LHC

Scattering and Neutrino Detector
at the LHC

SND@LHC upgrade plan

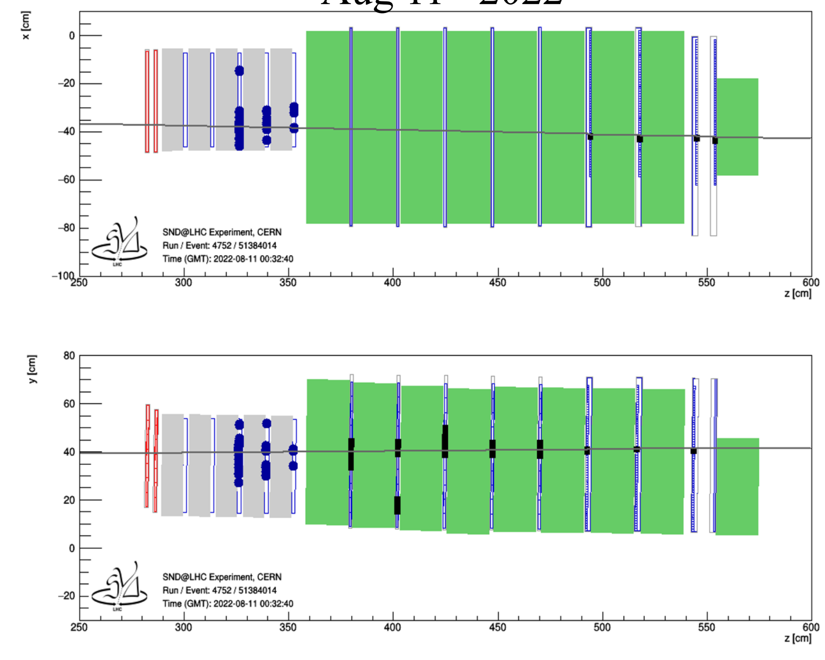
Giovanni De Lellis
On behalf of the SND@LHC Collaboration
PBC Annual Workshop, 25th Mar 2024

A few introductory remarks

- SND@LHC has taken data since the beginning of Run 3, integrating a luminosity of ~70 fb-1
- With the data collected in 2022, the Collaboration reported the observation of muon neutrinos, together with FASER, paving the way for ν physics at LHC
- The short timespan between approval (March 2021) and data taking (April 2022) did not allow for any civil engineering in the TI18 cavern
- Run 3 measurements will be statistically limited, given the geometrical constraints of the current detector and the expected integrated luminosity
- The Collaboration would like to continue with an improved detector in Run4
- This triggered the investigation of TI18 for the upgraded detector in Run4
- The acceptance in TI18 can be made optimal for the physics program, which is important for the Collaboration

Observation of collider muon neutrinos with 2022 data

Aug 11th 2022

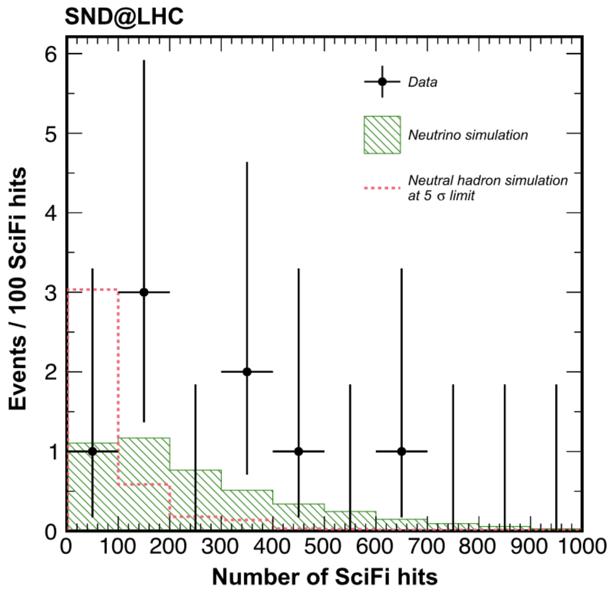


Editors' Suggestion

Observation of Collider Muon Neutrinos with the SND@LHC Experiment

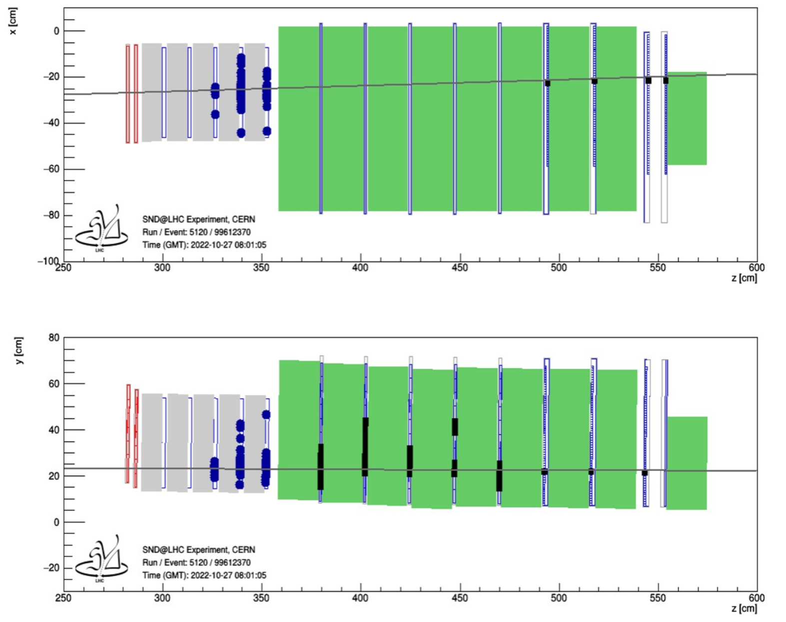
R. Albanese *et al.* (SND@LHC Collaboration)

Phys. Rev. Lett. **131**, 031802 (2023) – Published 19 July 2023



Distribution of SciFi hits for ν_μ candidates with the MC expectation for ν events and background (augmented to the 5 sigma level)

Oct 27th 2022



8 observed events and an expected background

$$(8.6 \pm 3.8) \times 10^{-2}$$

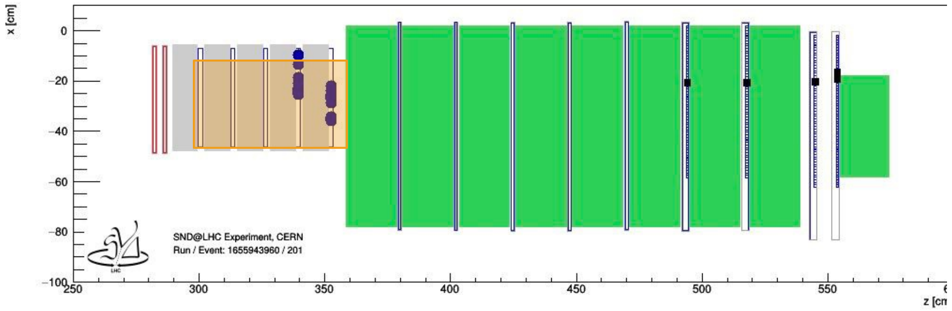
Background only hypothesis probability:

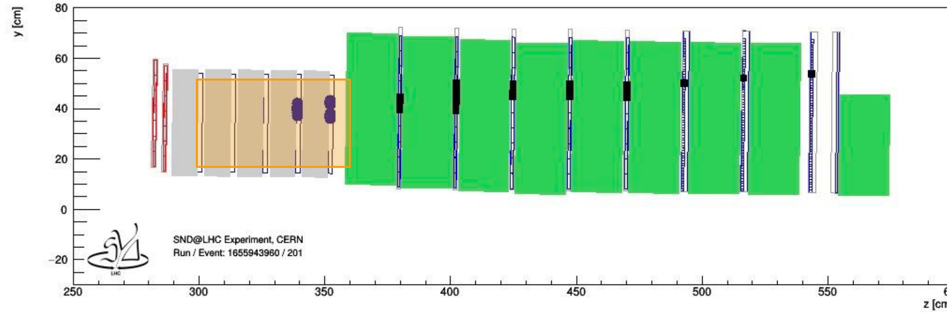
$$P = 7.15 \times 10^{-12}$$

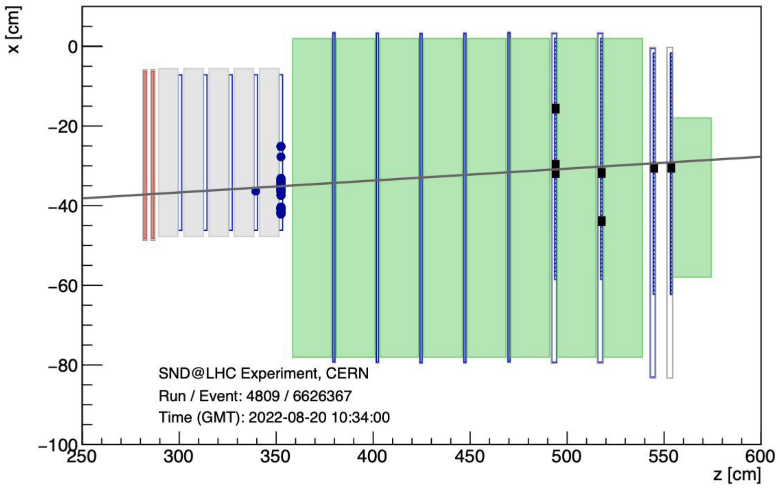
6.8 σ observation

https://journals.aps.org/prl/abstract/10.1103/PhysRevLett.131.031802

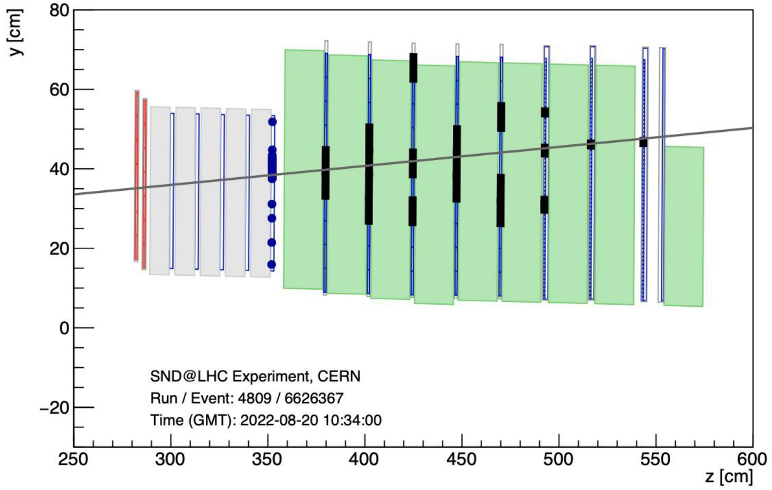
ν_μ CC selection with 2022-2023 data
in an extended volume (wall 2 and 5 included)

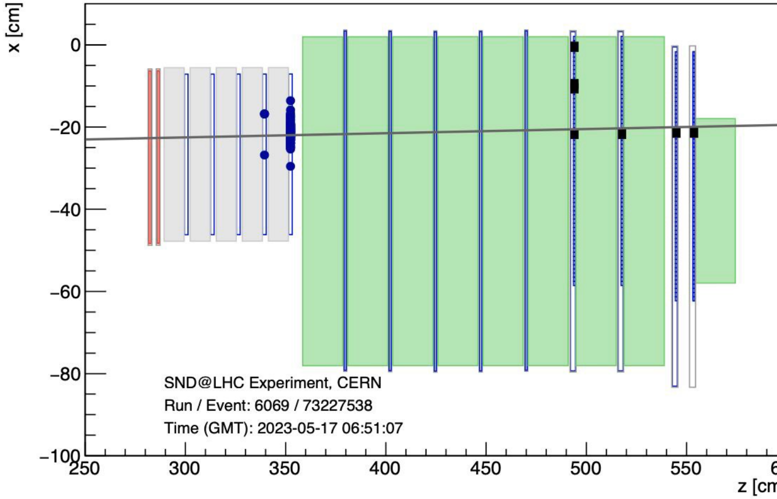




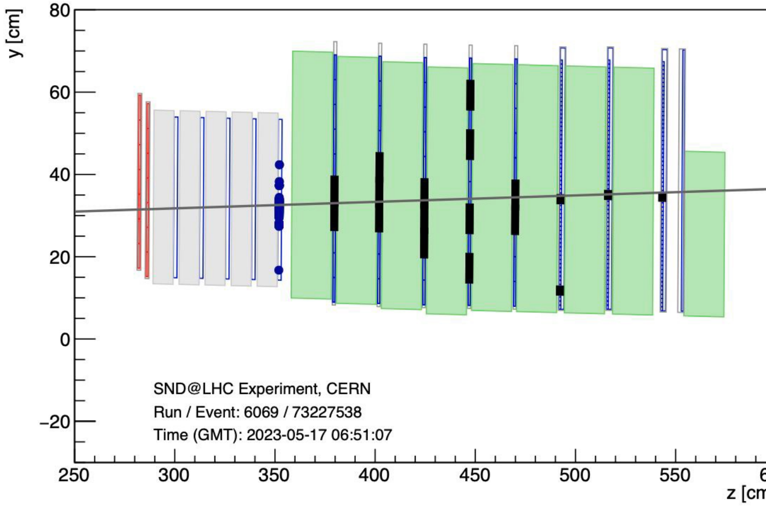


New 2022 event





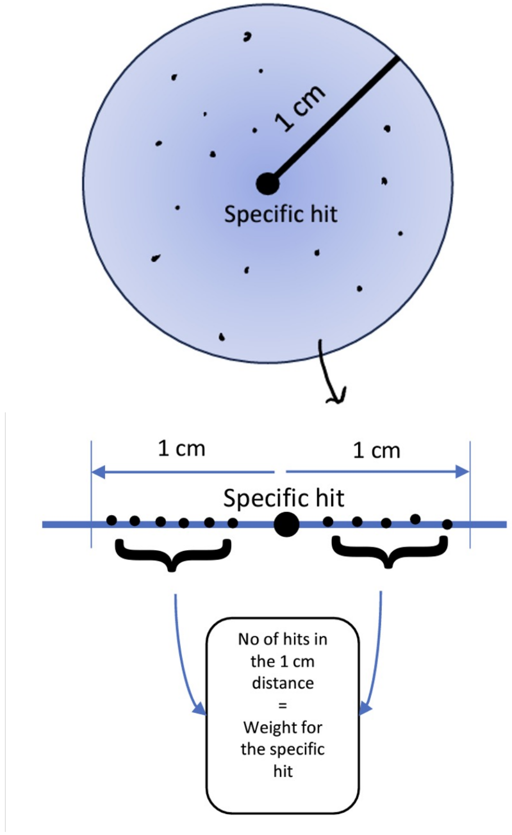
2023 event



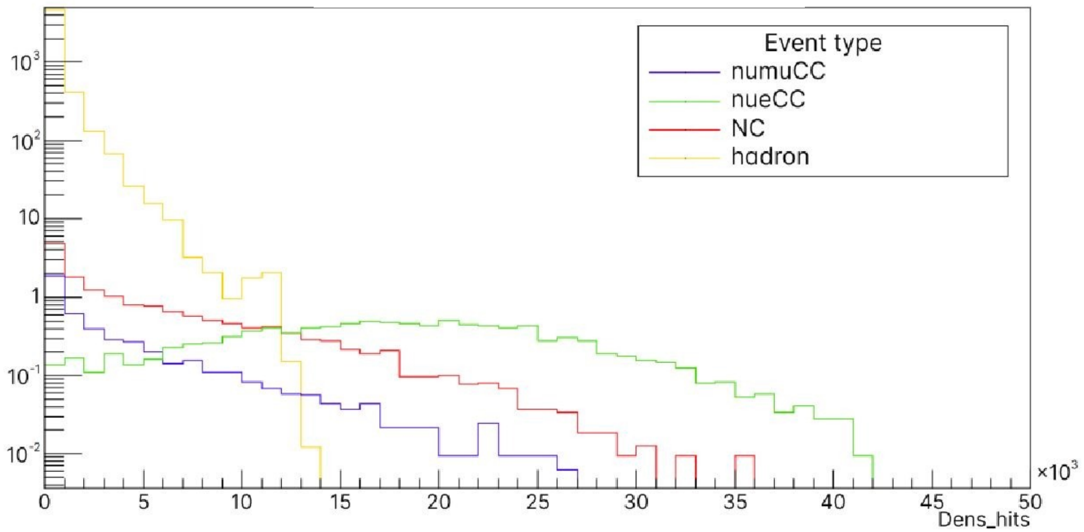
32 events: 15 in 2022 and 17 in 2023
expected events (DPMJET): 19

Results will be disclosed at winter conferences

Electron neutrino and neutral current identification



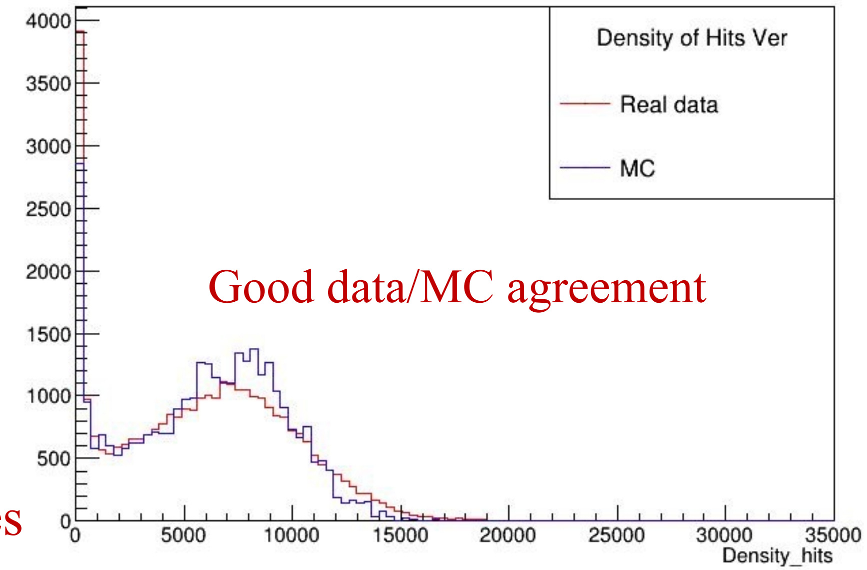
Hit density distribution



- Density of his > 12000
  - negligible neutral hadron background
- Density of hits > 25000
  - dominated by ν_e CC events

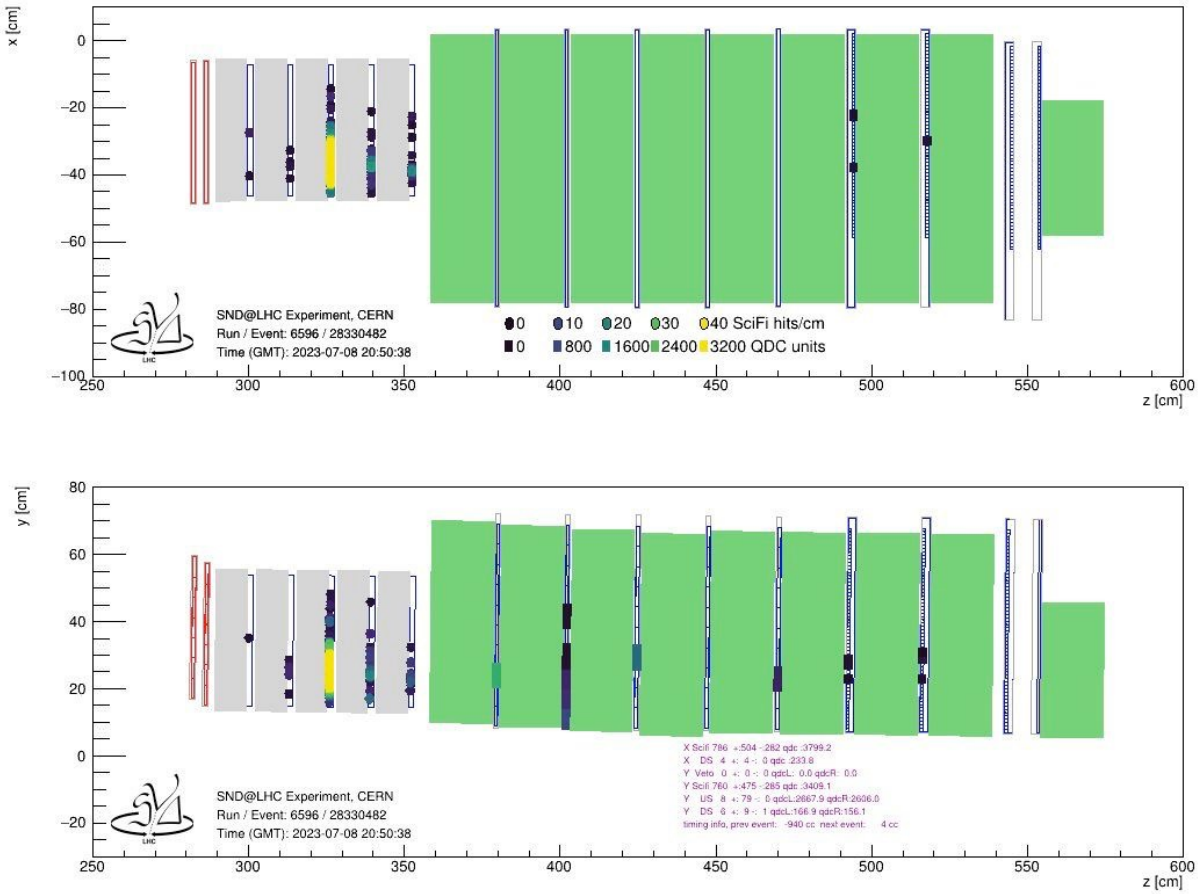
- Signal selection based on topological and calorimetric information
- Discriminating variable: density of hits in SciFi

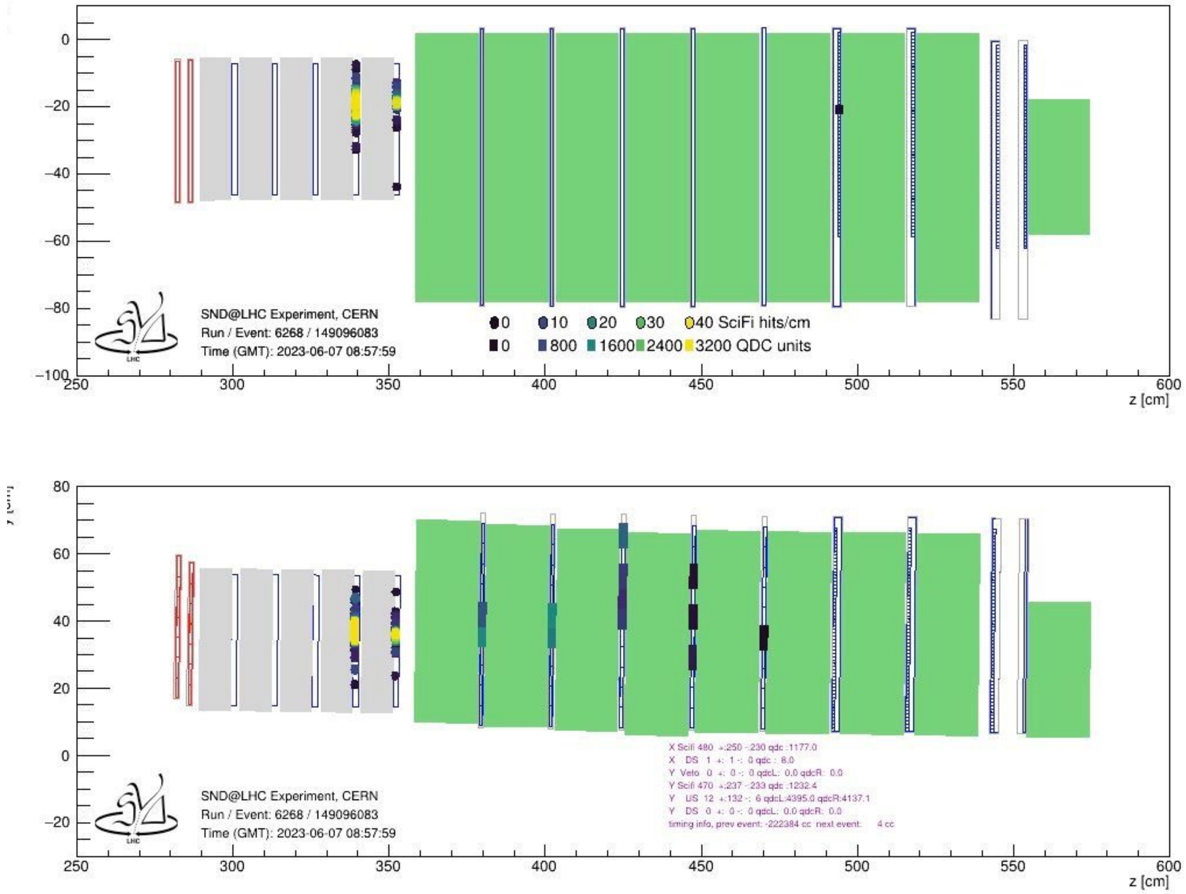
SciFi hit density distribution in Test Beam



Results will be disclosed at winter conferences

ν_e-ν_{NC} candidate events

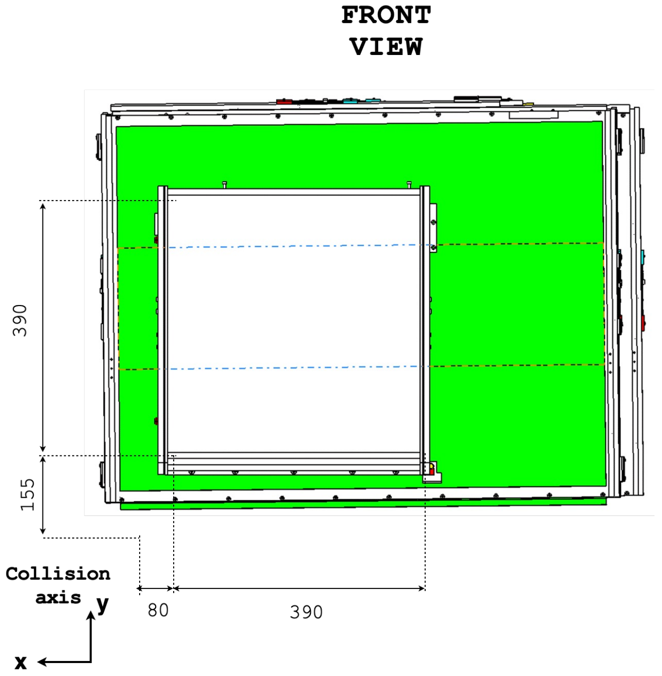




SND@LHC: an off-axis detector. Current layout

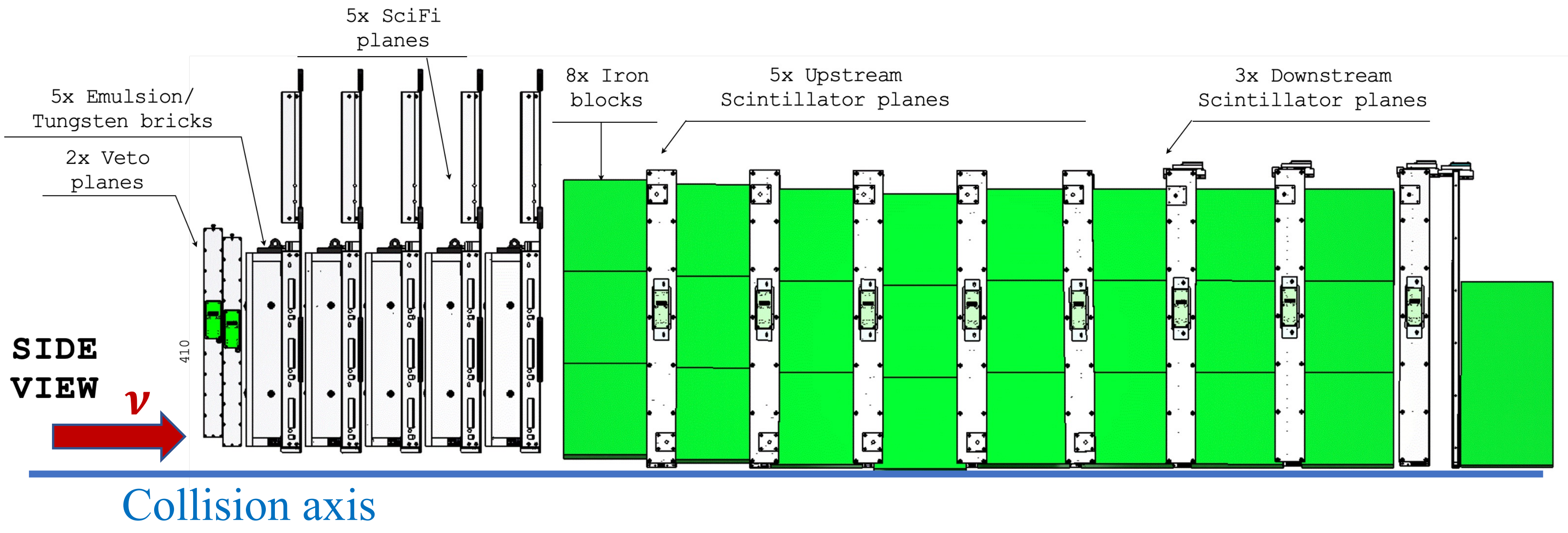
- Angular acceptance: $7.2 < \eta < 8.4$
- Target material: Tungsten
- Target mass: 830 kg
- Surface: 390x390 mm^2

Off axis location



Electromagnetic calorimeter ~40 X_0

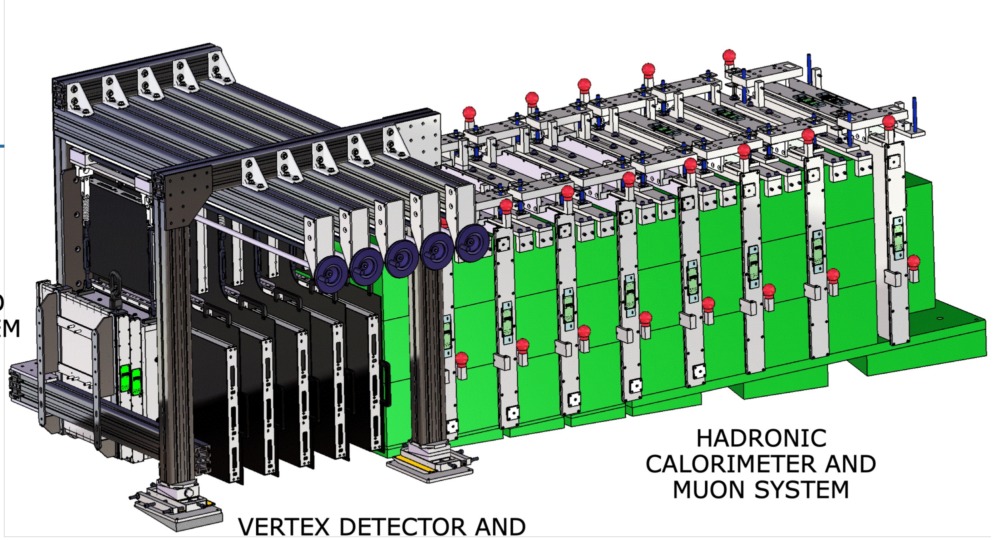
Hadronic calorimeter ~11 λ



Current limitations from the azimuthal angle coverage and from the sloping floor → severely limiting the Run 3 statistics

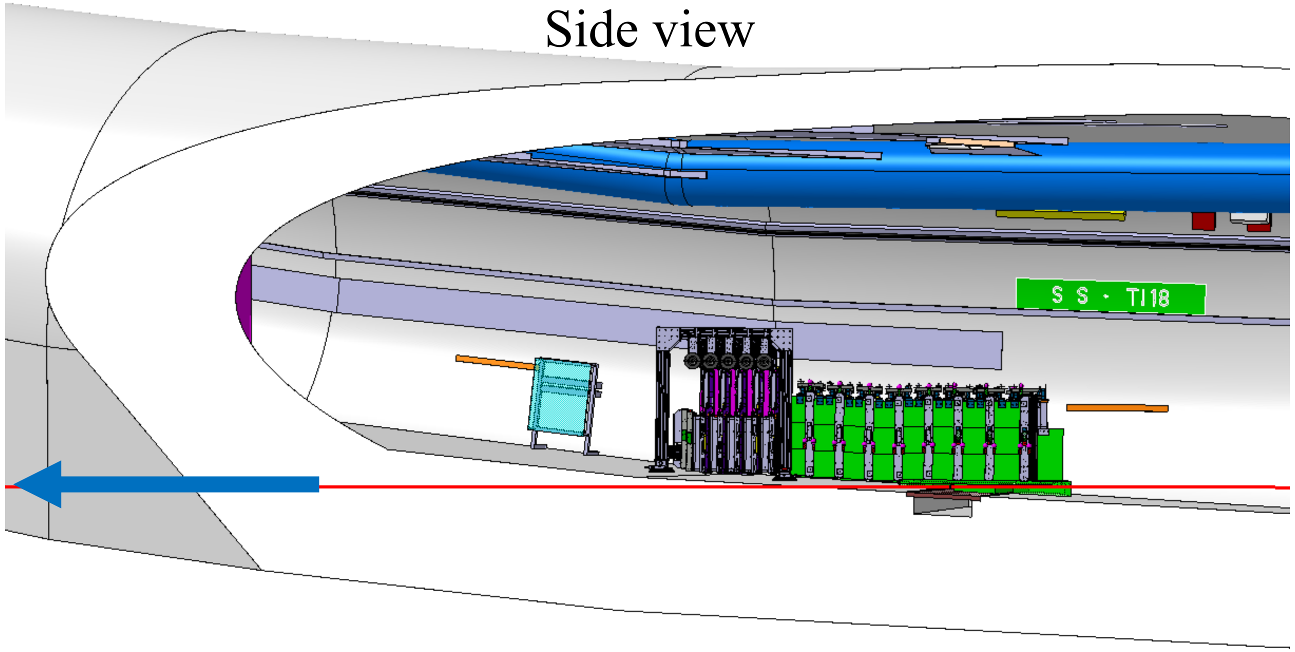
Current geometrical limitations

Longitudinal development limited by the sloping floor and wall
→ no space for a magnet → limiting the physics performance

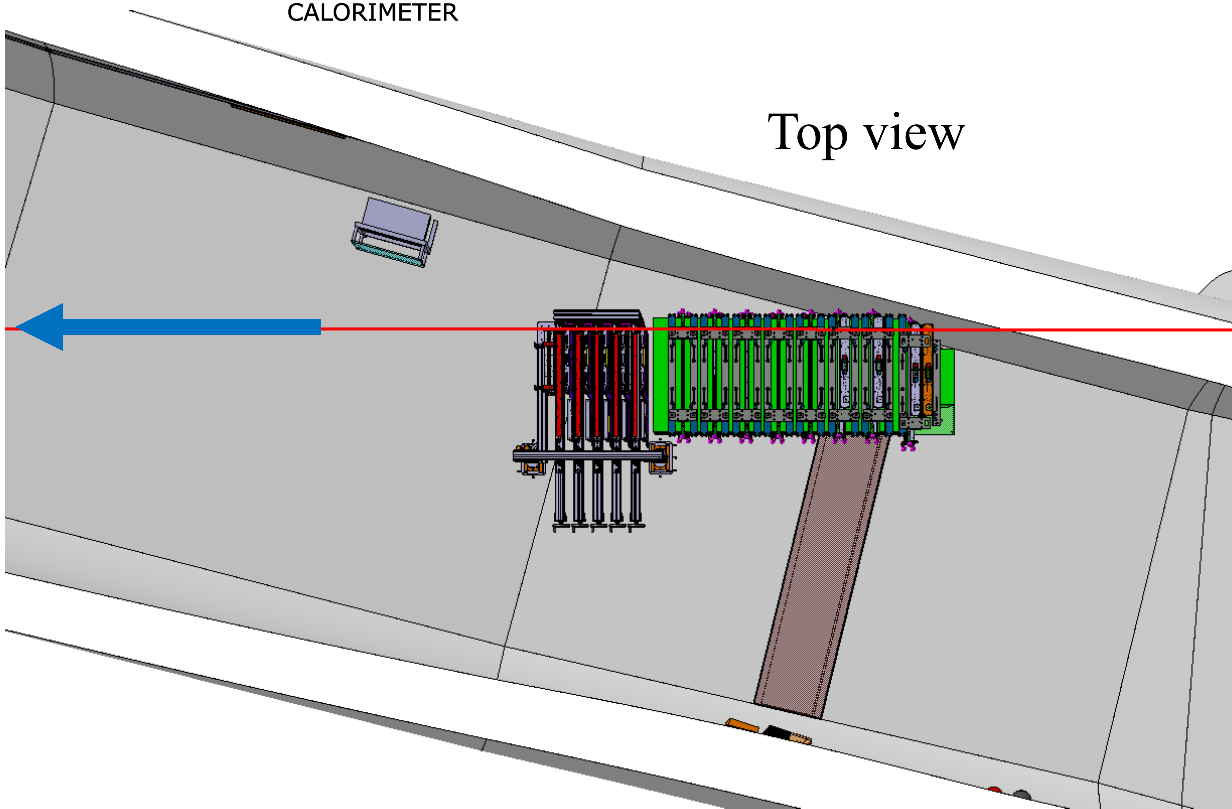


Scattering and Neutrino Detector at the LHC

Side view



Top view



Detector(s) concept to extend the physics case in HL-LHC

LHC
Scattering and Neutrino Detector at the LHC

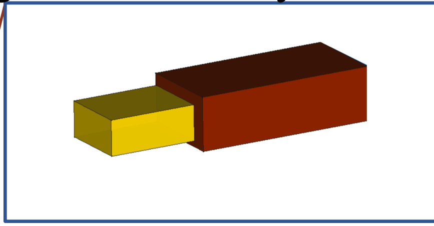
AdvSND-Far in TI18 (Run 4)

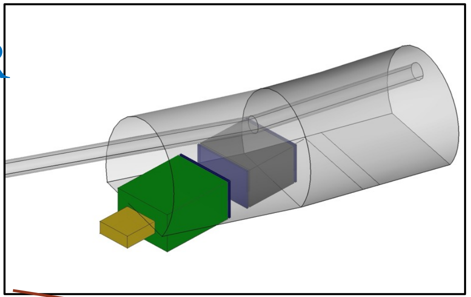
- Improve statistics, reduce systematics
- Separate ν from ν-bar
- Charm production measurements
- LFU

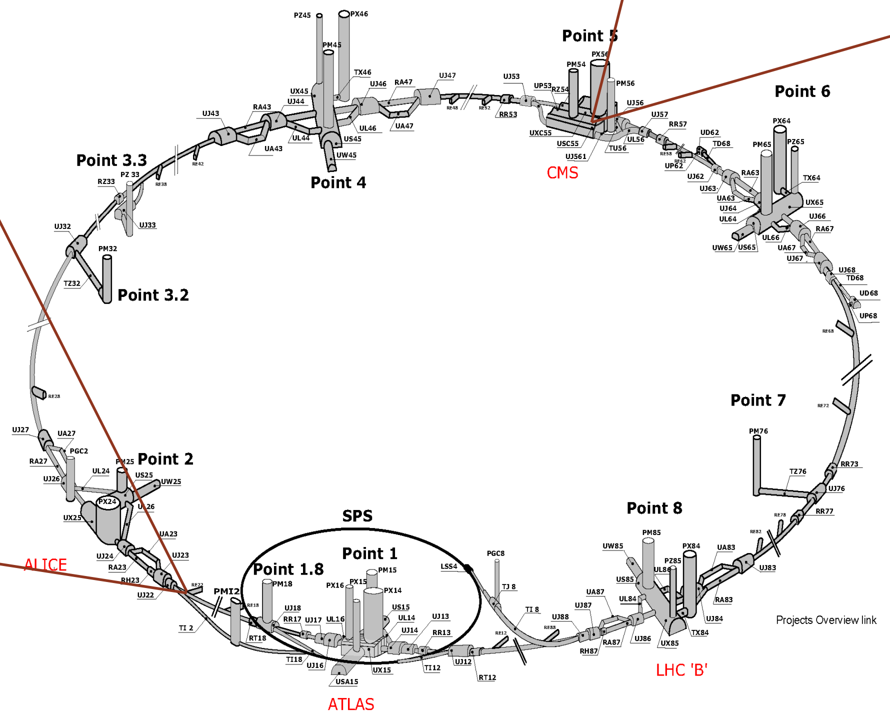
AdvSND-Near in UJ57/UJ56 (Beyond Run4)

- Overlap with LHCb η where c/b measured
- Reduce sys uncertainties for the FAR
- ν cross-section

AdvSND-Near: $4.0 < \eta < 4.5$
Other η region covered by LHCb



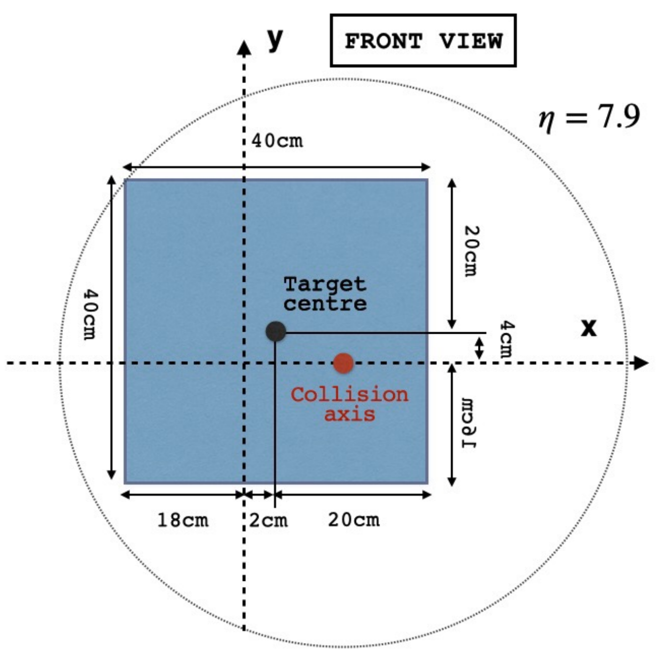


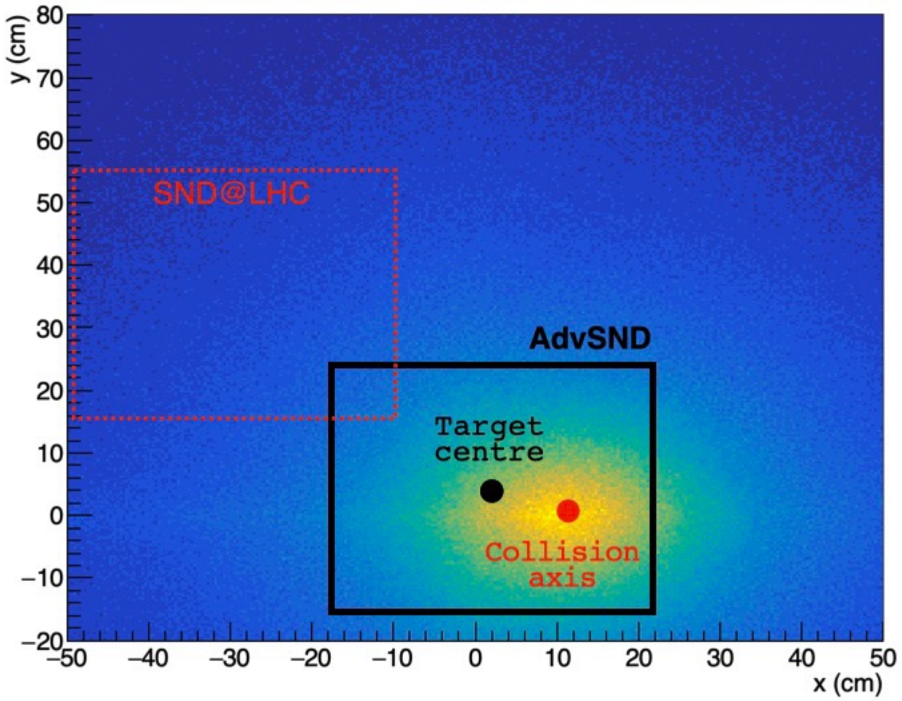


AdvSND-Far: $\eta > 7.9$

Geometrical configuration in Run 4: off-axis with an improved acceptance to cope with statistical limitations of Run 3

CROSSING ANGLE:
+250 µrad Horizontal





Account for the crossing angle in the horizontal plane in Run 4

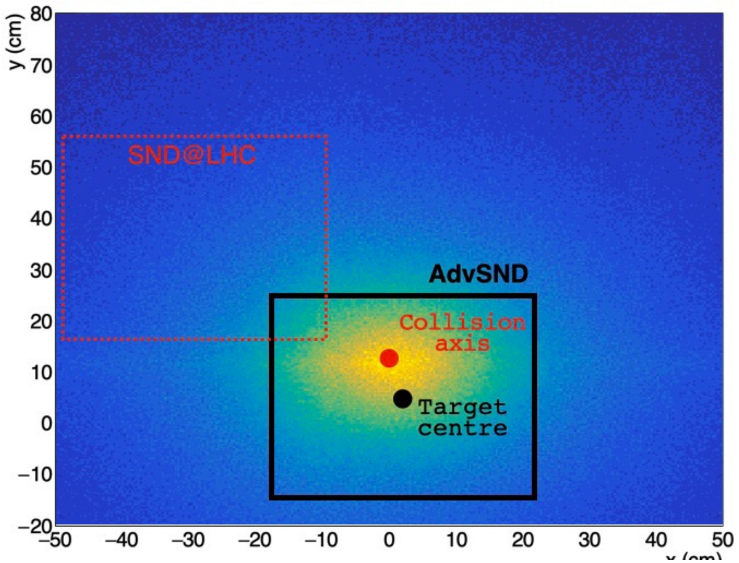
Main points of the upgrade:

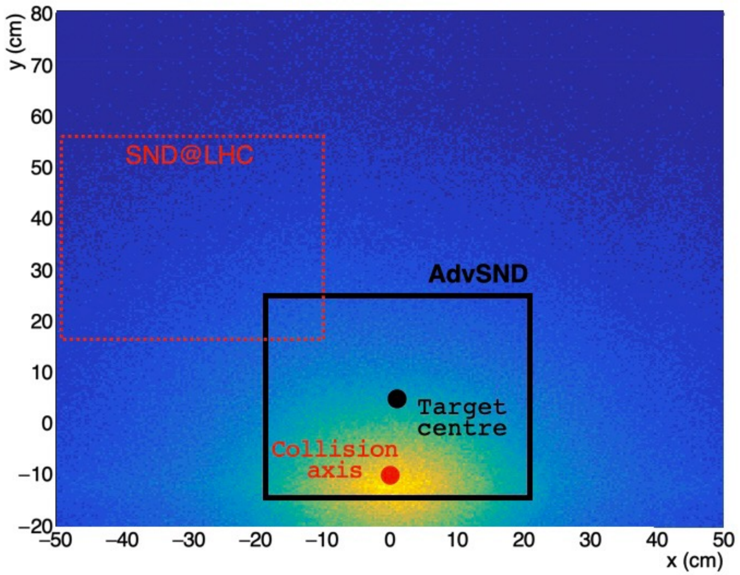
Better transverse position while keeping the off-axis characterization (and some useful overlap with FASER)

Replace emulsion technology in the target to withstand the high µ-rate of HL-LHC without need for frequent access as it is in Run 3

Add a magnetised spectrometer for the muon charge and momentum measurement (energy and ν/ν-bar separation)

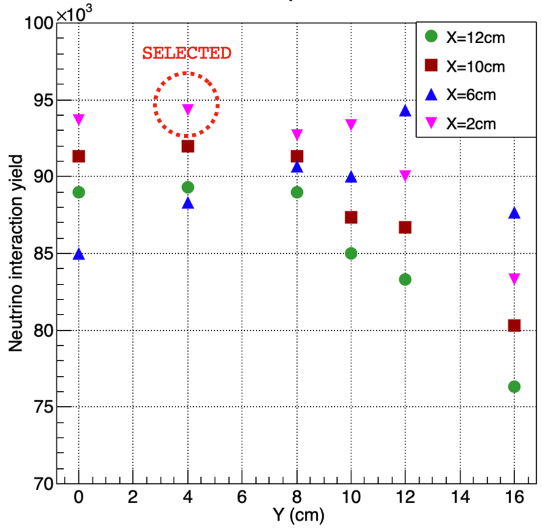
Crossing angle and optimal detector configuration



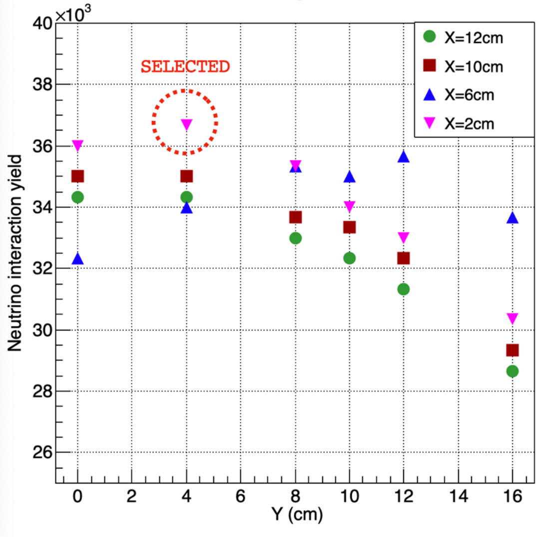


Beyond Run 4 the crossing angle can change from the H to V plane

ν_μ

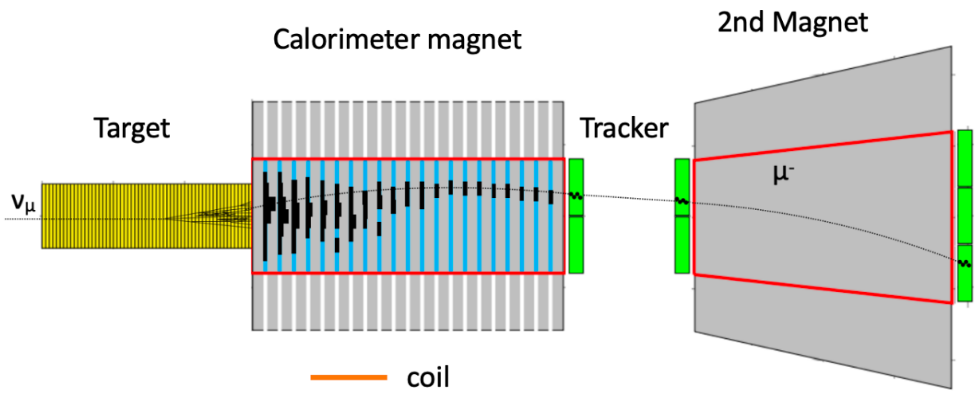


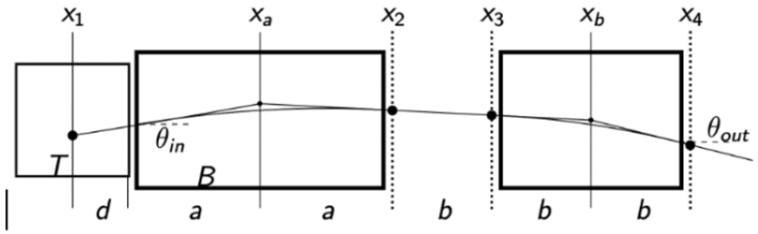
ν_e

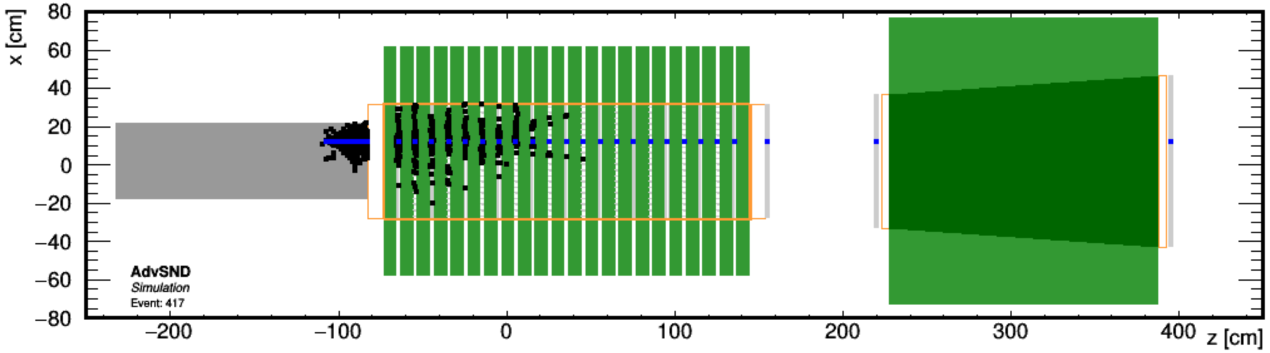


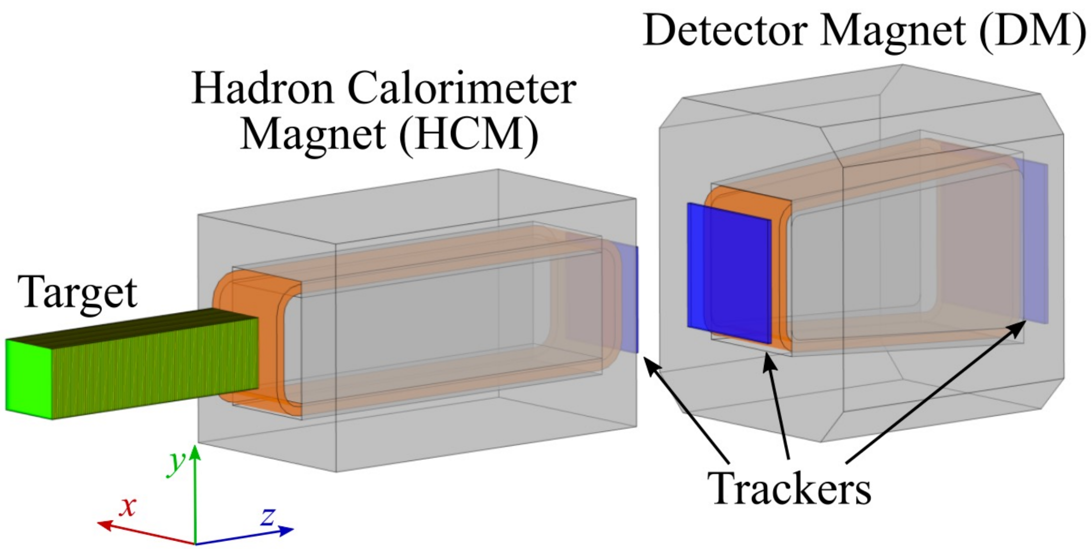
The chosen configuration maximises the average of the three possible configurations for all neutrino species as well as for those produced in charmed hadron decays

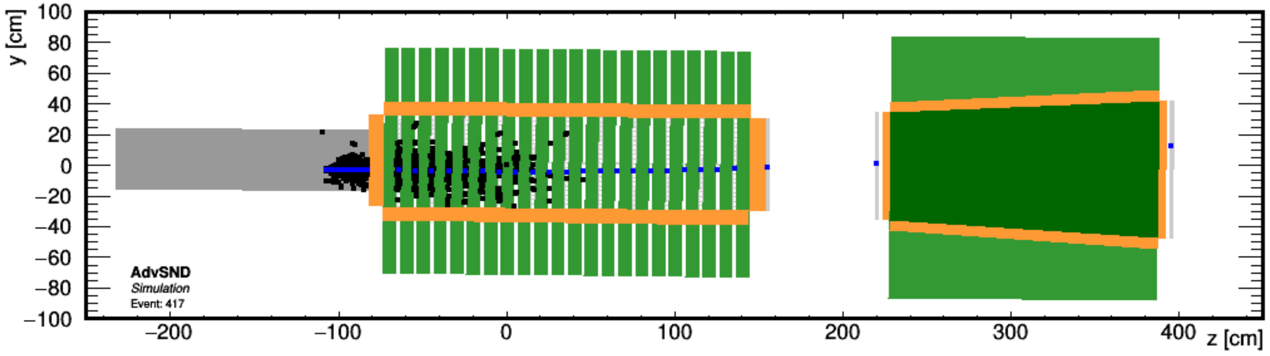
Overview of the upgraded detector



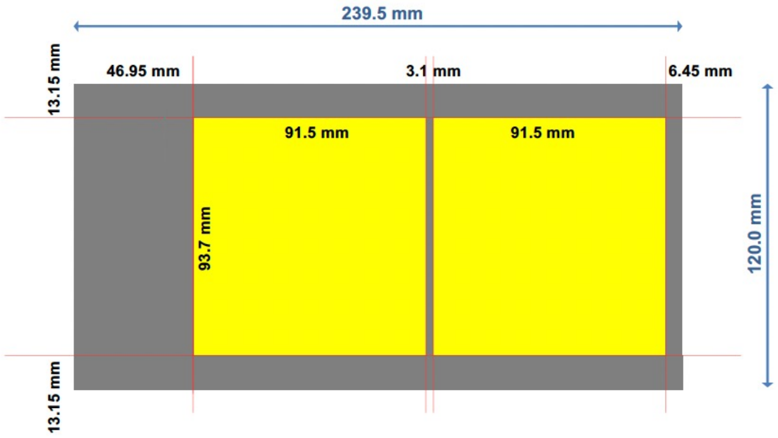






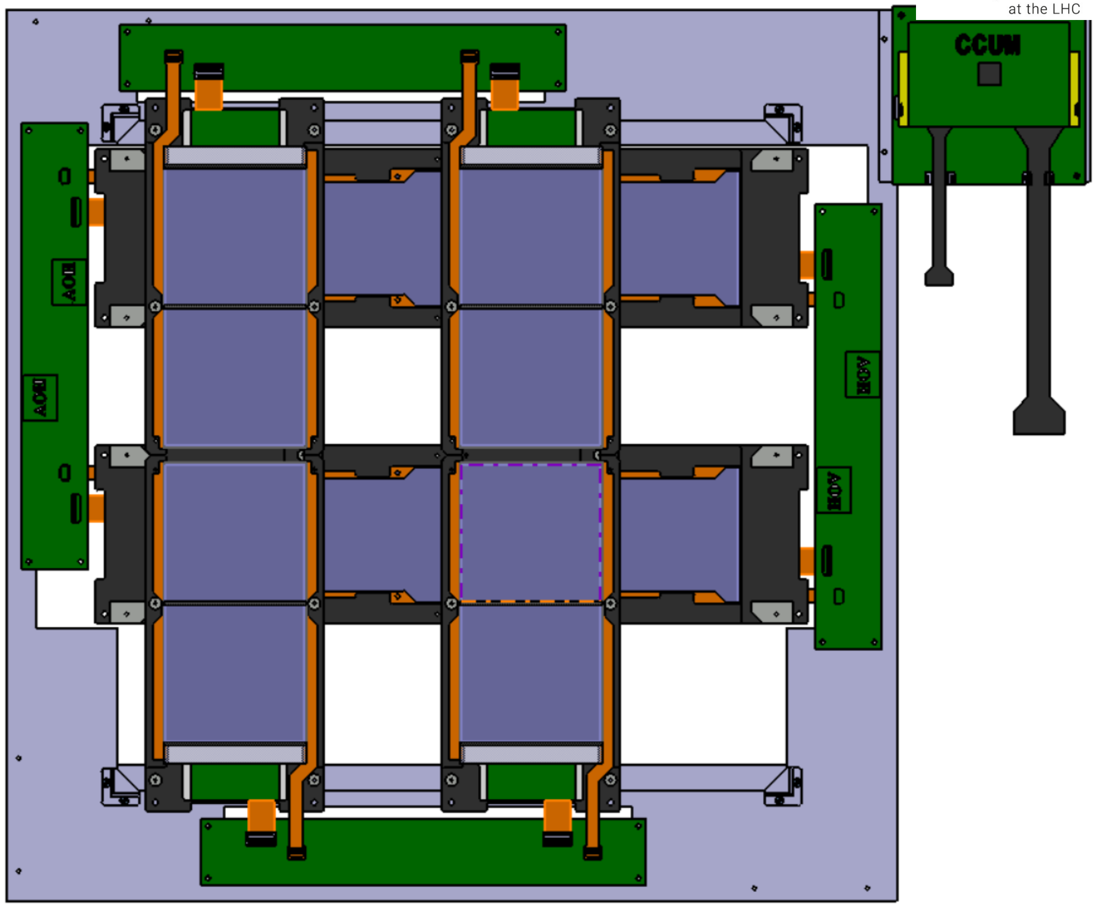


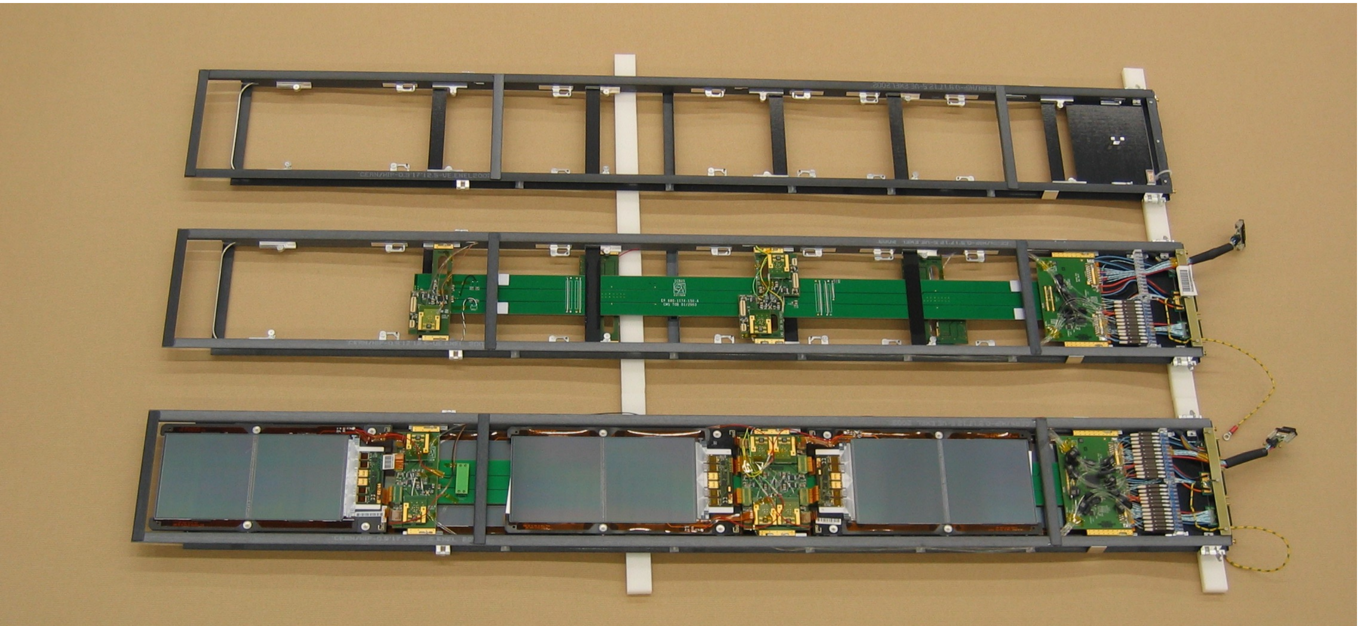
CMS silicon trackers as a vertex/ECAL detector



One module

One station with 8 modules (shown without the embedded tungsten plates)

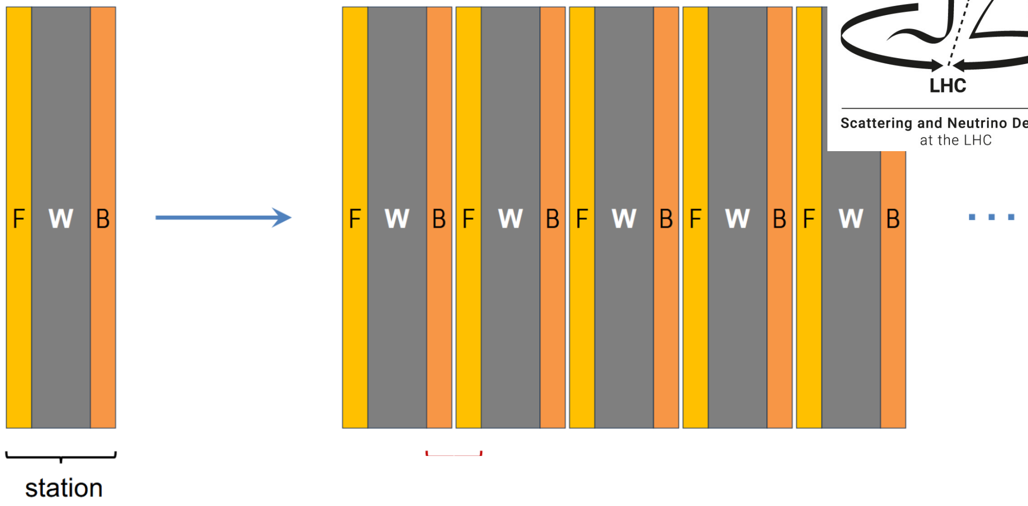


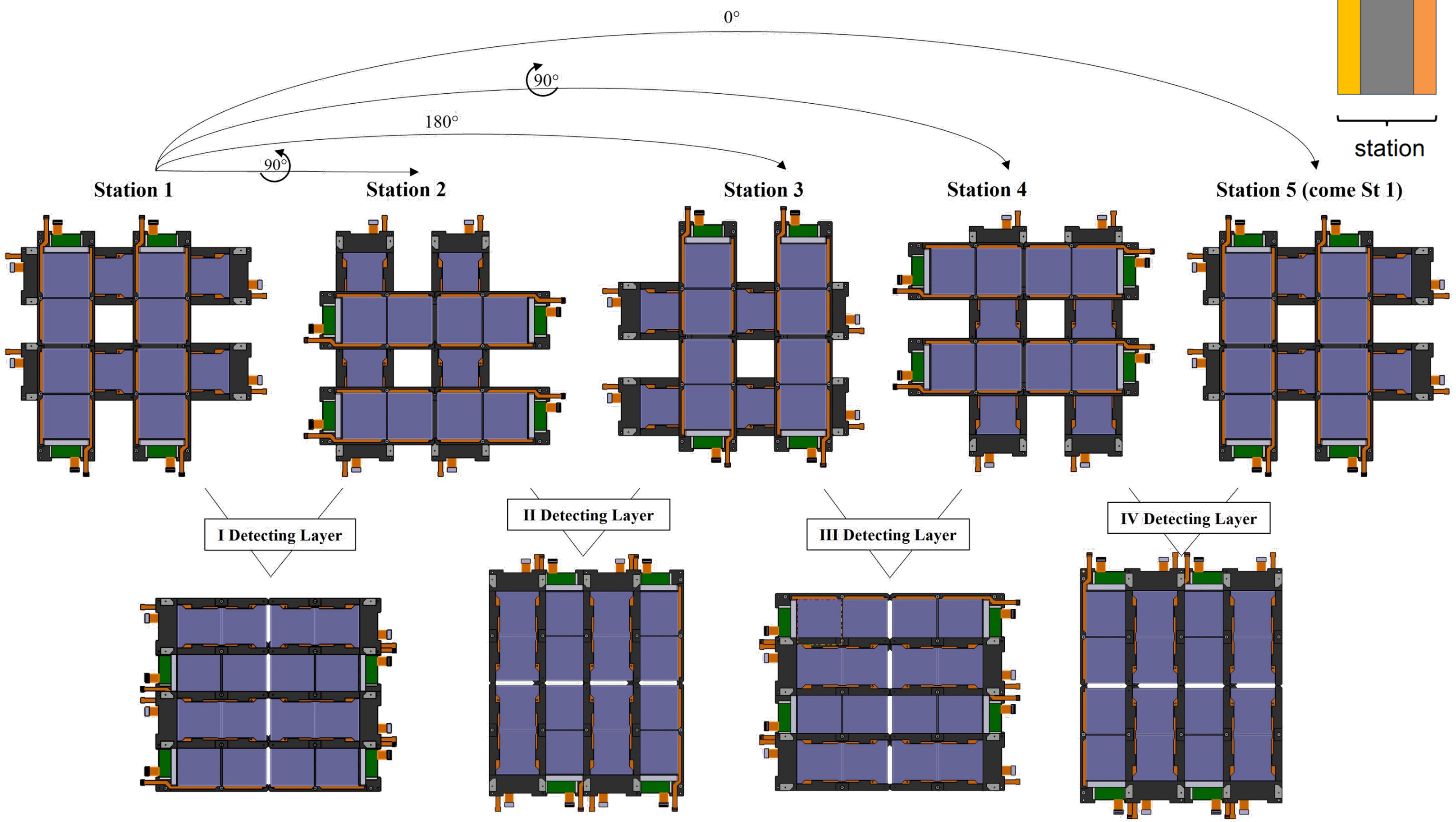


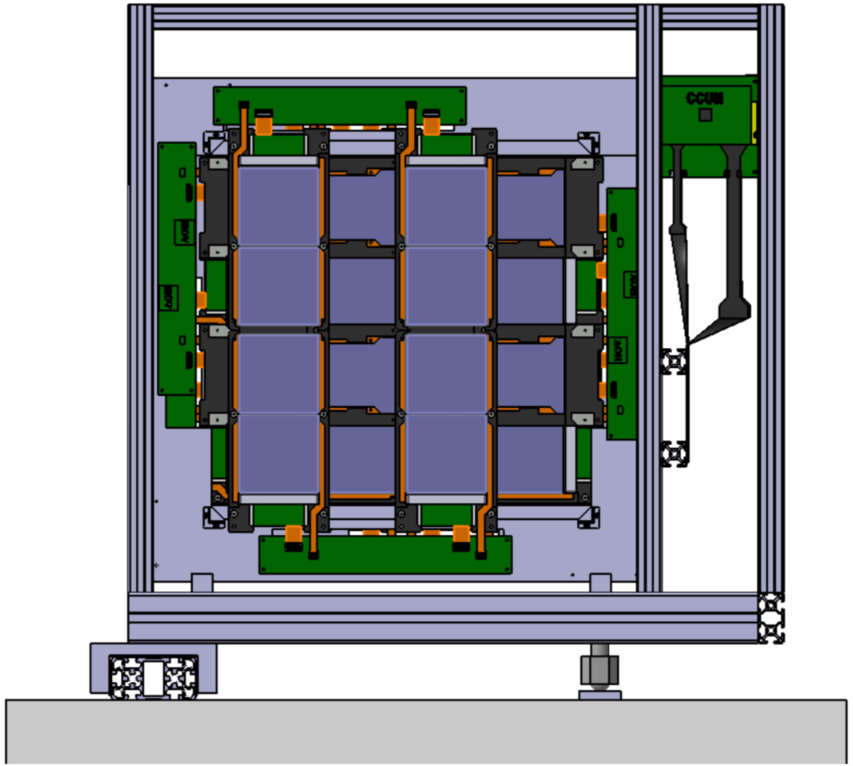
Agreement with CMS to reuse their TOB modules
(and their spare components)
approved by the CMS Board on Feb 9th 2024

Structure of the different stations

One detecting layer is “hermetic”





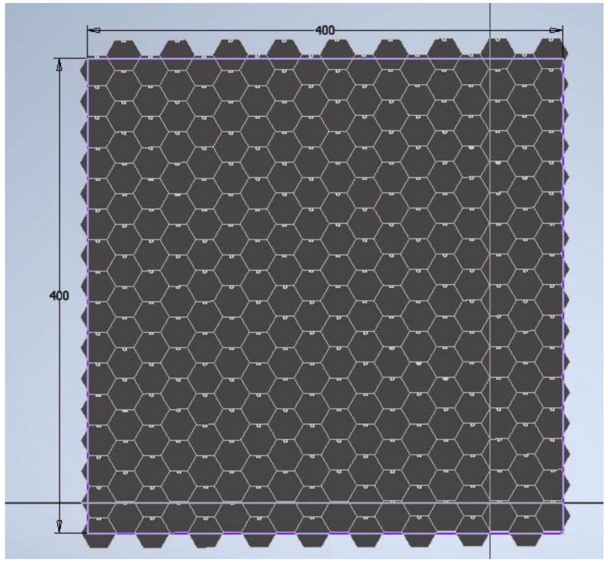


LHC
Scattering and Neutrino Detector
at the LHC

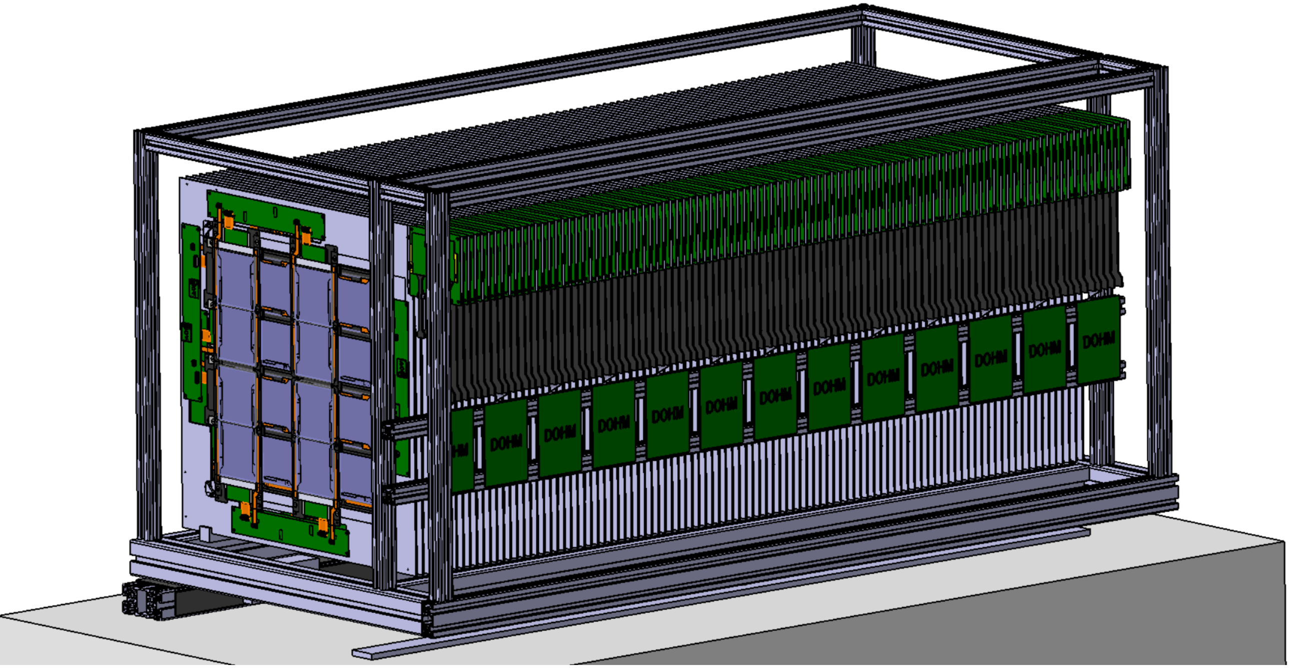
Neutrino target with VTX/Ecal and timing detector

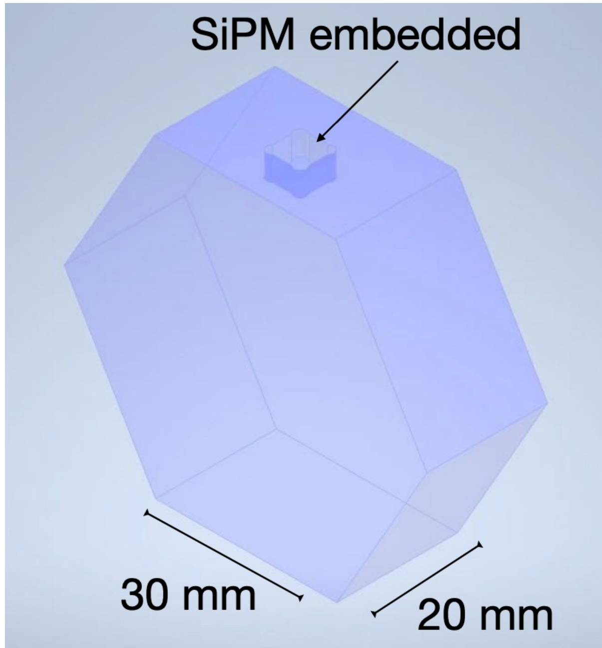
Property	EJ-204
τ_{decay} [ns]	1.8
Light Yield [kγ/MeV e-]	10.4

Timing planes with
~50 ps resolution



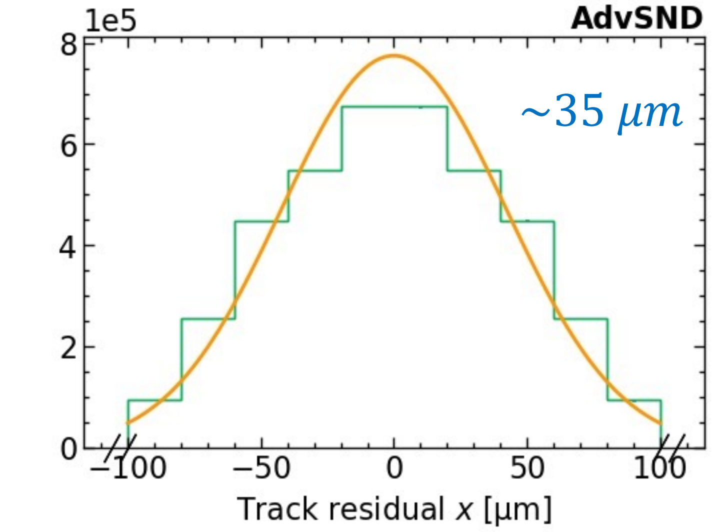
- Prototype under construction with spare modules
- Ecal performance will be tested in Summer

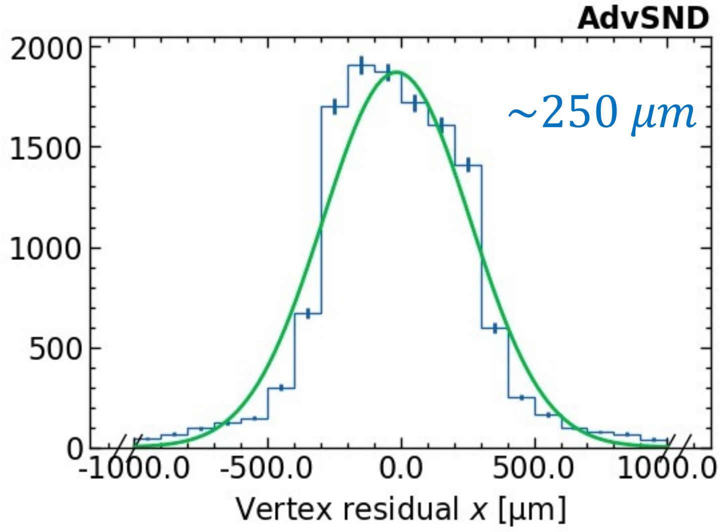


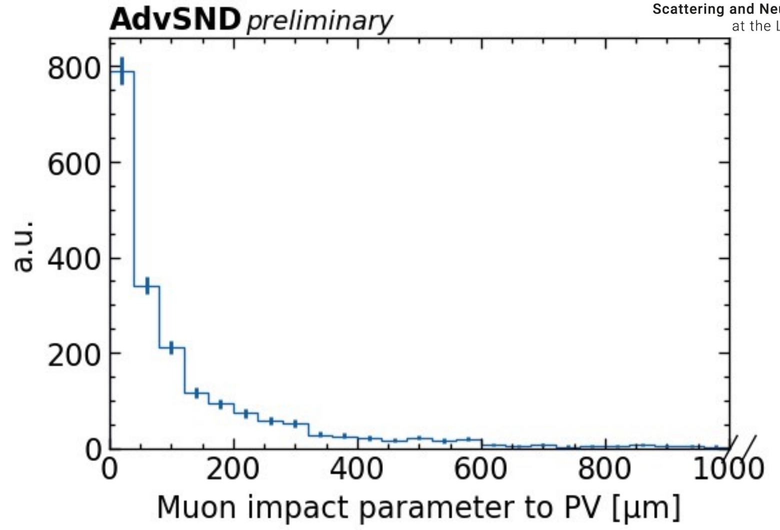


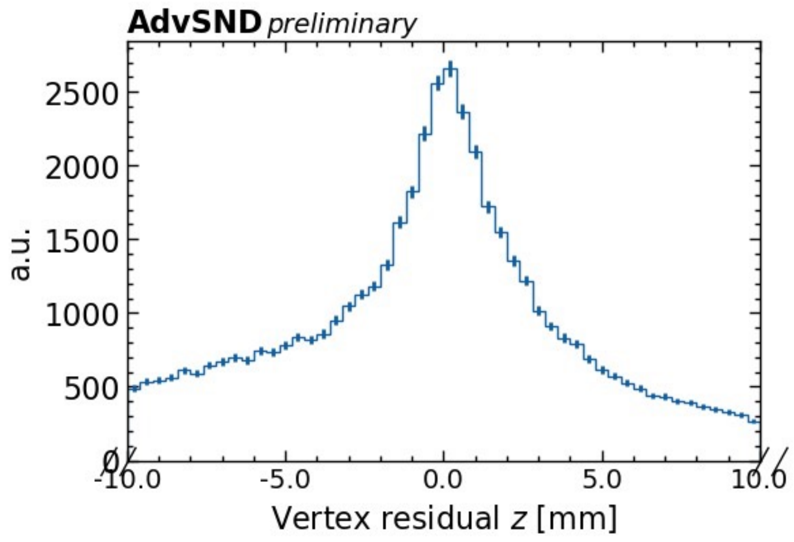
R&D on MOnolithic Stitched Sensor (MOSS) ongoing

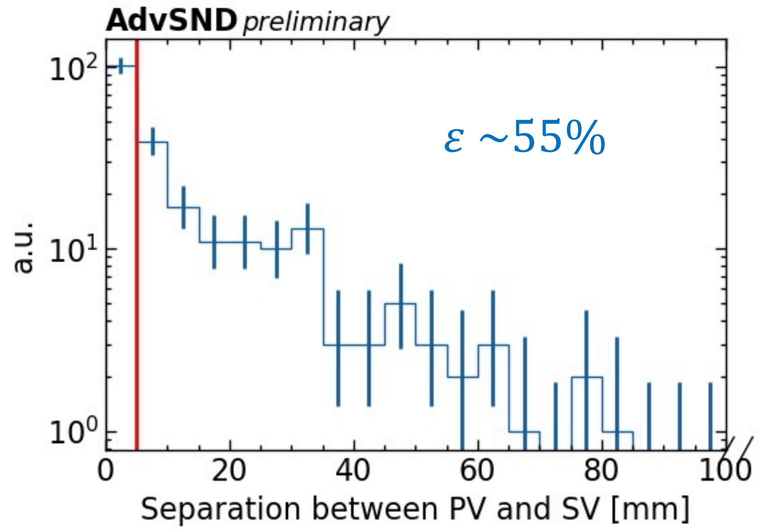
Some performance plots of the VTX/ECAL

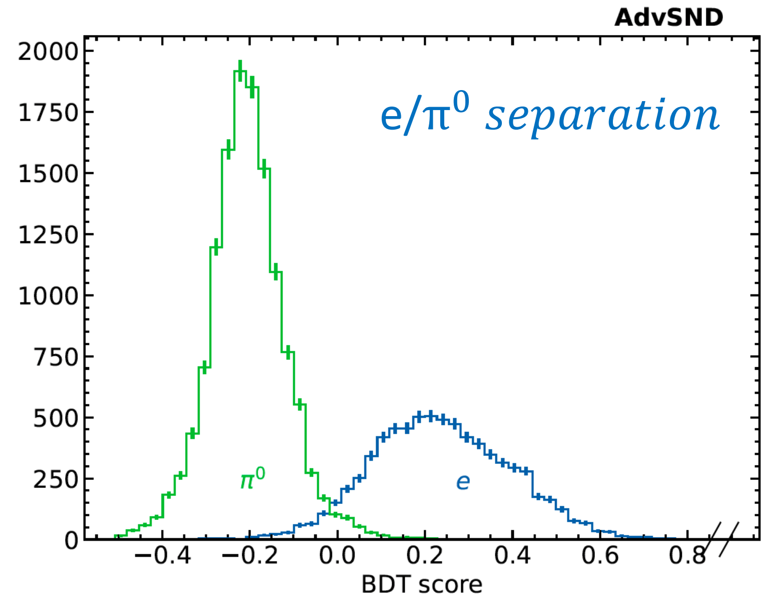




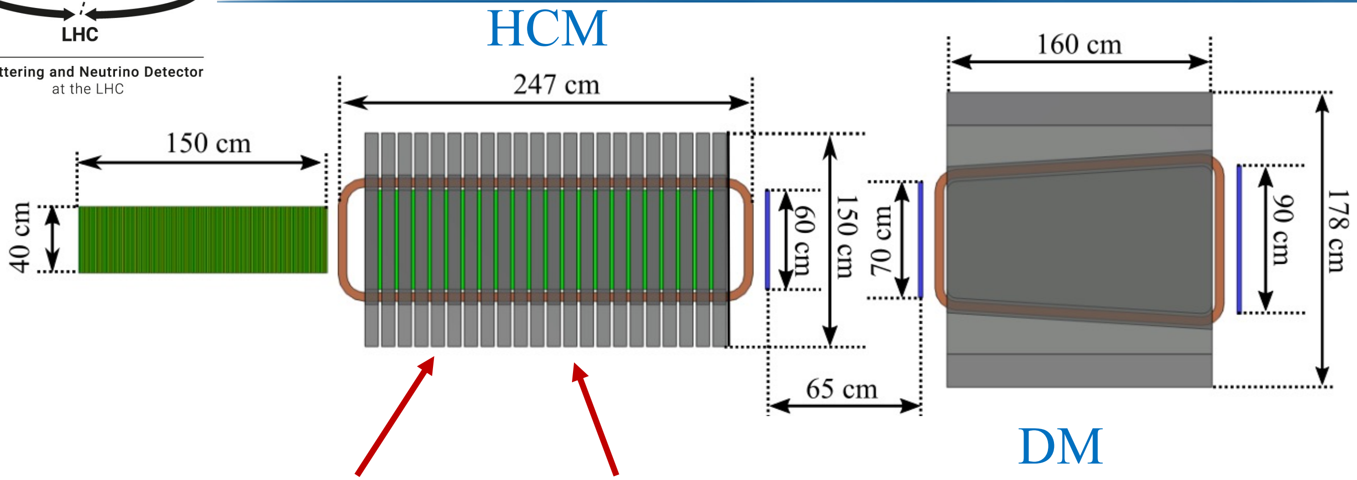




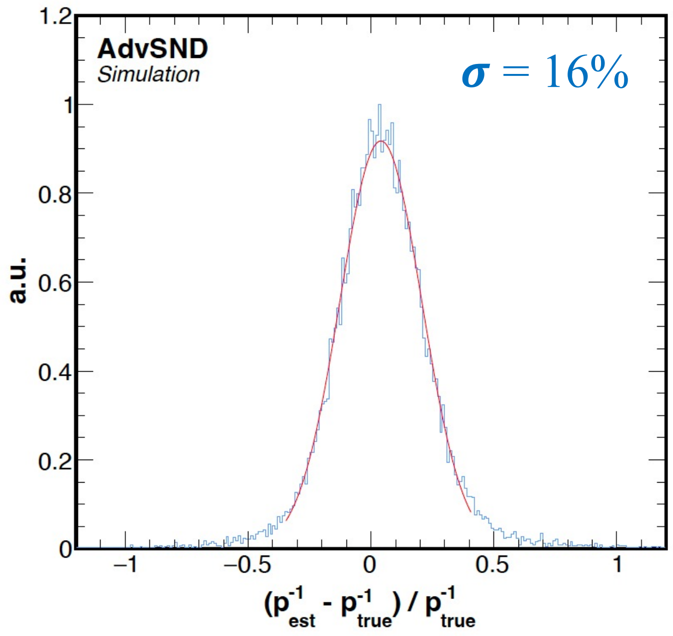


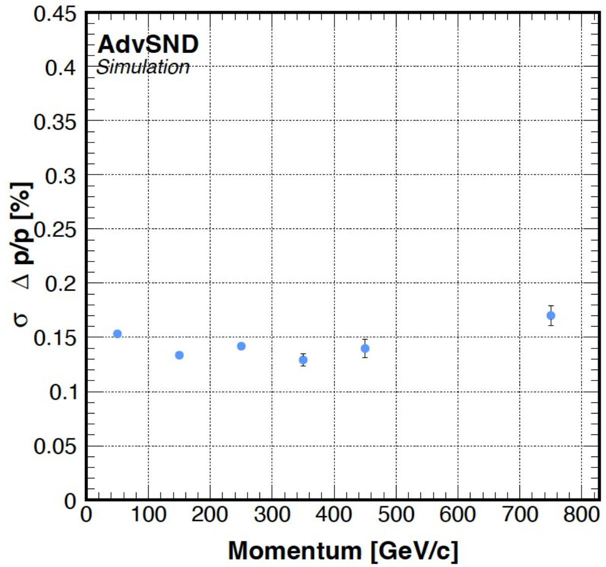


HCAL and μ spectrometer

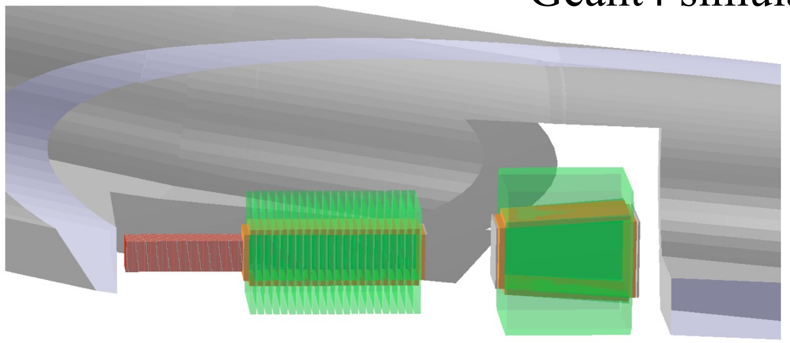


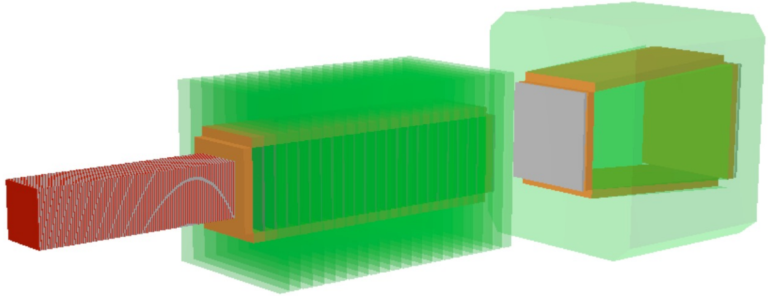
Magnetised Iron slabs interleaved
with scintillating bar planes



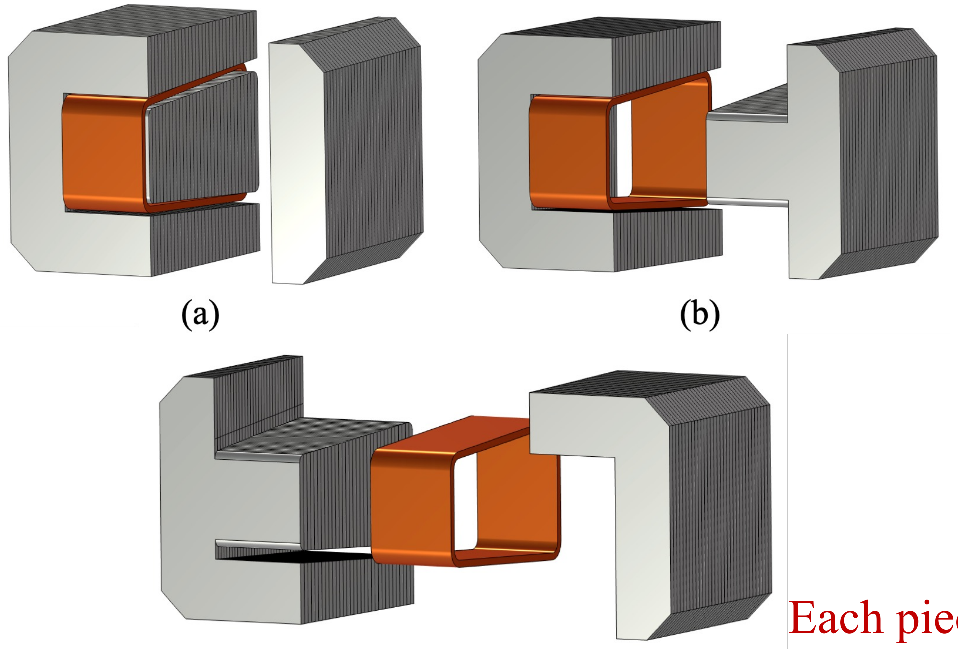


Geant4 simulation





Magnet made of iron pieces to ease transportation and assembly on site

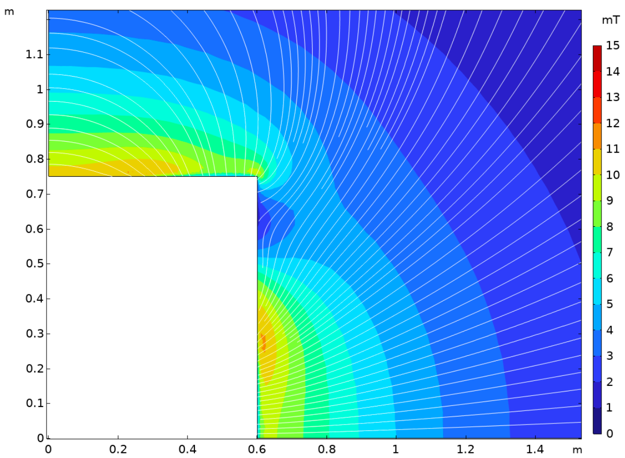


(a) (b)

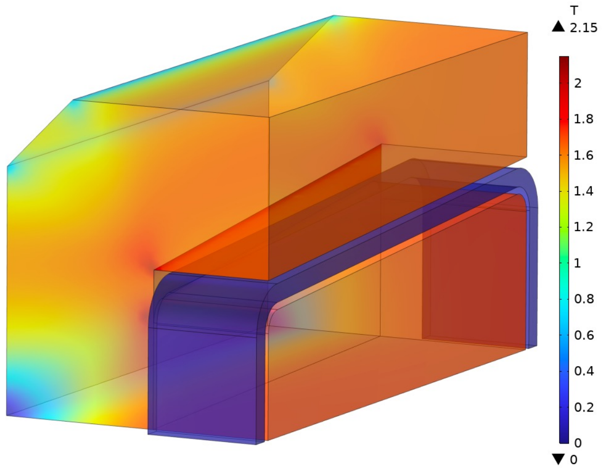
(c)

Each piece within 1.0 ton

Stray field well below operational limits



Magnetic flux density



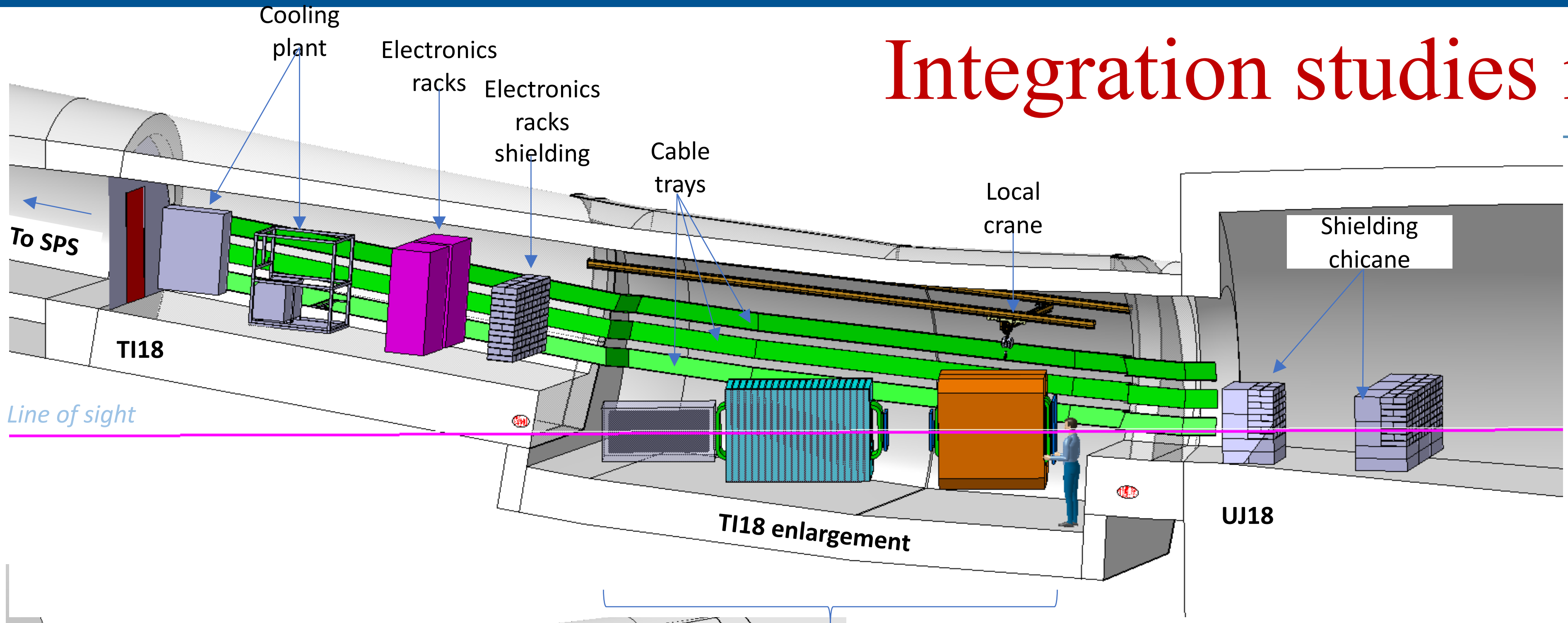
HCM

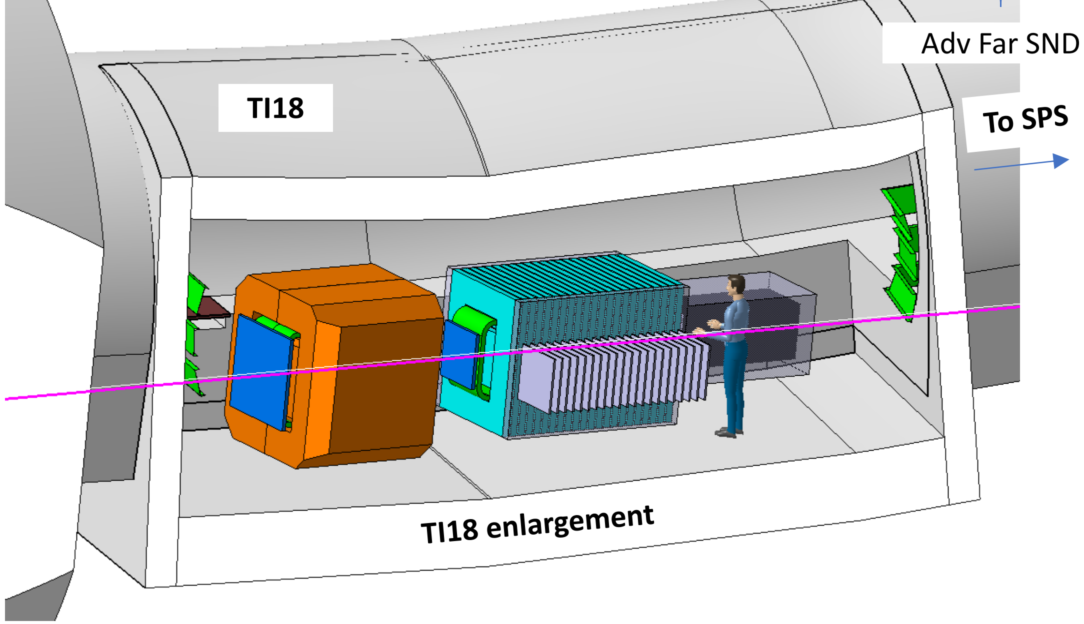
Stray field [@ iron surface, @ d >2m]	[mT]		[$\lesssim 10 \lesssim 1$]
Voltage at the coil terminals	[V]	V	3.1
Electrical current	[A]	I	500
Current density	[A/mm^2]	J	0.75
Magnetomotive force	[kA]	$\mathcal{F} = NI$	18
Electrical power	[kW]	P	1.5
Total conductor mass	[t]	m_{Cu}	1.3
Mass of a single iron slab	[t]	$\frac{m_{Fe}}{22}$	1.02
Total iron mass	[t]	m_{Fe}	22.5

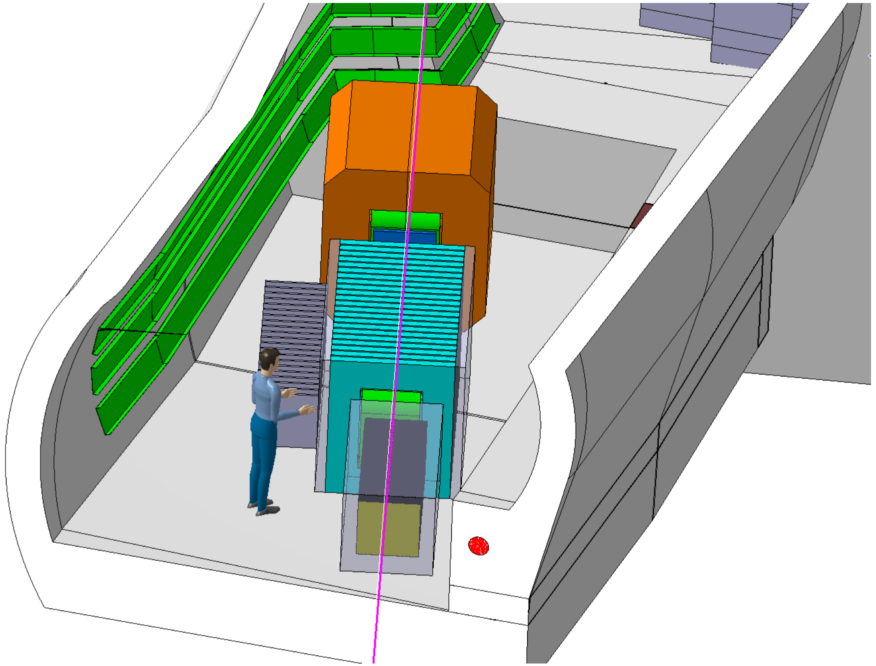
DM

Stray field [@ iron surface, @ d >2m]	[mT]		[$\lesssim 10 \lesssim 1$]
Voltage at the coil terminals	[V]	V	3.0
Electrical current	[A]	I	500
Current density	[A/mm^2]	J	0.74
Magnetomotive force	[kA]	$\mathcal{F} = NI$	21.0
Electrical power	[kW]	P	1.5
Total conductor mass	[t]	m_{Cu}	1.25
Total iron mass	[t]	m_{Fe}	33

Integration studies in TI18

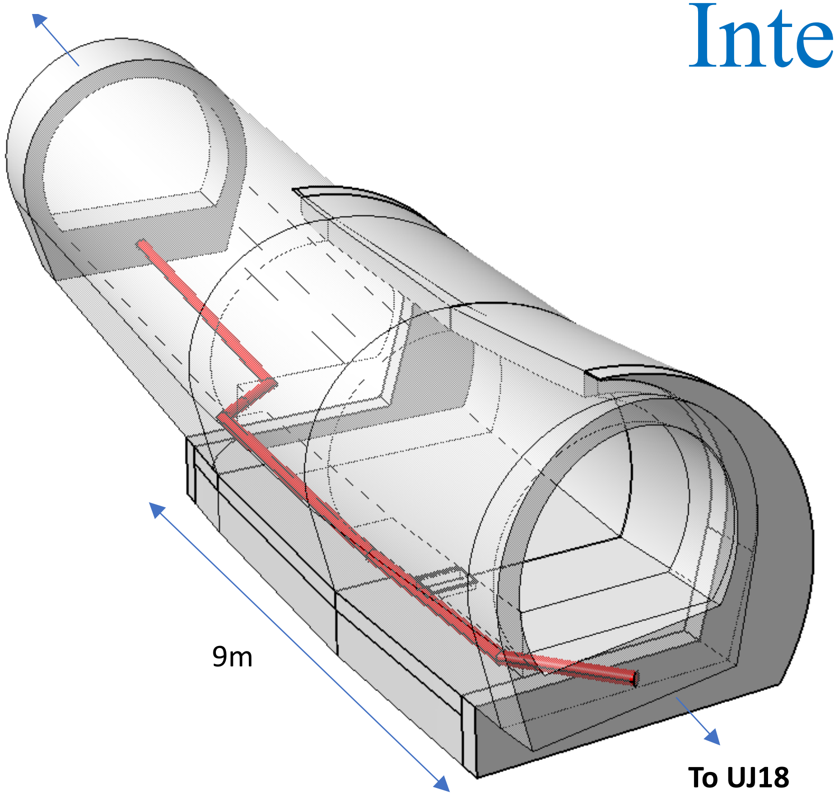


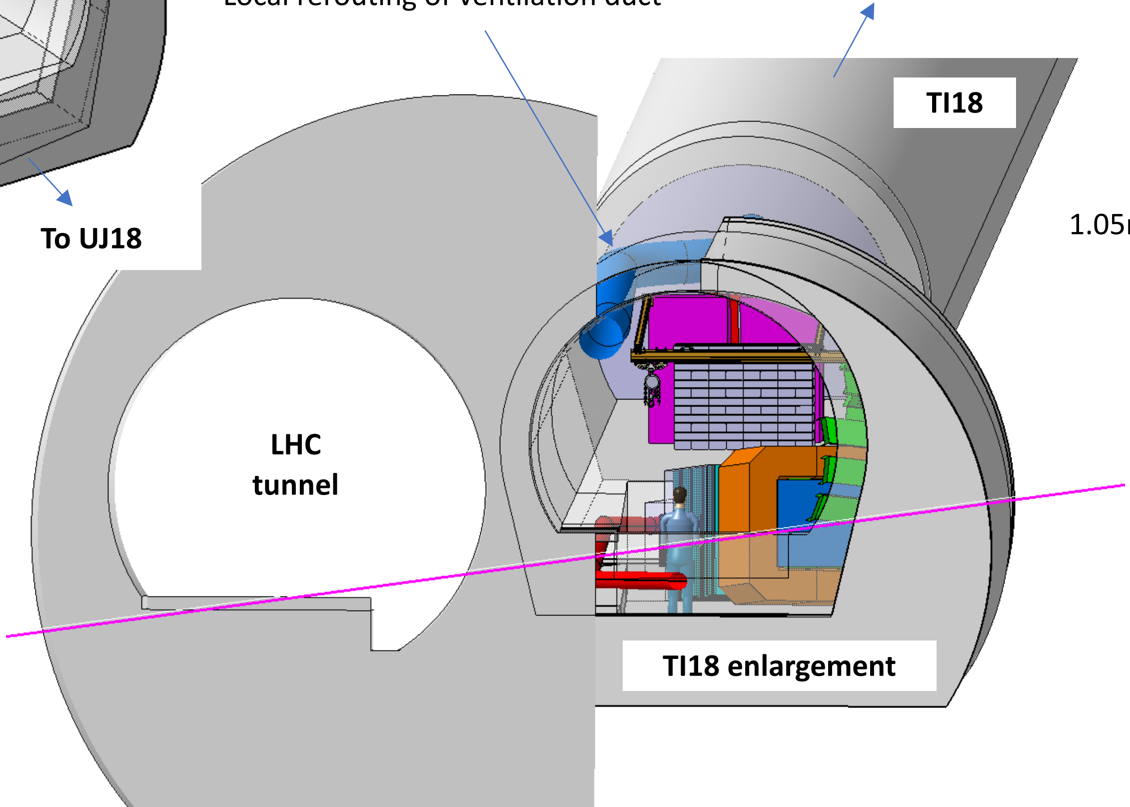


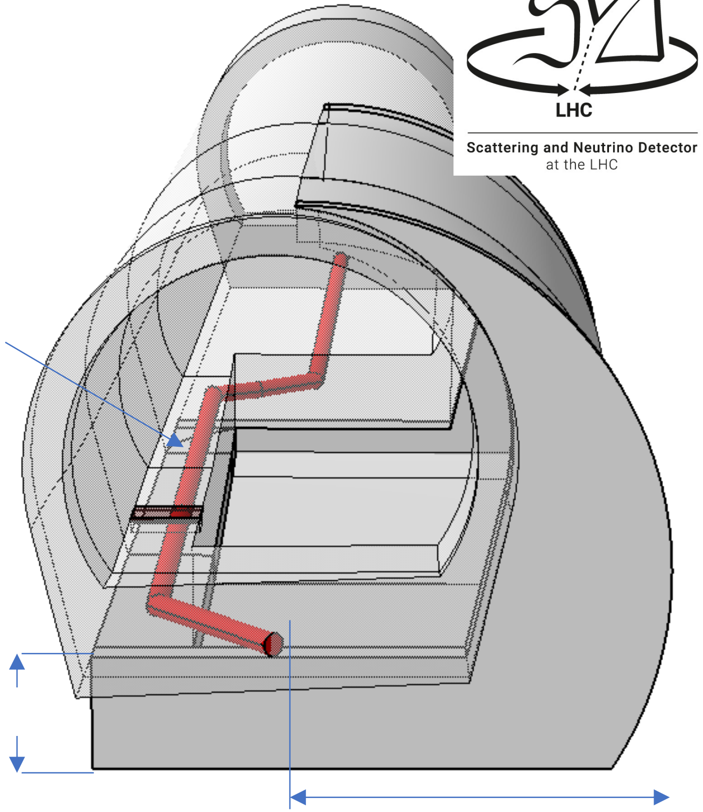


Integration studies in TI18

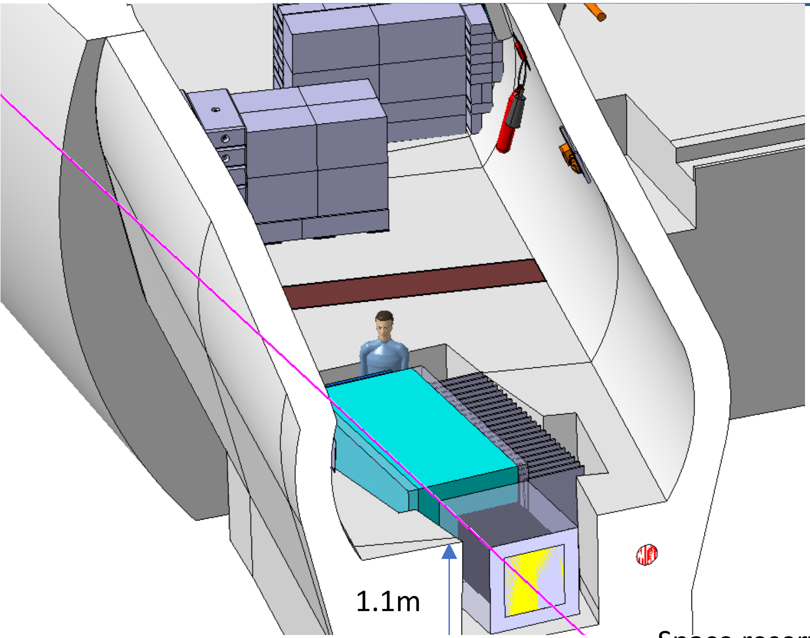
LHC
Scattering and Neutrino Detector at the LHC

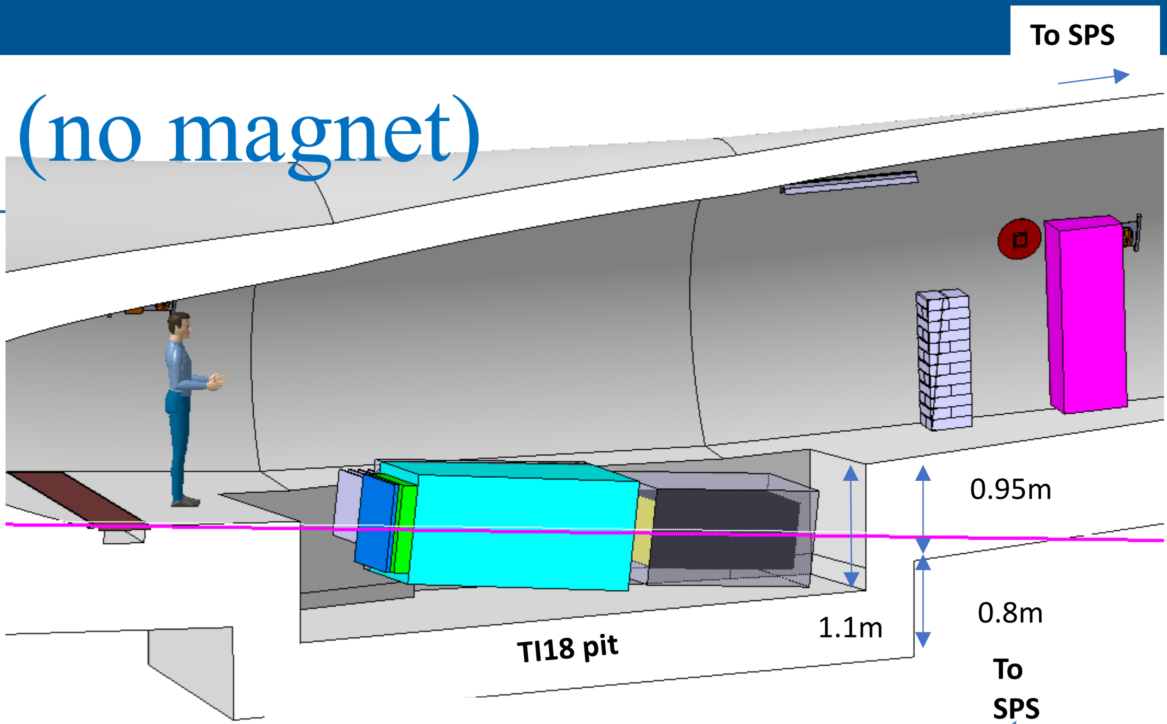


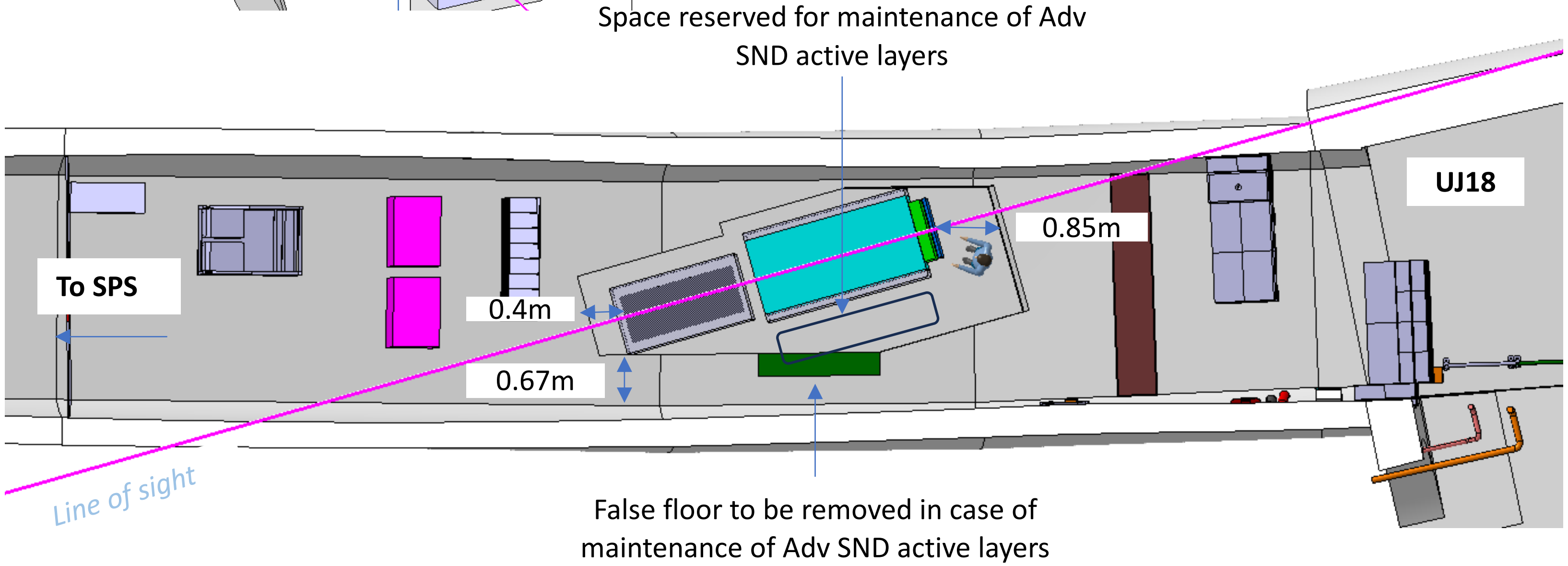


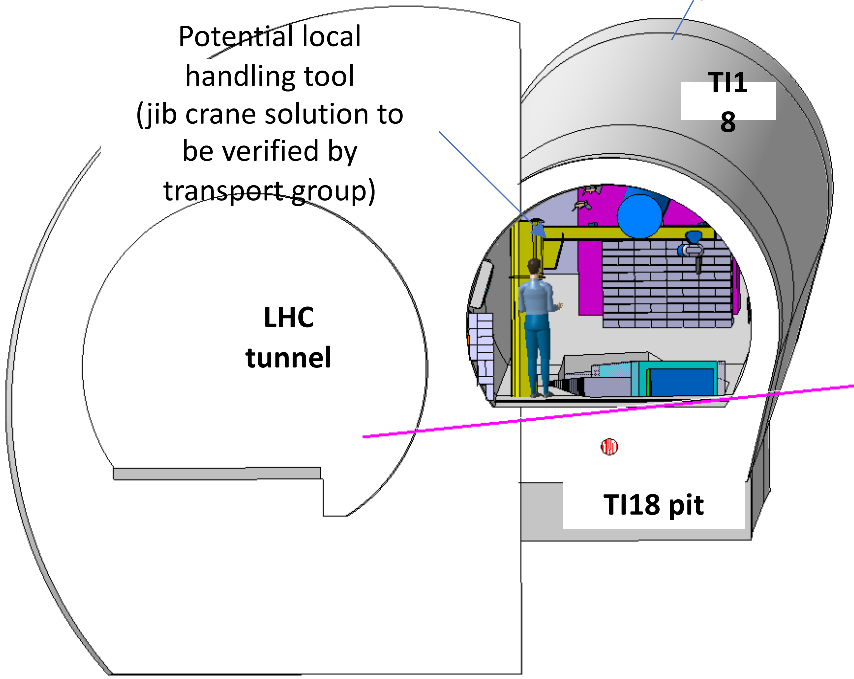


Configuration with minimal impact (no magnet)

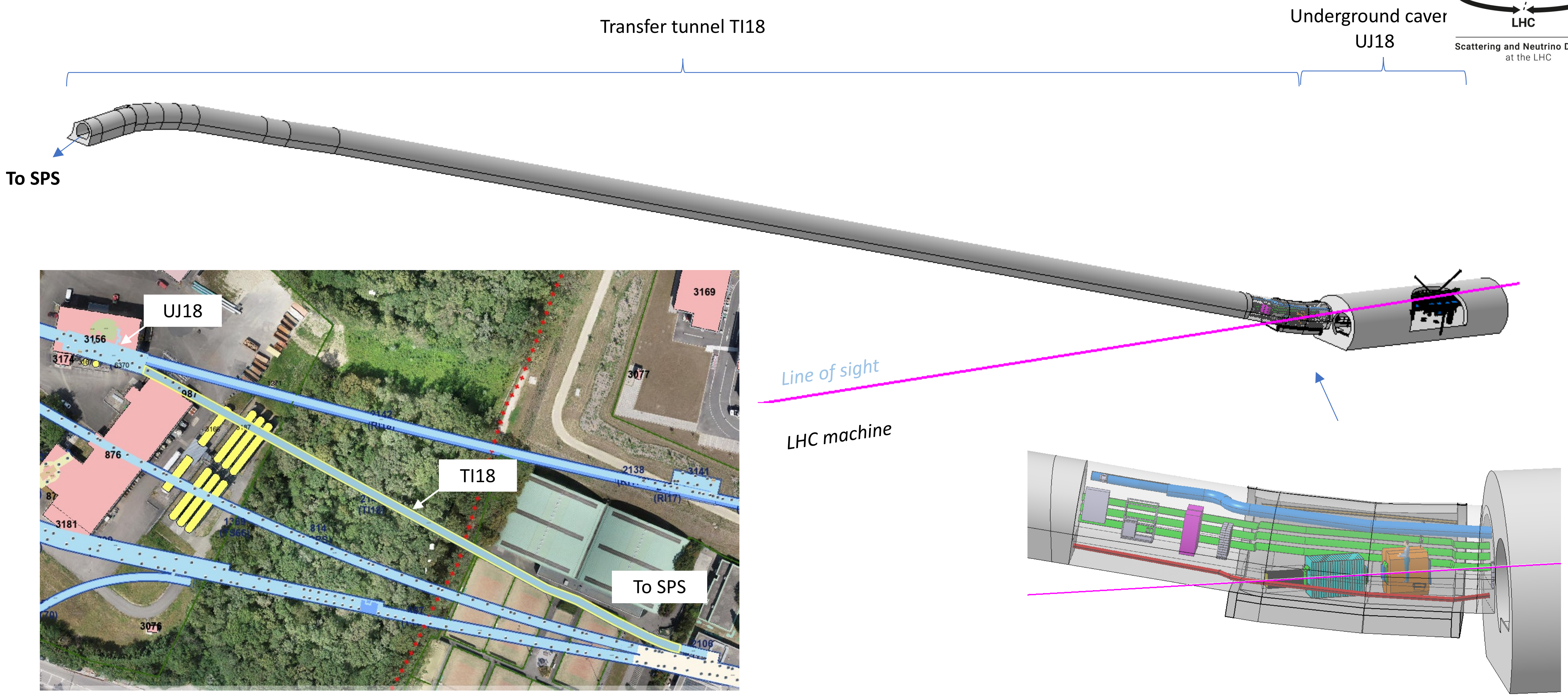






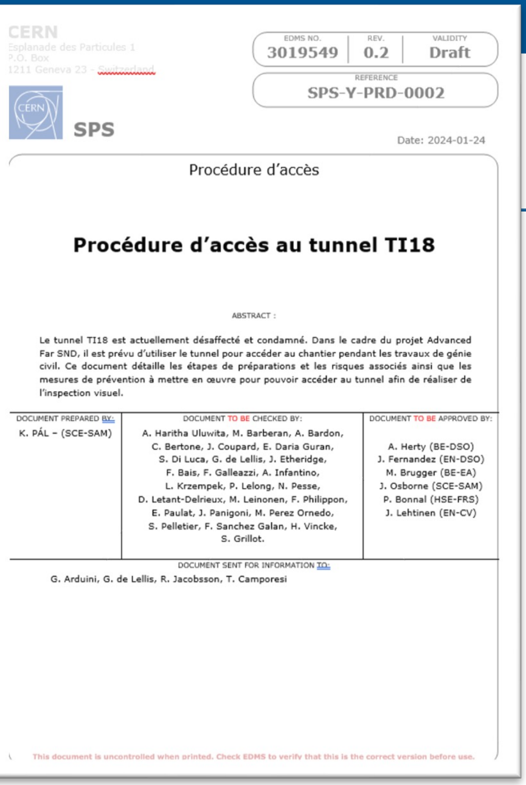


Use TI18 tunnel to bring the excavator and waste disposal



Visit to the TI18 tunnel on January 29th

LHC
Scattering and Neutrino Detector at the LHC



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EDMS NO.	REV.	VALIDITY
3019549	0.2	Draft

REFERENCE
SPS-Y-PRD-0002

Date: 2024-01-24

Procédure d'accès

Procédure d'accès au tunnel TI18

ABSTRACT :

Le tunnel TI18 est actuellement désaffecté et condamné. Dans le cadre du projet Advanced Far SND, il est prévu d'utiliser le tunnel pour accéder au chantier pendant les travaux de génie civil. Ce document détaille les étapes de préparations et les risques associés ainsi que les mesures de prévention à mettre en œuvre pour pouvoir accéder au tunnel afin de réaliser de l'inspection visuel.

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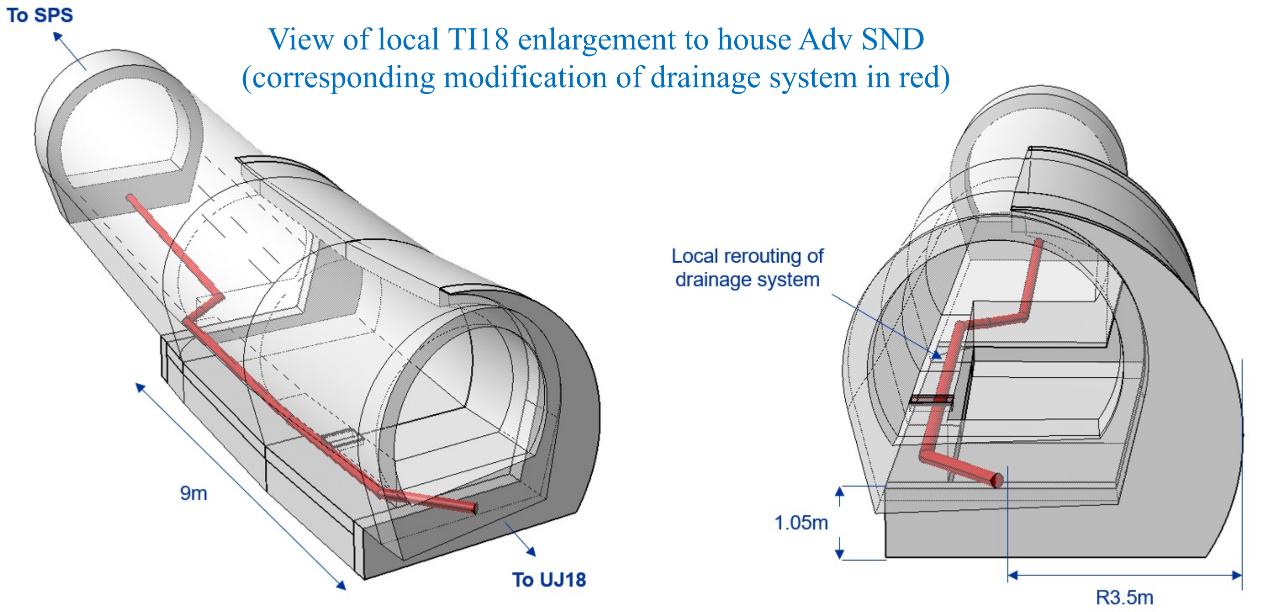
Conclusions:

- Good condition of tunnel – feasibility to make it operational throughout all its length (256m)
- Further studies are required to implement transport solution
- On-going studies concern:
  - Transport solution to cope with 14.5% slope of TI18 tunnel
  - Installation of required services (GSM, lightening, etc)
  - Reuse of existing services – ventilation duct

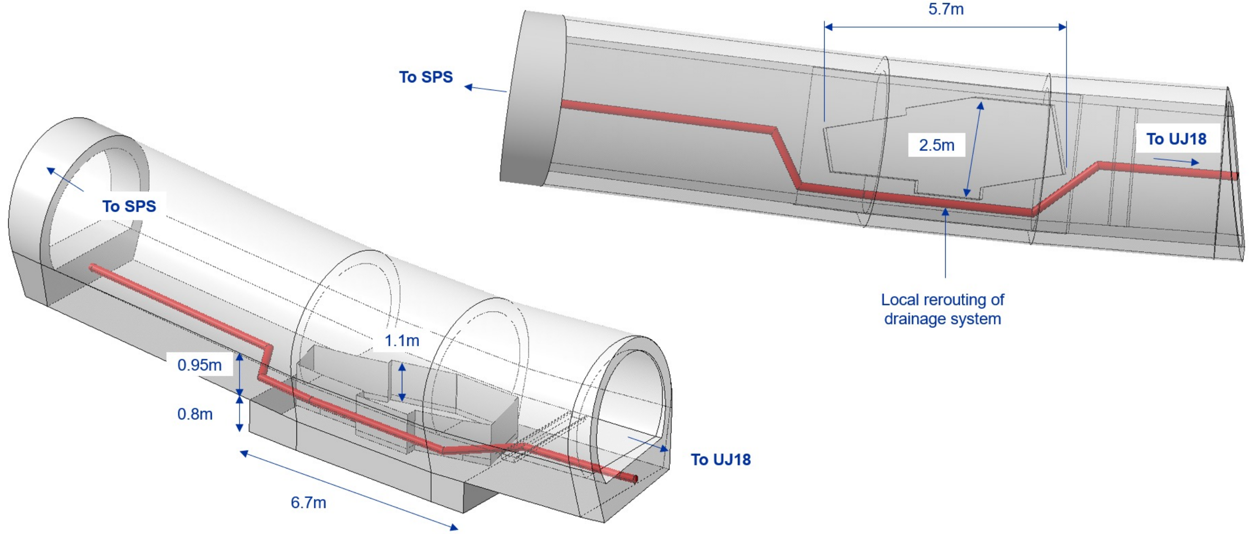
Civil engineering studies

- Confirmed feasibility of the needed excavation
- ~1 year for TI18 enlargement
- ~3-6 months for TI18 pit (Adv SND minimalistic solution)
- Civil engineering drawings based on 3D integration models
- Next steps
  - Ongoing studies by the civil engineering group on the way to remove the rubble
  - Civil engineering studies with external consultant
    - Drawings & options sent to the company in April
    - Feasibility and timeline check including recommendations and cost review (2-3 months) followed by common meeting with CERN
  - Contact PMP group for IRP (infrastructure request proposal)

View of local TI18 enlargement to house Adv SND (corresponding modification of drainage system in red)



View of local TI18 pit to house minimalistic solution of Adv SND (corresponding modification of drainage system in red)



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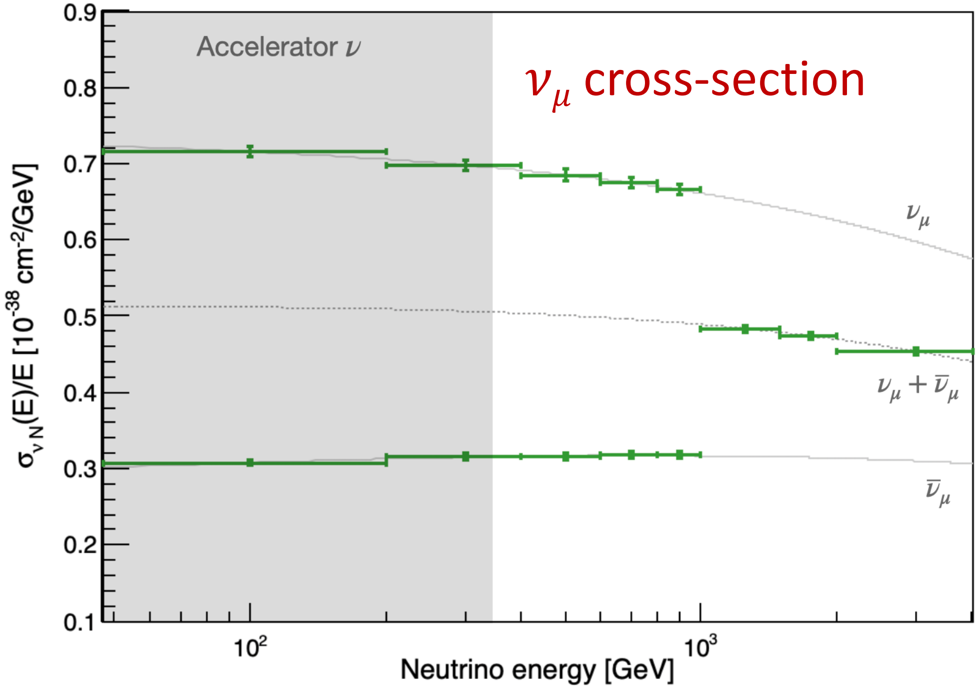
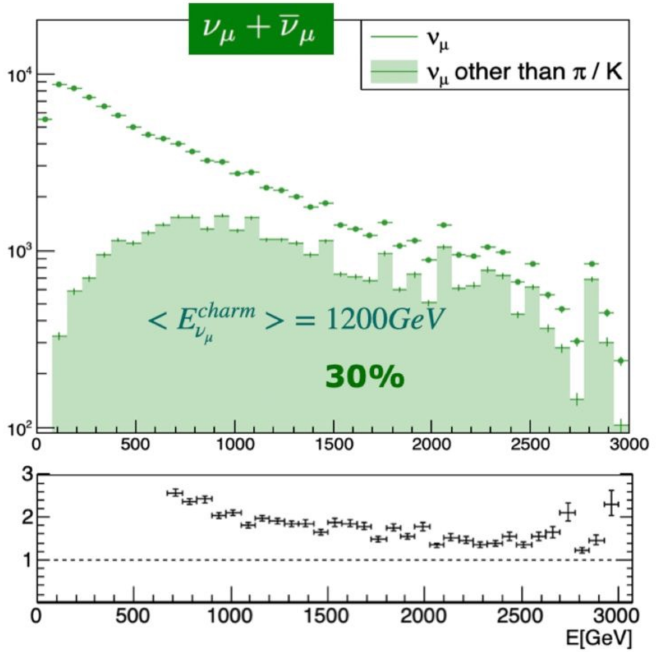
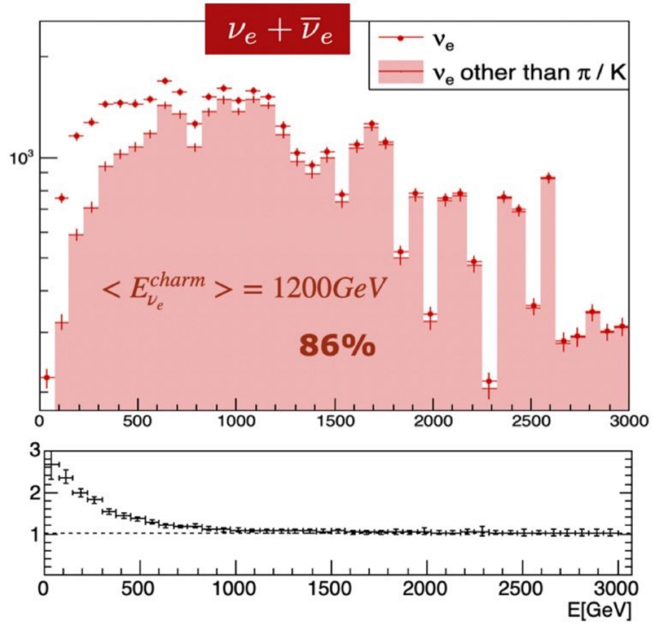
Physics performance in TI18

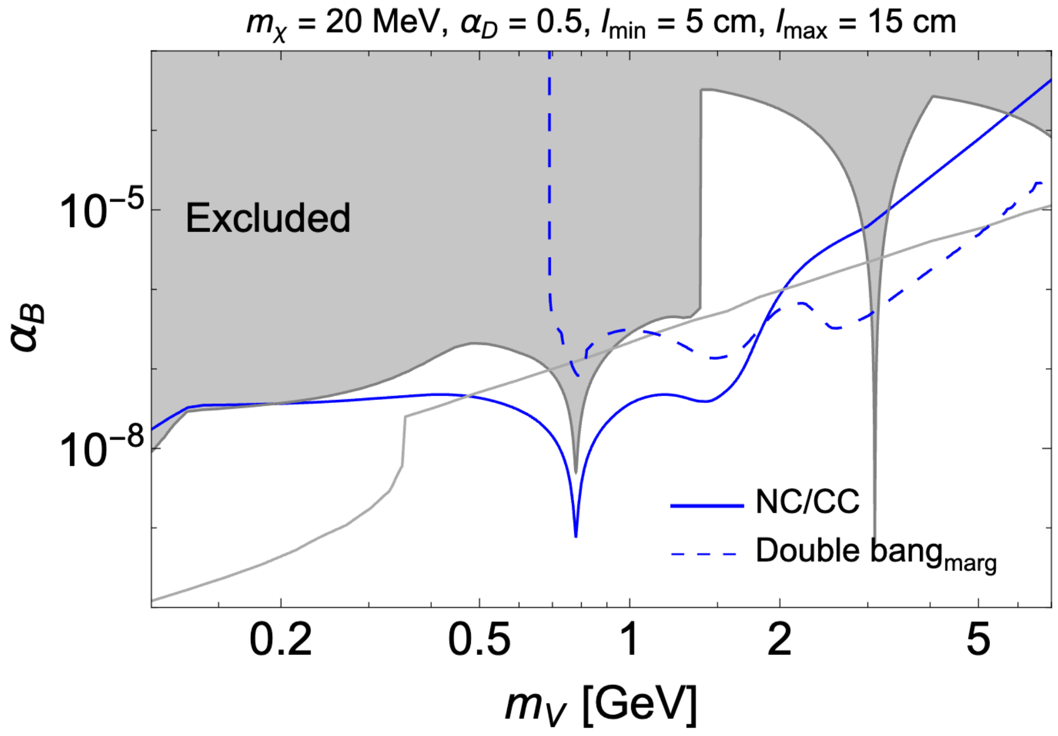
Flavour	Total (DPMJET+Fluka)	c-cbar (Pythia 8)
$\nu_\mu - \bar{\nu}_\mu$	1.6 x 10^5	1.5 x 10^4
$\nu_e - \bar{\nu}_e$	6.1 x 10^4	1.6 x 10^4
$\nu_\tau - \bar{\nu}_\tau$	3.2 x 10^3	8.7 x 10^2
Total	2.3 x 10^5	3.2 x 10^4







Sensitivity to dark matter (scattering)



$$\chi + p/n \to \chi + \text{hadrons},$$

EDM signature

$$\chi + p/n \to \chi' + \text{hadrons}, \quad \chi' \to \chi + \text{hadrons}$$

IDM signature

LDM coupled to a baryonic mediator: elastic DM model (EDM, solid blue), where the signature is an increase of the NC/CC ratio due to scatterings, and the inelastic DM model (IDM, dashed blue), with the signature being “double bang” – a scattering with the subsequent displaced decay

Current limits: CDF monojets, J/Ψ BES, E949 K rare decays, π^0 decays Brookhaven

For the EDM signature, 10% accuracy in the NC/CC measurement is assumed. IDM signature: min/max displacements l_{min} and l_{max} between 5 and 15 cm; lighter particle mass $m\chi$ = 20 MeV, to avoid constraints for the EDM case that are relevant at masses ≳ 100 MeV (bounds absent in the IDM case), while the marginalization is made over the mass splitting between χ’ and χ

Concluding remarks

SND@LHC
Scattering and Neutrino Detector at the LHC

- TI18 tunnel modifications allow optimal geometrical configuration to explore ν physics at the HL-LHC
- Optimised configuration accounts for the crossing angle configuration
- Optimal transverse position while keeping off-axis characterization (with useful overlap with FASER)
- Emulsion technology replaced by silicon to withstand the high μ-rate at HL-LHC
- Magnetised spectrometer for μ charge and momentum measurement (energy and $\nu/\bar{\nu}$ separation)
- Avoid interference with LHC → use TI18 from SPS side for the excavation work
- Ongoing studies are promising
- The TI18 is the closest location (480 m) to exploit this kind of physics → maximal flux
- Collaboration eager to take data in Run4
- A big thank to the PBC and all the groups involved in these studies!