Detection of high-energy neutrinos at LHC with SND@LHC

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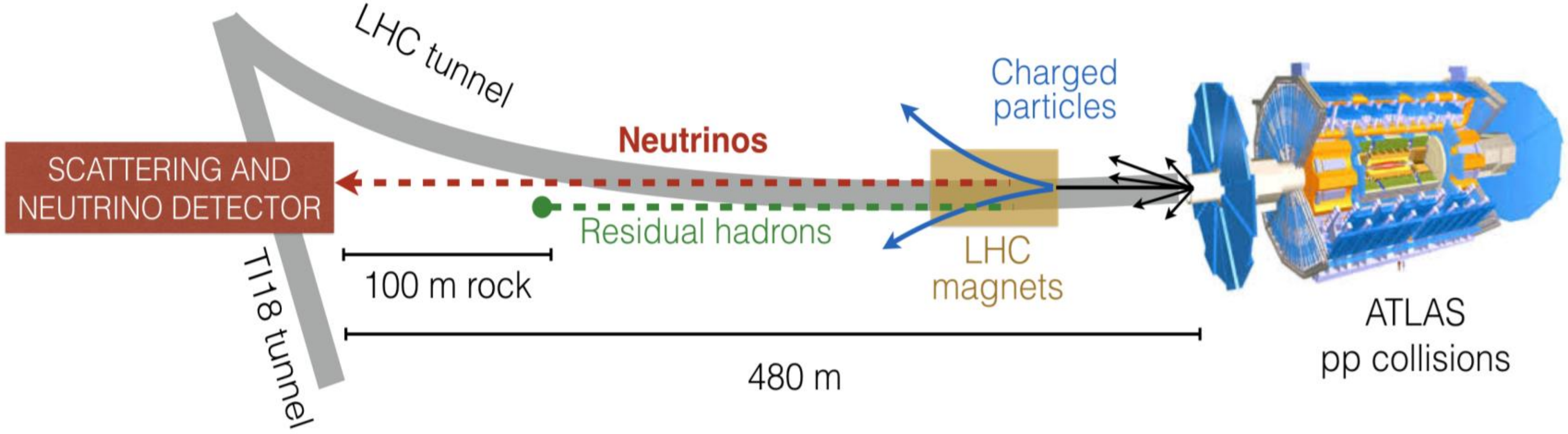
On behalf of the SND@LHC collaboration

Overview

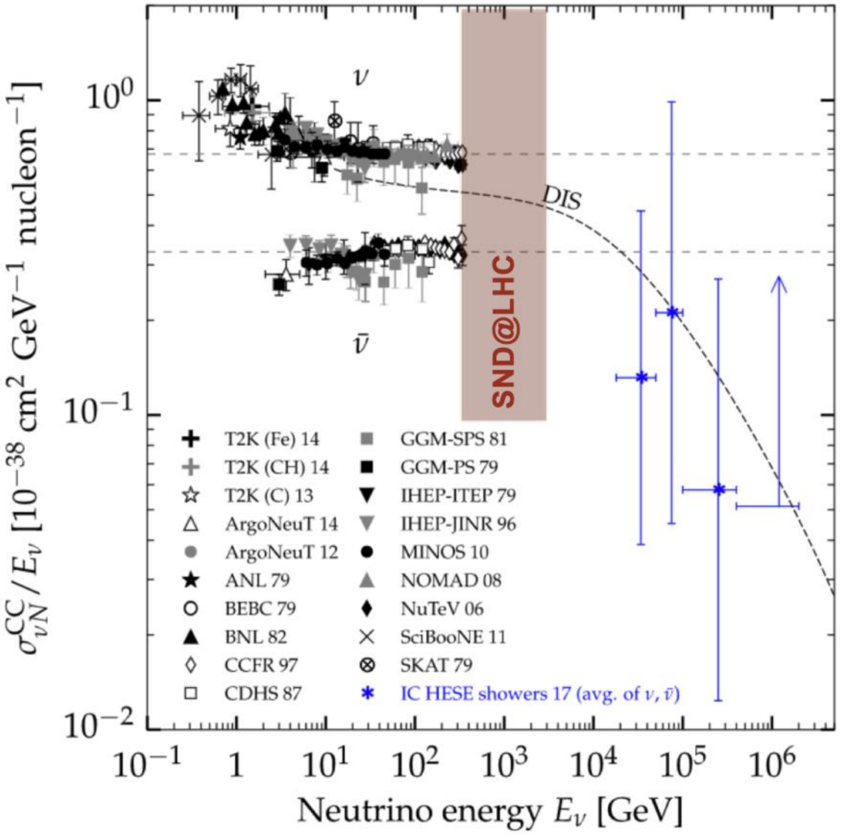


SND@LHC Technical Proposal
https://cds.cern.ch/record/2750060/files/LHCC-P-016.pdf

- The SND@LHC experiment
- Detector overview
- Neutrino physics program
- Commissioning, installation and run status

Motivation

- 1990, Klaus Winter point out possibility of tau neutrino detection at LHC neutrino
  - The first tau neutrino detection done by Fermilab E872 DONUT with 800 GeV proton beam dump in 2000. (Phys.Lett.B 504 (2001) 218-224)
  - Still number of observed tau neutrino interaction is limited (DONUT and OPERA)



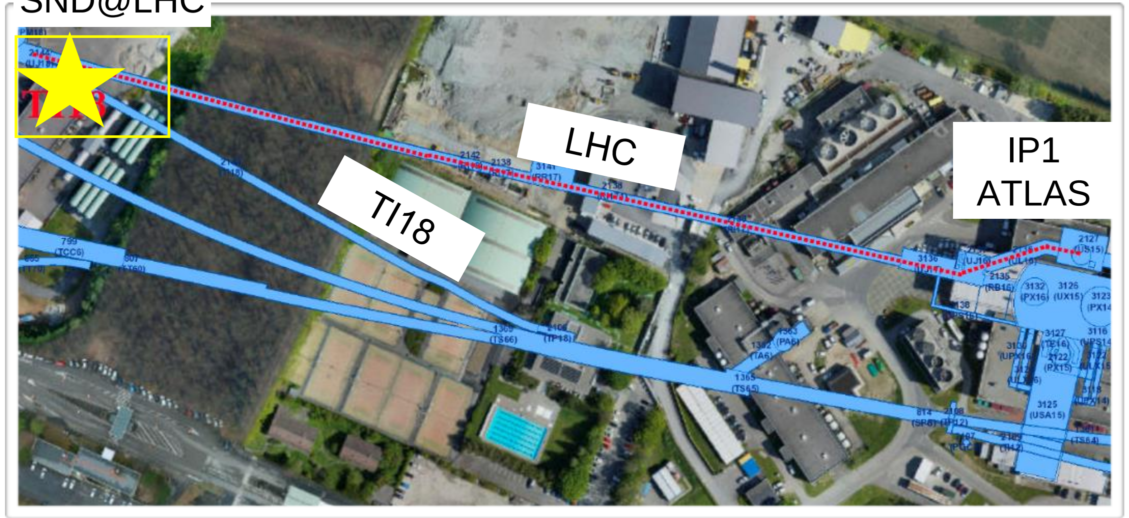
CERN is unique in providing high energy neutrinos in an unexplored energy region from LHC.

Also unique in measuring pp→**ν**X, equivalent with 10^{17} eV cosmic ray interaction which produce ultra high energy neutrinos.

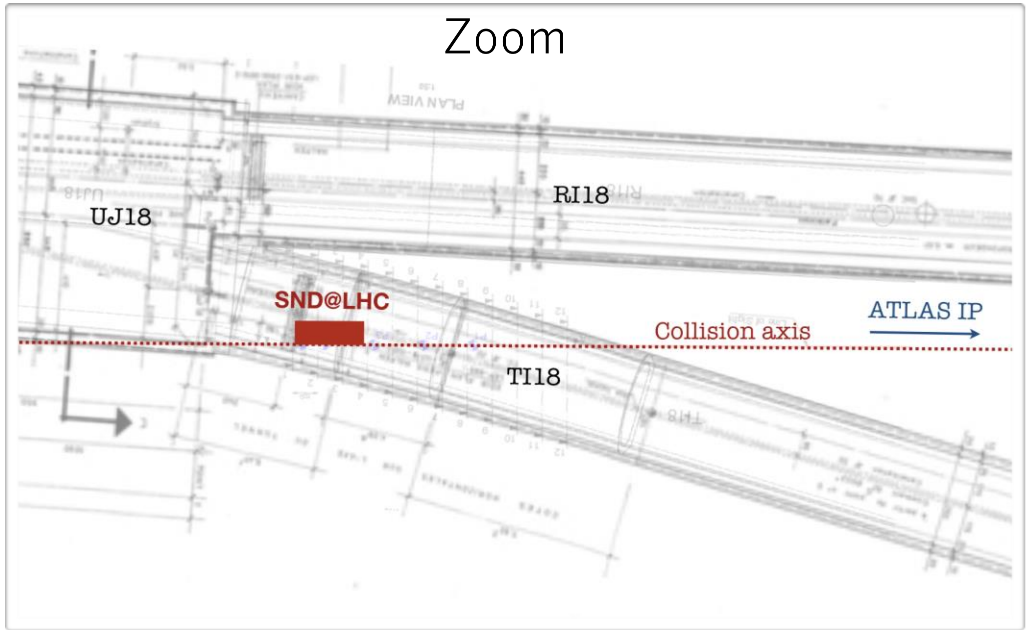
LHC neutrino contains all three kinds of high energy neutrino useful to study lepton flavor universality.

Location

SND@LHC



- About 480m away from the ATLAS IP
- TI18 tunnel : former service tunnel connected SPS to LEP. Not used anymore.
- Symmetric to TI12 tunnel where FASER is located.



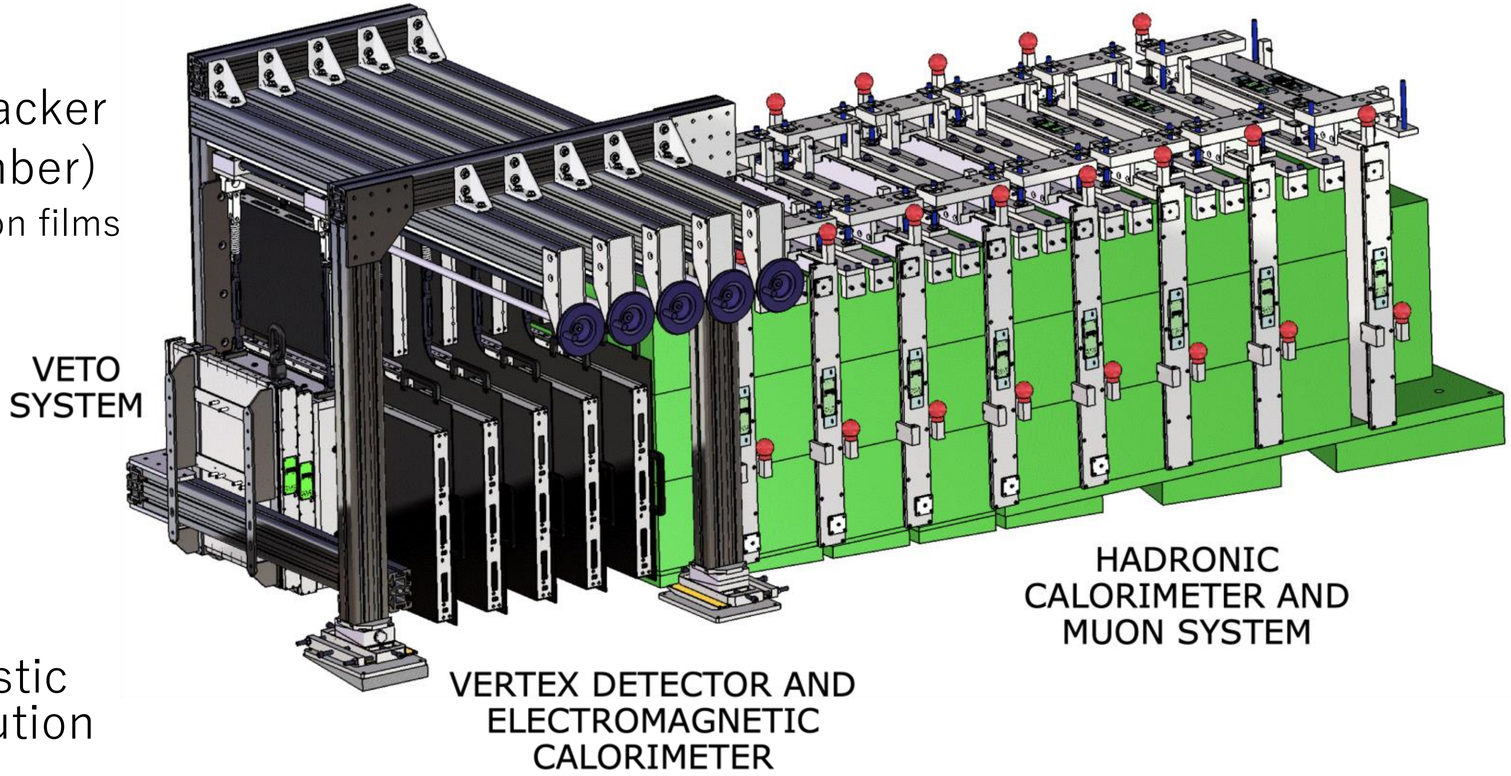
- Charged secondary particles deflected by LHC bending magnets
- Shielded by 100 m of rock
- Located slightly off axis
  - Angular acceptance: $7.2<\eta<8.4$
  - FASER is placed on axis covering $\eta>8.8$
- Aiming to collect 290 fb^{-1} (150 in proposal)
  - More luminosity become available in RUN3

SND@LHC detector

- Veto System
  - Tag penetrating muons (Scintillating bars)

- Vertex Detector and EM Cal
  - Five target walls followed by SciFi tracker
  - Tungsten ECC(Emulsion Cloud Chamber)
    - 59 1mm thick tungsten plate + 60 emulsion films
    - Neutrino interaction vertex detector
    - Flavor identification for ν_e and ν_τ
  - Scintillating fibers for timing and EM calorimetry
    - 17 X_0 each 5 target walls

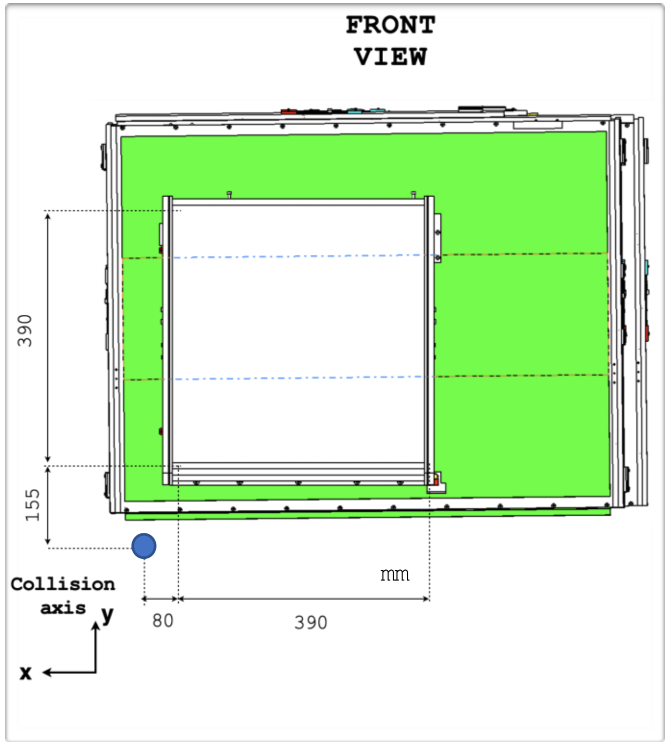
- Had Cal and Muon System
  - 8 iron walls (8λ) interleaved with plastic scintillator planes for fast time resolution and hadronic energy measurement



Layout

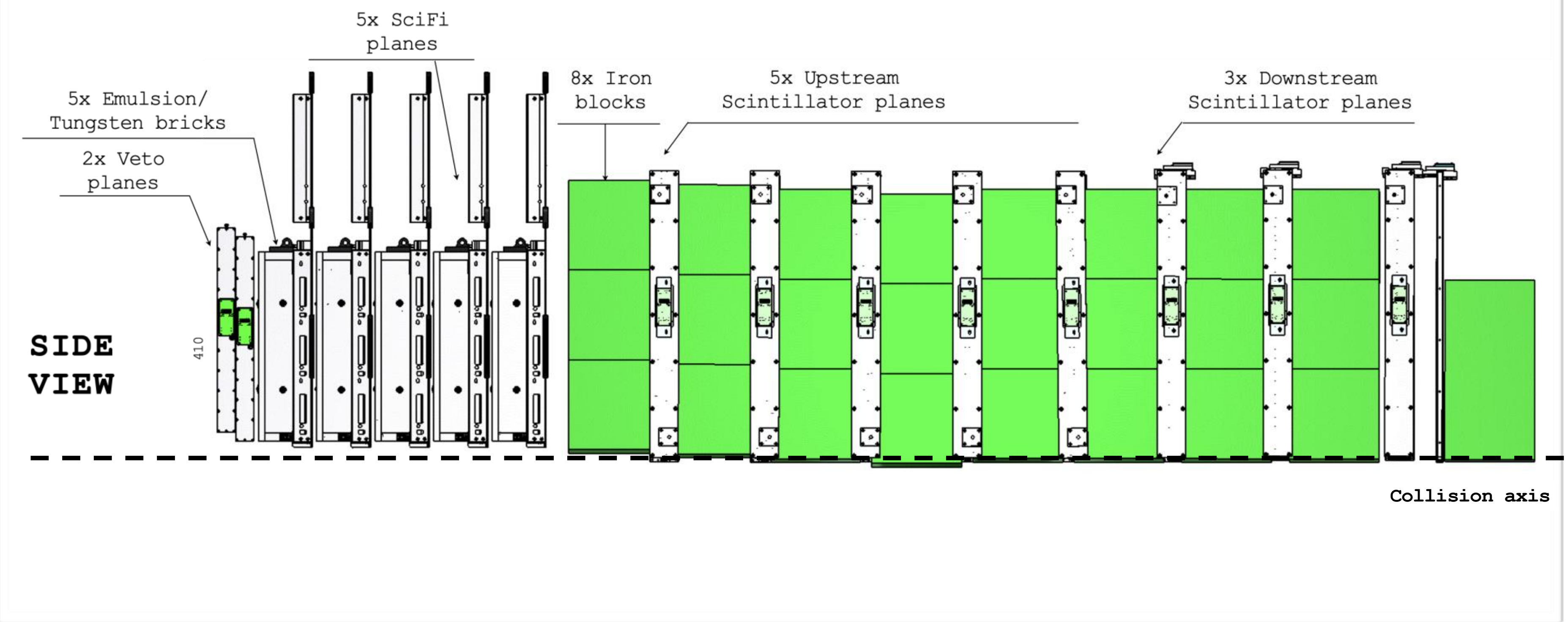
- Angular acceptance: $7.2 < \eta < 8.4$
- Target material: Tungsten
- Target mass: 830 kg
- Surface: 390x390 mm^2

Off axis location

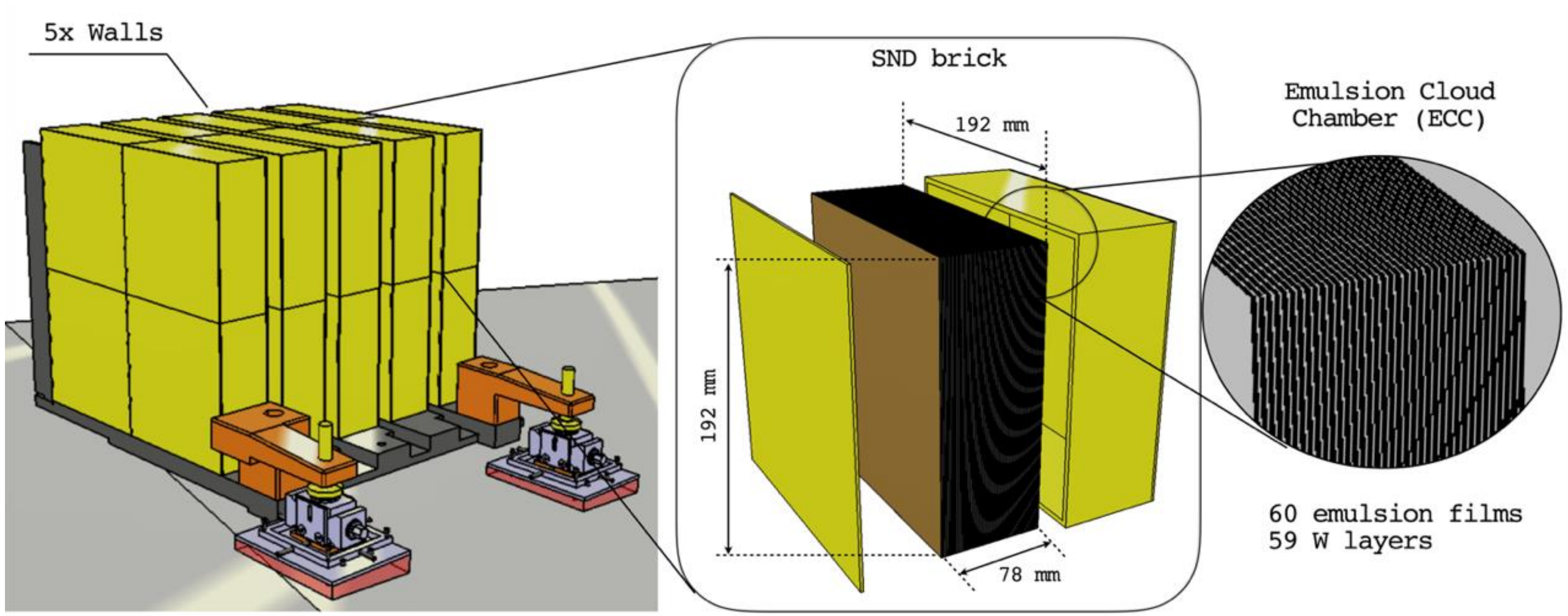


Electromagnetic calorimeter
~40 X_0

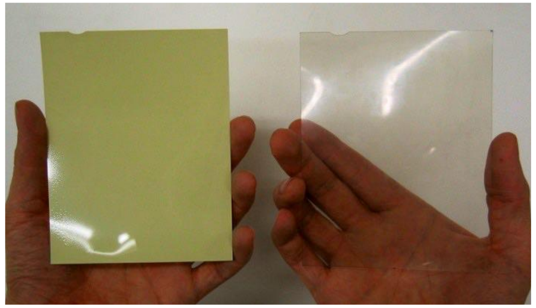
Hadronic calorimeter
~10 λ



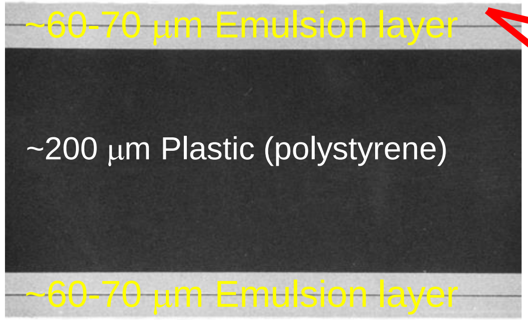
ECC target



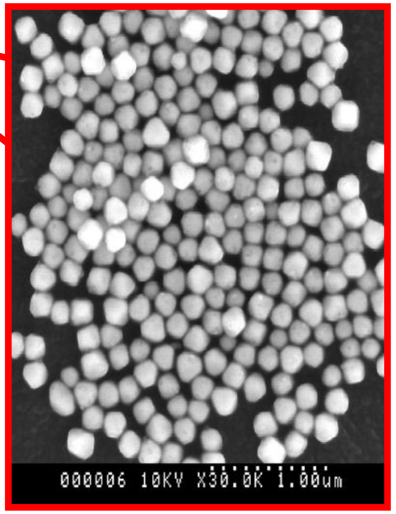
- Number of bricks : 20
  - walls: 5
  - Bricks per wall : 4
- Brick surface: 192x192 mm^2
  - Brick thickness: 78 mm
  - 60 films + 59 W plate
- Passive material : Tungsten
  - Total mass : 830 kg
  - Total emulsion surface : 44 m^2



Before and after development



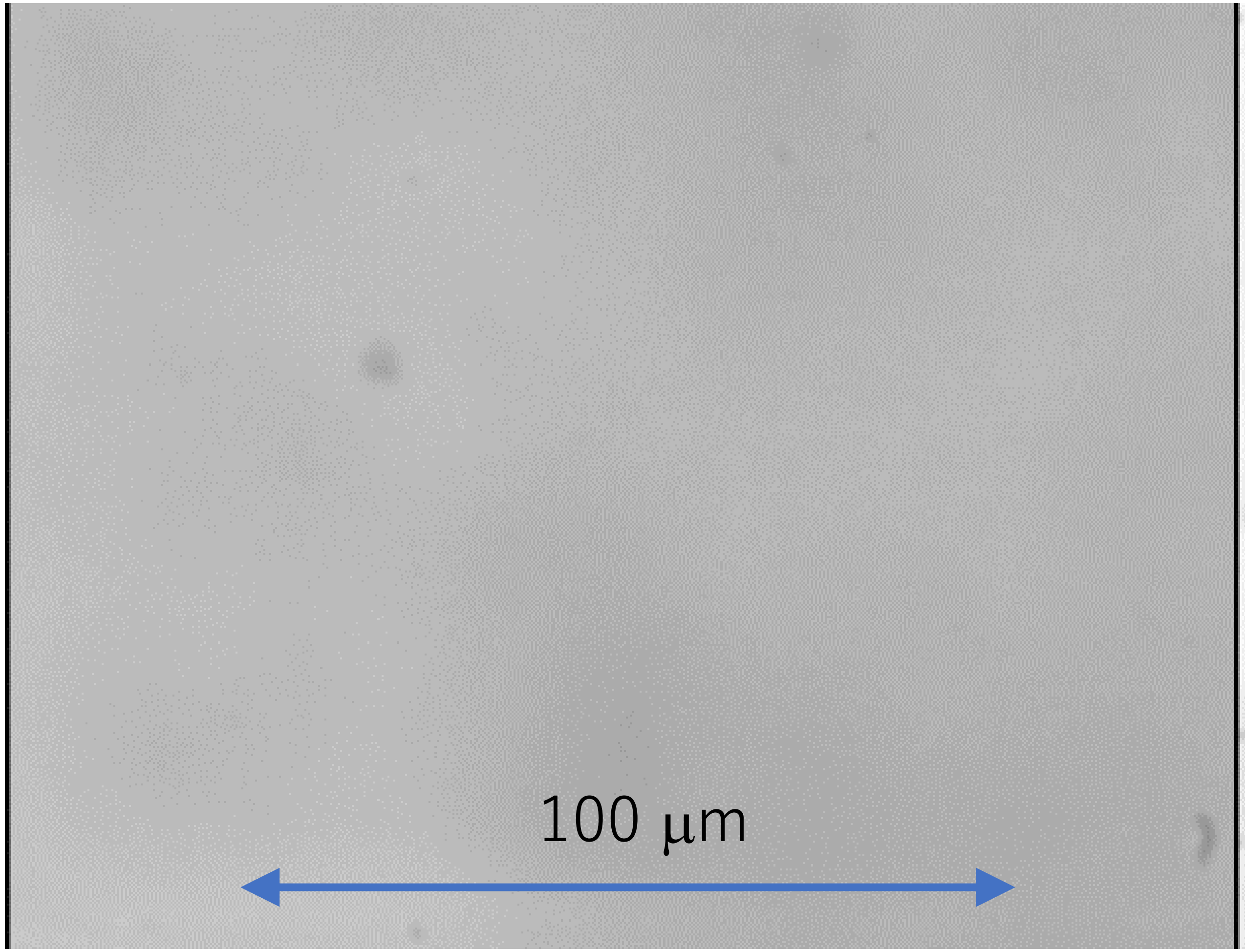
film cross section



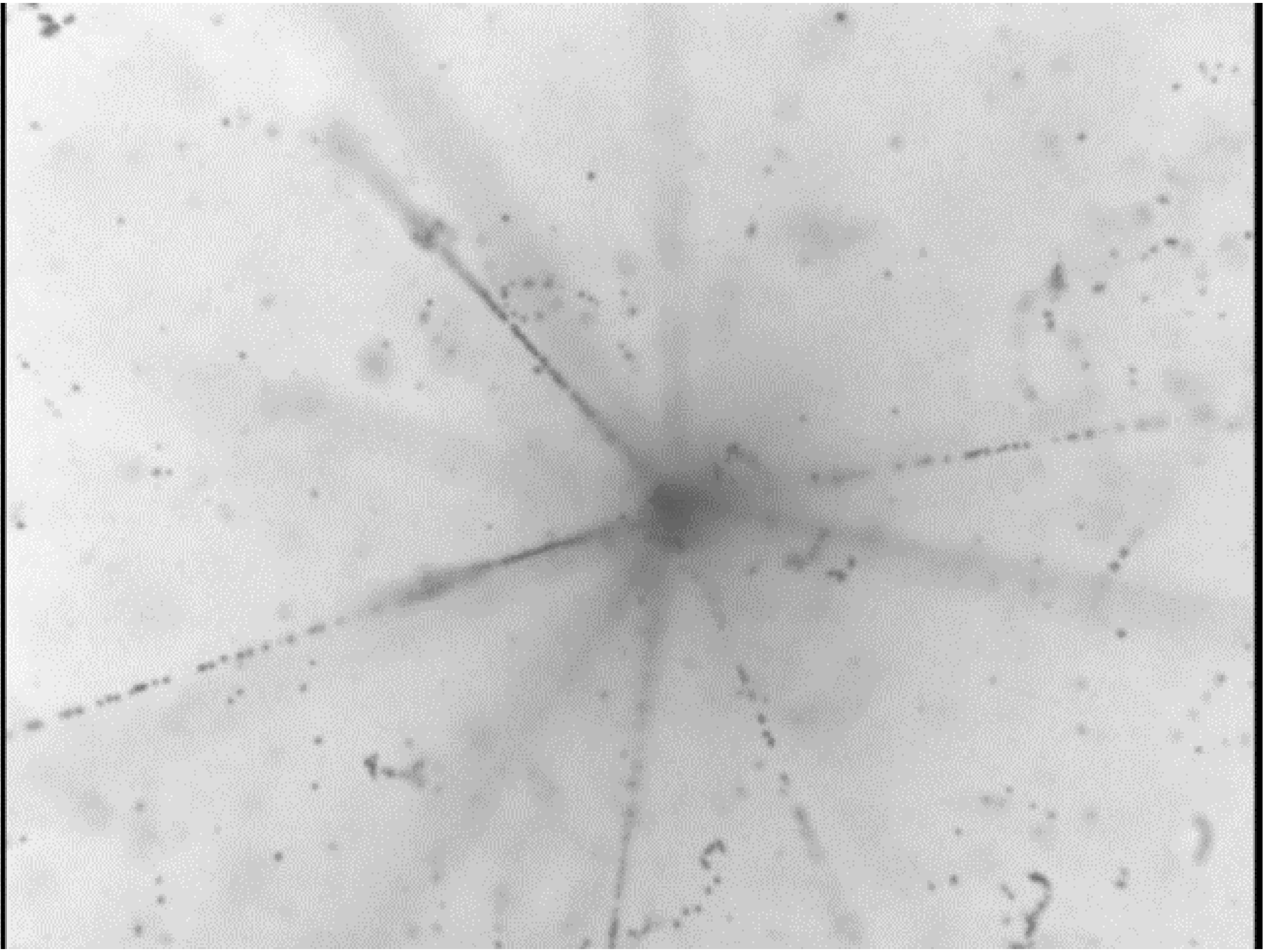
Fine 3D tracking detector composed of 0.2 μm diameter AgBr crystal in gelatin.

High energy interaction in emulsion

600 GeV π^-

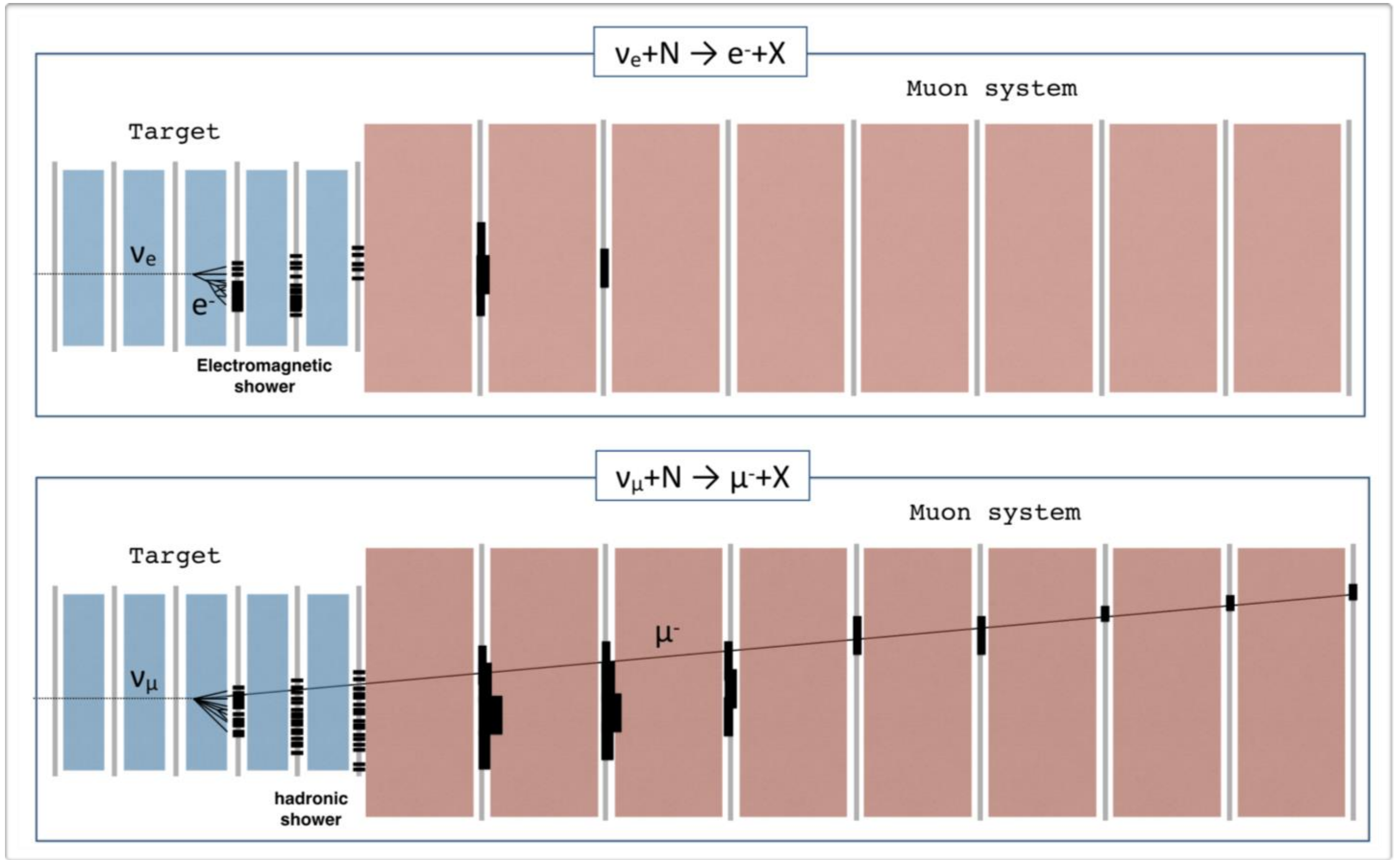


Sulfur 200 GeV/nucleon

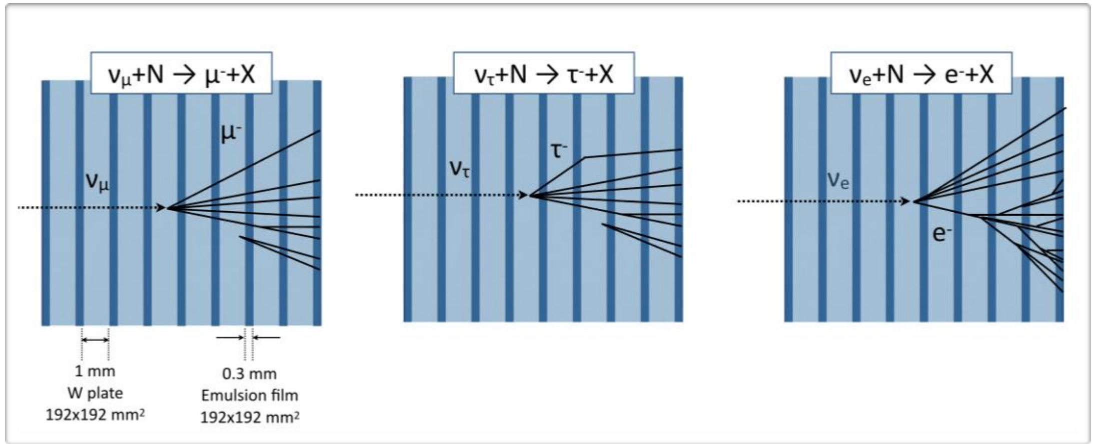


EVENT RECONSTRUCTION

- **FIRST PHASE: electronic detectors**
- Event reconstruction based on Veto, Target Tracker and Muon system
  - Identify neutrino candidates
  - Identify muons in the final state
  - Reconstruction of electromagnetic showers (SciFi)
  - Measure neutrino energy (SciFi+Muon)



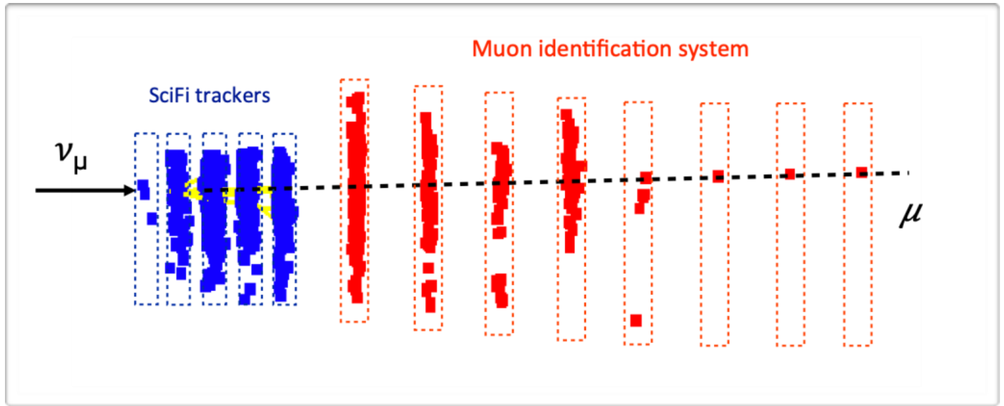
- **SECOND PHASE: nuclear emulsions**
- Event reconstruction in the emulsion target
  - Identify e.m. showers
  - Neutrino vertex reconstruction and 2ry search
  - Match with candidates from electronic detectors (time stamp)
  - Complement target tracker for e.m. energy measurement



KEY FEATURES

•Muon identification

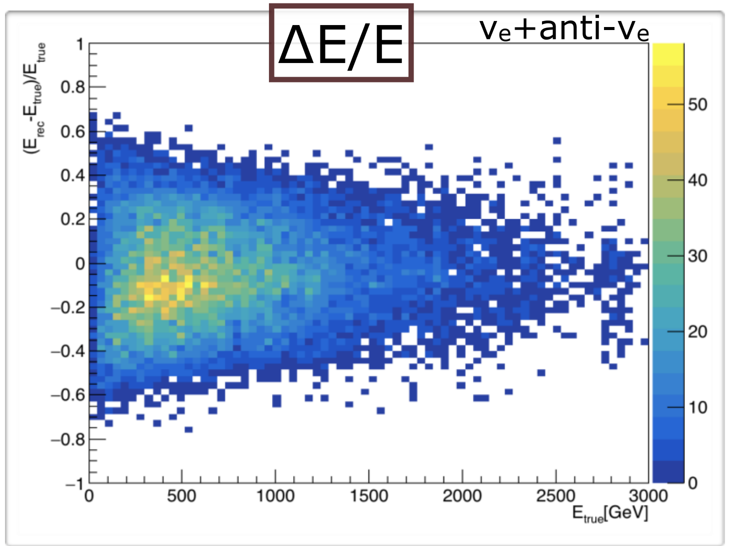
- ν_μ CC interactions identified thanks to the identification of the muon produced in the interaction
- Muon ID at the neutrino vertex crucial to identify charmed hadron production, background to ν_τ detection



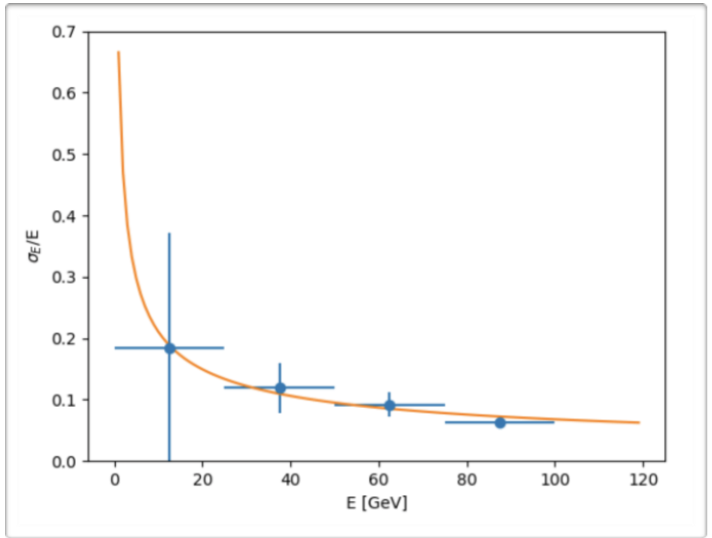
	% evts CC-DIS	% evts NC-DIS
0μ	31.1	99.6
1μ	67.6	0.27
2μ	1.1	0.06

•Energy measurement

- The detector acts as a non-homogeneous sampling calorimeter



- Combing information from SciFi (target region) and Scintillator bars (Muon System)
- Average resolution on ν_e energy: 22%

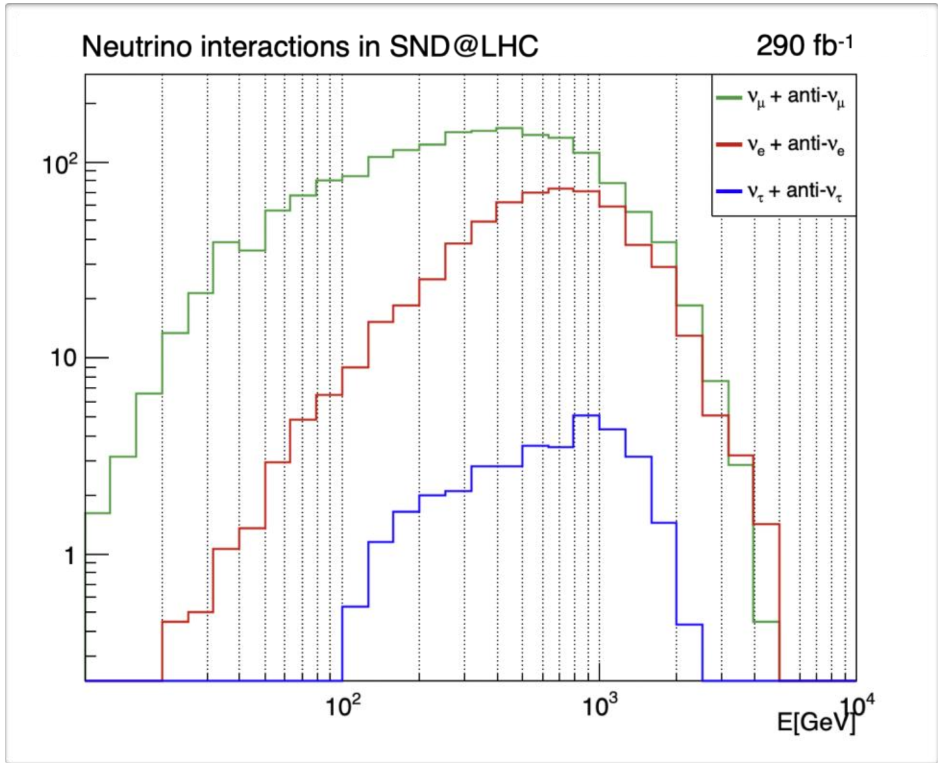


- Performance of SciFi tracker as sampling calorimeter, using a CNN
- Electron energy resolution

NEUTRINO EXPECTATIONS

- Integrated luminosity: **290 fb^{-1}**
- Upward/downward crossing angle: **0.43/0.57**

- Neutrino production in LHC pp collisions performed with **DPMJET3** embedded in FLUKA
- Particle propagation towards the detector through **FLUKA** model of LHC accelerator



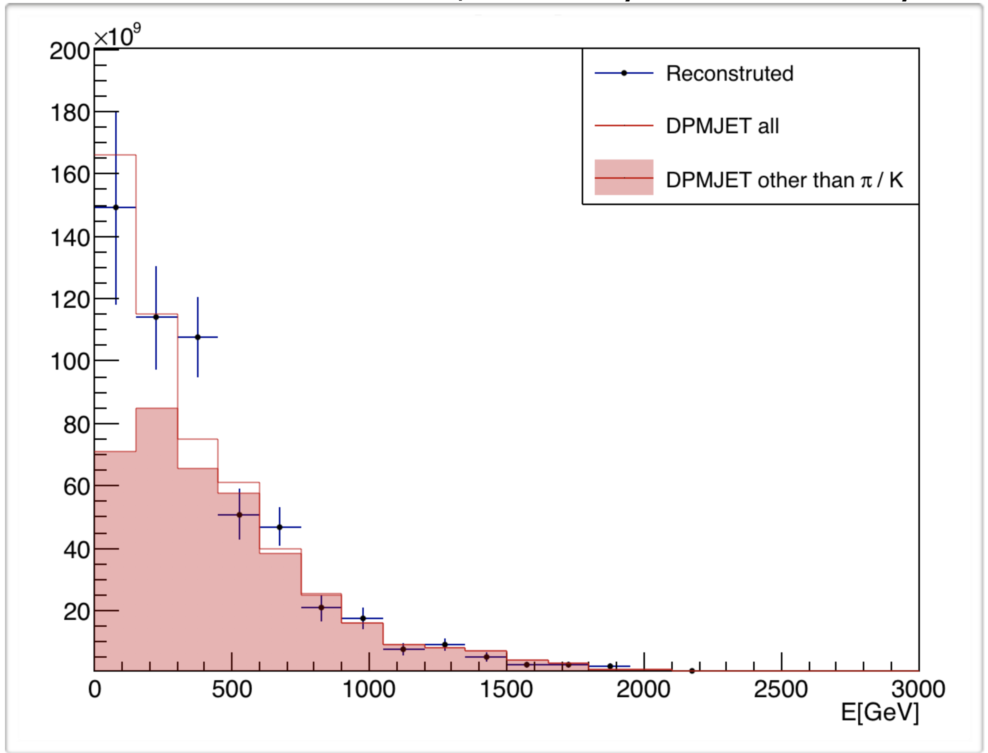
Flavour	Neutrinos in acceptance ⟨E⟩ [GeV]	Yield	CC neutrino interactions ⟨E⟩ [GeV]	Yield	NC neutrino interactions ⟨E⟩ [GeV]	Yield
ν_μ	120	3.4×10^{12}	450	1028	480	310
$\bar{\nu}_\mu$	125	3.0×10^{12}	480	419	480	157
ν_e	300	4.0×10^{11}	760	292	720	88
$\bar{\nu}_e$	230	4.4×10^{11}	680	158	720	58
ν_τ	400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

Neutrino physics program in RUN3

- $pp \rightarrow \nu_e X$ cross section and forward charmed hadron production
  - Neutrino beam simulation predicts that 90% ν_e+anti ν_e come from charmed hadron decays

▸ Reconstructed spectrum of ν_e+anti-ν_e flux in SND@LHC acceptance

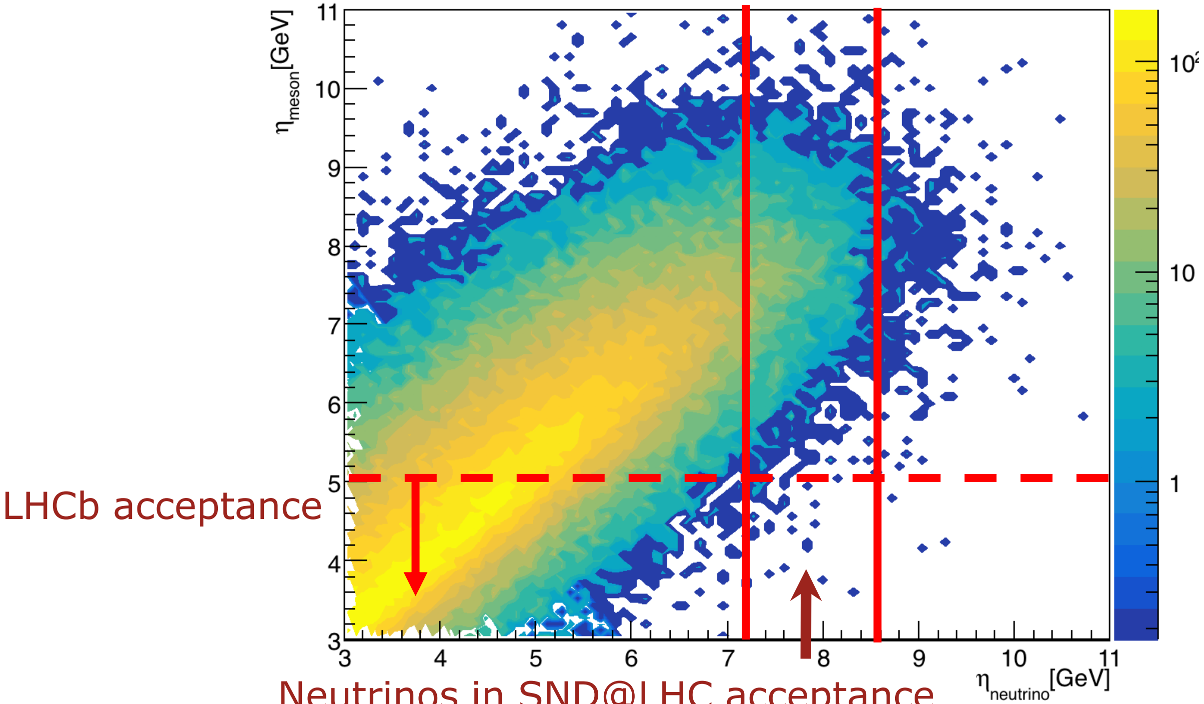
5% Stat. , 15% Sys. uncertainty



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

▸ Use neutrino as a probe for forward charm production

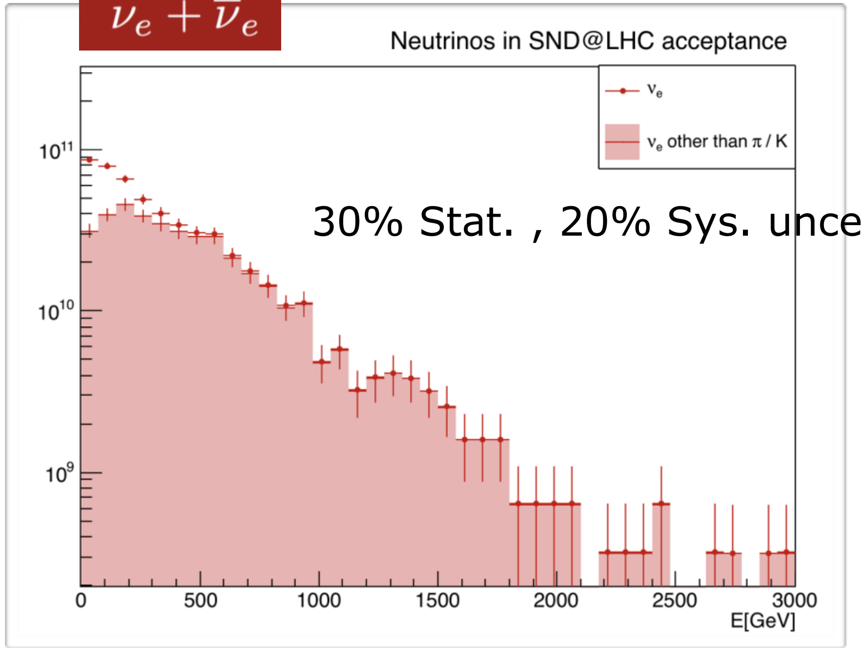
5% Stat. , 35% Sys. uncertainty



Neutrino physics program in RUN3

- Lepton Flavor Universality (LFU) test
  - LHC neutrino beam contain all three neutrino flavors and SND@LHC has flavor identification capability

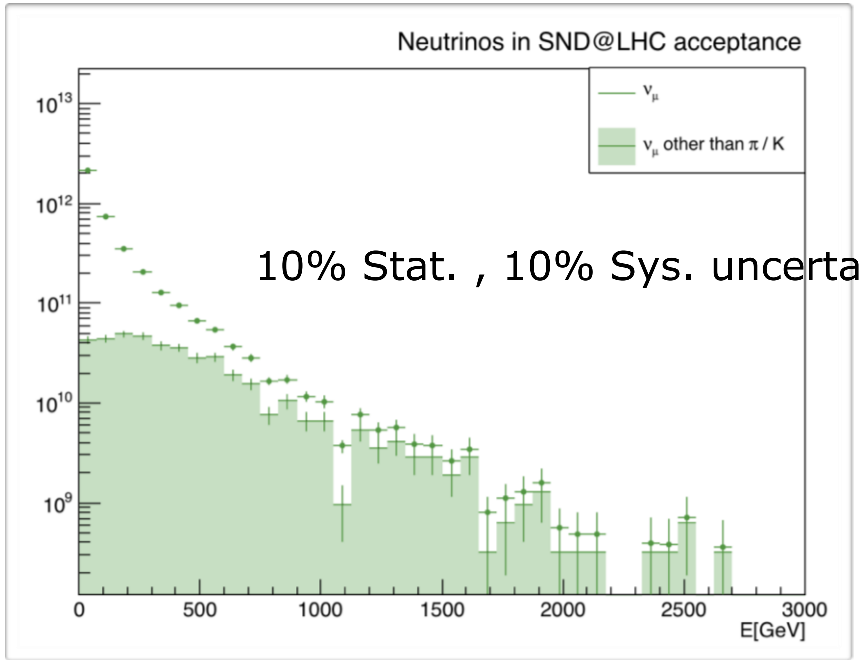
$\nu_e + \overline{\nu}_e$



30% Stat. , 20% Sys. uncertainty

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

- Sensitive to ν-nucleon interaction cross-section ratio of two neutrino species



10% Stat. , 10% Sys. uncertainty

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

contamination from π/k

- The measurement of the ν_e/ν_μ ratio can be used as a test of the LFU for E>600 GeV

Installation, commissioning and run status

- Installation in TI18 started on November 1st 2021
- Electronic detector installation completed on December 3rd 2021
- Installation of the neutron shield completed on March 15th 2022

September 2021

December 2021

March 2022

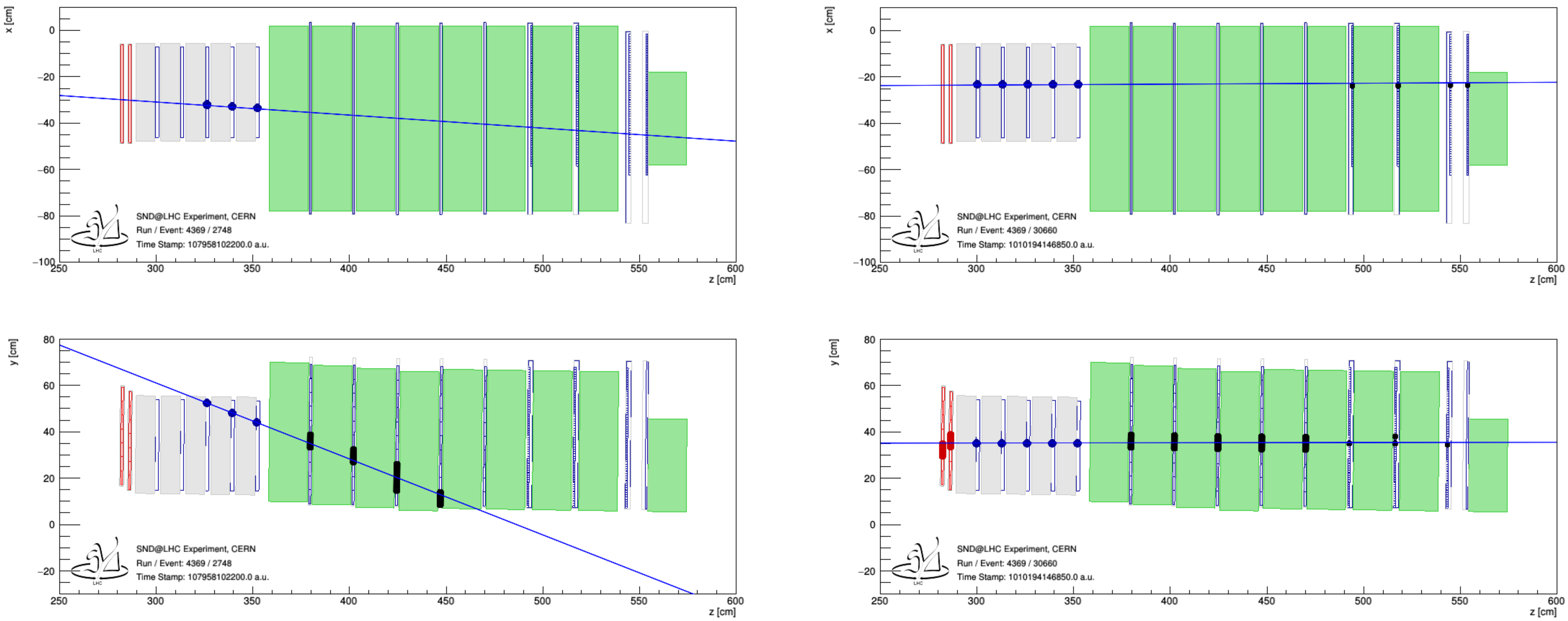
Installation, commissioning and run status

- View of the machine to the IP (left) and of the detector in TI18 (right)

Installation, commissioning and run status

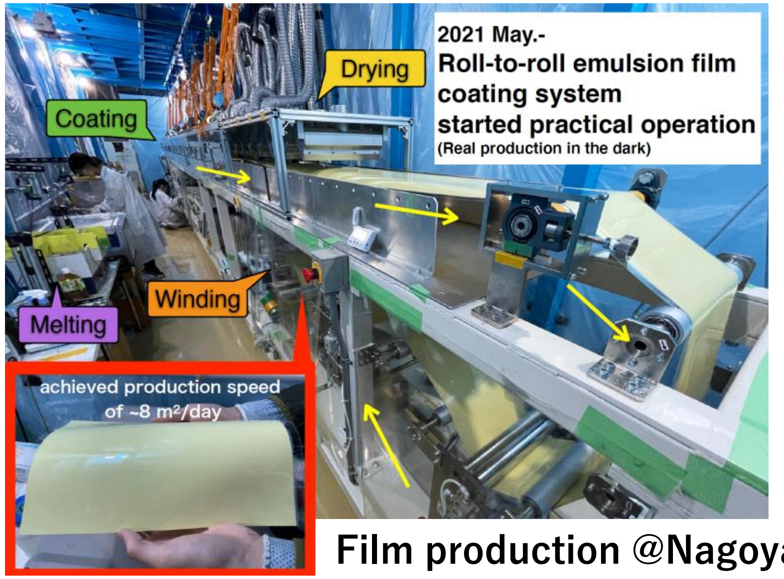
Cosmic ray
(March 5th 2022)

Muon from pp collisions @13.6 TeV
(July 6th 2022)



Installation, commissioning and run status

Emulsion film from Nagoya(JP) and Slavich(RU) Early July.



Film production @Nagoya

Tungsten ECC installed July 26th, 2022
Total mass : 830 kg
Number of emulsion films : 1200

Conclusions

- SND@LHC is approved on March 2021
  - We successfully prepared whole detector in time.
  - Data taking started in April 2022 with 1/20 emulsion module
  - Full ECC modules installed on July 26th
- Measuring unexplored region of high energy neutrino events
  - Cross section measurement at TeV region
    - Uncertainty 5±15%(ν_e + antu ν_e)
  - Forward region heavy flavor production through neutrino
    - Forward region ($7.2<\eta< 8.4$) where even LHCb can not explore
  - LHC neutrino beam contain all three kind of neutrino
    - Lepton Flavor Universality test with 10±10%(e/μ) to 30±20%(e/τ) uncertainty
- Stay tune for the result
  - Real run just started
  - 290 fb^{-1} in RUN3(2022-25) : 1930 events including 34 tau neutrino