

Charged particles interaction measurements in ProtoDUNE

F. Marinho on behalf of the DUNE collaboration

18/04/2024

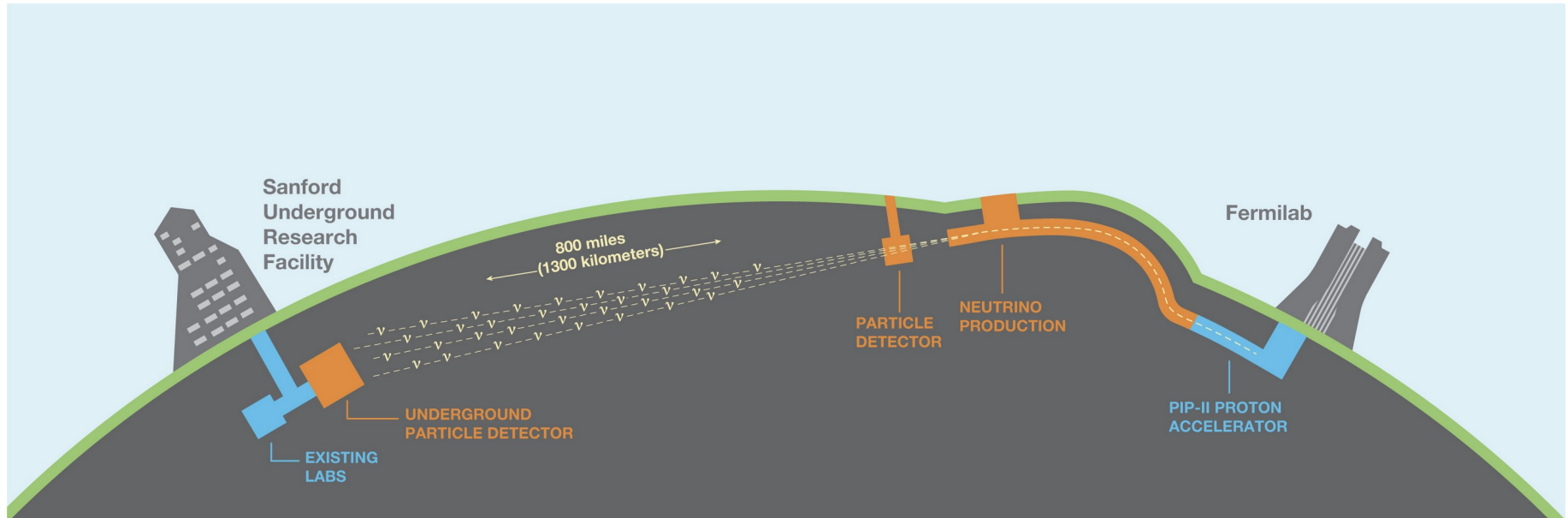


Content

- DUNE
- ProtoDUNE
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 - Physics data analysis
- Next prototypes runs
 - Perspectives

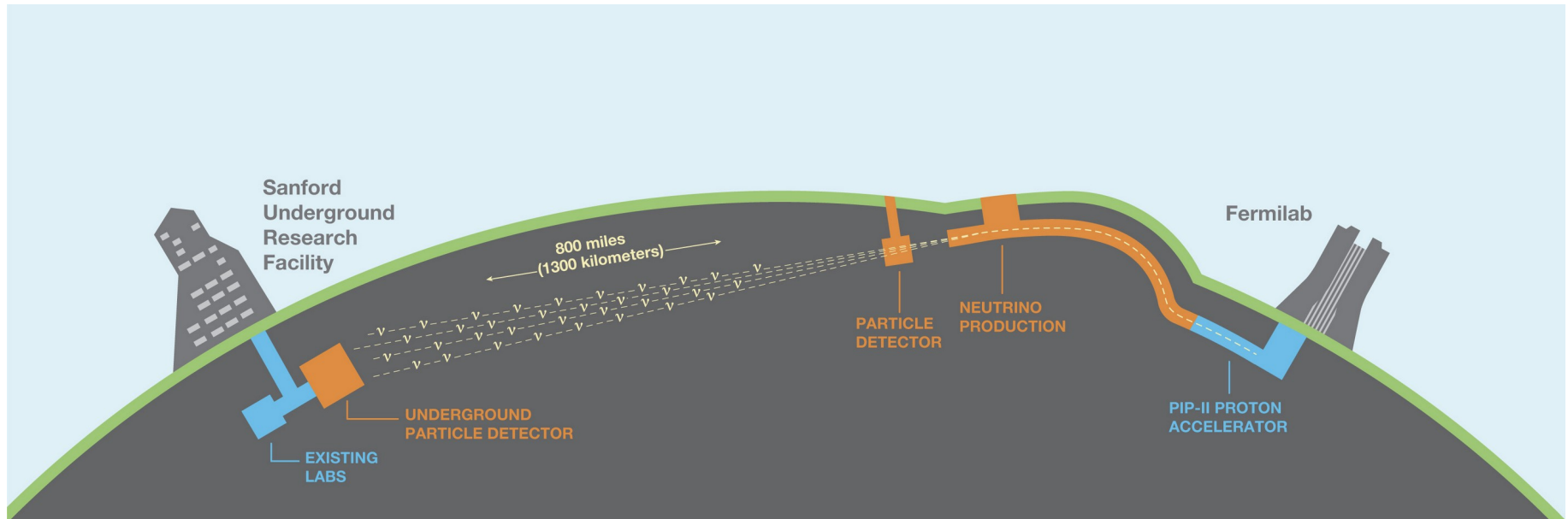


DUNE Experiment



- Intense neutrino beam: 1.2 MW \rightarrow 2.4 MW
- Near Detector system including a LAr TPC
- 4 Far Detector LArTPC modules (70 kton total mass)
 - 1300 km source distance, 1,5 km under surface

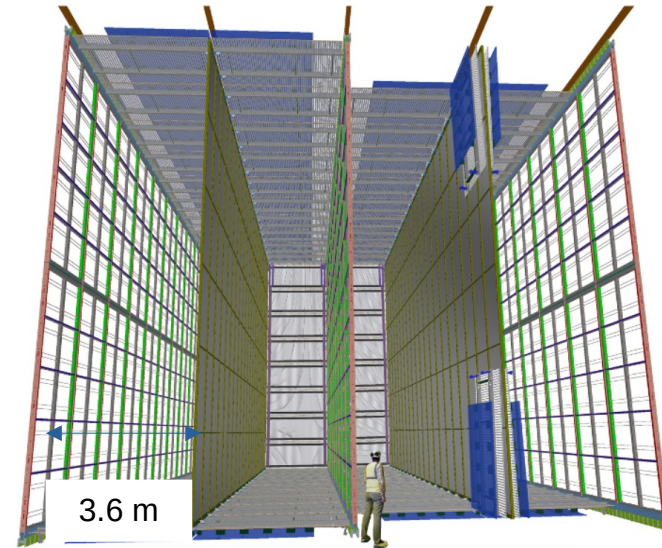
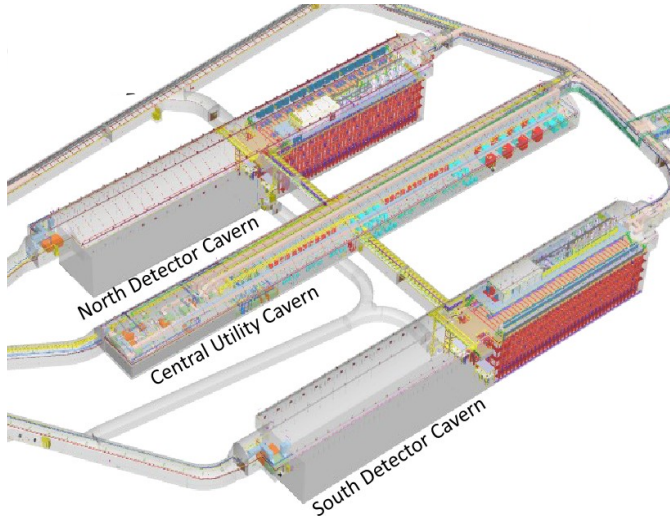
DUNE Physics



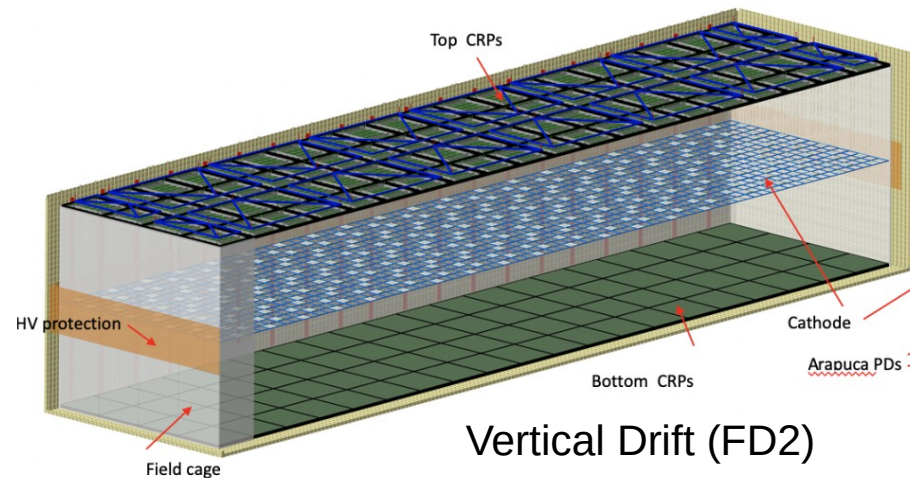
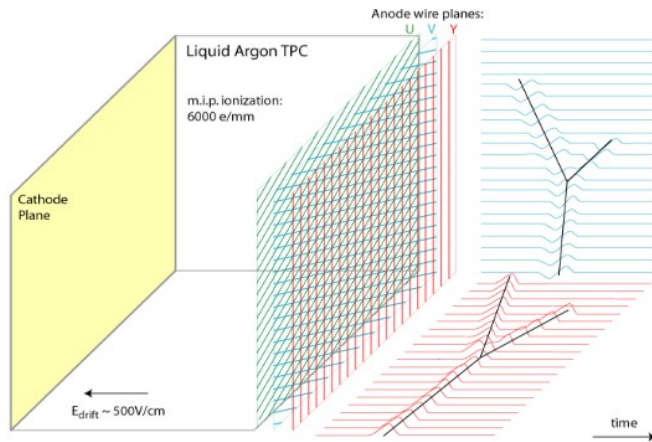
- Precise neutrino oscillations parameters determination
- Detection:
 - Galactic core supernovae neutrinos
 - Solar neutrinos
- Searches:
 - Proton decay ($p \rightarrow K^+ \bar{\nu}$, $p \rightarrow K^0 \mu^+$, $p \rightarrow K^+ \mu^- \pi^+$)
 - Non standard interactions

DUNE Far Detector (FD)

Far detector modules built in phases.
Phase I: First two modules

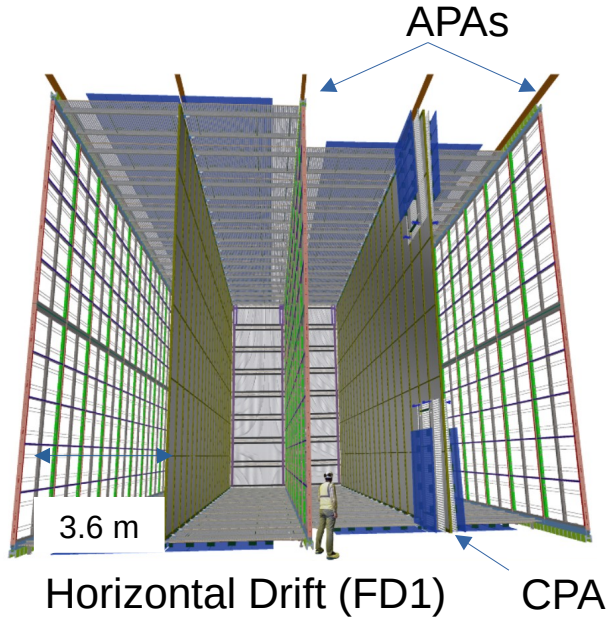


Horizontal Drift (FD1)

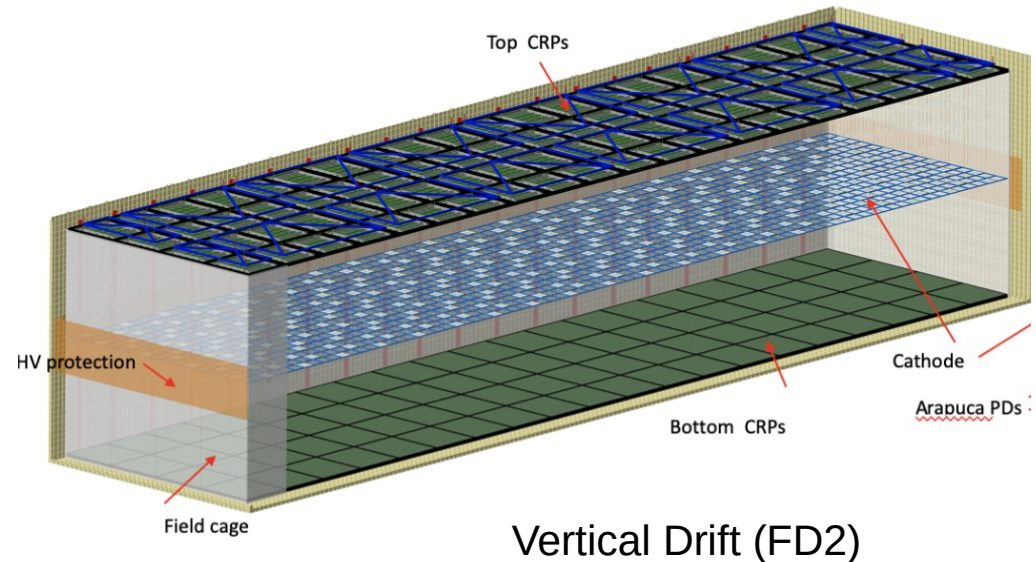
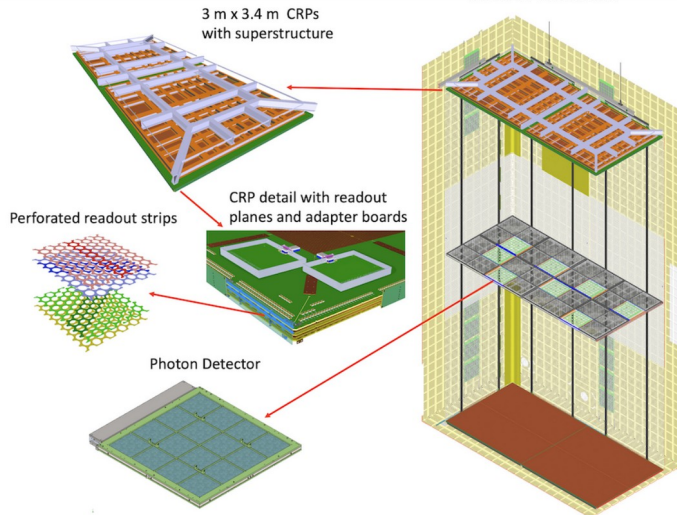


Vertical Drift (FD2)

DUNE Far Detector (FD)



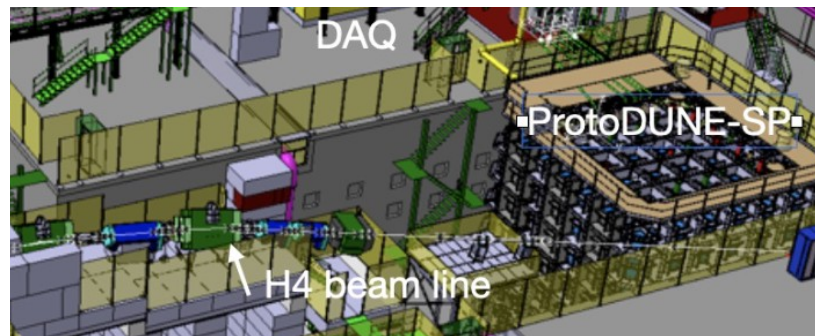
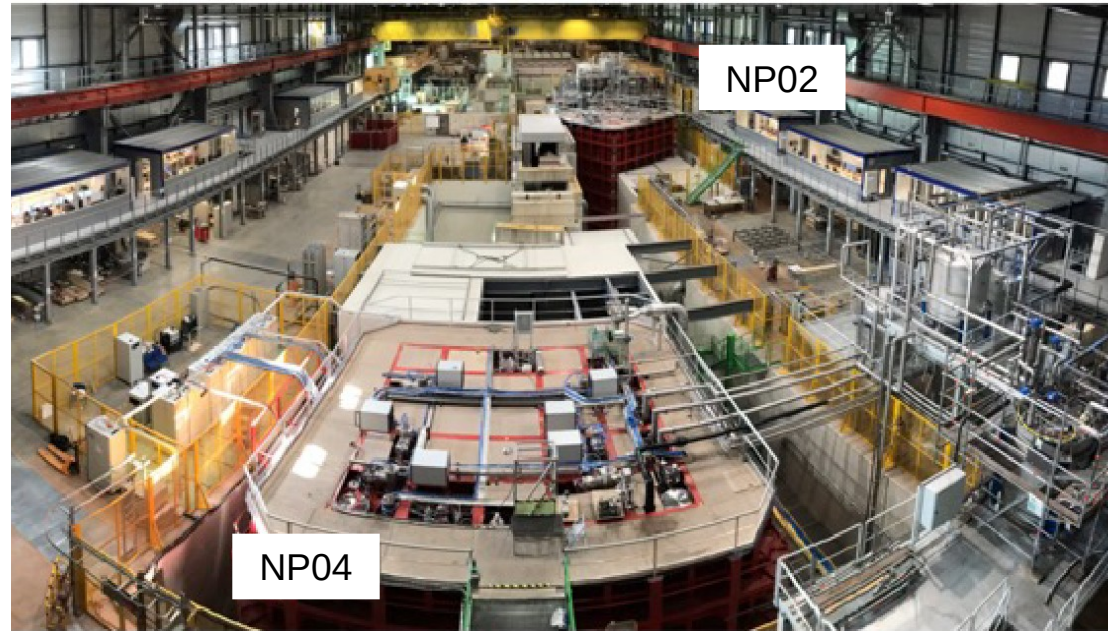
- APAs (FD1) and CRPs (FD2)
 - Readout: induction (2) and collection (1) planes
 - High resolution tracking (\sim mm)
- PDS sensors for timing (T_0 & calorimetry)



ProtoDUNE & NP@CERN

Two Far Detector prototypes

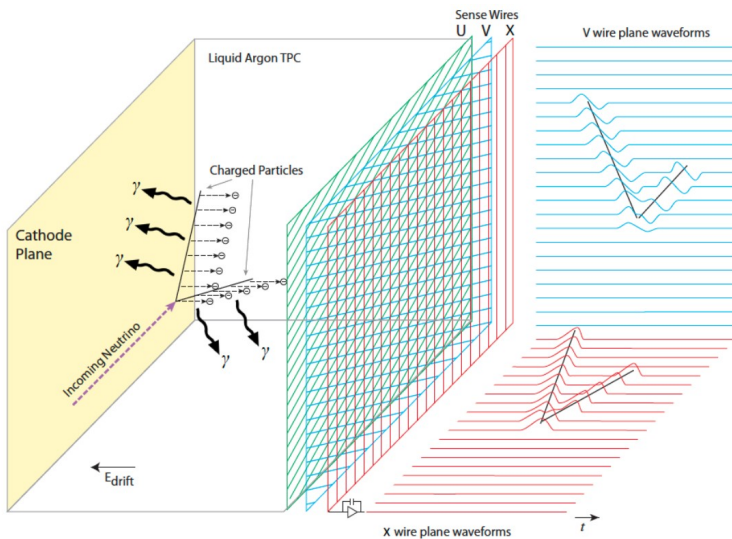
- Engineering and installation procedures
- Validation of LArTPC/PDS technologies
- Long term stability tests
- Charged particles beams at GeV scale



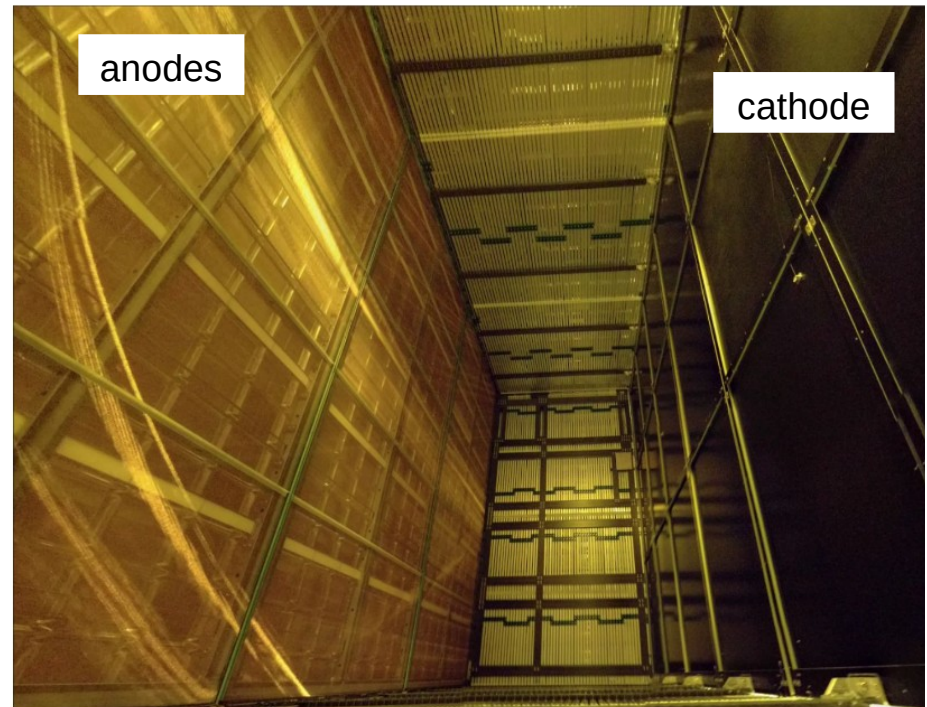
ProtoDUNE & NP@CERN

Two Far Detector prototypes

- Engineering and installation procedures
- Validation of LArTPC/PDS technologies
- Long term stability tests
- Charged particles beams at GeV scale
- Physics goal: Hadron-LAr interactions
Analyses on p , π , K & n .



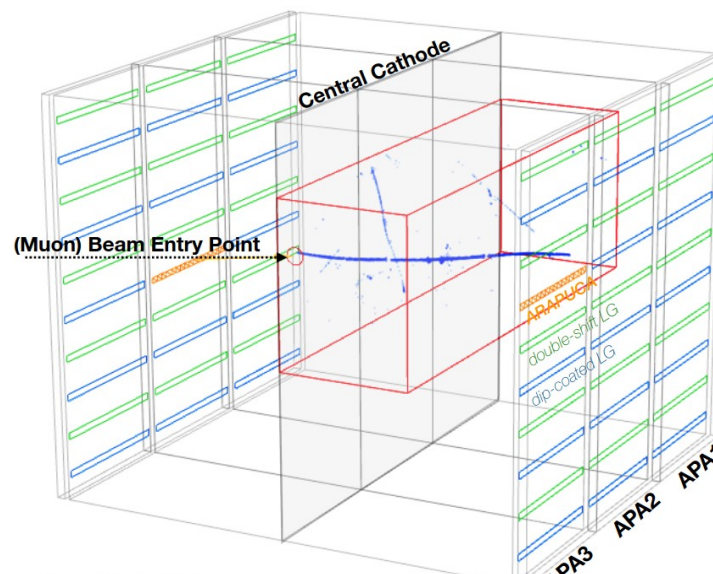
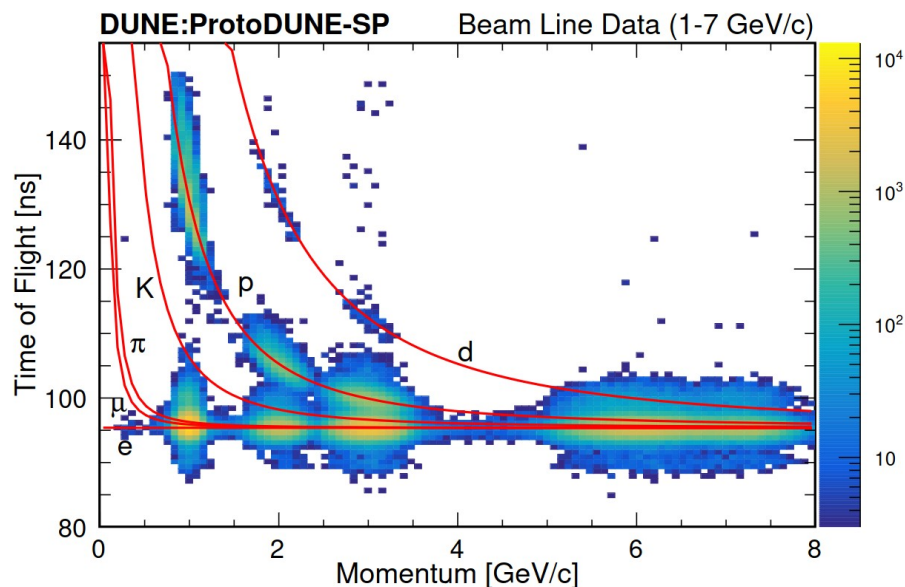
B. Abi et al 2020 JINST 15 T08008



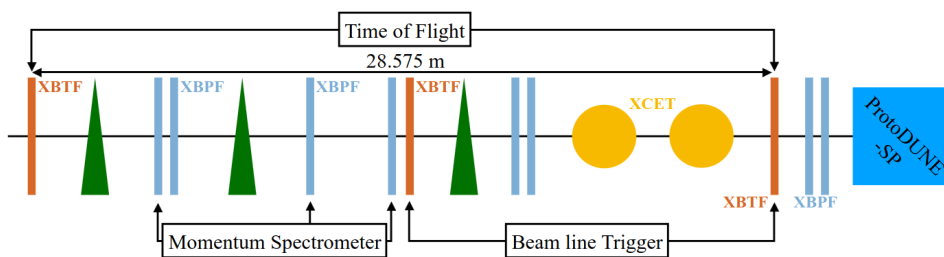
ProtoDUNE Single Phase (SP) : ~700-ton LArTPC

- Large scale test for DUNE Far Detector Module 1 technology
- Two drift chambers: wire readout for anode planes.
- Photon detector system: Arapucas + Acrylic WLS bars
- Beam data (2018) and cosmic data (2018-2020).

ProtoDUNE-SP beam data



H4-VLE beam line



Profile monitors (8), trigger counters (3) and Cherenkov counters (2)

| | | Momentum (GeV/c) | | | |
|-------------|----------|------------------|----------|---|-------|
| | | 1 | 2 | 3 | 6 - 7 |
| e | TOF (ns) | 0, 105 | 0, 105 | – | – |
| | XCET-L | 1 | 1 | 1 | 1 |
| | XCET-H | – | – | 1 | 1 |
| μ / π | TOF (ns) | 0, 110 | 0, 103 | – | – |
| | XCET-L | 0 | 0 | 0 | 1 |
| | XCET-H | – | – | 1 | 1 |
| K | TOF (ns) | – | – | – | – |
| | XCET-L | – | – | 0 | 0 |
| | XCET-H | – | – | 0 | 1 |
| p | TOF (ns) | 110, 160 | 103, 160 | – | – |
| | XCET-L | 0 | 0 | 0 | 0 |
| | XCET-H | – | – | 0 | 0 |

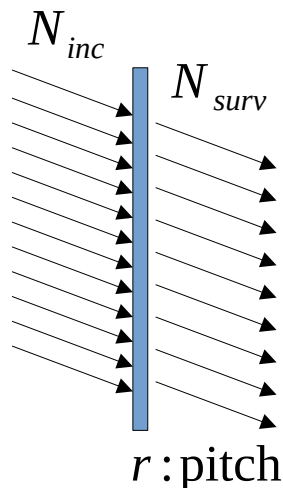
Hadron-Ar cross sections in ProtoDUNE-SP

Provide measurements of hadron interactions on LAr

- Neutrino interaction description for DUNE far detector
 - Final state and secondary interactions of hadrons

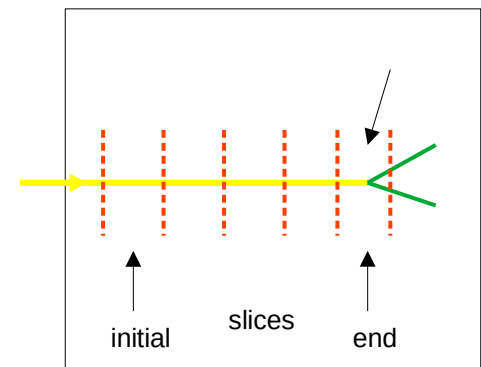
Methodology follows the thin-slice method (LArIAT: Phys. Rev. D 106, 052009)

- TPC divided into separate thin detectors
- Division adapted in terms of energy bin (instead of distance)
 - Beam momentum spread for each beam setting
- Cross section is defined by the ratio between interacting and incident hadrons



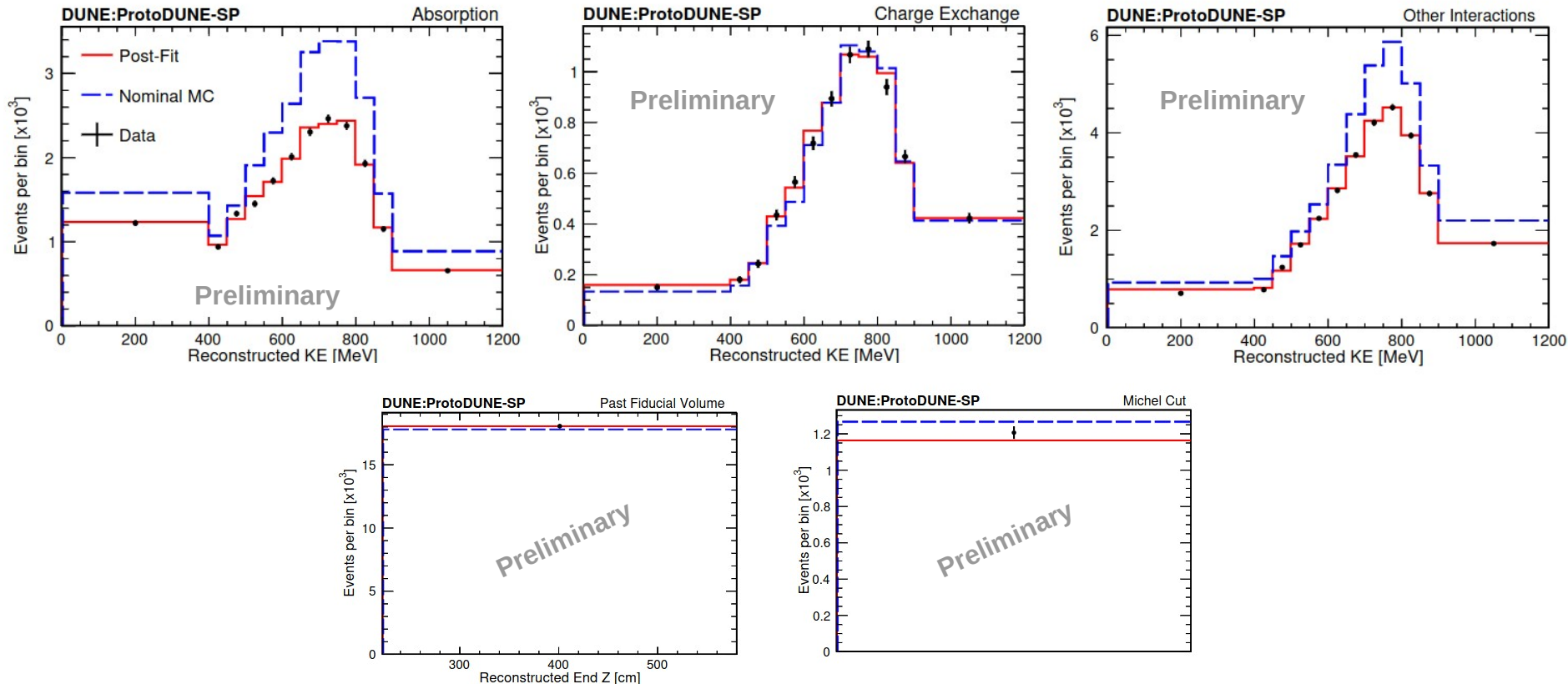
$$N_{inc} - N_{surv} = N_{inter}$$

$$\sigma = \frac{M_{Ar}}{\rho N_A r} \ln \left(\frac{N_{inc}(E)}{N_{inc}(E) - N_{inter}(E)} \right)$$

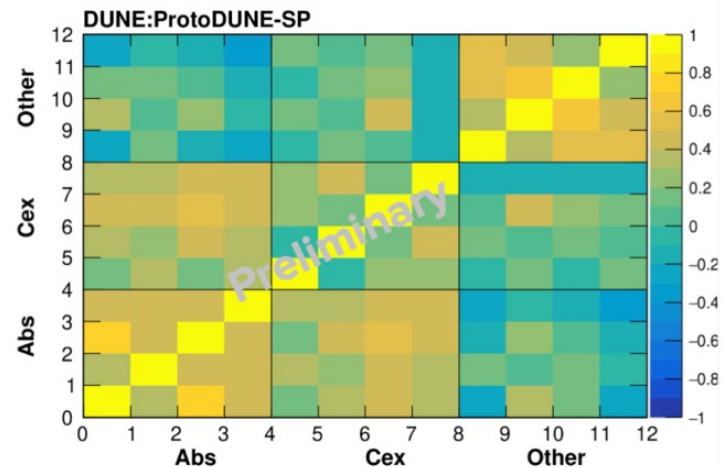
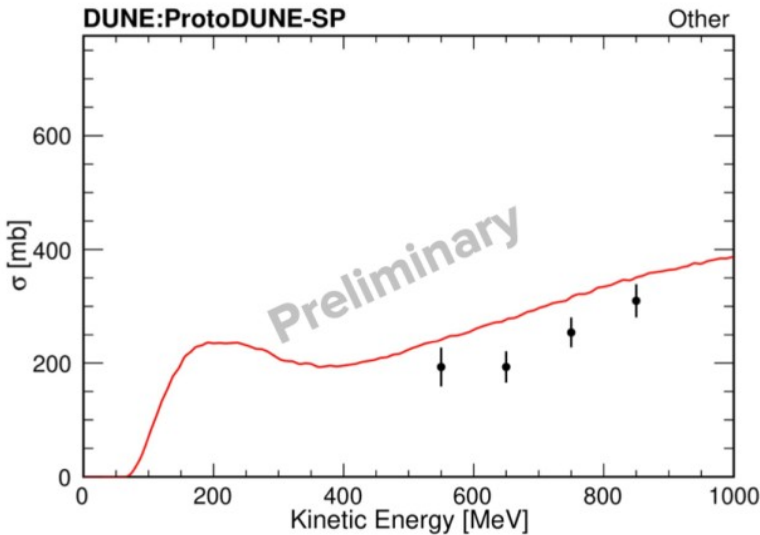
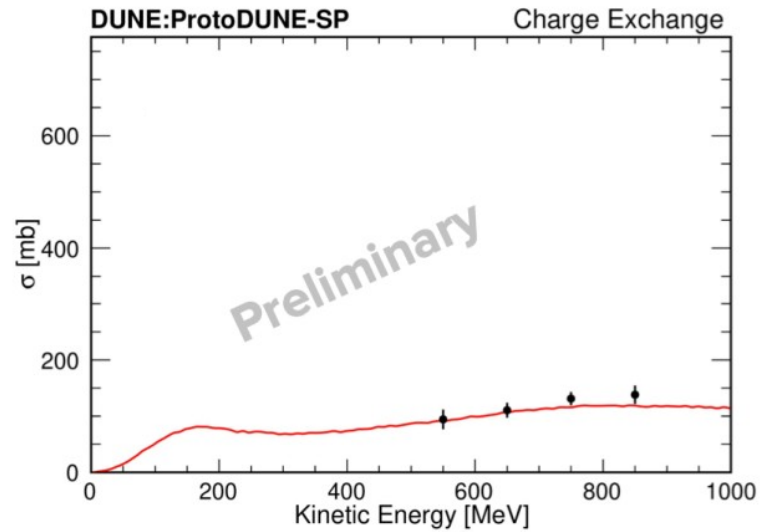
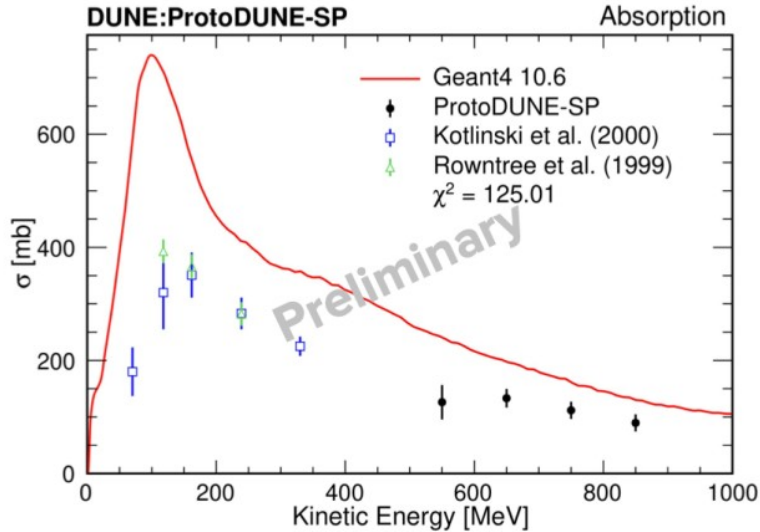


π^+ -Ar exclusive cross sections @ 1GeV/c

- Inelastic interaction events of beam particles categorized as:
 - **Absorption** (no π s), **charge exchange** (only π^0) and **other** (at least 1 π^\pm)
- Cross-sections obtained with binned likelihood fit
 - Accounts for detector smearing, efficiencies and backgrounds.



π^+ -Ar exclusive cross sections @ 1GeV/c



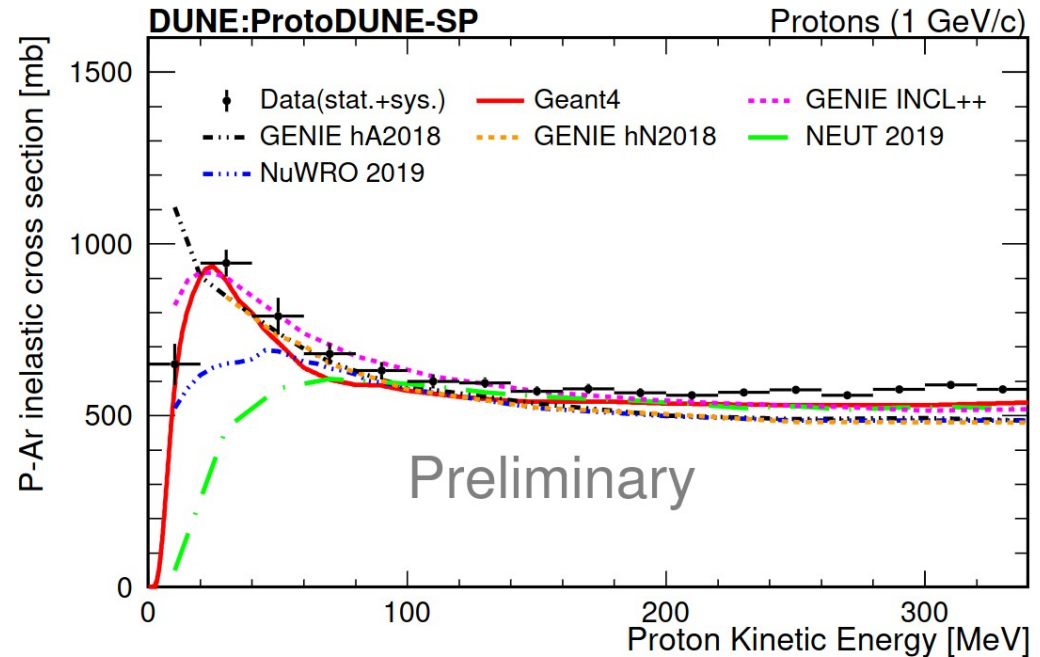
correlations between the measured cross sections for the different channels

Proton-Ar inelastic cross section @ 1 GeV/c

- Energy-slice method adopted

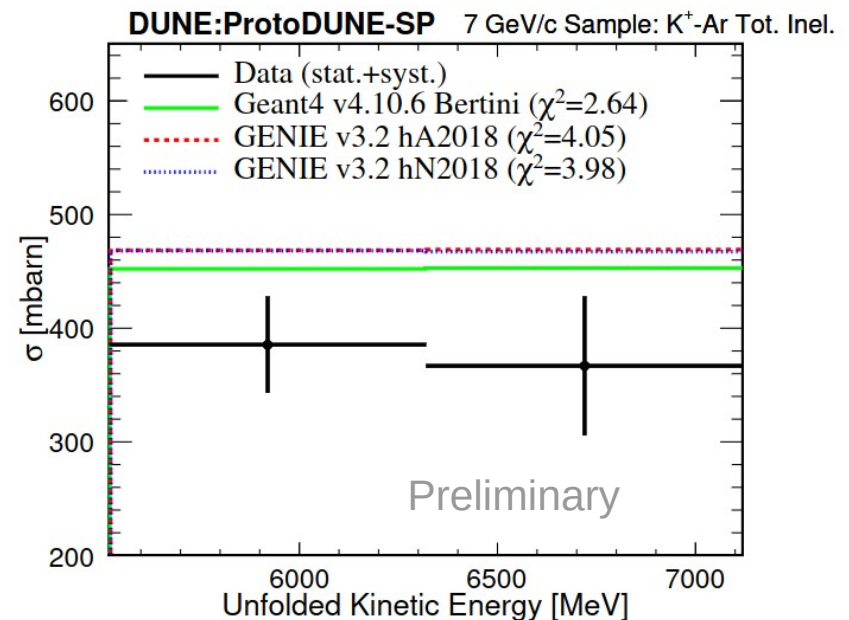
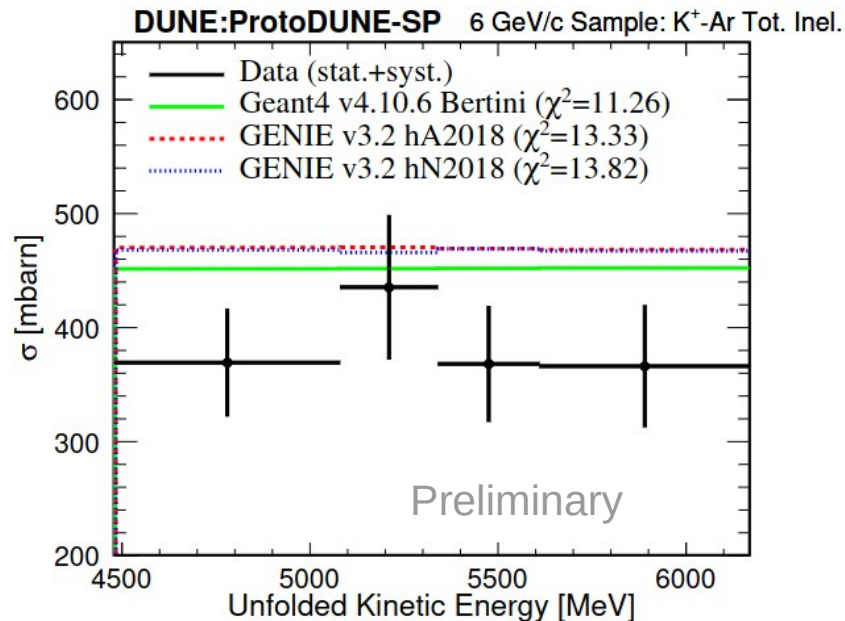
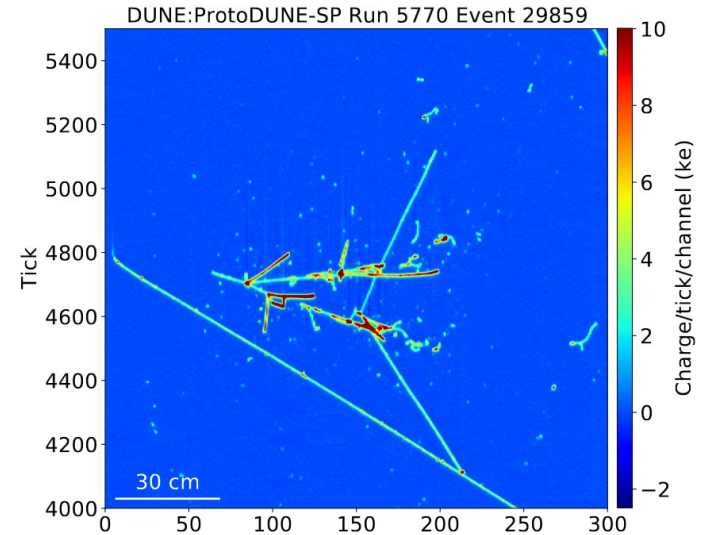
$$\frac{1}{\Delta x} = \frac{1}{\Delta E} \frac{dE}{dx}(E)$$

- Signal selection (TOF)/~85% purity
- Veto on no interacting protons (E loss)
- Similar amount to secondary protons
 - Background subtraction:
 - good agreement MC and data
- Measured spectrum as “folded” true
- D’Agostini method (iterative Bayesian)
 - Correlations between N_{ini} , N_{end} , N_{int} histograms in single unfolding



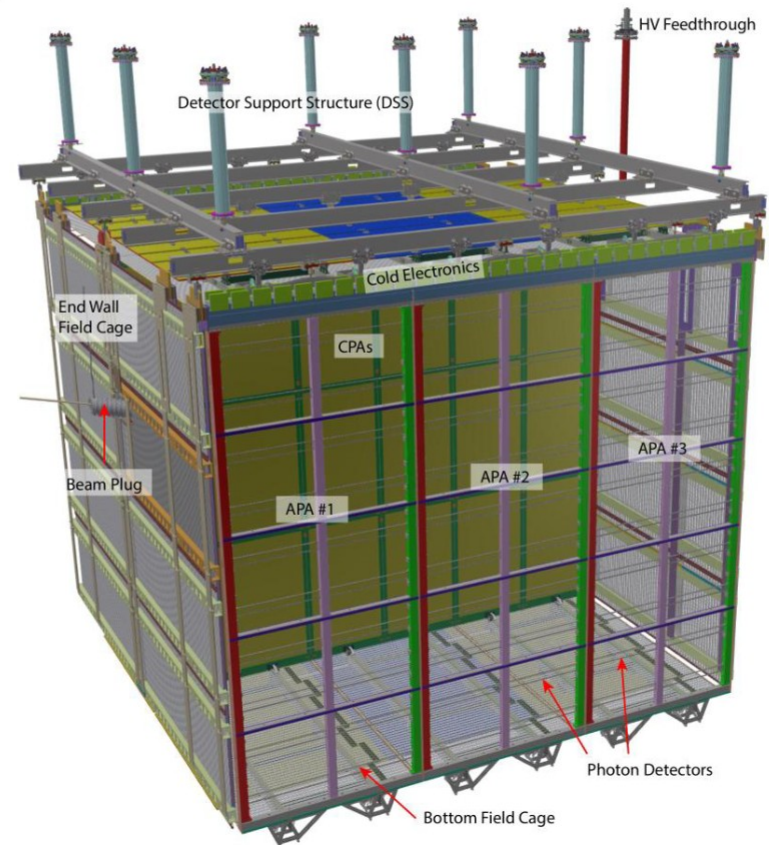
Total Kaon⁺-Ar inelastic X-section @6 & 7 GeV/c

- Particle Identification with Cherenkov
- Thin slice method adopted
- X-section extracted via unfolded raw histograms of incident and interacting
- (Bayes-like unfolding)



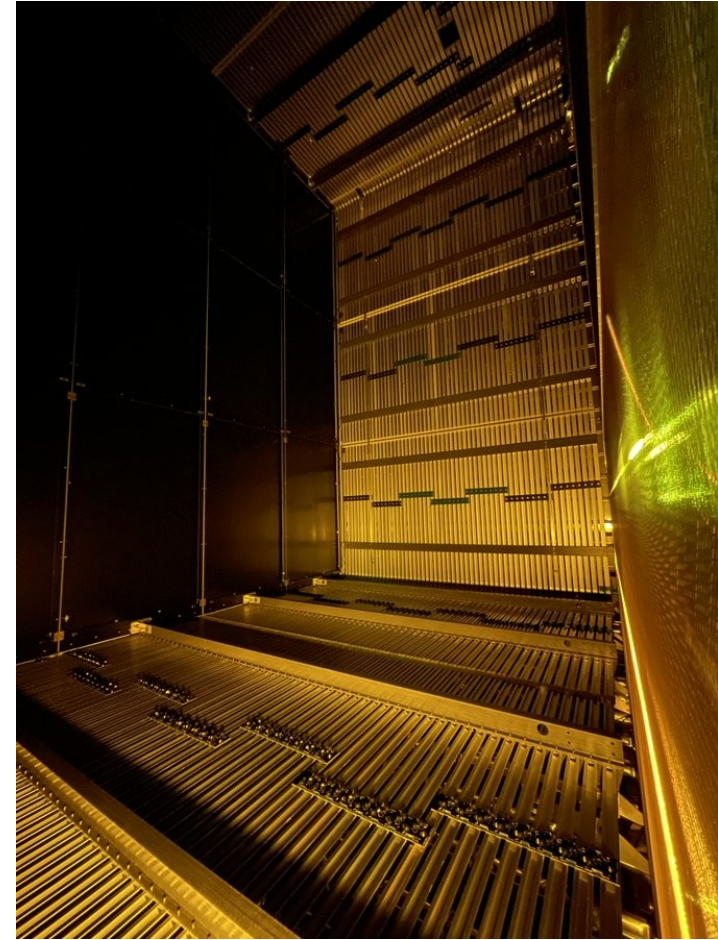
Conclusions

- Hadron beam data taken in ProtoDUNE-SP for DUNE far detector module 1 (FD1)
- A wealth of cross-section analyses being developed to provide new measurements
 - At advanced stage and should be published soon
- Feedback for simulations/modeling of particle passage through LAr and intranuclear cascade



Conclusions & perspectives

- Next ProtoDUNE data taking campaign
- Horizontal Drift (NP04): spring/summer 2024
 - Final components design for FD1
- More dedicated time on 0.5-2 GeV range
 - π^\pm and p – LAr full and differential cross-section
- Vertical Drift (NP02): Fill in fall 2024
 - Dedicated to further test FD2 technologies
 - Beam expected in early 2025
 - Measurements and statistics similar to HD
 - are expected



Conclusions & perspectives

- Vertical Drift (NP02): Fill in fall 2024
 - Dedicated to further test FD2 technologies
 - Beam expected in 2025
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