NA61/SHINE Experiment

– New Results from the Neutrino Program and Future Prospects –

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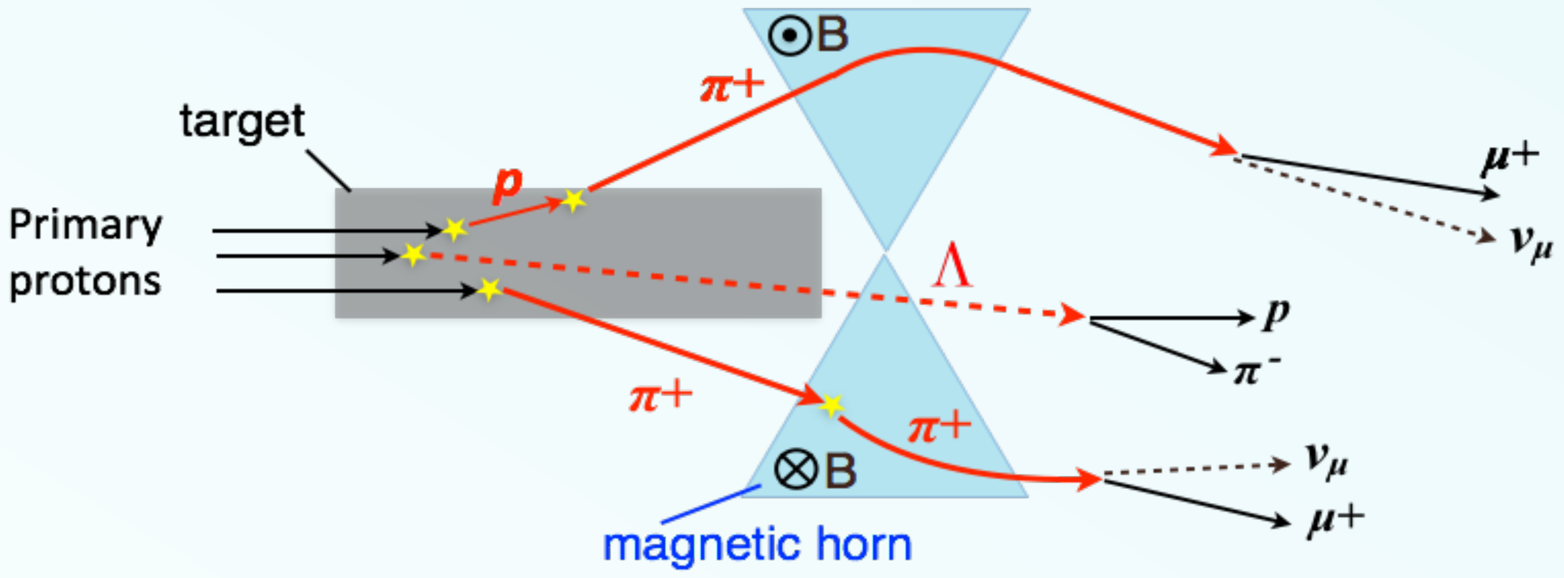
Abstract

A precise prediction of the neutrino flux is a key input for accelerator-based neutrino experiments. Neutrino beams are created from the decays of secondary hadrons produced in hadron-nucleus interactions. Hadron production is the leading systematic uncertainty source on the neutrino flux prediction; therefore, its precise measurement is essential.
This contribution will review recent hadron production measurements for precise neutrino flux predictions needed by Fermilab long-baseline neutrino experiments and will also review the status and prospects for future hadron production measurements.

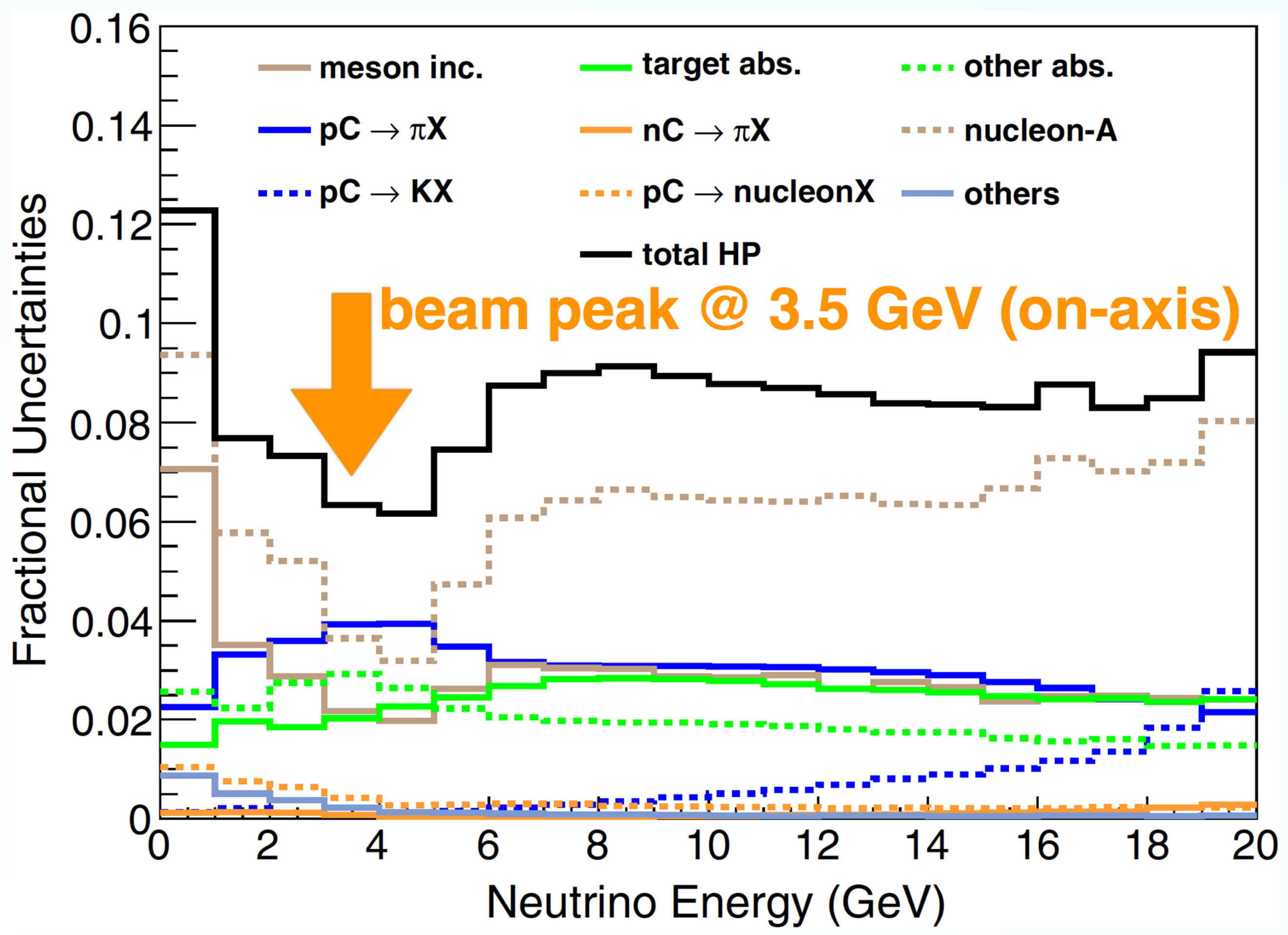
Introduction – How to make a neutrino beam

- ❑ Shooting proton beams on target (typically C, Be)
- ❑ Focusing hadrons to a beam direction
- ❑ Letting them decay to neutrinos



Flux Prediction – Hadron production uncertainty

- ❑ Hadron production is the leading uncertainty source of flux predictions
- ❑ An example from the MINERvA experiment at NuMI
  → **hadron production uncertainty is 7-10%**



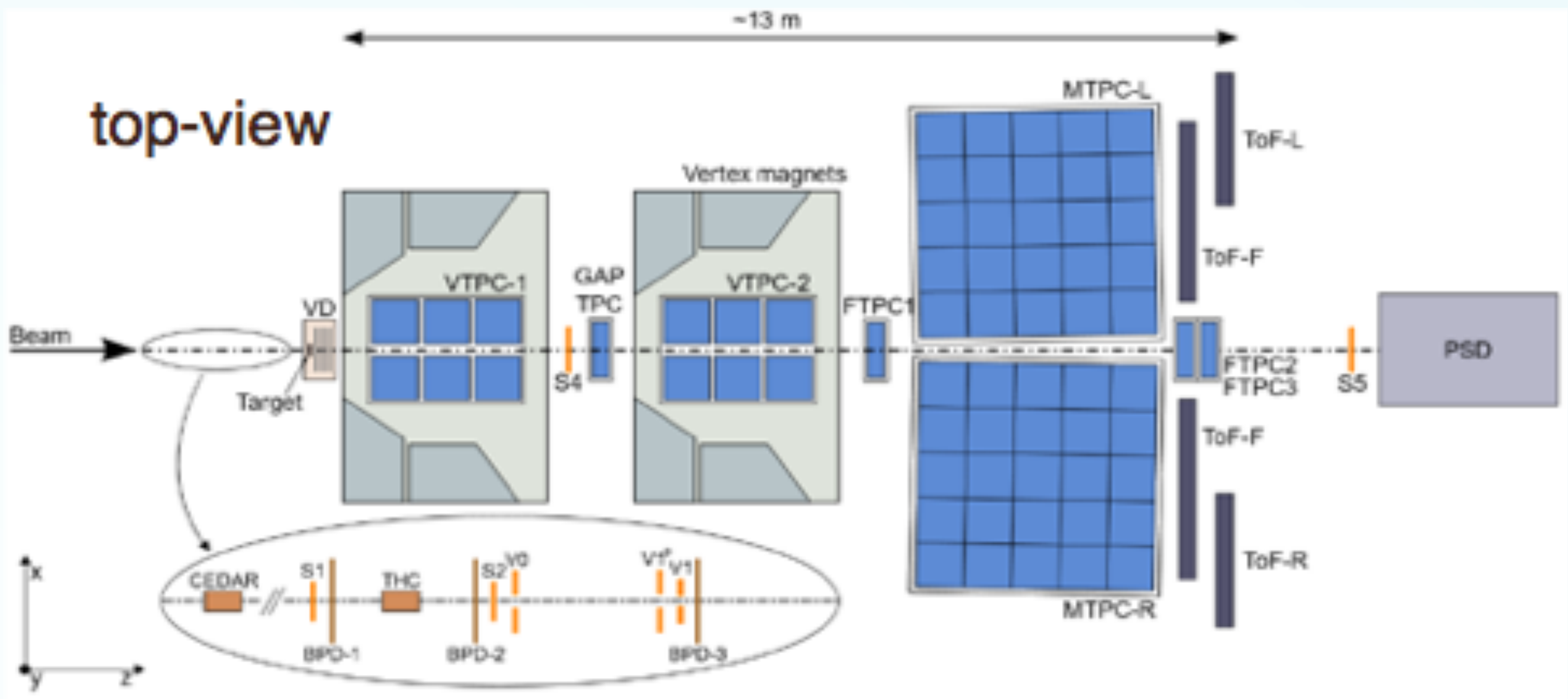
MINERvA: **Phys. Rev. D94, 092005 (2016)**

Requirement for LBNF/DUNE

- ❑ LBNF/DUNE is a next generation long-baseline neutrino experiment
- ❑ Goal for flux: **2-3% uncertainty for broad-range (sub GeV - 5 GeV)**
  → Hadron production will be the dominant uncertainty
  Expected 7-8% with existing data, situation is similar to NuMI
  → **Additional hadron production measurements are essential**

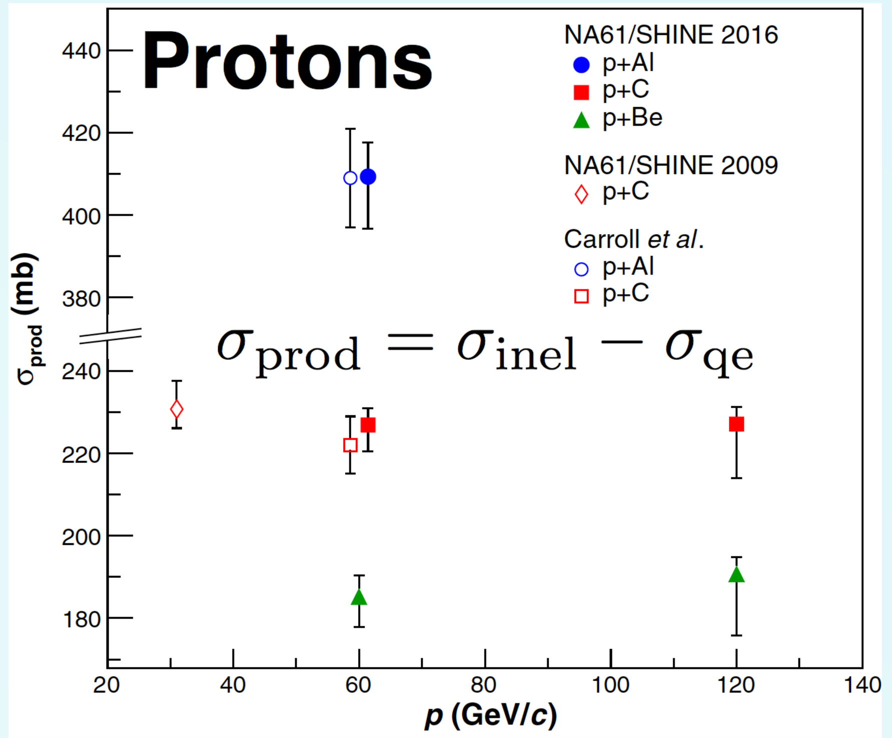
The NA61/SHINE experiment

- ❑ SHINE = The SPS Heavy Ion and Neutrino Experiment at CERN
  → Hadron beams (p, $\pi^\pm$, $K^\pm$) at 13-350 GeV/c and ion beams
- ❑ Large acceptance spectrometer for charged particles
  → Time projection chambers (track reconstruction and particle ID)
  → Superconducting dipole magnets (good momentum measurement)
  → Time-of-Flight detectors (particle ID)
- ❑ Broad physics program
  - ✔ **Neutrino physics** (hadron beams)
    → **Hadron production measurements to improve neutrino beam flux predictions**
  - ✔ Strong interaction / heavy ion physics (hadron and ion beams)
  - ✔ Cosmic ray physics (hadron and ion beams)



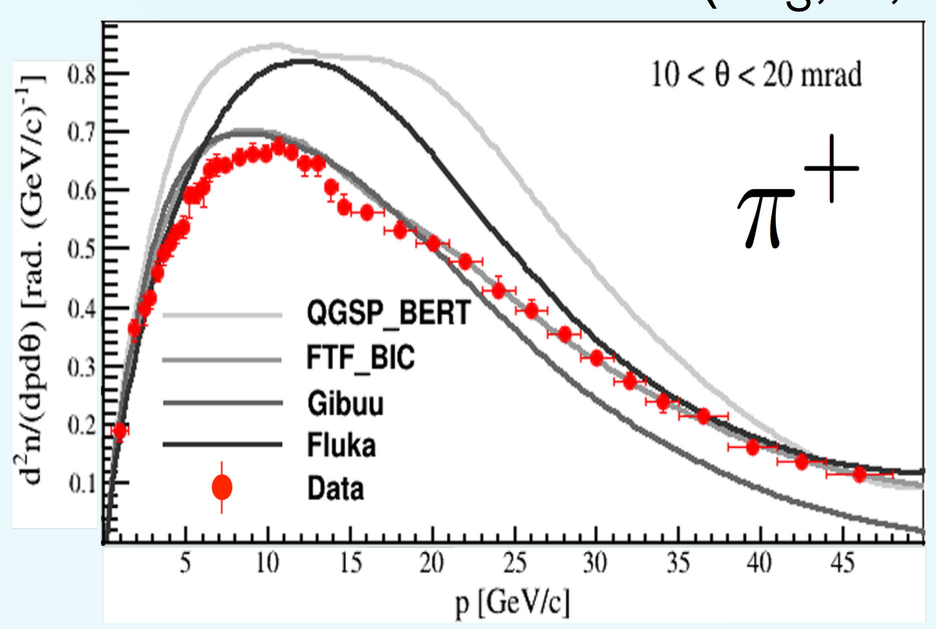
Results

❑ Production cross section measurements



Example: 60 and 120 GeV proton interactions on C, Be, and Al thin targets.
Precision:
2-4% uncertainty (60 GeV)
6-8% uncertainty (120 GeV)
→ Will be used to correct probability of interaction in model predictions

❑ Spectra measurements of charged hadrons (p, $\pi^\pm$, $K^\pm$) and neutral hadrons (K^0_S, Λ, $\overline{\Lambda}$)



Example: 60 GeV π^+ interactions on a thin C target
Method: data have been compared with various model predictions (Geant4 models, Gibuu, FLUKA)
→ Will be used to correct hadron multiplicity predictions

Future Prospects

- ❑ Coming soon: **proton spectra analyses at 60 & 120 GeV**
- ❑ Detector upgrade will be completed by mid-2021
  → 1 kHz DAQ rate (**10 times higher**)
- ❑ Planning for a low-energy beamline (**1-13 GeV**)
- ❑ Measurements will be resumed in 2021-2024
  → High statistic measurements with broad energy range (**1-120 GeV hadron beams**)

References

Total π^+ and K^+ cross section: **Phys. Rev. D98, 052001 (2018)**
Total proton cross section: **Phys. Rev. D100, 112001 (2019)**
π^+ spectra measurement: **Phys. Rev. D100 112004 (2019)**