INFN NAPOLI

LHC
Scattering and Neutrino Detector at the LHC

SND@LHC experiment at CERN

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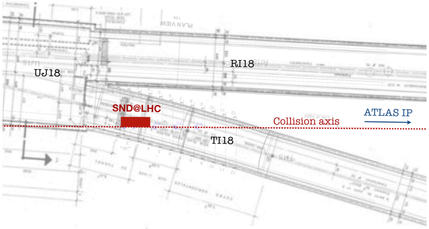
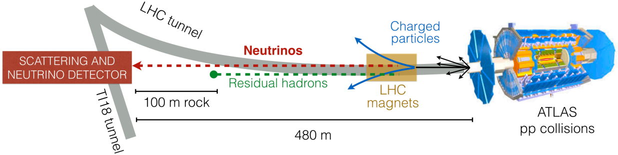
TeVPA 2023 — 14 Sept 2023

Location

- About 480 m away from the ATLAS IP in a former service tunnel, TI18
- Symmetric to TI12 tunnel where FASER is located



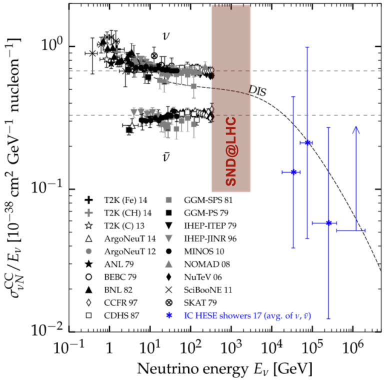


- Charged particles deflected by LHC magnets
- Shielding from the IP provided by 100 m rock
- Angular acceptance: $7.2 < \eta < 8.4$

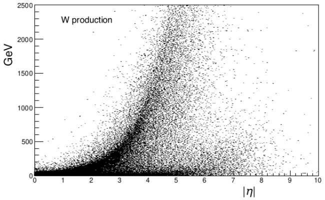
Neutrino physics at the LHC

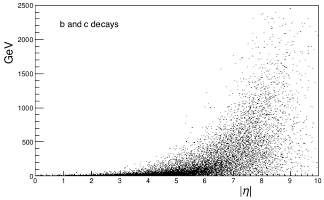
The LHC is a unique facility for the study of energetic neutrinos and for measuring $pp \to \nu X$ in an unexplored domain

PRL 122 (2019) 041101

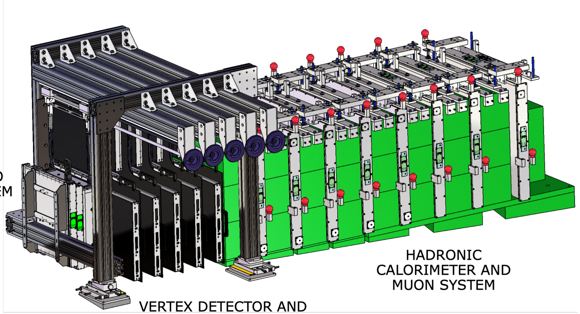


- XSEN [1804.04413]
- Physics potential of an experiment using LHC neutrinos [1903.06564]
- Further studies on the physics potential of an experiment using LHC neutrinos [2004.07828]





The SND@LHC experiment



Veto system:

- Tag penetrating muons using plastic scintillator

Vertex detector and EM calorimeter:

- Emulsion cloud chambers (Emulsion+Tungsten) for neutrino-interaction detection
- Scintillating fibers for timing information and energy measurement

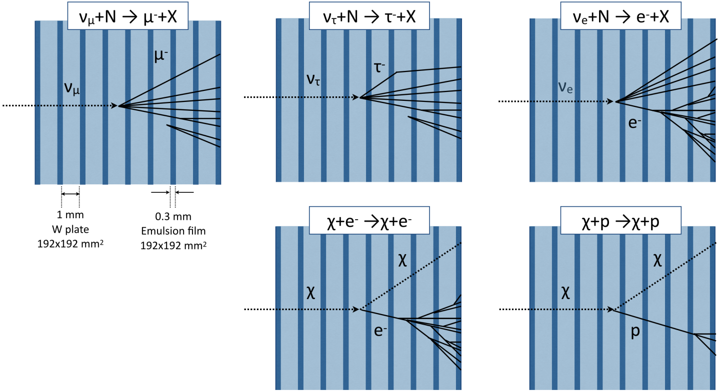
Hadronic calorimeter and muon system:

- Iron walls interleaved with plastic-scintillator planes for fast time resolution and energy measurement

Technical Proposal LHCC-P-016, detector paper arxiv:2210.02784 (to appear in JINST)

The vertex tracker

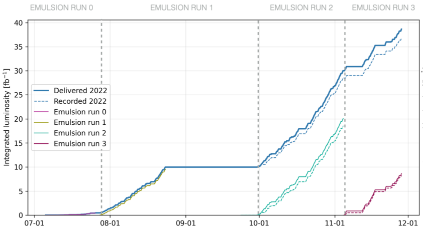
- 830 kg
- 390×390 mm^2
- Replacement every 25 fb^{-1} or three times a year
- SciFi tracker between walls measures showers and provides timing
- 2000 neutrino events expected in Run 3

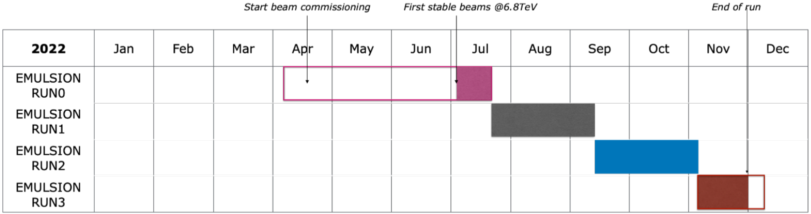


pp collision data in 2022

Successful data-taking since the beginning of Run 3

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



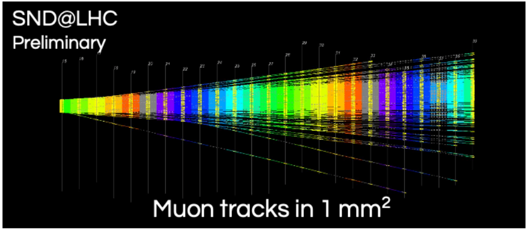


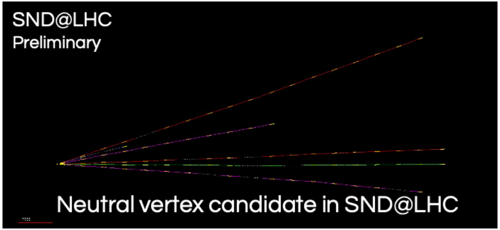
INSTRUMENTED TARGET MASS	INTEGRATED LUMINOSITY
39 kg	$0.46\ \mathrm{fb}^{-1}$
807 kg	$9.5\ \mathrm{fb}^{-1}$
784 kg	$20.0\ \mathrm{fb}^{-1}$
792 kg	$8.6\ \mathrm{fb}^{-1}$

Emulsion analysis

Emulsion analysis of 2022 data in full swing:

- Scanning at 4 different laboratories (+1 lab soon)
- Analysis progressing well





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

First results: Observation of collider muon neutrinos with the SND@LHC experiment

PRL 131 031802 (2023)

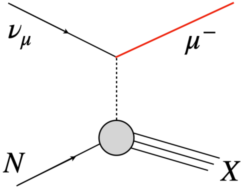
Analysis strategy

Search for ν_μ CC interactions in 2022 data using **only electronic detectors**

Analysis of 2022 dataset, corresponding to $36.8\ \text{fb}^{-1}$

- Expected signal yield ($\nu_\mu + \overline{\nu_\mu}$ interactions) : 157 ± 37
- Challenge: background from $\sim 10^9$ muons

$\rightarrow$ Very conservative selection to ensure pure signal sample



Selection

Fiducial Volume selection

- A Neutral vertex in the 3rd or 4th target walls
- Reject side-entering backgrounds

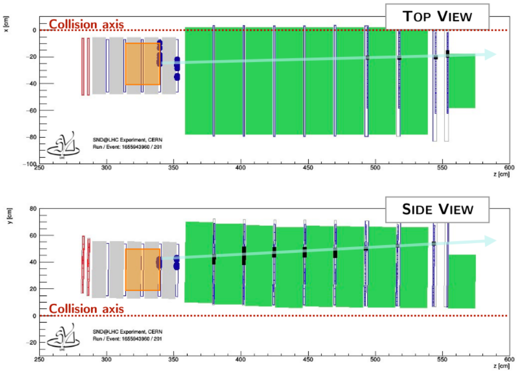
Signal acceptance: 7.5 %

Muon neutrino identification selection

- Large hadronic activity in SciFi and HCAL
- A reconstructed and isolated muon track

Signal selection efficiency: 36 %

ν_μ CC MC Simulation

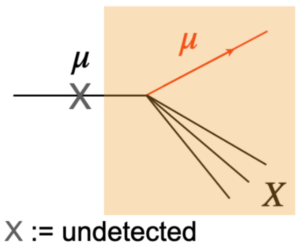


Total number of ν_μ CC events expected in $36.8\ \mathrm{fb}^{-1}$ after cuts: 4.2

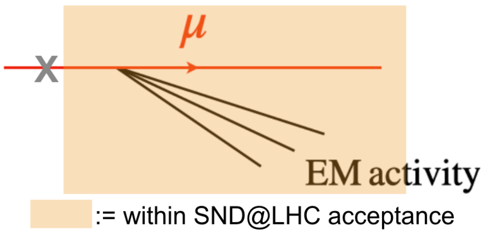
Entering muon background

Background due to muons being missed due to detector inefficiency

Muon DIS



Muon EM

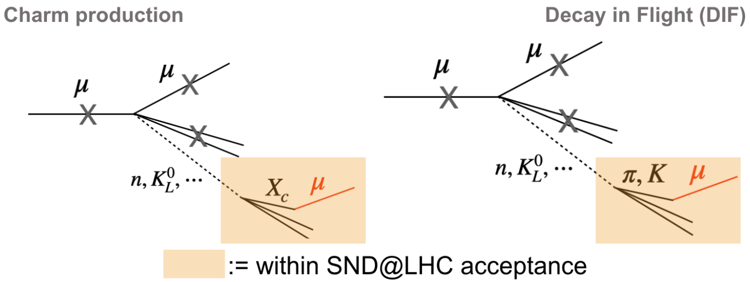


- Muons in acceptance: $N_\mu \sim 5 \times 10^8$ SNDLHC-NOTE-2023-001, paper forthcoming
- Detector inefficiency (two veto and two SciFi planes): 5×10^{-12}

→ COMPLETELY NEGLIGIBLE WITH APPLIED SELECTION

Neutral hadron background

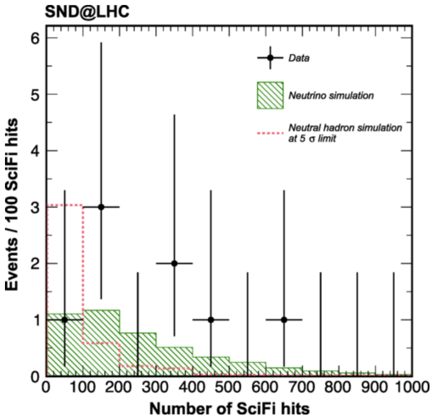
Neutral hadrons produced upstream of the detector by high energy muons



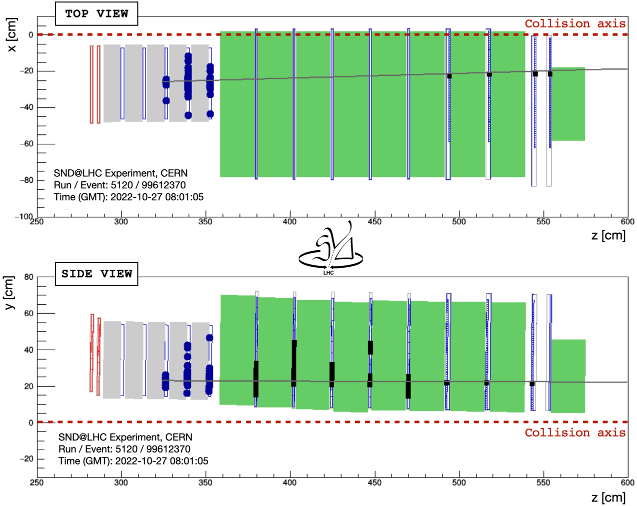
Total number of expected background events due to neutral hadrons: $(8.6 \pm 3.8) \times 10^{-2}$

Results

For more details, see PRL 131 031802 (2023)

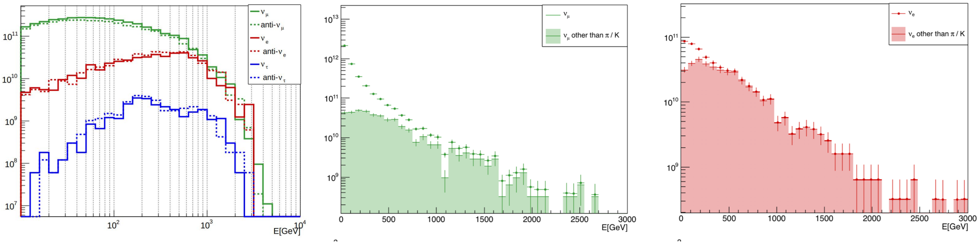


Observed 8 ν_μ CC candidates with a statistical significance of 6.8 σ



Lepton flavour universality (LFU)

SND@LHC can distinguish all three neutrino flavours and measure ratios $\frac{\nu_e}{\nu_\mu}$ and $\frac{\nu_e}{\nu_\tau}$



$$R_{e\mu} = \frac{1}{1 + \omega_{\pi,K}}$$

- Contamination fraction $\omega_{\pi,K}$ approximately constant above 600 GeV
- Measurement uncertainty of 10% stat. and 10% syst. expected

$$R_{e\tau} = \frac{\sum_i \tilde{f}_{c_i} \mathrm{BR}(c_i \to \nu_e)}{\tilde{f}_{D_s} \mathrm{BR}(D_s \to \nu_\tau)}$$

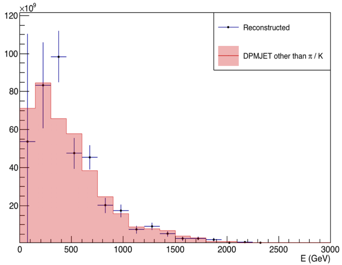
- Measurement uncertainty of 30% stat. and 22% syst. expected

Heavy flavour physics

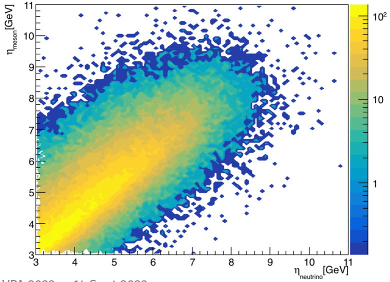
Due to the off-axis position, about 90% of $\nu_e + \overline{\nu_e}$ originate from charm decays

- Measurement of charm production at high pseudorapidity ($gg \to c\bar{c}$)
- Probe gluon PDF at low momentum fraction $x \sim 10^{-6}$.
  - Relevant for FCC detectors and
  - Extra-galactic neutrino observation (atmospheric neutrino background)

Neutrino origin



Charm and neutrino η

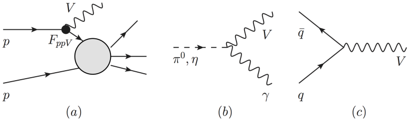


Scattering of light dark matter

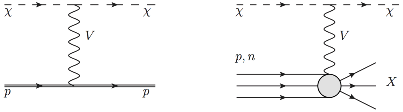
JHEP03(2022)006

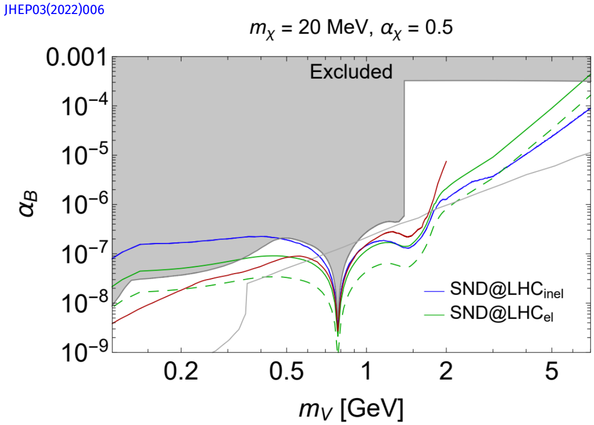
- Sensitivity model-dependent
- Considering as an example LDM coupled to the standard model via a leptophobic portal

Production



Detection





Direct searches for feebly interacting particles

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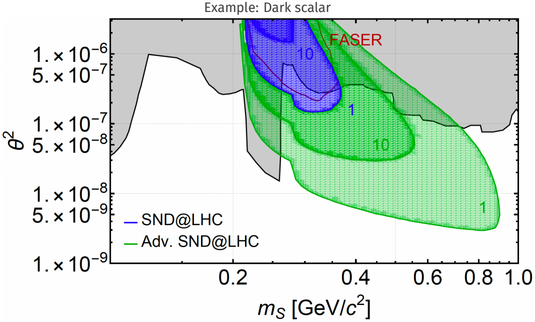


- Signature: Vertex with two charged tracks pointing back to IP

- Full background studies necessary
  - muon DIS
  - neutrino DIS
  - combinatorial
- Run 3: proof-of-concept, become competitive with AdvSND-far for Run 4
- Not (yet) taking into account AdvSND-near
  - Additional acceptance due to proximity to IP
  - AdvSND-near could benefit from reduced backgrounds off-axis

AdvSND

Upgrade of the detector in view of Run 4 using electronic vertex trackers

Two off-axis forward detectors:

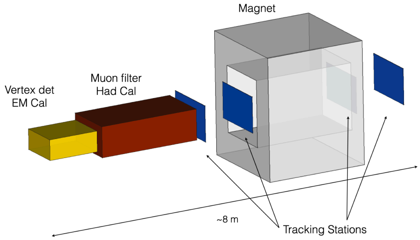
AdvSND-near: $4 < \eta < 5$

- Overlap with LHCb η coverage
- Reduction of systematic uncertainties
- Provide normalization

AdvSND-far: $7.2 < \eta < 8.4$

- Acceptance similar to SND@LHC
- Magnet for charge separation
- In TI18 or FPF

	AdvSND-near	AdvSND-far
η	$[4.0, 5.0]$	$[7.2, 8.4]$
mass [t]	5	5
surface [cm^2]	120×120	100×55
distance [m]	55	480 (FPF:630)



Conclusion

SND@LHC is a brand new experiment for neutrino physics and feebly interacting particle searches at the LHC

- Very successful datataking in 2022 with $36.8\ \mathrm{fb}^{-1}$ collected and an uptime of $\sim 95\%$, with $290\ \mathrm{fb}^{-1}$ in total expected in Run 3
- First result: **Observed muon neutrinos from the LHC with 2022 data**
- New detector at the LHC with a unique acceptance and technology:
  - Diverse physics programme for Run 3, with many measurements previously impossible at colliders
  - Even more versatile after upgrade for High Luminosity LHC

Stay tuned for first results from emulsions and much more!