An Introduction to ProtoDUNE-SP

Richie Diurba (Bern) for the DUNE Collaboration
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Overview of ProtoDUNE-SP

- ProtoDUNE Single Phase (SP) is the first “full-scale” engineering test of DUNE Far Detector Module 1.
- Liquid argon time projection chamber with 700 tons of argon.
- Took two months of beam data-taking from September to November 2018.
  - Beam used to measure hadron-Ar cross sections.
  - See status of all work in the CERN report.
- ProtoDUNE-SP has published five papers on its performance:
  - Detector performance (*JINST* **15** P12004)
  - Design and operation (*JINST* **17** P01005)
  - Track/shower separation using a CNN (*EPJC* **82** 903)
  - Michel electron reconstruction (*Phys. Rev. D* **107**, 092012)
  - Reconstruction of cosmic/beam using Pandora (*EPJC* **83** 618)

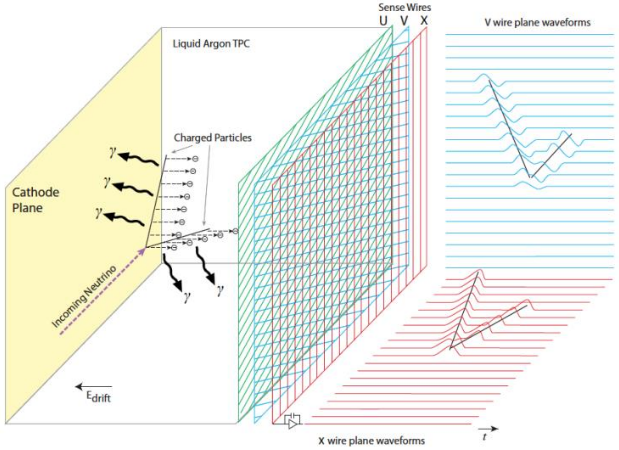


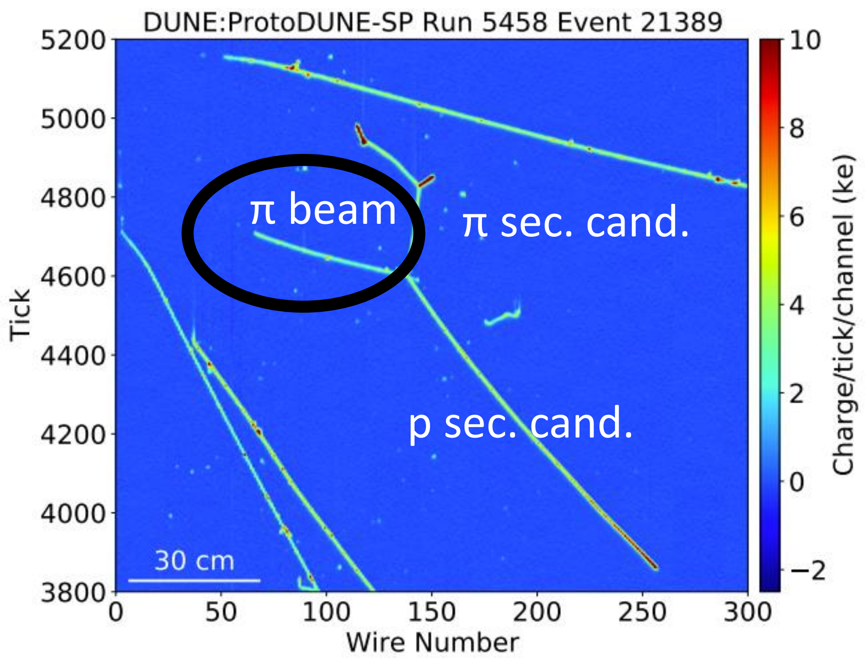
Diagram of the operating principle for liquid argon time projection chambers (TPCs). (arXiv:2002.03005)

ProtoDUNE-SP has surpassed technical specifications of DUNE FD Design Requirements (*JINST* **15** P12004):

Detector parameter	*ProtoDUNE-SP performance*	*DUNE specification*
Average drift electric field	500 V/cm	250 V/cm (min) 500 V/cm (nominal)
LAr e-lifetime	> 20 ms	> 3 ms
TPC+CE Noise Signal-to-noise ⟨SNR⟩	 (C) 550 e, (I) 650 e ENC (raw) (C) 48.7, (I) 21.2 (w/CNR)	 < 1000 e ENC
CE dead channels	0.2%	< 1%
PDS light yield	1.9 photons/MeV (@ 3.3 m distance)	> 0.5 photons/MeV (@ cathode distance — 3.6 m)
PDS time resolution	14 ns	< 100 ns

ProtoDUNE-SP Cross Sections

- CERN NP provided a hadron beam originating from SPS (*Phys. Rev. Accel. Beams* **22**, 061003).
- Operate as a traditional test beam experiment to measure how hadrons travel through argon using.



1 GeV/c positive pion candidate inelastic interaction

ProtoDUNE-SP in the Future

- Final state interactions (FSI) and secondary interactions (SI) systematic uncertainties present challenges for meas. like T2K's oscillation analyses.
  - Can tune and constrain these uncertainties with real data.
- Identifying secondary interactions and "vetoing" events to clean sample of events where $E_{vis.}$!=$E_{had.}$ due to secondary interactions.

Common reweight software for FSI and SI: GENIERW and Geant4RW.

FSI and SI Examples:
- Tuning to world pion data (used by T2K)
- Exploring cascades with alternative models and data.

Final-state interactions

MFP_pi	hA2018	+20%	-20%
MFP_N	hA2018	+20%	-20%
FrCEx_pi	hA2018	+50%	-50%
FrInel_pi	hA2018	+40%	-40%
FrAbs_pi	hA2018	+30%	-30%
FrPiProd_pi	hA2018	+20%	-20%
FrCEx_N	hA2018	+50%	-50%
FrInel_N	hA2018	+40%	-40%
FrAbs_N	hA2018	+20%	-20%
FrPiProd_N	hA2018	+20%	-20%

Final state interaction modeling uncertainties suggested for GENIE using GENIERW.

MFP="Mean Free Path"

What is Being Presented at NuSTEC

- Work-in-progress analyses for ProtoDUNE-SP with focuses on the methods used to extract the cross sections.
  - Richie Diurba: Unfolding two histograms to measure a K^+-Ar total inelastic cross section
  - Jake Calcutt: Abs+CeX+Other π+-Ar total inelastic cross section using a likelihood fitter.
  - Yinrui Liu: Multi-dimensional unfolding to be used for π+-Ar total inelastic cross section.
- All talks emphasize how the measurements are made and what tools and pitfalls exist.