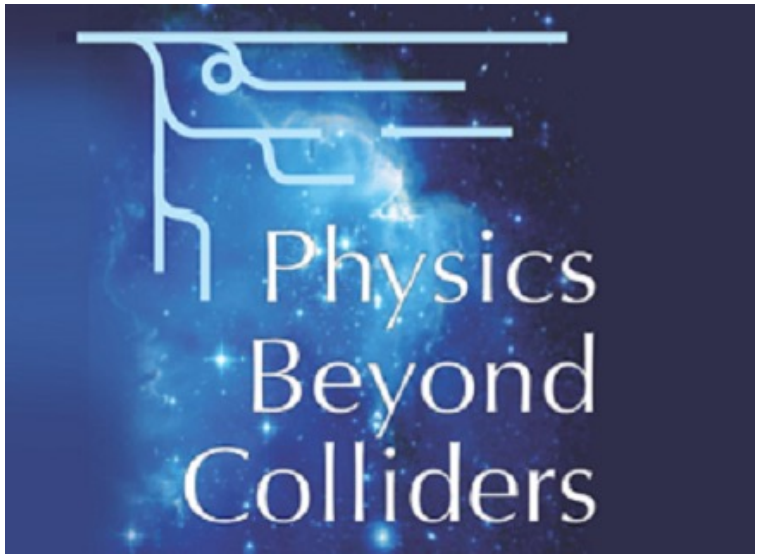
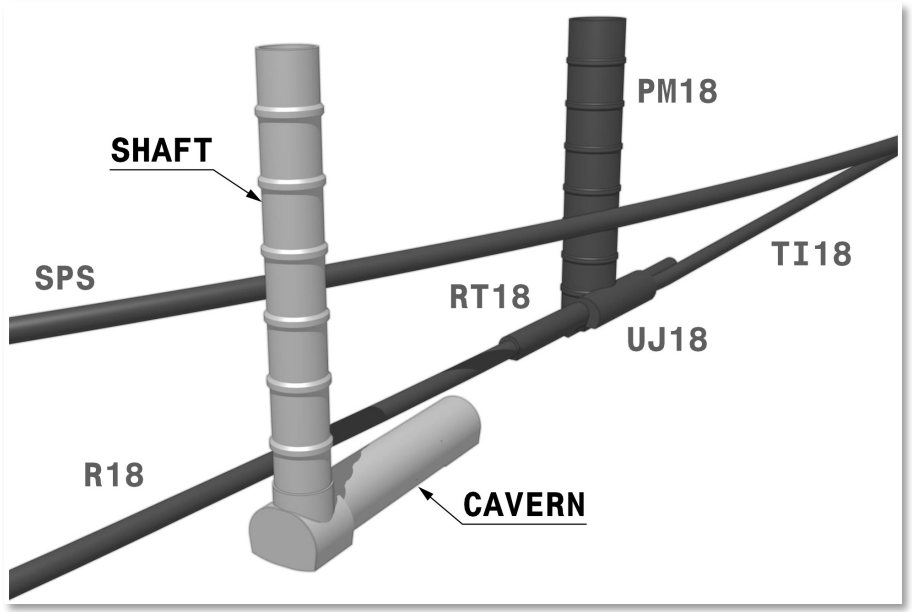
Forward Physics Facility @ LHC: preliminary design

PBC Annual Workshop

November 8th 2022

Jamie Boyd (CERN)



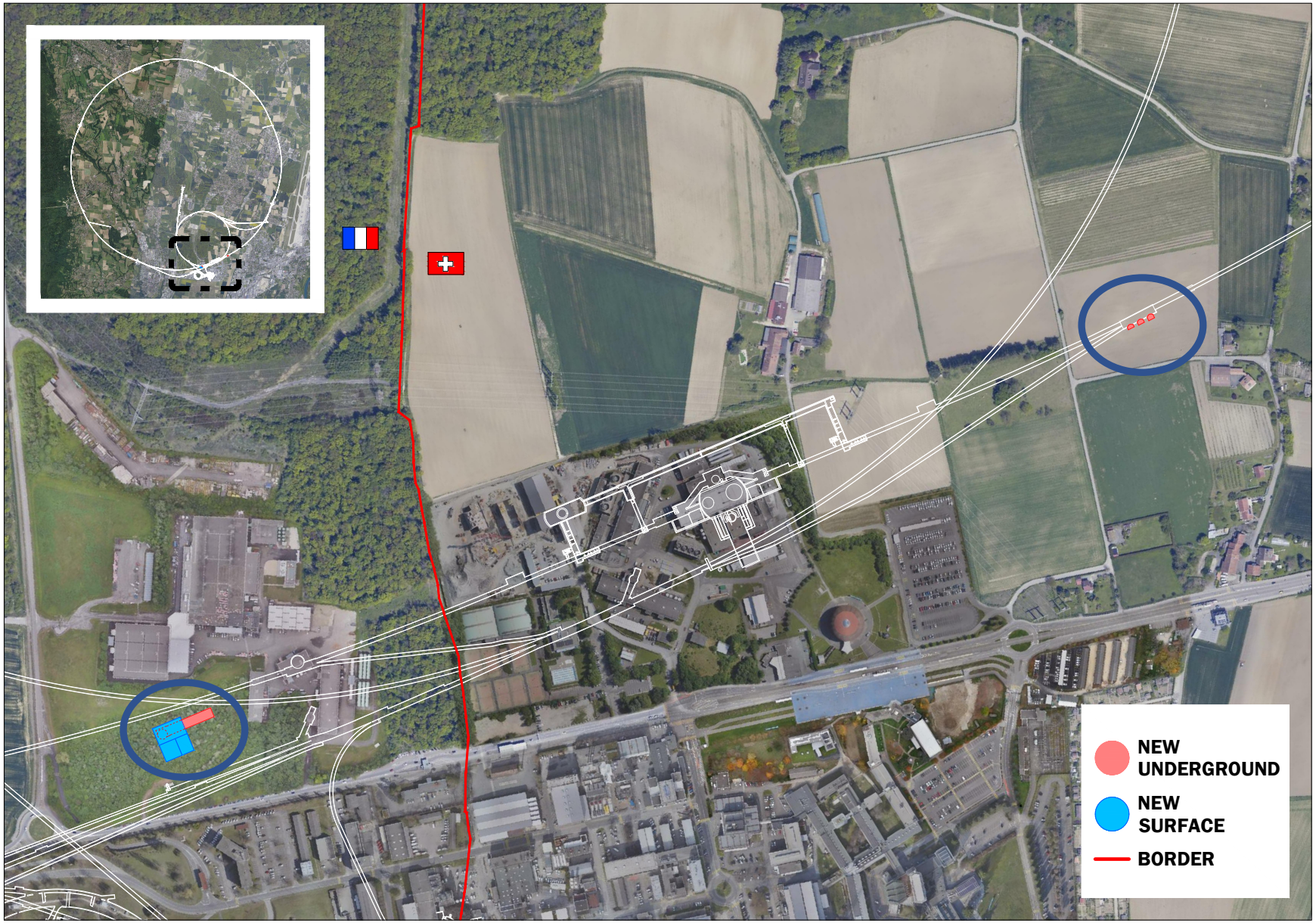


Introduction

- The Forward Physics Facility (FPF) is a proposed new facility to house several new experiments on the beam collision axis line of sight (LOS) at one of the LHC high luminosity interaction points
- There is a strong and broad physics case for experiments in this location related to:
  - Dark sector searches, neutrino physics and QCD
  - Physics case discussed in later talk
- This talk summarizes the significant progress in the facility design in the last year
  - Facility studies documented in public FPF White paper (arxiv:2203.05090) released in March 2022
  - Updates since then being documented in a PBC note (to be made public soon)
- Many thanks to the PBC FPF WG and the CERN teams for all their excellent work on the FPF facility

Site Selection

K. Balazs, J. Osborne - SCE



After several studies by CERN civil engineering team, looking at options around both the ATLAS and CMS interaction points, two options were retained for further detailed study. After a preliminary costing of each we have now converged on the dedicated new facility in the SM18 area as the baseline proposal. This is ~600m from the ATLAS IP (to the west), and is situated on CERN land.

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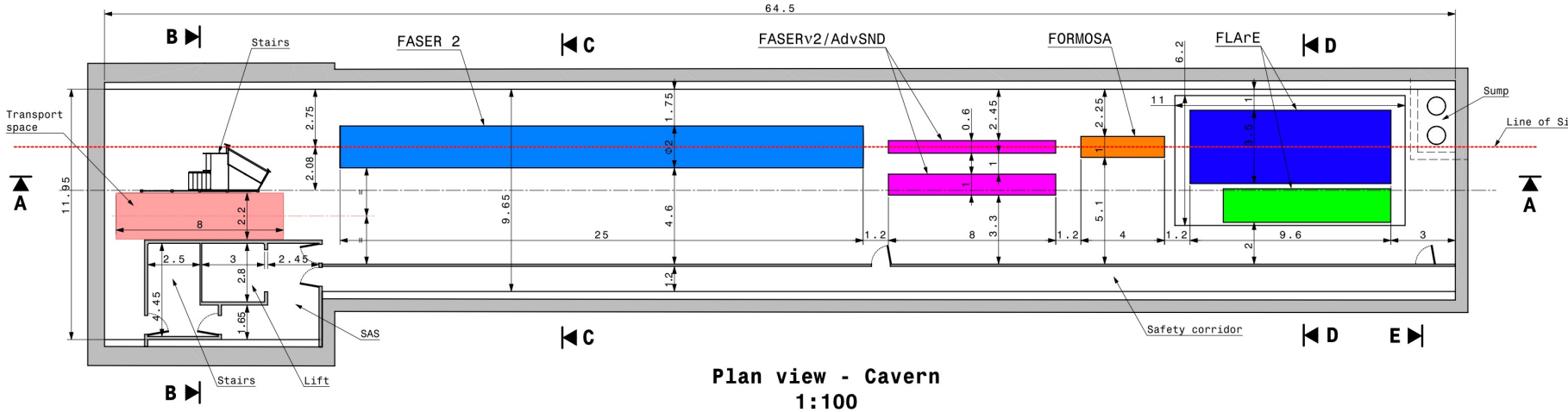
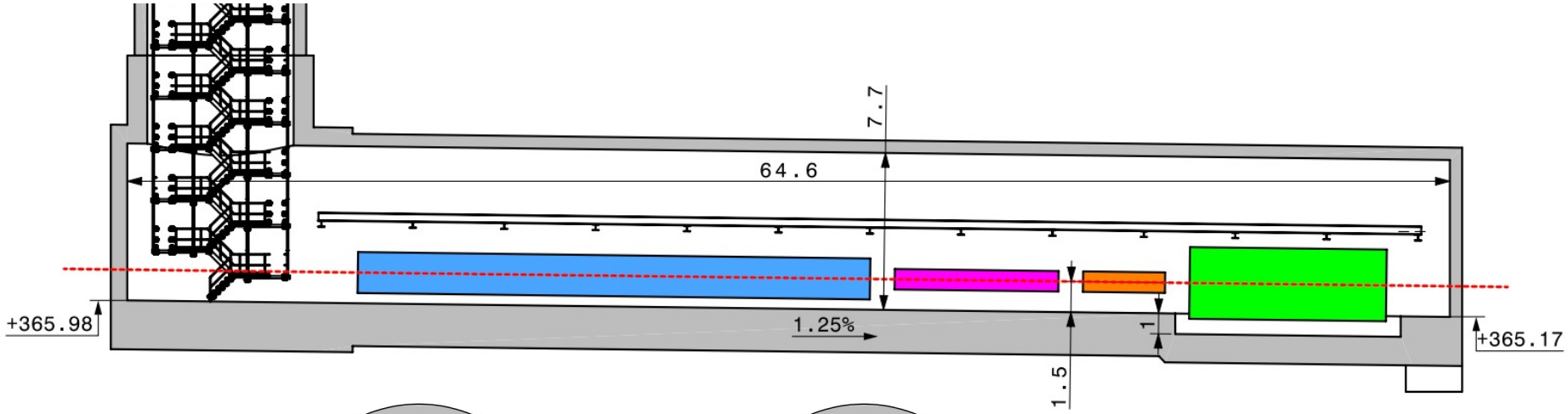
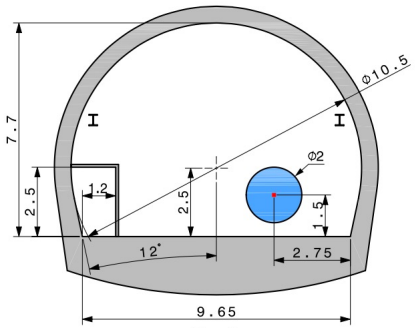
FPF Facility:

65m long, 9.7m wide, 7.7m high cavern.
Connected to surface through 88m high shaft (9.1m diameter): 617m from IP1.

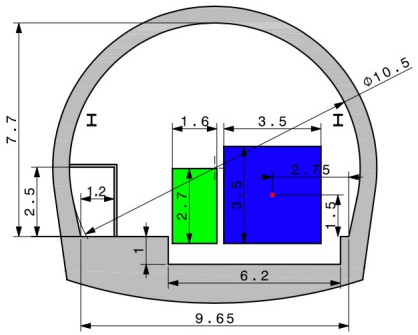


Plan view - Cavern
1:100





C-C
1:100

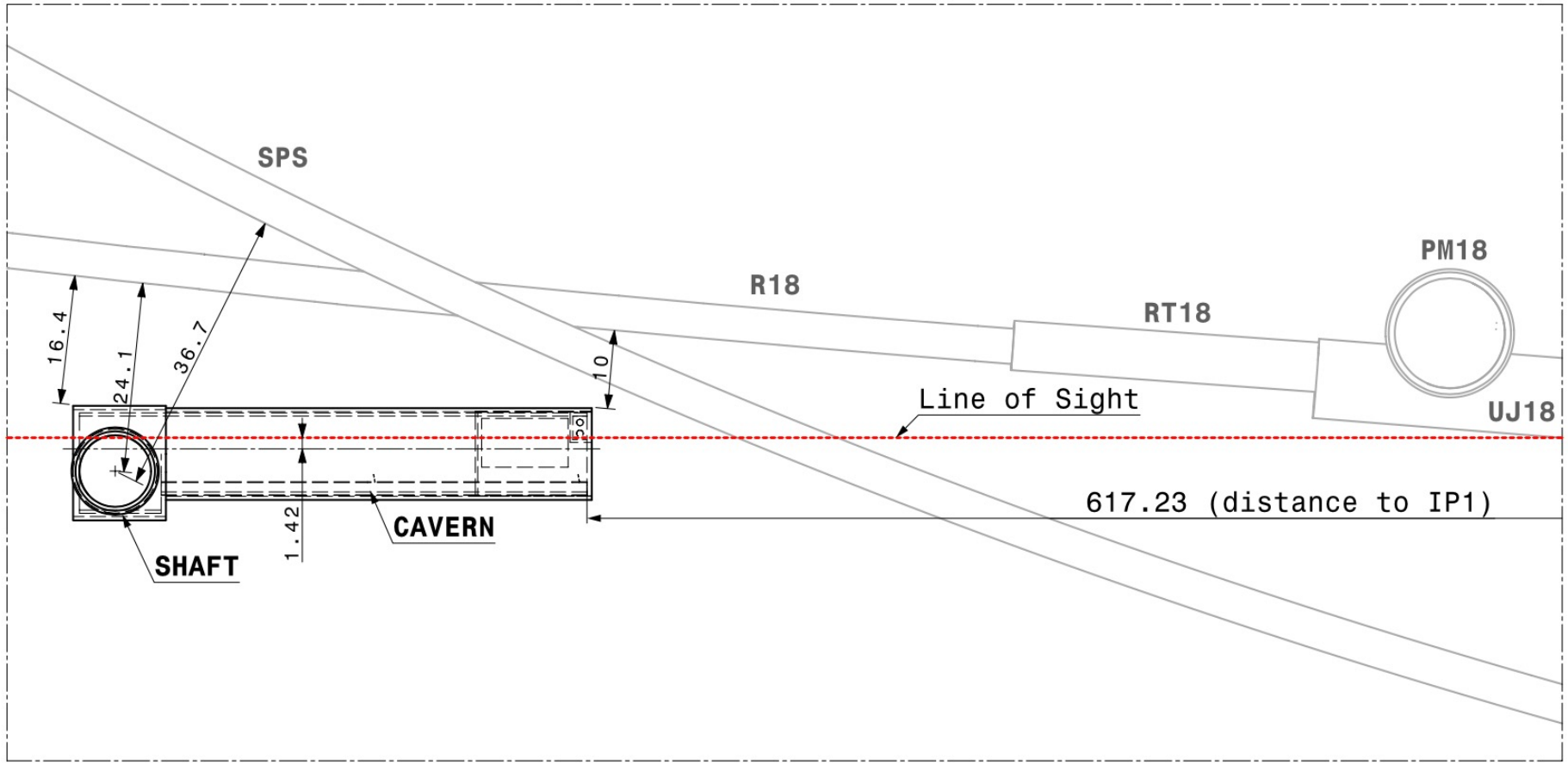


D-D
1:100

FPF Facility:

65m long, 9.7m wide, 7.7m high cavern.
Connected to surface through 88m high shaft (9.1m diameter): 617m from IP1.

Require that cavern is at least 10m from LHC for structural stability during digging.



Previous design had a connection from the FPF to LHC (as an emergency escape route). After discussing with HSE this has now been dropped, and replaced with a safety corridor (over pressure), which allows to get from the end of the cavern to the elevator/stairs in a safe way.
This reduces any risk to the LHC tunnel, and also increases the flexibility of when the facility could be implemented.

FPF Facili

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88m high
617m fro

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Previous
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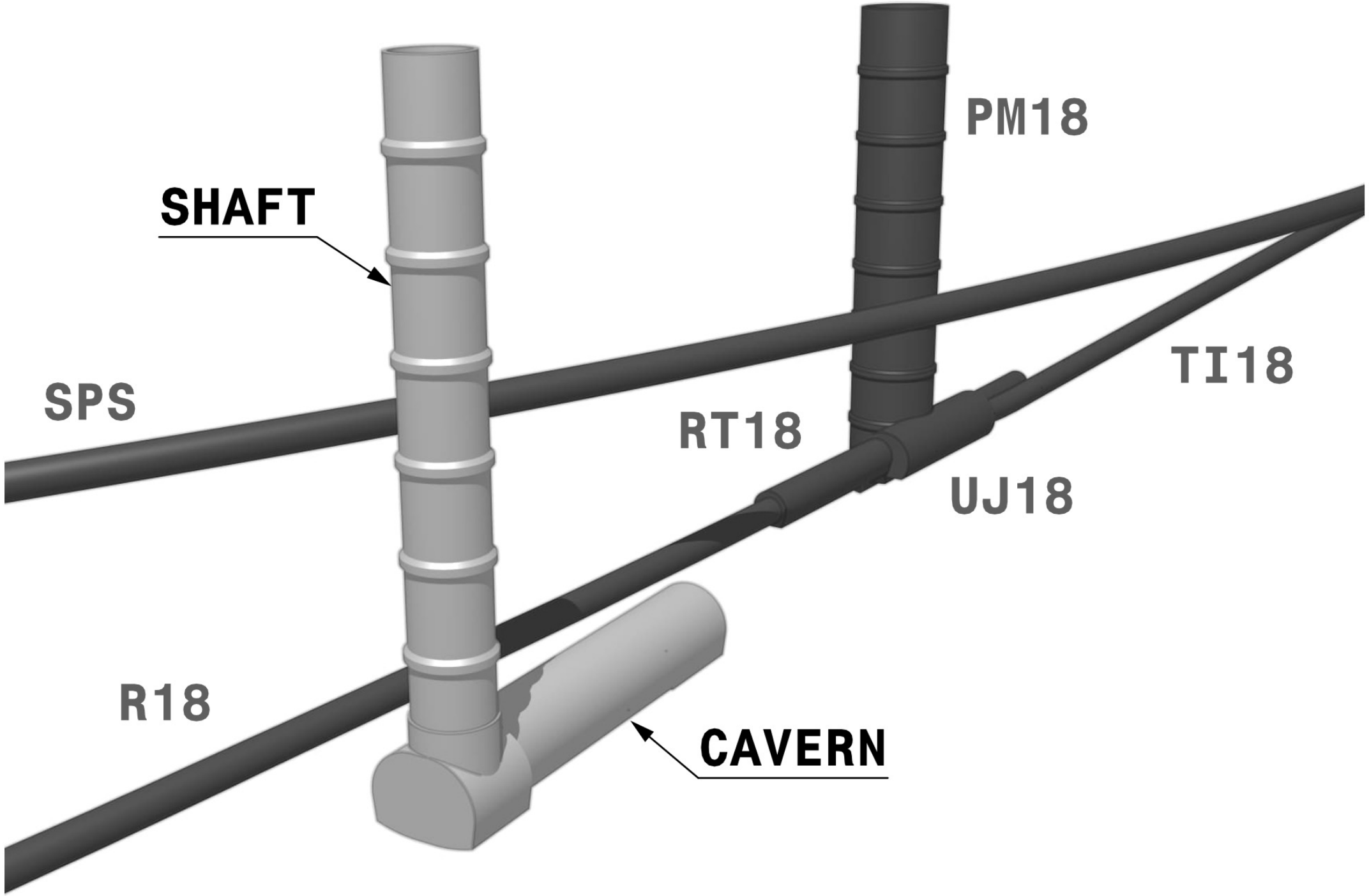
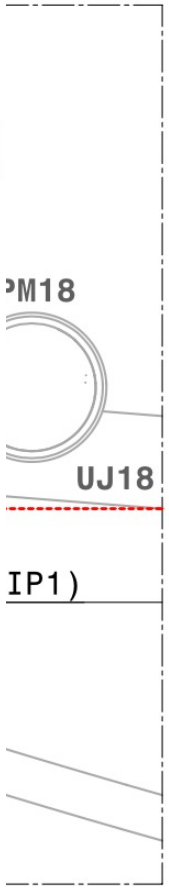
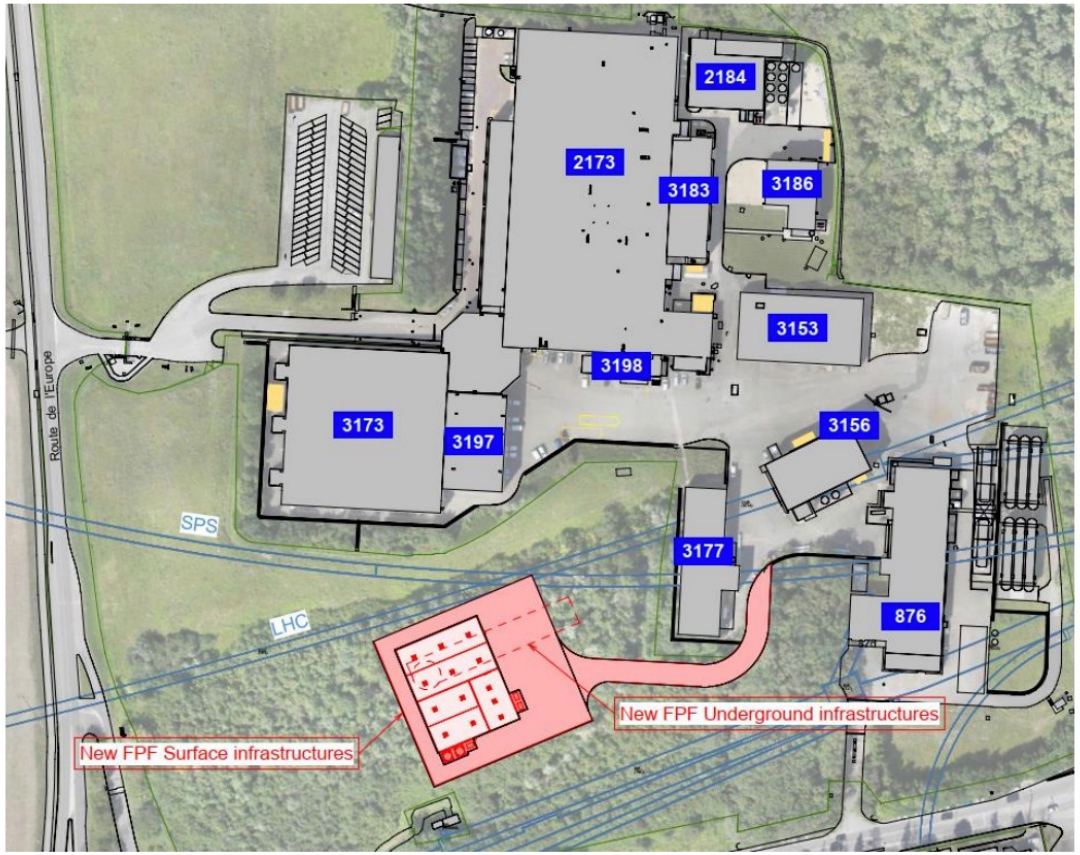
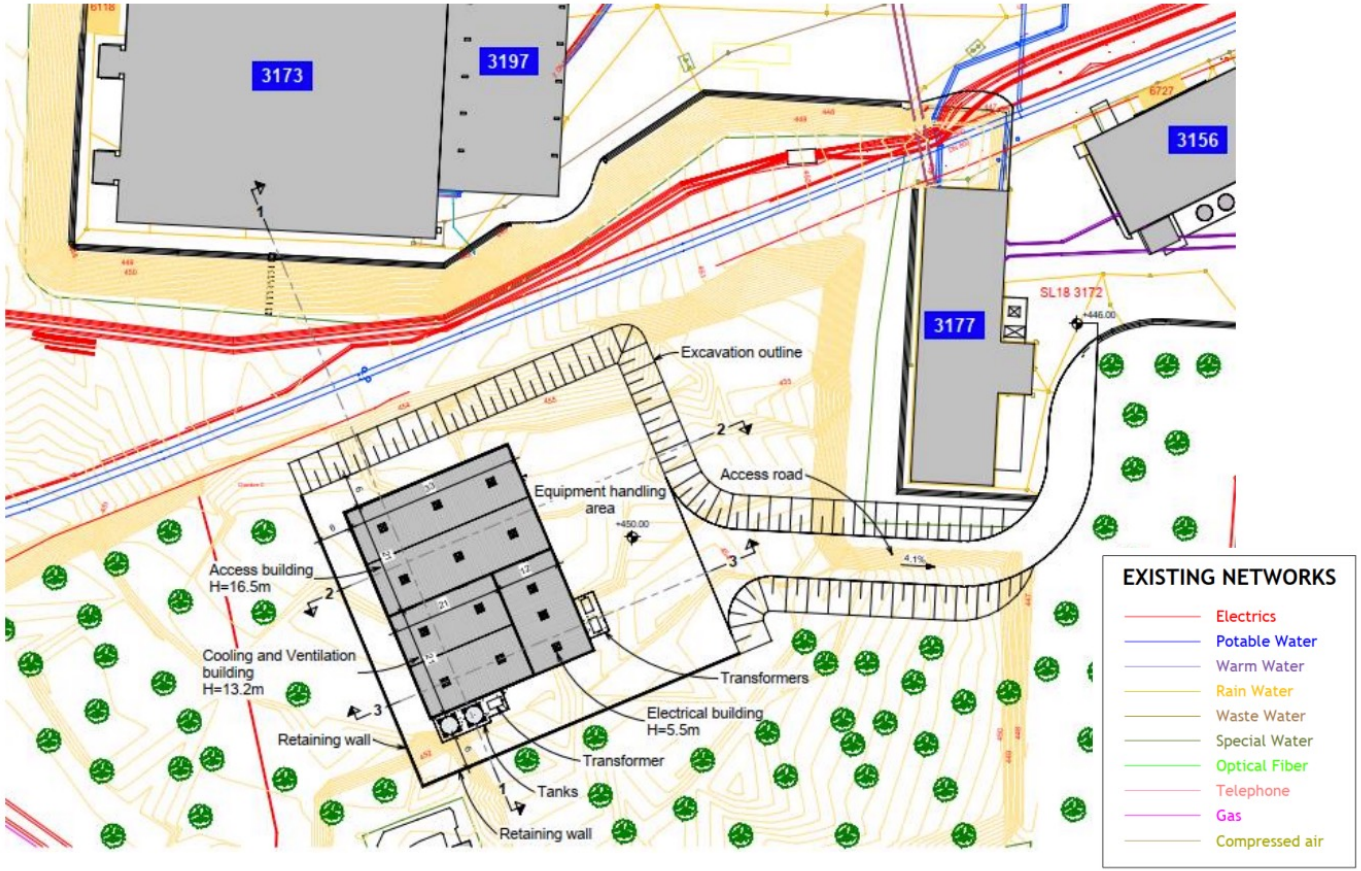




Update in surface works

- Site planning avoiding interference with the existing networks



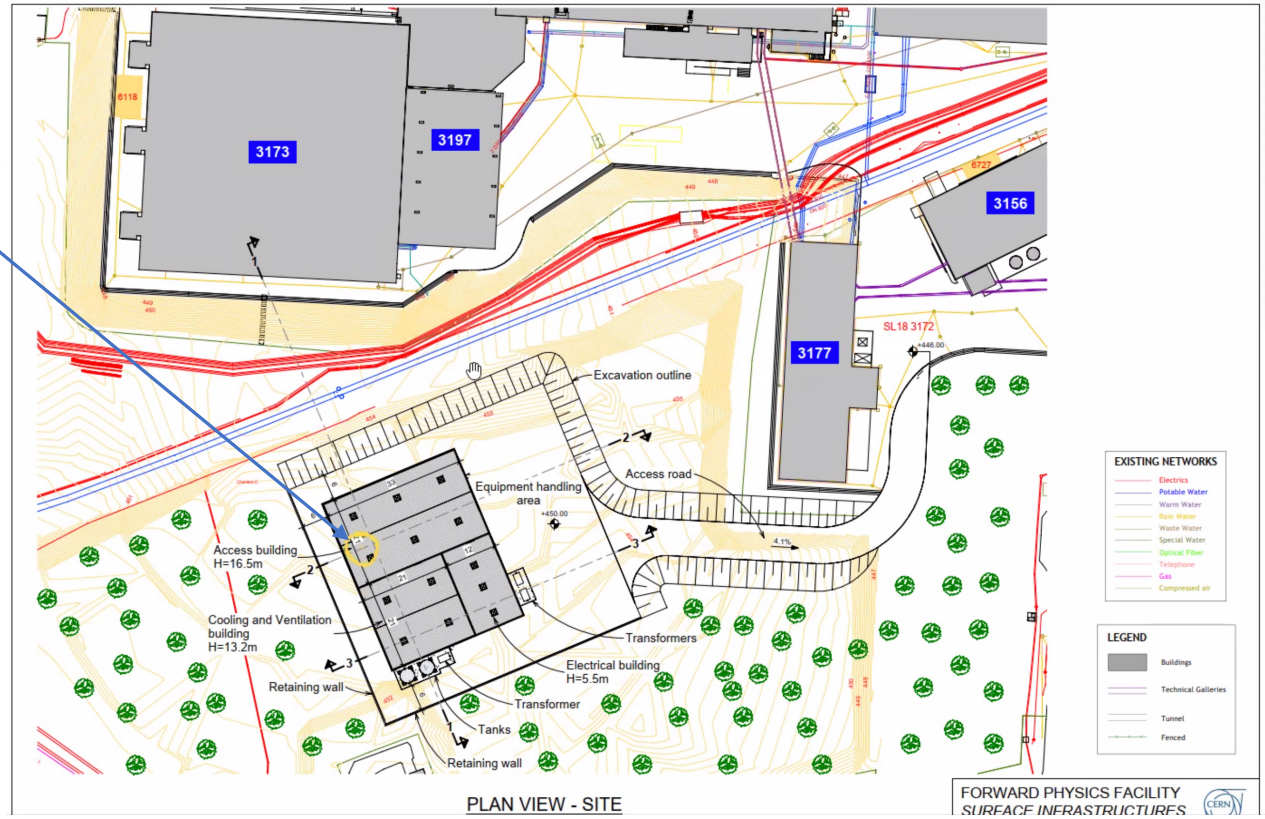


Update in the layout of the access road to avoid interference with existing shallow underground networks

Site Investigation

Next steps to refine the civil engineering design and costing is a detailed site investigation.
External consultant will drill a core down to proposed FPF cavern level (90m) at location of shaft. Will provide important information on the structural strength of the rock at the cavern location, as well as understanding any contaminates in the rock, and will be fed into a revised design/costing.
Plan to have drilling and analysis carried out early next year. Tender process launched.
Cost $\mathcal{O}$(100kCHF) paid by PBC budget.

Planned drilling location



Survey of exact location of shaft/drilling and tree cutting to allow needed equipment in, has already been done.

Technical Services

EN-EL, EN-CV, EN-AA, EN-HE groups

Based on previous similar projects at CERN the main cost drivers for services, with very approximate costing are as follows (this costing is from the FPF White paper, so done by March 2022):

Item	**Details**	**Approximate cost (MCHF)**
Electrical Installation	2MVA electrical power	1.5
Ventillation	Based on HL-LHC underground installation	7.0
Access/Safety Systems	Access system Oxygen deficiency hazard Fire safety Evacuation	2.5
Transport/Handling Infrastructure	Shaft crane (25 t) Cavern crane (25 t) Lift	1.9
Total		**12.9**

Round up to 15MCHF.

Some of the above depend on requirements from experimets which are in many cases not sufficiently defined. More detailed study of ventillation (including smoke extraction, Ar extraction and pressurization) costed at 2.5MCHF, less than in above table.

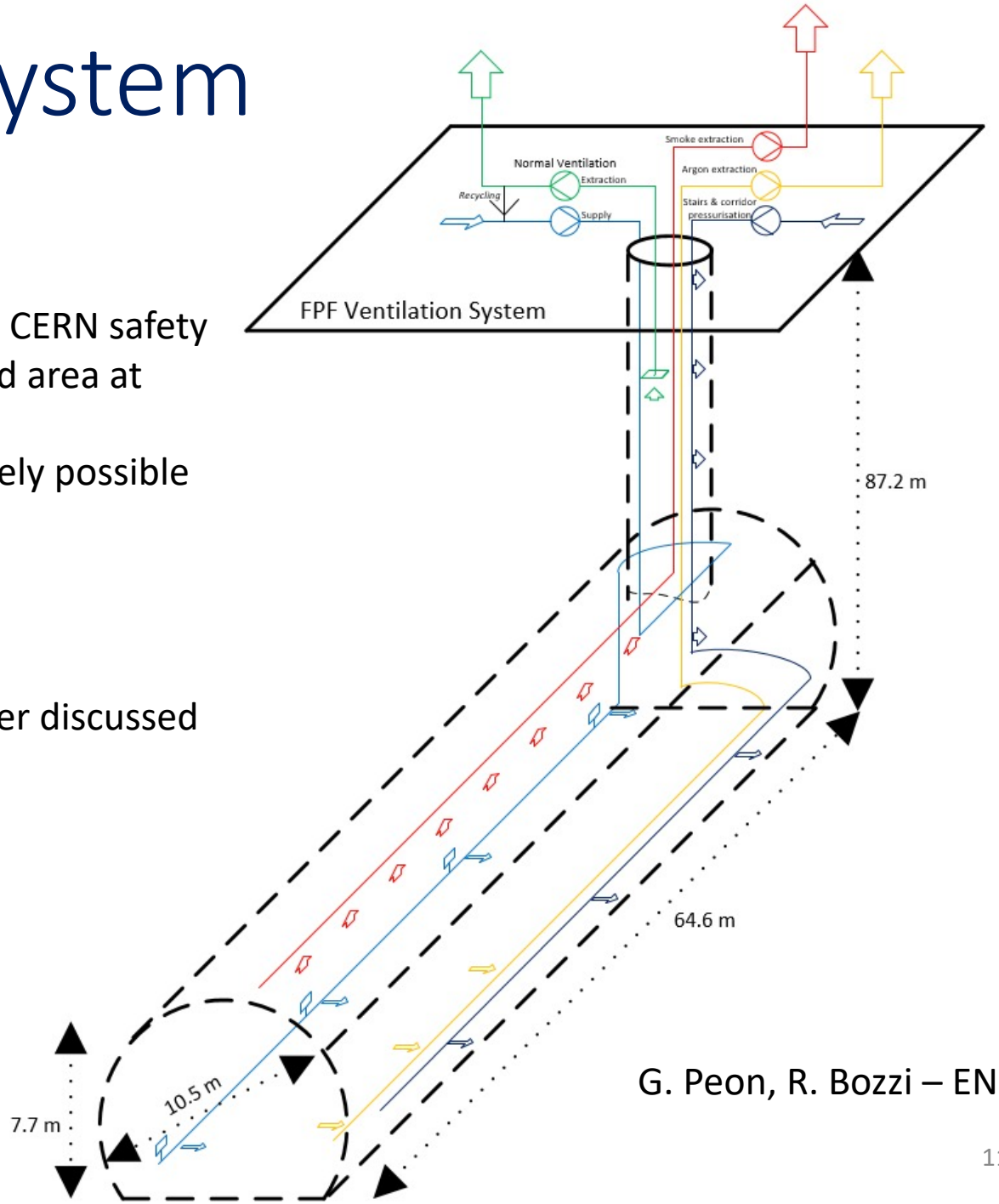
Ventillation System

More detailed study on ventillation carried out by CERN cooling/ventilation group (EN-CV), after discussion with CERN safety (HSE). Design based on solution for HL-LHC underground area at point-1.

Assumes shaft will not be covered (confirmed as very likely possible by RP), and includes separate system for:

- Fresh air
- Pressurization
- Smoke extraction
- LAr evacuation included, but details need to be further discussed with safety.

EDMS note in preparation.



G. Peon, R. Bozzi – EN-CV

First costing of CE works & services

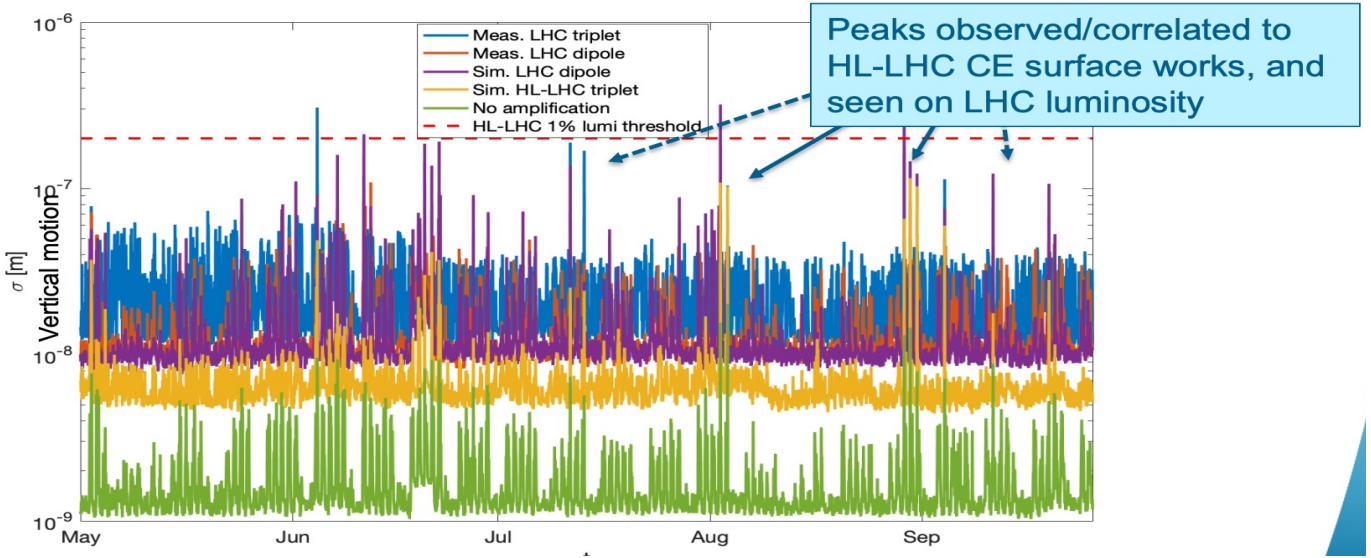
- Preliminary costing of civil engineering works, based on comparative costing to similar project:
  - HL-LHC Point 1 as reference point for new facility option
- Cost Estimates Class 4
  - Total could be 50% higher and 30% lower than the given estimate
- Pure civil engineering cost estimate 23MCHF
- Additional cost for services ~15MCHF
- **Total cost: ~40MCHF**

Civil engineering cost will be revised after site investigation study, and taking into account update in design of surface works.

Study on CE works during HL-LHC operation

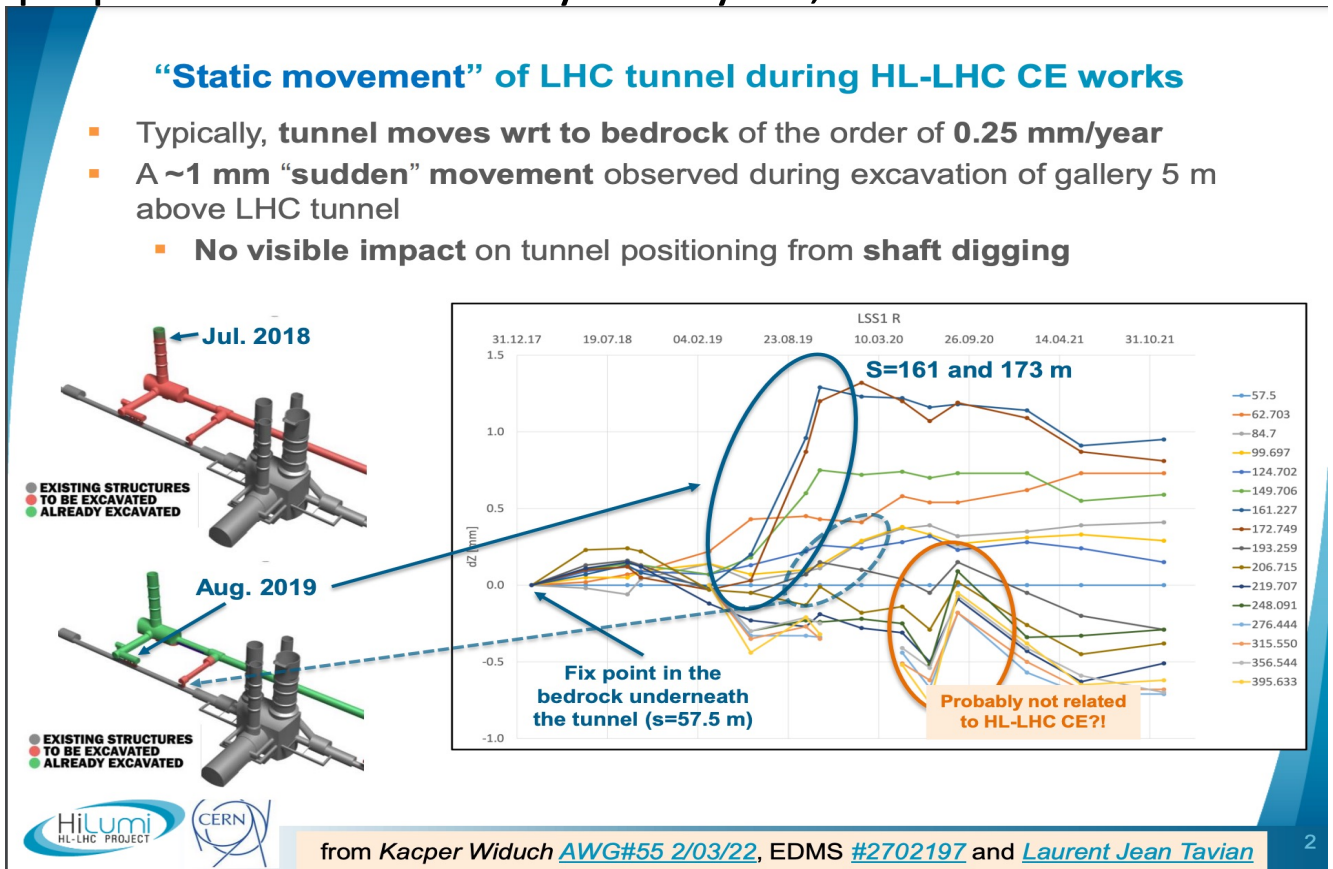
- Ongoing study on effect of CE works on HL-LHC operations
- Benefit from significant work done on this for HL-LHC underground works at IP1/5
  - FPF is much further from interaction point
    - About 4x more attenuation compared to HL-LHC works
  - FPF is closer to LHC tunnel
    - Up to 4x less attenuation compared to HL-LHC works
  - Net effect expect similar or smaller effect on beam operations from vibrations – a few punctual drops in luminosity at the 1% level, very low risk of beam dump from ground motion
- Previous studies show that compatification of spoil on surface is one of the most problematic operations
  - For FPF spoil will be taken off site before compatification
  - Compacting for road building / surface-works can try to be scheduled when LHC is not running

Example simulated and observed movements from 2018 when point-1 HL-LHC works ongoing.



Study on CE works during HL-LHC operation

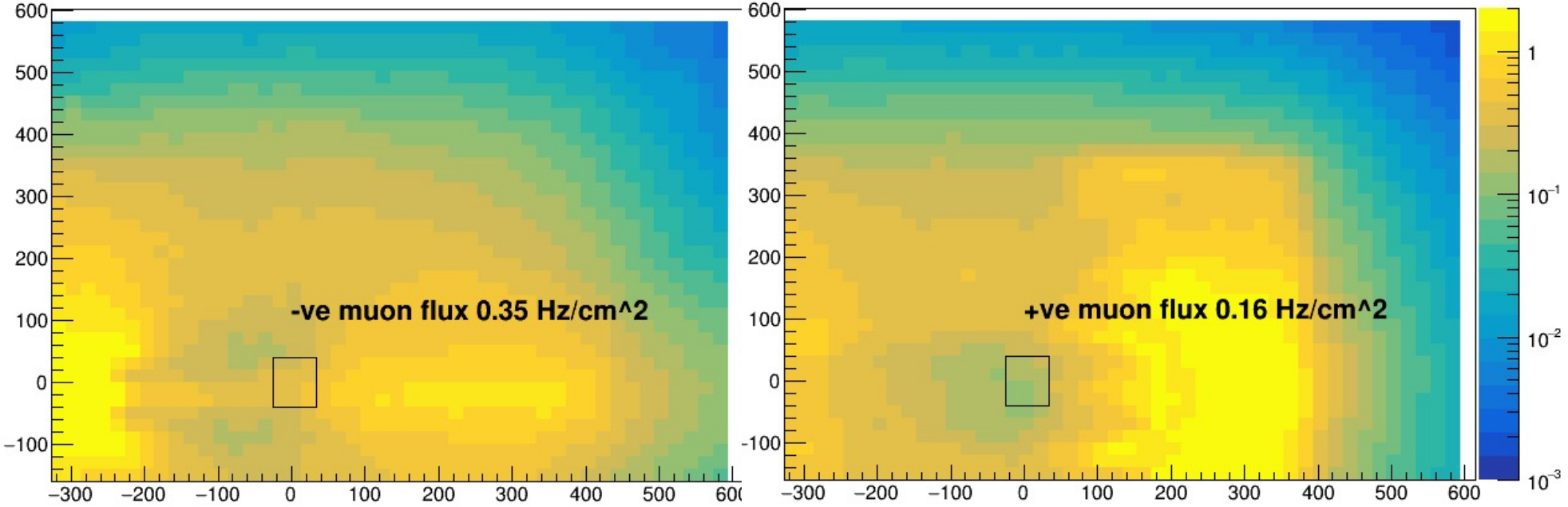
- Other points to consider:
  - Static movement of LHC tunnel due to works (previous experience suggests a maximum tunnel movement of <1mm may occur) study ongoing to check the beam can be corrected to deal with such a movement
  - Effect of works on SPS operations (FPF shaft is 36m from SPS)
- Plan to wrap up these studies early next year, and document in technical note



Muon background fluence

F. Cerutti, M. Sabate-Gilarte
SY-STI

- A key consideration for the FPF experiments is the rate of background particles
- With 200m shielding of rock from the IP, the only interacting particles that get to the FPF are high energy muons
- FLUKA simulations carried out to assess the muon flux at the FPF for the HL-LHC scenario
  - Initial simulations suggested a rate of ~1.5 Hz/cm^2 close to the LOS for a luminosity of 5e34cm^{-2}s^{-1}
- Refined simulations considering the full magnetic field outside of the magnet apertures in the Q4 and D2 magnets reduces the rate, with ~0.5 Hz/cm^2 expected for a 1m x 1m area centered on the LOS



FLUKA muon flux at start of FPF (617m from IP1). Baseline HL-LHC crossing angle of 250urad would push the LOS ~16cm to +ve x in these plots. (LHC tunnel would be at at -1300cm on these plots scale)

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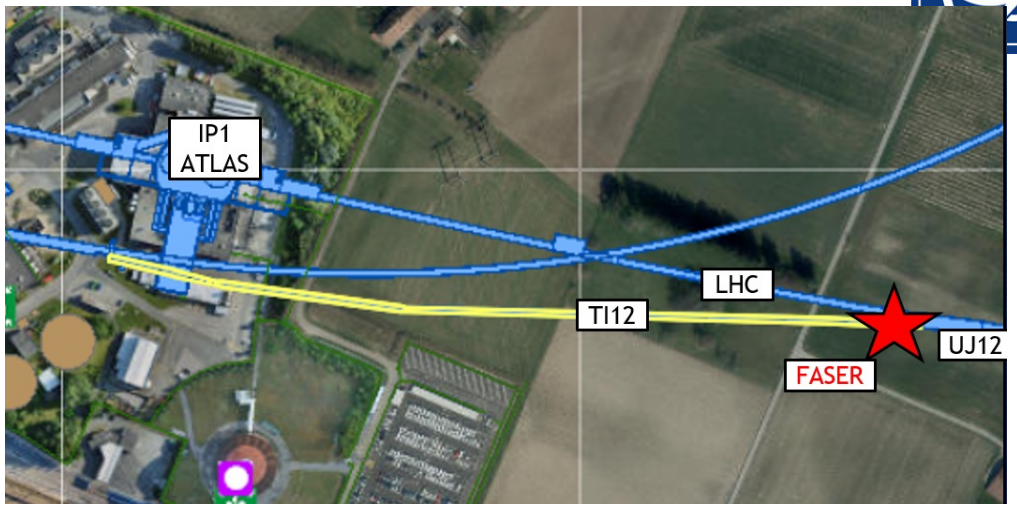
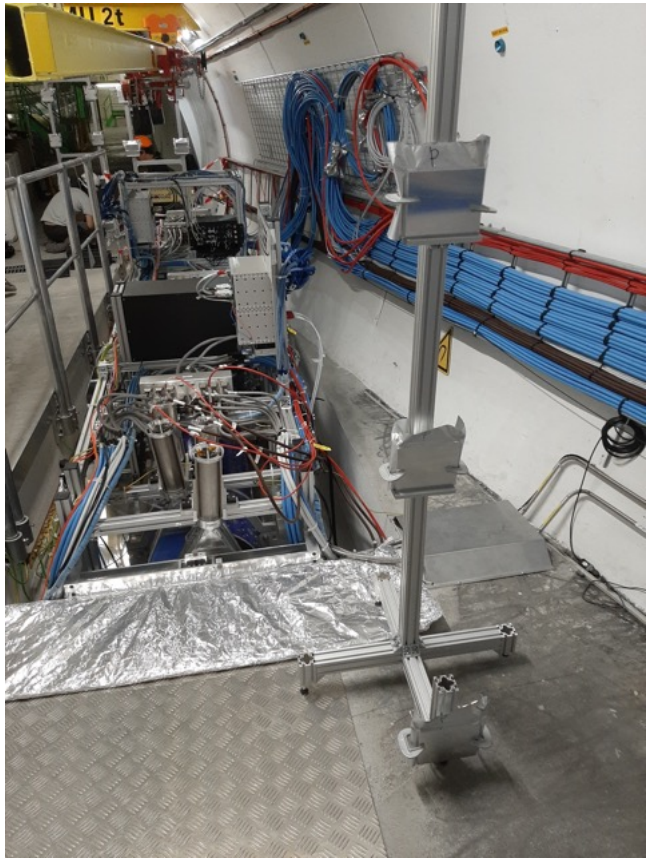
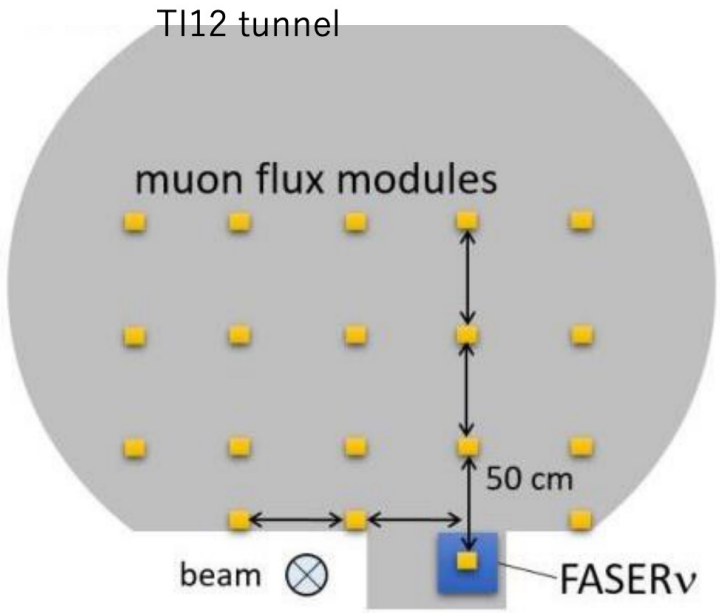
- Refined simulations considering the full magnetic field outside of the magnet apertures in the Q4 and D2 magnets reduces the rate, with ~0.5 Hz/cm^2 expected for a 1m x 1m area centered on the LOS
- First data with FASER and SND@LHC experiments validates FLUKA estimate of muon flux for LHC at ~25% level with an $\mathcal{O}(50\%)$ uncertainty on FLUKA estimate
  - FASER observed a strong dependence of the muon flux on the TCL6 collimator settings (tight settings for HL-LHC help reduce flux)
  - FASER has installed additional emulsion detectors up to 1.5m from the LOS to measure the muon flux in this region (see next slide)

Muon fluence measurements at FASER

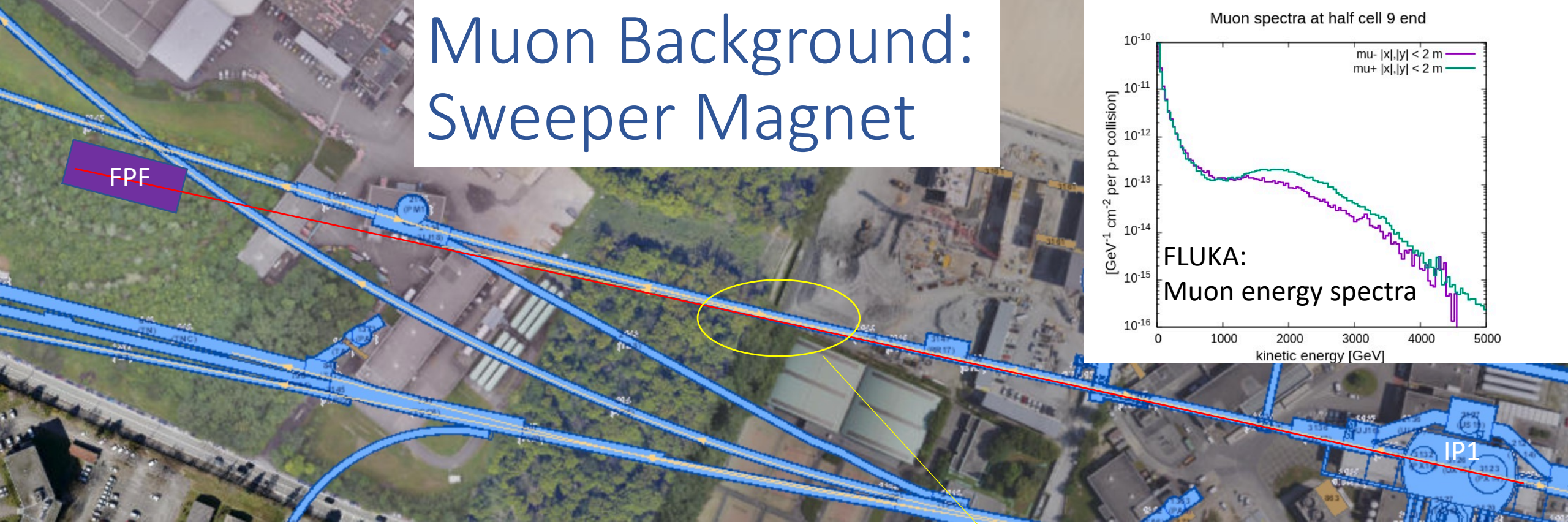
19 small emulsion detectors installed around FASER to measure the muon flux. Installed in LHC tunnel 26/7 - 14/8, exposure to 10/fb of collision data. The emulsion films have been developed and are undergoing scanning/analysis. First results should become available soon.





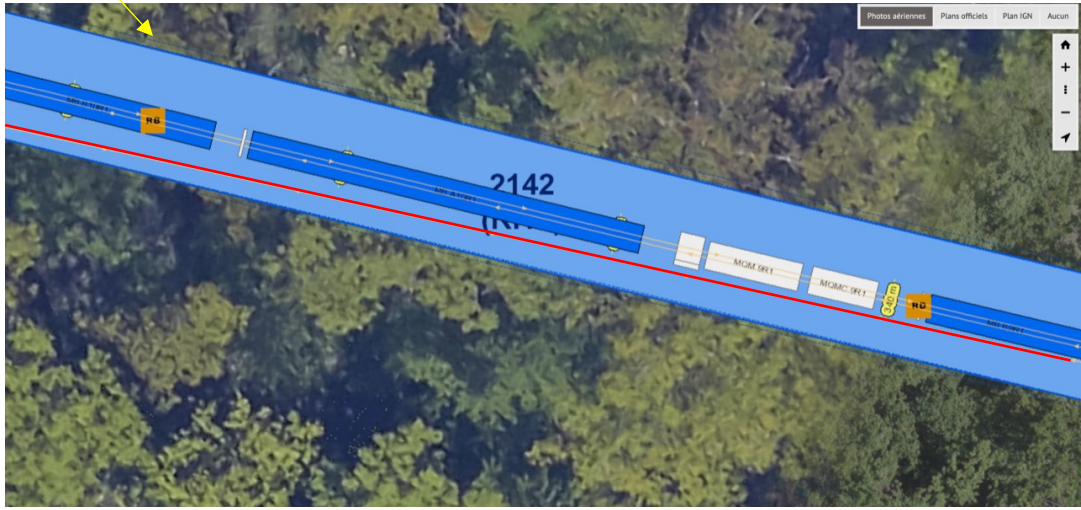


Muon Background: Sweeper Magnet



Placing a sweeper magnet on the LOS can deflect these muons and reduce the background.

Best place for such a magnet would be between where LOS leaves LHC magnets and where it leaves the LHC tunnel (200m lever-arm for deflected muons). FLUKA study ongoing to assess possible benefit of such a magnet, and best location. Based on this integration study required (will likely require some small local modifications to cryogenic infrastructure in the tunnel).



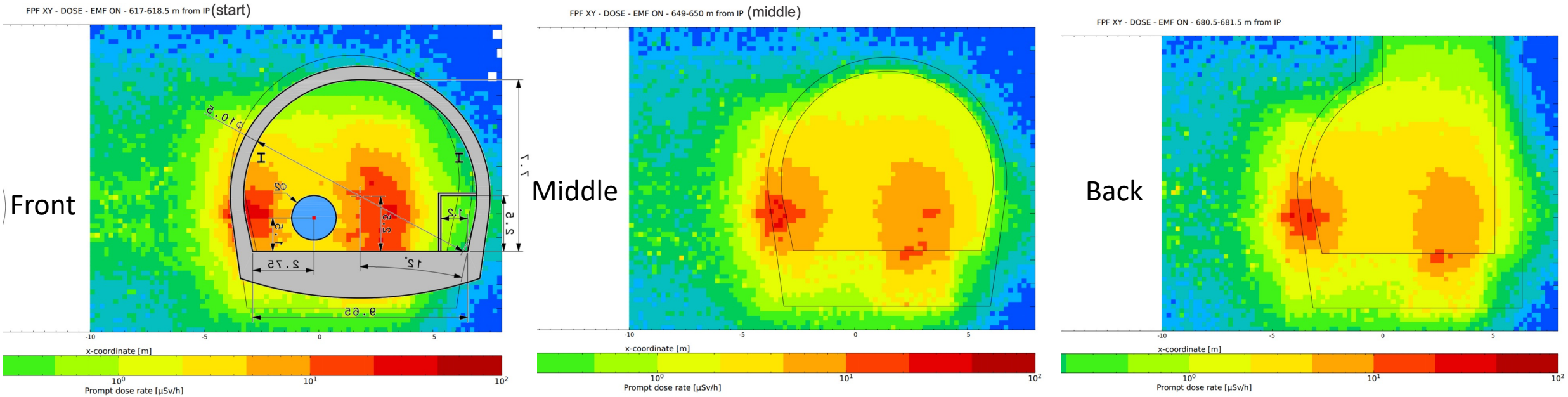
A. Infantino, L. Elie - RP

Access to the FPF during HL-LHC operations

The CERN Radio-Protection group has recently completed a detailed FLUKA study to see if people can access the cavern during HL-LHC operations. They have studied radiation from:

- Accidental beam loss close in the LHC or SPS close to the FPF,
- Radiation from beam-gas interactions in the LHC,
- Radiation dose from the prompt muons passing through the FPF

For the ultimate HL-LHC performance (L=7.5e34cm^{-2}s^{-1}) only the last of these is seen to be close to the limit. Assuming <20% occupancy (no control rooms in the cavern), and with some restrictions for local hotspots in the cavern, access should be possible during operations.



Instantaneous dose rate (assuming 7.5e34cm^{-2}s^{-1} lumi for full year).

Important encouraging result for feasibility of FPF implementation.

A. Infantino, L. Elie - RP

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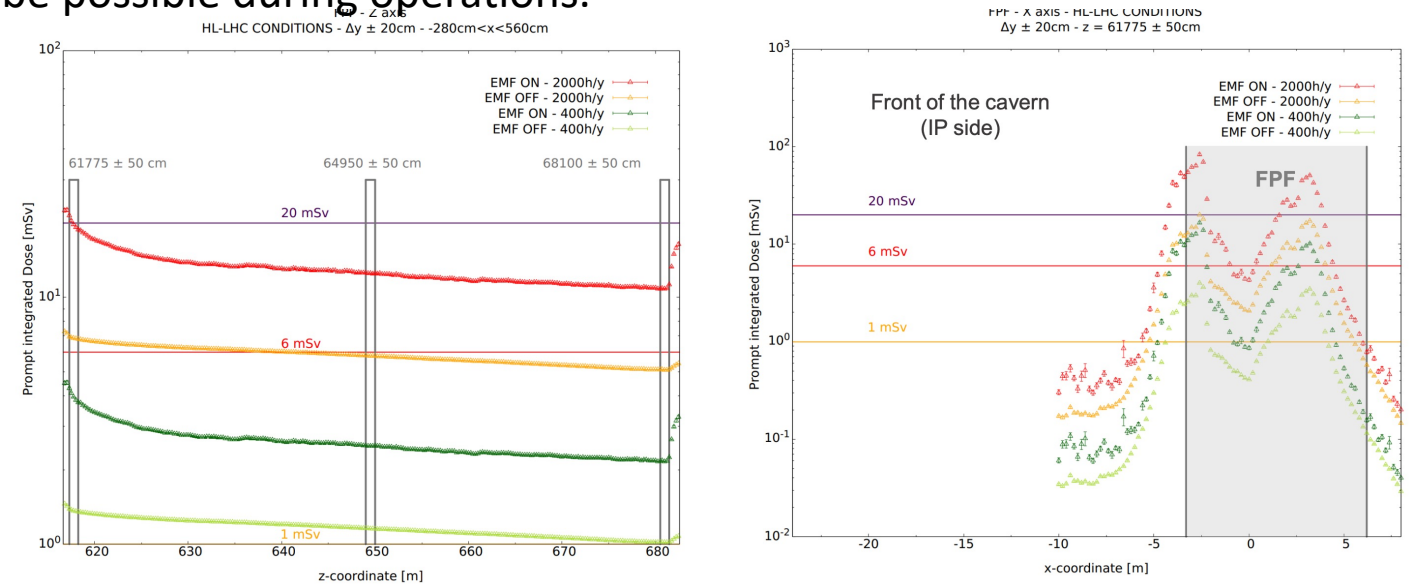
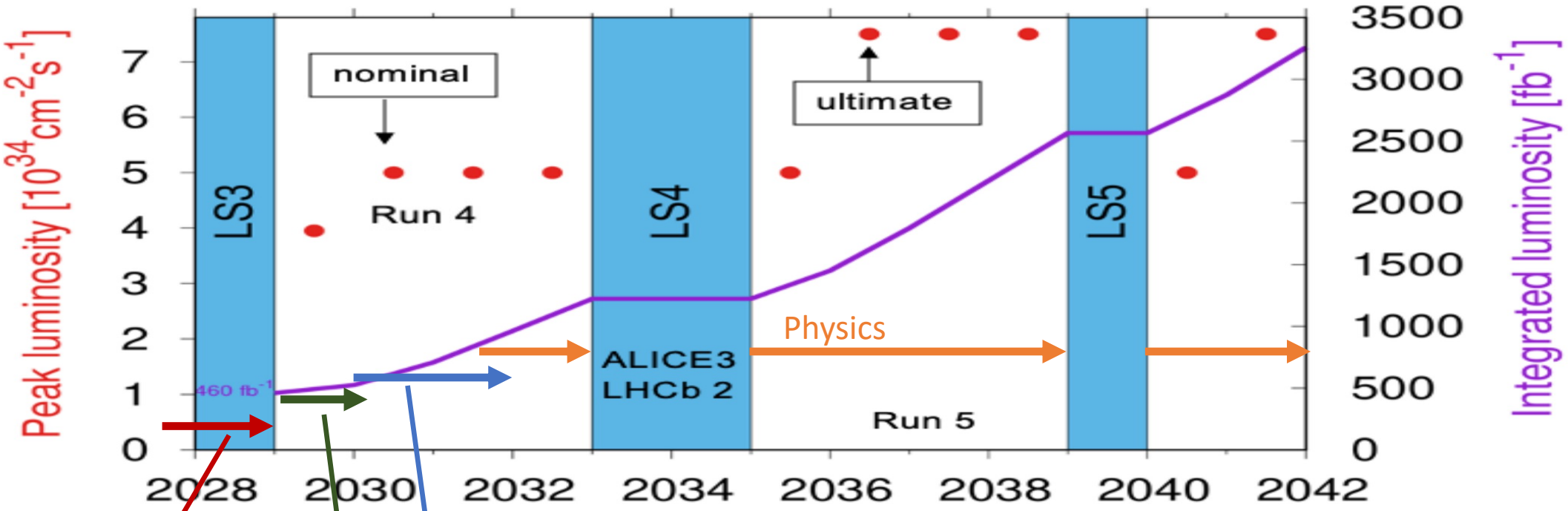


Yearly dose (assuming 7.5e34cm^{-2}s^{-1} lumi for full year – very conservative assumption). (EMF-ON, is better modelling in FLUKA).
Accumulated yearly dose limit is 6mSv for an area occupied <20% of the time. (Green is 20% of red curve).
Exceeded locally in limited number of locations (in muon hot spots).

Important encouraging result for feasibility of FPF implementation.

Possible FPF schedule



Pure CE works

Installation and commissioning of the experiments

Installation of services (CERN technical teams, busy during LS3)

Such a schedule would:

- Allow physics data taking for most of the luminosity of the HL-LHC
- Not overload CERN technical teams during LS3
- Design of facility would allow different experiments to come online at different times

Time is tight: Need to move fast towards CDR/TDR for funding and approval

Summary

- FPF has a strong and broad physics case, is consistent with the European Strategy recommendations and represents a sustainable/energy-efficient medium-term future project at CERN
- Great progress made in design of facility over the last year
  - The project benefits from recent similar work for the HL-LHC underground works at point-1
  - Site investigation an important next step for the CE design/costing
- Encouraging results from recent RP study on access to the cavern during HL-LHC operations
- Encouraging results from FLUKA simulations of muon background
  - Measurements from FASER and SND@LHC will be important to benchmark the FLUKA simulations
  - Studies ongoing on effectiveness of a possible sweeper magnet on the muon fluence
- Study on effect of FPF CE works on HL-LHC operations ongoing
  - Initial results look encouraging (again informed by similar studies for HL-LHC underground works)
- For updates on technical services and facility integration need more imput from the FPF experiments
- Work presented here documented in the FPF White paper, and in an upcoming PBC public note
- Many thanks to the PBC and CERN teams for their work on the FPF facility studies

FPF references: https://pbc.web.cern.ch/fpf-resources

Backup…

PBC FPF Working Group

Mandate

A Forward Physics Facility at the LHC could house a suite of experiments enhancing the LHC's potential for both BSM and SM physics extending the capabilities of the FASER detector installed in the line of sight of the interaction point IP1. The Working Group is mandated to provide a Conceptual Design of the facility after an analysis of the possible options and taking into account the impact on the LHC Machine during construction and installation and the HL-LHC operational scenario.

Objectives

Determine the experimental set-up based on the physics requirements identified by the Physics Working Groups. Study the possible civil engineering scenarios, their impact on the LHC machine and its infrastructure, and study the integration of the experiment in the LHC tunnel. Evaluate the performance based on the expected HL-LHC operational scenario.

Conceptual design report of the facility.

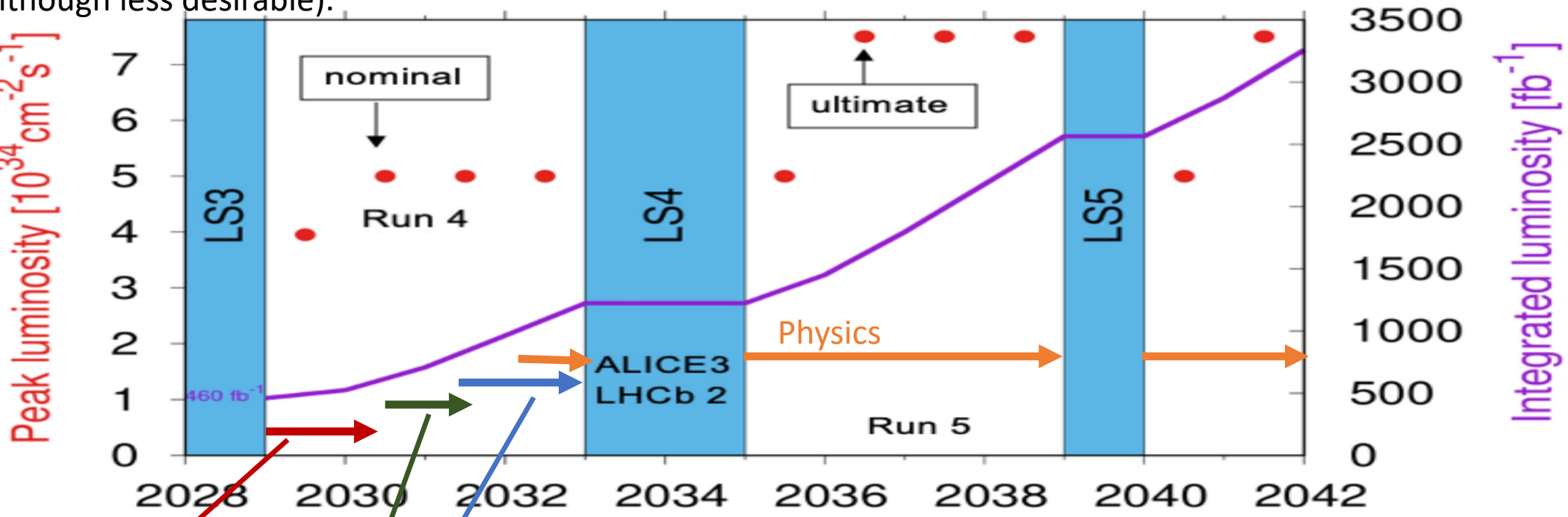
Working Group Core Members

Convener: Jamie Boyd

Core Members: Marco Andreini, Kincso Balazs, Jean-Pierre Corso, Jonathan Feng (UCI), John Osborne.

Possible FPF schedule

Based on RP study, and preliminary study on CE works during operations, a later schedule would also likley be possible (although less desirable).



Pure CE works

Installation and commissioning of the experiments

Installation of services

In such a scenario some experiments could start taking physics data during Run 4, while others are being installed/commissioned.

Site Investigation

For Facility Cost Plan 2022-2023

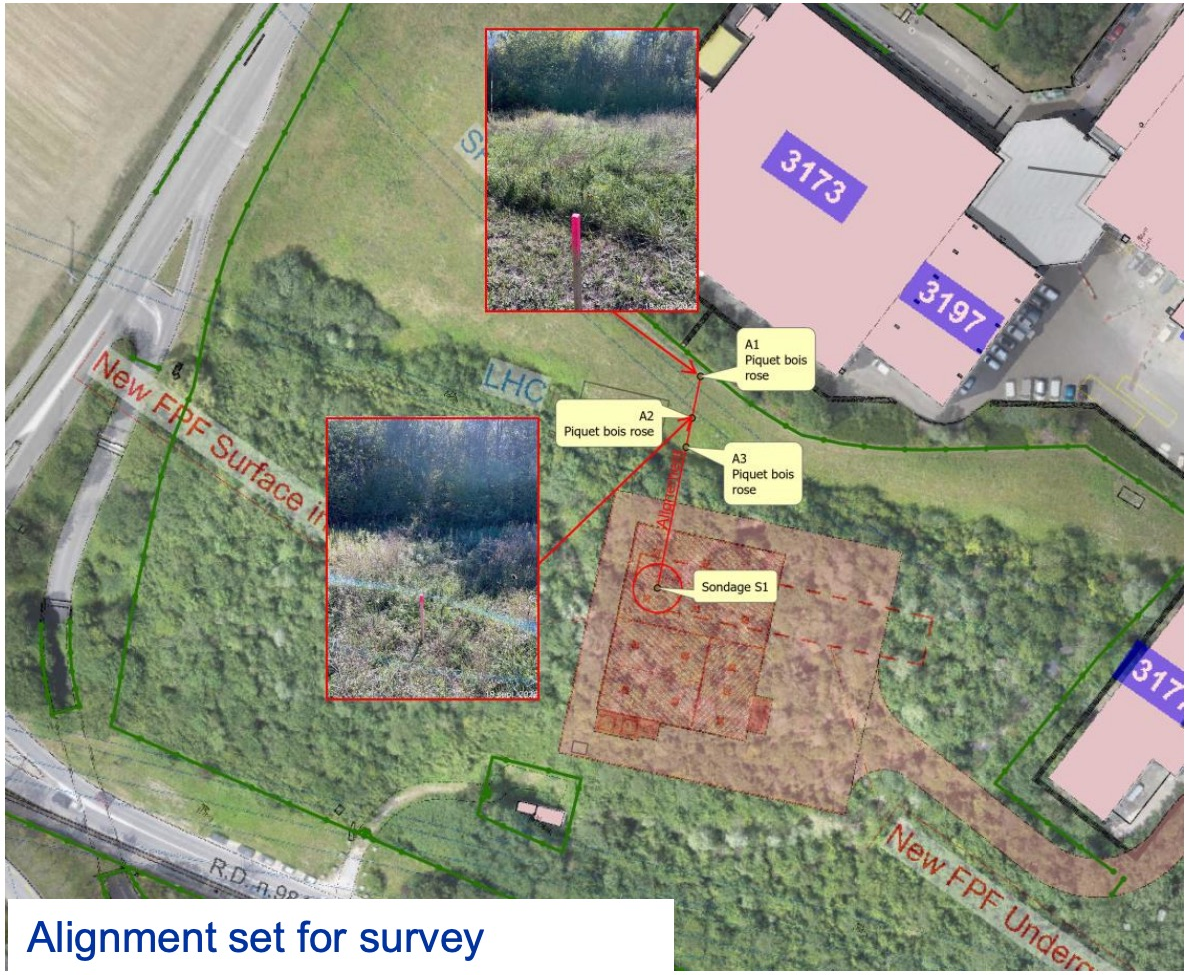
Ref.	Activity	Cost [CHF]	Remarks
1	**Site investigation works**	**79,068.50**	
1.1	Geotechnical consultant	24,840.50	*GADZ offer*
1.2	Contractor	52,500.00	*Estimate*
1.3	Site Access - Tree cutting	1,728.00	*Offer*
1.4	Replantation Cost - TBC		
2	**CE Consultancy (CE cost review/check of the site investigation results)**	**30,000.00**	*Estimate*
Total Cost		**109,068.50**	

CE Study Update – Site Investigation Works

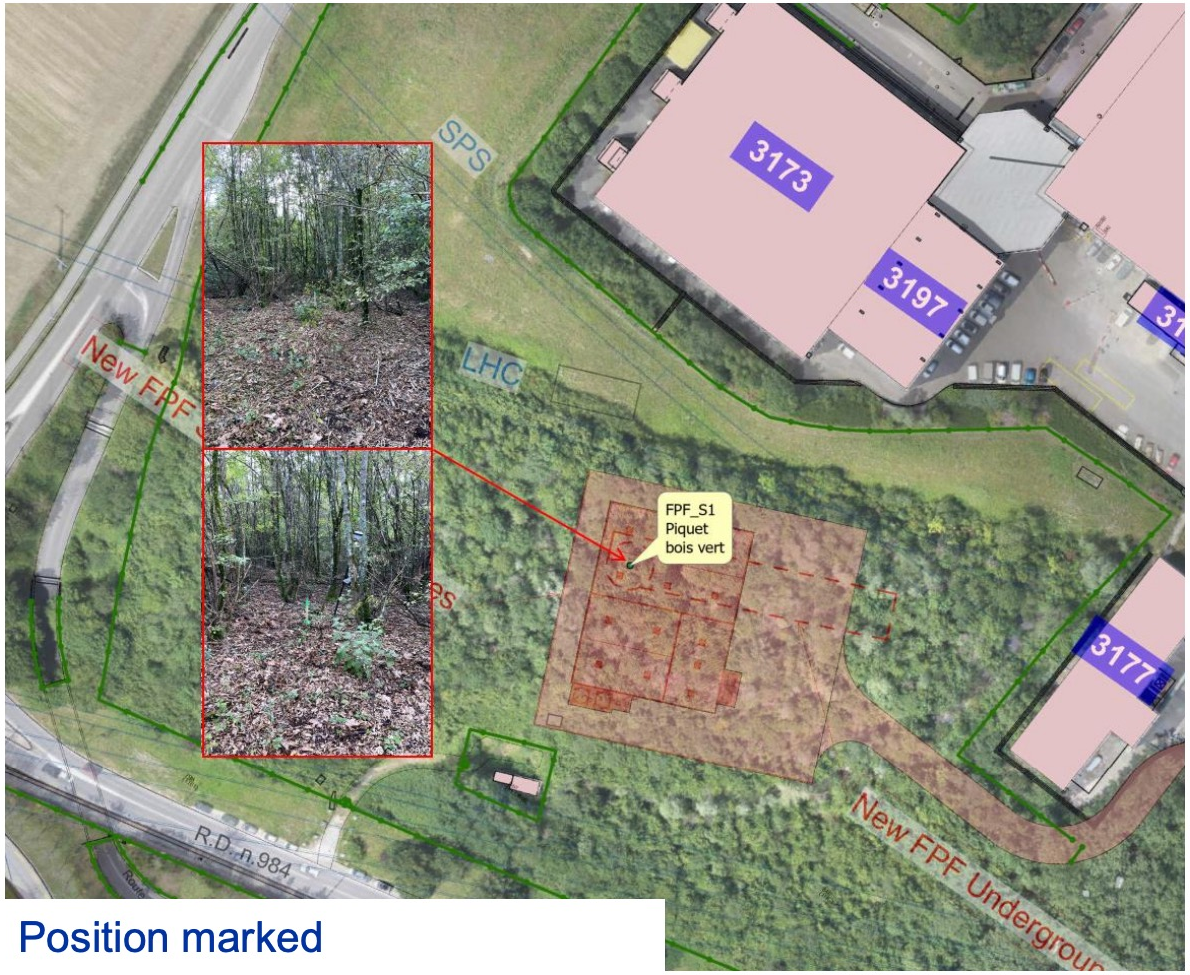
Required Works/ Studies

- Cutting trees to create a 30m long and 4m wide access path – *Works already completed by an external contractor*
- Survey Works – Installing a peg in the proposed location
- Execution of the drill – (to coordinate with LMC)
- Geotechnical report – external consultant already engaged

CE Study Update – Site Investigation Works
Survey



Alignment set for survey

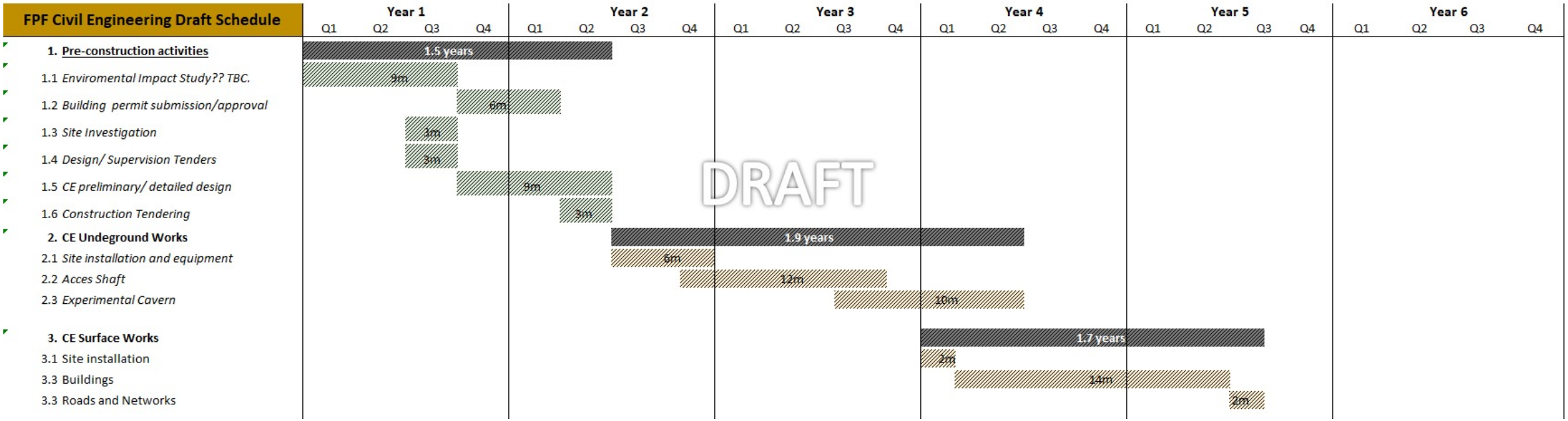


Position marked

CE Works – Proposed timeline

Initial time schedule :

- Shaft Excavation approx. 12 months
- Experimental cavern approx.10 months



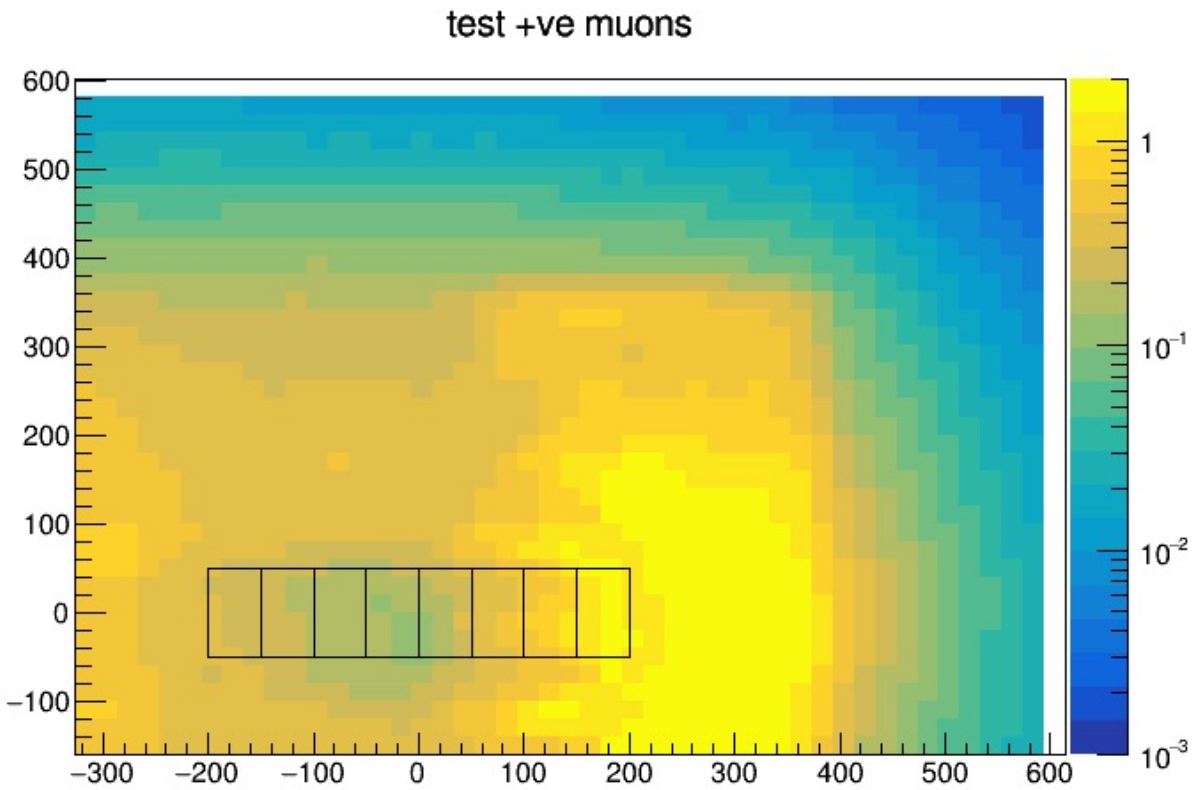
Muon background rate

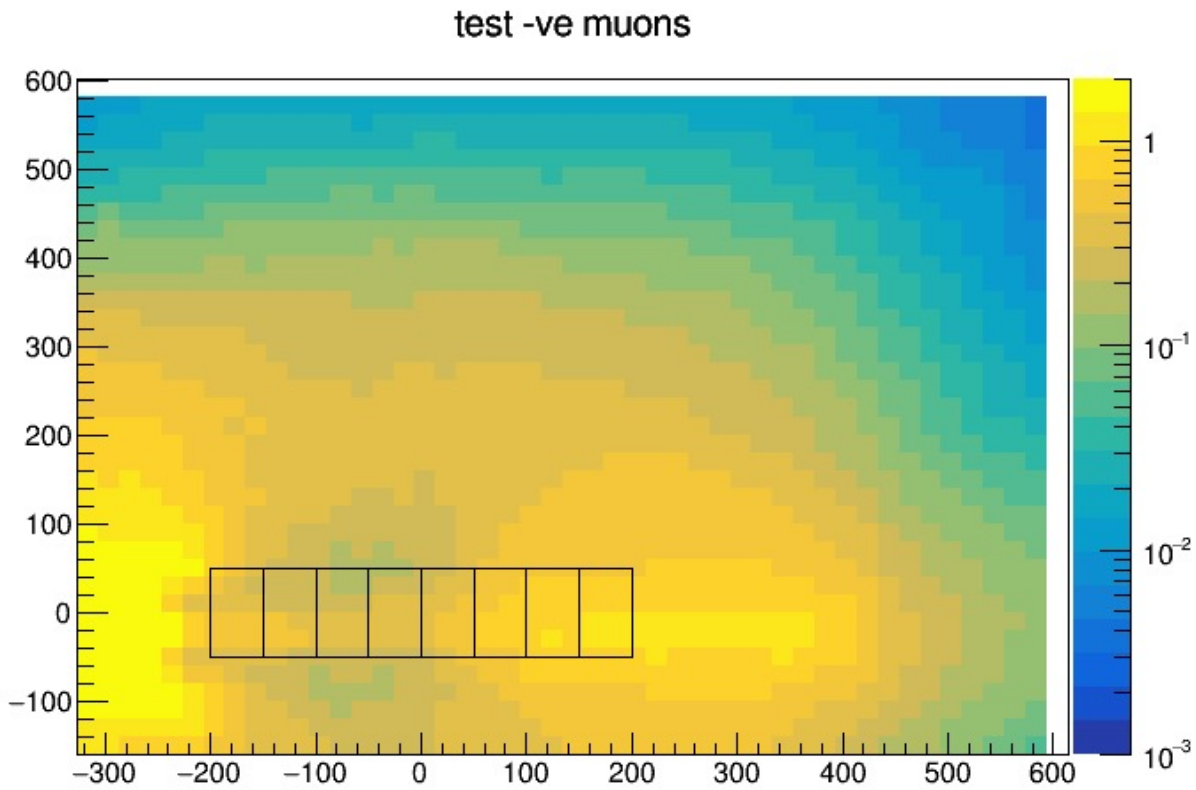
The FLUKA results suggest the following muon flux for the proposed FPF experiments (at L=5e34cm^{-2}s^{-1}):

Experiment	Dimensions	Flux (Hz/cm^2)	Rate (Hz)
FLArE/FORMOSA	Fiducial 1mx1m Full 1.8mx1.8m	0.5 0.6	5k 20k
FASER2	3mx1m	0.8	24k
FASERnu2	0.4mx0.4m	0.5	320
AdvSND	1m x 0.55m (displaced from LOS by 0.3m)	0.5 – 0.8 depending on location	2.8k – 4.4k

Proposed detector dimensions in FPF white paper:

Detector	R_{min}	R_{max}	Pseudorapidity Coverage
FASER2 (Sec. 3.1)	0	100 cm	$\eta > 7.1$
FASERν2 (Sec. 3.2)	0	28 cm	$\eta > 8.4$
AdvSND–FAR (Sec. 3.3)	28 cm	92 cm	$8.4 > \eta > 7.2$
FLArE (Sec. 3.4)	0	71 cm	$\eta > 7.4$
FORMOSA (Sec. 3.5)	0	71 cm	$\eta > 7.4$



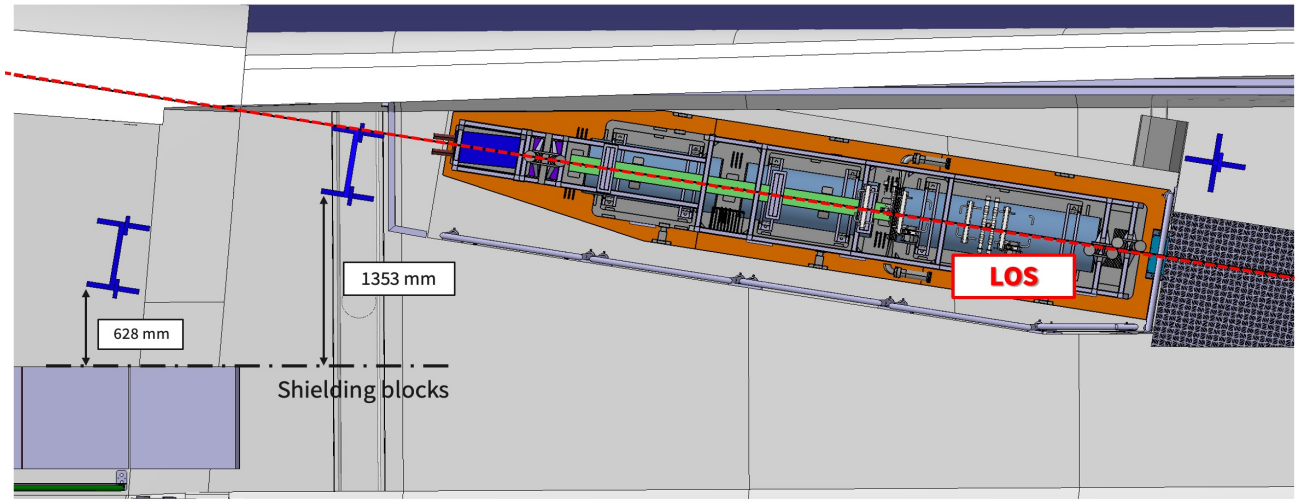


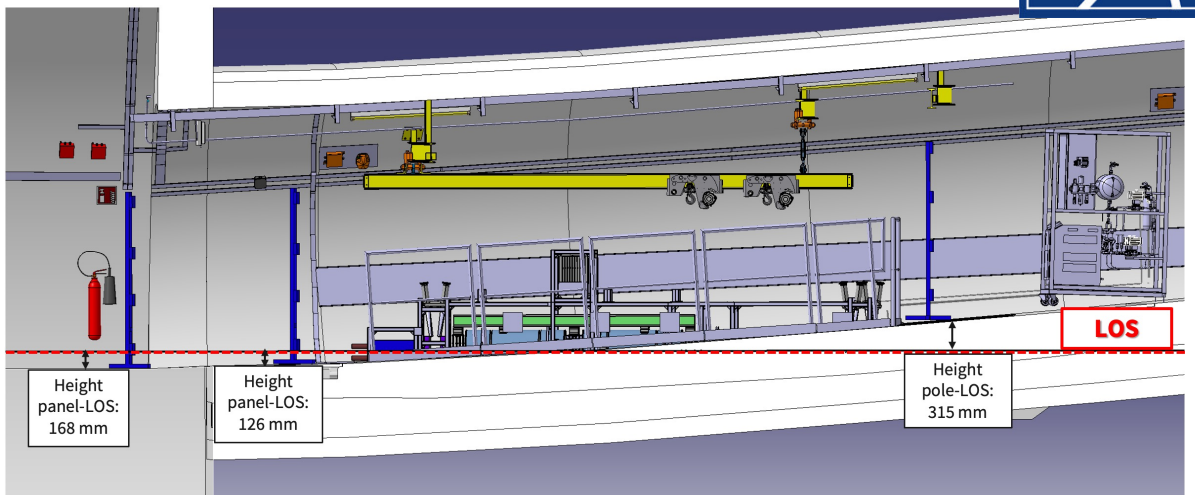
Looking in slices 0.5m wide, 1m high, covering region +/-2m away from the LOS in horizontal plane
Muon flux from FLUKA simulation in Hz/cm^2

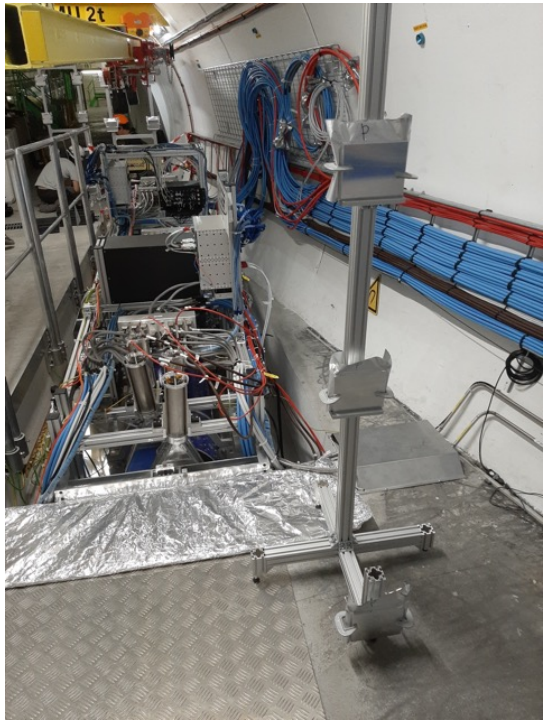
Slice	-2 - -1.5m	-1.5 - -1m	-1 - -0.5m	-0.5 – 0m	0 – 0.5m	0.5 – 1m	1 – 1.5m	1.5 – 2m
Mu+ flux	0.29	0.23	0.17	0.15	0.21	0.41	0.71	1.24
Mu- flux	0.44	0.34	0.28	0.29	0.40	0.62	0.78	0.84
Total flux	0.72	0.57	0.45	0.44	0.61	1.03	1.49	2.08

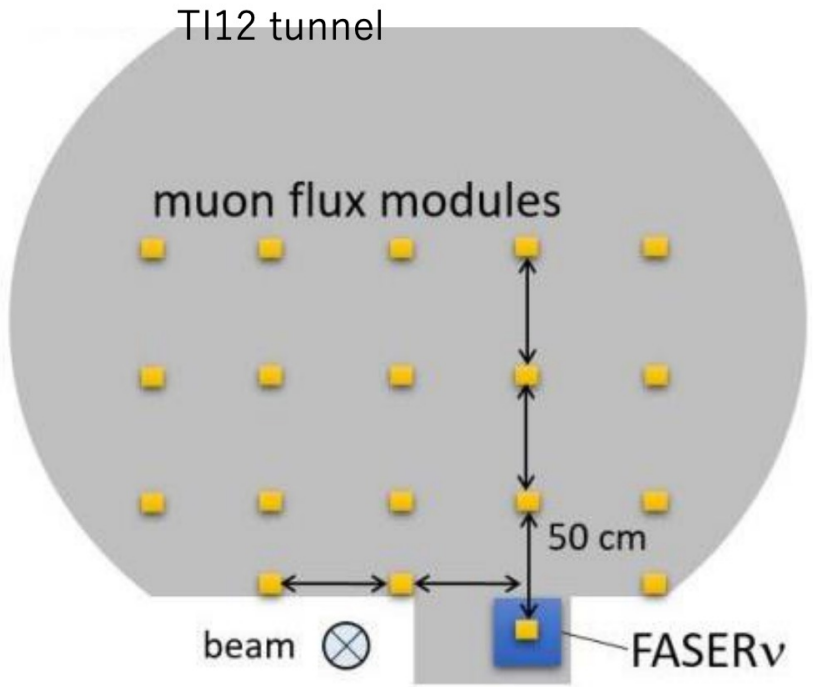
Over 1m x 1m square the rate is ~0.5Hz/cm^2

FASER Muon fluence measurements



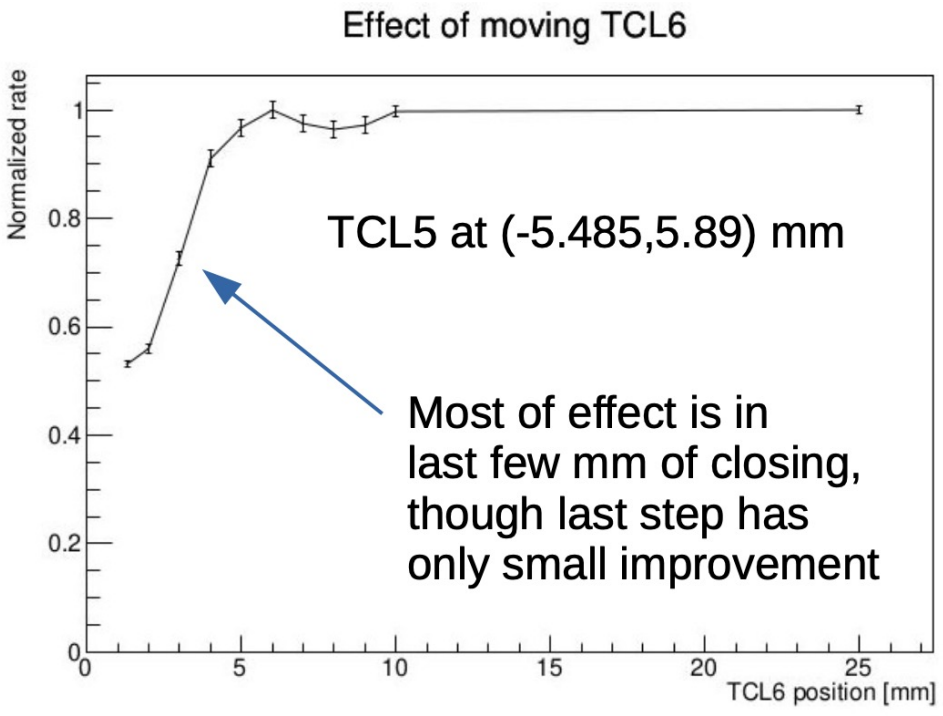


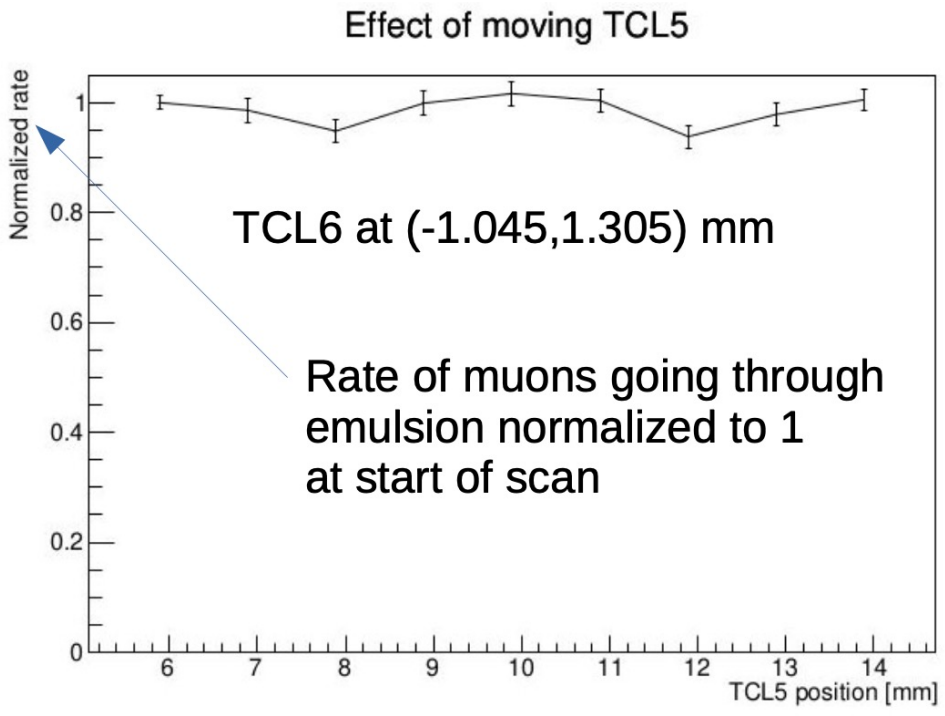




Muon fluence at FASER (on the LOS)

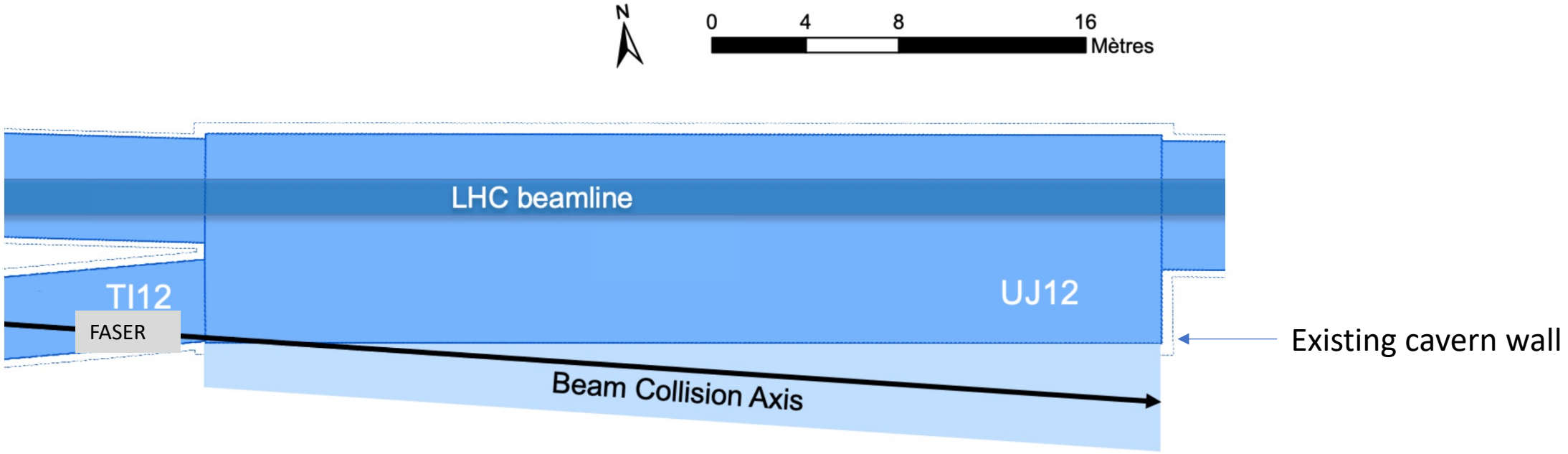
FASER experiment has been taking physics data since July 5th. Measures the rate of muon on the LOS.
In general the observed rate is broadly consistent with the expectation from FLUKA and previous in situ measurements.
Observe ~0.6Hz/cm^2 (FLUKA estimate ~0.5Hz/cm^2). Also see evidence for rate increasing away from LOS as predicted by FLUKA.
However, noticed a significant dependence on the TCL collimator settings (which are changed when the AFP Roman Pot detectors are inserted a few minutes into the fill). In order to understand this we did a dedicated scan of the TCL5 and TCL6 collimator settings to see how they effect the FASER trigger rate.





Strong dependence on TCL6 settings. FLUKA simulations for FPF used HL-LHC baseline TCL6 settings – may be interesting to simulate possible other options to see sensitivity for FPF.

First idea:
Widen UJ12 cavern by 2-4m to allow ~50 area for experiments to be installed along the LOS



Not possible from civil engineering side.
Impossible to get sufficiently large excavation machine here, without dismantling ~500m of the LHC machine.

Radiation Areas classification

EDMS 810149

Area	Annual dose limit (year)	Ambient dose equivalent rate		Sign
		permanent occupancy	low occupancy	
Non-designated	1 mSv	0.5 µSv/h	2.5 µSv/h	
Supervised	6 mSv	3 µSv/h	15 µSv/h	Dosimeter obligatory / *Dosimètre obligatoire*
Simple Controlled	20 mSv	10 µSv/h	50 µSv/h	SIMPLE CONTROLLED / *CONTRÔLÉE SIMPLE* — Dosimeter obligatory / *Dosimètre obligatoire*
Limited Stay	20 mSv	-	2 mSv/h	LIMITED STAY / *SÉJOUR LIMITÉ* — Dosimeters obligatory / *Dosimètres obligatoires*
High Radiation	20 mSv	-	100 mSv/h	HIGH RADIATION / *HAUTE RADIATION* — Dosimeters obligatory / *Dosimètres obligatoires*
Prohibited	20 mSv	-	> 100 mSv/h	NO ENTRY / *DÉFENSE D'ENTRER*

Radiation Area

Controlled Area

Low-occupancy:
< 20% working time

✓ The CERN RP group has reviewed the signage used in radiation areas, by introducing a new colour code for better visualizing the radiological risk level
✓ The RP rules determining the area classification were not changed

Cost breakdown compared to HL-LHC works

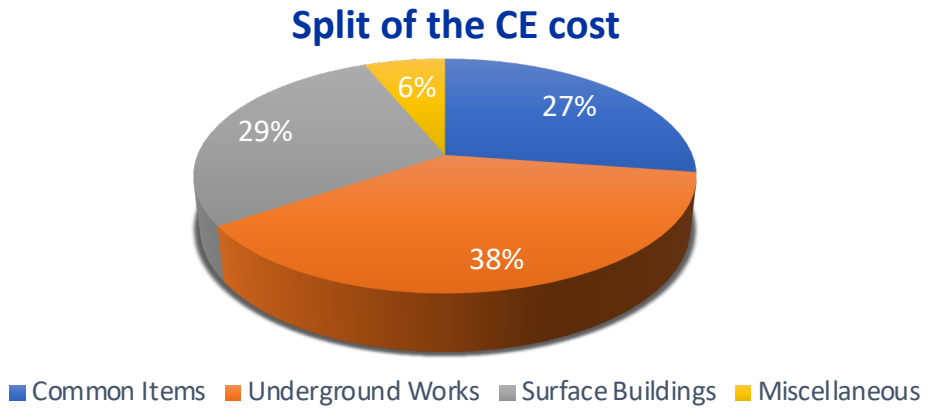
Rough comparison of cost breakdown with HL-LHC works (assuming FPF total cost is 40MCHF).
Clear that CV is more expensive and EL is less expensive than corresponding HL-LHC works fraction.

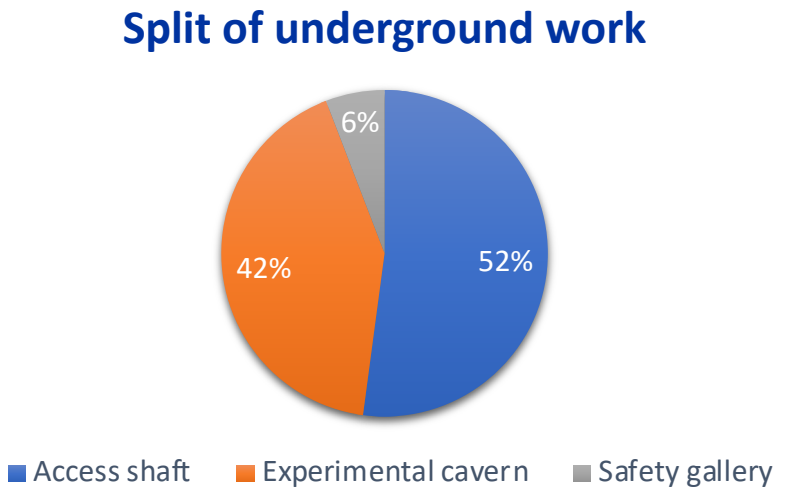
Infrastructures	**[% of WP17]**	**% for FPF costing**
Civil engineering	67	25/40 = 62.5
Electrical distribution	13	1.5/40 = 3.8
Cooling & ventilation	12	7./40 = 17.5
Alarm & access system	2.4	2.5/40 = 6.3
Handling equipment	2.2	1.5/40 = 3.8
Operational safety	1.6	
Logistics & storage	1.4	
Technical monitoring	0.6	

This is based on 25MCHF for pure CE, and 15MCHF for services

New Cavern – Very Preliminary Cost Estimate for CE

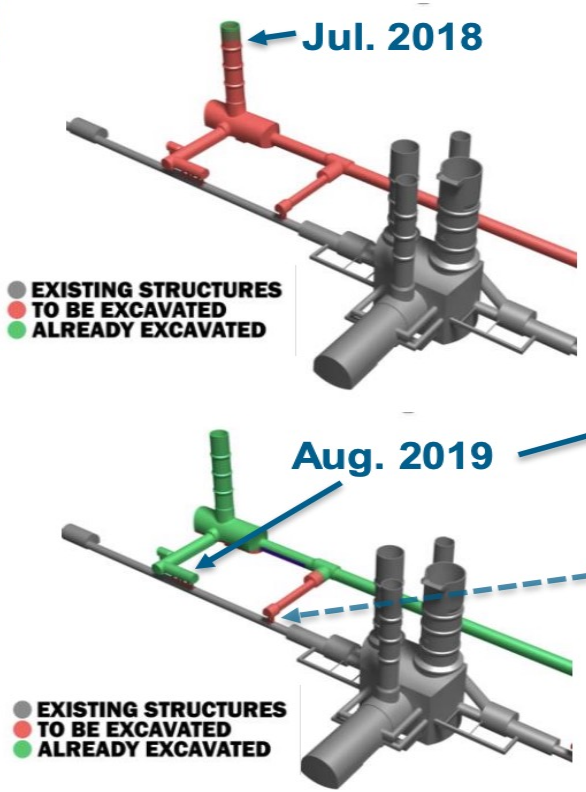
Ref.	Description of works	Cost [CHF]
1	**Common Items**	**6,356,824**
1.1	Contractual requirements (performance guarantee, insurances)	163,473
1.2	Specified requirements (Installation of barracks, Access road, Services etc.)	1,055,263
1..3	Method-related charges (Accommodations, Services, Site supervision, Project drawings)	5,054,772
1.4	Provisional sums	83,316
2	**Underground Works**	**8,859,608**
2.1	Site installation and equipment	3,689,097
2.2	Underground works	5,170,511
3	**Surface Buildings**	**6,598,589**
3.1	Generality	636,485
3.2	Top soils and Earthworks	882,051
3.3	Roads and Network	850,725
3.4	Buildings	4,229,328
4	**Miscellaneous**	**1,436,656**
4.1	Site investigation prior works	200,000
4.2	Project Management	1,236,656
	TOTAL CE WORKS	**23,251,677**

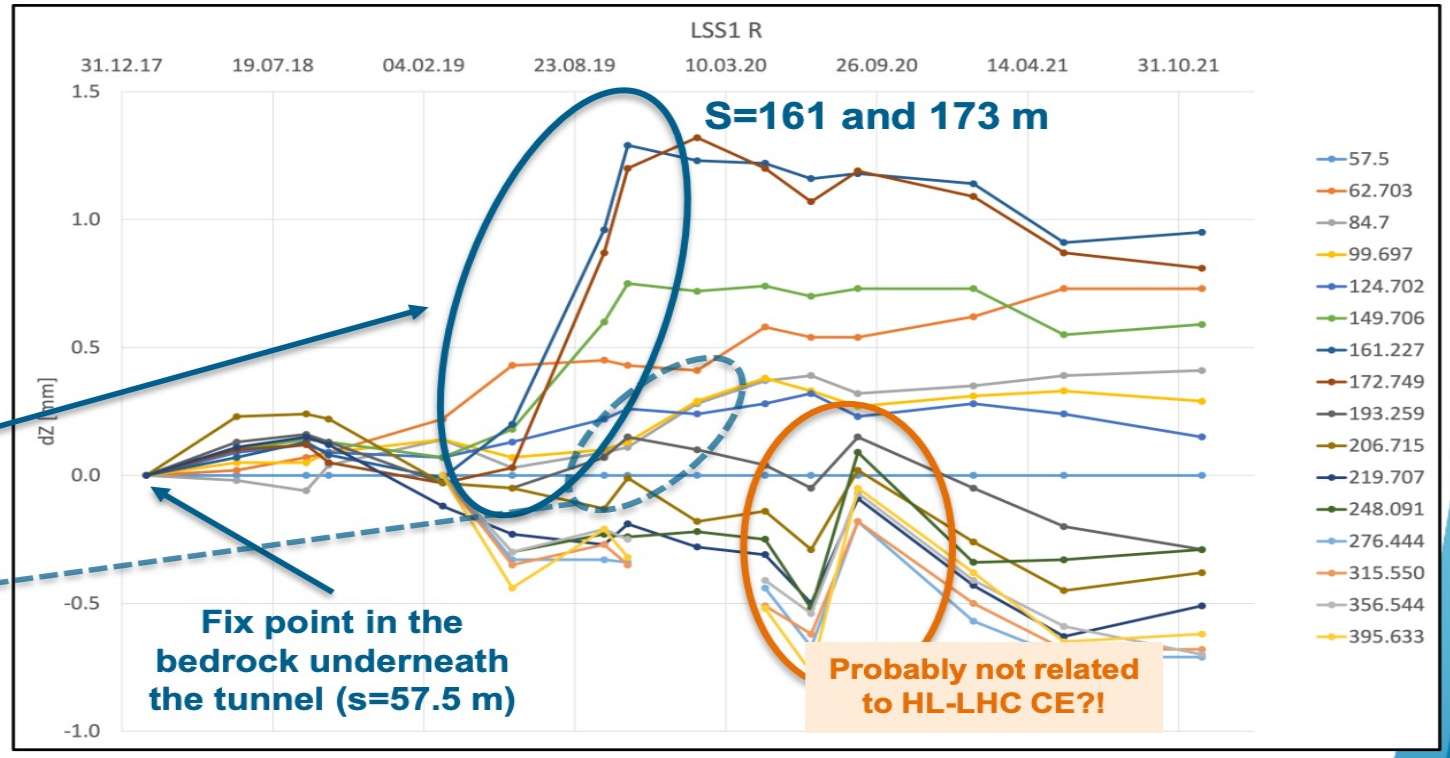




"Static movement" of LHC tunnel during HL-LHC CE works

- Typically, **tunnel moves wrt to bedrock** of the order of **0.25 mm/year**
- A **~1 mm "sudden" movement** observed during excavation of gallery 5 m above LHC tunnel
  - **No visible impact** on tunnel positioning from **shaft digging**

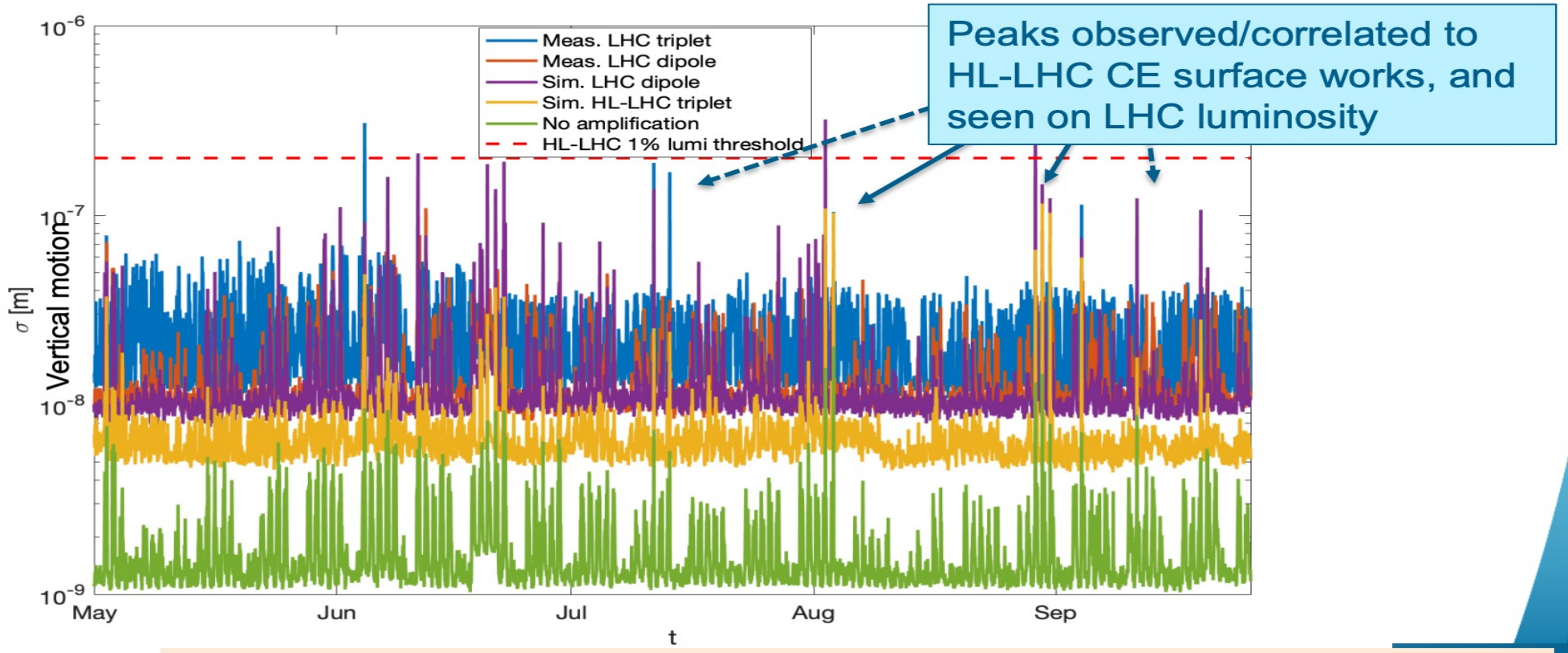




from *Kacper Widuch* AWG#55 2/03/22, EDMS #2702197 and *Laurent Jean Tavian*

Expected/Observed Beam Orbit Vibration during HL-LHC CE surface works in 2018

- Looking at **ground motion measurements (geophones) near IPs**
- Effect on beam **depends** on the **mechanical transfer function** of magnetic elements
  - **Examples using available transfer function estimates on 2018 data**
    - **Integration** over the whole range **3-100 Hz**
    - **PSD taken once every hour** from local geophones – several peaks probably missing



See H. Garcia Morales (TCC 26/11/20) and D. Gamba (HL-LHC CM 18/10/18)