ProtoDUNE Physics and Results

Jake Calcutt
On Behalf of the DUNE Collaboration

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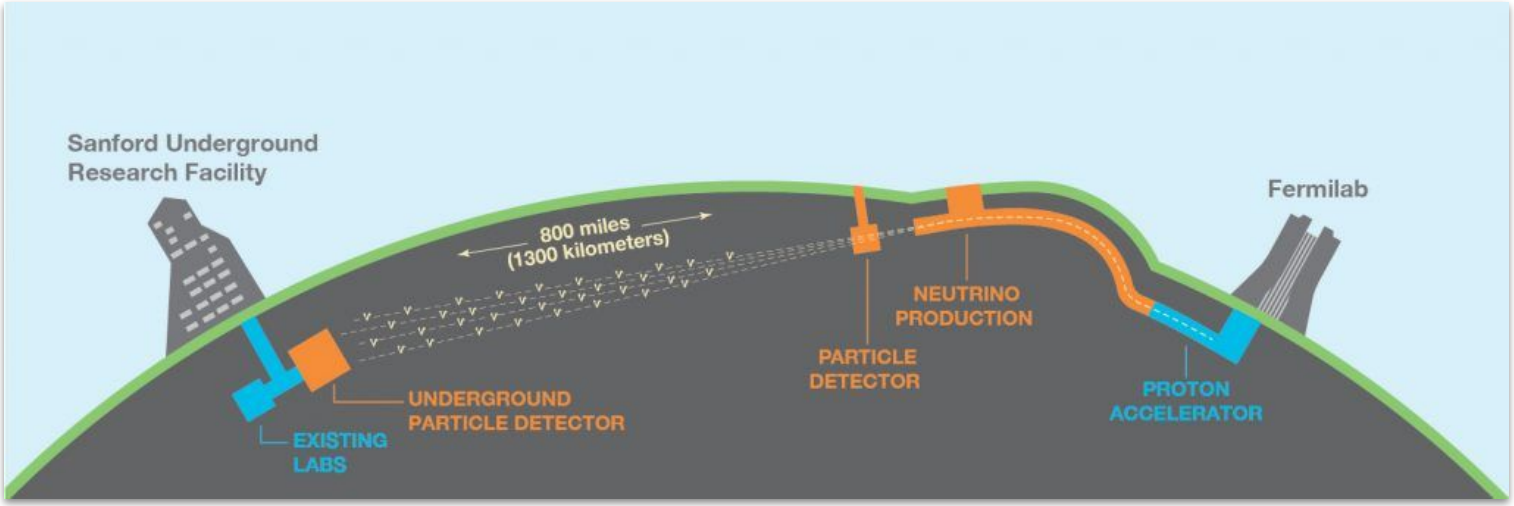
Deep Underground Neutrino Experiment (DUNE)



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)

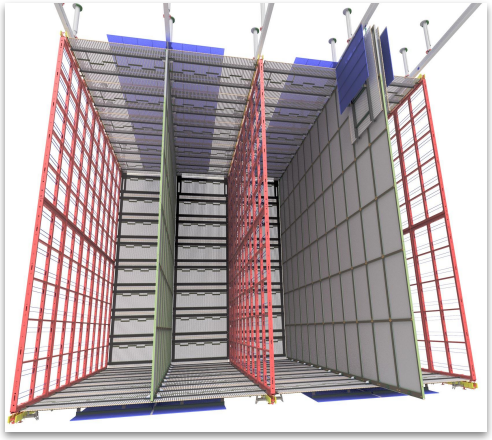
DUNE Single-Phase Far Detector

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

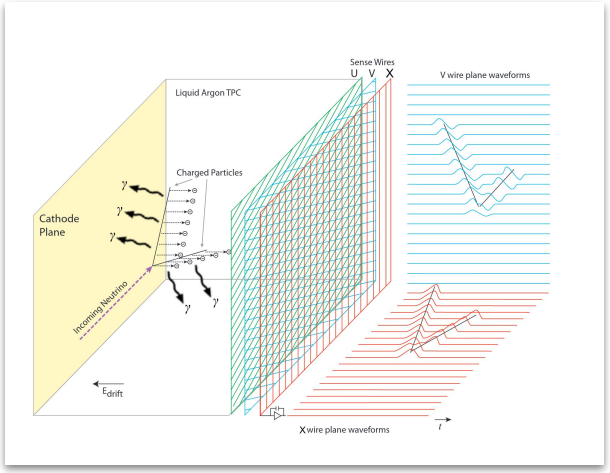
Needs large-scale prototyping
→ ProtoDUNE-SP



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

Prototype LArTPC located at CERN

419t active LAr mass/2 drift volumes
(1/25 of SP FD module)

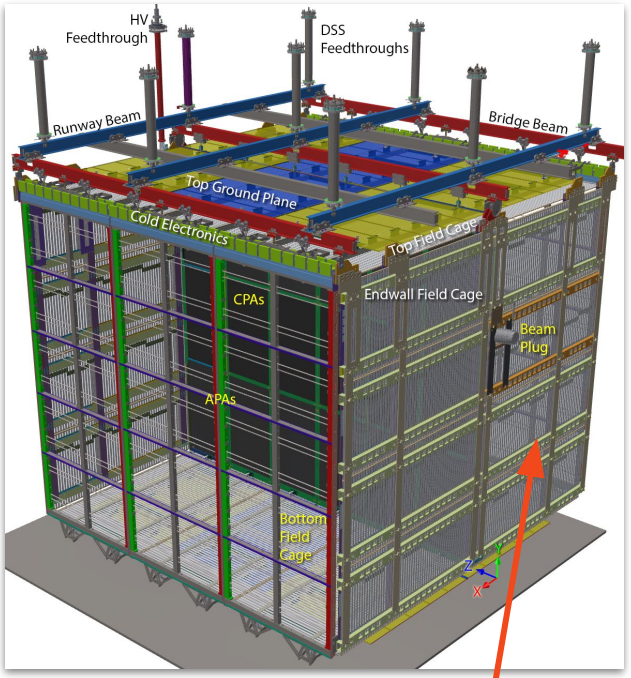
One side deployed with charged particle test beam

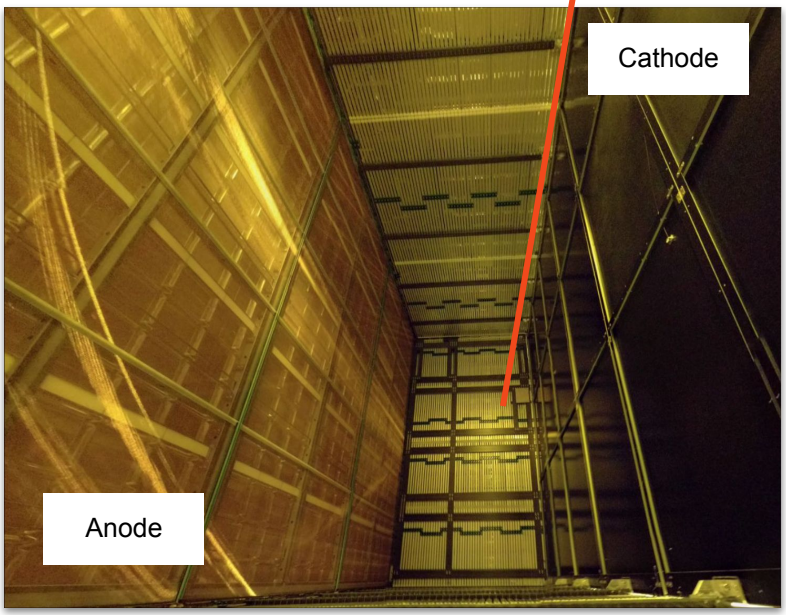
Installation: Summer 2018

Commissioning: Fall 2018

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

Cosmic Ray Data: Taken until decommissioning in Summer 2020





ProtoDUNE as Test Bench

ProtoDUNE-SP has excelled as a prototype & test bench for DUNE's far detector

- Largest successful operation of LArTPC to-date
- Successful test of DUNE readout electronics in a realistic environment
  - Excellent S/N results
- Powerful workspace for testing and development of DUNE's event reconstruction

Physics at ProtoDUNE

ProtoDUNE's excellent performance provides a chance for an array of physics measurements

- Seasonal variation of cosmic rays
- Electromagnetic energy reconstruction*
  - Michel electron energy reconstruction
  - Electron shower energy resolution
  - π^0 decay shower reconstruction
- Hadron–Ar interaction cross sections*
  - Proton, K^+, π^+, neutron
- Properties of LAr
  - Drift-electron diffusion
  - Recombination

* Posters at this conference

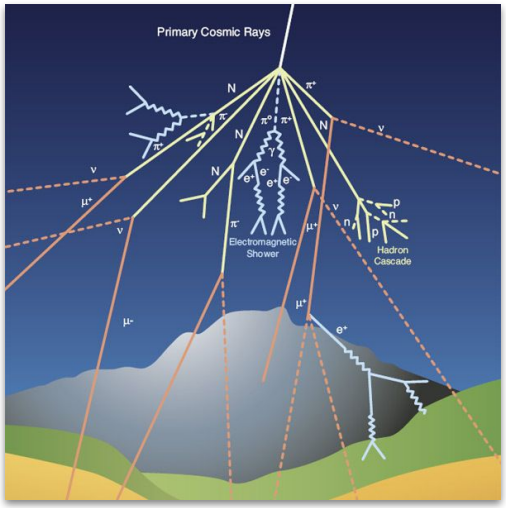
Seasonal Cosmic Ray Rate

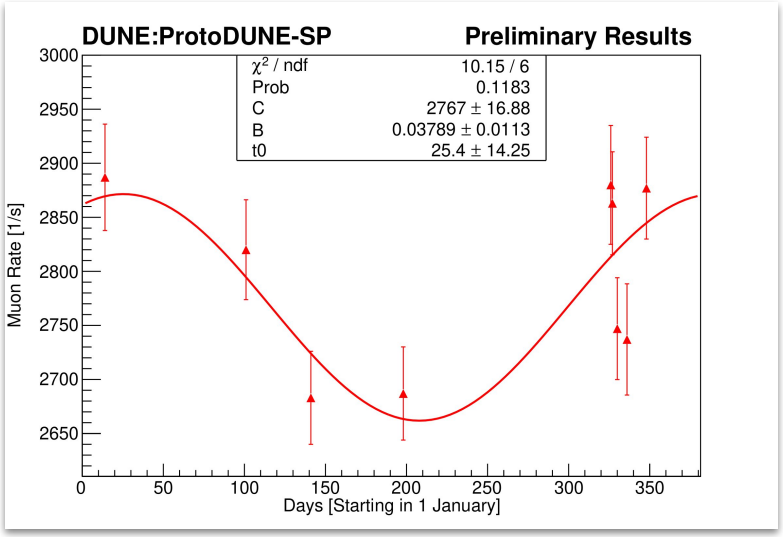
Cosmogenic muons produced from interactions of cosmic rays (protons/nuclei) with atmosphere

Seasonal temperature change expands/contracts atmosphere
→ μ from interactions higher/lower

ProtoDUNE-SP is a surface detector and is constantly bombarded by cosmic muons

- Measure seasonal variation of rate





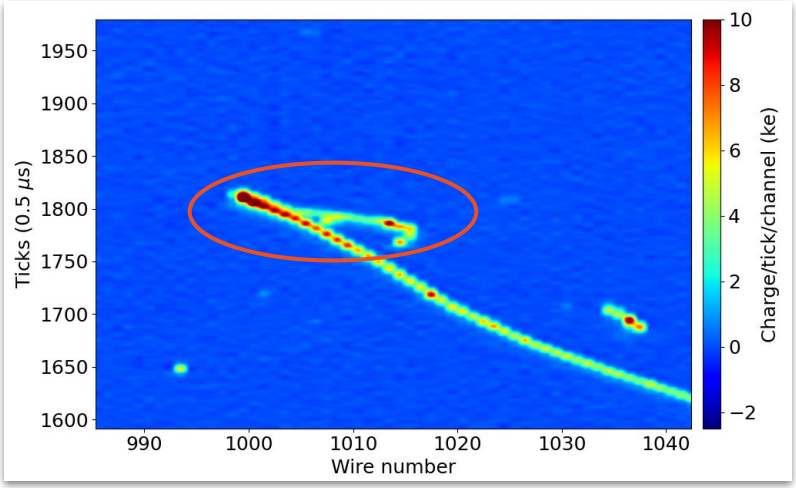
Michel Energy Reconstruction

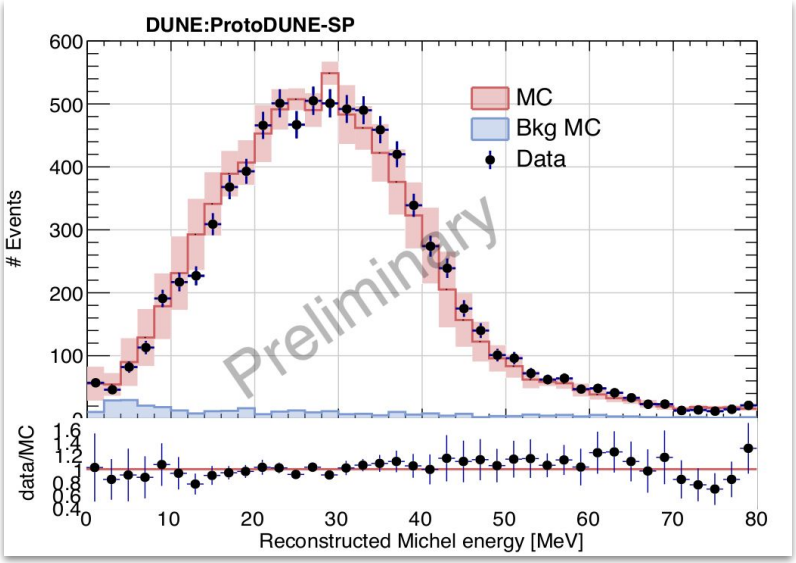
Muons (cosmic rays, ν–Ar interaction products, secondary particle decays) stop in the detector and decay to low energy (< 50 MeV) electrons

- Low-energy supernova signals
- Nucleon decay searches
- Oscillation analyses

Need to validate FD response to low energy electrons

Results show excellent agreement with simulation and agreement with MicroBooNE[1] and LArIAT[2] results



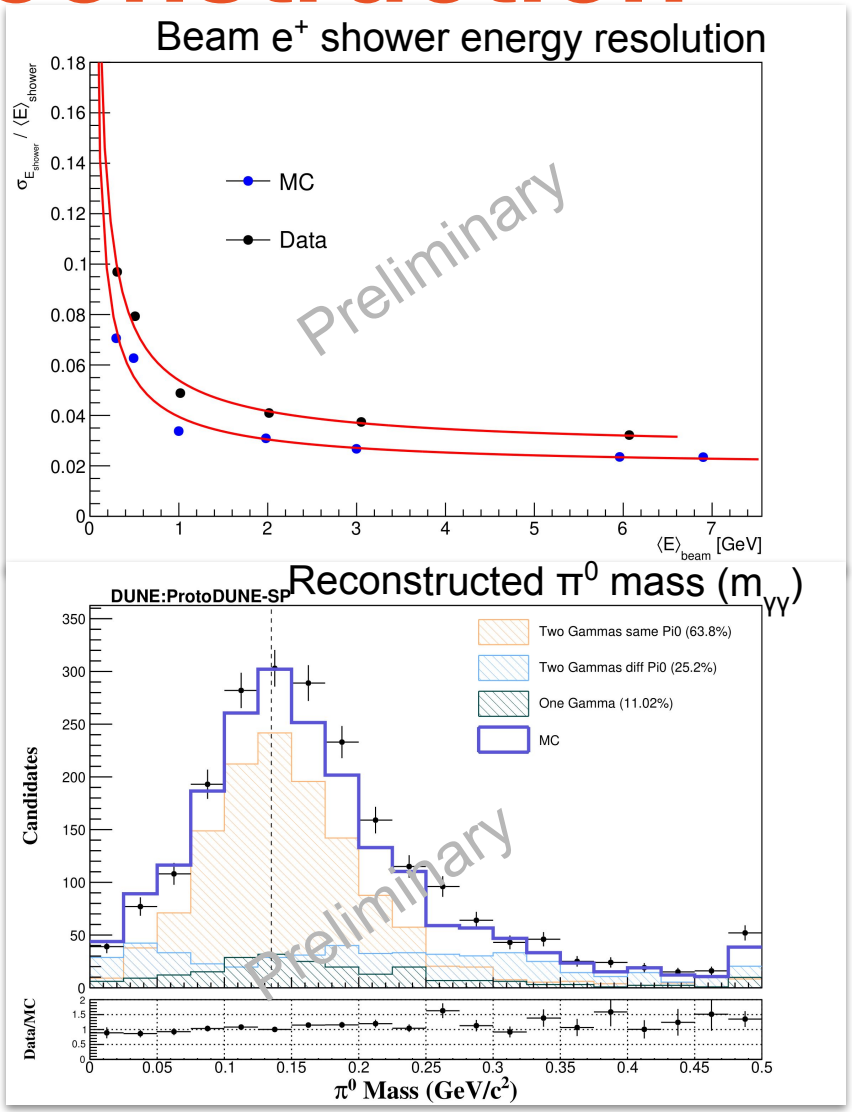


1. R. Acciarri et al. (MicroBooNE Collaboration), Journal of Instrumentation 12, 09 (2017) P09014
2. W. Foreman et al. (LArIAT Collaboration), arXiv:1909.07920v2

EM Shower Reconstruction

Important to study electromagnetic shower response

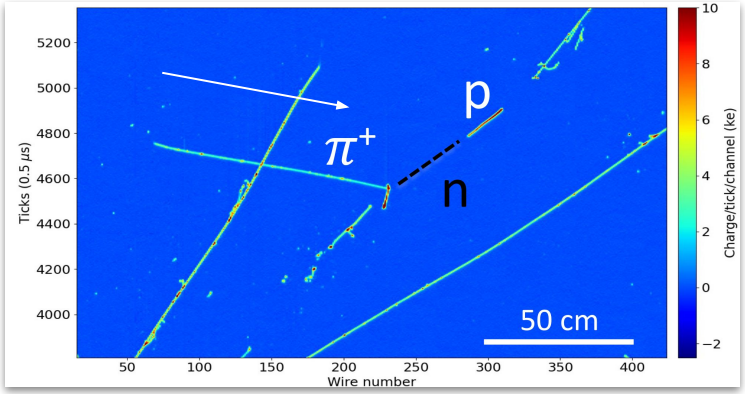
- Higher energy beam electrons
  - Oscillation analyses need to reconstruct ν_e energy
- π^0-decay showers
  - Identify π^0 backgrounds to ν_e events

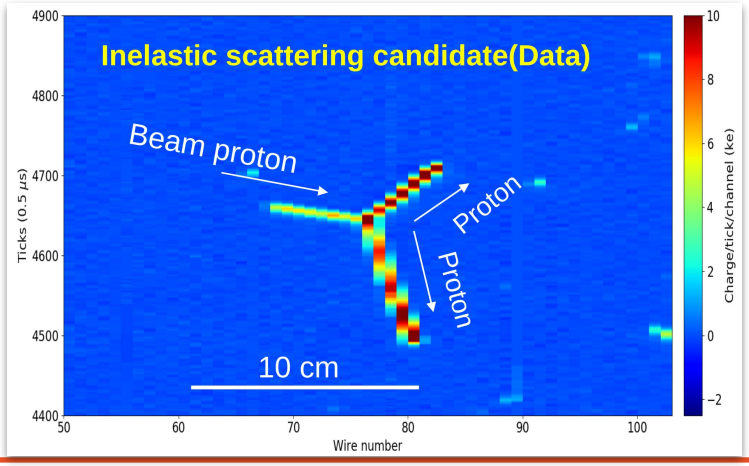


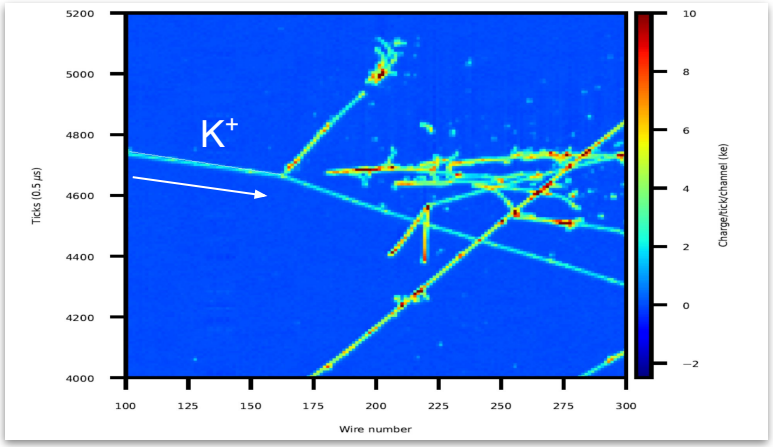
Hadron–Ar Cross Sections

Measuring interaction cross sections can help improve modeling across DUNE's physics program

- Oscillation analyses: π^+, p, n, K^+ interactions inform nuclear and secondary interaction models





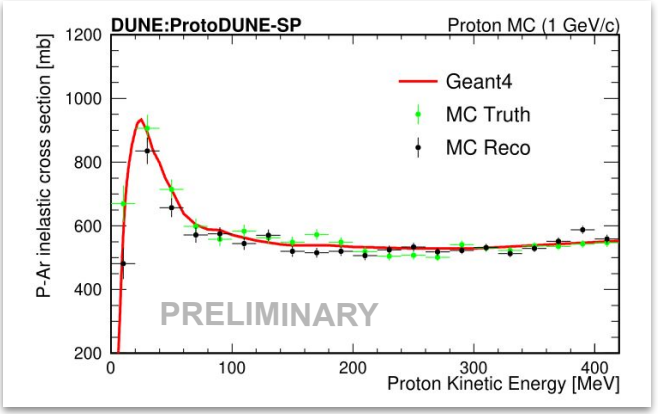


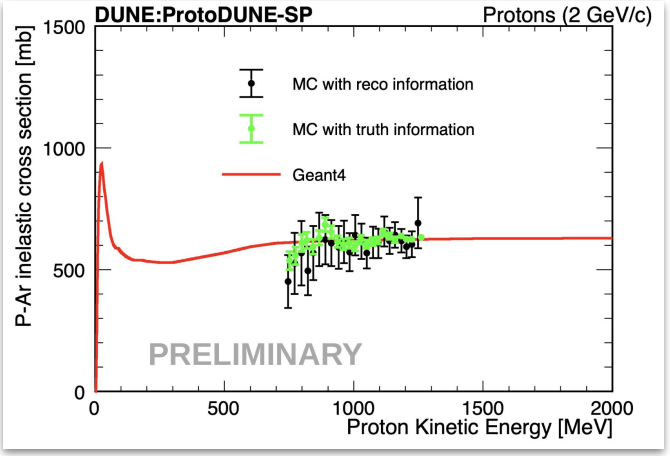
Proton Cross Section

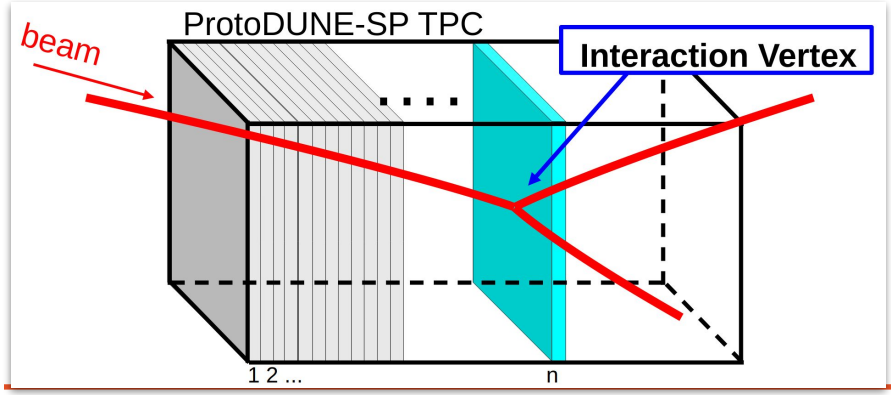
Segment extended TPC volume and treat as multiple, sequential thin targets
→ Build flux from segments
→ Identify interaction points
→ Use these to calculate cross section

Current analyses focusing on MC performance with 1 & 2 GeV/c central beam momentum runs

Will soon unblind





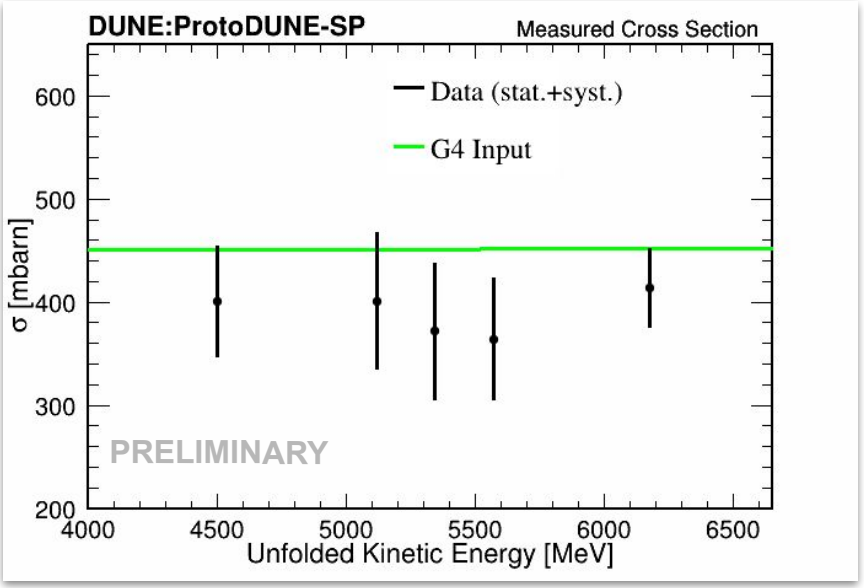


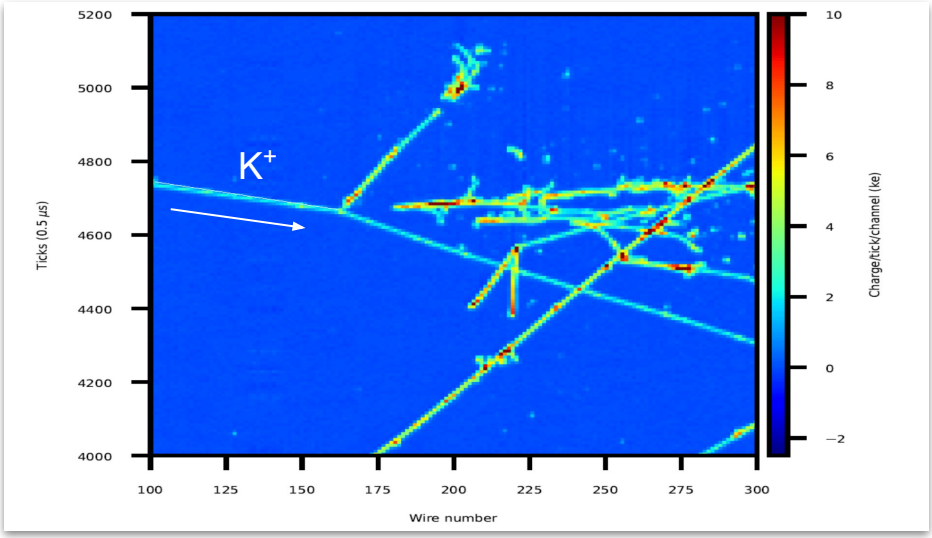
Kaon Cross Section

Similar procedure to the proton cross section measurement

Current analysis focusing on 6 GeV/c central beam momentum data

Paper in preparation





π^+-Ar Cross Sections

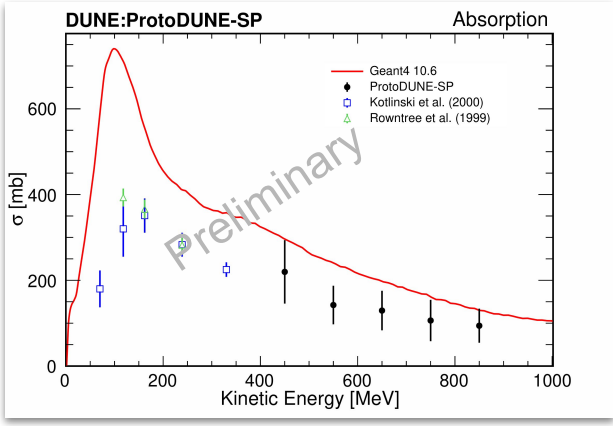
Likelihood-fit based analysis to measure exclusive interactions with 1 GeV/c pion beam

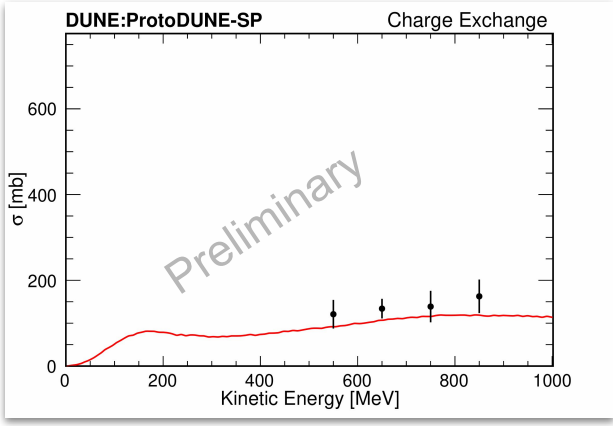
- Absorption: $\pi^+ + Ar \rightarrow X + \text{nucleons}$
- Charge Exchange: $\pi^+ + Ar \rightarrow X + \text{nucleons} + \pi^0$
- Other: remaining inelastic interactions

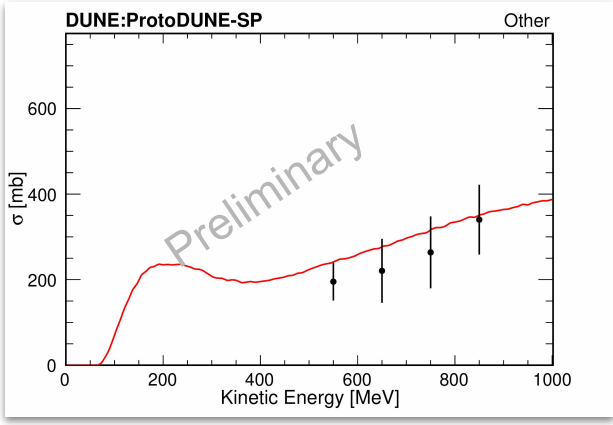
Preliminary results indicate misestimation by Geant4

- Similar to LADS[3,4] absorption results
- Possibly extend our analysis to lower energy range in future runs of ProtoDUNE

Paper in preparation







3. B. Kotlinski et al. (The LADS Collaboration). “Pion absorption reactions on N, Ar, and Xe”. In: The European Physical Journal A 9 (Dec. 2000), pp. 537–552

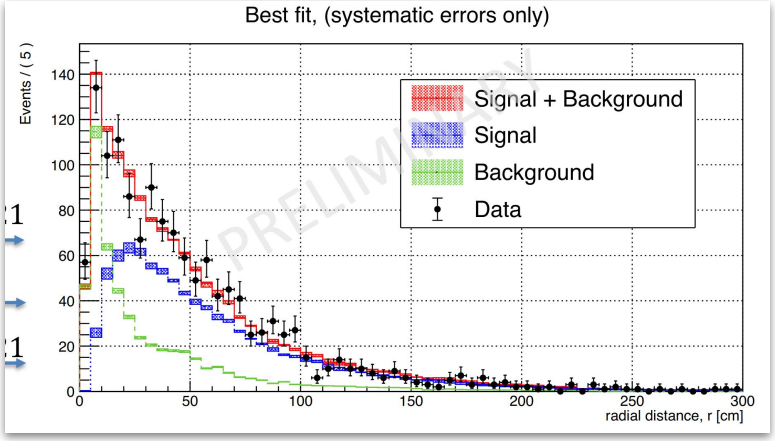
4. D. Rowntree et al. “pi+ absorption on N and Ar”. In: Phys. Rev. C 60 (1999). p. 054610. doi: 10.1103/PhysRevC.60.054610

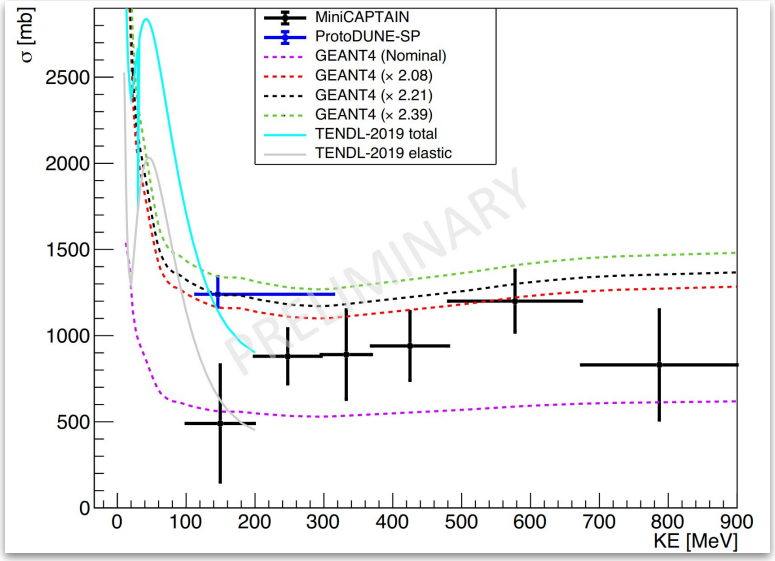
Neutron Cross Section

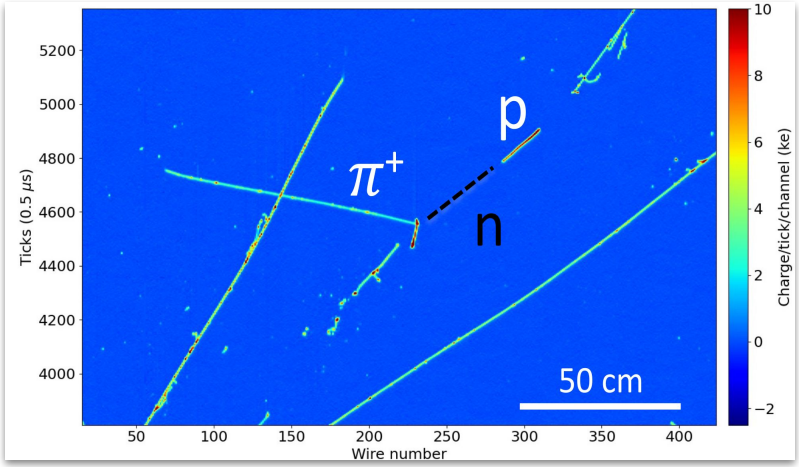
Identify neutrons resulting from primary pion interactions by looking for displaced proton tracks

Produce MC with varied neutron cross section model and fit to data

- Preliminary results indicate underestimation by Geant4







Future Analyses and ProtoDUNE-HD

The first round of analyses are nearing completion and are paving the way for future analyses

- Extending hadron cross section measurements to higher energy beam runs
- Differential cross section measurements
  - Provide more information about nuclear environment in Ar

A new configuration of ProtoDUNE is in preparation and plans to take more beam data late this year/early next year

- Can possibly provide lower momentum hadrons
  - Need to determine hadron yield from simulations

Summary

ProtoDUNE-SP excelled as a test bench for DUNE's single-phase LArTPC Far Detector technology

First round of physics results are quickly nearing completion and will provide vital inputs to DUNE's future neutrino analyses

Other exciting analyses are in preparation for the future

More data will be provided by future ProtoDUNE runs

Thank You For Listening

References

1. R. Acciarri et al. (MicroBooNE Collaboration), Journal of Instrumentation 12, 09 (2017) P09014
2. W. Foreman et al. (LArIAT Collaboration), arXiv:1909.07920v2
3. B. Kotlinski et al. (The LADS Collaboration). “Pion absorption reactions on N, Ar, and Xe”. In: The European Physical Journal A 9 (Dec. 2000), pp. 537–552
4. D. Rowntree et al. “pi+ absorption on N and Ar”. In: Phys. Rev. C 60 (1999). p. 054610. doi: 10.1103/PhysRevC.60.054610