DEEP UNDERGROUND NEUTRINO EXPERIMENT

The Deep Underground Neutrino Experiment at the Long-Baseline Neutrino Facility

Oct 20, 2016 Flavio Cavanna | Fermilab Yale University

The Worldwide Neutrino Program in the U.S.

Building for Discovery
Strategic Plan for U.S. Particle Physics in the Global Context

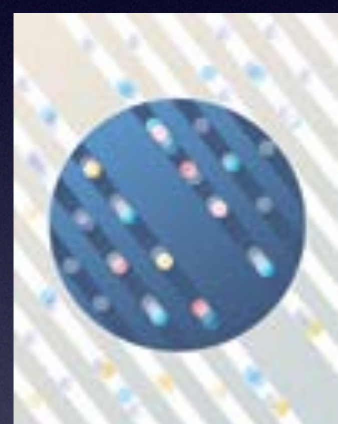
P5 - Strategic Plan for Particle Physics

The global High Energy Physics effort

Higgs boson

as a new tool for discovery

Neutrino mass

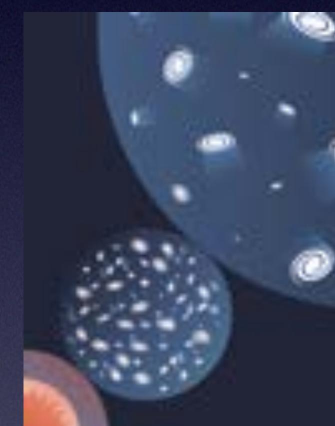


physics associated with Neutrino mass

Dark matter

new physics of Dark matter

Cosmic acceleration



dark Energy and inflation

Explore the unknown

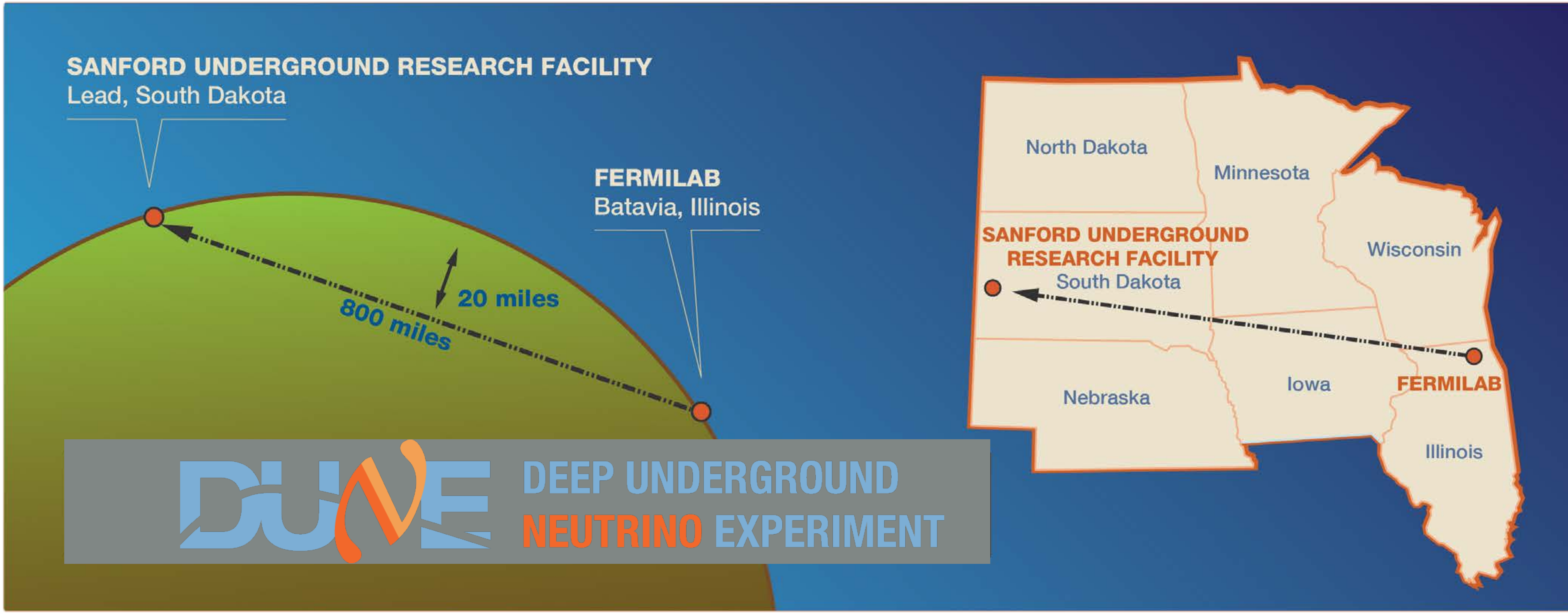
new particles, new interactions

Host a unique, world-class facility in the U.S. for:

- Long Baseline Neutrino Exp and Underground Search for Rare Phenomena
- Short-Baseline Neutrino Exp (see next talk by O. Palamara on SBN Program)

2

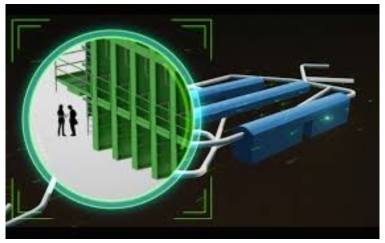
DUNE/LBNF: the Long Baseline Neutrino program



DUNE/LBNF: the Long Baseline Neutrino program

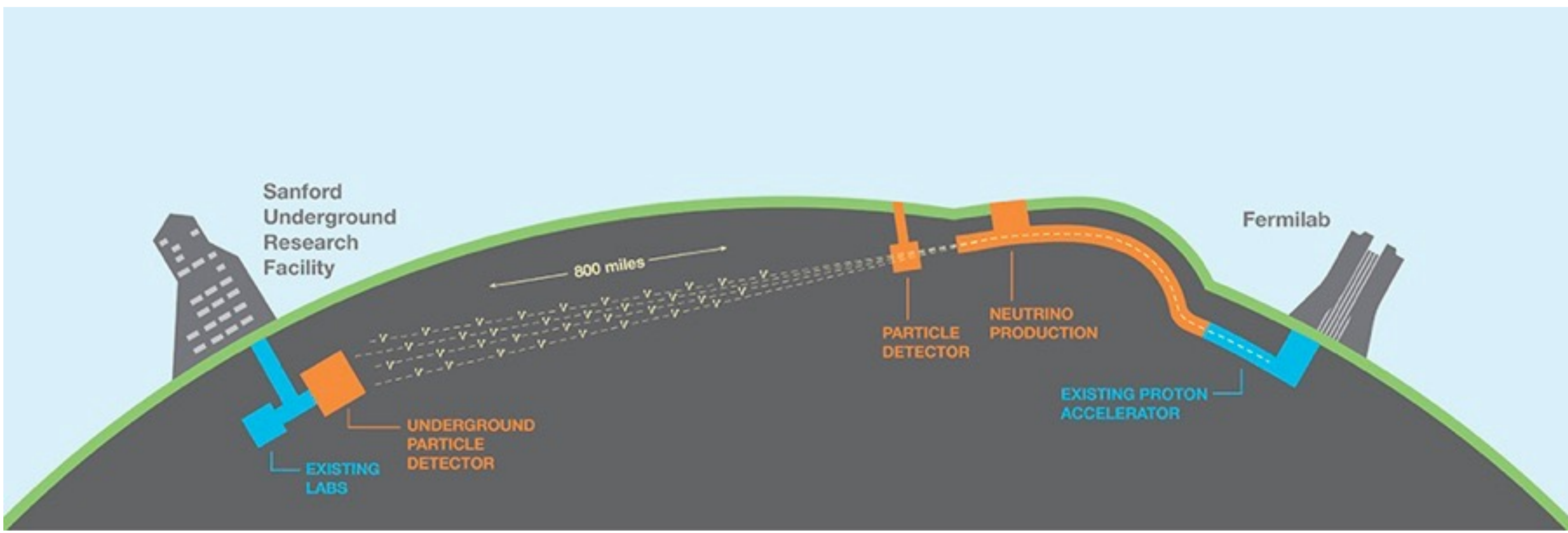
- **LBNF:** The Long-Baseline Neutrino Facility will build the infrastructure necessary to send a powerful beam of neutrinos 800 miles straight through the earth, and measure them deep underground at South Dakota's Sanford Underground Research Facility.
- LBNF supports **DUNE,** the Deep Underground Neutrino Experiment. The international DUNE scientific collaboration will construct and operate massive neutrino measurement apparatus at Fermilab and in South Dakota.
- The DUNE/LBNF project will be the first internationally conceived, constructed and operated mega-science project hosted by the Department of Energy in the United States.

LBNF will drive neutrino science forward the way CERN's Large Hadron Collider drove ATLAS/CMS Higgs discovery.

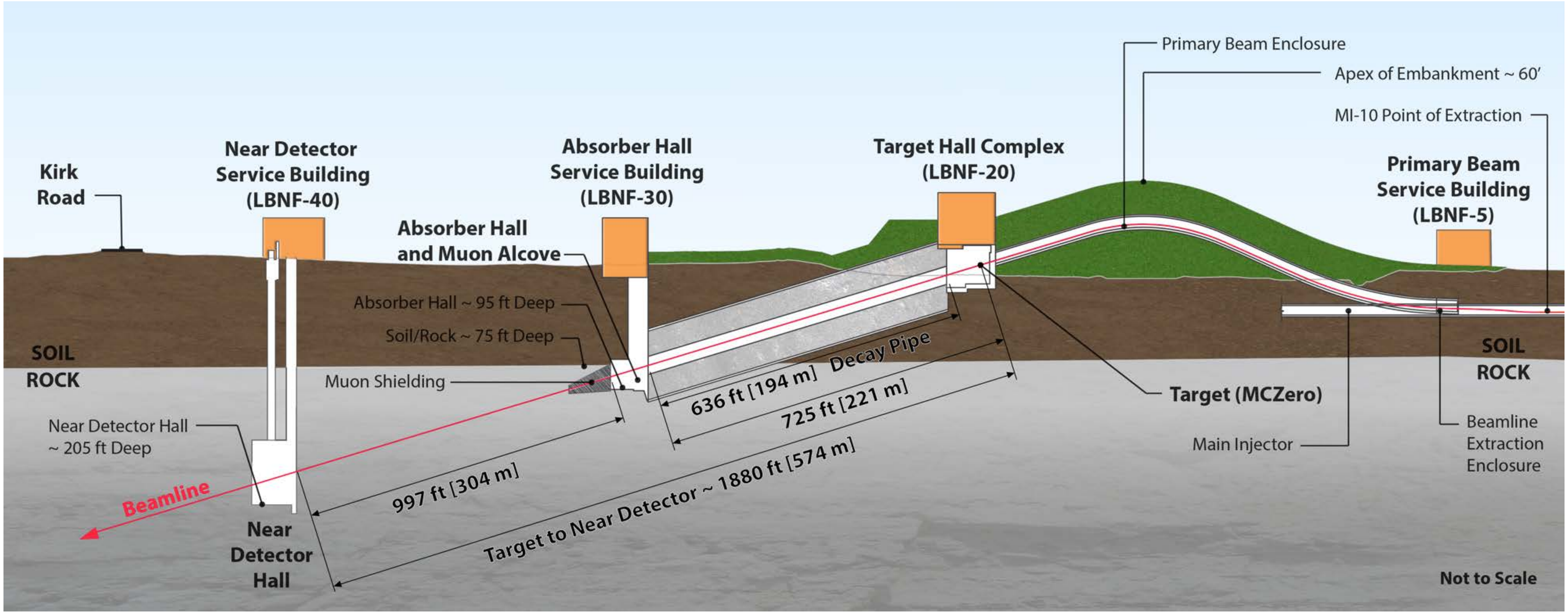


LBNF:
The Long-Baseline Neutrino Facility in Illinois and South Dakota

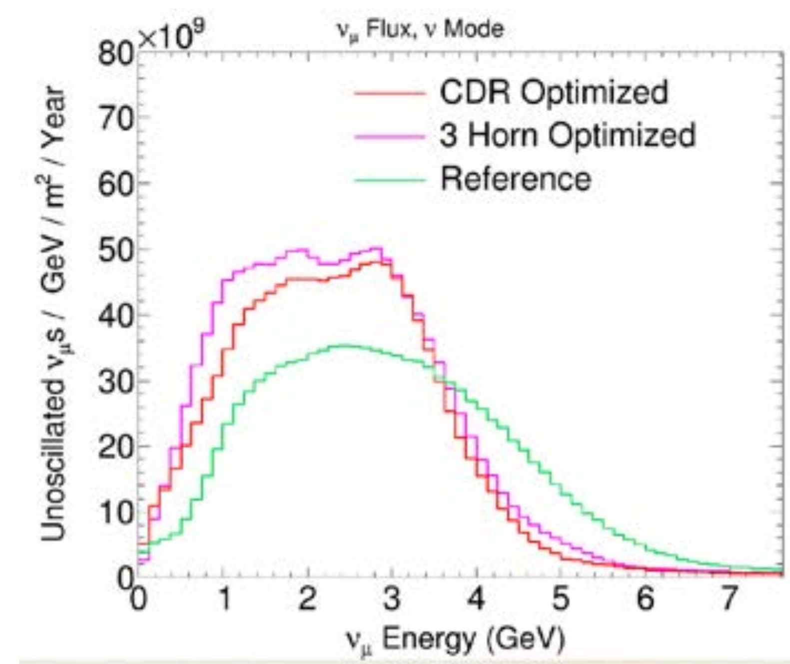
- Fermilab, host laboratory for DUNE/LBNF, will house the particle accelerators to create the neutrinos, and apparatus to measure them as they leave the site.
- The Sanford Underground Research Facility in Lead, SD will house the massive detectors one mile underground in the former Homestake gold mine to catch the neutrinos when arriving at the far site.

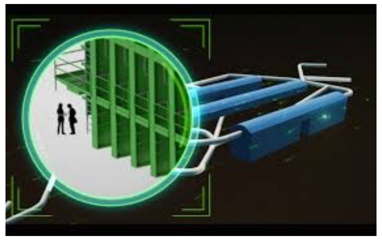


“Near Site” - LBNF at Fermilab, Batavia, IL

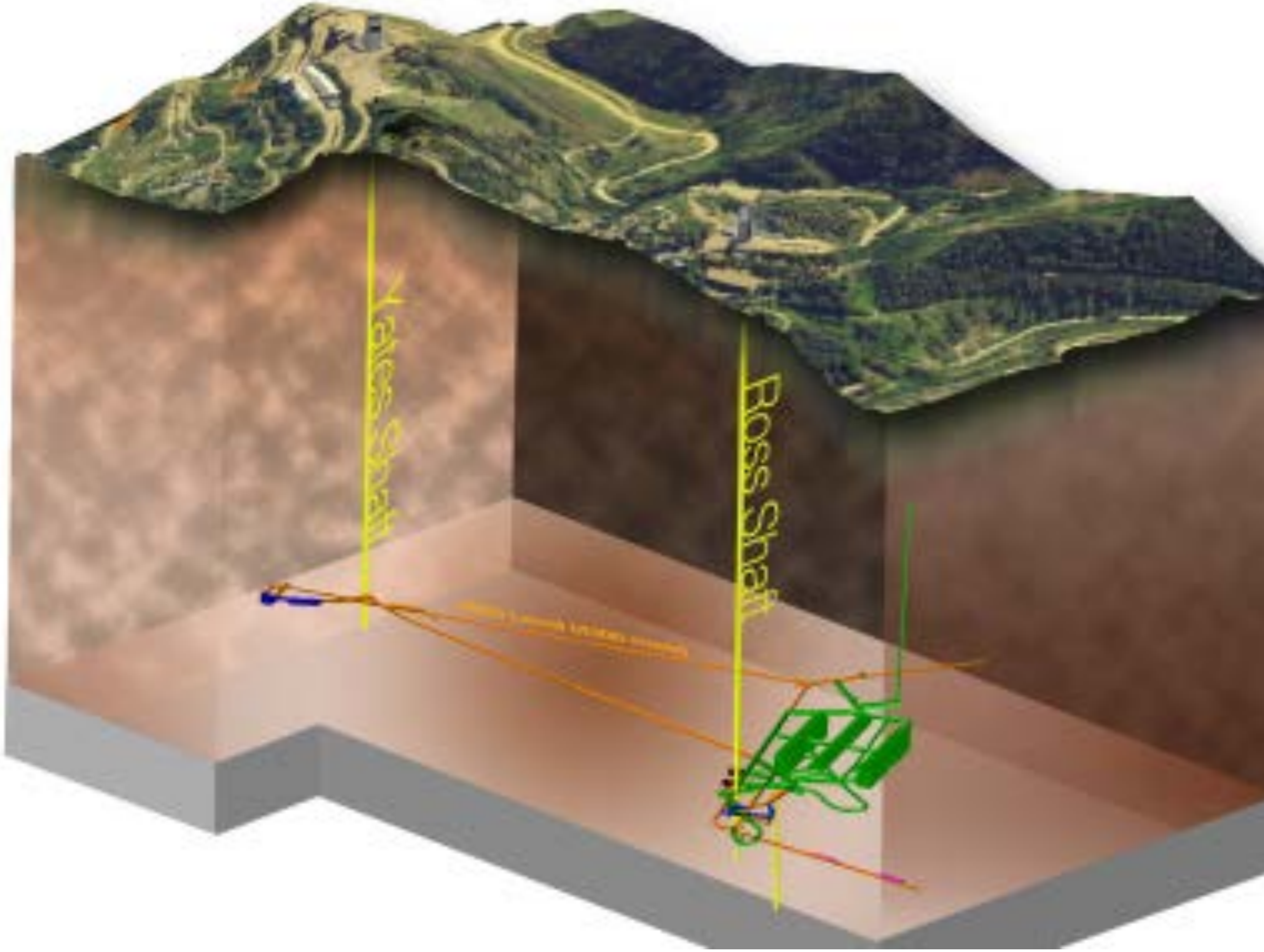


- Lab already home to world’s most powerful neutrino beams
- LBNF will use primary protons 60-120 GeV from Main Injector utilizing improvements from PIP-II with 1.2 MW beam power upgradable to 2.4 MW
- Beamline aimed at South Dakota planned for completion in 2025



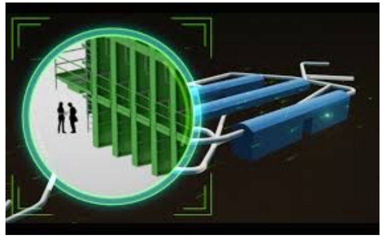


“Far Site” – LBNF at Sanford Lab, Lead, SD



- Major underground excavation removing ~800,000 tons of rock
- Two massive caverns at 4850L housing four membrane cryostats each 62m(L) x 14m(w) x 15m(h) and a central utility space
- 70,000 tons of cryogenic liquid argon to fill the cryostats
- “Ship in a bottle” detector construction 1 mile underground using existing, refurbished mine shaft

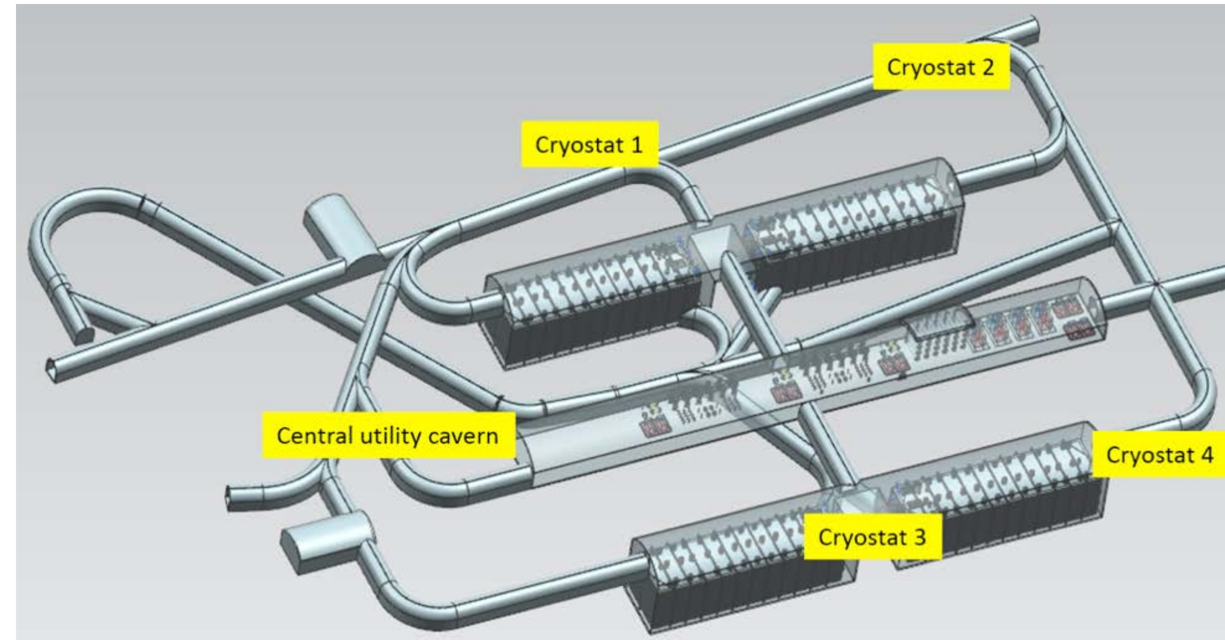
US President Budget includes budget for LBNF pre-excavation work in FY2017 (starts October 2016) - US Congress authorises start of construction



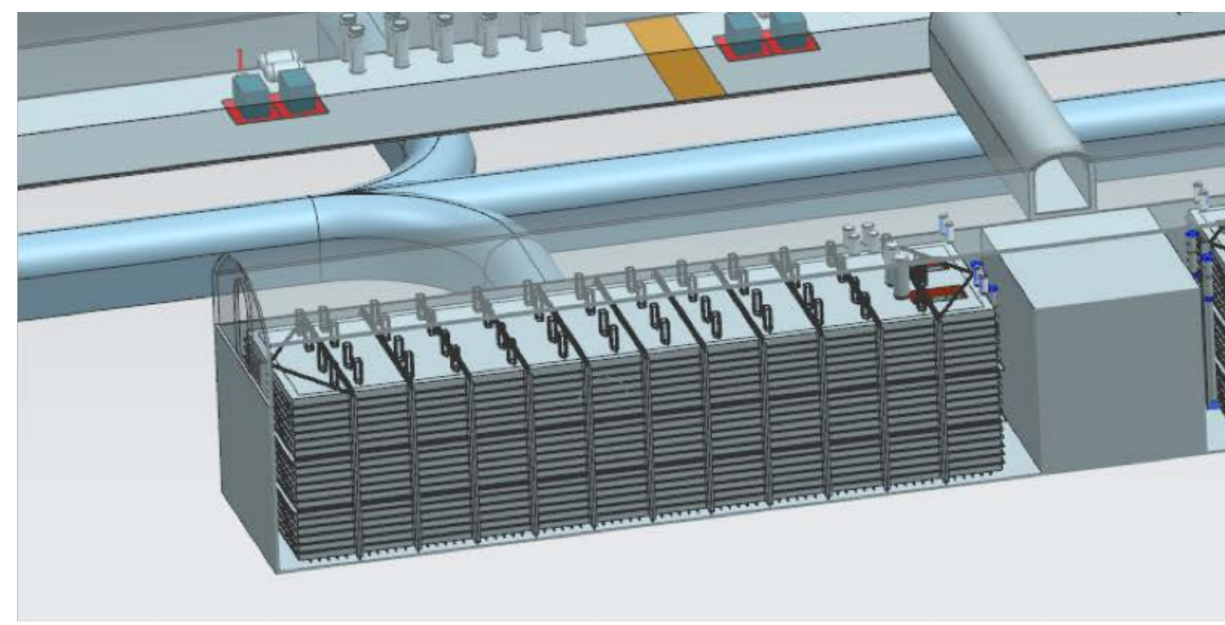
"Far Site" – LBNF/DUNE at Sanford Lab, Lead, SD

- **Conventional Facilities**:
  - Surface and shaft Infrastructure including utilities
  - Central utility cavern for conventional and cryogenic equipment
- **Cryogenic Systems**:
  - LN2 refrigeration system for cooling and re-condensing gaseous Argon
  - Systems for purification and recirculation of LAr
- **Cryostats**:
  - Four membrane cryostats supported by external steel frames

LBNF facilities will support the DUNE experiment



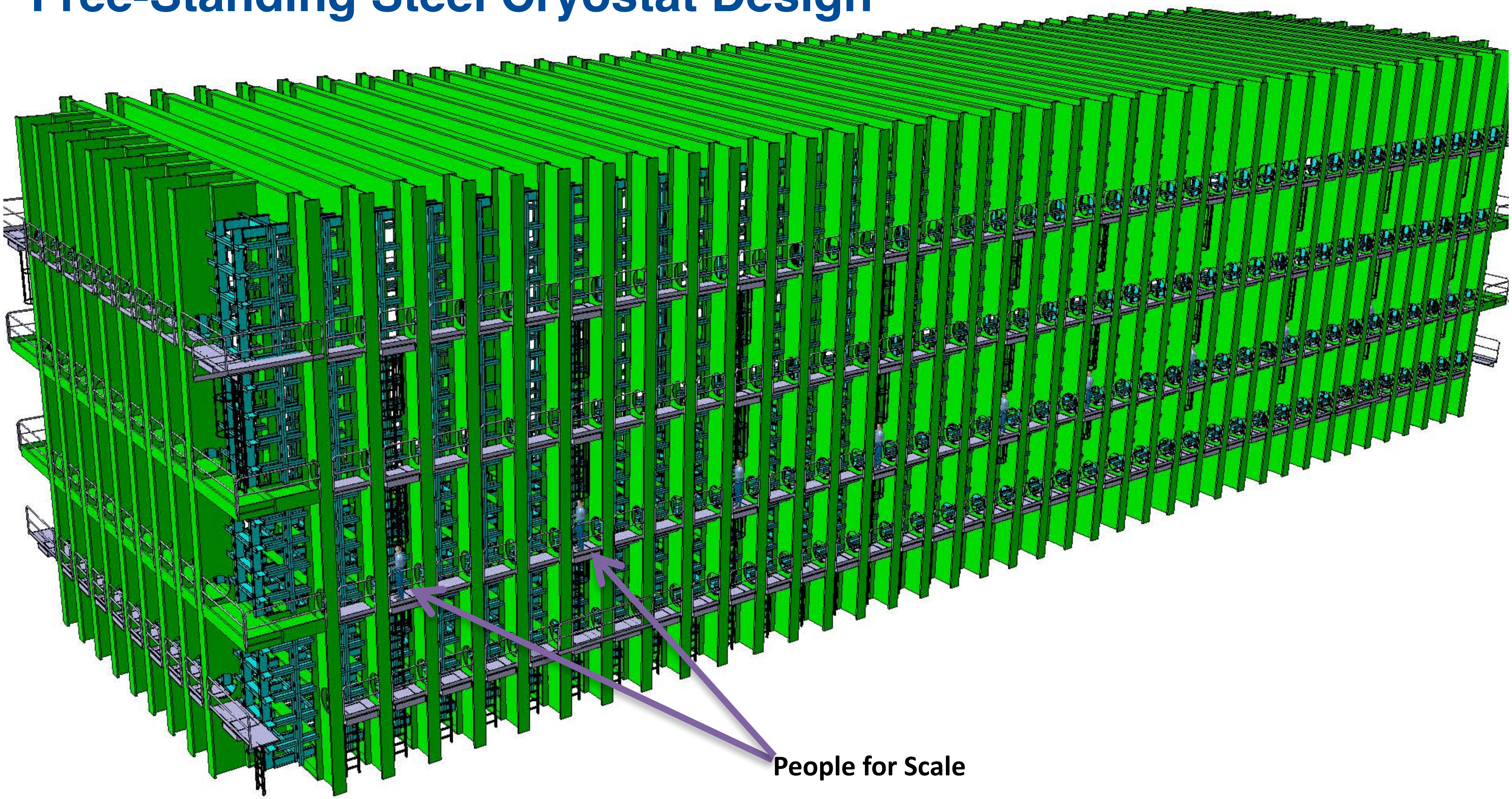
4850L cavern and drift layout



Single cryostat

- **DUNE LAr-TPC Detectors inside cryostats (4 x 10kt LAr active mass)**

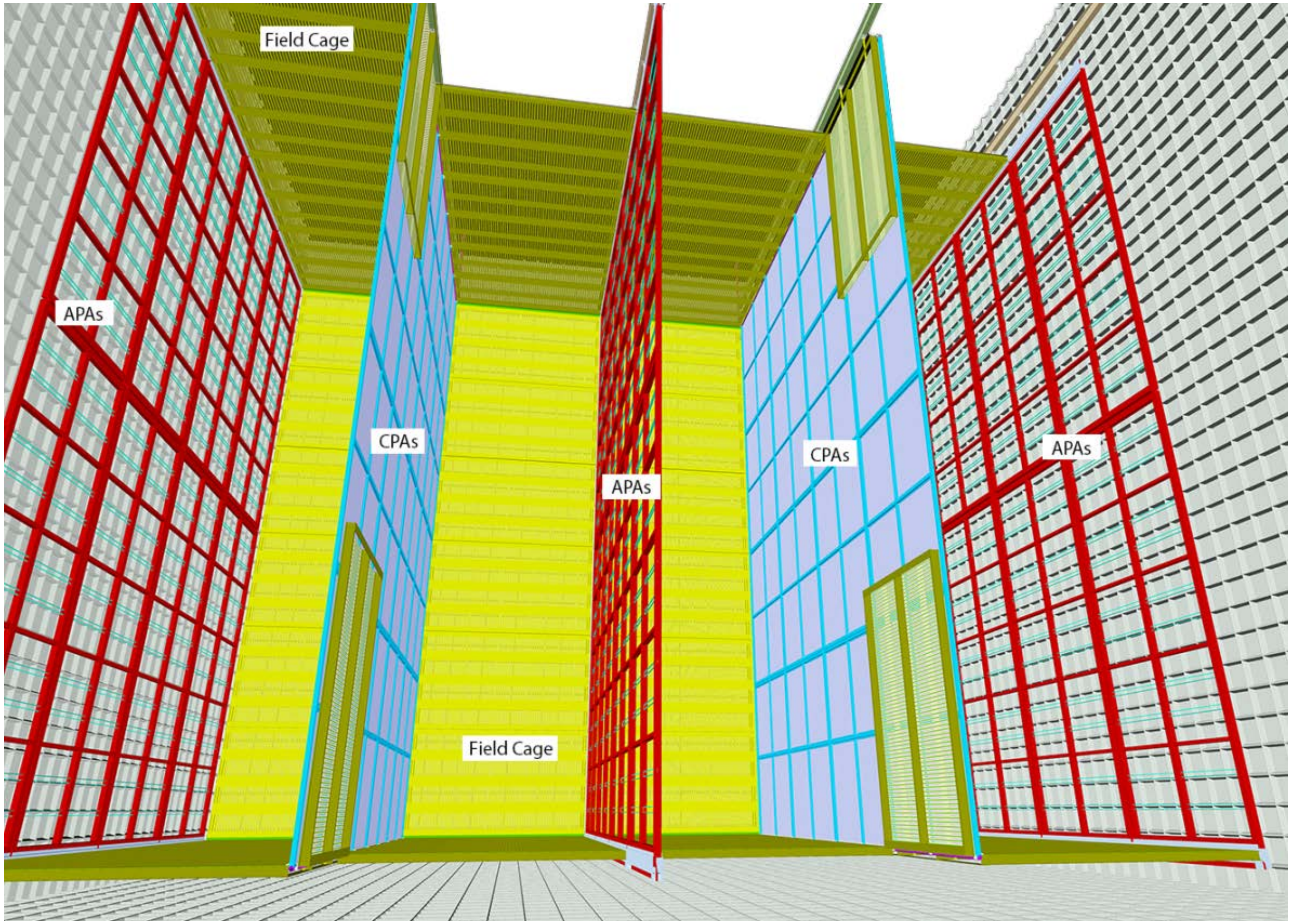
Free-Standing Steel Cryostat Design



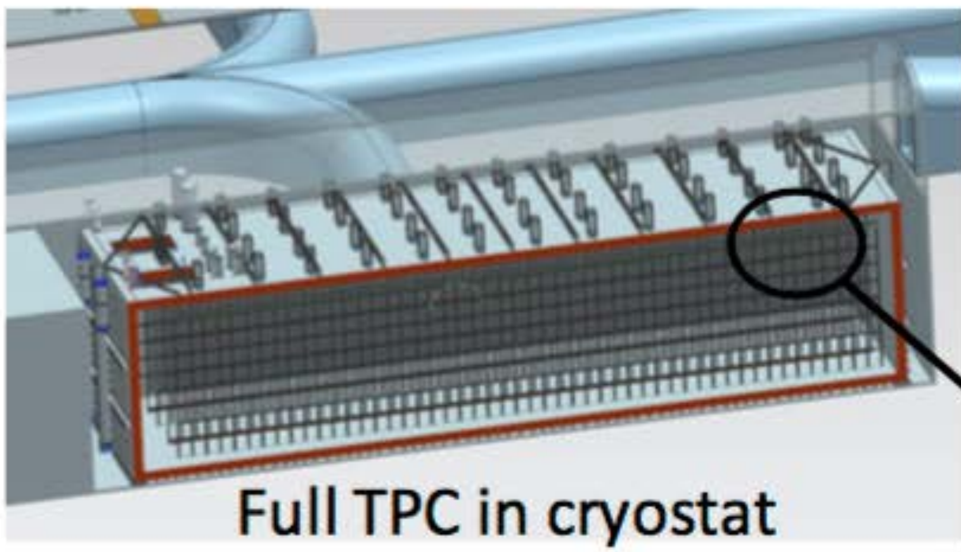
External (Internal) Dimensions
19.1m (15.1m) W x 18.0m (14.0m) H x 66.0m (62.0m) L

.. LArTPC inside cryostat

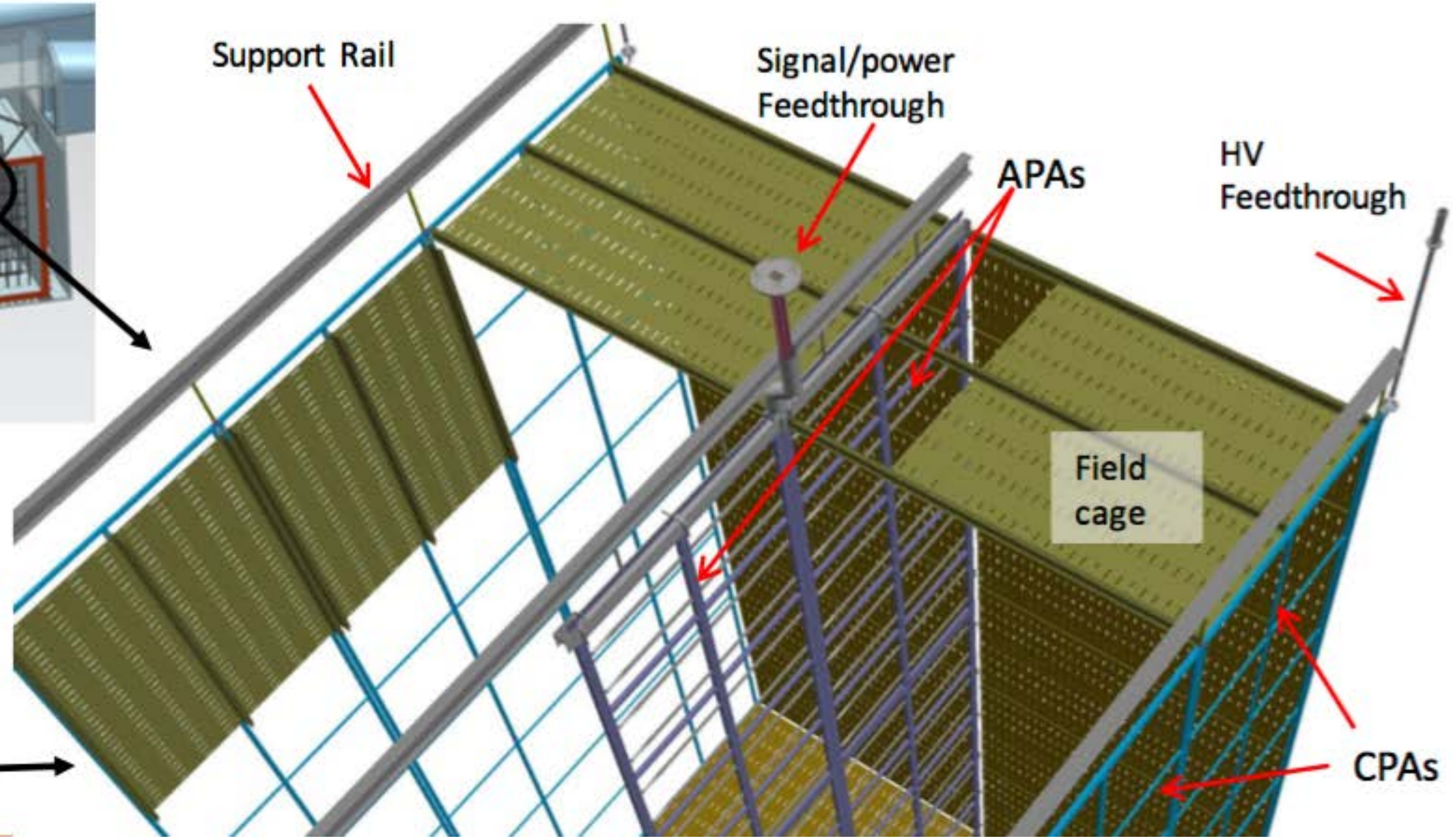
The TPC for a single 10kTon detector consists of three rows of anode planes, 2 high and 25 planes long (150 APAs total)



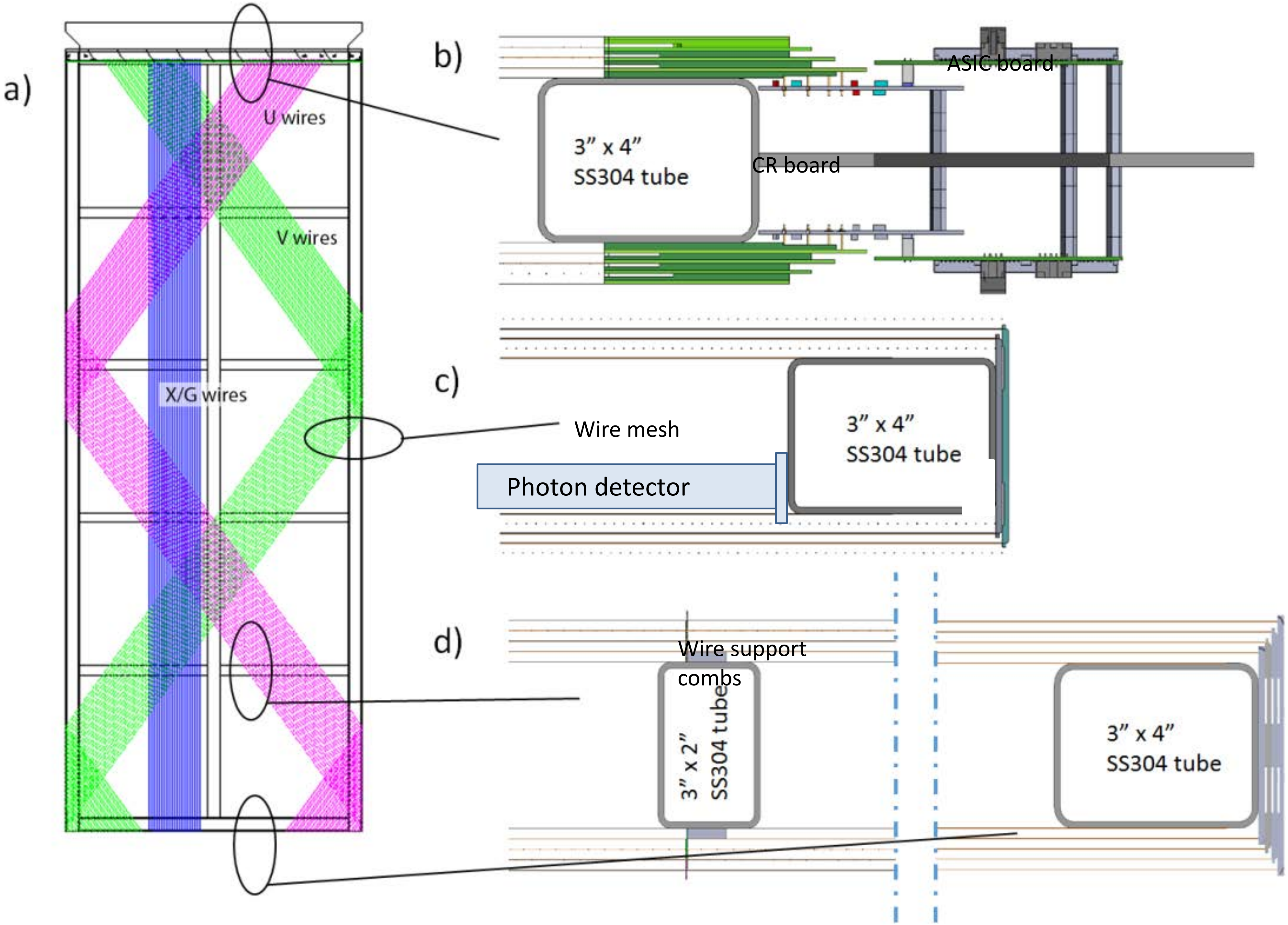
.. LArTPC inside cryostat



Components of TPC →



Anode Plane Assembly Configuration



APA dimensions:
2.3m x 6m active area, 12cm thick

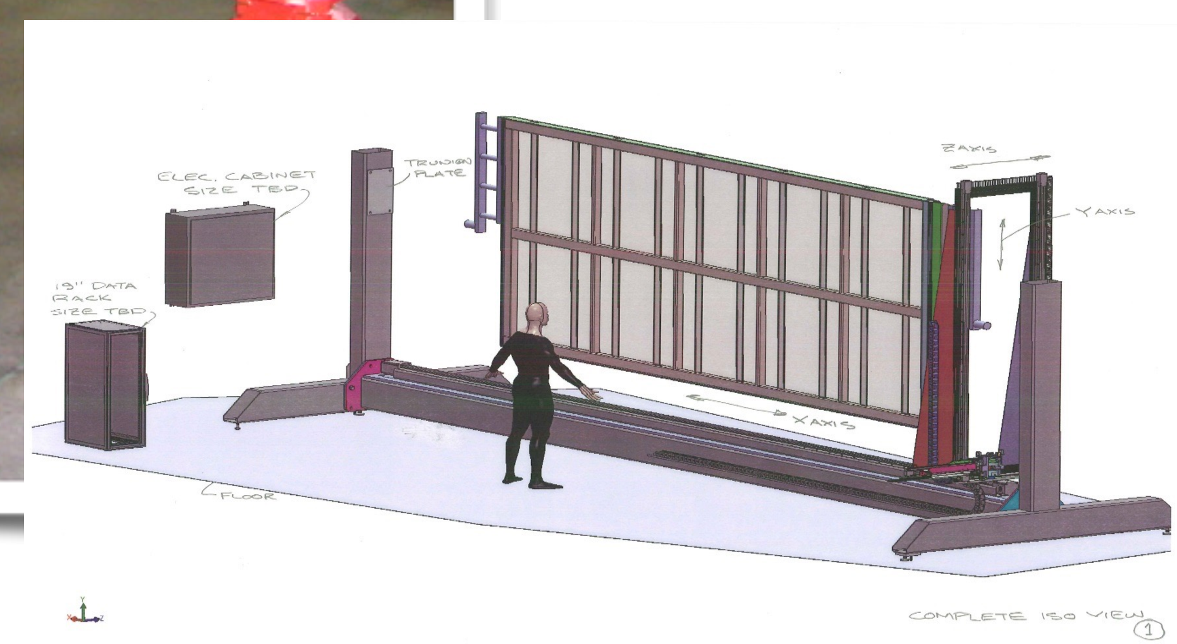
Induction wire angles: ±35.7° from vertical

Wire pitch :
X, G: 4.8mm
U, V: 4.7mm

2560 readout channels

An APA is sensitive to ionization from both sides. When placed on the outside row facing the cryostat, the grounded cryostat wall reverses the drift field, preventing electron collection from sources outside the TPC.

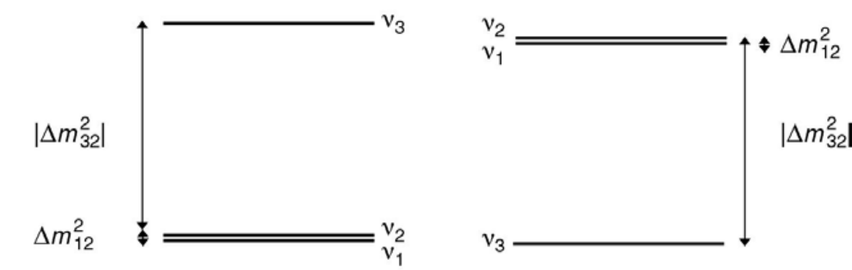
APA frame design prototype – 6 x 2.3m



Experiment: Primary Science Goals

Focus on fundamental open questions in particle physics and astro-particle physics:

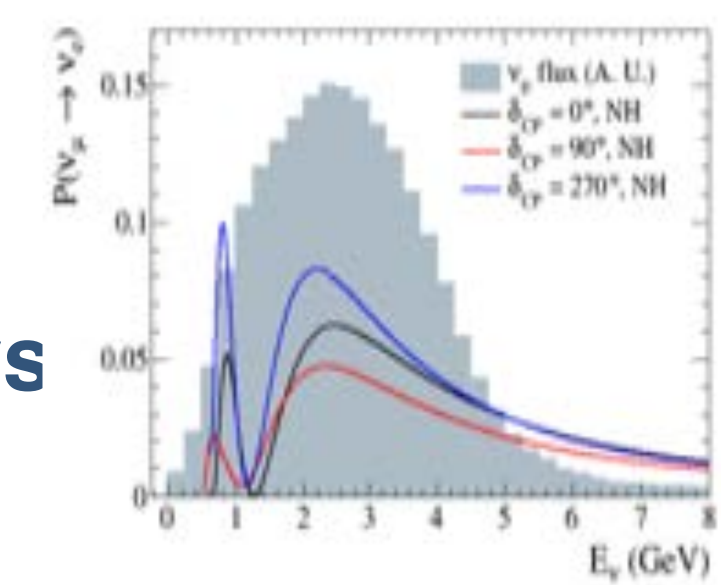
- **1) Neutrino Oscillation Physics**
  - **Discover CP Violation** in the leptonic sector
  - Determination of the Mass Hierarchy
  - Precision oscillation physics (θ_{23} octant, …)
  - Testing the 3-flavor paradigm (the Neutrino Standard Model)

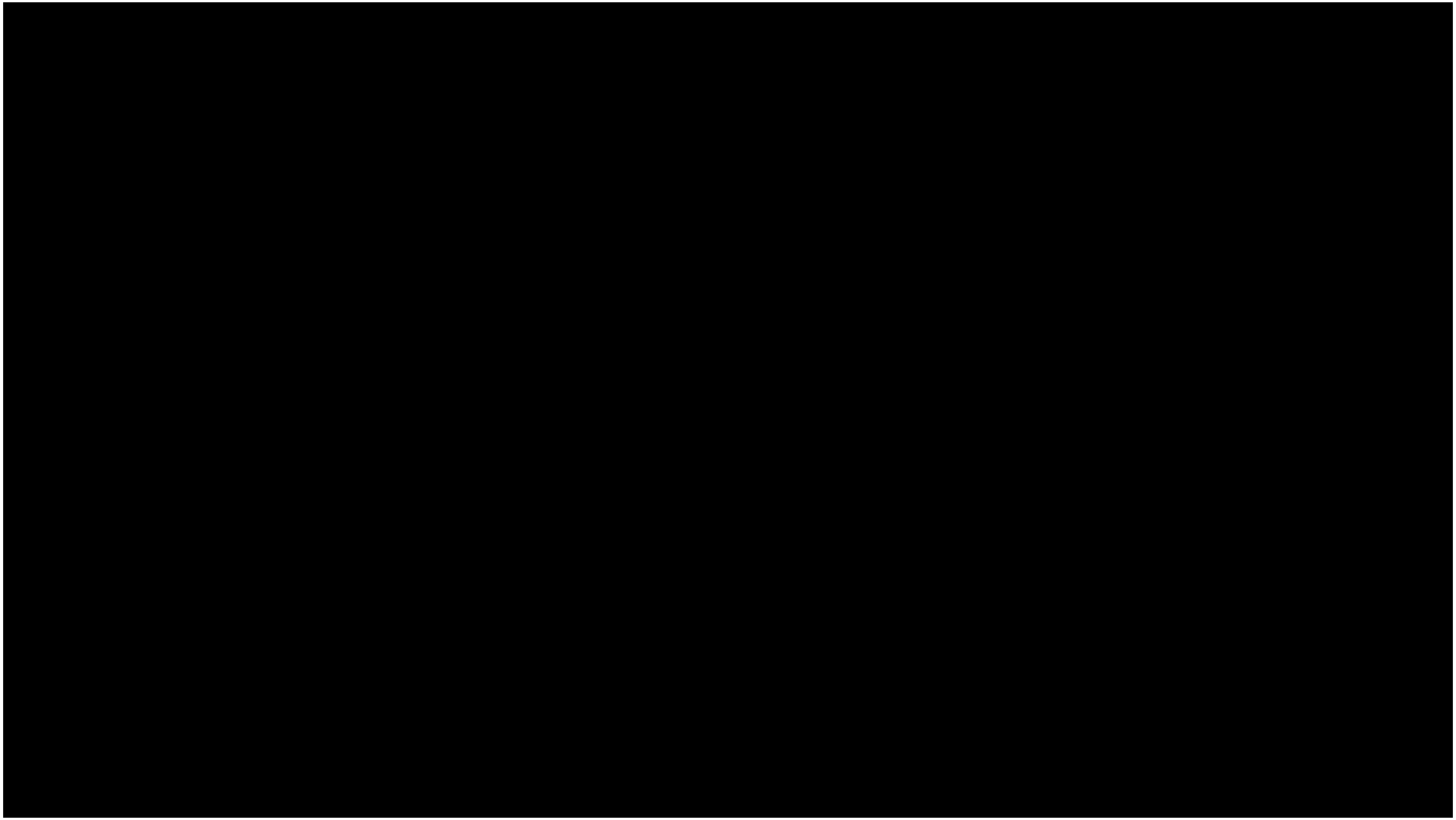


- **2) Nucleon Decay**
  - Targeting SUSY-favored modes, e.g.

$$p \rightarrow K^{+}\bar{\nu}$$

- **3) Supernova burst physics & astrophys**
  - Galactic core collapse supernova, sensitivity to ν_e



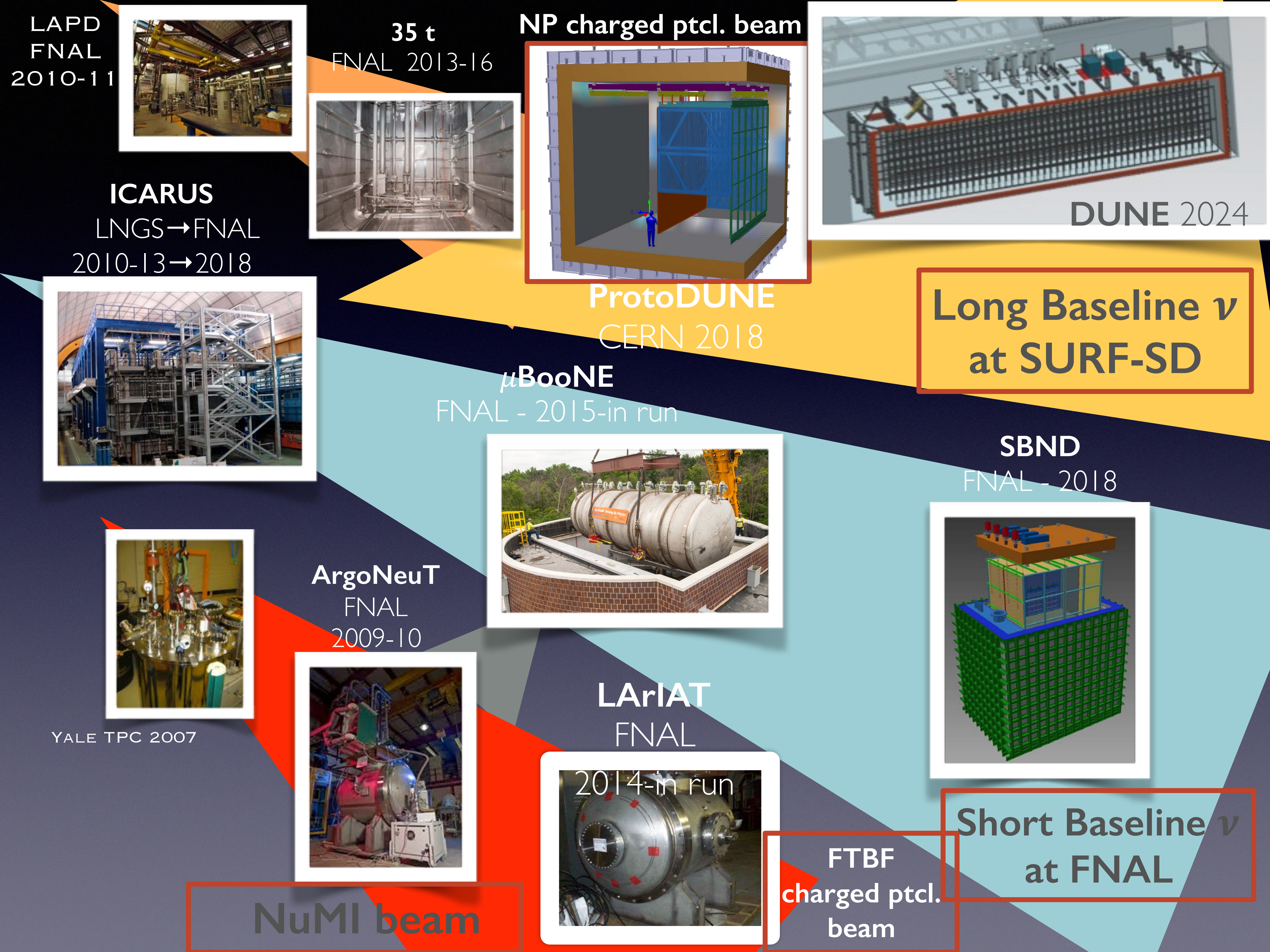


Collaboration

....the path to

DUNE

starting from ICARUS at GranSasso,
Fermilab SBN and CERN neutrino platform provide a strong LArTPC development and prototyping path toward DUNE



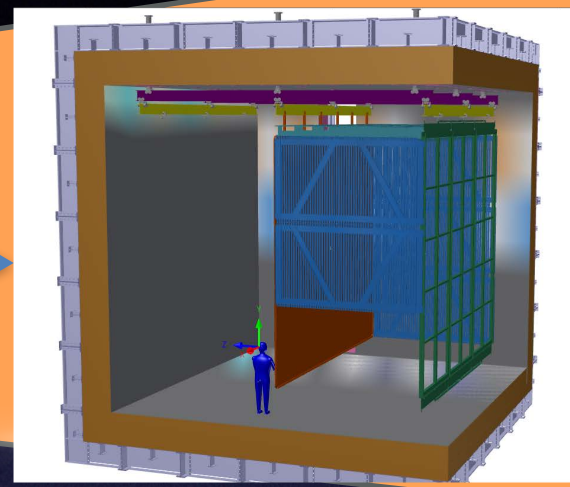
LAPD
FNAL
2010-11
35 t
FNAL 2013-16
NP charged ptcl. beam
DUNE 2024
ICARUS
LNGS→FNAL
2010-13→2018
ProtoDUNE
CERN 2018
Long Baseline ν
at SURF-SD
μBooNE
FNAL - 2015-in run
SBND
FNAL - 2018
ArgoNeuT
FNAL
2009-10
Yale TPC 2007
LArIAT
FNAL
2014-in run
Short Baseline ν
at FNAL
FTBF
charged ptcl.
beam
NuMI beam

Single-Phase

35-t prototype at FNAL

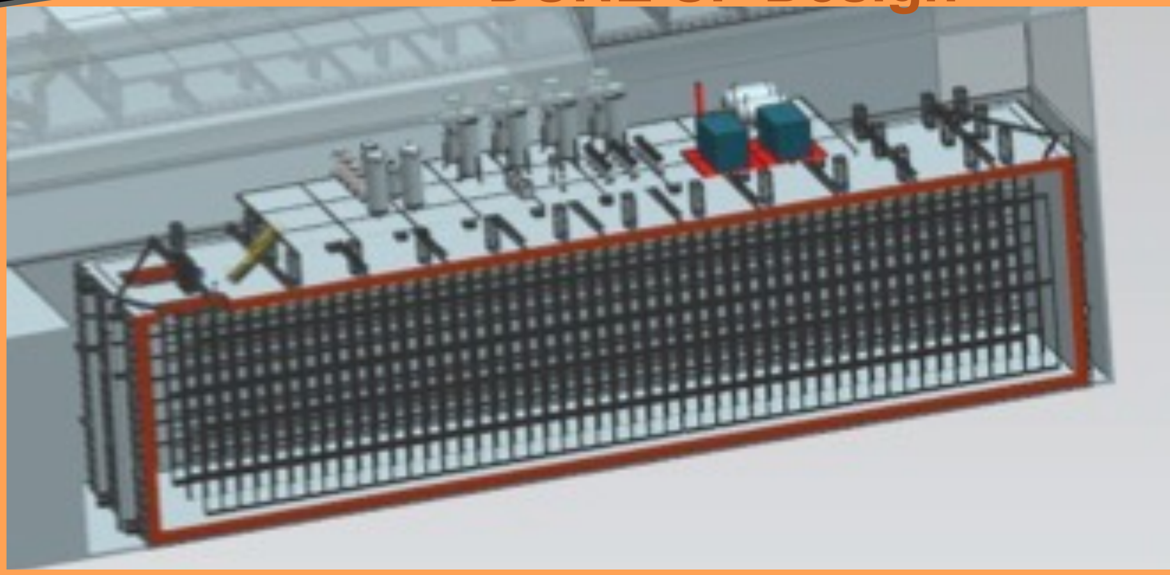
2015/16

ProtoDUNE-SP @ CERN



2018

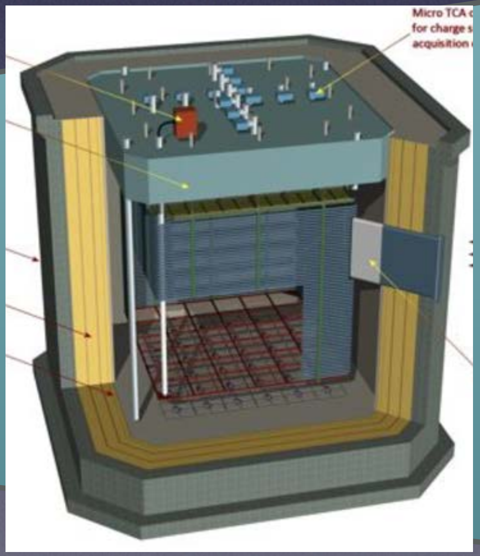
DUNE SP Design



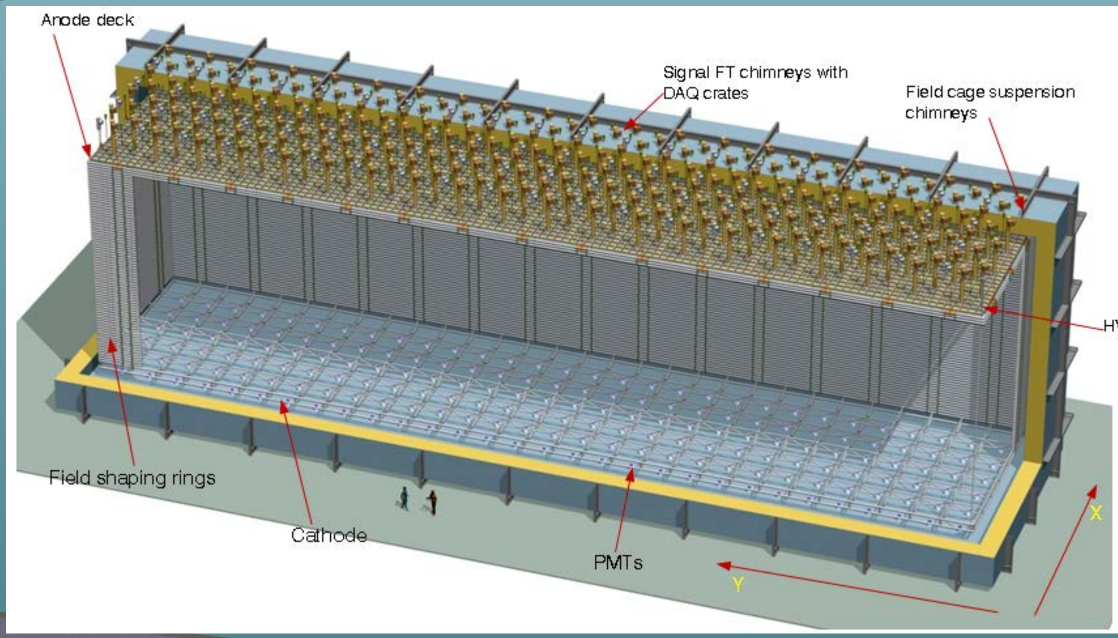
2016/17

WA105

2018

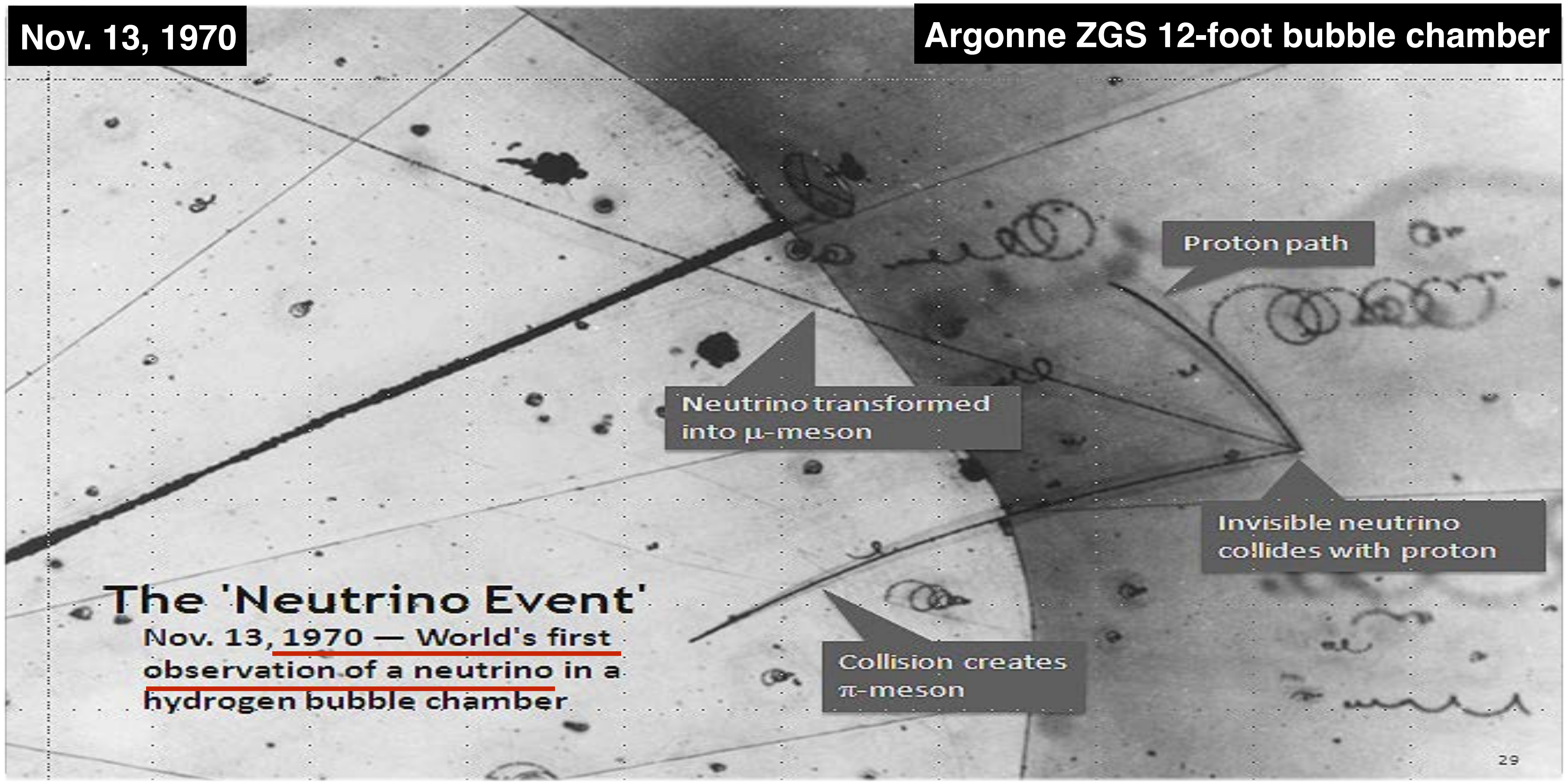


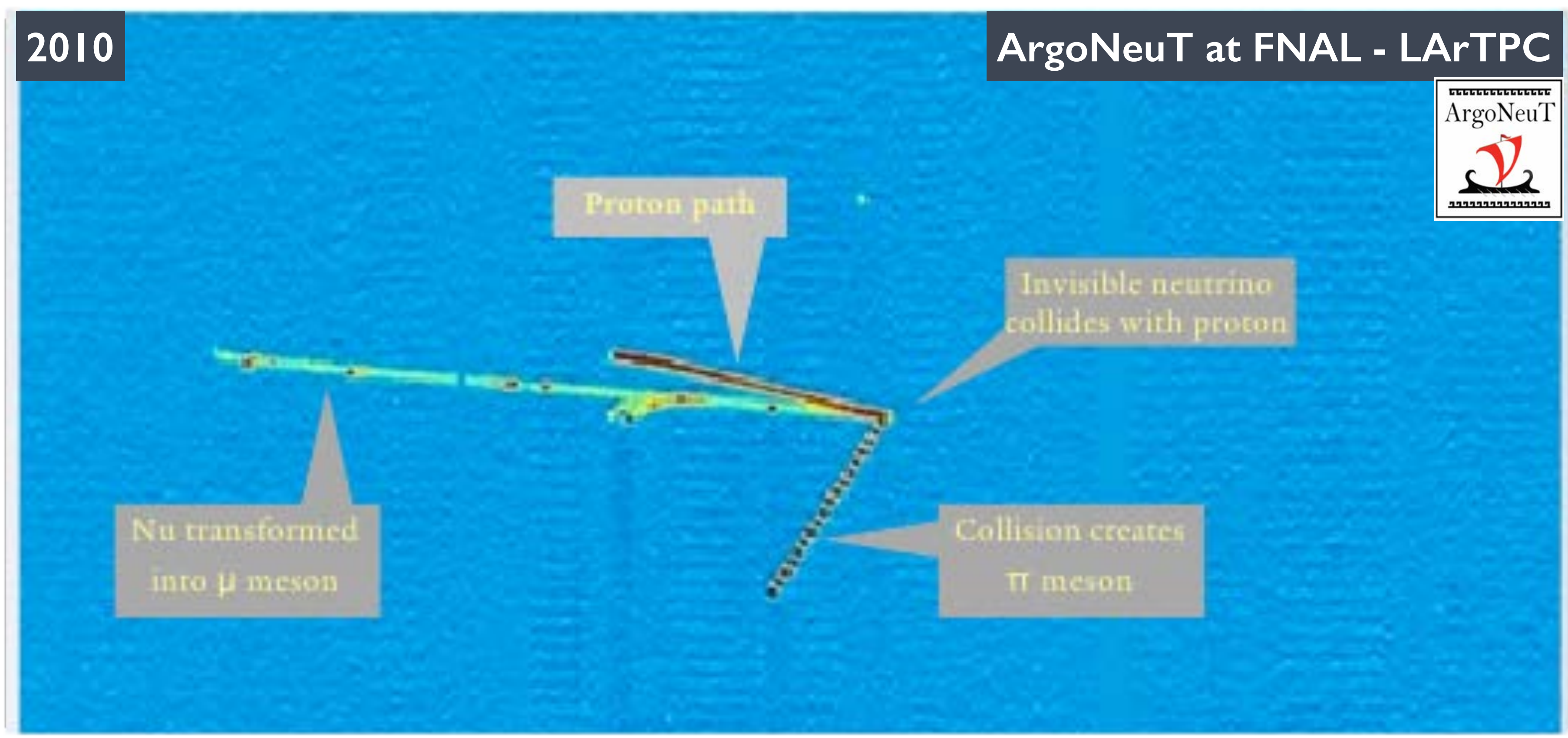
ProtoDUNE-DP @ CERN



DUNE DP Design

Dual-Phase





- *LArTPC* -
the Technology Choice for the SBN and LBN Program

Q: Why **Liquid Argon Time Projection Chamber**?

A: LAr TPC is a modern technology with Bubble chamber data quality:
Automated Imaging and Particle ID with added full calorimetry capability

"**Close** Enough to **Perfect**" for Neutrino Detection

Neutrino produce Charged Particles when interacting with target Ar nuclei inside the detector

LArTPC technology in a nutshell

Charged particles propagating through ionize/excite the medium (LAr), producing
- a trail of ionization electrons
- scintillation photons emitted isotropically along this trail

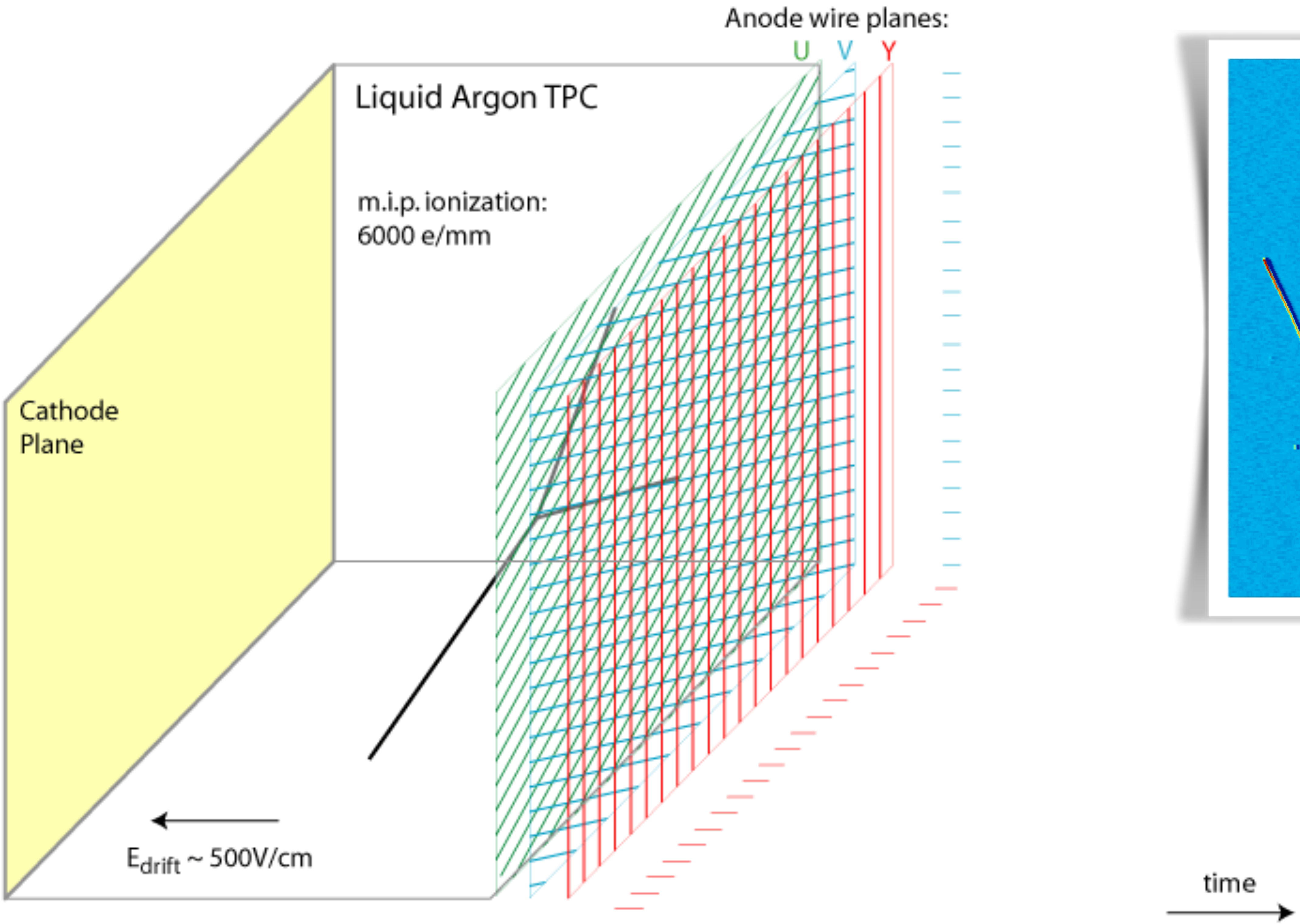
In LAr-Time Projection Chambers
- the trail of free ionization electrons drift towards the TPC readout wire-planes and produce digitized signals
- scintillation photons are wavelength-shifted and are detected by PMTs

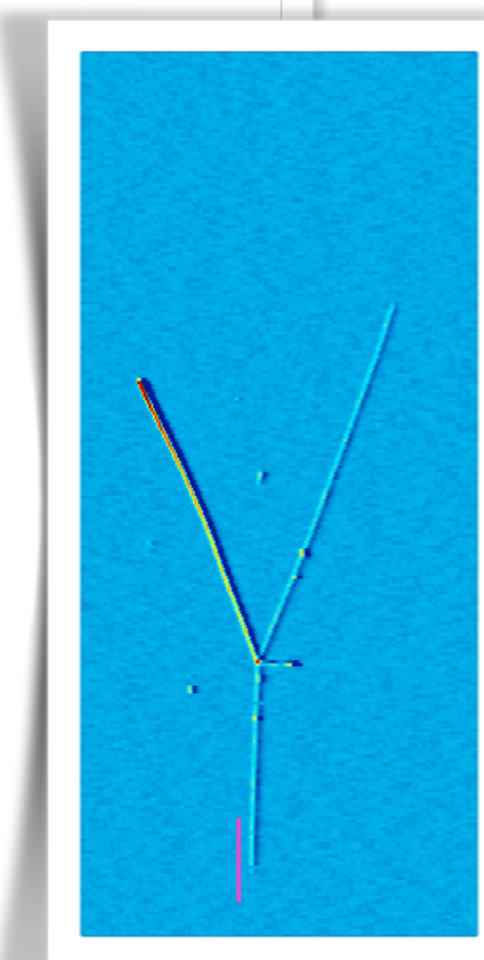
- Combining TPC signals ⇒ multiple 2D images of the **charged particles** tracks

(One coordinate is determined from measuring the drift time. Scintillation light gives the reference t_0 time)

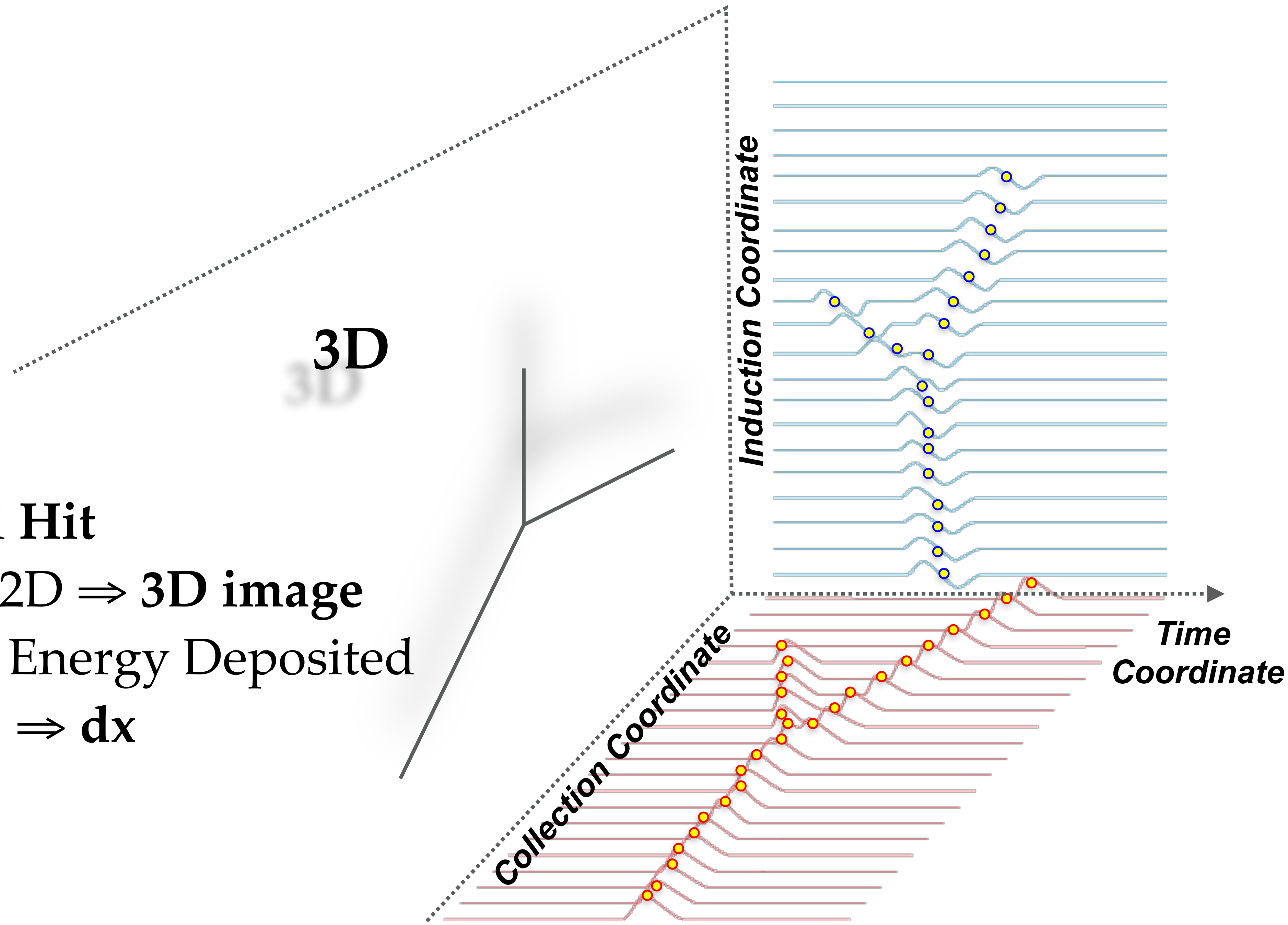
- Combining 2D images ⇒ full 3D reconstruction ⇒ **Direction**
- The total ionization charge (sum of TPC signals amplitude) is proportional to the deposited **Energy** (calorimetry). NB: also scintillation light is proportional to $\mathbf{E_{dep}}$
- Combining Energy & Direction ⇒ dE/dx along the track ⇒ **Particle Identification**

LArTPC at work: imaging and Energy



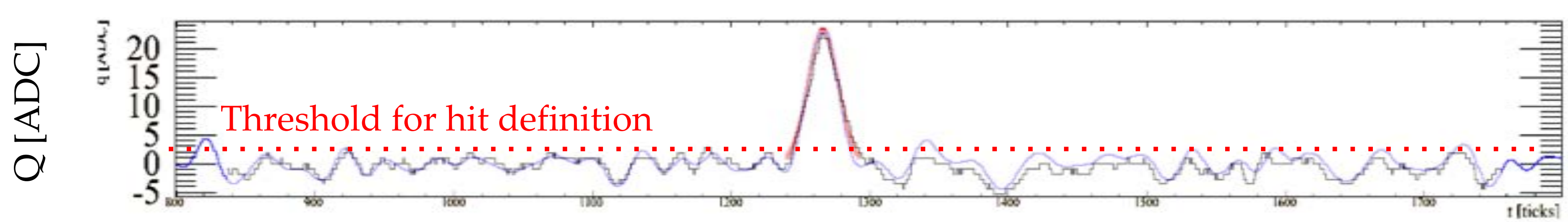


Tracking and calorimetry reconstruction



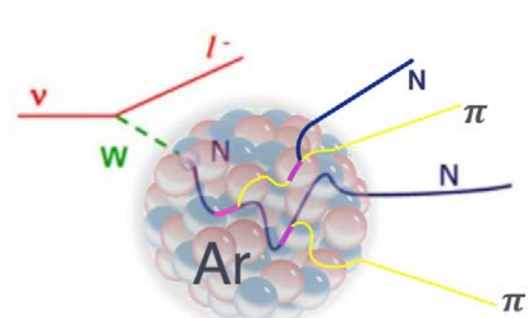
1. TPC wire Signal: find **Hit**
2. Hit coordinates ⇒ 2x2D ⇒ **3D image**
3. Hit Amplitude ⇒ **dE** Energy Deposited
4. Hit distance in space ⇒ **dx**
5. dE/dx ⇒ **Ptcl Id**

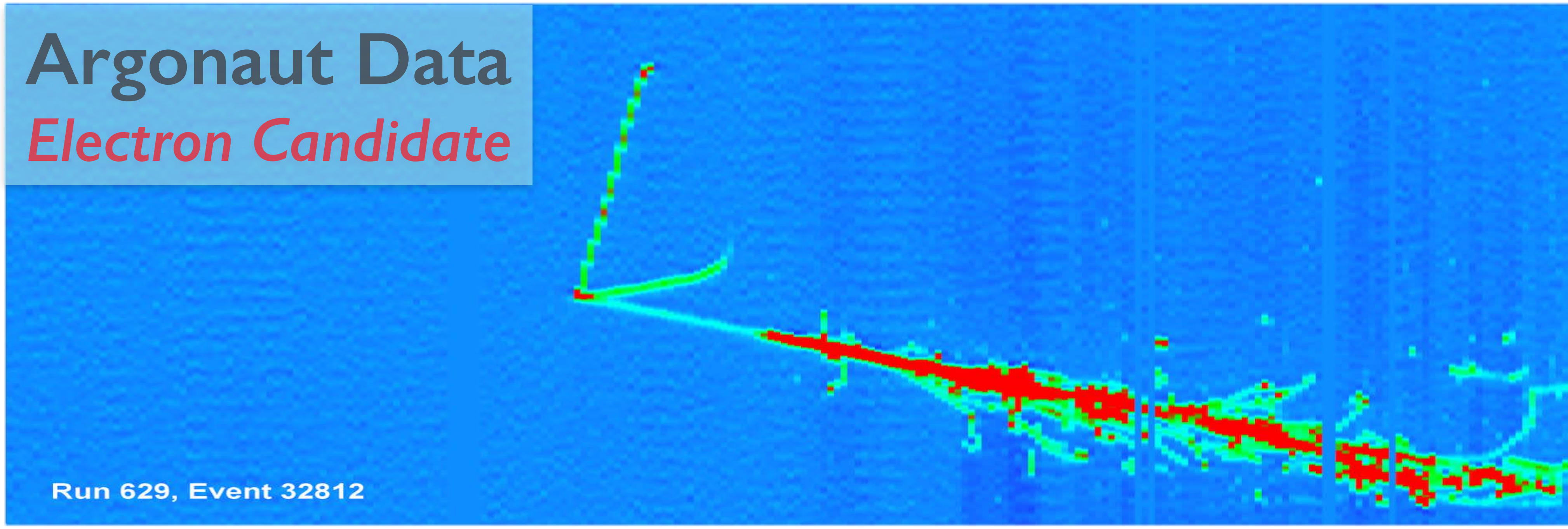
(real) TPC wire Signal

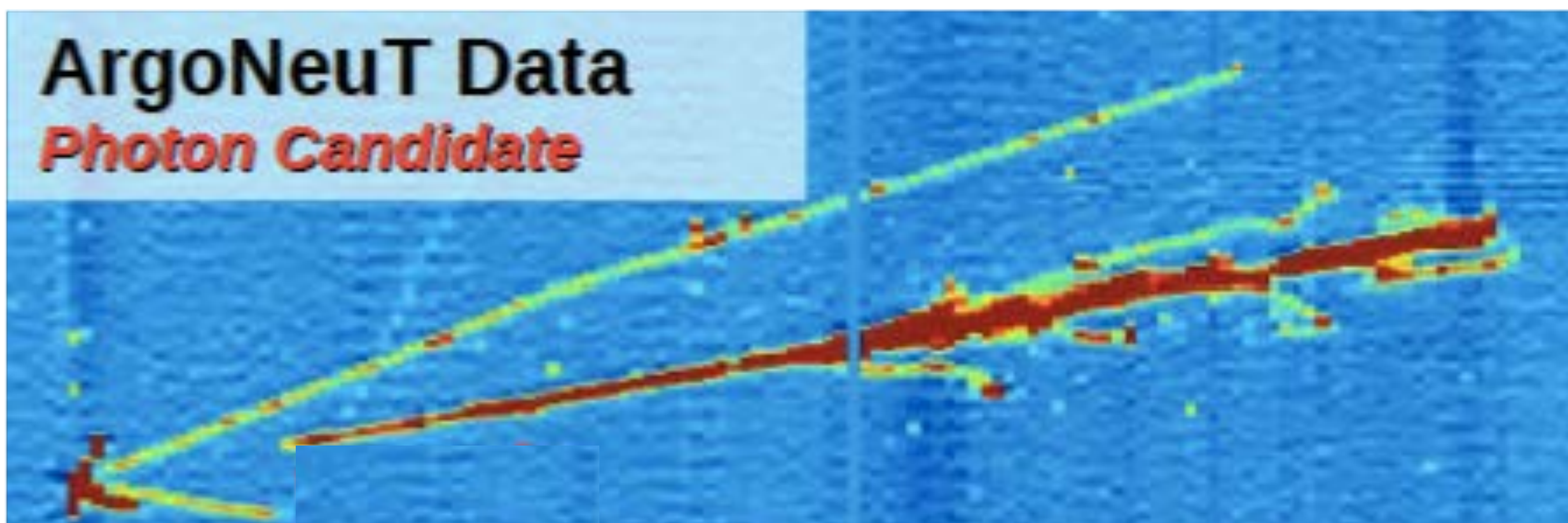


ν_e appearance and background rejection
electron / γ ($\Leftarrow \pi^0$) discrimination possible

ArgoNeuT
FNAL
2009-10

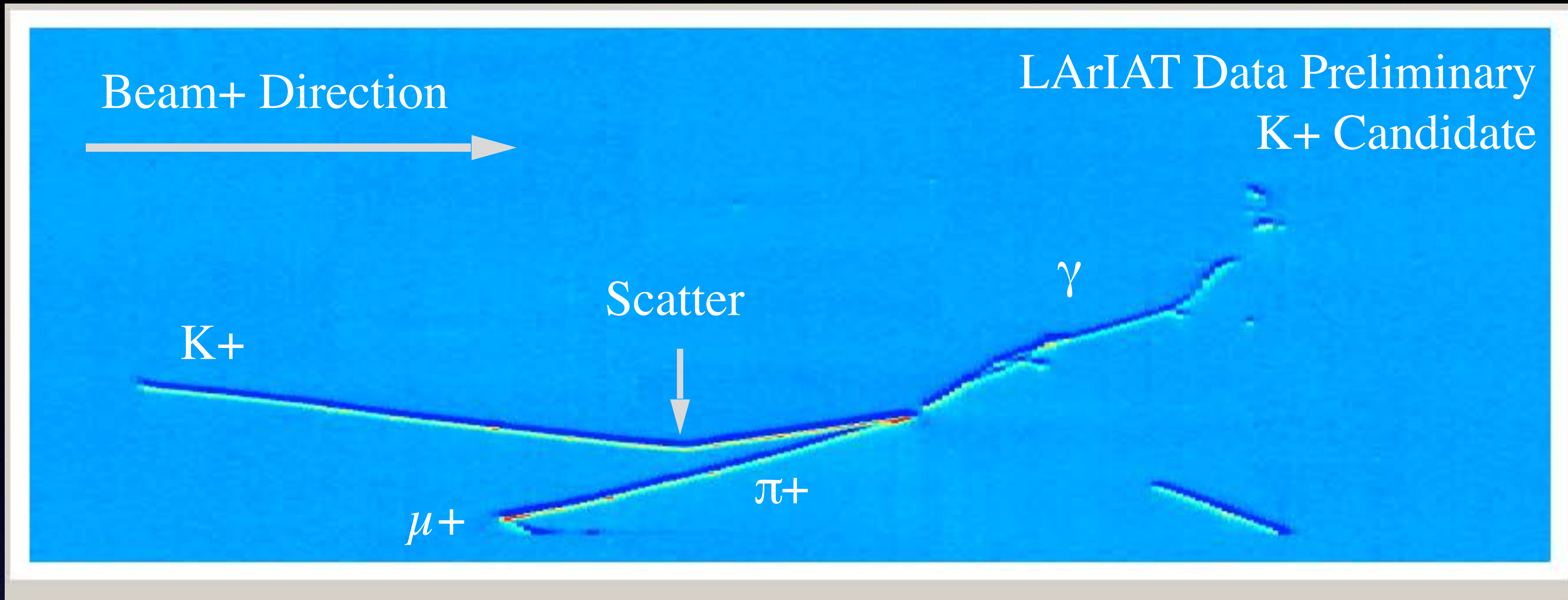


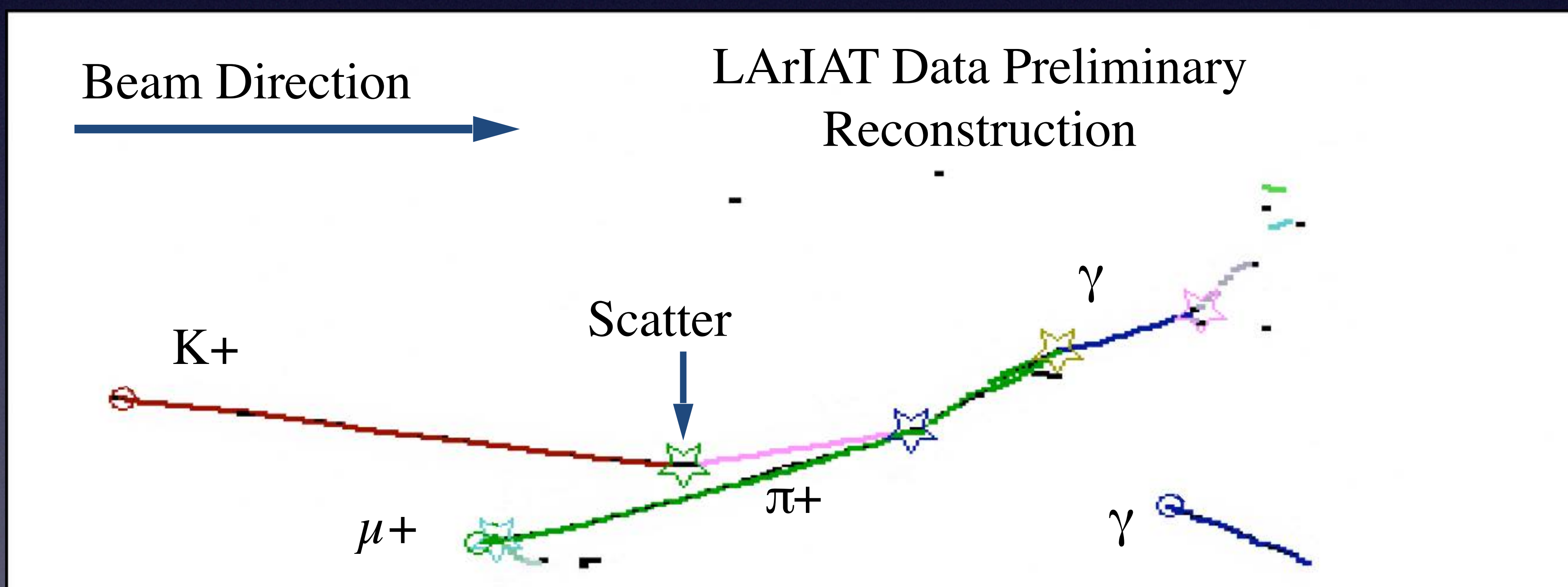




Kaon Identification

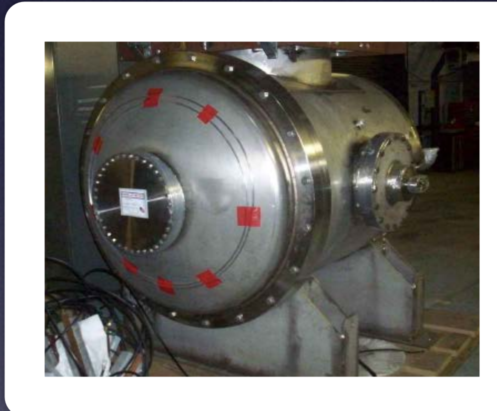
LArIAT





FNAL

2014-in run



LArIAT Data K+ candidate.
K+ enters TPC, undergoes a hadronic scatter, and then decays into π+ and π^0.
The π+ then decays into μ+ and ν_μ while the π^0 decays into 2γ,
one of which leaves the TPC before beginning to shower.

DUNE Far Detector Challenges

Perhaps the largest challenge is the scale

- Cryostat for 10-kt fiducial: 15.1 (W) x 14.0 (H) x 62 (L) m^3
- A big step up from ICARUS & MicroBooNE

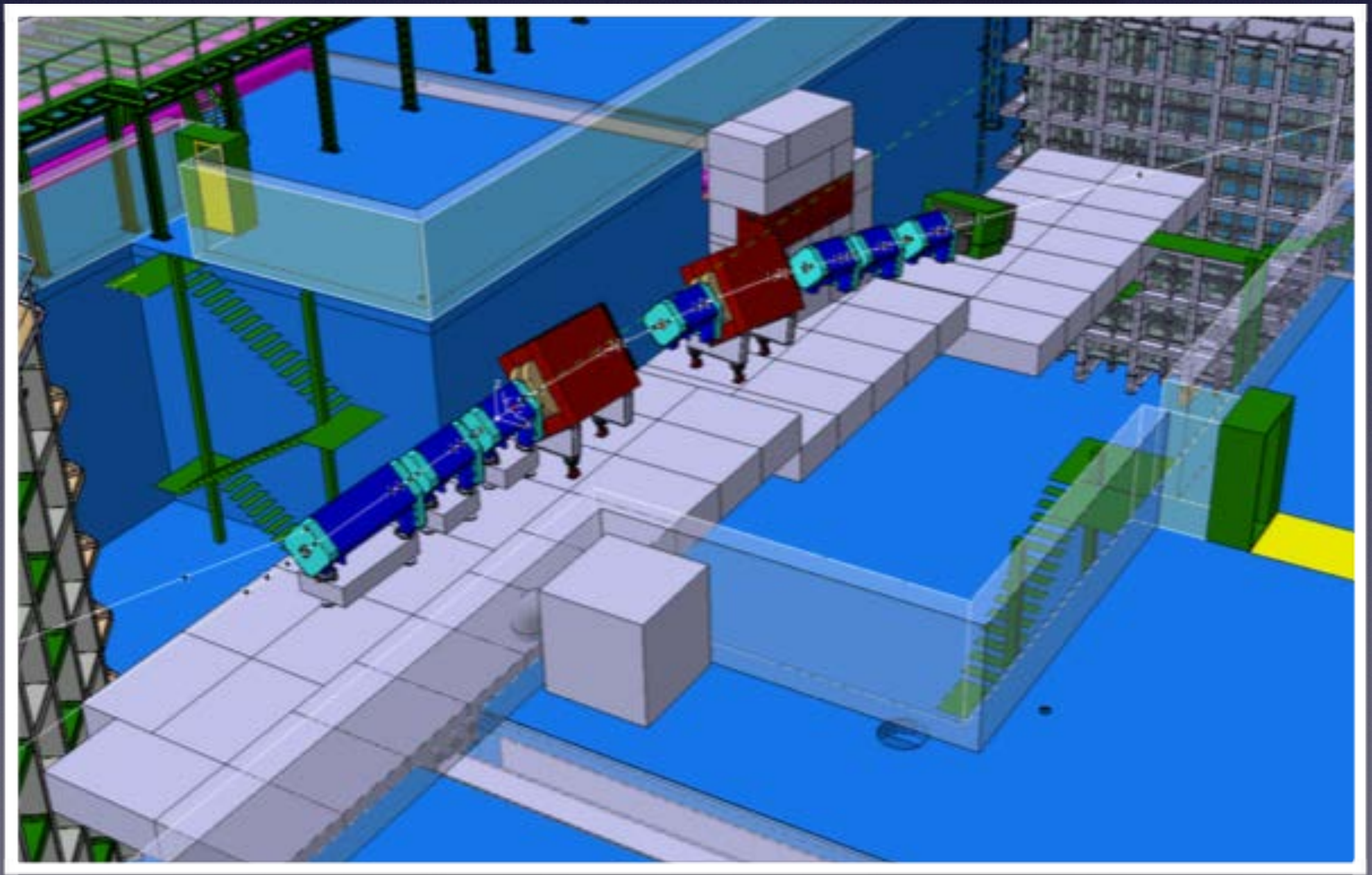
Technical challenges

- Mechanical engineering
- Light readout (Photon Detection System)
- Cold electronics
- …

Solutions exist

- But large-scale prototyping is essential
- + open to new ideas/approaches:
  - staged approach to the FD leaves open this opportunity
- For now, the priority is the large-scale prototypes

ProtoDUNE at CERN



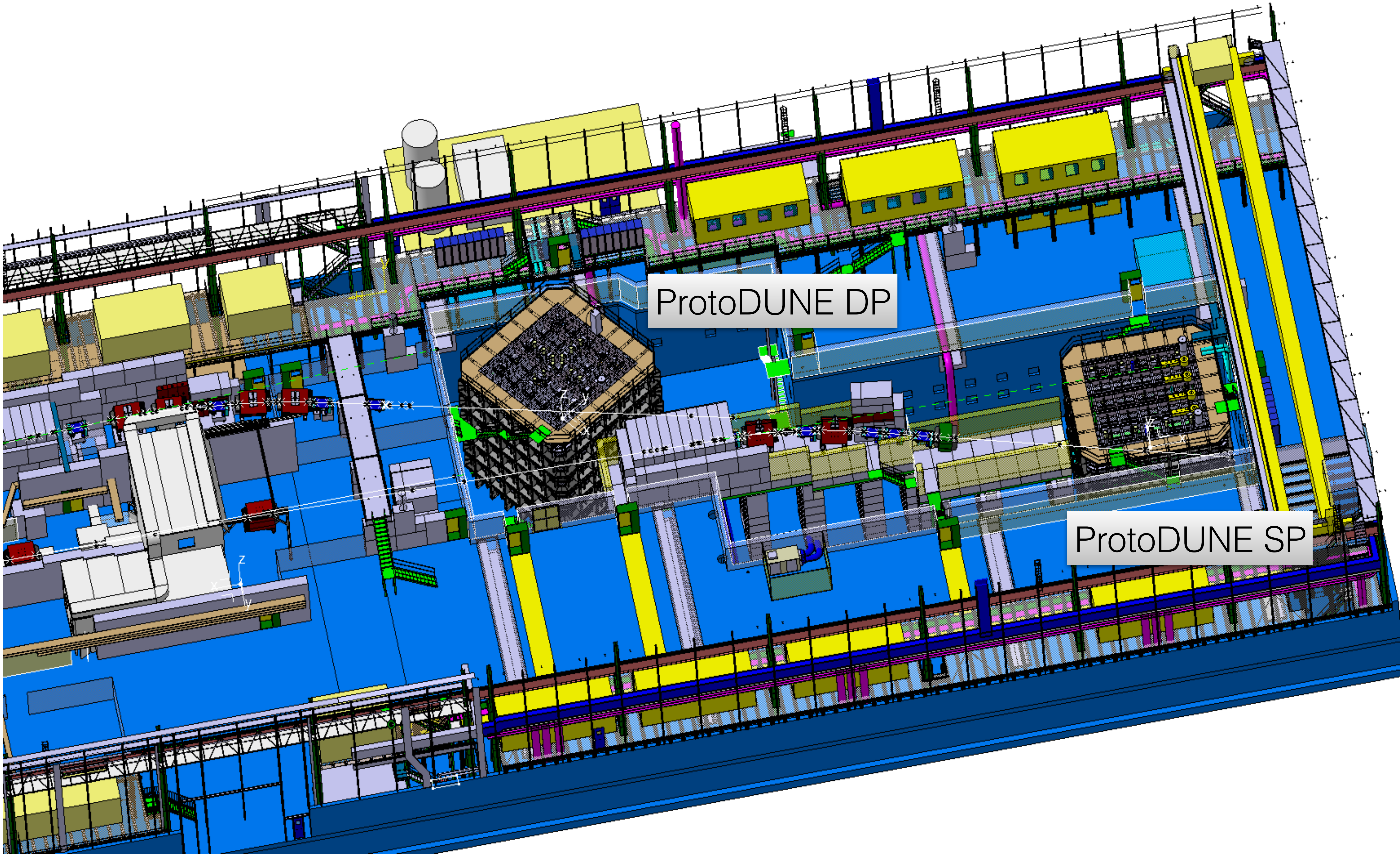
ProtoDUNE within DUNE

ProtoDUNE is a central part of the DUNE strategy for construction of the Far Detector

- *Production*: stress testing of the production and quality assurance processes of the detector components will mitigate the associated risks for the far detector.
- *Installation*: test of the interfaces between the different elements and will mitigate the associated risks for the far detector.
- *Operation* (cosmic-ray data): provide validation of the design and performance.
- *Test beam* (data analysis): essential detector and physics calibration benchmarks.

Prototyping, Risk Mitigation & Essential Calibration Data

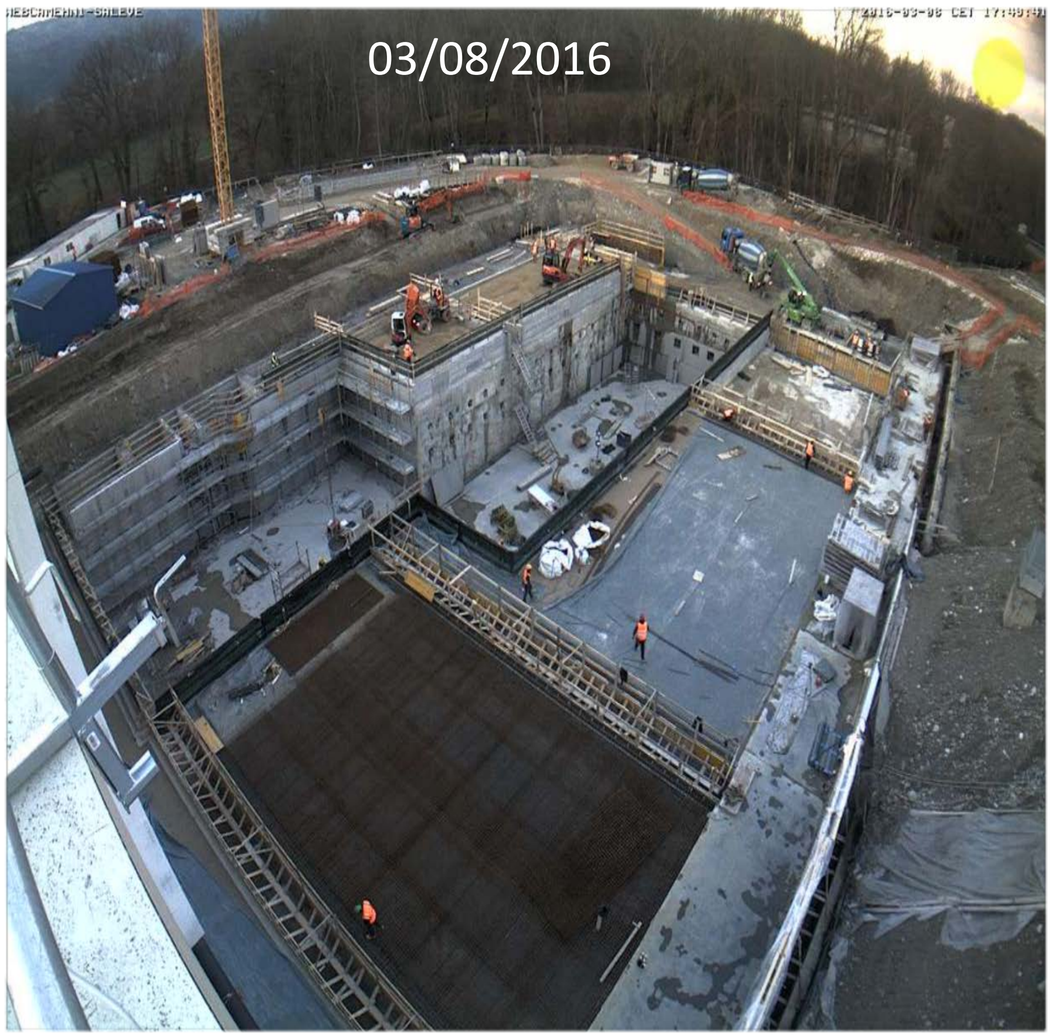
Large prototype(s) for LBNF/DUNE at the new CERN Neutrino Platform

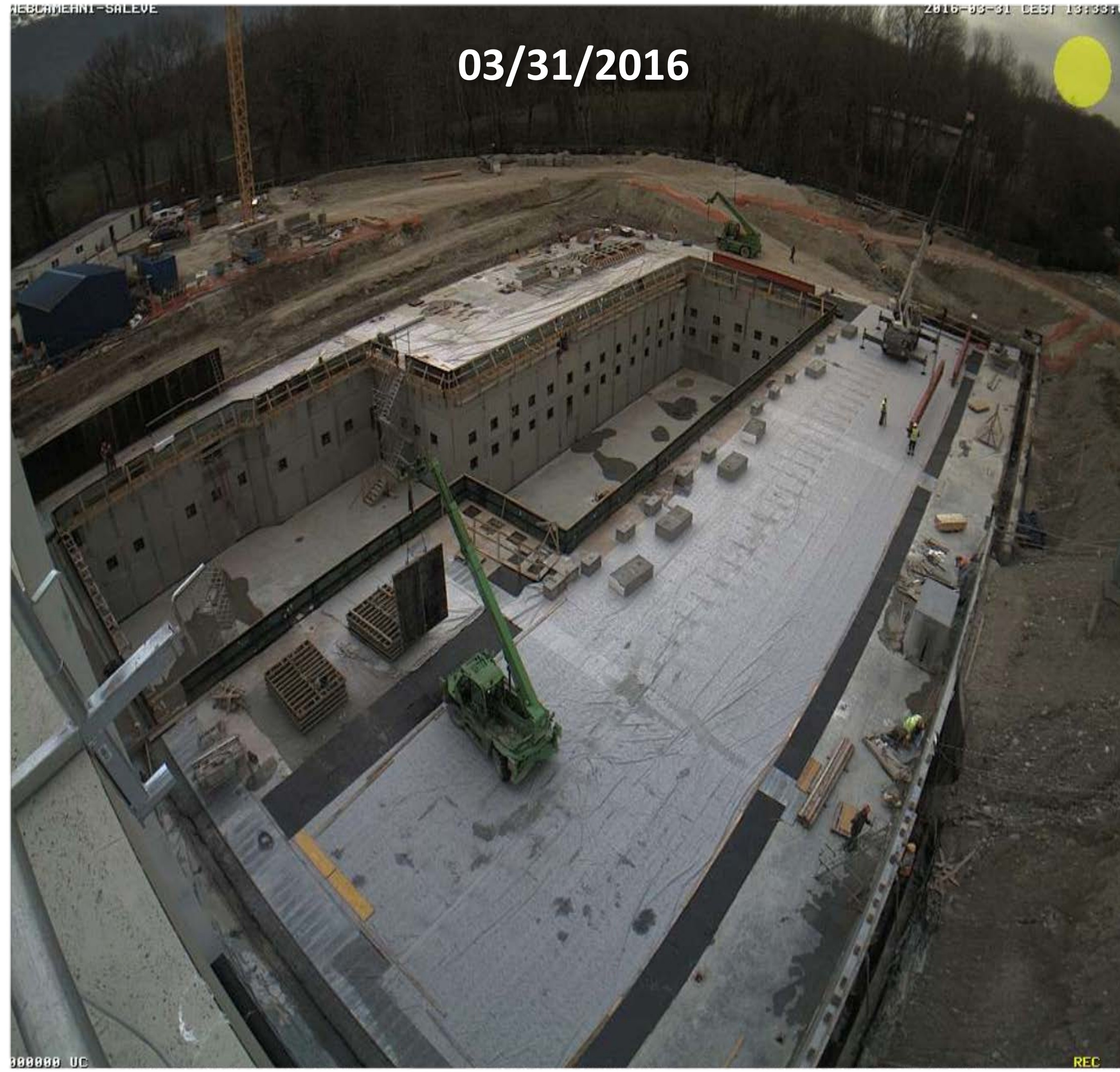


ProtoDUNEs at CERN:
the Neutrino-Platform - update

EHN1 extension status

M. Nessi - NP Report, 7-4-2016





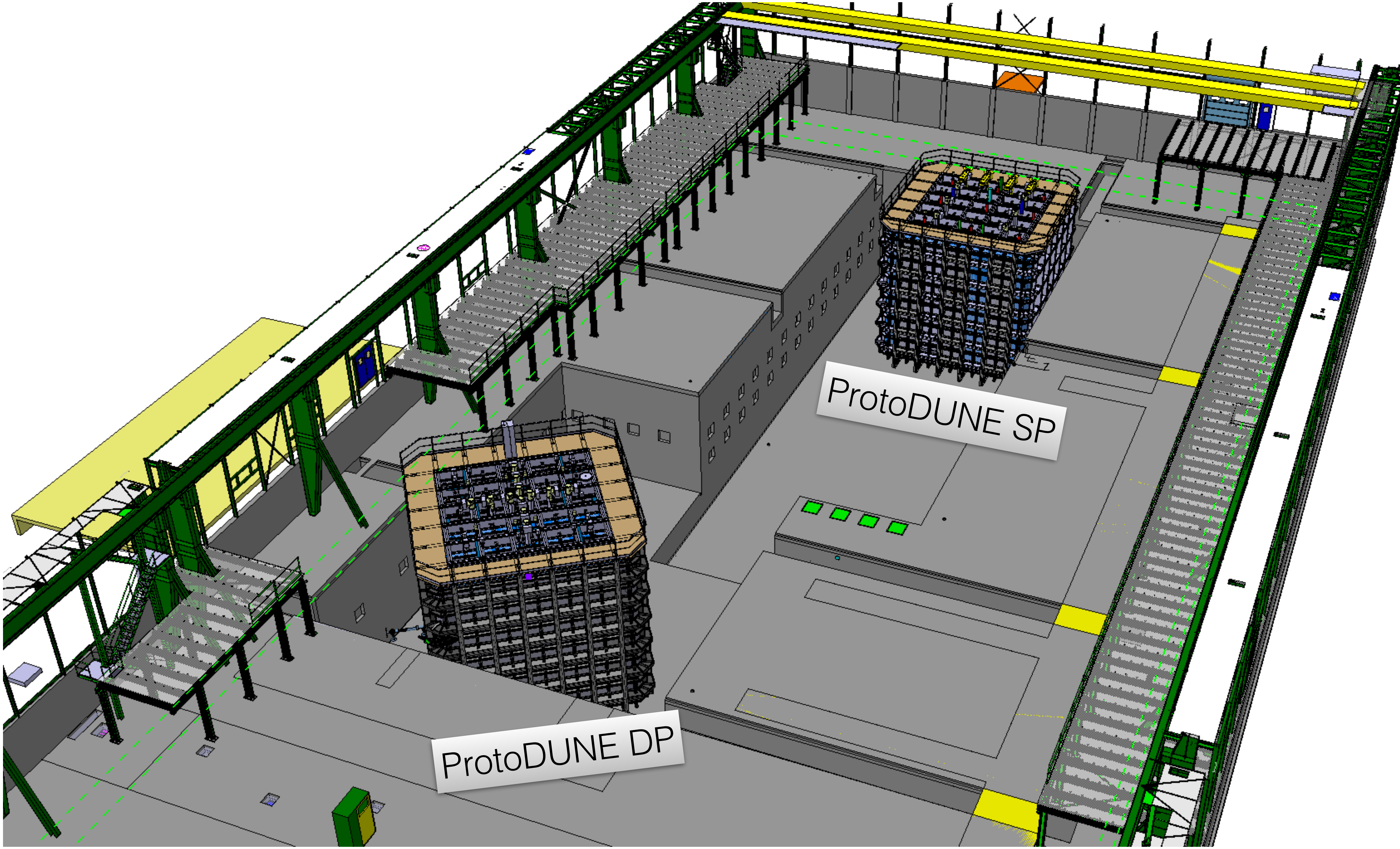
ProtoDUNE SP at CERN:

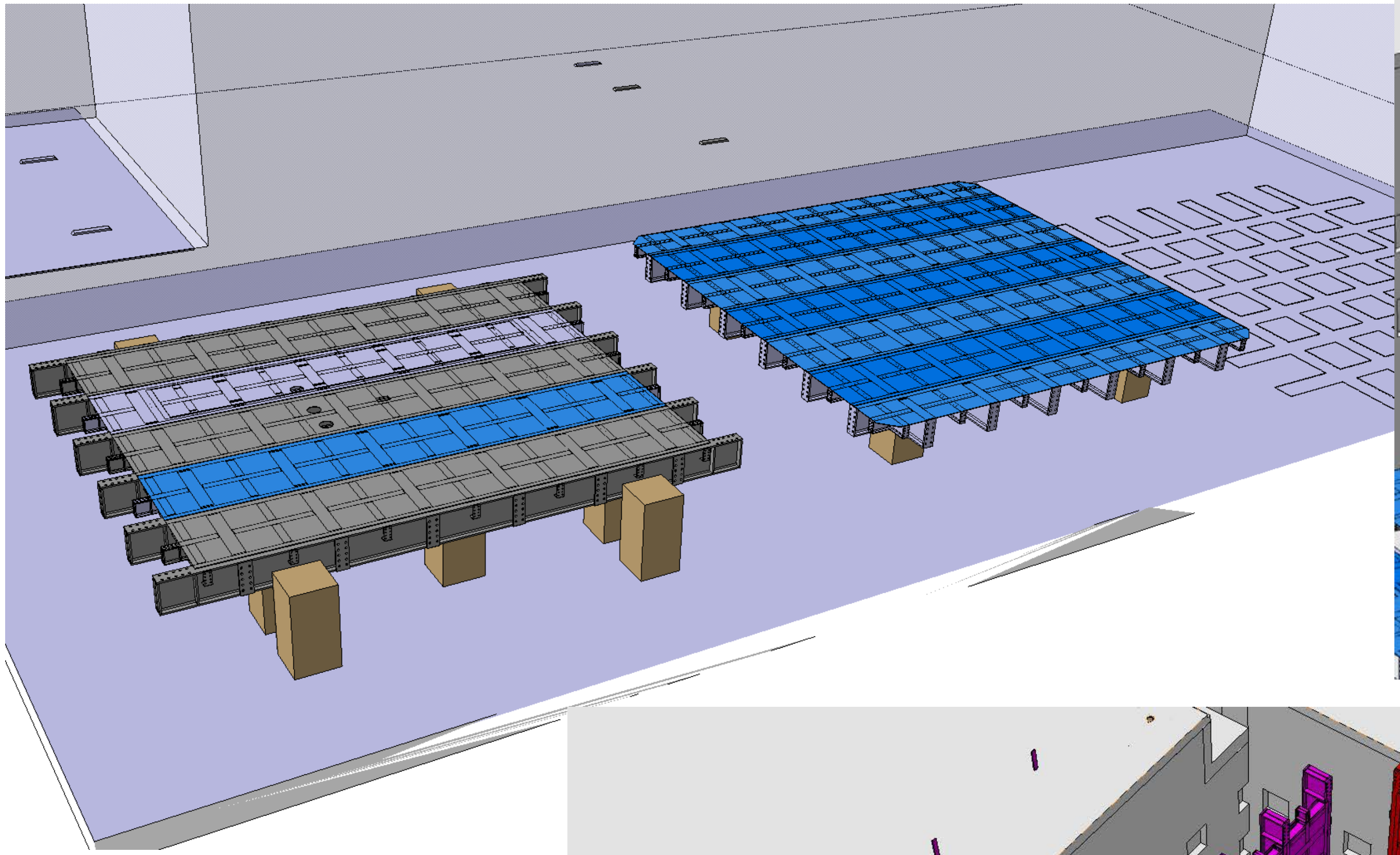
the Neutrino-Platform - update

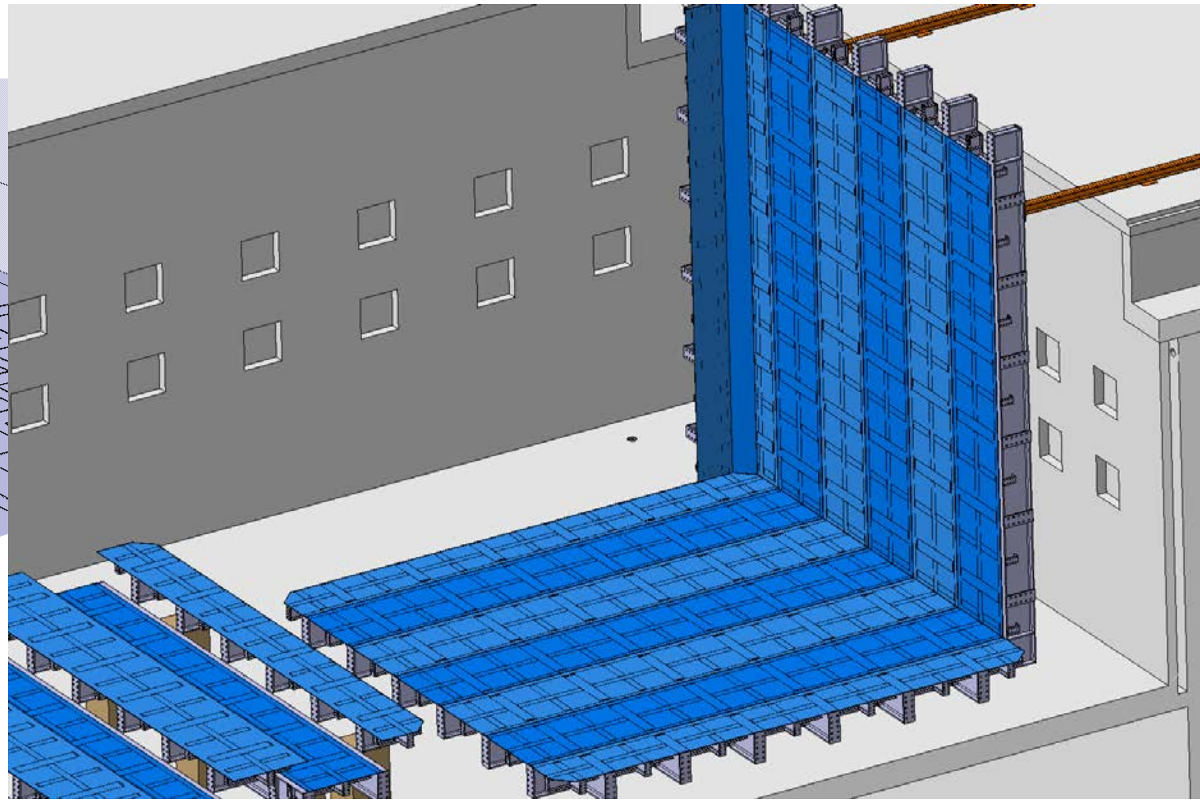
04/27/2016

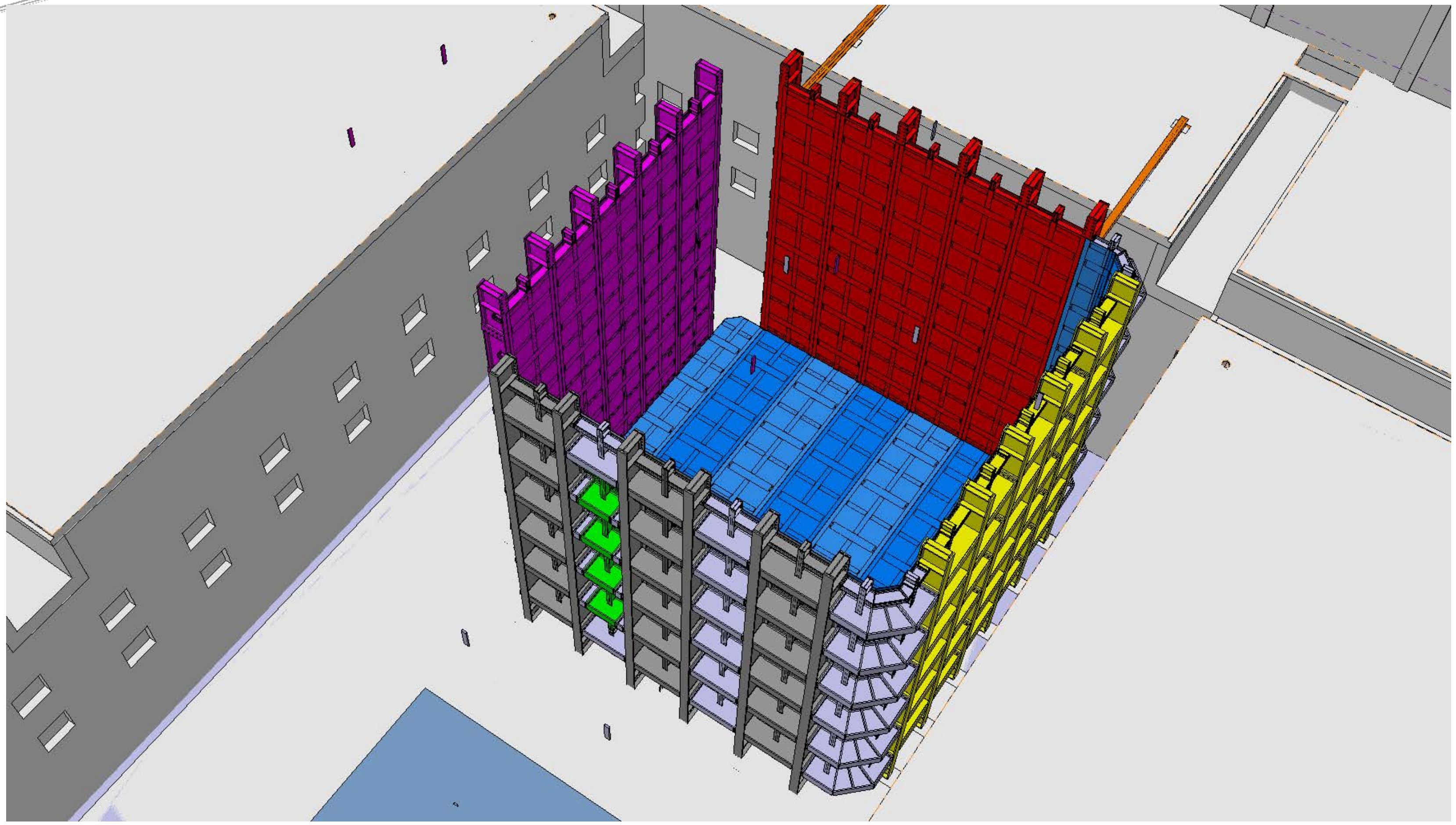
07/21/2016

Building EHN1-extension, beneficial occupancy September 5th

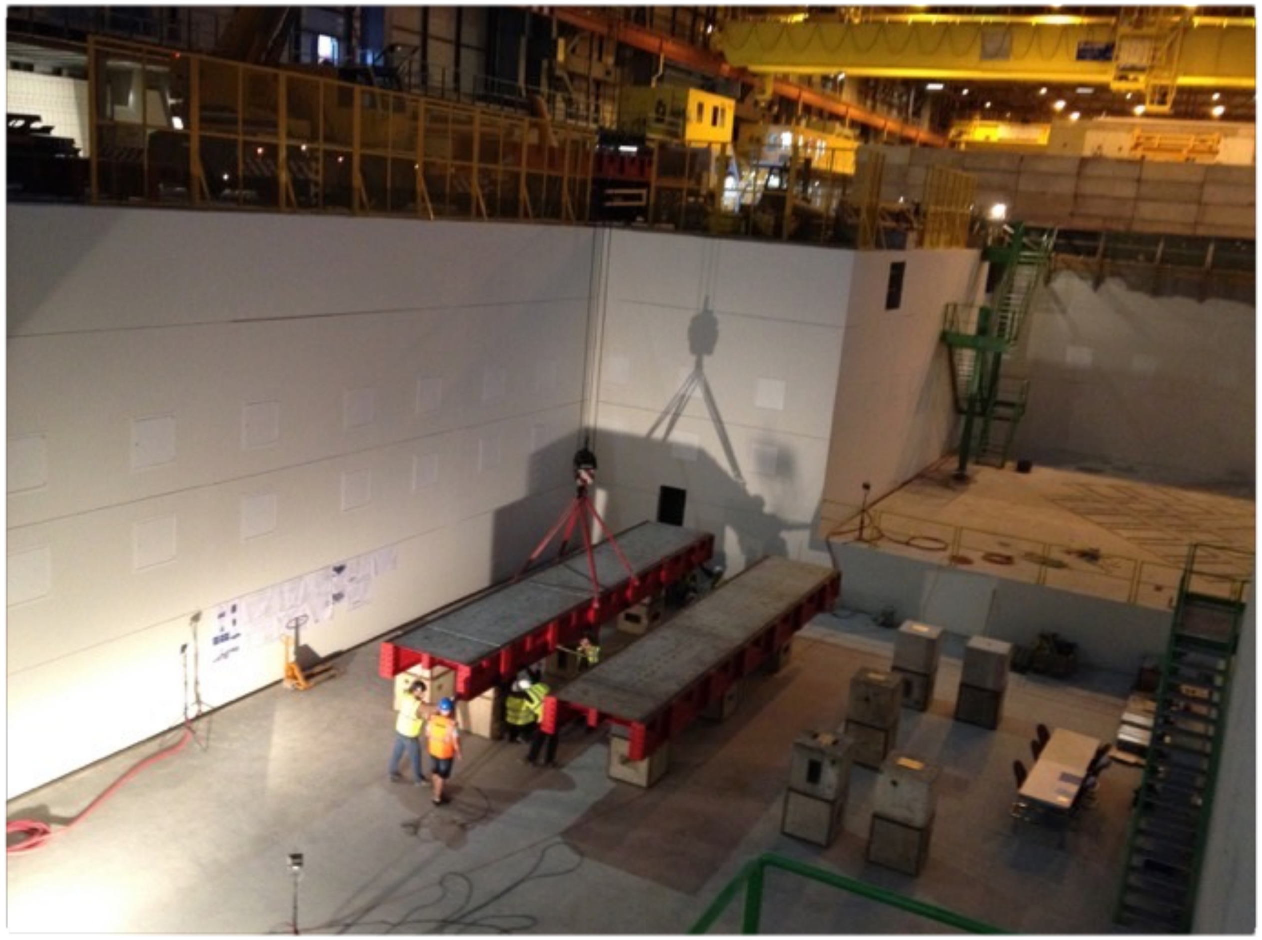

ProtoDUNE SP
ProtoDUNE DP



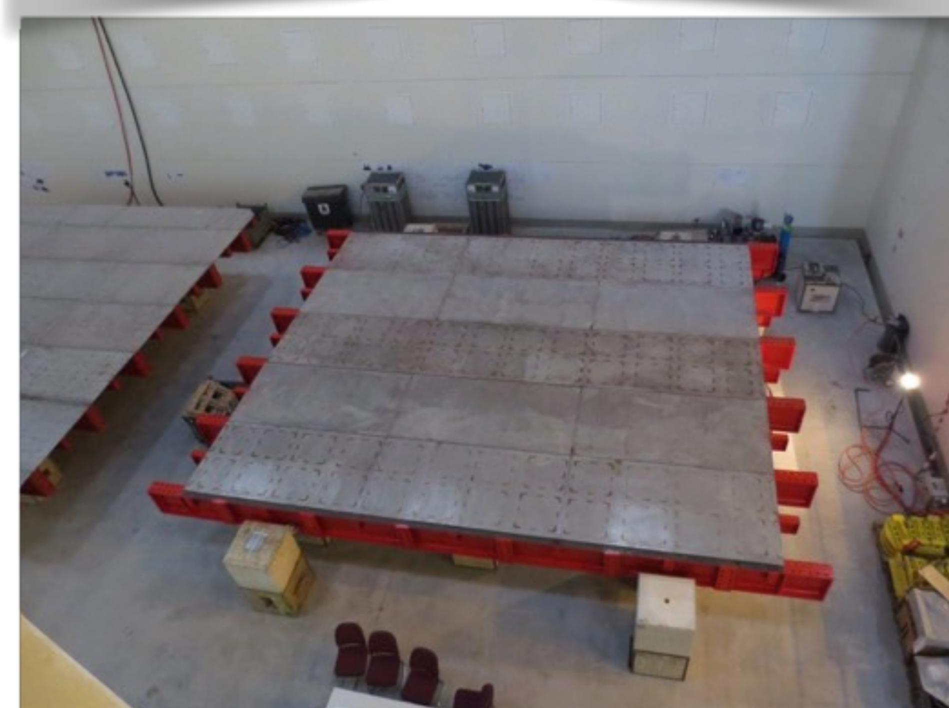




M. Nessi - DUNE Coll Mtg. Sept-2016



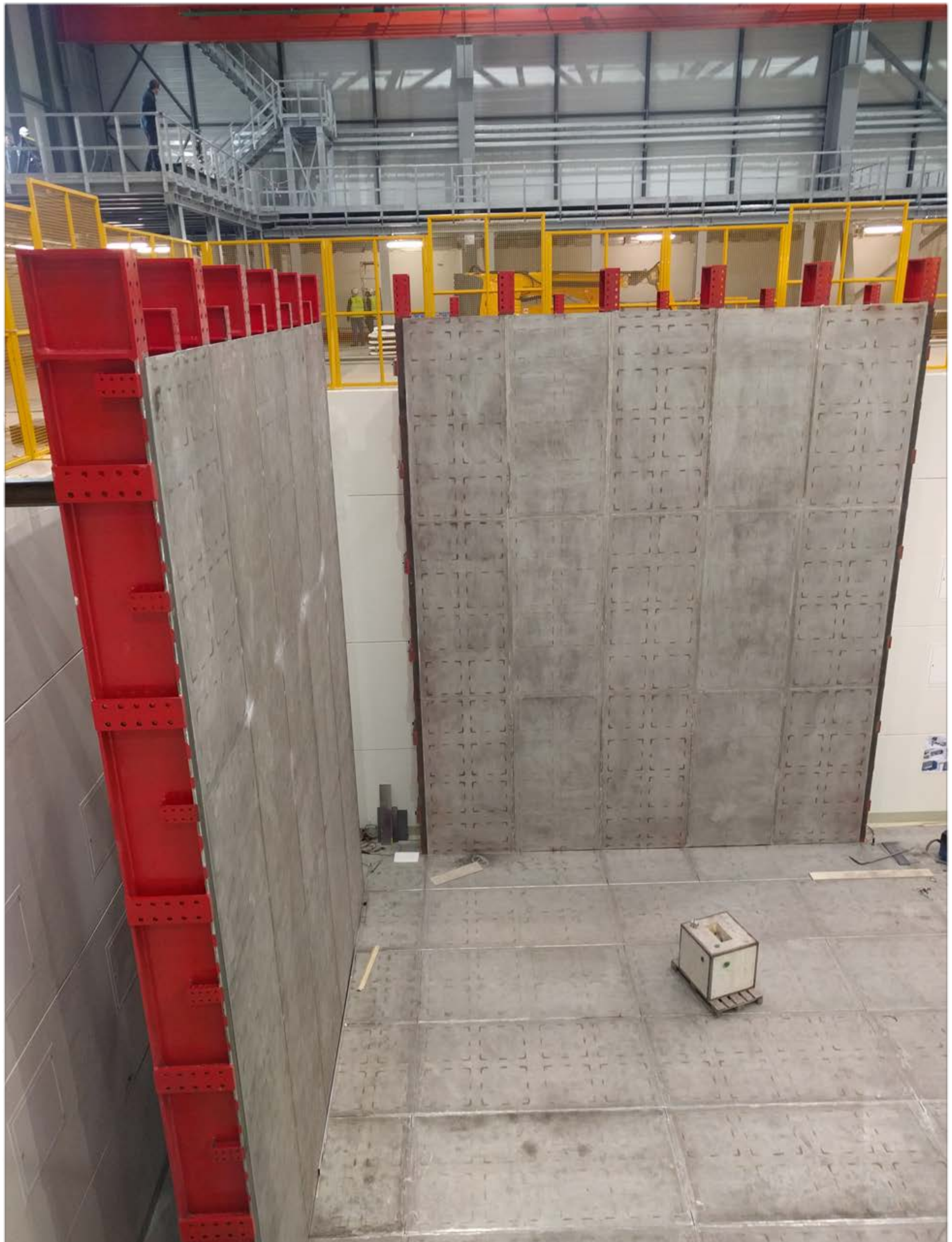
10/06/2016



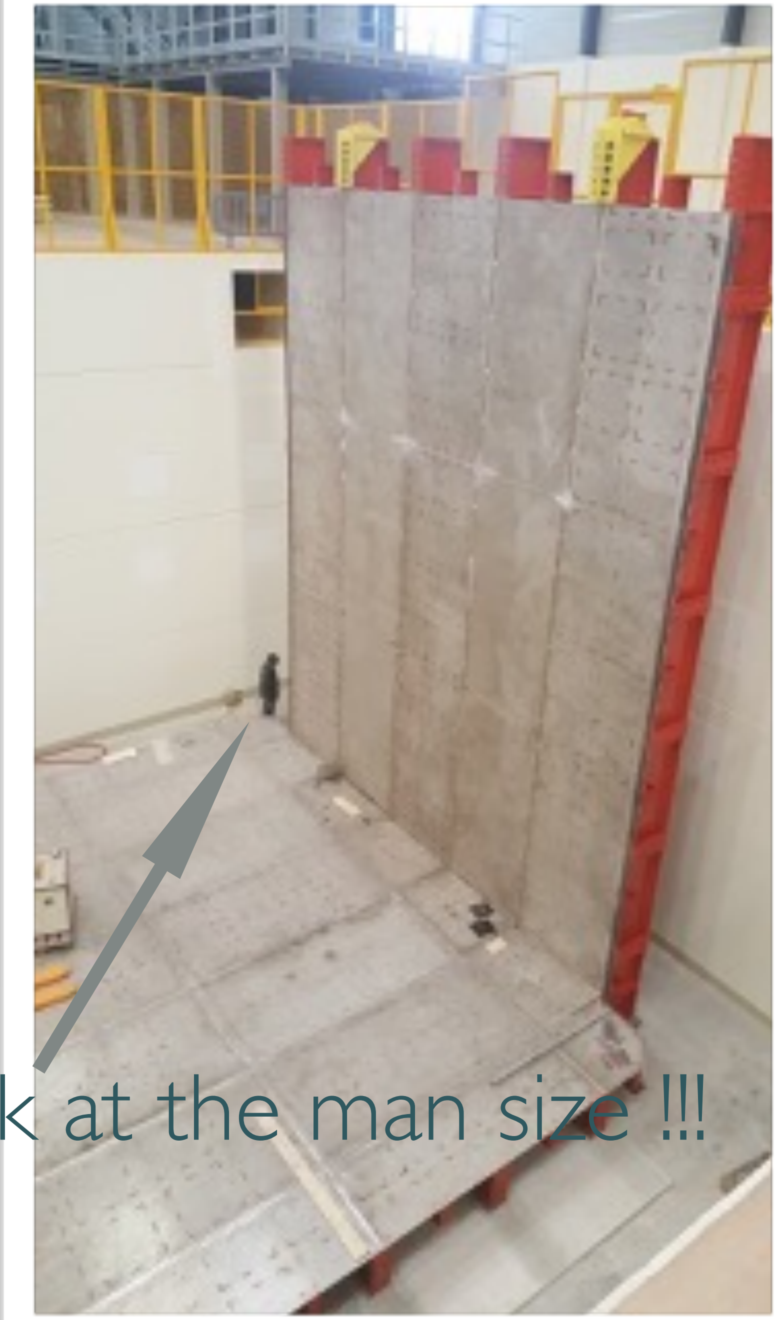
ProtoDUNE SP at CERN:

the Neutrino-Platform - update

10/19/2016 (yesterday !)



10/06/2016



look at the man size !!!

Fermilab DUNE

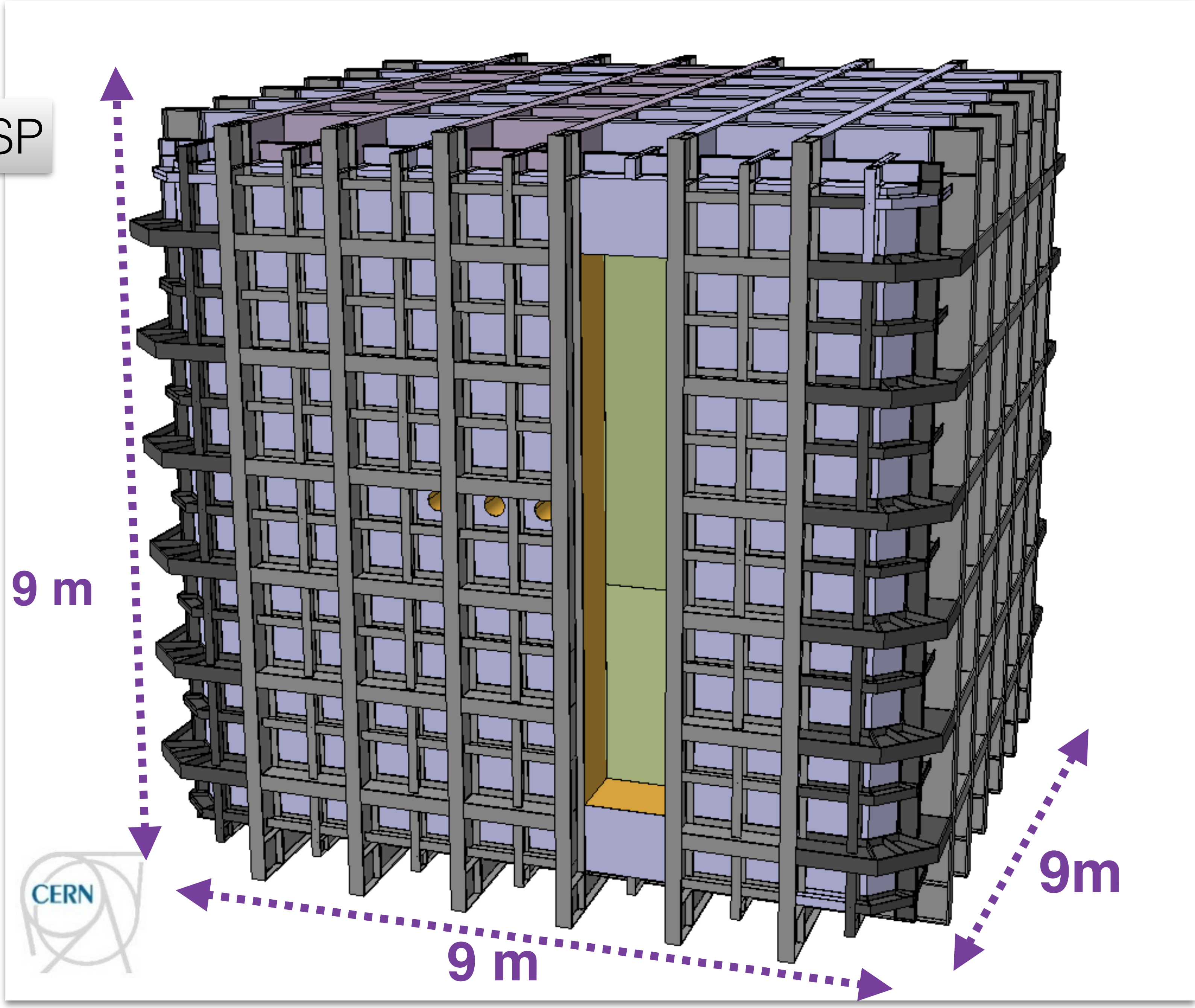
ProtoDUNE SP at CERN:

the ProtoDUNE cryostat at the Neutrino-Platform - update

ProtoDUNE SP

Membrane Cryostat: major contribution by CERN

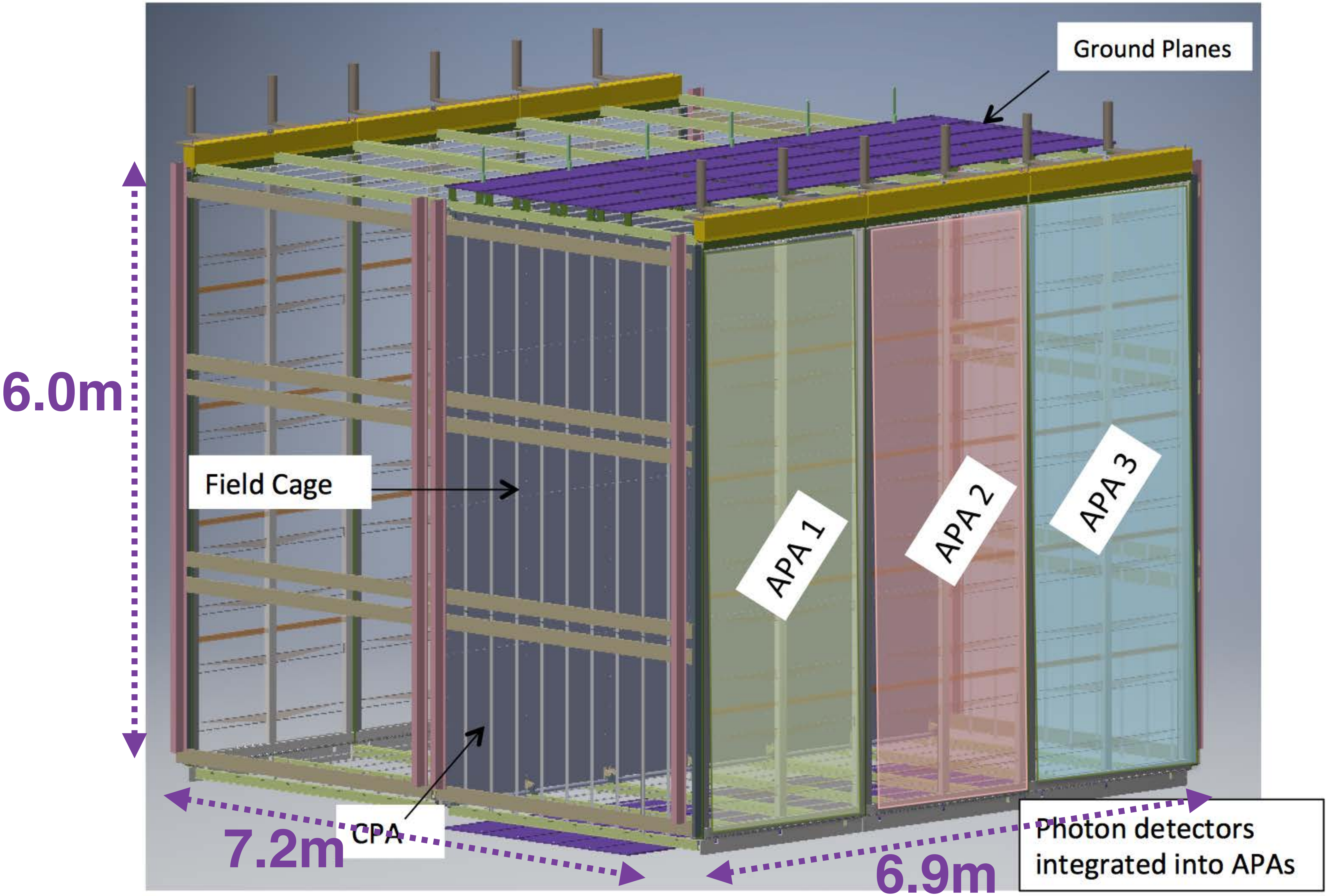
- **Goal: cryostat ready by spring 2017**

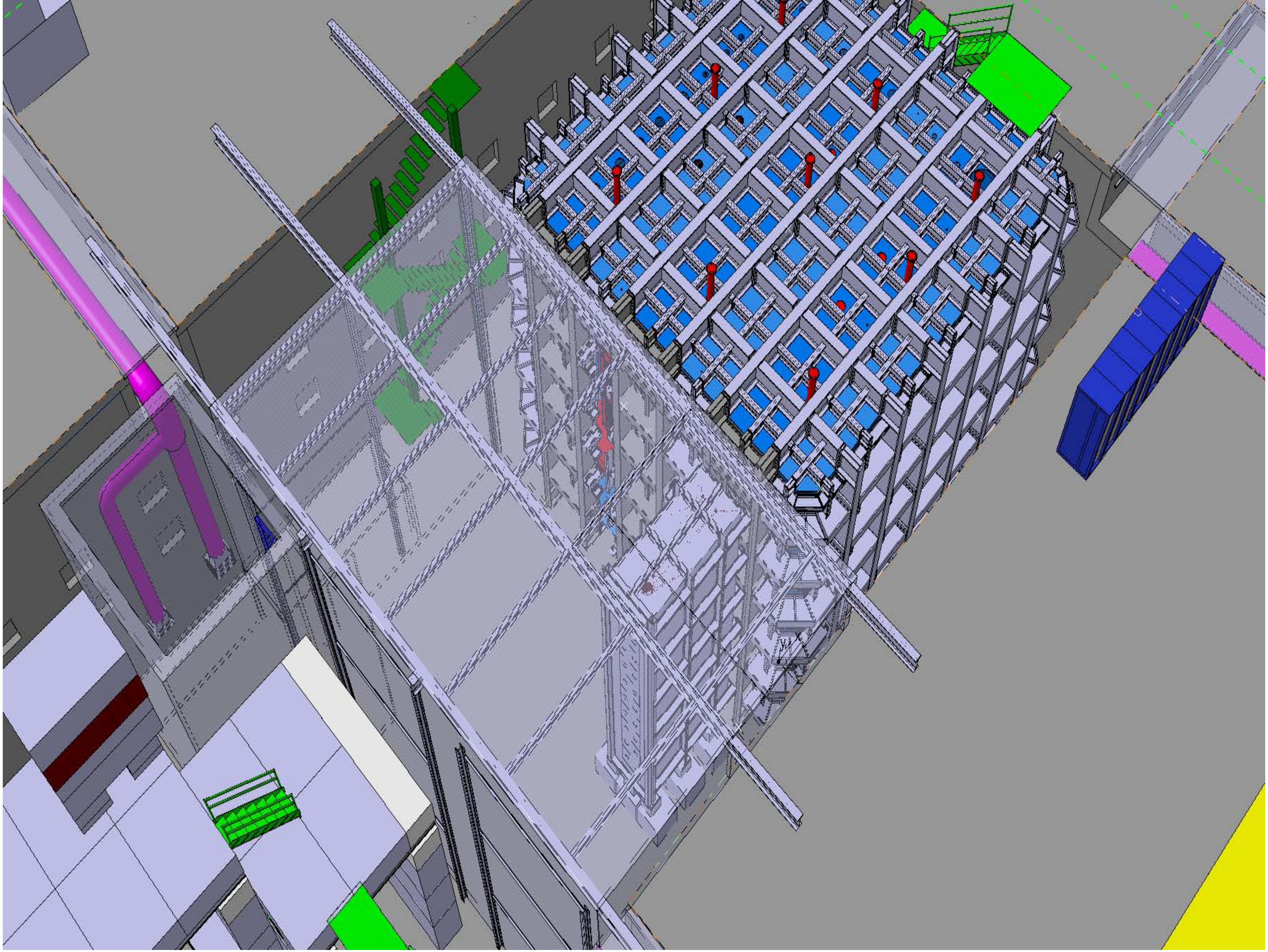


TEMPORARY CONSTRUCTION OPENING

ProtoDUNE SP

The LAr-TPC detector



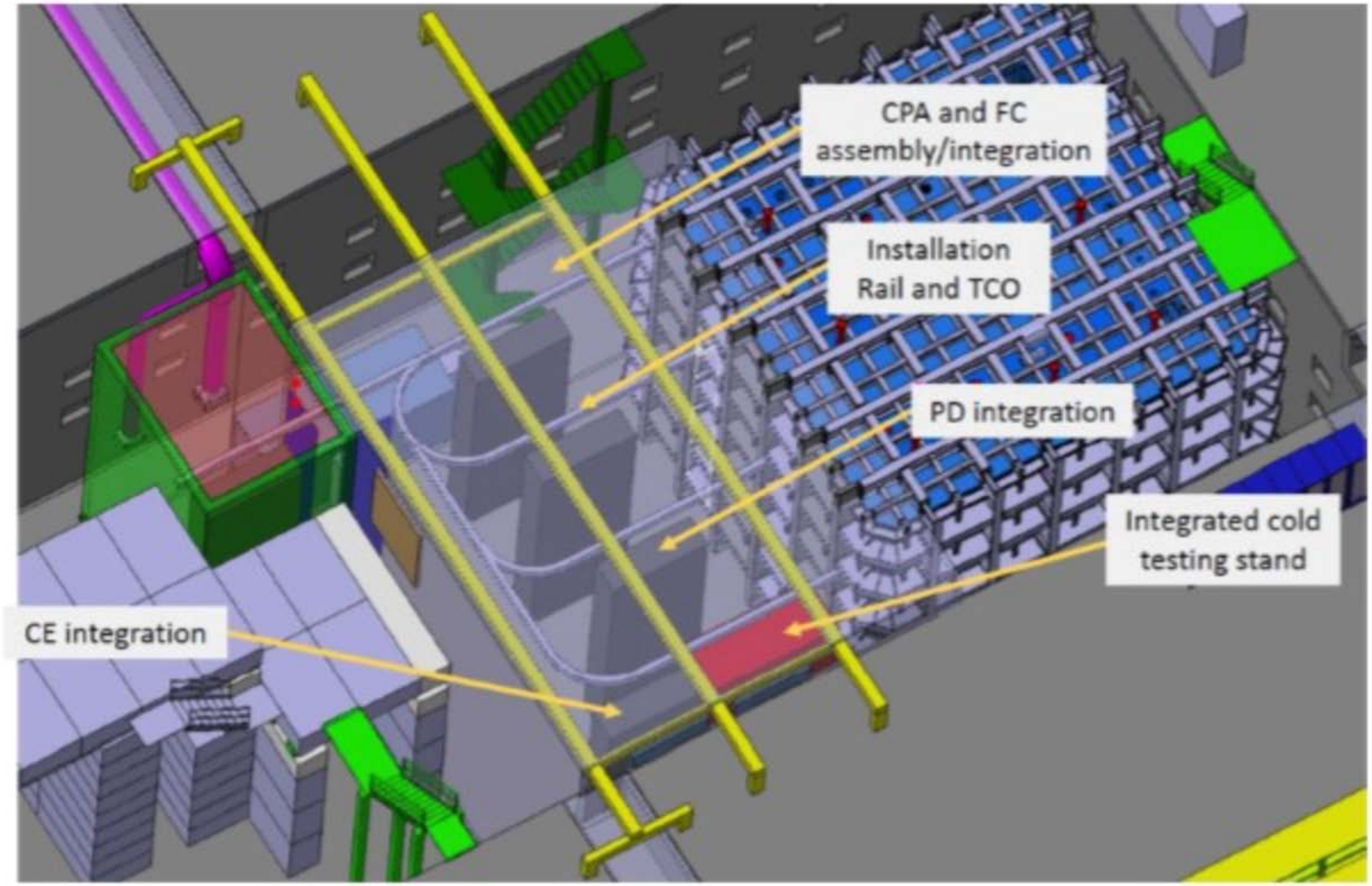


ProtoDUNE SP at CERN:

Detector integration and installation - update

Conceptual view of installation area in Pit B EHN1

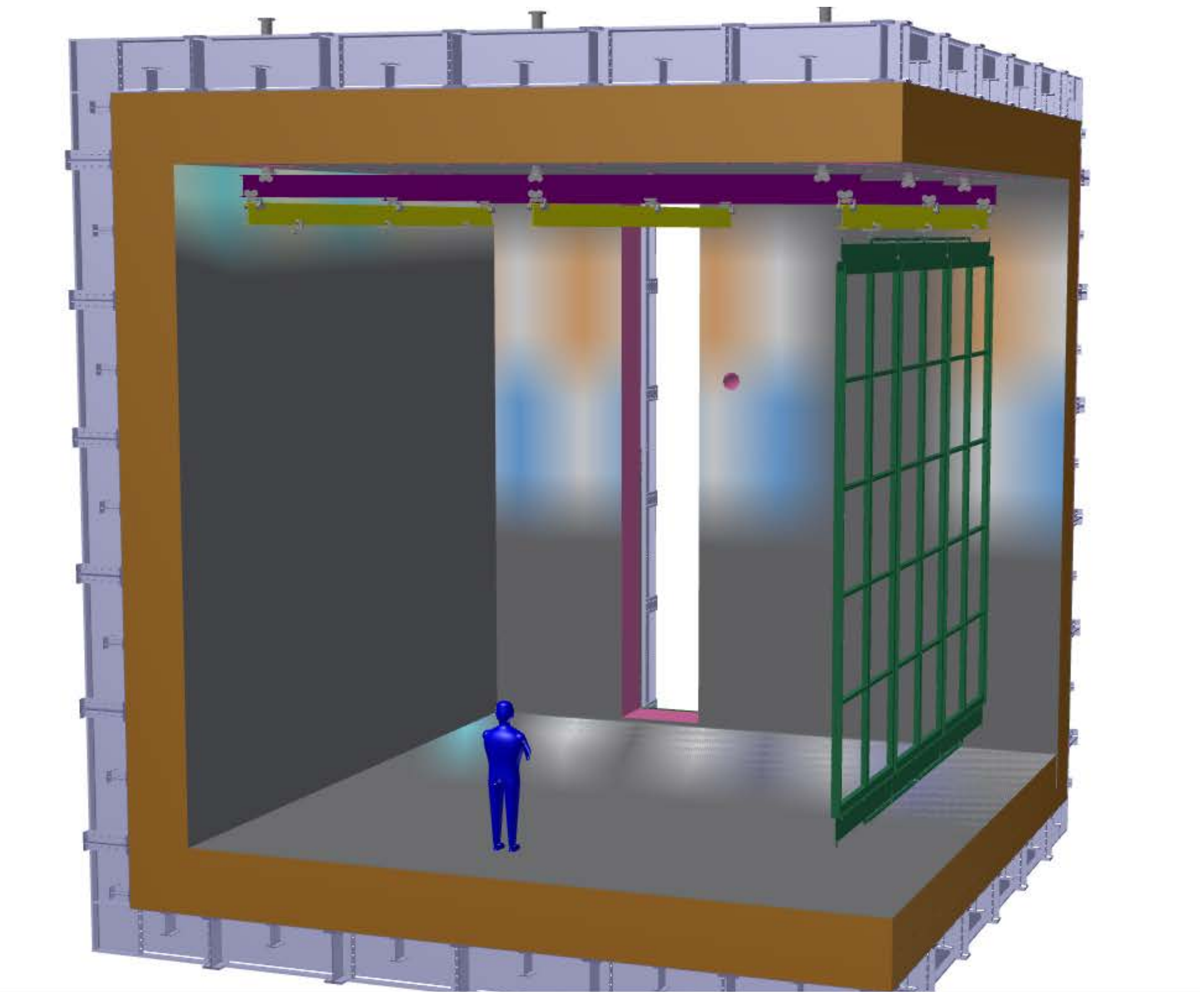
ProtoDUNE SP



ProtoDUNE SP at CERN:
Detector integration and installation - update

Detector installation #1

- After full row is complete, the APAs will be un-cabled and translated to the Jura position and cabled to Jura FT for continued testing.
- New rail will be moved into the "install position." The installation of the CPAs can begin.



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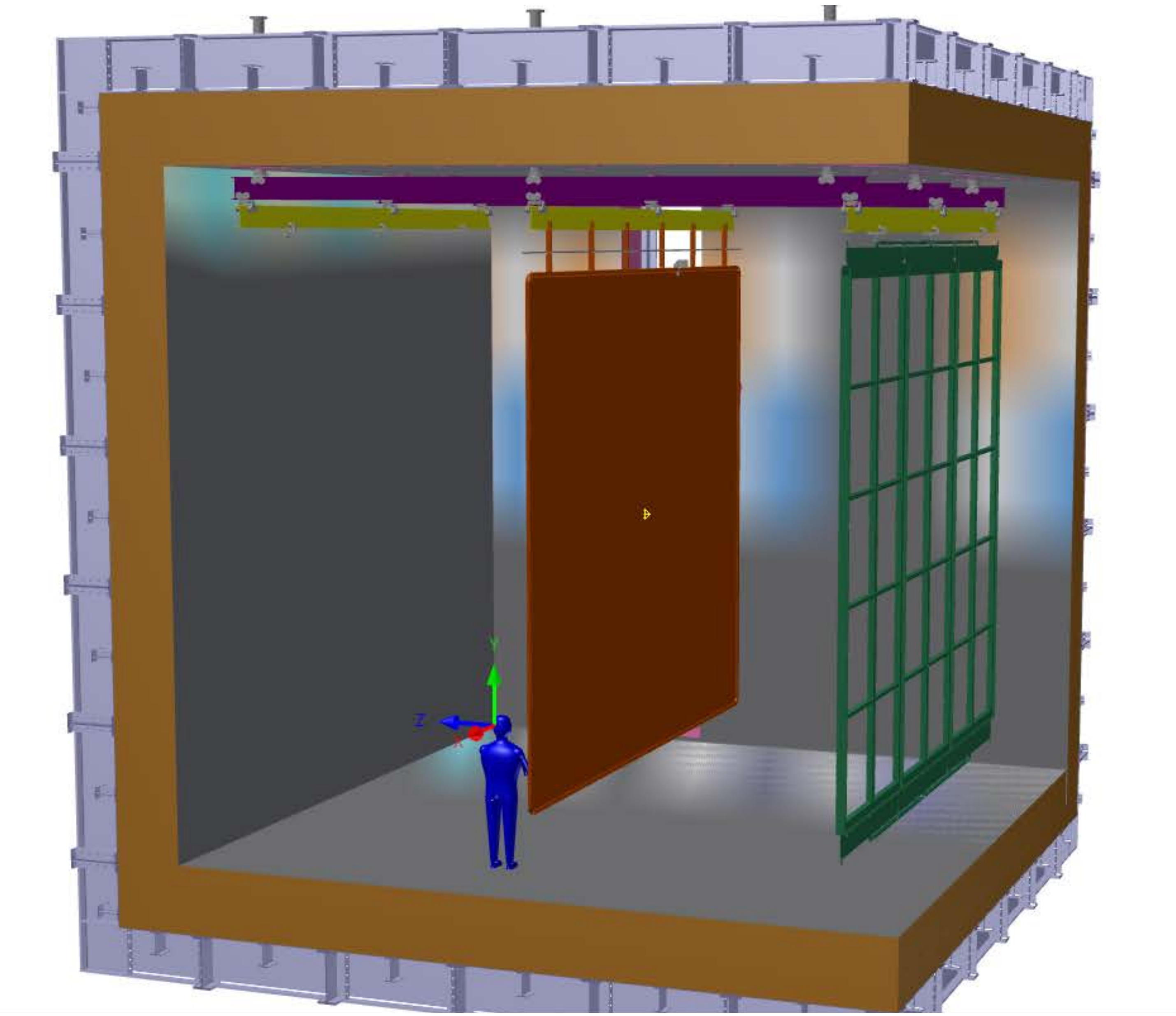
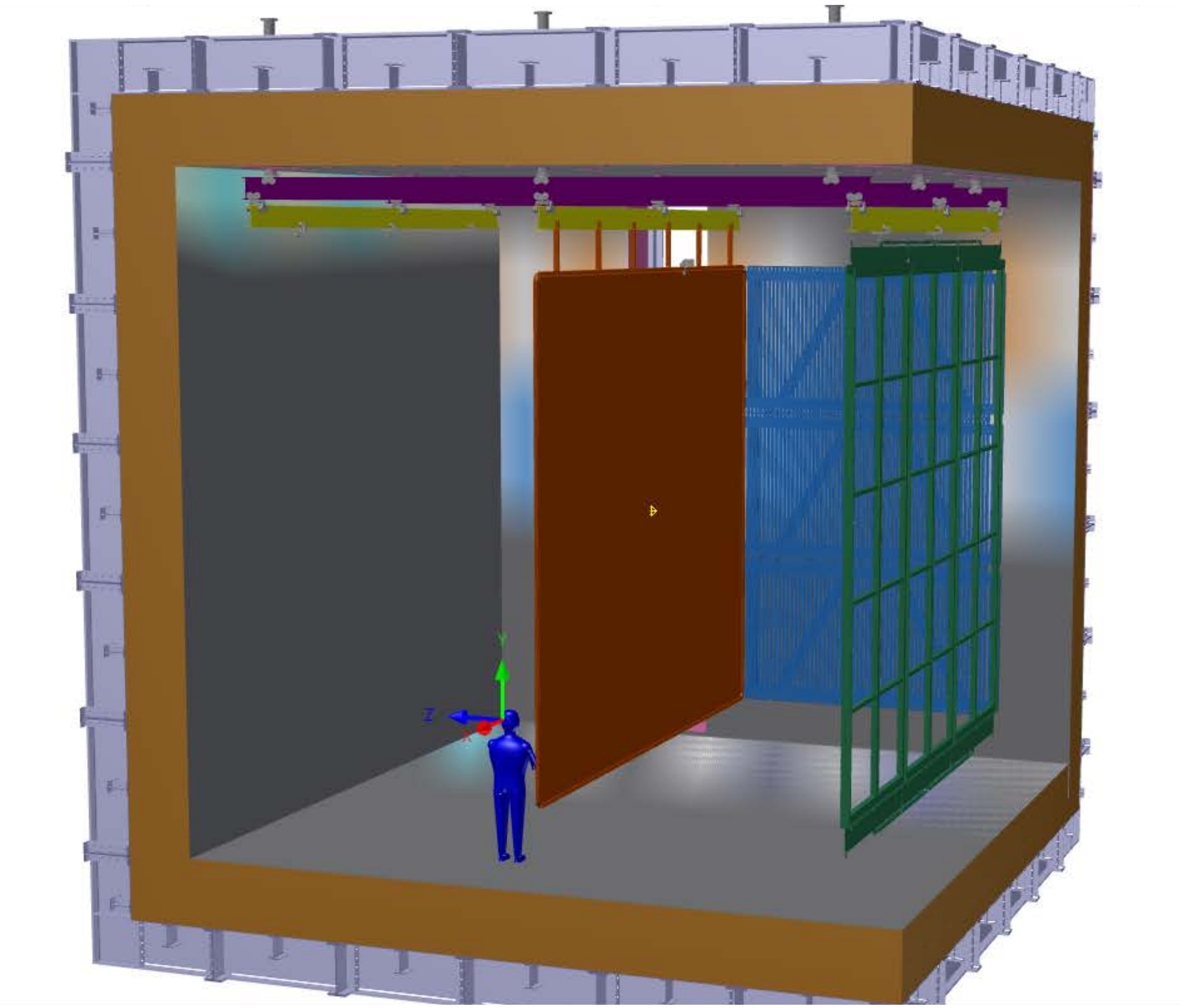
Detector installation #2

- After the CPA row is complete, it will be translated to the nominal position.
- Work can now begin on the installation of the Jura side FC.
- This order of installation is done to allow more time for APAs 4, 5 and 6 to be integrated and tested outside of the cryostat.
- Scaffolding or other access equipment will be available in the drift region between the APAs and CPAs.



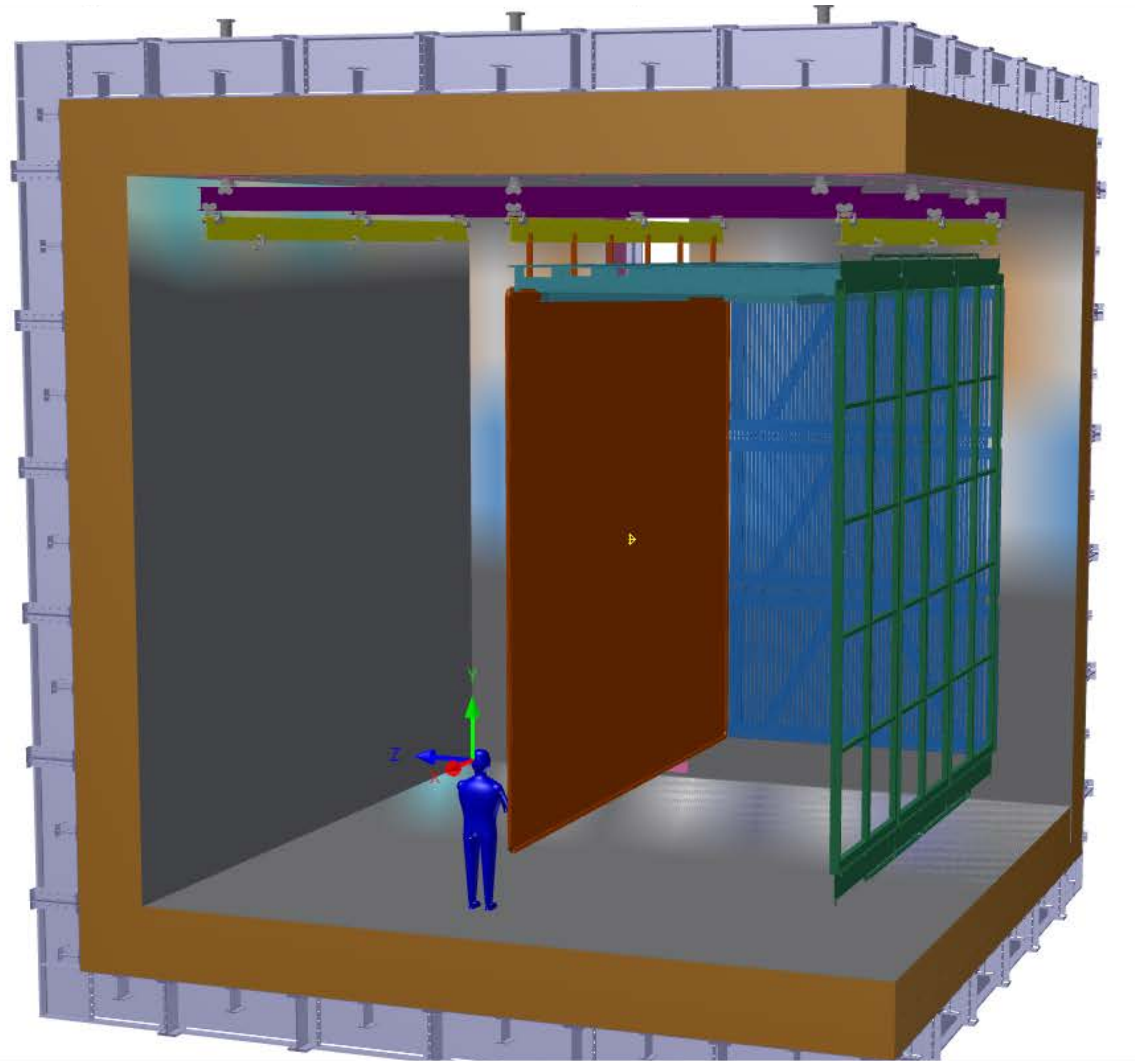
Detector installation #3

- The beam side end wall FC will be installed.
- The beam plugs for this drift volume will be installed on the end wall panels.



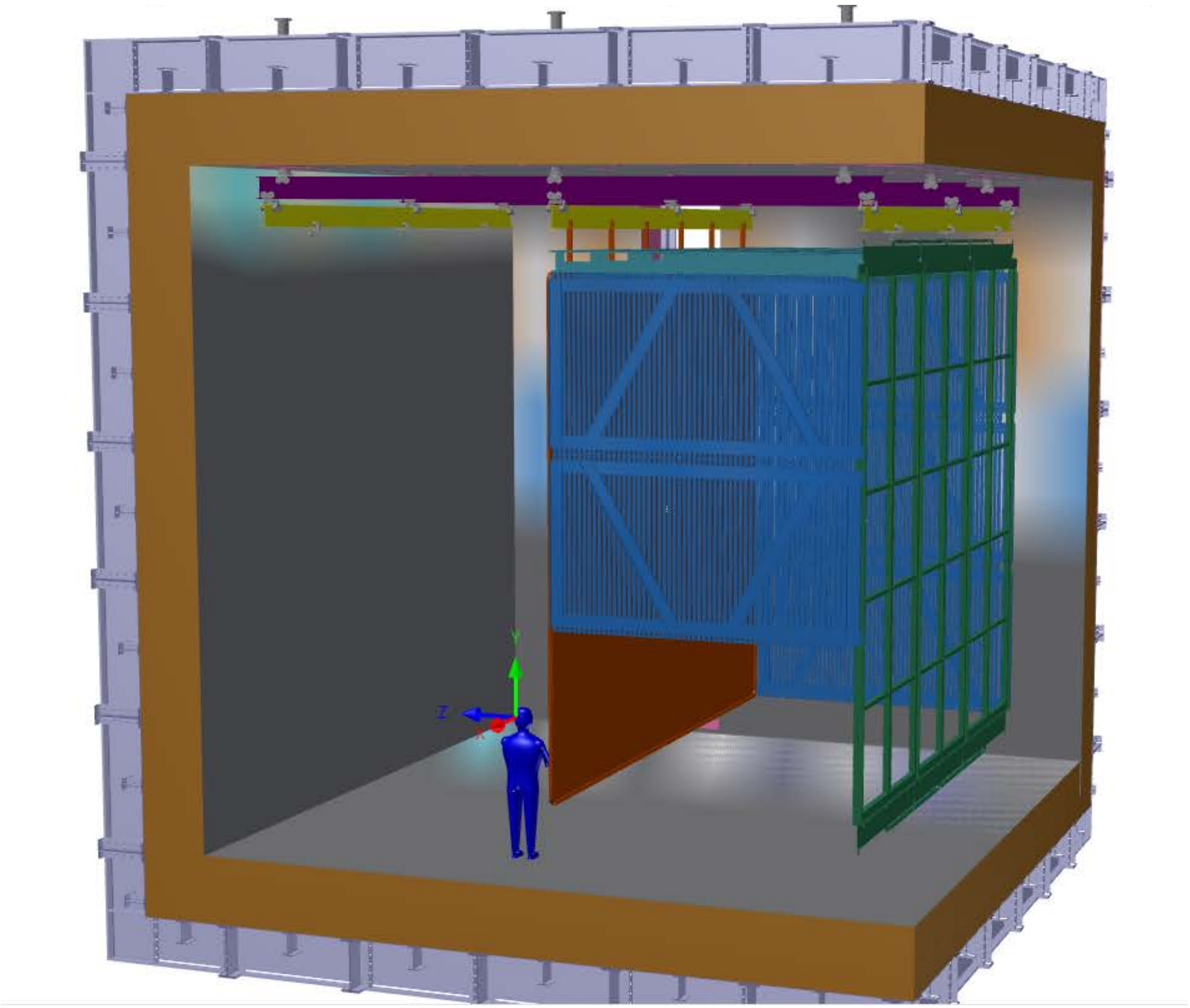
Detector installation #4

- The 3 upper field cage panels will be installed. This will be done starting from the beam window side.
- Note: Access to the CE on APAs 1, 2 and 3 is now not possible.



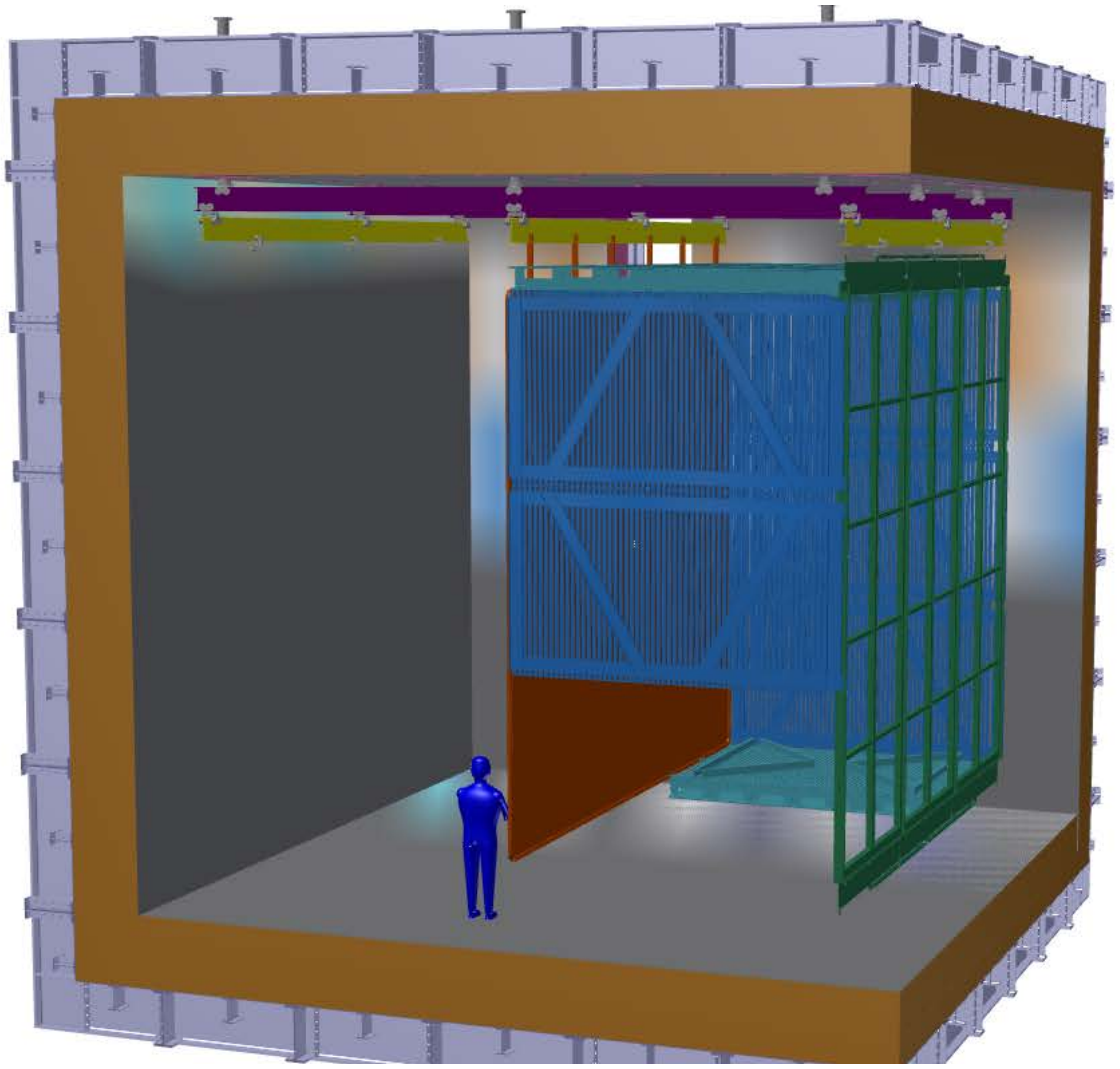
Detector installation #5

- Install the upper half of the north FC wall.
- Disassemble and remove scaffolding/ access equipment in this drift area.



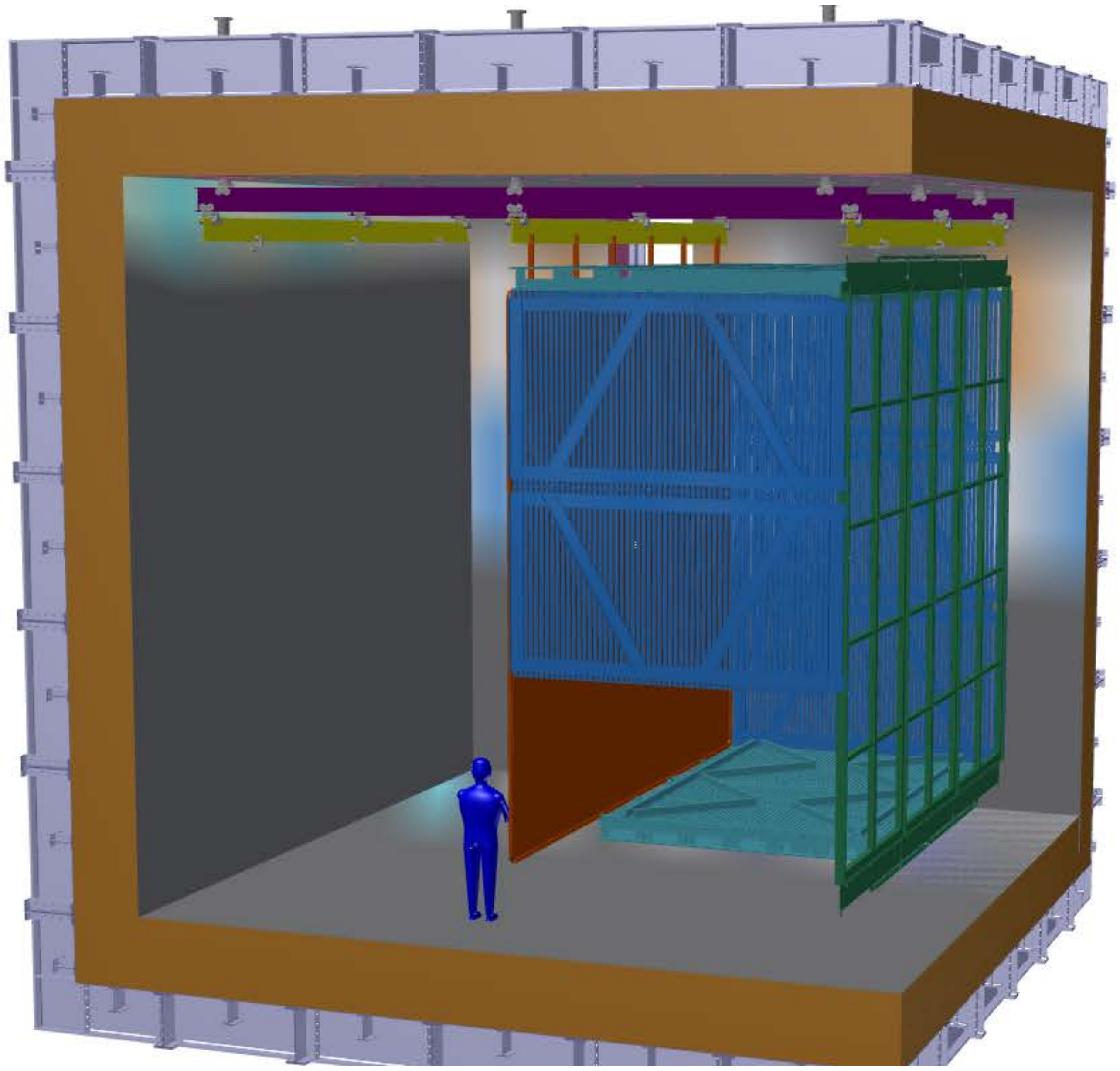
Detector installation #6

- Install the lower FC panels from beam window side to downstream.
- Removal of floor protective panels will be completed as this work progresses.
- Any work under this portion of the TPC must be completed at this point.
- One possible iteration on this, is to install the far top FC and then the bottom, indexing the scaffolding downstream away from the beam window side. This would require delaying the downstream end wall until after all three upper FC are in place but before the final lower FC is installed. This will be evaluated as the designs progress.



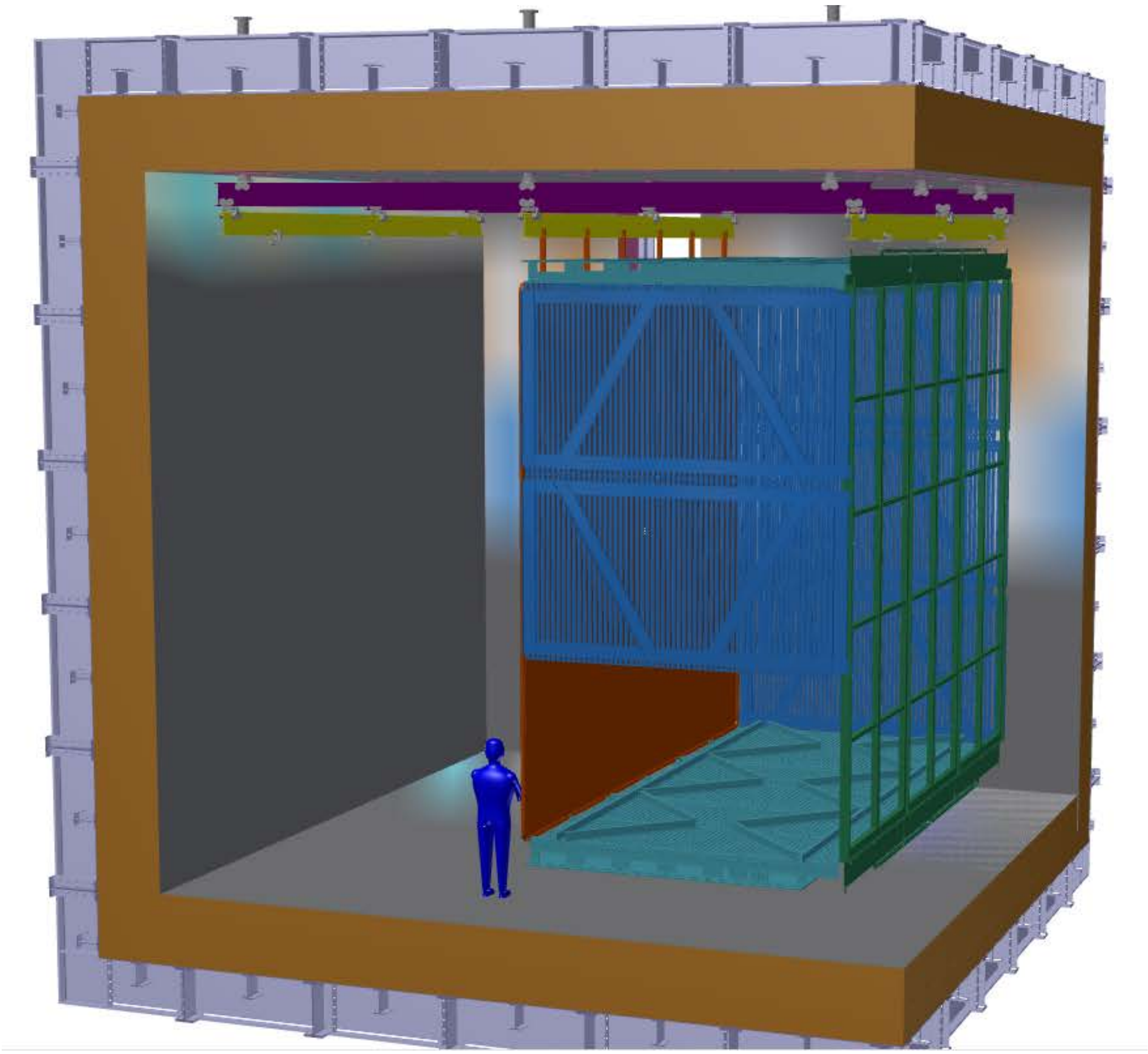
Detector installation #7

- Continuation of the lower FC panels.
- Note for all upper and lower FC panel : the cross bracing and support structure will need to be removed at they are installed. For the lower FC panels, this will require access to the top surfaces. We are in the process of determining what the minimum access required will be and how this will be done. It is likely that a temporary walking platform on top of the FC will be needed. Can the design support this or will temporary blocking be needed under the panels for support?



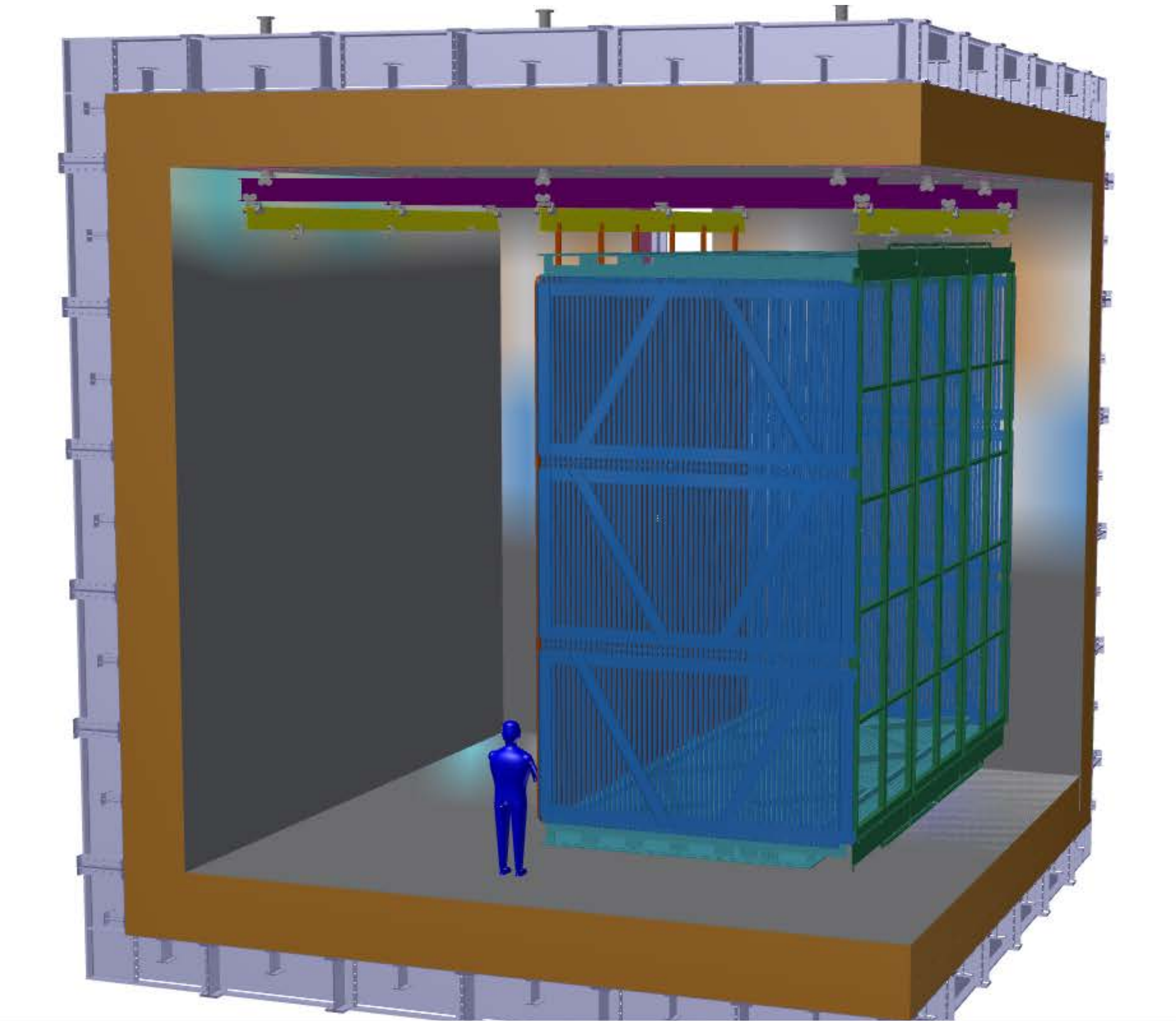
Detector installation #8

- Complete the lower FC panels.



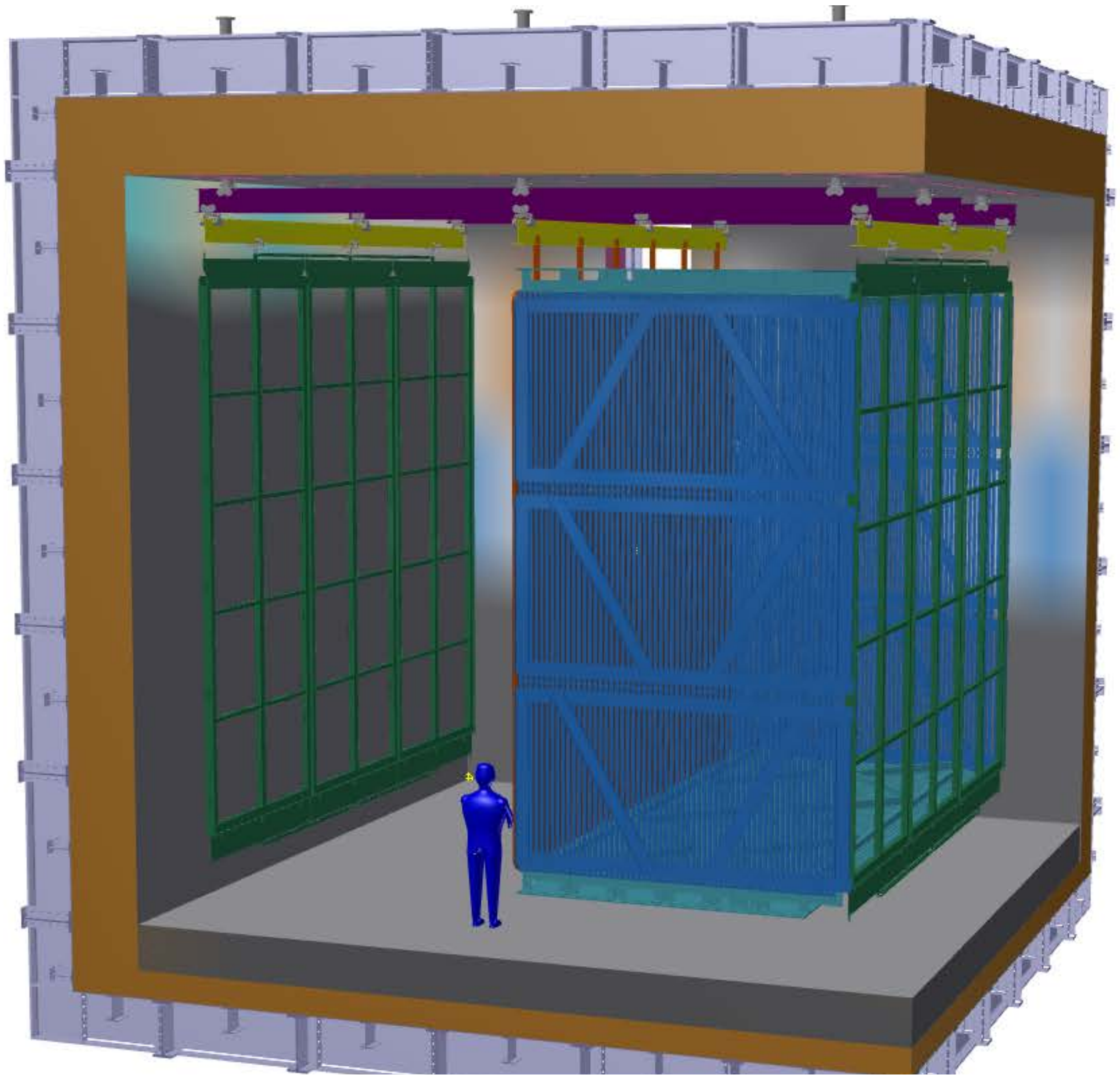
Detector installation #9

- Install the lower end wall FC panel.
- The installation in this drift volume is complete.
- Can the calibration system (fibers on the CPA) be designed and installed from one side of the CPA?
- The HV feed thru and donut can be installed at this point.
- Laser installation for this drift?



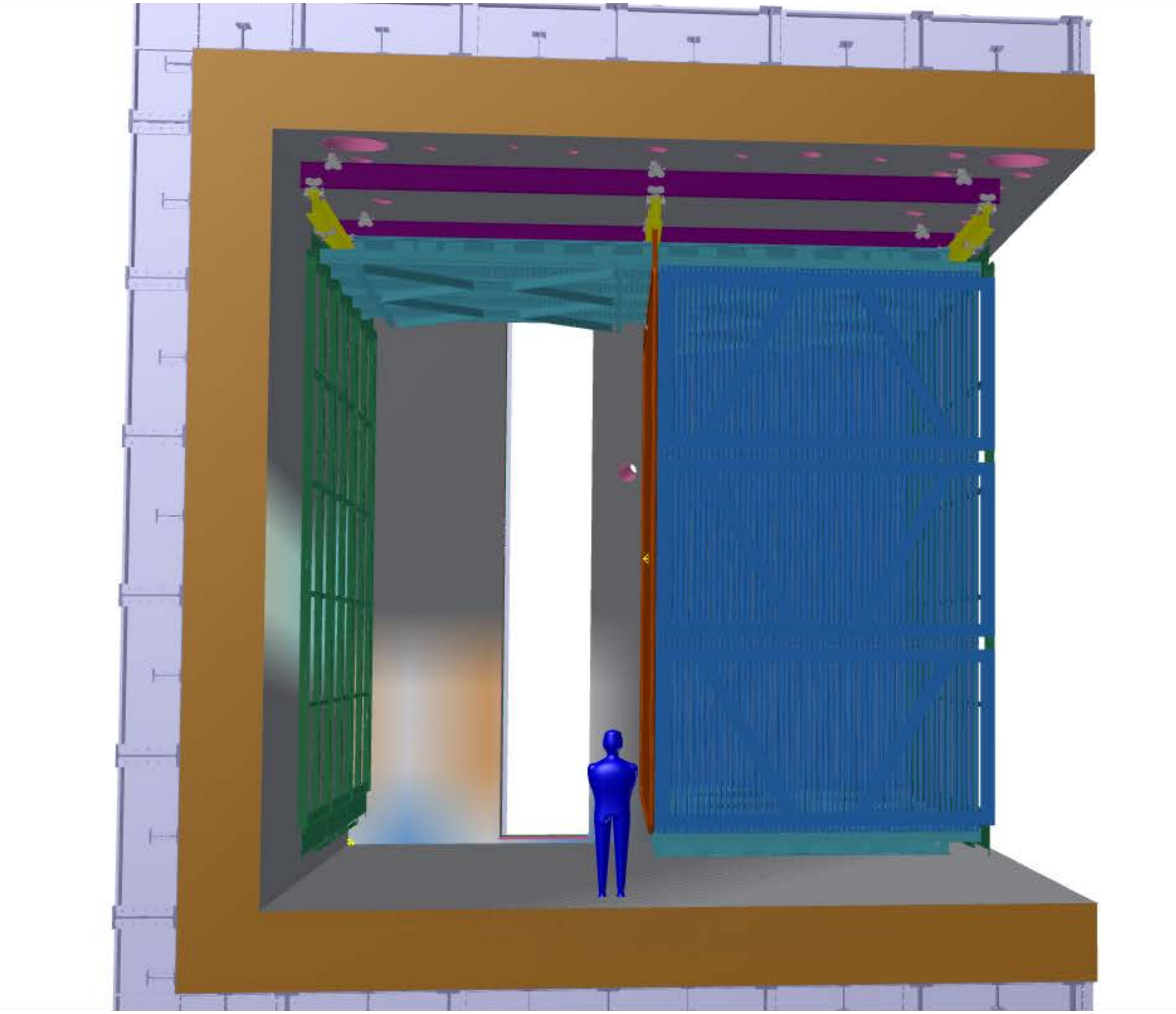
Detector installation #10

- APAs 4, 5 and 6 will be installed and translated into position.
- Scaffolding/access equipment will be in this drift region.



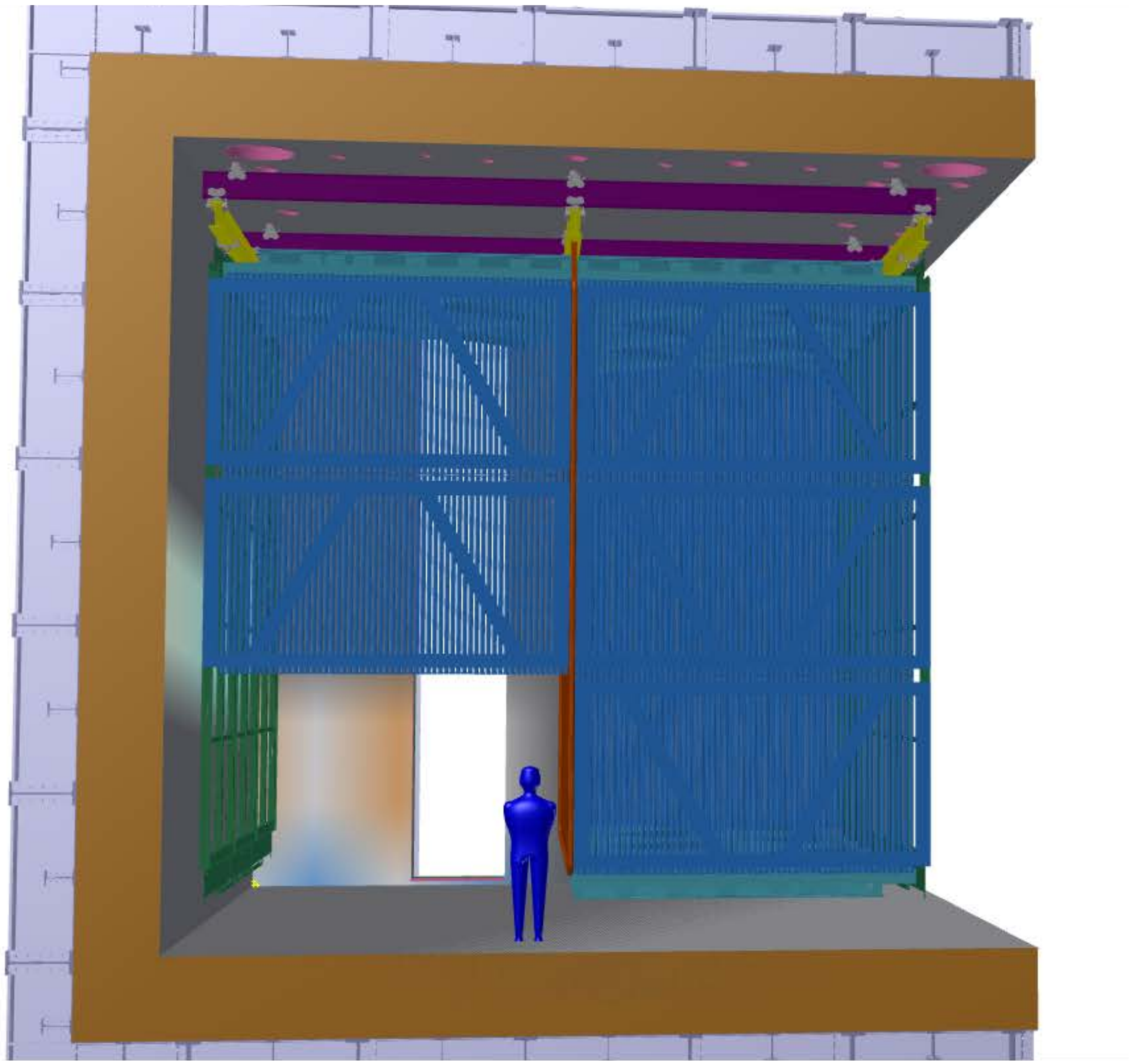
Detector installation #11

- Two of the upper FC panels can be installed (downstream and center).
- This will block access to the CE on these two APAs.



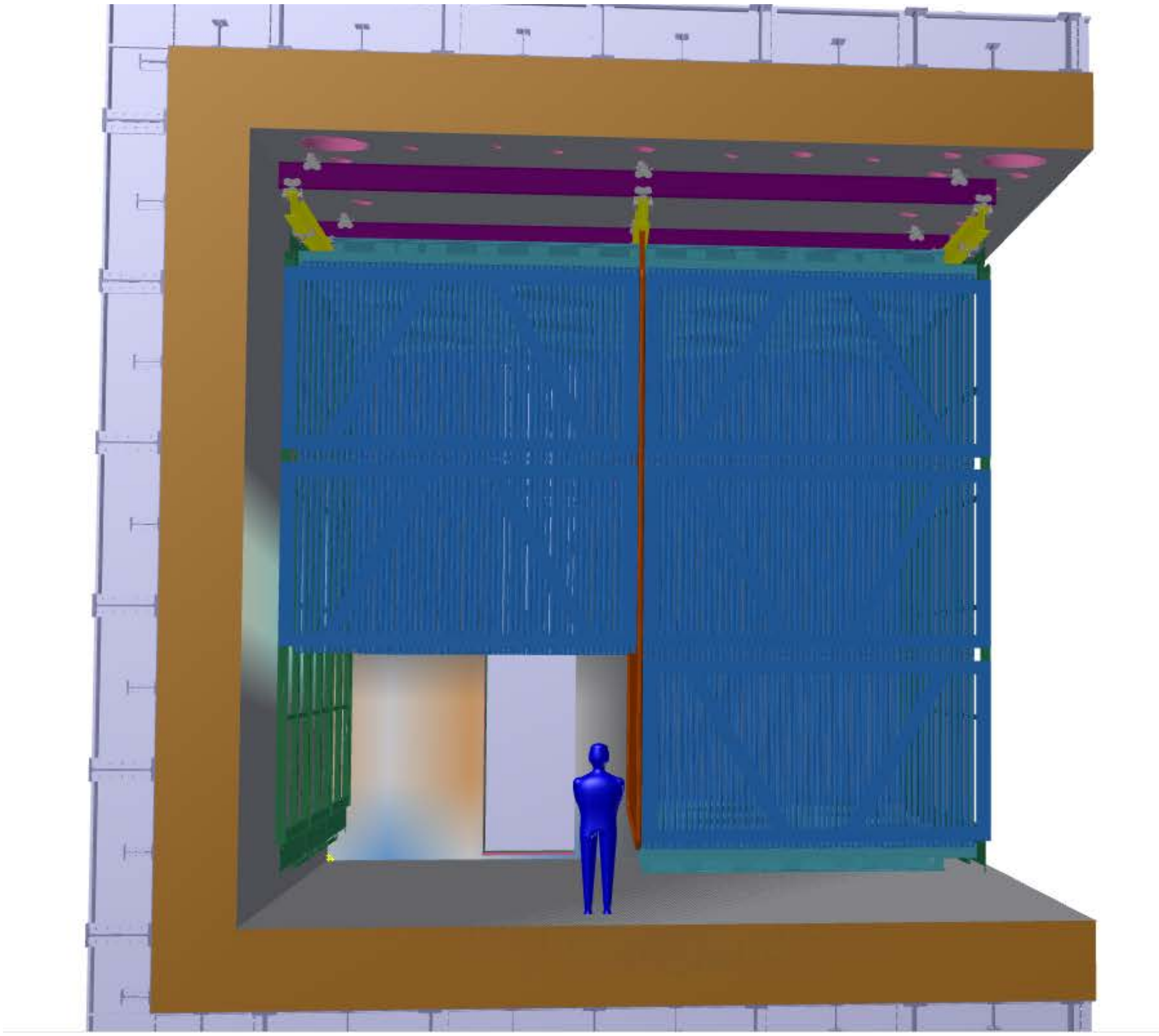
Detector installation #12

- The upper end wall FC panels will be installed on the downstream end of the TPC.
- Lasers?
- This completes the installation of all of the panels that can be installed before the closing of the TCO begins. This allows access to the full height of the TCO and the floor space in this drift.
- At this point there are still 8 FC panels to be installed. If the full TCO is closed all of these components must be in the cryostat along with all materials for closing of the TCO. Is there enough space?



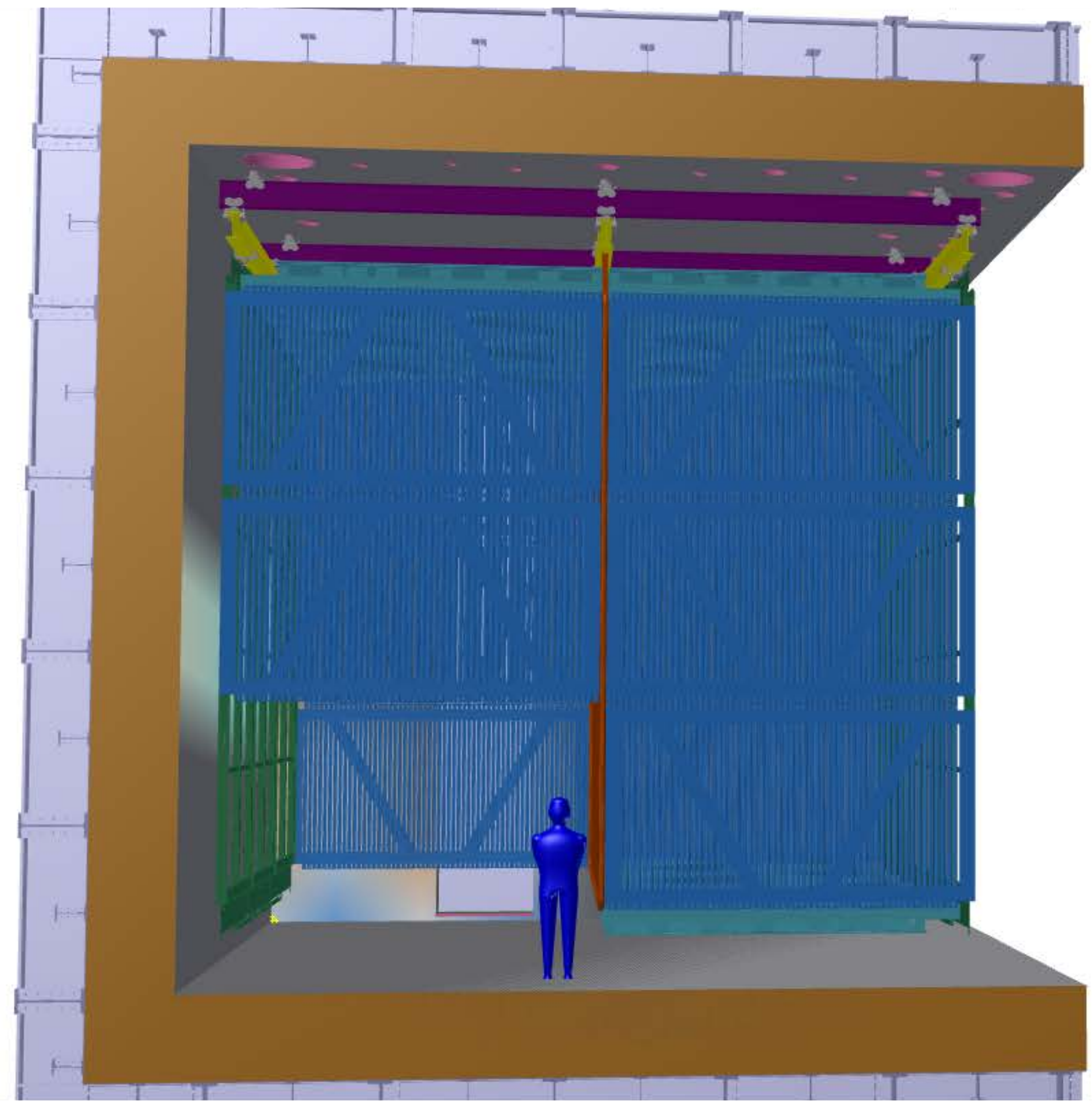
Detector installation #13

- If it is possible to close only the upper 2/3rds of the TCO:
- The final upper FC panel will be installed.
- The two upper FC panels will be installed on the beam window end.
- There is no longer the need for scaffolding/access equipment in this drift region and it can be removed through the lower portion of the TCO.
- The remaining 5 FC panels must now be in the cryostat along with the materials to complete the closing of the TCO.



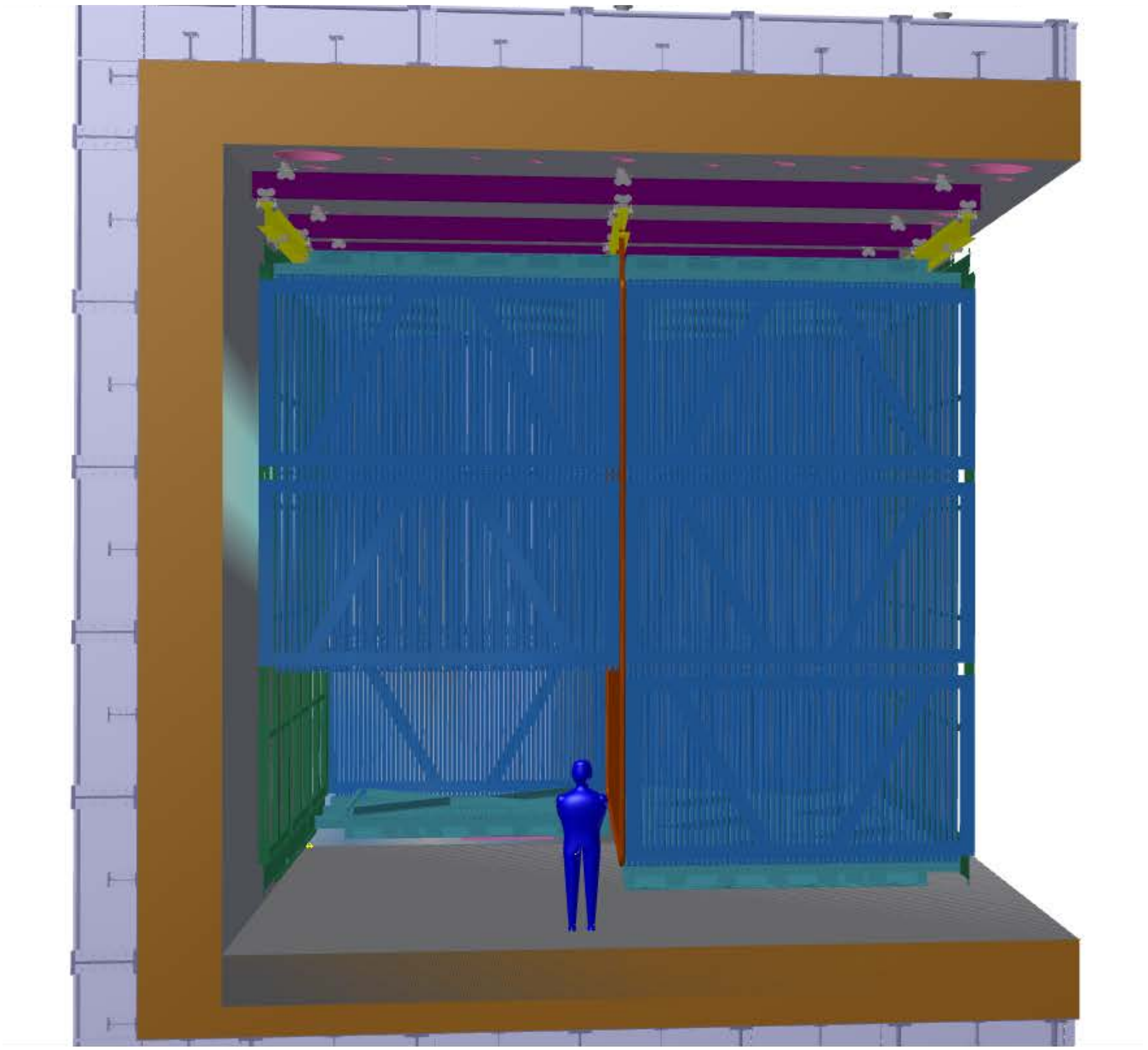
Detector installation #14

- After the closing of the lower portion of the TCO, access to the cryostat will only be available through the 710 mm diameter manholes.
- The bottom end wall FC will be installed on the beam window side.



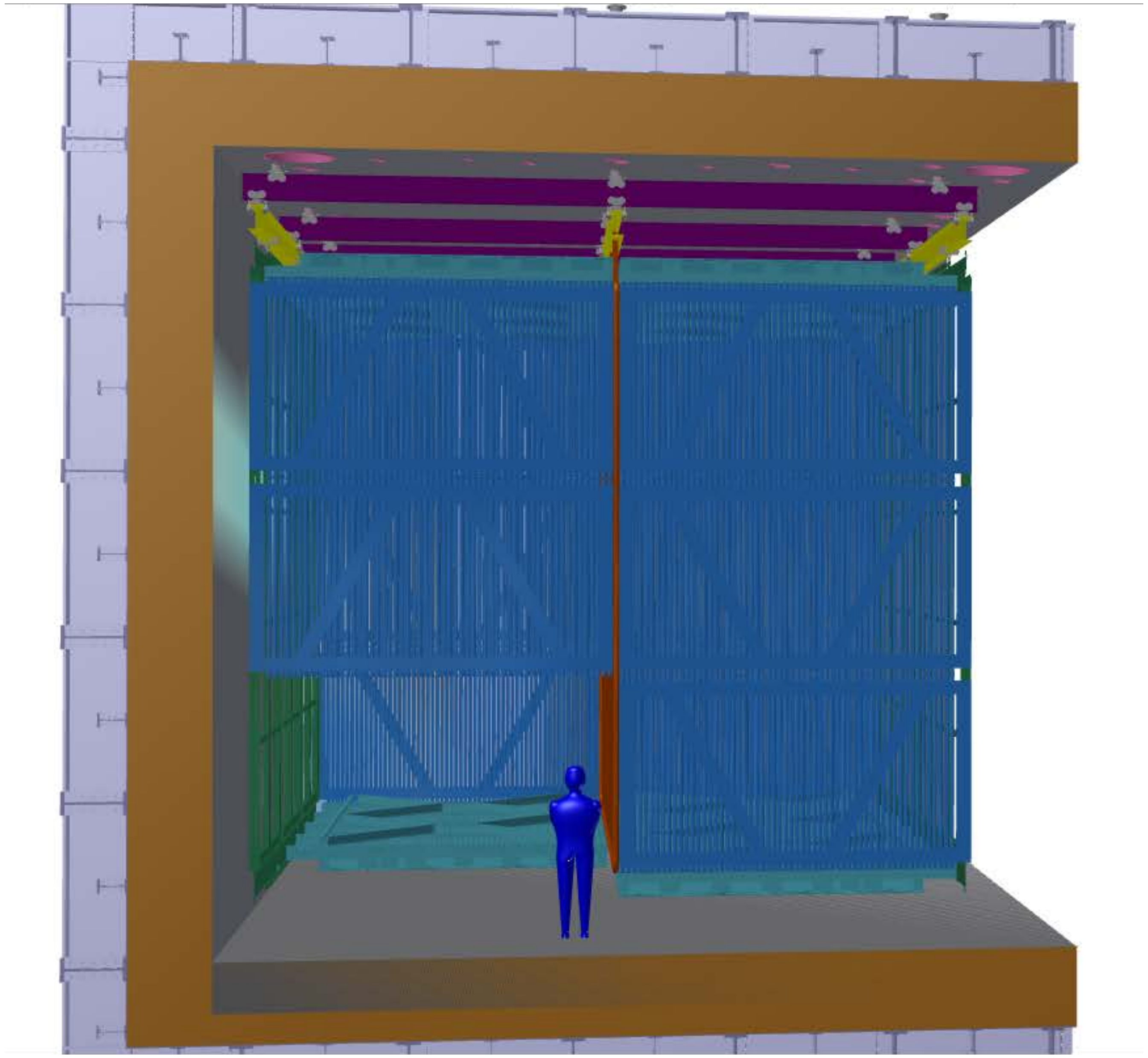
Detector installation #15

- The lower FC panels will be installed beginning at the beam window side of the cryostat.
- Protective flooring must be removed as this progresses.
- All items planned under the TPC must be in place as this progresses.
- Remove the structural bracing of the lower FC panels and remove through the manhole.



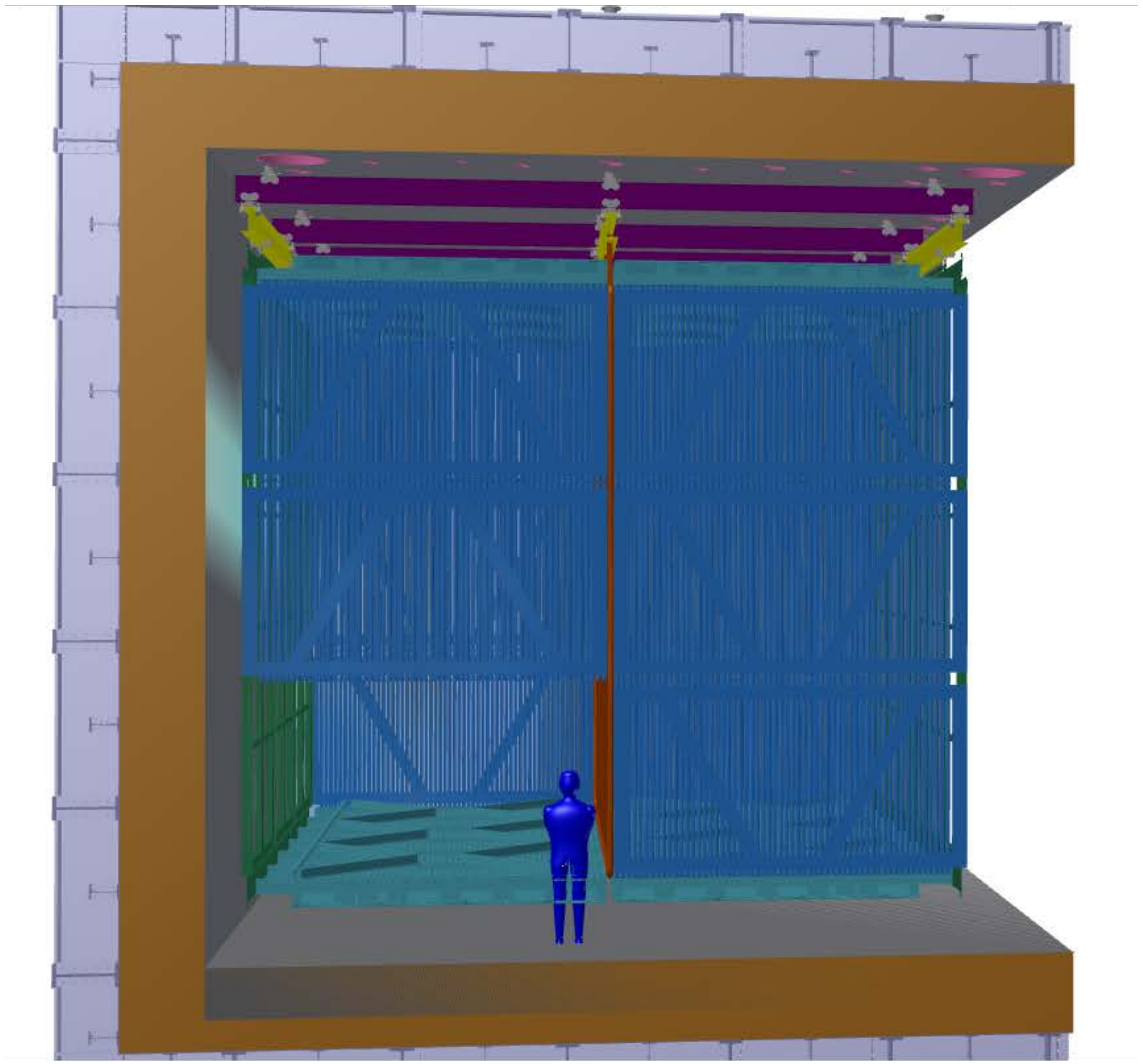
Detector installation #16

- Install the lower center FC panel.



Detector installation #17

- Install the final lower FC panel.



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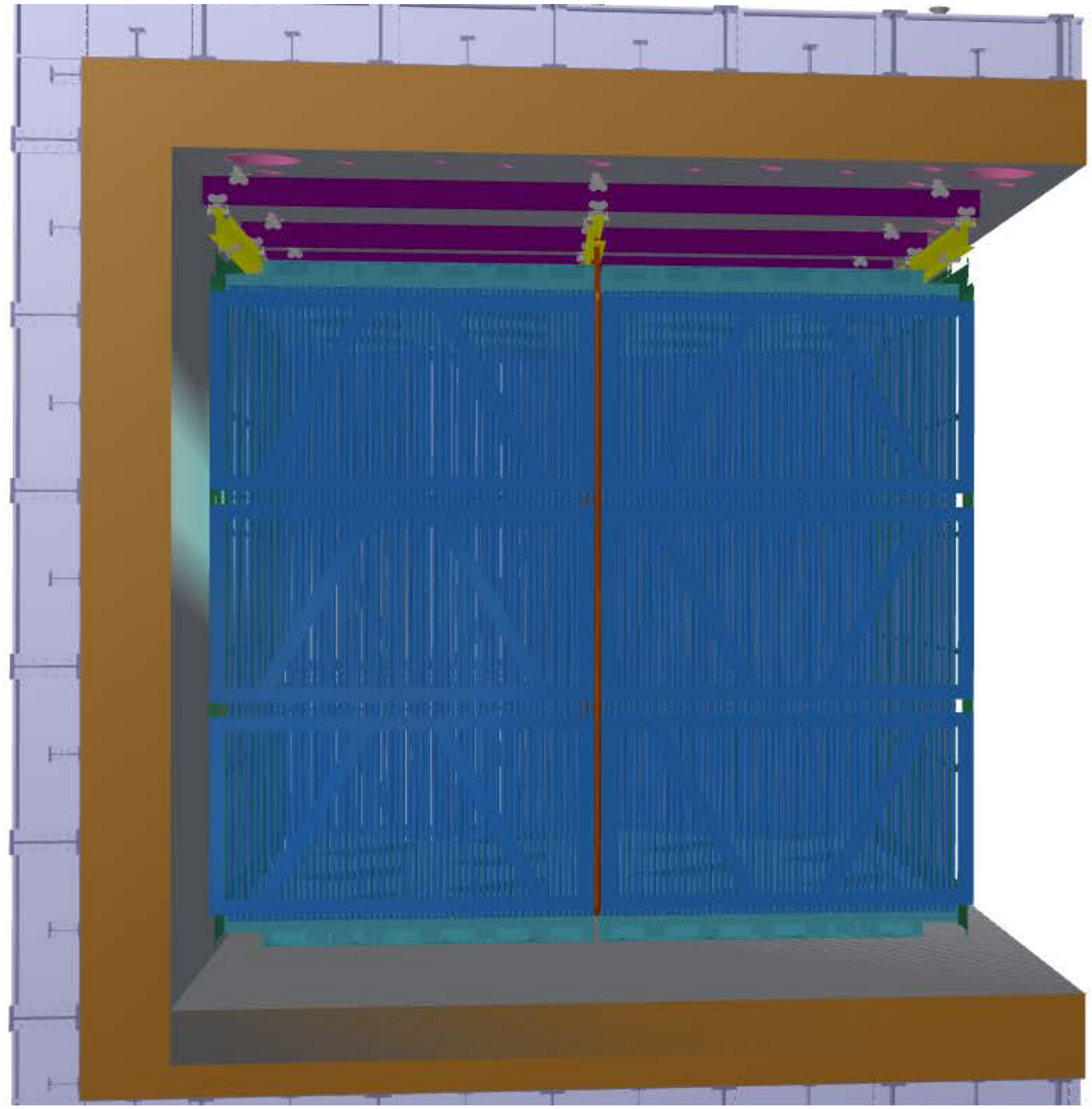
Detector installation #18

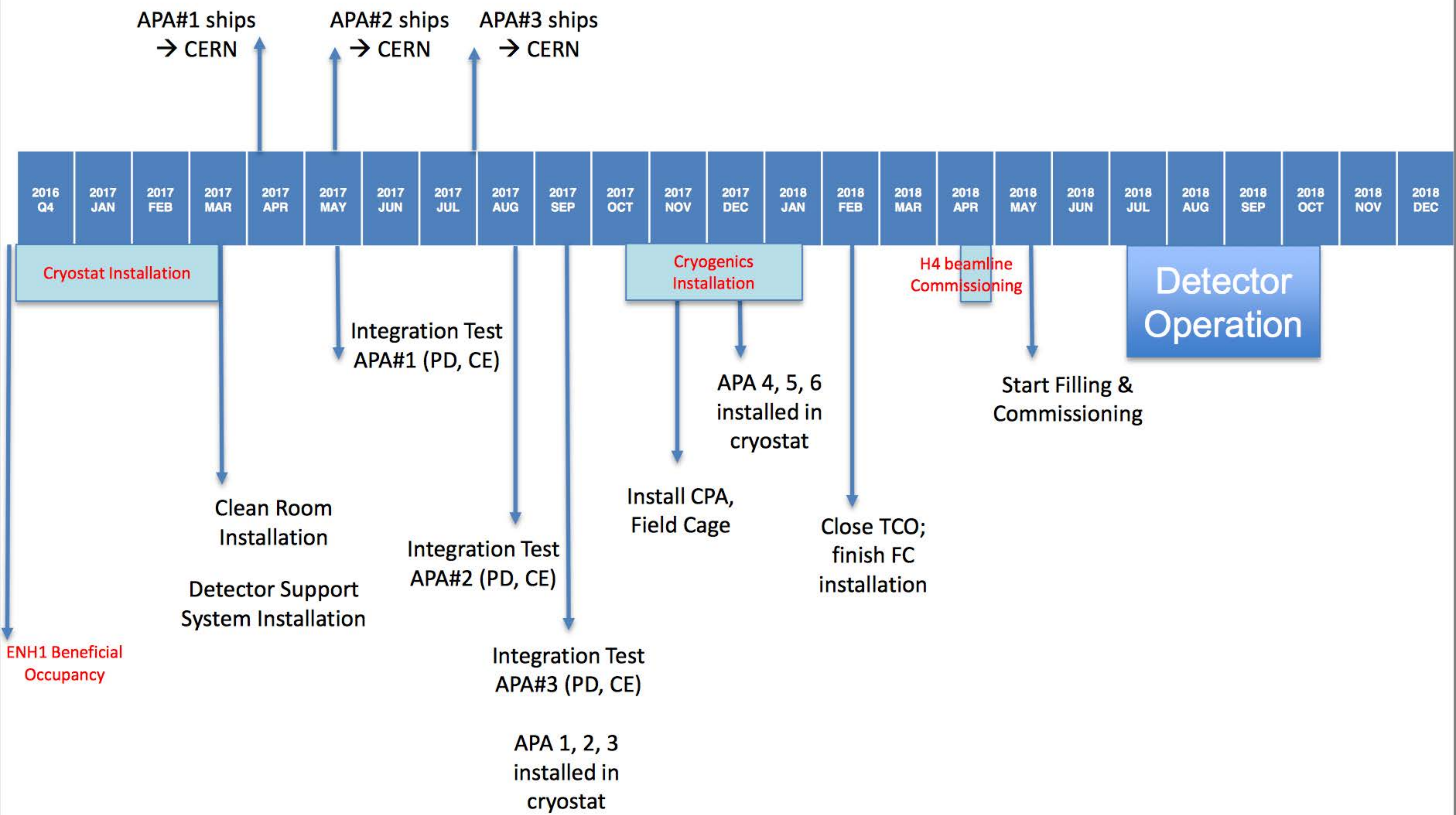
- Complete the installation of the downstream end wall FC.



Detector Installation inside Cryostat completed by **Mar. 2018**

Physics Run:
Jun. - Oct. 2018

ProtoDUNE-SP Integrated Schedule



Outlook:

The liquid Ar TPC is the new - extraordinary powerful - experimental technology adopted for the Worldwide Neutrino Program in the U.S.

The realization of the LBNF supported DUNE experiment will represent one of the most challenging and endeavoring effort in HEP.

The path toward DUNE is well identified, just need to stay on track !