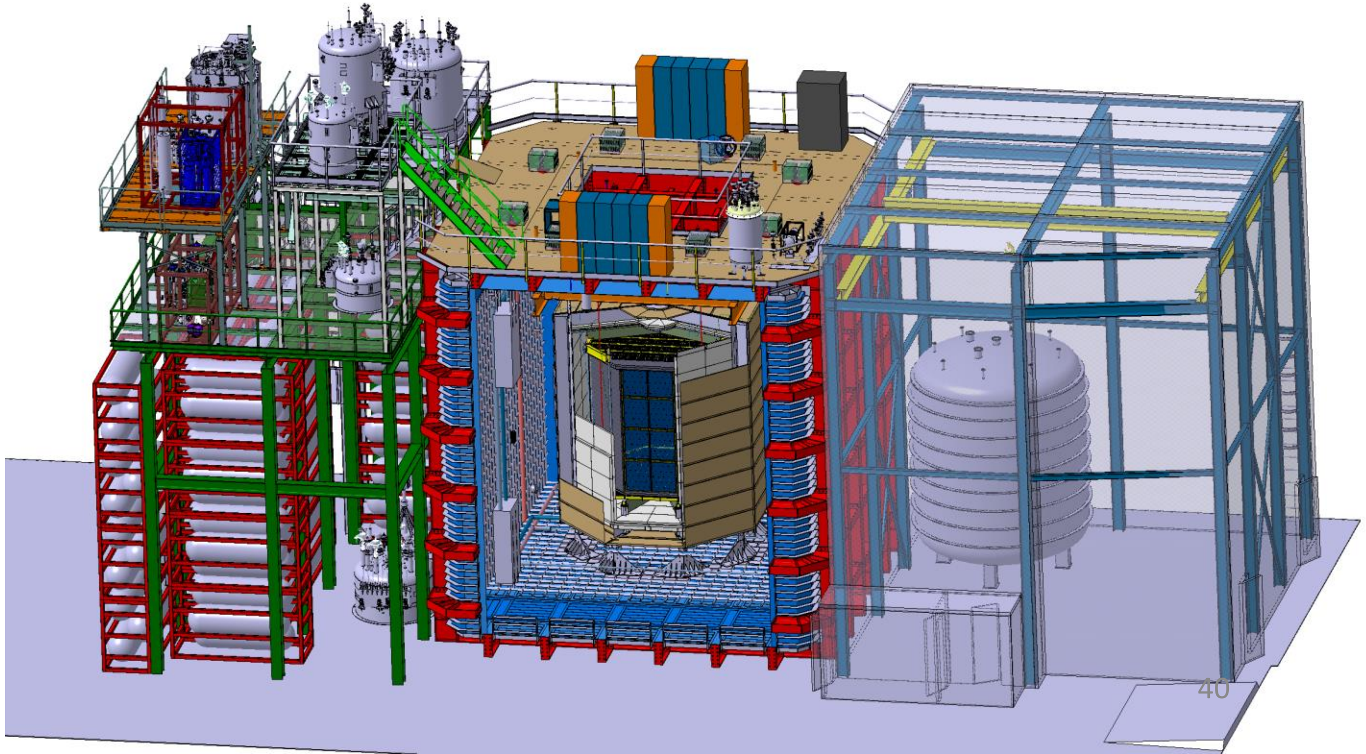


Shown is Time over Threshold and signal amplitude calibration



DarkSide

- New concept based on the NP04 cryostat
- The central TPC with primordial Argon 40 (no 39) is immerged in the large LAr bath. Internal TPC cryostat and material removed. Goal : a background free DM experiment!
- With INFN personnel at CERN the entire engineering concept has been worked out and is ready for implementation
- A CERN-INFN collaboration agreement on the subject signed



NP03: PLAFOND

PLAFOND

- ✓ as first step before proposing a new experiment or a change on an existing one
- ✓ as informal way to try out new ideas, to develop new concepts and alternatives
- ✓ as a first entry point to Neutrino or non accelerator based fundamental research
- ✓ as a way to initiate collaborations and explore synergies with new research partners
- ✓ for young scientists as a first pragmatic approach to our methods and technologies. A place to learn basic tools and instruments

→ Very successful R&D program for the benefit of the entire community

- **Short baseline at CERN, LOI's**
- **DUNE cryostats**
  - LBNF cryostat design and engineering
  - Virtual reality development for the DUNE far detector
- **Fundamental R&D on LAr properties**
  - LAr purification system R&D (new approach)
  - UV Light propagation velocity in LAr R&D
  - Studies of liquid argon scintillation light properties with radioactive sources and cosmic rays
- **ICARUS**
  - ICARUS readout and DAQ test and qualification
  - Tests and development of the ICARUS T600 scintillation light detection and trigger systems
  - Test and characterization of Hamamatsu PMT for ICARUS: timing, linearity and saturation
  - Studies of direct SiPM's performance as a future alternative for PMTs with alternative readout methods.
  - Test and qualification of LAr-TPC read-out with BNL cold analogue end and ICARUS warm digitizers/DAQ
- **DUNE/ProtoDUNE**
  - Aluminum modular field cage R&D for ProtoDUNE SP and DP
  - R&D on UV reflector(with WLS) foils on cathode in LAr and related Electric field uniformity map
  - HV system qualification (feedthough, power supplier, ripple suppression filters)
  - LAr doping tests and qualification with Xenon and Xe-N2
  - Alternative solutions to classical WLS ….. PEN?

Most of this is now part of the existing research program!

- **Dark Matter search**
  - Test and qualification of Dual phase detection in LAr for extremely low energy events
  - LAr Doping ternary mixture Xe-CH4 for active shielng in Dark Matter experiments
- **Future developments for LAr detector**
  - Vertical drift TPC readout and concept with perforated anode PCB replacing wires
  - SIPM in LAr on HV substrate with powering over fiber and optical read-out
- **Other R&D**
  - superFDG for T2K near detector and ND280upgrade
  - Silicon pixels for photon detection, fast

In general project lasting 2-3 months, making use of the existing infrastructure, a cryogenic laboratory, some minimal technical and engineering support …

…. and an healthy and informal proactive collaborative approach …..

Publications

- R&D on LAr fundamantal properties
  - Neutrino Plartform group, Qualification of the ProtoDUEN LAr purification filters: *in preapration*
  - M. Babicz, et al., *Experimental study of the propagation of scintillation light in Liquid Argon,* NIMA 936 (2019) 178-179;
  - M. Babicz et al. *A particle detector that exploits Liquid Argon scintillation light,* NIMA 958 (2020) 162421;
  - M. Babicz et al., *Propagation of scintillation light in Liquid Argon,* JINST 15 (2020) 03 C03035, arXiv:2002.09346
  - B. Ali-Mohammadzadeh et al., *Measurement of Liquid Argon Scintillation Light Properties by means of an Alpha Source placed inside the CERN 10-PMT LAr Detection System,* JINST 15 (2020) 06 C06042;
- ICARUS
  - L. Bagby et al., *New read-out electronics for ICARUS-T600 liquid Argon TPC. Description, simulation and tests of the new front-end and ADC system*, *JINST* 13 (2018) 12, P12007
  - M. Antonello et al., Study of space charge in the ICARUS T600 detector JINST_15_P07001
  - G. L. Raselli et al., *Test and characterization of 20 pre-series Hamamatsu R5916-MOD photomultiplier tubes for the ICARUS T600 detector*, NSS/MIC 2016;
  - M. Babicz et al., *Timing properties of Hamamatsu R5912-MOD photomultiplier tube for the ICARUS T600 light detection system*, NIMA 912 (2018) 231-234;
  - M. Babicz et al., *Linearity and saturation properties of Hamamatsu R5912-MOD photomultiplier tube for the ICARUS T600 light detection system,* 936 (2019) 554-555;
  - M. Babicz, eNIMAt al. *Scintillation Light DAQ and Trigger System for the ICARUS T600 Experiment at Fermilab*, NIMA 936 (2019) 358-359;
  - M. Babicz, et al. *A particle detector that exploits Liquid Argon scintillation light,* NIMA 958 (2020) 162421;
  - T. Cervi et al., *Study of SiPM custom arrays for scintillation light detection in a Liquid Argon Time Projection Chamber*, JINST 12 (2017) 03 C03007;
  - T. Cervi et al., *Study of SiPM custom arrays for scintillation light detection in a Liquid Argon Time Projection Chamber*, JINST 12 (2017) 03 C03007;
  - T. Cervi et al., *Comparison between large area PMTs and SiPM arrays deployed in a Liquid Argon Time Projection Chamber at CERN*, NIMA 912 (2018);
  - T. Cervi et al., *Characterization of SiPM arrays in different series and parallel configurations*, NIMA 912 (2018) 209-212;
  - M. Babicz, et al., *Characterization of SiPM arrays with common bias and common readout for applications in liquid argon*, NIMA 936 (2019);
- Dark Matter search
  - LAr Doping ternary mixture Xe-CH4 for active shielng in Dark Matter experiments: *paper in preparation*
- Future developments for LAr detector
  - *Xenon doping to improcescintillation light detection efficincy in Large LAr-TPC:* in preparation
  - Vertical drift TPC readout and concept with perforated anode PCB replacing wires: paper in preparation
  - X-ARAPUCAs characterization: in preparation
- Other R&D
  - D.Attié et al., *Performances of a resistive Micromegas module for the Time Projection Chambers of the T2K Near Detector upgrade*, NIMA, 957 (2020)
  - K.Aba, et al., *T2K ND280 Upgrade Technical Design Report*, arXiv:1901:0375
  - A. Blondel,*The SuperFGD Prototype Charged Particle Beam Tests*, in preparation

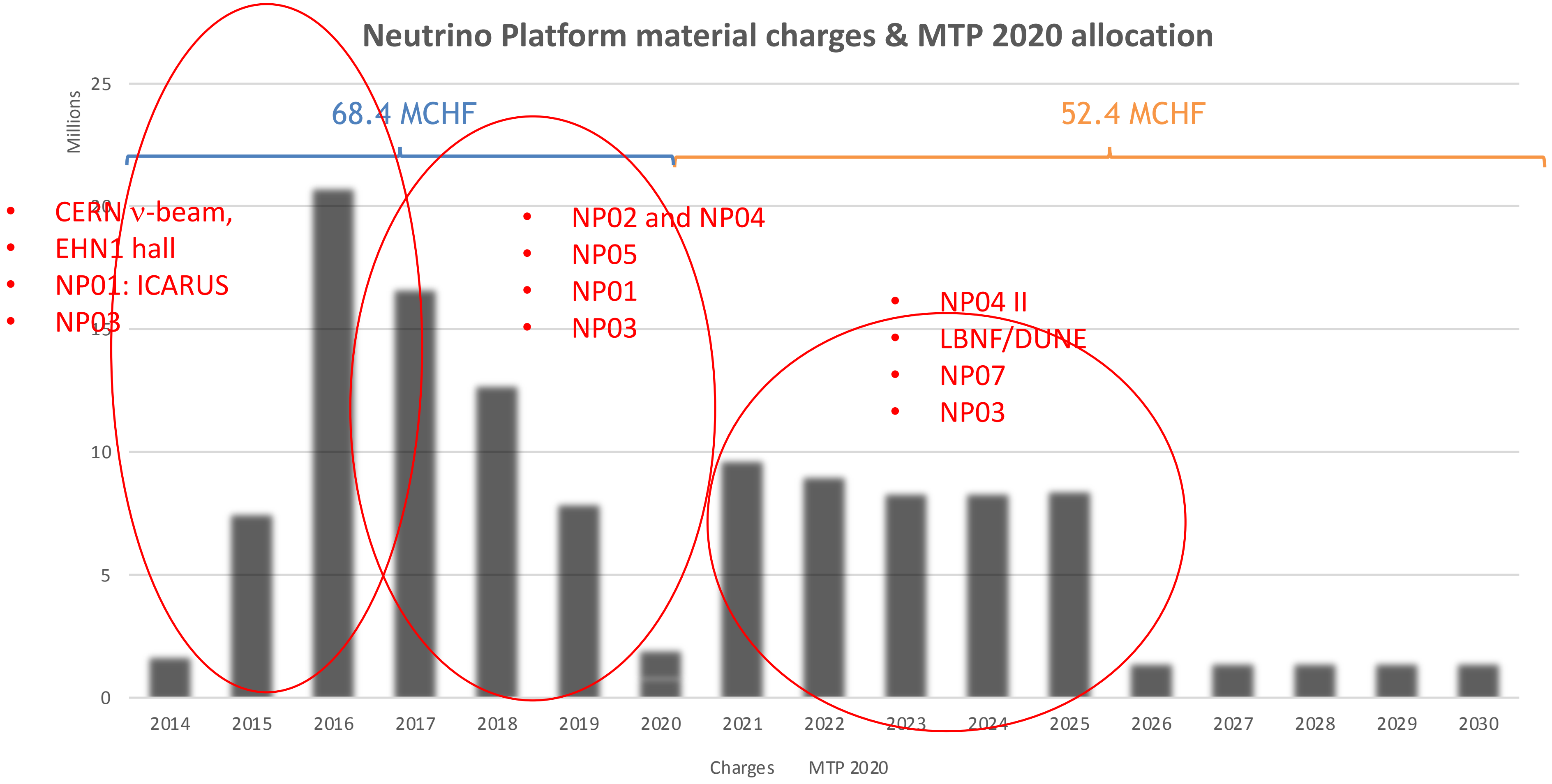
Summary

- Very intense level of activities over a period of 6 years
- Always under schedule pressure (personalities, beam availability, reviews processes, changes in top management, external funds, new requests, …..)
- Most of the activities are R&D, with all the risks associated (technical, financial and scientific)
- CERN focused on membrane cryostat technologies (7 constructed, 3-4 in the pipeline). Our contribution to this industrial technology is today well visible also outside our field
- We are sharing resources (in particular manpower) across the various projects, in order to be effective and lower the costs. The engaged team is very motivated at CERN and in the large collaborations
- The path chosen after the 2013 European Strategy update has been confirmed in the 2020 update
- LBNF/DUNE and SBN, today also exist because of NP fundamental contribution and delivery success

The Neutrino Platform concept

- It seems to be effective
- *It gives access to external users (not necessary already at CERN) of CERN infrastructure and specific technical knowhow*
- An effective way to bring in new ideas on fundamental research not directly related to the LHC program
- *A way to start new collaborations and bring in CERN as a collaborating partner (outside CERN)*
- It might extend to other fields of fundamental science in an effective way

Material budget summary



Courtesy FAP department

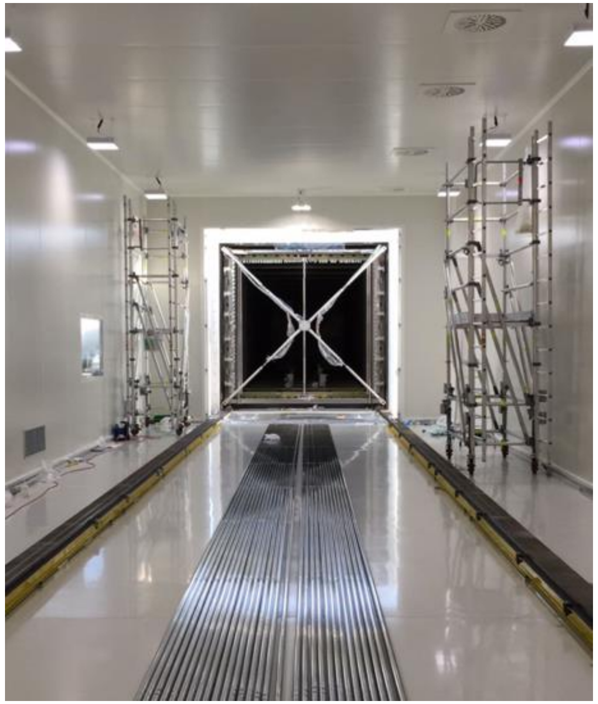
Backup slides

NP01: ICARUS

ICARUS
removal
from LNGS

Two special
transports to
CERN in new
boxes

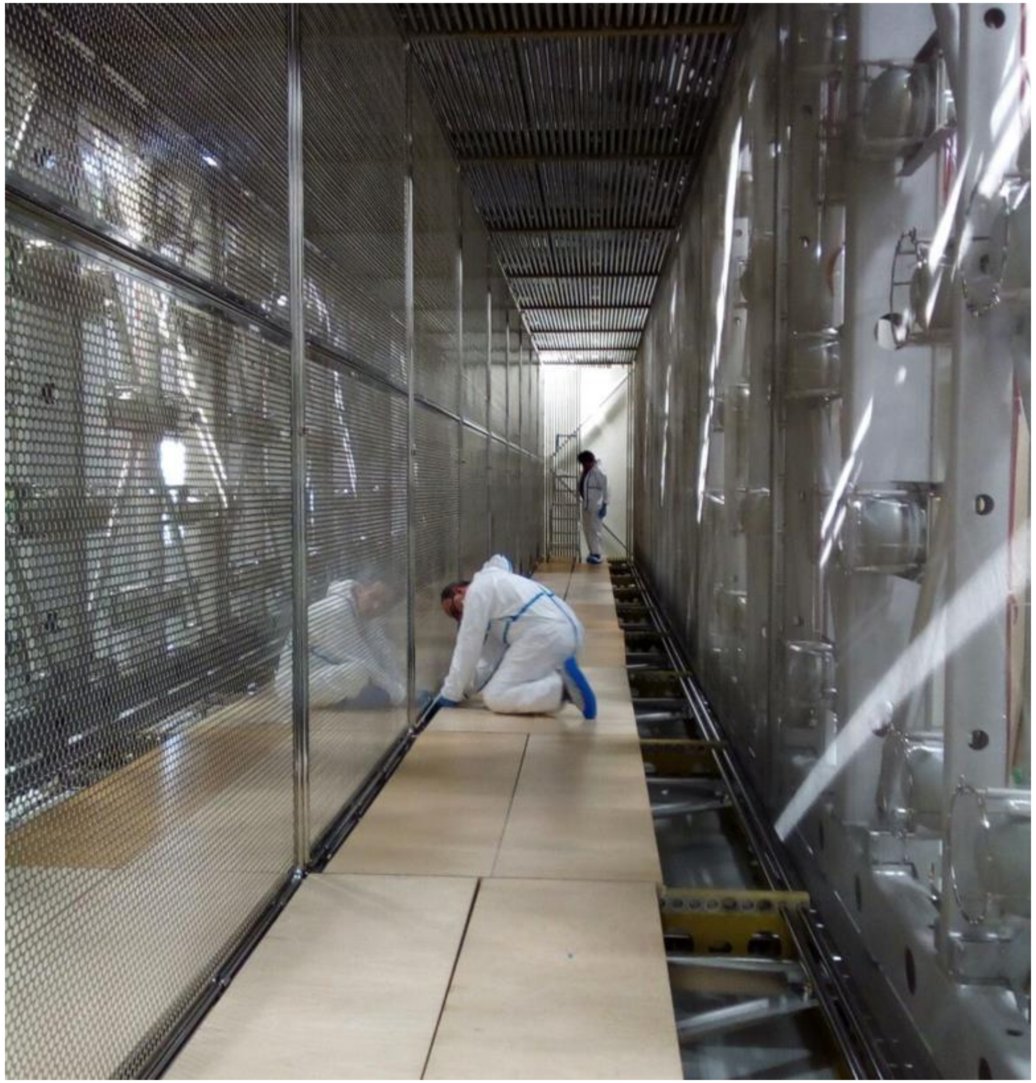
A new 10’000
class clean
room built in
b185



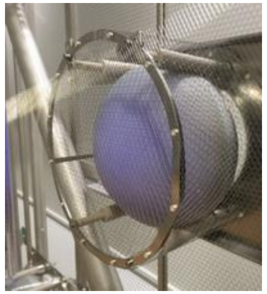
One ICARUS
TPC at the time
hosted in the
clean room
and ready for a
deep reshaping

Entire cabling removed and substituted with a new one. New special cables, new connectors, new routing

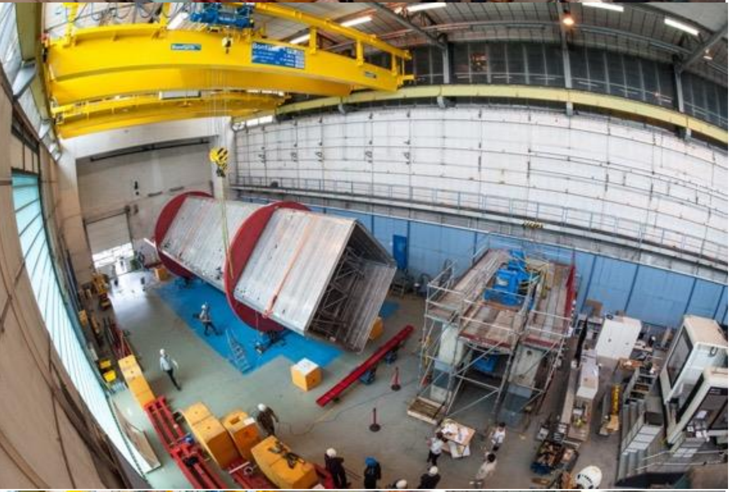
Entire structure cleaned and prepared for insertion into the new cryostats

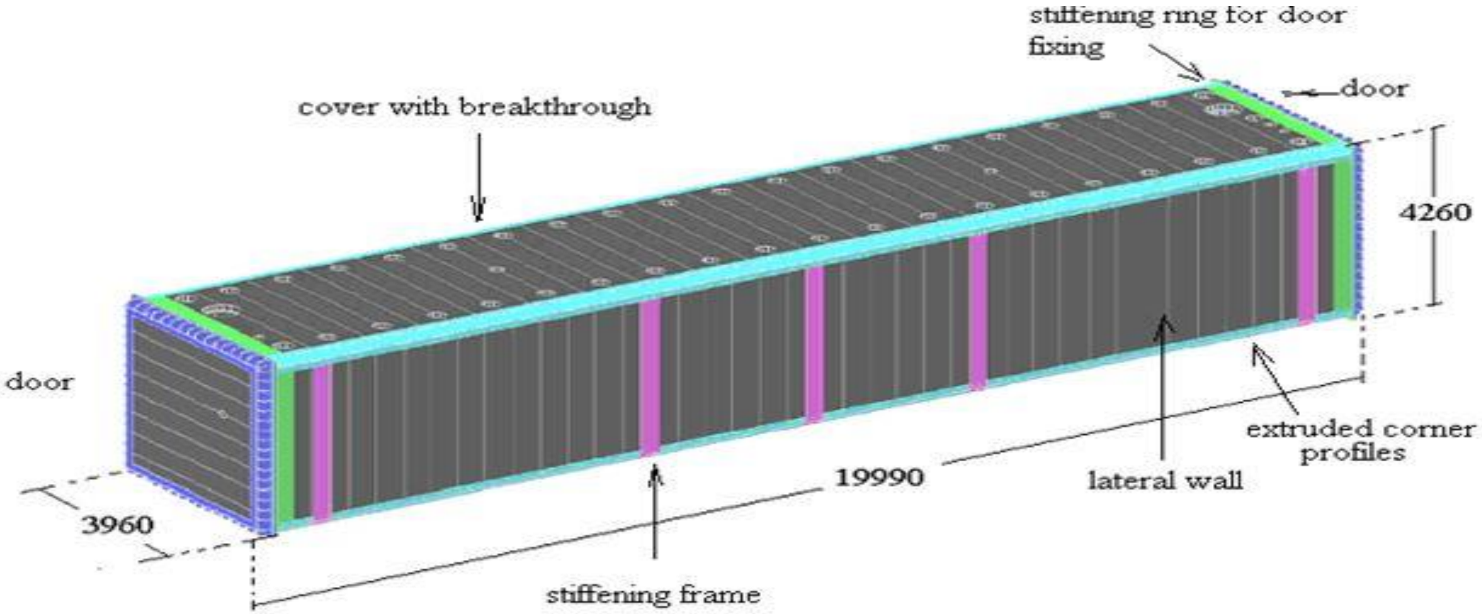


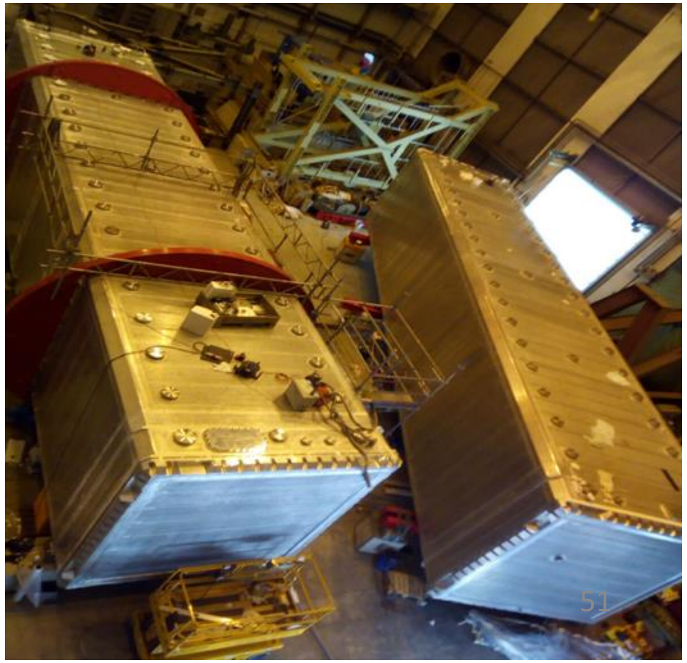
Cathode (bended) had to be dismounted, extracted and reshaped



New and more (x2) large PMTs procured, coated with WLS and installed




stiffening ring for door fixing
door
cover with breakthrough
4260
door
extruded corner profiles
lateral wall
19990
3960
stiffening frame



Leaving CERN 12 June 2017

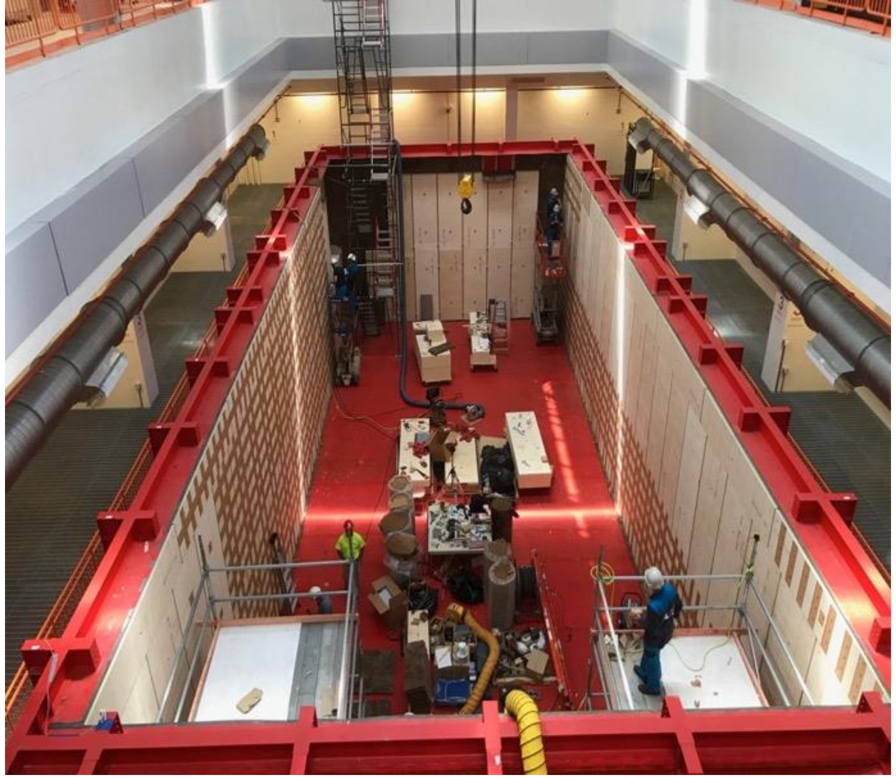
On a barge to Rotterdam

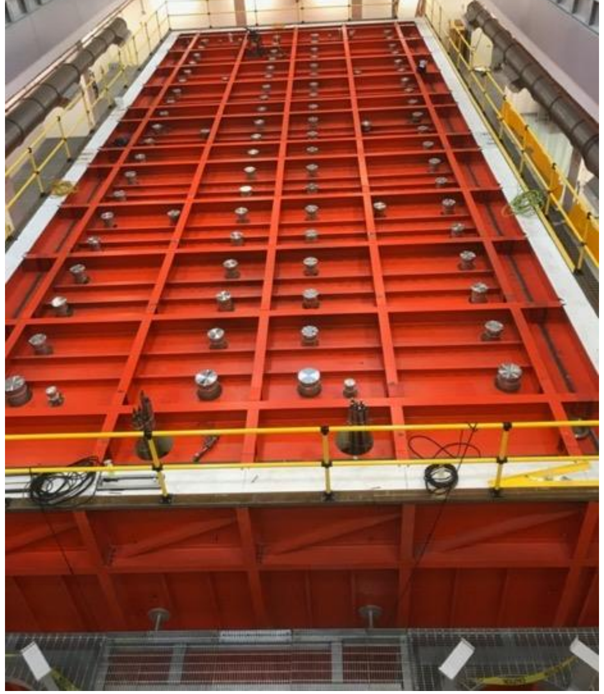
On the sea ship

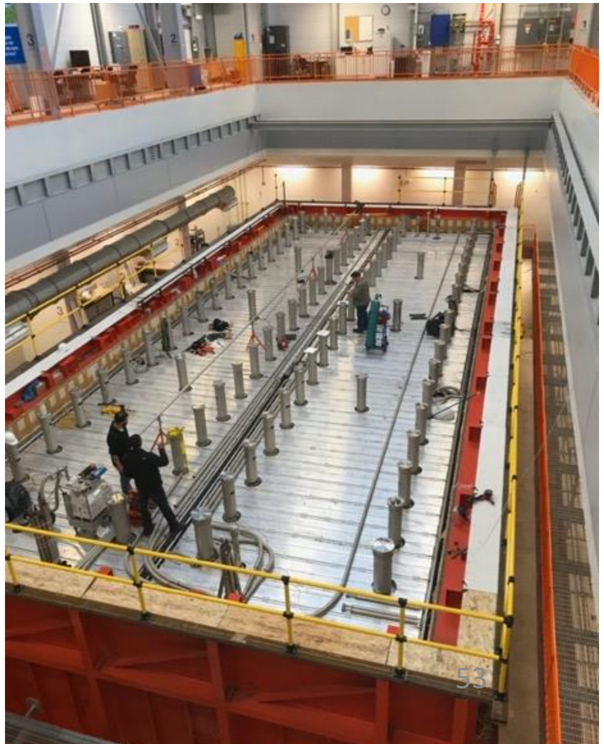
At the US harbor (Indiana)

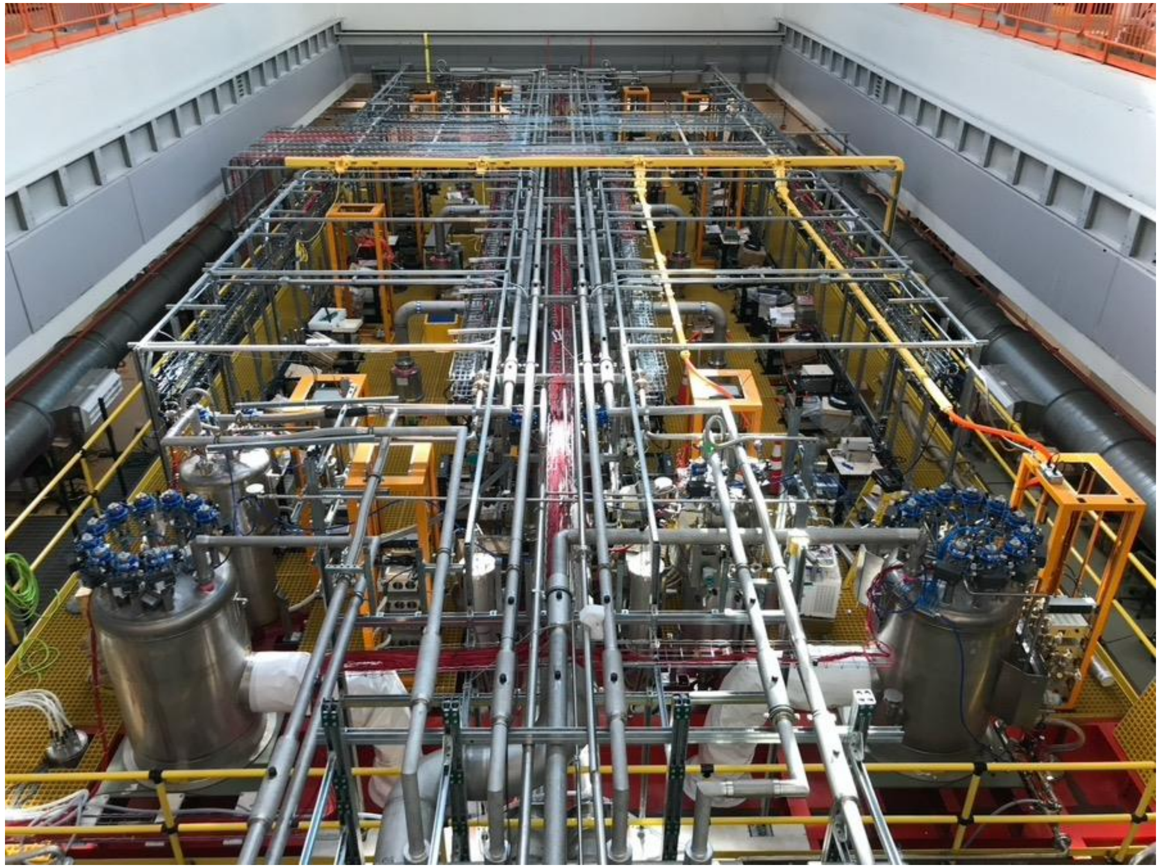
Transported to FNAL 12 June to 2 July 2017
Very complex US road transport

CERN Polish contract









Most of the construction work done in a firm in Holland, who also install it at FNAL !

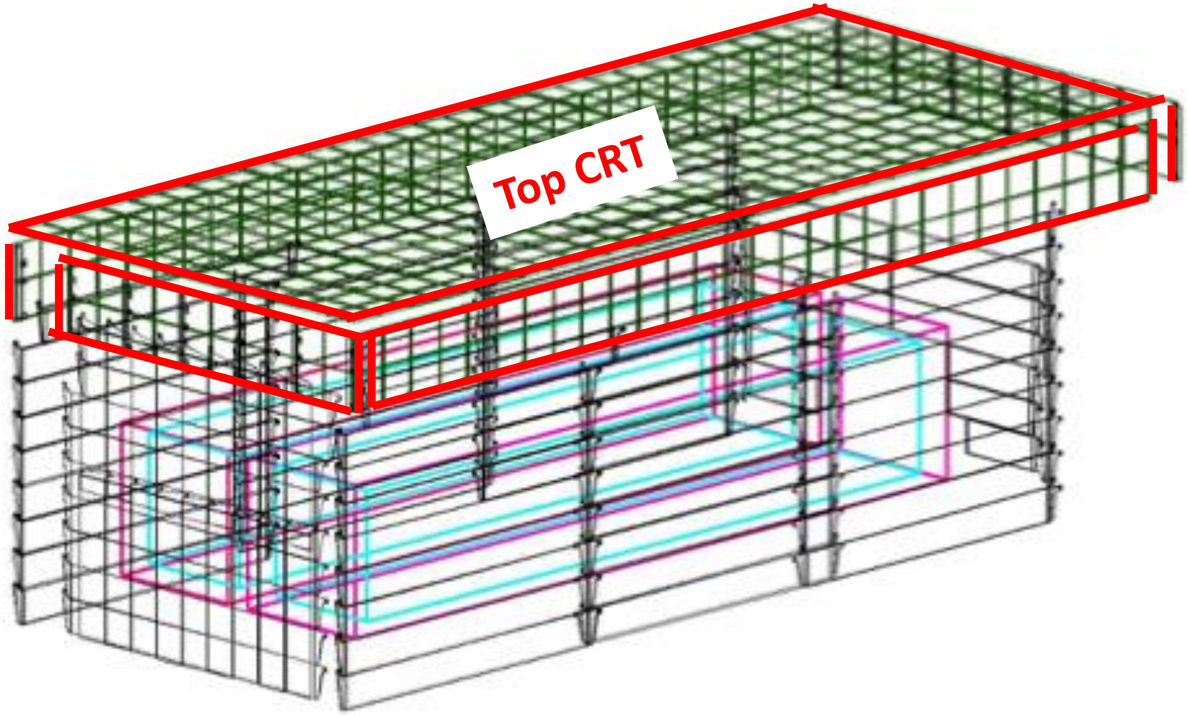
LAr cryogenics design, constructed, installed and commissioned by the CERN cryogenics group!

ICARUS is now cold and full with LAr, HV is on

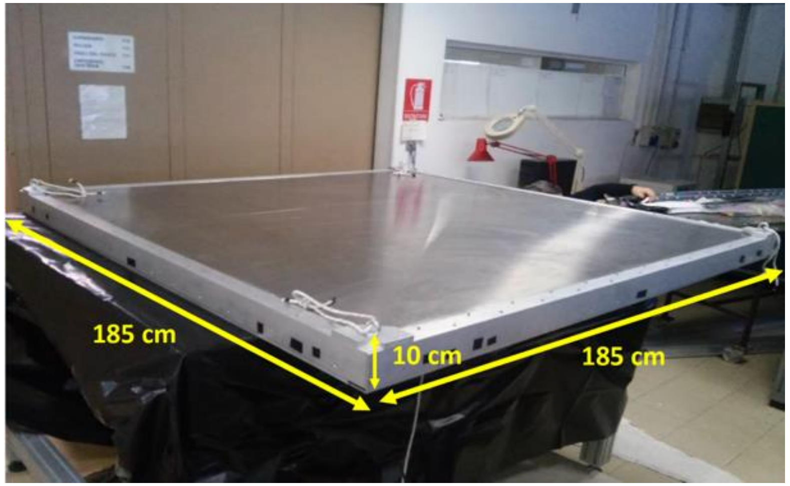
DAQ and DCS ready to go

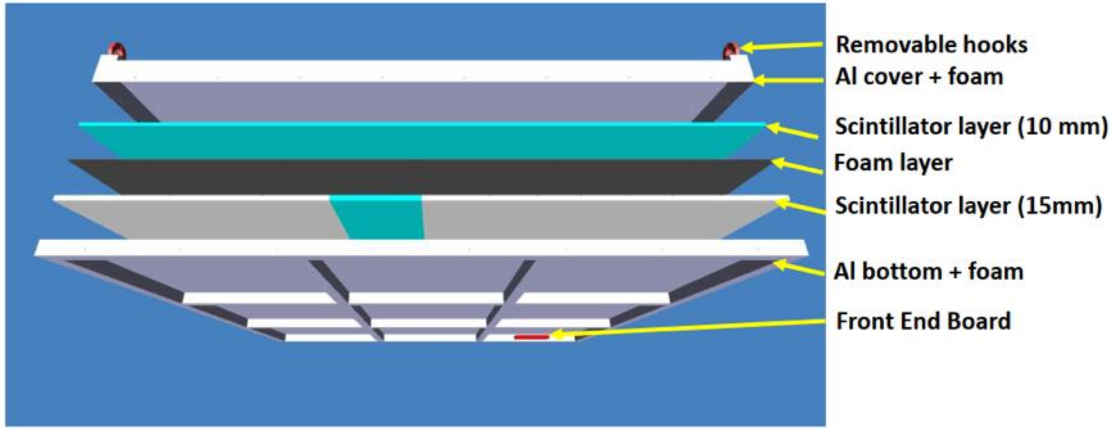
Next step: commission the electronics, the trigger and then install the muon tagger !

COVID is stopping us. We need the European experts in situ!



Cosmic muon tagger



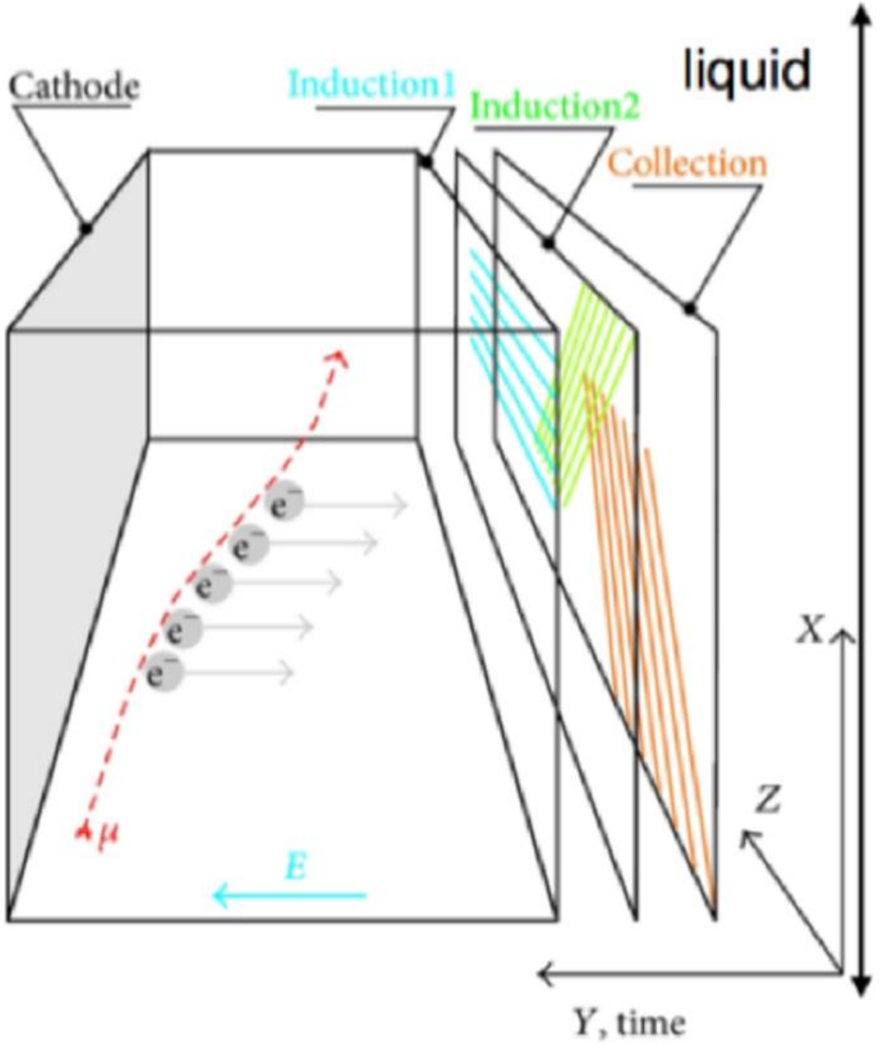


TOP CRT :

- CERN, INFN
- ~ 900 mq of scintillators produced in CZ and Ukraine
- 125 modules (~2x2 mq) assembled in Frascati by INFN and CERN

ProtoDUNE NP04 single phase

NP04: protoDUNE SP

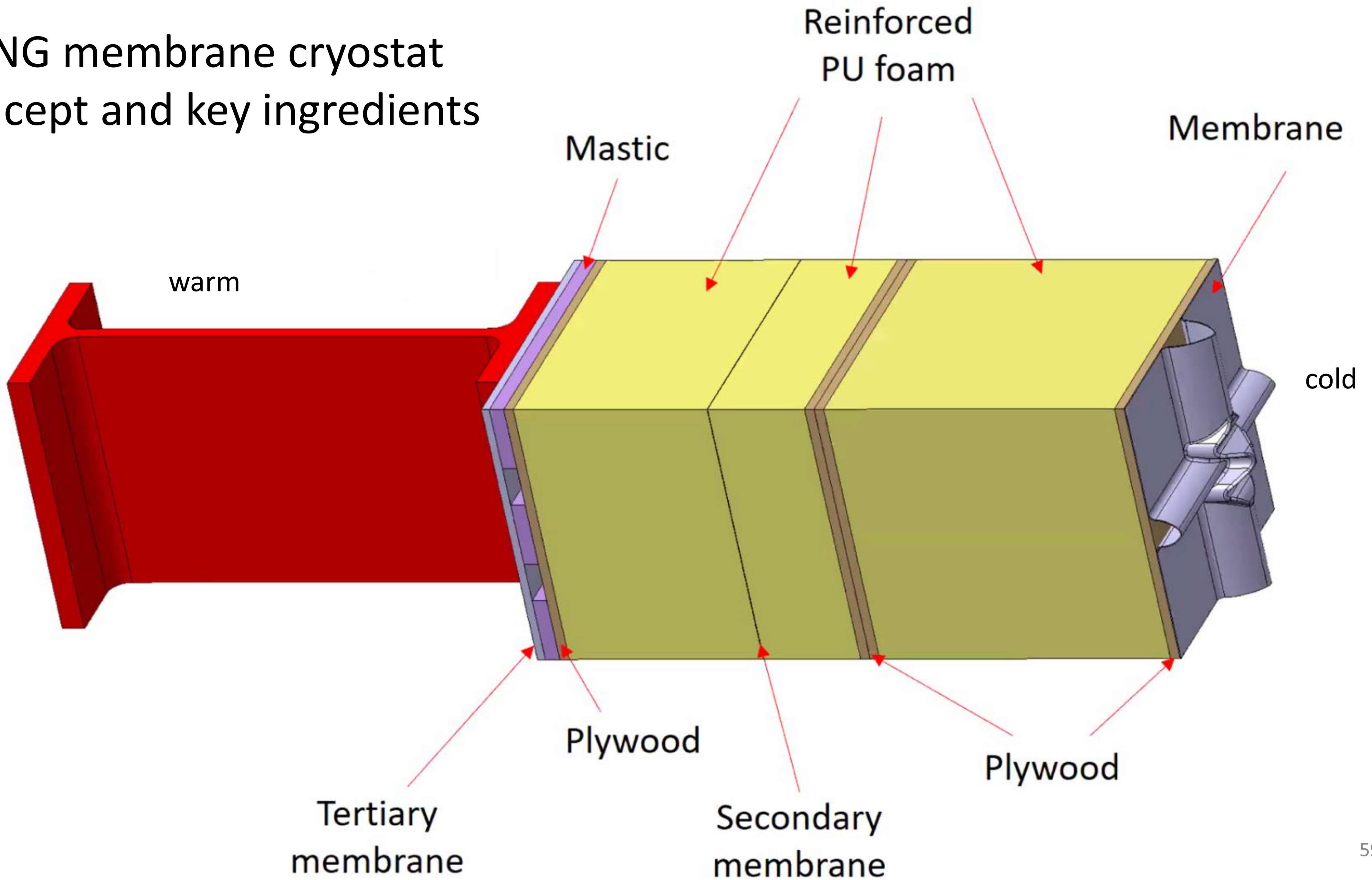


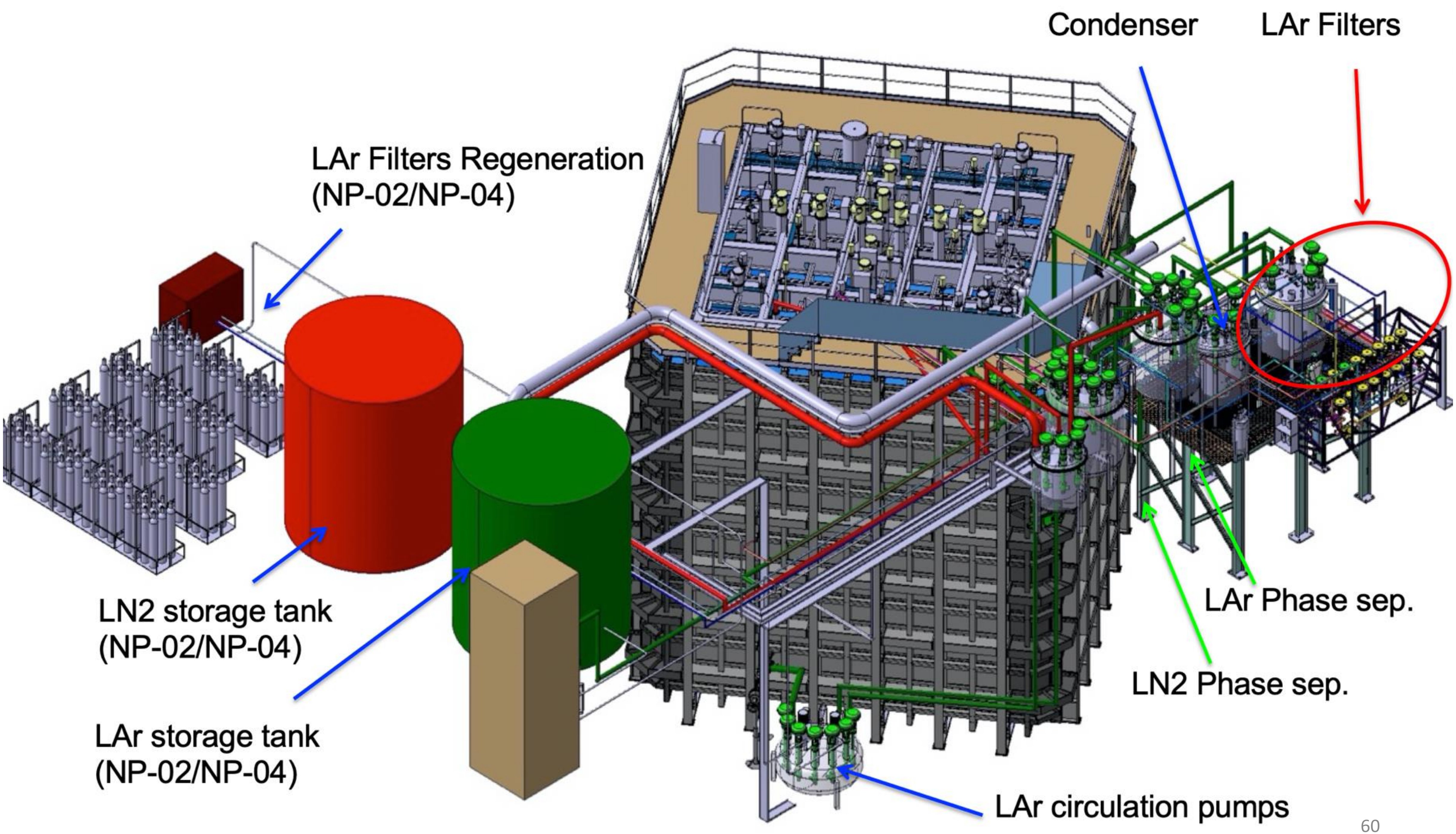
NP04 : The protoDUNE single phase

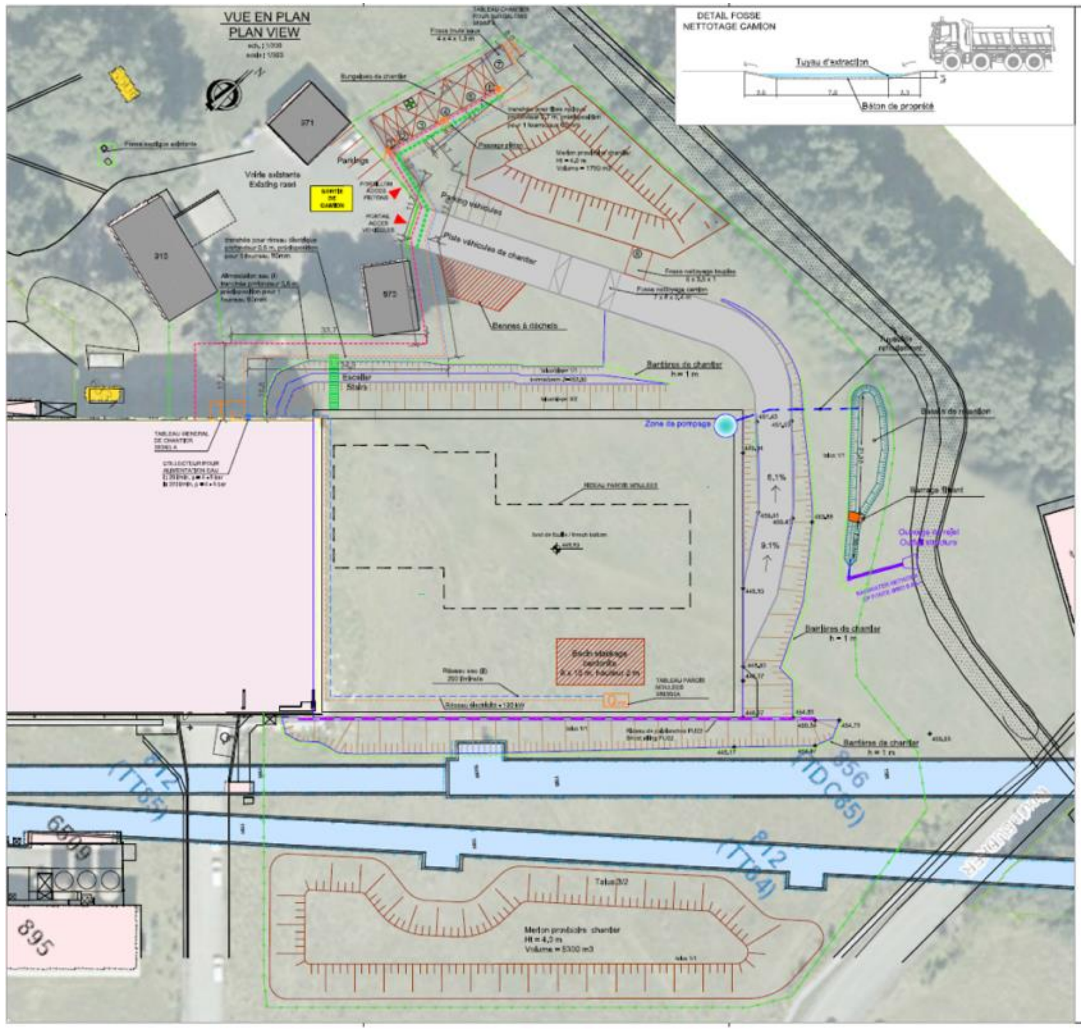
Steps :

- ✓ Workout the concept of a membrane cryostat (LNG type)
- ✓ Built a new experimental area, big enough (EHN1-NP)
- ✓ Construct a 800 tons LAr membrane cryostat
- ✓ Construct a large clean room in front of it
- ✓ Equip the clean room with a cold box, ready to test the active detector components at cold before insertion
- ✓ Collect all the active parts of the detector world wide
- ✓ Build a large cryogenics plant, able to recycle and purify the argon on a weekly cycle
- ✓ Insert the detector
- ✓ Install all the necessary infrastructures
- ✓ Construct a dedicated SPS beamline extension (~60m)
- ✓ Add a muon tagger
- ✓ Cool down and fill with LAr
- ✓ Commission it and exploit it on physics
- ✓ 4 months on beam before CERN LS2, 18 months on cosmics

LNG membrane cryostat concept and key ingredients

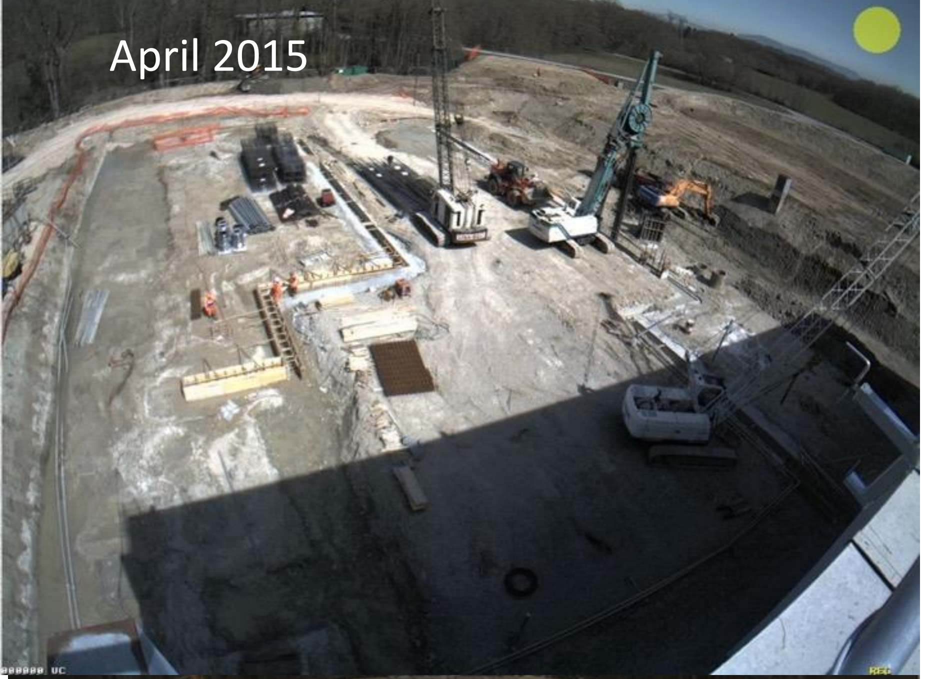


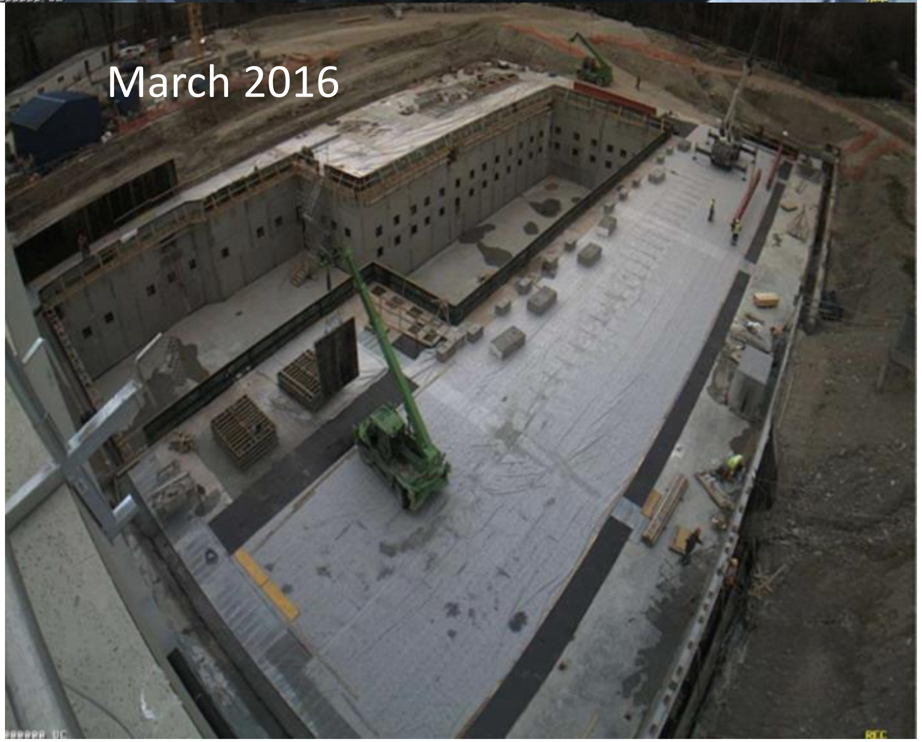

Condenser
LAr Filters
LAr Filters Regeneration
(NP-02/NP-04)
LN2 storage tank
(NP-02/NP-04)
LAr storage tank
(NP-02/NP-04)
LAr Phase sep.
LN2 Phase sep.
LAr circulation pumps


VUE EN PLAN
PLAN VIEW
DETAIL FOSSE
NETTOYAGE CAMION
Tuyau d'extraction
Béton de propreté


March 2015


2015 CAD simulation

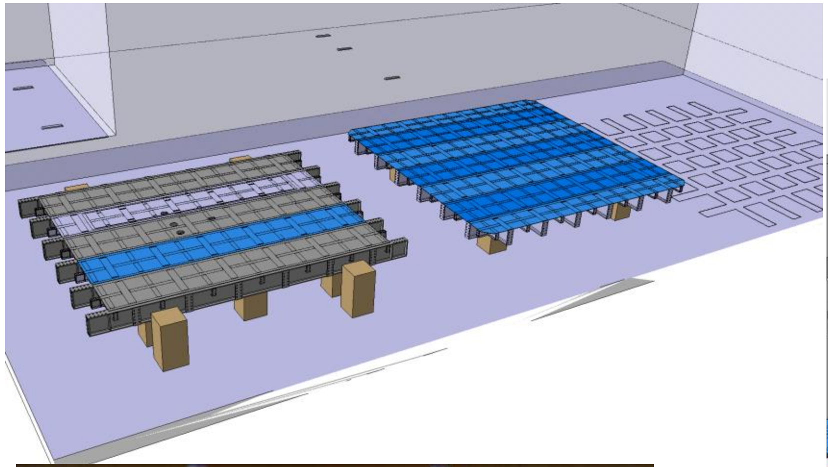


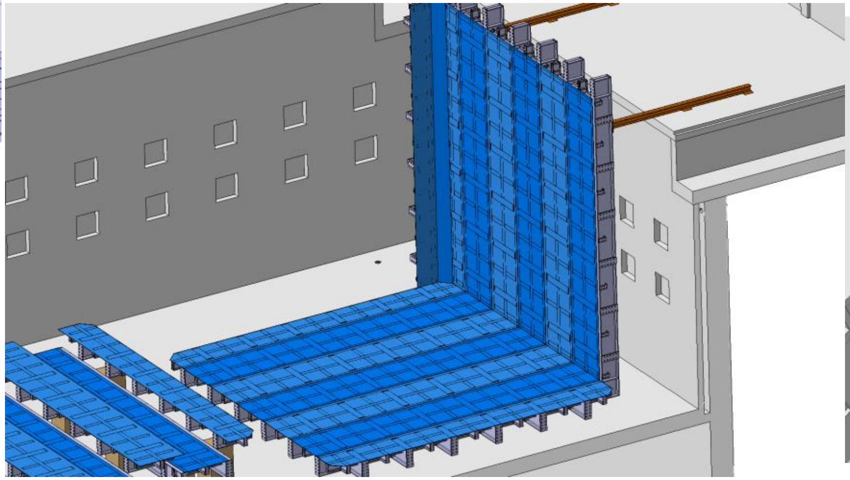


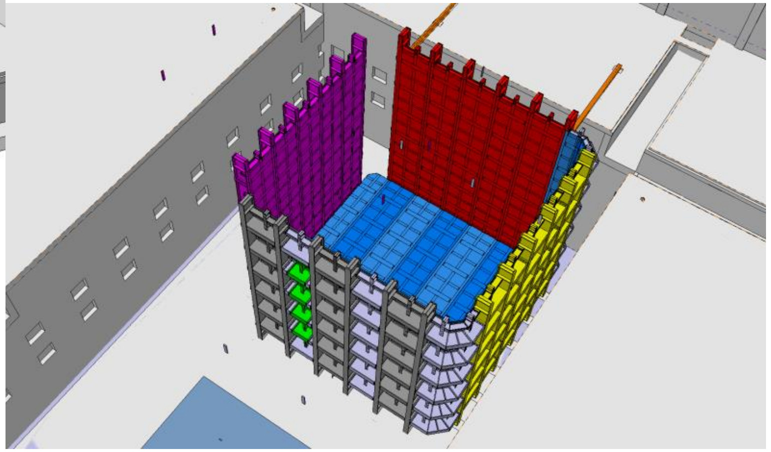
Civil engineering is over

Infrastructure work start inside the building

Warm structure assembly started in October

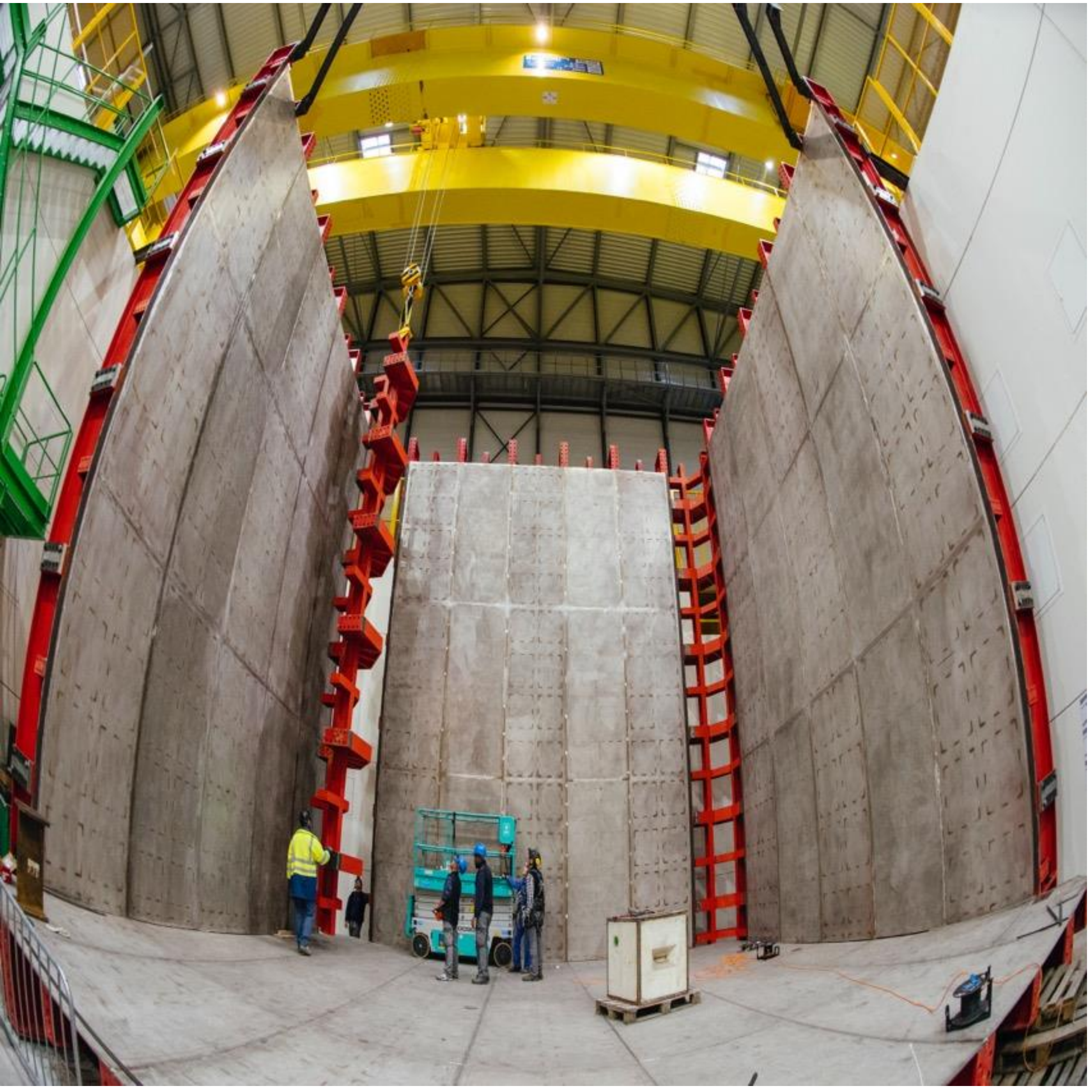






Components procured in Luxemburg, Romania, UK and Switzerland

October 2016 the cryostat construction started



Warm vessel completed in December 2016

Then the installation of the cold vessel can start

Membrane cold cryostat installed by a Spanish firm, material coming from S.Korea

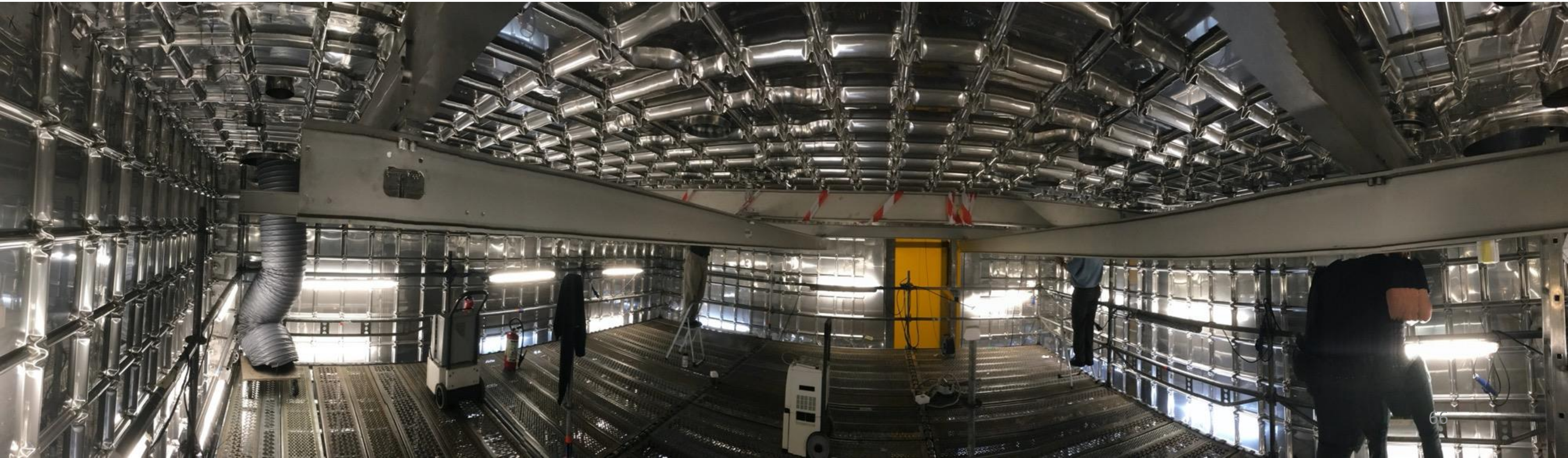




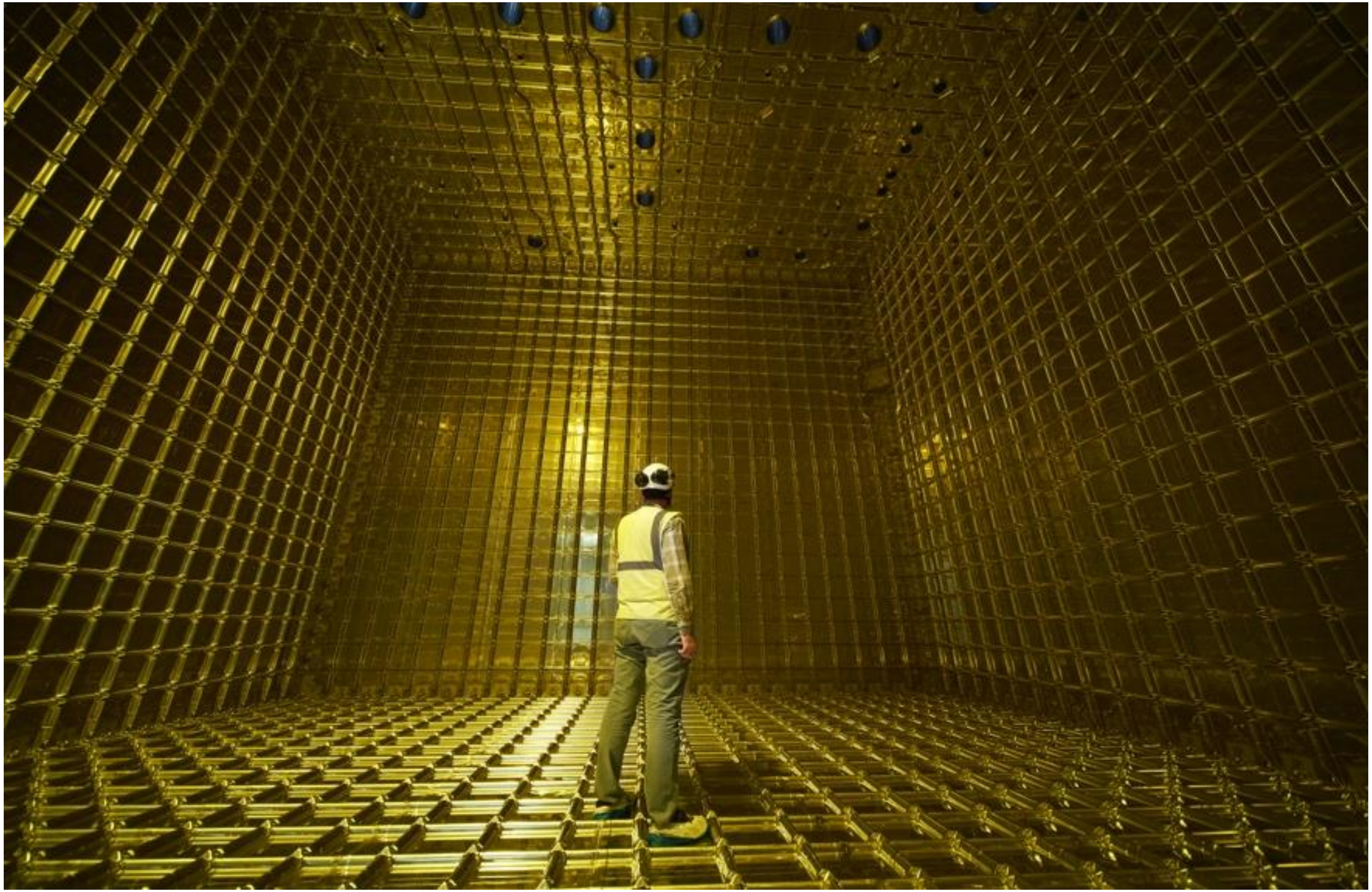


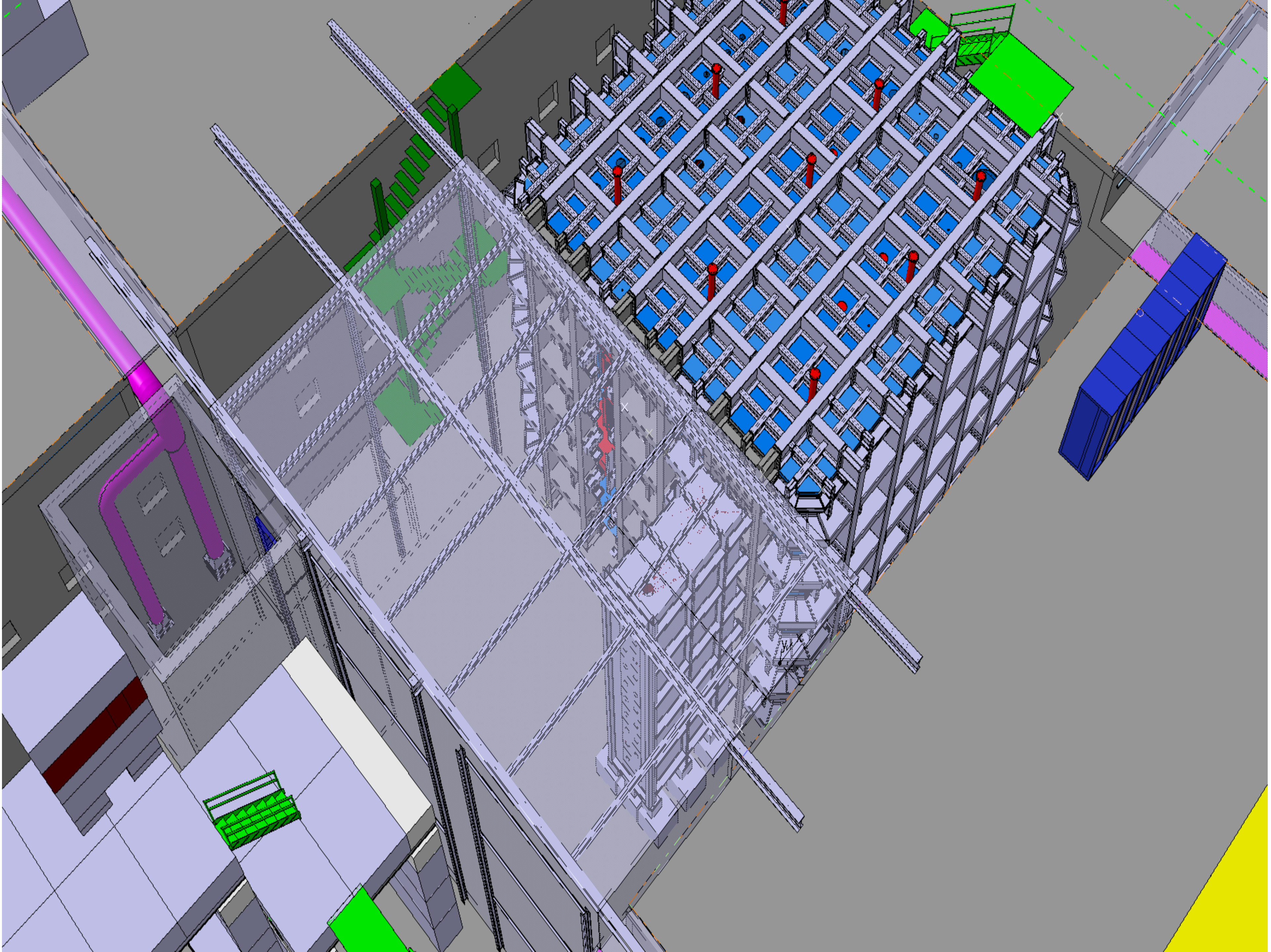


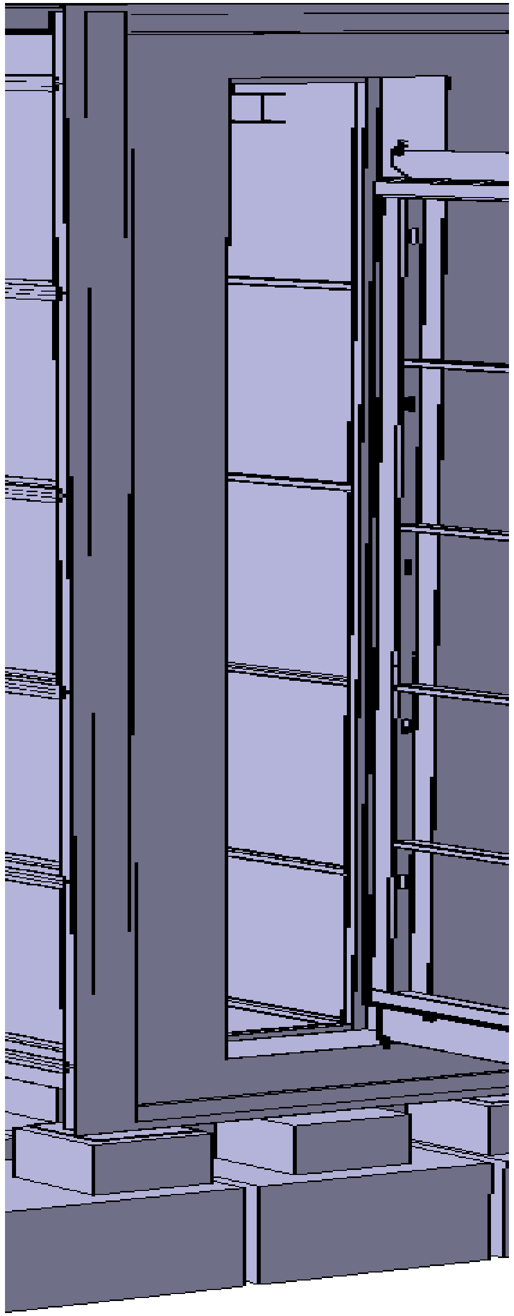
Final membrane welding in situ + penetrations and detector support structure



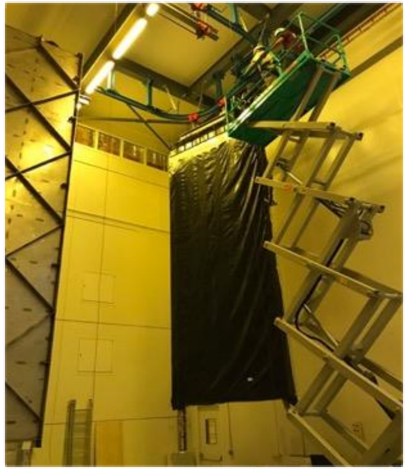
September 2017, cryostat completed

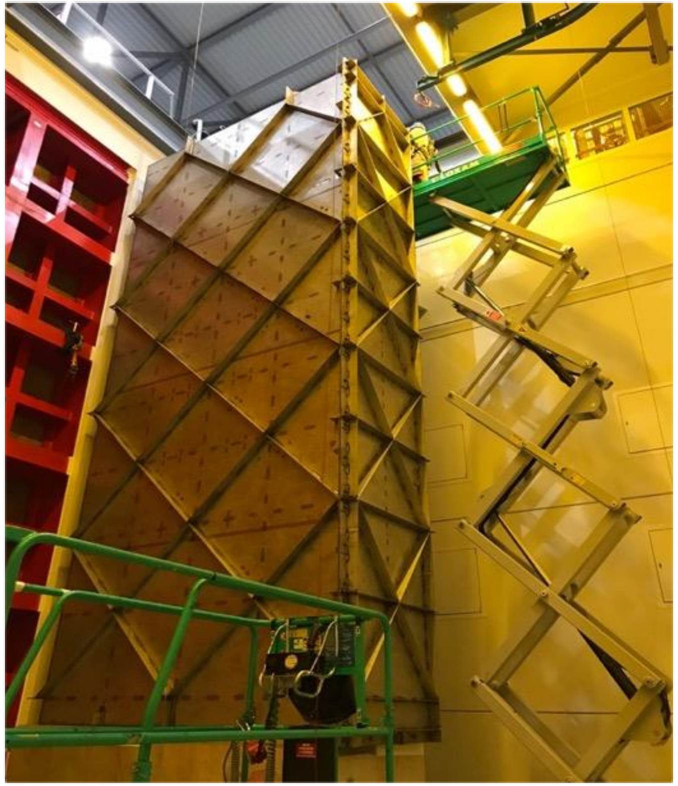






APA in cold box

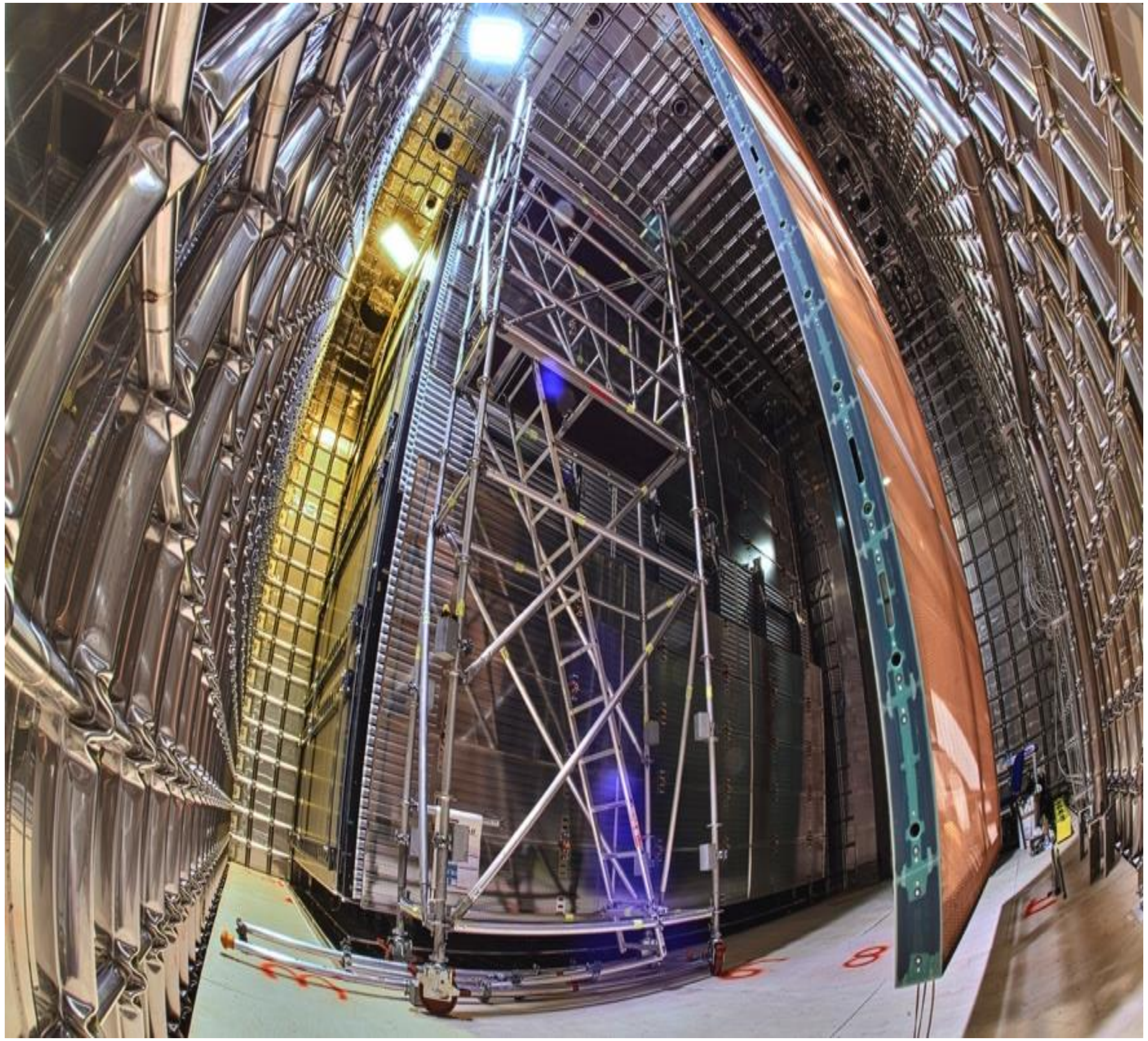




All electronics connected,
DAQ operational

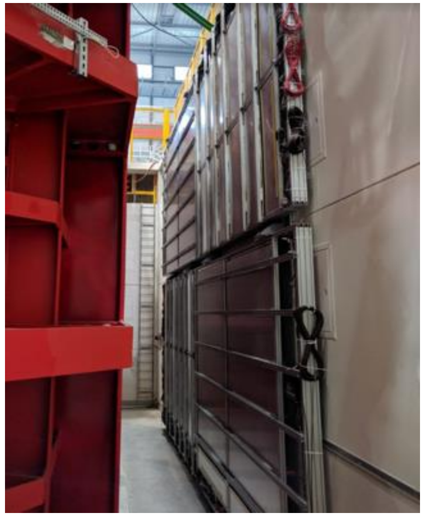
Noise test ongoing
at room temperature.

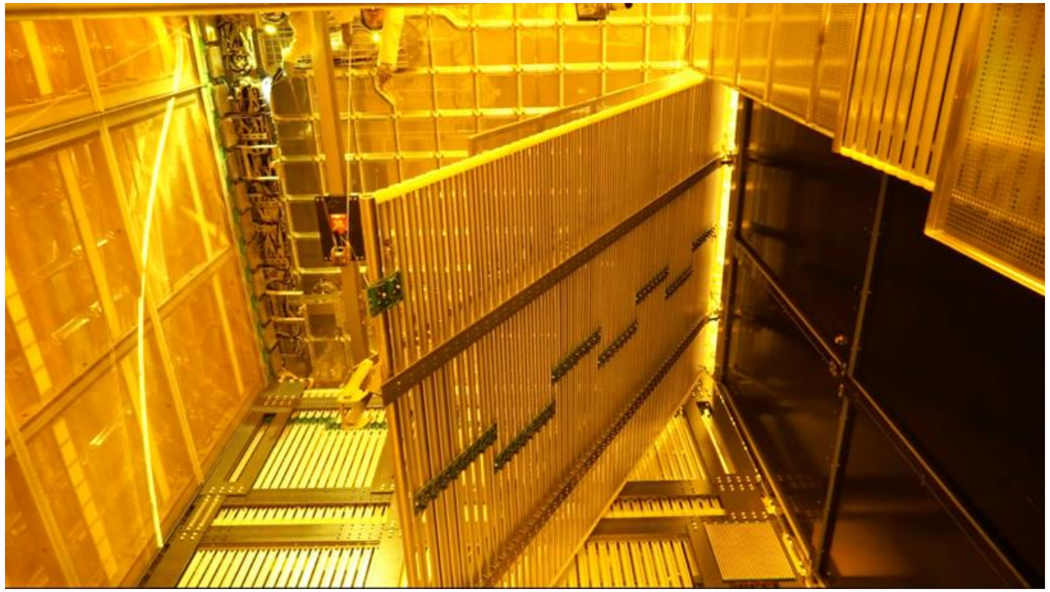
First cool-down of the APA
in the week of 30th October 2017

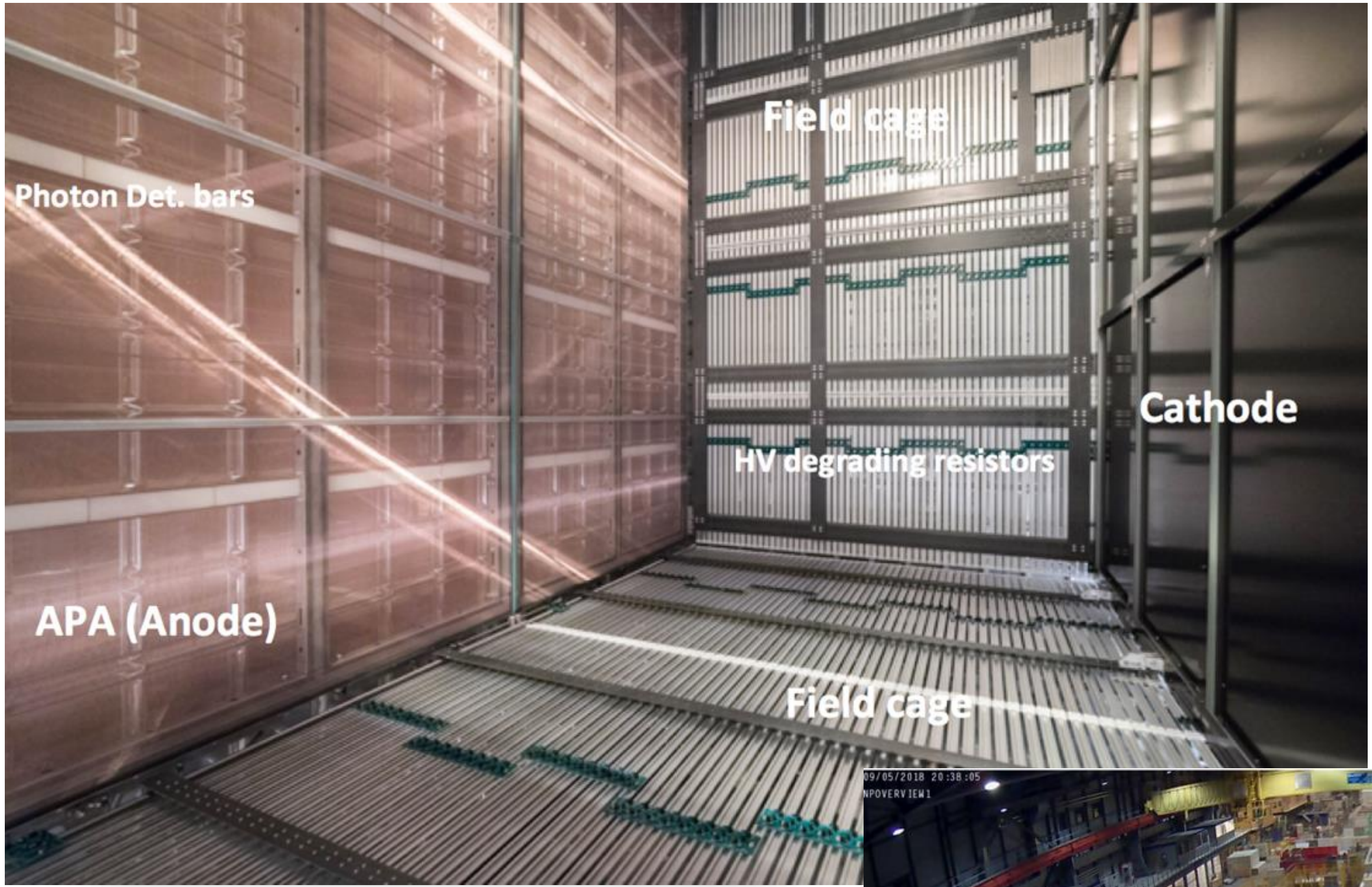


DAQ room

muons tagger







August 2018 ready to go!

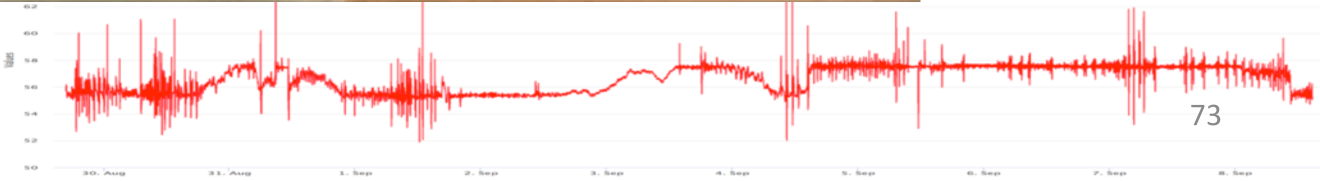
HV feedthrough
and 180KV supply

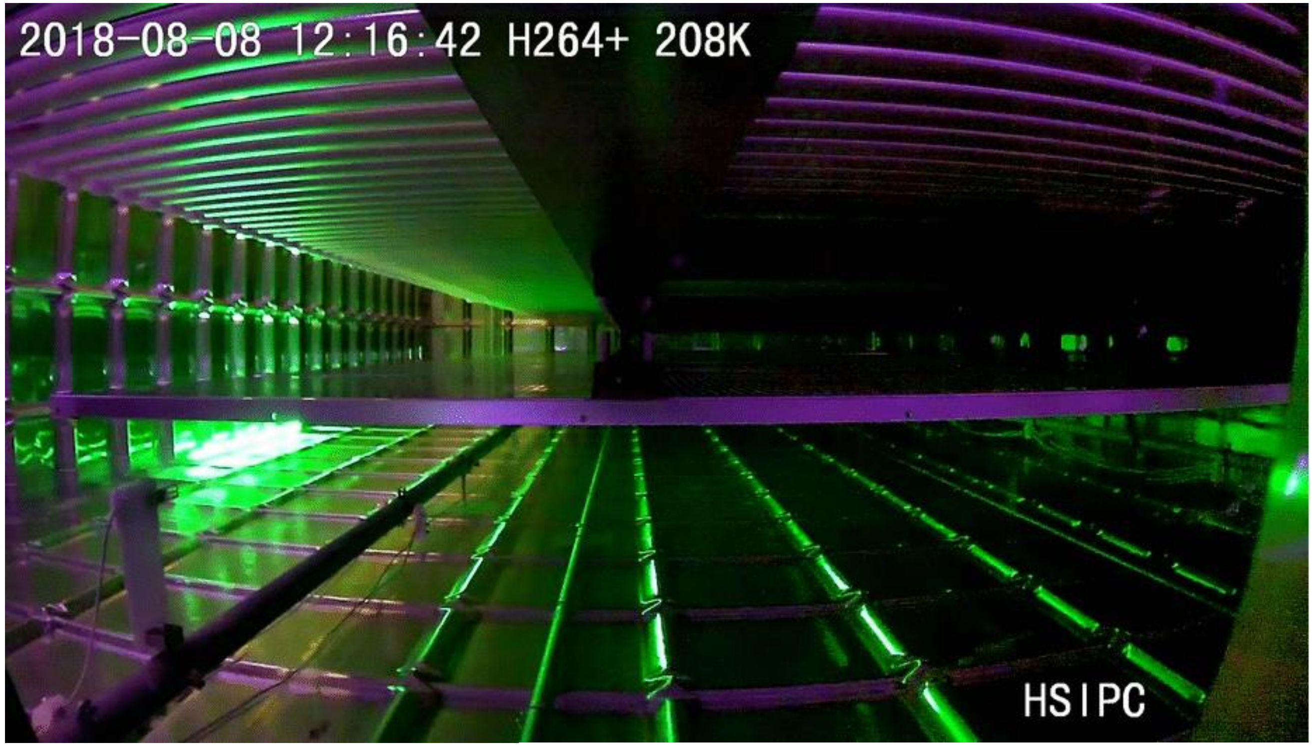
LAr cryogenics

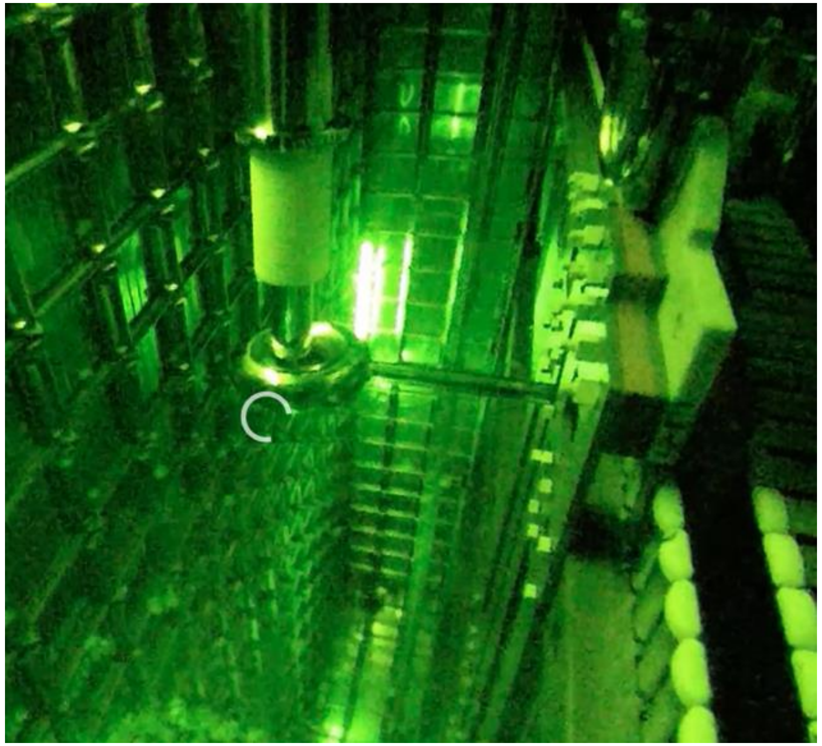
… and an online processing farm

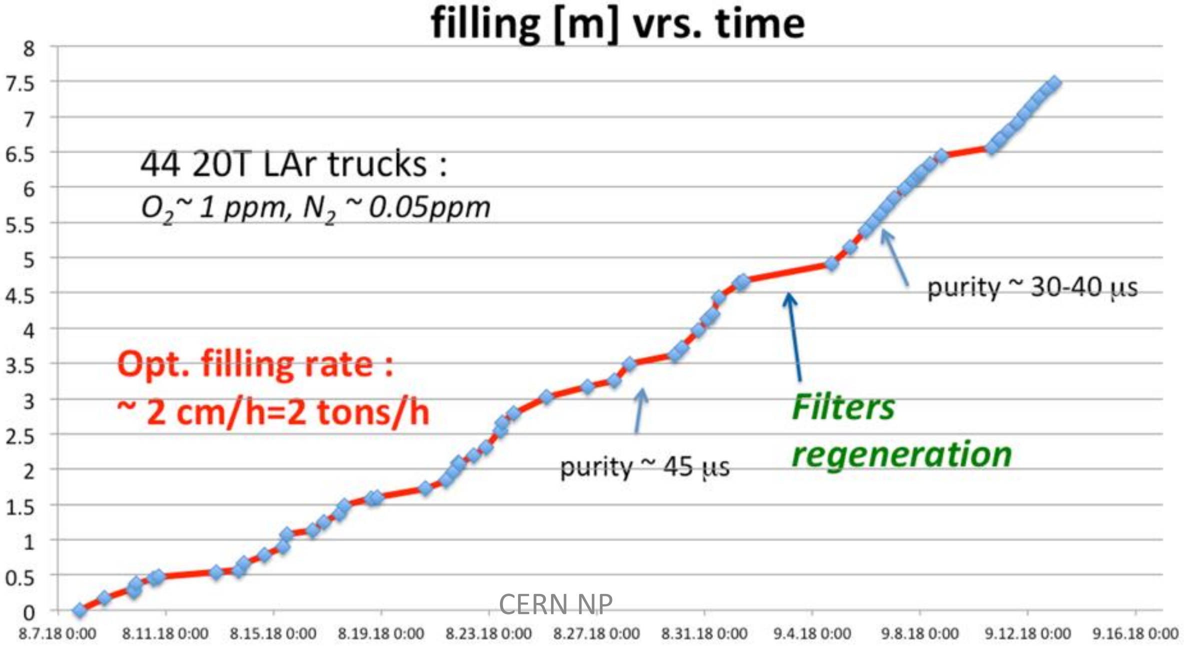
Detector infrastructure

Gas over-pressure in the cryostat gas volume very well controlled around **57 mbar**.

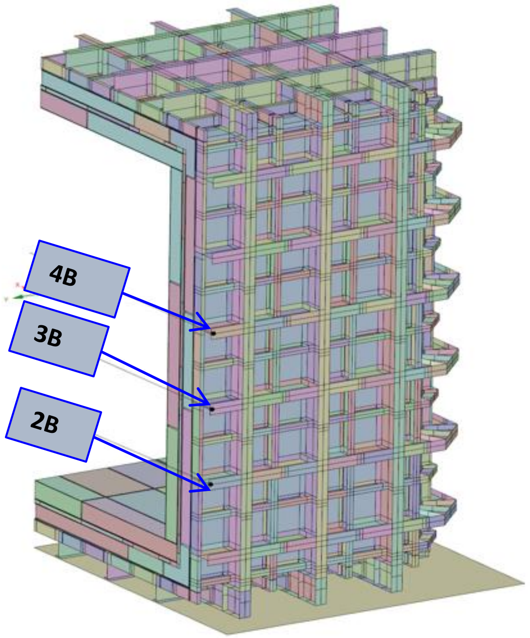



2018-08-08 12:16:42 H264+ 208K
HS I PC

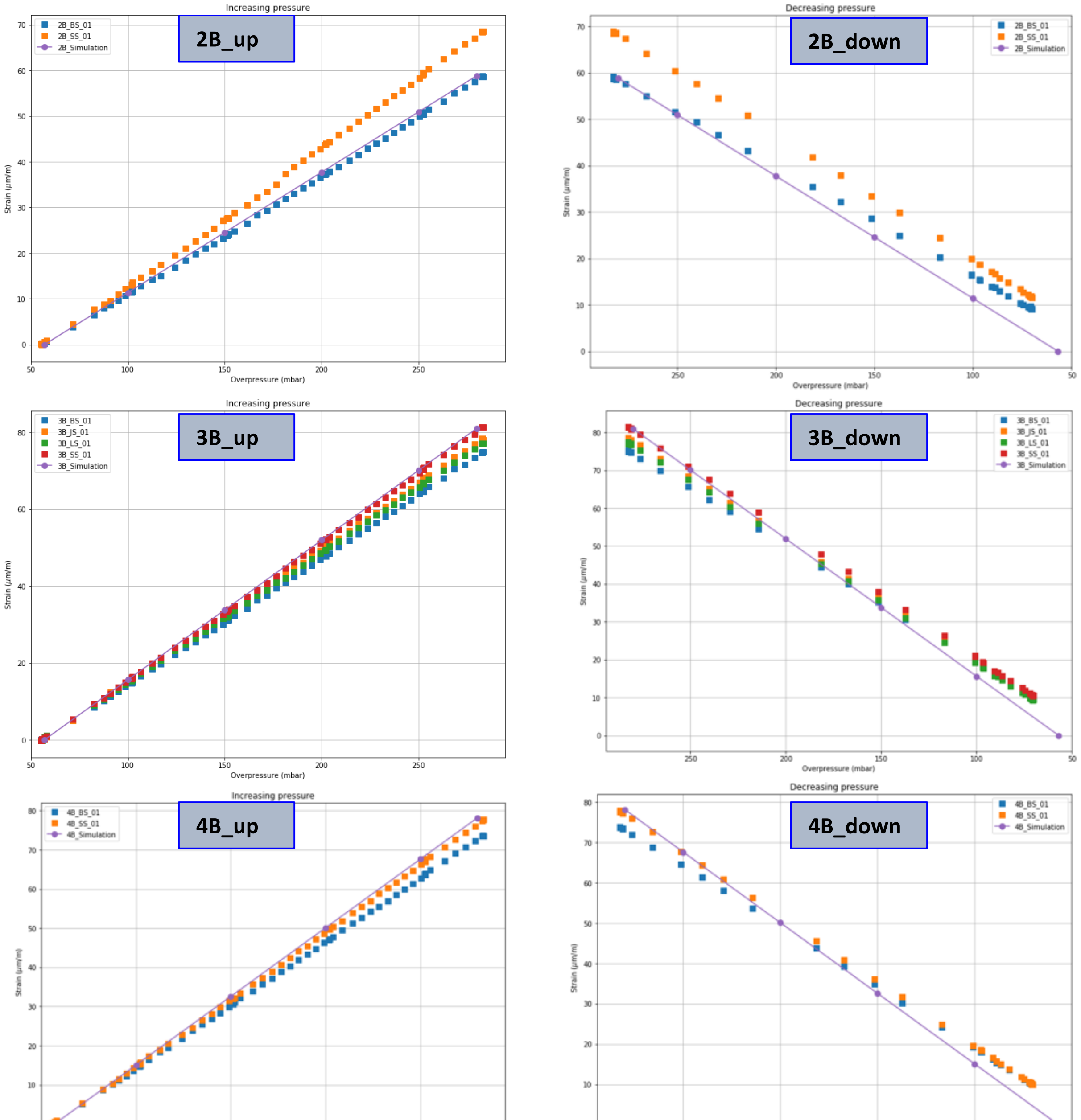



filling [m] vrs. time
44 20T LAr trucks :
O2~ 1 ppm, N2 ~ 0.05ppm
Opt. filling rate :
~ 2 cm/h=2 tons/h
purity ~ 45 µs
Filters
regeneration
purity ~ 30-40 µs
8
7.5
7
6.5
6
5.5
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
8.7.18 0:00
8.11.18 0:00
8.15.18 0:00
8.19.18 0:00
8.23.18 0:00
8.27.18 0:00
8.31.18 0:00
9.4.18 0:00
9.8.18 0:00
9.12.18 0:00
9.16.18 0:00

Cryostat concept final qualification

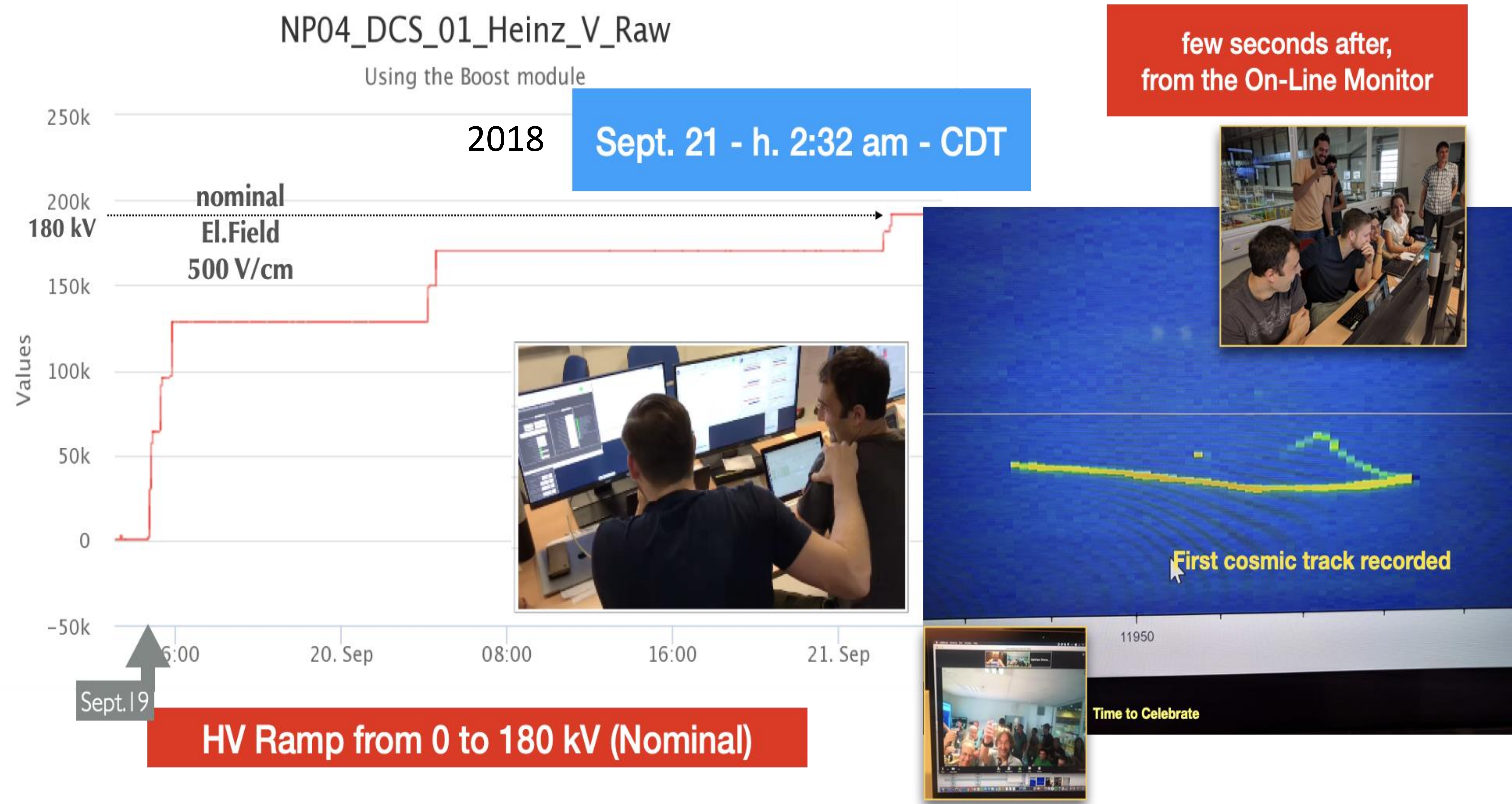


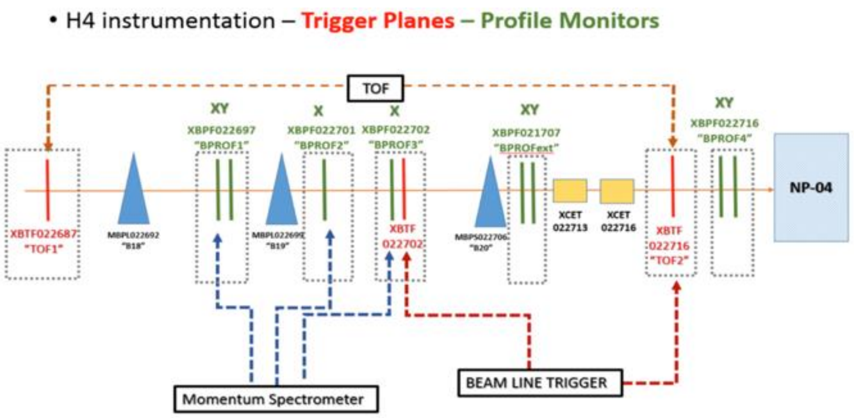
Strains – Side walls – 2nd/3rd/4th belts



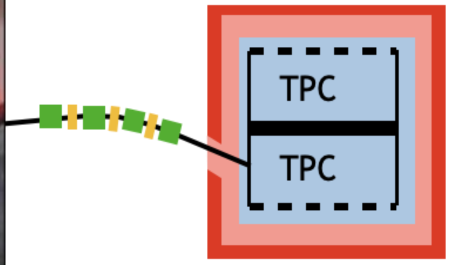
Linear and symmetric behavior of the strain gauges

Very good agreement with the FEA model


NP04_DCS_01_Heinz_V_Raw
Using the Boost module
2018
Sept. 21 - h. 2:32 am - CDT
few seconds after,
from the On-Line Monitor
250k
200k
180 kV
150k
100k
50k
0
-50k
Values
nominal
El.Field
500 V/cm
6:00
20. Sep
08:00
16:00
21. Sep
Sept.19
HV Ramp from 0 to 180 kV (Nominal)
First cosmic track recorded
11950
Time to Celebrate



New beam line, new beam monitors



H4 Beamline & extension

400 GeV/c p primary beam from SPS

➜ 80 GeV/c secondary π^+

➜ **0.5 – 7 GeV/c tertiary Positive Polarity**

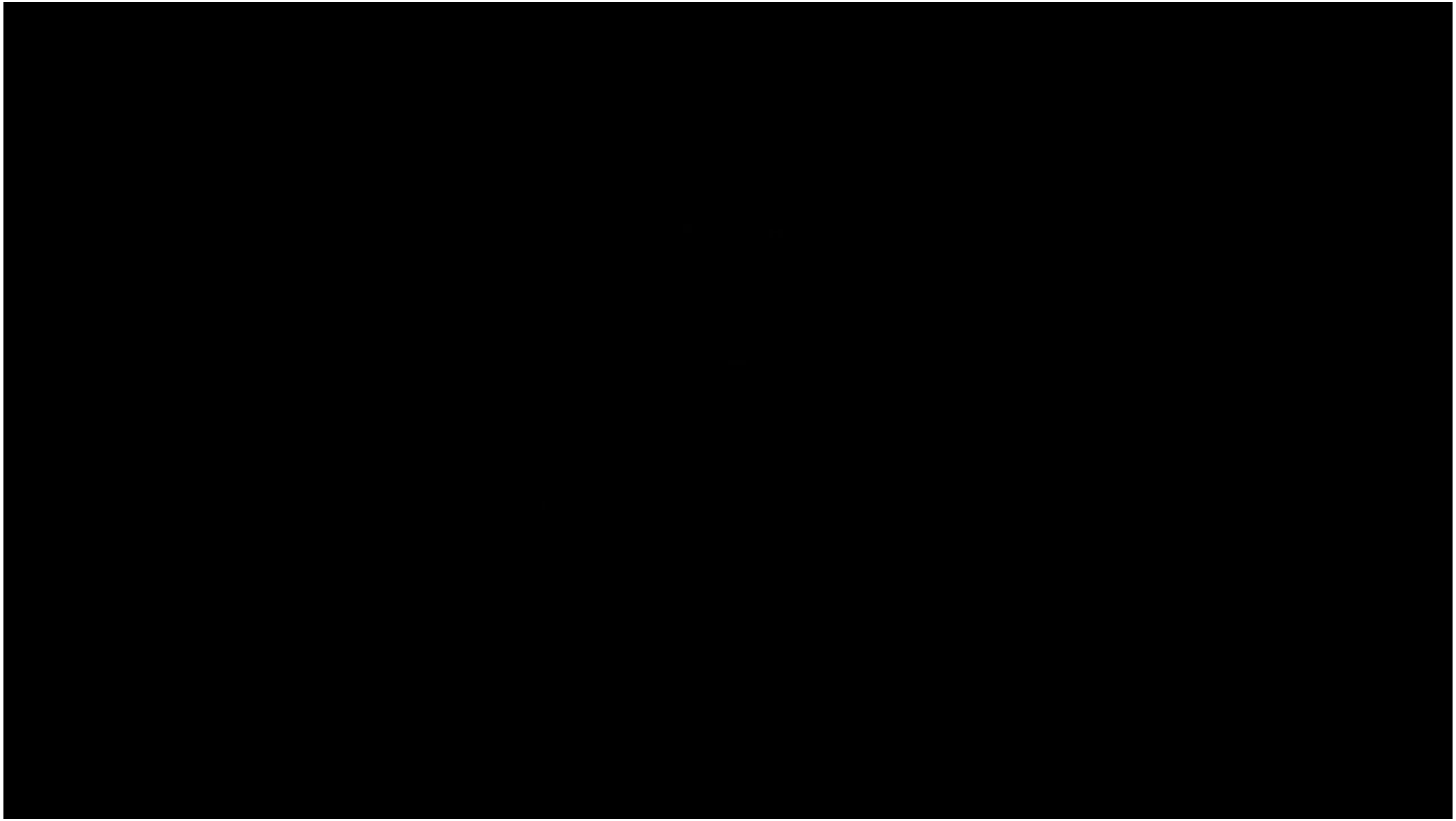
e^+, p, μ^+, π^+, (K^+)

54 days of beam from end August to mid November 2018

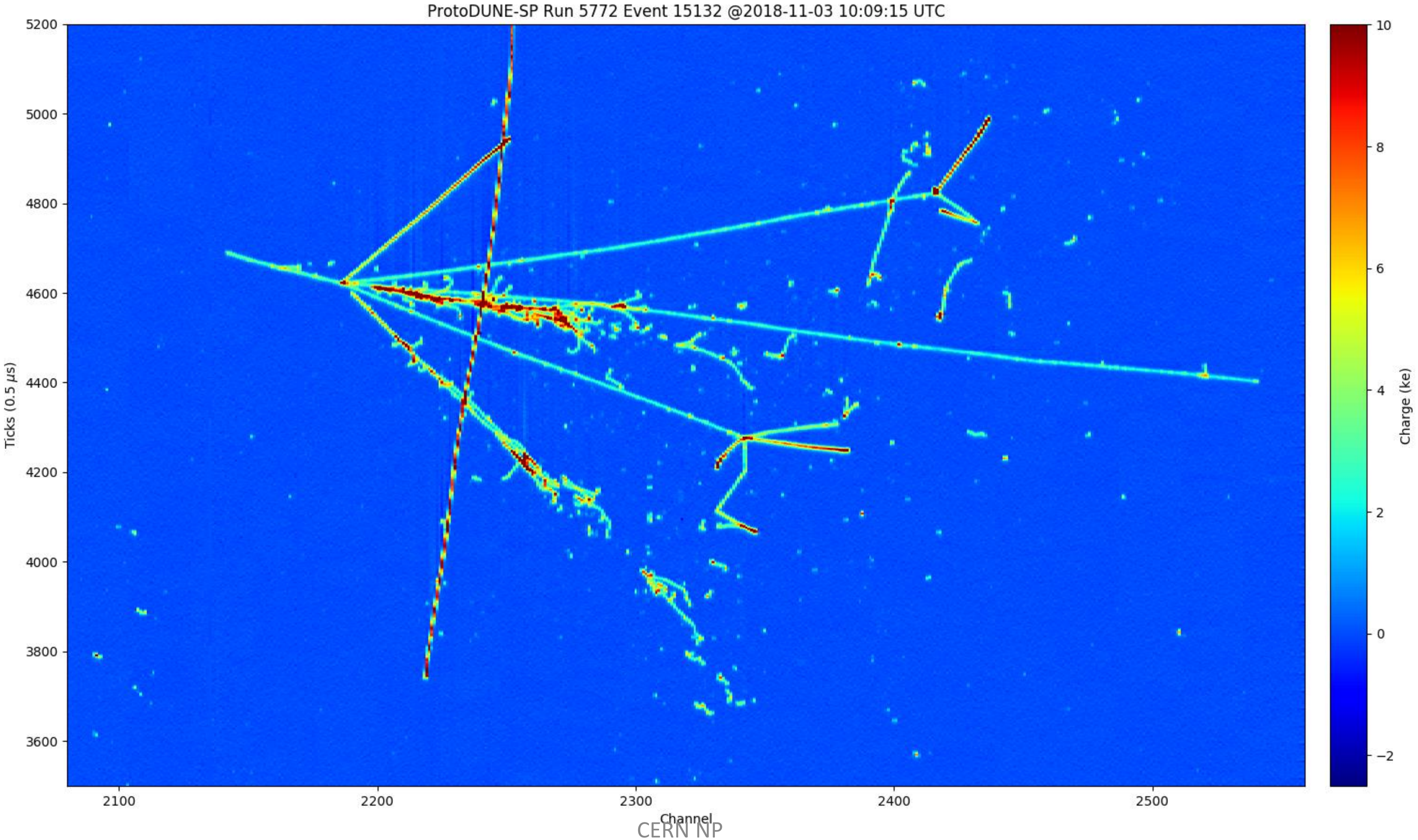
Momentum (GeV/c)	Total Triggers Recorded (K)	Total Triggers Expected (K)	Expected Pi trig. (K)	Expected Proton Trig. (K)	Expected Electron Trig. (K)	Expected Kaon Trig. (K)
0.3	269	242	0	0	242	0
0.5	340	299	1.5	1.5	296	0
1	1089	1064	382	420	262	0
2	728	639	333	128	173	5
3	568	519	284	107	113	15
6	702	689	394	70	197	28
7	477	472	299	51	98	24
All momenta	4173	3924	1693.5	777.5	1381	72

real beam event in 3D

Click to start

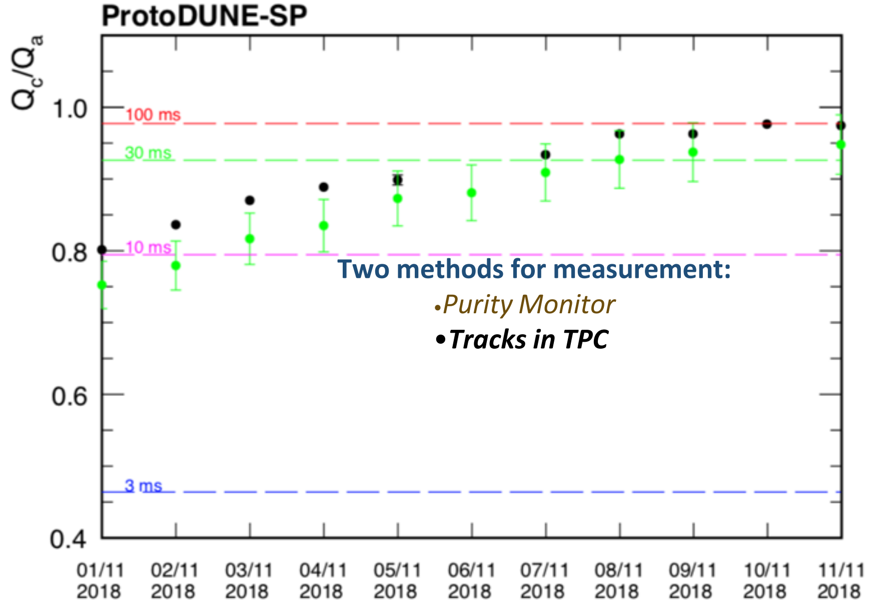


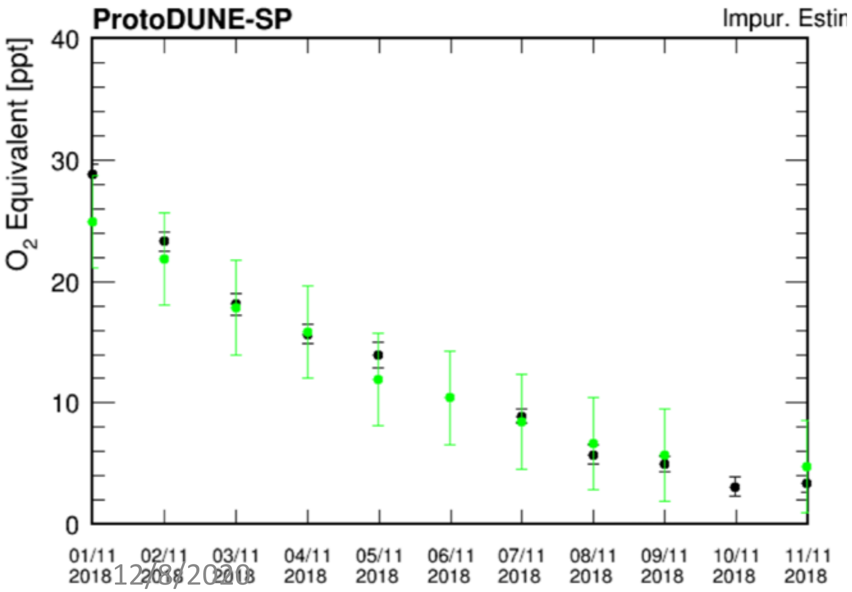
A spectacular collection of events with an extensive variety of nuclear and particle processes



Detector Parameter	Specification for DUNE	Goal for DUNE	ProtoDUNE Performance
Electric Drift Field	> 250 V/cm	500 V/cm	500 V/cm * (tested up to 650 V/cm)
Electron Lifetime *Impurity Concentration*	> 3 ms *(<100 ppt [O_2-equiv])*	10 ms *(<30 ppt [O_2-equiv])*	> ~30 ms in TPC ** *< 10 ppt*
TPC Electronics Noise	< 1000 e ENC	ALARA	550-650 e ENC (raw) 450-560 e ENC (cnr)***
TPC dead channels	< 1%	ALARA	0.2 % (of ~15,360 channels over 1.5 yr operation)
PhotoDetector Light Yield	> 0.5 Ph/MeV (at cathode plane - 3.6 m distance)		1.9 Ph/MeV ++ (at 3.3 m distance)
PhotoDetector Time Resolution	< 1μs	< 100 ns	14 ns ^^

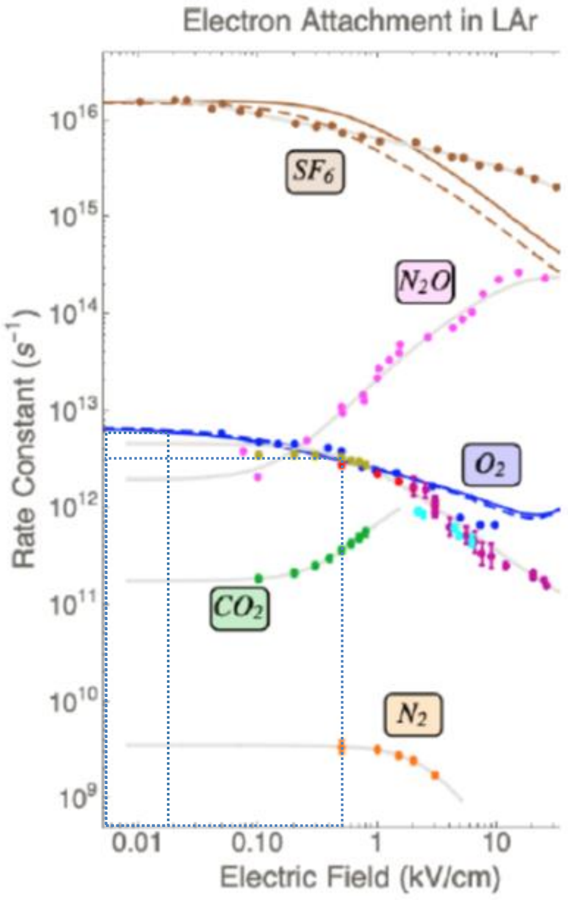
Liquid Argon Purity





A drift electron lifetime in LAr in excess of 20 ms has been achieved and it was sustained for an extended period of data-taking. It reached approximately (89 ± 22) ms for the last day of beam data-taking. This corresponds to a concentration of impurity in the liquid argon of 3.4±0.7 ppt oxygen equivalent. The DUNE Far Detector specification is for the impurity concentration to be less than 100 ppt O_2 equivalent.

$k_A(EF)$



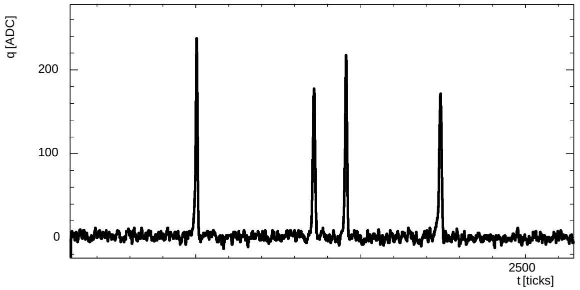
- Developed a new method to measure electron lifetime using CRT and TPC information.
- Impurity concentrations measured by CRT and purity monitor in a good agreement after correcting for different E-fields.

Impurity Concentration

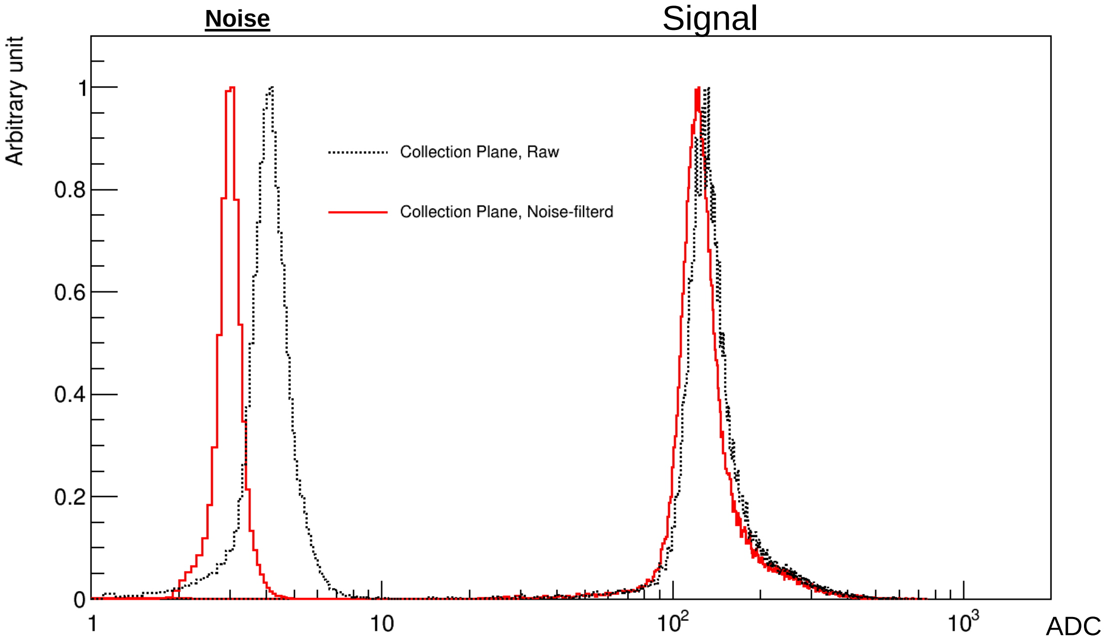
$$[X] = \frac{1}{k_A \tau_e} \qquad \tau_e = -\frac{t_d}{\ln\frac{Q_c}{Q_a}}$$

Signal-to-Noise

Typical waveform from a TPC wire-CE channel



$g = 130 \frac{e}{\mathrm{ADC}}$



Noise:σ of *baseline fluctuation* in corresponding channel waveform

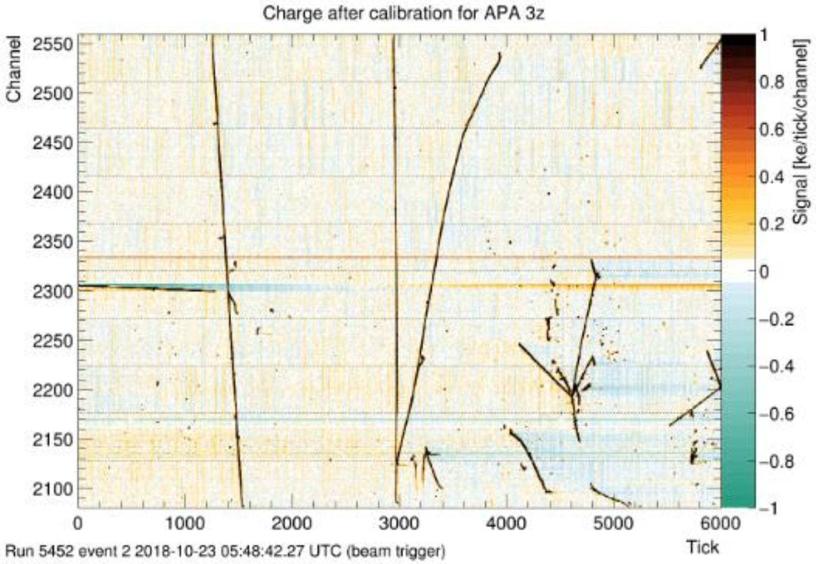
Signal: detected Charge (*hit Peak-amplitude)* in individual channel waveform from mip tracks (corrected by angle of incidence)

- **Very low noise (550 ENC - raw data)**
  - *Coherent noise can be removed*
- **Excellent signal-to-noise ratio**
- **Robust reconstruction**

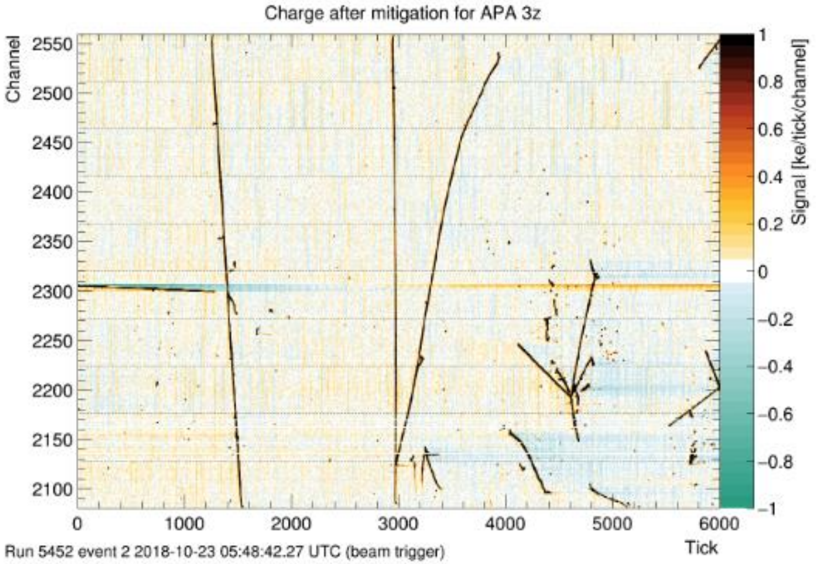
Plane	Peak signal-to-noise ratio			
	Raw Data		After Noise Filtering	
	MPV	Average	MPV	Average
Collection	30.9	38.3	40.3	48.7
U	12.1	15.6	15.1	18.2
V	14.9	18.7	18.6	21.2

stages of data processing and noise mitigat

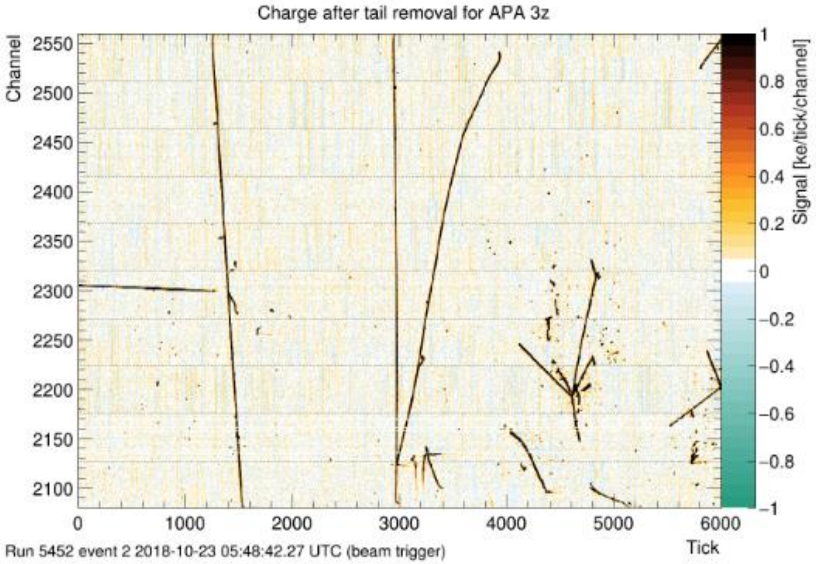
RAW DATA



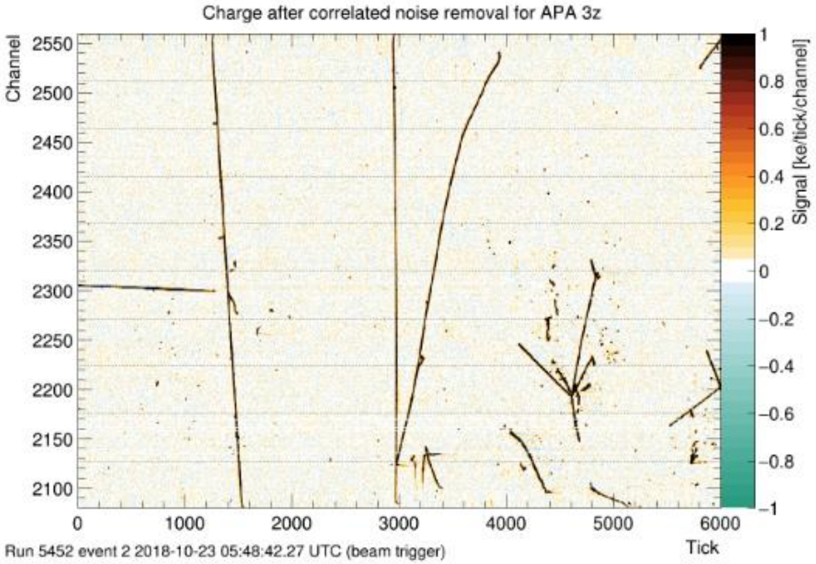
(a) After pedestal subtraction and calibration.



(b) After mitigation (Sticky code)



(c) After tail removal.



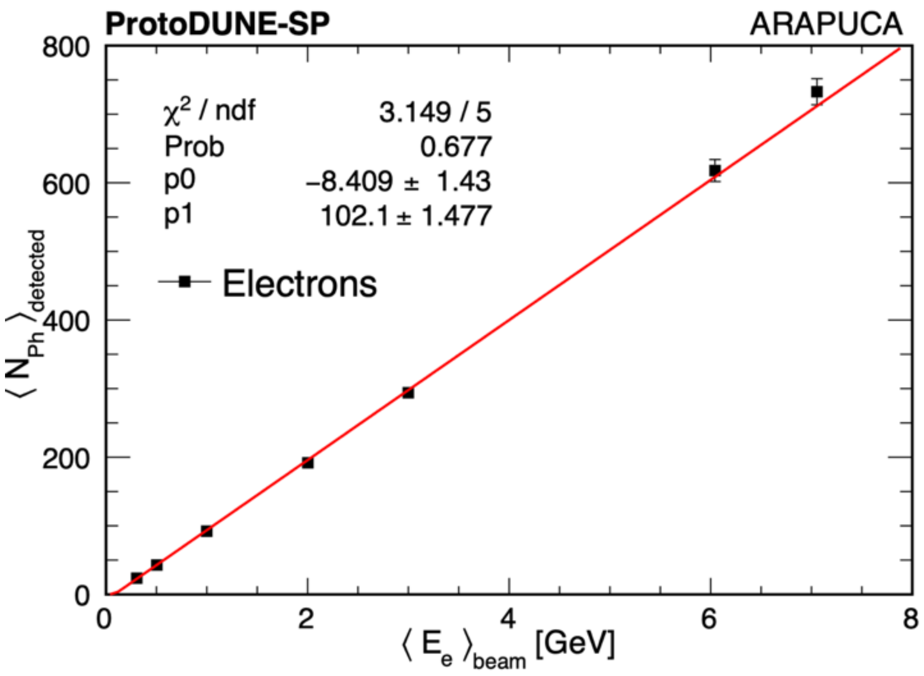
(d) After correlated noise removal.

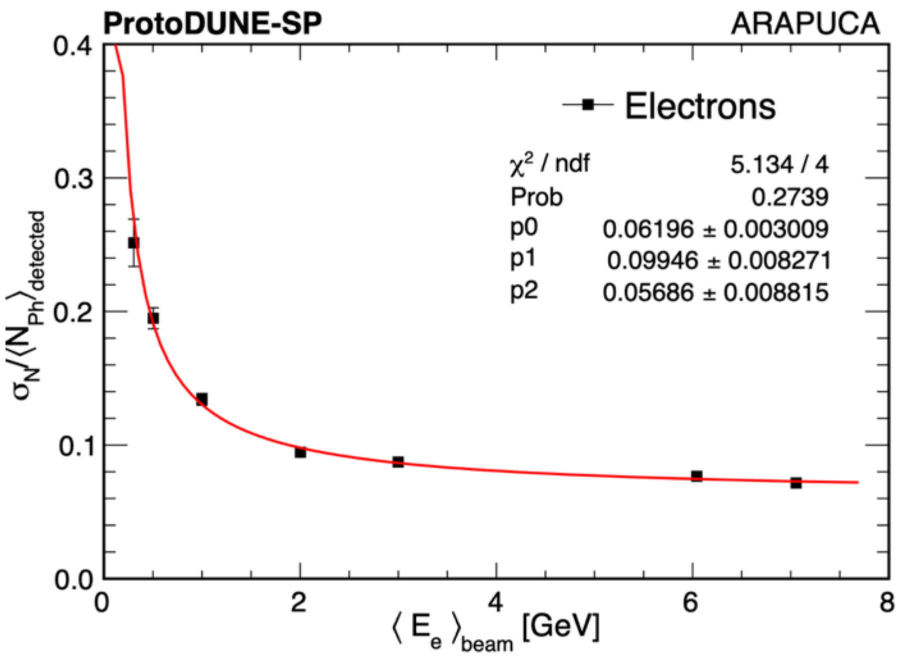
Off-line Reco
DATA

Electron energy measurement with photon detectors

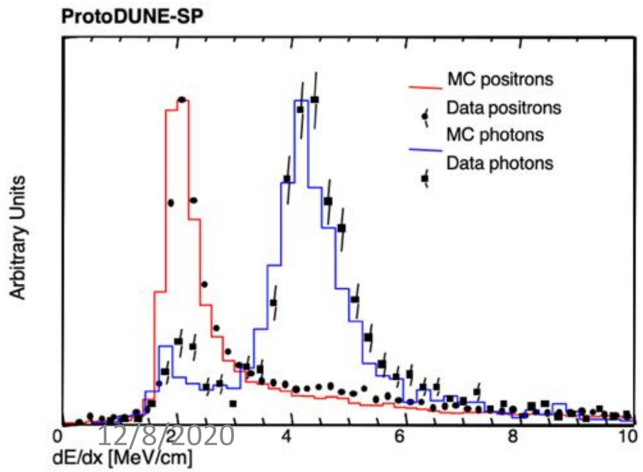
Linearity

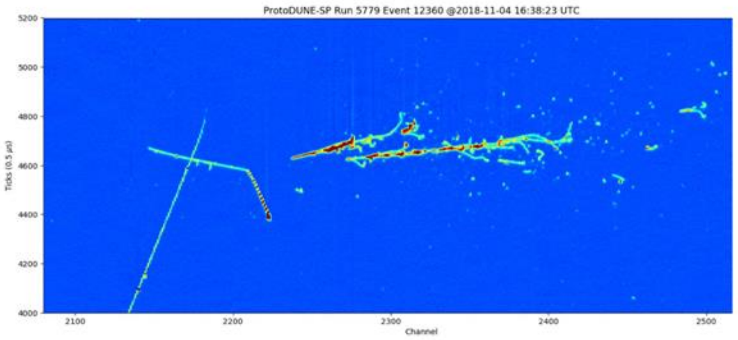
Observed (first approx) over the entire range of energies. The slope gives the light yield $LY = 102Ph/GeV$





Electron/Gamma Separation from dE/dx



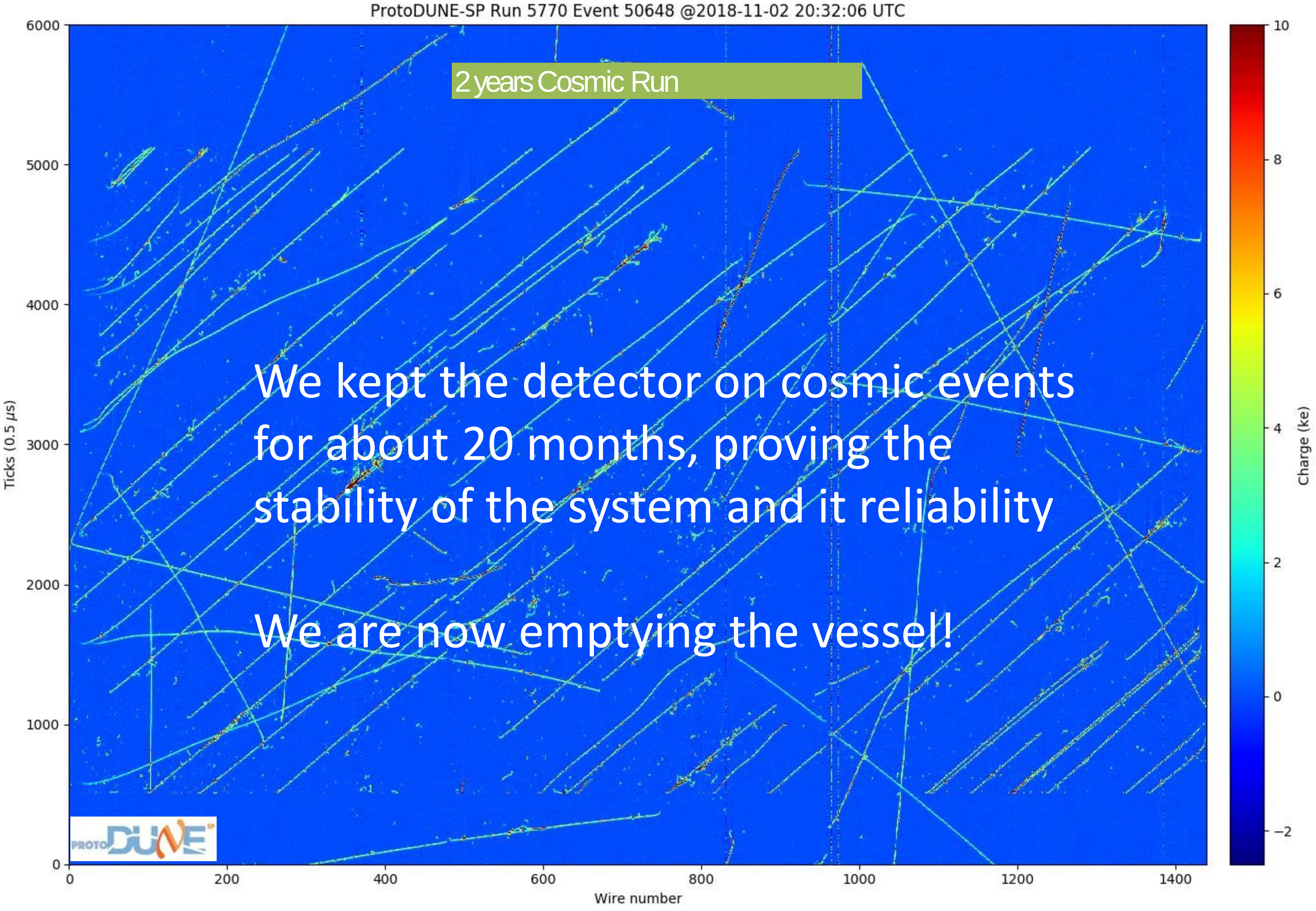


Energy Resolution from light

$$\frac{\sigma_E}{E} = p_0 \oplus \frac{p_1}{\sqrt{E}} \oplus \frac{p_2}{E}$$

- **Constant term:** $p_0 = 6.2\%$ *from beam momentum spread (5.8%) & fluctuations in the energy loss in the upstream materials (2%)*

Muon bundle
in a cosmic ray
atmospheric
Shower



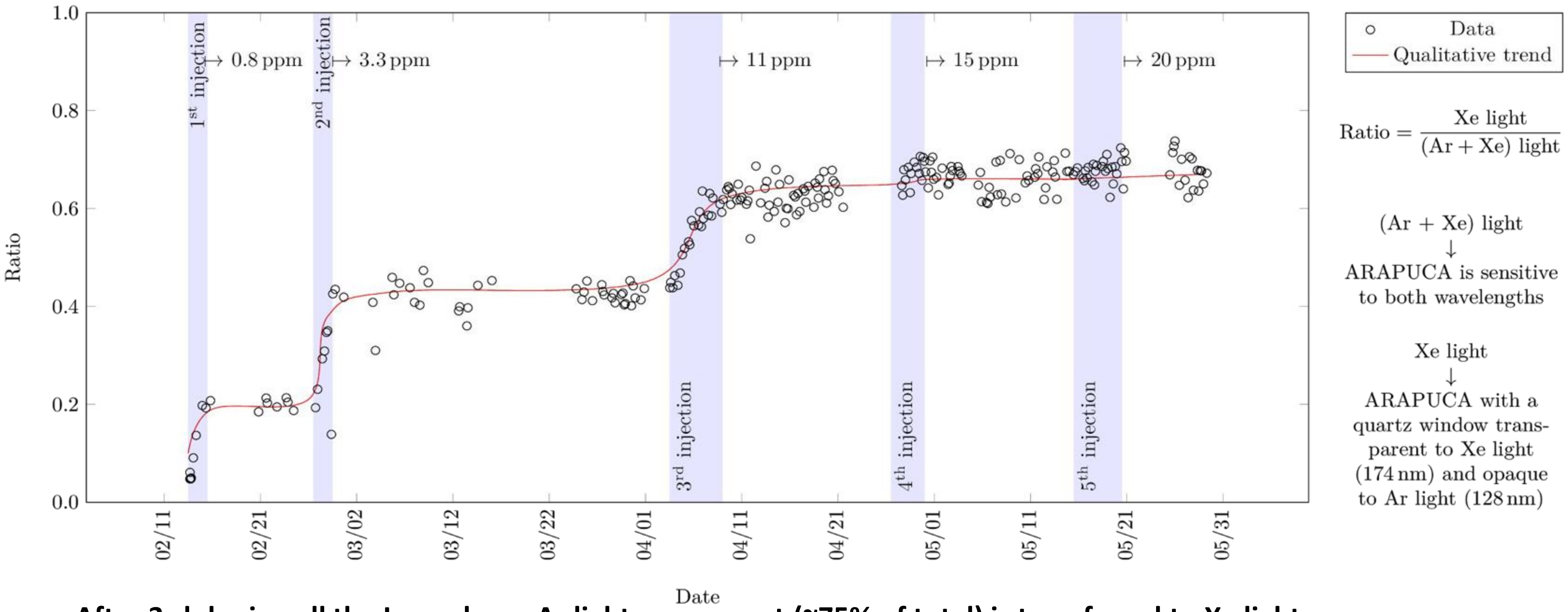
2 years Cosmic Run

We kept the detector on cosmic events for about 20 months, proving the stability of the system and it reliability

We are now emptying the vessel!

A cosmic muon bundle event.

Xe-doping test in ProtoDUNE-SP (Feb-Jul 2020)

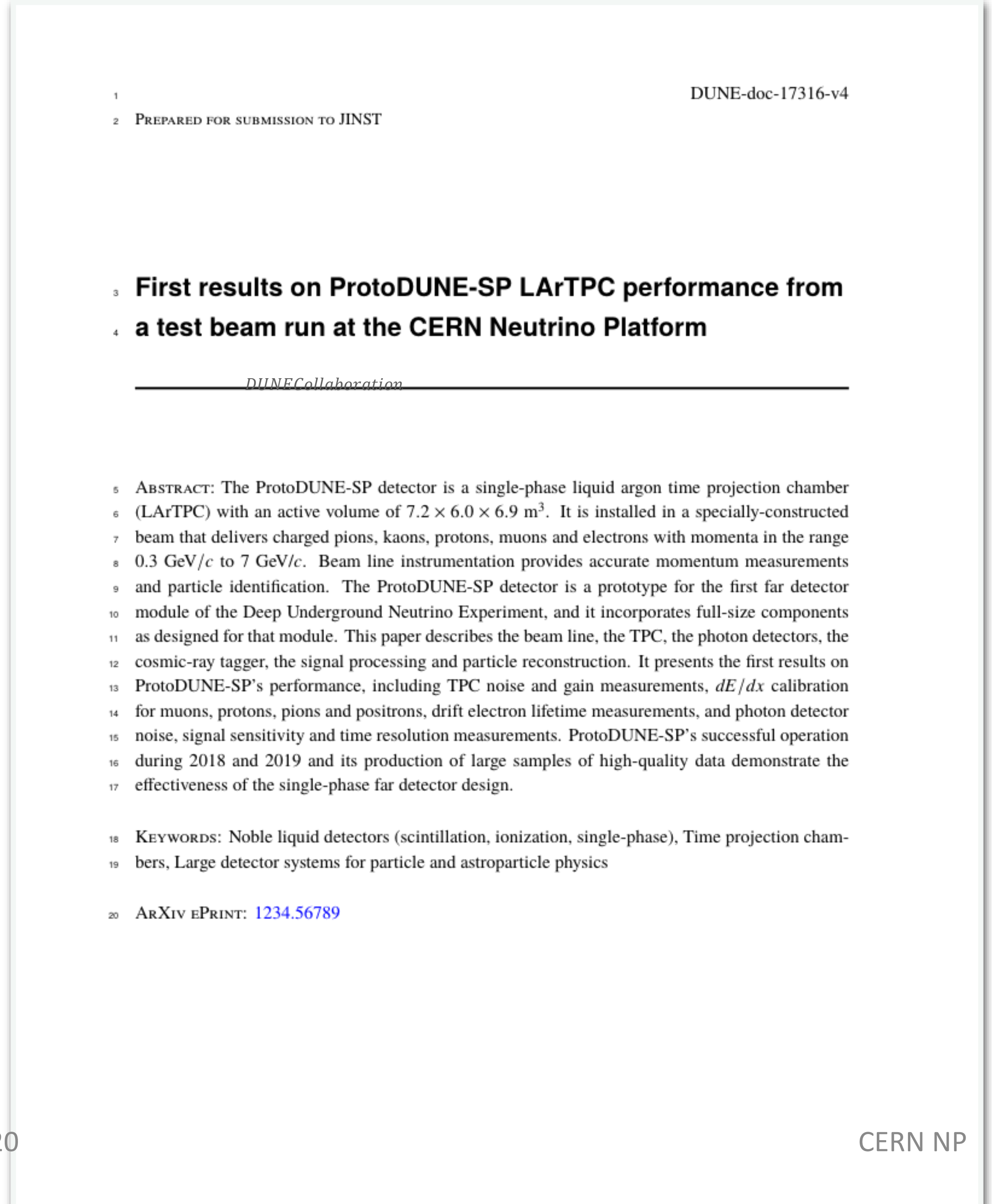


After 3rd doping all the Long-decay Ar light component (~75% of total) is transferred to Xe light.

Light loss due to Quenching from N_2 contamination fully recovered.

This is obtained at a much smaller Xe concentration than expected,

1st protoDUNE-SP Paper ready for publication



DUNE-doc-17316-v4

PREPARED FOR SUBMISSION TO JINST

First results on ProtoDUNE-SP LArTPC performance from a test beam run at the CERN Neutrino Platform

DUNECollaboration

ABSTRACT: The ProtoDUNE-SP detector is a single-phase liquid argon time projection chamber (LArTPC) with an active volume of $7.2 \times 6.0 \times 6.9$ m^3. It is installed in a specially-constructed beam that delivers charged pions, kaons, protons, muons and electrons with momenta in the range 0.3 GeV/c to 7 GeV/c. Beam line instrumentation provides accurate momentum measurements and particle identification. The ProtoDUNE-SP detector is a prototype for the first far detector module of the Deep Underground Neutrino Experiment, and it incorporates full-size components as designed for that module. This paper describes the beam line, the TPC, the photon detectors, the cosmic-ray tagger, the signal processing and particle reconstruction. It presents the first results on ProtoDUNE-SP's performance, including TPC noise and gain measurements, dE/dx calibration for muons, protons, pions and positrons, drift electron lifetime measurements, and photon detector noise, signal sensitivity and time resolution measurements. ProtoDUNE-SP's successful operation during 2018 and 2019 and its production of large samples of high-quality data demonstrate the effectiveness of the single-phase far detector design.

KEYWORDS: Noble liquid detectors (scintillation, ionization, single-phase), Time projection chambers, Large detector systems for particle and astroparticle physics

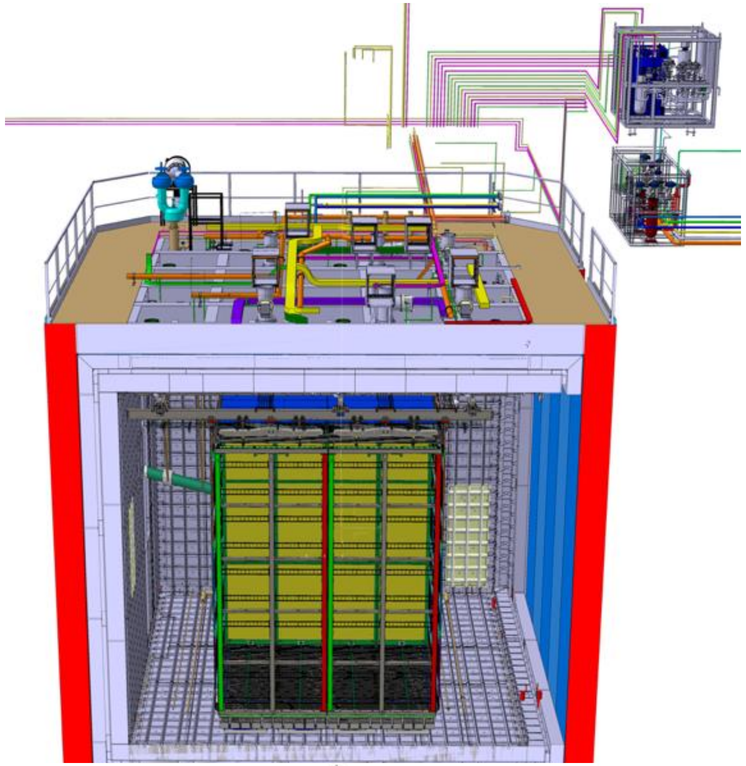
ARXIV EPRINT: 1234.56789

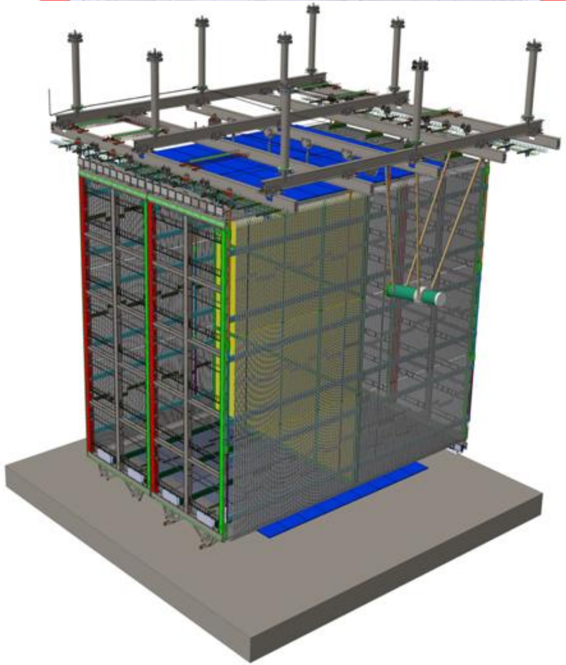
93 pages, 70 figures

- Aug. 16, 2019: Overleaf document created
- Dec. 13, 2019: paper completed and internal review started
- **May 28: Collaboration Review completed**
- **Jul.13: preprint on arXiv**
- **Paper submitted to JINST**
- **981 authors**
- **191 institutions**

ProtoDUNE II Configuration

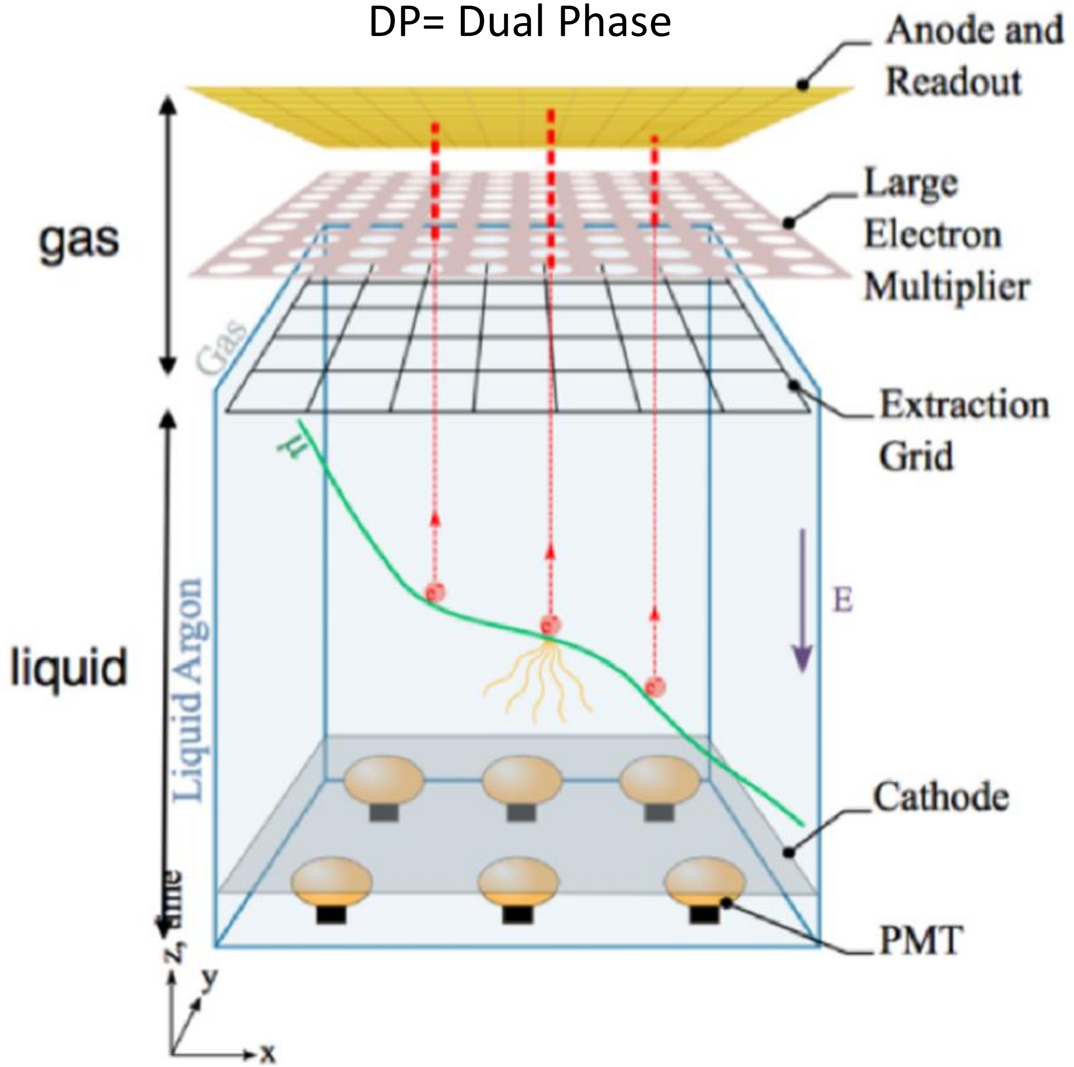
- Maintain the cryostat of ProtoDUNE-I
- Improved cryogenics systems (based on experience from ProtoDUNE-SP-I and ProtoDUNE-DP)
- As much as possible, final DUNE Far Detector components (Module 0)
- DUNE-like distances between Cryostat and Field Cage End Wall
- 4 APAs instead of 6
- Flipped APAs on one-side (electronics on bottom)
- New calibration and cryogenic instrumentation (laser, neutron source, temperature sensors on APAs, etc.)





NP02: 311, protoDUNE DP

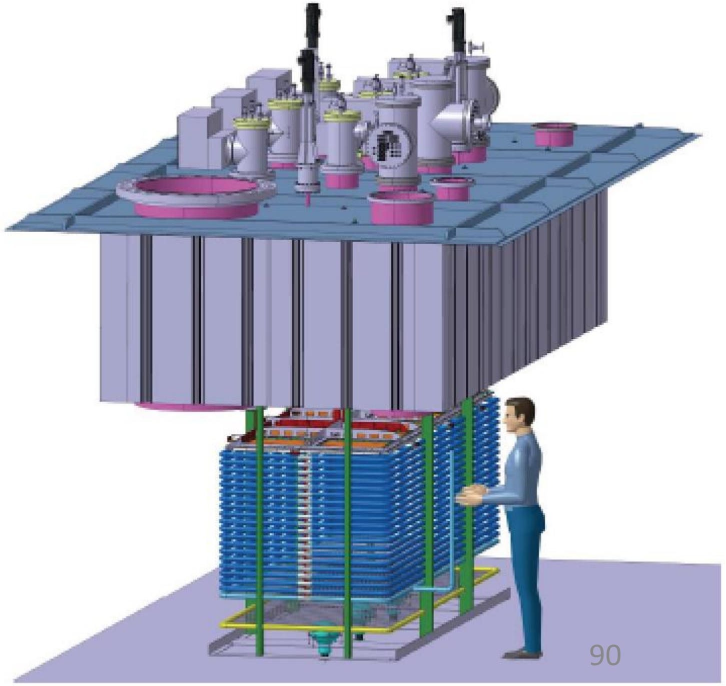
DP= Dual Phase



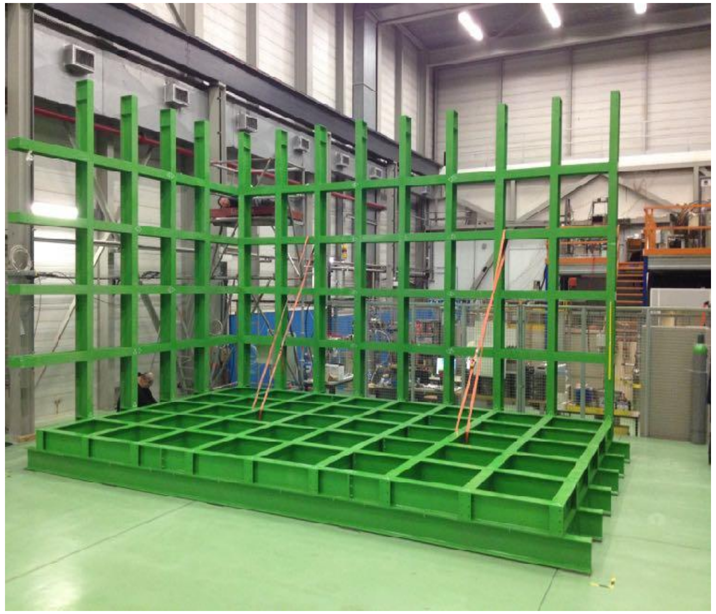
NP02 : 3x1x1 demonstrator

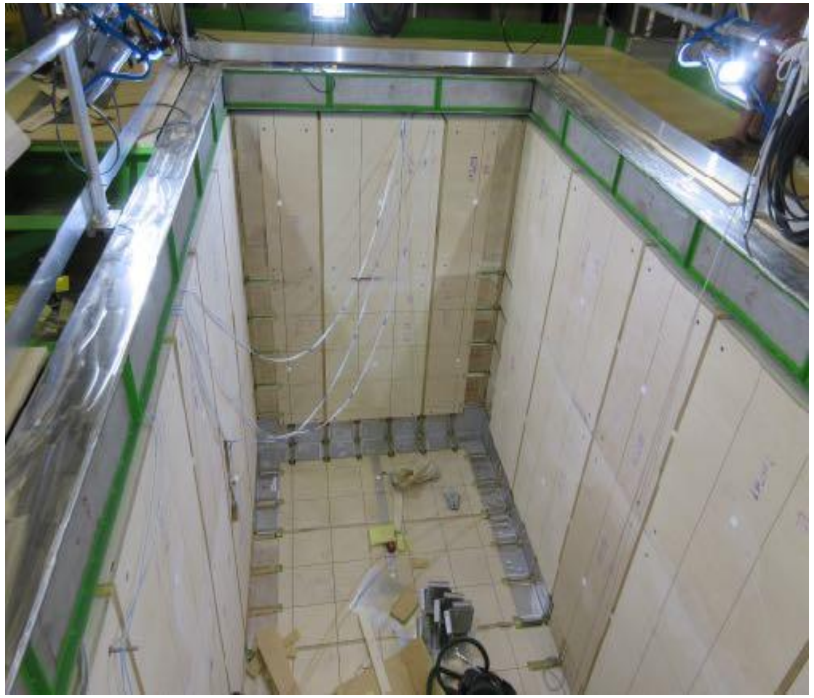
Steps : 3x1x1 demonstrator in b182

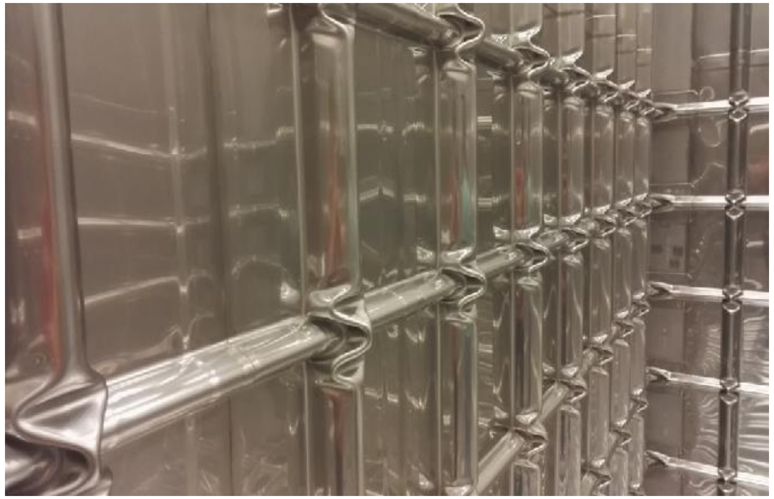
- ✓ Construct a clean room in b182
- ✓ Construct the first LAr membrane cryostat (25 T of Argon)
- ✓ Assemble the 3x1x1 prototype in the clean room
- ✓ Insert it in the cryostat
- ✓ Construct and assemble the LAr cryogenics plant
- ✓ Fill and cool down
- ✓ Commission the detector with cosmic muons

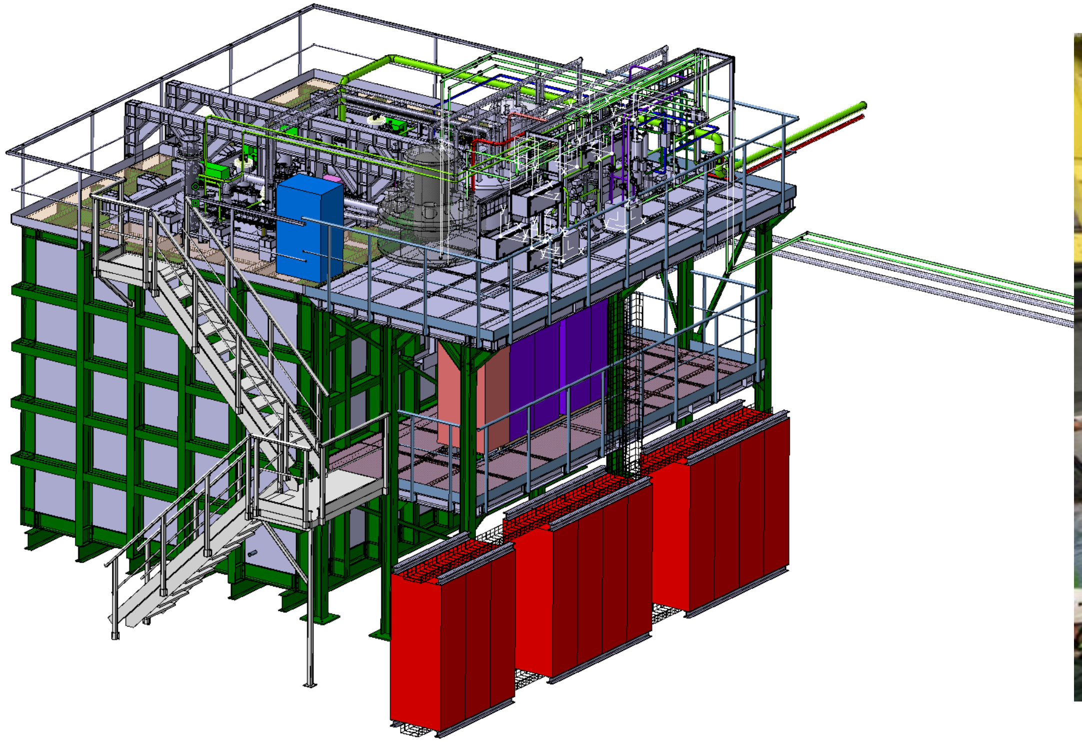


2015-16. 3x1x1 DP first membrane cryostat at CERN in b182

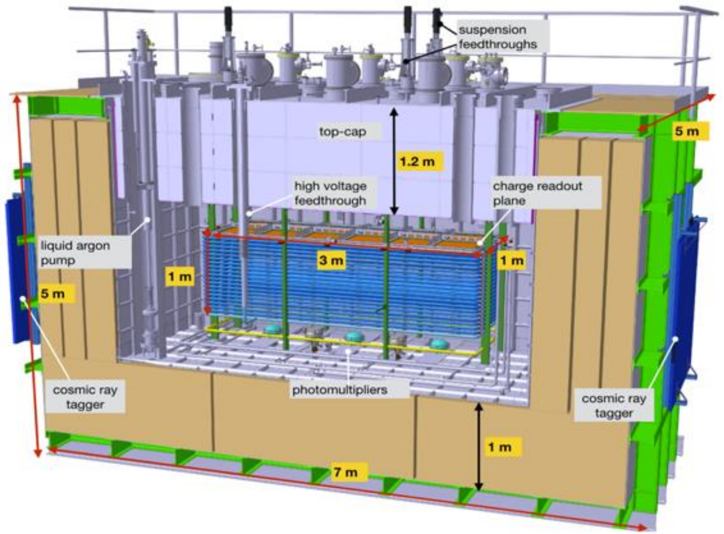


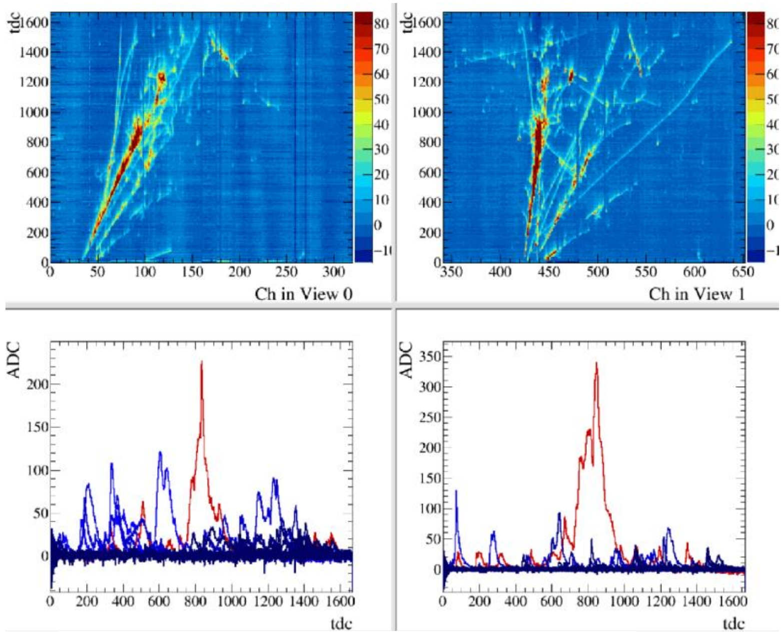






LAr TPC double Phase demonstratorbeing inserted





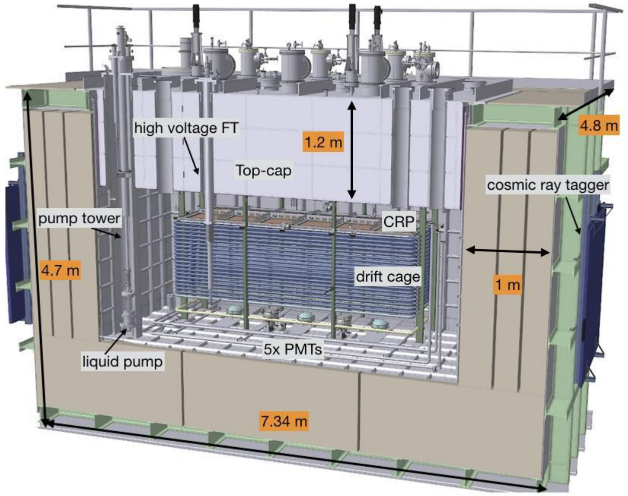
A 4 tonne demonstrator for large-scale dual-phase liquid argon time projection chambers

B. Aimard[q], Ch. Alt[g], J. Asaadi[v], M. Auger[b], V. Aushev[p], D. Autiero[s], M.M. Badoi[j], A. Balaceanu[j], G. Balik[q], L. Balleyguier[s], E. Bechetoille[s], D. Belver[d], A.M. Blebea-Apostu[j], S. Bolognesi[k], S. Bordoni[i,1], N. Bourgeois[e], B. Bourguille[i], J. Bremer[e], G. Brown[v], L. Brunetti[h], D. Caiulo[s], M. Calin[c], E. Calvo[d], M. Campanelli[f], K. Cankocak[m], C. Cantini[g], B. Carlus[s], B.M. Cautisanu[j], M. Chalifour[e], A. Chappuis[q], N. Charitonidis[e], A. Chatterjee[v], A. Chiriacescu[c], P. Chiu[g], S. Conforti[t], P. Cotte[k], P. Crivelli[g], C. Cuesta[d], J. Dawson[a], I. De Bonis[q], C. De La Taille[t], A. Delbart[k], D. Desforge[k], S. Di Luise[i], B.S. Dimitru[j], F. Doizon[s], C. Drancourt[q], D. Duchesneau[q], F. Dulucq[t], J. Dumarchez[r], F. Duval[e], S. Emery[k], A. Ereditato[b], T. Esanu[c], A. Falcone[v], K. Fusshoeller[g], A. Gallego-Ros[d], V. Galymov[s], N. Geffroy[q], A. Gendotti[g], M. Gherghel-Lascu[j], C. Giganti[r], I. Gil-Botella[d], C. Girerd[s], M.C. Gomoiu[j], P. Gorodetzky[a], E. Hamada[n], R. Hanni[b], T. Hasegawa[n], A. Holin[f], S. Horikawa[g], M. Ikeno[n], S. Jiménez[d], A. Jipa[c], M. Karolak[k], Y. Karyotakis[q], S. Kasai[o], K. Kasami[n], T. Kishishita[n], I. Kreslo[b], D. Kryn[a], C. Lastoria[d], I. Lazanu[c], G. Lehmann-Miotto[e], N. Lira[v], K. Loo[m], D. Lorca[b], P. Lutz[b], T. Lux[i], J. Maalampi[m], G. Maire[e], M. Maki[n], L. Manenti[f], R.M. Margineanu[j], J. Marteau[s], G. Martin-Chassard[t], H. Mathez[s], E. Mazzucato[k], G. Misitano[m], B. Mitrica[j], D. Mladenov[e], L. Molina Bueno[g], C. Moreno Martínez[i], J.P. Mols[k], T.S. Mosu[j], W. Mu[g], A. Munteanu[j], S. Murphy[g], K. Nakayoshi[n], S. Narita[l], D. Navas-Nicolás[d], K. Negishi[l], M. Nessi[e], M. Niculescu-Oglinzanu[j], L. Nita[c], F. Noto[e], A. Noury[a], Y. Onishchuk[p], C. Palomares[d], M. Parvu[c], T. Patzak[a], Y. Pénichot[k], E. Pennacchio[s], L. Periale[g], H. Pessard[q], F. Pietropaolo[e], Y. Piret[k], B. Popov[r], D. Pugnere[s], B. Radics[g], D. Redondo[d], C. Regenfus[g], A. Remoto[q], F. Resnati[e], Y.A. Rigaut[g], C. Ristea[c], A. Rubbia[g], A. Saftoiu[j], K. Sakashita[n], F. Sanchez[i], C. Santos[a], A. Scarpelli[a], C. Schloesser[g], L. Scotto Lavina[r], K. Sendai[n], F. Sergiampietri[e], S. Shahsavarani[v], M. Shoji[n], J. Sinclair[b], J. Soto-Oton[d], D.L. Stanca[j], D. Stefan[u], P. Stroescu[j], R. Sulej[u], M. Tanaka[n], V. Toboaru[j], A. Tonazzo[a], W. Tromeur[s], W.H. Trzaska[m], T. Uchida[n], F. Vannucci[a], G. Vasseur[k], A. Verdugo[d], T. Viant[g], S. Vihonen[m], S. Vilalte[q], M. Weber[b], S. Wu[g], J. Yu[v], L. Zambelli[q], M. Zito[k]

[a] *AstroParticule et Cosmologie (APC), Université Paris Diderot, CNRS/IN2P3, CEA/Irfu, Observatoire de Paris, Sorbonne Paris Cité, Paris, France*
[b] *University of Bern, Albert Einstein Center for Fundamental Physics, Laboratory for High Energy Physics (LHEP), Bern, Switzerland*
[c] *University of Bucharest, Faculty of Physics, Bucharest, Romania*
[d] *Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas (CIEMAT), Madrid, Spain*
[e] *CERN, Geneva, Switzerland*
[f] *University College London, Dept. of Physics and Astronomy, London, United Kingdom*
[g] *ETH Zurich, Institute for Particle Physics, Zurich, Switzerland*
[h] *Fermilab, Batavia, IL, USA*
[i] *Institut de Fisica d'Altes Energies (IFAE), Bellaterra (Barcelona), Spain*
[j] *Horia Hulubei National Institute of R&D for Physics and Nuclear Engineering - IFIN-HH, Magurele, Romania*
[k] *IRFU, CEA Saclay, Gif-sur-Yvette, France*

arXiv:1806.03317v2 [physics.ins-det] 12 Oct 2018

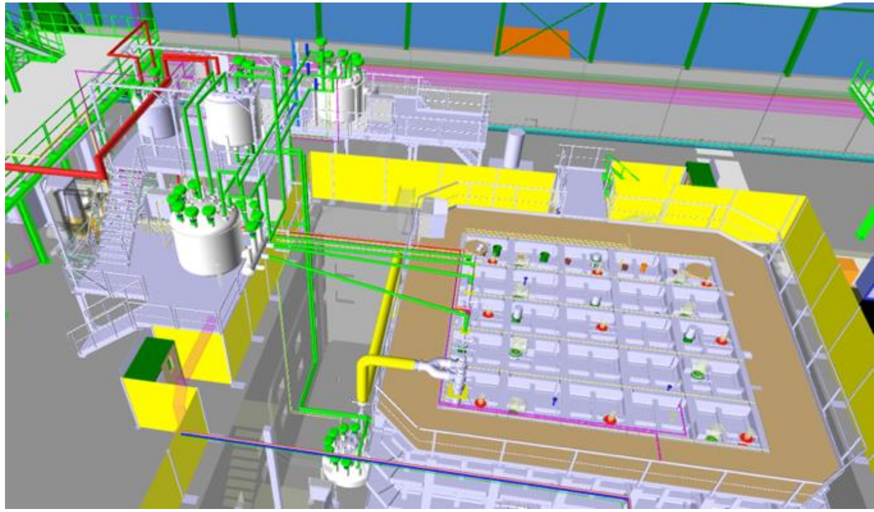
3x1x1 detector operation June-November 2017



- **First prototype of membrane cryostats**
- **Successful in proving the dual-phase concept for a LArTPC at the 3m² readout scale.**
- Detector working point limited by technical issues with **CRP extraction grid HV limited to 5 kV**
- LEM design also showed limitations, **most of the run at ΔV = 2.8 kV (effective gain ~3), max ΔV reached 3.1 kV**
- **CRP design already different for ProtoDUNE-DP, lessons learned on HV connections**
- Very **useful experience for FE electronics and DAQ operation** → good S/N despite low detector gain

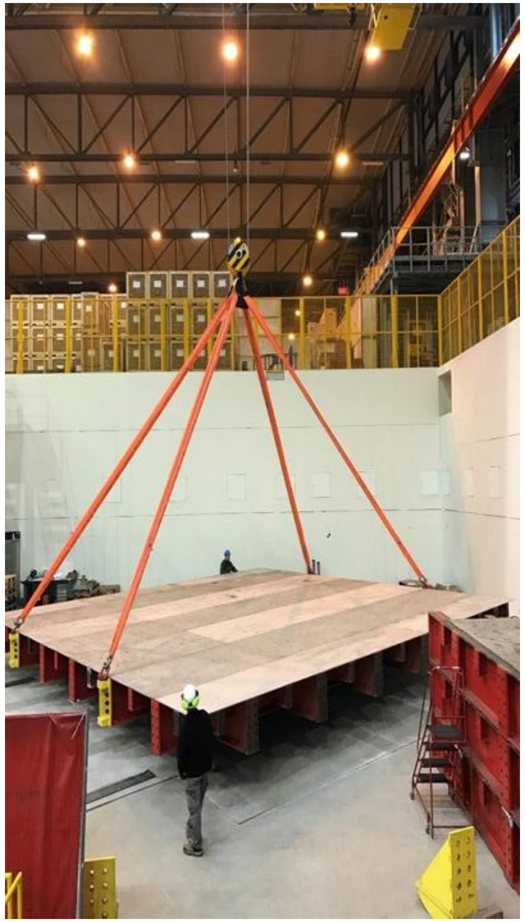
- **62 pages paper** on 3x1x1 published on JINST: https://arxiv.org/abs/1806.03317

NP02 : protoDUNE DP



Steps : Double Phase large prototype in EHN1

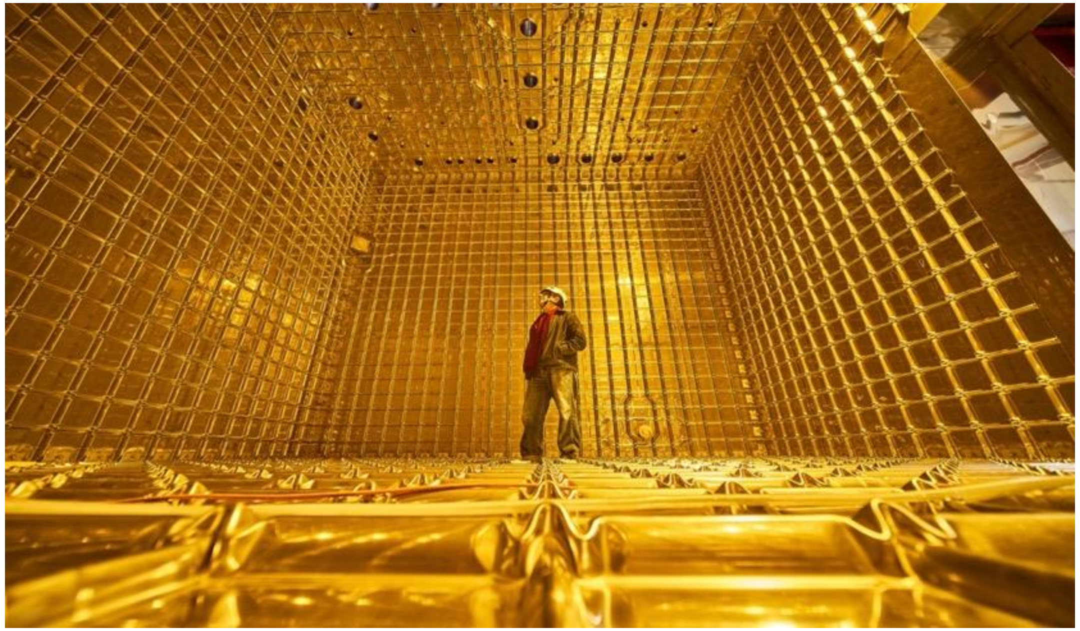
- ✓ Construct the LAr membrane cryostat (760 T of Argon)
- ✓ Construct a clean room in front of the cryostat
- ✓ Assemble the active readout components (CRP) in the ICARUS (b185) cleanroom (CEA, Lyon, LAPP, CERN)
- ✓ Construct and operate a cold box for testing all CRPs in b182
- ✓ Assemble the cathode (EHN1) and the field cage (311 clean room)
- ✓ Bring all components to the EHN1 clean room
- ✓ Assemble and test the field cage
- ✓ Install 4 CRPs
- ✓ Install the bottom PMTs (prepared in Spain)
- ✓ Install the cathode plane
- ✓ Install the LAr cryogenics
- ✓ Clean the inside of the cryostat and detector, close the cryostat door (TCO)
- ✓ Cooldown and fill with LAr
- ✓ Commission and debug the detector

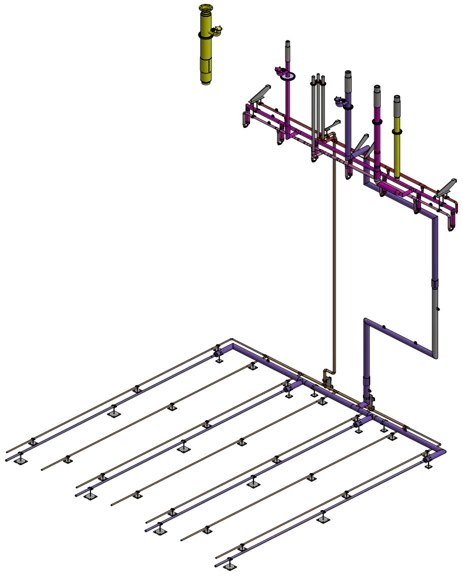


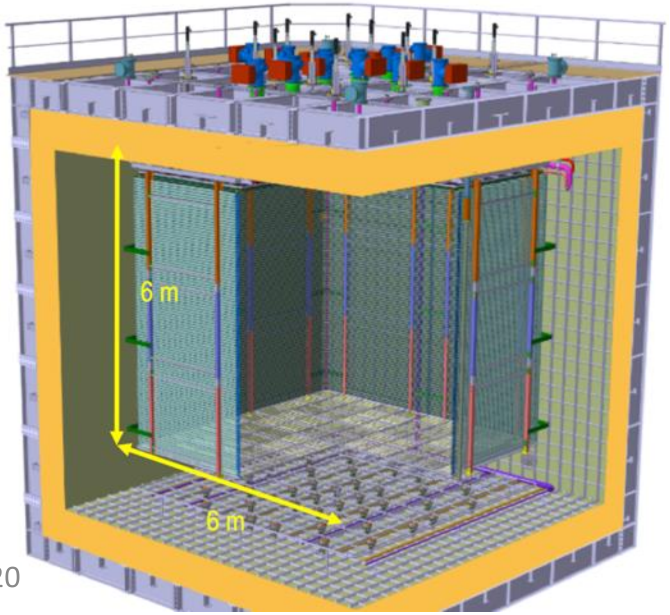
NP02 cryostat January 2017

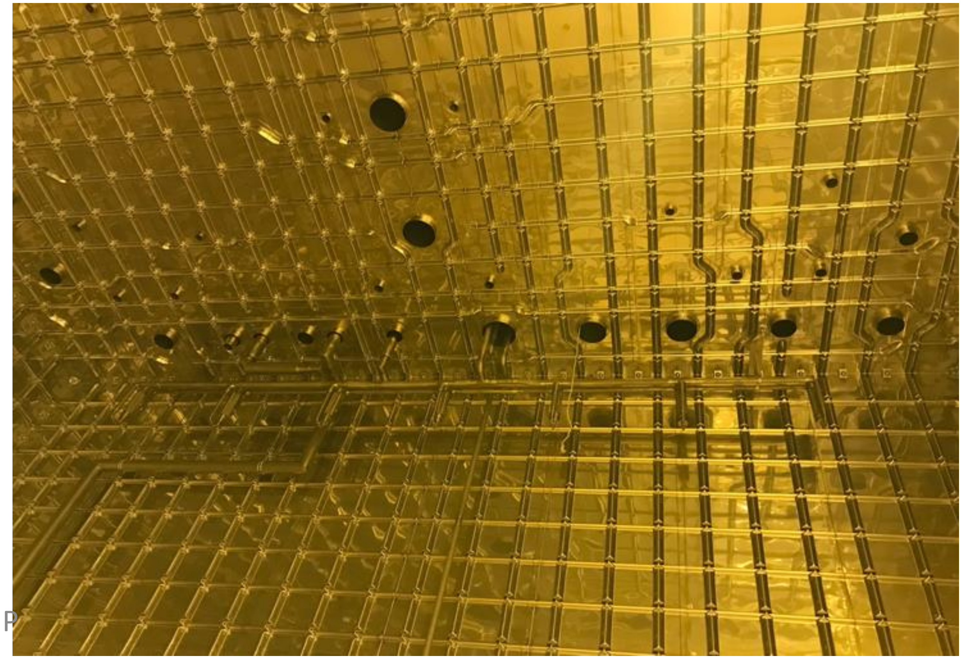
NP02 warm cryostat ready mid March 2017

Cryostat completed, Internal cryogenics completed



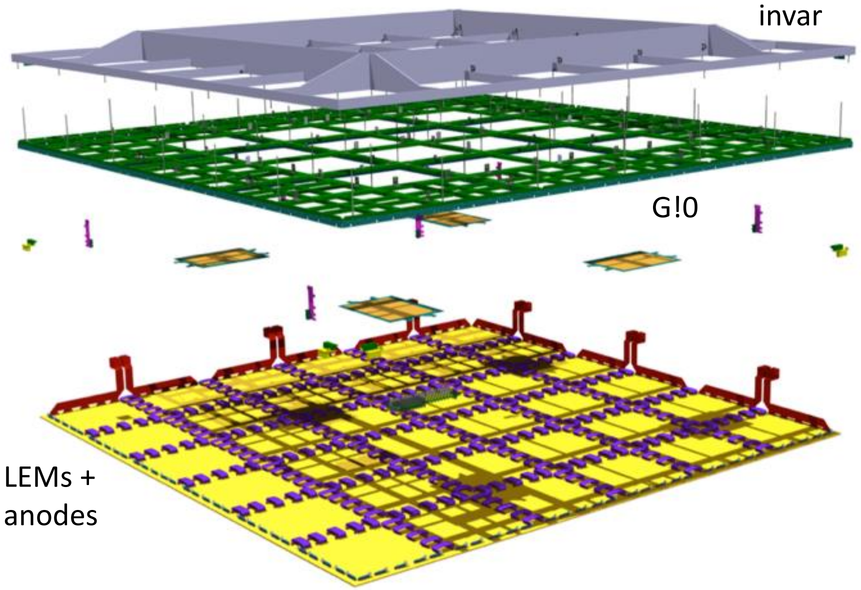


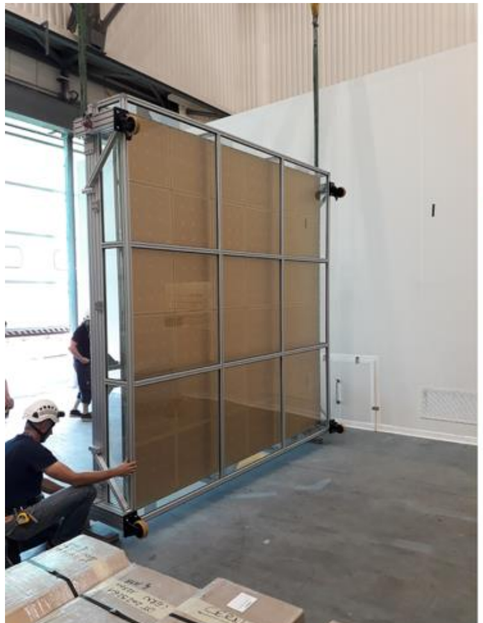




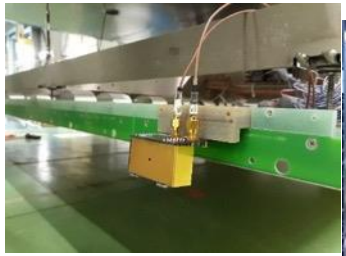
The Charge Readout Plane (CRP) assembled in the ICARUS cleanroom

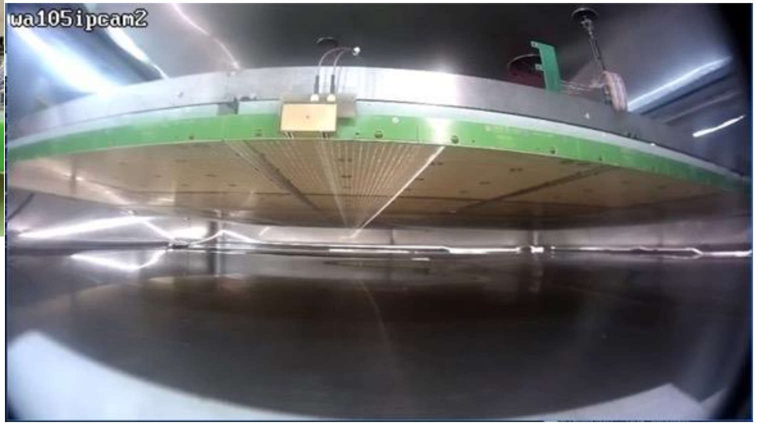
At this stage one of the major collaborating institution left, because of an internal problem. CERN had to step in various CRP procurements and various other detector items. DRC was involved!

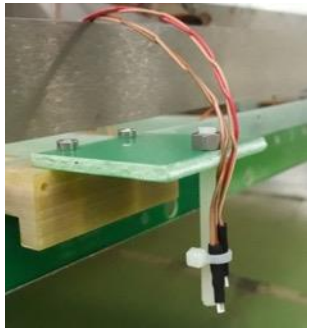




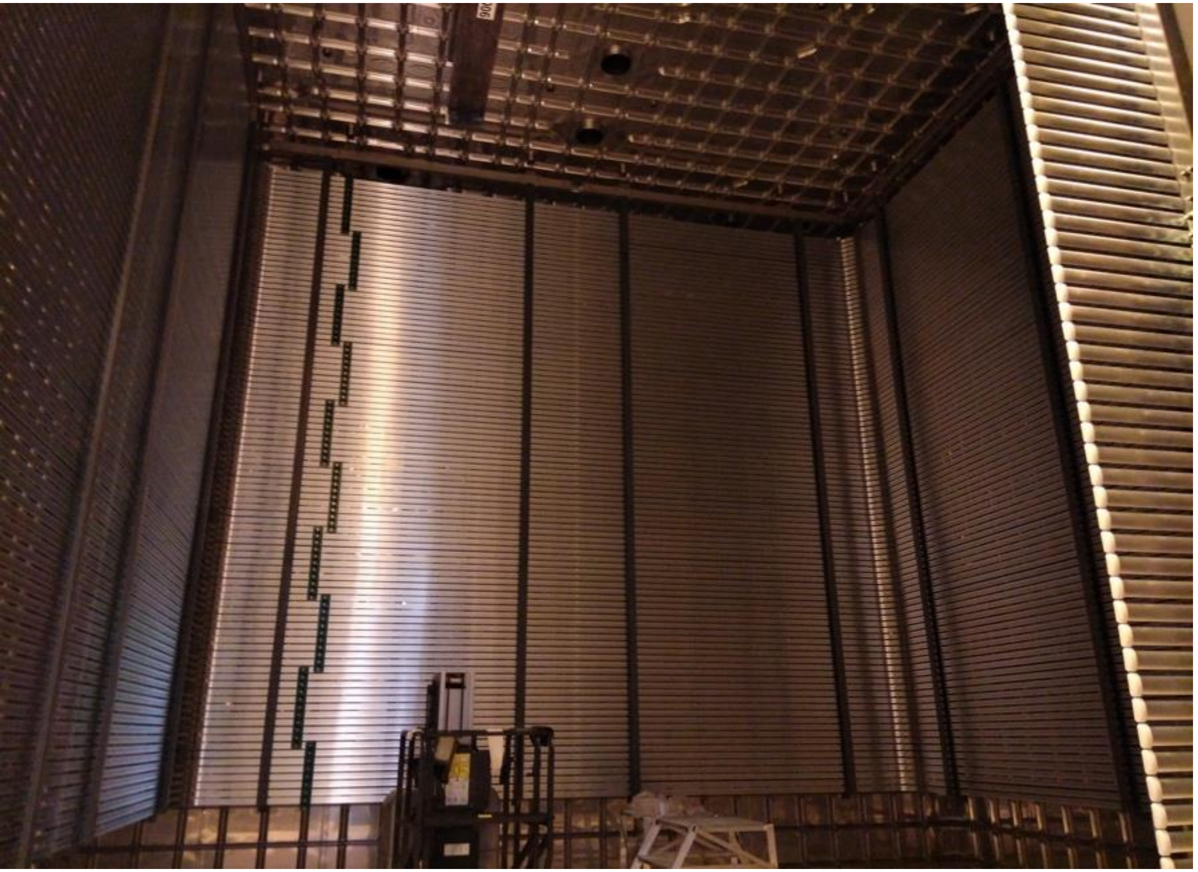
CRP#1 cold tested in a dedicated new cold box







NP02 Field cage and HV system



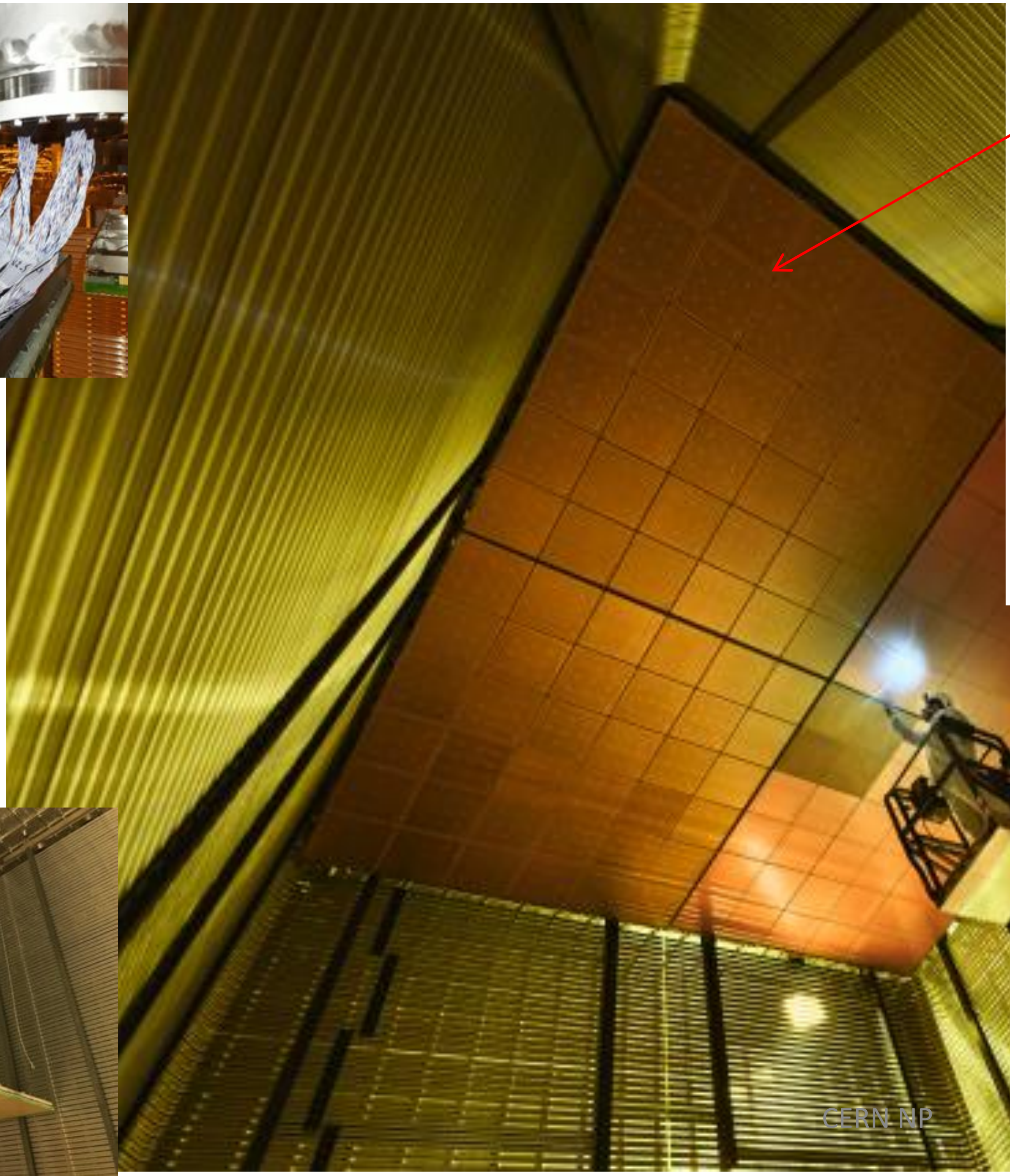
FC installed and fixed in final position:

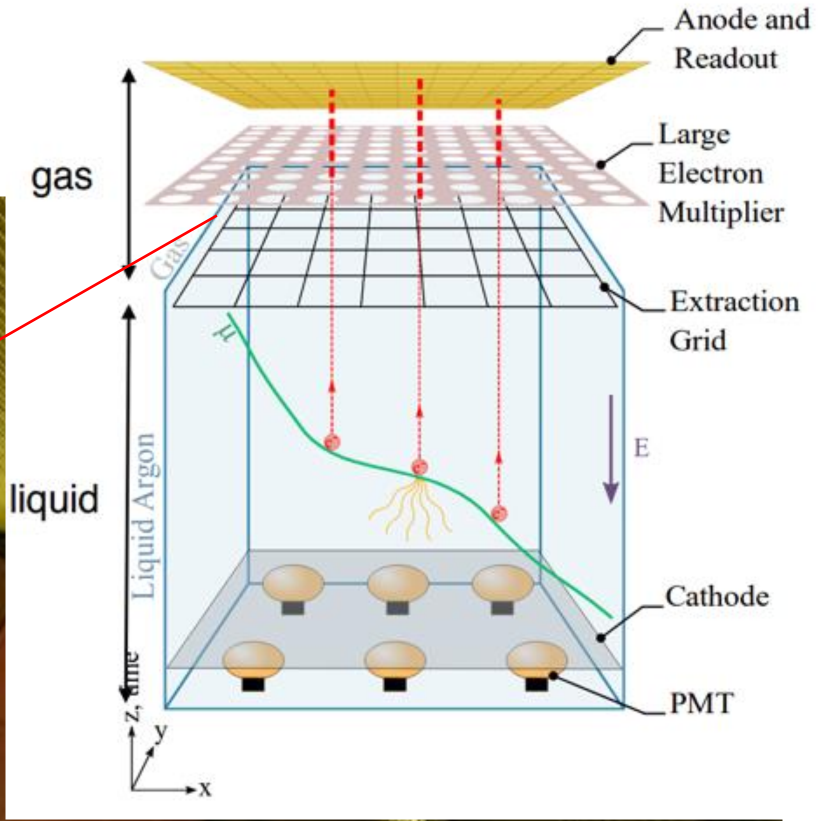
- Two sub-module removed to allow insertion and installation of CRP’s and Cathode/Ground grids.

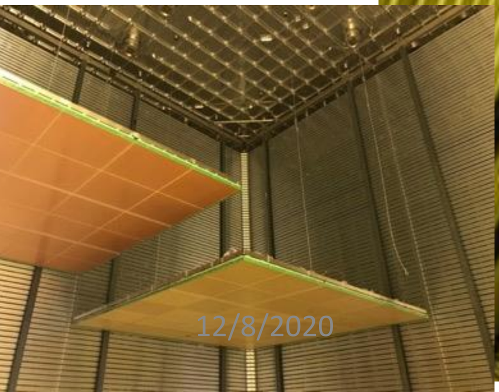
Long term HV test stability successfully performed

- 150 kV on FC ring at 3 m drift and nominal e-field between rings of 500 V/cm
- No discharge ever recorded;

NP02: double phase

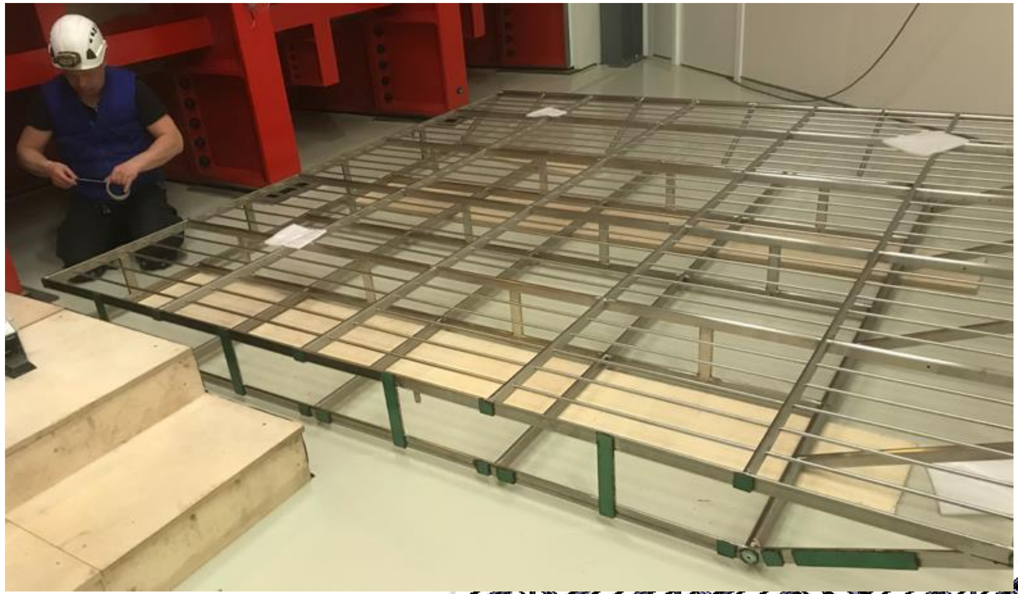


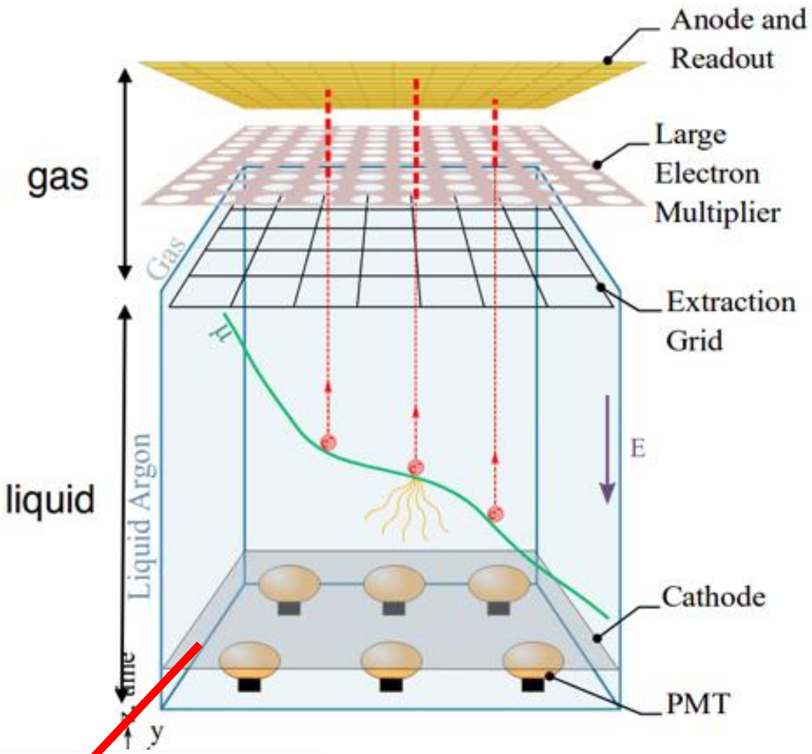




6 m drift

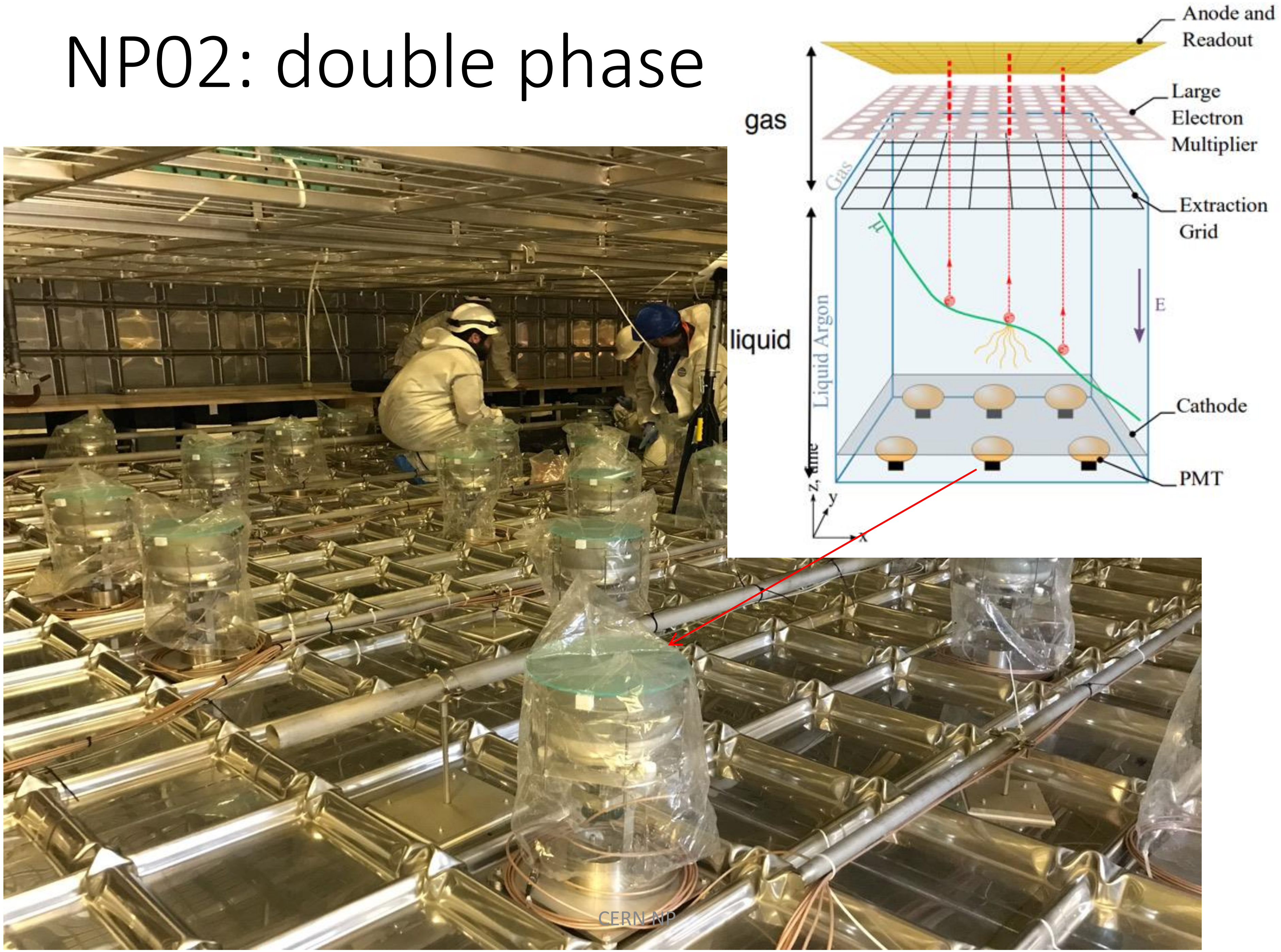
NP02: double phase



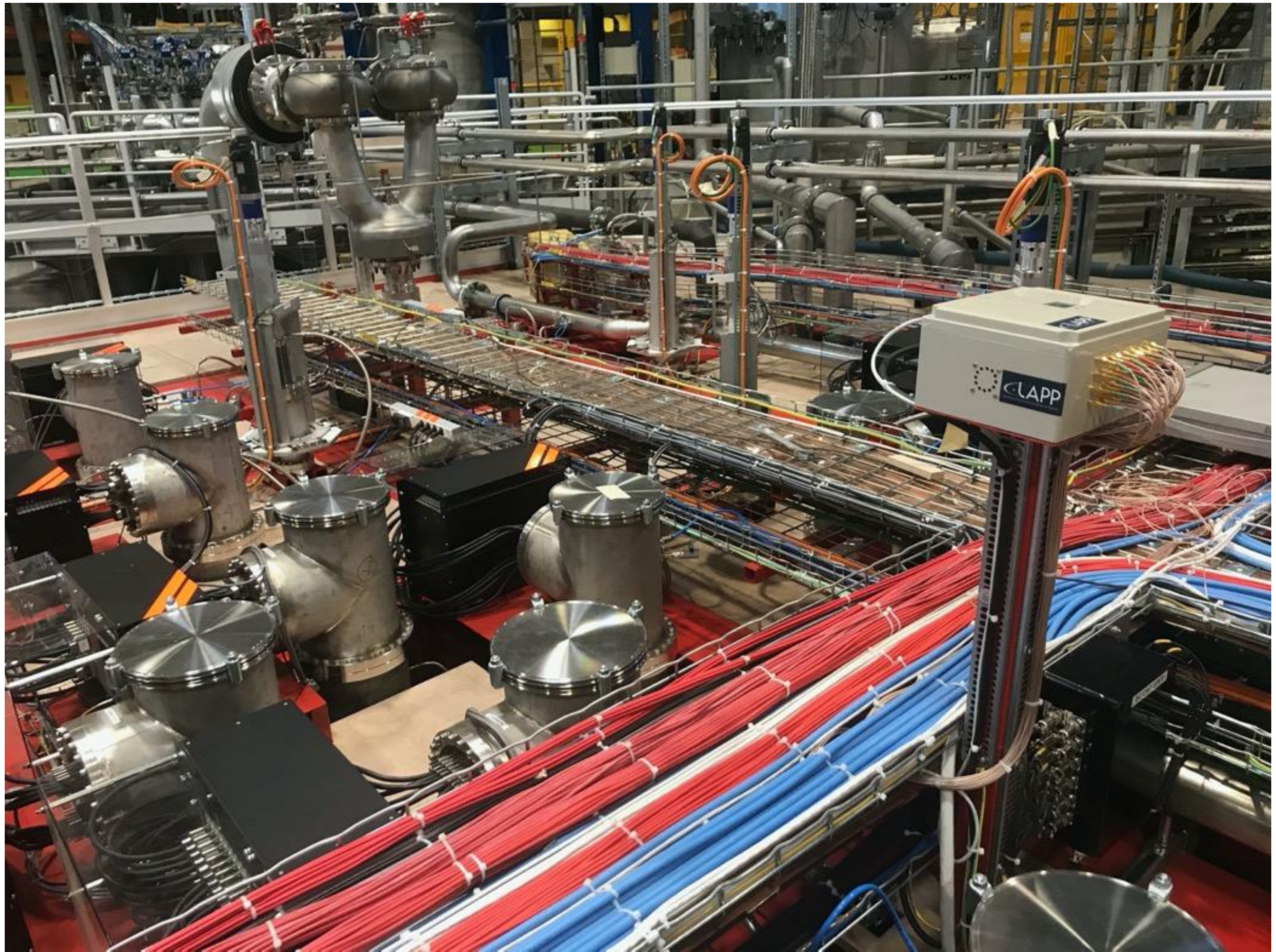


300 KV Cathode

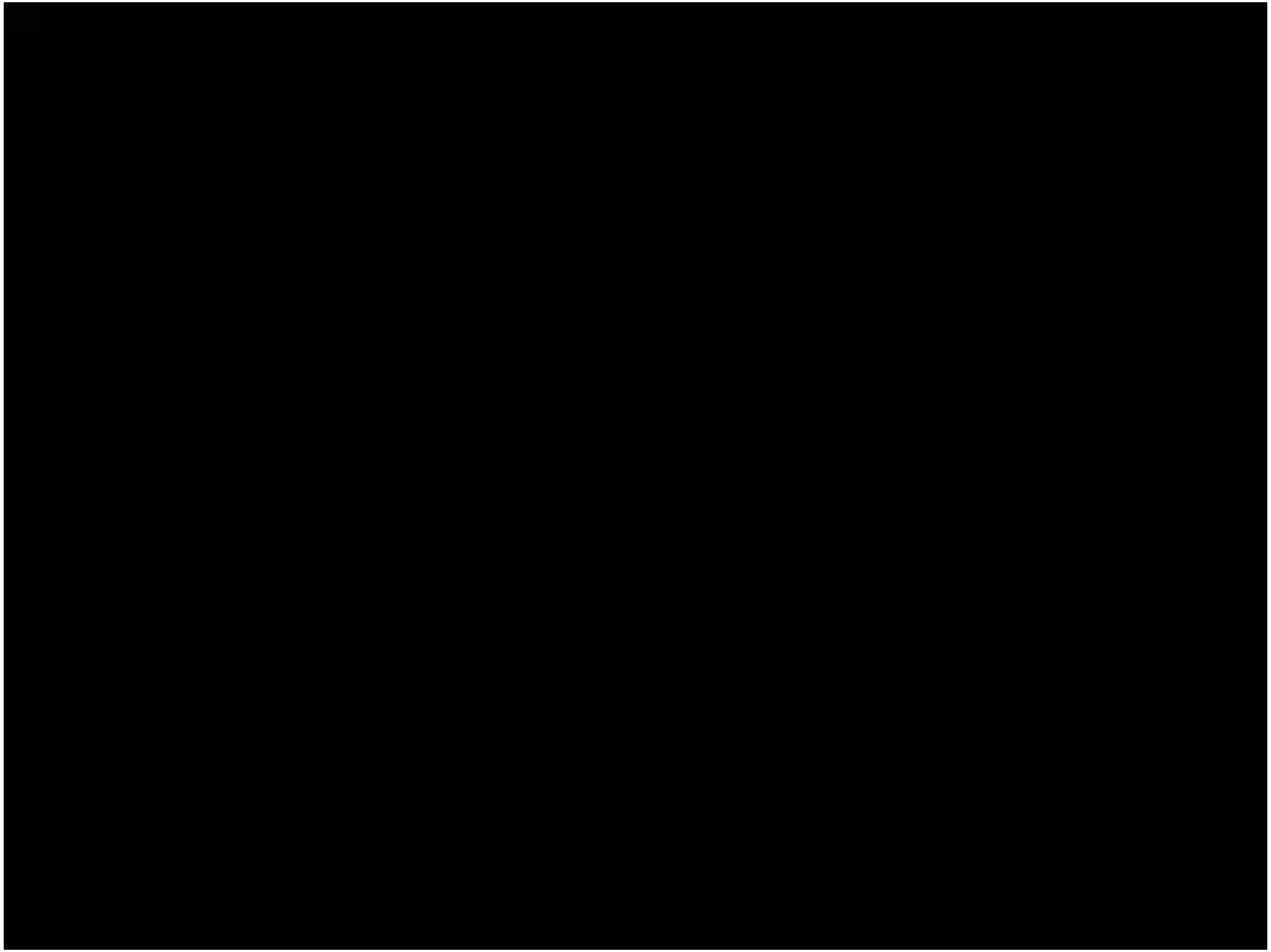
NP02: double phase



Top of the cryostat much more complex and busy

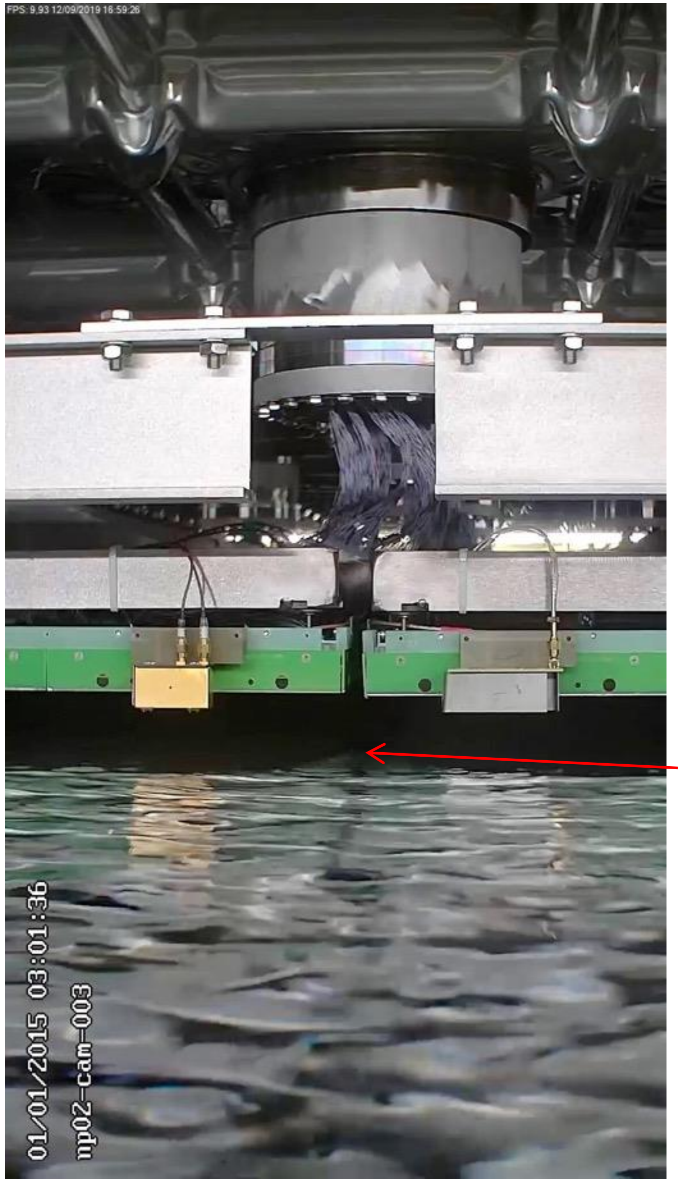


Several upgrades do to the cryogenics form the lesson learned with NP04. Still a filter problem is unresolved up to now!



Looking for bubbles

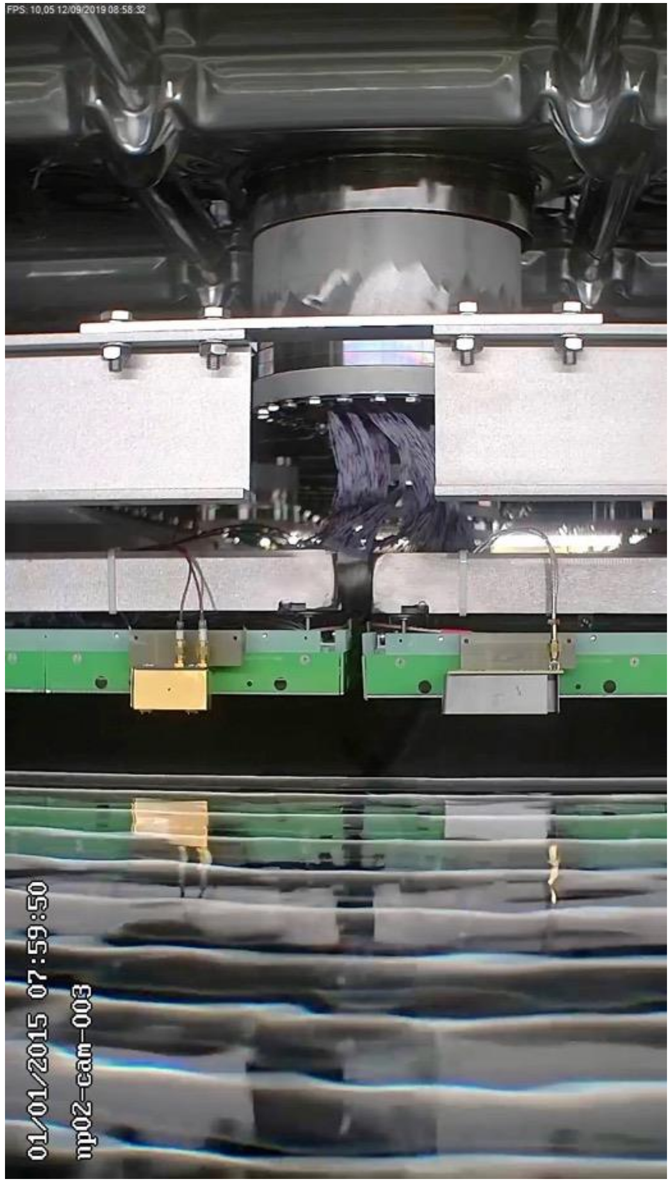
Gas pressure



1010 mbar

bubbles

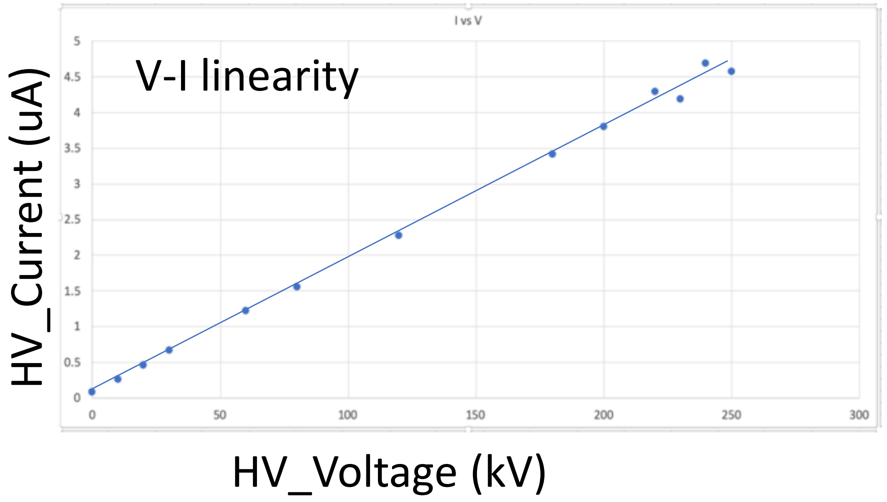
1045 mbar

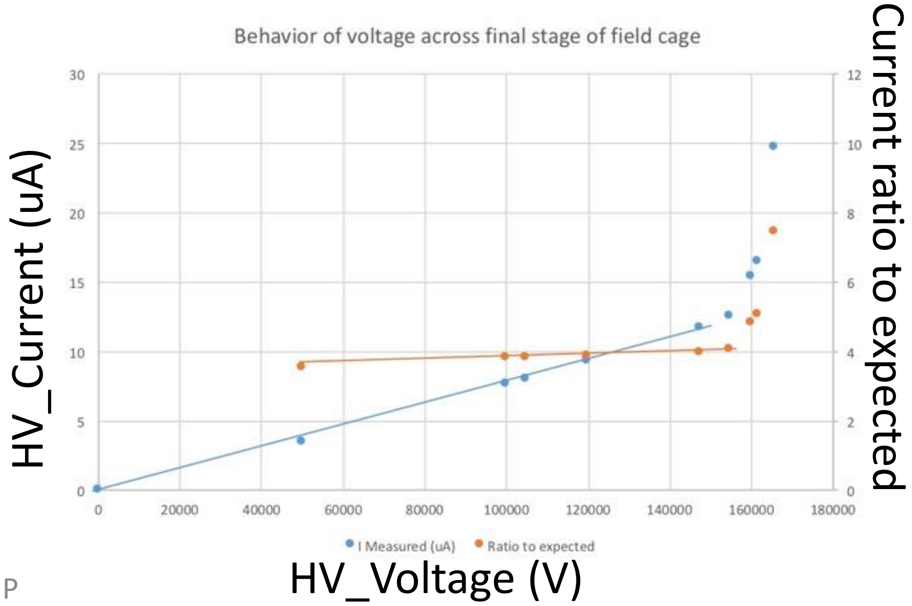


HV turn on

- On Monday 11th of August, after a weekend when the cathode was kept stably at -60 kV, the HV ramping up continued
- A value of -200 kV was reached in steps of 50 kV with a plateau of 15-30 minutes to measure noise on front end electronics
- A further increase in steps of 10 kV allowed to reach -250 kV
- After 10-15 minutes at -250 kV, a current trip (> 500 uA) reset the HV-PS voltage to zero

- *The system became very unstable with large current spikes when HV was set beyond -10 kV*
- *HV current through the divider boards increased about 3.5 to 4 times higher than nominal value*



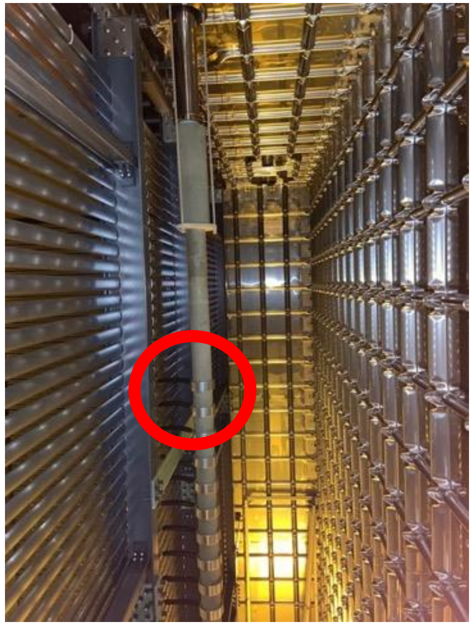


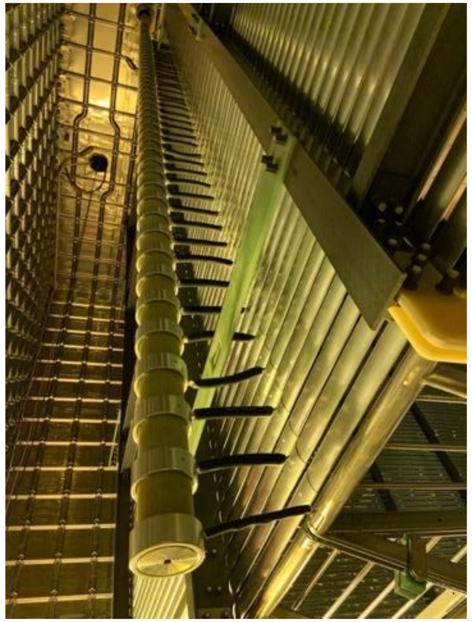
HV turn on

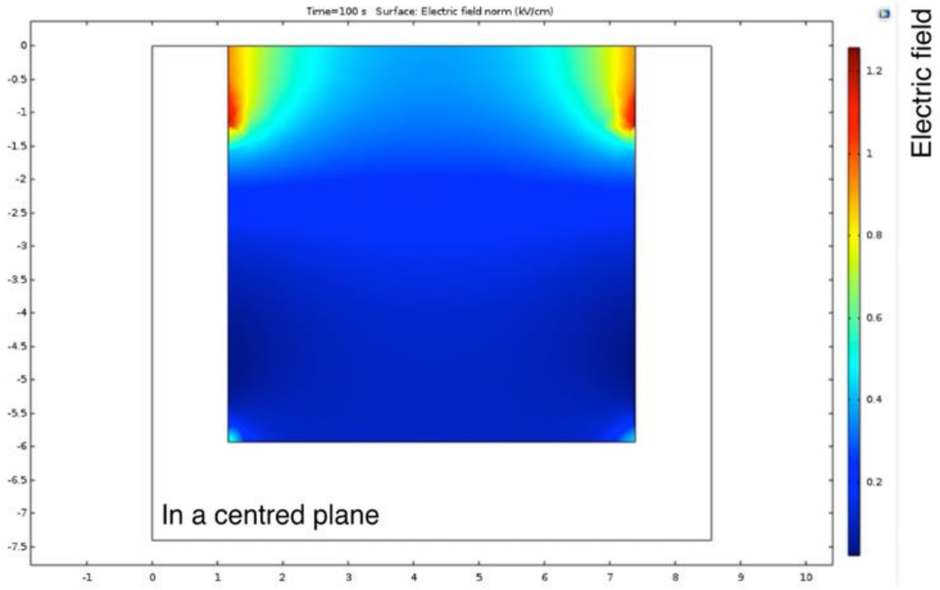
- Short circuit of the inner conductor of the HV extender with the first degrader ring connected to the corresponding field cage ring at about 1/4 of the drift height.
- Fault due to defect in the cylindrical shape of the extender (radial fabric planes are HV weaker)
  - not cryogenically and HV tested in a separate test-stand due to its length

- Solution under investigation:
  - resistive extruded cryogenic cable
  - cylindrically built FR4 tube

- Present operative conditions:
  - Maximum applicable potential with manageable impact on the electronic noise is limited to less than 150 kV
  - **Drift field is not uniform but close nominal in the upper 1/4 of the volume**







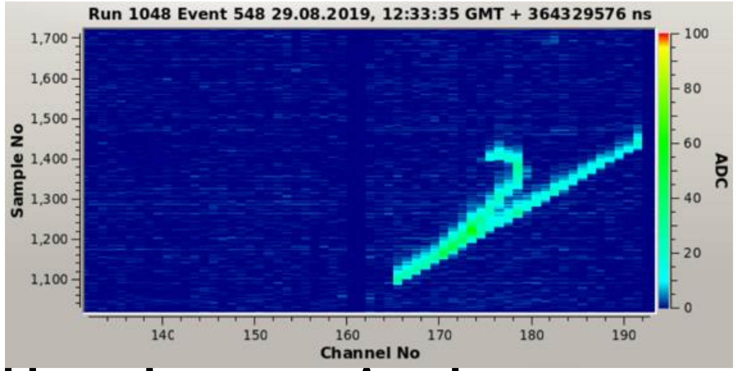
CRPs performance

- ✓ CRPs level meters calibration and alignment activities and HV tests performed → **grids of all 4 CRPs reaching goal of 7kV**

- ✓ **Observation of first short tracks on 29/8** with CRP 1 LEMs brought to **2.9 kV ΔV**, grid voltage 6kV, electrons lifetime 200 μs

- ✓ Since first operation on 29/8, **LEMs of both CRPs working in stable way at 2.9 kV ΔV with negligible LEMs sparking rate. When going further the sparking rate augment and becomes a real problem and a show stopper**

One of the very first tracks

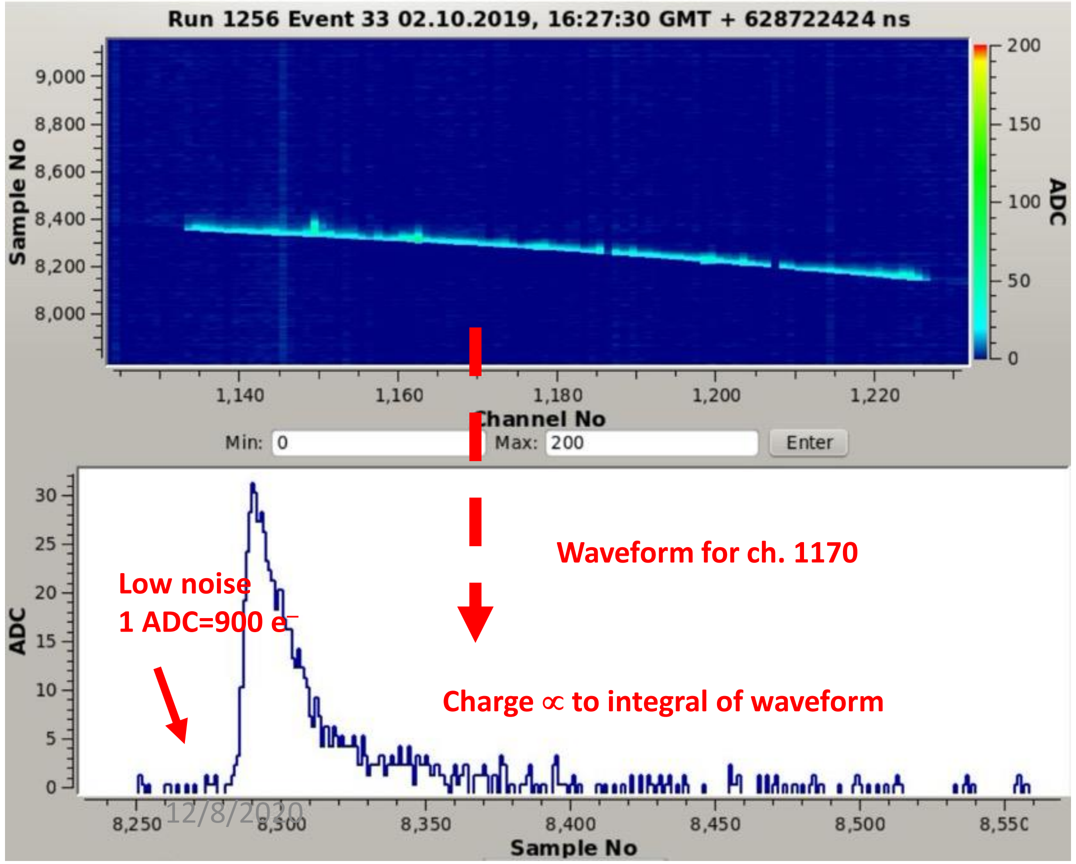


- ✓ **Electronics noise ~1.5 ADC counts, still dominated by coherent noise due to grounding of slow control cabling** which is being improved → goal: bring to intrinsic electronics noise ~<1 ADC count

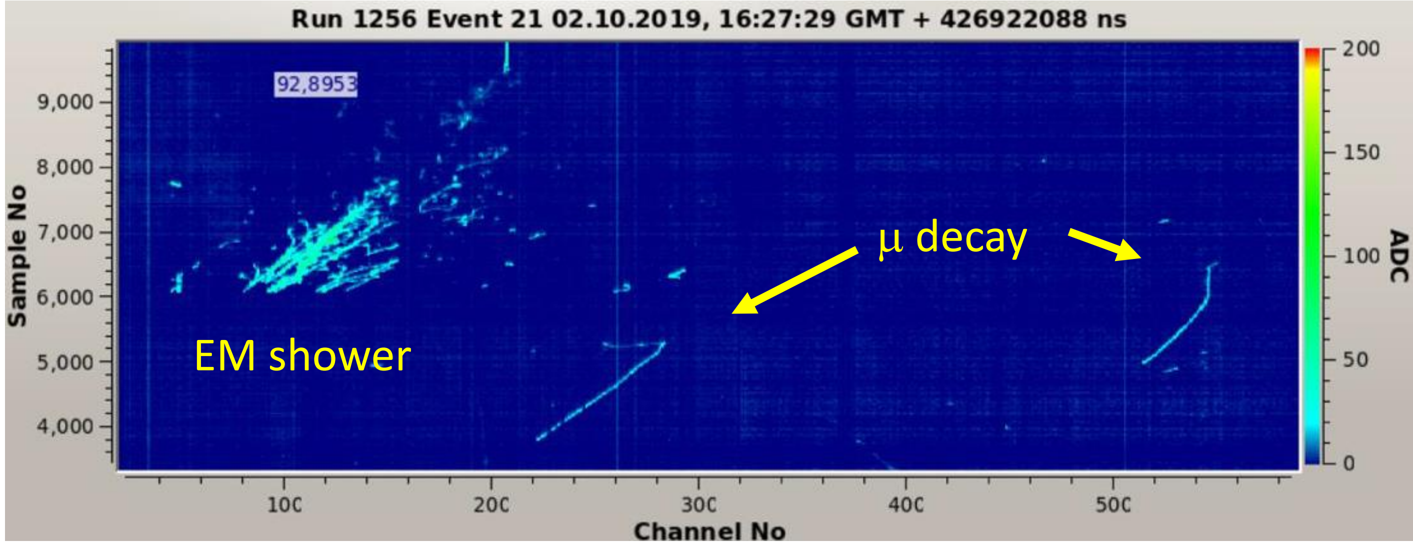
- ✓ Smooth operation of DAQ with random triggers (cosmic trigger counters being set up) **660k events** (4 ms drift) **~70 TB** acquired since 29/8, data transferred to FNAL

Cosmic ray events
in protoDUNEdual-phase
(October 2019)

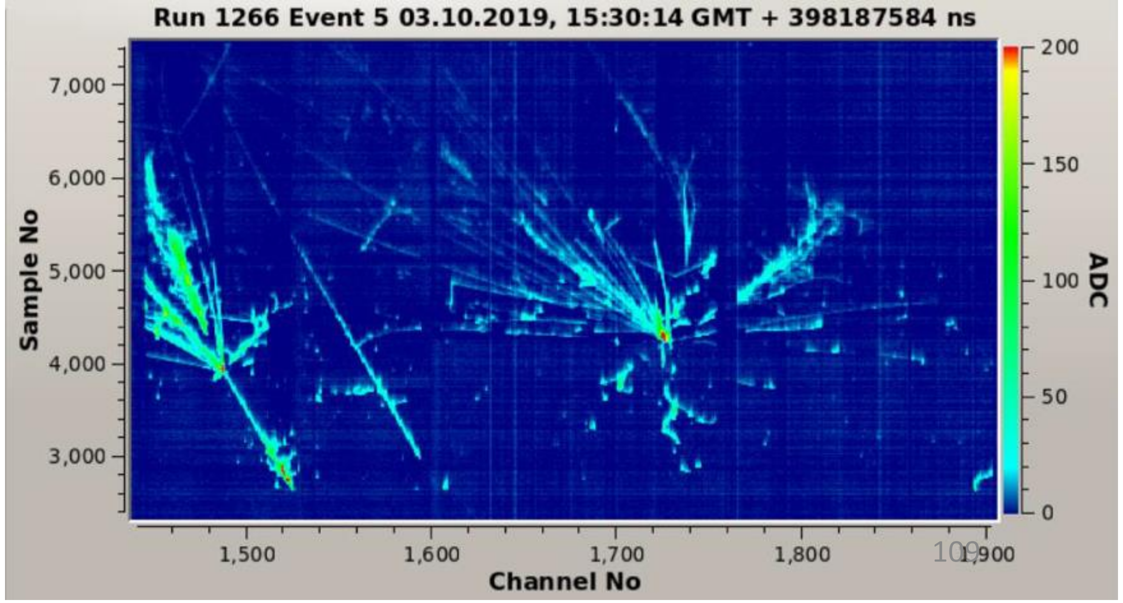
Horizontal muon track



Electromagnetic shower + two muons decay



Multiple hadronic interactions in a shower



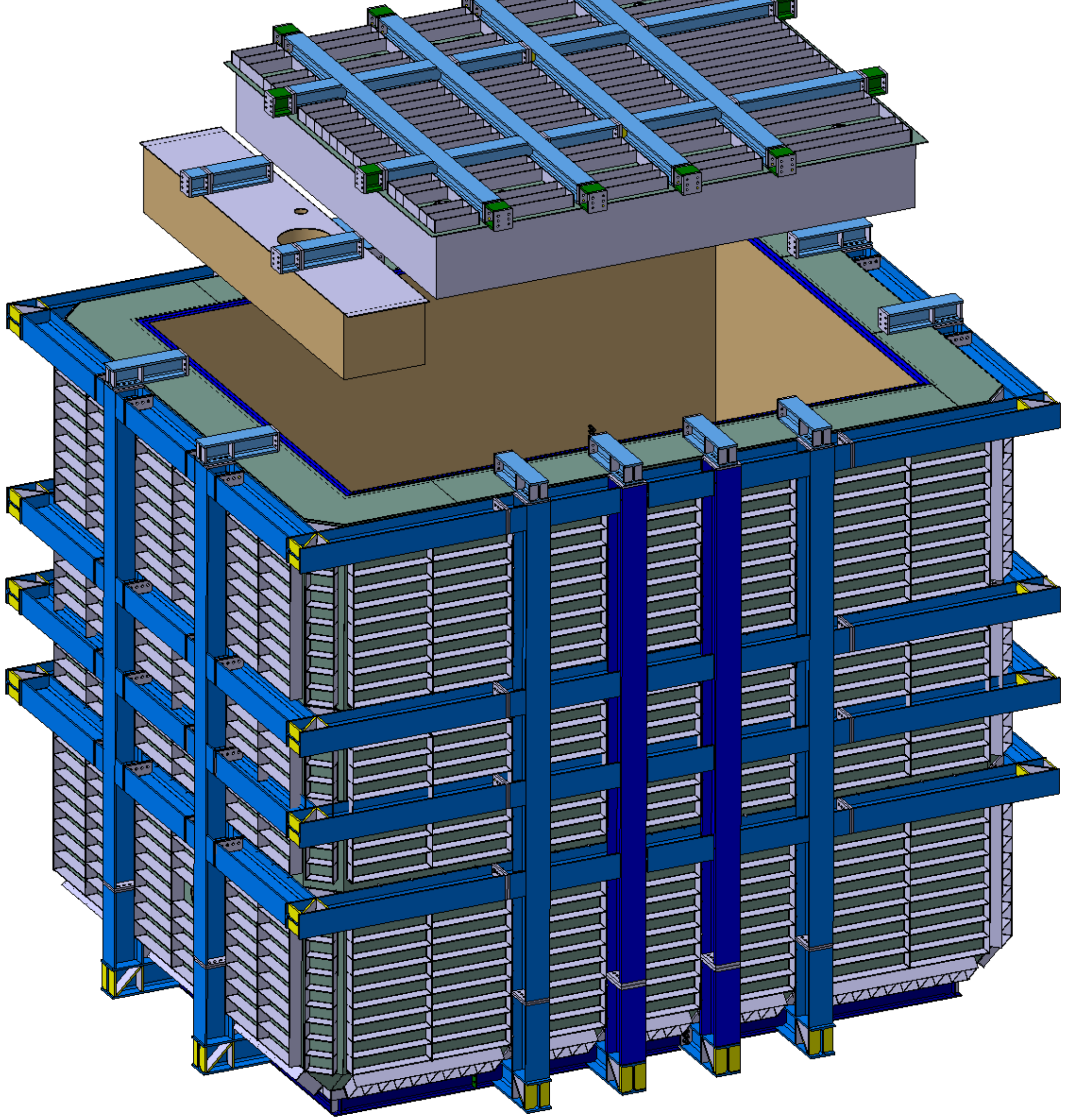
Lessons learned:

1. This DP technology is very complex and very demanding
2. The observed waves in the liquid (amplitude ~0.1mm) are not understood and might represent a problem in a large detector. We are not sure !
3. More R&D is necessary on the HV system. Other solutions need to be explored through R&D. We see problems at 300KV, the final requirement is for 600KV.
4. The main problem is the quality of the CRP (mechanics and material). We never arrived to the situation where the amplification is beneficial. A new R&D phase can be envisaged! The CRP mechanical structure was not as flat as required at cold. The readout package (LEM, Anode and wires) is too complex and demanding on many parameters. The instability and sparks rate are the the major problems. This part of the project has to revisited after considerable basic R&D.
5. The general layout, with an external field cage, an empty drift space with no dead material and all the readouts external to the drift space is very interesting and should be preserved. New ideas (long vertical drift SP TPC) are emerging.
6. The NP02 collaboration was compromised by internal problems between 3 main laboratories in France and Switzerland. To rescue the project, when already important investments were done, CERN NP had to come in heavily and supply components. The plan was developed in meetings convened by the Director of Research.

SBN: SBND near detector

- Warm cryostat design, procurement and installation at FNAL
- Cold cryostat design, procurement and installation at FNAL
- LAr proximity cryogenics design, procurement and installation at FNAL

✓ Agreement between FNAL and CERN by the previous CERN management
✓ MOU still since years in preparation by DOE and not yet issued



SBND : 200 T LAr membrane cryostat

LAr cryogenics installed

- Seen at the last prototype before LBNF
- Many structural and design changes done form the original protoDUNE experience both in the warm and the cold structures
- Excellent opportunity to prove the new design

SBDN – Cryostat installation movie – The Real Life

NP03: PLAFOND

PLAFOND

- ✓ as first step before proposing a new experiment or a change on an existing one
- ✓ as informal way to try out new ideas, to develop new concepts and alternatives
- ✓ as a first entry point to Neutrino or non accelerator based fundamental research
- ✓ as a way to initiate collaborations and explore synergies with new research partners
- ✓ for young scientists as a first pragmatic approach to our methods and technologies. A place to learn basic tools and instruments

- **Short baseline at CERN, LOI's**
- **DUNE cryostats**
  - LBNF cryostat design and engineering
  - Virtual reality development for the DUNE far detector
- **Fundamental R&D on LAr properties**
  - LAr purification system R&D (new approach)
  - UV Light propagation velocity in LAr R&D
  - Studies of liquid argon scintillation light properties with radioactive sources and cosmic rays
- **ICARUS**
  - ICARUS readout and DAQ test and qualification
  - Tests and development of the ICARUS T600 scintillation light detection and trigger systems
  - Test and characterization of Hamamatsu PMT for ICARUS: timing, linearity and saturation
  - Studies of direct SiPM's performance as a future alternative for PMTs with alternative readout methods.
  - Test and qualification of LAr-TPC read-out with BNL cold analogue end and ICARUS warm digitizers/DAQ
- **DUNE/ProtoDUNE**
  - Aluminum modular field cage R&D for ProtoDUNE SP and DP
  - R&D on UV reflector(with WLS) foils on cathode in LAr and related Electric field uniformity map
  - HV system qualification (feedthough, power supplier, ripple suppression filters)
  - LAr doping tests and qualification with Xenon and Xe-N2
  - Alternative solutions to classical WLS ….. PEN?

In general project lasting 2-3 months, making use of the existing infrastructure, a cryogenic laboratory, some minimal technical and engineering support …

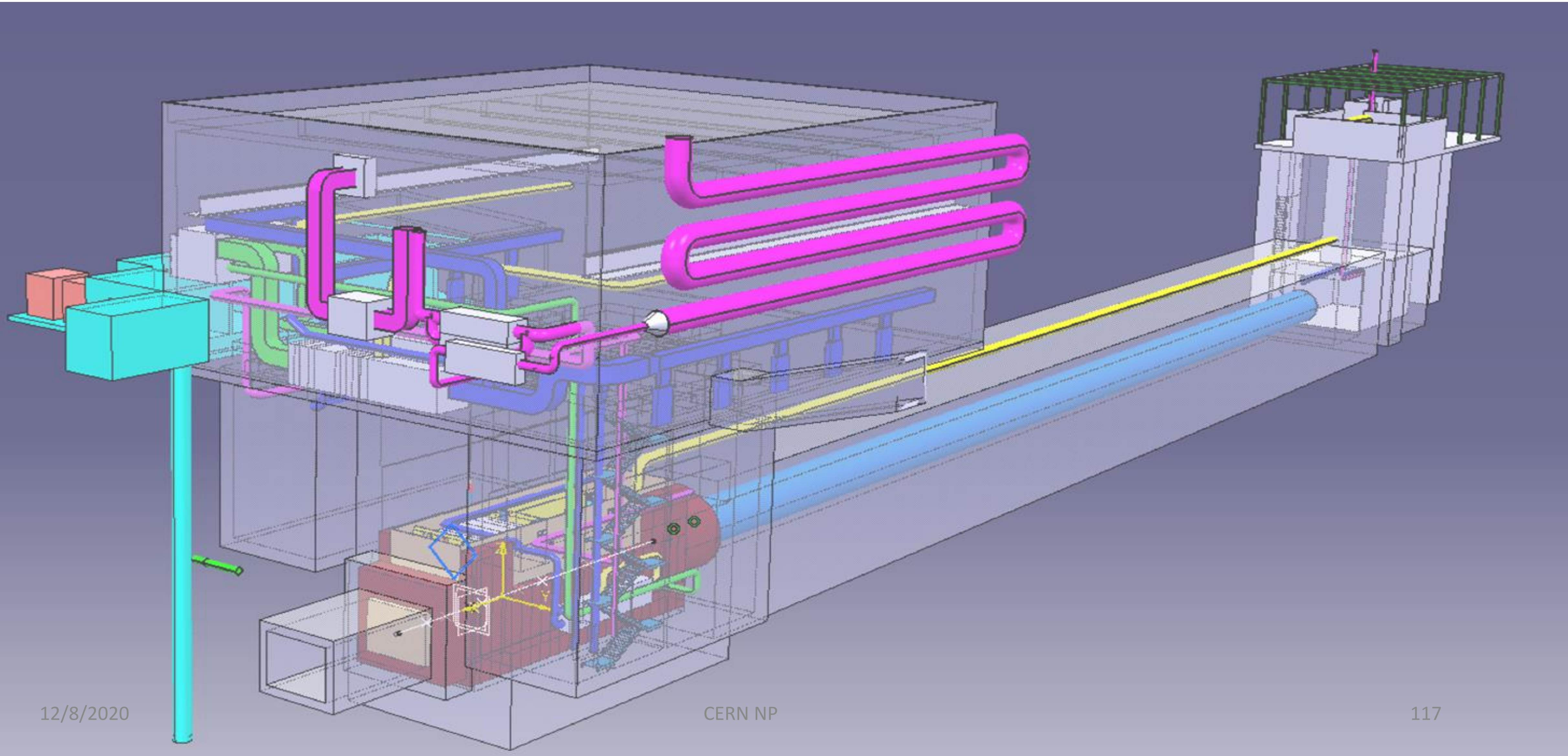
…. and an healthy and informal proactive collaborative approach …..

Most of this is now part of the existing research program!

- **Dark Matter search**
  - Test and qualification of Dual phase detection in LAr for extremely low energy events
  - LAr Doping ternary mixture Xe-CH4 for active shielng in Dark Matter experiments
- **Future developments for LAr detector**
  - Vertical drift TPC readout and concept with perforated anode PCB replacing wires
  - SIPM in LAr on HV substrate with powering over fiber and optical read-out
- **Other R&D**
  - superFDG for T2K near detector and ND280upgrade
  - Silicon pixels for photon detection, fast

- R&D on LAr fundamantal properties
  - Neutrino Plartform group, Qualification of the ProtoDUEN LAr purification filters: *in preapration*
  - M. Babicz, et al., *Experimental study of the propagation of scintillation light in Liquid Argon,* NIMA 936 (2019) 178-179;
  - M. Babicz et al. *A particle detector that exploits Liquid Argon scintillation light,* NIMA 958 (2020) 162421;
  - M. Babicz et al., *Propagation of scintillation light in Liquid Argon,* JINST 15 (2020) 03 C03035, arXiv:2002.09346
  - B. Ali-Mohammadzadeh et al., *Measurement of Liquid Argon Scintillation Light Properties by means of an Alpha Source placed inside the CERN 10-PMT LAr Detection System,* JINST 15 (2020) 06 C06042;
- ICARUS
  - L. Bagby et al., *New read-out electronics for ICARUS-T600 liquid Argon TPC. Description, simulation and tests of the new front-end and ADC system*, *JINST* 13 (2018) 12, P12007
  - M. Antonello et al., Study of space charge in the ICARUS T600 detector JINST_15_P07001
  - G. L. Raselli et al., *Test and characterization of 20 pre-series Hamamatsu R5916-MOD photomultiplier tubes for the ICARUS T600 detector*, NSS/MIC 2016;
  - M. Babicz et al., *Timing properties of Hamamatsu R5912-MOD photomultiplier tube for the ICARUS T600 light detection system*, NIMA 912 (2018) 231-234;
  - M. Babicz et al., *Linearity and saturation properties of Hamamatsu R5912-MOD photomultiplier tube for the ICARUS T600 light detection system,* 936 (2019) 554-555;
  - M. Babicz, eNIMAt al. *Scintillation Light DAQ and Trigger System for the ICARUS T600 Experiment at Fermilab*, NIMA 936 (2019) 358-359;
  - M. Babicz, et al. *A particle detector that exploits Liquid Argon scintillation light,* NIMA 958 (2020) 162421;
  - T. Cervi et al., *Study of SiPM custom arrays for scintillation light detection in a Liquid Argon Time Projection Chamber*, JINST 12 (2017) 03 C03007;
  - T. Cervi et al., *Study of SiPM custom arrays for scintillation light detection in a Liquid Argon Time Projection Chamber*, JINST 12 (2017) 03 C03007;
  - T. Cervi et al., *Comparison between large area PMTs and SiPM arrays deployed in a Liquid Argon Time Projection Chamber at CERN*, NIMA 912 (2018);
  - T. Cervi et al., *Characterization of SiPM arrays in different series and parallel configurations*, NIMA 912 (2018) 209-212;
  - M. Babicz, et al., *Characterization of SiPM arrays with common bias and common readout for applications in liquid argon*, NIMA 936 (2019);
- Dark Matter search
  - LAr Doping ternary mixture Xe-CH4 for active shielng in Dark Matter experiments: *paper in preparation*
- Future developments for LAr detector
  - *Xenon doping to improcescintillation light detection efficincy in Large LAr-TPC:* in preparation
  - Vertical drift TPC readout and concept with perforated anode PCB replacing wires: paper in preparation
  - X-ARAPUCAs characterization: in preparation
- Other R&D
  - D.Attié et al., *Performances of a resistive Micromegas module for the Time Projection Chambers of the T2K Near Detector upgrade*, NIMA, 957 (2020)
  - K.Aba, et al., *T2K ND280 Upgrade Technical Design Report*, arXiv:1901:0375
  - A. Blondel,*The SuperFGD Prototype Charged Particle Beam Tests*, in preparation

Short baseline at CERN

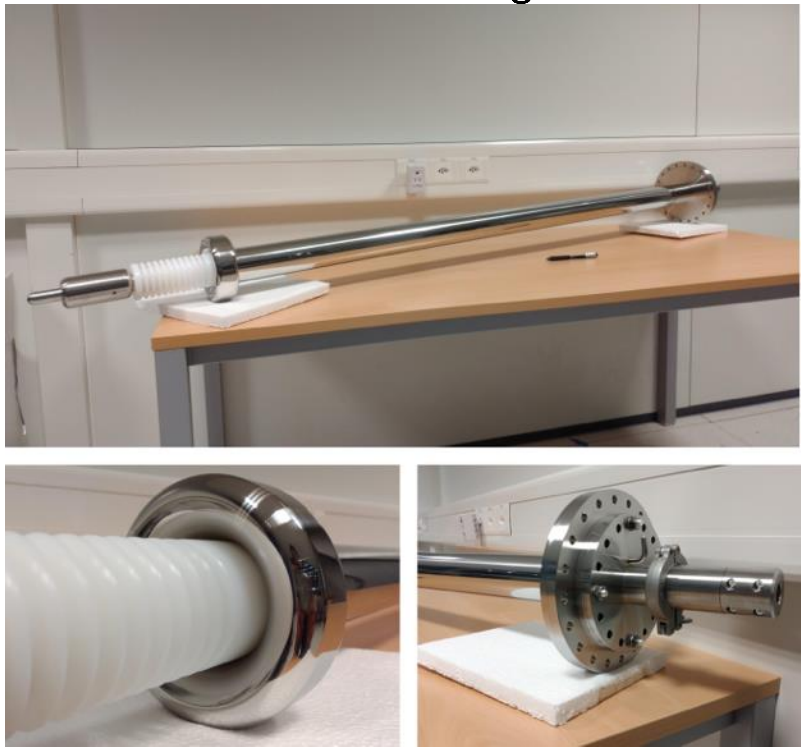


Short baseline at CERN → SBND HVFT tests

- Quality control, testing and validation of SBND HVFT at 150kV at CERN
- HVFT successfully worked and it will be used in the SBND experiment

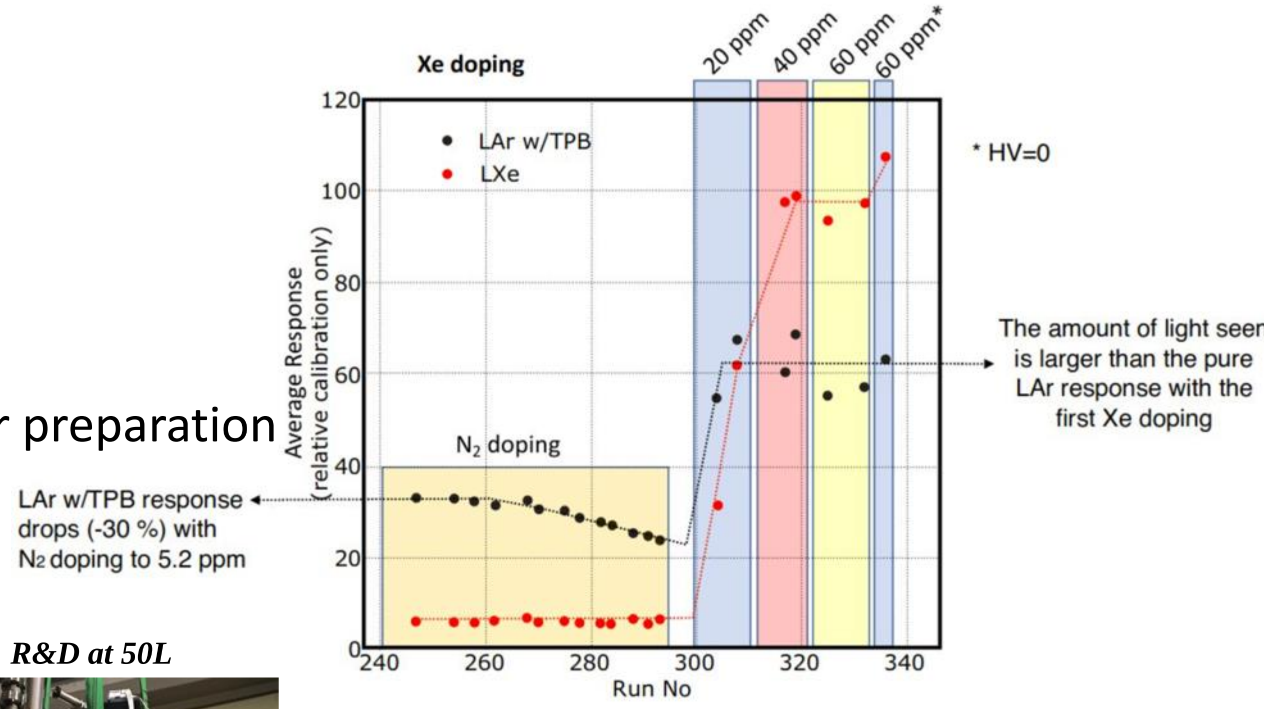
HV test setup

HV feedthrough

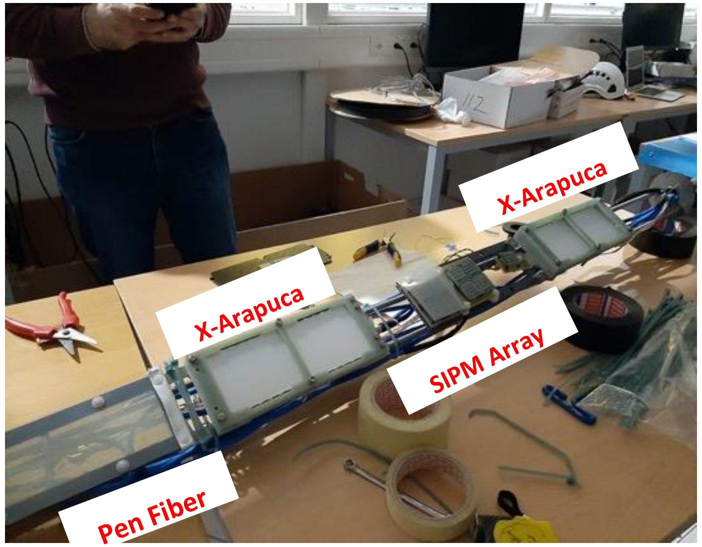


Xenon R&D

- R&D and proof of principle at 50L setup
  - Tests with PMTs
  - Tests with X-Arapucas, fiber-pen module and SiPMs
- Successful doping of ProtoDUNE-SP with ~20ppm of Xe
- Analysis has almost been finalized and publication under preparation



New readout modules for PD



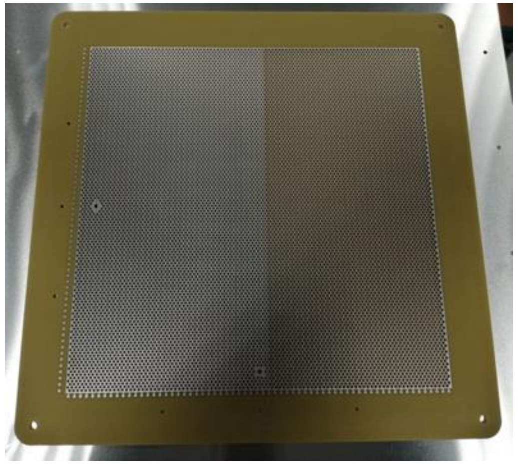
Xe injection system

R&D at 50L

Vertical drift TPC readout and concept

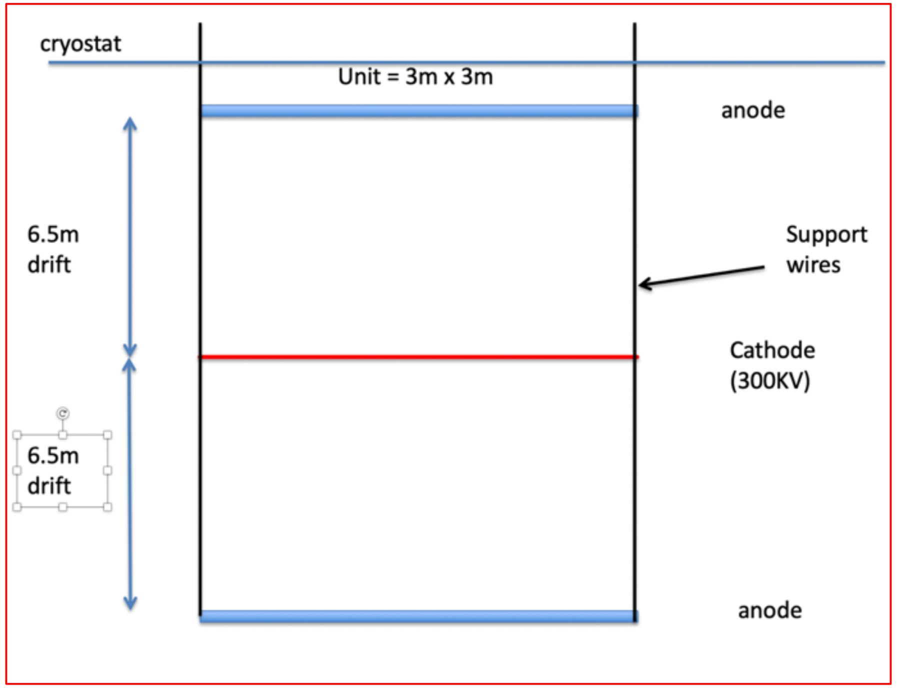
- PCB anode readout for the single phase vertical drift LArTPCs
- Successfully demonstrated proof of principle
- Publication is under preparation

PCB Anode

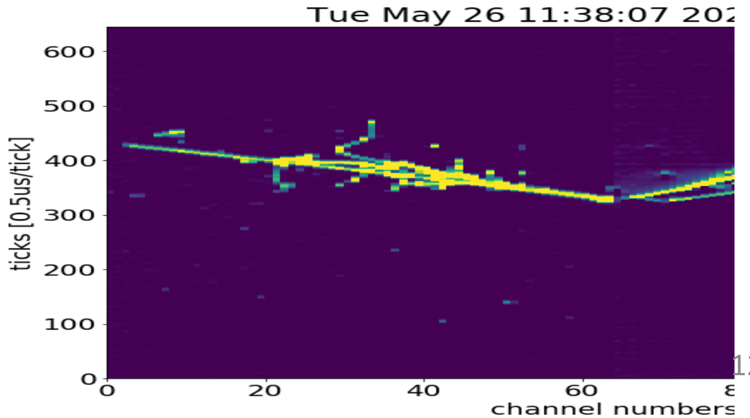


Readout electronics

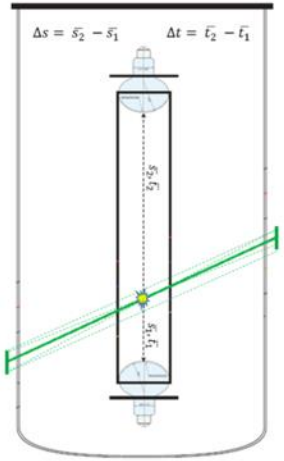
TPC with PCB anode and electronics

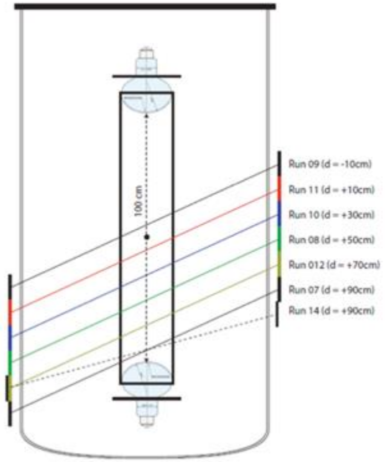


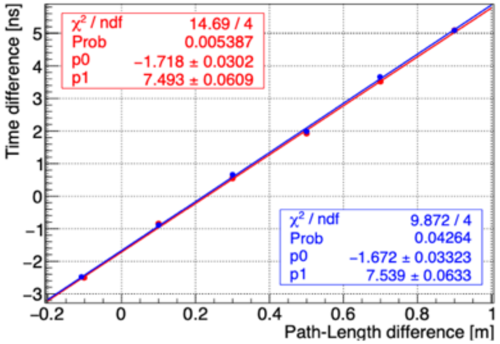
Event display of the PCB Anode



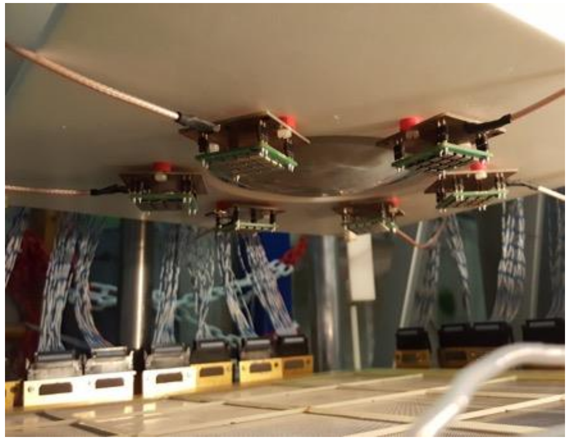
Studies of liquid argon scintillation light properties



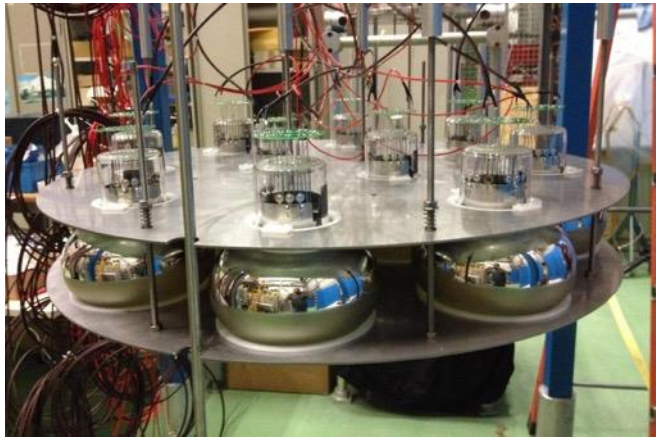




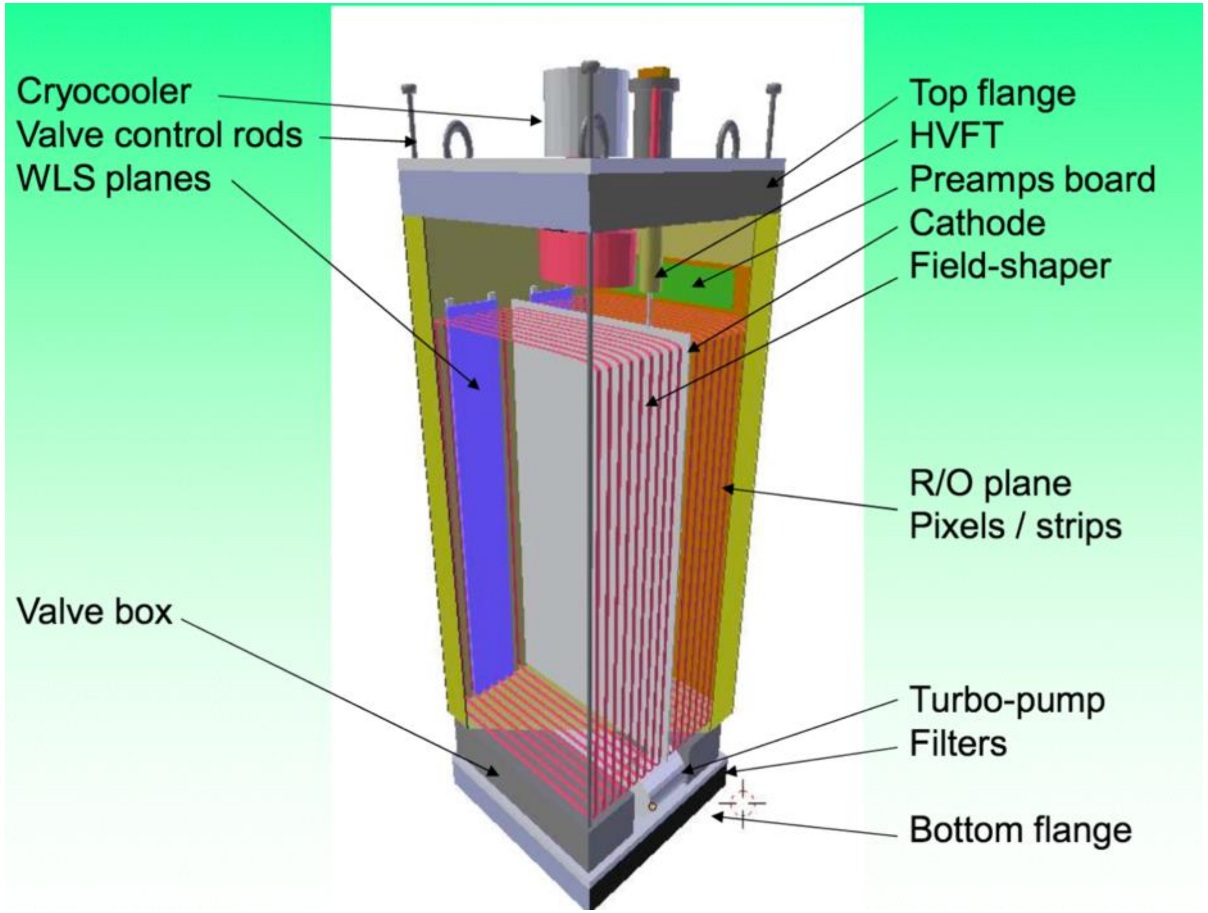
Studies of SiPMs performance as a future alternative for PMTs.

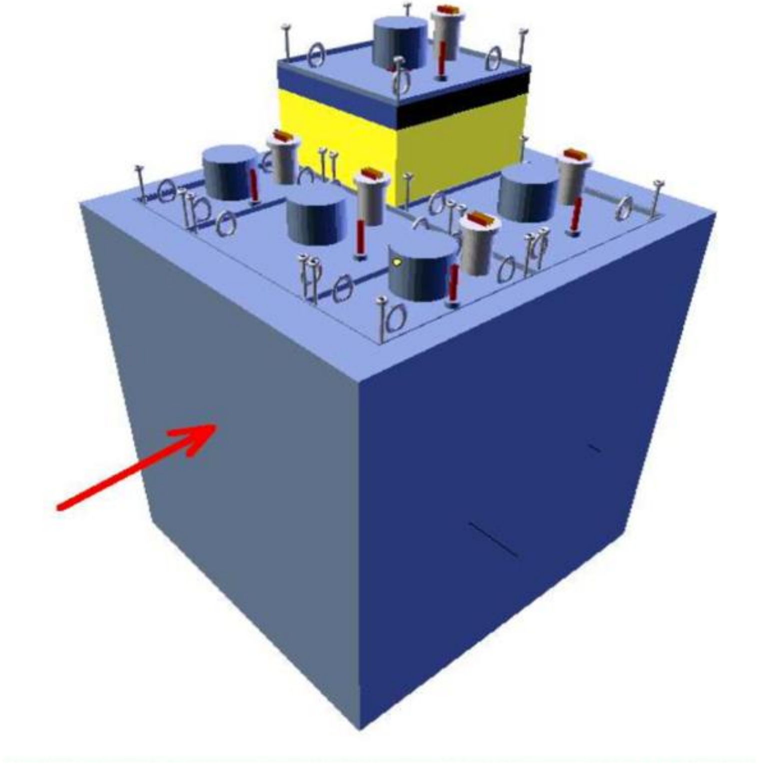


Tests and development of the ICARUS T600 scintillation light detection and trigger systems.



…. or a very modular TPC concept : argon cube

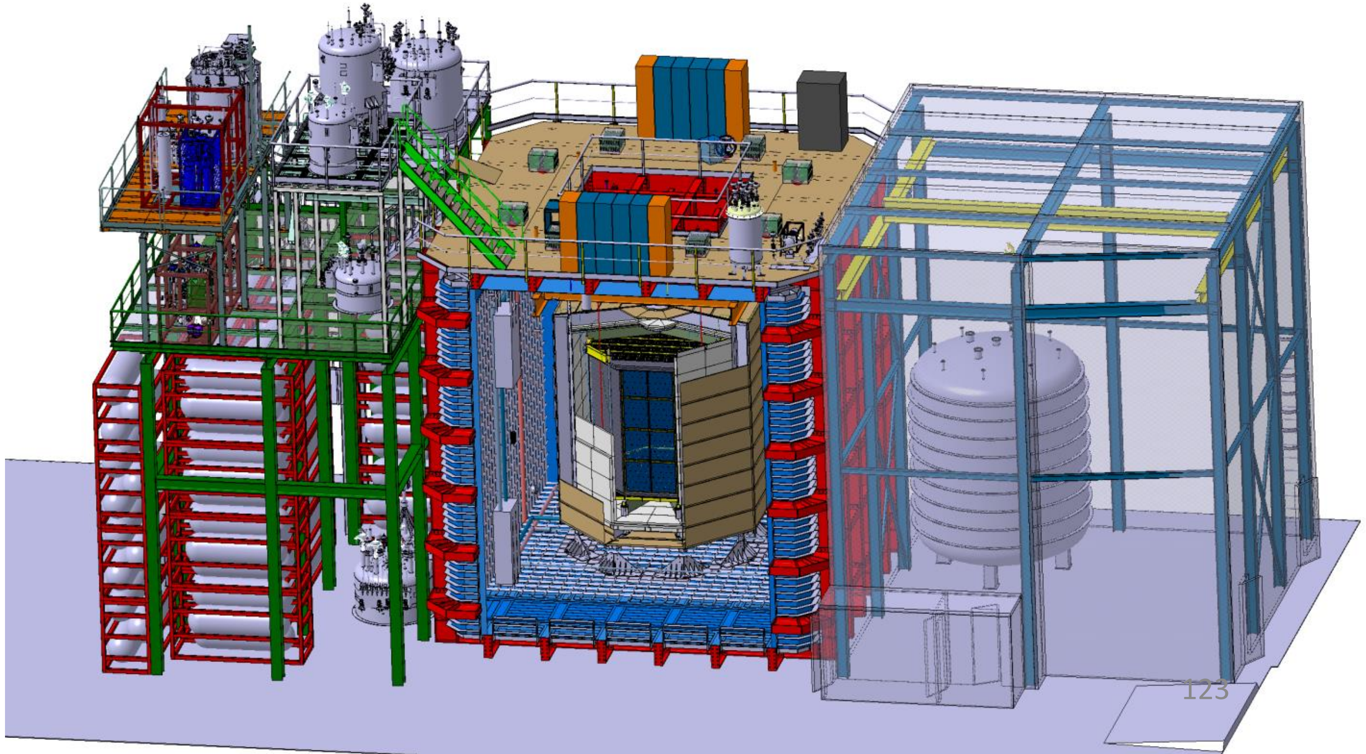




Now this concept has become the baseline for the DUNE near detector

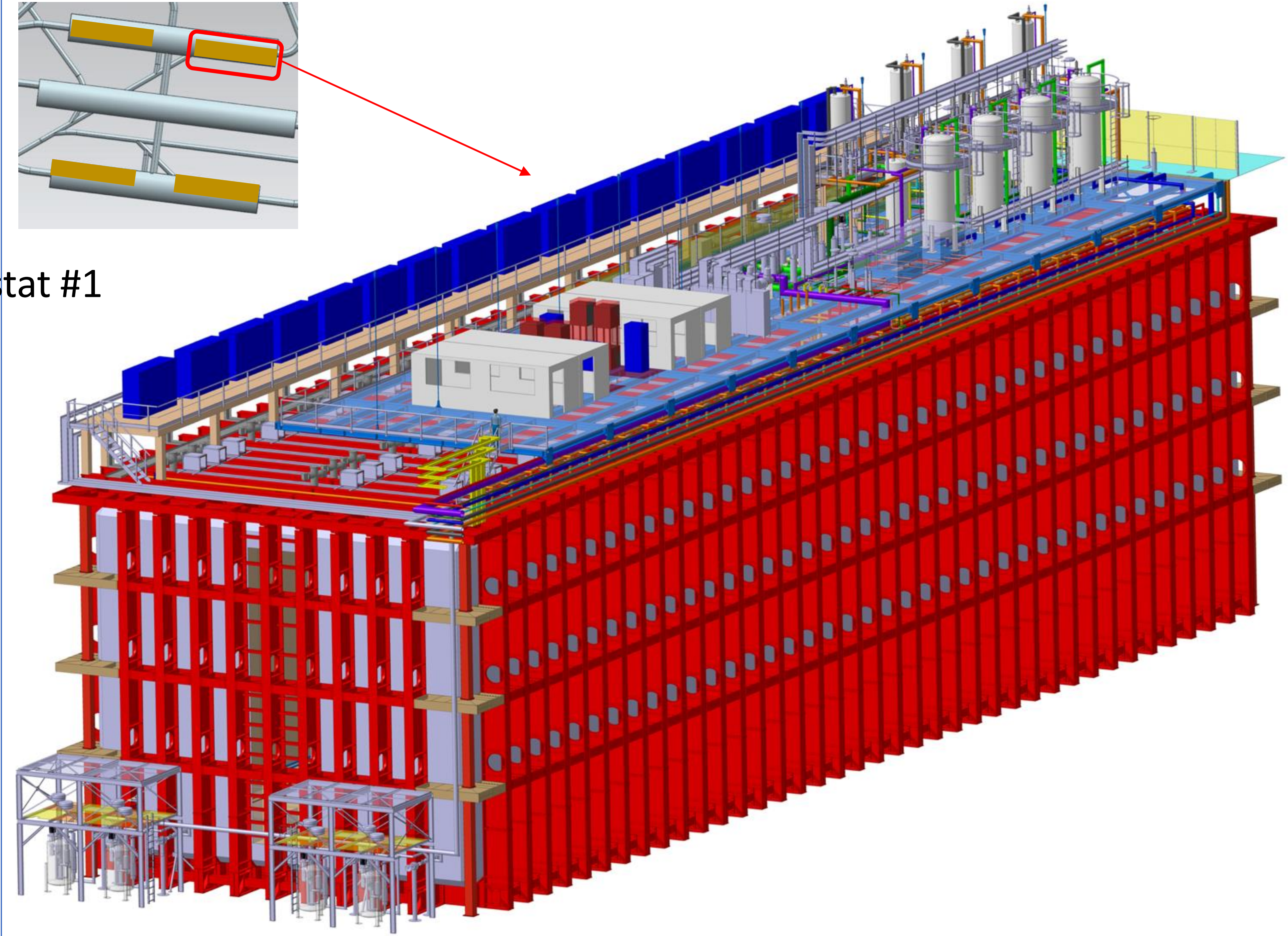
Darkside

- New concept based on the NP04 cryostat
- The central TPC with primordial Argon 40 (no 39) is immerged in the large LAr bath. Internal TPC cryostat and material removed. Goal : a background free DM experiment!
- With INFN personnel at CERN the entire engineering concept has been worked out and is ready for implementation
- A CERN-INFN collaboration agreement on the subject signed
- All financial resources comes to CERN via an Italian INFN Eu fund



LBNF cryostat

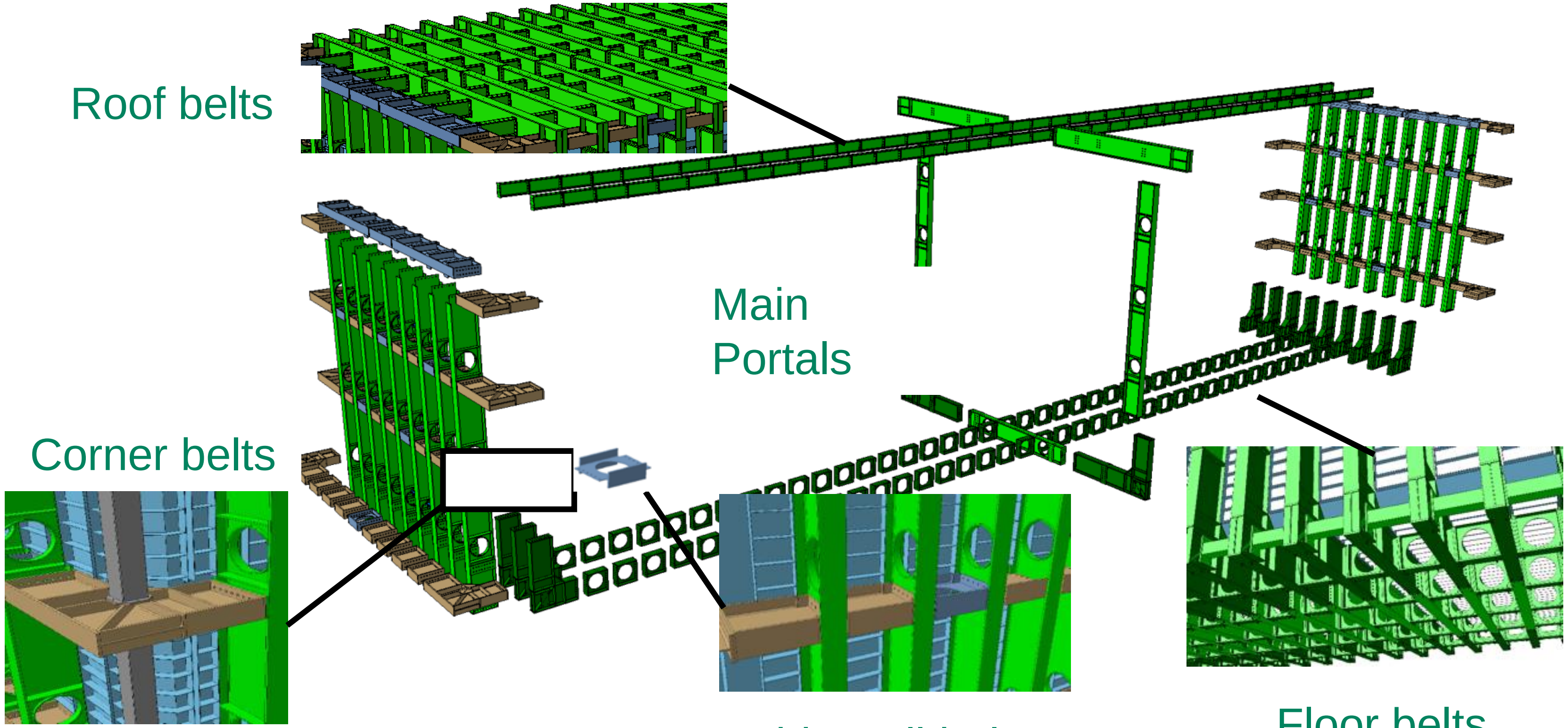
- Concept born at the beginning of the NP project, as a way for CERN and Europe to contribute to LBNF. Design and expertise all resident at CERN and augmented by the experience done with the various prototypes
- All design and engineering work done at CERN in collaboration between NP and EP/DT. Mostly done with staff and fellows resources.
- A full engineering of the cold vessel was contracted to the firm GTT in Paris holding the IP for such a technology
- All critical engineering calculations have been validated by scale 1:1 elements prototypes, tested under extreme conditions (contract with a specialized laboratory at the Coimbra University)



LBNF cryostat #1

Warm structure design status

- Design completed
- First review : May 2015 https://edms.cern.ch/document/1510834
- Final review : August 2017 https://edms.cern.ch/document/1833773



Cold structure design status

All files available on EDMS, but IP protected: ask if you need access!

https://edms.cern.ch/document/2141245

Engineering study - 12500 m³ LAr Storage Tanks for CERN

OPERATIONS

SECTION 5 : CONSTRUCTION

Section 5.1 : Installation Procedures
Equipment used for GST system installation

REVISION	LABEL	ECR NBR	DESCRIPTION	DATE DD/MM/YYYY	BY	CHECKED	APPROVED
1			First Issue	13/03/2019	YDU	GED	SKU

TECHNICAL DIVISION

Engineering study - 12500 m³ LAr Storage Tanks for CERN

TO BE APPLIED TO TANK NUMBERS : SEE DOC S229 TD LIST — GST SYSTEM

EQUIPMENT USED FOR GST SYSTEM INSTALLATION

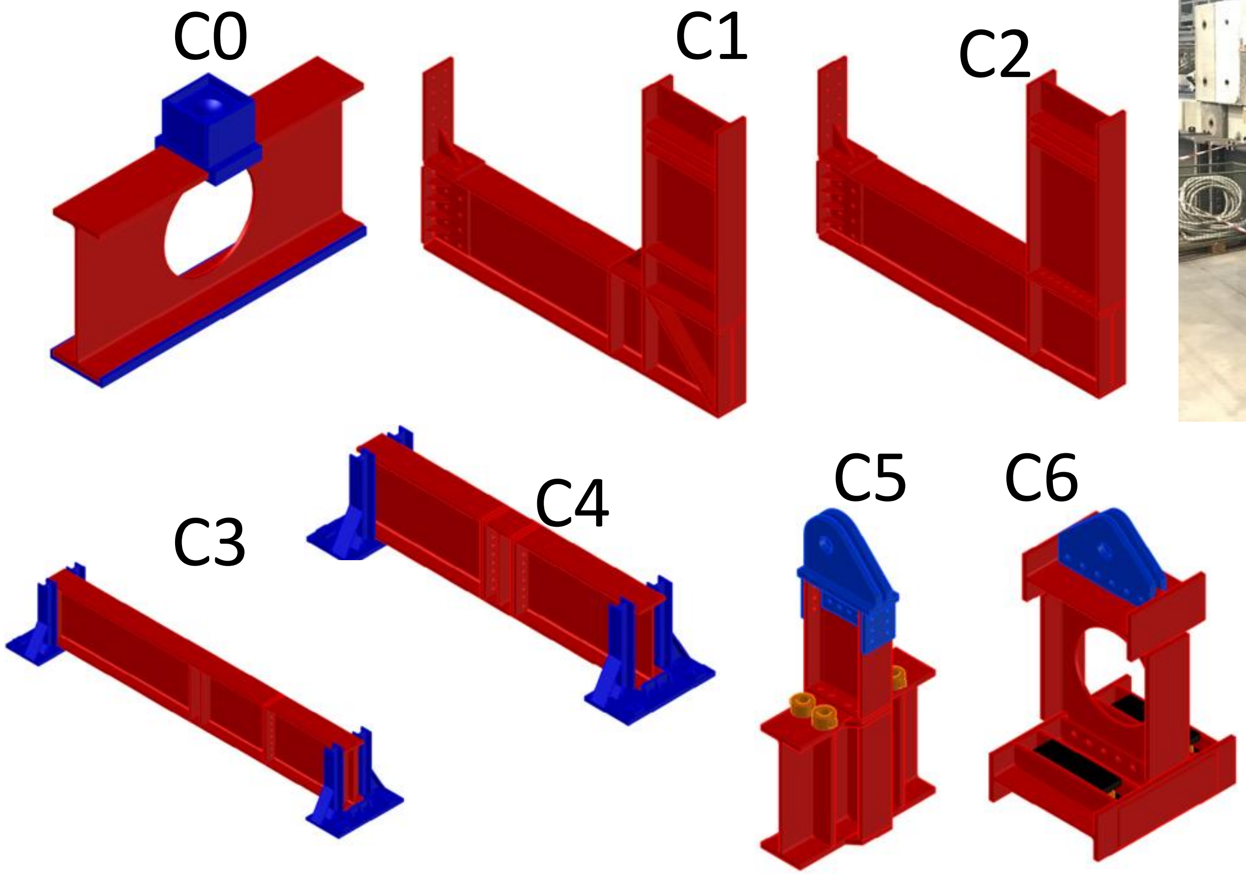
S229 OP EREC 000020

GTT
1, route de Versailles
78470 St-Rémy-lès-Chevreuse - FRANCE

PAGE: 1 — NBR OF PAGES: 24
SCALE: None — SHEET SIZE: A4

Mechanical test scale 1:1 for the most stressed components

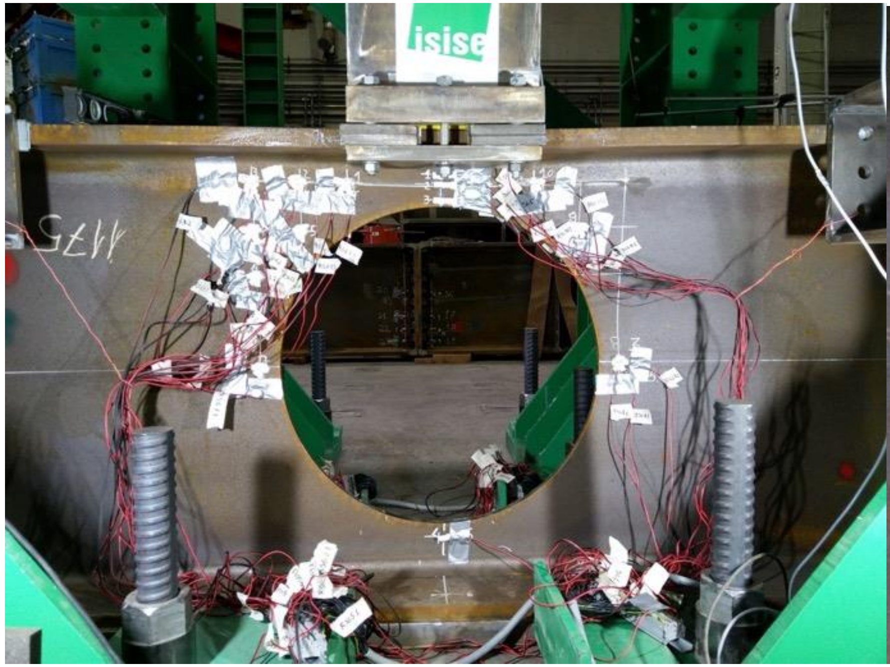
- ***Coimbra*** reports: https://edms.cern.ch/project/CERN-0000193941



7 key cryostat components constructed in the industry

Mechanical test scale 1:1

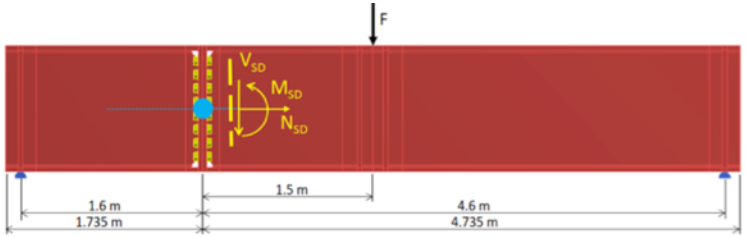
- ***Stress conditions :*** maximal from FEA, include safety factors + 25% : **all ok**



	Loads on the node				Actuator
Load steps	Target load	Additional comments	V_{SD} [kN]	M_{SD} [kN.m]	F [kN]
STEP 1	20% * 1.25 *$V_{SD.max}$	Load and unloading	453.78	726.05	= 2*V_{SD} = 907.6
STEP 2	1.25 *$M_{SD.max}$		1460.8	2337.3	= 2*V_{SD} = 2921.6
STEP 3	1.25 *$V_{SD.max}$		2268.9	3630.2	= 2*V_{SD} = 4537.8
STEP 4	Maximum actuator force		3007.2	4811.5	6014.4

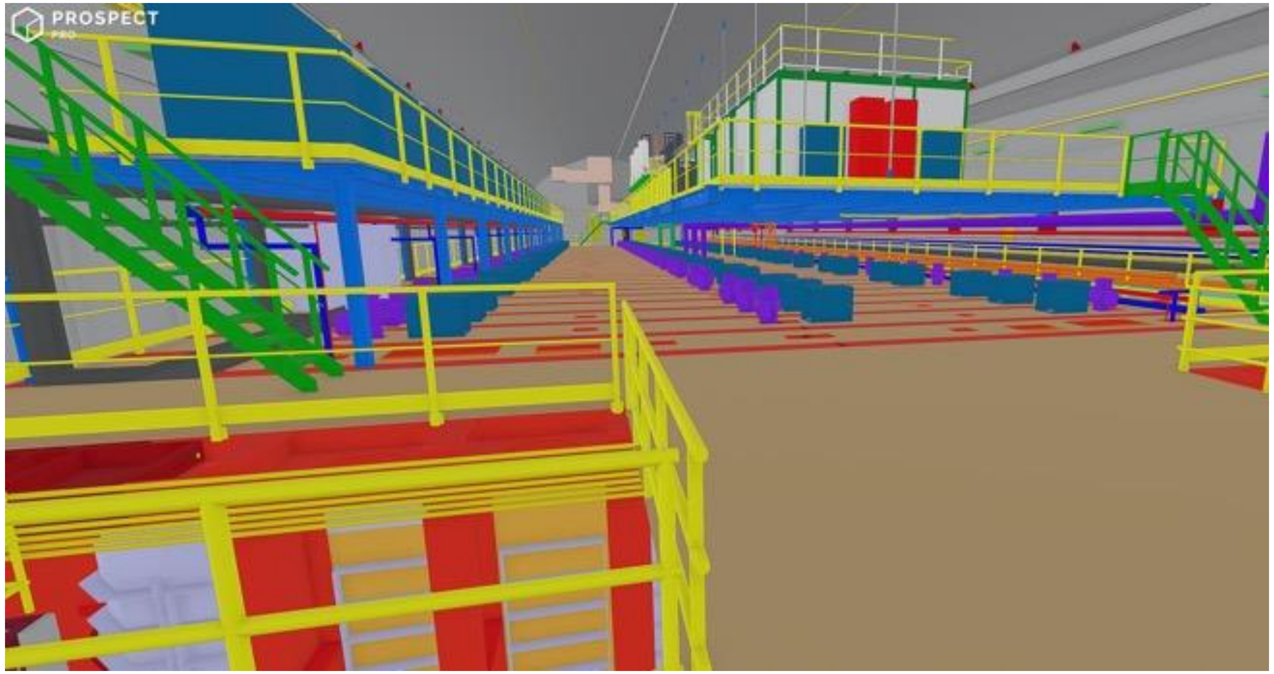
$V_{SD} = F/2$
$M_{SD} = F/2 \cdot 1.6\ m = V_{SD} \cdot 1.6\ m$

$1.66 \times V_{SD.max}$ with $2.57 \times M_{SD.max}$

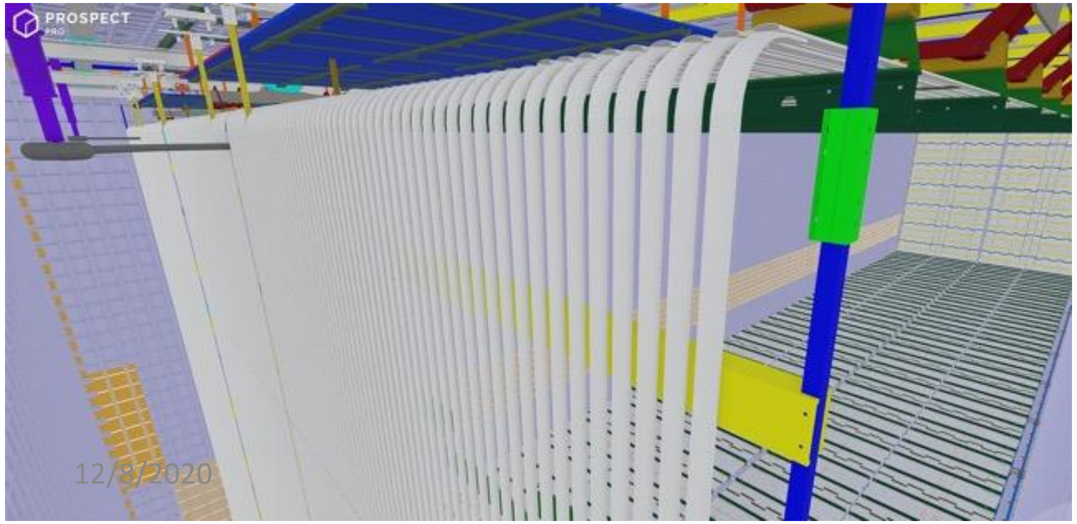


Virtual Reality as a tool to inspect engineering designs

- Overviews



- Inspection of elements in details



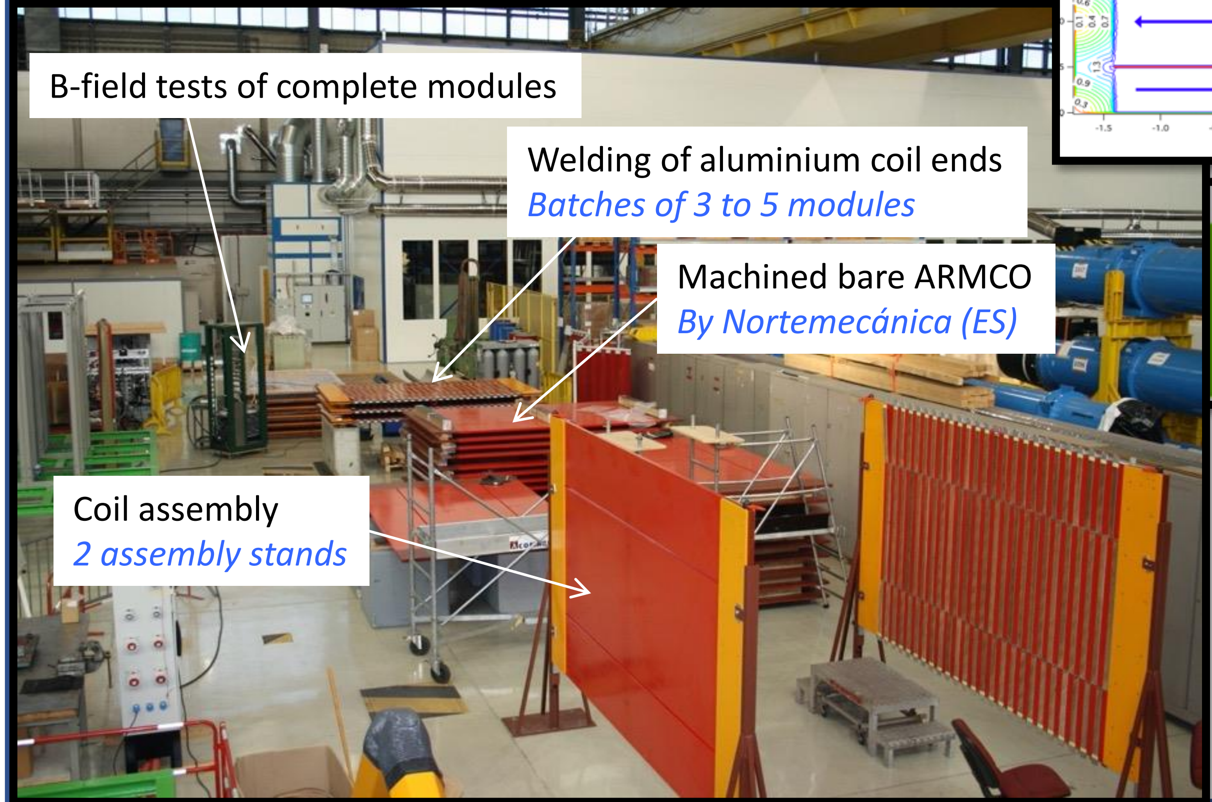
NP05 : Baby Mind
NP07 : ND280

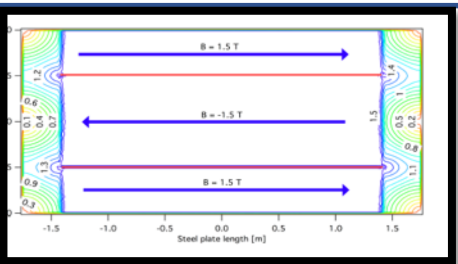
Contribution to the Japanese program: T2k Near detectors

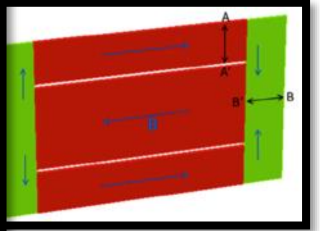
- Main systems (institutes responsible in brackets):
  - **Magnet** modules **(CERN)**
  - **Scintillator** modules **(INR Moscow and UniGe)** – assembled in building 190.
  - **Readout electronics (UniGe and Sofia)**
  - **Support mechanics (UniGe)**

- Magnet project:
  - Design and construction **(CERN)**
    - Excellent **modularity**
    - 2 tons ARMCO steel per module
    - aluminium coil
    - 1.5 T, **extremely uniform B-field** in the region of interest ($B=B_x$, with B_y and B_z components negligible)
    - Low power consumption: 350 W per module
  - First prototype March 2016
  - **Construction phase** September 2016 to mid-February 2017: building 180
    - 33 modules (construction 3-to-4 days/module)
    - completed 2 weeks ahead of schedule.

Magnet module assembly x 33 modules

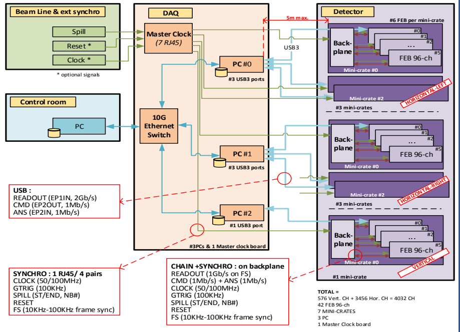






Custom scintillator modules x 18 modules

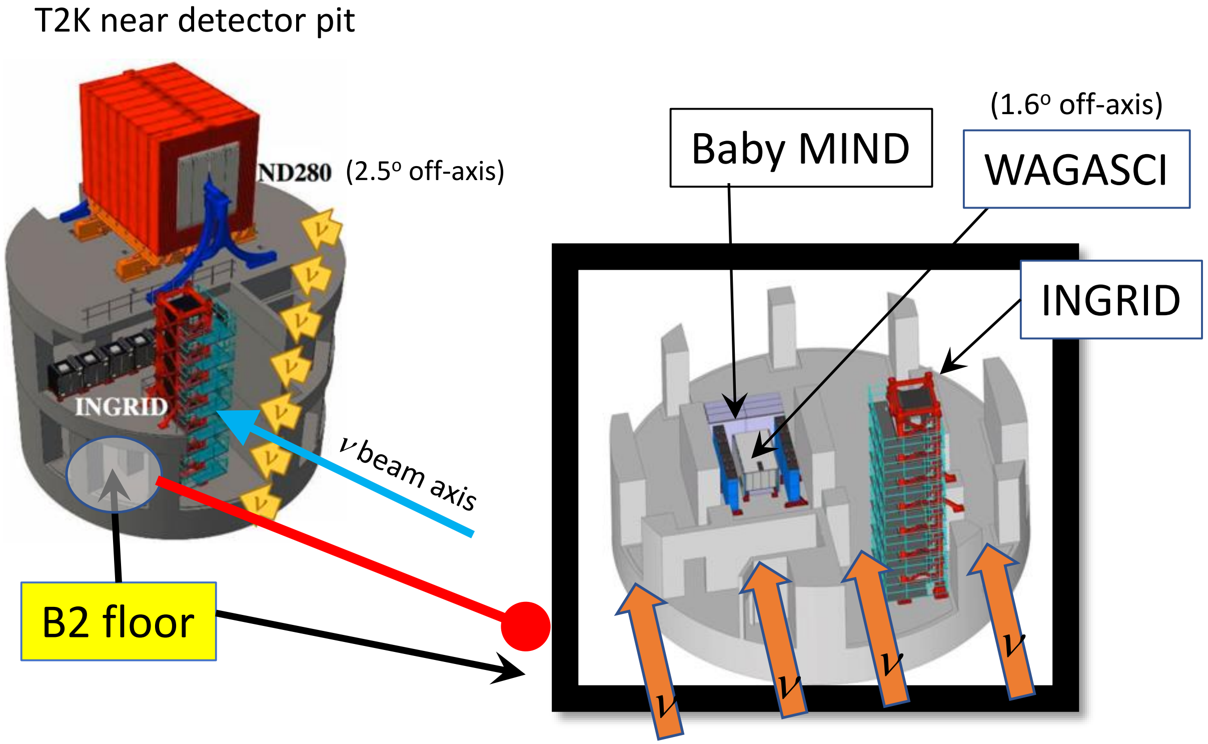
Custom readout electronics



Support mechanics for transport to Japan x 4 blocks

Baby MIND at J-PARC

Installation and data taking

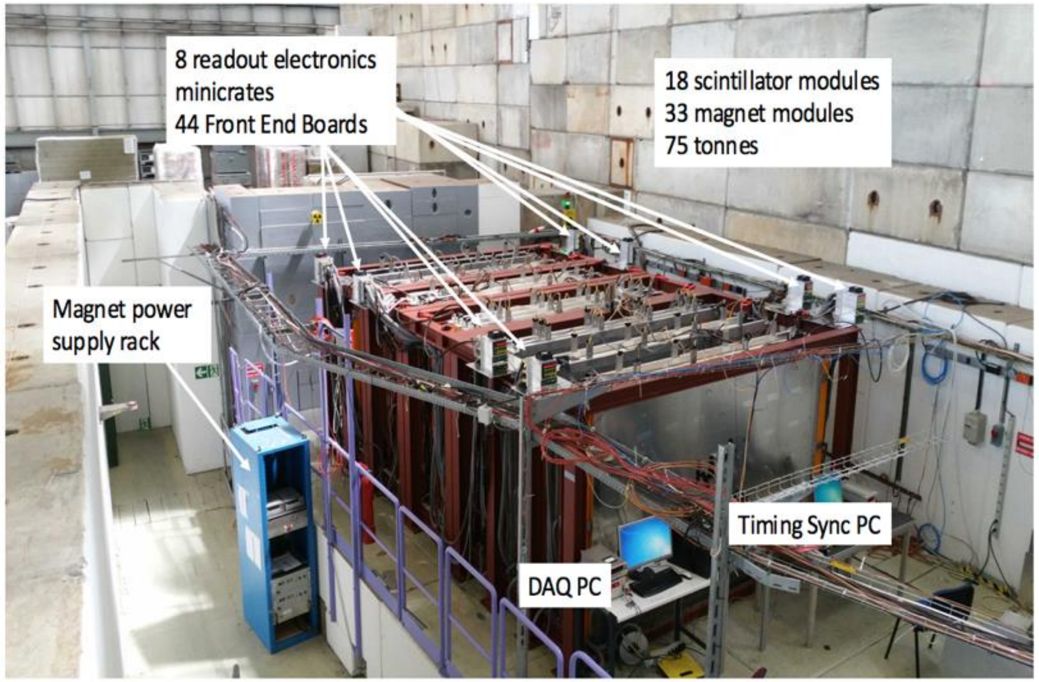


- **Transport** of 4 "chassis":
  - **Open top** containers **x4**
  - Leave **CERN**: October '17
  - Arrived **J-PARC**: December '17

- **Two phases at J-PARC:**
- **Phase 1:** ***Installation (Q1/2018), commissioning (Q2/2018)***
- **Phase 2:** ***Experimental programme:***

  - (anti) neutrino cross-section measurements with T59 (WAGASCI)
  - longer term possibilities for nu_mu/e, anti nu_mu/e with new detector systems for ND280 upgrade, high pressure TPCs…

WAGASCI/Baby Mind muon detector

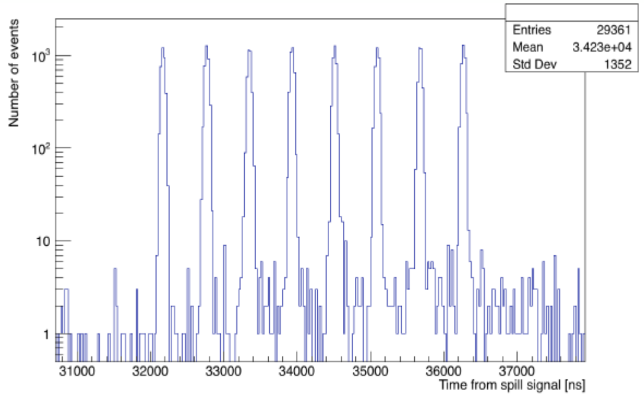


Assembled and tested in the SPS test beam in 2017

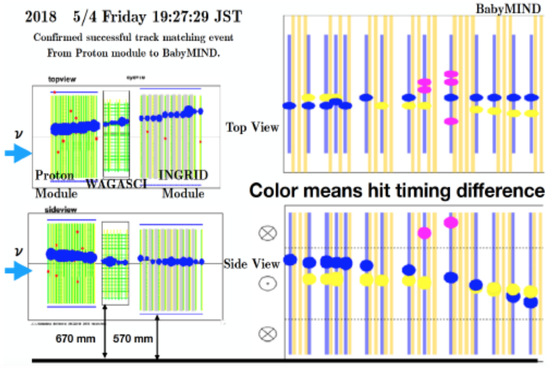
Transported and reassembled at J-Park in February 2018

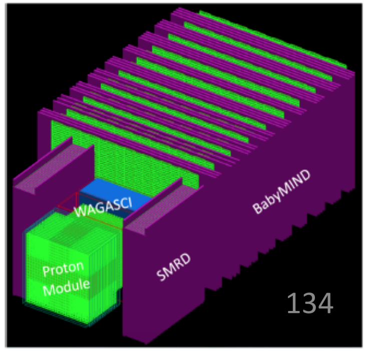
Commissioning with beam in anti-neutrino mode at J-PARC: 9 March - 31 May 2018

8-bunch beam structure clearly seen in neutrino interactions recorded by Baby MIND (J-PARC nu beam spill has 8 bunches)



Event rate measured by Baby MIND:
~ 5.246 +/- 0.656 (stat.) 10^4 events/1500 Kg (Fe)/10^{21} P.O.T.





NP07: T2K new near detector

- Support to the test beam activities in 2018
- Support to the SuperFGC prototype demonstrator and test beam in 2018
- A new laboratory at EHN1 for the assembly and test work
- Help in preparation of the LOI and Technical proposal
- Next MOU signature (see future chapter)

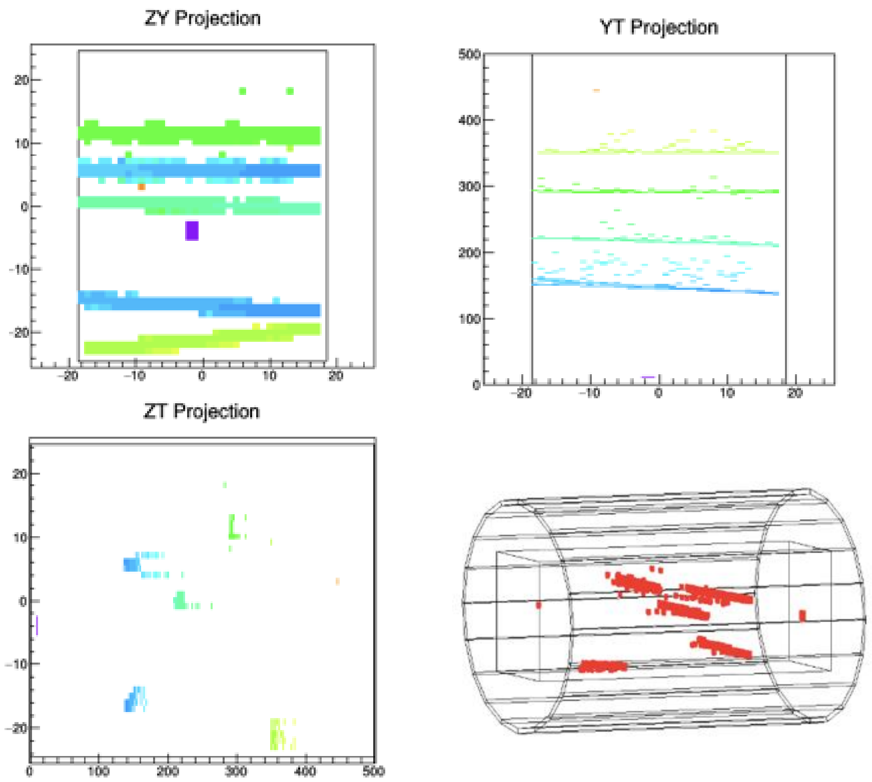
Near Detector studies, prototypes and test beams

New test beams in T9 area at CERN

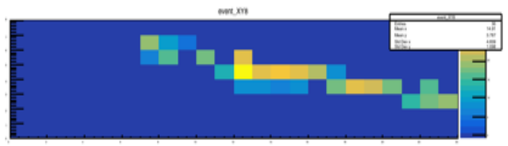
Atmospheric gas TPC with resistive MicroMegas

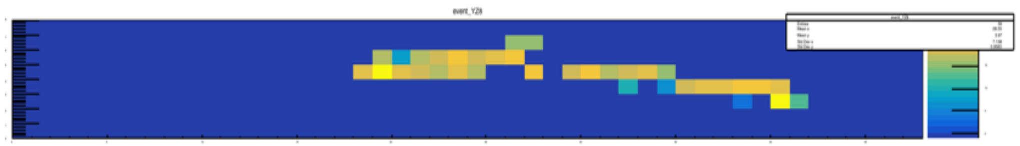
SuperFGD detector in B-field from 0.2T to 0.7T (MNP17 magnet)

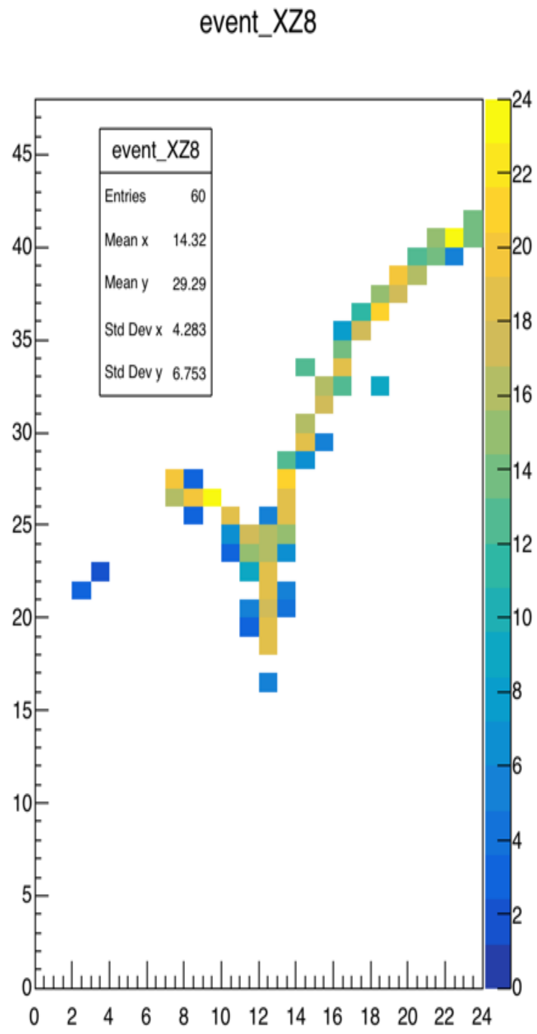
Electrons in the TPC during photon beam



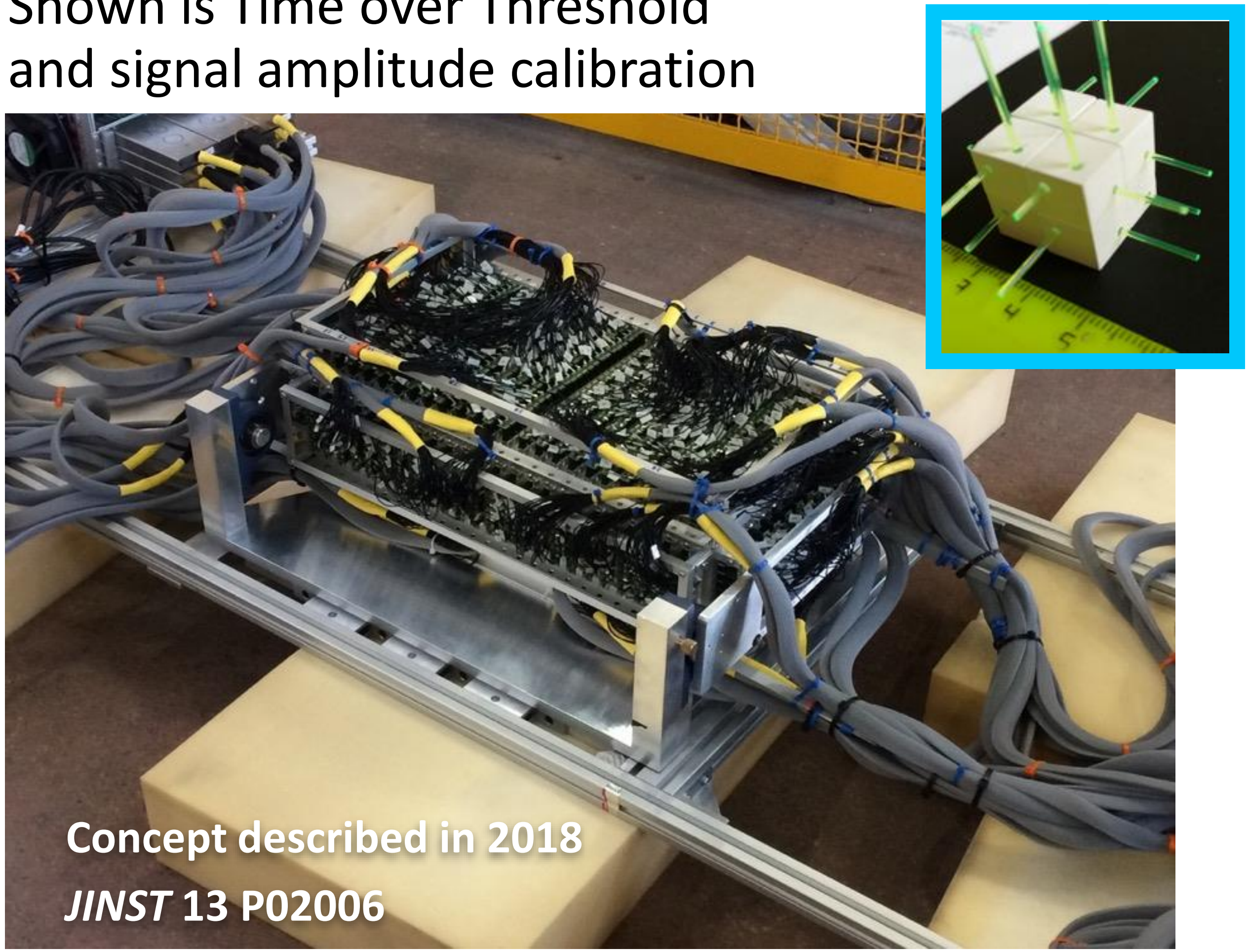
SuperFGD Detector size: 24 cm (width) x 8 cm (height) x 48 cm (length)



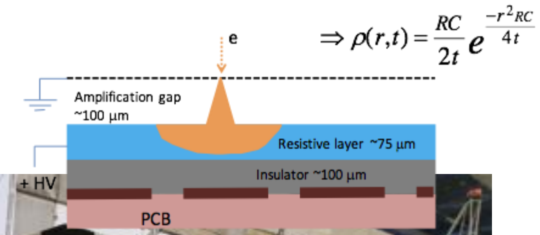


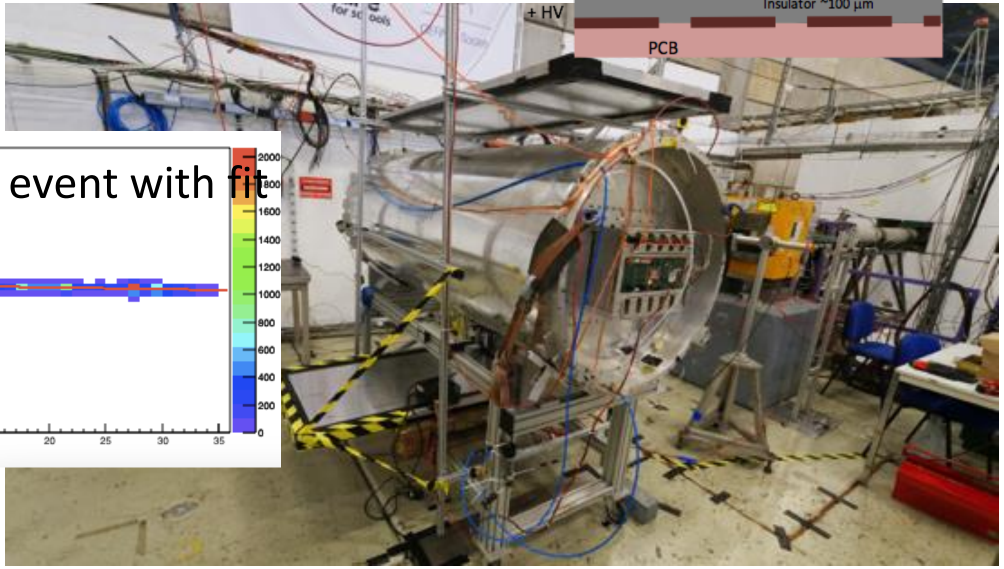


Shown is Time over Threshold
and signal amplitude calibration

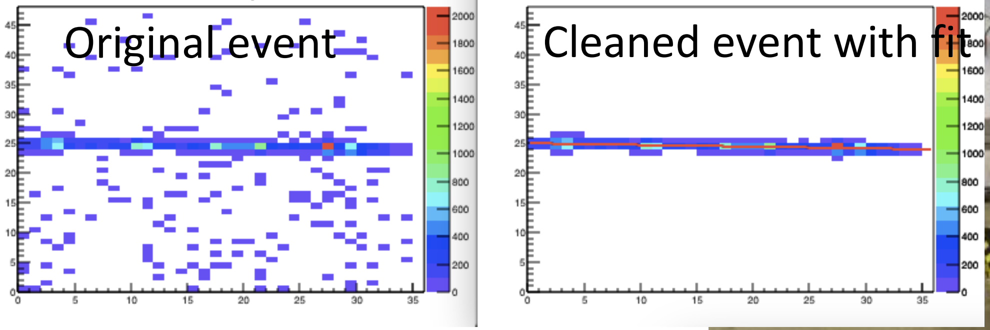


TPC test beam: characterization of the resistive Micro Mega Using HARP TPC

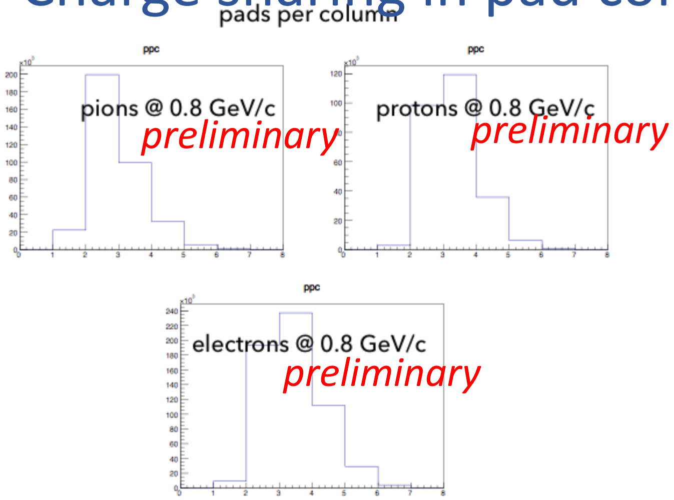




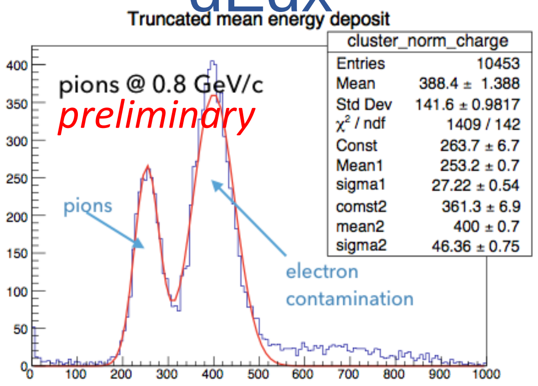
pions @ 0.8 GeV/c



Charge sharing in pad columns



dEdx



Point resolution