The DUNE Far Detector

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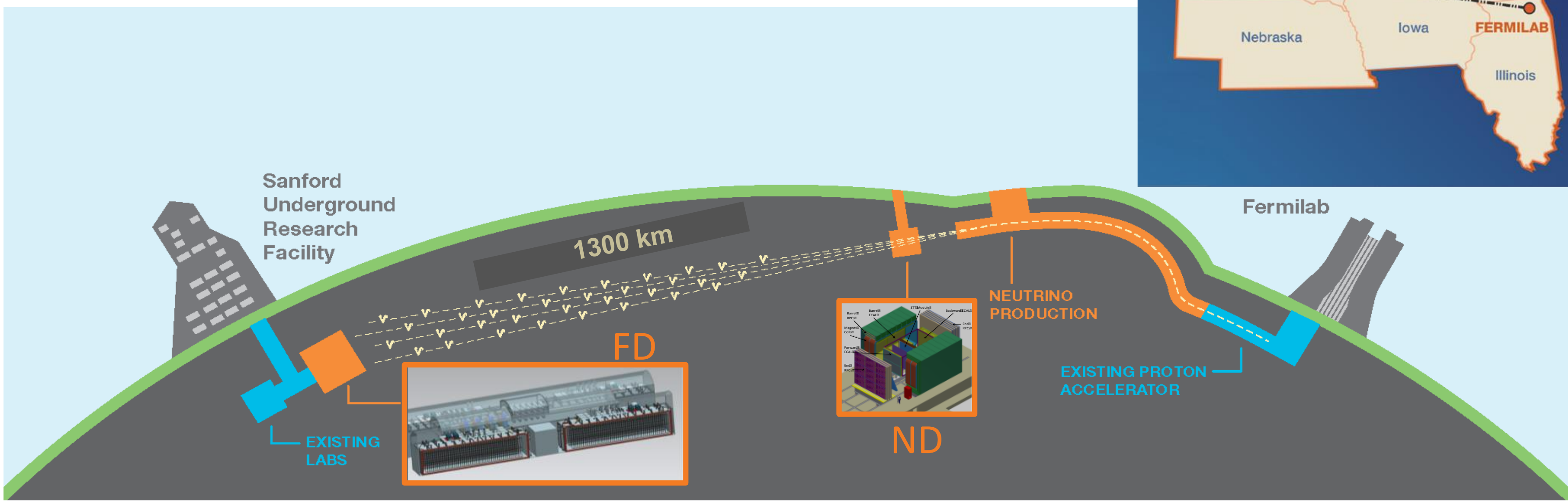
European Neutrino Meeting LBNF/DUNE

7/8 April 2016

DUNE Far Detector



- Approximately 40 kt fiducial mass liquid argon Far Detector.
- Located 1300 km baseline at SURF’s 1478 m level (2,300 mwe).
- Staged construction of four ~10 kt detector modules. First module installation starting in 2021.

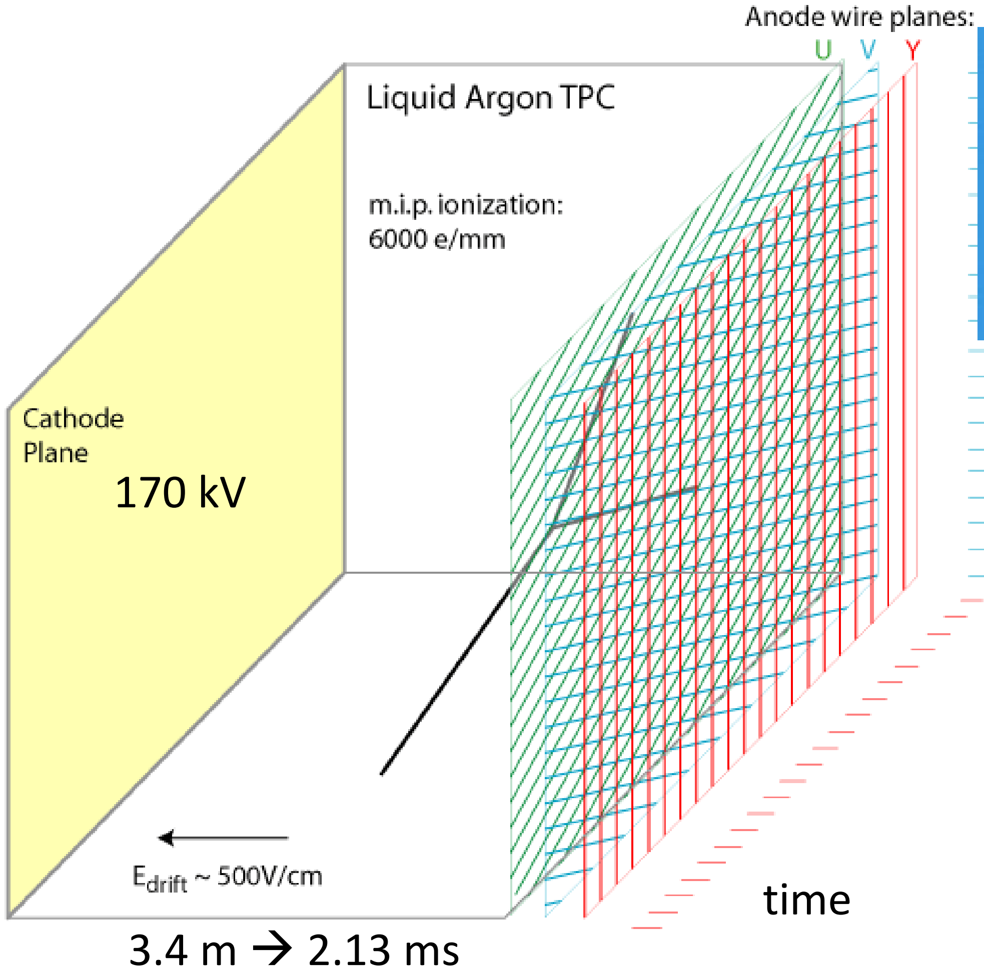
Long-Baseline Neutrino Facility (LBNF) and Deep Underground Neutrino Experiment (DUNE) Conceptual Design Report, Volume 4 The DUNE Detectors at LBNF, arXiv:1601.02984.

Detector Requirements

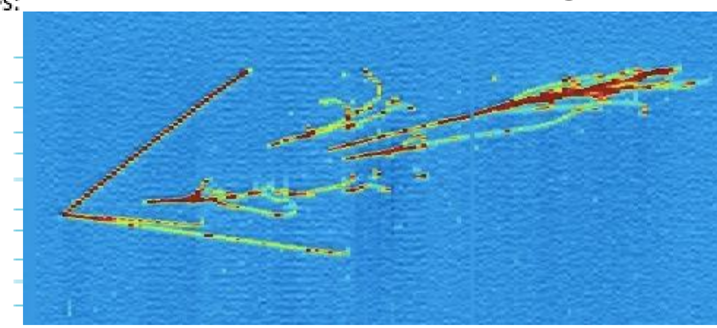
Driven by physics goals, see talk by Mark Thomson

- Ability to do a wide range of physics with different requirements: supernova detection, proton decay, oscillation physics
- Both beam and non-beam physics, wide range of energies
- Baseline to allow for CP and NMO measurements
- Identification of CC electron (anti-)neutrino events
- Identification of CC muon (anti-)neutrino events
- Identification of events with multiple tracks and EM showers
- Cosmic ray shielding (<1% of in-time events)
- Accuracy for event timing.

Time Projection Chamber (TPC)



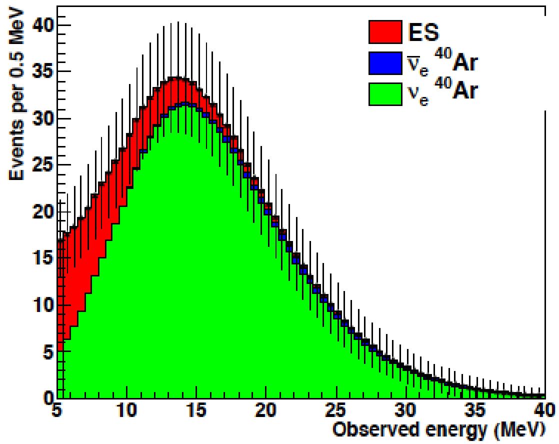
ArgoNeuT

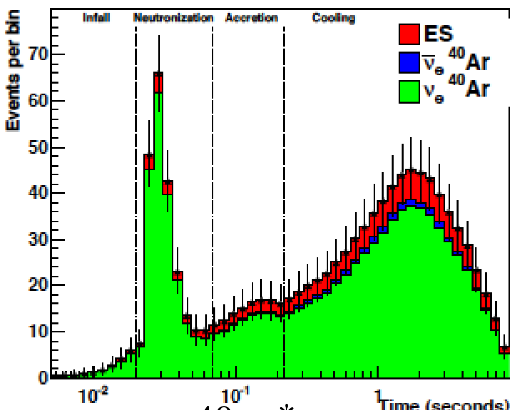


- “Bubble chamber” like imaging capabilities (few mm resolution).
- Excellent energy measurement.
- Excellent e-γ separation.
- Particle identification through dE/dx, range,..
- Timing through scintillation light

Detector Capabilities

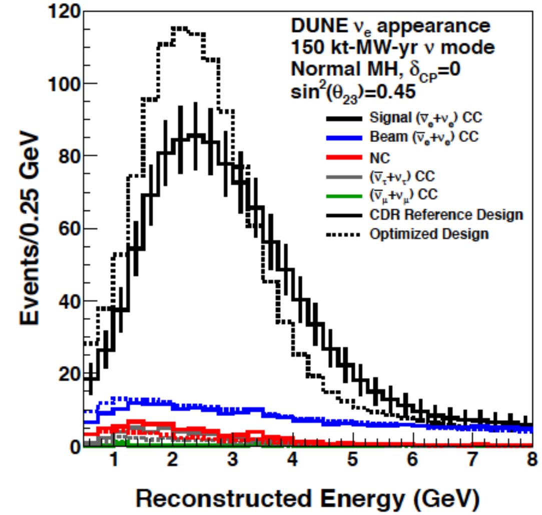
Supernova@10 kpc

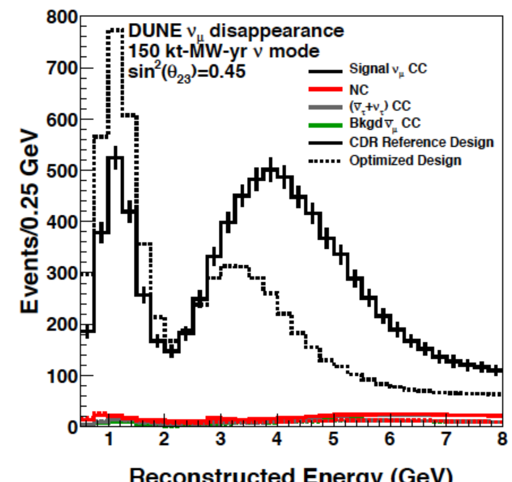




$$\nu_e + {}^{40}\mathrm{Ar} \rightarrow e^- + {}^{40}\mathrm{K}^*$$

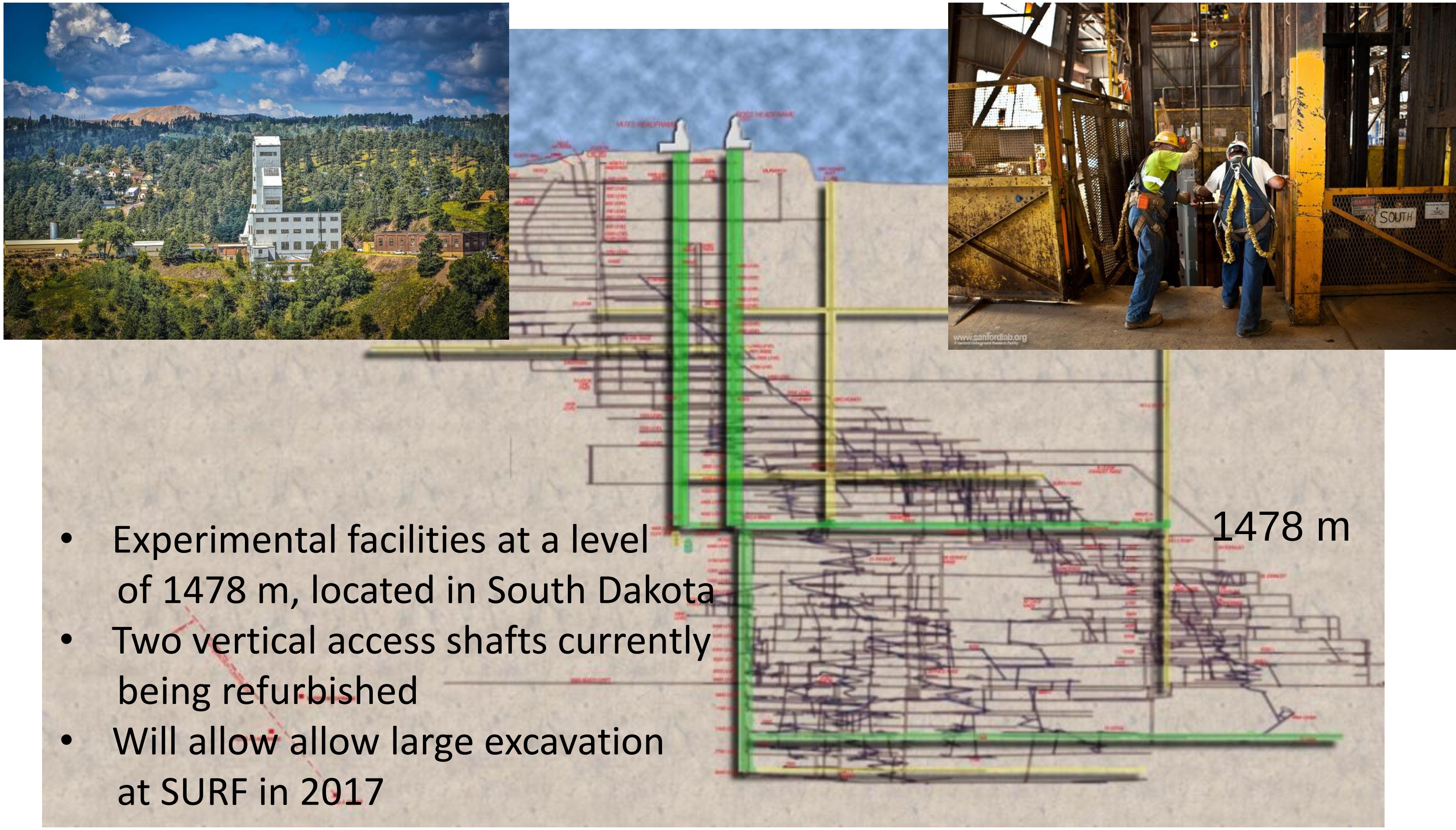
Oscillation physics





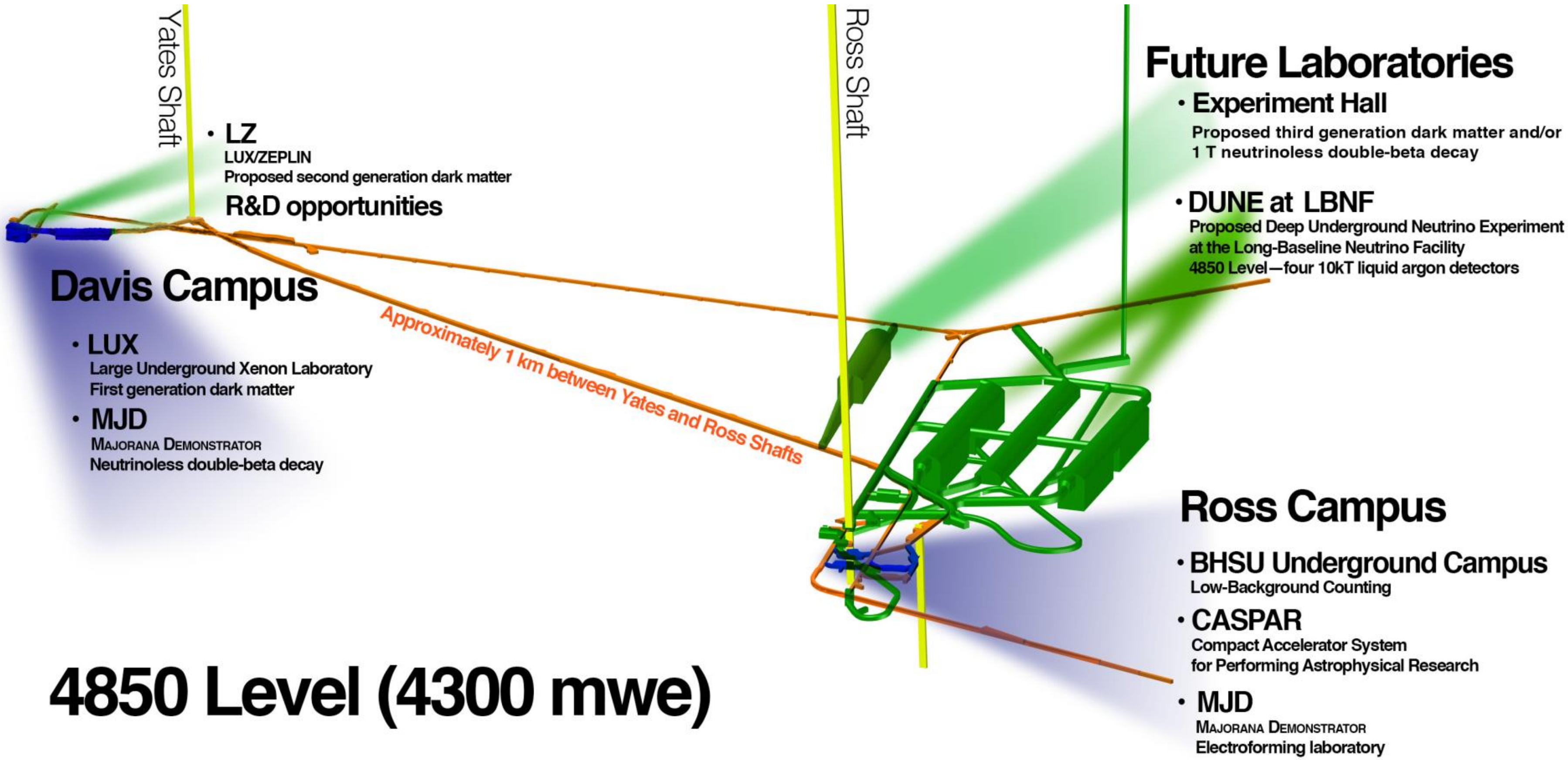
also: $p \rightarrow K^+ \nu$

Sanford Underground Research Facility (SURF)



- Experimental facilities at a level of 1478 m, located in South Dakota
- Two vertical access shafts currently being refurbished
- Will allow allow large excavation at SURF in 2017

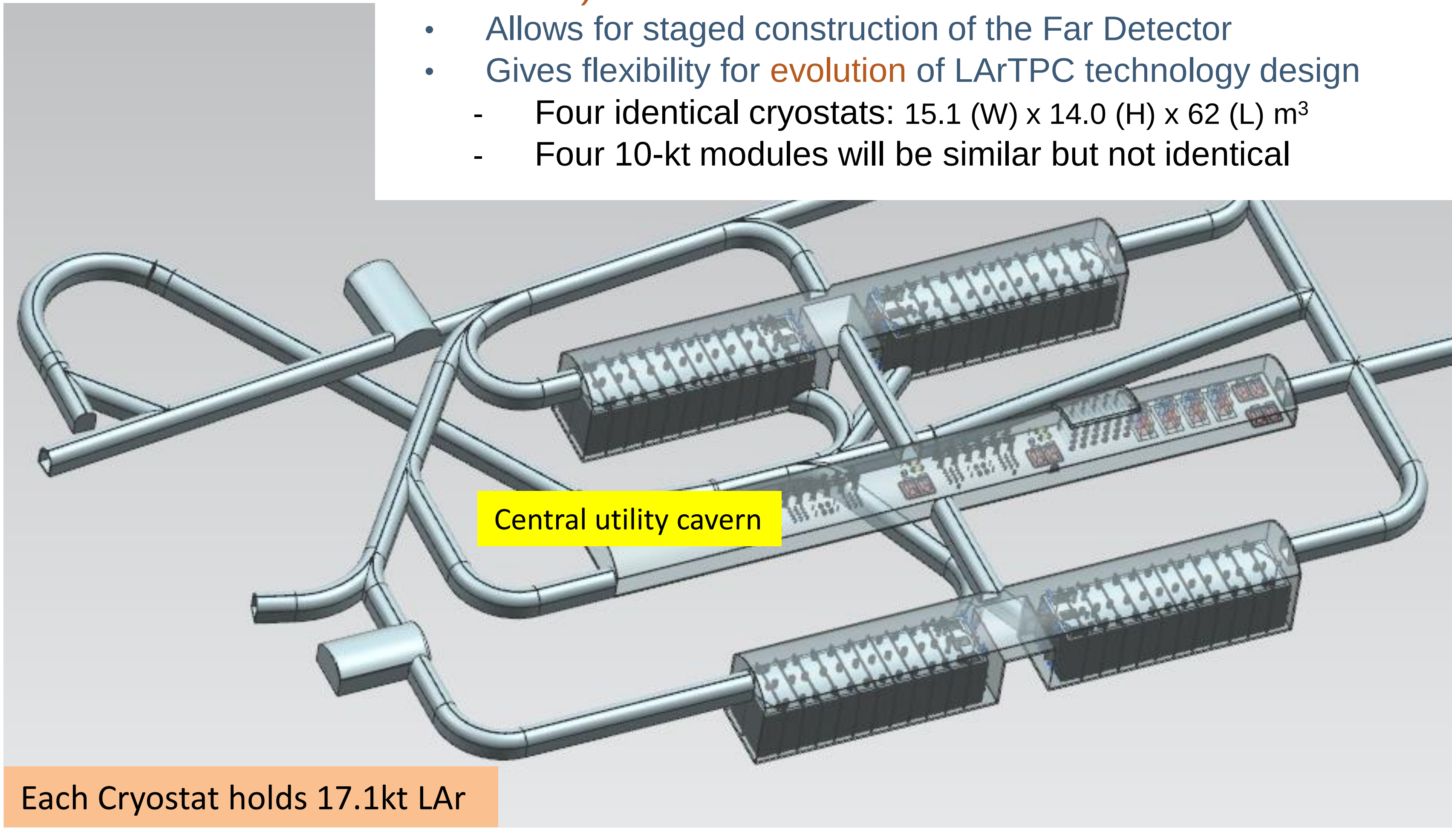
Sanford Underground Research Facility (SURF)



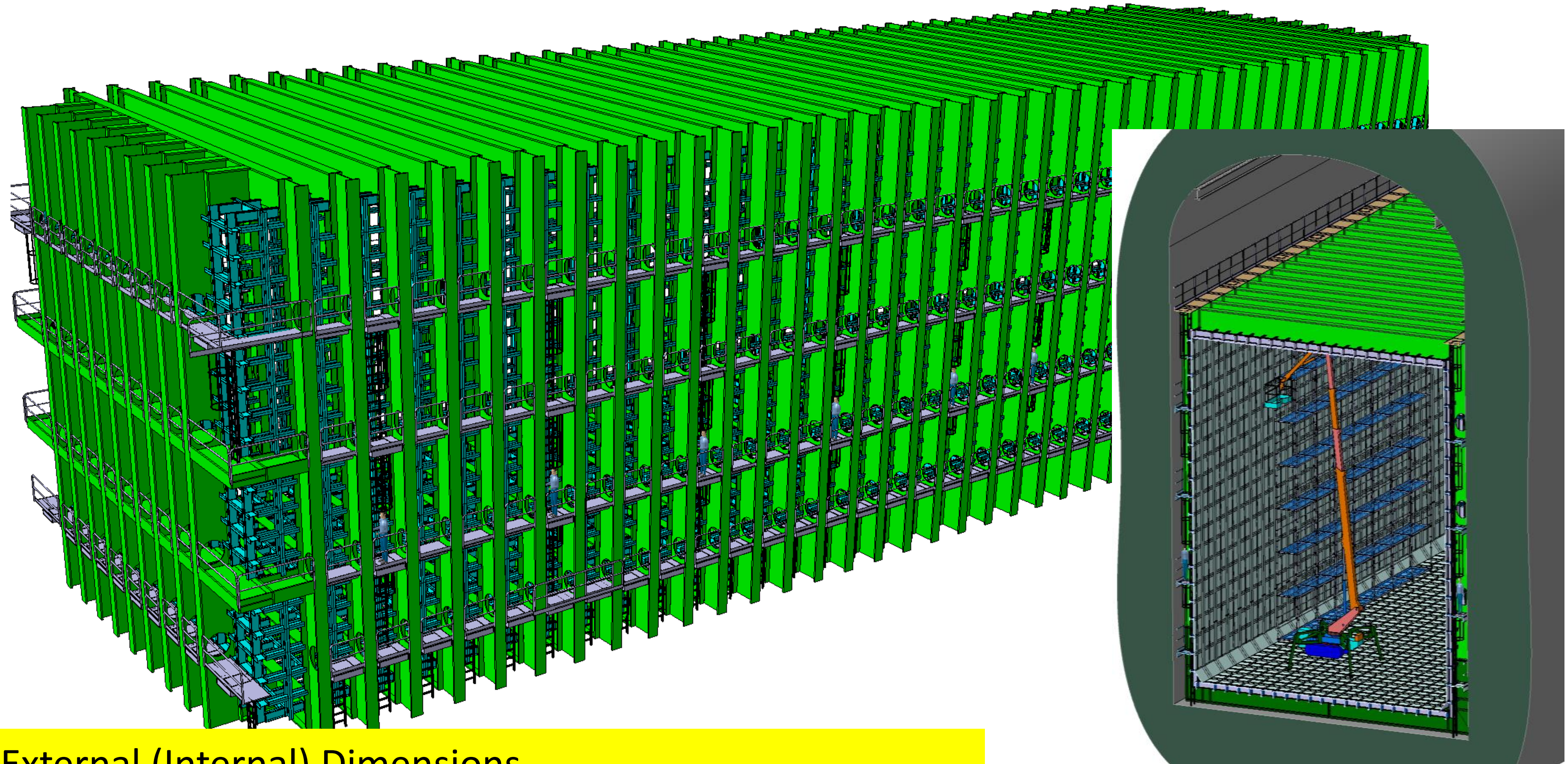
Far Detector Lay-out

Four caverns hosting four independent 10-kt (fiducial mass) Far Detector modules:

- Allows for staged construction of the Far Detector
- Gives flexibility for evolution of LArTPC technology design
  - Four identical cryostats: 15.1 (W) x 14.0 (H) x 62 (L) m^3
  - Four 10-kt modules will be similar but not identical



Free-standing Steel Cryostat

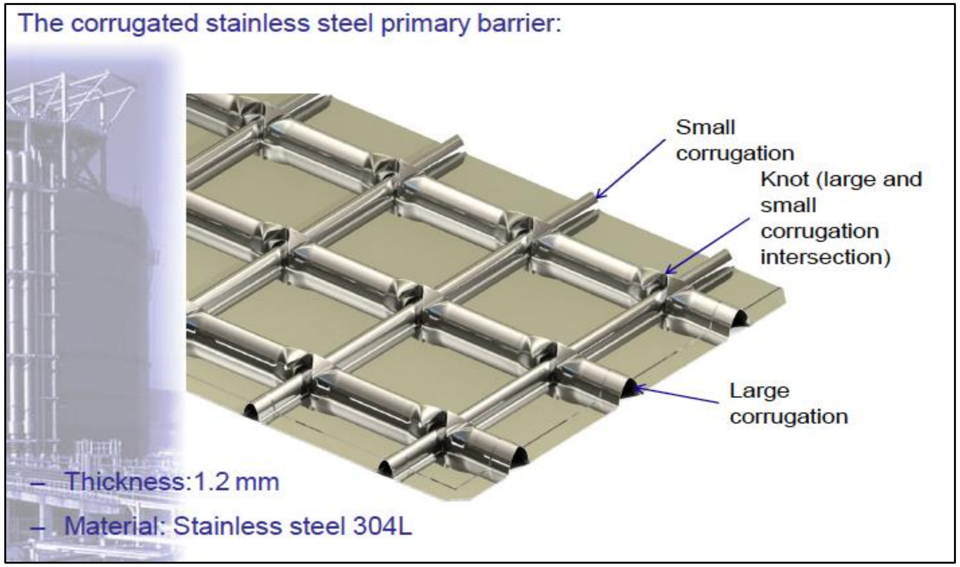


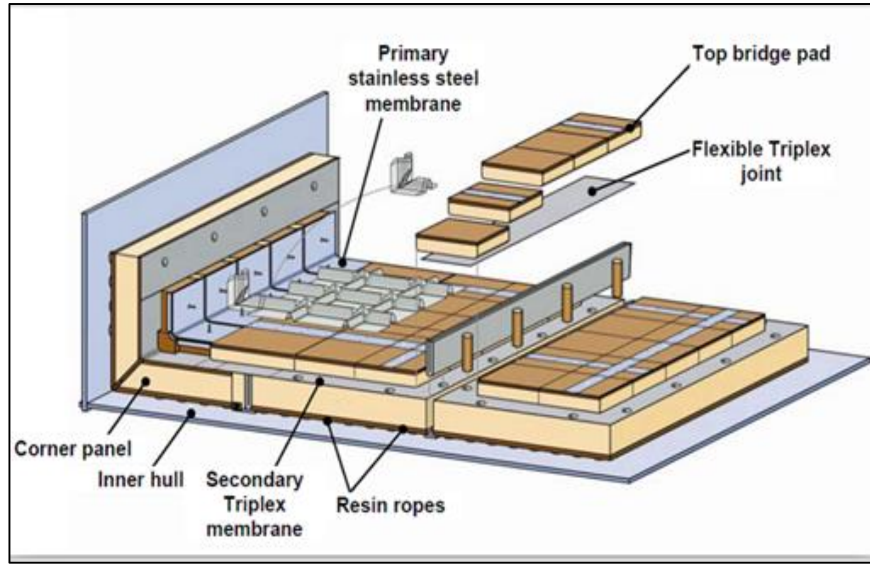
<u>External (Internal) Dimensions</u>

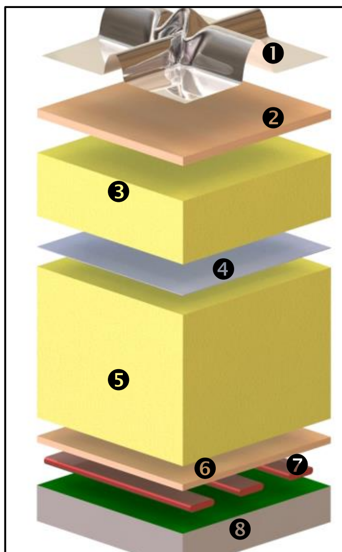
19.1m (16.9m) W x 18.0m (15.8m) H x 66.0m (63.8m) L

Membrane Cryostat Design

Standard for liquid natural gas

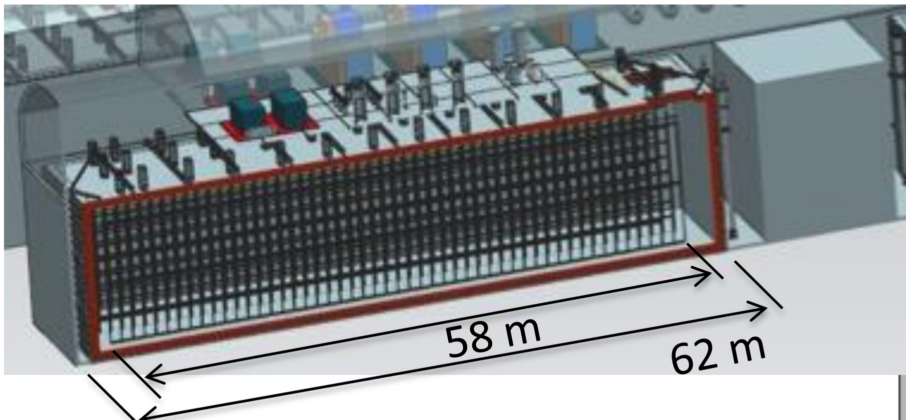




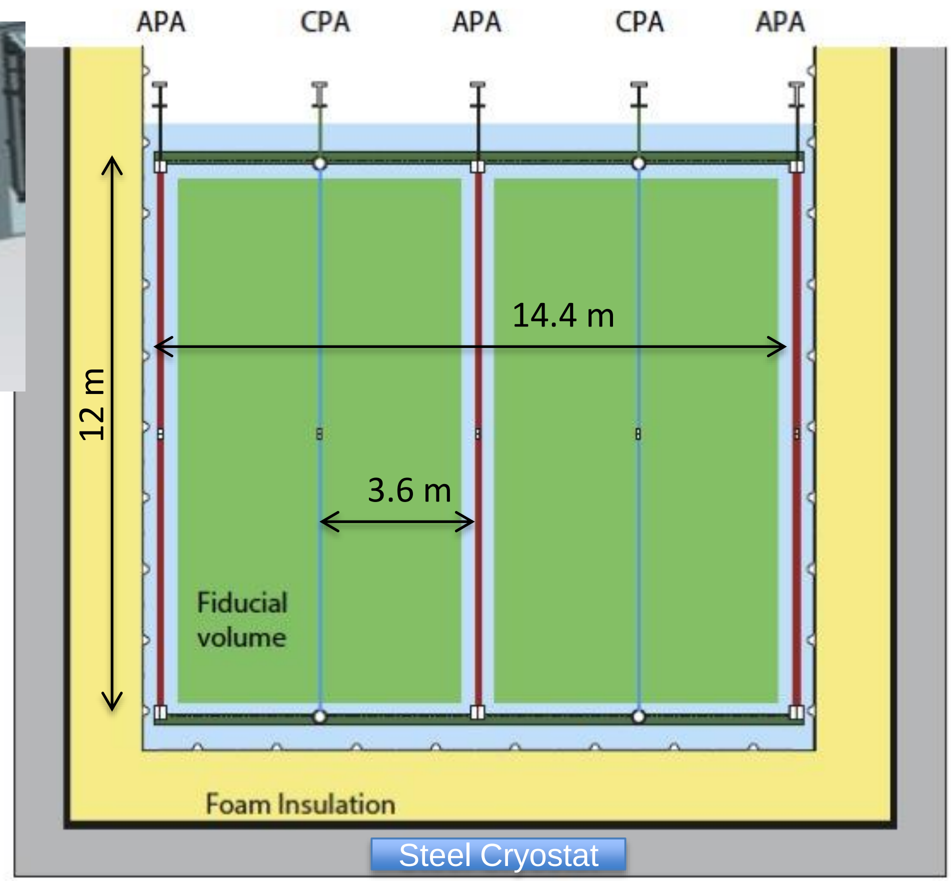


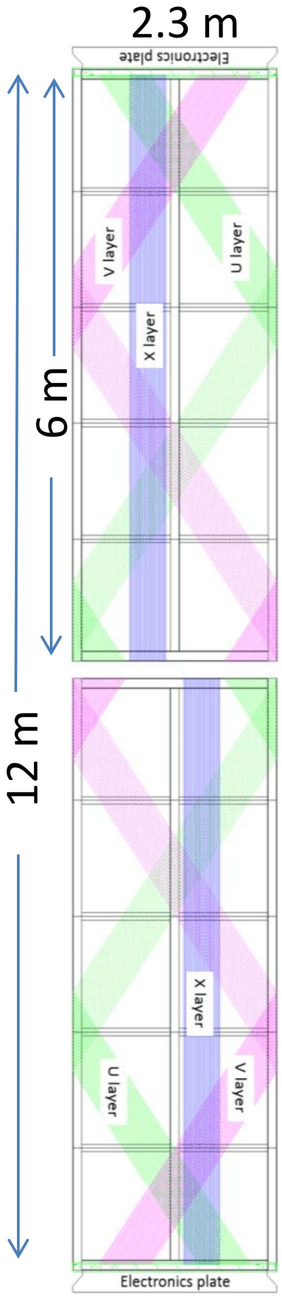
1. Stainless steel primary membrane
2. Plywood board
3. Reinforced polyurethane foam
4. Secondary barrier
5. Reinforced polyurethane foam
6. Plywood board
7. Bearing mastic
8. Steel structure with moisture barrier

First Detector: Single-phase

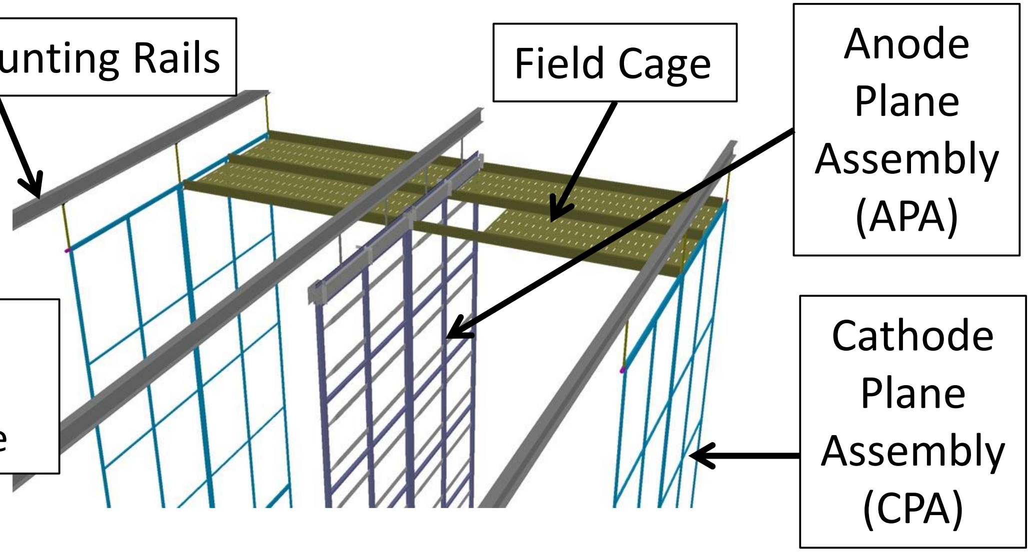


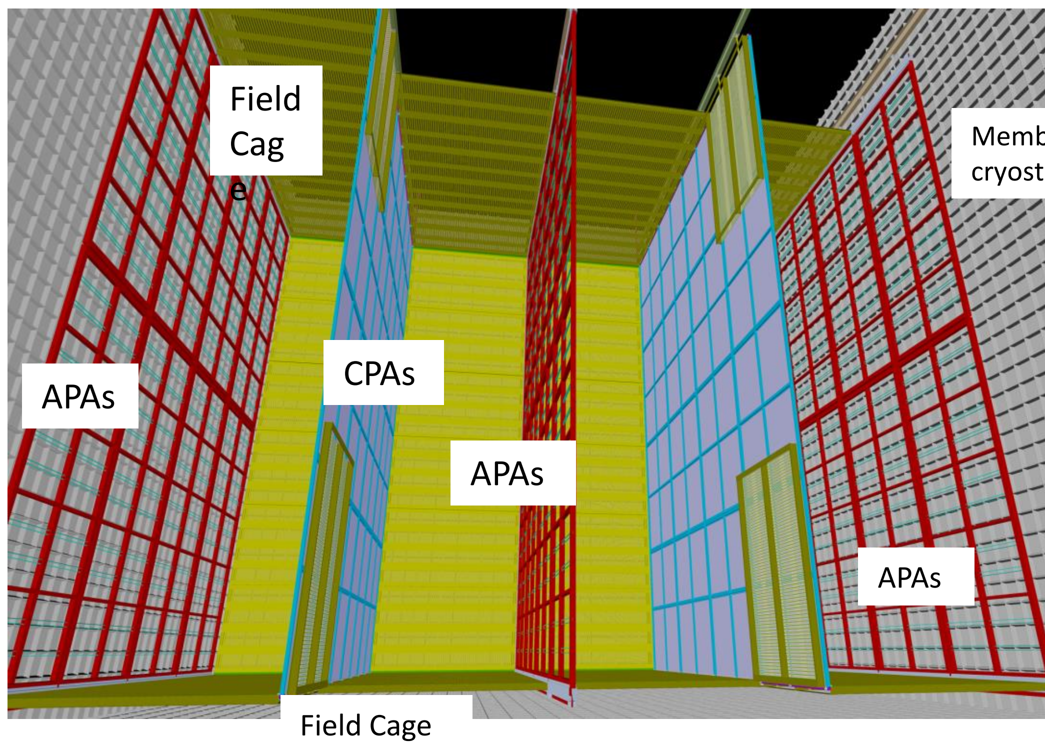
- 17.1/13.8/11.6 Total/Active/Fiducial mass
- 3 Anode Plane Assemblies (APA) wide (wire planes)
  - Cold electronics 384,000 channels
- Cathode planes (CPA) at 180kV
  - 3.6 m max drift length
- Photon detection for event interaction time determination for underground physics

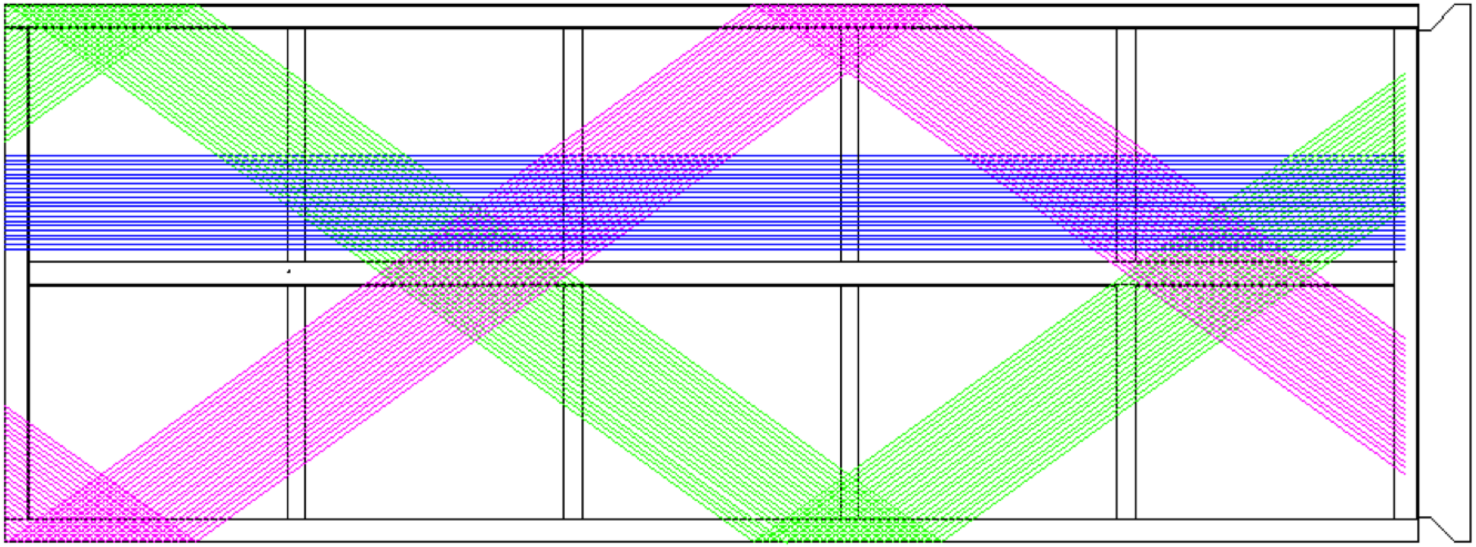




- wrapped wires
- 2 induction & 1 collection plane







We require 150 APAs and 200 CPAs per module

40% scale module produced at PSL, Madison

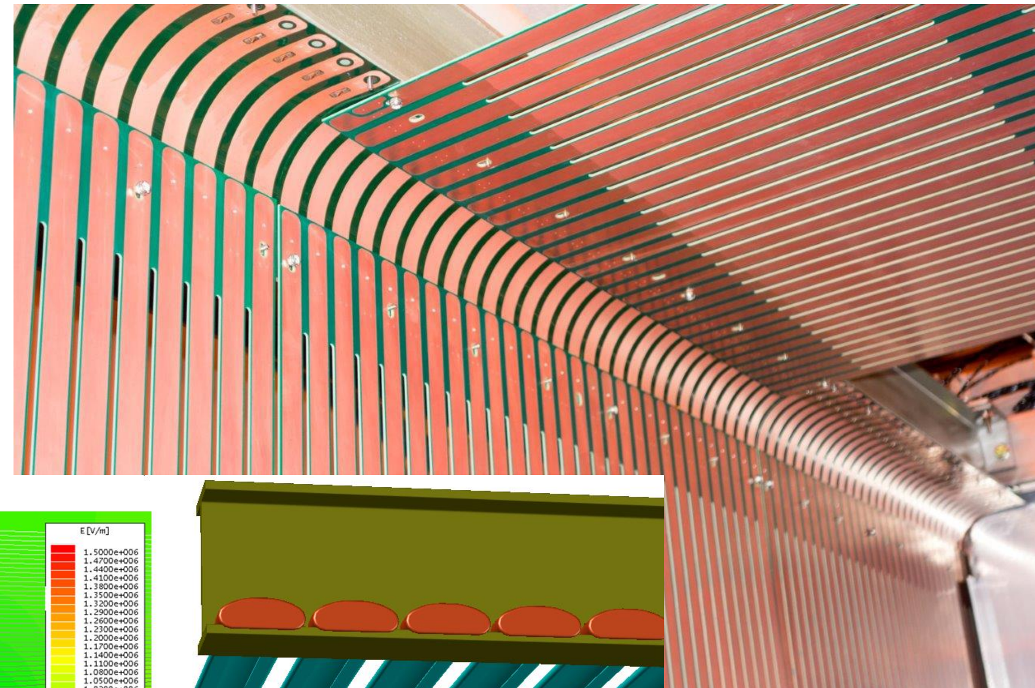
Field Cage

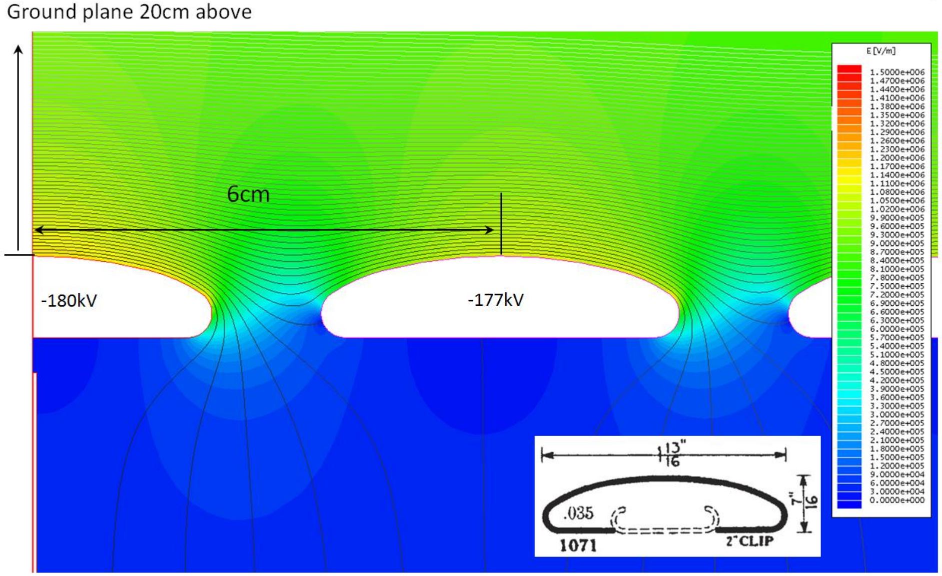
Ensures uniform magnetic field

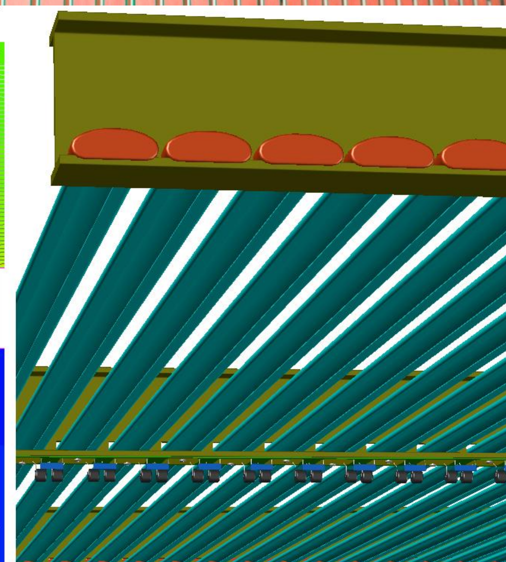
The field cage design now uses rolled form metal profiles, rather than a printed circuit board (CDR).

May be used for Dual Phase as well.

Corner of Fermilab 35-ton Field Cage

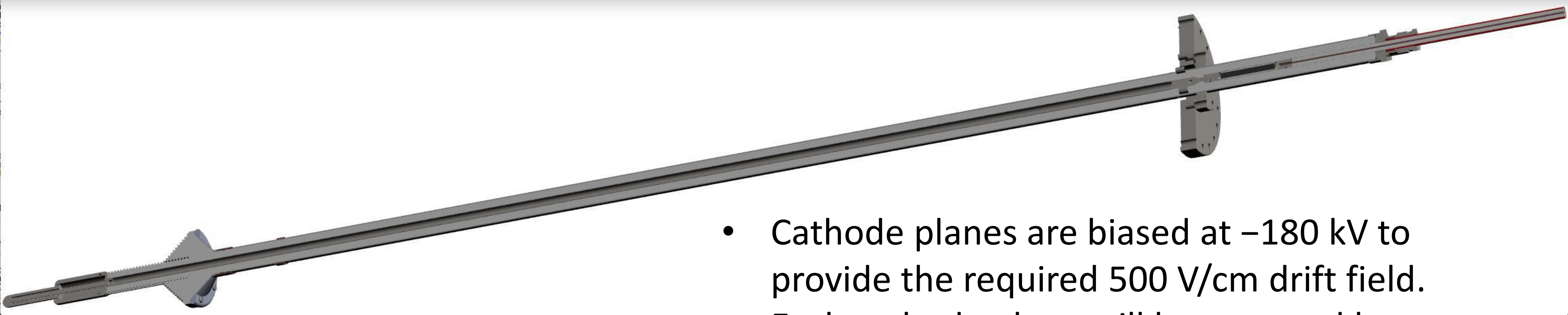






High Voltage Feedthrough

35-ton feedthrough



- Cathode planes are biased at −180 kV to provide the required 500 V/cm drift field.
- Each cathode plane will be powered by a dedicated HV power supply through an RC filter and feedthrough.
- HV bus will connect to cathode plane.

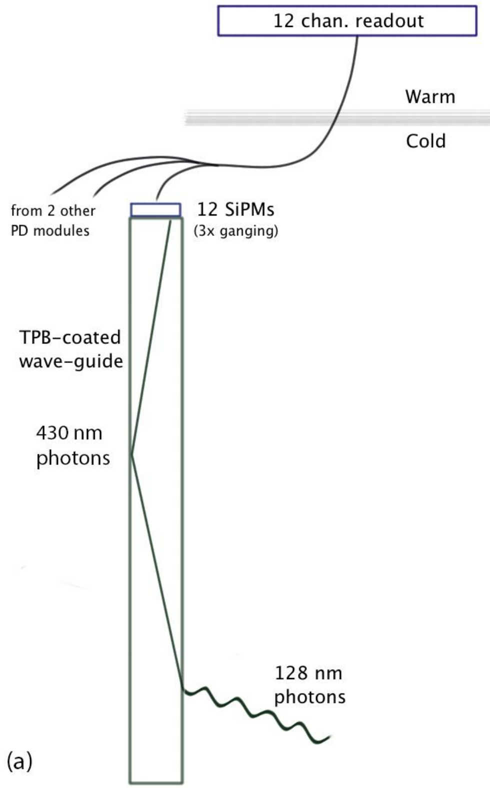
Photon Detection

Detect 128-nm VUV prompt and delayed photons

Bars coated with TPB wavelength shifter

Determine t_0 for non-beam related events with resolution of < 1 µs

Enable 3D localisation of events in liquid argon



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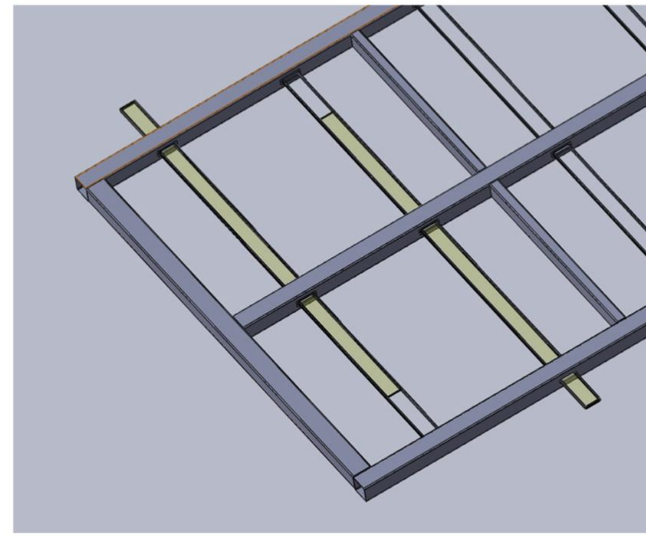
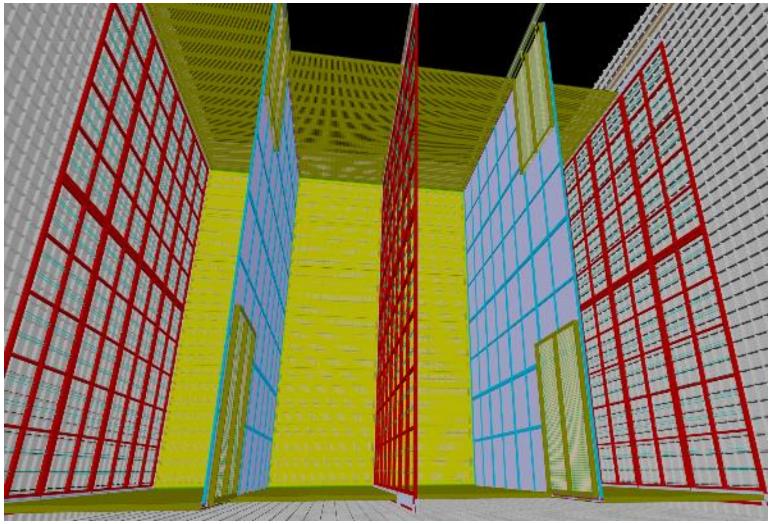


(b)

Alternative designs under consideration

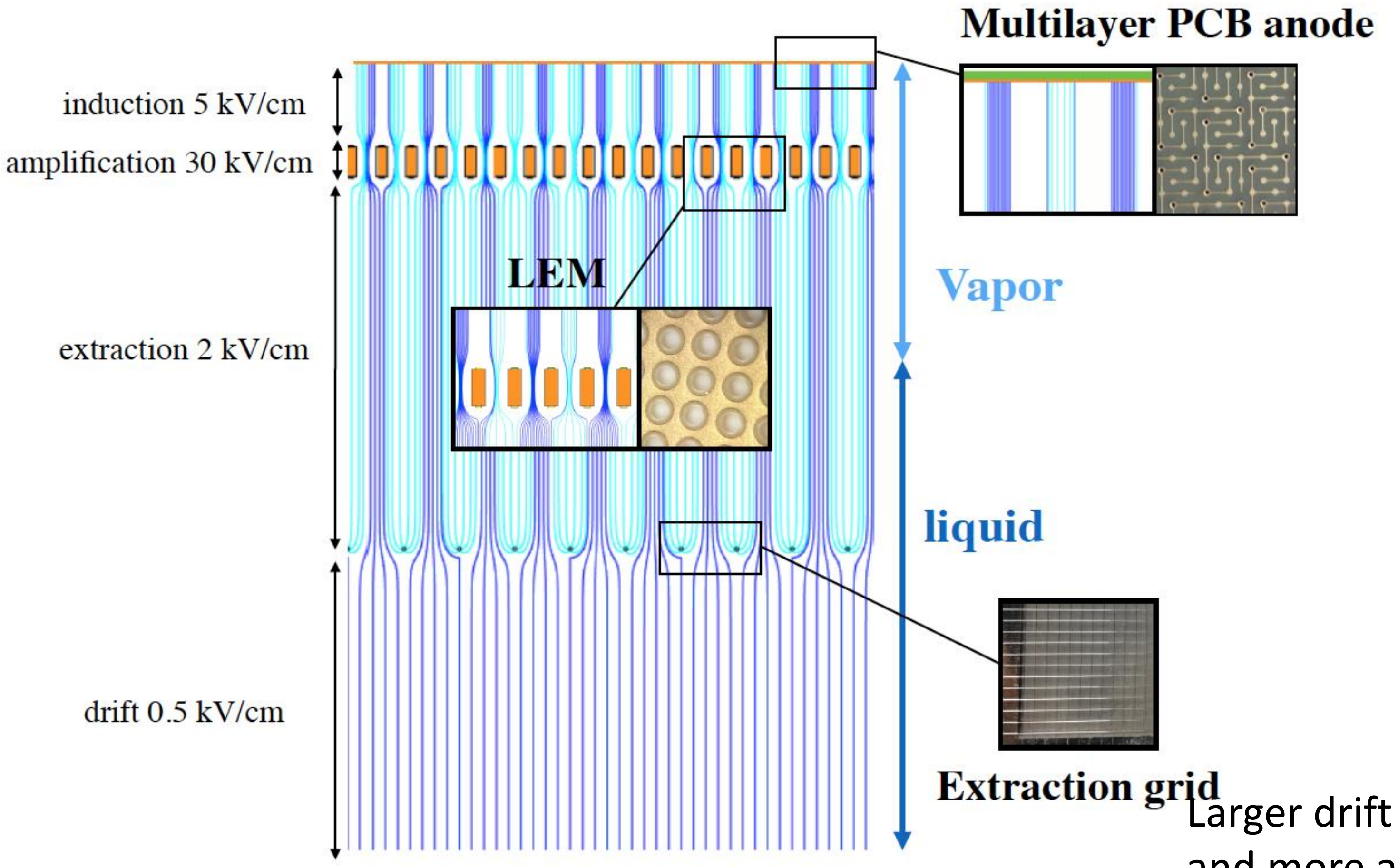
First 10 kt Far Detector Module

- Active volume: **12 m x 14 m x 58 m**
- 150 Anode Plane Assemblies
  - 6 m high x 2.3 m wide
  - Embedded photon detection system
- 200 Cathode Plane Assemblies
  - 3 m high x 2.3 m wide
- A:C:A:C:A arrangement
- Cathodes at -180 kV for 3.5 m drift
- APAs have wrapped wires – read out both sides
- Each side has one collection wire plane & two induction planes



Alternative Design: Dual-phase

Could form basis of second or subsequent 10-kt FD modules

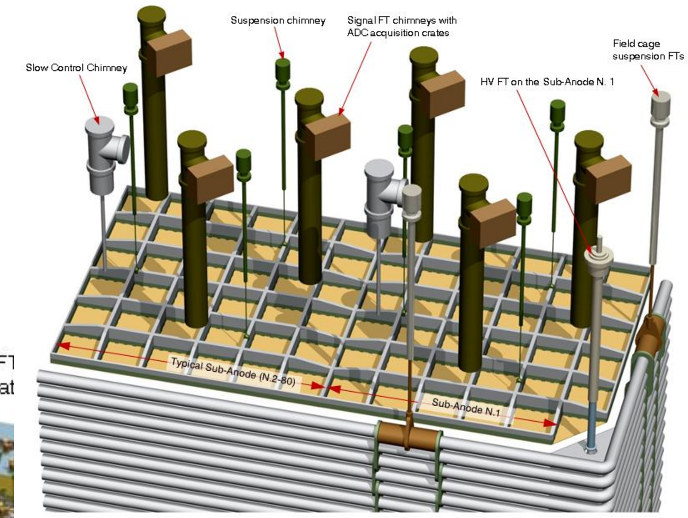


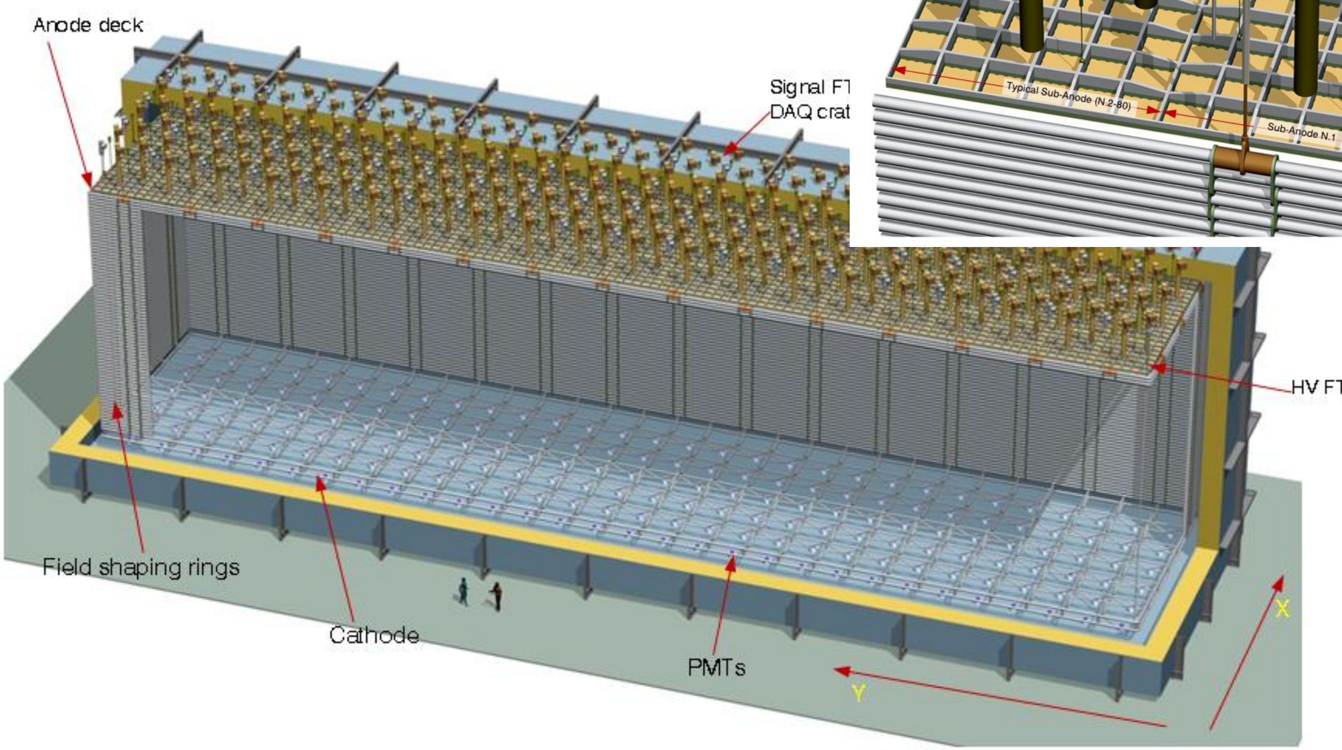
Larger drift distances and more active volume than single-phase

Alternative Design: Dual-phase

Read-out through nitrogen-filled chimneys on top of DP module

Also provide HV access

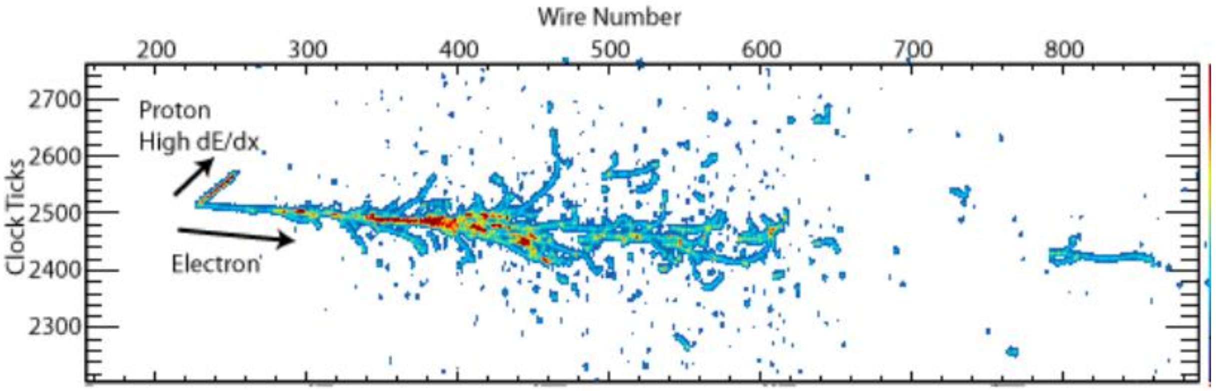




Synergies between designs

- Interface to the cryogenics system
- High voltage
- Photon detection
- Calibration
- Underground installation strategies
- Local computing infrastructure and DAQ
- Detector modeling and simulation

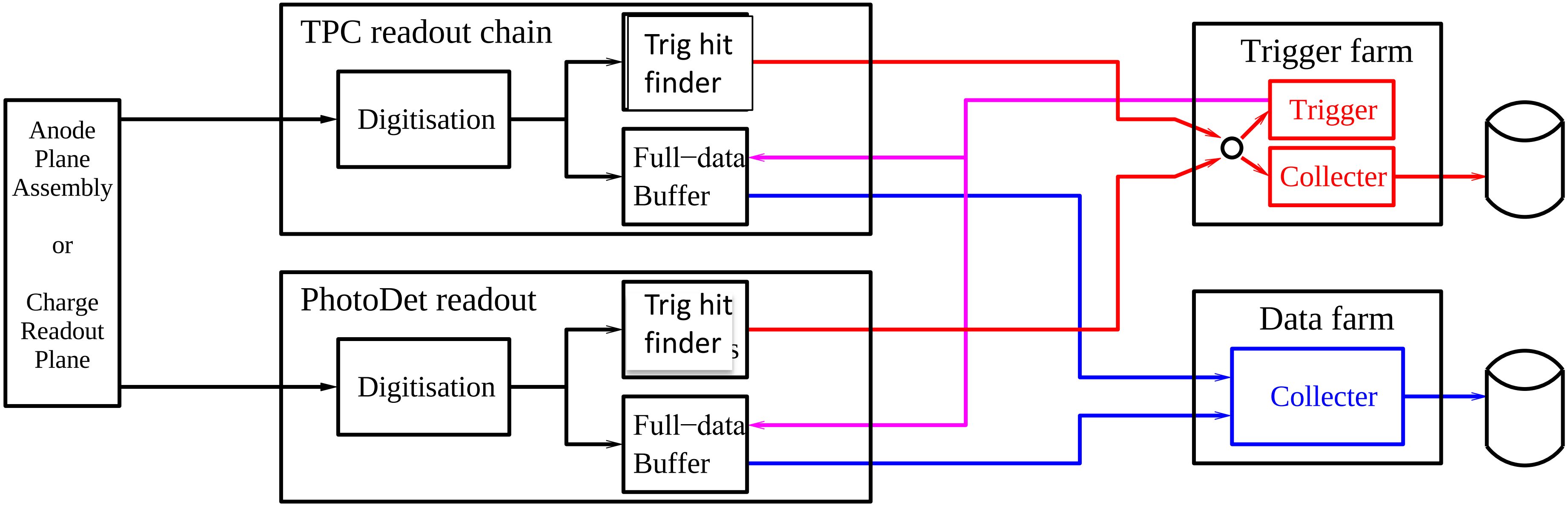
Data acquisition



Challenges:

- Detector always live
- Remove noise and compress data

- Per 10kt module:
  - **TPC**: 2MHz (2.5MHz) ADCs 390k (160k) channels for SP (DP)
  - **Photon detectors**: 3000 channels, faster ADC (64MHz)
- Pre-trigger TPC data rate of 1.1TB/s (SP), 0.77TB/s (DP).
- Low underground event rate (one beam spill per second, one cosmic ray per minute) allows online data processing.



DAQ and trigger concepts still being developed

- Multiple streams
- Multiple types of trigger
- Multi-level triggering

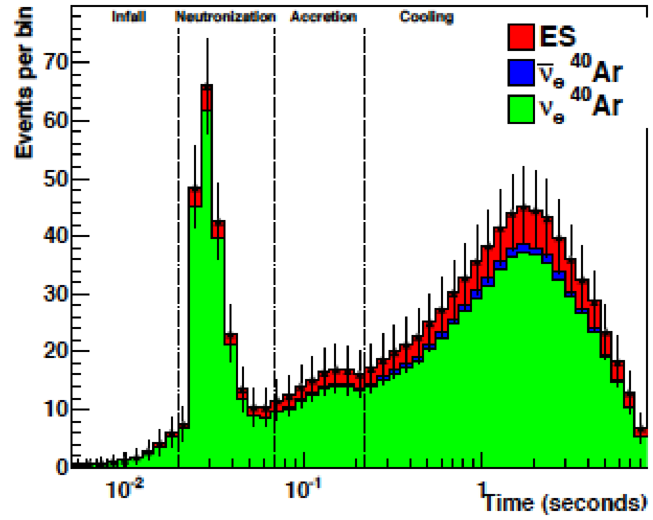
Supernova trigger

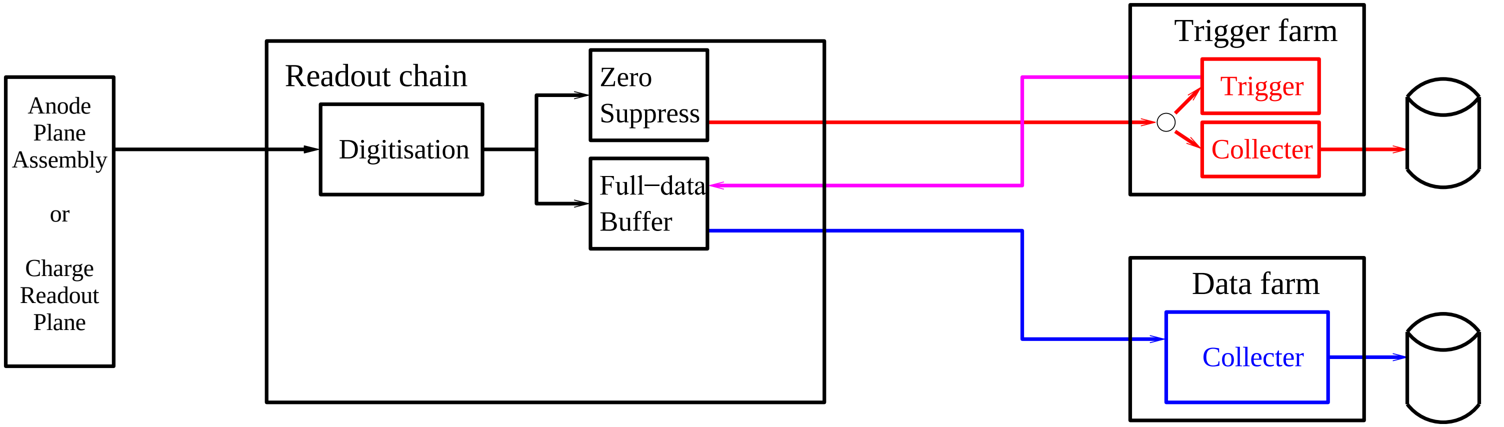
Supernova trigger is especially challenging:

Interested in low energy depositions about 20cm from neutrino interactions.

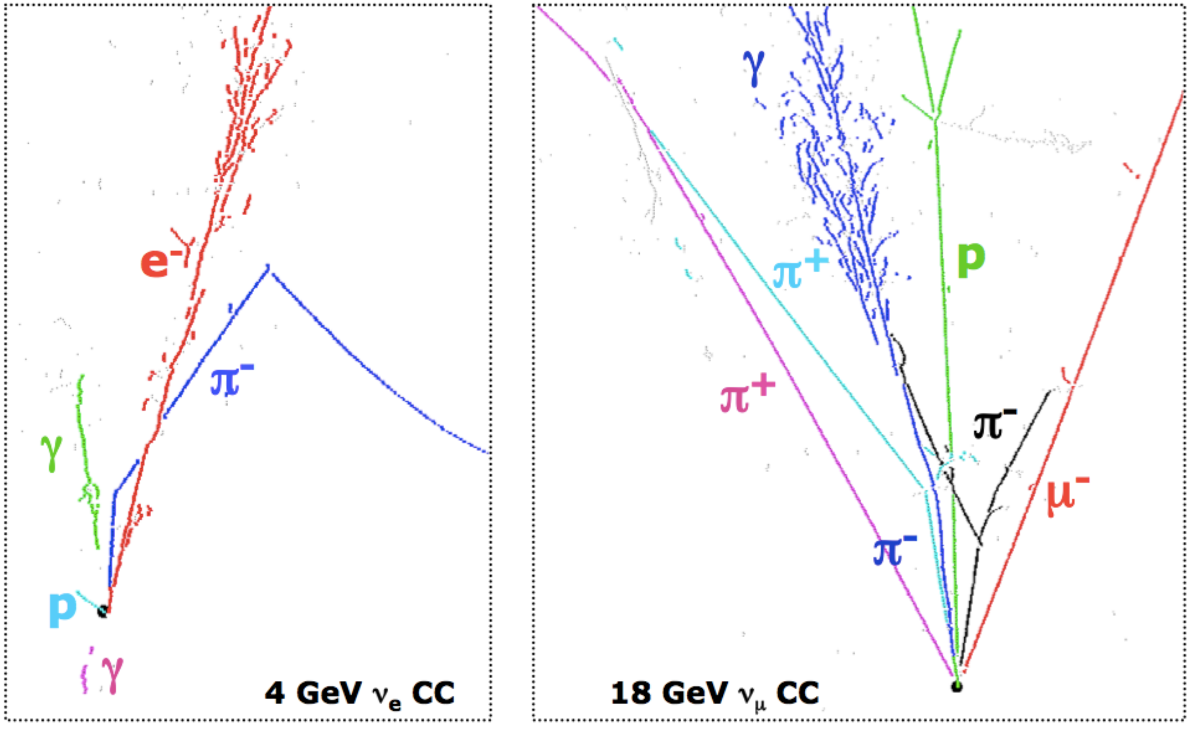
Events arrive over about 10 seconds.

Data recorded could be around 10TB.





Another Challenge: Event Reconstruction

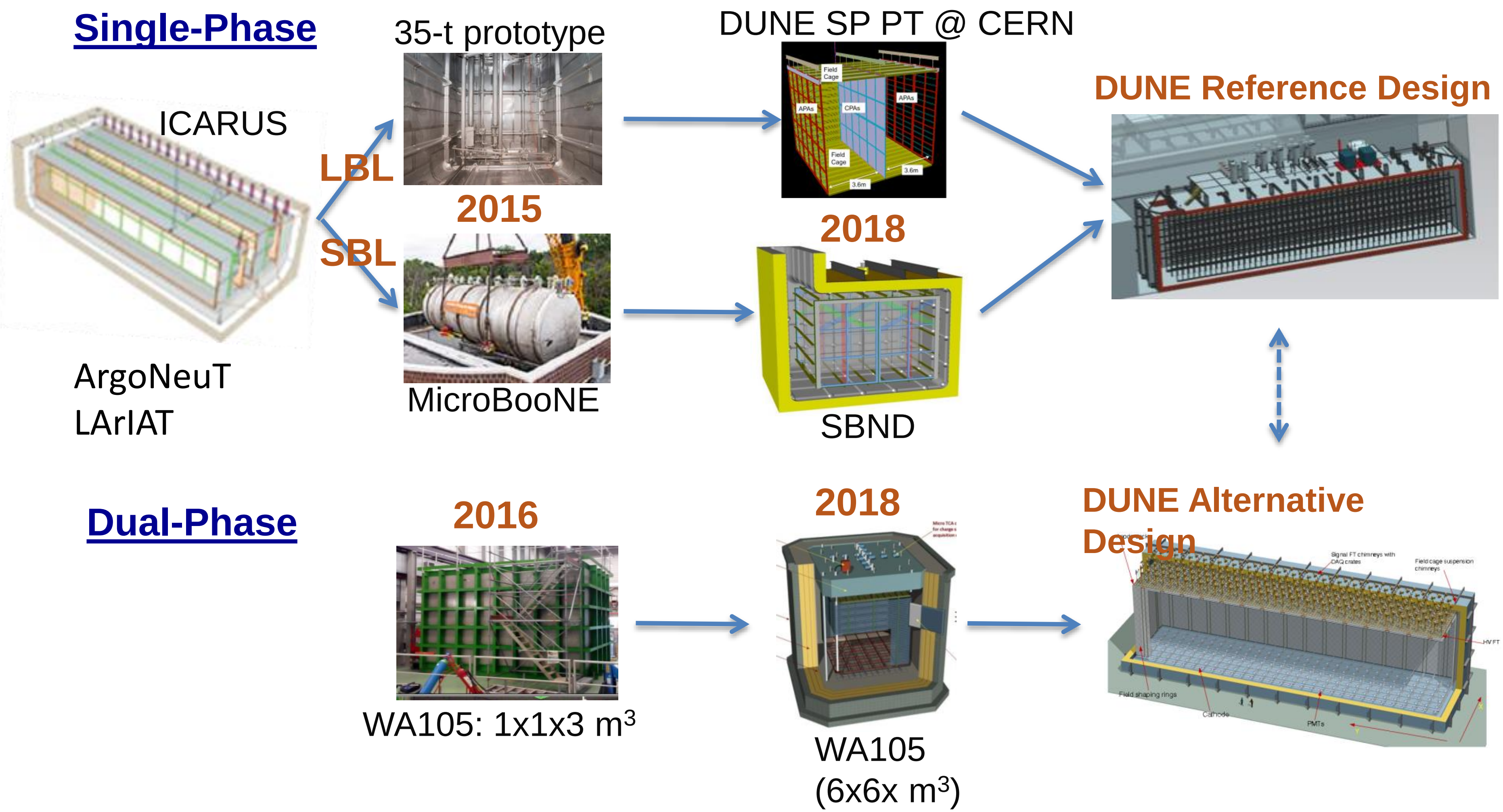


Highly complex event topologies that require sophisticated reconstruction algorithms.

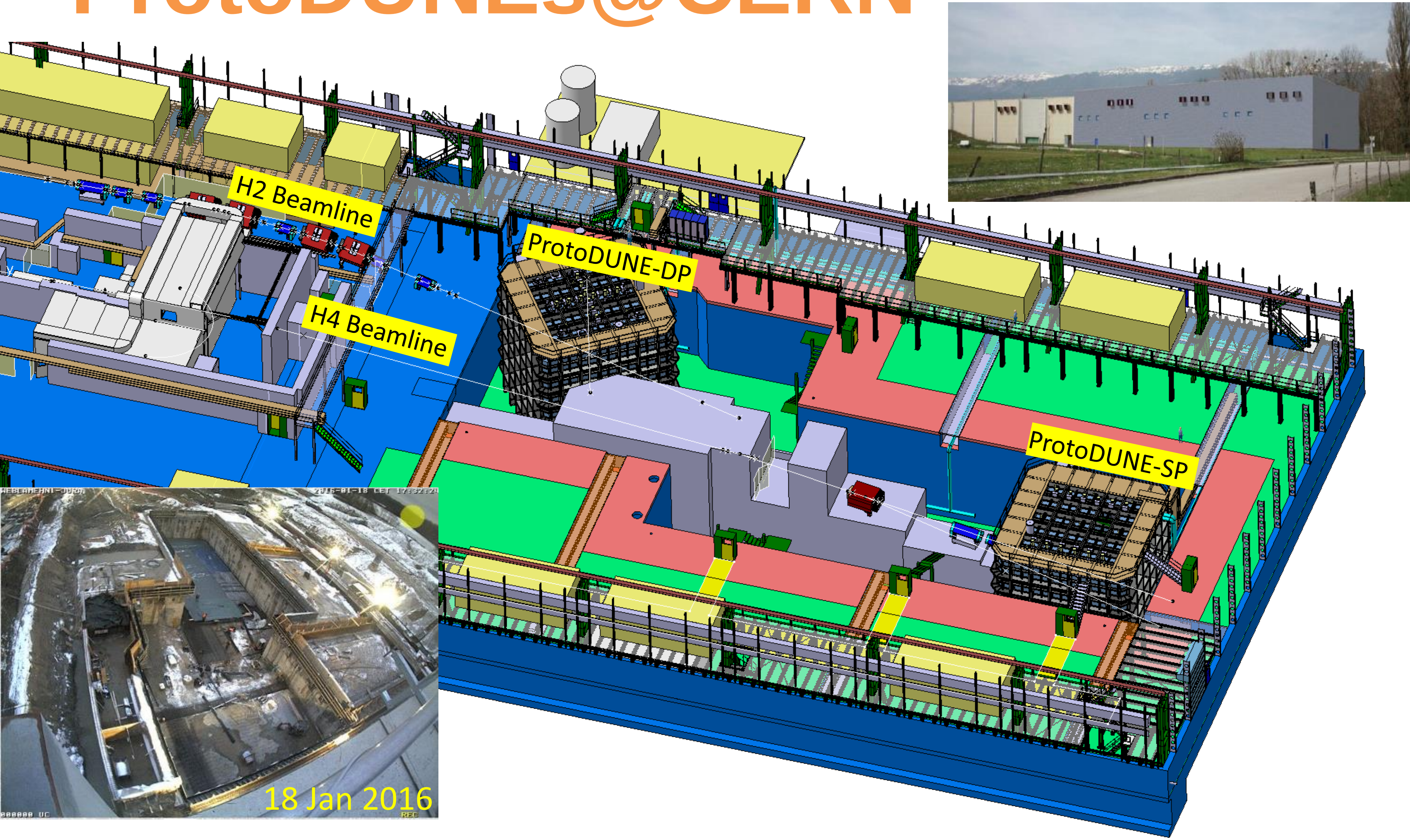
Need to reconstruct tracks and showers, measure their energy and perform particle identification. Automatisation a major challenge.

MANCHESTER 1824 DUNE

Far Detector Development Path



ProtoDUNEs@CERN



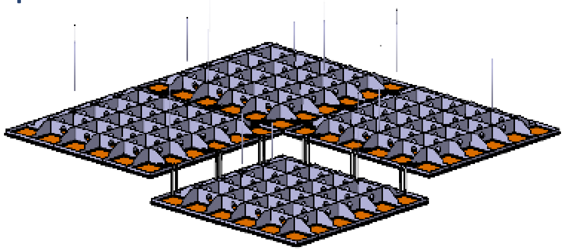
ProtoDUNE: Dual-phase Demonstrator

see talk by Dario Auterio

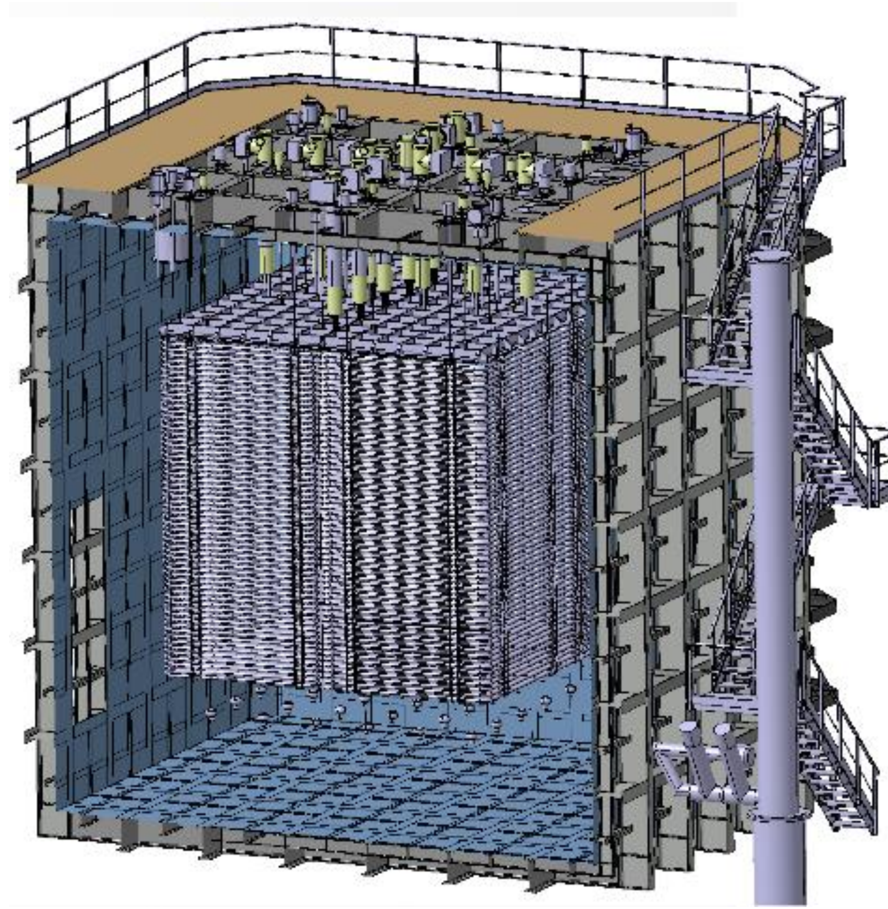
Validate construction techniques and operational performance of full-scale modules for DUNE FD

Calibrate detector with charged-particle beam

6 m x 6 m anode plane made of four 3 m x 3 m independent readout units



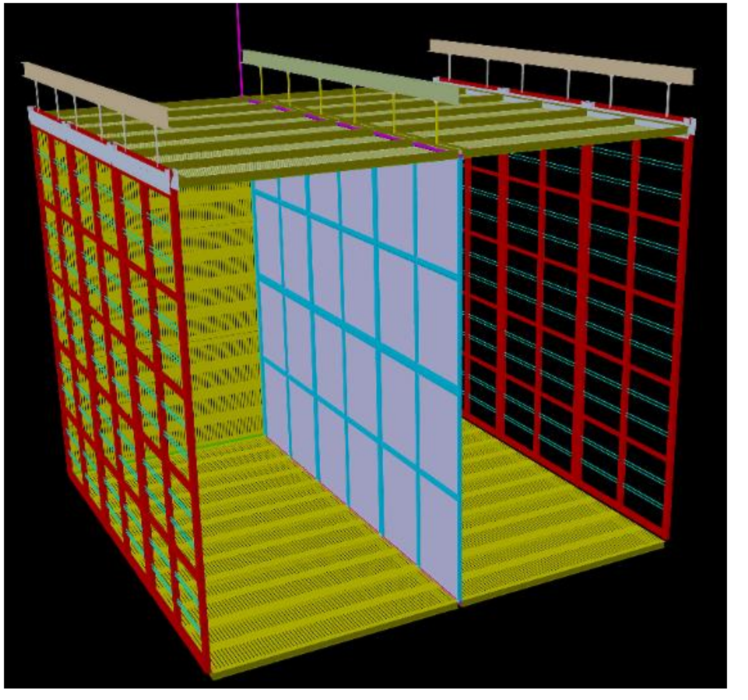
6 m vertical drift => 300 kV cathode voltage



ProtoDUNE: Single-phase Demonstrator

see talk by Christos Touramanis

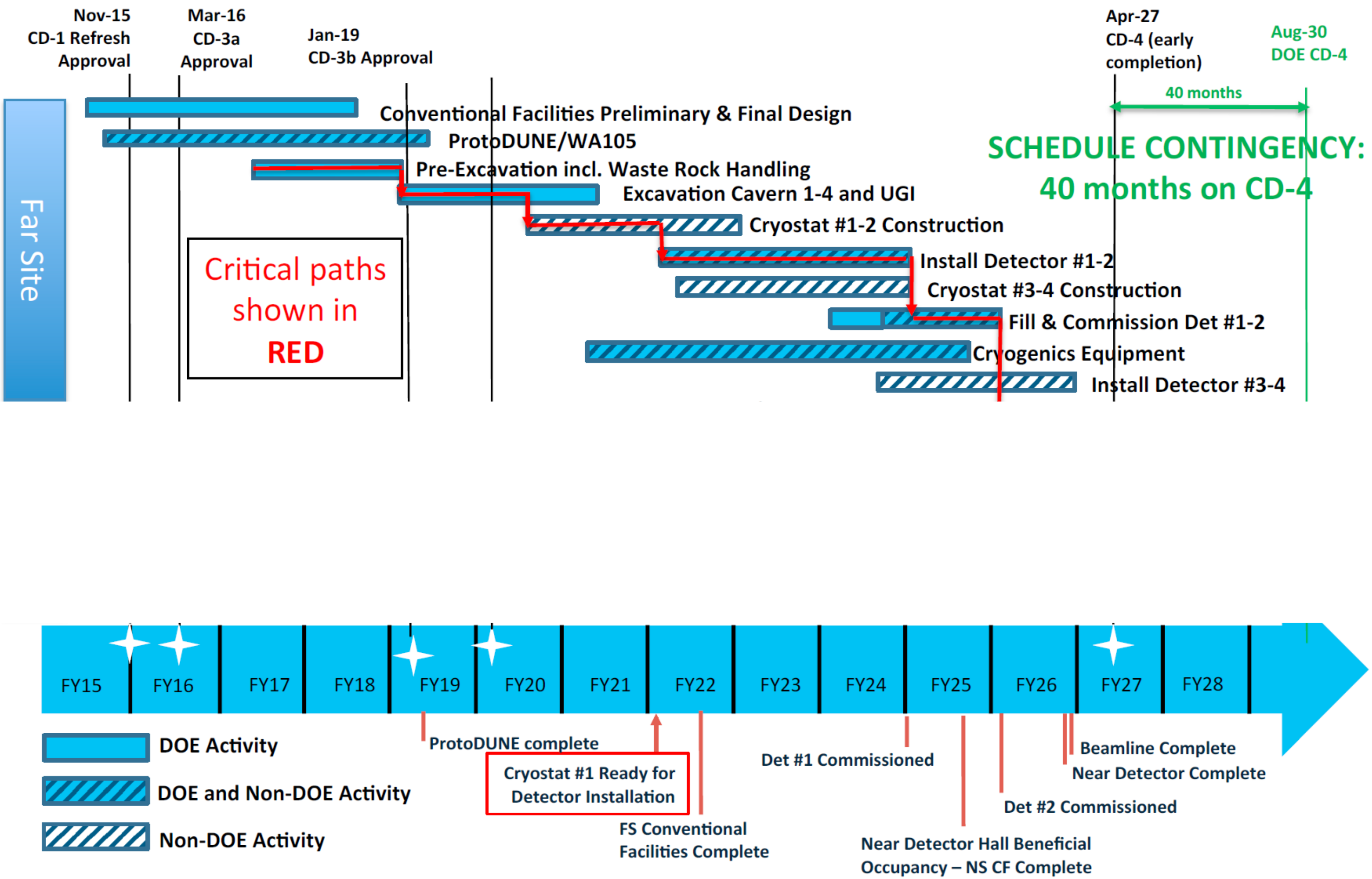
- Active volume: 6 x 7 x 7 m^3
- 6 Anode Plane Assemblies
  - 6 m high x 2.3 m wide
- 6 Cathode Plane Assemblies
  - 3 m high x 2.3 m wide
- A:C:A arrangement
- Cathode at -180 kV for 3.5 m drift



Validate and demonstrate design choices and construction techniques

Calibrate with charged particle beam

FD and ProtoDUNE Schedule



Opportunities and Challenges

- Will need two 10 kt modules in place in 2026 when beam turns on.
- Many technological challenges still need to be addressed and design of many components not yet finalized.
- First FD module (single-phase) to be installed in 2021. Dual-phase an exciting technology for second FD module.
- ProtoDUNE to be operational in 2018, will demonstrate technology using charged particle beams at CERN.

European institutes have a unique opportunity to make core contributions to the R&D and large-scale production of the DUNE Far Detector.