Refining Neutrino Beam Simulations Through Hadron Production Measurements

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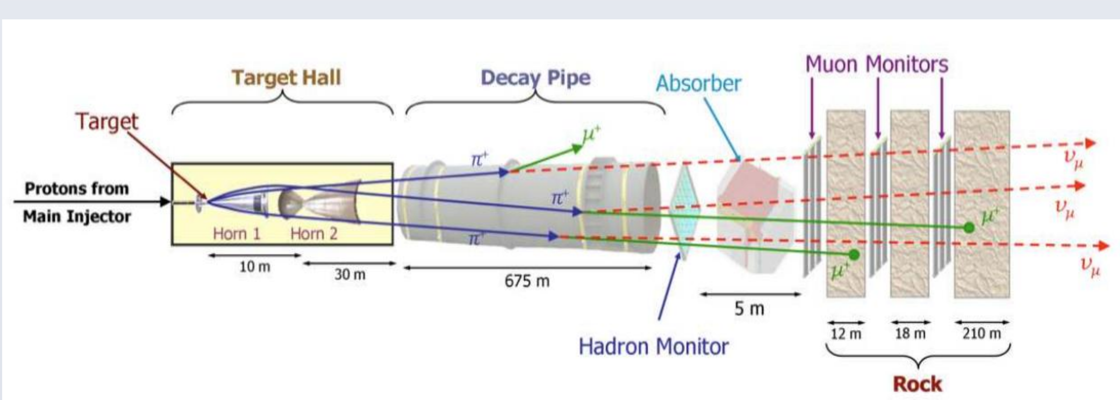
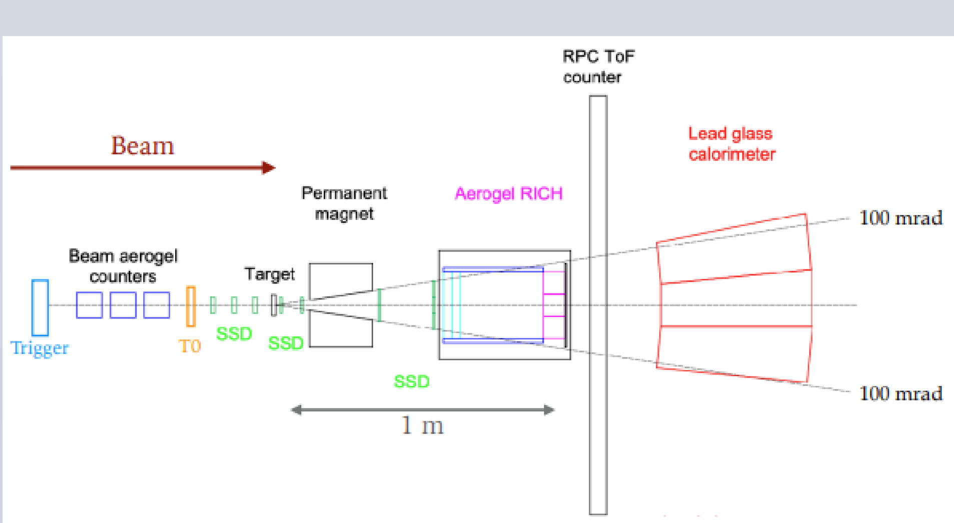
Neutrino Physics Program

- The motivation is to understand big questions in matter-antimatter asymmetry and Beyond Standard Model physics
- Take measurements on how neutrino beams evolve over long distances to measure neutrino oscillation parameters
- Oscillation measurements will benefit from more precise predictions of neutrino fluxes
- We can make better predictions of the neutrino flux by better understanding the hadron physics behind beam production



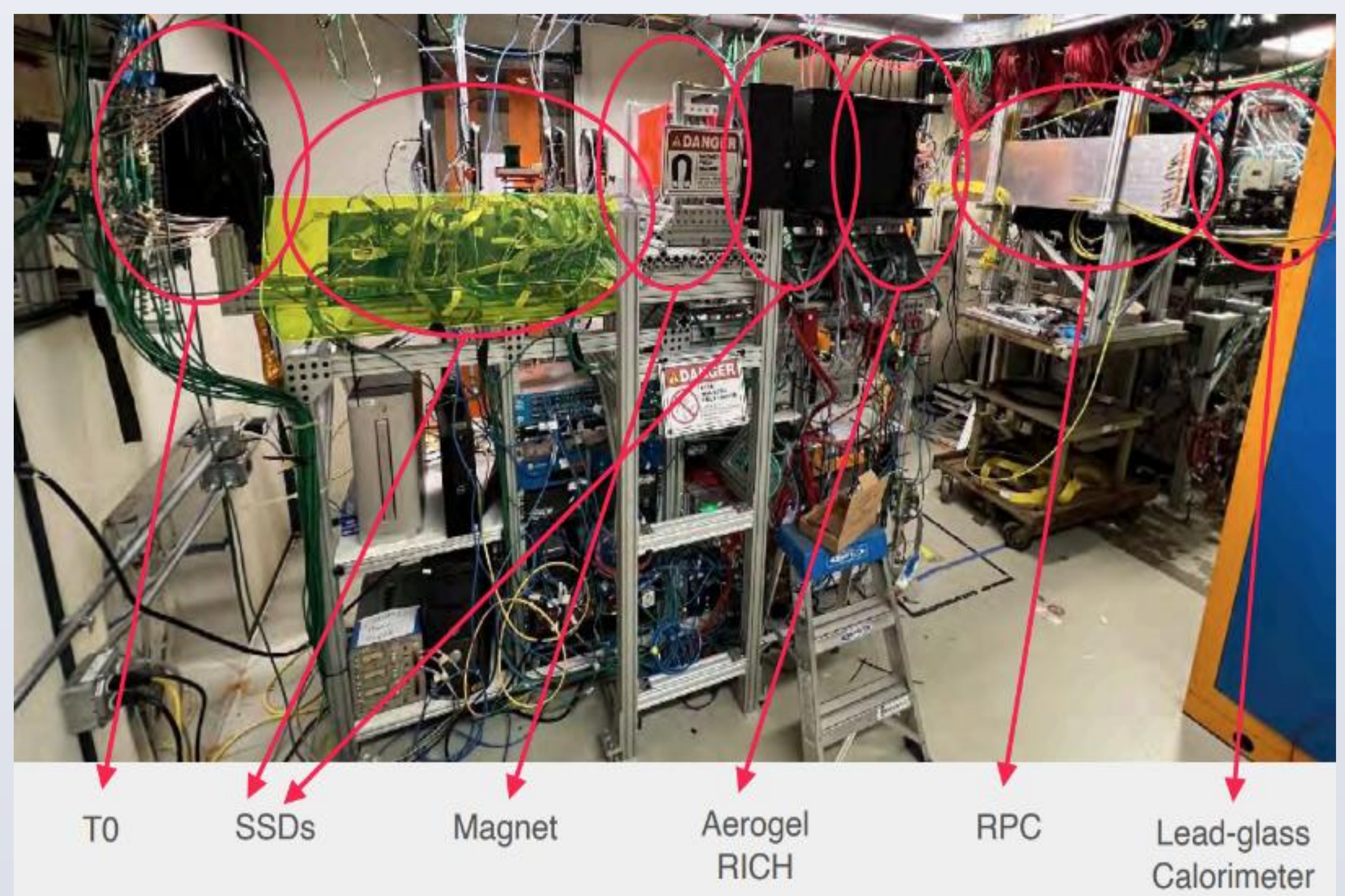
Neutrino Flux Predictions

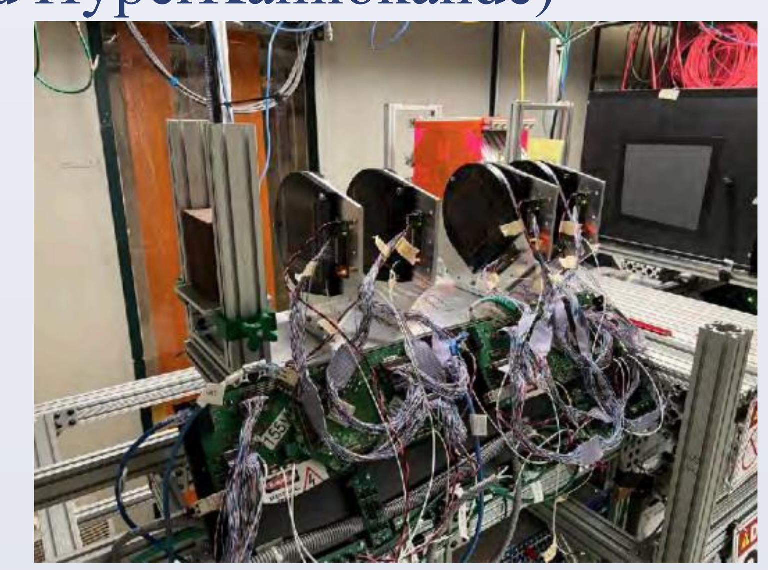
- Flux uncertainties are currently at the level of ~10%
- Large uncertainty source comes from hadron production and scattering cross sections[1]
- There are several experiments, including EMPHATIC, improving hadron measurements to reduce neutrino flux uncertainty and improve the precision of future neutrino experiments

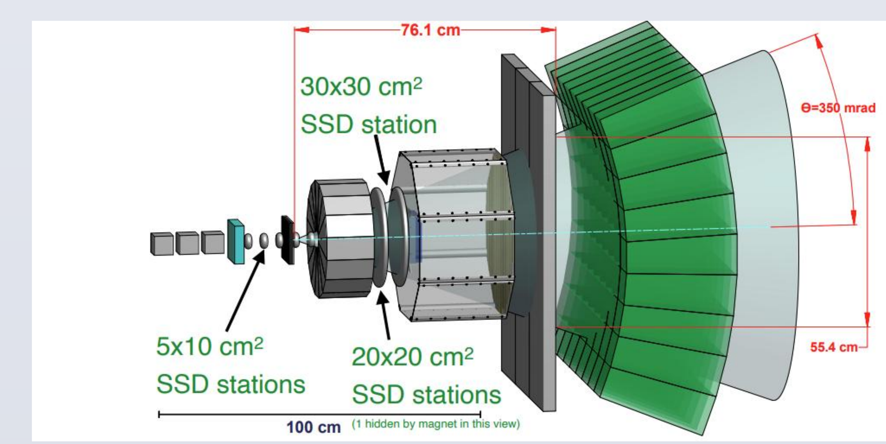


EMPHATIC Goals/Spectrometer Overview

- EMPHATIC aims to measure hadron scattering/production cross sections
- Utilizing a 100 mrad Acceptance Spectrometer experiment focused on hadron production measurements with beam momentum ranging from 2-120 GeV/c [2]
- EMPHATIC can take data on variety of thick and thin targets(Graphite, Aluminum, Iron, Beryllium, and CH2)
- Identical detectors used at both near and far locations (MINOS and NOvA Experiments)
- Beneficial to 3-flavor oscillation measurements (DUNE and HyperKamiokande)

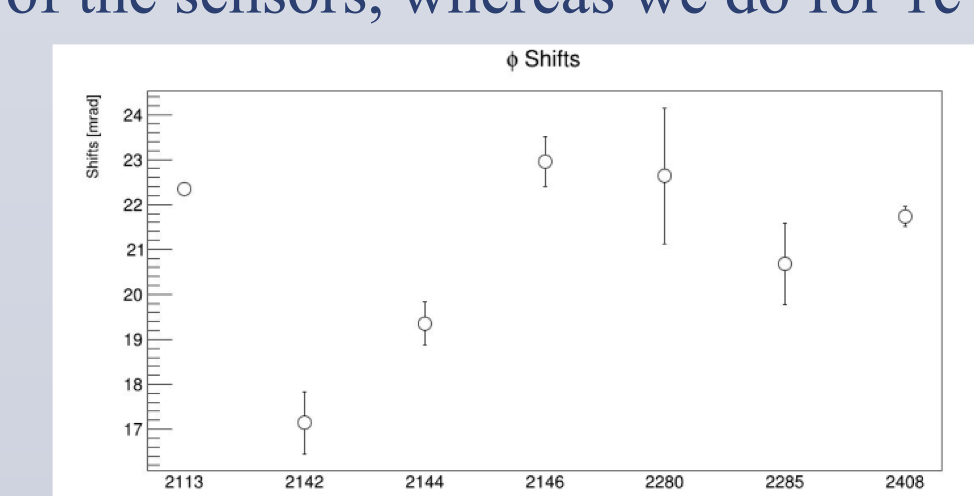






Tracking Detector Alignment

- Working toward aligning SSD detectors to high accuracy and precision to allow better determination on the momentum of the particles
- Demonstrating knowledge of alignment code by reproducing completed Phase 1c results
- Begin adapting alignment software to analyze Phase 1b data
- In Phase 1b we do no have the survey data that we can use to constrain the "z" (longitudinal) position of the sensors, whereas we do for 1c



Points on this plot show slide shifts in sensor angle determined by alignment algorithm, as a function of run number for Phase1c

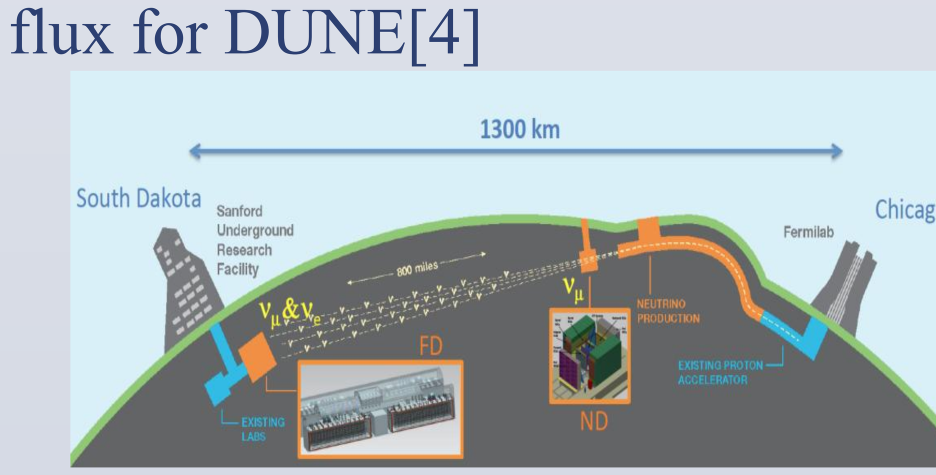
Run History

- Phase 0 was an engineering run using SSD sensors only[3]
- Phase 1b and 1c focused on incorporating new equipment such as: Beam Aerogel RICH, T0, Magnet, RPC, Lead-glass Calorimeter
- Data collection was completed using a mix of Graphite, Iron, and CH2 targets

Beam momentum (GeV/c)	Target	Total events
120	Graphite/Iron	1.0 M
31(+)	Graphite	9.7 M
20(-)	Graphite/CH2	11.8 M
12(-)	Graphite	17.9 M
8(-)	Graphite	15.1 M

Conclusion

- Hadron production uncertainties limit precision neutrino physics
- EMPHATIC aims to provide hadron-scattering and hadron-production measurements to reduce neutrino flux uncertainty
- Utilizing results from EMPHATIC, we can better understand absolute neutrino flux for DUNE[4]



References

[1] Soplin, L., "Neutrino Flux Prediction for the NuMI Beamline," Ph.D. thesis, William & Mary College, 2016

[2]Akaishi, T, et al. "EMPHATIC: A Proposed Experiment to Measure Hadron Scattering and Production Cross Sections for Improved Neutrino Flux Predictions." *ArXiv.org*, 2019, arxiv.org/abs/1912.08841.

[3] M.Pavin (2022). Measurement of proton-carbon forward scattering in a proof-of-principle test of the EMPHATIC spectrometer. *Institutional Repositories DataBase (IRDB), 106*, 112008. https://kek.repo.nii.ac.jp/records/2056897

[4]Abi, B., et al. "Deep Underground Neutrino Experiment (DUNE), Far Detector Technical Design Report, Volume I Introduction to DUNE," Journal of Instrumentation 15, T08008, 2020