Scattering and Neutrino Detector at the LHC

Istituto Nazionale di Fisica Nucleare
Sezione di Bologna

ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA

SND@LHC AND ADVSND

A ROADMAP FOR NEUTRINO DETECTION AT LHC AND HL-LHC

ICHEP
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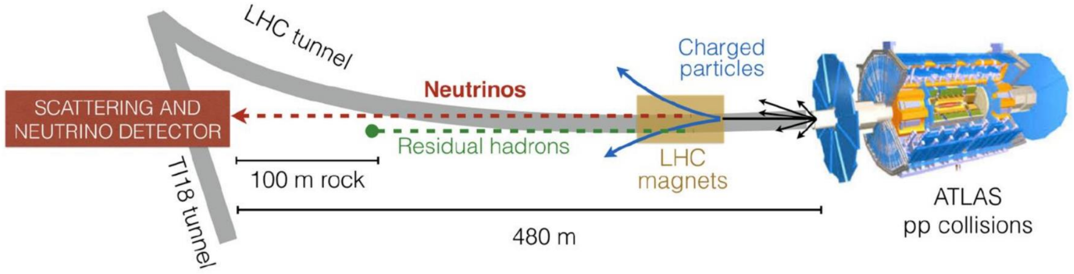
On behalf of the SND@LHC Collaboration

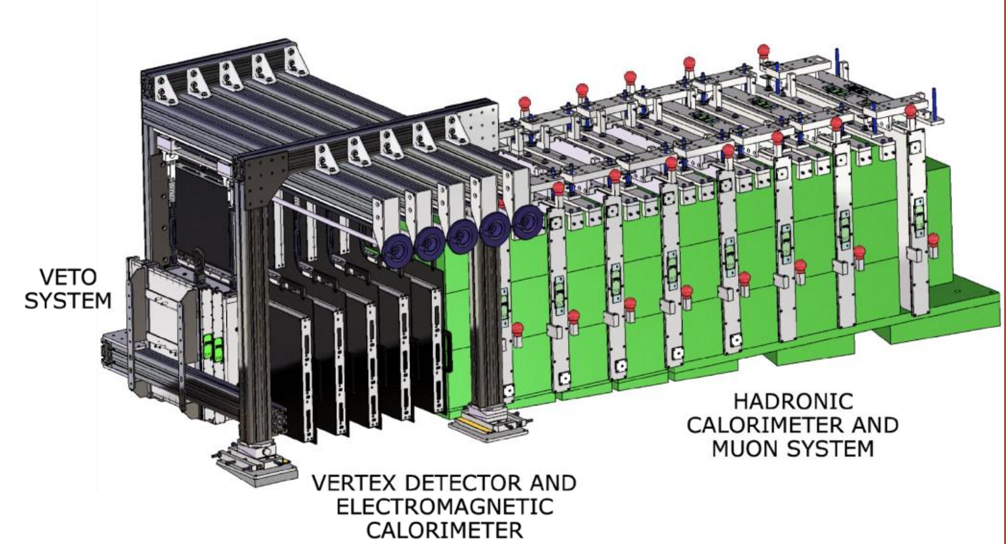
Riddhi Biswas talk

SND@LHC detector

Scattering and Neutrino Detector **at the LHC** [1]:
→ study pp→νX in a yet **unexplored energy range**

Identify **all flavours** at **TeV** energies allows for
→ Measure **charm production** at high η ($gg \rightarrow cc$)
→ Test lepton **flavour universality** measuring ν_e/ν_μ and ν_e/ν_τ
→ Direct search of **feebly-interacting particles**





Hybrid detector composed of:
→ Veto system: 3 planes of scintillating bars read by SiPMs
→ Target with vertex detector and electromagnetic calorimeter
  → Emulsion plates interleaved with tungsten (Emulsion cloud chamber)
  → scintillating fibers (SciFi) modules
→ Hadronic calorimeter and muon system: 5+3 scintillator planes read by SiPMs interleaved with iron

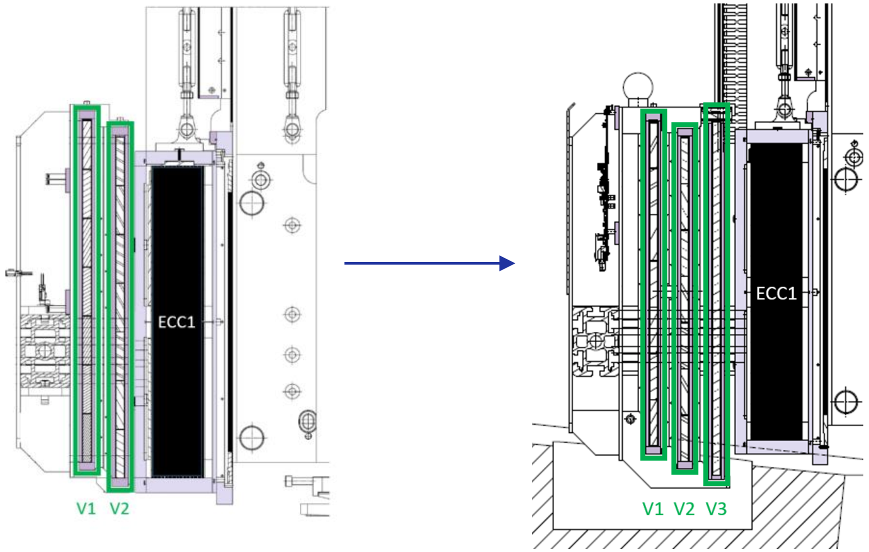
[1] SND@LHC collaboration, SND@LHC: The Scattering and Neutrino Detector at the LHC

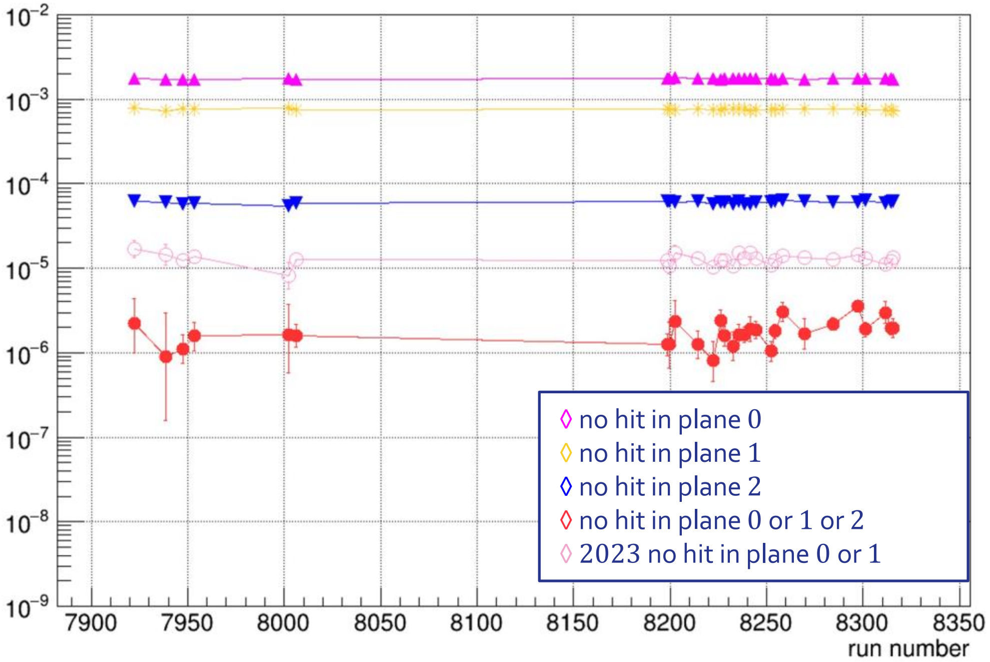
SND@LHC IN RUN 3

Veto upgrade

In the neutrino interactions from ν_μ analysis [2] the veto system's inefficiency [3][4] was such to require the use of the first two tracker planes to reach the necessary rejection power.

During 2023-2024 YETS added a third veto plane [5] with vertical instead of horizontal bars to
- → reduce inefficiency
- → better coverage at the bottom edge of the target





Veto system performance improved by an order of magnitude

[2] SND@LHC collaboration, Observation of collider muon neutrinos with the SND@LHC experiment
[3] T. Ruf. Estimate of the Veto System Inefficiency 2022.
[4] T. Ruf. Estimate of the Veto System Inefficiency 2023.

Emulsion target

Since the restart of LHC operations in 2024:

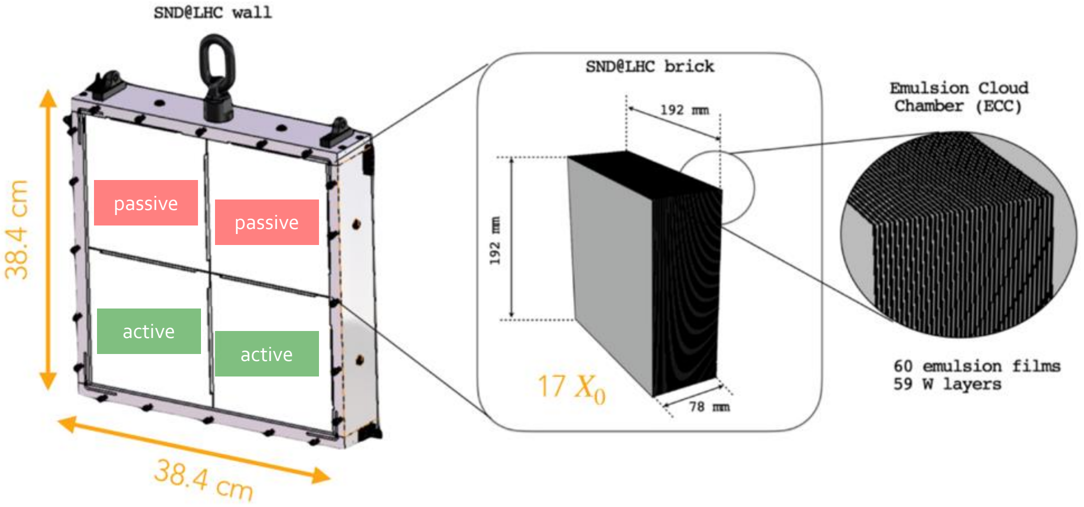
Muon background increased by a factor 2 → new LHC settings in the collimators near the detector

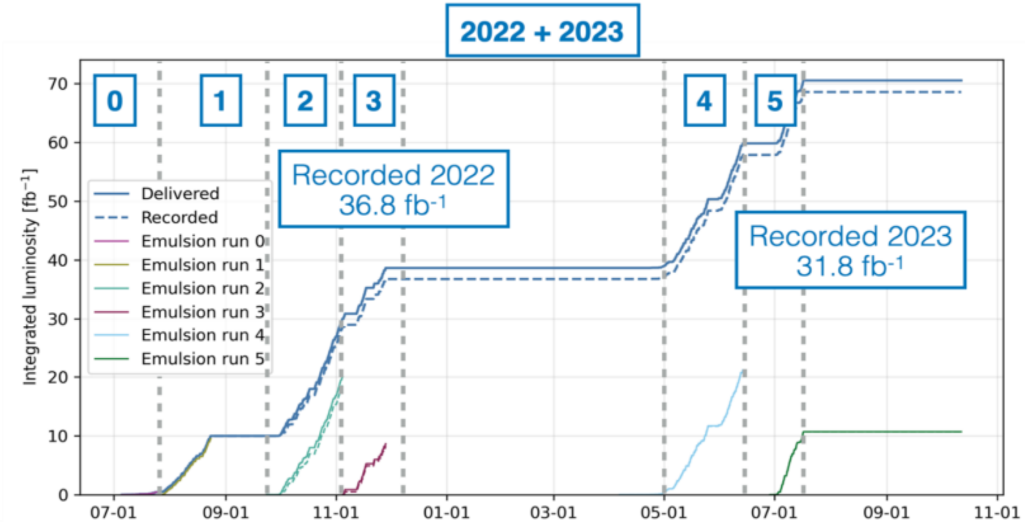
New strategy for the emulsion target replacement:

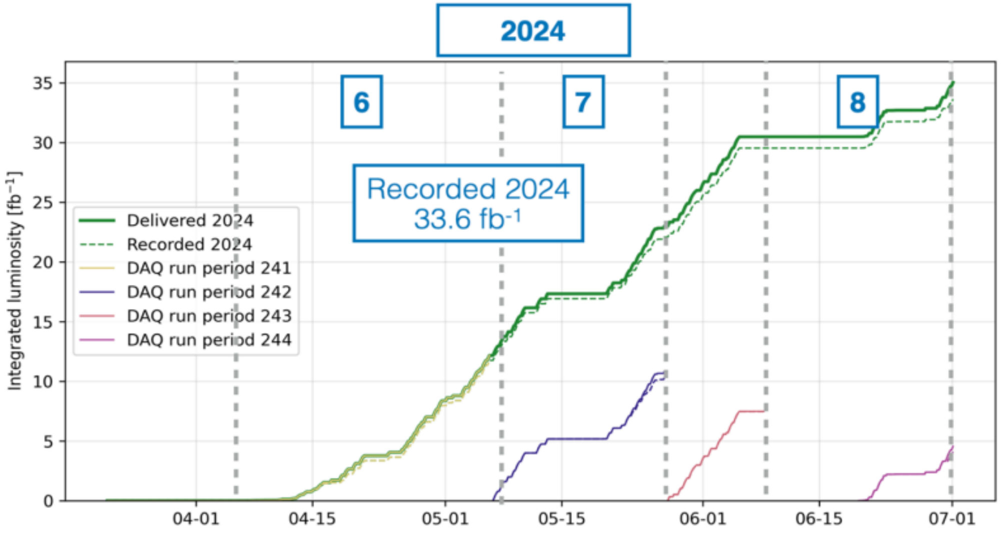
→ instrument only the lower half target: the muon flux is larger is the upper part of the target while the neutrino flux is higher at the bottom

→ keep 65% of events

→ limit exposure to 12 fb^{-1}







Paper in preparation

HCAL calibration

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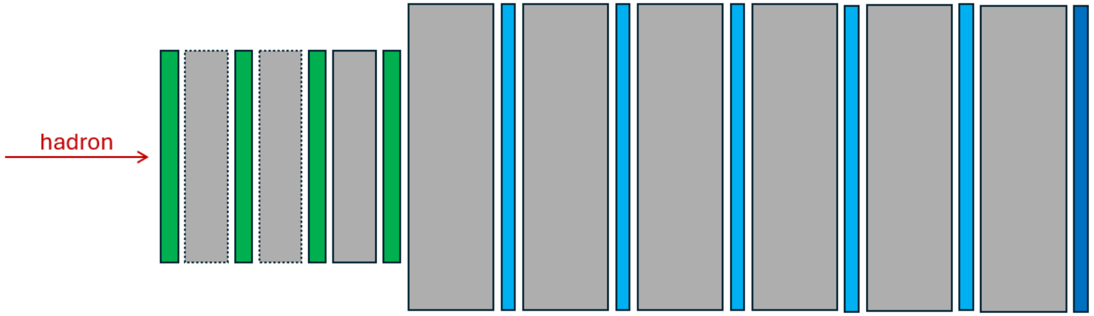
Test beam in August 2023 to **calibrate HCAL response**

The test beam setup consists of
- → 4 scintillating fibres (SciFi) modules, each made of an x and y plane;
- → 5 upstream modules (US), made of horizontal 6 cm thick scintillating bars;
- → 1 downstream module (DS), divided in a horizontal a vertical plane, made of 1 cm thick scintillating bars.
- → The active modules are interleaved by iron blocks 0.5 λ_{int} wide for the SciFi part and 1 λ_{int} in between the US and DS modules.



Reconstructing shower energy and direction is necessary to fully reconstruct ν interaction

↓

compute incoming neutrino energy

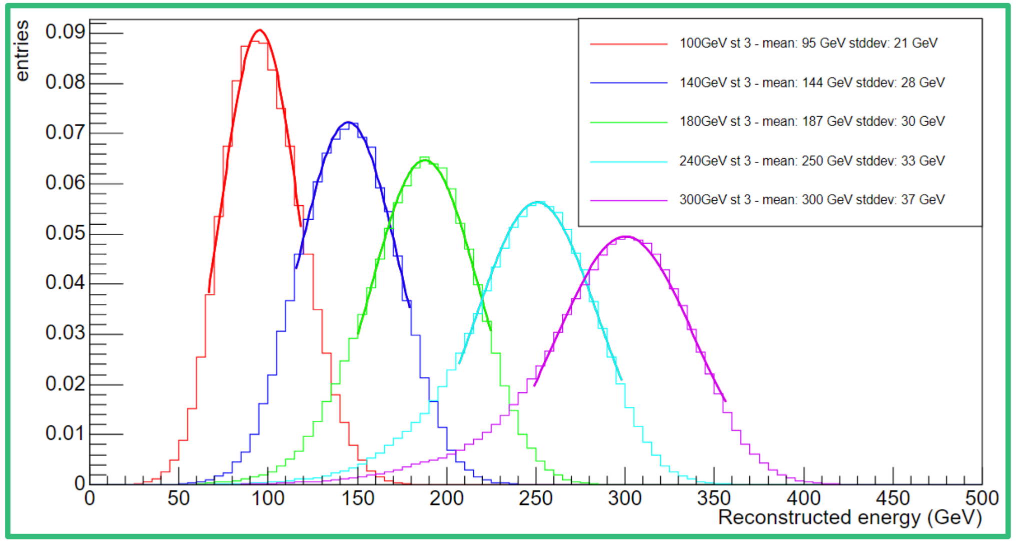
HCAL calibration

Paper in preparation

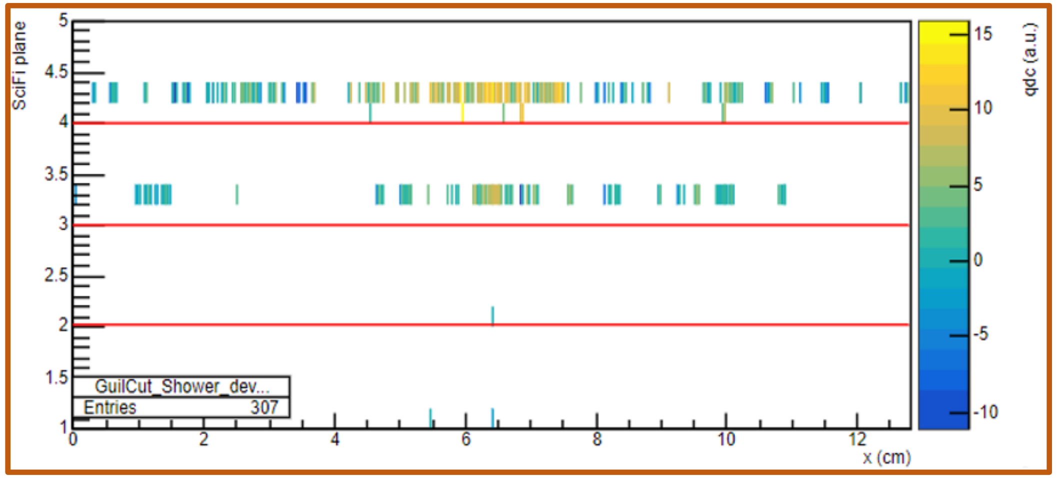
Studying the QDC (digitized value of integrated charge) in shower events

$$E = k \times QDC_{SciFi} + \alpha \times QDC_{US}$$

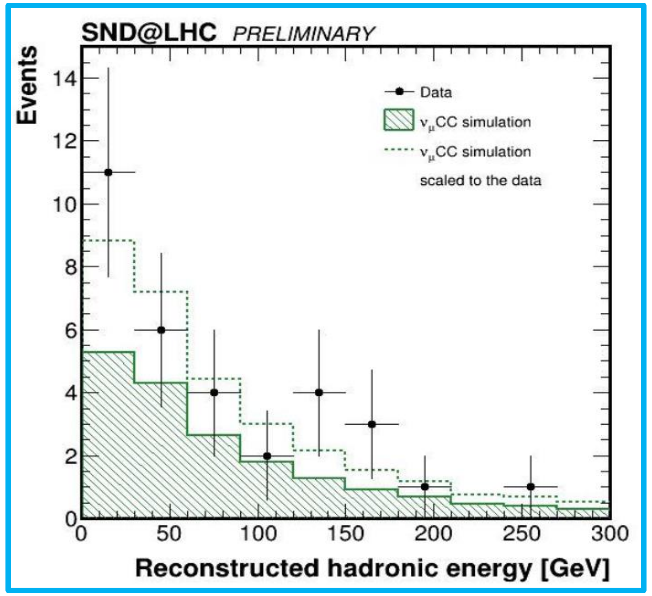
with E incoming hadron energy, k and α two calibration constants



Computed and validated with test beam data:
Obtained energy resolution ~12% to 22% depending on incoming particle energy



Next step:
optimize to apply on TI18 data

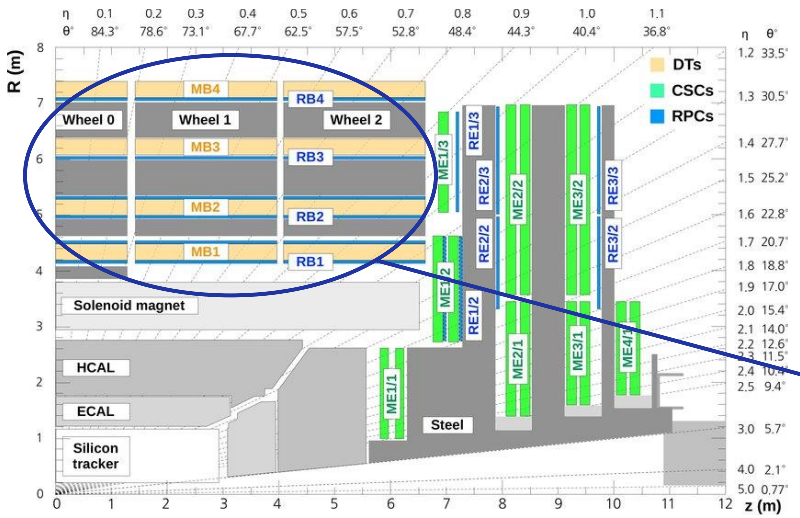


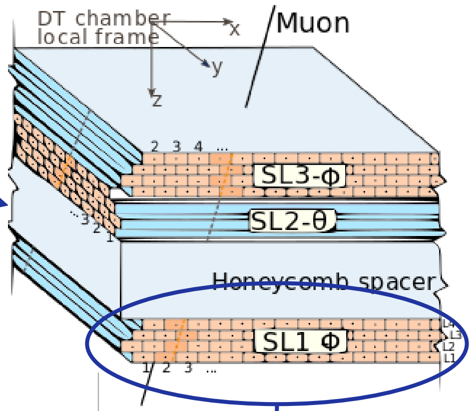
Muon system upgrade

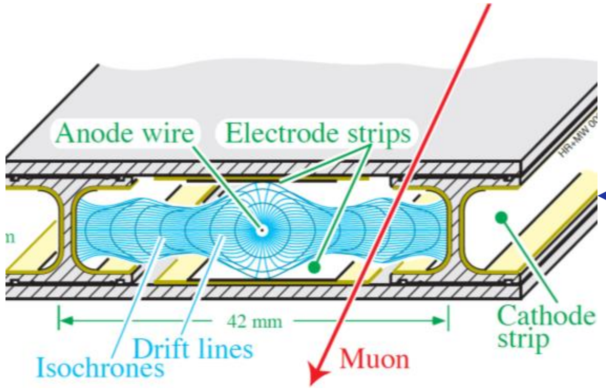
Under study the possibility to improve muon track reconstruction currently done with DS modules by adding drift tubes stations

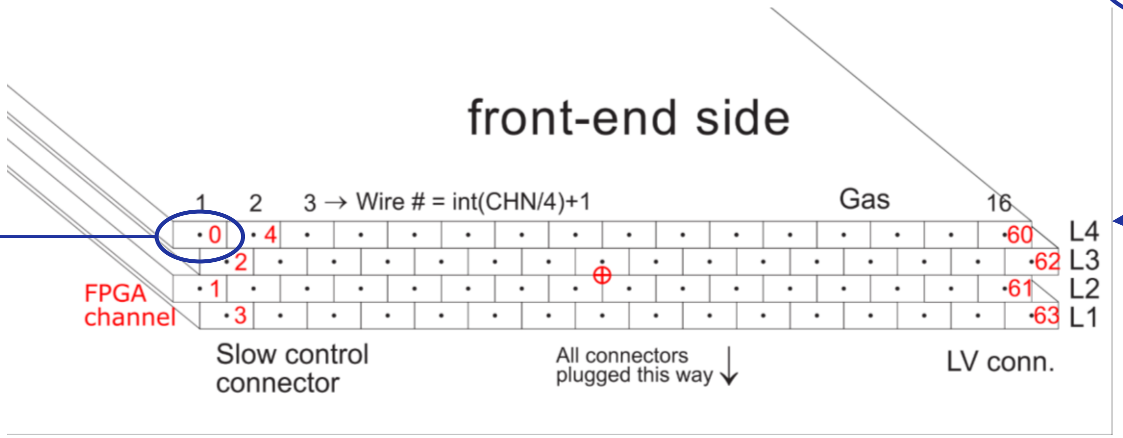
Measure muon trajectory with CMS Drift Tube small size replicas → **MiniDTs** [6]

Expected ~150 µm point resolution instead of ~cm of DS modules









[6] Paggi, Construction and test of a cosmic ray telescope based on CMS Drift Tube chambers and data acquisition prototypes of the Phase-2 upgrade

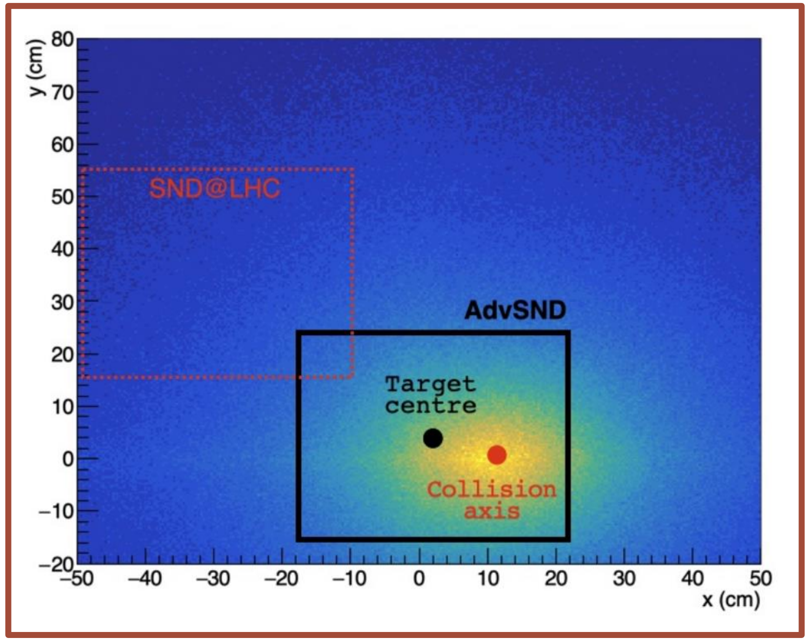
HL-LHC Upgrade
AdvSND

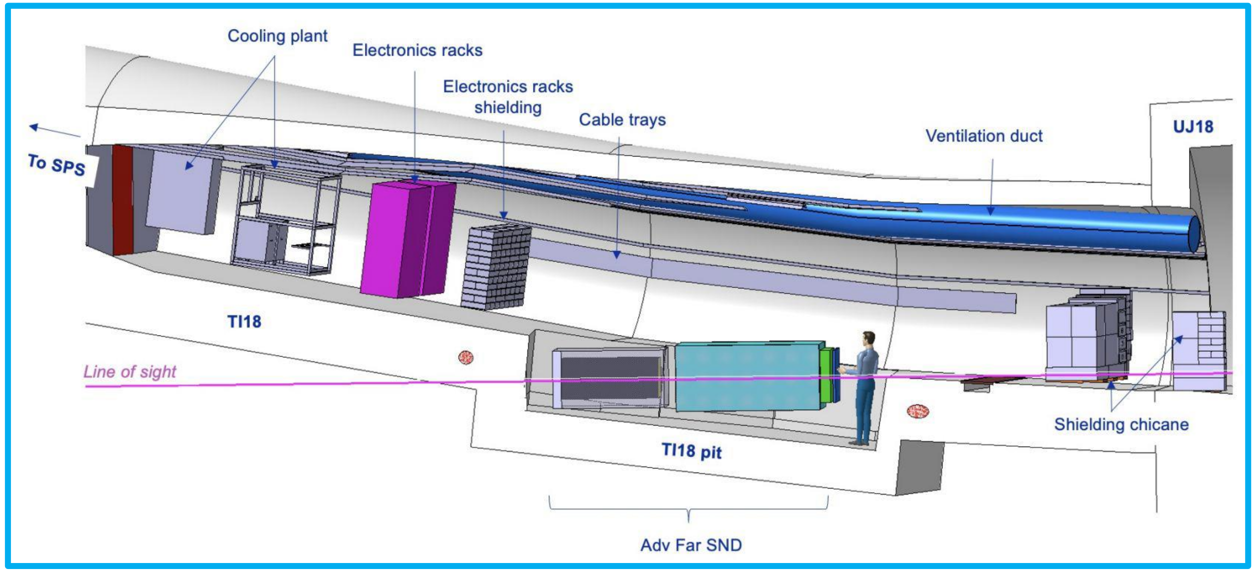
HL-LHC upgrade

Proposed **upgrade in LS 3**:

- Need for civil engineering → modify detector position to optimize acceptance with all crossing angle configurations proposed for LHC Run 4 and 5

Compact option → **only floor** excavation





Magnetize HCAL

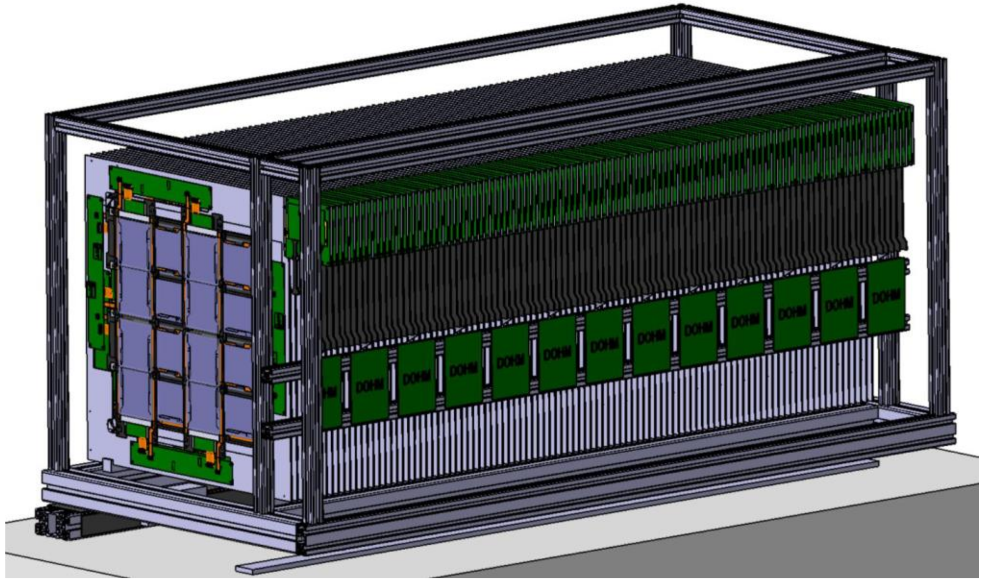
↓

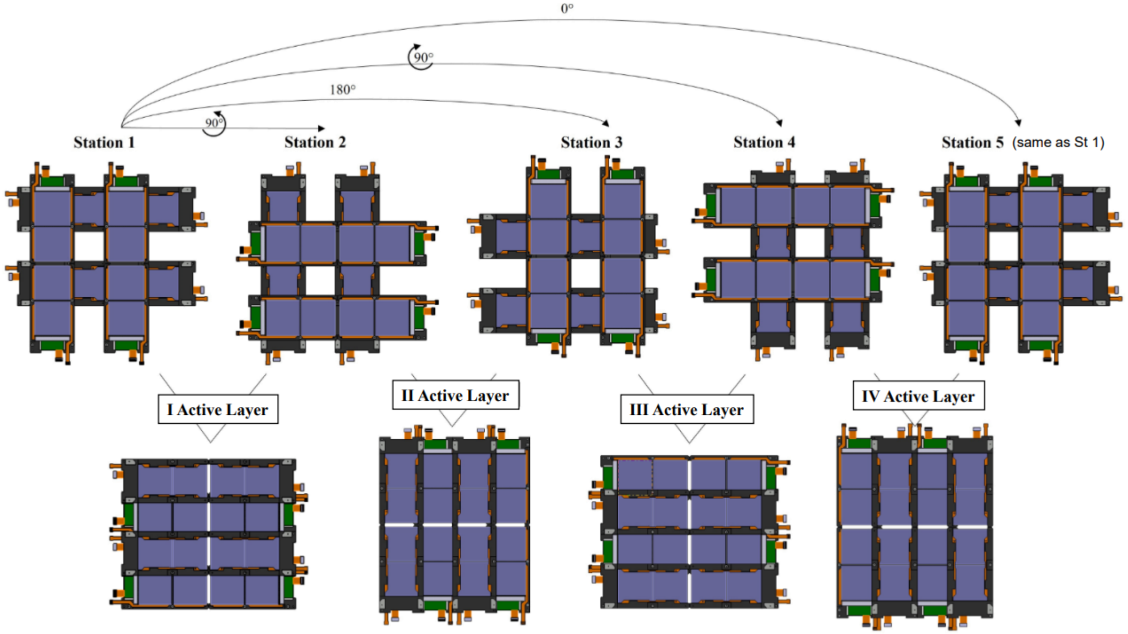
Aim: get ~20% momentum resolution for muons to achieve good charge identification for muons of ~1 TeV

Vertex detector upgrade

Need to replace vertex detector ⟶ HL-LHC will produce a **muon flux too intense** to use the emulsion cloud chambers

New silicon vertex detector ⟶ reuse **CMS Tracker Outer Barrel strips** modules



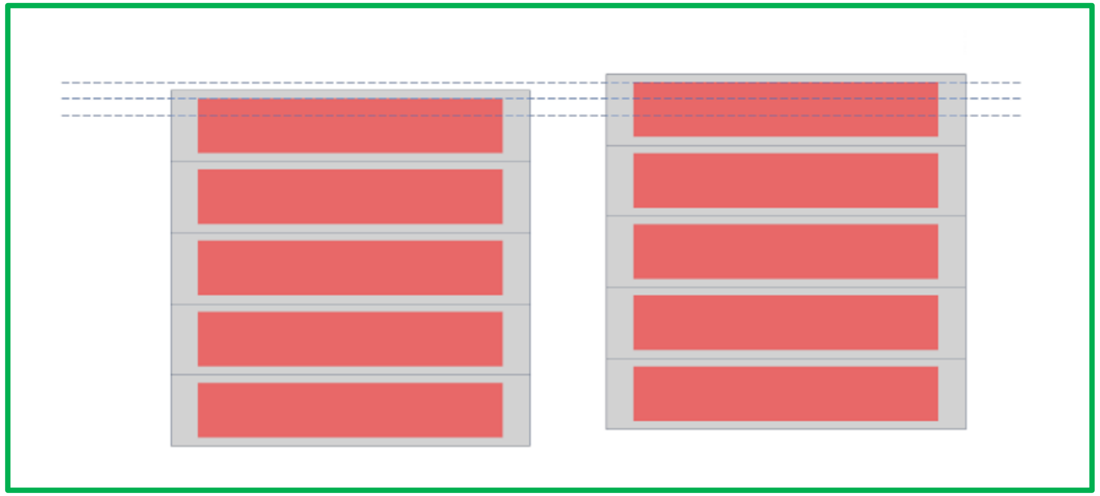


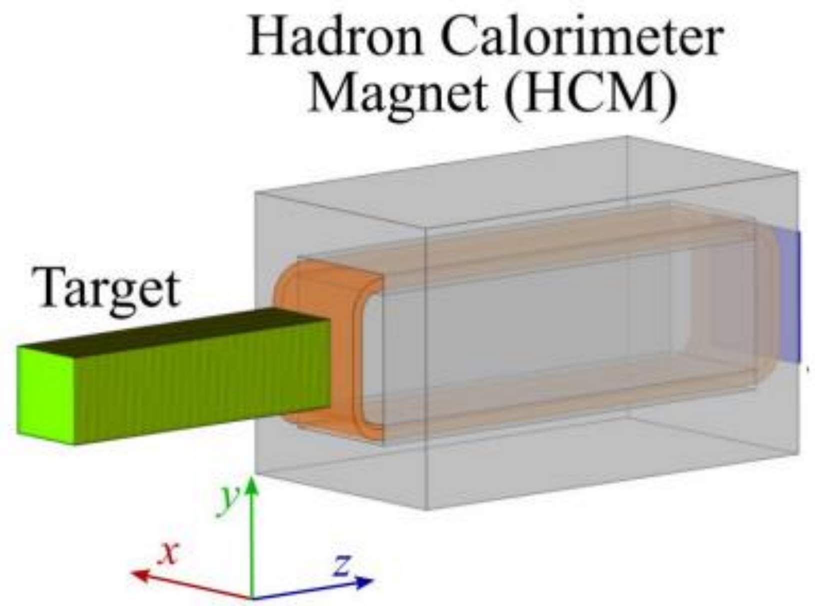
100 stations interleaved with tungsten
total mass 1.75 t

Magnetized hadronic calorimeter

- Add a coil around the detector →
  magnetize the iron with 1.75 T
  to increase muon charge sensitivity

- Use spare CMS TOB modules from target construction to equip several planes across the HCAL section → ~30 μm point resolution to achieve ~20% momentum resolution for 1 TeV muons





- 15 strip modules per layer
- Staggered front and back of same module to maximize coverage

Physics reach of AdvSND

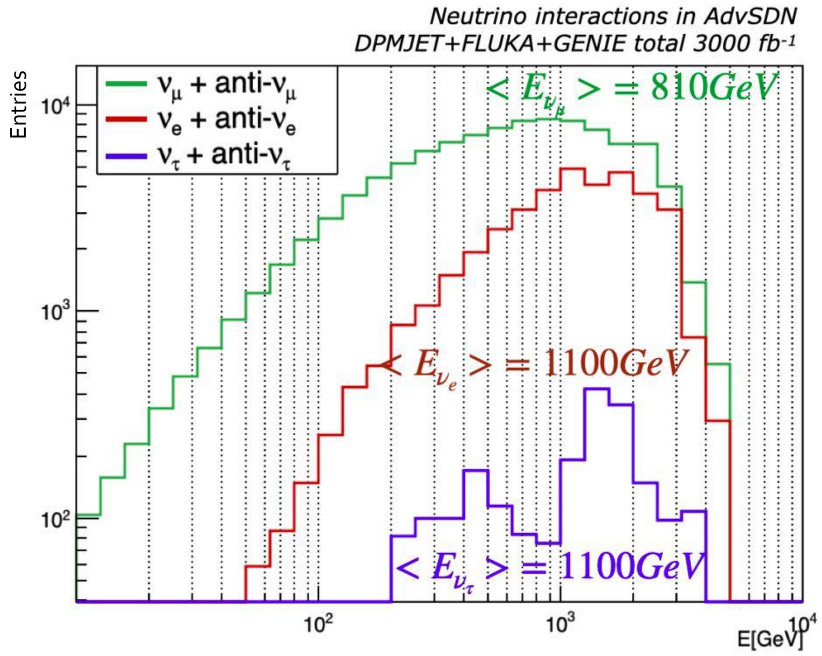
- Larger statistics → improved uncertainties
  - Lepton Flavour Universality (LFU) → expected uncertainty of this measurement in Run 3 dominated by a 30% statistical uncertainty due to the limited ν_τ sample

- ν_es can be used as a probe of charm production to constrain gluon PDF in the very small Bjorken x region

Measurement	Uncertainty Stat.	Sys.	Uncertainty Stat.	Sys.
Charmed hadron yield	5%	35%	1%	5%
ν_e/ν_τ ratio for LFU test	30%	22%	5%	10%
ν_e/ν_μ ratio for LFU test	10%	10%	1%	5%
ν_μ and $\overline{\nu}_\mu$ cross-section	-	-	1%	5%

Adding a magnetic field:

- allow separate identification of neutrino and anti-neutrino interactions for both muon and tau neutrinos
- **first experimental direct observation** and the study of tau anti-neutrinos up to 1 TeV



Summary

In Run 3:

- Modified detector setup
  - New veto plane → efficient charged particles tagging
  - Modified emulsion cloud chamber vertex detector → sustain muon background in new LHC configuration
- Working on full reconstruction of neutrino interaction → compute hadronic shower direction and energy
- Feasibility study for additional upgrade next YETS → enhance muon tracking capability

For HL-LHC:

- Proposed upgrade:
  - New vertex detector
  - Add magnetic field → identify muon and tau neutrinos and anti-neutrinos up to 1 TeV

Scattering and Neutrino Detector at the LHC

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Thank you for your attention

Backup slides

Neutrinos at LHC

Feasibility of high energy neutrino studies at LHC has been investigated since the 90's

→ Possibility to study pp→νX in an **unexplored range**

Small detector are possible [1] [2]:

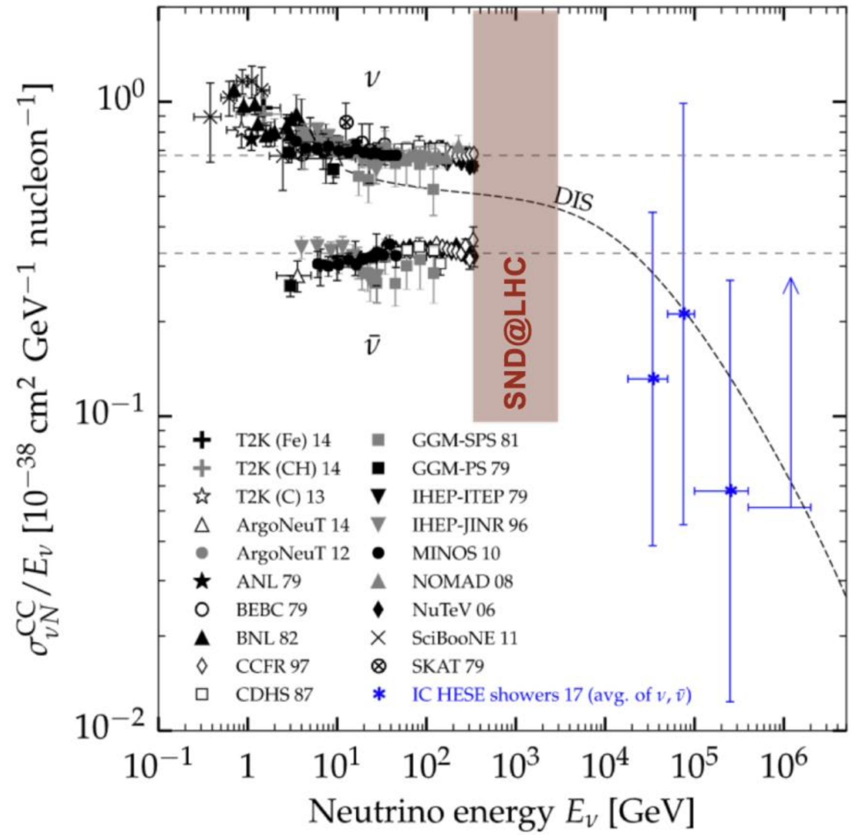
→ **Large ν flux** in forward region from pp collisions

→ **High ν energies**: E_ν $[10^2, 10^3]$ GeV, $\sigma_\nu \propto E_\nu$

Currently, two experiments in complementary ranges:

→ **FASERν** on axis: $\eta > 9$

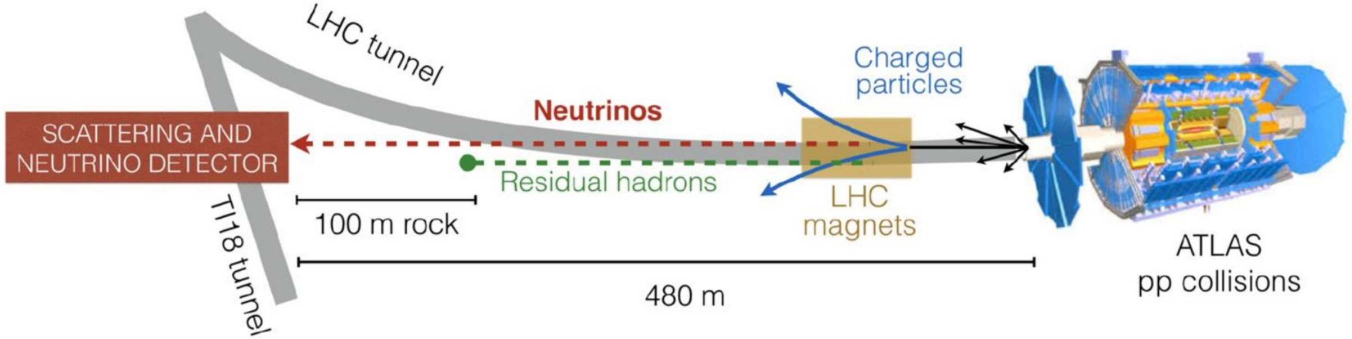
→ **S**cattering and **N**eutrino **D**etector **at the LHC** slightly off axis: $7.2 < \eta < 8.4$

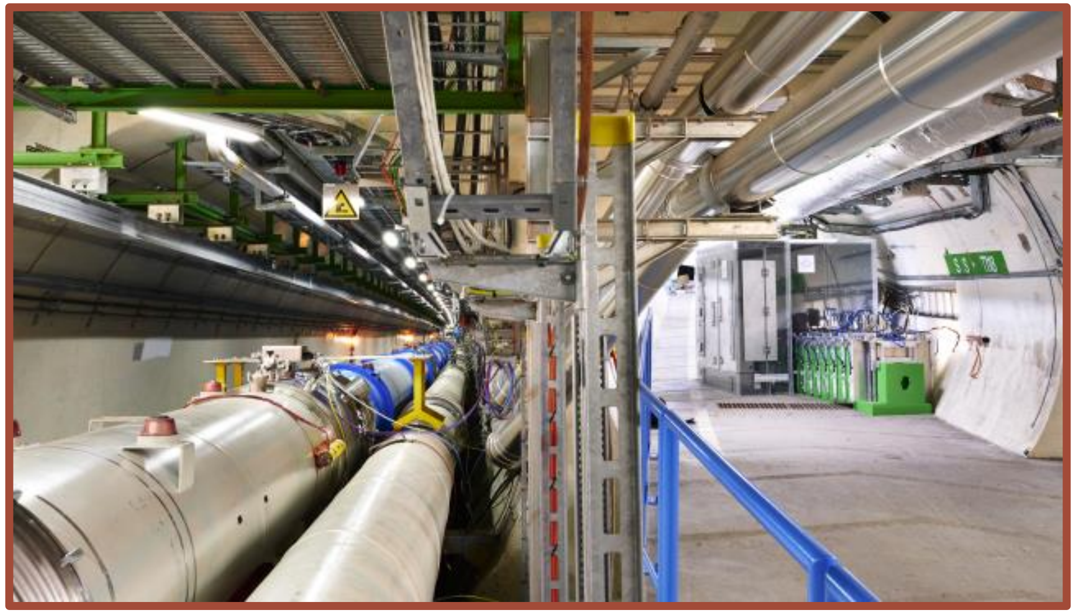


[1] Beni et al.,Physics Potential of an Experiment using LHC Neutrinos
[2] Beni et al, Further studies on the physics potential of an experiment using LHC neutrinos

The detector: location

480 m away from the ATLAS interaction point (IP1) in the TI18 tunnel



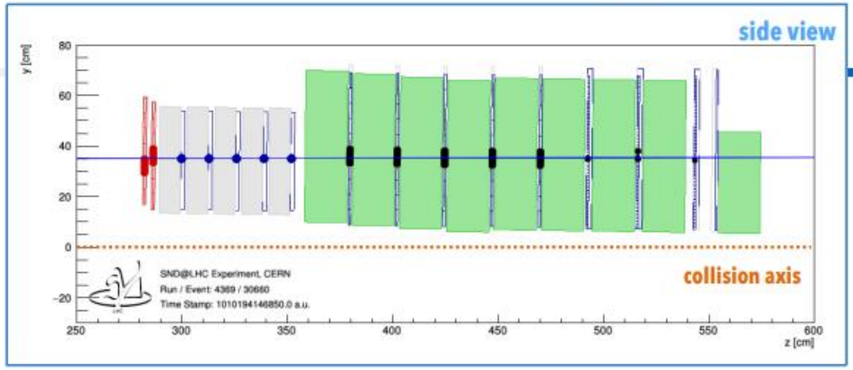


→ Shielded by **100 m rock**
→ **LHC magnet** deflects charged particles

Neutrinos and FIPs reach the detector
+
Muon background

Timeline

SND@LHC Event Display (6th of July 2022)



- **August 2020** *Letter of intent*
- **January 2021** *Technical Proposal*
- **March 2021** *Approval by CERN Research Board*
- **April 2022** *Beams Back in LHC*
- **July 2022** Run 3 starts ($\sqrt{s}$ 13.6 TeV)

September 2021

December 2021

March 2022

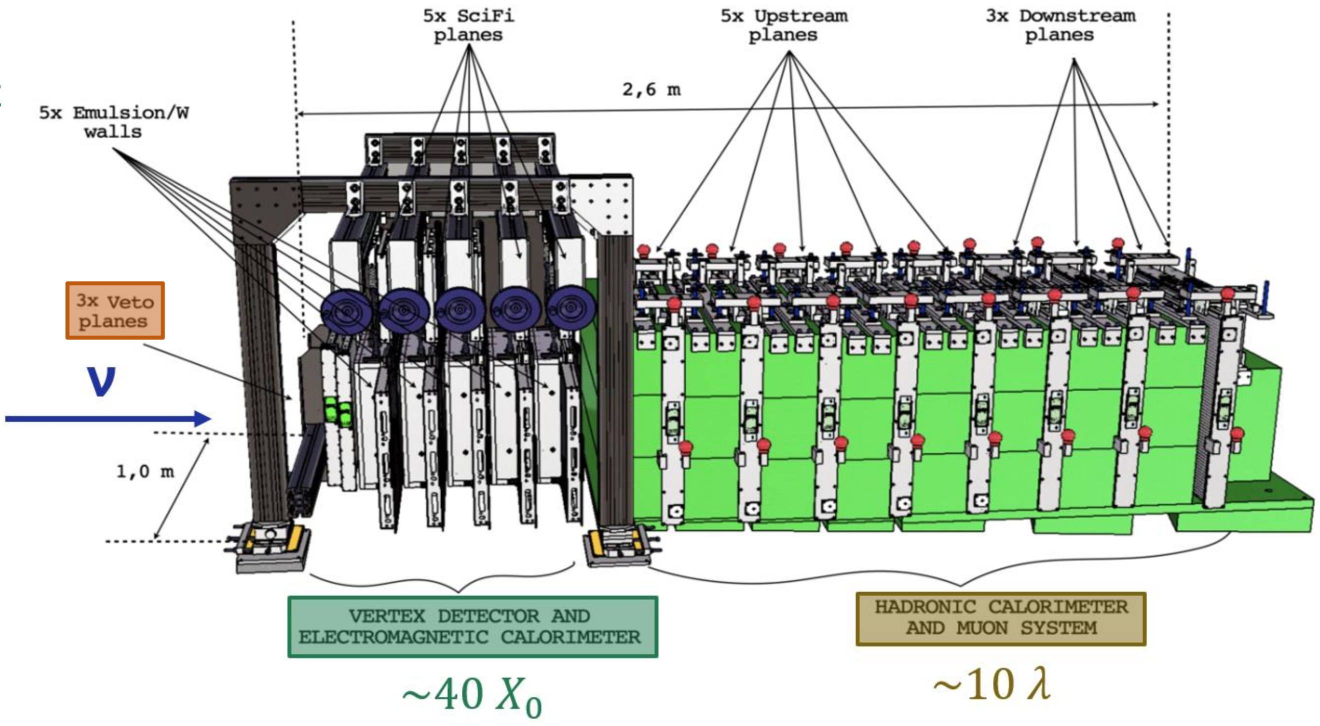
The detector: configuration

Hybrid detector composed of:

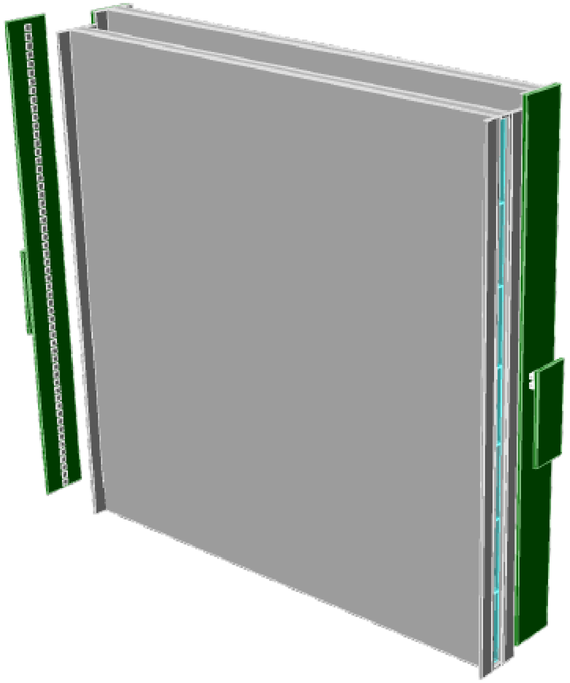
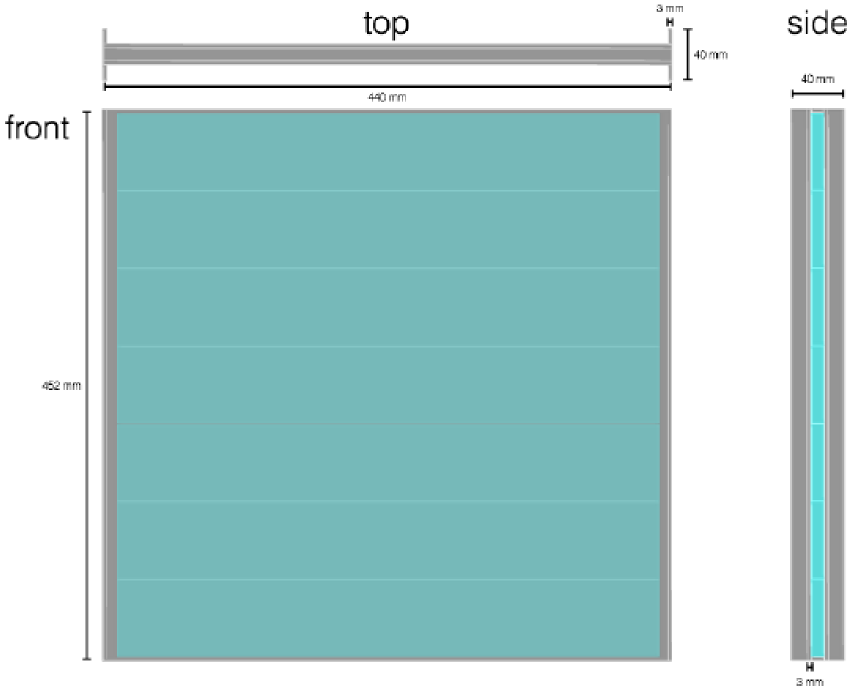
→ Veto system
  → 3 planes of scintillating bars **to tag incoming charged** particles

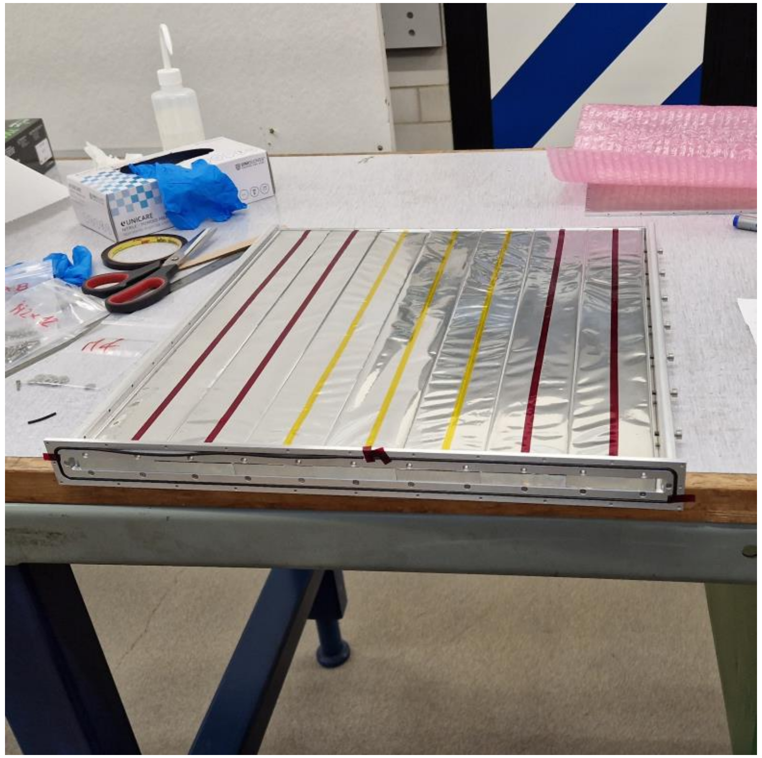
→ Target with vertex detector and electromagnetic calorimeter
  → Emulsion plates interleaved with tungsten (Emulsion cloud chamber) for **tracking and vertex identification**
  → Scintillating fibers (SciFi) for **time and calorimetric information**

→ Hadronic calorimeter and muon system
  → 5+3 scintillator planes read by SiPMs interleaved with iron
  → 5 US: horizontal bars, focus on **calorimeter**
  → 3 DS: horizontal and vertical bars, focus on **muon tracking**

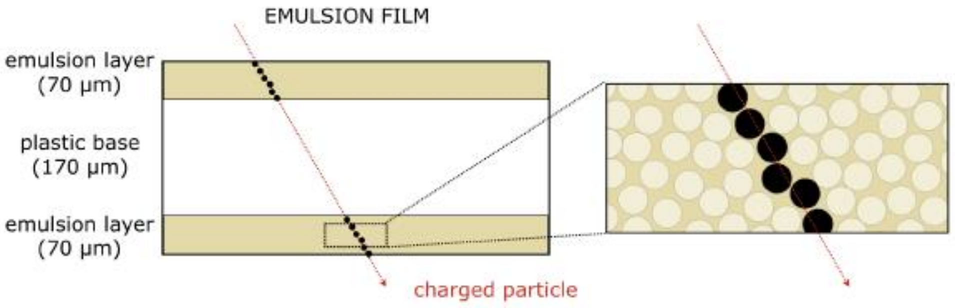


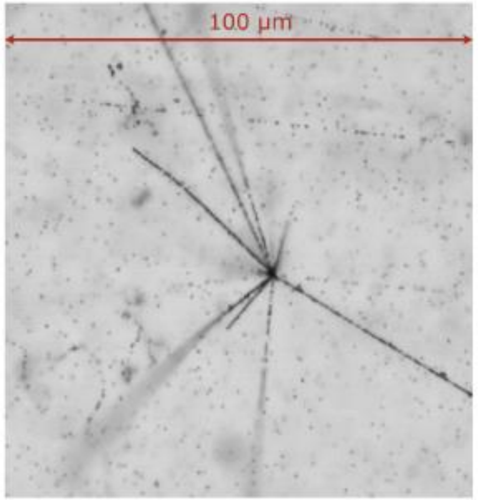
Veto

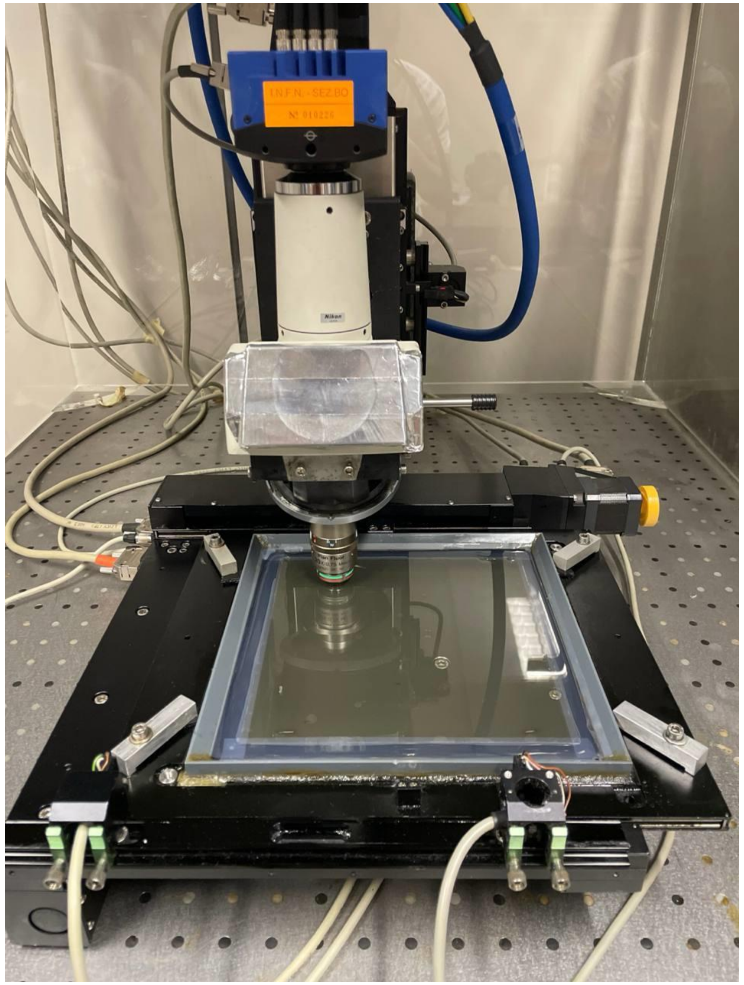





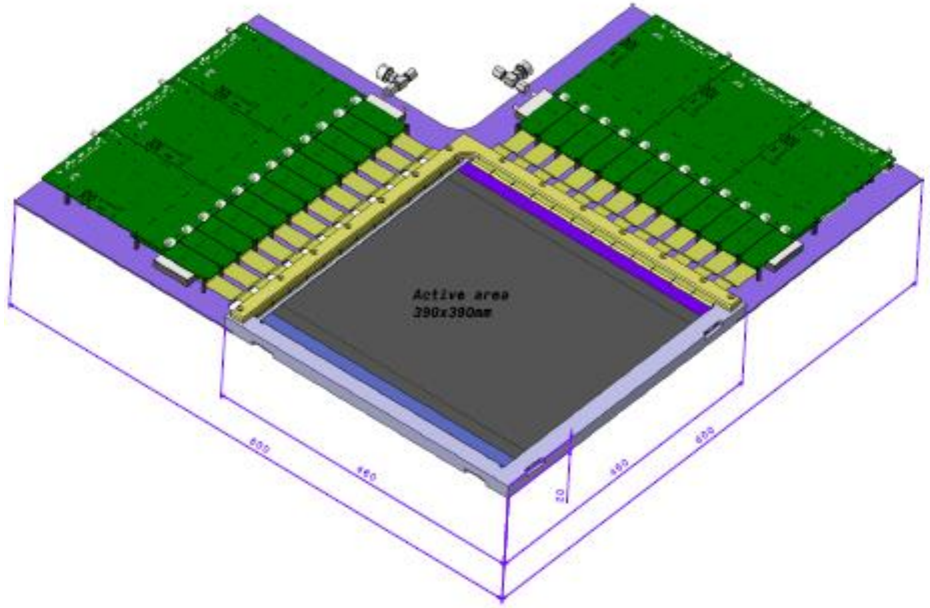
Emulsion cloud chambers



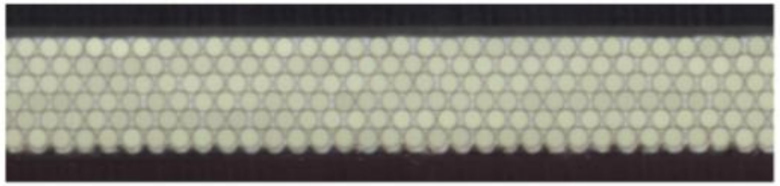


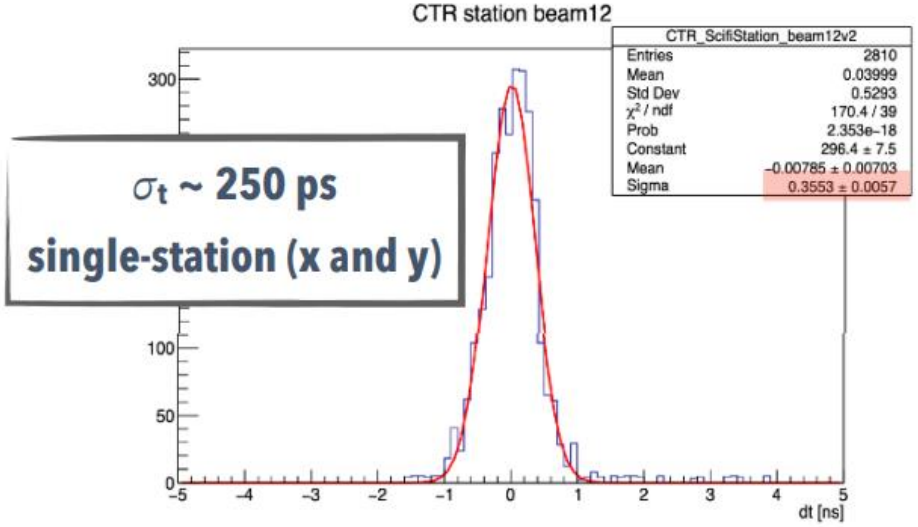


SciFi



~25 p.e. per MIP crossing mat





US and DS