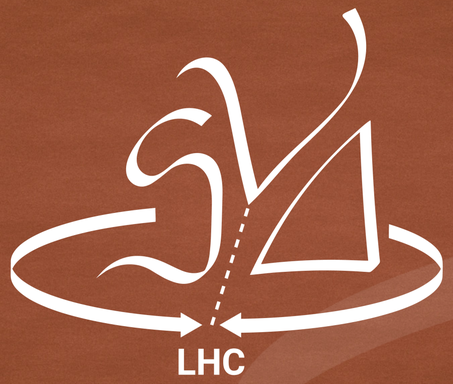
THE SCATTERING AND NEUTRINO DETECTOR AT THE LHC



A. Di Crescenzo
CERN, Università Federico II and INFN

on behalf of the SND@LHC Collaboration

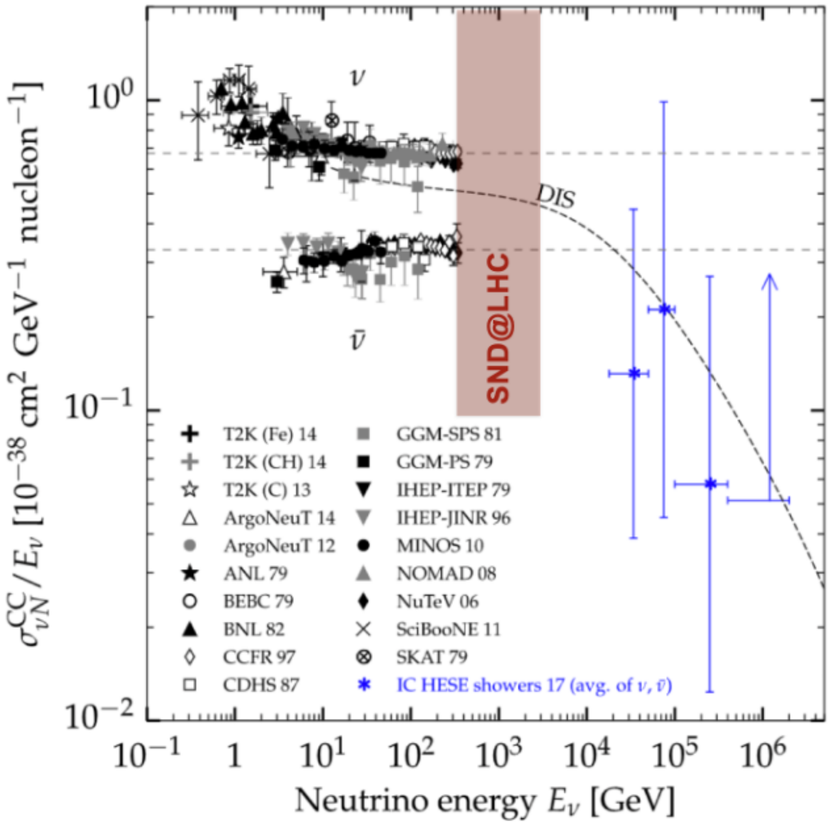
LHC Forward Physics Meeting, 24-25 October 2022

MOTIVATION

Neutrino physics at the LHC

- Klaus Winter, 1990, observing tau neutrinos at the LHC
- A. De Rùjula, E. Fernandez and J. J. Gòmez-Cadenas, 1993, Neutrino fluxes at LHC
- F. Vannucci, 1993, neutrino physics at the LHC
- http://arxiv.org/abs/1804.04413 April 12th 2018

PRL 122 (2019) 041101



CERN is unique in providing energetic ν (from LHC) and measure pp →νX in an unexplored domain

OPEN ACCESS
IOP Publishing
Journal of Physics G: Nuclear and Particle Physics
J. Phys. G: Nucl. Part. Phys. **46** (2019) 115008 (19pp)
https://doi.org/10.1088/1361-6471/ab3f7c

Physics potential of an experiment using LHC neutrinos

Eur. Phys. J. C (2020) 80:61
https://doi.org/10.1140/epjc/s10052-020-7631-5
THE EUROPEAN PHYSICAL JOURNAL C
Check for updates
Regular Article - Experimental Physics

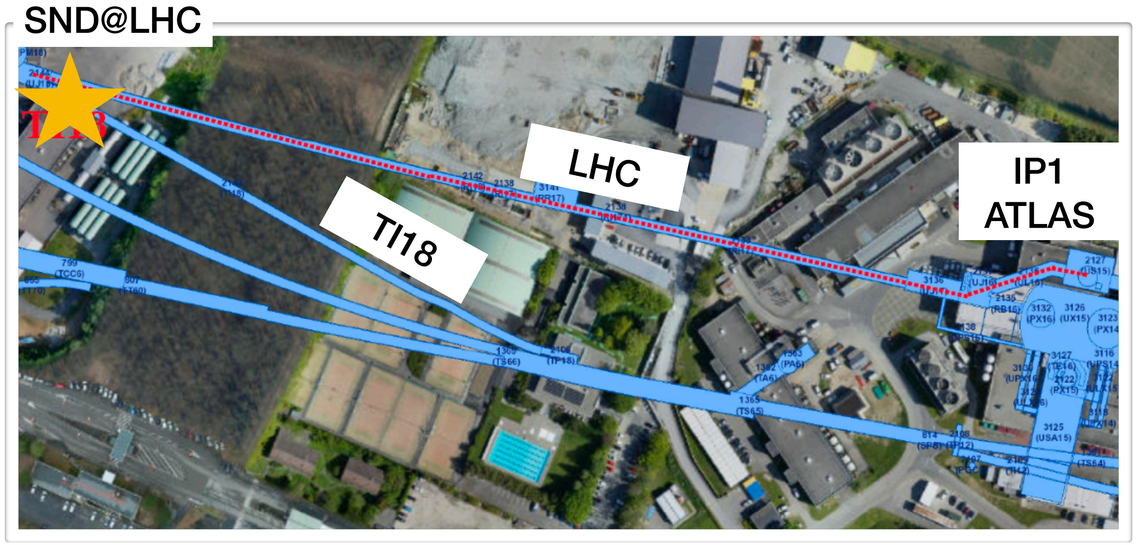
Detecting and studying high-energy collider neutrinos with FASER at the LHC

FASER Collaboration

OPEN ACCESS
IOP Publishing
Journal of Physics G: Nuclear and Particle Physics
J. Phys. G: Nucl. Part. Phys. **47** (2020) 125004 (18pp)
https://doi.org/10.1088/1361-6471/aba7ad

Further studies on the physics potential of an experiment using LHC neutrinos

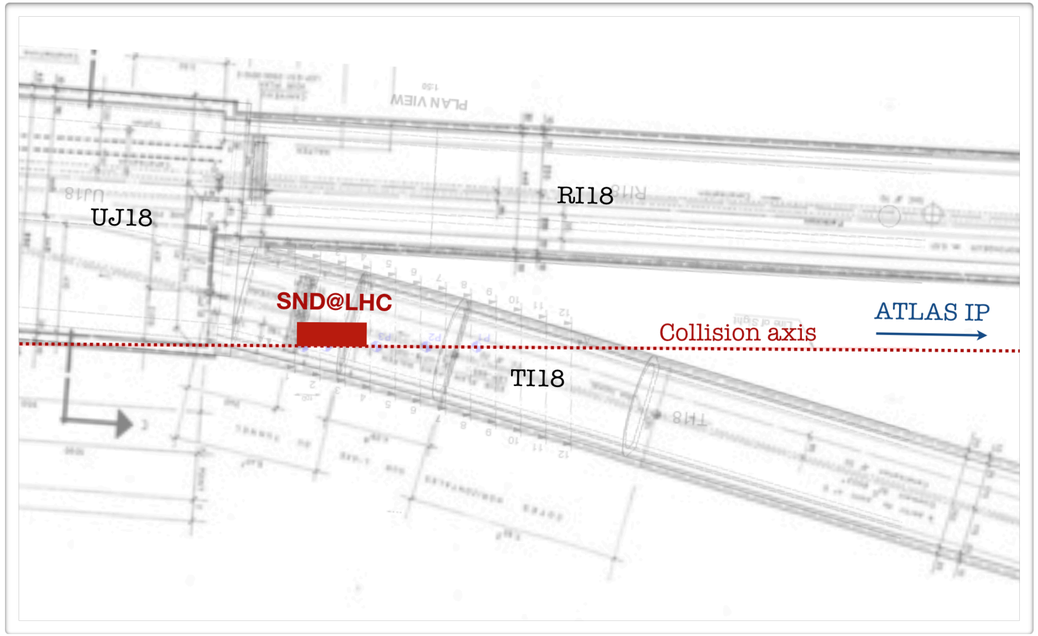
LOCATION



- 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 290 fb^{-1}



https://cds.cern.ch/record/2750060/files/LHCC-P-016.pdf

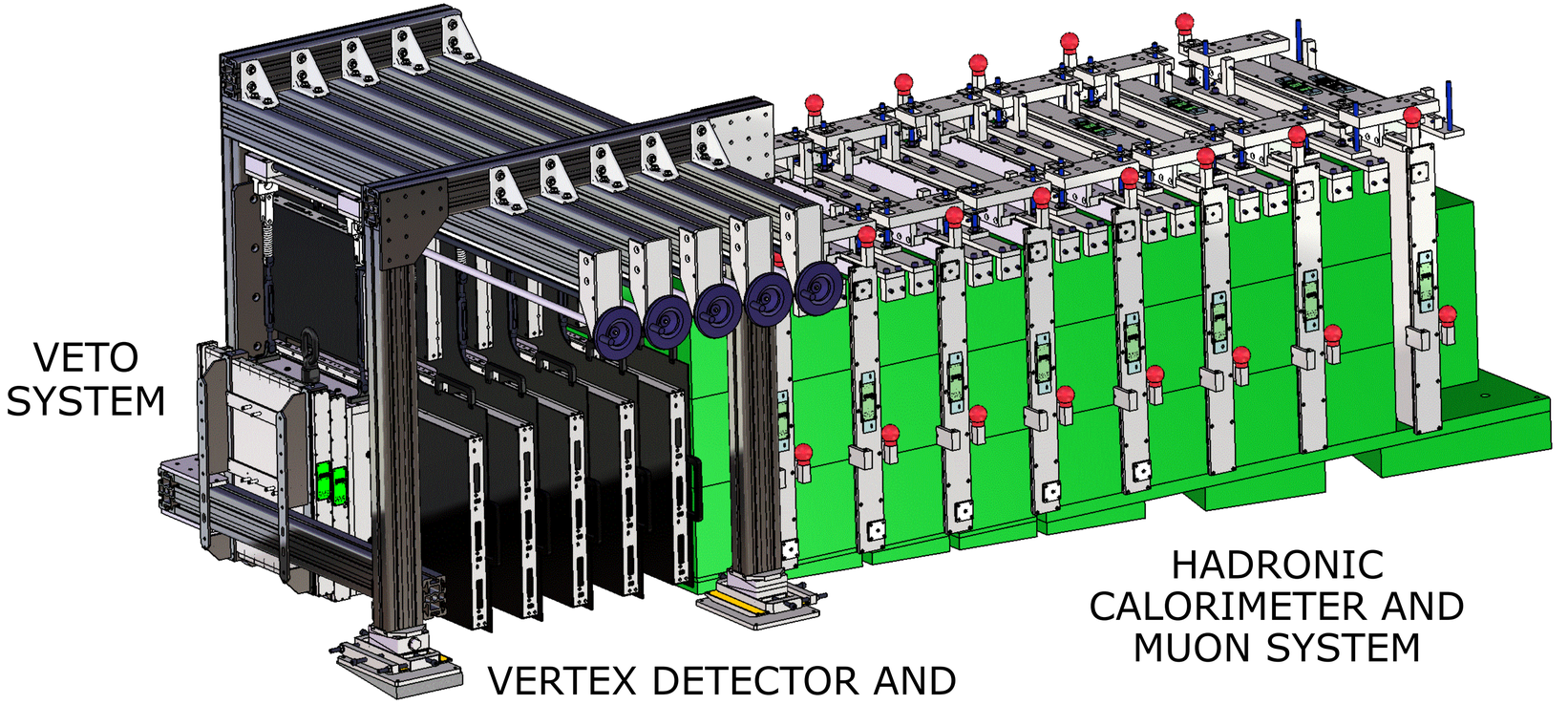
THE SND@LHC CONCEPT

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

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



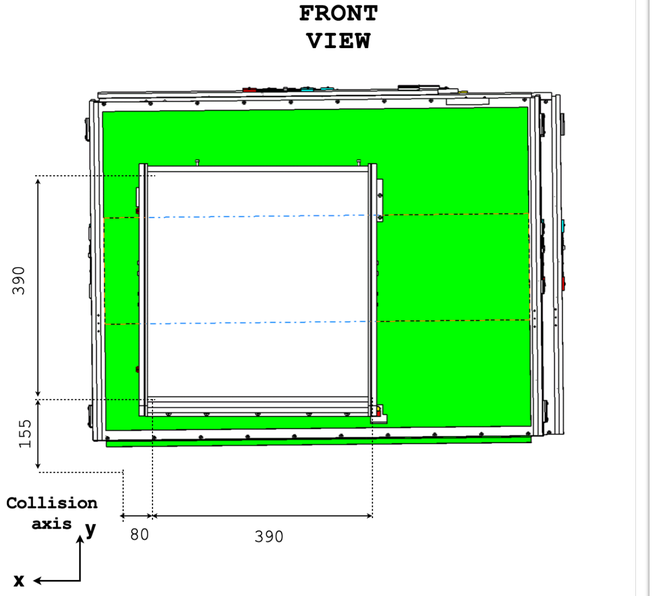
THE SND@LHC DETECTOR LAYOUT

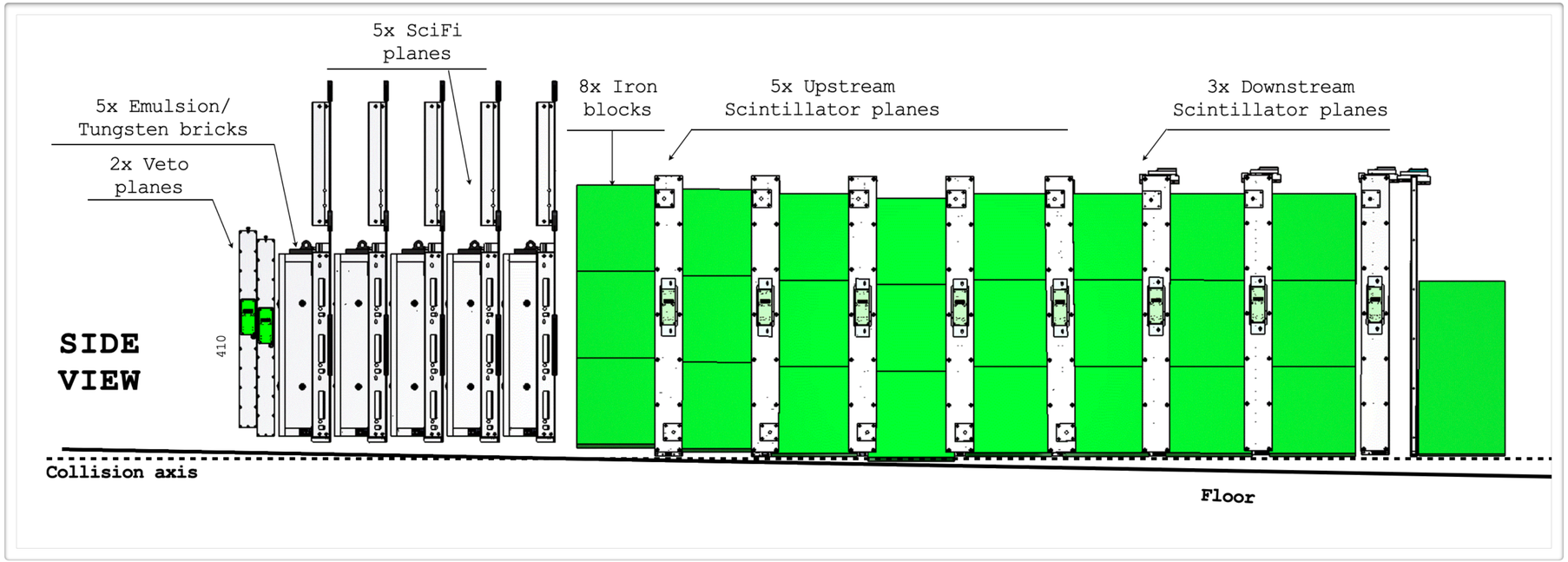
- Angular acceptance: $7.2 < \eta < 8.4$
- Target material: Tungsten
- Target mass: 830 kg
- Surface: 390x390 mm^2

Off axis location

Electromagnetic calorimeter
~40 X_0

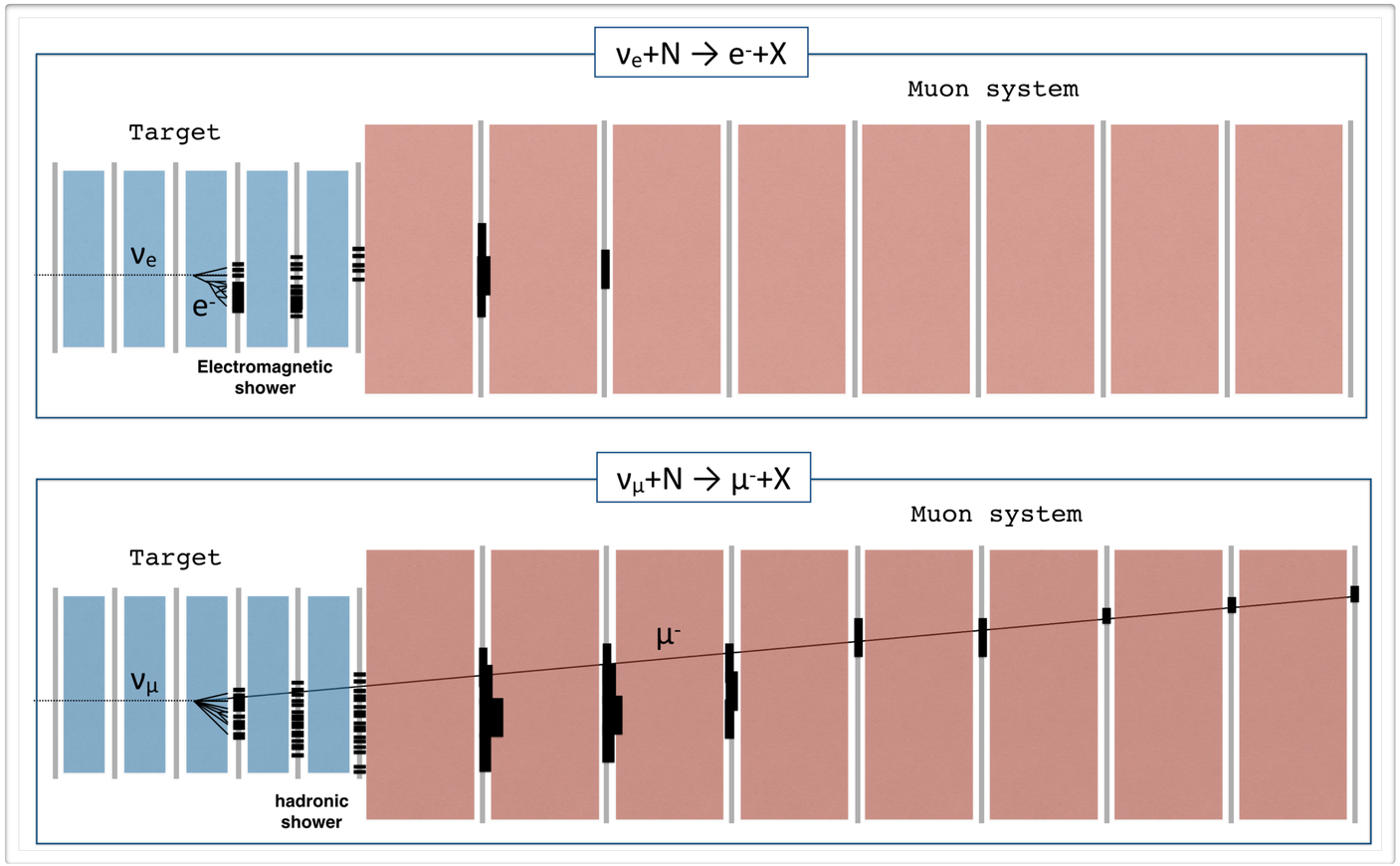
Hadronic calorimeter
~10 λ



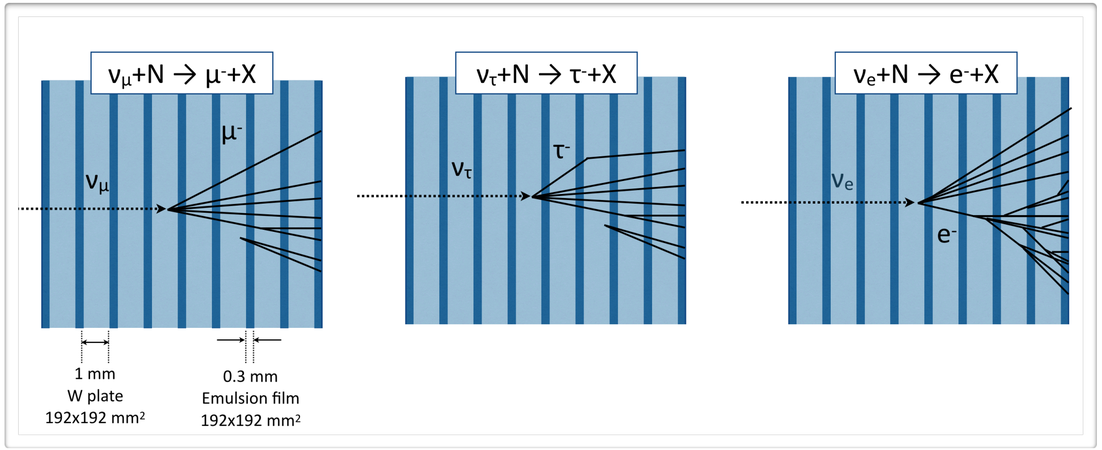


EVENT RECONSTRUCTION

- **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



SND@LHC INSTALLATION IN TI18

- Detector commissioning on surface (North Area @CERN) in September and October 2021
- Installation in TI18 started on November 1st 2021

September 2021

- Electronic detector installation completed on December 3rd 2021
- Installation of the neutron shield completed on March 15th 2022
- Installation of the first emulsion wall on April 7th 2022

December 2021

March 2022

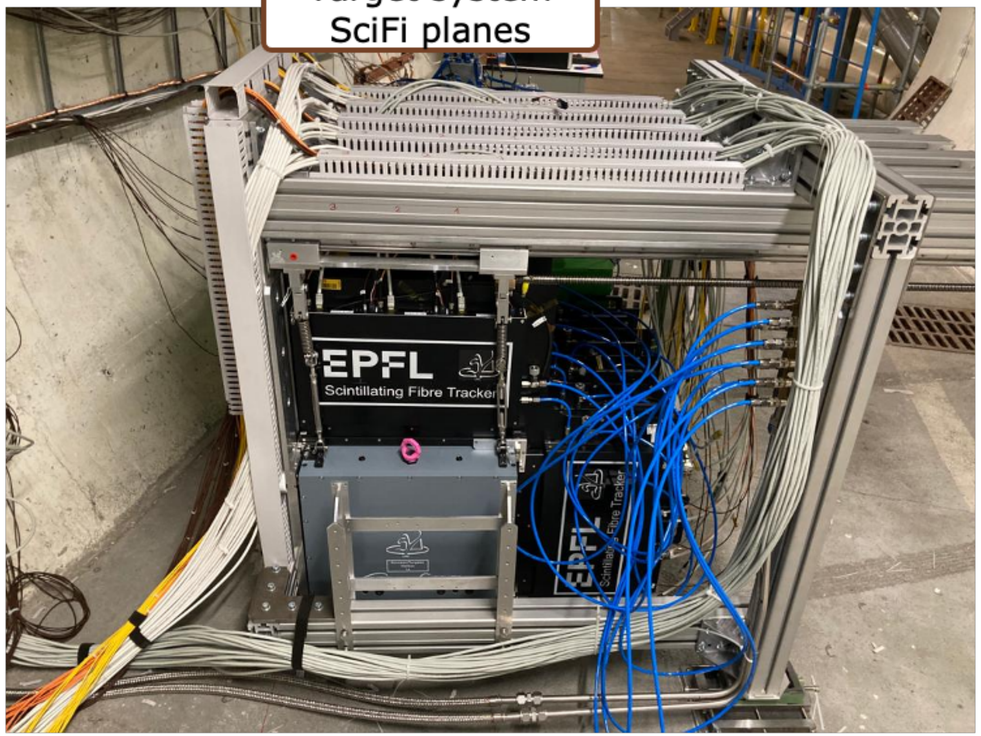
DETECTOR INSTALLATION IN TI18

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

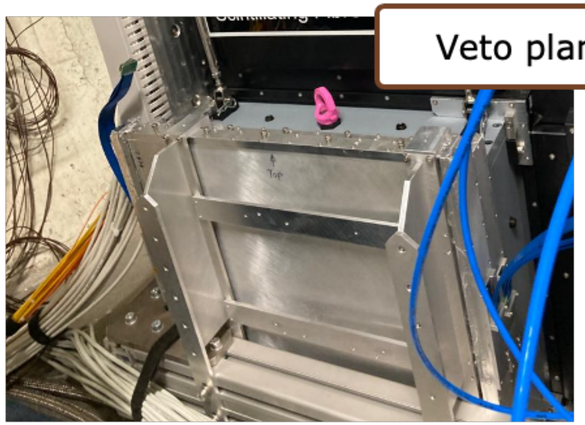
SND@LHC INSTALLATION IN TI18

Target wall

Target system
SciFi planes



Veto plane

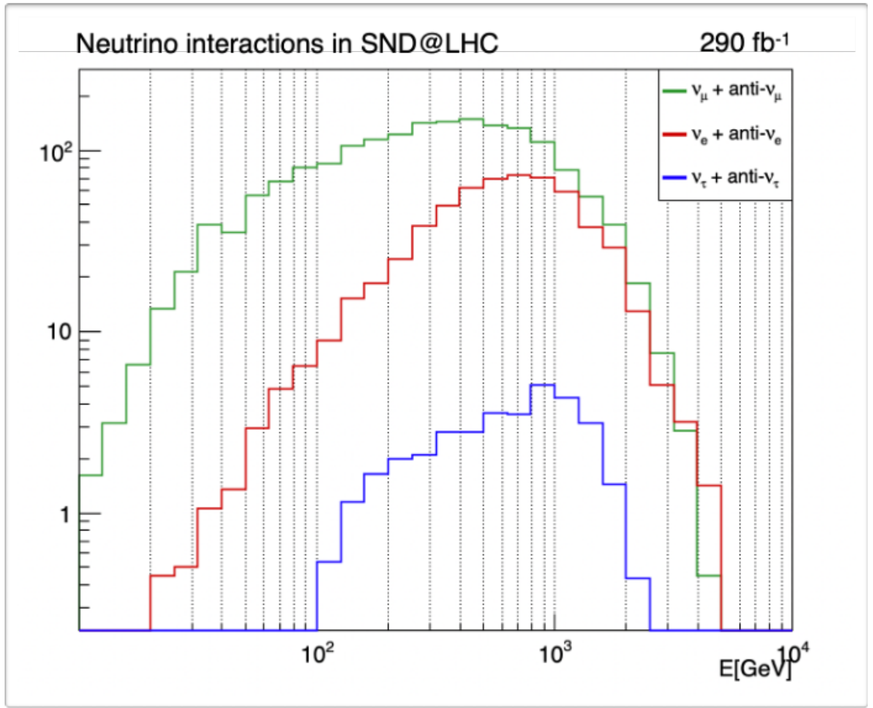


Muon system

NEUTRINO EXPECTATIONS

- Expectations in **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]	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
$\bar{\nu}_e$	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 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

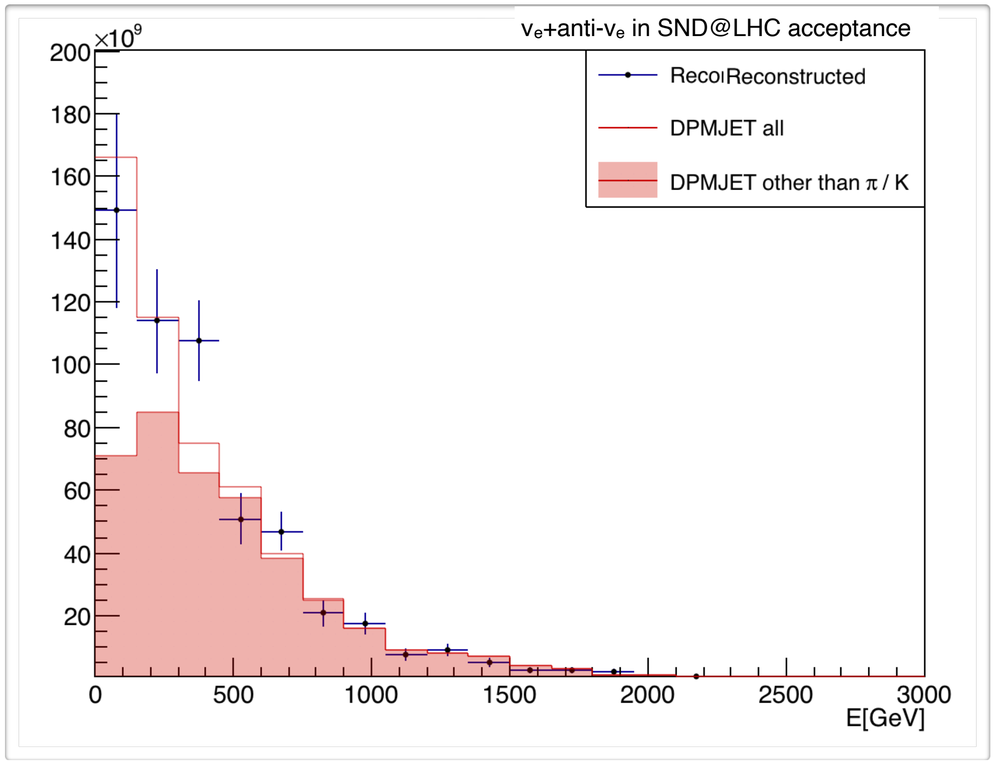
Measurement	Uncertainty	
	Stat.	Sys.
$pp \to \nu_e X$ cross-section	5%	15%
Charmed hadron yield	5%	35%
ν_e/ν_τ ratio for LFU test	30%	22%
ν_e/ν_μ ratio for LFU test	10%	10%

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

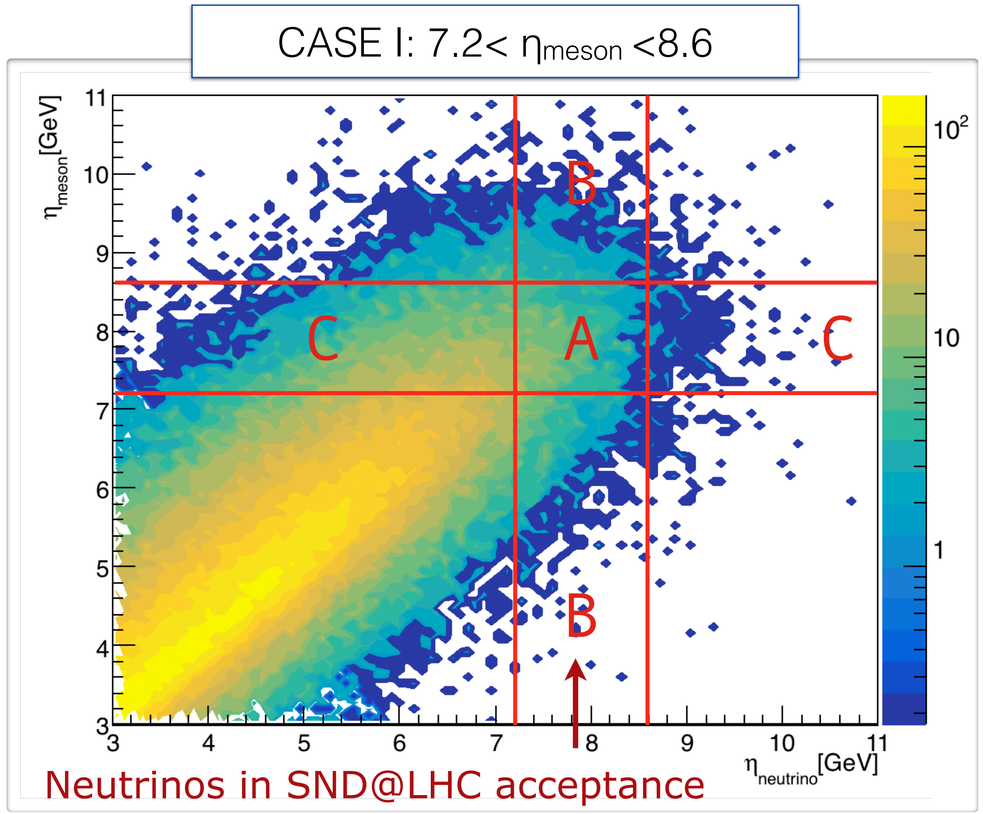
2. CHARMED HADRON PRODUCTION

- 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



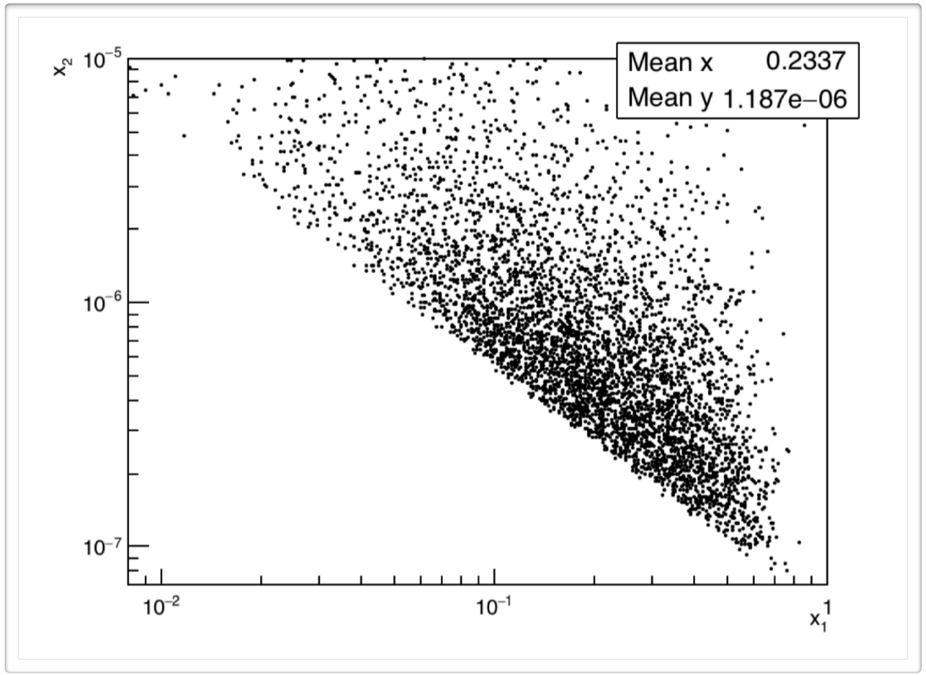
- Correlation between pseudo-rapidity of the electron (anti-)neutrino and the parent charmed hadron



QCD MEASUREMENTS

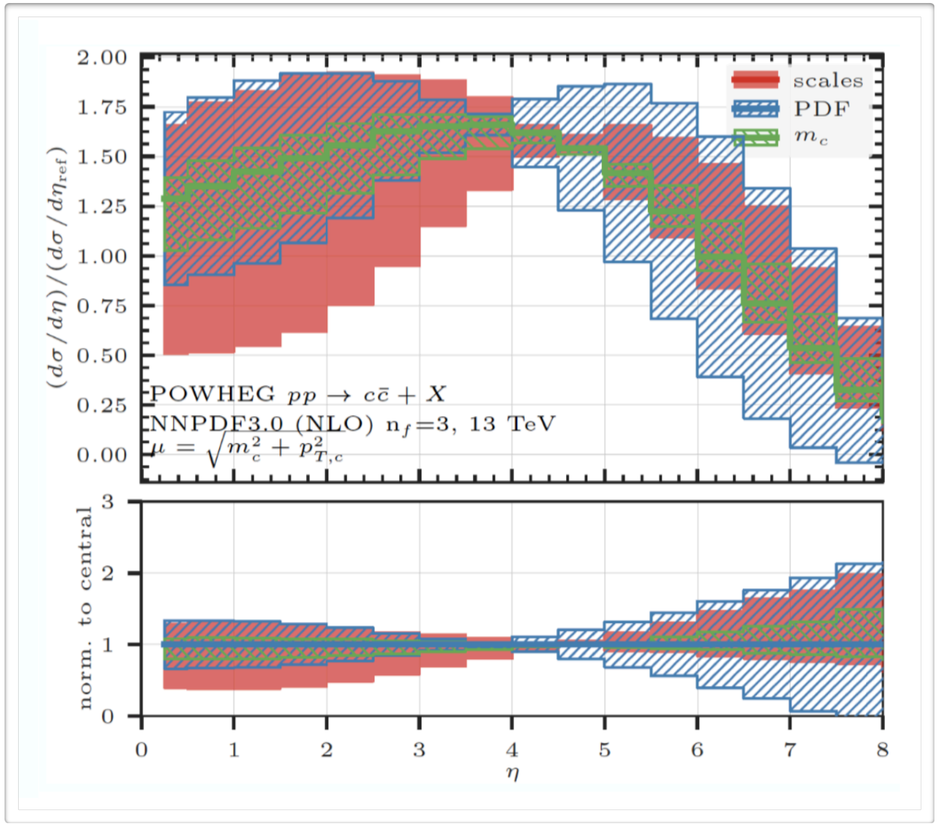
The dominant partonic process for associated charm production at the LHC is gluon-gluon scattering

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
- predictions of high energy neutrinos production in cosmic rays



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

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

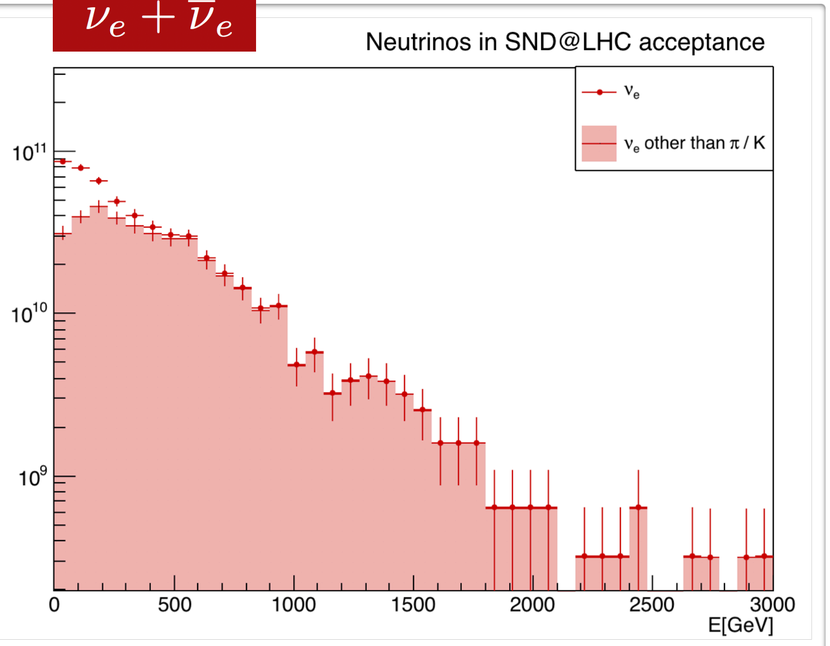
$\eta_{ref} = 4.5$

Reduction of scale uncertainties
Constraint the PDF with data

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)

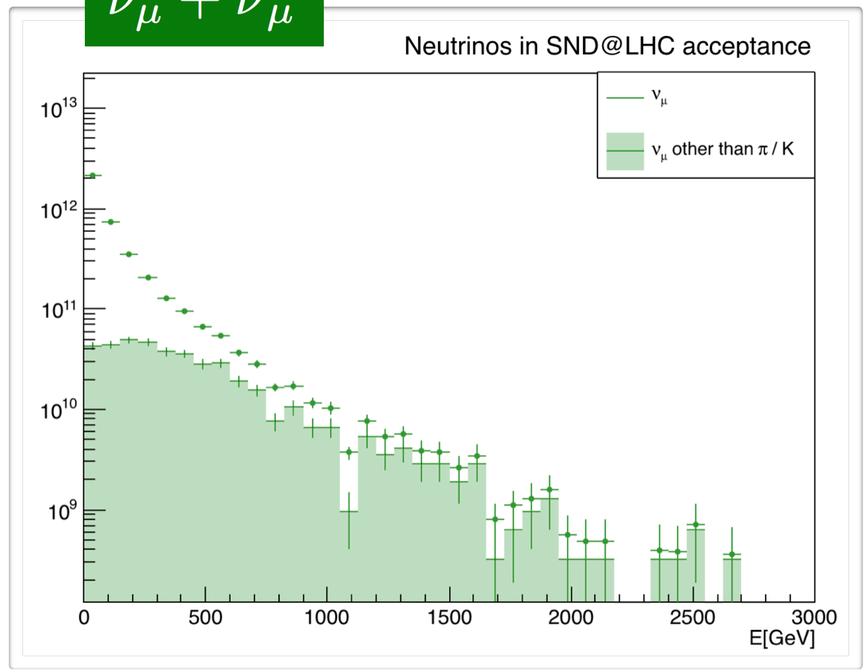
$\nu_e + \overline{\nu}_e$



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

- 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

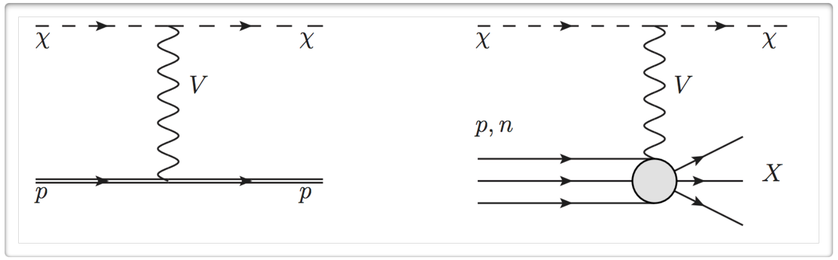
BEYOND STANDARD MODEL

Large variety of BSM scenarios describing Hidden Sector

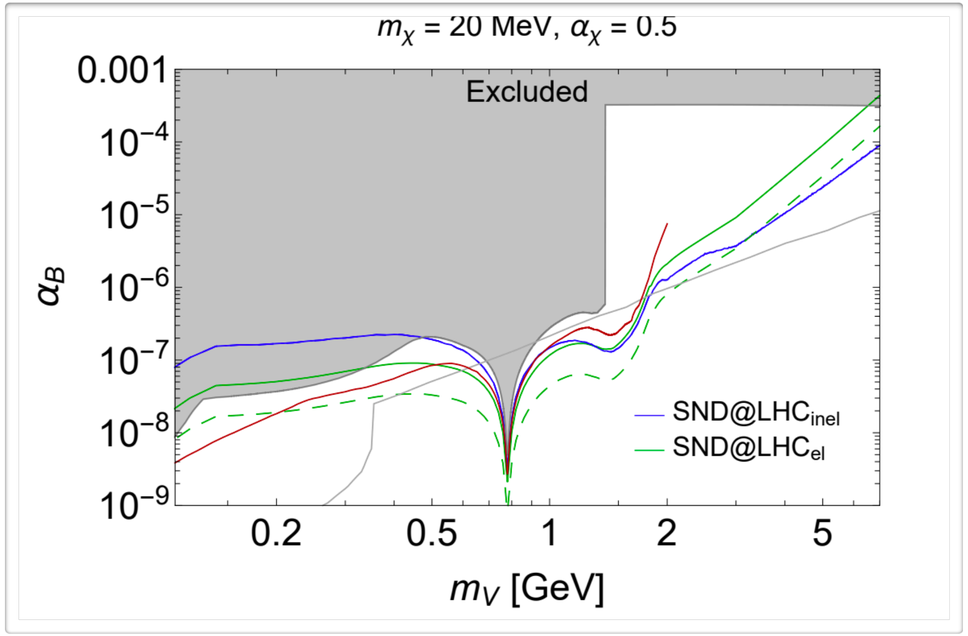
1. Scattering

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

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



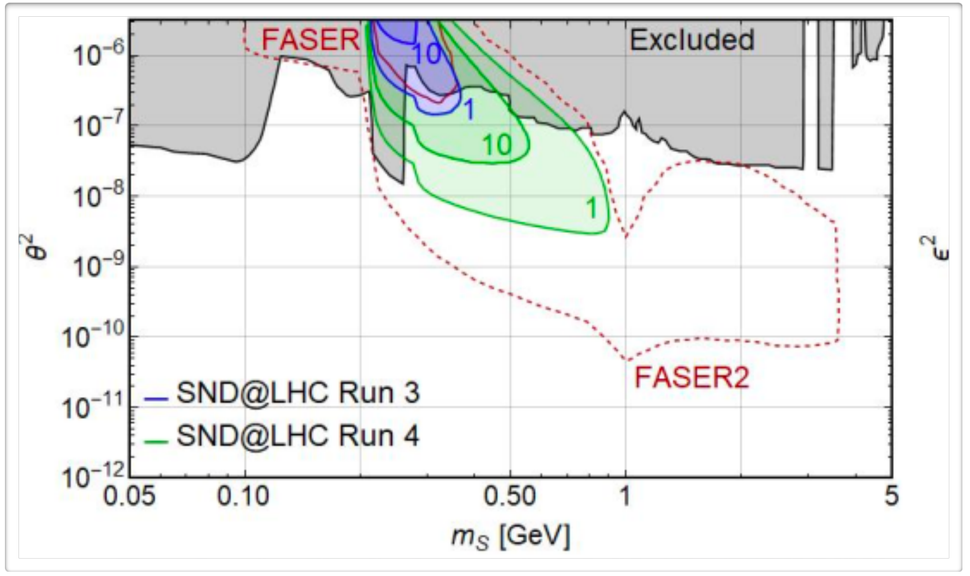
10.1007/JHEP03(2022)006



2. Decay of dark scalars, HNLs, dark photons

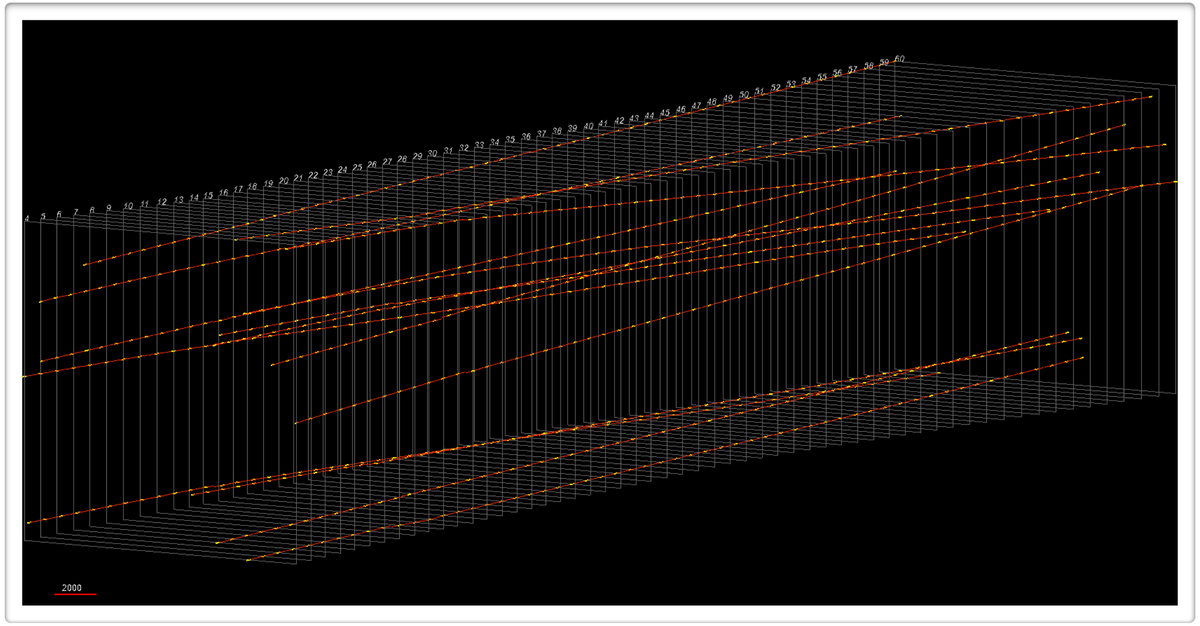
Production: dark scalars produced in the decay of B mesons, HLNs in the decay of B and D mesons, dark photons via leptophobic mediator

Detection: Decays in a pair of charged tracks or monophotons



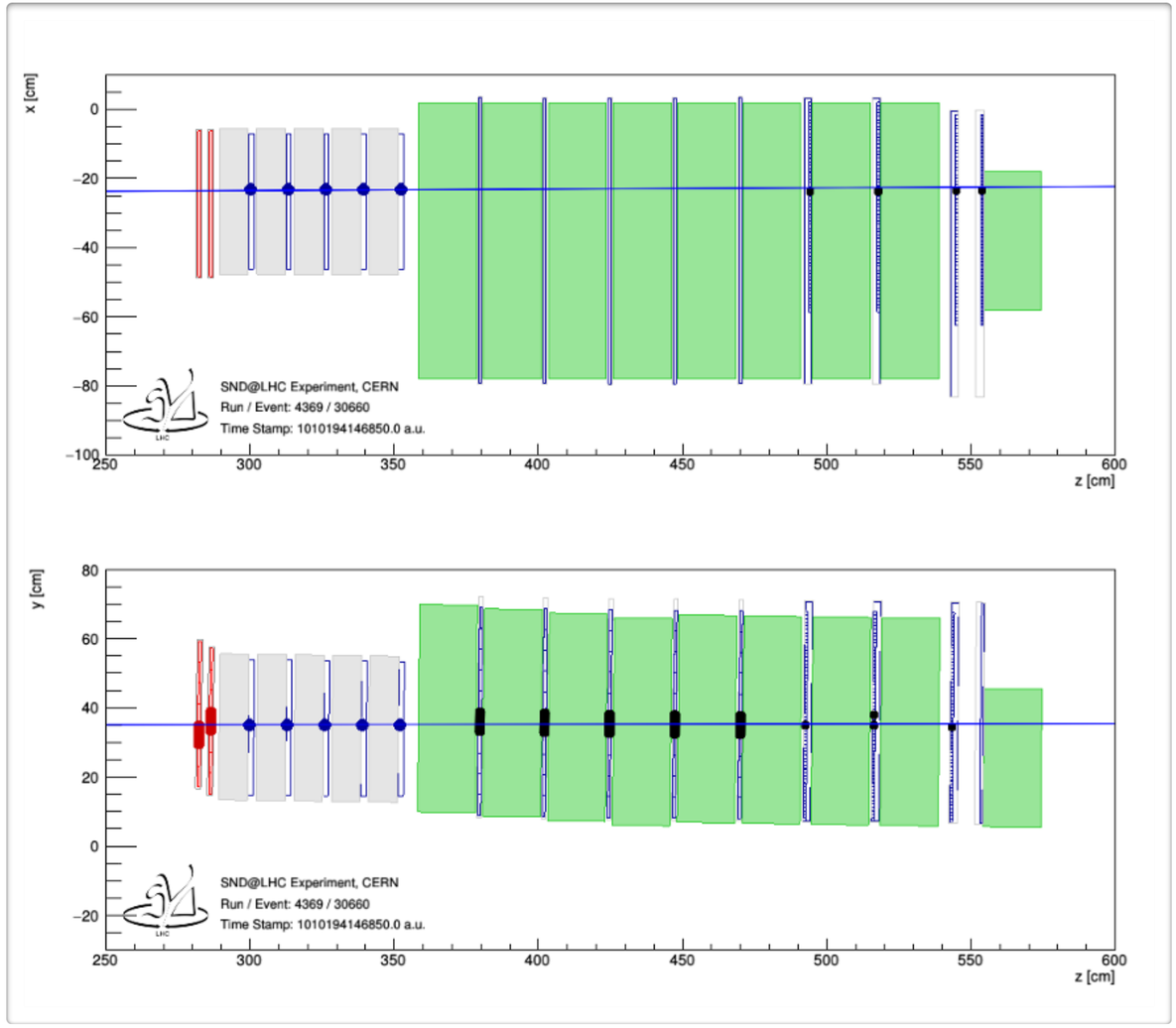
DATA TAKING IN RUN3

- Muon tracks reconstructed in the emulsion target



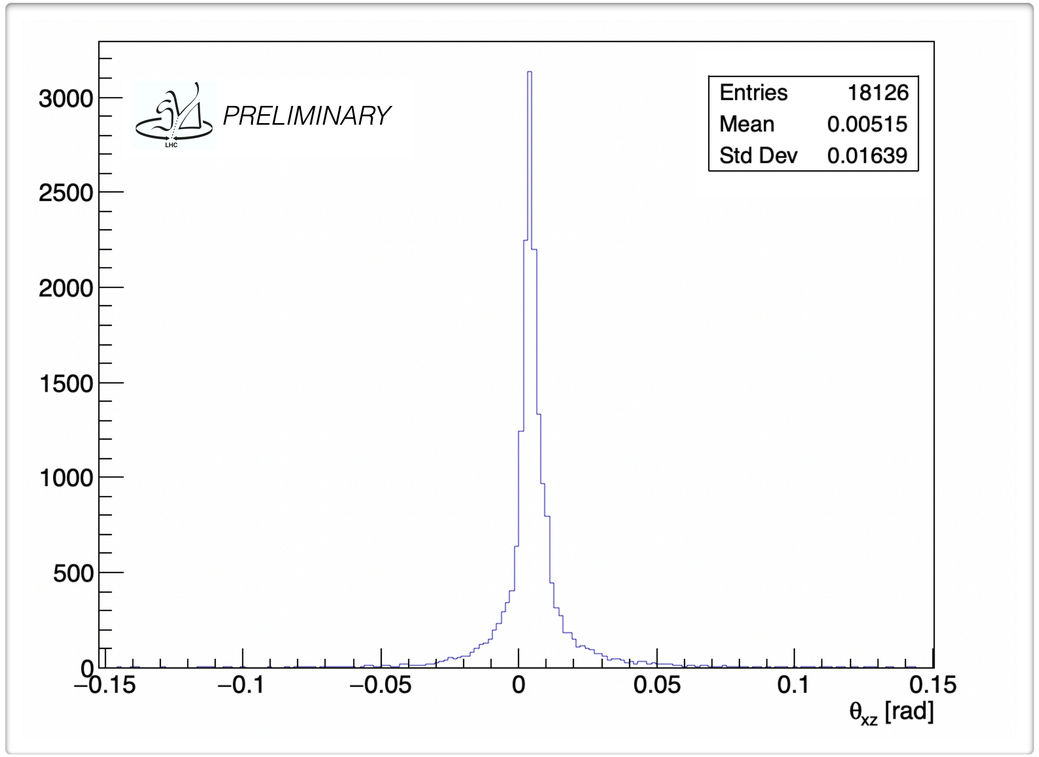
- 15 tracks selected randomly in 1x1 cm^2 - 57 emulsion films
- RUN0 emulsion target: April 7th - July 26th

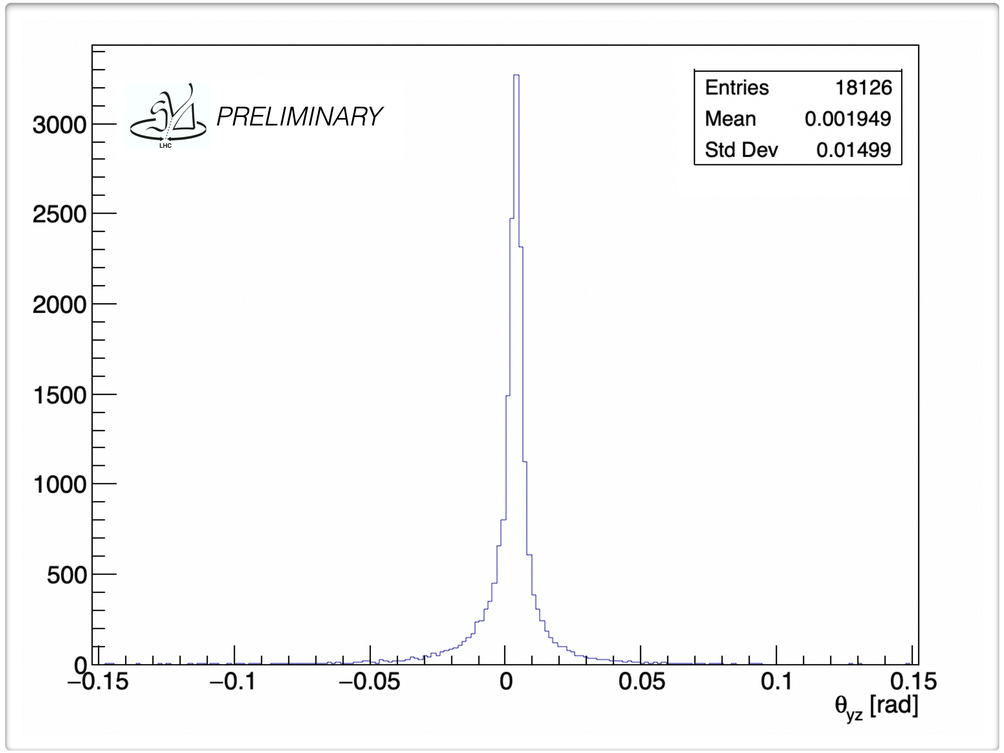
- Muon from pp collisions @13.6 TeV (July 16th 2022)



DATA TAKING IN RUN3

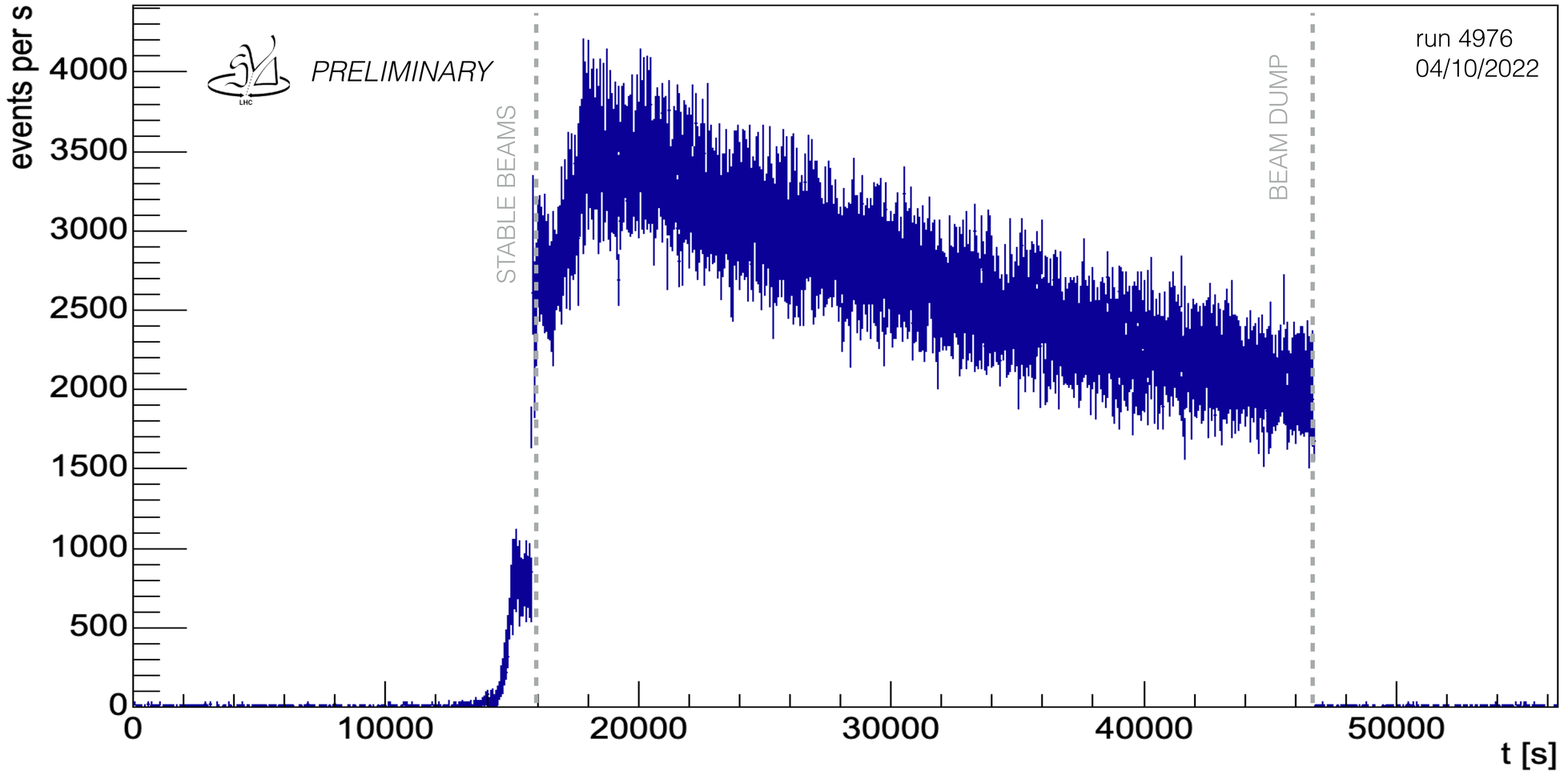
- Reconstructed tracks in the first runs @13.6 TeV, direction compatible with coming from pp collisions at IP1





DATA TAKING IN RUN3

- Event rate for one run
- Start:October 4th 2022, 18:12:22
- End: October 5th 2022, 09:52:21



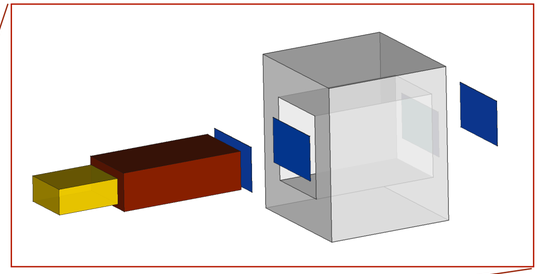
UPGRADE FOR HL-LHC

- Upgrade of SND@LHC in view of an extended run during Run 4:
  - Extension of the physics case
  - New technologies and detector layout
  - Two detectors
    - **AdvSND-Far** (7.2<η<8.4)

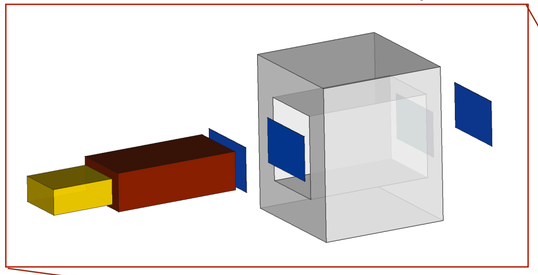
      Possible locations: TI18, Future Forward Facility
    - **AdvSND-Near** (4<η<5)

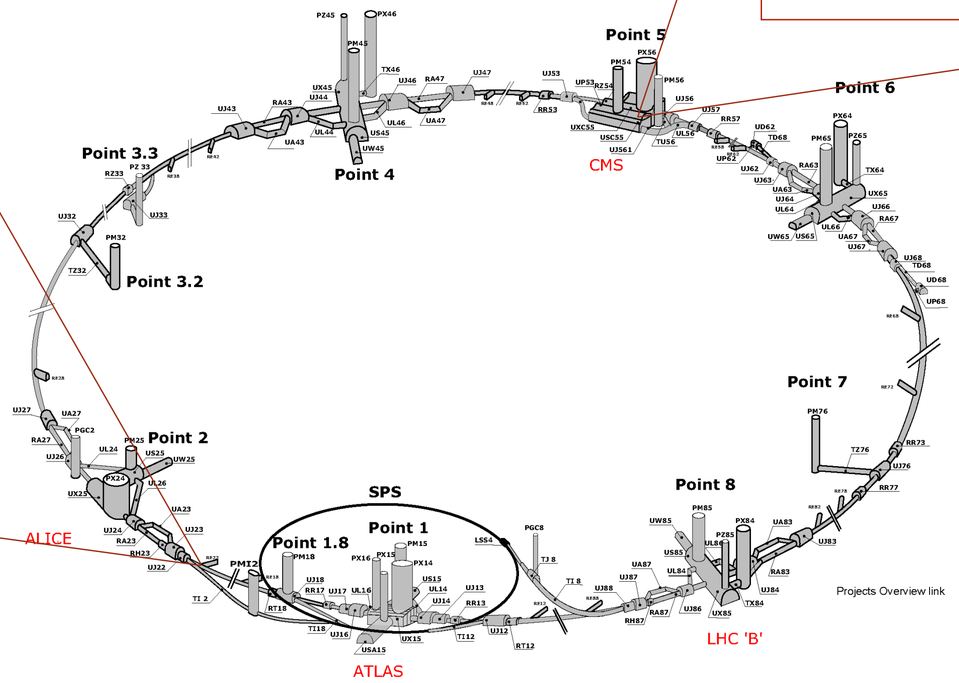
      Possible locations: existing caverns close to IP

AdvSND-Near: 4<η<5



AdvSND-Far: 7.2<η<8.4



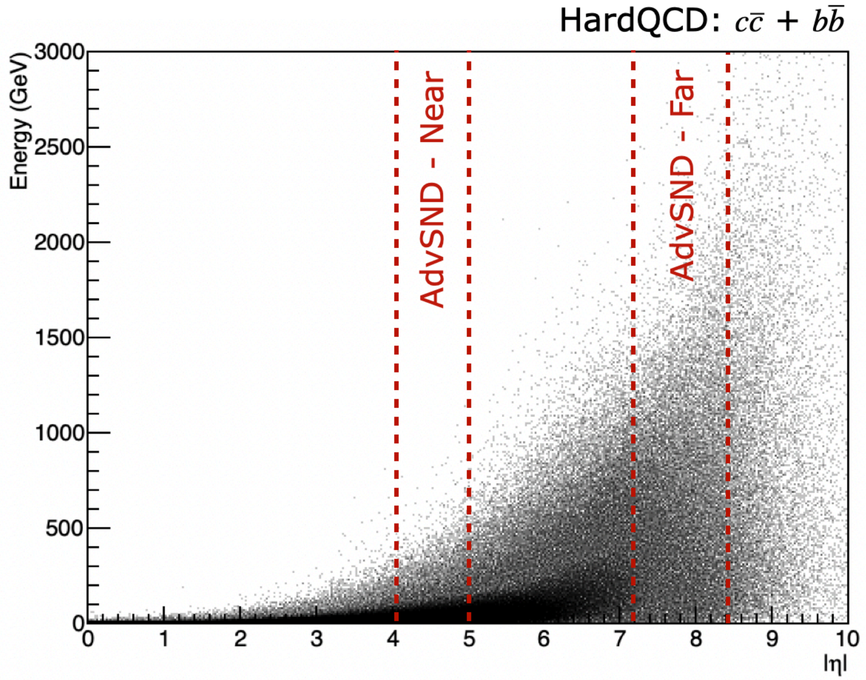


ADVANCED SND@LHC

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

- **AdvSND-Near:** $4<\eta<5$
  - Overlap with LHCb pseudo-rapidity coverage
  - Reduction of systematic uncertainties
  - Neutrino cross-section measurement
  - charm measurements in the region of interest for prompt ν fluxes

- **AdvSND-Far**: $7.2<\eta<8.4$
  - Acceptance similar to SND@LHC
  - Charm production measurements
  - Lepton flavour universality



CONCLUSIONS

- The LHC provides a unique possibility to measure neutrino production at the TeV scale
- SND@LHC covers a unique physics program covering LHC Run 3 (2022-2025) to study all three neutrino flavors
- SND@LHC is currently taking data.
- Future projects at the HL-LHC are under study