Pion-Argon Cross Section Measurement Using ProtoDUNE-SP

Jake Calcutt, On Behalf of the DUNE Collaboration

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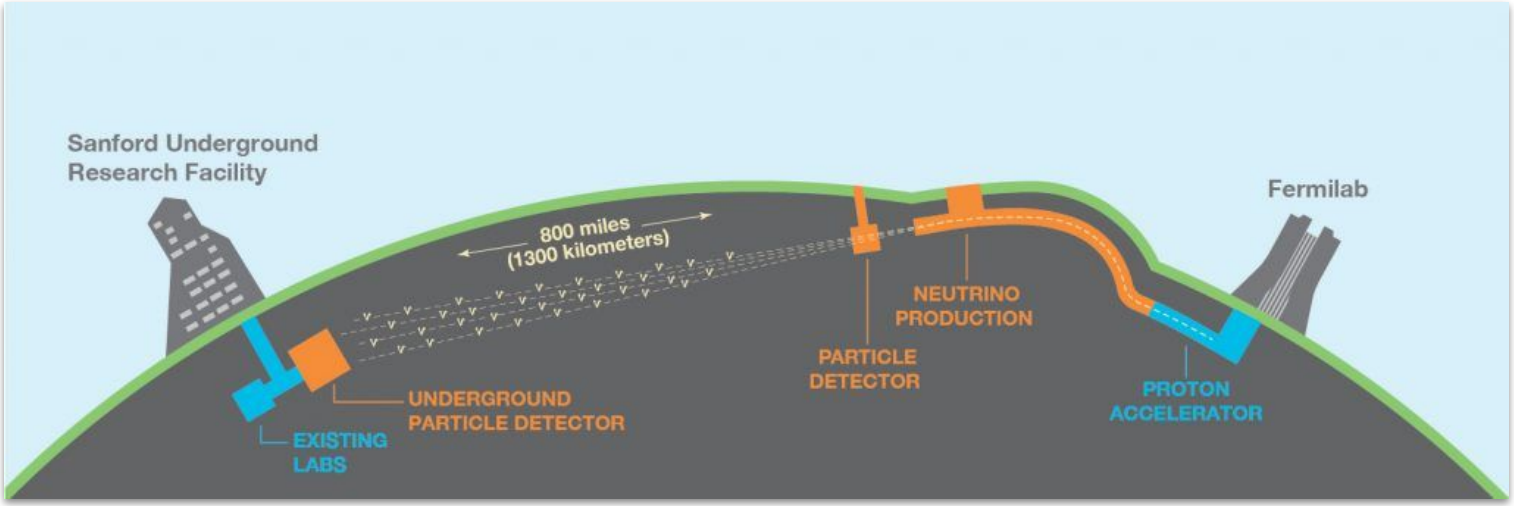
Deep Underground Neutrino Experiment (DUNE)



Next generation long baseline neutrino experiment in preparation

Physics program:

- Oscillations (including CP-violating phase δ_{CP})
- Supernova detection
- Beyond Standard Model Physics (nucleon decay, sterile ν)

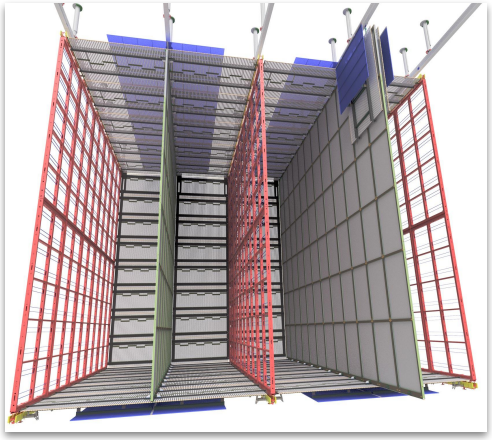
DUNE Single-Phase Far Detector

DUNE's first Far Detector (FD) module: Single-Phase (SP) Liquid Argon Time Projection Chamber (LArTPC)

Principle:

- Charged particles ionize LAr
- Drift field pulls ionization to anode
- Instrumented wires read out signals to provide positioning and calorimetry

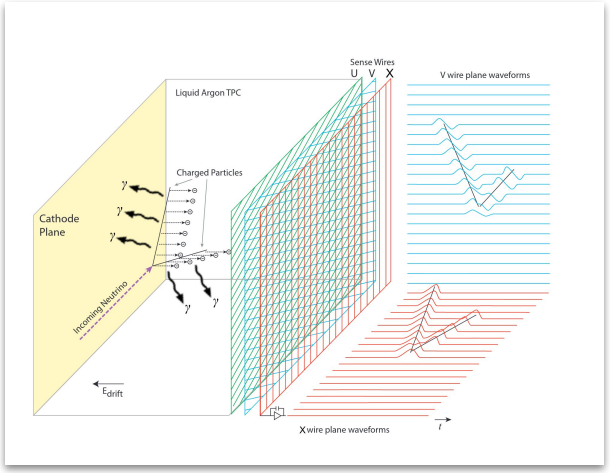
Needs large-scale prototyping
→ **ProtoDUNE-SP**



Cross-sectional schematic of SP LArTPC module

4 side-by-side drift volumes (anodes in red, cathodes in grey/green)

SP LArTPC operating principle



ProtoDUNE-SP (PDSP)

Prototype LArTPC located at CERN

419t active LAr mass/2 drift volumes

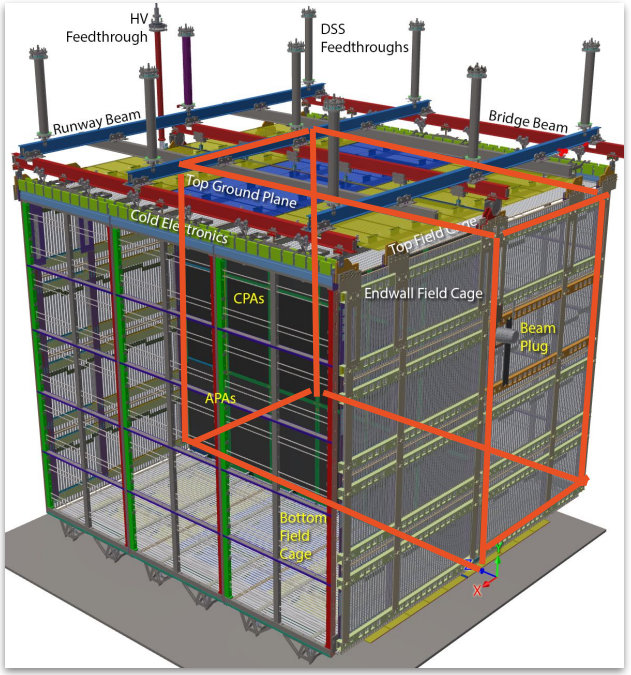
- 1/25 of SP FD module

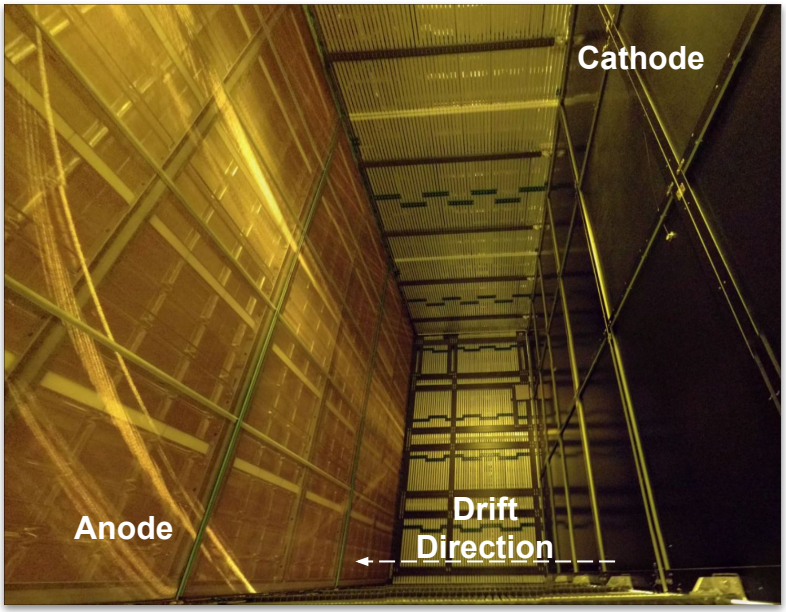
One side deployed with charged particle test beam

Installation: Summer 2018

Commissioning: Fall 2018

Beam Run: Fall 2018 (before CERN Long Shutdown 2)





Pion-Ar Interactions & DUNE

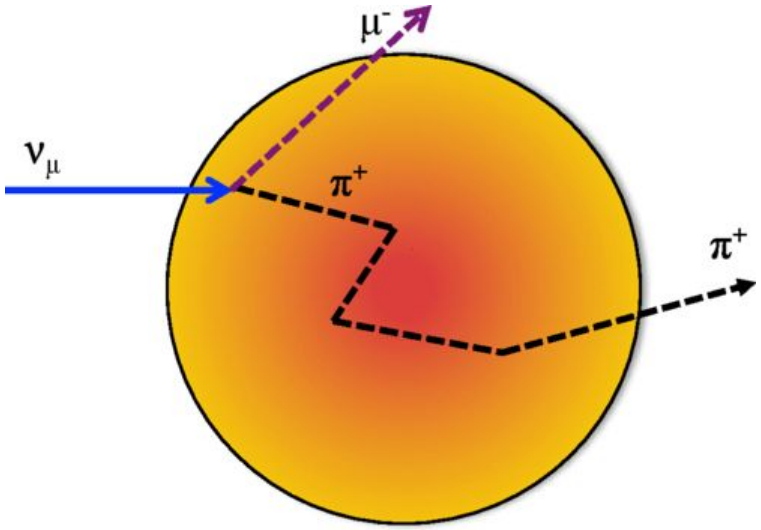
DUNE relies on signatures from particles emitted from nu-Ar interactions

Complications:

- Pions from primary interaction can undergo Final State Interactions (FSI)
- Can also be produced after primary interaction as a result of FSI

Need well-informed models

- Pion-Ar scattering data from PDSP can help!



Cartoon depicting ν_μ–nucleus scattering and Pion FSI[1]

1. https://doi.org/10.1103/PhysRevD.99.052007

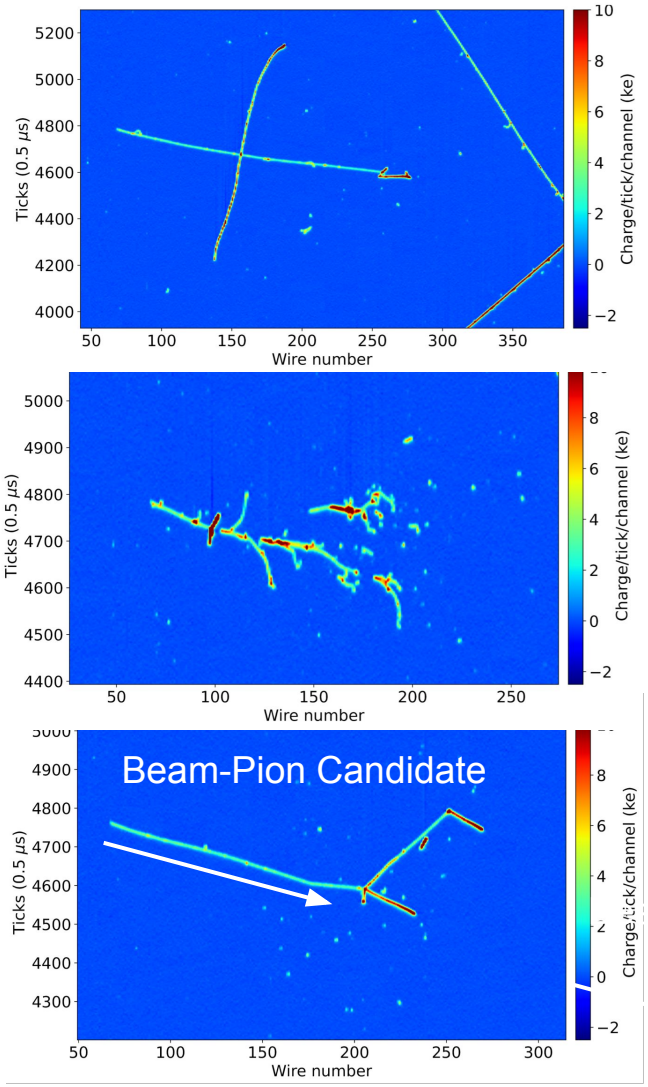
Pion-Ar Interactions at PDSP

PDSP's LArTPC technology provides the ability to characterize complex pion-Ar interactions

Use this to simultaneously study the rate of:

- Absorption
  $\pi^+ + Ar \rightarrow X$ (Nucleons)
- Charge Exchange
  $\pi^+ + Ar \rightarrow \pi^0 s + X$
- Other interactions
  $\pi^+ + Ar \rightarrow \pi^\pm + X$

(Note: consider 150 MeV/c $\pi^\pm$ threshold for Abs./Ch. Exch)



Analysis Technique

Broad Steps:

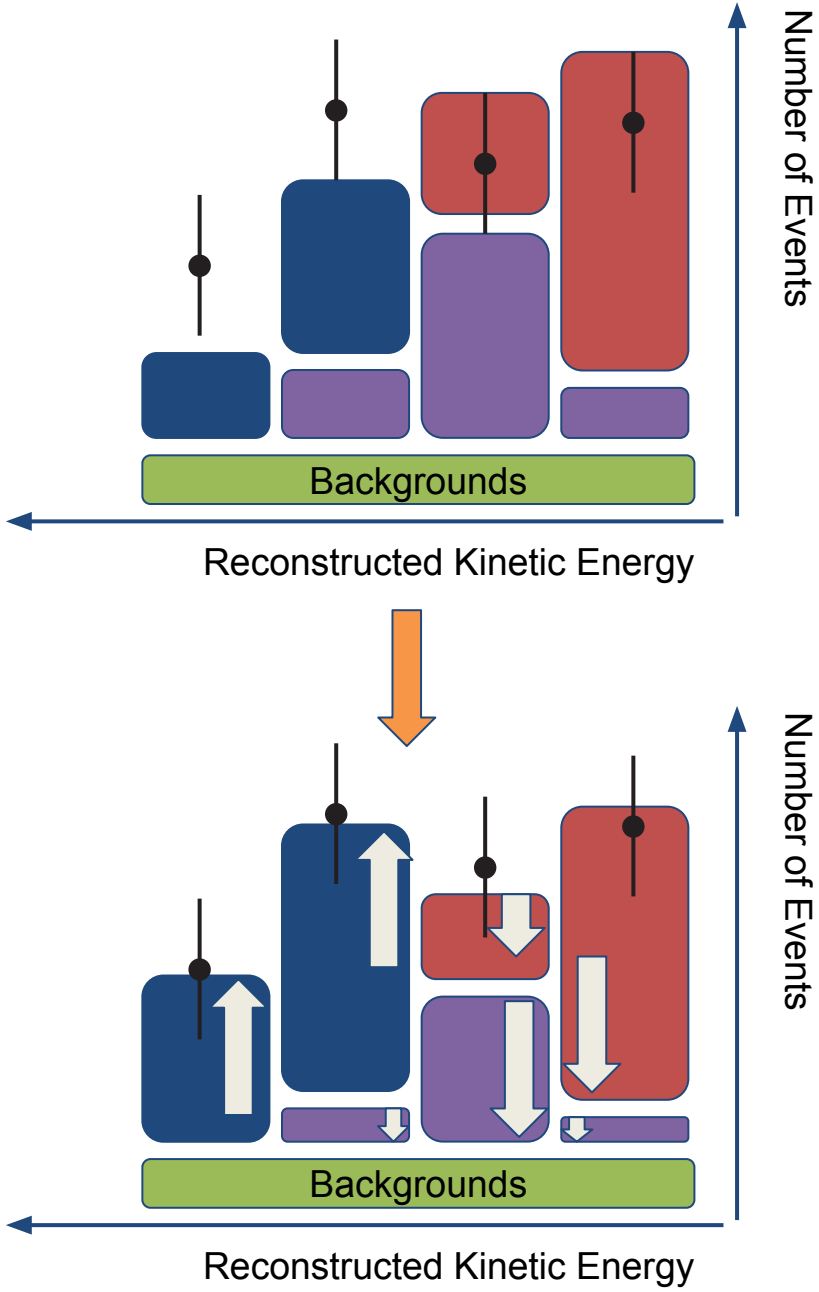
1. Categorize events in data and MC using calorimetric information
2. Binned Likelihood fit varies the number of signal and background events within the sample
3. Extract cross sections from MC Truth Information of best-fit MC ensemble

Fit Strategy

Fit parameters: scale factors that vary the number of true signal interactions within a given true kinetic energy range

- Different colors: different signal regions
  - Have some spread within reco. space

Same role as unfolding (i.e. Iterative-Bayesian/D'Agostini method)

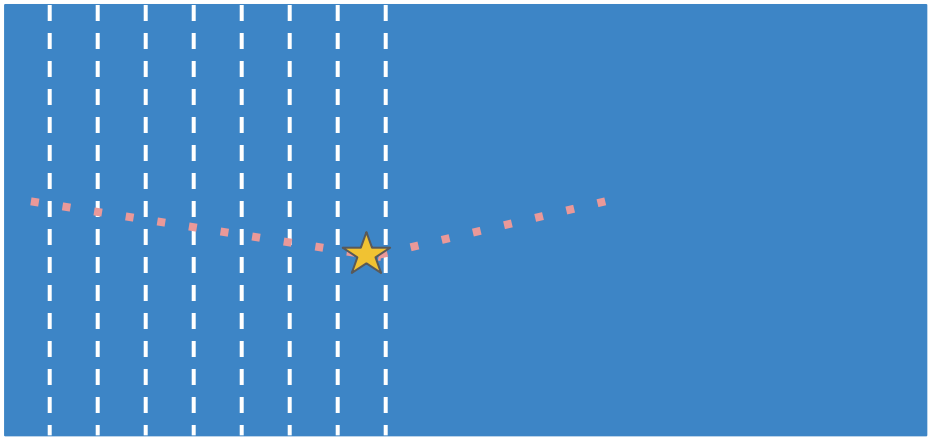


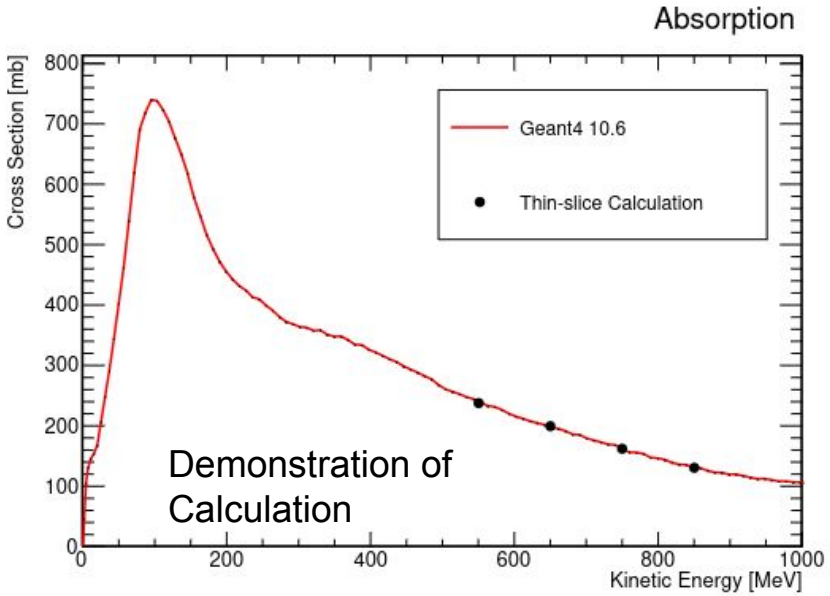
Cross Section Calculation

Using MC Truth Information: mock-up sequential thin-target scattering experiments

- Bookkeep when primary pion transitions into new ‘slice’
  - Provides flux (Φ) as in a classic thin-target experiment
- Count number of interactions (N_{Int})

$$\sigma(KE) \propto \frac{N_{\mathrm{Int}}(KE)}{\Phi(KE)}$$





Systematic Uncertainties

Experimental Apparatus/Detector Modeling

- Space Charge Effect
  - Buildup of positive charge in LAr distorts electric field
    - Affects selection & energy reconstruction
- Beam Line Modeling
  - Affects energy reconstruction & upstream losses
- Calibration

Physics Modeling

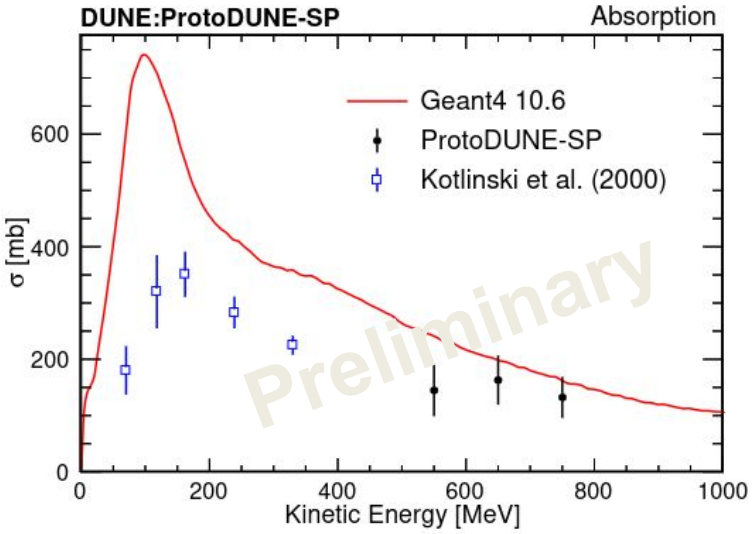
- Efficiencies couple to
  - Kinematic distribution of secondary particles
  - (Re-)interactions of secondary pions & protons

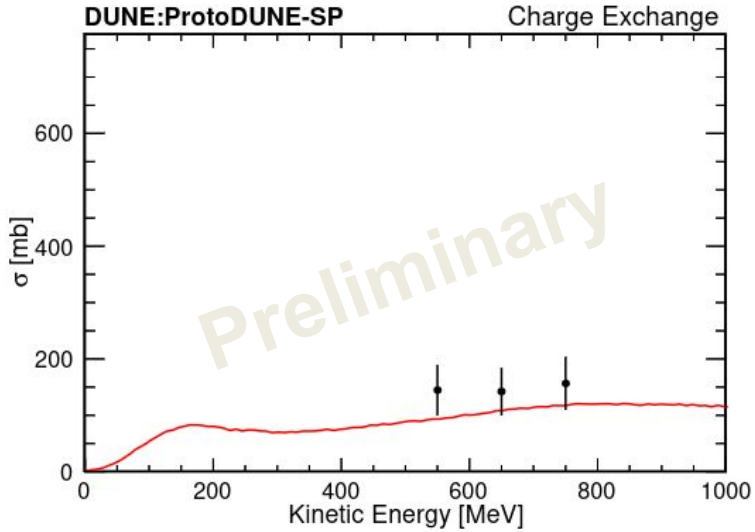
Preliminary Results

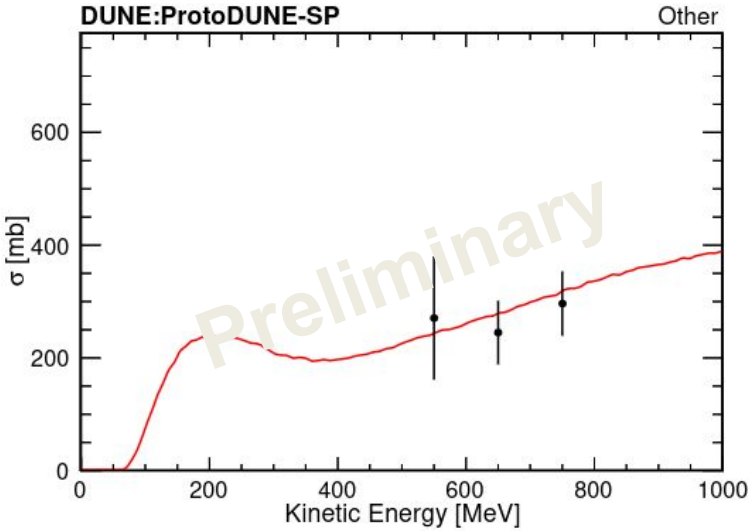
First measurement of charge exchange and ‘Other’ (Inelastic - (Abs. + Ch. Exch))

Absorption seems to be over-predicted by Geant4 10.6 (Bertini cascade model), similarly to previous results

- Note: Kotlinski did not have a threshold on the outgoing charged pions







Kotlinksi et al, Eur Phys J A **9**, 537-552 (2000)

Conclusion

Pion-Ar interaction modeling will play an important role in DUNE's physics analyses

ProtoDUNE-SP has provided a chance to study these interactions

- ProtoDUNE-HD will provide more data to study these interactions (and explore more complex projections)

Analysis of data is nearing completion

- Paper in preparation

Thank You!