Status of SND@LHC

The Scattering and Neutrino Detector at the LHC

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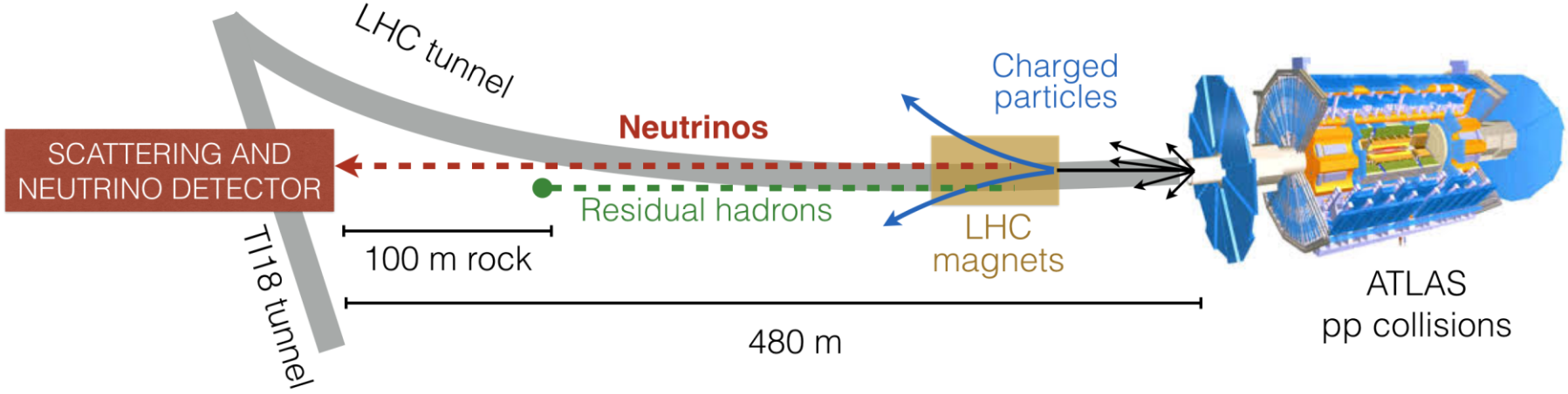
On behalf of the SND@LHC Collaboration

9 September 2021

Scattering and Neutrino Detector @ LHC

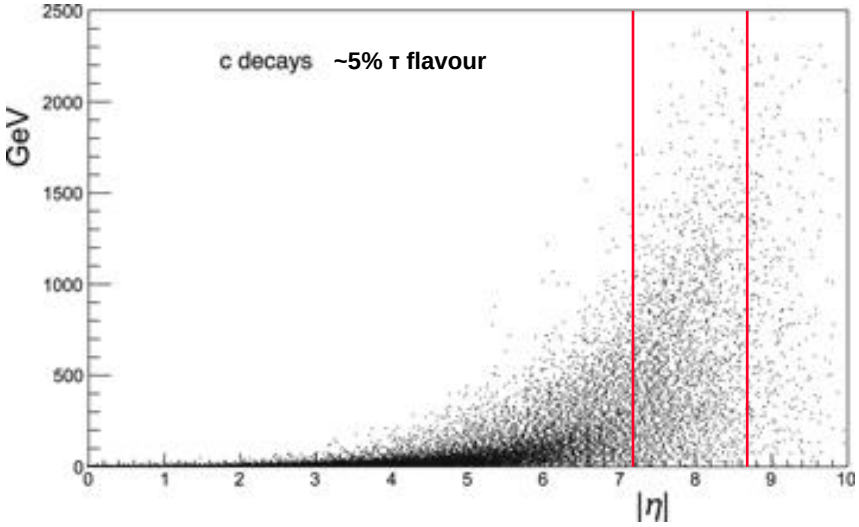


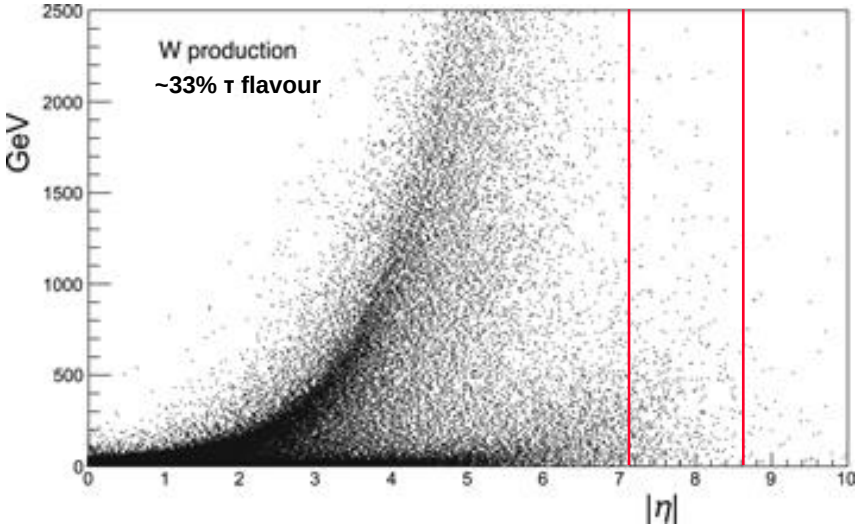
Stand-alone experiment 480m downstream of IP1 in TI18 to do measurements on neutrinos in the pseudorapidity region $7.2 < \eta < 8.7$

Approved by the CERN Research Board on 17 March 2021
https://snd-lhc.web.cern.ch/

Motivation

- **Large expected ν flux in forward direction**
- **High ν energies: relatively large ν cross sections**
  - **7.2 < η < 8.7: large nb high energy ν from heavy flavour**
  - **$\sqrt{s}$=14 TeV corresponds to cosmic ray neutrino energy of 10^5 TeV**

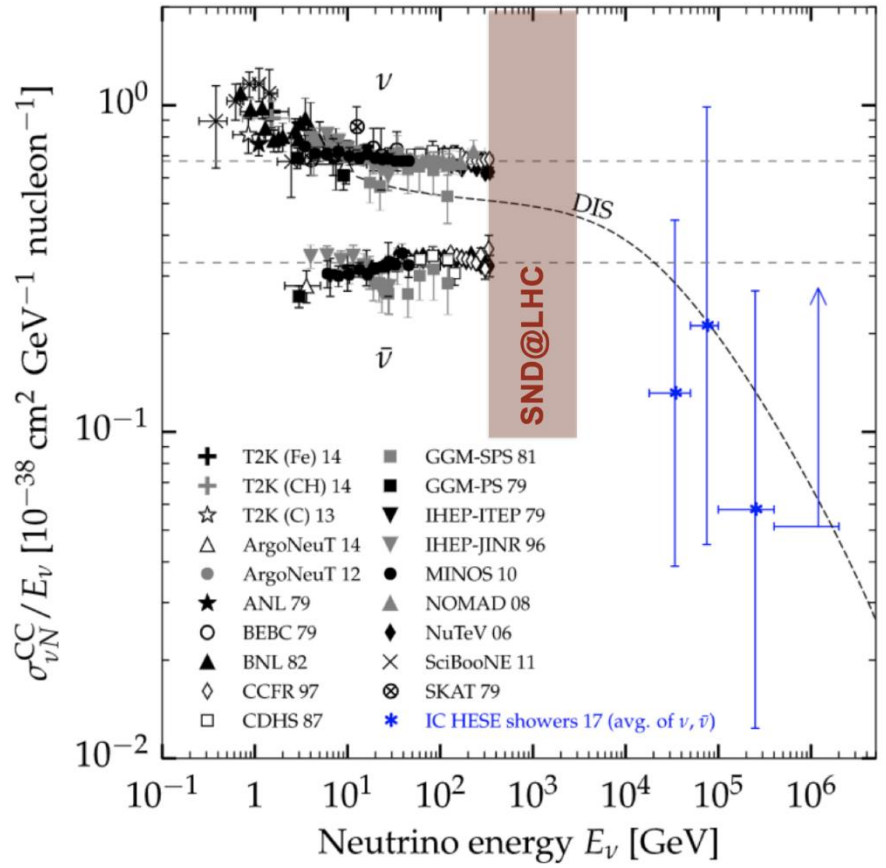




N. Beni et al., "Physics Potential of an Experiment using LHC Neutrinos", J. Phys. G: Nucl. Part. Phys. 46 (2019) 115008, doi:10.1088/1361-6471/ab3f7c [arXiv:1903.06564]

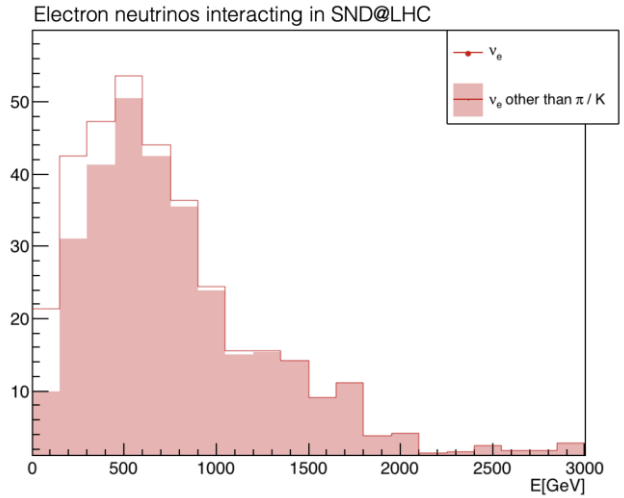
Physics program

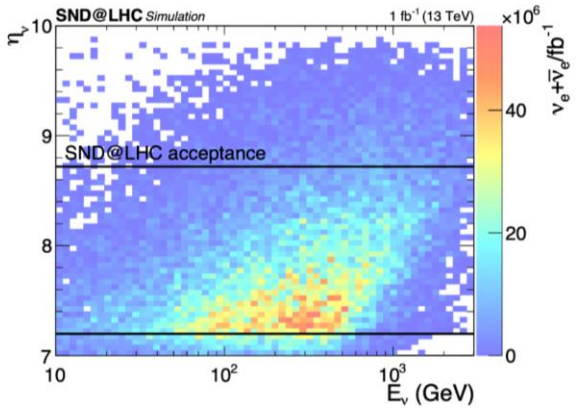
- $\sigma_{pp \to \nu X}$ in 7.2 < η < 8.7 range
- ν_e as a probe of charm quark production
- Lepton universality test: ν_τ/ν_e and ν_μ/ν_e
- Measurement of the NC/CC ratio
- Direct search for feebly interacting particles through their scattering

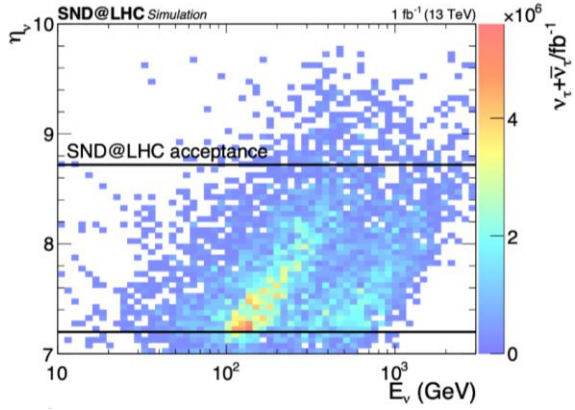


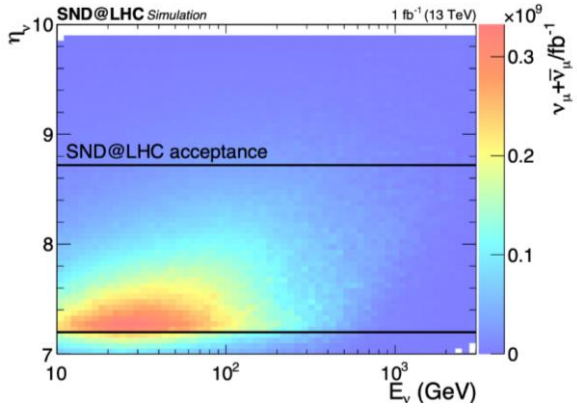
Flux and E_ν

- **ν_e , ν_τ mainly from decay of charmed hadrons**
  - **10% ν_e from π and K (<200 GeV), 3% from beauty interacting in acceptance**
- **measure charm production by observing ν_e and $\overline{\nu_e}$**
- **Soft ν_μ component from π and K decays**







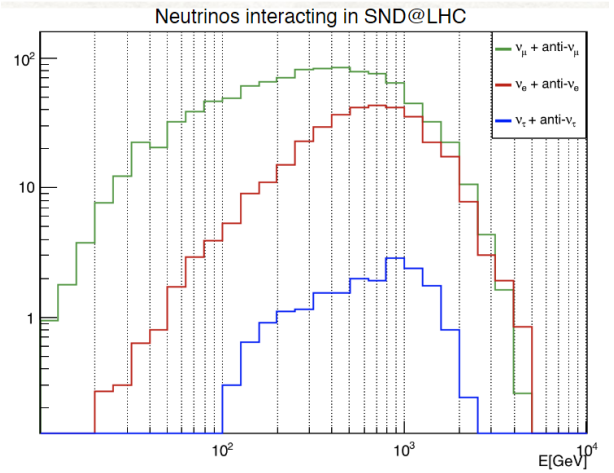


Neutrino expectations

Neutrino interactions in the acceptance estimated with DPMJET3/FLUKA for 150 fb^{-1}

Upward beam crossing angle

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



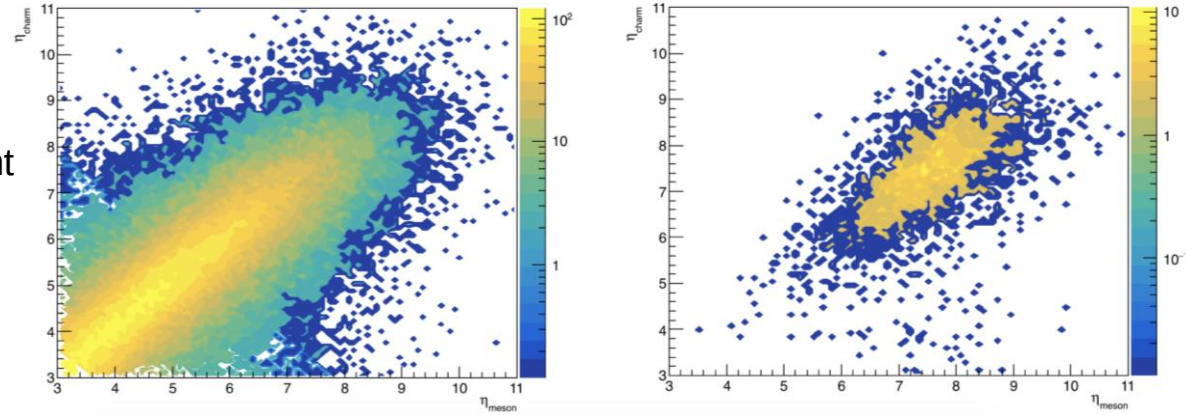
Downward beam crossing angle (35% decrease)

Flavour	CC neutrino interactions ⟨E⟩ [GeV]	CC neutrino interactions Yield	NC neutrino interactions ⟨E⟩ [GeV]	NC neutrino interactions Yield
ν_μ		483		145
$\bar{\nu}_\mu$		206		77
ν_e		130		38
$\bar{\nu}_e$		74		27
TOT		893		287

Charm production measurement

- **~(74)130 ($\overline{\nu_e}$) ν_e interactions expected in 150 fb^{-1}**
  1. **Measure the energy spectrum of $\nu_e + \overline{\nu_e}$**
  2. **Unfold energy resolution effects to get the reconstructed $\nu_e + \overline{\nu_e}$ energy spectrum**
  3. **Apply deconvolution of the (known/assumed) $\nu/\overline{\nu}$ cross-section to get incoming neutrino flux → ν_e X**
  4. **From ν_e back to charm, to estimate the charm production yield**
- **~5% (stat), ~35%(syst. K subtraction and unfolding)**

Correlation between η of parent charm and charmed hardon



Only events with neutrino in SND@LHC acceptance

Lepton flavour universality

- ν_τ mainly from $D_s \rightarrow \tau\, \nu_\tau$ (8% from beauty)
- ν_e from D^0, D, D_s and Λ_c
  - ν_e/ν_τ only depends on charm hadronization and decay branching fractions

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

  - Uncertainties due to charm quark production cancel out
  - ν_e/ν_τ : sensitive to ν-nucleon interaction cross section ratio (22% syst.)
  - test of lepton universality in neutrino interactions (30% stat. due to ν_τ statistics)
- ν_e/ν_μ branching fractions practically equal
  - Large contamination from π and K, stable above 600 GeV (15% accuracy)

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

← contamination from π/K

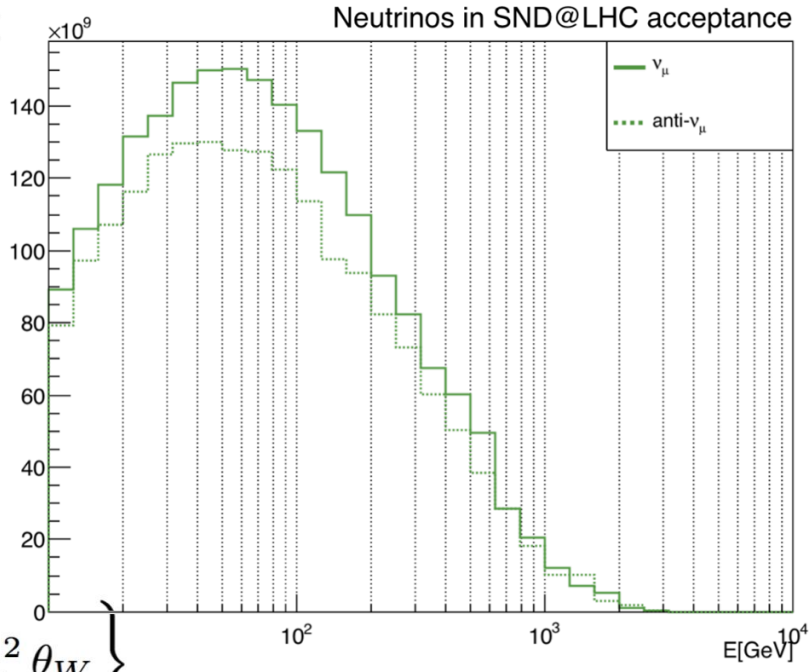
Measurement of σ_{NC}/σ_{CC}

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

- **Lepton identification for three flavours allows to distinguish CC from NC interactions**
- **If ν and $\bar{\nu}$ fluxes are equal:**

$$P = \frac{\sigma^{\nu}_{NC} + \sigma^{\bar{\nu}}_{NC}}{\sigma^{\nu}_{CC} + \sigma^{\bar{\nu}}_{CC}}$$

(~10% syst. $\nu/\bar{\nu}$ asym, μ id, n induced events; ~5% stat nb of NC ints)



- **In case of DIS:**

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

For tungsten, λ=0.04

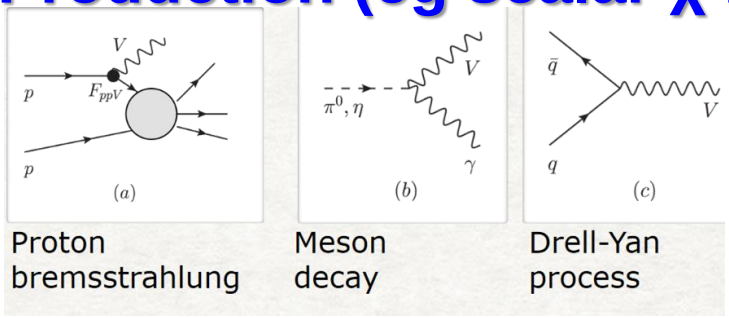
- **Use this as a control measurement**

Physics results with neutrinos

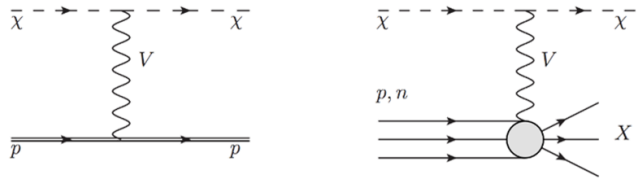
Measurement	Uncertainty	
	Stat.	Sys.
$pp \to \nu_e X$ cross-section	5%	15%
Charmed hadron yield	5%	35%
ν_e/ν_τ ratio for LFU test	30%	22%
ν_e/ν_μ ratio for LFU test	10%	10%
NC/CC ratio	5%	10%

Feebly interacting particles

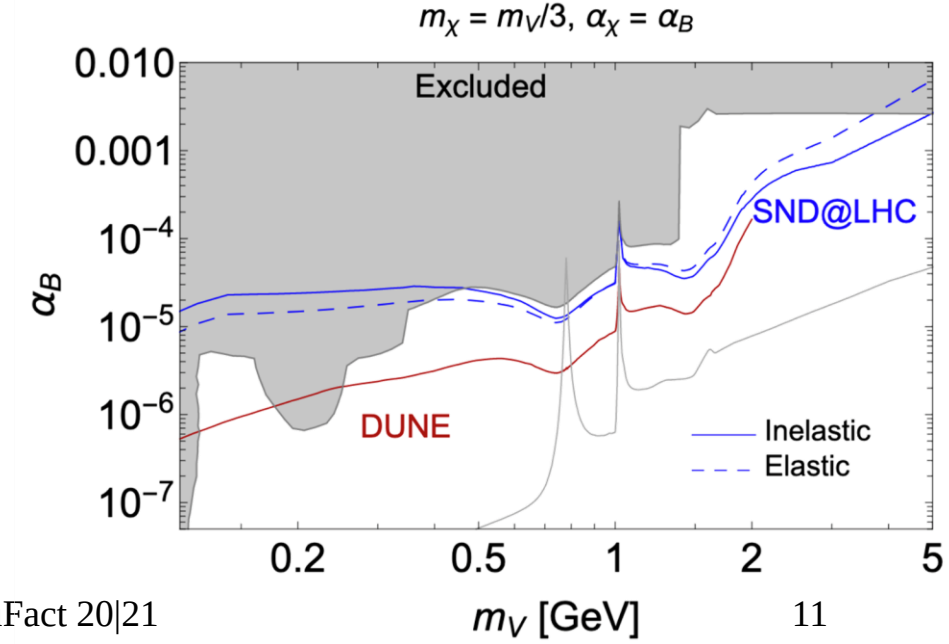
- **Sensitive to scattering off electrons and nucleons**
- **Search for recoil signature**
  - **combine with time of flight measurement to reject ν interactions**
- **Production (eg scalar χ in leptophobic model):**



- **Detection (scattering off target nucleons):**



https://arxiv.org/abs/2104.09688



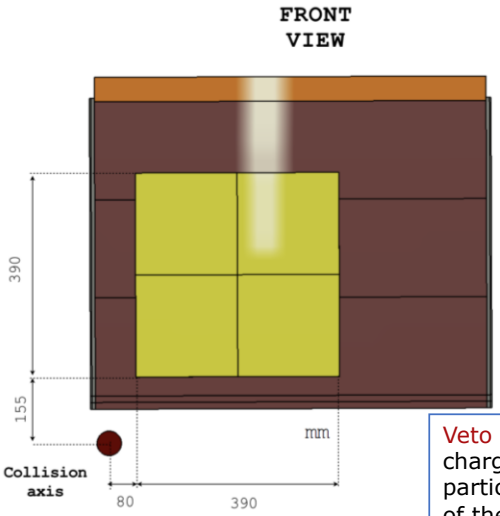
Detector concept

Scattering and Neutrino Detector at the LHC

National University of Science and Technology

Electromagnetic calorimeter
~40 X_0

Hadronic calorimeter
~10 λ



Off axis location
Angular acceptance:
$7.2 < \eta < 8.7$
Target material: Tungsten
Target mass: 830 kg
Surface: 390 x 390 mm^2

Veto plane for charged particles in front of the target region

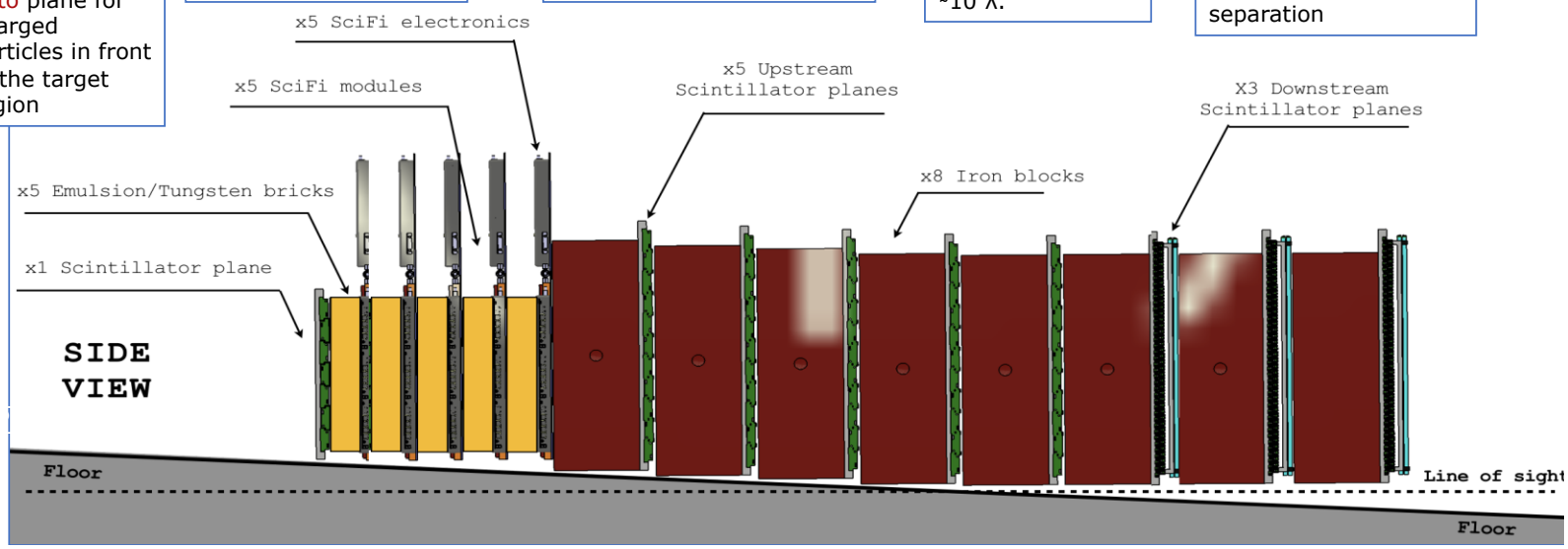
Emulsion Cloud Chamber, emulsion and W absorbers for micrometric accuracy in the detection of τ and FIPs, EM shower energy measurement.

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 ~10 X_0.

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

Timing upstream for the muon filtering

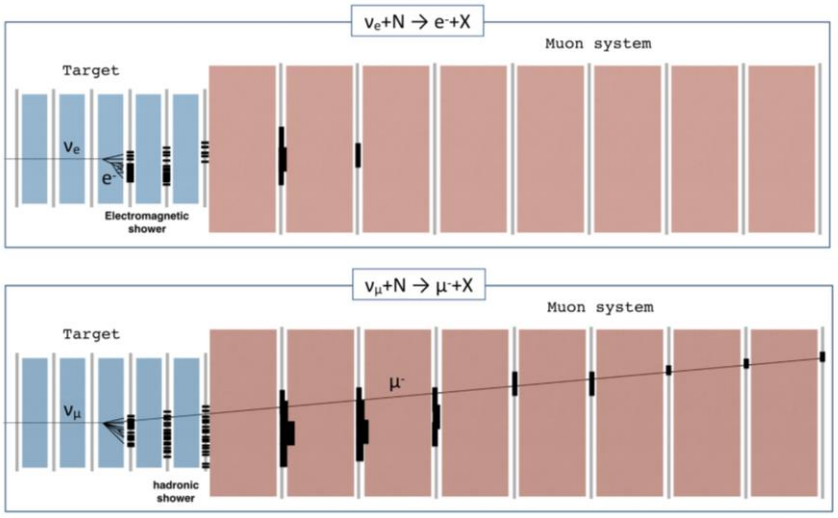
Timing downstream, double X-Y planes with higher granularity for muon-hadron separation



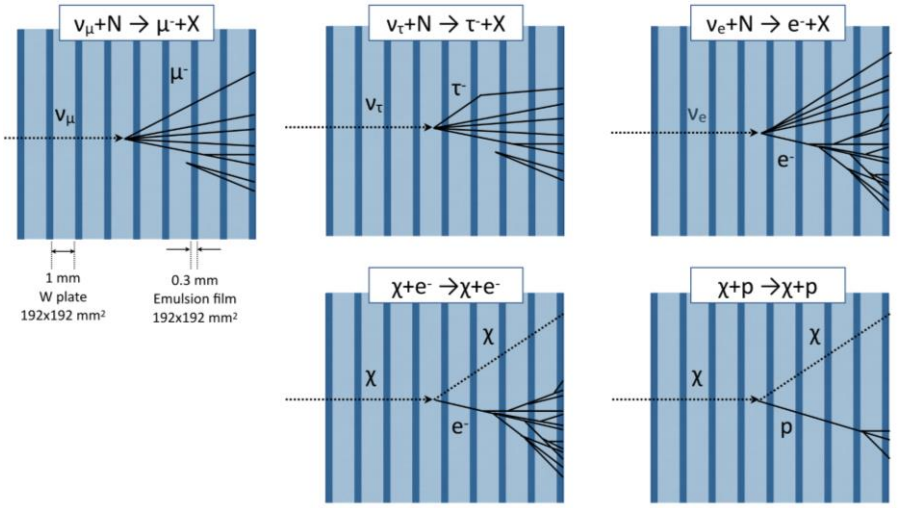
Event reconstruction

- **First phase: electronic detectors**
  - ν candidates
  - μ's
  - em showers (SciFi)
  - ν energy (SciFi+Muon)

- **Second phase: nuclear emulsion**
  - em showers
  - ν vertex reconstruction
  - match with candidates from electronic detectors



ν_e (top) and ν_μ (bottom) CC interactions

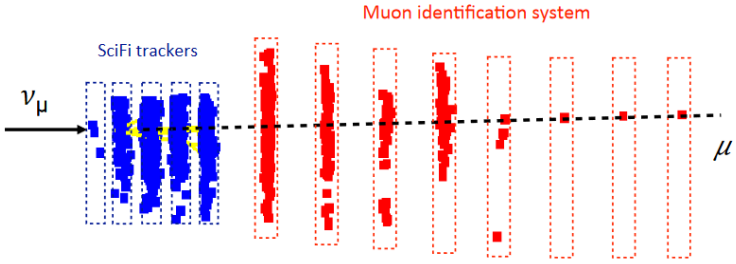


Reconstructible signal topologies in emulsion

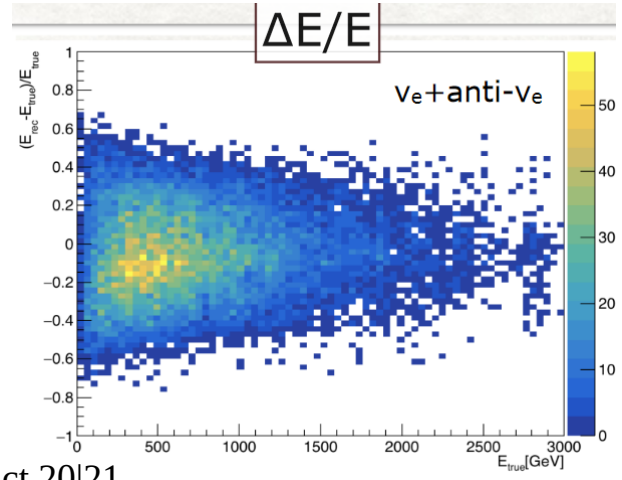
Muon identification, energy resolution

- ν_μ CC interactions identified by muons
- μ-ID at ν vertex crucial to identify charmed hadron production, background to ν_τ detection

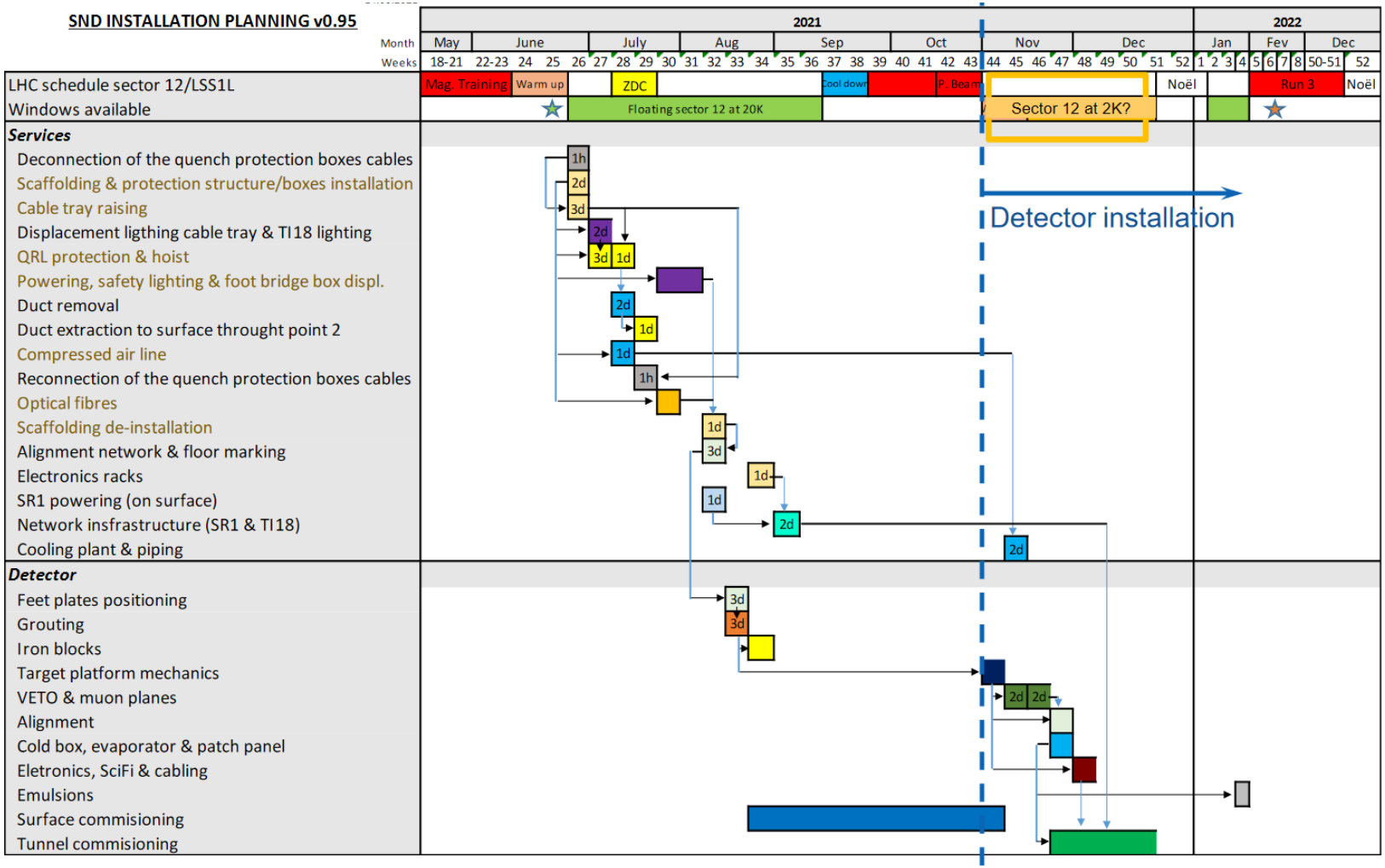
	% evts CC-DIS	% evts NC-DIS
0μ	31.1	99.6
1μ	67.6	0.27
2μ	1.1	0.06



- Sampling calorimeter
- Average resolution on ν_e energy: 22%



Timeline


SND INSTALLATION PLANNING v0.95
2021
2022
Month
May June July Aug Sep Oct Nov Dec Jan Fev Dec
Weeks
18-21 22-23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 1 2 3 4 5 6 7 8 50-51 52
LHC schedule sector 12/LSS1L
Mag. Training
Warm up
ZDC
Cool down
P. Beam
Noël
Run 3
Noël
Windows available
Floating sector 12 at 20K
Sector 12 at 2K?
Services
Deconnection of the quench protection boxes cables
Scaffolding & protection structure/boxes installation
Cable tray raising
Displacement ligthing cable tray & TI18 lighting
QRL protection & hoist
Powering, safety lighting & foot bridge box displ.
Duct removal
Duct extraction to surface throught point 2
Compressed air line
Reconnection of the quench protection boxes cables
Optical fibres
Scaffolding de-installation
Alignment network & floor marking
Electronics racks
SR1 powering (on surface)
Network insfrastructure (SR1 & TI18)
Cooling plant & piping
Detector installation
Detector
Feet plates positioning
Grouting
Iron blocks
Target platform mechanics
VETO & muon planes
Alignment
Cold box, evaporator & patch panel
Eletronics, SciFi & cabling
Emulsions
Surface commisioning
Tunnel commisioning

Status

On schedule. First 5 muon stations being tested (now) in H8 testbeam:

Conclusions

- **SND@LHC has a unique physics program measuring heavy flavour production**
- **Timeline is tight, installation challenging**
- **We are looking forward to taking data, understanding the detector, doing data analysis and see if we can live up to the expectations!**

Backup

Background

- Muon rates(produced at the IP) in the SND@LHC acceptance (DPMJET/FLUKA)
- 350 Hz ~ $2x10^4/cm^2/fb^{-1}$
- Low flux of K_L and n from muon DIS
- Thermal neutrons from beam gas interactions: shielding of emulsion required