PROCEEDINGS OF SCIENCE

SND@LHC neutrino results

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The Scattering and Neutrino Detector at the LHC (SND@LHC) is a compact and standalone experiment, which started taking data in 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–1 TeV and hitherto unexplored pseudo-rapidity region of $7.2 < \eta < 8.4$, complementary to all the other experiments at the LHC. The detector, located 480 m downstream of the ATLAS interaction point in the TI18 tunnel, comprises a veto system followed by an 830 kg target mass of tungsten plates, interleaved with emulsion and Scintillating Fiber (SciFi) electronic trackers, and then a calorimeter and a downstream muon system (DS). Using a data set collected by the SND@LHC electronic detectors in the first year of detector operation in 2022, eight muon neutrino candidates have been identified through their charged-current interactions in the detector with an estimated background of 0.086 events, yielding a significance of 6.8 standard deviations for the observed ν_μ signal. To facilitate the background assessment, the muon flux in the TI18 tunnel has been determined. These proceedings describe the first SND@LHC neutrino analysis and background estimation.

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1. Introduction and Motivation for SND@LHC

The potential of the Large Hadron Collider (LHC) as a neutrino factory was recognized about 30 years ago [1] in particular for the then undiscovered ν_τ [2]. During Run 3 of the LHC, proton-proton (pp) collisions at a center-of-mass energy of 13.6 TeV will produce large neutrino fluxes of O(10^{12}) neutrinos in the far forward direction, having all flavours and energies up to a few TeV [3]. Measuring these neutrinos will fill the gap between accelerator neutrino cross-section measurements and data from cosmic rays in energy range 350 GeV and 1 TeV [4].

The SND@LHC detector was installed in the TI18 unused LEP transfer tunnel in 2022 during the long shutdown 2 and has collected data since the beginning of the Run 3. The experiment will probe the neutrino production cross section $\sigma_{pp} \to \nu X$ in an unexplored energy domain [3]. Its slightly off-axis position enhances the neutrino flux from charmed particle decays and provides a handle on charm production at high rapidity, allowing to constrain the gluon PDF at very low momentum transfers($x \sim 10^{-6}$). The extraction of the gluon PDF at such low x values, where it is completely unknown, could provide valuable information for future colliders and the study of astrophysical neutrino sources. The detected neutrinos will also facilitate Lepton Flavour Universality in neutrino interactions: ν_τ/ν_e and ν_μ/ν_e, as well as a measurement of the NC/CC ratio as a control measurement for the physical accuracy of the experiment. Beyond neutrino physics, the experiment has a new physics programme including a direct search for feebly interacting particles (FIP) through their scattering [3].

2. Detector layout

The SND@LHC detector is located in the TI18 tunnel, 480 m away from the ATLAS interaction point, IP1. The detector is shielded from collision debris by around 100 m of rock and concrete. The detector is capable of identifying all three neutrino flavours with high efficiency. Its angular acceptance is $7.2 < \eta < 8.4$.

The detector consists of a hybrid system with a ~ 830 kg target made of tungsten plates interleaved with nuclear emulsions and electronic trackers, followed by a hadronic calorimeter and a muon system, as shown in Figure 1. The electronic detectors provide the time stamp of the neutrino interaction, preselect the interaction region, tag muons and measure the electromagnetic and hadronic energy, while the emulsion detectors provide excellent vertex reconstruction. A veto system is located upstream of the target region and is used to tag muons and other charged particles entering the detector from the IP1 direction.

3. Muon flux measurement

The SND@LHC detectors provides two independent electronic systems to measure the muon flux: the SciFi and the downstream muon system (DS). In their common acceptance range, 31×31 cm^2 area, there is excellent agreement between the results for the two detectors with less than 2% deviation [5]. The measured flux is 2.06×10^4 cm^{-2}/fb^{-1} within 25% of the prediction, thus validating the Monte Carlo simulation. The latter is prepared in collaboration with the CERN SY-STI group [5].

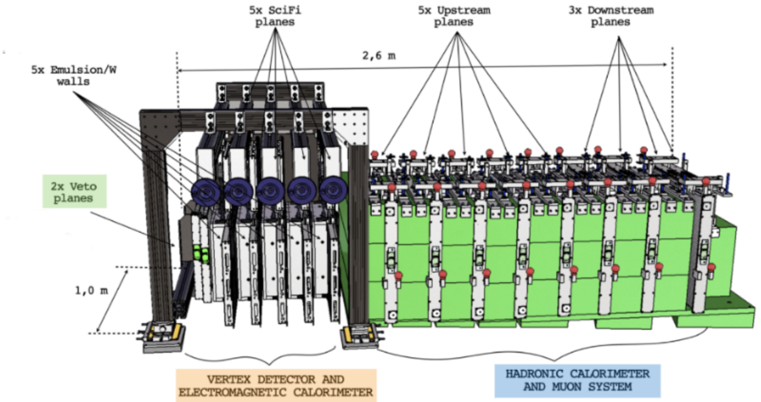

Figure 1: Schematic layout of the SND@LHC detector, showing the veto system, the emulsion walls and target tracker, the hadronic calorimeter and muon system.

4. Muon neutrino observation

A search for high energy ν_μ charged current deep inelastic scattering (CCDIS) has been performed using the electronic detectors data taken in 2022, which is 36.8 fb^{-1} [6]. The main background are the billion muons reaching the detector location, which can produce neutrino-like events. The strategy is to maximize the signal to background ratio and yield a set of clean events.

4.1 Signal selection

The selection of ν_μ CC events in the detector has two stages. The first one is a fiducial volume cut that rejects particles entering from the front and sides of the detector. To ensure that, it is asked that detector activity starts in the third or fourth target wall. This requirement is consistent with neutral particle interaction in the target region. The exclusion of events starting in the two most upstream target walls enhances the rejection power for muon-induced backgrounds. The detector hits must also be contained in an inner XY detector region of 25×26 cm^2. The overall efficiency of the fiducial volume cut on simulated ν_μ CCDIS interactions in the target is 7.5 %.

The second selection stage identifies the neutrino interaction: ν_μ CCDIS events have large hadronic activity in the SciFi and the HCAL, an isolated outgoing muon track reconstructed in the DS muon system, and hit timing that is consistent with an event originating from the IP1 direction. The efficiency of the full selection on simulated neutrino interactions in the target is 2.7 %.

In the end, 8 ν_μ CCDIS candidates are identified, while 4.2 are expected. One of the selected candidates is shown in Figure 2. The distribution of the number of hits in the SciFi detector for the selected events is consistent with the neutrino signal expectation, as shown in Figure 3.

4.2 Background

Muons reaching the detector location can enter the target without being vetoed and generate showers via bremsstrahlung or deep inelastic scattering. They can also interact in the surrounding material to produce neutral particles which can then mimic neutrino interactions in the target.

The estimate of the penetrating muon background is based on the expected flux in the fiducial volume and on the inefficiency of detector planes used as veto: the veto system and the two most

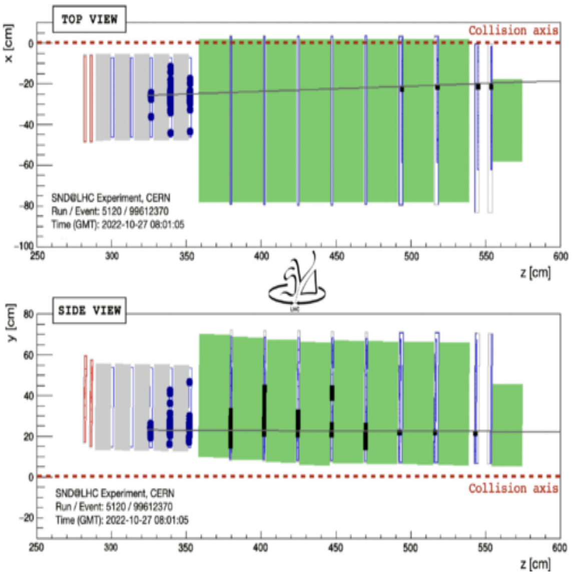

Figure 2: Display of a ν_μ CC candidate event. Hits in the SciFi, and hits in the hadronic calorimeter and muon system are shown as blue markers and black bars, respectively, and the line represents the reconstructed muon track.

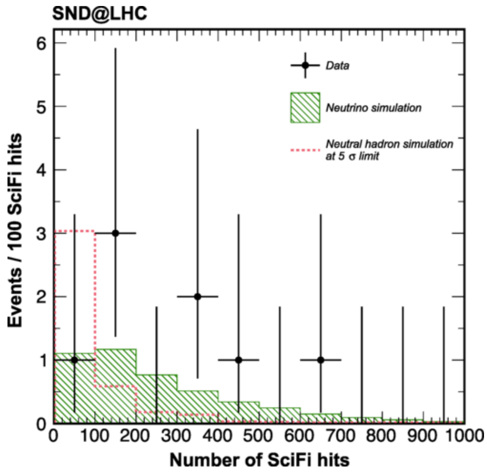

Figure 3: Distribution of SciFi hits for candidate events, along with the expectation from the neutrino signal. The dashed line shows the background-only hypothesis scaled up to a deviation from the nominal expectation at a level of 5 standard deviations. The vertical bars represent 68.3 % confidence intervals of the Poisson means.

upstream SciFi planes. Thanks to the low combined detector inefficiency of 5.3×10^{-12}, the large total number of muons in the target acceptance contributes to only 3×10^{-3} events and is negligible.

Neutral particles originating from primary muons DIS in rock and concrete in front of the detector can potentially mimic a neutrino interaction since they do not leave any incoming trace in the electronic detectors, and can create a shower in the target associated with a DS track produced by punchthrough or decay-in-flight $\pi^\pm$ and $K^\pm$. Although they are mainly rejected due to accompanying charged particles originating from the primary muon interaction, they constitute the main background source for the neutrino search. Their contribution is a convolution of the selection efficiency with the yield of neutral hadrons in the acceptance and not accompanied by a charged track producing hits in the Veto detector. The background yield after the selection amounts to $(8.6 \pm 3.8) \times 10^{-2}$ and is dominated by neutrons and K^0_L's.

The significance of the observation of 8 ν_μ CCDIS event candidates with an expected background yield of $(8.6 \pm 3.8) \times 10^{-2}$ is 6.8 standard deviations.

5. Conclusions

The SND@LHC detector was installed at the LHC in early 2022. Using the data collected that year from the pp collisions at $\sqrt{s}$ =13.6 TeV, the muon flux through the detector is determined, showing good agreement between detector sub-systems. This measurements serves also to estimate the background to a ν_μ CCDIS search in the target. Eight such candidate events were observed, while the muon-induced and neutral background levels total to $(8.6 \pm 3.8) \times 10^{-2}$, implying a 6.8 sigma excess of ν_μ CC signal events.

References

[1] A. De Rujula, E. Fernandez and J. J. Gomez-Cadenas, Nucl. Phys. B **405** (1993), 80-108 doi:10.1016/0550-3213(93)90427-Q

[2] G. Jarlskog and D. Rein, doi:10.5170/CERN-1990-010-V-2

[3] C. Ahdida *et al.* [SND@LHC] CERN-LHCC-2021-003, LHCC-P-016.

[4] M. Bustamante and A. Connolly, Phys. Rev. Lett. **122** (2019) no.4, 041101 doi:10.1103/PhysRevLett.122.041101 [arXiv:1711.11043 [astro-ph.HE]].

[5] R. Albanese *et al.* [SND@LHC], [arXiv:2310.05536 [hep-ex]].

[6] R. Albanese *et al.* [SND@LHC], Phys. Rev. Lett. **131** (2023) no.3, 031802 doi:10.1103/PhysRevLett.131.031802 [arXiv:2305.09383 [hep-ex]].