The SHiP scattering and neutrino detector (SND) operating at LHC

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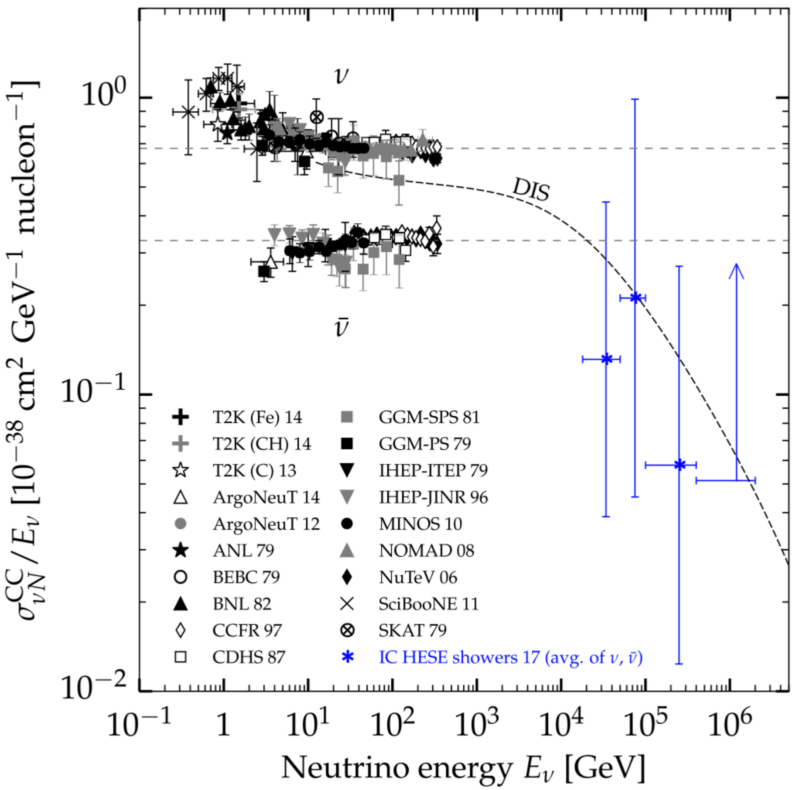
On behalf of the SHiP Collaboration

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 .

Bustamante and Connolly

PRL 122 (2019) 041101



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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

N Beni[1], M Brucoli[2], S Buontempo[5], V Cafaro[4], G M Dallavalle[4,8], S Danzeca[2], G De Lellis[2,3,5], A Di Crescenzo[3,5], V Giordano[4], C Guandalini[4], D Lazic[6], S Lo Meo[7], F L Navarria[4] and Z Szillasi[1,2]

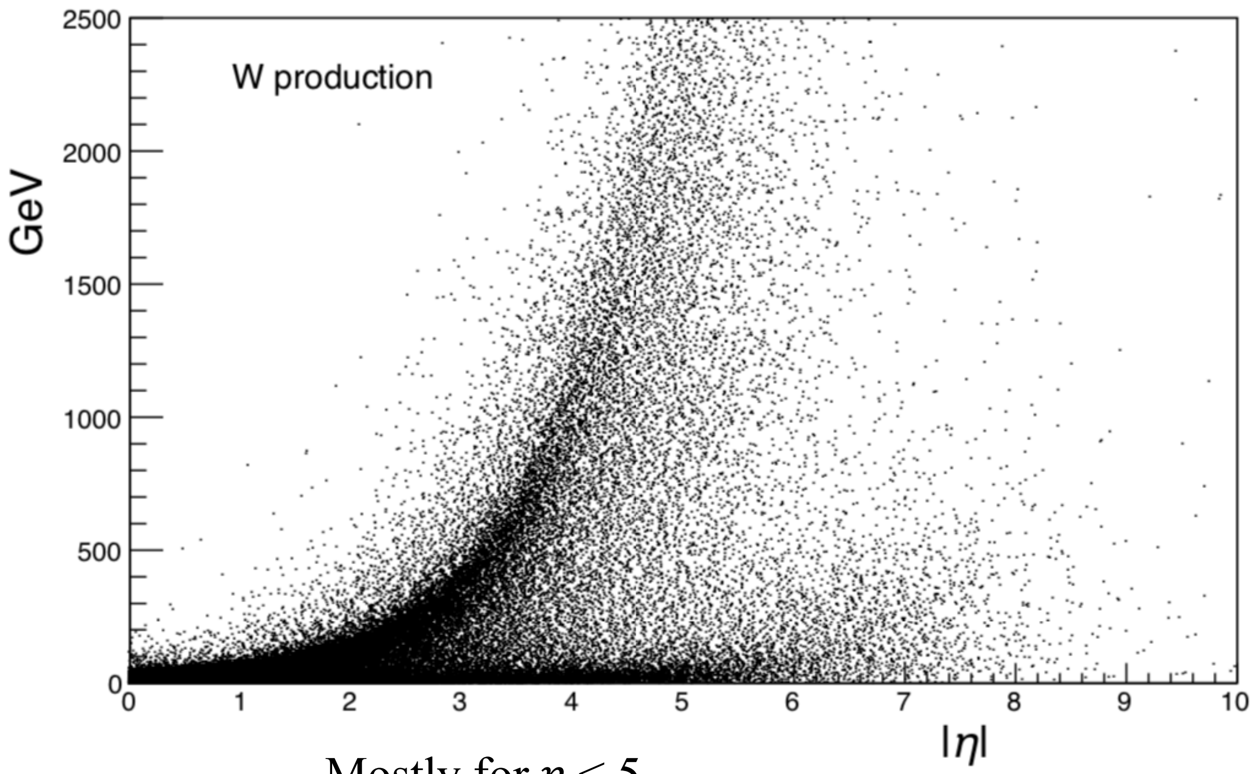
CERN is unique in providing energetic **ν** (from LHC)

→ measure pp → **ν** X in an unexplored domain

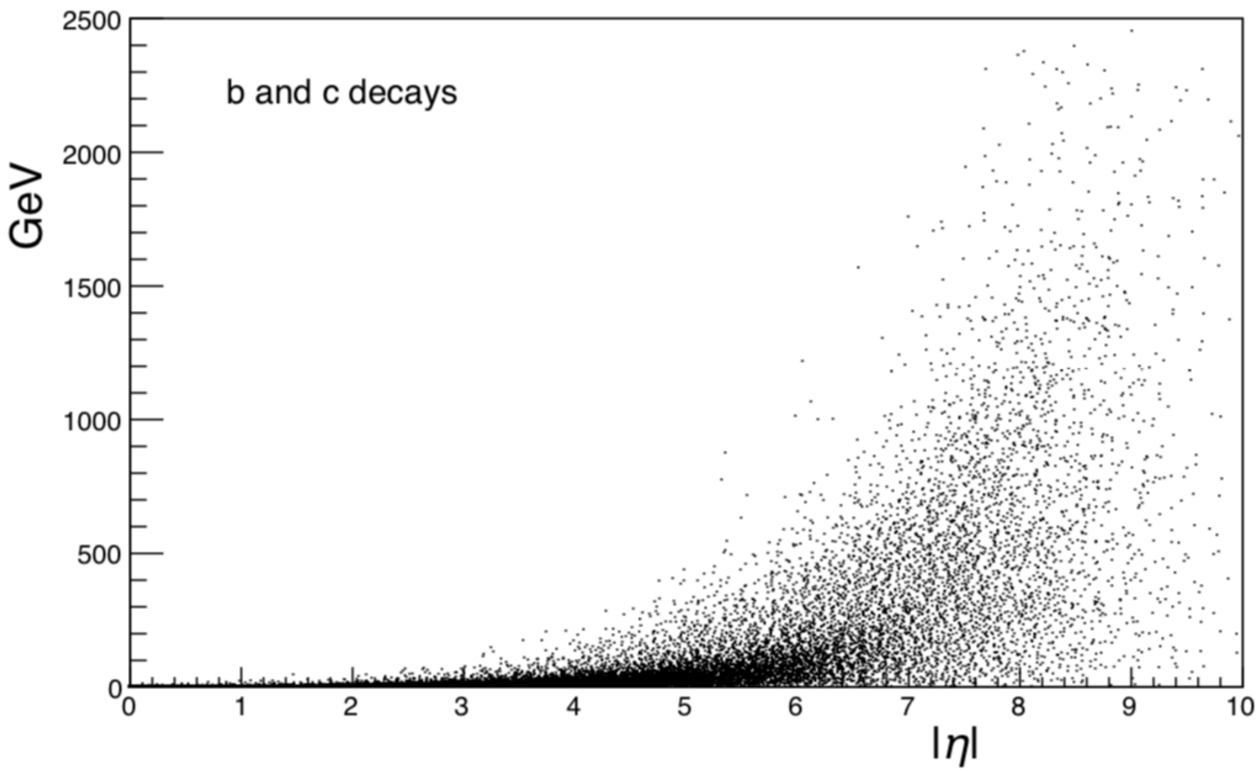
Neutrinos from W and b,c decays

Br (Tau neutrinos) ~ 33%

Tau neutrinos ~ 5% for $6.5 < \eta < 9$



Mostly for $\eta < 5$

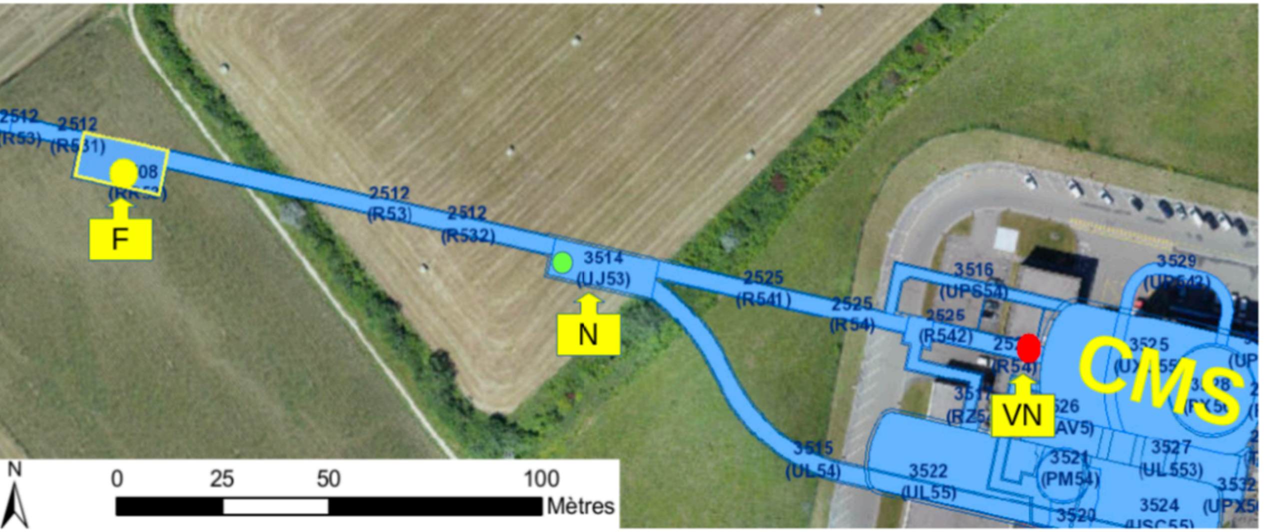


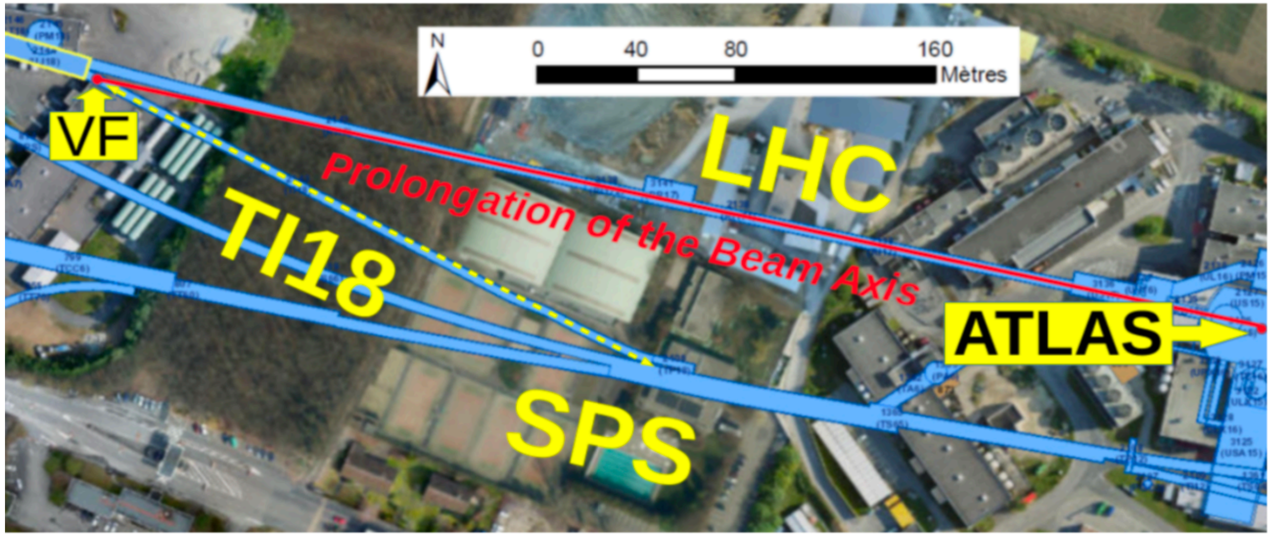
Also for $\eta > 6.5$

W decays could be tagged at IP detectors → tagging of the neutrino flavour → lepton flavour violation studies although with low statistics

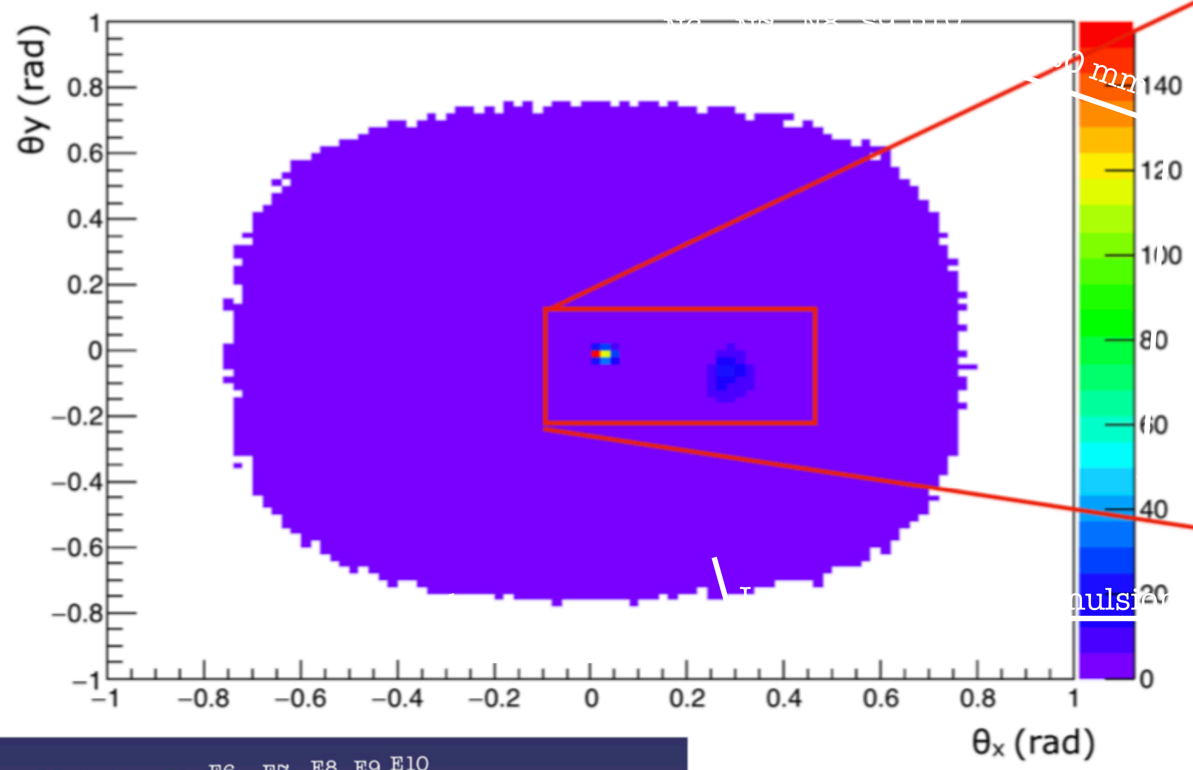
Investigating the background for a neutrino detector in different locations

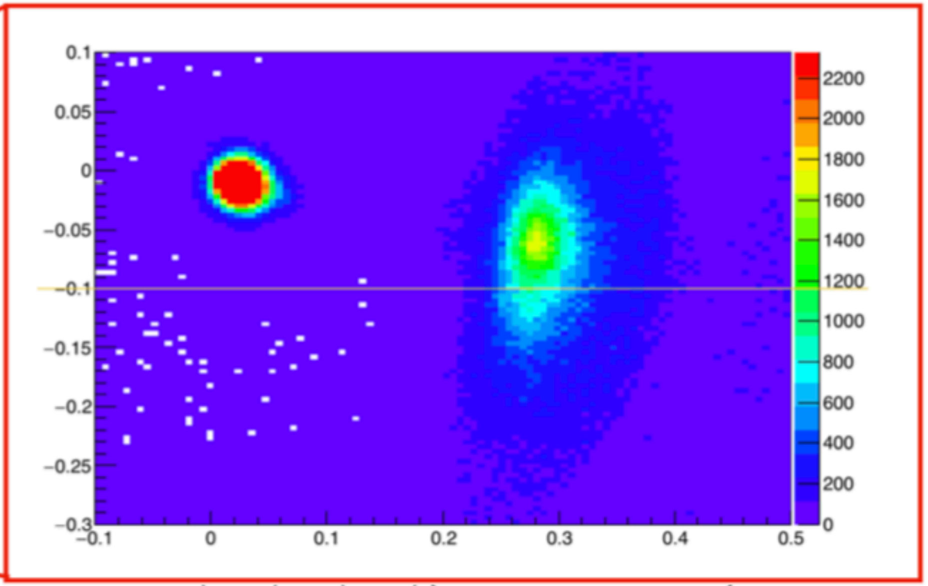
VN = Q1 in S45 at 25m
N = UJ53 and UJ57 at 90-120m
F = RR53 at 237m
VF = TI18 at 480m

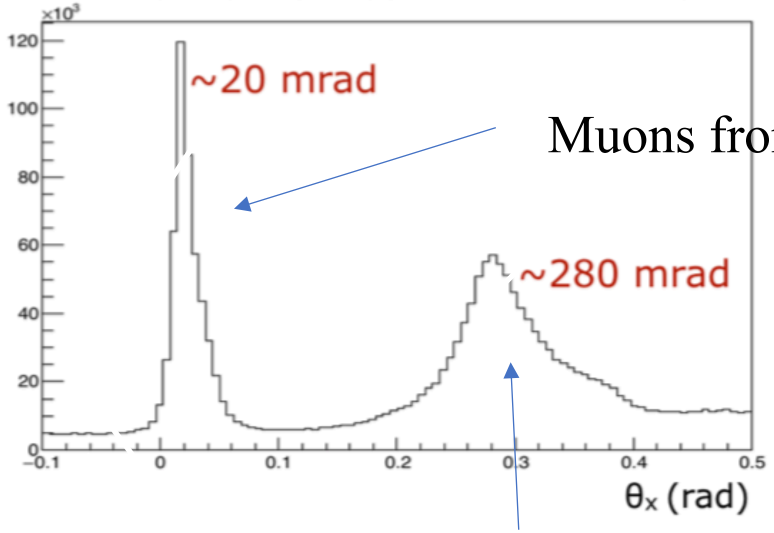




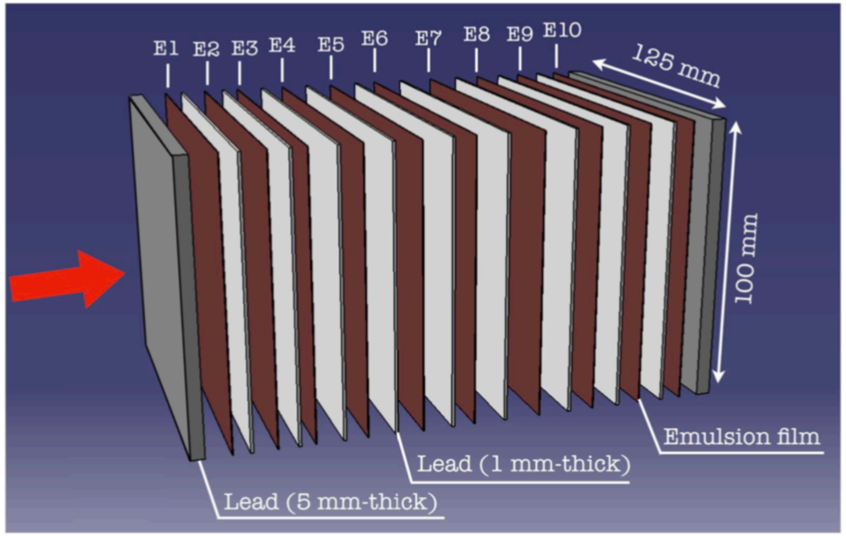
In situ measurements with an emulsion detector: e.g. at the F location







Muons from IP



MATERIALS

Lead, 5 mm-thick

Lead, 1 mm-thick

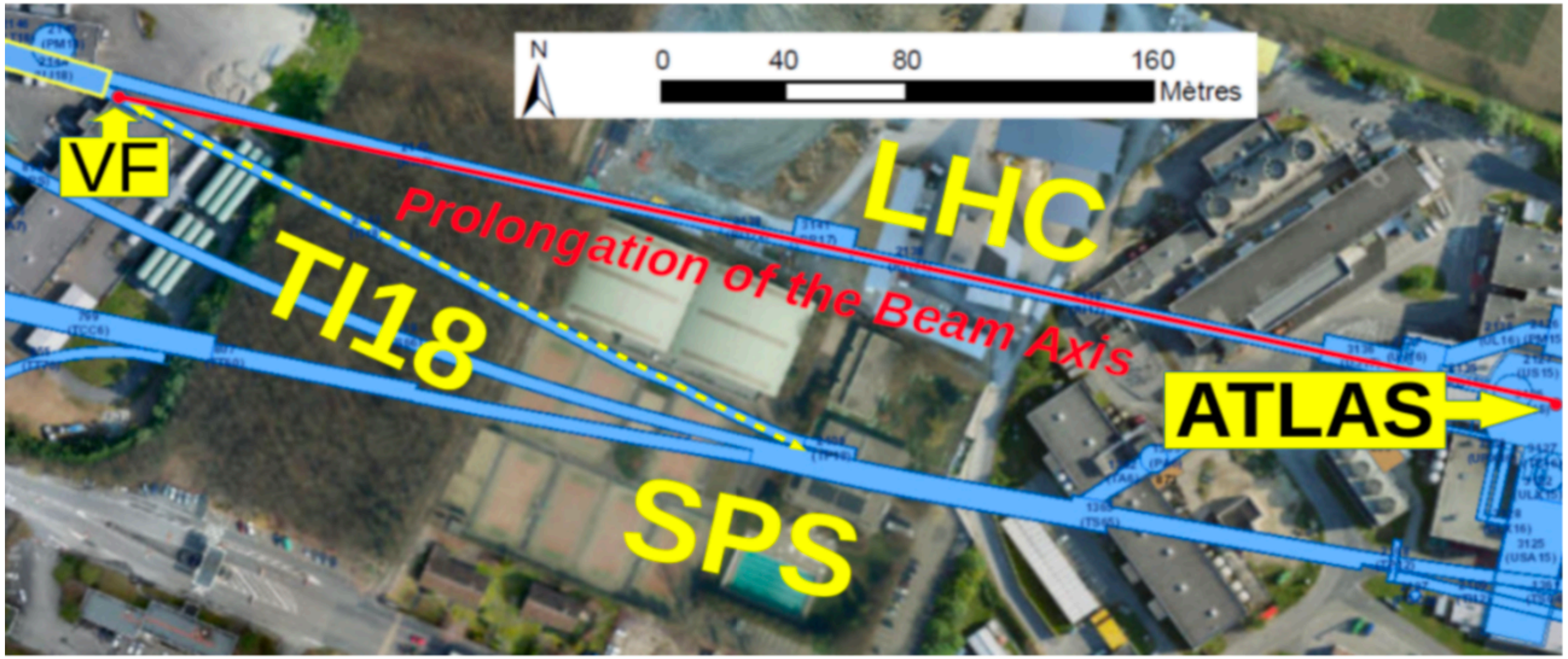
Emulsion film, 0.3 mm-thick

Muons from secondary interactions along the beamline nearest quadrupole magnet

In situ measurements

At the same time FASER inspected sites near IP1 and found that the decommissioned LEP injection tunnels are quite well protected (FASER TP, CERN LHC-2018-036, LHCC-P-013)

FASER installed in TI12 → TI18 available. It is symmetric to TI12 at opposite end of IP1 and in both areas the background is reduced due to LHC magnetic bend and the absorption in ~100 m of rock.

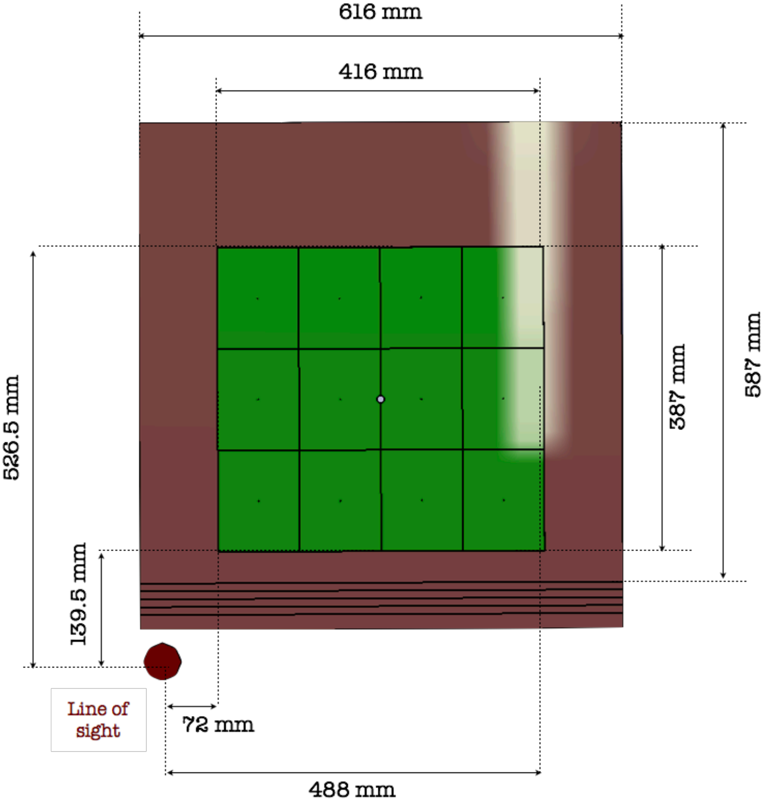


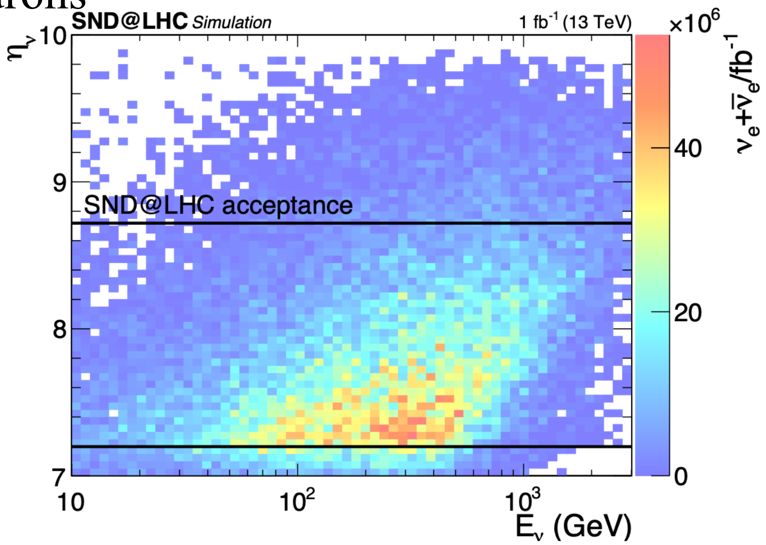
Physics perspective: neutrinos and QCD

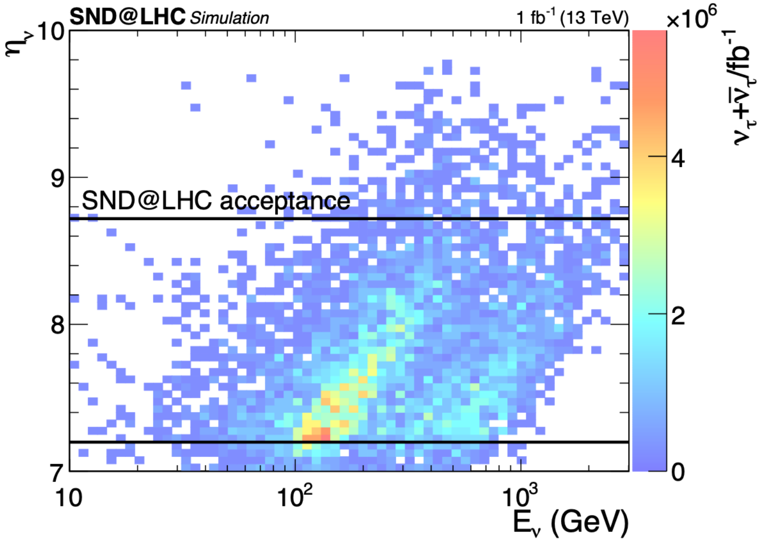
- pp → $\boldsymbol{\nu}$ X in the range $6.5 < \eta < 9$: neutrinos are mostly produced by charm decays in this angular range
- Prediction for (beauty and) charm yield at such small angles are affected by large uncertainties and unconstrained by measurements
- LHCb measurements covering larger (compared to ATLAS and CMS) η ranges but not to this extent
- Neutrino detection as a tool to measure heavy flavour production at very small angles (large η)→ important QCD task

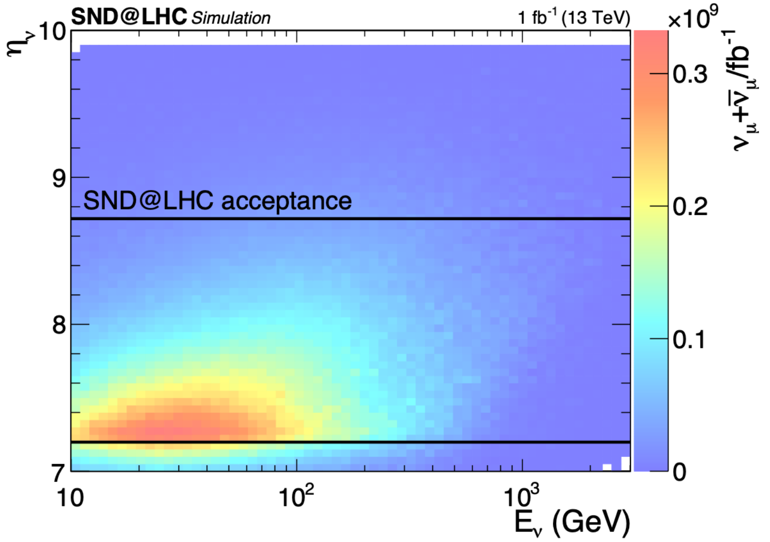
Flux of different neutrino types

- Transportation through machine elements and rock by Cerutti's group using FLUKA
- In the η region covered by the detector ($7.2 < \eta < 8.7$):
  - ν_e and ν_τ mainly from the decay of charmed hadrons
  - Soft ν_μ component produced by π and K decays



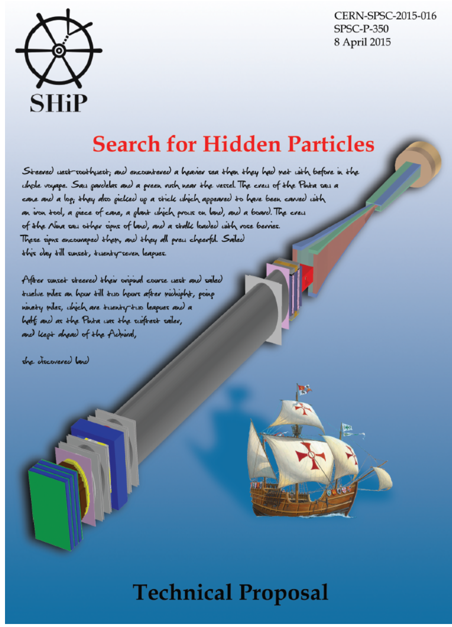




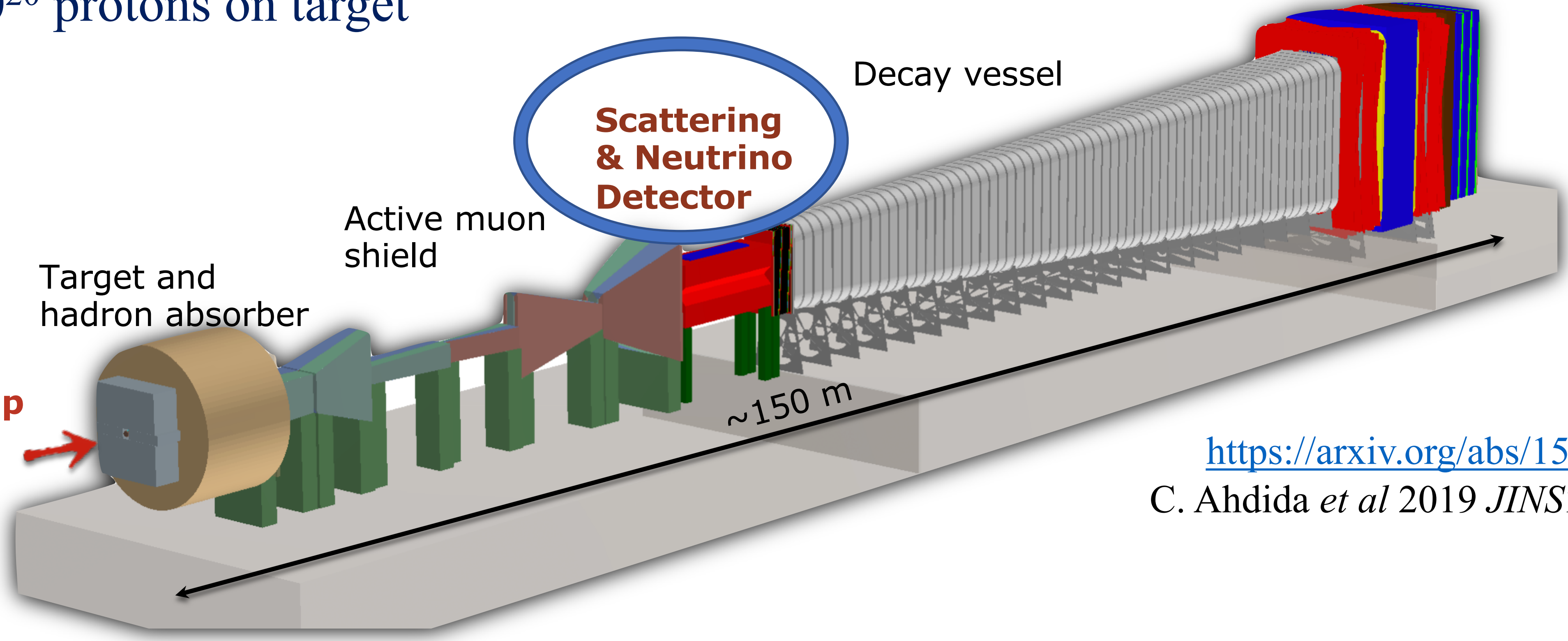


The SHiP experiment at the Beam Dump Facility

- Designed for **large acceptance** and **zero background**
- Wide physics program
  - Variety of possible decay modes
  - Tau-neutrino physics
  - Light Dark Matter



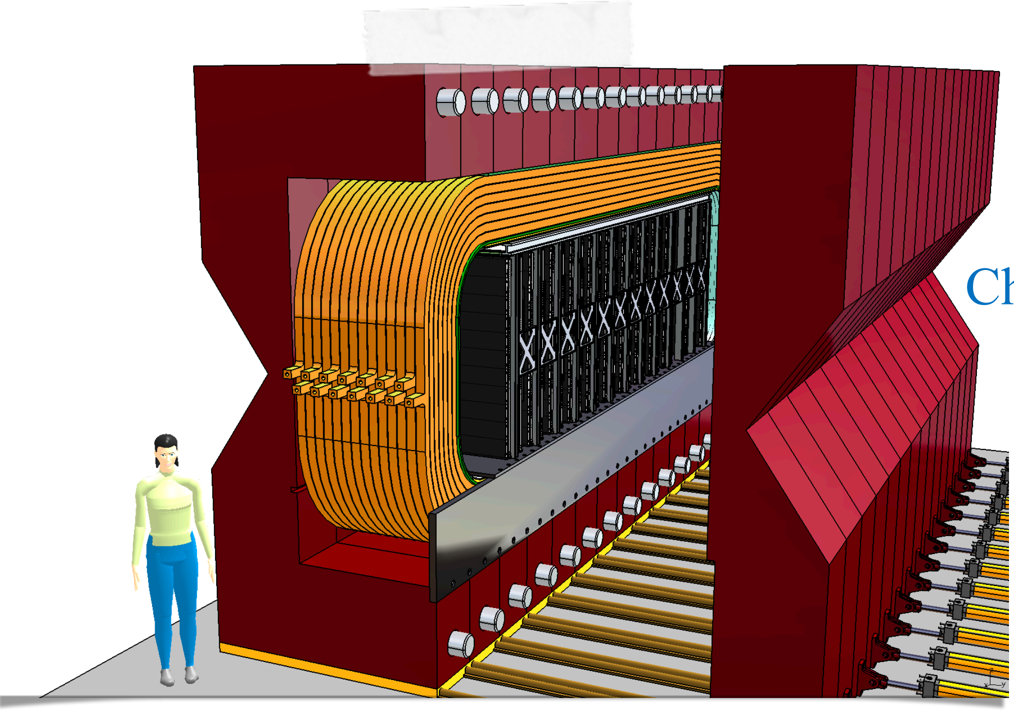
2 x 10^{20} protons on target



https://arxiv.org/abs/1504.04956

C. Ahdida *et al* 2019 *JINST* **14** P03025

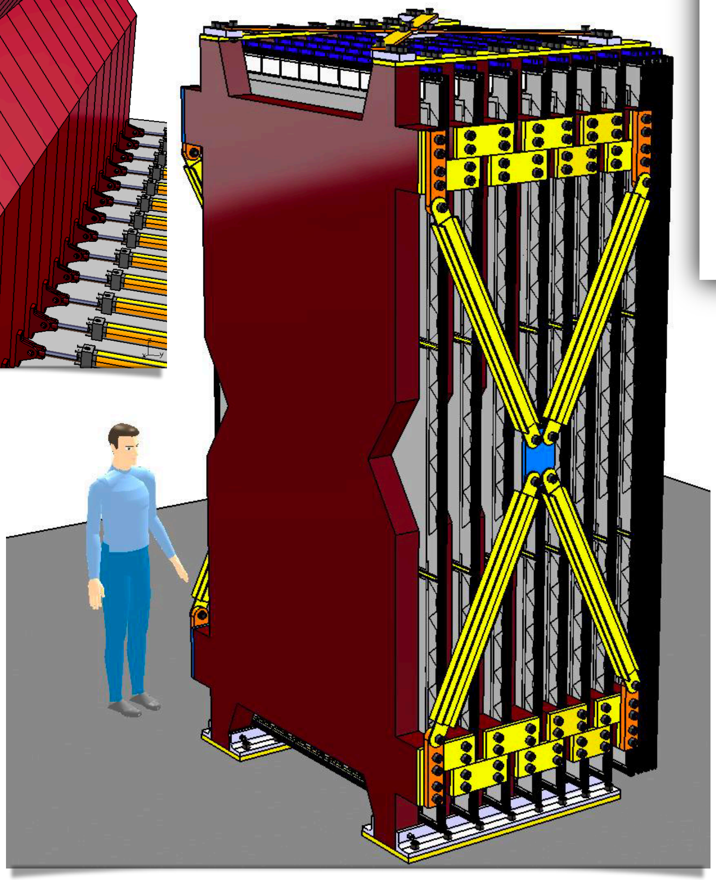
Scattering and Neutrino Detector

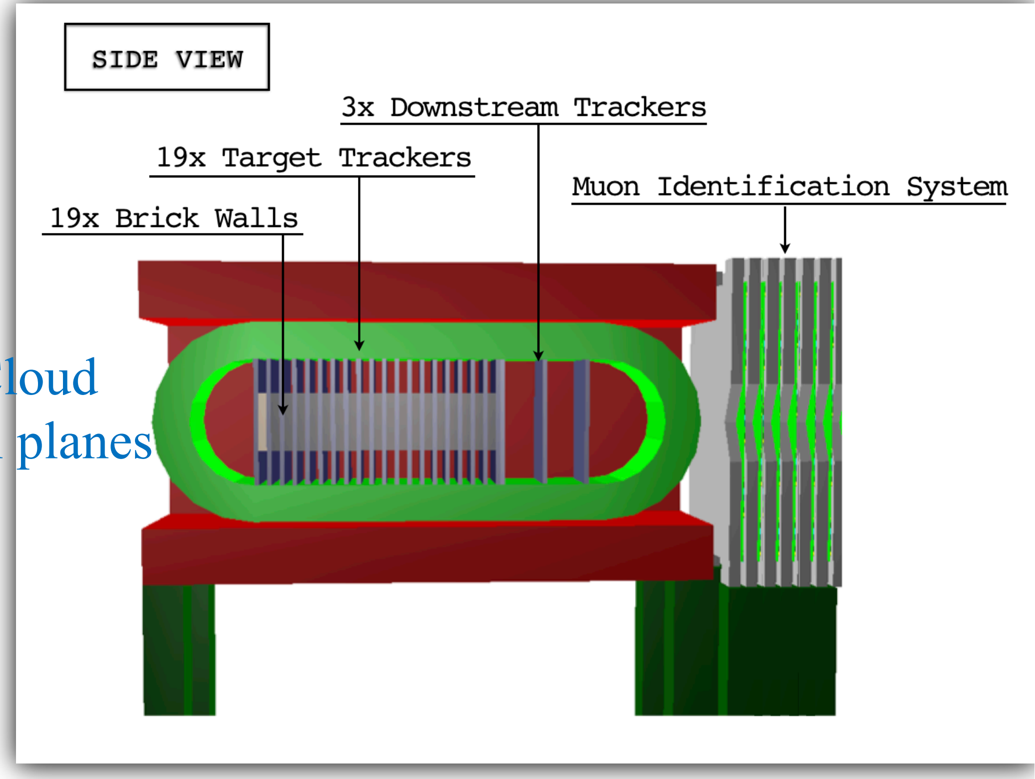


The magnet

- 1.2 T horizontal field
- Copper coil
- Cooling system
- Thermal insulation
- Internal volume temperature: 18°C

Alternating Emulsion Cloud Chamber (ECC) and SciFi planes





The Muon ID System

- Iron absorbers
- RPC as tracking detectors

SHiP Experiment - Comprehensive Design Study report https://cds.cern.ch/record/2704147

SND concept at the LHC

Veto plane for charged particles in front of the target region

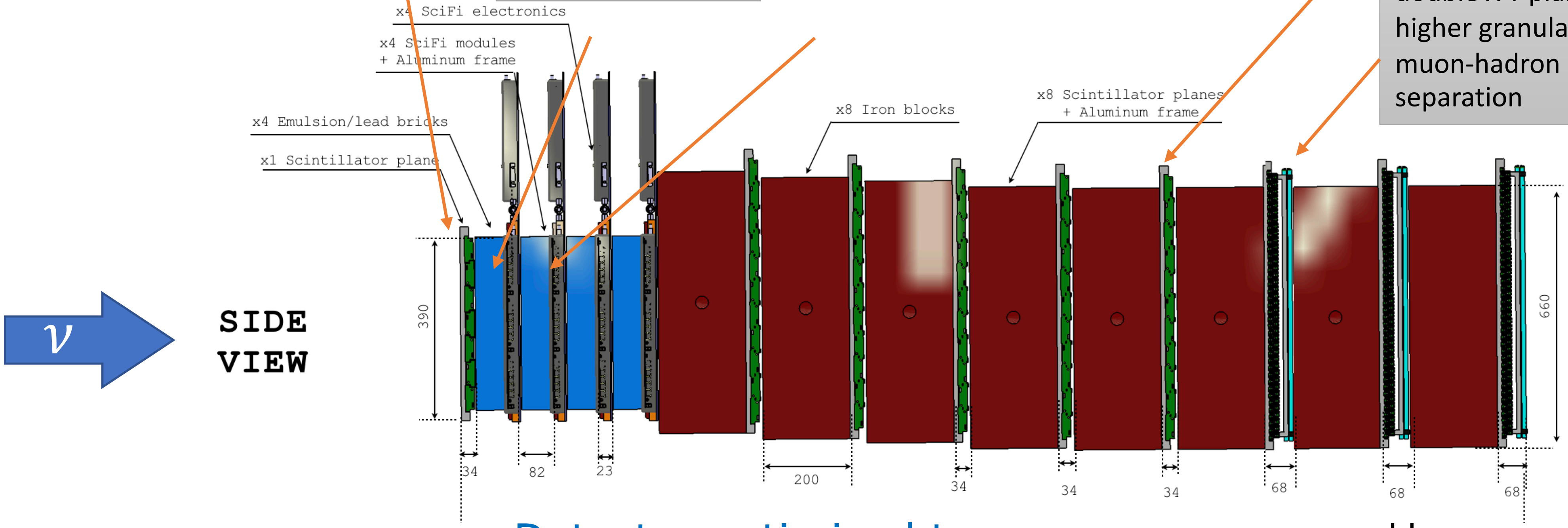
Emulsion Cloud Chamber, emulsion and Pb/W absorbers for micrometric accuracy in the detection of τ and LDM, EM shower energy measurement.

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



Detector optimized to see ν_e, ν_μ, ν_τ

Detector layout in the TI18 tunnel

Veto: 1 Scintillator plane

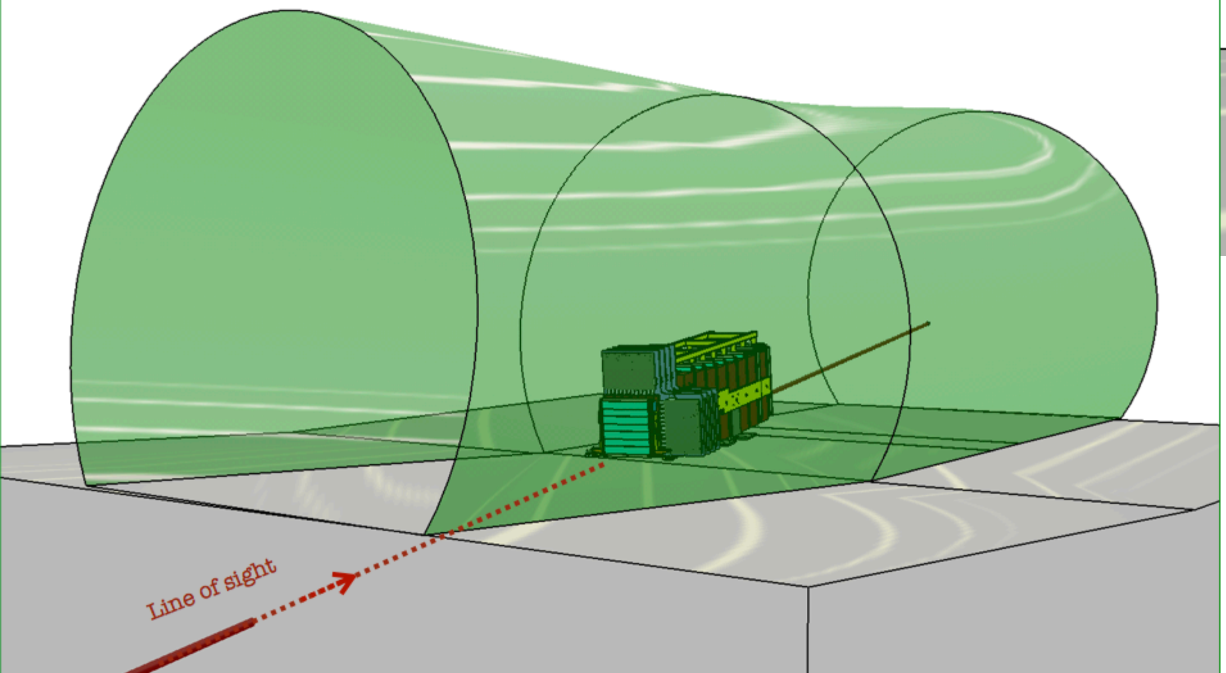
Target: 4-5 ECC brick walls

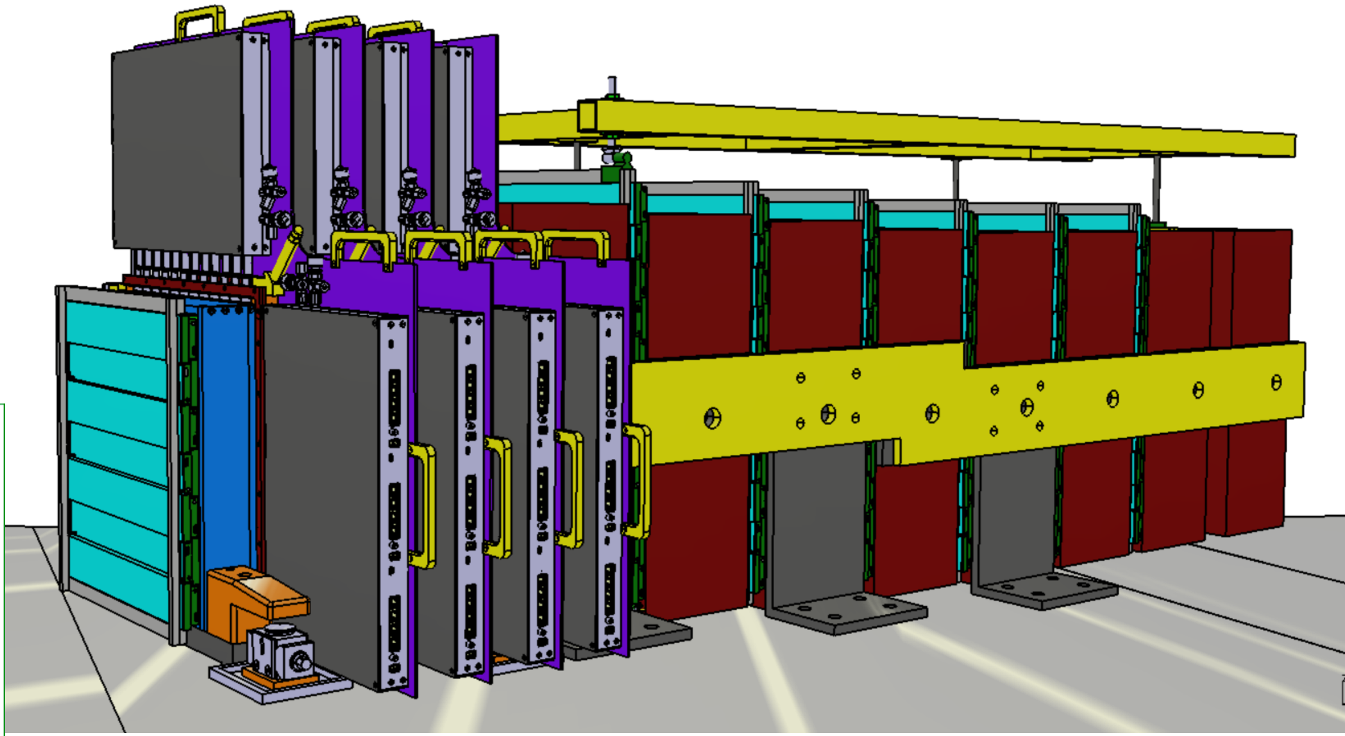
Target Tracker: 4-5 SciFi x-y planes

Muon Id system: 8x20 cm Iron blocks & scintillating bars

Timing detector: 8 Scintillator planes (<100 ps)

3D model of T18 tunnel

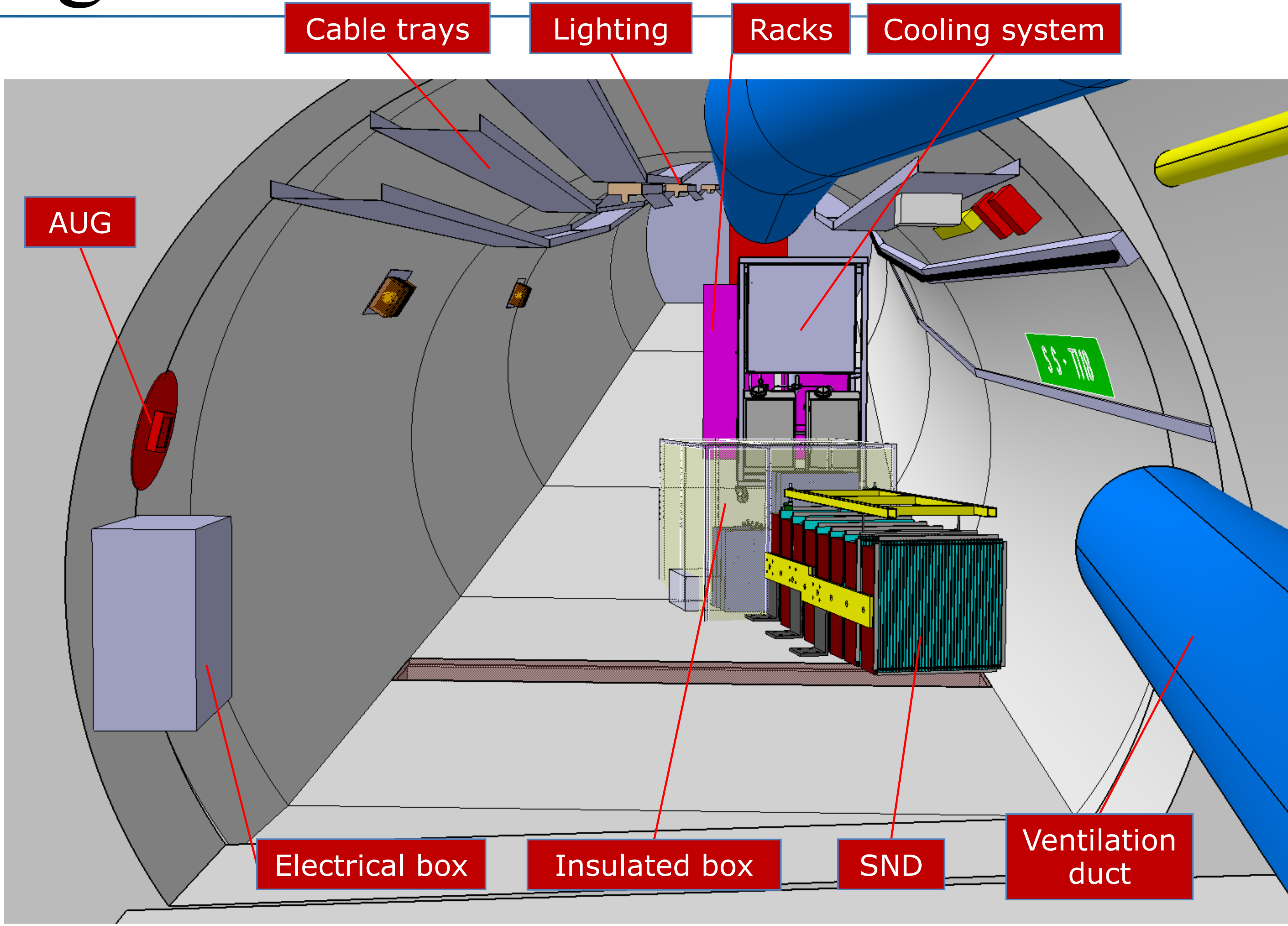




Mechanical design and integration

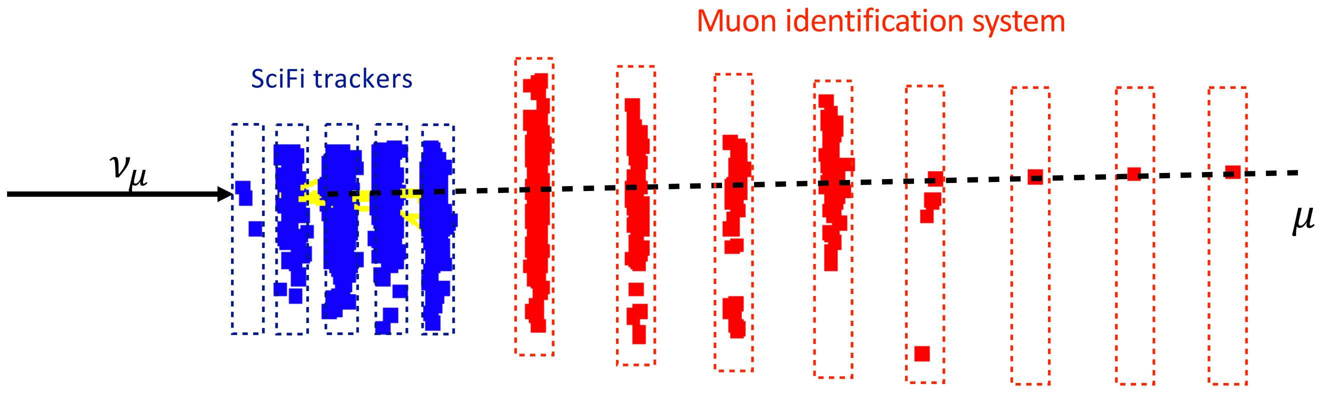
Detector Integration in the TI18 tunnel

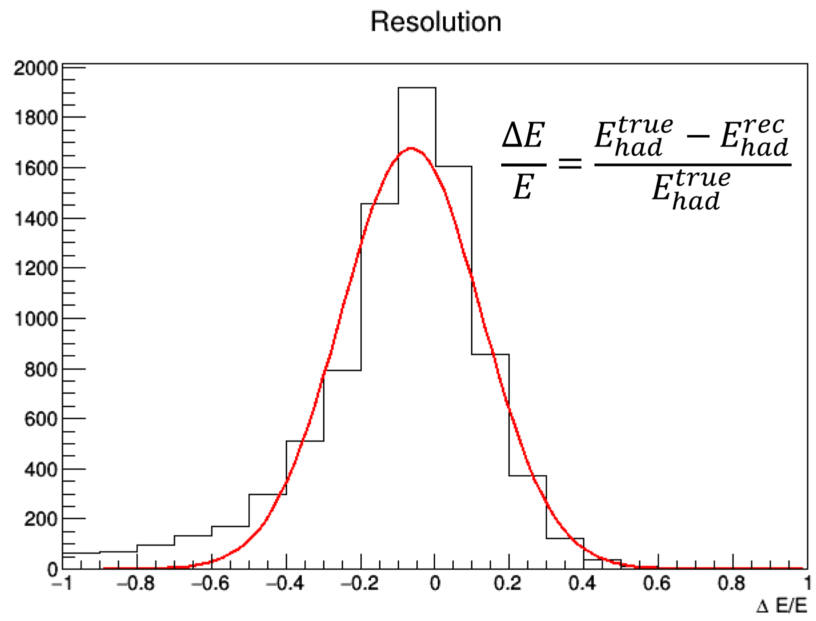
- Several iterations with the CERN groups:
  - EN-SMM, HSE-OHS, HSE-RP, EN-HE, EN-EL-EIC, EN-EL-FC, IT-CS-DO, EN-CV, IT-CS-CS, EN-STI-BMI, EN-EA-AS, BE-OP-LHC & EN-ACE-OSS.
- Items considered:
  - Cooling & ventilation.
  - Powering & lighting.
  - Signals, readout and networking.
  - Survey.
  - Transport.
  - Safety.
  - Radiation protection.
  - Radiation protection to electronics.



Key features: muon ID and energy measurement

- ν_μ CC interactions identified thanks to the identification of the μ produced in the interaction
- Muon ID at **ν** vertex crucial also to discard charmed hadron production, background to ν_τ CC interactions





$$\sigma(E_{had}) = (18.8 \pm 0.2)\%$$

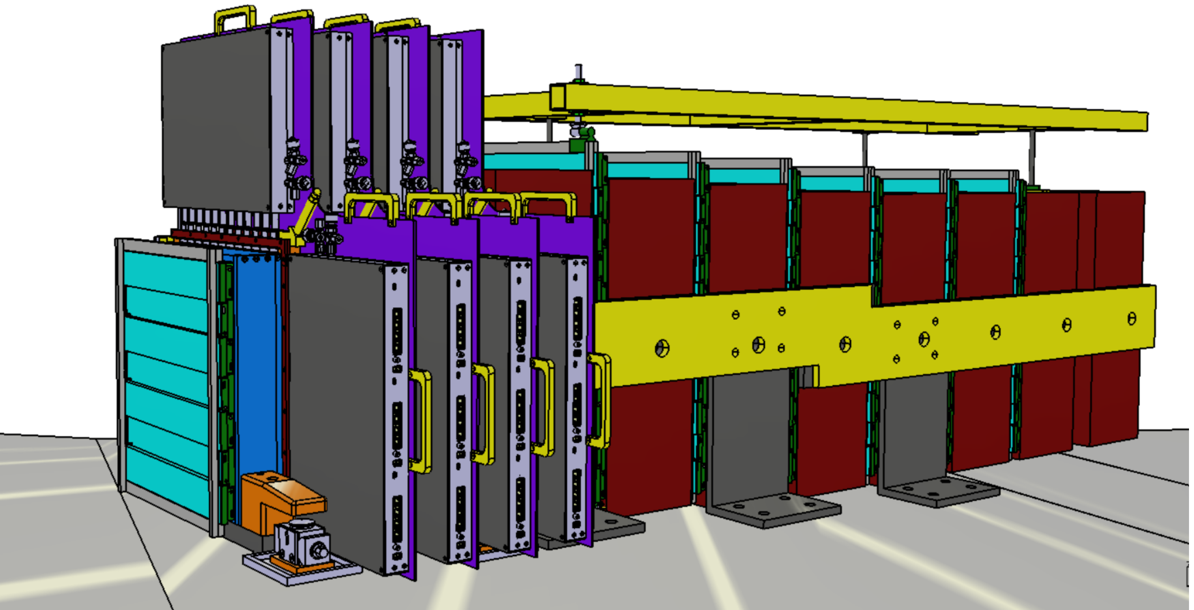
	% evts CC-DIS	% evts NC-DIS
0μ	34.1	99.7
1μ	64.5	0.3
2μ	1.2	0.03

Under optimization

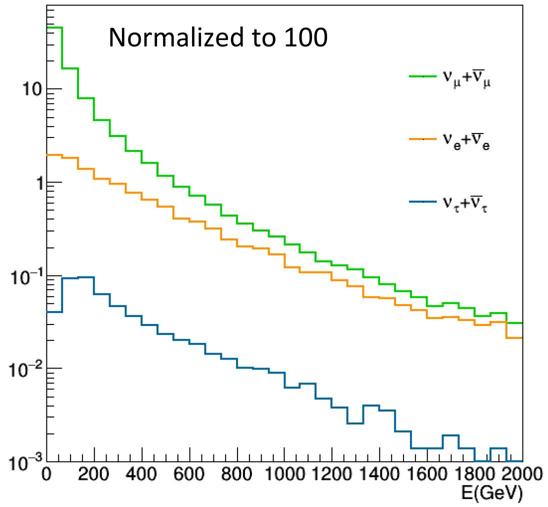
Neutrino statistics (150 fb^{-1} in Run3)

Neutrino flavour	< E > GeV	Neutrino Flux	< E > GeV	CC Interactions
ν_μ	146.4	2.5×10^{12}	471.1	975
ν_e	376.4	3.3×10^{11}	731.5	332
ν_τ	421.8	1.7×10^{10}	749.6	18
$\bar{\nu}_\mu$	150.3	2.2×10^{12}	500.2	429
$\bar{\nu}_e$	382.2	3.5×10^{11}	748.8	174
$\bar{\nu}_\tau$	401.6	1.5×10^{10}	747.6	7
TOT		54.1×10^{12}		1935

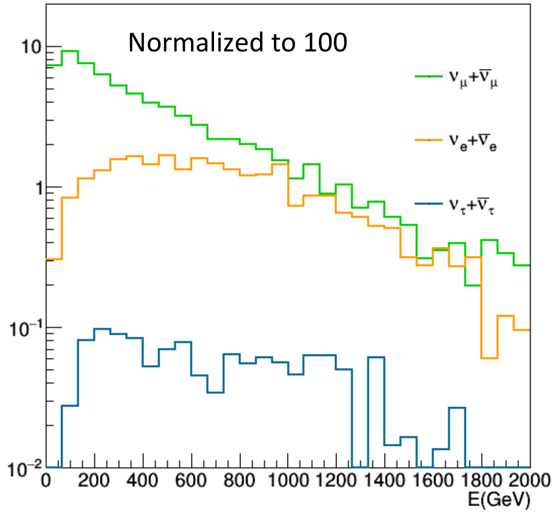
- Total target mass of ~850 kg



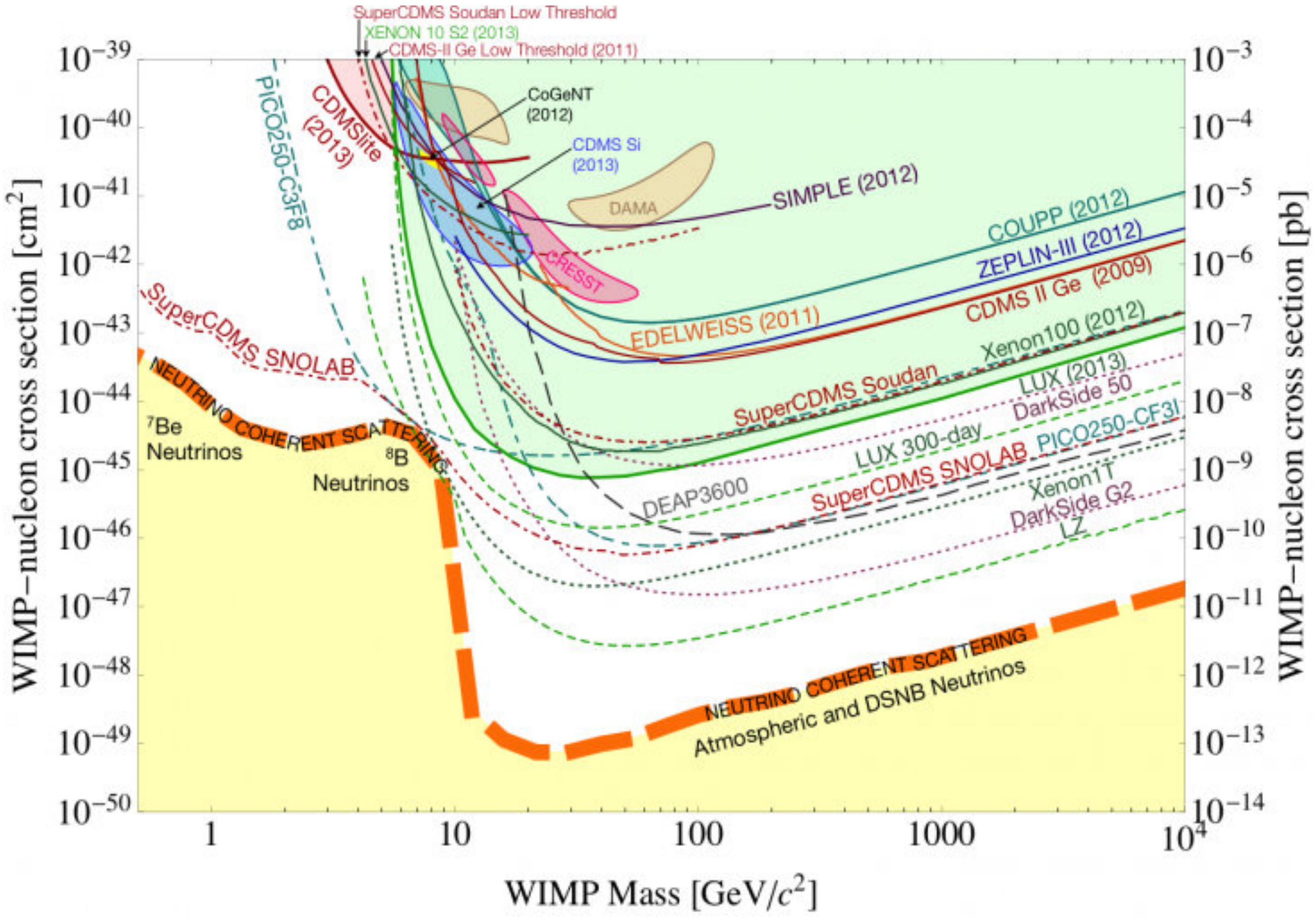
Incoming ν



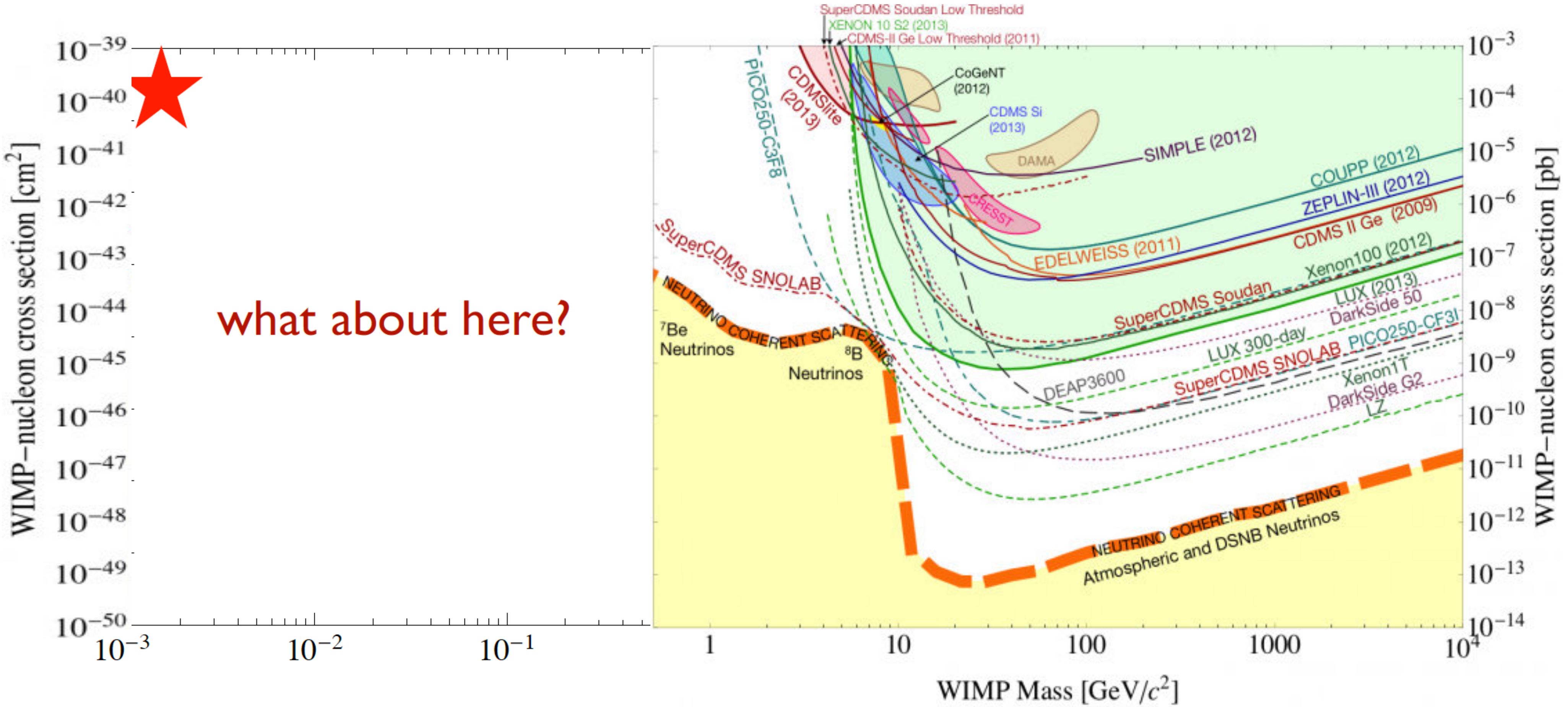
Interacting ν



DARK MATTER SEARCH



DARK MATTER SEARCH



□ **Important to explore sub-GeV mass region**

Light Dark Matter (LDM) search

Signal model

Production

We consider a scalar/fermionic LDM χ candidate, produced in the prompt decay of a **Dark Photon** (Vector Portal) in a minimal extension of the Standard Model $U'(1)$, with $m_{A'} \sim O(1\,\mathrm{GeV/c^2})$:

$$\mathcal{L}_{A'} = -\frac{1}{4}F'_{\mu\nu}F'^{\mu\nu} + \frac{m^2_{A'}}{2}A'^{\mu}A'_{\mu} - \frac{1}{2}\epsilon F'_{\mu\nu}F^{\mu\nu}$$

Interaction

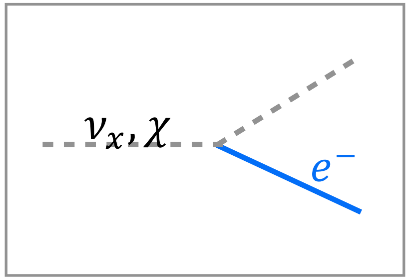
LDM observed through its **elastic scattering** off the detector atomic electrons, $\chi e^- \to \chi e^-$

Backgrounds

- **Neutrino interactions** mimicking the signal topology:

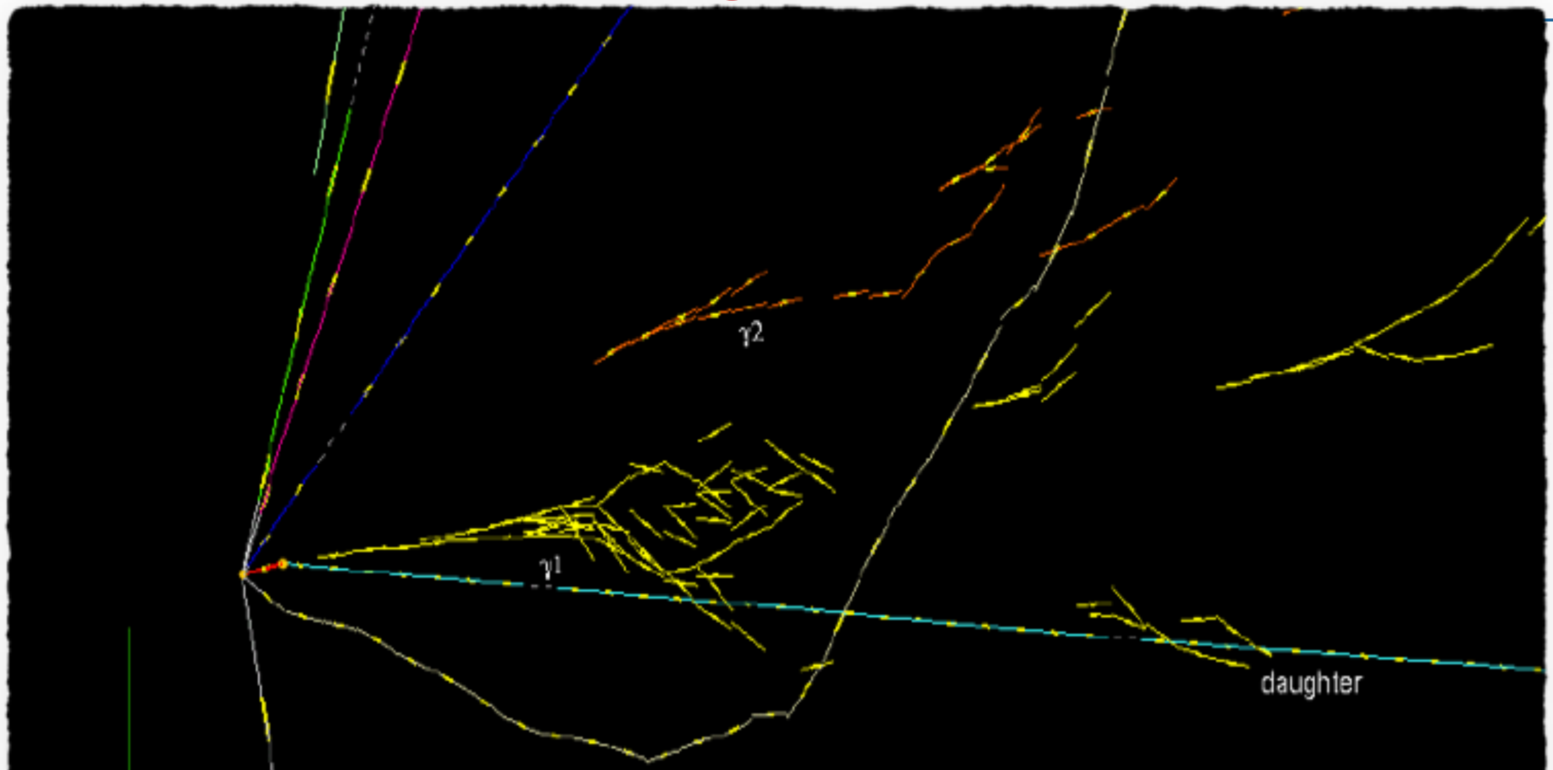
i.e. :
- $\nu_e, \overline{\nu}_e$ CC Deep Inelastic Scattering
- $\nu_e, \overline{\nu}_e$ CC Quasi-Elastic
- $\nu_e, \overline{\nu}_e$ CC Resonant
- $\nu_{e/\mu}, \overline{\nu}_{e/\mu}$ Elastic scattering with electrons

} Full MC simulation with *Fluka* and *Genie*



- **Visibility cut on the primary tracks momentum to identify background (charged:** 100 **MeV/c ; protons:** 170 **MeV/c)**
  - No event expected for both Pilot and Full runs. ⇒ **Zero - background search**

Electromagnetic shower detection in the ECC

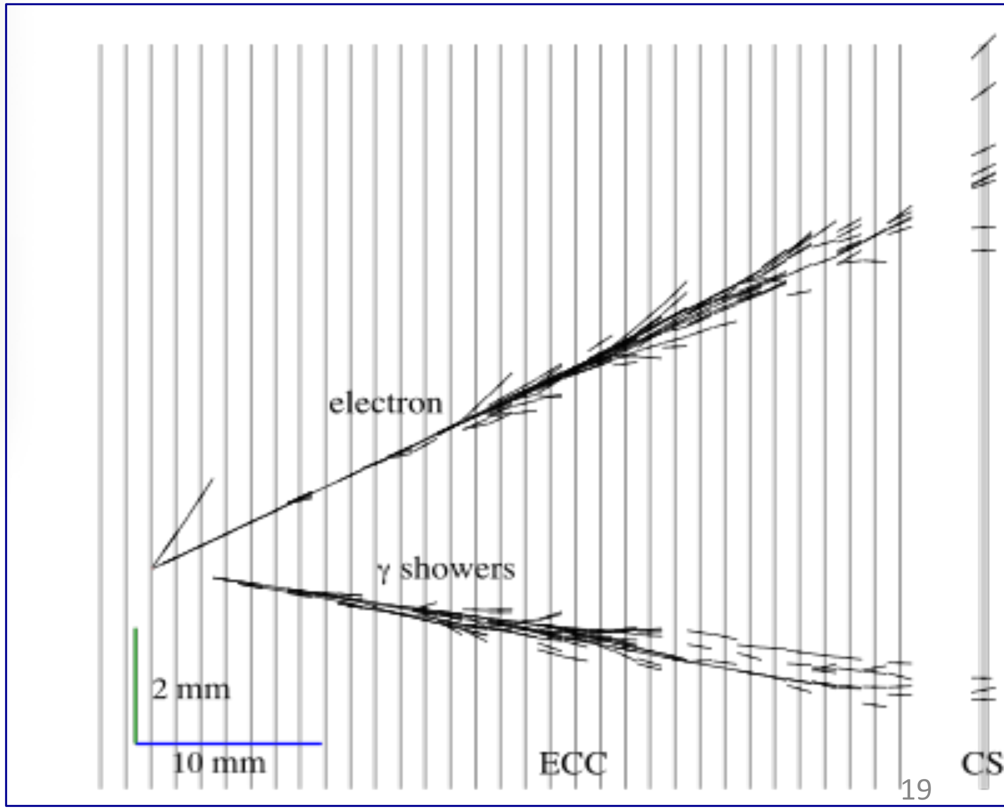


One of the 10 OPERA tau neutrino candidates

PRL 120 (2018) 211801

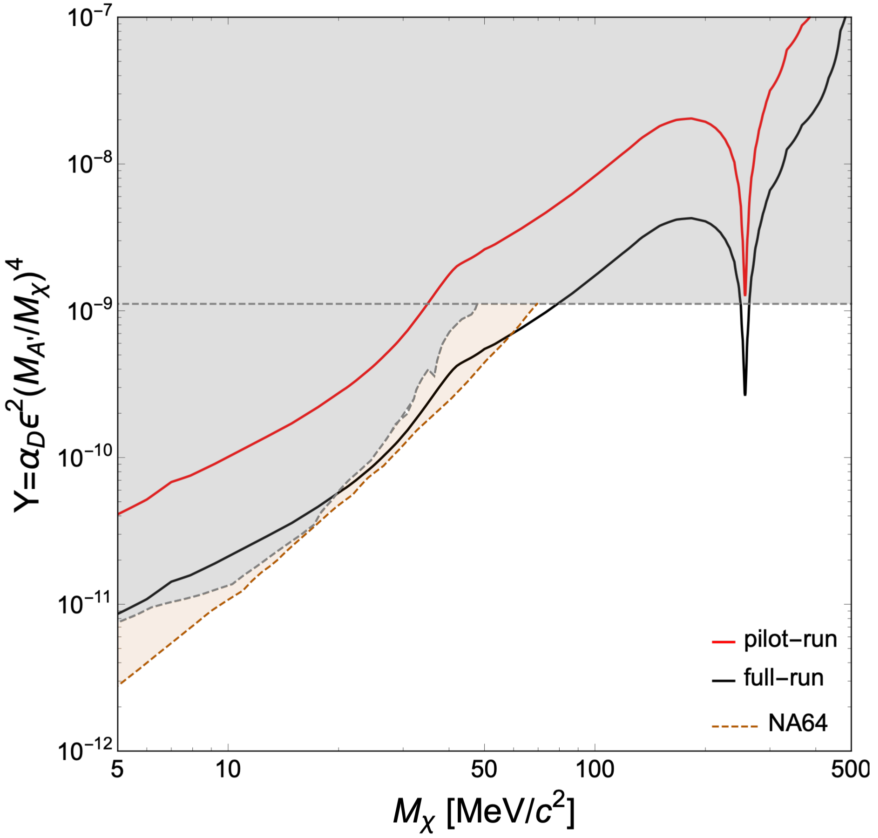
One of the OPERA electron neutrino candidates

JHEP 1307 (2013) 004



Sensitivity to Light Dark Matter with 150 fb^{-1}

- **Signal MC simulation with *Pythia* and *MadDump***
  - **Benchmark scenario adopted:** $m_{A'} = 3m_\chi\ ,\ \alpha_D = g_D^2/4\pi = 0.1$



Final remarks

- Interesting case for neutrino/QCD physics and dark matter search
- Proposal submitted to the LHCC in February, CERN-LHCC-2020-002 / LHCC-I-035, https://cds.cern.ch/record/2709550
- Detector design and integration study complete: the infrastructure can be installed during 6 months after the approval
- Electronic detector commissioning on surface in 2021
- Start taking data in 2022 feasible