PROCEEDINGS OF SCIENCE

# First results from the SND@LHC experiment

**Onur Durhan**[a,b,*] **on behalf of the SND@LHC collaboration**

[a] *Middle East Technical University,*
*Ankara, Türkiye*
[b] *Atilim University,*
*Ankara, Türkiye*

*E-mail:* onur.durhan@cern.ch

SND@LHC started taking data at the beginning of Run 3 of the LHC. The experiment is designed to perform measurements with neutrinos produced in proton-proton collisions at the LHC in an energy range between 100 GeV and 1 TeV. It covers a previously unexplored pseudo-rapidity range of $7.2 < \eta < 8.4$. The detector is located 480 m downstream of the ATLAS interaction point in the TI18 tunnel. The detector is composed of a hybrid system based on an 800 kg target mass of tungsten plates, interleaved with emulsion and electronic trackers, followed downstream by a calorimeter and a muon system. The configuration allows efficiently distinguishing between all three neutrino flavours, opening a unique opportunity to probe physics of heavy flavour production at the LHC in the region that is not accessible to ATLAS, CMS and LHCb. This region is of particular interest also for future circular colliders and for predictions of very high-energy atmospheric neutrinos. The detector concept is also well suited to searching for Feebly Interacting Particles via signatures of scattering in the detector target. The experiment has published several results. This work focuses on the experience gained from the first measurements and how this is being used to achieve the physics goals of SND@LHC.

****International Workshop on Deep Inelastic Scattering-DIS2024* ****
**** 8-12 April 2024****
**** Maison MINATEC, Grenoble, FRANCE* ****

*Speaker



https://pos.sissa.it/

PoS(DIS2024)061

## 1. Introduction

The SND@LHC experiment [1] aims to detect neutrino interactions in the unexplored TeV energy range. It will gather a large yield of $\nu_\tau$, more than doubling existing data from experiments such as DONuT [2] and OPERA [3] [4]. Since $\nu_e$ and $\overline{\nu}_e$ produced in SND@LHC predominantly come from charmed hadron decays, this allows for the measurement of $pp \to \nu_e X$ cross-section and the study of forward charm production via neutrinos. As an internal consistency check, Neutral-Current (NC) to Charged-Current (CC) ratio will be also measured. The identification of three neutrino flavors in the SND@LHC detector enables a unique opportunity to test the Lepton Flavor Universality (LFU). The SND@LHC experiment has also the capability of probing various BSM scenarios, including hidden sector particles and other phenomena not described by the Standard Model. The detector is located in the TI18 tunnel, 480 meters away from the ATLAS interaction point (IP1), covering the pseudo-rapidity range $7.2 < \eta < 8.4$.

## 2. Detector Overview

The SND@LHC detector features a hybrid design [5]. Its veto system comprises two horizontal planes and one vertical plane of stacked scintillating bars, with the vertical plane added in 2024. The primary function of the veto system is to reject charged particles entering the detector volume. The detector's target, weighing 830 kg, consists of five walls of Emulsion Cloud Chamber (ECC) bricks. Each ECC detector includes nuclear emulsion films interleaved with tungsten plates, providing excellent resolution for locating neutrino vertices. Five scintillating fiber stations, positioned between the ECC walls, serve as the electromagnetic calorimeter and provide timestamps for the vertices. The hadronic calorimeter and muon system are composed of eight plastic scintillating planes interleaved with iron blocks. The last three downstream planes have higher granularity, enhancing the resolution of muon tracks. The detector concept is depicted in Figure 1.

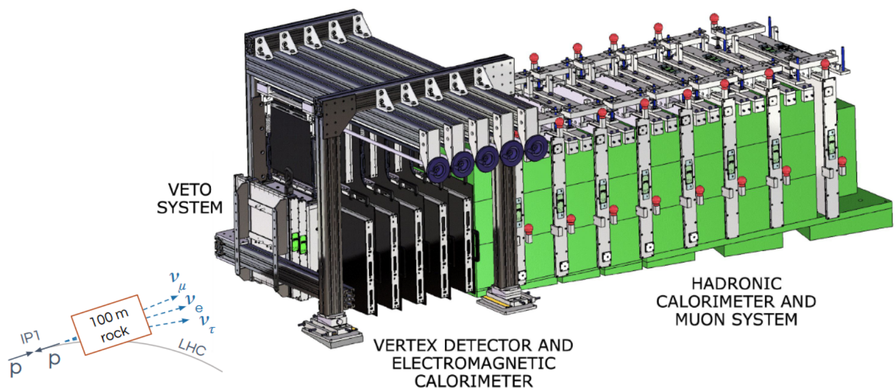


**Figure 1:** SND@LHC Detector Concept

A test beam for the hadronic energy calibration was conducted in August 2023, using a replica of the HCAL together with a downsized target. The resolution of hadronic energy measurement was found to be within 15-25% as shown in Figure 2. The energy resolution is well within our expected performance.

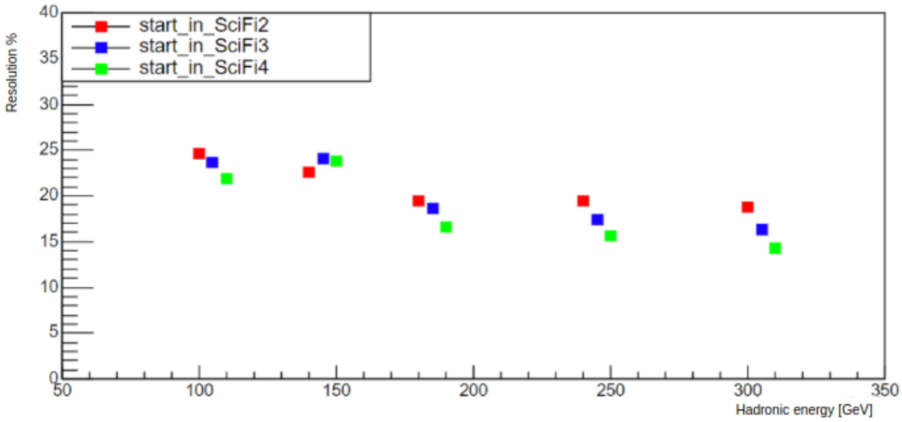


**Figure 2:** The energy resolution as a function of hadronic energy

## 3. Data Taking and Event Reconstruction

During the 2022 and 2023 data-taking campaigns, the SND@LHC recorded a luminosity of 68.6 fb$^{-1}$ of $pp$ collisions with an up-time of 97%. Emulsion wall extraction is performed after a few months of exposure to maintain integrated track quality for analysis. Event reconstruction is conducted in two phases: online with electronic detectors and offline with emulsion detectors.

## 4. Results

### 4.1 $\nu_\mu$ Analysis Update

The SND@LHC collaboration has already reported 8 neutrino event candidates with a statistical significance of $6.8\sigma$ with the analysis of 2022 data corresponding to 36.8 fb$^{-1}$ integrated luminosity. [6]. The analysis was updated by the inclusion of 2023 data with extended fiducial volume (see [7]). In the updated analysis, following the similar procedure in the previous work, the event selection is divided in two phases. In the first phase, the fiducial volume is required to span four downstream target walls as well as rejecting the side-entering backgrounds. The fiducial cut enhanced the signal selection efficiency from 7.5% to 18% compared to the previous work. In the second phase, large activity in the ECAL and HCAL, and single muon track associated with the neutral vertex is required to identify $\nu_\mu$ signal, resulting in 36% signal selection efficiency. After leveraging these cuts while expecting $19.1 \pm 4.1$ signal events, 32 $\nu_\mu$ candidates were found and the expected background from the neutral hadrons was $0.25 \pm 0.06$. The kinematics of the candidate events are in agreement with the Monte Carlo predictions as show in Figure 3 and 4.

### 4.2 Backgrounds

Muons from IP1 constitute the major background source for SND@LHC. They could either enter the detector volume without firing the veto system due to inefficiencies and generate showers through bremsstrahlung or deep inelastic scattering, or interact with the surrounding material which then could mimic the neutrino signal.

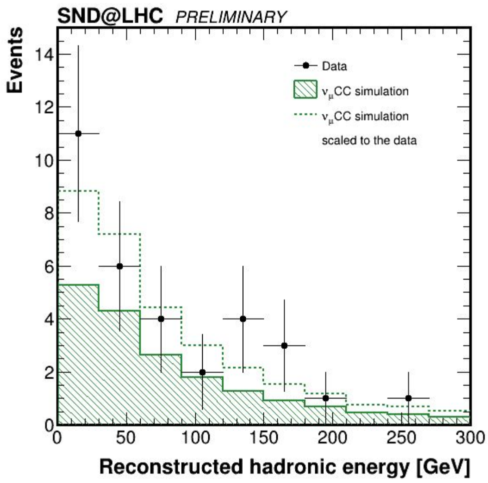


**Figure 3:** Reconstructed hadronic energy

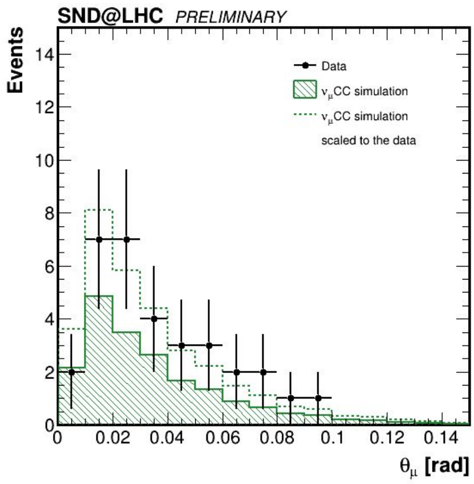


**Figure 4:** Outgoing muon angle

As an important input for the expected background, a dedicated muon flux measurement has been conducted [8], showing a muon flux of $(2.06 \pm 0.01\ \text{(stat.)} \pm 0.12\ \text{(sys.)}) \times 10^4$ fb/cm$^2$ for the SciFi system and $(2.02 \pm 0.01\ \text{(stat.)} \pm 0.08\ \text{(sys.)}) \times 10^4$ fb/cm$^2$ for the downstream system.

### 4.3 Search for Zero-Muon Events

The ongoing search for zero-$\mu$ events focuses on identifying shower-like events that account for signals $\nu_e$ CC and NC interactions (see [7]). The fiducial volume criteria include having no hits in the veto detector and rejecting side-entering events, with a signal acceptance rate of 12%. For signal identification, the search prioritizes events with large ECAL and HCAL activity and no tagged muons. Additionally, the search optimizes the density-weighted number of hits in the most active station to maximize expected significance, achieving a signal selection efficiency of 42%. A control region in the density-weighted number of hits, ranging between $2 \times 10^3$ and $5 \times 10^3$, dominated by neutral background is introduced to have a measure of the background, which then was scaled to the number of observed events (See Figure 5 and 6). It has been observed that the neutral hadron background is only one-third of the expected value. The expected neutral hadron background in the signal region is 0.01 events. The dominant background comes from $\nu_\mu$ CC interactions, with an expected value of 0.12 events, while the expected background from $\nu_\tau$ CC interactions is 0.07 events. Overall, the total expected background is $0.20 \pm 0.11$ events, and the expected signal is 4.66 events. Armed with these, 6 zero-$\mu$ events are observed with $4.7\sigma$ of significance.

## 5. Conclusion

The search for high energy neutrinos originating from $pp$ collisions with the SND@LHC detector is presented. The analysis of the CC $\nu_\mu$ is extended with the inclusion of 2023 data and relaxed fiducial cuts. 32 event candidates are reported. Furthermore, the status of the analysis of NC and $\nu_e$ events are presented. While the analysis is ongoing and the relevant paper is in preparation, 6 such event candidates are observed with 4.7 $\sigma$ of significance.



PoS(DIS2024)061

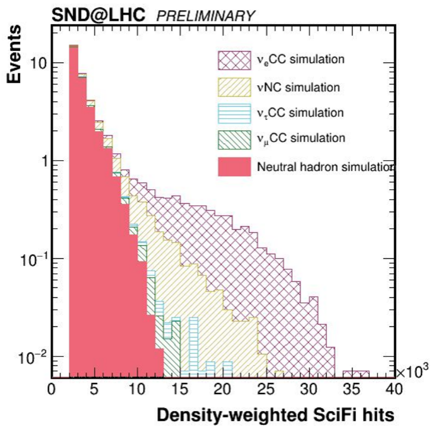


**Figure 5:** Density-weighted Scifi hits in MC.

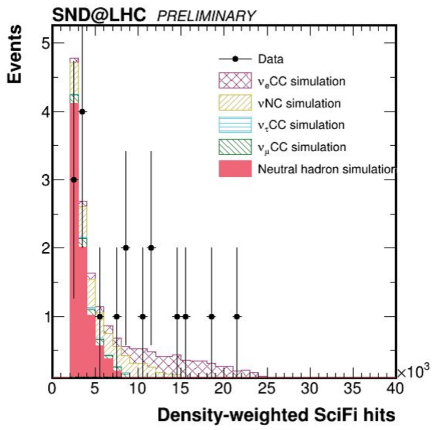


**Figure 6:** Density-weighted Scifi hits in MC (scaled to data) and in data.

## References


[1] C. Ahdida *et al.*, "SND@LHC - Scattering and Neutrino Detector at the LHC," Technical Report CERN-LHCC-2021-003, LHCC-P-016, CERN, Geneva, 2021.

[2] K. Kodama *et al.*, "Final tau-neutrino results from the donut experiment," *Phys. Rev. D*, vol. 78, p. 052002, 2008.

[3] N. Agafonova *et al.*, "Discovery of $\tau$ neutrino appearance in the cngs neutrino beam with the opera experiment," *Phys. Rev. Lett.*, vol. 115, p. 121802, 2015.

[4] N. Agafonova *et al.*, "Final results of the opera experiment on $\nu_\tau$ appearance in the cngs neutrino beam," *Phys. Rev. Lett.*, vol. 120, p. 211801, 2018.

[5] G. Acampora *et al.*, "Snd@lhc: the scattering and neutrino detector at the lhc," *Journal of Instrumentation*, vol. 19, p. P05067, May 2024.

[6] R. Albanese *et al.*, "Observation of collider muon neutrinos with the snd@lhc experiment," *Physical Review Letters*, vol. 131, jul 2023.

[7] C. Vilela, "Recent results from the snd@lhc experiment." Presented at the 58th Rencontres de Moriond on QCD and High Energy Interactions, April 2024.

[8] R. Albanese *et al.*, "Measurement of the muon flux at the snd@lhc experiment," *Eur. Phys. J. C*, vol. 84, no. 90, 2024.