High Voltage and TPC Status

Horizontal Drift
LBNC Meeting, March 4, 2021

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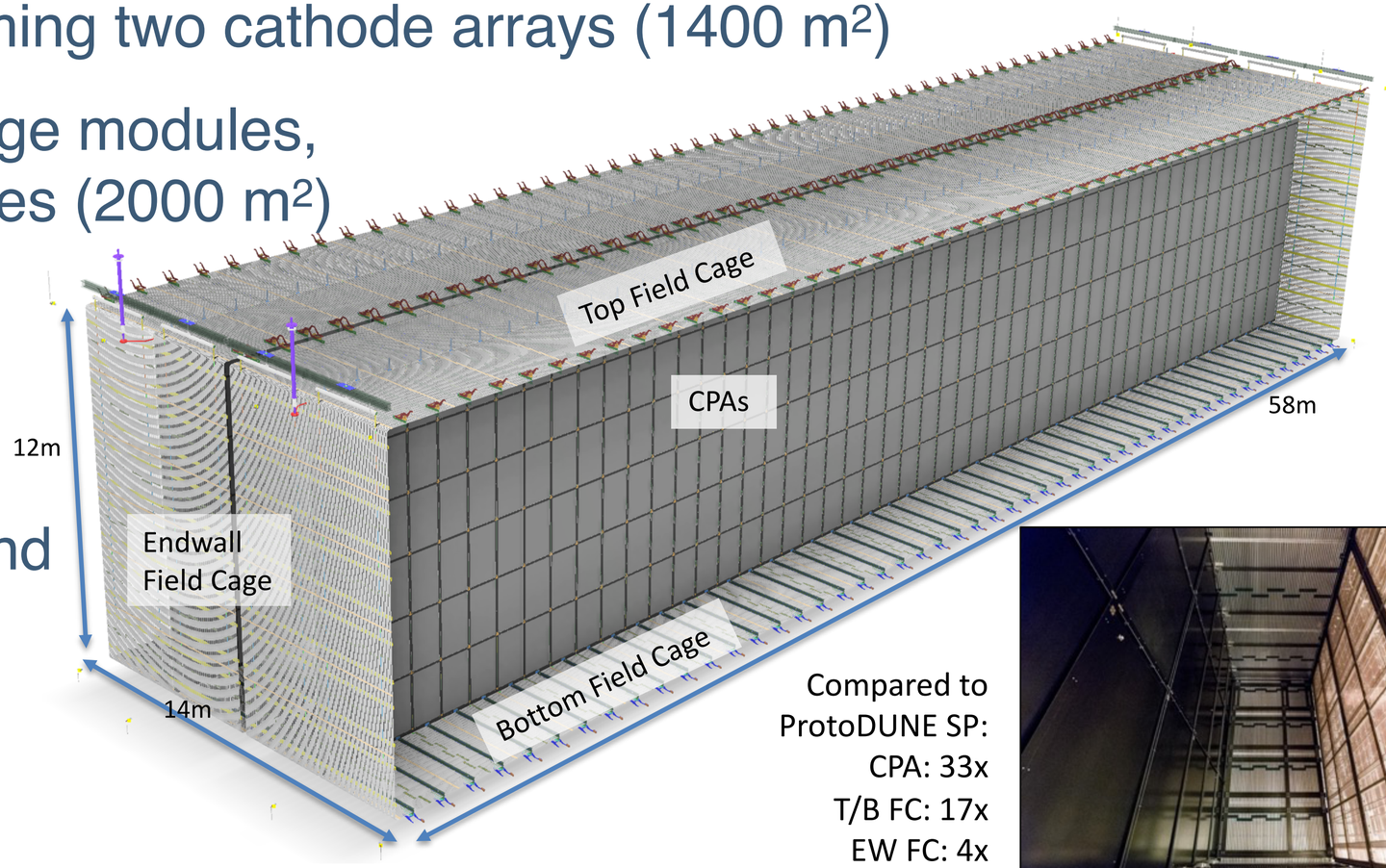
Fermilab DUNE

Outline

- Scope &Requirements
- Lessons learned from ProtoDUNE
- Improvements
- Status: design and interfaces
- Prototyping
- Plans

HVS Consortium Scope for the SP FD (HD)

- Design, fabricate, test and assemble
  - 100 CPA resistive panels forming two cathode arrays (1400 m²)
  - 100 top + 100 bottom field cage modules, 48 End Wall field cage modules (2000 m²)
  - 2 sets of HV power supplies, cables, ripple filters, and feedthroughs
  - Digitizers for HVPS and ground plane monitoring
  - Cameras for HV monitoring



Compared to ProtoDUNE SP:
CPA: 33x
T/B FC: 17x
EW FC: 4x

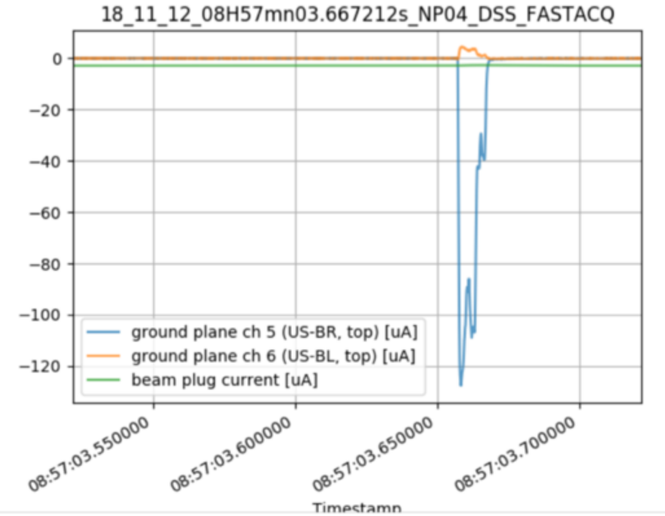
HVS High-Level Requirements

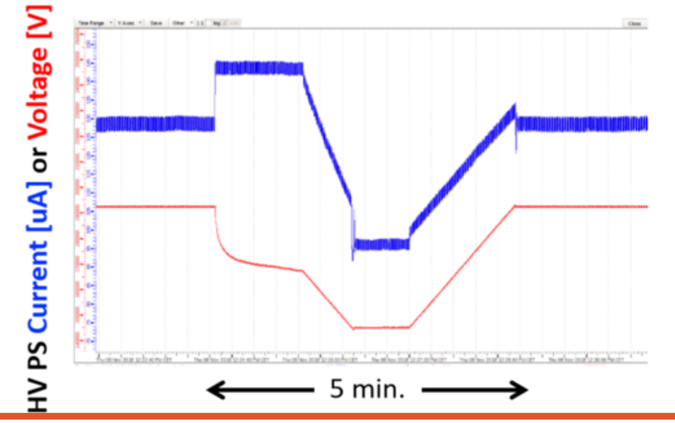
ID	Description	Spec (Goal)
SP-FD-1	Minimum drift field	250 V/cm (500 V/cm)
SP-FD-11	Minimum drift field uniformity	< ±1% [in 99.8% volume]
SP-FD-12	Cathode HV power supply ripple contribution to system noise	< 100 electrons
SP-FD-17	Cathode resistivity	> 1MOhm/sq. (1GOhm/sq.) [upper limit 10 Tohm/sq.]
SP-FD-24	Local electric field	< 30 kV/cm (with specific exceptions to be tested separately (e.g. HV feed through))
SP-FD-29	Detector uptime	> 98% (> 99%)
SP-FD-30	Individual detector module uptime	> 90% (> 95%)
SP-HV-1	Power supply stability	> 95% uptime
SP-HV-2	Provide redundancy in all HV connections	Two-fold (Four-fold)

- Most HVS requirements fulfilled in ProtoDUNE-I operation (lessons learned documents)
- The “TDR” design (based on ProtoDUNE-I HV system) successfully passed the PDR in June 2019
- The improved design passed the PDR refresh in June 2020.

Lessons Learned from ProtoDUNE NP04

- **<u>HVS goal of 180 kV on CPA reached soon after the LAr fill and maintained for ~2 years with remarkable uptime</u>**:
  - During beam run: > 98%
  - During long term stability run: ~ 99.5%.
  - No system degradation observed over nearly two years of operation
- 235 kV reached and maintained for several days at the end of 2020 run (the highest in a SP LAr-TPC)
- Two classes of instabilities recorded through out the detector live-time:
  - Fast discharges: O(10/day), ~10 ms duration; self recovering
  - Sustained excess current (“streamers”): mostly from the same specific location. Recovered by lowering the voltage using an auto-suppression script.
- CPA alignment measured with cosmic muons shows tilts but mostly within requirement.



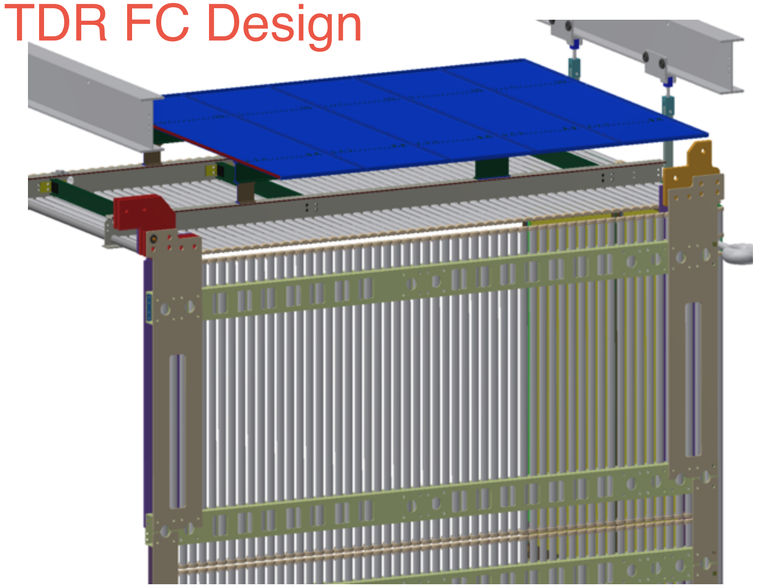


The behavior of the “streamers” possibly explained as a charging up effect of insulating materials in the strong e-field regions outside of the field cage

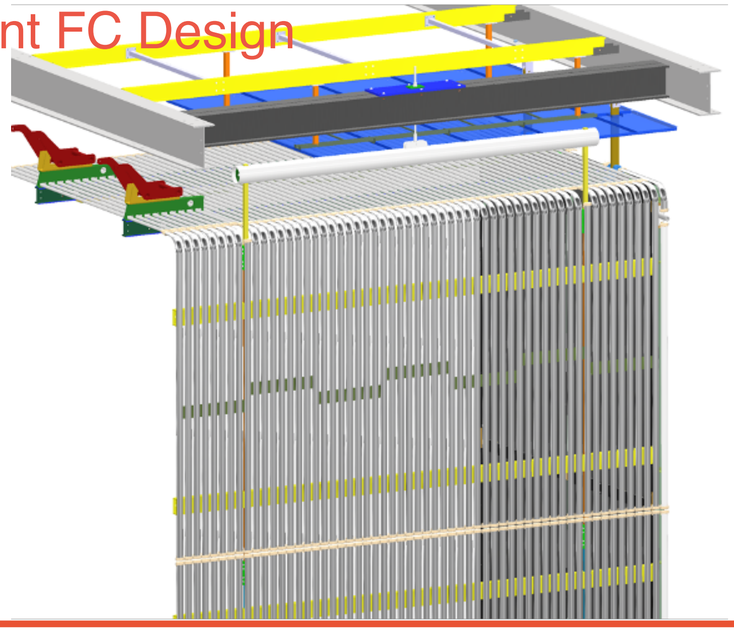
Improving the FC Design

- Optimization of the field cage:
  1. Eliminating nearly all insulating materials on the outside of the field cage to reduce the probability of surface charging in the high E field region
  2. Increasing field cage to top ground plane distance, and remove bottom ground plane to further reduce E field, and stored energy (GPs moved out of HVS scope)
  3. Introducing bent profiles at the End Wall field cage corner edges to improve drift field uniformity.
- Value engineering:
  - The changes result in simplified design, lighter, more robust construction, and significantly lower material cost.
  - All FC assembly and testing will be done underground; only shipping of the ”prepared and QC’ed components” of the field cage is required
  - the EWFC support design ensures EWFC verticality regardless of the cryostat roof motion

2019 TDR FC Design

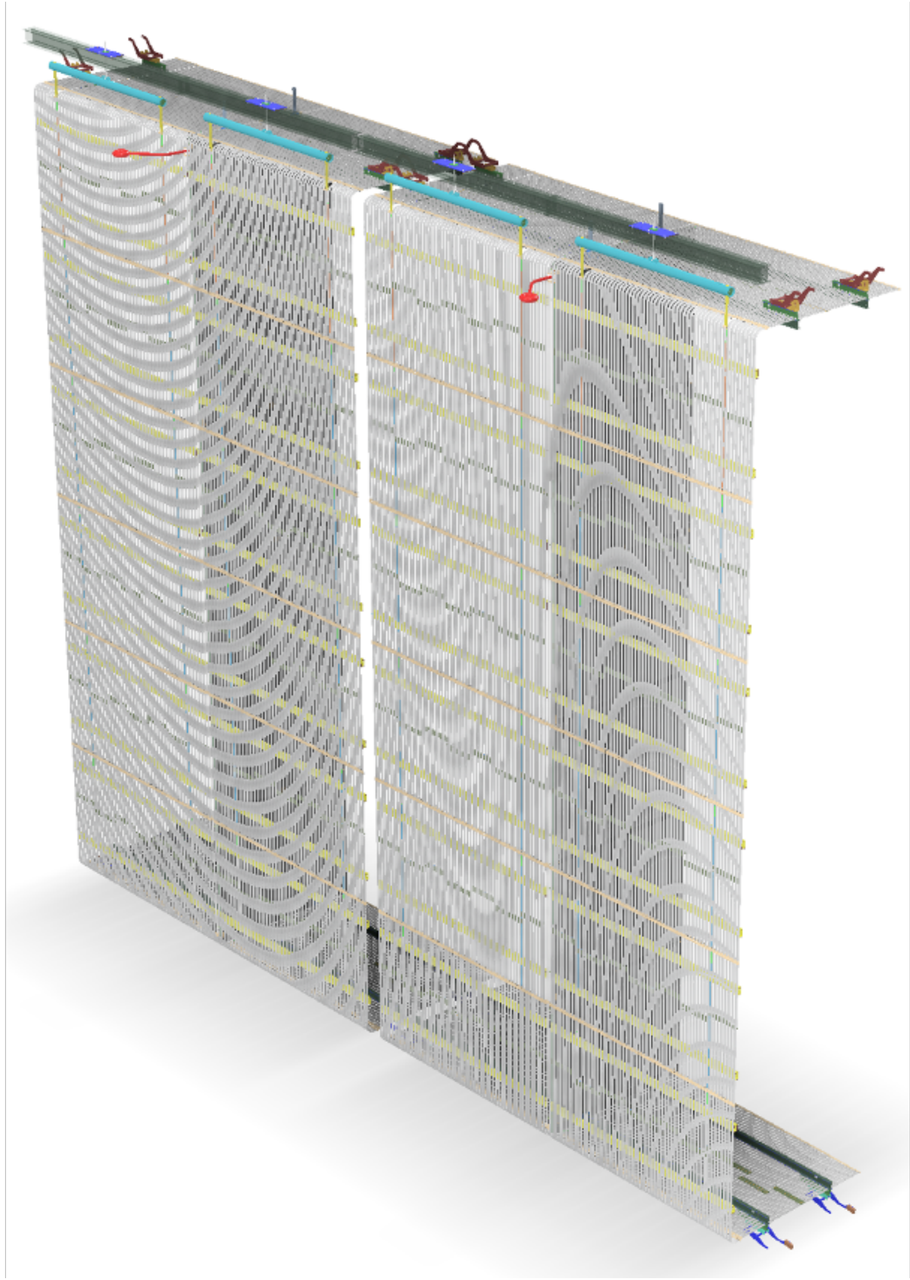


Present FC Design



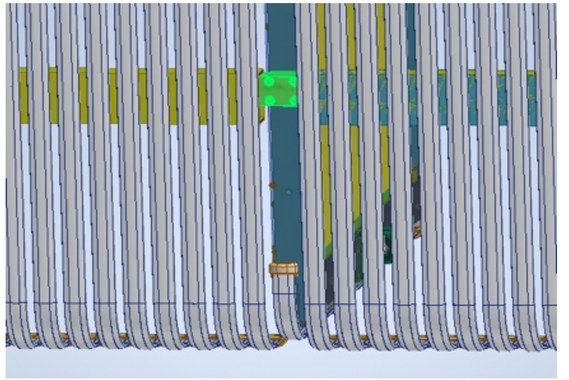
The New HVS Design

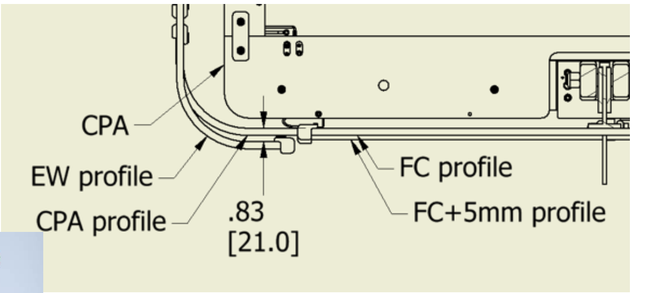
- 2 End Wall FC's each made of:
  - 24 2m x 3.5m EW modules (arranged in 4 identical columns, 6 modules tall) with top/bottom modules hosting bent aluminum profiles
- 25 mostly identical CPA/TBFC/GP rows, each made of:
  - 2 CPA's: 6 units each (1.15m x 4 m)
  - 8 Top/Bottom FC module (3.5m x 2.3m)
  - 4 Top Ground Planes (4 units each: 2.3m x 0.5m) hung independently to the DSS beams (NOT in HVS scope except for readout and monitoring)
- Assembly & Installation of FC modules:
  - Performed fully underground (NP02 experience on FC)
  - about 1 month for each EW
  - 1 week for each CPA/TBFC/GP slice: deployment of FC at the end of installation.



Design Status

- HV design basically complete – Final Tweaking is being finalized:
  - CPA-EW restraints added with clip on profile
  - FC modules: all warm dimensions defined to match nominal distances and FC profiles alignment at LAr temperature.
  - EW: change to center support to avoid cantilever load on DSS; same design for all EW columns
- Preparation for Final Design Review:
  - CPA/EW/FC drawings completed: available in DocDB# 21561 for internal review before posting to EDMS
  - FR4 material testing completed by selected vendors and in house (GUND, BNL)
  - EW structural analysis mostly completed in direct contact with CO
  - CPA analysis being updated with new material properties (with CO)
- ProtoDUNE-II
  - Model has been created with old CPAs, new FC, new EW.
  - Drawings for updates on CPA (hanging to DSS, FFS) started
  - Need to update model for new EW yoke and DSS
  - New beam plug to be finalized (with DSS team) and integrated into design
  - Need to work with AR/CERN team to develop assembly plan

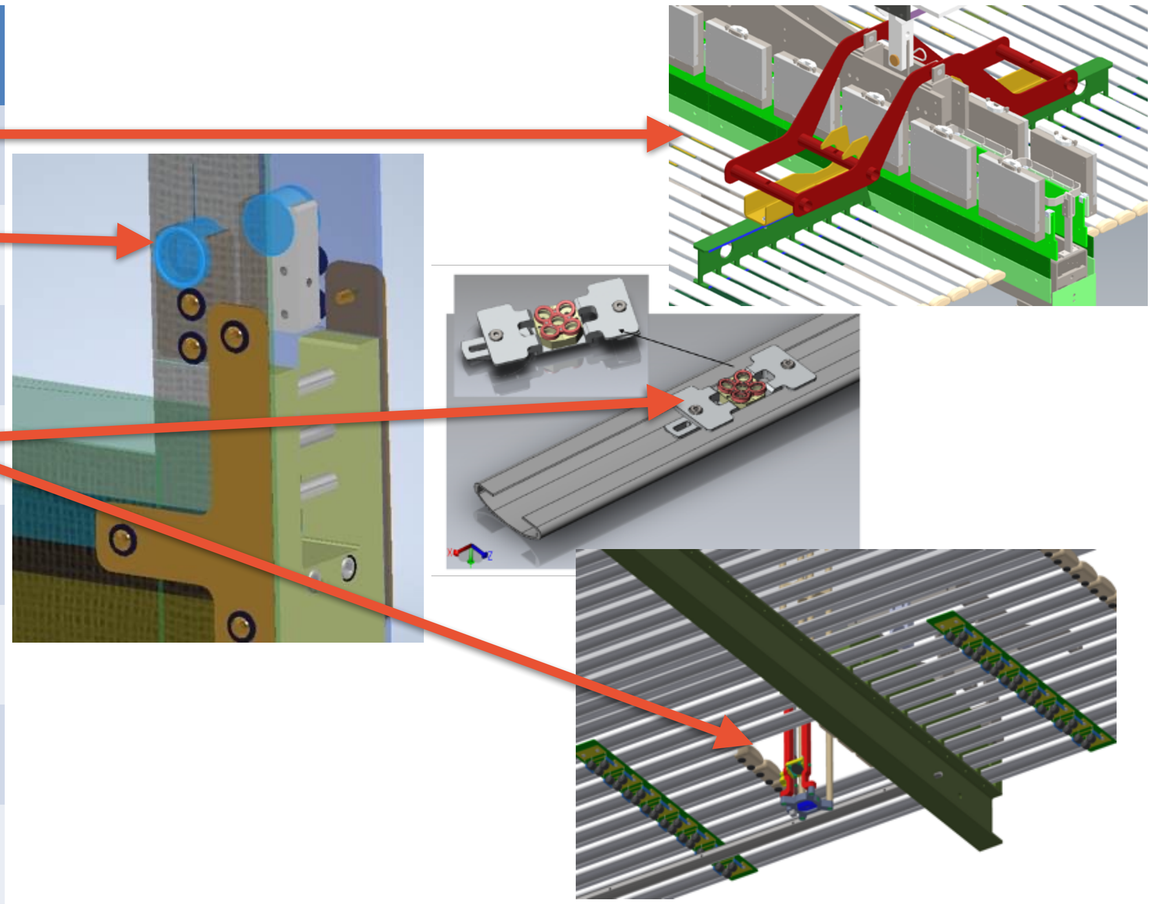




Status: Interfaces with Other Consortia

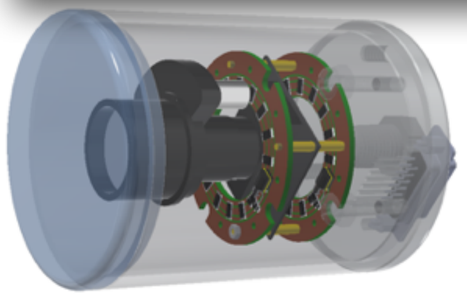
- Major rounds of updates to the ICDs (interface control documents) completed.
- Interface documents updates with CALCI, DSS, facility, installation are on going.

Consortia	EDMS number	Key Interface Items
APA	2088738	Field cage support on APA frames
PDS	2088721	PD calibration flashers and fibers on CPA
CE	2088706	FC termination and ground plane monitor cable routing, warm filters on SHV feedthroughs, termination bias supplies
CALCI	2145142	FC openings for lasers, target mirror assemblies on FC profiles
DAQSC	2145154	HV vs. LAr level interlock, ground plane and HVPS digitizers, cold camera power supplies
Installation	2145184	Installation activities in UG cleanroom, cryostat
Facility	2145170	HV feedthrough locations; rack and cable trays; liquid and gas flow in cryostat
DSS	2339392	Support of the CPA/FC modules on DSS; ground plane design, support, and installation; cable routing



Prototyping Activities

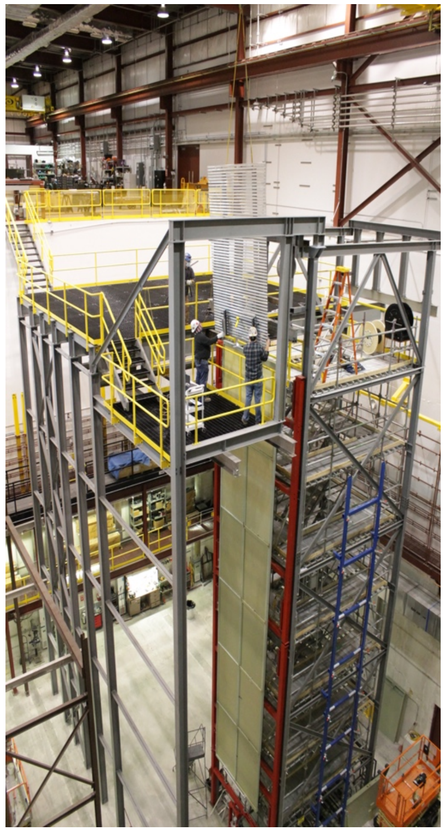
- **FC, EW**: modules construction tools and assembly procedures developed at production sites (LSU, SBU, UTA).
- **CPA**: Minor modifications wrt TDR and protoDUNE-I, (bent profiles at corners, FFS layout, double sided HV bus) (ANL, W&M).
- **HV distribution**: no major change with respect to TDR; HV FT & ripple filters upgrade in common with with VD (FNAL, CERN, BNL).
- **QA/QC**: procedures being finalized for all the HV sub system (production, shipping, installation); validation at Ash River trial assemblies and ProtoDUNE module-0 (ANL).
- **Monitoring**: as in TDR (GP current pickoff, voltage divider termination, HV-PS slow controls). Addition in HVS scope: cold cameras as in ProtoDUNE's to visualize HV critical spots (BNL, KSU).



Ash River Trial Assembly

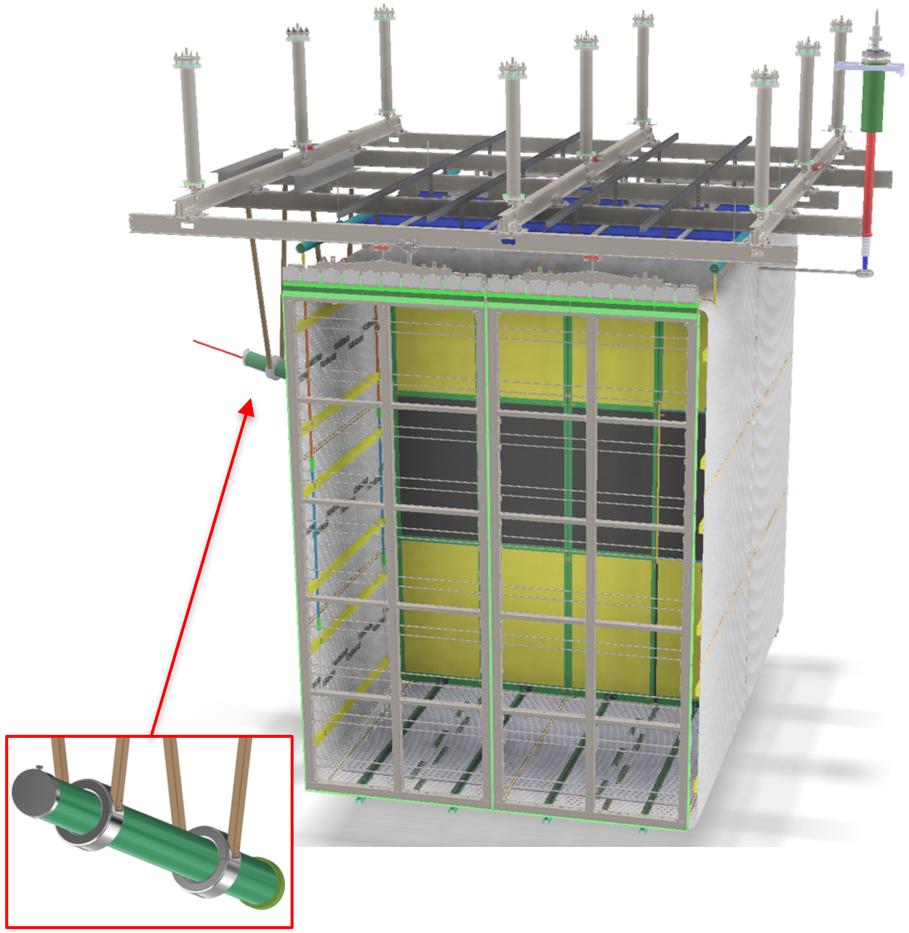
- Since last year, multiple rounds of mechanical trials for the HVS (UMN team)
  - ProtoDUNE-II installation trial validation (summer 2020):
    - New ground plane suspension from DSS
    - CPA assembly frame & Installation sequence
    - new T/B and EW field cage, on-site assembly and installation
    - Next round in summer 2021: full installation trial (need to complete ProtoDUNE II design and documentation approval process).
  - FD HVS & APA installation trial: double drift, 2 CPA panels, 4 TBFC modules, 12 EW Modules.
    - Completed first full scale test of CPA construction including Field Cage in late November, joined remotely by HV consortia.
    - Used the QC app developed at UMN to track components and QC on installation procedures
    - Everything went smoothly with minimal issues over the 2-1/2 days. Shipping box for the CPA panels needs some tweaking to better protect the load.

https://photos.app.goo.gl/gSn6CcTV7TPNyujk6



HVS Plans: ProtoDUNE-II & FDR

- TPC in ProtoDUNE-II: 2/3 of the volume of the first run, 2 of 4 APAs in inverted orientation. TPC centered in the beam direction with large clearance outside of End Walls (similarly to FD-SP-HD)
- Purpose for HVS: validate design, installation, performance of new field cage modules (FD module 0), and new ground plane configuration.
  - CPAs reused with minor modifications to reflect current design changes (ANL team on site)
  - Top/bottom, and End wall field cage modules replaced with the new ones. Most of the resistive divider boards reused.
  - Parts for FC modules prepared at US production sites (LSU, SBU, UTA) and shipped to CERN to be assembled on-site as planned for the FD.
  - Mechanical connections to APAs and DSS as much as possible as in the FD design.
  - New beam plug ~ 1.5m long. Most likely to be supported from above via DSS beams
- **Goal: Far Detector final design review & ProtoDUNE-II PRR before mid 2021, to enable the part procurement and production for ProtoDUNE.**



Summary and ProtoDUNE-II Schedule

- **The HVS design for the HD detector is mostly completed well supported by prototyping activities and trial tests:**
  - The plans toward the Final Design Review and ProtoDUNE-II are well advanced with no major critical issues identified
  - Cost and schedule of the entire HVS have been captured. Most of the M&S costs are supported by vendor quotes and correctly reflect the new HV system design.
  - Labor estimates for the production and installation has been refined based on the current prototyping experience