PROCEEDINGS OF SCIENCE

The SND@LHC experiment at CERN

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SND@LHC is proposed to exploit the high flux of energetic neutrinos of all flavours from the LHC in a hitherto unexplored pseudo-rapidity region of $7.2 < \eta < 8.4$, complementary to all the other experiments at the LHC. The compact apparatus was located 480 m downstream of IP1 in the unused TI18 tunnel. It is composed of a hybrid system based on an 830 kg target mass of tungsten plates, interleaved with emulsion and electronic trackers, also acting as an electromagnetic calorimeter, and followed by a hadronic calorimeter and a muon identification 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 physics programme includes studies of charm production, and test lepton flavour universality in neutrino interactions. The detector concept is also well suited to searching for Feebly Interacting Particles via signatures of scattering in the detector target. The first phase aims at operating the detector throughout LHC Run 3 to collect a total of 250 fb^{-1}. The experiment was collected its first data in 2022 and recently published its observation of muon collider neutrinos [1]. A new era of collider neutrino physics has started.

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1. Introduction

SND@LHC is designed to perform measurements with high-energy (100 GeV - 1 TeV) neutrinos produced at the LHC in an unexplored pseudo-rapidity region of $7.2 < \eta < 8.4$. The first phase of the experiment aims at collecting 250 fb^{-1} of data during the LHC Run 3. The analysis of the data taken in 2022 resulted in the observation of collider muon neutrinos [1]. The detector design is well suited to identify all flavours of neutrinos's interactions and measure their properties. Therefore, SND@LHC has a unique opportunity to probe physics of heavy flavour production in a region of phase space previously unexplored by the other LHC experiments. This region is also of interest for future circular colliders and astroparticle physics. In addition, it also allows for probing new feebly interacting particles via their scattering in the detector target.

2. The SND@LHC Detector

SND@LHC is a compact hybrid apparatus, shown in Figure 1, comprising nuclear emulsions with various electronic detectors. The target section is segmented into five walls. Each wall consists of four units of emulsion cloud chambers (ECCs) and is alternated with a scintillating fiber tracker (SciFi). The target section is followed by hadron calorimeter/muon detector with a final muon tracking section. The electronic detectors provide the time stamp of the neutrino interaction, preselect the interaction region, identify muons. The detector is located 480 m downstream of IP1 in the TI18 tunnel. In front of the target region there is a veto plane made of plastic scintillators, identifying muons arriving from IP1. It consists of two vertically shifted planes of seven 42x6x1 cm^3 bars, read at each end by 128 channel Hamamatsu SiPMs placed on a PCB common to each side of a detector plane. The neutrino target consisted of nuclear emulsion films, acting as very high precision tracking detectors for the detection of the short-lived particles like tau lepton. Each ECC module is a sequence of 60 emulsion films, 19.2x19.2 cm^2, interleaved with 59 (1 mm thick) tungsten. Its weight is approximately 41.5 kg, adding up to 830 kg for the total target mass. The SciFi consists of five 40x40 cm^2 x- y planes of staggered scintillating fibers. In order to control fading of emulsion films, the temperature of the target is kept in a cool box, covering the whole target region. The walls of the box also act as a passive neutron shield with a borated polyethylene layer. The muon system downstream of the target section consisting of two parts, upstream (US), first five stations, and downstream (DS), last three stations will stop hadrons. It acts, in combination with SciFi, as a coarse sampling (~ 9.5 interaction lengths) e.m./hadron calorimeter, providing the energy measurement of hadronic jets. Each US station consists of 10 stacked horizontal scintillator bars(82.5x6x1) cm^3, similar to the upstream veto detector. However, the DS part consists of two layers of thin bars, one arranged horizontally and one arranged vertically. The scintillating planes are interleaved with iron blocks with a thickness of 20 cm, which will act as passive material. In all stations, the read out is done by SiPMs which are followed by front-end electronics and TOFPET2 ASICs. All the active detectors are read out with the same Data Acquisition electronics. Electromagnetic showers are expected to be contained almost entirely within the target region and are identified by the target tracker.

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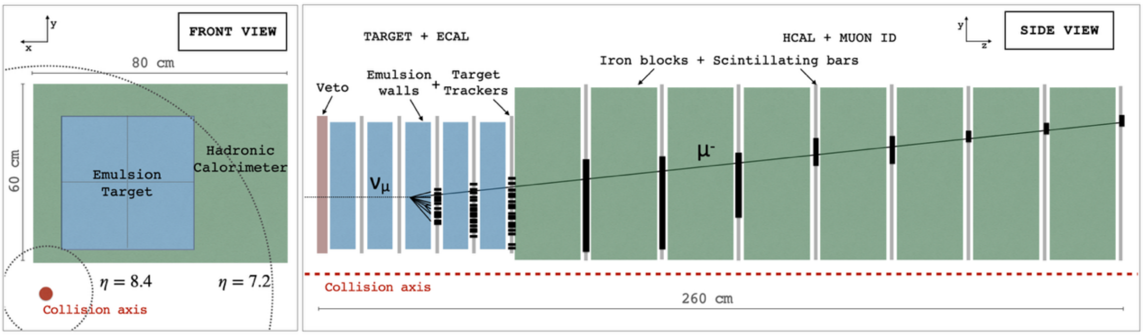

Figure 1: Schematic layout of the SND@LHC detector front view (left) and side view (right).

3. Detection of LHC neutrinos

SND-LHC has analyzed data, collected during 2022, from proton-proton collisions with a center of mass energies of 13.6 TeV. The integrated luminosity, delivered at IP1 during this period, was 39.0 fb^{-1} as estimated by the ATLAS collaboration. The SND@LHC experiment with 96% a detector uptime has recorded 37.6 fb^{-1}. The neutrino interactions were searched only using the data from the electronic detectors, as the emulsion data taking is going on. In the SND@LHC detector the dominant interaction at TeV energies is ν_μ the Charged-Current Deep Inelastic Scattering (CCDIS). Therefore, the signature of these interactions includes an isolated muon track in the Muon Identification system. Based on FLUKA and GENIE simulations, about 157±37 ν_μCCDIS interactions are expected in the target whose mass is about 800 kg.

In order to observe the rare neutrino signal over the backgound requires a selection that yields a clean set of events. The first step of the selection is to identify events happening in a fiducial region of the target, while rejecting the charged particles entering from the front and sides of the detector. Appliying the cuts on the hit multiplicity, only events in 3rd or 4th target wall SciFi planes are selected. The fiducial region cuts select events induced by a neutral-like particle located in the 3rd or 4th target wall while suppressing muon-induced backgrounds. The efficiency of this selection on simulated neutrino interactions in the target is 7.5 $\times 10^{-2}$. After applying the fiducial region selection, the second step is to identify signal-like signature patterns. ν_μ CCDIS interactions have a large hadronic activity in the calorimetric system, with a clean outgoing muon track reconstructed in the Muon Identification system, and hit time distribution consistent with an event originating from the IP1 direction. The muon track is defined by a set of Muon Identification hits in a straight-line pattern spanning at least three detector planes in both ZX and ZY views. Events with a large number of hits in the Muon Identification system are rejected to ensure cleanly reconstructed tracks. The achieved reduction factor on the data for the total selection (fiducial and neutrino identification cuts) amounts to 1.0 $\times 10^9$, while the overall efficiency on the ν_μ CCDIS Monte Carlo sample is 2.9 $\times 10^{-2}$. After applying the first and second steps of the selection, 8 ν_μ CCDIS candidates are identified, while 4.6 [1] are expected. The contribution of other neutrino flavours and neutral current interactions to the selected sample is less than 1% of the expected ν_μ CCDIS yield. Muons are the main source of background for the neutrino signal. Muons entering the detector without being vetoed generate showers via bremsstrahlung or deep inelastic scattering, or interact in the surrounding material and produce neutral particles whose decay or interaction may mimic neutrino interactions in the target. The estimate of the penetrating muon background 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 upstream Scifi planes. The proton-proton event generation was done with DPMJET. The subsequent muon production from pp collisions was simulated with FLUKA. The propagation of the collision debris in the LHC towards the SND@LHC detector was done using the LHC FLUKA model. The total number of muons integrated in 37.6 fb^{-1} amounts to 4.7 $\times 10^{8}$. The inefficiency of the Veto planes is estimated from data by using good quality tracks reconstructed in the SciFi detector and confirmed with a track segment in the DS detector. The tracks are extrapolated to the Veto fiducial volume. The overall Veto system inefficiency during the 2022 run is estimated to be 4.4 $\times 10^{-4}$. The inefficiency of the SciFi detector is estimated using SciFi tracks confirmed with a DS track and hits in the Veto system, and it is 1.1 $\times 10^{-4}$ per station. The combined inefficiency of the Veto system and the two most upstream SciFi planes is therefore 5.3 $\times 10^{-12}$, thus making the background induced by muons entering the fiducial volume negligible. Neutral particles (mainly neutrons and K_L's) originating from primary muons interacting in rock and concrete in front of the detector can potentially mimic a neutrino interaction. 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. Pythia v6.4 was used to simulate photo nuclear interactions of $\mu^{\pm}$ on protons or neutrons at rest using the muon spectrum expected at the detector location. The secondary particles are transported by GEANT4 in the detector surroundings. Neutral particles induced by muon DIS make interactions in the rock and concrete and only a small fraction of the particles leaves the tunnel wall and enters the SND@LHC detector. The residual background yield results from the 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.

4. Conclusions

A search for high energy neutrino neutrinos originating from pp collisions is presented using data taken by the electronic detectors from SND@LHC installed at the LHC in 2022. We observe 8 candidate events consistent with ν_μ CC interactions at the LHC. Our muon-induced and neutral backgrounds for the analysed dataset amount to (7.8 $\pm$ 2.9) $\times 10^{-2}$ events, which implies a 7.0 σ excess of ν_μ CC signal events [1].

References

[1] R. Albanese et. al. (SND@LHC Collaboration) Observation of Collider Muon Neutrinos with the SND@LHC Experiment, Phys. Rev. Lett. 131, 031802 (2023).