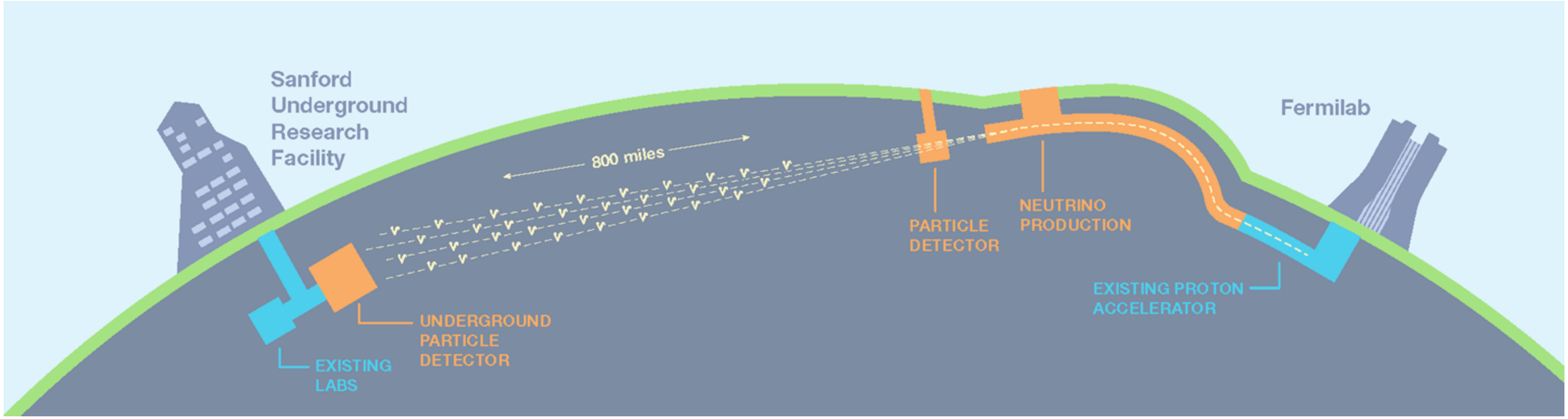


The HV System for the DUNE Single Phase LAr-TPC Far detector

Francesco Pietropaolo

HVS-SP Preliminary Design Review

CERN, June 4/5, 2019

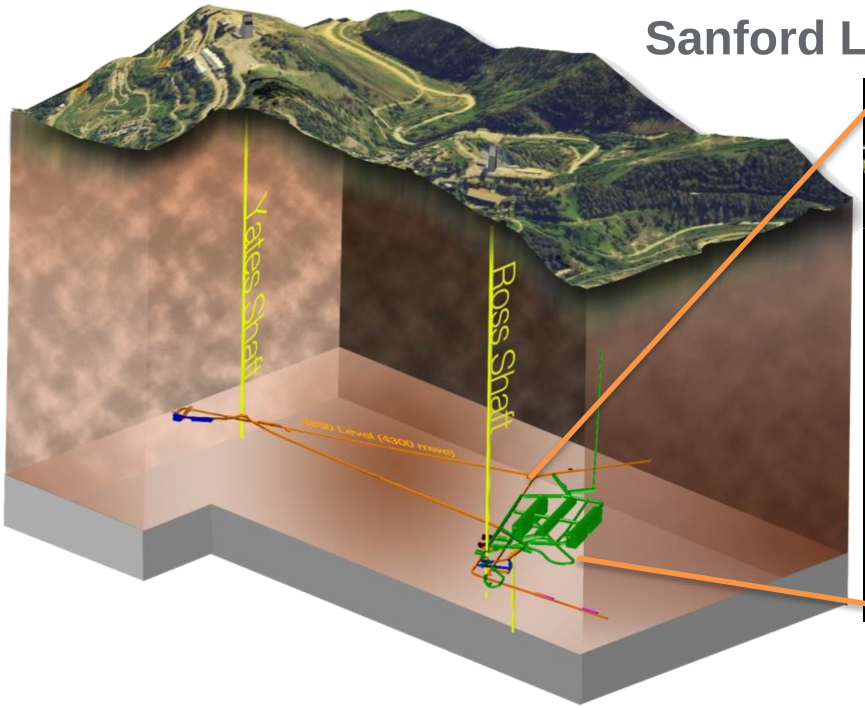
Review Charge

Charge Question:		Mainly addressed in talk:
1	Have design choices been fully identified and do they meet detector requirements?	System Overview
2	Are the specifications and drawings for standard and custom components substantially complete and available in EDMS? Are they of sufficient maturity to proceed to final design?	Mechanical Design Electrical Design HV Feedthrough Design HV interconnects
3	Have interfaces with other detector components been addressed and documented? Do risks of design changes in other systems have appropriate mitigation strategies?	Electrical Design and Interfaces
4	Are engineering analyses sufficient to ensure the design is safe during all phases? Which applicable design codes and standards have been used?	Mechanical Design
5	Are system grounding details documented and in EDMS? Are electrical connections specified and do schematics exists in EDMS? Are all wires, cables and connections documented?	Electrical Design and Interfaces
6	Is the design in accordance with possible procurement strategy and manufacturing scenari?	Fabrication Plan and Schedule
7	Are quality assurance and testing plans sufficiently developed to proceed to final design?	QA/QC
8	Have lessons learned from ProtoDUNE been implemented?	ProtoDune Lessons Learned
9	Are plans for additional prototyping reasonable and sufficient?	R&D, Value Engineering Ash River tests
10	Are plans for the next post TDR design being sufficiently justified and presented ?	R&D, Value Engineering Ash River tests
11	Have appropriate cost estimates and schedule been determined? Are plans for required technical resources consistent with scope of remaining work?	System Overview Fabrication Plan and Schedule

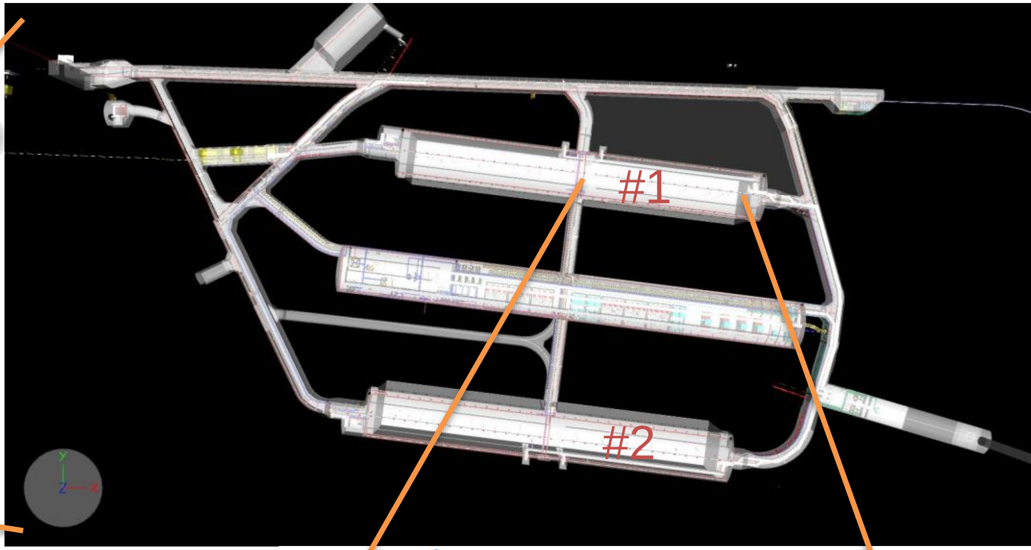
HV system design overview

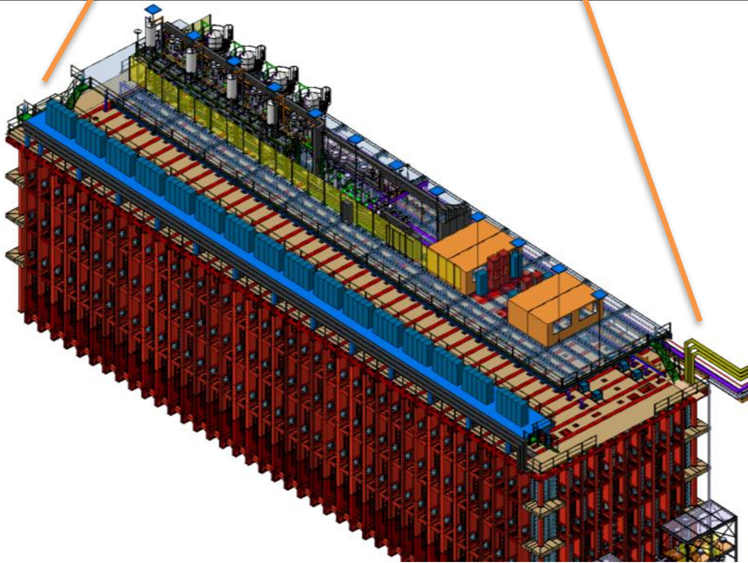
- Outline: from ProtoDUNE NP04 to DUNE SP
  - HVS requirements
  - Risk Assessments
  - Institutional Responsibilities for Consortia Deliverables
  - Preliminary Cost Estimates / Sharing / HL schedule
- References:
  - HVS-SP chapter of the DUNE TDR:
    - https://edms.cern.ch/ui/#!master/navigator/document?P:100233199:100366287:subDocs
  - Engineering Design Paper (dune-docdb 10452):
    - https://edms.cern.ch/ui/file/2151115/1/FD-CPA-FC-HV-Design-ver18.pdf
  - EDMS tree:
    - https://edms.cern.ch/ui/#!master/navigator/project?P:100233199:100233212:subDocs

Deep Underground Neutrino Experiment



Sanford Lab Homestake Mine 4850L





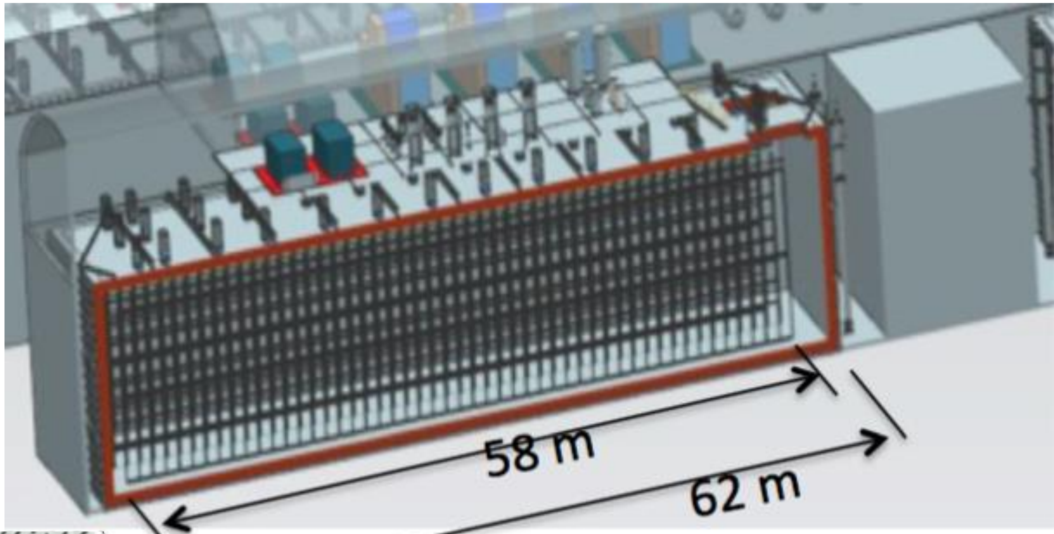
- Four identical cryostats deep underground
- Membrane cryostats
- Staged approach to four independent 10 kt LAr detector modules
- 1st detector will be Single-Phase LAr-TPC
- 2nd detector: Dual or Single-Phase readout under consideration

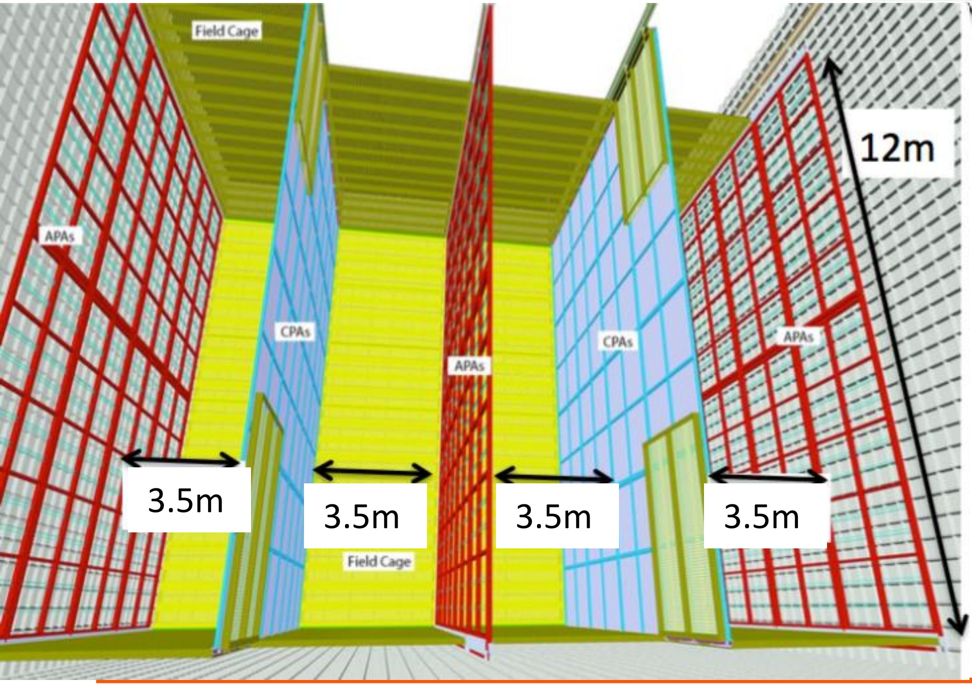
DUNE SP LAr-TPC far detector

Readout of :

- Ionization charge
- scintillation light

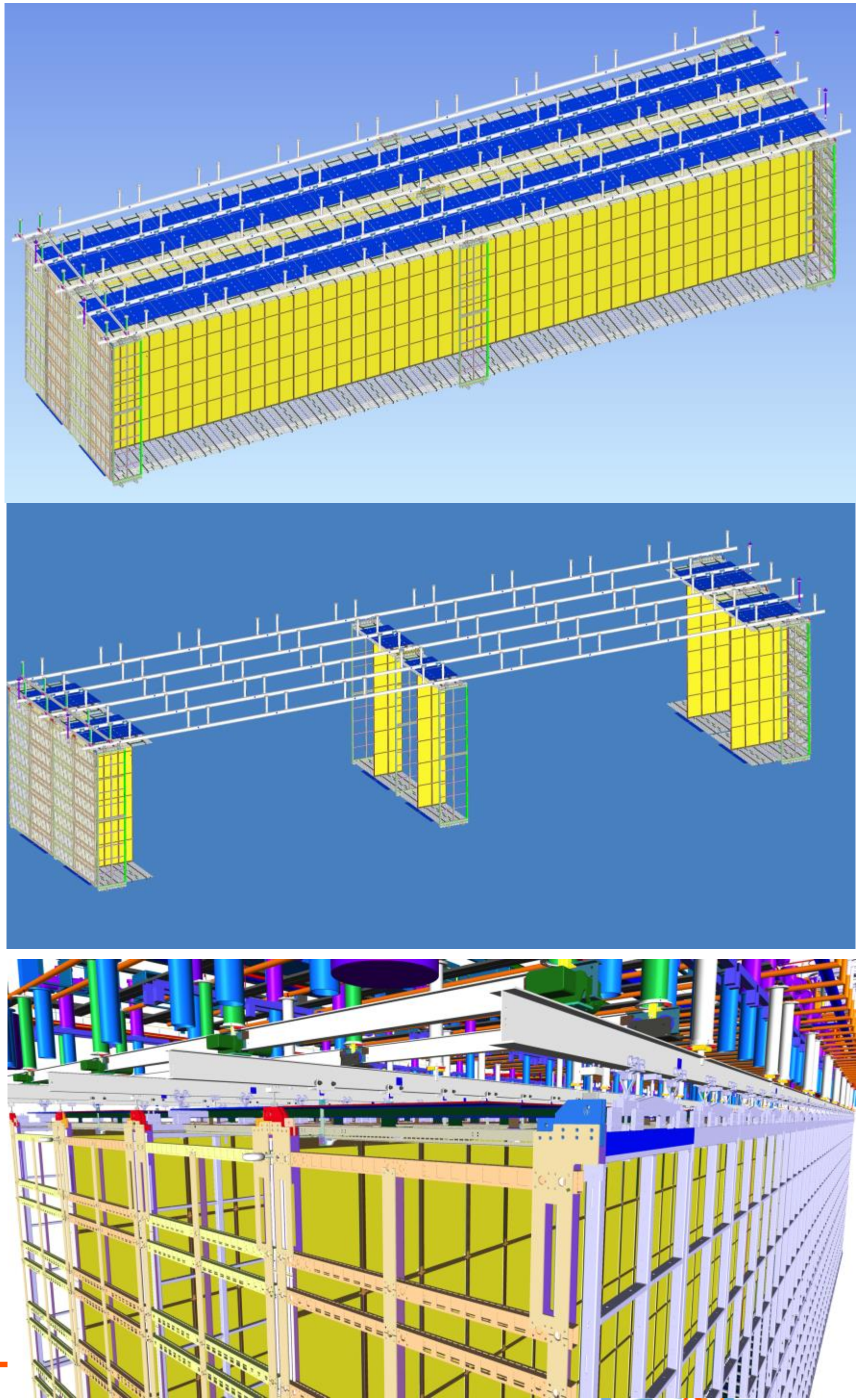
Detector mass [kt]	
total	17.1
active	13.8
fiducial	11.6





- Charge readout:
  - Anode Planes Assembly (APAs)
  - 2 induction + 1 collection wire planes
- Photon Detectors integrated in APAs
  - Arapuca design based on SiPM
- Drift volumes (4x3.5 m drift):
  - Cathode Planes Assembly (CPA)
  - V_{CPA} = -180 kV, E_{drift} = 500 V/cm
  - Field cage for E uniformity

HVS design concept



- HV Field Cage elements:
  - Cathode Plane Assembly (CPA) opposite the APA in the drift direction,
  - Top and Bottom Field Cage (FC) units
  - End Walls (EW) at the beginning / end of the 58 m long structure.
- The whole TPC is made of:
  - 25 rows of the field cage elements (2.3m wide, 12m tall) between the EWs
  - configured as APA-CPA-APA-CPA-APA
  - APA-CPA connections are made at the top and bottom of the 12 m tall structure by the FCs in the drift direction.
  - Modularity driven by access shaft
- CPAs and APAs hang from the rail system below the cryostat roof

CPA Requirements

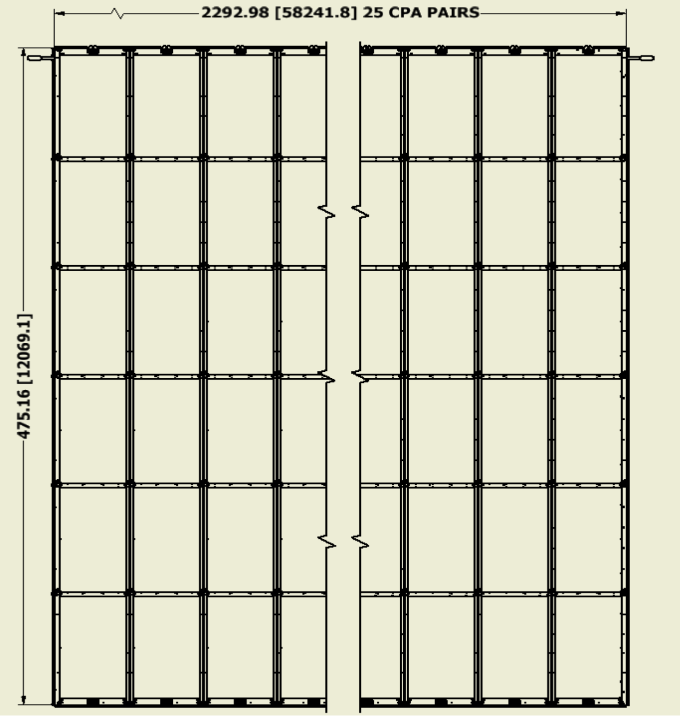
- Provide equipotential surfaces at -180kV nominal bias voltage
- Maintain a flatness better than 1cm*
- Use materials with comparable CTEs to that of stainless steel
- Limit the electric field exposed to LAr to under 30kV/cm
- Prevent damage to the TPC including its readout electronics in case of a 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
- Accommodate reflective foils + shifter to improve light collection from the PD

**based on the requirements:*

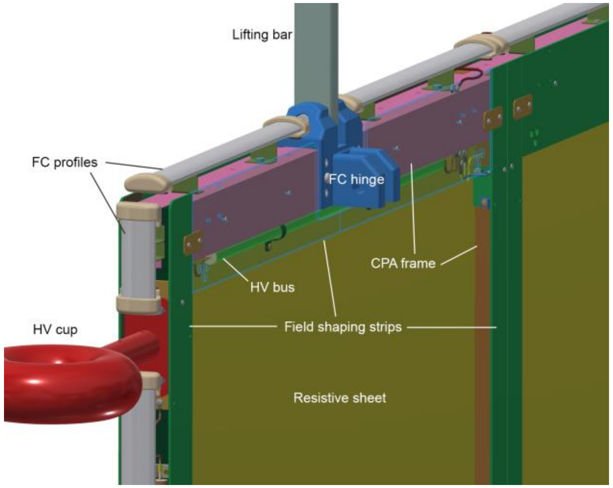
the fiducial volume of the detector shall be known with a precision of at least 1%

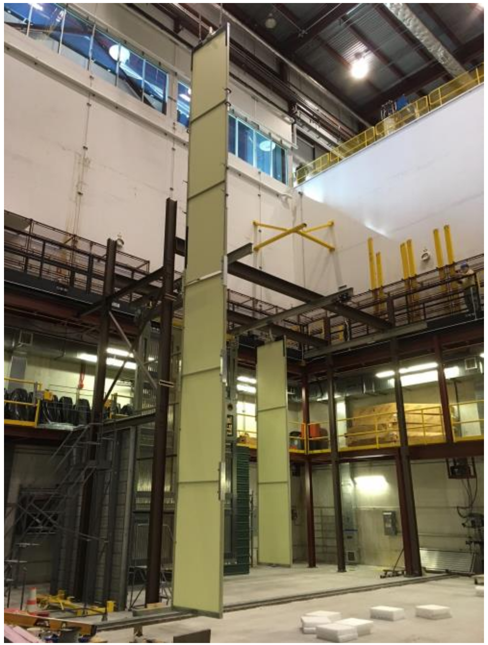
E_field uniformity.

CPA design



- Each cathode plane is constructed from 50 side by side CPA (Cathode Plane Assembly) Panels.
- Each CPA Panel is 1.15m in width and 12m tall, formed with 6 vertically stacked modules, and supported by the CPA installation rail above through a single link.
- HV bus is integrated in CPA Panel
- The cathode bias is provided by an external high voltage power supply with a HV feedthrough connecting the cathode inside the cryostat via “donut” shaped receivers attached to the outermost CPA panels.





Field Cage Requirements

- Provide uniform drift field at the nominal value 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
- 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%

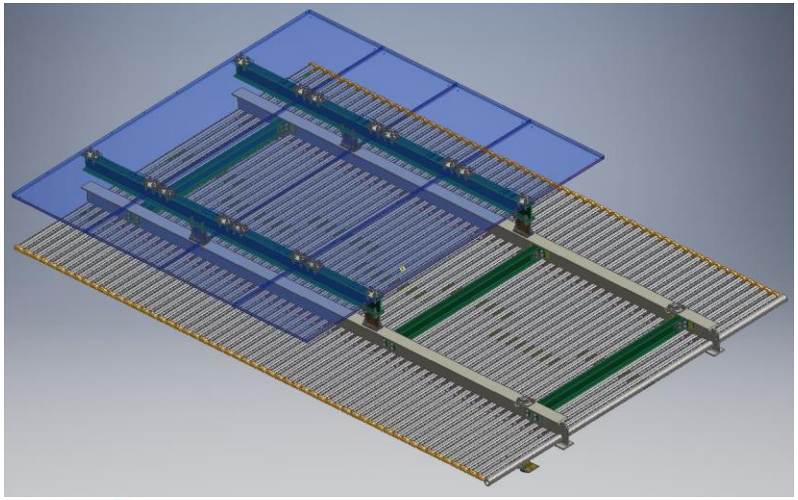
E_field uniformity.

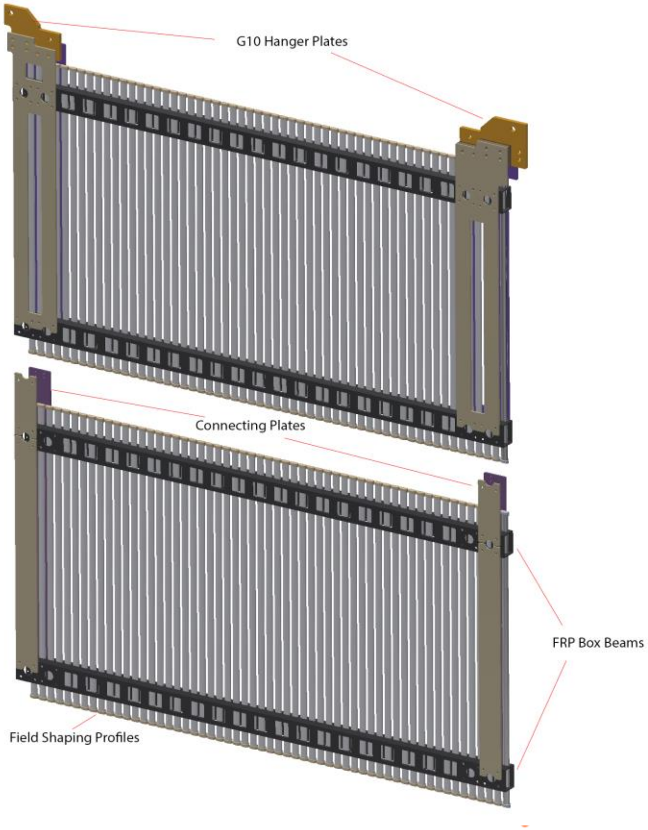
Field cage design

- The field cage modules have two distinctive styles: the top/bottom, and the end wall.
- Each module is constructed from an array of extruded aluminum open profiles supported by two FRP (fiber reinforced plastic) structural beams.
- A resistive divider chain interconnects all the metal profiles to provide a linear voltage gradient between the cathode and anode planes. Varistors included for redundancy.
- Insulating PE endcaps are mounted on the profiles ends to avoid arcing between adjacent modules in case of discharge.

Field cage for DUNE SP

- The top/bottom modules
  - nominally 2.3m wide by 3.5m long.
  - Ground plane in the form of tiled perforated stainless steel sheet panels mounted on the outside surface of the top/bottom field cage module with a 30cm clearance.
  - The T/B modules are supported by the CPAs and APAs.
  - Attached to CPA before installation and deployed when CPA is in final position
- The end wall modules:
  - 1.5 m tall by 3.6 m long.
  - stacked 8 units high to cover the 12m height of the TPC.
  - supported by the installation rails above the APAs and CPAs.





DUNE SP development path

- The large size of the DUNE far detectors required a strong LAr-TPC development and prototyping effort: ProtoDUNE SP (NP04)

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-SP TPC Overview

Main Components:

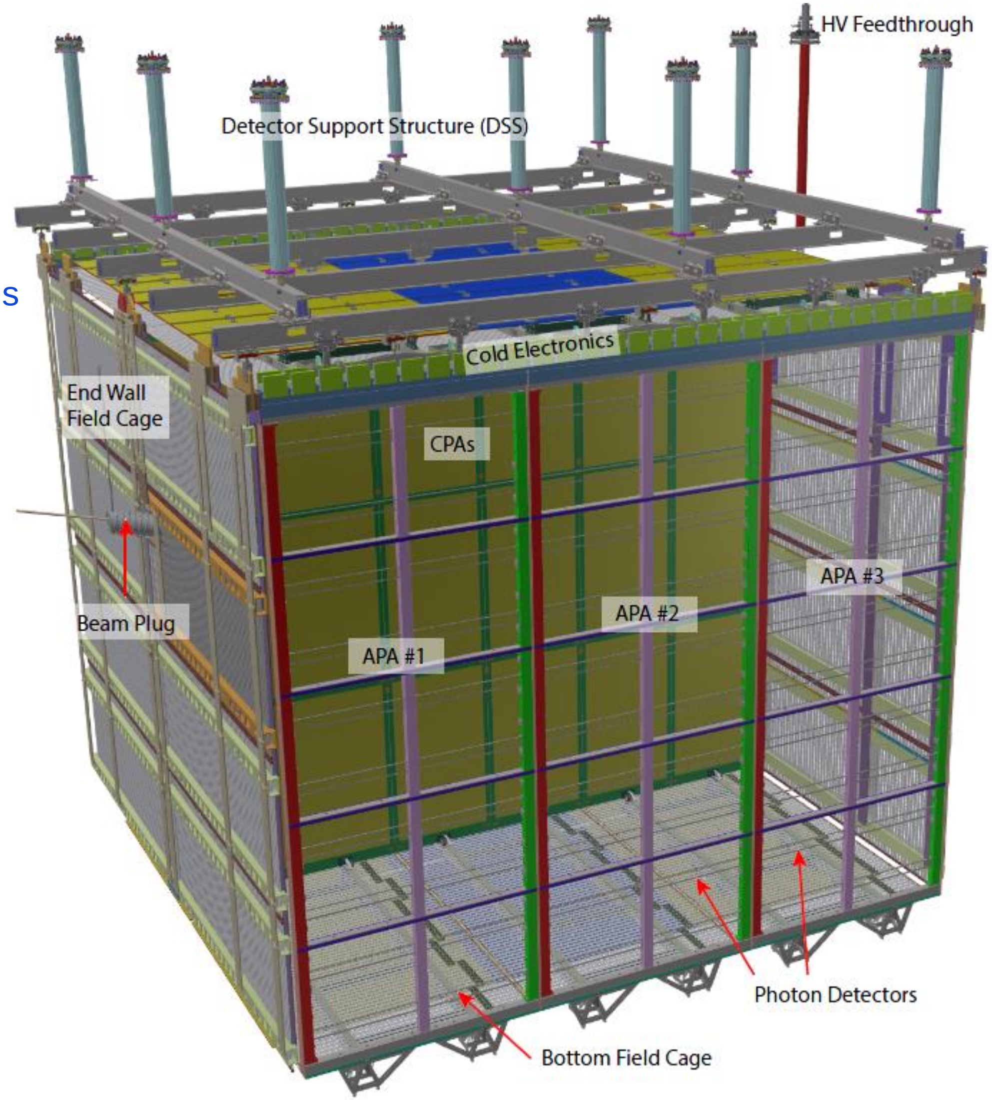
- 6 Anode Plane Assemblies (APA) with integrated photon detectors
- 15k ch. of integrated cold front-end and digitizing electronics
- 18 Cathode Plane Assemblies (CPA) resistive panels
- 28 field cage modules
- Top/bottom Ground plane with 20 cm clearance,
- The entire TPC is suspended on the Detector Support System.
- The APA, CPA and field cage modules are intended to be nearly identical to the DUNE FD counterparts.

TPC Active Volume:

- 7m (L) x 6m (H) x 2x3.6m (W)
- 420 ton active mass

Cryostat Inside Dimensions:

- 8.5m (L) x 8m (H) x 8.5m (W)
- 770ton liquid argon

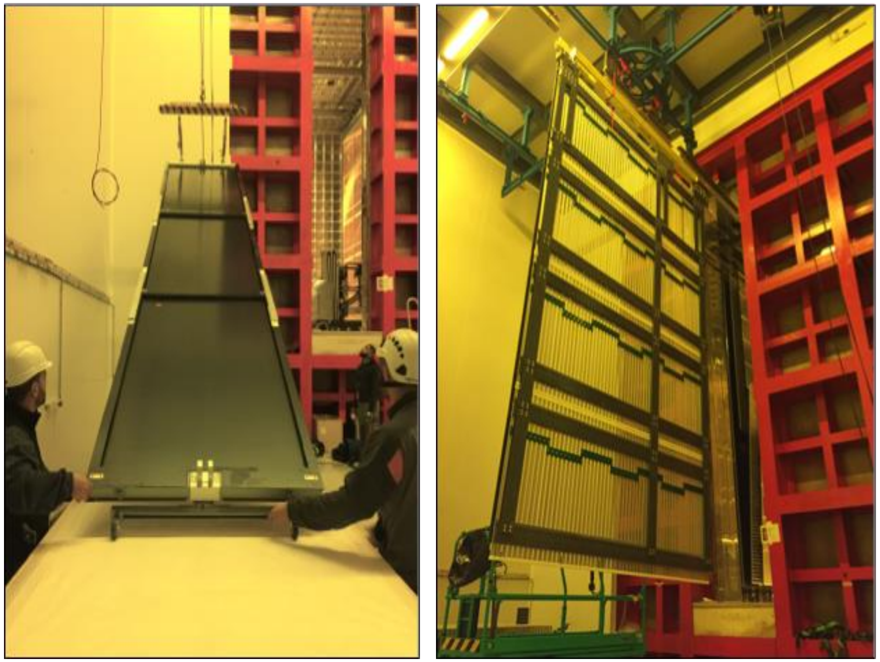


HVS construction for ProtoDUNE

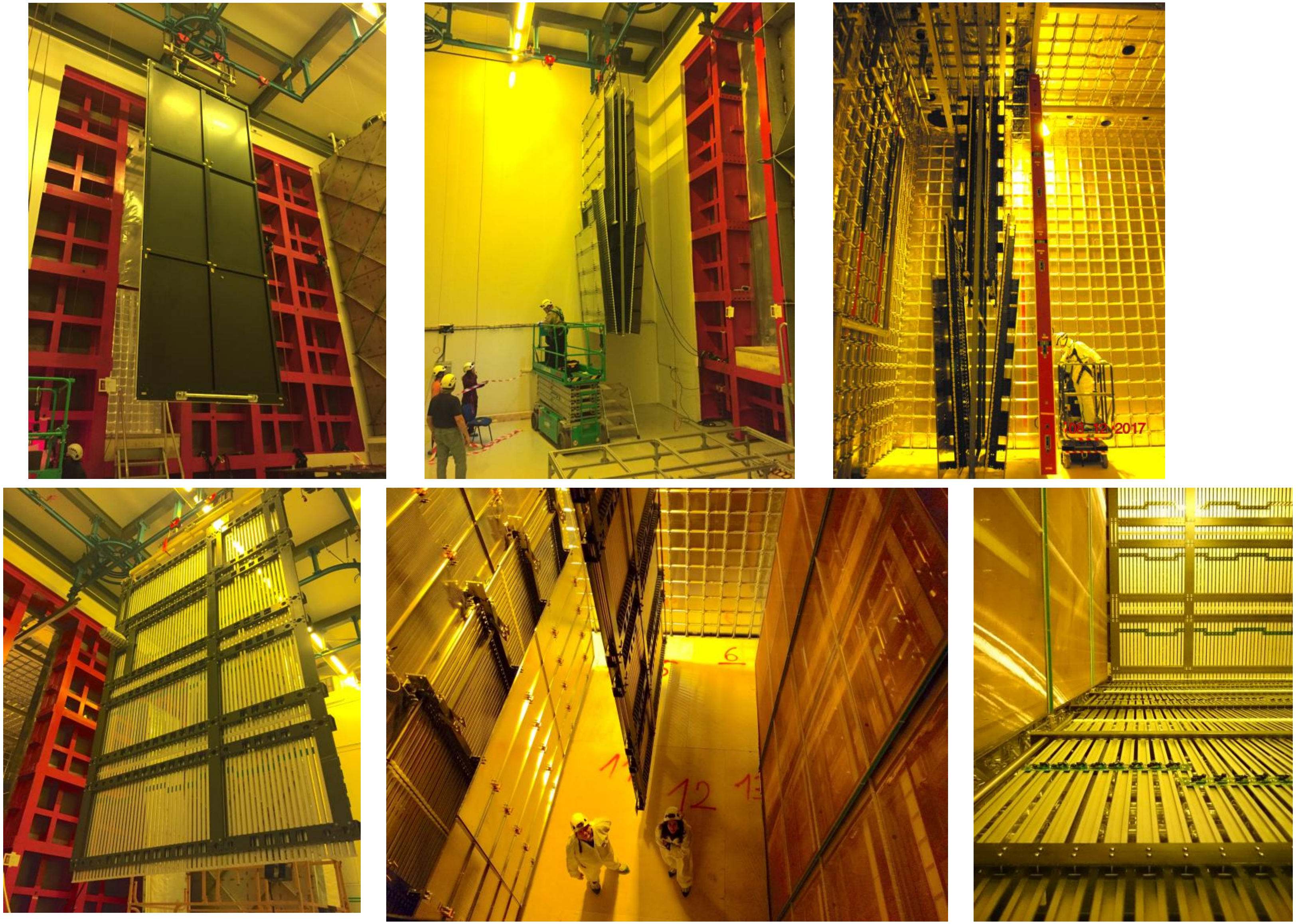
- CPA units
  - Raw resistive panels laminated in Italy.
  - Sent to ANL to be mounted on FR4 frames, including HV bus and surrounding Aluminum profiles
  - QC tests performed in situ before packaging in RP units
  - Sent to CERN assembled in crates
- Field cage aluminum profiles
  - Extruded, cut to length and machined in Italy
  - Conductive coating in Sweden
  - Sent to CERN for assembly
  - Small fraction sent to LSU for preassembly on EW frames
- Ground planes
  - Produced and electro polished in Sweden
  - Sent to CERN for Assembly on Top/bottom FC
- Resistive divider boards:
  - PCB produced in USA
  - Resistors, Varistors selected and mounted on PCB at LSU
  - QC tests performed in situ
  - Sent to CERN for assembly
- FRP beams
  - Procured and machined in US
  - Top/Bottom: machined, cleaned and preassembled in SBU; sent to CERN dismounted
  - EW: machined, cleaned and assembled in LSU: sent to CERN pre-mounted in crated
- Beam Plug: produced / tested at LBL and sent to CERN

HVS assembly for ProtoDUNE

- FC modules
  - Assemble at CERN in clean room (b182) on dedicated mounting frames
  - 2-3 modules per week (learning curve) including QC; 2 FTE
  - Stored on their mounting frames at EHN1
- CPA
  - Assemble in column on dedicated flat tables in clean room in front of ProtoDUNE-SP
  - Perform & test electrical connections between RP
  - install PD calibration diffusers on CPA surfaces
  - Flip vertical on DSS rails and hang top/bottom FC modules (& electrical connection)
  - Insert in cryostat: 3 days, 3 people
- EW:
  - stack 4 panels vertically (hanging from DSS rails in ProtoDUNE-SP clean room) to make a wall
  - Insert in cryostat



HVS installation in ProtoDUNE

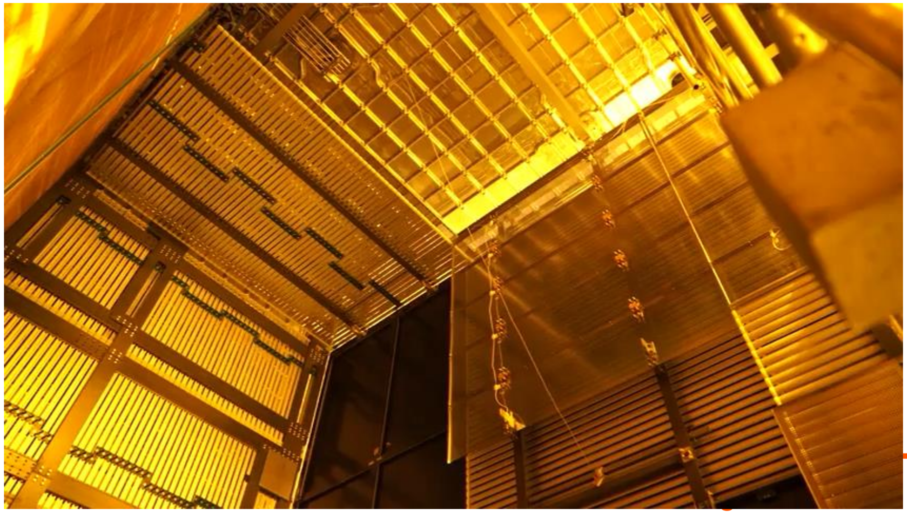


HVS installation sequences in P-DUNE

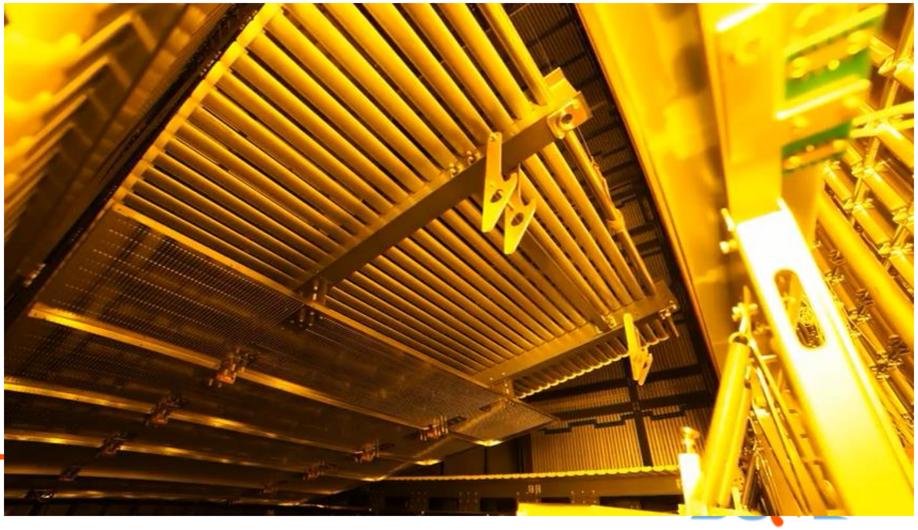
- To/bottom FC assembly

- CPA and T/B FC assembly in Clean room and insertion in Cryostat

- Top FC deployment



- Bottom FC deployment



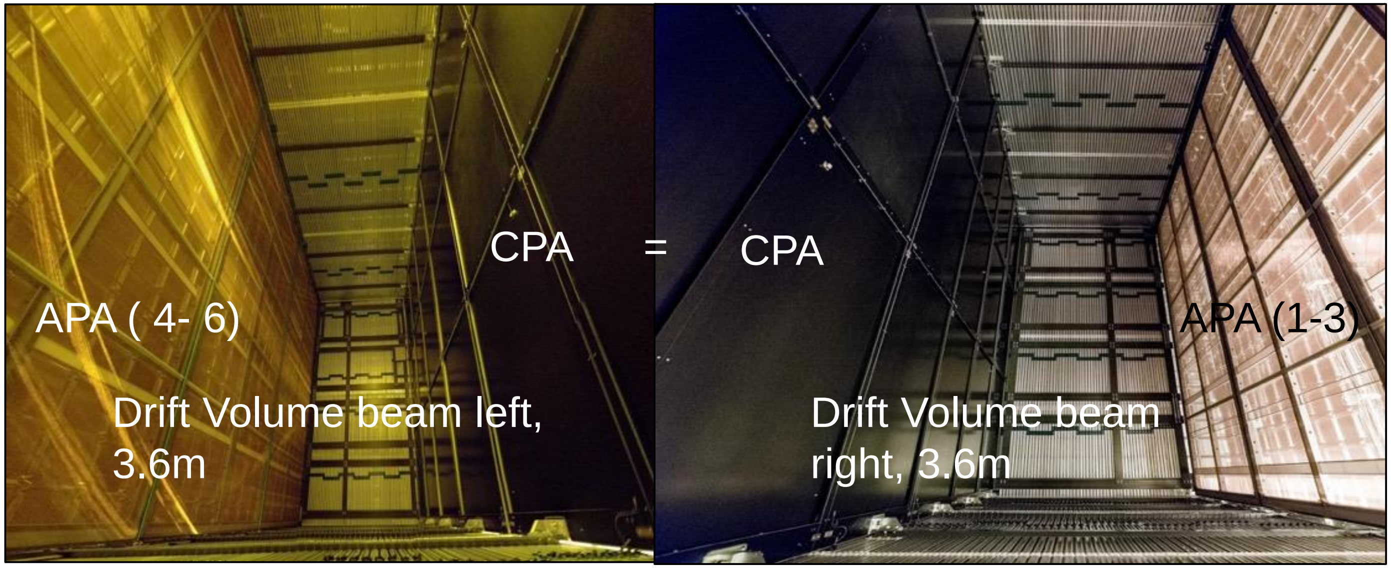
ProtoDUNE SP LAr-TPC in EHN1

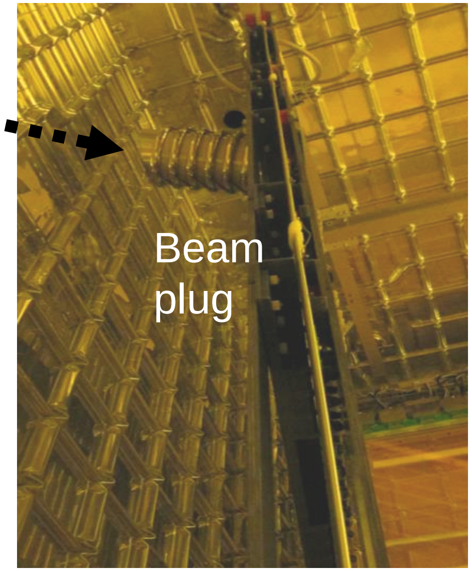
- *All elements of TPC Installed - May 2018*
- *Cryostat portal closed - June 2018*
- *Final positioning of TPC elements and installation of instrumentation -June 2018*
- *Filling and purification of argon - August 2018*
- *Final beam installation and HV on and ready for beam September 2018*

6 x Anode **Pl**ane **A**ssembly (APA): 3 sensing planes, 4.7mm pitch, 15 360 total ch.

3 x Cathode **P**lane **A**ssembly (CPA)

Photon **D**etectors Integrated in APA (3 different types)

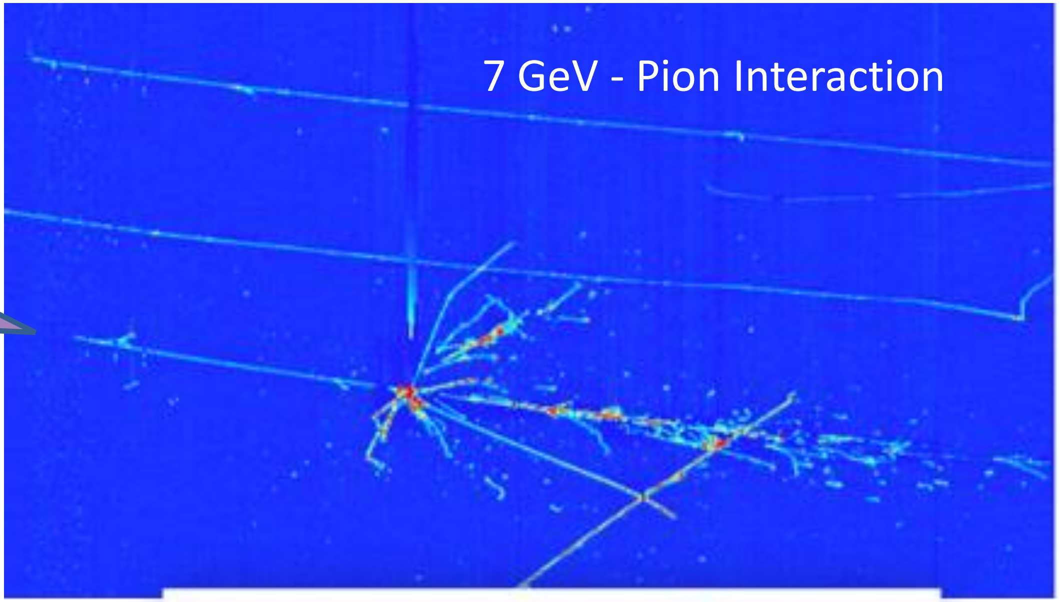


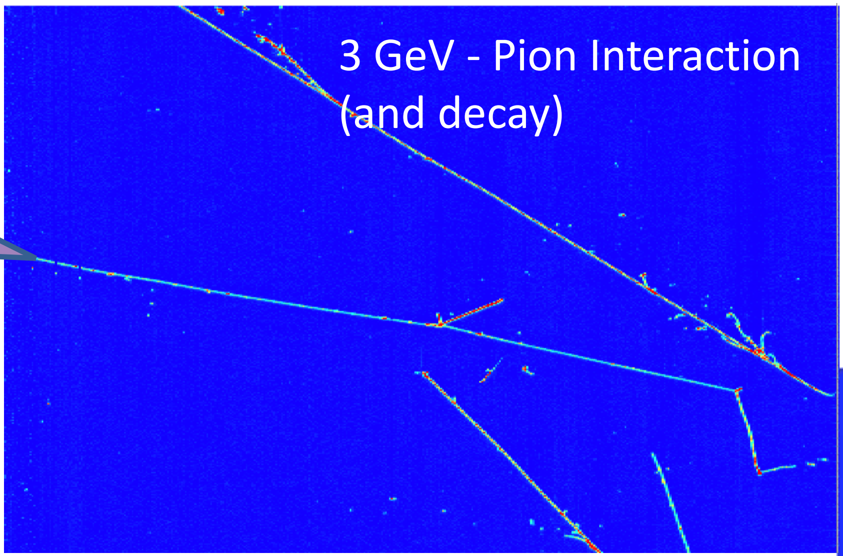


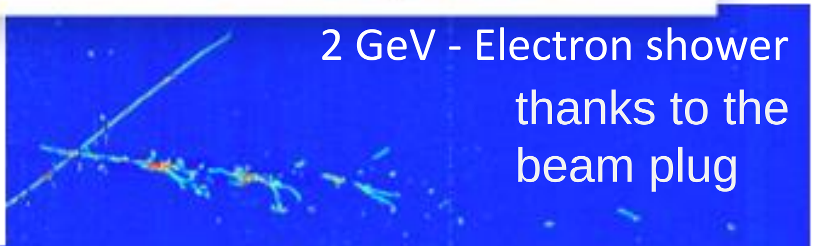
At a glance

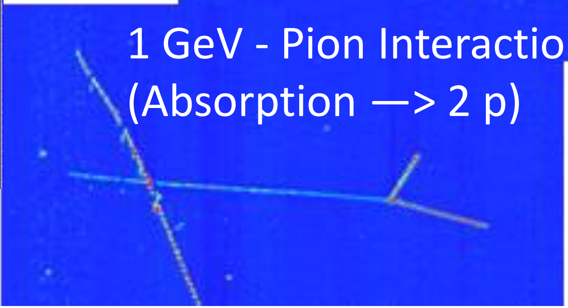
LAr -TPC data of unprecedented quality
Very high LAr purity

Beam direction


7 GeV - Pion Interaction

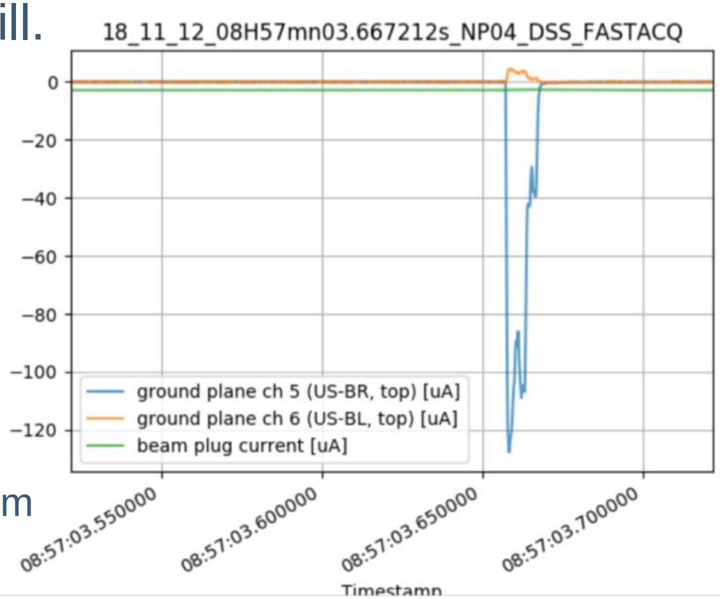

3 GeV - Pion Interaction (and decay)

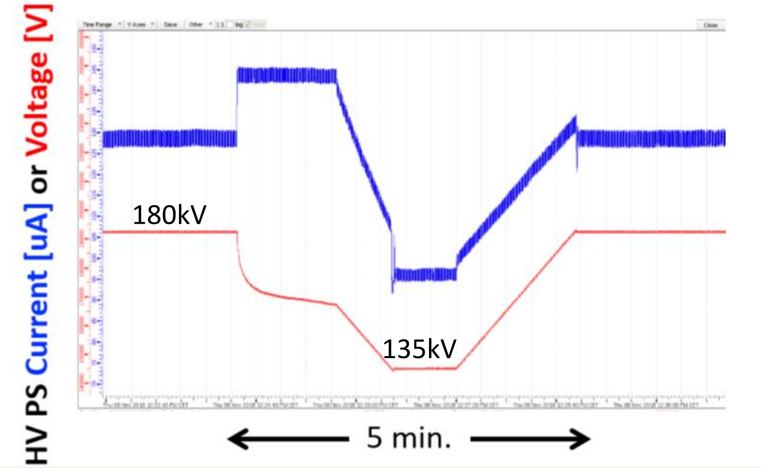

2 GeV - Electron shower thanks to the beam plug


1 GeV - Pion Interaction (Absorption —> 2 p)

ProtoDUNE SP HVS operation

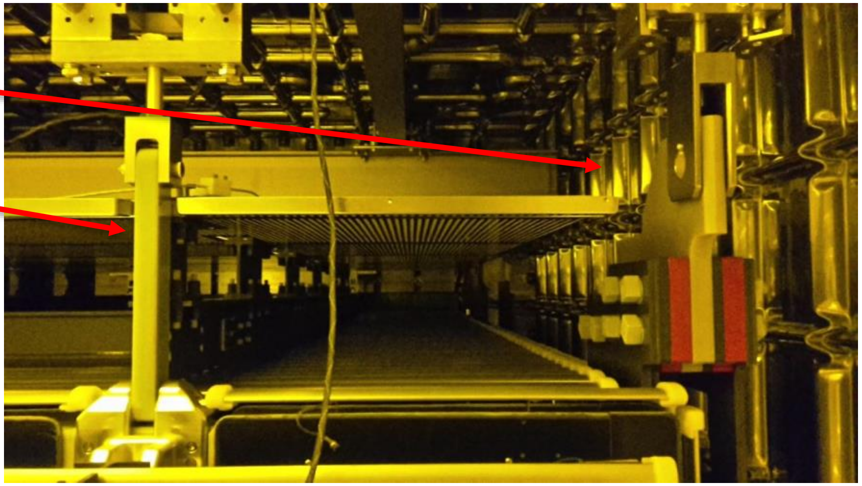
- Goal voltage of 180kV (the highest in a LArTPC) reached and maintained very quickly after LAr fill.
- Uptime during beam > 98%.
- Two classes of instabilities observed:
  - Fast discharges:
    - O(10/day), ~10ms duration
    - Matching current signal between GP and HVPS
  - Sustained excessive current (“streamers”):
    - Few per day (rate builds up over time)
    - Only a fraction of the PS current visible on GP & beam plug.
    - Ground plane activity is usually localized on a single US-BL-Top channel (#6).
    - Quenched by dropping the voltage
    - Auto-suppression script on HVPS to minimize downtime.
- Recently: auto-suppression disabled
    - long lasting streamers → self quenching in hours
    - Rate → < 1 / week
- More details in lessons learned talk.



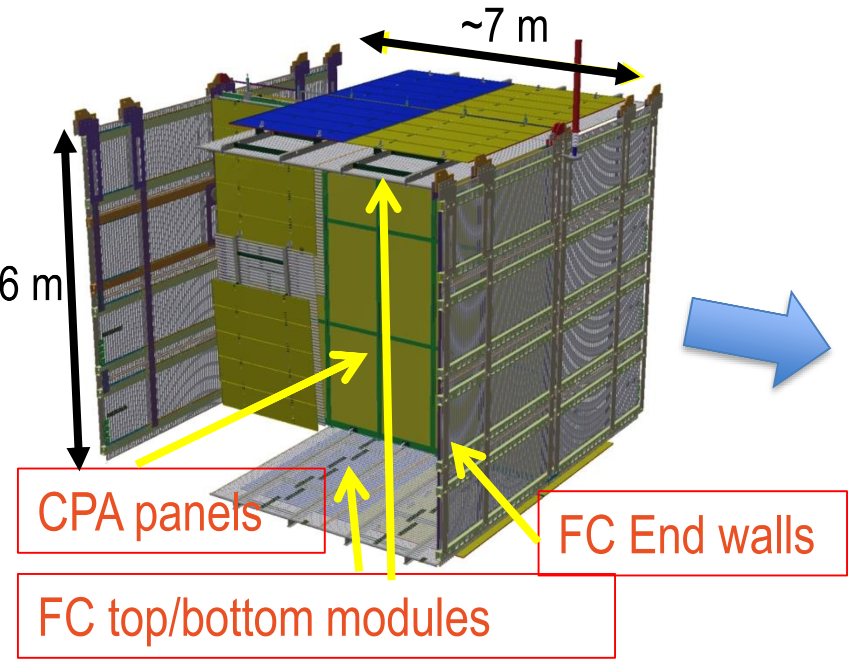


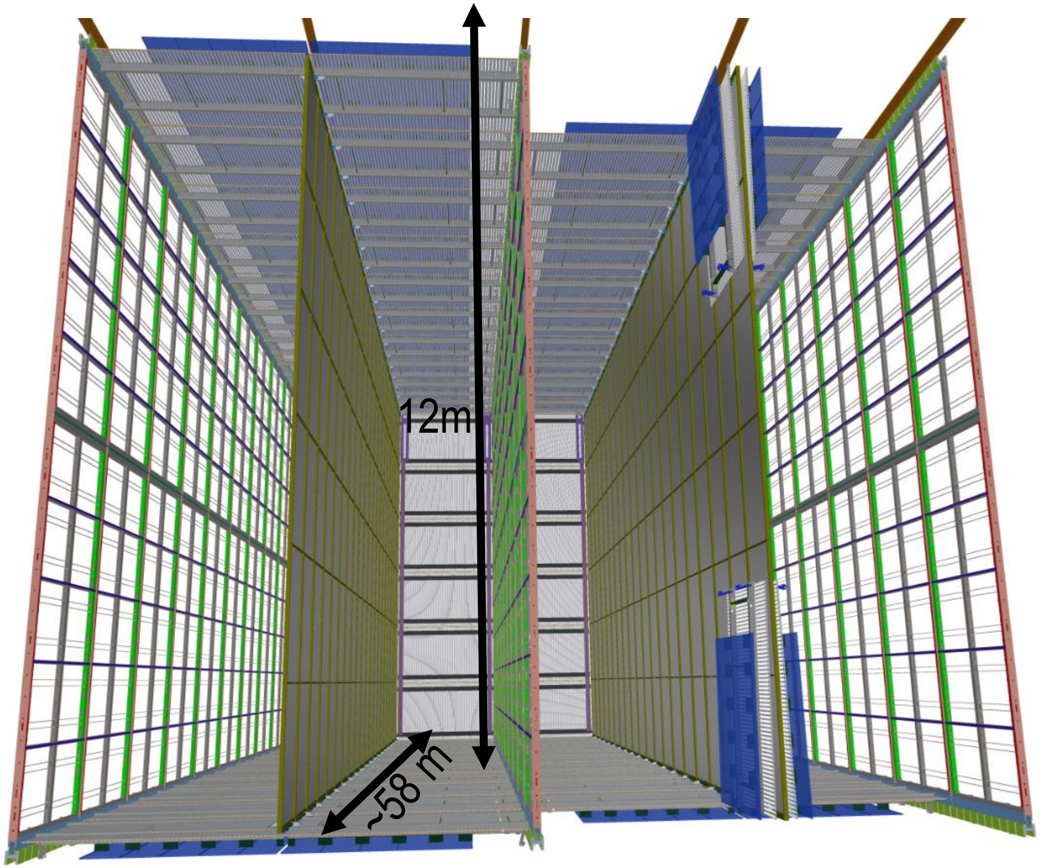
Understanding instabilities

- NO excess noise recorded on APA electronics with any HV instability
- Some excess activity recorded on Photon Detectors close to affected GP only in coincidence with streamers
- NO evidence of direct relation with LAr purity (maybe stream quenching)
- Very likely NO instability current from EW to GD
- Origin of streamer still on-going
  - CPA to ground path through the FRP surface
    - End Wall supports?
    - CPA hangers?
    - HV Feed-through?
- Mitigation in DUNE HVS design
  - Increase GP distance from FC
  - Reduce number of GP-FC FRP spacers



From ProtoDUNE SP to DUNE SP Far Detector

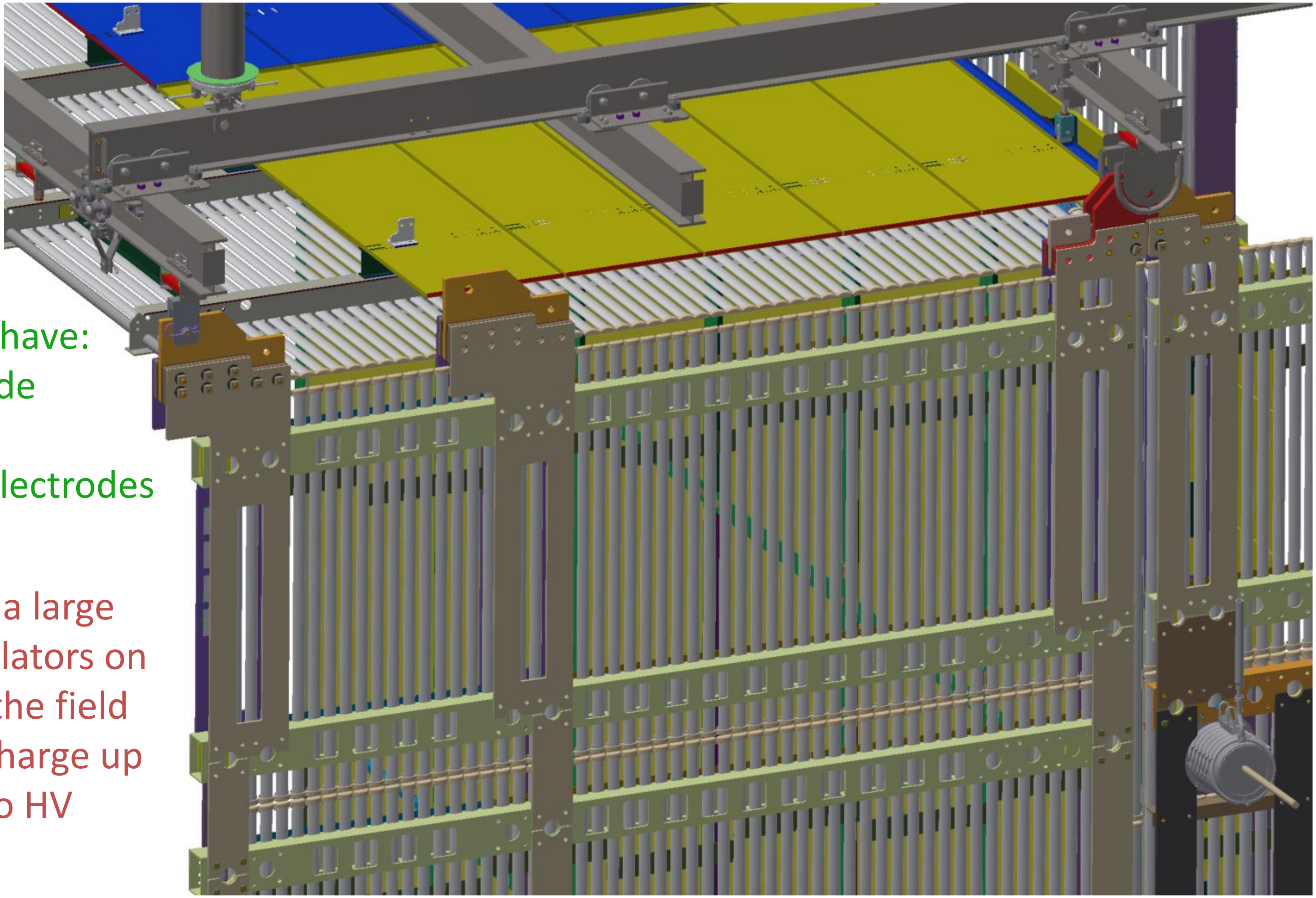




- 33x CPA modules, 12m high
  - 600 1.15x2m^2 resistive panels
- 17x top/bottom FC modules
  - equipped with Ground Planes
- 4x End-wall FC modules
  - Each 1.5m tall
- Same modularity as ProtoDUNE SP

Improving the HVS Design

ProtoDUNE SP HVS: reached 180kV with ~98% uptime

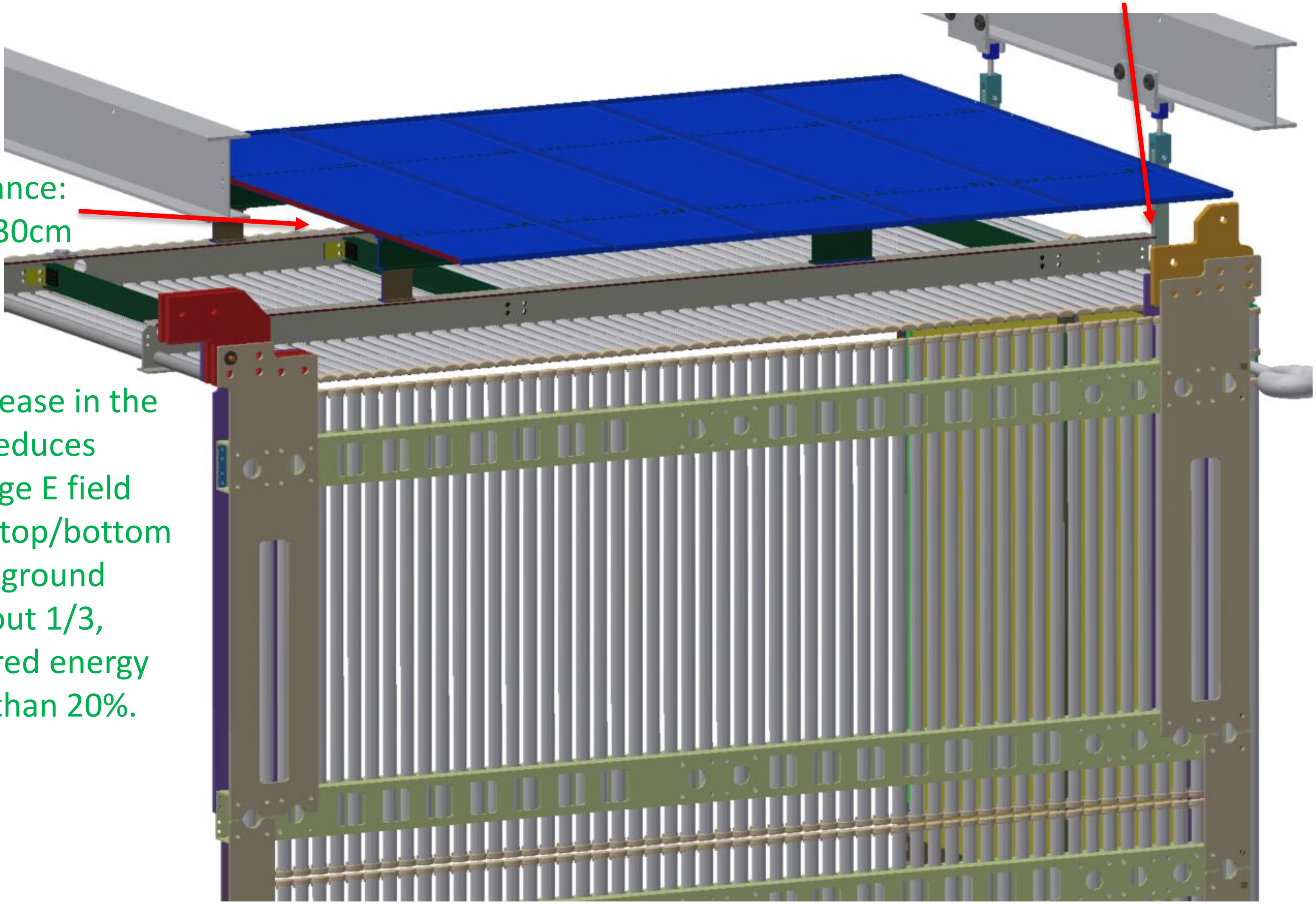


First LArTPC to have:
Resistive cathode
Segmented FC
Aluminum FC electrodes

The design has a large number of insulators on the outside of the field cage that can charge up and may lead to HV instabilities.

The DUNE SP HVS Baseline Design

Major changes from ProtoDUNE SP:



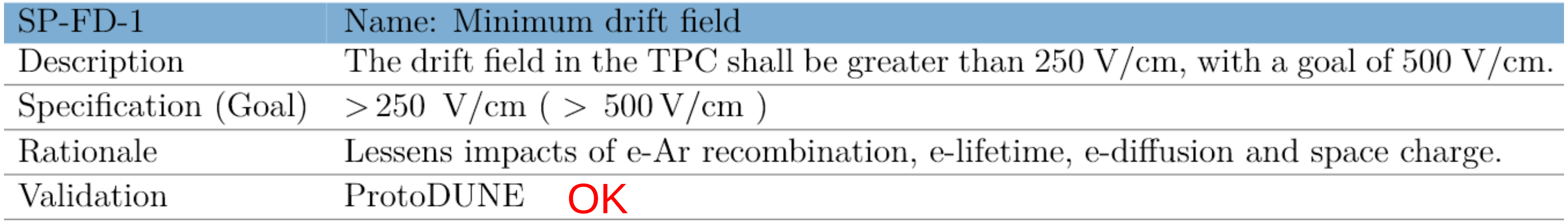
Removed several GP-FC standoffs in the high field region

FC to GP clearance: from 20cm to 30cm

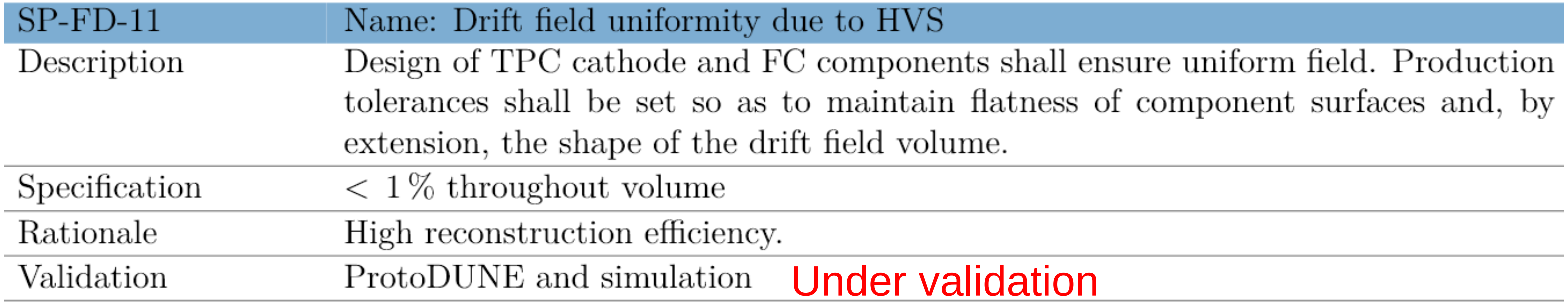
The 50% increase in the FC-GP gaps reduces

- the average E field between top/bottom FC to the ground plane about 1/3,
- TPC's stored energy by more than 20%.

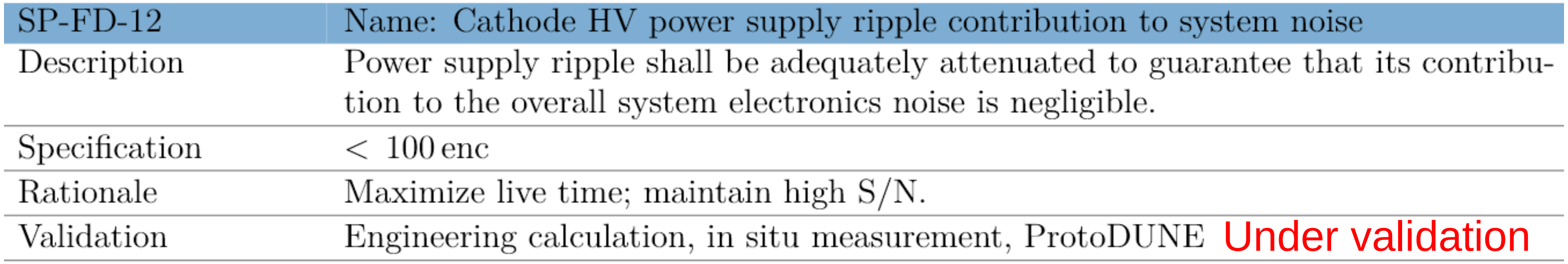
Key Performance Requirements (DocDB-6434)



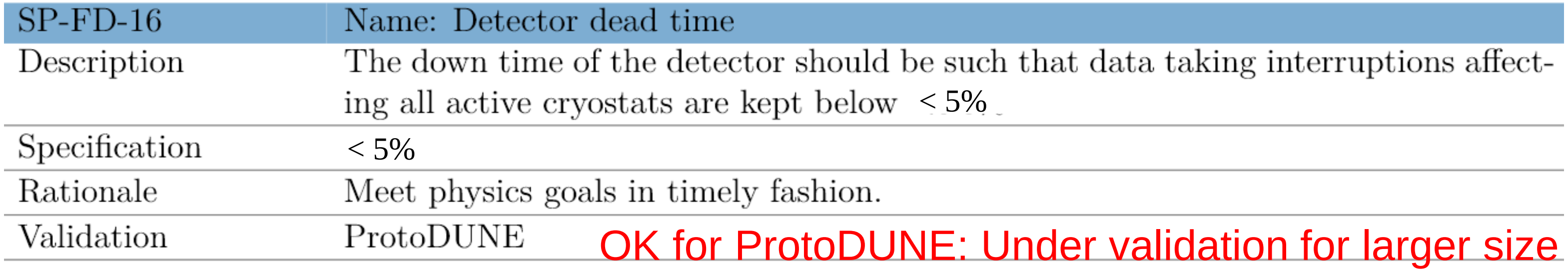
SP-FD-1	Name: Minimum drift field
Description	The drift field in the TPC shall be greater than 250 V/cm, with a goal of 500 V/cm.
Specification (Goal)	> 250 V/cm (> 500 V/cm)
Rationale	Lessens impacts of e-Ar recombination, e-lifetime, e-diffusion and space charge.
Validation	ProtoDUNE OK



SP-FD-11	Name: Drift field uniformity due to HVS
Description	Design of TPC cathode and FC components shall ensure uniform field. Production tolerances shall be set so as to maintain flatness of component surfaces and, by extension, the shape of the drift field volume.
Specification	$< 1\,\%$ throughout volume
Rationale	High reconstruction efficiency.
Validation	ProtoDUNE and simulation Under validation

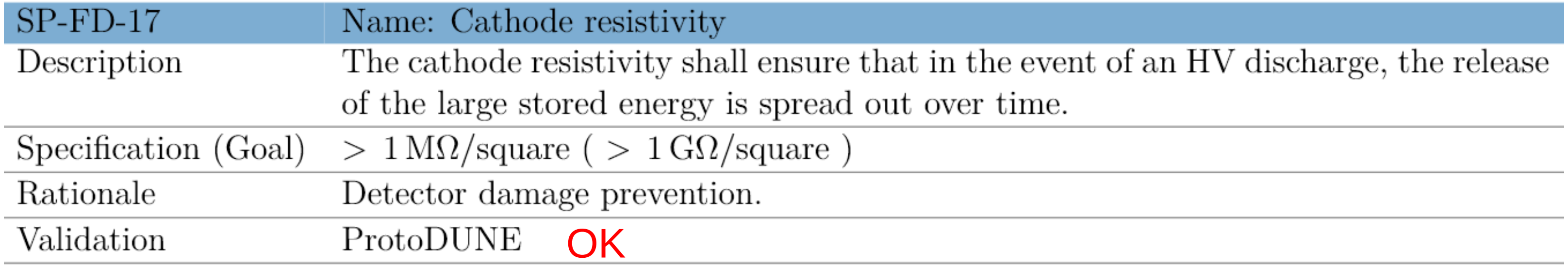


SP-FD-12	Name: Cathode HV power supply ripple contribution to system noise
Description	Power supply ripple shall be adequately attenuated to guarantee that its contribution to the overall system electronics noise is negligible.
Specification	< 100 enc
Rationale	Maximize live time; maintain high S/N.
Validation	Engineering calculation, in situ measurement, ProtoDUNE Under validation

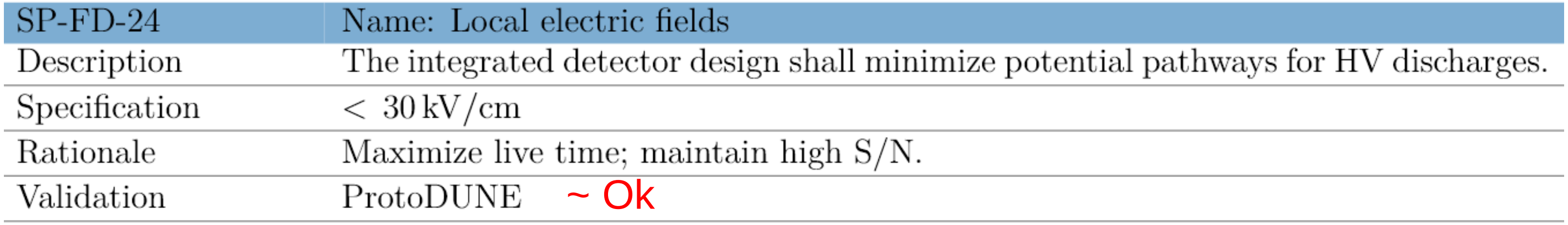


SP-FD-16	Name: Detector dead time
Description	The down time of the detector should be such that data taking interruptions affecting all active cryostats are kept below $< 5\%$.
Specification	$< 5\%$
Rationale	Meet physics goals in timely fashion.
Validation	ProtoDUNE OK for ProtoDUNE: Under validation for larger size

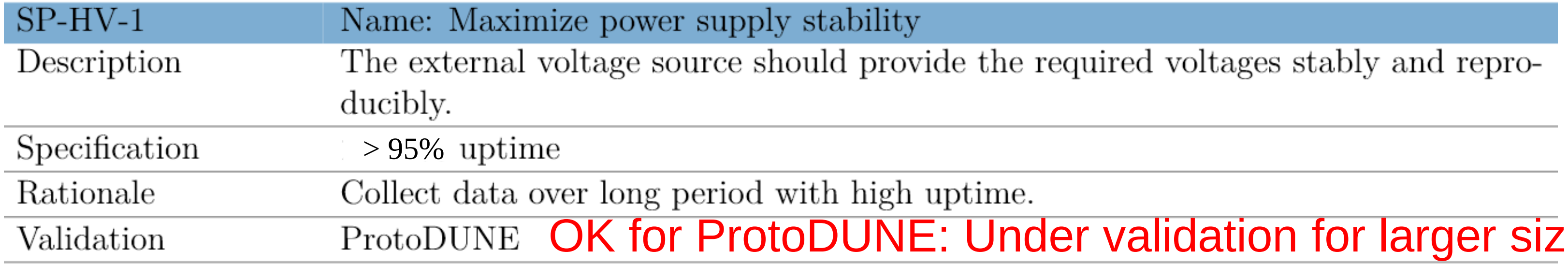
Key Performance Requirements (DocDB-6434)



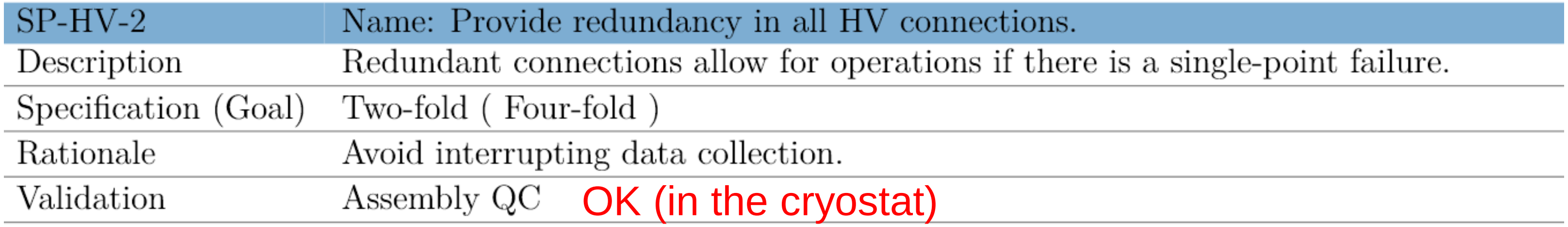
SP-FD-17	Name: Cathode resistivity
Description	The cathode resistivity shall ensure that in the event of an HV discharge, the release of the large stored energy is spread out over time.
Specification (Goal)	$> 1\,\mathrm{M\Omega/square}$ ($> 1\,\mathrm{G\Omega/square}$)
Rationale	Detector damage prevention.
Validation	ProtoDUNE OK



SP-FD-24	Name: Local electric fields
Description	The integrated detector design shall minimize potential pathways for HV discharges.
Specification	$< 30\,\mathrm{kV/cm}$
Rationale	Maximize live time; maintain high S/N.
Validation	ProtoDUNE ~ Ok



SP-HV-1	Name: Maximize power supply stability
Description	The external voltage source should provide the required voltages stably and reproducibly.
Specification	$>95\%$ uptime
Rationale	Collect data over long period with high uptime.
Validation	ProtoDUNE OK for ProtoDUNE: Under validation for larger size



SP-HV-2	Name: Provide redundancy in all HV connections.
Description	Redundant connections allow for operations if there is a single-point failure.
Specification (Goal)	Two-fold (Four-fold)
Rationale	Avoid interrupting data collection.
Validation	Assembly QC OK (in the cryostat)

Risks (Docdb 6443)

- These are the SP HVS risks in the risk registry.
- Some of the ratings have been updated after the ProtoDUNE SP run.
- Many mitigations are built into the ProtoDUNE SP/FD system design.

ID	Risk	Probability	Impact
1	CPA: scratches on double-coated resistive panels	L	L
2	CPA: scratches on resistive strips on the frame	L	L
3	Damages (scratches, bending) to aluminum profiles of FC modules	L	L
4	Detector components are damaged during shipment to the far site	L	L
5	Broken resistors on voltage divider boards	L	L
6	Broken varistors on voltage divider board	L	L
7	Electric field uniformity is not within requirements	L	L
8	Electric field is below specification during stable operations	M	L
9	Damage to cold electronics (CE) in event of discharge	L	L
10	Free hanging frames can swing in the fluid flow	L	L
11	FRP/UHMWPE/Kapton component lifetime is less than expected	L	L
12	Sole source for Kapton resistive surface; and may go out of production	M	L
13	International funding level for SP HVC too low	M	M
14	Underground installation is more labor intensive or slower than expected	L	L

Const/assemb /instal

operation

technical

schedule

Risk Mitigations, 1

- 1-4, Component damages from construction through installation:
  - CPA: minor scratches can be tolerated. Large area damages can be repaired on site.
  - FC profile scratches are replaced with spares or repaired on site.
  - Spare parts are made available in LW/cleanroom. FC/CPA modules can be swapped from buffer stock in LW and replaced from factories in a few days.
- 5-6, Resistor/varistor damage:
  - Stringent selection including cold tests. Varistors are robust and added for the protection of resistors, which are installed two in parallel per tap. No failure in MicroBooNE/35ton/ProtoDUNE SP.
  - Impact on electric field is understood and can be corrected with calibration laser (if available) or cosmic rays (with some delay).
- 10, Cathode movement forced by LAr flow
  - CPA structure is designed to withstand pressure from LAr flow based on fluid model predictions.
  - Static deformation can be calibrated by lasers or cosmic rays (over time).

Risk Mitigations, 2

- 7, Drift field uniformity out of spec.
  - Caused by 5,6,10. See discussion in previous slide
  - Space charge distortion is negligible in SP module
- 8, Achievable stable E field is below goal (500V/cm)
  - We have occasional instabilities in ProtoDUNE SP @ 500V/cm: 1/4hrs
    - If due to surface charge buildup, should scale down with ionization flux: x 0.01.
  - In the current baseline design: Increase top/bottom FC to ground plane clearance by 50%, and remove all FC-GP standoffs on the cathode side.
  - Remove most insulating structural elements on the FCs in an updated FC design.
- 9, Damage to CE in a HV discharge
  - The unique HV system design (resistive cathode, segmented FC) is aimed at mitigating this risk.
  - Looking for higher resistivity cathode coating to further increase safely factor.
  - Perform full system circuit analysis to identify additional mitigation scheme.

Risk Mitigations, 3

- 11, FRP/UHMWPE/Kapton component life time
  - Experience in Atlas (Kapton, PCB, 20+ years), Icarus (G10, feedthrough 4+ years, make it exchangeable) is showing stable behavior.
- 12, Resistive Kapton is sole source from DuPont
  - About 12 rolls of resistive Kapton are needed (4ft wide, 300m per roll) for the CPA's panels of one SP module. The cost is 20k$ per roll from the only vendor available up to now.
  - Recently other source of resistive Kapton have been identified. An early purchase is also under consideration in case of single source.
- 13, International funding level low for SP HVS
  - Current cost estimates suggest that International funding could be a potential issue.
  - Cost reduction through design optimization and scaling. Increase effort to include more international collaborating institutes.
- 14, UG installation is more labor intensive then expected
  - Add more labor contingency. Installation schedule is planned with TC and consistent with other subsystems.
  - Early full-scale installation trial at Ash River, and two rounds of ProtoDUNE installations.
  - HVS installation is not on the critical path.

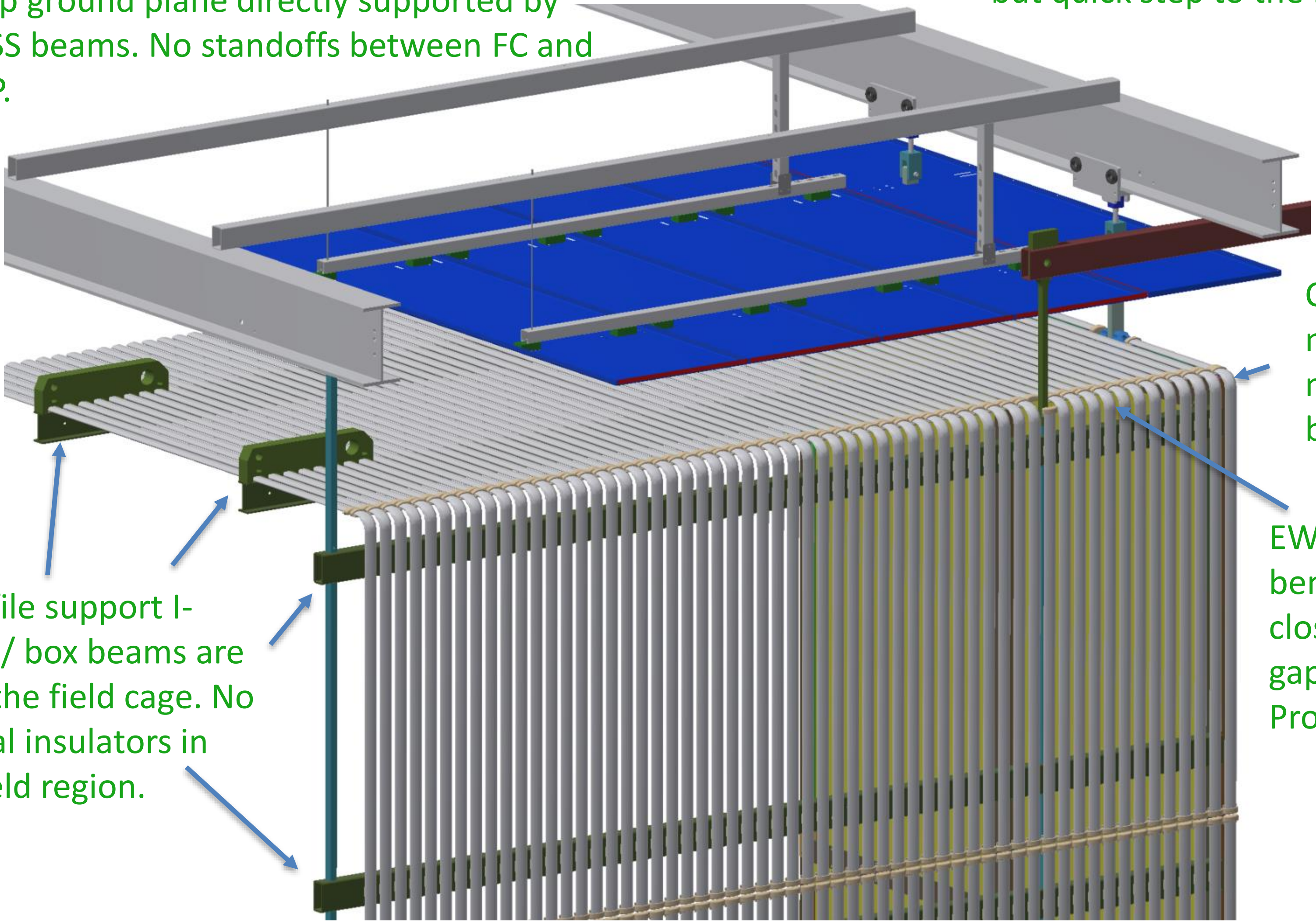
Additional options, design evolution

- Studies & R&D on going for:
  - Laser Electric Field uniformity Calibration
  - UV Reflector on CPA
- In principle small impact on HVS design
- Implementation be decided by Tech. Board in early 2020 if to be included in ProtoDUNE II

- Further HVS design evolution:
  - Simplified layout construction and installation. Improved reliability at HV.
  - Dedicated assembly/installation tests started in Ash river Integration facility:
  - Aiming at presenting it as base design at final Design Review in ~ 1 year, and at PRR for ProtoDUNE II as module “0” for the DUNE far detector.

Further design evolution

Changes from the baseline design:



Top ground plane directly supported by DSS beams. No standoffs between FC and GP.

Top ground plane installed as a separate but quick step to the DSS support beams.

CPA corners need to be modified with bent profiles

EW profiles have bent corners to close the large gap in ProtoDUNE SP FC

FC profile support I-beams / box beams are inside the field cage. No external insulators in high field region.

HVS consortium membership

- The consortium structure reflects the present HV/FC/CPA organization in ProtoDUNE:
  - Same institutions with same responsibilities as in ProtoDUNE in detector component design, developments, integration, assembly
  - Natural merging scheme of SP and DP groups anticipated from ProtoDUNE experience

Institution			Contact	Email
CERN	SP+DP	CERN	Francesco Piertropaolo	francesco.pietropaolo@cern.ch
USA	SP	Argonne National Lab	Steve Magill	srm@anl.gov
USA	SP+DP	Brookhaven National Lab	Bo Yu	yubo@bnl.gov
USA	SP	University of California (Berkeley)	Cheng Ju Lin	cjslin@lbl.gov
USA	SP	University of California (Davis)	Emilija Pantic	pantic@ucdavis.edu
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USA	SP	South Dakota School of Mines and Technology	Juergen Reichenbacher	Juergen.Reichenbacher@sdsmt.edu
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USA	SP+DP	University of Texas (Arlington)	Jae Yu	jaehoonyu1@gmail.com
USA	SP	Virginia Tech.	Jon Link	jmlink@vt.edu
USA	SP	College of William and Mary	Jeff Nelson	jknels@wm.edu

SP, DP: ProtoDUNE membership

- Participation likely to be expanded in the near future: effort on new EU participants

Management Structure & Organization

- Consortium Leader: *Francesco Pietropaolo*
- Technical Leader: *Bo Yu*
- TDR/TP Editor : *Rob Plunkett* (SP), *J(DP)*
- HVS design & integration lead: *Vic Guarino (SP), D. Mladenov (DP)*

Working groups

- **WG1.** Design optimization for SP and DP; assembly, system integration, detector simulation, physics requirements for monitoring and calibrations.
  - *Lead: Jeff Nelson, Vic Guarino, Bo Yu, D. Mladenov*
- **WG2.** R&D activities, R&D facilities
  - *Francesco Pietropaolo, Ting Miao*
- **WG3.** Single phase-CPA: Procurement, in situ QC, resistive Panels, frame strips, Electrical connections of planes / QC, Assembly, Shipment to assembly site / QC.
  - *Lead: Stephen Magill, F. Pietropaolo*
- **WG4.** DP Cathode:
  - *Lead: Jae Yu, F. Pietropaolo*
- **WG5.** Field cage modules
  - *Lead: Thomas Kutter, Michael Wilking, Jeff Nelson, Jae Yu*
- **WG6.** HV supply and filtering, HV PS + cable procurement, R&D tests, filtering and receptacle design and tests.
  - *Lead: Franco Sergiampietri, Sarah Lockwitz*

Testing Facilities

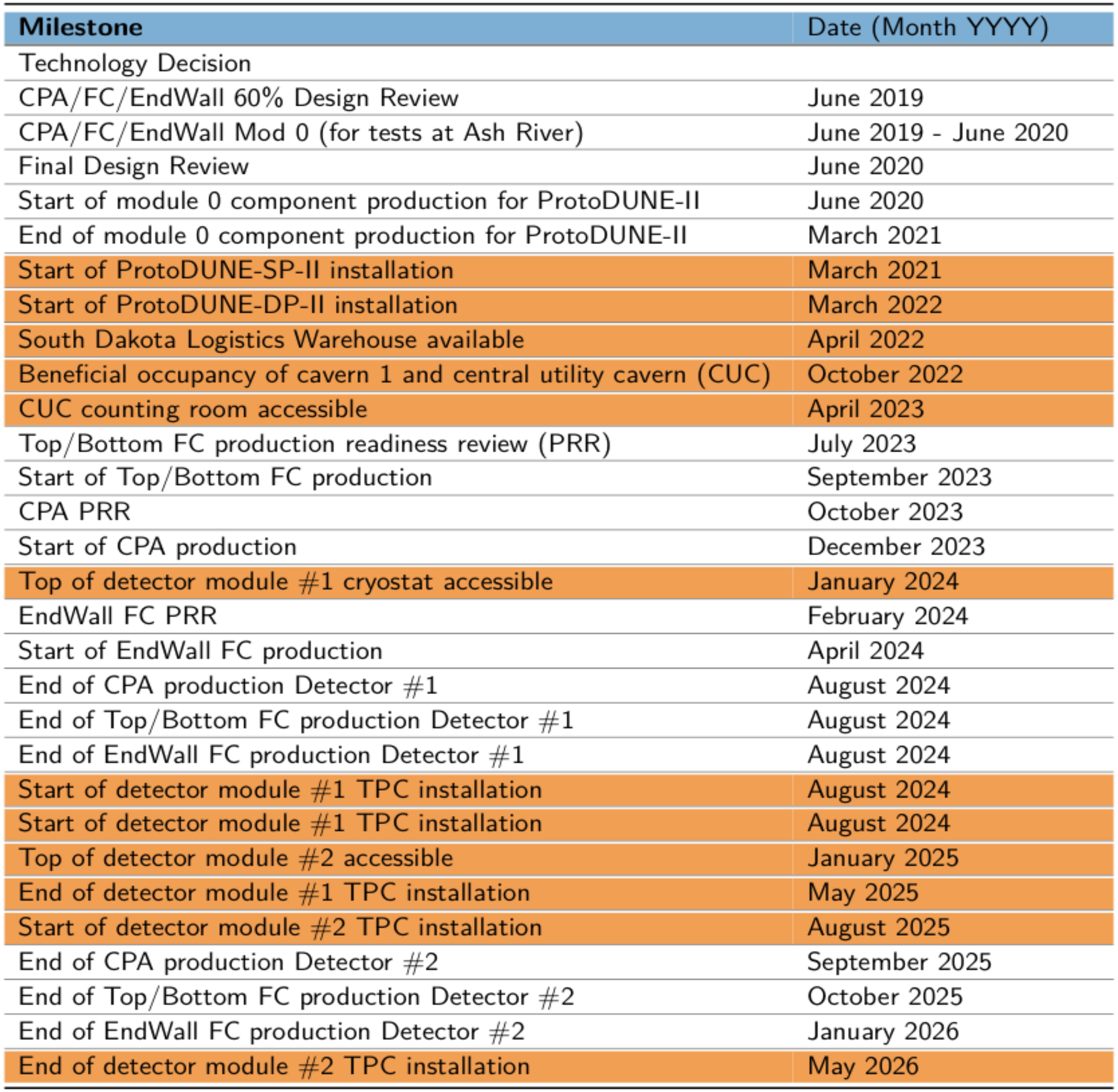
- ProtoDUNE SP and DP will be our benchmark for the validation of the HV System design.
- Additional options for testing the HV System components and their assembly chains.
  - measurements of HV breakdown (sparks/streamer), resistivity (CPA), cryogenic tolerance, thermal behavior/damage (survey/photogrammetry), robustness to HV sparks etc. We plan to take advantage of facilities already exploited for the ProtoDUNE developments:
    - CERN: ICARUS 50 liter (FC tests), DP cold-box, etc.
    - FNAL: PAB facility
    - ANL: building 366
    - BNL: cold LN2 box
  - The Ash River Integration test facility, proven to be essential in fine tuning the assembly procedures for ProtoDUNE, is also be perfectly adequate for the DUNE far detector cases, given the size and tooling of the laboratory matching the requirements for the far detector cases.

WBS & cost estimate

- Core costs and labor for one SP Far Detector :
  - reliable estimate extrapolated from ProtoDUNE.
  - Possible optimization due to large scale factor
  - Manpower mostly available within the present consortium institutions
  - (Under evaluation by the Neutrino Cost Group)
- Aiming to include new EU institutions at the level of 25% of core costs

WBS	WBS Element Name	M&S	Engineer	Designer	Tech	Student Tech	Grad-Student	Post-Doc	Faculty/Staff
2.8	**SP HV System (SP-HV)**	$**6'527'676**	15'666	2'950	40'545	29'522	14'615	15'636	10'482
2.8.1	Project Management	$180'000	9'612	120	0	0	0	0	888
2.8.2	Physics and Simulations	$20'000	400	20	0	0	100	220	340
2.8.3	Design, Engineering and R&D	$226'423	2'580	1'900	2'544	760	824	600	693
2.8.4	Production Setup	$186'000	432	250	2'463	457	180	200	808
2.8.5	Production	$5'915'253	2'410	660	29'386	28'305	13'247	11'800	7'753
2.8.5.1	CPA Production	$2'405'411	2'100	440	6'690	0	0	0	2'469
2.8.5.2	FC Common Components	$502'467	0	20	6'768	15'305	0	0	792
2.8.5.3	T/B FC Production	$1'964'456	80	0	840	4'500	4'827	4'500	800
2.8.5.4	EW FC Production	$757'000	230	200	14'400	8'500	8'300	7'300	3'000
2.8.5.5	HV Distribution Production	$285'919	0	0	688	0	120	0	692
2.8.5.1	CPA Production	$2'405'411	2'100	440	6'690	0	0	0	2'469

High level Schedule and Milestones



Milestone	Date (Month YYYY)
Technology Decision	
CPA/FC/EndWall 60% Design Review	June 2019
CPA/FC/EndWall Mod 0 (for tests at Ash River)	June 2019 - June 2020
Final Design Review	June 2020
Start of module 0 component production for ProtoDUNE-II	June 2020
End of module 0 component production for ProtoDUNE-II	March 2021
Start of ProtoDUNE-SP-II installation	March 2021
Start of ProtoDUNE-DP-II installation	March 2022
South Dakota Logistics Warehouse available	April 2022
Beneficial occupancy of cavern 1 and central utility cavern (CUC)	October 2022
CUC counting room accessible	April 2023
Top/Bottom FC production readiness review (PRR)	July 2023
Start of Top/Bottom FC production	September 2023
CPA PRR	October 2023
Start of CPA production	December 2023
Top of detector module #1 cryostat accessible	January 2024
EndWall FC PRR	February 2024
Start of EndWall FC production	April 2024
End of CPA production Detector #1	August 2024
End of Top/Bottom FC production Detector #1	August 2024
End of EndWall FC production Detector #1	August 2024
Start of detector module #1 TPC installation	August 2024
Start of detector module #1 TPC installation	August 2024
Top of detector module #2 accessible	January 2025
End of detector module #1 TPC installation	May 2025
Start of detector module #2 TPC installation	August 2025
End of CPA production Detector #2	September 2025
End of Top/Bottom FC production Detector #2	October 2025
End of EndWall FC production Detector #2	January 2026
End of detector module #2 TPC installation	May 2026

Summary

- A baseline design for the HV System of the DUNE SP Far Detector is presented, as described in in the DUNE TDR.
  - Successfully validated in ProtoDUNE SP construction, installation and operation.
  - Simple changes to the field cage added to further reduce the external E field in the critical regions between the FC profiles and the ground planes to gain additional safety margins.
- The HVS consortium WBS structure reflects the successful ProtoDUNE institutional sharing of responsibilities. The preliminary cost estimates and BOEs are submitted to the NCG. The construction schedule matches the latest cryostat availability date.
- Design evolution:
  - Additional optimization is under study, allowing to shed nearly all insulation materials on the outside of the FC to eliminate instabilities caused by insulator charging, and reduce cost and speed up assembly.
- More details in the following talks…