Los Alamos
NATIONAL LABORATORY

Calibration of the position reconstruction using a laser system in ProtoDUNE

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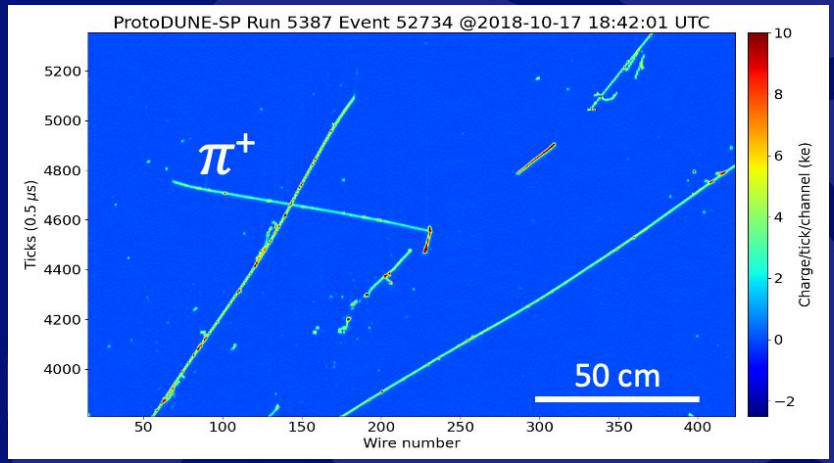
Space Charge Distortions in Surface-based LArTPCs

- Liquid argon time projection chambers (LArTPCs) like DUNE and the ProtoDUNEs face a number of sources of distortions of the electric field applied across the TPC volume
  - Anode Plane assembly (APA) and cathode plane assembly (CPA) misalignments
  - Broken field shaping components
  - Cosmic ray interactions
- For surface based detectors like the ProtoDUNEs, cosmic rays are of greatest concern

Space Charge Distortions in Surface-based LArTPCs

- Accumulation of slow moving argon ions at the cathode results in Space Charge Effect (SCE) distortions
  - Alters the drift velocities of ionization electrons along their path to the anode.
- Can create large uncertainty in the reconstruction of particle tracks
- Effects can be very large (see image)

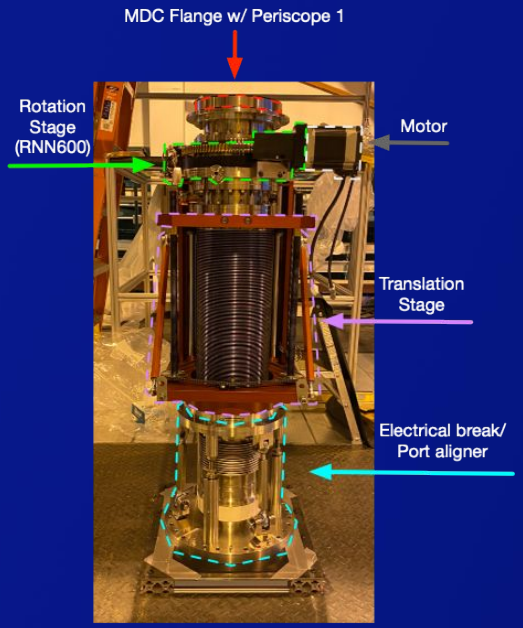


Particle interaction reconstructed 55 wires (26 cm) to the right of its true location. B. Abi et al 2020 JINST 15 P12004

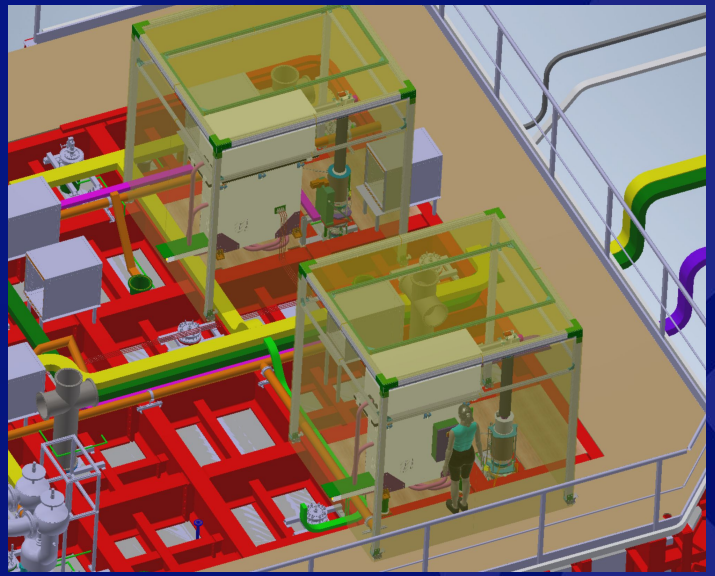
Laser Calibration System

- Ultraviolet (UV) laser calibration system is being installed in the ProtoDUNE horizontal drift geometry at CERN
- Trajectories of laser tracks are unaffected by the E-field or any other distortions
  - can be used to ionize the liquid at high enough intensities
  - Ionization trajectory is linear throughout the TPC volume
  - Provides a method of calibrating position reconstruction
- Lasers have steerable mirrors for optimal coverage

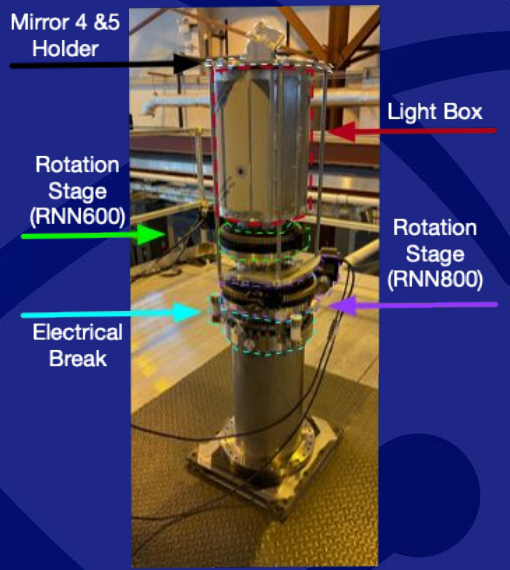
Images of laser periscope feedthroughs



Periscope 1 feedthrough



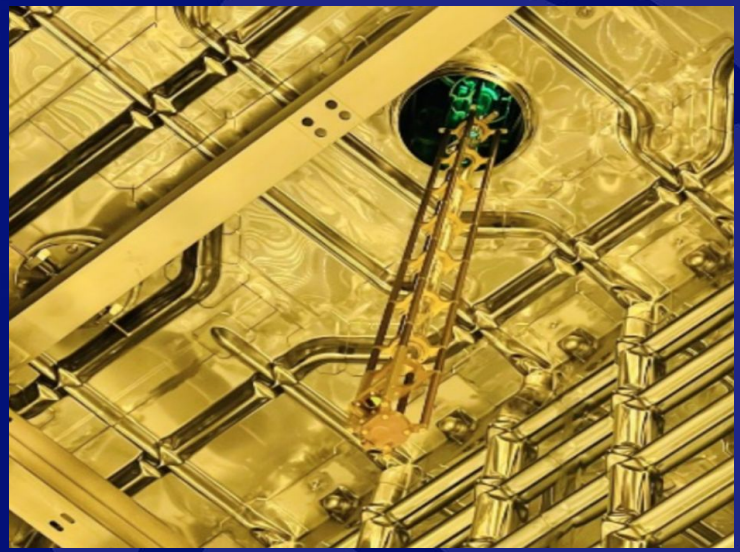
Laser periscope setup



Periscope 2 feedthrough

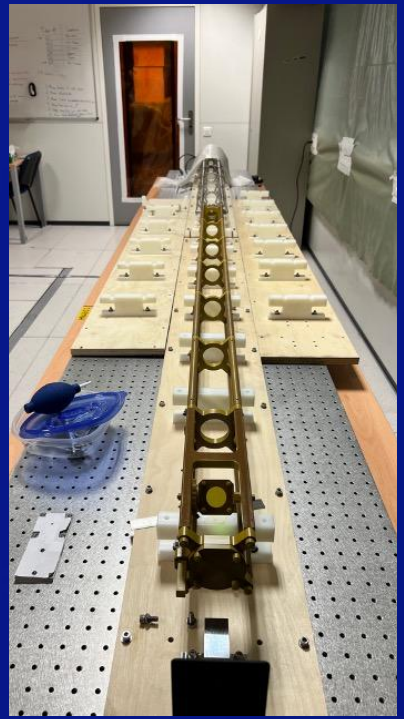
Images

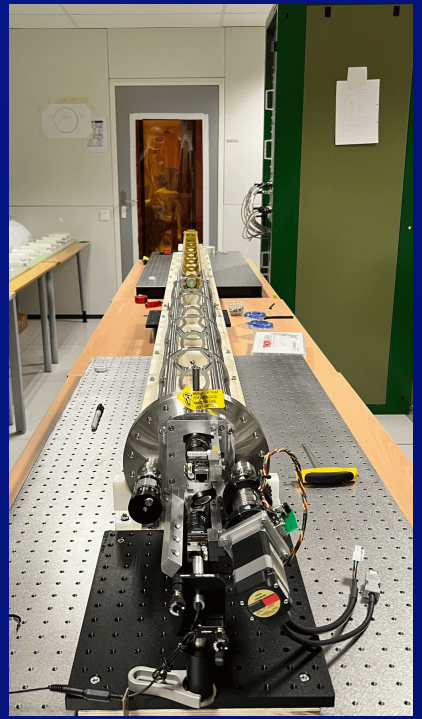
Periscope 1 fully extended into the cryostat (view from below)



Periscope 2 during an alignment test

Images





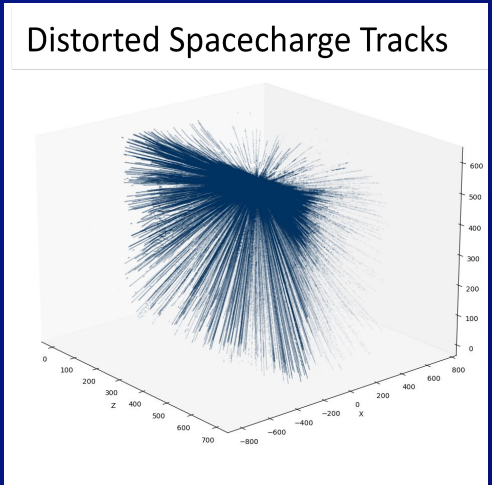
Tents for both laser periscopes (black) sitting on top of the ProtoDUNE cryostat

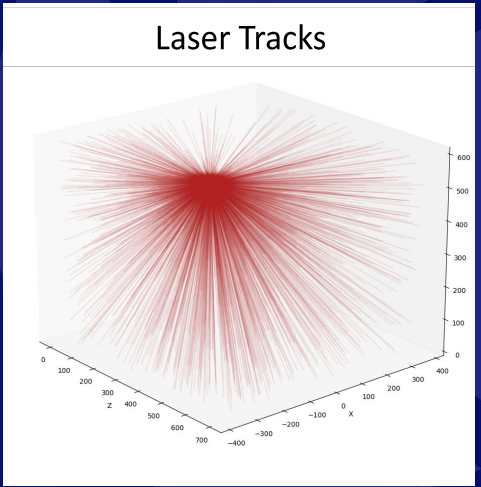
Simulation

- This study utilized Monte Carlo data generated by LArSoft simulation engines to map the distorted electric field in the TPC
  - ProtoDUNE-SP refactored geometry (v7) was used
  - Includes physics tools for simulating and reconstructing particle interactions in LArTPCs
  - MC for the analysis includes the standard ProtoDUNE data-driven space charge simulation
- Adapted methodology from MicroBooNE, which used similar analysis

Simulation

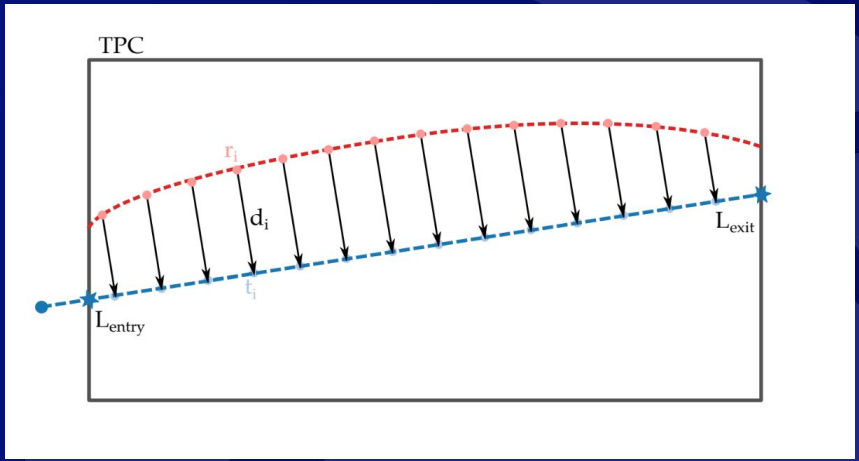
- Distorted particle tracks and true laser tracks were simulated for periscopes 1 and 2
- Reconstructed space point tracks are then fit to second degree parametric polynomials





Analysis

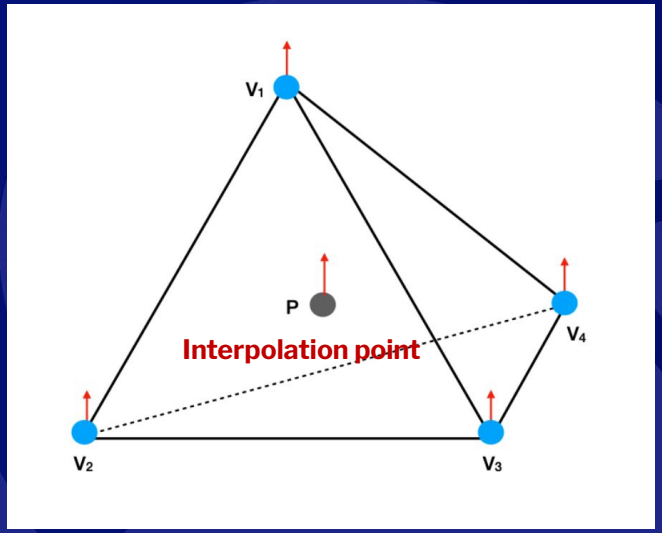
- Displacement vectors from distorted tracks to true tracks are calculated using orthogonal projection
- Displacement vector basepoints are polynomial fits to reconstructed spacepoints
- Vectors point from polynomial fits to true tracks, as shown



Displacement vectors pointing orthogonally from reconstructed track points to true track points (C. Adams et al 2020 JINST 15 P07010).

Delaunay Triangulation

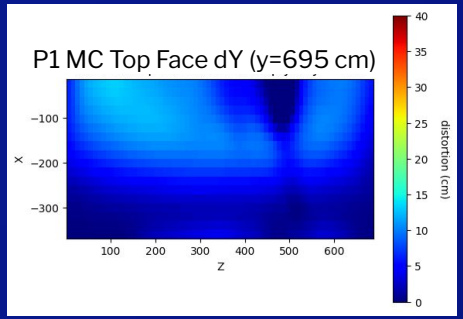
- Create a 3D triangulation mesh using Delaunay triangulation
  - Provides a method to estimate distortions more continuously
- Vertices of tetrahedrons are polynomial fits to reconstructed spacepoints
- Each vertex has an associated displacement vector
- Reweight each displacement vector according to how close it is to the center of the tetrahedron
- Apply weights displacement vectors at each tetrahedron vertex to estimate displacement in the center of each tetrahedron.

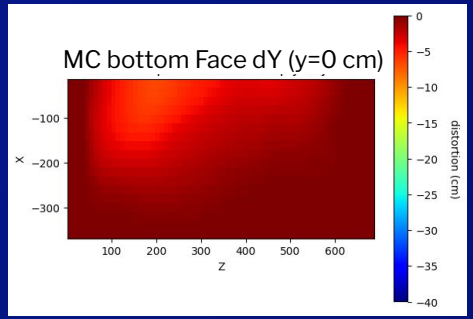


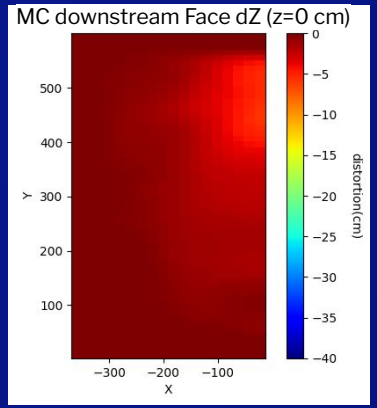
Representative tetrahedron containing point of interpolation and estimated displacement vector (C. Adams et al 2020 JINST 15 P07010)

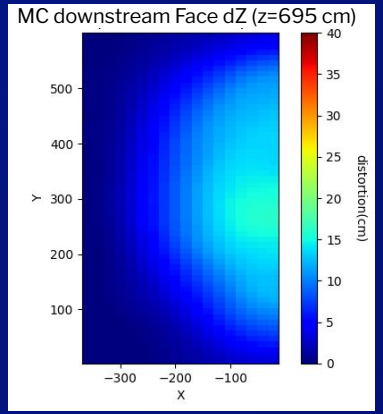
Distortion Maps

This study

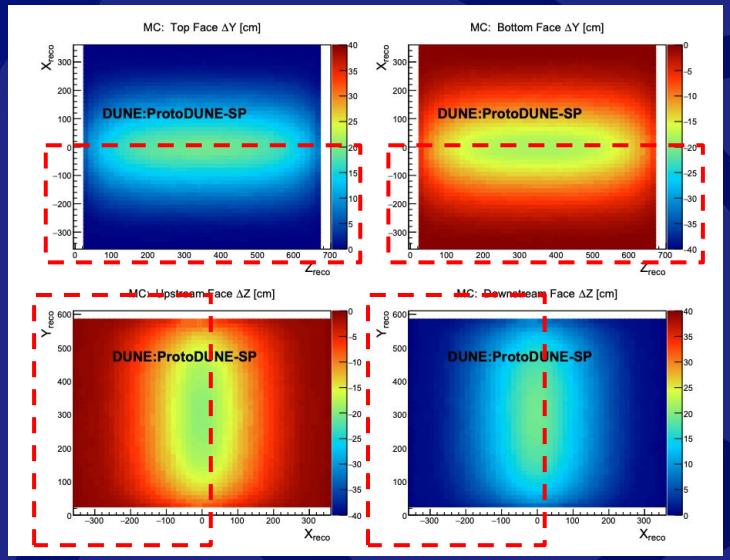








Previous ProtoDUNE-SP analysis



B. Abi et al 2020 JINST 15 P12004

Future direction

- Conduct bias study using periscope 2 simulation data
- Calculate the electric field and electron drift velocity inside the detector
- Test the distortion map by using it to obtain the true tracks from the distorted spacepoints
- Final installation of the laser systems for ProtoDUNE-HD will happen in January with data taking expected in 2024
- Simulate using ProtoDUNE-HD geometry

Acknowledgements

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Backup

$$\begin{pmatrix}\lambda_1\\ \lambda_2\\ \lambda_3\end{pmatrix} = T^{-1}(P - V_4)$$

$$T = \begin{pmatrix}x_1 - x_4 & x_2 - x_4 & x_3 - x_4\\ y_1 - x_4 & y_2 - x_4 & y_3 - x_4\\ z_1 - x_4 & z_2 - x_4 & z_3 - x_4\end{pmatrix}$$