Snowmass2021 - Letter of Interest

DRAFT *The future NA61/SHINE program on hadron production*

NF Topical Groups: (check all that apply □/■)

□ (NF1) Neutrino oscillations
□ (NF2) Sterile neutrinos
□ (NF3) Beyond the Standard Model
■ (NF4) Neutrinos from natural sources
□ (NF5) Neutrino properties
□ (NF6) Neutrino cross sections
□ (NF7) Applications
□ (NF8) Theory of neutrino physics
■ (NF9) Artificial neutrino sources
□ (NF10) Neutrino detectors
□ (Other) *[Please specify frontier/topical group(s)]*

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Abstract: The NA61/SHINE experiment at CERN uses a tagged secondary/tertiary beam and a large-acceptance spectrometer to study particle production cross-sections on thin targets and replica targets for neutrino beams. Recent data sets have been collected specifically for the study of the NuMI beam at Fermilab. In the future, measurements for LBNF/DUNE will be a high priority. A major set of upgrades are underway during CERN's current long shutdown; these upgrades will allow a factor of ten increase in data collection rates. New capabilities for low-momentum beams (useful for atmospheric neutrino predictions as well as lower-energy beamlines) and upgrades for better reconstruction of production in long targets are under consideration.

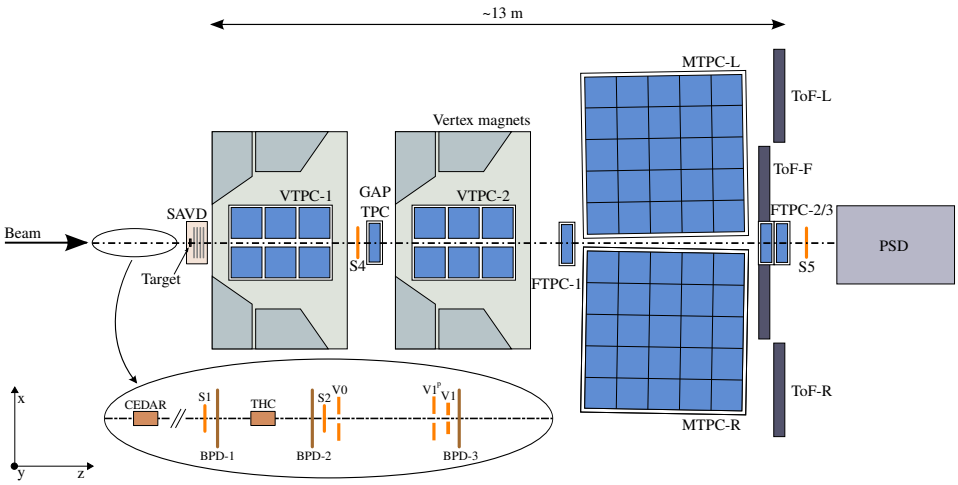

Figure 1: The NA61/SHINE spectrometer as configured for 2017 and 2018 data collection.

1 Introduction

NA61/SHINE[1] is a multi-purpose experiment that studies hadron-proton, hadron-nucleus and nucleus-nucleus collisions at the CERN Super Proton Synchrotron (SPS). Initially approved in 2007, NA61/SHINE has been a key facility for measuring hadron production processes relevant for accelerator-based neutrino beams in addition to its role in heavy-ion and cosmic-ray production physics. The first physics data with hadron beams were recorded in 2009 and with ion beams in 2011. The results from NA61/SHINE have been critical for reducing the uncertainty in T2K's neutrino flux [2]. Several US groups (Colorado, Fermilab, Los Alamos[1], and Pittsburgh) joined the collaboration in 2014 to pursue measurements of hadron production processes relevant for neutrino beam production, especially for the Fermilab neutrino program.

2 NA61/SHINE

The NA61/SHINE spectrometer (Fig. 1) consists of a series of beam position detectors (BPDs) upstream of a target, followed by two sets of time projection chambers (TPCs) inside a pair of superconducting dipole magnets. The target can be either a thin material sample or a full-size replica of a neutrino production target. Downstream of the magnets, a pair of 5 m $\times$ 5 m main TPCs provides more dE/dx information for particle identification. A time-of-flight (TOF) system follows.

For the 2017-18 runs, the US-NA61 groups contributed a new set of tracking chambers (the Forward TPC, or FTPC system [3]) to extend NA61/SHINE's acceptance into the forward phase space region, as well as new DRS4-based controller crates for the forward TOF readout. Data were collected for processes relevant to NuMI and LBNF/DUNE: thin-target measurements with protons and pions on carbon, aluminum, and beryllium targets; and a long data set with 120 GeV/c protons on a replica of the NuMI/NOνA target.

[1]Reverted to limited membership status after death of PI G. Mills

3 Recent results

Several results from the NA61/SHINE neutrino program have been published in the past two years. These include total production and inelastic cross-sections for $p + \mathrm{C}$, $p + \mathrm{Be}$, and $p + \mathrm{Al}$ at 60 GeV/c and $p + \mathrm{C}$ and $p + \mathrm{Be}$ at 120 GeV/c [4]; total production cross-sections for π^+ and K^+ on the same targets at 60 and 30 GeV/c [5]; particle production spectra for $\pi^+ + \mathrm{C}$, $\pi^+ + \mathrm{Be}$ interactions at 60 GeV/c [6]; and particle yields from a replica of the T2K target [7]. The T2K result allowed the reduction of (anti-)neutrino flux systematic errors to the 5% level. Analysis of the remaining data sets are underway, with production spectra from 120 GeV/c protons on carbon (the first physics results from the new FTPC system) expected in a few months.

4 Upgrades underway

The three physics communities in NA61/SHINE are planning a new series of measurements in the period between LS2 and LS3 (roughly 2022-2025) [8], for which significant detector upgrades are underway. These upgrades include replacement of the trigger and DAQ, replacement of the BPDs with silicon trackers, replacement of all TPC readout electronics with the system used by ALICE, replacement of the side time-of-flight walls, and the addition of new vertex detectors and a hadron calorimeter both used primarily for heavy-ion measurements. The US will contribute electronic components for the upgrade of the TPC readout system and the TOF.

5 Future measurements

After the long shutdown, several neutrino-related measurements are foreseen. The highest long-term priority for the US-NA61 program is a high-statistics measurement of particle yields from a replica of the LBNF/DUNE target. This will probably take place in 2023, depending on availability of the replica target. At present, studies are underway to optimize the detector configuration for this very long (at least 1.5 m) target. The ability to reconstruct a track's exit position from the target may suffer from the long distance from the upstream end of the target to the TPCs. One possible enhancement is to add small tracking detectors along the side of the tracker and/or immediately downstream of it, and the collaboration is determining whether to pursue this option.

Additional measurements of processes with thin targets will be carried out as well, to improve modeling of secondary processes in targets and horns. We also foresee measurements with new T2K replica targets, in collaboration with colleagues from KEK and Okayama University. The CERN beam group is developing a concept for a new low-energy beamline ($\sim$1-20 GeV) for NA61/SHINE, which will open up the possibility for a new program of measurements of secondary interactions for T2K as well as cross-sections for predicting atmospheric neutrino fluxes. This beam may also be useful for studying the Fermilab Booster Neutrino Beam flux. Low-energy measurements on mercury targets could also improve our understanding of neutrinos from spallation neutron sources, as there is little existing data at the GeV scale.

The NA61/SHINE collaboration is now exploring possible future programs with the detector beyond CERN's Long Shutdown 3 (roughly 2026).

References

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