AIDA 2020

WP8/NA7 Large scale cryogenic liquid detectors

AIDA 2020 Final Annual Meeting

Videoconference 30/4/2020

Conveners: D.Autiero (IP2I Lyon) and S.Murphy (ETHZ)

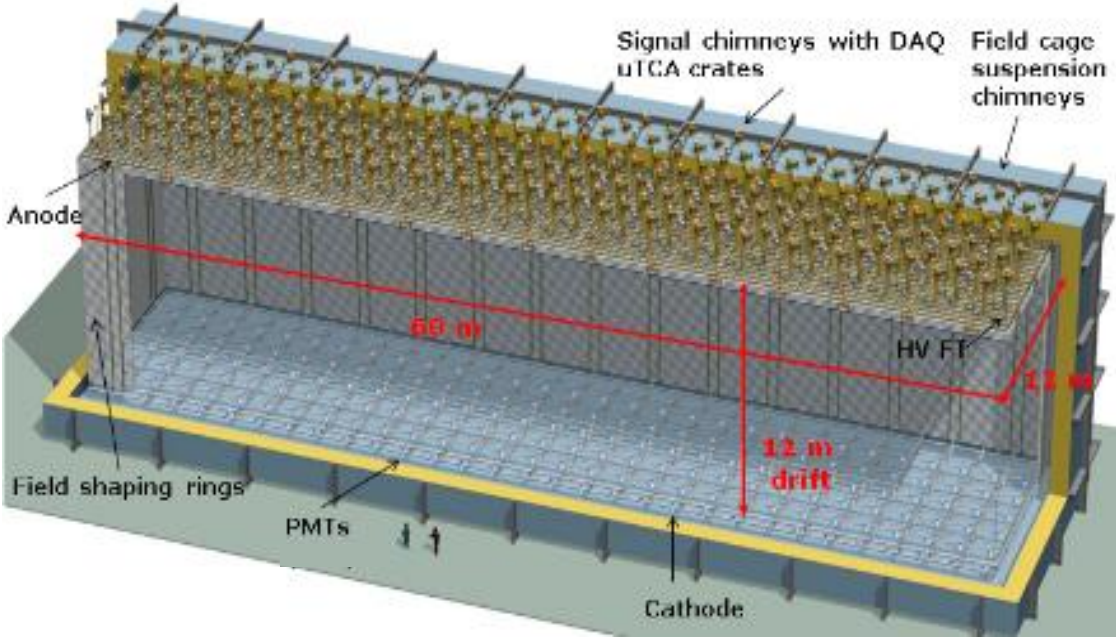
Cryogenic Detectors NA

Table 1.2: Quantities of items or parameters for the 12.096 kt DP module

Item	Number or Parameter
Anode plane size	W = 12 m, L = 60 m
CRP unit size	W = 3 m, L = 3 m
CRP units	4 × 20 = 80
LEM-anode sandwiches per CRP unit	36
LEM-anode sandwiches (total)	2880
SFT chimney per CRP unit	3
SFT chimney (total)	240
Charge readout channels / SFT chimney	640
Charge readout channels (total)	153,600
Suspension feedthrough per CRP unit	3
Suspension feedthroughs (total)	240
Slow Control feedthrough per sub-anode	1
Slow Control feedthroughs (total)	80
HV feedthrough	1
HV for vertical drift	600 kV
Voltage degrader resistive chains	4
Cathode modules	80
Field cage rings	197
Field cage modules	288
PMTs (total)	720 (1/m^2)

Dual-Phase DUNE FD: 20 times replication of Dual-Phase ProtoDUNE (drift 6m → 12m) DUNE Conceptual Design Report, July 2015

Active LAr mass:12.096 kton, fid mass:10.643 kton, N. of channels: 153600



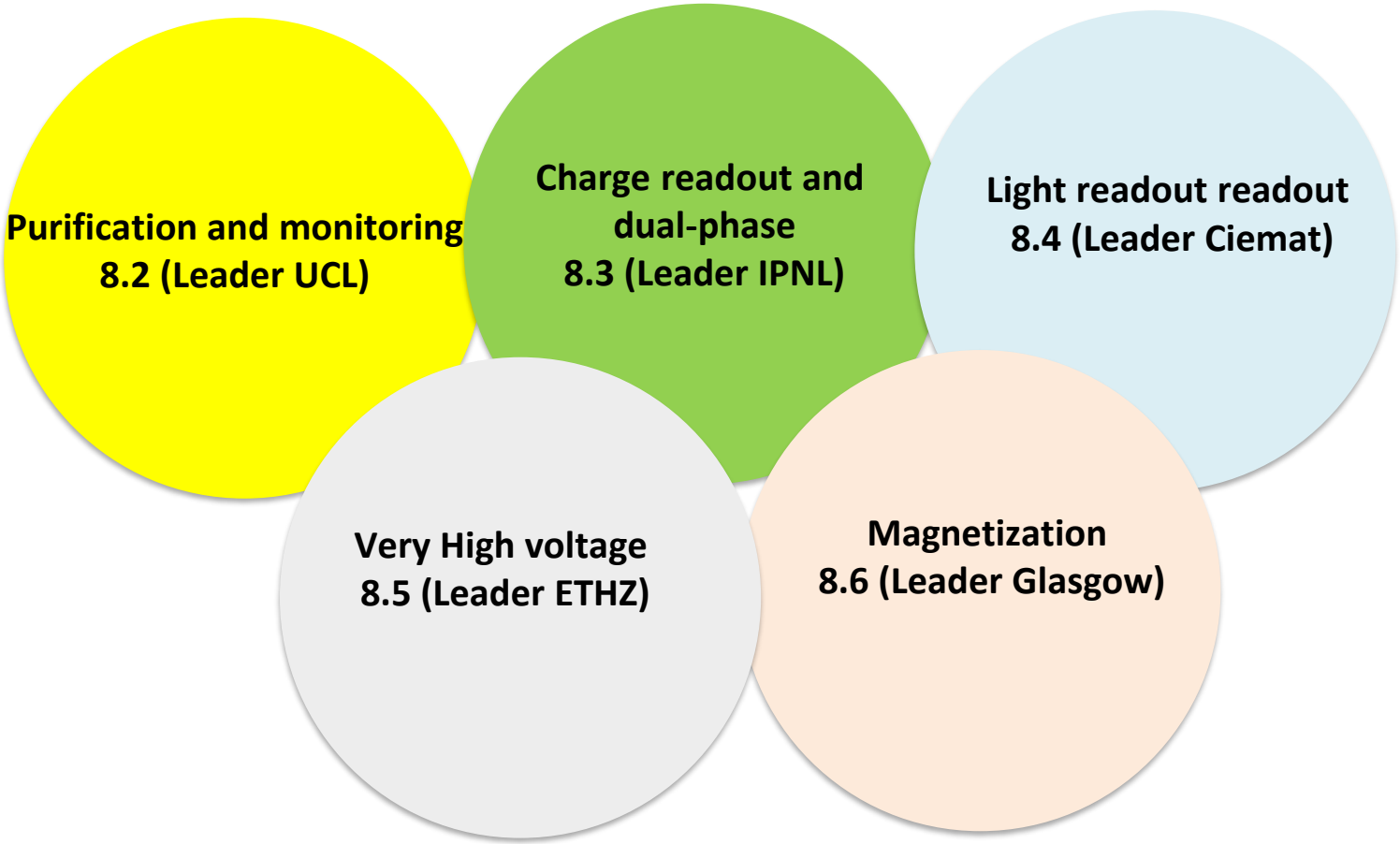
Advantages of dual-phase design:

- Gain in the gas phase → robust and tunable S/N, lower detection threshold, compensation for charge attenuation due to long drift paths
- Finer readout pitch (3.125 mm), implemented in two identical collection views (X,Y) on 3m long strips
- Long drift projective geometry: reduced number of readout channels (153,600 for DP less than half of equivalent SP FD), absence of dead materials in the drift volume
- Fewer construction modules
- Full accessibility and replaceability of cryogenic front-end (FE) electronics during detector operation

Cryogenic Detectors NA

Five strategic topics corresponding to the frontier developments in the field in the direction of making possible the construction of large cryogenic detectors

→ Worldwide impact on the community working on large cryogenic detectors



Collaborating institutes: CIEMAT, CEA, LHEP Bern, ETHZ, Genève, Glasgow, IN2P3 (IPNL, APC, LPNHE, LAPP), UCL; strong connections with the US groups involved in the common project DUNE

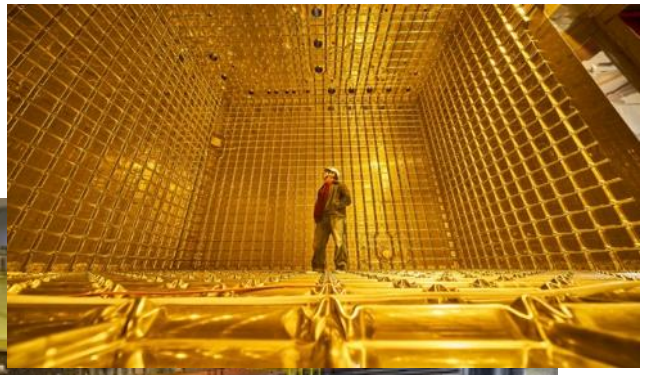
Cryogenic Detectors NA

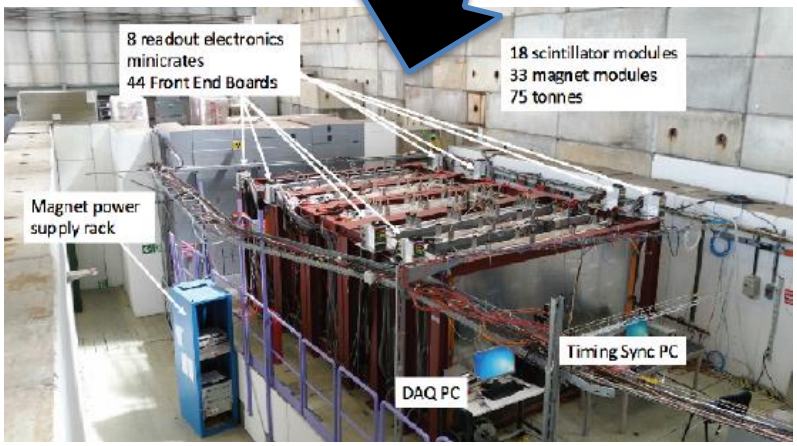
Common infrastructures of the WP8 for the R&D activities at CERN supported by the CERN Neutrino Platform

- 3x1x1 m^3 Dual-phase WA105 Pilot detector

- 6x6x6 m^3 Dual-phase Demonstrator (WA105/NP02/dual-phase ProtoDUNE)

- Baby MIND prototype (NP05)





Cryogenic detectors Networking Activity:

Basic concept and modus operandi:

- **Benefit from the R&D infrastructure at CERN for WA105** and of other infrastructures available in different laboratories (piggy-back)
- Integrate the hardware available in these infrastructures in a networking activity with dedicated personnel (→main requests to AIDA II in terms of manpower: postdocs contracts)
- Matching funds from other personnel involved in the activities and existing equipment

Goals:

- Networking and exchange among the existing EU expert groups involved in the development of the most innovative experimental techniques
- Reviewing and reporting on some crucial development aspects for large cryogenic detectors.
- Sharing of information and tools (dissemination) in the community and creation of a state of the art common knowledge of the field broadly applicable in future projects

Deliverables

https://twiki.cern.ch/twiki/bin/view/AIDA2020WP8/WebHome

Welcome to the AIDA2020 WP8 wiki pages

The Networking Activity (NA7) on Large Scale Cryogenic Liquid Detectors is a Work Package (WP8) of the AIDA2020 project. WP8 fosters knowledge sharing and common tools in the neutrino community as regards state-of-the-art in very large cryogenic liquid detectors.

The construction of liquid argon detectors at the 10 kton scale is an essential ingredient of the international long-baseline neutrino program unifying the European and USA efforts.

WP8 activities focus on some among the most challenging aspects related to this large scale detectors development:

- Task 8.2 Purification and monitoring
- Task 8.3 Charge readout and dual-phase readout technology
- Task 8.4 Light readout
- Task 8.5 Very High Voltage (VHV)
- Task 8.6 Magnetisation

WP8 benefits, in order to conduct specific R&D activities, of hardware infrastructures and prototypes (3x1x1 m^3 LAr detector, 6x6x6 m^3 LAr detector and Baby Mind) supported by the CERN Neutrino Platform.

These wiki pages are devoted to the **dissemination** of the outcome of the WP8 reviewing and networking activities and of the results of some specific R&D aspects developed in the framework of WP8

The deliverables of AIDA2020 are defined in more general terms independently on the single test infrastructures/experiments (3x1x1, cold-box ProtoDUNE-DP, Baby-Mind, DUNE,)

Deliverables include a part related to networking and general dissemination (Networking Reviewing and Sharing) and aspects of the R&D which have been isolated from the context of the specific experiments

→ combine the general dissemination goal and the documentation of specific aspects by writing the deliverables under the form of Twiki pages for broader diffusion in the community

Cryogenic Detectors NA

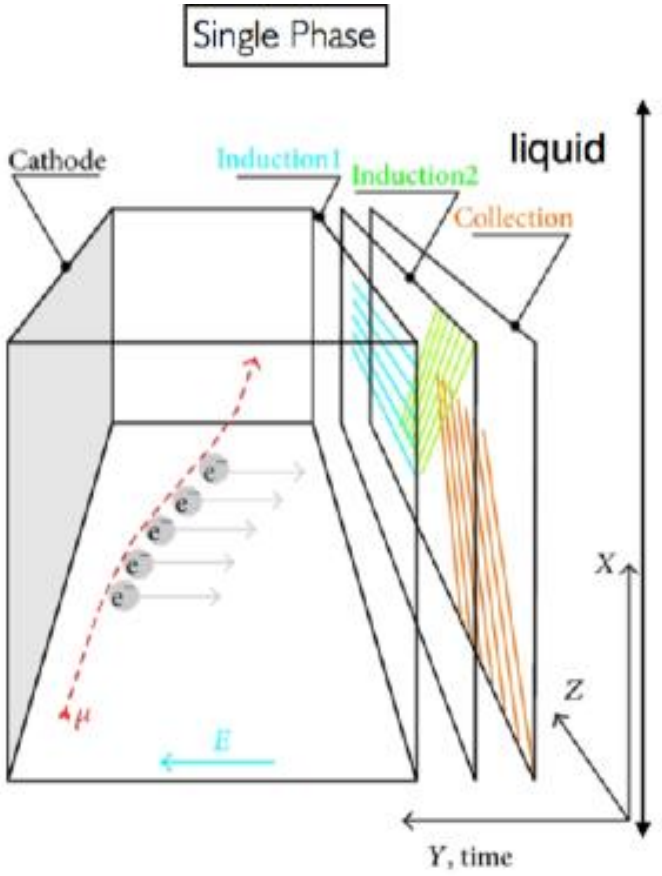
- **Deliverables successfully achieved:**

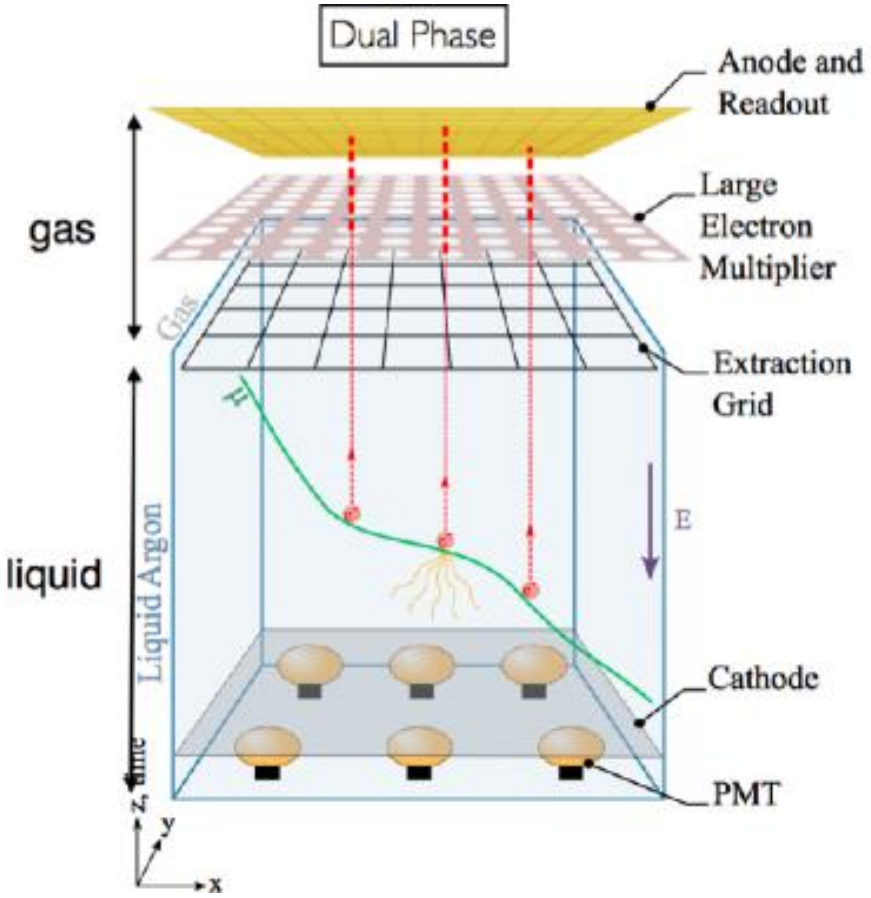
D8.4	Very high Voltage	WP8	M40	31/08/2018	Achieved	Report
D8.1	Purification and monitoring	WP8	M44	21/12/2018	Achieved	Report
D8.3	Light readout	WP8	M46	29/03/2019	Achieved	Report
D8.5	Magnetisation of large-scale cryogenic liquid detectors	WP8	M46	08/03/2019	Achieved	Report
D8.2	Charge readout and double phase	WP8	M54	19/12/2019	Achieved	Report

- Role of WP8 also in the education of young scientists (4 Postdoc and 2 PhD students)
- Synergies with WP13 (micro-pattern gas detectors) and WP3 (reconstruction)

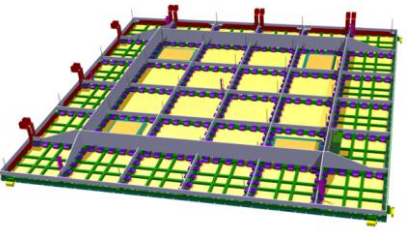
Cryogenic Detectors NA

Liquid Argon Time Projection Chamber readout

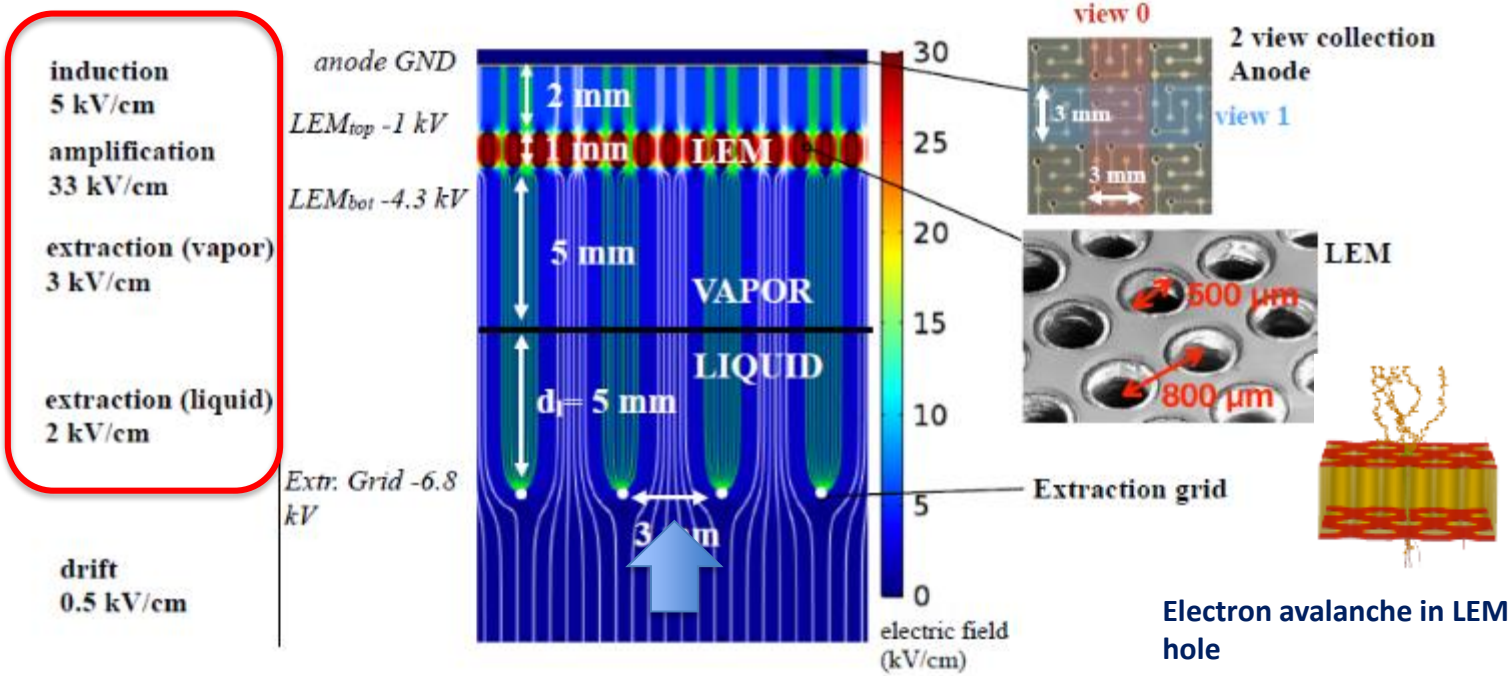




Cryogenic Detectors NA

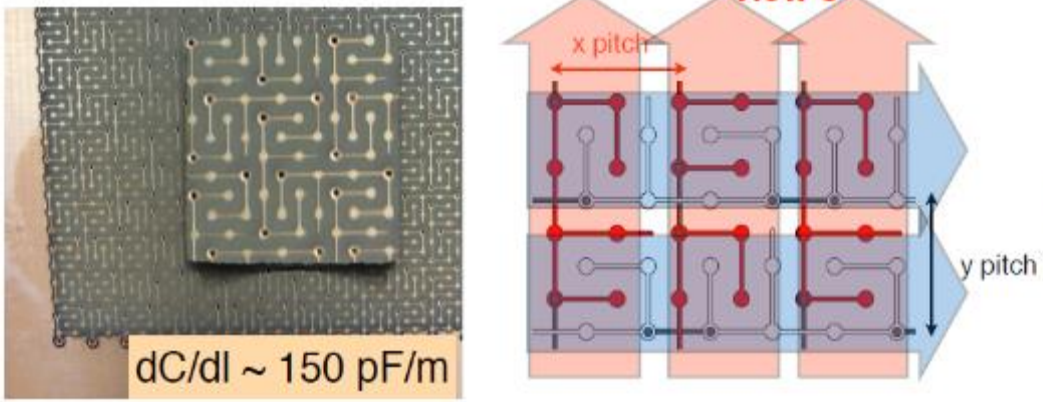


Charge Readout Plane integrating LEM-anode sandwiches

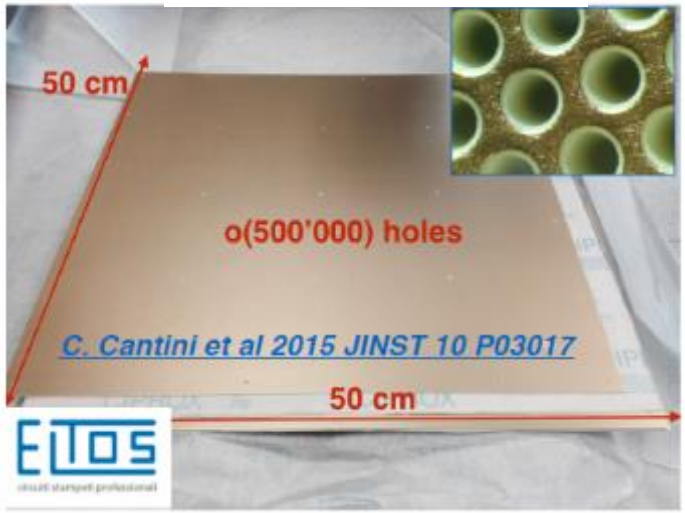


Electron avalanche in LEM hole

50x50 cm² anodes with 2 collection views



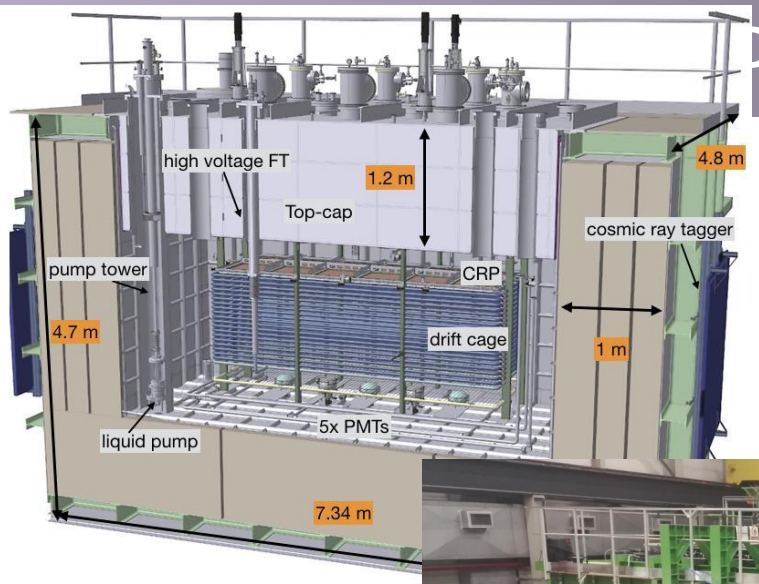
50x50 cm² LEM

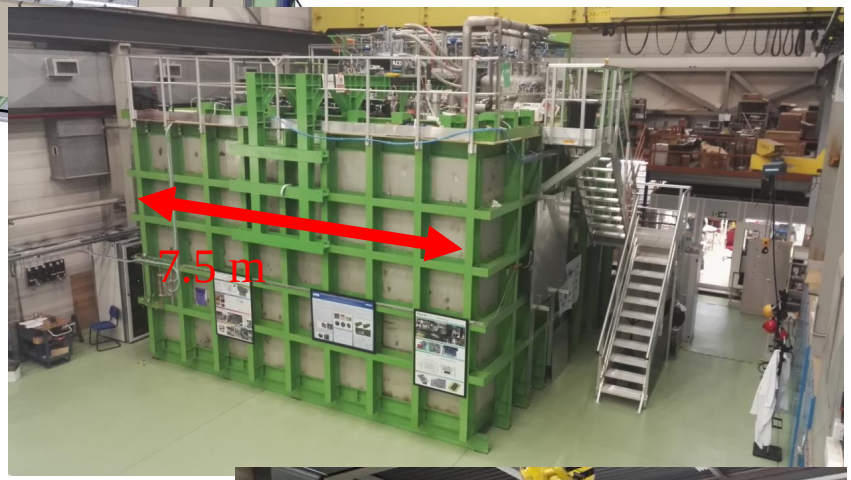


ors NA

3x1x1:
1280 readout channels
Operation 2016-2017

Successful in proving the dual-phase concept for a LArTPC at the $3m^2$ readout scale.

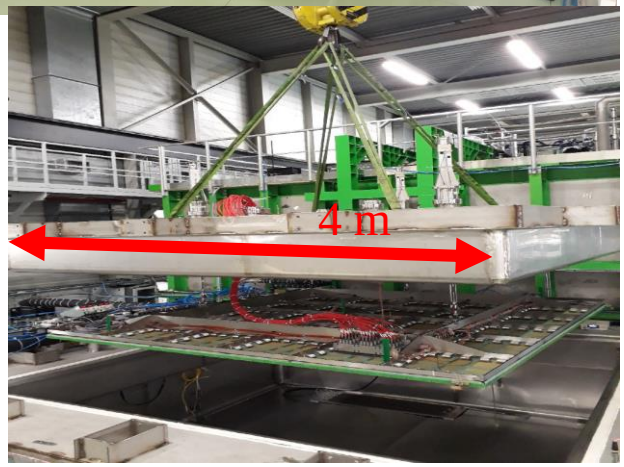




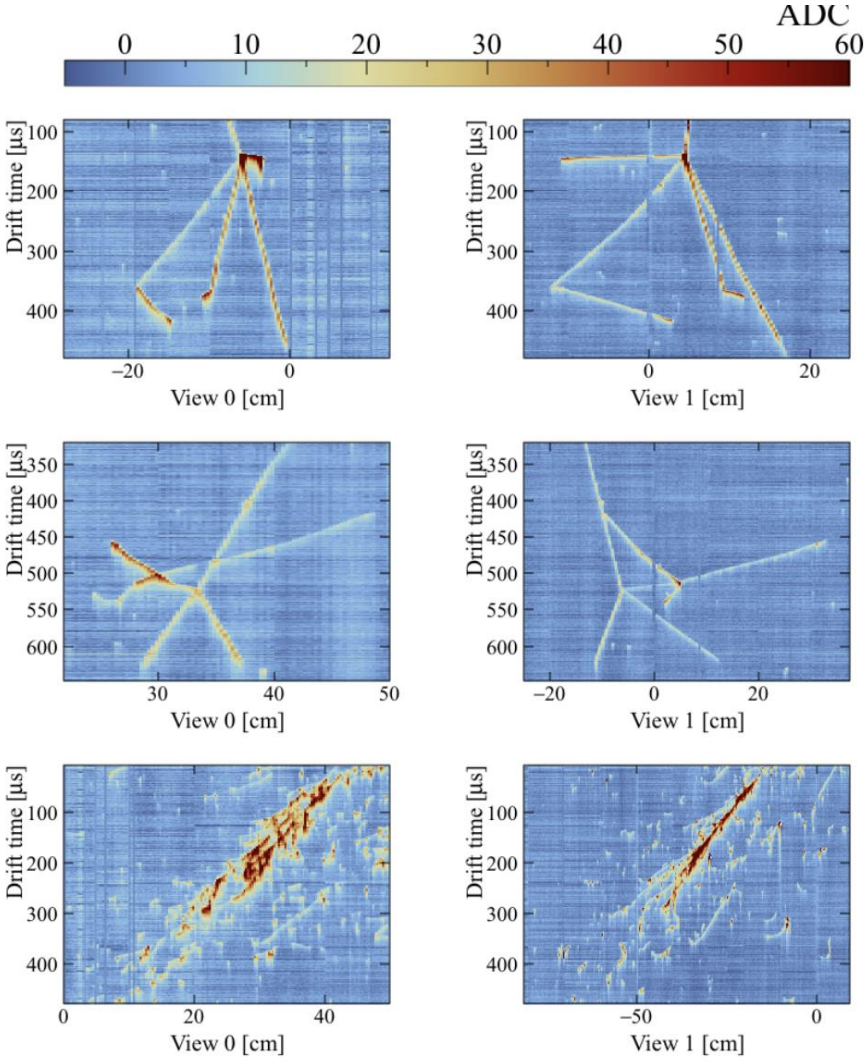
- 1st GTT membrane cryostat prototype
- Purification and monitoring
- Charge readout Electronics + DAQ
- Light readout
- Very High Voltage

Cold Box:
Summer 2018
Perform electrical and mechanical tests of each final CRP in nominal thermodynamic conditions:

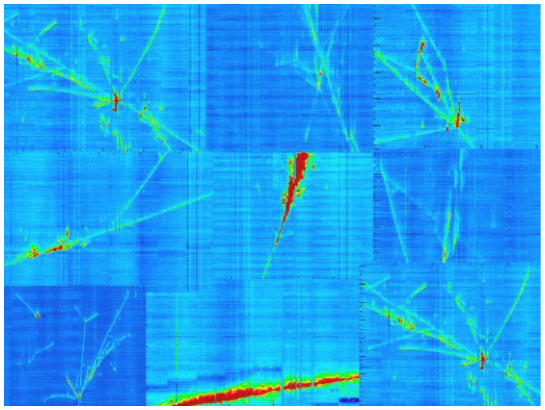
- Characterization of the HV operation of each LEM
- Characterization of the HV operation of the extraction grid
- CRP planarity test
- Test the tensioning of the extraction grid wires
- Test of the HV contacts and connections (LEM & grid)



Cryogenic Detectors NA



hadronic and EM showers from cosmic rays recorder in the 3x1x1

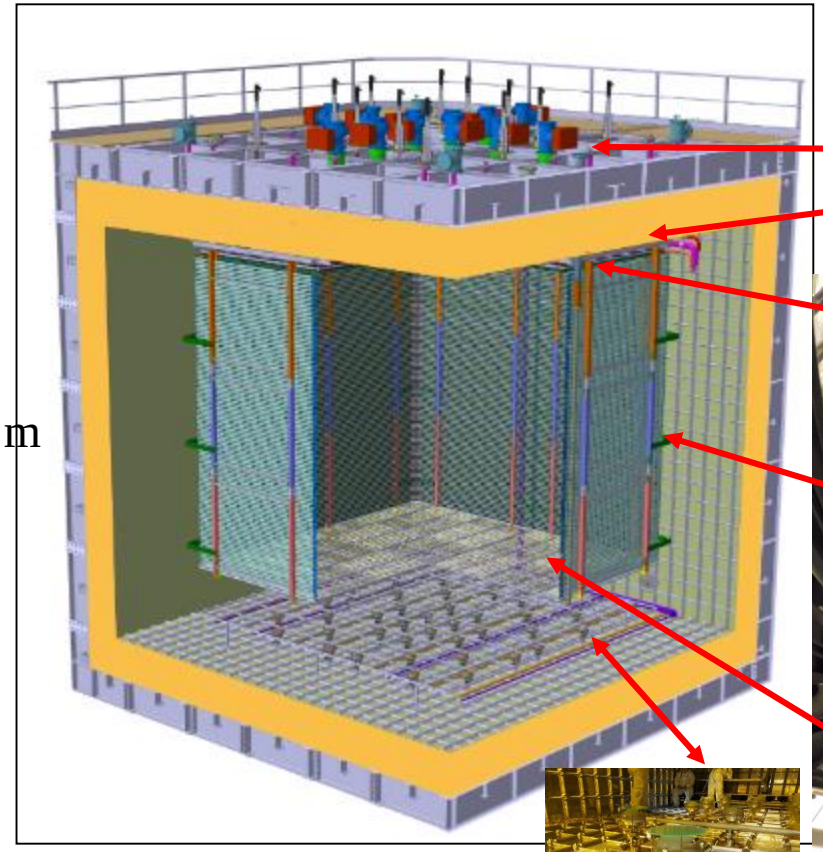


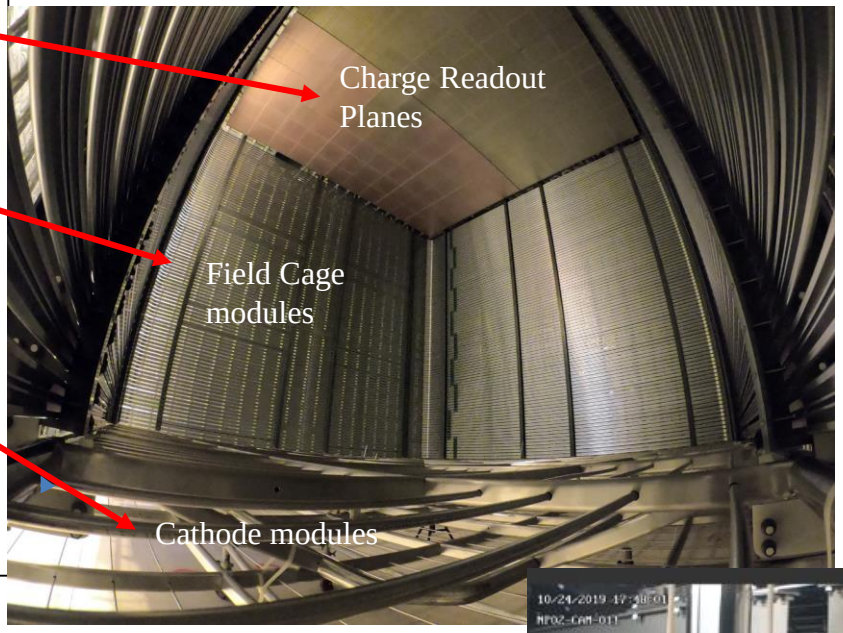
350 k cosmic events recorded with a ton scale dual phase LAr TPC. The operation allowed for tests and results concerning the activities of task 8.2 (purification), 8.3 (charge readout) 8.4 (light readout) and 8.5 (Very high voltage). Includes interface to WP13 for the event reconstruction.

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

Cryogenic Detectors NA

DUNE 10 kton dual-phase design based on protoDUNE dual-phase:
6x6x6 active volume

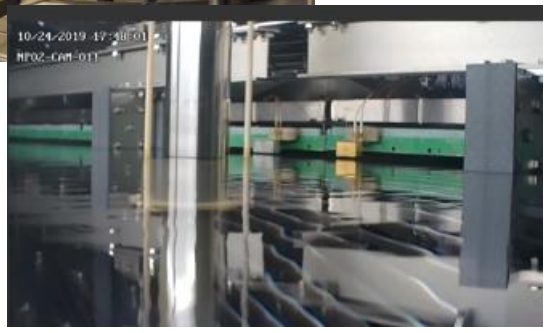




36 cryogenic photomultipliers with wavelength shifting coating

Operating at CERN since August 2019

Inside view of the detector filled with Liquid Argon



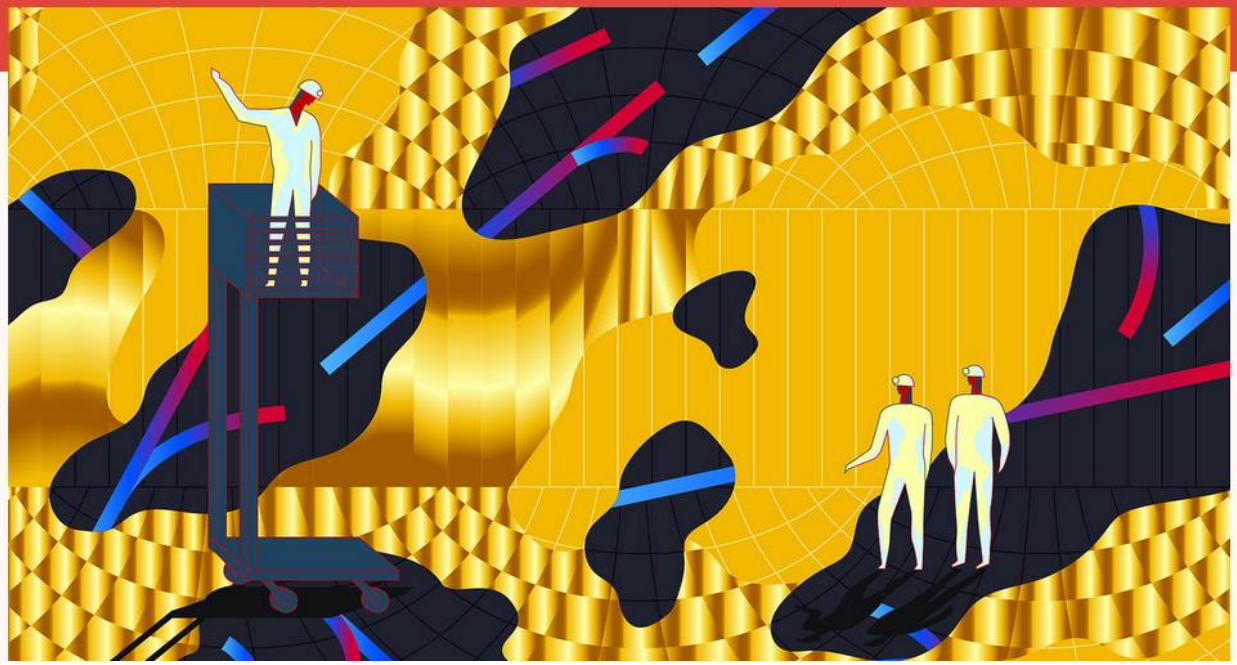
Cryogenic Detectors NA

symmetry
dimensions of particle physics
topics
follow +
A joint Fermilab/SLAC publication

DUNE scientists see particle tracks with dual-phase technology

10/14/19 | By Kurt Riesselmann

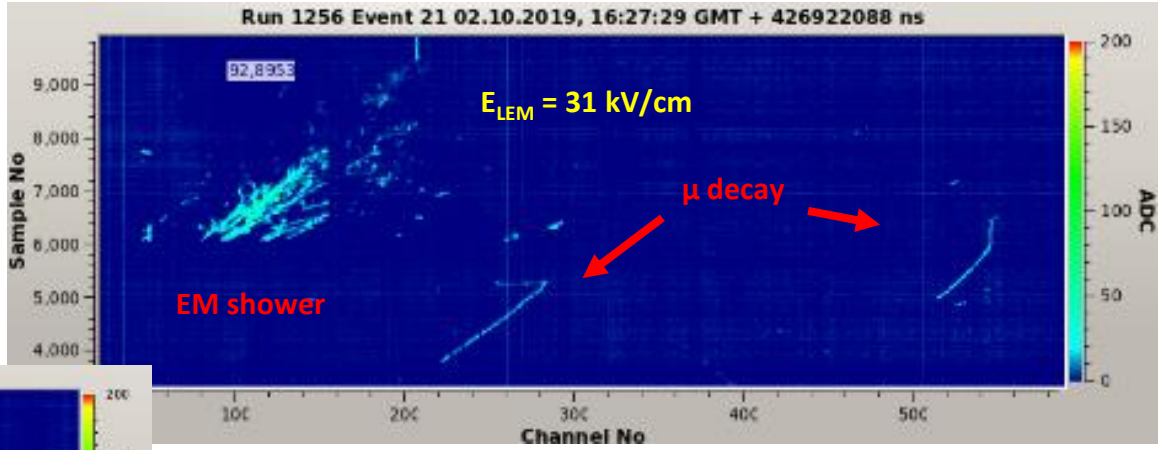
Scientists working at CERN have started tests of a new neutrino detector prototype that uses a promising technology called "dual phase."



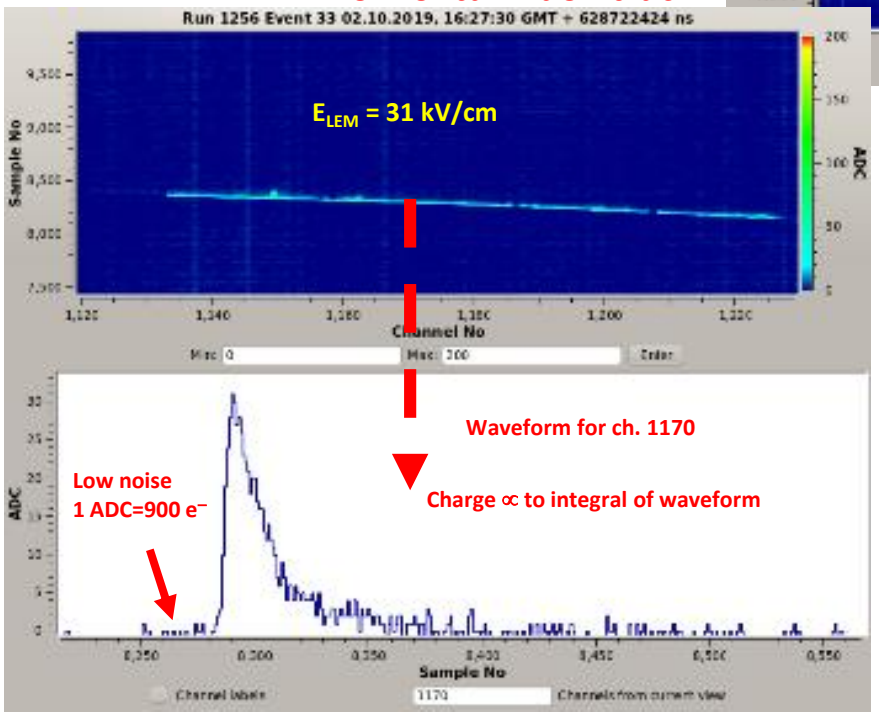
Cryogenic Detectors NA

Cosmic ray events
in protoDUNE dual-phase

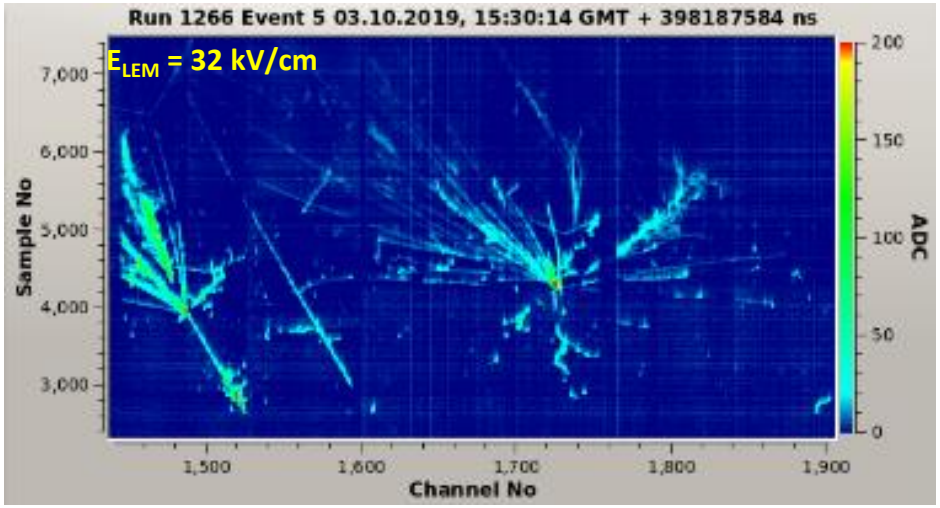
Electromagnetic shower + two muon decays



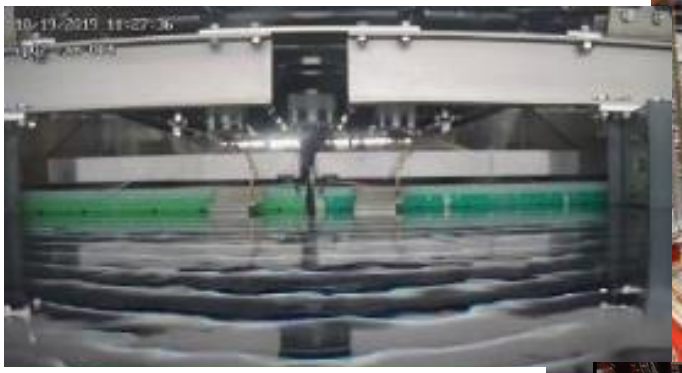
Horizontal muon track

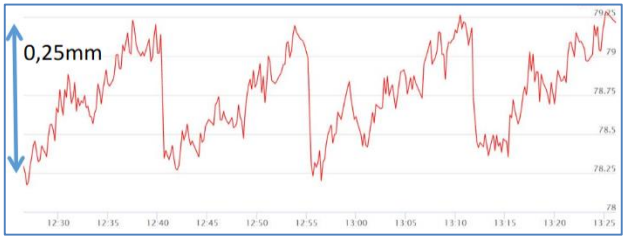


Multiple hadronic interactions in a shower

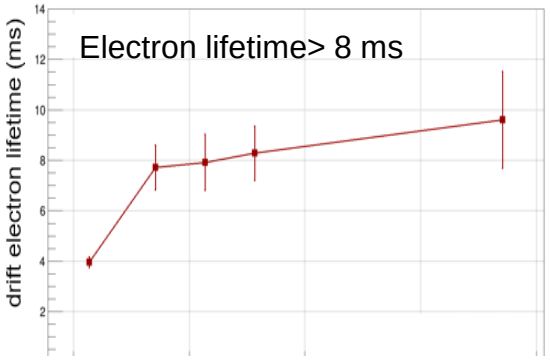


Cryogenic Detectors NA

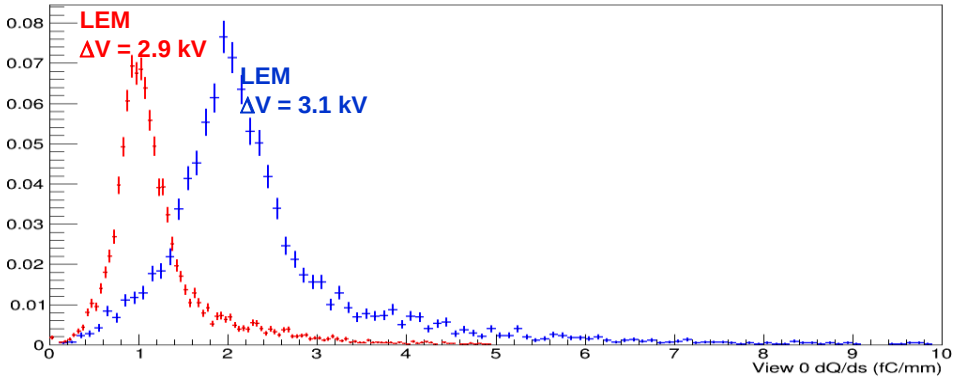




- Example of CRP adjustment w.r.t. LAr level in steps of 0.25 mm performed with high accuracy level meters during constant LAr level increase in the cryostat



- Accessibility from the cryostat roof to Front-End cryogenic electronics at the bottom of the SFT chimneys during detector operation



- dQ/dx distributions changing LEM gain and some examples of CRP gain measurements and S/N

LEM HV	CRP gain	CRP Efficiency	LEM gain	S/N (900 e-, conservative)
2.9	2	0,63	3,2	17
3.0	2,8	0,63	4,4	24,5
3.1	4	0,63	6,3	35
3.2	7,4	0,63	12	64,8

Cryogenic Detectors NA

Task 8.6 has been dealing with the study of novel magnetization schemes for neutrino detectors, such as the Baby-MIND magnetized iron neutrino detector and with the possibility of also magnetizing large liquid argon volumes. This networking activity, involving several institutions, under the coordination of Glasgow and Geneva, has been carried out by exploiting the infrastructure provided by the CERN neutrino platform with the construction of the Baby-Mind and its exposure to a low energy beam line at the CERN PS. The Baby MIND detector was then transported to Japan and installed at the J-PARC neutrino beam, where it was commissioned and the novel magnetization scheme was able to measure neutrino interactions for the first time in May 2018.

Task 8.6 has been focusing on:

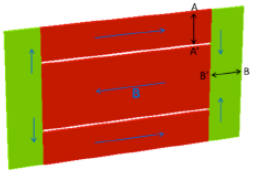
-Construction and commissioning of the novel magnetization scheme of the Baby MIND detector

-Measurements of properties of charged tracks at test beams at CERN

-Measurements of neutrino interactions in the Baby MIND detector at J-PARC

-A study on how to deal with liquid argon magnetization using superconducting lines

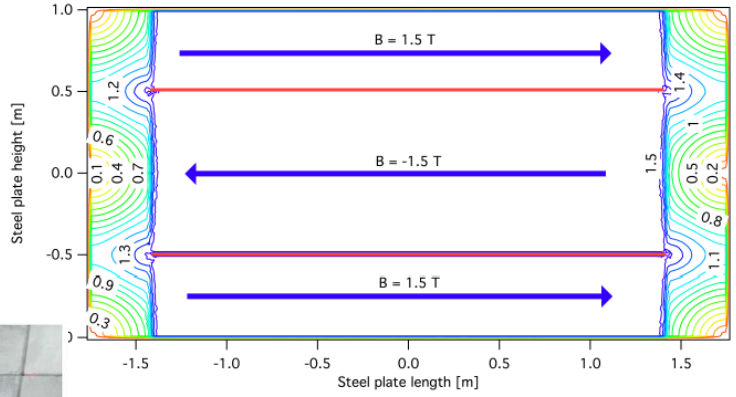
Baby MIND Magnet: A new magnetisation scheme!

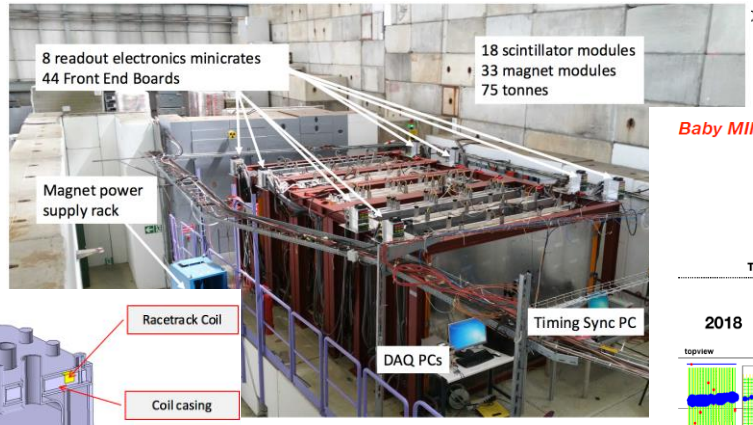


Motivations:

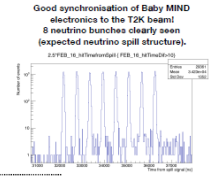
- Optimisation of B-field map.
- Address installation constraints.

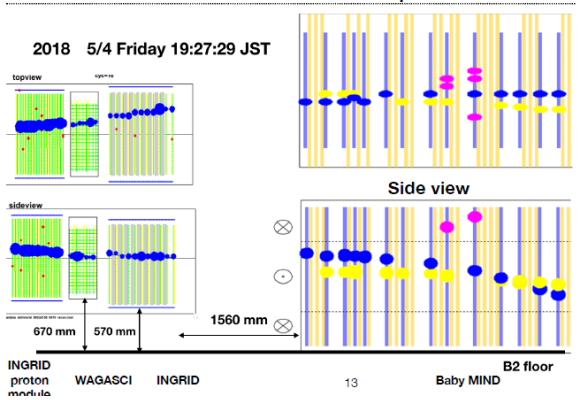
—> narrow shaft meant it was impossible to lower large objects down the experimental pit at J-PARC

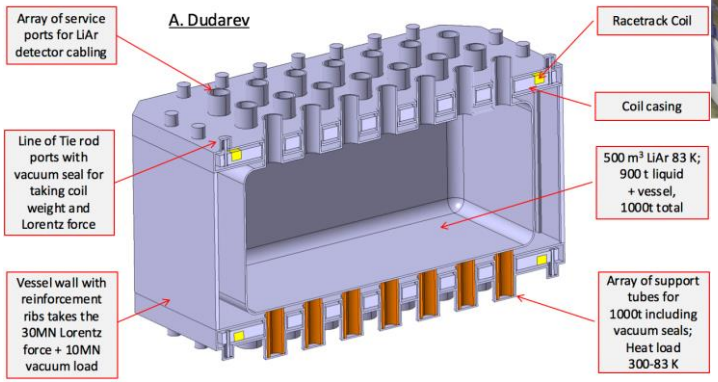




Baby MIND with WAGASCI: T2K beam



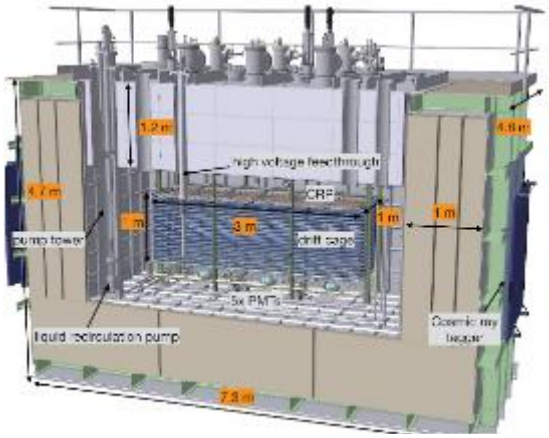


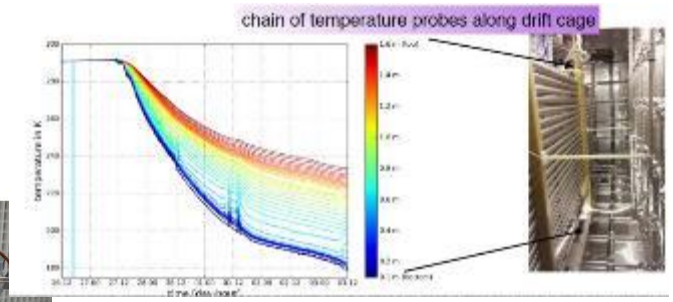


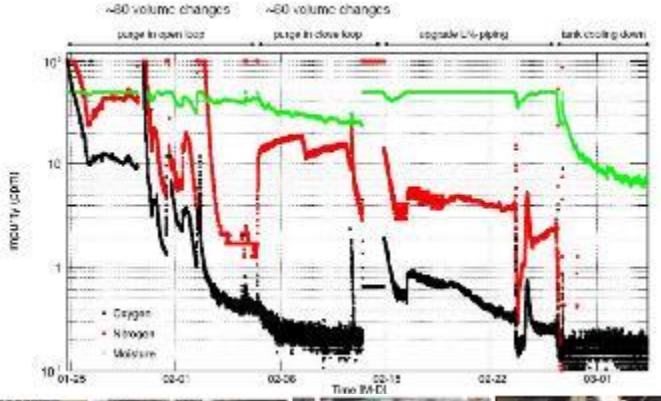
Cryogenic Detectors NA

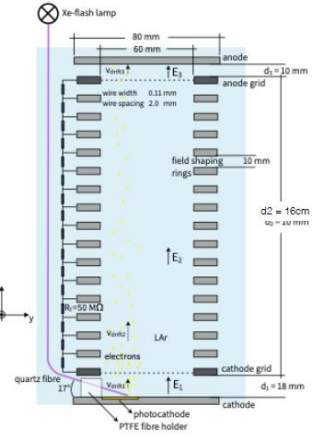
Task 8.2 deals with the study for large size scaling of purification systems for massive cryogenic detectors the assessment of common measurement techniques for purity monitoring and the review of techniques for levels control and measurement of thermodynamic conditions. This networking activity, involving several institutions, under the coordination of UCL and main contributions by ETHZ and CERN, has been regularly carried on by exploiting the infrastructure provided by the CERN neutrino platform, exploiting in 2016-2017 as a test bench application for many of these techniques the 3x1x1 m^3 WA105 prototype. For the following topics results were extracted from the 3x1x1 integration, commissioning and operation:

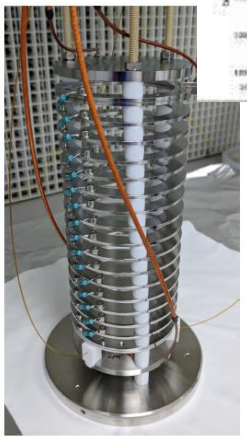
- *Large scale monitoring systems for LAr detector*
- *LAr level monitoring*
- *Cryogenic cameras*
- *Gas purity during cryostat purge*
- *LAr purity and recirculation*
- *Purity and stability of thermodynamic conditions in industrial LNG vessels*











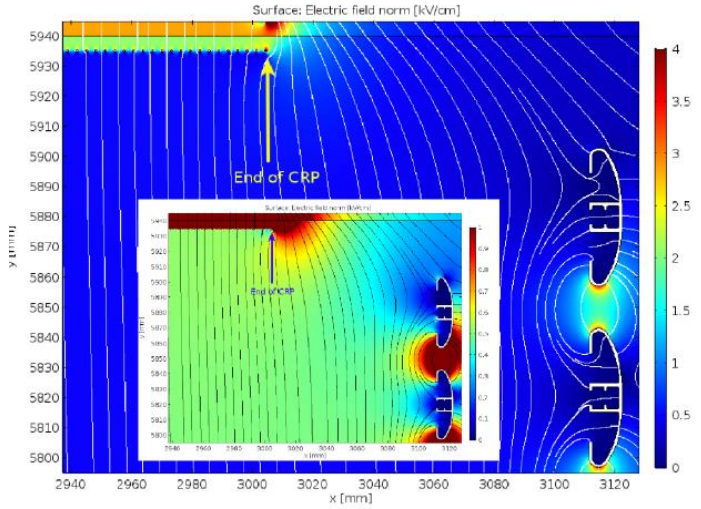
First assessment of purity in membrane cryostats
Development of various purity and control techniques
Perspective on assessment of purity limitation factors on the two protoDUNEs

Cryogenic Detectors NA

Task 8.5 deals with the delicate aspects of the generation and transport of VHV (>200 kV) in ultra pure noble liquids. The main fields that are explored are:

- *Review: very high voltage methods for large noble liquids TPCs*
- *Development of VHV simulations, critical aspects in detector design*
- *Development of VHV feedthroughs and generators, tests*
- *Construction techniques for large field cages/cathodes*

Specific results extracted from the 3x1x1 m^3 prototype activity, together with a general review on VHV generation and transport have been documented on wiki pages structure. This structure provides the AIDA-2020 deliverables for WP8 while at the same time contributing to the general dissemination of these techniques and global networking in the community.



AIDA 2020 WP8 The 300 kV power supply and feedthrough ETH

Generation of voltages at the hundred of kV scale and transport towards the cathode.

Generation: Investigated and found a 300 kV PSU, low ripple (1e-5).
transport through the cryostat exterior/interior interface:
the VHV feedthrough. **Requirements:**

- **length (>2m)** to traverse the thick passive insulation and reach the liquid
- **VHV compatibility:** FEA simulations, shaping of electrodes + surface finish to reduce electric fields
- **"cryo-compatibility":** thermal shrinkage, avoid formation of empty volumes where gas may get caught, use material with matching CTE,..
- **UHV rating**. Must not pollute the liquid bulk. Tested down to 1e-9 mbar l.s leak rate

Other VHV detector components studied in WP8

Drift cage

- eight vertical modules of 6.3 m x 3 m, each one consisting of three sub-modules.
- On each module, there are 98 aluminium extruded profiles one on top of the other with a vertical pitch of 6 cm

cathode

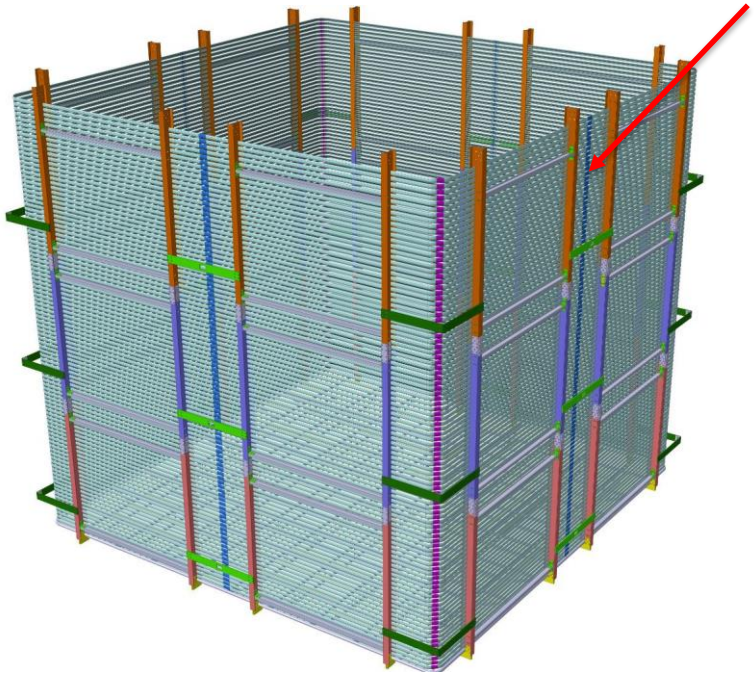
- four 3 × 3 m2 sub-modules
- Electrically connected via resistors to slow down stored energy release in case of a sudden discharge

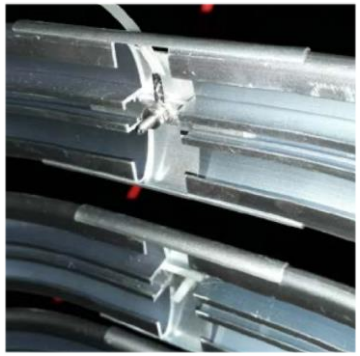
18

Large progress in HV generation, transport, simulations and construction of large field cage systems (common elements for SP and DP)

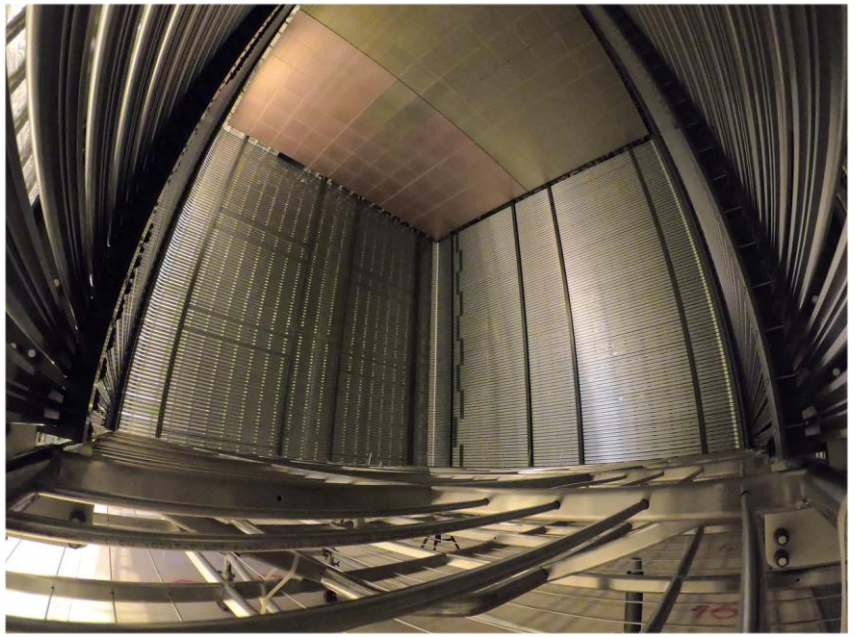
Cryogenic Detectors NA

Drift cage/cathode design implementation in protoDUNE-DP





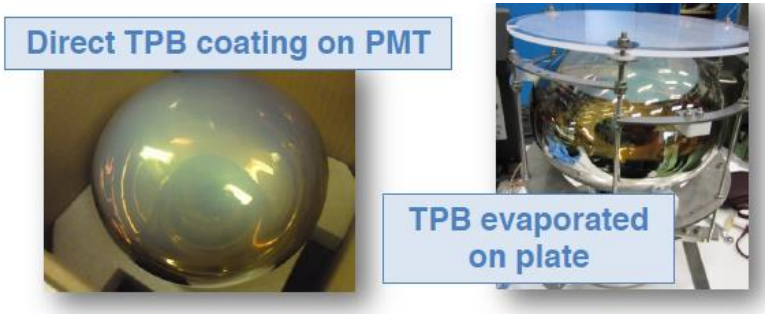
Equipotential rings implemented with Aluminum profiles joined with clips

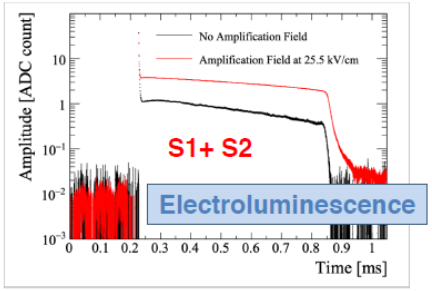


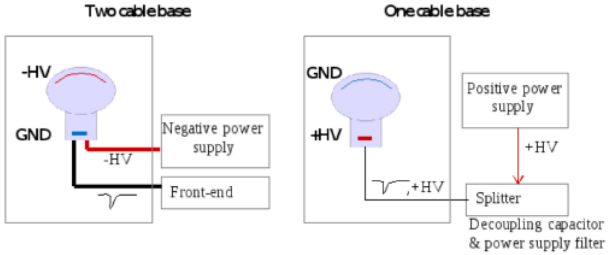
Cryogenic Detectors NA

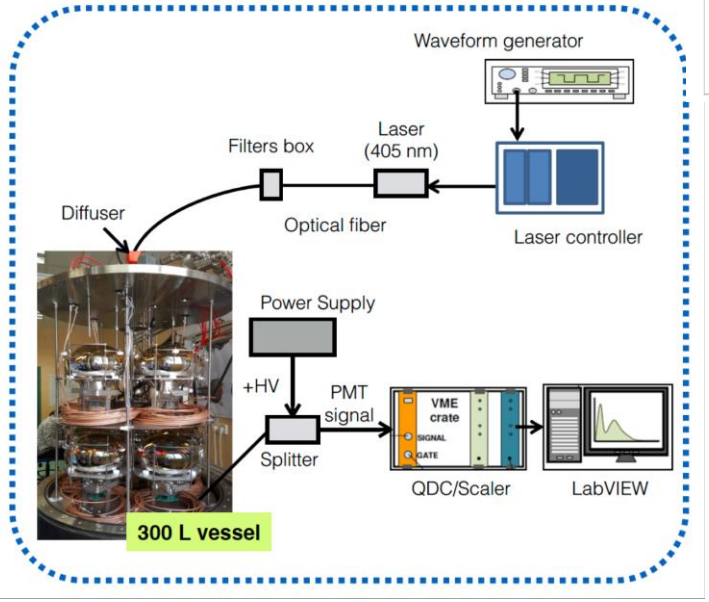
Task 8.4 deals with the study of light readout techniques in noble liquefied gases and the assessment of photo-detection systems to assess large size scaling of these systems for massive cryogenic detectors. This networking activity, involving several institutions, under the coordination of CIEMAT and main contributions by IFAE, APC and ETHZ, has been regularly carried on by exploiting the infrastructure provided by the CERN neutrino platform, exploiting in 2016-2017 as a test bench application for many of these techniques the 3x1x1 m^3 WA105 prototype. For the following topics results were extracted from the 3x1x1 integration, commissioning and operation and from the R&D, design and preparation activity for the 6x6x6 m^3 WA105 (ProtoDUNE dual-phase) detector:

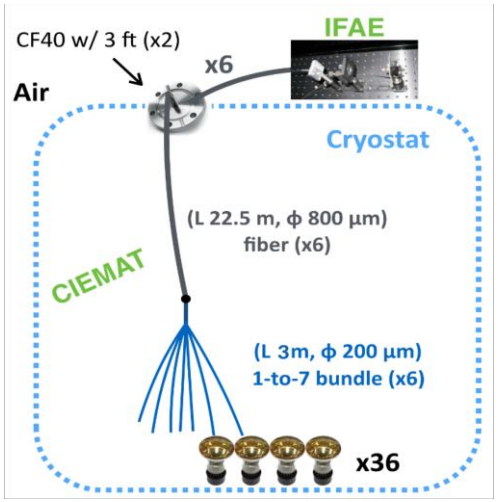
- *Coating techniques for PMTs (direct TPB coating, plastic plate coating), uniformity assessment*
- *QA methods for PMTs testing*
- *Digitization of light signals*
- *HV/signal unified cabling (comparison positive and negative bases)*
- *Transparent cathodes with TPB coating*

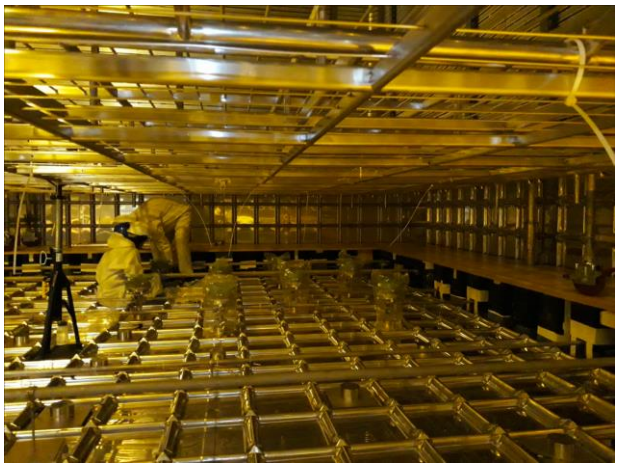








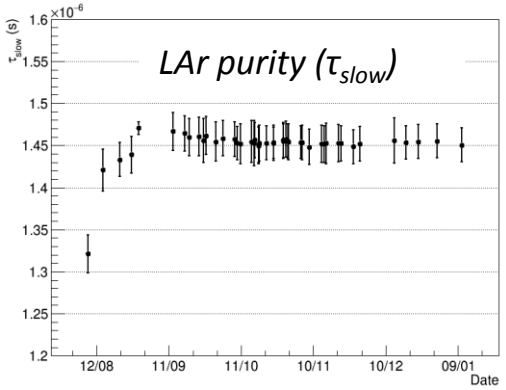


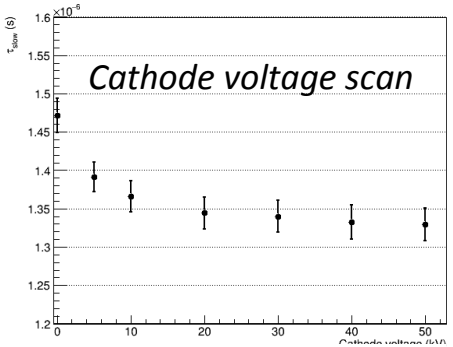


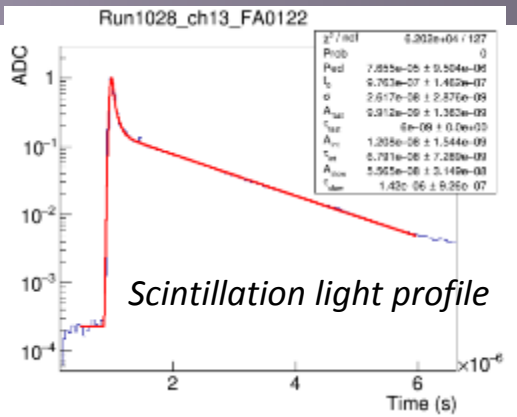
Cryogenic Detectors NA

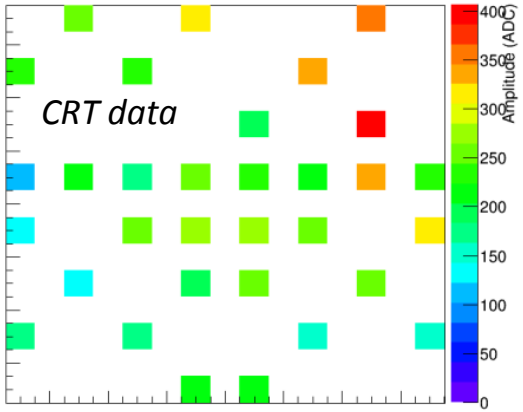
ProtoDUNE-DP LRO analyses:

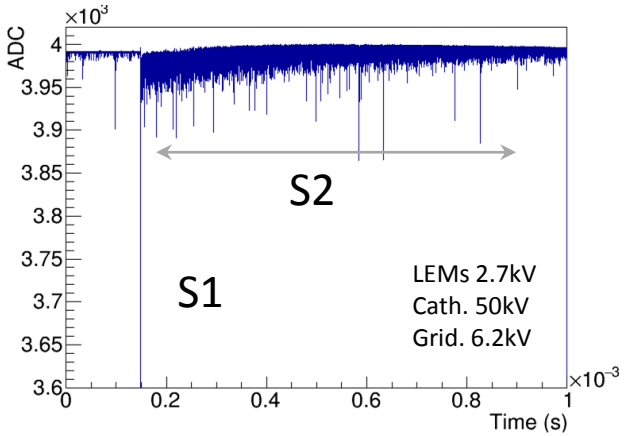
- Purity measurements and scintillation light profile
- Scan as a function of drift field
- S1 identification from cosmic muons
- PEN/TPB WLS performance
- Electroluminescence signals observed
- CRT triggered data analysis

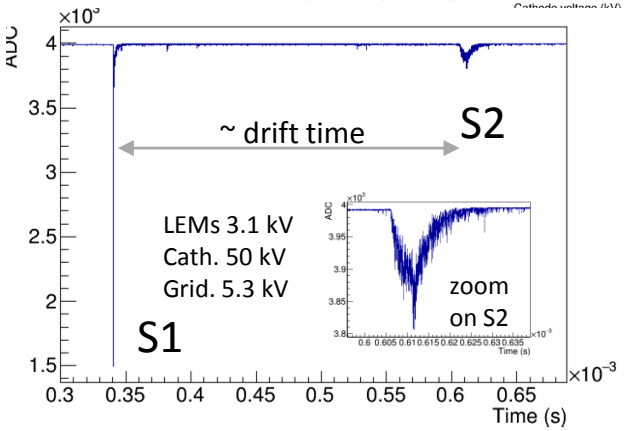


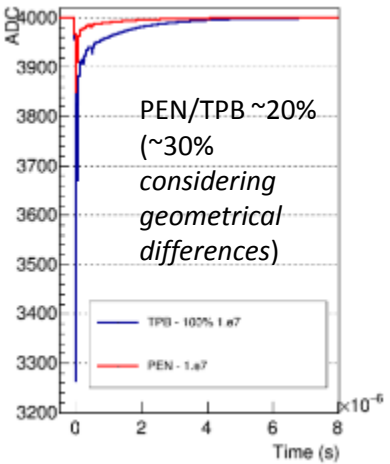




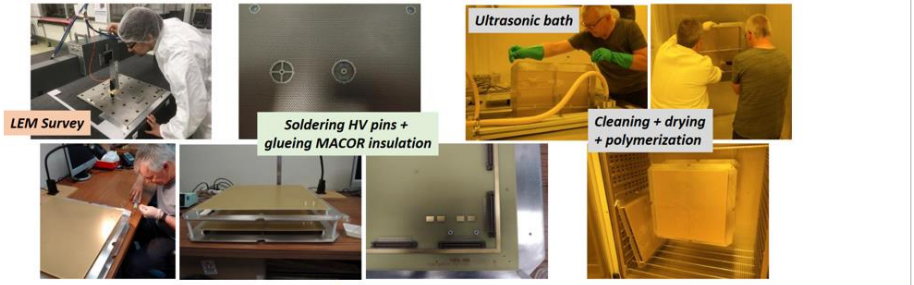




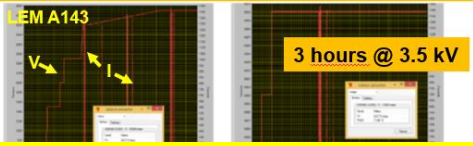




Cryogenic Detectors NA



Fully automated HV training in GAr @3.3 bar up to 3.5kV

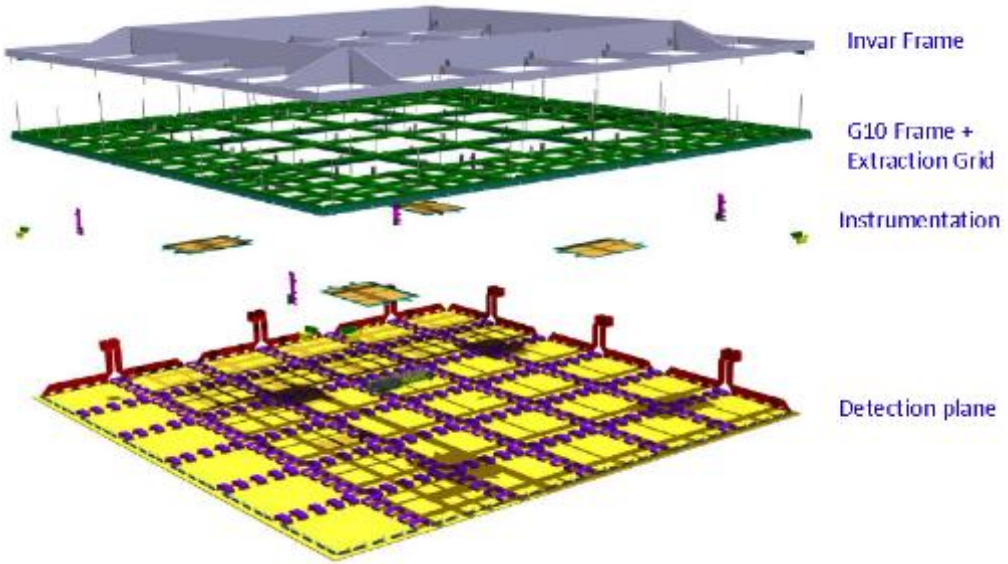


Task 8.3 Dual-phase and charge readout
- Review: single and dual-phase charge readout
- LEM production/cleaning/tests procedures
- LEM integration on large DP readout surfaces
- Cryogenic DP accessible electronics
- High bandwidth DAQ system for giant LAr detectors
- Synchronization system for giant LAr detector

Charge Readout Planes design

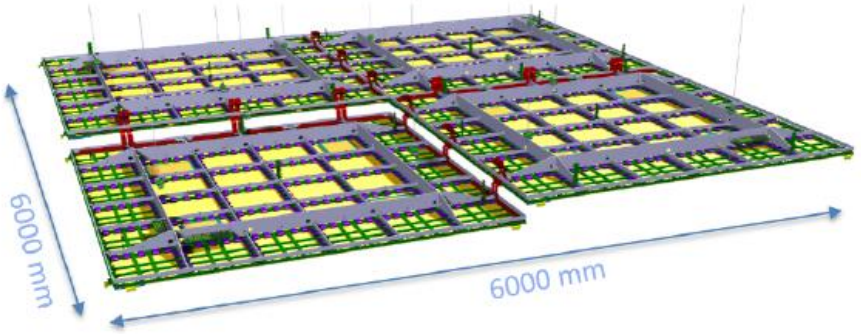
3x3 m^2 CRPs integrating the LEM-anode sandwiches (50x50 cm^2) and their suspension feedthroughs (CRP specific to dual-phase technology: critical item)

→ Invar frame + decoupling mechanisms in assembly in order to ensure planarity conditions +- 0.5 mm (gravity, temperature gradient) over the 3x3 m^2 surface which incorporates composite materials and ensure minimal dead space in between CRPs



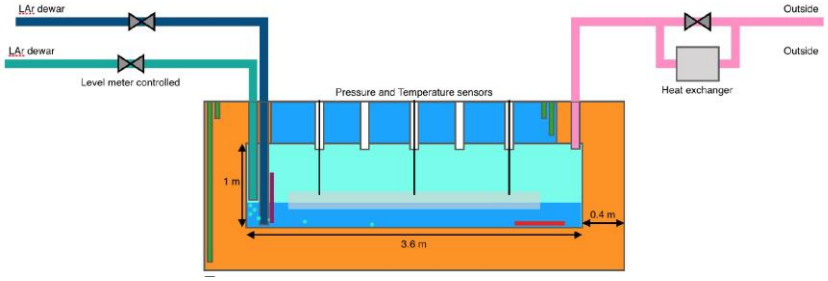
Three main parts:

- Mechanical Invar frame
- G10 frame
- Detection plane



Full size cold-box tests experience

→ Large surface CRP characterization (electrical and mechanical tests) in realistic cryogenic thermodynamic condition (summer 2018)



- Pressure monitored
- Temperature monitored
- LAr purity of the order of 100 ppm
- CPR position and planarity adjustable

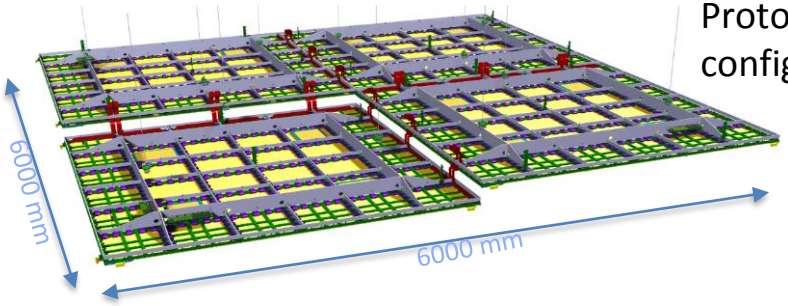
Goals:

- Characterization of the HV operation of each LEM
- Characterization of the HV operation of the extraction grid
- Test of all HV contacts from feedthroughs to the LEM and grid connectors
- Measurement of flatness of the CRP before and after cool down

Results:

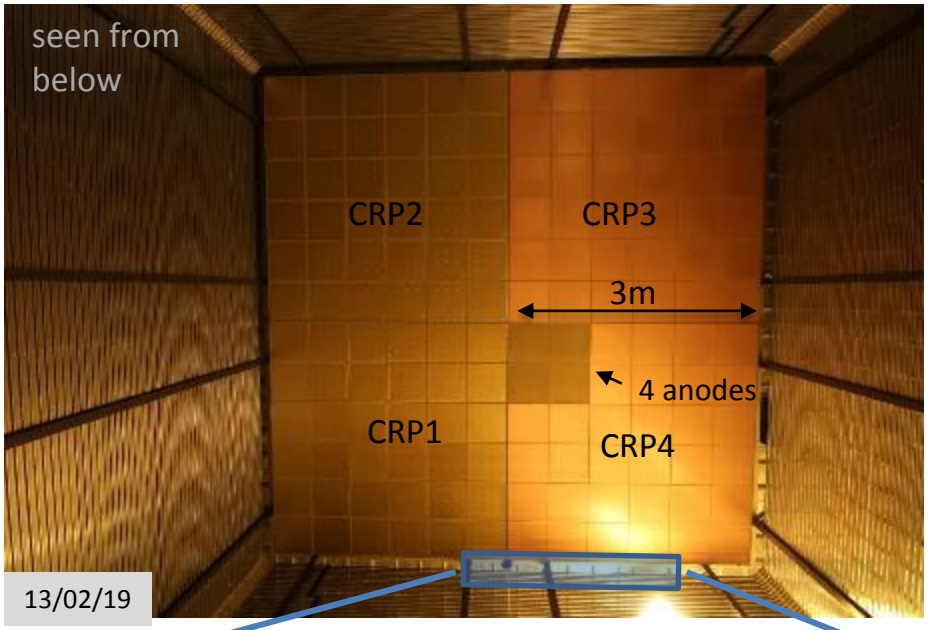
- Grid has been operated successfully at any voltage to maintain an extraction field at its maximum efficiency
- Found an optimal HV setting

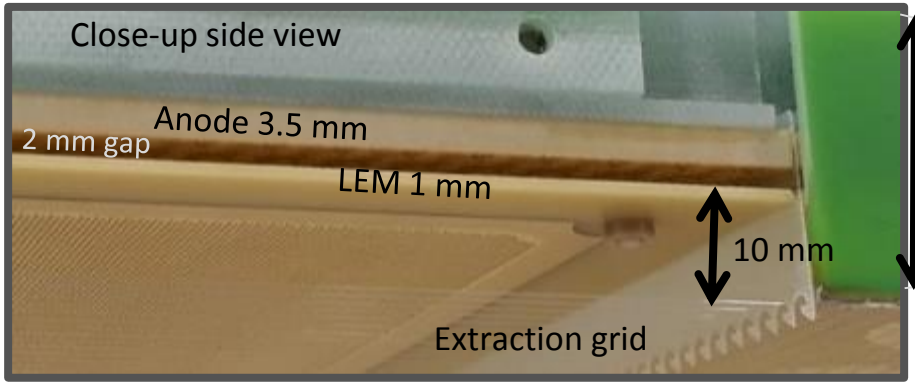
Cryogenic Detectors NA



ProtoDUNE-DP configuration

4 CRPs



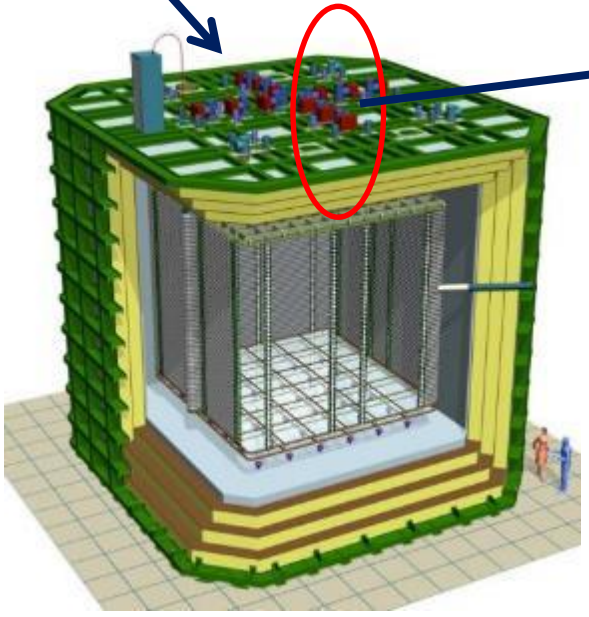


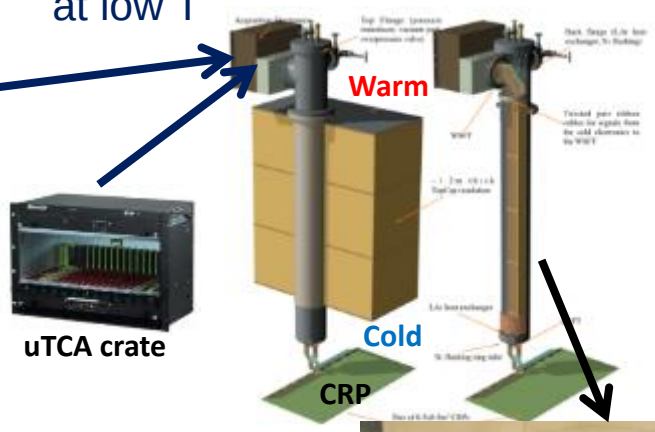
25 mm

Dual-phase electronics

ProtoDUNE-DP accessible cold front-end electronics and uTCA DAQ system 7680 ch

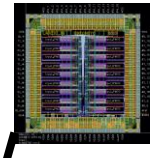
- **Digital electronics at warm on the tank deck:**
  - Architecture based on uTCA standard
  - 1 crate/signal chimney, 640 channels/crate
    → 12 uTCA crates, 10 AMC cards/crate, 64 ch/card
- **Cryogenic ASIC amplifiers (CMOS 0.35um) 16ch externally accessible:**
  - Working at 110K at the bottom of the signal chimneys
  - Cards fixed to a plug accessible from outside
    →Short cables capacitance, low noise at low T



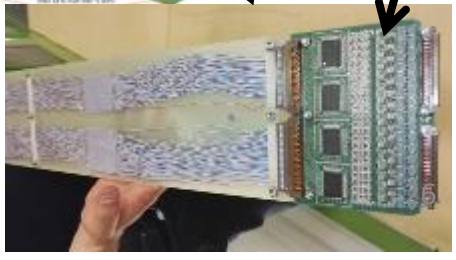


uTCA crate

ASICs 16 ch. (CMOS 0.35 um)

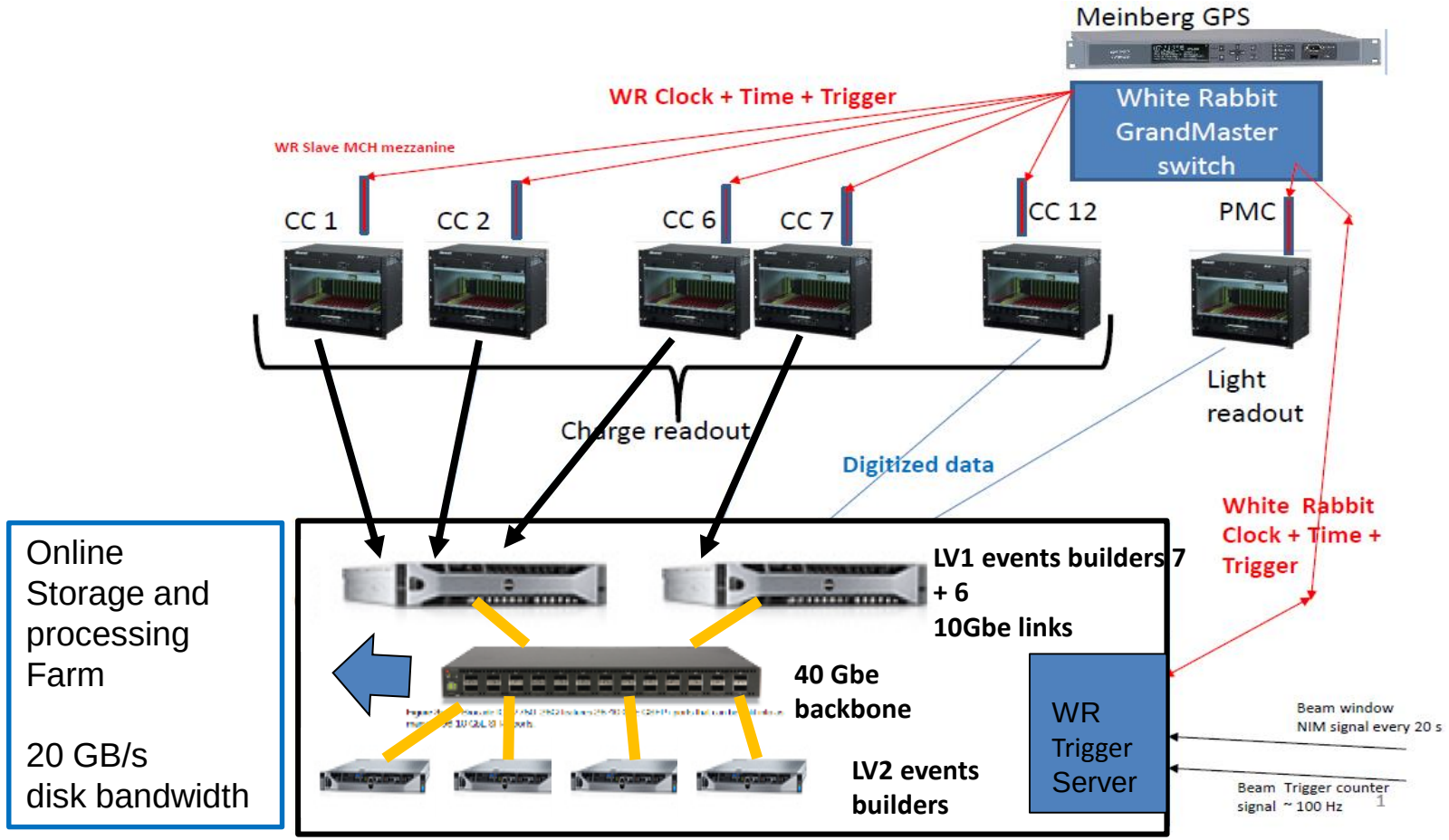


FE cards mounted on insertion blades



Global uTCA DAQ architecture for ProtoDUNE-DP

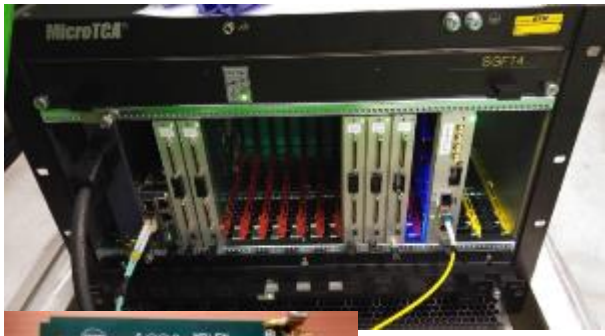
integrated with White Rabbit (WR) Time and Trigger distribution network.
White Rabbit slaves MCH nodes in uTCA crates + WR system (time source, Grand Master, trigger system)



Readout components

- **Cryogenic front-end analog cards**
  - Cryogenic ASIC amplifiers DP-V3, 0.35um CMOS → production performed at the beginning of 2016
  - 64 channels FE cards with 4 cryogenic ASIC amplifiers
  - First batch of 20 cards (1280 channels) operational on the 3x1x1 since the fall 2016
  - Production of remaining 100 cards for 6x6x6 completed at the beginning of 2018
- **AMC digitization cards**
  - uTCA 64 channels AMC digitization cards (2.5 MHz, 12 bits output, 10 Gb/s connectivity)
  - 20 cards operational on the 3x1x1 since the fall 2016
  - Production of remaining 100 cards for the 6x6x6 completed at the beginning of 2018
- **White Rabbit timing/trigger distribution system**
  - Components produced in 2016 for the entire 6x6x6, full system operational on the 3x1x1 since the fall 2016. The uTCA slave nodes were then produced for the entire 6x6x6 m^3 detector

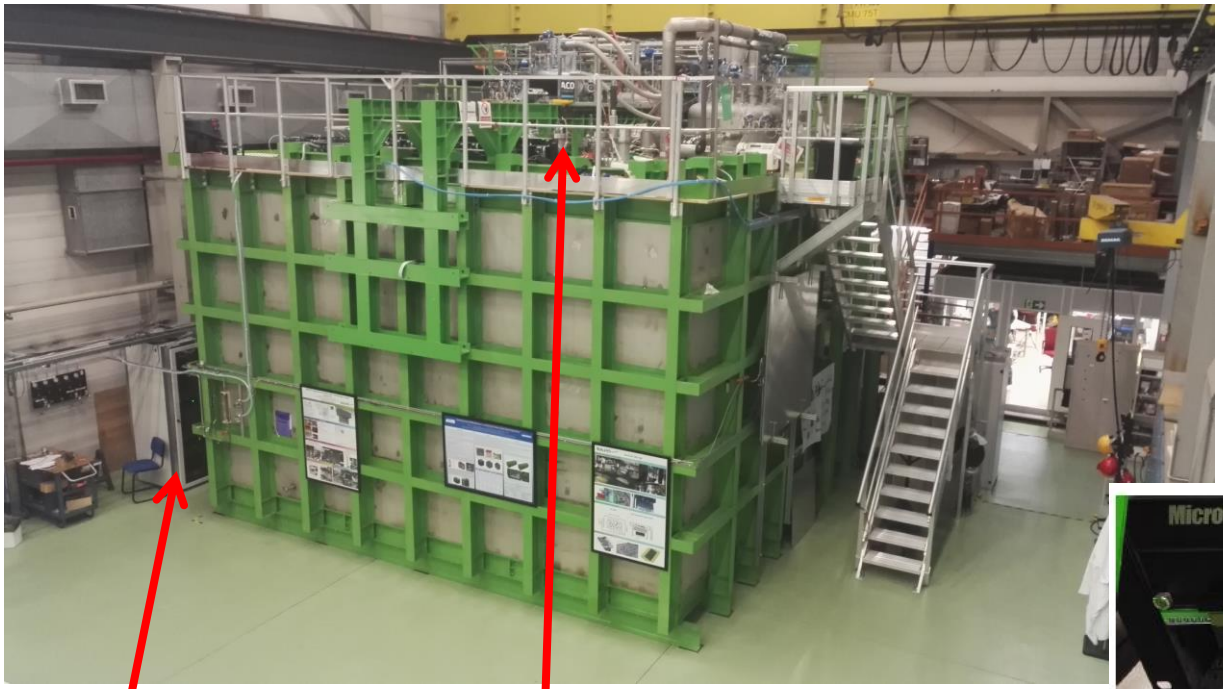



Cryogenic Detectors NA

6x6x6: 12 uTCA crates (120 AMCs, 7680 readout channels)

→ 3x1x1: 4 uTCA crates (20 AMCs, 1280 readout channels)

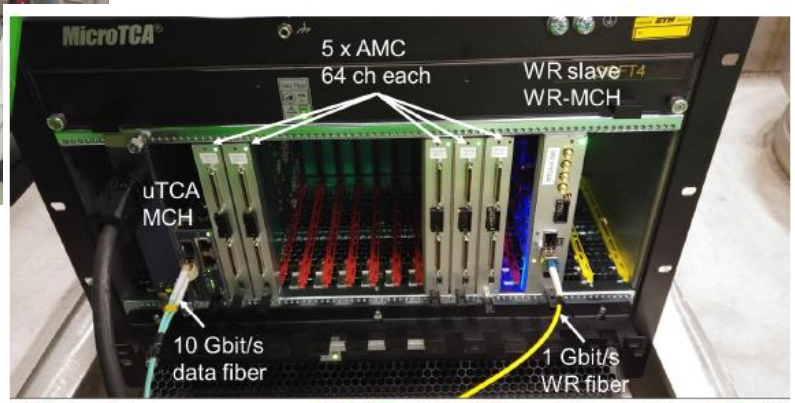


Signal Chimneys and uTCA crates

Event builder, network, GPS/White Rabbit GM, WR Trigger PC

First application of the charge readout detectors (first CRP and LEMs design on 3m2 surface) and of a subset of the electronics/DAQ system of this R&D:

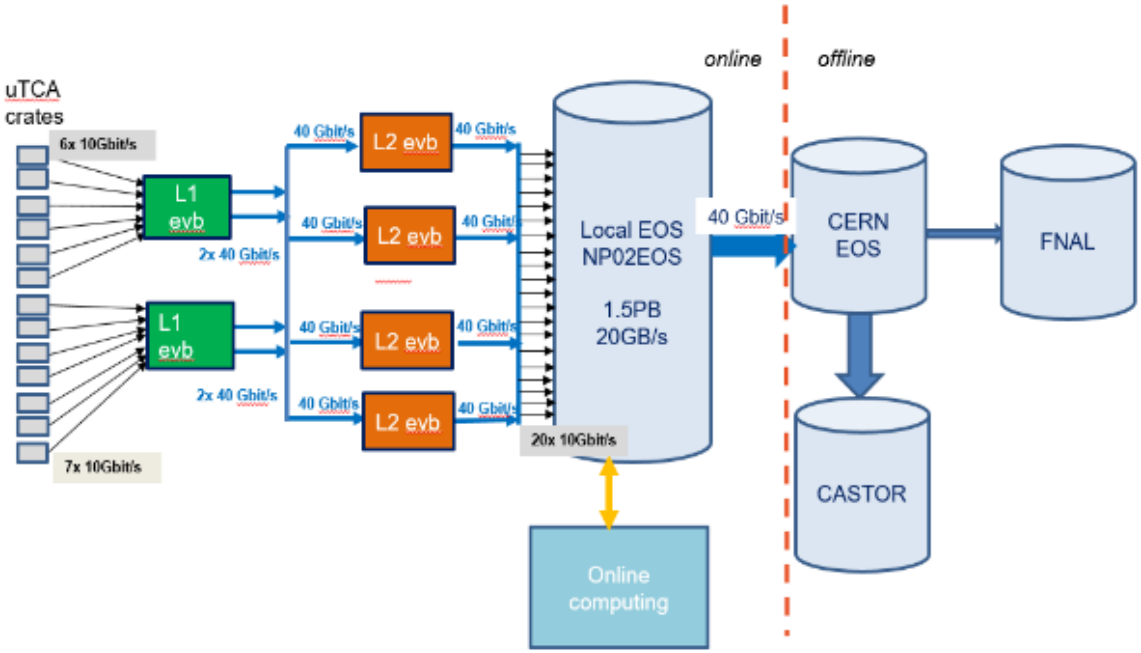
Electronics operational in the period November 2016-March 2018



The big-data/DAQ challenge

ProtoDUNE dual-phase DAQ/online storage facility /online processing system/offline data handling

NP02 DAQ/network infrastructure



- ✓ **Excellent performance of front-end analog cryogenic electronics, digital uTCA front-end electronics and DAQ back-end system (20 GB/s data storage bandwidth)**
- ✓ **2 M events (4ms drift) acquired corresponding to 200 TB, data transferred to CERN EOS and FNAL**
- ✓ **Fast reconstruction (15s/event) performed on real time on the online computing farm (450 cores)**

Cryogenic Detectors NA

AIDAinnova WP8→WP9:

Task 9.2. **Pixel charge readout**

- Optimised pixel tile pattern for the DUNE LAr far detector
- Design and prototype for large scale tile-based anode plane

Task 9.3. **Dual-phase charge readout**

- Novel dual-phase Large Electron Multipliers (LEMs) design to increase active area, spark prevention and stability
- Development and tests of novel design of the Charge Readout Plane (CRP) integration surface of the LEMs and of extraction grids design
- Developments and tests of integrated cold electronics, new feedthrough chimneys design
- Developments in associated digitisation hardware and online data treatment

Task 9.4**. Light readout**

- Characterisation of new photon detection methods, calibration devices and readout electronics
- Implementation and characterisation of a more efficient light collection system in ProtoDUNE phase II (Xe doping and Wave Length Shifting (WLS) combined with reflective foils)
- Dissemination of R&D results and ProtoDUNE II light-collection performance (web site)

Conclusions

- AIDA2020 was very effective in supporting a variety of key activities strategic for the construction of large-scale cryogenic detectors including: new Charge and light readout methods, Very High Voltage and Purification and Monitoring and Magnetization

- A large set of interesting new results on various techniques were obtained with different setups

- Innovation will continue in AIDAinnova on further improvements of two existing R&D lines (Dual-phase charge readout and light readout) and a new one (pixelated charge readout).

→ Looking forward to a successful new AIDA program

Thanks for all your support and these nice years spent in the stimulating detector R&D environment of AIDA2020 !