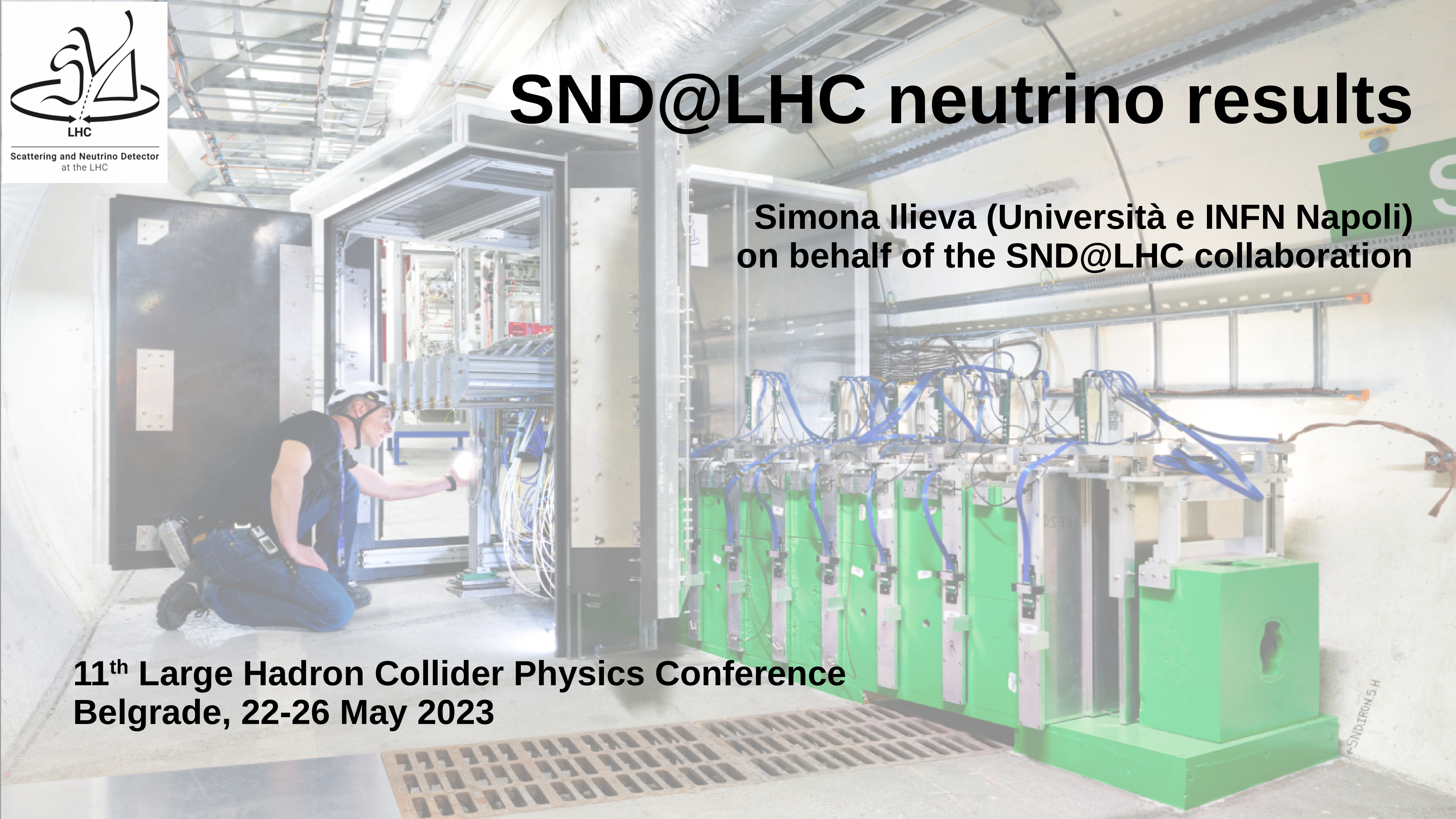


Scattering and Neutrino Detector at the LHC

SND@LHC neutrino results

Simona Ilieva (Università e INFN Napoli)
on behalf of the SND@LHC collaboration

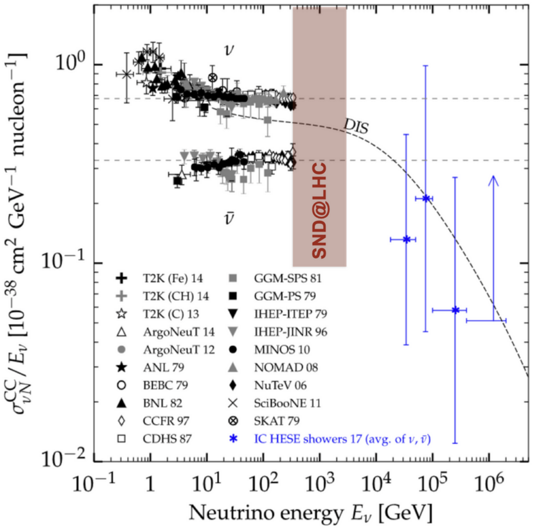
11th Large Hadron Collider Physics Conference
Belgrade, 22-26 May 2023

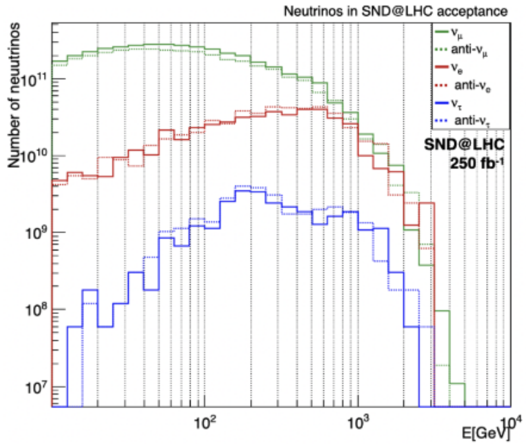
Neutrino experiments at the LHC

Potential of observing neutrinos at the LHC recognized in the early 90s

- Large neutrino fluxes in forward region from pp collisions
- High ν energy: E_ν [10^2 - 10^3] GeV, $\sigma_\nu \propto E_\nu$
- A small-scale LHC experiment can observe neutrinos of all three types
- Probe pp → νX in an unexplored energy domain

PRL 122 (2019) 041101



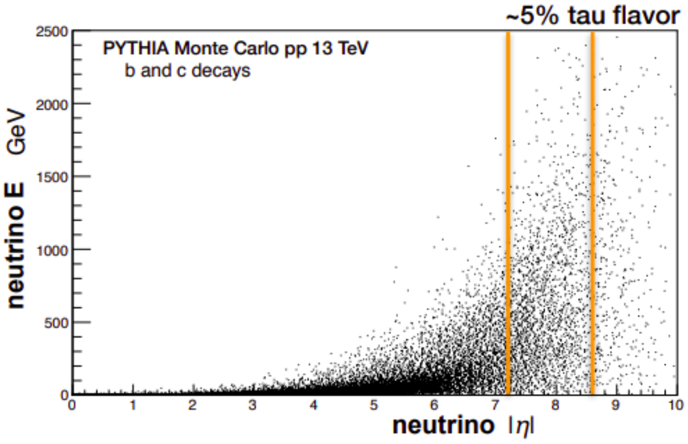


- Two experiments presently operating
  - FASERν on-axis (η>9) [T. Boeckh talk]
  - SND@LHC slightly off-axis (7.2 <η< 8.4)

SND@LHC physics programme

SND@LHC TP: LHCC-P-016

- Measure charm production at high η
  - Neutrinos in the detector acceptance are mostly coming from charmed hadrons decay
    J. Phys. G: Nucl. Part. Phys. 47 125004
- ν_e as a probe of forward charm quark production
  - constrain gluon PDF at very low momentum fraction ($x \sim 10^{-6}$)
- Lepton universality test: ν_τ/ν_e and ν_μ/ν_e
  - The detector is designed to distinguish all neutrino flavours
- Measurement of the NC/CC ratio
- Direct search for feebly interacting particles (FIP) through their scattering

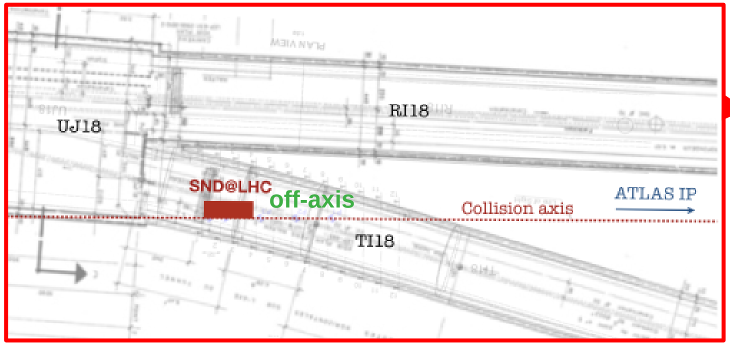


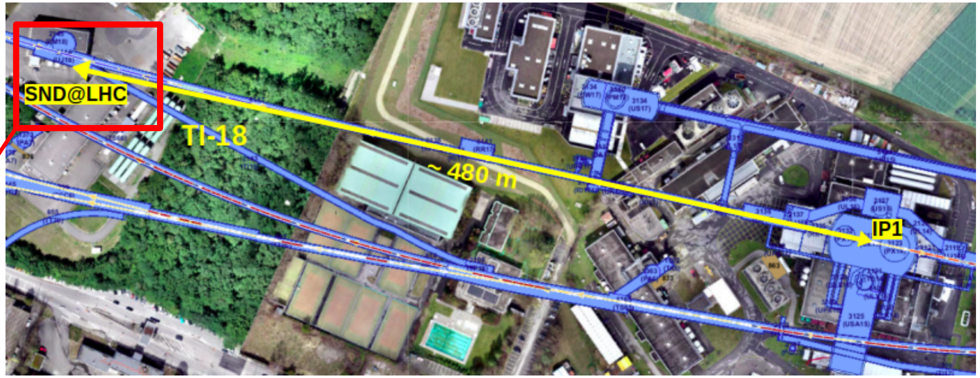
Run3: 250fb^{-1}

Flavour	Neutrinos in acceptance ⟨E⟩ [GeV]	Neutrinos in acceptance Yield	CC neutrino interactions ⟨E⟩ [GeV]	CC neutrino interactions Yield
ν_μ	130	3.0×10^{12}	452	910
$\bar{\nu}_\mu$	133	2.6×10^{12}	485	360
ν_e	339	3.4×10^{11}	760	250
$\bar{\nu}_e$	363	3.8×10^{11}	680	140
ν_τ	415	2.4×10^{10}	740	20
$\bar{\nu}_\tau$	380	2.7×10^{10}	740	10
TOT		4.0×10^{12}		1690

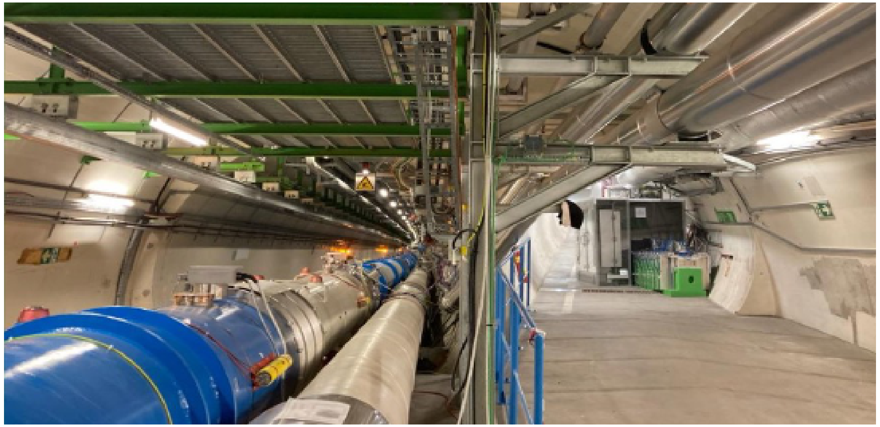
Detector location

- In the TI18 tunnel
  - former SPS to LEP transfer line
- ~ 480m away from ATLAS interaction point(IP1)





Machine to IP1(left) - SND@LHC in TI18(right)



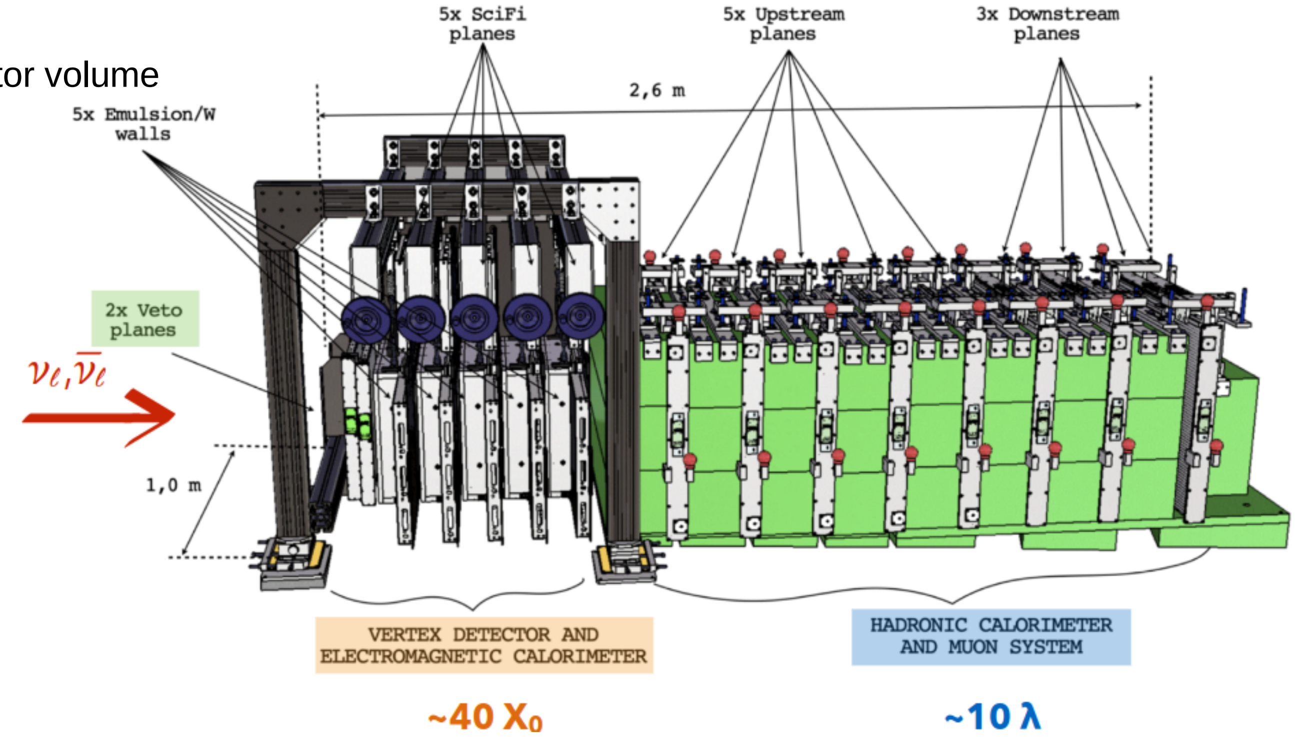
- Shielded by:
  - ~ 100m rock
  - LHC magnets deflecting charged particles
- Angular acceptance $7.2 < \eta < 8.4$

Detector concept

- Hybrid detector design
- Optimized for the identification of three ν flavours and feebly interacting particles.

arXiv:2210.02784

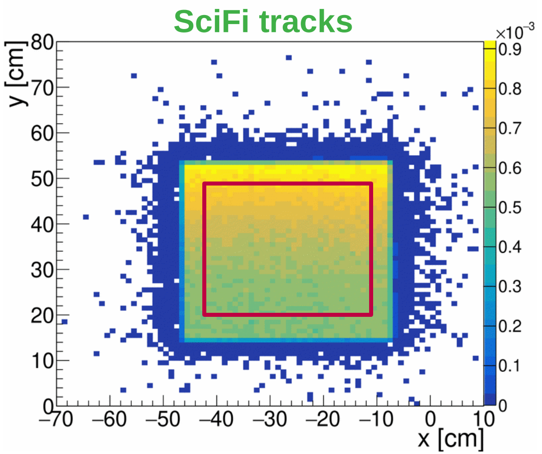
- **Veto system**
  - 2 planes of stacked scintillator bars
  - tag charged particles entering the detector volume
- **Vertex detector + EM CAL**
  - Emulsion cloud chambers(emulsion/W)
    - neutrino target mass ~830kg
  - Scintillating fiber planes
- **HAD CAL + MUON ID SYSTEM**
  - 5+3 plastic scintillator planes interchanged with iron walls

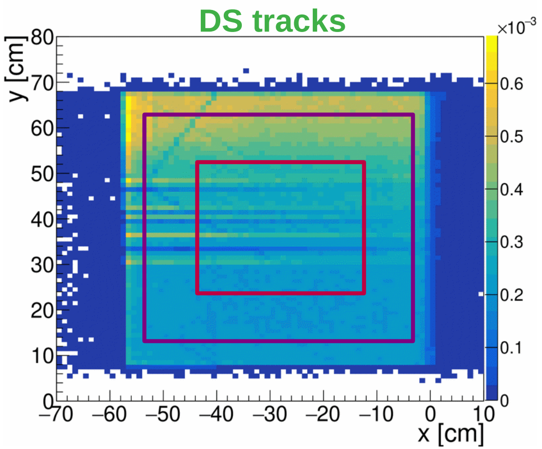


Muon flux

SNDLHC-NOTE-2023-001

- Using data from SciFi and DS detectors, the muon flux is
  - **SciFi**: 2.06×10^4 cm^{-2}/fb^{-1} area: $31x31cm^2$
  - **DS**: 2.35×10^4 cm^{-2}/fb^{-1} area: $52x52cm^2$
    - Vertical flux gradient
  - 2% deviation of SciFi and DS fluxes in the same acceptance range ($31x31cm^2$)
    - while systematic error is 3%(SciFi) and 5%(DS) on muon flux per detector
  - data/MC simulation agreement level 20-25%
    - MC sim.: **SciFi**: 1.60×10^4 cm^{-2}/fb^{-1} area: $31x31cm^2$
    - MC sim.: **DS**: 1.79×10^4 cm^{-2}/fb^{-1} area: $52x52cm^2$
  - Providing feedback to CERN SY-STI team for the FLUKA simulation
    - In return, SND@LHC collaboration is provided with updated simulation samples

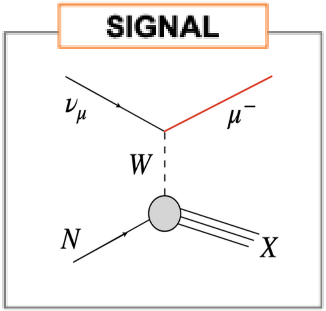


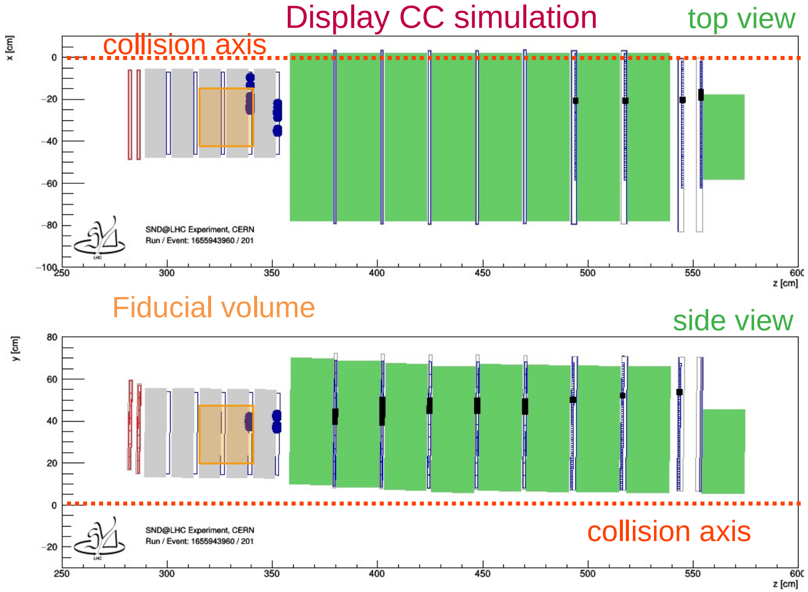


Observation of ν_μ using electronic detectors

arXiv:2305.09383

- Goal: high-purity sample of ν_μ charged current interaction (CC) events
- Analysis strategy:
  - Maximase signal/background ratio
    - Background: ~10^9 μ events
    - Strong rejection power needed
- Dataset: full 2022 run, 36.8 fb^{-1}



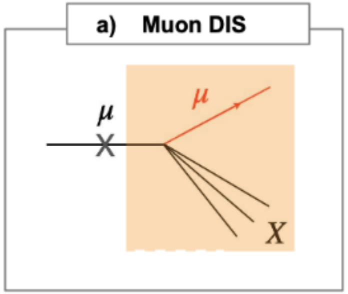


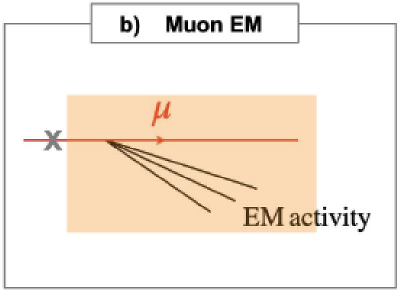
- Signal selection:
  - *Fiducial volume cut* : reject charged particles entering from the front and sides of the detector
    - Detector activity starts in the 3rd or 4th target wall
      - consistent with a neutral particle interaction
      - probing the ν_μ-induced shower already in SciFi
    - Detector activity is constrained in an inner XY detector region, size 25×26 cm^2
    - Efficiency of this cut on simulated neutrino interactions in the target is 7.5%
  - *Neutrino interaction ID*
    - Large hadronic activity in the calorimetric system (SciFi and HCAL)
    - Isolated outgoing muon track reconstructed in the Muon Identification system
    - Hit time consistent with an event originating from the IP1 direction

Background assesment

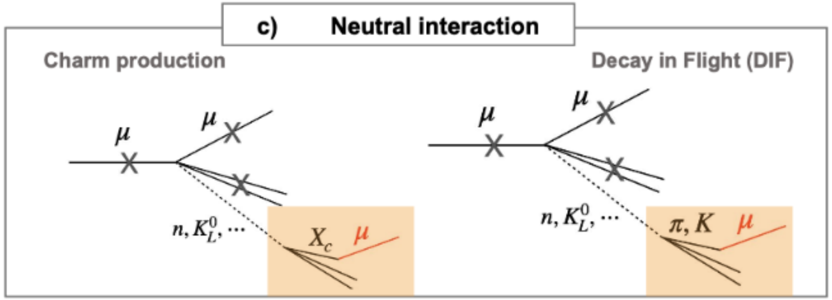
arXiv:2305.09383

- Muons reaching the detector location
  - Not vetoed, generate showers(bremsstrahlung, DIS in the detector) **(a,b)** – using the data
  - Interact in the surrounding material to produce neutral particles which can then mimic neutrino interactions in the target **(c)** – rely on simulations





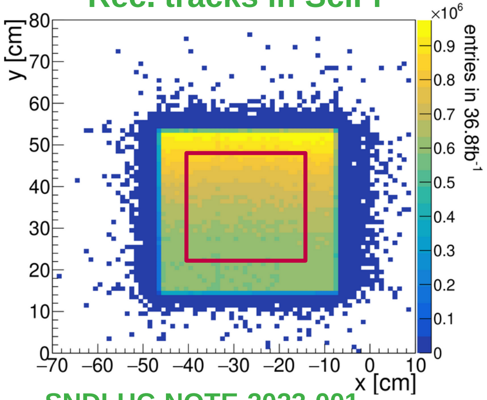
X = undetected
= in detector volume



$$N^{\text{bkg}}_{\text{neutrals}} = N_{\text{neutrals}} \times P_{\text{inel}} \times \epsilon_{\text{sel}}$$

$= (7.6 \pm 3.1) \times 10^{-2}$

Rec. tracks in SciFi



SNDLHC-NOTE-2023-001

~5.0x10^8 ~5.3x10^-12

$$N_\mu^{bkg} = N_\mu \times (1-\epsilon_{Veto}) \times (1-\epsilon_{SciFi1}) \times (1-\epsilon_{SciFi2}) = 3 \times 10^{-3}$$

Total number of muons in target acceptance

Veto inefficiency

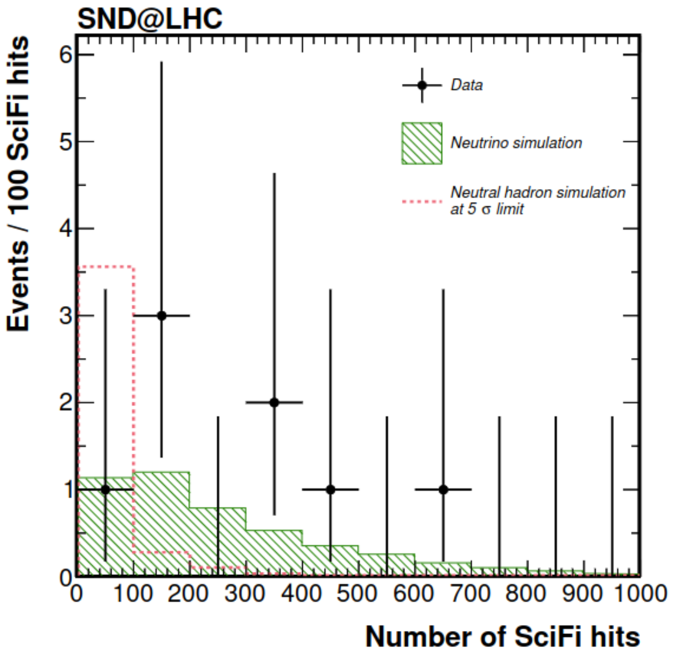
SciFi plane inefficiency

deemed negligible

Observation of ν_μ using electronic detectors

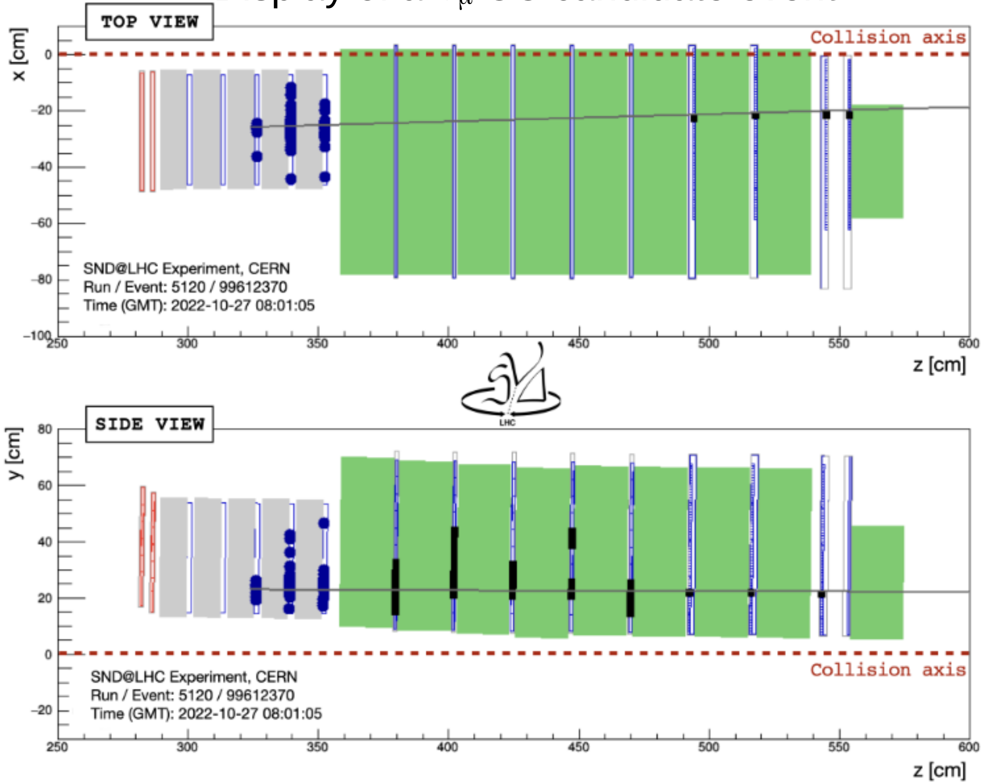
arXiv:2305.09383

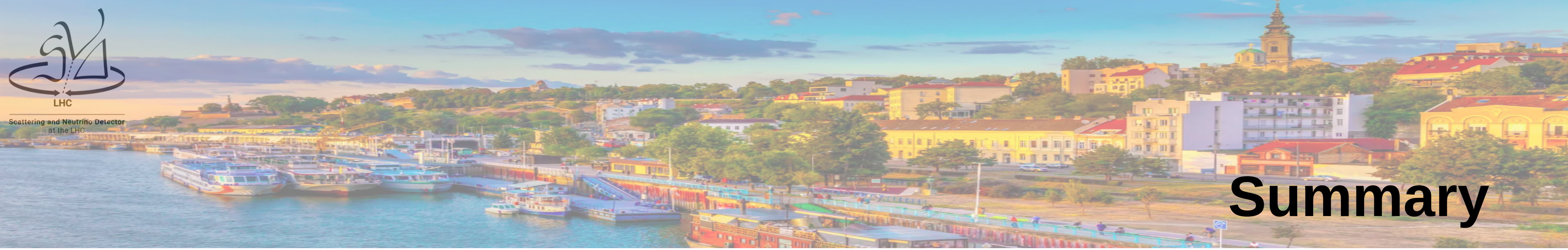
- Observed 8 ν_μ CC candidates
- Observation significance 7σ



Side note: hit multiplicity in SciFi discriminates against neutral-hadron background

Display of a ν_μ CC candidate event





Summary

- SND@LHC detector is operating since the start of the LHC Run 3
  - has collected 36.8 fb^{-1} (95% efficiency)
- Completed a measurement of the muon flux in the detector
- Reporting the observation of incoming ν_μ in the electronics detectors
- Observed 8 ν_μ CC candidates against an expected background of $(7.6 \pm 3.1)\times10^{-2}$
- Observation significance 7σ
- Reached the first analysis cornerstone
- Started to unveil the physics capacity of the experiment

Exciting studies ahead!

Thank you!

Additional slides

Experiment timeline

Scattering and Neutrino Detector at the LHC

Letter of Intent

August 2020

TECHNICAL PROPOSAL

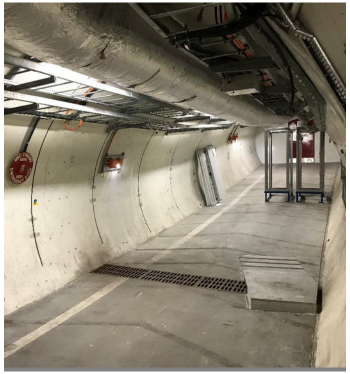
SND@LHC

January 2021

CERN approves new LHC experiment

SND@LHC, or Scattering and Neutrino Detector at the LHC, will be the facility's ninth experiment

March 2021

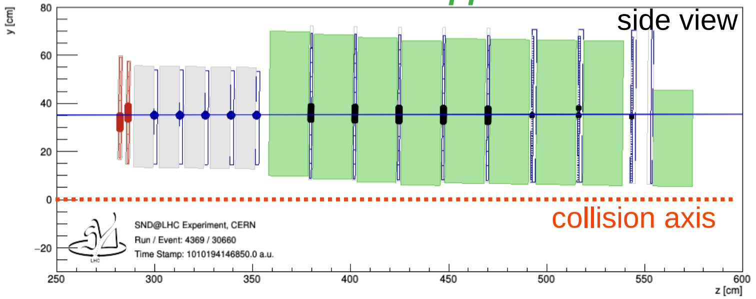


September 2021

December 2021

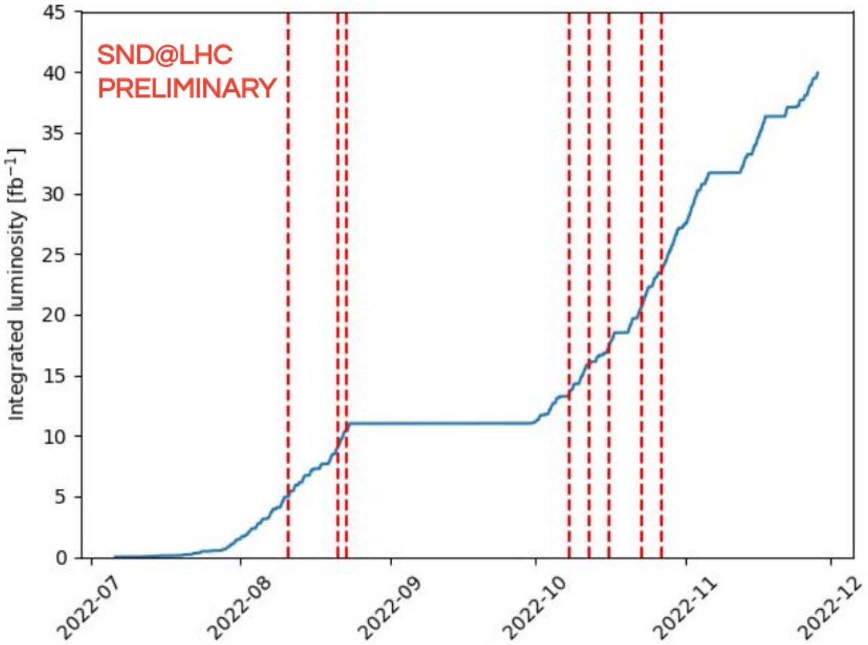
March 2022

Muon from 13.6 TeV pp collision



6th July 2022

Neutrino events timeline



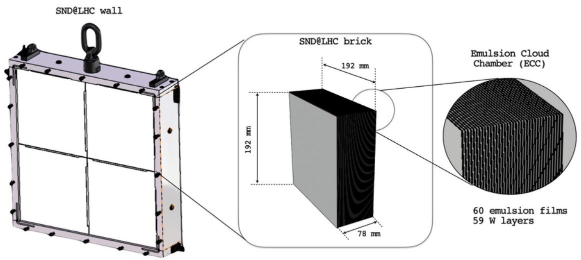
Start beam commissioning (Apr) — *First stable beams @6.8TeV* (Jul) — *End of run* (Nov/Dec)

2022	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	INSTRUMENTED TARGET MASS	INTEGRATED LUMINOSITY
EMULSION RUN0													39 kg	0.46 fb^{-1}
EMULSION RUN1													807 kg	9.5 fb^{-1}
EMULSION RUN2													784 kg	20.0 fb^{-1}
EMULSION RUN3													792 kg	8.6 fb^{-1}

Detector components

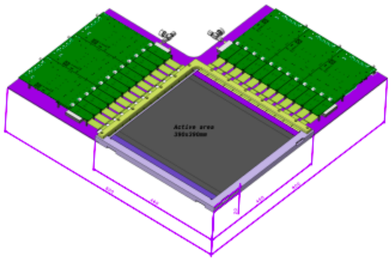
Emulsion Cloud Chambers

- Goal: tracking and vertex ID
- Sub-micrometric resolution
- Geometry
  - 5 walls of 2x2 bricks
- Shielding(protect from neutrons, stabilise T and humidity)
- Brick layout
  - 60 layers of 300 μm-thick emulsions
  - Interleaved by 1 mm tungsten plates
- Target mass ~830 kg



SciFi

- Goals:
  - Precise timing information (~350 ps time resolution)
  - EM energy measurement
  - Spatial information (<100 μm spatial resolution)
- Geometry
  - 5 planes of scintillating fibres mat pairs (x-y)
  - Mats built of 6 layers of staggered fibres

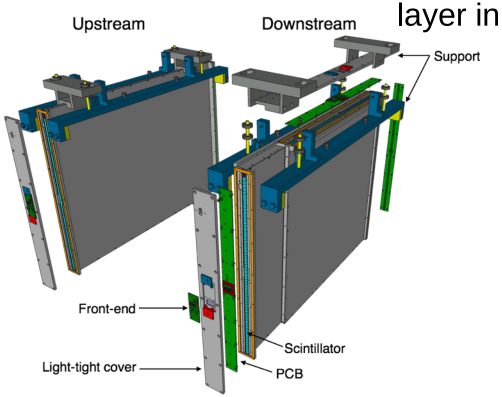


Hadronic calorimeter

- Goals:
  - Timing information
  - Hadronic energy measurement
  - Spatial information
- Geometry
  - 5 stations of horizontal scintillation bar layers
  - Readout on both ends of a bar

Muon ID system

- Goals:
  - Timing information
  - Muon tracking and isolation
- Geometry
  - 3 stations of orthogonal scintillation bar layer pairs
  - Horizontal bars read out on both ends
  - Vertical bars read out on one end (one additional layer in last station)

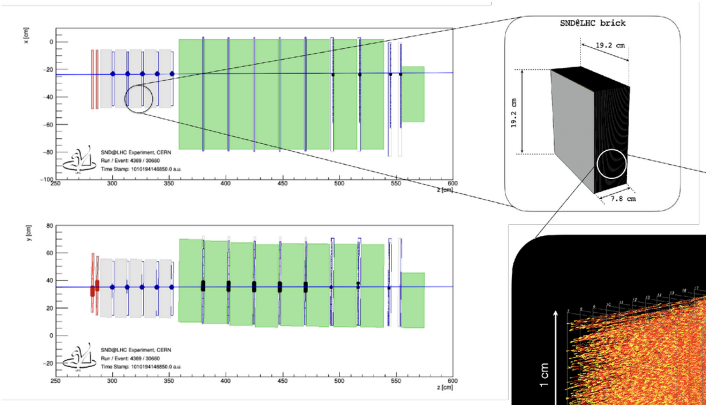


Muon flux

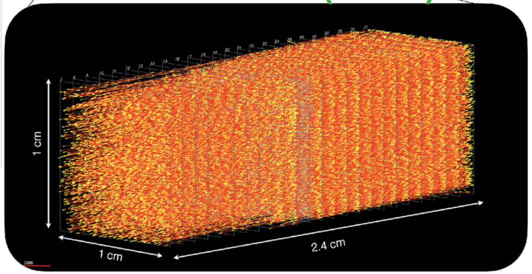
Using data from SciFi and DS, the muon flux is

- **SciFi**: 2.06×10^{4} cm^{-2}/fb^{-1} **DS**: 2.35×10^{4} cm^{-2}/fb^{-1} **SNDLHC-NOTE-2023-001**
- 2% deviation of SciFi and DS fluxes in the same acceptance range
  - while systematic error is 3%(SciFi) and 5%(DS) on muon flux per detector
- data/MC simulation agreement level 20-25%

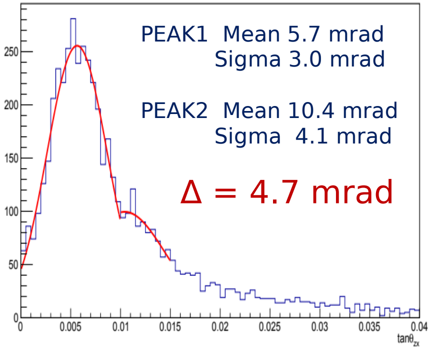
- Comparison of Emulsions/SciFi distributions with early data in good agreement, preliminary flux measurement agree within 10%
  - Input to target replacement strategy definition



Emulsion tracks: 1 cm² x-y section RUN0 (0.5 fb^{-1})



Emulsion tracks: RUN0



SciFi tracks: RUN0