경상국립대학교
Gyeongsang National University

LHC
Scattering and Neutrino Detector at the LHC

SND@LHC

Scattering and Neutrino Detector at LHC

Kang Young Lee
GNU
On behalf of SND@LHC Collaboration

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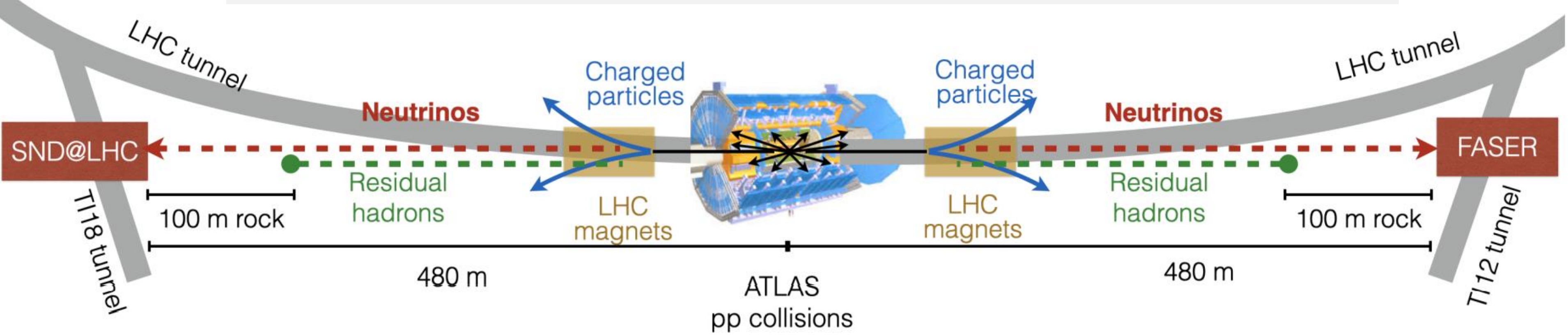
Outline

- Introduction
- SND@LHC
- Analyses & Results
- 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)



FASER & FASERν

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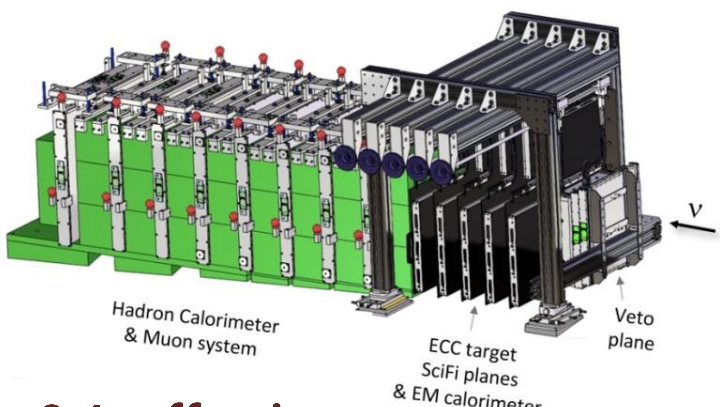
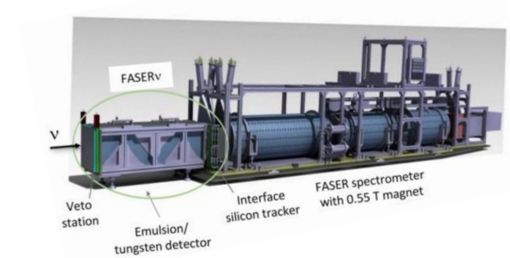
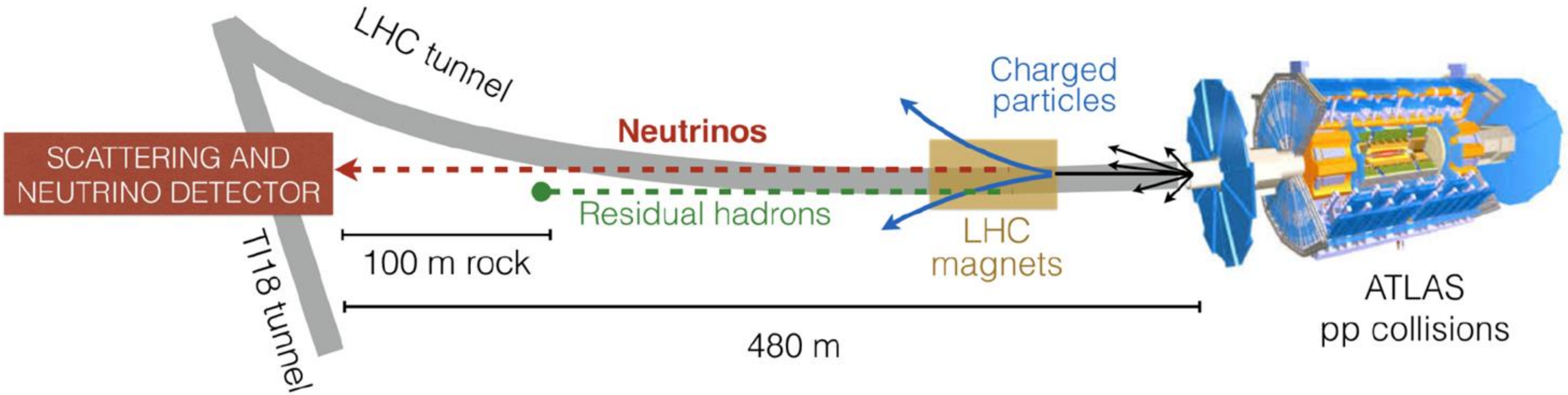




7.2 < η < 8.4, off-axis

η > 8.8
on-axis

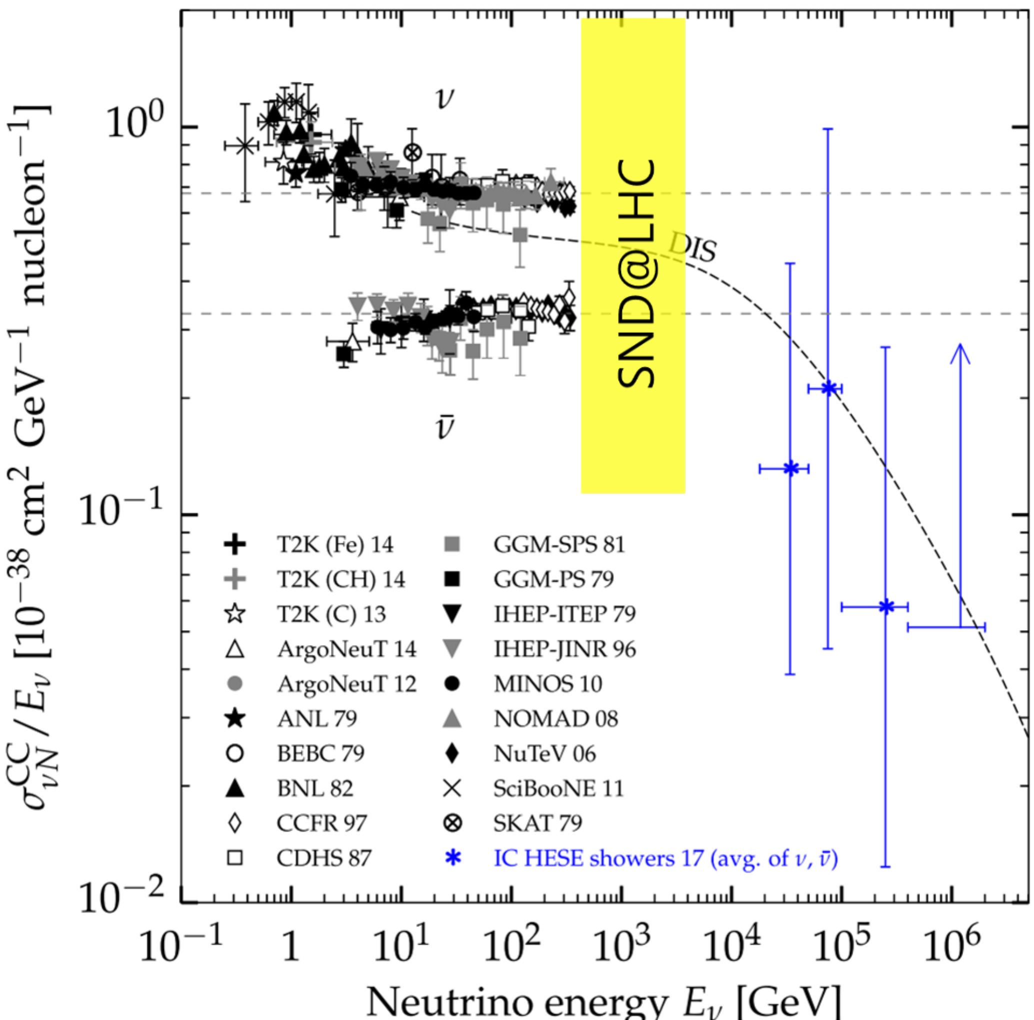
The SND@LHC



- 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.

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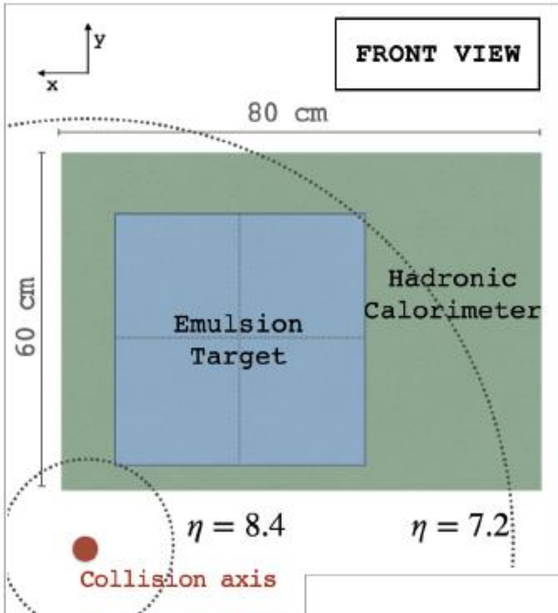
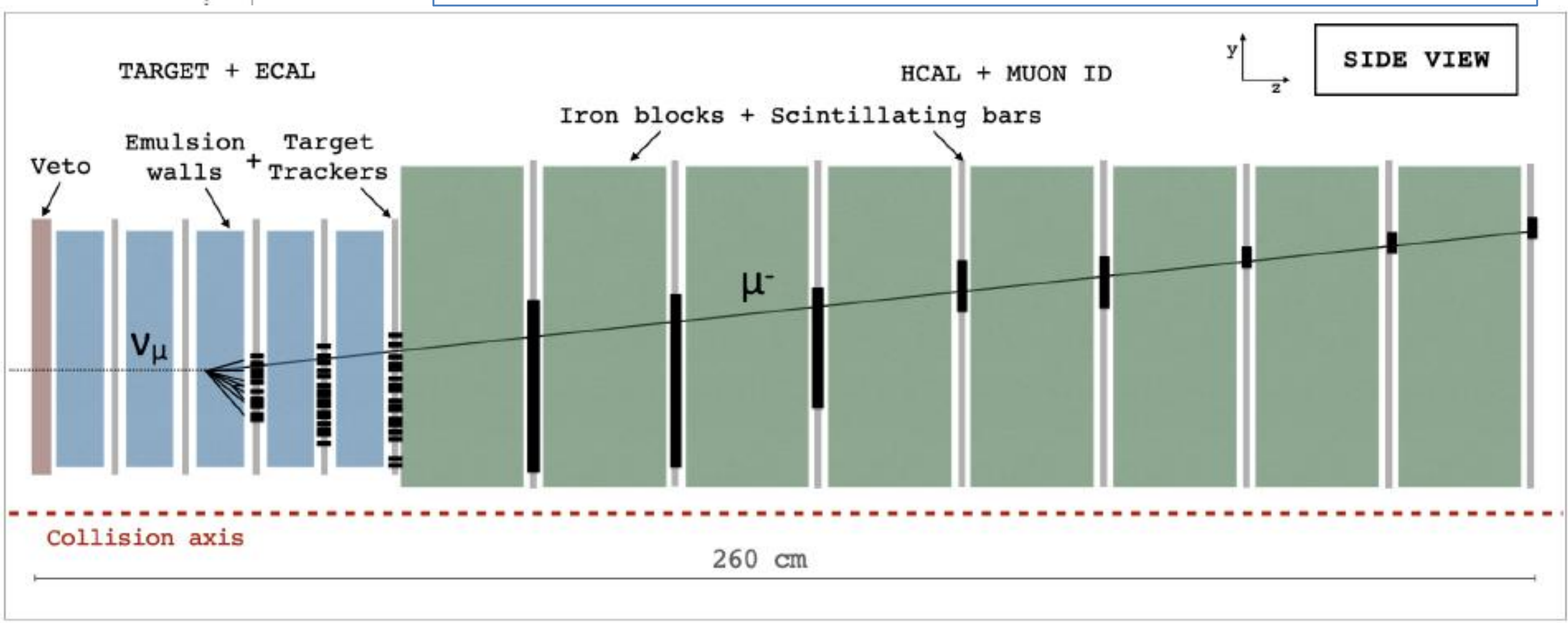
The SND@LHC Detector

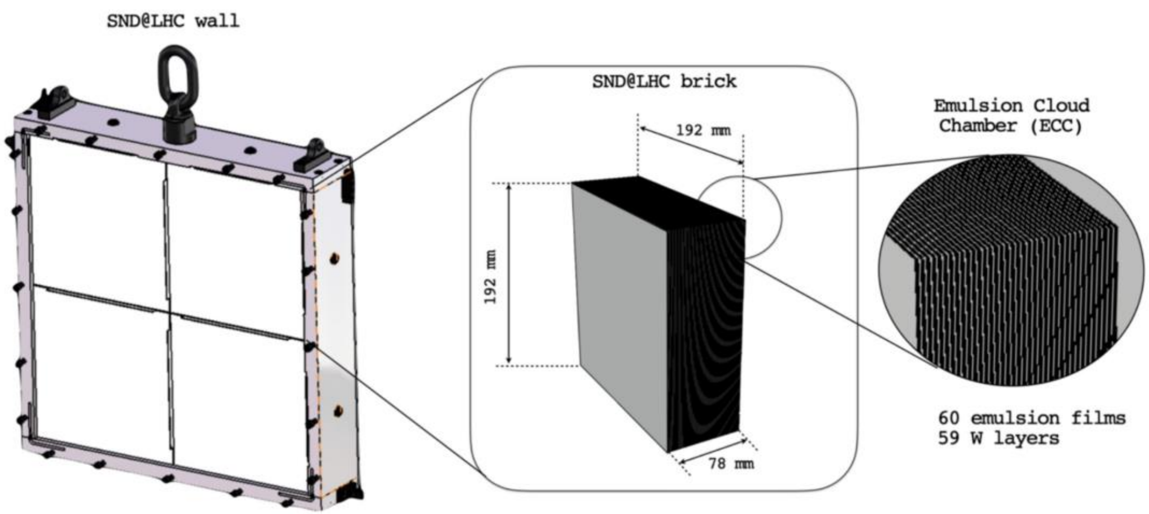


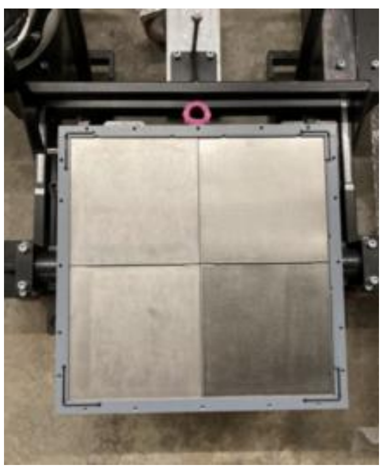
Hybrid detector optimised for the identification of all three neutrino flavours and the FIPs
- Veto plane
- Vertex detector and EM calorimeter (~40 X_0) : ECC and SciFi
- Hadron calorimeter and muon system (~10 λ)

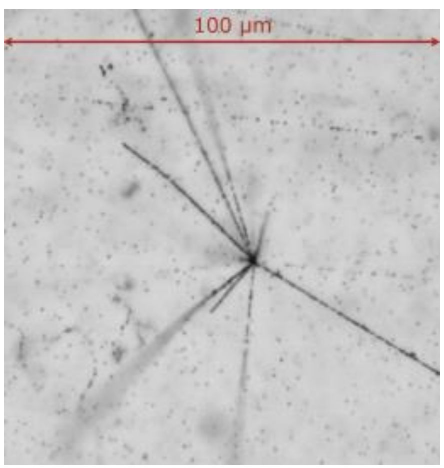
Detector paper : arXiv 2210.02784 to appear on JINST



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

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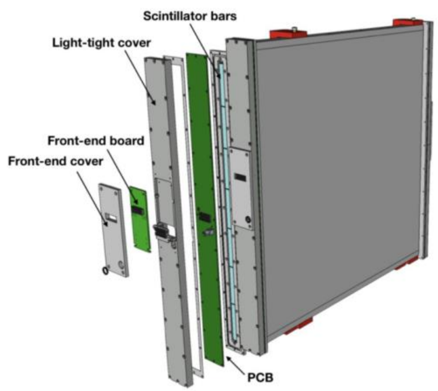
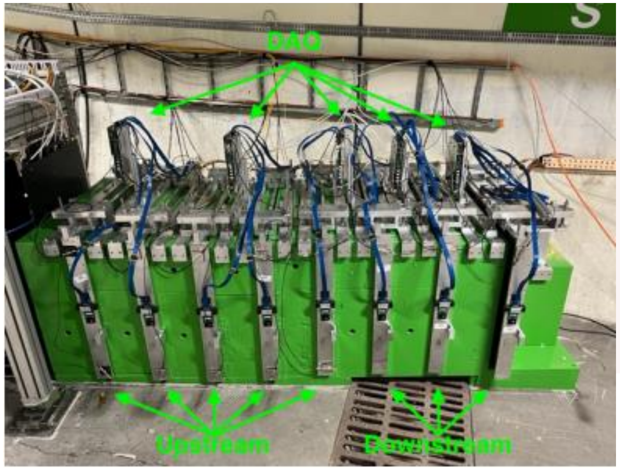


Veto system

- 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



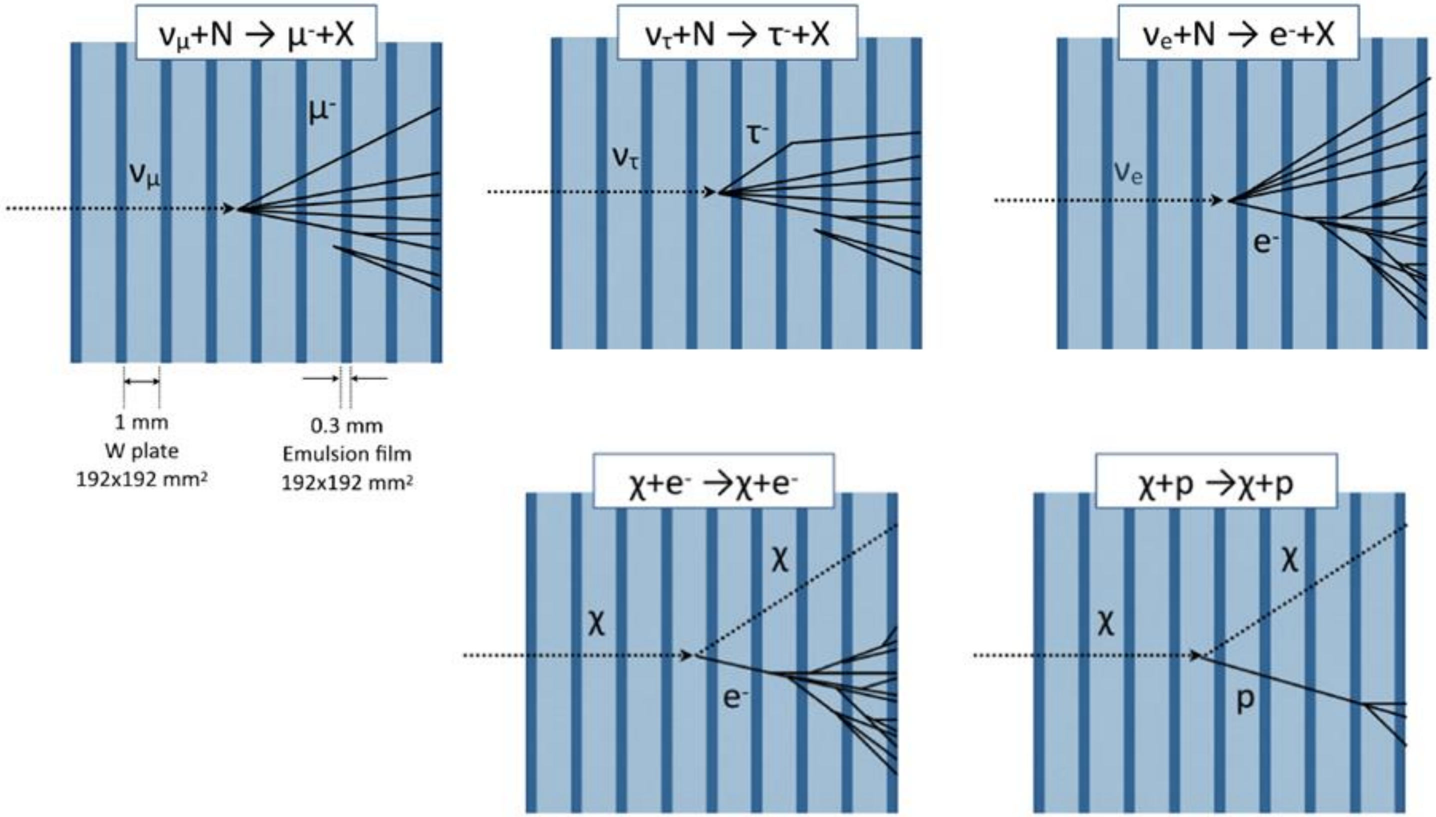
Hadronic calorimeter and muon system

- 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

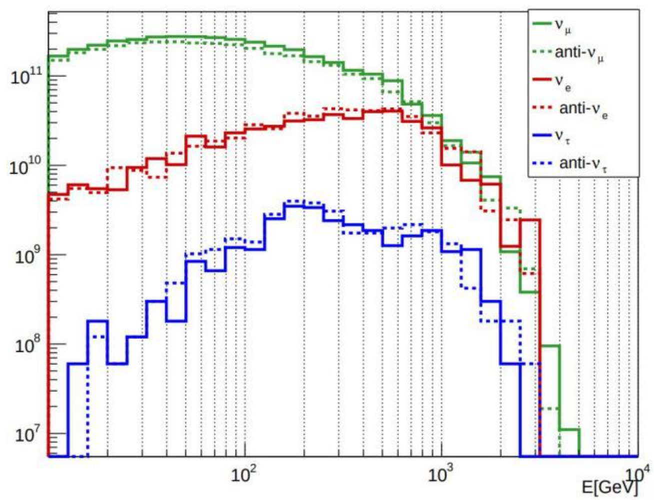
Physics Cases – Event Topology



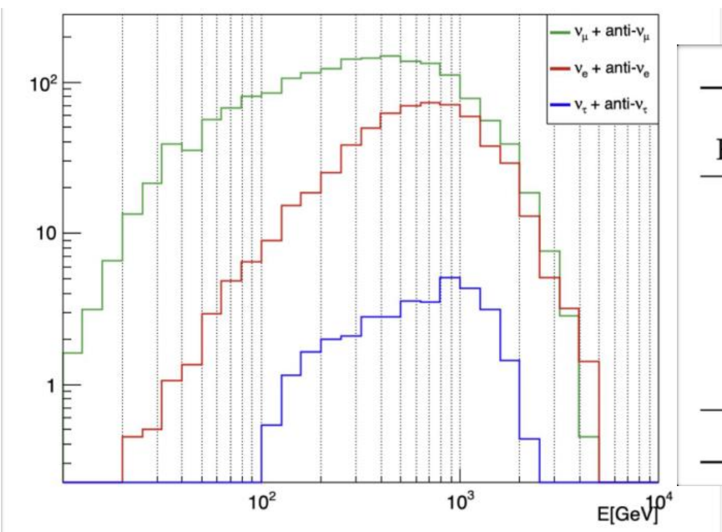
Identification of all three neutrino flavours and FIPs by event topologies in the ECC brick

Physics Cases – Neutrino Production

Incoming Neutrinos to SND



Neutrino interactions in SND



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

- $\nu_\mu + \bar{\nu}_\mu$ 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

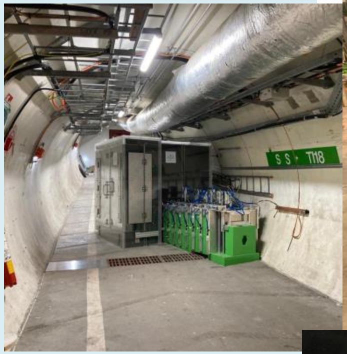
Scattering and Neutrino Detector at the LHC

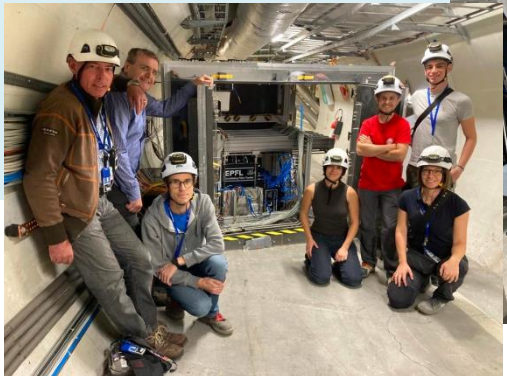
Letter of Intent

TECHNICAL PROPOSAL

SND@LHC

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



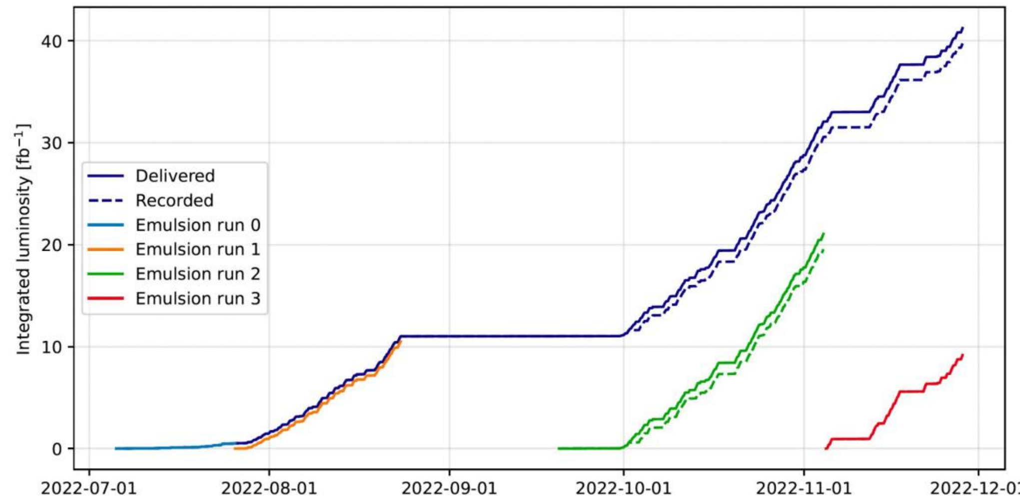


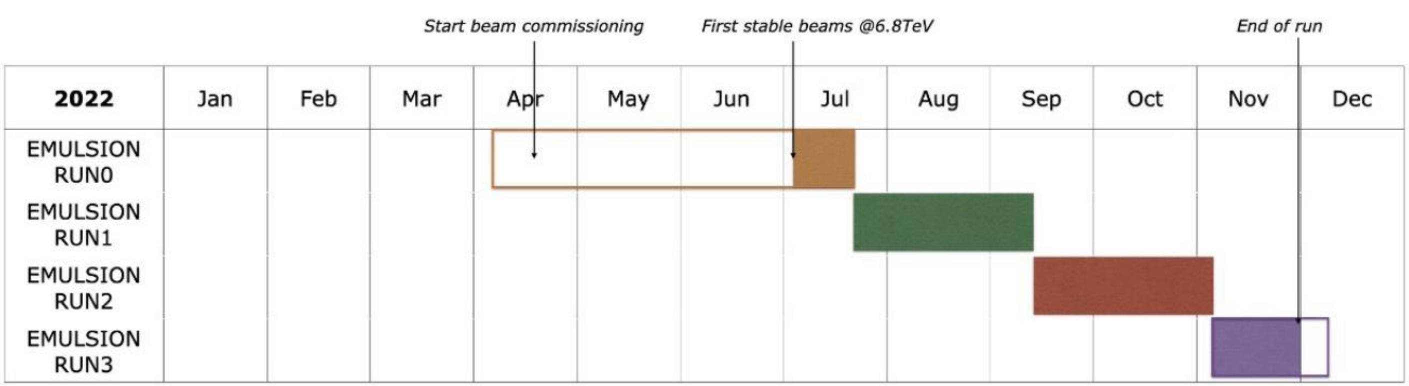
Analyses & Results

Data taking in 2022

Run3 in 2022

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





2022	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	$9.2\ fb^{-1}$

Emulsion Development & Scanning

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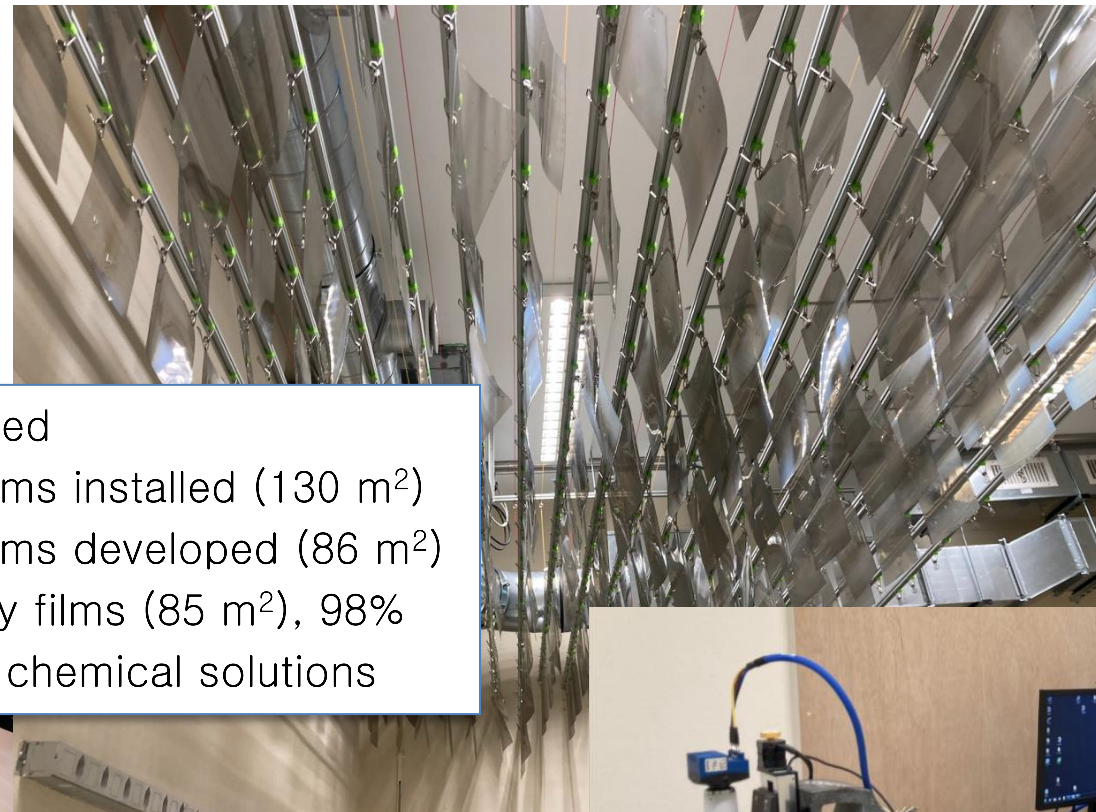
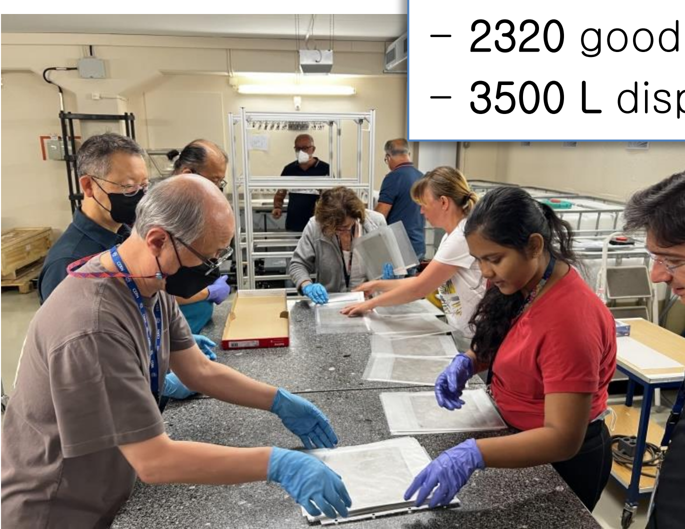
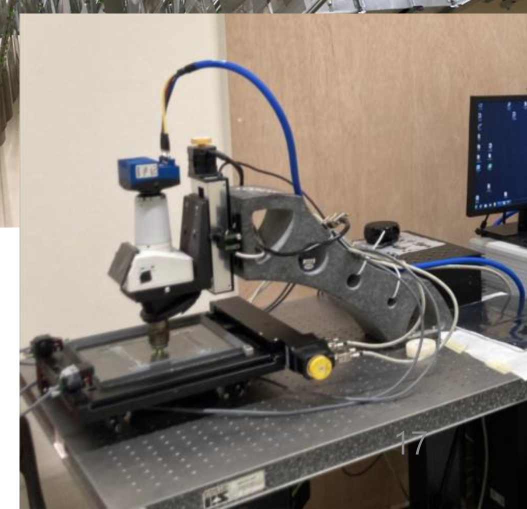


- **16** walls assembled
- **3522** emulsion films installed (130 m^2)
- **2370** emulsion films developed (86 m^2)
- **2320** good quality films (85 m^2), 98%
- **3500 L** disposed chemical solutions





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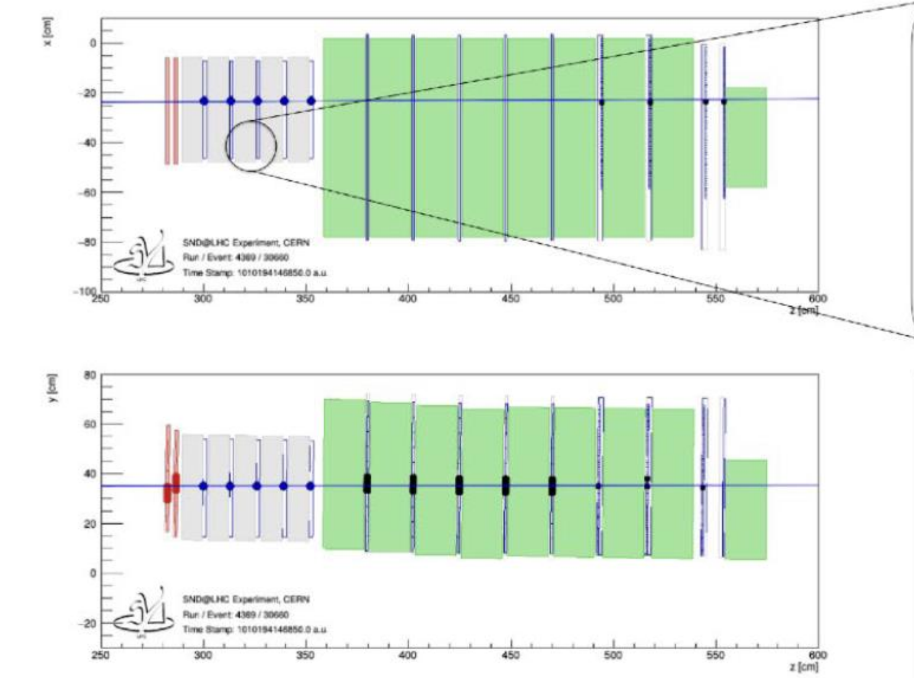
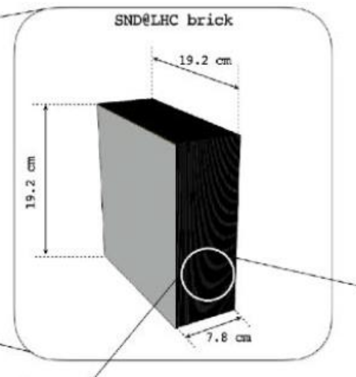
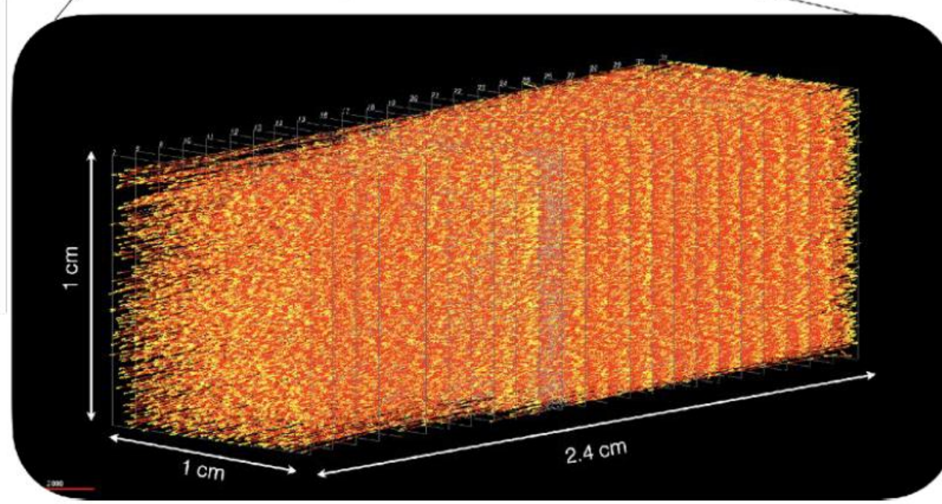
Muon Track Reconstruction



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



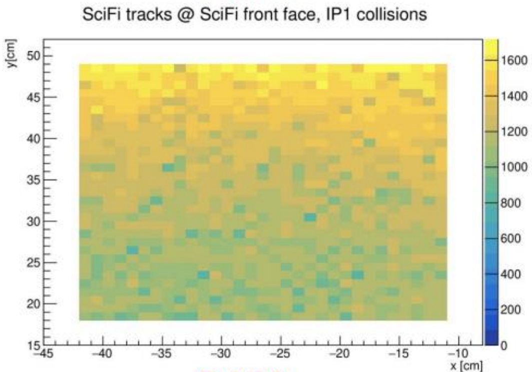
Emulsion Reconstruction
Muon tracks in 1x1cm²
Integrated in Run 0 of
0.51 fb^{-1} (07/04-26/07)



Data/MC Comparison

Scattering and Neutrino Detector at the LHC

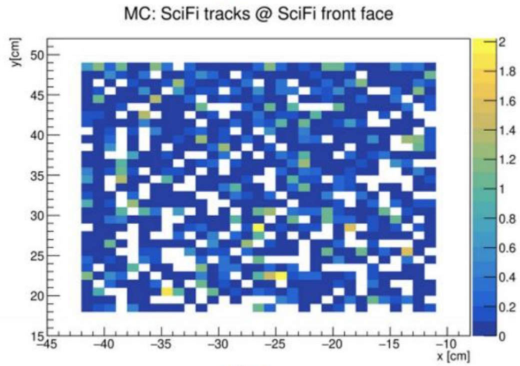
DATA



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

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

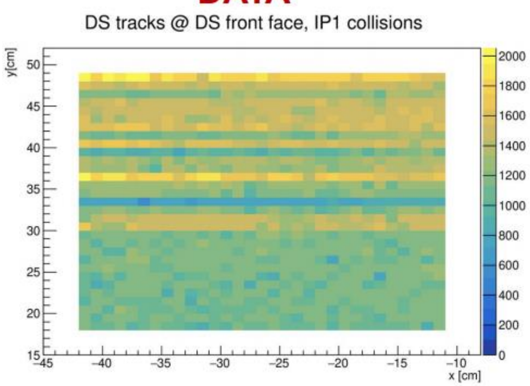
MC



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

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

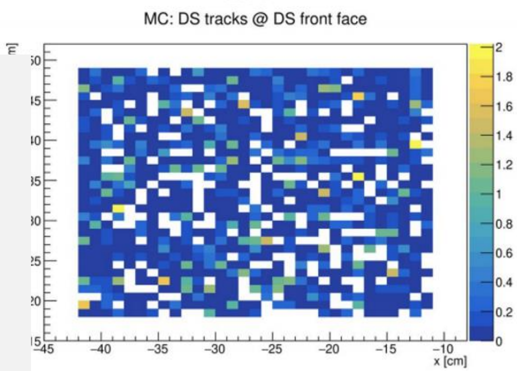
DATA



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 Muon system (31x31 cm^2):

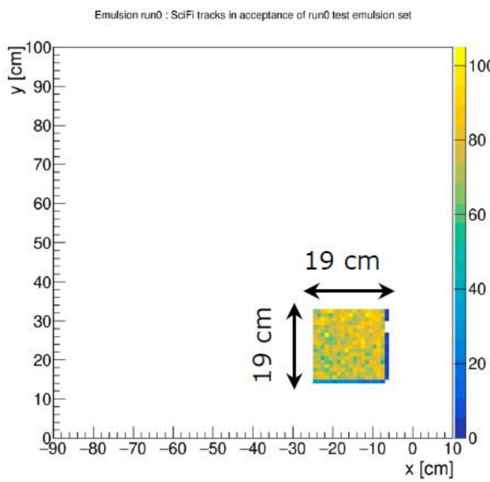
$(1.59 \pm 0.10_{stat}) \times 10^4$ fb/cm^2

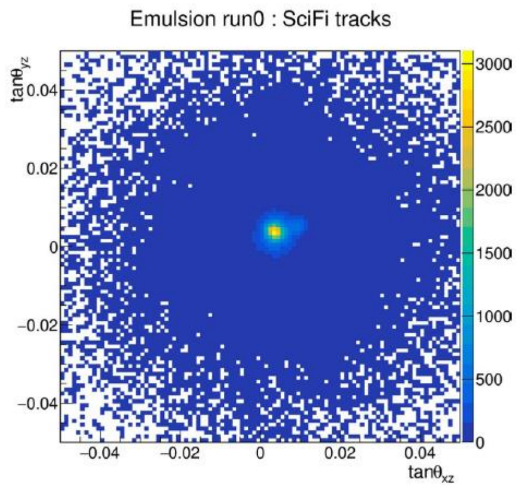
Muon flux from FLUKA
F. Cerutti, M.S. Gilarte
CERN-SY/STI

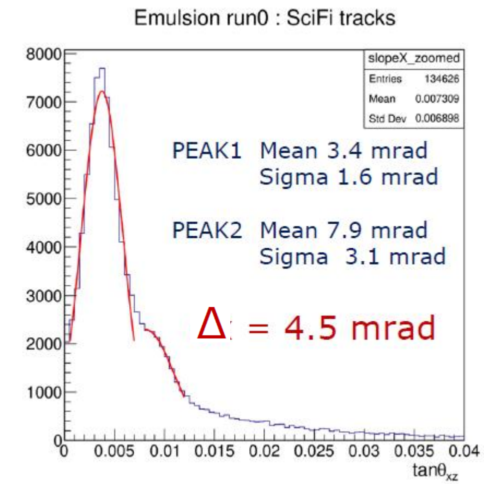
SciFi/Emulsion Comparison

SciFi

Measured rates on BRICK1 surface
1.6×10^4 fb/cm^2

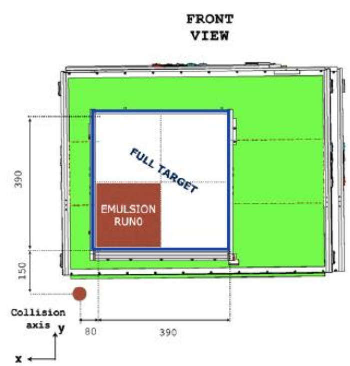


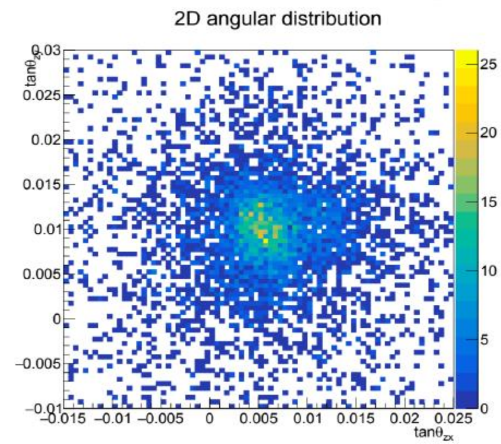


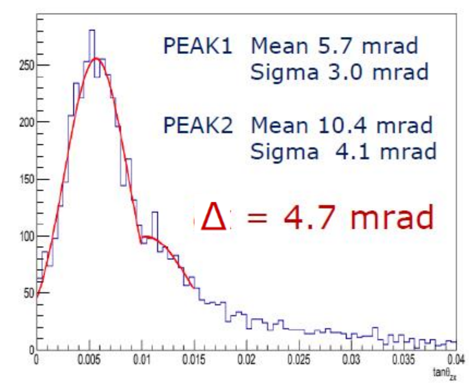


EMULSIONS

Measured rates in BRICK1
1.5×10^4 fb/cm^2



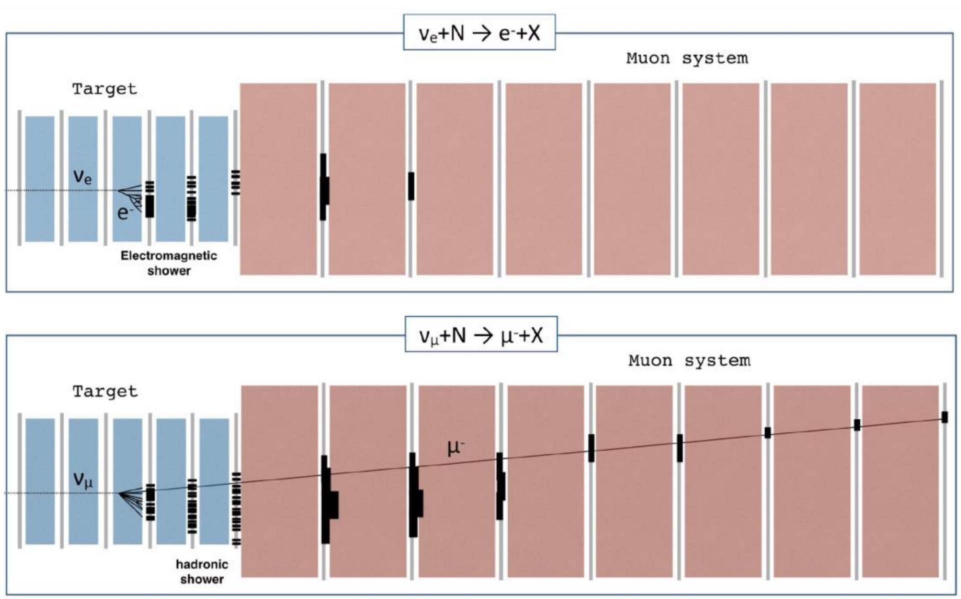


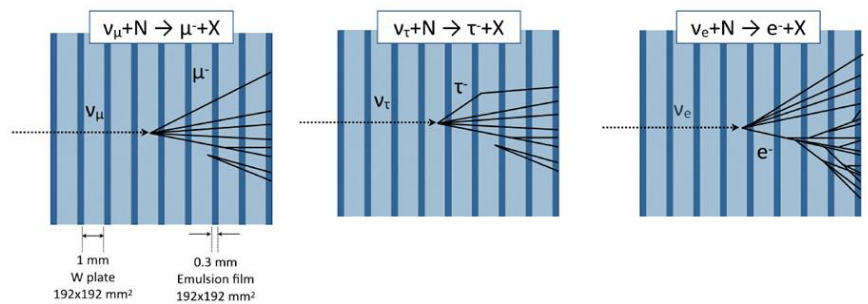


Neutrino Identification Strategy

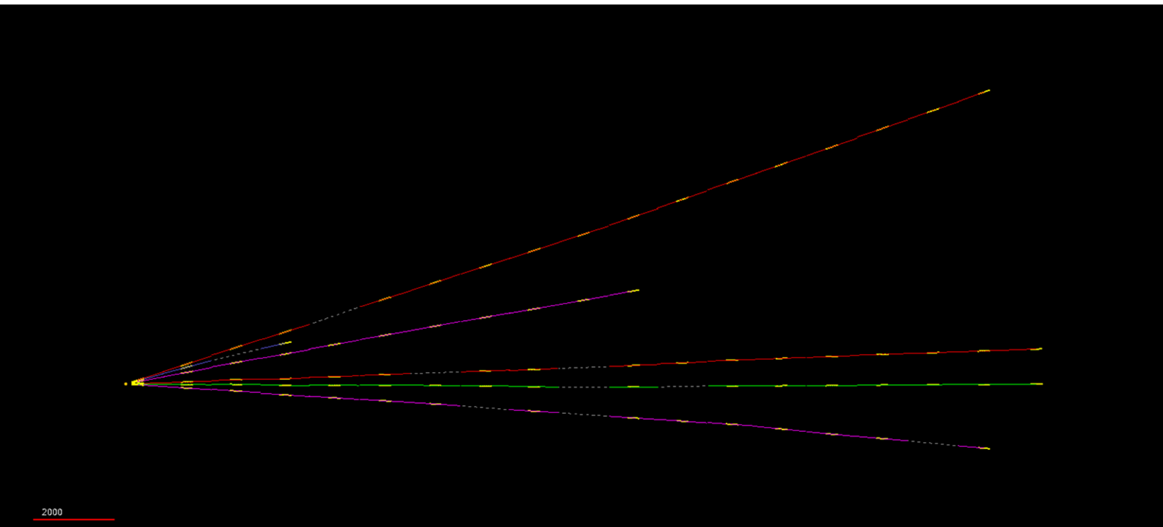
First Stage
- Identify the neutrino candidates in electronic detector data
- Tag muons in the muon system
- Measure electronic and hadronic energies in calorimeters

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

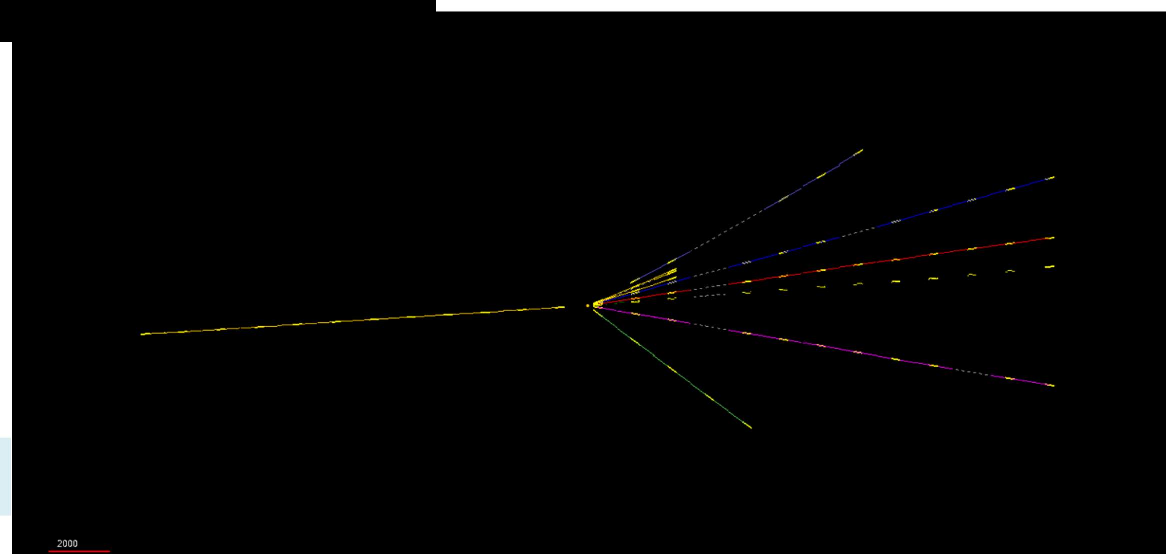




Vertex Reconstruction in Emulsion



Neutral particle interaction



Charged particle interaction

Neutrino Identification with Electronic Detectors

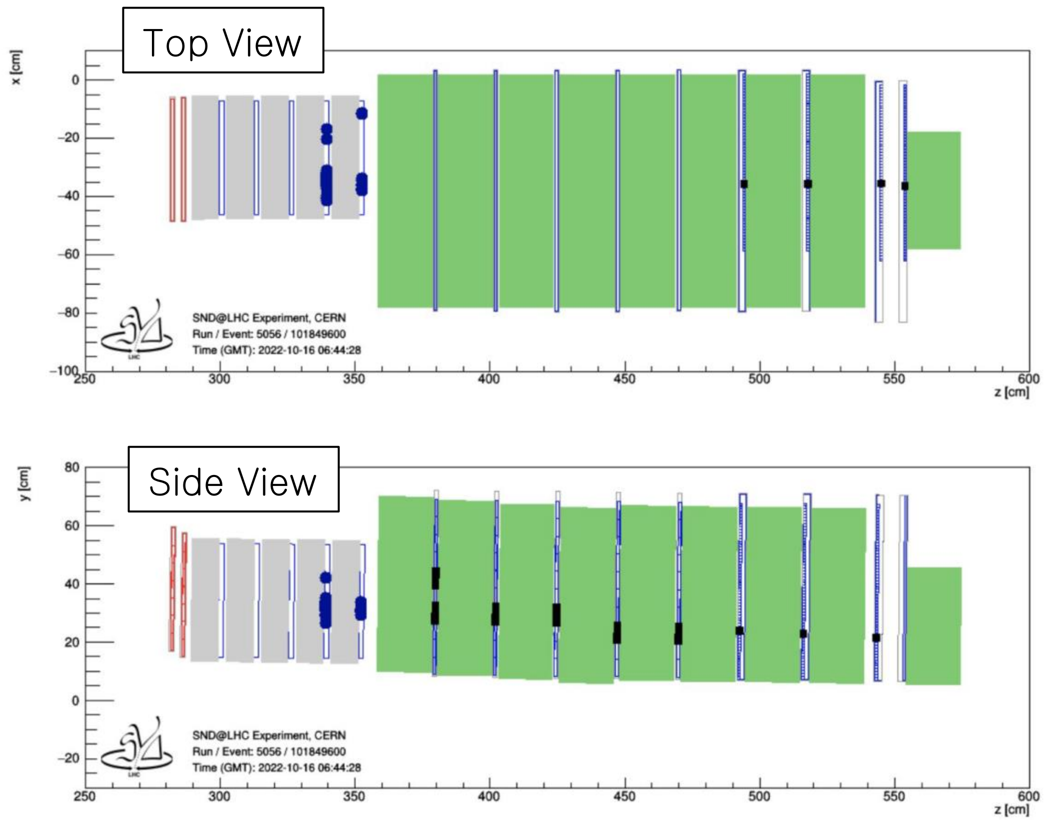
Neutrino selection criteria for electronic detectors

▶ **Fiducial volume cuts**

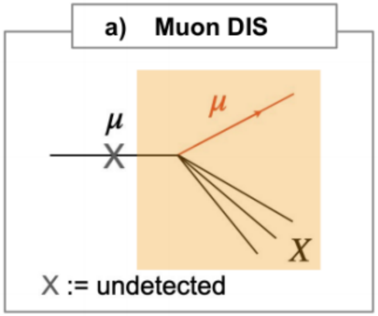
– Require an event from a neutral vertex, located in the 3rd or 4th wall
– Select fiducial cross-sectional area to reject entering backgrounds

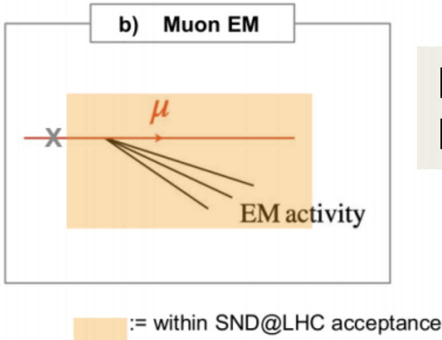
▶ **Neutrino ID cuts**

– 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

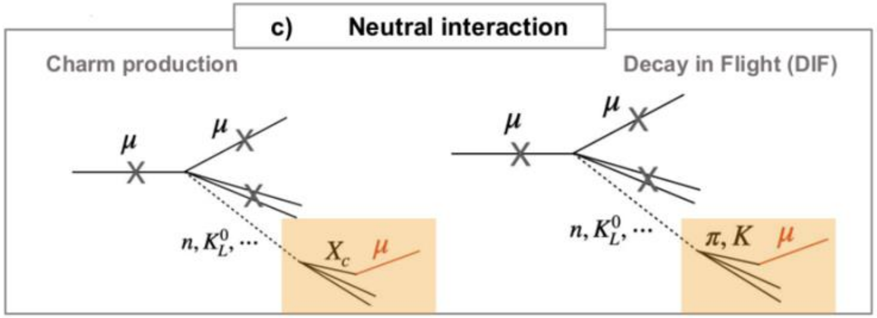




Muon induced DIS and EM backgrounds
Number of undetected muons entering the target

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

SND@LHC PRELIMINARY

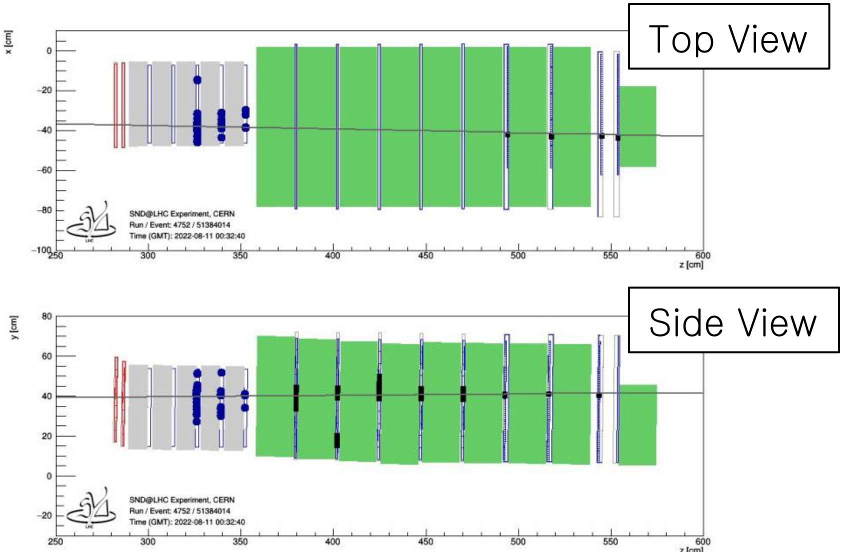


Muon induced neutral interaction backgrounds

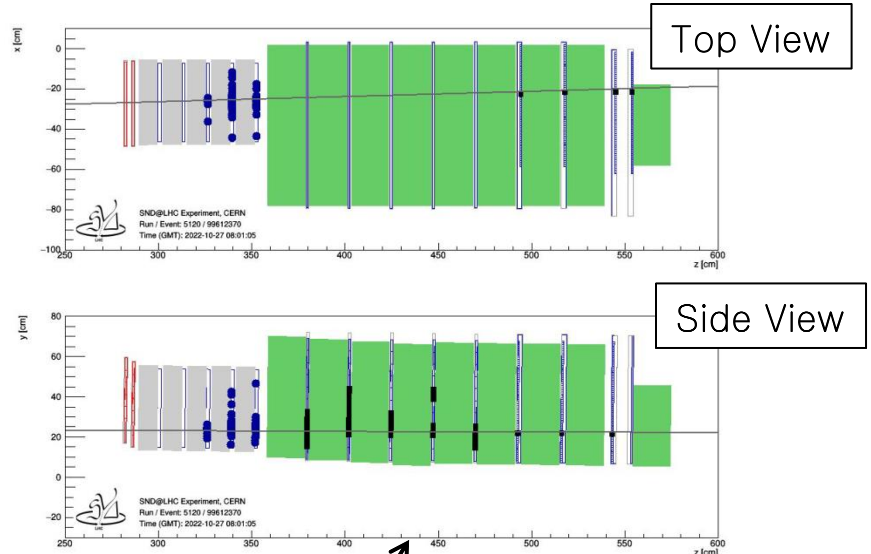
$$N_{\mathrm{neutrals}}^{\mathrm{bkg}} = N_{\mathrm{neutrals}} \times P_{\mathrm{inel}} \times \epsilon_{\mathrm{sel}} \sim 0.2$$

Systematic uncertainty study is ongoing.

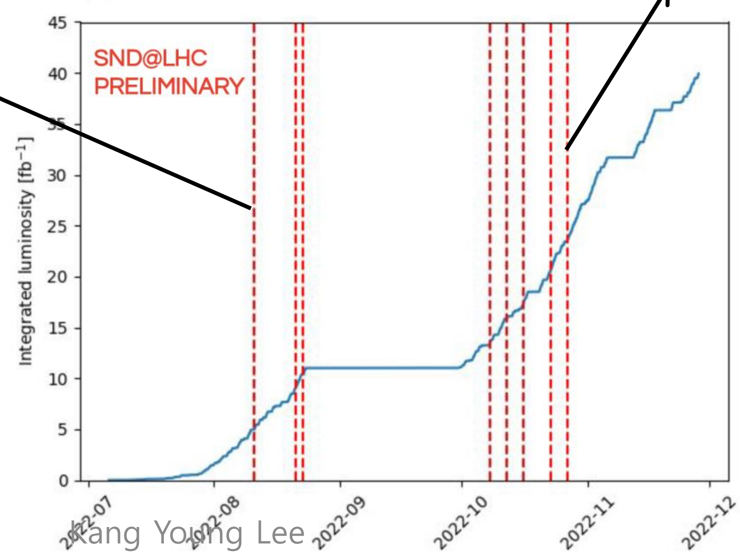
Observed Neutrino Candidates



Aug 11th



Oct 27th



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

Paper Released

hep-ex] 16 May 2023

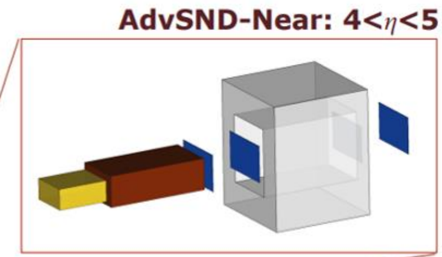
Observation of collider muon neutrinos with the SND@LHC experiment

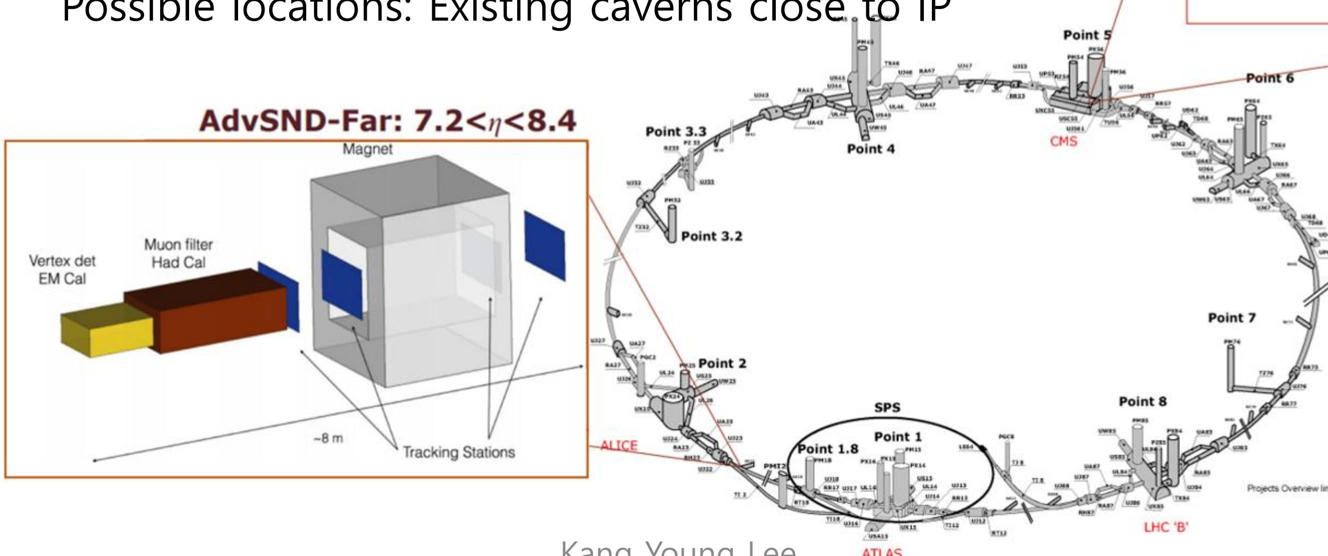
R. Albanese[1,2] A. Alexandrov[1] F. Alicante[1,2] A. Anokhina[3] T. Asada[1,2] C. Battilana[4,5] A. Bay[6] C. Betancourt[7] A. Blanco Castro[8] M. Bogomilov[9] D. Bonacorsi[4,5] W.M. Bonivento[10] P. Bordalo[8] A. Boyarsky[11,12] S. Buontempo[1] M. Campanelli[13] T. Camporesi[14] V. Canale[1,2] A. Castro[4,5] D. Centanni[1,15] F. Cerutti[14] 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[14] A. De Rújula[14] 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[13] M. Ferrillo[7] M. Ferro-Luzzi[14] R.A. Fini[20] A. Fiorillo[1,2] R. Fresa[1,23] W. Funk[14] A. Golovatiuk[1,2] A. Golutvin[24] E. Graverini[6] A.M. Guler[22] V. Guliaeva[3] G.J. Haefeli[6] J.C. Helo Herrera[25,26] E. van Herwijnen[24] P. Iengo[1] S. Ilieva[1,2,9] A. Infantino[14] A. Iuliano[1,2] R. Jacobsson[14] C. Kamiscioglu[22,27] A.M. Kauniskangas[6] E. Khalikov[3] S.H. Kim[28] Y.G. Kim[29] G. Klioutchnikov[14] M. Komatsu[30] N. Konovalova[3] S. Kovalenko[25,31] S. Kuleshov[25,31] H.M. Lacker[18] O. Lantwin[3] F. Lasagni Manghi[4] A. Lauria[1,2] K.Y. Lee[28] K.S. Lee[32] 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[11] M.C. Montesi[1,2] F.L. Navarria[4,5] S. Ogawa[33] N. Okateva[3] M. Ovchynnikov[11] G. Paggi[4,5] B.D. Park[28] A. Pastore[20] A. Perrotta[4] D. Podgrudkov[3] N. Polukhina[3] A. Prota[1,2] A. Quercia[1,2] S. Ramos[8] A. Reghunath[18] T. Roganova[3] F. Ronchetti[6] T. Rovelli[4,5] O. Ruchayskiy[34] T. Ruf[14] M. Sabate Gilarte[14] 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[33,35] S. Simone[20,21] G.P. Siroli[4,5] G. Sirri[4] G. Soares[8] O.J. Soto Sandoval[25,26] M. Spurio[4,5] N. Starkov[3] I. Timiryasov[34] V. Tioukov[1] C. Trippl[6] E. Ursov[3] A. Ustyuzhanin[1,36] G. Vankova-Kirilova[9] V. Verguilov[9] N. Viegas Guerreiro Leonardo[8] C. Vilela[8,*] C. Visone[1,2] R. Wanke[17] E. Yaman[22] C. Yazici[22] C.S. Yoon[28] E. Zaffaroni[6] and J. Zamora Saa[25,26]
(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 ($7.2 < \eta < 8.4$)
    - Possible location: Forward Physics Facility
  - AdvSND-Near ($4 < \eta < 5$)
    - 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!

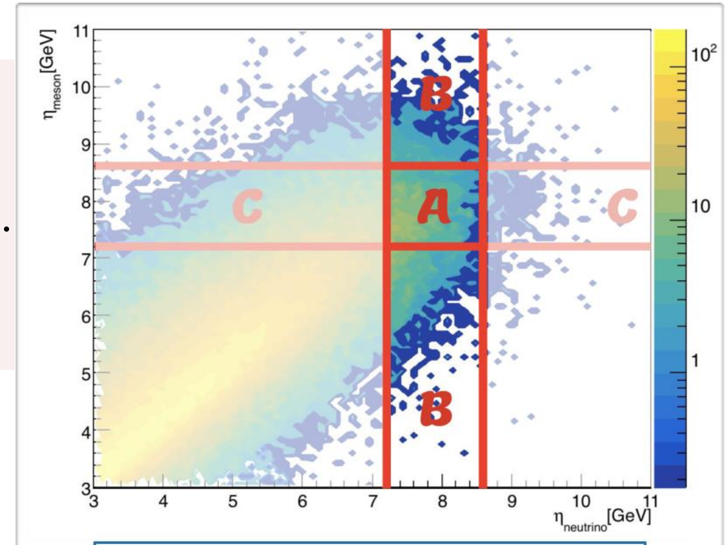
Thank you!

Backup Slides

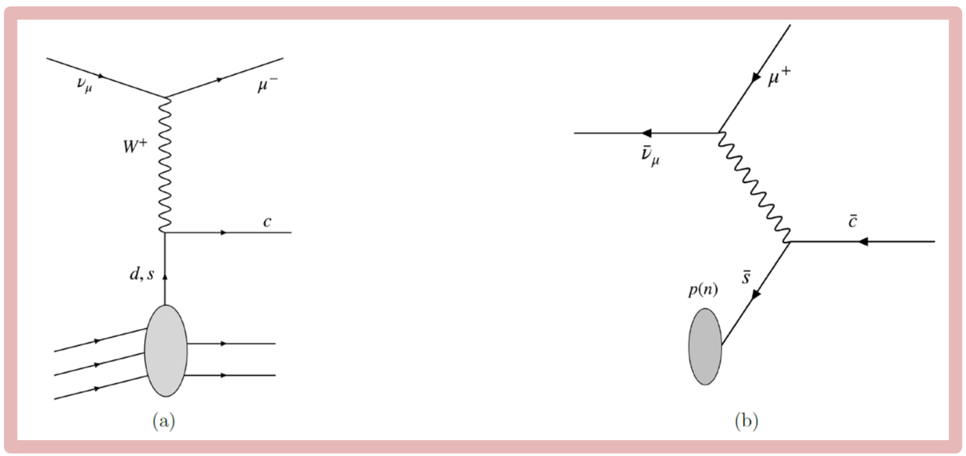
Physics Cases – Charm Physics

Neutrino production from charm decays

90% of ν_e production is expected to be charm decays.
→ as a probe of charm production
→ impact on the gluon PDF at very small x



Correlation between η_ν and η_c



Charm production in neutrino CC interactions

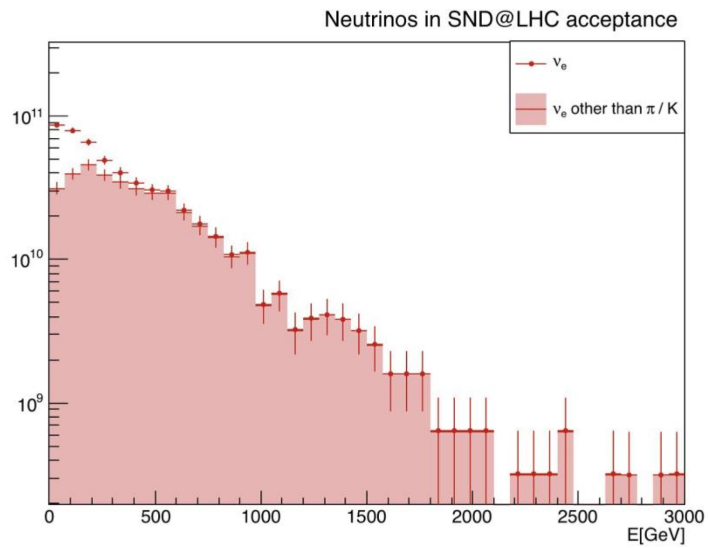
High energy neutrino can produce charm quark via DIS

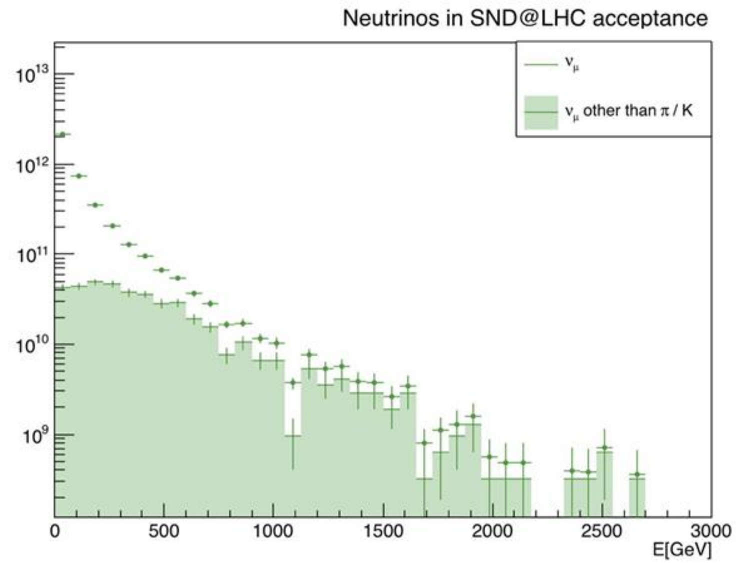
Physics Cases – Lepton Universality Test

- All 3 flavors of neutrinos can be identified.
- Unique opportunity to test lepton flavour universality with neutrinos
- ν_e / ν_τ and ν_e / ν_μ ratios

Expected uncertainties

- ν_e/ν_τ
  - Statistical: 30%
  - Systematic: 20%
- ν_e/ν_μ
  - Statistical: 10%
  - Systematic: 10%



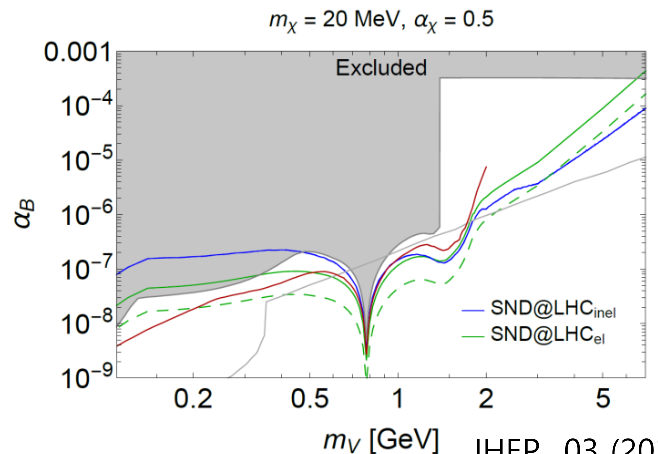


$$R_{13} = \frac{N_{\nu_e+\bar{\nu}_e}}{N_{\nu_\tau+\bar{\nu}_\tau}} = \frac{\sum_i \tilde{f}_{c_i} \tilde{Br}(c_i \to \nu_e)}{\tilde{f}_{D_s} \tilde{Br}(D_s \to \nu_\tau)},$$

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

Physics Cases – FIP search

Direct search for FIP through scattering in the detector



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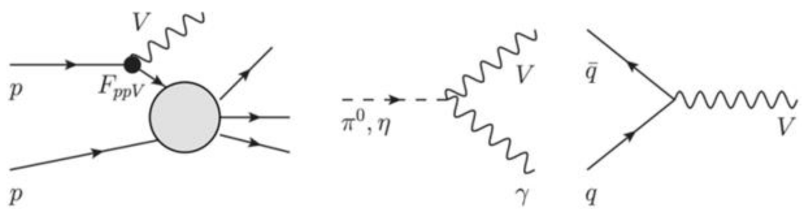
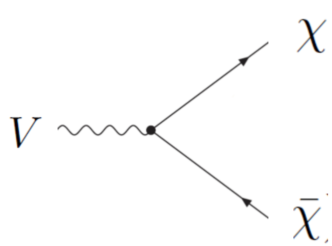
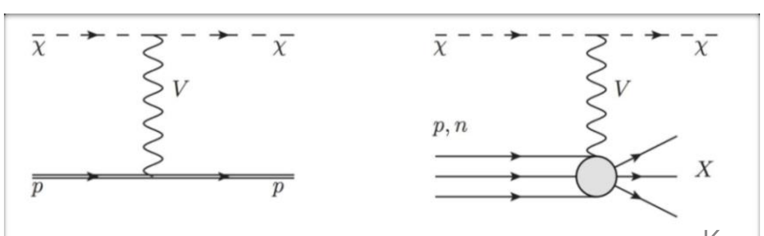
e.g. leptophobic dark photon and light DM



Dark photon can be produced at IP1 through p bremsstrahlung, meson decays, Drell-Yann process etc..



Dark photon decays into LDM.



LDM scatterings in the detector
LDM decays in the detector