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Overview of SP and DP technologies

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Pixel LArTPC Workshop - Argonne

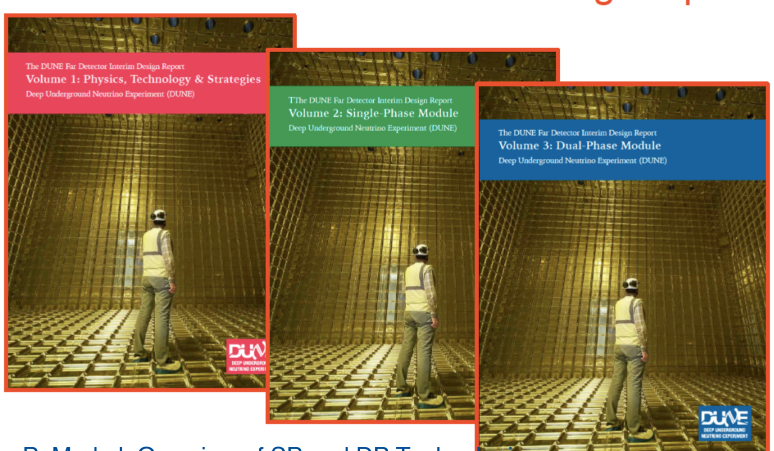
14 August 2018

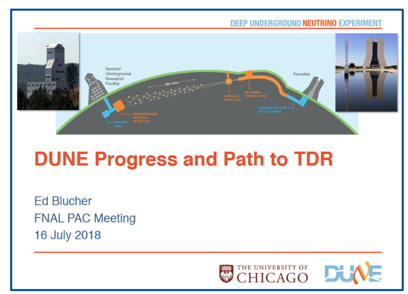
Disclaimer

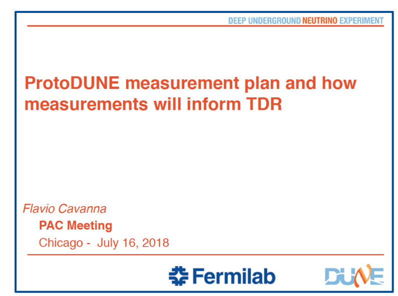
- I am not a DUNE member
- I am not a TPC expert

➔ I will try to give an overview of the technical design and current status of the baseline far detector technologies from an outsider's perspective

DUNE Far Detector Interim Design report







Outline

- Broadbrush DUNE detector concept
- Single Phase (SP) LArTPC
- Dual Phase (DP) LArTPC
- ProtoDUNE status
- Summary and Outlook

DUNE Timeline

2018: protoDUNEs at CERN

2019: Technical Design Report

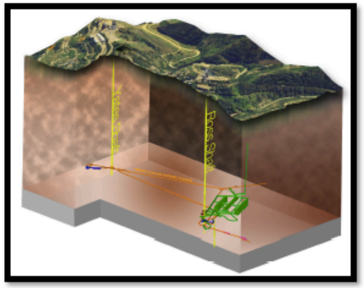
2019: Far Site Primary Excavation Begins

2022: First Module Installation Begins

2026: Neutrino Beam + 2 Far Detectors

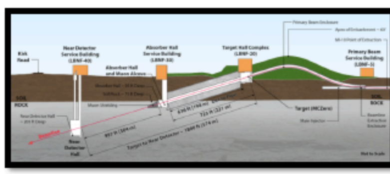
DUNE Far Detector Interim Design Report (2018)

Just posted on arXiv



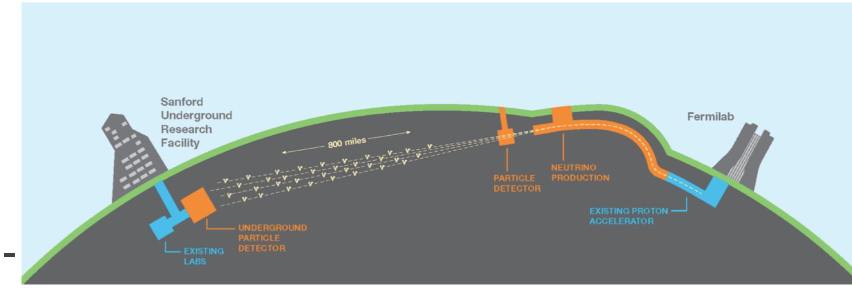
Physics data as soon as 1st module complete

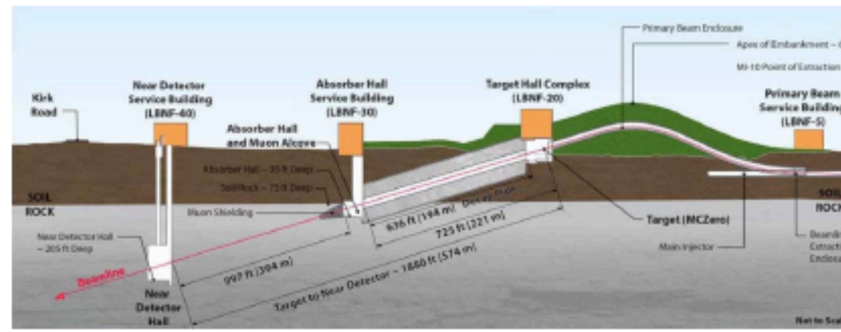
- Atmospheric νs
- SNB and solar νs
- Baryon number violation
- Detector calibration

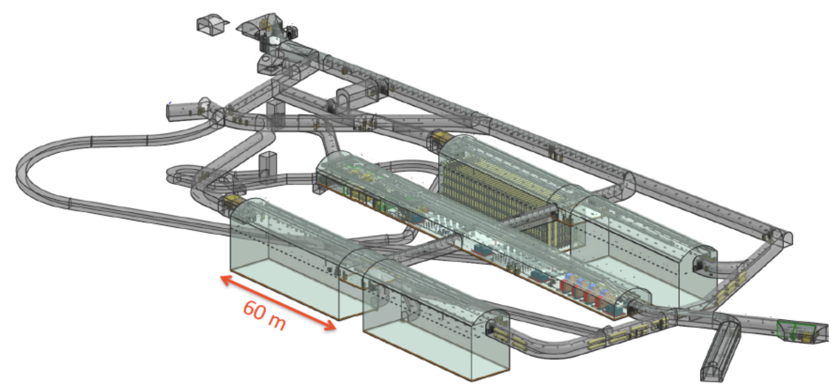


DUNE Detector Concept

- Long baseline neutrino beam from Fermilab to SURF facility in SD
- Near Detector (ND) at Fermilab:
  - Design concept near final (CDR in 2019): highly segmented LArTPC, magnetized multi-purpose tracker, EM calorimeter, muon chambers
  - Preserve option to move off-axis
- Far Detector (FD) at SURF:
  - Four independent 10kt detector modules
  - Flexibility for staging and evolution
  - DUNE is pursuing two LArTPC technologies:
    - Single Phase: mature (ICARUS, MicroBooNE)
    - Dual Phase: lower technical readiness; a number of potential advantages and challenges
  - DUNE is committed to deploying both technologies; decision on staging depends on ProtoDUNE results and funding/interests





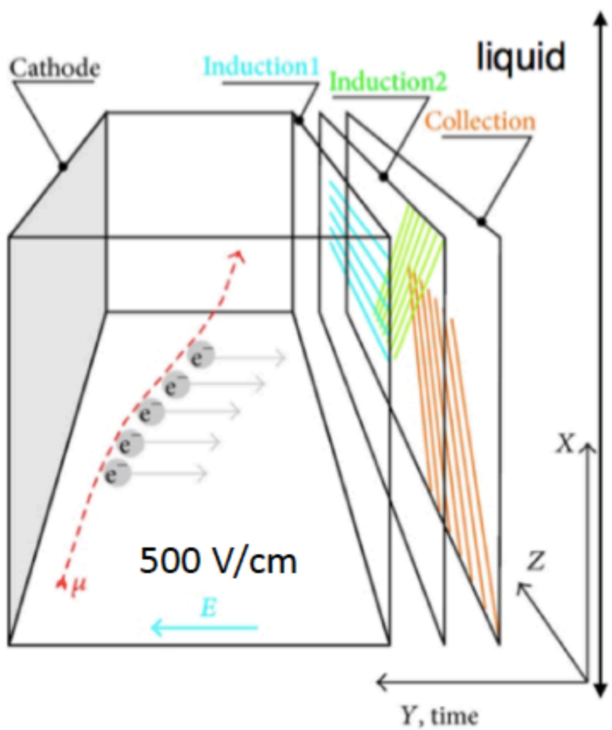


DUNE FD LArTPC Concepts

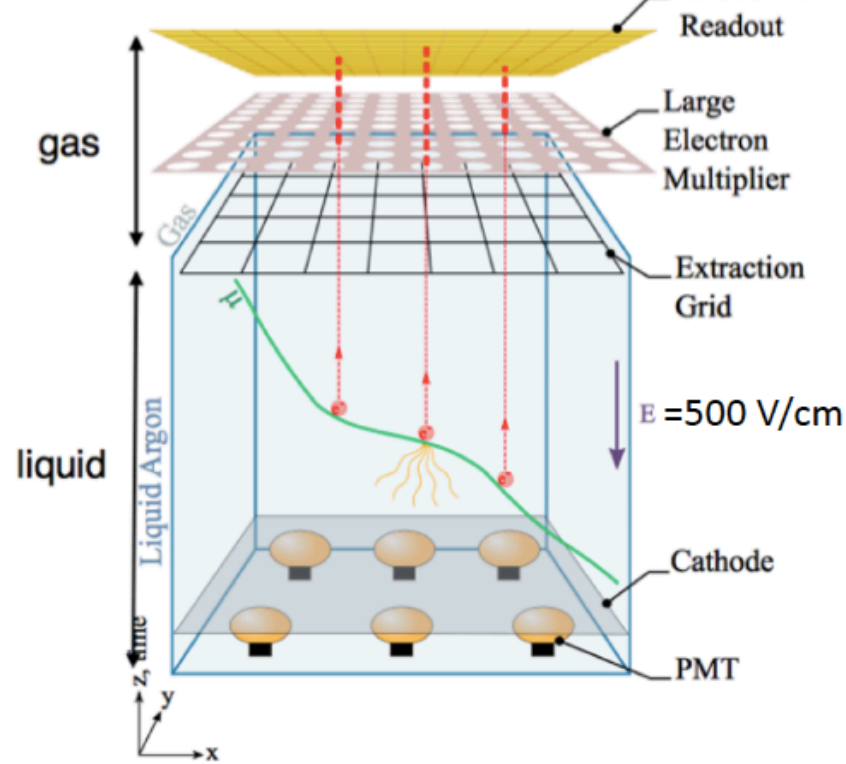
- Ionization charges drift horizontally and are read out with wires
- No signal amplification in liquid
- 3.6 m maximum drift

- Ionization charges drift vertically and are read out on PCB anode
- Amplification of signal in gas phase by LEM
- 12 m maximum drift

Single Phase



Dual Phase

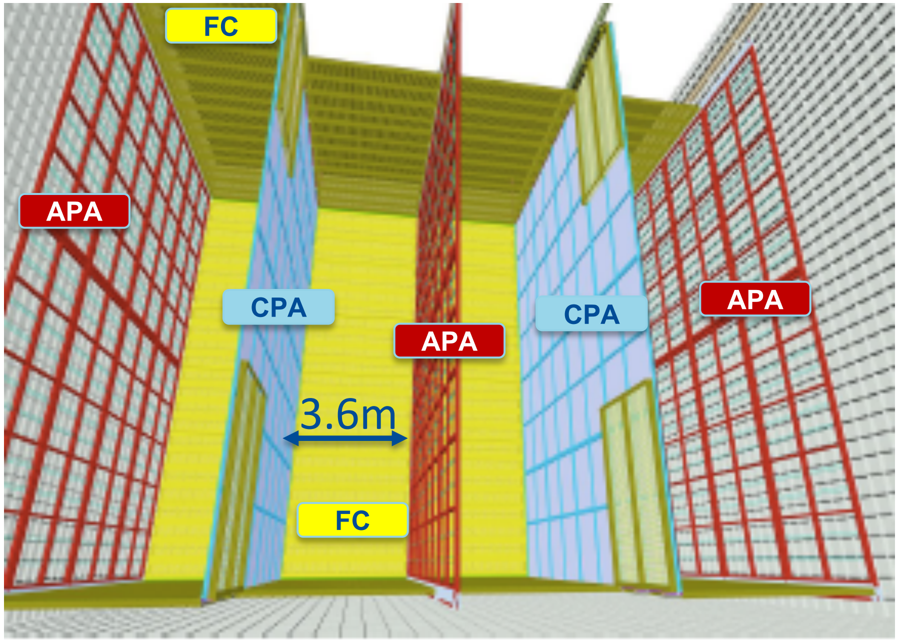


Single Phase LArTPC Far Detector Module

- Profits from experience w/ design, construction, operation, data analysis w/ numerous SP LArTPC experiments and prototypes
- 10kt active LAr mass
- Charged particles ionize the medium while also producing scintillation light
- Ionization drifts along E-field towards anode layers (*several ms*)
- TPC segmented into four horizontal drift volumes (APA ← CPA → APA ← CPA → APA)
- Anodes are covered with finely spaced wires at different angles, which terminate the drift charge in a collection layer (*current vs time*)
- Scintillation light in Ar is in deep UV (127nm) and needs wavelength shifters to be detected in photon detectors (*pulse characteristics vs time*)

Table 1.1: SP module parameters

Parameter	Value	Note
Cryostat LAr mass	17.5 kt	
Active LAr mass	10 kt	
Active Height	12 m	
Active Length	58 m	
Maximum Drift	3.53 m	
Number of anode plane assembly (APA) channels	384,000	
Number of photon detection system (PDS) channels	6000	



Anode Plane Assembly (APA)

- Anode plane: 25(h)x2(v) APA frames = 58m x 12m
- APA frame: 2.3m x 6m x 12cm (hollow stainless steel tubes covered by fine (80μm) bronze mesh as ground plane) [150 APAs/FD module]
- Active on both sides of plane: covered in 2560 sense wires in three planes oriented at angles: X (vertical collection plane), U, V (±35.7° induction planes) → reduces ambiguities
- Wires (150μm BeCu) are wrapped around frame, allowing read out from one end of APA
- Wire pitch (4.7±0.5mm) meets performance requirements for MIPs and particle ID
- Read out through wire termination boards, which connect to FE readout electronics inside LAr
- Photon detectors are housed inside APA frames,

Table 2.2: APA design parameters

Parameter	Value
Active height	5.984 m
Active width	2.300 m
Wire pitch (U, V)	4.669 mm
Wire pitch (X, G)	4.790 mm
Wire pitch tolerance	±0.5 mm
Wire plane spacing	4.75 mm
Wire plane spacing tolerance	±0.5 mm
Wire Angle (w.r.t. vertical) (U, V)	35.7°
Wire Angle (w.r.t. vertical) (X, G)	0°
Number of wires / APA	960 (X), 960 (G), 800 (U), 800 (V)
Number of electronic channels / APA	2560
Wire material	beryllium copper
Wire diameter	150 μm

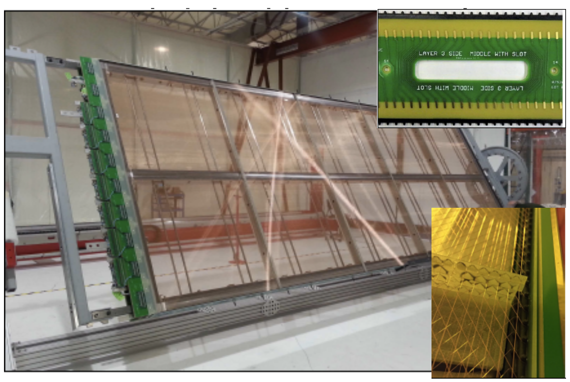


Figure 2.4: Completed ProtoDUNE-SP APA ready for shipment to CERN.

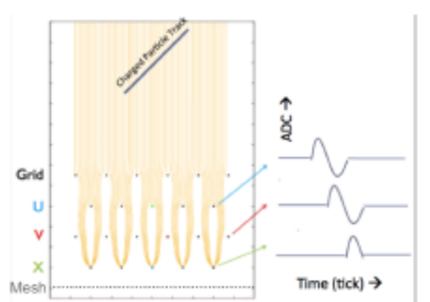
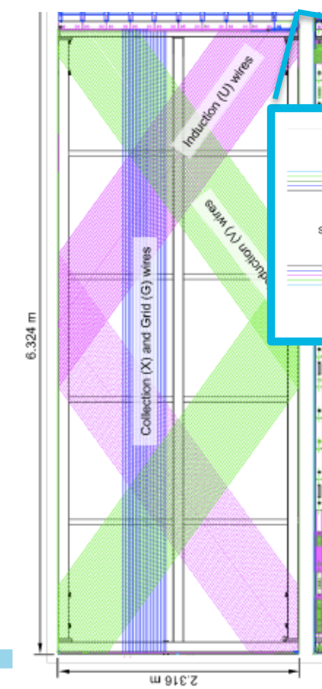
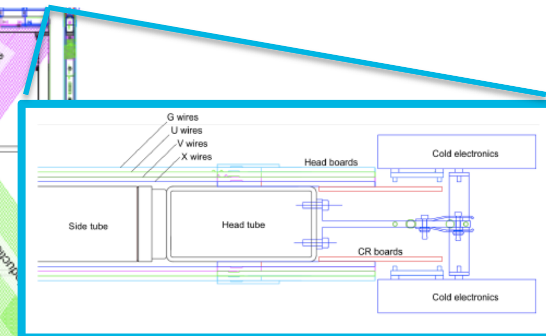


Figure 2.6: Field lines and resulting signal shapes on the APA induction and collection wires.





Anode Plane	Bias Voltage
G - Grid	−665 V
U - Induction	−370 V
V - Induction	0 V
X - Collection	820 V
Grounding Mesh	0 V

Table 2.1: Baseline bias voltages for APA wire layers.

Cathode Plane Assembly (CPA) and Field Cage (FC)

- CPA provides constant potential surface at -180kV
- 6cm thick FR4 frames at 1.2m intervals reinforce stiffness of resistive panels: thin layer of carbon-impregnated Kapton laminated on both sides of a 3mm thick FR4 sheet
- FC consists of extruded Al profiles to establish equipotential surfaces and uniform E-field
- Local electric fields need to be ≪30kV/cm

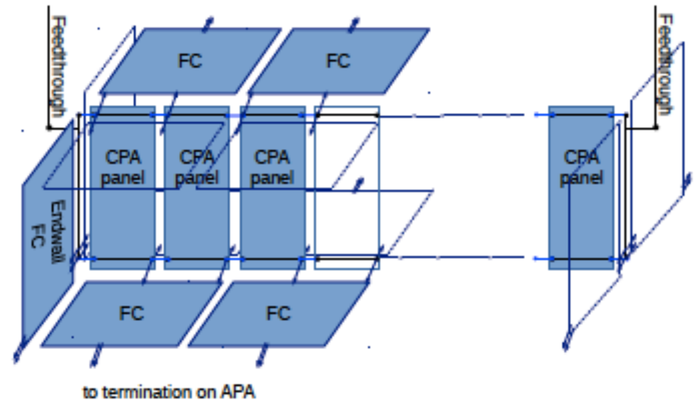


Figure 4.13: High-level topology of the HV interconnections

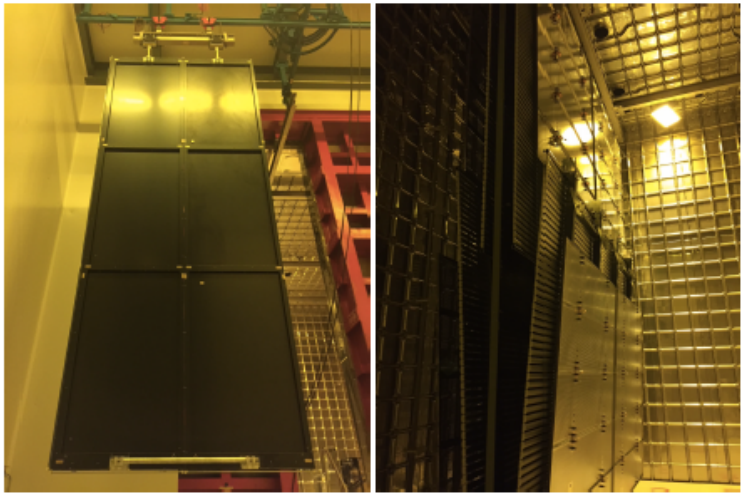
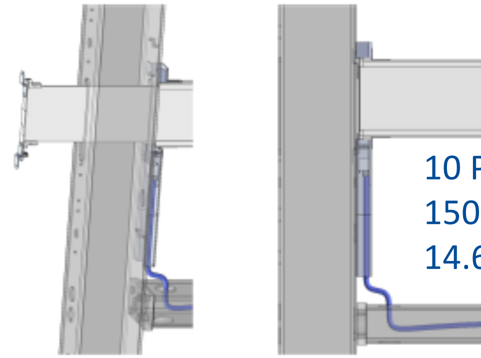


Figure 4.18: Left: Completed ProtoDUNE-SP CPA plane ready for FC attachment. Right: Two completed CPA-FC assemblies in the ProtoDUNE-SP cryostat. The top and bottom FCs with their GPs attached are visible to the right of the cathode plane in their folded-up pre-installation position.

Photo Detection System (PDS)

- Detection of prompt scintillation light emitted in coincidence w/ an ionizing event allows determination of event time (→ allows to reconstruct drift time → allows to localize event in space, important for energy corrections
- Scintillation light may be used as trigger
- LAr scintillation light: 40 photons/keV w/o E-field, smaller w/ E-field due to recombination
- Nominal DUNE: 500V/cm → 24 photons/keV
- Most common wavelength shifter TPB: absorbs VUV photons and re-emits them around 420nm
- Ongoing R&D for TPB coating in LAr
- Ongoing intense R&D to maximize photon detection efficiency: different PD designs considered (read out by SiPMS):
  - ARAPUCA (baseline)
  - Wavelength shifting light guides
  - ArCLight
- Some R&D w/ VUV sensitive SiPMs from Hamamatsu also ongoing



10 PD modules/APA
1500 total
14.6cm x 9.6cm x 212.7 cm

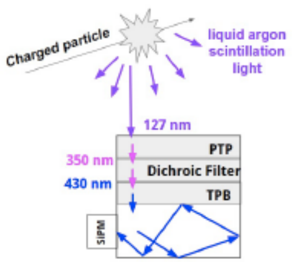


Figure 5.5: Schematic representation of the ARAPUCA operating principle.

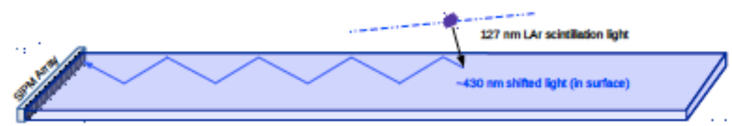


Figure 5.10: Schematic of scintillation light detection with dip-coated light guide bars.

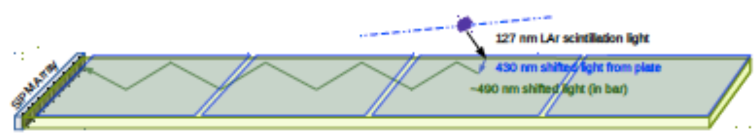
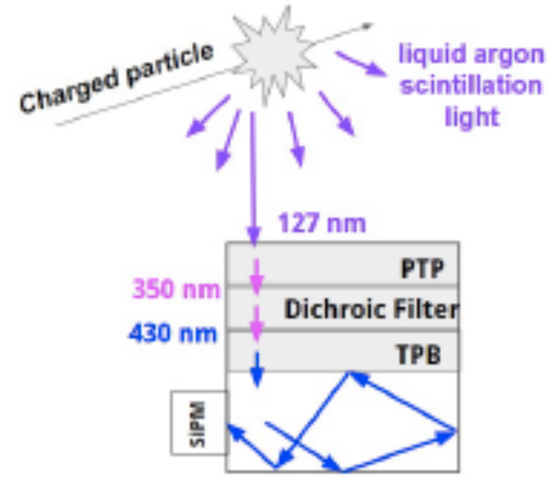
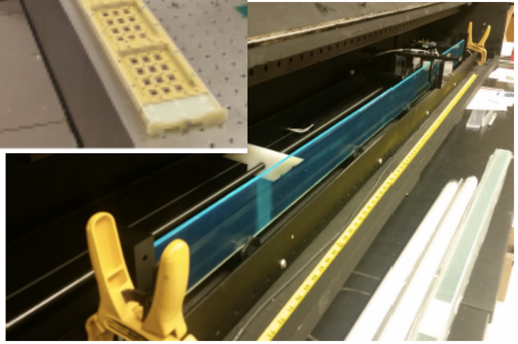


Figure 5.11: Schematic of the double-shift light guide concept.

PDS - continued

- ARAPUCA:
  - VUV light enters through dichroic filter (pTP), which shifts wavelength to near-visible
  - Inside of the box: highly reflective walls coated w/ TPB
  - Light collected with SiPMs
- ARAPUCA prototypes have shown detection efficiencies of 0.4 – 1.8%, significantly higher than light guide concept
- One option is to coat CPA w/ wavelength shifter to improve uniformity of light collection throughout LAr volume
- SiPMs:
  - R&D still needed for reliable operation in cryogenic LAr
  - Ongoing investigations of MPPCs (multi-pixel photon counters) from Hamamatsu, and a device by FBK in collaboration w/ DarkSide
  - Need to develop (passive or active) ganging of SiPMs to reduce channel count
- ProtoDUNE-SP has 2 ARAPUCA trays, 29 double-shift guides and 29 dip-coated guides
- Baseline design anticipated by time of TDR (mid-2019)





Charge Readout Electronics

- Anode wire signals → charge sensitive amplifiers → pulse shaping circuit → ADC → merge onto high-speed serial links (1.28 Gbps)
- Cold electronics boxes mounted on APAs inside LAr to reduce input capacitance/noise
- Advantage of operating at LAr temperatures:
  - Higher charge carrier mobility in Si
  - Lower thermal fluctuations
  - → substantially higher gain and ~1/2 noise for CMOS electronics
- Placing digitizing and multiplexing electronics inside cryostat minimizes feedthroughs
- Continuous readout: digitized ADC sample from each APA channel up to every 500ns (2MHz sampling rate)
- ASICs:
  - Baseline:
    - 16-channel FE ASIC for amplification and pulse shaping (LArASIC)
    - 16-channel 12-bit cold ADC ASIC operating at 2MHz (Cold ADC)
    - 64-channel control and communications ASIC (COLDATA)
  - Alternatives: 64-channel ASIC that will consolidate all three functions (SLAC nEXO CRYO ASIC), LBNL's LArPix, and ATLAS ADC (Columbia University)

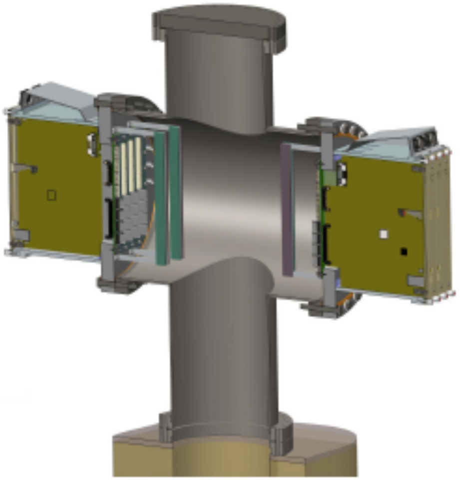


Table 3.1: TPC electronics components and quantities for a single APA of the DUNE SP module.

Element	Quantity	Channels per element
Front-end mother board (FEMB)	20 per APA	128
FE ASIC chip	8 per FEMB	16
ADC ASIC chip	8 per FEMB	16
COLDATA ASIC chip	2 per FEMB	64
Cold cable bundle	1 per FEMB	128
Signal flange	1 per APA	2560
CE feedthrough	1 per APA	2560
Warm interface board (WIB)	5 per APA	512
Warm interface electronics crate (WIEC)	1 per APA	2560
Power and timing card (PTC)	1 per APA	2560
Power and timing backplane (PTB)	1 per APA	2560

First prototypes late summer/fall

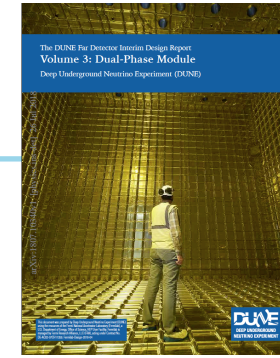
SP Performance Parameters

- Extremely high Ar purity (ppt) → undisturbed drift
- Very low noise readout electronics (<1000e^- ENC) → detect faint ionization signals, two track separation, vertex resolution
- Robust and stable HV system → uniform E-field over entire detector volume
- Long operating lifetimes at LAr temperatures for all internal devices due to inaccessibility for decades
- Vertex resolution of 1.5cm → able to determine fiducial volume to 1%
- FE peaking time 1-3μs, determined by drift time
- ADC sampling frequency 2MHz (matching shaping time [1μs] while minimizing data rate)
- Linear response up to >500,000e^- (<5% of beam related events saturate)
- Dynamic range ≧3000:1 → 12-bit ADC
- Power: <50mW/channel

SP: Crucial Ongoing R&D

- Photon detectors:
  - ARAPUCA vs light guides
  - X-ARAPUCA
  - ArCLight
- ASICs:
  - LArASIC+Cold ADC+COLDATA vs nEXO CRYO ASIC
  - LArPix ASIC as developed for Near Detector
  - +ADC backup from ATLAS

Dual Phase LArTPC Far Detector Module



- Amplification of ionization signal in an avalanche process
- Electrons drift vertically upward towards an extraction grid just below liquid-vapor interface
- After reaching grid, an E-field stronger than drift field extracts the electrons
- Electrons encounter micro-pattern gas detectors w/ high-field regions (LEMs)
- Amplified charge is collected and recorded on a 2D anode
- Scintillation light is collected by PMTs (coated w/ wavelength shifter) below the cathode

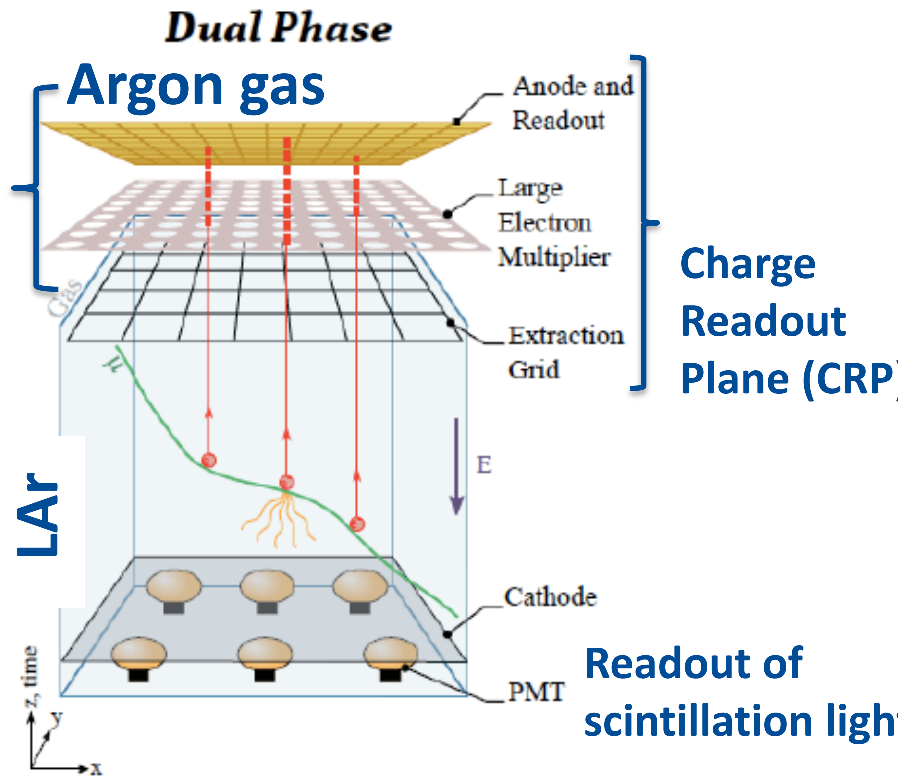


Figure 1.1: Principle of the DP readout

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Key Parameters

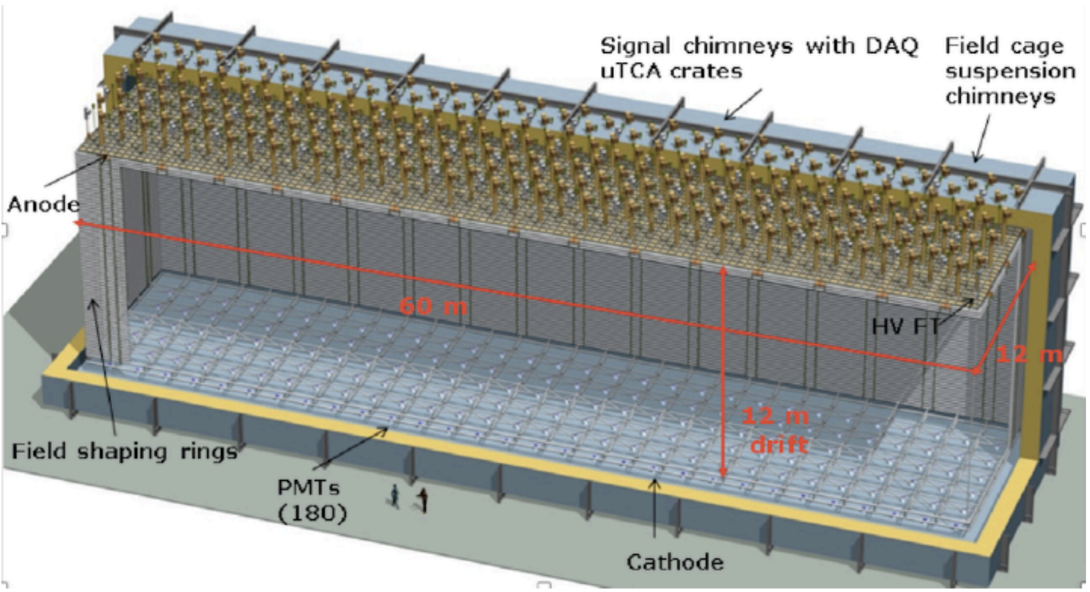


Table 1.2: Quantities of items or parameters for the 12.096 kt DP module

Item	Number or Parameter
Anode plane size	W = 12 m, L = 60 m
CRP unit size	W = 3 m, L = 3 m
CRP units	$4 \times 20 = 80$
LEM-anode sandwiches per CRP unit	36
LEM-anode sandwiches (total)	2880
SFT chimney per CRP unit	3
SFT chimney (total)	240
Charge readout channels / SFT chimney	640
Charge readout channels (total)	153,600
Suspension feedthrough per CRP unit	3
Suspension feedthroughs (total)	240
Slow Control feedthrough per sub-anode	1
Slow Control feedthroughs (total)	80
HV feedthrough	1
HV for vertical drift	600 kV
Voltage degrader resistive chains	12
Cathode modules	80
Field cage rings	197
Field cage modules (3 m×12 m)	48
PMTs (total)	720 ($1/m^2$)

- 12m max. drift length
- 10.643kt fiducial volume

Table 1.1: DP module parameters

Parameter	Value	Note
Cryostat LAr Mass	17.5 kt	
Active LAr Mass	12.096 kt	
Active height	12 m	
Active length	60 m	
Maximum drift	12 m	
Number of CRPs	80	
Number of CRP channels	153,600	
Number of PMT channels	720	

Charge Readout Plane (CRP)

- Three-layered sandwich of extraction grid + LEM + anode
- Connected horizontally to modular units of 9m^2
- Partially immersed in LAr
- CRPs collect charge in a projective way w/o dead regions, readout signals in 2 collection views, no induction view → simplifies reco

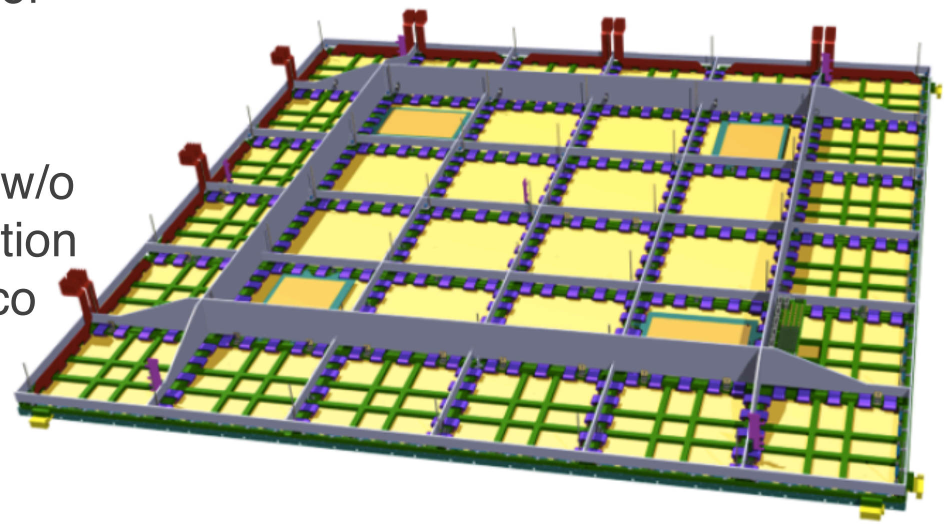


Table 2.2: Important parameters for the CRP system design

Parameter	Value
Planarity tolerance on the detection plane over 3×3 m^2	±0.5 mm
CRP vertical positioning precision	±0.5 mm
Range of vertical displacement	±20 mm
Lateral inter-CRP dead space	< 10 mm
Distance between the extraction grid wires and the LEM plane	10mm
HV of the extraction grid wires in LAr	6.8 kV
HV of the LEM down surface in gas argon	4.5 kV
HV of the LEM up surface in gas argon	1 kV

CRP - continued

- Extraction grid: submerged array of x and y oriented stainless steel wires (Ø=0.1mm) w/ 3.125mm pitch
- LEMs (Large Electron Multiplier): 1mm-thick PCB w/ electrodes on both sides; drilled through w/ many holes (E<35kV/cm) to form micro-pattern structure (Townsend multiplication of ionization electrons)
- Anode: amplified charge collected on 2D anode consisting of two sets of 3.125mm-pitch gold-plated copper strips
- E-field ~2kV/cm across liquid-gas interface → aim for ~100% extraction efficiency for electrons
- E-field 30kV/cm in argon gas → increases S/N by x20-100 (tunable, high S/N)
- Amplification gain in S/N compensates for loss due to very long drift time → same purity requirement as SP (100ppt oxygen equiv.)

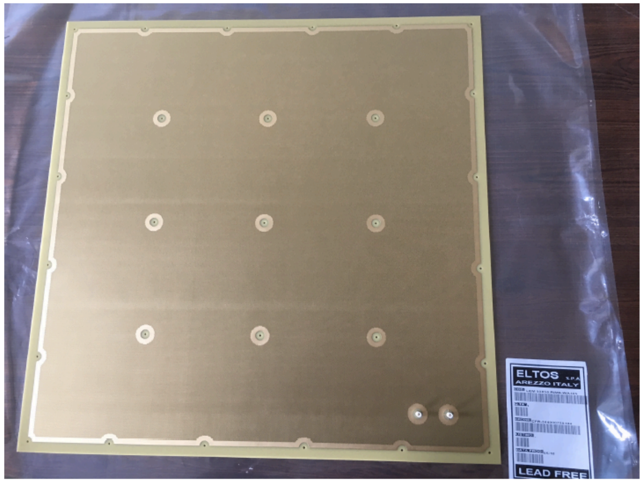


Figure 2.8: Picture of a LEM module used for ProtoDUNE-DP

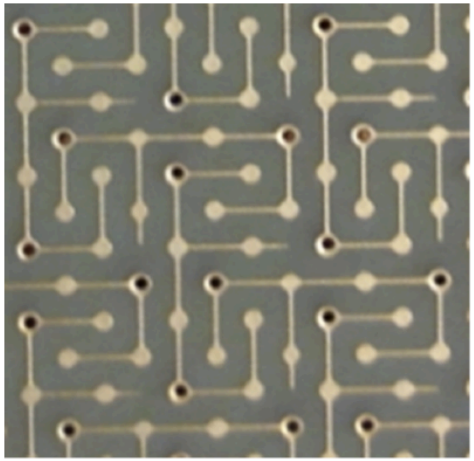
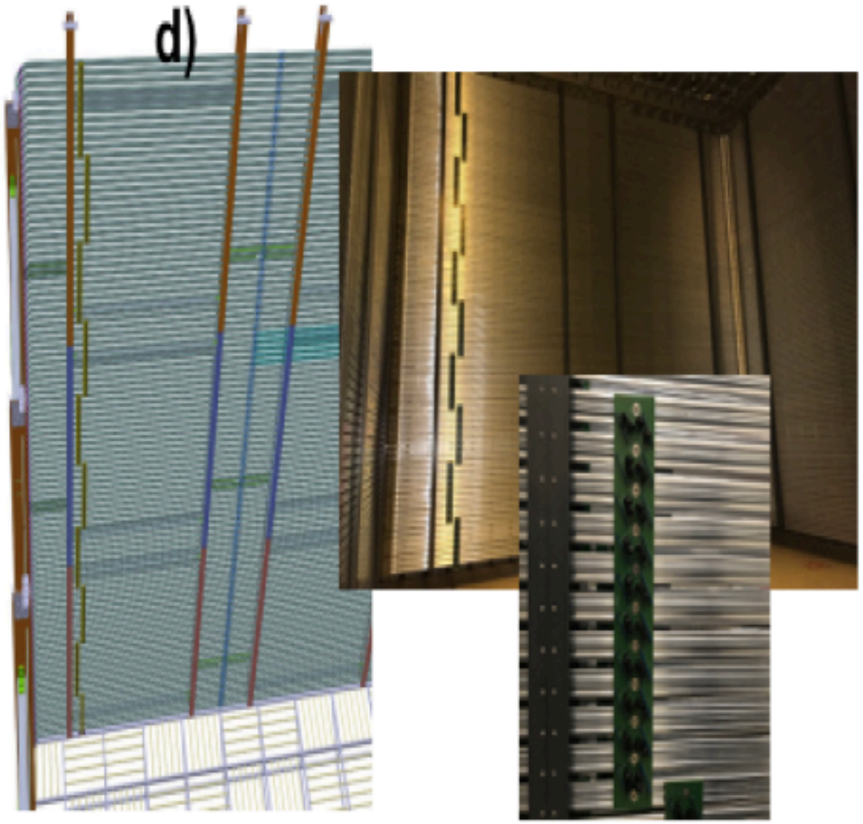


Figure 2.9: Picture of the anode symmetric 2D strip design.

HV, Cathode Plane & Field Cage

- HV: 500V/cm E-field
- Cathode Plane (CP): 80 modules à $3x3m^2$
  – Stainless steel mechanical structure and grid
  – 60% optical transparency, uniform potential
  – Max. local field required: 30kV/cm
- Ground Plane: stainless steel tubes below CP
- Field Cage: Aℓ profiles attached to structural elements made of FRP

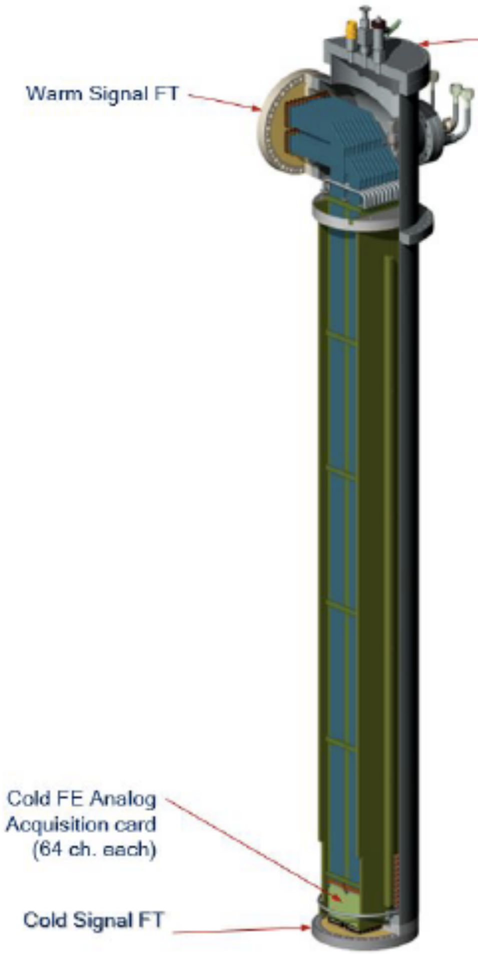


Photon Detection System

- PDS delivers time stamp for beam and non-beam events, trigger for non-beam events, and enables calorimetric measurements
- Layer of PMTs installed below Cathode Plane, 1 PMT(8")/m^2
- PMTs are coated w/ wavelength shifter (TPB)
  - R&D ongoing to study dissolution of TPB in LAr
- In addition to primary scintillation light, one also has proportional scintillation component from amplified electrons in the gas
  - Small fraction of this reaches PMTs
- Light detection efficiency a challenge: require 2.5 photoelectrons/MeV light yield
- PMTs are powered between 1.5-2.0kV → gain of 10^7-10^9
- Light collectors to increase detected photons are under study

Readout Electronics

- RO electronics connected through Signal Feed Through (SFT) chimneys
- FE cards house analog cryogenic pre-amps in CMOS ASICs matching signal dynamics of a DP module
- FE cards actively cooled to 110K inside chimney
- FE cards can be accessed and replaced during data taking
- Digital electronics sits at room temperature: high-speed, low-cost networking technologies from telecom industries [μTCA] (2.5MHz digitization, 10Gbits/s links)
- PMTs read out by μTCA cards, based on CATIROC ASIC for light readout and triggering; high precision charge and start time of signals from each PMT
- Light Readout (LRO) needs to be sensitive to single photoelectron (precise timestamp)
- Precise charge measurement allows for gain monitoring of PMTs



Parameter	Value
CRO channels	153,600
CRO continuous sampling rate	2.5 MHz
CRO ADC resolution	12 bit
CRO data compression factor	10
CRO data flow	430 Gibit/s
LRO channels	720
LRO continuous sampling rate	2.5 MHz
LRO ADC resolution	14 bit
LRO data compression factor	1
LRO data flow	24 Gibit/s

DP Performance Requirements/Design Specifications

- Measure charge signals up to 1200fC w/o saturation
  - Determined by max. occupancy in shower events
  - A MIP is ~30fC → operation range of up to 40 MIPs
- Charge readout noise <2500e^-
  - Driven by min. S/N = 5:1
- 2.5MHz sampling rate w/ 12-bit resolution and 1μs pulse-shaping time → <1mm drift resolution
- Power dissipation of FE electronics <50mW/channel
- Replaceable FE electronics for long-term reliability
- ADC noise on order of 1 count w/ large dynamic range (12-bit ADC)
- Warm digital electronics → use latest, cost effective commercial components
- Purity requirement of 100ppt leads to 3ms electron lifetime:
  - Example: w/ drift field of 0.5kV/cm, LEM gain of 20 → S/N=40:1 for tracks up to 6m from anode, reaching 11:1 for MIPs that are 12m from anode

DP: Crucial Ongoing R&D

- Much less experience in building and operating a DP detector than a SP
- ProtoDUNE-DP is a crucial testbed for DP technology choices
- Especially HV requirements (up to 600kV)
- And Photon Detection System (light detection efficiency, TPB dissolution in LAr)

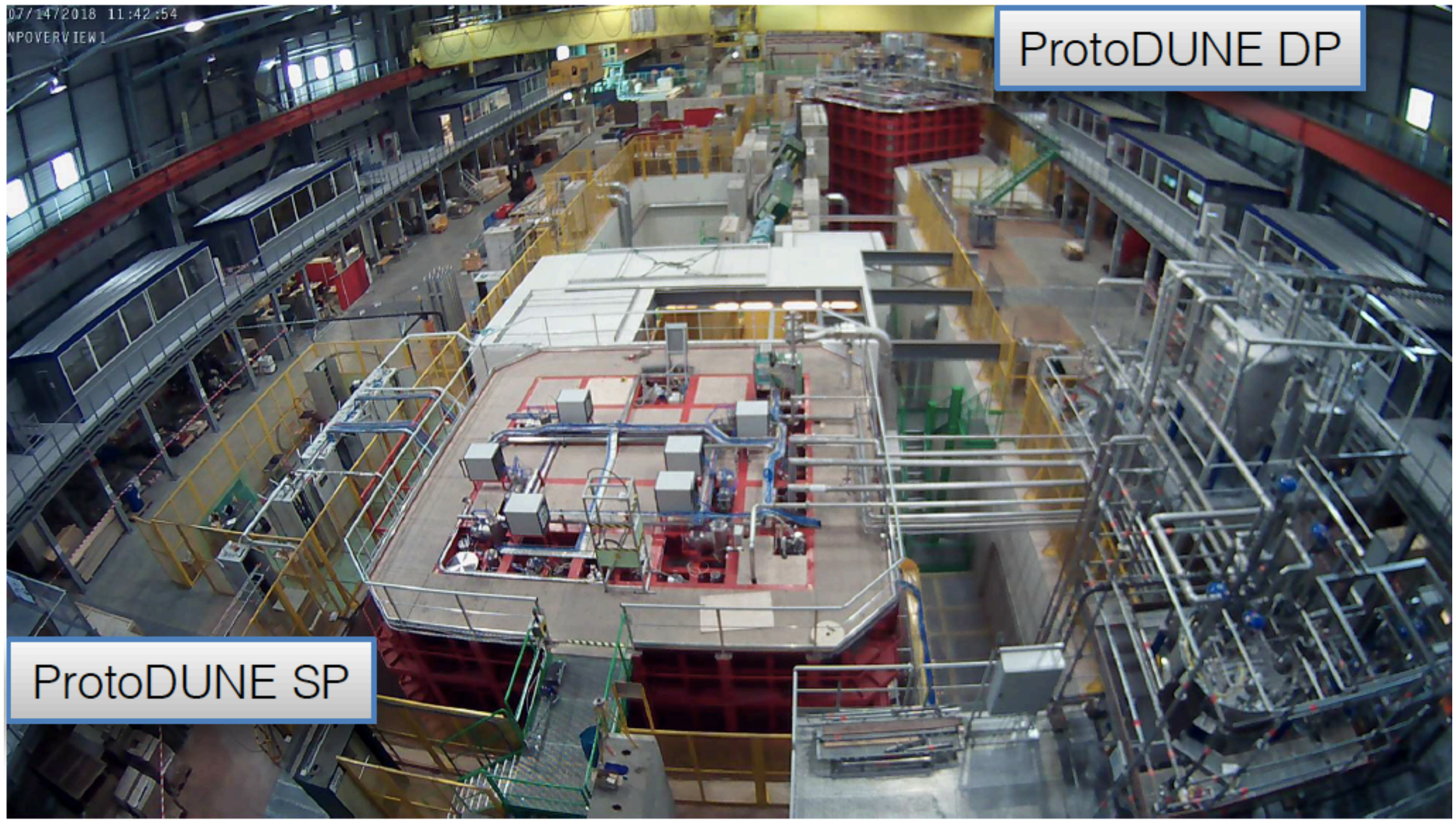
Comparison of DP and SP technologies

- Construction of larger drift volumes:
  - Reducing quantity of non-active materials in the LAr achieved by DP design
  - Reduces number of components to be built → *lower cost*
  - Allows for a single, fully homogeneous LAr volume w/ a much longer drift length, *but need higher S/N to compensate*
  - But, need to apply much higher HV (600kV)
- S/N of charge readout:
  - Higher in DP, lowering threshold for smallest observable signals, *but offset by longer drift length*
- Readout granularity:
  - DP has finer anode pitch, *but could be done in SP as well*
  - Number of readout channels: 153,600 (DP) vs 384,000 (SP) → *lower cost*
- Reliability:
  - DP's FE electronics is fully accessible and replaceable during operations
  - SP design allows for lower HV on the cathode due to shorter drift → *safer*
  - DP needs to reach 600kV, not yet achieved?
  - DP has no active electronics elements in cryostat except PMT bases
  - More construction, operation and reconstruction experience w/ SP technology

ProtoDUNE Status at CERN

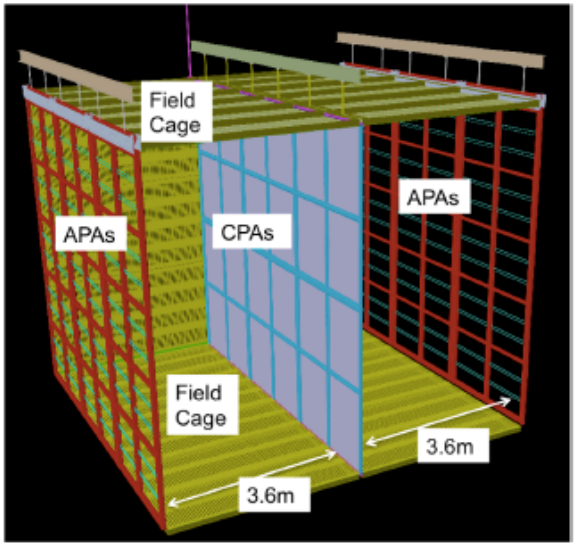
PROTODUNEs at the EHN1 extension

Neutrino PLATFORM



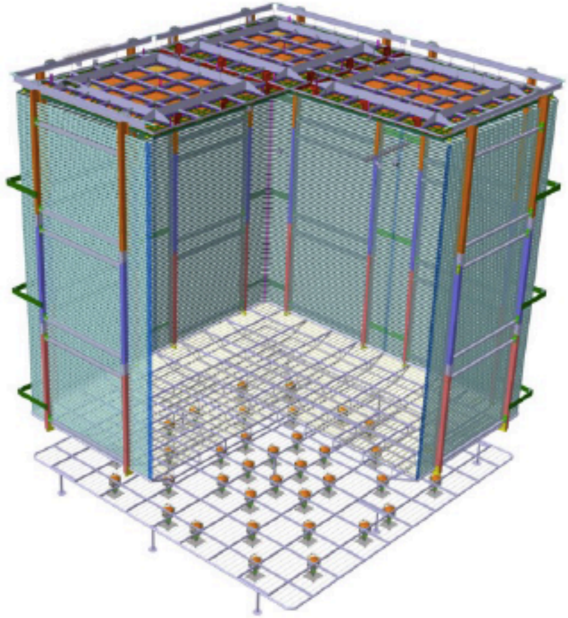
ProtoDUNE(s)

ProtoDUNE-SP



- 6 full-sized drift cells with 6×2.3m APAs (150 in far detector)
- Same 3.6 m maximum drift length as far detector
- Testing 3 light detection systems embedded in APAs

ProtoDUNE-DP



- 4 3×3m CRPs (80 in far detector)
- 6 m vertical drift → 300 kV cathode voltage (half of drift required for DUNE far detector)
- PMT light detection system

Role of ProtoDUNE

- **Large-scale prototyping/calibration**
  - **Production (delivery of the detector components to CERN):**
    - **stress testing of the production and quality assurance processes** of detector components
    - mitigate the associated risks for the far detector.
  - **Installation:**
    - **test of the interfaces** between the detector elements
    - mitigate the associated risks for the far detector.
  - **Operation (cosmic-ray data):**
    - **validation** of the detector designs and performance
  - **Test beam (data analysis):**
    - **essential measurements** of physics response of detector
    - not necessary for the finalization of the FD design

Risk mitigation and understanding of costs for TDR

Detector validation for TDR

Physics calibration for oscillation analyses

Fermilab

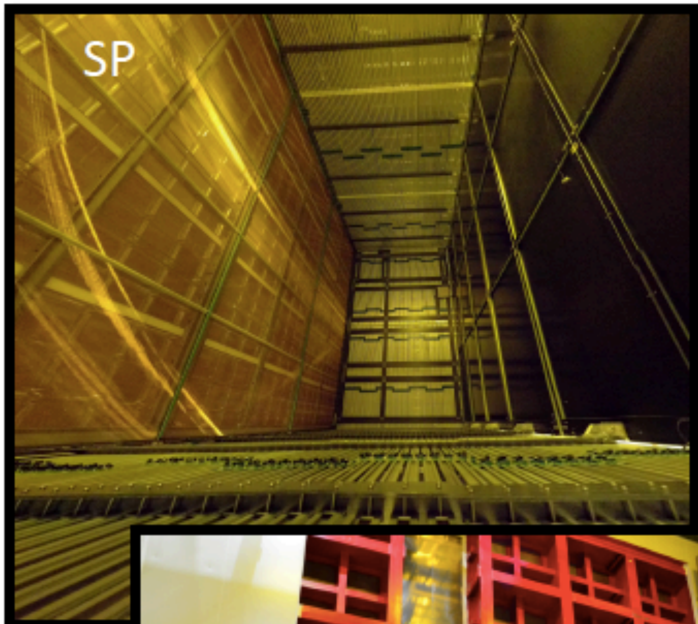
ProtoDUNE Programme

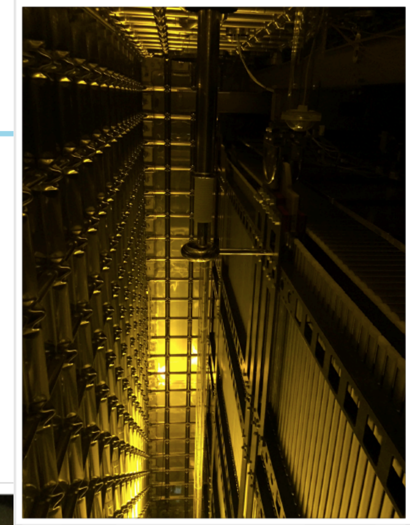
- 2018: Detector activation, **Test-Beam Run** + Cosmics
- 2019: (**) endurance Run with Cosmics ["long term stability"]
- 2020: continuing Operation (Cosmics) if desired
- 2021: keep open the option of recording Test Beam data after CERN LS2
- 2022: *no Operation is foreseen in and beyond 2022.*

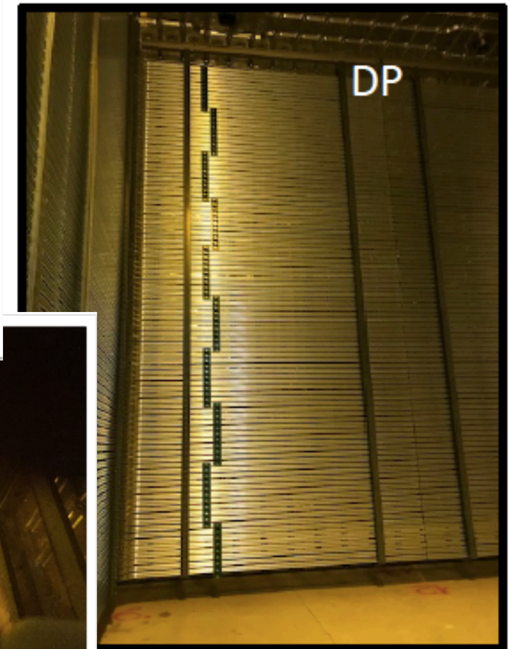
Status as of July'18 Fermilab PAC Meeting:

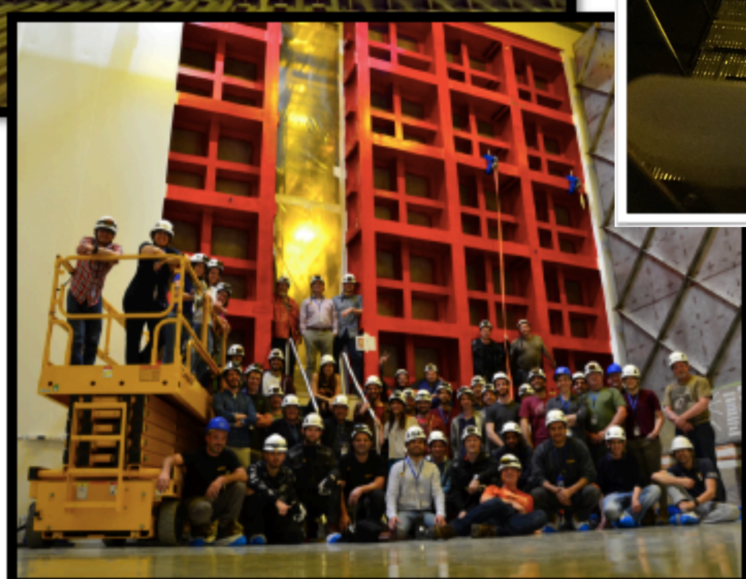
- ProtoDUNE-SP: installation complete, cooling down now, cosmic and test beam data Aug-Nov'18
- ProtoDUNE-DP: FC installed, coldbox tests of first CRP ongoing, close cryostat w/ 2 out of 4 CRPs in Oct'18, cosmic data end of '18

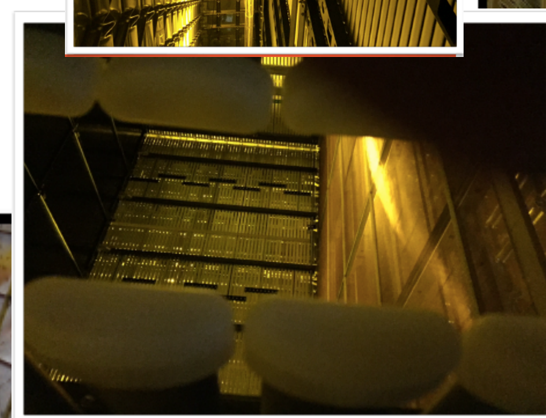
ProtoDUNE Assembly

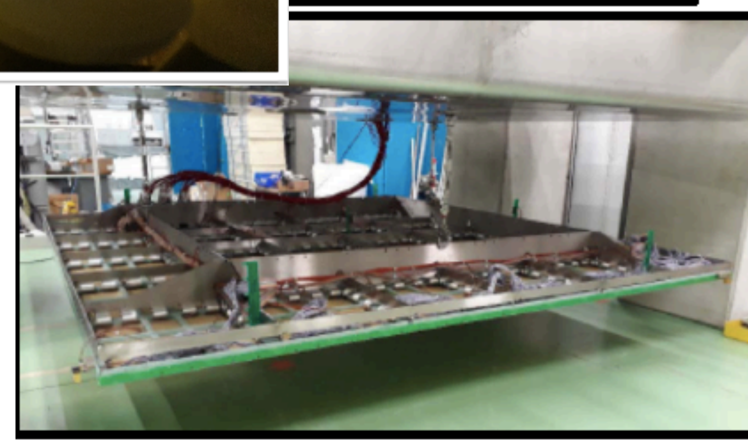












Summary and Outlook

- Two conceptually different designs foreseen for FD modules
- Both, SP and DP designs quite mature, but a few crucial R&D topics still ongoing
- Both designs able to fulfill DUNE physics requirements
- Experience and results from building and operating ProtoDUNE detectors crucial to inform final designs for TDR
  - Results expected over next half year

Backup

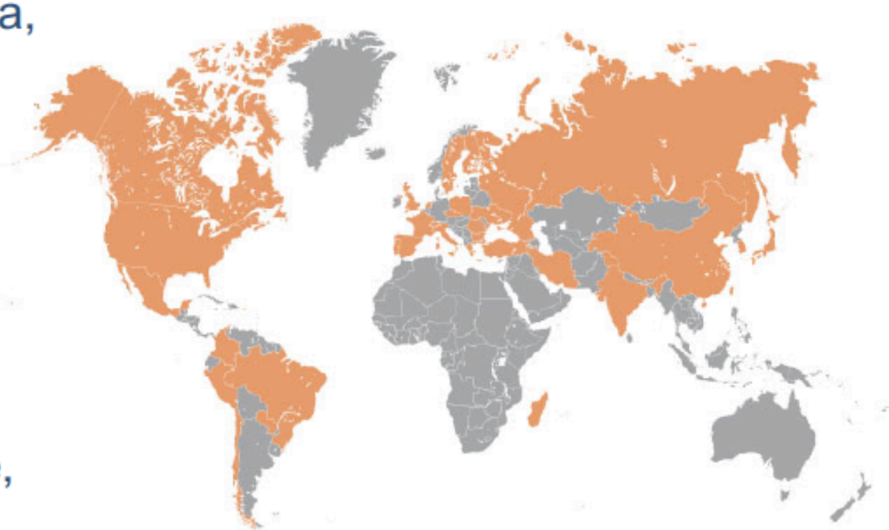
The DUNE Collaboration

As of today:

60 % non-US

1143 collaborators from 178 institutions in 32 nations

Armenia, Brazil, Bulgaria, Canada, CERN, Chile, China, Colombia, Czech Republic, Spain, Finland, France, Greece, India, Iran, Italy, Japan, Madagascar, Mexico, Netherlands, Paraguay, Peru, Poland, Portugal, Romania, Russia, South Korea, Sweden, Switzerland, Turkey, UK, Ukraine, USA



DUNE is still growing: dN/dt > 100 collaborators/year!
Ultimate size: 1500?

DUNE International Progress

- **Europe:**
  - UK: $88M commitment to LBNF/DUNE/PIP-II
  - France: DUNE now on the research infrastructure road map
  - Portugal: joined DUNE at May 2018 meeting
  - Germany: growing interest within community (including DESY)
  - Italy: engaged and interested in near detector, far detector
  - Spain: engaged and funding requests pending
  - Netherlands: discussions ongoing
  - Switzerland: DUNE on Swiss road map
- **Americas:**
  - Latin America: Meetings with FA representatives: Brazil, Colombia, Mexico, Peru
  - Canada: new joint FNAL-York position on DUNE
  - US NSF: discussions ongoing
- **Asia:**
  - India: annex 2 for cooperation on neutrinos was signed
  - Korea: DUNE Satellite Meeting for Korean groups at ICHEP 2018
  - Japan: eager to have broader involvement of Japanese groups

DUNE Strategic Goals 2017 - 2019

- **Preparation of DUNE TDRs for LBNC review**
  - A major scientific and technical goal for the collaboration
- **Construction and operation of large-scale prototypes at CERN**
  - Critical to demonstrate that the DUNE collaboration can implement a major construction activity
- **Enlarging the Collaboration**
  - Define responsibilities for far and near detectors
- **Resource matrix for construction of DUNE**
  - Funding for TDR scope needs to be understood in 2019

FD Planning Strategy

- **Agreed by DUNE Executive Committee**
- **Assumes success of both protoDUNE detectors**
  - Success is defined in dune-doc-2765
- **For planning purposes:**
  - "we are assuming that the first far detector module will be single-phase and the second will be dual-phase"
  - "This planning strategy is not intended to prejudice the actual technology decision in late 2018/early 2019, which will be based on the full knowledge at that time and the availability of funding."
  - i.e., plan so that all options can be on the table

Strategy for TDR: 2 + 1 + 1

- **Full detector requires 4 FD modules: "2 + 1 + 1 model"**
  - Reflects current expectations *of what might be reasonable from funding perspective* at time of TDR in 2019
    - 2 Single-phase FD modules, one of which will be the first module
    - 1 Dual-phase FD module
    - 1 [As yet] uncovered "Opportunity" FD module
- **For TDR in 2019**
  - Seeking approval of (at least) two FD modules
  - Requires technical readiness and funding model

23 16 July 2018 Ed Blucher I FNAL PAC Meeting

THE UNIVERSITY OF CHICAGO

Success depends on consortia

Excellent Consortia Leadership

- **Single-Phase**
  - APA: Christos Touramanis (Liverpool)
  - Photon Detection System: Ettore Segreto (Campinas)
  - TPC Electronics: Dave Christian (FNAL)
- **Dual-Phase**
  - **CRP (Interim): Dominique Duchesneau (LAPP)**
  - Photon Detection System: Ines Gil Botella (CIEMAT)
  - TPC Electronics: Dario Autiero (IPNL)
- **Joint**
  - HV System: Francesco Pietropaolo (CERN)
  - DAQ: Dave Newbold (Bristol)
  - Slow Controls/Instrumentation: Sowjanya Gollapinni (Tennessee)

Timeline

- **Assumed timeline for DUNE (and LBNF) reviews**
  - May 2018: Interim Design Report for DUNE Far Detectors
  - March 2019: **RRB** for to provide funding status
  - April 2019: LBNF and DUNE internal/external TDR reviews
  - July 2019: **LBNC** review of TDRs
    Review of international DUNE project
  - Sept 2019: **RRB** to review funding status for construction; validation of international funding model
  - October 2019: DOE **CD-2** Review of LBNF/DUNE & "**CD-3**" review for far site and (at least) two far detector modules
  - July 2020: **LBNC** review of TDR for near detector
- **In less than one year**
  - Need technical designs and understanding of inst. responsibilities

Summary

- **We have had a very good year**
  - Groundbreaking at SURF
  - Interim Design Report submitted to LBNC
  - Amazing CERN NP & ProtoDUNE progress
  - Consortia driving far detector activities
  - Funding progress (UK, US)
  - Increased interest from other funding agencies
  - Unwavering support from DOE and US Congress

- **Coming year will be critical**
  - Complete, commission, and take data with protoDUNEs
  - Complete far detector TDR
  - Develop near detector design and write CDR
  - Need further progress on funding

The coming months will be challenging and exciting!

(**) Note about the Long-Term Stability Run 2019

The long term stability Run with Cosmic
- 6 to 12 months extending in 2019 -
has been communicated to CERN SPSC on April 20

Plan for the long term stability Run under development

- minimal goal: maintain detector active and
  acquire short Cosmic Run every day
- *dedicated tests at different cryogenic system settings and detector operating parameters to be defined and included in the plan*
- additional inputs for specific tasks from DUNE Consortia to be collected

Single Phase Milestones

Table 2.5: APA design and construction milestones

Date	Milestone
	Pre-TDR
December 2018	Test two-APA assembly
January 2019	Formal review of complete modifications to the winder design
February 2019	Formal review of ProtoDUNE-SP APA performance
February 2019	Complete assembly test of FD prototype APA
March 2019	Decision on location of factories and required number of assembly lines
March 2019	APA cost estimate for SP module
March 2019	APA schedule for SP module
April 2019	APA section of TDR delivered
	Post-TDR
2020	Preparation of APA factories
2021 – 2023	Construction of anode plane assemblies
2022/3	Installation of anode plane assemblies in SP module 1
2024	Commissioning of SP module 1

Table 3.4: Milestones of the Cold Electronics consortium.

Date	Milestone
Jun 2018	Submission of first version of all custom ASICs
Oct 2018	Bench test of first version of all custom ASICs
Feb 2019	System tests of first version of all ASICs and FEMBs
Feb 2019	Conceptual design of fibers and cabling plant
Feb 2019	Demonstrate cable routing through APA frames
May 2019	Submission of second version of all custom ASICs
Dec 2019	System tests of second version of all ASICs and FEMBs
Mar 2020	Revise design of WIBs and crates
Jun 2020	Revise design of cryostat penetrations
Sep 2020	Revise design of detector components outside the cryostat
Nov 2020	Launch pre-production of ASICs and FEMBs
Jun 2021	Integrate CE with pre-production anode plane assemblies
Jul 2021	Availability of all test stands for ASICs and FEMBs
Jul 2021	Availability of vertical slice test with final production components
Oct 2021	Launch pre-production of all detector components
Mar 2022	Begin integration of CE on production anode plane assemblies
Nov 2022	Integration of CE on anode plane assemblies 50 % complete
Nov 2022	Launch production of cryostat penetrations
Nov 2022	Launch production of warm interface electronic crates and boards
Jun 2023	Start detector installation in the cryostat at SURF
Oct 2023	Complete integration of CE on anode plane assemblies
Jan 2024	Complete APA installation at SURF
Feb 2024	Complete initial tests of detector prior to TCO closing

Table 5.6: Pre-TDR key milestones.

Milestone	Date
Preliminary PD technology selection criteria determined	03/21/18
Results from final prototype light collector studies available	02/21/19
Final PD technology selection criteria available	02/21/19
Down-select to primary (and potential alternate) light collector technology	02/22/19
Submit initial TDR draft for internal review	03/29/19

High-level post-TDR milestones are listed in Table 5.7.

Table 5.7: Post-TDR key milestones.

Milestone	Date
PD pre-production review(s) complete	03/2020
Initial PD module fabrication begins	09/2020
Final PD production review based on initial production QA	02/2021
First PD modules delivered for installation	05/2021
Installation into anode plane assemblies begins	06/2021
PD fabrication complete (first SP module)	07/2023

Table 4.6: DRAFT- HV system R&D program and Milestones to lead to CD-2 approval.

WBS	Task Name	Start	Finish
1.5	CD-2 DOE Review	10/4/19	10/4/19
7	HV system		
7.1	Finalize SP FC design	06/27/18	09/30/19
7.2	Finalize SP cathode design	06/27/18	09/30/19
7.3	Run SP HV design integration test	01/01/18	12/31/19
7.4	HV TDR - submit for internal review	03/29/19	03/29/19
7.5	CPA procurement	09/21/21	12/06/22
7.6	ground plane procurement	08/08/22	12/06/22
7.7	Assemble and test voltage dividers	08/08/22	12/06/22
7.8	FC procurement	03/11/22	12/06/22
7.9	Production readiness reviews	01/02/23	01/07/23
7.10	Cryostat ready for TPC installation	05/01/23	05/01/23
7.11	CPA assembly	01/31/23	07/25/23
7.12	Top-bottom FC assembly	01/31/23	07/25/23
7.13	Endwall FC assembly	01/05/23	04/23/23

Dual Phase Milestones

Table 3.9: DP TPC electronics consortium key milestones.

Date	Milestone
September 2018	Number of LRO channels finalized
November 2018	Final routing for LRO AMCs for production
March 2019	Costing model for technical design report (TDR) finalized
March 2019	Firmware for CRO AMCs finalized
March 2019	Commissioning of ProtoDUNE-DP finished
January 2023	Start of component production and procurement
July 2023	μTCA infrastructure components produced
July 2023	Components of WR system delivered and validated
January 2024	SFT chimneys produced and tested
January 2024	Cryogenic FE analog electronics produced and tested
January 2024	AMCs for CRO and LRO produced and tested
August 2024	Cryostat of the second detector module is ready
November 2024	SFT chimneys installed
December 2024	Cryogenic FE electronics installed
December 2024	μTCA crates and WR network installed
January 2025	Installation of AMCs completed
January 2025	Commissioning of the DP TPC electronics system
August 2025	Closure of the cryostat temporary construction opening (TCO)

Table 3.10: DP TPC electronics consortium schedule.

Techincal activity	Days	Start date	End date
Preparation of costing for interim design report (IDR)	20	02/26/18	03/23/18
Initial development of installation schedule	20	02/26/18	03/23/18
Further development of installation schedule	145	09/03/18	03/22/19
Installation and commissioning of ProtoDUNE-DP	320	01/01/18	03/22/19
Finalization of the number of channels for LRO	20	09/03/18	09/28/18
Implementation of routing for digital cards of LRO	40	10/01/18	11/23/18
Preparation of final costing for TDR	85	11/26/18	03/22/19
Firmware development for charge readout cards	145	09/03/18	03/22/19

Table 5.4: Pre-TDR key milestones

Milestone	End date
Simulations and physics: Implementation of DP optical simulation in LArSoft for ProtoDUNE-DP	08/2018
Simulations and physics: Optimization of the DP module performance to fulfill the physics requirements and definition of a trigger strategy	05/2019
Photosensors: Components selection and final design	03/2019
PMT calibration system design and selection of components	03/2019
Cabling definition and design of flange	03/2019
Design review in light of ProtoDUNE-DP calibration data	03/2019
QC plan	06/2018
Identification of Interfaces	06/2018
Integration, installation and commissioning plans	12/2018
DP module TDR	06/2019

Table 5.5: Post-TDR key milestones

Milestone	Start date	End date
PMT preparation and installation (can be done in batches)		
PMT procurement procedure and production	01/2021	12/2022
PMT base design and manufacturing	01/2022	12/2022
PMT support structure production and assembly	08/2022	01/2023
PMT characterization - 10 PMTs/week (two facilities)	02/2023	12/2023
TPB coating (two facilities similar to that for CERN ICARUS)	01/2024	12/2024
Splitter production and tests	05/2024	12/2024
Installation at SURF		
PMT cable and fiber routing in cryostat from flange to bottom (depends on FC and flange installation)	09/2024	09/2024
PMT testing, installation in cryostat and cabling (72 PMTs/month)	10/2024	07/2025
PMT support installation on the membrane (in parallel by sector with PMT installation)	10/2024	07/2025
Splitter installation (in parallel with PMT installation to test cabling and connections)	10/2024	07/2025
Light calibration system		
Fibers, light source tests and procurement	06/2023	05/2024
Fiber calibration system installation (in parallel with PMT installation with validation test)	09/2024	07/2025

Table 8.1: Overall DUNE Project Tier-1 milestones.

Milestone	Date
RRB Approval of Technical Design Review	09/02/2019
Beneficial Occupancy of Integration Test Facility	09/01/2021
Construction of steel frame for Cryostat #1 complete	12/17/2021
Construction of Mezzanine for Cryostat #1 complete	01/17/2022
Begin integration/testing of Detector #1 components at ITF	02/01/2022
Beneficial Occupancy of Central Utility Cavern Counting room	04/16/2022
Construction of steel frame for Cryostat #2 complete	07/01/2022
Construction of Mezzanine for Cryostat #2 complete	08/01/2022
Beneficial occupancy of Cryostat #1	**12/23/2022**
Cryostat #1 ready for TPC installation	05/01/2023
Begin integration/testing of Detector #2 components at ITF	11/01/2023
Beneficial occupancy of Cryostat #2	**03/01/2024**
Begin closing Temporary Construction Opening for Cryostat #1	05/01/2024
Cryostat #2 ready for TPC installation	08/01/2024
Cryostat #1 ready for filling	10/01/2024
Begin closing Temporary Construction Opening for Cryostat #2	07/18/2025
Detector #1 ready for operations	**10/01/2025**
Cryostat #2 ready for filling	12/05/2025
Detector #2 ready for operations	**12/18/2026**

Single Phase FD Task Force

- Studies of reducing wire pitch from 4.7mm to 3mm, or changing the angle from 35.7° to 45° show no significant impact on main physics goals
- Substantial cost impact on making these changes to SP module design not justified

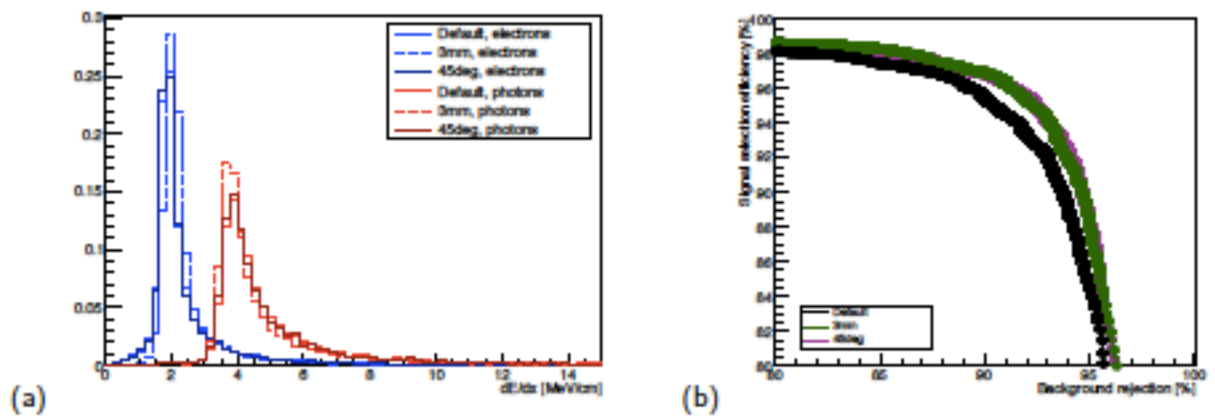


Figure 2.5: Summary of electron–photon separation performance studies from the DUNE Far Detector Task Force. (a) e–γ separation by dE/dx for the nominal wire spacing and angle (4.7 mm/37.5°) compared to 3 mm spacing or 45° induction wire angles. (b) Electron signal selection efficiency versus photon (background) rejection for the different detector configurations. The 3 mm wire pitch and 45° wire angle have similar impacts, so the 45° curve is partially obscured by the 3 mm curve.

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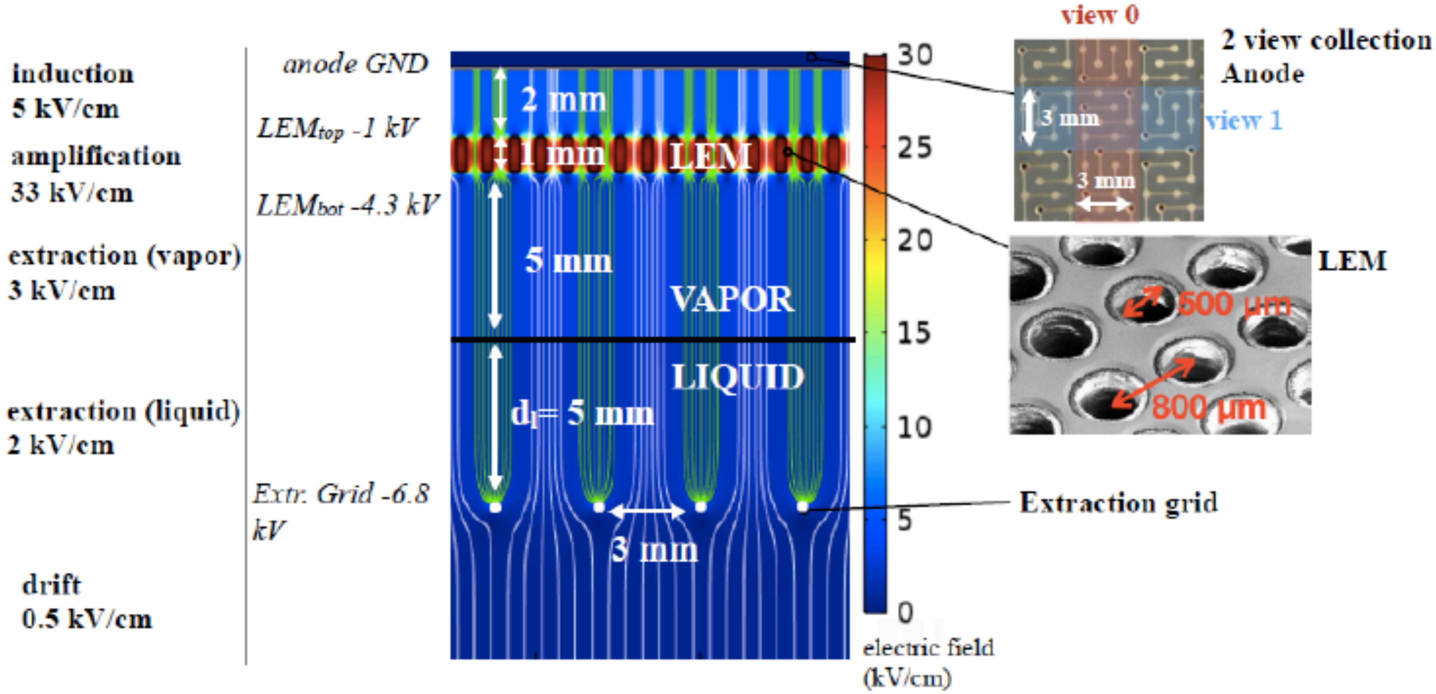


Figure 2.1: Illustration of the E fields in the amplification region of a DP LArTPC. The simulated field lines in dark blue indicate the paths followed by the drifting charges (without diffusion).

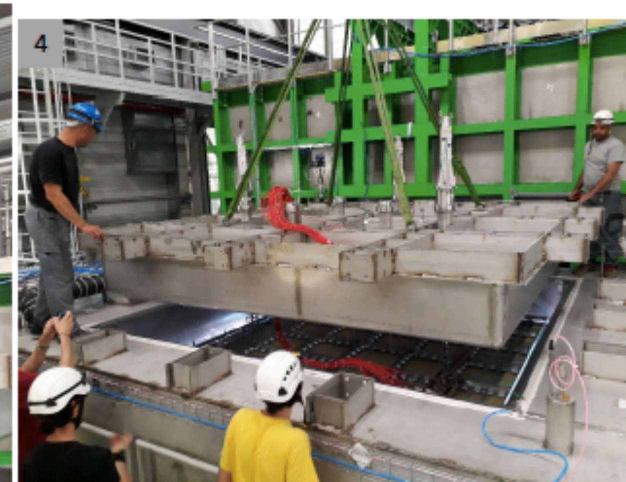
Table 2.1: Interstage distances and E field settings of the DP readout components.

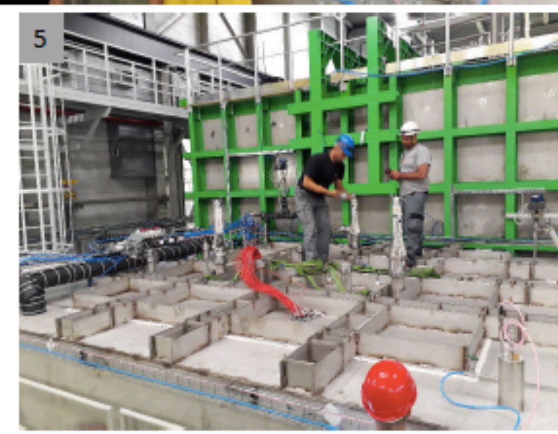
Component	Distance [mm]	Tolerance [mm]	E field [kV/cm]
Anode-LEM top electrode	2	0.1	5
LEM top-bottom electrode	1	0.01	30 to 35
LEM bottom electrode-grid	10	1	2 (in LAr) and 3 (in gaseous argon)

ProtoDUNE-DP CRP Test in Cold Box

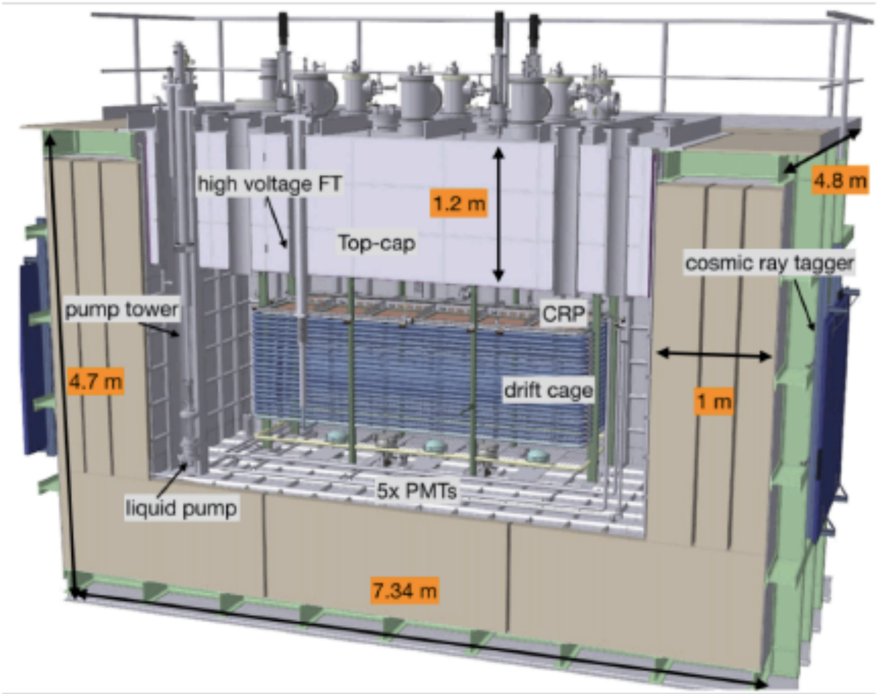
Insertion of the first CRP in the cold box in building 182

22/06/2018

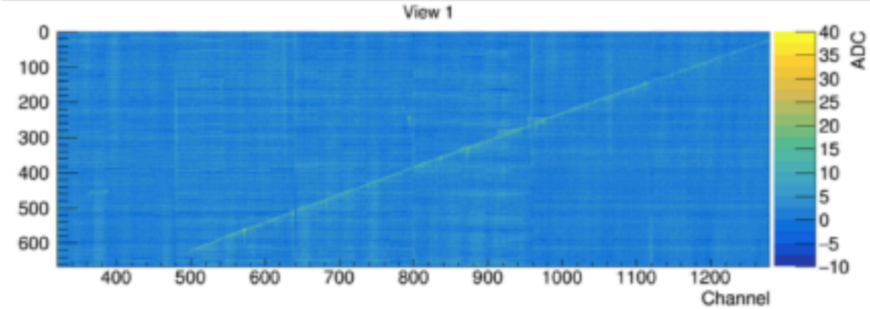




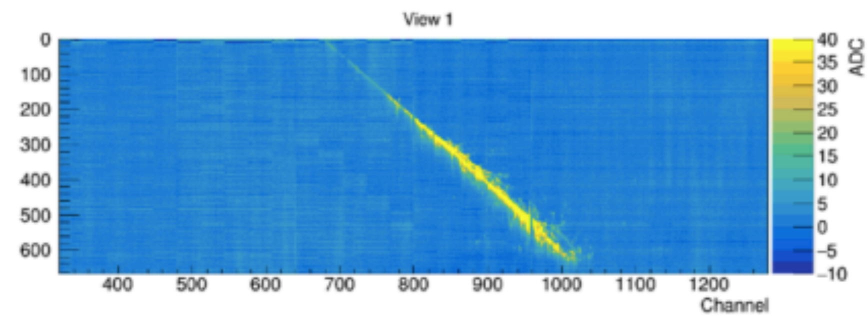
3x1x1 DP Prototype (WA105) at CERN



Muon



EM Shower



- 3x1x1 prototype ran from June to November 2017
- Successful demonstration of dual phase LArTPC concept
- ENC <1800 e^- (S/N ≈ 100 for a MIP)
- Led to improved designs for protoDUNE dual phase

arXiv:1806.03317