SND@LHC Recent results and future prospects

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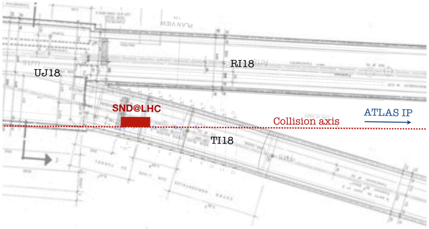
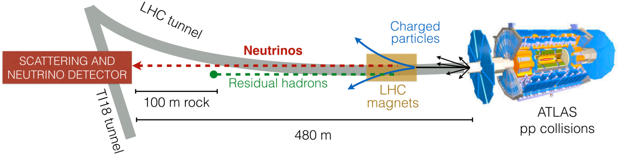
DPF-PHENO 2024 — 15 May 2024

Location

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



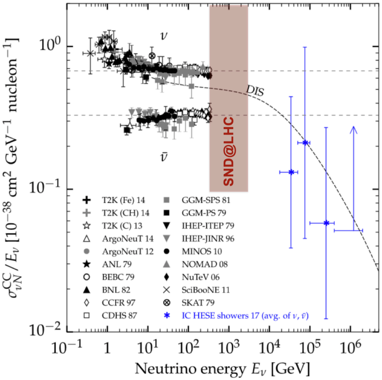


- Charged particles deflected by LHC magnets
- Shielding from the IP provided by 100 m rock
- Angular acceptance: $7.2 < \eta < 8.4$

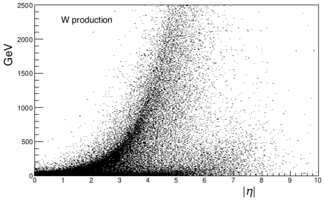
Neutrino physics at the LHC

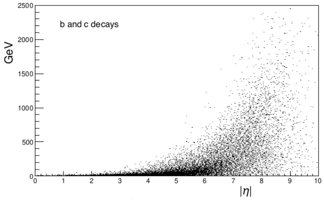
The LHC is a unique facility for the study of energetic neutrinos and for measuring $pp \to \nu X$ in an unexplored domain

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]



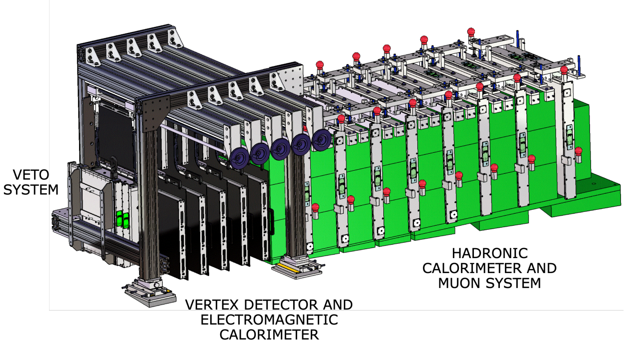


But also for the study of FIPs: JHEP03(2022)006

The SND@LHC experiment

Veto system:

- Tag penetrating muons using plastic scintillator
- **New in 2024:** 3rd plane added for improved coverage and efficiency



Vertex detector and EM calorimeter:

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

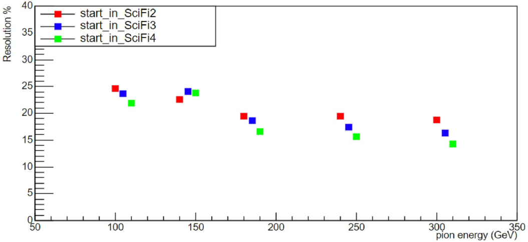
Hadronic calorimeter and muon system:

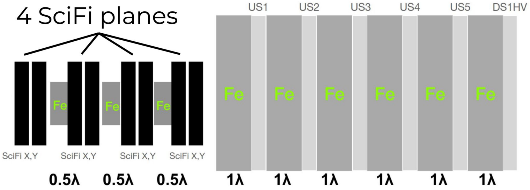
- Iron walls interleaved with plastic-scintillator planes for fast time resolution and energy measurement

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

Hadronic calorimeter test beam

- Very successful test beam data taking campaign in August 2023.
  - Exact replica of the hadron calorimeter.
  - Downsized mockup of the target with narrow beam spot
- Calibrated calorimeter response, confirming expected performance

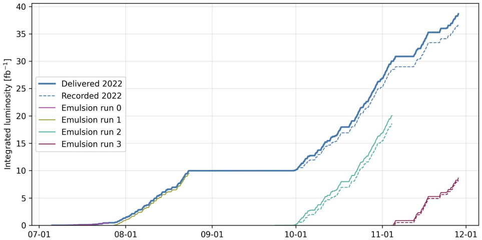


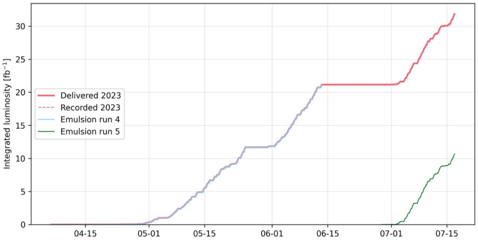


pp collision data

Successful data-taking since the beginning of Run 3

- Detector operation uptime $\sim 97\%$
- Total recorded luminosity: $68.6\ \mathrm{fb}^{-1}$ in 2022 and 2023 (and already $> 14\ \mathrm{fb}^{-1}$)
- Six emulsion replacements in 2022 and 2023 (limit exposure to $20\ \mathrm{fb}^{-1}$, equivalent to $< 4 \times 10^5\ \mathrm{tracks/cm}^2$)
- Dummy target for the LHC ion runs at the end of 2023

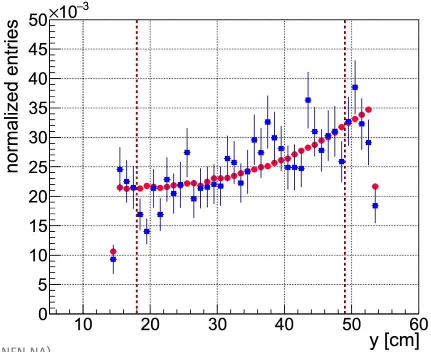


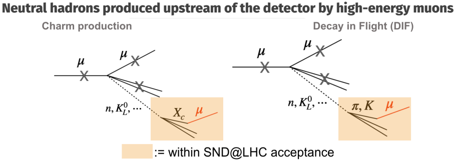


Muon flux measurement

Eur. Phys. J. C (2024) **84**: 90

- Backgrounds to neutrino signals in SND@LHC are mainly due to muon interactions in the tunnel walls.
- Precise measurements of the muon flux allow for validating and constraining our background model.





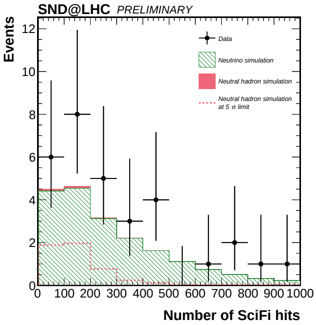
System	Muon flux $[10^4\ \mathrm{fb/cm^2}]$
SciFi	$2.06 \pm 0.01(\mathrm{stat.}) \pm 0.12(\mathrm{sys.})$
DS	$2.02 \pm 0.01(\mathrm{stat.}) \pm 0.08(\mathrm{sys.})$

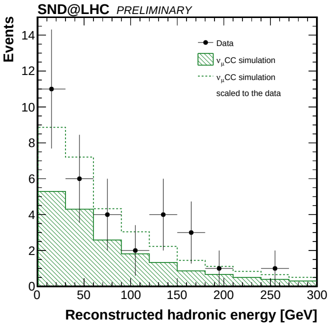
- Measurements with the SciFi tracker, downstream muon system and emulsion detectors give consistent results.

Muon neutrino observation update

Phys. Rev. Lett. 131, 031802: 8 muon neutrino candidates in 2022 data, at 6.8 σ

New this year: Add 2023 data and extend fiducial volume





Number of events expected in $68.6\ \text{fb}^{-1}$:

- Signal: 19.1 ± 4.1
- Neutral hadrons: 0.25 ± 0.06
- Kinematics in good agreement with simulation

Number of events observed: 32

Observation of 0μ neutrino events (ν_e CC + ν_{all} NC)

Neutral hadron background

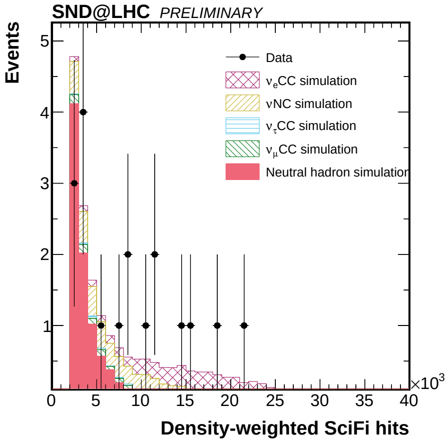
- Define background-dominated control region.
- Scale the background prediction to the number of observed events in the control region.
  - Observed neutral hadron background is 1/3 of the predicted value.
- Events expected in signal region: 0.01

Neutrino background

- Muon neutrino CC interactions expected: 0.12
- Tau neutrino CC (1μ) interactions expected: 0.002

0μ observation significance

- Total expected background: 0.20 ± 0.11 events
- Expected signal: 4.7 events
- Expected significance: 4.9 σ



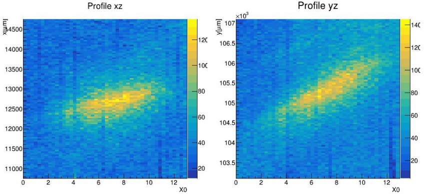
Signal region: $> 11 \times 10^3$

6 event observed ($5.8\ \sigma$)

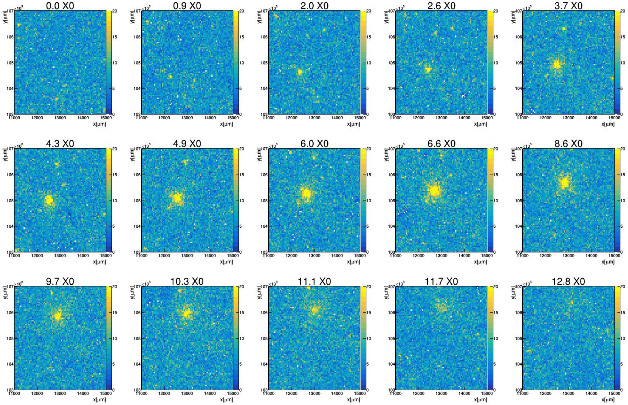
Paper in preparation

Search for ν_e CC interactions in the emulsion target

- Use track overdensities in subsequent plates to identify shower candidates
- Select shower profiles consistent with electromagnetic showers
- Match to reconstructed neutral vertices and showers seen in electronic detectors



Shower evolution ($4 \times 4\ \mathrm{mm}^2$)



Some promising candidates have been identified, full analysis ongoing

AdvSND

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

Two off-axis forward detectors:

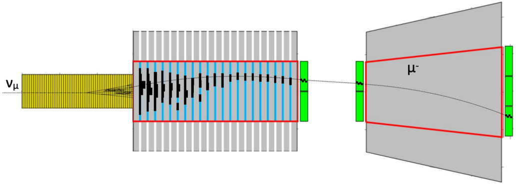
AdvSND-near: $4 < \eta < 5$

- Overlap with LHCb η coverage
- Reduction of systematic uncertainties
- Provide normalization
- After Run 4, Location TBD (UJ57?)

	SND@LHC	AdvSND-far
η	$[7.2, 8.4]$	> 7.9
mass [t]	0.6	2
neutrino yield	1.4×10^4	2.3×10^5

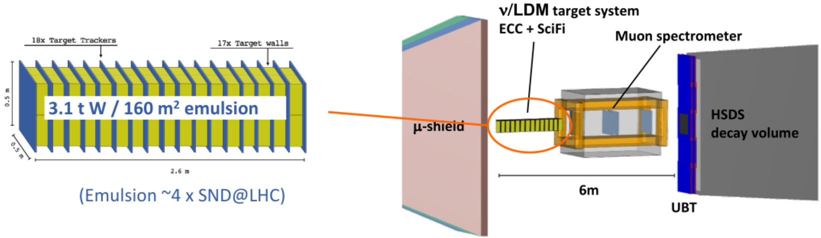
AdvSND-far: $7.9 < \eta$

- Acceptance similar to SND@LHC
- Magnet for charge separation
- In TI18 or FPF
- Run 4



SND@SHiP

- SND@LHC evolution of proposed subsystem of SHiP, now SND@LHC and AdvSND allow developing and perfecting technologies for SHiP



- Emulsion (SND@LHC-like) and Si options (AdvSND-like) under study
- SPS offers possibilities complementary to HL-LHC, lower energy and boost, space, large (anti-)neutrino yields (approx. $10^6\ \nu_e$, $10^7\ \nu_\mu$, $10^5\ \nu_\tau$)

Conclusion

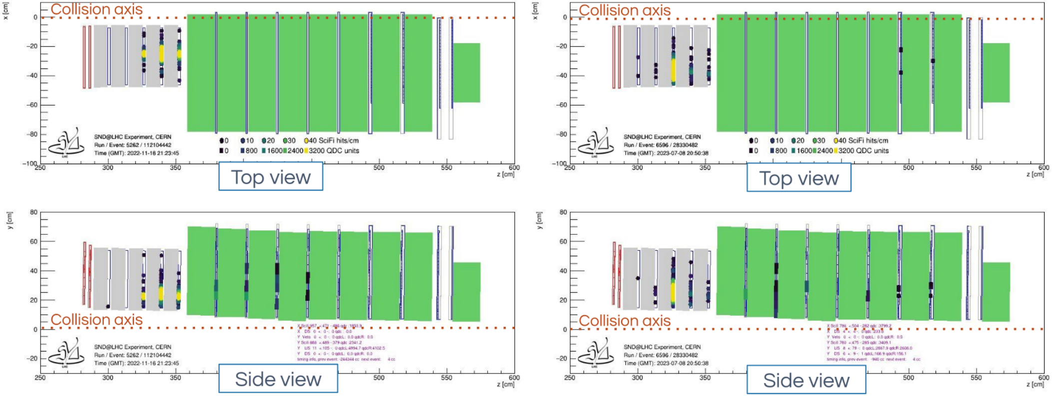
SND@LHC is a brand new experiment for neutrino physics and feebly interacting particle searches at the LHC

- Successful datataking in 2022 and 2023 with $68.6\ \mathrm{fb}^{-1}$ collected and an uptime of $\sim 97\%$, with $290\ \mathrm{fb}^{-1}$ in total expected in Run 3 (and already $> 14\ \mathrm{fb}^{-1}$ in 2024)
- Muon neutrino observation updated with refined selection and 2023 data
- Observation of shower-like neutrino events with electronic detectors, complementing electron-neutrino search in progress with emulsion data
- Upgrade for HL-LHC and SND@SHiP offer exciting prospects beyond Run 3
  - AdvSND LoI submitted to LHCC
  - SHiP (including SND@SHiP) approved for TDR

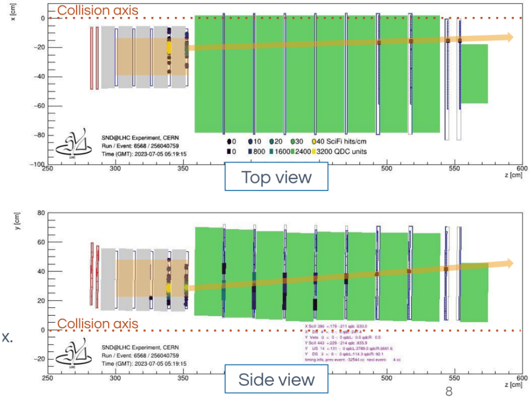
The next years will be exciting!

Backup

0μ candidates



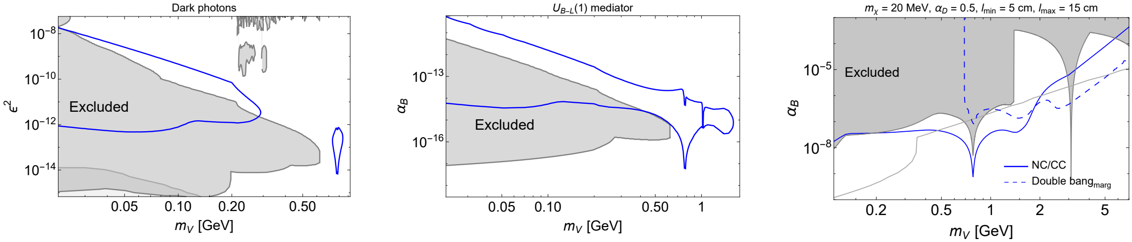
ν_μ candidate



- Fiducial volume shown in orange
- Original search excluded second and last wall, which were now added.
- Matching to emulsion data under study

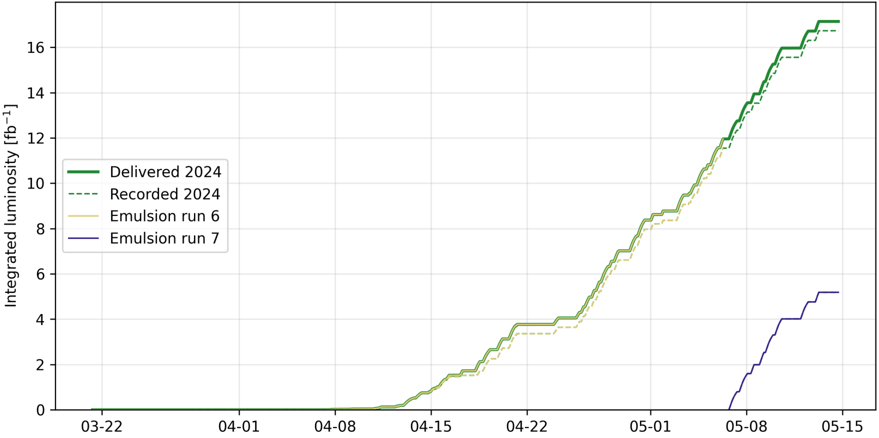
LDM/FIP sensitivities JHEP03(2022)006, AdvSND LoI

AdvSND can test a variety of models, with proof-of-concept measurements possible at SND@LHC



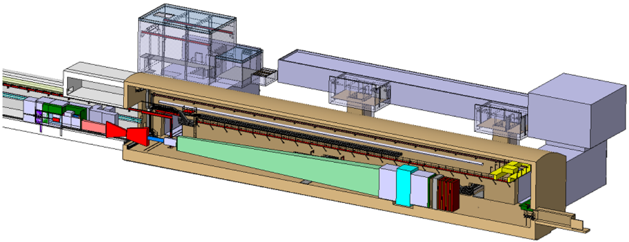
For SHiP sensitivities, see e.g. the BDF/SHiP@ECN3 proposal and references therein

2024 data



Integrated luminosity [fb^{-1}]
0
2
4
6
8
10
12
14
16
03-22
04-01
04-08
04-15
04-22
05-01
05-08
05-15
Delivered 2024
Recorded 2024
Emulsion run 6
Emulsion run 7

The beam dump facility



High intensity proton beam line: 4×10^{19} PoT per year for 15 years, with annually:

- 2×10^{17} charmed hadrons
- 1.4×10^{13} beautry hadrons
- 2×10^{15} tau leptons
- $\mathcal{O}(10^{20})$ photons above 100 MeV

Unprecendented samples of all neutrino flavours:

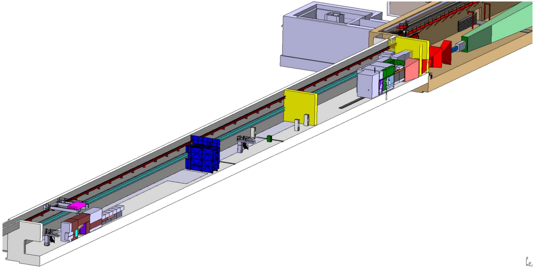
	<E> [GeV]	beam dump	<E> [GeV]	SND target acceptance	<E> [GeV]	CC DIS interactions
N_{ν_e}	6.3	4.1×10^{17}	30	1.3×10^{16}	63	2.8×10^{6}
N_{ν_μ}	2.6	5.4×10^{18}	8.4	1.5×10^{17}	40	8.0×10^{6}
N_{ν_τ}	9.0	2.6×10^{16}	22	1.0×10^{15}	54	8.8×10^{4}
$N_{\bar{\nu}_e}$	6.6	3.6×10^{17}	22	9.3×10^{15}	49	5.9×10^{5}
$N_{\bar{\nu}_\mu}$	2.8	3.4×10^{18}	6.8	1.2×10^{17}	33	1.8×10^{6}
$N_{\bar{\nu}_\tau}$	9.6	2.7×10^{16}	32	1.0×10^{15}	74	6.1×10^{4}

For muonic ν_τ, charge determination possible, precision $\bar{\nu}_\tau$ measurements!

Decay channel	ν_τ	$\overline{\nu}_\tau$
$\tau \to \mu$	4×10^3	3×10^3
$\tau \to h$	27×10^3	
$\tau \to 3h$	11×10^3	
$\tau \to e$	8×10^3	
total	53×10^3	

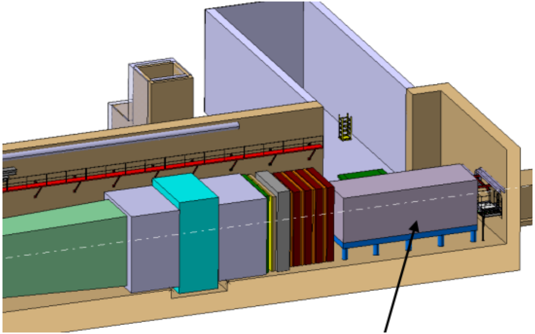
BDF beyond SHiP

Space for other experiments (by independent collaborations) upstream and downstream of SHiP



e.g. TauFV, skim % of protons

- Target complex also offers unprecedented neutron fluxes for materials and rad-hard electronics testing



e.g. LAr TPC for scattering studies, benefit from high signal fluxes, protected by the SHiP muon shield