경상국립대학교 Gyeongsang National University

Supercomputing Everywhere Connected!

KSC2023 & NSC35th Anniversary Conference

LHC Scattering and Neutrino Detector at the LHC

WORKSHOP

Machine Learning in HEP

SND@LHC : Scattering and Neutrino Detector at LHC

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GNU

On behalf of K-SND Group

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후원 과학기술정보통신부 Ministry of Science and ICT

Outline

I. Introduction

II. SND@LHC Experiment

III. Analyses & Results

IV. Conclusion

Introduction

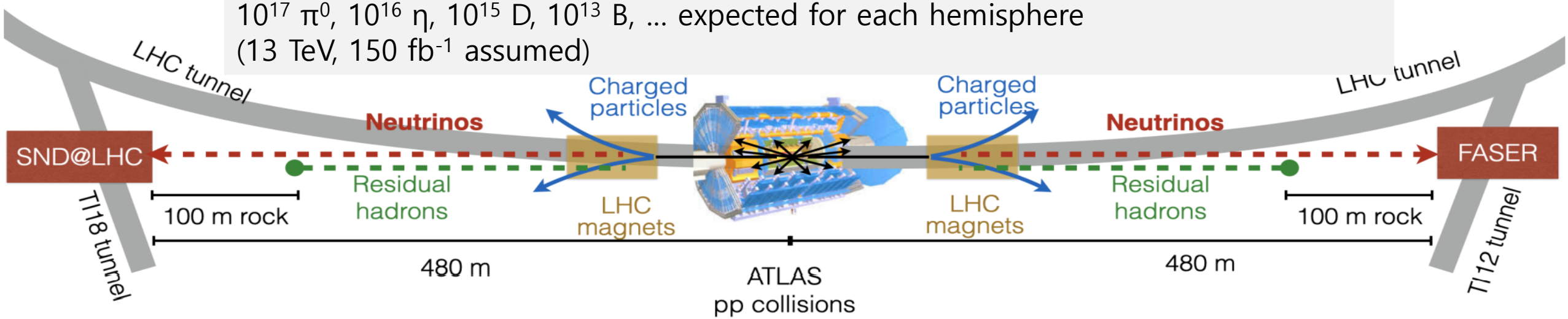
Forward Experiments at the LHC

Physics in the Forward Region

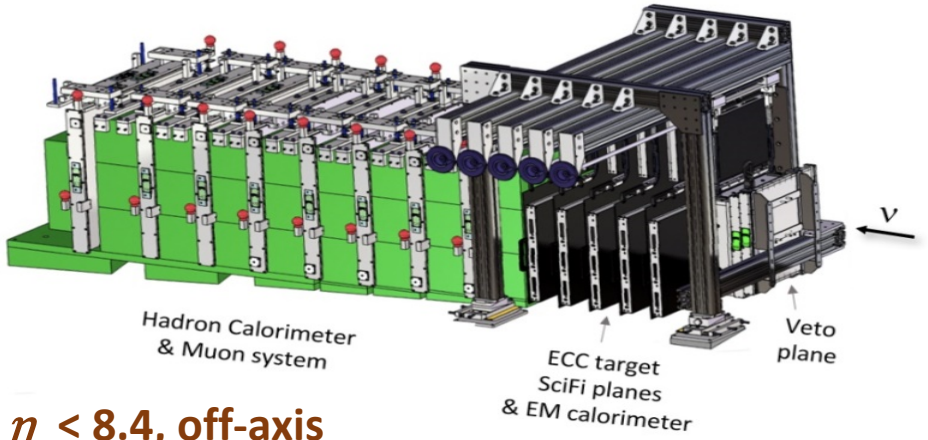
10^{16} inelastic pp scattering events for LHC Run 3

10^{17} π^0, 10^{16} η, 10^{15} D, 10^{13} B, … expected for each hemisphere

(13 TeV, 150 fb^{-1} assumed)

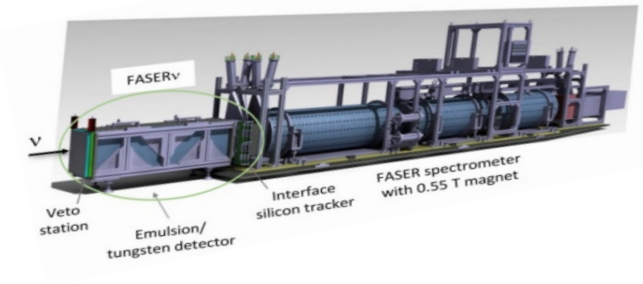


SND@LHC



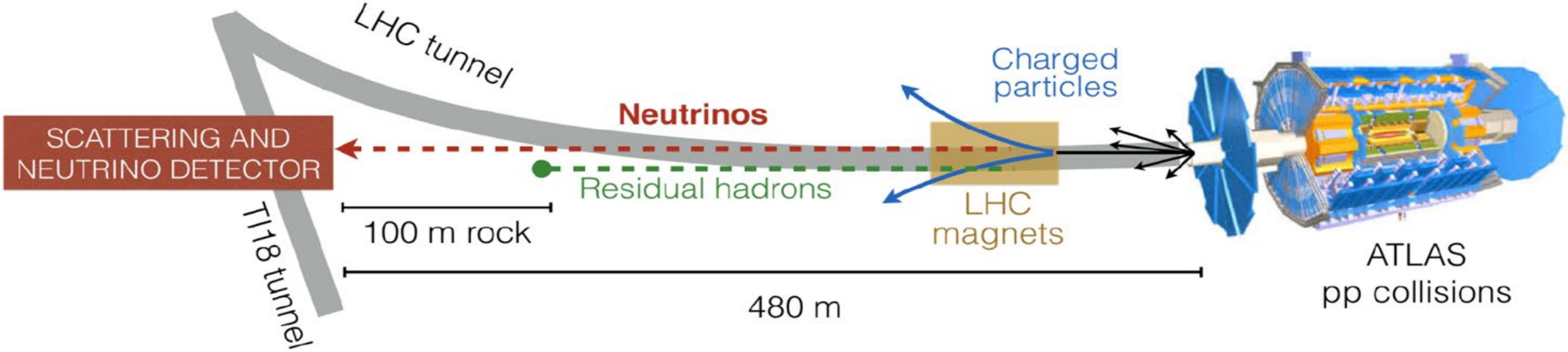
7.2 < η < 8.4, off-axis

FASER & FASERν



η > 8.8 on-axis

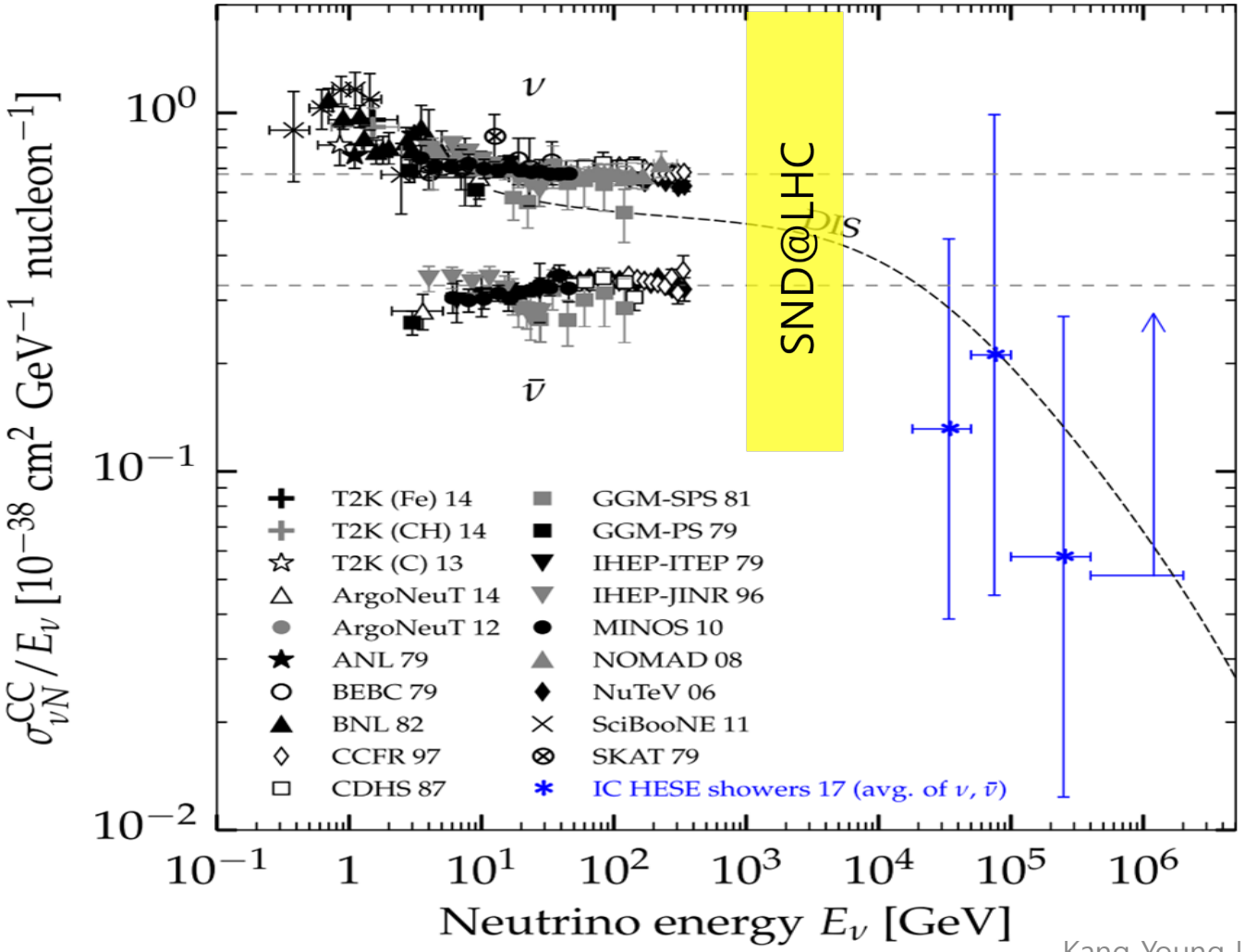
The SND@LHC



- 480 m away from the ATLAS interaction point (IP1)
- Located in the TI18 tunnel, former positron transfer line to LEP
- Shielded by 100 m rock
- LHC magnet deflects charged particles
- Neutrinos and (if exist) feebly interacting particles (FIPs) arrive at the detector

Neutrinos at the LHC

PRL 122 (2019) 041101

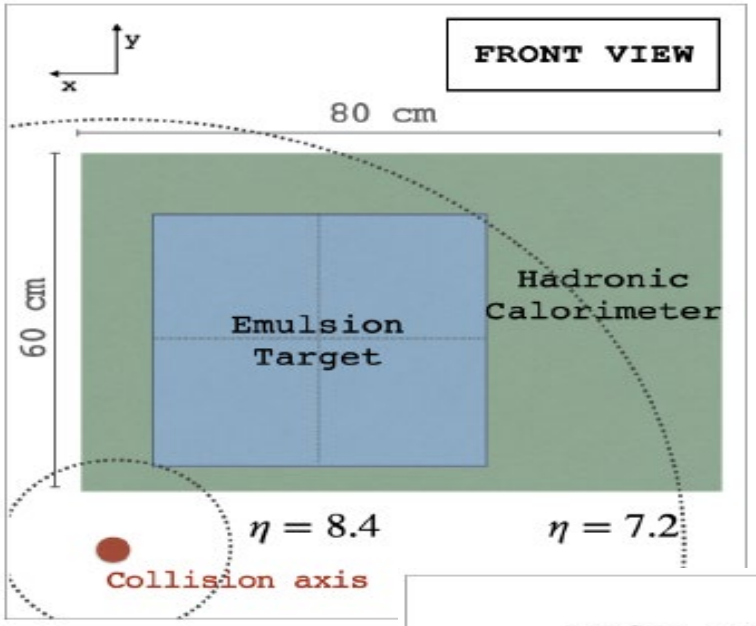


The LHC neutrinos are interesting because…

- First observation of the collider neutrinos
- High energy neutrinos of not explored region,
  300 GeV ~ a few TeV
- Large fluxes in the forward region
- All the 3 flavour neutrinos can be observed.

SND@LHC

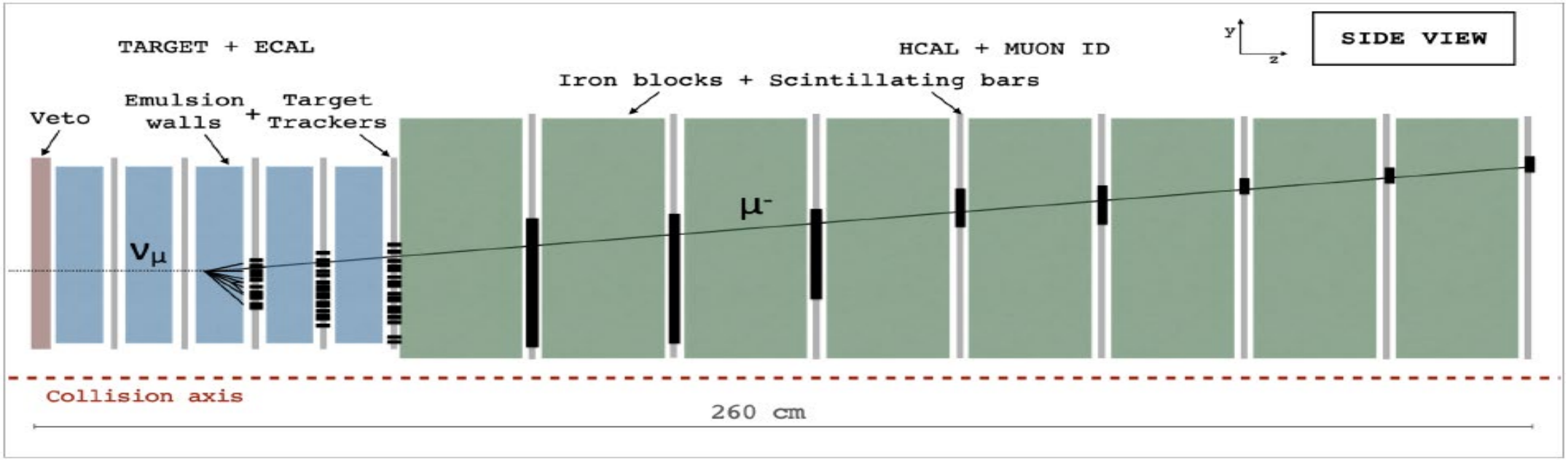
The SND@LHC Detector



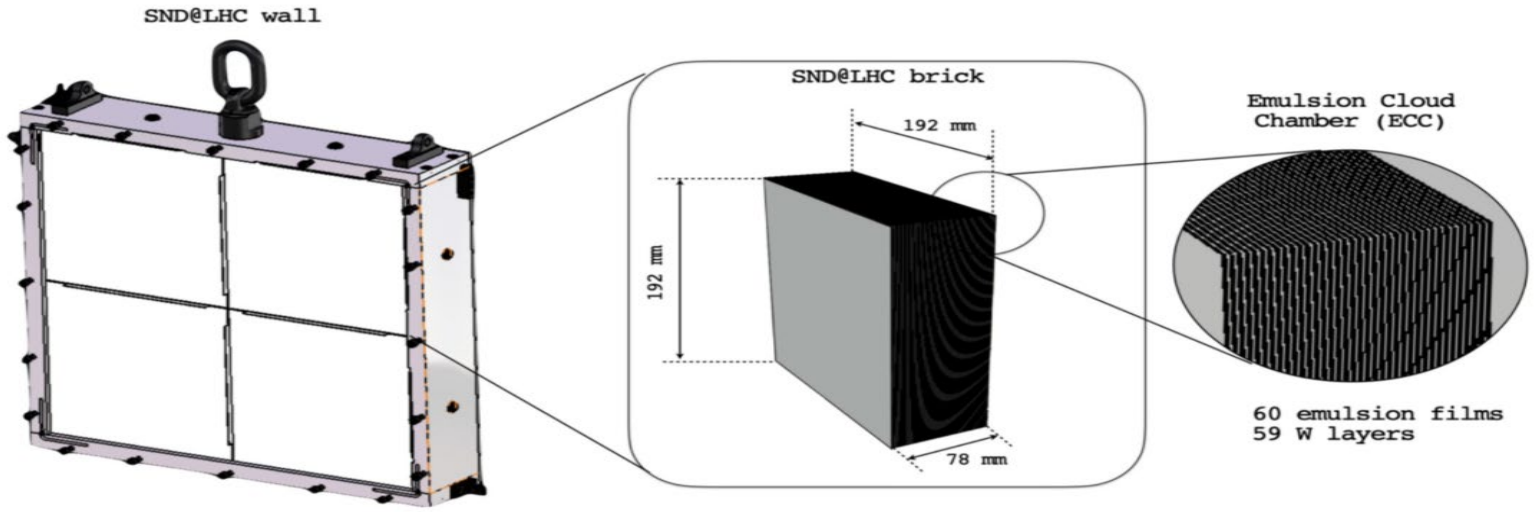
Hybrid detector optimised for the identification of all three neutrino flavours and the FIPs

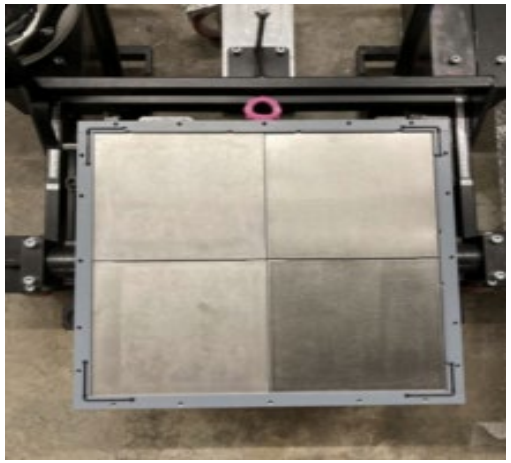
- Veto plane
- Vertex detector and EM calorimeter (~40 X_0) : ECC and SciFi
- Hadron calorimeter and muon system (~10 λ)

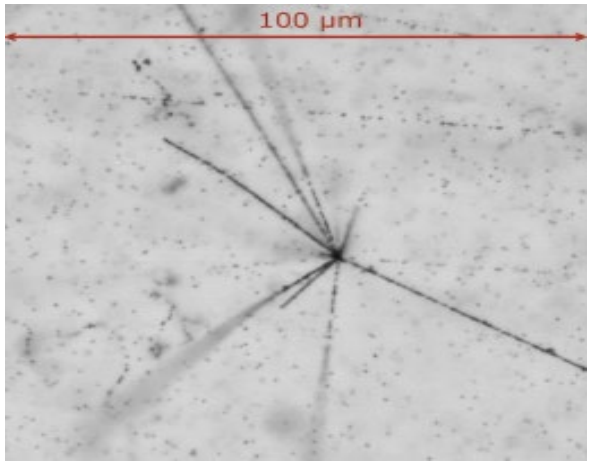
Detector paper : arXiv 2210.02784 to appear on JINST



Emulsion Cloud Chamber



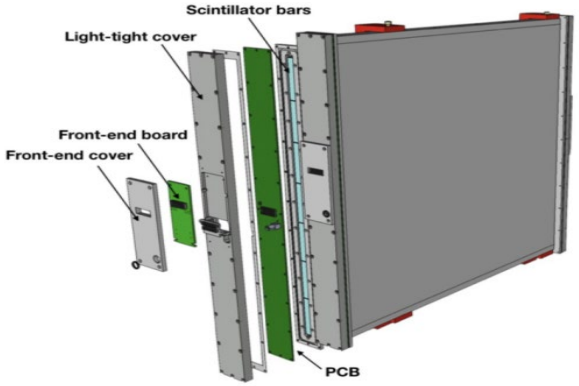




Emulsion target

- Emulsion cloud chamber (ECC) brick consists of 60 emulsion films interleaved with 59 tungsten plates
- Total tungsten mass 830 kg
- 5 walls x 4 bricks x 60 emulsion films
- Replaced every 20 fb^{-1}

Other Detector Components



Veto system
- Tags incoming charged particles and consists of 2 planes with 7 Sci bars

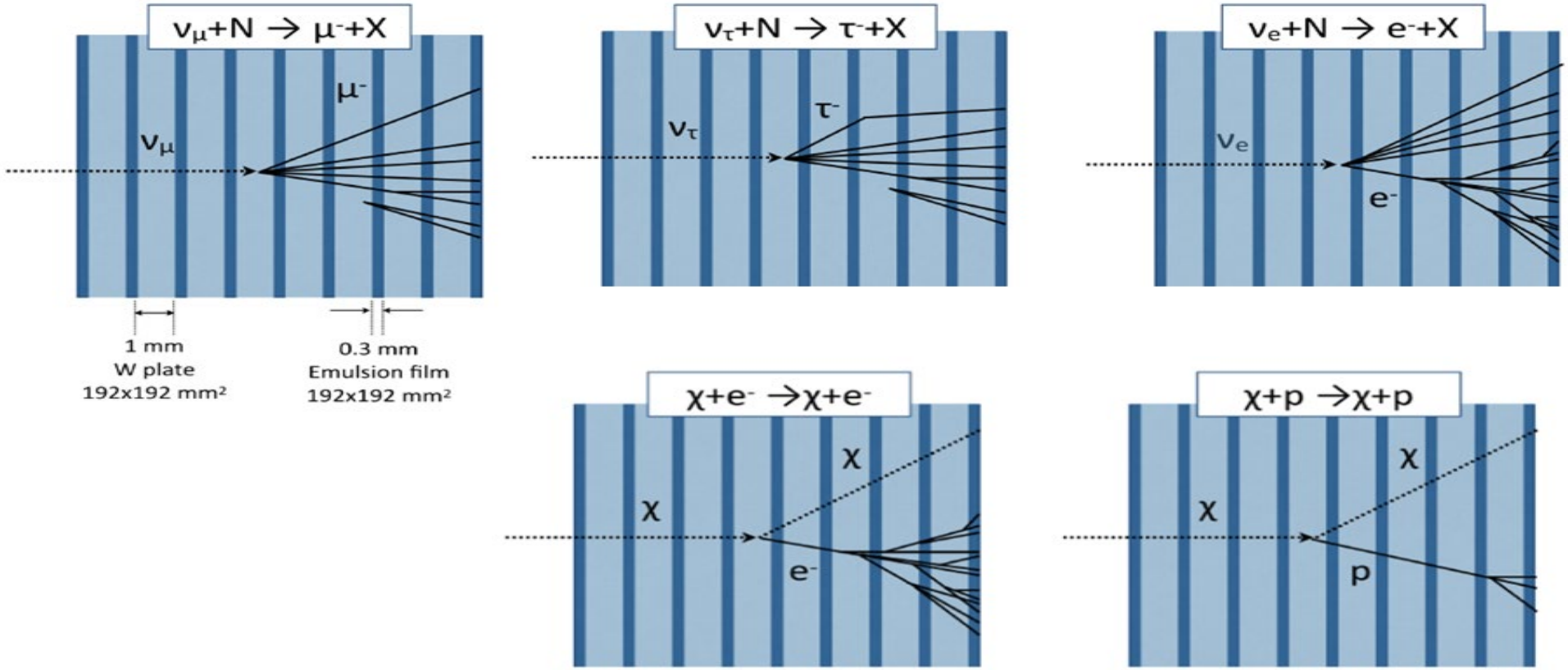
SciFi detector
- Scintillating Fiber detectors interface emulsion with electronic detectors for position prediction and timing of outgoing particles.
- Electromagnetic calorimetry

Hadronic calorimeter and muon system
- Upstream : 5 stations of Fe blocks with 10 Sci bars for hadronic calorimetry
- Downstream : 3 stations with 60 horizontal and 60 vertical Sci bars for muon tagging

Physics Cases

- Measurement of the ν **production cross section**
- Measurement of the **forward charm production**
- Neutrino induced **charm production**
- **Lepton flavor universality test** in neutrino interactions
- Measurement of the **NC/CC** ratio
- Direct search for **FIP** through their scattering

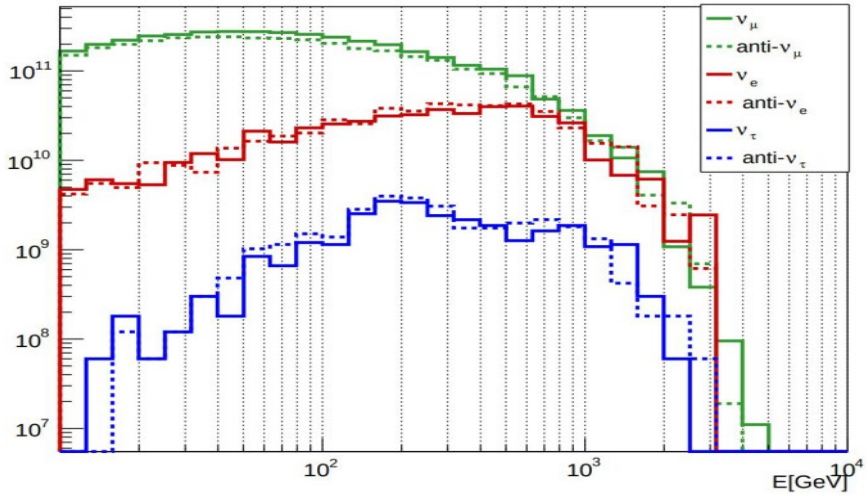
Physics Cases – Event Topology Production



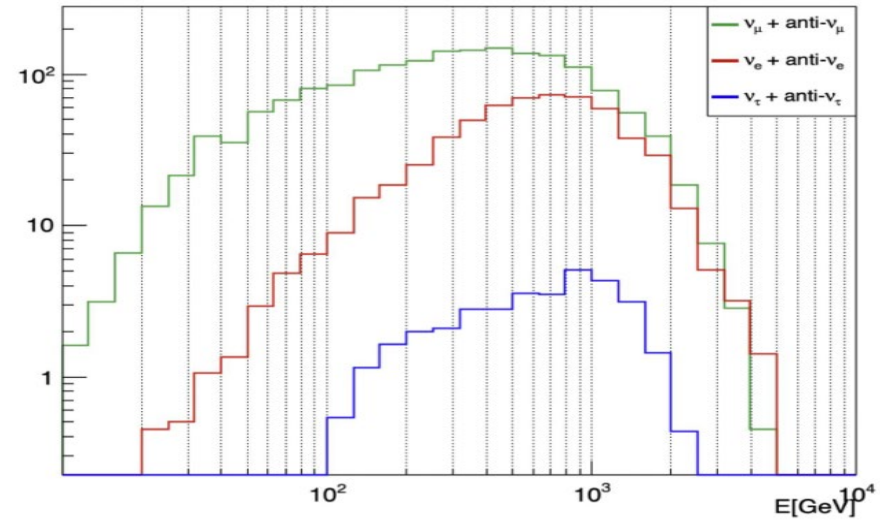
Identification of all three neutrino flavours and FIPs by event topologies in the ECC brick

Physics Cases – Neutrino Production

Incoming Neutrinos to SND



Neutrino interactions in SND



Measurement of $\sigma(pp \rightarrow \nu X)$

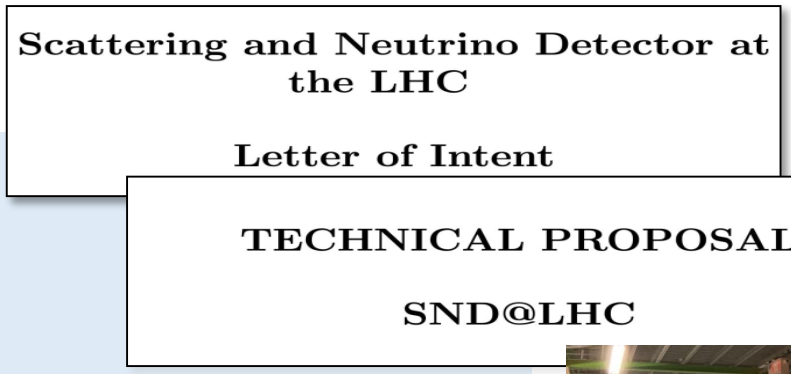
- $\nu_\mu+\bar{\nu}_\mu$ charged-current: 1447
- $\nu_e+\bar{\nu}_e$ charged-current: 450
- $\nu_\tau+\bar{\nu}_\tau$ charged-current: 34

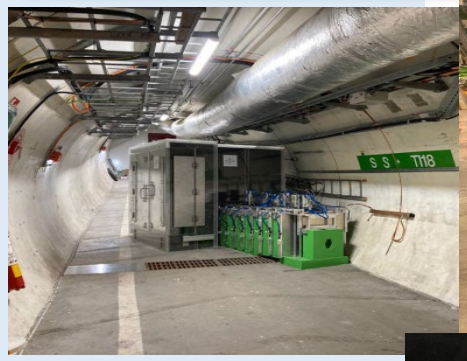
Estimated from
290 fb^{-1} in LHC Run 3
Angular acceptance $7.2 < \eta < 8.4$

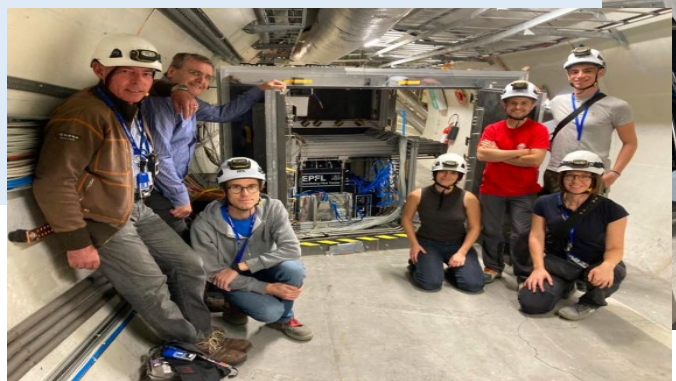
Flavour	Neutrinos in acceptance ⟨E⟩ [GeV]	Yield	CC neutrino interactions ⟨E⟩ [GeV]	Yield	NC neutrino interactions ⟨E⟩ [GeV]	Yield
ν_μ	120	3.4×10^{12}	450	1028	480	310
$\bar{\nu}_\mu$	125	3.0×10^{12}	480	419	480	157
ν_e	300	4.0×10^{11}	760	292	720	88
$\bar{\nu}_e$	230	4.4×10^{11}	680	158	720	58
ν_τ	400	2.8×10^{10}	740	23	740	8
$\bar{\nu}_\tau$	380	3.1×10^{10}	740	11	740	5
TOT		7.3×10^{12}		1930		625

Timeline

Aug. 27th, 2020	Letter of Intent
Jan. 22nd, 2021	Technical Proposal
March, 2021	Approval by CERN RB
August, 2021	Infrastructure
Oct.13th, 2021	Detector construction completion
December, 2021	Detector installation in TI18
Apr. 7th, 2022	Installation of the first emulsion films
July, 5th, 2022	First 13.6 TeV collisions
July, 26th, 2022	Full target installation





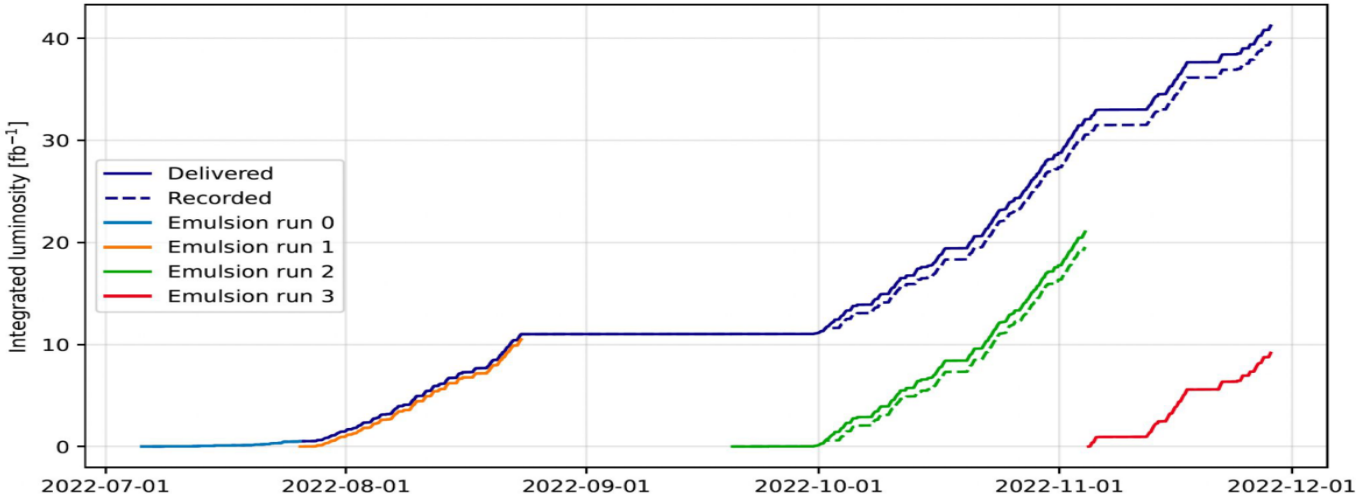


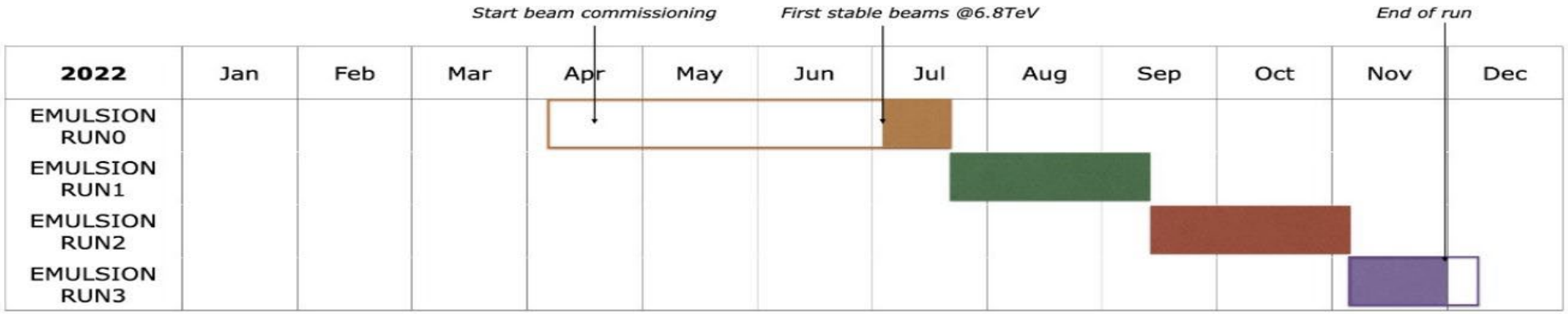
Analyses & Results

Data taking in 2022

Run3 in 2022

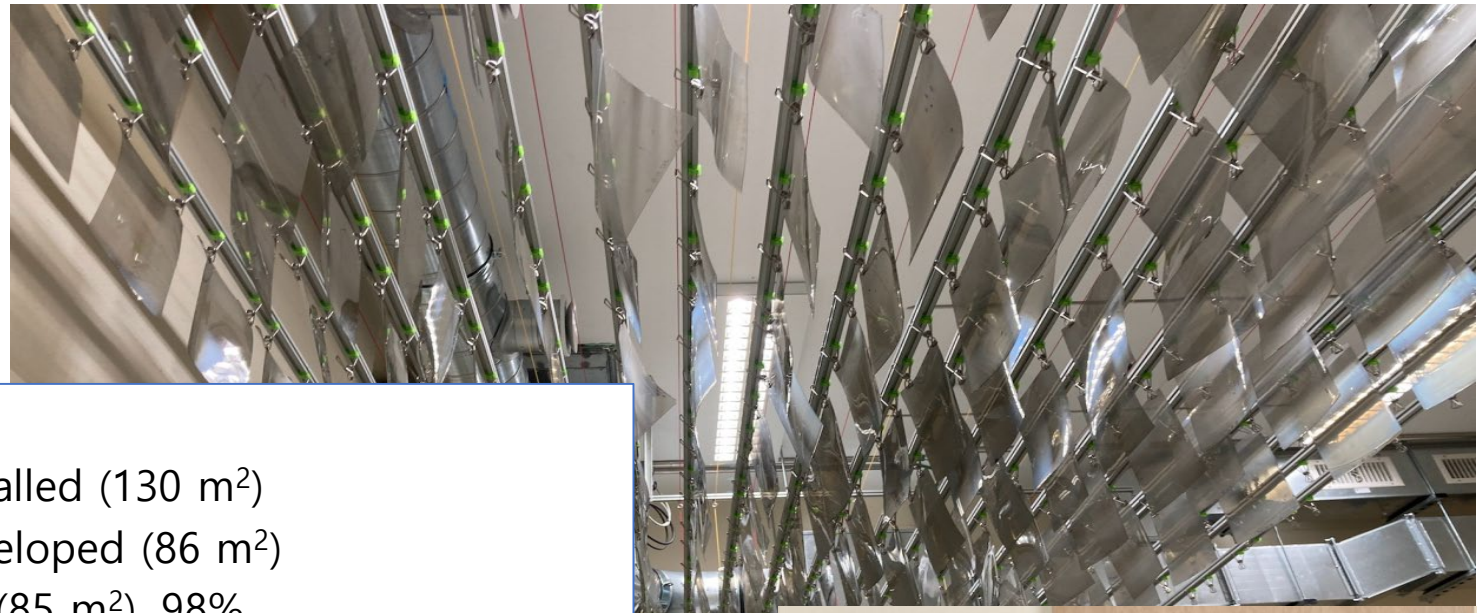
41.25 fb^{-1} delivered
39.74 fb^{-1} recorded (96%)



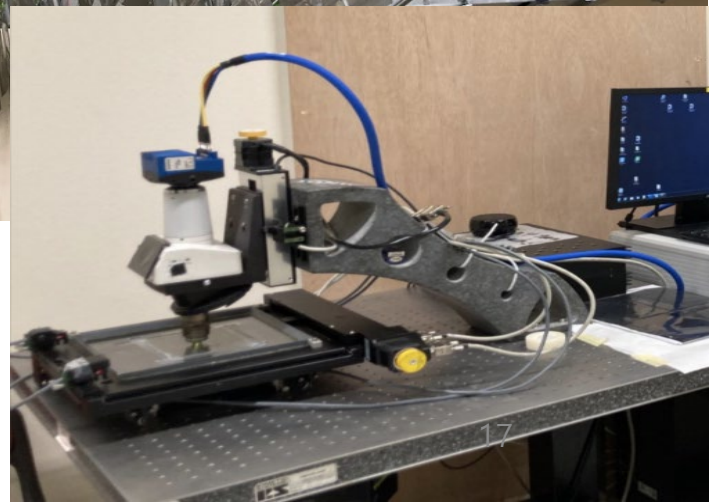


INSTRUMENTED TARGET MASS	INTEGRATED LUMINOSITY
39 kg	0.5 fb^{-1}
807 kg	10.5 fb^{-1}
784 kg	21.1 fb^{-1}
792 kg	9.2 fb^{-1}

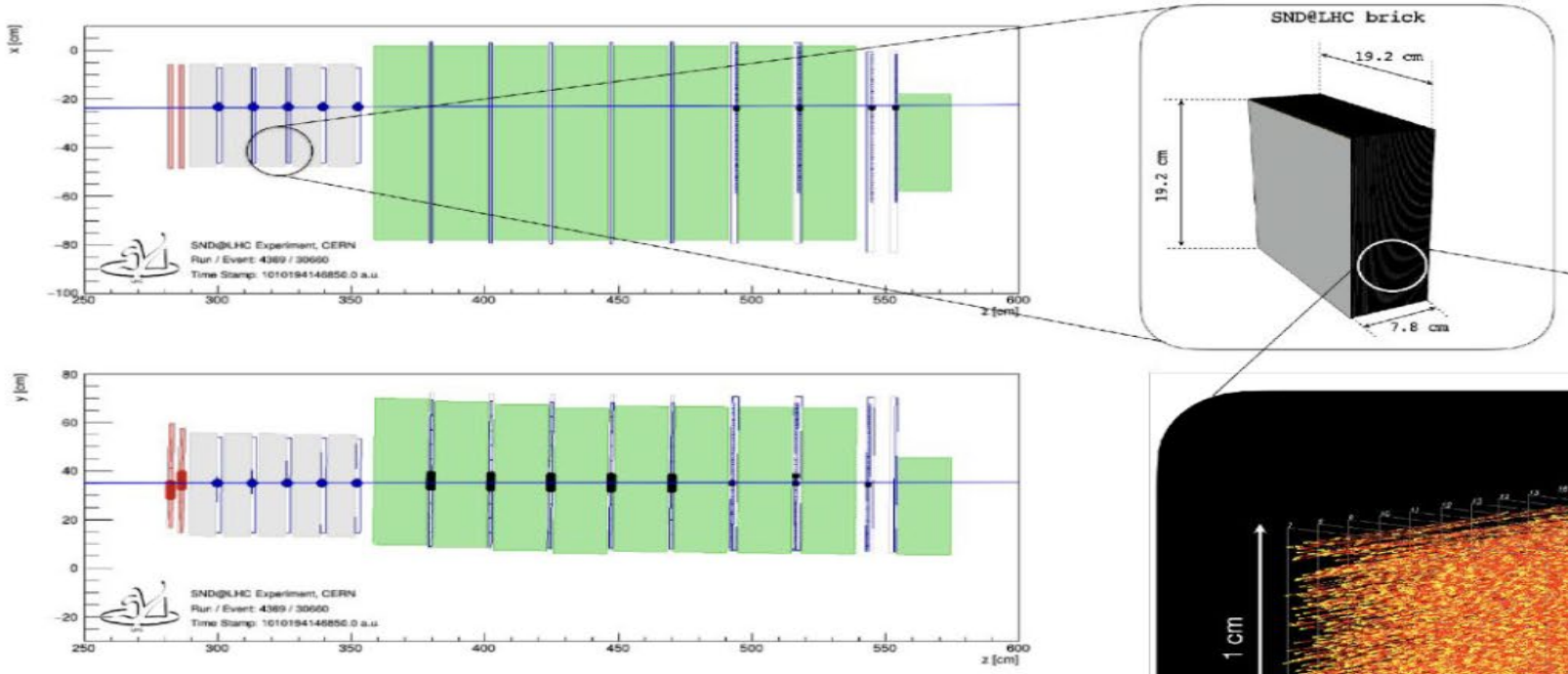
Emulsion Development & Scanning



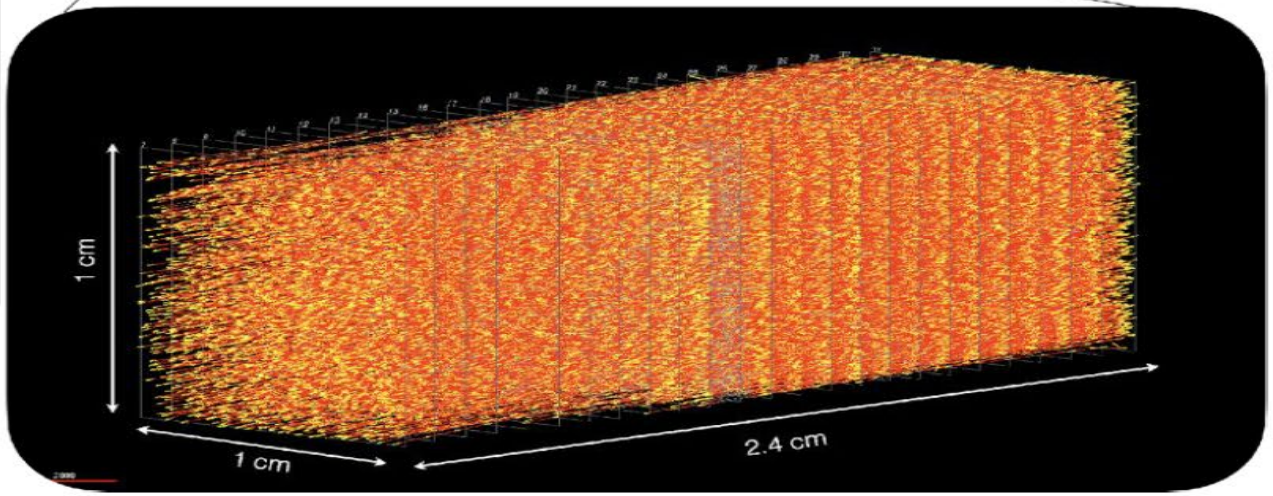
- **16** walls assembled
- **3522** emulsion films installed (130 m^2)
- **2370** emulsion films developed (86 m^2)
- **2320** good quality films (85 m^2), 98%
- **3500 L** disposed chemical solutions



Muon Track Reconstruction



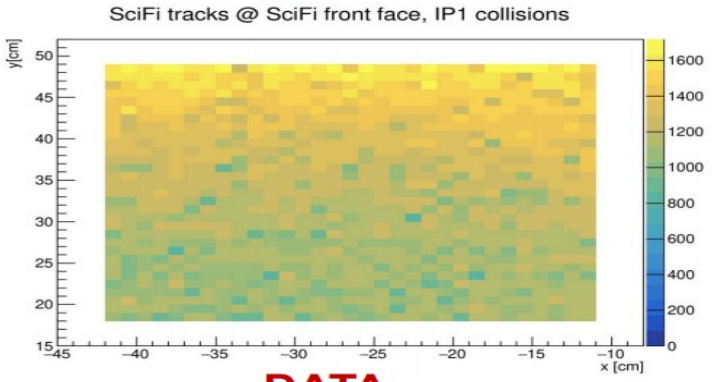
Emulsion Reconstruction
Muon tracks in 1x1cm²
Integrated in Run 0 of
0.51 fb^{-1} (07/04-26/07)



Electronic Detector Reconstruction
Muon track from pp collisions
at 13.6 TeV (06/07/2022)

Data/MC Comparison

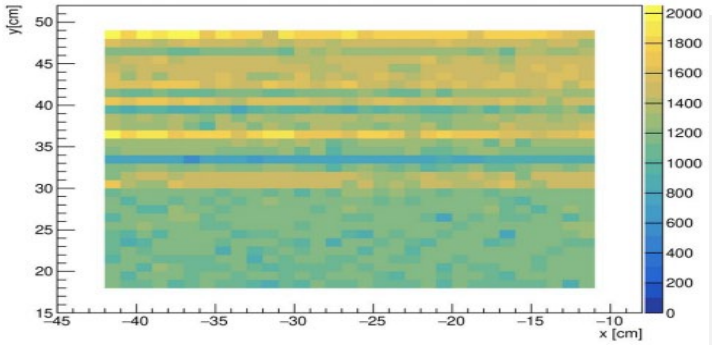
DATA



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

$(1.60 \pm 0.01_{stat}) \times 10^4$ fb/cm^2

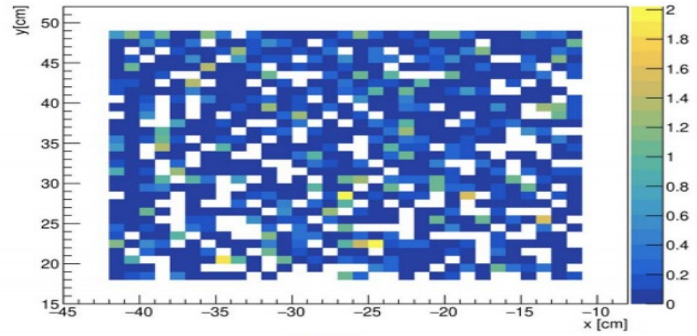
DATA



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

$(1.67 \pm 0.01_{stat}) \times 10^4$ fb/cm^2

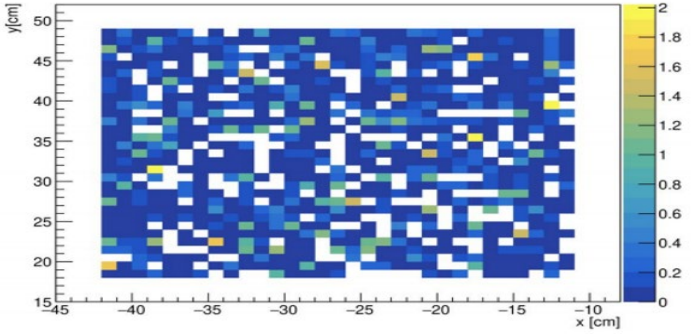
MC



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

$(1.57 \pm 0.10_{stat}) \times 10^4$ fb/cm^2

MC



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

$(1.59 \pm 0.10_{stat}) \times 10^4$ fb/cm^2

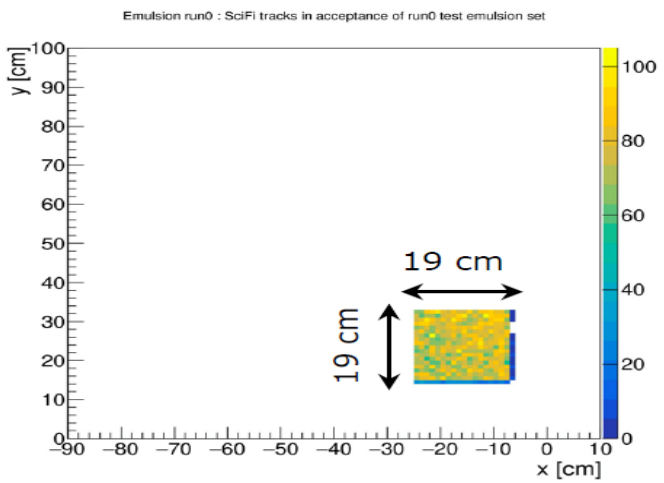
Muon flux from FLUKA
F. Cerutti, M.S. Gilarte
CERN-SY/STI

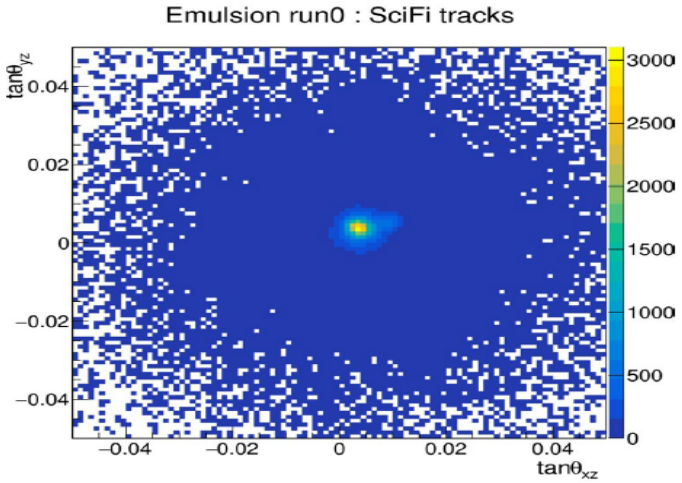
LHC
Scattering and Neutrino Detector
at the LHC

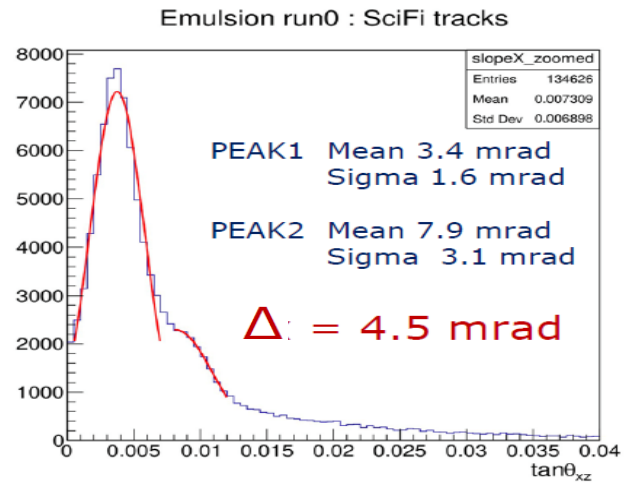
SciFi/Emulsion Comparison

SciFi

Measured rates on BRICK1 surface
1.6x10⁴ fb/cm²

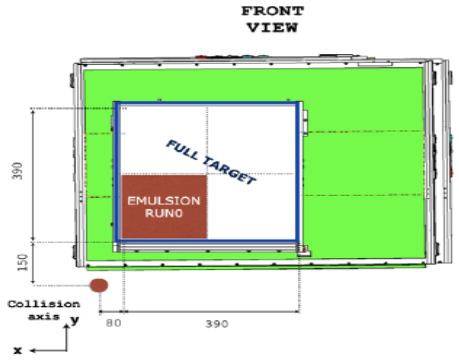


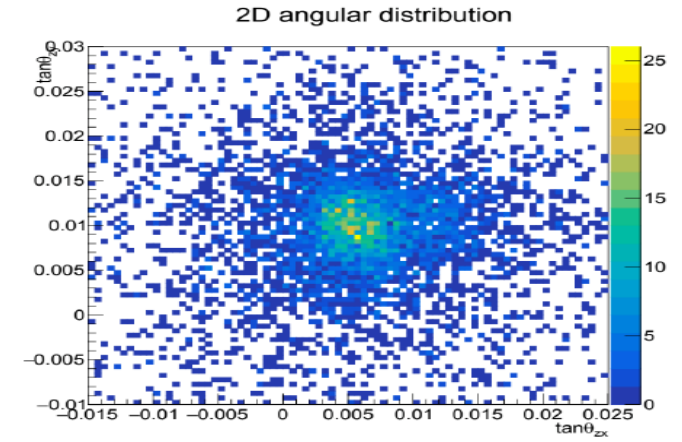


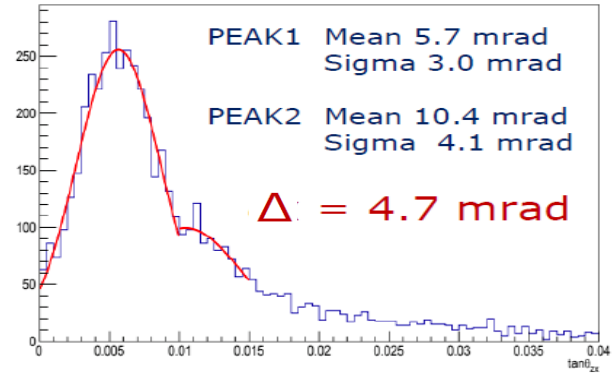


EMULSIONS

Measured rates in BRICK1
1.5x10⁴ fb/cm²



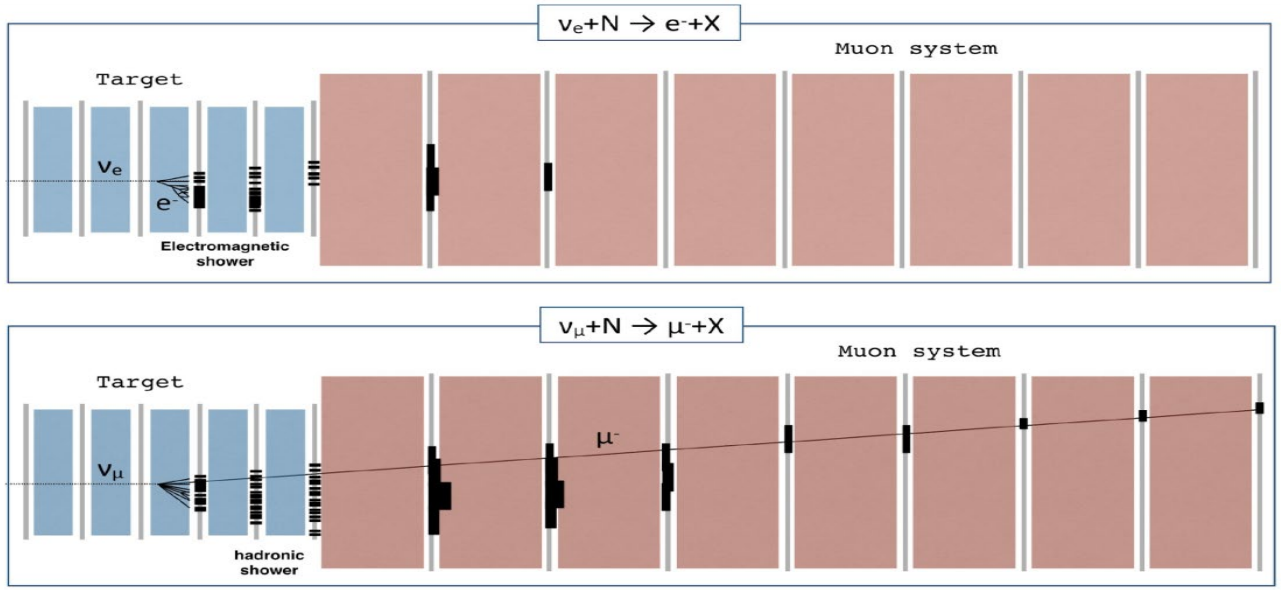


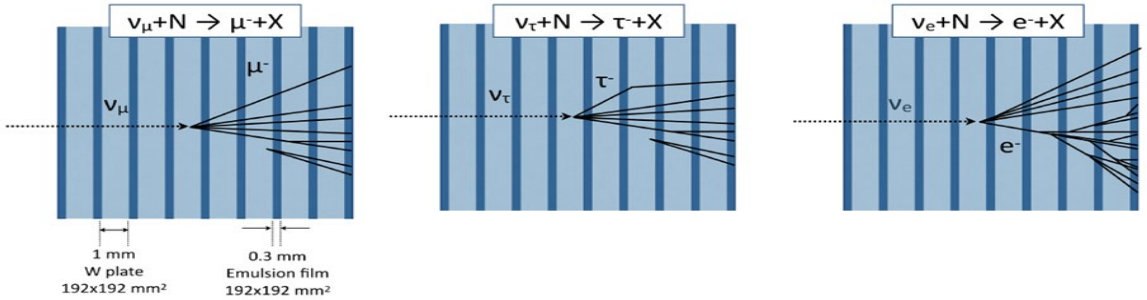


Neutrino Identification Strategy

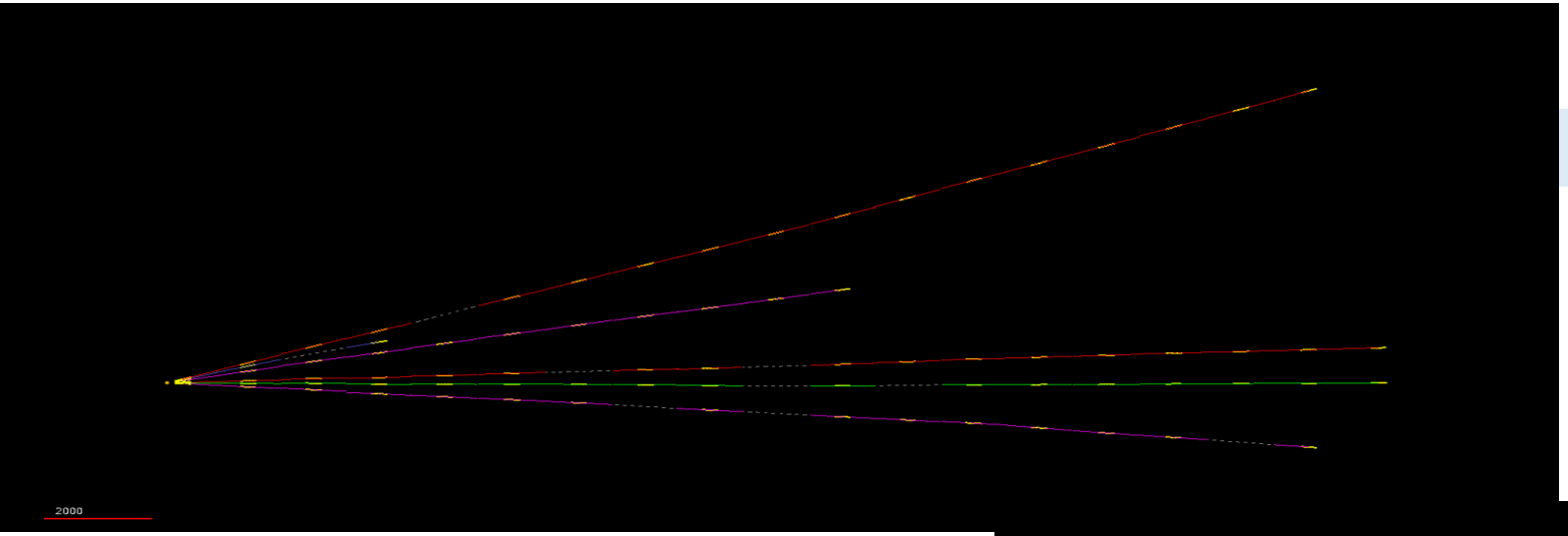
First Stage
- Identify the neutrino candidates in electronic detector data
- Tag muons in the muon system
- Measure electronic and hadronic energies in calorimeters

Second Stage
- Identify the neutrino candidates in emulsion data
- Tag electromagnetic showers
- Match events to electronic detector data
- Identify neutrinos of all flavours!

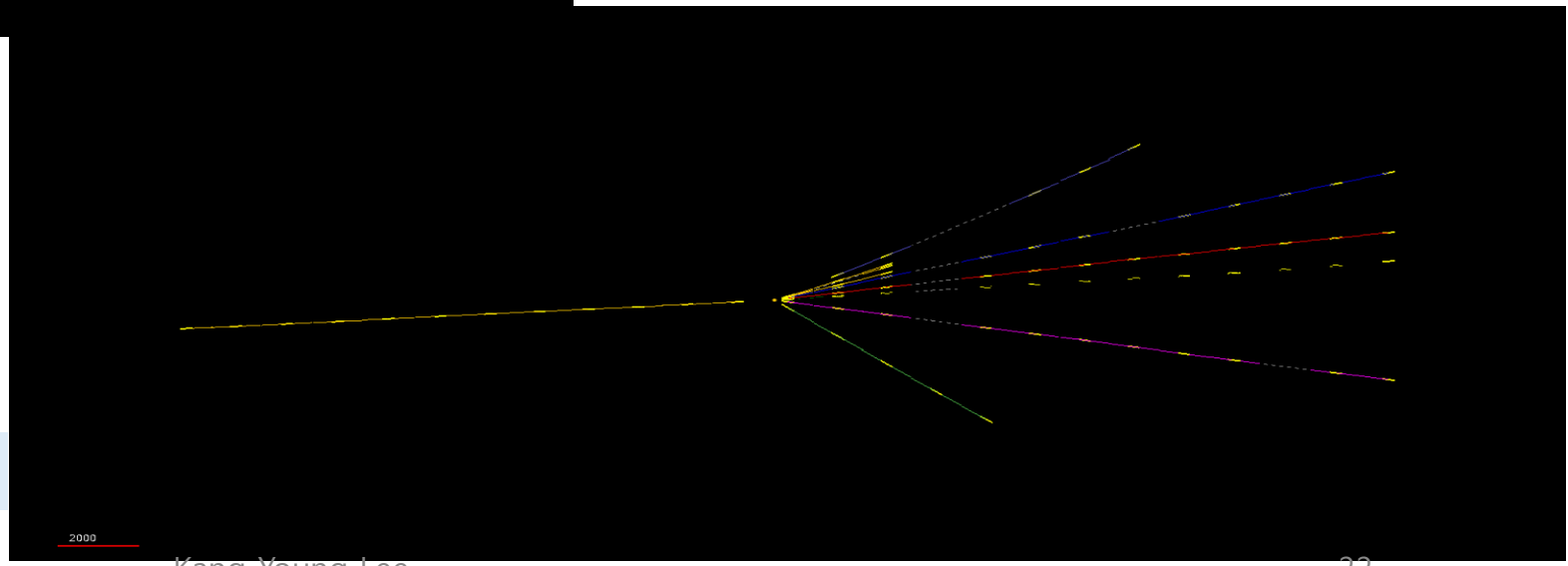




Vertex Reconstruction in Emulsion



Neutral particle interaction



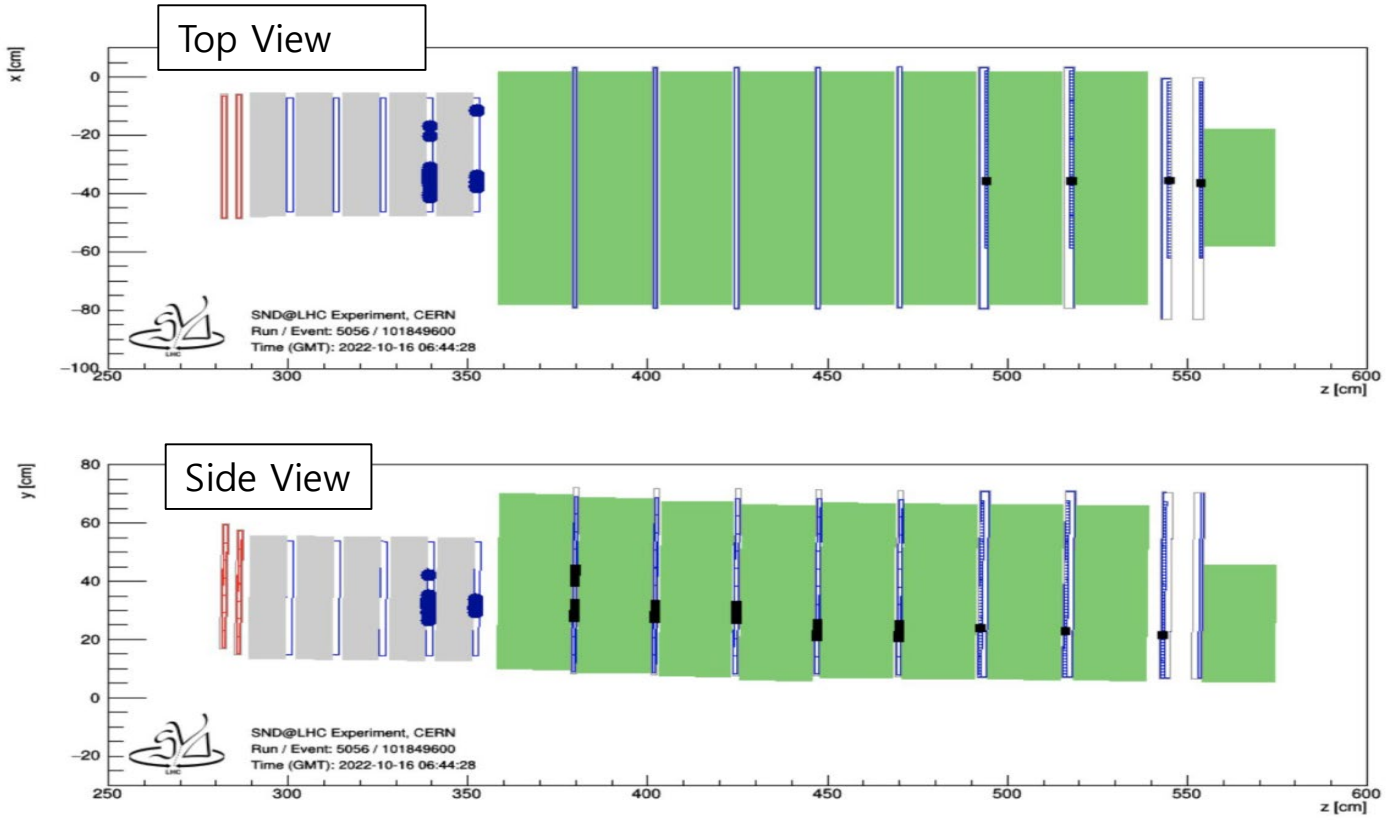
Charged particle interaction

Neutrino Identification with Electronic Detectors

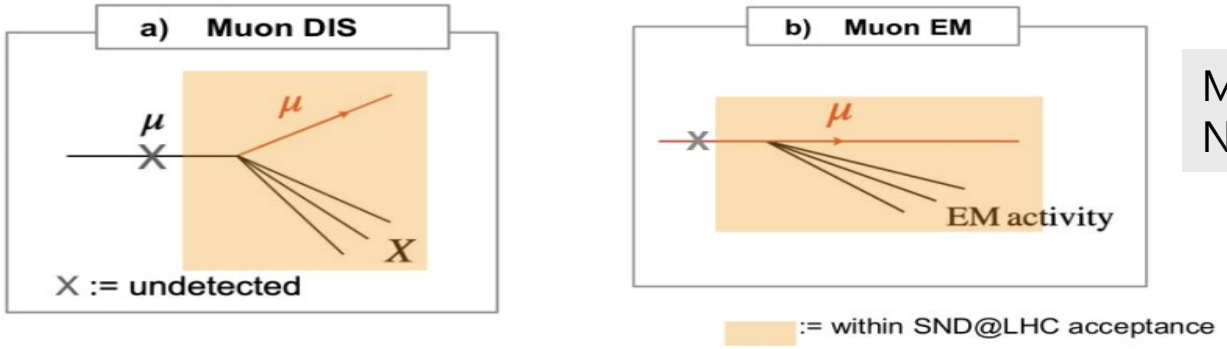
Neutrino selection criteria for electronic detectors

▶ Fiducial volume cuts
- Require an event from a neutral vertex, located in the 3rd or 4th 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
- Require timing for event produced upstream
- Muon reconstructed and isolated in the muon system



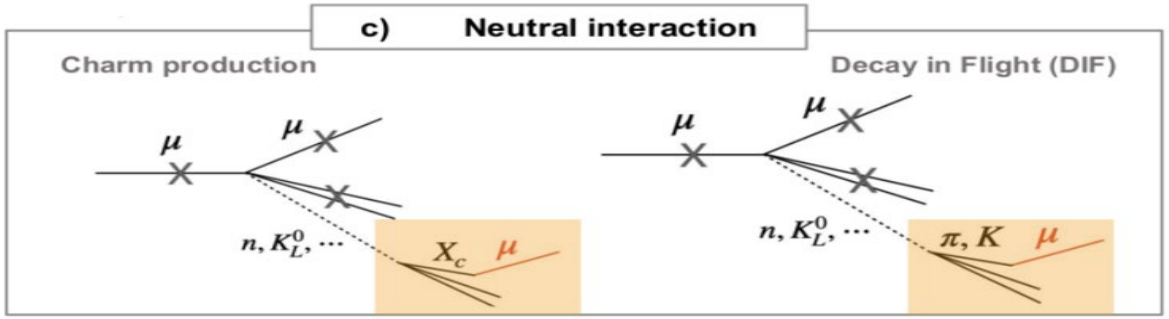
Background Estimation



Muon induced DIS and EM backgrounds
Number of undetected muons entering the target

$$N_u^{bkg} = N_\mu \times (1 - \epsilon_{Veto}) \times (1 - \epsilon_{SciFi1}) \times (1 - \epsilon_{SciFi2}) \sim 10^{-2}$$

SND@LHC PRELIMINARY

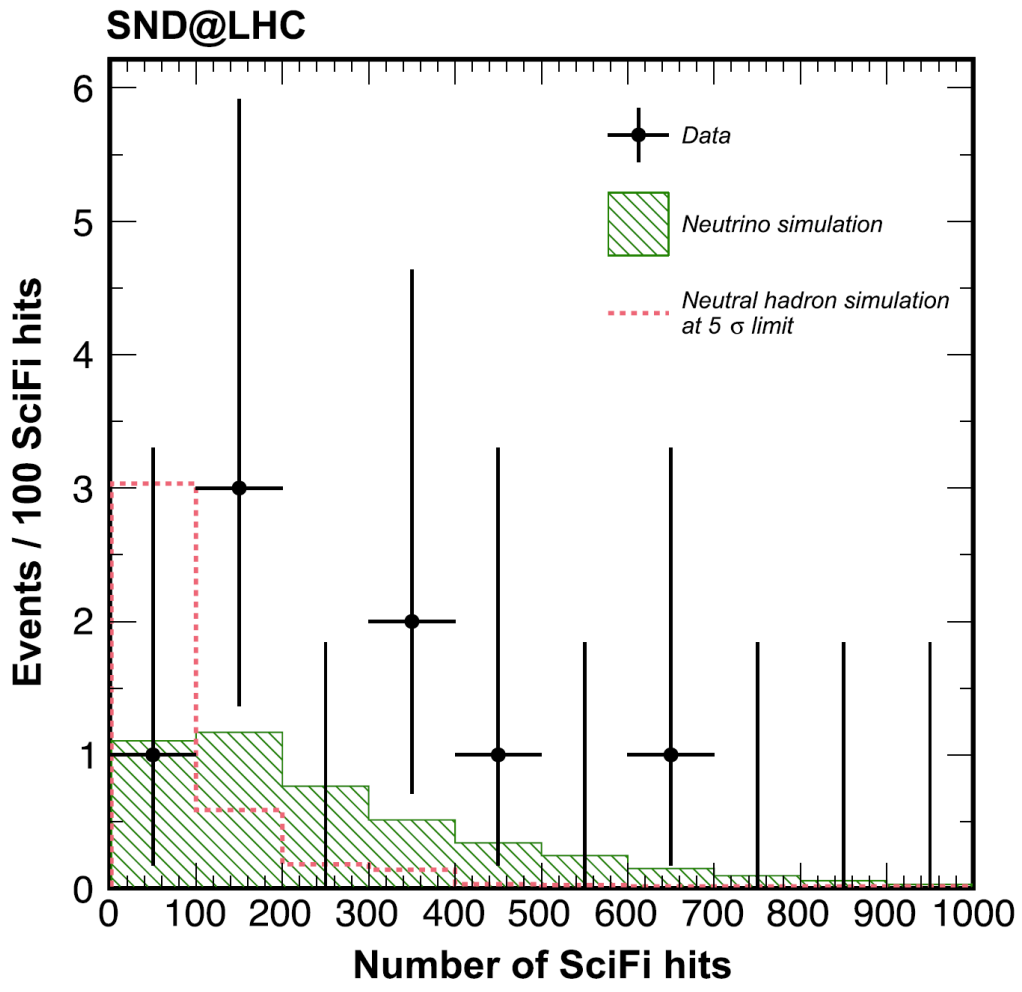


Muon induced neutral interaction backgrounds

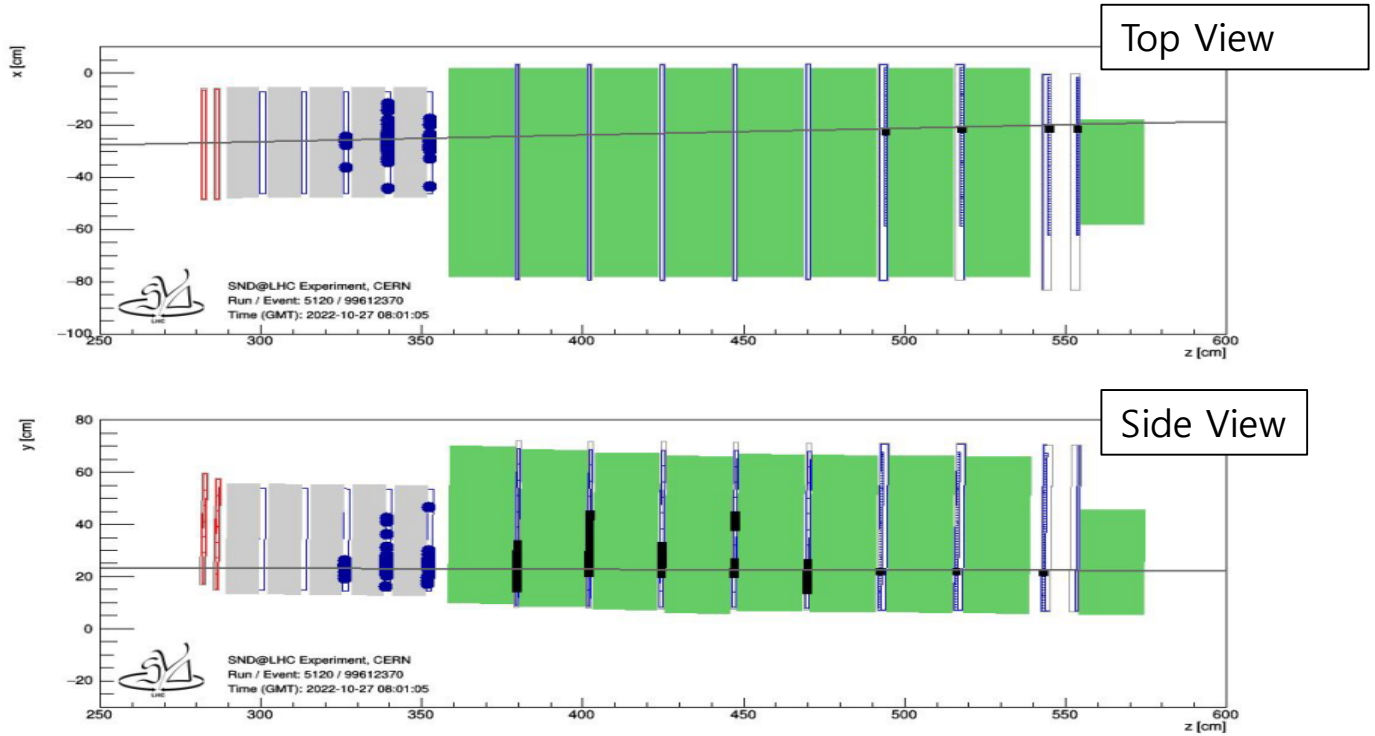
$$N^{\text{bkg}}_{\text{neutrals}} = N_{\text{neutrals}} \times P_{\text{inel}} \times \epsilon_{\text{sel}} \sim 0.2$$

Systematic uncertainty study is ongoing.

Observed Neutrino Candidates



8 ν_μ CC candidates observed
(4.2 expected)
0.2 background yields estimated



Oct 27th

Paper Released

PHYSICAL REVIEW LETTERS **131,** 031802 (2023)

Editors' Suggestion

Observation of Collider Muon Neutrinos with the SND@LHC Experiment

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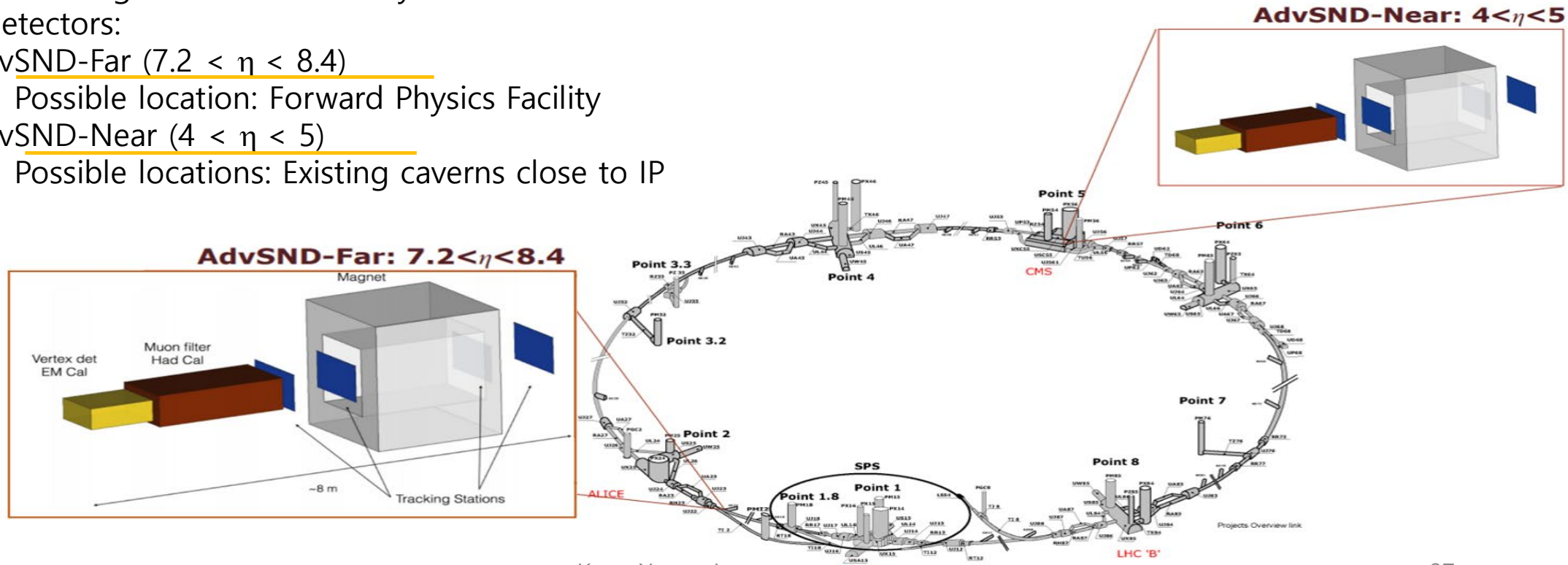
(SND@LHC Collaboration)

Beyond Run 3

Advanced SND@LHC

- Future project at HL-LHC era

- Upgrade of SND@LHC during LS 4
- Extension of the physics case
- New technologies and detector layout
- Two detectors:
  - AdvSND-Far (7.2 < η < 8.4)
    - Possible location: Forward Physics Facility
  - AdvSND-Near (4 < η < 5)
    - Possible locations: Existing caverns close to IP



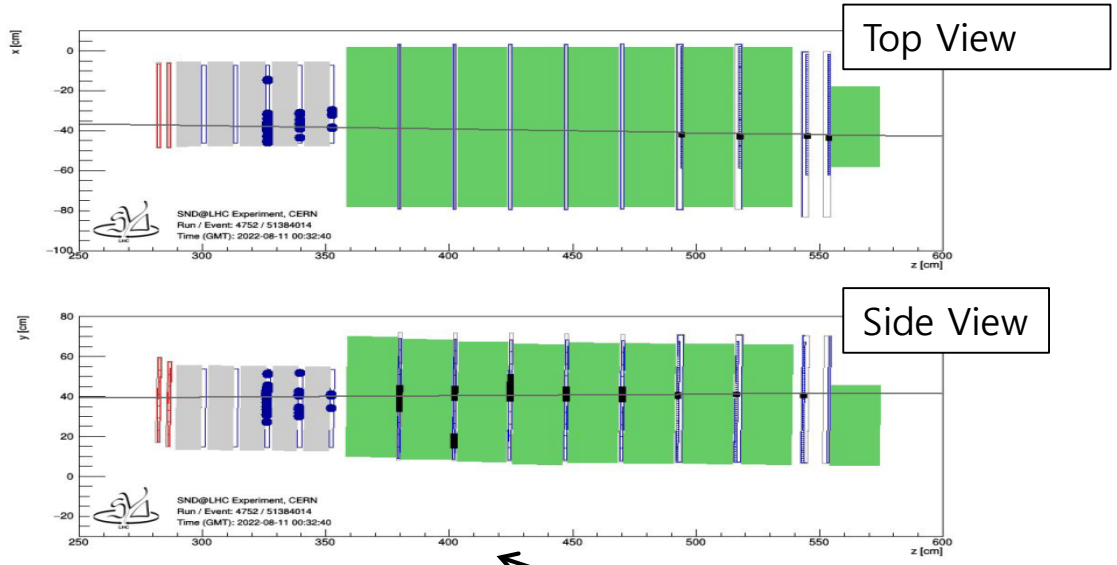
Conclusion

- SND@LHC starts running to perform measurements of ν and search for FIP in the forward region of the LHC.
- SND@LHC collected 39 fb^{-1} data at the LHC Run 3.
- Measurement of muon flux with emulsions and electronic detectors shows good agreements with MC calculation.
- **8 ν_μ CC candidates** are identified with the electronic detectors while the estimated backgrounds are 0.2. Systematic uncertainty is under evaluation to expect significance ~5σ.
- Emulsion scanning & analysis is ongoing. Stay tuned!

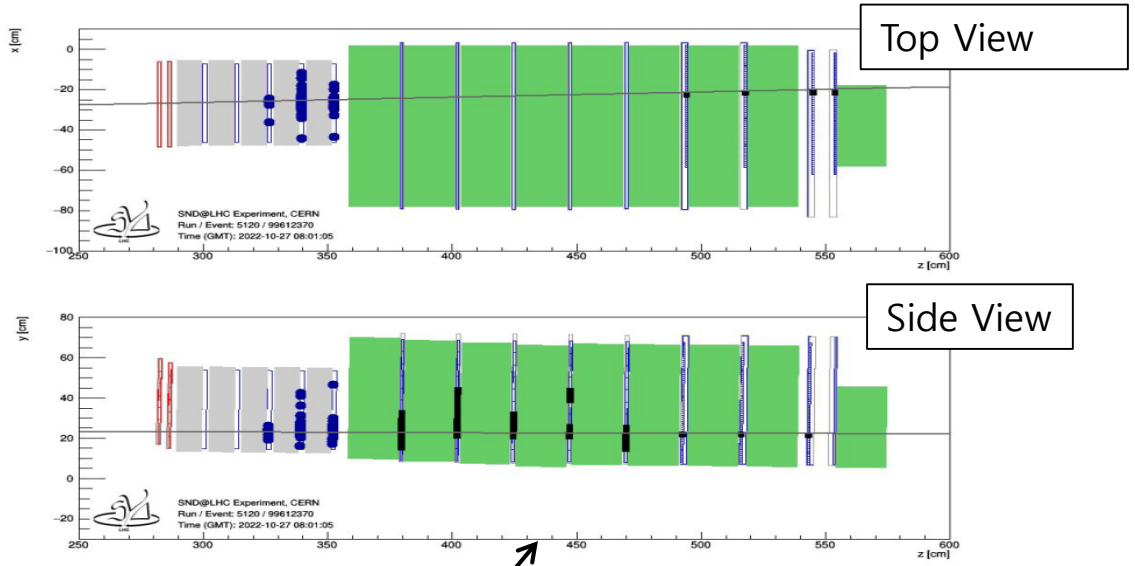
Thank you!

Backup Slides

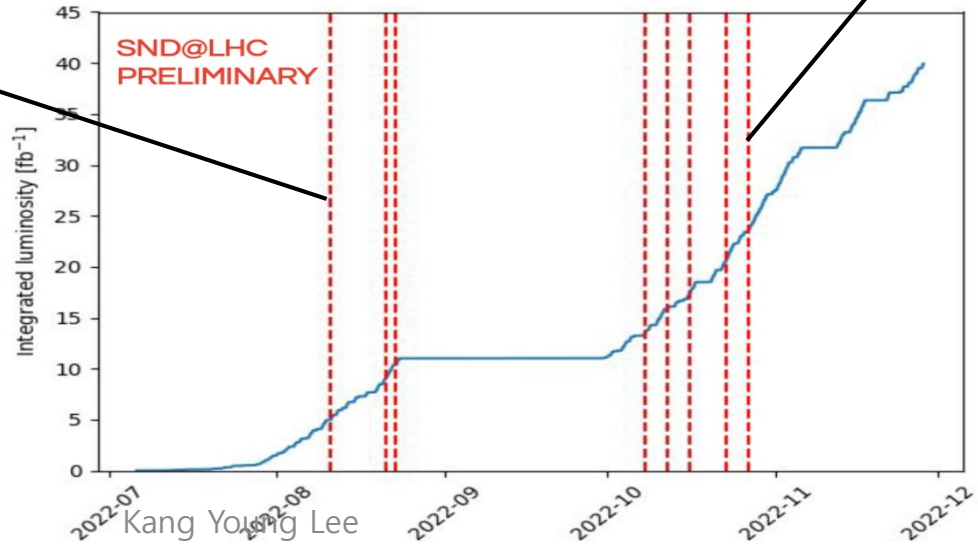
Observed Neutrino Candidates



Aug 11th



Oct 27th



8 ν_μ CC candidates observed
(5 expected)
0.2 background yields estimated