PROCEEDINGS OF SCIENCE

SND@LHC - A new Scattering and Neutrino Detector at the LHC

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SND@LHC is a compact and stand-alone experiment designed to perform measurements with neutrinos produced at the Large Hadron Collider in a hitherto unexplored pseudo-rapidity region of $7.2 < \eta < 8.6$, complementary to all the other experiments at the LHC. The experiment is located 480 m downstream of IP1 in the otherwise unused TI18 tunnel. The detector is composed of a hybrid system based on an 800 kg target mass of tungsten plates, interleaved with emulsion films 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. In the first phase the detector will operate throughout LHC Run 3 to collect a total of 290 fb^{-1}. The experiment was approved by the Research Board at CERN in 2021, and it is currently taking physics data.

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1. Introduction

SND@LHC (Scattering and Neutrino Detector at the LHC) is a compact experiment, developed to measure neutrinos of all three flavours, produced in LHC proton-proton collisions in the pseudo-rapidity range of $7.2 < \eta < 8.6$. It will perform, together with FASERν [1], the first observation of neutrinos produced at a particle collider, in an energy range inaccessible to other experiments. SND@LHC and FASERν will measure neutrinos in different angular ranges, where the relative compositions of the various sources are different, and will contribute to the search of new physics beyond the Standard Model (BSM) because it is sensitive to Feebly Interacting Particles (FIP).

The SND@LHC experiment is installed in the TI18 tunnel, 480 m downstream of the ATLAS interaction point and shielded by ~100 m of rock. It has been taking data since the beginning of LHC Run 3, in May 2022 and it has accumulated over 35 fb^{-1} of integrated luminosity.

2. Physics goals

Neutrinos allow precise tests of the Standard Model (SM) [2–5] and are a probe for new physics [6, 7]. The region of neutrino energies between 350 GeV and 10 TeV is currently unexplored [8], as shown in Figure 1. Measurements of neutrino interactions in the last decades were mainly performed at low energies, where neutrino oscillations are observable at a reasonable distance. SND@LHC will study neutrinos at higher energies, up to a few TeV.

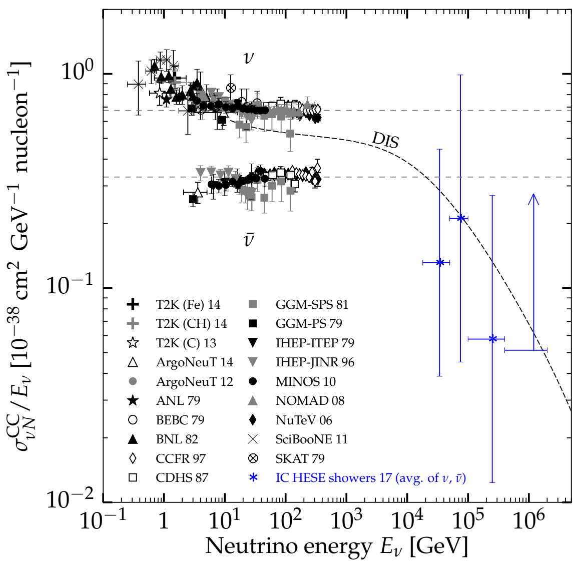


Figure 1: Measurements of the ν and $\bar{\nu}$ cross-section at different energies [8].

The SND@LHC experiment will make use of the wealth of neutrinos of all flavours produced at the LHC. It will study the charmed hadrons production in pp collisions at high pseudorapidity using ν_e and perform tests of the lepton flavour universality in neutrino interactions. Additionally, it will measure the neutral current to charged current cross section (NC/CC) ratio and use it as an internal consistency check.

Furthermore, SND@LHC can perform model-independent direct searches for FIPs by combining the search for a recoil signature with a time-of-flight (TOF) measurement to reject background from NC neutrino interactions. A time resolution of the order of ∼200 ps allows to disentangle the scattering of massive FIPs and neutrinos, with a significance that depends on the particle mass [9].

3. The detector and the data acquisition system

The detector, shown in Figure 2, is composed of a target region, followed by a hadronic calorimeter (HCAL) and a muon identification system. The target region is composed of five Emulsion Cloud Chamber (ECC) walls interleaved with Scintillating Fibres (SciFi) tracker planes. The HCAL and muon identification system consist of eight iron slabs, each followed by a plane of scintillating bars, with higher granularity in the three downstream planes. In addition, two planes of scintillating bars are placed in front of the target region to act as a veto for incoming charged particles.

All the active detectors are based on scintillators and are read out using Silicon Photomultipliers (SiPMs), with different characteristics based on their application: the SciFi tracker uses finely segmented multichannel SiPM arrays, to achieve a space resolution better than 100 µm, while the other subsystems use larger SiPMs, to achieve a higher efficiency and dynamic range.

The combination of SciFi and the muon detector also acts as a non-homogeneous hadronic calorimeter, with an average length of 9.5 interaction lengths[1], for the measurement of the hadronic showers energy produced in neutrino interactions.

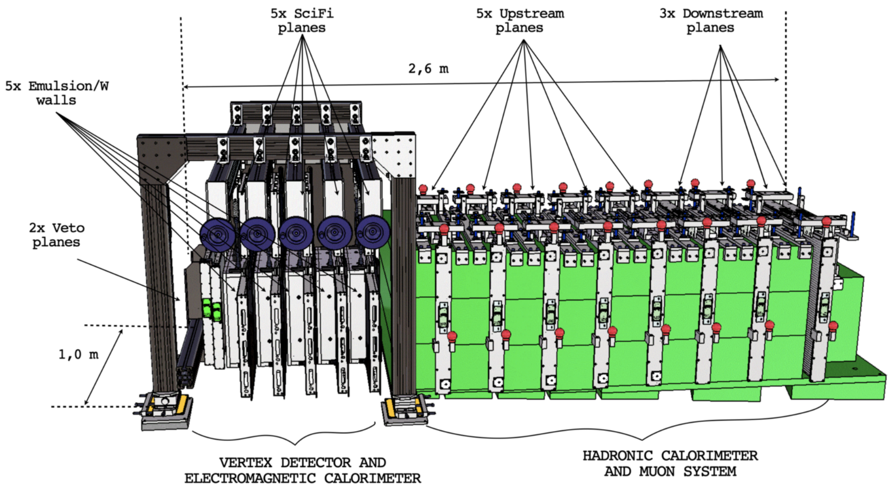


Figure 2: Layout of the SND@LHC detector. Particles form IP1 arrive from the left and encounter the two veto planes, the target, the hadronic calorimeter and the muon system [10].

All the active subsystems are read out with the same Data Acquisition (DAQ) electronics, based on a main DAQ board, featuring a Cyclone V FPGA, and up to four front-end (FE) boards, based on the TOFPET2 ASIC, by PETsys.

[1] 8 to 11 λ_{int} depending on the position of the neutrino interaction within the target

The detector uses a total of 37 DAQ boards, which run synchronously with the LHC bunch crossing clock, received from the Beam Synchronous Timing (BST) system, and delivered to the boards using the Timing, Trigger and Control (TTC) system optical fibres.

The detector is operated in a triggerless fashion, i.e. all hits recorded by each board are transmitted to the DAQ server. Noise reduction is performed at the front-end level, by setting an appropriate threshold for each channel, and in software, during event building [10].

4. Detector commissioning and operation

The commissioning of the SND@LHC detector has been performed in 2021 and in the first half of 2022. After being tested separately, the subdetectors have been assembled together at CERN, in the SPS testbeam hall, to proceed with the commissioning of the full detector. Initially, the hadronic calorimeter has been tested with pions of different energies, to calibrate its energy response. Later on, the full detector has been commissioned using a muon beam.

The detector has been finally installed in the TI18 tunnel between the end of 2021 and the first months of 2022, in time to complete the commissioning and start data taking at the beginning of Run 3.

The SND@LHC detector has been taking data since the beginning of Run 3 and it has currently accumulated more than 35 fb^{-1} of integrated luminosity, with an availability of over 96%.

The emulsion films have been replaced twice already and they are currently being scanned and analysed to estimate the background and refine the replacement strategy.

5. Data analysis and event reconstruction

The data taken with the electronic detectors is being used to estimate the performance of the various sub-detectors in terms of spatial resolution, efficiency, energy and time resolution. These studies take advantage of the high muon rate (~0.8 Hz/cm^2) from the ATLAS interaction point to verify the track reconstruction algorithm, the time alignment of the sub-detectors and the spatial alignment of the various planes. Additionally, the sources of beam-induced background present in the tunnel are being analysed to have a full picture of the detector behaviour. As an example, a plot with the slope of the reconstructed muon tracks is shown in Figure 3.

In parallel with these studies, the event reconstruction is being developed. It will be performed in two phases. At the beginning, data from the electronics detectors will be used to identify neutrino candidates with and without the muons in the final state, to reconstruct the electromagnetic showers in SciFi and finally to estimate the neutrino energy combining SciFi and HCAL data. This will allow to distinguish between ν_μ and ν_e/ν_τ events, based on the presence of a muon in the final state. A schematic representation of the different signatures is shown in Figure 4a.

In a second time, the emulsions will be extracted and analysed. This will allow to identify the neutrino interaction vertex and separate ν_e from ν_τ events, thanks to the presence of the displaced τ lepton decay vertex. A schematic representation of the signature of the three neutrino flavours is shown in Figure 4b. Data from the ECC will then be matched to candidates from the electronics detectors, to verify the presence of a muon in the final state and to complement the electromagnetic energy measurement.

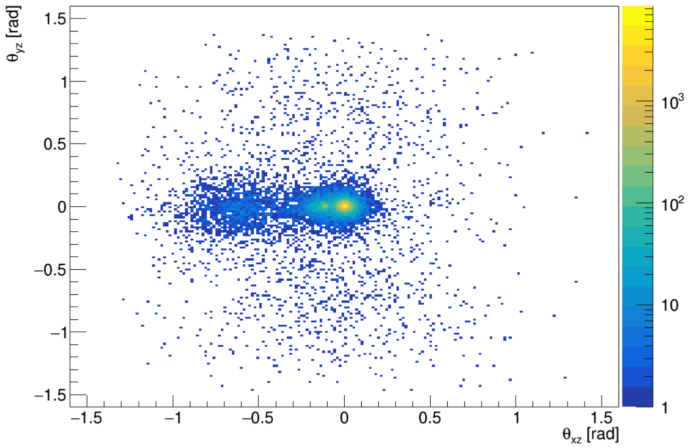
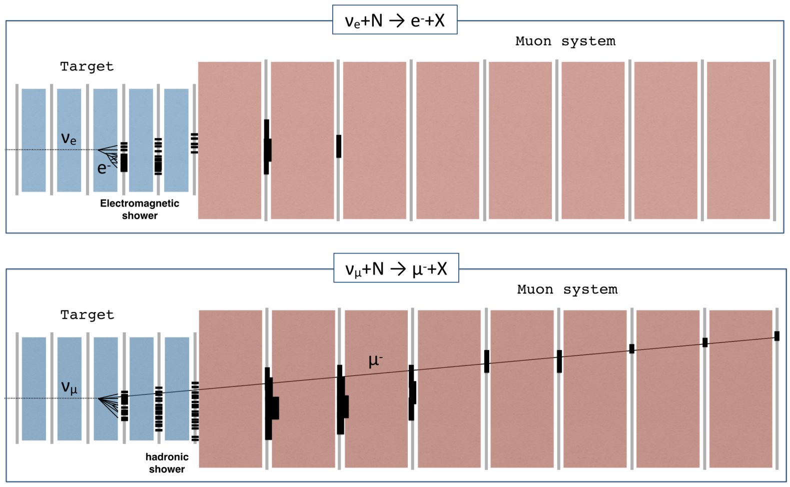
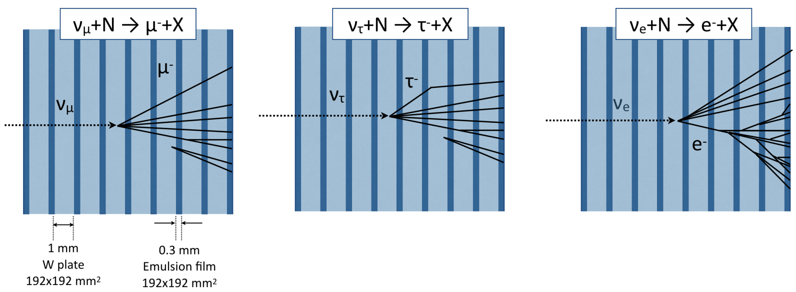


Figure 3: Distribution of the reconstructed muon track slopes in the SND@LHC detector. The peak around 0 corresponds to the tracks coming from the ATLAS interaction point. There are other peaks, correlated to tracks coming from machine elements in the tunnel. The tracks at higher $|\theta_{yz}|$ are produced by cosmic rays.



(a)



(b)

Figure 4: Schematic representation of the event reconstruction phases: the first, with electronics detectors only (a) and the second, with the ECC used to identify the neutrino flavour and interaction vertex (b).

6. Conclusions

The SND@LHC detector is a compact experiment optimized to measure the three neutrino flavours and search for physics beyond the Standard Model. It is composed of a veto plane, a target region (made of emulsion walls interleaved with a scintillating fibre tracker), a hadronic calorimeter and a muon system. It features a triggerless read-out, with online event building and noise suppression. It has been taking data since the beginning of Run 3 and it has accumulated an integrated luminosity of over 35 fb^{-1}.

Two whole emulsion targets has been already replaced and the data analysis of both the electronic detectors and emulsion films is underway. Its initial focus is the detector performance estimation and the definition of the details of the event reconstruction strategy. These steps will be fundamental to accurately identify neutrino events, but also to estimate the systematic uncertainties and have full control of instrumental effects.

References

[1] FASER collaboration, *Detecting and Studying High-Energy Collider Neutrinos with FASER at the LHC*, *Eur. Phys. J. C* **80** (2020) 61 [1908.02310].

[2] CTEQ collaboration, *Handbook of perturbative QCD: Version 1.0*, *Rev. Mod. Phys.* **67** (1995) 157.

[3] J.M. Conrad, M.H. Shaevitz and T. Bolton, *Precision measurements with high-energy neutrino beams*, *Rev. Mod. Phys.* **70** (1998) 1341 [hep-ex/9707015].

[4] J.A. Formaggio and G.P. Zeller, *From eV to EeV: Neutrino Cross Sections Across Energy Scales*, *Rev. Mod. Phys.* **84** (2012) 1307 [1305.7513].

[5] G. De Lellis, P. Migliozzi and P. Santorelli, *Charm physics with neutrinos*, *Phys. Rept.* **399** (2004) 227.

[6] D. Marfatia, D.W. McKay and T.J. Weiler, *New physics with ultra-high-energy neutrinos*, *Phys. Lett. B* **748** (2015) 113 [1502.06337].

[7] C.A. Argüelles et al., *White Paper on New Opportunities at the Next-Generation Neutrino Experiments (Part 1: BSM Neutrino Physics and Dark Matter)*, 1907.08311.

[8] M. Bustamante and A. Connolly, *Extracting the Energy-Dependent Neutrino-Nucleon Cross Section above 10 TeV Using IceCube Showers*, *Phys. Rev. Lett.* **122** (2019) 041101.

[9] C. Ahdida et al., *SND@LHC - Scattering and Neutrino Detector at the LHC*, Tech. Rep. CERN-LHCC-2021-003, LHCC-P-016, CERN, Geneva (Jan, 2021).

[10] SND@LHC Collaboration, *SND@LHC: The Scattering and Neutrino Detector at the LHC*, 2022. 10.48550/ARXIV.2210.02784, https://arxiv.org/abs/2210.02784.