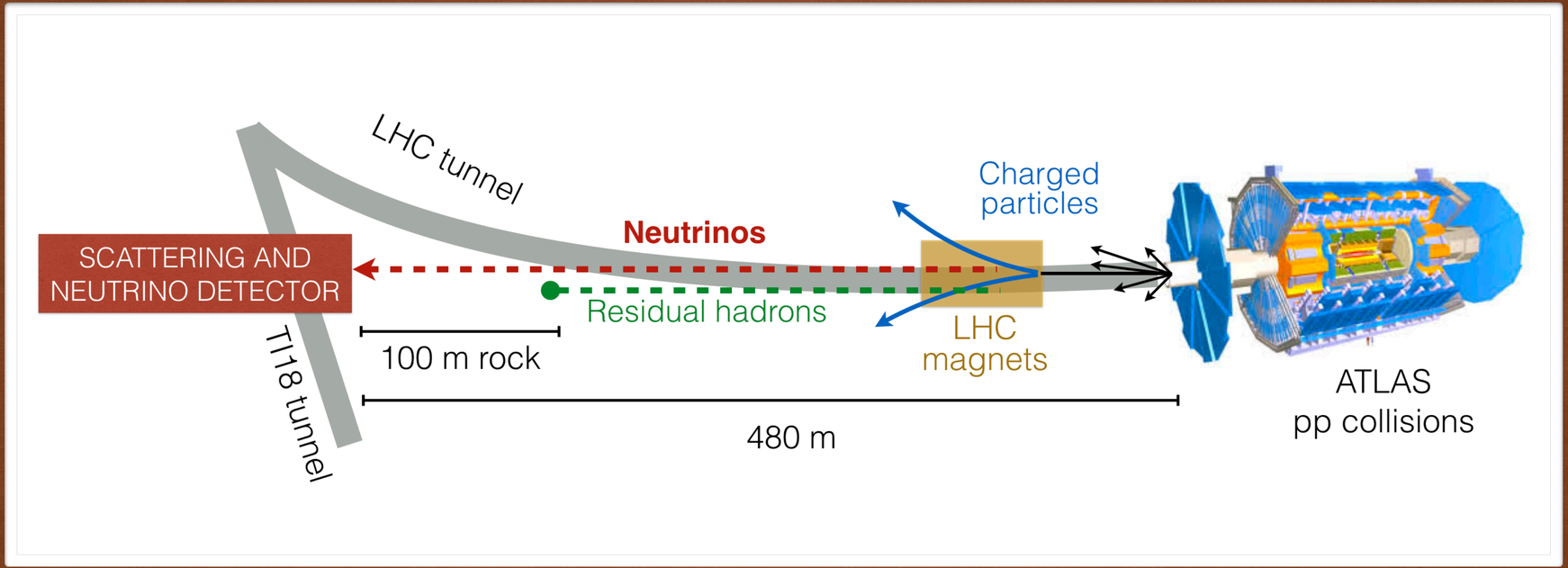
ADVANCED SND@LHC

THE SCATTERING AND NEUTRINO DETECTOR AT THE LHC



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CERN, Università Federico II and INFN

On behalf of the SND@LHC Collaboration

3rd Forward Physics Facility Meeting - 2021 October 25th

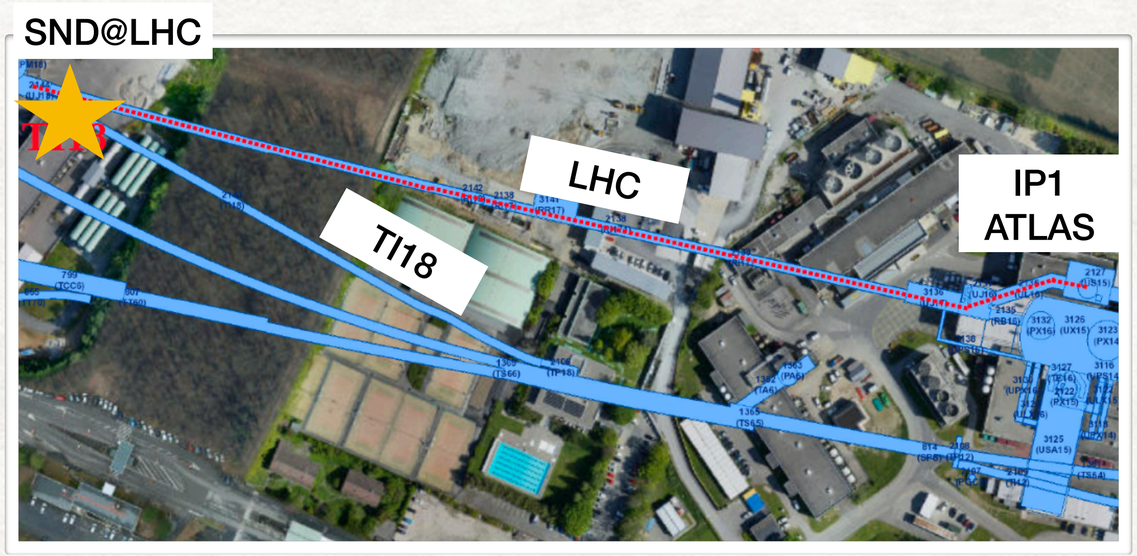
OVERVIEW

- The SND@LHC experiment
- Neutrino physics program
- QCD measurements
- Advanced SND@LHC

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

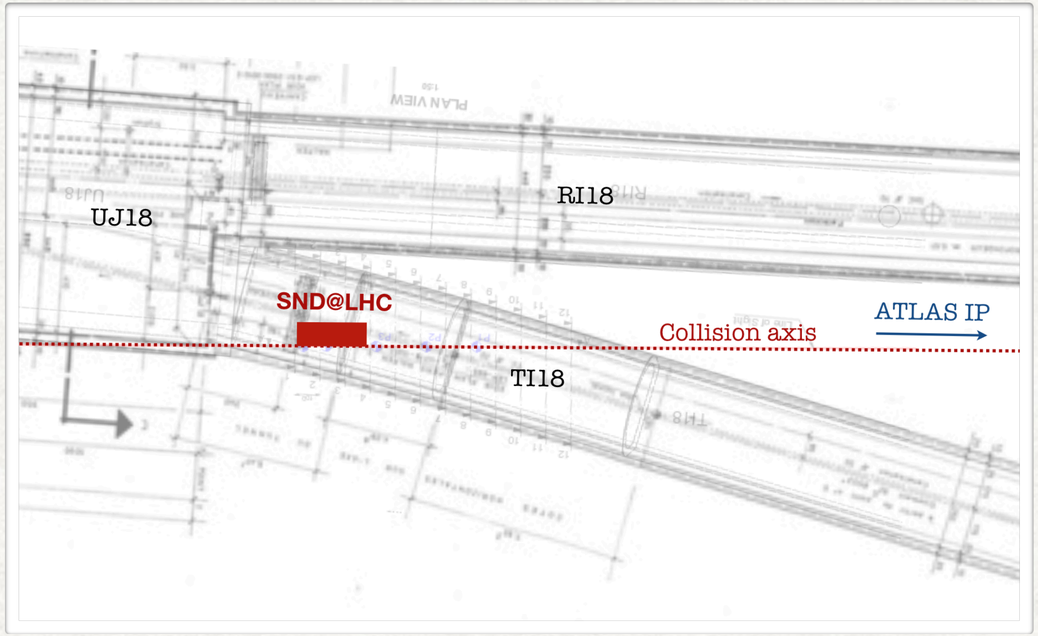
Approved by the Research Board on March 2021

LOCATION



- About 480 m away from the ATLAS IP
- Tunnel TI18: former service tunnel connecting SPS to LEP
- Symmetric to TI12 tunnel where FASER is located

- Charged particles deflected by LHC magnets
- Shielding from the IP provided by 100 m rock
- Angular acceptance: $7.2<\eta<8.6$
- First phase: operation in Run 3 to collect 150 fb^{-1}



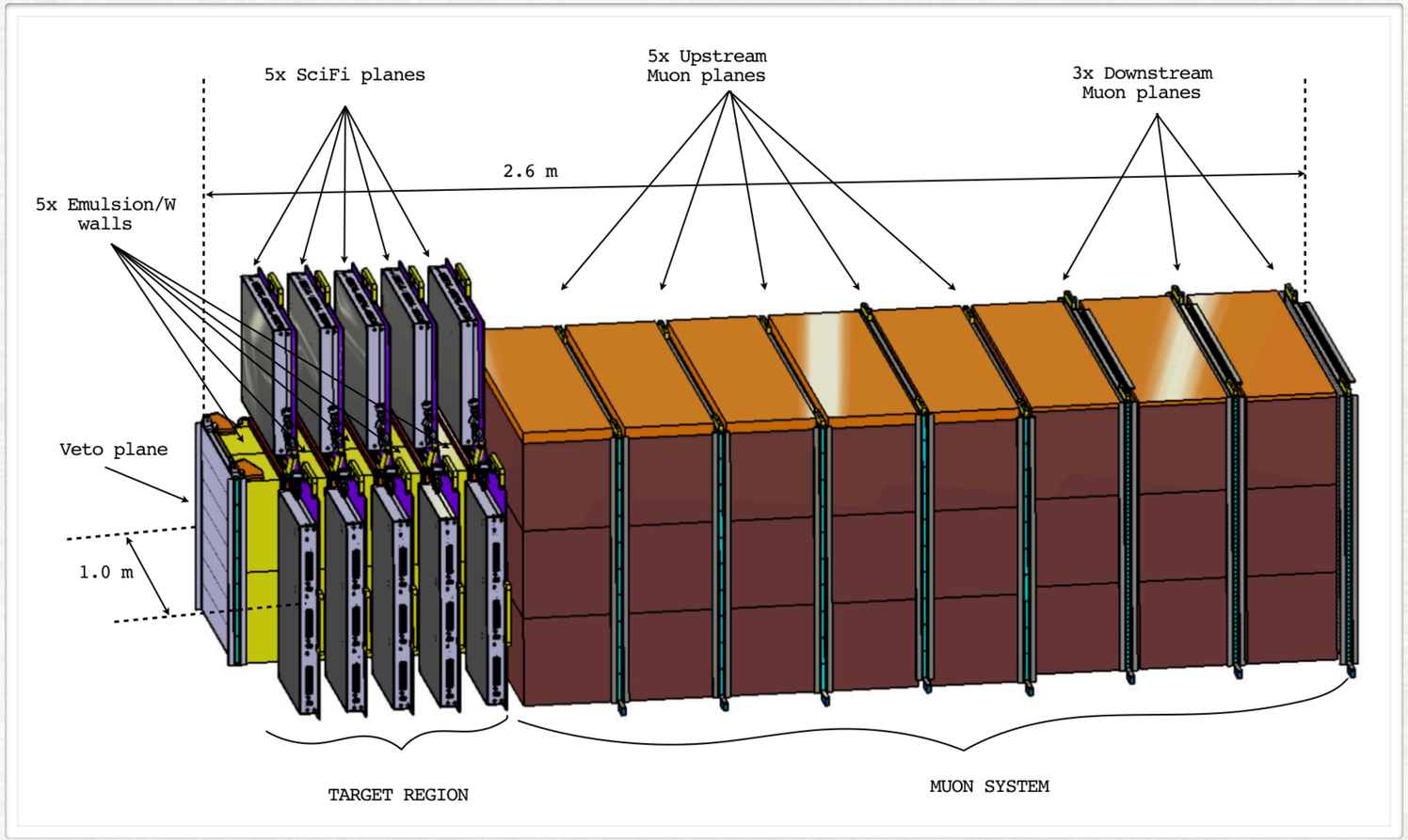
THE SND@LHC CONCEPT

Hybrid detector optimised for the identification of three neutrino flavours and for the detection of feebly interacting particles

VETO PLANE:
tag penetrating muons

TARGET REGION:
- Emulsion cloud chambers (Emulsion+Tungsten) for neutrino interaction detection
- Scintillating fibers for timing information and energy measurement

MUON SYSTEM:
iron walls interleaved with plastic scintillator planes for fast time resolution and energy measurement



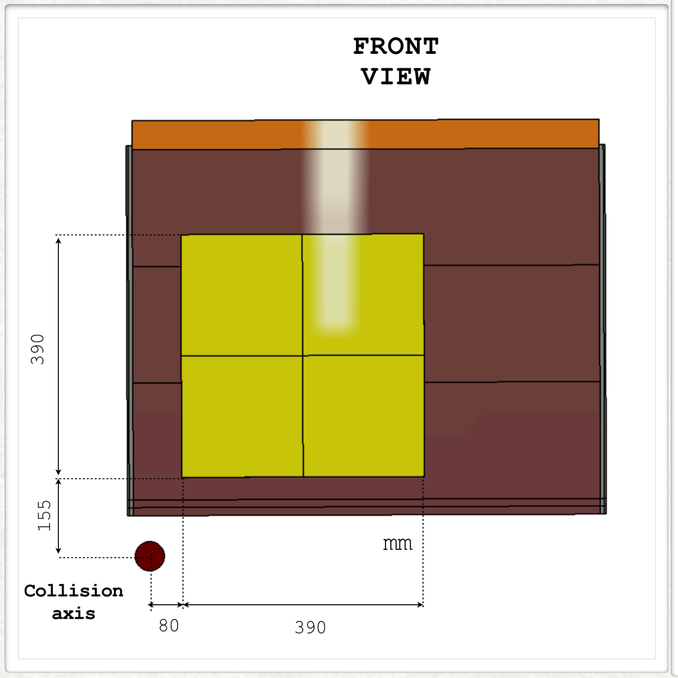
THE DETECTOR LAYOUT

- Angular acceptance: $7.2 < \eta < 8.6$
- Target material: Tungsten
- Target mass: 830 kg
- Surface: 390x390 mm^2

Off axis location

Electromagnetic calorimeter
~40 X_0

Hadronic calorimeter
~10 λ



Veto plane for charged particles in front of the target region

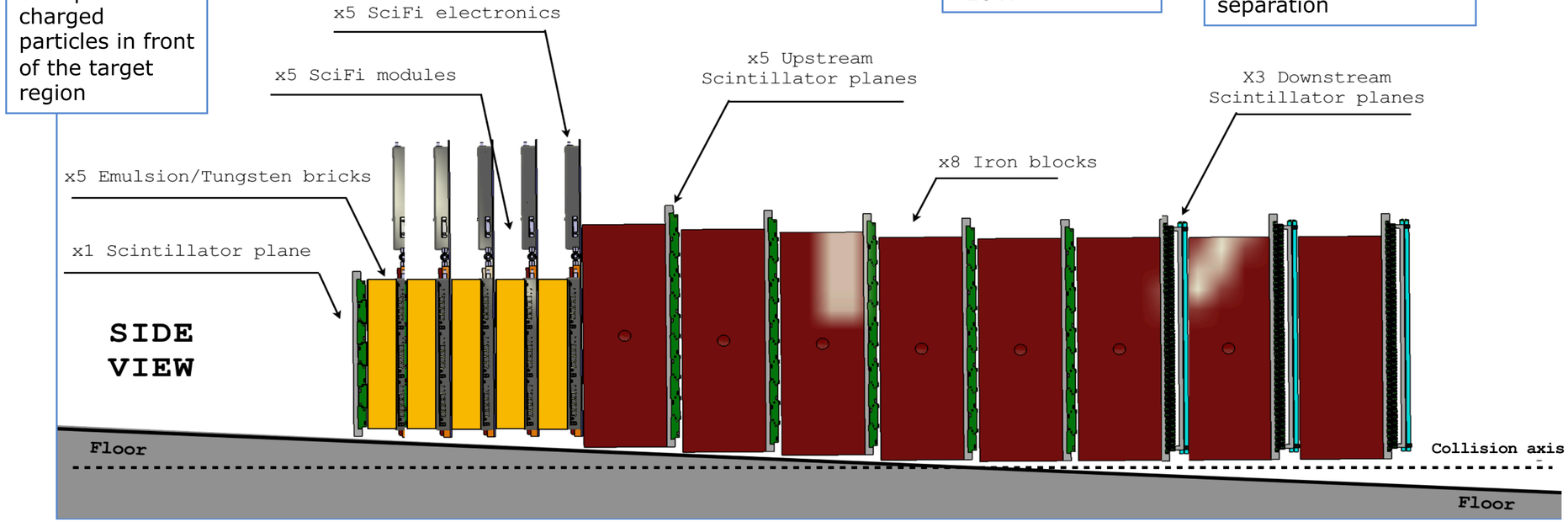
Emulsion Cloud Chamber, emulsion and W absorbers for micrometric accuracy in the detection of τ and FIPs, EM shower energy measurement.

SciFi with timing, provide time stamp to emulsion, records TOF information of events in the target region, track matching with ECCs. EM shower measurement as sampling calorimeter every ~17 X_0.

Muon system – hadronic calorimeter 8 λ, sampling every λ, with target region ~10 λ.

Timing upstream for the muon filtering

Timing downstream, double X-Y planes with higher granularity for muon-hadron separation



DETECTOR CONSTRUCTION AND COMMISSIONING

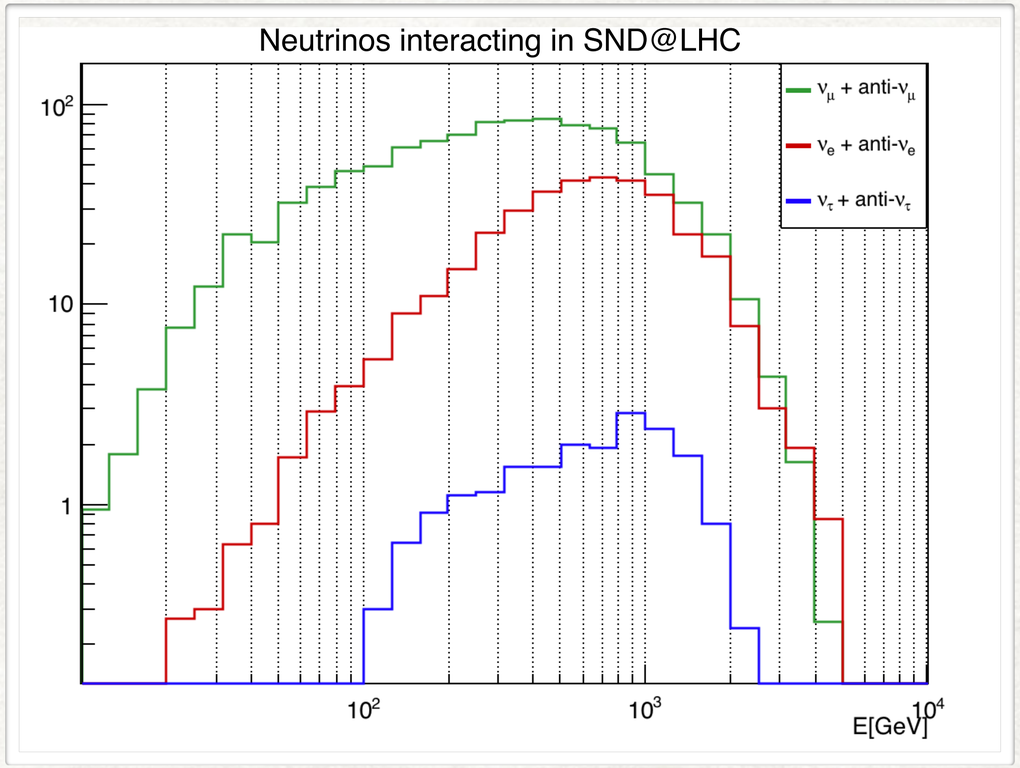
Detector commissioning @North Area

TI18 Tunnel

NEUTRINO EXPECTATIONS

- Expectations in 150 fb^{-1}
- 50/50 upward/downward crossing angle

- 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	130	1.9×10^{12}	452	606	480	182
$\bar{\nu}_\mu$	133	1.7×10^{12}	485	248	480	93
ν_e	339	2.2×10^{11}	760	182	720	54
$\bar{\nu}_e$	363	2.0×10^{11}	680	97	720	35
ν_τ	415	1.5×10^{10}	740	14	740	4
$\bar{\nu}_\tau$	380	1.7×10^{10}	740	6	740	2
TOT		4.0×10^{12}		1153		370

NEUTRINO PHYSICS PROGRAM IN RUN 3

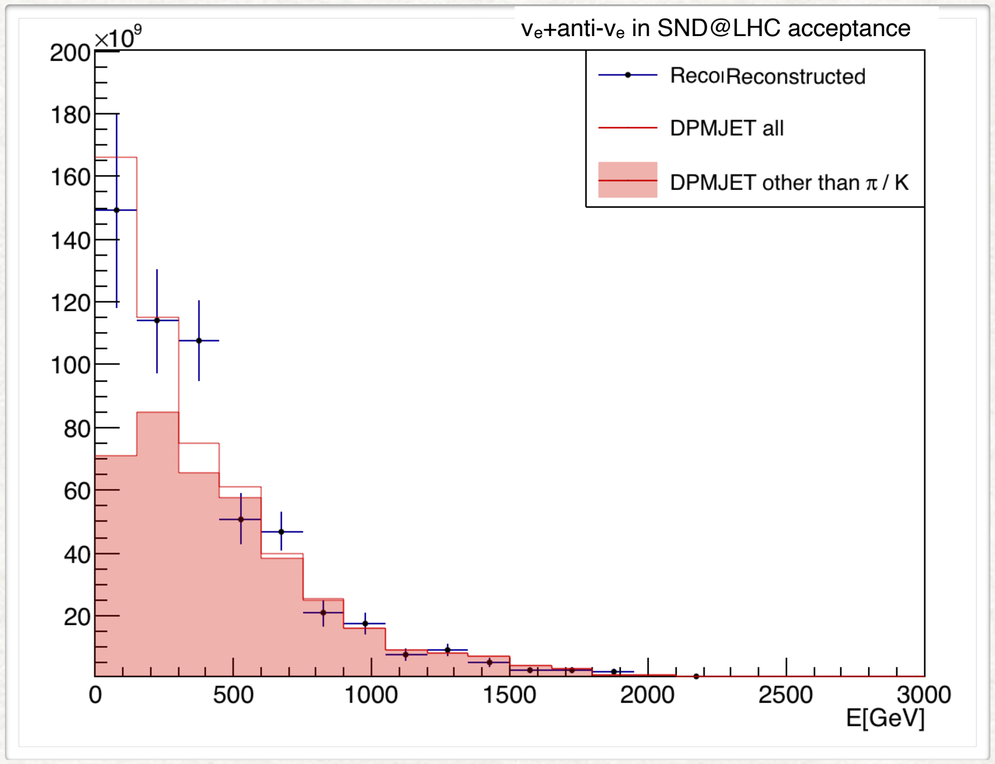
1. Measurement of the $pp \longrightarrow \nu_e X$ cross-section
2. Heavy flavour production in pp collisions
3. Lepton flavour universality in neutrino interactions
4. Measurement of the NC/CC ratio

1. MEASUREMENT OF $pp \rightarrow \nu_e X$ CROSS-SECTION

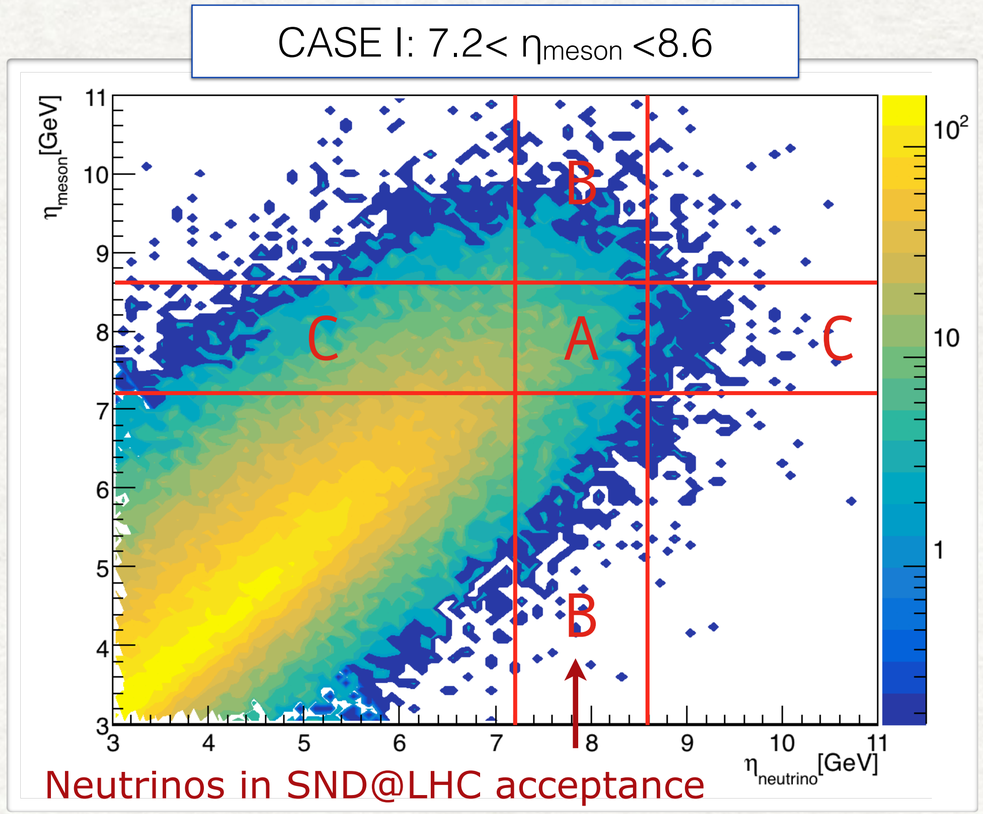
2. CHARMED HADRON PRODUCTION

- Simulation predicts that 90% ν_e+anti-ν_e come from the decay of charmed hadrons
- Electron neutrinos can be used as a probe of the production of charm in the relevant pseudo-rapidity range after unfolding the instrumental effects

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



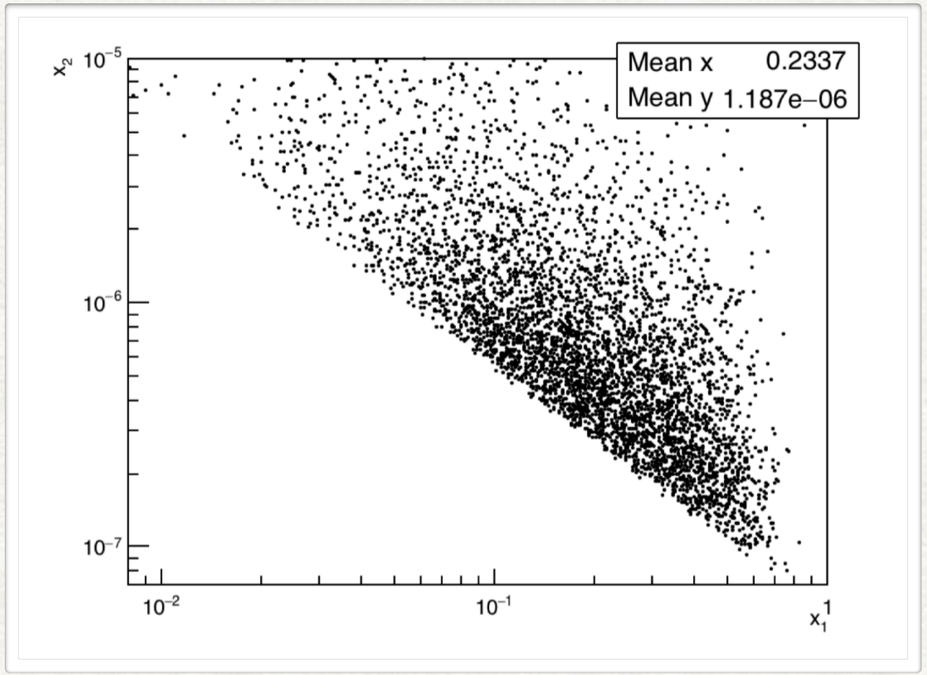
- Correlation between pseudo-rapidity of the electron (anti-)neutrino and the parent charmed hadron



QCD MEASUREMENTS

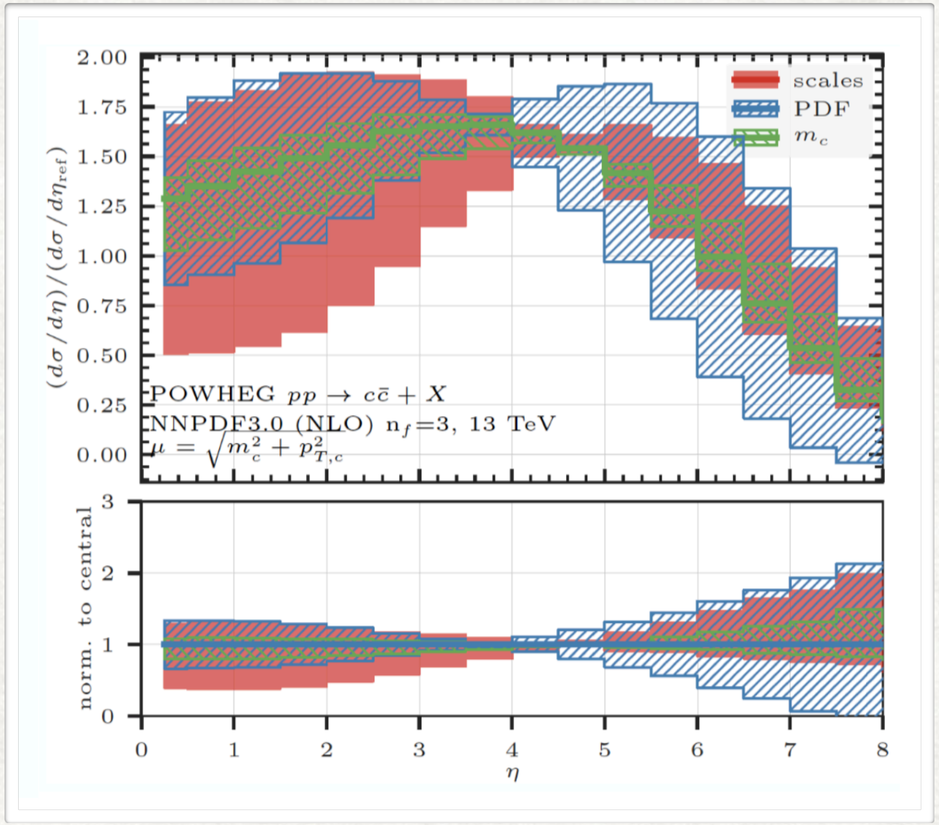
The dominant partonic process for associated charm production at the LHC is gluon-gluon scattering

Average lowest momentum fraction: 10^{-6}



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

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

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

$\eta_{ref} = 4.5$

Reduction of scale uncertainties
Constraint the PDF with data

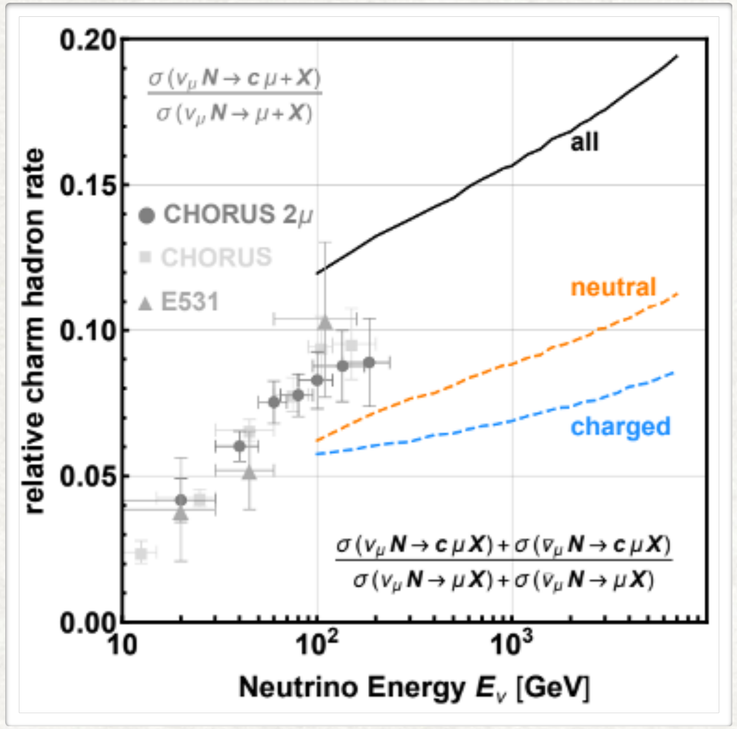
NEUTRINO PHYSICS IN RUN 3

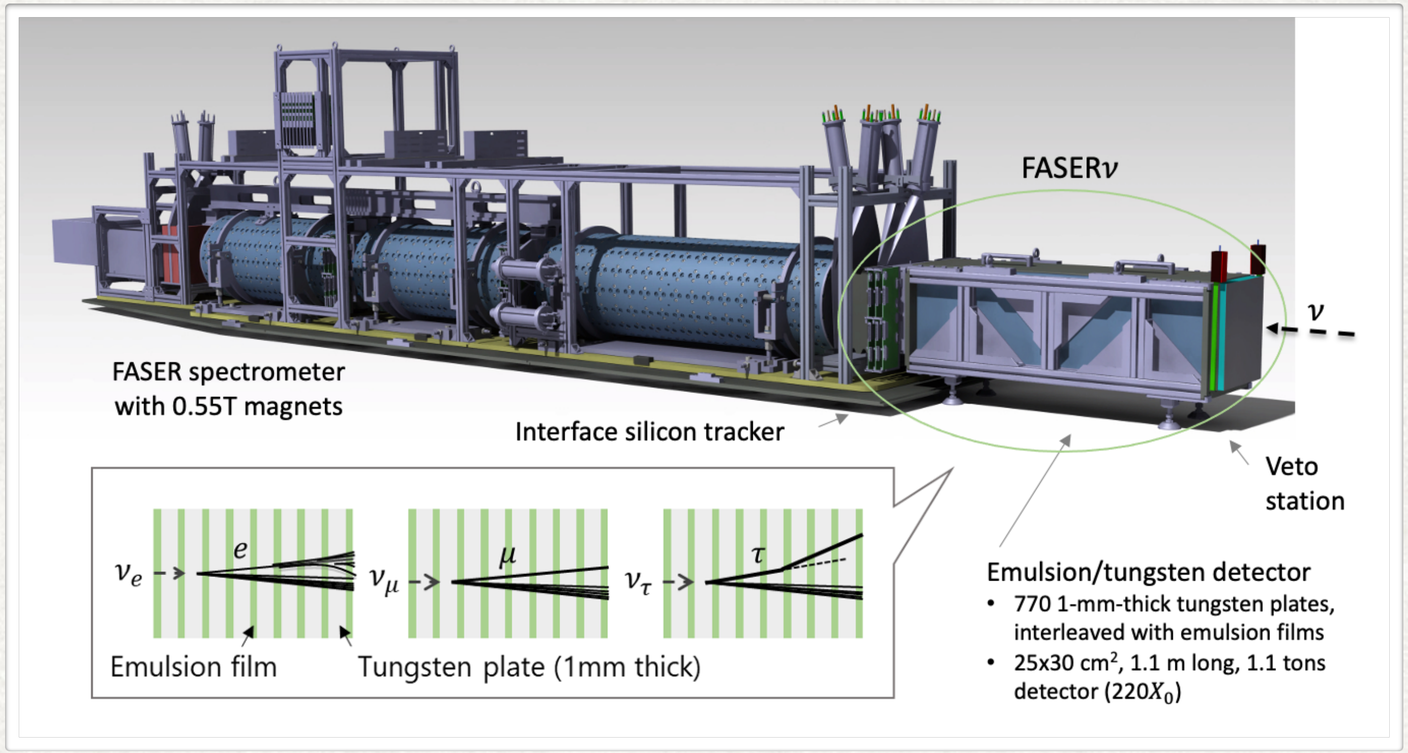
- Summary of SND@LHC performances

Measurement	Uncertainty	
	Stat.	Sys.
$pp \to \nu_e X$ cross-section	5%	15%
Charmed hadron yield	5%	35%
ν_e/ν_τ ratio for LFU test	30%	20%
ν_e/ν_μ ratio for LFU test	10%	10%
Measurement of NC/CC ratio	5%	10%

COMPLEMENTARITY WITH FASERnu

- Pseudo-rapidity range: η >8.8
- Main physics goals:
  - ~2000 ν_e, 7000 ν_μ, 50 ν_τ CC interactions expected *[Eur. Phys. J. C 80 (2020) 61]*
  - NC measurements could constrain neutrino non-standard interactions *[Phys. Rev. D 103, 056014 (2021)]*
  - Neutrino CC interaction with charm production ($\nu s \to l c$)
  - Study the strange quark content
  - Relevant to predict the W production at the LHC





ADVANCED SND@LHC

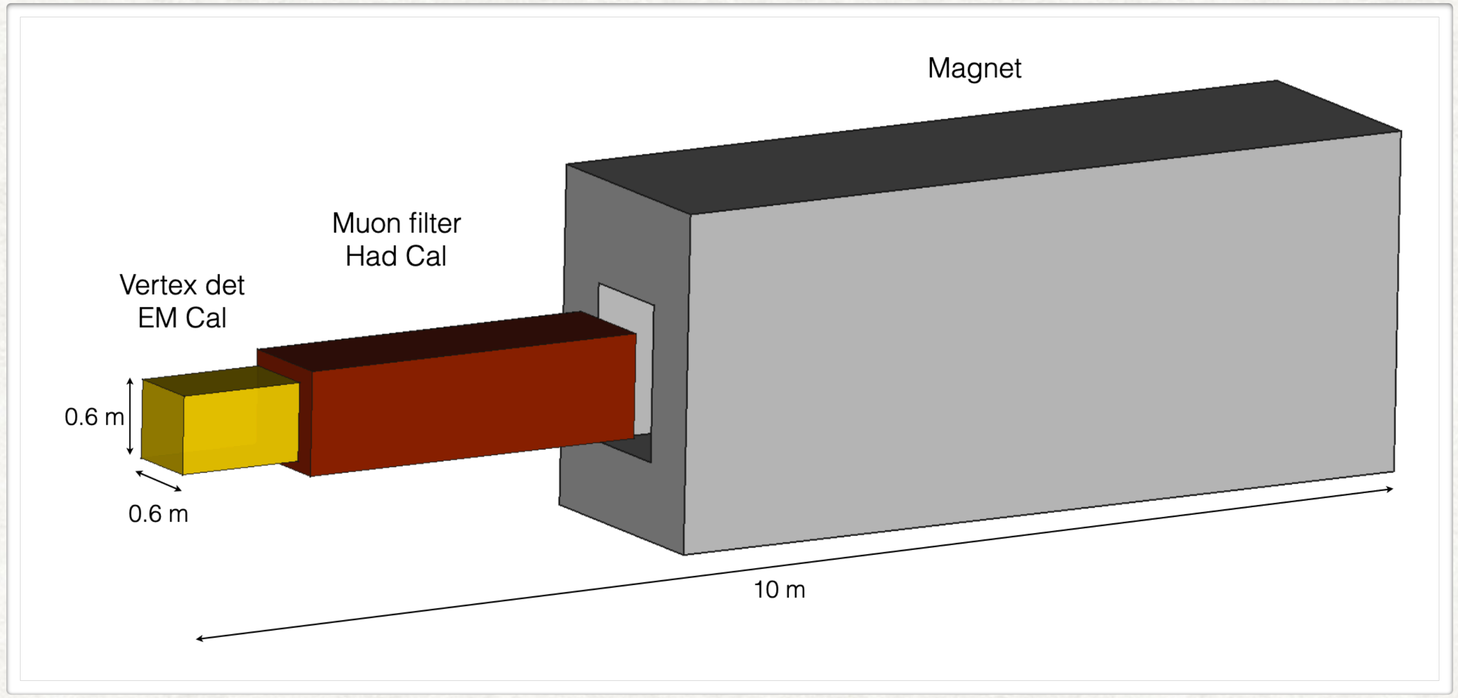
- Upgrade of the detector in view of an extended run during Run 4:
- Two off-axis forward detectors:

- **Adv-SND1**: η~8
  - Acceptance similar to SND@LHC
  - Charm production measurements
  - Tau neutrino studies
  - Lepton flavour universality

- **Adv-SND2**: η~5
  - Overlap with LHCb pseudo-rapidity coverage
  - Reduction of systematic uncertainties
  - Provide normalization for neutrino physics studies
  - Search for location in existing cavern closer to IP

ADVANCED SND@LHC: DETECTOR LAYOUT

1) Target region:
   - Vertex identification and electromagnetic calorimeter
   - Thin sensitive layers interleaved with Tungsten plates
   - Replace emulsions with electronic trackers to cope with high intensity muon rates
   - Target mass: from 2 to to 10 tons
2) Muon ID system and hadronic calorimeter
   - 10 interaction lengths
3) Magnet with two high-resolution tracking stations
   - measure charge of the muon (ν_μ/anti-ν_μ, ν_τ/anti-ν_τ in the $\tau \longrightarrow \mu$ channel)
   - 1.5 T field over a ~3 m length



CONCLUSIONS

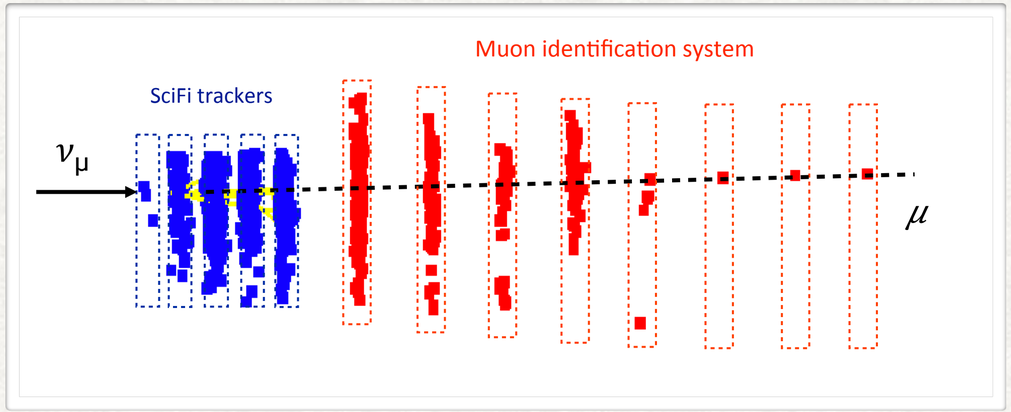
- SND@LHC is a recently approved experiment at CERN aiming measuring neutrinos produced at the LHC in an unexplored pseudo-rapidity region
- Detector under construction
- Data taking will start in early 2022
- Possible extensions beyond Run3 would highly benefit from the development of a Forward Physics Facility

BACKUP SLIDES

KEY FEATURES

• Muon identification

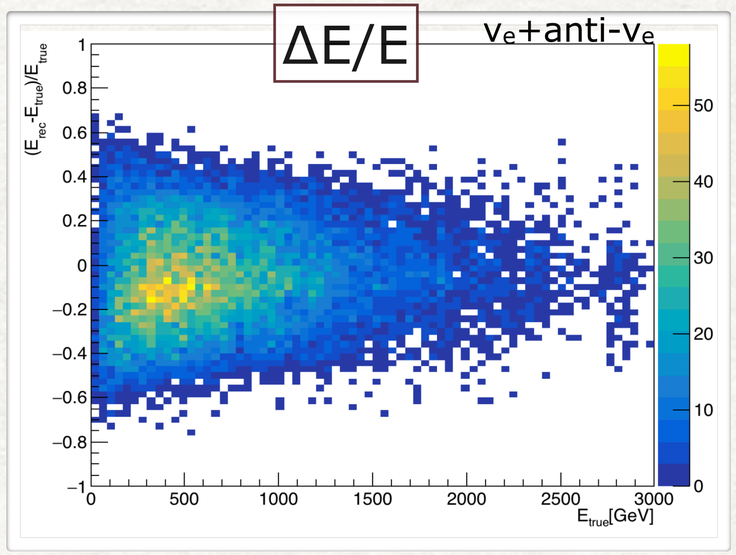
- ν_μ CC interactions identified thanks to the identification of the muon produced in the interaction
- Muon ID at the neutrino vertex crucial to identify charmed hadron production, background to ν_τ detection



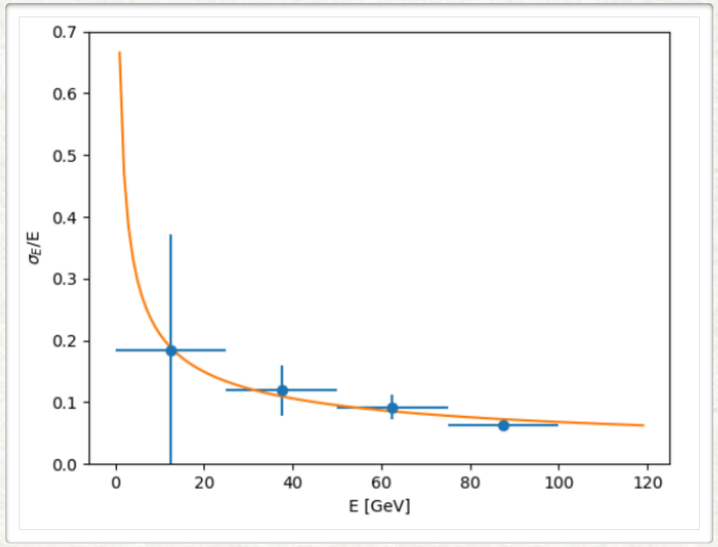
	% evts CC-DIS	% evts NC-DIS
0μ	31.1	99.6
1μ	67.6	0.27
2μ	1.1	0.06

• 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%

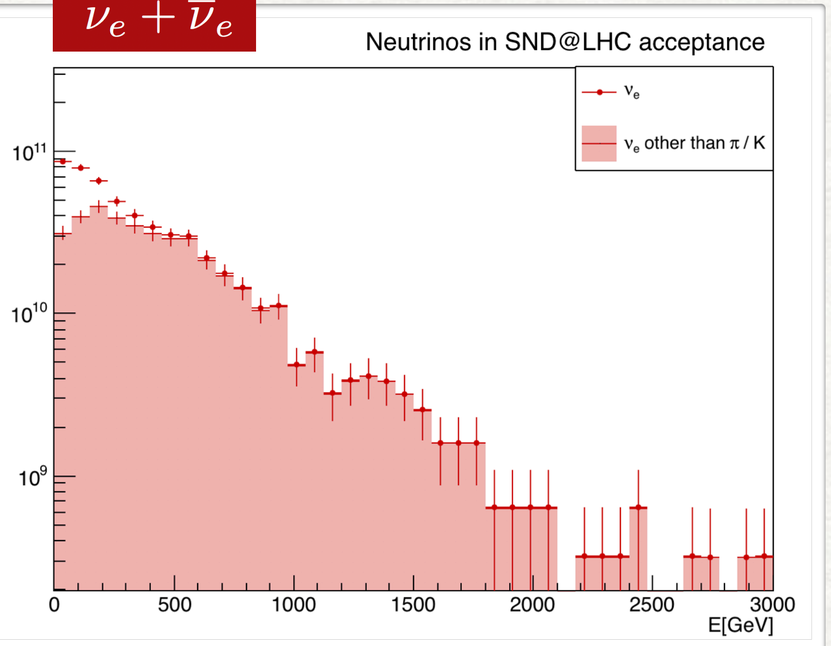


- Performance of SciFi tracker as sampling calorimeter, using a CNN
- Electron energy resolution

3. LEPTON FLAVOUR UNIVERSALITY TEST

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

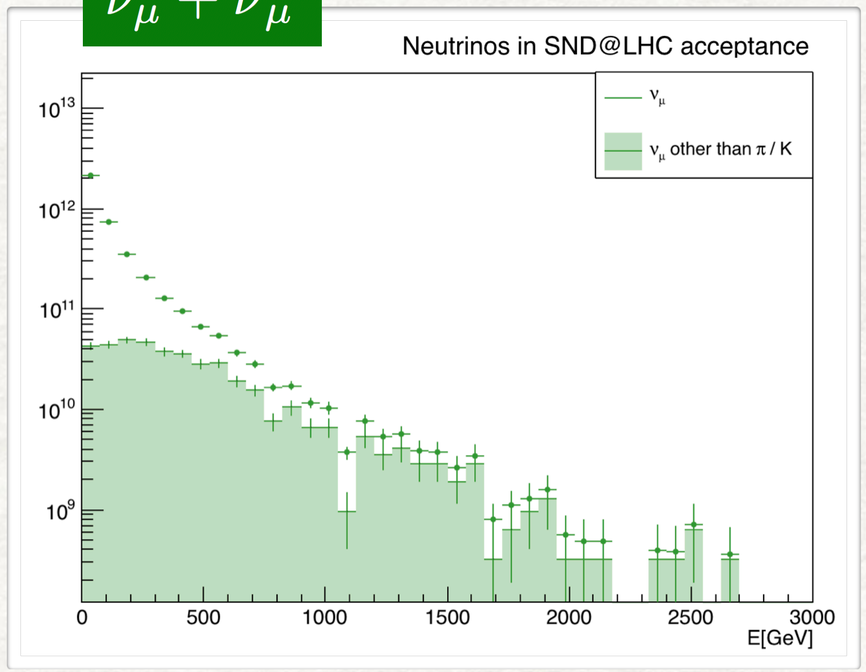
$\nu_e + \overline{\nu}_e$



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

- 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

4. MEASUREMENT OF NC/CC RATIO

- Lepton identification for the three different flavors allows to distinguish CC to NC interaction at SND@LHC
- If differential neutrino and anti-neutrino fluxes are equal, the NC/CC ratio can be written as

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

- In case of DIS, *P* can be written as

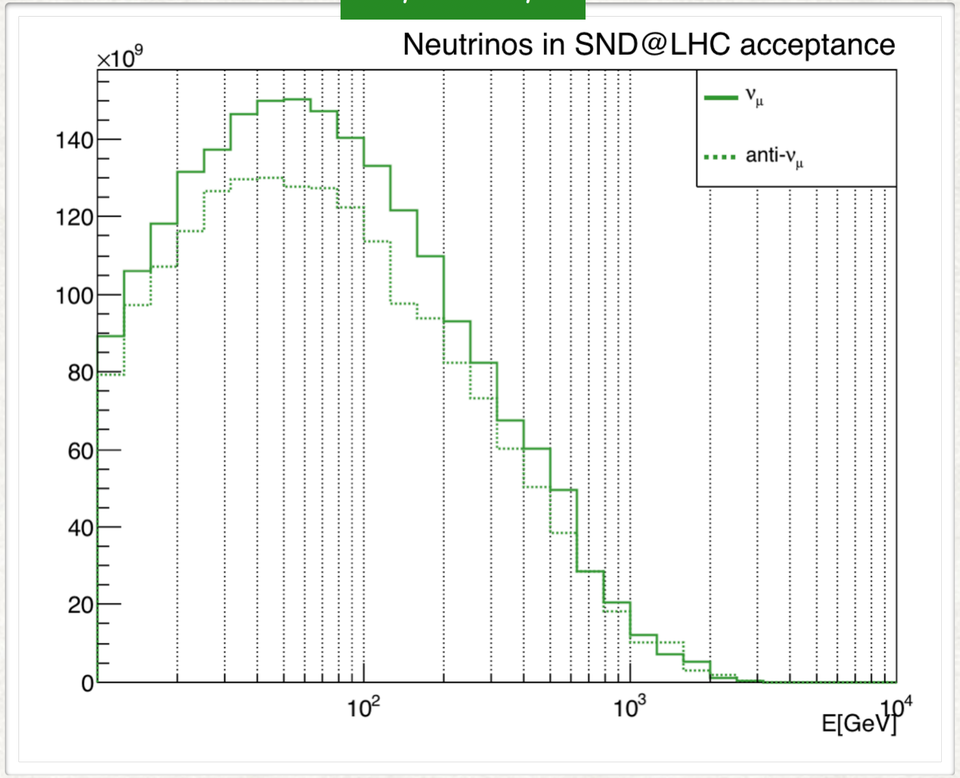
$$P = \frac{1}{2}\left\{1 - 2\sin^2\theta_W + \frac{20}{9}\sin^4\theta_W - \lambda(1 - 2\sin^2\theta_W)\sin^2\theta_W\right\}$$

For a Tungsten target λ=0.04

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

- P measurement used as an internal consistency check

ν_μ vs $\bar{\nu}_\mu$

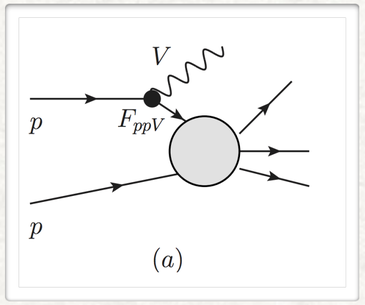


FLEEBLY INTERACTING PARTICLES

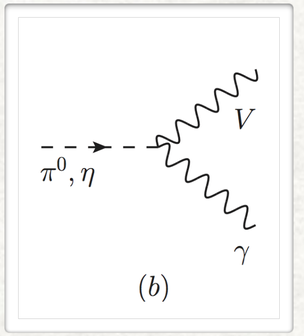
- SND@LHC experiment can explore a large variety of Beyond Standard Model (BSM) scenarios describing Hidden Sector

Production: we consider a scalar χ particle coupled to the Standard Model via a leptophobic portal,

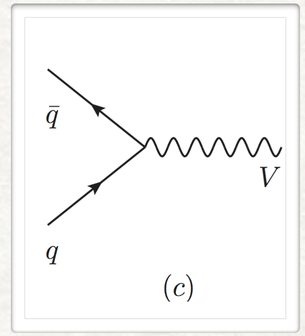
$$\mathcal{L}_{\text{leptophob}} = -g_B V^\mu J^B_\mu + g_B V^\mu (\partial_\mu \chi^\dagger \chi + \chi^\dagger \partial_\mu \chi),$$



Proton bremsstrahlung



Meson decay



Drell-Yan process

Detection: χ elastic/inelastic scattering off nucleons of the target