UNIVERSITY OF LIVERPOOL

The LBNE TPC

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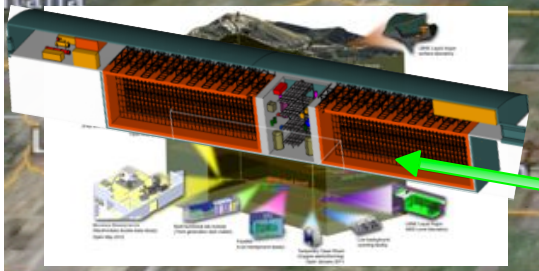
7th International Symposium on Large TPCs for Low-Energy Rare Event Detection

Paris, December 17th 2014

Outline

- **The LBNE/ELBNF program**
- **The LBNE Far Detector TPC and Prototyping**
- **The 35t TPC**
- **Full Scale Detector Beam Test at CERN**

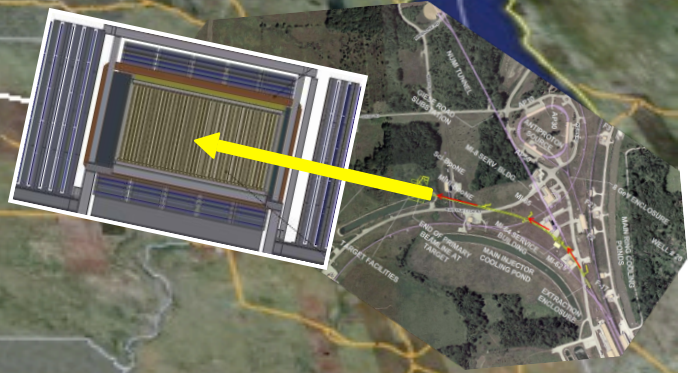
Long-Baseline Neutrino Experiment



1300 km

New Neutrino Beam at Fermilab…

Precision Near Detector
on the Fermilab site



…aimed at the Sanford Underground
Research Facility (SURF)
in Lead, South Dakota

Capacity for 34 kt Liquid Argon TPC
Far Detector at a depth of 4850 feet

And all the Conventional Facilities required to support the
beam and detectors

Image NASA
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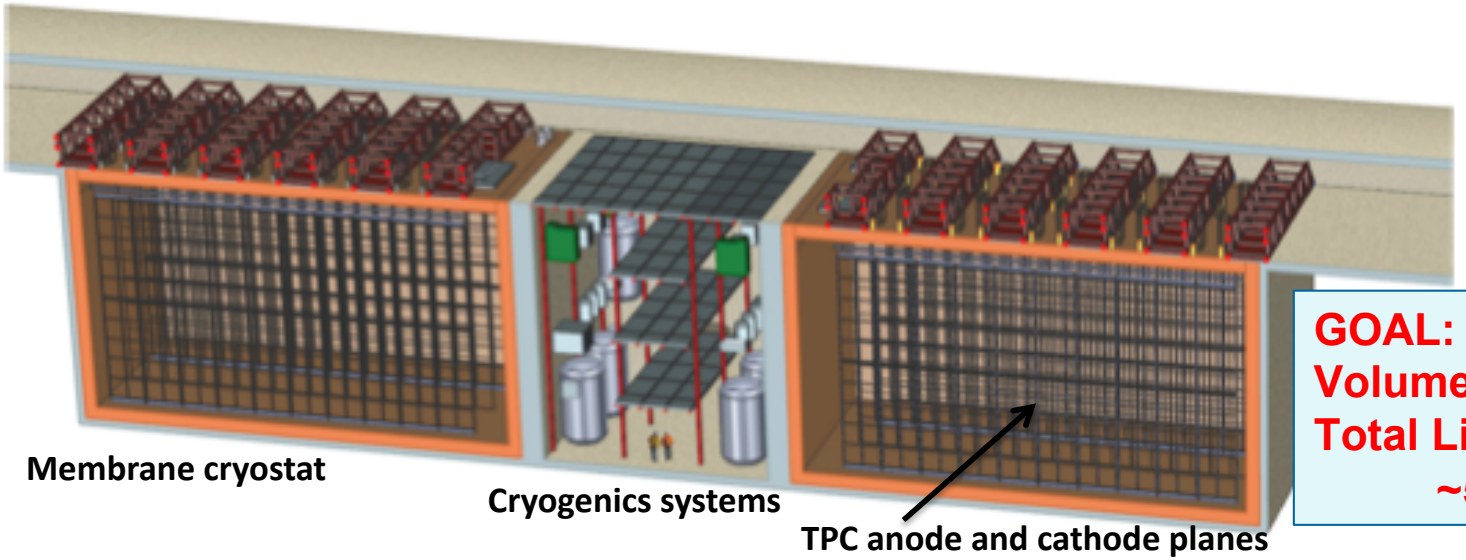
LBNE Far Detector Reference Design



GOAL: ≥35 kt fiducial mass
Volume: 18m x 23m x 51m x 2
Total Liquid Argon Mass:
~50,000 tonnes

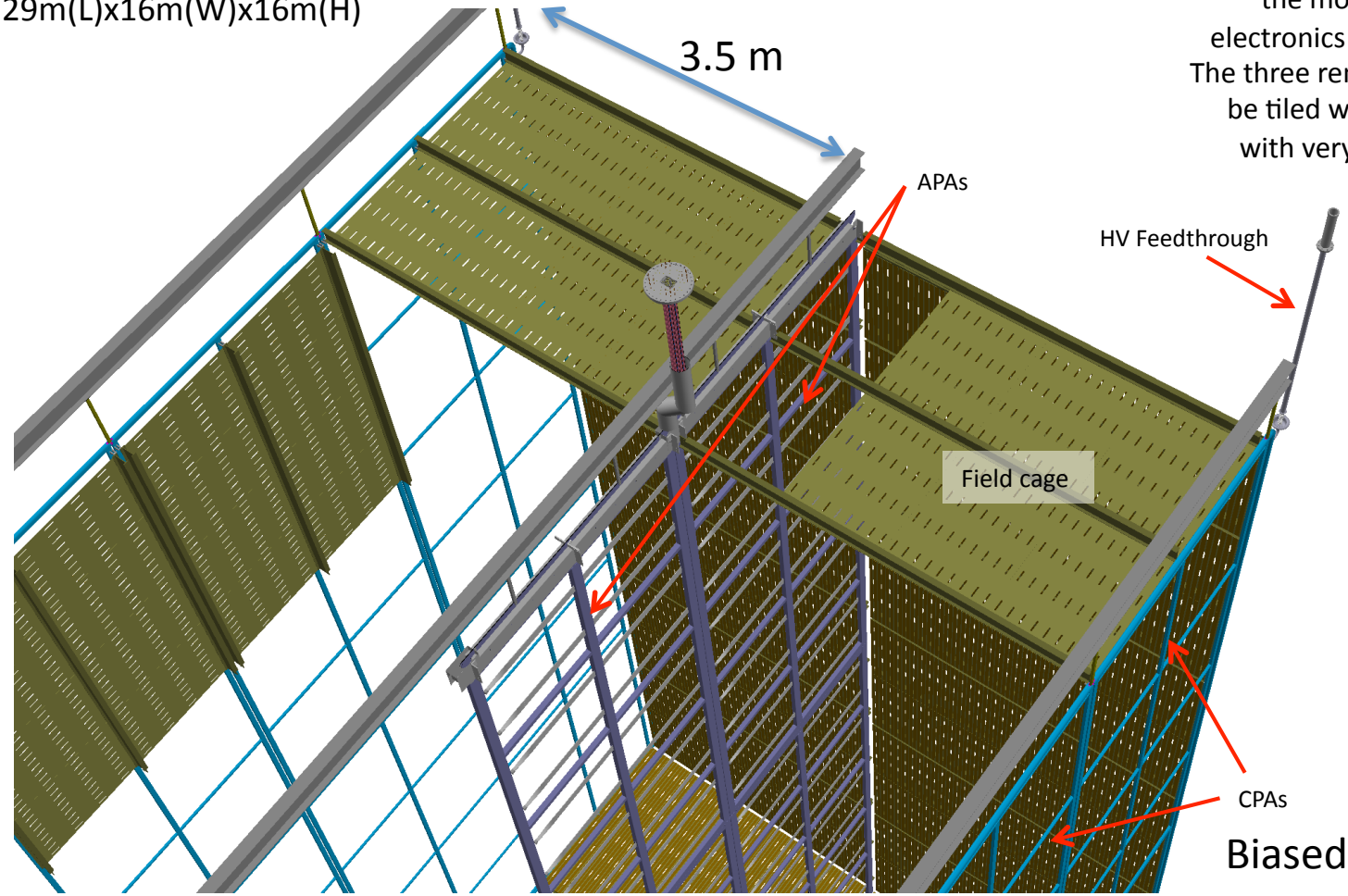
- Reference design for a potential first phase of 10 kt (2 x 5 kt)
- Prepared conceptual design for 34 kt fiducial mass (40 kt active, 50 kt total), but it is modular and scalable
- A scenario for the experiment is 10 kt in one cavern and >= 24 kt in a second cavern
- New collaboration Experiment Long-Baseline Neutrino Facility (ELBNF) is being formed that will develop a plan including consideration of both single and double-phase LArTPC –This talk covers only the single phase detector

Far Detector TPC Overview

Current TPC reference design:

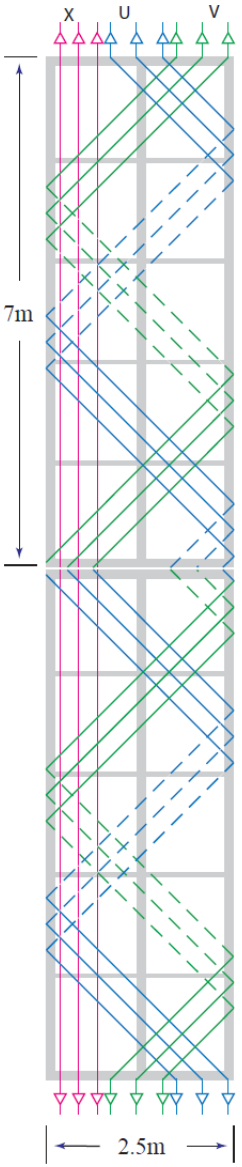
Each 5 kton cryostat has:
40 APAs, 60 CPAs, 1100 m^2 field cage
6.72 kton active mass
29m(L)x16m(W)x16m(H)

The entire TPC structure is supported by 5 mounting rails Under the cryostat ceiling



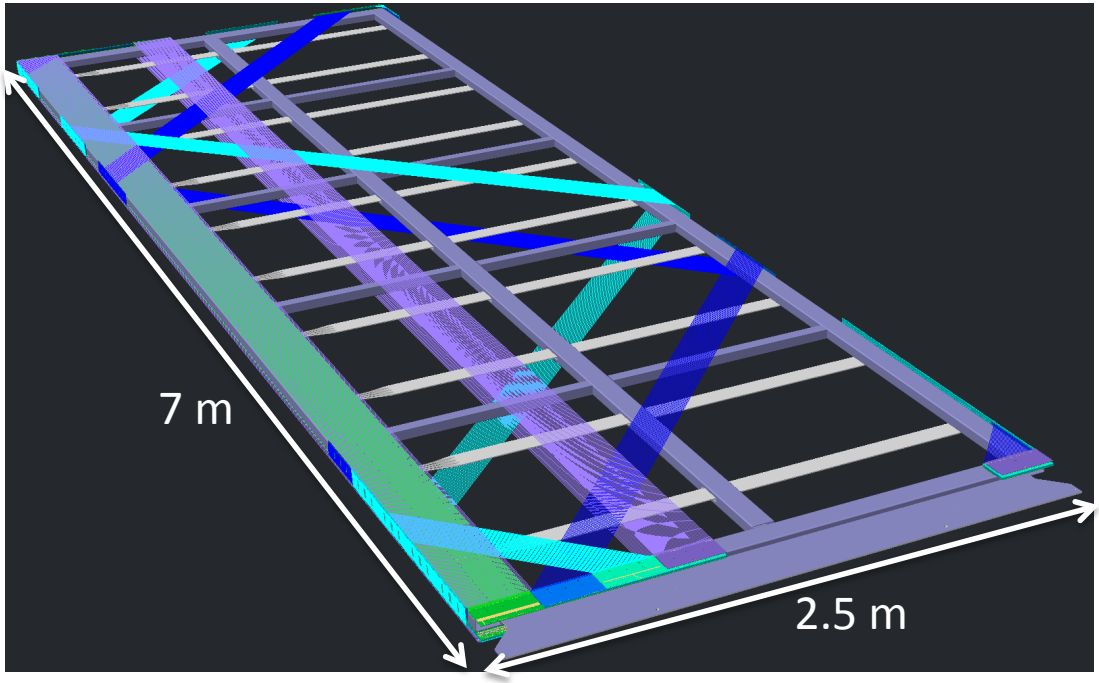
Biased ~-180kV

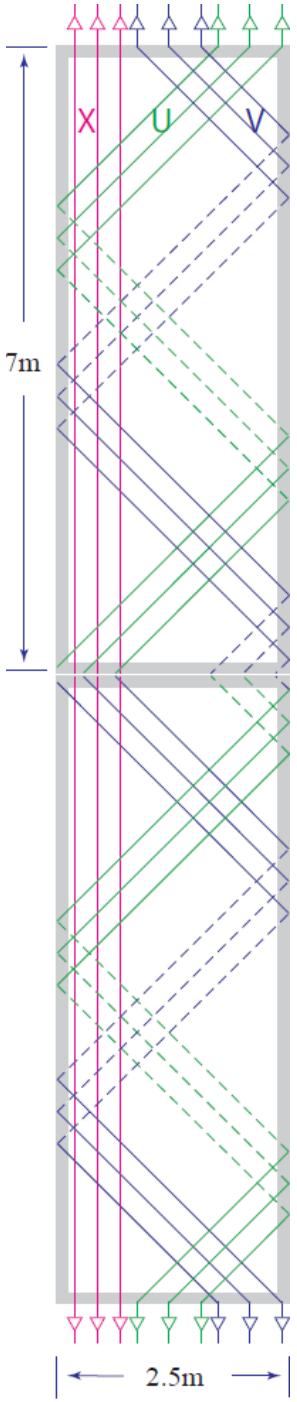
A unique APA wire wrapping design enables signal detection from both sides of the module with readout electronics on one edge only. The three remaining edges can be tiled with other modules with very little dead space.



Anode Plane Assemblies (APA)

The central part of a TPC cell is the anode plane assembly. It is a stainless steel framework, with 4 layers of wires on either side. The two induction wire planes (U & V) are ±45°*, and wrap around the APA in a helical fashion. This enables all the wires to be read out at one narrow end of the APA, greatly simplifying the placement of the front-end electronics. In the cryostat, two APAs are stacked with minimal dead space at the joint.

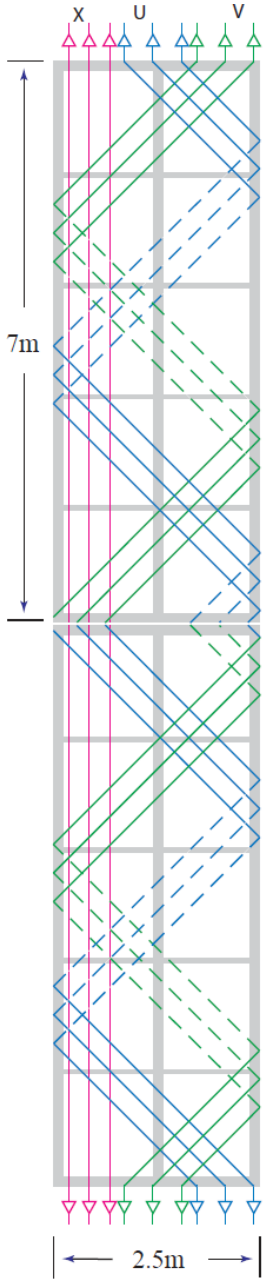


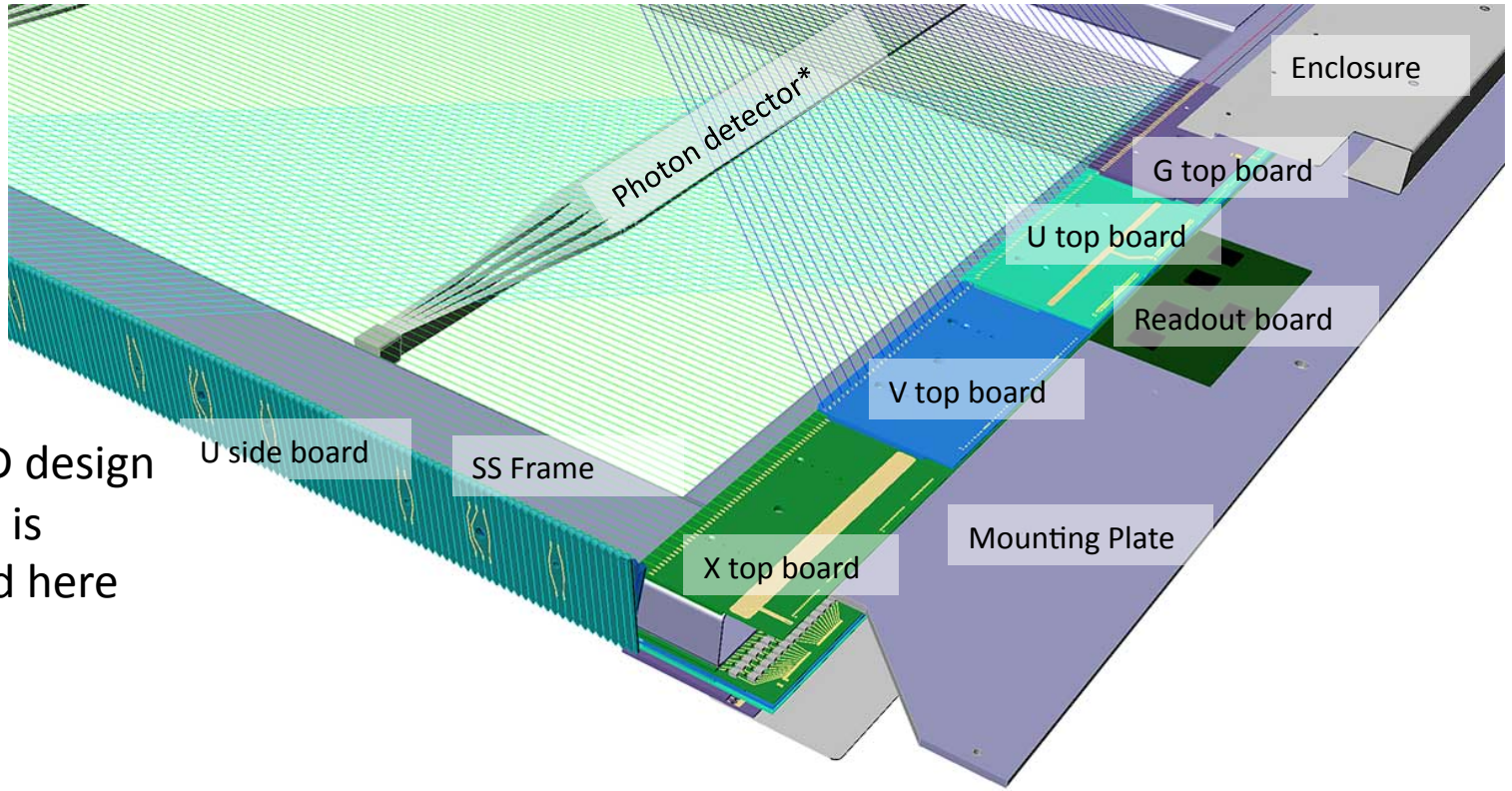


7mx2.5m, stainless steel construction, 250kg
4 planes of wires @ 5mm pitch
2304 sense wires, 3312 wires total
Electronics on one end of the frame

* This will change to ~36 degrees to avoid wrapping the wires more than one revolution

APA Close-up View





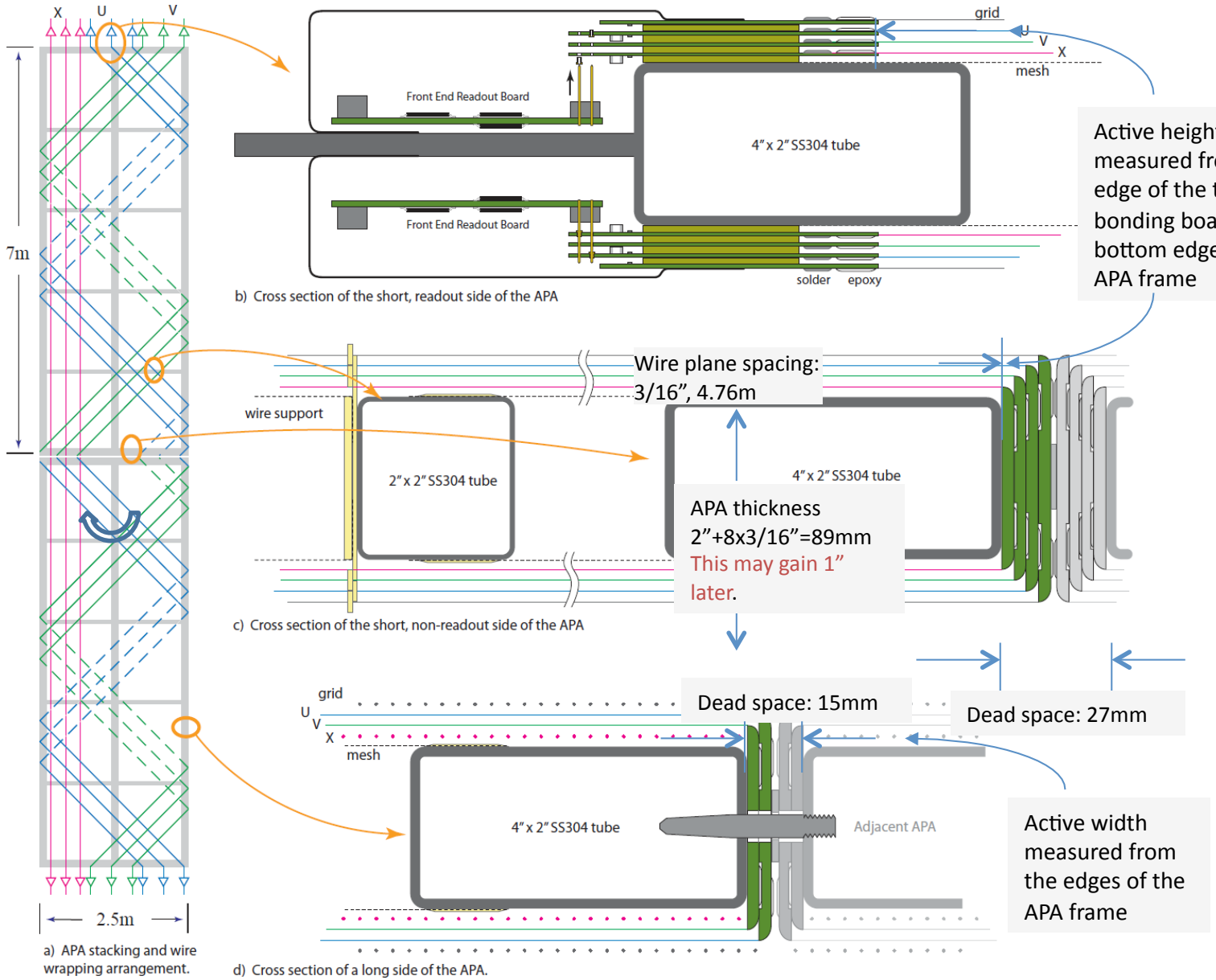
* Old PD design concept is depicted here

On each APA:
1120 X wires @ 4.5mm pitch
720 U wires @ 4.9mm pitch
720 V wires @ 5.0mm pitch
1120 grid wires @ 4.5mm pitch
20 front end mother boards (128ch) mounted on one end of the frame (cold electronics WBS).
10 photon detectors installed inside the APA frame (photon detectors WBS)

150µm CuBe wires mechanically bonded to FR4 boards, then soldered for electrical connections.
Wire tension is set at 1/6 of the break load.
Dead space is 15mm along vertical APA joints and 27mm between horizontal joints.

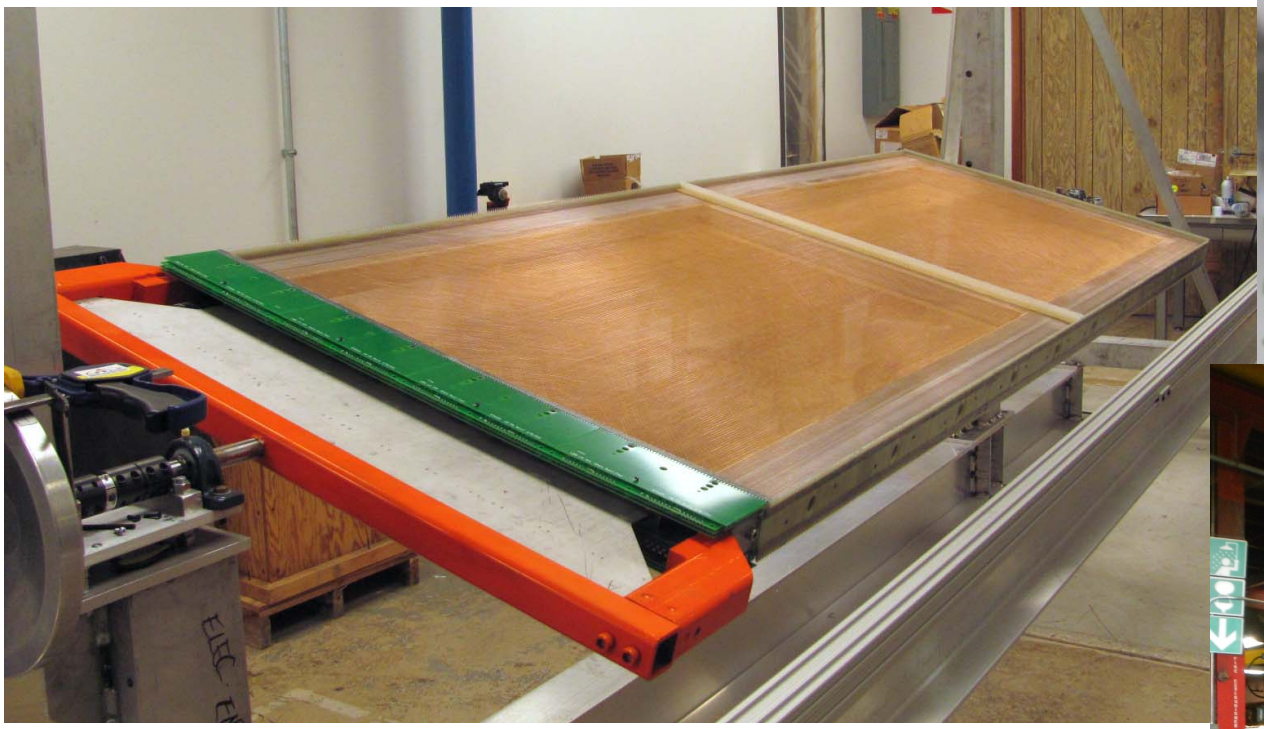
APA Cross Section Views

A design to achieve modularity and minimum dead space between modules

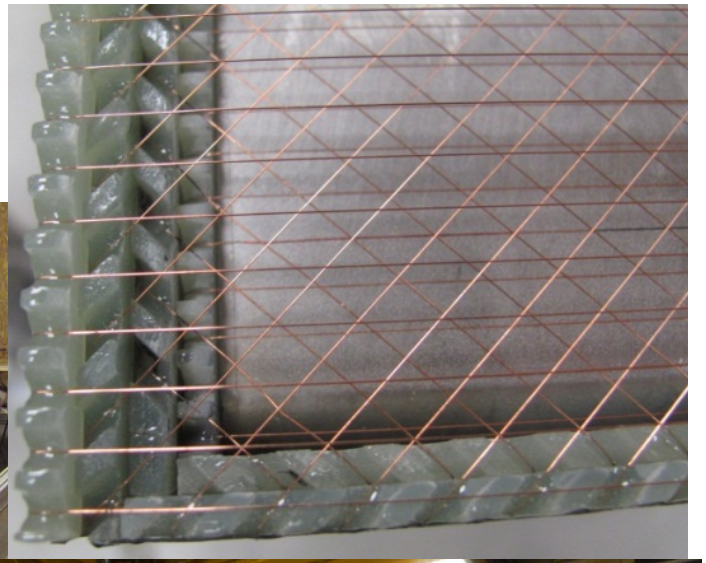


Design hasn't been finalised yet

Prototyping APA



40% APA made by Physical Science Lab (PSL)

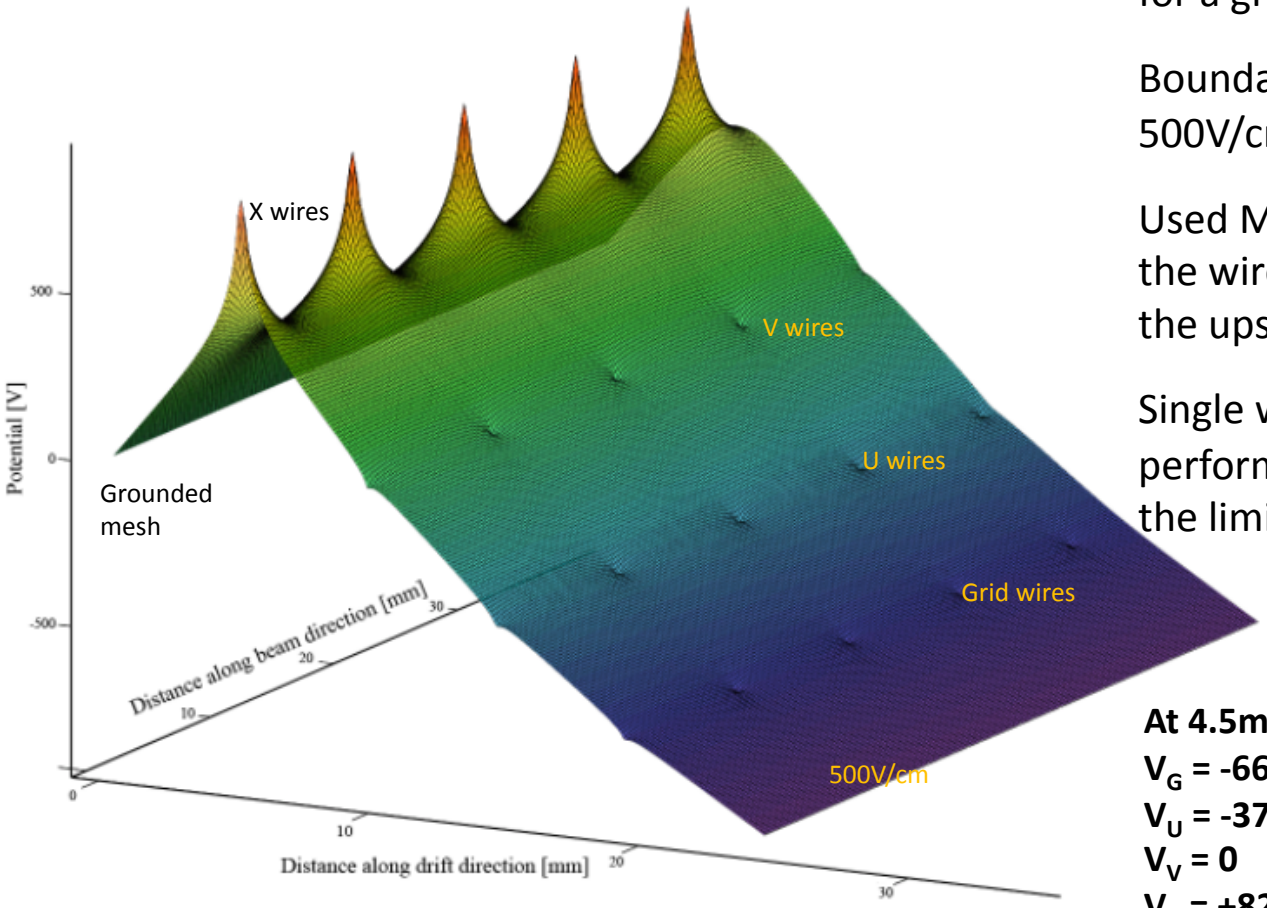


Full size APA frame at PSL

Bias Voltages on the Wires

Transparency condition: (O. Bunemann et al., Canadian Journal of Research, v A27 (1949) pp191-206)

$$\frac{E_2}{E_1} \geq \frac{1+\rho}{1-\rho} \qquad \text{Where } \rho = \frac{2\pi r}{d},\ d \text{ is the wire pitch and r is the wire radius.}$$

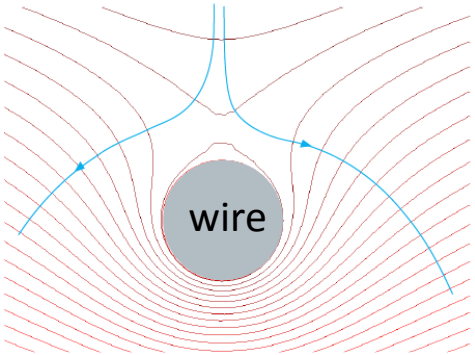


The field ratio needs to be greater than 1.23 for a grid with 150 µm wires at 4.5 mm pitch.

Boundary conditions:
500V/cm drift, 0V on the mesh plane.

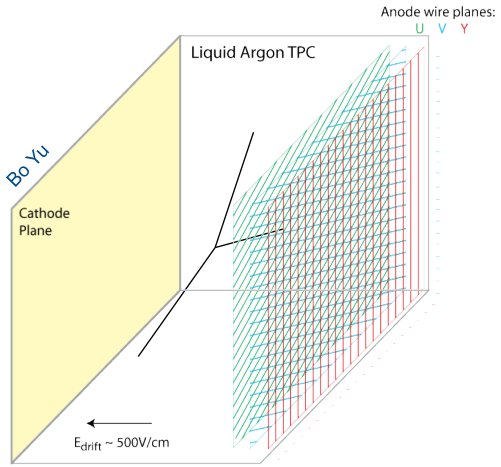
Used Maxwell 2D, adjust the bias voltages on the wire planes until saddle points emerge on the upstream side of the induction wires.

Single wire displacement studies were performed to insure electron transparency at the limits of the mechanical tolerances



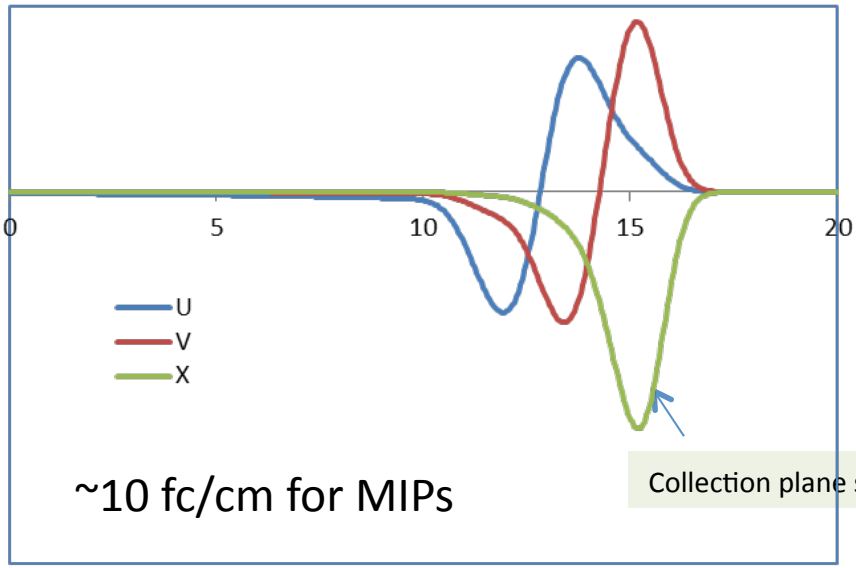
At 4.5mm wire pitch:
V_G = -665V
V_U = -370V
V_V = 0
V_X = +820V

Track Waveforms on the Wires



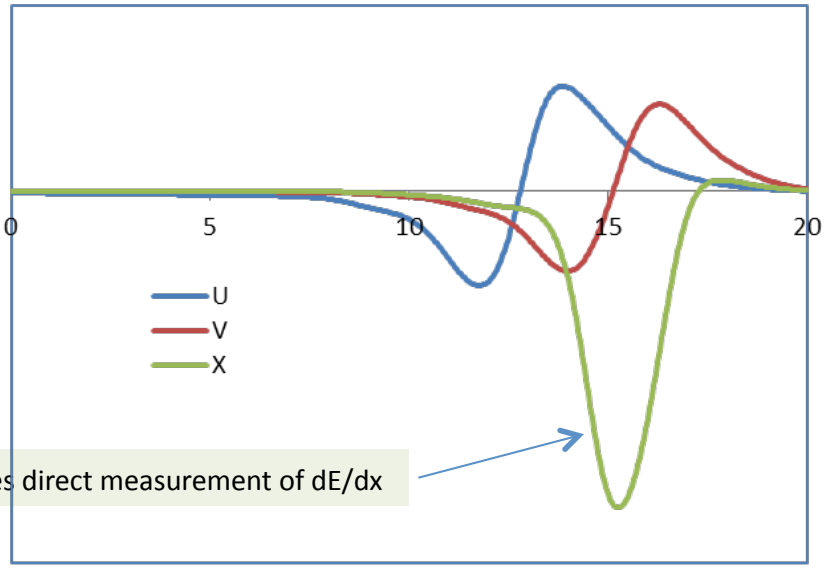
LBNE style wire arrangement: 3 instrumented wire planes + 1 grid plane
The grid plane makes the first induction plane waveform symmetrically bipolar
Raw current waveforms convolved with a 0.5 μs Gaussian to simulate the effect of diffusion

Current waveforms from a 0° track



Drift time [μs]

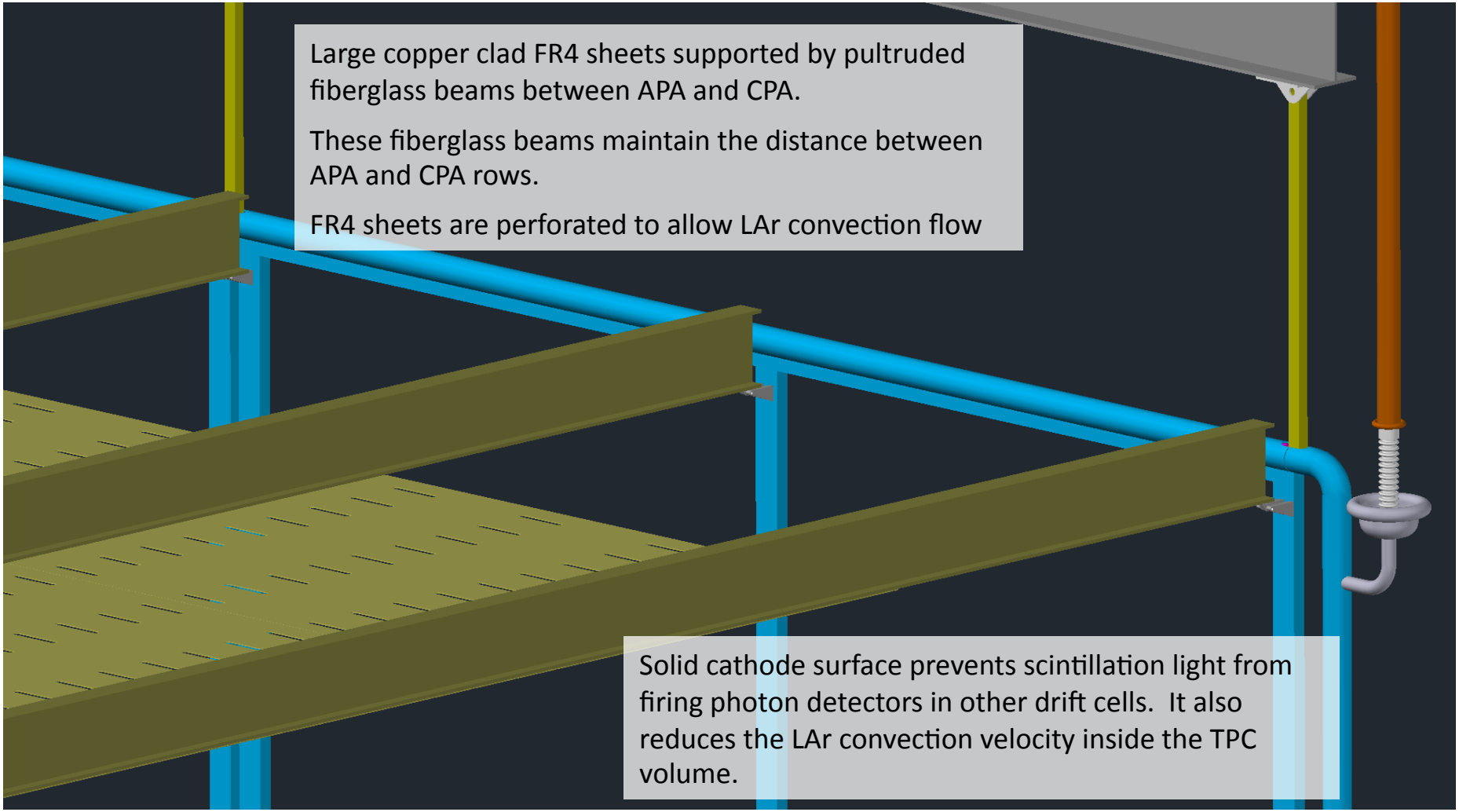
Current waveforms from a 45° track



Drift time [μs]

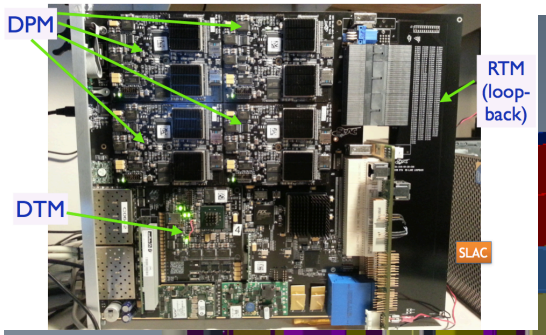
The expected signal for *5mm* wire spacing is *≈10^4 electrons*, for ***the collection signal (X)***.

CPA, Field Cage, HV Feedthrough



Many of the design/performance issues will be evaluated in the 35ton TPC

Prototype TPC for the 35t Cryostat



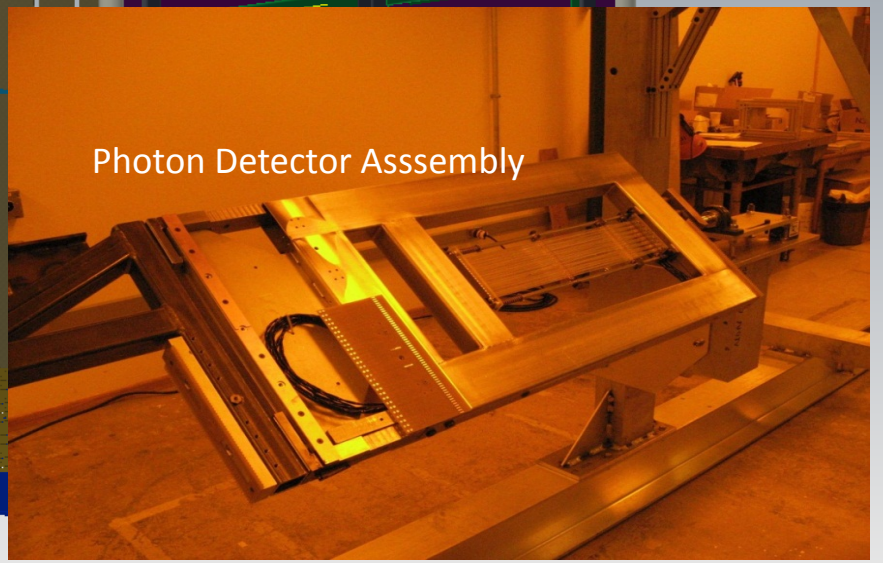
Cold Electronics

Field Cage

Photon Detectors

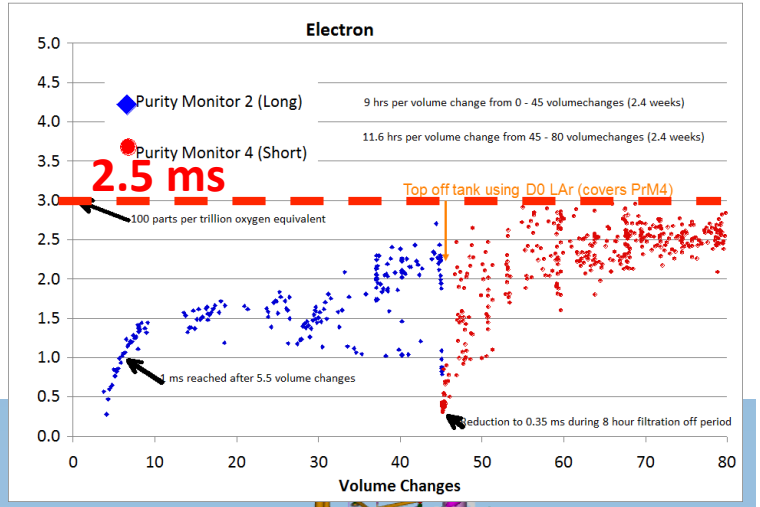
CPA

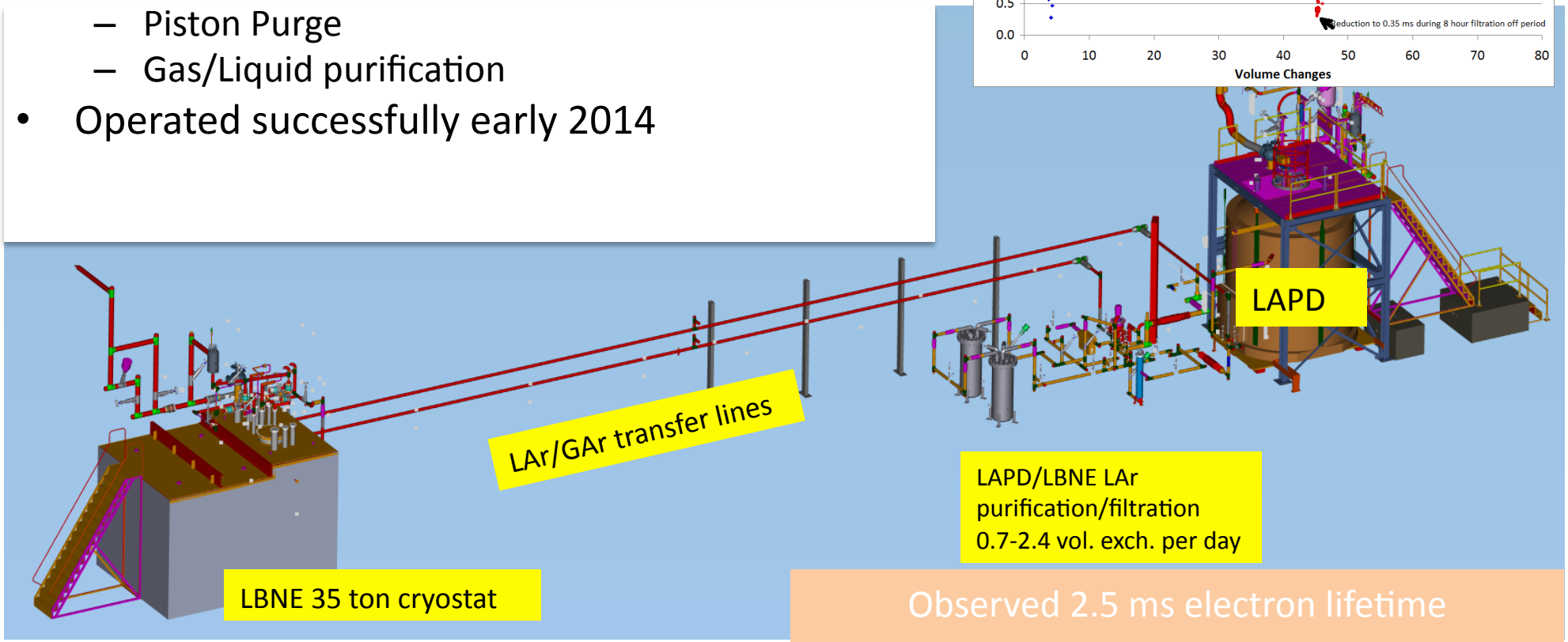
APA



Cryogenics and Cryostat 35t Prototype

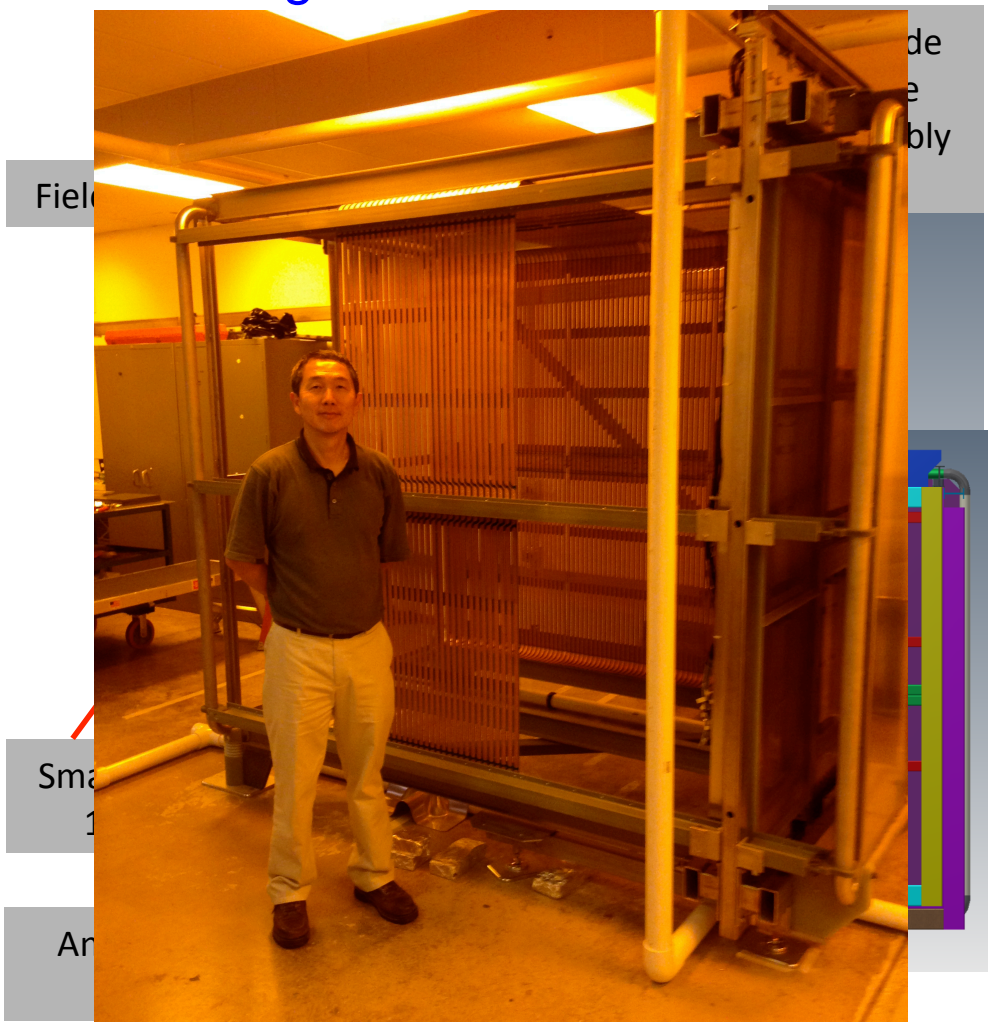
- First membrane cryostat for scientific applications
  - Safety and other DOE/LAB requirements met
  - Contract and procurement process understood
  - Construction finished Fall 2013
- Cryo-plant laid analogous to final configuration
  - Internal pumps
  - Piston Purge
  - Gas/Liquid purification
- Operated successfully early 2014





Prototype TPC – 35t Prototype

A device as close as possible to the final construction techniques and configurations



- Wrapped wires with one end only readout.
- Cold pre-amp and cold ADC readout.
- APA frames with small gaps between planes.
- One bottom APA hung from a top APA.
- Copper clad G-10 field cage
- Tube and Sheet CPA construction
- Integrated photon detection system

Parameters:

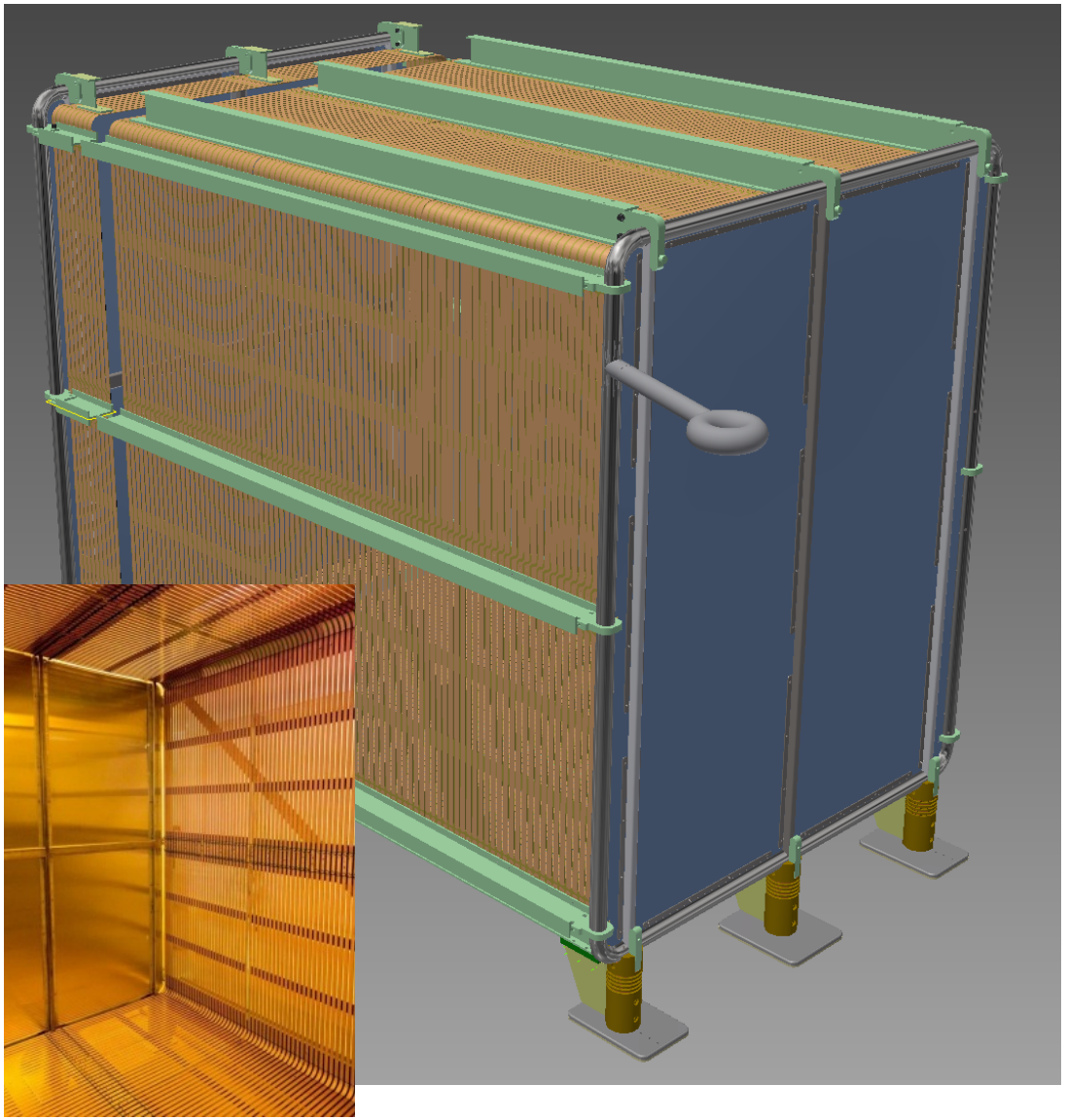
- 0.27 m and 2.27 m max drifts
- 1.5 m wide and 2 m tall
- 1.1 t and 9.3 t active volumes.

35t TPC Design Features: APAs

- 4 APAs to test APA horizontal and vertical interconnect features, and to study detector response at the horizontal and vertical gaps between APAs
- Wire wrapping angle based on the conceptual design: ±45° on the induction planes with small delta angles to break symmetry
- 8 embedded PDs with different designs
- One APA does not have the grounded shielding mesh
- One long APA does not have intermediate wire support so long wire (2m) behavior can be studied
- All FEE boards on an APA are enclosed in a Faraday cage which also serve as containment for gas argon boil off from the electronics

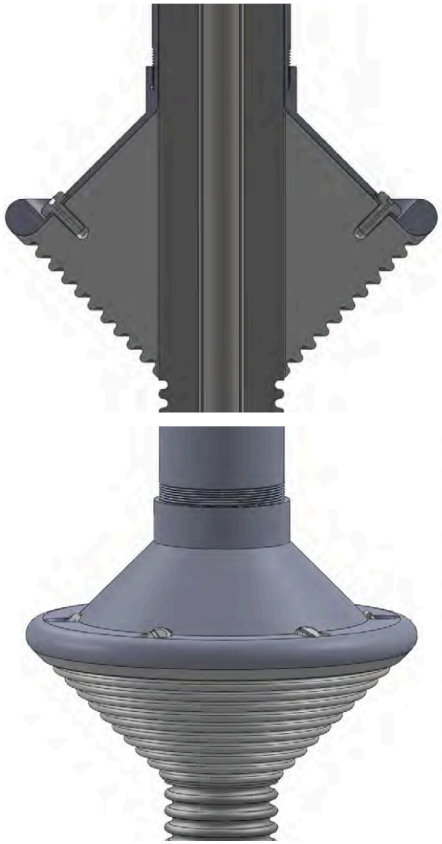
35t TPC Design Features: CPAs and Field Cage

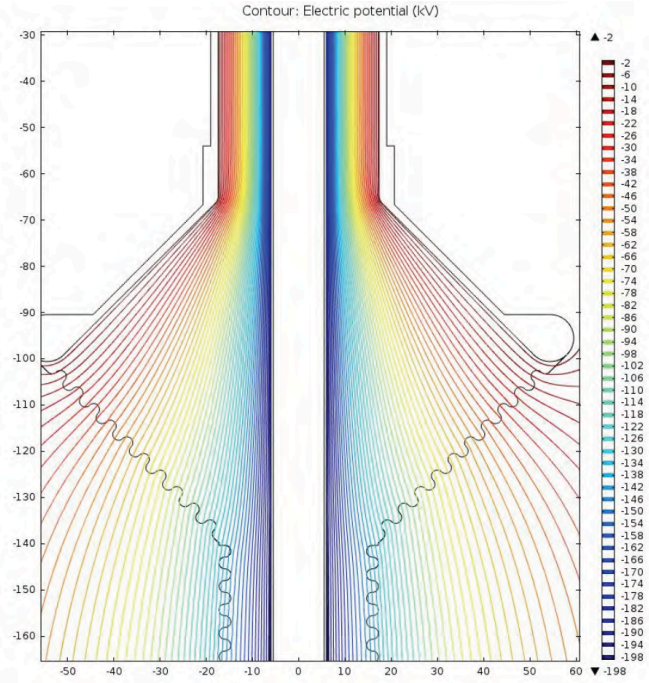
- **CPAs**
  - Solid stainless steel cathode surfaces with rectangular frames to study local drift field non-uniformity in larger FD CPAs
  - 2” OD tubular outer edges to minimize electric field
- **Field Cage**
  - 1.6 mm double sided Cu clad FR4 PCBs.
  - All edges of the copper strips are covered by solder mask to reduce high field exposure in LAr.
  - Integrated inter-strip capacitors to minimize over voltage condition in a spark



200 kV HV Feedthrough

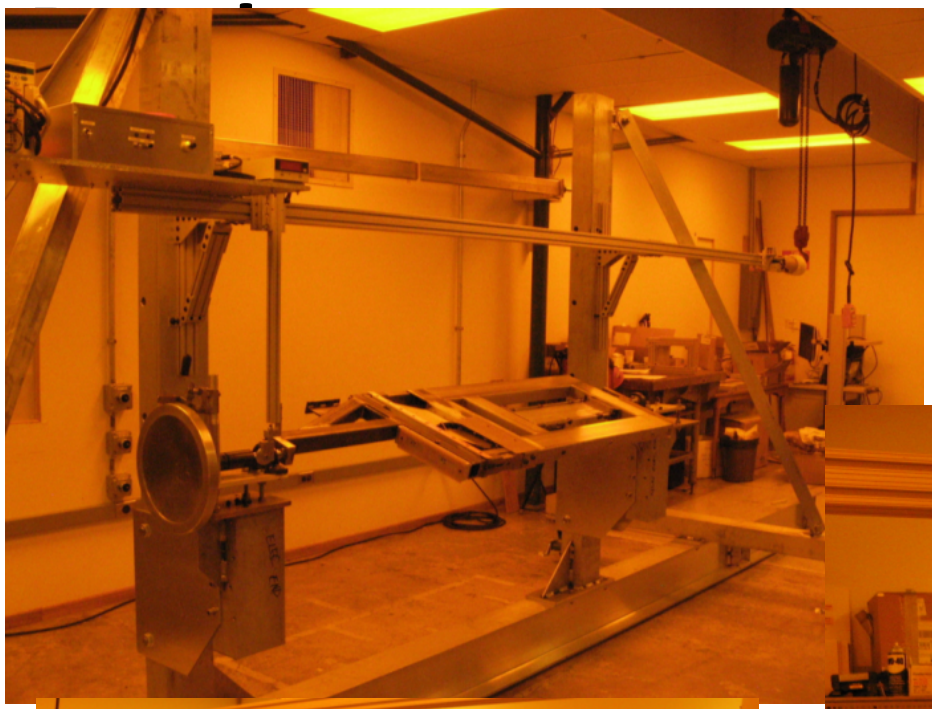
-- New design with flared shield to minimize electric field.
-- Current limiting resistor built inside the feedthrough.
-- Has been tested successfully to 200 kV at UCLA





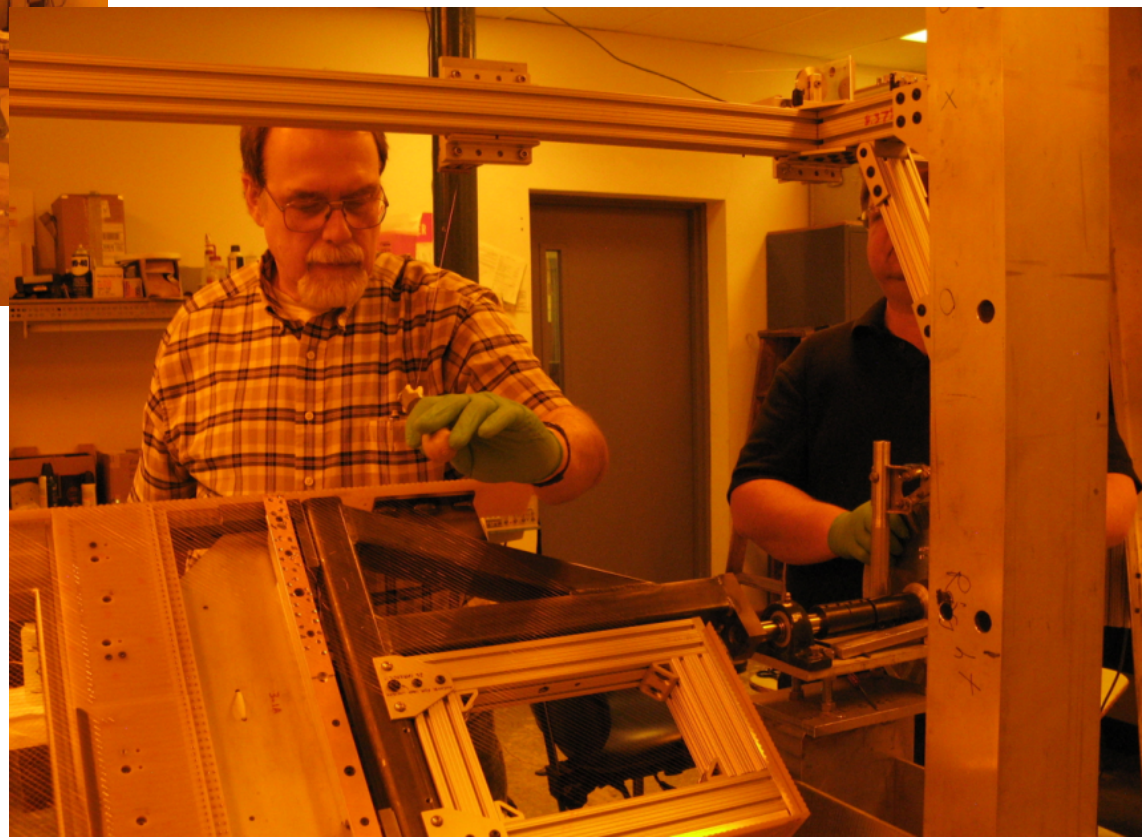
Hanguo Wang
Artin Teymourian
UCLA

APA Winding Technique

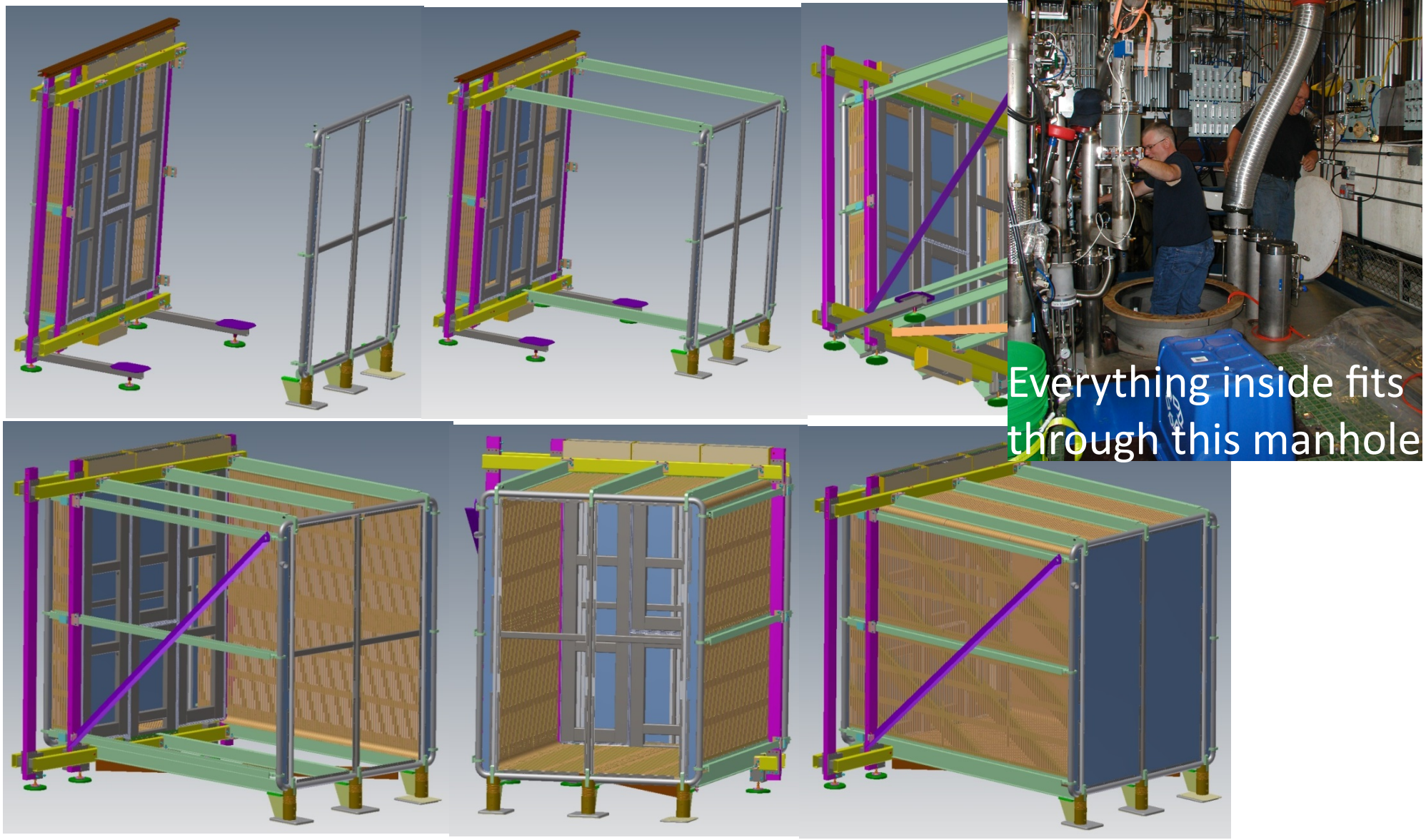


- The APA rotated in a gantry to wind wire onto the frame.
- A tensioner on the wire spool maintains wire tension at any speed and in either direction

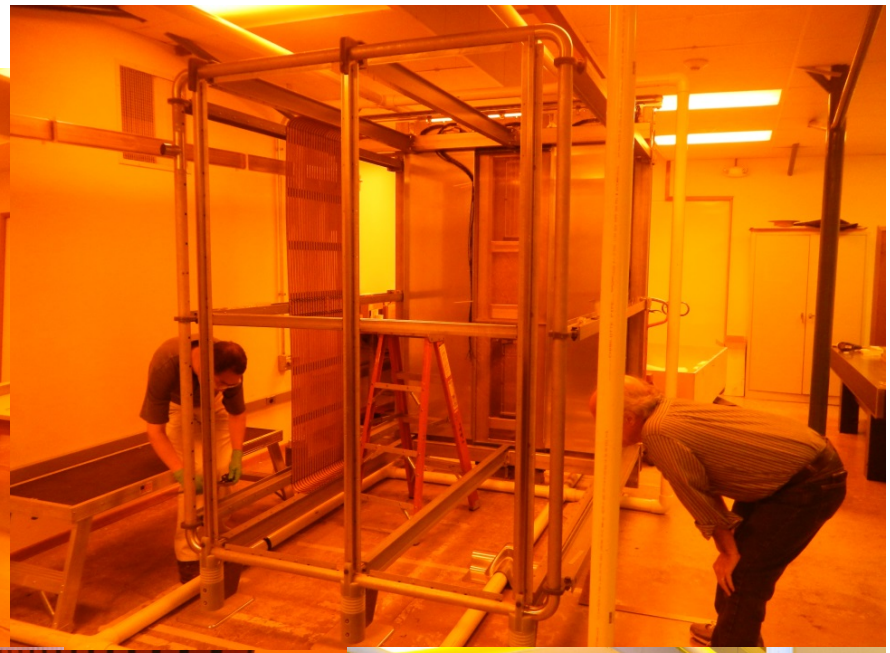
the photo color is yellow due to room light filter to protect the PDs

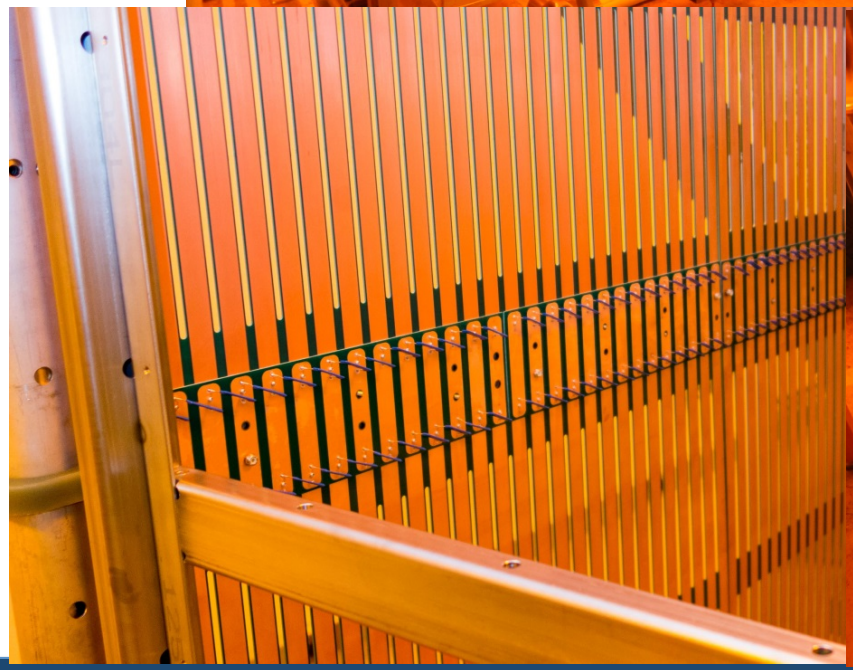


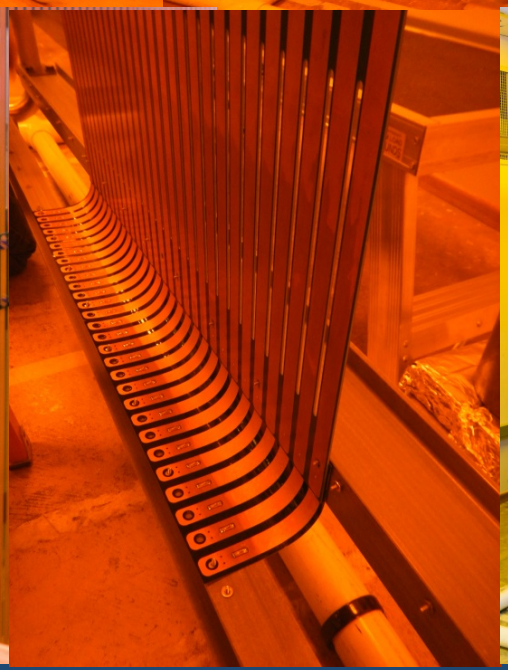
Installation Procedure Tests



Installation Procedure Tests at the Physical Science Lab (PSL) Wisconsin



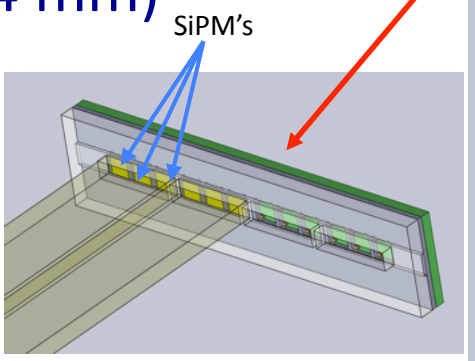




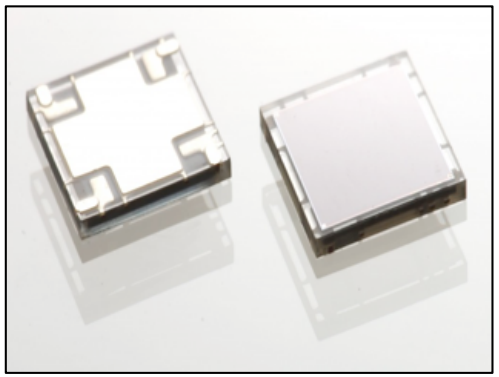
Photon Detector System Design

The photon detection system baseline design is based on plastic bars coated with wavelength shifter, coupled to silicon photo-multipliers (SiPMs), and mounted inside the anode plane assemblies (APA).

- Plastic bars (6 mm x 25 mm x 1054 mm)
- 4 bars per photon detector (PD)
- 3 SiPMs (channels) per bar
- 20 PDs per APA
- 9600 channels for far detector



readout end of paddle



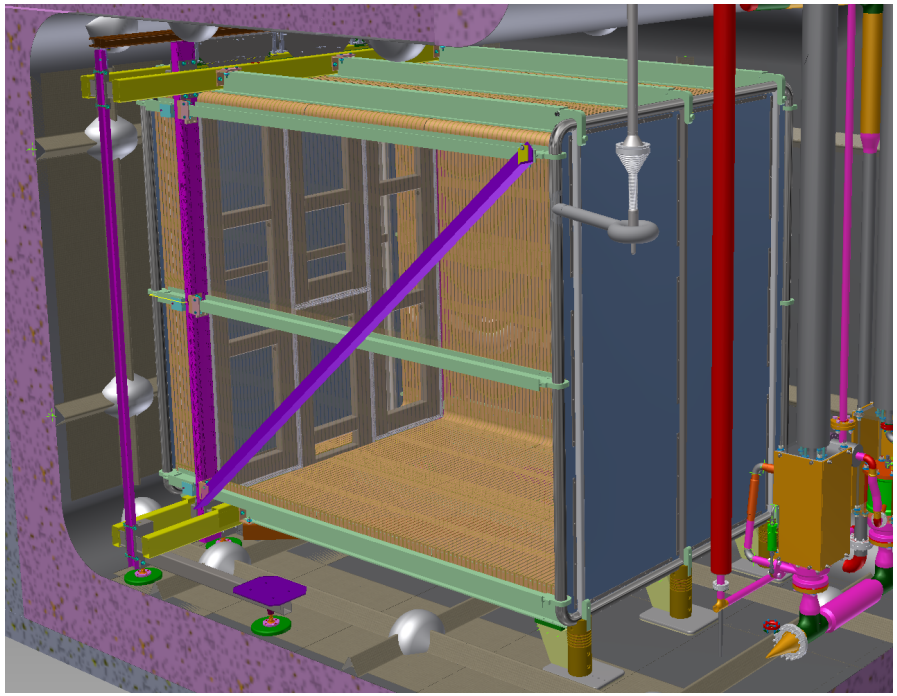
SENSL MicroFB-60035-SMT SiPM

- 6 mm x 6 mm active sensor (~19000 microcells)
- 24.5 V breakdown voltage (V_{br})
- peak wavelength 420 nm
- QE 31% @ V_{br} + 2.5 V
- Gain 3E6 @ V_{br} + 2.5 V

35t Prototype TPC Status

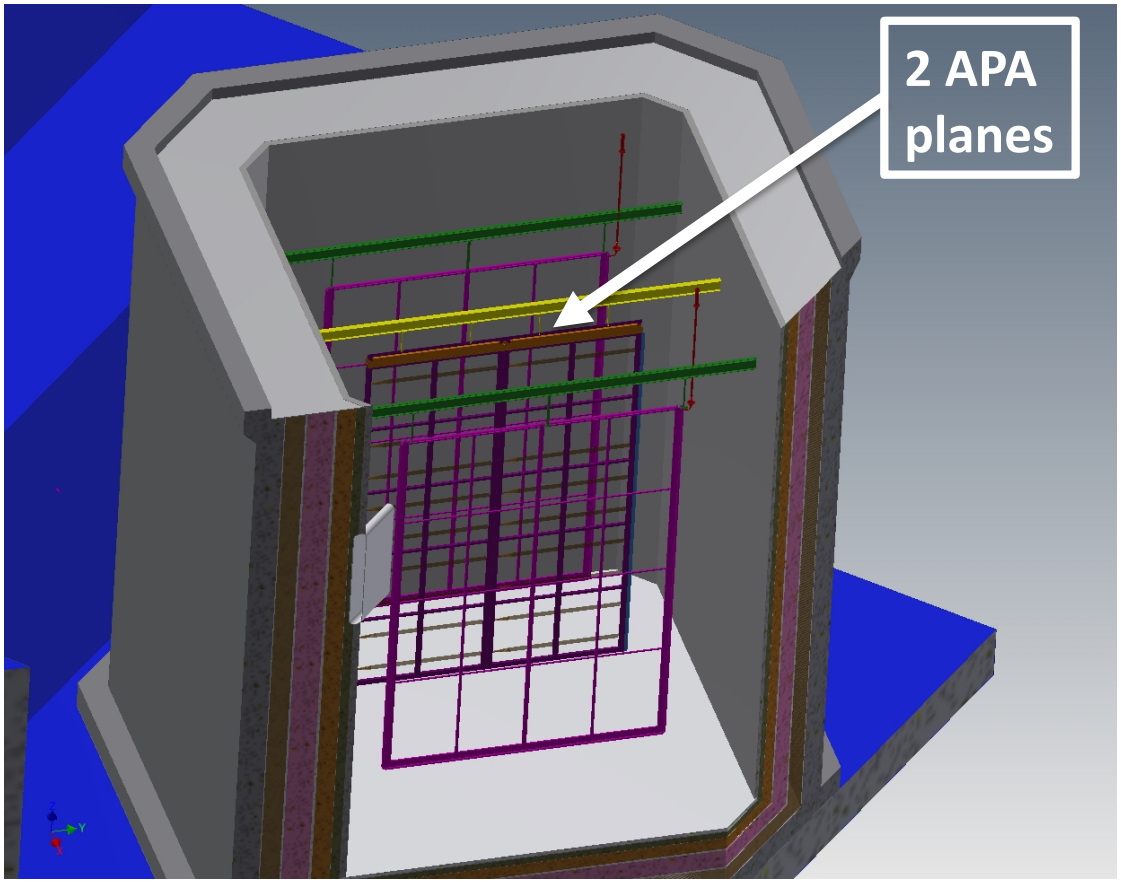
- 35t Phase 2 Detector Installation Readiness Review held Aug. 25, 2014 at FNAL
- Progress since then
  - Trial TPC assembly at PSL completed
    - TPC now disassembled and parts being shipped to FNAL
    - Installation started at FNAL

➔ **Commissioning/data-taking to begin March 2015**



Full Scale Detector Beam Test at CERN

- Collaborate with CERN within the ELBNF program (8mx8mx8m cryostat)
- Two full scale (2.3mx6.6m) APA's including 36 degrees wire wrapping angle and electronics to be constructed in 2015/16
- HV and field cage suitable for final detector will be built
- Will be instrumented with photon detectors
- Possible beam test in 2017 – 2018



Expression of interest submitted to the CERN SPSC. Response was positive and a proposal will be prepared by Spring.

Summary and Conclusions

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- LBNE TPC far detector design has been making good progress towards final configuration for data taking in 2025
- 35t Prototype initial trial completed successfully and ready to take in full scale APA and CPA along with PD systems
  - Preparing for commissioning and data taking in spring 2015
- Collaborative beam test efforts using full size LBNE TPC at CERN in progress

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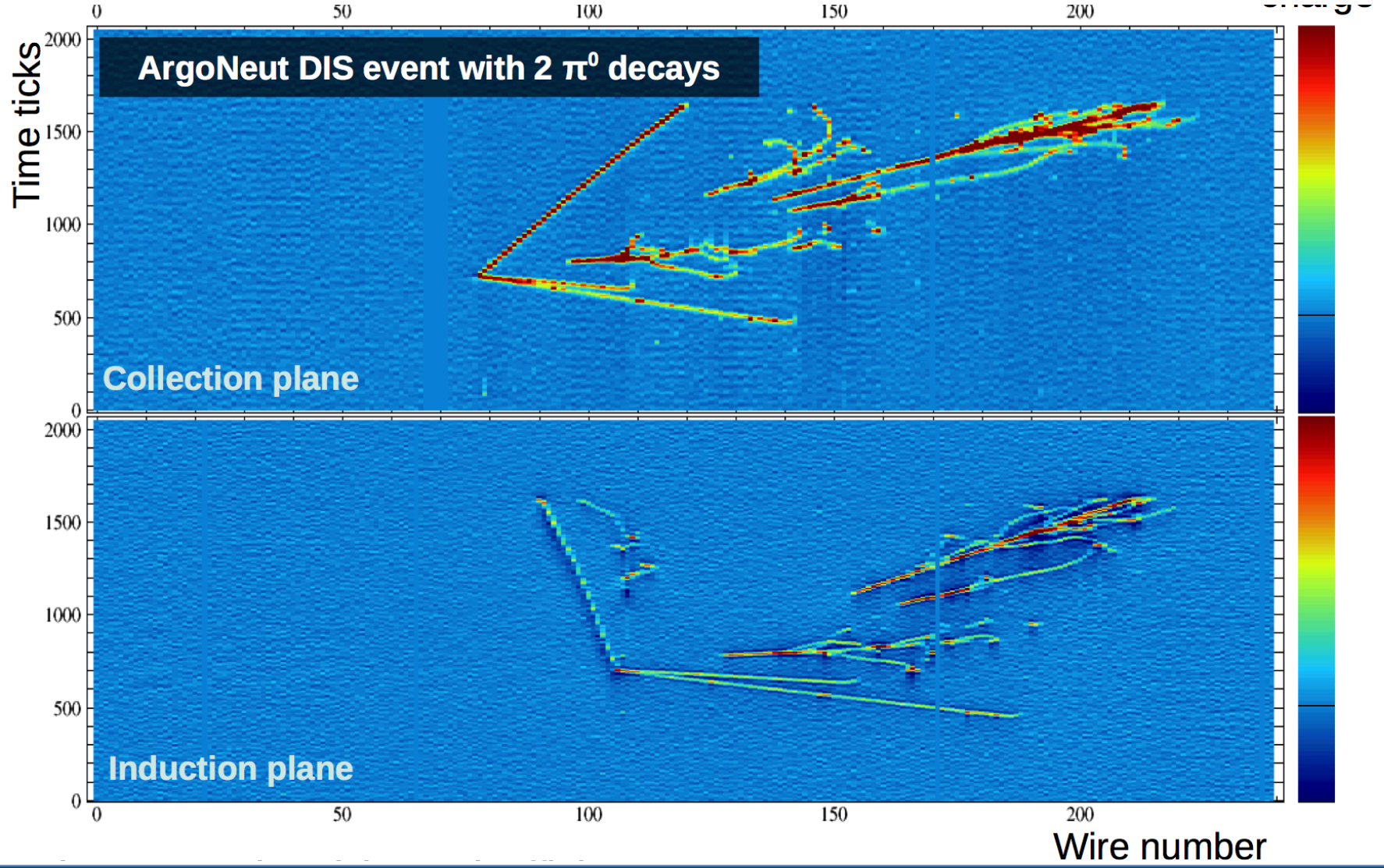
Additional Material

Reconstruction and Analysis Software

Neutrino-scattering events are complex and the the LArTPC readout provides enormous detail.



LBNE PD Designs

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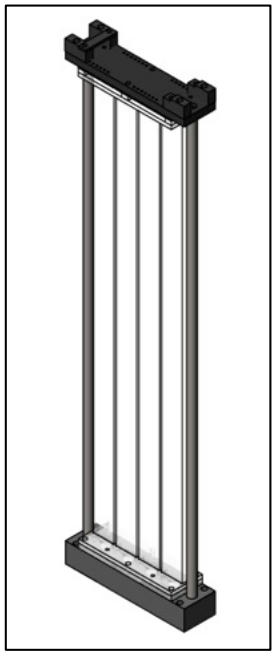
Baseline Design

WLS-doped or coated acrylic bars.

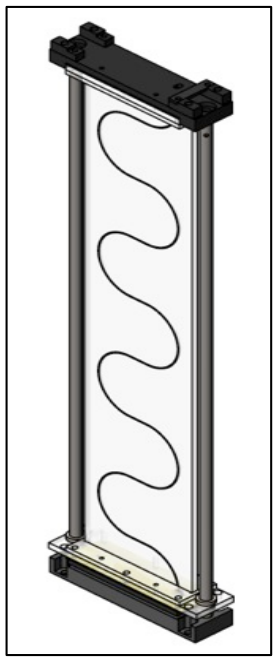
- Each bar couples to 3 SiPMs (72% of bar end couples to active SiPM area)
- 12 SiPMs per PD module

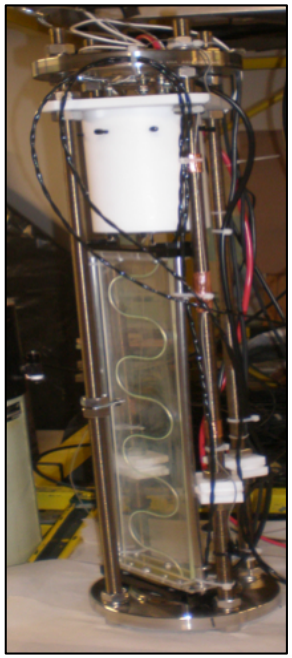


Alternate Designs

Fiber-embedded sheet

- Y11 Clad fibers inside TPB-coated sheet.
- Read out by 2 SiPMs – potential cost savings





Fiber-bundle w/ radiator

- Y11 Clad fiber bundle behind thin TPB-coated radiator
- Minimum losses due to attenuation in TPB coated/doped plastics