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Recent results from the SND@LHC experiment

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SND@LHC is a stand-alone experiment to measure neutrinos produced at the LHC in an unexplored pseudo-rapidity region (7.2<η<8.6). It is located at 480m from IP1 in the TI18 tunnel. Its hybrid detector is composed of 800kg tungsten target-plates, interleaved with emulsion and electronic trackers, followed by a calorimeter and a muon system. This allows to identify all three neutrino flavours, opening a unique opportunity to probe heavy flavour production at the LHC in a pseudorapidity region not accessible to ATLAS, CMS and LHCb. This region is of particular interest also for future circular colliders and for studies of very high-energy atmospheric neutrinos. The detector is also well suited to search for Feebly Interacting Particles in scattering signatures. The experiment has been running successfully during 2022 and 2023 and has published several results. This talk will focus on the experience gained from the first measurements and on the overall physics goals of SND@LHC.

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1. Introduction

The large flux of neutrinos produced in the forward region of the proton-proton collisions at the Large Hadron Collider (LHC) ($pp \longrightarrow \nu_X X$) have been of interest since the 1980s. This is because their energy lies in the unexplored energy range of 100 GeV to a few TeV, and measuring them can help fill the gap between accelerator neutrino cross-section measurements and data from cosmic rays. Also, they are produced via weak decays of charmed hadrons, thereby opening doors to heavy flavor physics [1], [2]. By placing a small scale experiment in the forward region of an LHC IP, we can harness these physics potentials. Thus, two neutrino experiments started running in the LHC Run 3: FASER [3] and SND@LHC [4].

The Scattering Neutrino Detector at the LHC (SND@LHC) is a compact stand-alone neutrino experiment approved in March 2021 and installed in 2022 in the previously unused TI18 tunnel. This experiment is designed to achieve the major physics goal - measure the neutrino interactions in the unexplored ~ TeV energy range (including the least studied tau neutrinos). Its slightly off-axis position enhances the neutrino flux from charm hadron decays, aiding in constraining the gluon PDF at very low momentum transfers(x $\sim 10^{-6}$). The detected neutrinos will also facilitate Standard Model tests such as the Lepton Flavour Universality in neutrino interactions: ν_τ/ν_e and ν_μ/ν_e, and the NC/CC ratio as a control measurement for the physical accuracy of the experiment. Beyond neutrino physics, the experiment will explore Beyond Standard Model such as feebly interacting particles (FIP) through their scattering.

2. Detector layout

The SND@LHC experiment is located in the TI18 tunnel, 480 m away from the ATLAS interaction point (IP1) and placed off-axis in a pseudo-rapidity range of $7.2 < \eta < 8.4$. The detector is shielded from collision debris by 100 m of rock and concrete and is downstream dipole magnets that help deflect charged particles.

It is designed to be a hybrid detector to achieve the physics goals: identifying all three neutrino flavours with high efficiency and searching for feebly interacting particles by their scattering. It

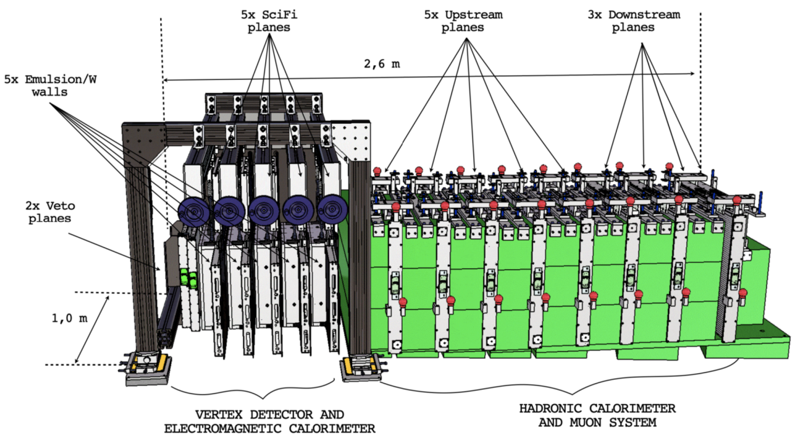

Figure 1: Detector Layout for SND@LHC

has three major sub-systems: veto system; vertex detector and electromagnetic calorimeter; and hadronic calorimeter and muon system as seen in Figure 1. The veto system was upgraded during the year end technical stop of 2023 to three 1 cm thick scintillator planes to tag the penetrating muons. Next is 830 kg tungsten target plates interleaved with nuclear emulsions and electronic trackers. The electronic detectors provide the timing information and measure the electromagnetic and hadronic energy, while the emulsion detectors provide excellent vertex reconstruction. Lastly is the hadronic system made up of eight 20 cm iron blocks and scintillator planes. It can adequately measure the energy and timings for the hadronic showers. The last 3 planes have finer granularity for muon identification [4].

3. Results

3.1 Muon Flux Measurement

The major background to the neutrino signals are the muons produced in proton-proton collisions at IP1. Thus, it is necessary to measure the muon flux experienced by our detector to validate and constrain our background model.

Initial measurements with the electronic SciFi tracker, downstream muon system and emulsion detectors give a consistent muon flux measurement of $2.06 \pm 0.01(stat) \pm 0.12(sys) \times 10^4 \mathrm{fb/cm^2}$ ($31\times31cm^2$ area); $2.35\pm0.01(stat)\pm0.10(sys)\times10^4\mathrm{fb/cm^2}$ ($52\times52cm^2$ area); and $1.5\pm0.1(stat)\times 10^4\mathrm{fb/cm^2}$ ($18 \times 18cm^2$) respectively. The total relative uncertainty on the measurements is 6% and 4% for the SciFi and DS respectively. In the same area of acceptance for SciFi and emulsion, or for SciFi and DS, the measured muon fluxes are in good agreement [5]. To further validate these results, a muon telescope is placed to measure the muon flux outside of the SND@LHC acceptance.

3.2 Muon Neutrino Analysis - Update

For muon neutrino, 8 muon neutrino candidates were observed in the 2022 data with a significance of 6.8σ [4]. This analysis is updated with the 2023 data and an extended fiducial volume.

3.2.1 Signal selection

The selection of ν_μ CC events in the detector is two steps - defining the fiducial volume and identifying neutrino interactions. The fiducial volume is defined such that we reject side-entering background and reject events in the first SciFi wall. The fiducial volume previously accepted events only in the SciFi walls 3 and 4, but it is now extended to wall 2, resulting in signal acceptance of 18%. This is an increase from the previous signal acceptance by 7.5%.

In the detector, the high energy neutrino candidates will interact with the tungsten target via deep inelastic scattering (CCDIS). For ν_μ CCDIS interactions, the outgoing lepton would be a muon accompanied by hadronic showers. Hence, for identifying them, an isolated muon track with large shower activity in the detector would be a fitting selection criteria. Building on this idea, the selection cuts are large SciFi and hadronic calorimeter activity along with one muon track associated to a vertex. This results in a signal selection efficiency of 35%. An example of such an event candidate is shown in Figure 2.

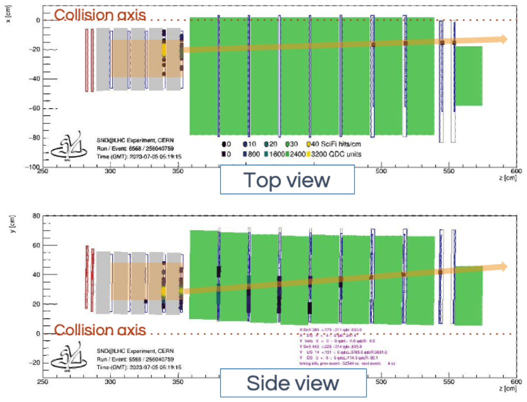

Figure 2: An event display of candidate

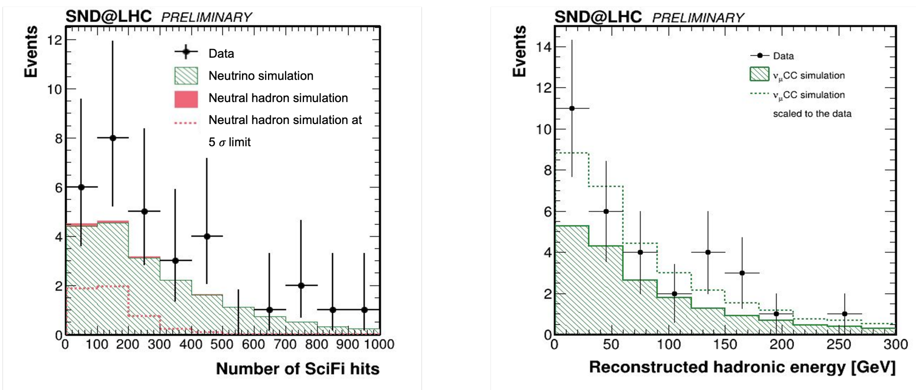

Figure 3: Distribution of SciFi hits & reconstructed hadronic energy of the candidate events

3.2.2 Updated results

Applying the selection over the 2023 data resulted in the observation of 32 events. The expected number of events in 68.6 fb^{-1} for signal: 19 ± 4 (sys) ± 4 (stat); and neutral hadrons: 0.25 ± 0.06. The kinematics of these candidates like the reconstructed hadronic energy agree with the signal predictions (Figure 3).

3.3 Observation of 0μ events

Apart from muon neutrinos, electron neutrino ν_e CC and NC interactions are also of interest. An electron neutrino CC DIS interaction would result in an electromagnetic shower along with hadronic showers. Hence, to search for such events, the first step would be to search for shower-like 0μ neutrino events.

3.3.1 Signal selection

A similar principle like the muon neutrino search was adopted for designing the the signal selection cuts. The fiducial volume has no hits from the veto detector and no side-entering background, resulting in a signal acceptance of 12%. For identifying 0μ neutrinos, large SciFi and hadronic calorimeter activity and no hits in the last two muon system planes Lastly, for identifying these showers effectively, a selection cut is designed based on the shower density - the density weighted number of hits in the most active station > 11×10^3. The density-weighted number of hits is the total hit weights, where the hit weight of a specific hit is the number of hits lying in a 1 cm distance from the hit. The signal cut threshold is determined for maximum expected observation significance. These cuts result in shower like events with no reconstructable muon track.

3.3.2 Results

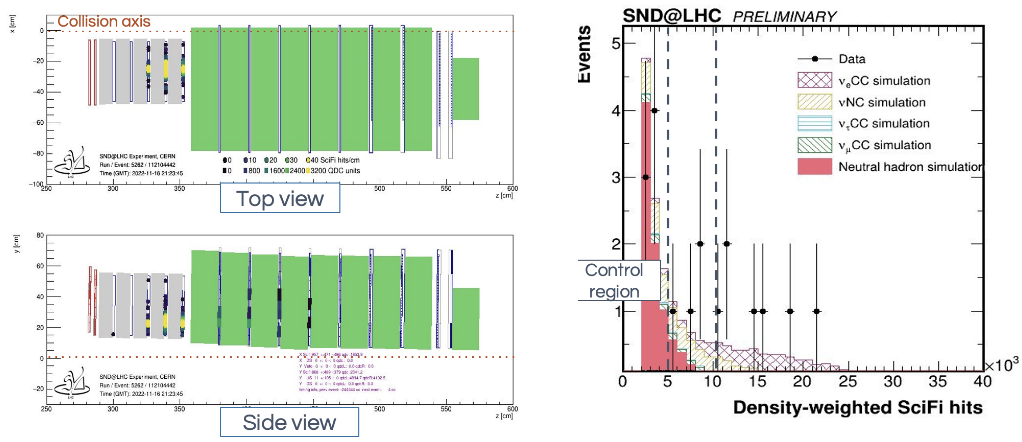

Figure 4: Electron neutrino candidate event display and distribution of density weighted SciFi hits.

The background to the signal is expected to be the neutral hadron, muon neutrino CC and tau neutrino CC 1μ background. The neutral background expection is evaluated by defining a background-dominated control region which is scaled to the number of events in this defined region. In the signal region, the expected neutral hadron events is 0.01, the muon neutrino CC events is 0.12 and tau neutrino CC 1μ events is 0.002, giving the total expected background events as 0.13±0.11. The expected signal events would be 4.7 events at an expected significance of 4.9 σ. In the data, 6 events were observed with a significance of 5.8 σ. An event display and the distribution of the weighted Sci-Fi hits is shown in Figure 4.

3.4 Searches for Electron neutrino in emulsion

There are ongoing efforts to search for ν_e CC interactions in the emulsion data. The strategy is to first identify regions of high track density in the emulsions consistent with electromagnetic shower development, and then search for neutral vertices associated to identify showers. Currently, electromagentic shower patterns have been identified as shown in Figure 5

3.5 Exotic Studies: Search for Muon trident events

There are also searches for muon trident events occuring interacting in the rocks upstream the detector or in the detectors. Preliminary searches have found events with 3 muon tracks compatible with the muon trident signature [6].

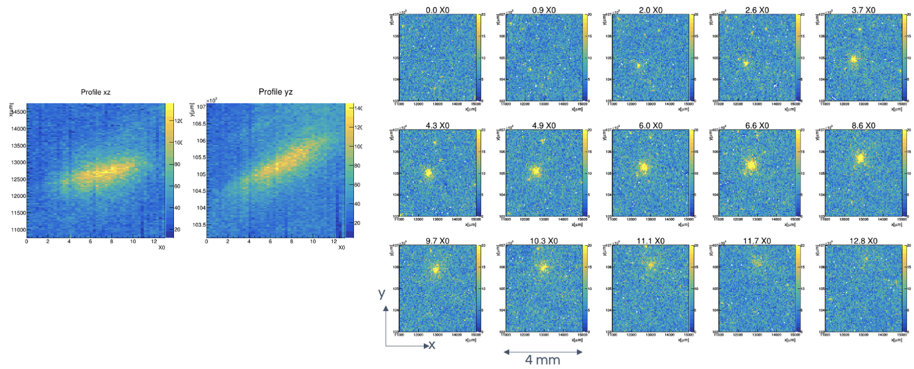

Figure 5: Electromagnetic shower patterns identified in the emulsions. The plots on the left show the xz and yz profile of the shower and the plots on the right show the Z slices of an electromagnetic shower developing in the emulsions.

4. Conclusion

To summarise, the muon flux reaching the detector has been measured to validate the background model [5]. With the 2023 data and extended fiducial volume, the 2022 muon neutrino analysis has been updated to 32 events. Shower-like (0μ) neutrino events have been observed with a significance of 5.8 σ. There are ongoing searches for electron neutrino interactions in the emulsions data and the study of muon trident-like events is underway.

References

[1] N. Beni, M. Brucoli, V. Cafaro, T. Camporesi, F. Cerutti, G.M. Dallavalle et al., *Further studies on the physics potential of an experiment using LHC neutrinos*, *Journal of Physics G: Nuclear and Particle Physics* **47** (2020) 125004.

[2] N. Beni, M. Brucoli, S. Buontempo, V. Cafaro, G.M. Dallavalle, S. Danzeca et al., *Physics potential of an experiment using LHC neutrinos*, *Journal of Physics G: Nuclear and Particle Physics* **46** (2019) 115008.

[3] FASER Collaboration collaboration, *First Direct Observation of Collider Neutrinos with FASER at the LHC*, *Phys. Rev. Lett.* **131** (2023) 031801.

[4] SND@LHC collaboration, *Observation of collider muon neutrinos with the snd@lhc experiment*, *Phys. Rev. Lett.* **131** (2023) 031802.

[5] R. Albanese, A. Alexandrov, F. Alicante, A. Anokhina, T. Asada, C. Battilana et al., *Measurement of the muon flux at the SND@ LHC experiment*, *The European Physical Journal C* **84** (2024) 90.

[6] D. Abbaneo, S. Ahmad, R. Albanese, A. Alexandrov, F. Alicante, K. Androsov et al., *Results and Perspectives from the First Two Years of Neutrino Physics at the LHC by the SND@LHC Experiment*, *Symmetry* **16** (2024) .