Review of liquid argon detector developments at the CERN Neutrino Platform

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Introduction

- Future Long/Short baseline neutrino programs are considered strategic by EU Particle Physics Community.
- In this context, the CERN "Neutrino platform", part of present CERN Medium-Term-pan (MTP), has been created:
  - to perform detector R&D
  - to offer support for future international neutrino experiments
  - to foster an active involvement of Europe and CERN in the new US and Japanese projects.
- In particular, significant R&D effort is made on the development of LAr-TPC technologies.
- As a part of the Neutrino platform facilities, CERN is constructing a large test area (EHN1 extension of SPS North Area) with charged beams capabilities devoted to neutrino detectors, which will be available from 2017.

ν future landscape

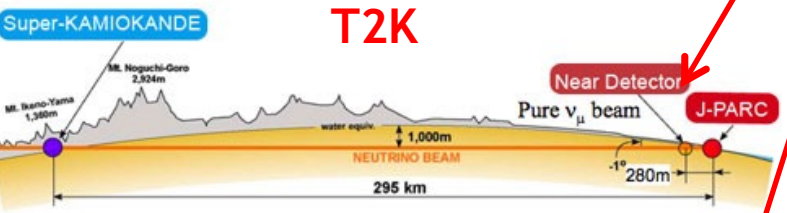
(accelerator based oscillation physics)

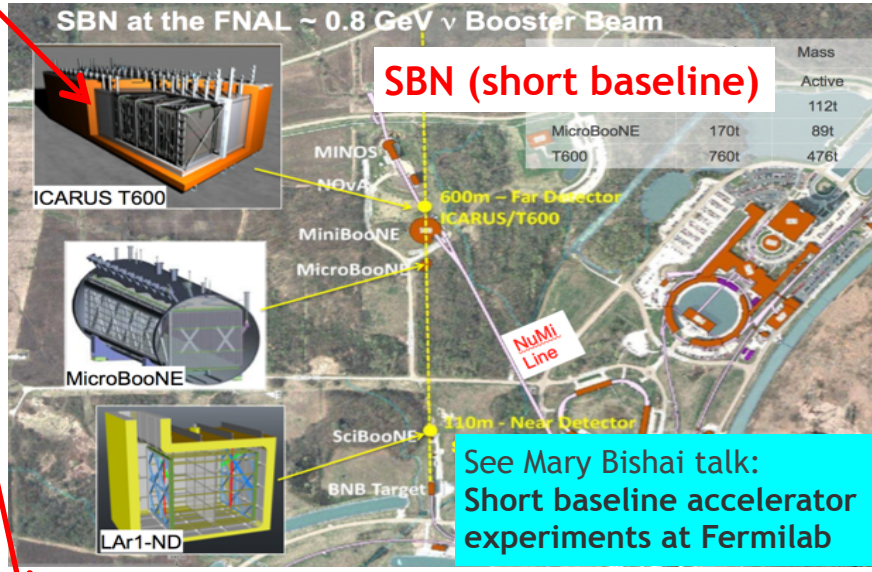
CERN Neutrino Platform

Water Cherenkov

LAr technology

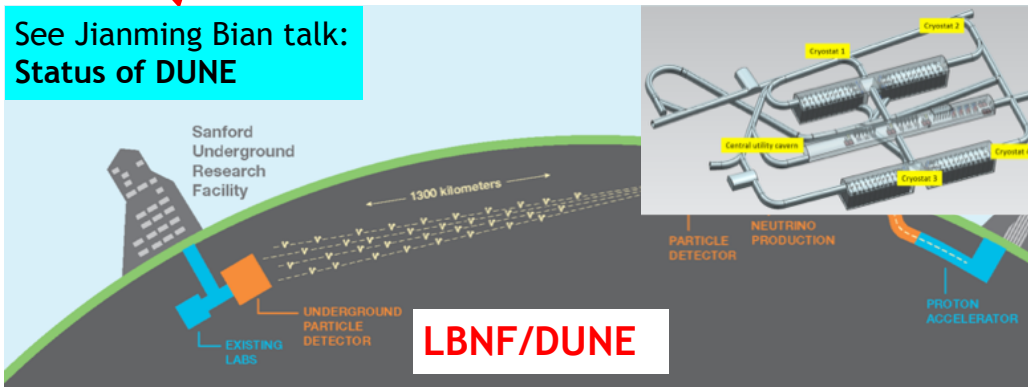
T2K





See Mary Bishai talk:
Short baseline accelerator experiments at Fermilab

See Jianming Bian talk:
Status of DUNE



Neutrino Platform Projects

6 Projects presented to the SPSC and approved as experiments at CERN:

✓*NP01: WA104, ICARUS as far detector for FNAL short baseline*

✓*NP02: WA105, double phase LAr-TPC demonstrator + ProtoDUNE DP engineering prototype for a double phase LAr-TPC for DUNE*

✓*NP03: PLAFOND, general R&D framework*

✓*NP04: ProtoDUNE SP, engineering prototype for a single phase LAr-TPC for DUNE*

✓*NP05: Baby Mind, a muon spectrometer for the WAGASCI experiment at T2K*

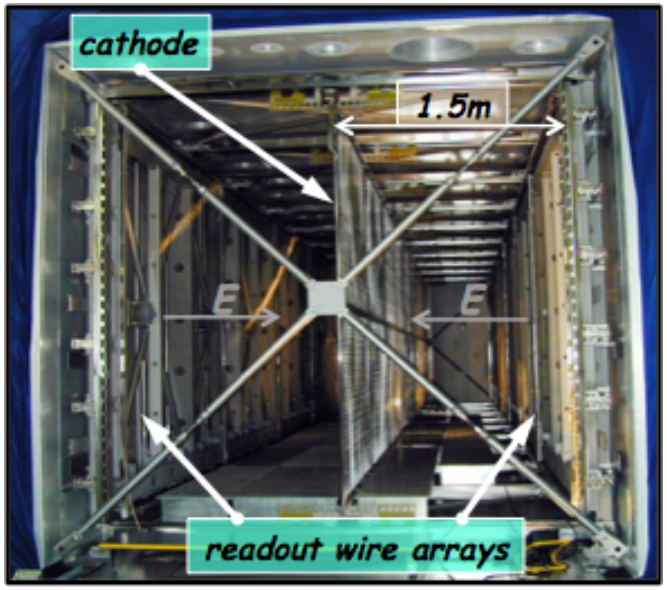
✓*ArgonCube: a modular LAr-TPC R&D*

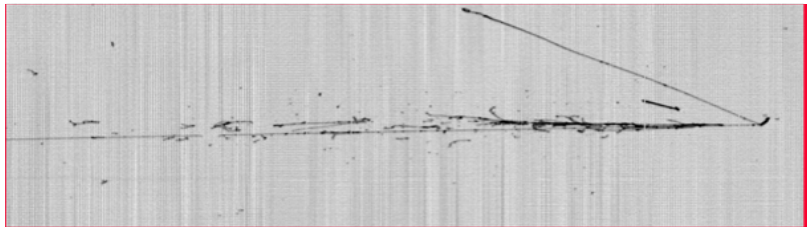
More that 50 European Institutions participating and well as many US Institutions

The ICARUS T600: pioneering the LAr-TPC

- The T600 LAr-TPC, built in the year 2000 as a technology demonstrator, has been successfully operated (2009-2013) at LNGS, completing a 3 year physics run at the CNGS neutrino beam and collecting atmospheric neutrino events.

- 2 independent and identical T300 modules, 3.6x3.9x19.6 = 275 m^3 each: 476 t LAr active mass
- 4 TPC chambers, 2 per T300, 3 wire planes 3 mm apart, 52000 wires with 3 mm pitch, directions at 0°, ±60°
- 74 photomultiplier tubes (PMTs), VUV sensitive with TPB wavelength shifter
- Evacuable aluminum cryogenic vessel.
- Continuous recirculation and filtering (Oxysorb/Hydrosorb) in liquid and gas phases for e^- lifetime exceeding tens of milliseconds





- The T600 is undergoing renewal phase before being moved to FNAL where it will be used as far detector for the SBN program.

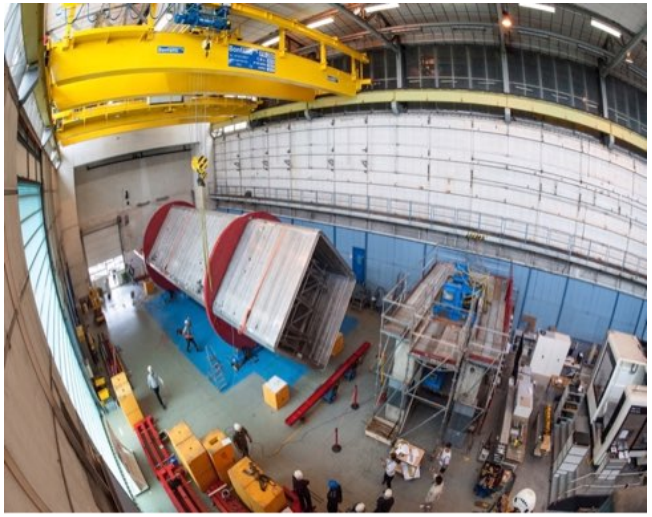
NP01: overhauling of ICARUS T600

- Joint INFN/CERN/US WA104 program: T600 is being upgraded at CERN, with the introduction of technological developments to match the additional requirement of operating on surface with high interaction rates and CR background:
  - New light collection system with high efficiency PMTs
  - New j-fet based low noise (<10^3 e^-) "warm" electronics
  - Internal cabling and wire biasing components
  - Flattening of existing cathode panels
  - New LAr containers and purely passive insulation (GTT technology)
  - Refurbished cryogenics system
  - New regenerable (copper based) purification filters
- The Cosmic Ray Tagger and filtering/selection tools are developed at the CERN Neutrino Platform jointly with the three SBN collaborations.

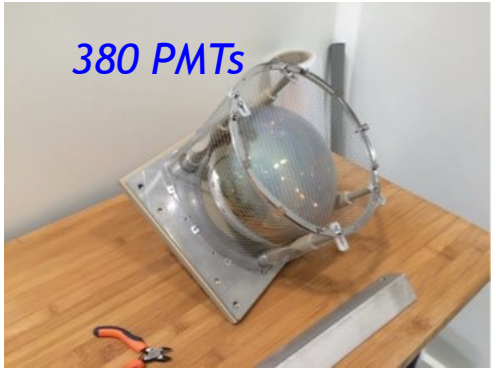
See talk:
Meng Guang: ICARUS

NP01: T600 delivery to FNAL early 2017, installation and commissioning during 2017

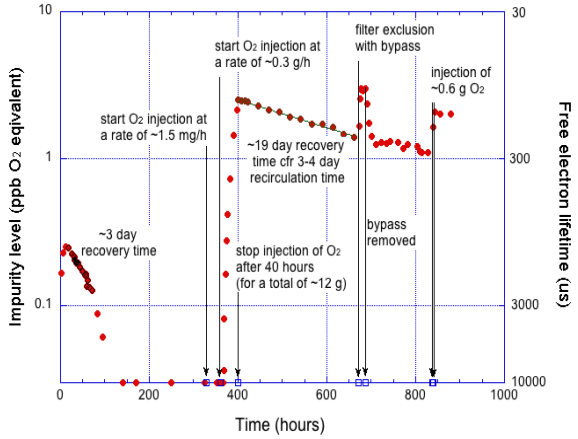
New aluminum cold vessel being assembled at CERN



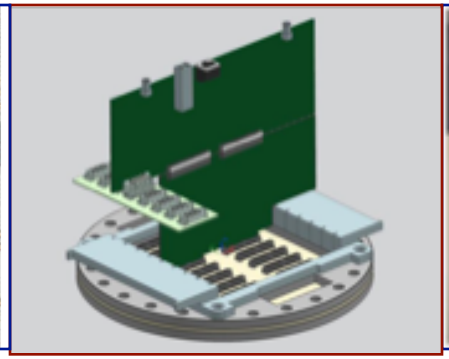
TPC cabling / "cold" biasing circuitry

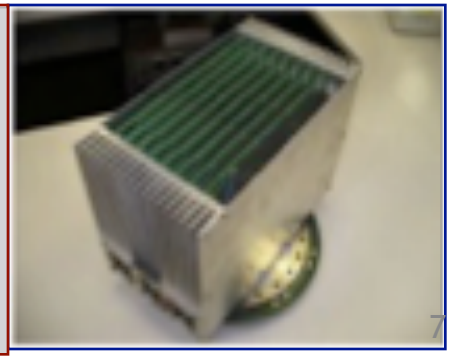


New purification system efficiency study



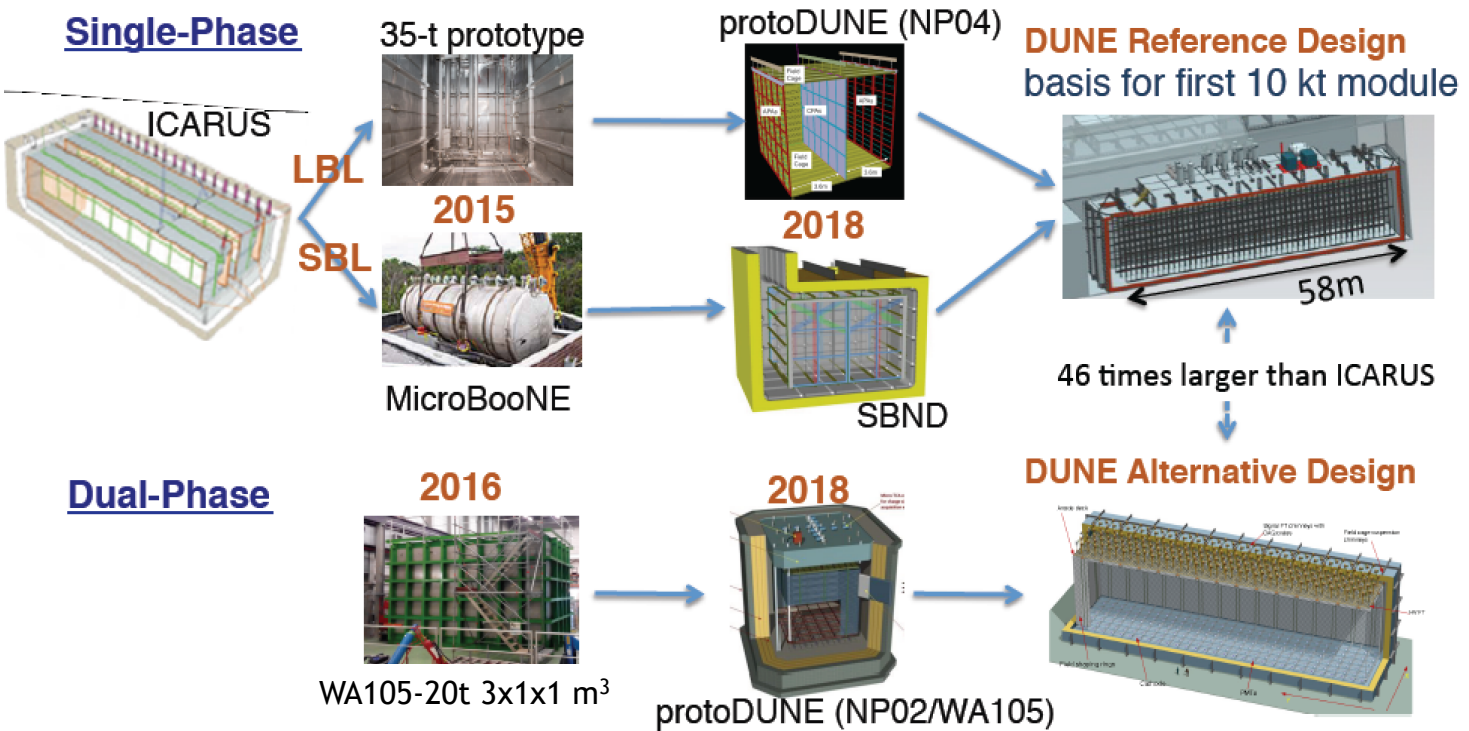
New readout board, feed through flange and compact crate





NP02/04: DUNE Development Path

- The LAr-TPC technologies are demonstrated by ICARUS, ArgoNEUT/LArIAT, MicroBooNE and WA105. The much larger size of the DUNE far detectors requires:
  - prototyping/calibration at the scale of a major experiment
  - testing of all final DUNE far detector elements and assembly procedure
- A strong LAr-TPC development and prototyping effort is pursued at the CERN Neutrino Platform with the construction and operation of ProtoDUNE SP (NP04) and DP (NP02) and performed in parallel with the Fermilab SBN program.



ProtoDUNE goals (NP02/NP04)

- Detector Engineering:
  - full scale detector components: installation procedures, operation, performance
  - manufacturing methods, capabilities at multiple sites
  - QA/QC chains for all detector elements
  - DAQ strategies, algorithms and data handling

- Physics Measurements / detector calibration:
  - systematic uncertainties
  - Validation/tuning of MC simulations
  - reconstruction tools and PID tests
  - Study particle interactions (pion, muon, kaon)
  - muon capture, anti-proton annihilation, …

Exposure to charged particle beam to cover energy range and particle types as expected for DUNE ν interactions

- Infrastructure and Alternate:
  - Validation of cryostats solutions and cryogenics system
  - Comparison of single and double phase LAr technologies

NP02&NP04 will make use of similar facilities

- ***Large scale cryostats based on the LNG transport technology***

- ***Large scale LAr cryogenics system with ppt purity requirements***

- ***Large scale conventional facilities (experimental hall, clean rooms, testing facilities, ….)***

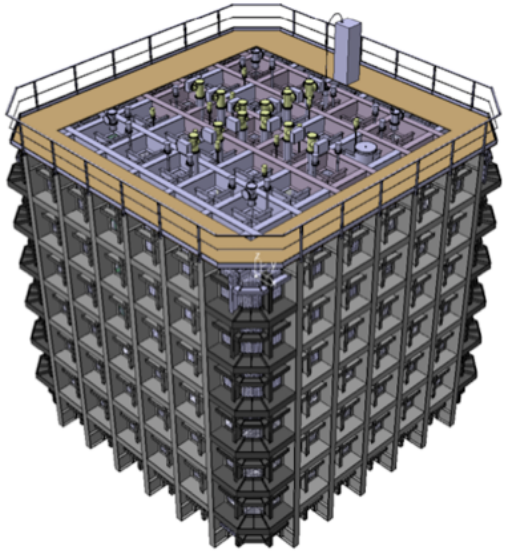
- ***Charged beams facilities (e,μ,p,π,...) down to ~ 0.5 GeV MeV/c for calibration and performance studies***

- ***Big data handling facilities (online computing, tier0, tier1, ...)***

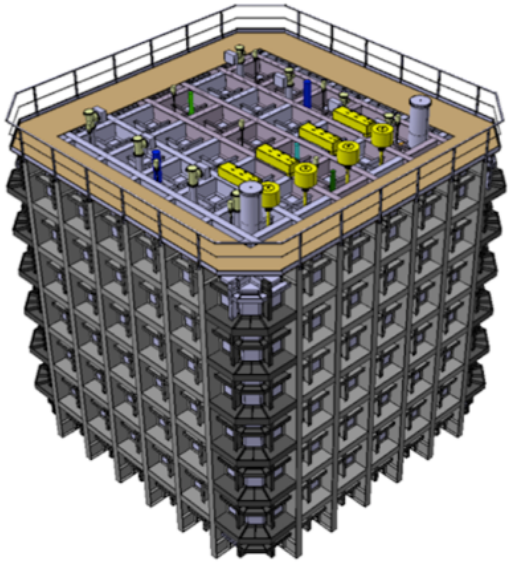
ProtoDUNE Cryostats

- Large active volume required (~6x6x6 m^3):
  - Measurement: energy bias studies require full shower containment
  - Engineering: test full scale-components assembled into functional sub-unit
- Nearly identical membrane cryostats for single and double phase protoDUNE:
  - 770 t total LAr mass
  - Internal: 7.9 m x 8.5 m x 8.1 m
  - External: 10.8m x 11.4 m x 11.0 m
- Similar cryogenic and operation procedures:
  - Piston Purge, LAr/GAr cool down, LAr Filling, continuous LAr circulation/purification with cryogenic LAr pumps
- Engineered and constructed by CERN:
  - Outer steel structure under construction; delivery summer 2016
  - Insulation, Membrane: engineering in progress
  - Design scalable to DUNE FD dimensions
- Cryostats ready in 2017

NP02 (double phase)

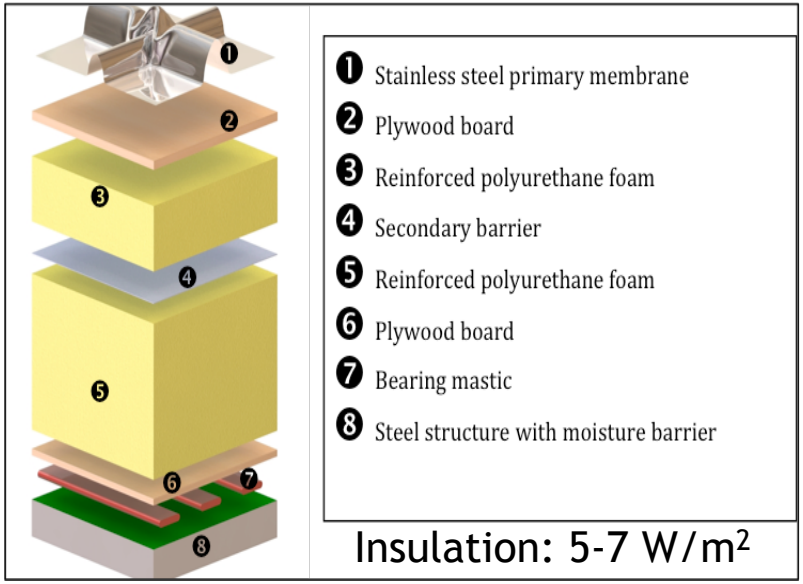


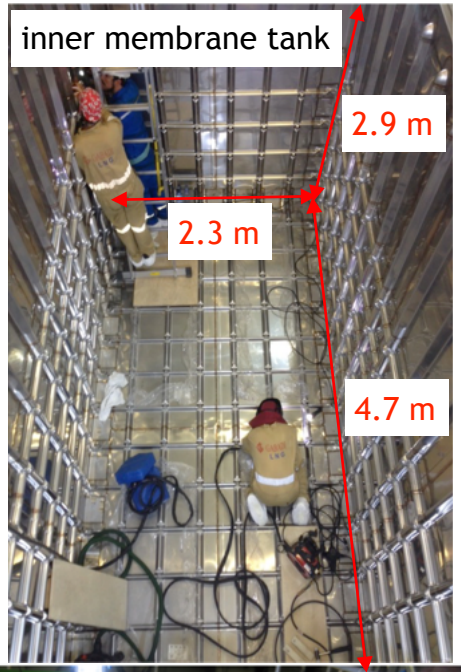
NP04 (single phase)

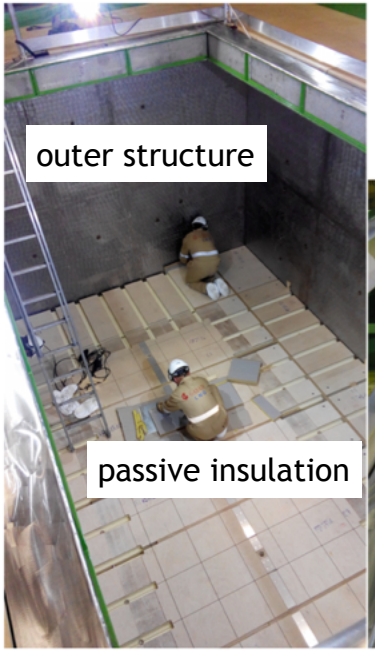


Membrane cryostat: LNG industry technology

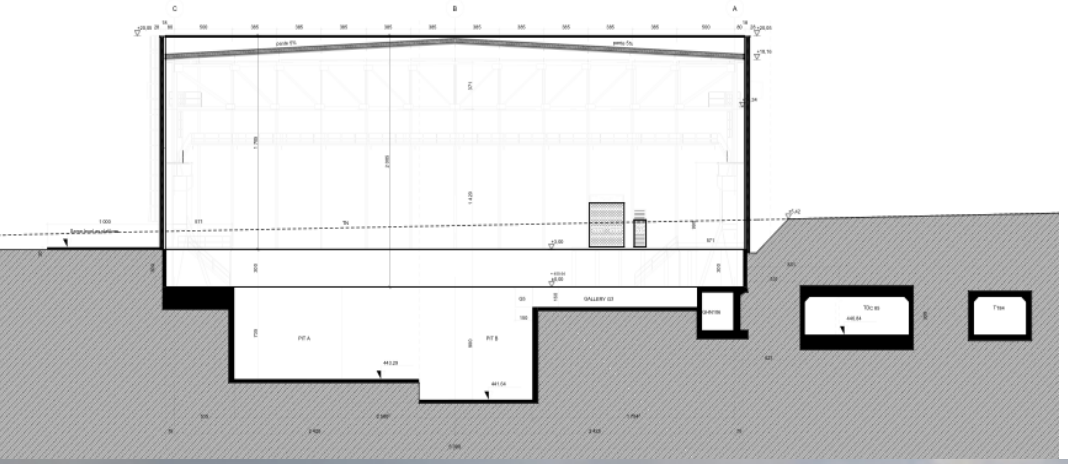
- First prototype at CERN, vessel for the WA105 3x1x1 m^3 detector:
  - Designed and funded by CERN (70%) and ETHZ (30%)
  - GTT membrane technology
  - Validation for ultra-high purity environment (leak detection tests, piston purge prior filling)
  - Now ready for operation

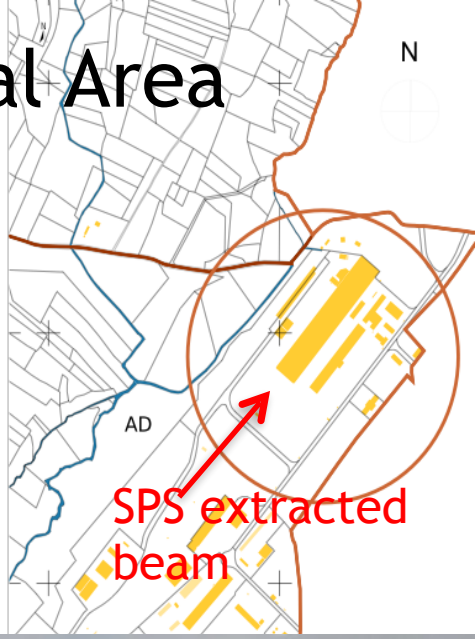






CERN infrastructure: experimental Area





Nord Area EHN1 extension (~53'000 m³)

designed & contracted in 2014 (Q3-4)

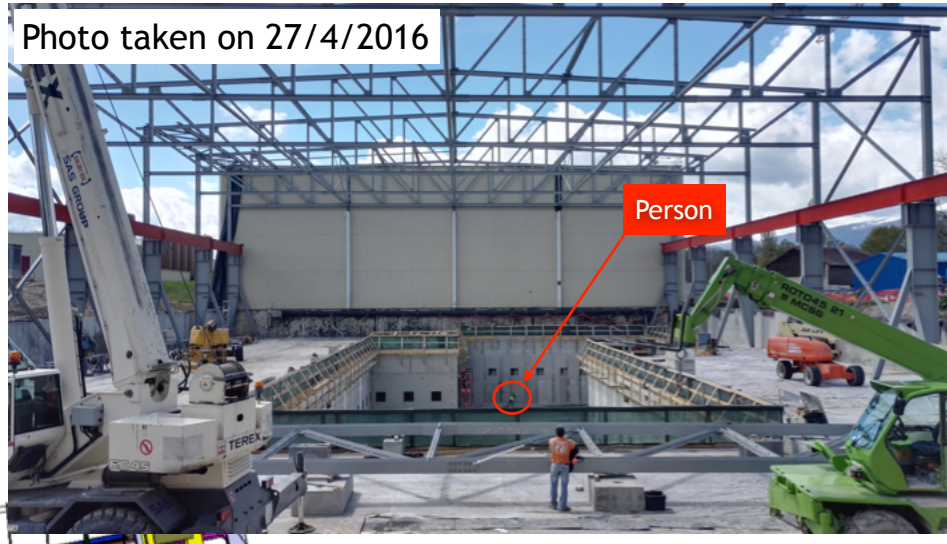
C.E. construction started in January 2015

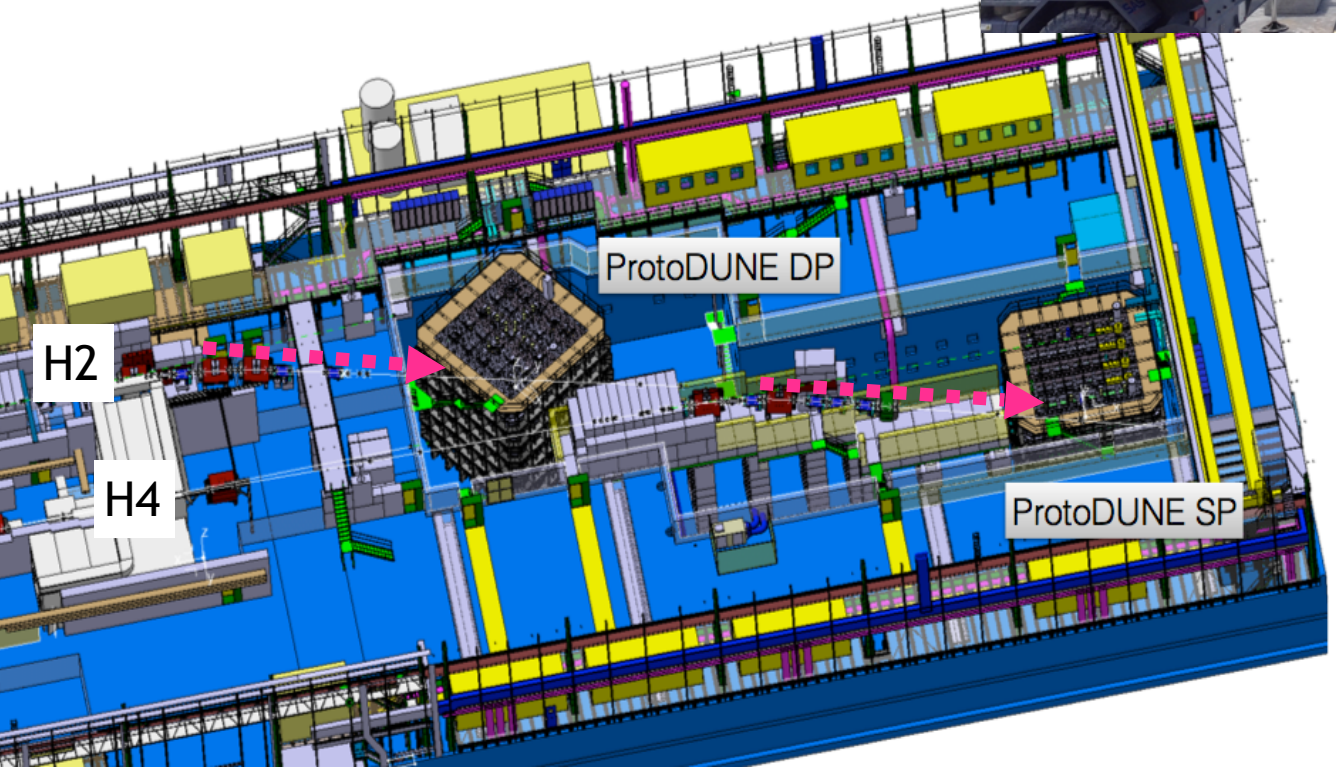
photo taken Sep. 2016

ProtoDUNEs at the CERN neutrino platform

EHN1 extension, ν Experimental Area

- **Beneficial occupancy Sep. 2016**
- **Cryostats ready for detectors installation in April 2017**
- **Charged beam Spring 2018**





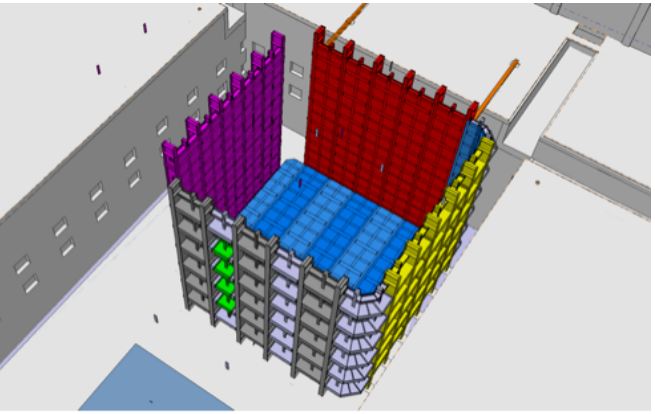
Tertiary beams on H2 and H4: 0.2-12 GeV/c, momentum bite 5% (can be reduced to 1% with integrated spectrometer measurements)

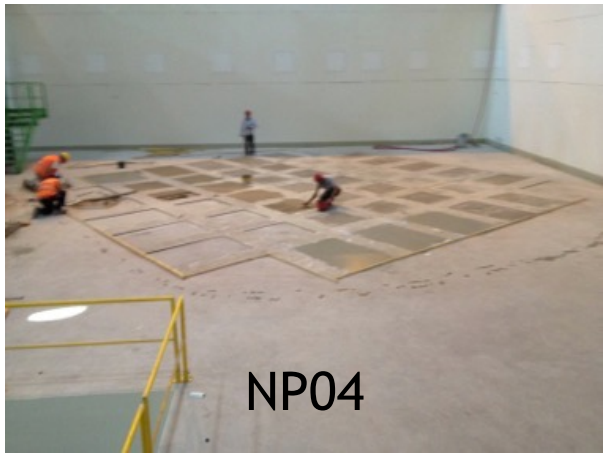
Mixed hadrons beam:

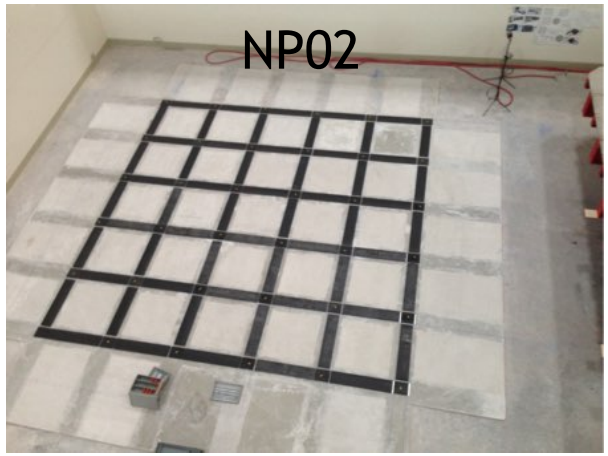
- (±) π, K, p with e contamination at low energies
- pure e beams
- parasitic μ halo

EHN1 NP extension (Sep. 2016)

NP02 and NP04 cryostats under construction



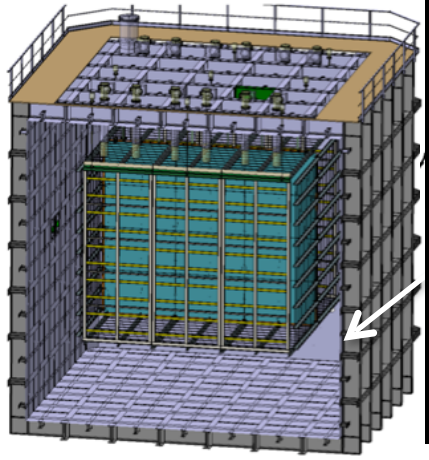


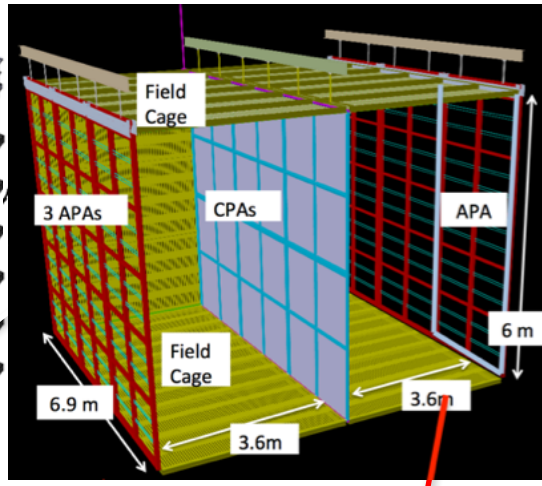


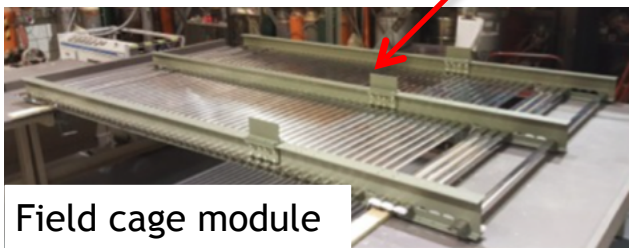
NP04: protoDUNE Single phase LAr-TPC

See Jonathan Asaadi talk:
Single phase LAr TPC

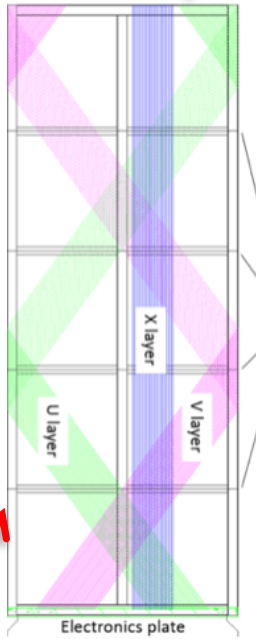
- Same detector components and modular assembly concept as for DUNE Single Phase far detector based on:
  - APA (wire chamber);
  - Fully cryogenic readout electronics;
  - Modular Field Cage (FC) Concept;
  - CPA (Resistive Cathode) and HV feed-through
  - Photon detectors embedded in APA.
- Option to reduce drift distance to 2.5m
  - to mitigate space charge effects.

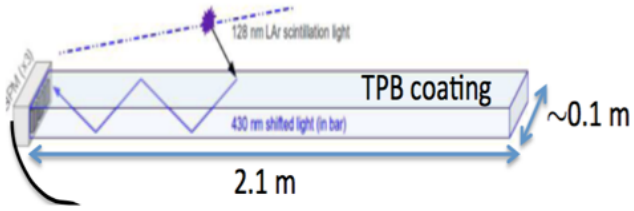




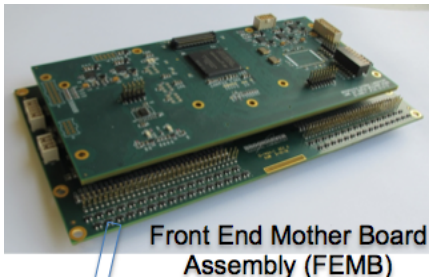


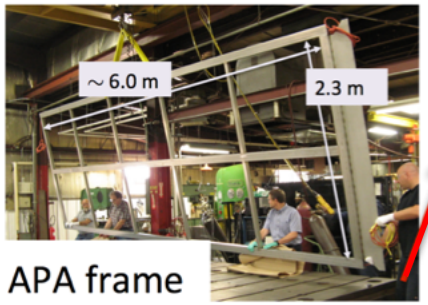
Field cage module





SiPM coupled to WLS bars

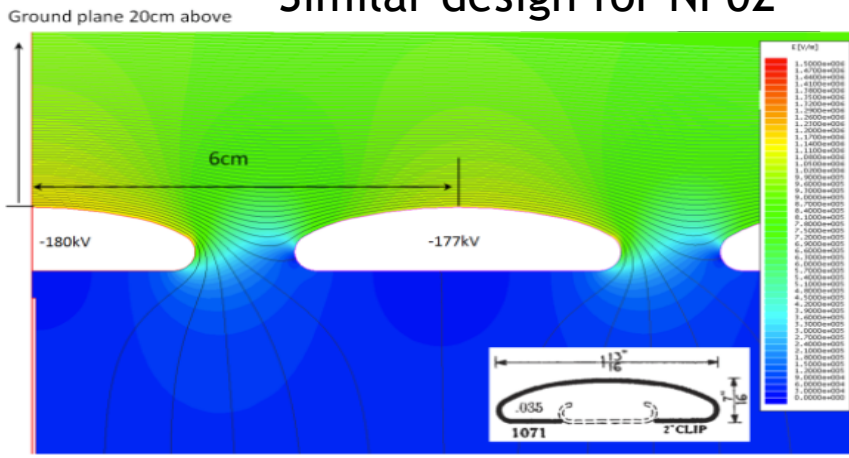




APA frame

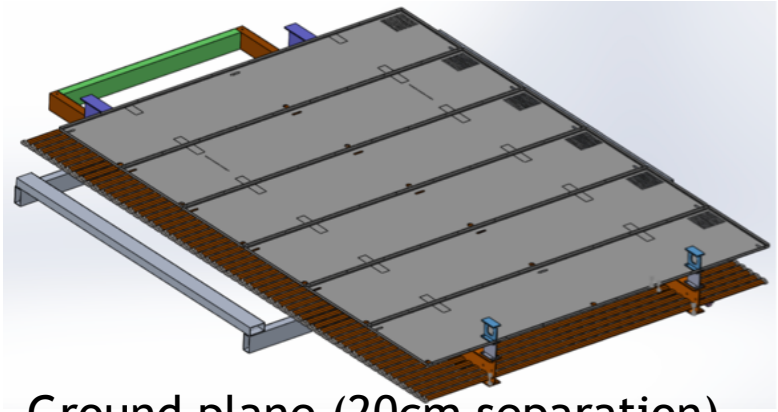
NP04: design and R&D of Field Cage

Similar design for NP02

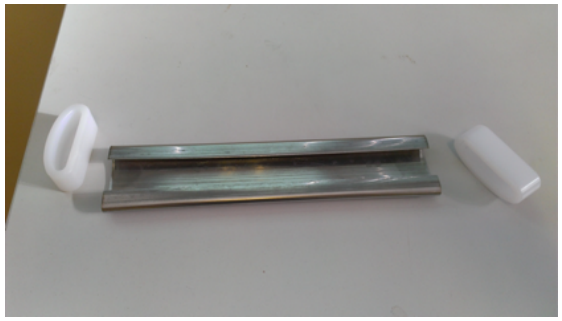


Modular concept constructed from:

- Open roll formed Al or SS profiles (Purity)
- Shape chosen to minimize e-field intensity
- Plastic caps to prevent discharges
- Fiberglass I-beams support
- Ground planes on top and bottom



Ground plane (20cm separation)

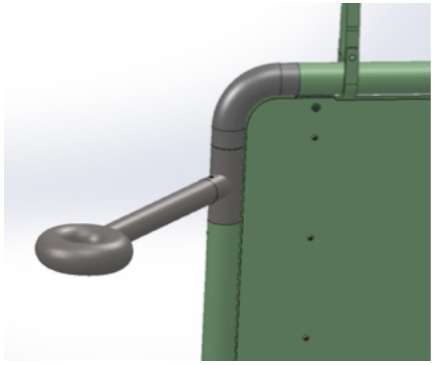


Functional tests at CERN in purified LAr:

- No sparks observed up to 100 kV (6.6 cm gap)
- Occasional sparks above 80 kV if bubbles present

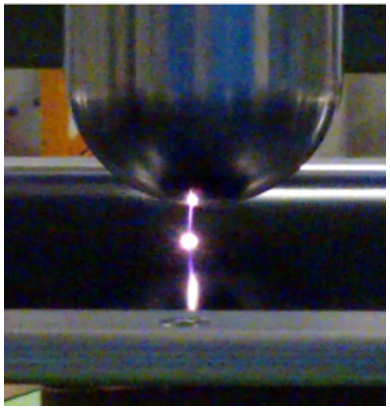
NP04: design and R&D for CPA

FR4 planes laminated with resistive kapton (double sided): 1-10 MOhm/square to dump possible damage to detector membrane / FE electronics due to accidental HV break-down with sudden energy release



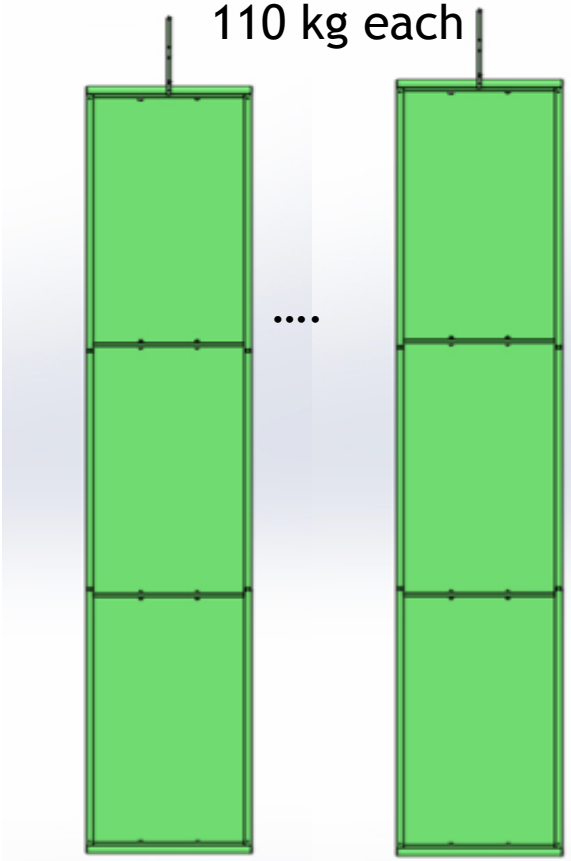
Dedicated tests at CERN in pure LAr allowed verifying:

- Robustness to sparks
- Ageing in cryogenic environment
- Lamination stability in LAr
- LAr purity compatibility



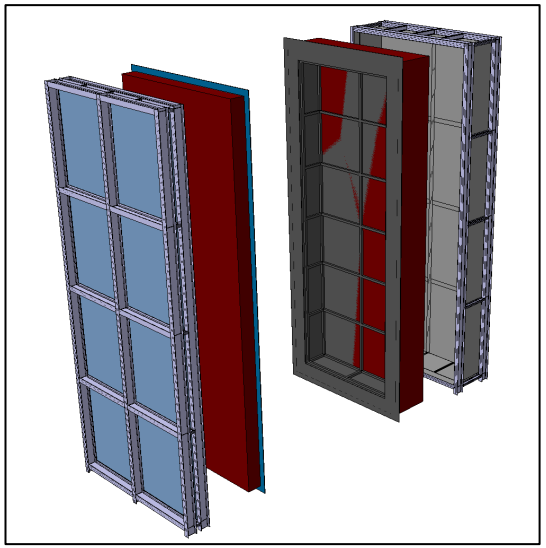
Modular structure:

- 6 interconnected CPA columns
- Vbias = -180kV
- HV bus embedded in panel frames



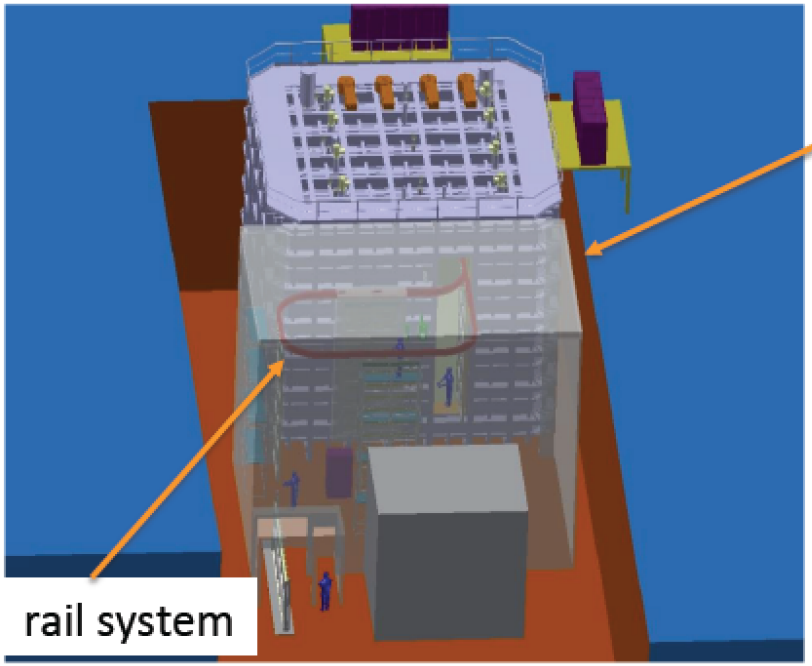
NP04: detector integration

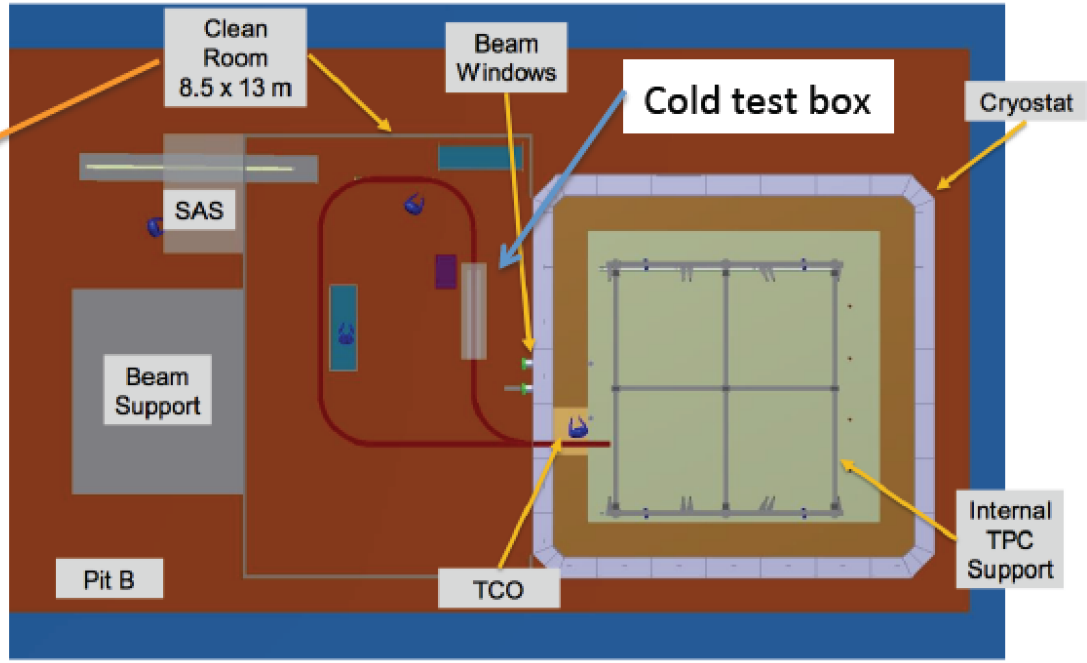
Cold box for NP04 APA integration tests



Definition of installation procedures and tooling construction:

- Integration and tests of APA, CE and PD in clean room
- Perform warm and cold testing (dedicated cold-box)
- Insert APA through TCO into cryostat
- Retest APA once installed in final position

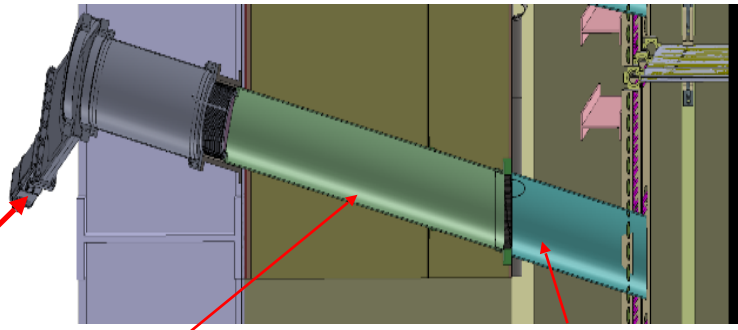




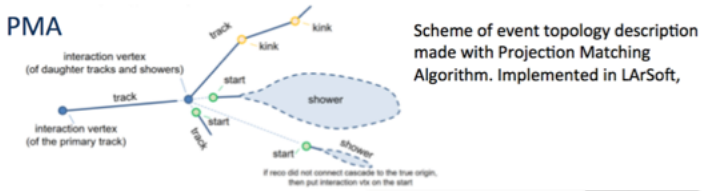
Additional activities involving CERN NP

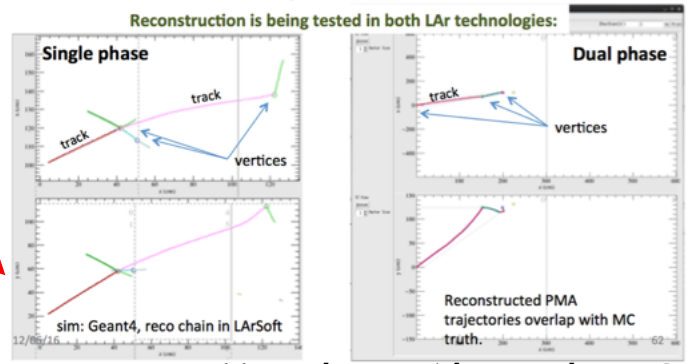
- ✓ Work on Detector Control Systems done for the WA105-b182 prototype extended to EHN1.
- ✓ Possibility to develop a new DAQ system based on the ATLAS FELIX concept with CERN support: https://indico.cern.ch/event/530990/ .
- ✓ Detector simulation including beam plug design optimization
- ✓ Participation in tool developments for data reconstruction
- ✓ Computing infrastructure: large server cluster (>55) *neutplatform.cern.ch with **LArSoft installed and widely used.***

Beam plug to propagate test beams into active LAr volume.



Beam plug in LAr Penetration in cryostat walls

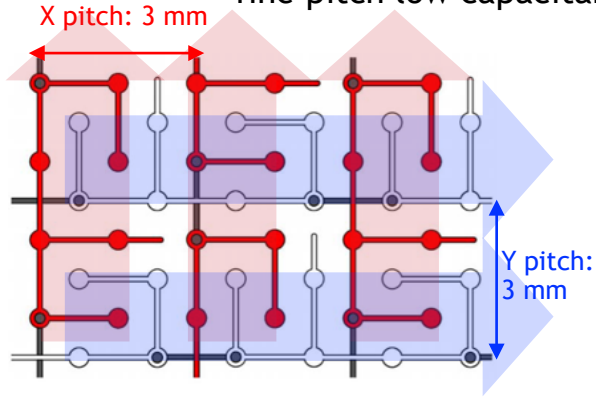


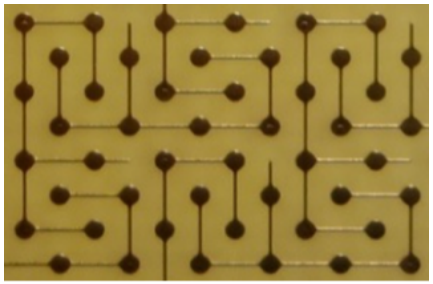


Projection Matching Algorithm

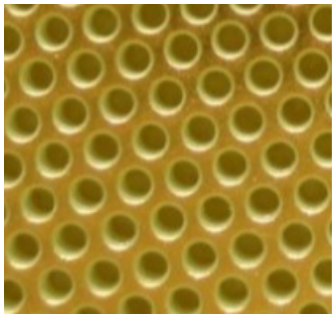
NP02: Double phase readout

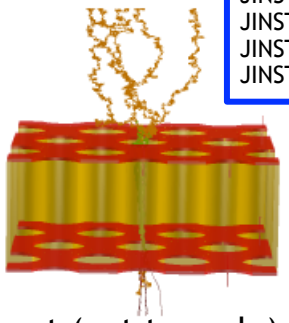
Charge collection:
fine pitch low capacitance (150 pF/m) anode





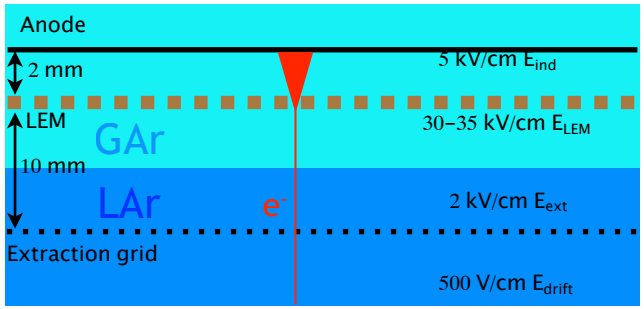
Charge multiplication:
Large electron multiplier (LEM)



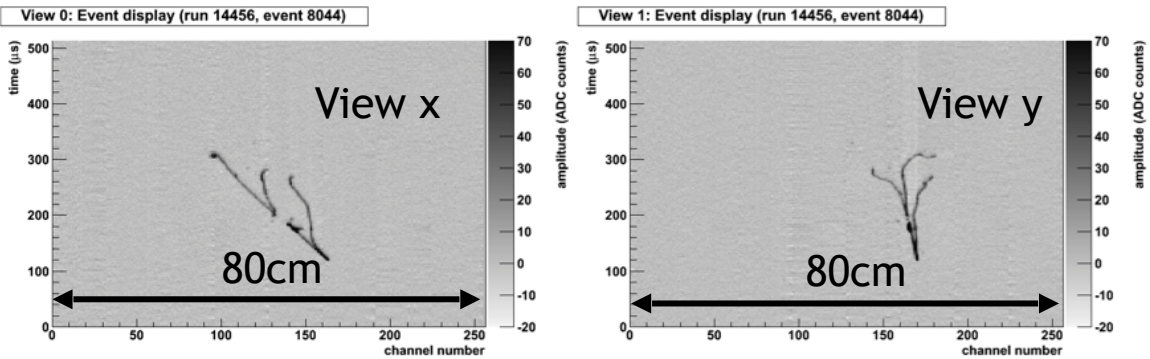


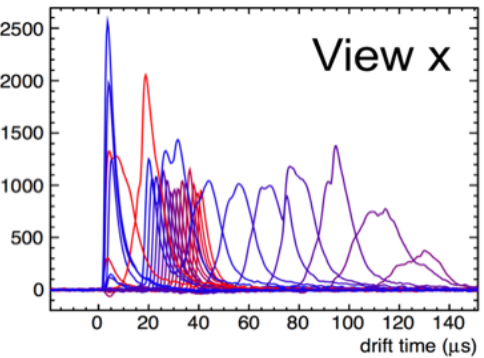
NIM A617 (2010) 188-192
NIM A641 (2011) 48-57
JINST 7 (2012) P08026
JINST 8 (2013) P04012
JINST 9 (2014) P03017
JINST 10 (2015) P03017

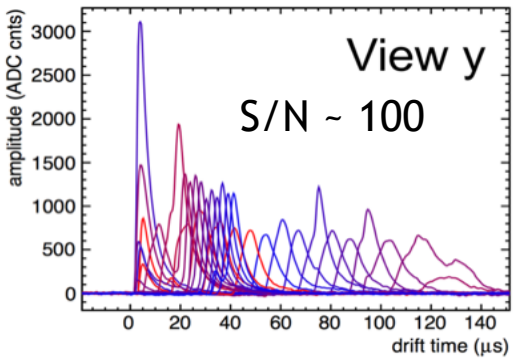
Concept (not to scale):



muon event







Advantages:

- Longer drift path with less #channels
- Finer readout pitch
- More robust S/N ratio with tunable gain
- Lower detection energy threshold
- Better pattern reconstruction of events
- Only charge collection views (no induction)

See Shuoxing Wu talk: Double phase LAr TPC

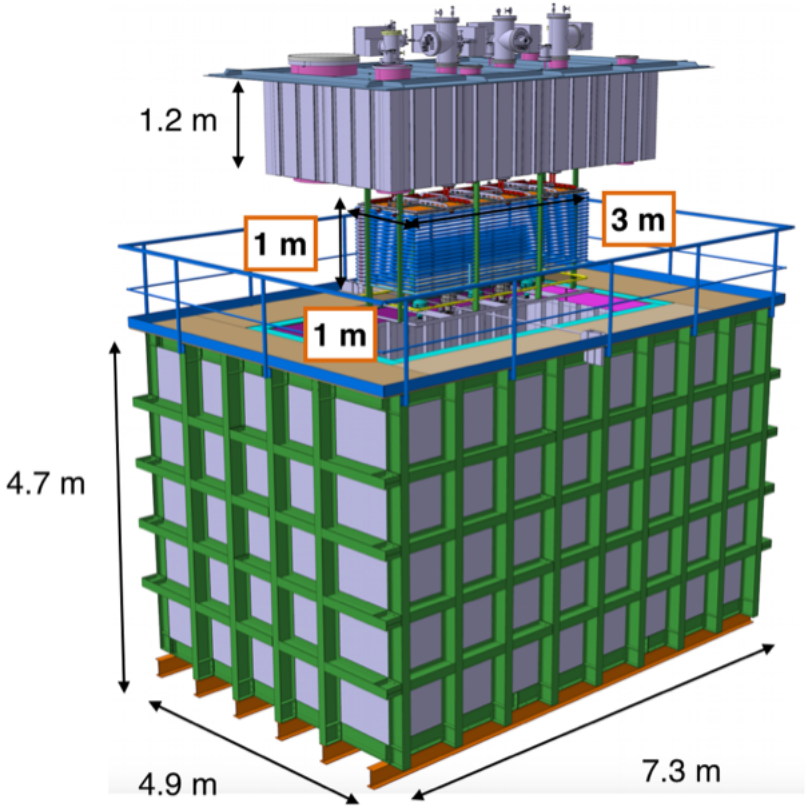
NP02: WA105-3x1x1@ CERN B182

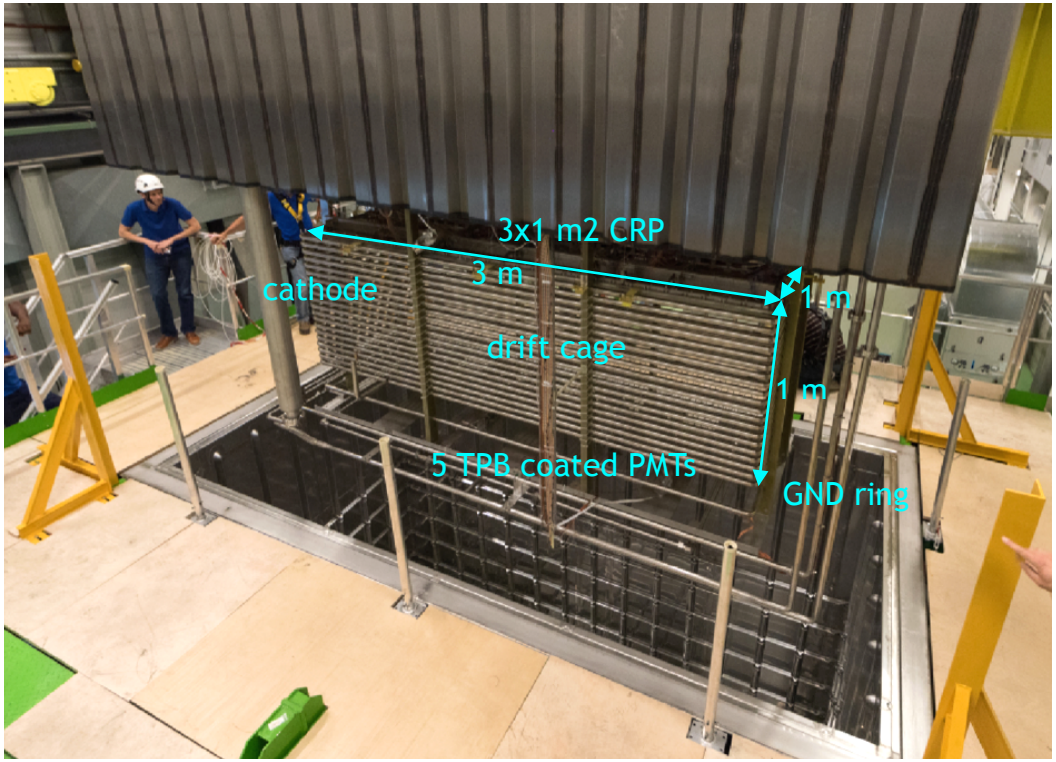
First engineering prototype of dual phase technology before ProtoDUNE-DP

- ***Charge readout area = 3x1 m2***
- ***drift length = 1 m***
- ***Gain = 10-20 (adjustable)***
- ***Cold F/E electronics in chimneys (accessible)***

To demonstrate:

- Detector feasibility and principles
- Components engineering and QA&QC
- Cryostat and cryogenics design and construction



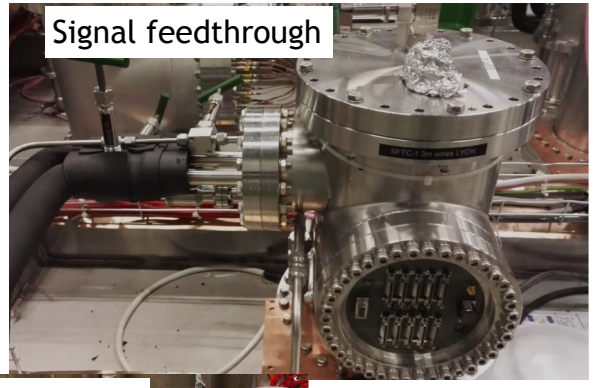


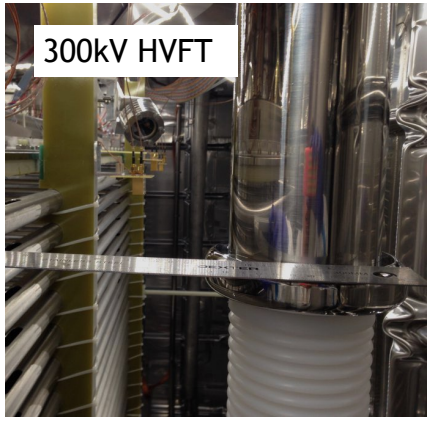
Readiness for cooling down Nov. 2016

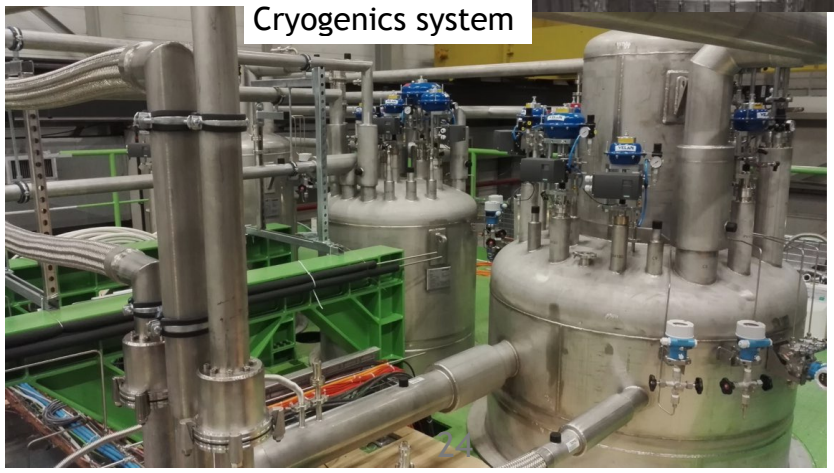
NP02: WA105-3x1x1 ready for cryogenics operation!


Slow control racks

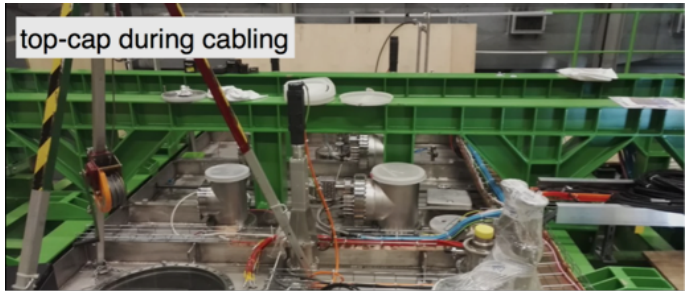

3x1 m2 CRP


Signal feedthrough


300kV HVFT

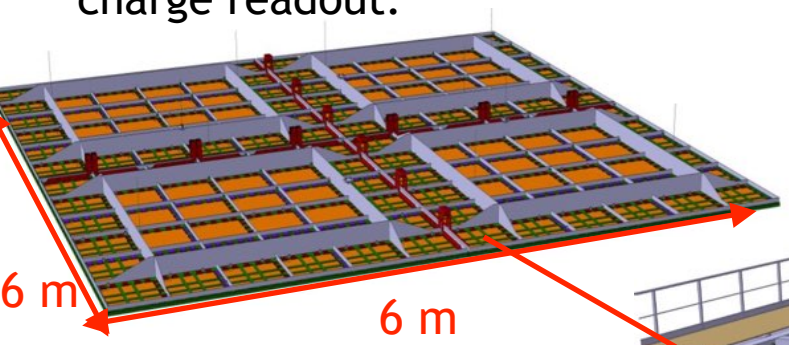

Cryogenics system


LAr pump

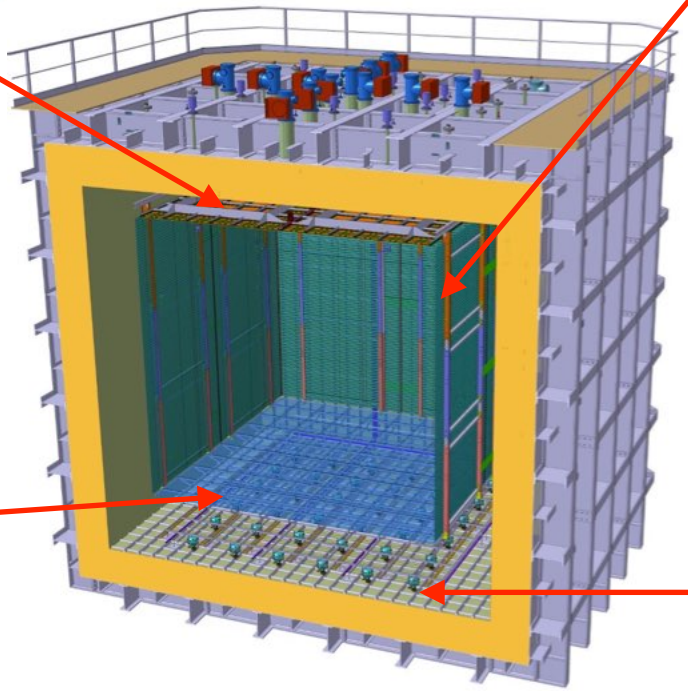

top-cap during cabling

NP02: Dual-Phase ProtoDUNE/WA105 6x6x6 m^3 as the final step before DUNE-DP

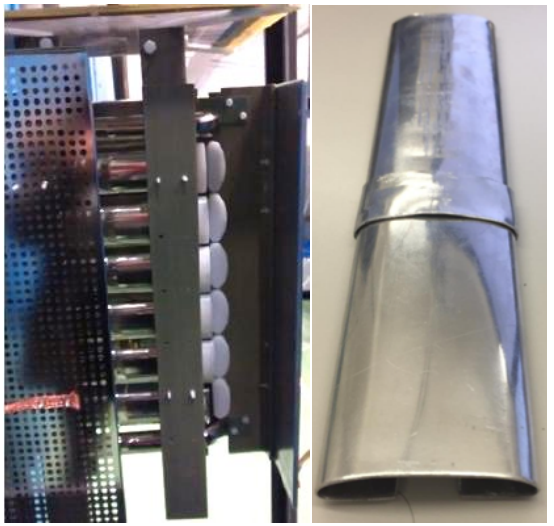
charge readout:



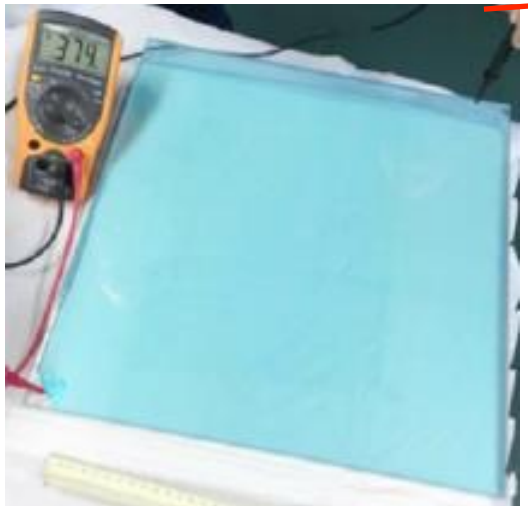
- 4 identical 3x3 m2 CRPs
- 144 50x50 cm2 anode and LEM panels
- 7648 signal readout channels
- accessible cold front-end electronics



drift cage based on Alu profile (same as NP04)

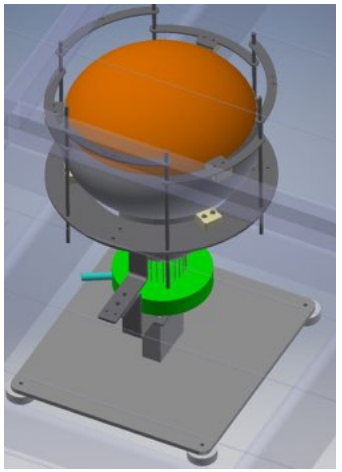


cathode:

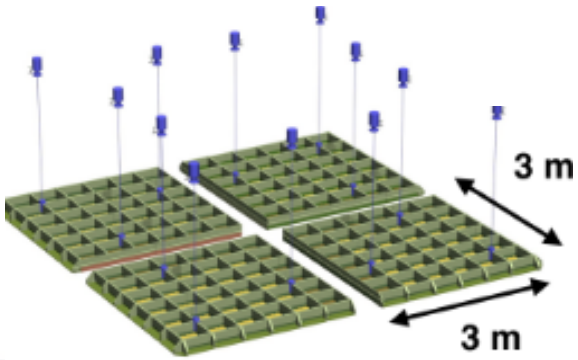


- PMMA plates coated with conductive ITO (Indium Tin Oxide) coating
- TPB coating for VUV shifting
- Protection against discharges due to possible bubbles from bottom of the tank

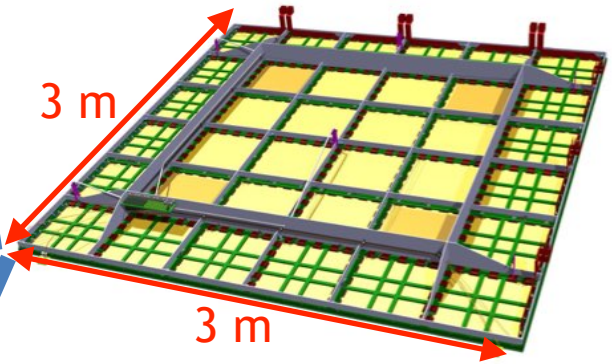
light readout: 36 PMTs



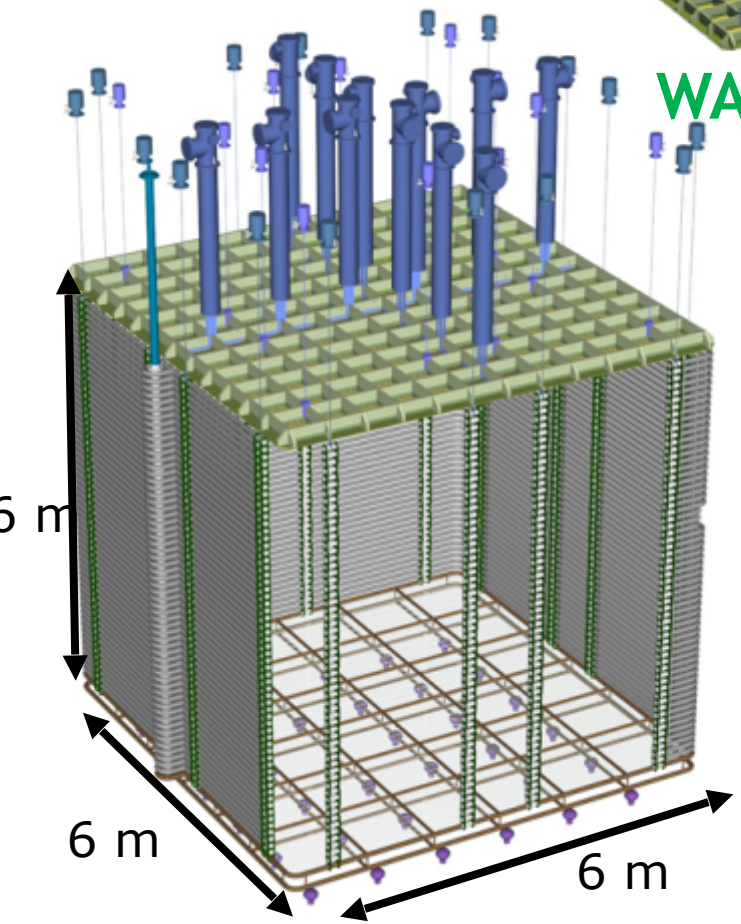
Scaling up from 3x1 m^2 to 3x3 m^2 CRP for DUNE



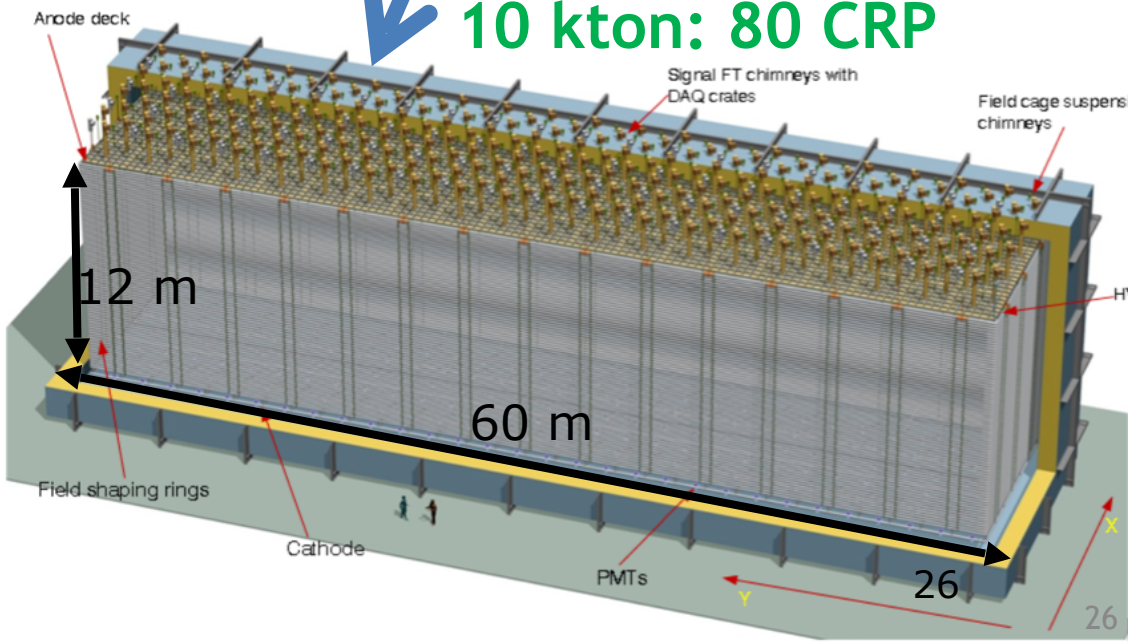
3x3 m2 CRP



WA105: 4 CRP



10 kton: 80 CRP

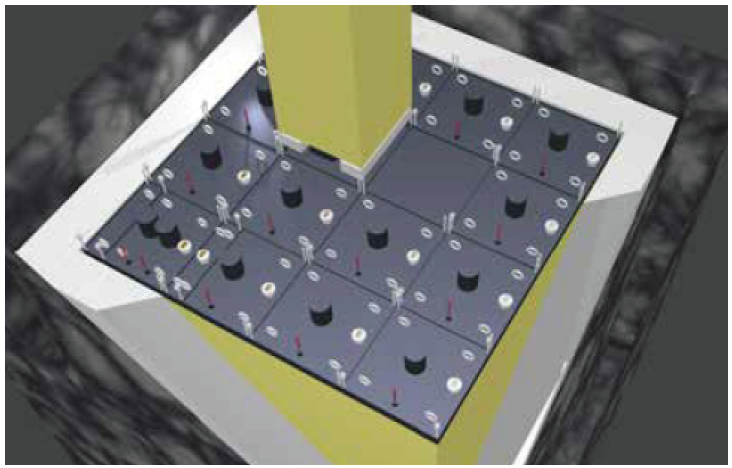


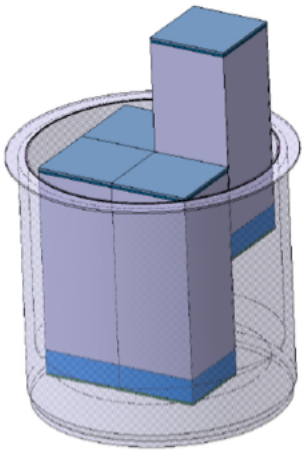
NP02 & NP04: time scale

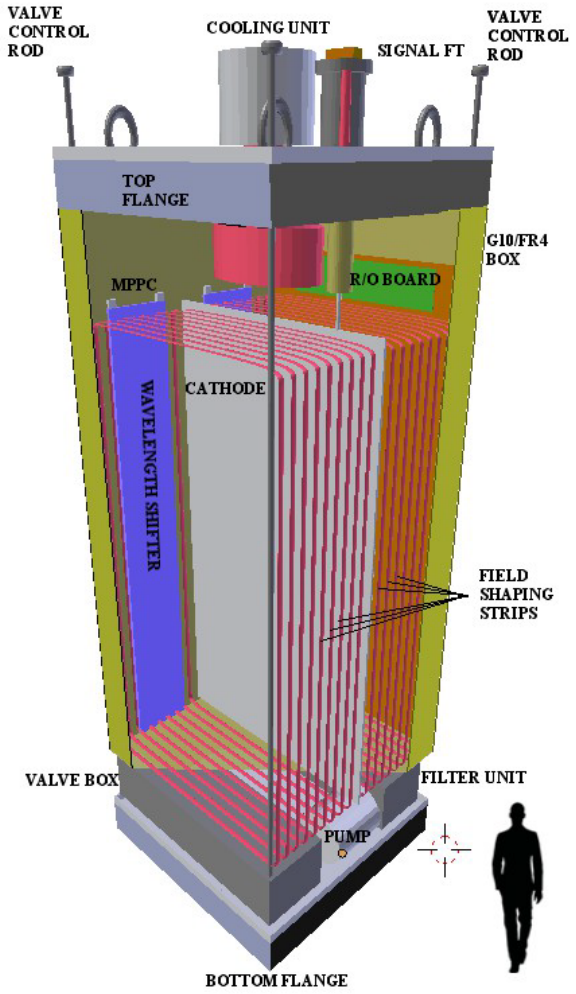
- ✓ Experimental hall delivery from CE by August 2016
- ✓ Two cryostats construction up to spring 2017
- ✓ 2017 detector installation
- ✓ By end 2017 detectors and cryogenics ready
- ✓ Early 2018 cooling down and first commissioning
- ✓ 2018 exposure to SPS beams
- ✓ After 2021 (LHC large shutdown) new possibility to exploit the SPS beams

ArgonCube: a Modular LArTPC

- Proposal (Bern) as alternative design for (Magnetized) DUNE Near Detector:
  - Shorter drift-times - Less stringent purity, less pileup & lower voltage
  - Light contained - Less optical pileup, accurate trigger & veto
  - Pixel readout - Live 3D reconstruction with reduced ambiguities
  - Several modules sharing the same LAr bath.





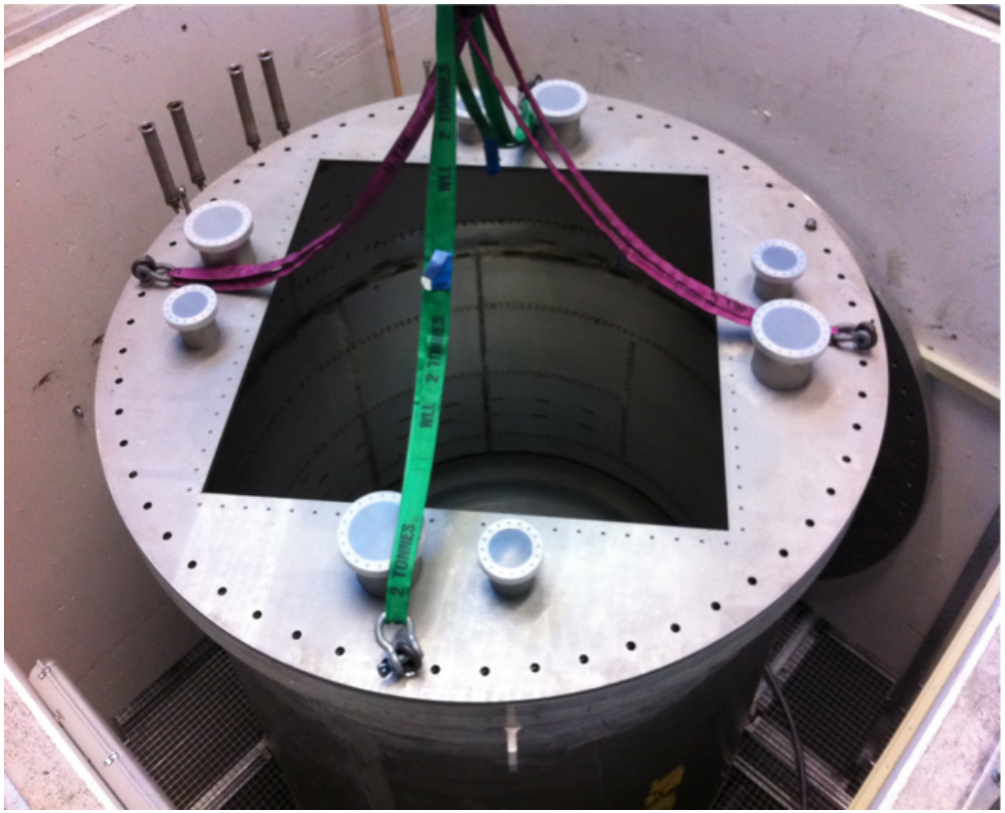


One Module:
2 m x 2 m x 3 m
1 m drift length

Modular LArTPC construction in progress

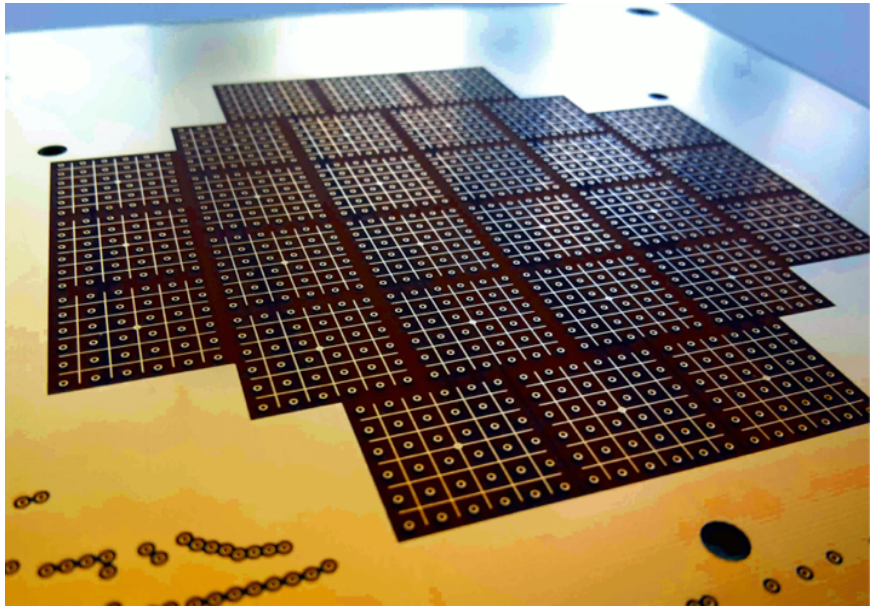
Modular prototype (ArgonCube) under construction.
Containing 4 modules:
1 x Reference wire readout (Sheffield)
3 x Pixel readout (Bern,CERN)

First TPC tests in the fall of 2016.
Using pixel demonstrator TPC



Pixel Readout: Initial Successful Test

See Jonathan Asaadi talk:
Single phase LAr TPC



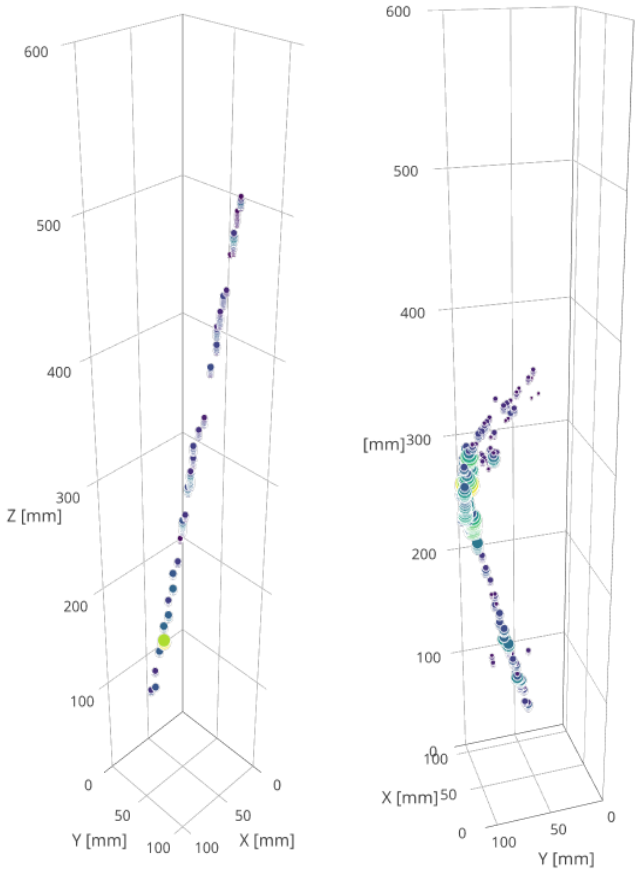
2.86 mm pitch, 28 inductive regions, 36 pixels per region, 64 channels

Demonstrated operation in LAr at 60 kV, triggering on cosmics and Co60.

Successful triggering on scintillation light (cold SiPM).

Successful readout from pixel plain.

Preliminary
Courtesy of LHEP-Bern



60 cm drift at 60 kV, 1 kV/cm.
Cold BNL pre-amps.
Bias focusing adjustable from 0 V to 300 V

Summary

- The CERN Neutrino Platform is a unique R&D framework for the International Neutrino community.
- Immediate physics potential with the exploitation of the short baseline at FNAL (and the T2K new near detector).
- Major contribution to the infrastructure of LBNF
- Design and construction of new large detector prototypes
- Generic R&D on new detectors and data handling
- Participation in the construction, commissioning and physics exploitation of the new neutrino facilities

Thank you for your attention!

Backup Slides

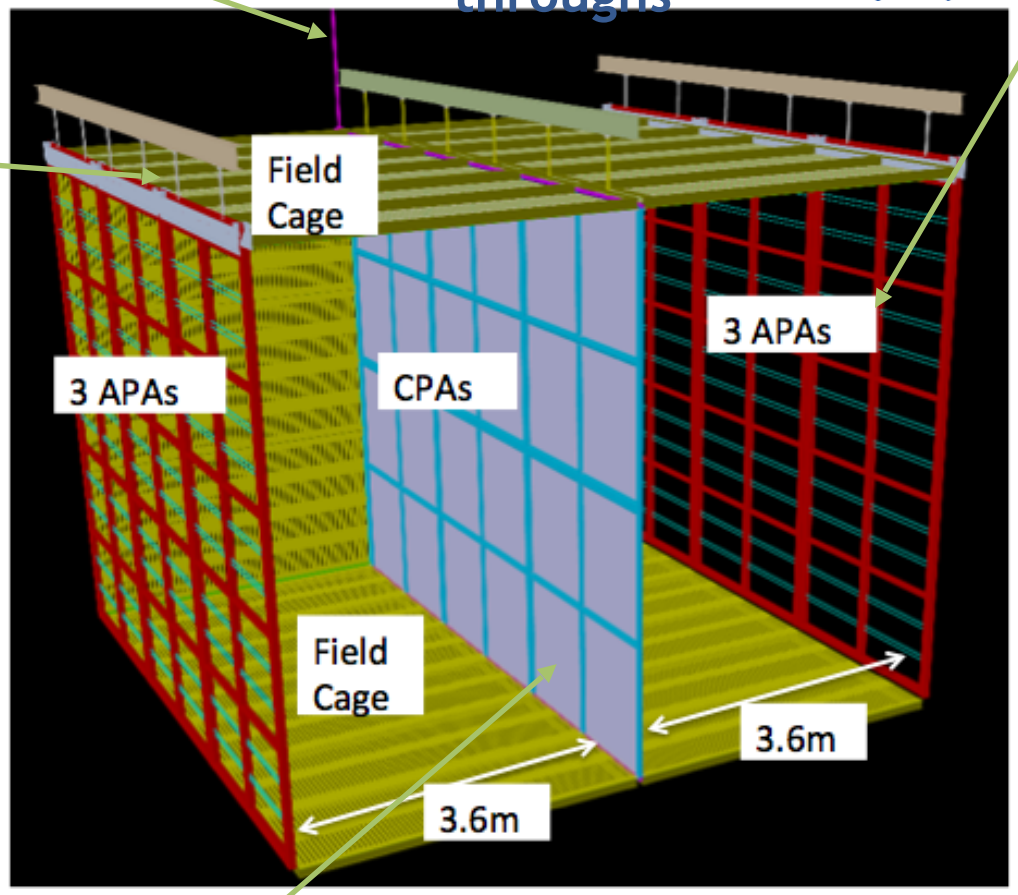
Single phase protoDUNE (NP04)

Drift HV system

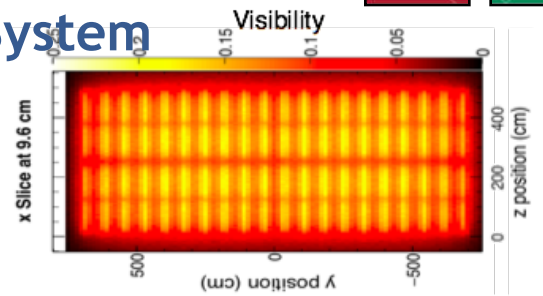
Signal feed-throughs

Anode Plane Assemblies (APA)

Field cage



Photon Detector System



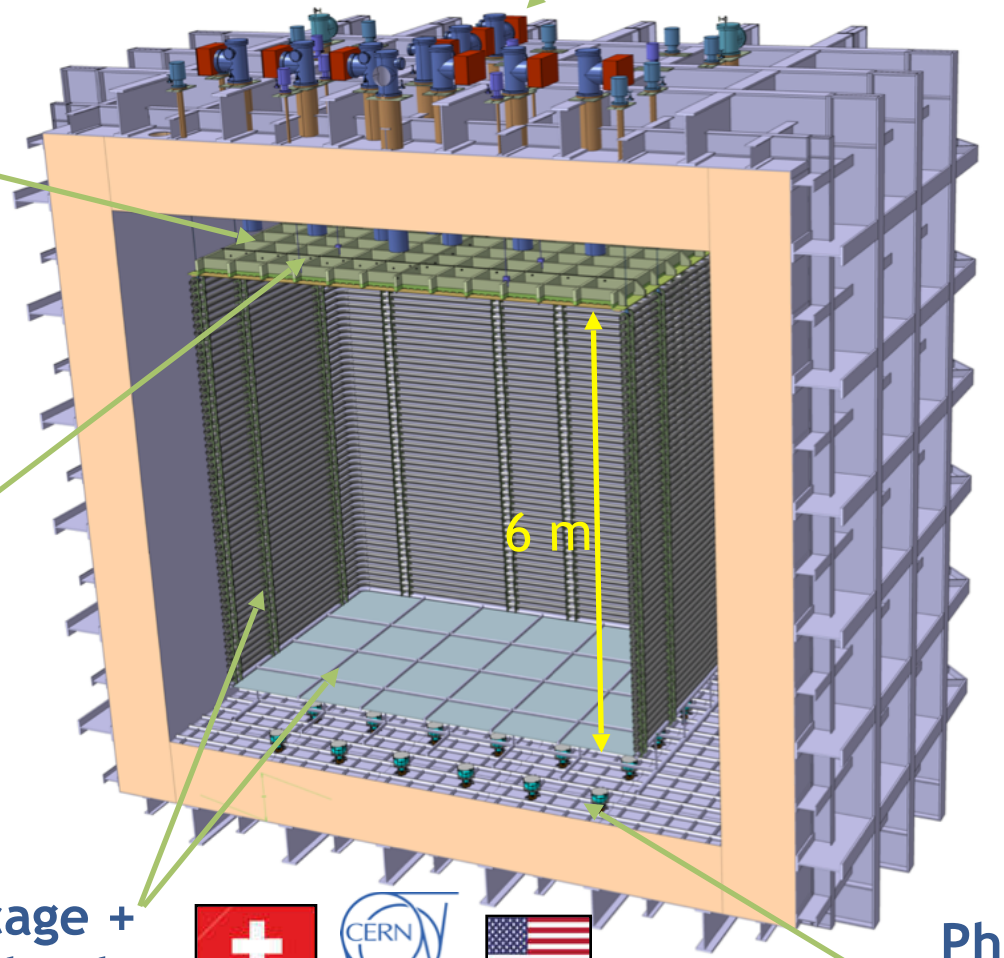
Cold readout electronics

DAQ

Slow control

Cathode Plane Assemblies (CPA)

Dual phase protoDUNE (NP02)



Drift HV system

Signal feed-throughs

CRP frame + hanging system

CRP readout planes

Drift cage + cathode plane

Photon Detectors

Photon Electronics

Cold readout electronics

DAQ

Online computing

Purity monitor

Slow control

Cosmic tracker