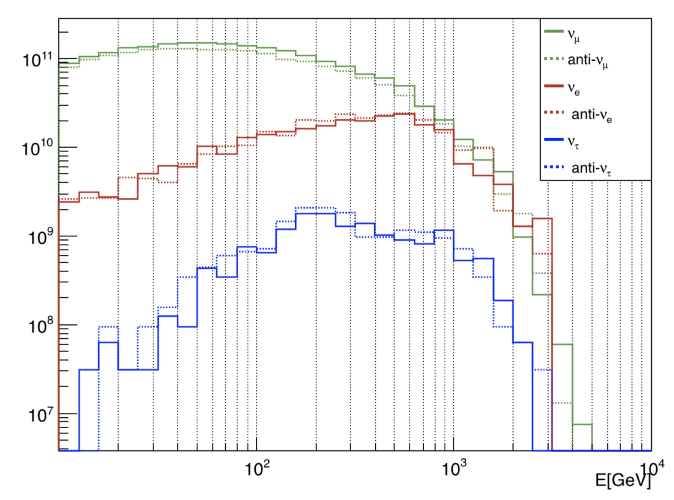
The physics case of the SND@LHC experiment by Paul de Bryas

Scattering and Neutrino Detector @ LHC

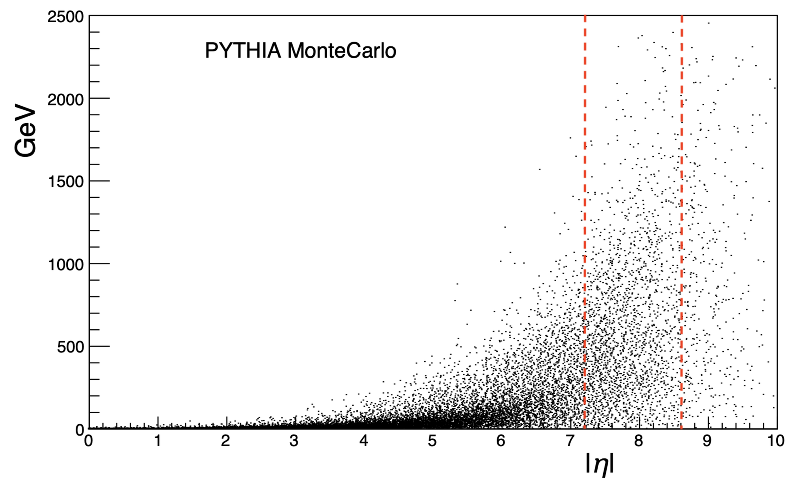
- **2020** The letter of intent [CERN-LHCC-2020-013] lays the foundations of SND@LHC.
- **January 2021** Technical proposal released [CERN-LHCC-2021-003], and approved by CERN Research Board in March 2021.

The chosen location for SND@LHC (TI18 tunnel) is located at 480 m away from ATLAS interaction point. SND@LHC's main goals are to:

- ☐ measure high energy ν of all flavours at LHC.
- ☐ measure the charmed hadron production in pp interactions in an **unexplored pseudo-rapidity region 7.2 $< \eta <$ 8.6**.
- ☐ test lepton flavor universality.
- ☐ search for feebly interacting particles (FIP).



Expected energy spectrum of the incoming ν and $\bar{\nu}$.

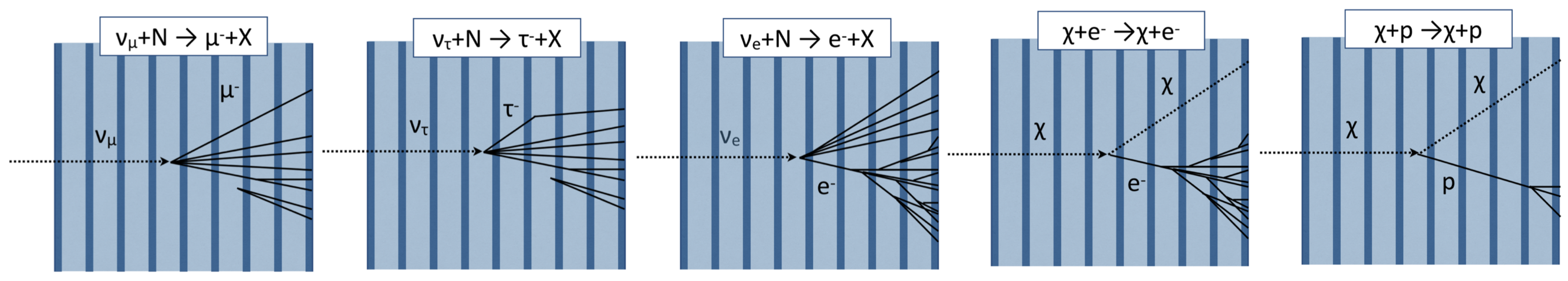


Energy versus η of ν from b and c decays.

The detector idea and configuration

The detector is composed of an upstream veto detector, the target region and a downstream muon identifiation system:

- **Veto**: two parallel planes of scintillating bars, read out by silicon photomultipliers.
- **target region**: hybrid system made of 800 kg of tungsten plates interleaved with nuclear emulsion bricks with micrometric accuracy, and combined with scintillating fibre tracking planes, that offer the possibility of real-time event analysis and aid in the matching between successive bricks.
- **muon ID system**: scintillating bars interleaved with iron plates. Provides muon identification and acts as hadronic calorimeter.



The goal of such configuration is to:

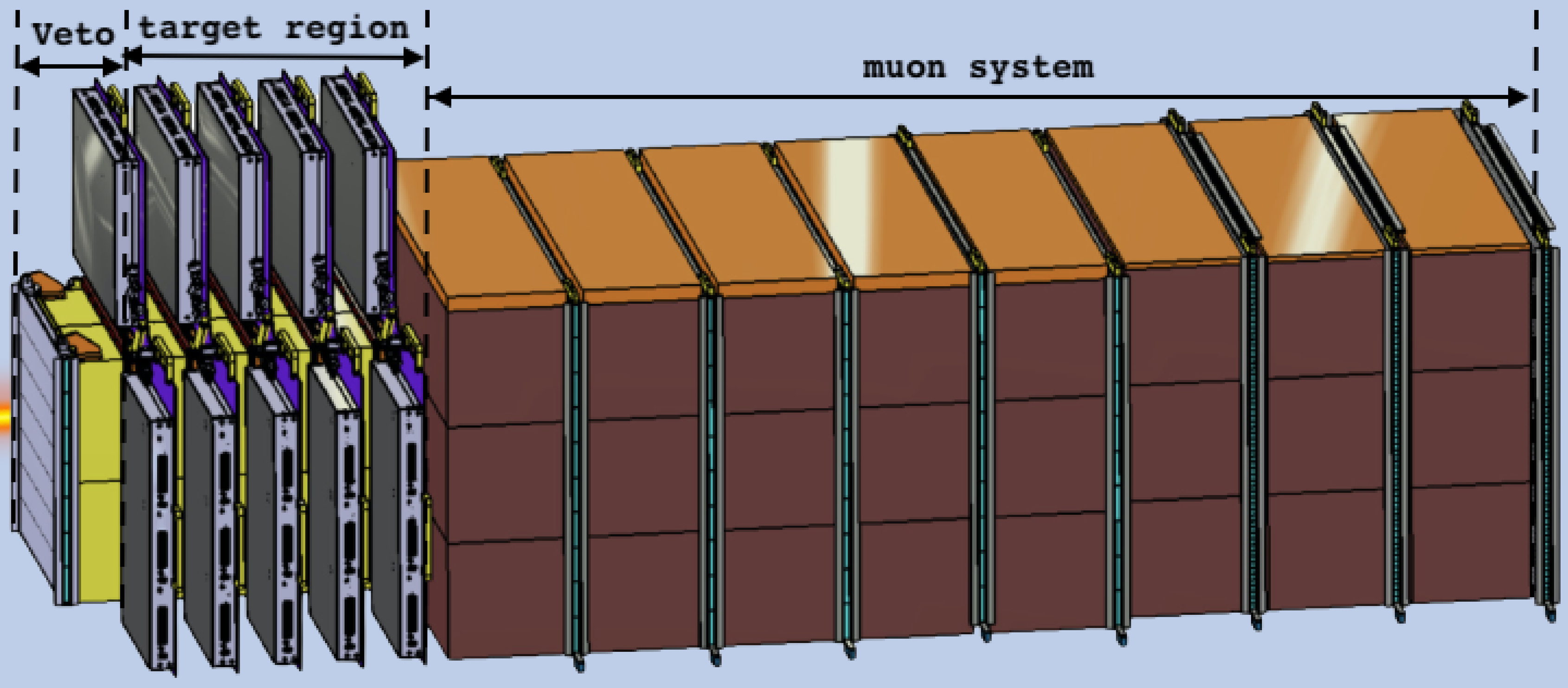
- ☐ identify the charged lepton produced at the primary vertex to distinguish between neutrino flavours
- ☐ detect scattering off electrons/nucleons in the target region to identify light dark matter signature.

Physics performance

First phase: start operations during LHC Run 3 to collect neutrinos from 150 fb^{-1} of pp collisions: $\sim$1845 expected ν interactions

Measurement	σ_{stat}	σ_{sys}
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%
$pp \to \nu_e X$ cross-section	5%	15%

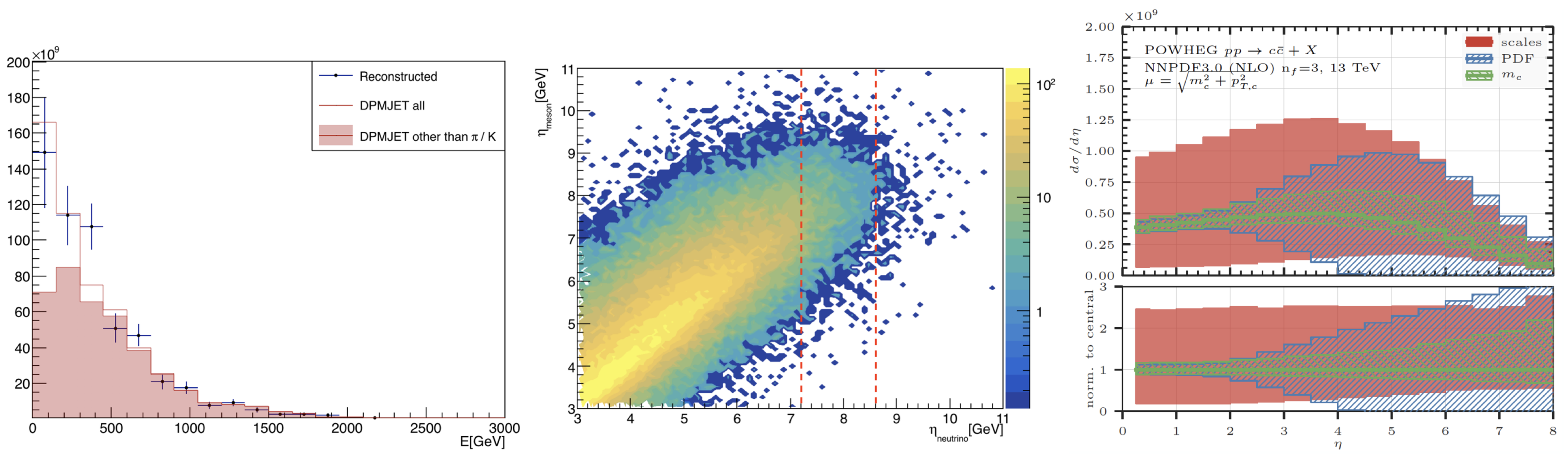
Table: Measurements proposed with Run 3 data.



ν flavour	CC neutrino interactions		NC neutrino interactions	
	$\langle E\rangle$ [GeV]	Yield	$\langle E\rangle$ [GeV]	Yield
ν_μ	450	730	480	220
$\bar{\nu}_\mu$	485	290	480	210
ν_e	760	235	720	70
$\bar{\nu}_e$	680	120	720	44
ν_τ	740	14	740	4
$\bar{\nu}_\tau$	740	6	740	2
TOT		1395		450

Table: CC and NC neutrino interactions in the detector target expected during Run 3.

Neutrino physics



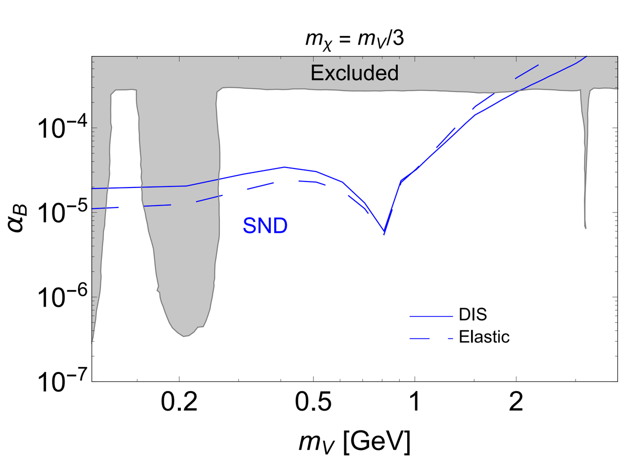
(1) (2) (3)

- **Measure charm production in pp collisions**
  (1) Reconstructed energy spectrum of $\nu_e/\bar{\nu}_e$ produced in the LHC pp interactions in SND@LHC acceptance compared with simulation → measurement of $pp \to \nu_e X$ cross section
  (2) Correlation in pseudo-rapidity between ν_e and the parent charmed hadron, and correlation in pseudo-rapidity of the parent charm and the charmed hadron → measurement of charm production in an unexplored pseudo-rapidity range (red lines)
  (3) Differential cross-section $d\sigma/d\eta$ for charm production at 13 TeV → charm quarks measurement will help reduced uncertainty on gluon PDF (highly dominant at high η).
- **ν_e/ν_τ and ν_e/ν_μ lepton flavour universality (LFU) test**
  - The location of SND@LHC gives access to ν_τ through the decays of D_s mesons. Assuming that ν_e and ν_τ come only from charmed hadrons decay → compute $\boldsymbol{\nu_e/\nu_\tau}$ with 30% uncertainty.
  - For E $\geq$ 600 GeV, contamination of ν_μ and $\bar{\nu}_\mu$ from pions/kaons is relatively uniform (35%) → compute $\boldsymbol{\nu_e/\nu_\mu}$ with 10% uncertainty.
- **First study of ν_τ physics**
- Measurement of the NC/CC ratio using all neutrino flavours as internal consistency check

Event reconstruction

- **Real-time:** identify neutrino candidates & reconstruct particle showers (target tracker); identify muon candidate (muon system); measure neutrino energy (target tracker + muon). Ongoing machine learning studies to drastically improve energy resolution, allowing e.g. to discriminate dark matter and neutrino scattering in real time!
- **Offline:** develop emulsion films and reconstruct neutrino vertex and secondary vertices; identify tau leptons. Match with electronic detectors to improve energy resolution.

Feebly Interacting Particles



model-independent search for light Dark Matter: recoil signature + time-of-flight to reject neutrino scattering background
good sensitivity in $\chi p \to \chi p$ processes
direct $\chi e \to \chi e$ search complementary to *missing energy* techniques as e.g. in NA64