성균관대학교
SUNG KYUN KWAN UNIVERSITY

LHC
Scattering and Neutrino Detector
at the LHC

Physics at SND@LHC

Ki -Young Choi

The 4th Workshop on New Physics Opportunities at Neutrino Facilities

3-5, June, 2024, IBS

The SND@LHC experiment at CERN

LHC
Scattering and Neutrino Detector
at the LHC

Collaboration: 180 members

24 Institutes in 14 countries and CERN

Letter of intent presented on August 27th 2020

Technical Proposal presented in January 2021

Experiment approved in March 2021

1. Neutrino experiment
2. Search for Feebly Interacting Particles

Korean Group

Gyeongsang National University (GNU)

S. H. Kim, K. Y. Lee, B. D. Park, J. Y. Sohn, C. S. Yoon

Korea University (KU)

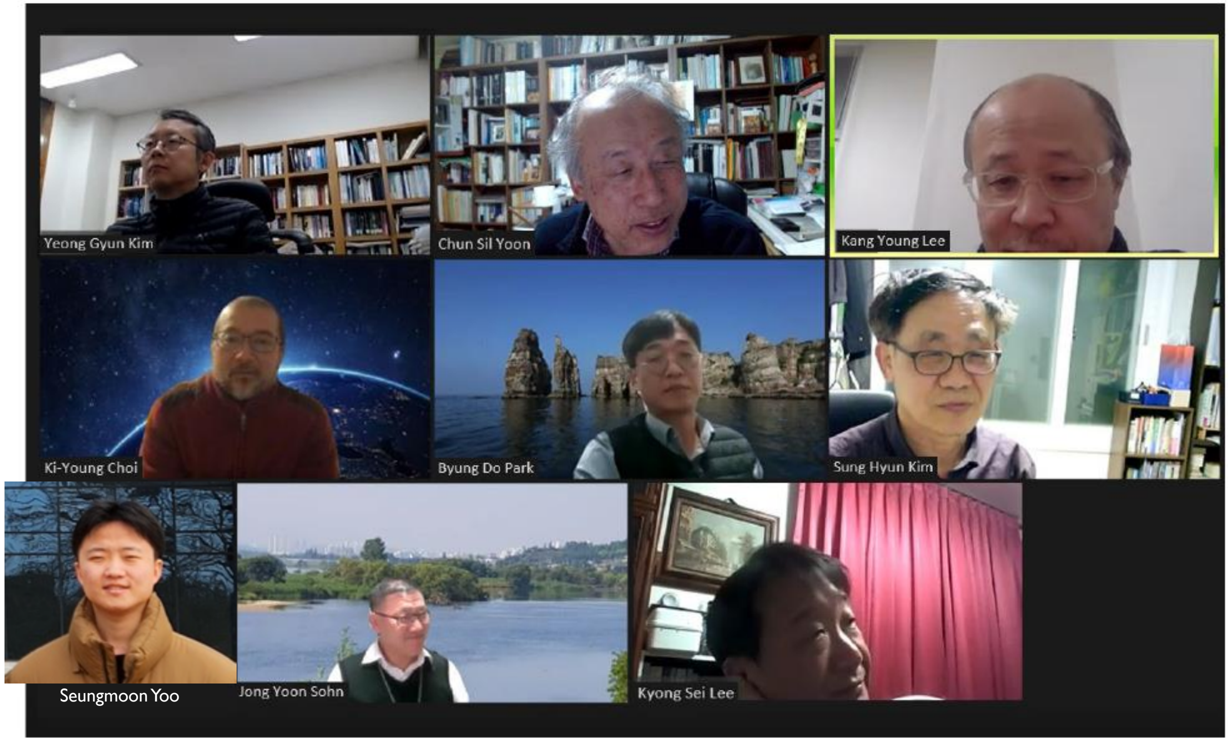
K. S. Lee

Gwangju National University of Education (GNUE)

Y. G. Kim

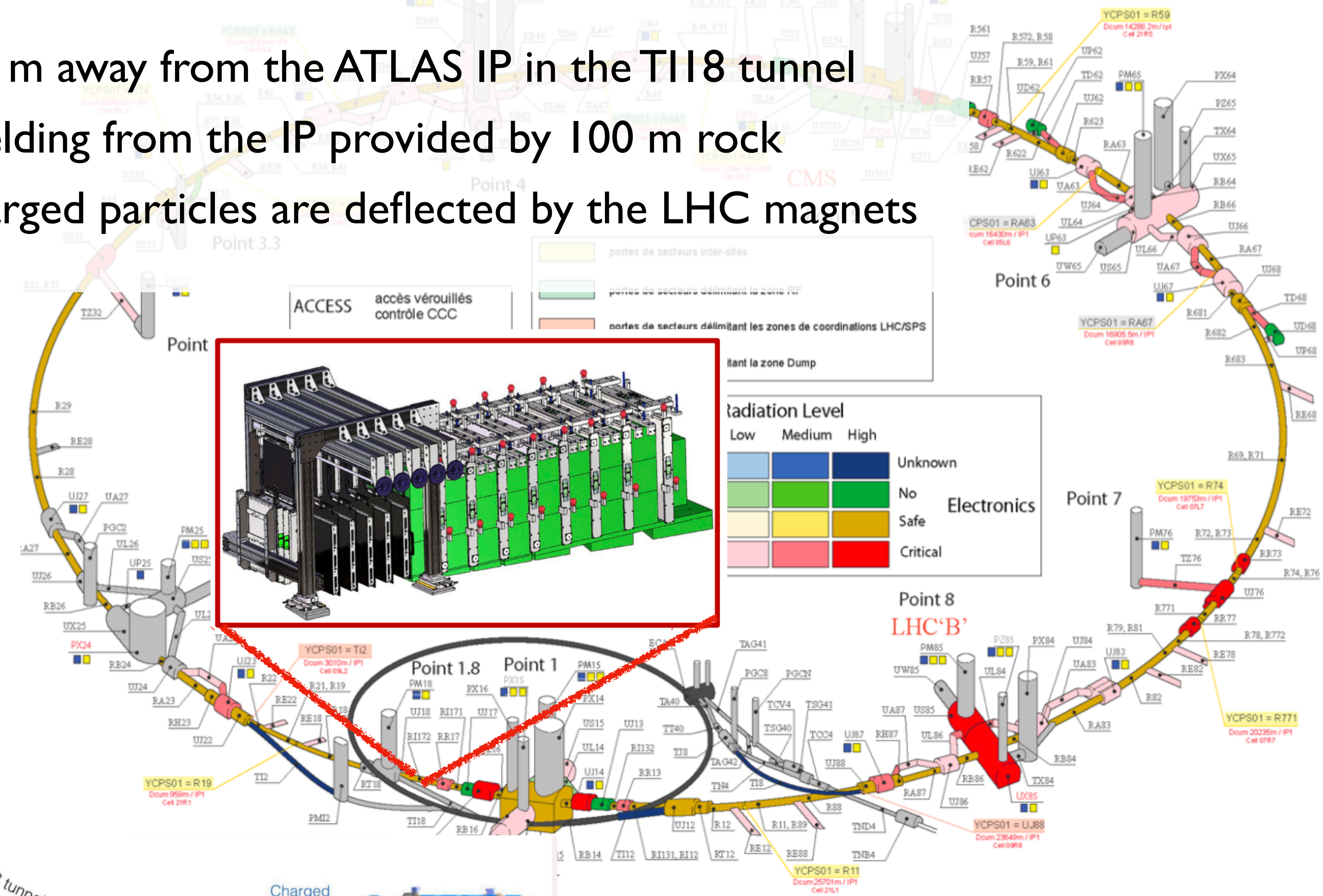
Sungkyunkwan University (SKKU)

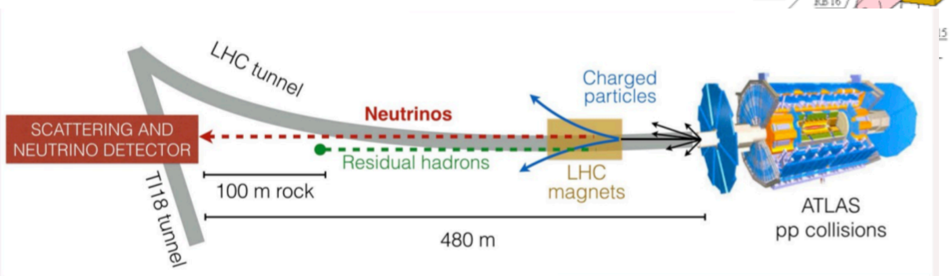
K.-Y. Choi Seungmoon Yoo



Location: TI18, transfer tunnel connecting SPS to LEP

- 480 m away from the ATLAS IP in the TI18 tunnel
- Shielding from the IP provided by 100 m rock
- Charged particles are deflected by the LHC magnets





Detector installation in TI18

- Started on November 1st 2021
- Electronic detector completed on December 3rd 2021
- Neutron shield completed on March 15th 2022
- First emulsion films in the target on April 7th 2022

September 2021

December 2021

March 2022

[From Giovanni's slide]

Experiment Concept

Hybrid detector optimized for the identification of all three neutrino flavors

Veto Plane:
tag penetrating muons

Neutrino Target & Vertex Detector:
Emulsion cloud chambers, 830kg tungsten plates interleaved with nuclear emulsion and electronic trackers

SciFi Planes as EM Calorimeter:
Scintillating fibres for timing information and EM energy measurement

Hadronic Calorimeter:
Iron walls interleaved with plastic scintillator planes

Muon Identification System:
3 most downstream plastic scintillator stations based on fine-grained bars, meant for the muon identification and tracking

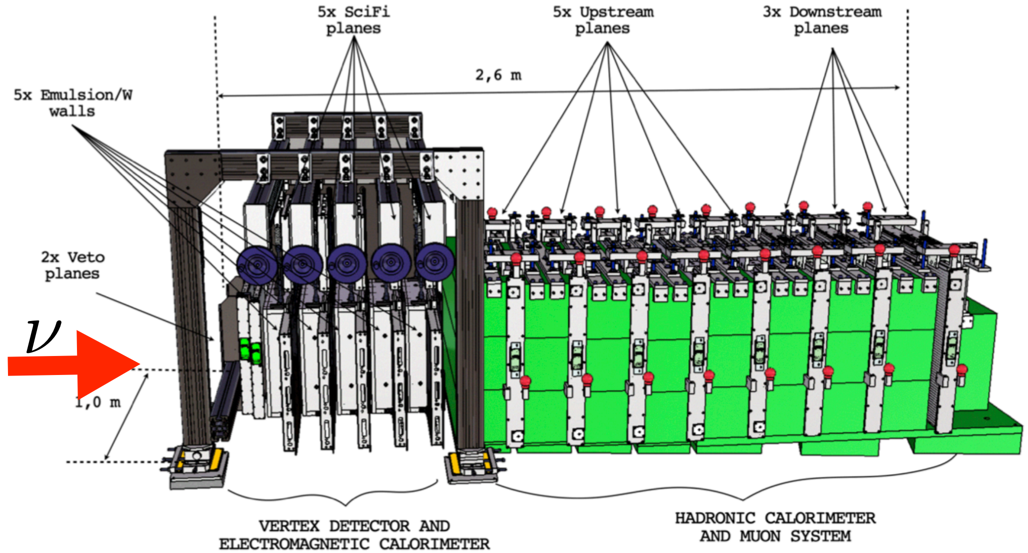


Figure 3: Layout of the SND@LHC experiment.

[SND@LHC, 2210.02784]

SND@LHC Detector

[SND@LHC, PRL 2023]

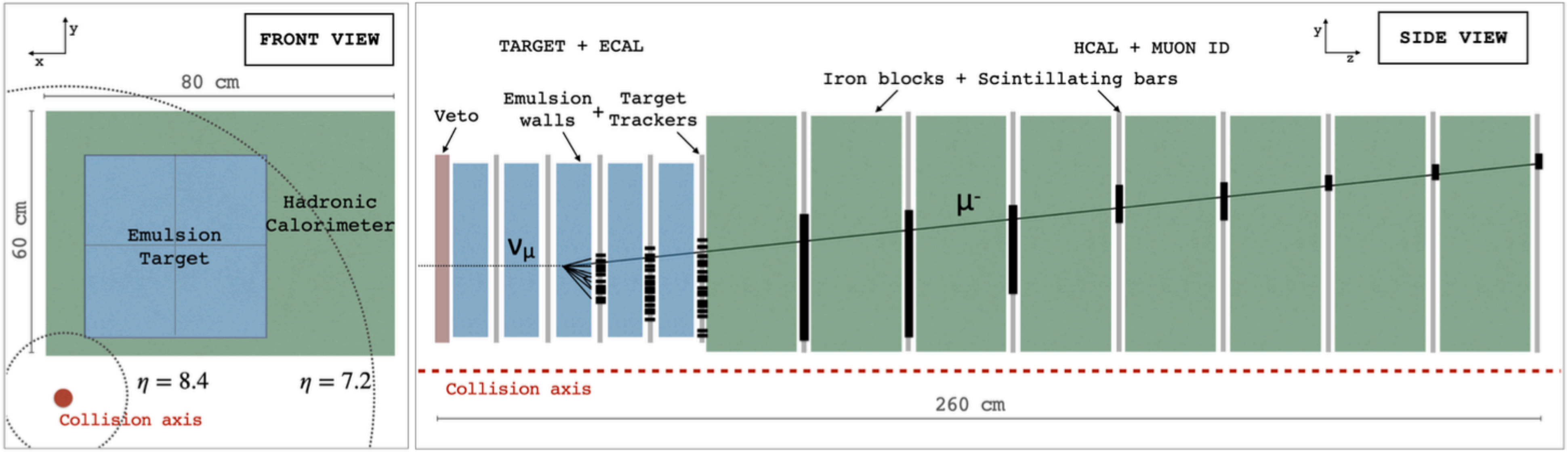
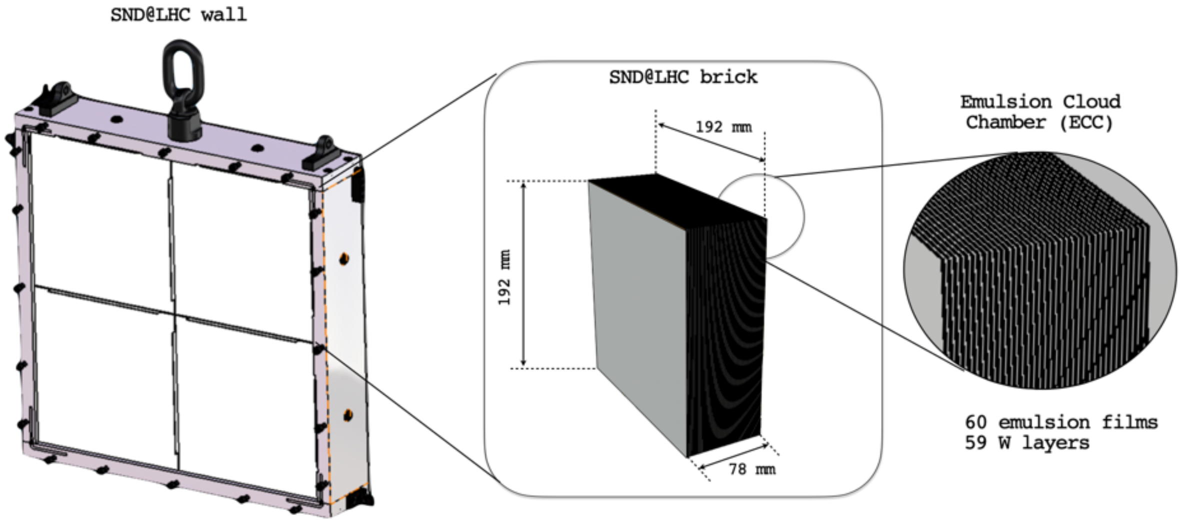


FIG. 1. Schematic layout of the SND@LHC detector front view (left) and side view (right). The side view includes an illustration of a ν_μ charged-current interaction in the target with a hadronic shower sampled in the emulsion target, target trackers, and hadronic calorimeter, and a muon track visible in the muon system.

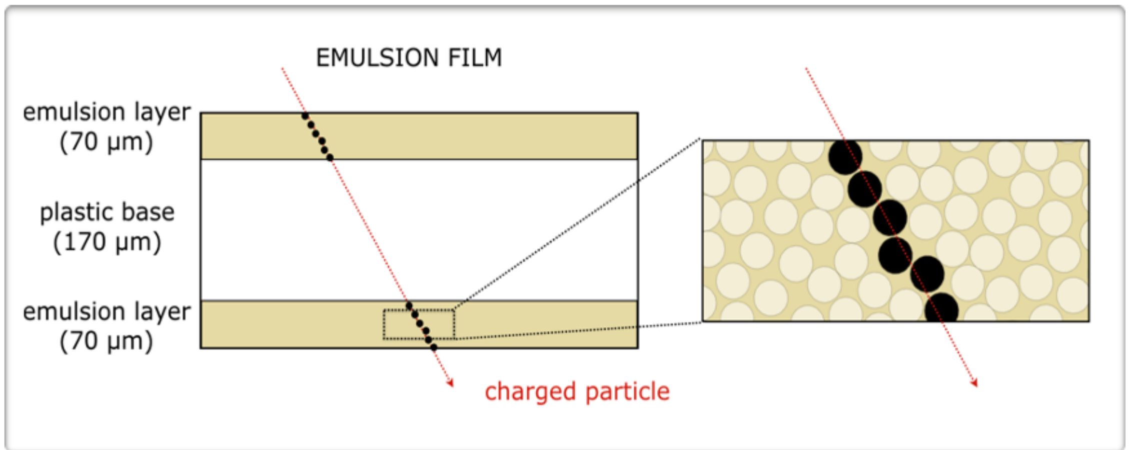
- off-axis wrt ATLAS IP1, pseudo-rapidity $7.2 < \eta < 8.4$
- hybrid detector with nuclear emulsion and electronic detectors
- e and tau neutrinos mostly come from charm decays for this pseudo-rapidity,
- muon neutrinos mainly from decay of pion and Kaon
- around 2,000 neutrino events fro RUN3

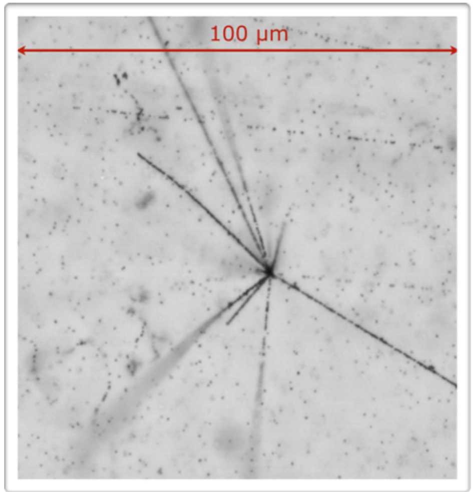
Emulsion Target and ECC block



60 emulsion films
59 tungsten layers

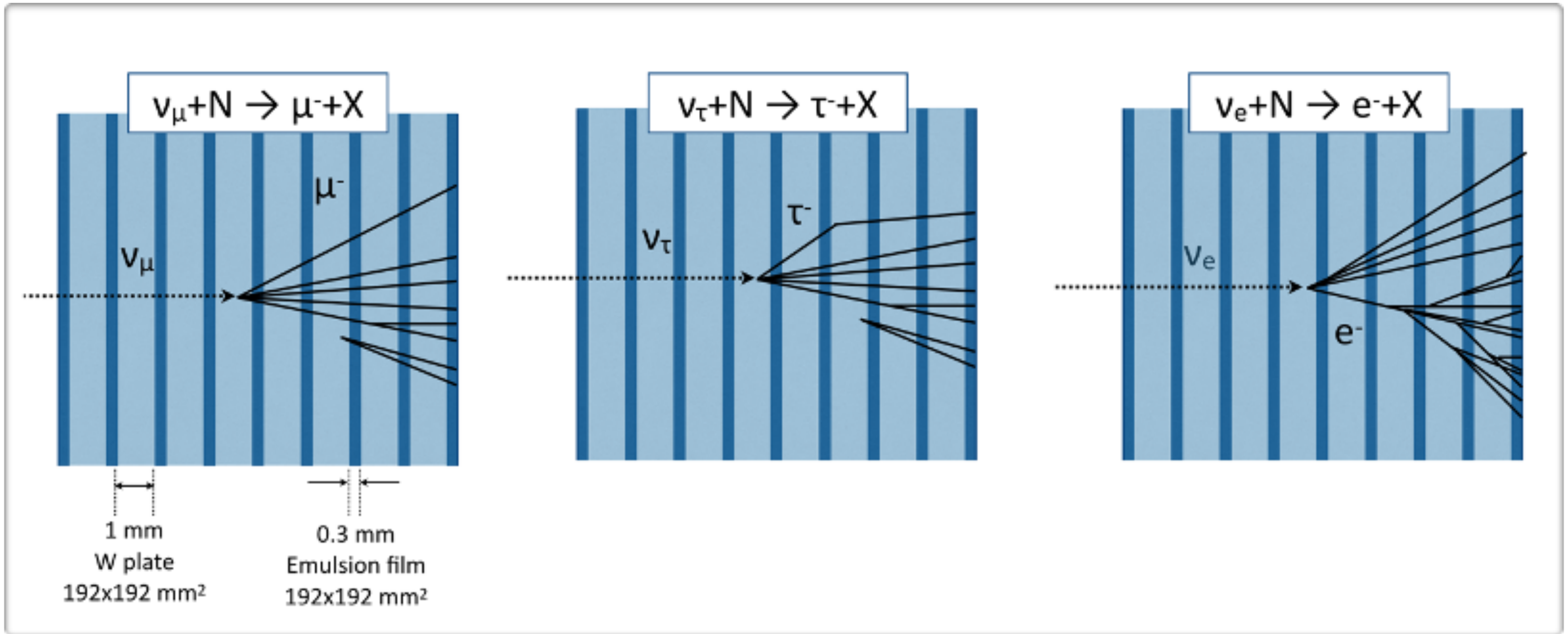
Target assembled according to the Emulsion Cloud Chamber (ECC) technique:
Tungsten layers (1mm-thick) alternated to nuclear emulsion films





Sub-micrometric position resolution

Neutrino Flavor Identification



Muon Neutrino at SND@LHC

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

Editors' Suggestion

Observation of Collider Muon Neutrinos with the SND@LHC Experiment

R. Albanese,[1,2] A. Alexandrov,[1] F. Alicante,[1,2] A. Anokhina,[3] T. Asada,[1,2] C. Battilana,[4,5] A. Bay,[6] C. Betancourt,[7] R. Biswas,[8] A. Blanco Castro,[9] M. Bogomilov,[10] D. Bonacorsi,[4,5] W. M. Bonivento,[11] P. Bordalo,[9] A. Boyarsky,[12,13] S. Buontempo,[1] M. Campanelli,[14] T. Camporesi,[8] V. Canale,[1,2] A. Castro,[4,5] D. Centanni,[1,15] F. Cerutti,[8] M. Chernyavskiy,[3] K.-Y. Choi,[16] S. Cholak,[6] F. Cindolo,[4] M. Climescu,[17] A. P. Conaboy,[18] G. M. Dallavalle,[4] D. Davino,[1,19] P. T. de Bryas,[6] G. De Lellis,[1,2] M. De Magistris,[1,15] A. De Roeck,[8] A. De Rújula,[8] M. De Serio,[20,21] D. De Simone,[7] A. Di Crescenzo,[1,2] R. Donà,[4,5] O. Durhan,[22] F. Fabbri,[4] F. Fedotovs,[14] M. Ferrillo,[7] M. Ferro-Luzzi,[8] R. A. Fini,[20] A. Fiorillo,[1,2] R. Fresa,[1,23] W. Funk,[8] F. M. Garay Walls,[24] A. Golovatiuk,[1,2] A. Golutvin,[25] E. Graverini,[6] A. M. Guler,[22] V. Guliaeva,[3] G. J. Haefeli,[6] J. C. Helo Herrera,[26,27] E. van Herwijnen,[25] P. Iengo,[1] S. Ilieva,[1,2,10] A. Infantino,[8] A. Iuliano,[1,2] R. Jacobsson,[8] C. Kamiscioglu,[22,28] A. M. Kauniskangas,[6] E. Khalikov,[3] S. H. Kim,[29] Y. G. Kim,[30] G. Klioutchnikov,[8] M. Komatsu,[31] N. Konovalova,[3] S. Kovalenko,[26,32] S. Kuleshov,[26,32] H. M. Lacker,[18] O. Lantwin,[3] F. Lasagni Manghi,[4] A. Lauria,[1,2] K. Y. Lee,[29] K. S. Lee,[33] S. Lo Meo,[4] V. P. Loschiavo,[1,19] S. Marcellini,[4] A. Margiotta,[4,5] A. Mascellani,[6] A. Miano,[1,2] A. Mikulenko,[12] M. C. Montesi,[1,2] F. L. Navarria,[4,5] S. Ogawa,[34] N. Okateva,[3] M. Ovchynnikov,[12] G. Paggi,[4,5] B. D. Park,[29] A. Pastore,[20] A. Perrotta,[4] D. Podgrudkov,[3] N. Polukhina,[3] A. Prota,[1,2] A. Quercia,[1,2] S. Ramos,[9] A. Reghunath,[18] T. Roganova,[3] F. Ronchetti,[6] T. Rovelli,[4,5] O. Ruchayskiy,[35] T. Ruf,[8] M. Sabate Gilarte,[8] M. Samoilov,[3] V. Scalera,[1,15] O. Schneider,[6] G. Sekhniaidze,[1] N. Serra,[7] M. Shaposhnikov,[6] V. Shevchenko,[3] T. Shchedrina,[3] L. Shchutska,[6] H. Shibuya,[34,36,†] S. Simone,[20,21] G. P. Siroli,[4,5] G. Sirri,[4] G. Soares,[9] O. J. Soto Sandoval,[26,27] M. Spurio,[4,5] N. Starkov,[3] I. Timiryasov,[35] V. Tioukov,[1] F. Tramontano,[1] C. Trippl,[6] E. Ursov,[3] A. Ustyuzhanin,[1,36] G. Vankova-Kirilova,[10] V. Verguilov,[10] N. Viegas Guerreiro Leonardo,[9] C. Vilela,[9,*] C. Visone,[1,2] R. Wanke,[17] E. Yaman,[22] C. Yazici,[22] C. S. Yoon,[29] E. Zaffaroni,[6] and J. Zamora Saa[26,32]

(SND@LHC Collaboration)

We report the direct observation of muon neutrino interactions with the SND@LHC detector at the Large Hadron Collider. A dataset of proton-proton collisions at $\sqrt{s} = 13.6$ TeV collected by SND@LHC in 2022 is used, corresponding to an integrated luminosity of 36.8 fb^{-1}. The search is based on information from the active electronic components of the SND@LHC detector, which covers the pseudorapidity region of $7.2 < \eta < 8.4$, inaccessible to the other experiments at the collider. Muon neutrino candidates are identified through their charged-current interaction topology, with a track propagating through the entire length of the muon detector. After selection cuts, 8 ν_μ interaction candidate events remain with an estimated background of 0.086 events, yielding a significance of about 7 standard deviations for the observed ν_μ signal.

DOI: 10.1103/PhysRevLett.131.031802

Muon Neutrino at LHC

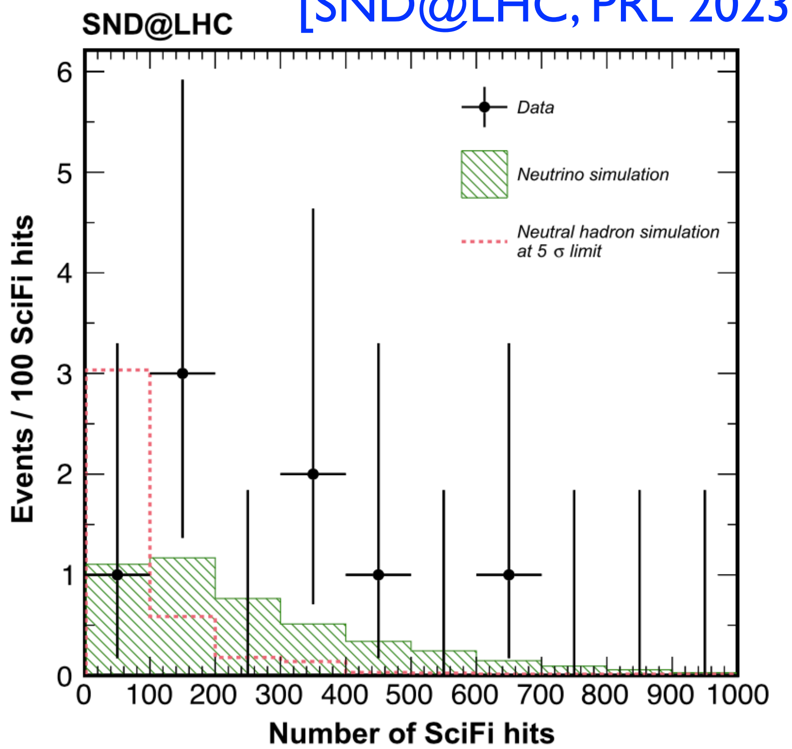
Direct observation of muon neutrino CCDIS interactions solely using electronic detector with SND@LHC at LHC in 2022.

Data collected with proton-proton collision at $\sqrt{s} = 13.6\,\mathrm{TeV}$

with integrated luminosity of $36.8\,\mathrm{fb}^{-1}$ total 8.3x10^9 events

[SND@LHC, PRL 2023]

pseudo rapidity region $7.2 < \eta < 8.4$



After selection cuts, 8 muon neutrino events with an estimated bkg 0.086 events.

Updated muon neutrino results (2022-2023)
32 events observed [From Giovanni's slide]

(cf) FASER also detected muon neutrino on axis at eta > 8.5 using 2022 data.

Eur. Phys. J. C (2024) 84:90
https://doi.org/10.1140/epjc/s10052-023-12380-3

THE EUROPEAN PHYSICAL JOURNAL C

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Regular Article - Experimental Physics

Muon Flux
at SND@LHC

Measurement of the muon flux at the SND@LHC experiment

Abstract The Scattering and Neutrino Detector at the LHC (SND@LHC) started taking data at the beginning of Run 3 of the LHC. The experiment is designed to perform measurements with neutrinos produced in proton-proton collisions at the LHC in an energy range between 100 GeV and 1 TeV. It covers a previously unexplored pseudo-rapidity range of $7.2 < \eta < 8.4$. The detector is located 480 m downstream of the ATLAS interaction point in the TI18 tunnel. It comprises a veto system, a target consisting of tungsten plates interleaved with nuclear emulsion and scintillating fiber (SciFi) trackers, followed by a muon detector (UpStream, US and DownStream, DS). In this article we report the measurement of the muon flux in three subdetectors: the emulsion, the SciFi trackers and the DownStream Muon detector. The muon flux per integrated luminosity through an $18\times18\,\text{cm}^2$ area in the emulsion is:

$$1.5 \pm 0.1(\text{stat}) \times 10^4\ \text{fb/cm}^2.$$

The muon flux per integrated luminosity through a $31\times31\,\text{cm}^2$ area in the centre of the SciFi is:

$$2.06 \pm 0.01(\text{stat}) \pm 0.12(\text{sys}) \times 10^4\text{fb/cm}^2$$

The muon flux per integrated luminosity through a $52\times52\,\text{cm}^2$ area in the centre of the downstream muon system is:

$$2.35 \pm 0.01(\text{stat}) \pm 0.10(\text{sys}) \times 10^4\ \text{fb/cm}^2$$

The total relative uncertainty of the measurements by the electronic detectors is 6% for the SciFi and 4% for the DS measurement. The Monte Carlo simulation prediction of these fluxes is 20–25% lower than the measured values.

Physics Goals of SND@LHC

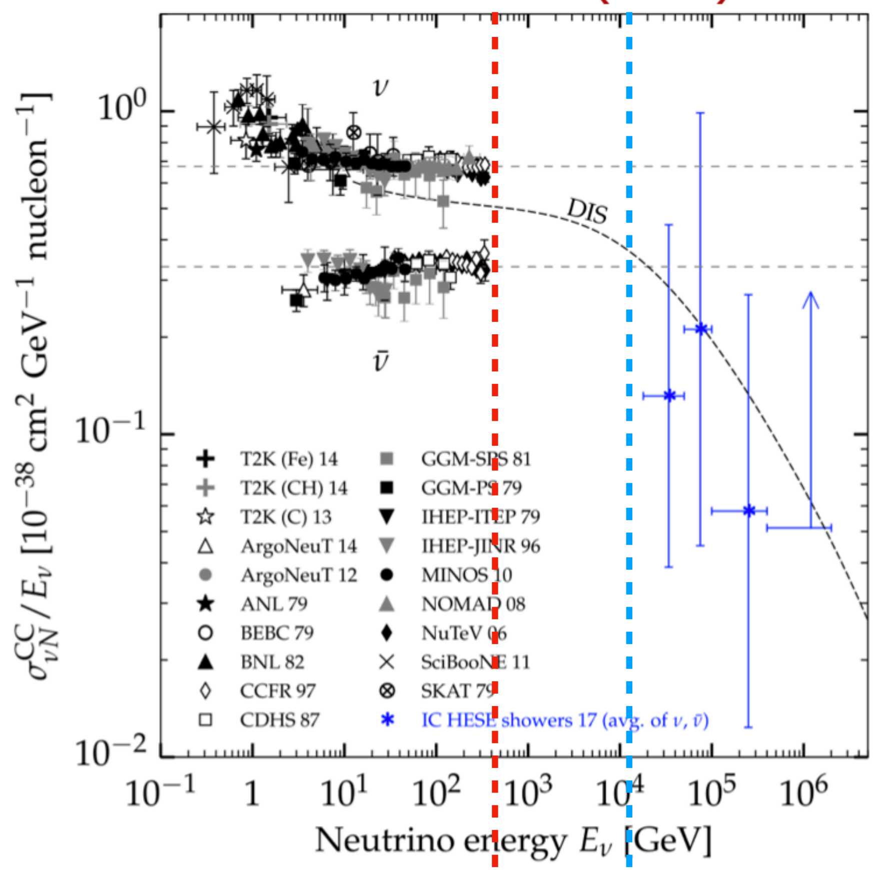
1. Precise test of Standard Model with neutrinos

2. Searching for New Physics with Feebly Interacting Particles

Neutrino Interaction Measurement

[Bustamante, Connolly]

PRL 122 (2019) 041101



~ 350GeV

10TeV ~ PeV

ICeCube

- Neutrino interaction is unexplored energy between 350GeV-10TeV

- LHC produces energetic neutrino from pp collisions around 100GeV - a few TeV

- During RUN3, 2000 neutrino signal can be used to study the interaction of neutrinos.

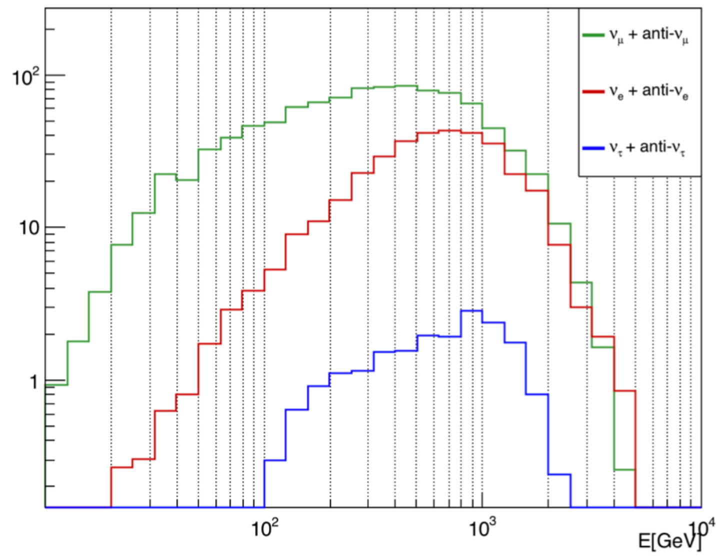
Neutrino Detection

- Neutrino detector covers pseudo rapidity $7.2 < \eta < 8.4$
- The spectra and yield for three different flavors are observed
- Neutrinos from leptonic decay of W, Z boson, b and c decays, and subsequent decays of pions and Kaons.

Flavour	Neutrinos in acceptance ⟨E⟩ [GeV]	Neutrinos in acceptance Yield	CC neutrino interactions ⟨E⟩ [GeV]	CC neutrino interactions Yield	NC neutrino interactions ⟨E⟩ [GeV]	NC neutrino interactions Yield
ν_μ	145	2.1×10^{12}	450	730	480	220
$\bar{\nu}_\mu$	145	1.8×10^{12}	485	290	480	110
ν_e	395	2.6×10^{11}	760	235	720	70
$\bar{\nu}_e$	405	2.8×10^{11}	680	120	720	44
ν_τ	415	1.5×10^{10}	740	14	740	4
$\bar{\nu}_\tau$	380	1.7×10^{10}	740	6	740	2
TOT		4.5×10^{12}		1395		450

Table 15: Number of neutrinos in the SND@LHC acceptance, charged-current and neutral-current neutrino interactions in the detector target, assuming 150 fb^{-1}. Average energies are also reported.

[SND@LHC, Techinical Proposal]



Neutrino Physics

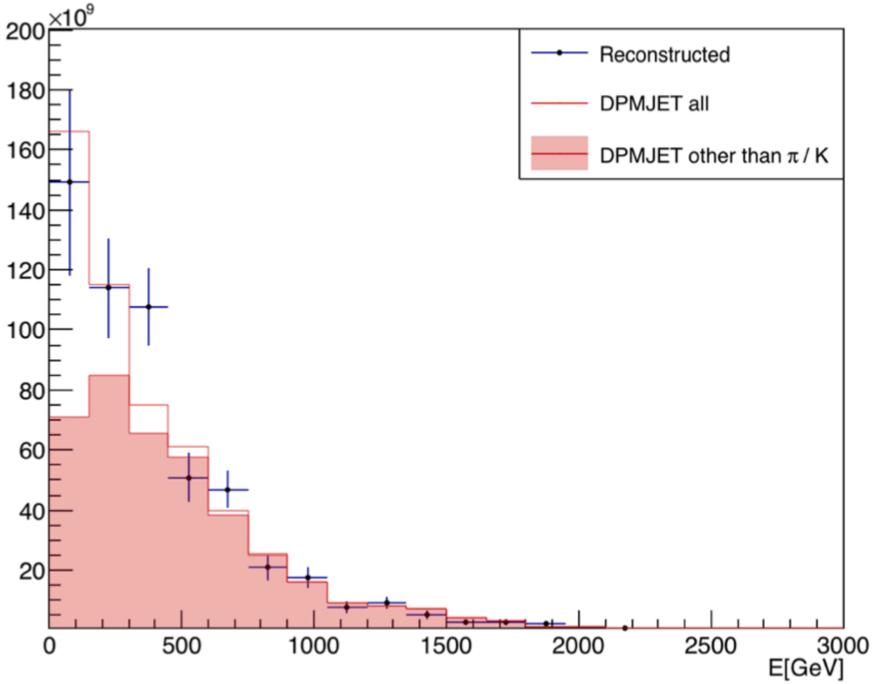
1. Measurement of the $pp \to \nu_e X$ cross-section

2. Charmed hadron production in pp collisions

3. Lepton flavor universality in neutrino interactions

4. Measurement of the NC/CC ratio

1. Measurement $pp \to \nu_e X$ cross-section



- Electron (anti)-neutrinos are dominantly (90%) produced from charmed -hadron decays for $7.2 < \eta < 8.4$

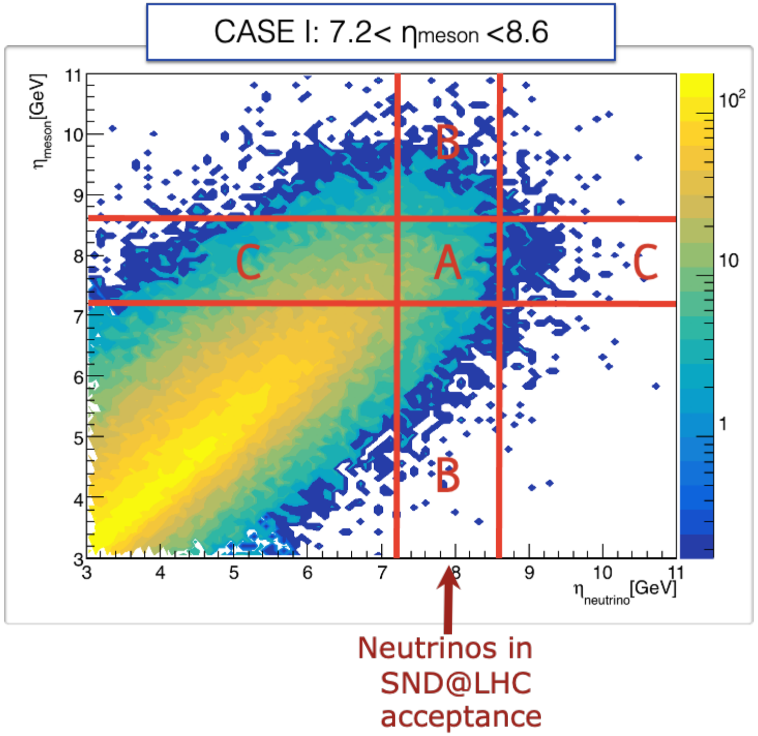
- 10% of Electron and anti-neutrinos are from Kaon decays, and 3% from beauty-hadron decay

- Data can measure the $pp \to \nu_e X$ cross section with an accuracy 15%

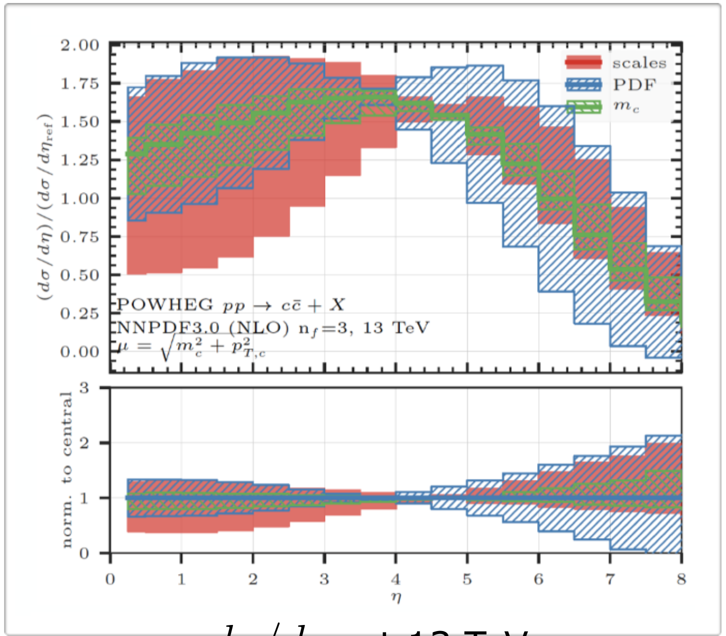
- SND@LHC is capable of measuring charmed-hadron production indirectly through the observation of electron neutrinos and anti-neutrinos

2. Charmed hadron production in pp collisions

Correlation between pseudo-rapidity of the electron (anti-) neutrino and the parent charmed hadron



The dominant partonic process for associated charm production at the LHC is gluon-gluon scattering



$d\sigma/d\eta$ at 13 TeV

Extraction of gluon PDF in very small x-region relevant for Future Circular Colliders

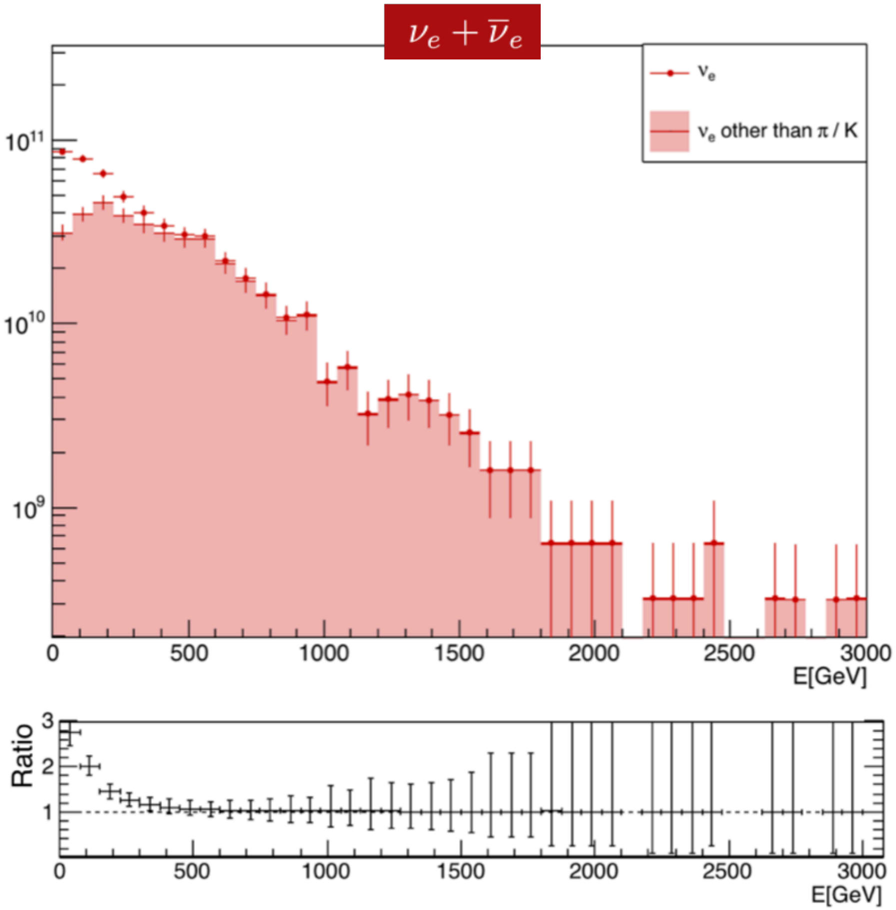
Ratio between the cross-section measurements at different energies and pseudo-rapidities

$$R = \frac{d\sigma/d\eta(13\,TeV)}{d\sigma/d\eta_{ref}(7\,TeV)}$$

η_ref=4.5

3. Lepton flavor universality (LFU) test

- The identification of 3 neutrino flavor offers a unique possibility to test LFU in neutrino interactions



- tau nu produced essentially only in D_s decays

- nu_e produced in the decays of all charmed hadrons(D^0, D, D_s, Λ_c)

- the ratio depends only on charm hadronisation fractions

- sensitive to nu-Nucleon cross-section ratio

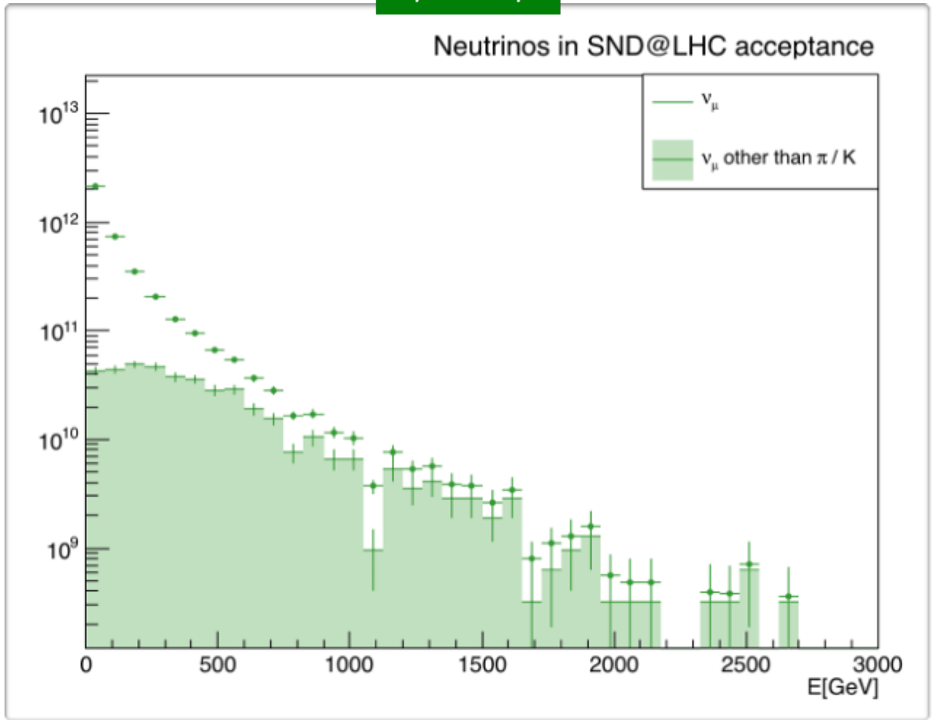
$$\boxed{R_{13} = \frac{N_{\nu_e+\overline{\nu}_e}}{N_{\nu_\tau+\overline{\nu}_\tau}} = \frac{\sum_i \tilde{f}_{c_i}\tilde{Br}(c_i \to \nu_e X)}{\tilde{f}_{D_s}\tilde{Br}(D_s \to \tau\nu_\tau)}}$$

$\tilde{f}_{c_i}$ charmed hadron fraction

$\tilde{Br}(c_i \to \nu_e X)$ branching ratio of each charm species

3. Lepton flavor universality (LFU) test

$\nu_\mu + \overline{\nu}_\mu$



- muon neutrino spectrum at low energy is dominated by pion/Kaon decays

- nu_e/nu_mu as a LFU test in nu interaction for E>600 GeV

$$R_{12} = \frac{N_{\nu_e+\overline{\nu}_e}}{N_{\nu_\mu+\overline{\nu}_\mu}} = \frac{1}{1+\omega_{\pi/k}}.$$

contamination from π/k

4. NC/CC ratio as a consistency check

- Lepton identification allows to distinguish between CC and NC interactions

- The ratio of NC/CC

$$P = \frac{\sum_i \sigma_{NC}^{\nu_i} + \sigma_{NC}^{\bar{\nu}_i}}{\sum_i \sigma_{CC}^{\nu_i} + \sigma_{CC}^{\bar{\nu}_i}}$$

can be written for DIS as

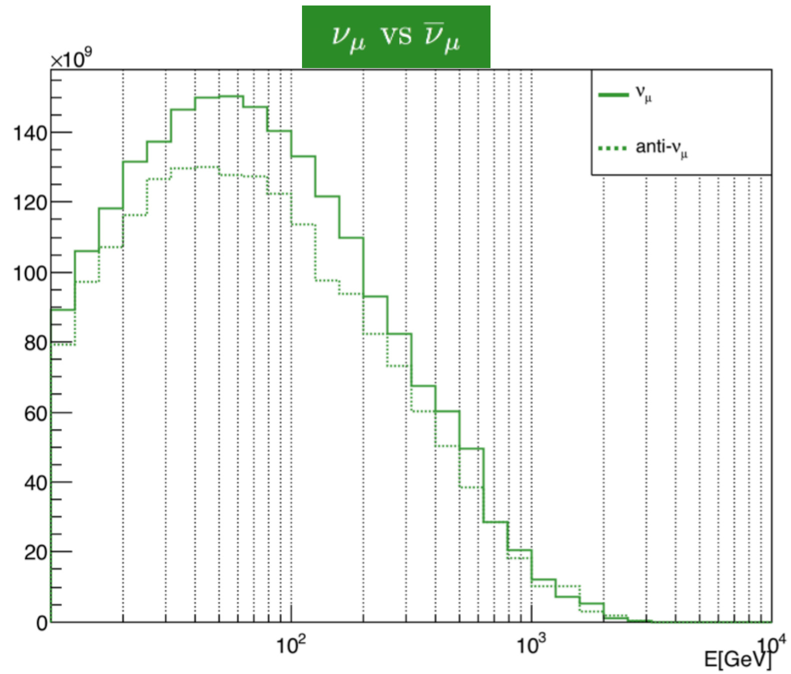
$$P = \frac{1}{2}\left\{1 - 2\sin^2\theta_W + \frac{20}{9}\sin^4\theta_W - \lambda(1 - 2\sin^2\theta_W)\sin^2\theta_W\right\}$$

$\lambda = 0.04$ for tungsten target

Rept.Prog.Phys. 79 (2016) 12, 124201

θ_W Weinberg mixing angle

- P measurement can be used as an internal consistency check



Feebly Interacting Particle (FIP) Physics

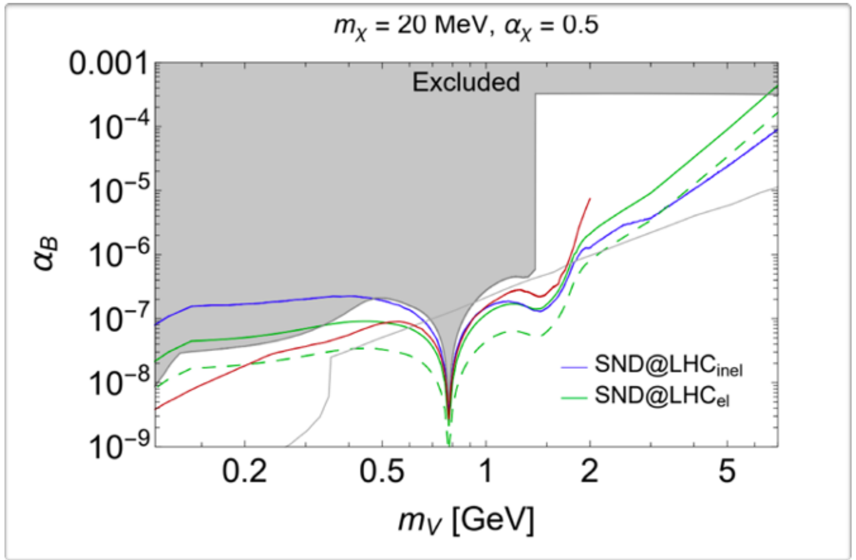
stable FIP: scattering with electron or nucleon

unstable FIP: decay inside detector

Scattering and Decay of FIP

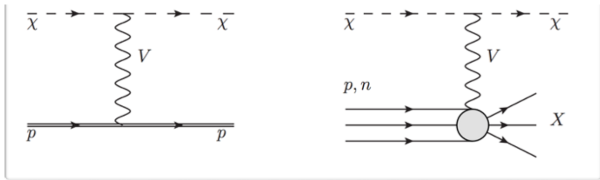
SND@LHC experiment can explore a large variety of Beyond Standard Model (BSM) scenarios describing Hidden Sector

Detection with scattering:
elastic/inelastic scattering off nucleons

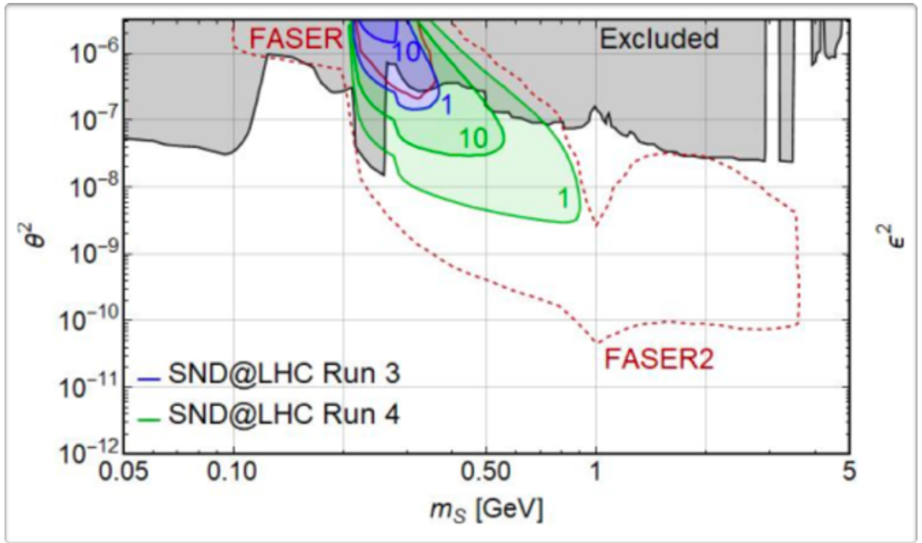


Case for leptophobic model

$$\mathcal{L}_{\text{leptophob}} = -g_B V^\mu J^B_\mu + g_\chi V^\mu (\partial_\mu \chi^\dagger \chi - \chi^\dagger \partial_\mu \chi), \quad J^B_\mu = \frac{1}{3}\sum_q \bar{q}\gamma_\mu q$$



Decays in a pair of charged tracks or monophotons



Sensitivity of SND@LHC to (top left) dark scalars

Conclusion

SND@LHC is a recently approved experiment at CERN aiming at:

- measuring neutrinos produced from LHC in an unexplored pseudo-rapidity region
- searching for feebly interacting particles

SND@LHC is currently taking data

Thank You!