



Chula
Chulalongkorn University



Scattering and Neutrino Detector
at the LHC

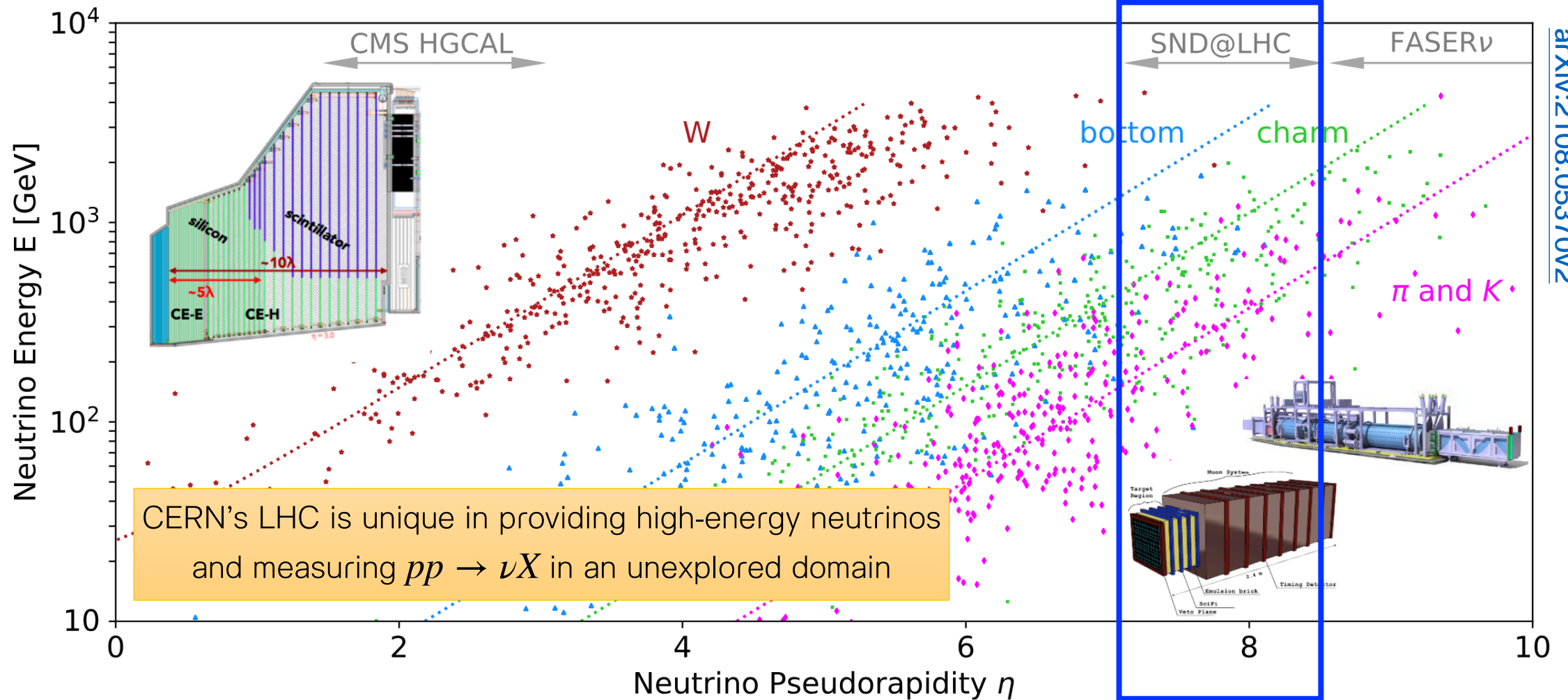
Recent results from the SND@LHC Experiment

FPCP 2024, 27 – 31 May 2024, Bangkok

Chayanit Asawatangtrakuldee (Chulalongkorn University)

on behalf of the SND@LHC Collaboration

High energy neutrinos from LHC pp collisions



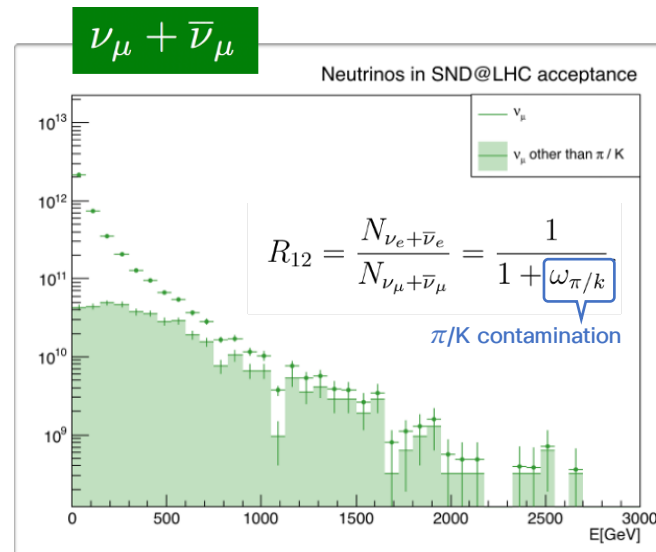
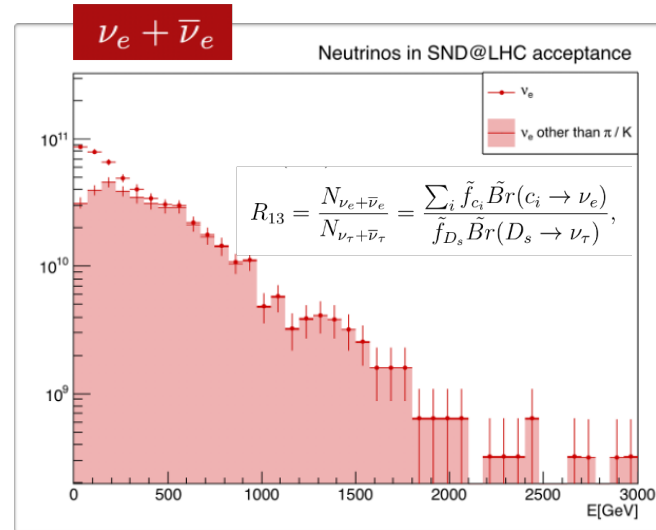
CERN's LHC is unique in providing high-energy neutrinos and measuring $pp \rightarrow \nu X$ in an unexplored domain

Lepton Flavor Universality

- Detection of all three types of neutrinos allows for tests of lepton flavor universality (LFU)

Heavy flavor physics

- 90 % of ν_μ and $\bar{\nu}_\mu$ produced at SND@LHC come from charmed hadron decays. This provides opportunities to:
 - Measure $pp \rightarrow \nu_e X$ cross section
 - Measure forward charm production with $\nu_e S$
 - Constrain gluon PDF at very **small** x



Recent results from the SND@LHC Experiment

Neutrino Interactions

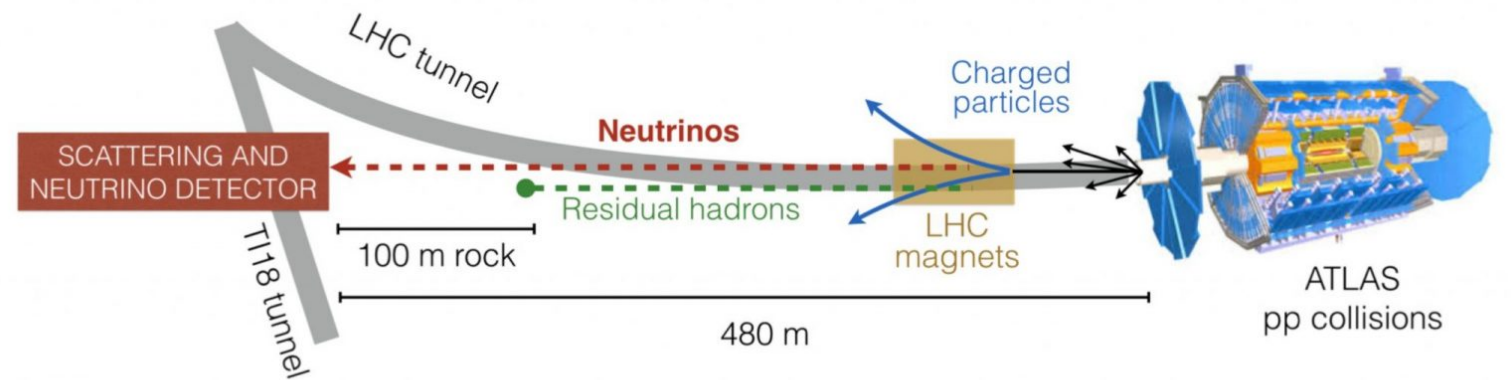
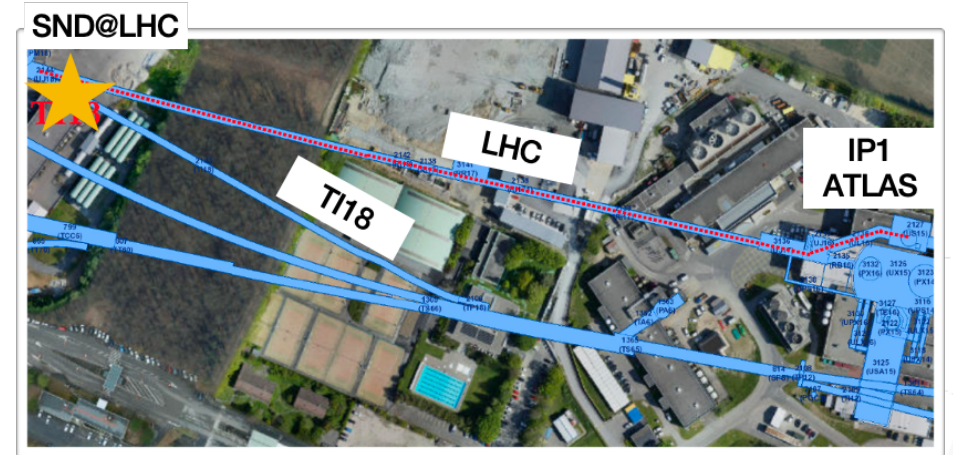
- Detect neutrino interactions in unexplored \sim **TeV** energy range
- Measure NC/CC ratio
- Yield of ν_τ will be more than double existing data
 - about 20 events observed by DONuT and OPERA

Beyond Standard Model

- SND@LHC experiment can probe into large variety of Beyond Standard Model (BSM) scenarios describing Hidden Sector

SND@LHC Location

- About 480 m away from the ATLAS IP in a former service tunnel, **T118**
- Symmetric to T112 tunnel where FASER is located
- Charged particles deflected by LHC magnets
- Shielding from the IP provided by 100 m rock
- Angular acceptance: $7.2 < \eta < 8.4$ (charm origin)





SND MID. RR

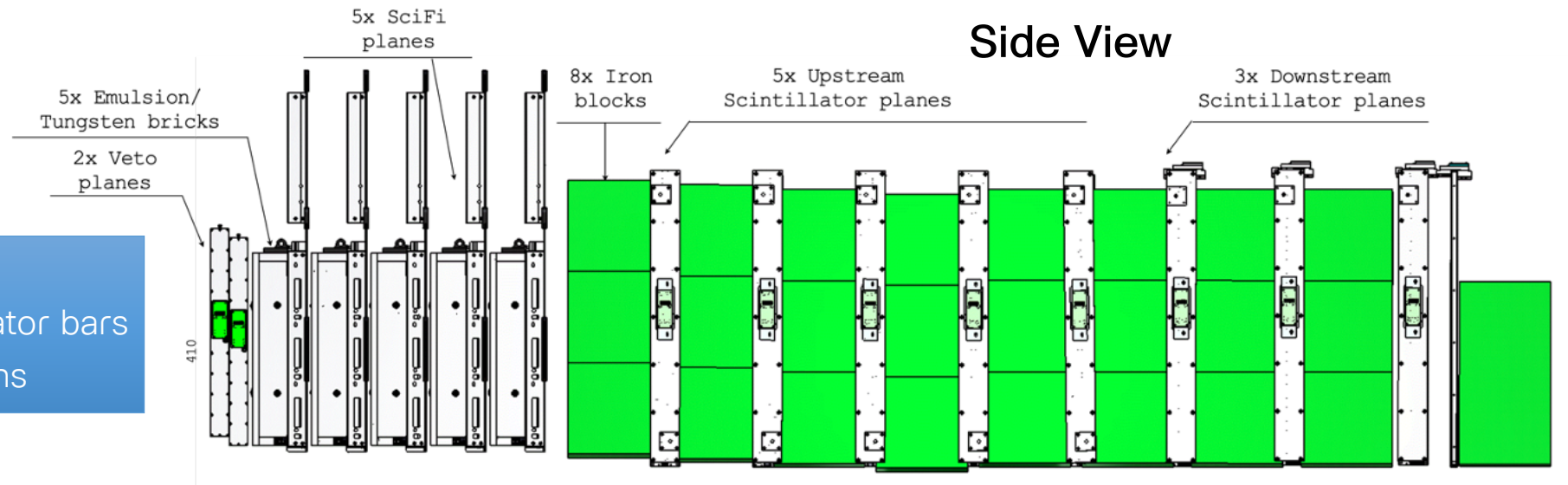
S

DS 3H

SND IRON 5.H

- **Hybrid detector** optimized for the identification of three neutrino flavors and for the detection of feebly interacting particles

[JINST 19 P05067](#)



VETO SYSTEM:

2+1 planes of stacked scintillator bars
to tag penetrating muons

VERTEX DETECTOR + ECAL:

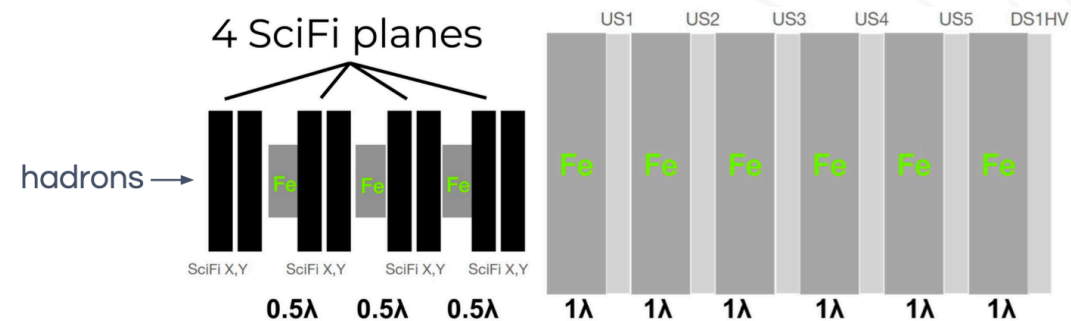
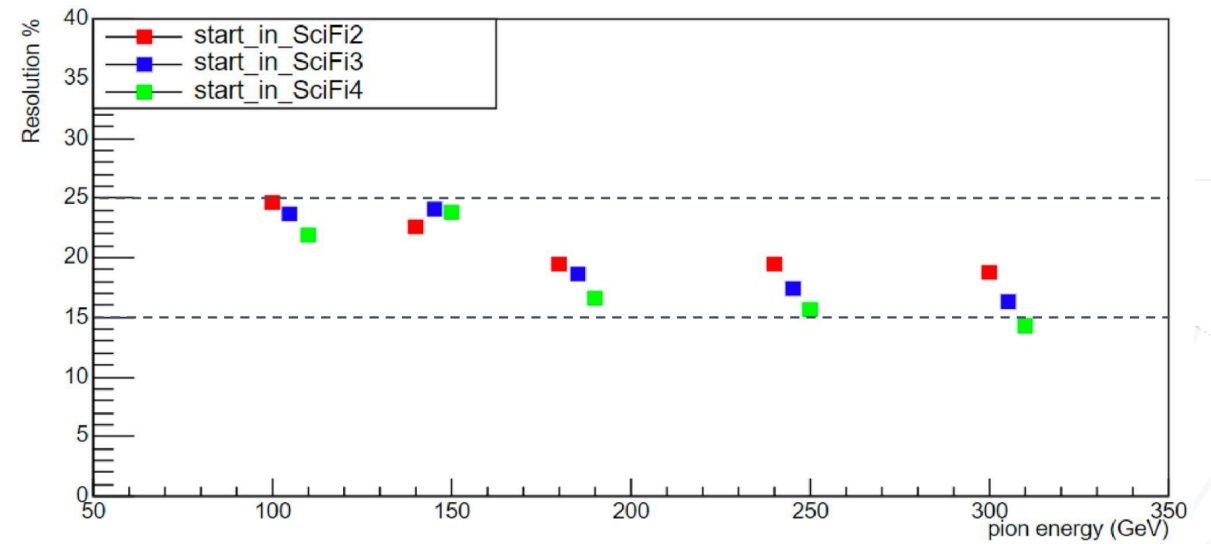
- Emulsion cloud chambers (Emulsion+Tungsten) for neutrino interaction detection
- Scintillating fibers (SciFi) for timing information and energy measurement

HCAL + MUON SYSTEM:

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

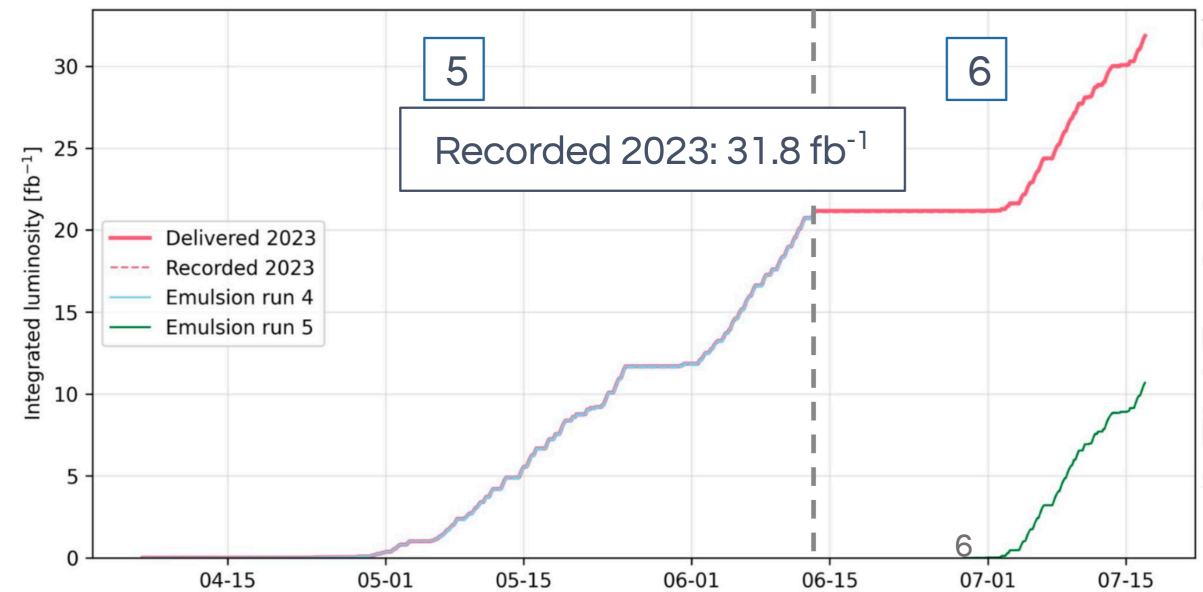
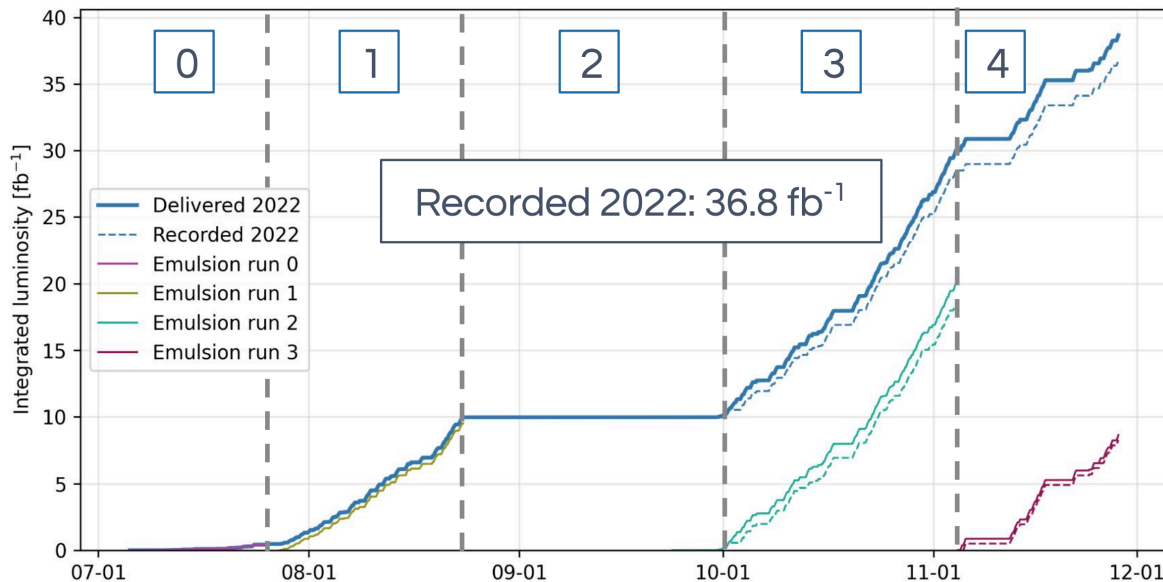
Hadronic Calorimeter Test Beam

- Very successful test beam data taking campaign in August 2023 (hadron beams from SPS)
 - Exact replica of HCAL with downsized mock up of the target for narrow beam spot
- Calibrated calorimeter response
 - Resolution of hadronic energy is within 15-25 %



Data Taking in pp Collisions

- **Successful** data-taking since the beginning of Run 3
 - Total recorded luminosity (2022 + 2023) **68.6 fb⁻¹**
 - Detector operation uptime of **97%**
- Six emulsion exchanges during 2022 + 2023 data taking
 - Aim to limit each exposure to **20 fb⁻¹**, equivalent to density of muon tracks < **4×10⁵ tracks/cm²**

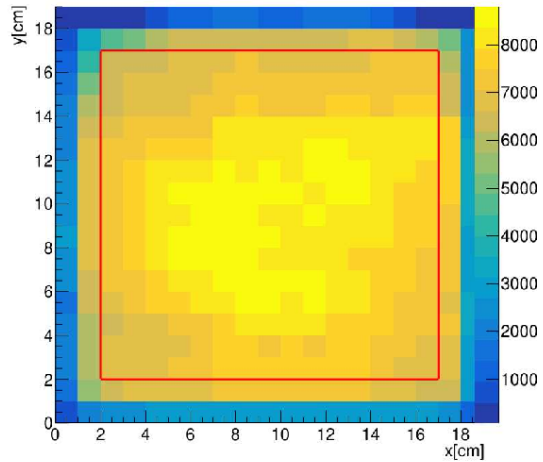


Measurement of Muon Flux at SND@LHC

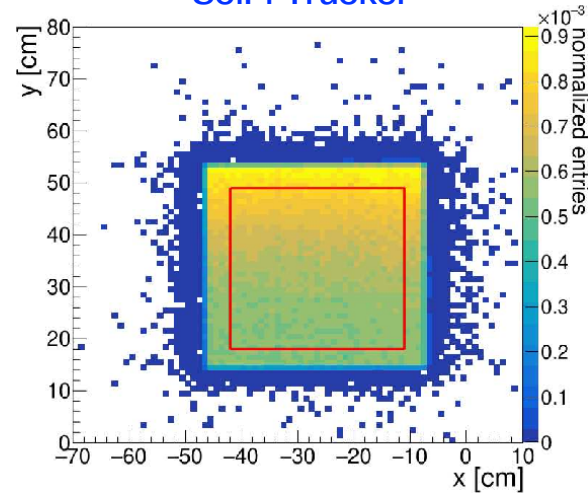
[Eur. Phys. J. C 84 \(2024\) 90](#)

- Muons from IP1 constitute the major background source for SND@LHC
- Precise measurements of muon flux allow for validating and constraining background model

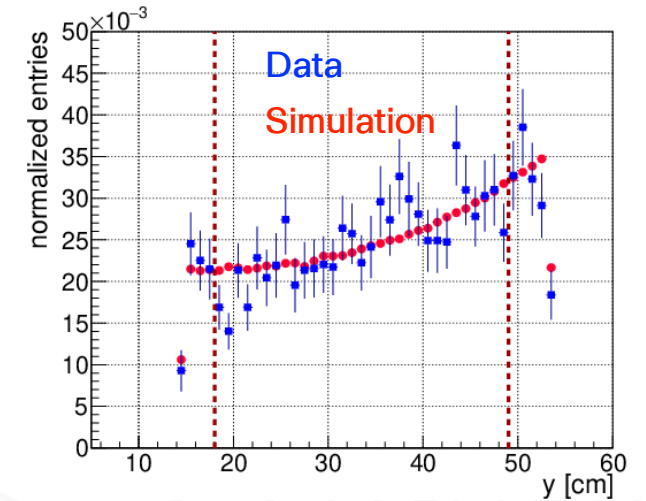
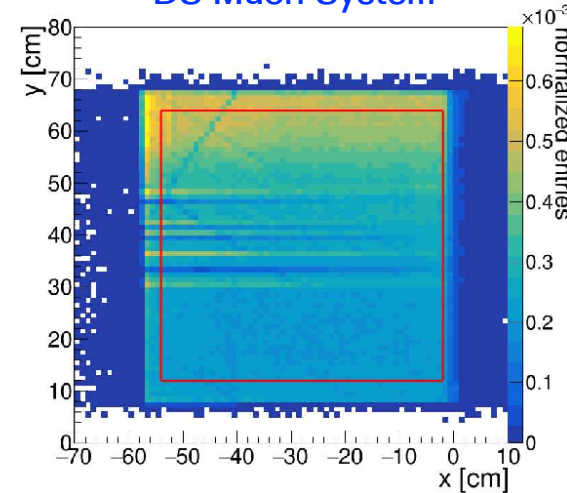
Emulsion Film



SciFi Tracker



DS Muon System

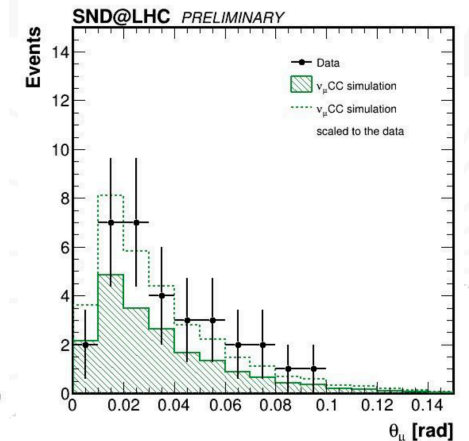
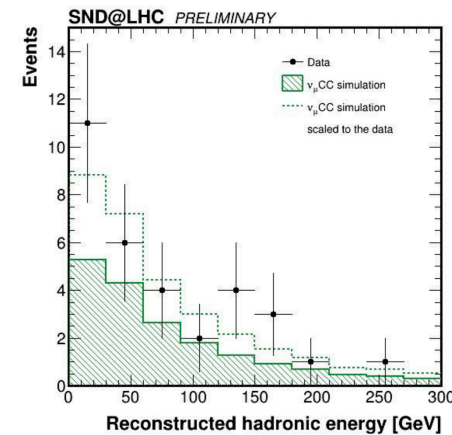
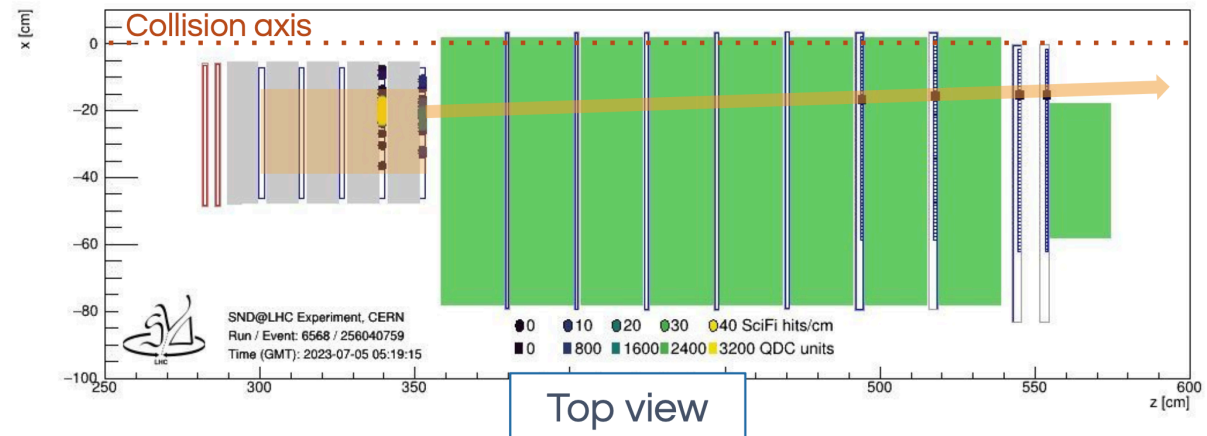


- Measurements with the SciFi tracker, DS muon system and Emulsion detectors give consistent results considering the same acceptance (2022)

System	Muon Flux [10^4 fb/cm ²]
ECC (18 x 18 cm ²)	1.5 ± 0.1 (stat.)
SciFi (31 x 31 cm ²)	2.06 ± 0.01 (stat.) ± 0.12 (syst.)
DS (52 x 52 cm ²)	2.35 ± 0.01 (stat.) ± 0.10 (syst.)

Updated Results of ν_μ Observation

- With 2022 data, first observation of 8 muon neutrino candidates at 6.8σ ([Phys.Rev.Lett.131,031802](#))
- **New today**: updated analysis with 2022 + 2033 data (68.6 fb^{-1}) and extended fiducial volume
- **Event selections** (updated from PRL)
 - **Fiducial volume**
 - Reject events in first wall (previously used only walls 3 and 4)
 - Reject side-entering backgrounds
 - Signal acceptance: 18% (from 7.5%)
 - **Muon neutrino identification**
 - Large scintillating fibre detector and HCAL activities
 - One muon track associated to the vertex.
 - Signal selection efficiency: 35%



	Neutral Hadrons	Signal	Observed
ν_μ CC	0.25 ± 0.06	19.1 ± 4.1	32 (12σ)

Observation of Shower-like (0μ) Events

- Signal: ν_e CC (+ ν_τ CC 0μ) and NC interactions

- Neutral hadron background

- Define background-dominated control region
- Scale to the number of observed events in the control region
 - observed neutral hadron background 1/3 of predicted value
- Expected events in signal region: 0.01

- Neutrino background

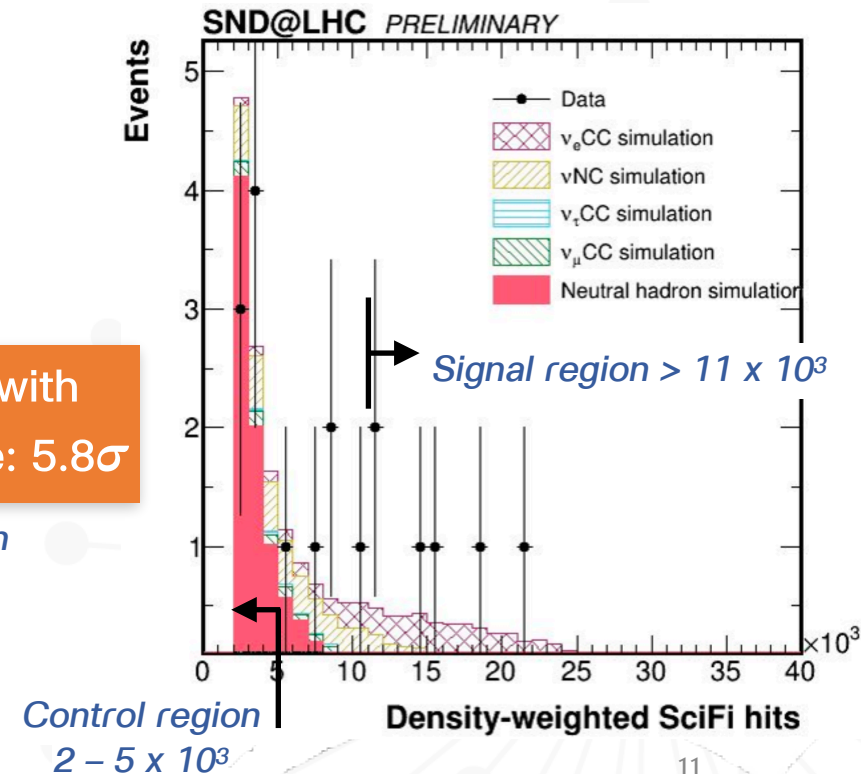
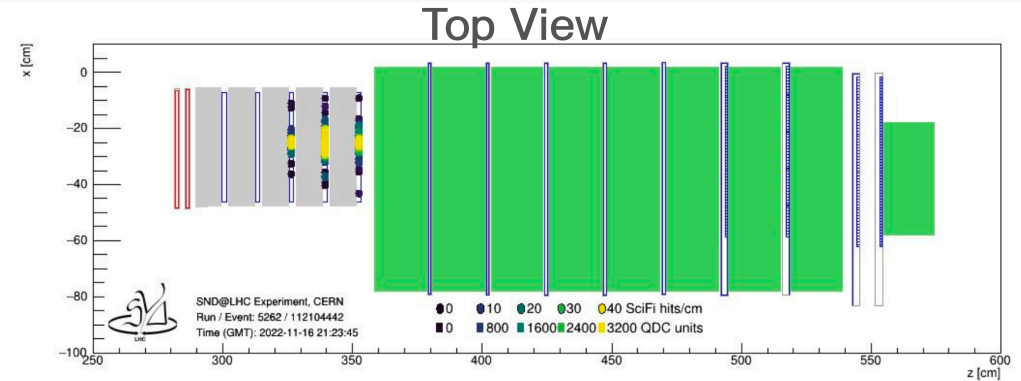
- ν_μ CC interactions (dominant) with 0.12 expected events
- ν_τ CC interactions expected: 0.07

- 0μ observation significance

- Total expected background: 0.20 ± 0.11 events
- Expected signal: 4.66 events and expected significance: 4.9σ

6 events observed with
observed significance: 5.8σ

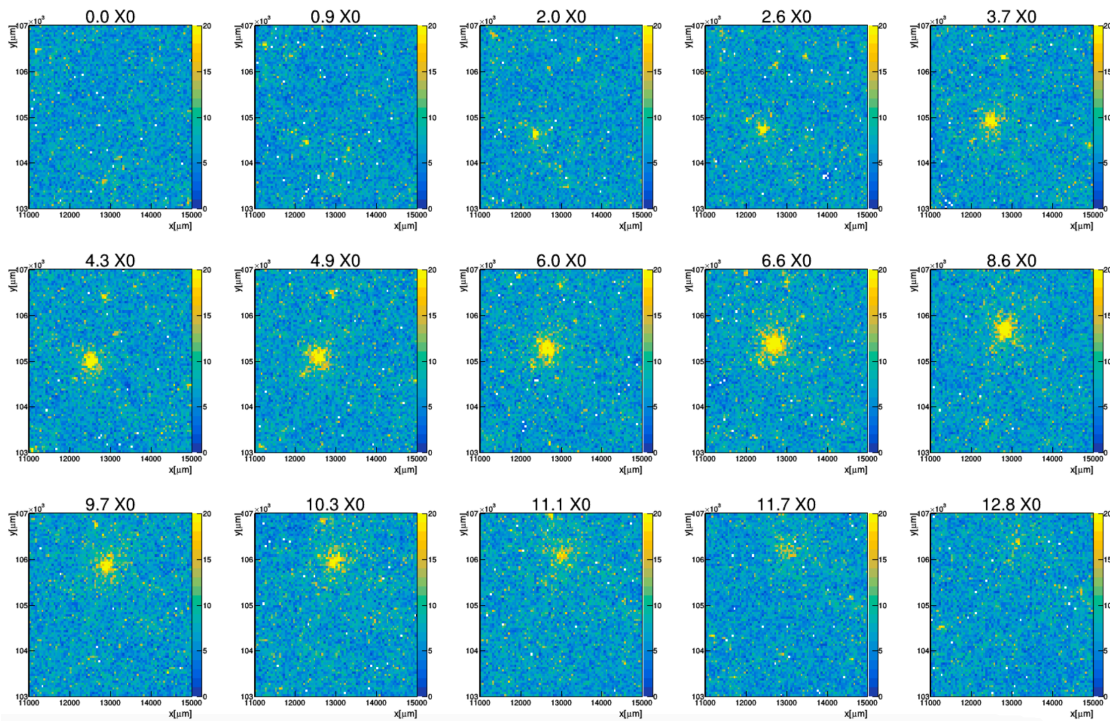
Paper in preparation



Ongoing Analyses

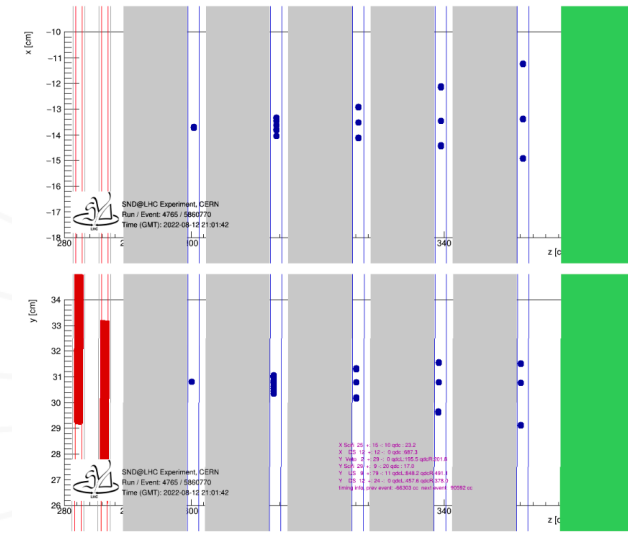
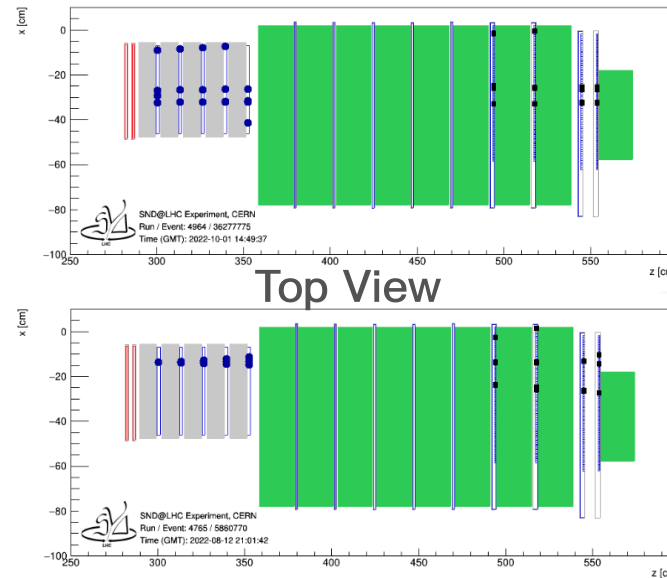
- Search for ν_e CC with emulsion data

- EM shower patterns identified, vertex association in progress



- Search for multi-muon (μ^3) events

- Three tracks almost in parallel or incoming tracks, vertex in the target, three outgoing tracks
- Possible explanations:
 - $\mu^\pm + N \rightarrow \mu^+ \mu^- \mu^\pm + N$ (genuine trident)
 - $\mu^\pm + N \rightarrow \mu^\pm + N + \gamma, \gamma + N \rightarrow N + \mu^+ \mu^-$ (muon brems followed by γ conversion)



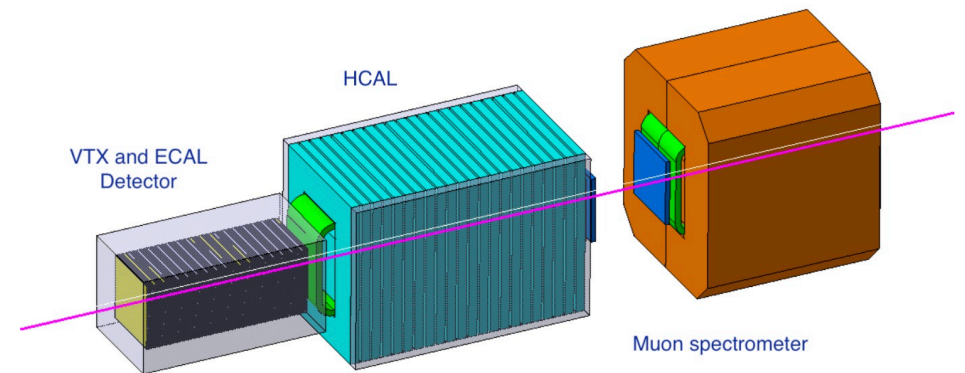
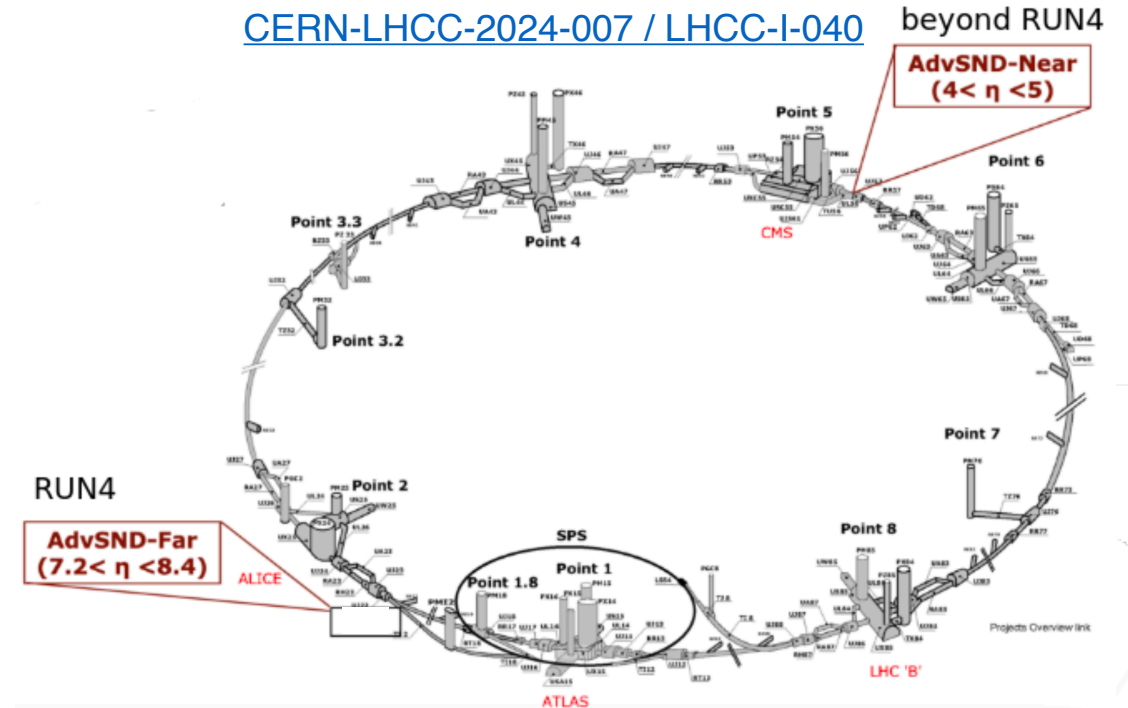
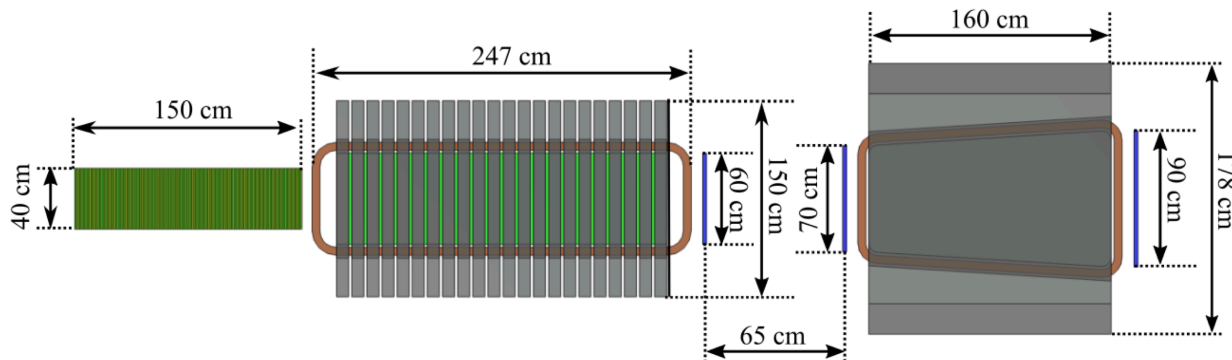
AdvSND beyond LHC Run 3

Run 4

- Electronic **vertex** detector with Si
- Iron-core muon spectrometer
- Improved HCAL and timing detectors

Beyond Run 4

- AdvSND-Near detector ($4 < \eta < 5$) to constrain systematic uncertainties in addition to AdvSND-Far detector ($7.2 < \eta < 8.4$) same range as the current detector



- Fruitful physics programs with **the SND@LHC** in the forward region of pp collisions
 - lepton flavor universality, charm production, neutrino interactions, etc.
- Measurement of muon flux results are consistent between electronic and emulsion detectors within the same acceptance
- Updated results of muon neutrino observation with 2022 + 2023 data and extended fiducial volume
 - 32 observed events with significance of 12σ
- First observation of shower-like (0μ) events with the SND@LHC at 5.8σ
- Many ongoing analyses and upgraded plan of the SND@LHC detector beyond Run 3