DEEP UNDERGROUND NEUTRINO EXPERIMENT

Prototyping the single phase LArTPC DUNE far detector design

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on behalf of the DUNE collaboration

TPC 2016, University of Paris Diderot

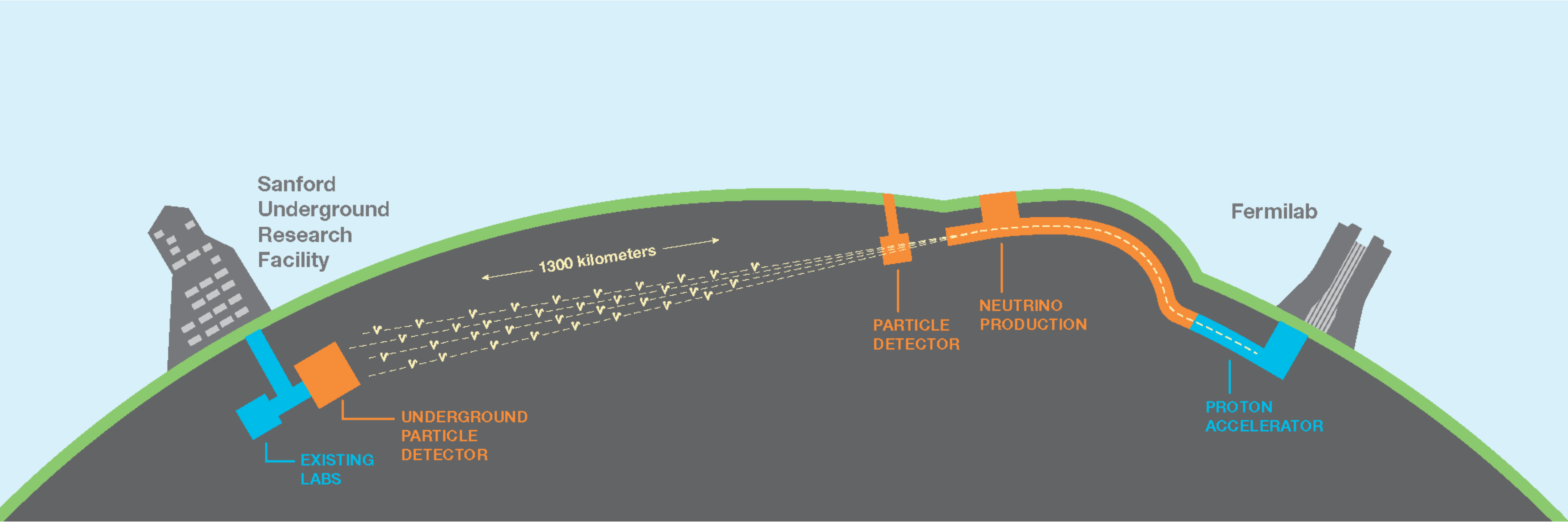
5th December 2016

The University Of Sheffield.

Outline

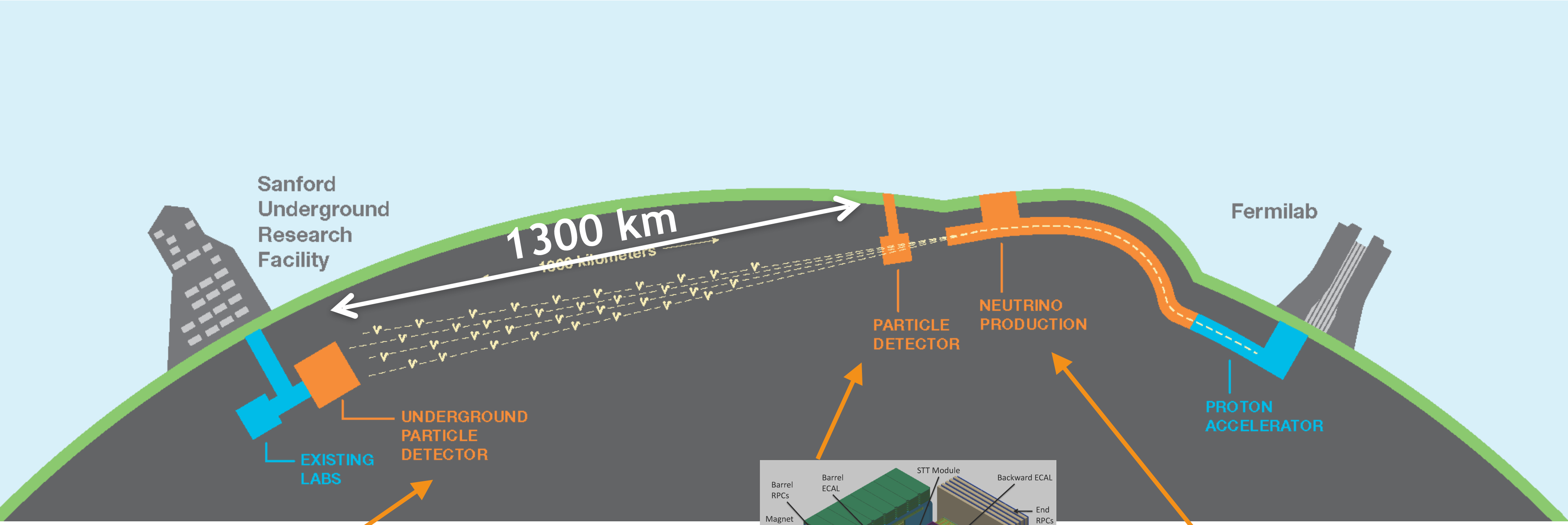
- The DUNE experiment
- DUNE physics goals
- DUNE single-phase LArTPC design
- The road to DUNE
- The 35-ton prototype @ FNAL
- The ProtoDUNE-SP prototype @ CERN
- Summary

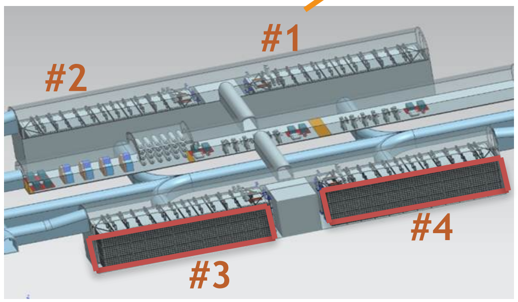
The DUNE Experiment



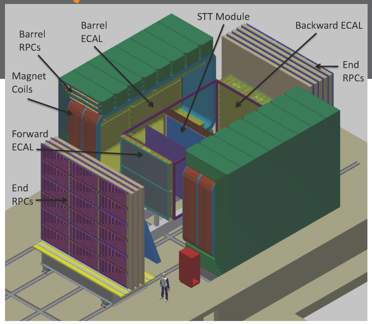
- Future long-baseline neutrino oscillation experiment with a rich program in neutrino physics, nucleon decay and astroparticle physics.
- Near detector will also allow precision measurements of neutrino interactions.
- Far detector utilises LArTPC technology to make highly sensitive physics measurements.

The DUNE Experiment





High precision near detector at 574 m



Wide band, high purity beam with peak flux at 2.5 GeV operating at ~1.2 MW and upgradable

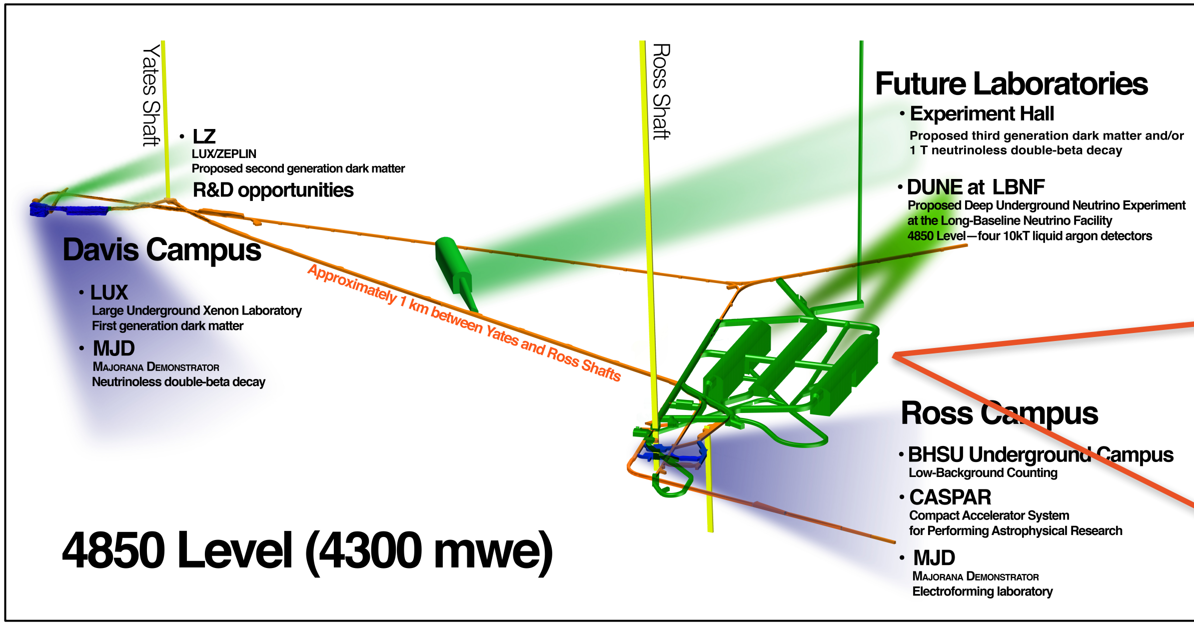
40 kton fiducial LAr neutrino detector 1.5 km underground. Four identical cryostats staged approach to four independent 10kton LAr detector modules

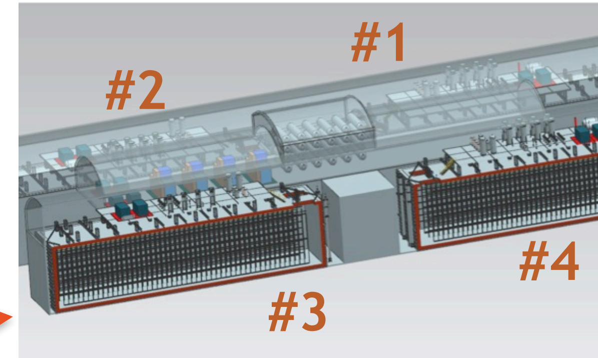
The DUNE Experiment

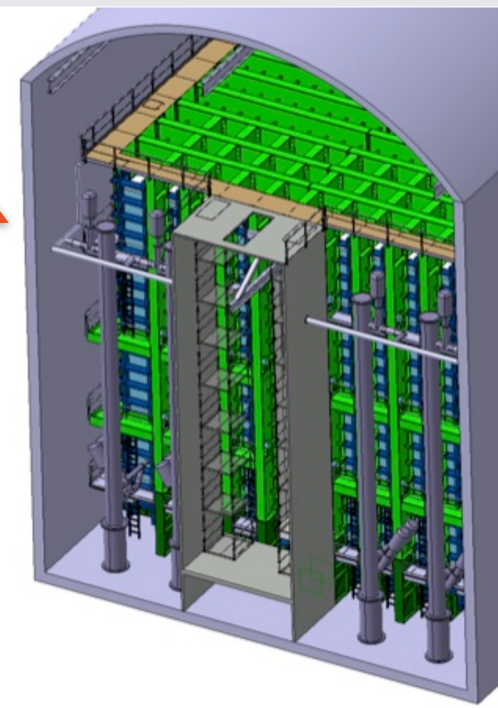
Sanford Underground Research Facility

Fermi National Accelerator Laboratory

The DUNE Far Detector



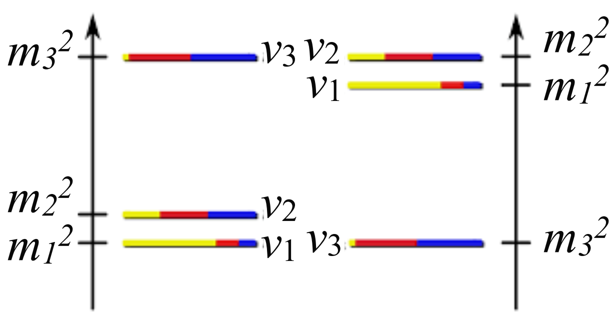




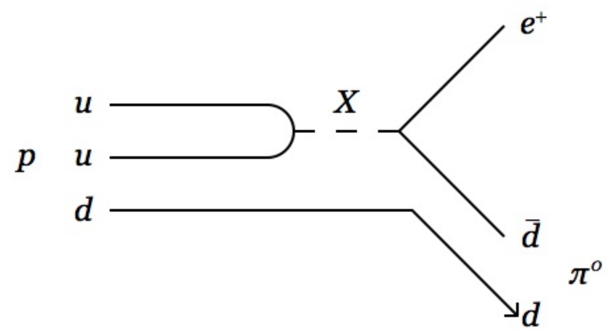
- LAr both the interaction target and the detector.
- 4 identical cryostats, each 17 kton total volume, can house either single phase (SP) or dual phase (DP) detector modules.
- First module, built by 2024, will be SP.
- Future modules may be either.

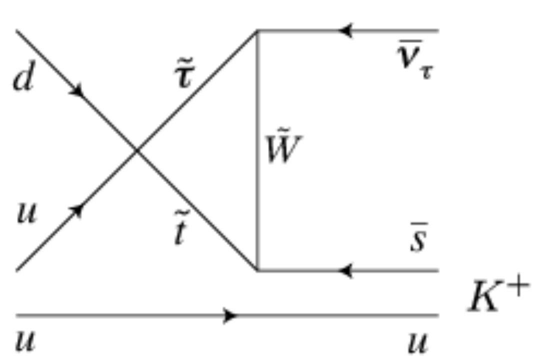
DUNE Physics Goals

Make precision measurements of neutrino oscillation parameters, including searching for leptonic CP violation and determining mass hierarchy.

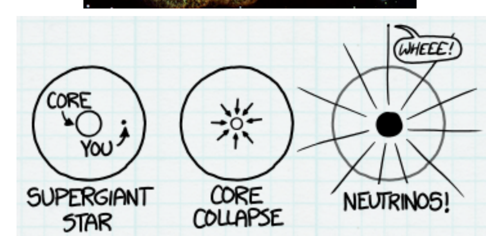


Potential detection of nucleon decay.





Measure spectrum and flavour composition of neutrinos from supernova burst in our galaxy.



DUNE Physics Requirements

Make precision measurements of neutrino oscillation parameters, including searching for leptonic CP violation and determining mass hierarchy.

Potential detection of nucleon decay.

Measure spectrum and flavour composition of supernova burst in our galaxy.

Requirements

- Large detector mass;
- Long baseline;
- Good energy resolution up to several GeV;
- Efficient electron neutrino identification.

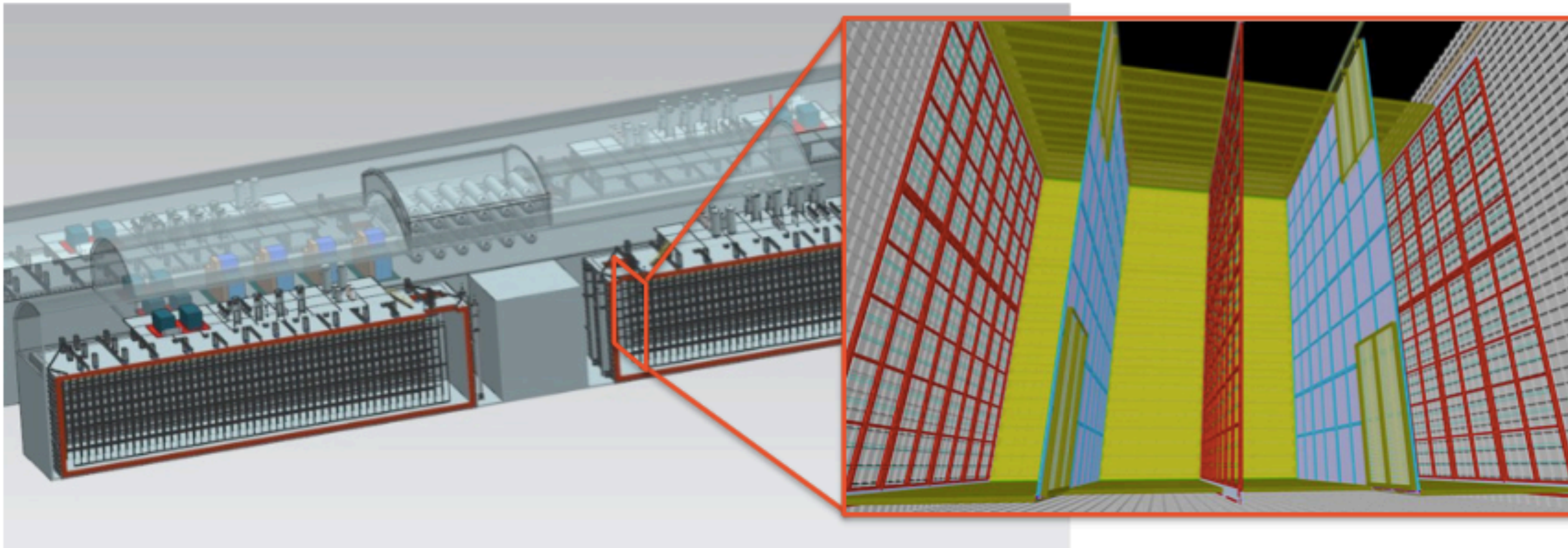
- Large detector mass;
- Low cosmic ray backgrounds;
- Timing for non-beam events;
- Efficient K+ identification;
- Continuous data taking.

- Large detector mass;
- Low energy threshold (~few MeV);
- Continuous data taking.

DUNE Physics Requirements

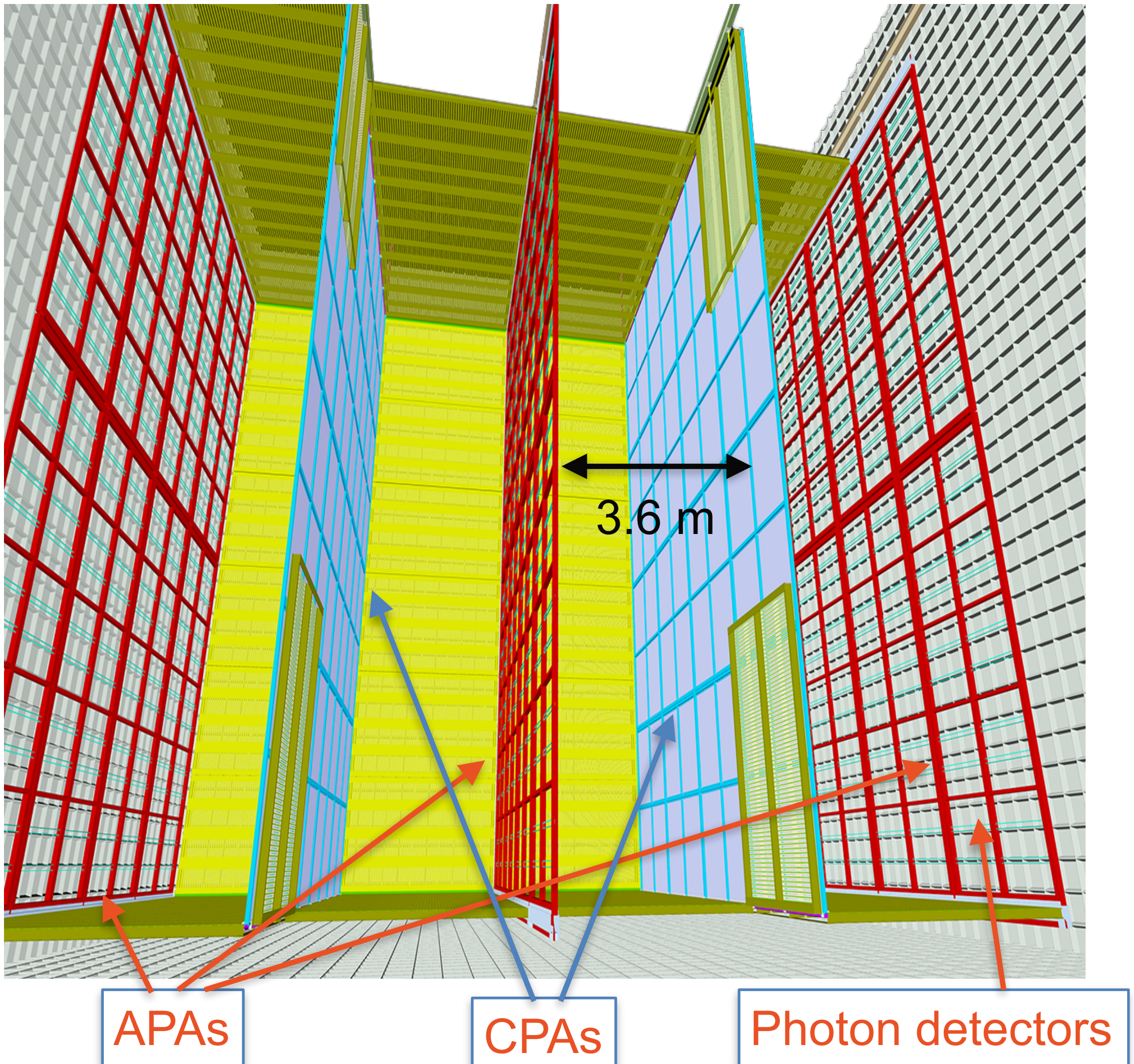
- Large detector mass — Large fiducial volume
- Long baseline
- Low cosmic backgrounds — Deep underground
- Good energy resolution — Liquid argon TPC
- Efficient electron neutrino identification — Good NC background rejection
- Low energy threshold — Good signal/noise on wires — cold electronics; High argon purity (contamination < 100 ppt)
- Timing for non-beam events — Photon detection system
- Continuous data taking. — Triggerless DAQ readout

DUNE Single-Phase Detector Design



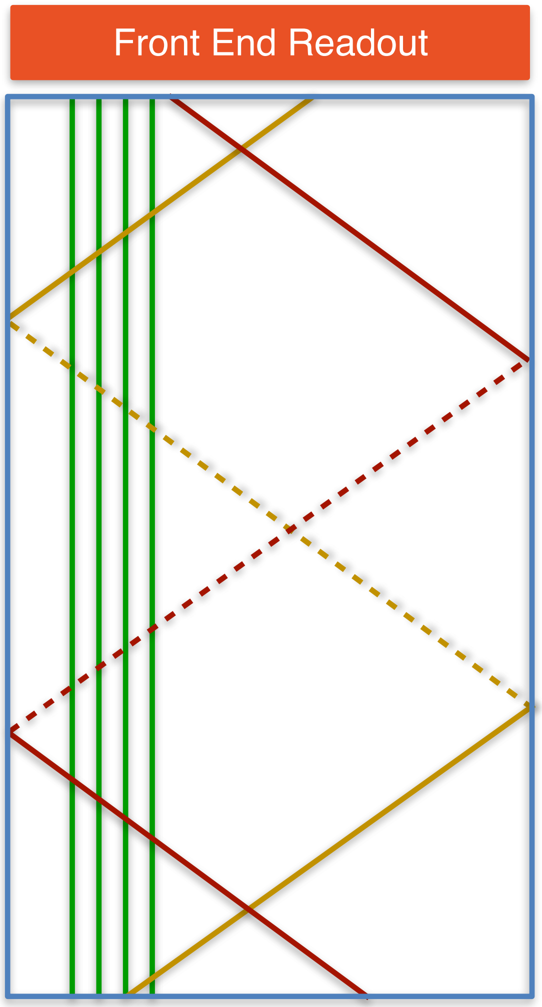
Active volume: 12 m x 15 m x 58 m (2x3x22 units, see next slide)

DUNE Single-Phase Detector Design



- Suspended Anode Plane Assemblies (APAs) and Cathode Plane Assemblies (CPAs).
- APAs have three active readout planes on each side (two induction, one collection) to read out ionisation charge.
- CPAs (180 kV) to provide drift field of 500 V/cm.
- Four drift regions (3.6 m each) perpendicular to beam direction; beam direction parallel to APA frames.
- Photon Detection System inside the APAs to detect scintillation light.
- Cold electronics (pre-amplifiers and digitisers).

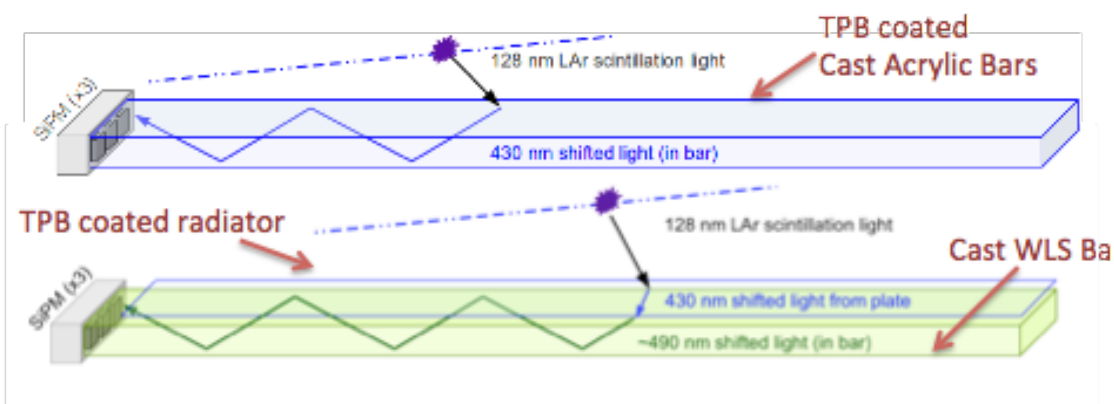
DUNE Single-Phase APA Design



- Wrapped wires read out charge from both sides of the APAs to reduce number of channels.
- Readout at the top of the upper APAs and at bottom of the lower APAs.
  - Allows APAs to be placed next to each other thus helps reduce dead region.
- Induction channels at angle of ~36° to vertical; collection channels vertical.
- Collection wires are not wrapped.
- Grounded mesh at centre of APAs.

DUNE Single-Phase Photon Detection

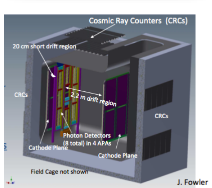
- Scintillation light is detected instantaneously on the timescale of the TPC information
  - Sets an absolute time, and hence position, of an event.
- LAr is an excellent scintillator (24,000 ɣ/MeV) but the light is at 128 nm.
  - Wavelength shifting lightguides with SiPM readout will be embedded in APAs.
  - Multiple designs being considered.

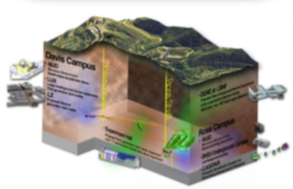


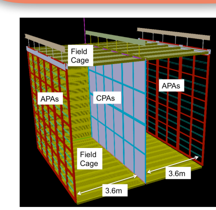
Prototyping the DUNE SP Detector

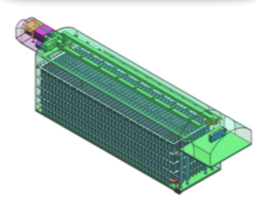
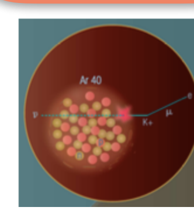
- Mitigation of risks associated with benchmark design;
- Establishment of construction facilities required for full-scale production of detector components;
- Early detection of potential issues with construction and detector performance;
- Provide calibration of detector response to particle interactions;
- Develop and test fully automated reconstruction techniques required for final detector.

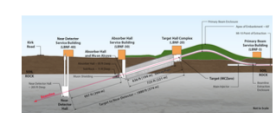
2016: 35-ton run → 2017: Far detector construction begins → 2018: ProtoDUNEs at CERN → 2021: Far detector installation begins → 2024: Physics data begins → 2026: Neutrino data taking





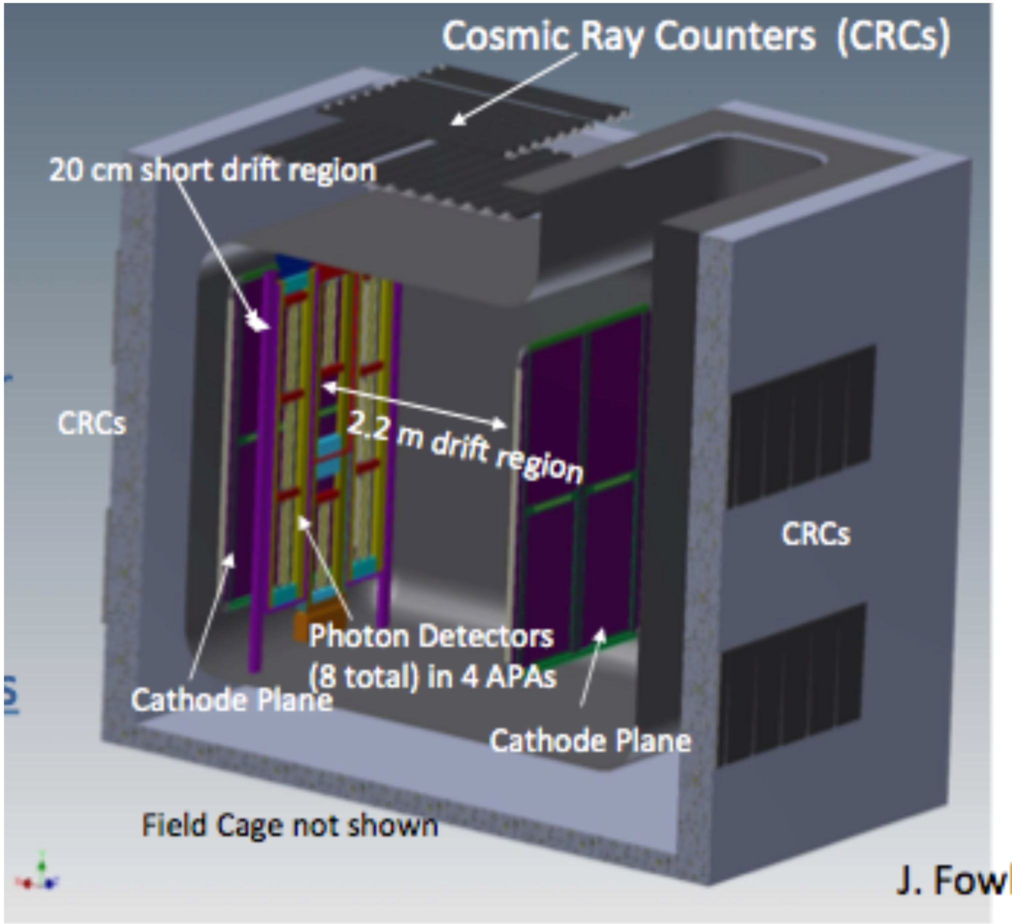




The 35-ton Prototype

- Test many design features of DUNE far detector:
  - Membrane cryostat;
  - FR4 printed circuit board field cage (LBNE design);
  - Light-guide style photon detectors (& SiPM detection);
  - Wrapped wire planes;
  - Multiple drift volumes;
  - Cold electronics (FE ASIC & ADC ASIC);
  - Triggerless DAQ operation.



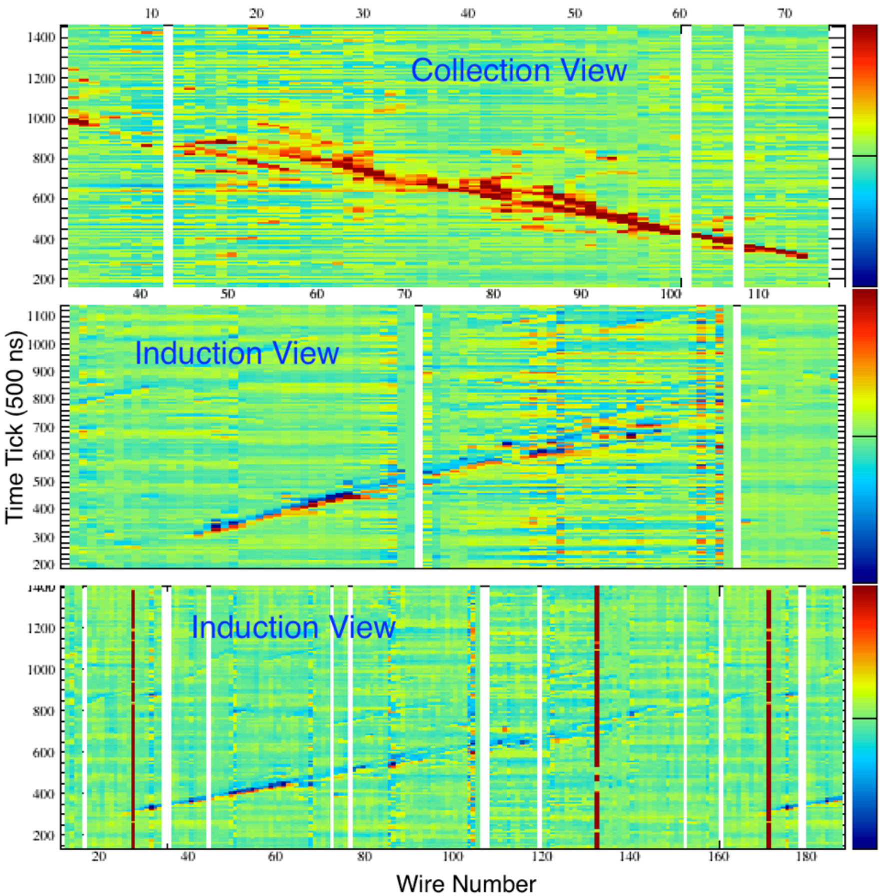
J. Fowler

The 35-ton Prototype Runs

- Run I (January — March 2014):
  - Initial run without detector to demonstrate required purity can be reached and maintained in membrane cryostat.
  - Achieved and held electron lifetime of 3 ms.
- Run II (January — March 2016):
  - Run with detector installed.
  - TPC (with 4 APAs), photon detectors and external counters.
  - Achieved and held electron lifetime of 3 ms with detector components present and validated integrated system.
  - Data analysis ongoing.

35-ton Outcomes

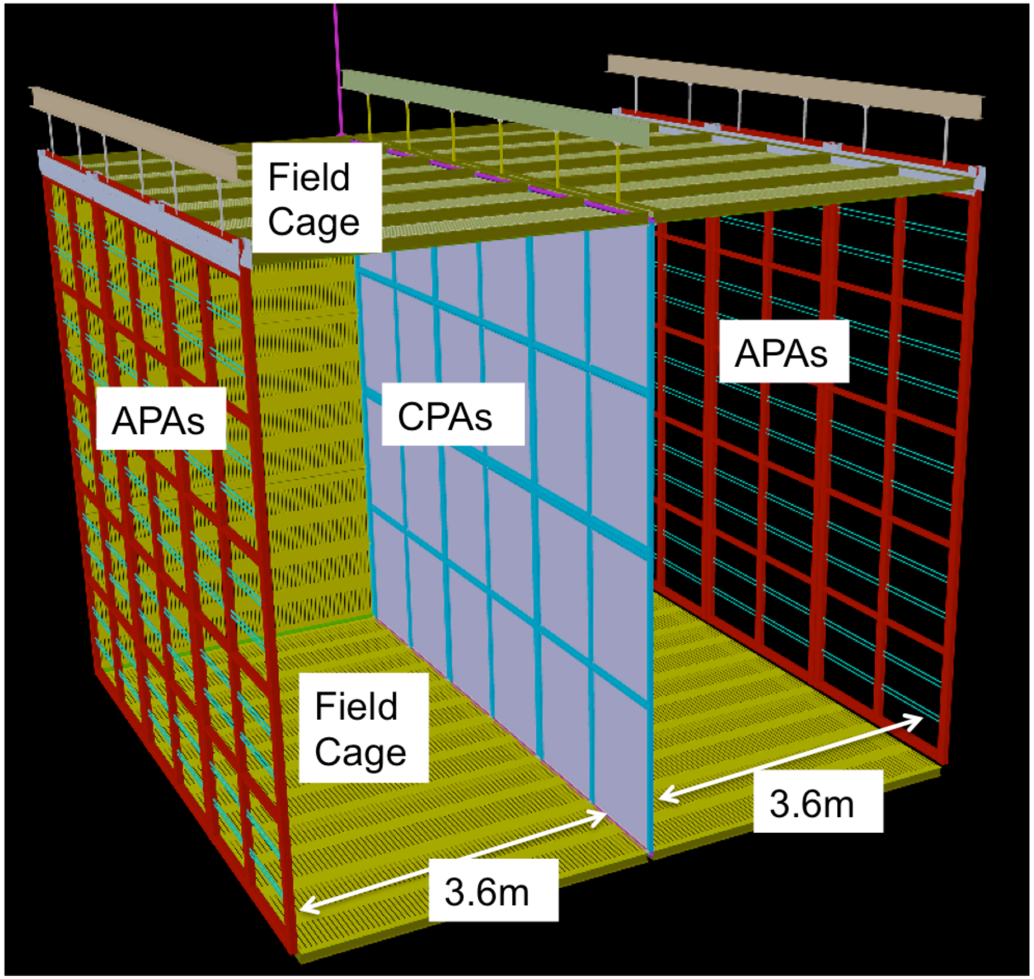
- DUNE requirement of 3 ms lifetime in a membrane, non-evacuable cryostat with fully implemented detector achieved.
- Automated reconstruction shown to work on real data.
- Unexpected issues with data:
  - Higher electronic noise than expected, mainly in FE electronics.
  - Signal/noise ~10 (collection channels), ~2 (induction channels).
  - Most noise problems have been identified and understood.
    - Successful prototype!
- Experience will be taken forward to the ProtoDUNE-SP experiment.
- Look out for papers in the new year!



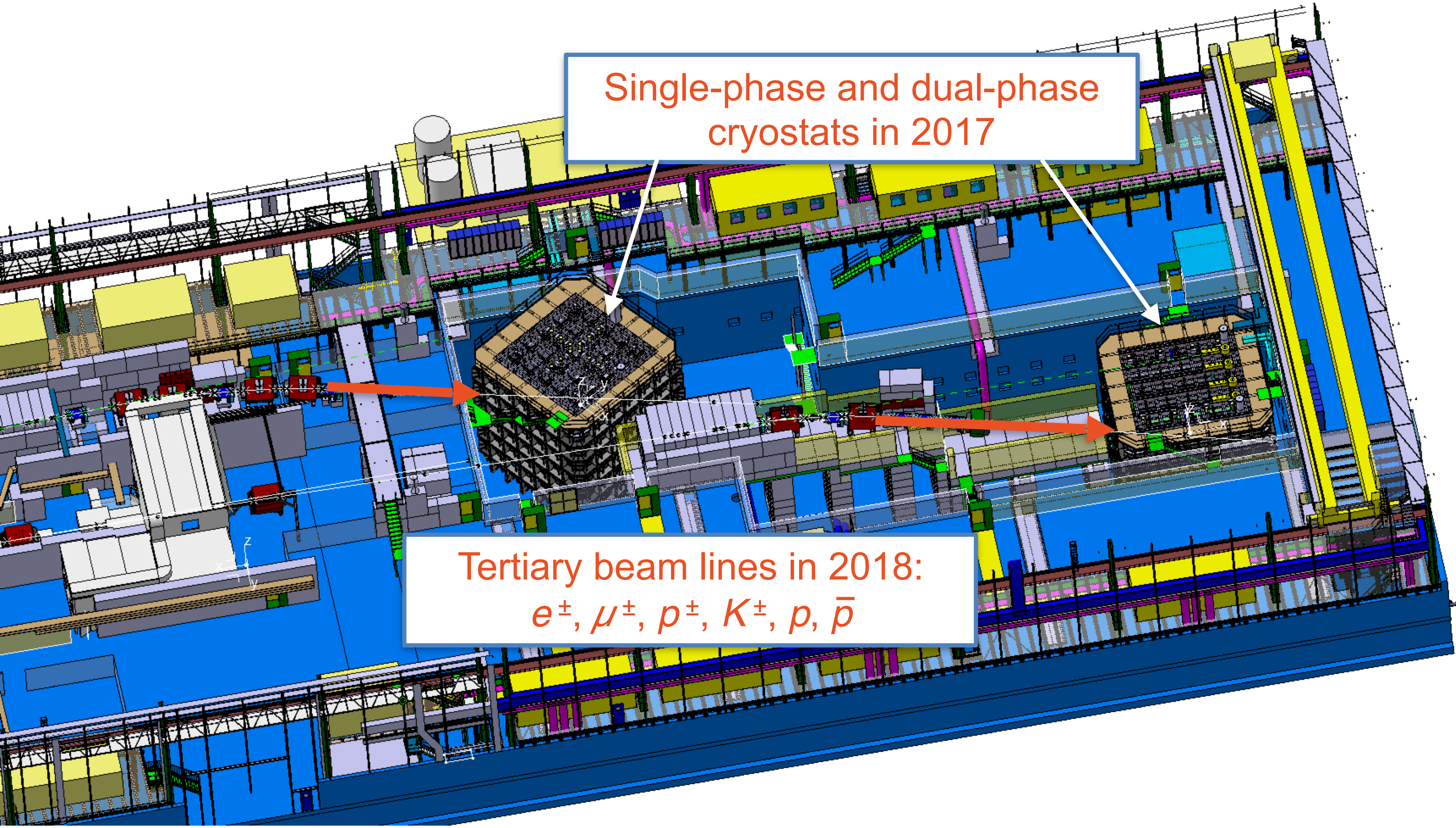
Electron shower seen in three views in 35-ton

ProtoDUNE-SP

- Full-scale engineering prototype:
  - Full scale APAs, CPAs and drift distance.
  - Comparing two different photon detector designs.
  - Test of component construction, installation, commissioning and performance.
- Will run in a test beam at CERN neutrino platform;
  - Scheduled to take test beam data late 2018.



CERN Neutrino Platform



ProtoDUNE-SP Programme

- Calibration for final far detector.
  - EM shower energy resolution, e/ɣ separation, particle ID (using dE/dx etc.)
- Assess detector systematics.
- Validate MC simulation and reconstruction.

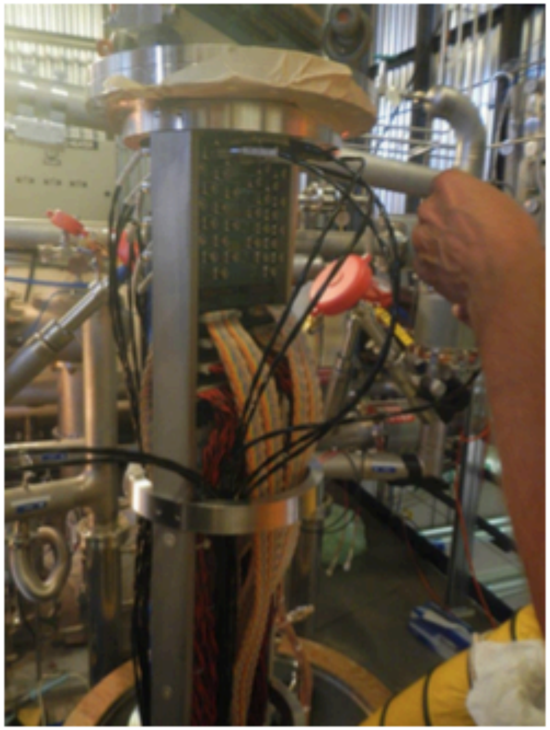
Particle	Momenta (GeV/c)	Sample Size	Purpose
π^+	0.2, 0.3, 0.4, 0.5, 0.7, 1, 2, 3, 5, 7	10k	hadronic cal, π^0 content
π^-	0.2, 0.3, 0.4, 0.5, 0.7, 1	10k	hadronic cal, π^0 content
π^+	2	600k	π^o/γ sample
proton	0.7, 1, 2, 3	10k	response, PID
proton	1	1M	mis-ID, PD, recombination
e^+ or e^-	0.2, 0.3, 0.4, 0.5, 1, 2, 3, 5, 7	10k	e-γ separation/EM shower
μ^-	(0.2), 0.5, 1, 2	10k	E_μ, charge sign
μ^+	(0.2), 0.5, 1, 2	10k	E_μ, Michel el.,charge sign
μ^- or μ^+	3, 5, 7	5k	E_μ MCS
anti-proton	low-energy tune	(100)	anti-proton stars
K^+	1	(13k)	response, PID, PD
K^+	0.5, 0.7	(5k)	response, PID, PD
μ, e, proton	1 (vary angle $\times 5$)	10k	reconstruction

Summary

- On the road to building 40 kton LAr TPC detectors underground at SURF.
- Each 10 kton module is a factor of ~15 increase from anything previously built, so prototyping is essential for the success of the DUNE experiment.
- Many novel features of the DUNE far detector design have been tested using the 35-ton prototype at FNAL;
  - Successfully validated the concept of the detector in membrane cryostat,
  - Learnt much which can be carried forward ensuring futures prototypes, and the final detector itself, will be even more successful.
- Next step: ProtoDUNEs at CERN;
  - Full-scale prototype in a test beam.
  - Will help us understand the detector even further.
- Exciting times ahead for the DUNE experimental program!

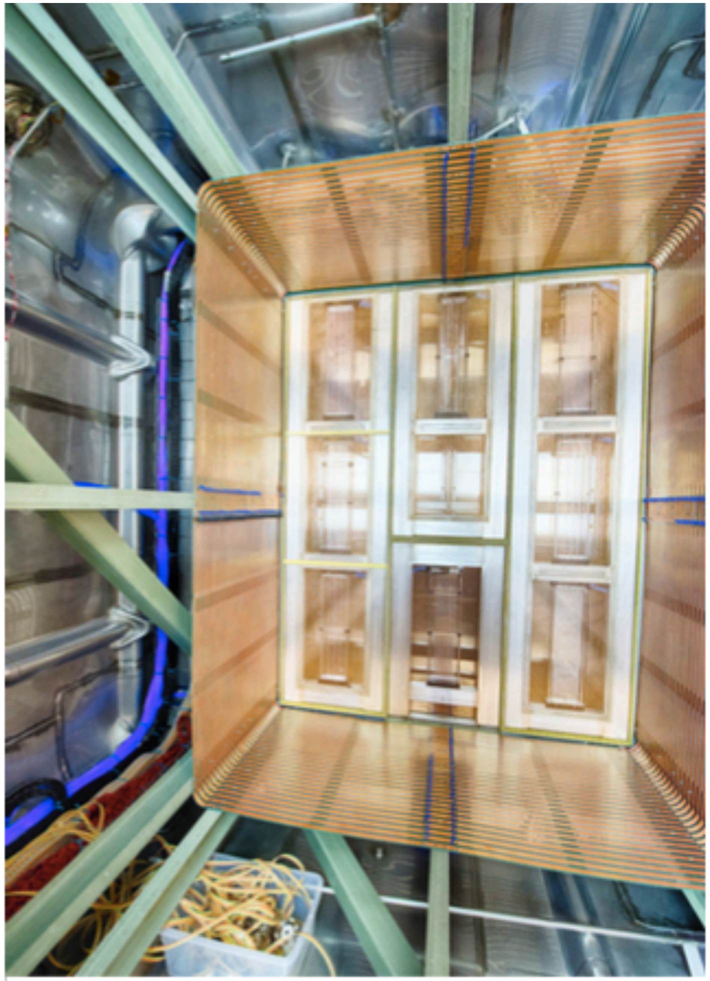
Back-ups

35-ton Pictures



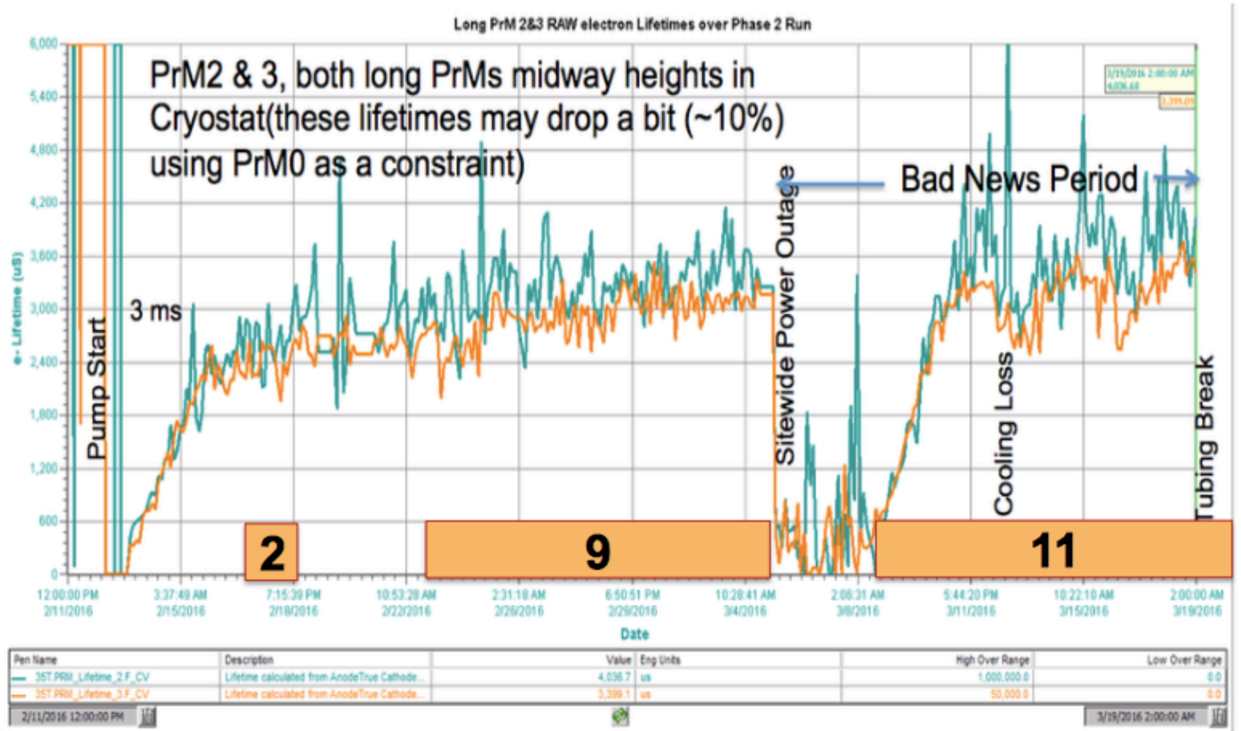
Flange Board outside

Cable Plant inside



APAs and partially assembled Field Cage

35-ton Data Taken



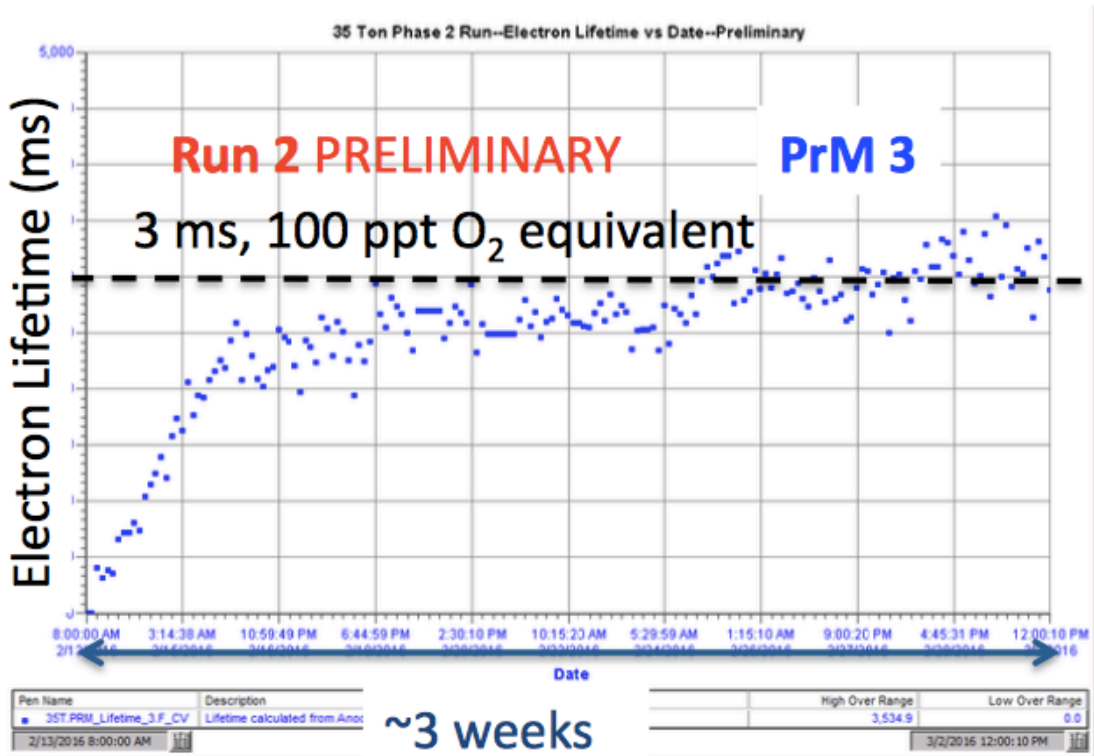
N - Drift field on at 250 V/cm for N days

- 14 TB on disk, 200k events.

35-ton HV

- HV distribution system (field cage, cathode, feedthrough) held 60 kV (half design stably over 6 weeks in pure liquid argon.
- No indications of field non-uniformities visible in TPC tracks.
- I contaminated argon, it was stable for several days at 90 kV and 120 kV (design).
    - Didn't get chance to raise the field before the argon contamination incident, 19th March 2016.

35-ton Purity/Lifetime



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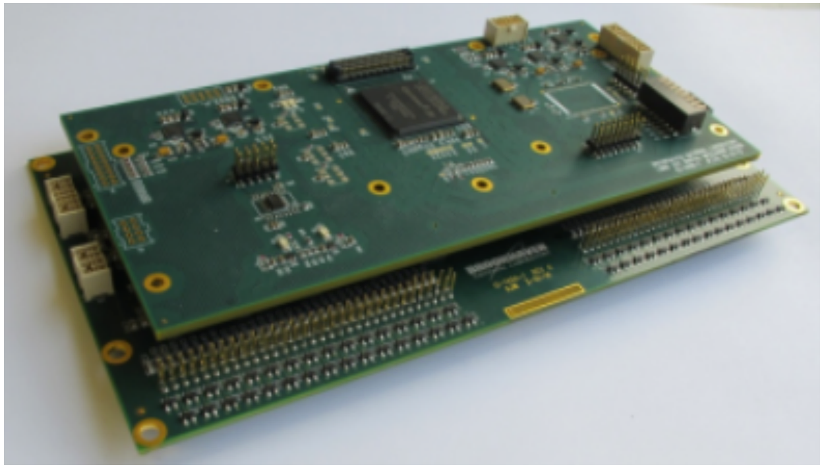
DUNE

35-ton Field Cage

- Held 130 kV in contaminated argon

35-ton Cold Electronics

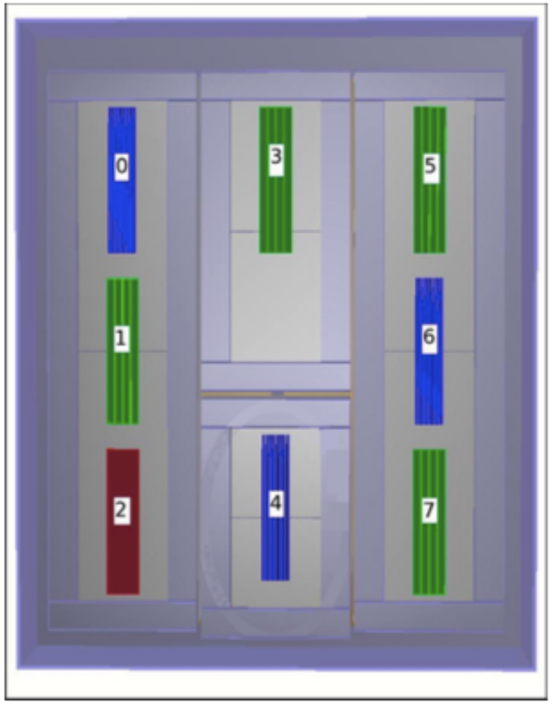
- First deployment of cold electronics (still under development).
- FE & ADC immersed in LAr.
- 128 channels per FEMB
  - High resonant noise, not all FEMB read out at same time.
- Noise tests have determined source of a lot of the noise (see next slide).
- Continuous testing during installation built into ProtoDUNE-SP installation process.



35-ton Noise Issues

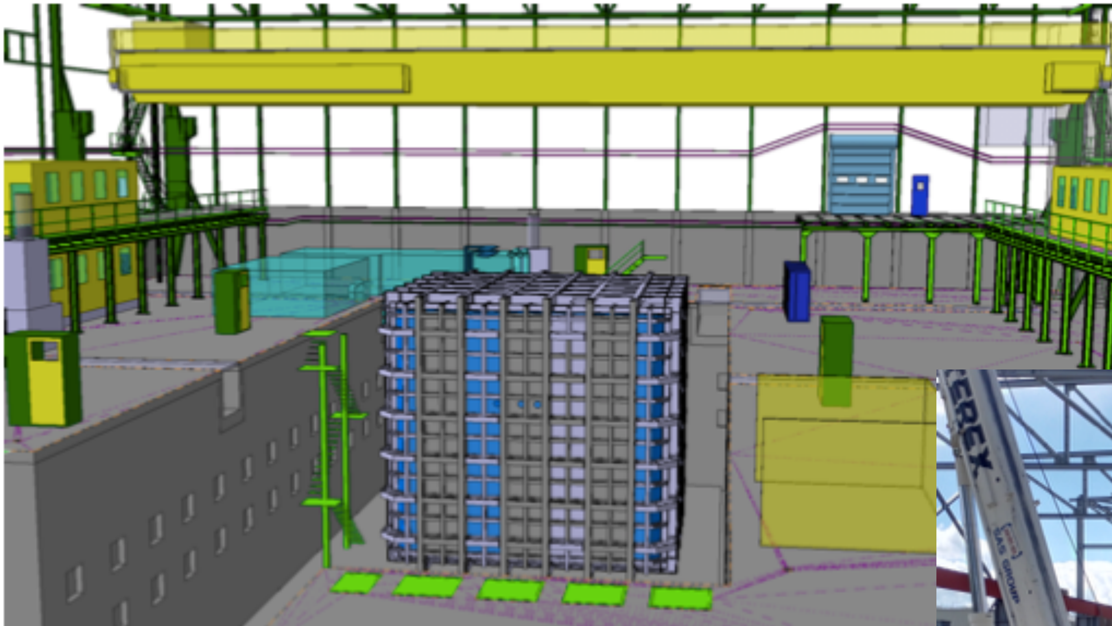
- 11 kHz — appears to come form regulator chip (each regulate voltage on 4 FE ASIC chips (64 channels)). Resistor in series (low pass filter) removes this.
- 100 kHz — phase difference between each FEMB; each has its own low voltage supply. Short found on low voltage cabling between supply line for FE ASIC chips and chassis ground for supply.
- Minimum noise value — twice MicroBooNE. Unsure yet, possibly wire length.
- High noise state — origins unknown, only speculation (although well justified, not confirmed).

35-ton Photon Detection System



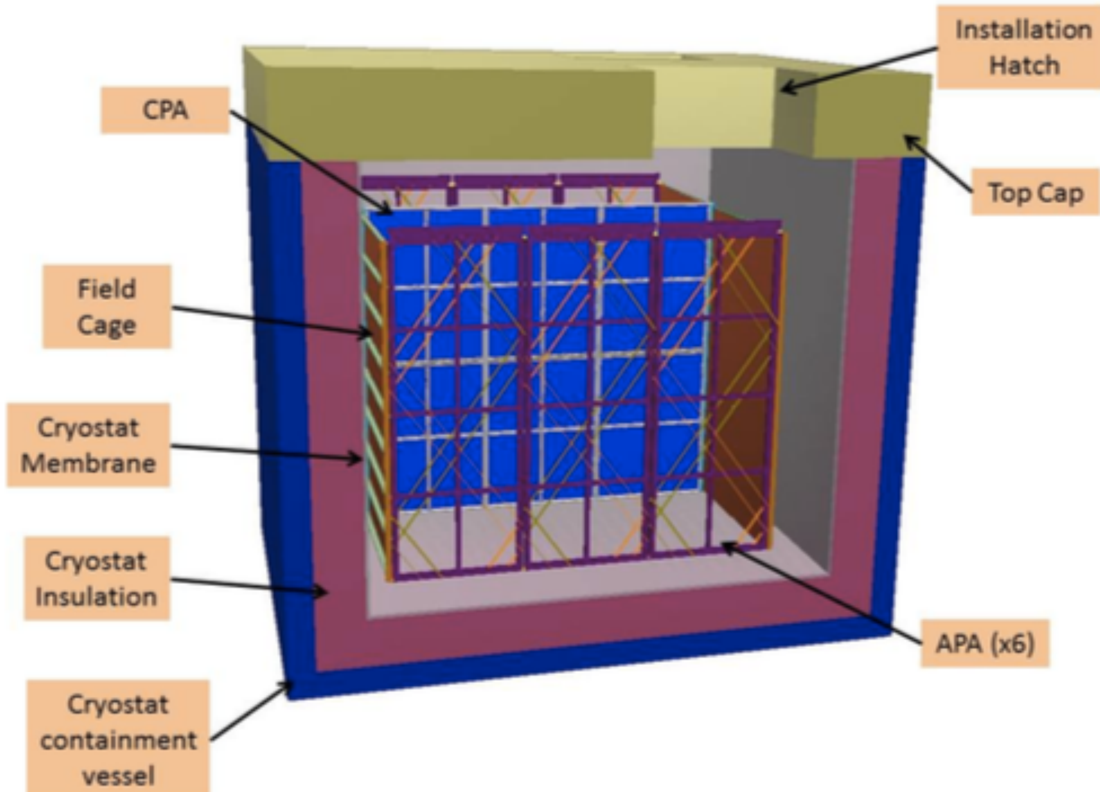
- Time resolution of photon detection system shown to be < 100 ns
  - Based on differences in muon counter times and photon detection.
- Successful system; look out for dedicated paper in the New Year.

CERN Neutrino Platform

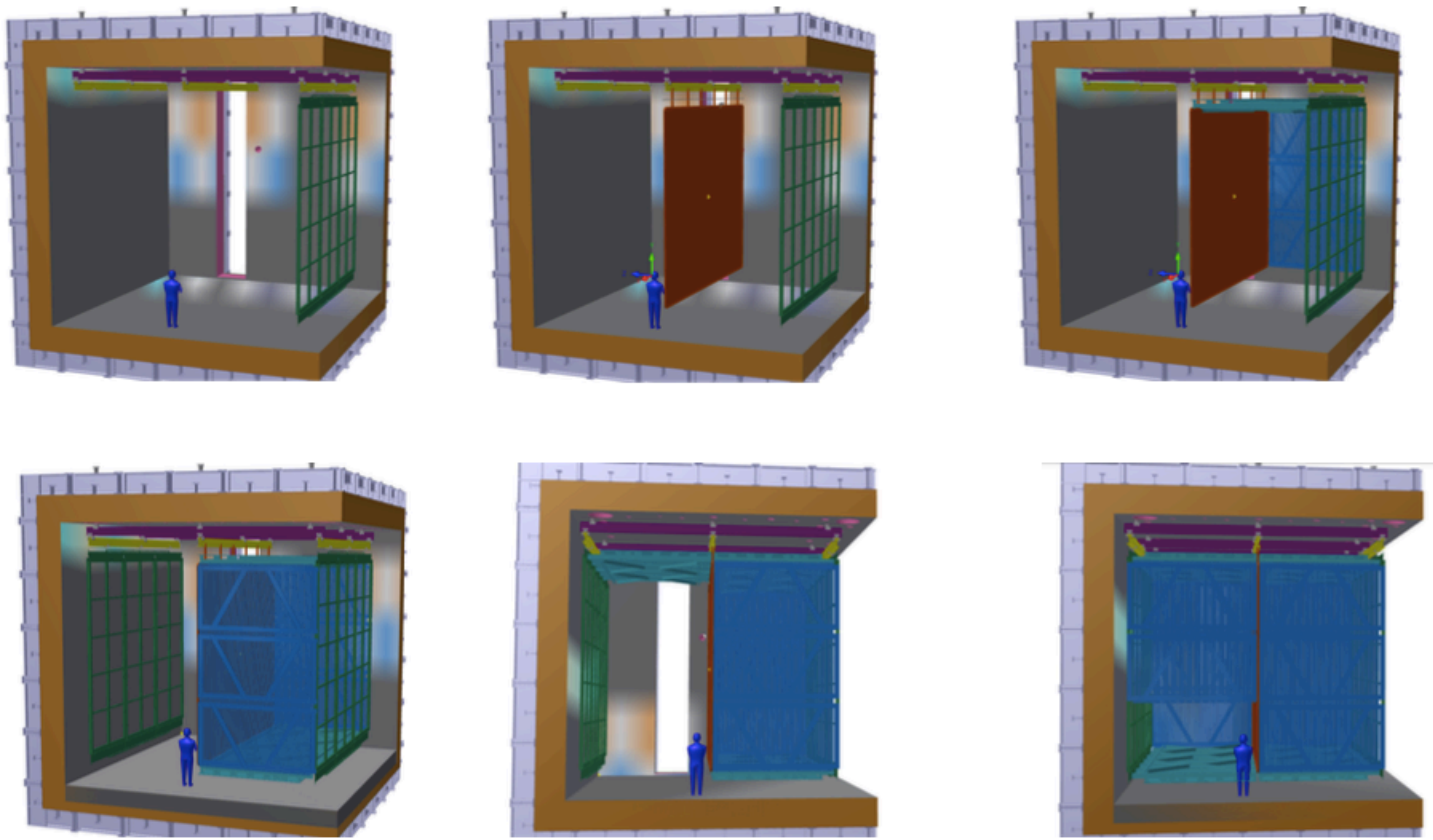


Under construction now (picture from summer 2016)

ProtoDUNE-SP in Cryostat

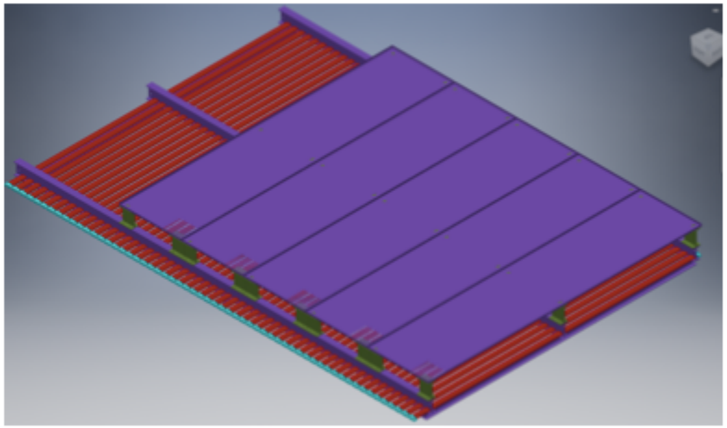


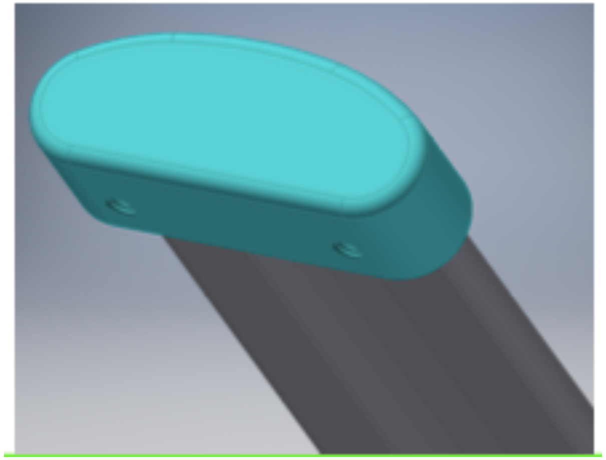
ProtoDUNE-SP Installation



ProtoDUNE-SP Field Cage

- Field cage will be constructed of roll-formed metal profiles: aluminium or stainless.
- Plastic caps prevent discharge of more than one panel.



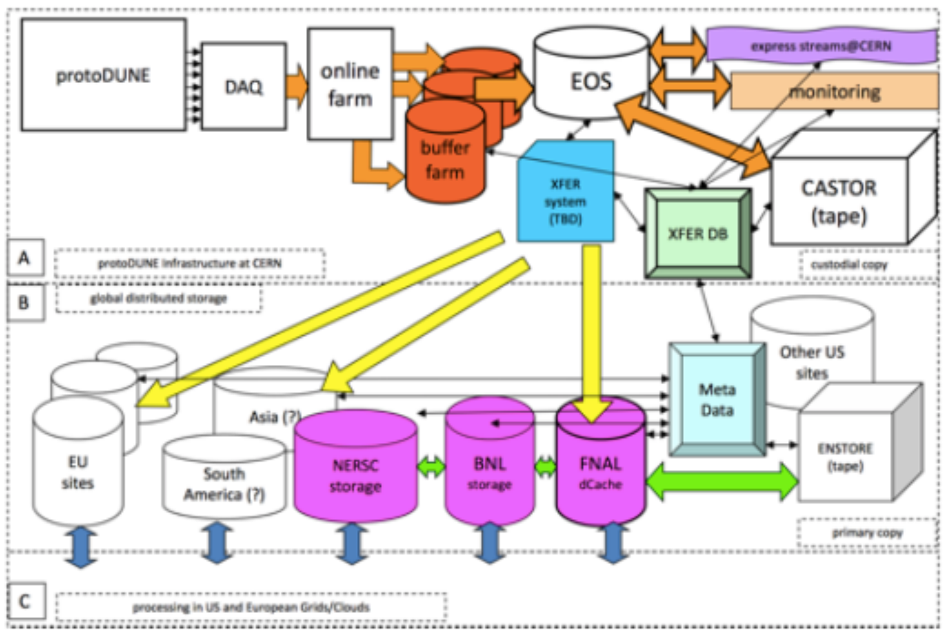


ProtoDUNE-SP DAQ

- 6 APAs, 2560 channels each, 2 MHz 12 bit ADCs.
- Trigger using beam counters and SPS beam spill.
- DAQ challenging due to large volume of data produced.
  - Raw rate pre-trigger TPC: 46 GB/s.
  - Trigger reduction: less than factor of 10.
- Two modes of data taking considered:
  - Triggered mode — from beam counters.
    - 50 Hz, 225 events per spill.
    - Inter-spill gap is sufficient to get data to computers.
  - Continuous mode (like far detector), used later.

ProtoDUNE-SP Computing

- Collaboration between CERN-IT, FNAL-SCD and ProtoDUNE SP & DP.
- Raw files transferred from both online disk buffer farms to CERN disk, from there to CERN tape and FNAL tape and other end-points.



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ProtoDUNE-SP Testing & Installation

- All detector components will arrive at clean room in EHN1.
- Integration and tests of APA+CE+PD will take place in the clean room.
- When one APA is equipped and tested it will be inserted inside the cryostat for further tests.
- Consecutive test cycles with increasing detector complexity.
- Crucial to learn/debug how the detector works from a slice to a full detector.
- Construction experts will participate in the installation.