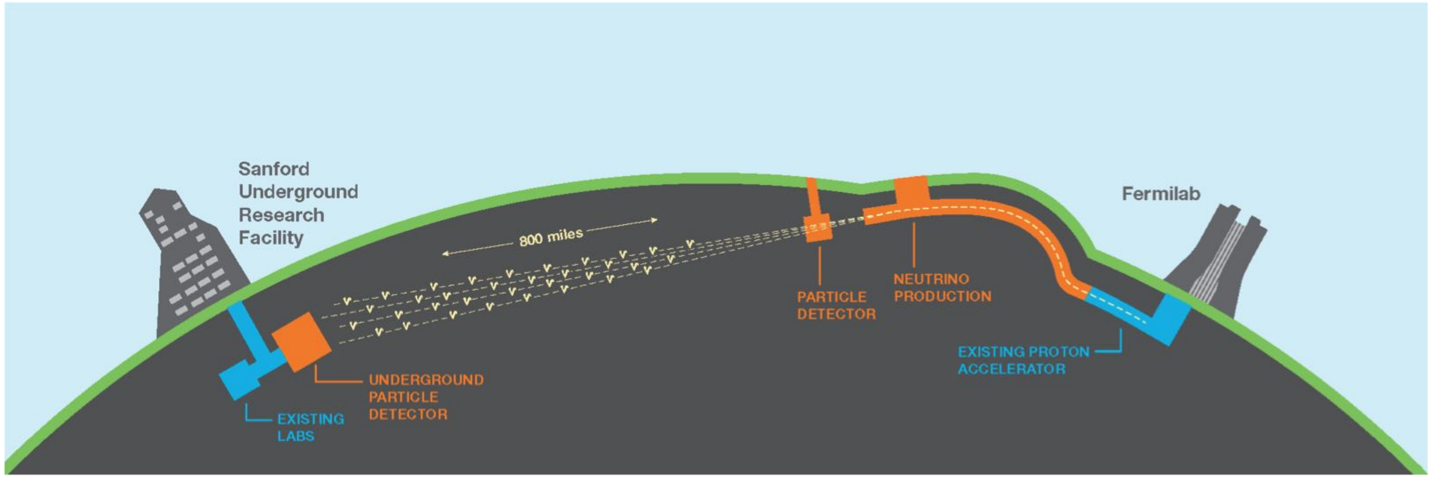


DUNE Far Detector Joint HVS Consortium: Status and plans

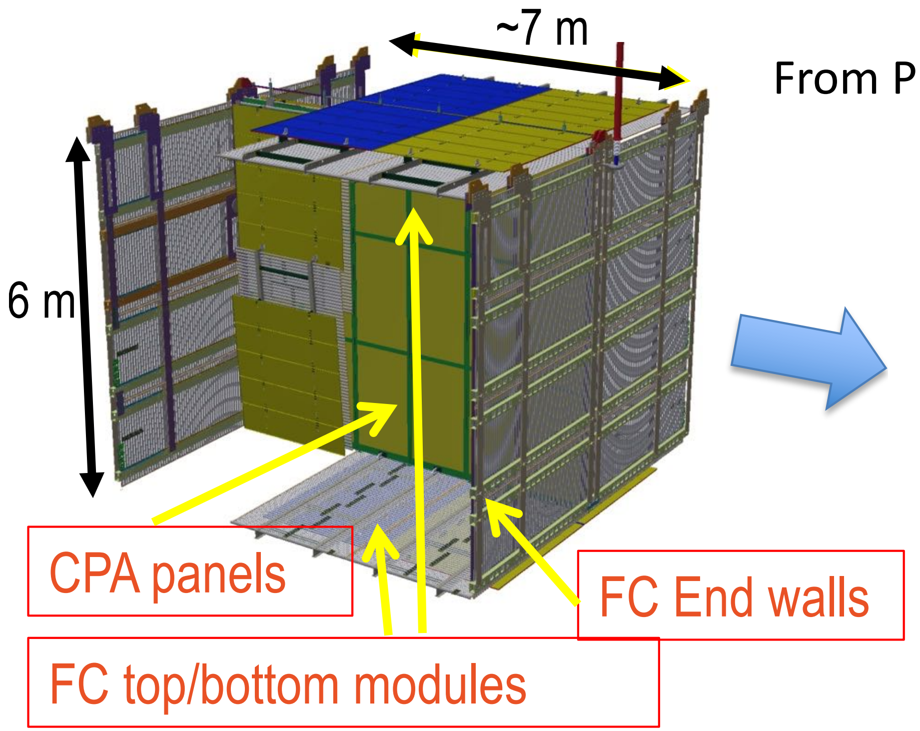
F. Pietropaolo

LNBC Meeting, FermiLab, February 19th, 2018

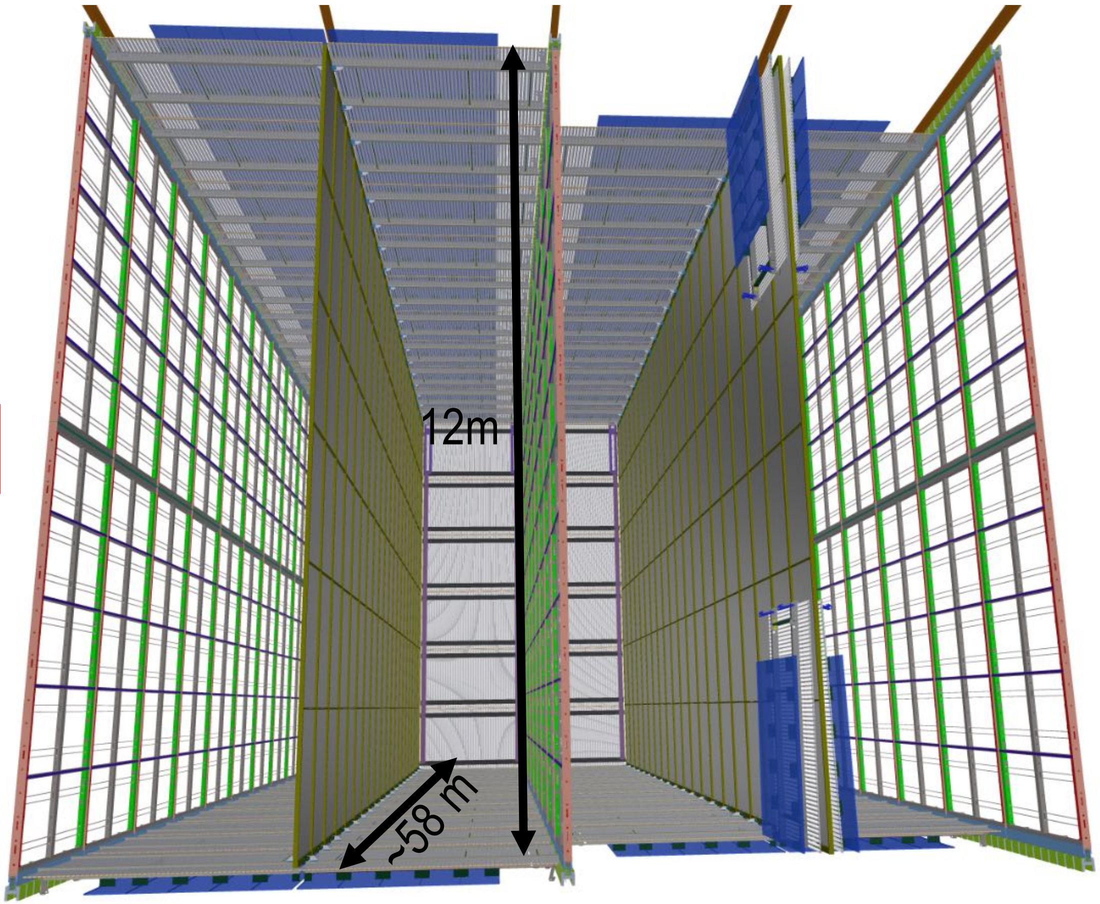
Consortium scope

- Provide uniform and stable electric field in the Fiducial Volumes of the SP and DP far detectors at the nominal value of 500 V/cm.
- Design, build and install the Cathodes, Field cages and HV distribution systems of the SP and DP far detectors.
  - Conceptually same detector components and same functionality
  - HOWEVER: very different designs and required performance
    - drift distance: 3.6 m (SP) vs 12 m (DP)
    - HV supply: 180 kV (SP) vs 600 kV (DP)
    - modular (SP) vs monolithic (DP) approach
    - Resistive opaque cathode (SP) vs metallic transparent structure (DP)
  - Expected strong synergies on:
    - Field Cage electrode profiles
    - Supporting FRP beams
    - HV feed-throughs
    - Voltage dividers boards
    - Assembly infrastructures
- For TP/TDR: two independent HV systems

Scope: DUNE SP HV System

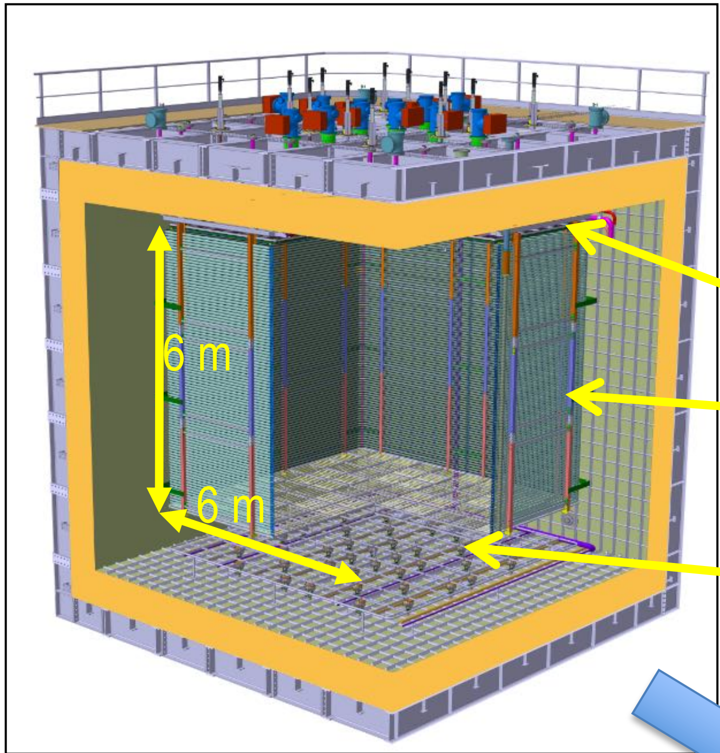


From ProtoDUNE to DUNE Far detector



10 kton fiducial cryostat.
~33 x larger CPA resistive surface
~17 x more top/bottom FC modules
~8 x more endwall FC modules
Same modularity as ProtoDUNE SP
Active volume: W: 14.5m, H: 12m, L: 58m (3.6 m drift distance, 180kV)
Installed under 5 mounting rails suspended under the cryostat ceiling.

Scope: DUNE DP HV System



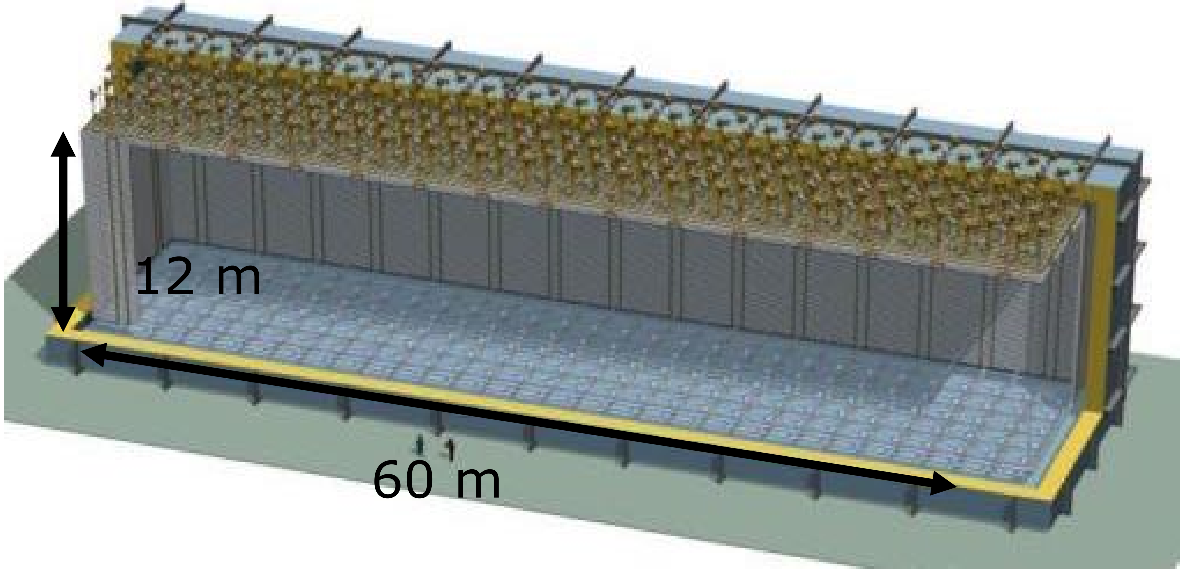
- Field Cage and cathode hang off of the ceiling
- Each FC panel consists of 3 sub-modules of 3mx2m
- Essential to have light yet sturdy structure
- Based on modular concept as SP

Charge Readout Planes

Field Cage (common structural elements with SP)

Cathode

From ProtoDUNE to DUNE Far detector



DUNE: 2x Drift distance (6m → 12m)
6x field shaping ring (24→ 144m)
12x N_sub-modules (24→288)
2x HV (300kV → 600kV supply)

HVS consortium organization & 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	SD+DP	CERN	Francesco Piertropaolo	francesco.pietropaolo@cern.ch
USA	SP	Argonne National Lab	Steve Magill	srm@anl.gov
USA	SP	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
USA	SP	Fermi National Accelerator Lab	Sarah Lockwitz	lockwitz@fnal.gov
USA	SP	University of Houston	A. Renshaw	arenshaw@central.uh.edu
USA	SP	Kansas State University	Glenn Horton-Smith	gahs@ksu.edu
USA	SP	Lawrence Berkeley National Lab	Cheng Ju Lin	cjslin@lbl.gov
USA	SP	Louisiana State University	Thomas Kutter	kutter@phys.lsu.edu
USA	SP	South Dakota School of Mines and Technology	Juergen Reichenbacher	Juergen.Reichenbacher@sdsmt.edu
USA	DP	Stony Brook University	Micheal Wilking	michael.wilking@stonybrook.edu
USA	SP	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 organization

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

Management Structure

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

Strategy for DUNE Single Phase HV systems

- Baseline design for all elements of the DUNE SP far detector (CPA, top/bottom FC, End-Wall FC and HV distribution) follow the ProtoDUNE design as it has been produced and is being assembled.
  - All FC/CPA modules with approximately the same dimensions as in ProtoDUNE.
  - The CPA-to-FC interconnections will also be the same as well as the voltage divider board layout.
  - The HV feed-through and the HV distribution to the CPA will be a copy of that of ProtoDUNE.
- Some design modifications/simplifications could be implemented to take into account the double height of the CPA and the end-wall modules and to adapt the installation procedure to the underground environment.
- Additional design modifications are to be expected based on the 35 ton test results at FNAL and if the ProtoDUNE run identifies weaknesses in the present baseline option.

Strategy for DUNE Dual Phase HV systems

- DP Field Cage also based on ProtoDUNE DP design, including HV Divider Boards, with possible segmentation to account for increased perimeter.
- The cathode design and interface with FC will also follow the ProtoDUNE experience (work-in-progress).
- The DP HV System distribution will require instead intense R&D given the unprecedented value of the required HV (-600 KV):
  - The strategy towards the 600 kV is presently under definition and should consist in a joint R&D program with Power Supply Producer (Heinzinger).
  - The R&D will rely on:
    - 600 kV PS are feasible scaling the present industrial technology;
    - the same is possibly true for the HV cryogenic feed through (to be verified);
    - the weak points of the HV distribution are then in the cable and its connectors on the PS and the HV-FT sides.
    - FT + Cathode connection need to be tested in LAr at 600kV
  - Basic idea: eliminate cables/connectors, build PS around the HV-FT. PS Producer interested in this R&D because of possible new industrial applications.

Requirements: current state (DocDB-6434) & plans for further development

- Non-exhaustive list with impact on the detector response to physical parameters, detector live time and stability, and field condition:

Item	Explanation	Requirement	Goal
Electric field in TPC drift volume	Maintain adequate signal pulse height and particle ID, which are impacted by slower drift speed and increased recombination, diffusion and possibly space charge effects (DP)	>250 V/cm	500 V/cm
Electric field uniformity	Affected by space charge (<1% for SP, few % for DP), voltage divider defects, surface charge and mechanical planarity; affects momentum reconstruction and absolute energy scale measurements.	1% at fiducial volume boundary	
Electric field in outer LAr volume	Avoid damage to detector to enable data collection over long periods.	30 kV/cm	ALARA
Power supply ripple & stability	Minimize external noise on R/O electronics. Maintain data taking over long period.		
Adequate decay constant for discharges	Affected by surface resistivity of CPA to avoid damage to detector to enable data collection over long periods. Maintain high operational uptime to maximize experimental statistics.	MOhm / square	GOhm / square
HV connection redundancy	Avoid single point failures in detector which interrupt data taking.		
High operational live time	The overall goal is 90% operational lifetime for the entire detector. Includes maintenance, ramping, and any periods of instability.	95%	99%

- Work in progress to better quantify these requirements (jointly with other consortia: physics, reconstruction, simulation)

Key interfaces with other consortia (I)

Doc	Doc#	Descriptions
SP APA	6673	Mechanical: Field cage support on APA frames: same NP04 design for upper FC support, similar/modified designs for the lower and end wall FC modules. Electrical: FC termination wires, filters, electron diverter boards
SP PD	6721	PD calibration flash diffusers and fibers on CPAs TPB coated reflector foil on CPAs
SP TPC Elec.	6739	Field cage termination wire connectors on CE feedthrough flange, wires routed with CE cables
DP CRP	6754	Minimal interface.
DP PD	6799	To be developed: Electric field near PDs, cathode transparency, PMT locations, (HV discharge damage) etc.
Cryo. Inst. & Slow Control	6787	HV vs. LAr level interlock, sensor locations (high field region), cold/warm camera coverage, HV signal monitoring, etc.

Key interfaces with other consortia (II)

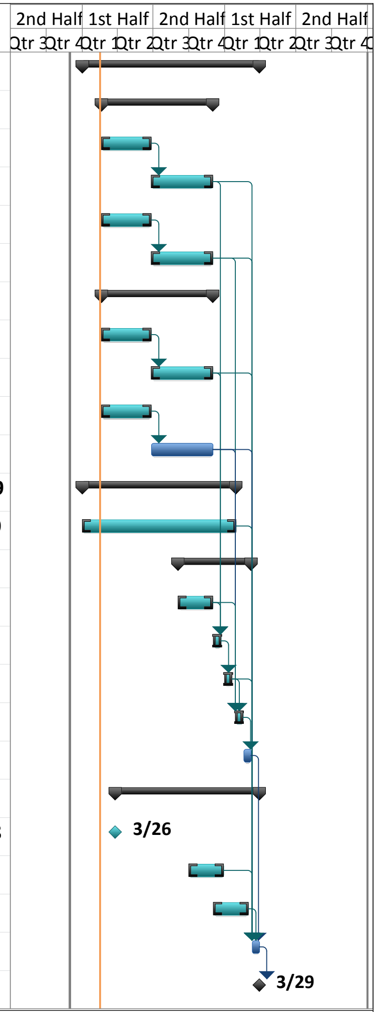
Other System	Doc#	Descriptions
Facility	6985	Under development: support of the CPA/FC modules on DSS; HV feedthrough locations; rack and cable trays; liquid and gas flow in cryostat
Installation	7012	CPA, FC final assembly; installation inside cryostat
Integration Facility	7039	Storage buffer, inspections/tests, repackage for underground delivery
Calibration	7066	Field cage openings for the calibration laser heads
Physics	7093	Requirements: range of operating drift field, uniformity of the drift field

Timelines for technical decisions

- **By the end of 2018**, the HV System designs should have been validated with ProtoDUNE SP and DP detectors.
  - Testing strategy will vary a lot depending of the performance of ProtoDUNE's.
  - However, 2018 will be devoted to component R&D and 2019 for system integration test.
  - DP integration test could in principle go beyond 2019.
  - A balance between R&D and ProtoDUNE operation will be needed due to limited resources.
  - Instrumentation R&D task is also required.
- By the time of finalization of the TDR (**Q2 2019**),
  - the consortium will be able to decide whether to adopt the baseline design solution
  - or if additional modifications are required (hopefully it should also be clear which modifications will need to be further tested before implementation).

Schedule up to TDR sumbission

ID	WBS	Task Name	Duration	Start	Finish
135	**7**	**HV System Consortium**	**325 days**	**Mon 1/1/18**	**Fri 3/29/19**
136	**7.1**	**Field Cage R&D**	**205 days**	**Mon 2/19/18**	**Fri 11/30/18**
137	7.1.1	Additional studies of SP field cage design	92 days	Mon 2/19/18	Tue 6/26/18
138	7.1.2	Finalize SP field cage design	113 days	Wed 6/27/18	Fri 11/30/18
139	7.1.3	Additional studies of DP field cage design	92 days	Mon 2/19/18	Tue 6/26/18
140	7.1.4	Finalize DP field cage design	113 days	Wed 6/27/18	Fri 11/30/18
141	**7.2**	**Cathode Panel Assembly R&D**	**205 days**	**Mon 2/19/18**	**Fri 11/30/18**
142	7.2.1	Additional studies of SP cathode design	92 days	Mon 2/19/18	Tue 6/26/18
143	7.2.2	Finalize SP cathode design	113 days	Wed 6/27/18	Fri 11/30/18
144	7.2.3	Additional studies of DP cathode design	92 days	Mon 2/19/18	Tue 6/26/18
145	7.2.4	Finalize DP cathode design	113 days	Wed 6/27/18	Fri 11/30/18
146	**7.3**	**HV Feedthrough R&D**	**281 days**	**Mon 1/1/18**	**Mon 1/28/19**
147	7.3.1	Complete necessary R&D on Feedthrough design	281 days	Mon 1/1/18	Mon 1/28/19
148	**7.4**	**HV System Design Integration Tests**	**135 days**	**Mon 9/3/18**	**Fri 3/8/19**
149	7.4.1	Design Instrumentation for HV Design Integration test	65 days	Mon 9/3/18	Fri 11/30/18
150	7.4.2	Assemble Test facility for SP-HV Design Integration Test	15 days	Mon 12/3/18	Fri 12/21/18
151	7.4.3	Run SP-HV Design Integration Test	15 days	Mon 12/31/18	Fri 1/18/19
152	7.4.4	Assemble Test facility for DP-HV Design Integration Test	15 days	Mon 1/28/19	Fri 2/15/19
153	7.4.5	Run DP-HV Design Integration Test	15 days	Mon 2/18/19	Fri 3/8/19
154	**7.5**	**TP/TDR**	**265 days**	**Mon 3/26/18**	**Fri 3/29/19**
155	7.5.1	HV Technical Proposal - Submit for Internal Review	0 days	Mon 3/26/18	Mon 3/26/18
156	7.5.2	Analysis of ProtoDUNE SP HV System Performance	65 days	Mon 10/1/18	Fri 12/28/18
157	7.5.3	Analysis of ProtoDUNE DP HV System Performance	65 days	Mon 12/3/18	Fri 3/1/19
158	7.5.4	Final editing of TDR	15 days	Mon 3/11/19	Fri 3/29/19
159	7.5.5	HV TDR - Submit for Internal Review	0 days	Fri 3/29/19	Fri 3/29/19



Project: FD Int schedule
Date: Fri 2/16/18

Task, Split, Milestone, Summary, Project Summary, External Tasks, External Milestone, Inactive Task, Inactive Milestone, Inactive Summary, Manual Task, Duration-only, Manual Summary Rollup, Manual Summary, Start-only, Finish-only, Deadline, Progress

Page 1

Detailed Milestones (2018/19)

- **Apr 2018**
  - Sections for Technical Proposal
- **Sep 2018**
  - Initial ProtoDUNE SP operation
- **Dec 2018**
  - Review of ProtoDUNE HVS performance: impact on HVS design for FD-SP
- **Mar 2019**
  - Definition of HVS baseline design for 1st SP module of FD
- **Mar 2019**
  - Revision of cost and schedule of HVS for 1st SP modules in view of TDR
- **Apr 2019**
  - SP HVS Sections of Technical Design Report
- **Nov 2019**
  - Review of HVS design to prepare production sites and to start material procurement
- **A similar Schedule is foreseen for the DP far detector module:**
  - possible delays, depending on ProtoDUNE DP schedule and results

Risks and concerns (DocDB-7186)

Risk		Mitigation
Electric field uniformity not adequate for muon momentum reconstruction	M	Addition of a laser calibration in case calibration with muons is inadequate.
Electric field below specification during stable operations.	M	Purity vs breakdown to be understood. The electric field gradient should be safely below the expected breakdown. More R&D to understand the results of the 35ton HV tests
DP: unable to make a HV distributions system that reaches 600kV	H	6x6x6 operational experience at 300 kV. Test on dedicated set-up at 600 kV.
Damage to CE in event of discharge from Cathode	L	SP: Make the cathode resistive to slow rate of discharge, DP: accessible electronics in low field regions with many protective shields in front of it.
Damages (scratches, bending) to aluminum profiles of Field Cage modules	L	Require sufficent spare profiles for on-site last minute substitution. Alternatively: local coating with epoxy resin.
International funding level for HVSC too low	M	Delay production or not supply all of the required parts
DP - Bubbles from heat in PMTs or resistors cause HV discharge and unstable operations	M	ProtoDUNE and 1x1x3 experience.
DP: lack of collaboration effort on this HV system	M	Recruit additional collaborators or extend DP participation from a subset of the SP collaborators.
FPR/Polyethene/laminated Kapton component unkown lifetime in LAr	L	Rely on material experience from other long lived LAr detectors (ICARUS, MicroBoone, Atlas). ProtoDUNE and 35T HV test experience. Make HV feed through exchangeable.

Summary

- The design of the HV system for SP (and DP) is progressing. It is derived from that realized for ProtoDUNE and as such will be described in the Technical Proposal in April 2018.
- Any further optimization of the protoDUNE design for FD will start from lessons learned from protoDUNE operation (and dedicated R&D set-up), adapted with the necessary changes to the FD situation.
- Interfaces with other detector components will also be developed relying on the ProtoDUNE experience. A baseline design for the FD is then predicted to be finalized in 2019 in close connection to TDR effort.
- Installation and Integration of the HV System components will also be addressed in view of the TDR, and tests with mock-ups (possibly in Ash River and/or equivalent facilities) will be started already in 2018

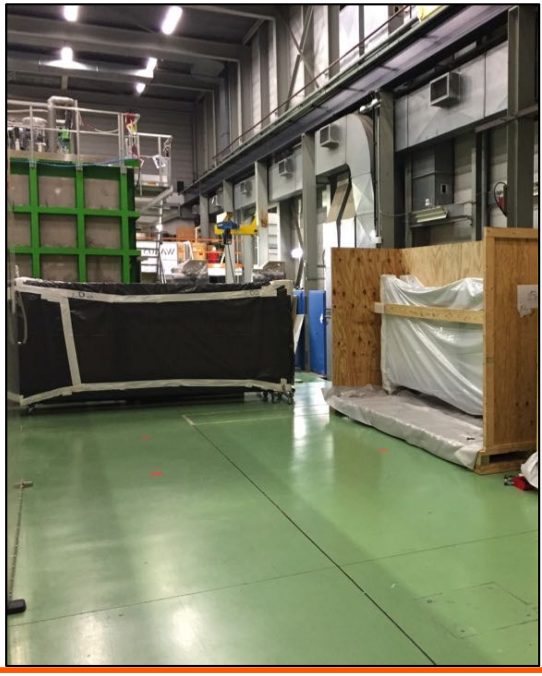
Back-up slides

- Consortium Activities
- ProtoDUNE-SP: CPA+FC Assembly
- SP design optimization
- ProtoDUNE DP: Floor Trial Assembly & First Few Modules Installation
- Towards DUNE DP
- R&D and test activity
- HV tests with the 35 ton facility at FNAL
- Testing facilities
- TP/TDR editing

Consortium activities (SP/DP):

- ProtoDUNE, opprotunity to understand and optimize:
  - Detector element assembly, installation sequence, integration;
  - Manpower, Space and tooling, Time required. Details:
    - SP: https://indico.fnal.gov/event/14581/session/7/contribution/45/material/slides/0.pdf
    - DP: https://indico.fnal.gov/event/14581/session/7/contribution/49/material/slides/0.pdf
- SP Far detector HV system design:
  - First integration drawings/3D-PDF/STP files of assembled detector under production
  - Interfaces with other consortia under study(APA, UIT, ITF, Calibration)
  - Production scheme, Installation sequence and schedule, underground space required, transportation scheme under study/optimization
  - Details: https://indico.fnal.gov/event/14581/session/7/contribution/46/material/slides/0.pdf

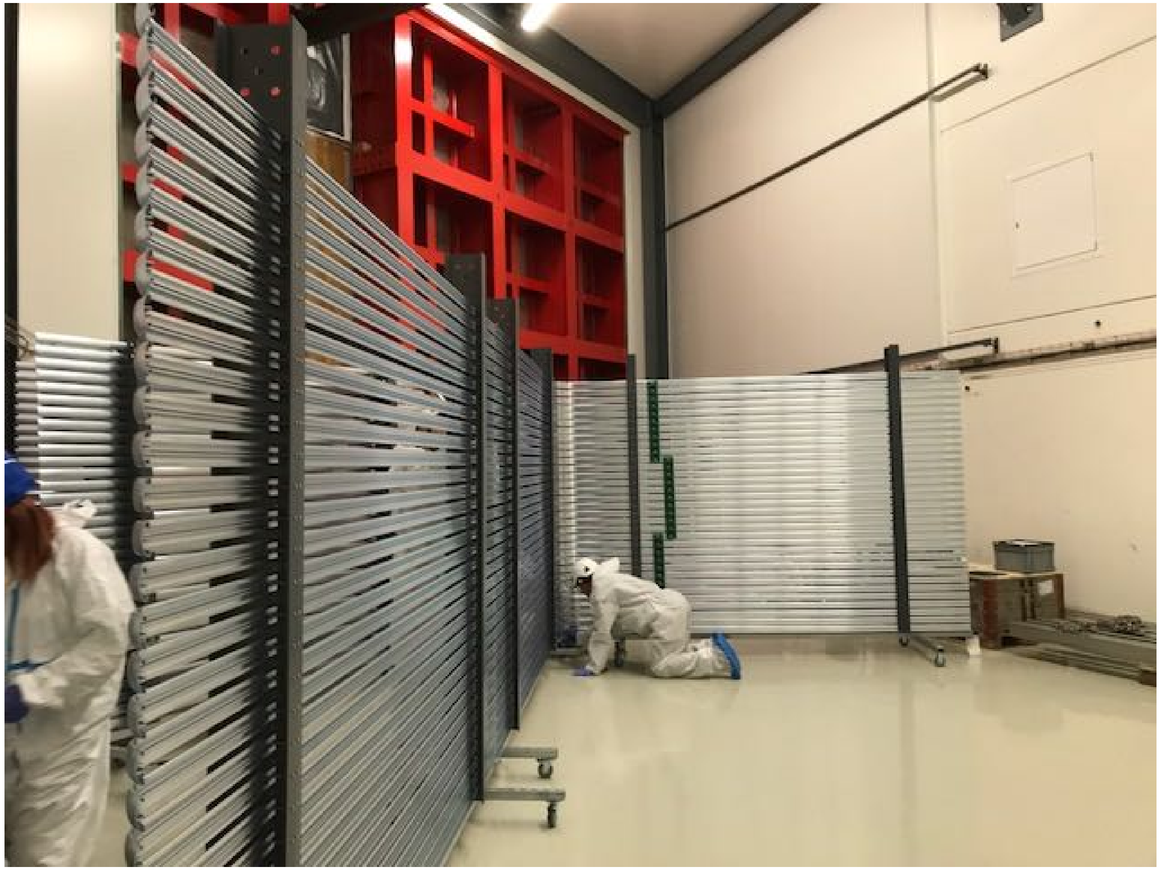
ProtoDUNE-SP: CPA+FC Assembly

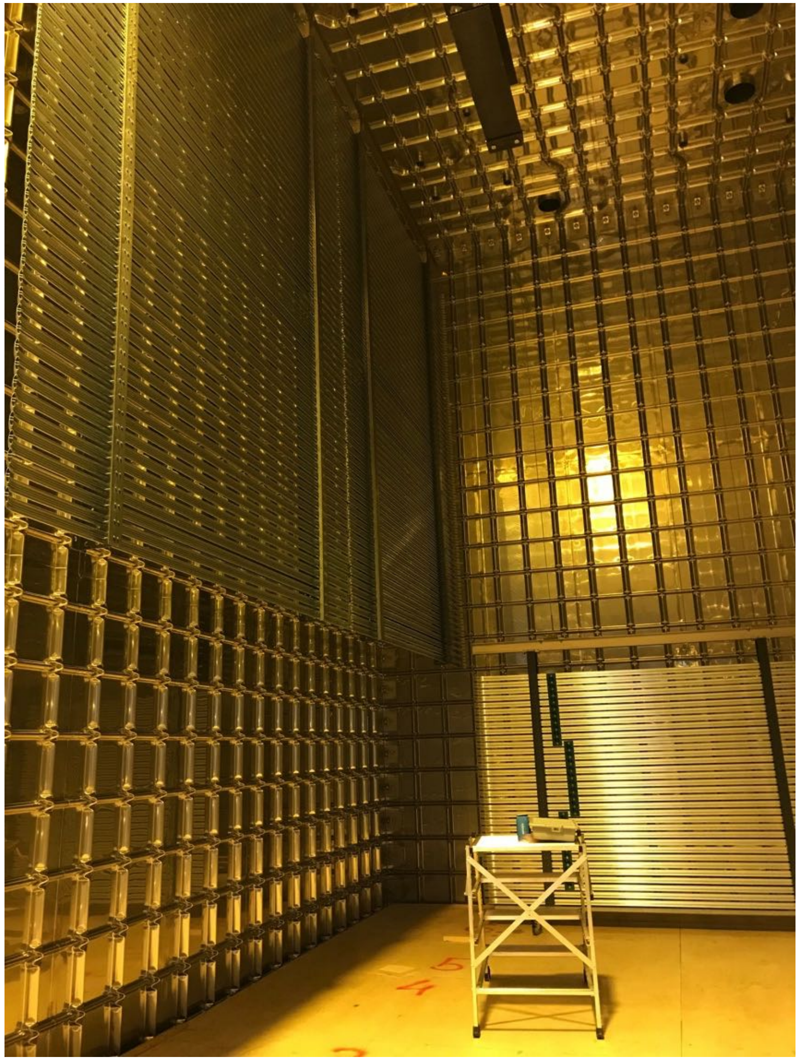


SP design optimization

- Present design assumes no major issues in the HVS operation of ProtoDUNE SP and therefore the basic HVS concepts are sound
  - Must change due to FD SP configuration
    - Dimensional adjustments to fit FD: impact FC, CPA, FC-APA interface
    - Possible new feature: laser heads inside field cage (jointly with Calibration Consortium)
  - E field considerations
    - Increase GP to FC distance (possibly decouple GP from FC)
    - Ground plane overhang
    - Remove solder bumps on back of R-divider boards
  - Value Engineering
    - Reduce number of end wall modules
    - Change GP from stainless steel to aluminum
    - Find a better FSS protection method for CPA
    - Simplify FC termination lines
- Details: https://indico.fnal.gov/event/14581/session/7/contribution/47/material/slides/1.pdf

ProtoDUNE DP: Floor Trial Assembly & First few module Installation





Towards DUNE DP

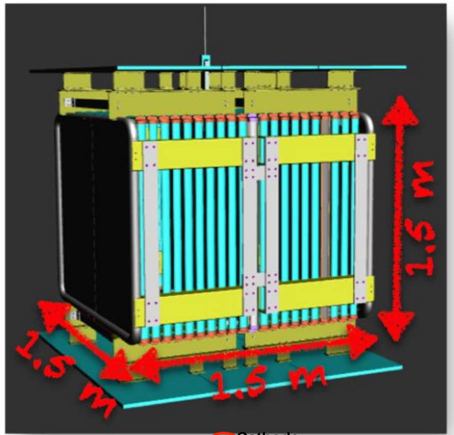
- The current design and installation scheme seem to work very well and can in principle to be used for DUNE DP
  - The final assembly the FC in front of or inside the cryostat in a clean area
    - Most time consuming work is conditioning the FRP parts → takes about 8 MH
    - Eliminate the risk of damaging or getting dirty the flimsy profiles
    - Packages are small (0.15x0.15x2m^3) and thus carry down many (~50~1500kg) on the SURF elevator at once
  - Sub-modules are light since we hang them on the ceiling (expected load for a 12m module to be less than 400kg)
  - Mechanically independent to other components → No interface
  - Simple structure → easy to handle, assemble and install (~1hr each by 2 and 4 people, respectively)
  - Many teams can work at the same time, dramatically reducing the time for installation

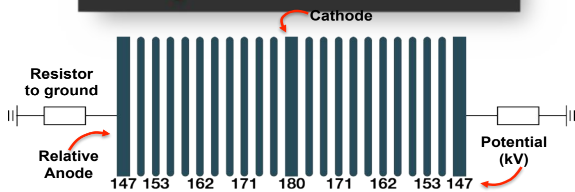
R&D and test activity

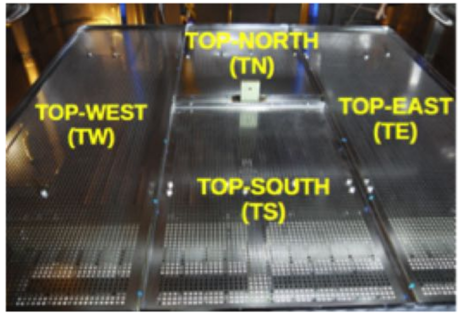
- To face possible flaws of the present design, we plan to develop testing tools for design validation and prototype test in a two-year schedule.
- Items to be tested include (non exhaustive list):
  - Field Cage:
    - (SP) end-cap alternatives: conductive or resistive profile ends; Insulator charging behavior (caps, support structure); field cage corner configuration: bent corner profiles, …
    - (DP) alternative to connecting clips for 144m long race tracks, surge suppression scheme optimization for large system
  - CPA/Cathode:
    - (SP) FSS Edge treatment, industrial process; Incorporate WLS reflectors;
    - (DP) segmented vs monolithic cathode; transparent resistive cathode option;
  - Instrumentation R&D for HV Breakdown Tests (jointly with Calibration monitoring :
    - Cryogenic cameras, Current sensors, Acoustic sensors, Radio-active sources (to stimulate breakdown, for example)
- Details: https://indico.fnal.gov/event/14581/session/7/contribution/48/material/slides/0.pdf

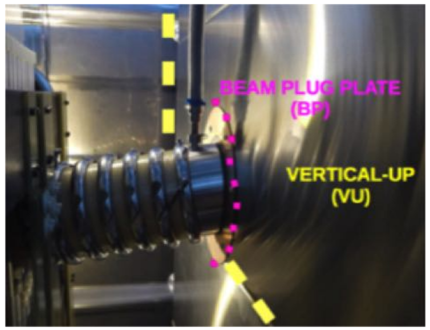
HV tests with 35 ton at FNAL

- Test CPA/FC ProtoDUNE SP design in LAr:
  - CPA (-180 kV) + first 10 FC profiles + res. divider to GND;
  - with/without Beam plug.
- Three runs (since April 2017)
  - 1. Test of the Field Cage design - No Beam Plug:
    - Plagued by anomalous current draws;
    - Analysis of the excess current draw points at CPA-FSS → design modified for ProtoDUNE and in following test runs.
  - 2. Test of New Cathode Frame Design and Beam Plug
    - Instrumented ground planes were (also in ProtoDUNE)
    - Ok up to 105 kV (300 V/cm)
    - Voltage instability and/or PS trip at higher Voltages
    - Concerned Ground Planes: mostly in the Beam plug region.
  - 3. Test of New Cathode Frame Design without Beam Plug
    - Similar voltage instability behavior as run 2
    - Analysis on-going but beam plug seems not to be the cause
- More details in dedicated talk from 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), 3x1x1, etc.
    - FNAL: 35t, Blanche, lab spaces (wideband)
    - ANL: building 366
    - BNL: cold LN2 box
  - The Ash River Integration test facility, proven to be essential to trim the assembly procedures for ProtoDUNE, will 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.

TP/TDR editing

- Outline of the TP for SP: chapters editing assigned, first draft expected by Feb. 23rd: https://indico.fnal.gov/event/14581/session/7/contribution/50/material/slides/1.pdf

1.0 High Voltage System (Total 33.5 pages)	Pages
1.1 Overview (2 pages)	
1.1.1 Introduction	0.5
1.1.2 Design Considerations	0.5
1.1.3 Scope	1.0
1.2 HV System Design (8 pages)	
1.2.1 High Voltage Power Supply and Feedthroughs	1.6
1.2.2 CPA	2.4
1.2.3 Field Cages	
1.2.3.1 Top and Bottom Field Cages	1.6
1.2.3.2 Endwall Field Cages	1.6
1.2.4 Electrical Interconnects and Voltage Dividers	0.8
1.3 Production and Assembly (7 pages)	
1.3.1 High Voltage Power Supply and Feedthroughs	1.4
1.3.2 CPA	1.6
1.3.3 Field Cages	
1.2.3.1 Top and Bottom Field Cages	1.6
1.2.3.2 Endwall Field Cages	1.6
1.4.4 Electrical Interconnects and Voltage Dividers	0.8

1.4 Interfaces (4.5 pages)	
1.4.1 Interfaces to APA	1.0
1.4.2 Interface to DSS	1.0
1.4.3 Interface to PDS	1.0
1.4.4 Interface to CE	1.0
1.4.5 Interface to Calibration	0.5
1.5 Installation, Integration, and Commissioning (3 pages)	
1.5.1 Transport and Handling 1.5	
1.5.2 Integration	1.5
1.6 Quality Control (3 pages)	
1.6.1 Protection and Assembly (Local)	1.5
1.6.2 Post-factory Installation (Remote)	1.5
1,7 Safety (2 pages)	2.0
1.8 Organization and Management (4 pages)	
1.8.1 HV System Consortium Organization	0.5
1.8.2 Planning Assumptions	0.5
1.8.3 WBS and Responsibilities	2.0
1.8.4 High-level Cost and Schedule	1.0

- Similar scheme is to be adopted for DP with dedicated editor (more challenging due to fewer institution involved)