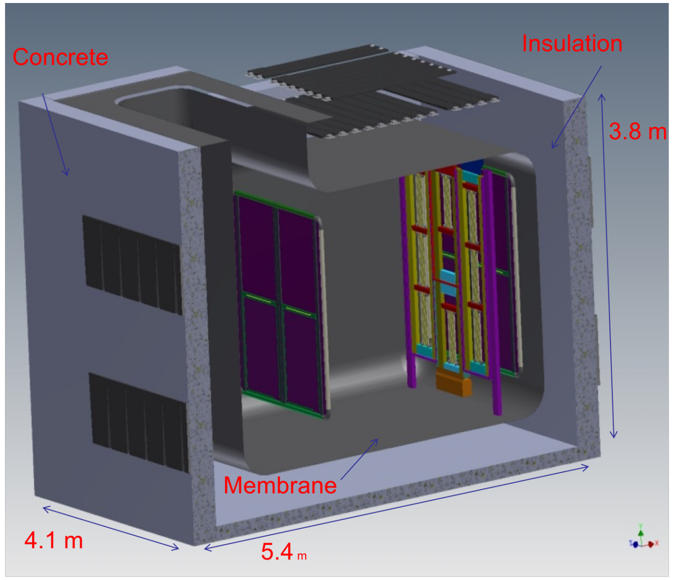
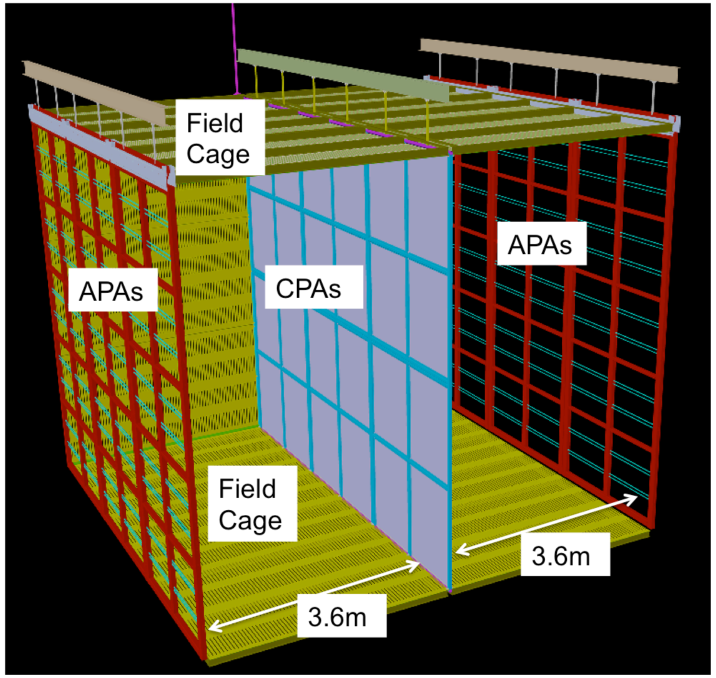
DUNE Single Phase Liquid Argon TPC Prototyping at CERN and Fermilab

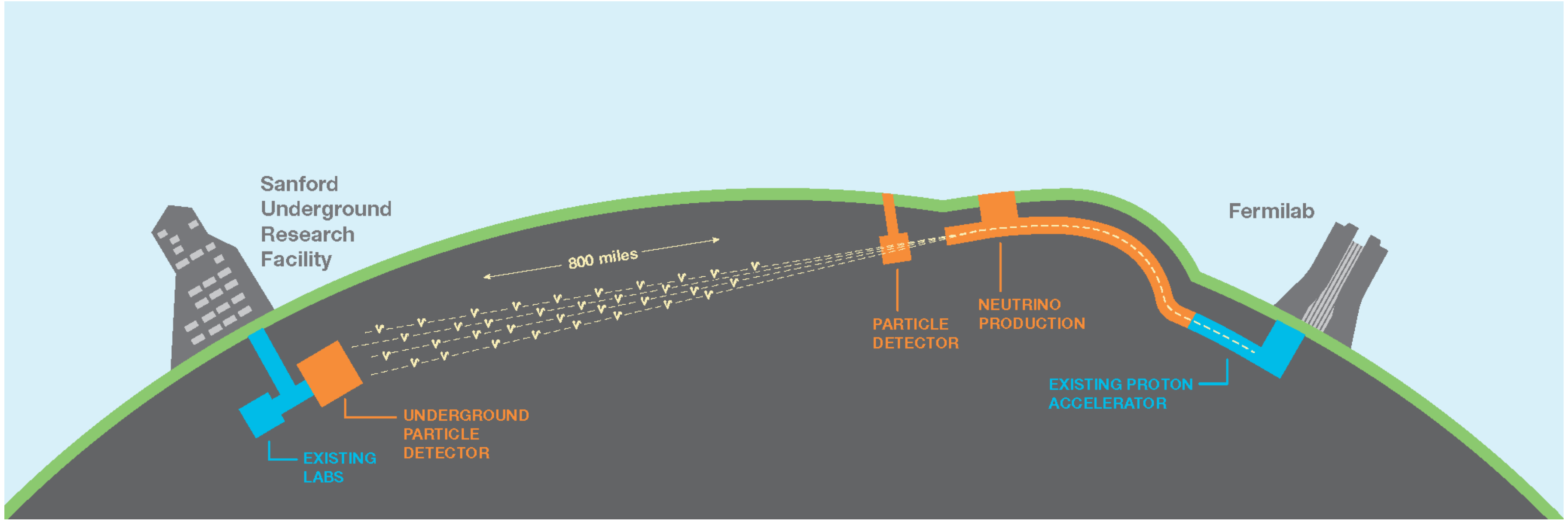


Jonathan Insler
for the DUNE collaboration

NNN15
October 28, 2015



Deep Underground Neutrino Experiment



- DUNE will observe a beam of neutrinos with ~2.5 GeV mean energy from Fermilab 1300 km through the earth to a far detector at the Homestake Mine in SD
- ν_μ will be produced at Fermilab and measured with a Near Neutrino Detector 574 m from the target; a 40 kt FD at Homestake will measure ν_μ disappearance and ν_e appearance

Goals of DUNE:

- Search for CP violation in neutrino sector
- Determine mass hierarchy of neutrinos
- Precision oscillation measurements
- Proton decay
- Supernova neutrinos

See DUNE@LBNF by Thomas Kutter for more details

DUNE Far Detector Prototypes

- DUNE far detector at SURF will be 4 individual LAr-TPC modules of 10 kt fiducial mass

- DUNE FD will be largest single phase LAr-TPC ever constructed and presents multiple engineering and data processing challenges
  - Need to scale up cryostat, electronics
  - Cold digital electronics to minimize number of cables and cable length

- 35t and protoDUNE are prototype single phase LAr-TPC integrated detectors which will test FD design and components

35t Prototype Motivation

- 35t prototype at Fermilab will begin taking cosmic data this December for ~2 month run

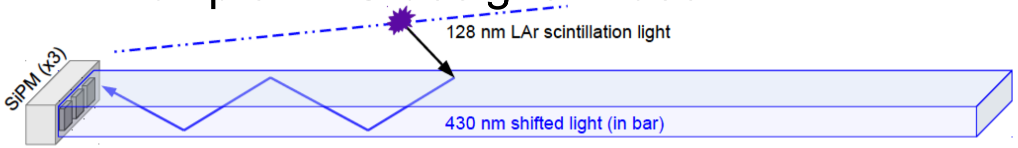
- 35t will test new engineering solutions
  - Examine new LAr-TPC features in an integrated system
  - Characterize technology's performance
  - Provide data sample for reconstruction algorithms

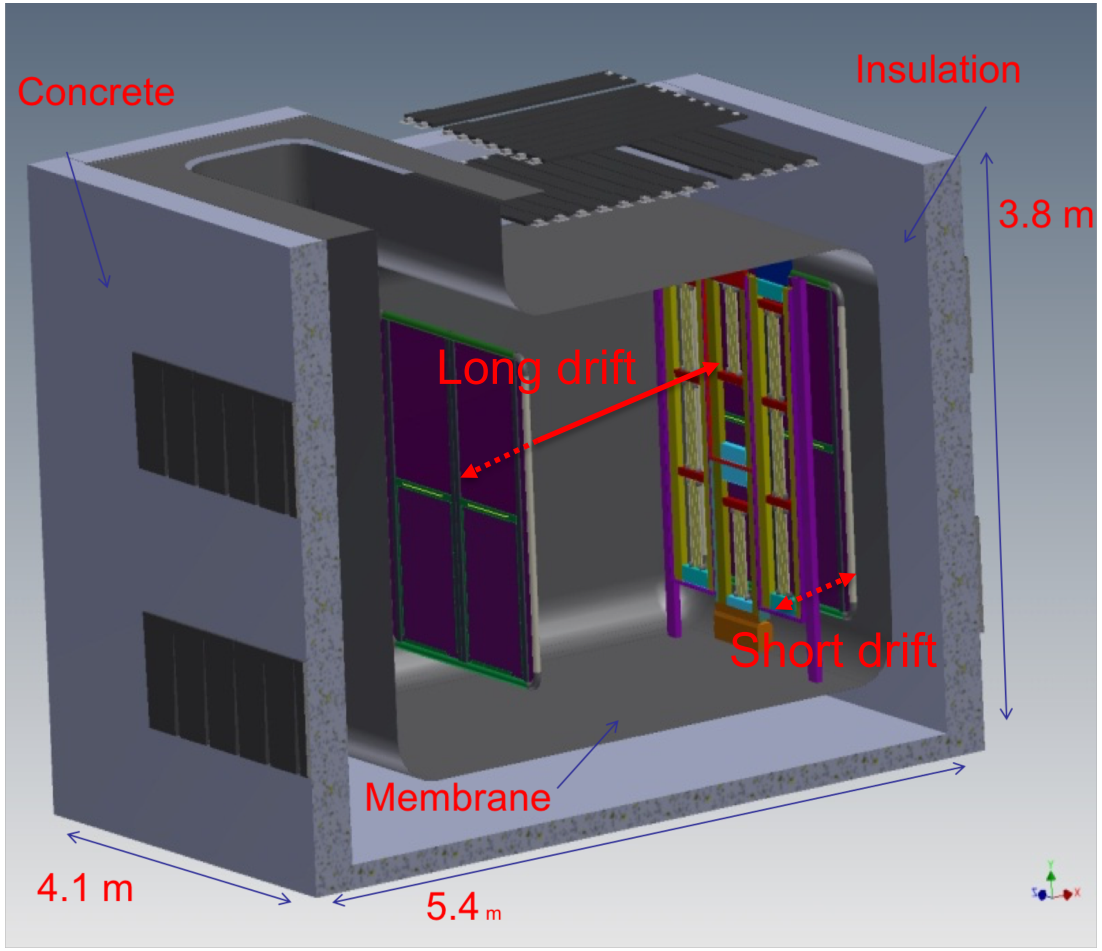
35t Detector at Fermilab

Characteristics:

- Active volume of 2.5 m × 1.5 m × 2.0 m
- Two drift volumes on either side of APA, long (2.23m) and short (0.23m); electric field will drift electrons across volumes to APA
- Eight sets of wire planes
- Field cage constructed with FR4 printed circuit boards

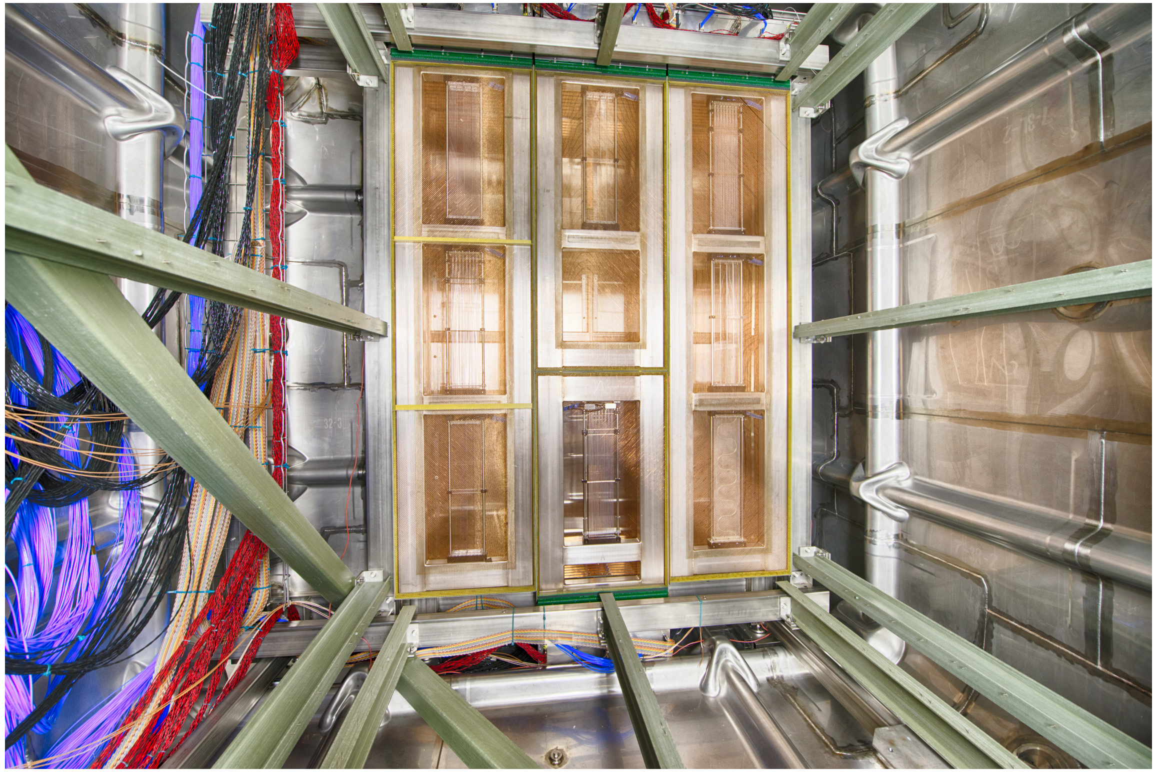
- Multiple PDS designs in use





35t Status and Data Sample

- Installation is nearing completion
- Two month data run expected to begin in December
- We expect about 1 cosmic ray muon per 1.4 ms drift window (long drift distance of 2.23m)
- Cosmic ray counter (CRC) trigger rate will be about 60 Hz for vertical cosmics plus around 3 Hz for close to horizontal cosmics



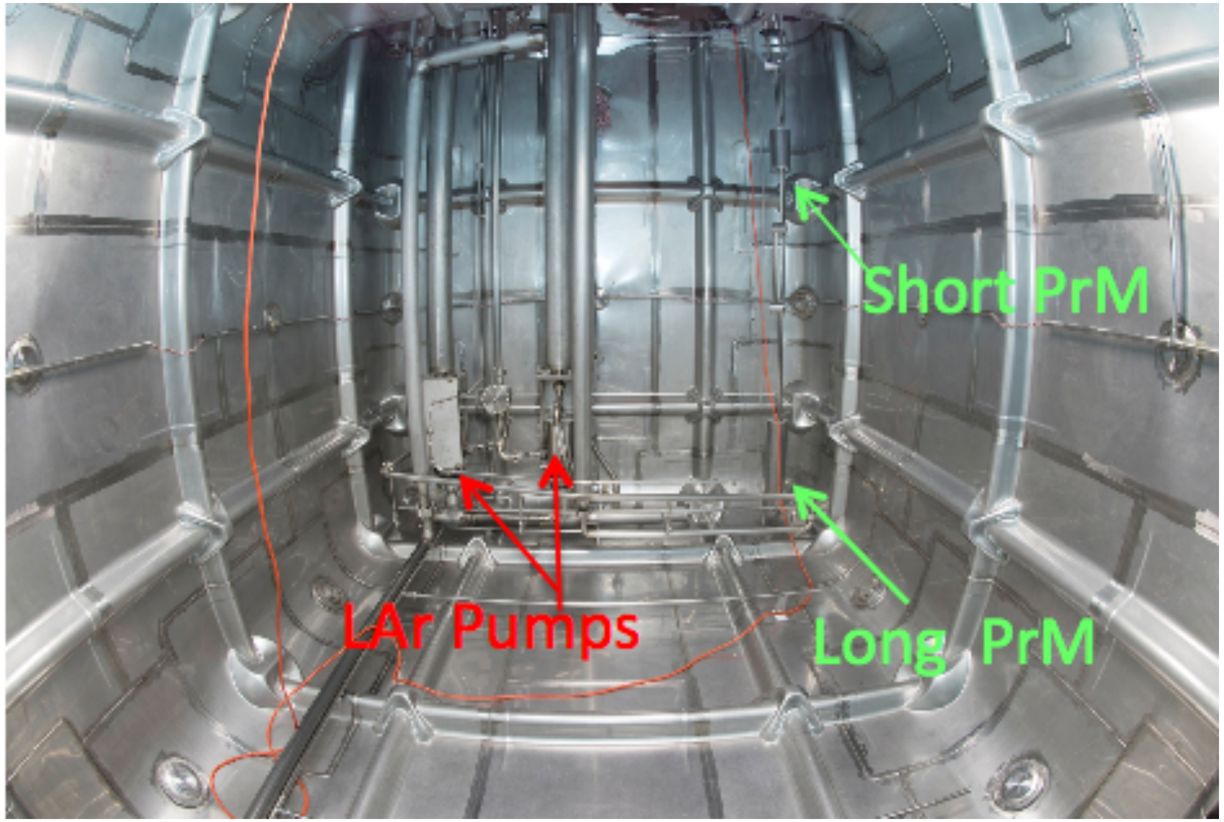
New Features of 35t Prototype

- Membrane cryostat
- Field cage with FR4 printed circuit board based construction
- Cold electronics (Front end and ADC ASICs) – 1st use of ADC ASICs in cold!
- Wire planes with wrapped wires
- Photon detectors utilizing light guides to SiPMs
- Continuous readout, i.e. triggerless DAQ operation
    - CRCs will record t_0 even in triggerless operation for time resolution of PD measurement

These features will be tested in 35t and will inform design of DUNE LAr-TPC far detector!

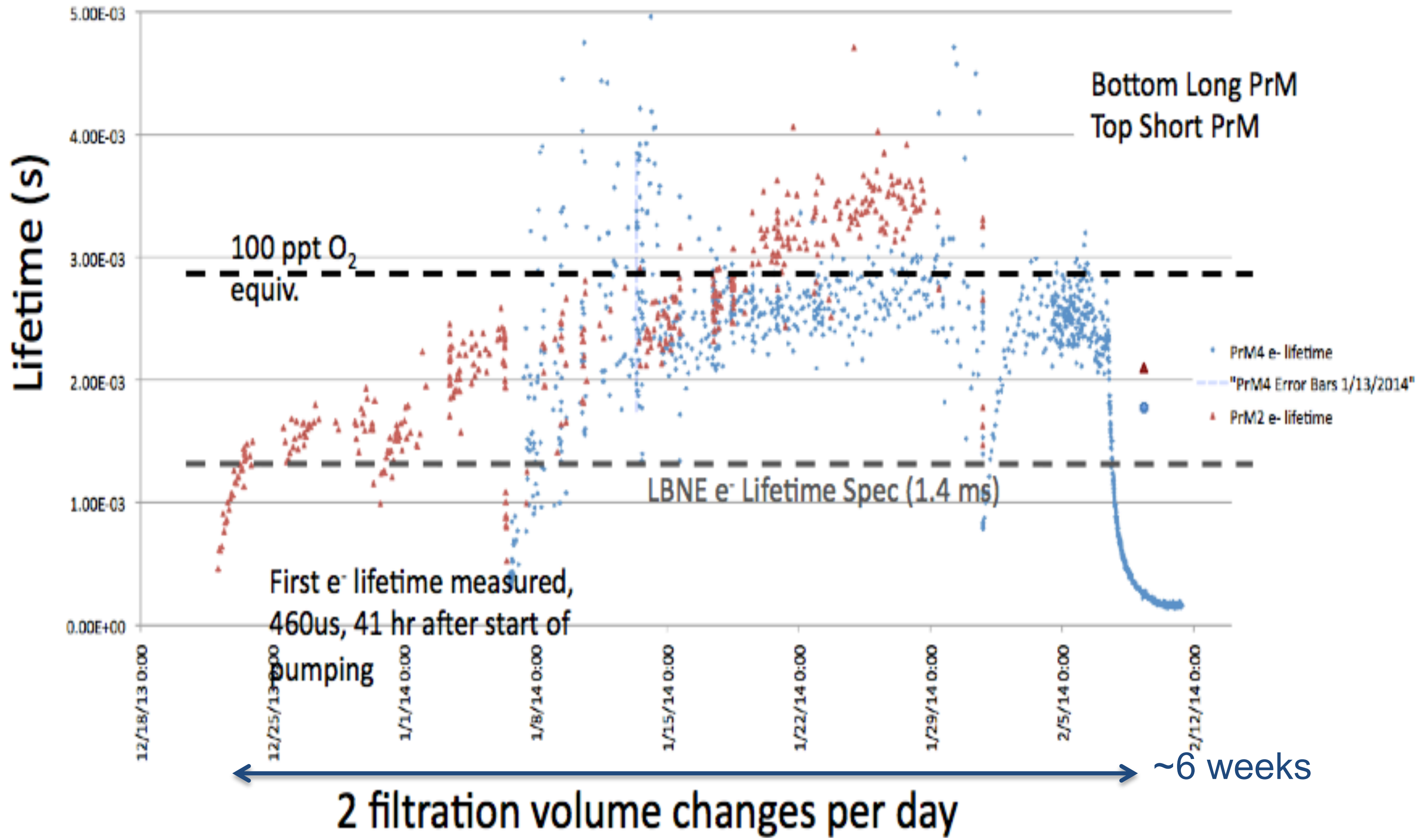
35t Phase 1 (2014) Membrane Cryostat Performance

Phase 1 test of membrane cryostat achieved LAr purity required for detector operations (next slide)



- Goal of >1.4ms electron lifetime exceeded!

35t Phase 1 (2014) Purity Measurements



35t Phase 1 (2014) Lessons Learned

- Leaks found in vacuum relief valve and dielectric-break seals leaked
  - Mitigated in Phase 1
- Purity monitors vibration-sensitive
  - Redesigned for Phase 2
- Purity loss during filling and pump switching
  - Filling procedure to be modified for large detector
  - Pump will be moved outside future cryostat

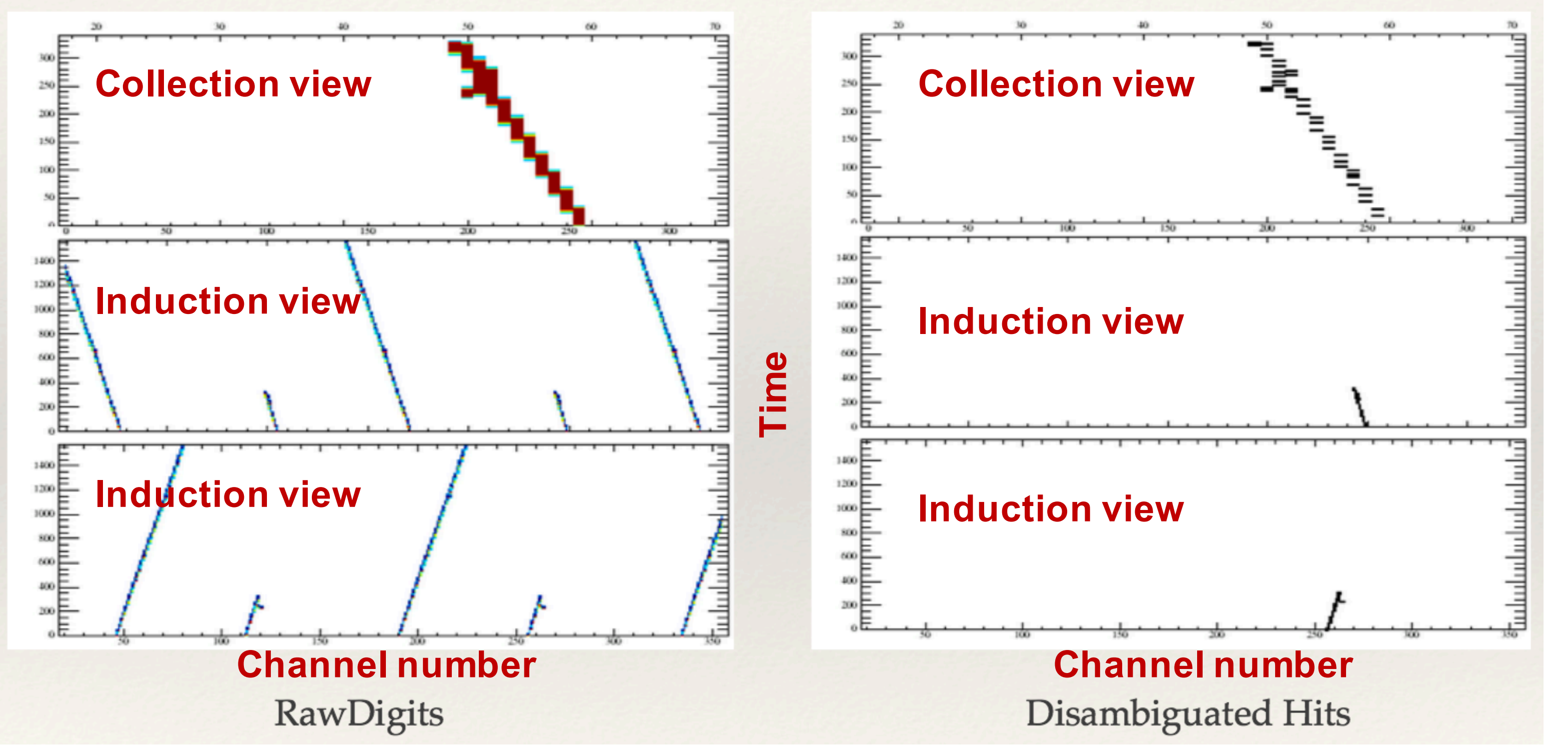
Technology RD Goals

- Build and test TPC with same design principles as projected DUNE FD
  - Multiple drift volumes
  - Integrated TPC and PDS – can reconstruct full events and measure light
  - Wrapped wires on APAs – conserve space taken by readout electronics and allow APA tiling to minimize dead space (~1.3% of active area)
- Hardware:
  - Evaluate performance uniformity of channel and cold electronics
  - Test detector grounding plan
- Software:
  - Fully reconstruct particle interactions in event display to test integrated system of whole detector
- Operation:
  - Test zero suppression algorithms for data taking in continuous readout

35t TPC Performance Evaluation

- Reconstruct straight tracks across gaps in wire planes via stitching
  - Examine edge effects of electric field near wire plane edges and gaps

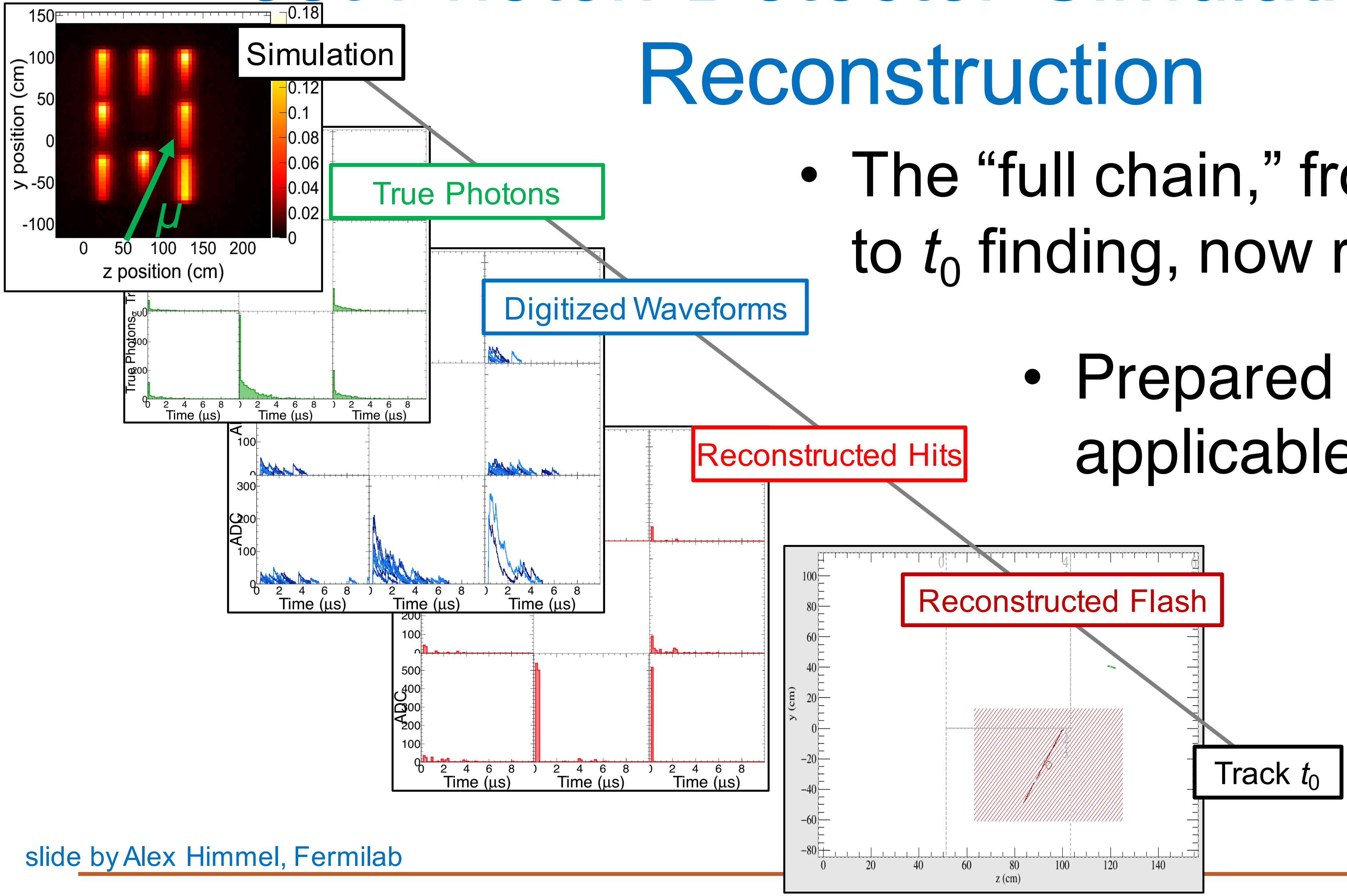
- Test disambiguation of hit positions on wrapped wires



35t Photon Detector Goals

- Test PD systems for use in DUNE FD
  - Slightly different PDS technologies are being used; 35t detector data will allow comparison of performance
- First test of light guide to SiPM photon detectors integrated with a TPC
- Event time resolution determined from PD flashes
- Use Michel electrons identified by TPC to optimize small signal detection and measure energy resolution in photon detectors

35t Photon Detector Simulation and Reconstruction



- The “full chain,” from simulation to t_0 finding, now running

- Prepared for 35ton, but applicable to FD as well

slide by Alex Himmel, Fermilab

35t Performance Measurements

Measure basic performance parameters of LAr-TPC technology for DUNE FD design decisions:

- Signal/noise ratio for minimum ionizing particles (MIPs)
  - Reference performance of 9:1
- Drift electron lifetime in LAr cryostat from cosmic muon tracks
  - Expected performance: > 3 ms
- Time resolution of photon detector events

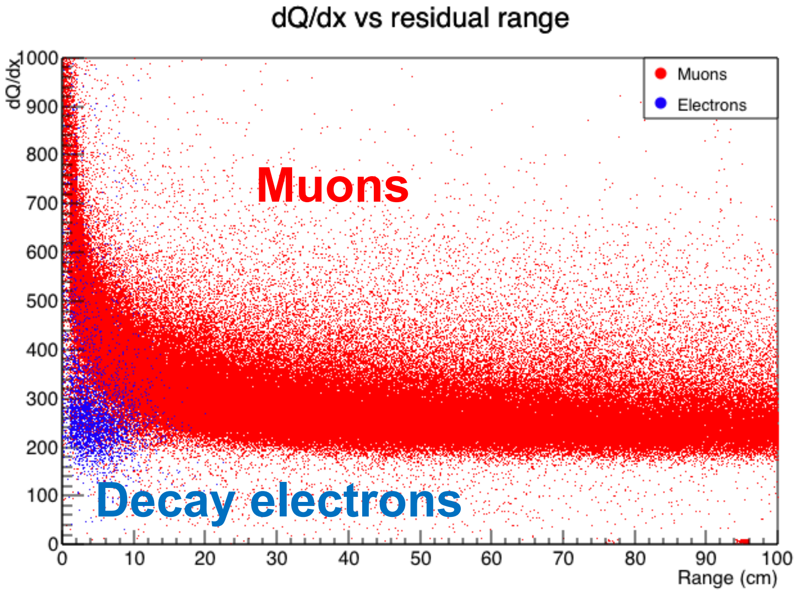
35t Precision Measurements

- Use Michel electrons, π^0s, and residual range of charged hadrons to determine energy resolution and scale

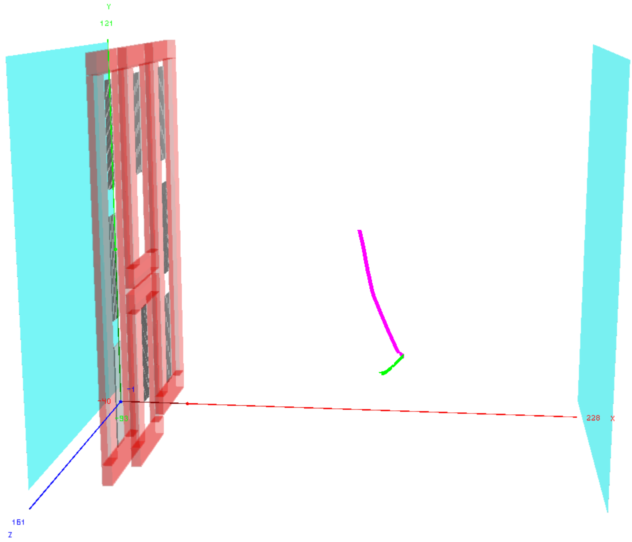
- Vary drift field to measure:
  - Ionization charge and scintillation light yields to check against models and data and characterize detector
  - Validate space charge model and field edge effects by measuring track distortions

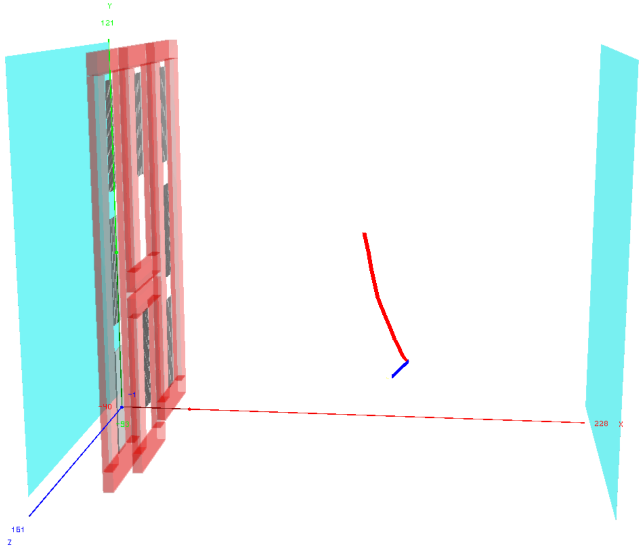
35t Reconstruction and Event Displays

Reconstructed dQ/dx vs residual range for muons and decay electrons



Stopping Muon in MC truth



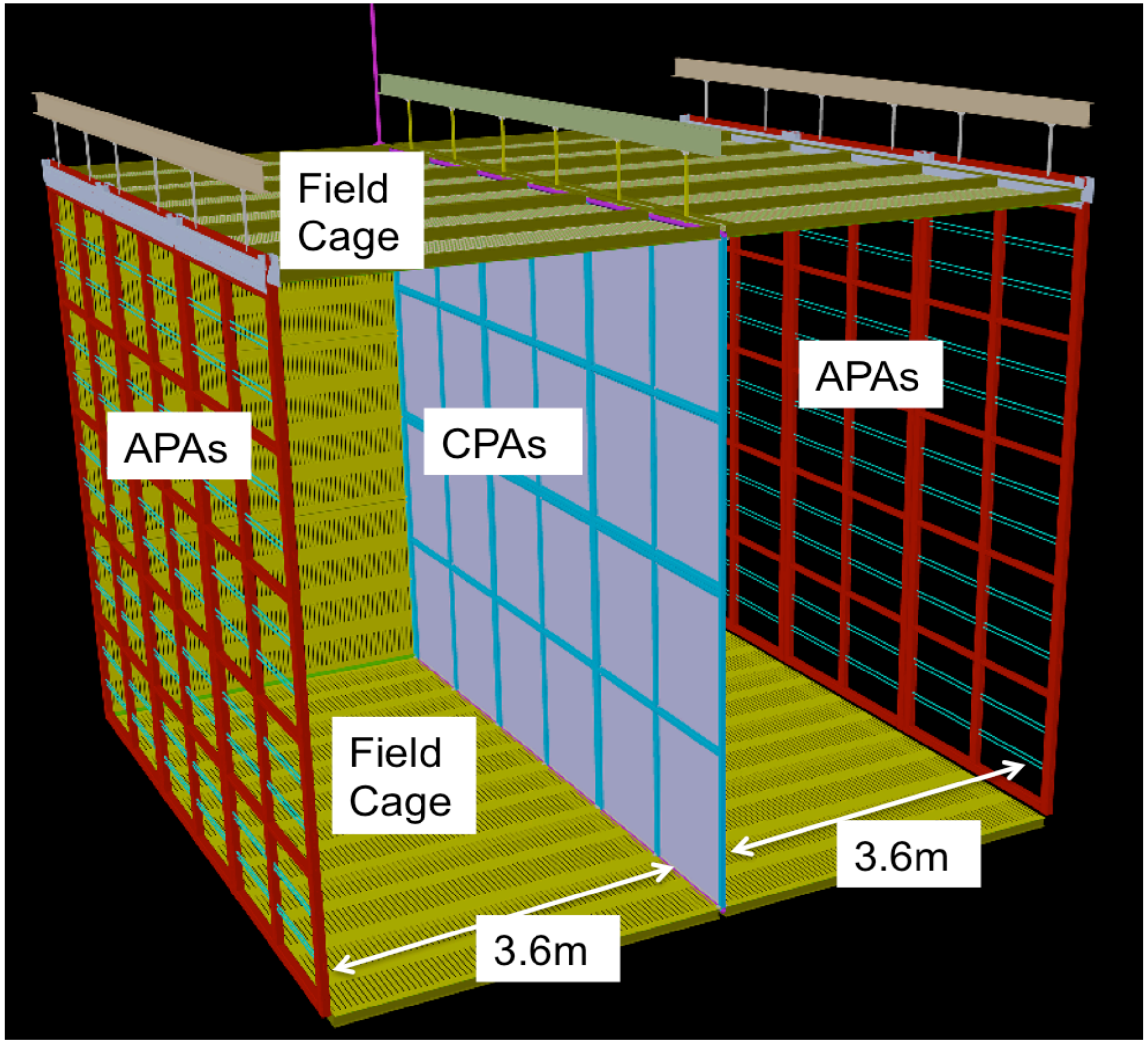


Reconstructed Stopping Muon

protoDUNE Motivation

- "protoDUNE" is the single-phase LAr-TPC to be built at CERN
- Measure, benchmark performance of full-scale **components**
  - Full size APAs, CPAs, photon detector panels
- Take measurements with test beam from CERN SPS
- Experience and data will inform DUNE FD development and design decision-making

protoDUNE at CERN



protoDUNE is a LAr-TPC detector that will use full scale components and receive charged particle beam from CERN SPS

Detector Engineering:

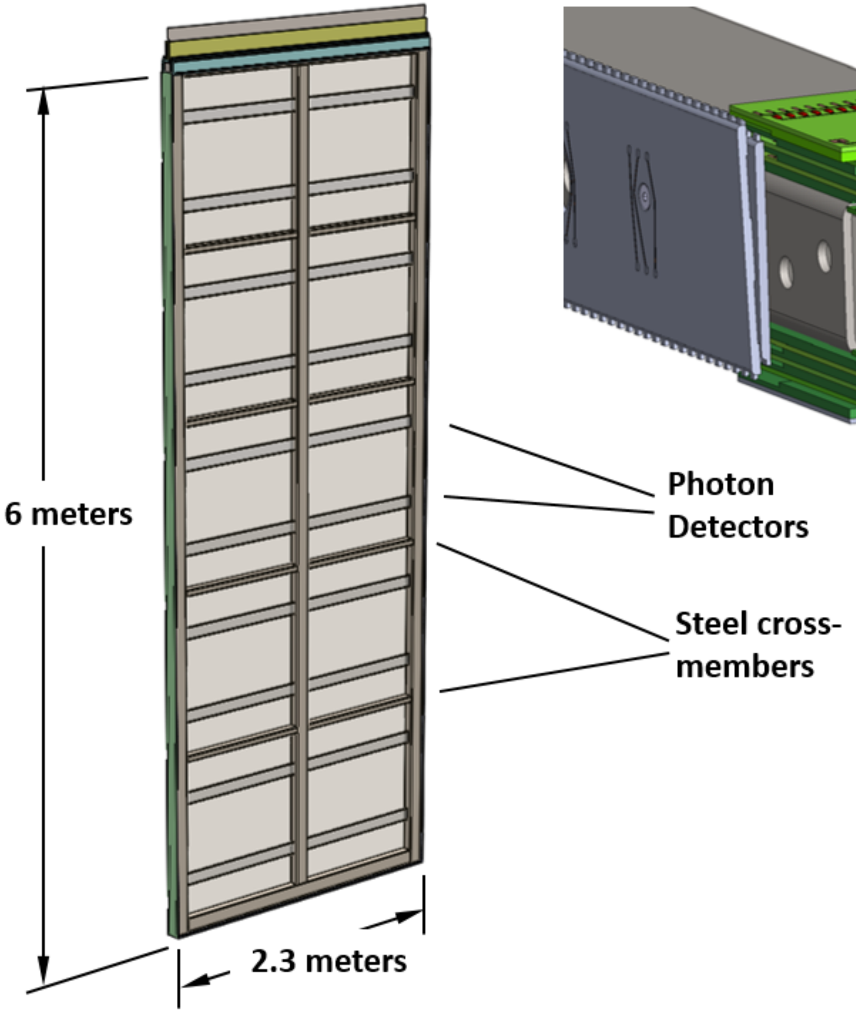
- Quantify and benchmark full scale detector components' performance
- Develop installation and operation procedures for full scale components

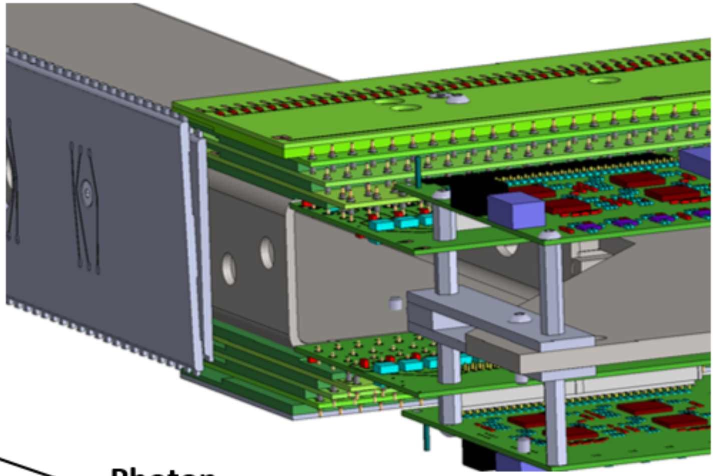
Measurements:

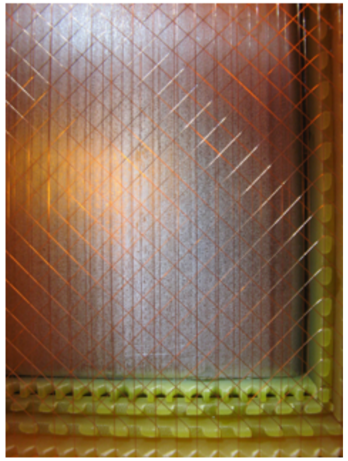
- Examine systematic uncertainties of full scale LAr-TPC
- Use data to validate and tune MC simulations
- Test and further develop reconstruction and PID techniques

protoDUNE Design

- Identical components as in DUNE far detector
- Drift distance will be adjustable to 2.5 m to diminish effects of space charge
- 35t space charge studies wi determine strategy

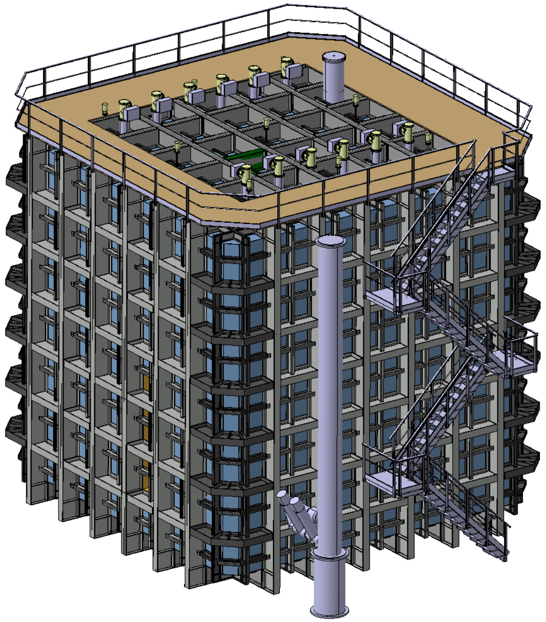






Full-scale APA design

protoDUNE Parameters

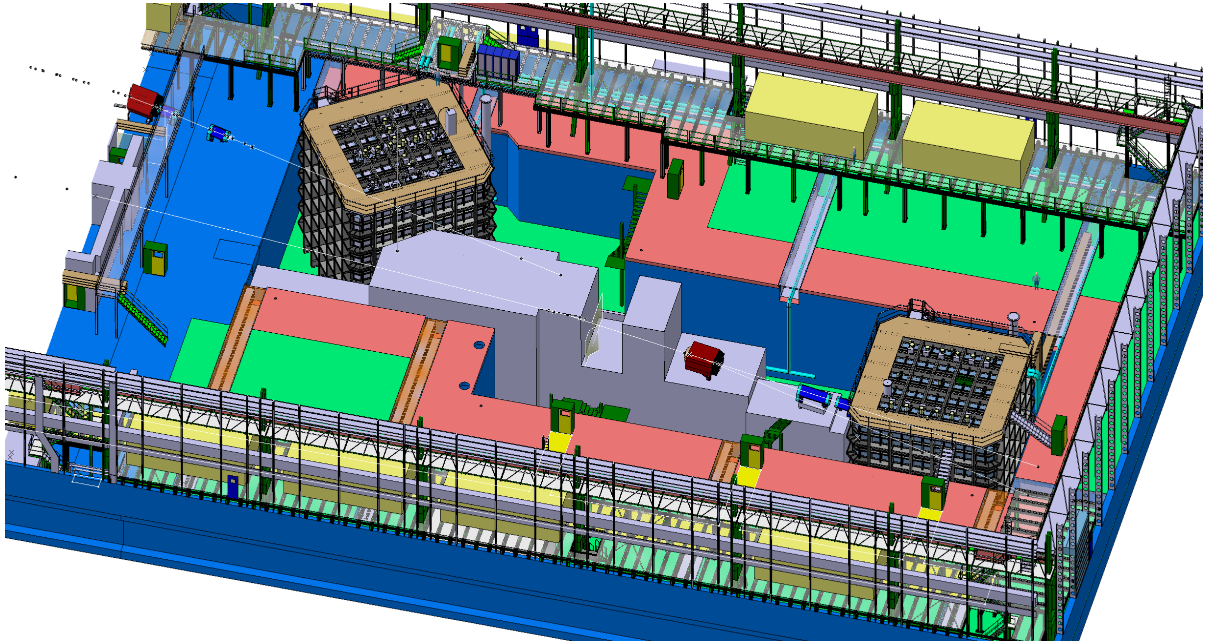


- Total LAr mass of 700t with active mass of 400t
- 6 full size APAs with identical design to DUNE FD 10 kt module
- 15360 total readout wires in TPC
- 60 photon detector panels (dimensions $2.1 \times 1.1 m^2$) with total of 240 PDS readout channels
- 6 cathode plane assemblies (CPAs)

Dimensions: (transverse × parallel × height)

- Internal: 8.5m × 8.5m × 8.6m
- External: 10.6m × 11.7m × 10.9m
- Tank capacity: ~600m^3 (liquid volume ~0.96%)

protoDUNE Test Beam



Experimental hall EHN1 layout

- 60-80 GeV/c pion beam from T2 target will generate tertiary particles
- H4ext beamline will take particles to experimental area
- Particle types: $e^{\pm}, \mu^{\pm}, \pi^{\pm}, K, p$
- Momentum range: ~0.5 – 7 GeV/c
- Momentum spread: $\Delta p/p < 5\%$
- Multiple beam windows
- Beam rate: 200 Hz
- Beam position detectors:
  - Upstream and downstream of last bending magnets
  - Wire chambers and/or scintillating fiber trackers
- PID: TOF system for lower *p*, threshold Cherenkov detector for higher *p*

Template Measurement Plan

Positive Sample						
P (GeV)	# of Spills	Time (hours)	# of π^+	# of μ^+	# of K^+	# of p
0.2	900	11	**15k**	180k	≈0	160k
0.3	200	3	**15k**	30k	≈0	50k
0.4	150	**2**	22k	18k	≈0	32k
0.5	150	**2**	26k	12k	≈0	38k
0.7	150	**2**	40k	10k	≈0	45k
1	350	4	120k	**10k**	≈0	65k
2	600	8	320k	**10k**	3k	130k
3	500	6	290k	**5k**	7k	70k
5	1800	23	1M	**5k**	5k	270k
7	1200	15	660k	**6k**	3k	120k
Total	6000	76	2.5M	286k	18k	1M

Negative Sample				
P (GeV)	# of Spills	Time (hours)	# of π^-	# of μ^-
0.2	600	8	**15k**	88k
0.3	200	3	**15k**	30k
0.4	150	**2**	30k	18k
0.5	150	**2**	40k	13k
0.7	150	**2**	50k	12k
1	150	**2**	70k	12k
2	200	3	135k	**6k**
Total	1600	22	350k	180k

Electron Sample			
P (GeV)	# of Spills	Time (hours)	# of electron
0.2,0.3,0.4,0.5,0.7,1,2,3,5,7	150 per bin	2 hours per bin	140k per bin
Total	1500	20	1.4M

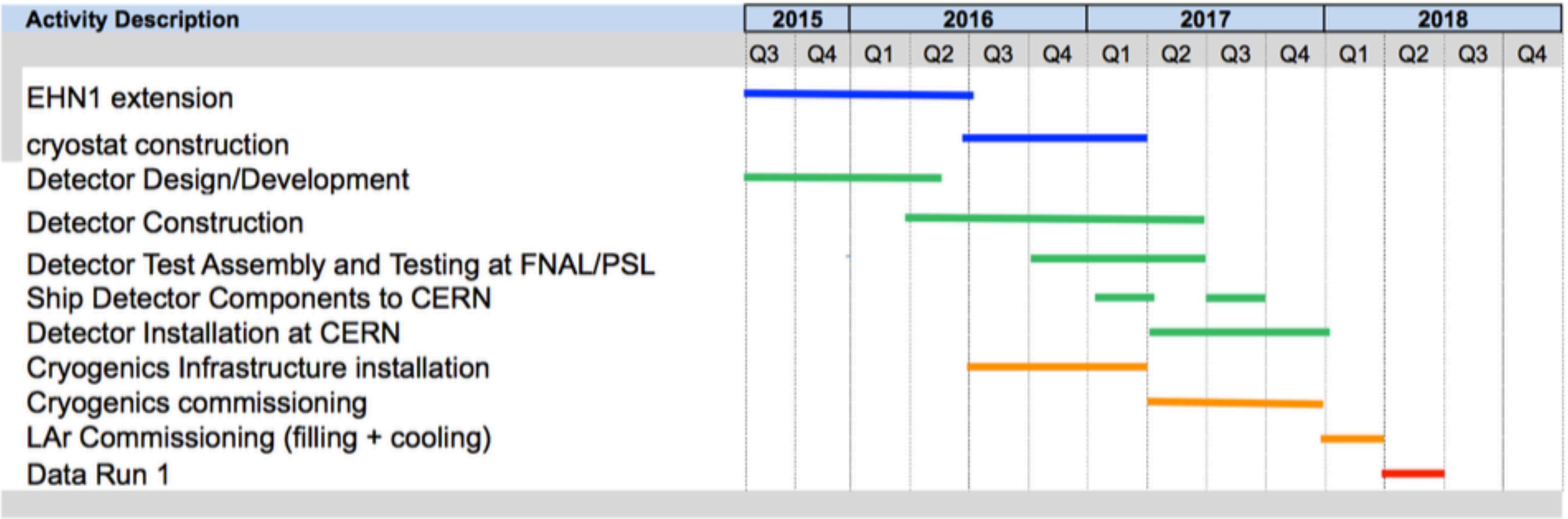
- Response for multiple beam injection points and directions will be studied
- Projected measurement time is on the order of several weeks
- Estimates shown for only one angular configuration
- Red indicates rate-limiting numbers that define runs

protoDUNE Beam Measurements

Refine DUNE FD measurements systematics assumptions by performing following measurements in protoDUNE:

- Shower calibration
  - Electromagnetic showers (π^0, γ, e)
  - Hadronic showers $(\pi^{\pm}, K^{\pm}, p)$
  - Test beam has known particle type and incoming momentum; will be used to characterize detector response for interacting hadrons in beam's energy ranges
- Angular dependence
  - Recombination with different angles between drift direction and (secondary) particles
- Bethe-Bloch parameterization of particle identification and charged particles for each particle at different angles and energies
- Reconstruction at all angles, validation of 2D vs. 3D reconstruction
- e/γ separation

protoDUNE Timeline and Goals



protoDUNE has been approved by CERN!

Milestones:

- 2016: TPC Production readiness review
- 2016/17: Engineering trial assembly
- 2017: Detector installation complete
- 2018: Commission detector and collect cosmics data

Goal: Collect initial beam data in 2018

Summary

- DUNE is a long-baseline neutrino experiment that will observe neutrino oscillations with a 40 kt LAr-TPC underground far detector
- The 35t prototype at Fermilab is a smaller scale LAr-TPC using the same technology as the far detector
- 35t will take cosmic data over two months to test detector performance and provide data for reconstruction development
- protoDUNE is a prototype LAr-TPC to be constructed at CERN and will characterize full-scale FD components
- protoDUNE will receive beam from CERN SPS and perform measurements of different particles at different energies and angles
- Experience gained from and data taken by 35t and protoDUNE will inform DUNE FD design and technology development/decision-making process