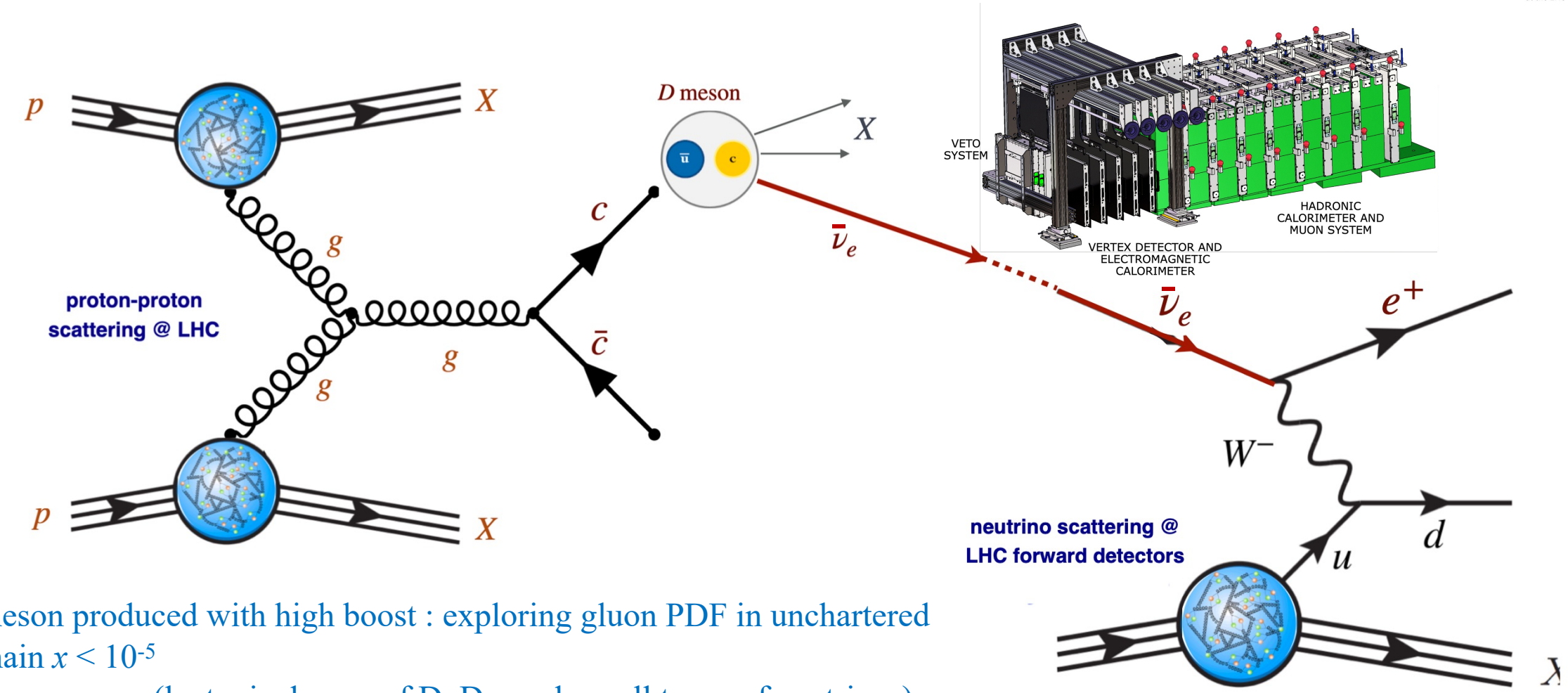
LHC

Scattering and Neutrino Detector
at the LHC

SND@LHC upgrade plan

Giovanni De Lellis
On behalf of the SND@LHC Collaboration
7th Forward Physics Facility meeting, 29th Feb 2024

High energy neutrino production at LHC



D meson produced with high boost : exploring gluon PDF in unchartered domain $x < 10^{-5}$

Charm mesons (leptonic decays of D, D_s produce all types of neutrinos)

Ratio between charmed hadrons and lighter parents increases with the angle (→ lower η)

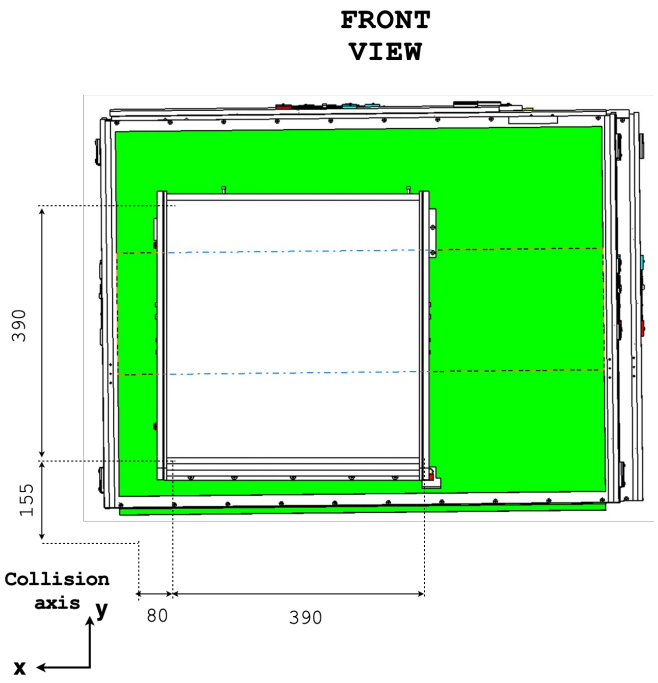
A few introductory remarks

- 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 has 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

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

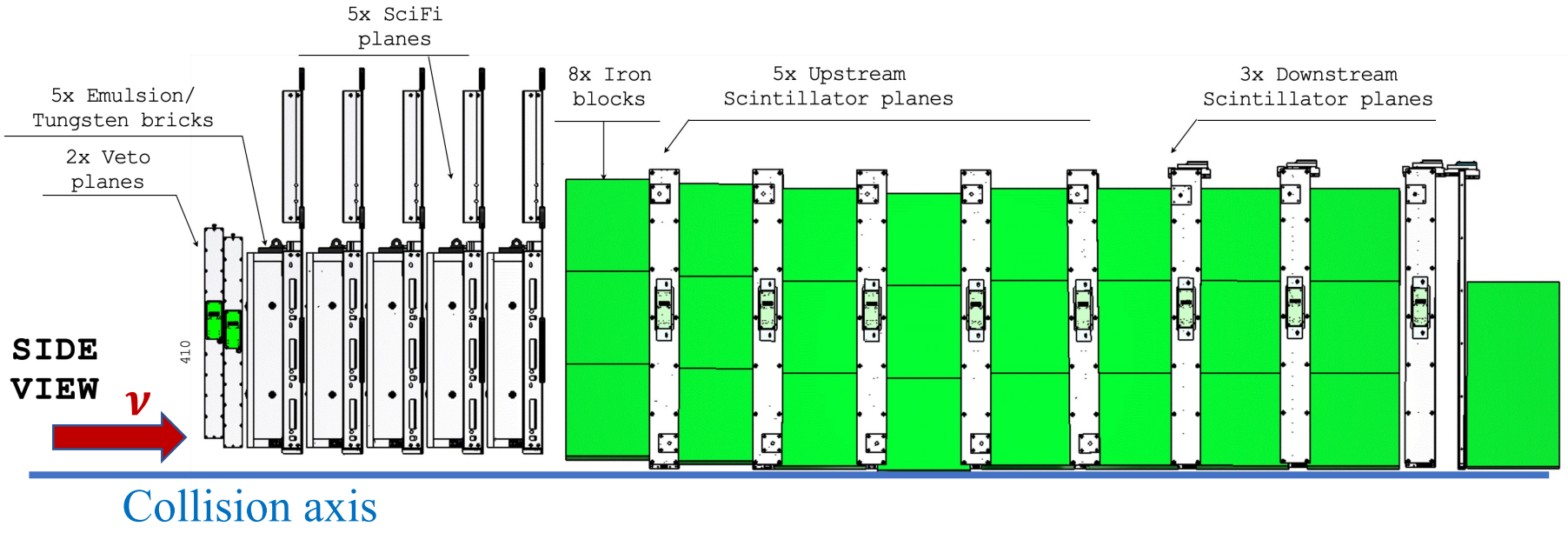
- Angular acceptance: $7.2 < \eta < 8.4$
- Target material: Tungsten
- Target mass: 830 kg
- Surface: 390x390 mm^2

Off axis location



Electromagnetic calorimeter
~40 X_0

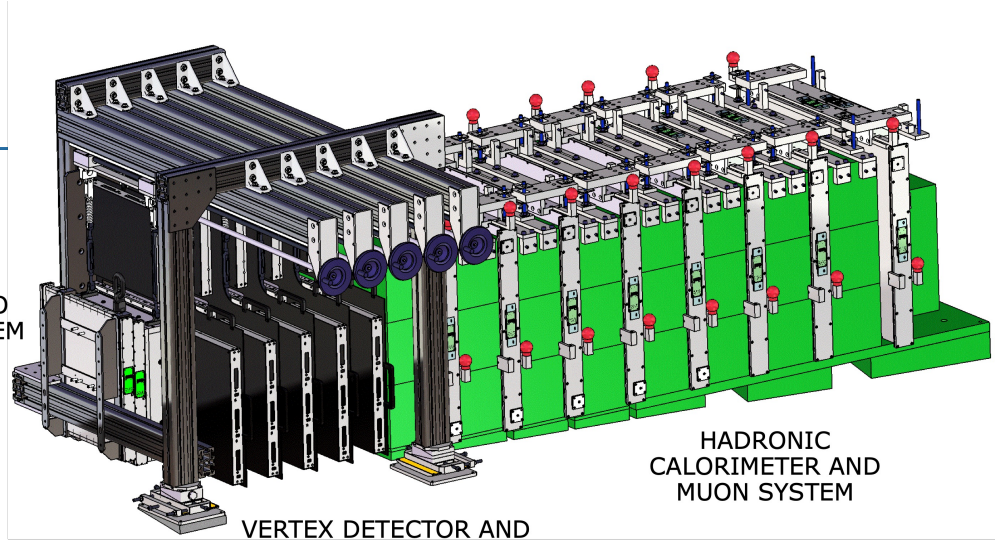
Hadronic calorimeter
~11 λ



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



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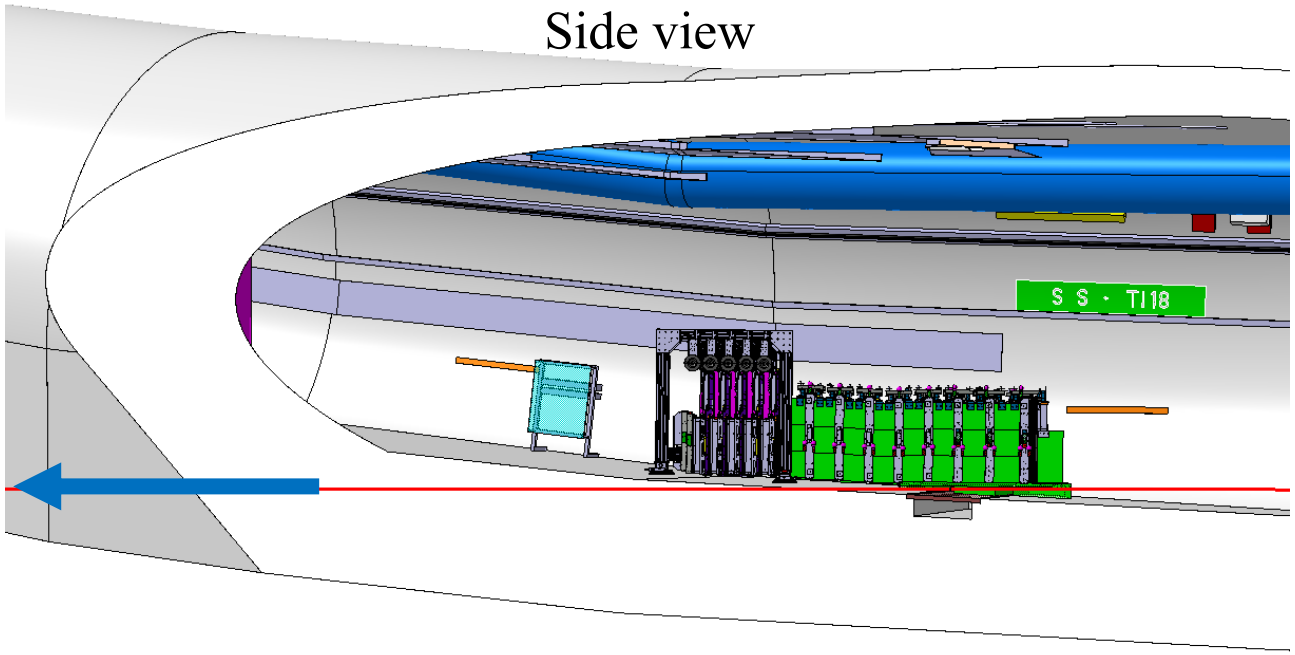
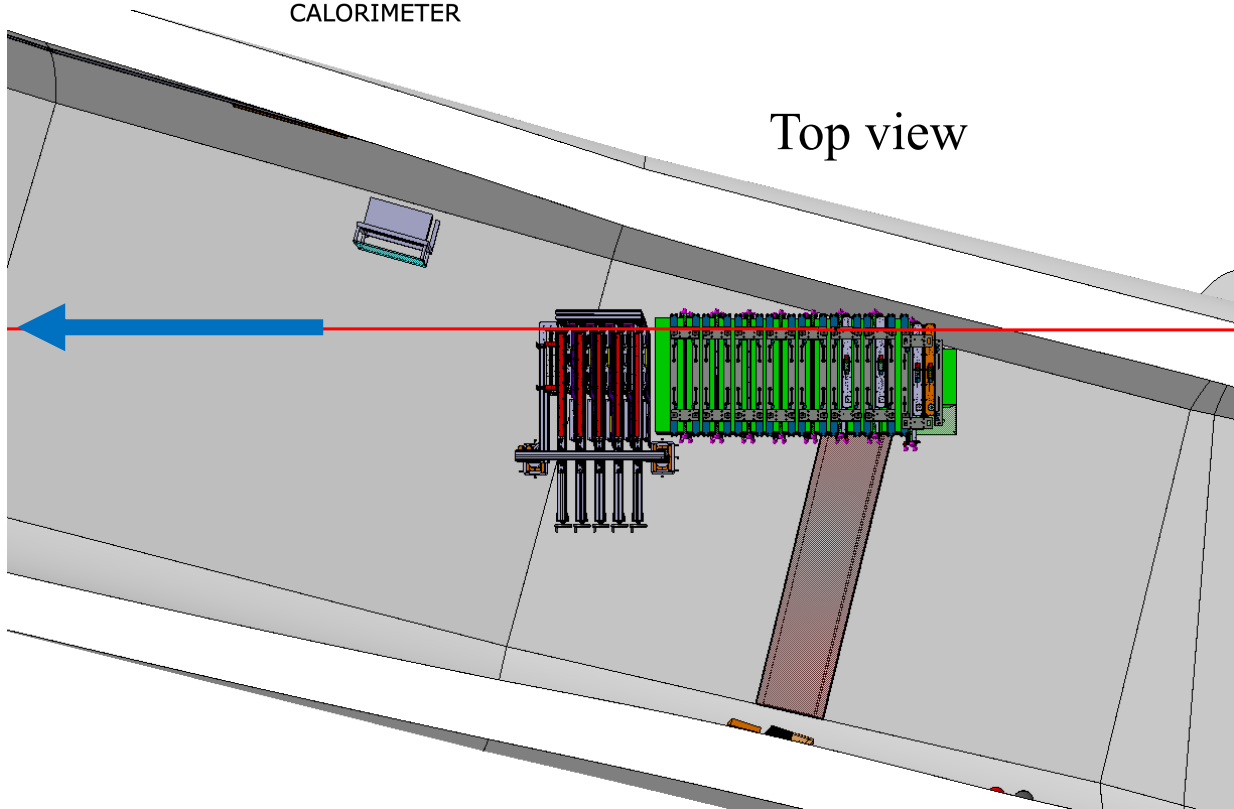
Scattering and Neutrino Detector at the LHC

Side view



Top view



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

Scattering and Neutrino Detector at the LHC

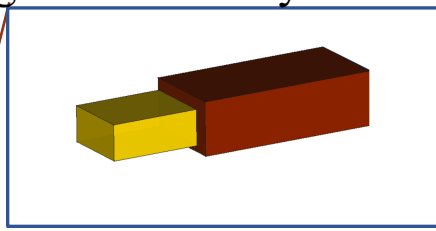
AdvSND-Far in TI18 (Run 4)

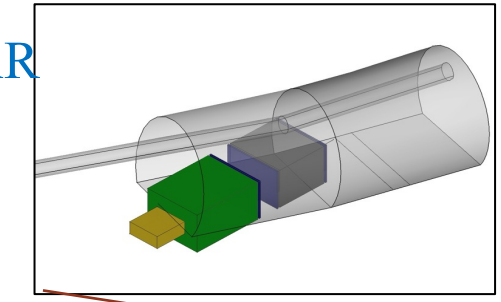
- Improve statistics, reduce systematics
- Separate ν from ν-bar
- Charm production measurements
- LFU

AdvSND-Near in UJ57/UJ56 (Run 5)

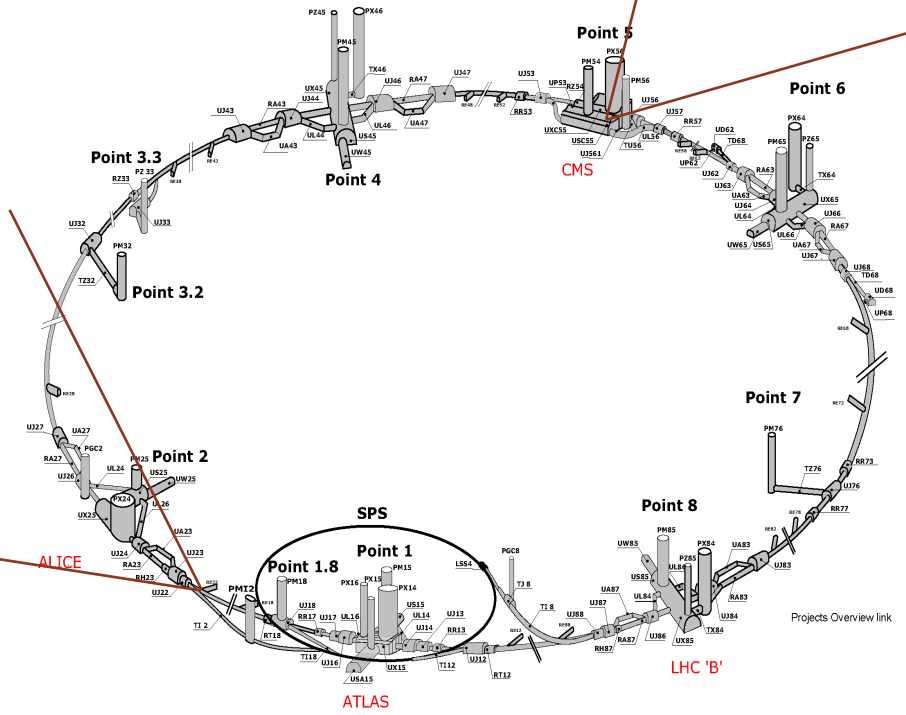
- Overlap with LHCb η where c/b measured
- Reduce sys uncertainties for the FAR
- ν cross-section

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



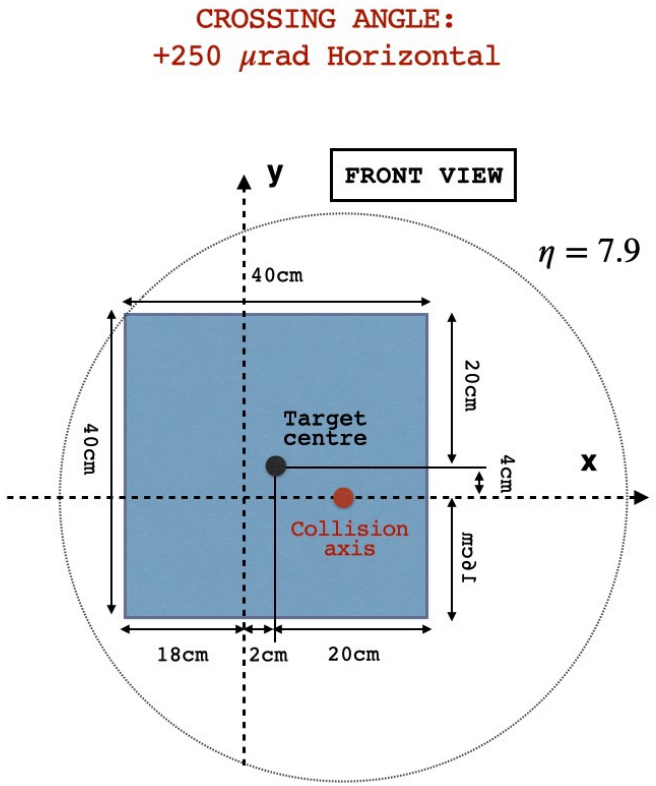


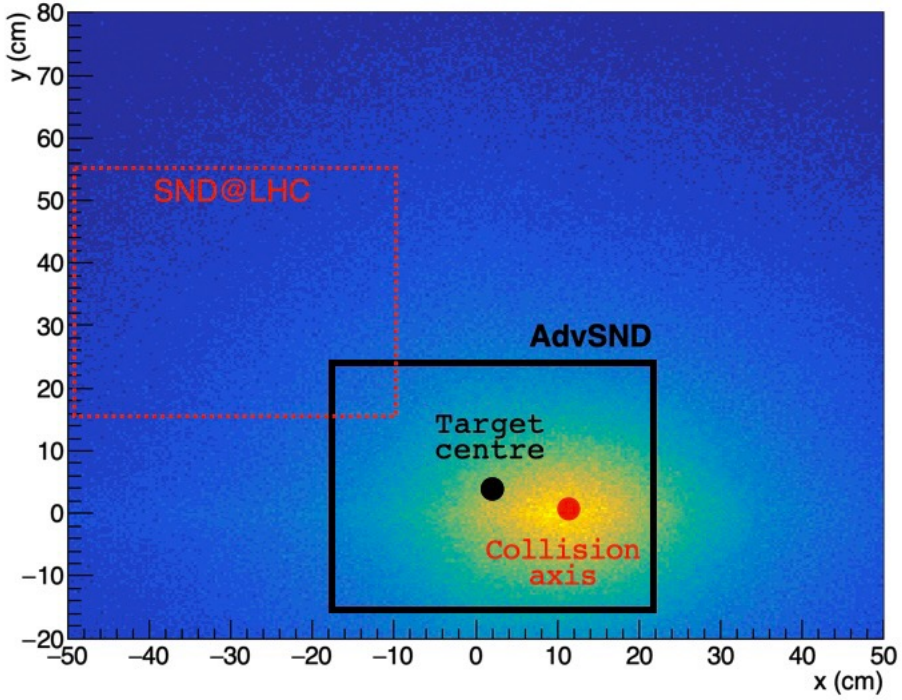
AdvSND-Far: $\eta > 7.9$



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

Scattering and Neutrino Detector at the LHC





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

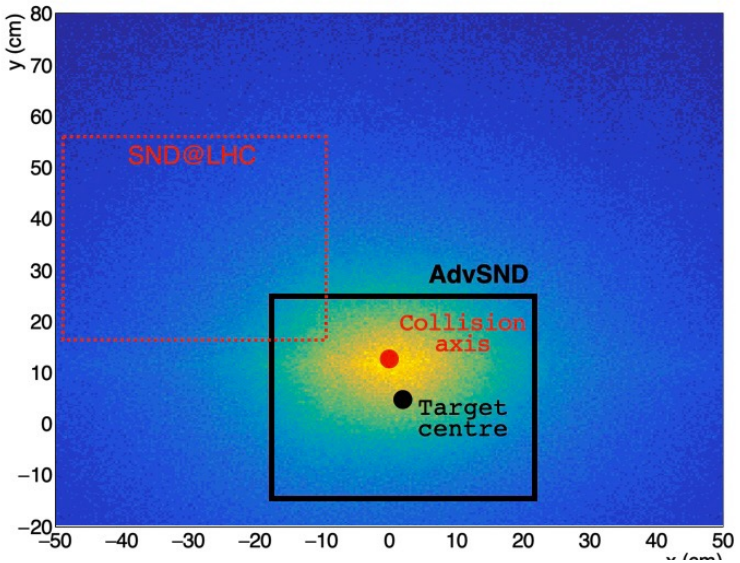
Main points of the upgrade:

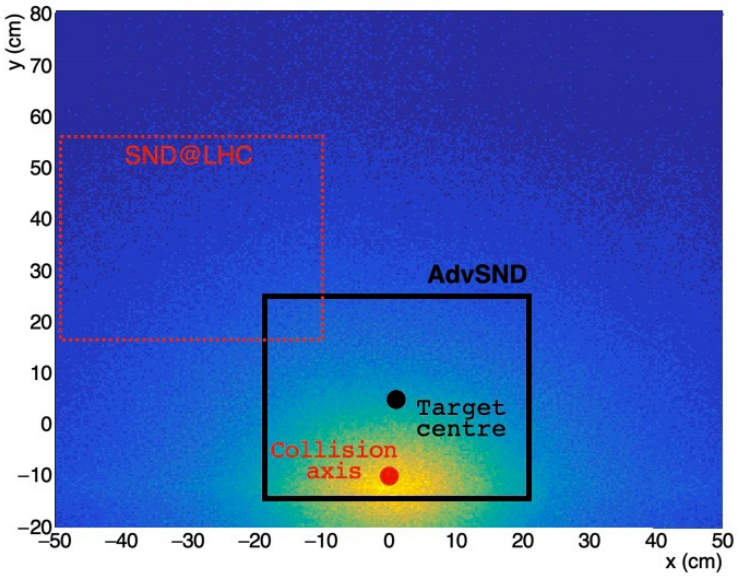
Better transverse position while keeping the off-axis characterization (and some useful overlap with FASER)

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)

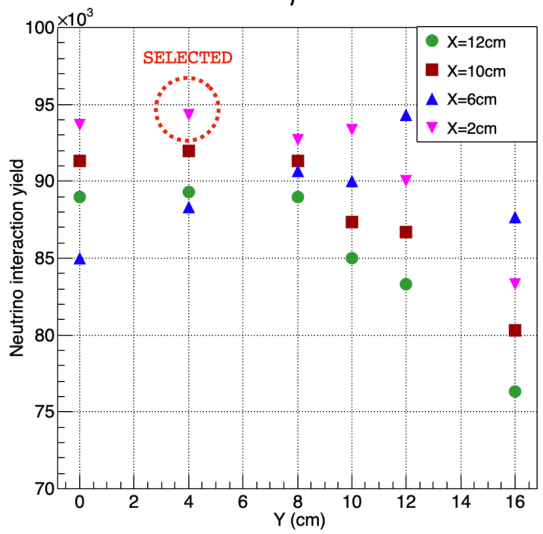
Crossing angle and optimal detector configuration



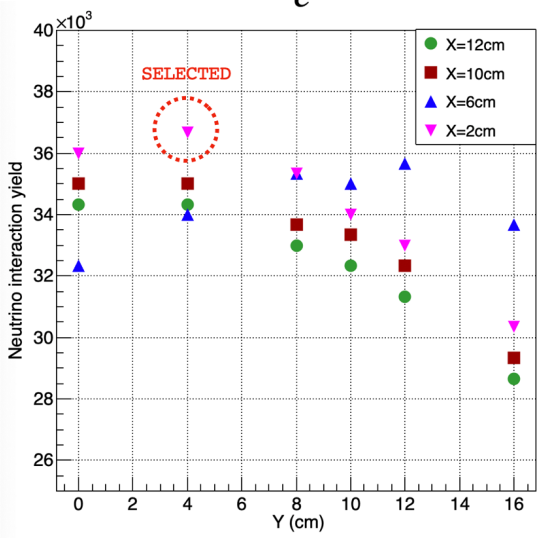


Beyond Run 4 the crossing angle can change from the H to V plane

ν_μ

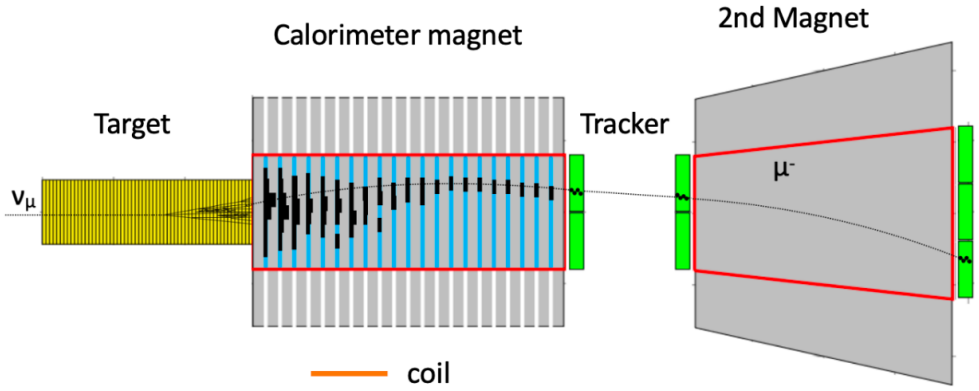


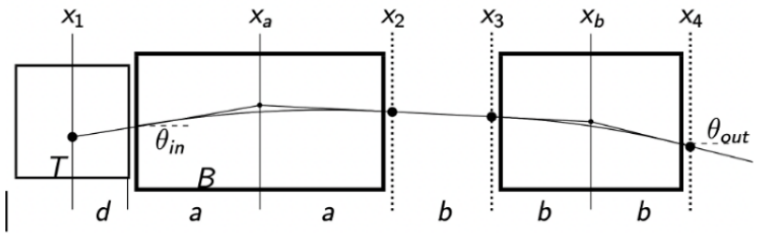
ν_e

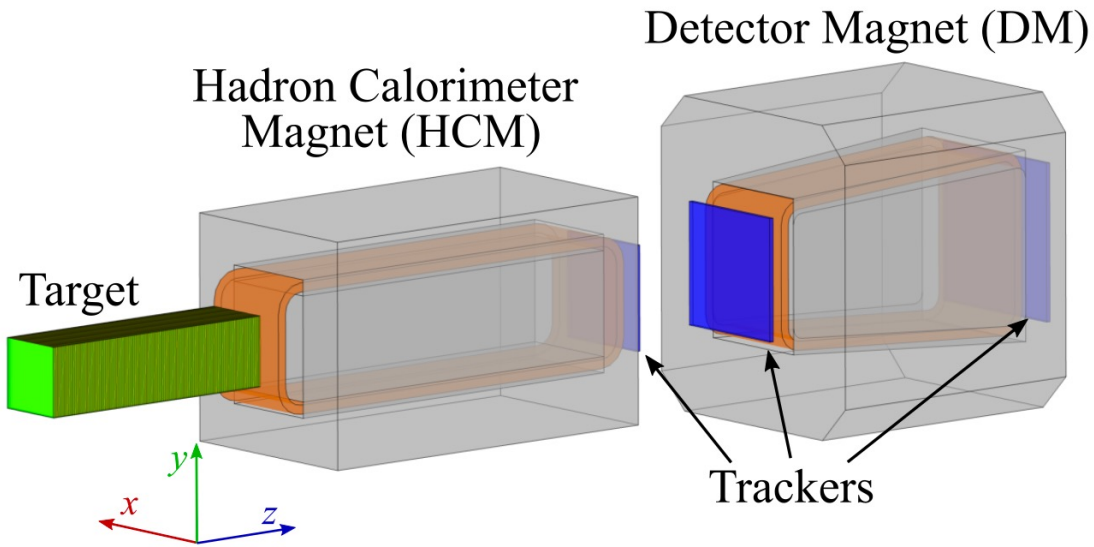


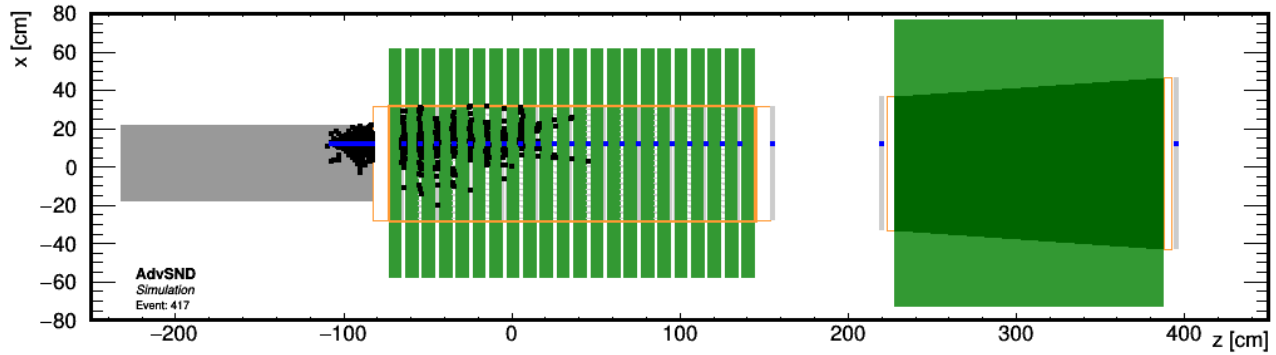
The chosen configuration maximises the average of the three possible configurations for all neutrino species as well as for those produced in charmed hadron decays

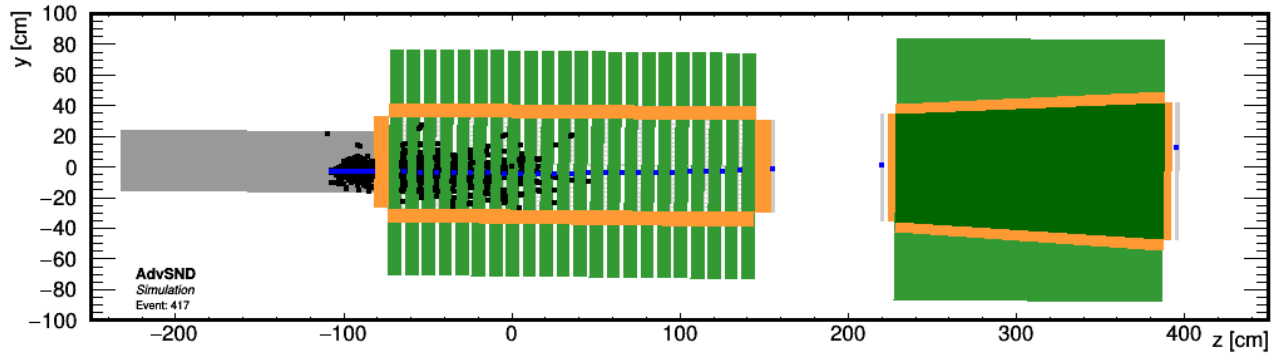
Overview of the upgraded detector



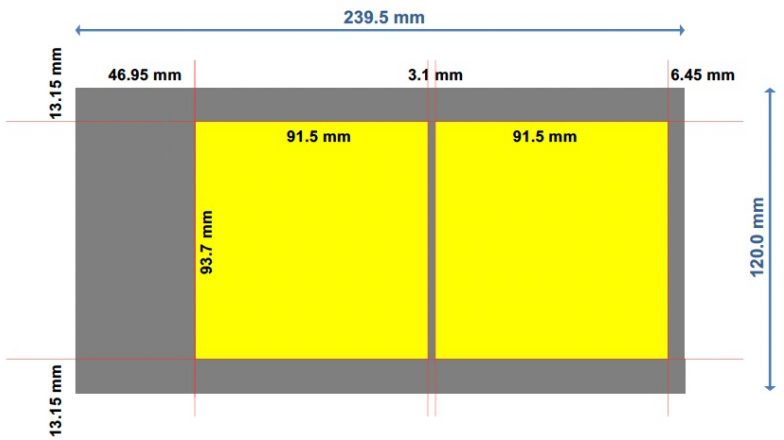






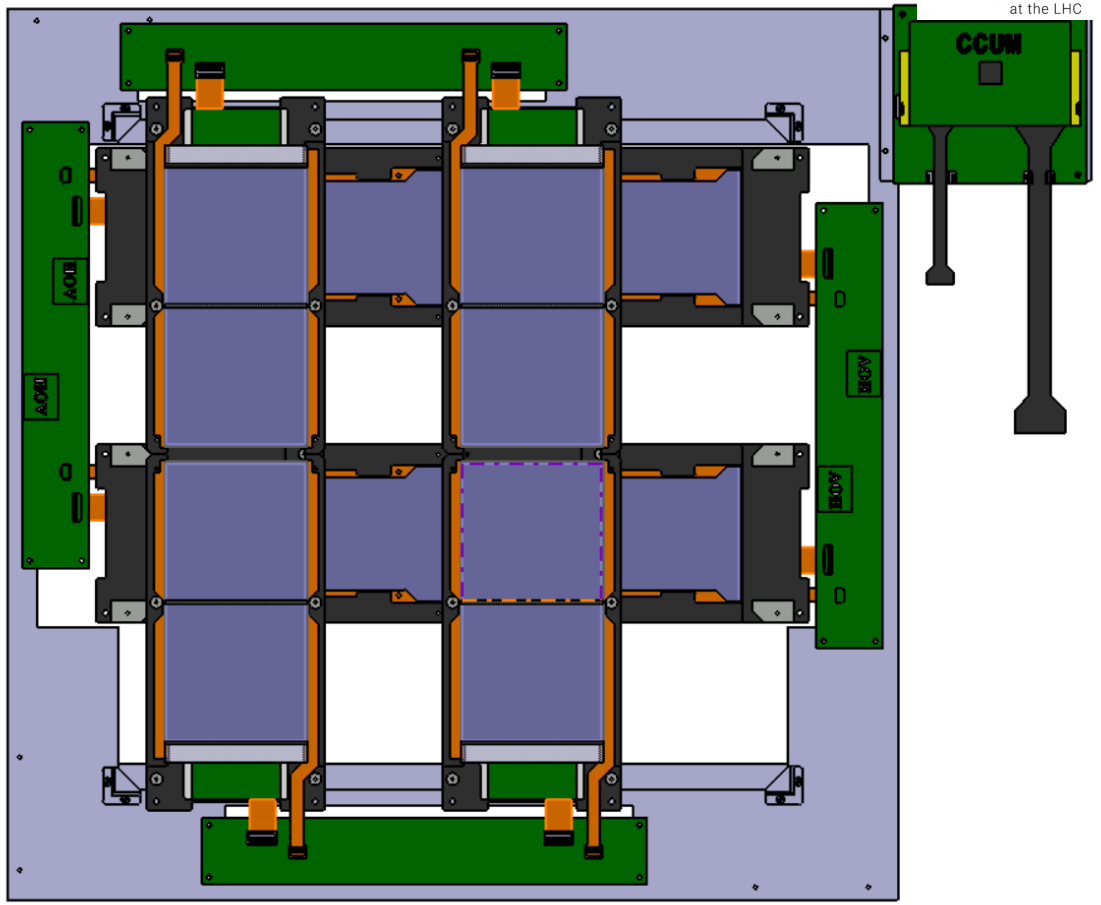


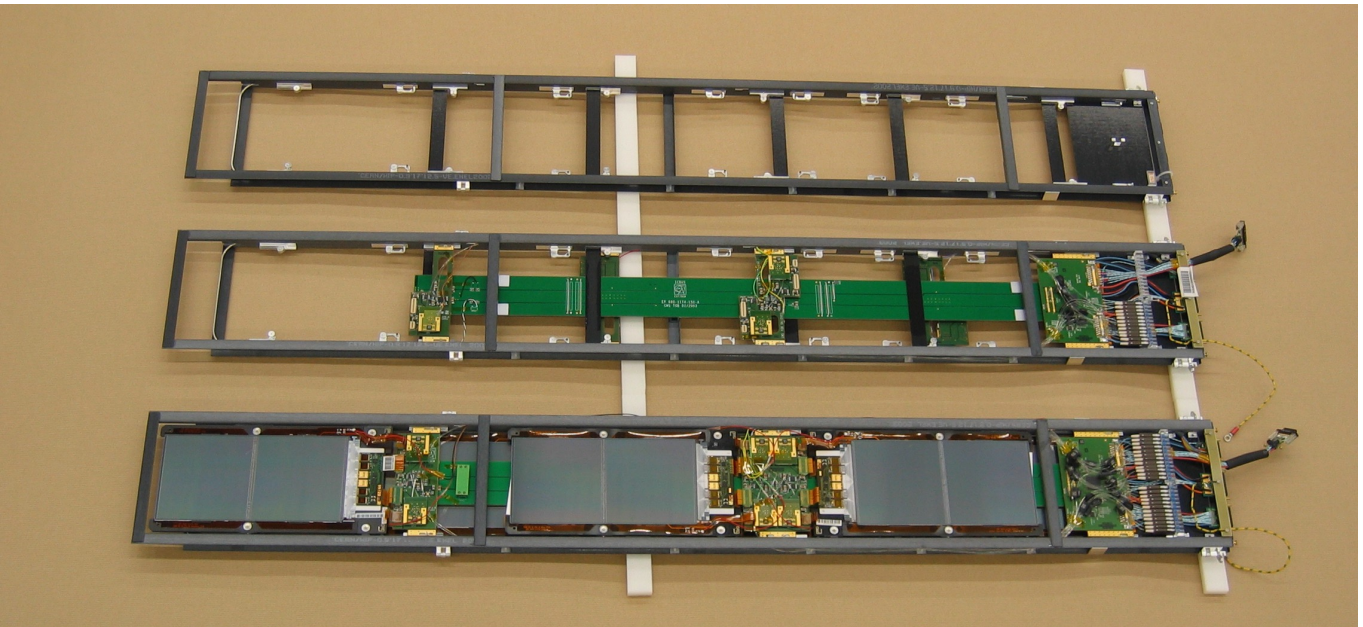
CMS silicon trackers as a vertex/ECAL detector



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)
CMS Board approved the request on Feb 9th 2024

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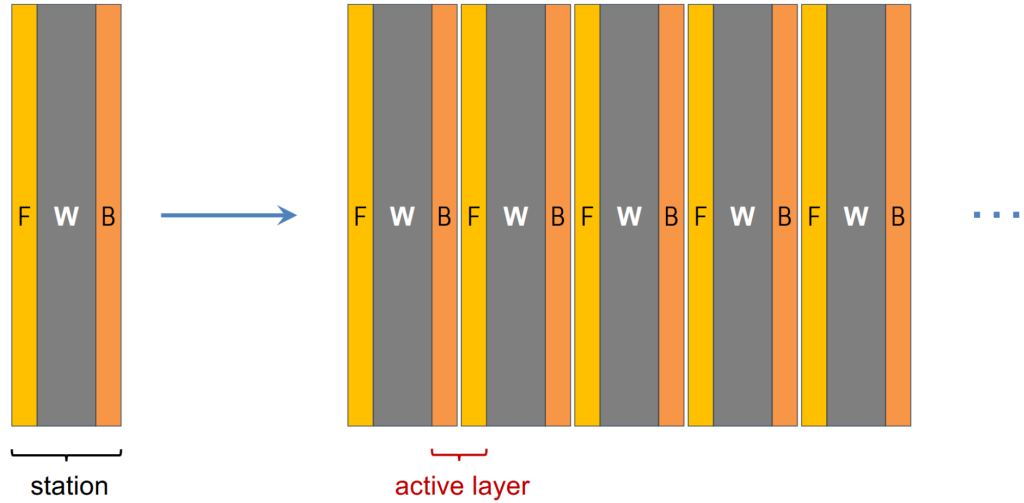
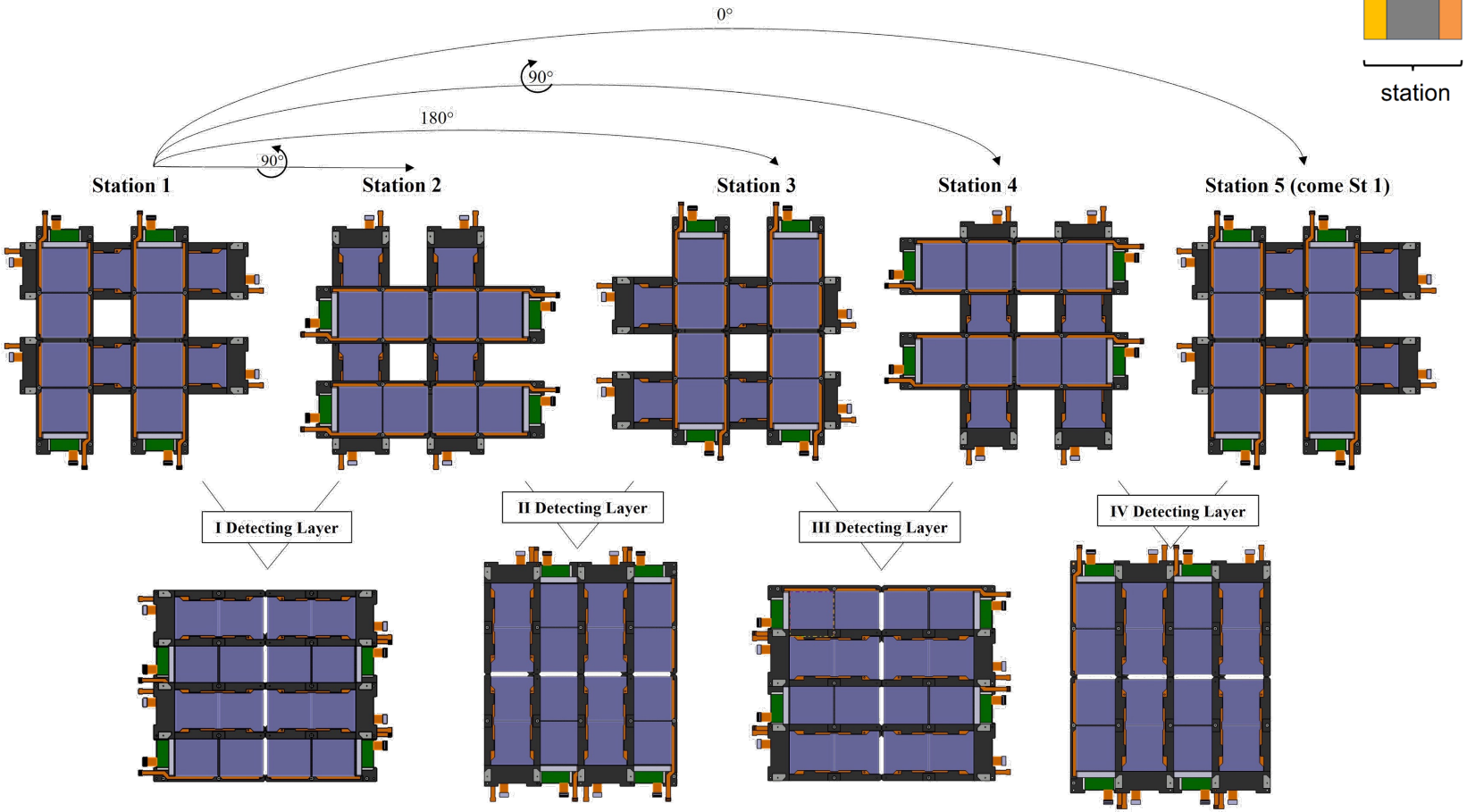
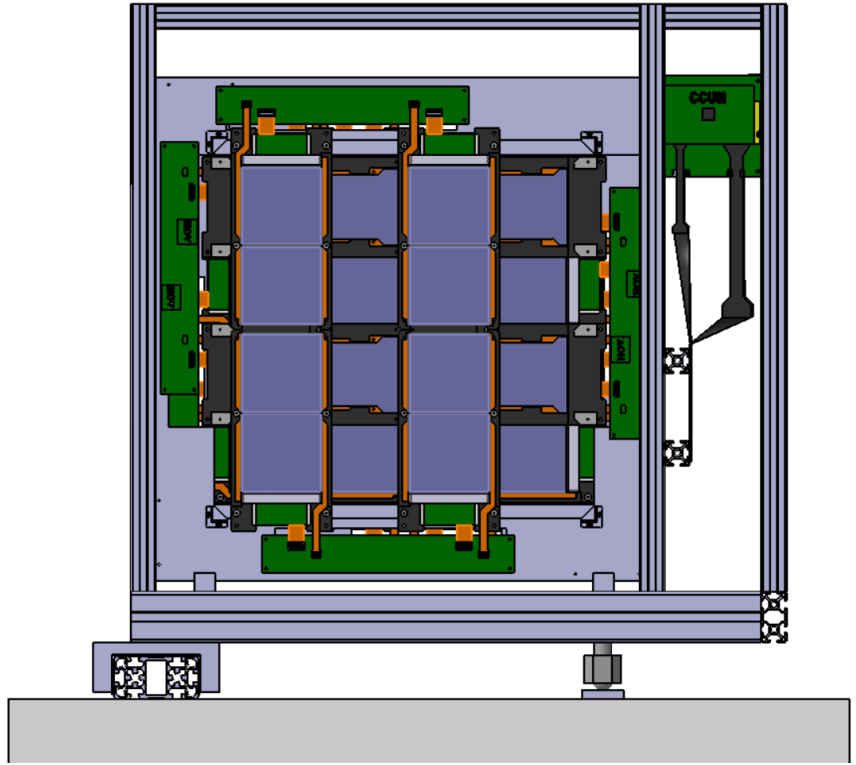
Structure of the different stations

One detecting layer is “hermetic”



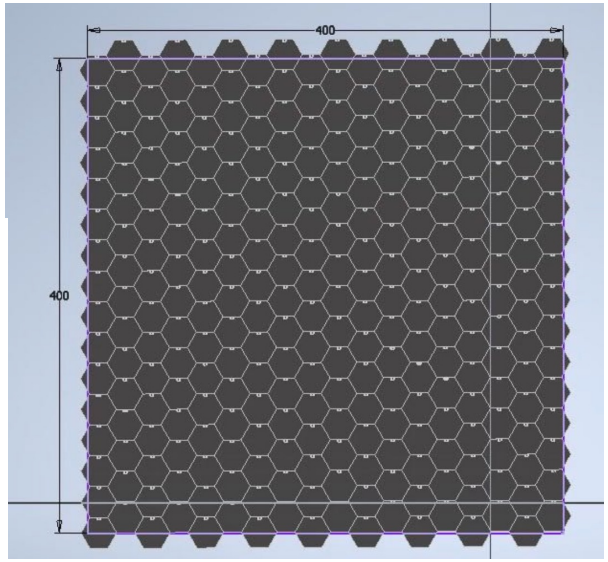




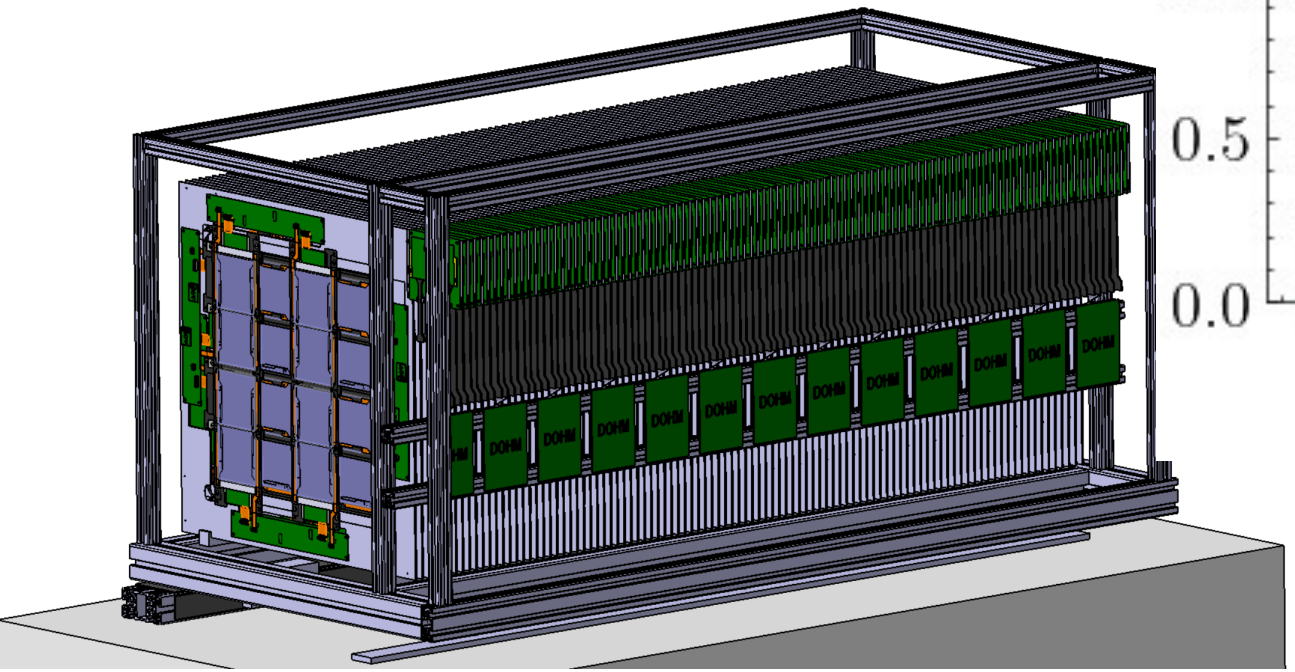
Neutrino target with VTX/Ecal and timing detector

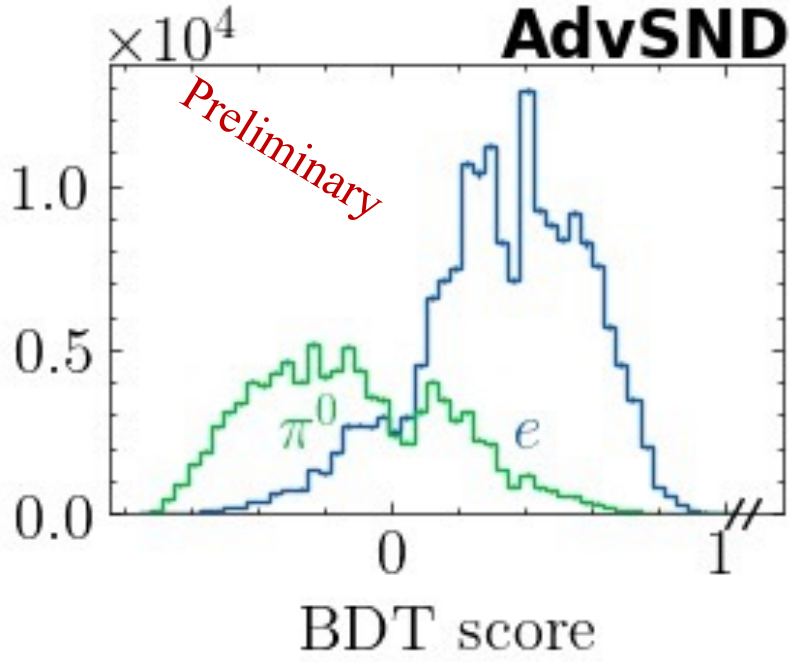
Property	EJ-204
τ_{decay} [ns]	1.8
Light Yield [kγ/MeV e-]	10.4

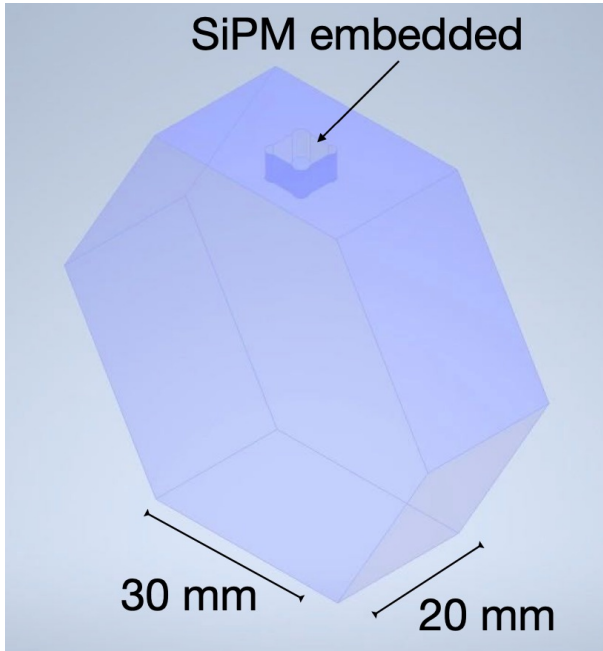
Timing planes with ~50 ps resolution



- Prototype being built
- Ecal performance will be tested next Summer







R&D on MOnolithic Stitched Sensor (MOSS) ongoing

HCAL and μ spectrometer

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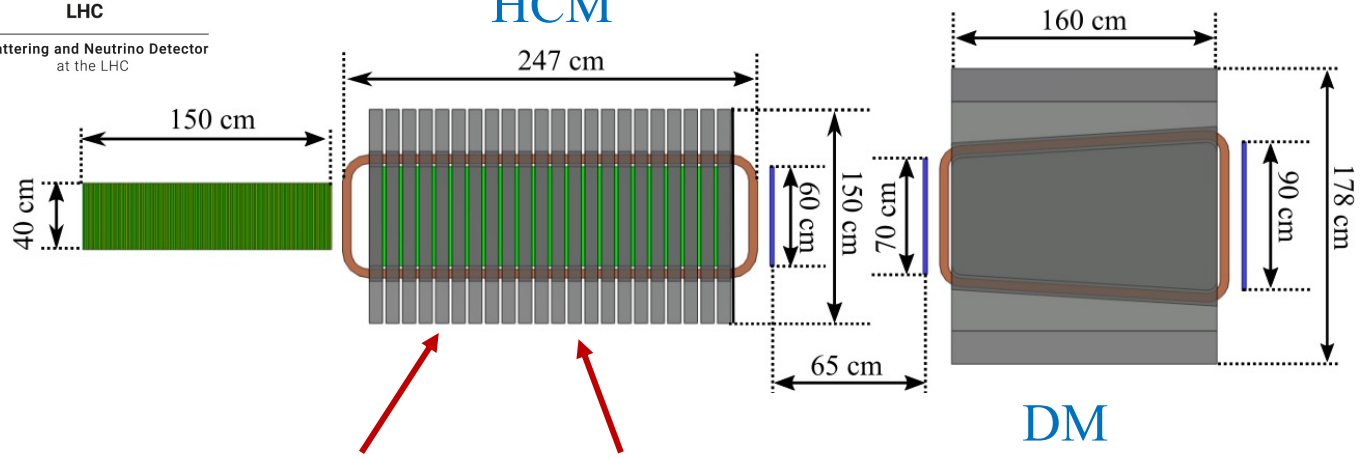
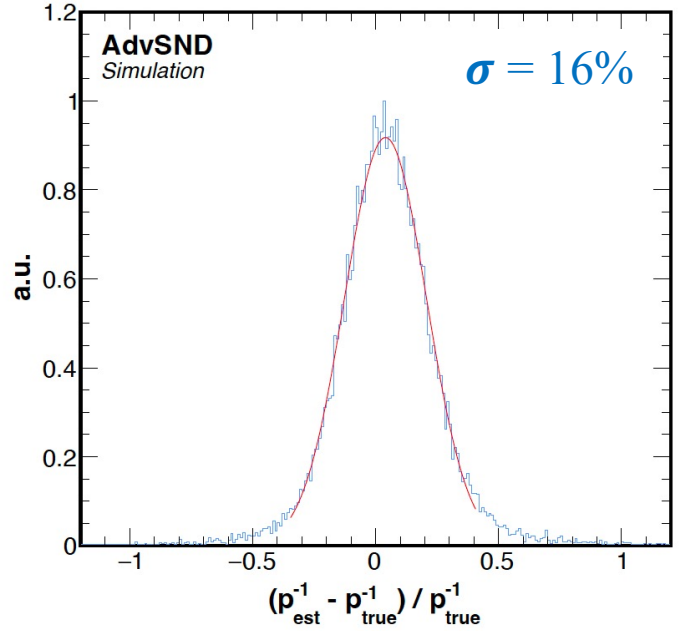
HCM

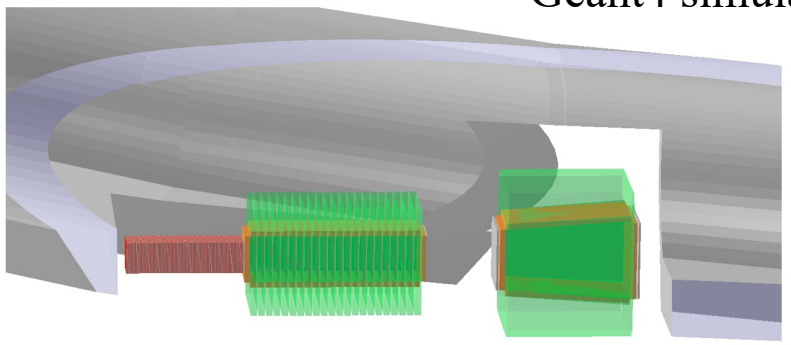


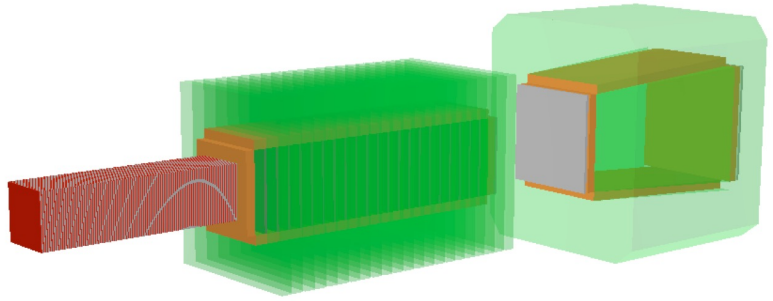
DM

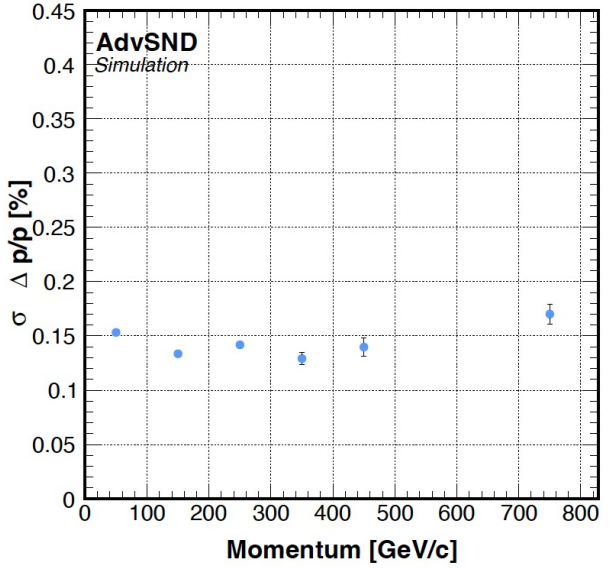
Magnetised Iron slabs interleaved with scintillating bar planes



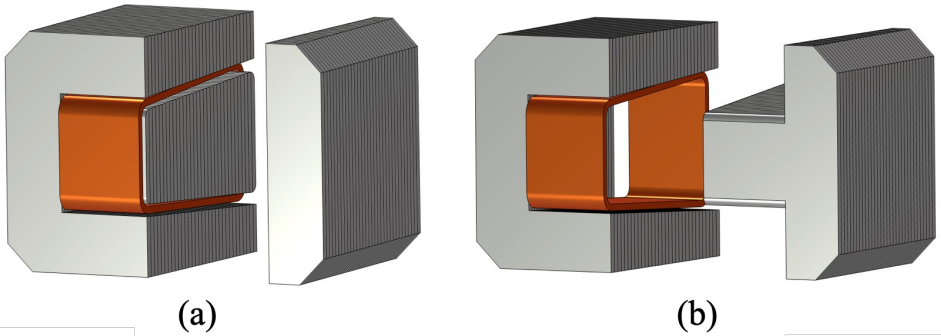
Geant4 simulation





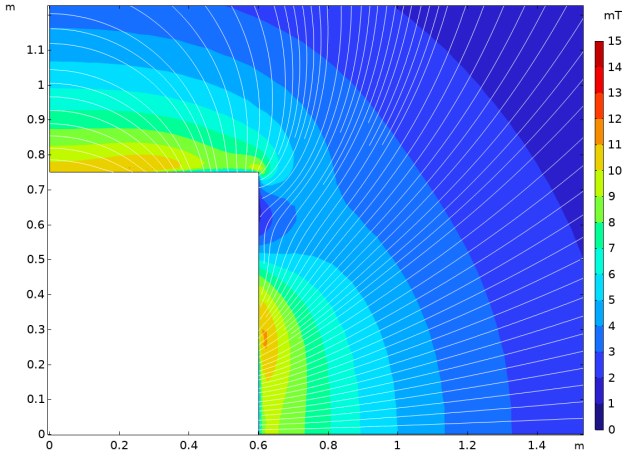


Magnet made of iron pieces to ease transportation and assembly on site

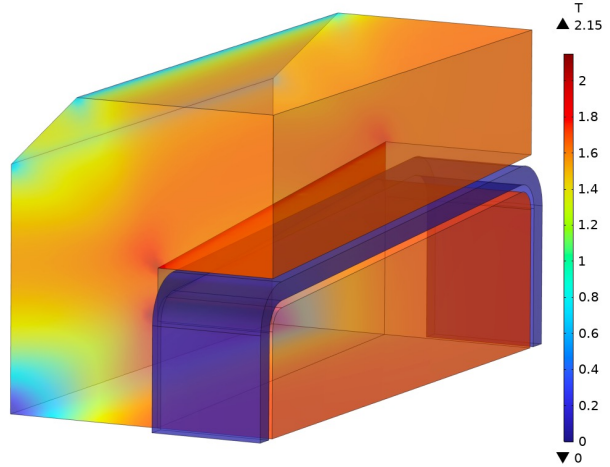


Each piece within 1.0 ton

Stray field well below operational limits



Magnetic flux density



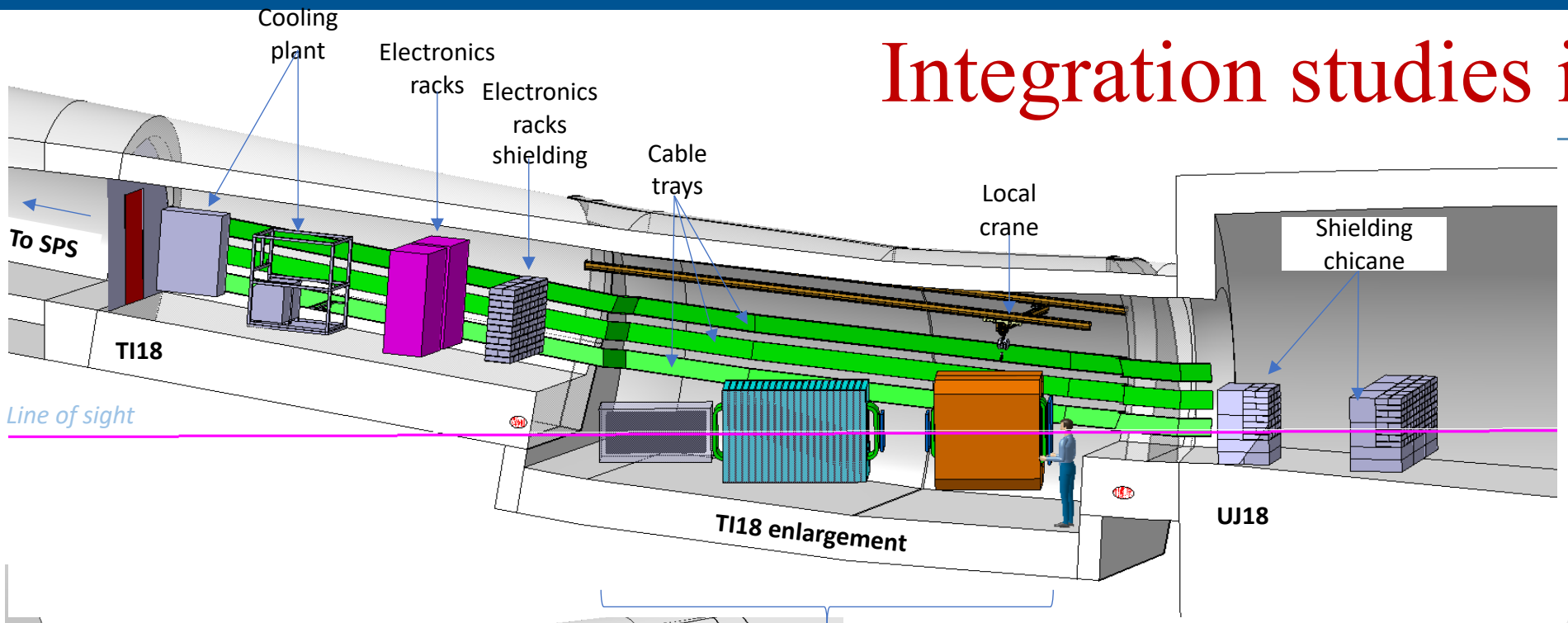
HCM

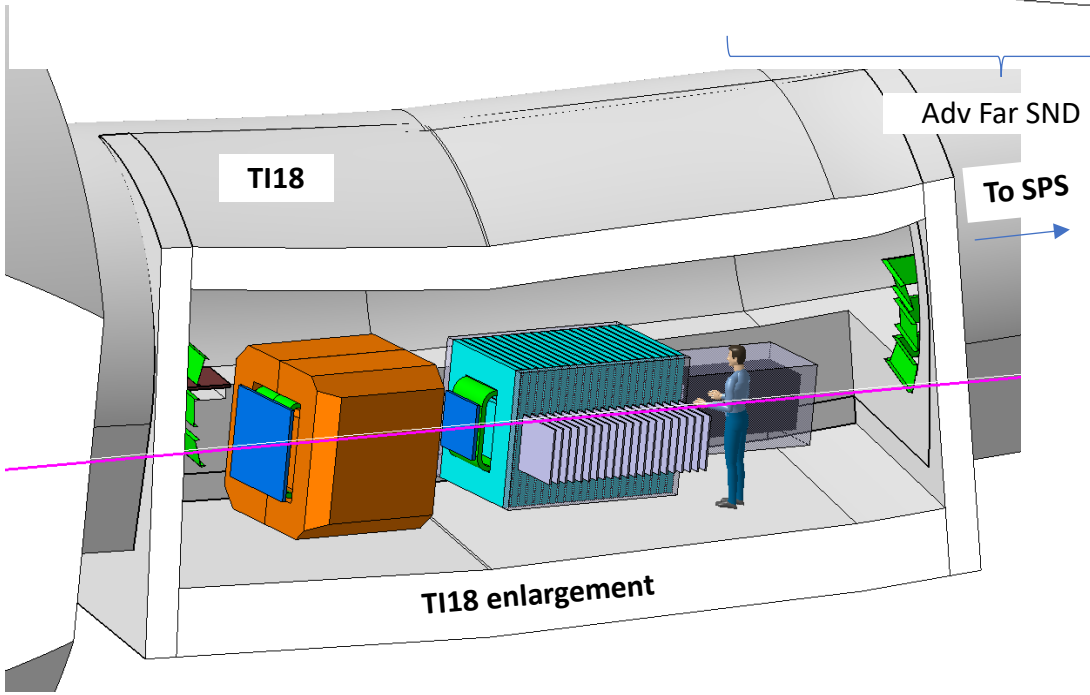
Stray field [@ iron surface, @ d >2m]	[mT]		[≲ 10 ≲ 1]
Voltage at the coil terminals	[V]	V	3.1
Electrical current	[A]	I	500
Current density	[A/mm^2]	J	0.75
Magnetomotive force	[kA]	$\mathcal{F} = NI$	18
Electrical power	[kW]	P	1.5
Total conductor mass	[t]	m_{Cu}	1.3
Mass of a single iron slab	[t]	$\frac{m_{\mathrm{Fe}}}{22}$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

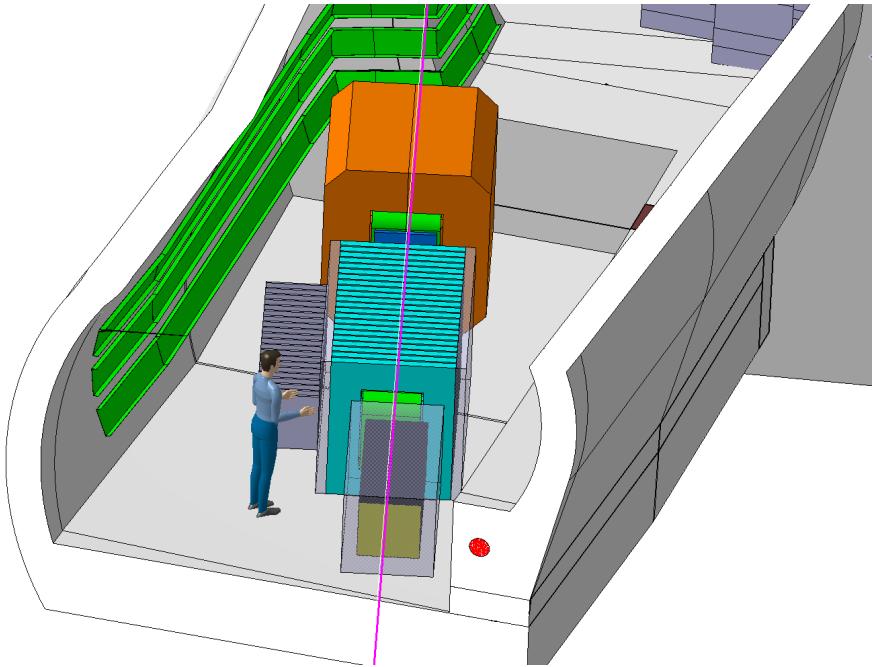
DM

Stray field [@ iron surface, @ d >2m]	[mT]		[≲ 10 ≲ 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







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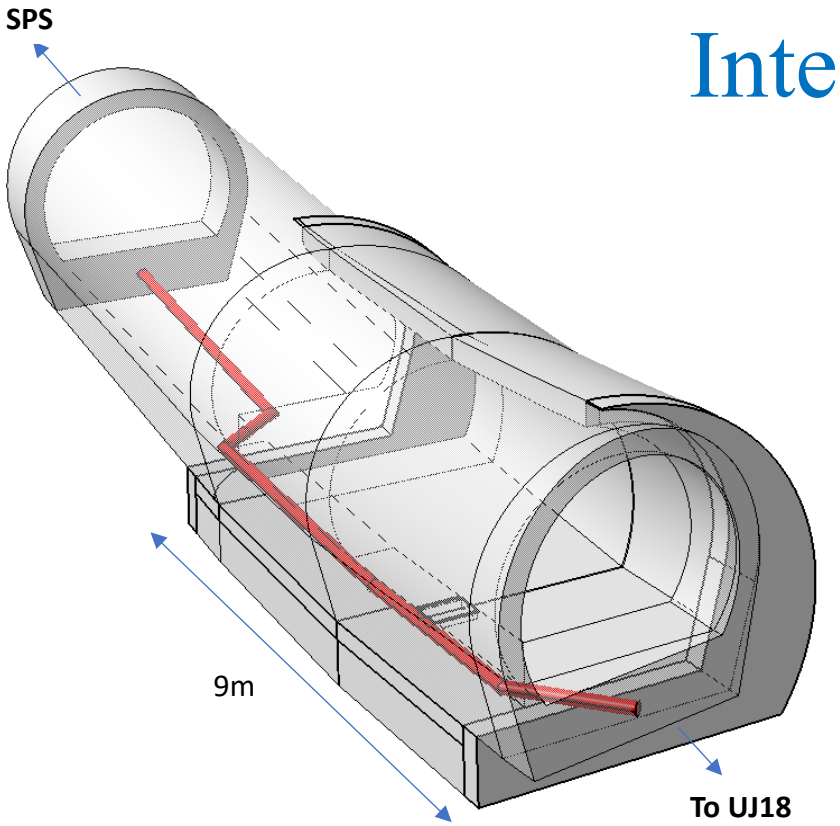
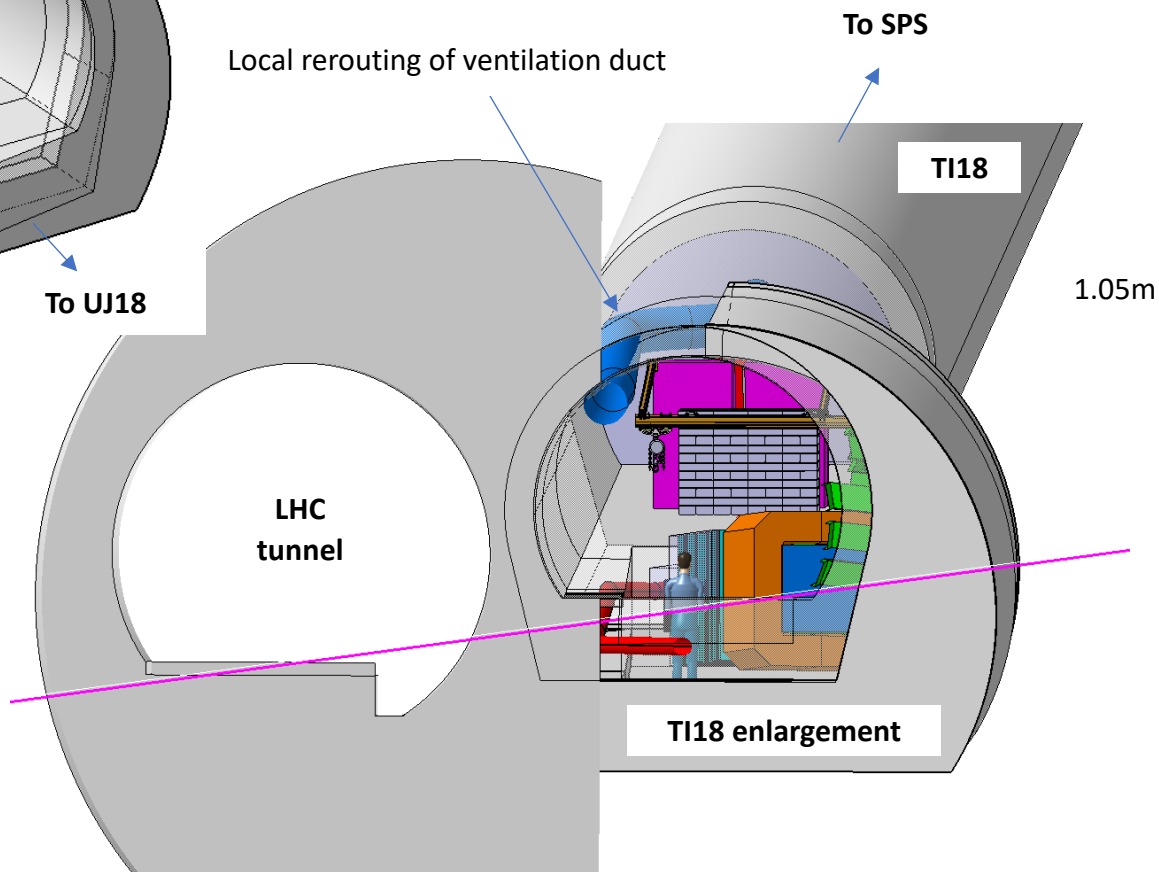
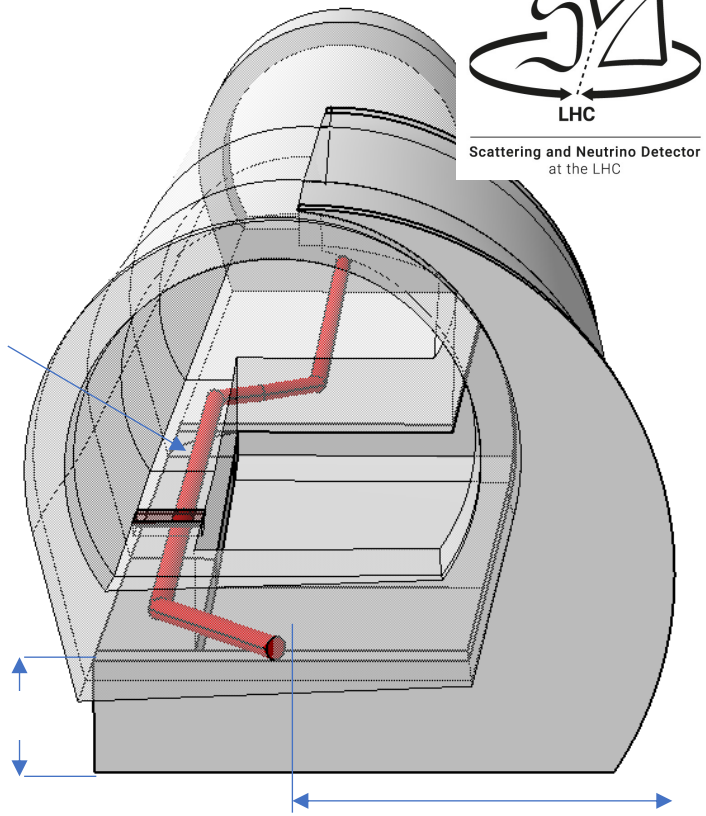
Integration studies in TI18







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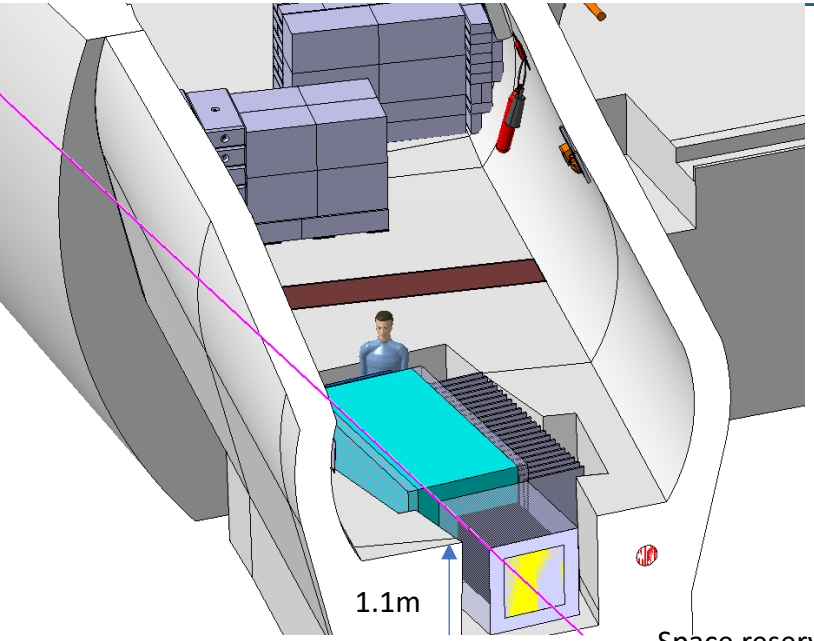
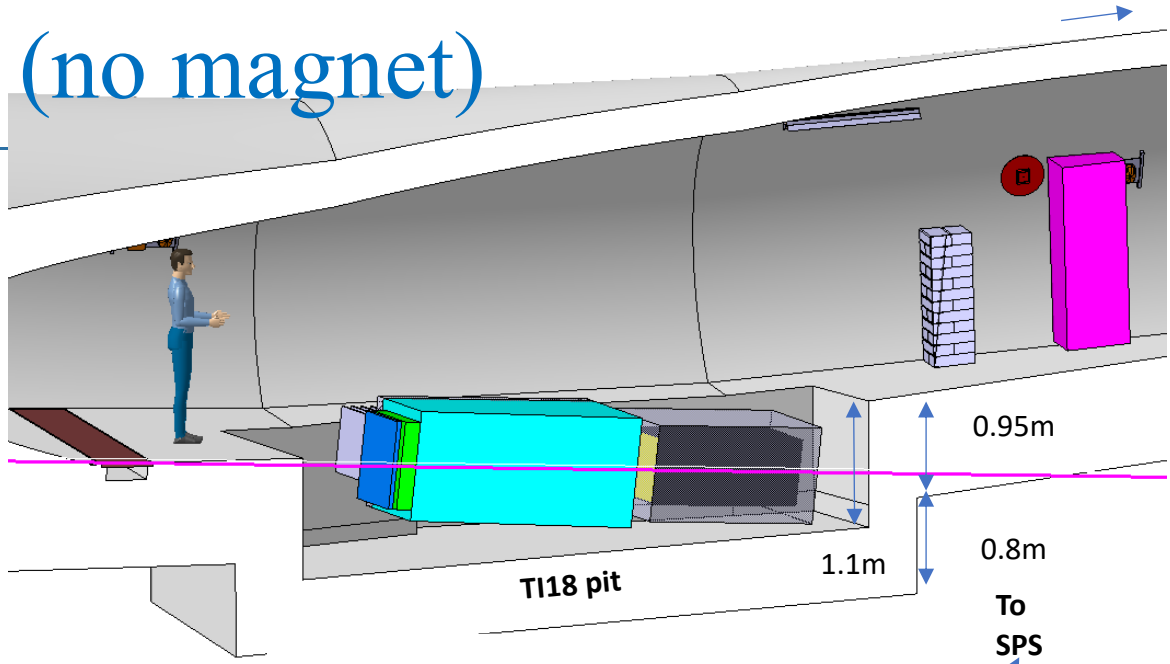
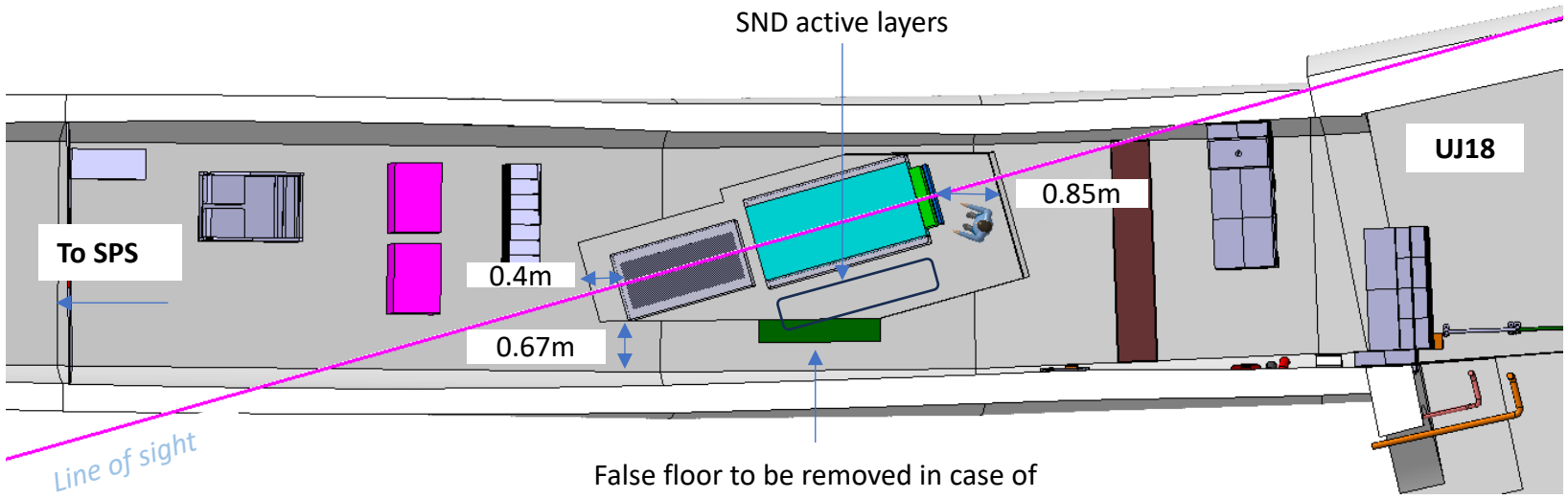
Configuration with minimal impact (no magnet)

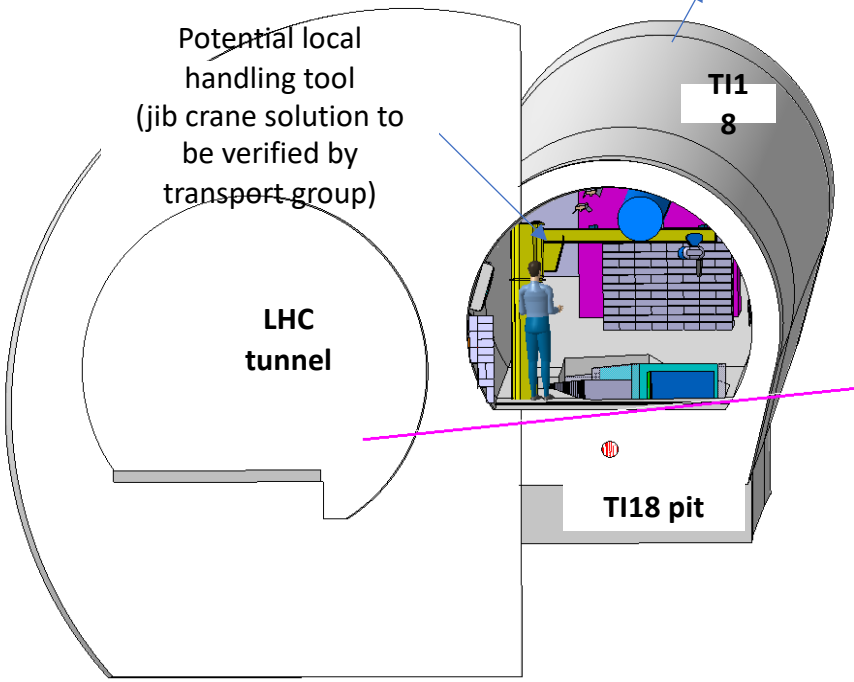




Space reserved for maintenance of Adv SND active layers



False floor to be removed in case of maintenance of Adv SND active layers



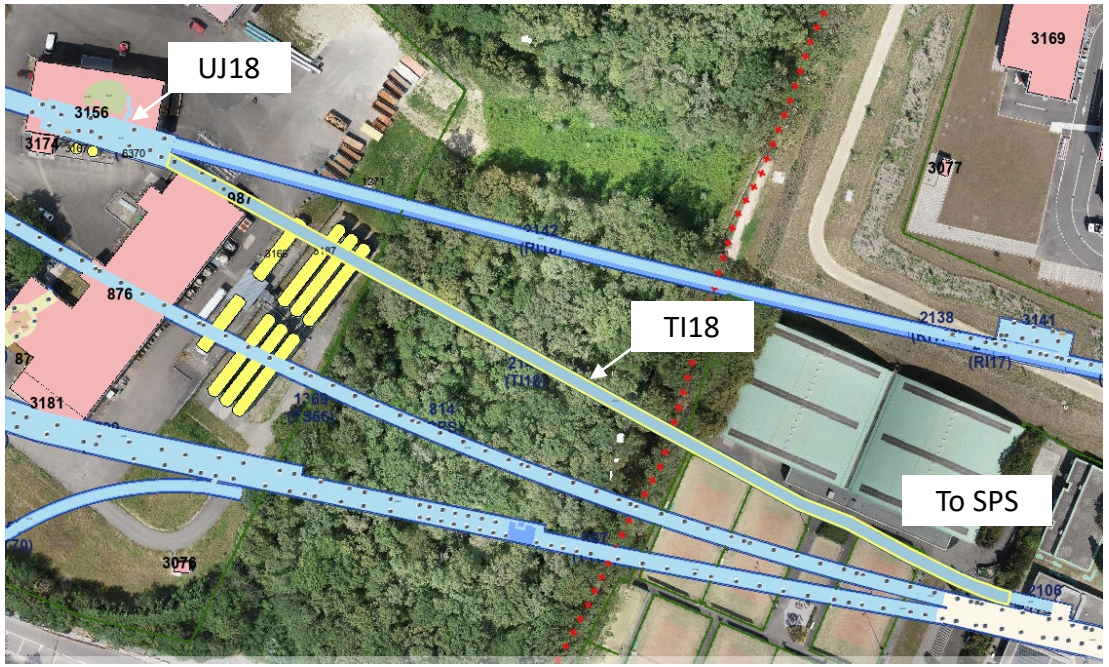
Use TI18 tunnel to bring the excavator and waste disposal

Scattering and Neutrino Detector at the LHC

Transfer tunnel TI18

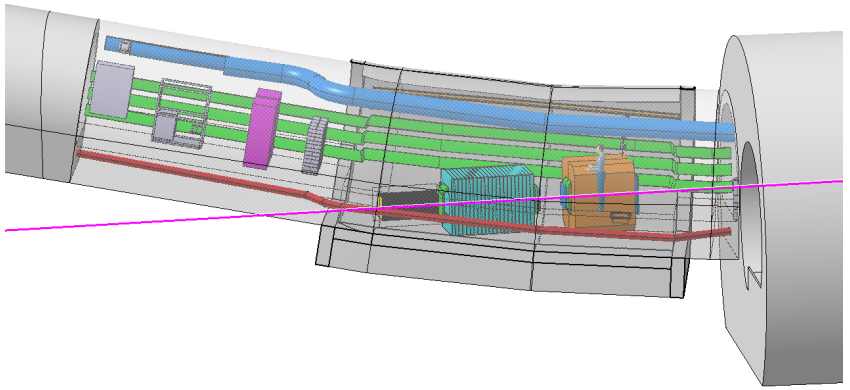
Underground caver
UJ18

To SPS

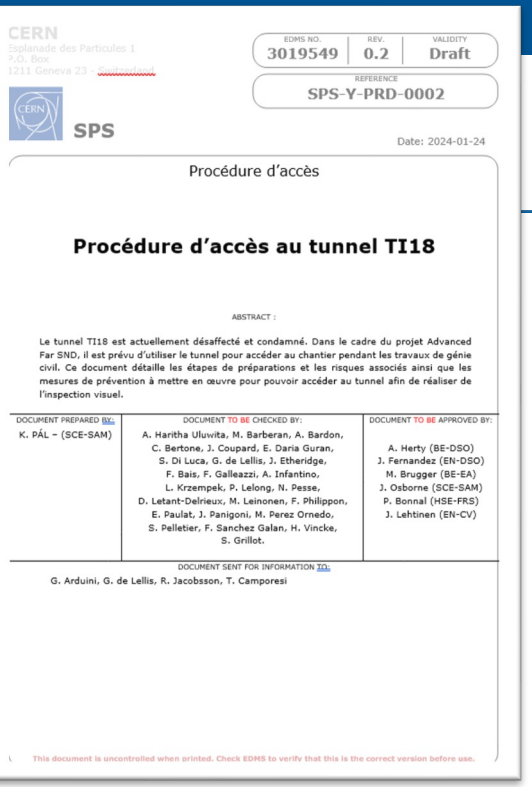


Line of sight

LHC machine



Visit to the TI18 tunnel on January 29th



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SPS

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:

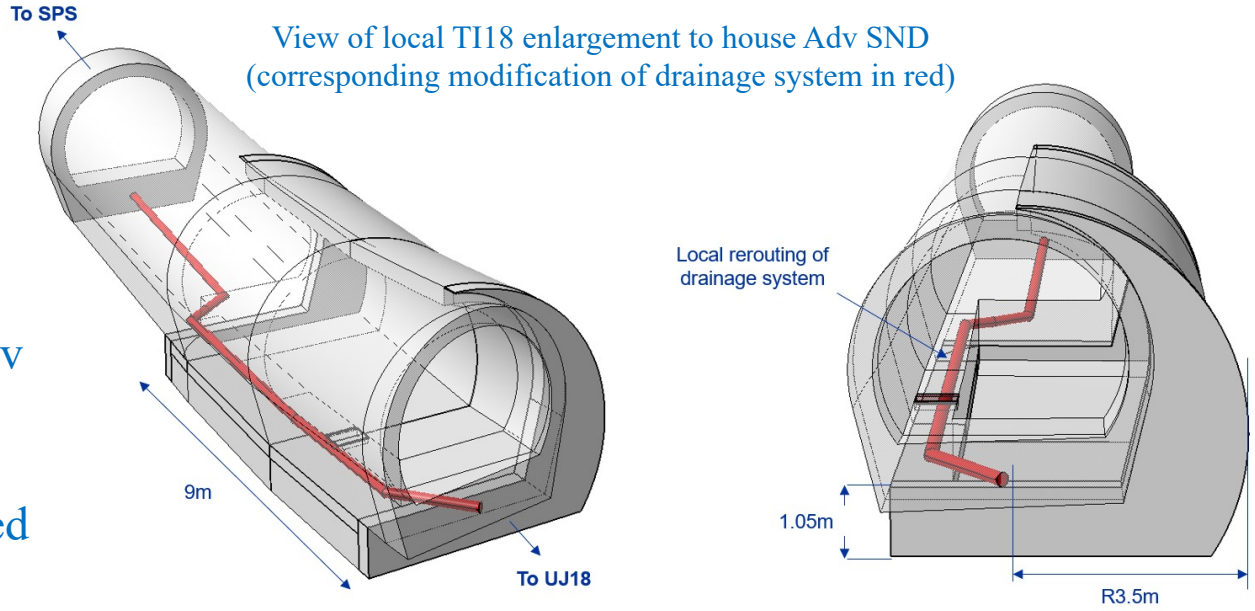
- Good condition of tunnel – feasibility to make it operational throughout all its length (256m)
- Further studies are required to implement transport solution
- On-going studies concern:
  - Transport solution to cope with 14.5% slope of TI18 tunnel
  - Installation of required services (GSM, lightening,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

LHC
Scattering and Neutrino Detector
at the LHC

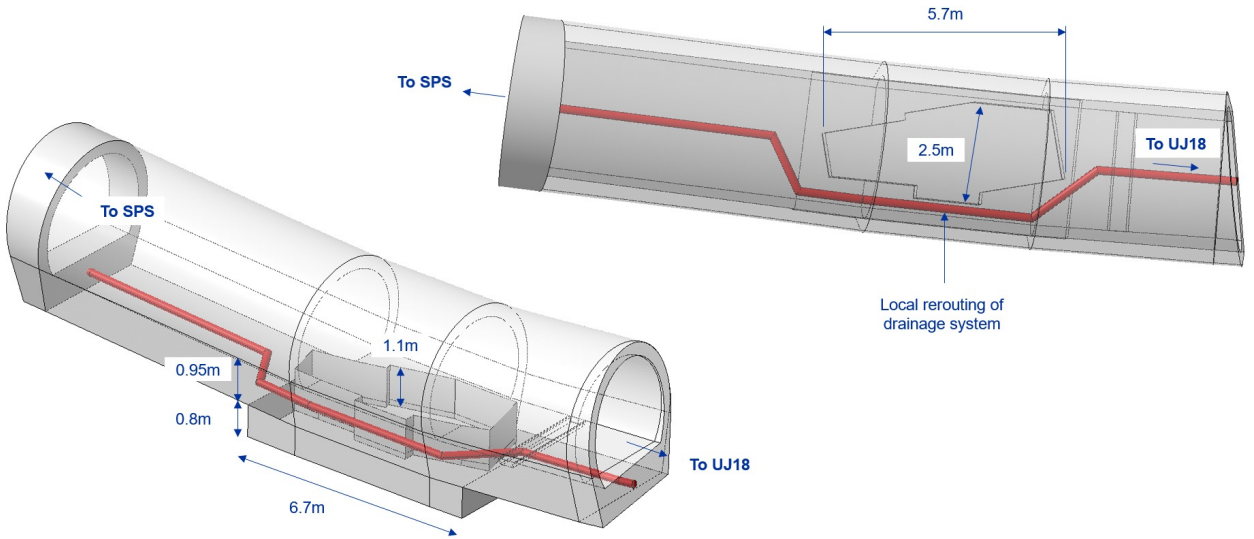
Civil engineering studies

- Confirmed feasibility of the needed excavation
- Timeline of excavation works - ~1 year for TI18 enlargement
- Timeline of excavation works - ~3-6 months for TI18 pit (Adv SND minimalistic solution)
- Next steps
  - On-going preparation of civil engineering drawings based on 3D integration models
  - Civil engineering studies with external consultant
    - Drawings sent to the company in March
    - Feasibility and timeline check including recommendations/suggestions 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)

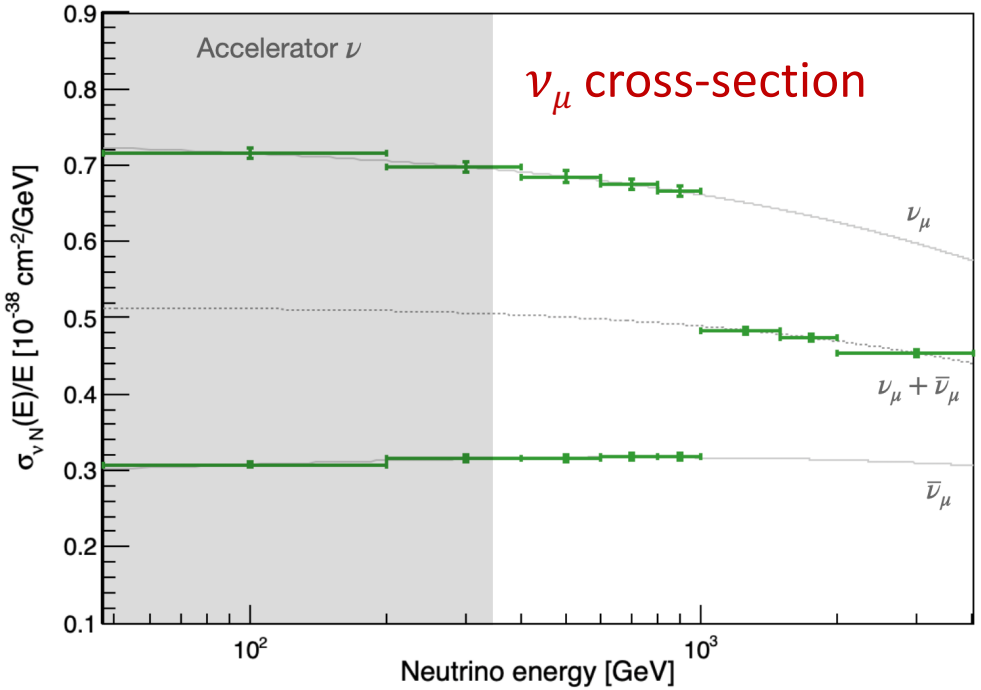


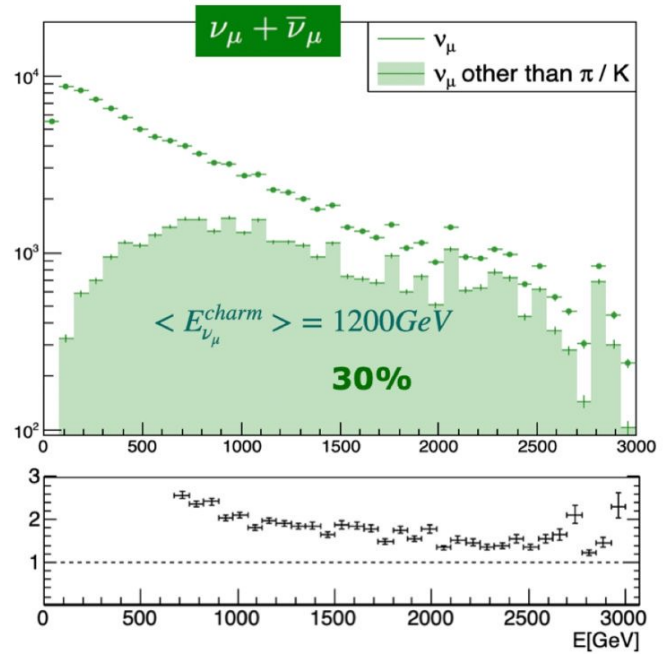
View of local TI18 pit to house minimalistic solution of Adv SND (corresponding modification of drainage system in red)

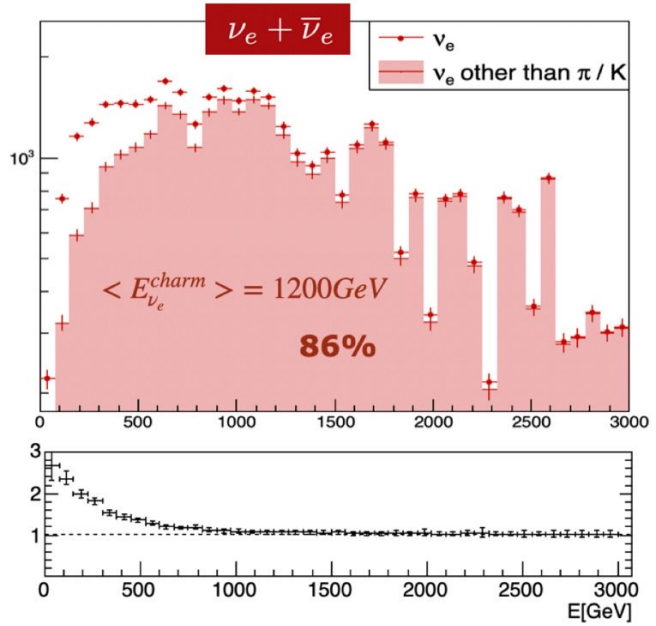


Physics performance in TI18

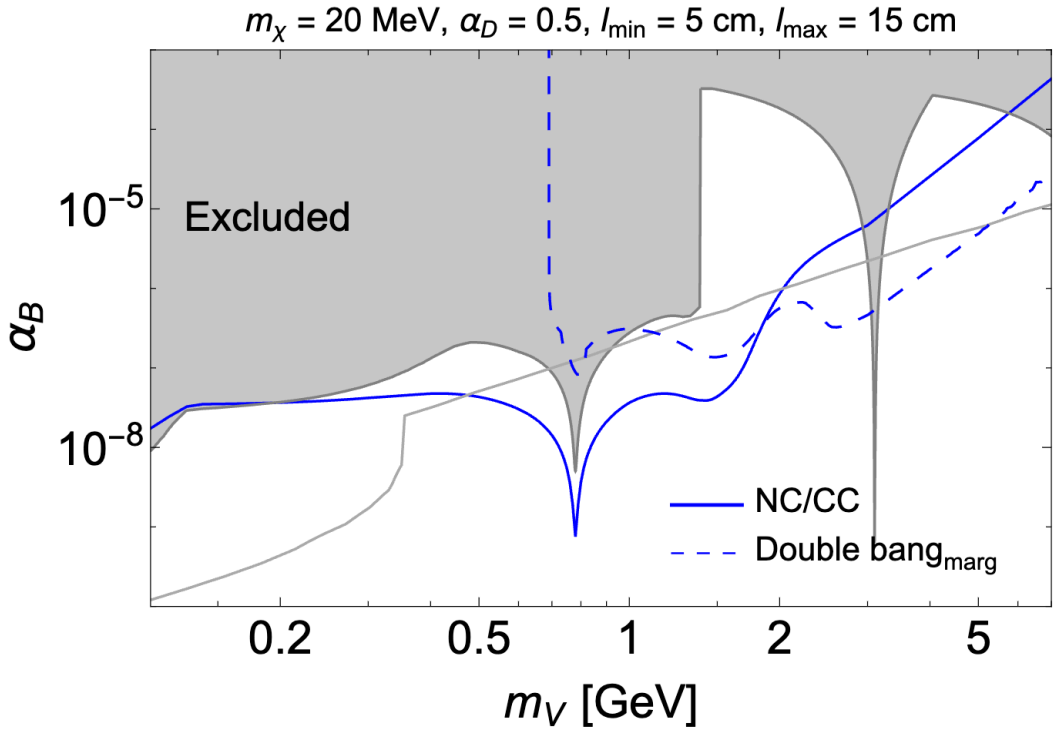
Flavour	CC DIS Interactions (3000 fb^{-1}, 2 ton mass)		
	total (DPMJET)	cc-bar (DPMJET)	cc-bar (PYTHIA8)
$\nu_\mu + \bar{\nu}_\mu$	1.6x10^5	5.1x10^4	1.5x10^4
$\nu_e + \bar{\nu}_e$	6.1x10^4	5.3x10^4	1.6x10^4
$\nu_\tau + \bar{\nu}_\tau$	3.2x10^3	3.2x10^3	8.7x10^2
Total	**2.3x10^5**	**1.1x10^5**	**3.2x10^4**







Sensitivity to dark matter (scattering)



EDM signature

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

IDM signature

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

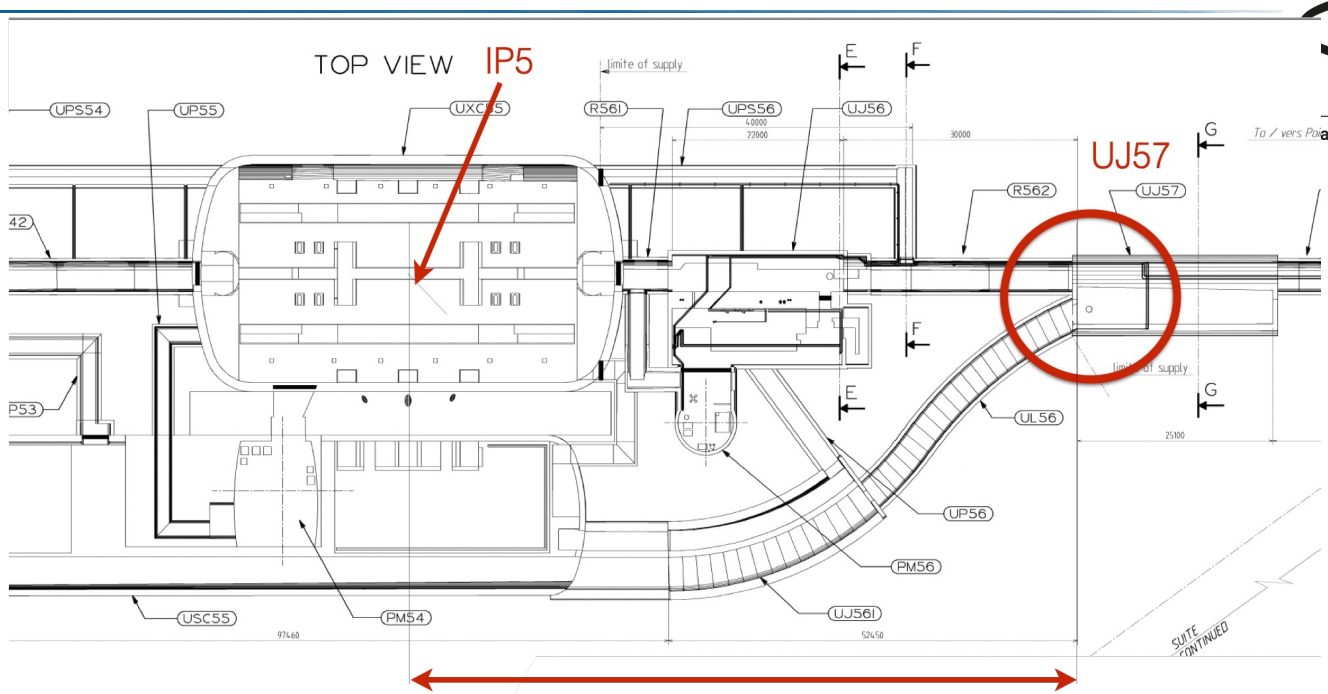
LDM coupled to a baryonic mediator: elastic DM model (EDM, solid blue), where the signature is an increase of the NC/CC ratio due to scatterings, and the inelastic DM model (IDM, dashed blue), with the signature being "double bang" – a scattering with the subsequent displaced decay

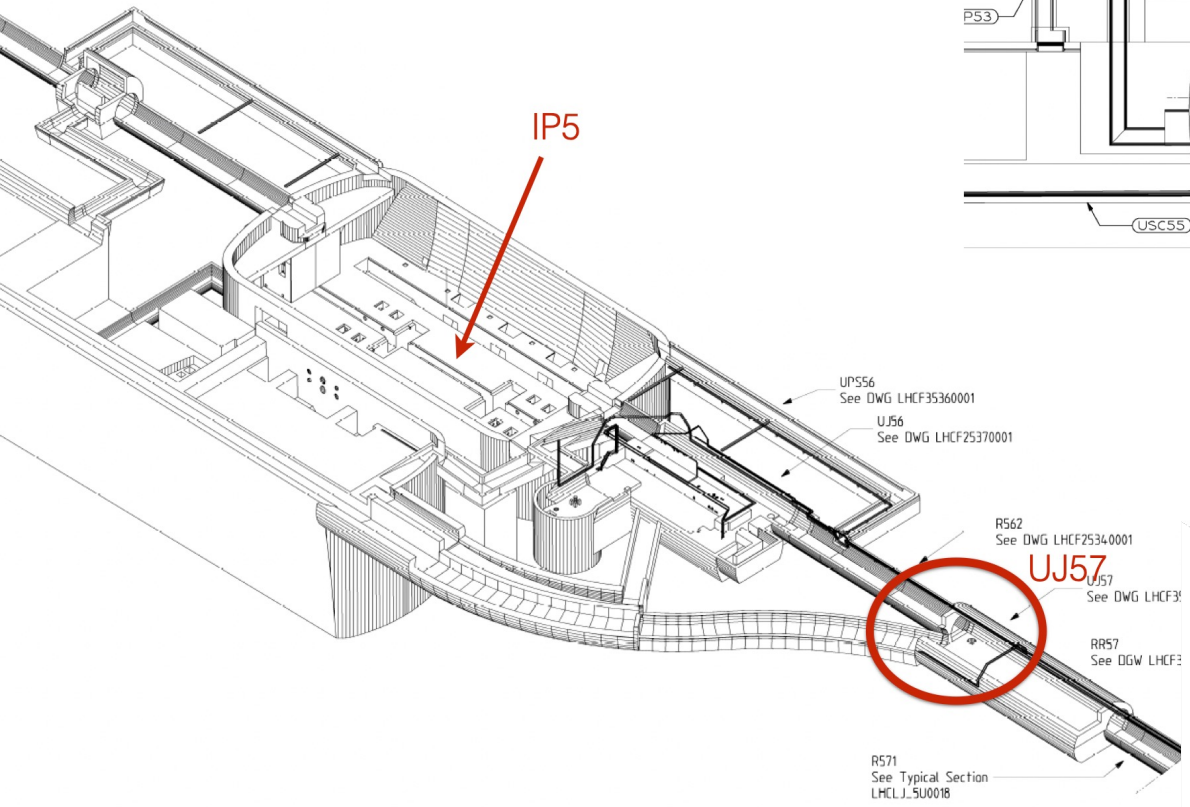
Only inelastic scattering off protons considered. For the EDM signature, 10% accuracy in the NC/CC measurement is assumed. IDM signature: for the first bang, a minimal energy deposition of 600 MeV is required; the minimal/maximal displacements l_{min} and l_{max} range between 5 and 15 cm; the lighter particle mass is assumed to be $m\chi$ = 20 MeV, to avoid the direct detection constraints on DM for the EDM case that become relevant at masses $\gtrsim$ 100 MeV (bounds absent in the IDM case), while the marginalization is made over the mass splitting between χ' and χ

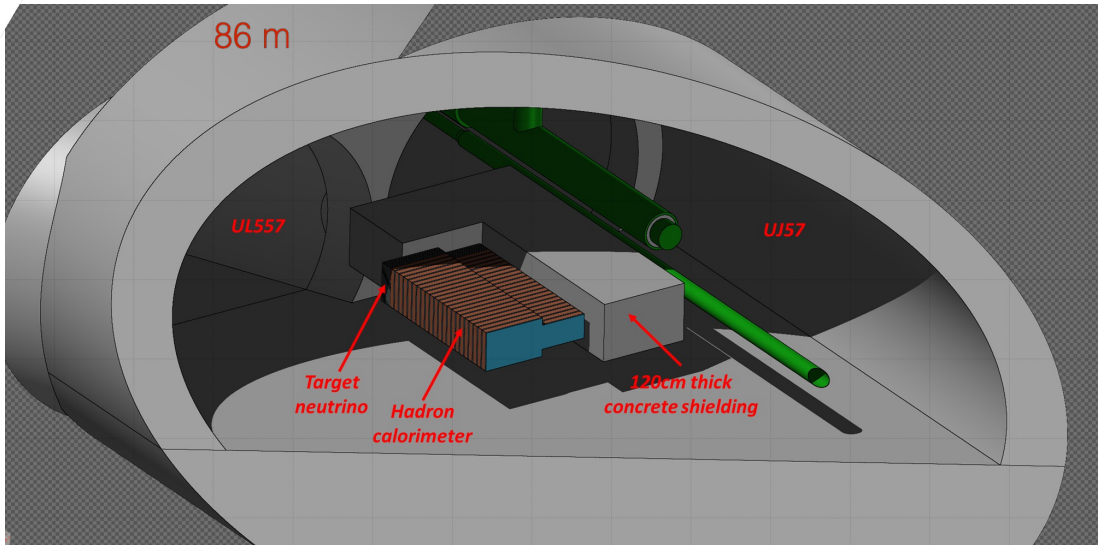
Studies for the NEAR detector (Run 5)

UJ57 tunnel at 86 m from CMS IP

Sufficiently close to allow triggering CMS (→ 4π view of the event)

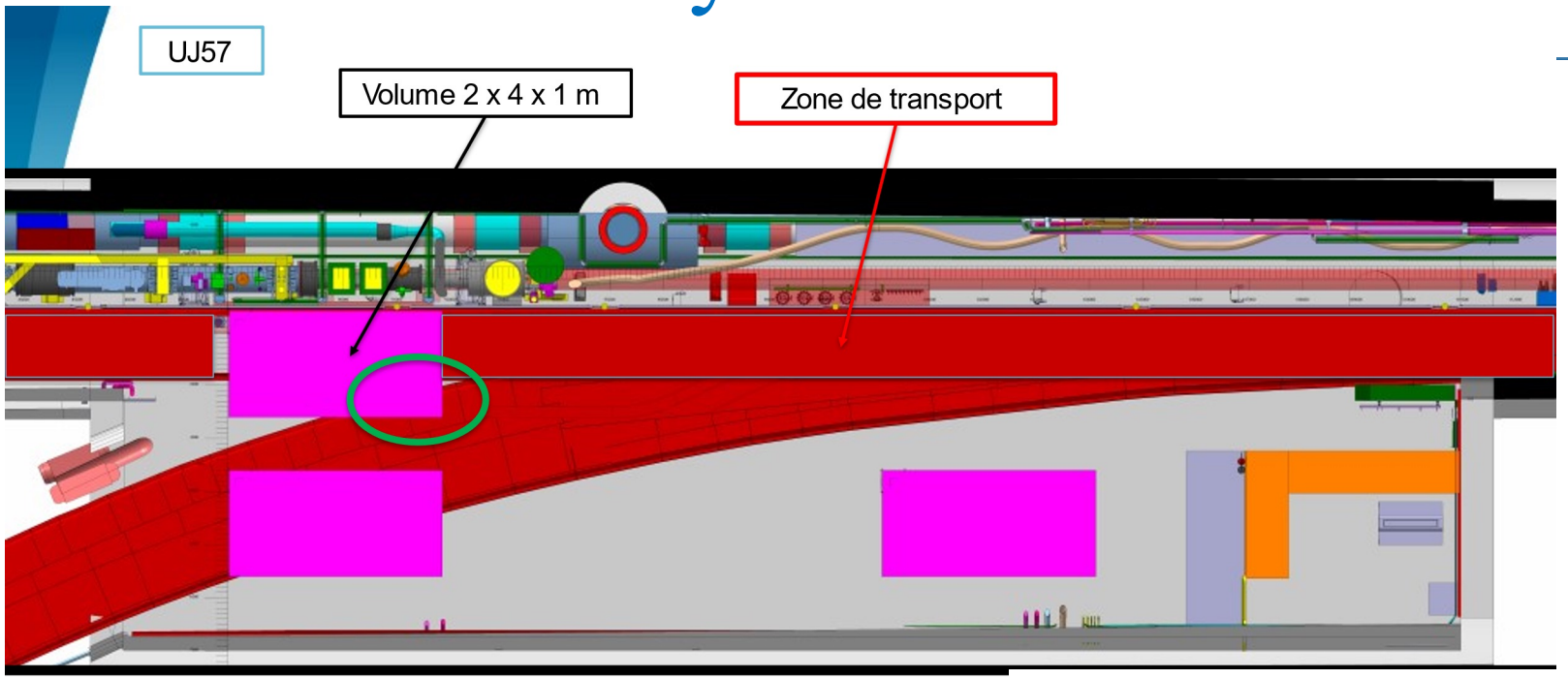






attering and Neutrino Detector
at the LHC

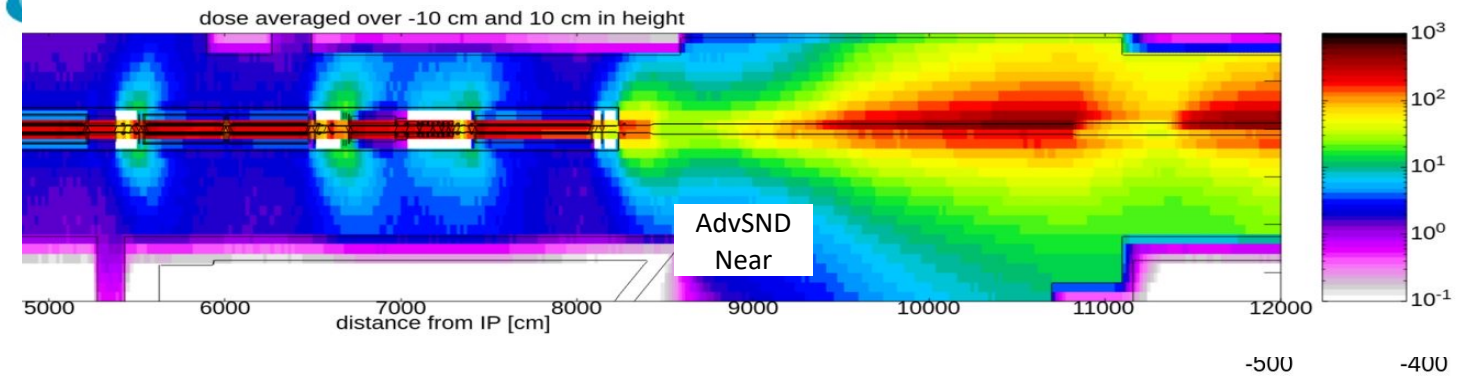
Preliminary studies of the NEAR detector

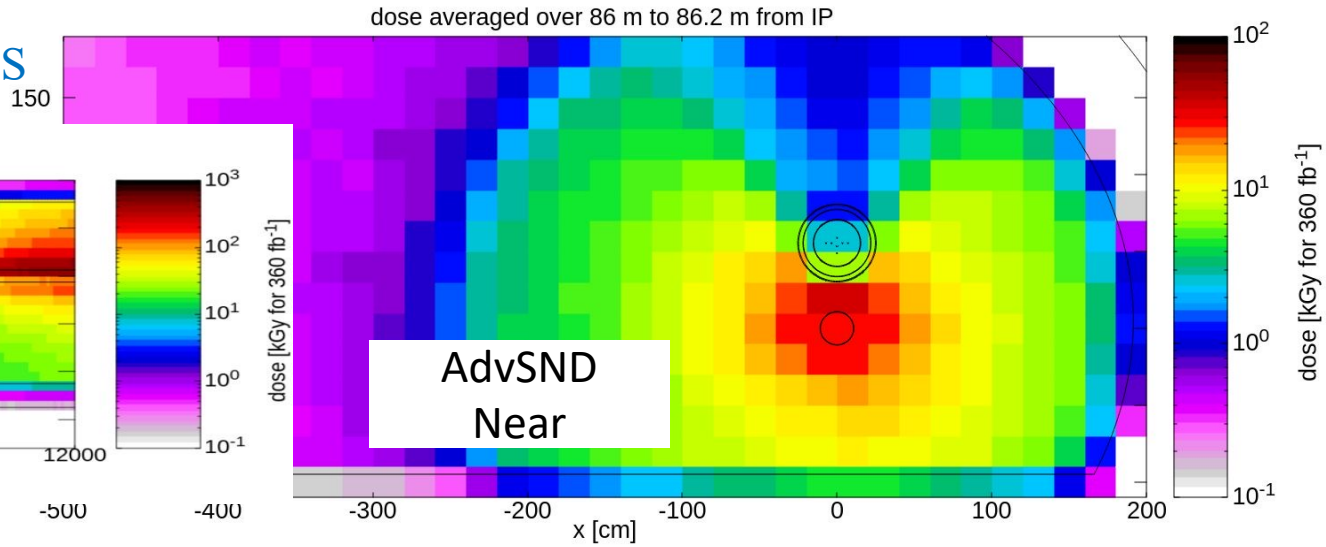


Scattering and Neutrino Detector at the LHC

Dose distribution in the transverse plane, 86 m from CMS

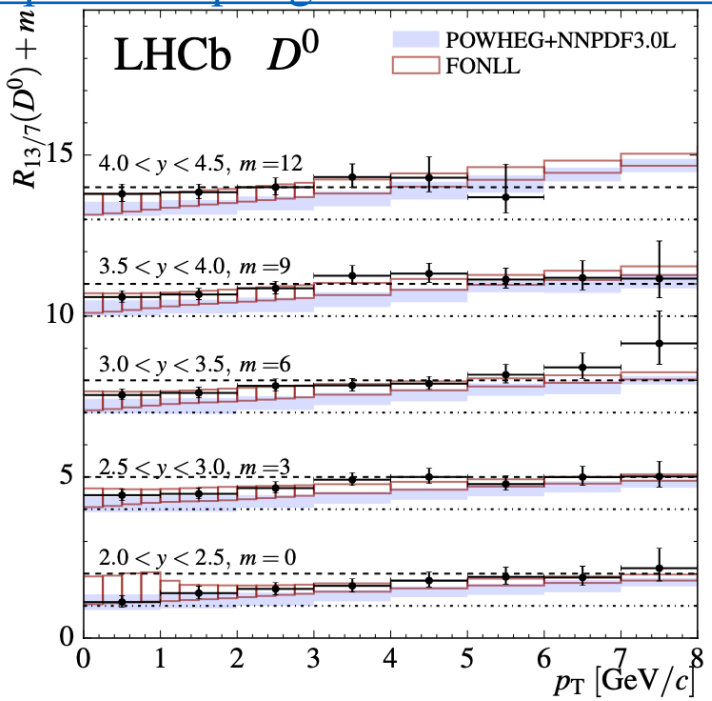
Dose distribution along the beamline vs distance from CMS

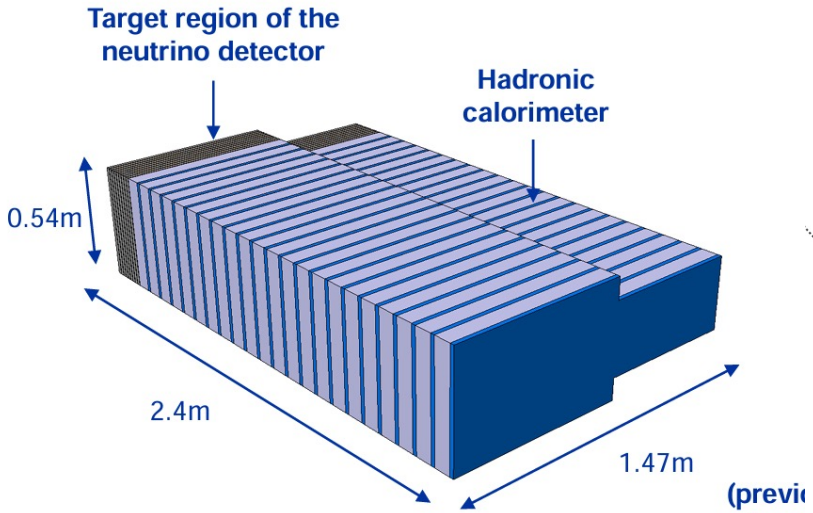


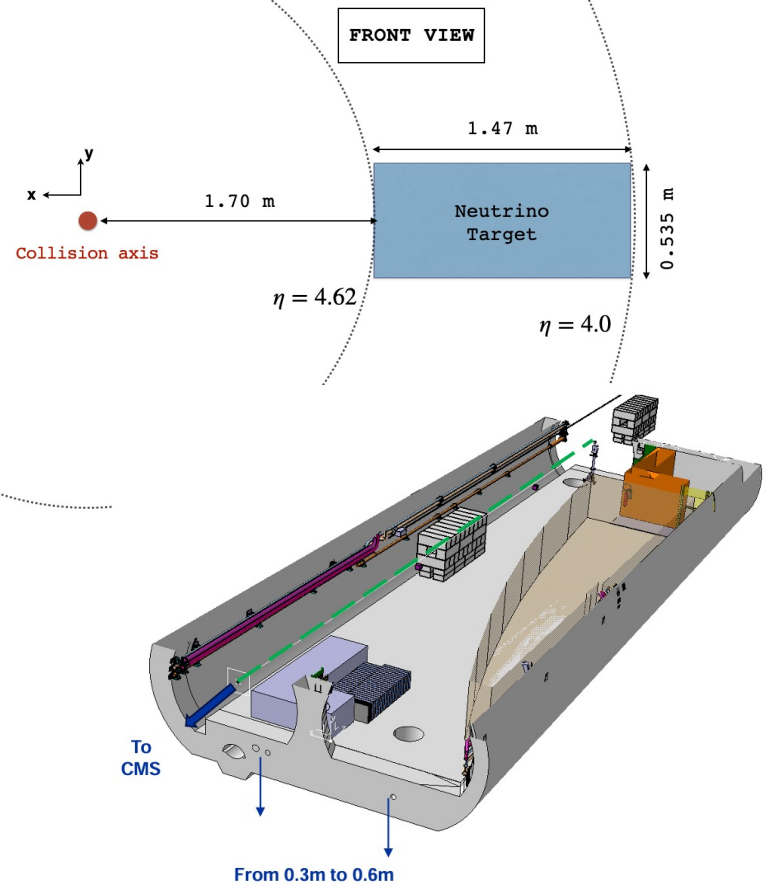


LHCb measurements and ν

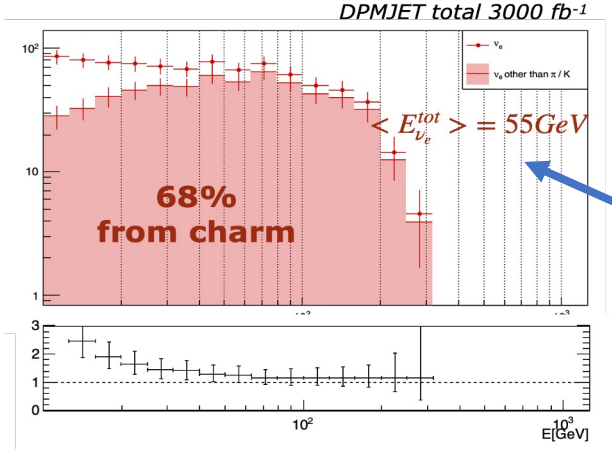
https://link.springer.com/article/10.1007/JHEP05(2017)074







Neutrino interactions in AdvSDN-Near
DPMJET total 3000 fb-1



LHCb ~ 180k charmed hadrons in the 4 to 4.5 η range → ~ 18k ν_e

Flavour	CC DIS Interactions (3000 fb-1) total (DPMJET)	cc-bar (DPMJET)	cc-bar (PYTHIA8)	bb-bar (PYTHIA8)
$\nu_\mu + \overline{\nu}_\mu$	1.7x10⁴	1.0x10³	0.9x10³	47
$\nu_e + \overline{\nu}_e$	1.8x10³	1.1x10³	1.0x10³	50
$\nu_\tau + \overline{\nu}_\tau$	75	75	75	10
Total	**1.9x10⁴**	**2.2x10³**	**2.0x10³**	**107**

Concluding remarks

- TI18 tunnel modifications allow optimal geometrical configuration to explore ν physics at the HL-LHC
- Optimised configuration accounts for the crossing angle configuration in Run 4 and beyond
- 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 ν/ν-bar separation)
- Avoid interference with LHC → use TI18 from SPS side for the excavation work
- No show-stopper identified so far
- The TI18 is the closest location (480 m) to exploit this kind of physics → maximal flux
- Present FPF scheme shows geometrical constraints preventing an optimisation of the Advanced SND
- Collaboration eager to take data in Run4
- If civil engineering work for the magnet setup turns to be unfeasible for any reason, we would consider installing the detector at FPF
- The enlargement of the TI18 tunnel can be considered as an FPF ancillary facility
- A big thank to all the groups involved in these studies!