PROCEEDINGS OF SCIENCE

SND@LHC upgrades

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SND@LHC is a forward experiment measuring neutrinos produced at the LHC, operating since the beginning of Run 3 in 2022. The first physics data yielded, among the rest, the first observation of neutrinos produced at a collider.
The detector currently in use is a hybrid system based on a 830 kg nuclear emulsions and tungsten target, with interleaved scintillating fiber tracker planes, followed by a hadronic calorimeter and a muon system. Its configuration allows to identify all three neutrino flavours, opening a unique opportunity to probe heavy flavour production in a η region not accessible to ATLAS, CMS and LHCb.
A thorough upgrade is foreseen for LHC Run 4: in the new detector emulsions will be replaced with silicon sensors and a magnetised hadronic calorimeter will be used. The sensitive material of both systems will consist of silicon strips from the current CMS tracker, which will be decommissioned at the end of Run 3.
The upgraded detector will lead to a significant reduction of statistical and systematic uncertainties and will allow to measure the $\nu_\mu N$ interaction cross section.

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1. Introduction

SND@LHC (Scattering and Neutrino Detector at the LHC) is a compact experiment, developed to measure neutrinos produced in LHC proton-proton collisions, in the pseudo-rapidity range of $7.2 < \eta < 8.4$ [1]. It performed, together with FASERν, the first observation of neutrinos produced at a particle collider, in an energy range inaccessible to other experiments [2, 3].

SND@LHC has a diverse physics programme: it performs SM measurements, probing the strong interaction and nuclear structure in new energy regimes, it can test lepton flavour universality (LFU) in the neutrino sector and can be exploited to search for physics beyond the Standard Model.

The SM measurements focus on studying the charm quark production in the very forward region by studying the electron neutrino flux. The charm quark production measurement, in turn, provides an important constraint on the gluon parton distribution function (PDF) at very low momentum fraction, where it is unknown. In addition, it will perform measurements of lepton flavour universality in the neutrino sector, by studying the ratio in the yields of ν_e/ν_μ and ν_e/ν_τ. In the search for new physics beyond the Standard Model it is sensitive in particular to feebly interacting particles (FIPs) through their scattering on the target nuclei and electrons.

2. The SND@LHC detector

The SND@LHC detector, visible in Figure 1, is composed of a target region followed by a hadronic calorimeter (HCAL) and muon identification system. The target region is instrumented with an emulsion cloud chamber (ECC) and a target tracker, based on scintillating fiber mats (i.e. planes composed of tightly packed layers of scintillating fibers) read out by multichannel SiPM arrays.

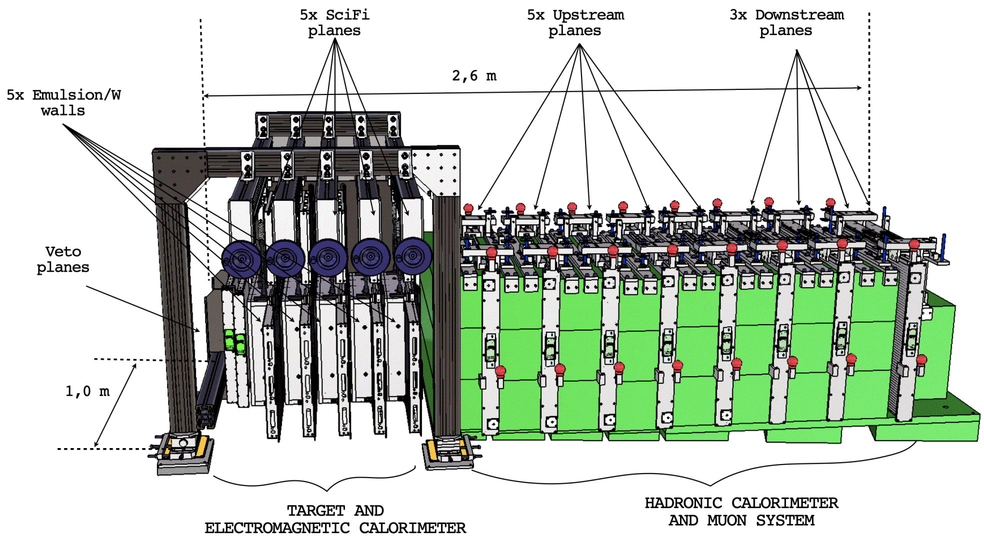

Figure 1: Layout of the SND@LHC detector. The neutrinos from the pp collisions in ATLAS arrive from the left side of the picture [1].

The ECC is used to detect the neutrino interaction vertices, but it will provide no timing information at all. The target tracker adds the time information to the events allowing to link the hadronic showers found in the ECC with the rest of the electronics detector systems. The tracker also acts as a coarse sampling electromagnetic calorimeter, contributing in the measurement of the energy of electromagnetic showers.

The veto, hadronic calorimeter and muon system are based on EJ-200 plastic scintillator bars read out by SiPMs. Three veto planes in front of the target are used to tag events containing incoming charged particles (predominantly muons and secondaries produced in the tunnel walls). The HCAL and muon system are composed of alternating layers of scintillating bars and 20 cm iron blocks: the difference between the two systems is that the HCAL uses large horizontal bars of scintillator (6 cm tall), while the muon system has a higher segmentation (1 cm) and features both vertical and horizontal bars.

The detector is optimized to distinguish neutral current (NC) and charged current (CC) neutrino interactions and, for the latter, to tag the flavour of the incoming neutrinos.

The experiment is located in a secondary tunnel and it is shielded from the ATLAS interaction point by ∼100 m of rock and concrete. The only particles that reach it are muons (with a rate of up to 0.8 Hz/cm^2), neutrinos and (possibly) yet undiscovered particles.

3. The proposed upgrade for HL-LHC

An upgrade of the detector, called Advanced SND, or AdvSND for short, has been proposed for LHC Run 4, in order to fully exploit the potential of the increase in luminosity of the HL-LHC accelerator [4].

The design of the upgrade, visible in Figure 2 has been driven by the characteristics of the interactions of the three neutrino flavours, and it includes: a veto detector in front, to tag incoming charged particles; a high-density target, instrumented to act as a high-granularity electromagnetic calorimeter; a magnetised hadronic calorimeter and muon detection system, to fully contain the hadronic showers produced in neutrino DIS interactions and identify the charge of muons.

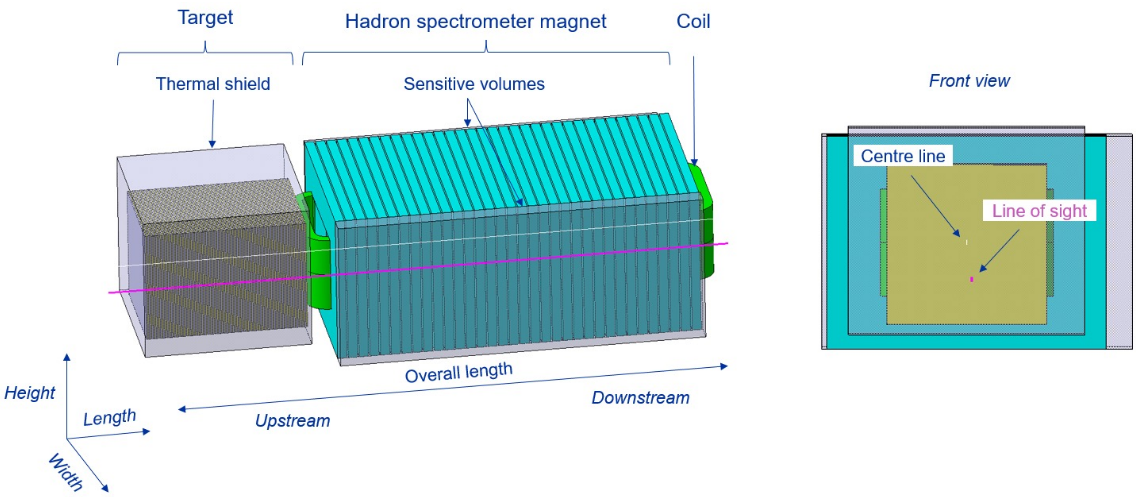

Figure 2: Layout of the AdvSND detector, with the line of sight highlighted in magenta.

The design of the veto system will be based on the veto for the current detector, increasing the segmentation of the scintillator. The current design uses 6 cm wide bars, read out by 8 SiPMs each, while in the new design this will be reduced to 2 or 3 cm, mitigating the inefficiency caused by pile-up.

For the target, the use of nuclear emulsions will not be viable: the increase in luminosity will translate in an increase in muon background, requiring an unsustainable target replacement rate. It will therefore be built with alternating layers of tungsten absorber and silicon microstrip detectors.

Strip modules from the Tracker Outer Barrel of the CMS detector [5] will be used, arranged in alternating vertical and horizontal layers as shown in Figure 3, covering a total area of 40 cm $\times$ 40 cm. They will be mounted directly on the front and back of 7 mm thick tungsten plates: the combination of a back module with the following front one will consitute an active layers with almost complete coverage of the target cross section.

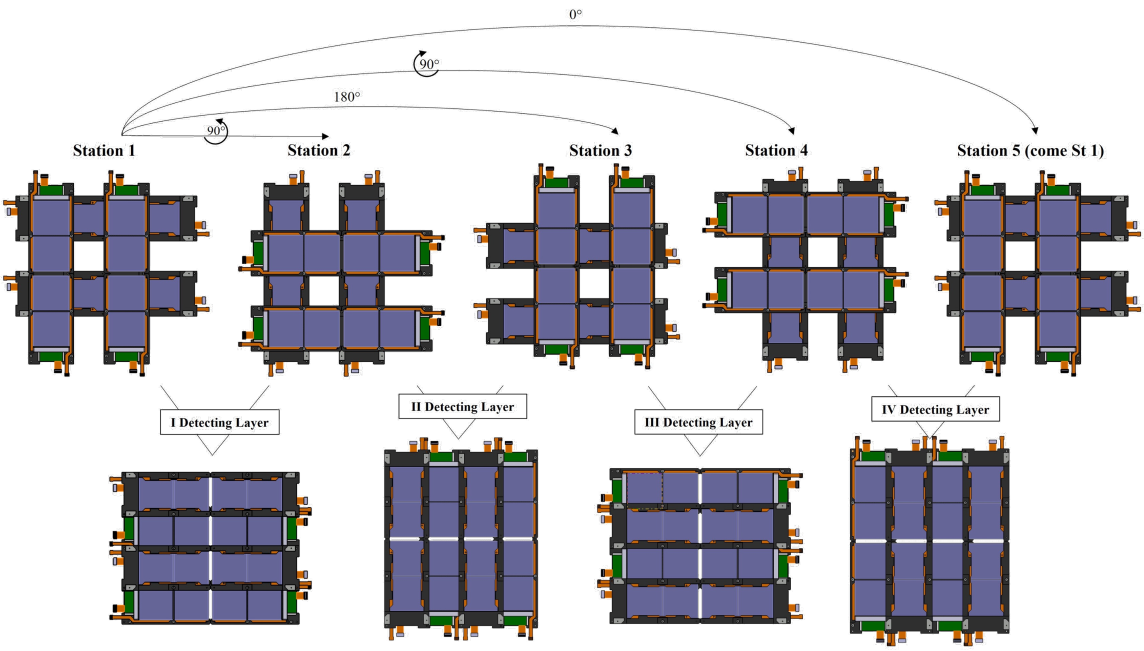

Figure 3: Arrangement of consecutive layers the strip modules to guarantee a hermetic coverage of the target cross section. The tungten plates (not shown for clarity) are located between the horizontal and vertical modules in each station [4].

After the target, a magnetised hadronic calorimeter, visible in cyan in Figure 2, will be installed. It will consist of 34 alternating layers of 5 cm thick iron absorber and the same silicon strip modules used in the target, for a total length of 1.97 cm. The sensitive area will be surrounded by a coil generating a 1.7 T magnetic field. The iron absorbers will have a total cross section of 80 cm $\times$ 105 cm, and will also act as the return yoke for the magnet.

To optimize the detector acceptance, it will be located in a trench that will be excavated in TI18, as shown in Figure 4. The trench depth and length have been determined to optimize the acceptance of the detector, while guaranteeing the structural integrity of the tunnel.

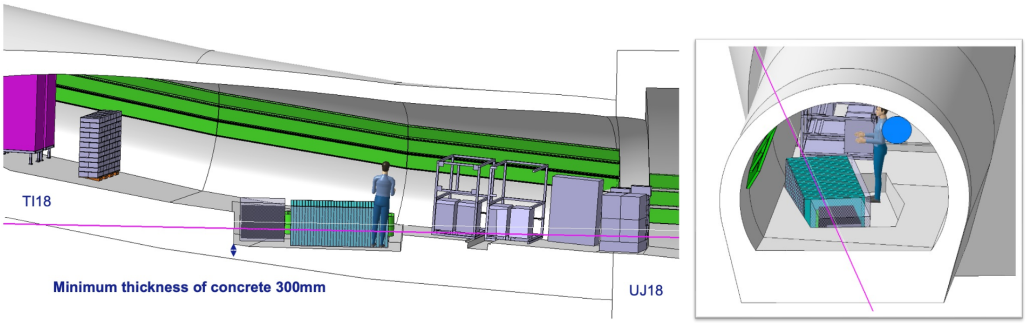

Figure 4: The integration of the AdvSND detector in TI18: side view (left) and front view (right).

4. Physics performance

The AdvSND detector will significantly improve the physics reach of SND@LHC [4]. The higher luminosity will translate into a higher neutrino flux (see Figure 5) drastically reducing the statistical uncertainties in the QDC measurements, from the current 10% to 1%. Similarly, the LFU measurements will see these uncertainties drop from 30% to 5% for the ν_e/ν_τ channel and from 10% to 1% for the ν_e/ν_μ one.

The addition of a near detector, foreseen for Run 5, and the use of novel methods to estimate systematic uncertainties will reduce these as well: from 35% to 5% in the QDC measurements, from 20% to 10% for the LFU ν_e/ν_τ channel and from 10% to 5% for the ν_e/ν_μ one.

The new detector will also be capable of measuring the interaction cross section of $\nu_\mu N$ and $\bar{\nu}_\mu N$ in the currently unexplored TeV energy range, thanks to the precise estimate of the neutrino flux in the forward region provided by the LHCf collaboration [6].

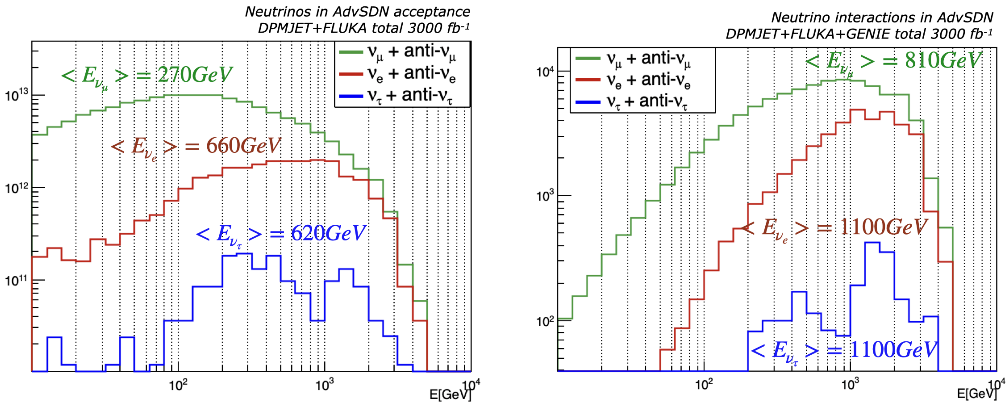

Figure 5: Energy spectra of the neutrinos in the Target acceptance (left) and undergoing CC DIS interactions in the Target (right) [4].

5. Conclusions

The SND@LHC detector has been successfully taking data since 2022. To improve the uncertainties of its results and to unlock the capability to perform new measurements, an upgrade has been proposed for HL-LHC and will start taking data in Run 4.

The new detector will feature a tungsten-silicon target, capable of determining the neutrino interaction vertex: the currently used emulsion cloud chamber technology cannot be used due to the high rate of muons produced at the increased luminosity. The target will be followed by a magnetized hadronic calorimeter, to measure the hadronic showers energy, isolate muons in the final state and determine their charge.

This upgrade will have a significant impact on the physics reach, by reducing the statistical and systematics uncertainties by a factor up to 10, and unlocking the possibility to measure the $\nu_\mu N$ and $\bar{\nu}_\mu N$ interaction cross sections.

References

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