LHC
Scattering and Neutrino Detector at the LHC

Results of SND@LHC

Ettore Zaffaroni, for the SND@LHC collaboration

57th Rencontres de Moriond

19/03/2023

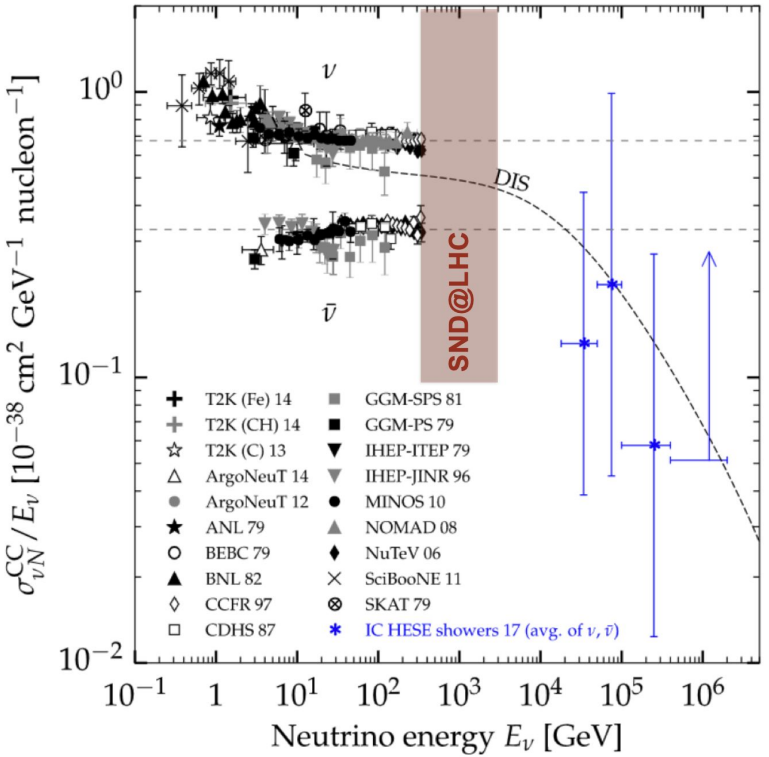
EPFL

Outline

- The physics programme
- The SND@LHC detector
- First results

Motivation

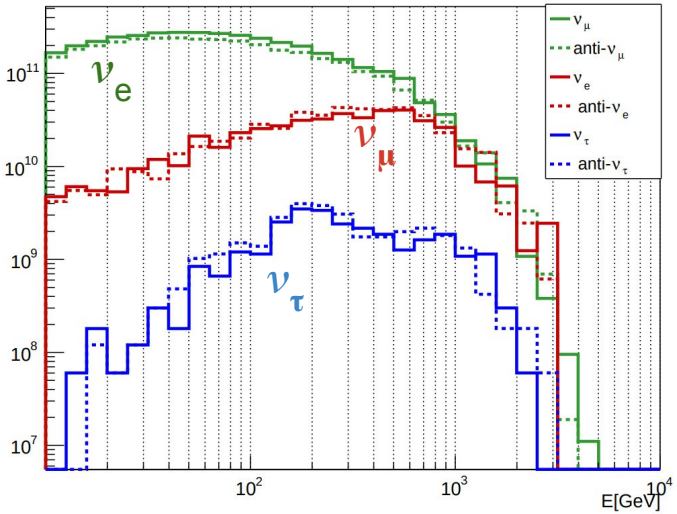
- LHC provides high-energy neutrinos
  - LHC neutrino studies proposed ~30 years ago
- Measure of pp→νX in unexplored domain
  - Energy range from 100s GeV to few TeV
- 2 experiments
  - FASERν, on axis ($\eta > 9$)
  - **SND@LHC**, off axis ($7.2 < \eta < 8.4$), ν mainly produced in charmed hadrons decay



PRL 122 (2019) 041101

Physics programme

- Measurement of charm production at high pseudorapidity ($gg \rightarrow c\bar{c}$)
- Probe gluon PDF at low momentum fraction $x \sim 10^{-6}$. Relevant for
  - FCC detectors
  - Extra-galactic neutrino observation (atmospheric neutrino background)
- Test lepton flavour universality with neutrinos
  - Thanks to the ability to distinguish all neutrino flavours
- Direct search of feebly-interacting particles

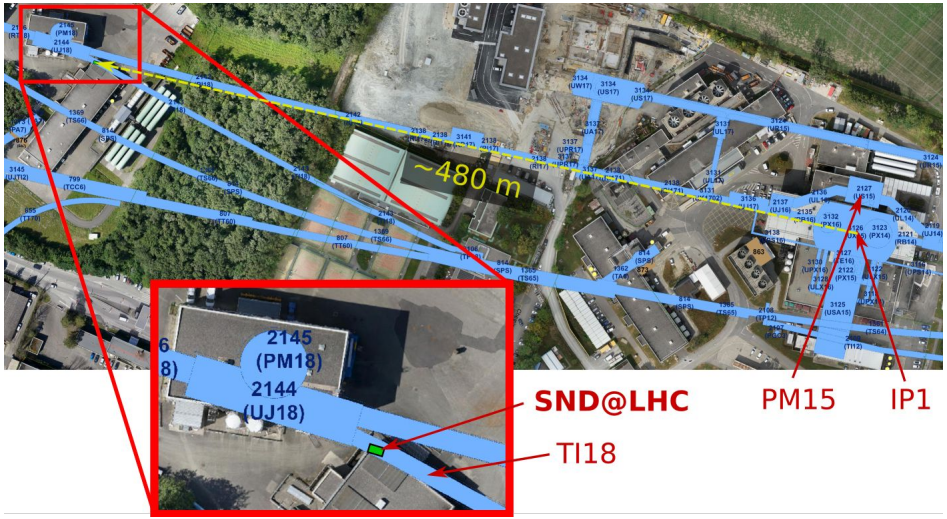


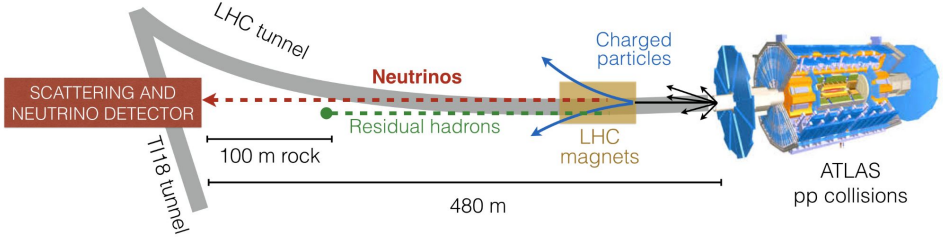
LHCC-P-016

arxiv 2210.02784

SND@LHC

- About 480 m from ATLAS interaction point
- TI18 tunnel
  - Used in the past as transfer line from SPS to LEP
- Shielded by 100 m of rock and LHC magnet deflection
- Angular acceptance: $7.2 < \eta < 8.4$
- First phase: collect 250 fb^{-1} in Run 3





Experiment timeline

Scattering and Neutrino Detector at the LHC

Letter of Intent

August 2020

TECHNICAL PROPOSAL

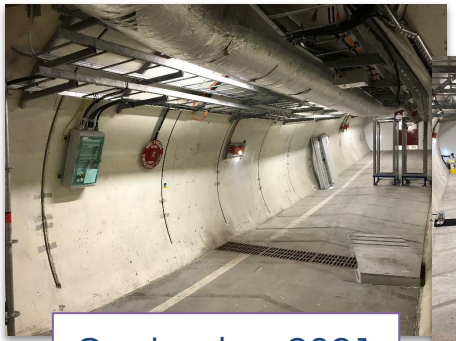
SND@LHC

January 2021

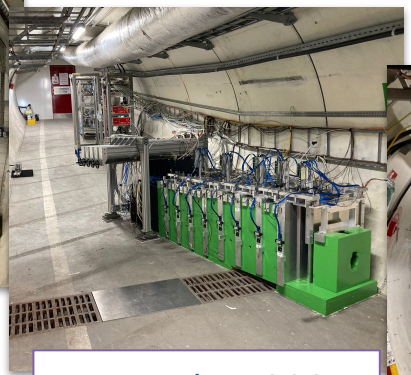
CERN approves new LHC experiment

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

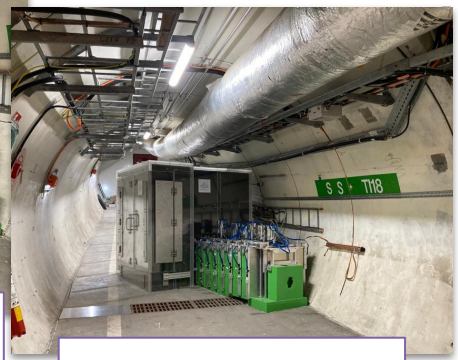
March 2021



September 2021

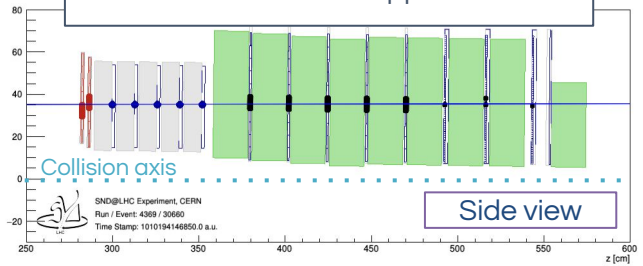


December 2021



March 2022

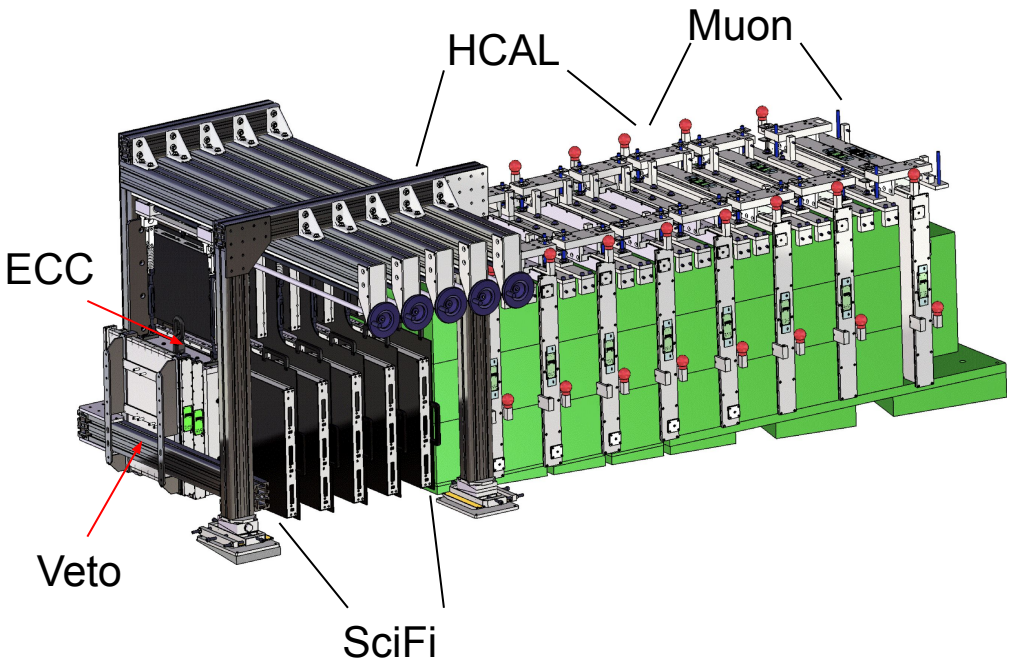
Muon from 13.6 TeV pp collision



July 2022

Detector

- Veto
  - Scintillators: tag incoming muons
- Vertex detector and EM calorimeter
  - Emulsion cloud chambers (ECC) w/ tungsten, 5 walls, 830 kg: neutrino interaction detection
    - Replaced every 20 fb^{-1}
  - Scintillating fibres (SciFi) tracker, 5 modules: timestamp, position and energy measurement
- HCAL-Muon system
  - Iron walls (green) and scintillators: energy measurement and muon detection

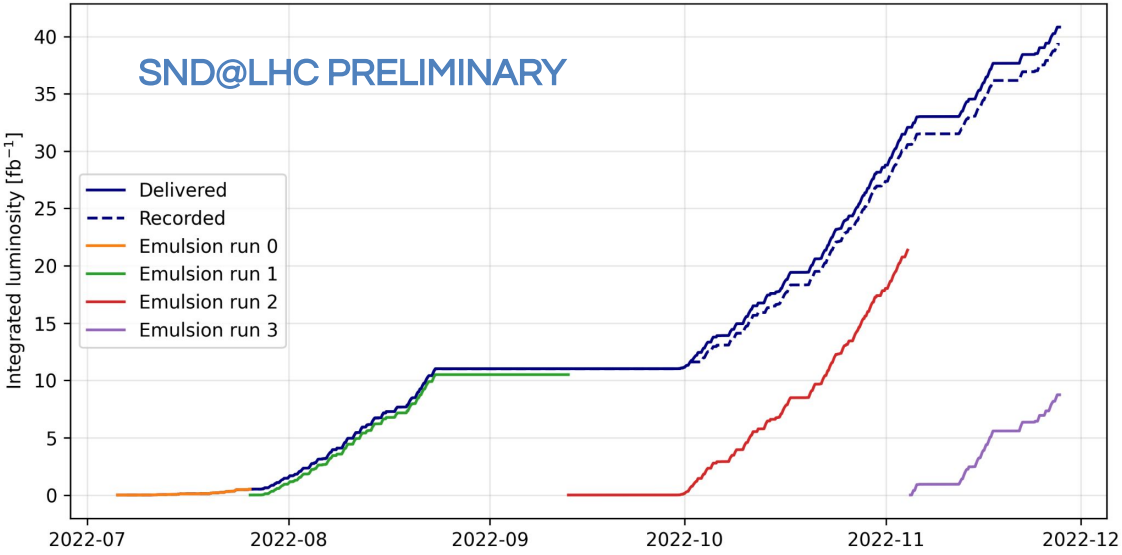


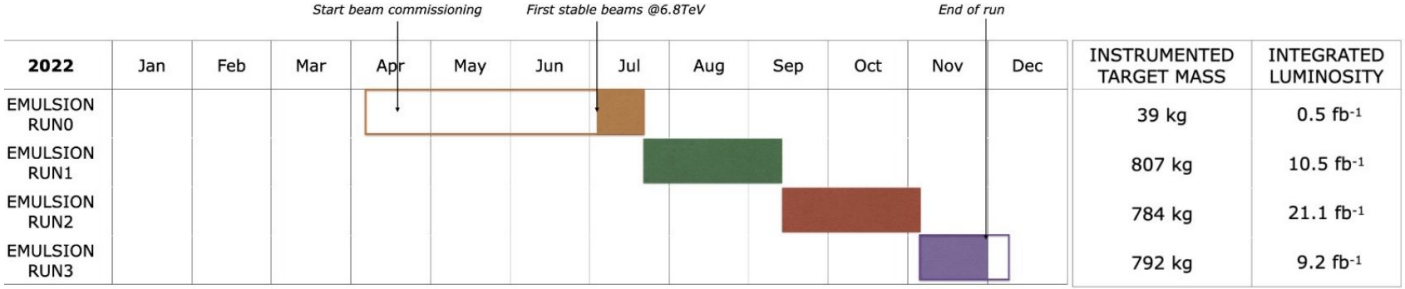
Detector paper: arxiv 2210.02784 to appear on JINST

Run 3 data taking

Delivered: 41.25 fb^{-1}
Recorded: 39.74 fb^{-1} (96%)

Quoted values don't account for the new ATLAS integrated luminosity estimation (5.4% less)



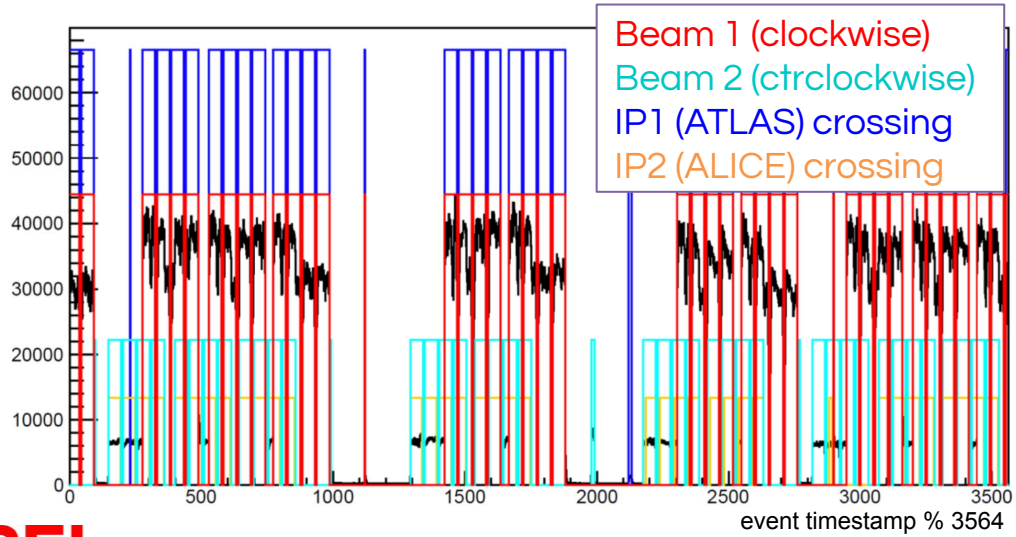


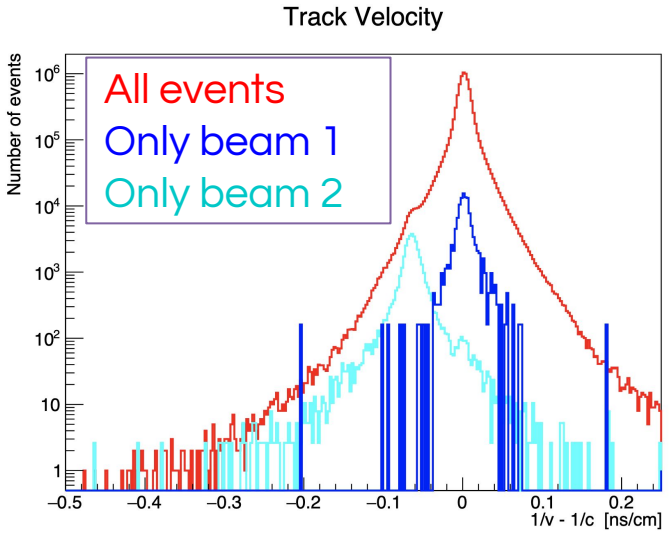
	INSTRUMENTED TARGET MASS	INTEGRATED LUMINOSITY
EMULSION RUN0	39 kg	0.5 fb^{-1}
EMULSION RUN1	807 kg	10.5 fb^{-1}
EMULSION RUN2	784 kg	21.1 fb^{-1}
EMULSION RUN3	792 kg	9.2 fb^{-1}

Bunch structure

- Event rate at SND@LHC follow the LHC filling scheme
- Events associated to non-colliding bunches used to measure non-collision backgrounds
  - Significant event rate induced by Beam 2 non-colliding bunches
    - These events enter the detector from the downstream end
    - Clearly observed in track direction measurements

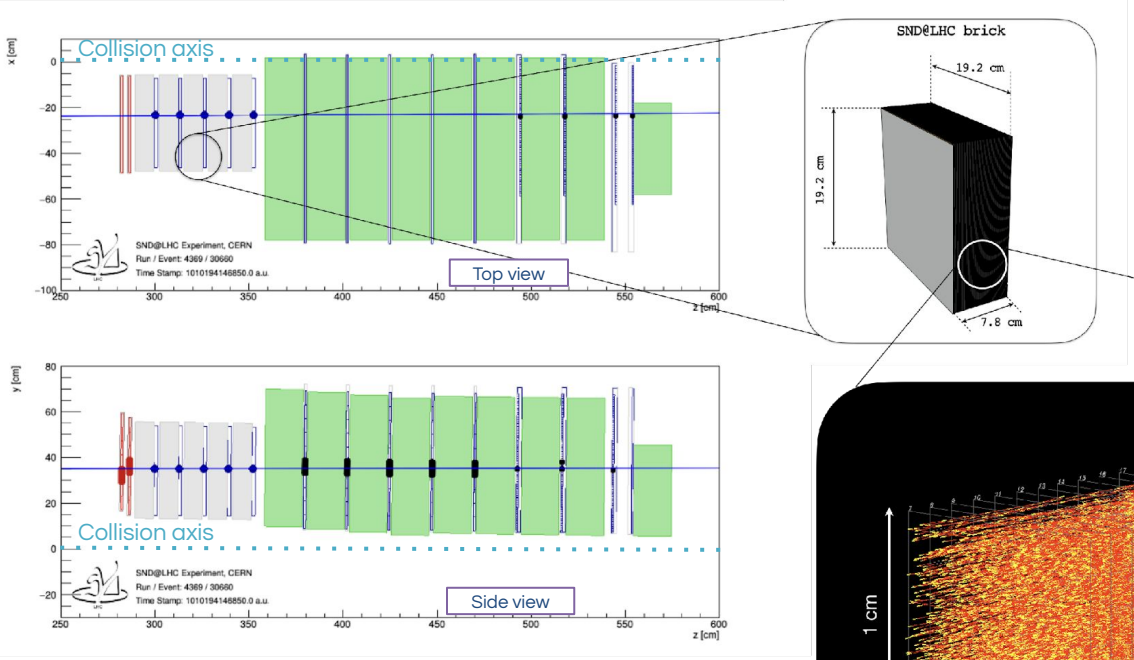
tracks from beam 1 <1.5%
tracks from beam 2 <1.0%



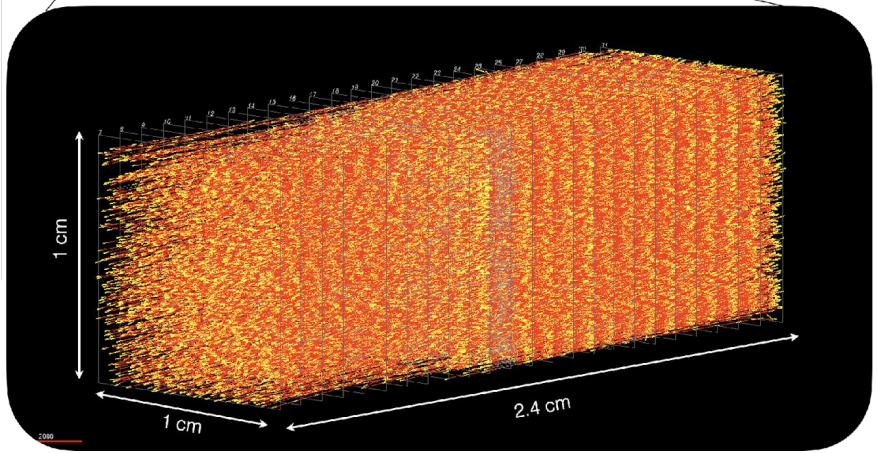


Muon flux measurement

Track reconstruction performed in electronic detectors and emulsion target



Emulsion reconstruction
Muon tracks in 1x1 cm^2 integrated in EMULSION RUN0 (7/4/22 - 26/7/22)

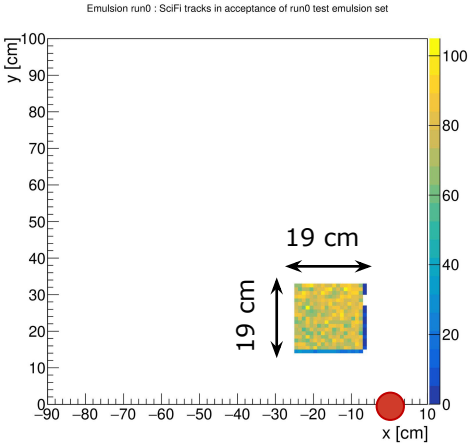


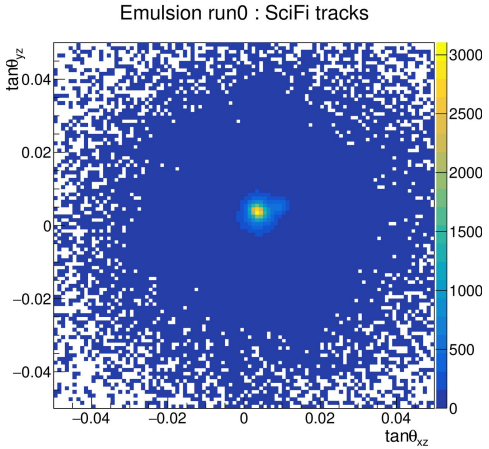
Electronic detector reconstruction
Muon tracks from pp collisions @13.6 TeV (6/7/22 - 26/7/22)

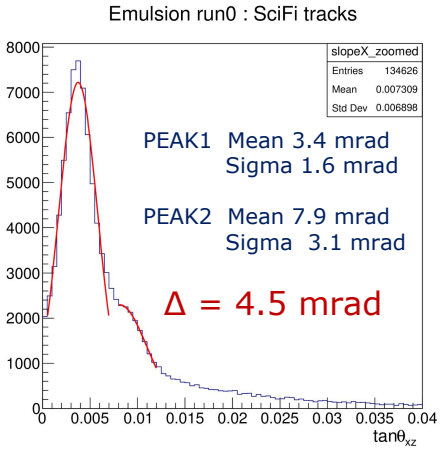
Emulsions / SciFi comparison

SciFi

Measured rates on BRICK 1 surface
1.6×10^4 cm^{-2}/fb^{-1}

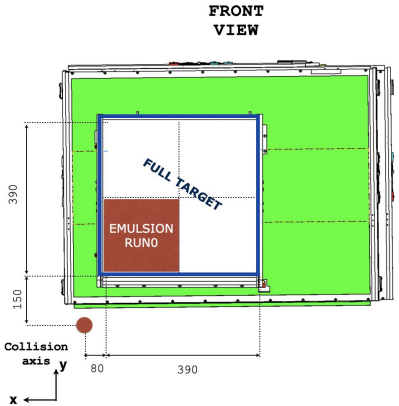


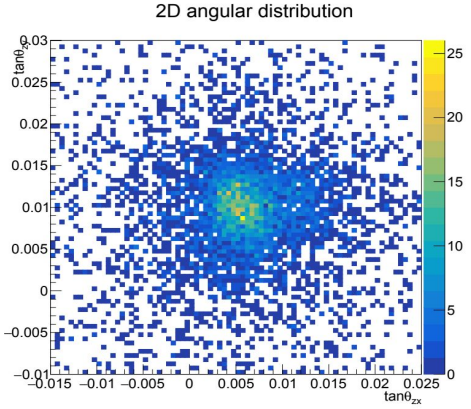


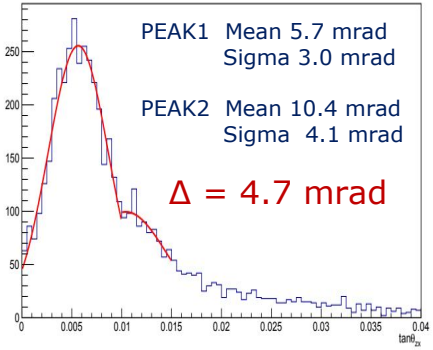


Emulsions

Measured rates in BRICK 1
1.5×10^4 cm^{-2}/fb^{-1}







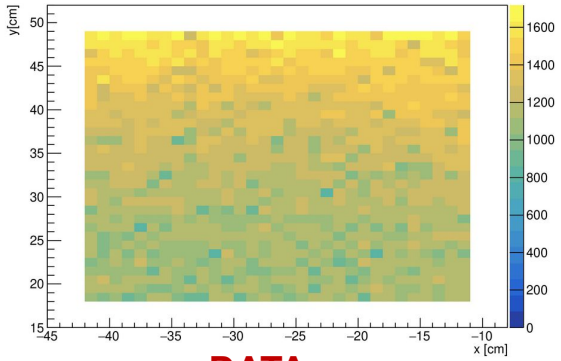
EPFL

Data/MC comparison

F. Cerutti, M.S. Gilarte
CERN-SY/STI

DATA

SciFi tracks @ SciFi front face, IP1 collisions

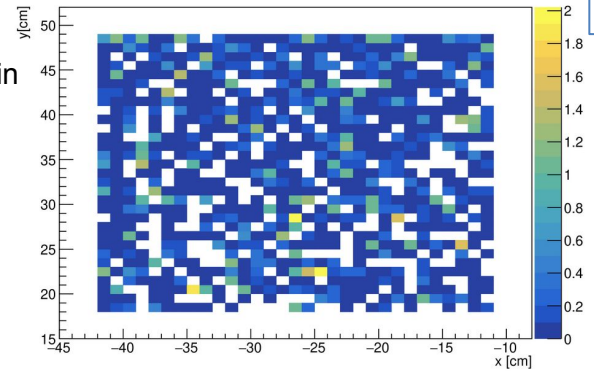


Measured muon track rate in SciFi (31x31 cm^2):

$(1.60 \pm 0.01_{stat})\times10^4$ cm^{-2}/fb^{-1}

MC

MC: SciFi tracks @ SciFi front face

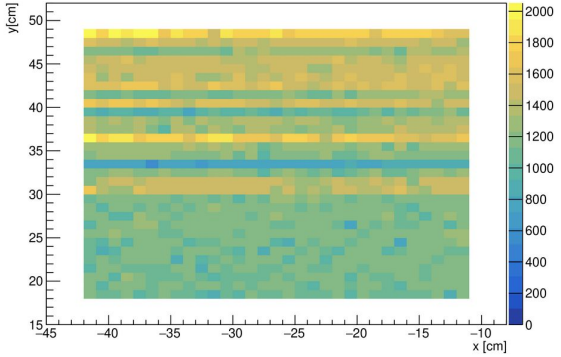


Expected muon track rate in SciFi (31x31 cm^2):

$(1.57 \pm 0.10_{stat})\times10^4$ cm^{-2}/fb^{-1}

DATA

DS tracks @ DS front face, IP1 collisions

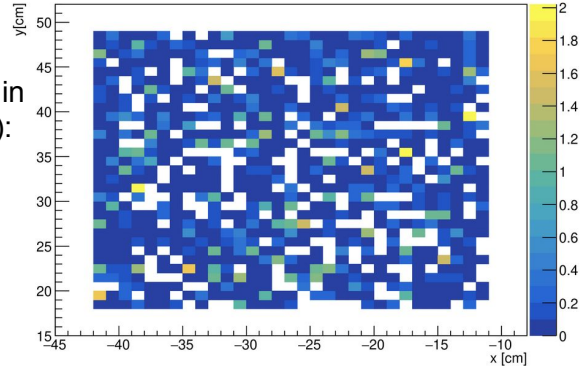


Measured muon track rate in Muon system (31x31 cm^2):

$(1.67 \pm 0.01_{stat})\times10^4$ cm^{-2}/fb^{-1}

MC

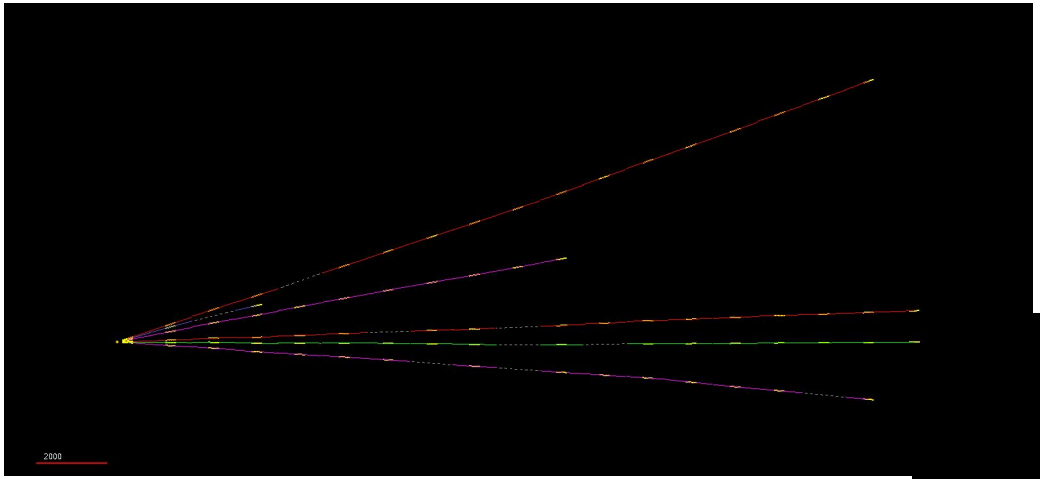
MC: DS tracks @ DS front face



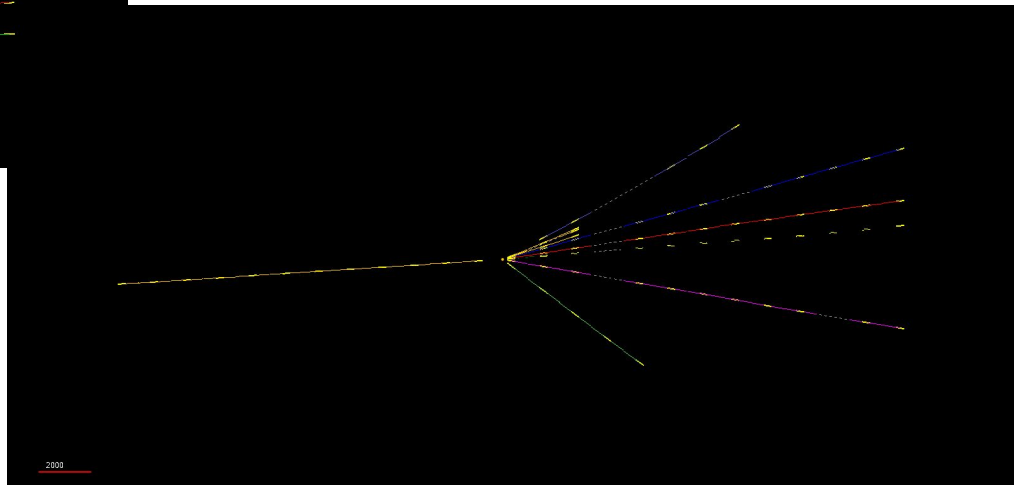
Expected muon track rate in Muon system (31x31 cm^2):

$(1.59 \pm 0.10_{stat})\times10^4$ cm^{-2}/fb^{-1}

Vertex reconstruction in emulsion data



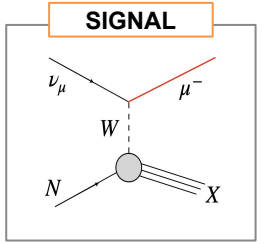
← Neutral-like particle interaction



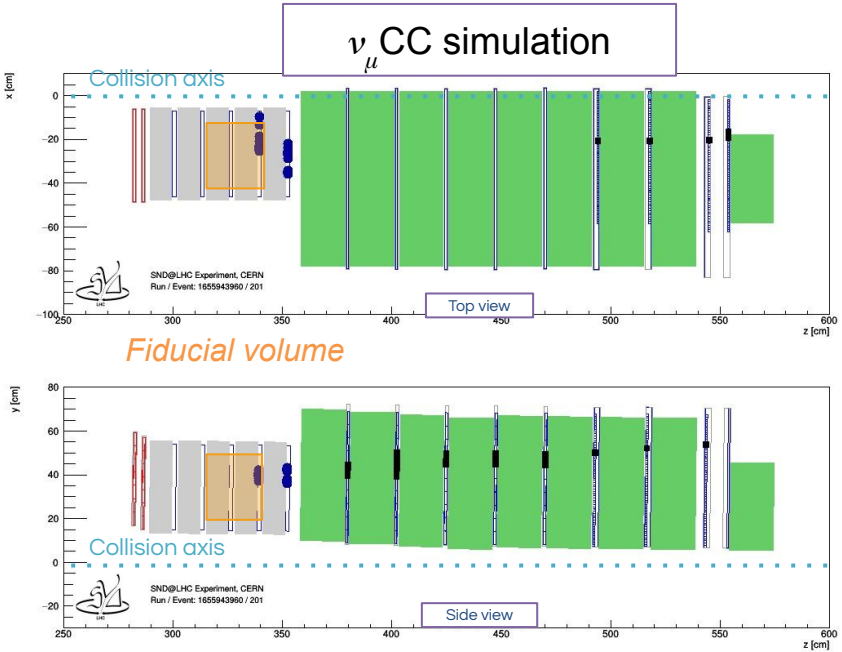
Charged-like particle interaction →

Neutrino observation with electronic detectors

- Analysis strategy:
  - Full Run 3 **2022 dataset**, 39 fb^{-1}
  - Observe ν_μ **Charged Current** interactions with **electronic detectors only**
  - **Maximise S/B**, counting-based approach
  - ~10^9 muon events: apply **cuts with a strong rejection power** to reach a negligible background level



- Signal selection:
  - **Fiducial Volume (1, 2)** cuts
    - Require an event from a **neutral vertex**, located in the 3rd or 4th target wall
    - Select fiducial cross-sectional area to reject entering backgrounds
  - **Neutrino ID** cuts
    - Require large EM activity in SciFi and hadronic activity in the HCAL
    - Event produced upstream (timing)
    - **Muon** reconstructed and **isolated** in the Muon system



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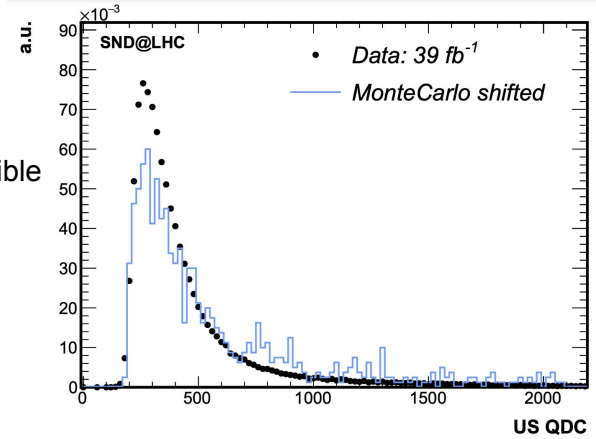
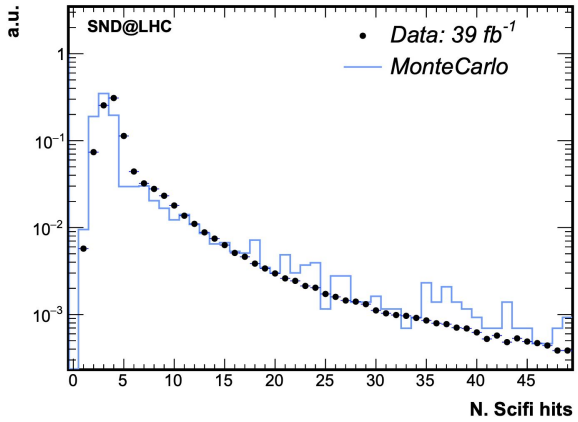
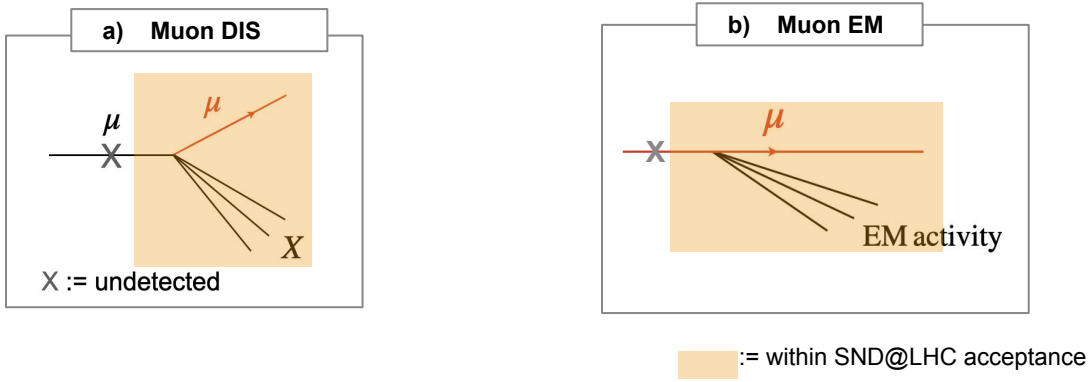
SND@LHC PRELIMINARY





Background estimates (I)

SND@LHC PRELIMINARY



- Muon induced background
  Number of undetected muons entering the target (2022 Run3 data)

$$N_{\mu}^{bkg} = N_{\mu} \times (1 - \epsilon_{Veto}) \times (1 - \epsilon_{SciFi1}) \times (1 - \epsilon_{SciFi2})$$ ~ 10^{-2} *totally negligible*

Total number of muons in target acceptance

Veto inefficiency

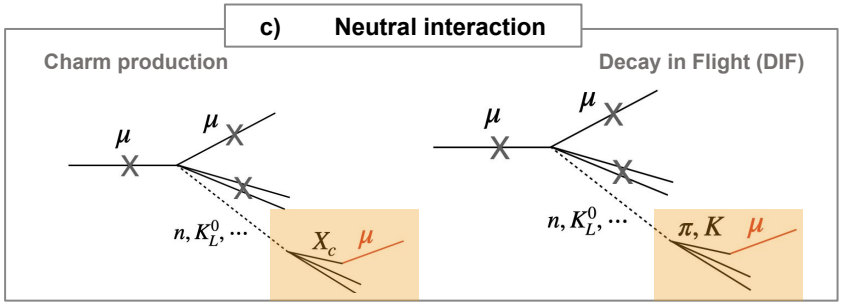
SciFi plane inefficiency

$$N_{\mu} = \frac{28 \times 10^{6}}{fb^{-1}} \times 39\, fb^{-1} = 1.1 \times 10^{9}$$

$$(1 - \epsilon_{Veto}) \times (1 - \epsilon_{SciFi1}) \times (1 - \epsilon_{SciFi2}) \sim 10^{-11}$$

Background estimates (II)

SND@LHC PRELIMINARY

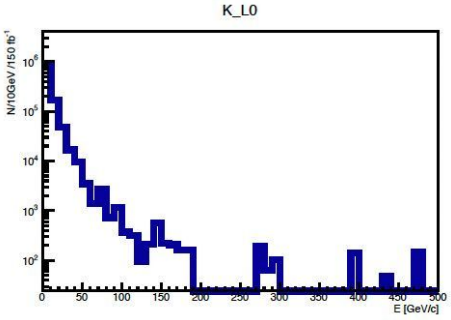


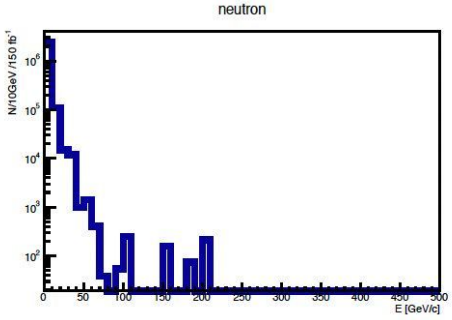
:= within SND@LHC acceptance

- Muon-induced neutral interactions

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

~ 0.12 (K^0_L) + 0.06 (neutrons) **~ 0.2**



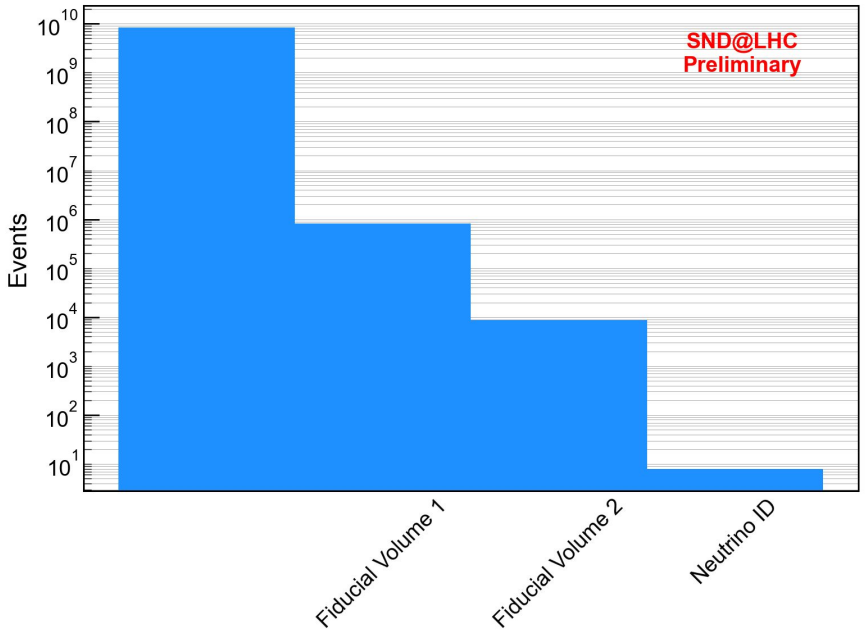


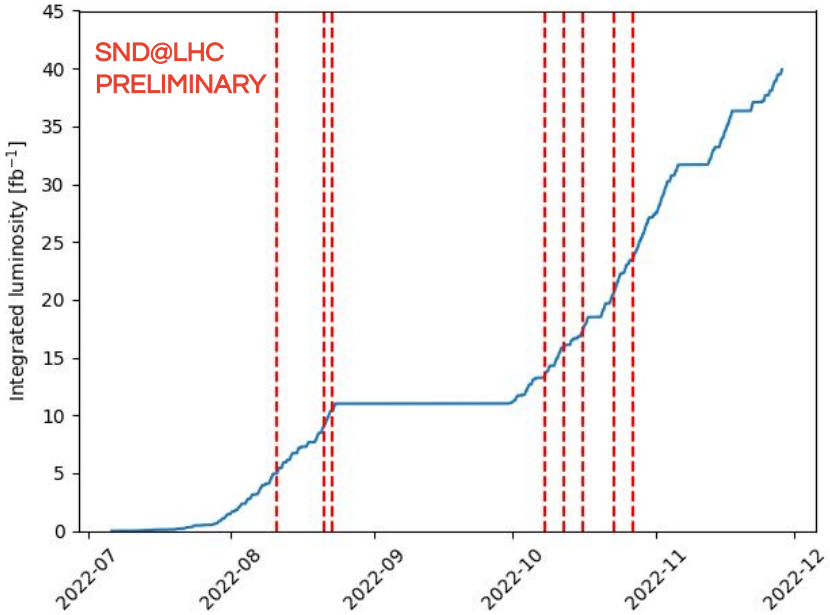
Systematic uncertainty estimation is ongoing

Observed candidates

SND@LHC PRELIMINARY

- Observed ν_μ **candidates**: 8 (expected 5)
- Preliminary estimate of background yield: 0.2

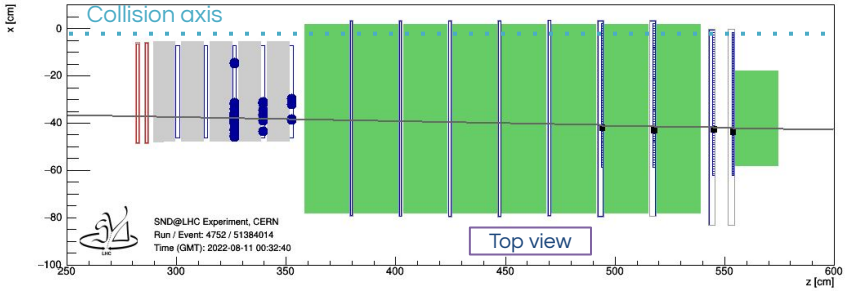


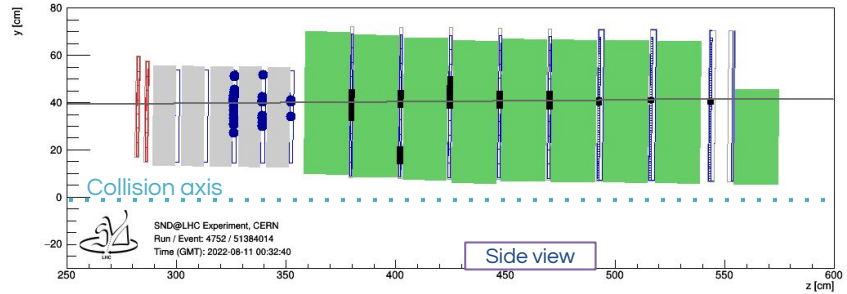


Selected candidates

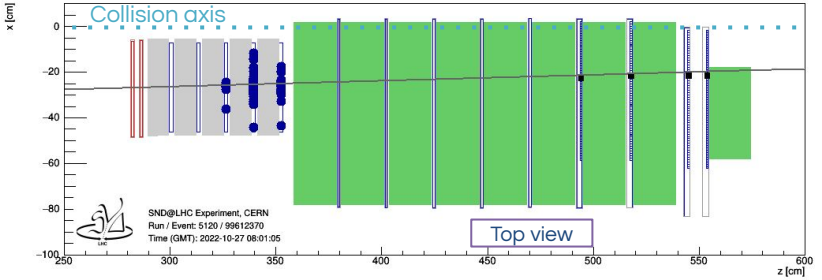
ν_μ CC candidate events in Run 3 data

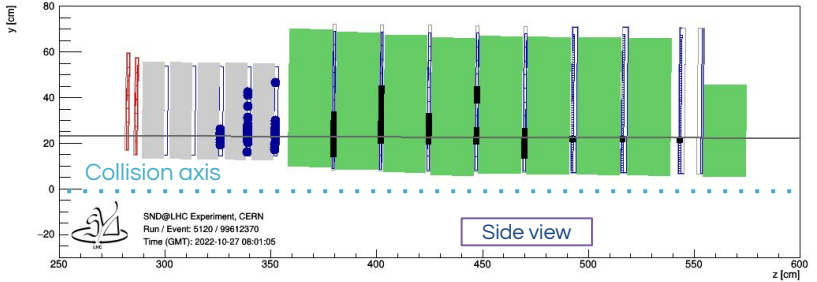
Aug 11th 2022





Oct 27th 2022





Summary

- Analysis of 2022 Run3 data: 39 fb^{-1}
- Measurement of muon flux with emulsions and electronic detectors
  - good agreement with MC estimates
- First selection of ν_μ CC based on electronic detectors only
  - While emulsion data analysis for full reconstruction of neutrino interactions ongoing
- Observed **8 ν_μ CC candidates from collider**
  - expected background of 0.2
- Systematic uncertainties on the background under evaluation
  - Expected significance of the observation ~5 sigma


THANK YOU!