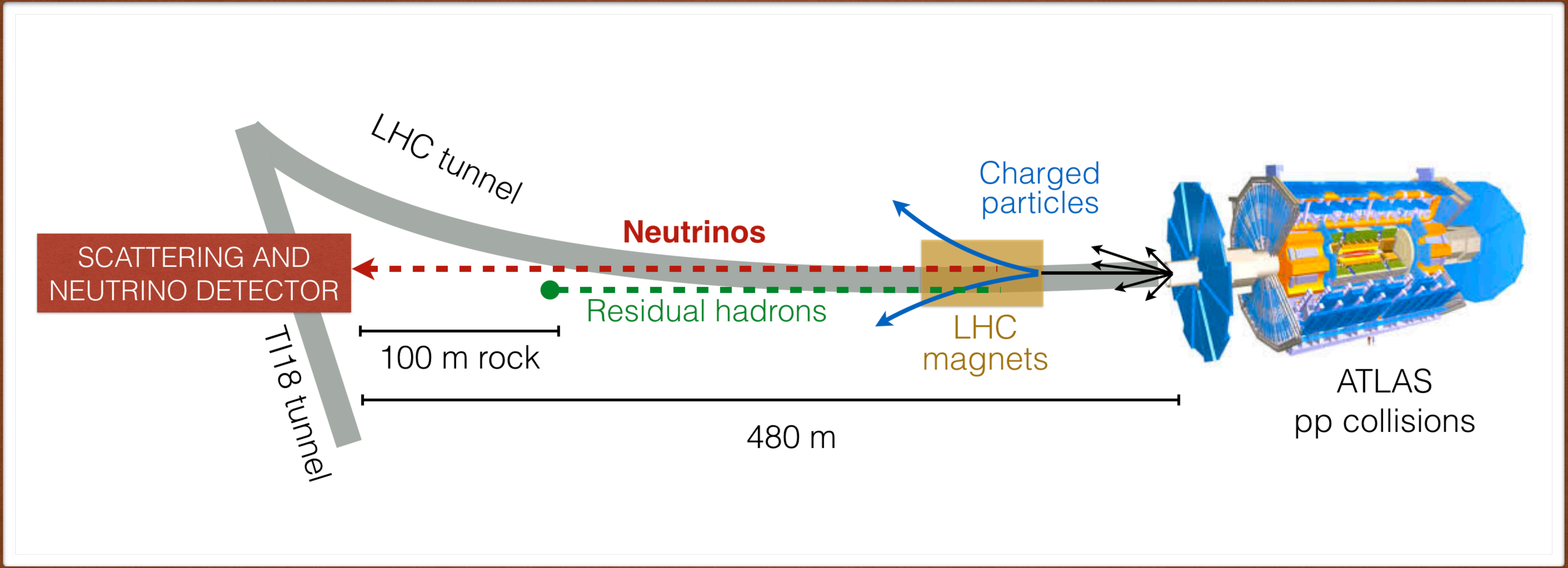
NEWS FROM SND@LHC

THE SCATTERING AND NEUTRINO DETECTOR AT THE LHC



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On behalf of the SND@LHC Collaboration

2nd Forward Physics Facility Meeting - 2021 May 27th

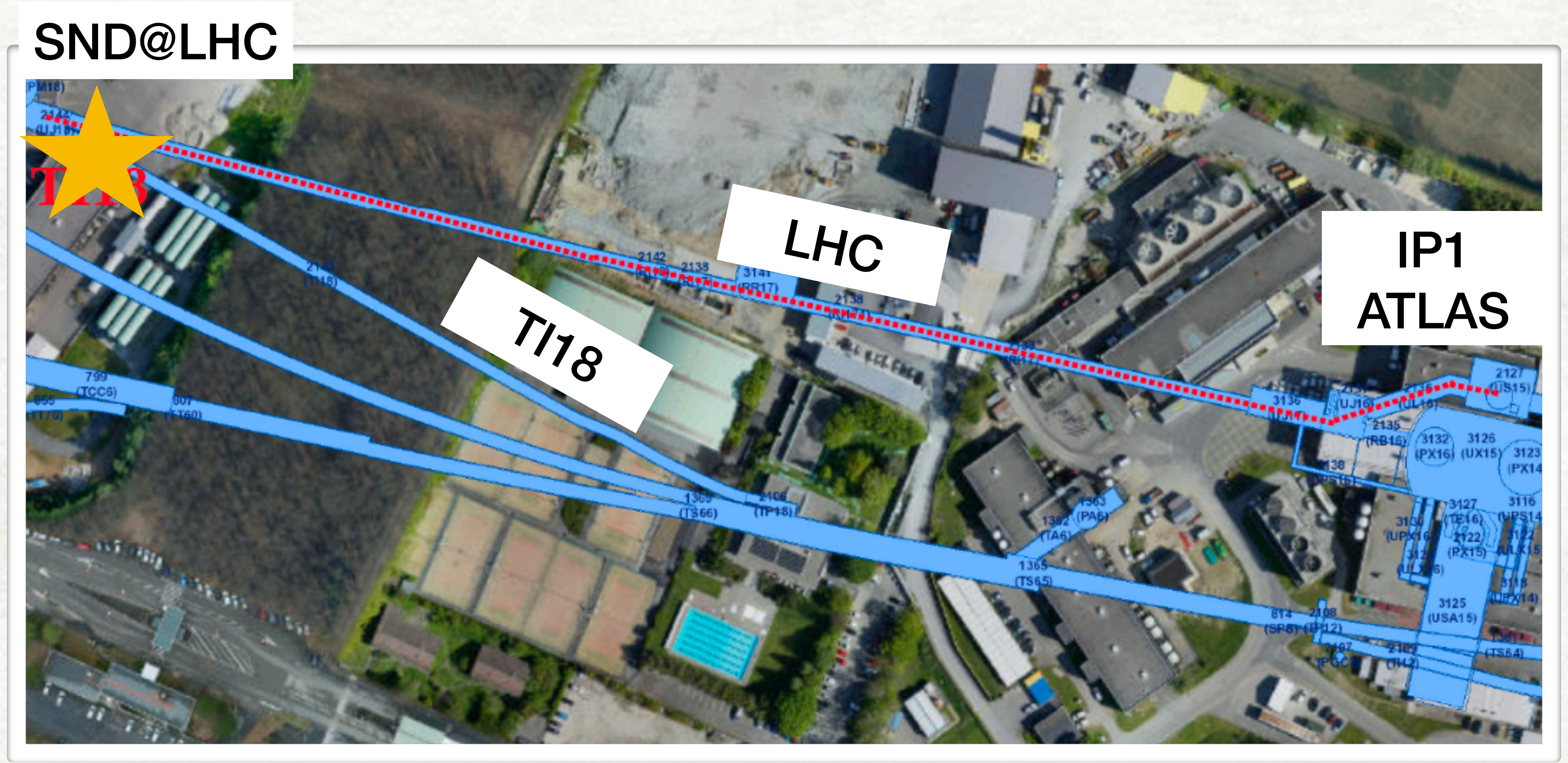
OVERVIEW

- The SND@LHC experiment
- Neutrino expectations
- Neutrino physics program
- Search for feebly interacting particles
- Outlook

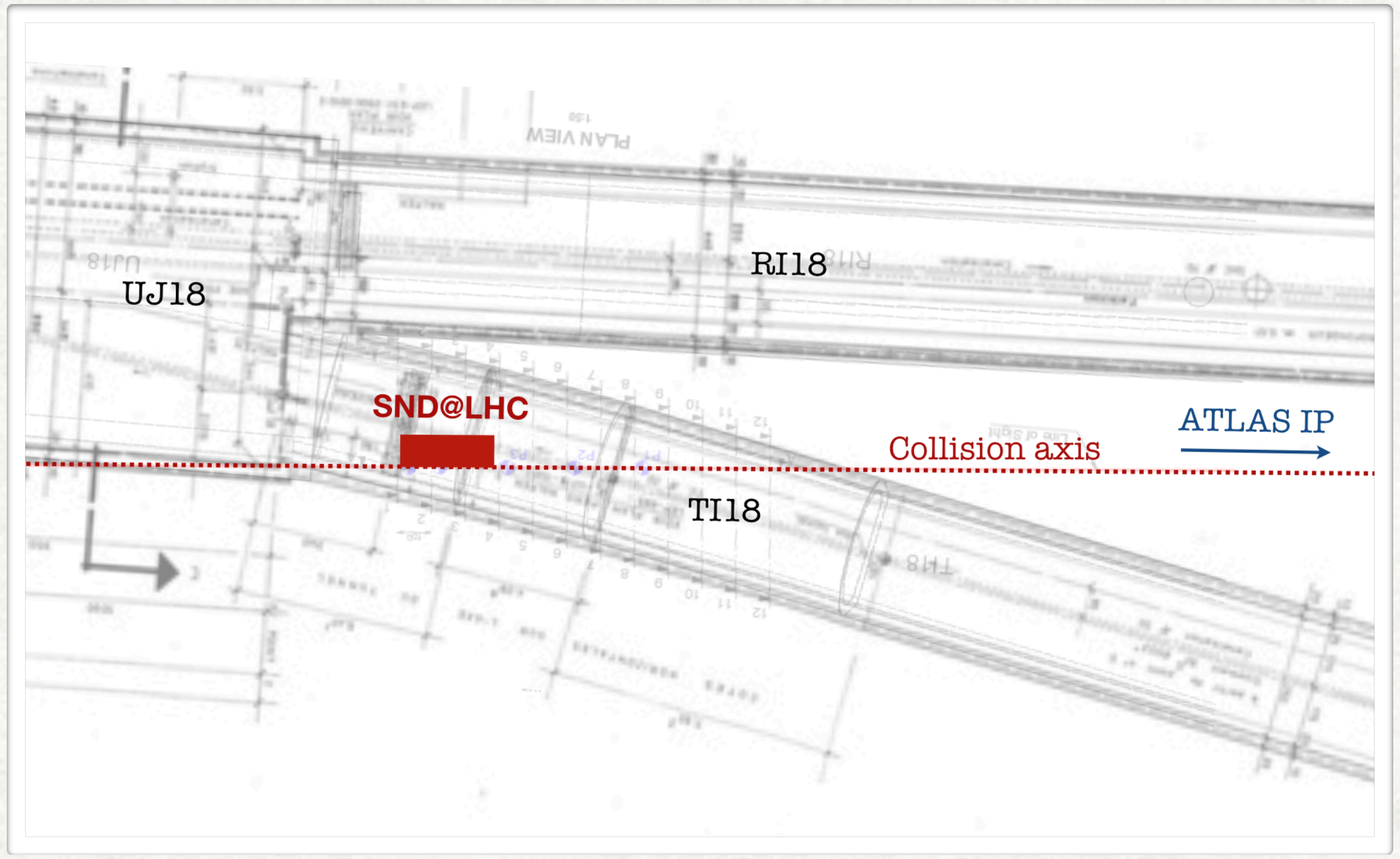
SND@LHC Technical Proposal
https://cds.cern.ch/record/2750060/files/LHCC-P-016.pdf

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}

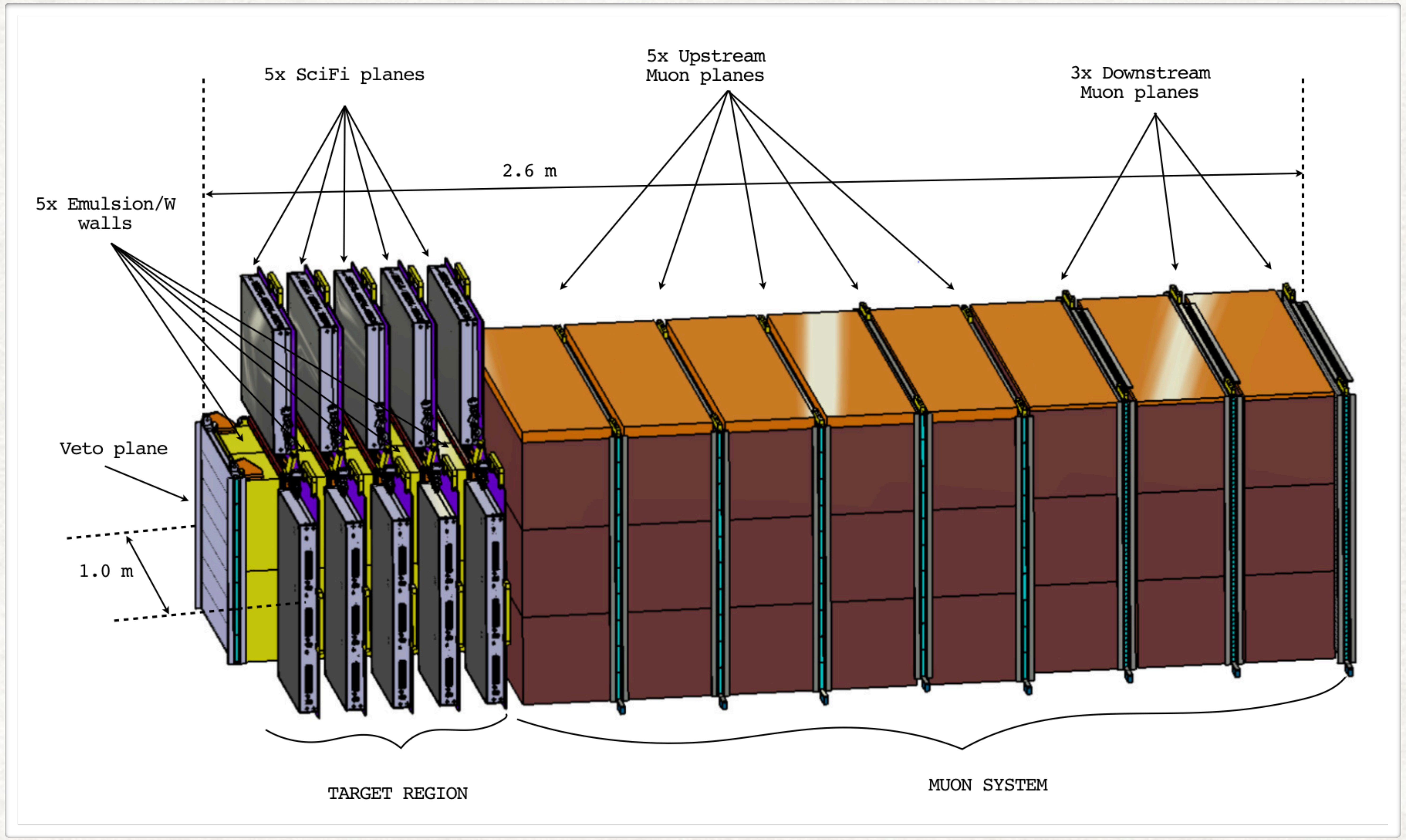
THE SND@LHC CONCEPT

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



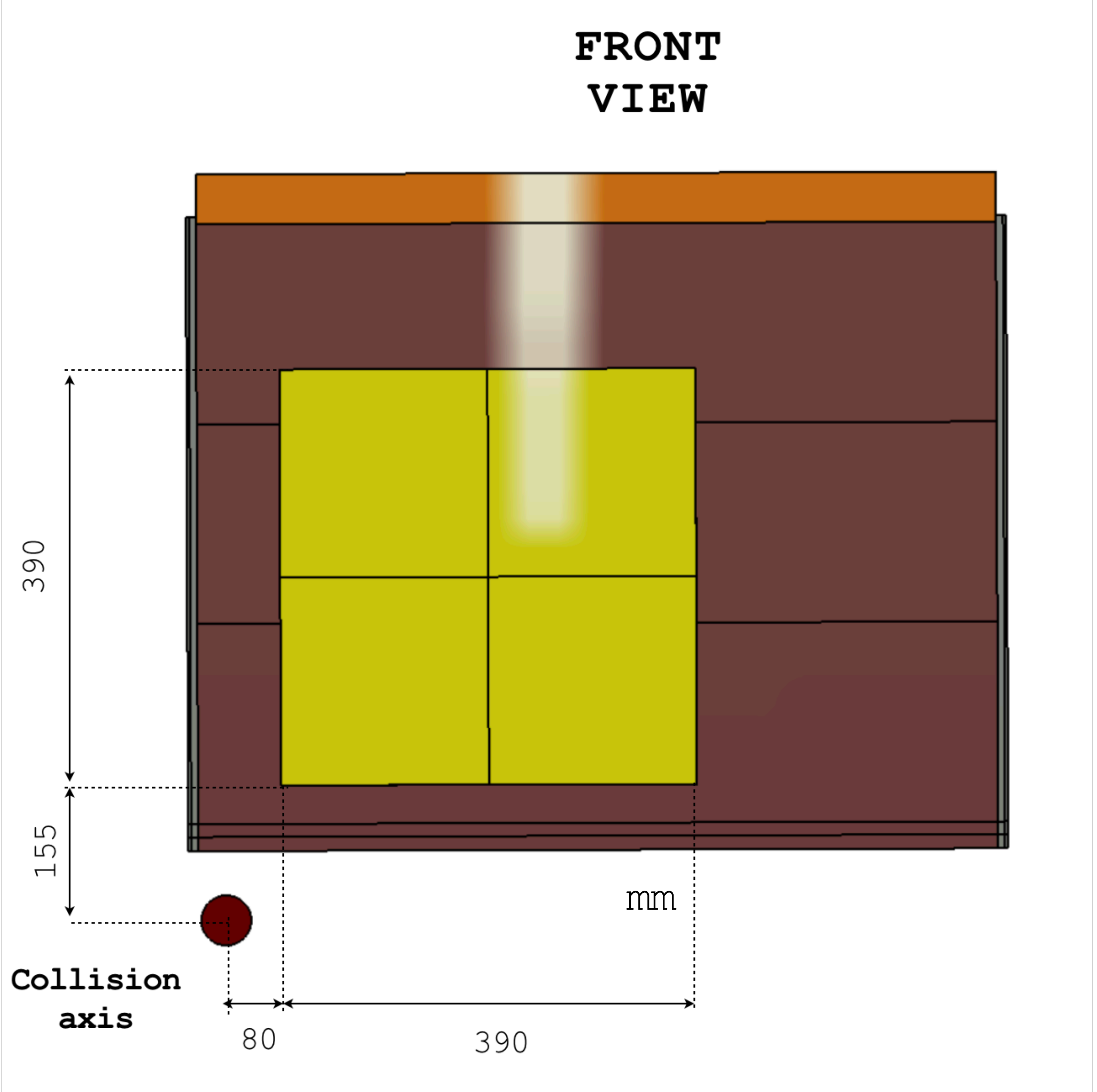
THE DETECTOR LAYOUT

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

Electromagnetic calorimeter
~40 X_0

Hadronic calorimeter
~10 λ

Off axis location



Veto plane for charged particles in front of the target region

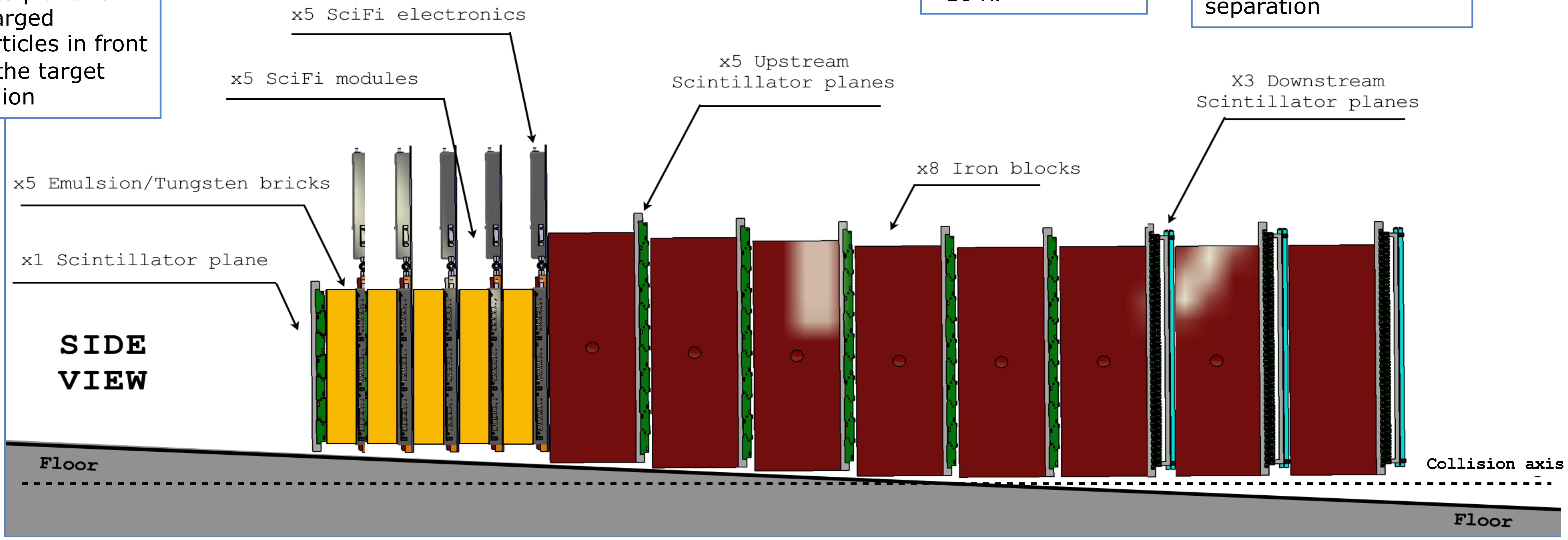
Emulsion Cloud Chamber, emulsion and W absorbers for micrometric accuracy in the detection of τ and FIPs, EM shower energy measurement.

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.

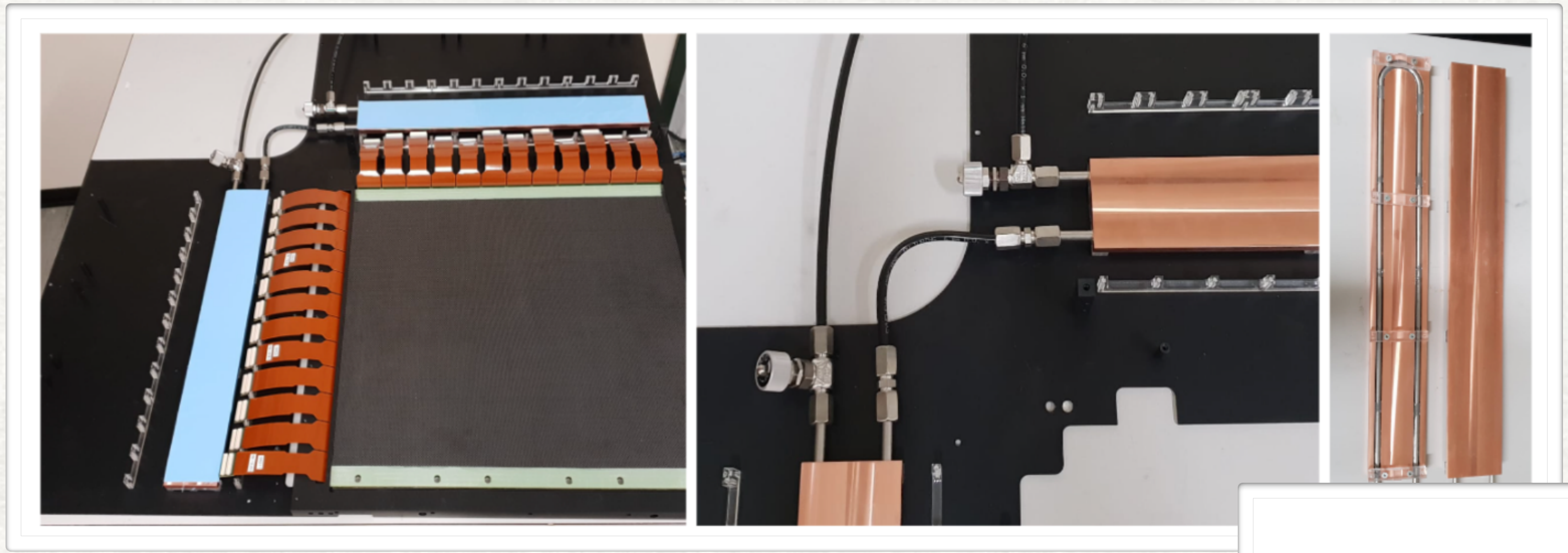
Muon system – hadronic calorimeter 8 λ, sampling every λ, with target region ~10 λ.

Timing upstream for the muon filtering

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

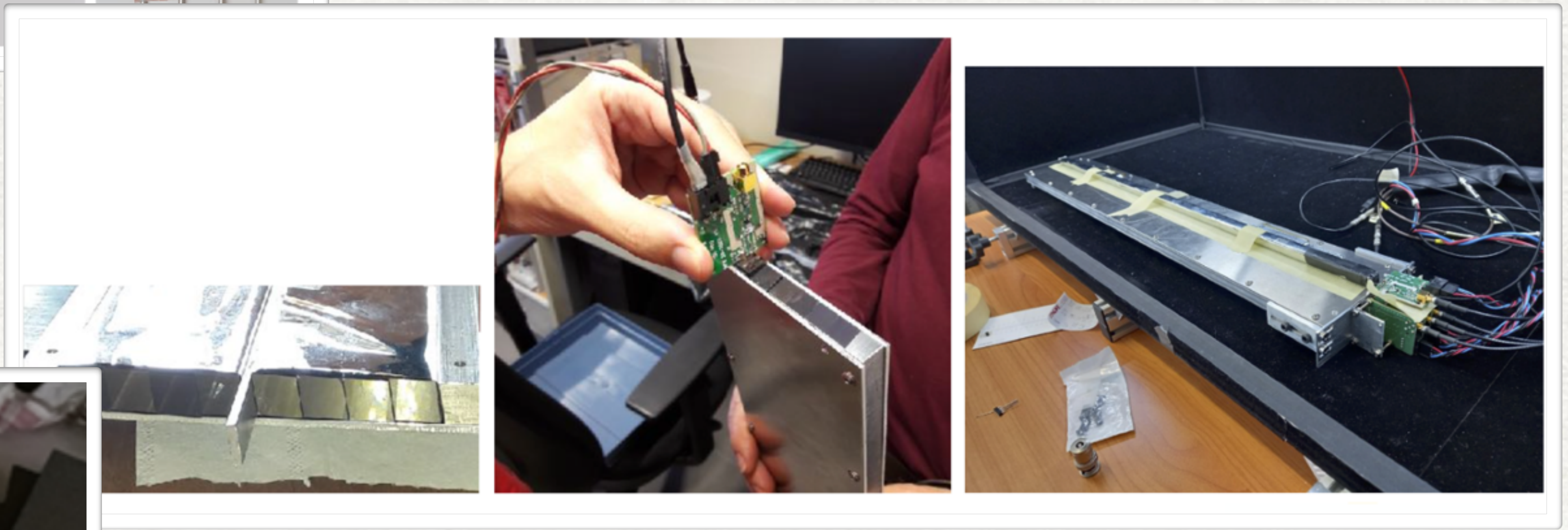


DETECTOR CONSTRUCTION



- Construction of SciFi planes @EPFL

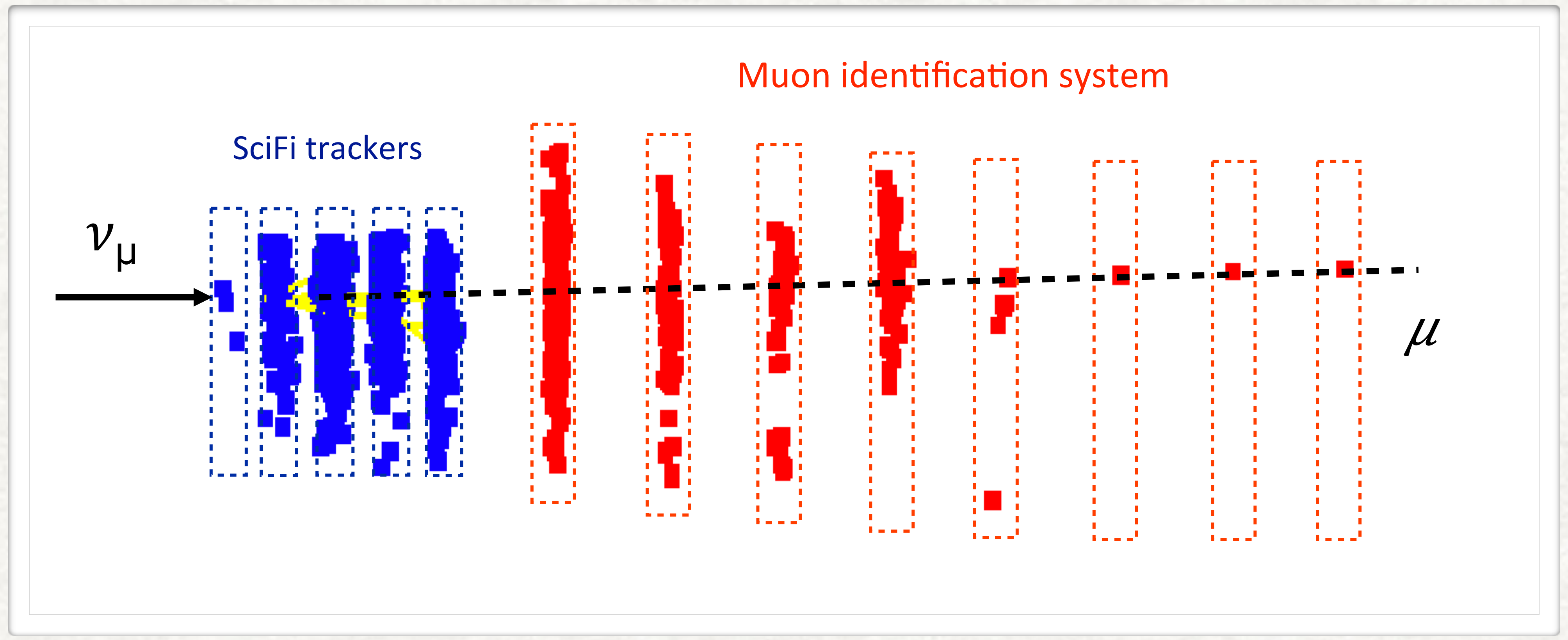
- Test of scintillator bars @Bologna



- Tungsten plates delivered @CERN

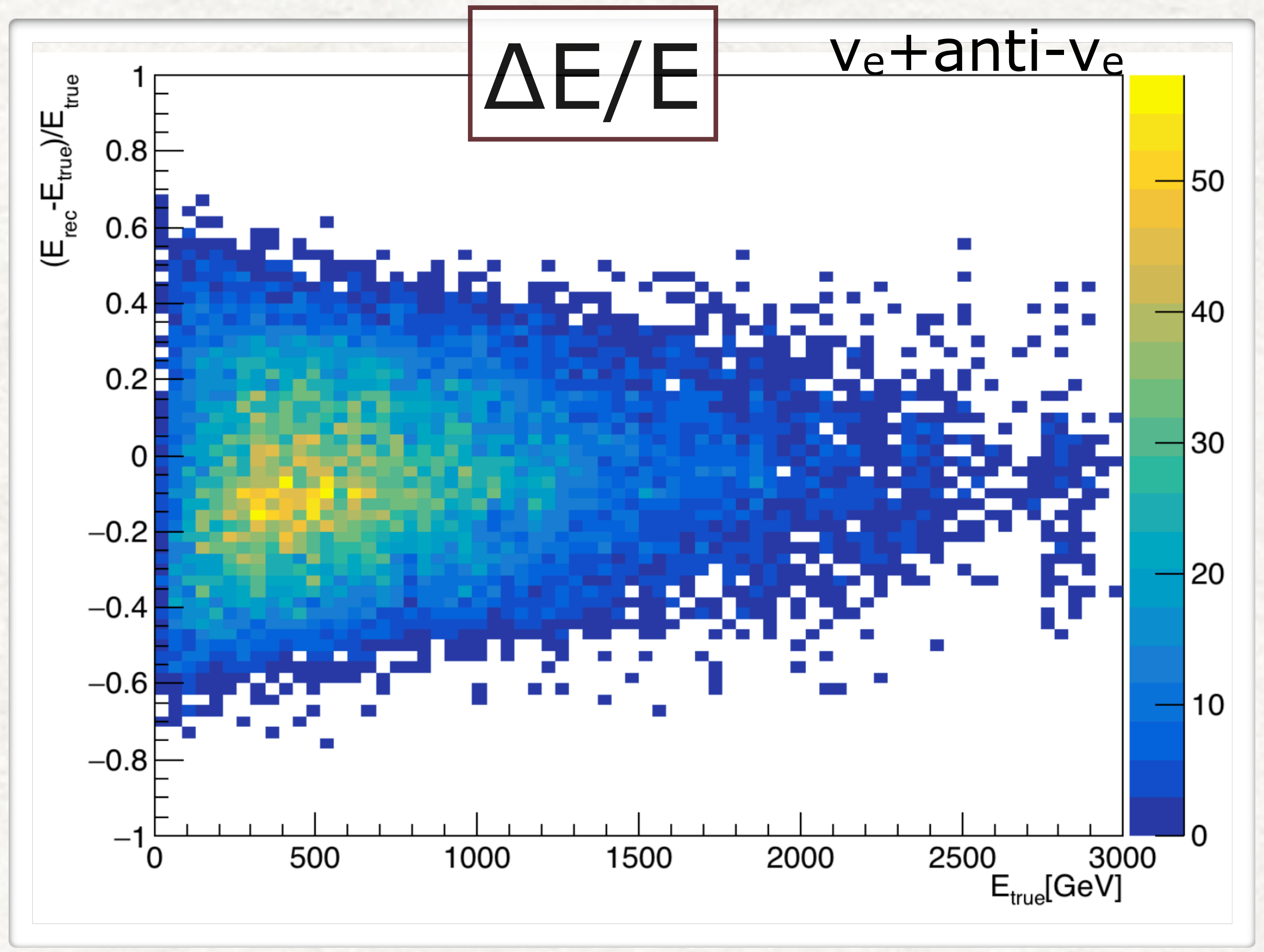
KEY FEATURES

- 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

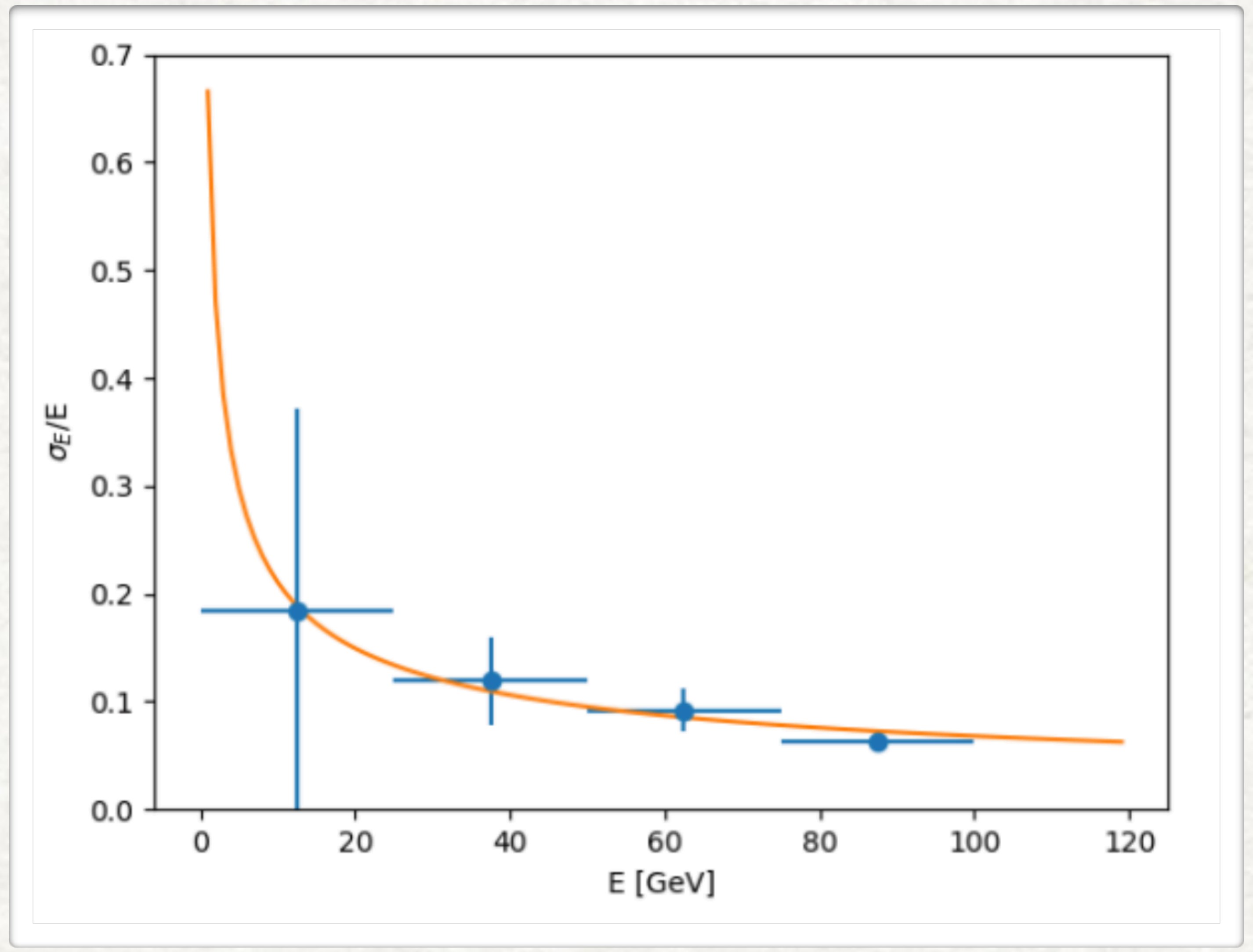


	% evts CC-DIS	% evts NC-DIS
0μ	31.1	99.6
1μ	67.6	0.27
2μ	1.1	0.06

- 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%

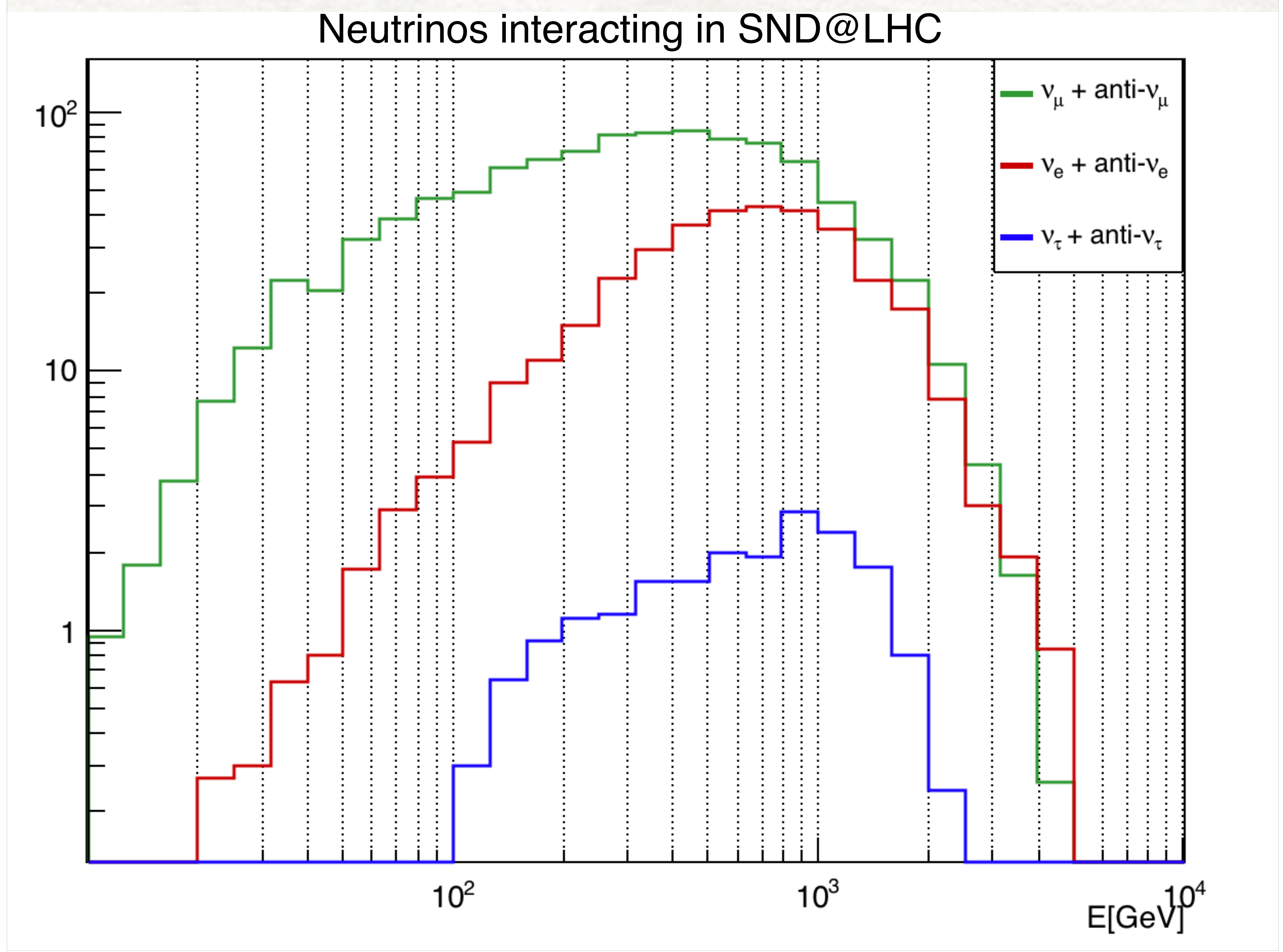


- Performance of SciFi tracker as sampling calorimeter, using a CNN
- Electron energy resolution

NEUTRINO EXPECTATIONS

- Expectations in 150 fb^{-1}
- Upward 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	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

NEUTRINO PHYSICS PROGRAM IN RUN 3

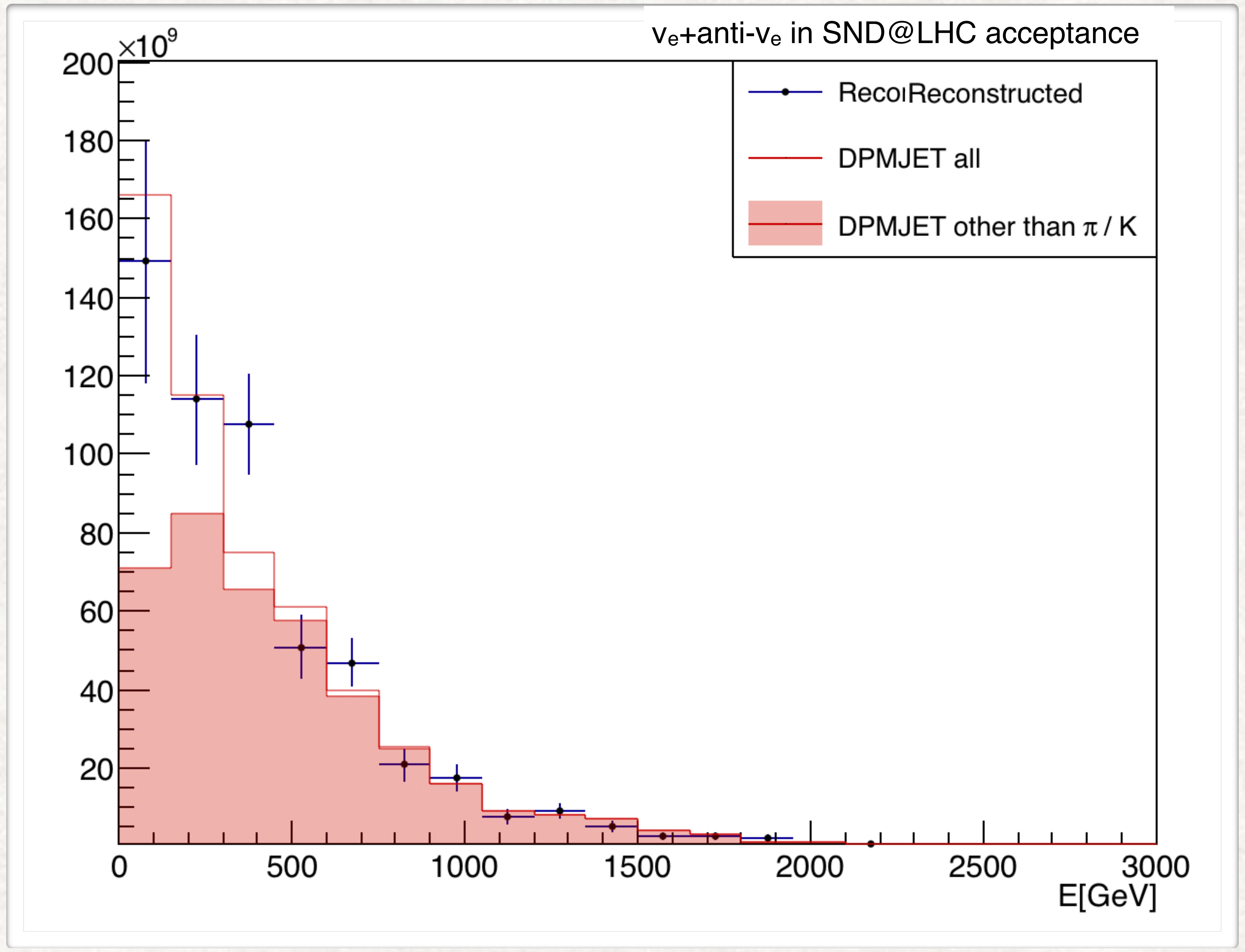
1. Measurement of the $pp \longrightarrow \nu_e X$ cross-section
2. Heavy flavour production in pp collisions
3. Lepton flavour universality in neutrino interactions
4. Measurement of the NC/CC ratio

1. MEASUREMENT OF *pp*→ν_eX CROSS-SECTION

2. CHARMED HADRON PRODUCTION

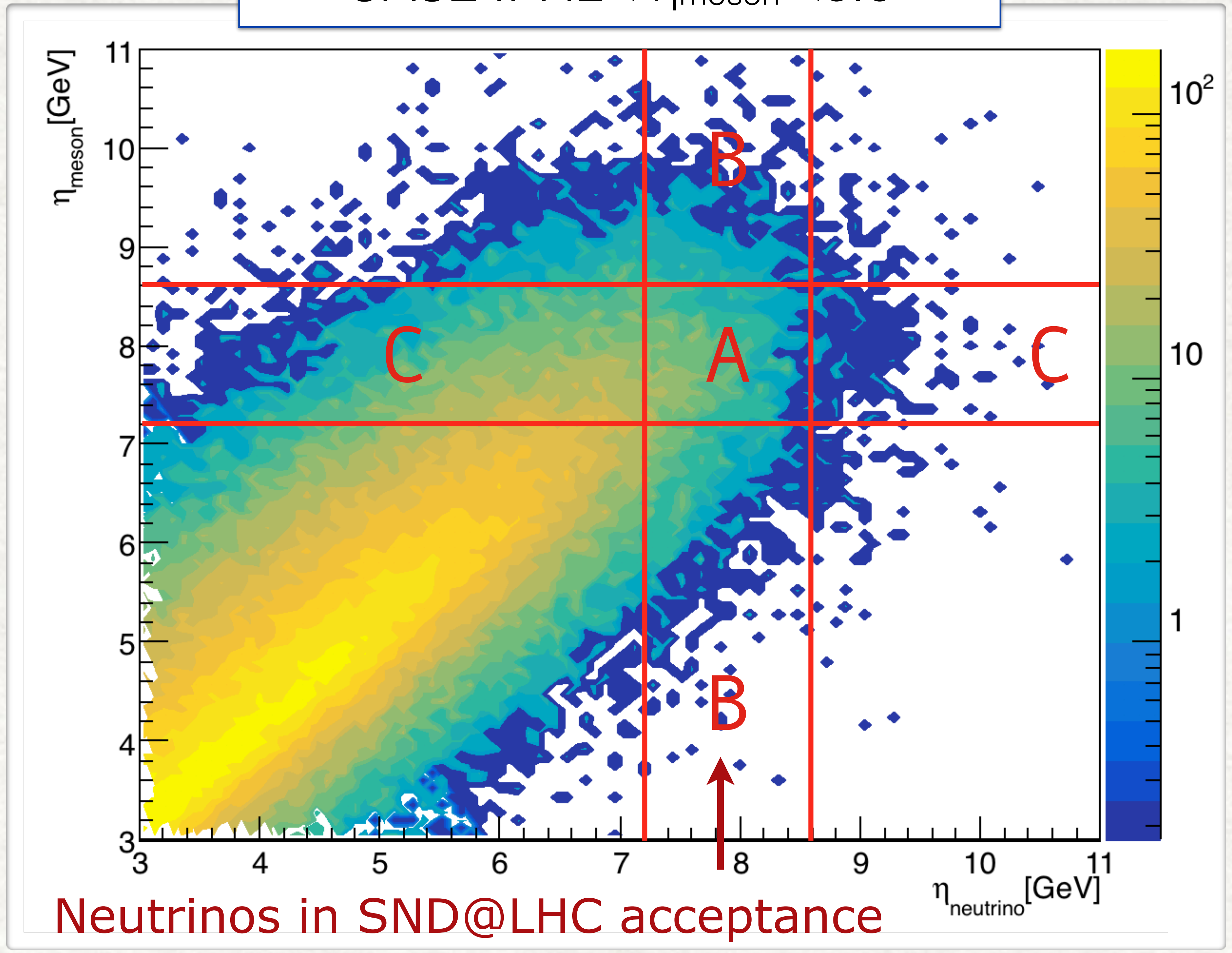
- Simulation predicts that 90% ν_e+anti-ν_e come from the decay of charmed hadrons
- Electron neutrinos can be used as a probe of the production of charm in the relevant pseudo-rapidity range after unfolding the instrumental effects

- 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

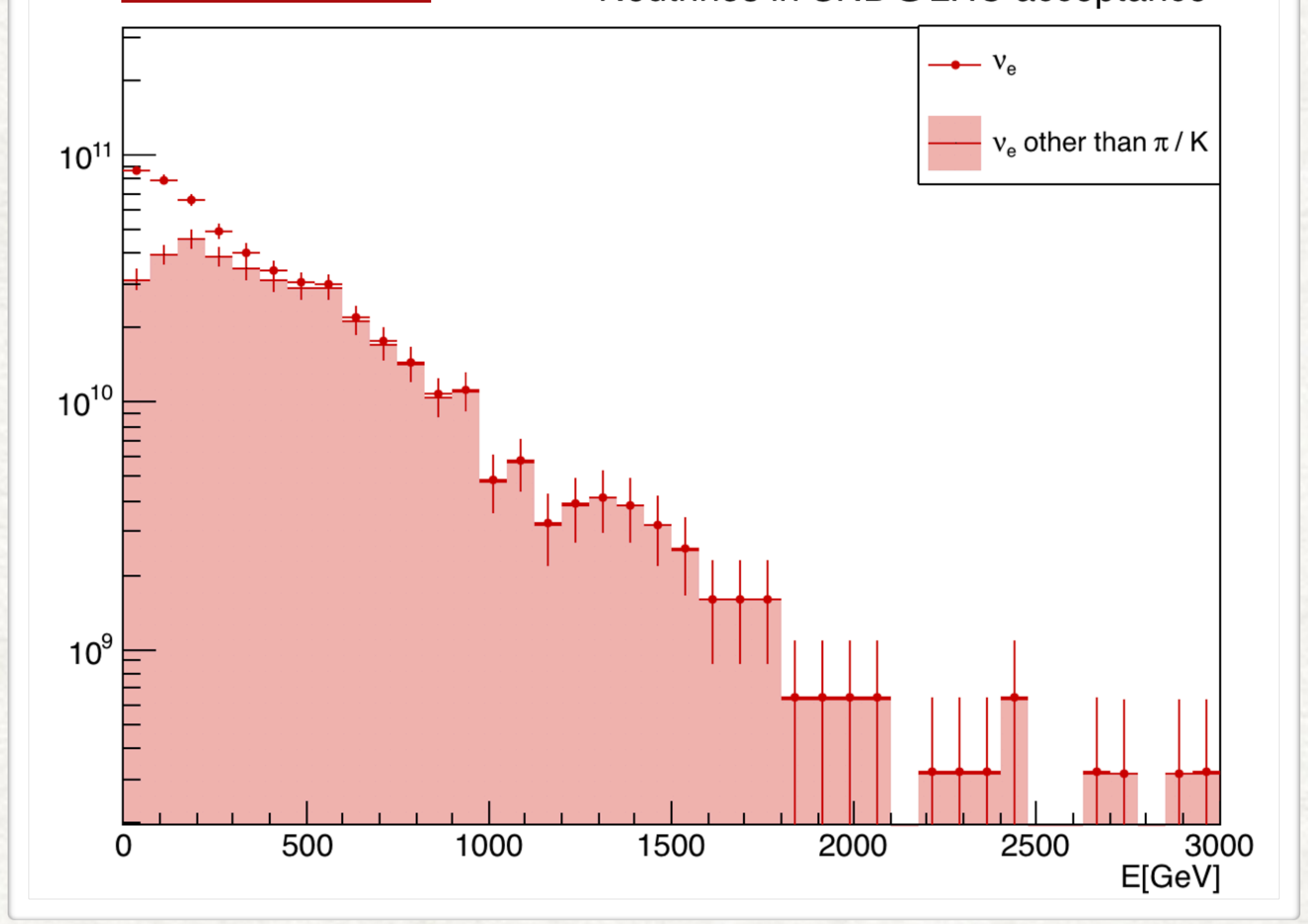
CASE I: 7.2< η_{meson} <8.6



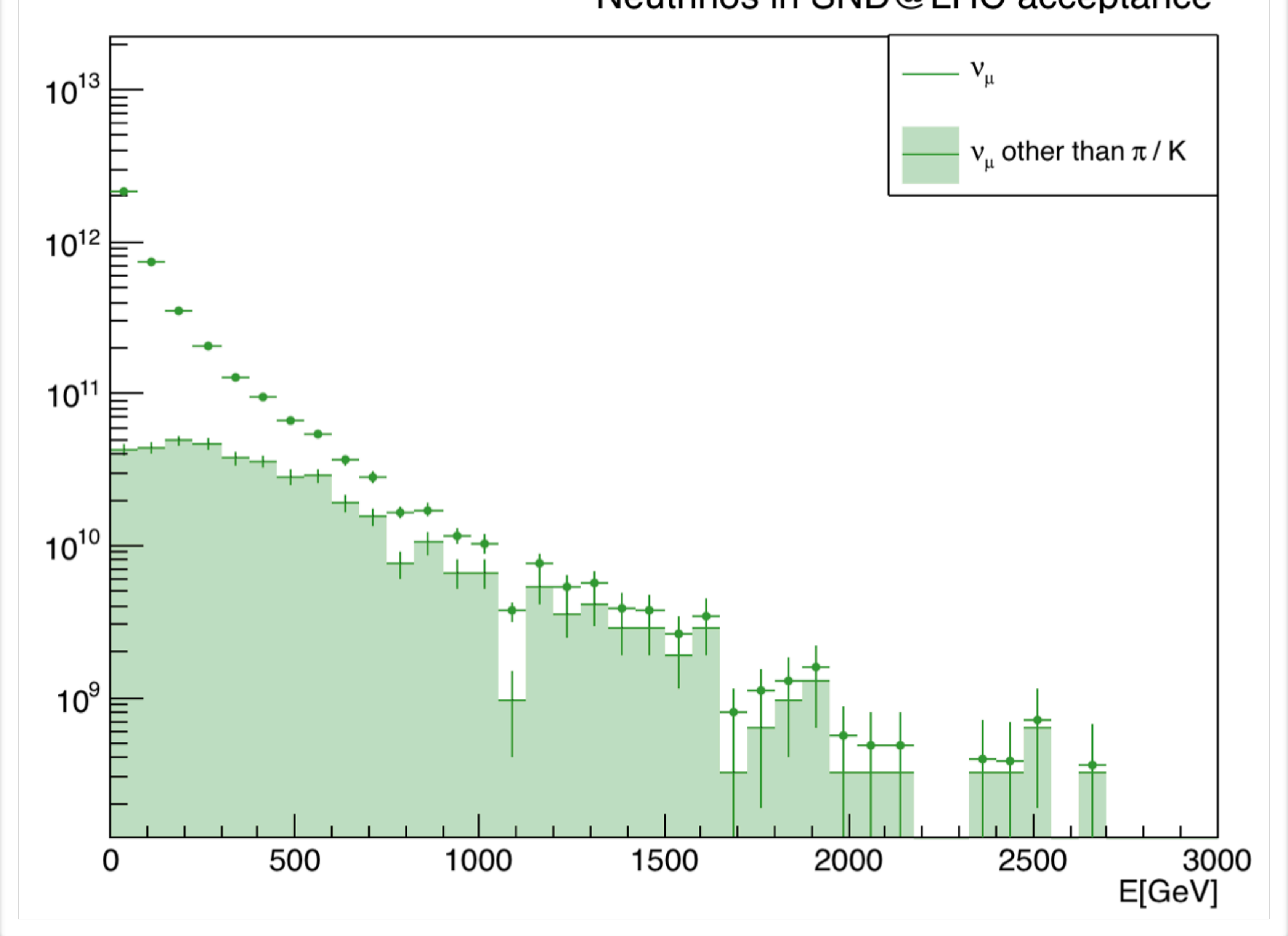
3. LEPTON FLAVOUR UNIVERSALITY TEST

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

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



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



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

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

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

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

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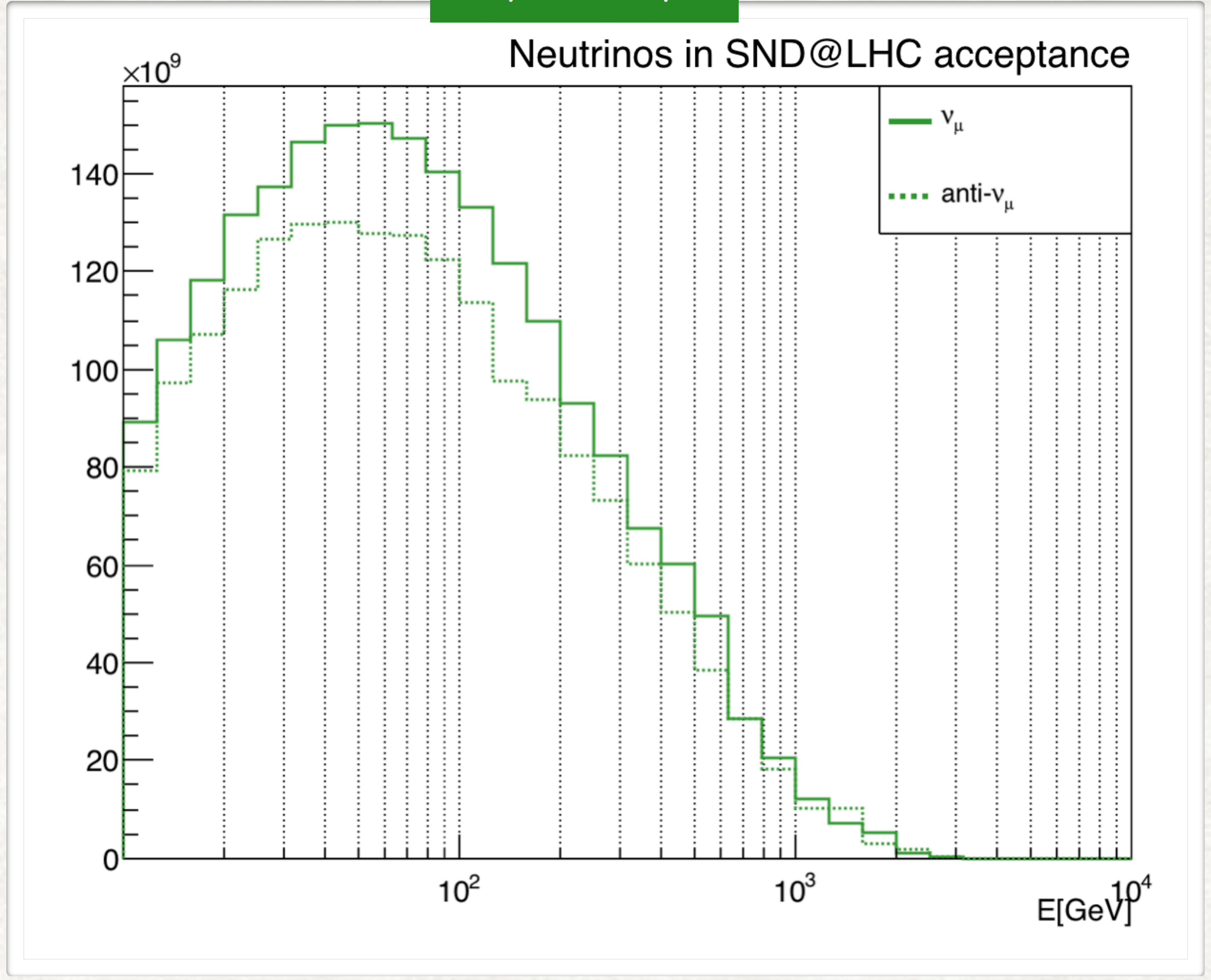
- P measurement used as an internal consistency check

ν_μ vs $\overline{\nu}_\mu$



NEUTRINO PHYSICS IN RUN 3

- Summary of SND@LHC performances

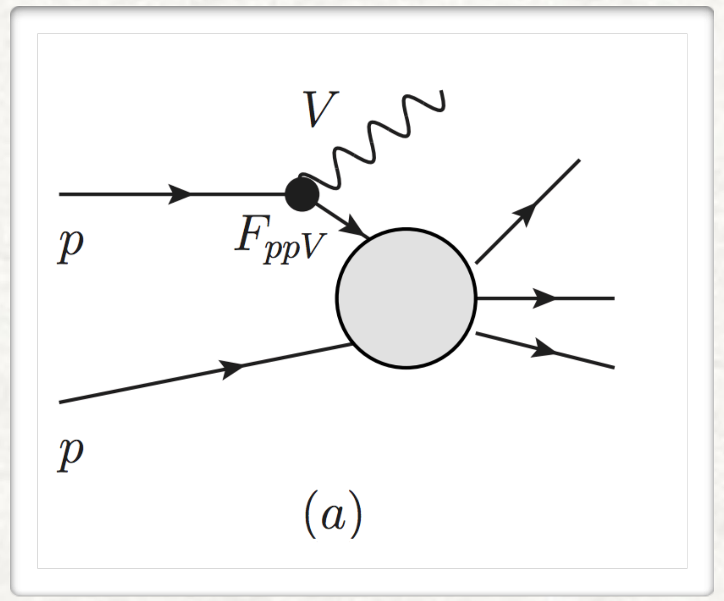
Measurement	Uncertainty Stat.	Uncertainty Sys.
$pp \to \nu_e X$ cross-section	5%	15%
Charmed hadron yield	5%	35%
ν_e/ν_τ ratio for LFU test	30%	20%
ν_e/ν_μ ratio for LFU test	10%	10%
Measurement of NC/CC ratio	5%	10%

FLEEBLY INTERACTING PARTICLES

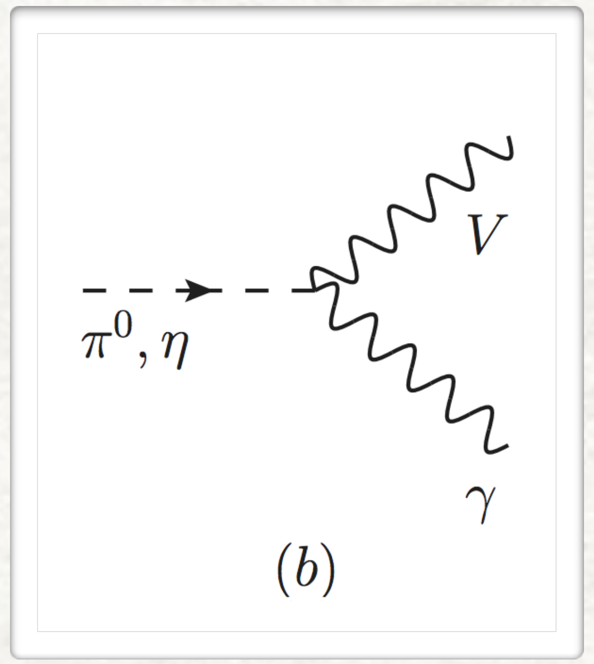
- SND@LHC experiment can explore a large variety of Beyond Standard Model (BSM) scenarios describing Hidden Sector

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

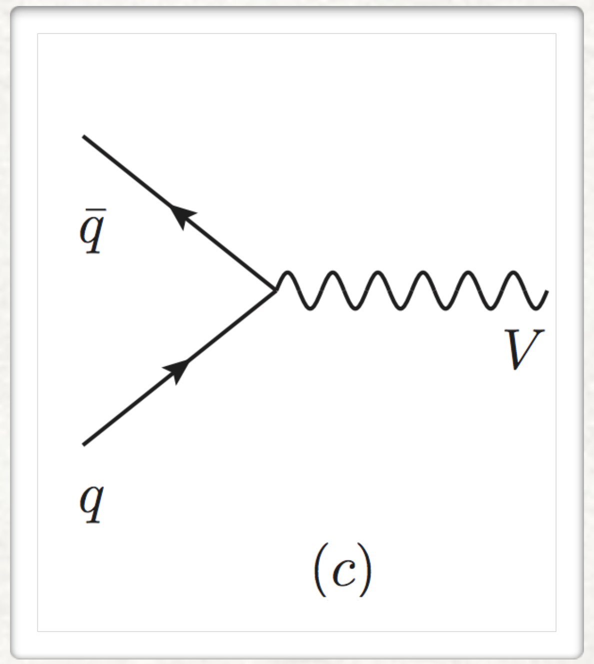
$$\mathcal{L}_{\text{leptophob}} = -g_B V^\mu J^B_\mu + g_B V^\mu (\partial_\mu \chi^\dagger \chi + \chi^\dagger \partial_\mu \chi),$$



Proton bremsstrahlung

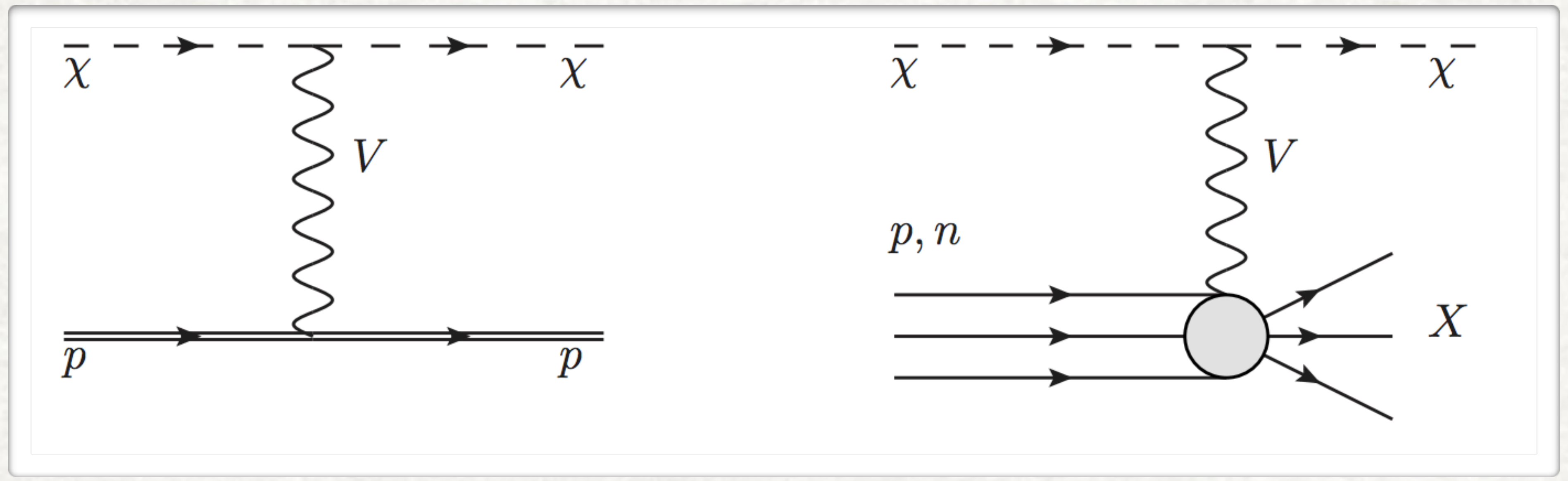


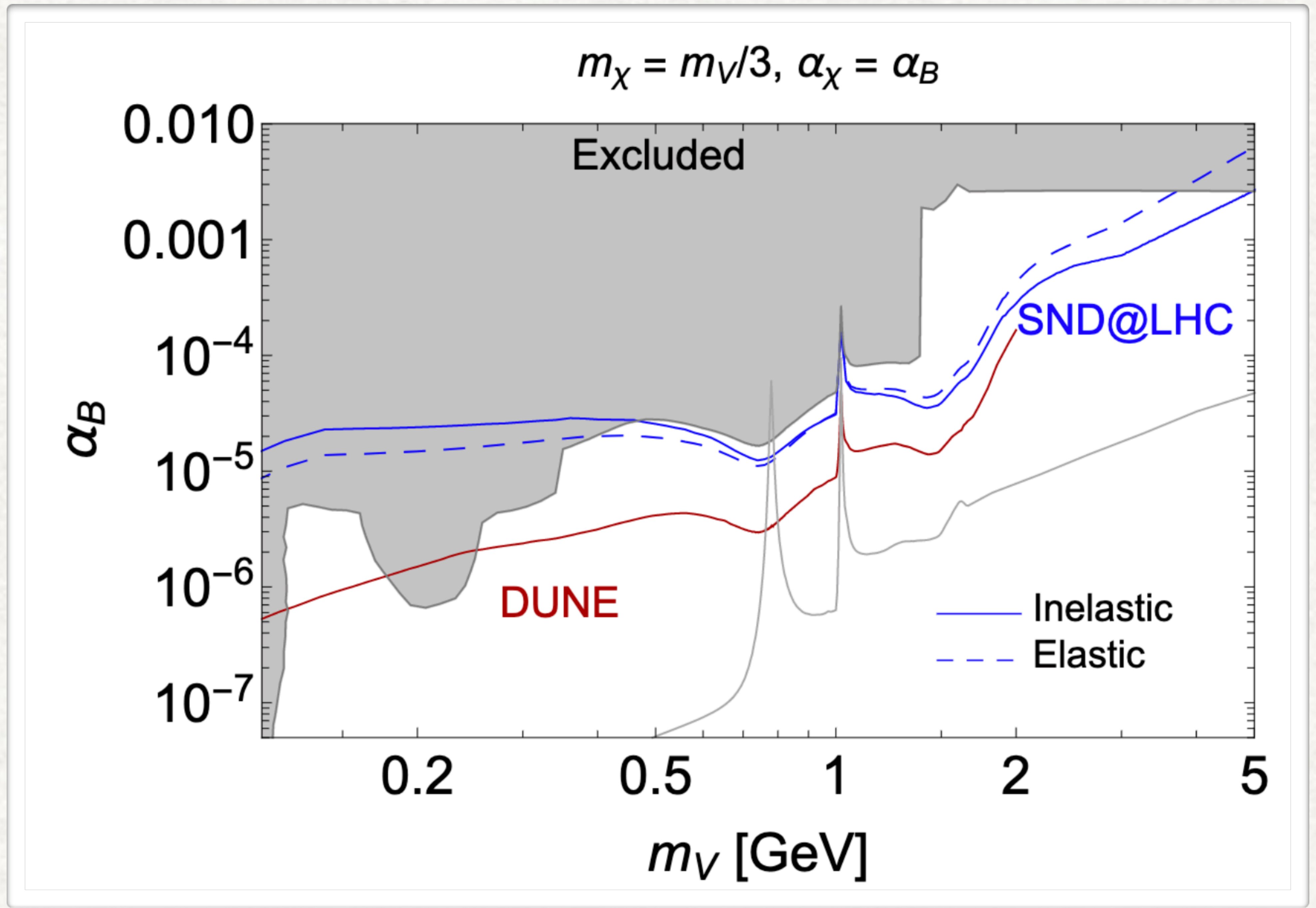
Meson decay



Drell-Yan process

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



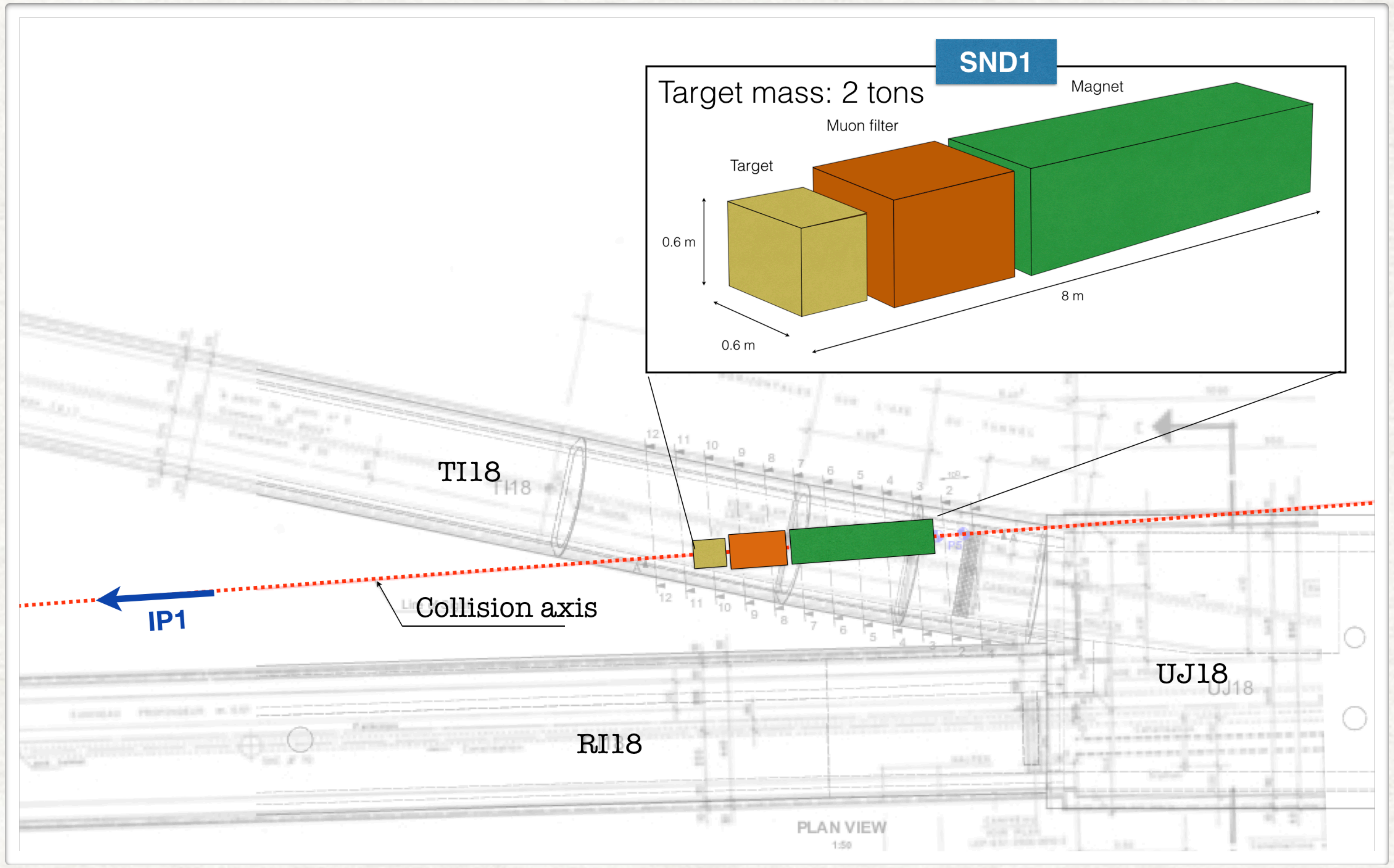


OUTLOOK

- Upgrade of the detector in view of an extended run during Run 4:
  - Magnetised region to measure charge of the muon (ν_μ/anti-ν_μ, ν_τ/anti-ν_τ in the $\tau \longrightarrow \mu$ channel)
  - Larger target region
  - Replace emulsions with electronic trackers

- Two off-axis forward detectors:
  - SND1: η~8
    Reduce systematic uncertainties
  - SND2: η~4.5
    Useful link to LHCb measurements
    High energy neutrino physics

- Shielded location is required



CONCLUSIONS

- SND@LHC is a recently approved experiment at CERN aiming at:
  - measuring neutrinos produced at the LHC in an unexplored pseudo-rapidity region
  - searching for feebly interacting particles
- 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