RECENT RESULTS FROM SND@LHC

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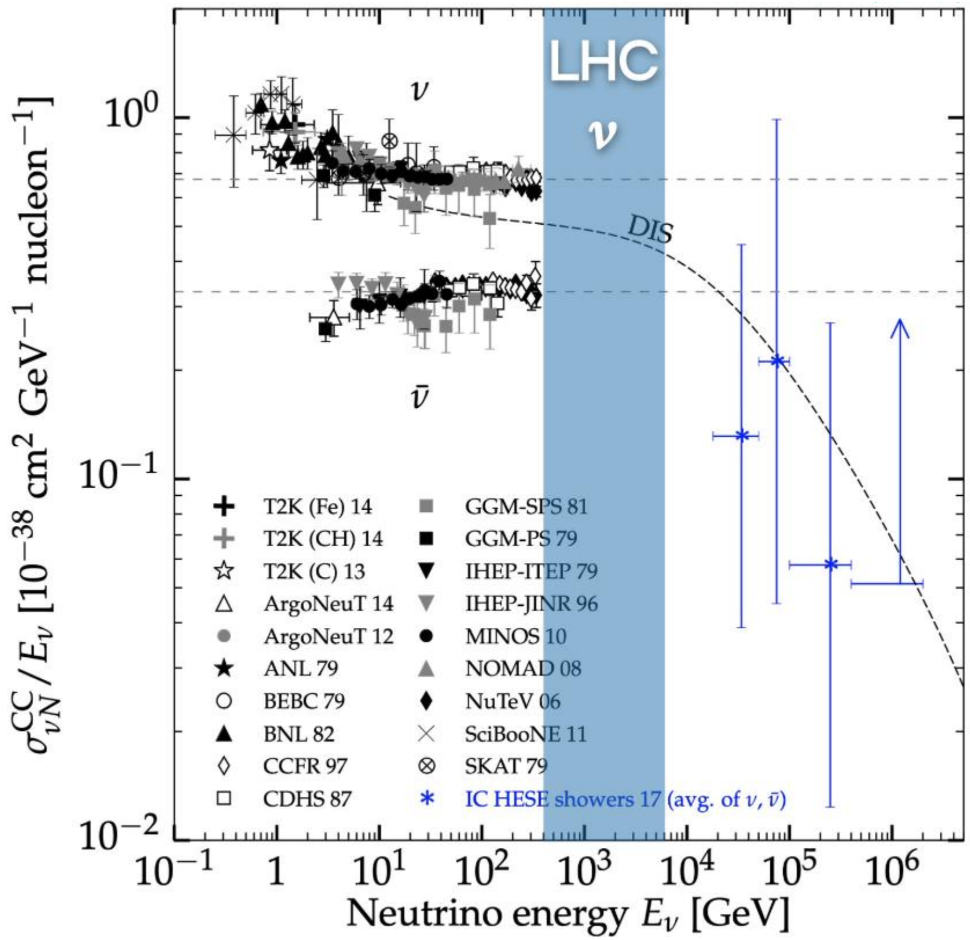
NEUTRINO EXPERIMENTS AT THE LHC

The **neutrino** physics program at the **LHC** started in the **1980s** ([CERN-1984-010-V-2.571](); [Nucl. Phys. B405, 80](); [LPNHE-93-03]()).

- pp collisions produce **large neutrino fluxes** in the **forward** region.
- Very **high** neutrino **energy** ($10^2 - 10^3$ GeV, $\sigma_\nu \propto E_\nu$).
- A small-scale LHC experiment can observe **neutrinos** of **all three** flavors.

Two **neutrino experiments** currently **in operation** at the ATLAS interaction point (IP1):

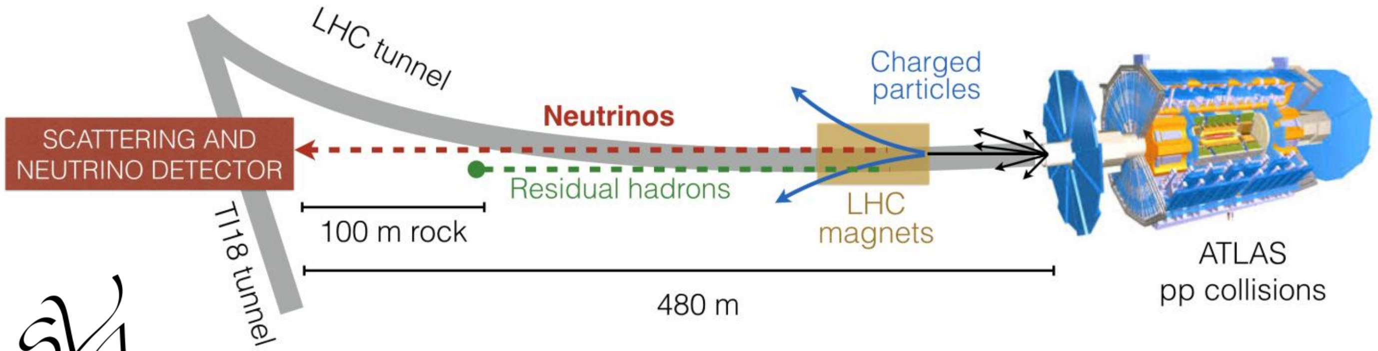
SND@LHC and **FASERν**.

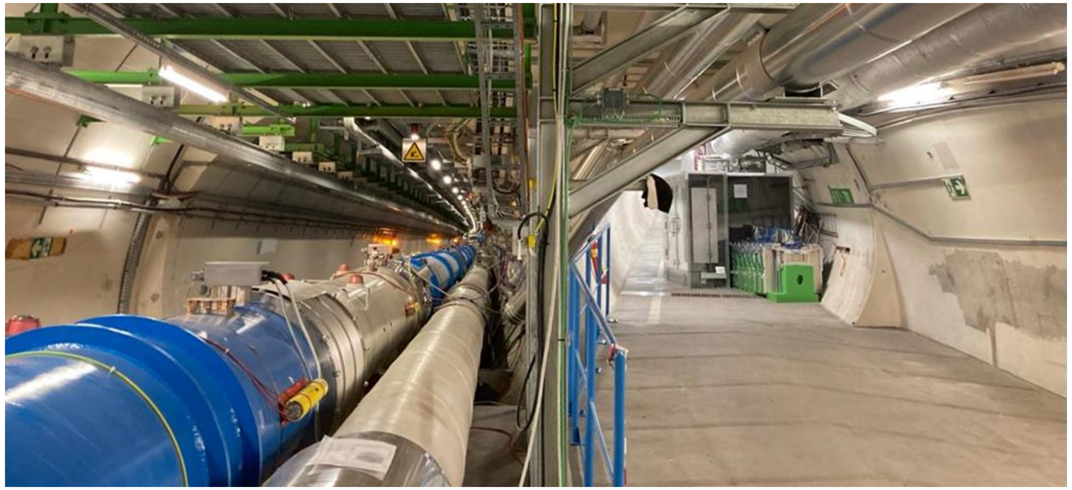


THE SND@LHC EXPERIMENT

Full name - **Scattering and Neutrino Detector** at the **LHC**

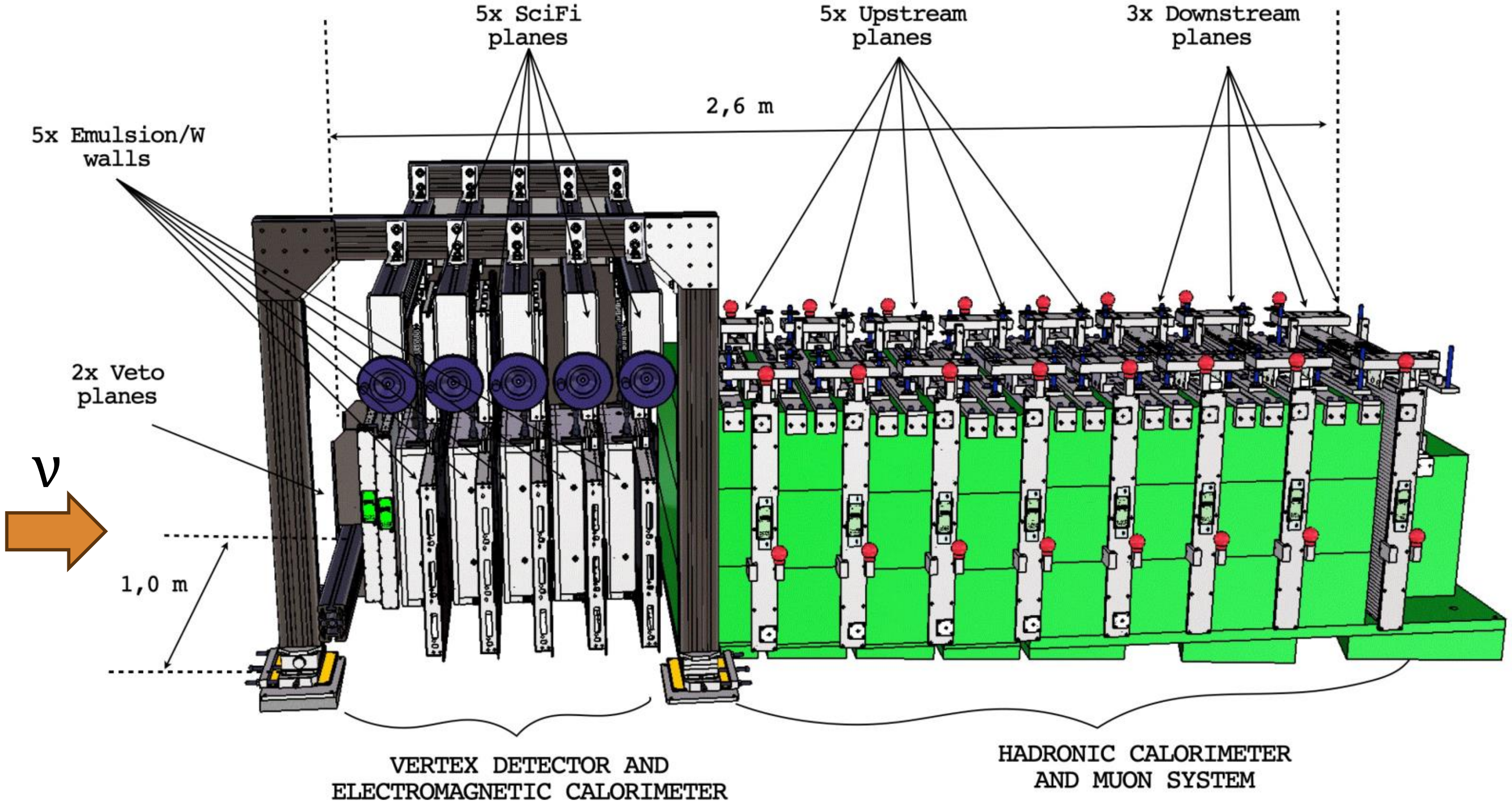
- To measure **high-energy neutrino** interactions from the LHC at the **TeV** scale.
- Located in **TI18**, a former transfer line from SPS to LEP, **480m** away from the **ATLAS** interaction point (IP1).
- Shielded by **~100m rock** and **LHC magnet**s deflecting charged particles.
- Angular acceptance of **7.2 < η < 8.4** (off axis).





DETECTOR LAYOUT

Hybrid detector design is optimized for the identification of **three ν flavors** and **feebly interacting particles** and consists of **three parts:**



arXiv:2210.02784

Veto system

- **2 planes** of stacked **scintillator bars** to tag entering charged particles

Vertex detector + target + ECAL

- **830 kg** tungsten **target**
- **Emulsion** cloud **chambers** interleaved with **tungsten** to reconstruct neutrino vertices
- **Five sci-fi planes** (calorimetry + timing)

HCAL + muon ID system

- **5+3** plastic **scintillator planes** interleaved with **iron walls** (upstream and downstream stations).
- **Higher granularity** in **downstream** stations for muons tracking and identification.

PHYSICS PROGRAM

Neutrino interactions

- Registering ν **interactions** in the unexplored **~TeV energy** range allows for **ν_τ and $\bar{\nu}_\tau$ search.**
- Measuring the **NC/CC ratio.**

Heavy flavor physics

90% of ν_e and $\bar{\nu}_e$ reaching the SND@LHC come from **charmed hadron** decays. This provides opportunities to: J. Phys. G: Nucl. Part. Phys. 47 125004

- Measure the **pp → ν_eX cross section.**
- Measure forward **charm production** with neutrinos.
- Constrain **gluon PDF** at very small x.

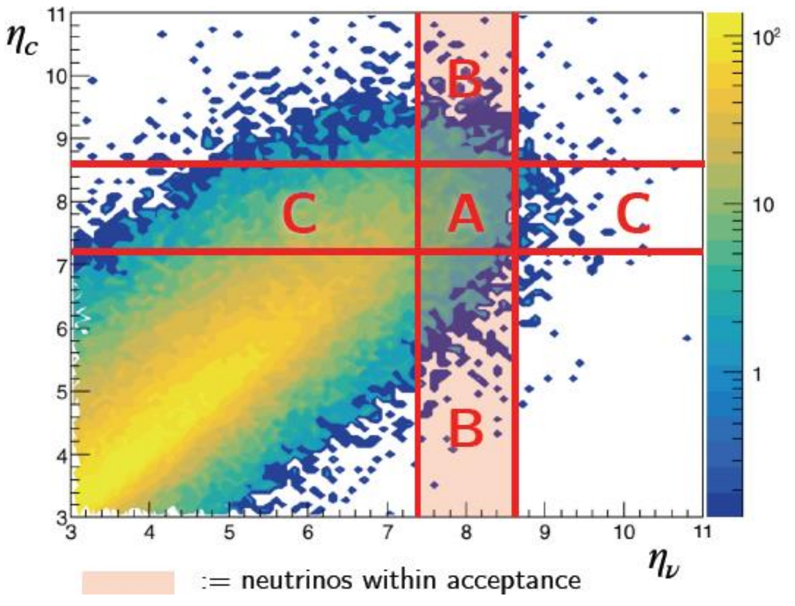
Flavor universality

- Detection of all three types of neutrinos allows for **tests of lepton flavor universality** using the ratio of events ν_e/ν_μ and ν_e/ν_τ.

Beyond the Standard Model

- Exploration of Hidden Sector models and **search** for new, **feebly interacting, particles** that decay in the detector or scatter off the target.

CORRELATION BETWEEN η_ν AND η_c



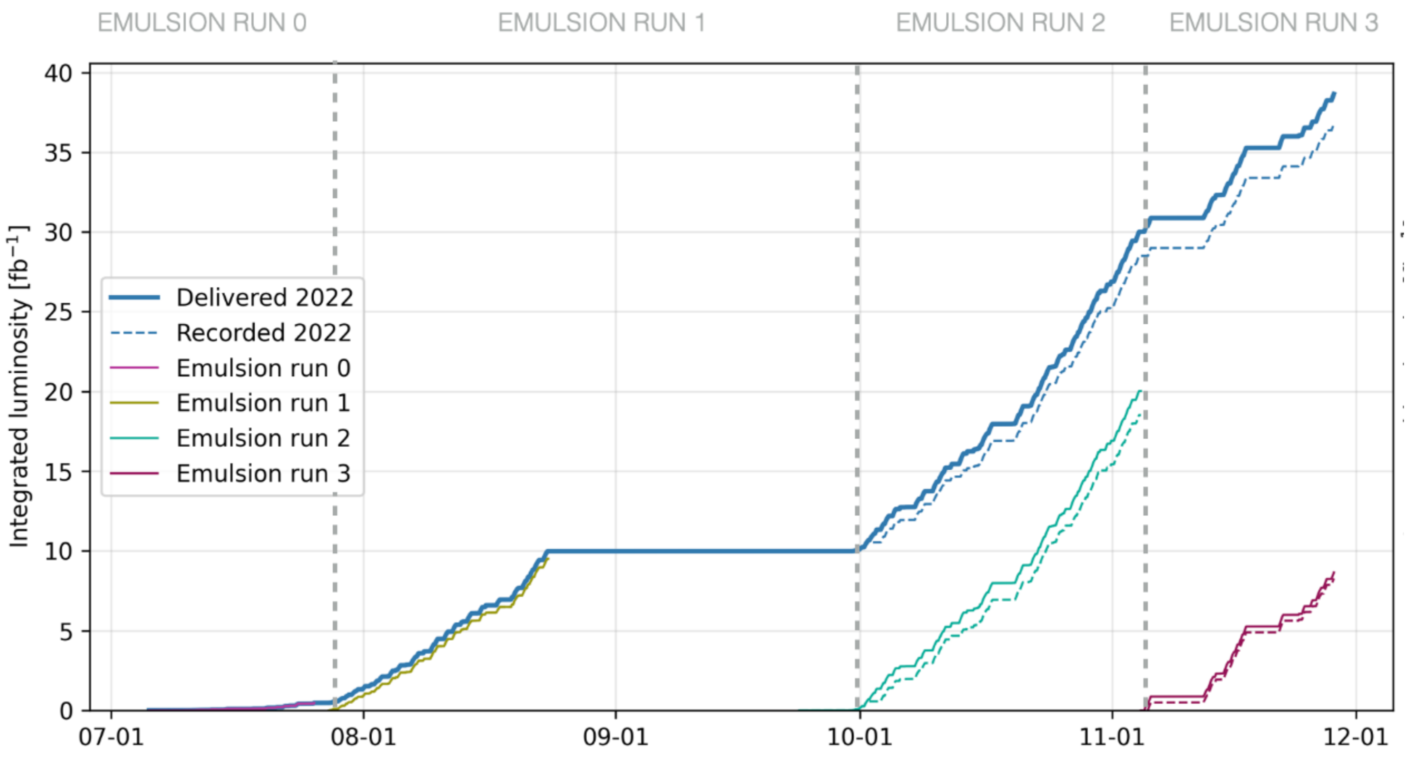
Measurement	Uncertainty Stat.	Sys.
$pp \to \nu_e X$ cross-section	5%	15%
Charmed hadron yield	5%	35%
ν_e/ν_τ ratio for LFU test	30%	22%
ν_e/ν_μ ratio for LFU test	10%	10%
NC/CC ratio	5%	10%

TIMELINE AND PP-COLLISION DATA

Aug 2020: Letter of Intent published	Mar 2021: Approval by CERN Research Board	Dec 2021: Detector installed	Apr 2022: First data taken

Successful stable data-taking since **July 2022** (Run 3):

- **Detector** operation **uptime** ~ 95%.
- **Total** recorded **luminosity**: 36.8 fb^{-1}.
- Three **emulsion** detector **replacements** in 2022.
- Additional ~ **30 $\mathbf{fb^{-1}}$** collected in 2023.



ANALYSIS STRATEGY & EVENT SELECTION

Goal: **high-purity** sample of ν_μ **charged current** interaction (CC) events.

Analysis strategy: counting method, use **electronic** detectors only, reject **high-level background** (10^9 μ).

Dataset: full 2022 run, **36.8 fb^{-1}**.

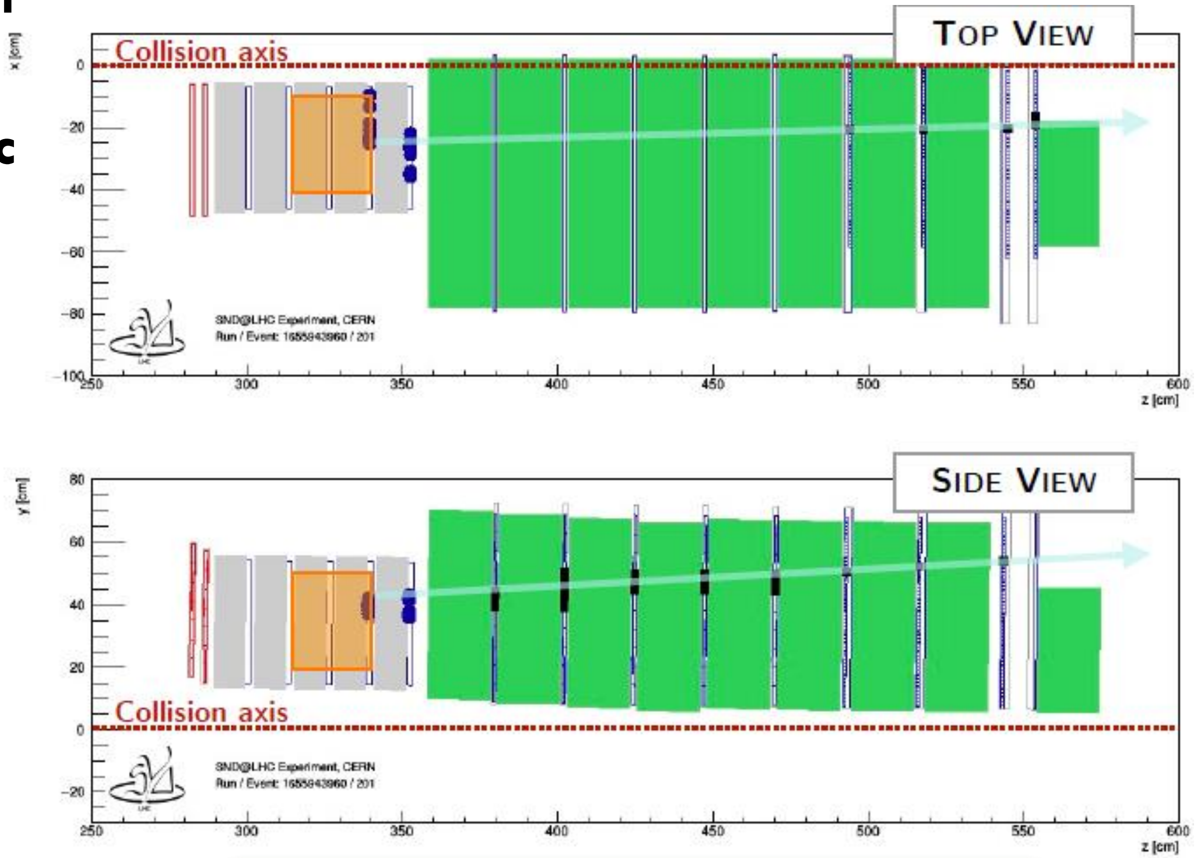
Fiducial volume cut

- A neutral vertex in the **3rd or 4th** target wall.
- Reject **side-entering** backgrounds.
- Signal acceptance: **7.5%.**

Muon neutrino identification

- **Large hadronic activity** in SciFi and HCAL.
- A **reconstructed** and isolated **muon track.**
- Signal selection efficiency: **36%.**

ν_μ CC MC SIMULATION



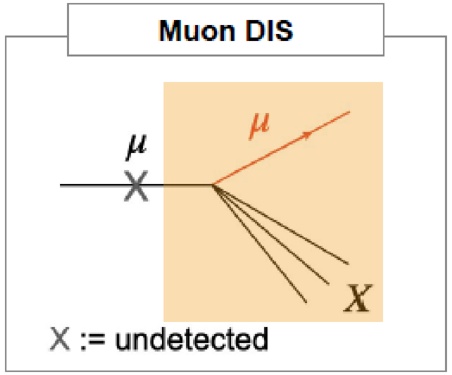
TOTAL NUMBER OF CC EVENTS EXPECTED IN 36.8 fb^{-1} AFTER CUTS: 4.2

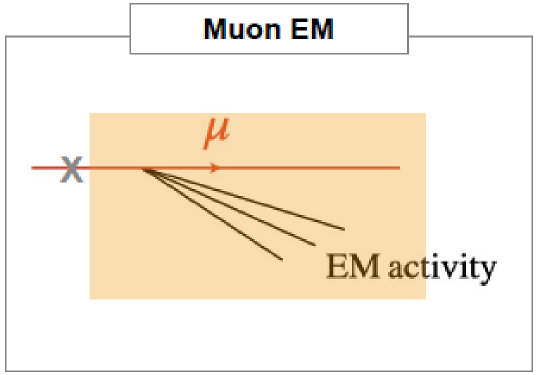
BACKGROUND ESTIMATION

Entering muons

- Incoming muon track **may be missed** due to detector inefficiency.
- **Shower** induced by **muon DIS** interaction or **EM** activity.
- Muons in acceptance: $N_\mu \sim 5 \times 10^8$. SNDLHC-NOTE-2023-001
- Detector inefficiency (2 veto and 2 SciFi planes): 5×10^{-12}.

NEGLIGIBLE BACKGROUND WITH CURRENT SELECTION.

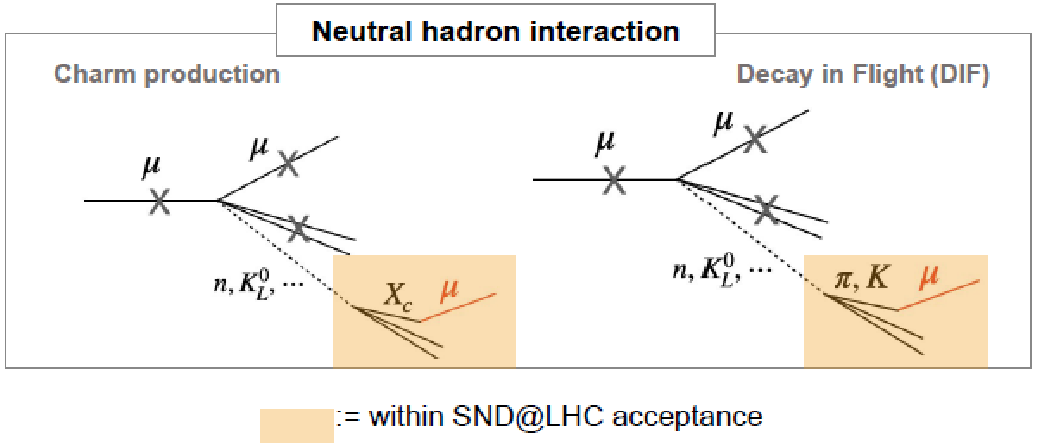




Neutral hadrons from muon DIS

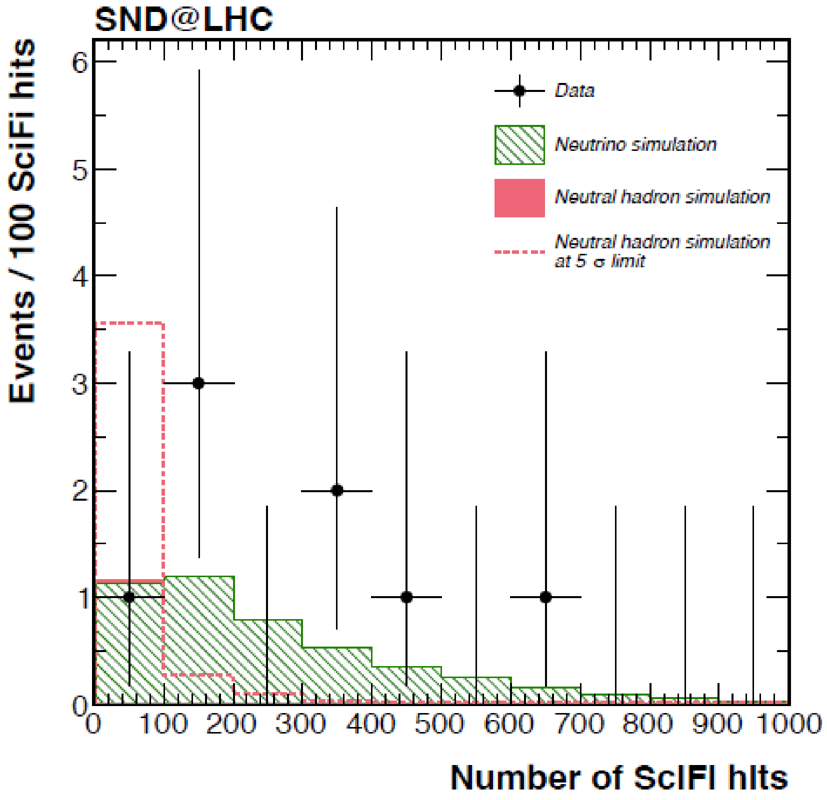
- **Neutral hadrons** produced by **muon DIS upstream** of the detector.
- **Muons** originating from **charm production** or Decay-In-Flight **pions.**

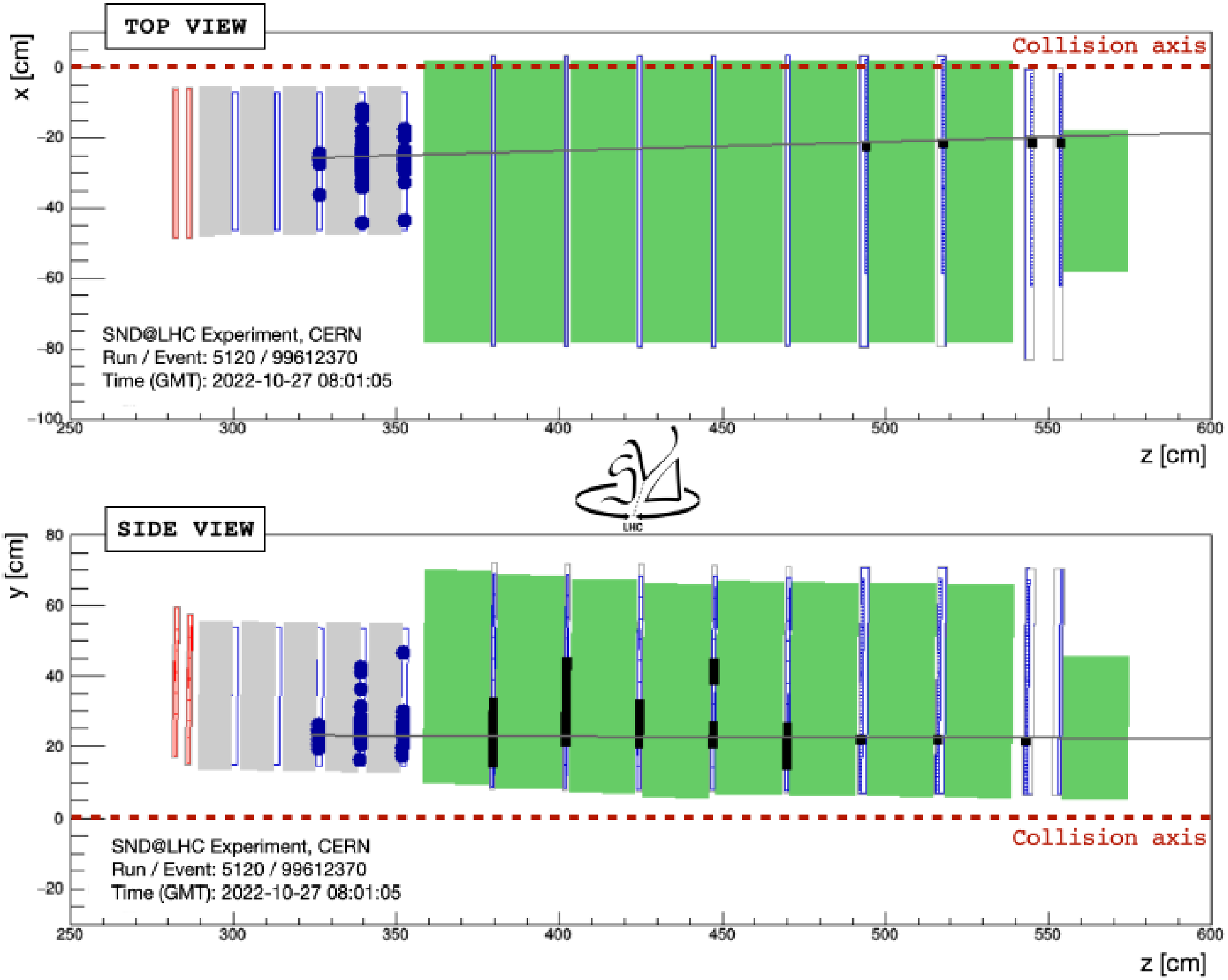
TOTAL NUMBER OF **BACKGROUND** EVENTS **DUE TO NEUTRAL HADRONS:** $(8.6 \pm 3.8) \times 10^{-2}$.



FIRST RESULTS: MUON NEUTRINO OBSERVATION

Observed **8** ν_μ CC candidates with a statistical significance of **6.8σ.**





PRL 131, 031802 (2023)

SUMMARY

The **SND@LHC** experiment is measuring **neutrinos** produced in the LHC **high-energy pp collisions** in an **unprecedented energy range** ($\mathbf{10^2 - 10^3}$ GeV).

- **Successful** detector **operations** in 2022, with **95%** uptime and **36.8** $\mathbf{fb^{-1}}$ recorded luminosity, continued collecting data in 2023.
- First physics result: **observation** of **8 muon neutrinos** from proton-proton LHC collisions against an expected background of $(\mathbf{7.6 \pm 3.1}) \times \mathbf{10^{-2}}$ with **high** statistical **significance** (**6.8σ**).
- This marks the beginning of a **new era of neutrino measurements** at the LHC, with a **wide physics program** including Heavy Flavor production, QCD, Lepton Flavor Universality and FIP searches.

BACKUP SLIDES

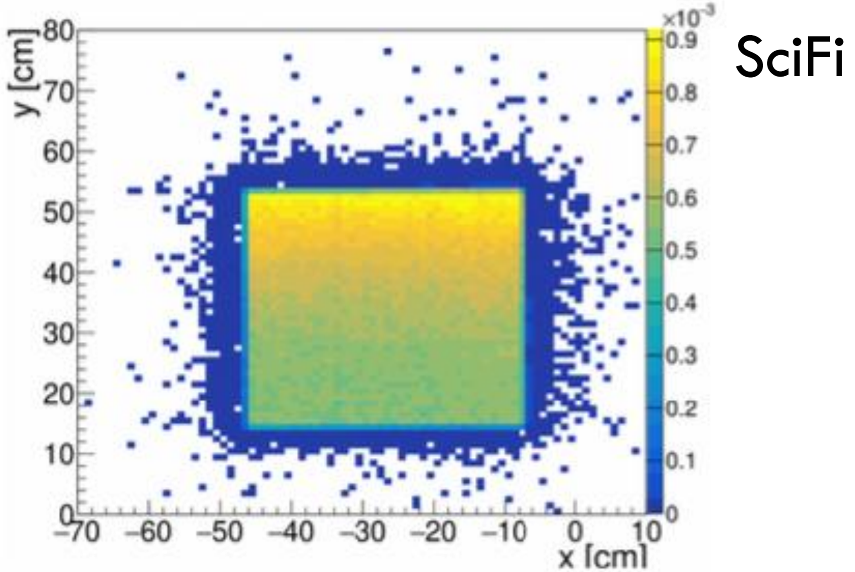
FIRST RESULTS: MUON NEUTRINO OBSERVATION

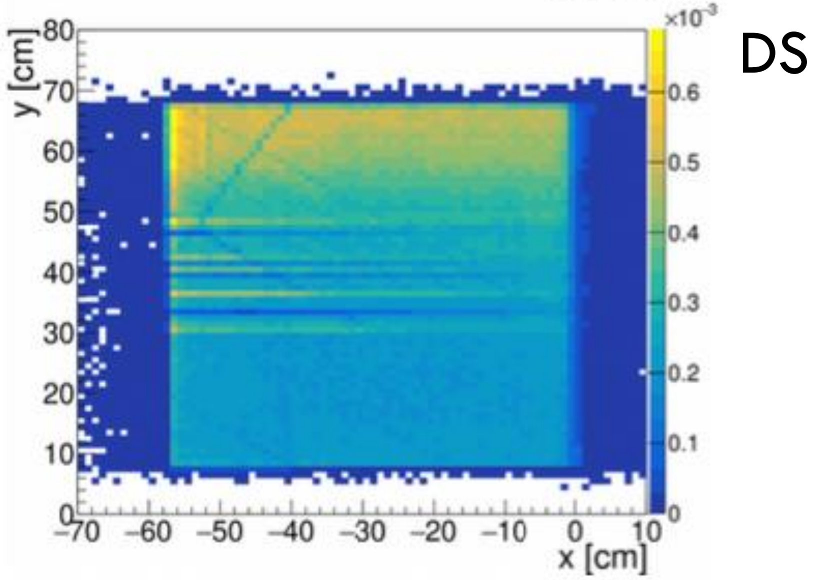
Muon flux measured using electronic detectors

- **SciFi**: **2.06 × 10^4** $cm^{-2}/\ \mathrm{fb}^{-1}$ (sys. uncert. **3%**).
- **Downstream Stations**: **2.35 × 10^4** $cm^{-2}/\ \mathrm{fb}^{-1}$ (sys. uncert. **5%**).
- Agreement between SciFi/DS: **2%.**

Agreement between data and MC at the level of **20 − 25%.**

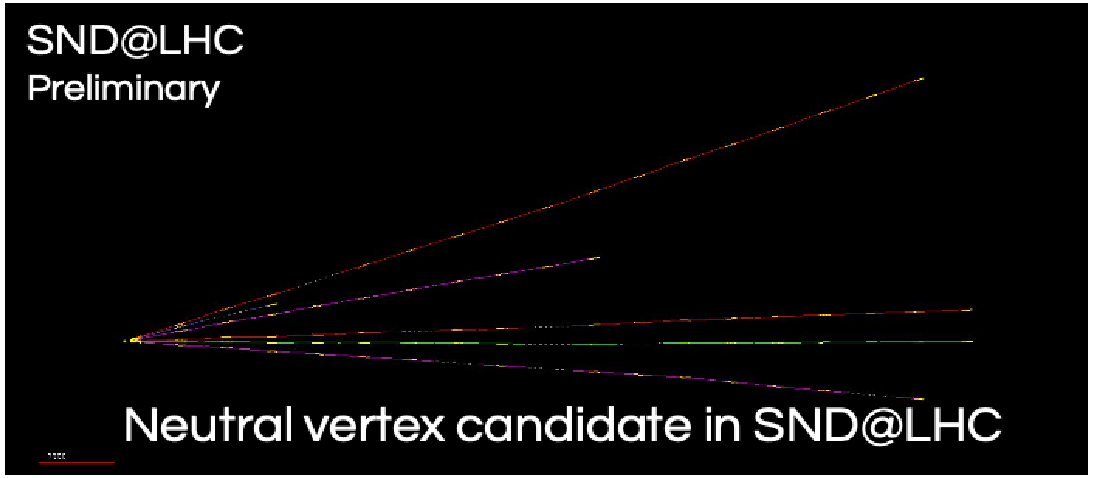
- **SciFi**: **1.60 × 10^4** $cm^{-2}/\ \mathrm{fb}^{-1}$.
- **Downstream Stations**: **1.79 × 10^4** $\mathrm{cm}^{-2}/\ \mathrm{fb}^{-1}$.

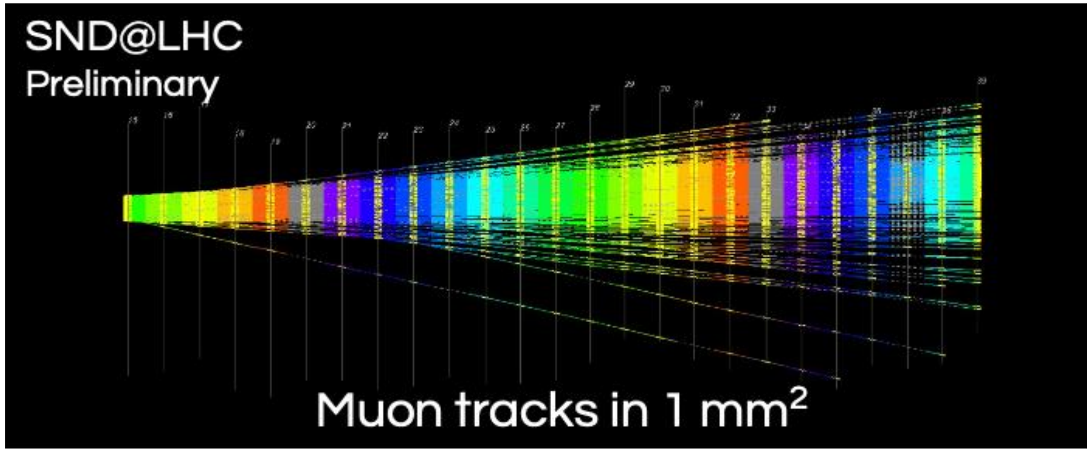


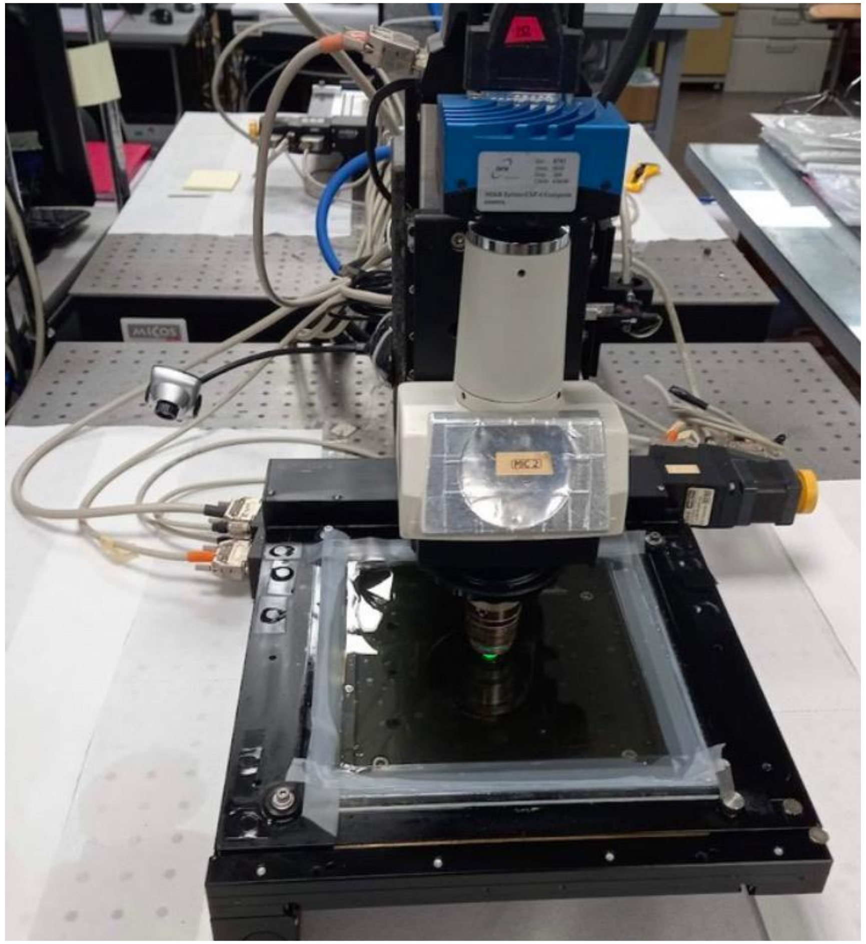


NUCLEAR EMULSIONS

The analysis of the emulsions data is currently ongoing.







Measured track density per 10 fb^{-1}: $\mathbf{10^5\ cm^{-2}}$.

EVENT RECONSTRUCTION

Trigger-less data acquisition and event reconstruction in two steps:

FIRST PHASE (ONLINE, ELECTRONIC DETECTORS)

- Identify signal candidates (neutrino or FIPs).
- Identify muons candidate (SciFi + Muon System).
- Energy measurement (SciFi + Muon System).

SECOND PHASE (OFFLINE, NUCLEAR EMULSIONS)

- Extract, develop, scan, and analyze the emulsion data.
- Reconstruct neutrino primary and secondary vertices.
- Matching between the emulsion and electronic detectors data (timestamp and Energy measurement).