Status of single phase and dual phase protodetectors at CERN

L.Molina Bueno on behalf of **WA105** collaboration

ETH Zurich

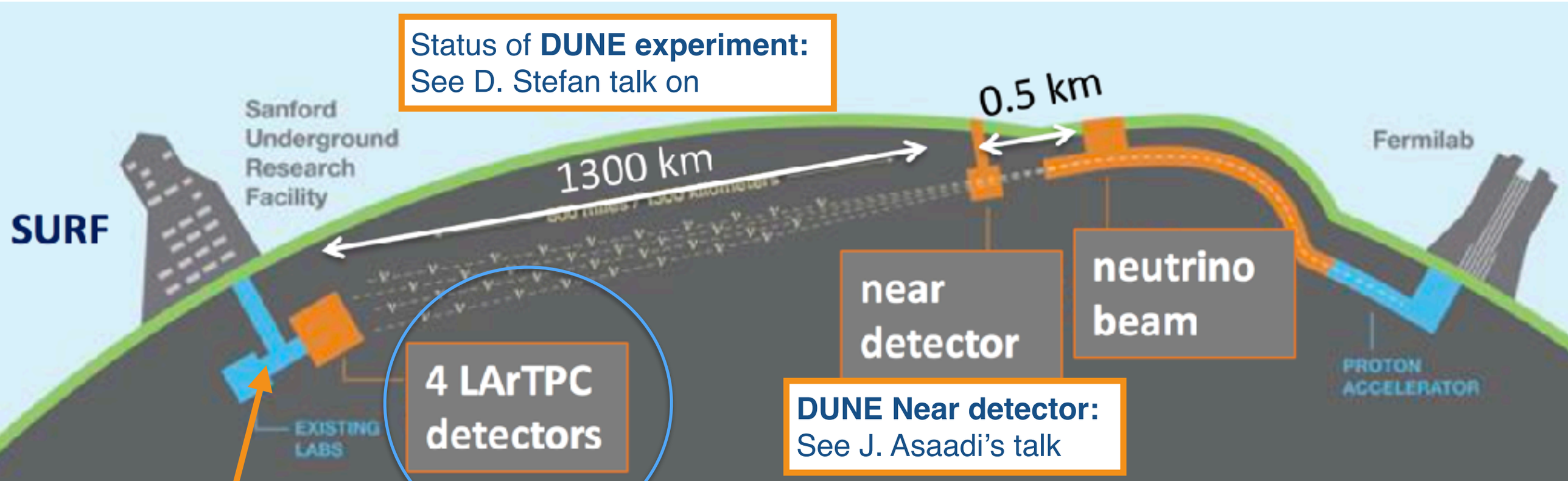
International workshop on Next Generation Nucleon Decay and Neutrino Detectors (NNN 17)

26-28th October University of Warwick

DEEP UNDERGROUND NEUTRINO EXPERIMENT

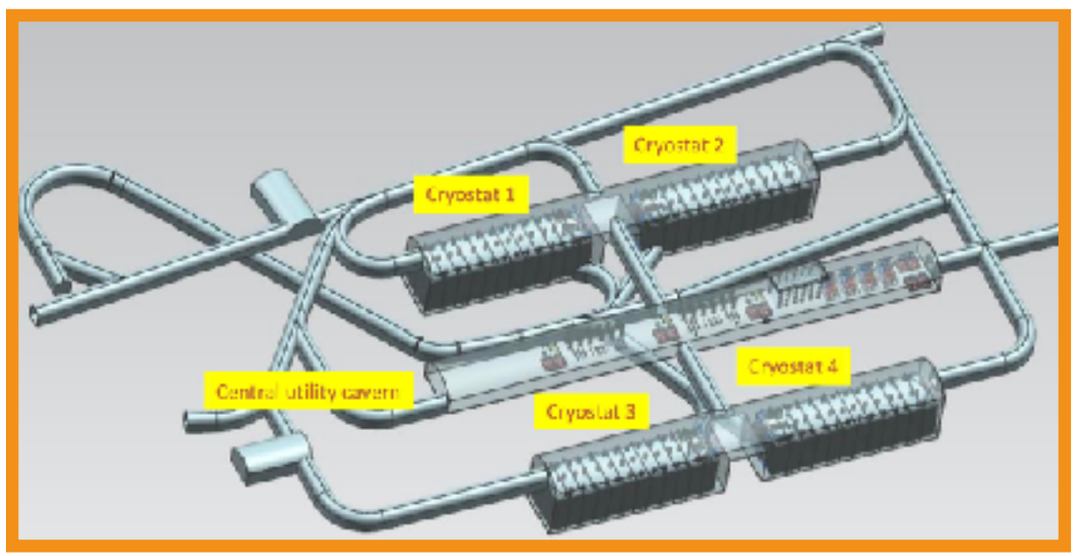
The DUNE experiment

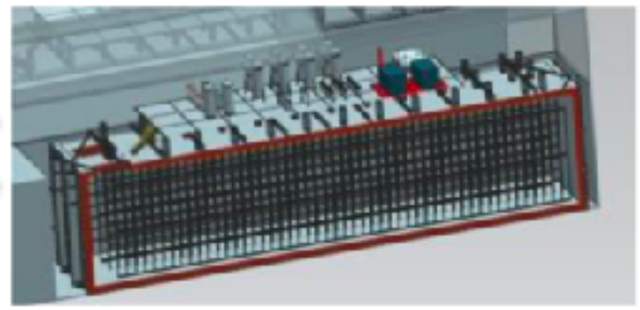
Status of **DUNE experiment:**
See D. Stefan talk on



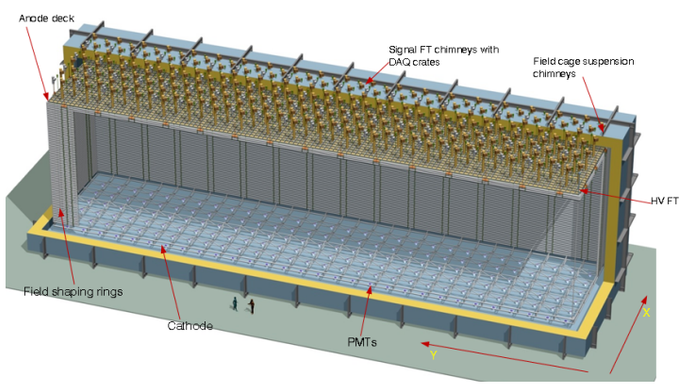
DUNE Near detector:
See J. Asaadi's talk

DUNE Far detector:
4modules of 10kton detectors





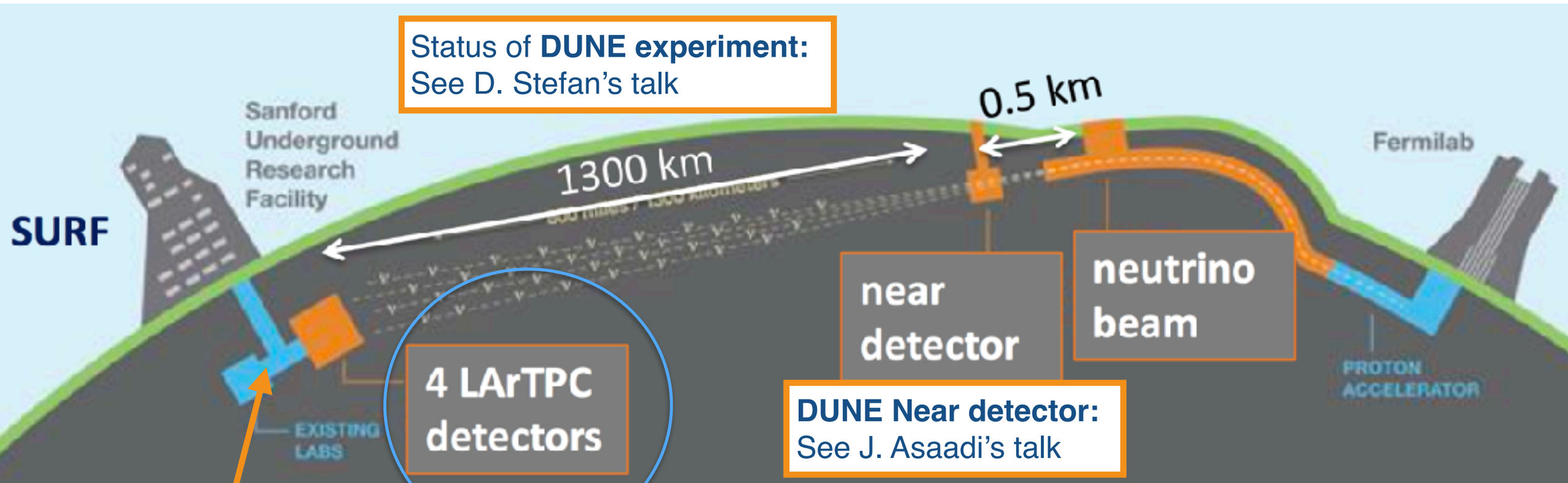
DUNE Far detector SP



DUNE Far detector DP

The DUNE experiment

Status of **DUNE experiment:**
See D. Stefan's talk



DUNE Near detector:
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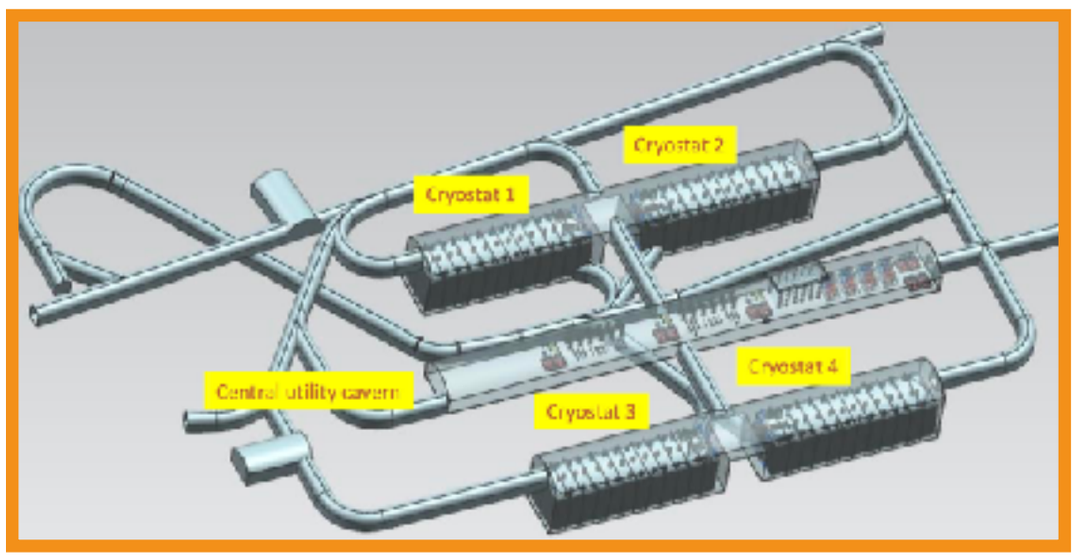
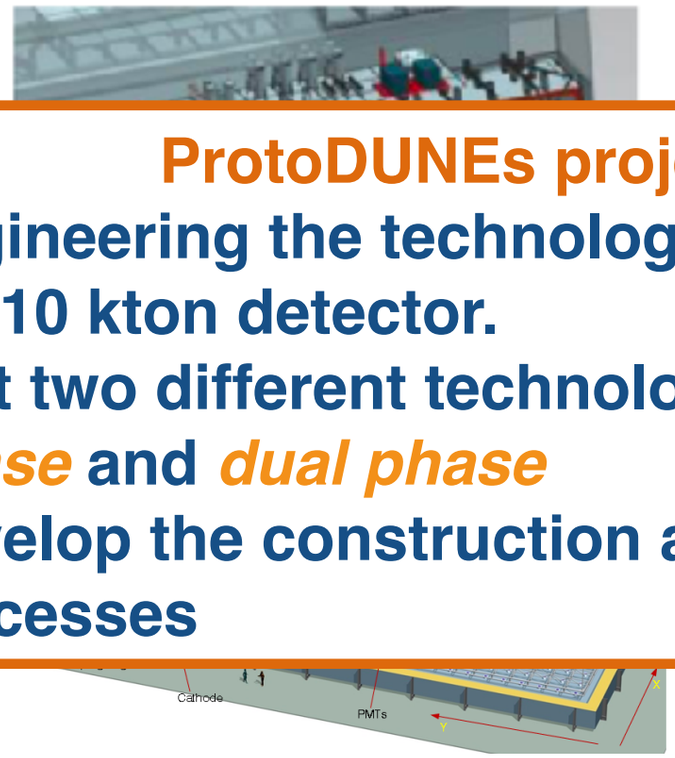


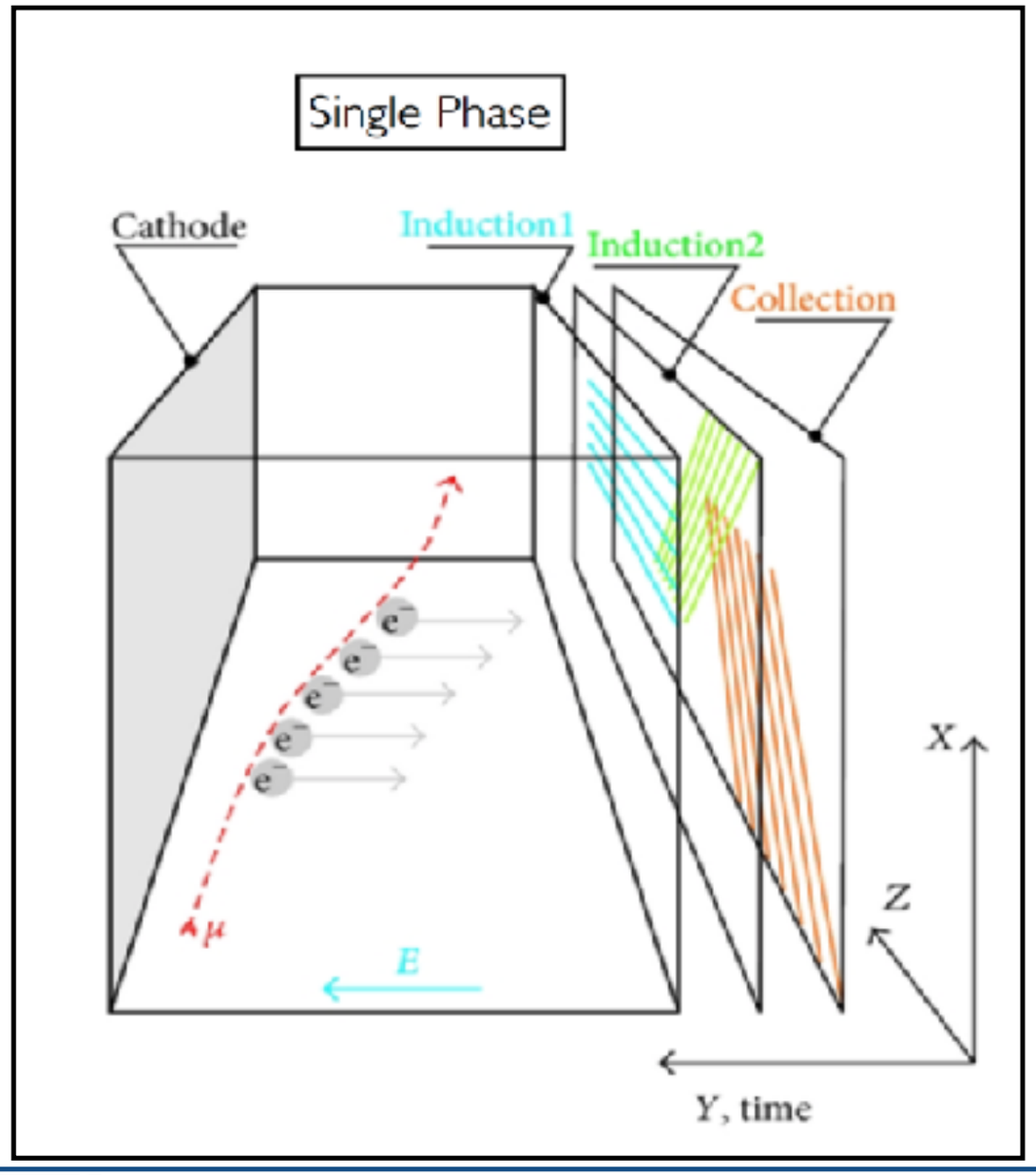


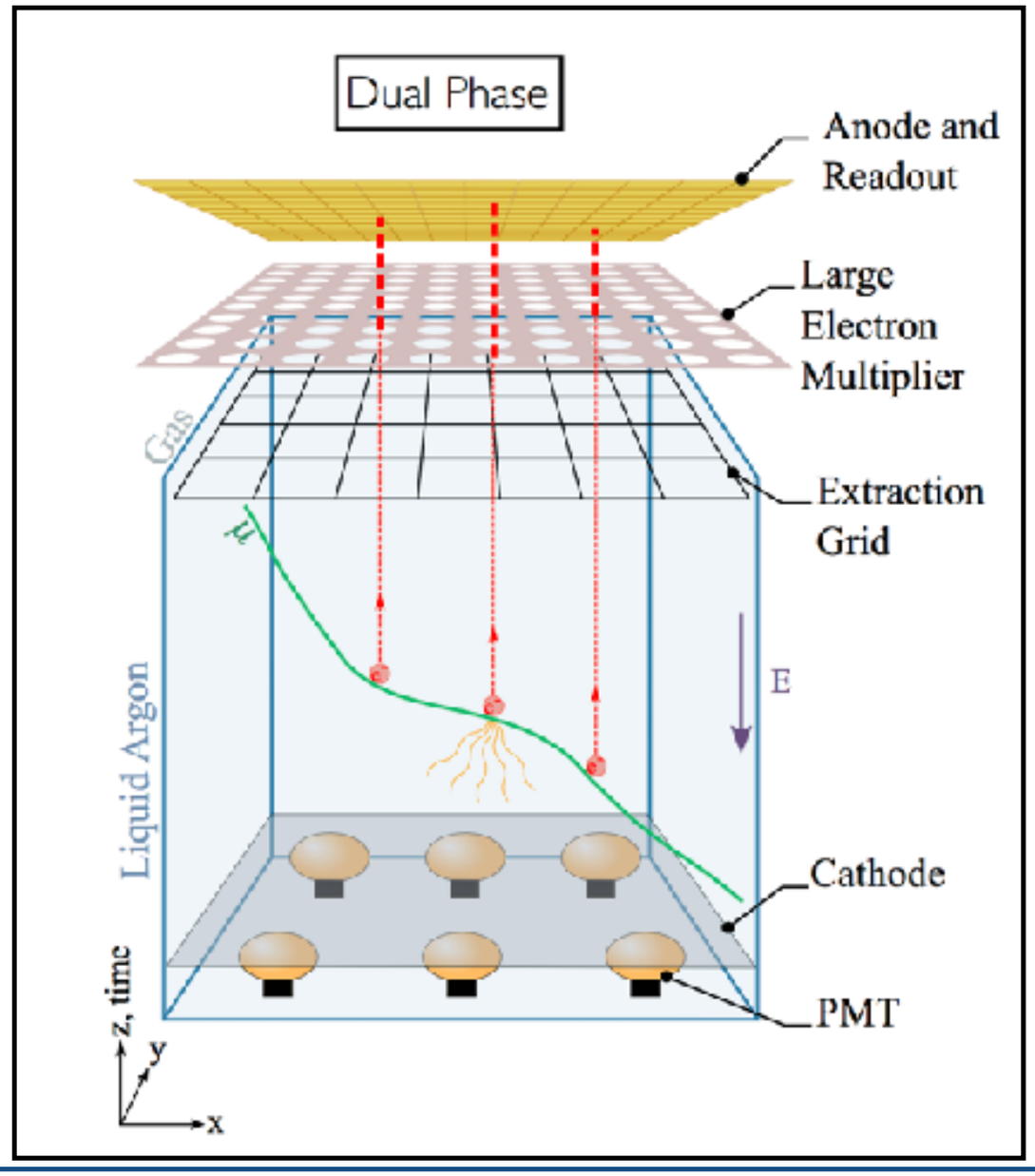
ProtoDUNEs project

- **Engineering the technology through the 10 kton detector.**
- **Test two different technologies: *single phase* and *dual phase***
- **Develop the construction and QA processes**

Single Phase vs Dual Phase

Liquid Argon Time Projection Chambers (TPCs): excellent calorimeters which allow for precise 3D reconstruction of the track of ionising particles traversing the liquid.





ProtoDUNEs timescale

Sep16 | Aug17 | Sep17 | Oct17 | Nov17 | Dec17 | Jan18 | March18 | Aug18 | Nov18

Cryostat construction

First APA at CERN

Beginning of AP field cage assembly

Cryogenic installation

Start first CRP Assembly

Beam ready

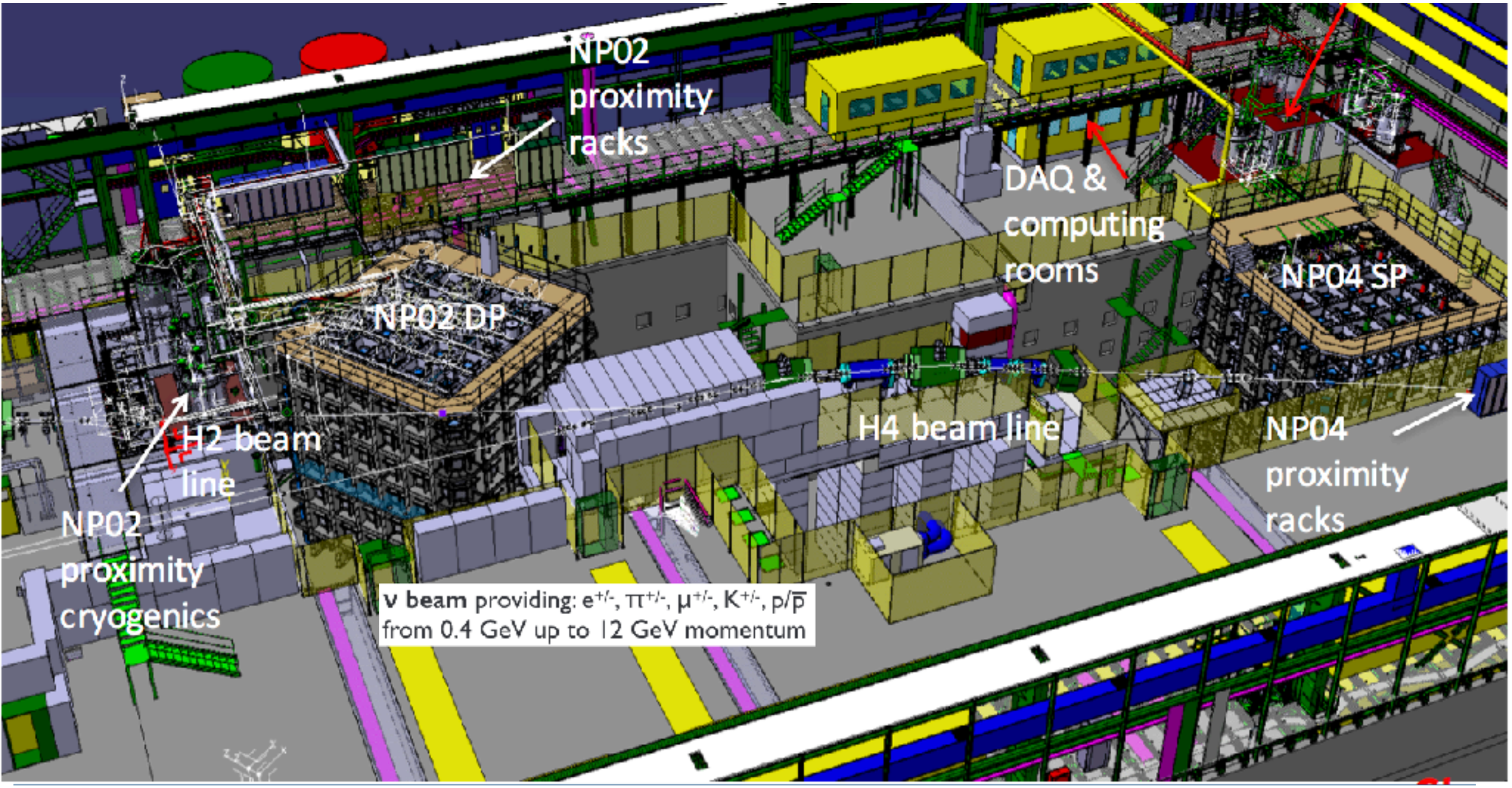
Beam run ends

Both detectors assembled

CERN
ProtoDUNE SP
ProtoDUNE DP

EHN1 infrastructure

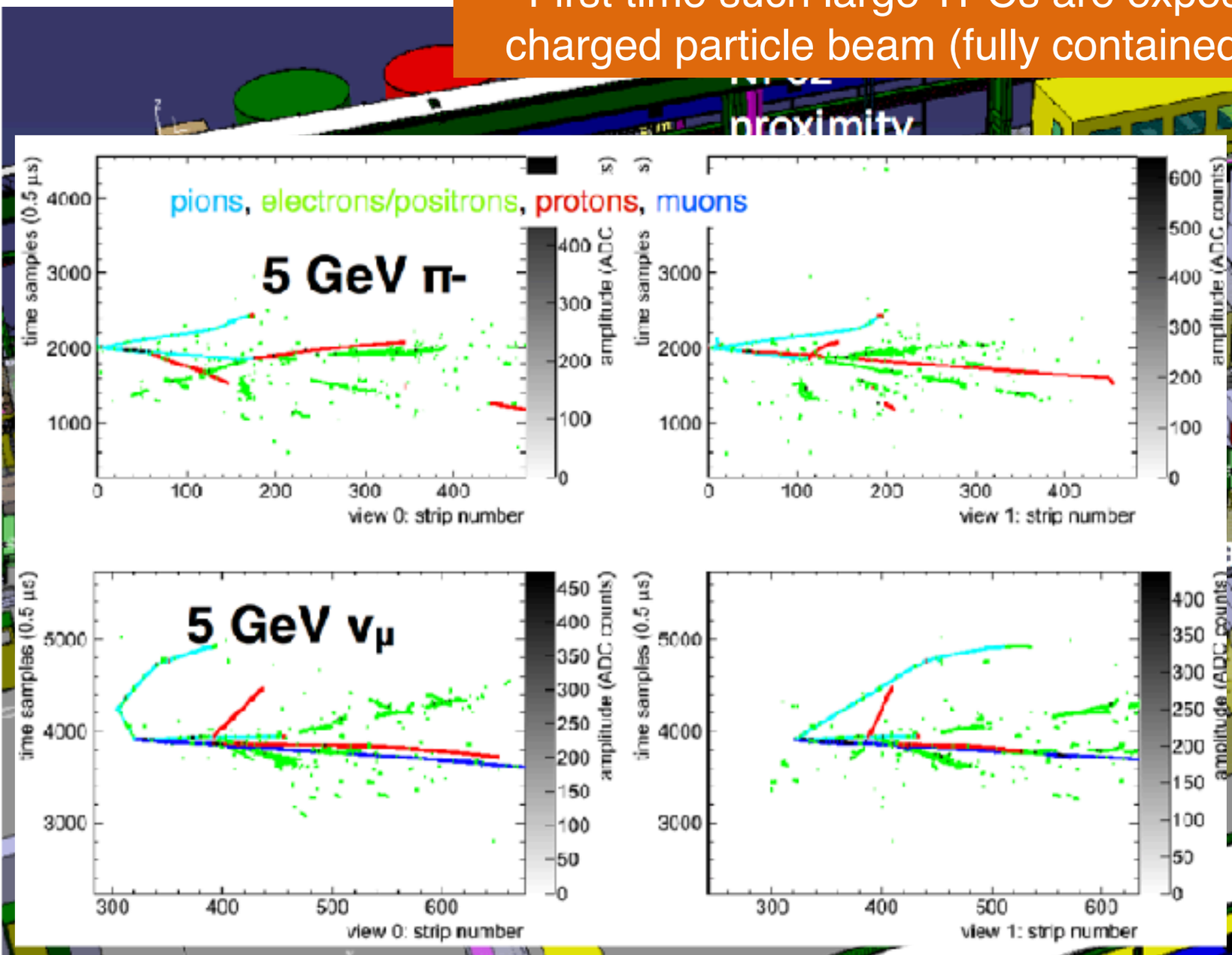
- ProtoDUNE detectors are located in the north area extension extension at CERN
- The CERN neutrino platform is responsible for the cryostat, the cryogenic system and the beam facilities.

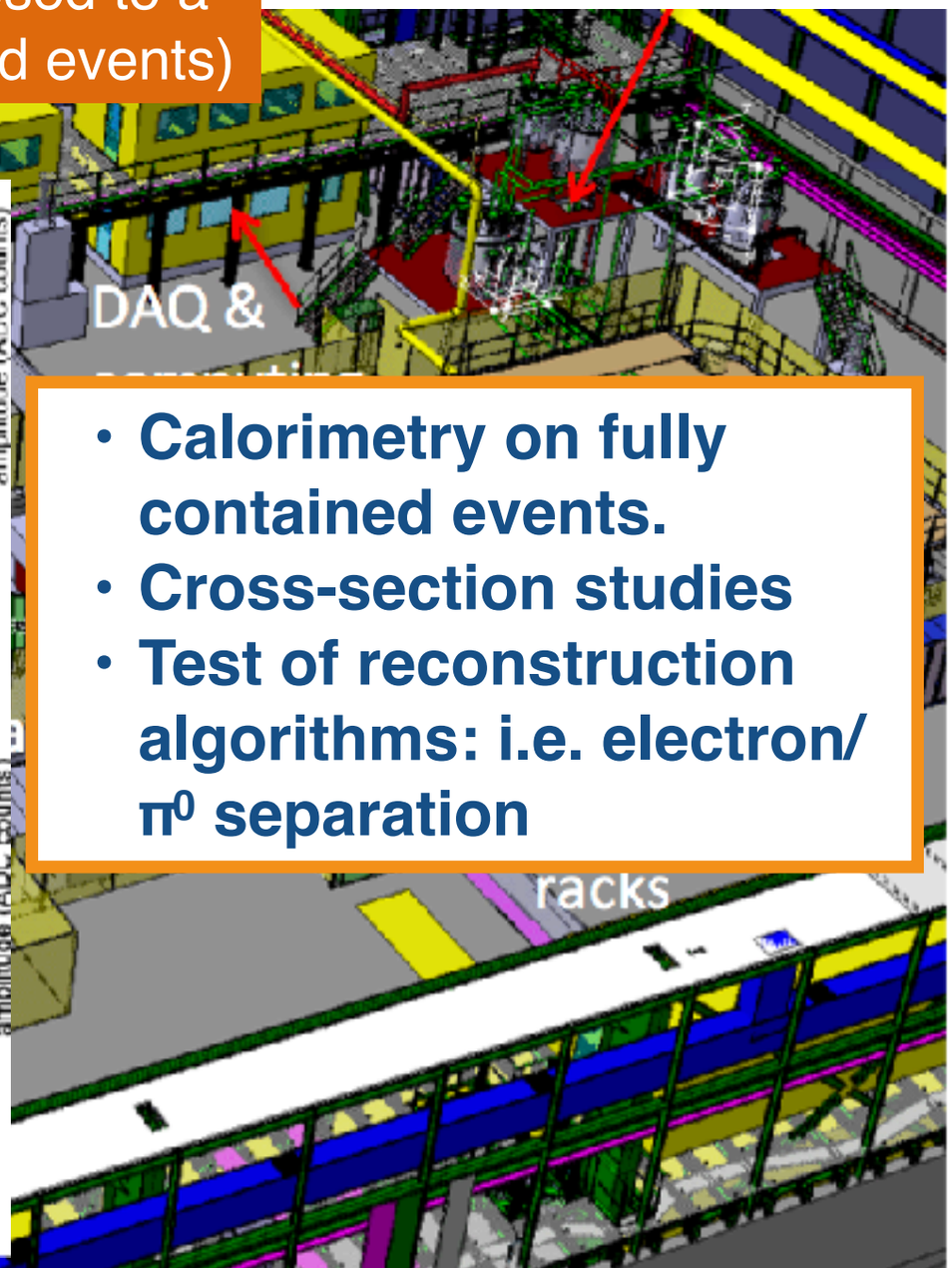


EHN1 infrastructure

- ProtoDUNE detectors are located in the north area extension extension at CERN
- The CERN neutrino platform is taking care about the cryostat, the cryogenic system and the beam facilities.

First time such large TPCs are exposed to a charged particle beam (fully contained events)





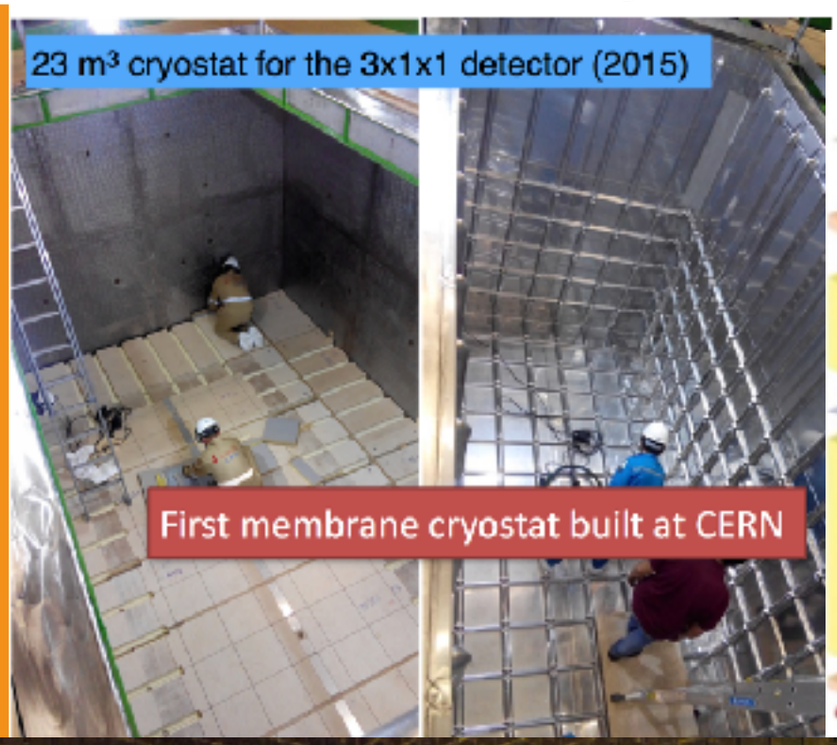
- **Calorimetry on fully contained events.**
- **Cross-section studies**
- **Test of reconstruction algorithms: i.e. electron/ π^0 separation**

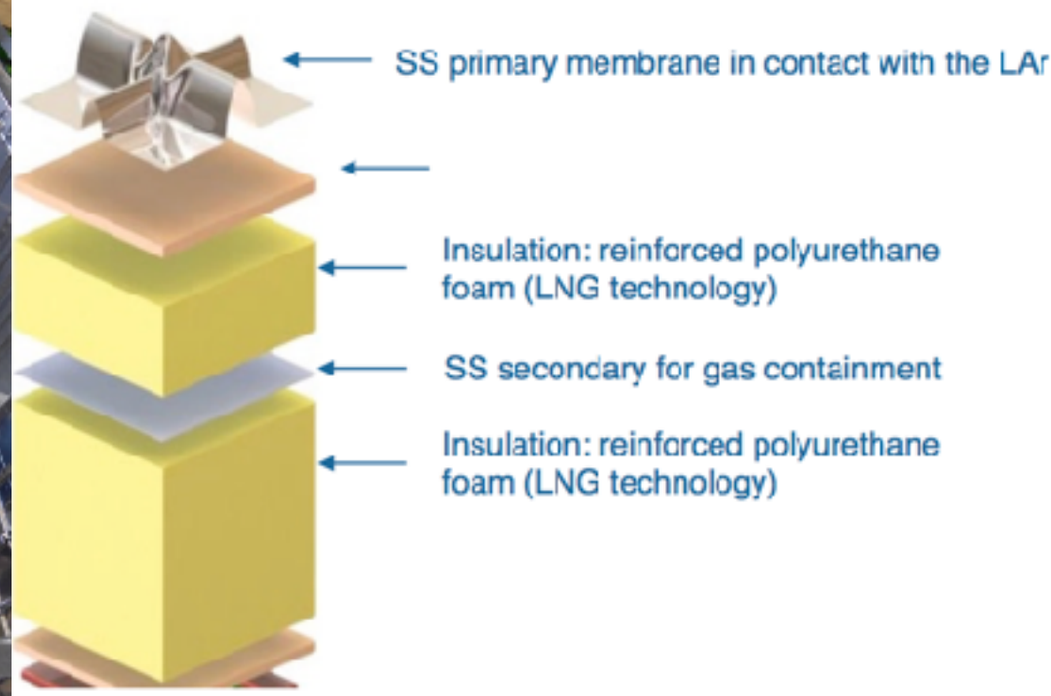
The cryostat: Design

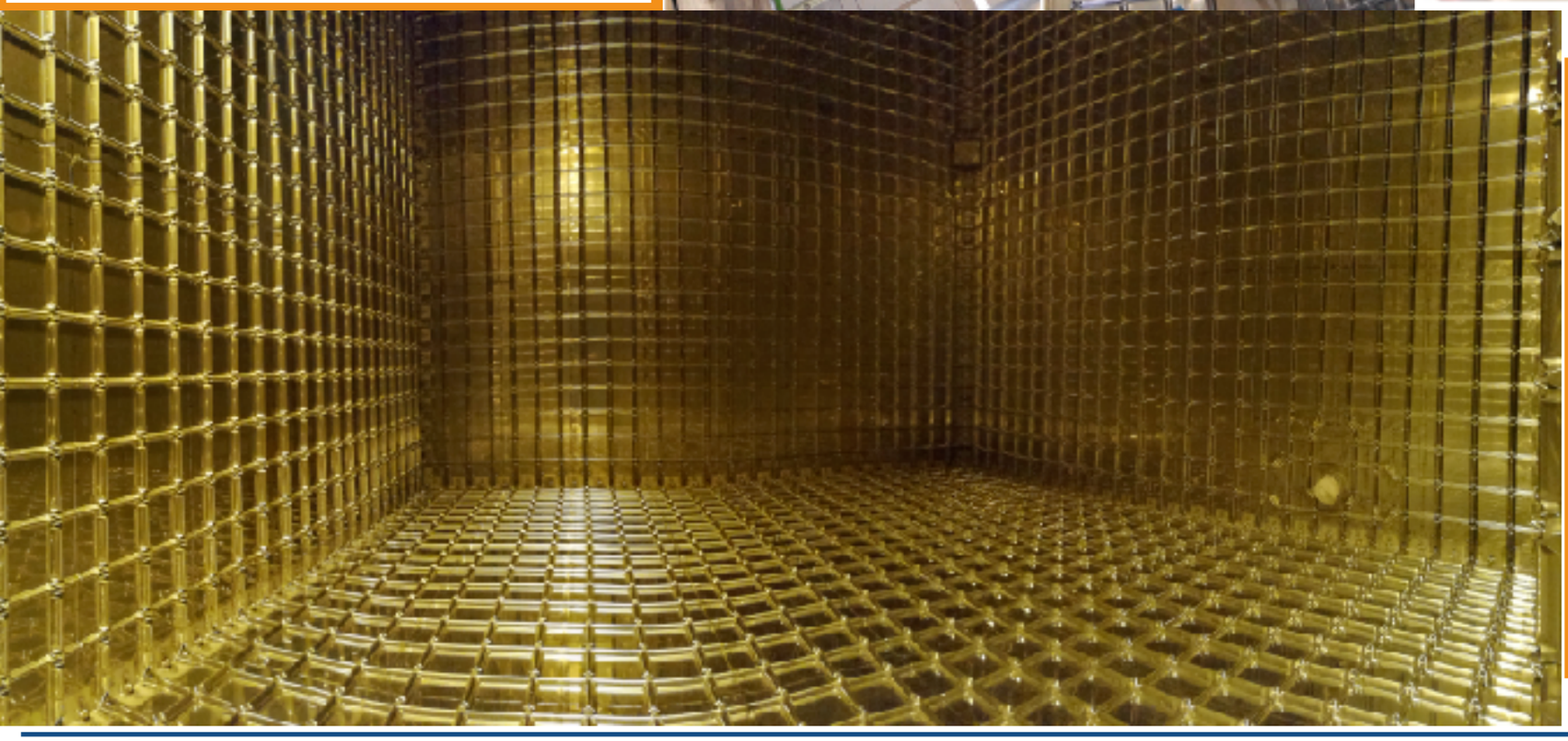
Same design for both protoDUNEs constructed by Gaz Transport and Technigaz (GTT) company.

First GTT constructed cryostat for LAr at CERN for the 3x1x1 dual-phase prototype.

- Three levels of passive insulation with less than 1 m thickness made with polyurethane foam and plywood.
- Designed for 5W/m² heat input



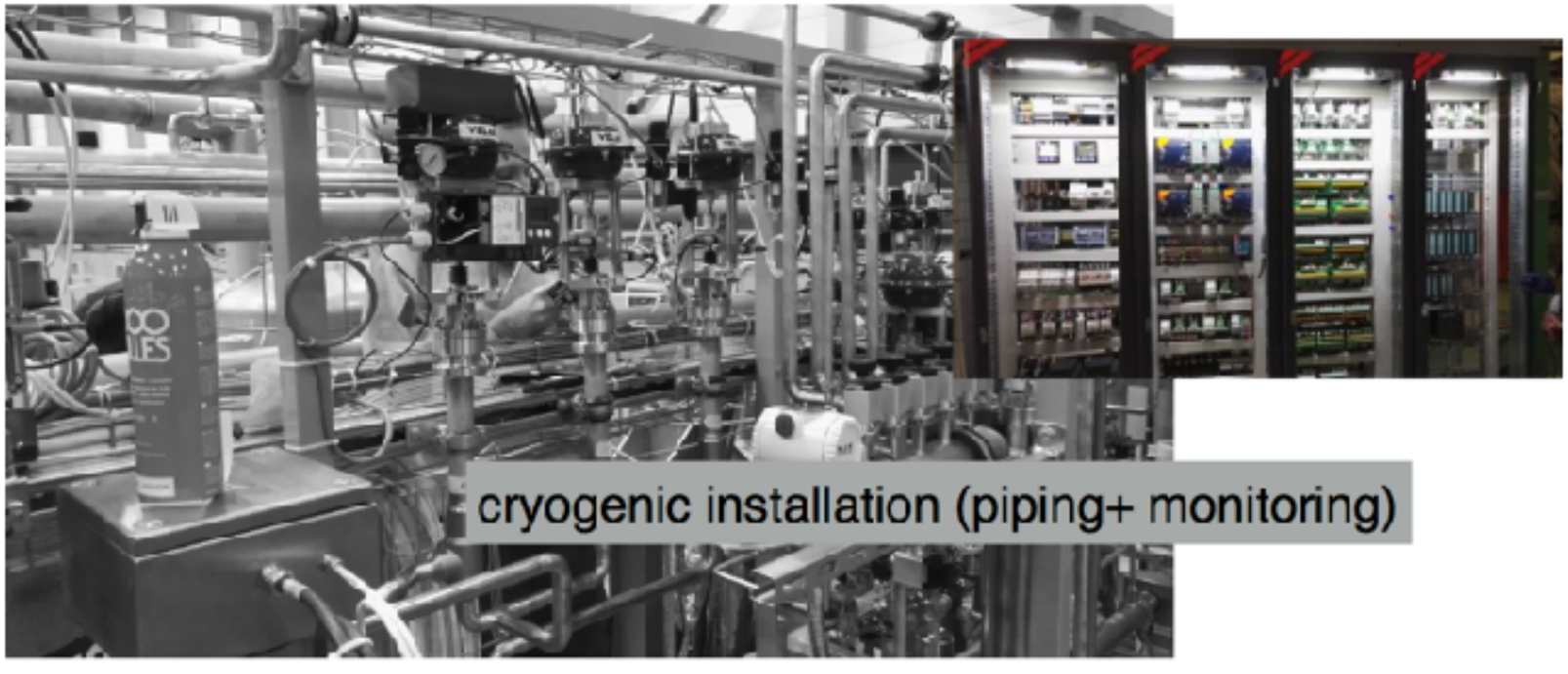


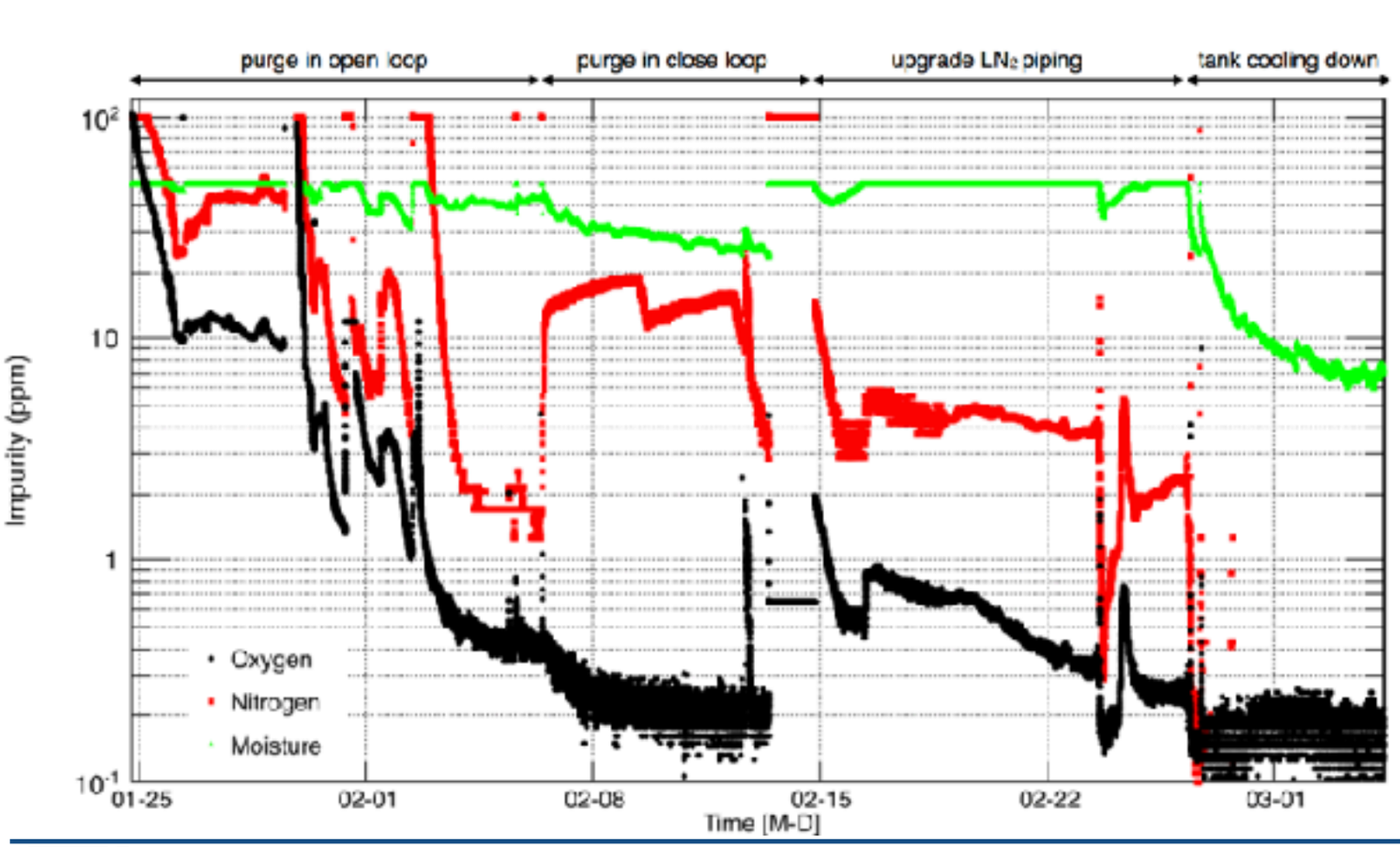


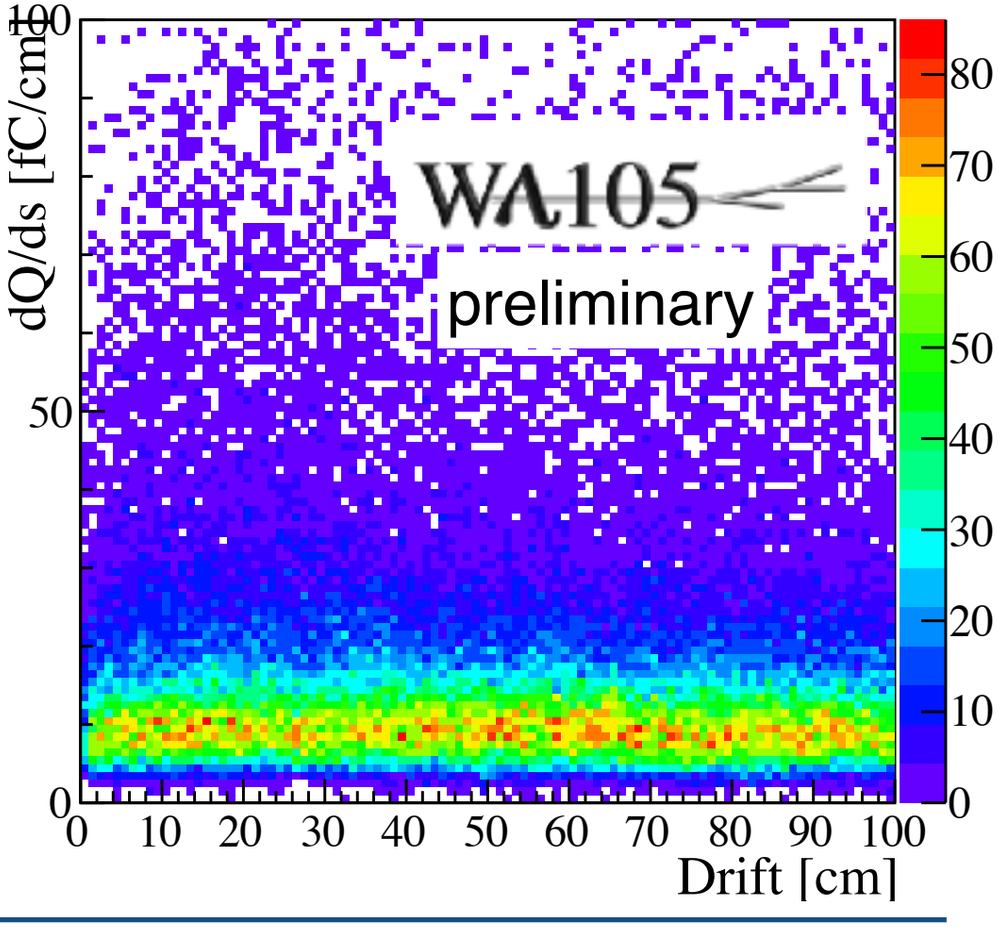
- **Both cryostats already constructed at EHN1**
- **Leak test already done by GTT and higher sensitivity leak test by CERN ongoing.**
- **The cleaning is ongoing and will finish on 19th October.**
- **The installation of the cryogenic piping system has started.**

Cryogenic performance

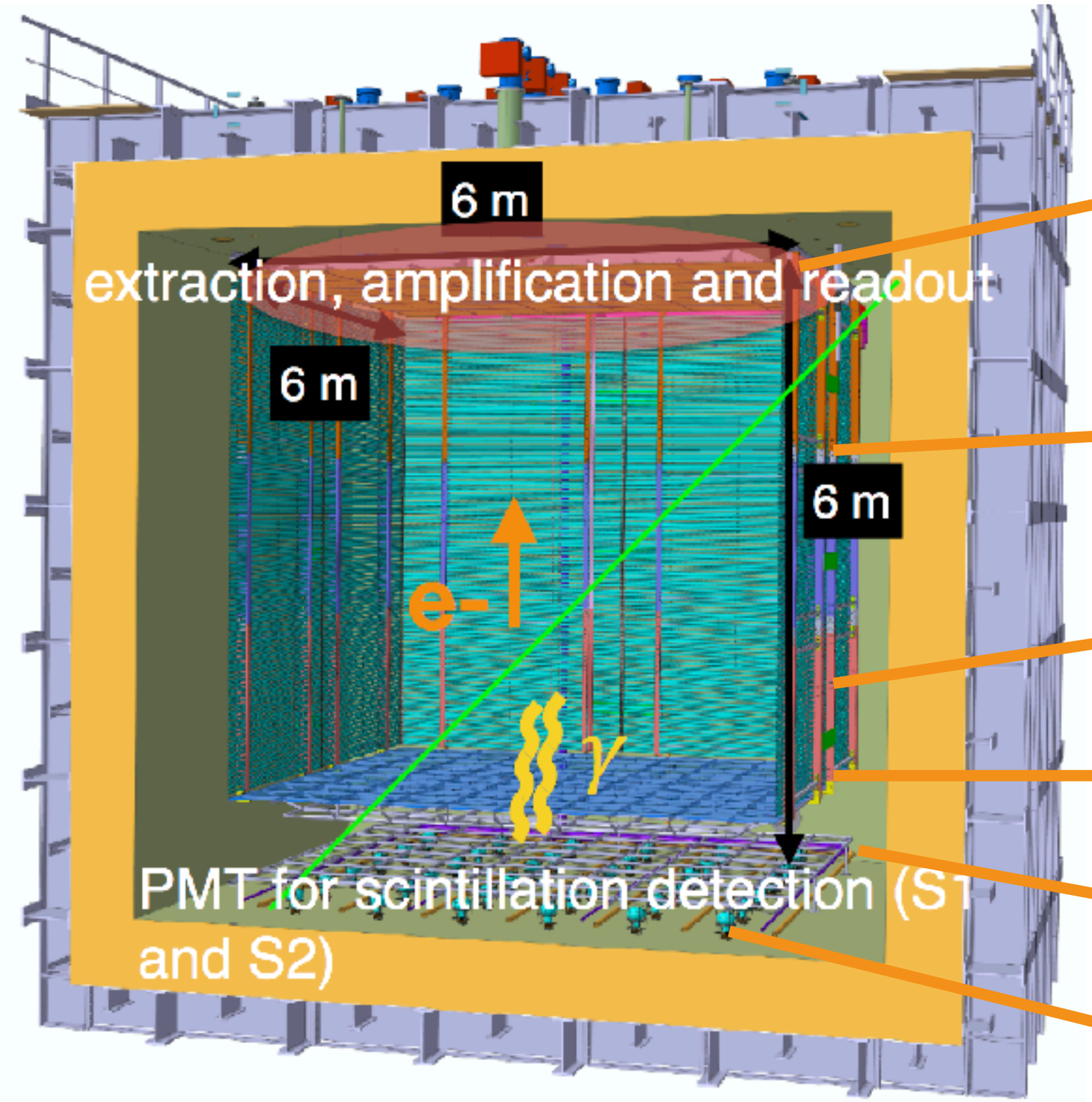
- ProtoDUNE cryogenic system will be designed and operated by CERN cryogenic group
- **Successful test of the performance on the 3x1x1 prototype where a purity compatible with ms electron lifetime has been achieved.**

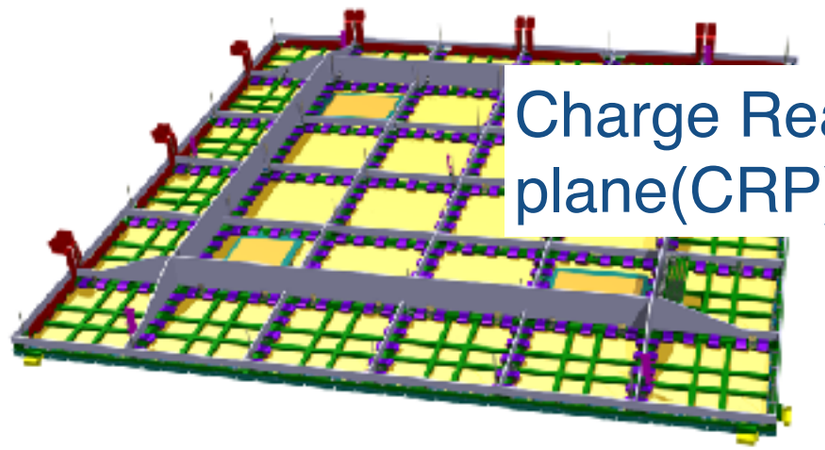






ProtoDUNE-DP





Charge Readout plane(CRP)

Very high voltage system to generate the bias voltage

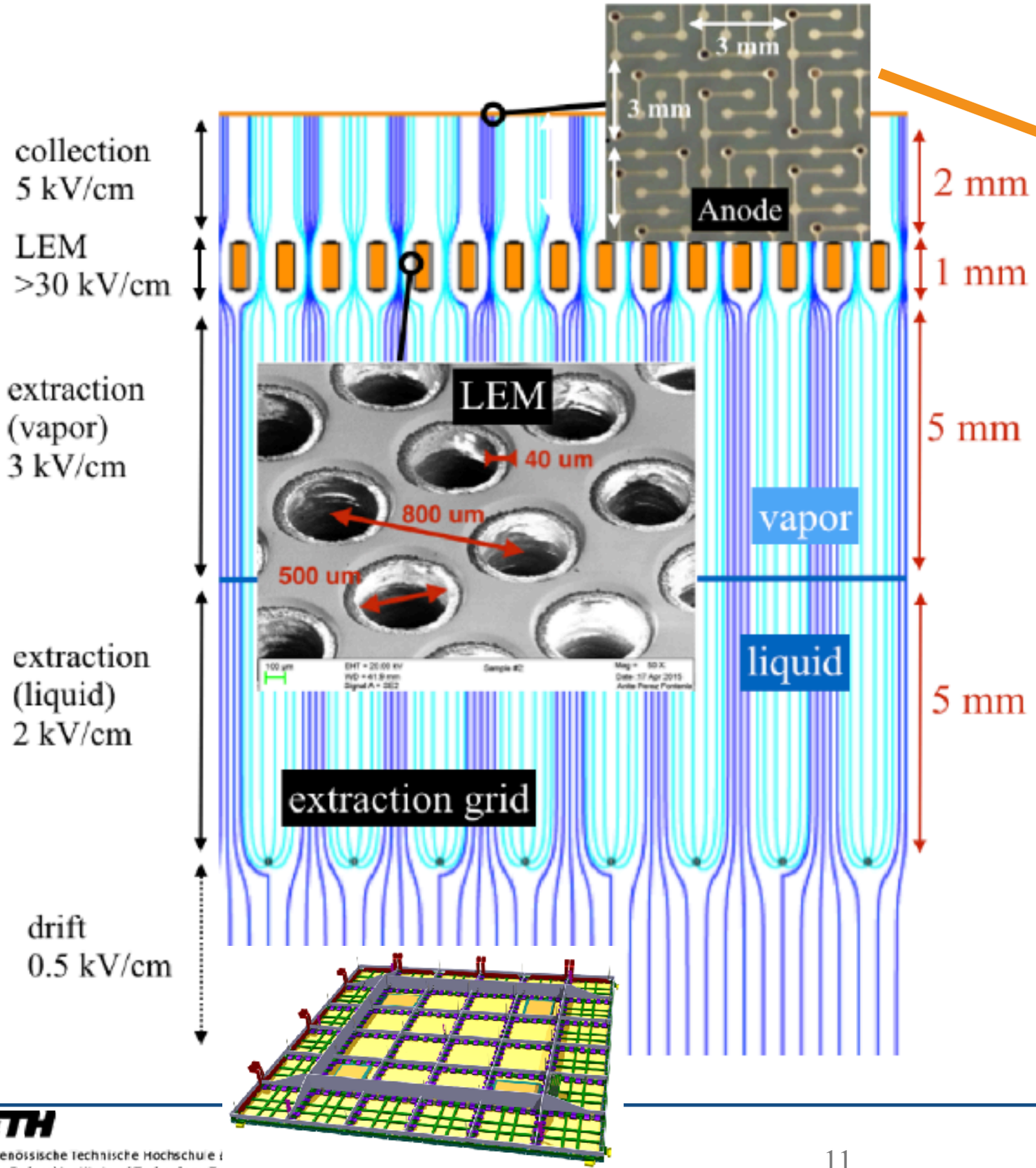
Field cage to guarantee an uniform drift of 500V/cm

Cathode at -300kV

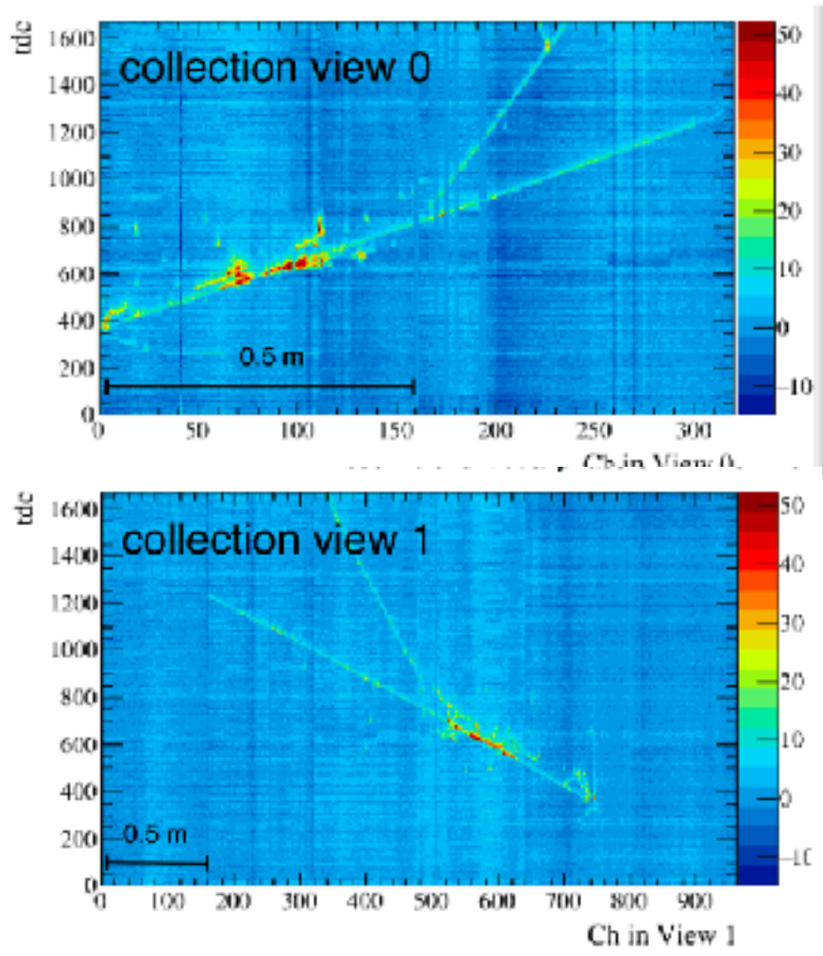
Shielding grid for PMTs

PMTs

ProtoDUNE-DP

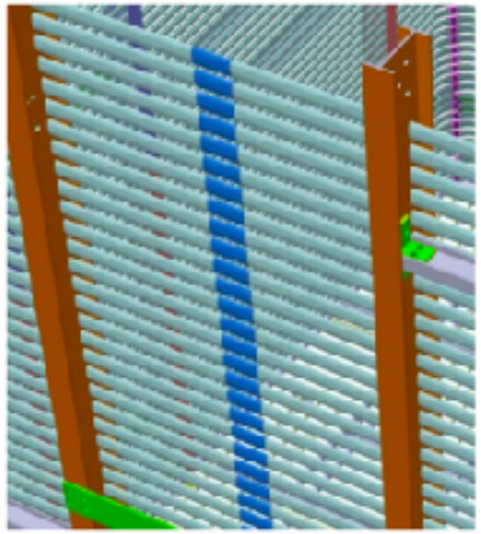


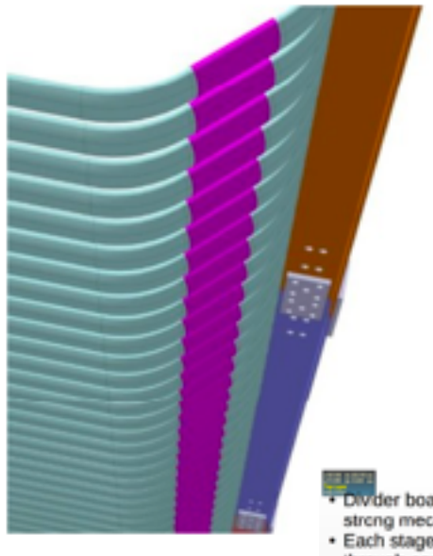
Electrons are collected on both anode views (charge equally shared between the views)



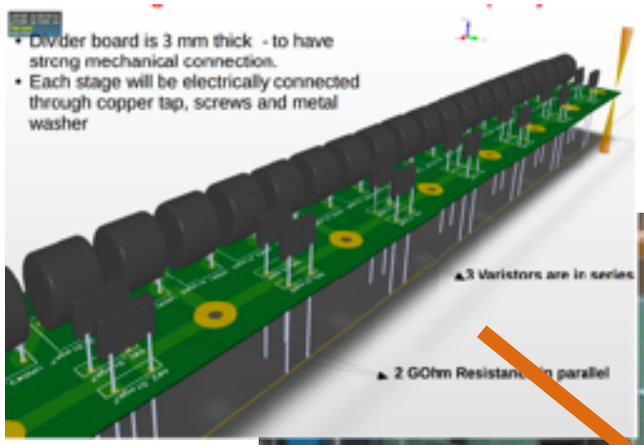
Real event without noise filtering recorded in the 3x1x1 DP prototype

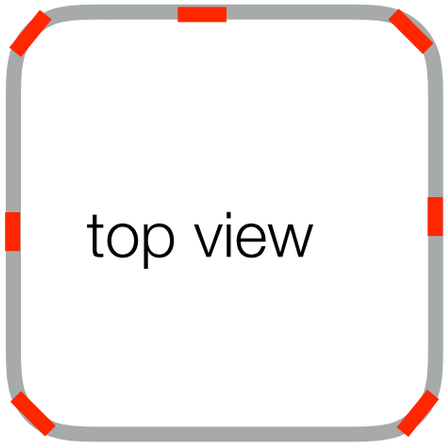
ProtoDUNE-DP: Field cage

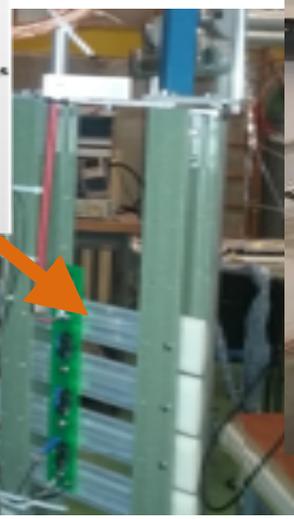


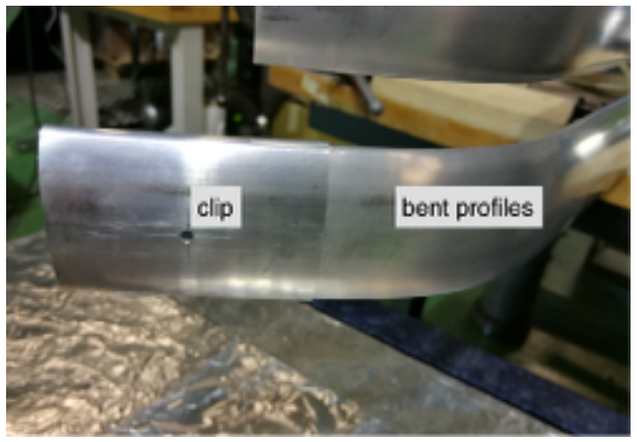


- Aluminium profiles, same designed for both protoDUNEs
- Joint effort between WA105 and CERN
- Resistor boards to electrically connect all modules





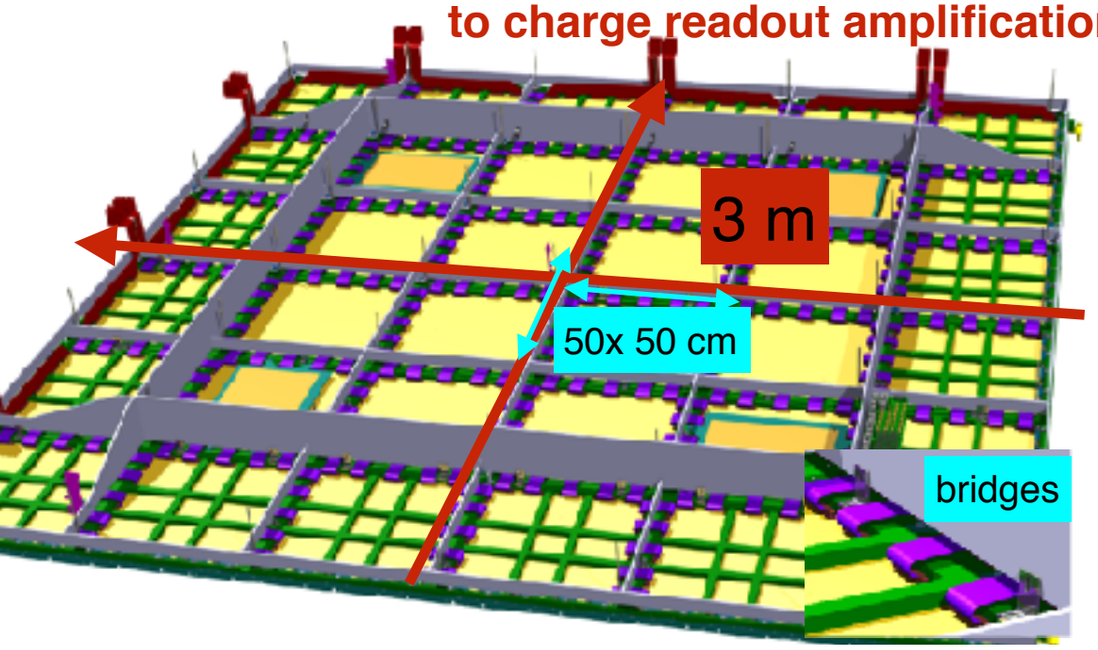


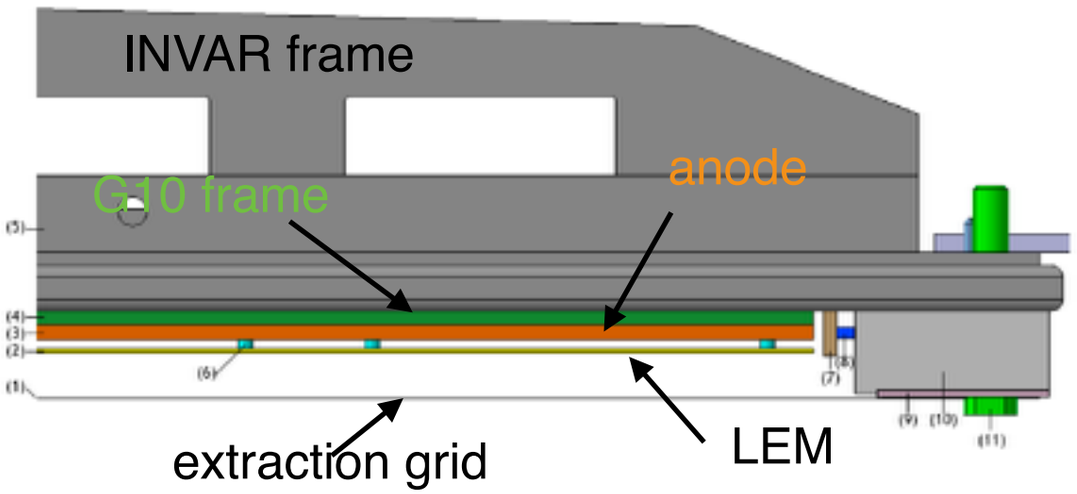


AI clips attached between modules to guarantee electrical continuity

ProtoDUNE-DP: Charge readout plane

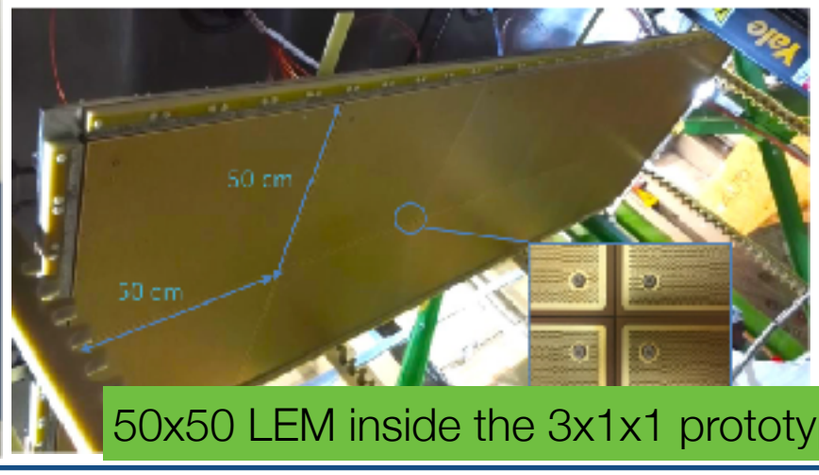
to charge readout amplification and digitisation





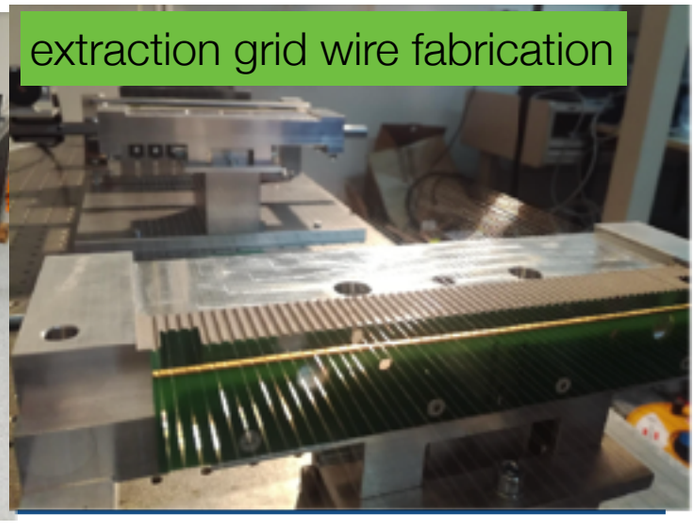
- 4 independent CRP modules
- The CRP is its own detector. It is fully constructed, cabled and tested in the clean room before transportation.
- The most delicate and time consuming elements to fabricate are the 50x50 LEMs and anodes. Both are fabricated in industry.
- Ordered 80 LEMs and 80 anodes last May/ June. The first 36 to be assembled in CRP 1 already at testing and cleaning in CEA Saclay
- The assembly of the first CRP module will start in November.


Clean room for CRP assembly

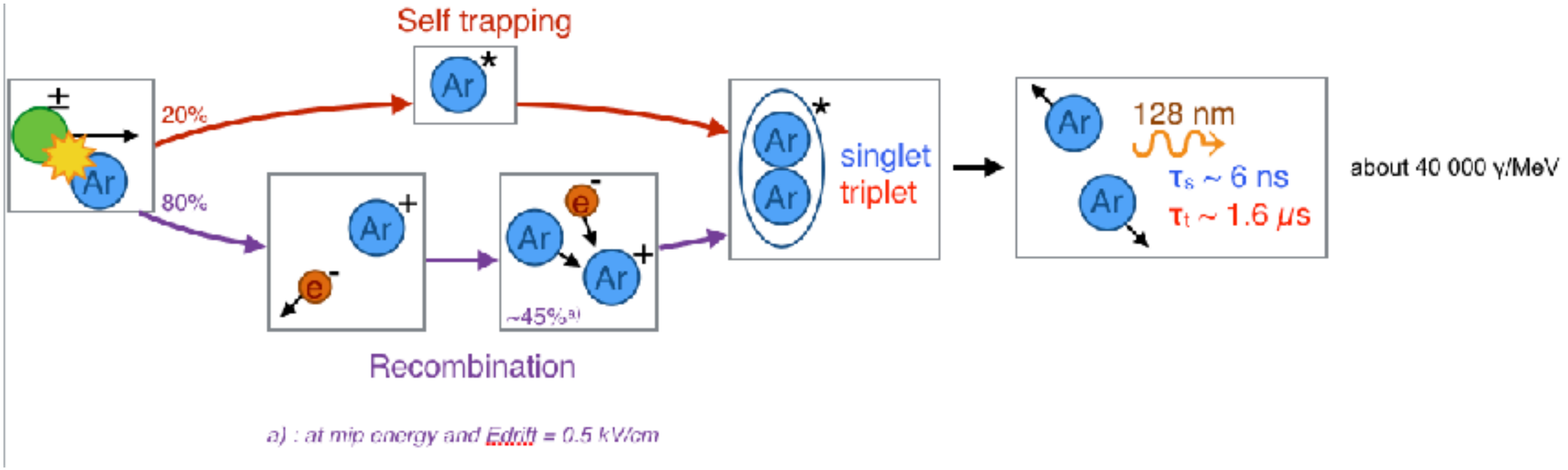


50x50 LEM inside the 3x1x1 prototype

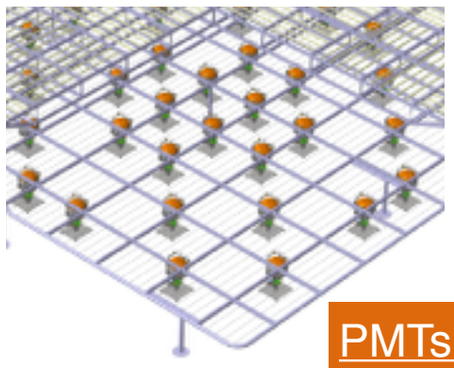

SS wires


extraction grid wire fabrication

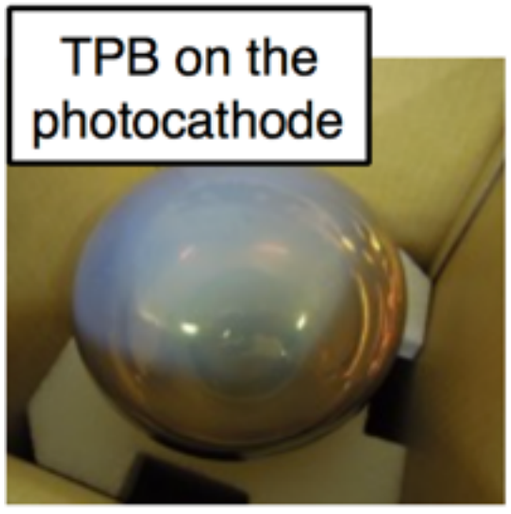
ProtoDUNE-DP: Light detection system

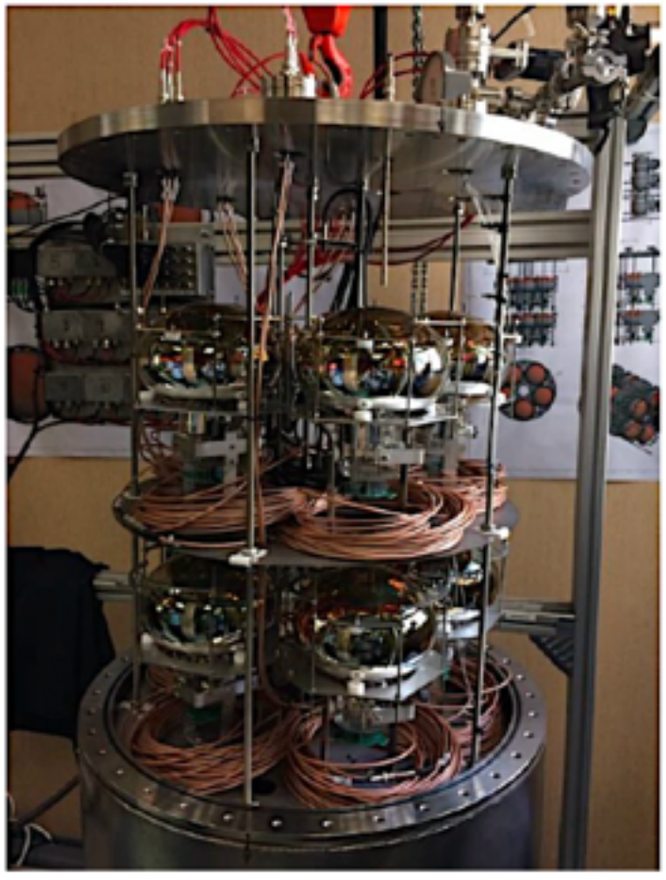


- 40 PMTs delivered, testing ongoing.
- TPB coating ongoing at CERN September/October
- Readout electronics provide sampling of the analog PMT signal at high frequency (160 MHz). CatiROC

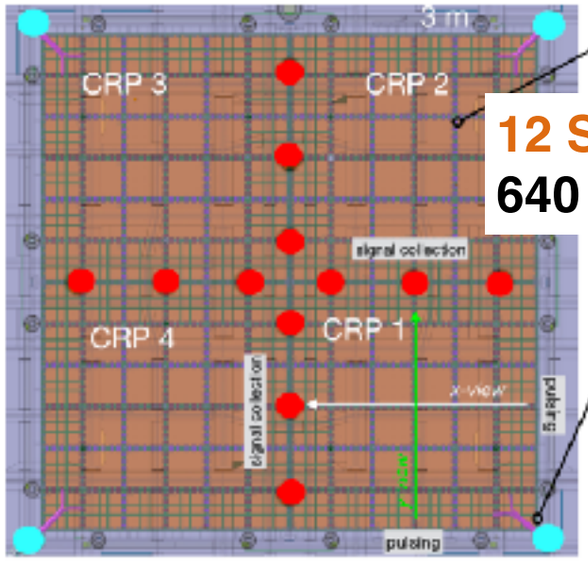


PMTs:
36 pieces on individual bases 0.3x0.3x0.2 m2

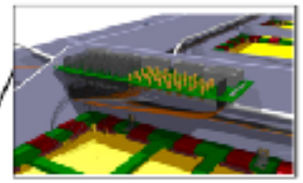




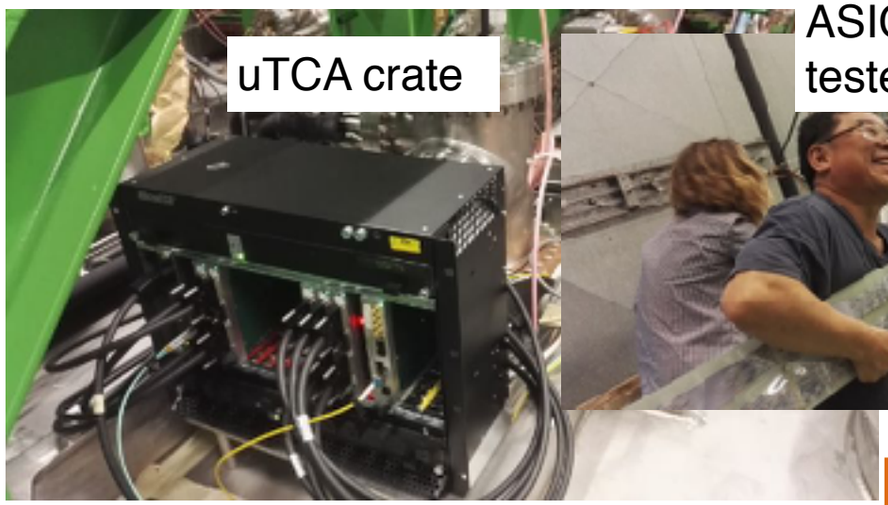
Noise and dead channels in warm and cold



12 SGFT: each reads 640 channels

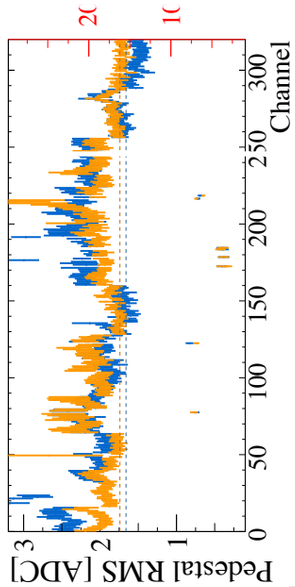


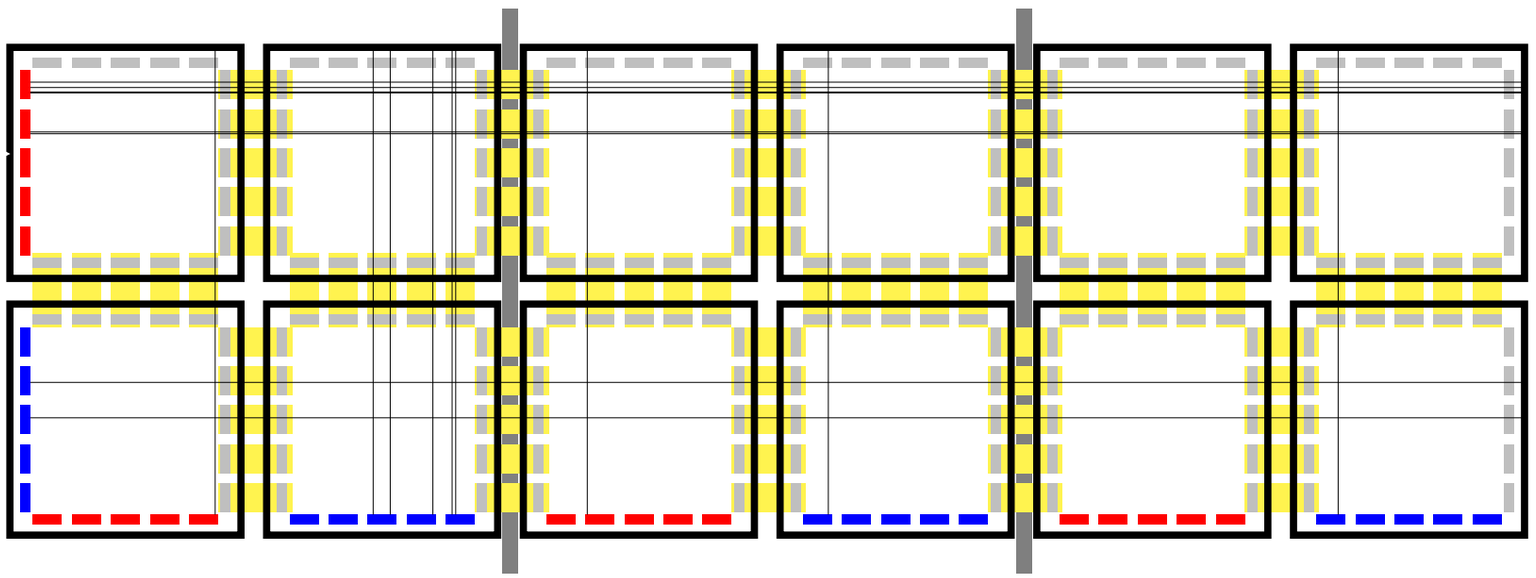
patch panel

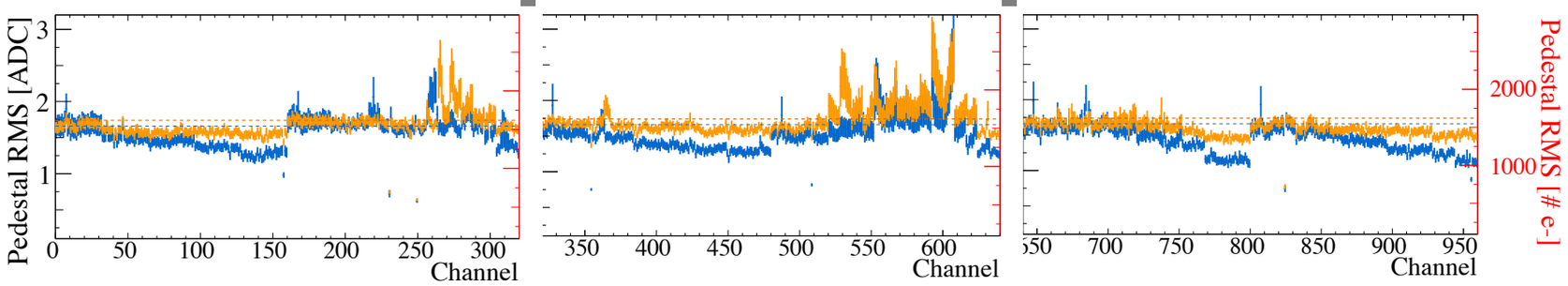


ASICs insertion via 2 m blade tested in **warm** and **cold**

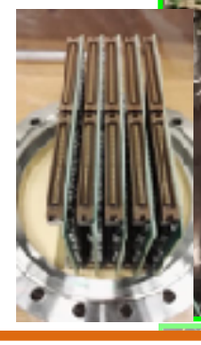
accessible cold amplifiers.Sealed in chimney separate from main argon volume







cold ASICs

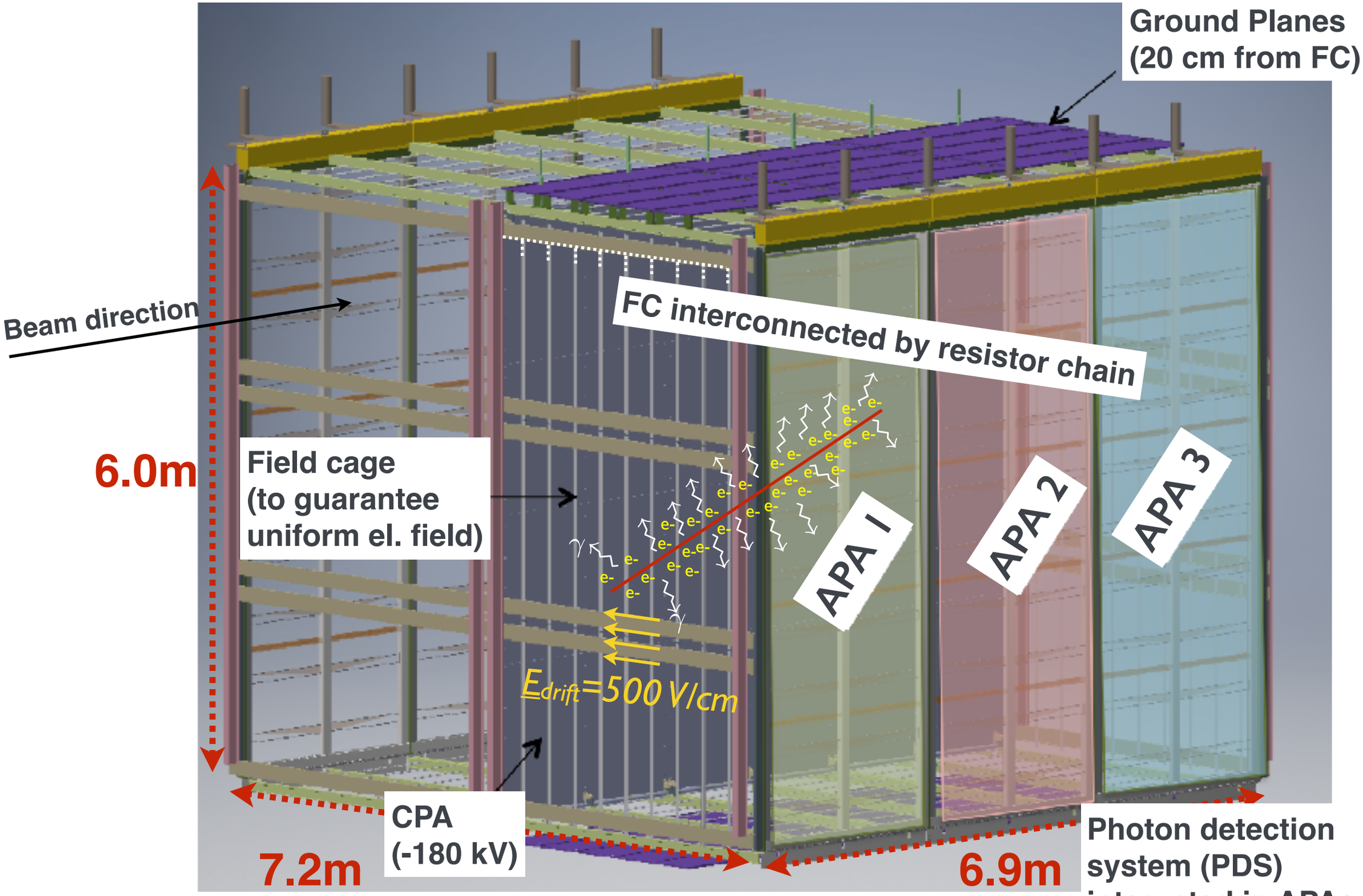


(20adc=3fC)

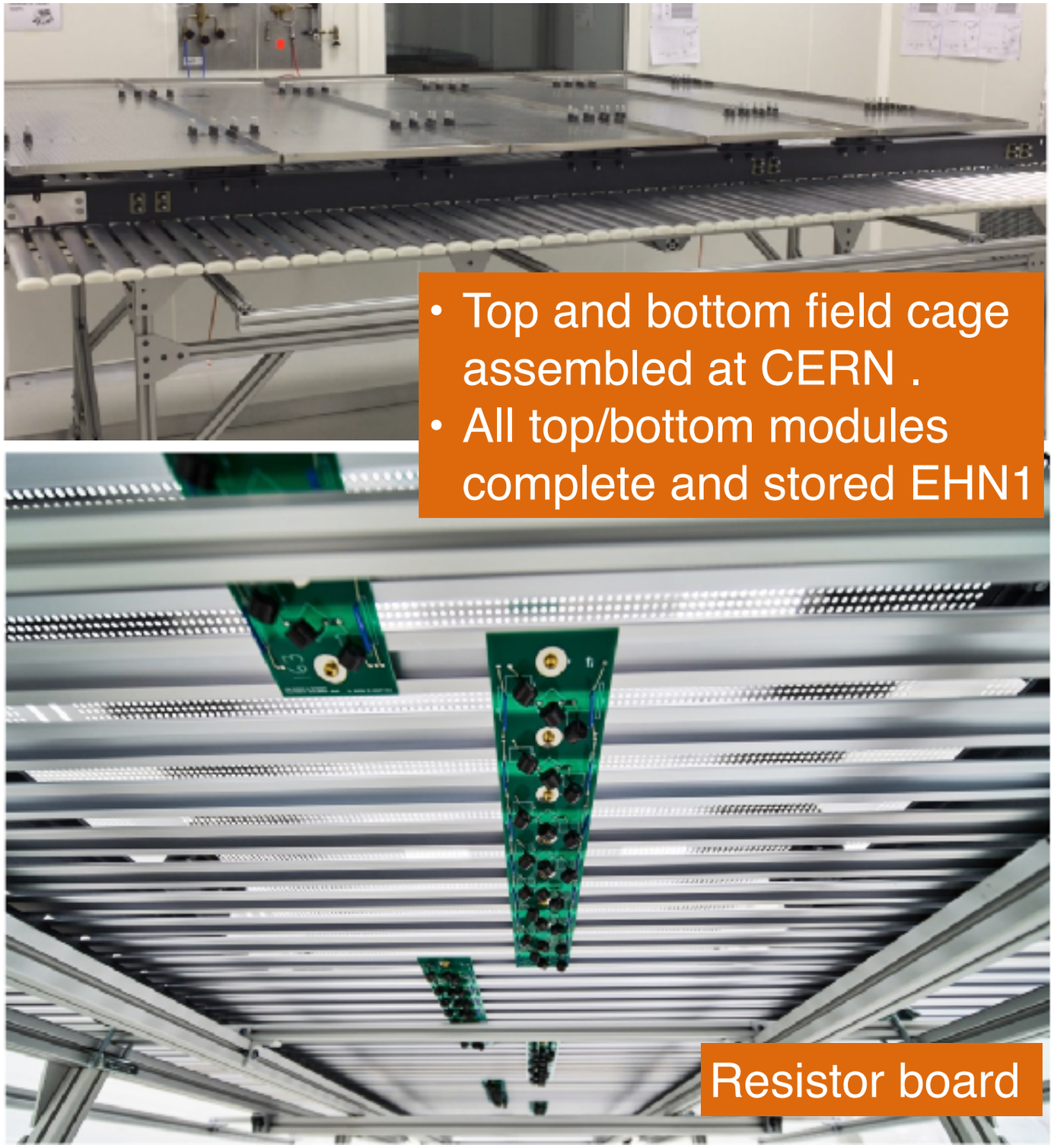
3 meter strips, 3 mm granularity

Low noise condition at cold: 1.66 adc counts (1600 e$^-$) RMS noise

ProtoDUNE-SP

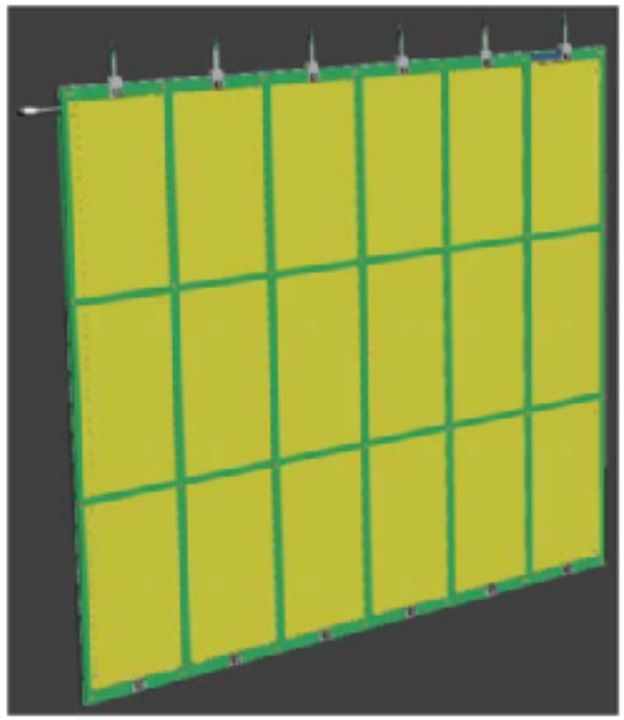


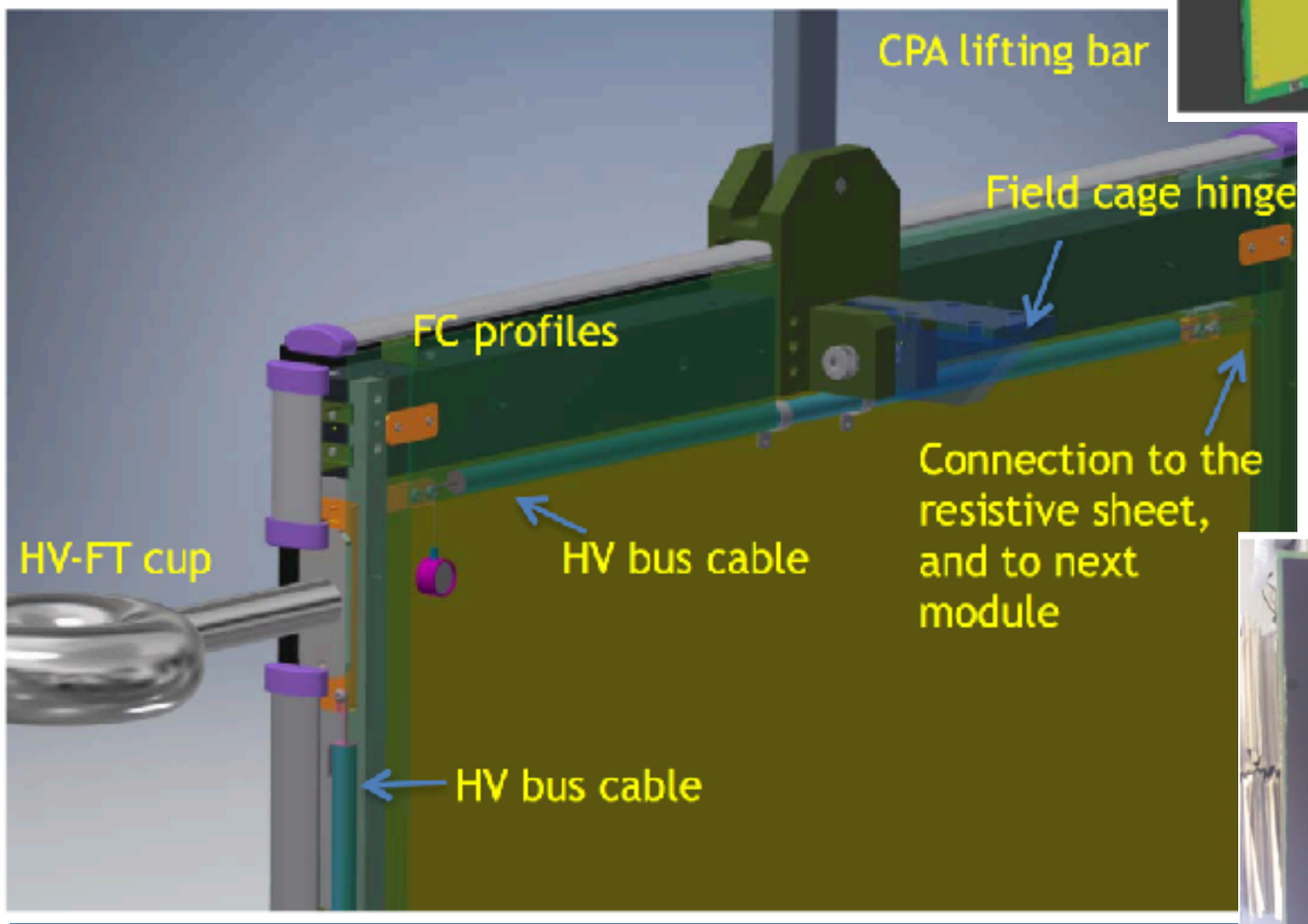
ProtoDUNE-SP: Field cage



ProtoDUNE-SP: Cathode

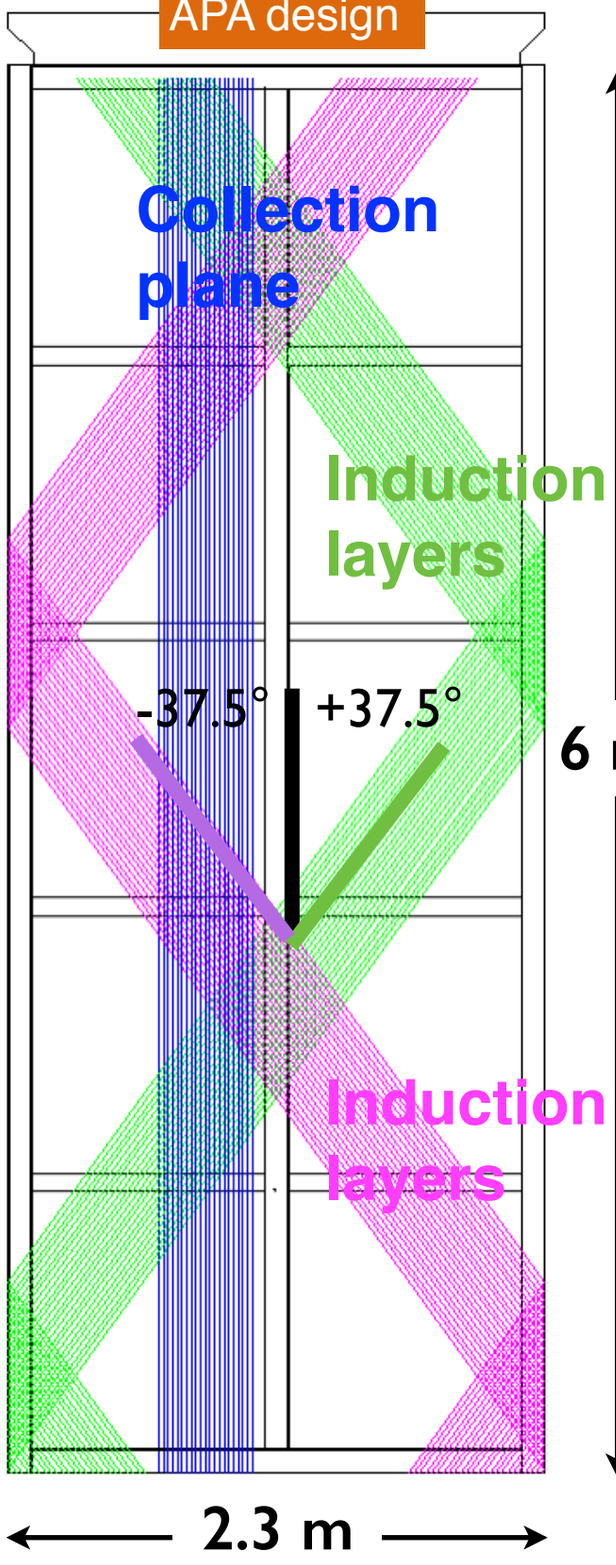
- Cathode bias voltage -180 kV
- Resistive cathode to quench discharges



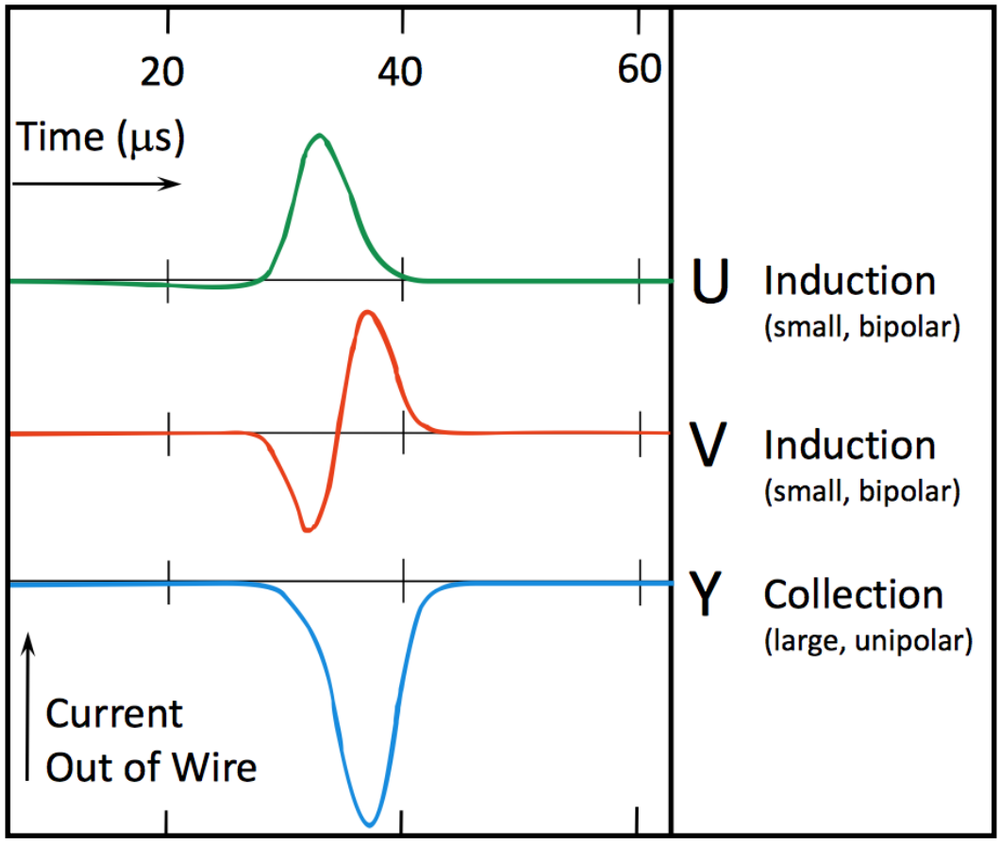


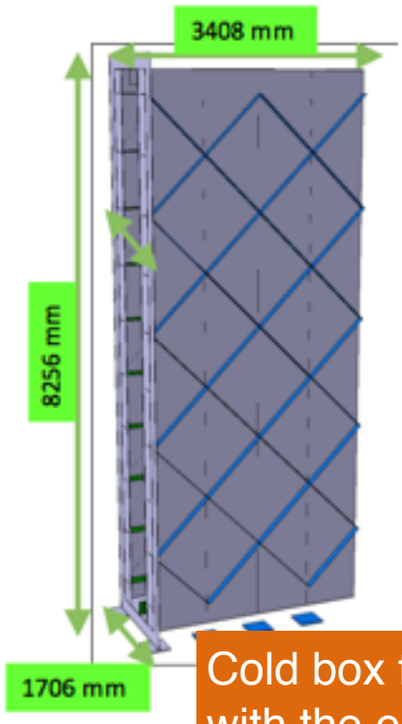
ProtoDUNE SP: Anode Plane Assembly

APA design



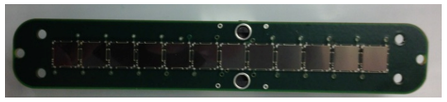
First APA in EHN1 cleanroom since August 2017



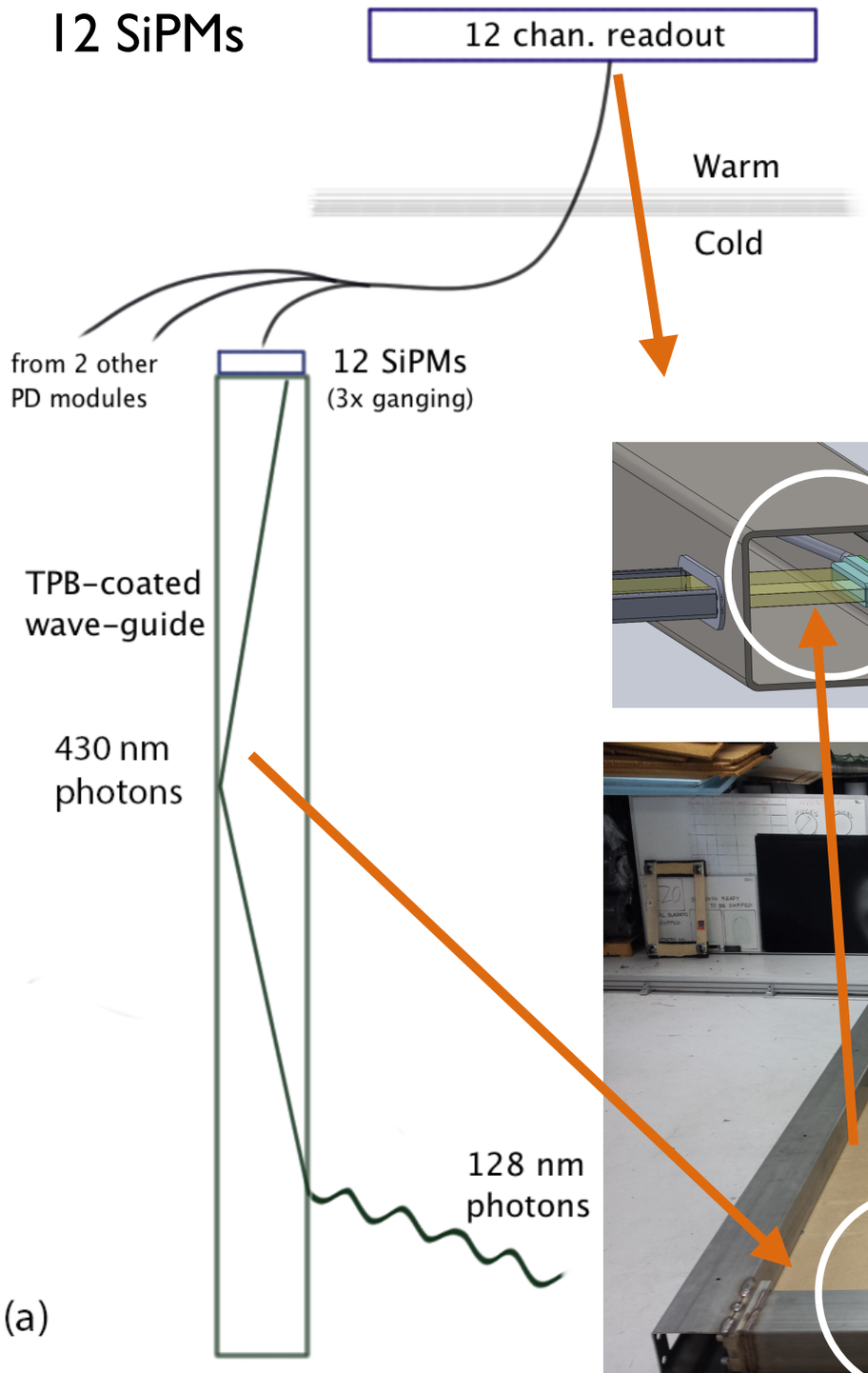


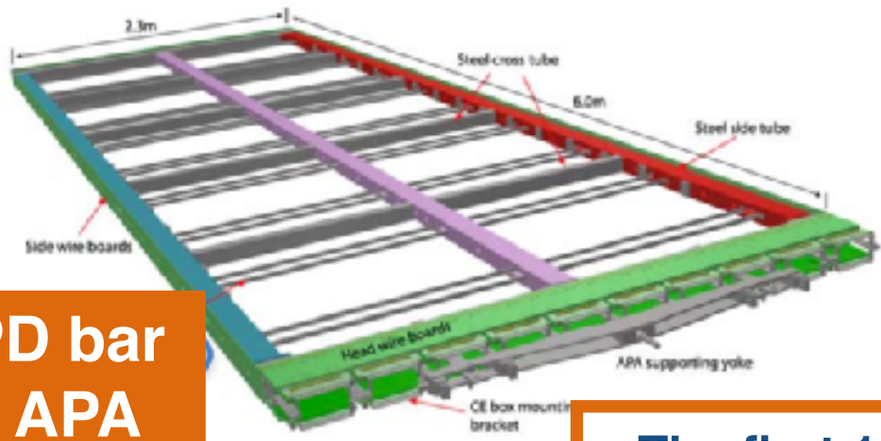
Cold box for testing the APAs together with the electronics and PDS system before installing inside the cryostat

ProtoDUNE-SP: Photon detection system

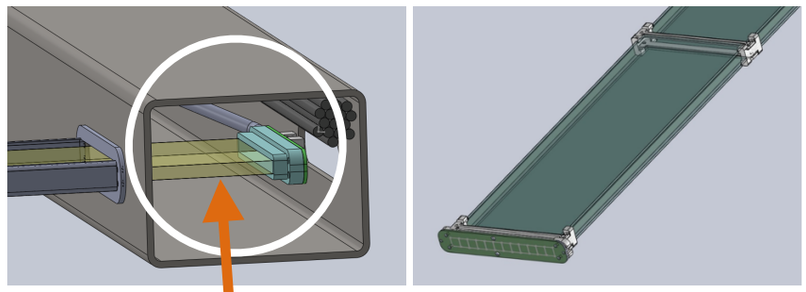


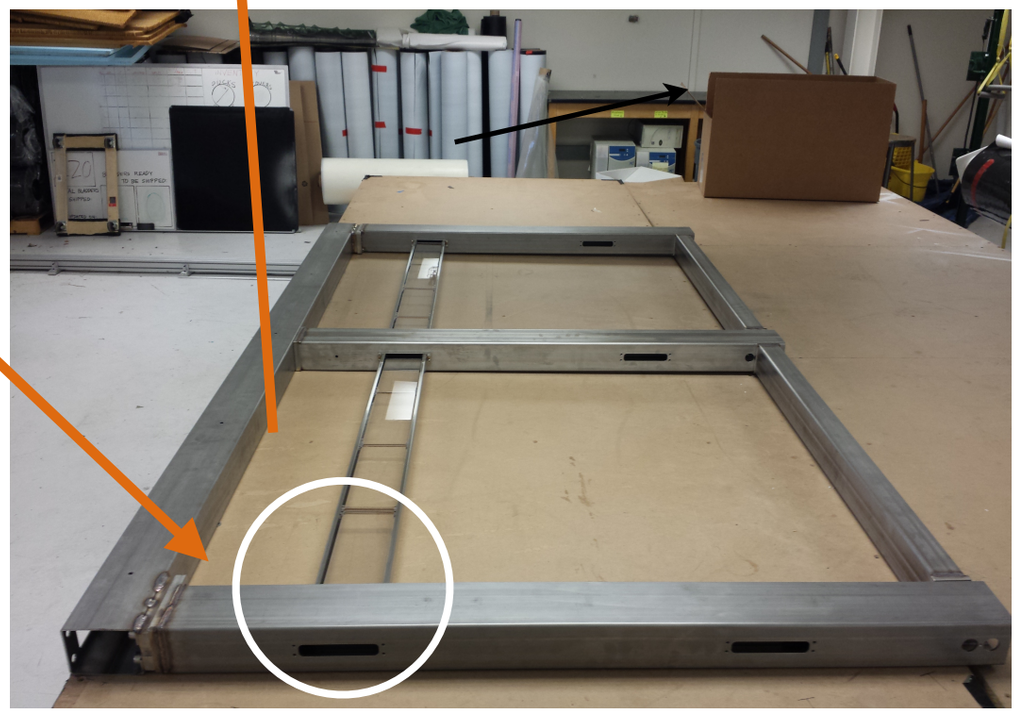
12 SiPMs





10 PD bar per APA





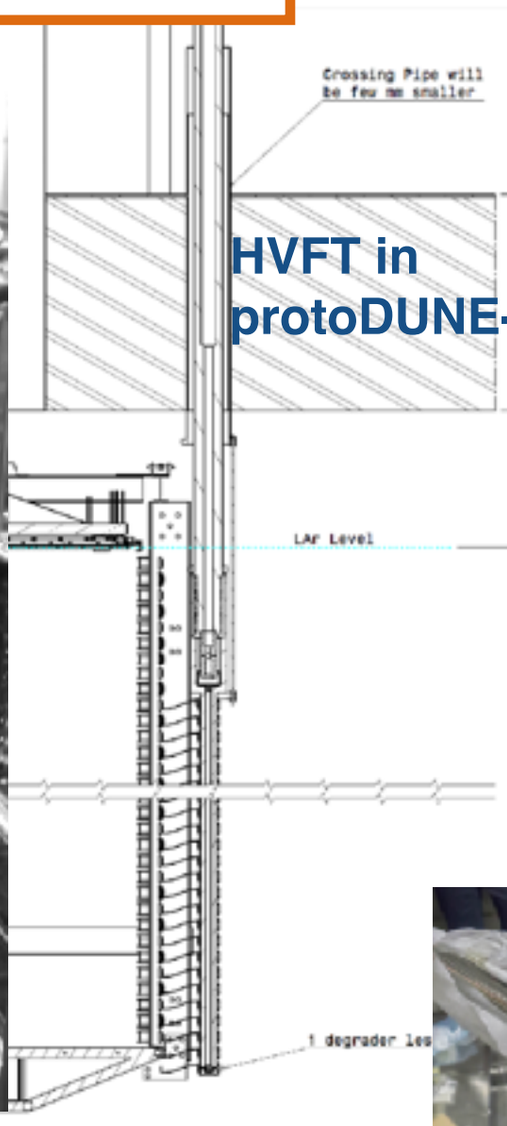
- **The first 10 photon detectors installed in APA1**
- **All channels tested and responding successfully**
- **Next step test them inside the cold box.**
- **Assembly on APA2 ongoing.**

Very high voltage(VHV) system

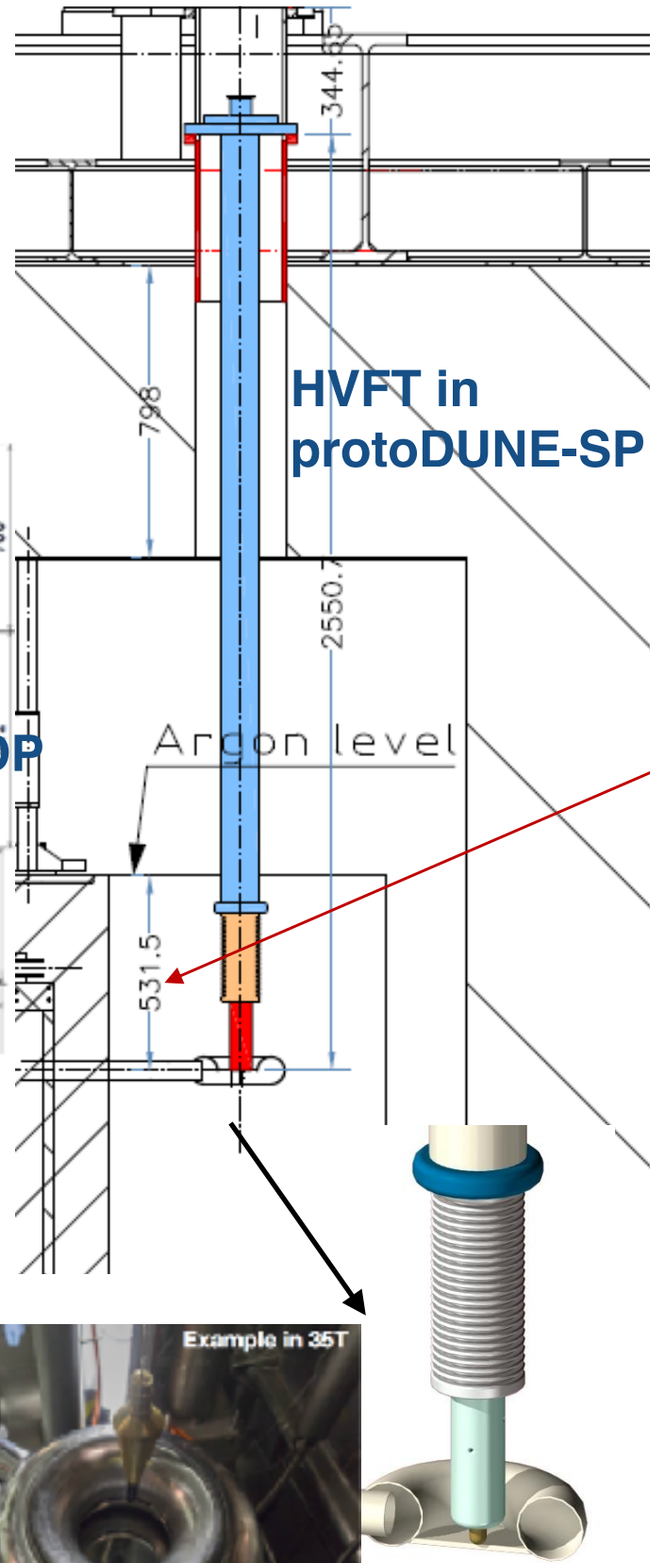
Common DP/SP effort:

- VHV system= the PSU, the feedthrough and the extension (for DP).
- PSU: all available (2 of 300 kV + 1 spare of 200 kV)
- Feedthrough: 3 in production (rated for 300 kV). Should arrive November. To be tested
- Extension (DP): designed needs ordering (and tested)

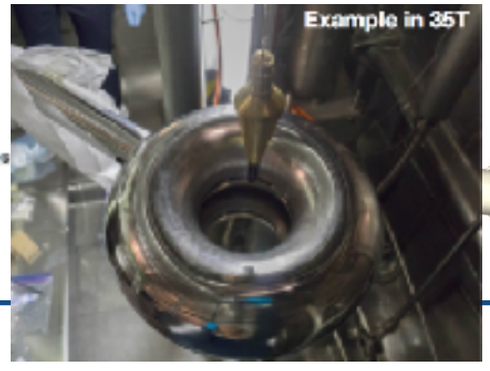
new 300 kV in EHN1.
Organising test ~November



HVFT in protoDUNE-DP



HVFT in protoDUNE-SP

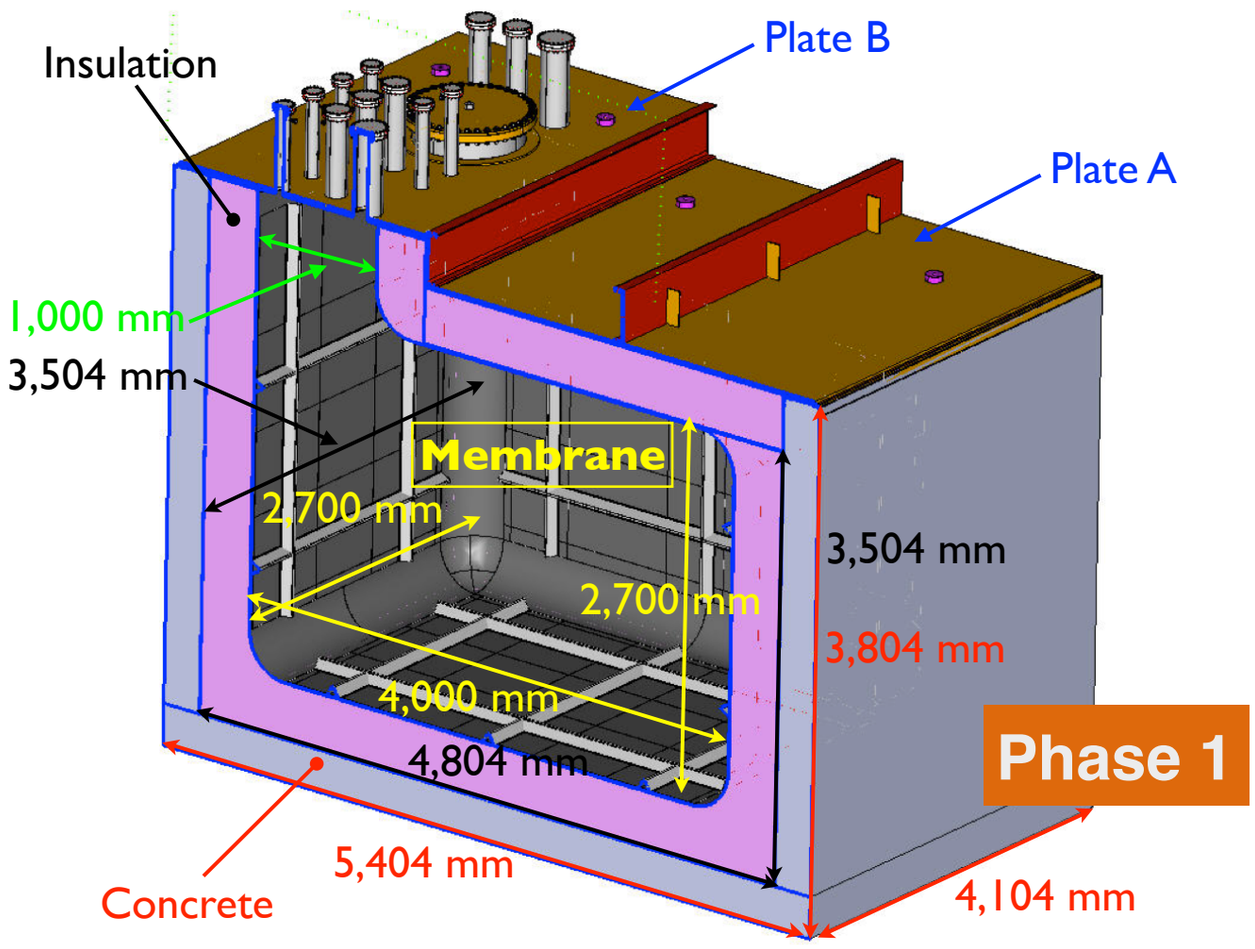


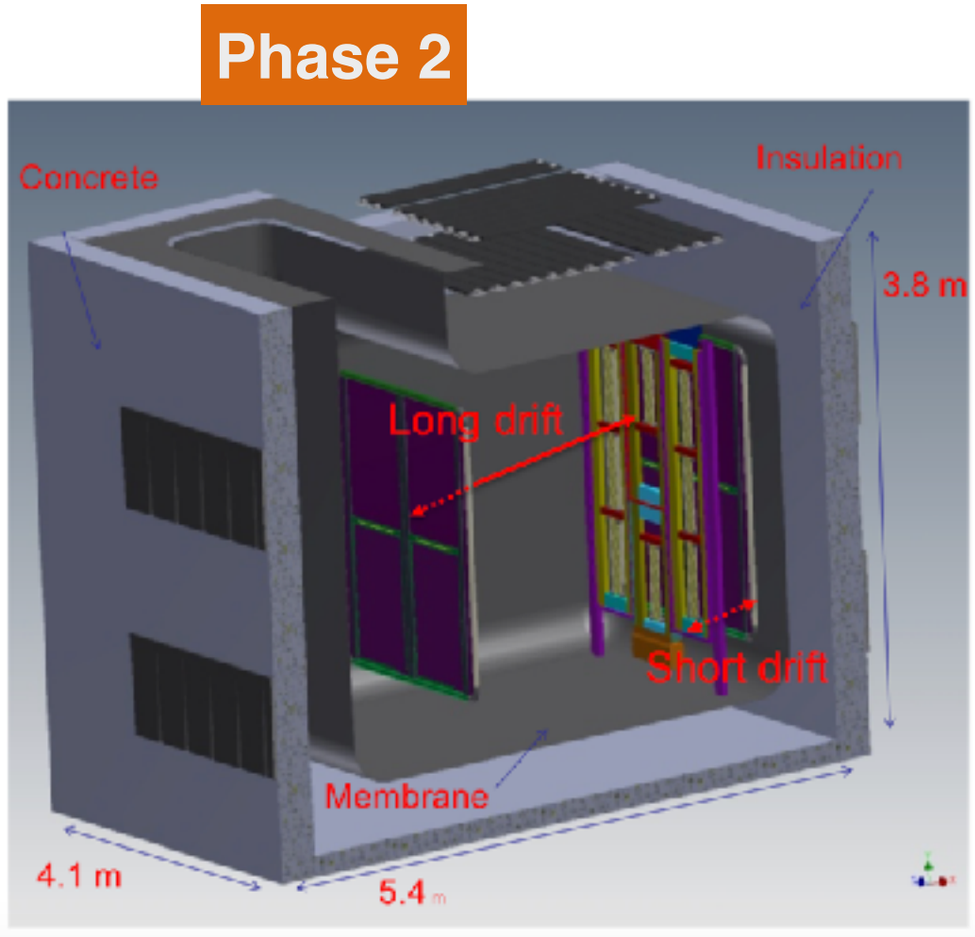
HVFT tested up to 300 kV JINST 12 P03021 arXiv:1611.02085

Pilot prototypes: 35t

Motivation

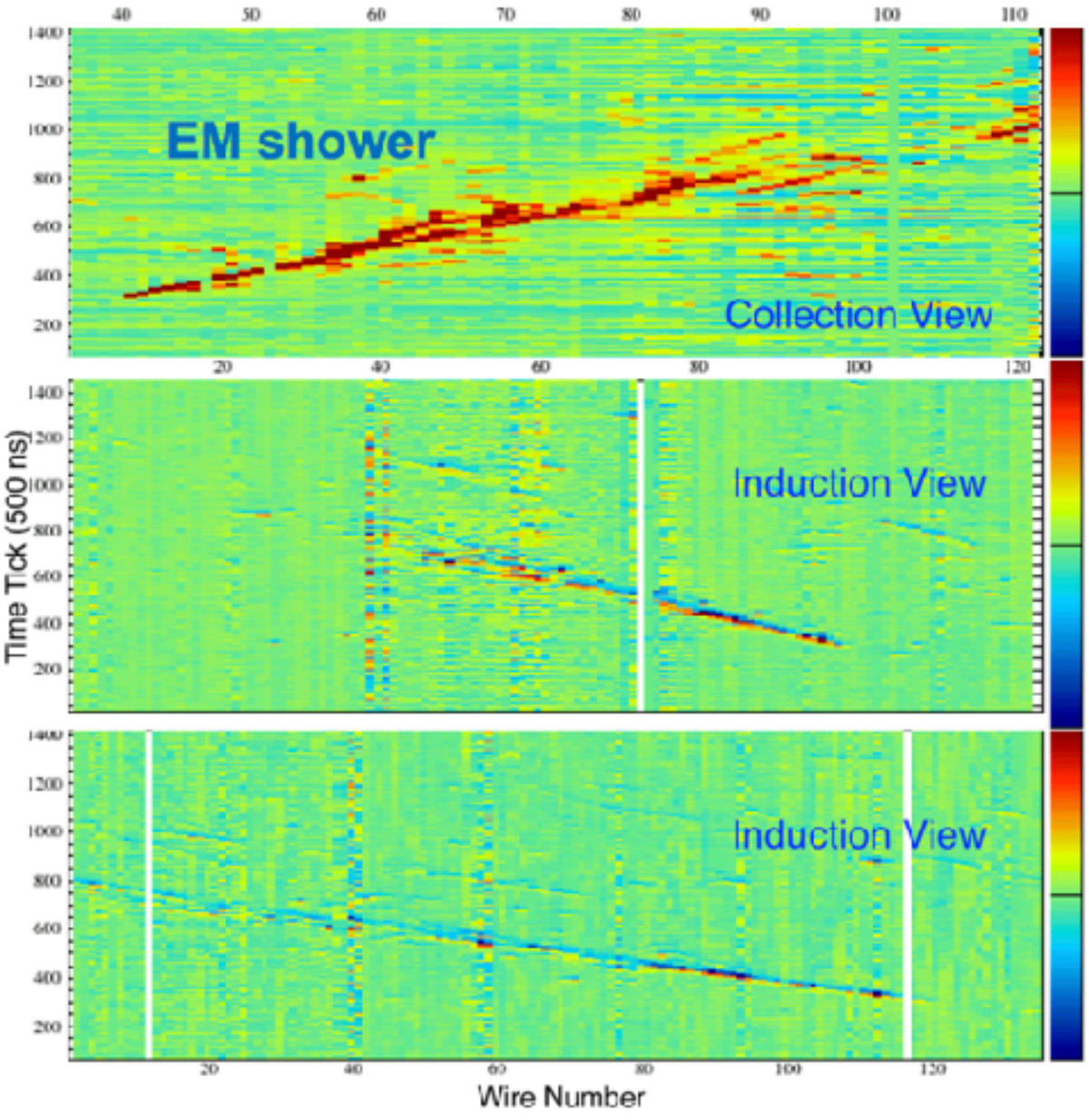
- ✓ **Phase 1-Dec. 20, 2013 – Feb. 15, 2014:** Demonstrate that a non-evacuable "membrane" cryostat can reach better electron lifetime than 1.4 ms
- ✓ **Phase 2 Feb. 1 – April 4, 2016:** Test of the LAr-TPC and photon detectors exposed to cosmic rays.
- ✓ **Phase 3 Ongoing!!:** Detail test of protoDUNE-SP elements such as HV, field cage and beam plug.

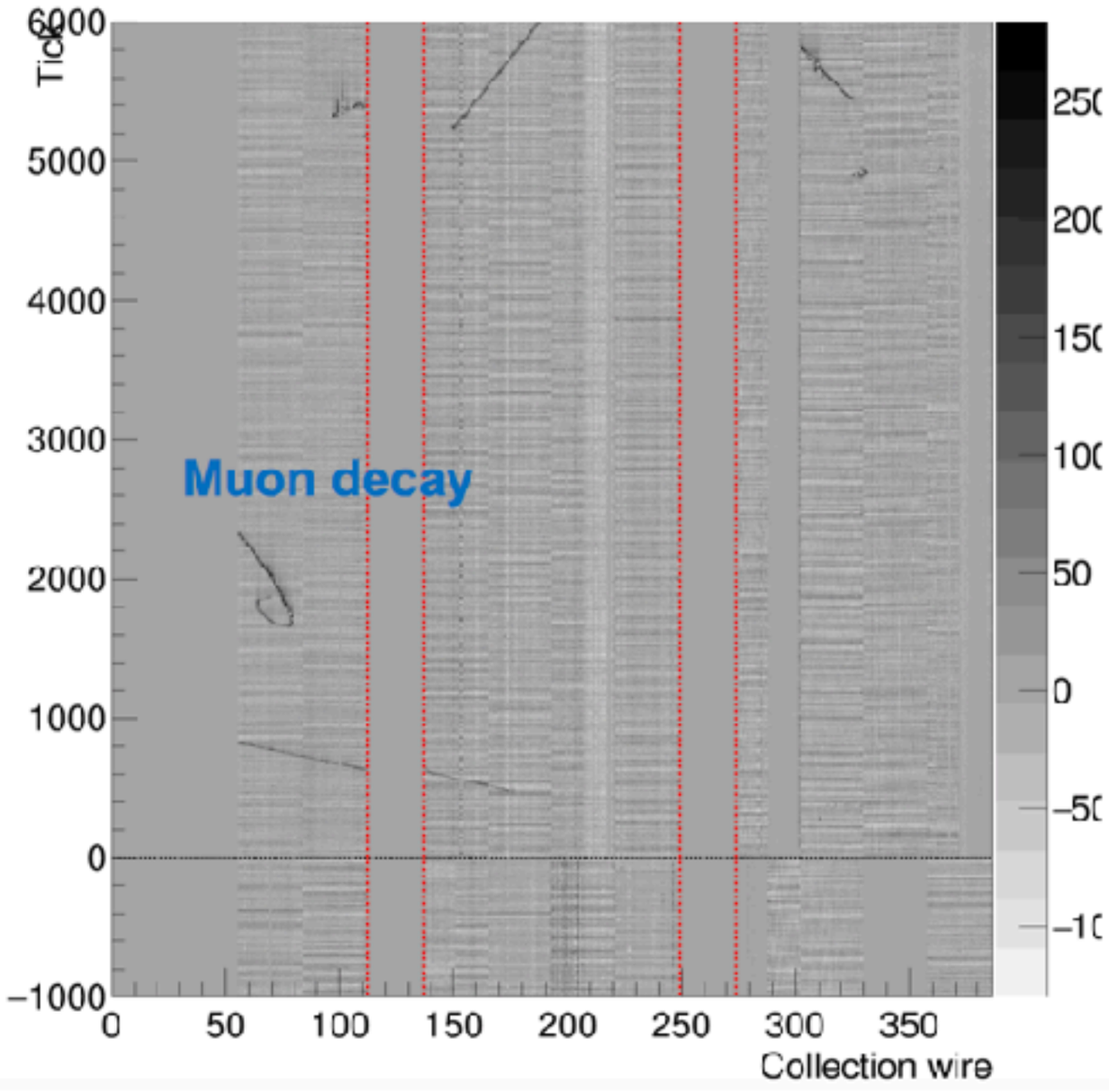




Pilot prototypes: 35t

After noise filtering





Pilot prototypes: The 3x1x1 m³

DUNE WA105

Two DP- LAr TPCs → Same technology→different sizes→different goals

Common aspects

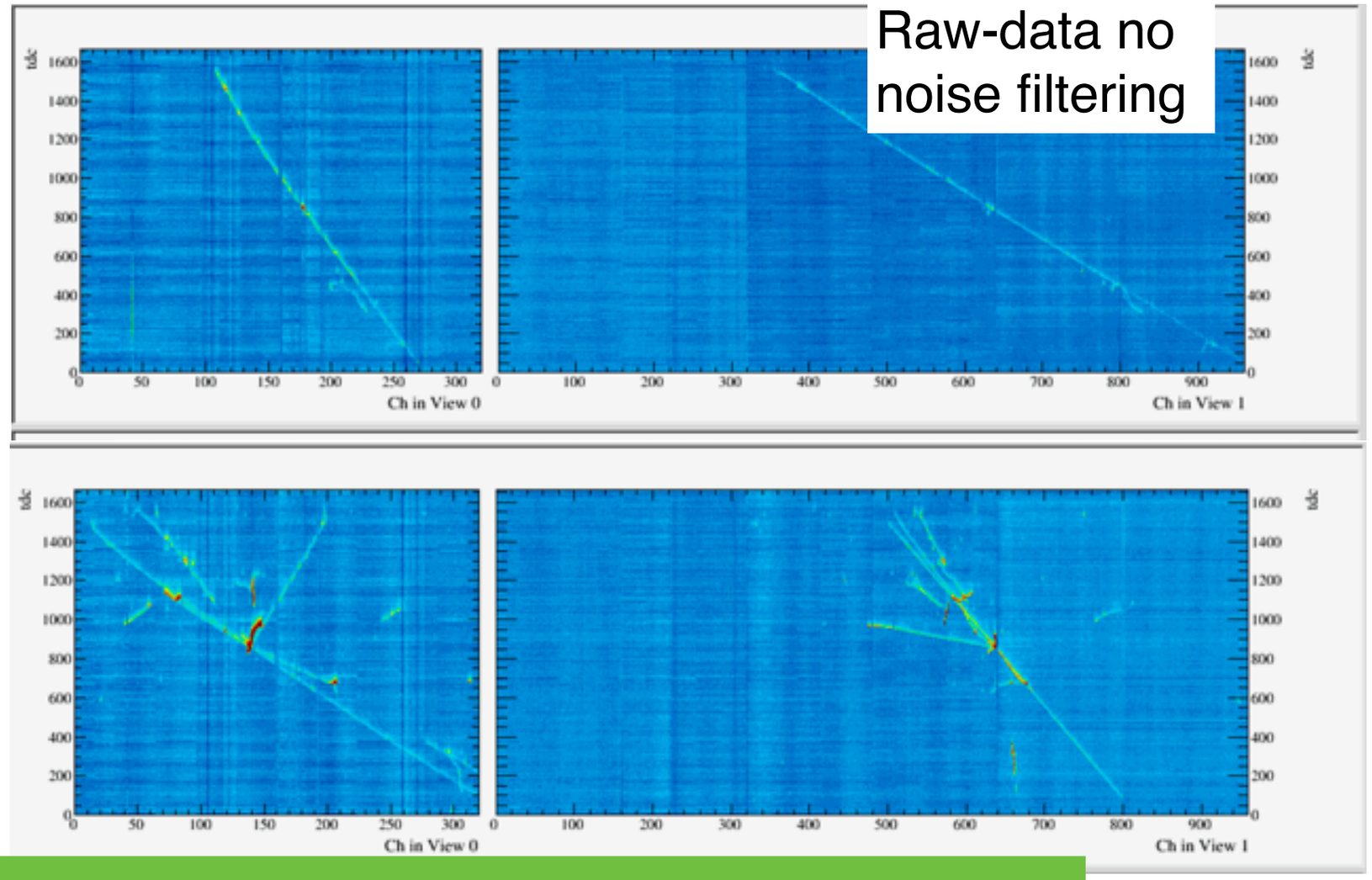
- ✓ LEMs and anode: design, purchase, cleaning and QA
- ✓ chimneys, FT and slow control sensors
- ✓ membrane tank technology
- ✓ Accessible cold front-end electronics and DAQ system
- ✓ amplification in pure Ar vapour on large areas

Pilot prototypes: The 3x1x1 m³

DUNE WA105

More than 350K events collected!!!

Crossing muons + showering events
Many topological interesting events to test neutrino reconstruction algorithms

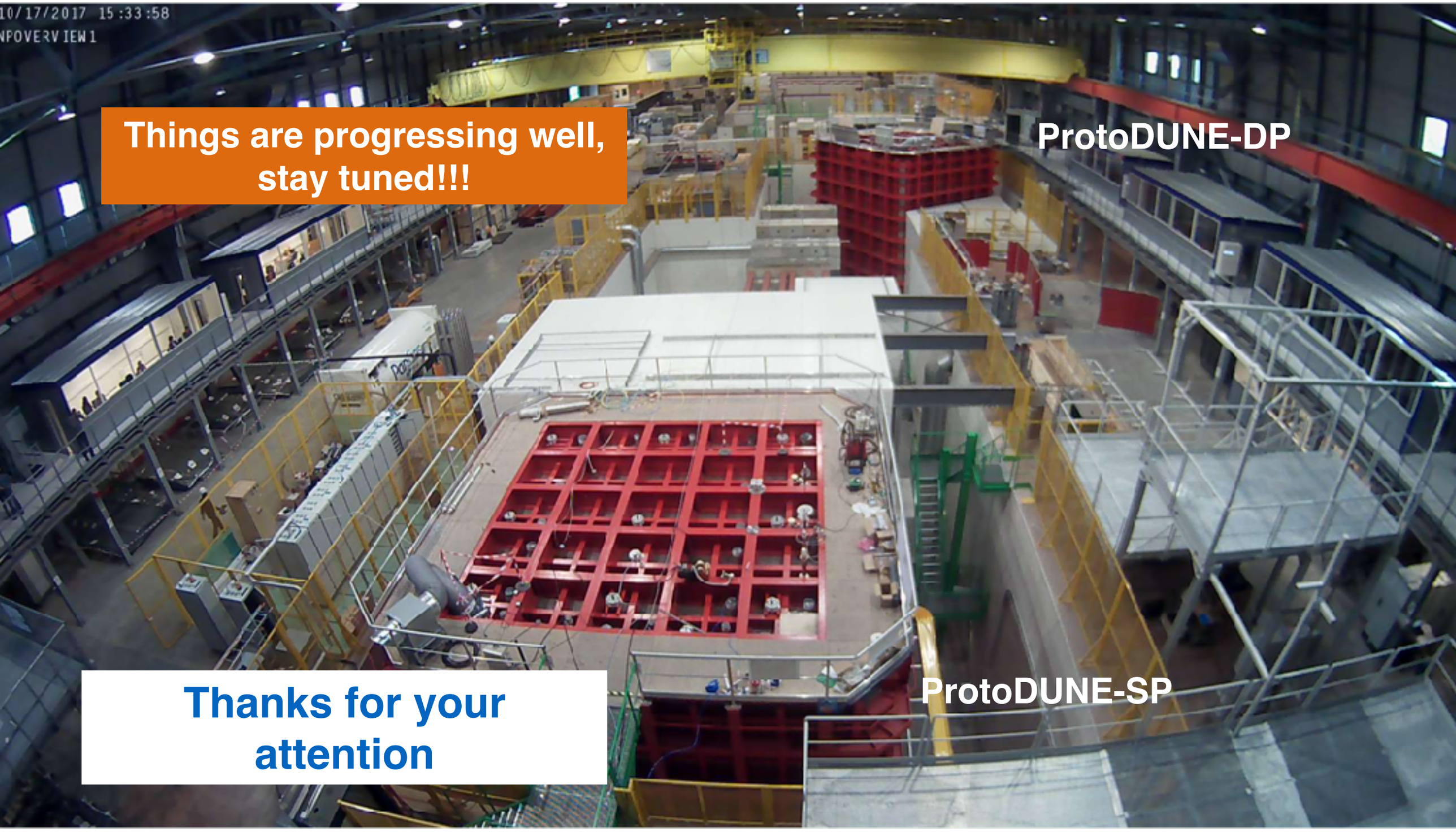


- **First GTT constructed cryostat for LAr**
- **Fully engineered versions of many detector components** with pre-production and direct implementation
- **First overview of the complete system integration**: set up full chains for QA, construction, installation and commissioning
- **First results of extraction and amplification in 3 square meter area and LEM 50x50 cm amplification**
- **Stable drift field of 500V/cm over 1m**
- **Purity compatible with 1ms electron lifetime**

Summary

- The protoDUNE detectors would be the largest LAr TPC exposed to a charged particle beam.
- The main components of both detectors are similar to the ones that will be used for DUNE far detector. Large experience has been gained for design, construction and installation of such large detectors.
- The 3x1x1 prototype built at CERN has allowed us to test a non-evaluable membrane cryostat built by the same company in charge of protoDUNEs and DUNE far cryostat.
- A strong cryogenic team has been developed at CERN. The main requirements for purity have been reached in the 3x1x1 DP prototype, where a purity compatible with ms electron lifetime has been achieved.
- An intense R&D activity is ongoing at both sides of the ocean to have the protoDUNE detectors ready by the fall of next summer.

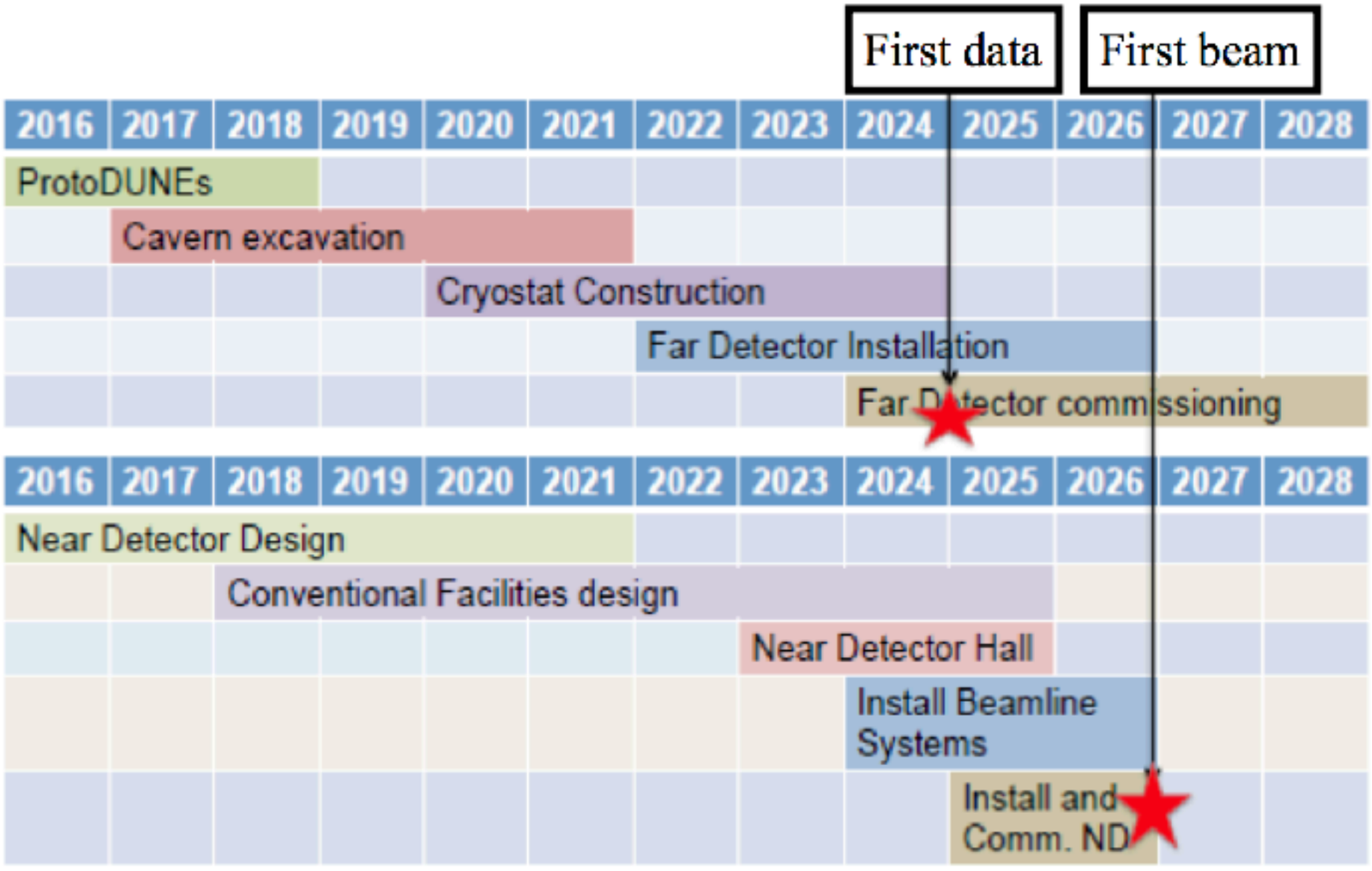
Last but not least…



Thanks for your attention

Back-up

DUNE timeline



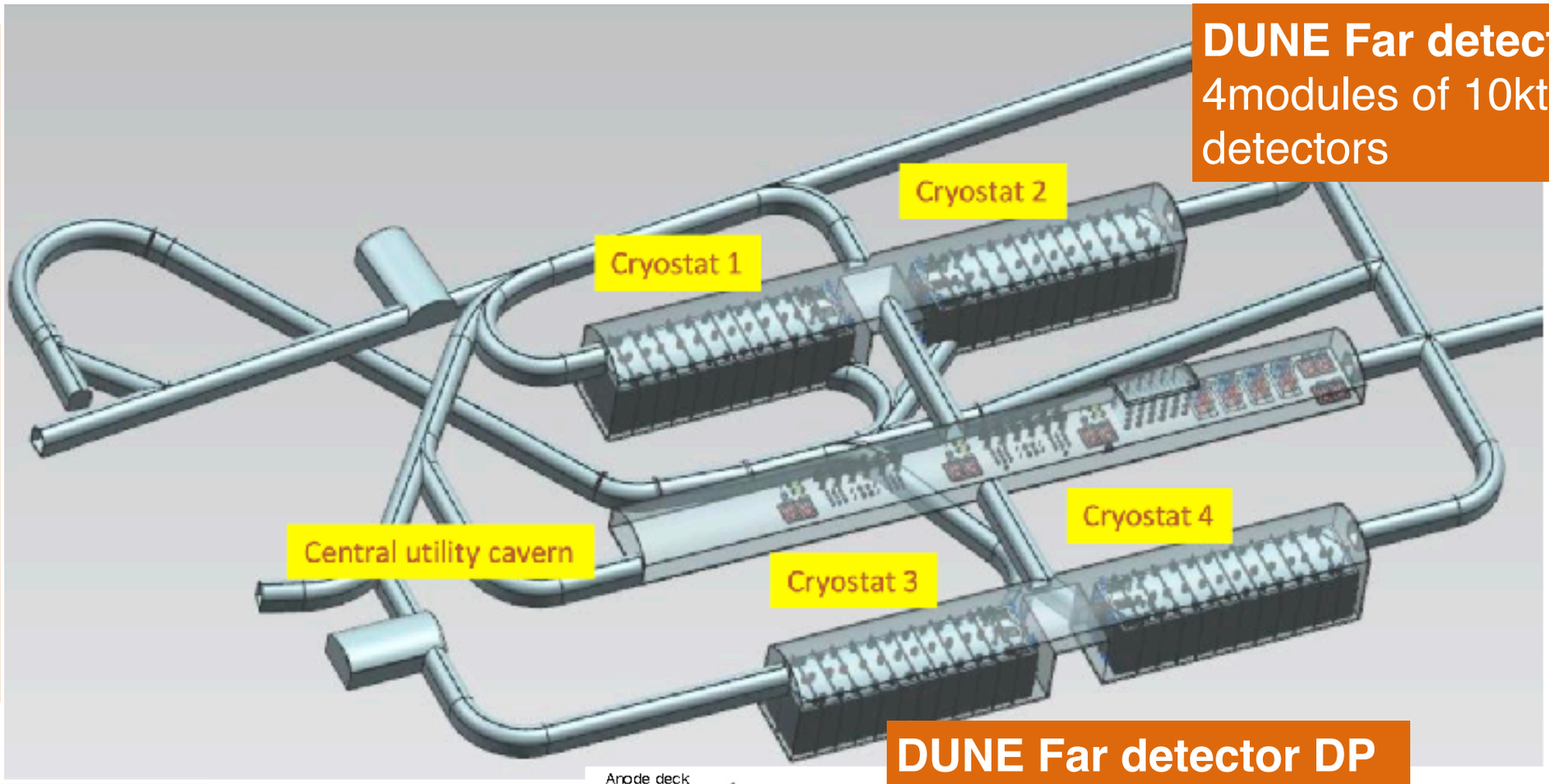
ProtoDUNE and DUNE

DUNE WA105

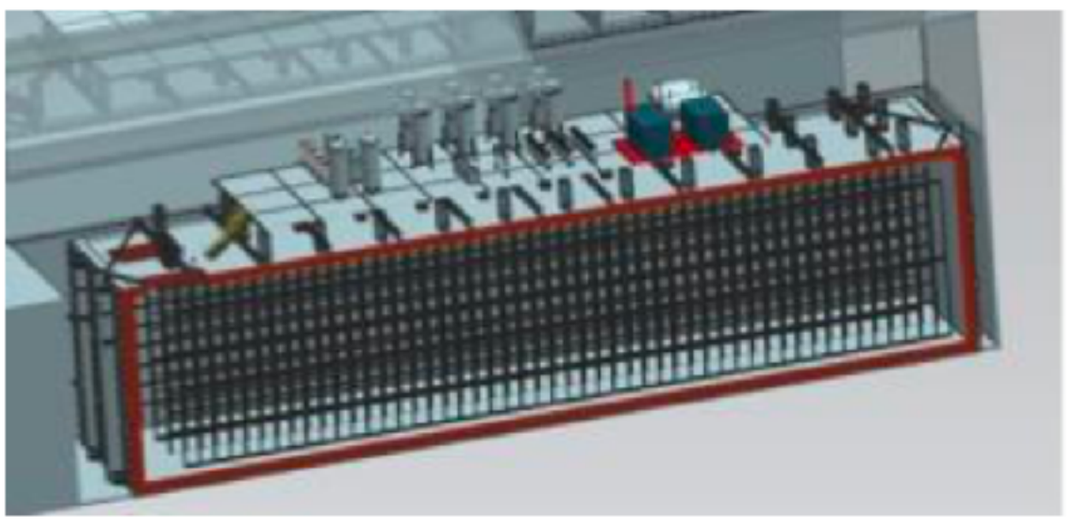
GOAL

- **Engineering the technology through the 10 kton detector.**
- **Develop the construction and QA processes**
- **Test two different technologies: *single phase* and *dual phase***

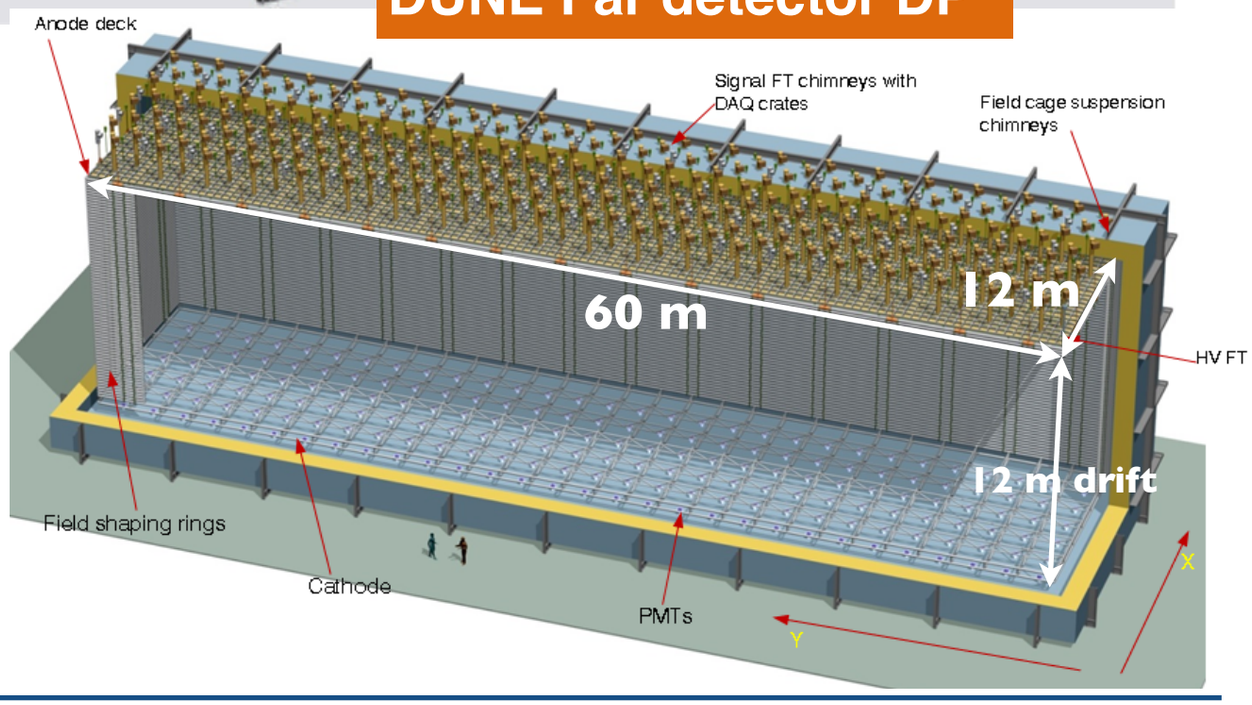
DUNE Far detector: 4modules of 10kton detectors



DUNE Far detector SP

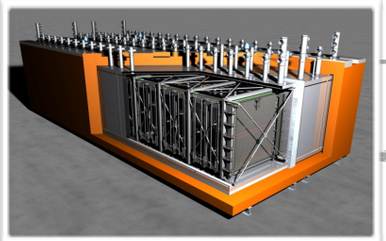


DUNE Far detector DP



Roadmap of LAr technology

ICARUS
LNGS→FNAL
2010-13→2018

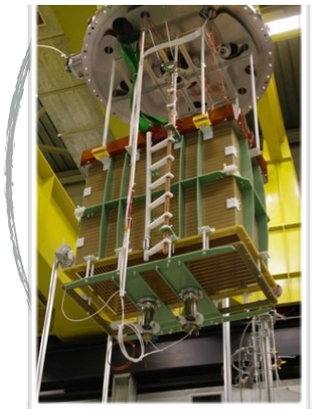


ArgoNeuT
FNAL 2009-10

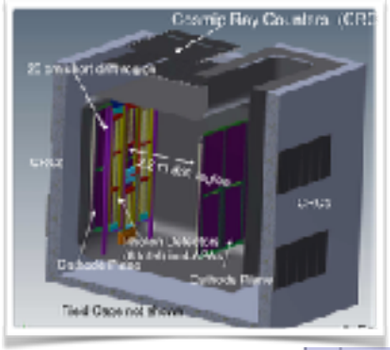
LAPD
FNAL 2010-11

3L 10x10 cm³ TPC
ETHZ R&D (at CERN)

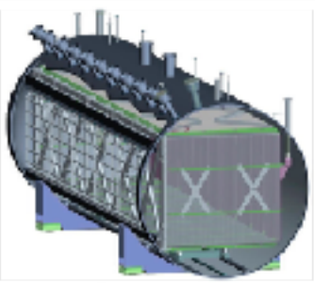
250L 40x80 cm³ TPC
ETHZ R&D (at CERN)



35 t
FNAL 2013-in run

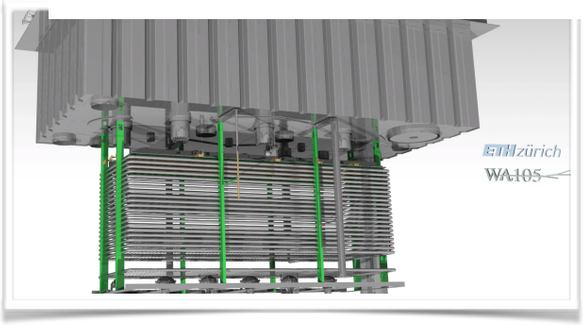


μBooNE
FNAL 2015-in run

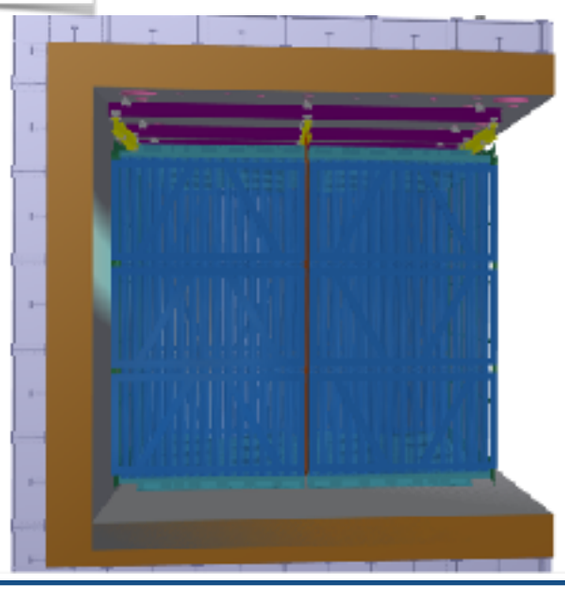


LArIAT
FNAL 2014-in run

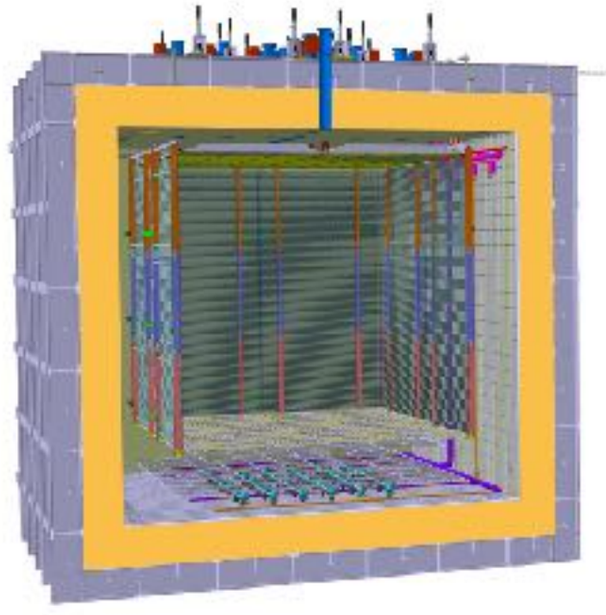
WA105 3x1x1 m³
DP LAr TPC demonstrator
CERN - 2014-now



ProtoDUNE
Single-Phase

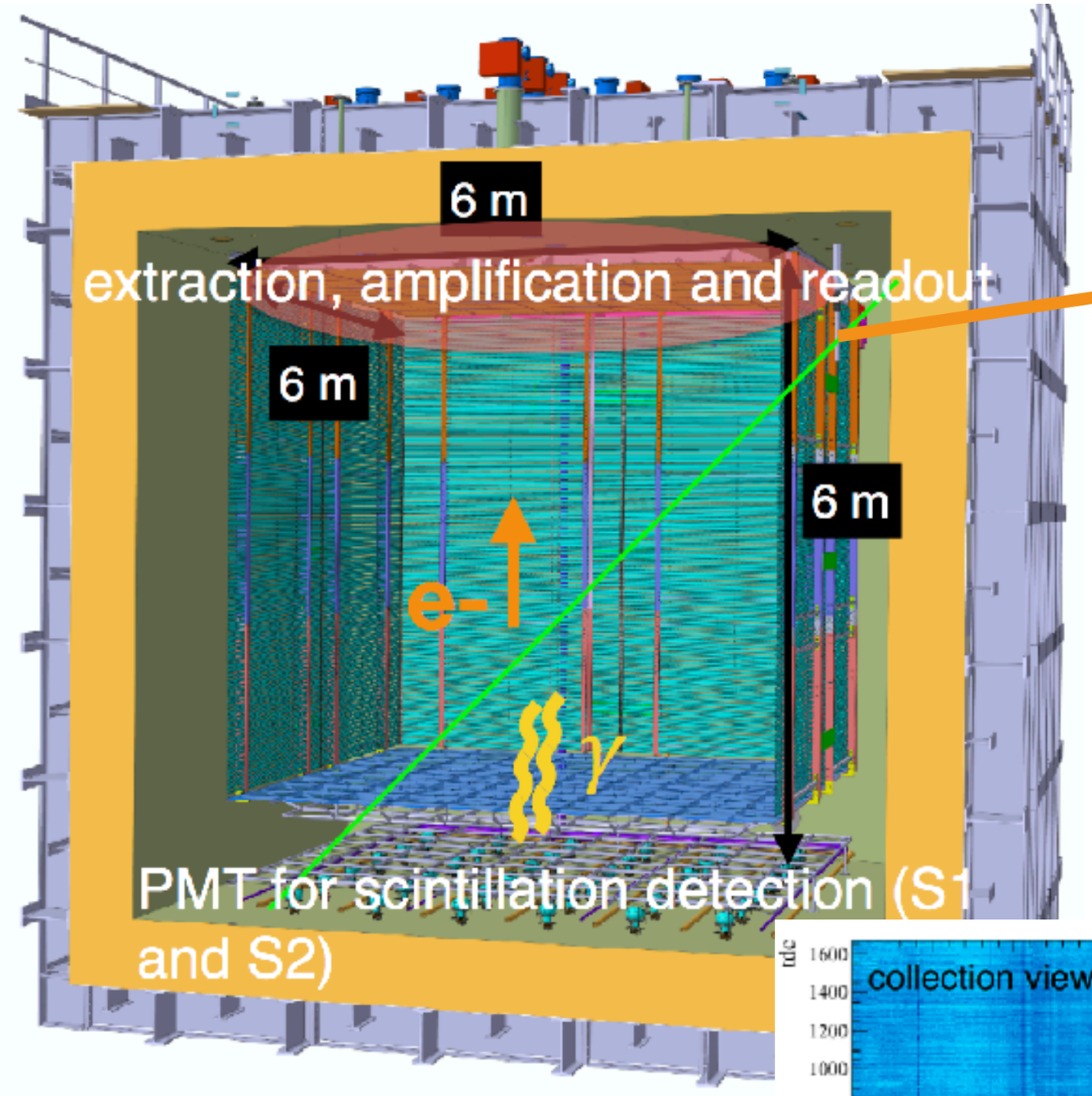


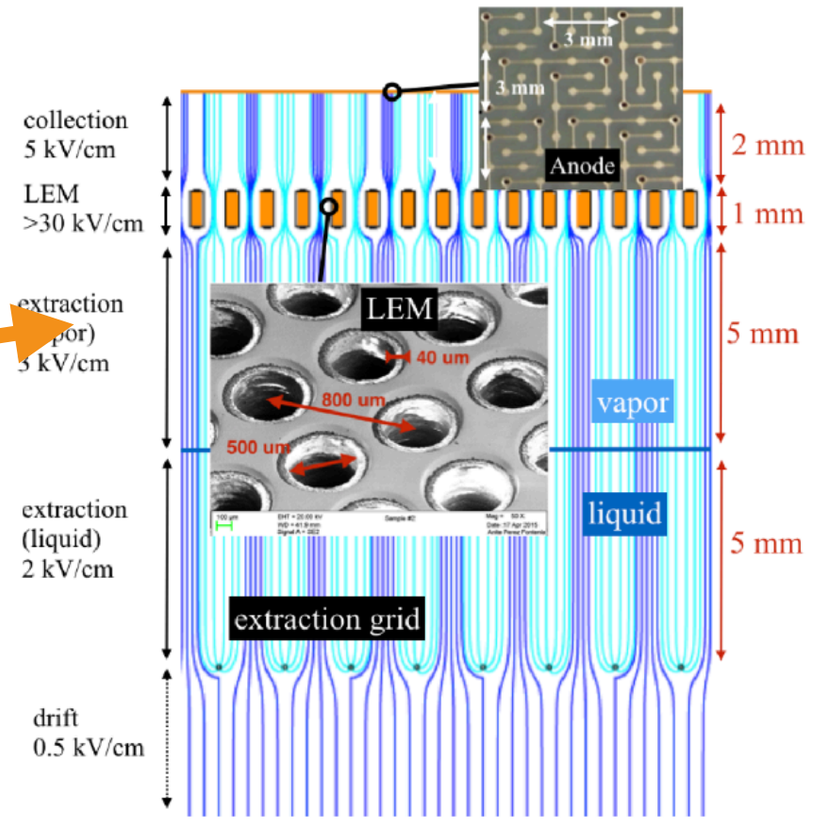
After many decades of R&D, the technology has matured into a fundamental and necessary technique to address the current neutrino physics challenges.



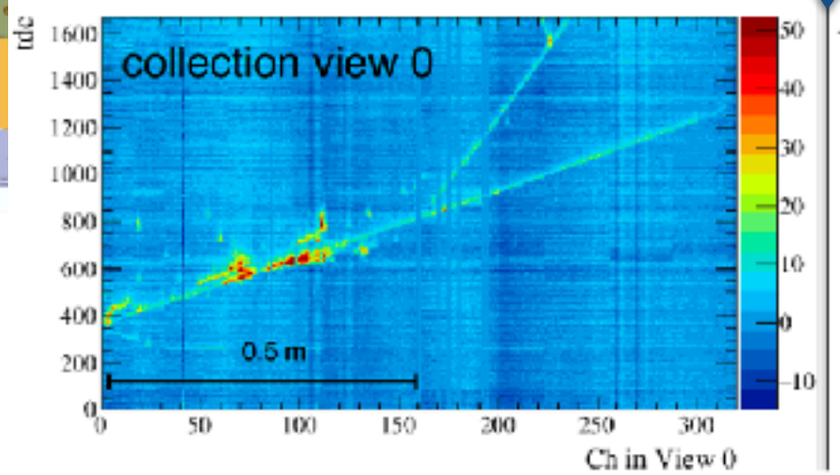
ProtoDUNE
Dual-Phase

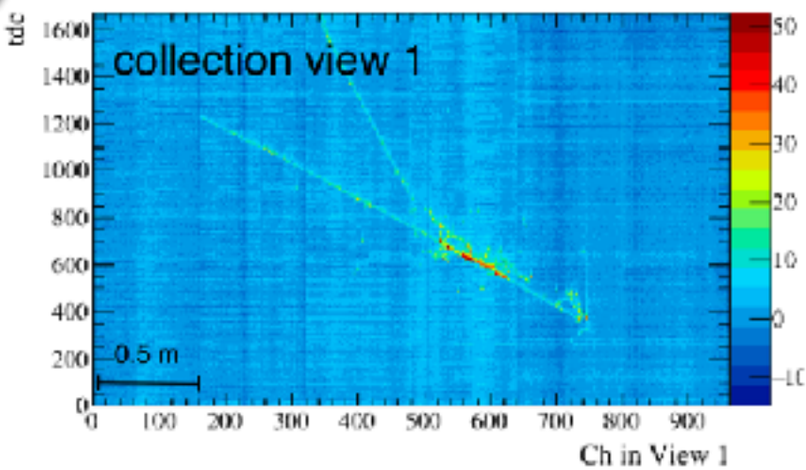
ProtoDUNE-DP





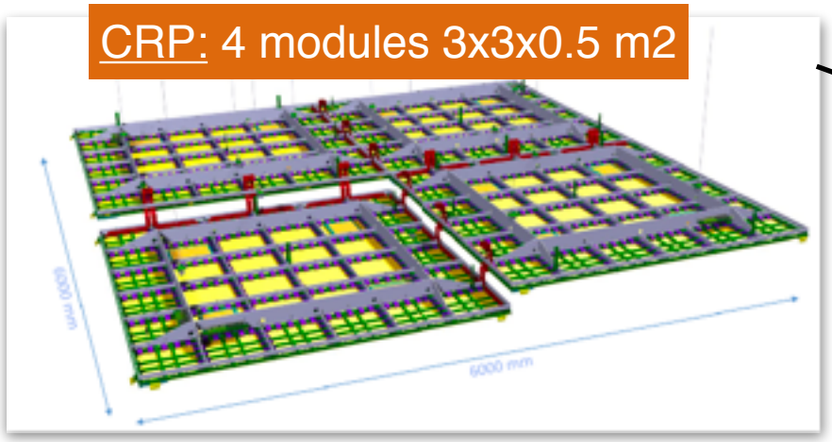
Electrons are collected on both anode views (charge equally shared between the views)



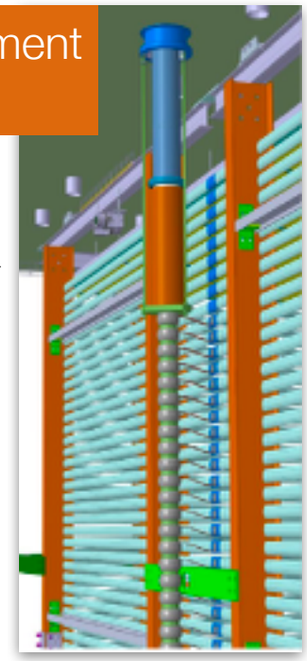


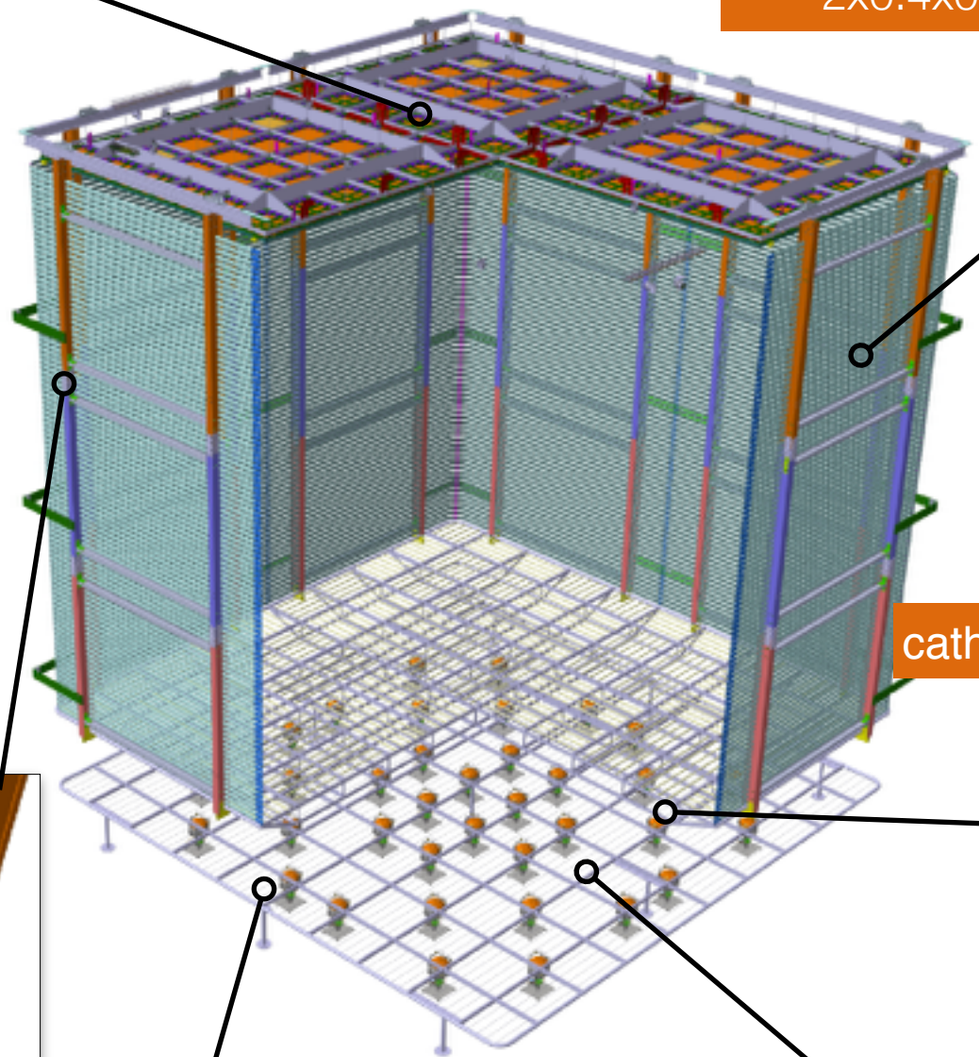
ProtoDUNE-DP

CRP: 4 modules 3x3x0.5 m2

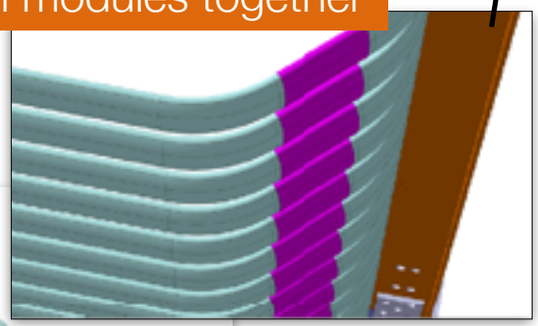


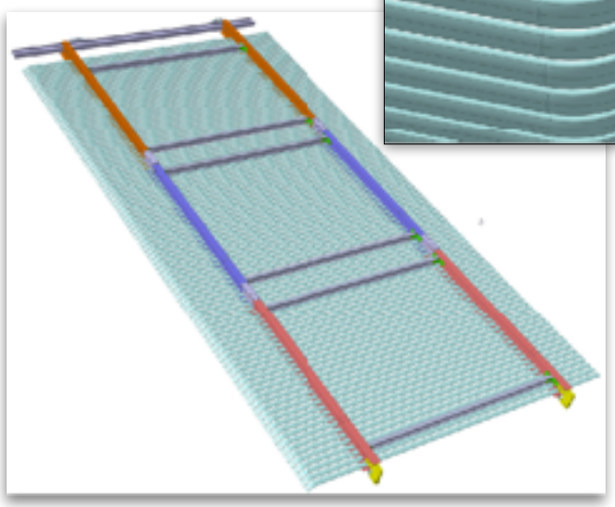
VHV-FT single element
2x0.4x0.4 m2



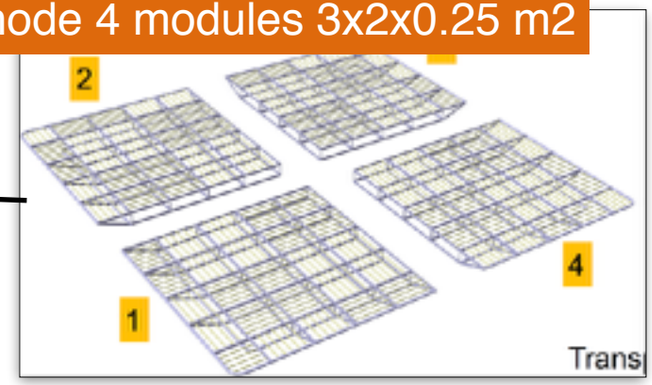


Drift cage:
24 sub-modules 3x2x0.25 m2
784 Al clips to join modules together

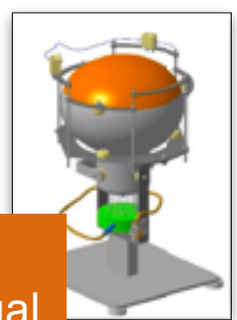




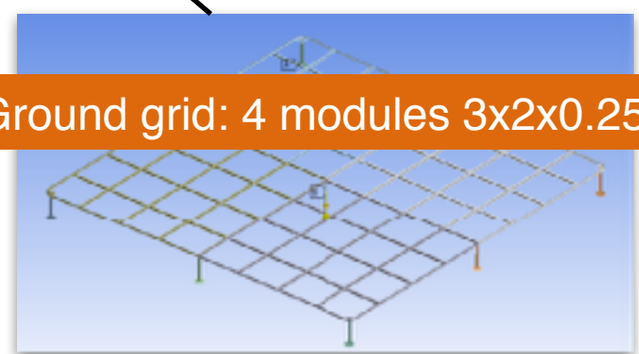
cathode 4 modules 3x2x0.25 m2



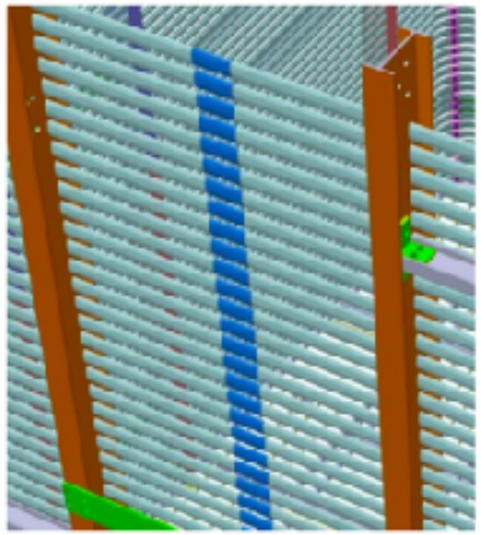
PMTs:
36 pieces on individual
bases 0.3x0.3x0.2 m2

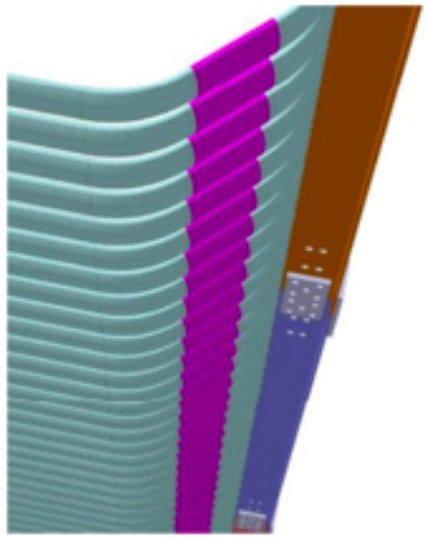


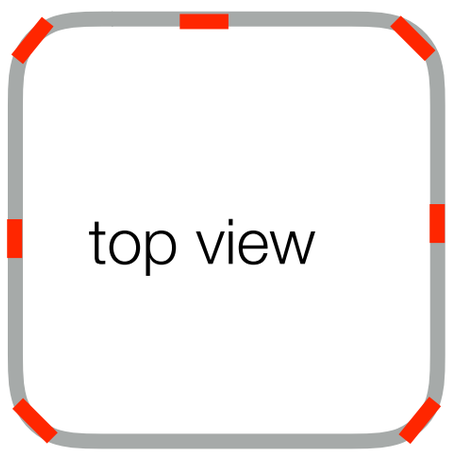
Ground grid: 4 modules 3x2x0.25 m2



ProtoDUNE-DP: Field cage

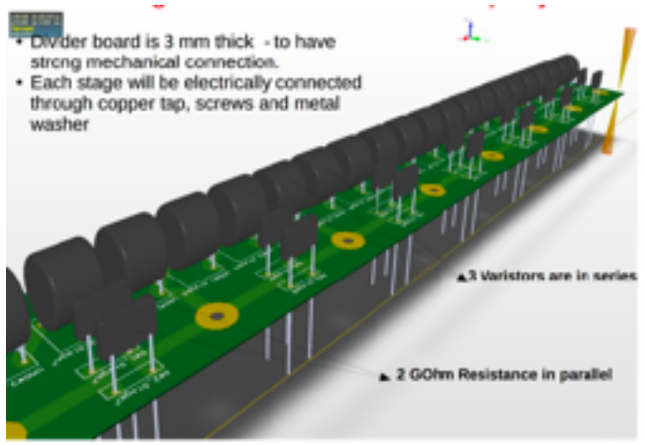


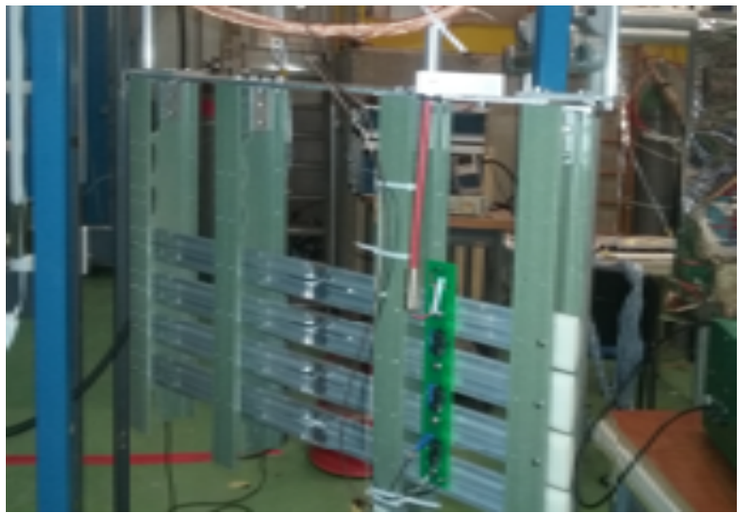




Al clips attached between modules to guarantee electrical continuity

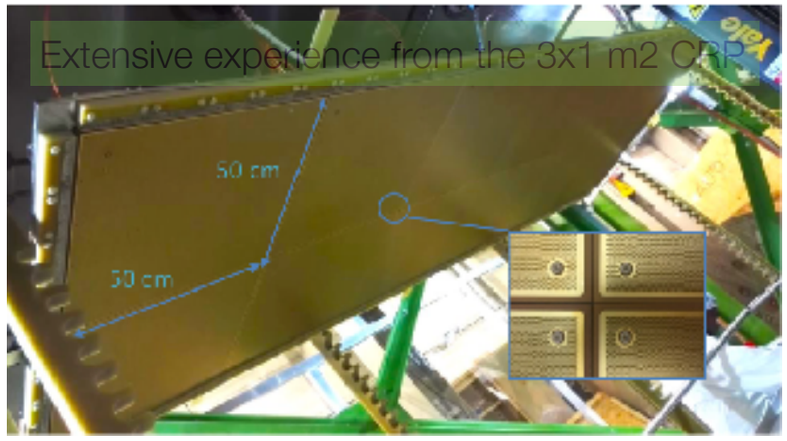
Resistor boards to electrically connect all modules

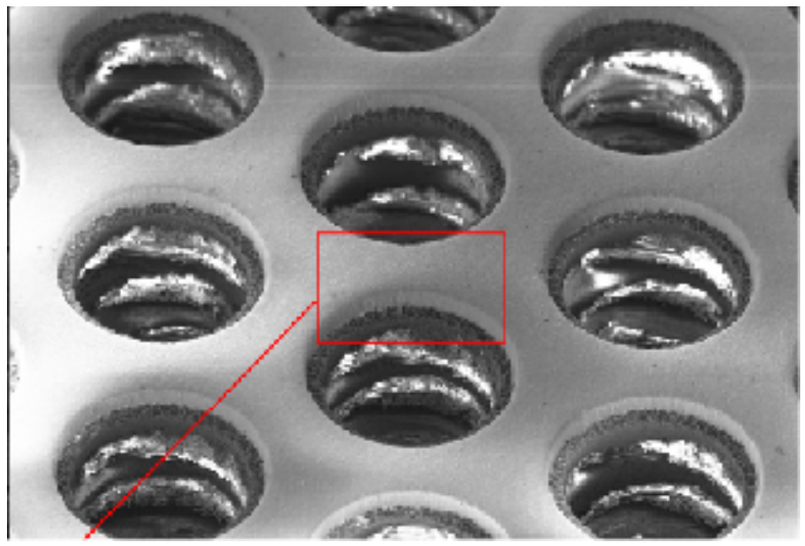




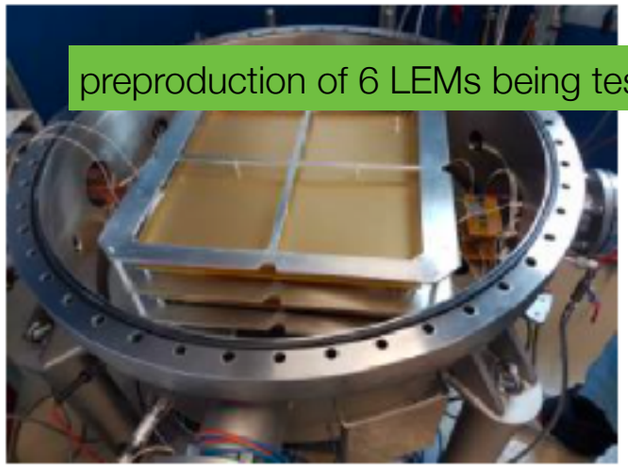
- Two 2GOhm resistors (rated 20kV, 1%, 2.5W, -55°C) in parallel each stage, 1GW effective resistance
- Four varistors with 1.8kV nominal clamping voltage each, giving 7.2kV clamping voltage in series for circuit protection
- Varistor string is connected to the resisters in parallel

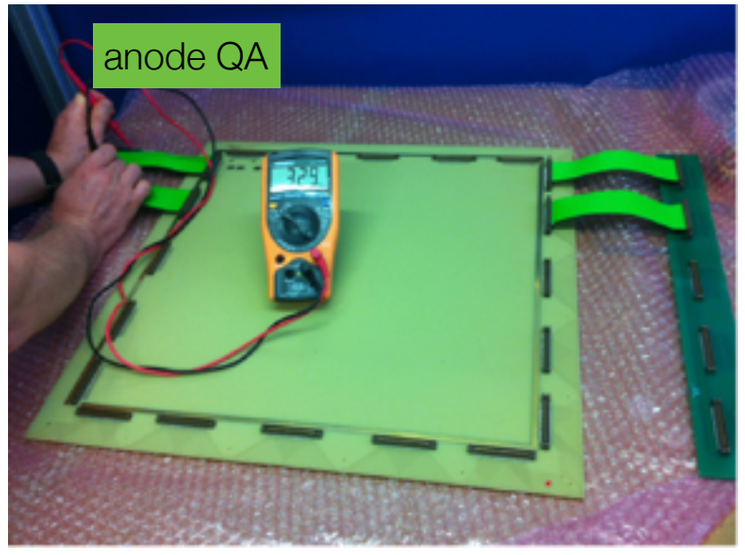
ProtoDUNE-DP: Charge readout plane





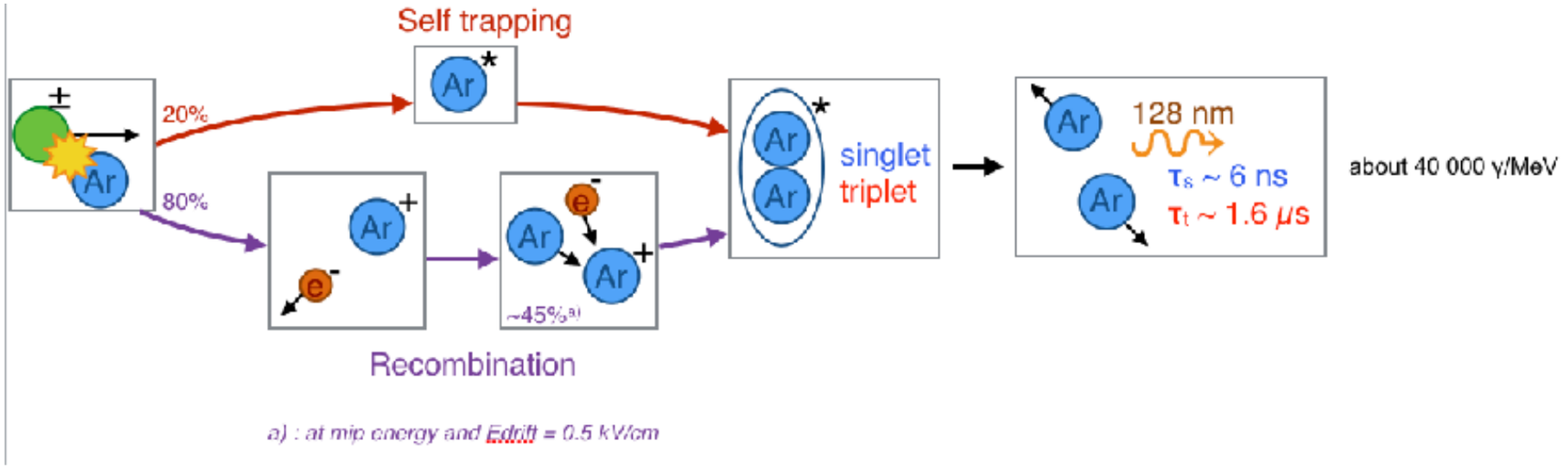
- The most delicate and time consuming elements to fabricate are the 50x50 LEMs and anodes. Both are fabricated in industry.
- Ordered 80 LEMs and 80 anodes last May/June.
- LEMs are shipped to CEA-Saclay for cleaning and testing. Once certified they are shipped to CERN for assembly.
- 36 LEMs+ Anodes will have arrived in time for CRP #1 assembly.

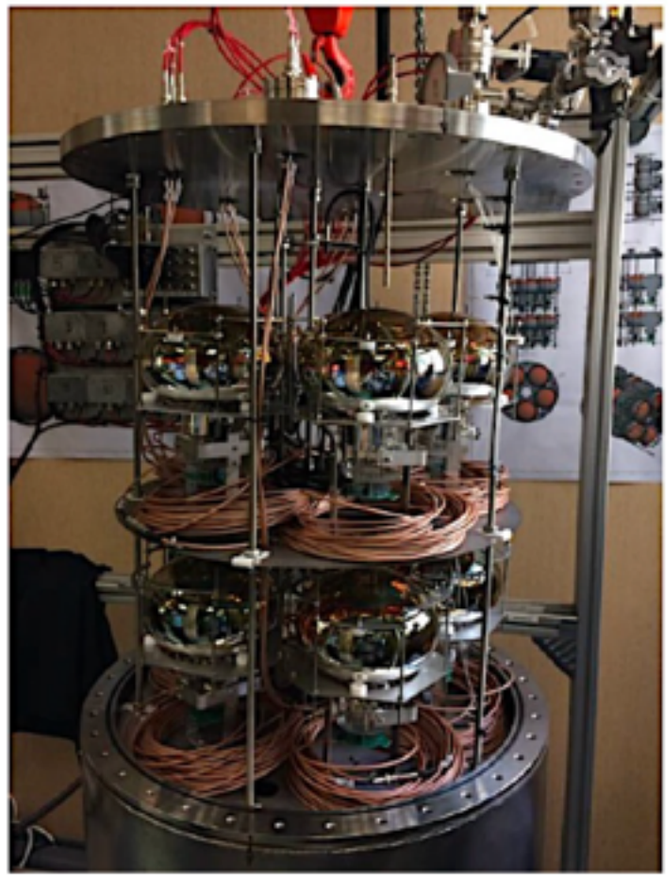


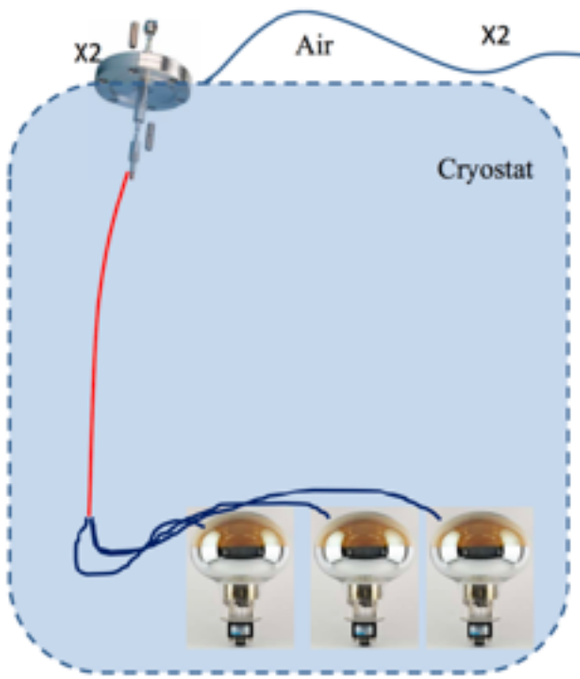


ProtoDUNE-DP: Light detection system

- 40 PMTs delivered, testing ongoing.
- TPB coating ongoing at CERN September/October
- Readout electronics provide sampling of the analog PMT signal at high frequency (160 MHz). CatiROC



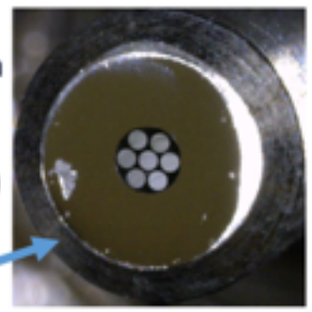


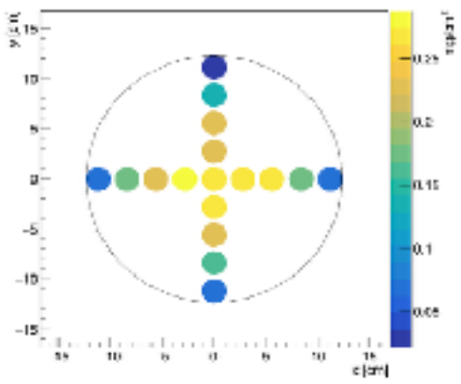


Black box
(described by Thorsten Lux at previous meting)

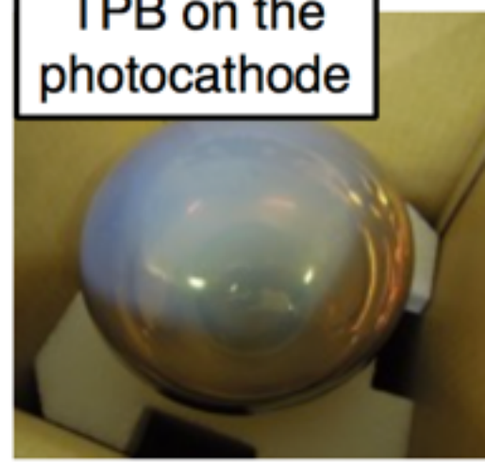
Inside the cryostat (6x):

- Flange: SMA (female ft) from Allectra
- Fiber: FT800UMT from Thorlabs
  22.5 m long, 800 μm diameter
  Jacket FT05SS (Stainless steel tubing)
  SMA connectors
- Bundle: FG200UEA from Thorlabs
  1x7 fanout bundle
  2.5 m long, 200 μm diameter (individual fibers)
  Common end: 25 m FT061PS (Stainless steel tubing)
  Split ends: 2.25 m FT030
  SMA connectors



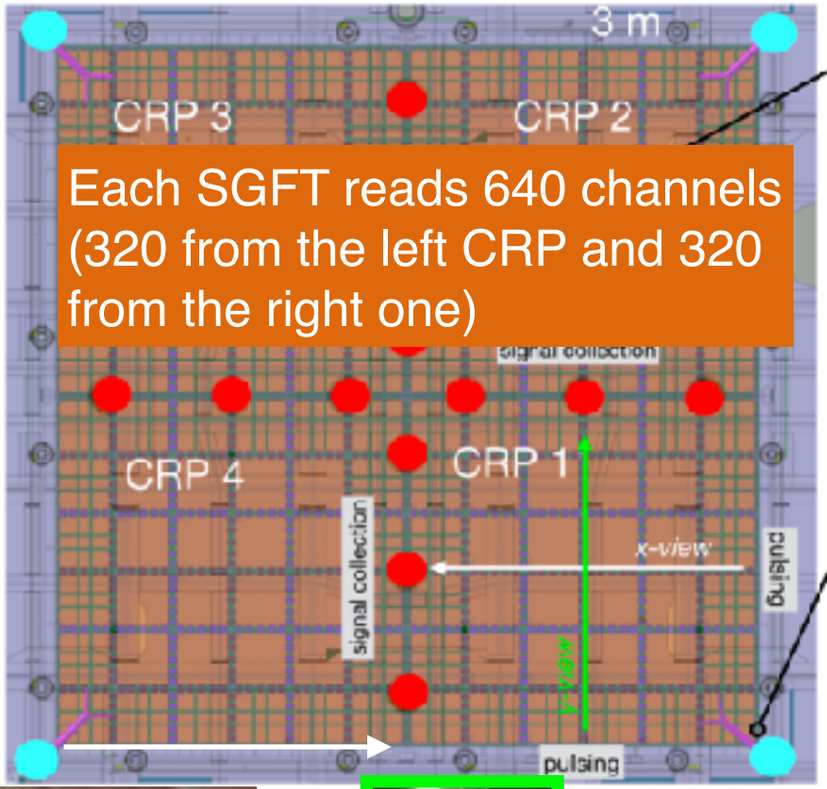


TPB on the photocathode

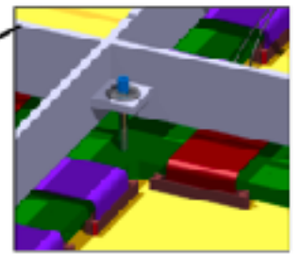


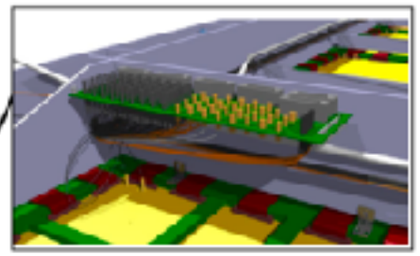
Calibration system

ProtoDUNE-DP: Front-end electronics



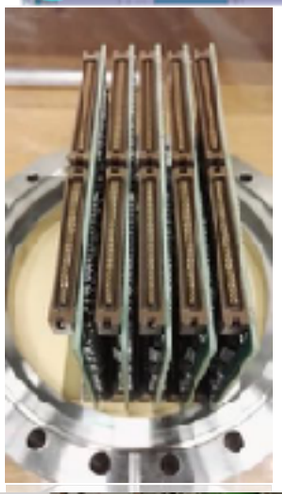
Each SGFT reads 640 channels (320 from the left CRP and 320 from the right one)


anode jumpers


patch panel

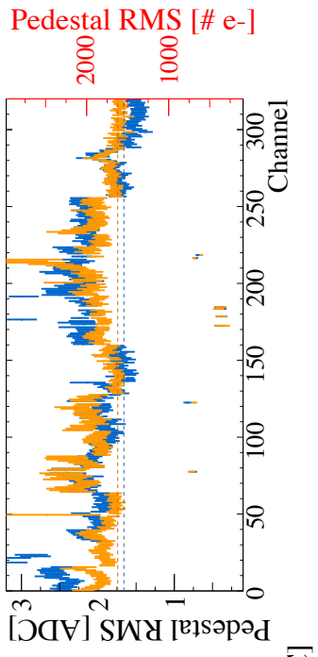
3 meter strips, 3 mm granularity, accessible cold analogue front-end electronics

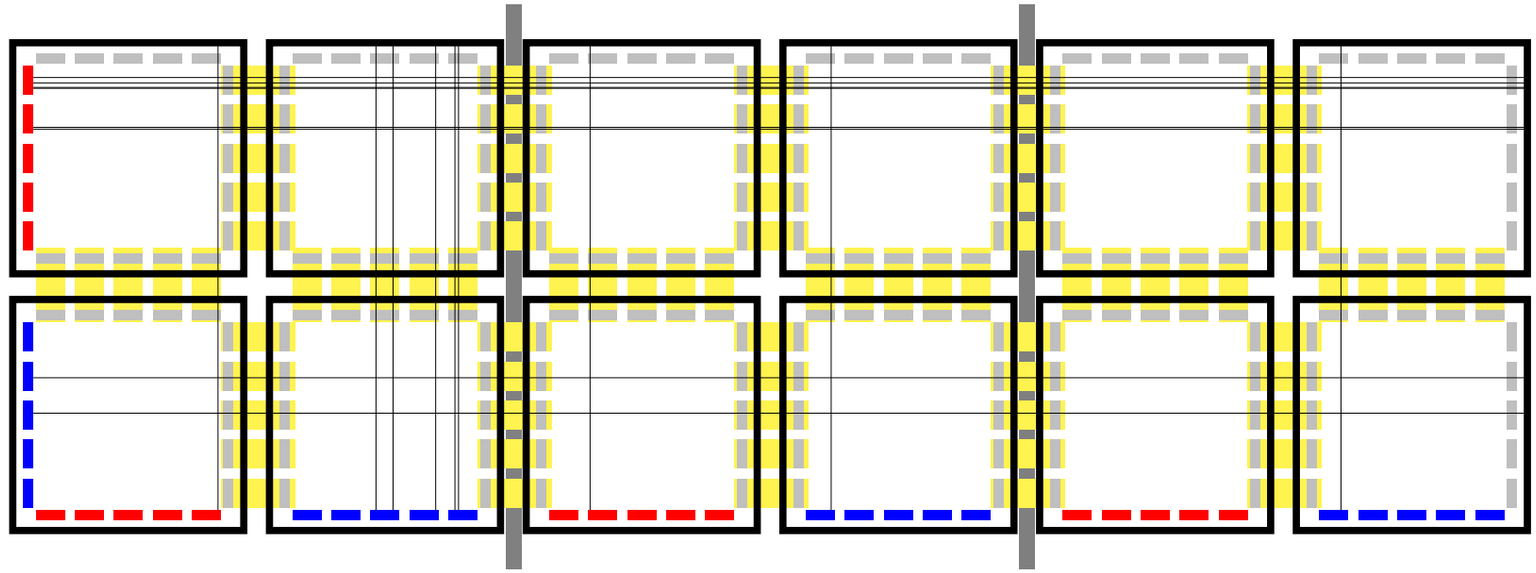
Test on the 3x1x1 prototype at warm and at cold: 17 (1.3%) dead or problematic channels.
Low noise condition at cold: 1.66 adc counts (1600 e$^-$) RMS noise

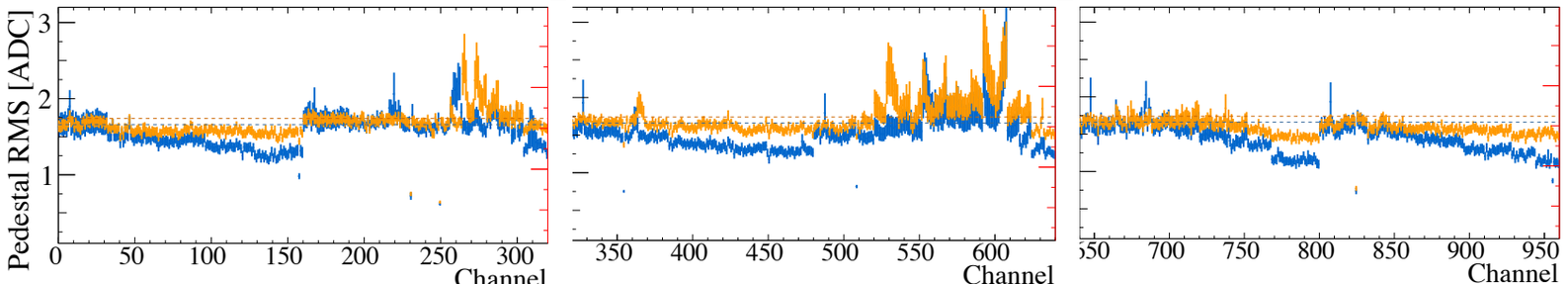


ADCs in uTCA rack

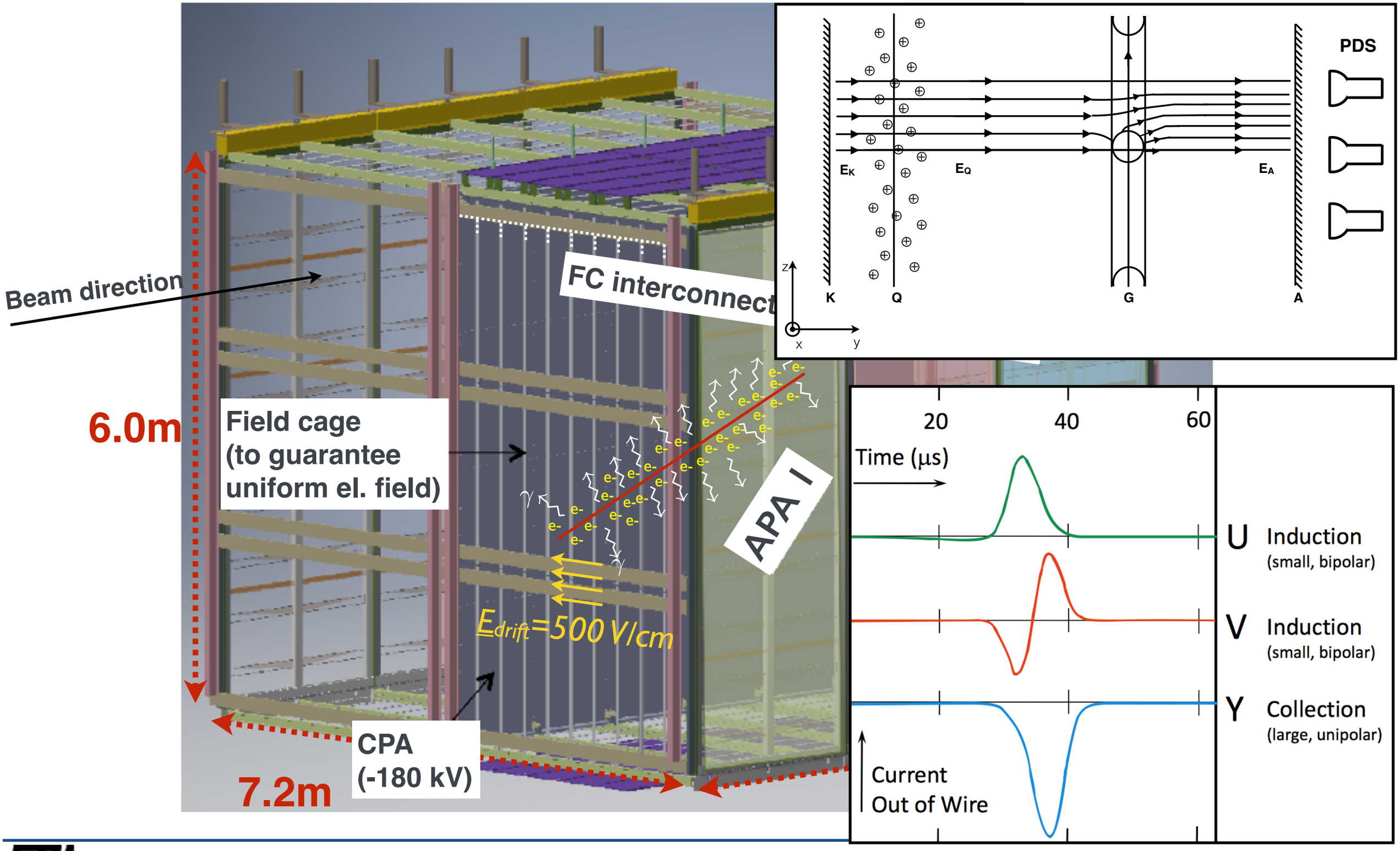
(20adc=3fC)





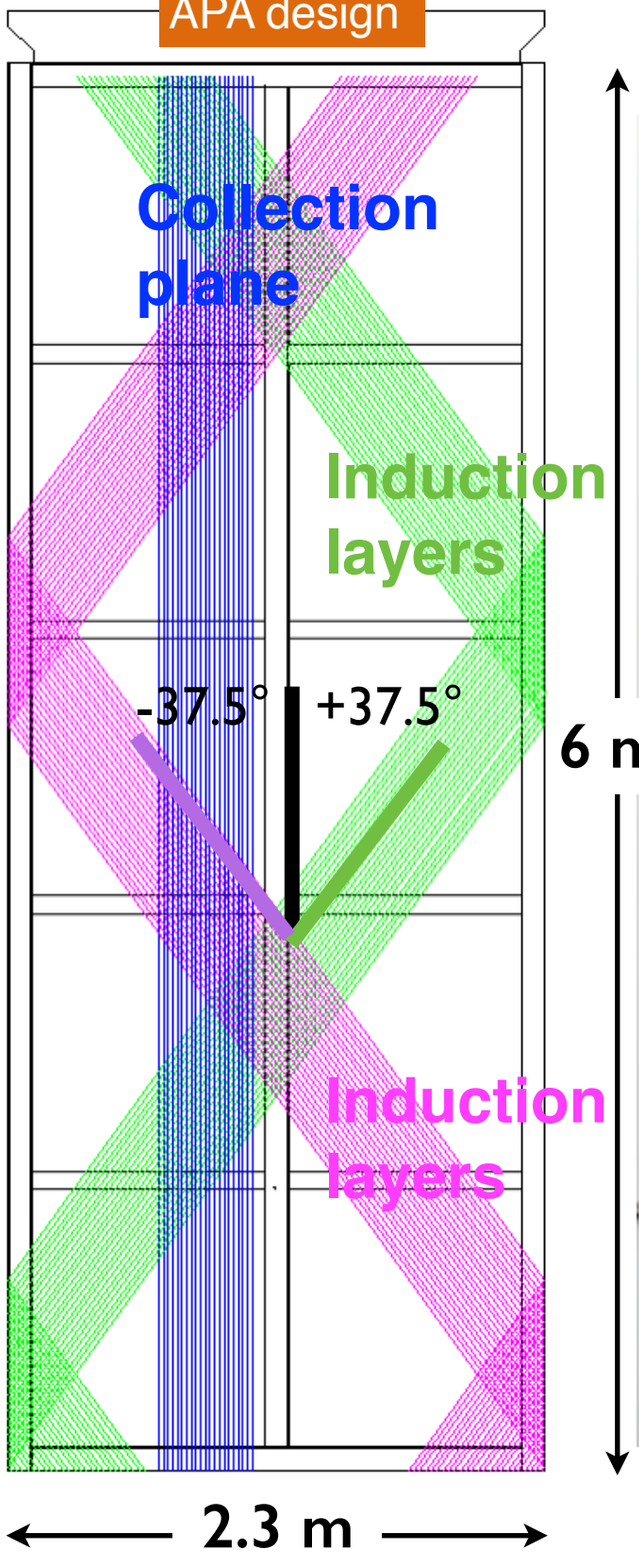


ProtoDUNE-SP



ProtoDUNE SP: Anode Plane Assembly

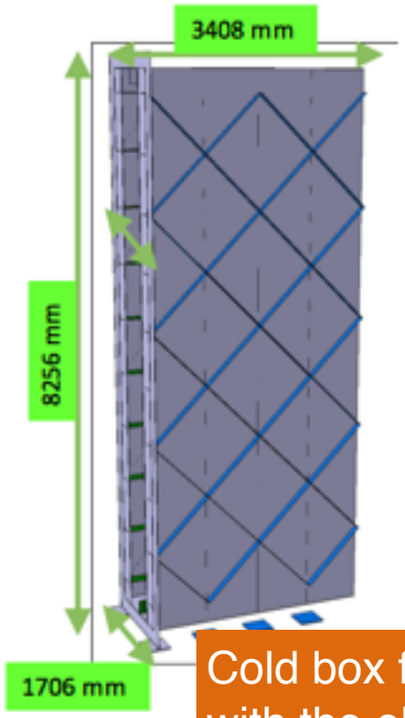
APA design



First APA in EHN1 cleanroom since August 2017

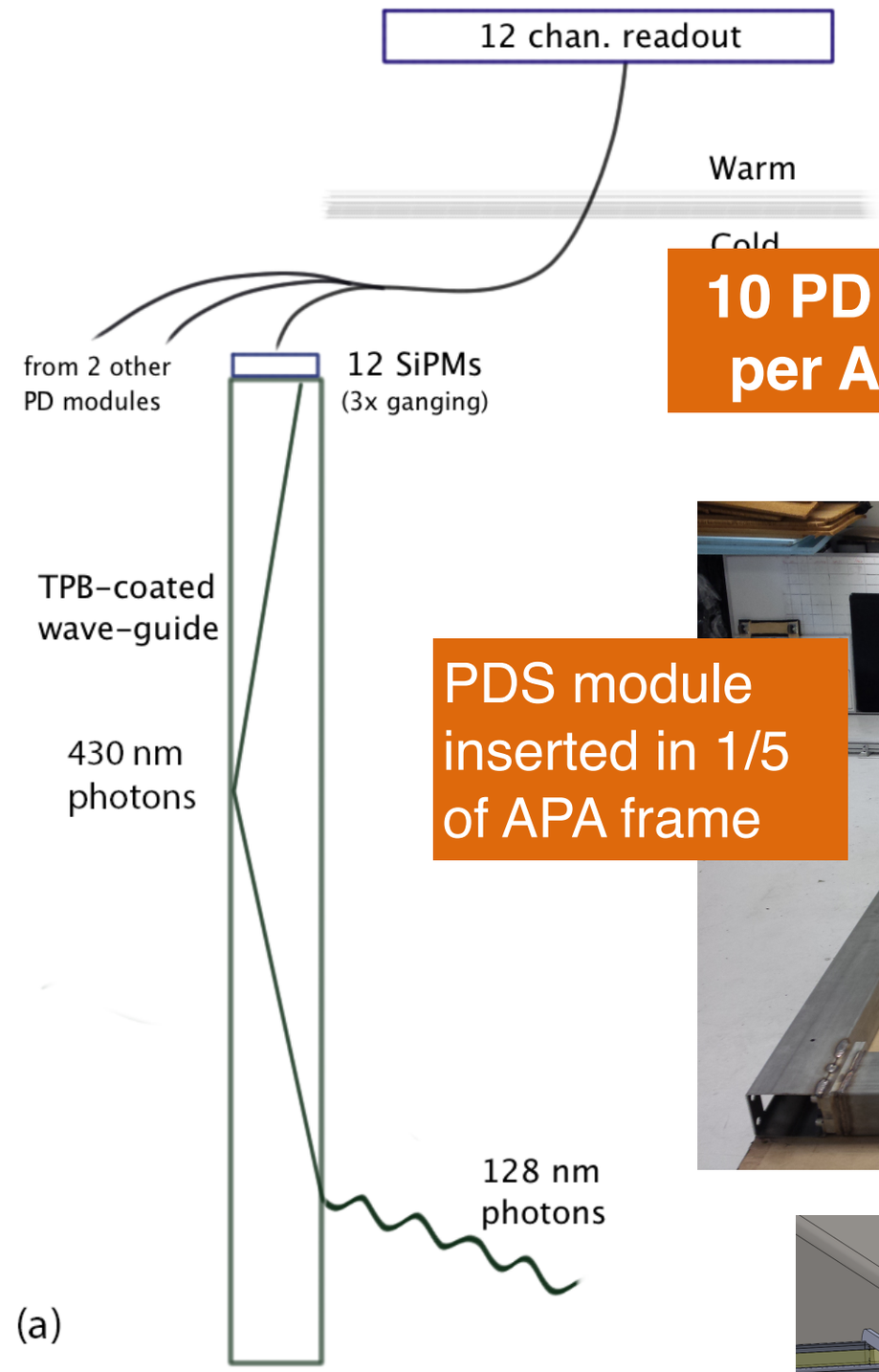
Four wire planes of 150 µm CuBe wire

- **Grid plane run vertically (-665V bias voltage and pitch of 4.8 mm).** The grid shields the outer planes from the effect of charges drifting from the cathode to the anode.
- **Induction layers (pitch 4.7mm)** inclined at +/-37.5° and at -370V/0V. Both read the current induced when charges traverse them in the form of a bipolar signal.
- **Collection plane X (pitch 4.8mm)** run vertically and collects the charge (unipolar signal).
- A **ground mesh which** shields the photon detection system.

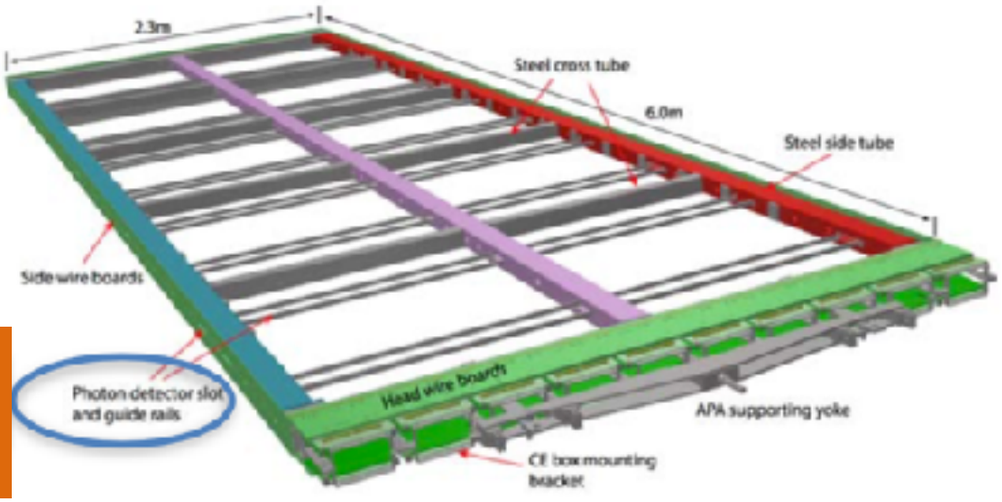


Cold box for testing the APAs together with the electronics and PDS system before installing inside the cryostat

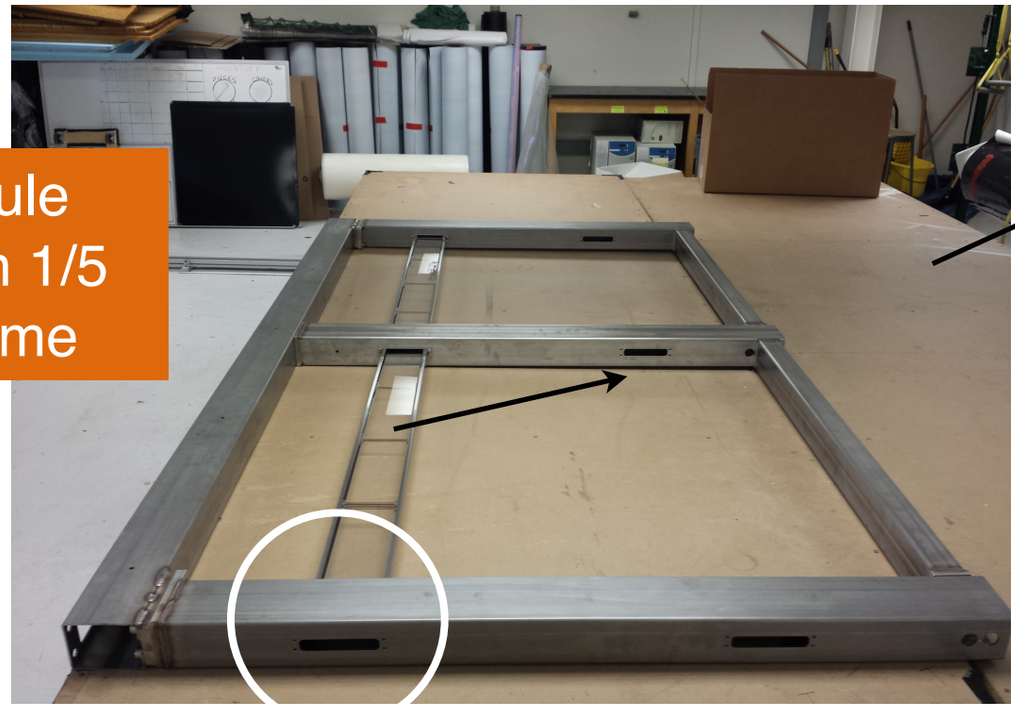
ProtoDUNE-SP: Photon detection system

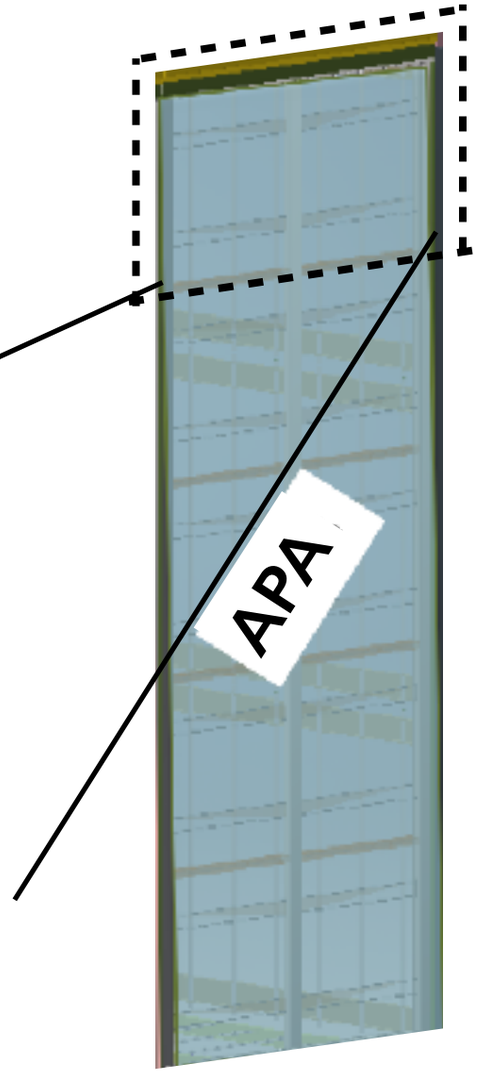


10 PD bar per APA

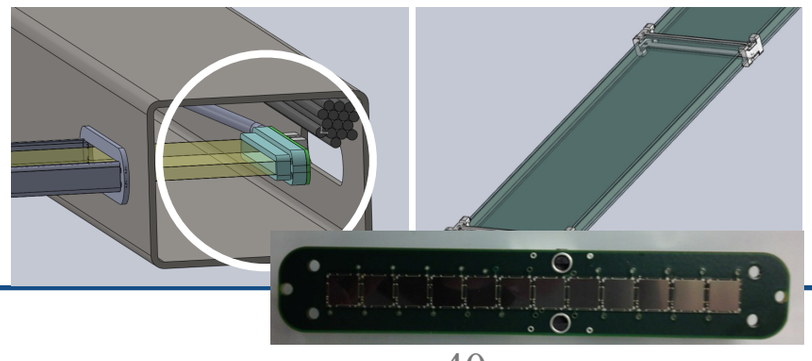


PDS module inserted in 1/5 of APA frame



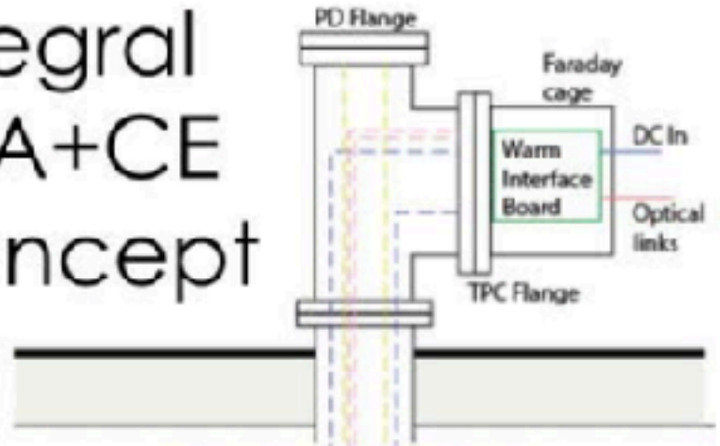


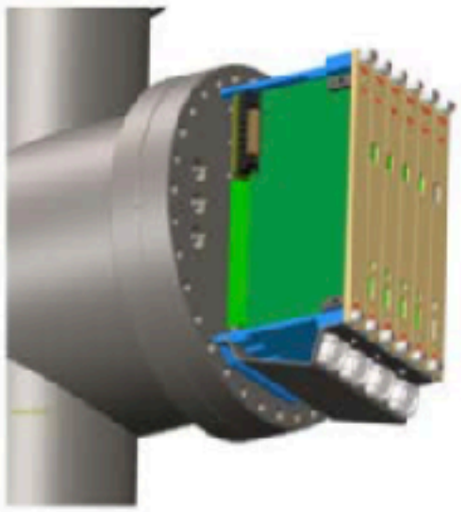
12 SiPMs

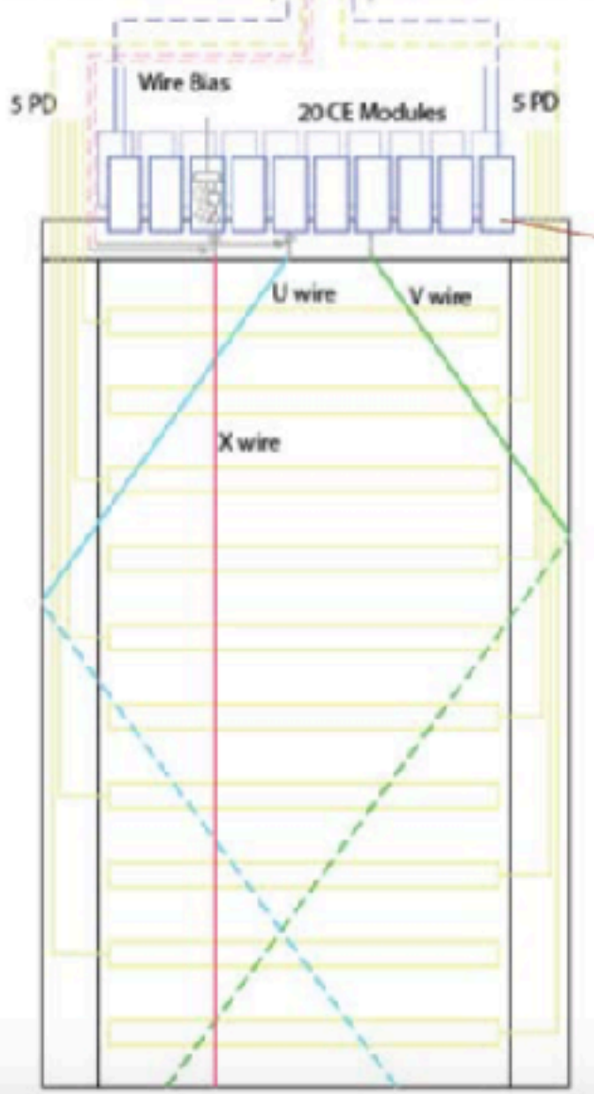


ProtoDUNE-SP: Cold electronics

Integral APA+CE Concept







ProtoDUNE-SP

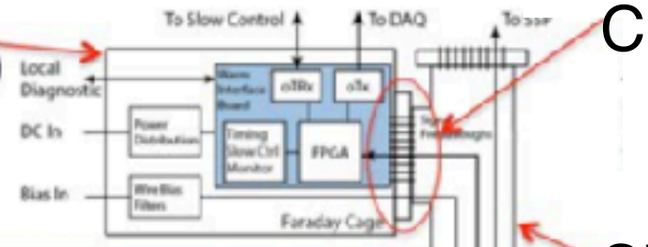
Warm electronics

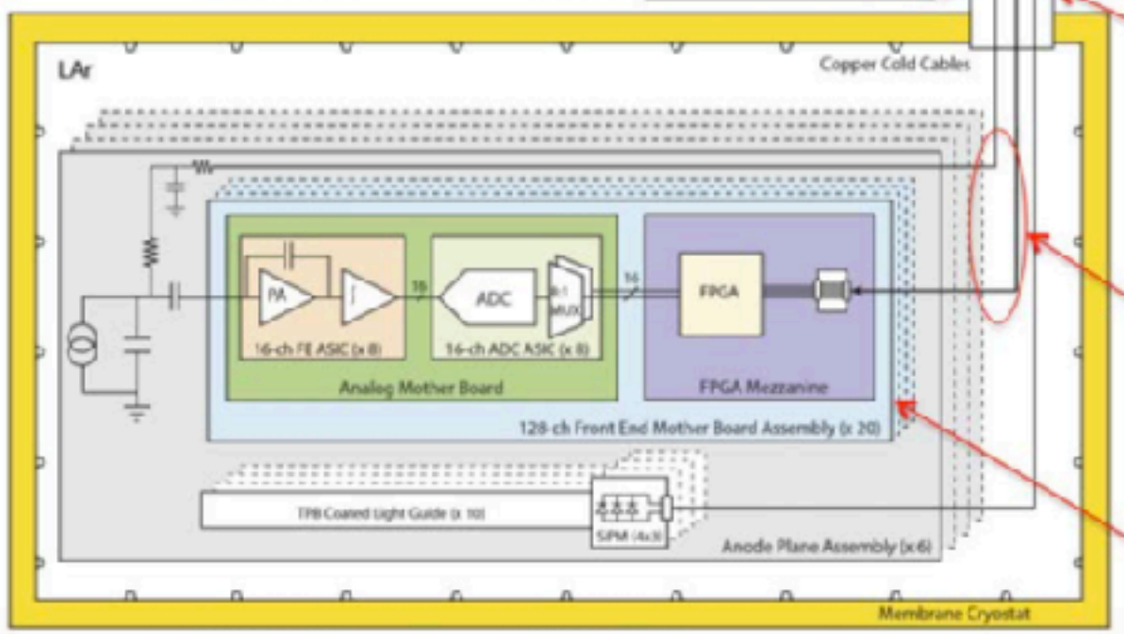
Warm Interface Electronics Crate (6)

Warm Interface Board (30)

Power and Timing Card (6)

Power and Timing Backplane (6)





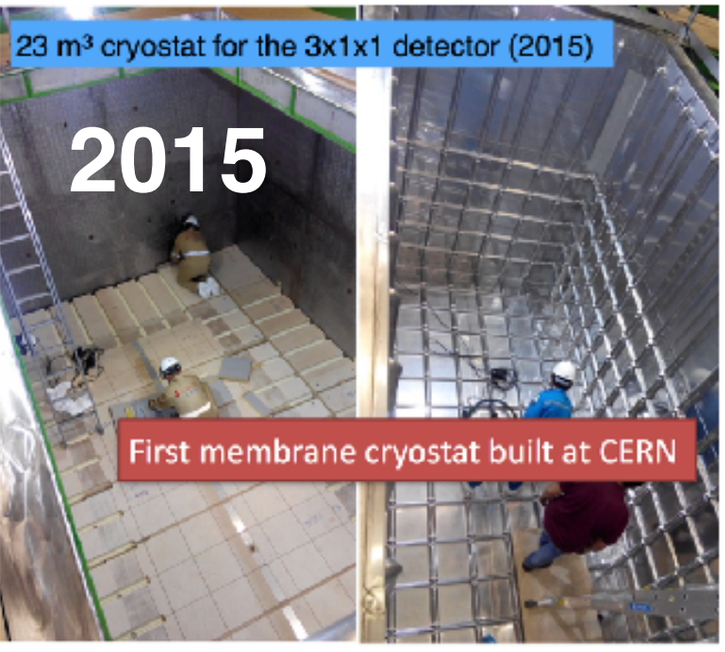
CE flange

Signal feedthrough

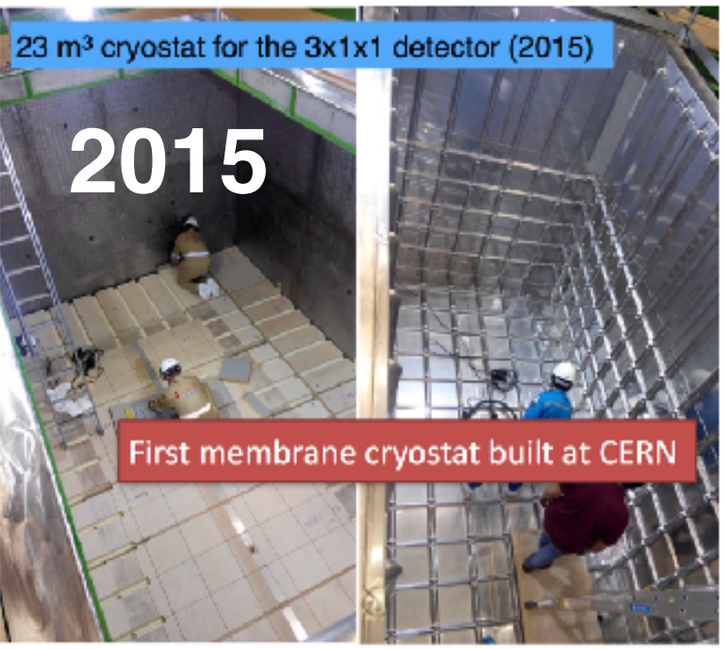
Cold cable

FE motherboard

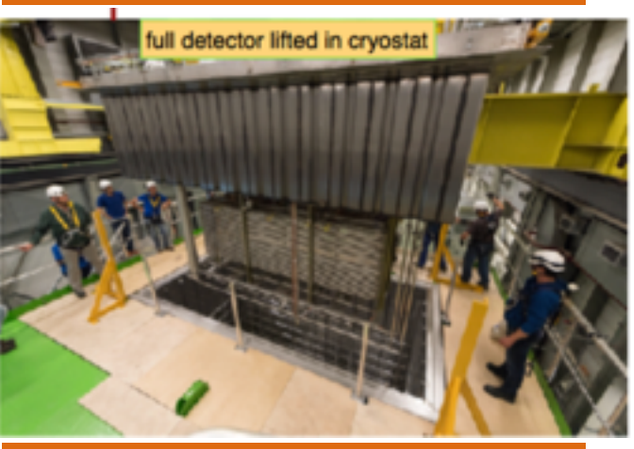
Pilot prototypes: The 3x1x1 m³



Pilot prototypes: The 3x1x1 m³

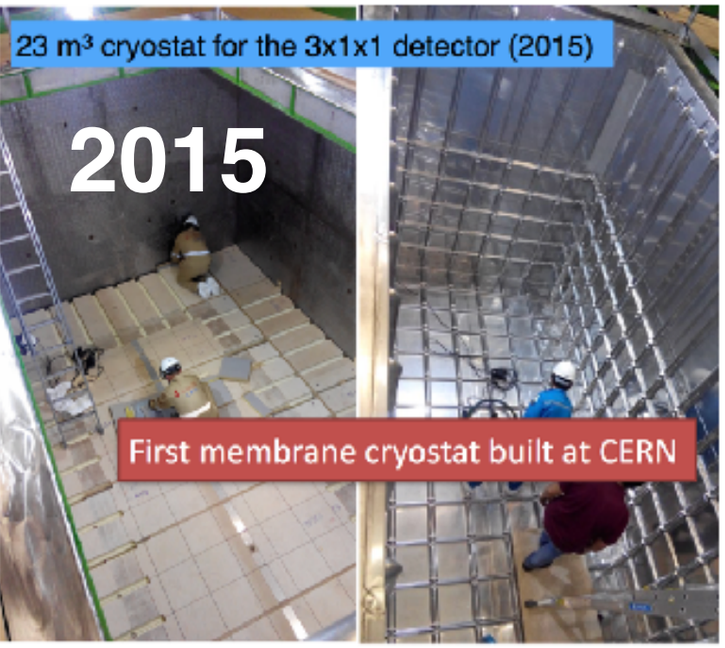


Installation complete in 2016

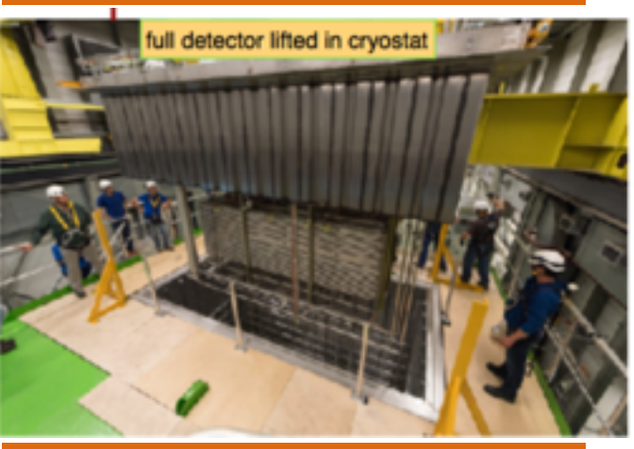


Commisioning phase started in January 2017

Pilot prototypes: The 3x1x1 m³



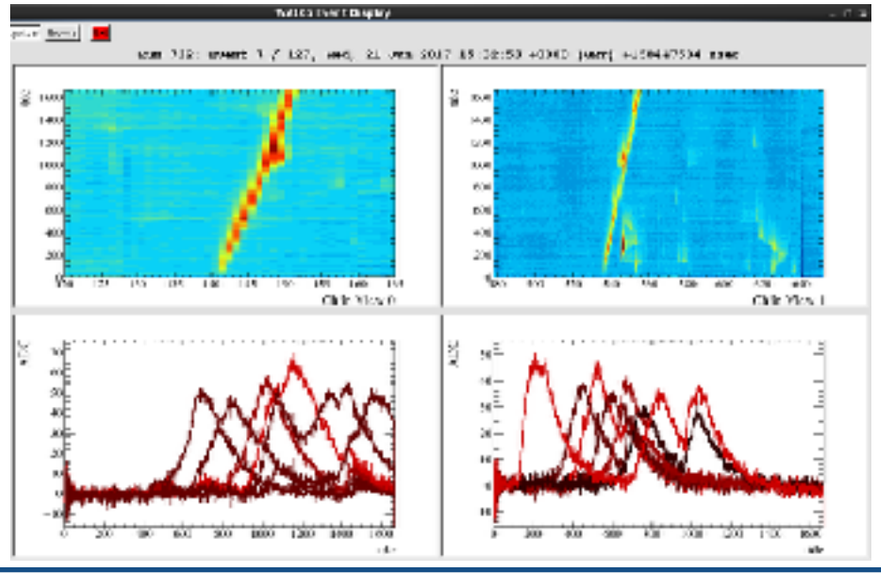
Installation complete in 2016



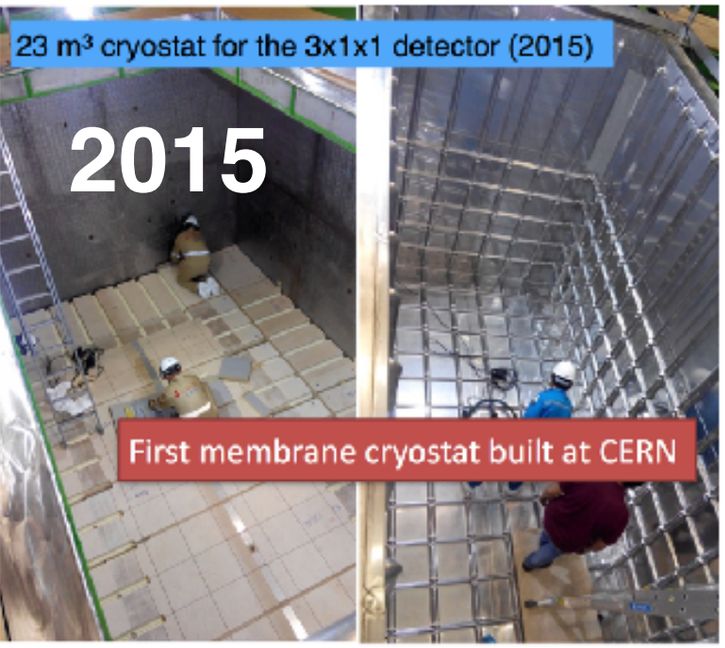
Commisioning phase started in January 2017

Recirculation started on June 12th

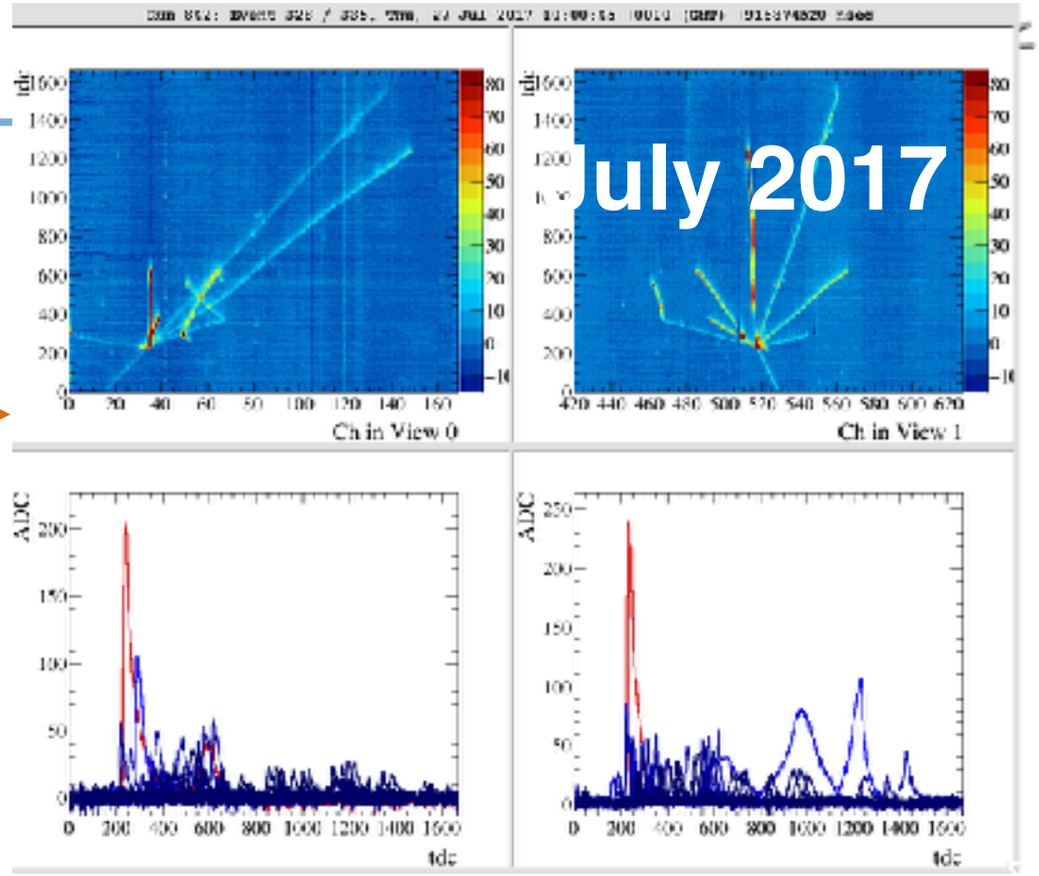
First trackon June 24th



Pilot prototypes: The 3x1x1 m³

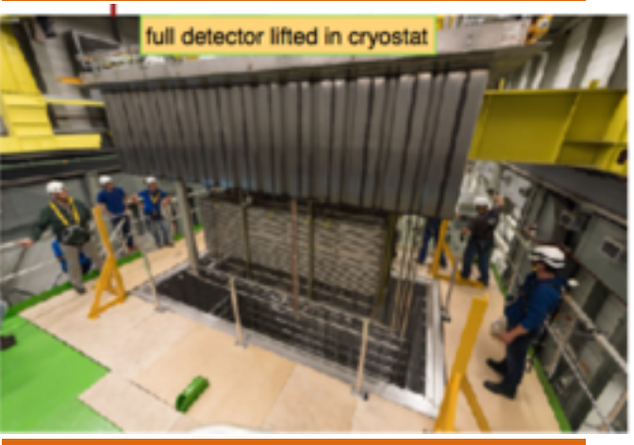


Raw-data no noise filtering

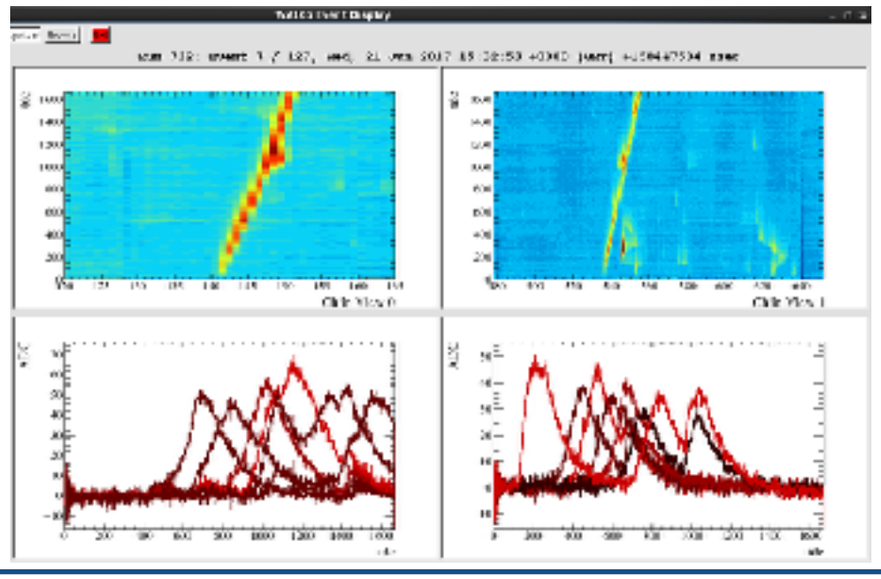


Installation complete in 2016

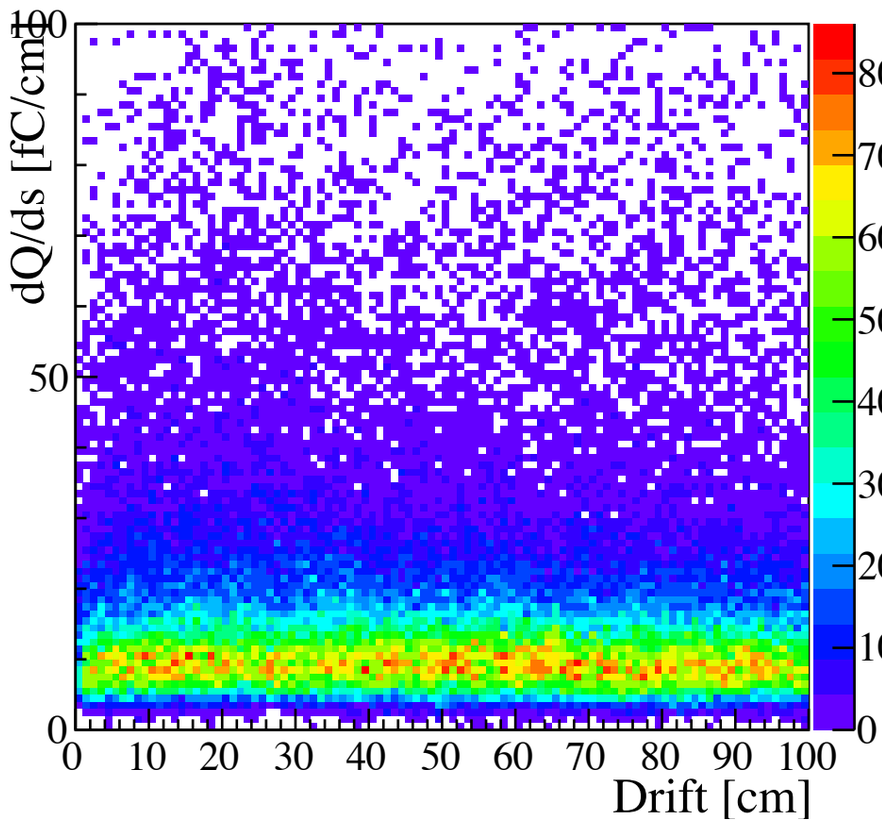
Recirculation started on June 12th



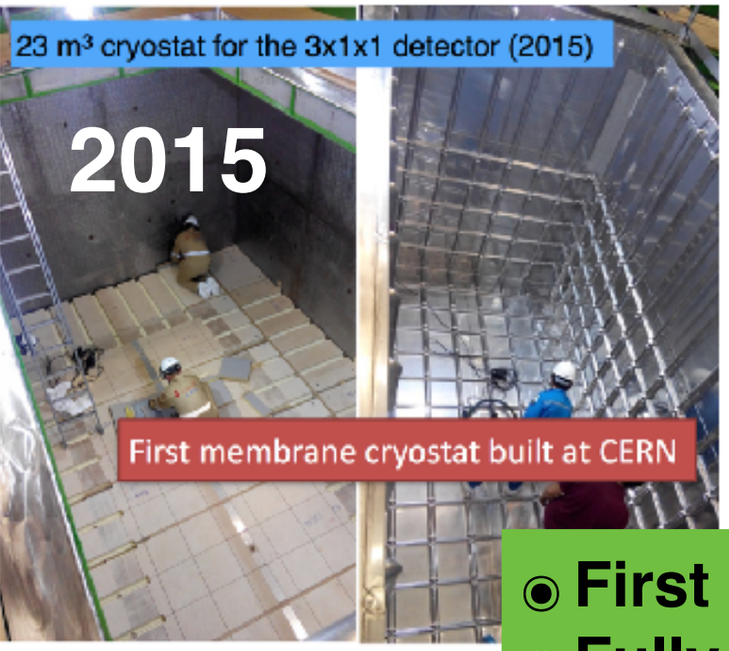
First trackon June 24th



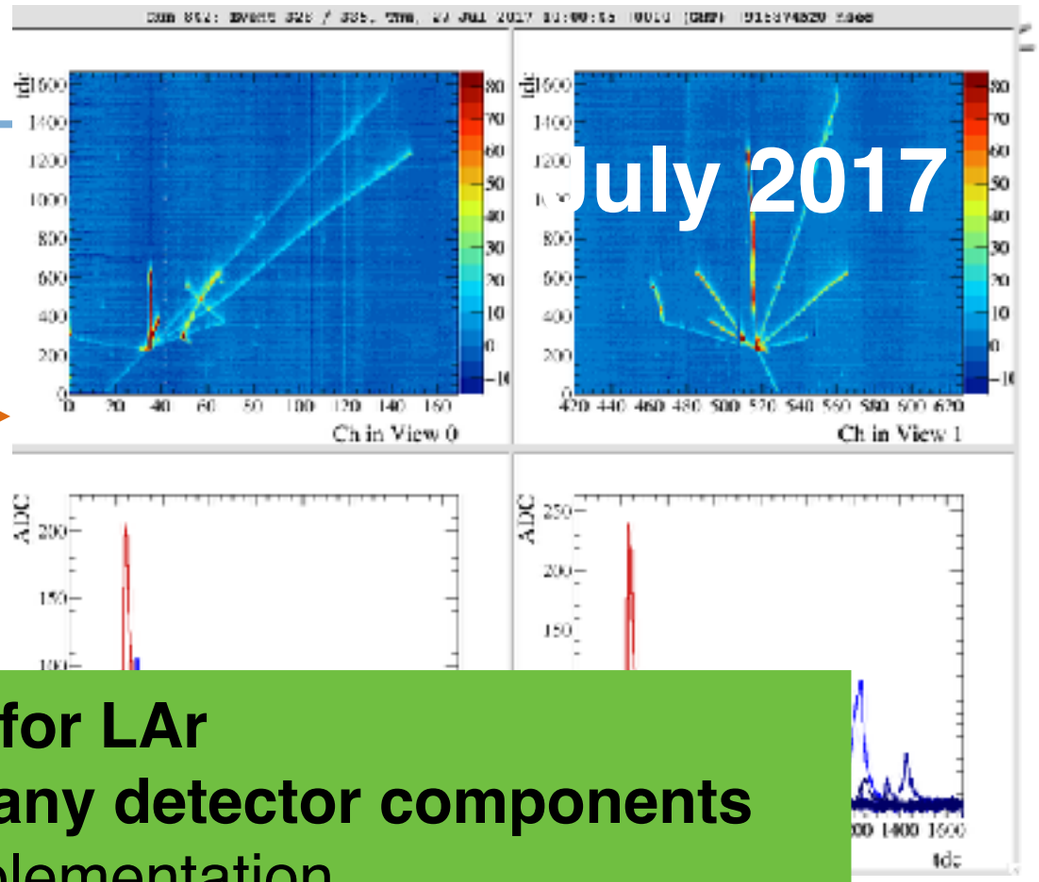
Commisioning phase started in January 2017



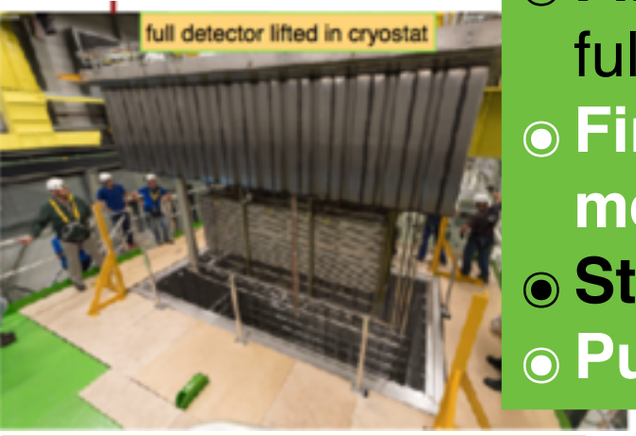
Pilot prototypes: The 3x1x1 m³



Raw-data no noise filtering



Installation complete in 201



Commisioning phase started in January 2017

- **First GTT constructed cryostat for LAr**
- **Fully engineered versions of many detector components** with pre-production and direct implementation
- **First overview of the complete system integration**: set up full chains for QA, construction, installation and commissioning
- **First results of extraction and amplification in 3 square meter area and LEM 50x50 cm amplification**
- **Stable drift field of 500V/cm over 1m**
- **Purity compatible with 1ms electron lifetime**