FPF Forward Physics Facility

CERN

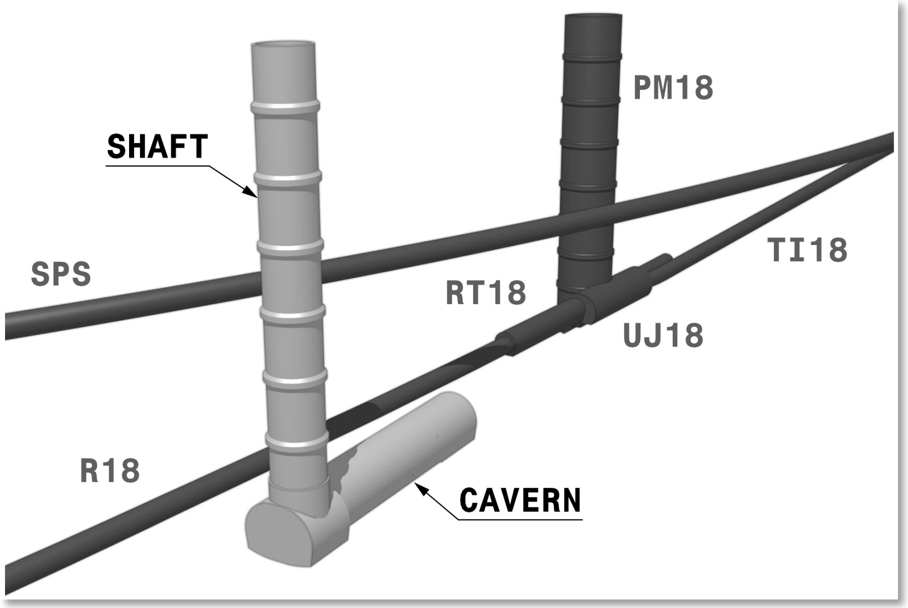
Facility:
Non Civil Engineering Update

FPF 6 Workshop

June 8th 2023

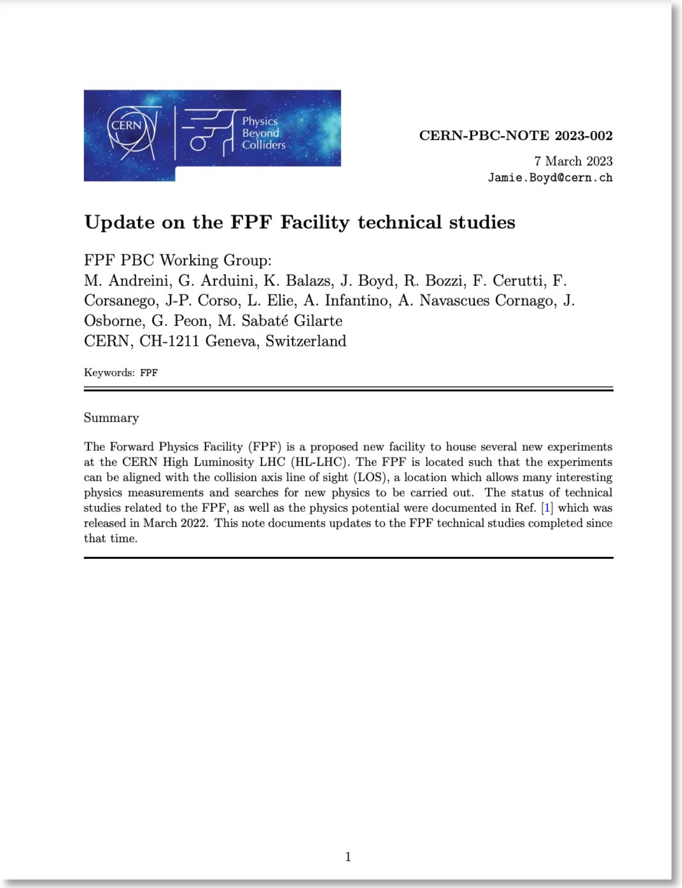
Jamie Boyd (CERN)

Physics Beyond Colliders



Introduction

- First rough design of facility, including CE and technical services/infrastructure and very rough costing carried out for FPF white paper released in March 2022
- Following that several updates and new studies carried out
  - Some of these presented at the last FPF workshop and PBC workshop (both ~6 months ago)
  - The updates have been documented in a public PBC note:
  - https://cds.cern.ch/record/2851822 (CERN-PBC-Notes-2023-002)
- In this talk I will summarize these updates (not related to CE), and some next steps…
- The work shown here is supported by the CERN PBC
  - ***Many thanks!***



CERN-PBC-NOTE 2023-002

7 March 2023

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Update on the FPF Facility technical studies

FPF PBC Working Group:
M. Andreini, G. Arduini, K. Balazs, J. Boyd, R. Bozzi, F. Cerutti, F. Corsanego, J-P. Corso, L. Elie, A. Infantino, A. Navascues Cornago, J. Osborne, G. Peon, M. Sabaté Gilarte
CERN, CH-1211 Geneva, Switzerland

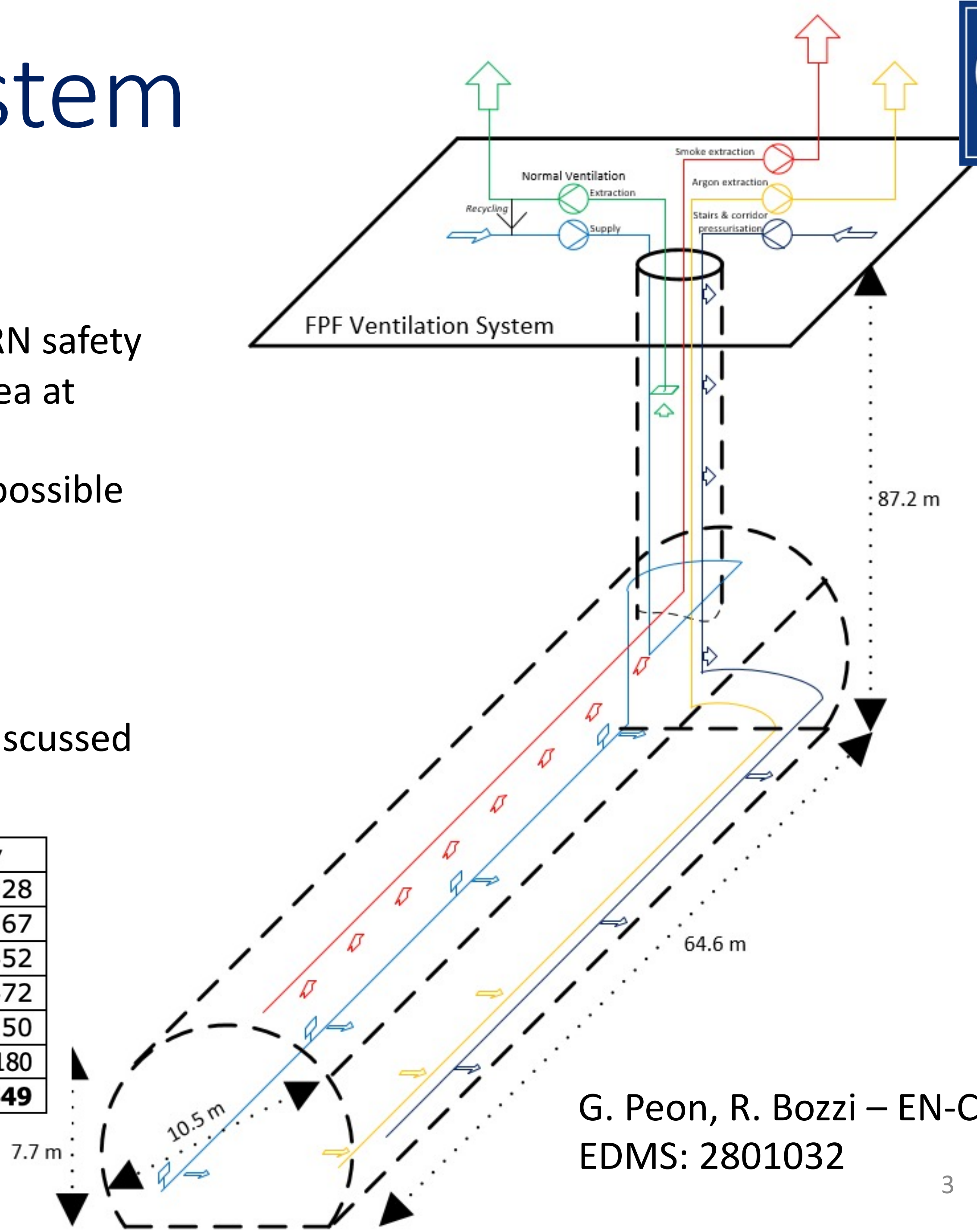
Keywords: FPF

Summary

The Forward Physics Facility (FPF) is a proposed new facility to house several new experiments at the CERN High Luminosity LHC (HL-LHC). The FPF is located such that the experiments can be aligned with the collision axis line of sight (LOS), a location which allows many interesting physics measurements and searches for new physics to be carried out. The status of technical studies related to the FPF, as well as the physics potential were documented in Ref. [1] which was released in March 2022. This note documents updates to the FPF technical studies completed since that time.

1

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 (10000 m^3/h)
- Pressurization
- Smoke extraction (25000 m^3/h)
- LAr evacuation included, but details need to be further discussed with safety.

	Budget (kCHF)	Budget (kCHF) +20% contingency
Smoke extraction	690	828
Argon Extraction	306	367
Pressurisation	377	452
Supply	393	472
Return	208	250
Studies	150	180
TOTAL	**2 124**	**2 549**

Original cost estimate 7MCHF

G. Peon, R. Bozzi – EN-CV
EDMS: 2801032

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~~ 2.5
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~~ 8.4

Round up to 10MCHF.

Open questions:
- Is 2MVA electrical power sufficient?
- Is 25t crane capacity sufficient?

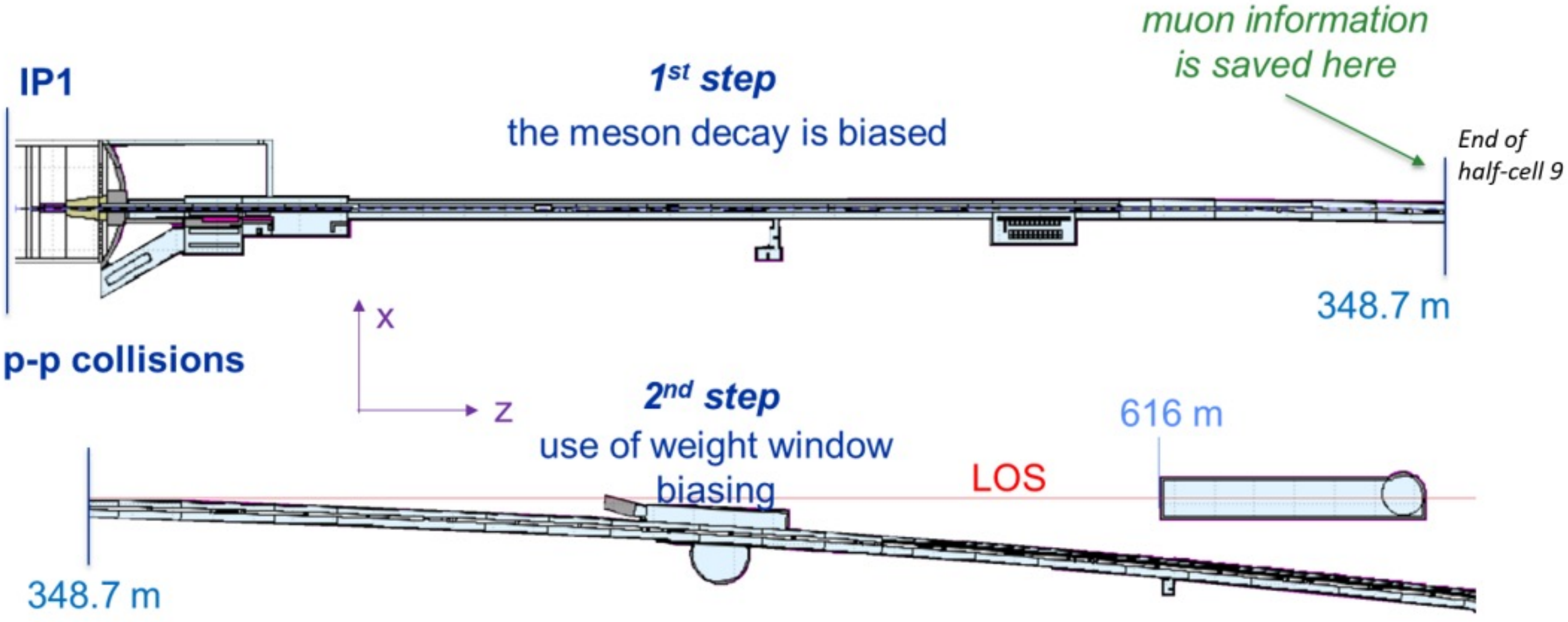
Background Muon Rate

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

FLUKA simulations. Two steps:

- Simulate up to 350m from IP
- Simulate remaining 250m -> FPF (616m)

Efficient way to simulate and allows to test possible sweeper magnets at ~350m from IP



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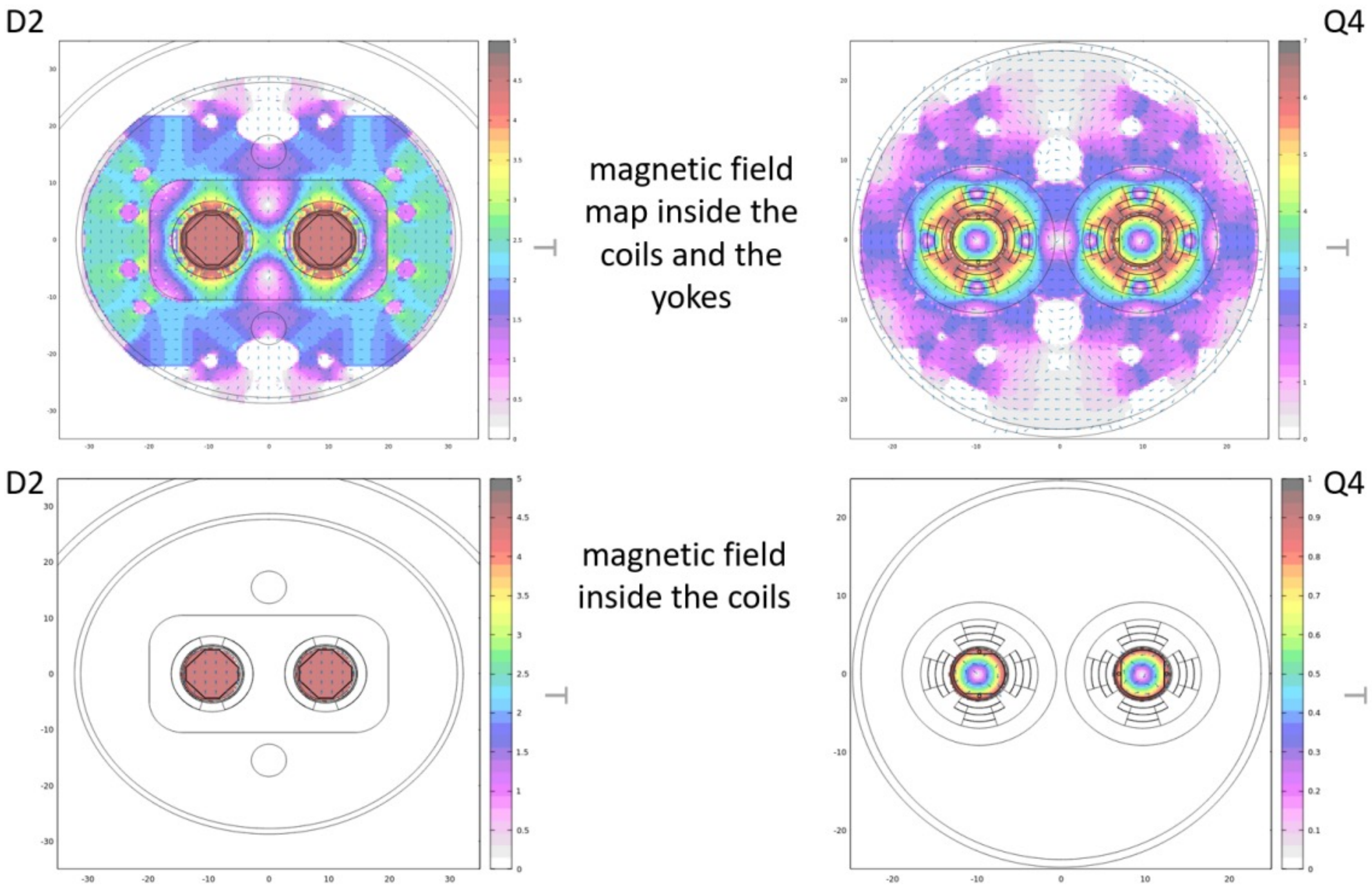
Background Muon Rate

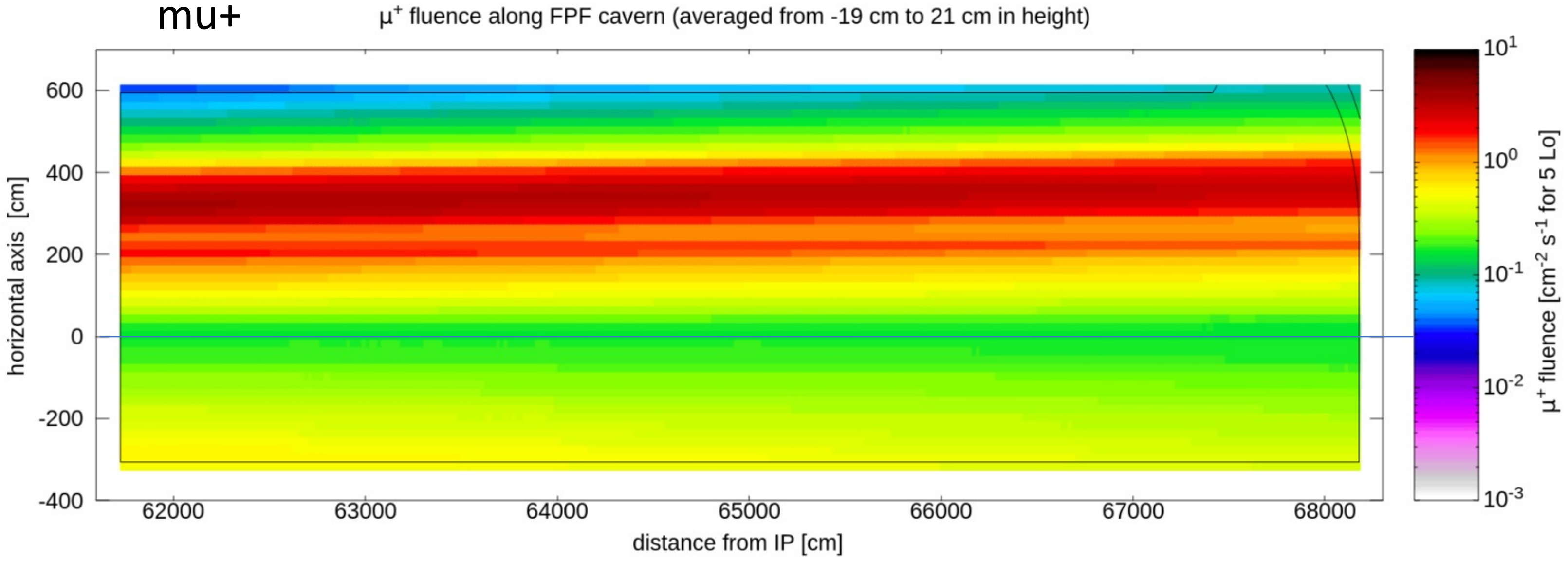


FLUKA model updates to include full magnetic field map (including field in yoke) in all relevant magents (e.g. including Q4 and D2).
Leads to almost factor of 2 reduction of muon fluence at FPF, down to 0.6 Hz cm^{-2} for L=5e34$cm^{-2}s^{-1}$ (0.45 mu- / 0.15 mu+).
For 20x20cm^2 area on the LOS.

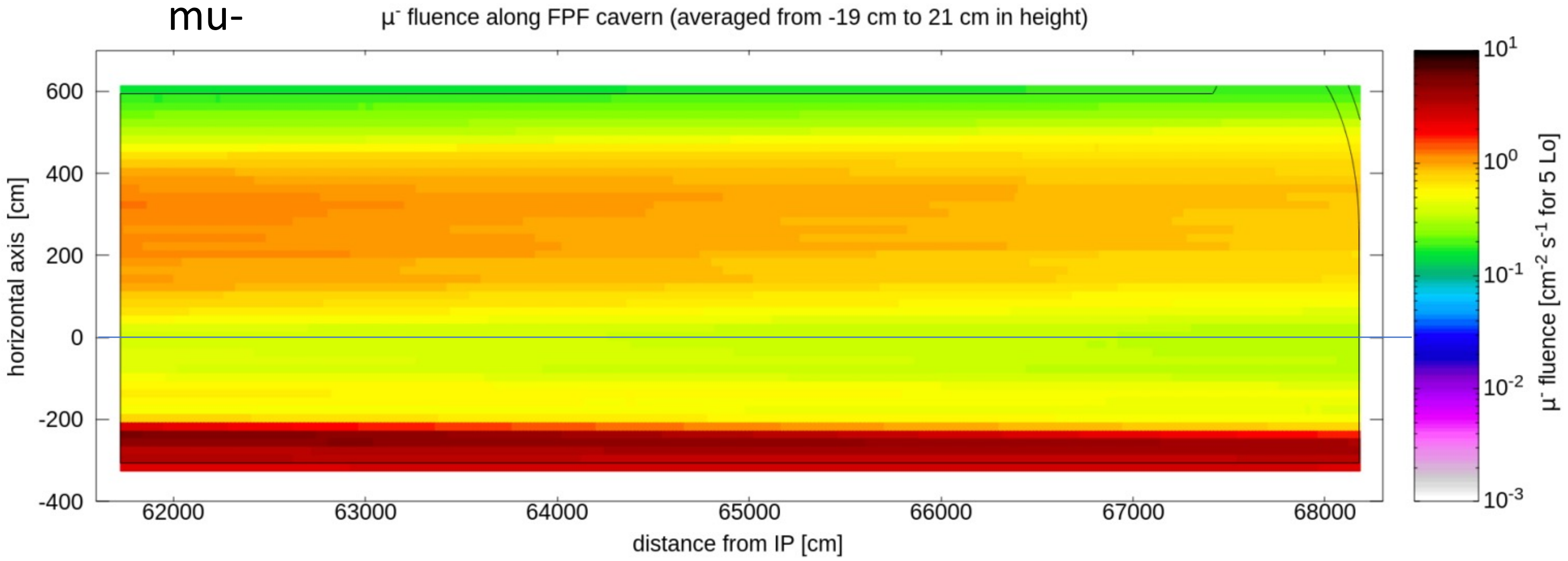
F. Cerutti, M. Sabate-Gilarte
SY-STI

Background Muon Rate

mu+

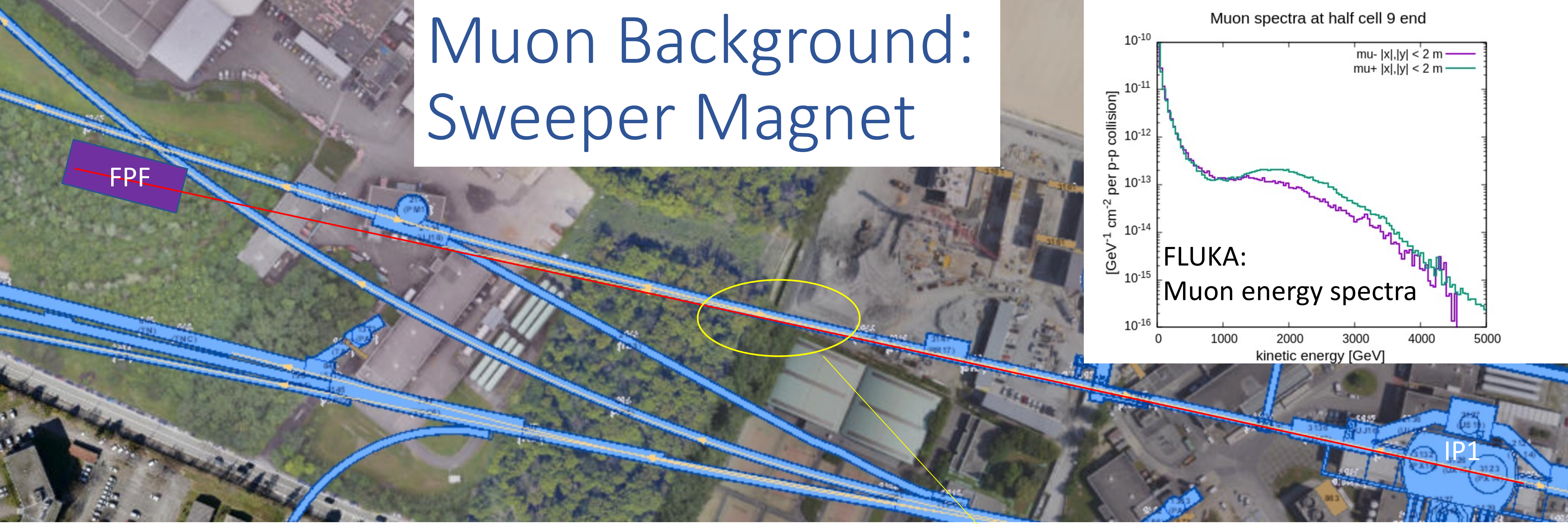


mu-



Fluence in x/z plane in FPF location. (20cm from LOS in vertical plane). Clear hotspots at ~2m from LOS in horizontal.

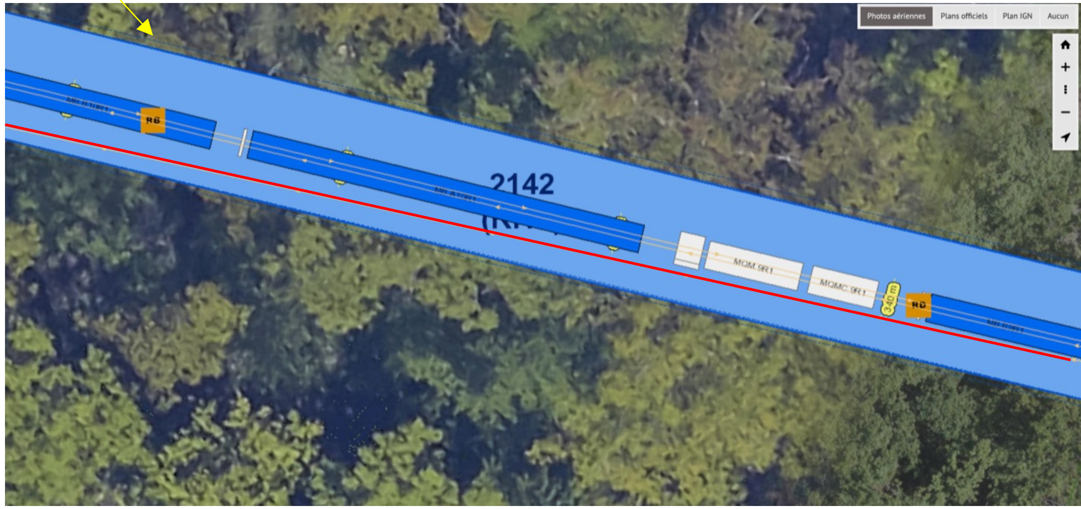
Muon Background: Sweeper Magnet



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).

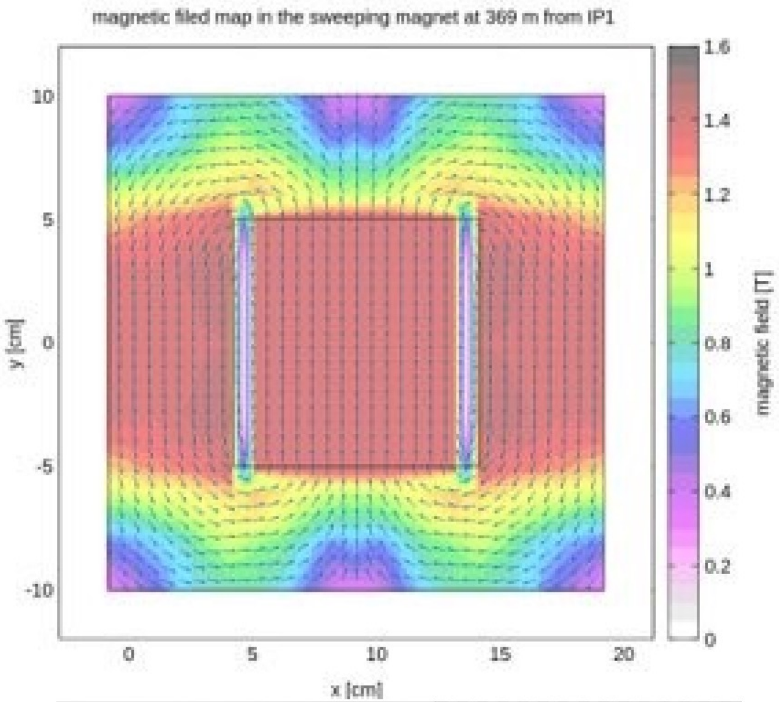
Based on quick integration study required (will likely require some small local modifications to cryogenic infrastructure in the tunnel).

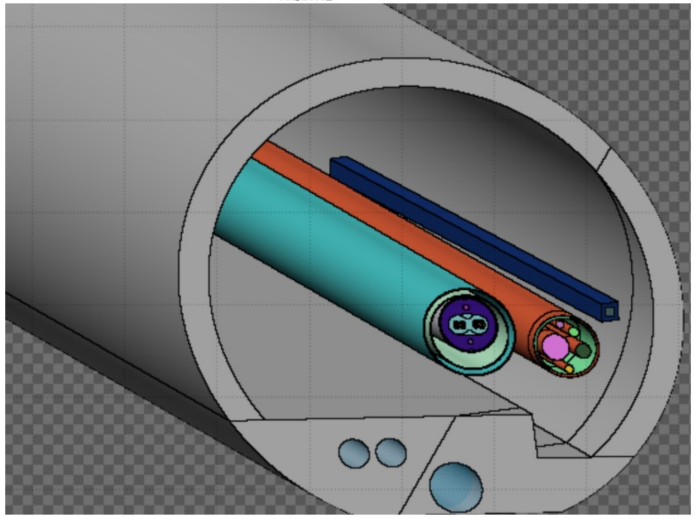


Sweeper Magnet

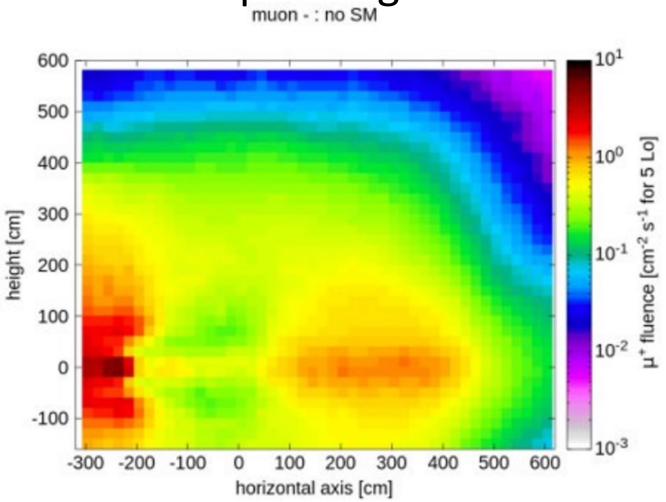
F. Cerutti, M. Sabate-Gilarte
SY-STI

Investigated sweeper magnet to reduce muon flux using FLUKA.
Design tested found not to be effective, due to multiple scattering in 200m of rock, re-populating depleted region.

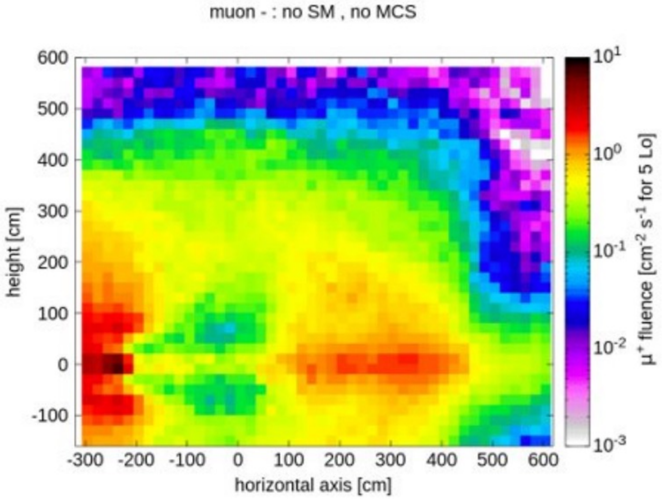


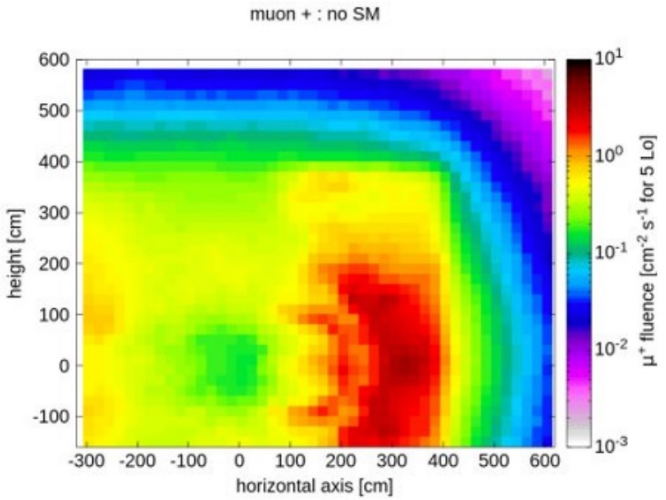


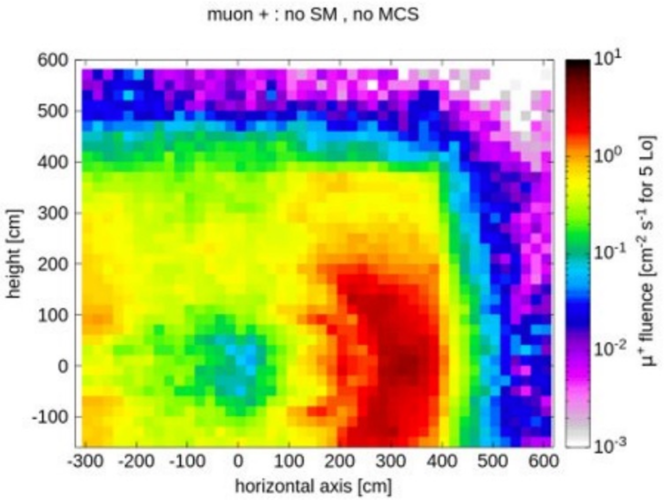
No sweeper magnet



No sweeper magnet – no MCS







Neutron Dose at FPF

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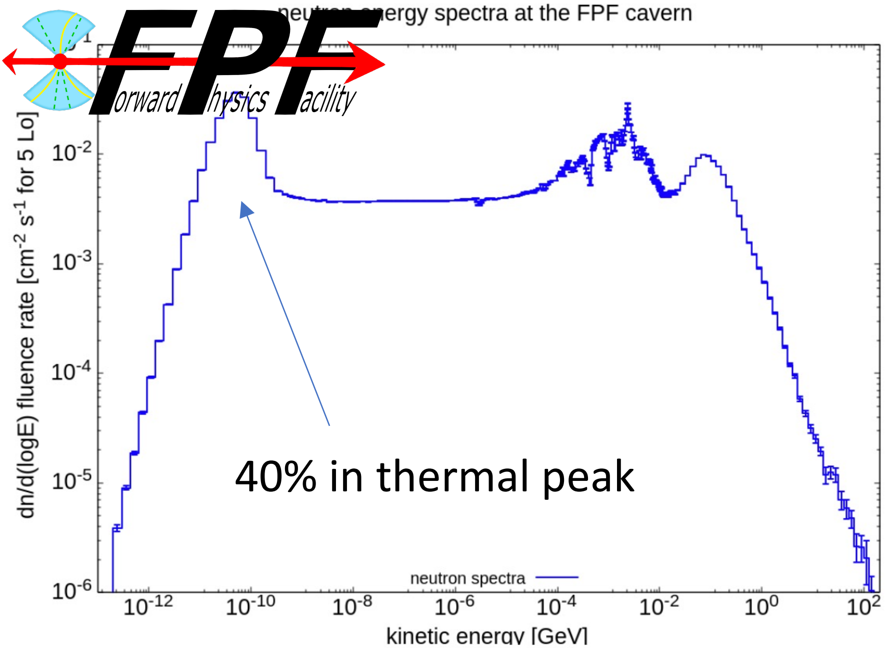
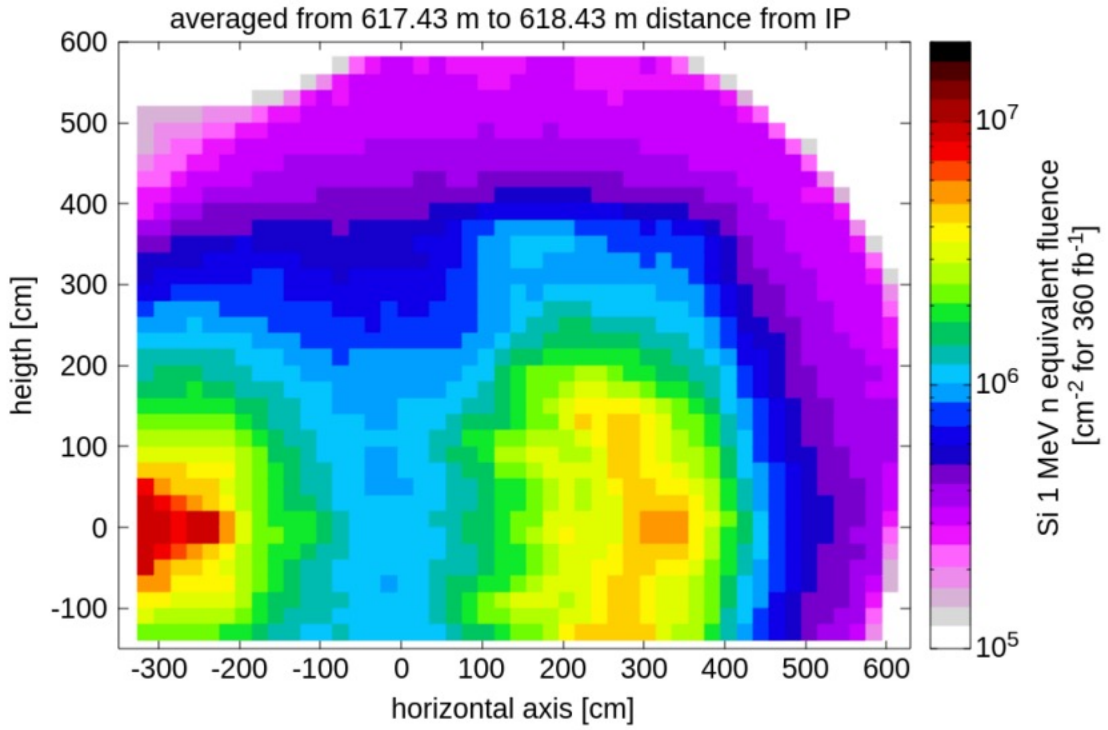
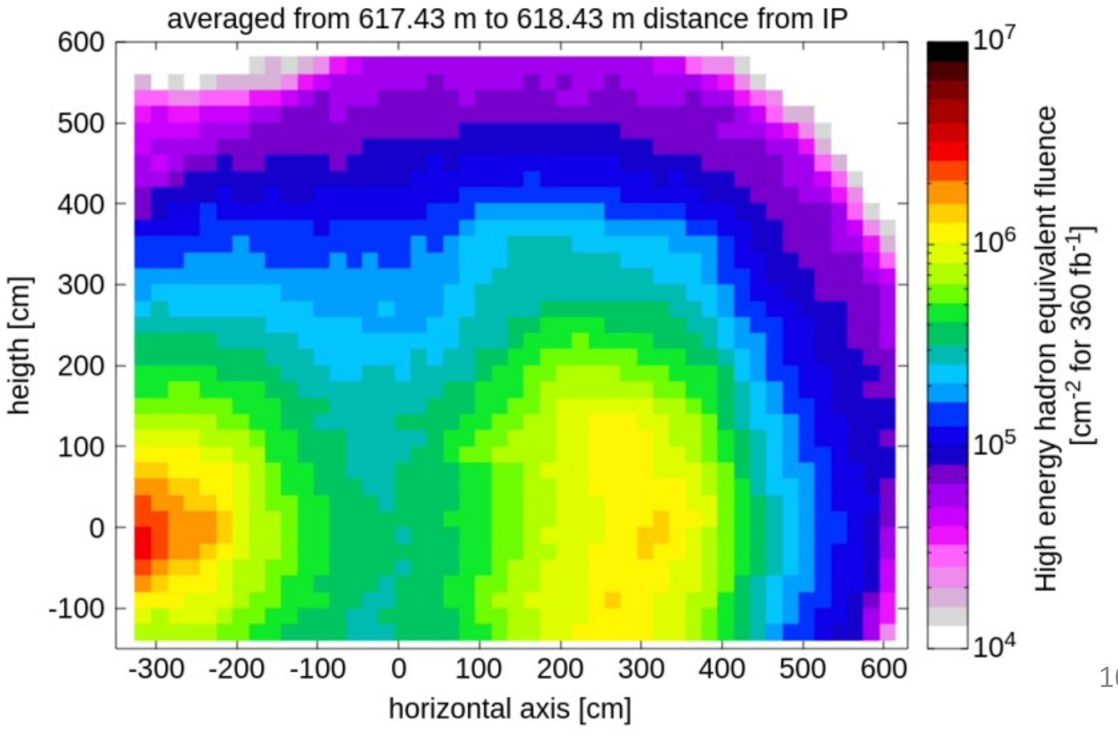
SY-STI



FLUKA simulations used to look at neutron dose level in FPF (relevant for radiation to electronics and radiation damage).
Neutron dose ~0.2Hz/cm^2 at L=5e34.

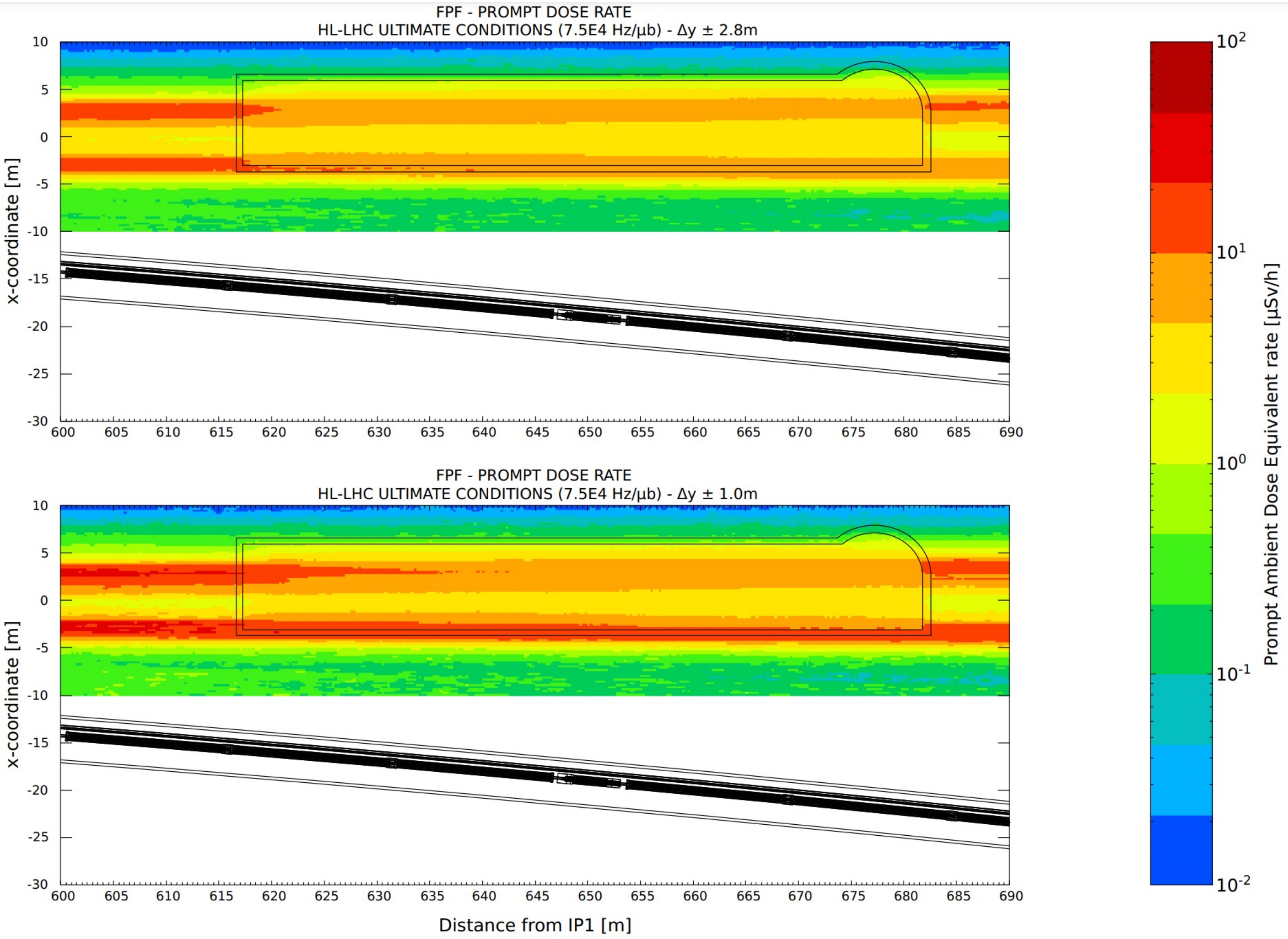
Also shown:
1MeV n equiv fluence (relevant for silicon radiation damage)
High energy hadron fluence (relevant for SEU in electronics)
Both shown for 1 year at L=7.5e34 (ultimate HL-LHC lumi)
HEH fluence <3e16cm^{-2}y^{-1} (LHC threshold for radiation for electronics).





Radio Protection Studies

A. Infantino, L. Elie - RP



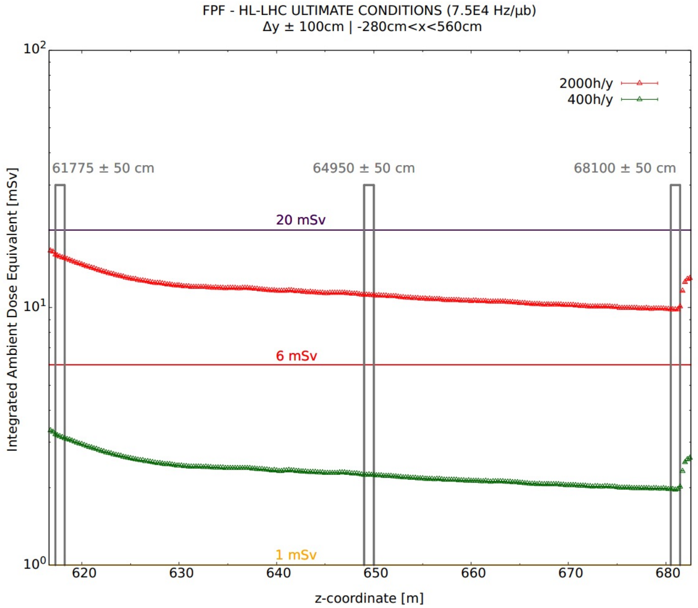
RP studies based on FLUKA simulations of dose from muons in FPF. (Other potential sources of radiadition considered, but found to be negligiable).

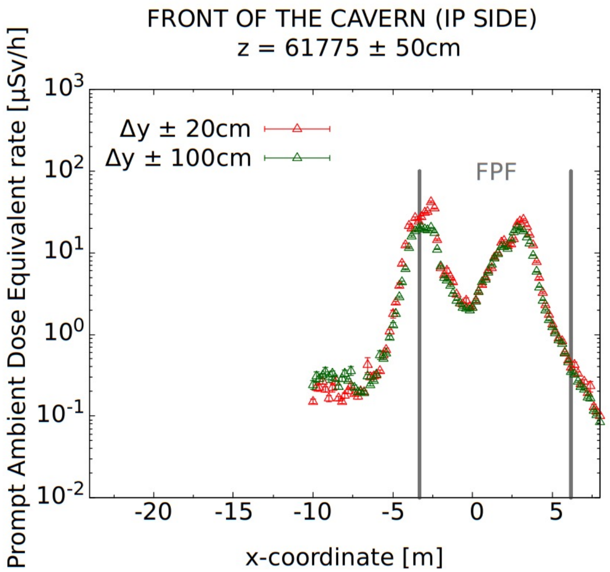
Higher dose when muons go through or close to material (rock) – due to short lived hadron production.

Conclusions: Radio Protection Studies

A. Infantino, L. Elie - RP

- Direct contribution from muons from IP1/LSS1 can limit the accessibility to the cavern during LHC operation
  - > 6 mSv/year may be achieved locally;
- Classification of the cavern as Simple Controlled/Supervised Radiation Area
  - low occupancy, i.e. < 20% working time seems possible;
- Access to the cavern during LHC beam operation will be limited to Radiation Workers
  - Also relevant for external personnel involved in the excavation (of the cavern and the lower part of the shaft) if done during beam operation
- No permanent control rooms are foreseen underground.
  - During installation and commissioning there may be people in the cavern for an extended period: this time shall be quantified to finalize the RP risk assessment;
- Final study to be done considering a full integration model, i.e. including detectors, service equipment, …





Vibrations etc…

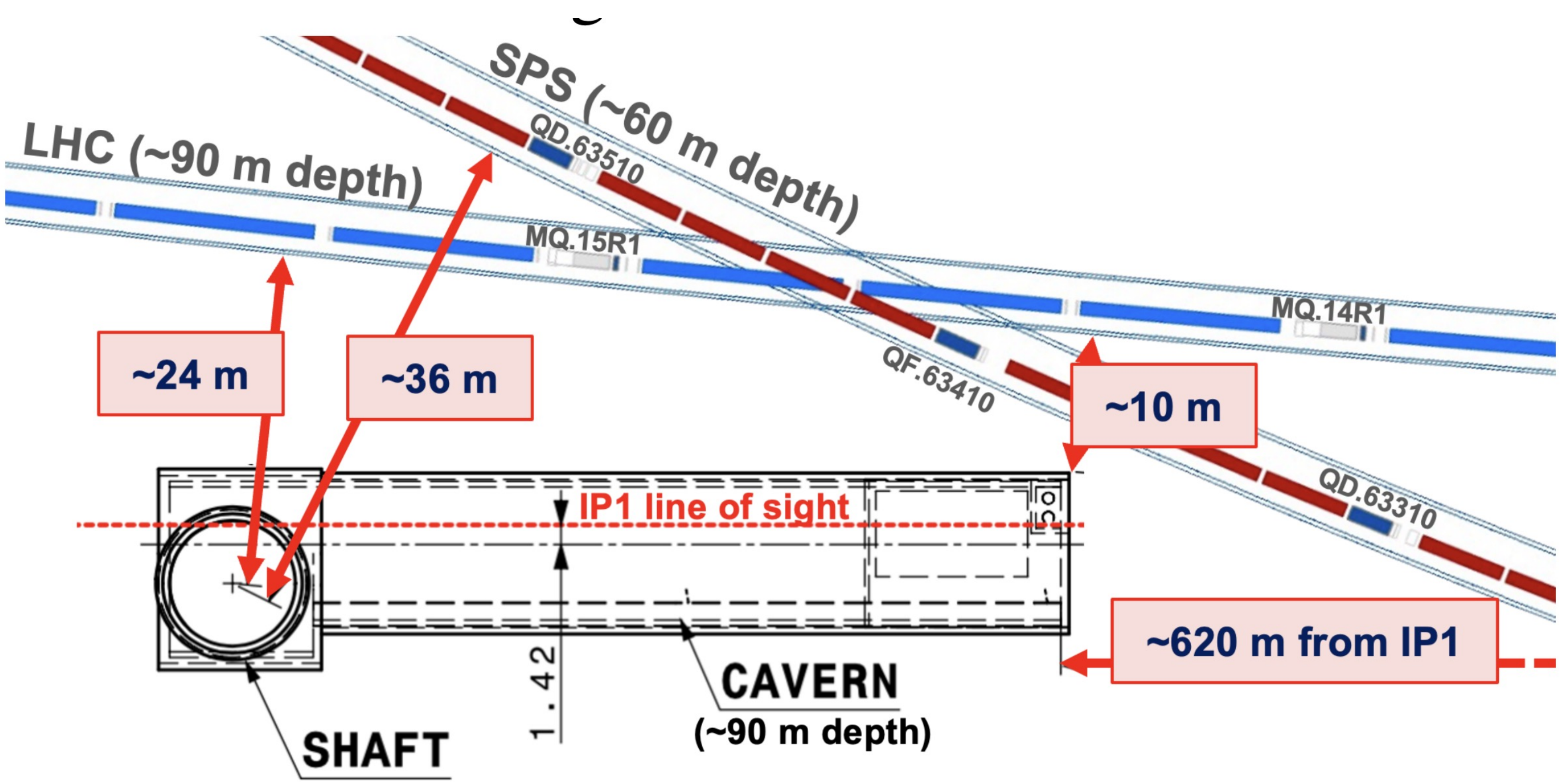
https://www.ipac23.org/preproc/pdf/THPA039.pdf

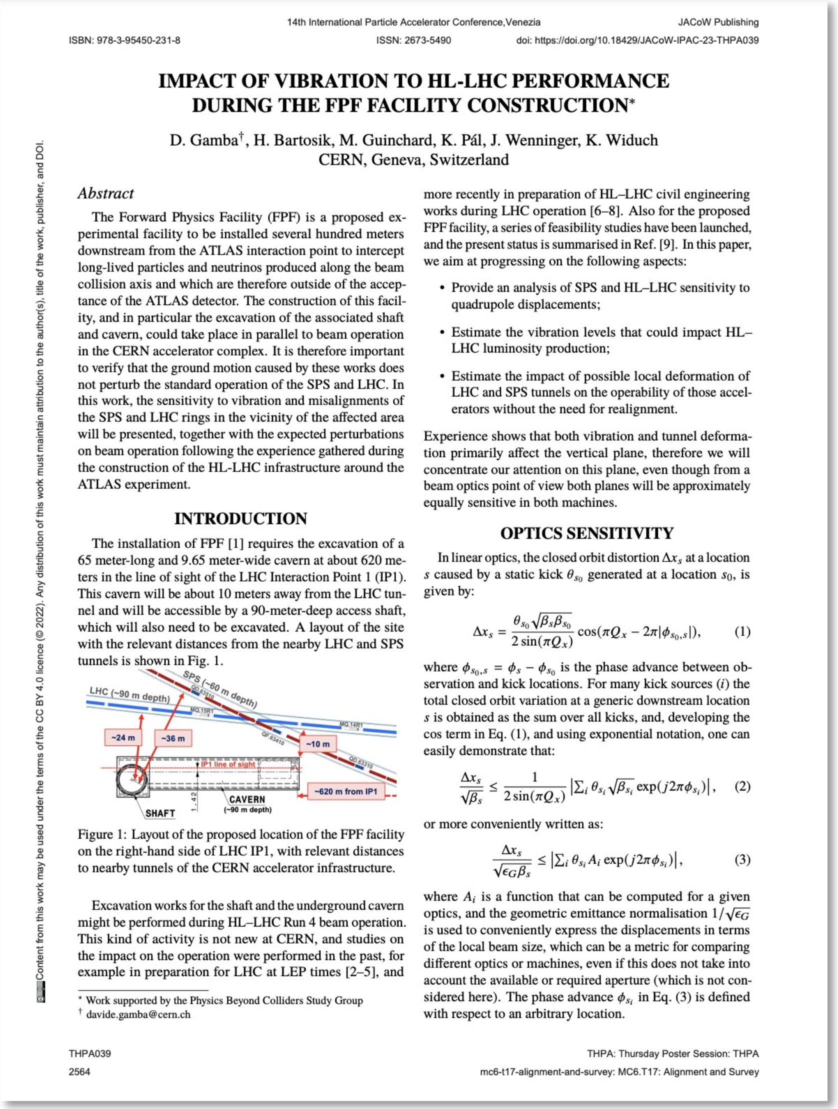
D. Gamba - CERN BE-ABP, M. Guinchard – CERN EN-MME

Study on effect of excavation work on HL-LHC (& SPS) operations in terms of vibrations and possible tunnel movements.

Preliminary results presented at IPAC conference in May and public document available.

Relevant parameters….





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IMPACT OF VIBRATION TO HL-LHC PERFORMANCE DURING THE FPF FACILITY CONSTRUCTION*

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CERN, Geneva, Switzerland

Abstract

The Forward Physics Facility (FPF) is a proposed experimental facility to be installed several hundred meters downstream from the ATLAS interaction point to intercept long-lived particles and neutrinos produced along the beam collision axis and which are therefore outside of the acceptance of the ATLAS detector. The construction of this facility, and in particular the excavation of the associated shaft and cavern, could take place in parallel to beam operation in the CERN accelerator complex. It is therefore important to verify that the ground motion caused by these works does not perturb the standard operation of the SPS and LHC. In this work, the sensitivity to vibration and misalignments of the SPS and LHC rings in the vicinity of the affected area will be presented, together with the expected perturbations on beam operation following the experience gathered during the construction of the HL-LHC infrastructure around the ATLAS experiment.

INTRODUCTION

The installation of FPF [1] requires the excavation of a 65 meter-long and 9.65 meter-wide cavern at about 620 meters in the line of sight of the LHC Interaction Point 1 (IP1). This cavern will be about 10 meters away from the LHC tunnel and will be accessible by a 90-meter-deep access shaft, which will also need to be excavated. A layout of the site with the relevant distances from the nearby LHC and SPS tunnels is shown in Fig. 1.

Figure 1: Layout of the proposed location of the FPF facility on the right-hand side of LHC IP1, with relevant distances to nearby tunnels of the CERN accelerator infrastructure.

Excavation works for the shaft and the underground cavern might be performed during HL–LHC Run 4 beam operation. This kind of activity is not new at CERN, and studies on the impact on the operation were performed in the past, for example in preparation for LHC at LEP times [2–5], and more recently in preparation of HL–LHC civil engineering works during LHC operation [6–8]. Also for the proposed FPF facility, a series of feasibility studies have been launched, and the present status is summarised in Ref. [9]. In this paper, we aim at progressing on the following aspects:

- Provide an analysis of SPS and HL–LHC sensitivity to quadrupole displacements;
- Estimate the vibration levels that could impact HL–LHC luminosity production;
- Estimate the impact of possible local deformation of LHC and SPS tunnels on the operability of those accelerators without the need for realignment.

Experience shows that both vibration and tunnel deformation primarily affect the vertical plane, therefore we will concentrate our attention on this plane, even though from a beam optics point of view both planes will be approximately equally sensitive in both machines.

OPTICS SENSITIVITY

In linear optics, the closed orbit distortion Δx_s at a location s caused by a static kick θ_{s_0} generated at a location s_0, is given by:

$$\Delta x_s = \frac{\theta_{s_0}\sqrt{\beta_s\beta_{s_0}}}{2\sin(\pi Q_x)}\cos(\pi Q_x - 2\pi|\phi_{s_0,s}|), \quad (1)$$

where $\phi_{s_0,s} = \phi_s - \phi_{s_0}$ is the phase advance between observation and kick locations. For many kick sources (i) the total closed orbit variation at a generic downstream location s is obtained as the sum over all kicks, and, developing the cos term in Eq. (1), and using exponential notation, one can easily demonstrate that:

$$\frac{\Delta x_s}{\sqrt{\beta_s}} \leq \frac{1}{2\sin(\pi Q_x)}\left|\sum_i \theta_{s_i}\sqrt{\beta_{s_i}}\exp(j2\pi\phi_{s_i})\right|, \quad (2)$$

or more conveniently written as:

$$\frac{\Delta x_s}{\sqrt{\epsilon_G\beta_s}} \leq \left|\sum_i \theta_{s_i} A_i \exp(j2\pi\phi_{s_i})\right|, \quad (3)$$

where A_i is a function that can be computed for a given optics, and the geometric emittance normalisation $1/\sqrt{\epsilon_G}$ is used to conveniently express the displacements in terms of the local beam size, which can be a metric for comparing different optics or machines, even if this does not take into account the available or required aperture (which is not considered here). The phase advance ϕ_{s_i} in Eq. (3) is defined with respect to an arbitrary location.

* Work supported by the Physics Beyond Colliders Study Group

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Vibrations etc…

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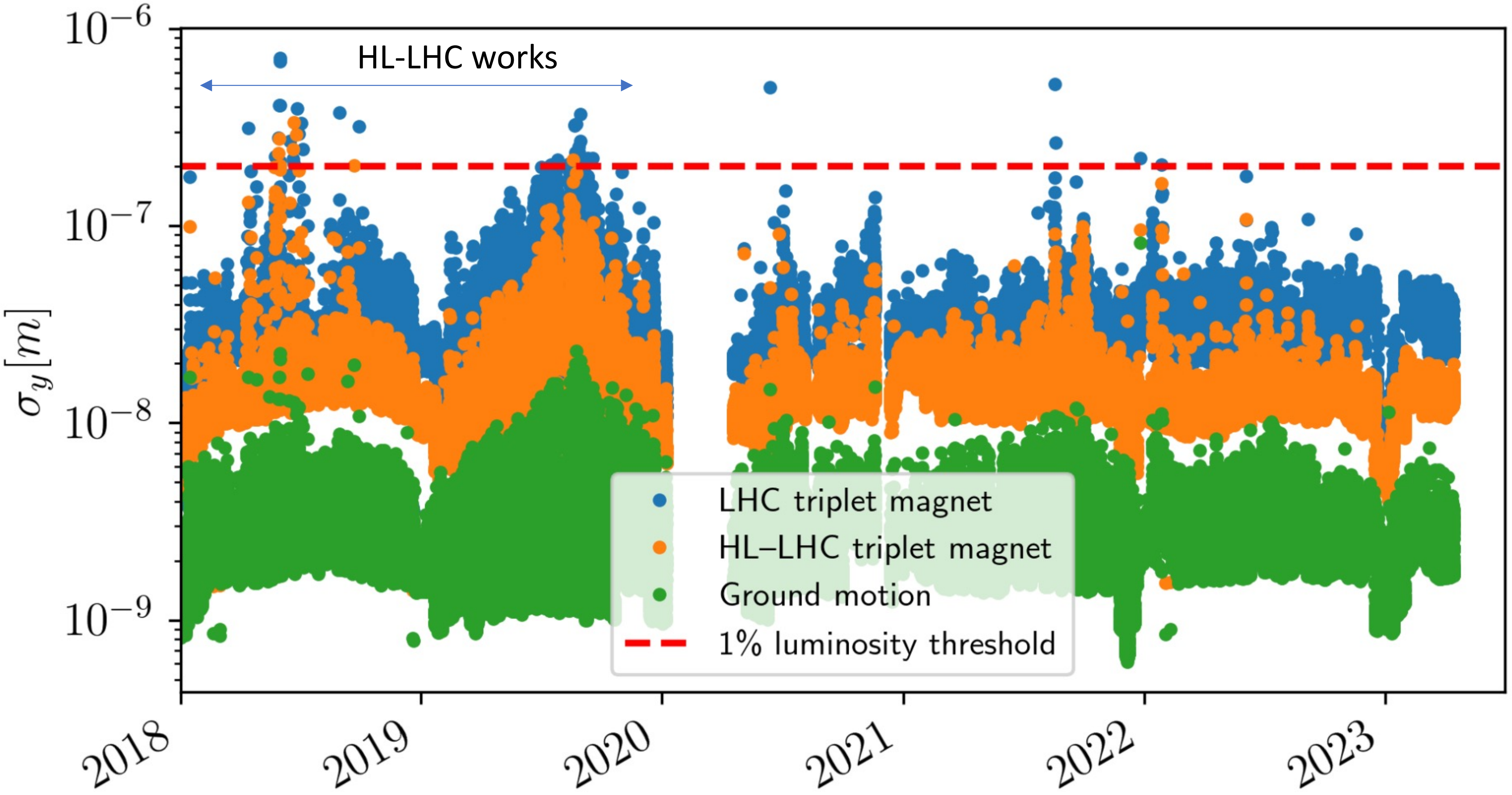

Vertical rms ground motion measured at IP1 (green)
Amplified by triplet magnet transfer functions (blue = LHC, orange HL-LHC)

Vibrations etc…

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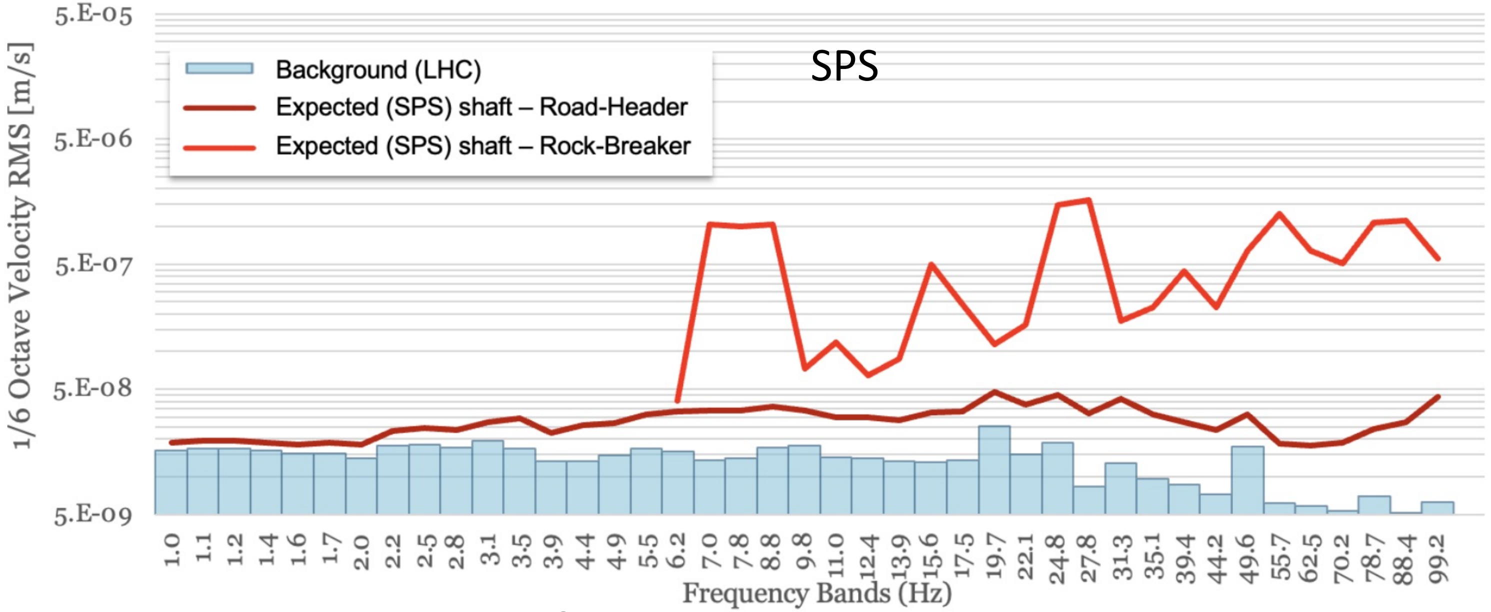
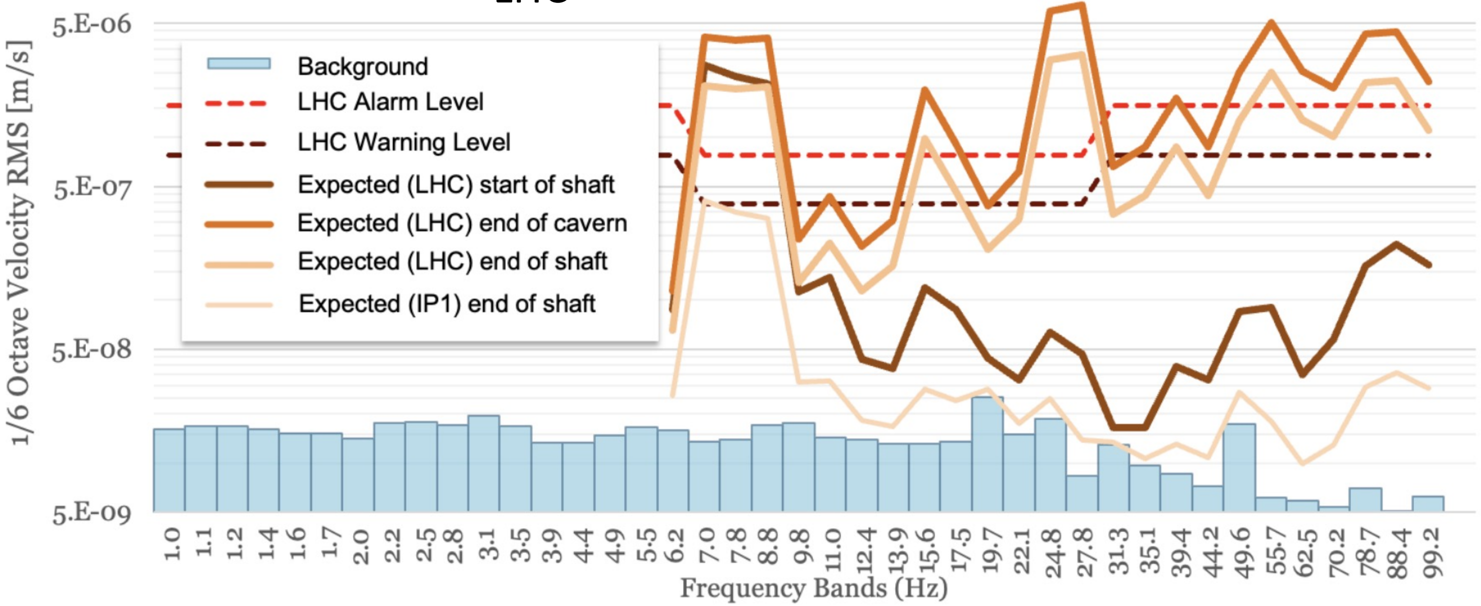
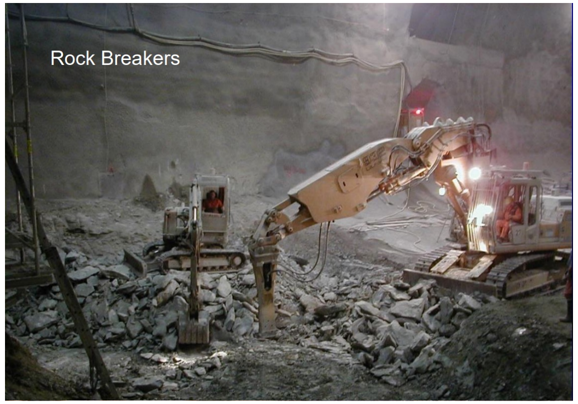




Rock breakers



Road headers

Vibrations etc…

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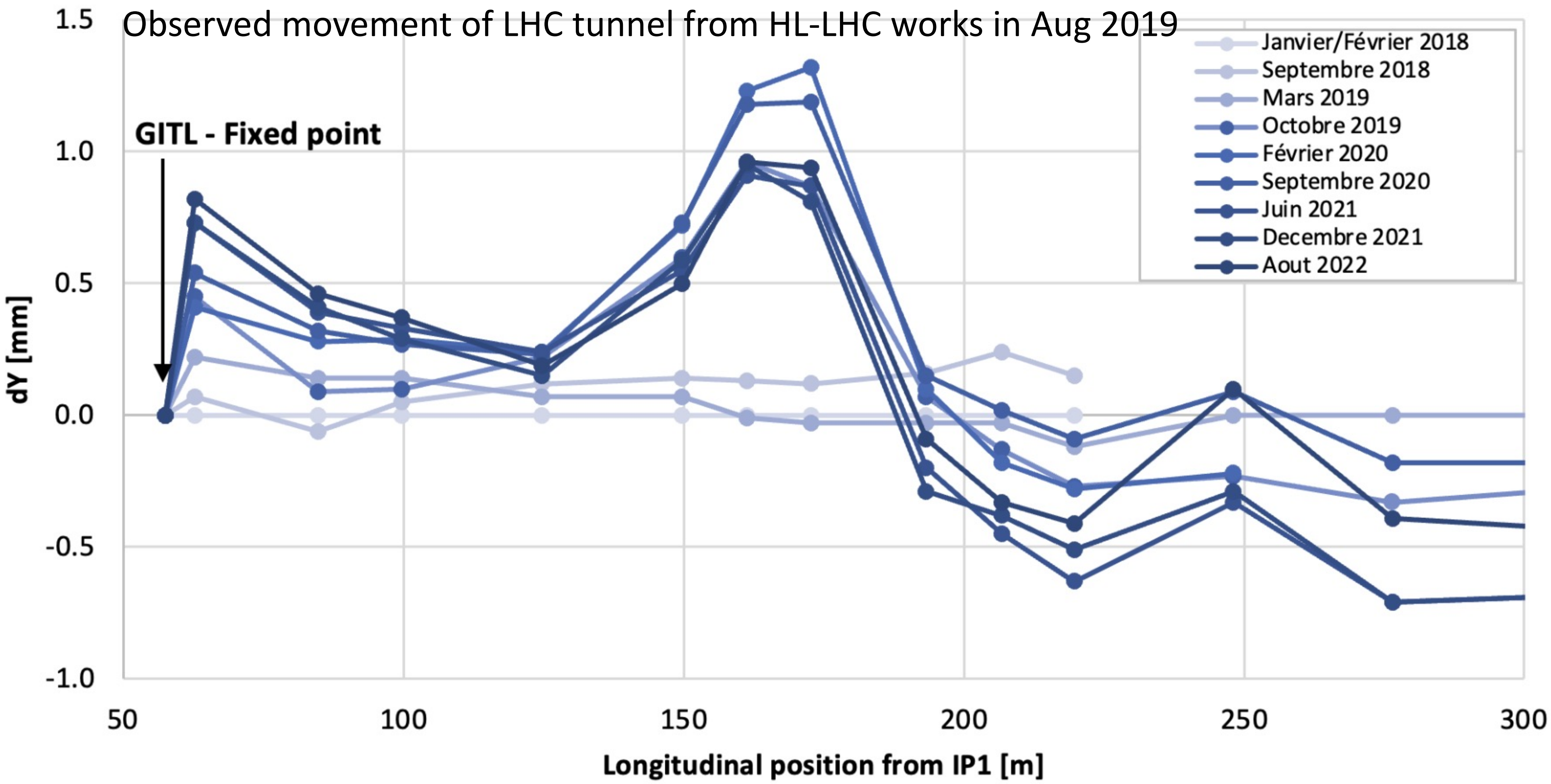

Based on HL-LHC works experience, a static movement of up to 1mm of the LHC or SPS tunnels could be possible. This can be dealt with with the available corrector strength and for the relevant appeture and beam emmitances.

Vibrations etc…

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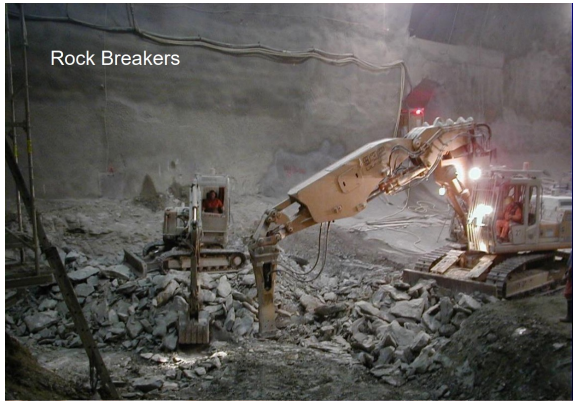
Positive conclusions:

The optics sensitivity of HL–LHC in the area of the FPF facility excavation works is about a factor of 10 smaller than in the triplet area, and a factor of 3 more than in the SPS optics. Vibration levels and associated impact on orbit stability and luminosity production are expected to be comparable to what was observed during HL–LHC civil engineering works during the LHC 2018 run. In case of excessive vibration levels, road headers might be employed instead of rock breakers. No major tunnel deformations are expected. If any, they could be compensated during the run with orbit correctors (at least for the HL–LHC) followed by re-alignment of the concerned area during a winter shutdown. The general conclusion is that no major disruption of HL–LHC and SPS performance is expected during the FPF excavation works.

Rock breakers



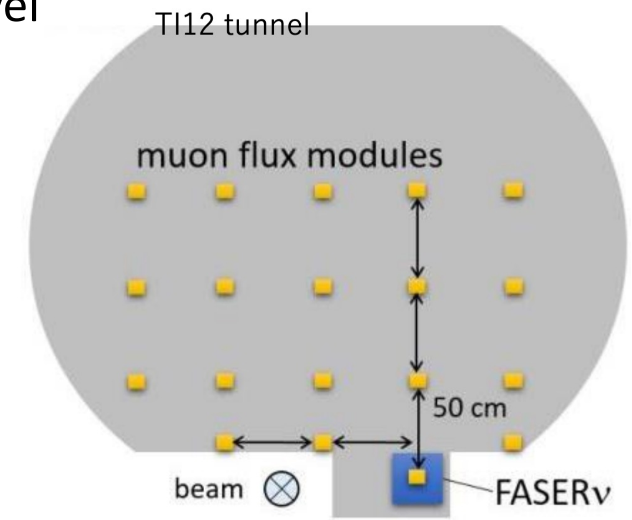
Road headers

As reported by Kincso – no issue seen during site investigation works.

Possible effect of long term slow movement of the tunnel still be evaluated.

Next Steps

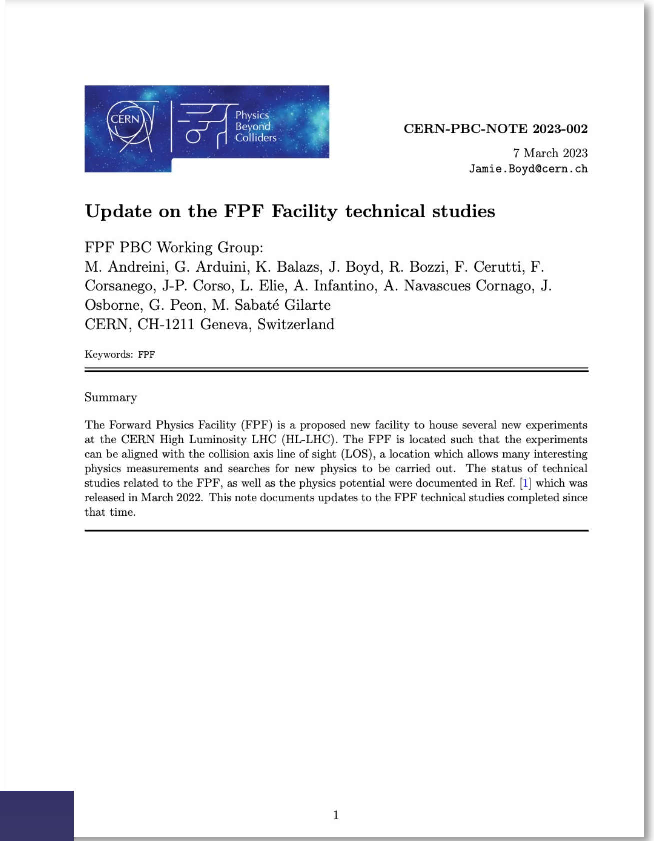
- Need to clarify technical infrastructure and services requirements of experiments and build this into design:
  - e.g. requirements on total electrical power, cranes, cooling, .. needs
- Progress on experiment footprint and location in cavern
  - Discussion later
- Background muons
  - Want to continue to pursue possible sweeper magnet options to reduce muon fluence on LOS
    - Need new ideas to look at
  - FASER experiment working on benchmarking FLUKA and BDSIM simulations of muon fluence up to 1.5m away from LOS for Run 3 LHC setup using dedicated emulsion measurements
    - Muon fluence on LOS validated by FASER/SND@LHC at the ~30% level



Summary

- Updates to technical studies related to the facility documented in public PBC note released in March
  - Updated ventilation design (2.5MCHF rather than 7MCHF)
  - Detailed FLUKA muon flux estimate (~0.6Hz/cm^2 on LOS)
  - Sweeper magnet design studied not effective – new ideas needed
  - Neutron flux in cavern should not be a problem for experiments
  - RP studies show access to cavern during beam operation should be OK for RP classified works, with some local restrictions and partial occupancy
    - Relevant for excavation workers if during beam operation
- Study of effect of excavation on beam operation documented in IPAC paper
  - Generally positive
- Some useful material available on FPF eos space:
  - FLUKA muon spectra
  - BDSIM muon spectra

  /eos/experiment/fpf-sim/
  - The 3D model of the FPF cavern is also available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Update on the FPF Facility technical studies

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CERN, CH-1211 Geneva, Switzerland

Keywords: FPF

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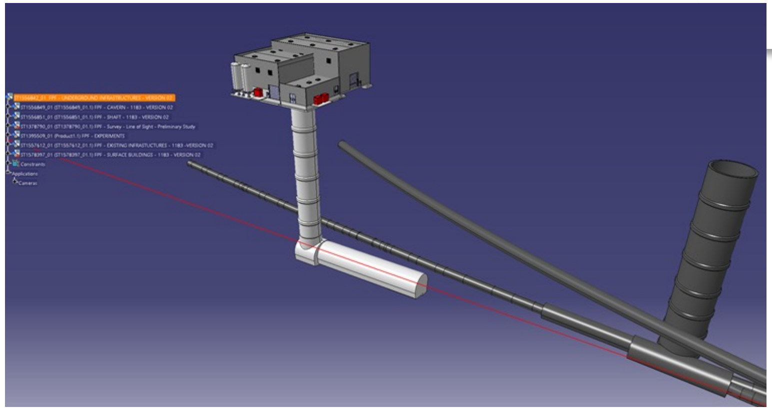
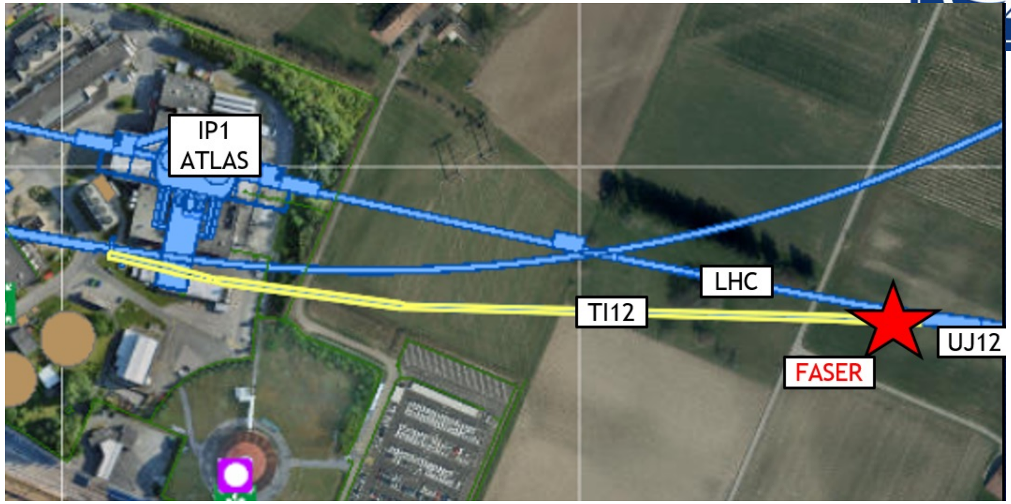
1

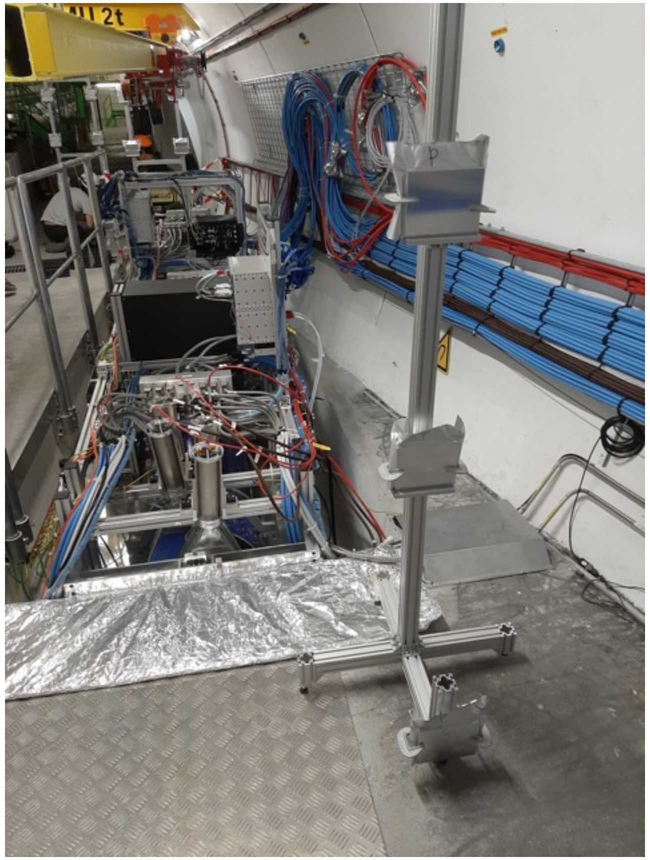


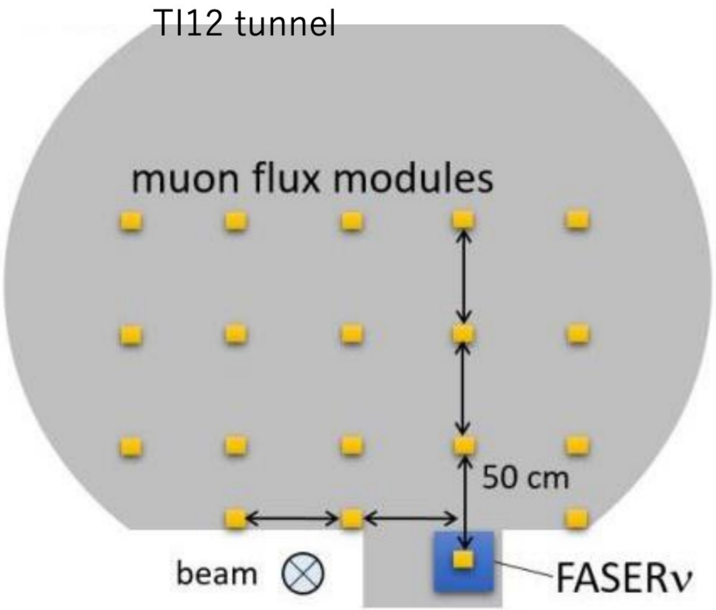
Backup…

Muon fluence measurements at FASER

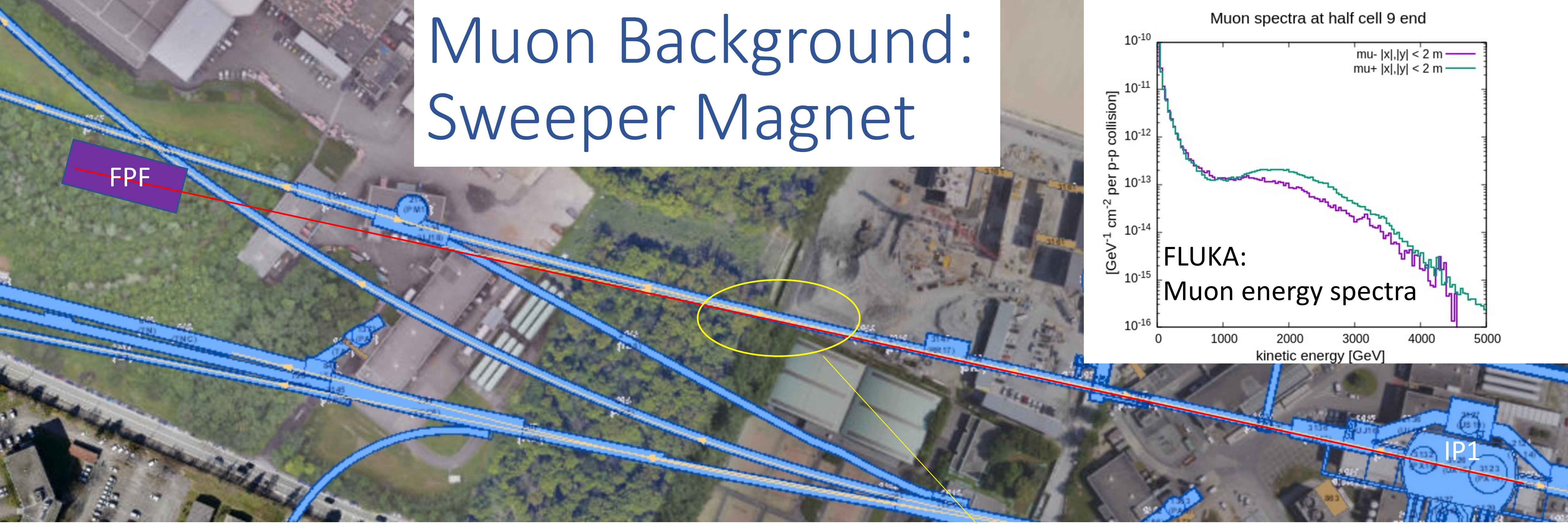
19 small emulsion detectors installed around FASER to measure the muon flux. Installed in LHC tunnel 26/7 - 14/8, exposure to 10/fb of collision data. The emulsion films have been developed and are undergoing scanning/analysis. First results should become available soon.

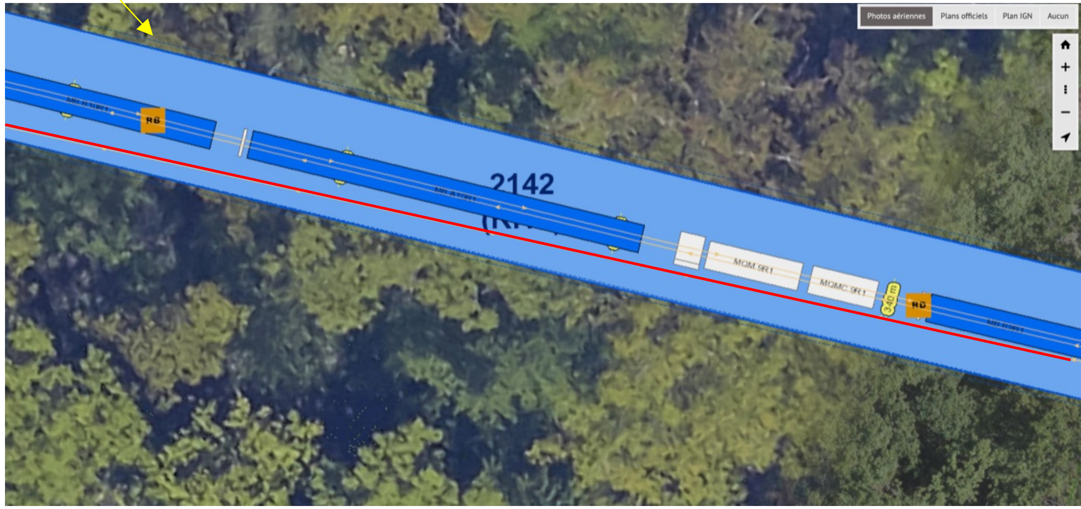






Muon Background: Sweeper Magnet





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).

Radiation Areas classification

EDMS 810149

Area	Annual dose limit (year)	Ambient dose equivalent rate: permanent occupancy	Ambient dose equivalent rate: low occupancy	Sign (RADIATION)
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