PROCEEDINGS OF SCIENCE

Status of SND@LHC (Scattering and Neutrino Detector at the LHC)

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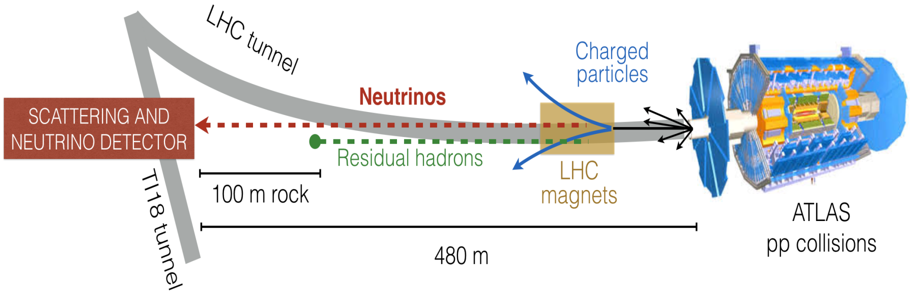
SND@LHC is a standalone experiment at the Large Hadron Collider (LHC), positioned 480m downstream of IP1 (ATLAS) in the disused service tunnel TI18, that will detect high energy neutrinos produced by heavy flavour quarks in the pseudo-rapidity (η) region $7.2 < \eta < 8.6$. It is a hybrid system, comprising nuclear emulsions and electronic detectors, that enables detecting and distinguishing all three ν flavours. This allows probing the physics of charm production in the very forward region. The first phase aims at operating the detector throughout LHC Run 3 collecting a total of 150 fb^{-1}. The electronic subdetectors were assembled in the summer, recently operated in test beams and have now been installed in TI18.



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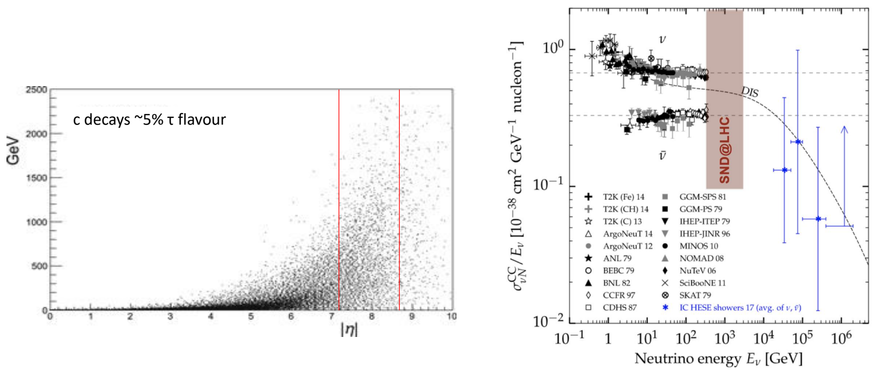
1. Introduction and motivation

The LHC is a source of highly energetic neutrinos (100 – 3000 GeV/c). The detection of the ν_e, ν_μ and ν_τ flux in the forward direction [1] (see Figure 1(a)) can fill the gap between accelerator measurements and data from cosmic rays [2](see Figure 1(b)). This motivated the creation of the



(a) (b)

Figure 1: (a) Neutrino energy vs η (from b and c decays). (b) Measurements of ν_μ and $\bar{\nu}_\mu$ CC cross sections.

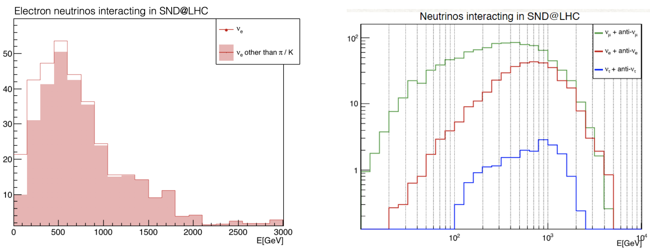
SND@LHC experiment [3].

2. Physics program

The neutrino production at the LHC is simulated with FLUKA [4] and DPMJET3 [5] as event generator. GENIE [6] is used to simulate neutrino interactions with the detector material. The output of GENIE is fed to GEANT4 [7] for particle propagation through the detector.

2.1 $\sigma_{pp\to\nu X}$ in the $7.2 < \eta < 8.7$ range

The ν_e and ν_τ come mainly from the charmed hadron dedays. 10% of ν_e come from K decays with an energy below 200 GeV (see Figure 2 (a)). The ν_μ and $\bar{\nu}_\mu$ spectra contain a soft component from π and K decays. The energy spectrum of interacting neutrinos is shown in Figure 2 (b).



(a) (b)

Figure 2: (a) Electron neutrino spectrum. (b) Spectra for all neutrinos for 150 fb^{-1}.

2.2 Charm production in pp collisions

Starting from the observed ν_e energy spectrum, and unfolding the energy resolution effects one predicts the energy spectrum of the incoming ν_e flux. Data is used to measure $\sigma_{pp\to\nu X}$ with an accuracy of 15%. The subtraction of the K contribution adds a 20% uncertainty. Correlating the yield of charmed hadrons in a given η region with the neutrinos in the measured η region adds 25% to the systematic uncertainty. The measured charmed-hadron production will thus have a statistical uncertainty of about 5% with a systematic error of 35%.

2.3 Lepton Flavbour Universality

Cross section ratios provide lepton flavour universality (LFU) tests in neutrino interactions. Since ν_τs come from $D_s \to \tau\nu_\tau$ and ν_e come from D_0, D, D_s and Λ_c decays, uncertainties due to charm production mechanism cancel out. $R_{13} = N_{\nu_e}/N_{\nu_\tau}$ only depends on charm hadronization and decay branching fractions. R_{13} is sensitive to the ν-nucleon interaction cross section ratio with a systematic error of 22% and a 30% statistical uncertainty due to the ν_τ sample size.

2.4 Measurement of σ_{NC}/σ_{CC}

Using the charged lepton ID, CC can be distinguished from neutral current (NC) interactions. Assuming that the fluxes of ν and $\bar{\nu}$ as a function of energy are equal, the ratio $P = (\sigma^{\nu}_{NC} + \sigma^{\bar{\nu}}_{NC})/(\sigma^{\nu}_{CC} + \sigma^{\bar{\nu}}_{CC})$ is equal to the ratio of the observed events. P can be written as a function of the Weinberg angle [8]. This measurement will be used as a control measurement.

2.5 Feebly interacting particles (FIPs)

The SND@LHC experiment is also capable of performing model-independent direct searches for FIPs by combining the search for a recoil signature with a time-of-flight (TOF) measurement to reject neutrino interactions that can act as background.

3. The detector

The detector (see Figure 3) is a compact hybrid system, containing passive and active subdetectors. A target section consists of emulsion cloud chambers (ECCs) interleaved with a scintillating fiber tracker (SciFi), and a hadron calorimeter/muon detector with a muon tracking section [3]. The target region is protected by a veto wall made of plastic scintillators that detects impinging charged particles. It is made of two vertically shifted planes of seven $42 \times 6 \times$ cm^3 bars, read out at each end by SiPMs placed on a PCB common to each side of a detector plane. Each ECC comprises 60 nuclear emulsion films, 19.2×19.2 cm^2, with 59 1 mm thick W-alloy plates in between, for a weight of 41.5 kg. The total weight of the target is about 830 kg. The total emulsion surface is about 44 m^2. The SciFi consists of five 40×40 cm^2 x-y planes of 55 staggered scintillating fibers each 250 μm in diameter read out by customized 128 channel Hamamatsu SiPMs. Apart from tracking, the SciFi plays also the role of a coarse sampling (16.8 X_0 or 0.59 λ_I) e.m./hadron calorimeter. For single hits/tracks the space resolution is ≈ 50 μm, sufficient to link the hits with an interaction in an EEC brick, and the time resolution is ≈ 250 ps. For multiple tracks or showers, the time resolution is expected to be considerably better. For the long-term stability of emulsion films, the temperature

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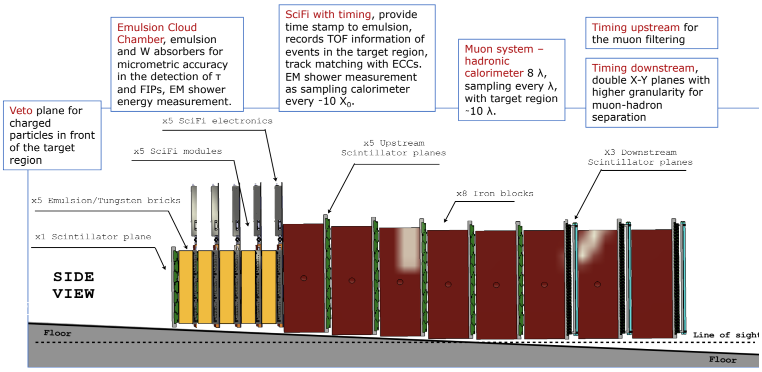
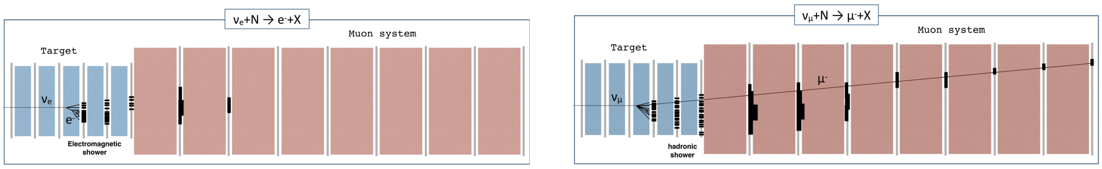


Figure 3: The SND@LHC detector.



(a) (b)

Figure 4: ν_e (a) and ν_μ (b) CC interactions.

of the target will be kept at 15 ± 1°C and the relative humidity in the range 50 to 55%. For this purpose an insulated box is built around the target region and a cooling system is installed. The walls of the box act as a passive neutron shield with a borated polyethylene layer.

4. Two stage event reconstruction

The first stage of the event reconstruction uses the electronic detectors. Neutrino interactions are first detected by the target tracker and the muon system. Electromagnetic showers are identified by the target tracker, while muons are reconstructed by the muon system (see Figure 4). The muon identification efficiency is ≈ 69%, with a purity of almost 99%. The detector as a whole acts as a sampling calorimeter. The average energy resolution is ≈ 22%. Data taken from both SciFi and muon systems is used to measure the hadronic and electromagnetic energy of the event. The second stage uses nuclear emulsions and provides: identification of e.m. showers; primary vertex reconstruction and secondary vertex search; matching with candidates from electronic detectors (acquiring a time stamp). The topology of some signal events are shown in Figure 5. The neutrino flavour idenbtification is done by identifying the charged lepton produced at the primary vertex. Electrons are clearly separated from π^0s. The accuracy of the EEC enables photon conversions downstream of the neutrino interaction vertex to be identified. The electron ID efficiency is > 95%, and reaches ≈ 99% including the SciFi information. Tau leptons are identified through the observation of a tau decay vertex in the absence of any electron or muon. The tau decay search (total ID) efficiency ranges from 80-82% (48-50%) for 1-prong events to 89% (54%) for 3-prongs.

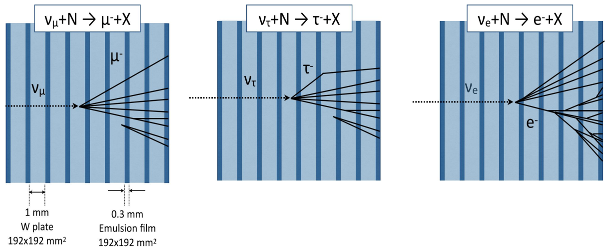


Figure 5: Reconstructible topologies in emulsion

5. Detector assembly and status

All subdetectors have been commissioned with testbeams at the H6 and H8 CERN SPS beamlines during the autumn of 2021. A large part of the detector has been installed in TI18.

6. Conclusions

SND@LHC is capable of detecting the interactions of different neutrino flavours and should detect thousands of them in the next run of the LHC, starting in June 2022. These will be used to probe the physics of charm production in the forward direction.

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