SND@LHC
Scattering and Neutrino Detector at LHC

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on behalf of the SND@LHC Collaboration

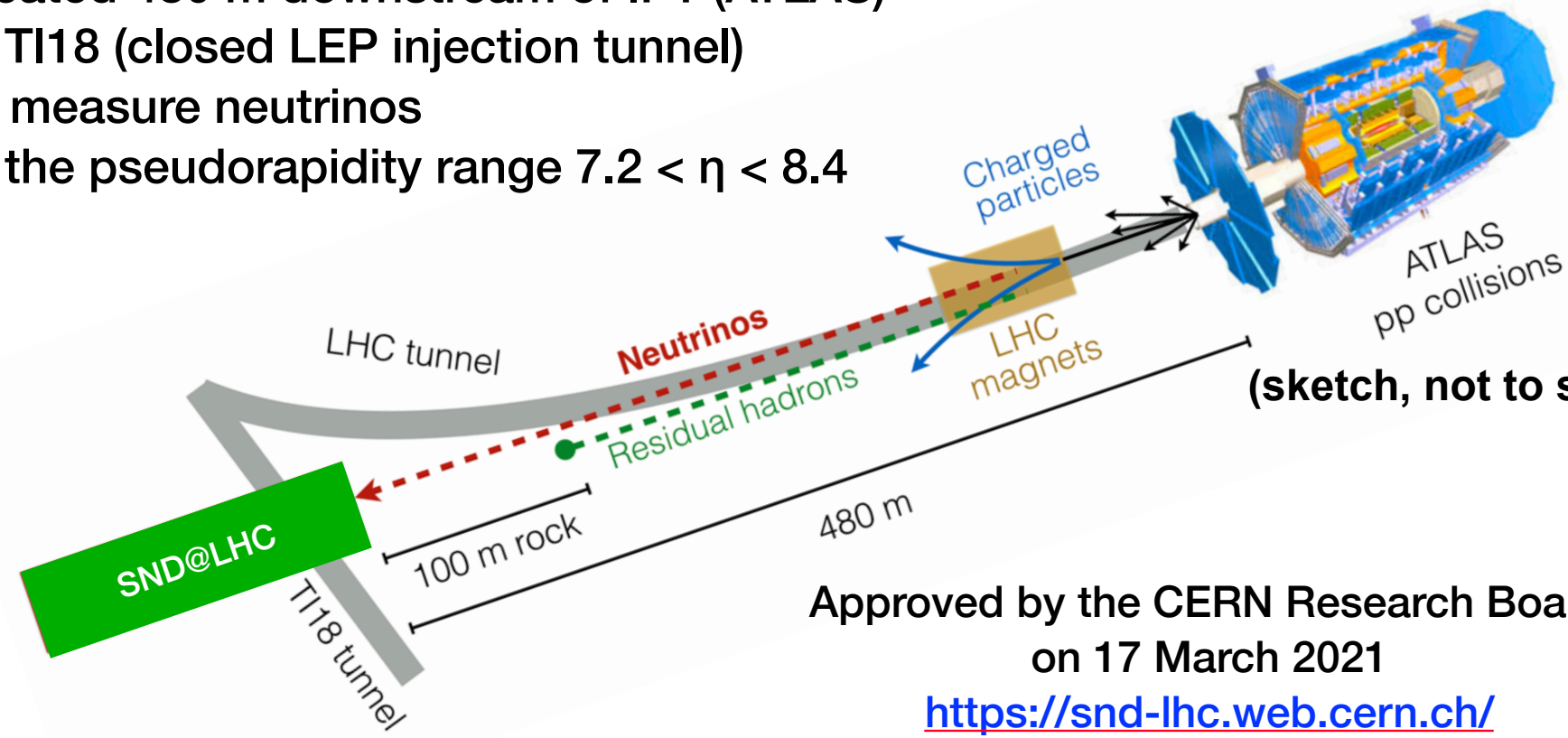
May 3, 2022

WG6:
Future
Experiments

SND@LHC

Scattering and Neutrino Detector at the LHC

Stand-alone experiment,
located 480 m downstream of IP1 (ATLAS)
in TI18 (closed LEP injection tunnel)
to measure neutrinos
in the pseudorapidity range $7.2 < \eta < 8.4$



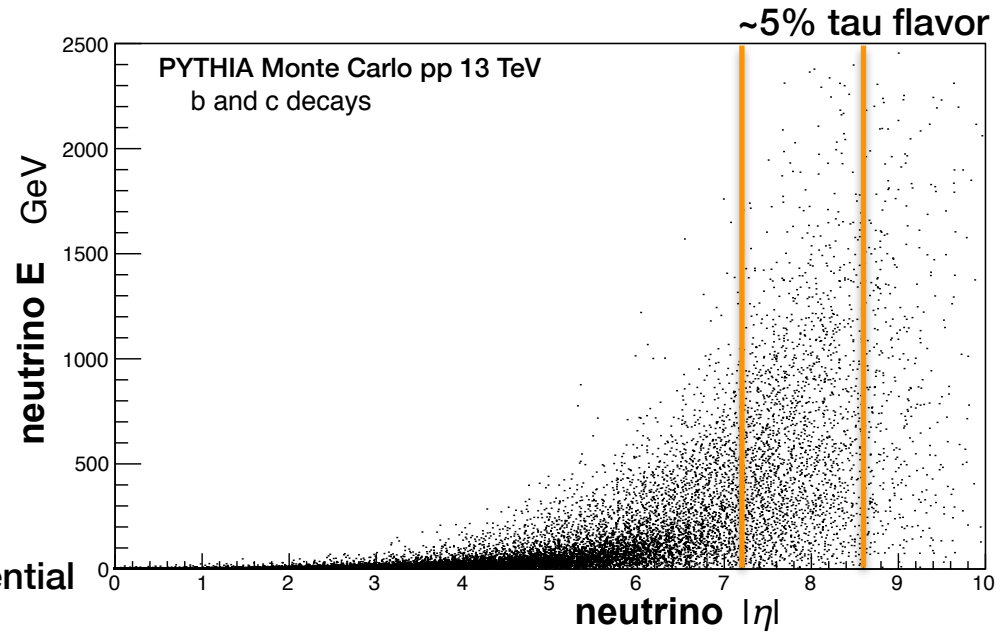
(sketch, not to scale)

Approved by the CERN Research Board
on 17 March 2021
https://snd-lhc.web.cern.ch/
to take data in 2022-2025

Neutrinos at the LHC

N. Beni et al., "Physics Potential of an Experiment using LHC Neutrinos", J. Phys. G: Nucl. Part. Phys. 46 (2019) 115008, doi:10.1088/1361-6471/ab3f7c [arXiv:1903.06564]

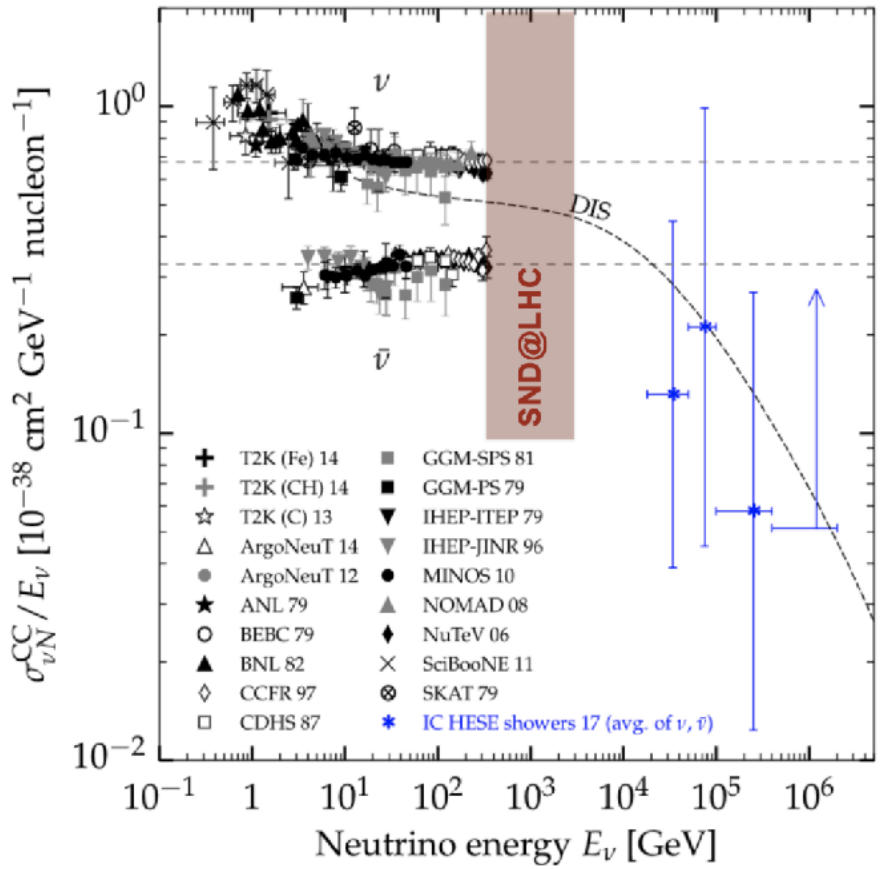
- Large ν flux in forward direction
- High ν energies: large νN cross sections
- $7.2 < \eta < 8.4$: ν (all three flavors) from heavy quarks (ν_e , ν_τ >90% charm*)



* N. Beni et al., "Further studies on the Physics Potential of an Experiment using LHC Neutrinos", J. Phys. G: Nucl. Part. Phys. 47 (2020) 125004, doi:10.1088/1361-6471/aba7ad

Physics program

PRL 122 (2019)041101

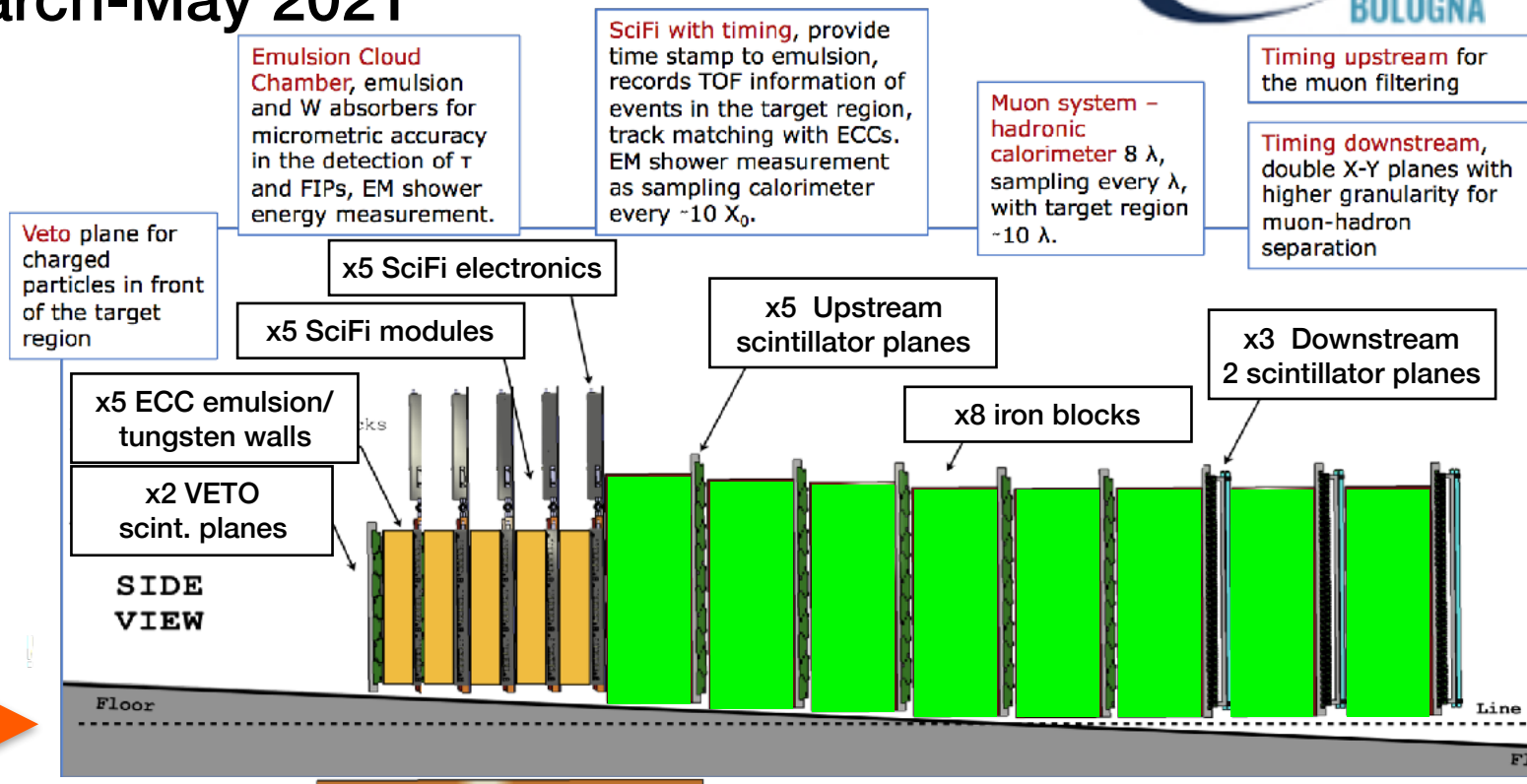


- $\sigma_{pp \to \nu X}$ in $7.2 < \eta < 8.4$ range
- ν_e as a probe of charm quark production
- Lepton universality test: ν_τ/ν_e and ν_μ/ν_e
- Benchmark measurement of NC/CC to verify detector understanding
- Search for feebly interacting particles

detector design and protyping

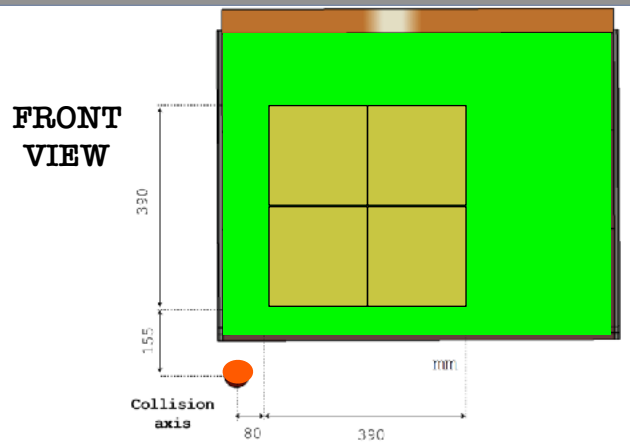
March-May 2021

Hybrid detector optimised for the identification of all three neutrino flavors



EM calorimeter
~ 40 X_0
Hadronic calo
~ 10 λ

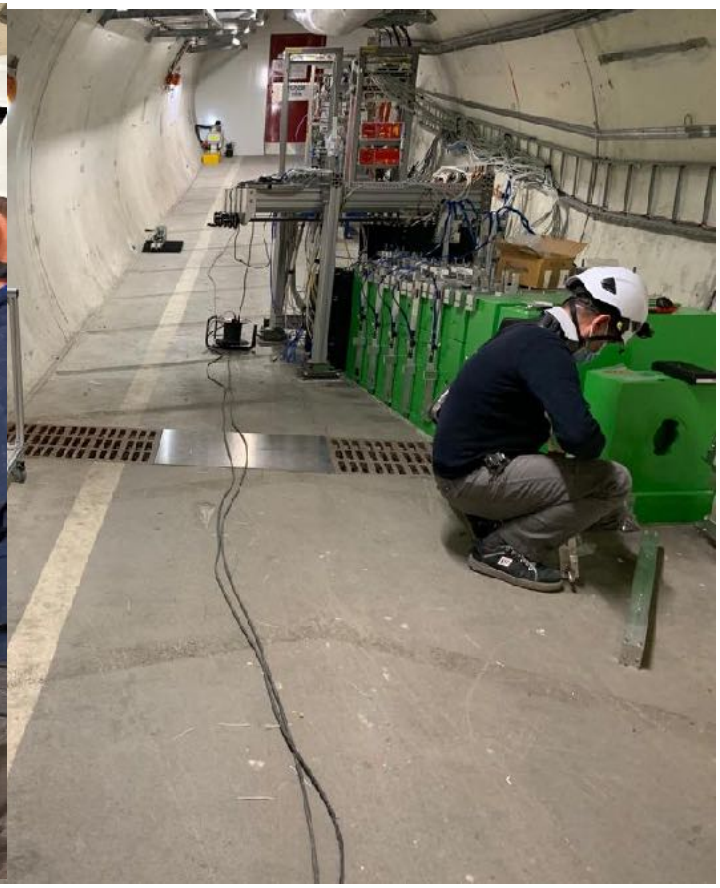
SND@LHC Technical Proposal
https://cds.cern.ch/record/2750060/files/LHCC-P-016.pdf



Off axis location
Angular acceptance:
$7.2 < \eta < 8.4$
Target material: Tungsten
Target mass: 830 kg
Surface: 390 x 390 mm^2

detector and site infrastructure

June-November 2021



SND@LHC Collaboration:

~180 members from 23 Institutes of 13 countries and CERN

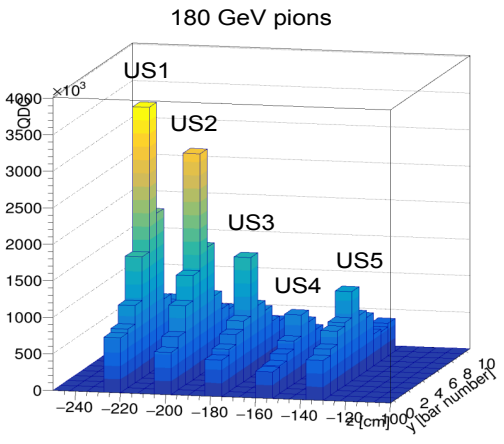
detector commissioning

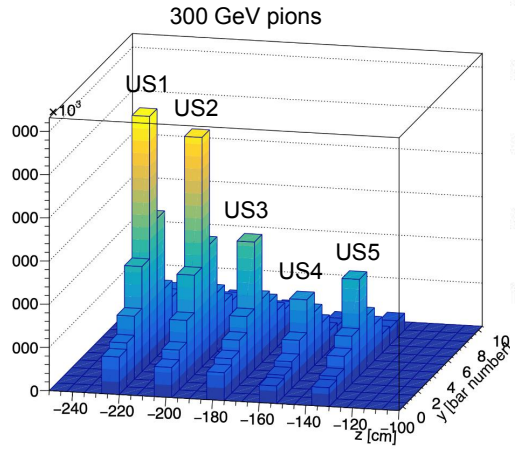
hadronic energy

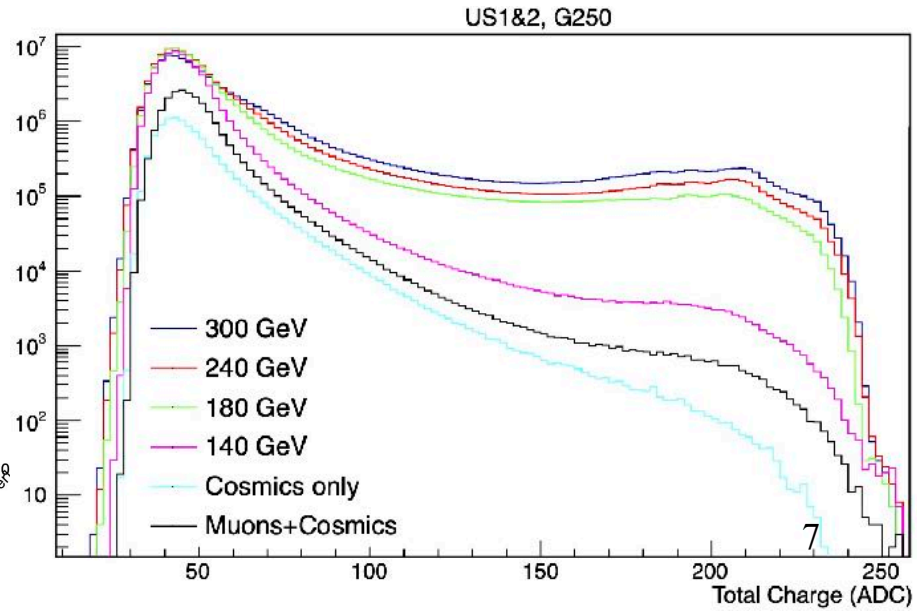
Scattering and Neutrino Detector at the LHC

SND@LHC is a non-homogeneous sampling calorimeter

- **Upstream Stations**, located behind the target region, used to identify muons and, together with SciFi, to act as HCAL
- 5 planes of 10 1x6x80 cm^3 stacked scintillating bars r/o by 8 SiPMs at both bar ends
- Tested with **π beam** of 100, 140, 180, 240, 300 GeV at CERN H8 (Sept-Oct 2021)







detector commissioning

muons and timing

Scattering and Neutrino Detector at the LHC

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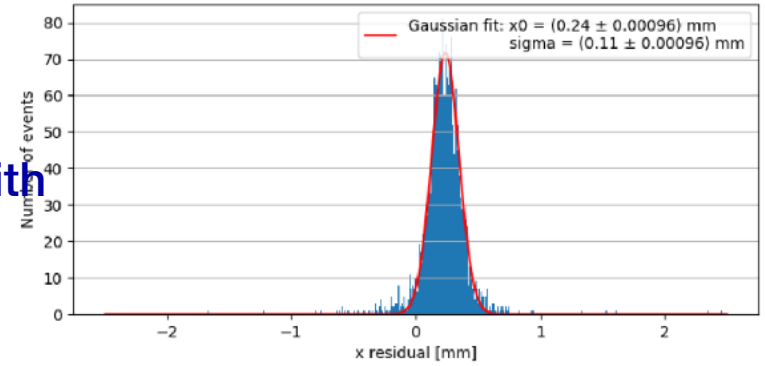
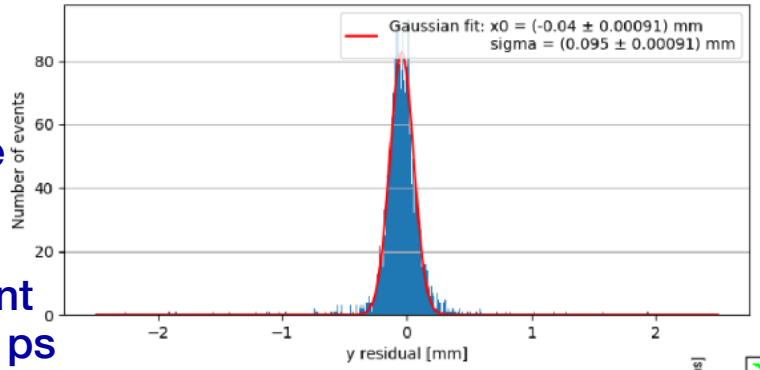
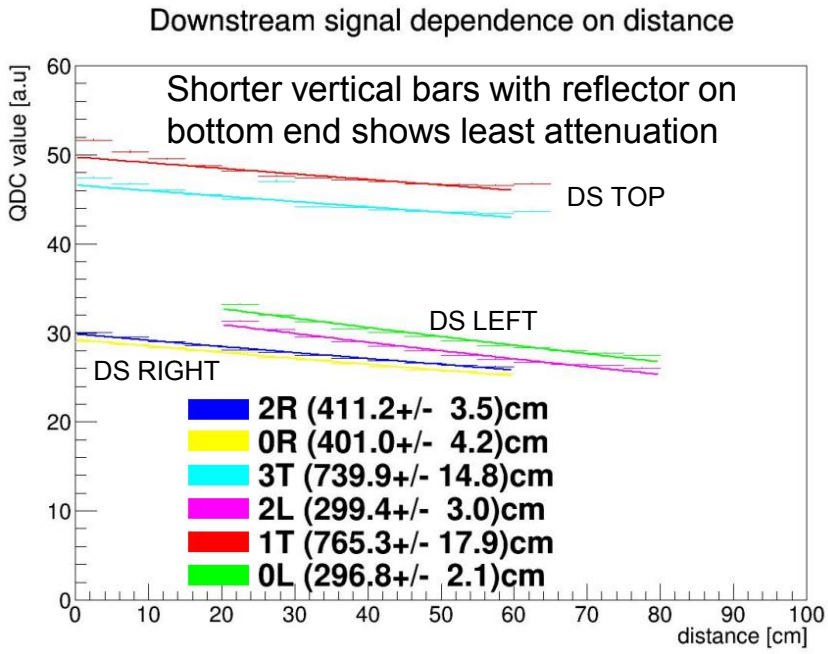
Test with cosmics and with μ beam at the CERN H6 line (Oct-Nov 2021)

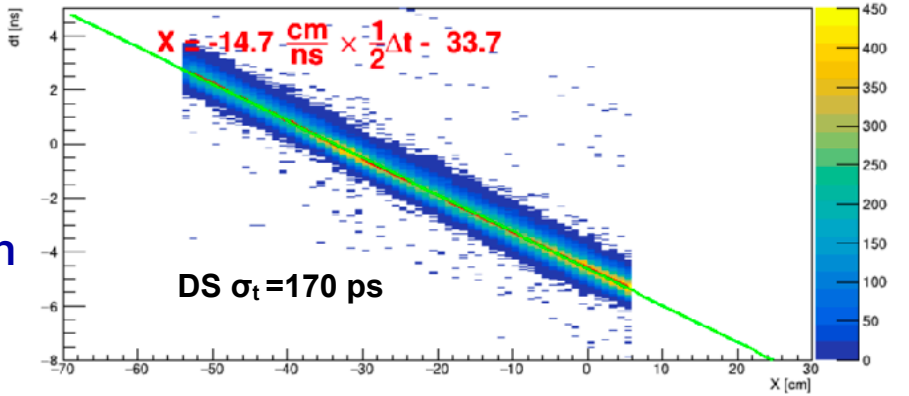






- 5 planes of **Scintillating Fibre** mats to be embedded in the target to give event timestamp to 100 ps

- **Downstream muon Stations:** 3 double planes (horizontal and vertical) of 1x1x 80(60) cm³ scintillating bars r/o by single SiPMs per bar end for horz. and only from top for vert. Additional 4th vert. layer to increase redundancy



LHC

Scattering and Neutrino Detector at the LHC

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Installed detector

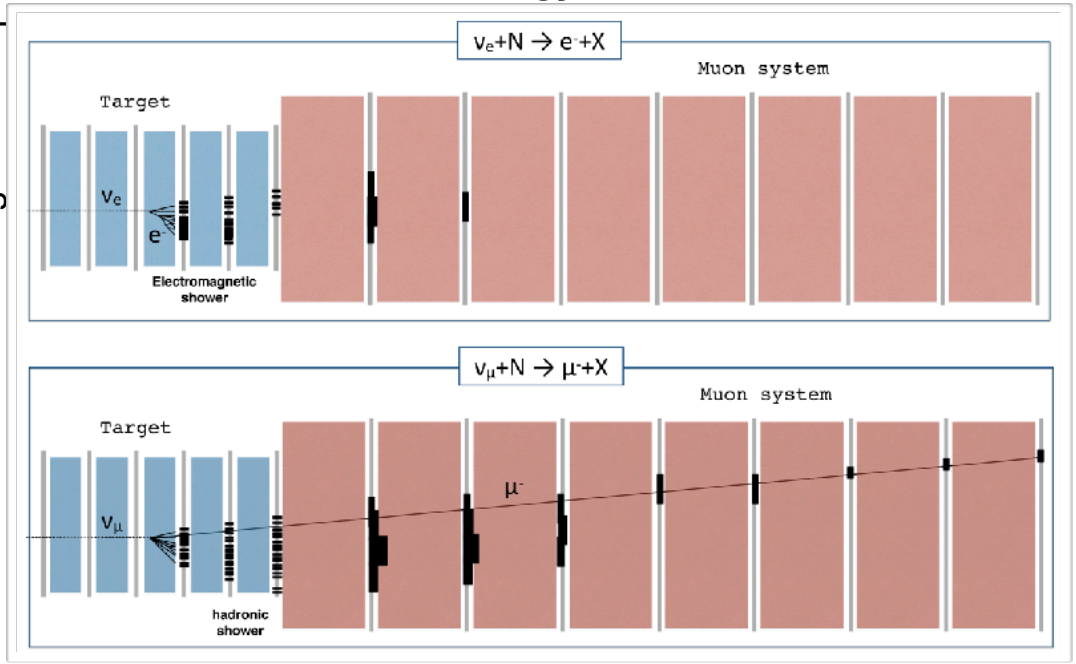
Data taking

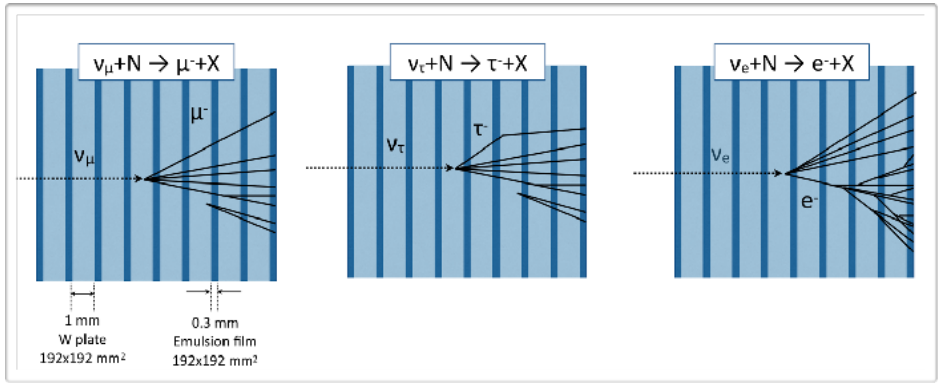
any activity in the detector is recorded;
a 0-bias noise filter at SW level

Two phases :

- FIRST: electronic detectors
- Veto, SciFi Tracker and Muon system
  - select neutrino interactions
  - Identify muons
  - Reconstruct of EM/hadron showers
  - Measure neutrino energy

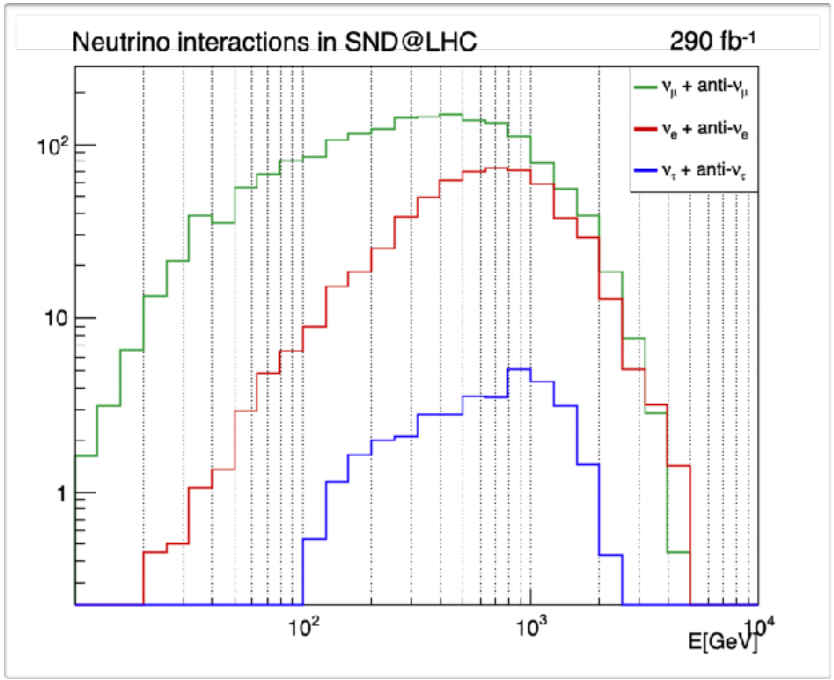
- SECOND: nuclear emulsions
- Emulsion Cloud Chambers
  - Neutrino interaction vertex
  - identify secondary vertices
  - Match event with electronic detectors
  - Complement e.m. energy measurement





Neutrino expectations

- Simulation of LHC pp collisions performed with DPMJET3 embedded in FLUKA
- All particles propagated through the FLUKA model of LHC up to the SND@LHC
- Detector geometry and surrounding tunnel implemented in GEANT4
- Both “prompt” neutrinos (mainly from charm decay) and neutrinos from pion/ Kaon decays interact with the detector (GENIE)

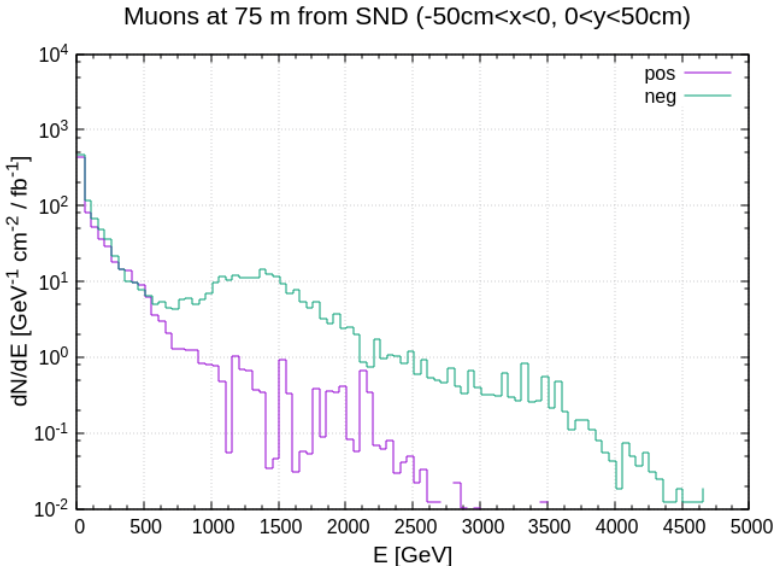


predicted Neutrino event statistics

- Integrated luminosity: 290 fb^{-1} (LHC Run3)
- luminosity sharing of Upward/downward pp crossing angle : 0.43/0.57
- neutrinos interacting in the target fiducial volume; detection and reconstruction efficiencies not included (expect >90% for ν_μ , ν_e , and >50% for ν_τ)

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	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
$\bar{\nu}_e$	320	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

in-situ backgrounds



- SND@LHC will measure the flux of **muons** (predicted ~350 Hz), thus providing a stringent test of the FLUKA simulations of the LHC machine

- Isolated neutrons and K_L particles can be generated by DIS of muons in the rock upstream of the SND@LHC detector, which can mimic neutrino NC events, if interacting in the target. Estimated to be very low.

particles/fb^{-1}	E>10 GeV	E>100 GeV	E>200 GeV	E>500 GeV
K_L	48	11.7	4.4	0.5
neutron	17	5.4	2.0	0.5
anti-neutron	12	3.3	1.5	0.1

- low energy neutrons are generated in the interactions of the protons with the residual gas inside the LHC vacuum pipe. 50% are thermal neutrons at ~0.025 eV. They can produce a fog of random hits in the emulsions as a result of neutron capture in Ag-109 silver nuclei. The emulsion detector is protected with a thick layer of borated polyethylene.

planned measurements in LHC Run3

ν detected in $7.2<\eta<8.4$, $0.4<\theta<1.5$ mrad

Measurement	Statistical Uncertainty	Systematic Uncertainty	dominant systematics
pp —> ν_e X cross-section, differential in E	5%	15%	subtraction of ν_e from K decay (mainly E<200GeV). unfolding of ν_e/antiν_e Xsec on Nucleon
Charmed hadron yield, energy spectrum	5%	35%	unfolding of detector response and ν_e-charm hadron correlation
ν_e / ν_τ ratio for LFU test	30%	20%	Uncertainties due to charm quark production cancel out. ν_e/ν_τ only depends on charm hadronisation and decay branching fractions: ν_e from D0, D, Ds and Λc; ν_τ mainly from $D_s \rightarrow \tau\nu_\tau$
ν_e /ν_μ ratio for LFU test	10%	10%	contamination of ν_μ from π and K decays

APRIL 22 - LHC beam test

Scattering and Neutrino Detector at the LHC

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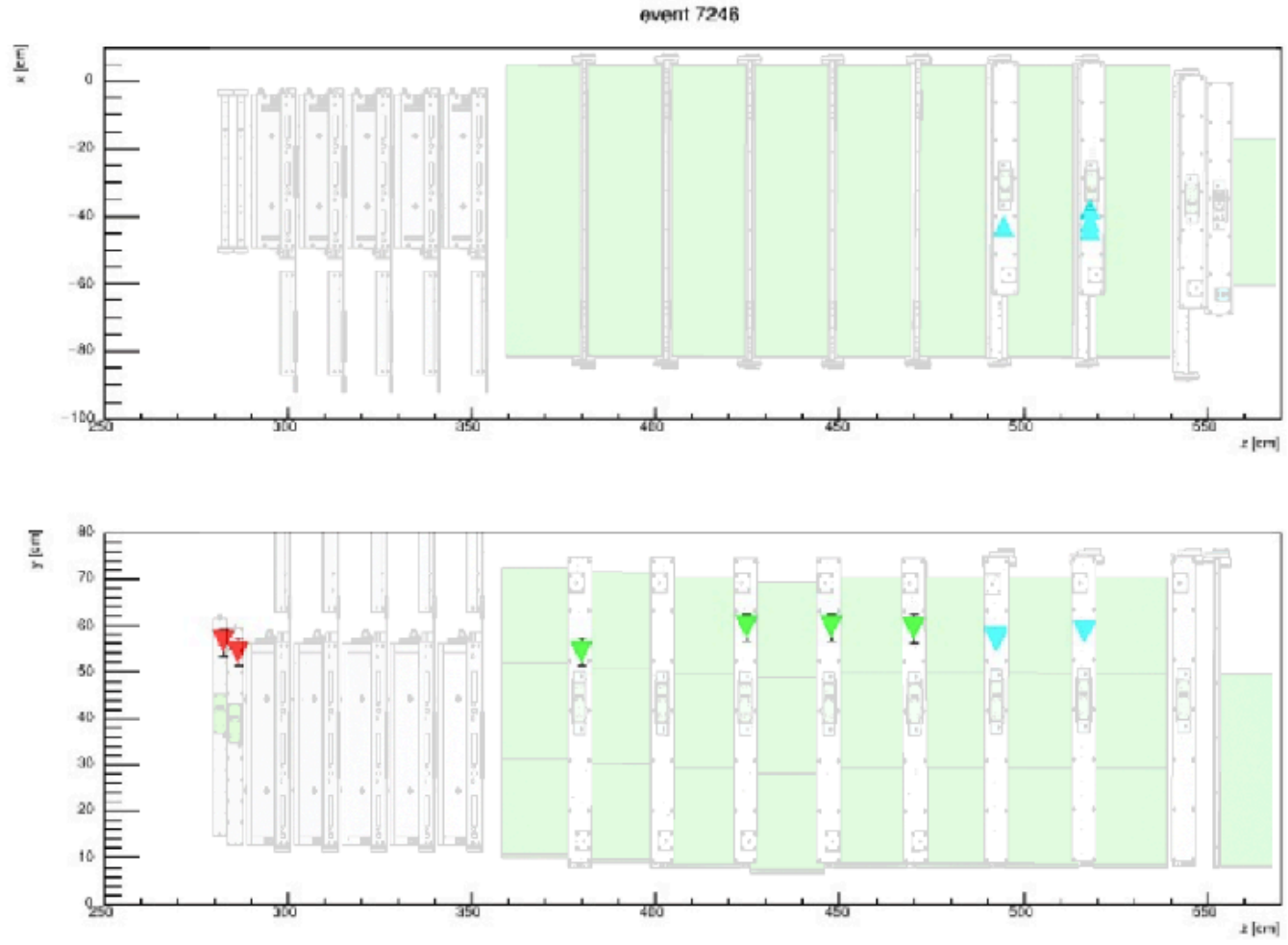
first muon from beam “splash”



top view

side view

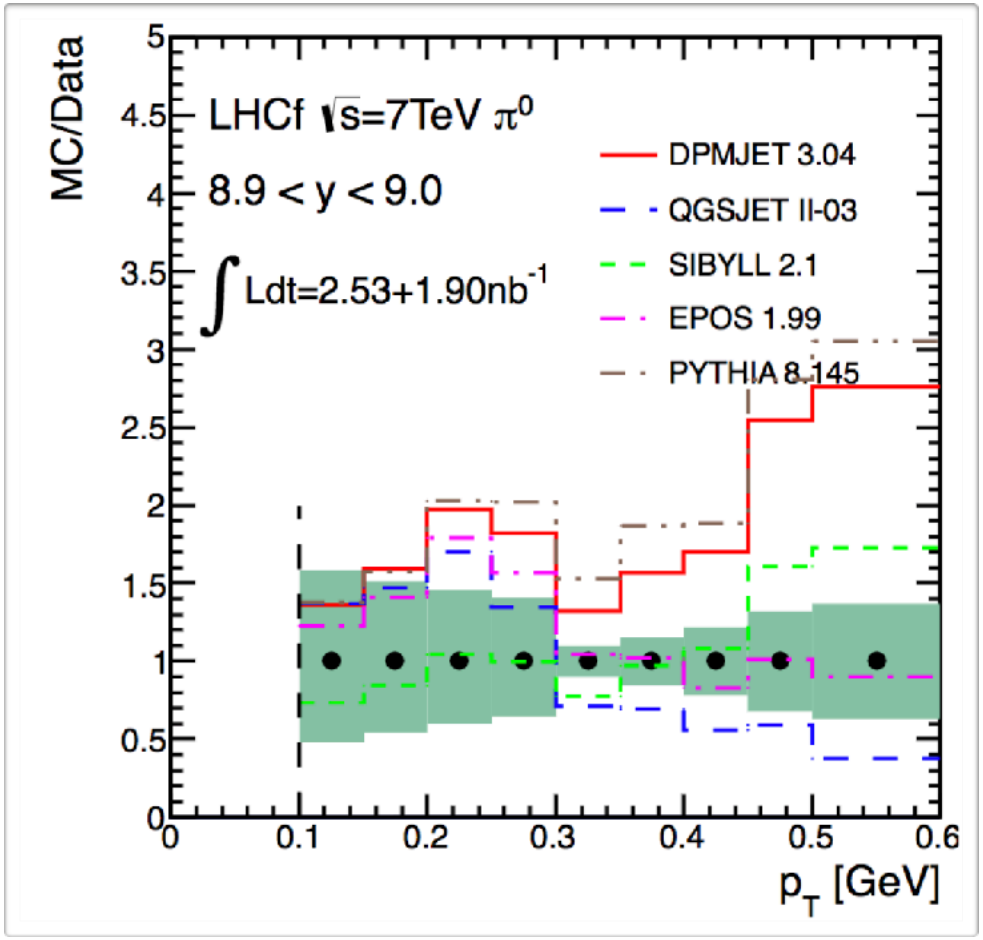
Summary and outlook

- SND@LHC was approved, constructed and commissioned in record time. It comprises a veto system, target tracker (emulsions+SciFi) and a downstream muon/hcal system.

- SND@LHC has a unique Physics program to study all 3 neutrino flavors from LHC pp interactions in $7.2 < \eta < 8.4$. Expect to collect over 2000 high energy neutrino events in LHC Run3.

- beyond Run3, an upgrade for HL-LHC is begin studied: gain x10 in Lumi; x10 in target mass; replace emulsions with electronic tracker; install a twin detector closer to IP for $4<\eta<5$ (high E νs from Ws, 33% tau flavor)

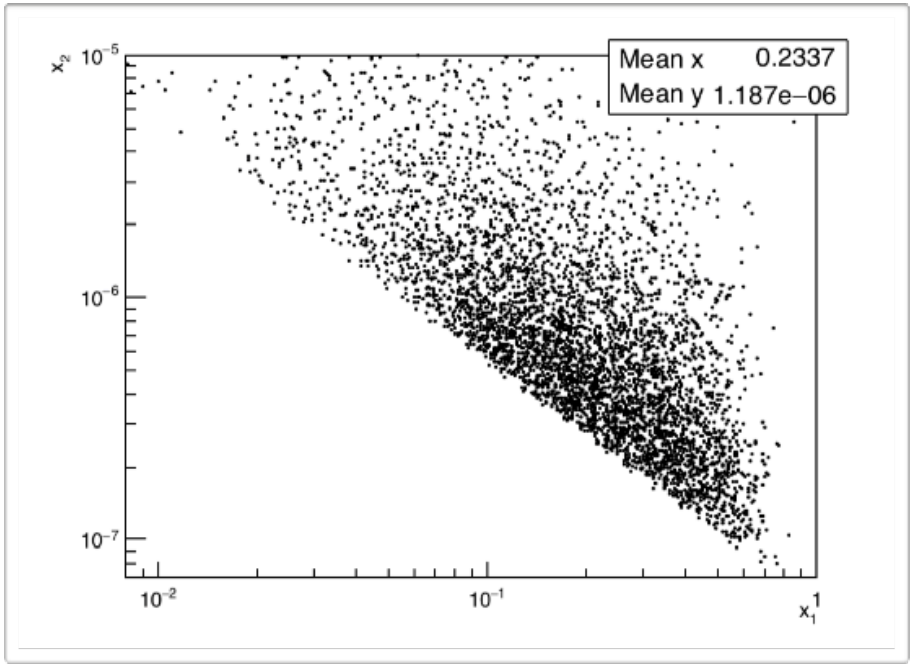
additional material


MC/Data
LHCf √s=7TeV π0
8.9 < y < 9.0
∫ Ldt=2.53+1.90nb-1
DPMJET 3.04
QGSJET II-03
SIBYLL 2.1
EPOS 1.99
PYTHIA 8.145
pT [GeV]

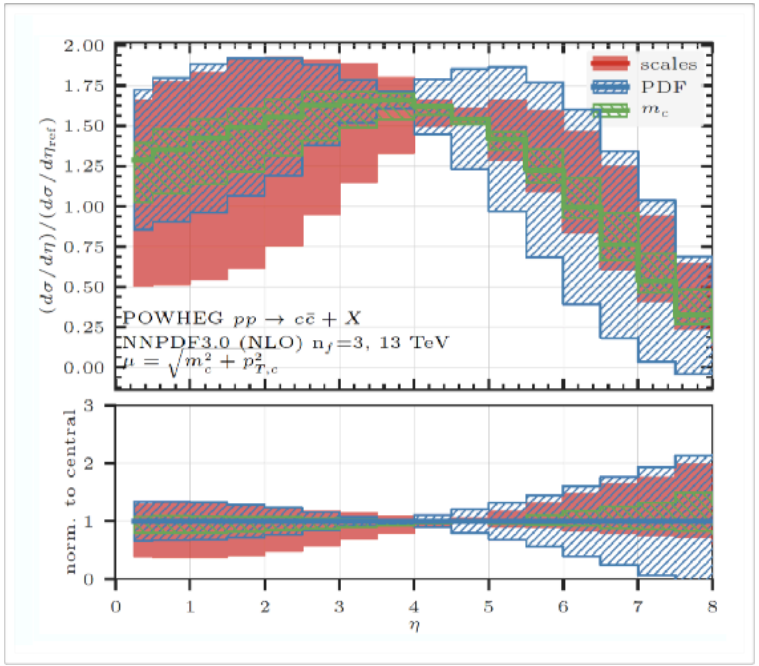
QCD MEASUREMENTS

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

Average lowest momentum fraction: 10^{-6}



Correlation between x1 and x2 for events in the SND@LHC acceptance

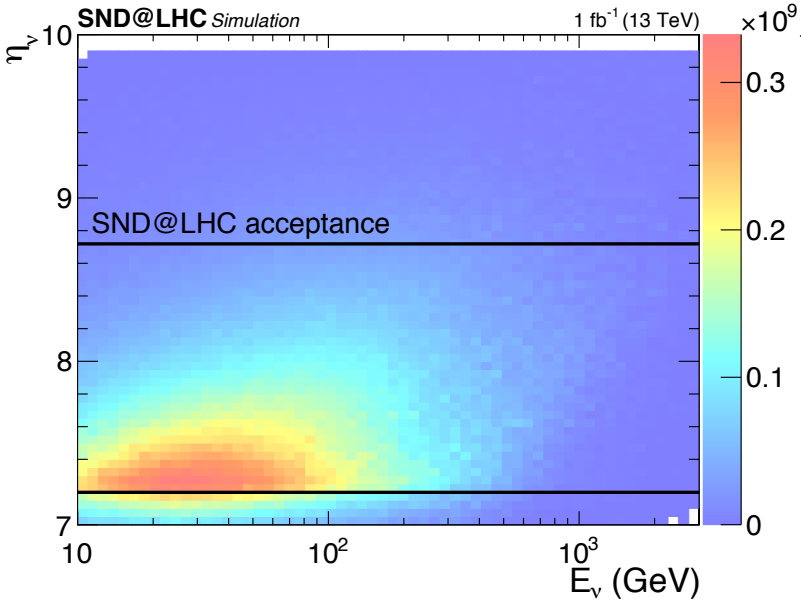


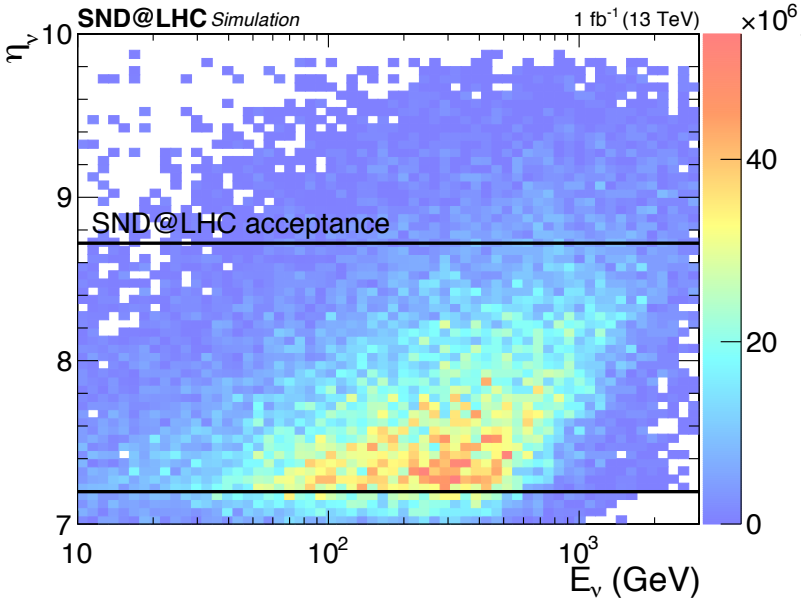
Ratio between the cross-section measurements at different energies and pseudo-rapidities

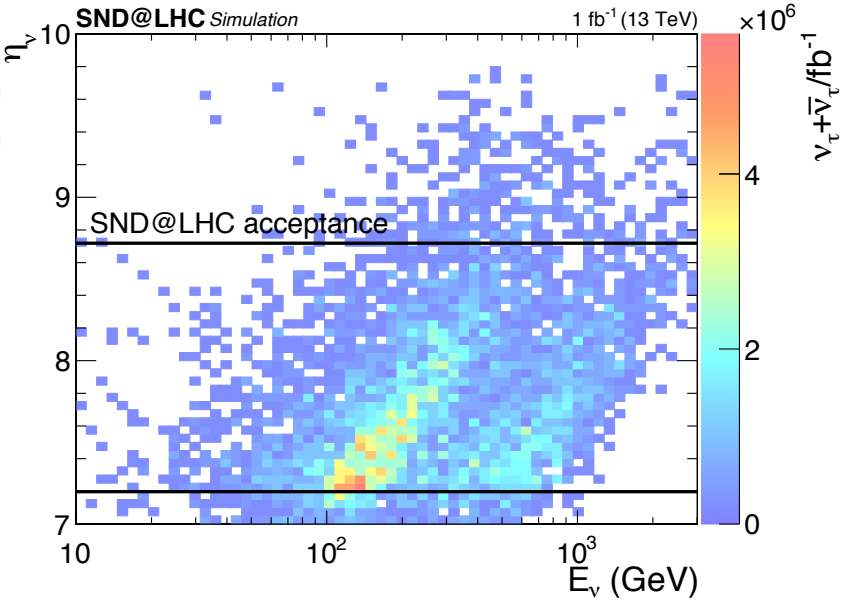
$$R = \frac{d\sigma/d\eta(13\,TeV)}{d\sigma/d\eta_{ref}(7\,TeV)}$$

$\eta_{ref} = 4.5$

Constraint the PDF with data

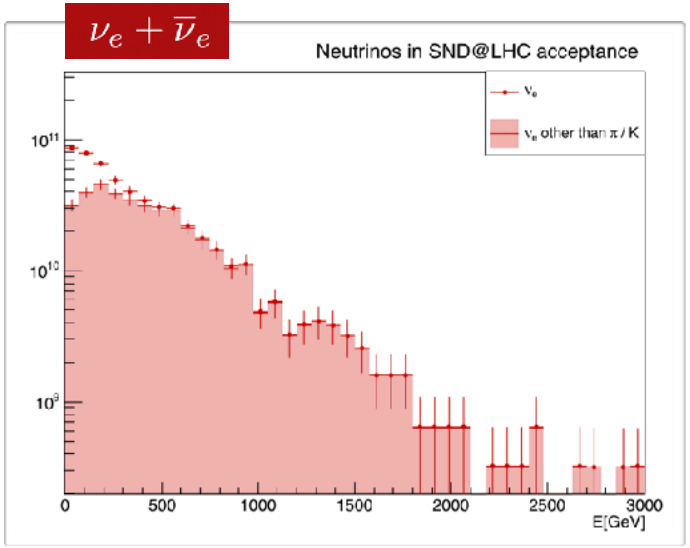

SND@LHC Simulation
1 fb-1 (13 TeV)
×10^9
SND@LHC acceptance
ην
Eν (GeV)
νμ+ν̄μ/fb-1


SND@LHC Simulation
1 fb-1 (13 TeV)
×10^6
SND@LHC acceptance
ην
Eν (GeV)
νe+ν̄e/fb-1


SND@LHC Simulation
1 fb-1 (13 TeV)
×10^6
SND@LHC acceptance
ην
Eν (GeV)
ντ+ν̄τ/fb-1

- The identification of three neutrino flavours in the SND@LHC detector offers a unique possibility to test the Lepton Flavor Universality (LFU)

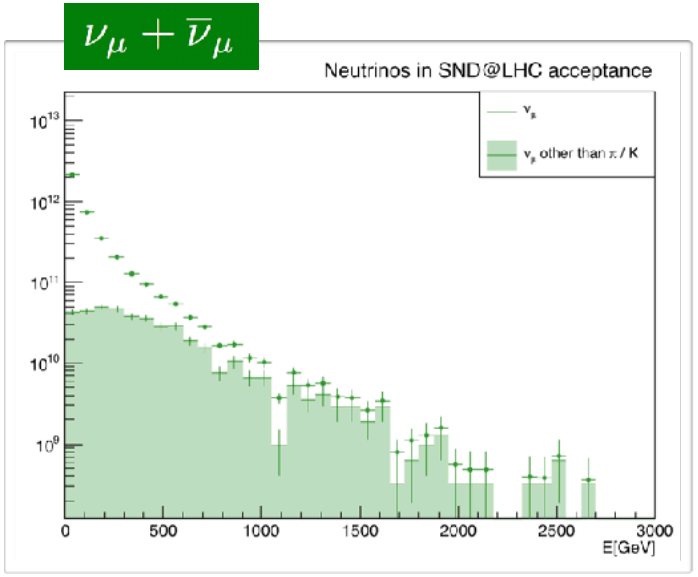
$\nu_e + \overline{\nu}_e$



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

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

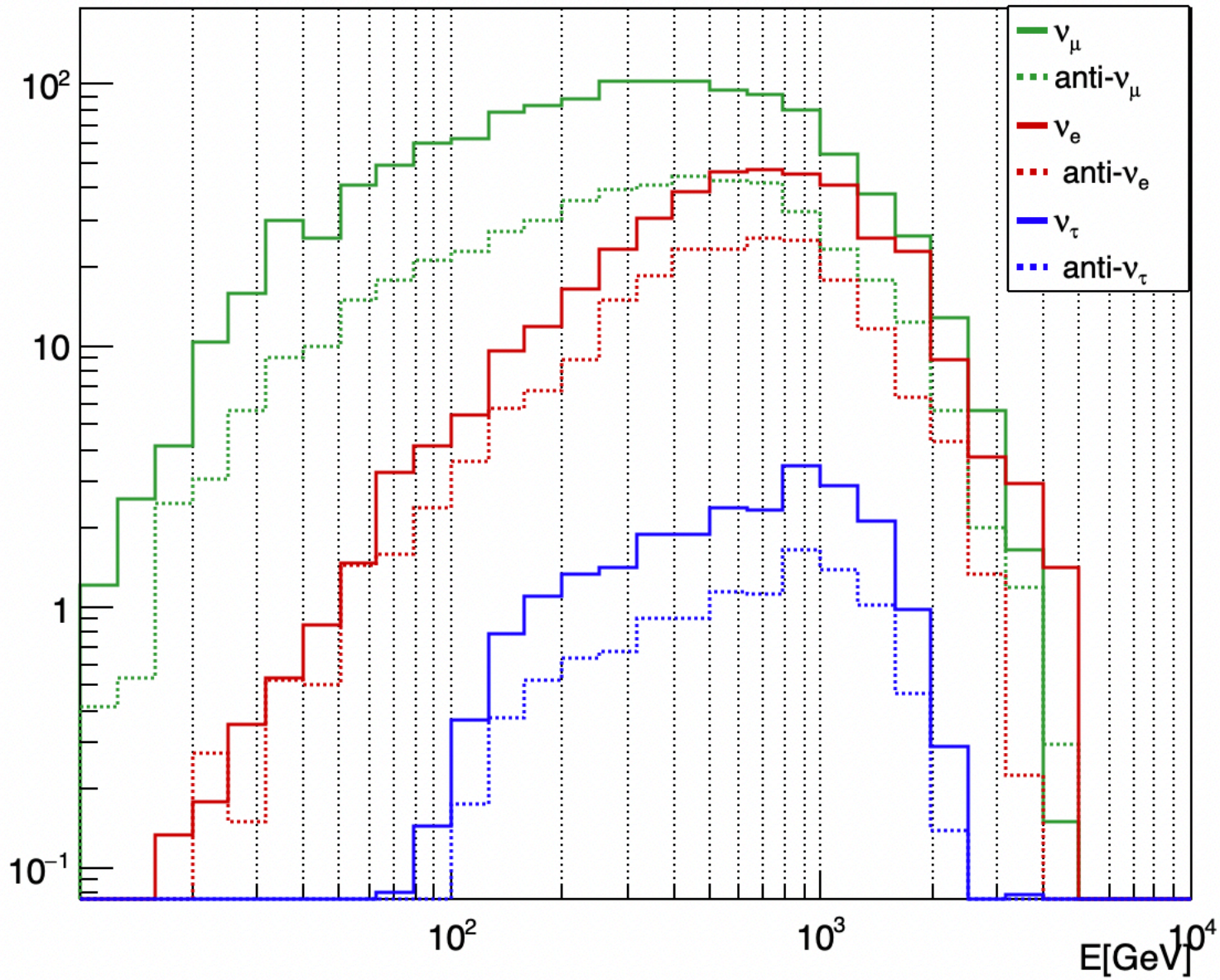
$\nu_\mu + \overline{\nu}_\mu$

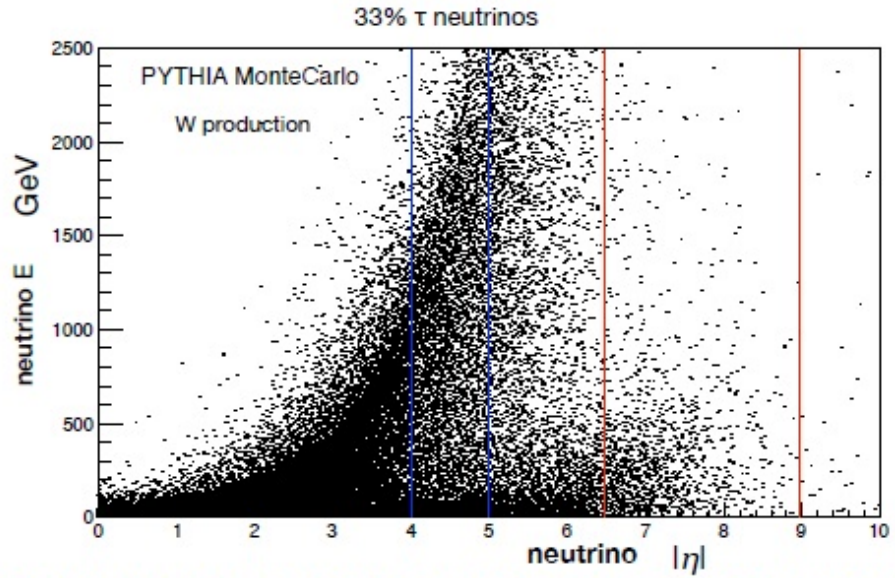


$$R_{12} = \frac{N_{\nu_e+\overline{\nu}_e}}{N_{\nu_\mu+\overline{\nu}_\mu}} = \frac{1}{1+\omega_{\pi/k}}.$$

← 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


10^2
10
1
10^{-1}
10^2
10^3
10^4
E[GeV]
ν_μ
anti-ν_μ
ν_e
anti-ν_e
ν_τ
anti-ν_τ



N. Beni et al., Physics Potential of an Experiment using LHC Neutrinos, J. Phys. G 46 (2019) 115008

http://arxiv.org/abs/1903.06564