Techniques Developed Calibrating ProtoDUNE-SP Using a Cosmic Ray Tagger (CRT)

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ProtoDUNE-SP

- 770-ton LAr prototype for the DUNE Far Detector single-phase module under a charged particle test beam from CERN SPS.

- The front and back cryostat faces of the TPC covered by the CRT, an array of scintillator strips.

- CRT enables external reconstruction of cosmic muons to calibrate and evaluate the TPC.

- 16 CRT modules cover the front face and 16 modules cover the back face.

- Overlapping CRT modules enable three-dimensional hit reconstruction.

- Timing resolution of a CRT module is 20 ns.

- 64 strips of 5-cm width overlaid to give an effective width of 2.5 cm in each direction.

See Jianming Bian, Heng-Ye Liao, Aleena Rafique and Alex Dvornikov’s contributions for more information on ProtoDUNE-SP physics.
CRT-TPC Matched Tracks

• Search for CRT three-dimensional hits to draw CRT candidate tracks and match by extrapolating the TPC track onto the CRT.

• Purity in simulation found to be above 99.9%.

• Can use CRT-TPC matched tracks for:
  • Positional distortion measurements
  • Drift electron lifetime measurements
  • Photon detector performance
  • TPC reconstruction evaluation and much more.

• We will focus on the first two.

Angular resolution for the CRT and TPC track for a CRT-TPC matched track. 0.9998 = cos(1.1 degrees)
Distortion Measurements with the CRT

- Measure distortions due to the space charge effect, an effect caused by a high cosmic muon flux.
- Distortions on the TPC face measured by interpolating the distance from the TPC face to the endpoint of the track.
- Distortions inside the detector measured using track pairs that intersect and comparing the intersection point between the CRT and TPC.
  - Useful for evaluating distortions across the drift distance.

Example of a crossing-track pair (left) and measurements of distortions across the drift volume in the center of the detector using crossing tracks (right). Distortions are in units of centimeters.
As ionized electrons drift, electronegative impurities may capture them and lead to a loss of measured charge on the wires.

The effect is measured as a drift electron lifetime whereby surviving charge is:

\[ Q(t) = Q_0 \exp\left(-\frac{t_{\text{drift}}}{\tau}\right) \]

CRT provides an external timestamp to calibrate \( t_{\text{drift}} \) and the track position.

Measure charge per unit length (\( dQ/dx \)) and then fit the Most Probable Value (MPV) across the drift volume. Fit these values to find \( \tau \).

ProtoDUNE-SP saw lifetime consistently above the 10 ms DUNE technical specification.

Results consistent with measurements from the purity monitors.
Conclusion

- External tracking, like that from a CRT, provides a reference timestamp and tracking information for TPC reconstruction.

- In addition, it enables numerous detector physics analyses ranging from calibration to evaluating liquid argon purity.

- The DUNE Far Detector will require less than percent level performance across multiple detector parameters.
  - Providing the DUNE Far Detector with preliminary evaluations using the CRT of these parameters will expedite DUNE’s science program.

Estimated oxygen contamination in ProtoDUNE-SP from the drift electron lifetime measurements.