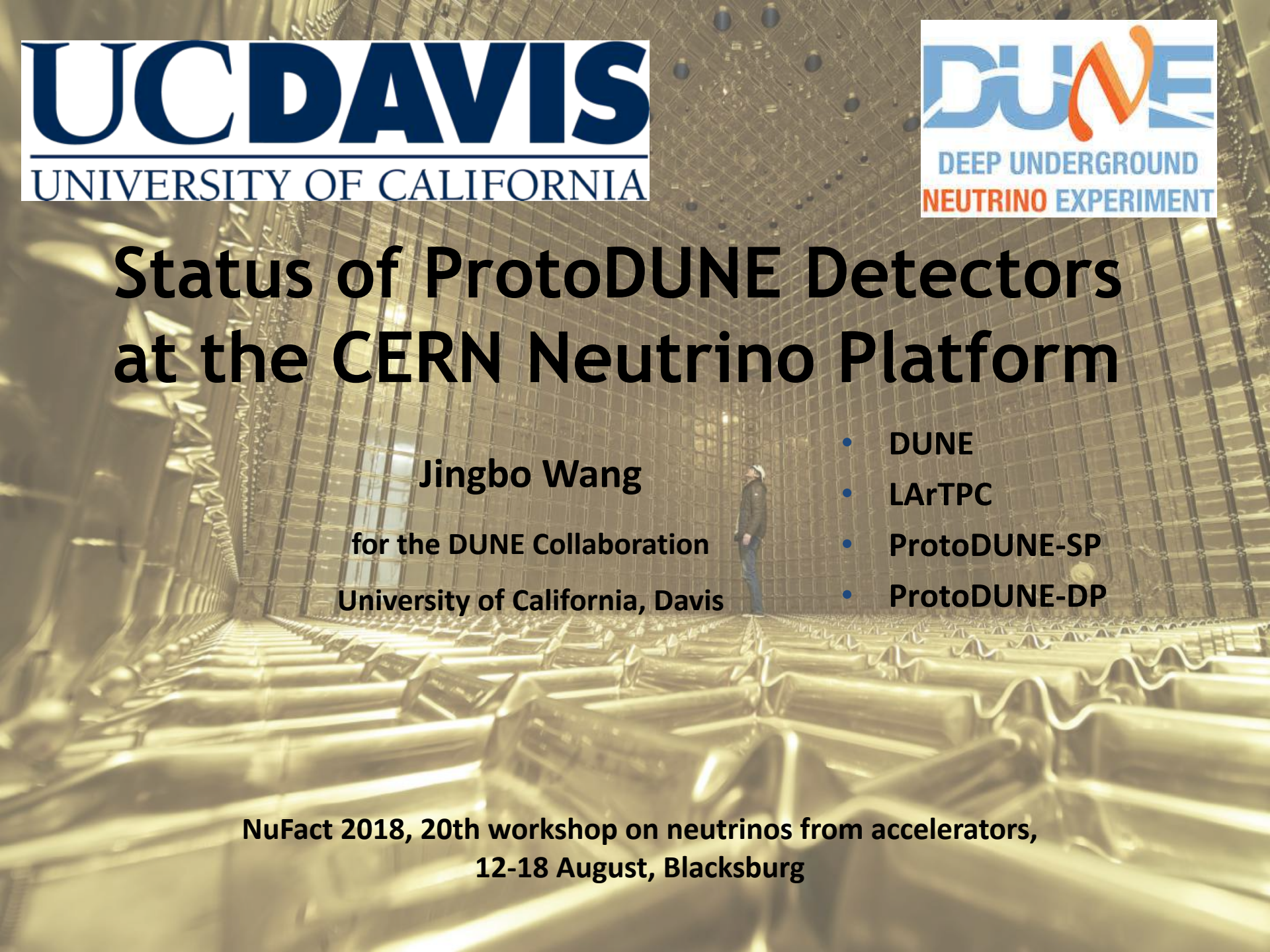


Status of ProtoDUNE Detectors at the CERN Neutrino Platform

Jingbo Wang

for the DUNE Collaboration

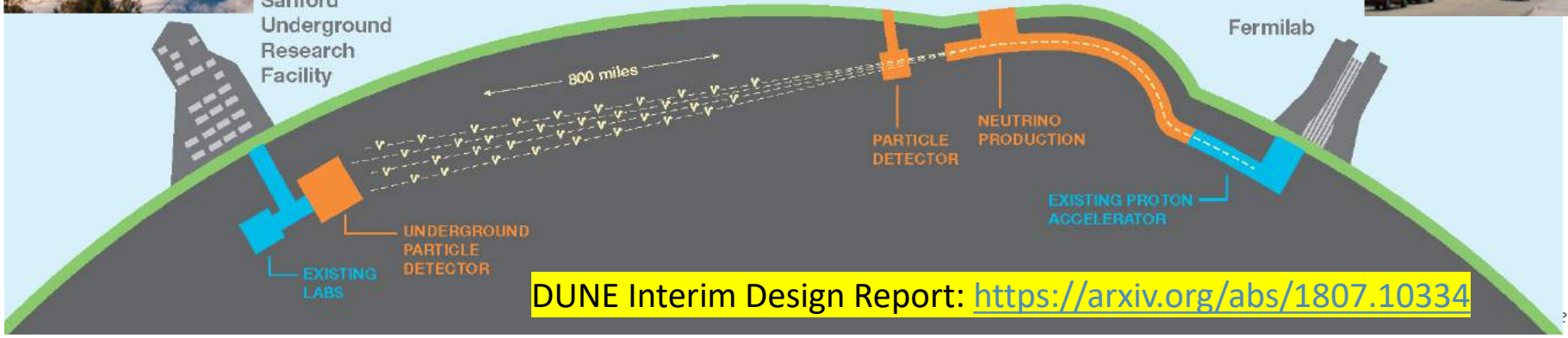
University of California, Davis

- **DUNE**
- **LArTPC**
- **ProtoDUNE-SP**
- **ProtoDUNE-DP**

NuFact 2018, 20th workshop on neutrinos from accelerators,
12-18 August, Blacksburg

DEEP UNDERGROUND NEUTRINO EXPERIMENT

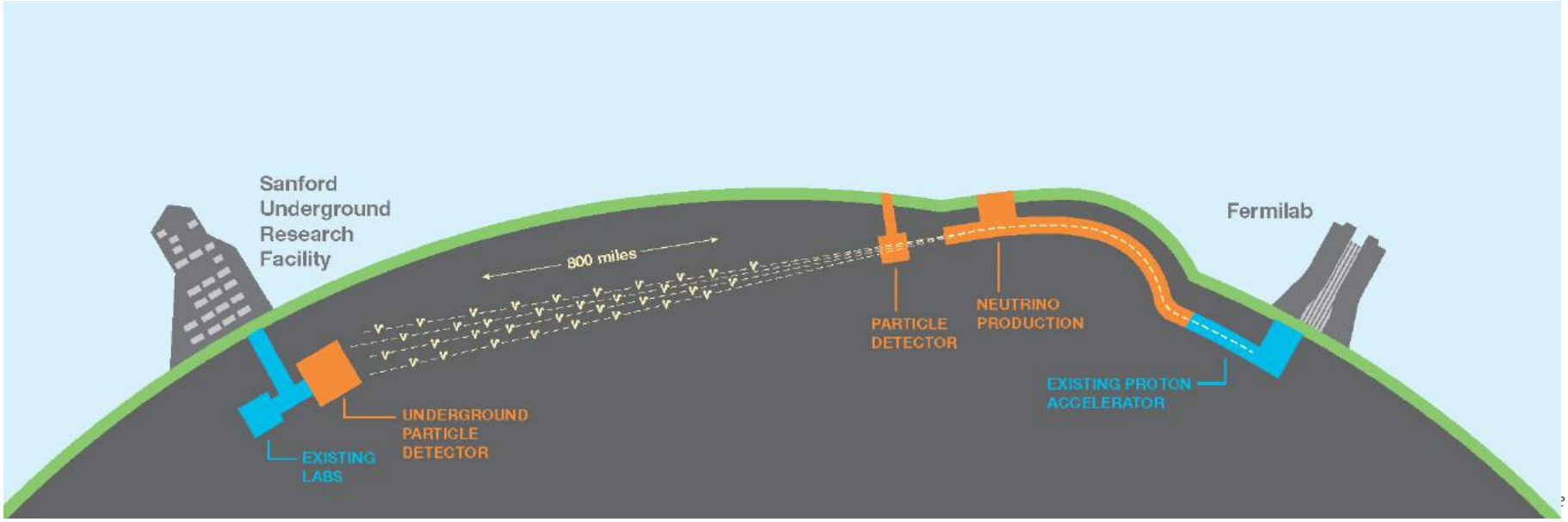
- Intense neutrino beam with **1300 km** baseline: Initially 1.2 MW @ 80GeV, upgradeable to 2.4 MW
- Near detector on-site at Fermilab to characterize the beam
- Far detector at SURF in South Dakota: **4 x 10 kton (fiducial mass)** Liquid Argon TPCs, **1.5 km** underground
- International collaboration: 1000+collaborators/175+institutions/32+countries



DUNE Interim Design Report: https://arxiv.org/abs/1807.10334

DUNE Physics

- Neutrino oscillation measurements (ν_μ disappearance + ν_e appearance)
  - CP violation, Mass hierarchy, Octant of θ_{23}
- Detection of core-collapse supernovae neutrinos
- Search for proton decay
- Other accelerator-based measurements: non-standard interactions (NSIs), CPT violation, sterile neutrinos…



DUNE Physics

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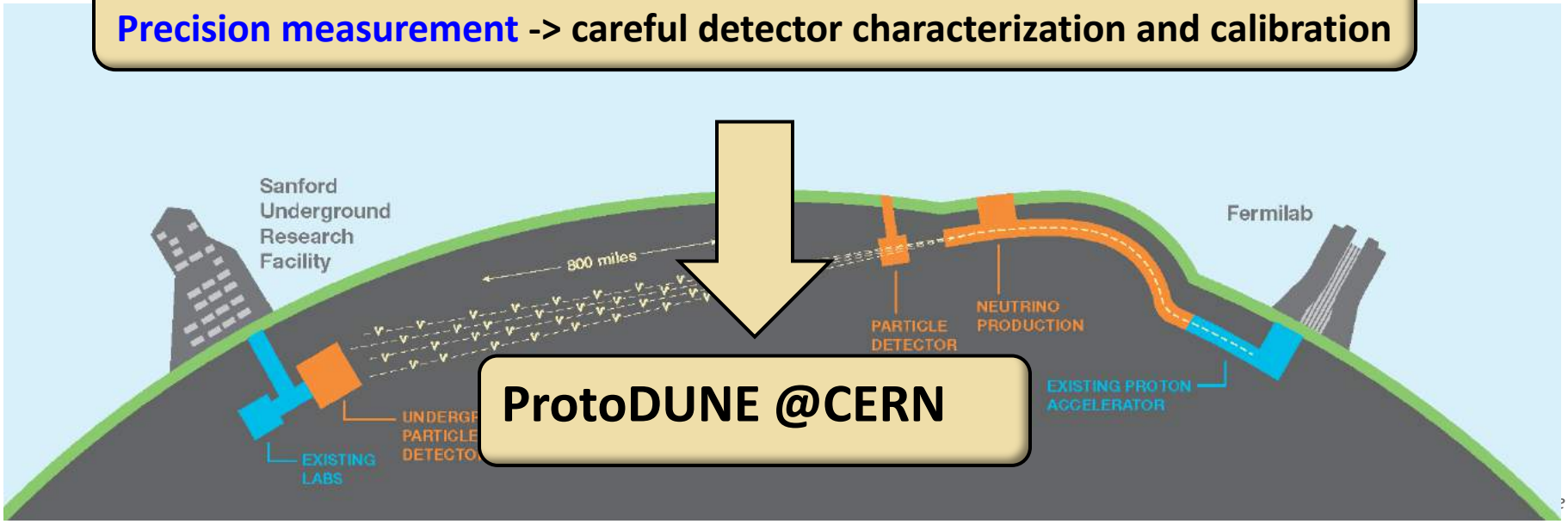
Giant far detector -> new engineering and technological challenges
Precision measurement -> careful detector characterization and calibration



ProtoDUNEs @CERN

- **ProtoDUNE is a set of two LArTPC detectors being constructed at CERN neutrino platform**: one single phase and one dual phase

- **ProtoDUNE is the "BIGGEST SMALL" detector**
  - **"SMALL"**: only 1% of the DUNE far detector
  - **"BIG"**: the largest liquid argon detector ever built so far (800-ton liquid argon, real-size detector components)

- **ProtoDUNE is in beam:** Detectors exposed to two independent beam lines

- **Strategic Goals of the program**
  - Prototyping **production and installation procedures**
  - Validating the **design from the basic detector performance**
  - Accumulating test-beam data for **detector response understanding/calibration**
  - Demonstrating the **long-term operational stability**

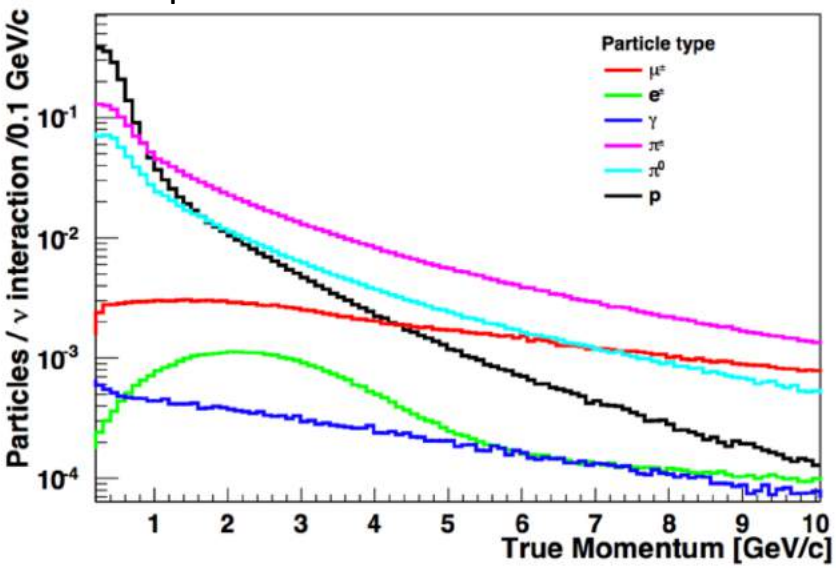
ProtoDUNE Measurements

CERN beam particles: , e, μ, p, $K^{\pm}$, $\pi^{\pm}$ from (500 MeV – few GeV)

ProtoDUNE beam data

- Measure hadron-argon interaction cross-section
  - Of interest for the entire LAr community
  - key to control systematics for DUNE
- Validate the reconstruction algorithm performances
  - Track and shower reconstruction
  - Electron/gamma separation

Simulation of neutrino-induced particle rates in DUNE far detector

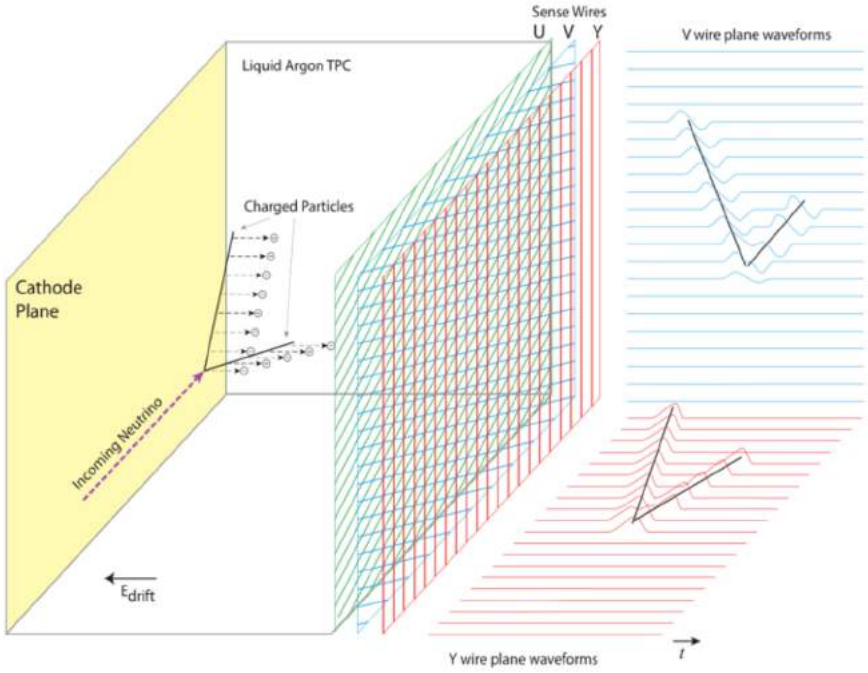


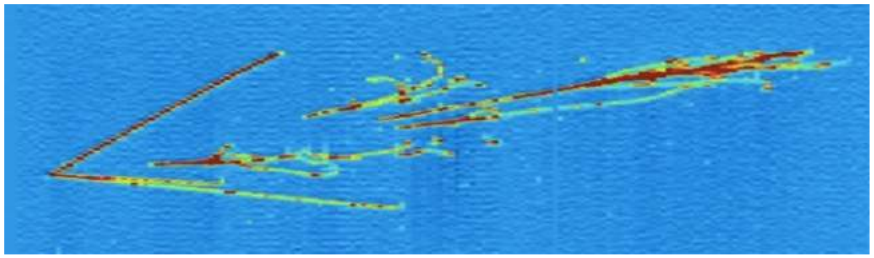
ProtoDUNE cosmic data

- Study space charge and electric field distortion in 3D
- Understand dE/dx, dQ/dx, and charge recombination models
- Reconstruct Michel electrons for energy range relevant to supernova neutrino

LArTPC Concept

- Liquid Argon Time Projection Chamber (LArTPC) is imaging detector that offers exceptional capabilities for detecting neutrinos
- Charged particles from neutrino interactions create ionization tracks and scintillation light
- Ionization charges drift to anode , creating hits on wire or micro-pattern readout plane
- Separate photon detection system allows t_0 determination (needed for coordinate along E field)





DUNE is considering two LArTPC technologies: Single-Phase and Dual-Phase

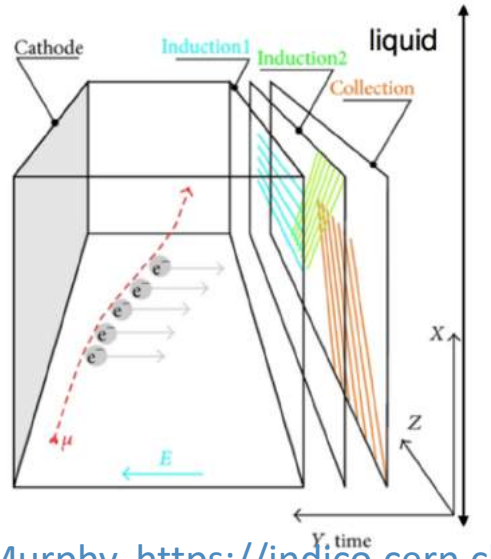
Single Phase VS Dual Phase

Single Phase Detector:

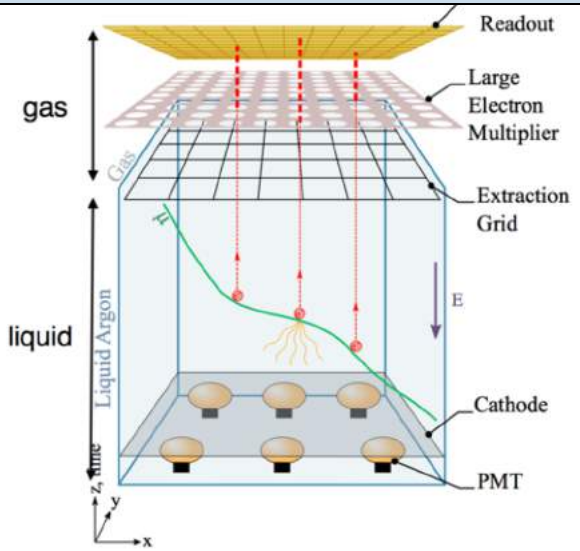
- Only liquid argon
- Ionization and collection in liquid phase
- Ionization charges drift in liquid, pass by induction plane(s) and are collected by anode collection plane
- No amplification of the initial ionization charge: grounding is important

Dual Phase Detector:

- Liquid argon and gaseous argon
- Ionization in liquid argon
- Ionization charges drift in liquid phase, are amplified in LEM and are collected on anode readout board in gaseous phase
- Expect higher signal-to-noise ratio: high field requires careful design



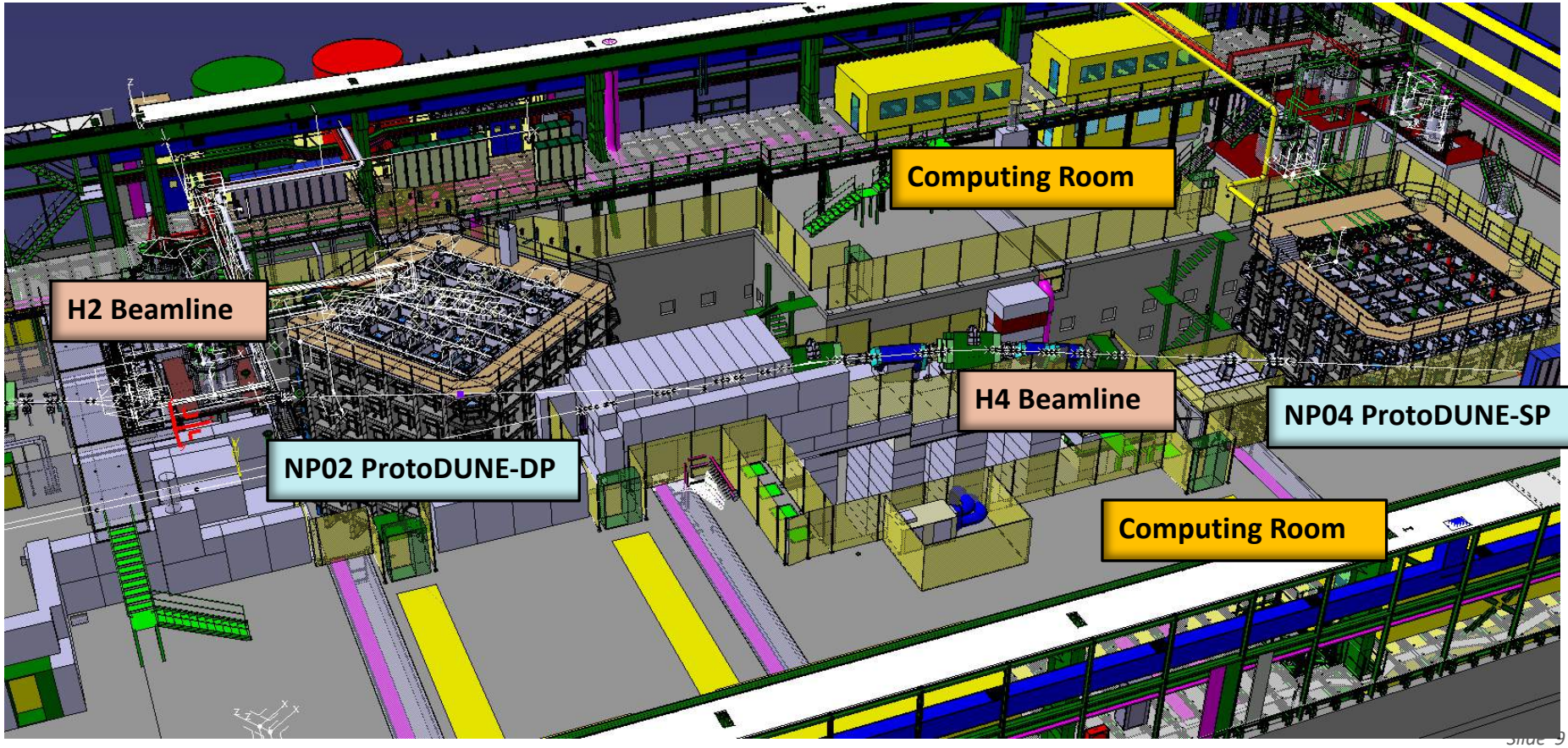
VS



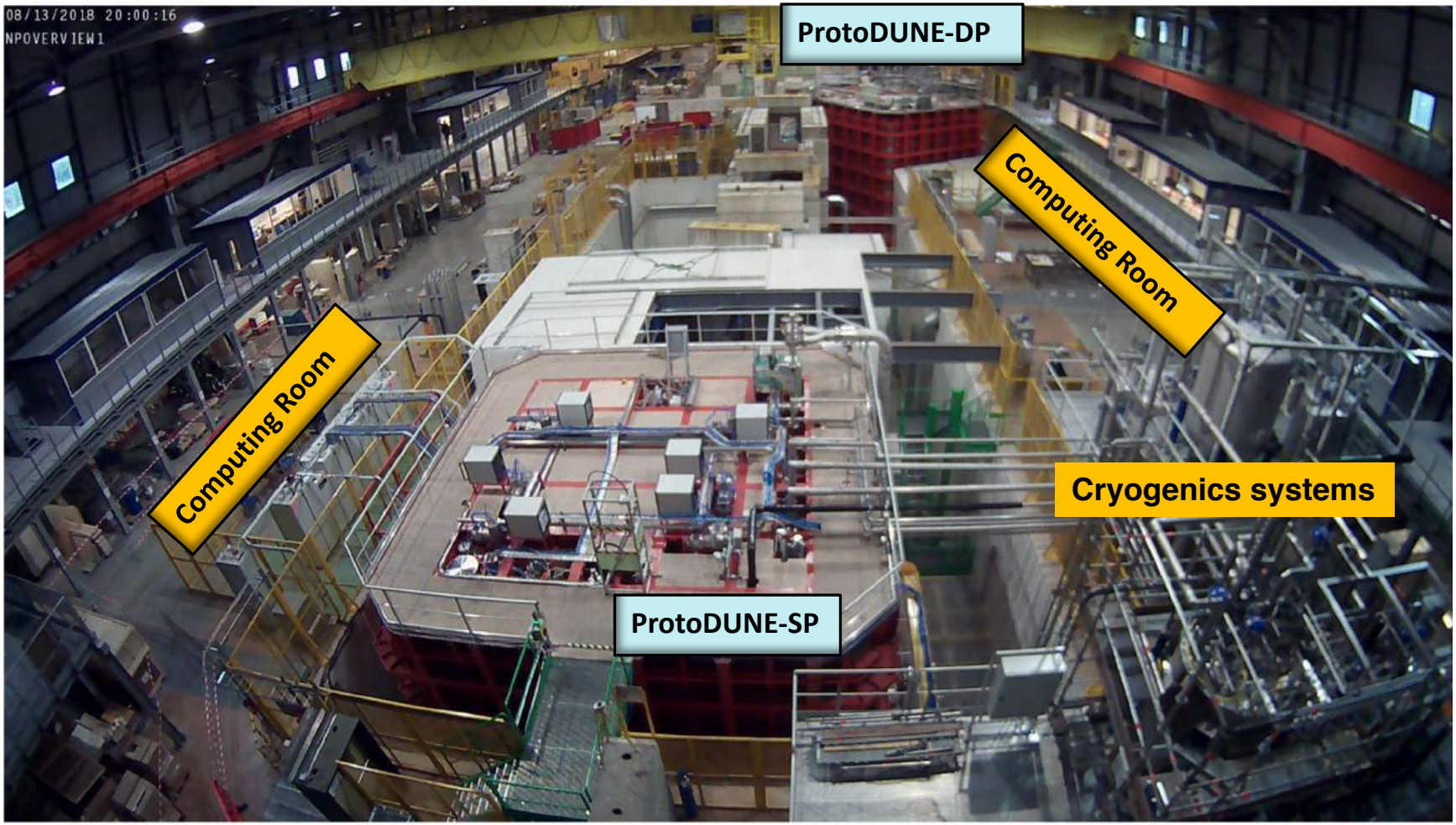
S. Murphy, https://indico.cern.ch/event/649662/

ProtoDUNE Layout @EHN1

- Both single phase and dual phase detectors are located in the north area extension at CERN EHN1
- The CERN neutrino platform is responsible for the cryostat, the cryogenic system, and the beam facilities.



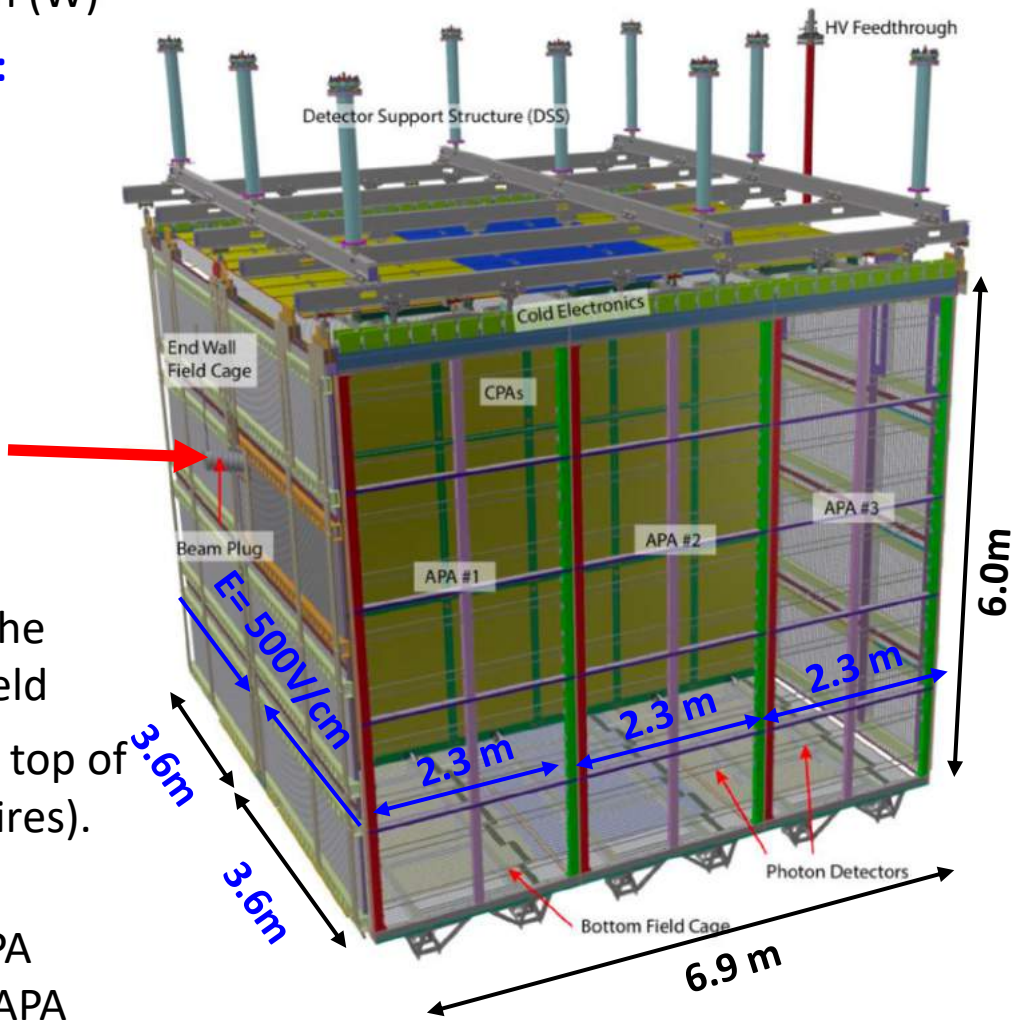
ProtoDUNE Layout @EHN1



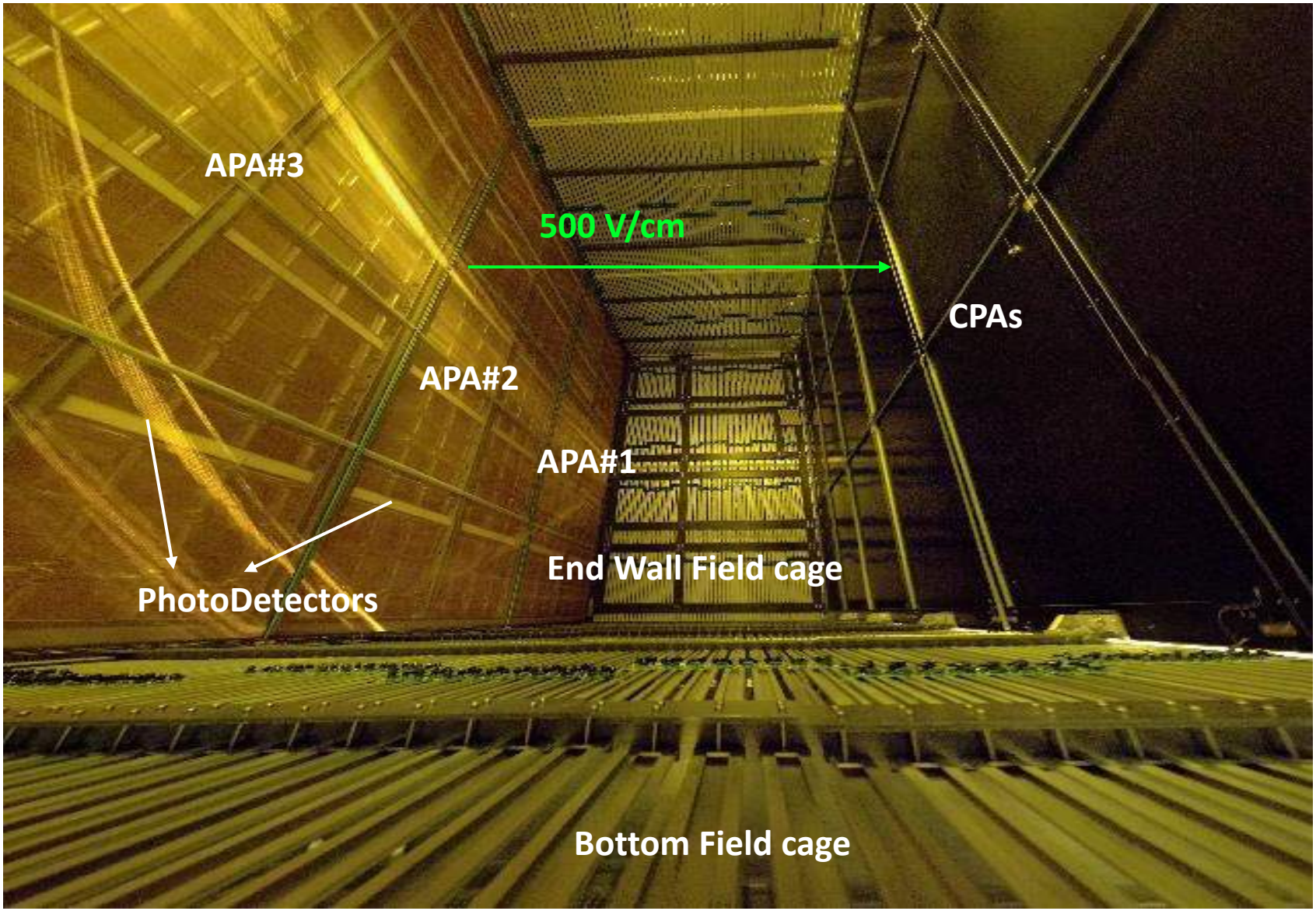
Latest webcam_1 image from the inside-work of the Neutrino Platform Hall (EHN1). (Images updated every 30'.)

ProtoDUNE Single Phase

- **Active Volume**: 6m (H) x 7m (L) x 2x3.6m (W)
- **Central Cathode Plane Assembly (CPA) :**
  - 18 CPA modules
  - at 180 kV 3.6 m drift length
  - 500 V/cm field in drift volume
- **Anode Plane Assembly (APA)**:
  - 2 APA planes, each with 3 APAs
  - APA module: 6m high, 2.3m wide
  - Photodetectors integrated in APA
- **Field cage** surrounds the open sides of the drift region, ensuring uniform electric field
- **Cold electronics** directly attached to the top of the APA (2560 wires/APA, 15360 total wires). Expect S/N of 15-70
- **The photon detectors** integrated into APA frame bars: 10 photodetector modules/APA



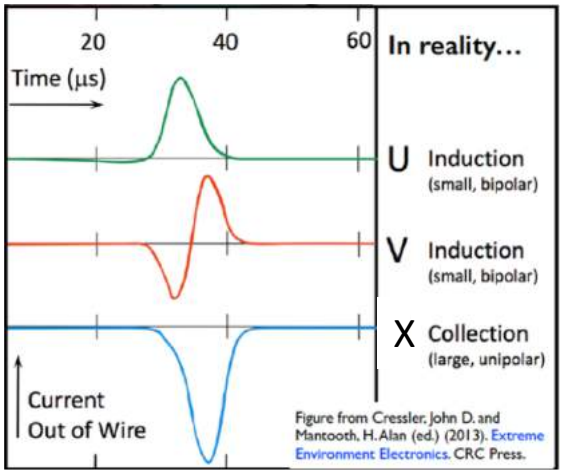
ProtoDUNE-SP: Inside Field Cage

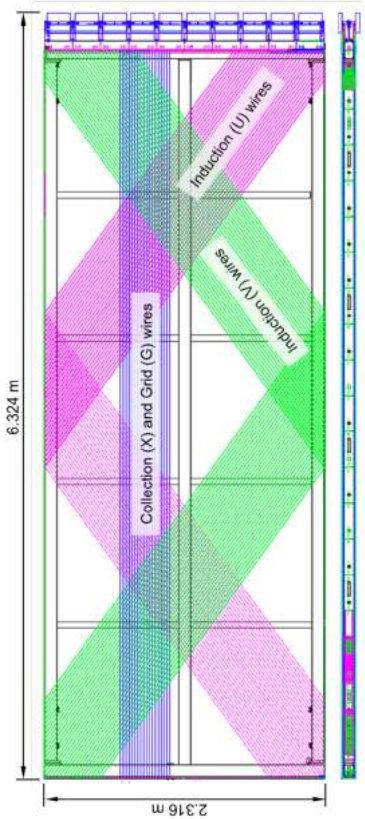


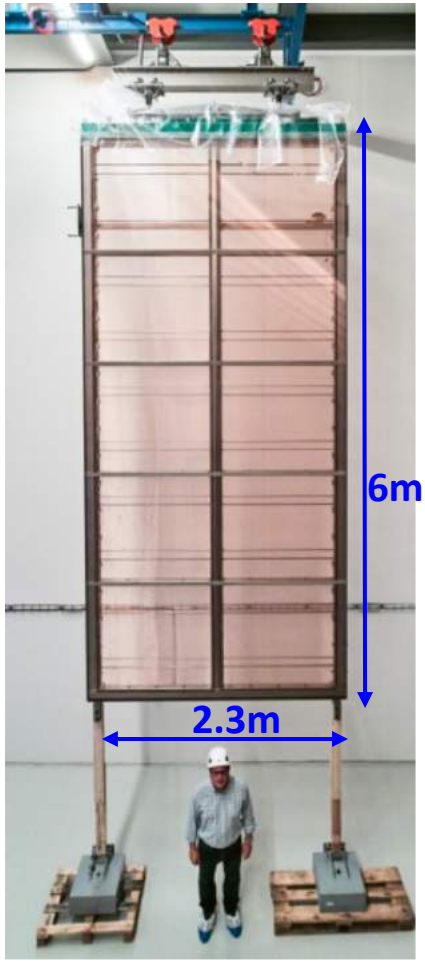
ProtoDUNE-SP: Anode Plane Assembly(APA)

- **APA: three wire planes (UVX) + one grid plane(G)**
  - **The grid wires** (G, not shown): shield the effect from charge drifting in drift region
  - **Induction wires** (**U**, **V**): inclined at +/- 35.7°; both transparent to charges
  - **Collection wires** (**X**): collect the charge forming unipolar signal
  - **Grounding Mesh** M (not shown): shields photon detection system

- **Wrapped wire design** reduces number of electronic channels and allows more active volume: all electronics are on top

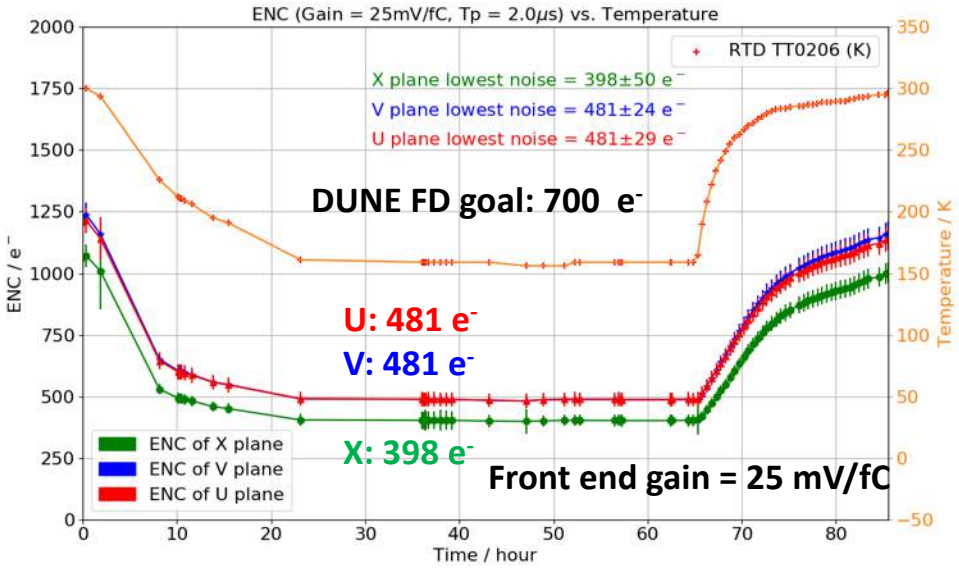


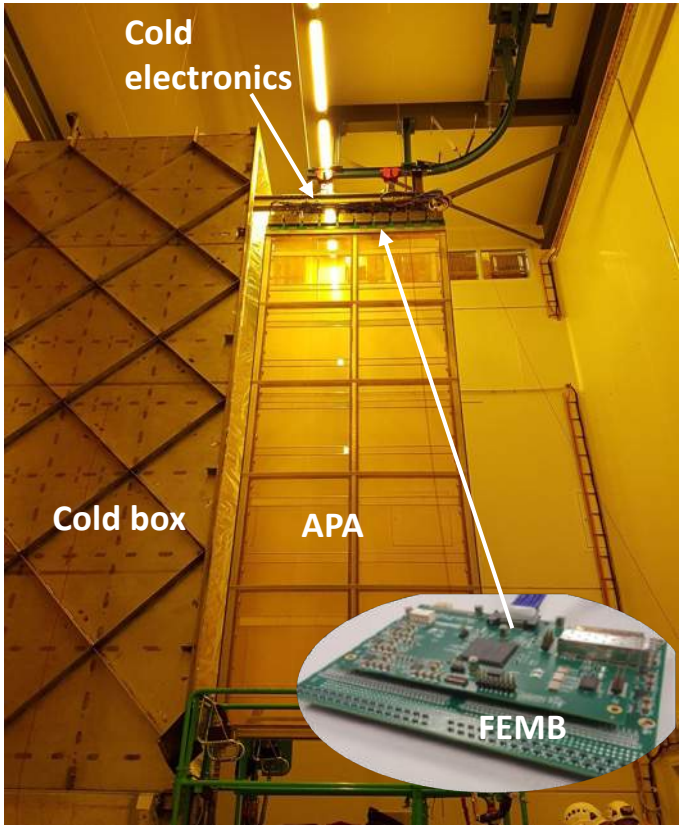




ProtoDUNE-SP: Cold Electronics

- FEMB (Front End Mother Board) are mounted on top of the APA
- Assembled APA and cold electronics are tested in a cold box before installation
- Cold box is filled with nitrogen gas for testing at “cold” temperature (150 K)
- ENC (Equivalent Noise Charge) is charge (in e-) injected to detector capacitance which produces on the output side a signal with amplitude equals the output RMS noise



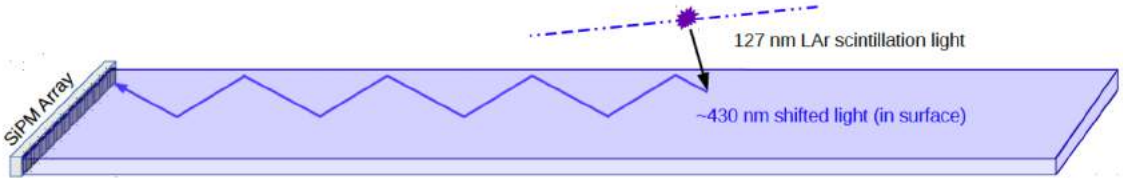


ProtoDUNE-SP: Photon Detection System

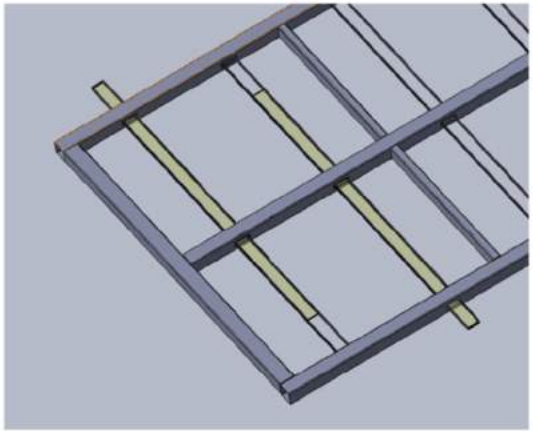
- LAr is an excellent scintillating medium: **20,000 photons/MeV @ 500 V/cm, with a wavelength of 128 nm**
- Wavelength shifter converts VUV light to visible light that is readout by SiPMs
- **3 photodetector designs will be tested in ProtoDUNE-SP**

Design#1: Dip-coated light guide (MIT and Fermilab)

- ✓ Acrylic light guide bar dip-coated with wavelength shifting material.
- ✓ Transport shifted light via total internal reflection to SiPM readout

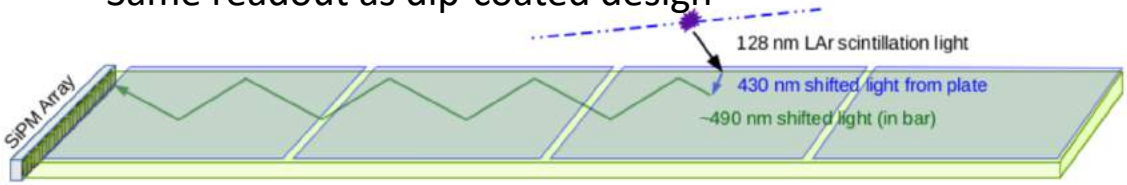


PDS module inserted into an APA frame

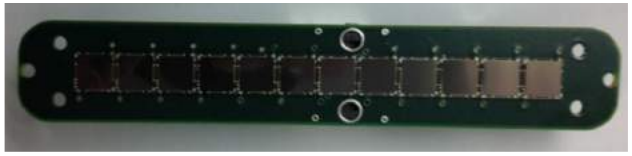


Design#2: Double-shift light guide (Indiana University)

- ✓ Wavelength shifting plates + wavelength shifting light guide
- ✓ Same readout as dip-coated design

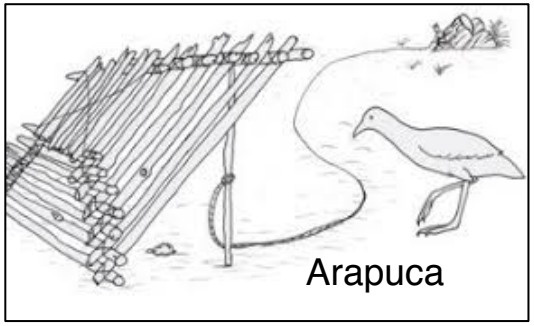


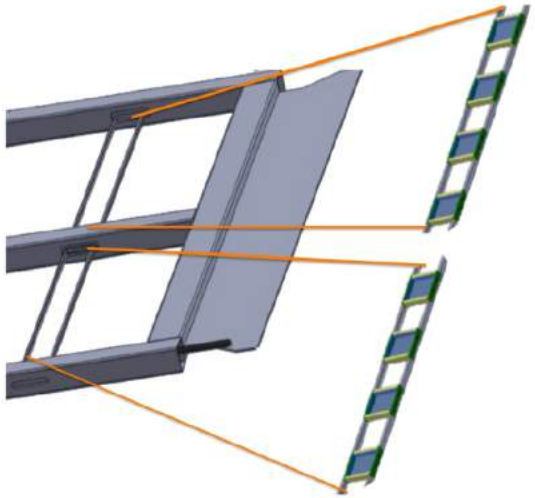
An array of SiPMs

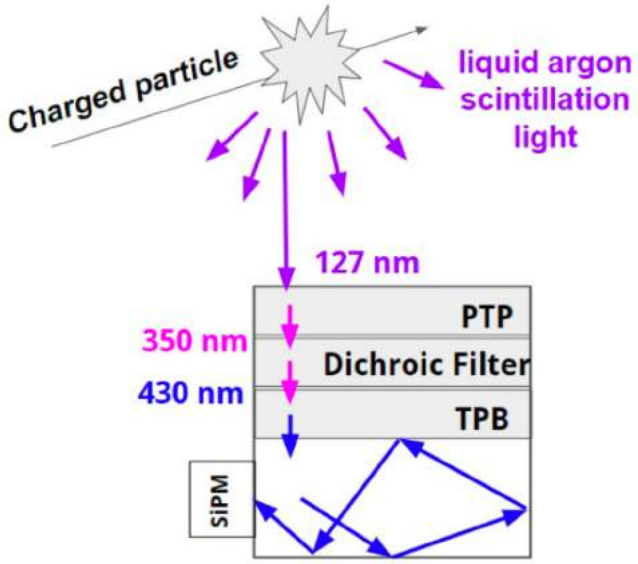


ProtoDUNE-SP: Photon Detection System

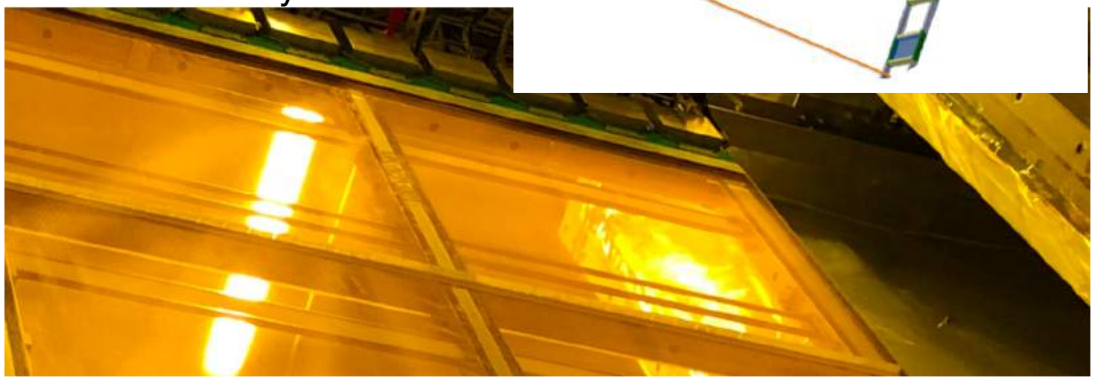
- **Design#3: ARAPUCA (Campinas University and Fermilab)**
  - ✓ Recent concept allowing higher light collection and finer spatial segmentation
  - ✓ Light is wavelength-shifted by commercially available **dichroic filter -> light is trapped!**
  - ✓ Shifted light is collected by SiPM
  - ✓ Light yield expected to be increased by a factor of 5 to 10
- **Two ARAPUA arrays will be mounted into two different APAs**





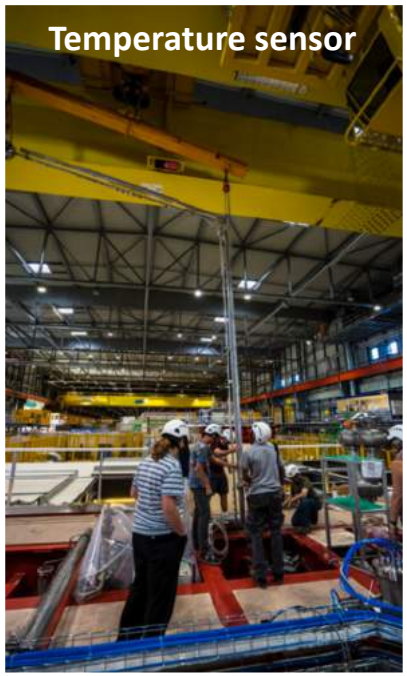


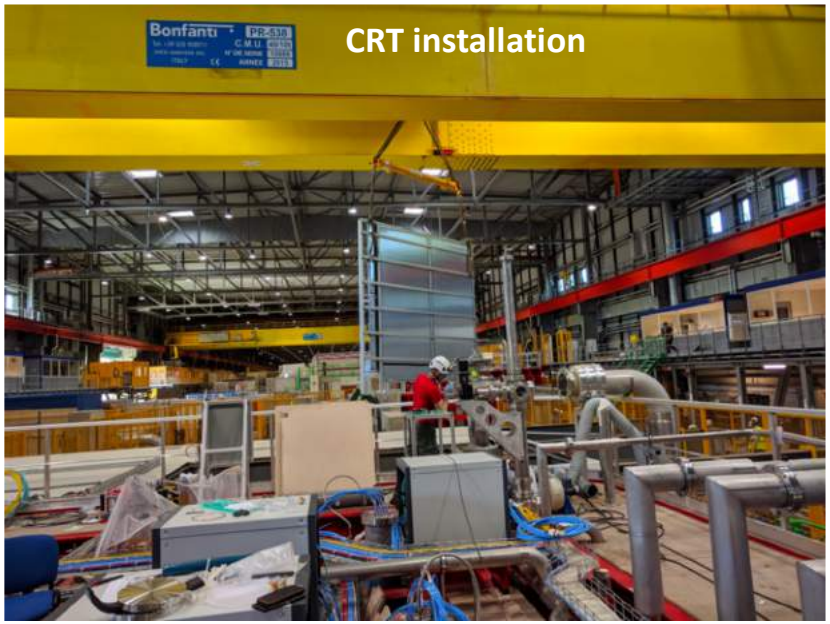
ARAPUCA array



ProtoDUNE-SP: Current Status

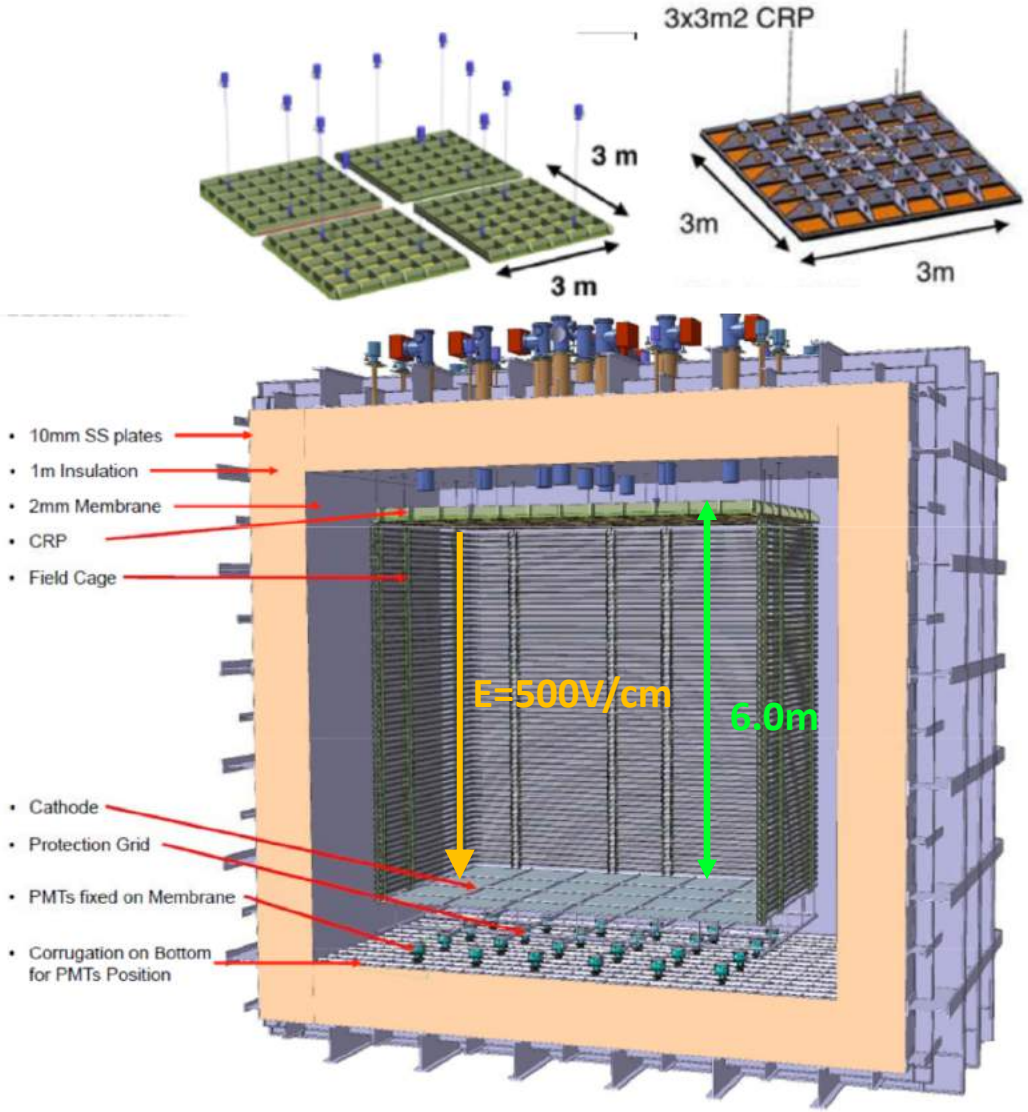
- April 27th 2018, all detector elements were completed, tested and inserted.
- August 8th 2018, cryostat filling has started.
- Purity monitor, temperature sensor and camera operational during the cryostat filling
- Cosmic Ray Tagger (CRT) is being installed
- **August 29th 2018, ProtoDUNE-SP will be ON for beam data!**





ProtoDUNE Dual Phase

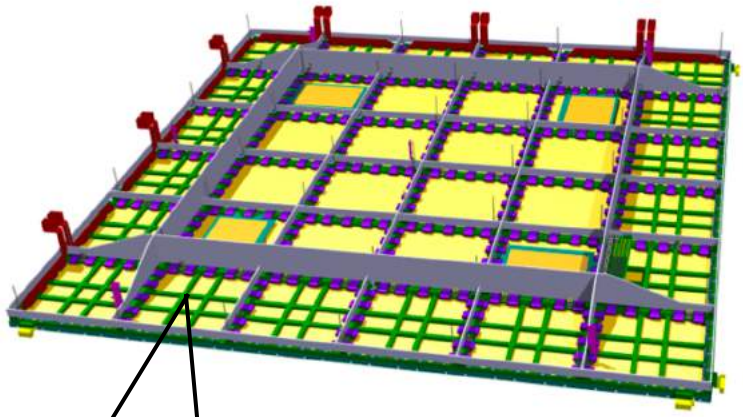
- **Active volume**: 6m x 6m x 6m
- **Transparent cathode plane** on bottom
- Anode plane on top: made of four 3m x 3m independent **Charge Readout Plane (CRP)** units
- Vertical drift: 6m distance, 500 V/cm, ~ 300 kV at the cathode
- Charge amplified by **Large Electron Multiplier (LEM)** in gaseous phase: expected 80 – 100 S/N (tunable)
- Micro-pattern large area charge readout: 7680 readout channels
- 36 8” cryogenic photomultipliers below the cathode for light collection



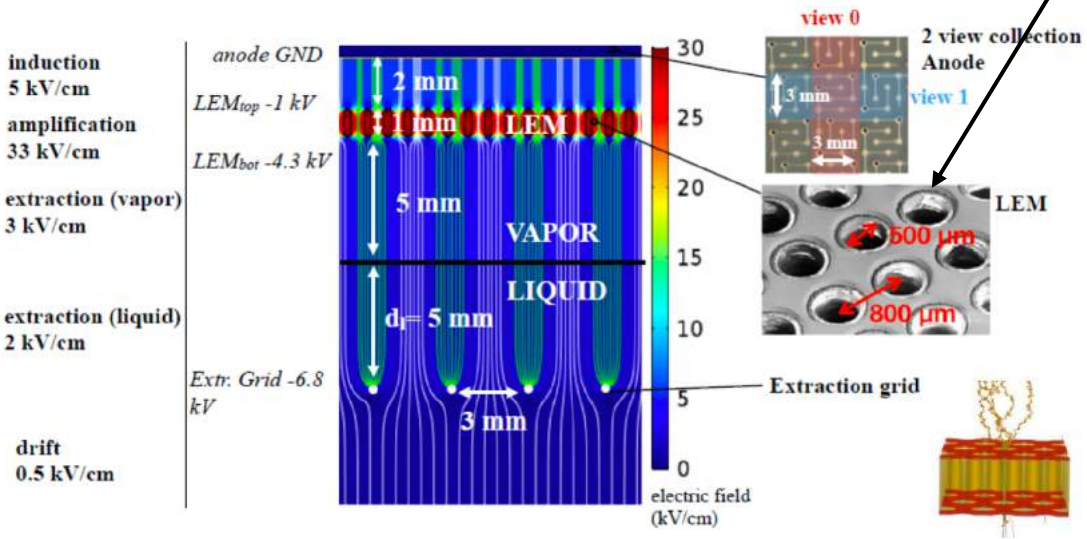
ProtoDUNE DP: Charge Readout Plane

- Large Electron Multiplier (LEM) and anodes are mounted to CRP
- Charge is amplified in LEM and then collected by multi-layer Printed Circuit Board (PCB) anode, providing track views in two directions
- 3x3 m^2 LEM and readout module completed and tested in dedicated GN2 cold box

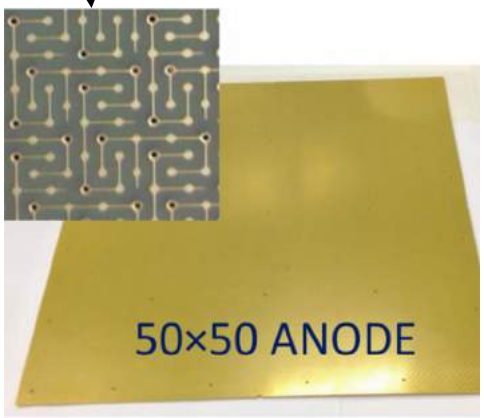
Completed 3m x 3m CRP



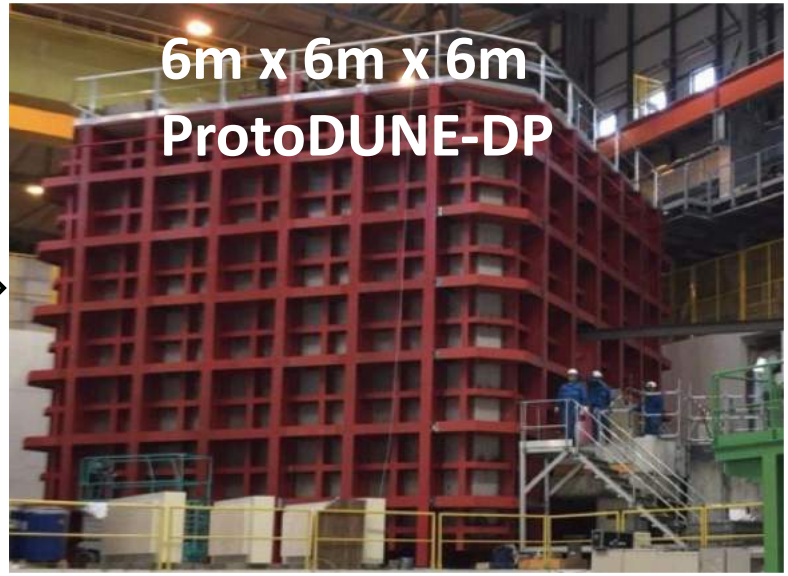
Large Electron Multiplier (LEM)

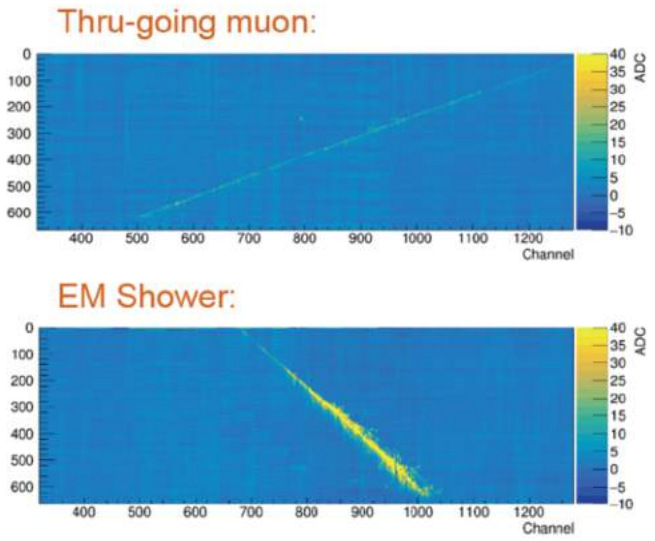


Micro-pattern Anode



Dual Phase Detectors @CERN



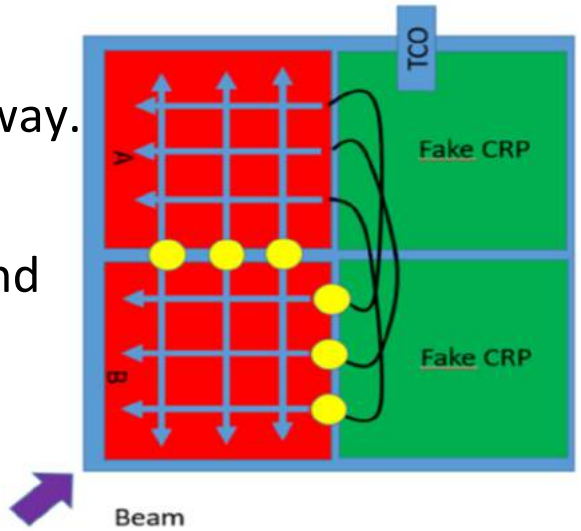


- 3x1x1 m^3 dual phase prototype ran from June to November 2017
- Successfully demonstrated dual phase LArTPC concept
- Signal to noise (S/N) ~100 for a minimum ionizing particle (MIP) in Liquid argon
- Technical issues are being addressed for ProtoDUNE-DP

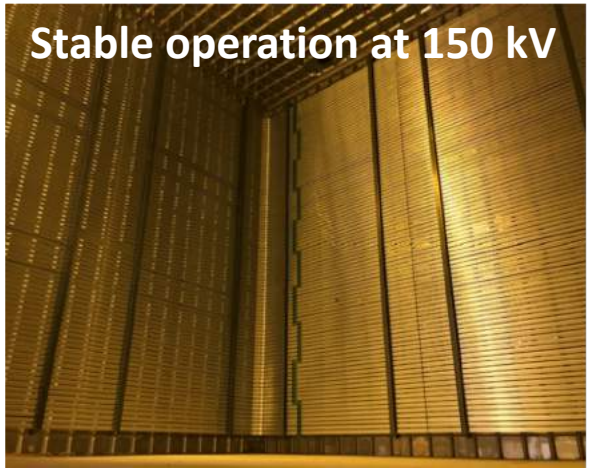
ProtoDUNE-DP: Current Status

- Apr 2018, completed field cage installation and demonstrated stable operation at 150 kV
- Aug 2018, CRP construction and cold box test underway.
- Sep 2018, Photon detection system installation
- Oct 2018, plan to close cryostat with 2 active CRPs and 2 non-instrumented CRP frames
- Dec 2018, start taking cosmic data

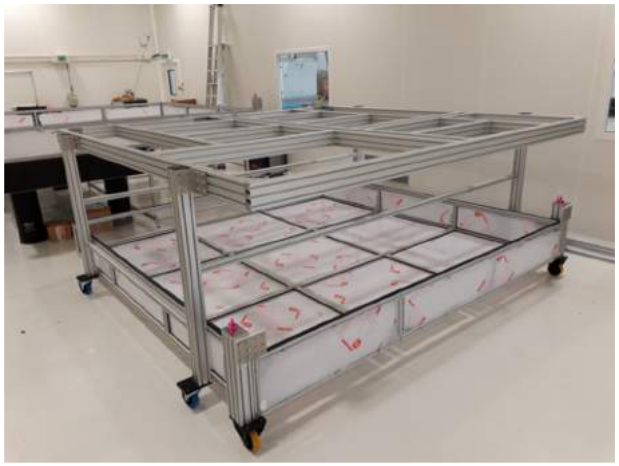
Top view of the CRP positions in the cryostat



Field Cage assembled on April 4th



CRP being assembled



PMT test under way

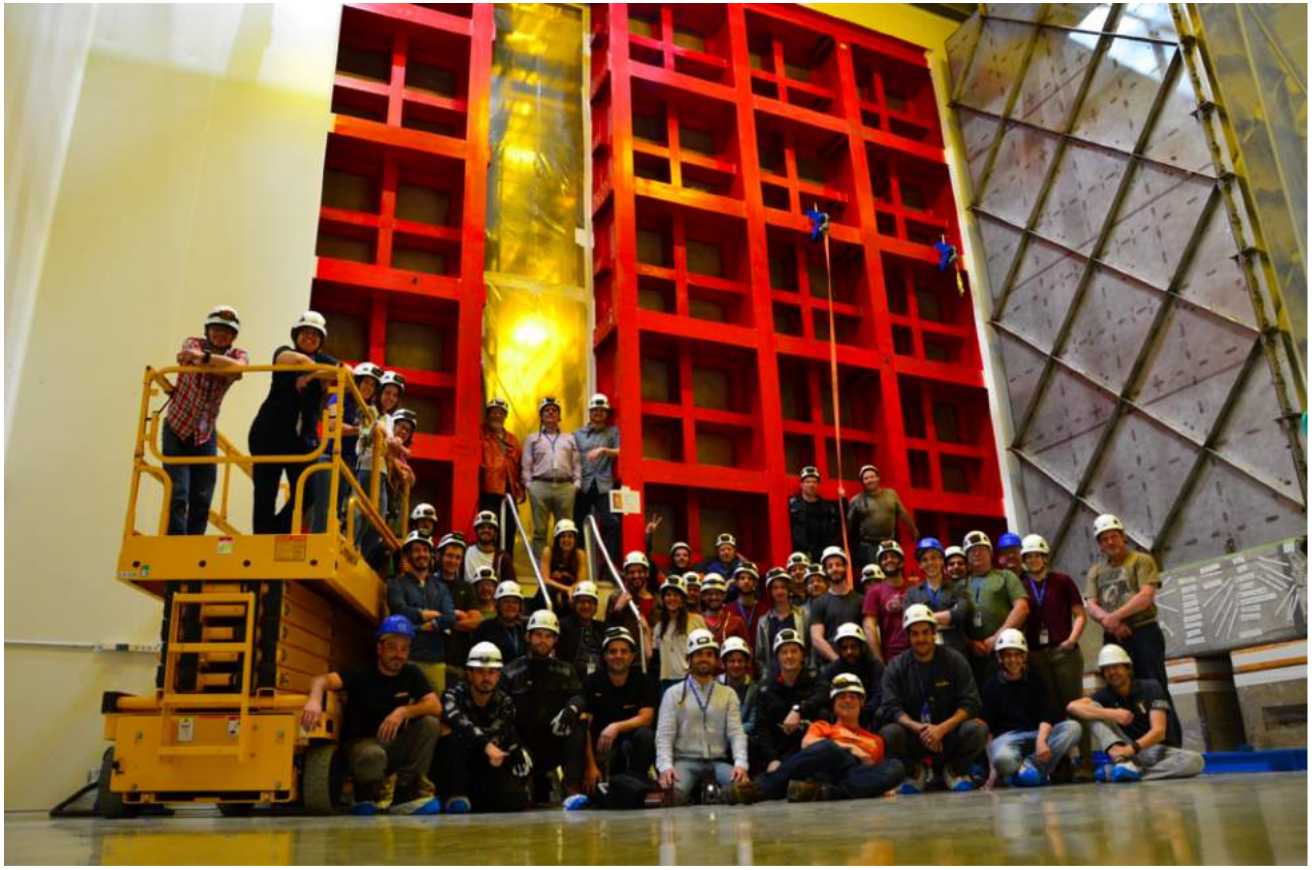
Moving Forward

June 2018: ProtoDUNE-SP complete

August 2018: ProtoDUNE-SP LAr filling complete

September 2018: ProtoDUNE-SP Starts taking beam data

December 2018: ProtoDUNE-DP complete



Conclusion

- DUNE far detector requires real-size prototypes to test the design and engineering solutions. ProtoDUNE detectors at CERN will test all the features in kton scale liquid argon TPC.

- ProtoDUNE has made impressive progress in building the detectors in the past two years: ProtoDUNE-SP is completed; ProtoDUNE-DP will be completed by the end of 2018

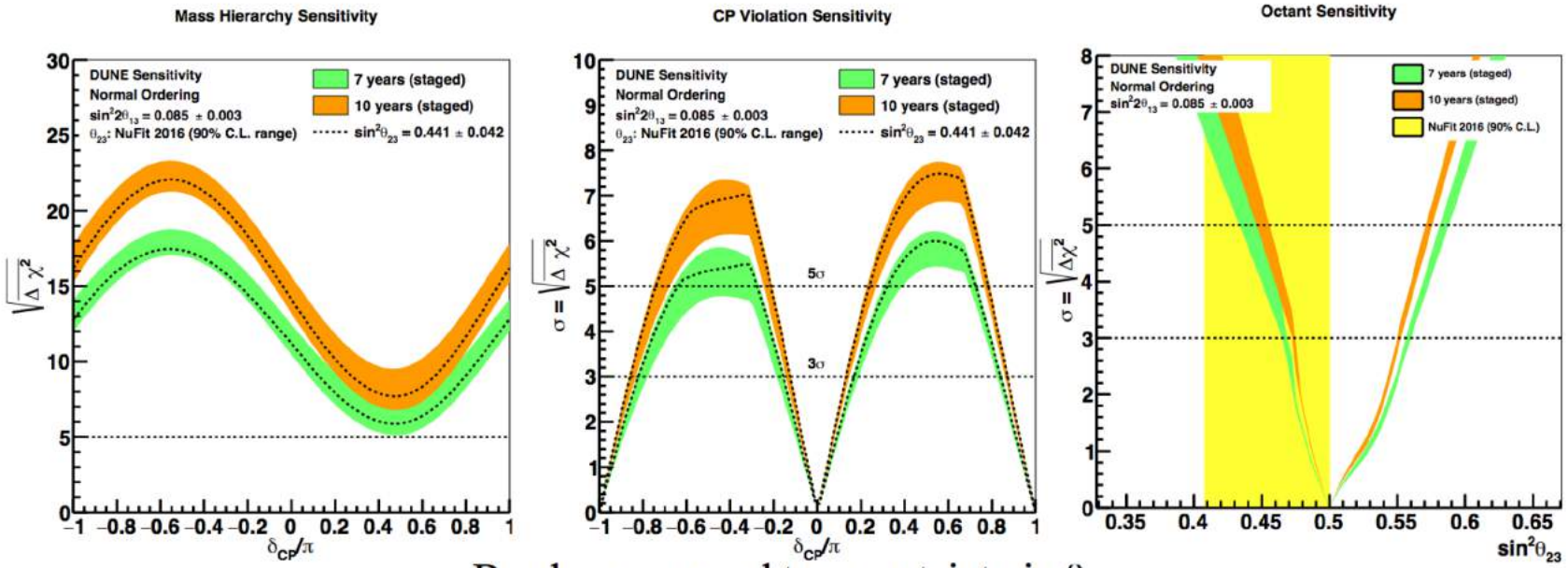
- **Beam is coming next month! We are ready to turn on the world's largest liquid argon TPC!**

Backup

DUNE Physics

Strong scientific programs in both beam physics and non-beam physics

ν_e appearance + ν_μ disappearance:
Decisive measurements to CP violation, Mass Hierarchy and Octant of θ_{23}



Bands correspond to uncertainty in θ_{23}

Also supernova neutrino burst, atmospheric neutrinos, proton decay, $n - \bar{n}$ oscillation, etc.