ProtoDUNE Single Phase CPA/FC/HV Overview

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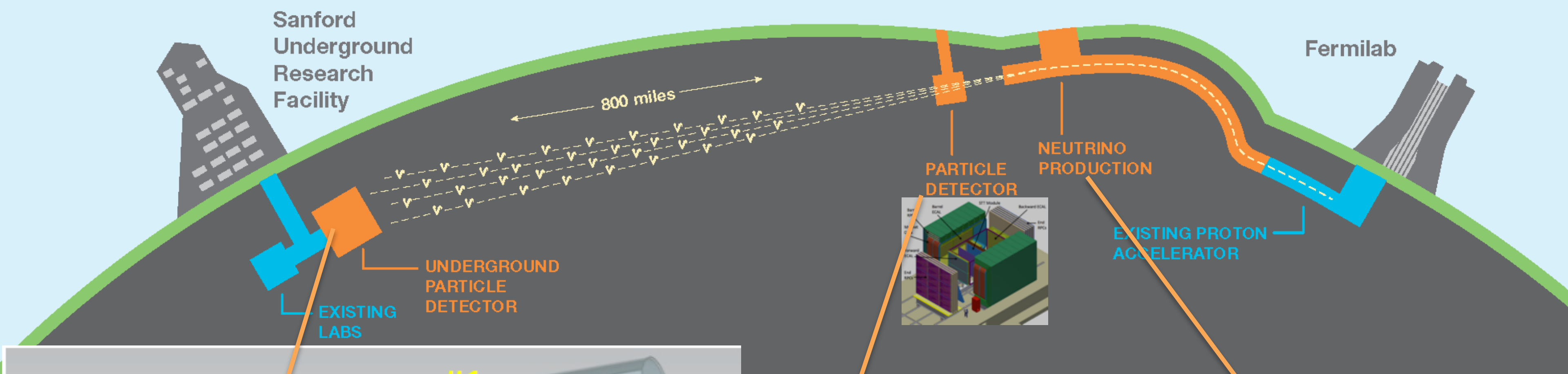
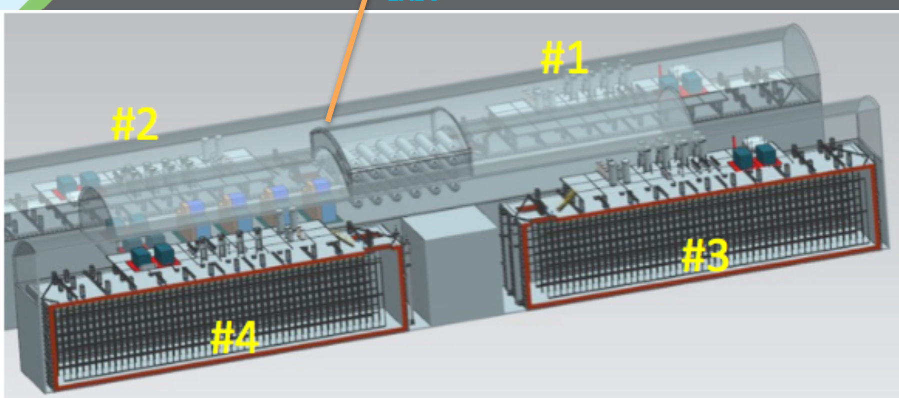
DUNE Experimental Program

Neutrino oscillations physics over LBL (CVP in lepton sector, ν mass hierarchy, osc. param.)
Zero background nucleon decay search
Supernova neutrino physics & astro-physics

(arXiv:1512.06148)





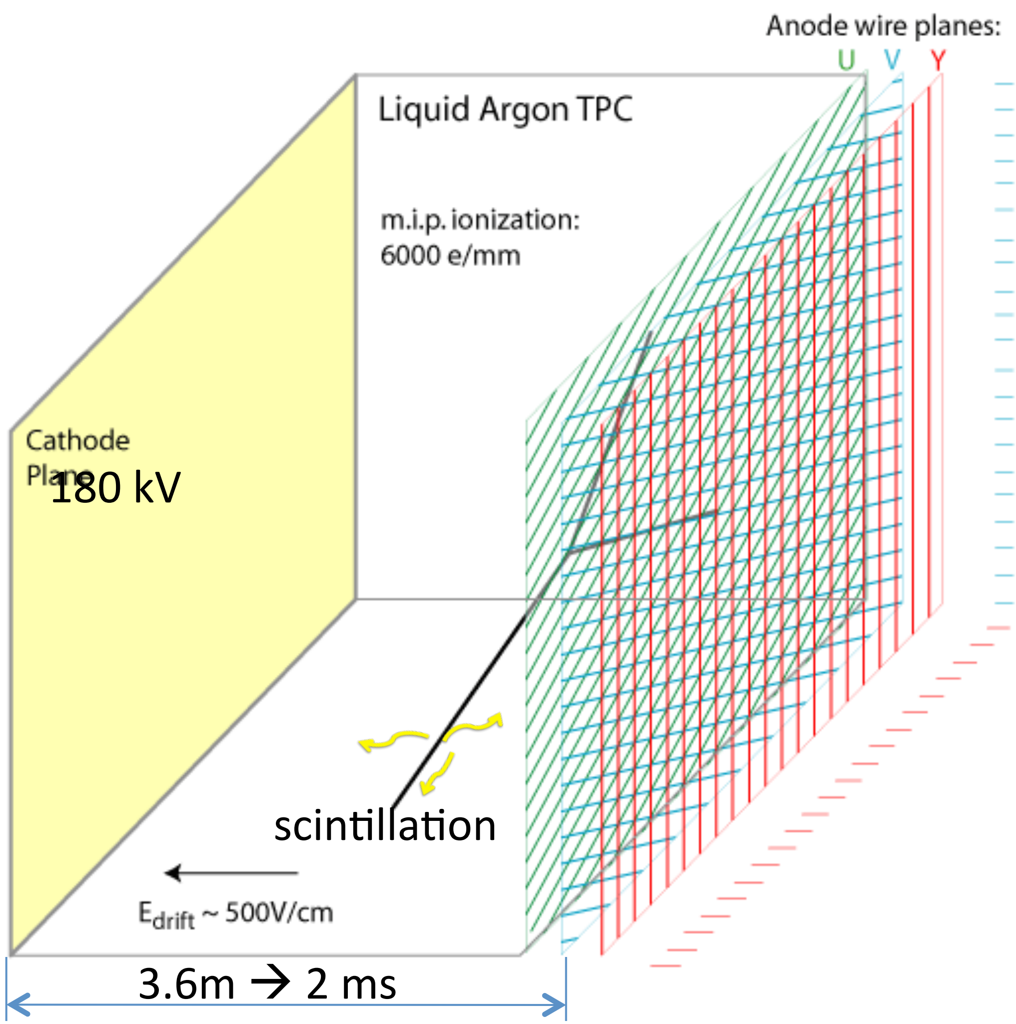
High precision
near detector at 574m

Wide band, high purity μ beam with peak flux at 2.5 GeV operating at ~ 1.2 MW and upgradeable

- Four identical cryostats deep underground
- Staged approach to four independent 10 kt LAr detector modules
- Single-phase and dual-phase readout under consideration

CDR Volume 4: The DUNE Detectors at LBNF
arXiv:1601.02984

Time Projection Chamber (TPC) Operation



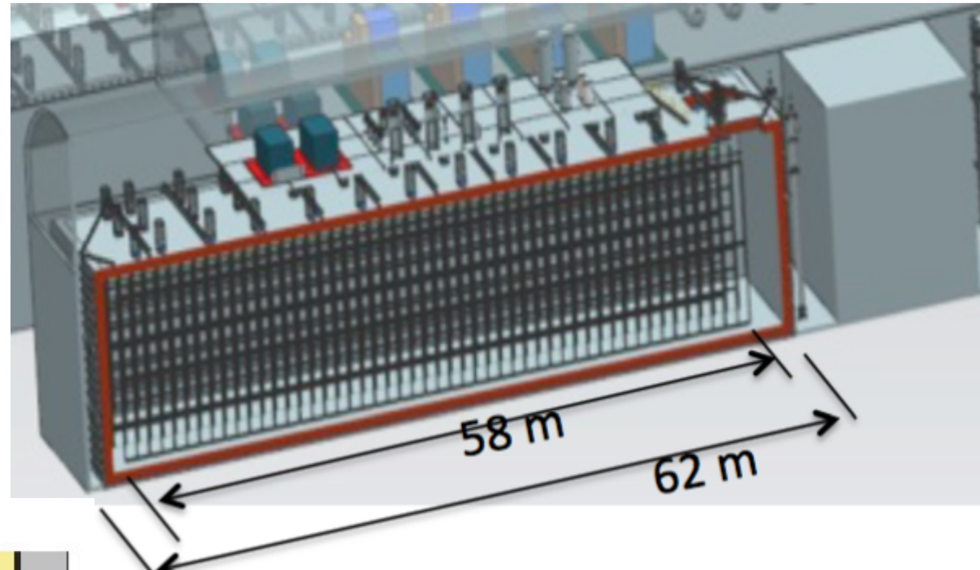
- Ionization signal provides detailed imaging, calorimetric and particle identification (PID).
- Prompt scintillation offer event trigger, t_0 information and improved calorimetric information.
- @ E_drift = 500V/cm:
  - ≈ 60,000 e^-/cm for mip,
  - ≈ 24,000 VUV photons/MeV
- In ultra pure LAr ionization, electron can drift unperturbed over several meters allowing the construction of multi kton LAr TPC's:
  - Electron attenuation length: ~ 5m for 0.1 ppb O_2 equivalent impurities

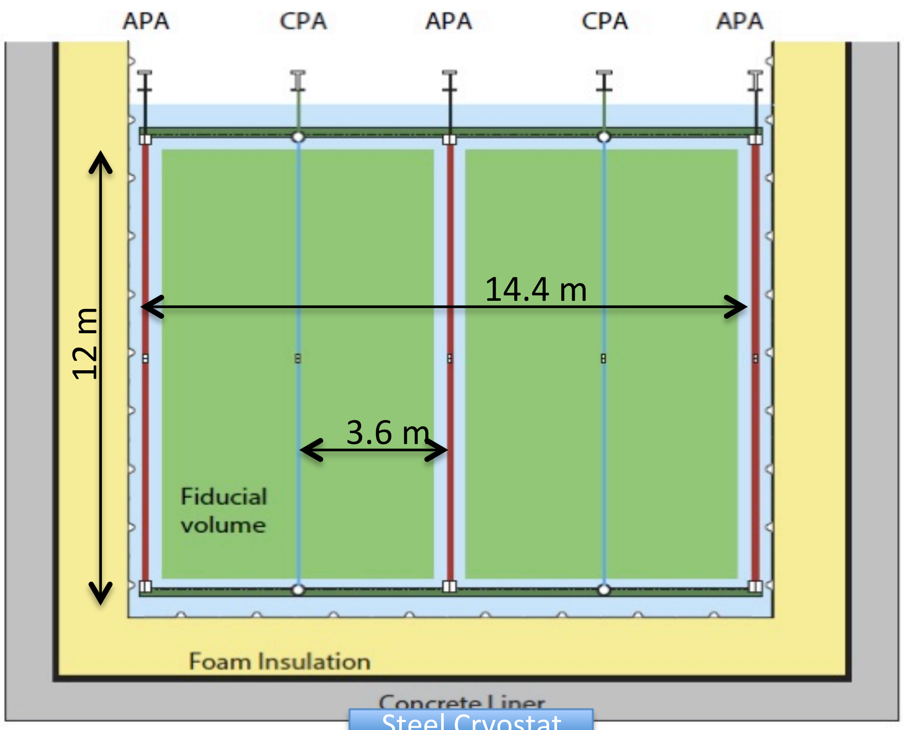
TPC design is modular.

DUNE Single-Phase LAr Far Detector

Readout of :
- Ionization charge
- scintillation light

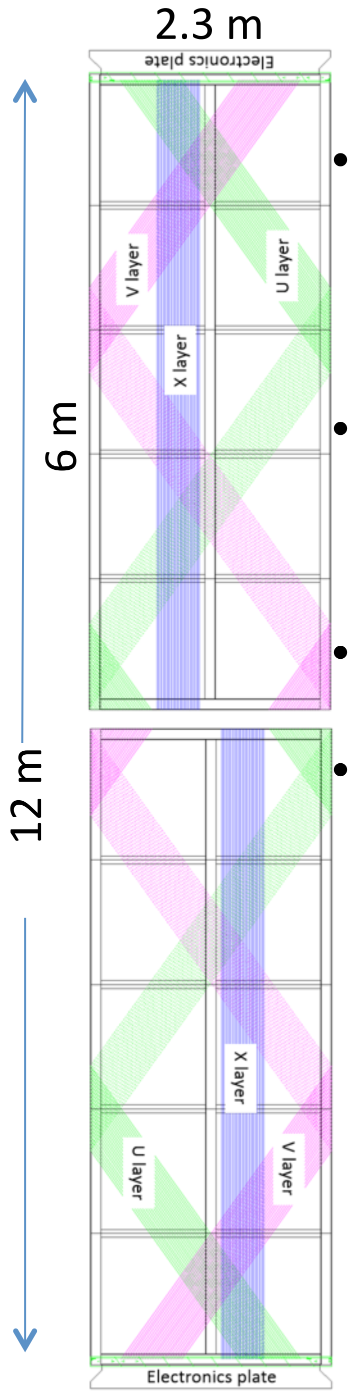
Detector mass [kt]	
total	17.1
active	13.8
fiducial	11.6



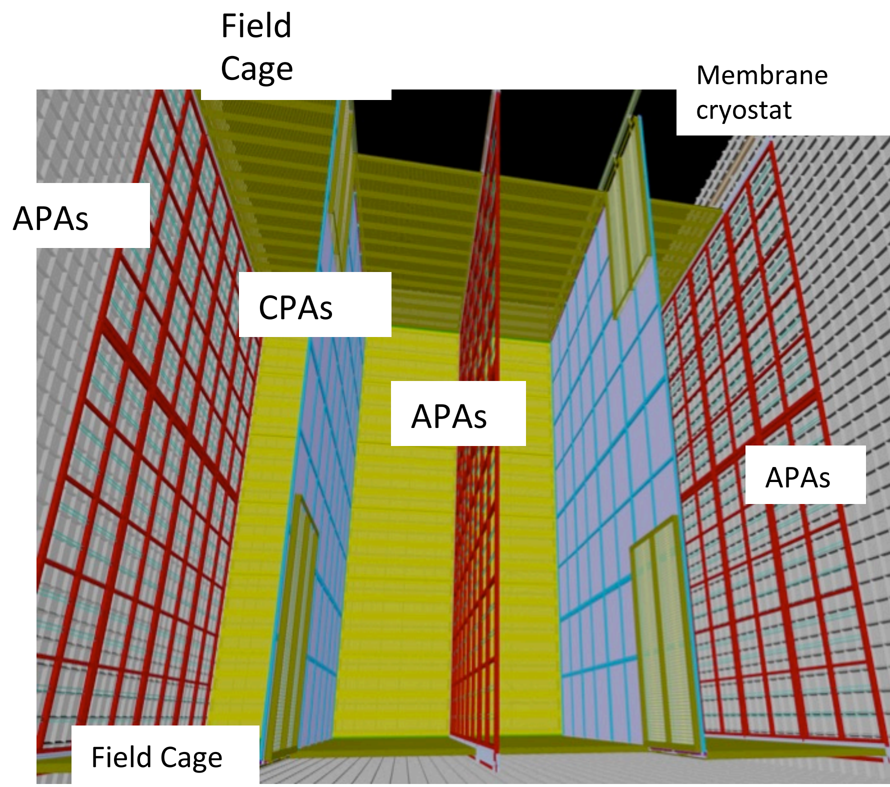


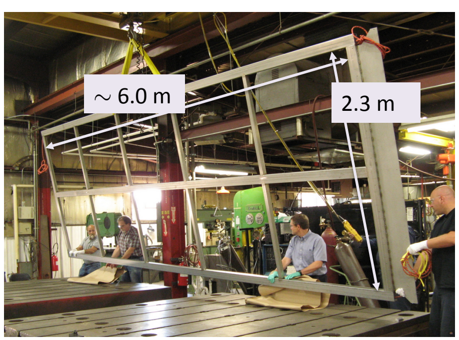
- Time Projection Chamber:
  - wire Anode Planes (APAs)
  - induction + collection wires
- 2 cathode planes at -180 kV:
  - E drift = 500 V/cm
- 4 drift regions: 3.6m drift each
- Photon Detection System integrated in APAs
  - to measure event timing
- Modular construction of CPA, APA, FC

Modular assembly concept



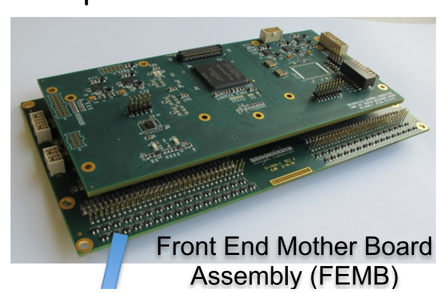
- Modular APAs - 2.3m by 6m
  - width limited by Ross shaft, and shipping
  - Length limited by wire capacitance and noise
- Fully cryogenic readout electronics (analogue and digital) mounted on APA;
  - Winding wires
- Photon detectors embedded in APA.
- Cathode and field cage geometry and modularity fixed by APA and 3.6m drift → HV limitations and purity



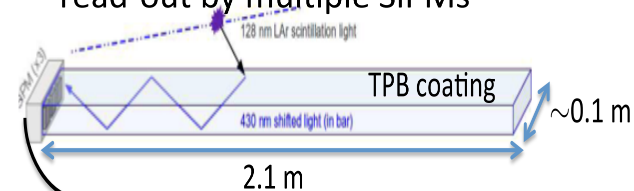


APA frame

Cold electronics bards: Analog CMOS Preamplifiers , ADC ASICs (16ch) FPGA with multiplexers



Wave shifter bars (different variants) read-out by multiple SiPMs



NP02/04: DUNE Development Path

- The basic LAr-TPC technologies are demonstrated by ICARUS, ArgoNEUT/LArIAT, MicroBooNE and WA105.
- The much larger size of the DUNE far detectors requires a strong LAr-TPC development and prototyping effort: ProtoDUNE SP (NP04) and DP (NP02) at CERN, SBN at Fermilab.

Main goals of ProtoDUNEs:

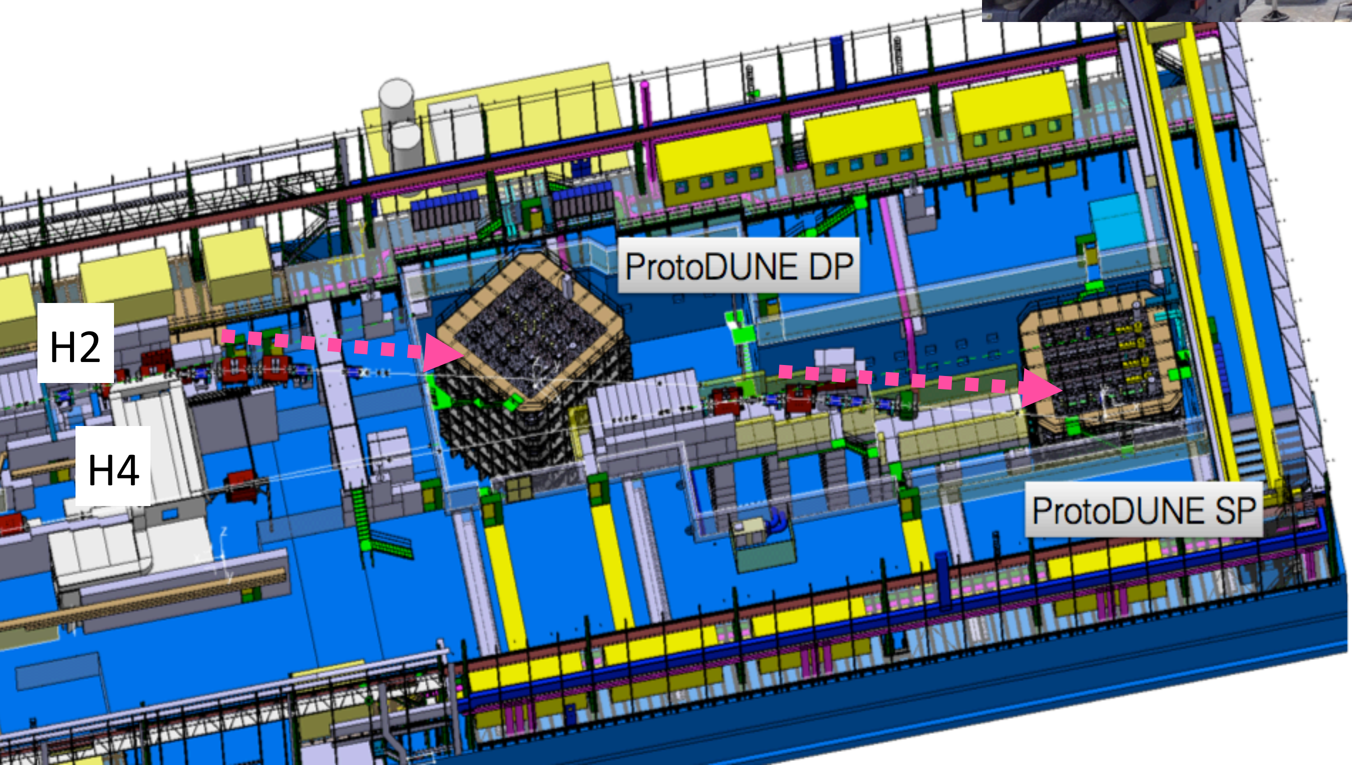
- Engineering validation of the full-scale DUNE detector components.
  - Test the full scale detector elements under realistic (but high rate) conditions.
  - Use as close to final detector components as possible.
- Develop the construction and quality control process.
- Validate the interfaces between the detector elements and identify any revisions needed in final design.
- Validate the detector operation using cosmic rays.
- Study the detector response to known charged particles.
- Improve the detector reconstruction and response model
- Validate the Monte Carlo Model accuracy

Engineering validation

Performance validation

ProtoDUNE at the CERN neutrino platform

EHN1 extension, ν Experimental Area
Beneficial occupancy September 2016
Membrane cryostats ready for detectors installation in April 2017
Charged beam Spring 2018



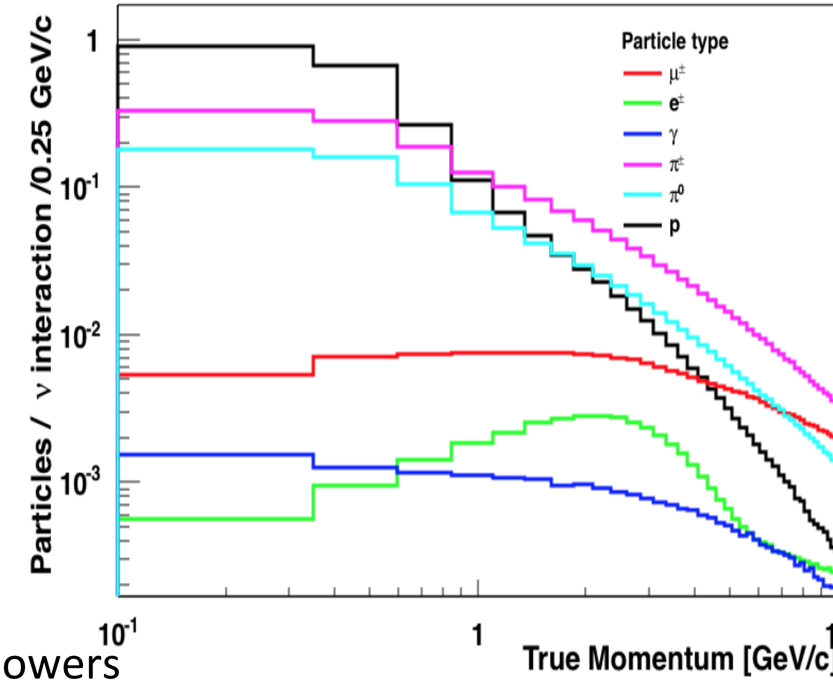
Tertiary beams on H2 and H4: 0.2-12 GeV/c, momentum bite 5% (can be reduced to 1% with integrated spectrometer measurements)

Mixed hadrons beam:

- (±) π, K, $\mathbf{p}$ with e contamination at low energies
- Pure e beams
- Parasitic μ halo

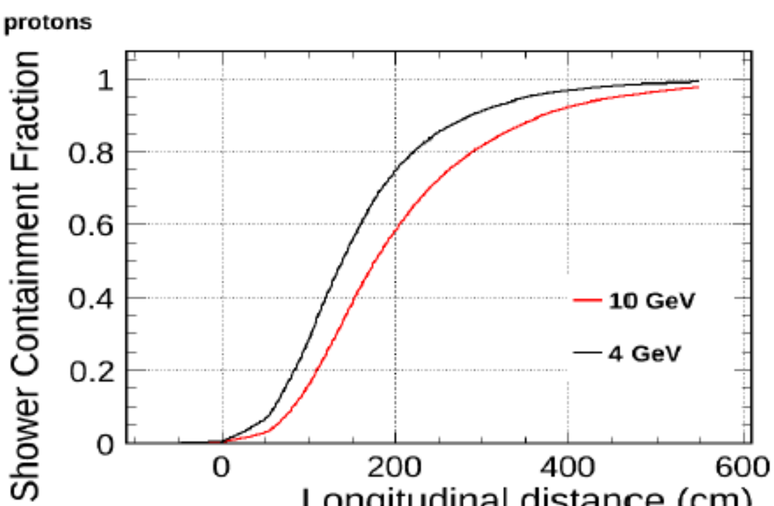
Desired ProtoDUNE-SP Data

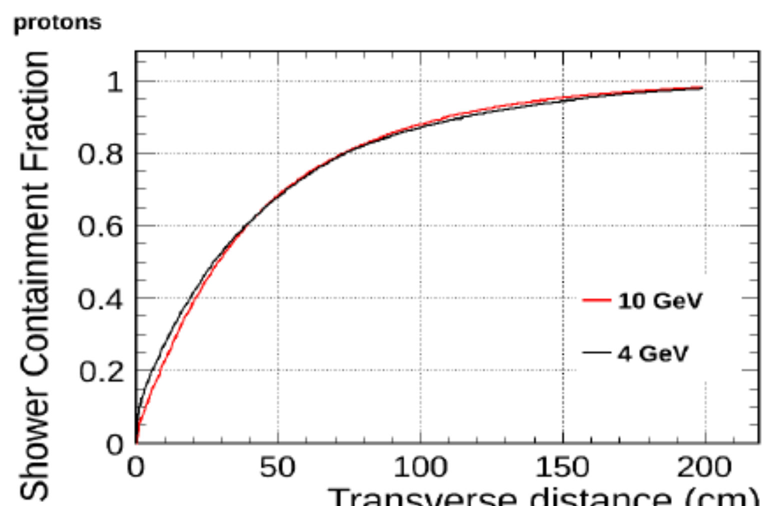
Particles produced in neutrino interactions at DUNE



ProtoDUNE needs to be capable of measuring low energy pion, kaon, and electron showers well.
The vertex reconstruction is critical for PID.
Maximum hadronic shower size is 2m radius and 6m deep.
A 3APA deep (6.9m) by two drift cell wide (7.2m) provides optimal coverage

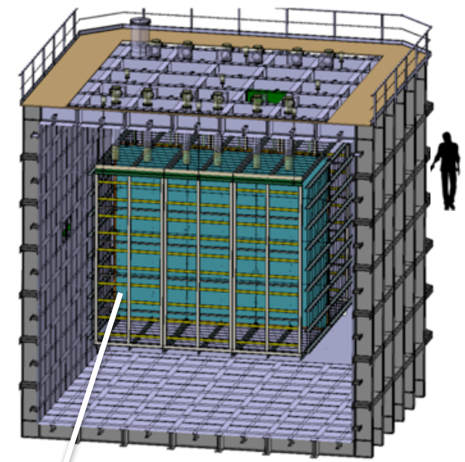
Largest complex event topology is from hadronic showers

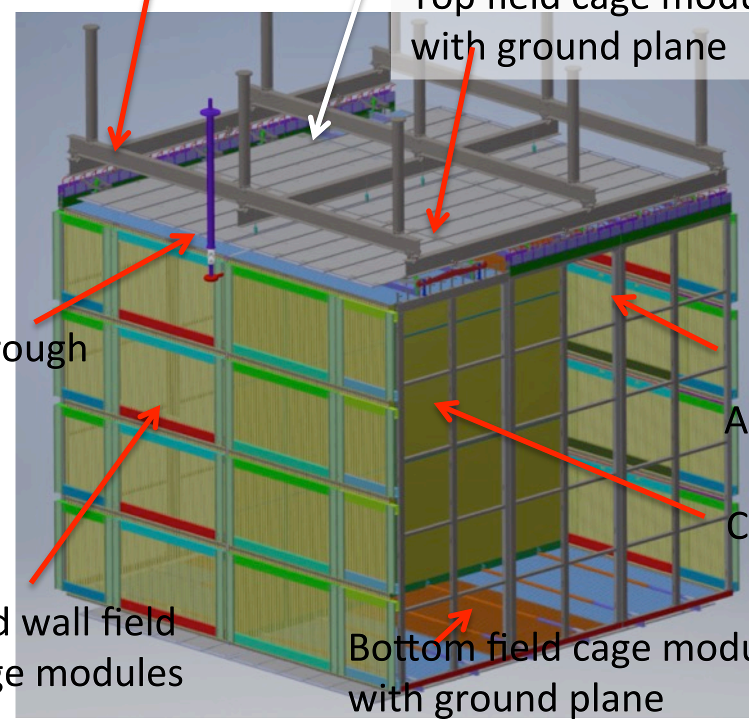




NP04: protoDUNE Single phase LAr-TPC

- Full scale modules of DUNE SP far detector, but only half height.
- The TPC has 6 APAs, 6 CPAs, 28 field cage modules, 15k readout channels
- Active volume:
  - W: 3.6mx2, H: 6m, L: 7m
  - 300 ton active mass
- Installed hanging under 3 mounting rails suspended under the cryostat ceiling
- Innovative features:
  - Cold analog and ADC ASICs and FPGAs
  - Double sided APA readout with electronics on one end only
  - All resistive cathode plane
  - Modular field cage with metallic profiles
  - APAs with integrated photon detectors
  - Low mass beam plug on field cage





CPA Requirements for ProtoDUNE SP

- Provide equipotential surfaces at -180kV nominal bias voltage
- Maintain a flatness better than 1cm*
- Use materials with comparable CTEs to that of stainless steel
- Limit the electric field exposed to LAr to under 30kV/cm
- Prevent damage to the TPC including its readout electronics In case of a HV discharge anywhere on the cathode
- Provide constant bias voltage and current to all attached field cage resistor divider chains
- Support half of the weight of the field cage
- Constructed in modular form that can be easily installed in the cryostat
- Accommodate PD calibration devices

**based on the requirements:*

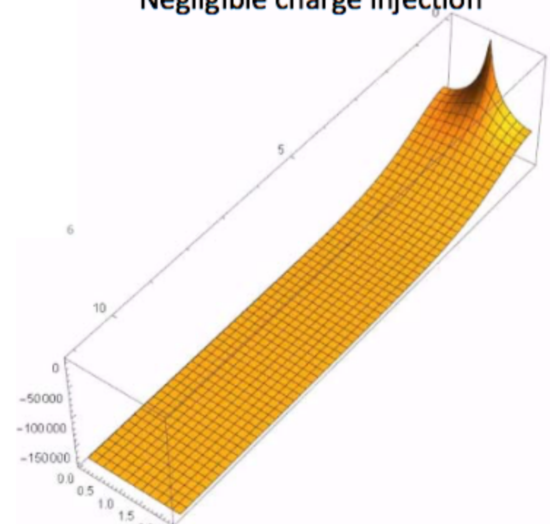
the fiducial volume of the detector shall be known with a precision of at least 1%

E_field uniformity.

Resistive Cathode Concept

- With a conventional metallic cathode assembly, in the DUNE LAr-TPC layout, several tens of J of energy on each interior cathode are stored when energized to -180kV.
- In the event of a discharge from a cathode edge to the facing cryostat wall, there is a risk of physical damage to either the cathode or the membrane. The voltage on an all metal cathode will also collapse very quickly (ns), injecting high current into the cold electronics, risking damage to the front end ASICs.
- To minimize these risks, it has been proposed to use of a cathode made out of insulating material with a resistive coating in the MΩ to GΩ/square range. This will greatly reduce the peak power transfer to the cryostat and peak current injection into the front-end ASICs in a HV discharge*.

R_{frame}=10GΩ/m
$R_{interior}$=1GΩ/sq
@200ms, 85% energy remains
Negligible charge injection



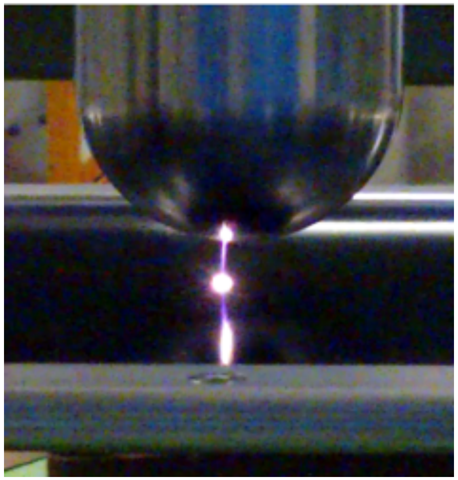
Study of the Charge Injection to the Electronics in a HV Discharge
- By Sergio Rescia (LBNE docdb 10749,10865)

R&D for CPA resistive panels

- Commercially available resistive Kapton film from DuPont (125 um thick) identified as candidate to provide the necessary resistivity on the cathode surfaces: 1-10 MOhm/square adequate for surface operation of the LAr-TPC.
- The film can be laminated (double sided) on insulating FR4 sheets using commercial printed circuit board process: consolidated technique currently used at CERN for thick GEM development
- Large Press available (> 2.1 x 1.2 m2) in Europe

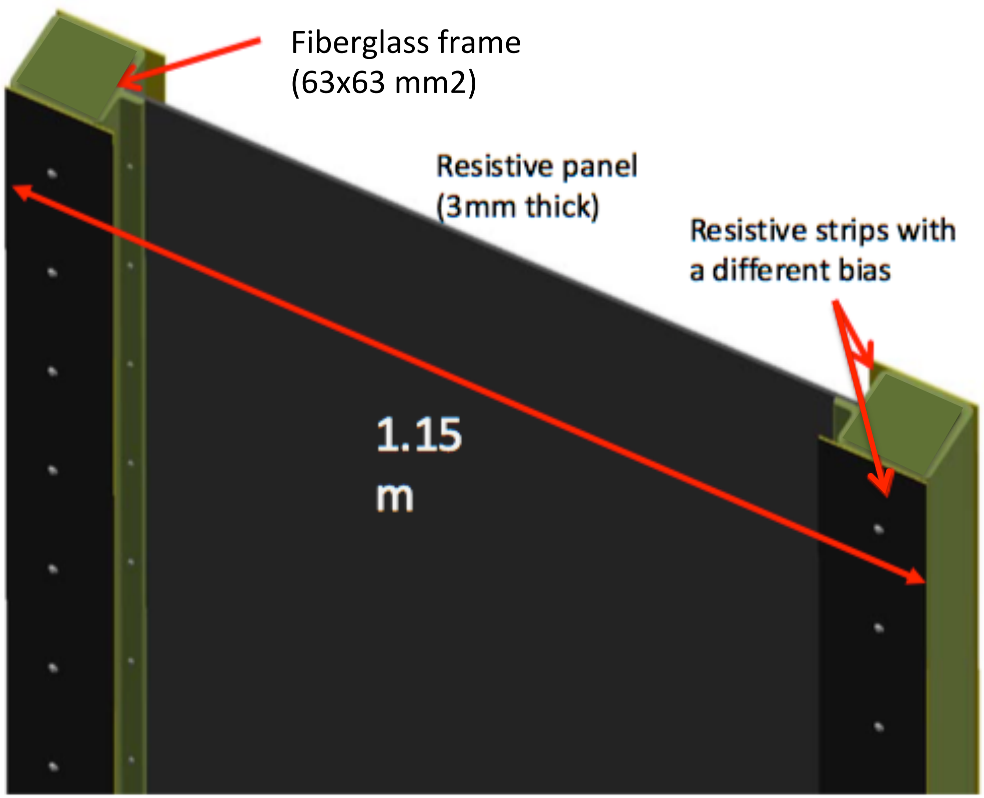
Dedicated tests at CERN in pure LAr allowed verifying:

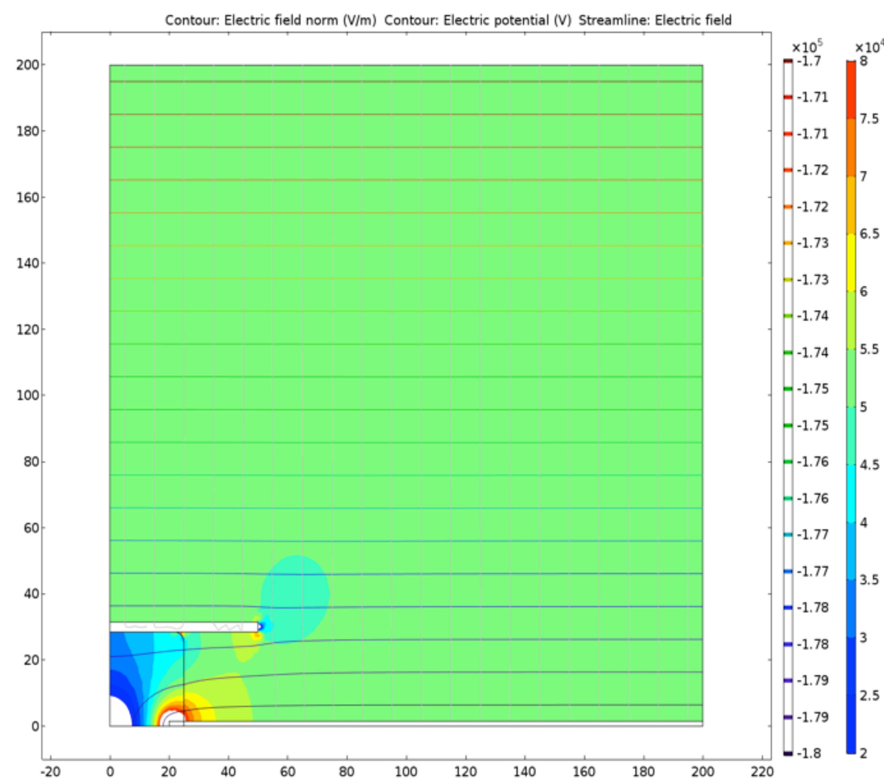
- Robustness to sparks
- Ageing in cryogenic environment
- Lamination stability in LAr
- LAr purity compatibility



CPA panels

- Cathode surface area is 3mm thick (beneficial for fiducial volume definition)
- The surrounding (63x63 mm2) frame prevents deformation of the cathode plane from the convective force of the liquid, and provide support of the field cage.
- Local field distortion due to the frame thickness are minimized adding resistive strips on the surfaces of the frame facing the anode plane
- Each strip are biased at the natural voltage through dedicated resistive divider and will overhang the sides of the frame by 1".

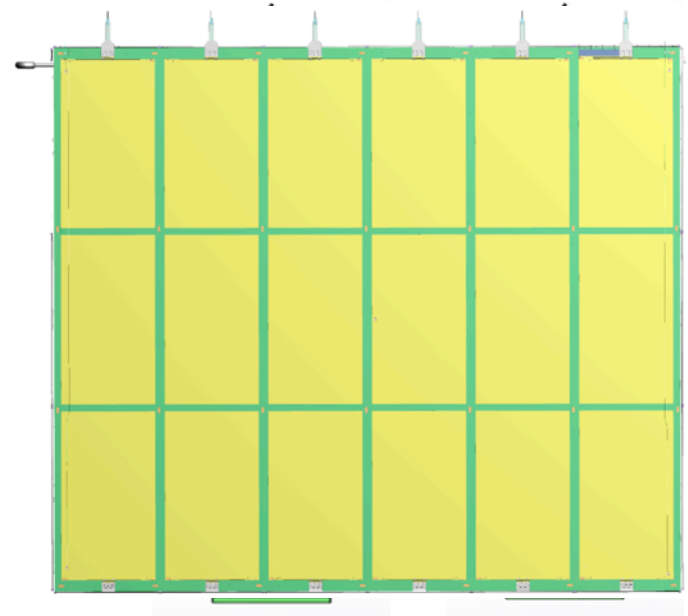




ProtoDUNE CPA design

- The cathode plane: array of 18 modules constructed from 6-cm-thick FR4 frames.
- The frames hold 3-mm-thick FR4 panels laminated on both sides with resistive Kapton.
- Each CPA module is 1.16 m wide and 2 m high, and they stack to form six CPA columns of height 6 m.
- The six-column CPA matches the dimensions of the APA planes, with a width of about 7 m.
- Each column hangs on the supporting rail in a single middle point to allow for small relative vertical displacement (cryostat root deformations)
- The assembled plane of 6 CPAs will have FC profiles attached to them around the outside perimeter
- The top and bottom FC hinges are aligned with the CPA lifting point to minimize moment load to the CPA.

80 kg each column



FC Requirements for ProtoDUNE SP

- Provide the nominal drift field of 500V/cm
- Withstand -180kV near the cathode
- Define the drift distance between the APAs and CPAs to <1cm*
- Use materials with comparable CTEs to that of stainless steel along the length of the TPC, minimal CTE in the drift direction
- Limit the electric field exposed to LAr to under 30kV/cm
- Prevent damage to the TPC In case of a HV discharge anywhere on the field cage, or cathode.
- Provide redundancy in the resistor divider
- The divider current must be >> the ionization current in the TPC drift cell, yet less than the power supply current limit when all dividers are connected in parallel
- Constructed in modular form that can be easily installed in the cryostat
- Integrate Beam Plug for low mass x-section along beam line
- If a laser calibration system is adopted, allow laser beams to enter into the active volume

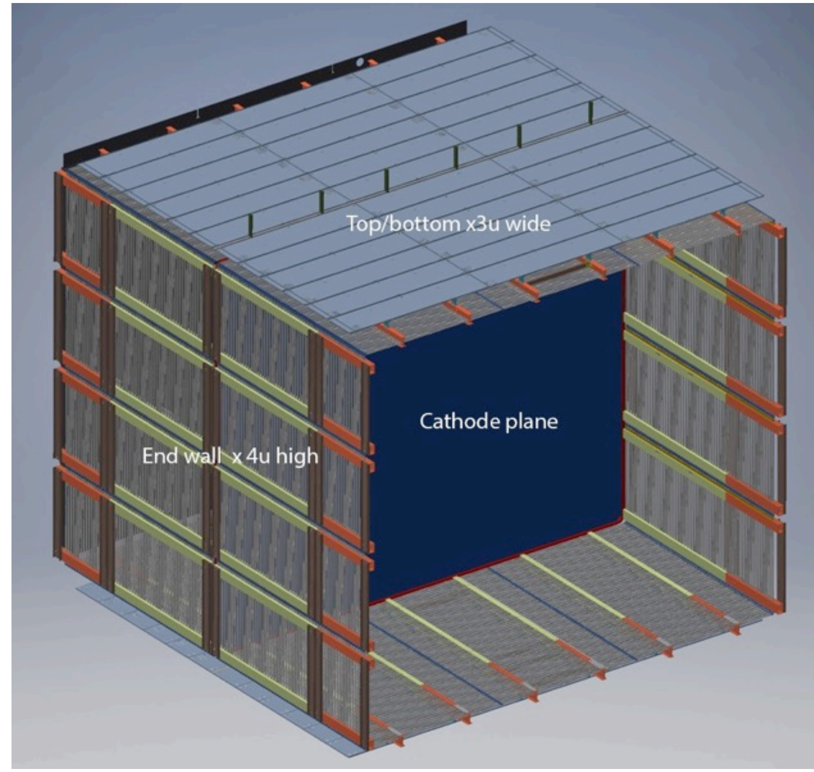
**based on the requirements:*

the fiducial volume of the detector shall be known with a precision of at least 1%

E_field uniformity.

Proposed field cage for ProtoDUNE SP

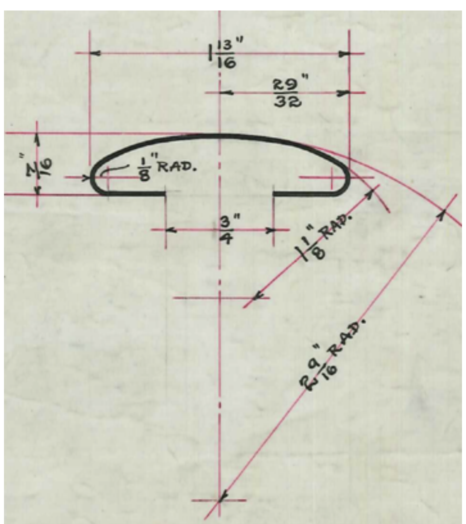
- The present design of the ProtoDUNE single phase field cage is based on several independent panels of roll-formed (or extruded) metallic profiles held together through pultruded fiber glass beams.
- Each panel will have his own resistor-chain for voltage degrading and will be electrically insulated from the adjacent ones
- The field cage profiles are electrically isolated between modules to minimize peak energy dump in case of sparks

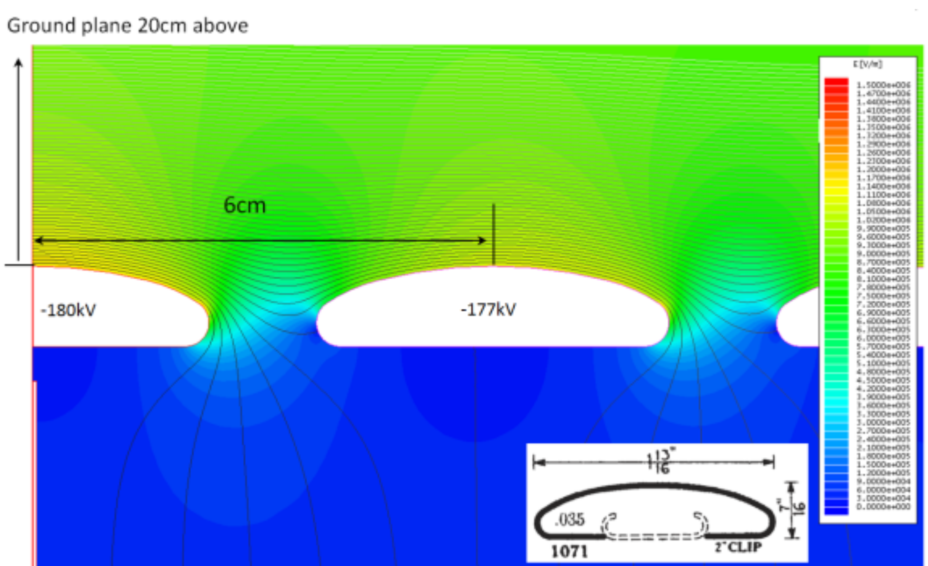


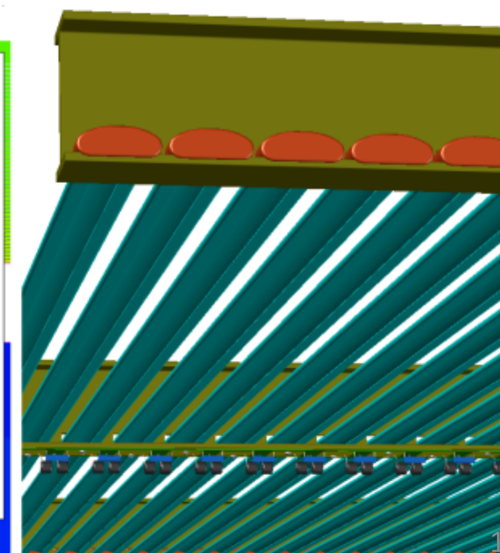
- All field cage modules can be reconfigured between 2.5m and 3.6m drift lengths.
- Top and bottom field cage modules have integrated ground plane panels to shield the high voltage from entering the top (gas ullage and rails) and bottom (cryogenic pipes) service regions.
- *Baseline for profiles material choice is stainless-steel; extruded aluminum is the alternative.*

Roll-formed profiles

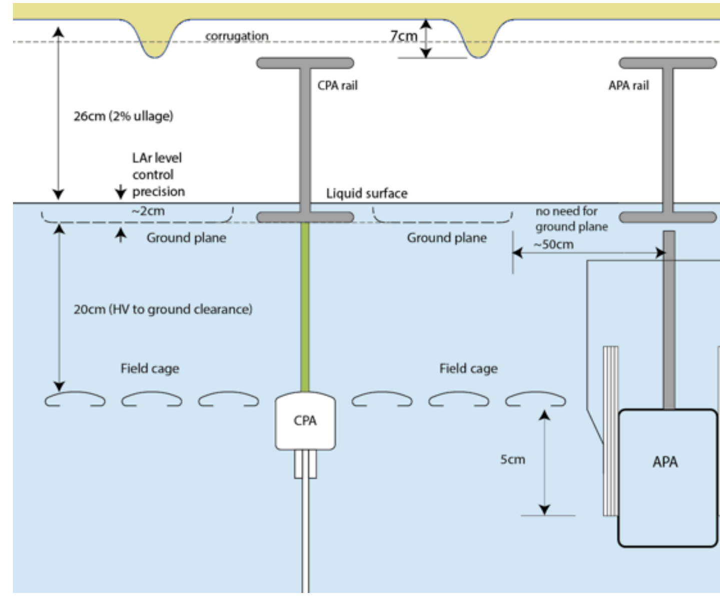
- Open roll-formed metallic profiles for field cage electrodes are preferred for LAr purity considerations.
- Optimized shape of profiles allows keeping the electric field strength on the highest biased electrodes under 15kV/cm even with only 20 cm clearance from the ground plates.
- A safe way of dealing with the ends of the profiles based on PE caps allows minimizing the top and bottom TPC clearance thus making more efficient use of the LAr.



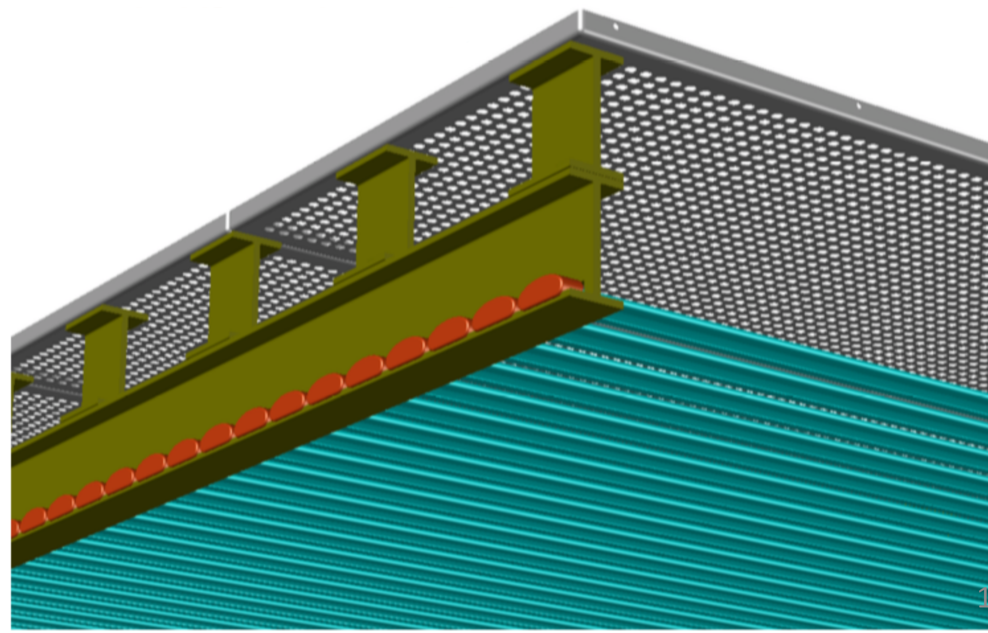




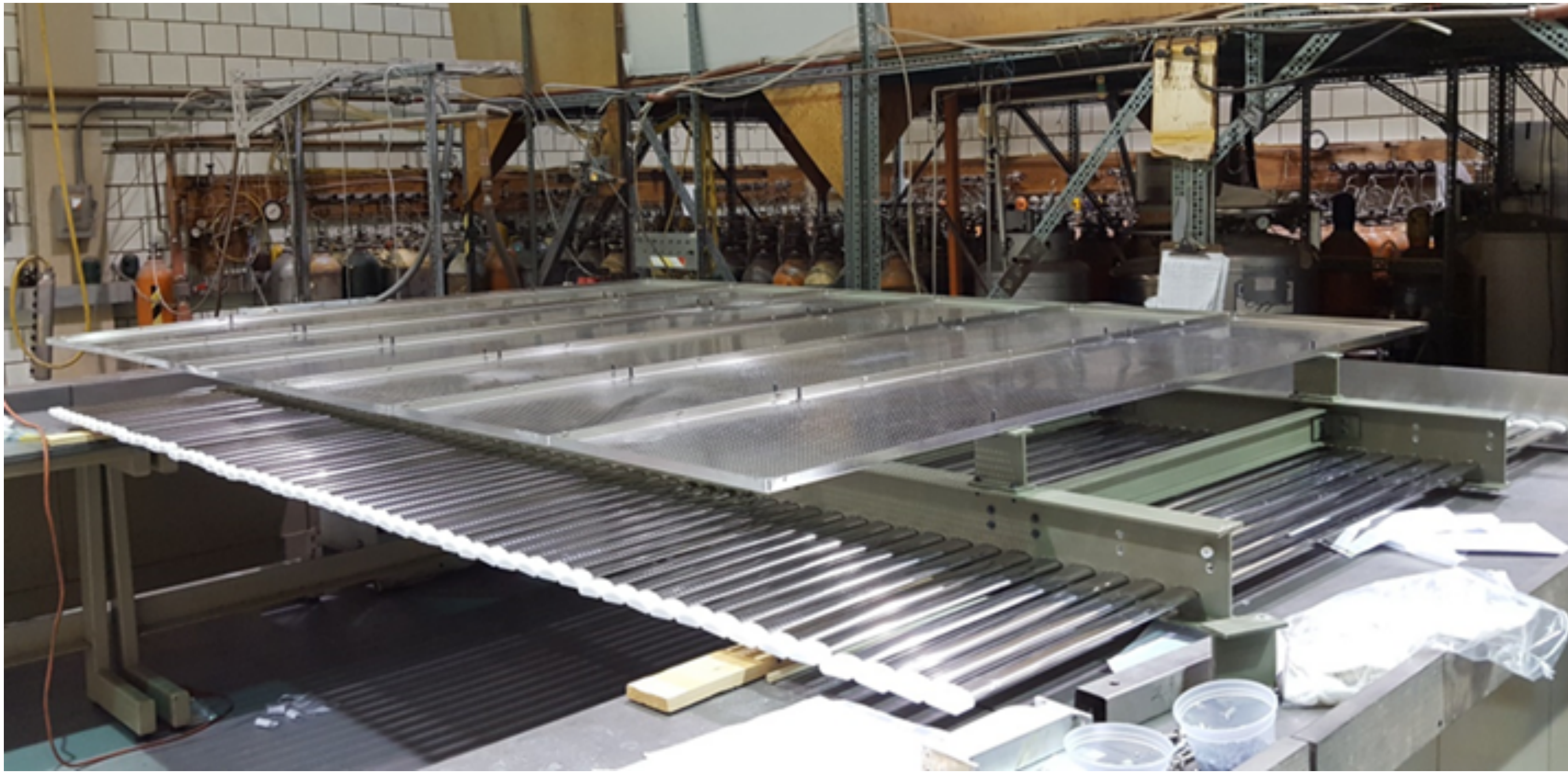
The Addition of Ground Planes



- If the field cage is placed close to the gas ullage, the E field in the gas would be high and increase the risk of arcing in the gas.
- The solution is to place a ground plane just under the liquid surface, to shield the high E field around the TPC from entering the ullage.
- Similar ground plane are used to reduce the TPC to cryostat floor distance (piping, membrane corrugations)
- The current ground plane consists of multiple tiles of perforated stainless steel tiles mounted 20cm above the field cage.
- The edges of the tile and the rounding radius of the holes must be carefully controlled to avoid local high field.



Top/Bottom FC Construction



- Each top and bottom panel is as wide as the APA/CPA (2.3 m) and are hold with FRP I-profiled beams (~ 6x3 inches)
- Full scale mock-ups constructed in US at assembly sites
  - Assembly sequence
  - Mounting operation
  - QA/QC
- Structural analysis show minimal deflections (~mm level).

End Wall Panel with Hangers

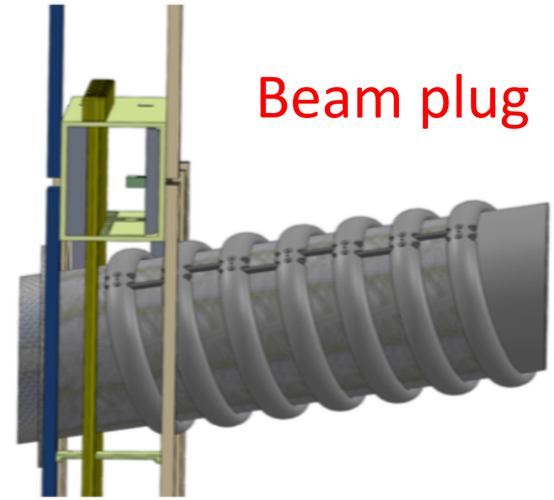
Vertical Wall FC Design:

- Four panels, 1.5m wide, on top of each other to build up to the 6m height of the APA. Top panel has hangers design incorporated in it. A special panel is designed to incorporates beam plug.
- Box-shaped FRP beams (~ 6x3 inches) for structural optimization
- No ground planes
- Four full scale mock-ups also completed in US (one complete end-wall)

Material Budget in the ProtoDUNE-SP Beam

- Required Particles:
  - Hadrons starting 1 GeV/c , electrons from 0.5 GeV/c
  - Energy uncertainty <=1%
  - Minimize electron showering, for e/γ discrimination test
  - Avoid large scatterings, for "good" particle identification and checks of angular resolution/reconstruction
- Dead materials are an issue, especially if the composition/ thickness is not well defined.
- Reminder: without plug,
  - all electrons would shower before the active volume,
  - >=50% hadrons would interact in the passive layer
  - 1GeV un-collided protons would loose 36% of their energy

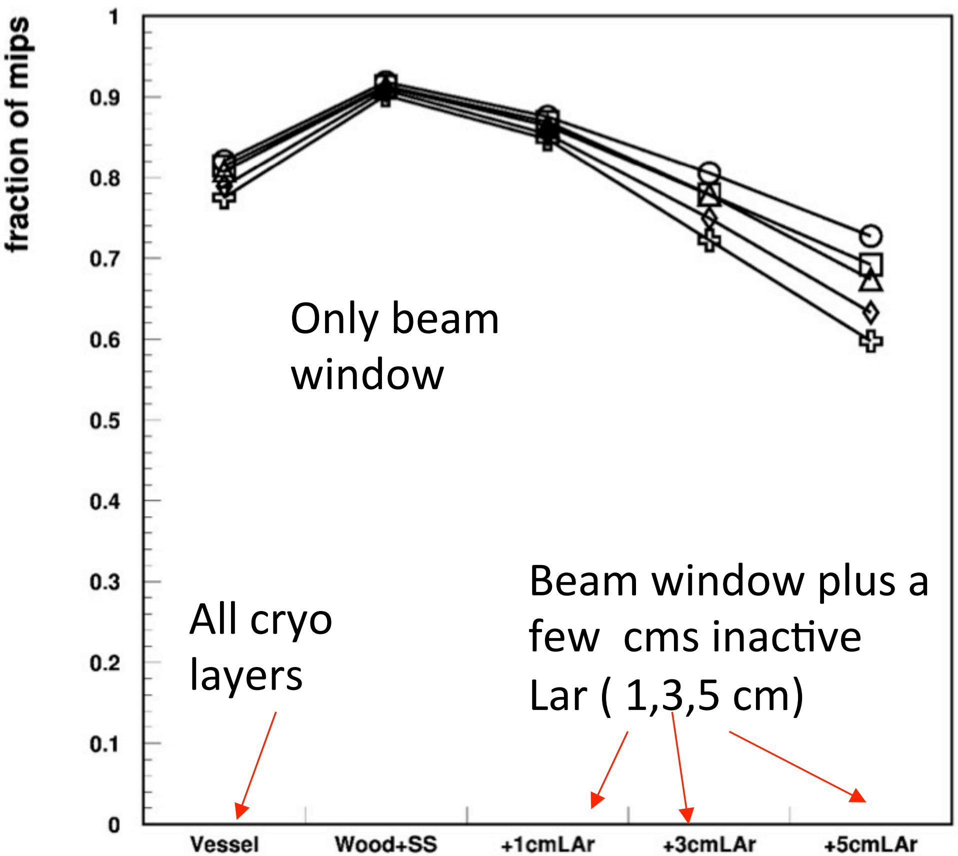
Beam plug



- fiberglass can filled with nitrogen gas (neutral buoyancy).
- connected to a dedicated middle FC end-walls near the CPA.
- field shaping electrodes on the beam exit window and cylindrical surface of the can
  - to stand up to 165 kV over plug length
  - to minimize field distortions in the active volume.

Effect of materials energy measurements

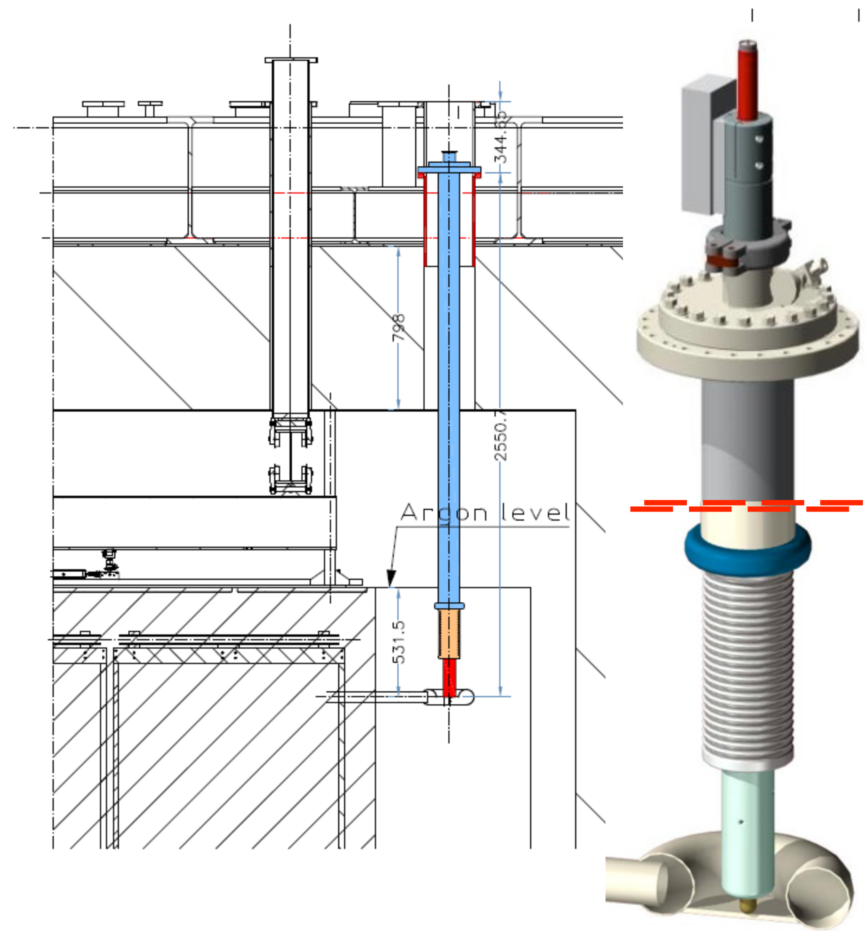
- Electrons
  - Fraction of electrons not showered after dead layers in various configurations ➔ study e/γ discrimination



- For protons at 1GeV/c, every cm of inactive LAr adds 1.5% energy loss. ➔ few cms can be afforded IF PRECISELY KNOWN (better than 1-2 mm)
- For pions at 1 GeV/c, absolute energy loss is relatively less important, however
  - angular deflection becomes large, 20mrad rms for 5cm inactive LAr
  - Spread in energy loss 0.5% at 5 cm inactive LA
  - Also for pions safe limit is few cm, need knowledge
- Combining electron and hadron requirements, acceptable LAr inactive layer is or the order of 1cm.
- Needed good knowledge of the actual thickness

HV Feed-through (-180 kV)

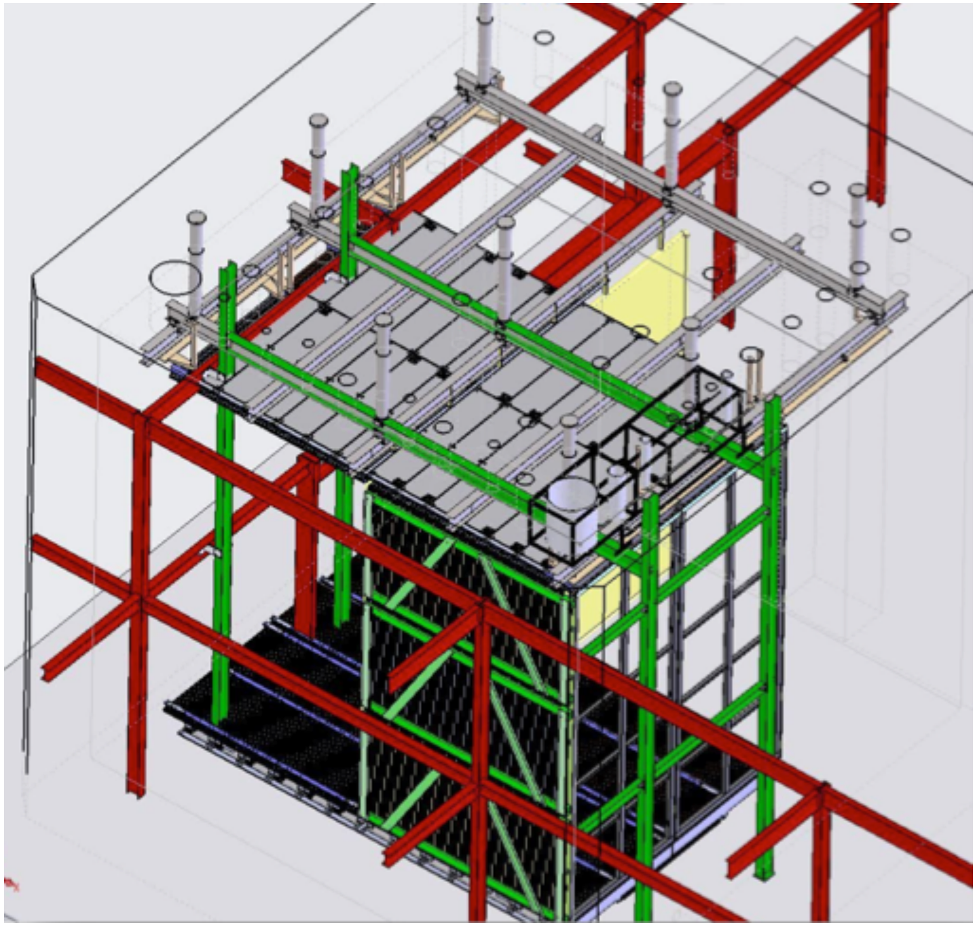
- In the baseline option, the design of the HV feed-through will take advantage of the strong synergies between the single phase and dual phase prototypes.
- The present DP HV feed-through design (HV up to 300 kV, based on the ICARUS experience) is easily adapted to the SP without any major modification in the dimensions or in the mechanical features.
- The feed-through connects to a rounded, donut-shaped "cup" mounted on one side of the CPA at one end of the cathode plane.
- The cup is connected to the mounting point on the frame via a cylindrical tube in order to position the receptacle directly under the feed-through flange.



Mechanical mock-up in Ash River, MN

- Full scale ProtoDUNE-SP components (FC, CPA, support structures)
- Tests of interfaces and handling
- Test of assembly procedures

Presently underway



ProtoDUNE SP CPA-FC HV test setup

This setup will be able to test the following features at full scale for E field purpose:

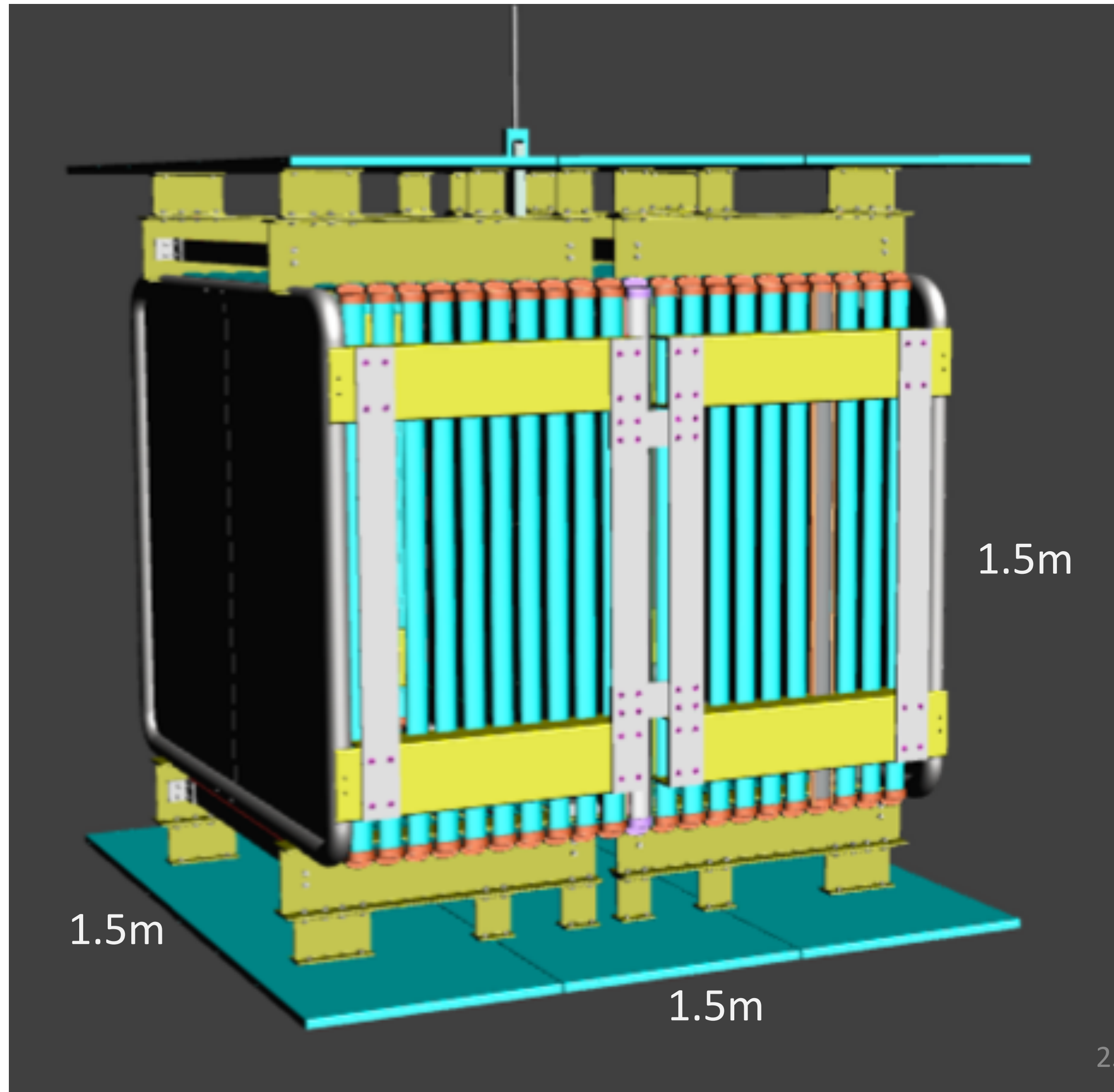
- CPA lifting fixture
- Ground plane
- Ground plane overhang
- Field cage support structure
- CPA edges
- Field cage profiles
- Profile caps
- End wall FC box beams
- HV cup

First Run foreseen in next months

Second Run beginning of next year including:

- Laser window
- Beam plug window
- Aluminum profiles

in the 35 ton facility at FNAL



In the following talks …

- A design of the TPC has been developed to meets the physics requirements.
- The design of the CPA and FC is based on experience learned from past experiments, although with the addition of innovative and original solutions.
- Extensive testing of materials and the construction of prototypes have been performed to thoroughly understand the design.
- Full size mechanical prototypes are being constructed to evaluate the installation of the TPC into the cryostat
- Large scale HV test is being prepared to study the electrostatic performance of the CPA-FC system.