FPF PBC Working Group Status

FPF4 workshop

31/1/22

Jamie Boyd (CERN)

The PBC at CERN

The Physics Beyond Colliders Study Group

Overview

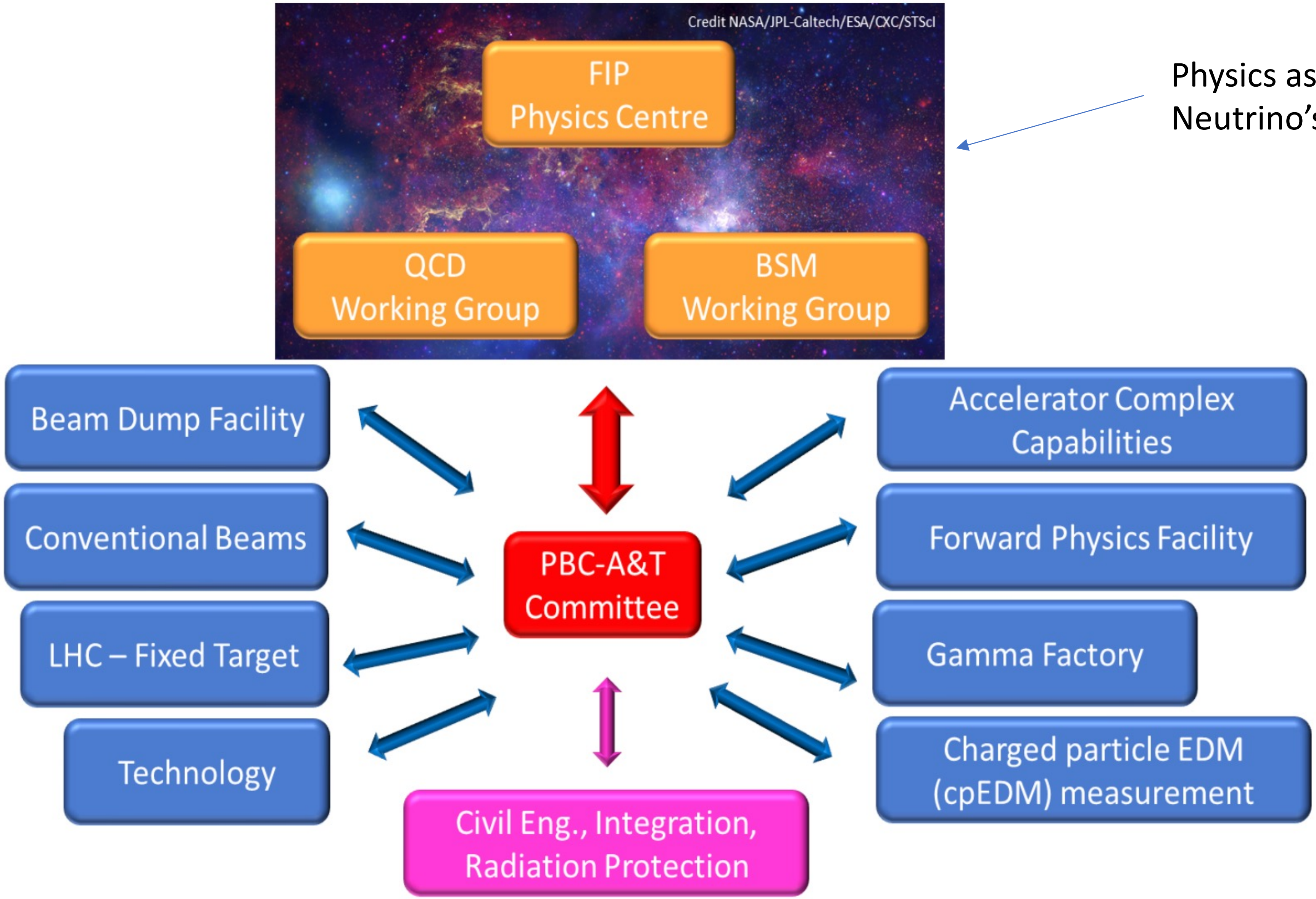
Physics Beyond Colliders (PBC) is an exploratory study aimed at exploiting the full scientific potential of CERN's accelerator complex and technical infrastructure, as well as its know-how in accelerator and detector science and technology. PBC projects complement the goals of the main experiments of the Laboratory's collider programme. They target fundamental physics questions that are similar in spirit to those addressed by high-energy colliders, but require different types of beams and experiments. The PBC mandate is available **here**.

Organization

The kick-off workshop held in September 2016 identified a number of areas of interest. Working groups have been set-up to pursue studies in these areas. See '**Organization**' for a detailed breakdown of the current structure.

Full mandate can be seen here: https://pbc.web.cern.ch/mandate
The PBC is chaired by: G. Arduini (CERN) (accelerator), C. Vallee (IN2P3) (experiment), J. Jaeckel (Heidelberg) (theory)

The PBC Projects



Physics aspects of the FPF discussed here:
Neutrino's mostly discussed in the QCD WG

Technical aspects on the FPF discussed here https://pbc.web.cern.ch/fpf-mandate

Forward Physics Facility

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.

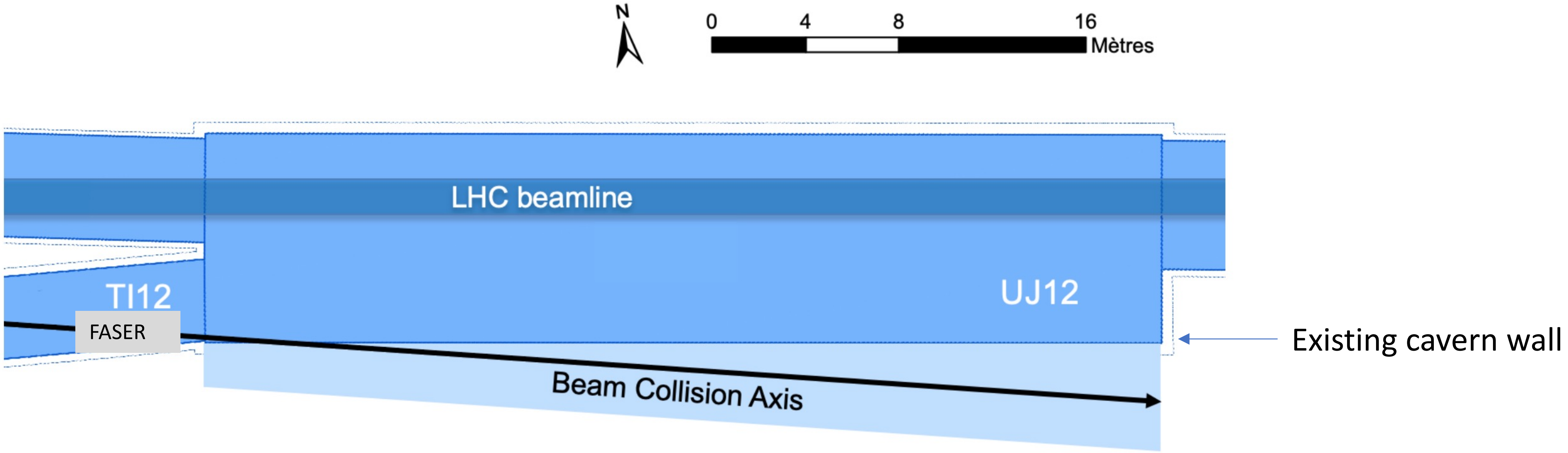
Working Group Core Members

Convener: Jamie Boyd

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

First idea:

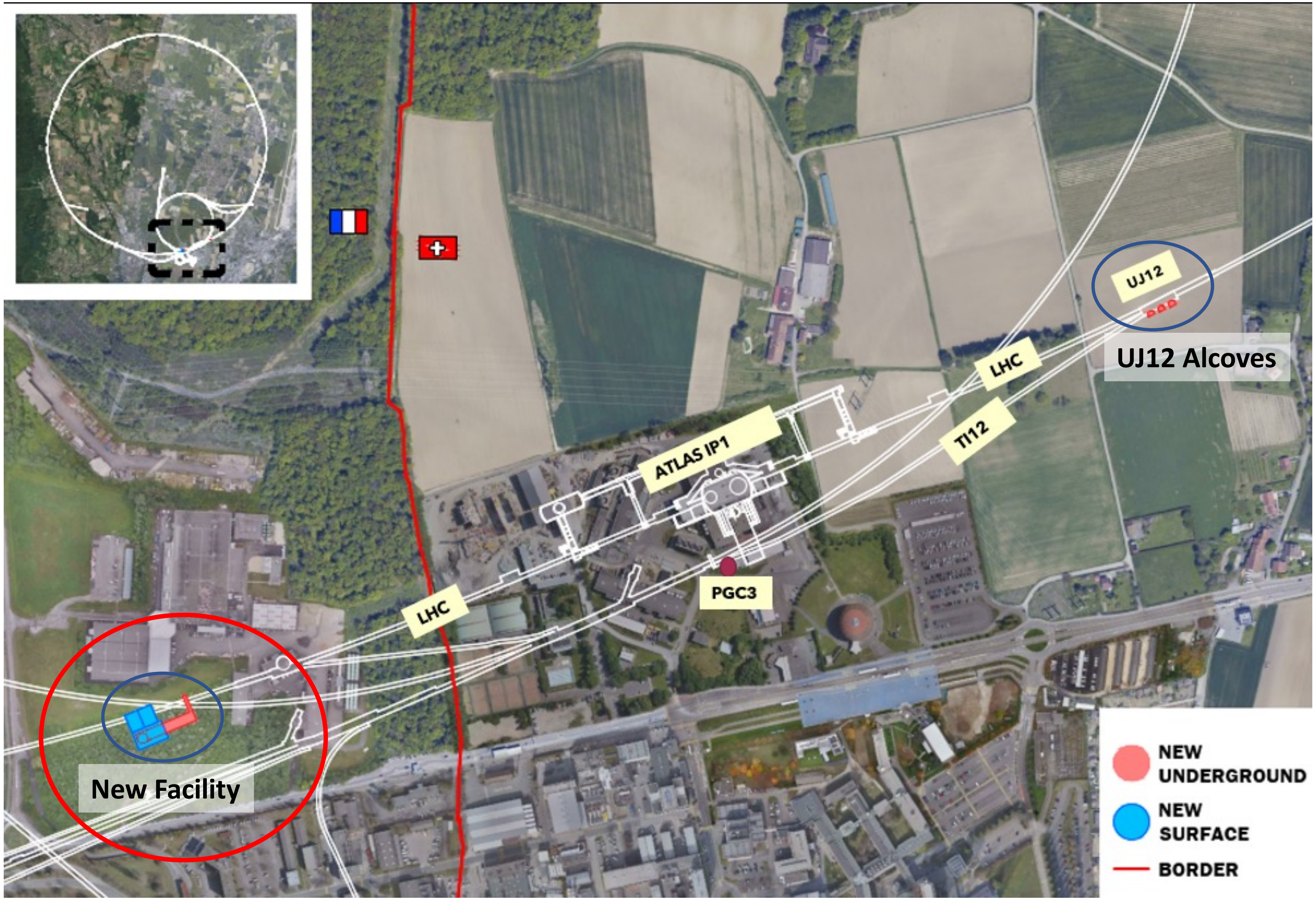
Widen UJ12 cavern by 2-4m to allow ~50 area for experiments to be installed along the LOS



Not possible from civil engineering side.

Impossible to get sufficiently large excavation machine here, without dismantling ~500m of the LHC machine.

After several studies by CERN civil engineering team, the baseline option is a dedicated new facility ~600m from the ATLAS IP (to the west).



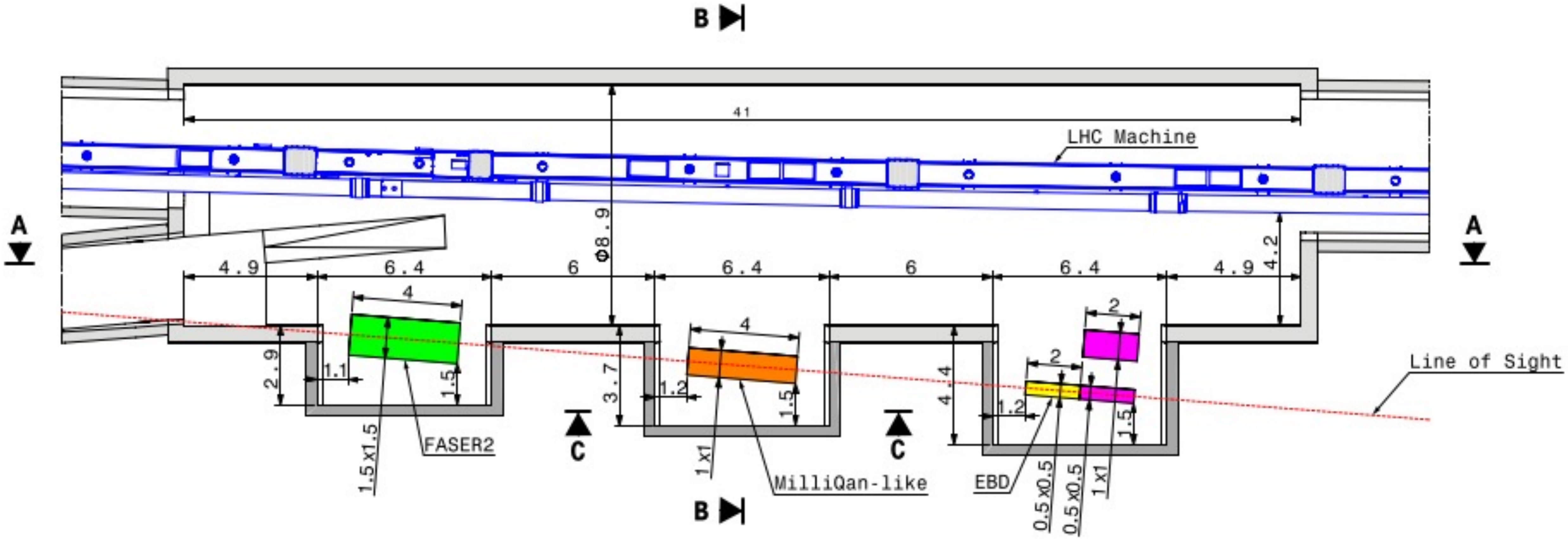
Alcoves in UJ12 cavern considered as an alternative option, but not retained.

K. Balazs, J. Osborne, J. Gall - CERN SCE

K. Balazs, J. Osborne, J. Gall - CERN SCE

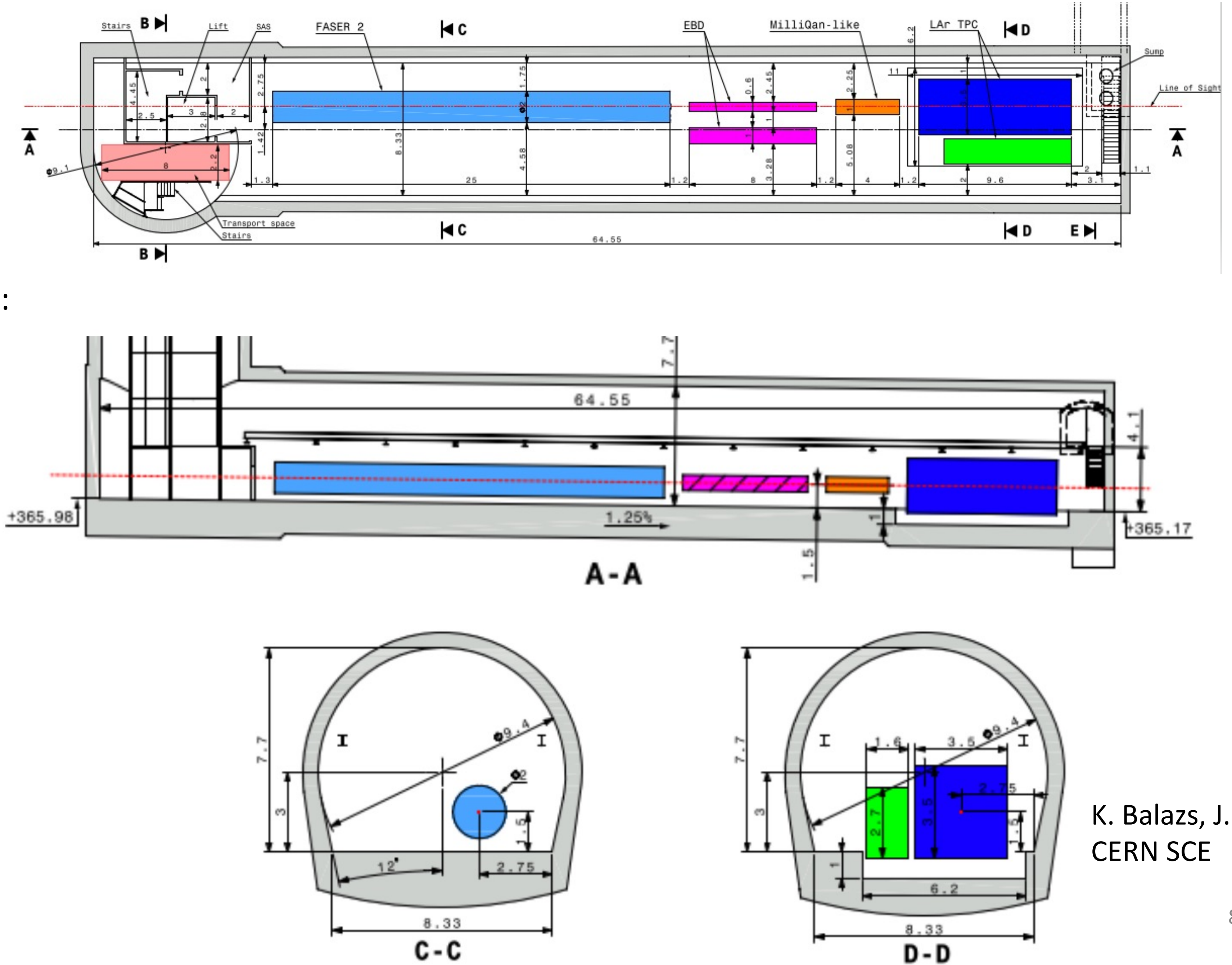
UJ12 Alcoves

Three ‘alcoves’ in UJ12 cavern wall, would allow some more room on the LOS for experiments.
For works the full UJ12 area would need to be emptied out (LHC magnets, QRL, EN-EL/CV equipment etc…).
Seems possible but significant work.
Background / radiation from beamline may be problematic for experiments.



New Facility:

65m long, 8m wide/high cavern
Connected to surface through
88m high shaft (9.1m diameter):
612m from IP1.



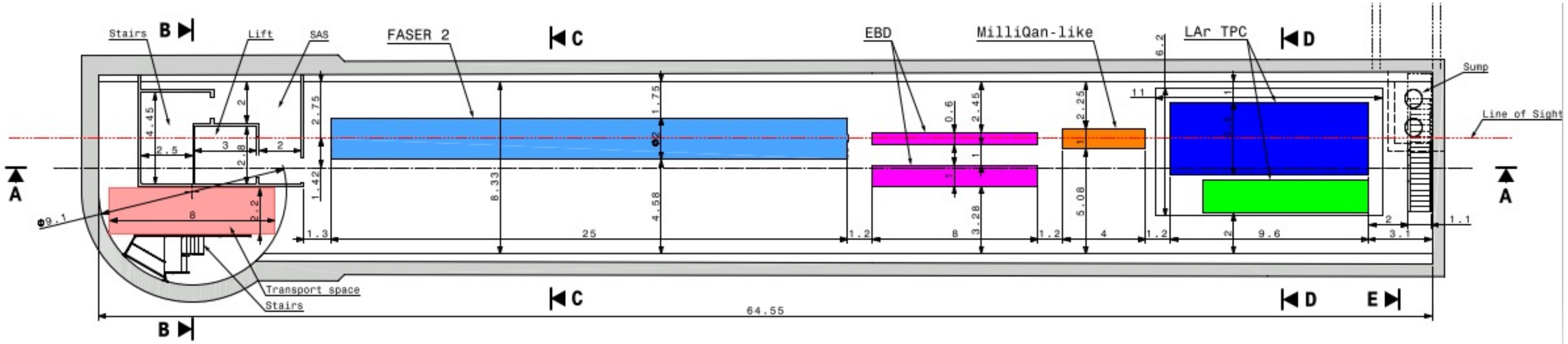
K. Balazs, J. Osborne
CERN SCE

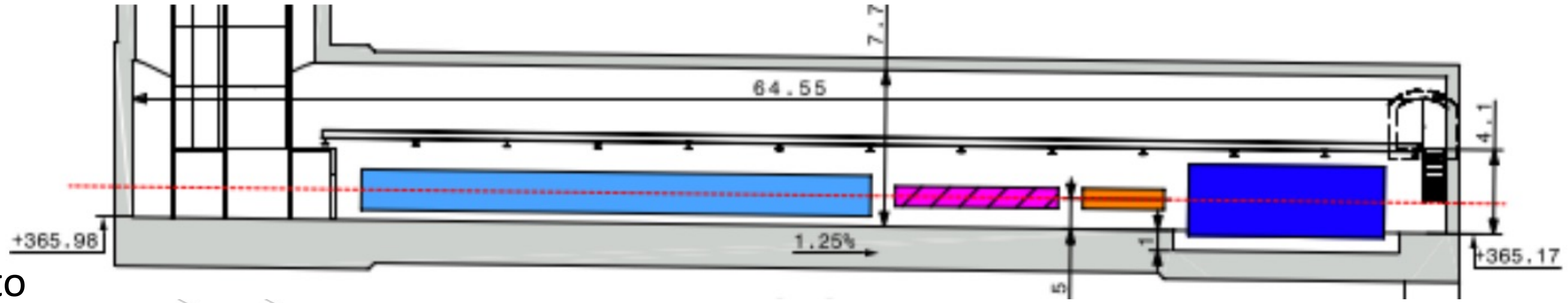
New Facility:

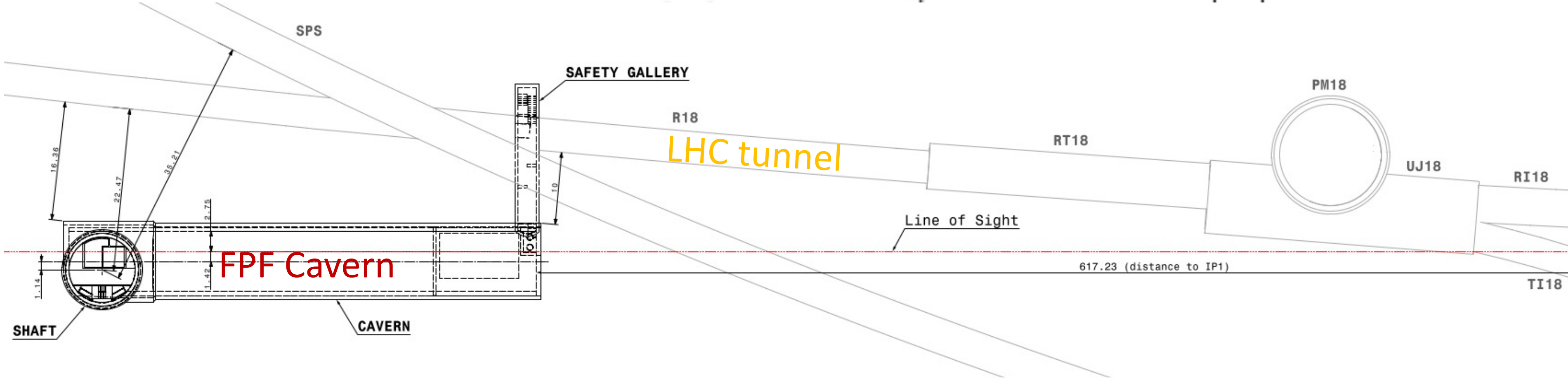
65m long, 8m wide/high cavern
Connected to surface through 88m high shaft (9.1m diameter): 612m from IP1.

New cavern >10m from LHC tunnel. Should mean that can access cavern during LHC operations – RP study ongoing to confirm this.

Connection (safety gallery) from cavern to LHC for emergency evacuation.

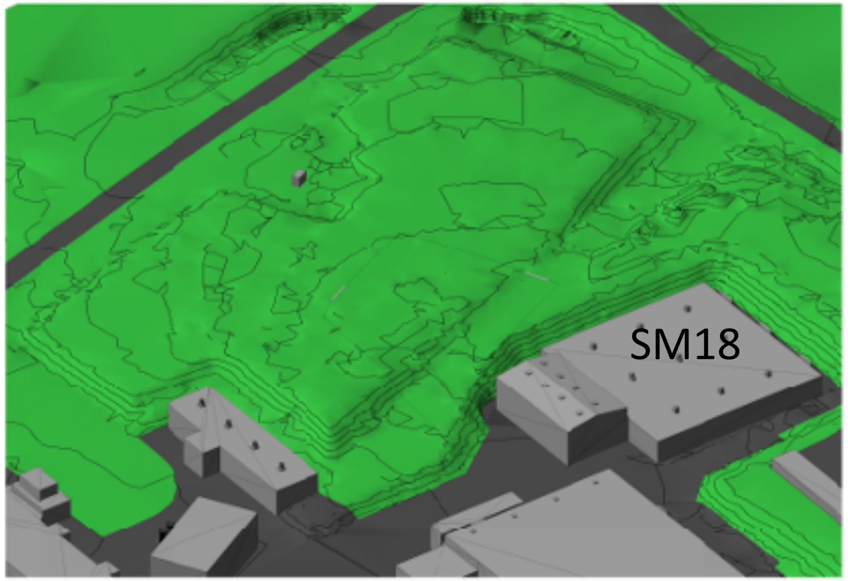




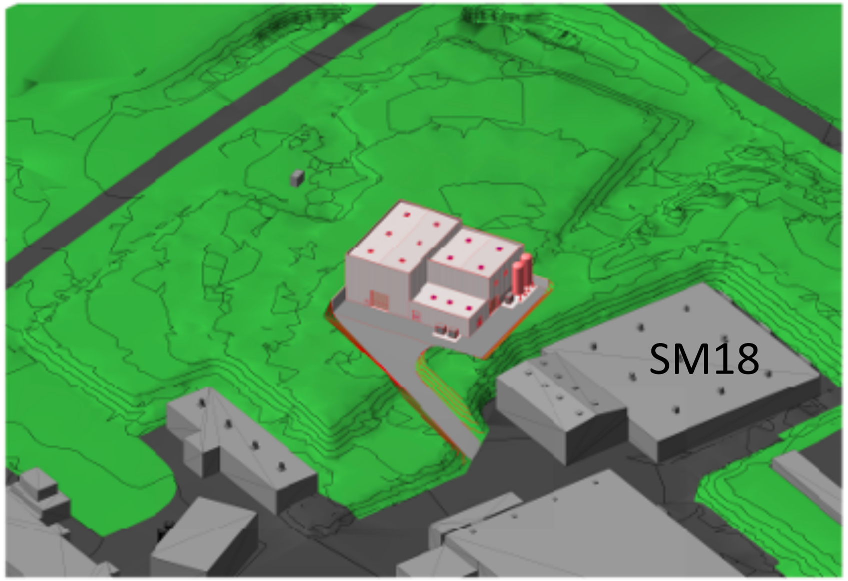


New Cavern: Surface works

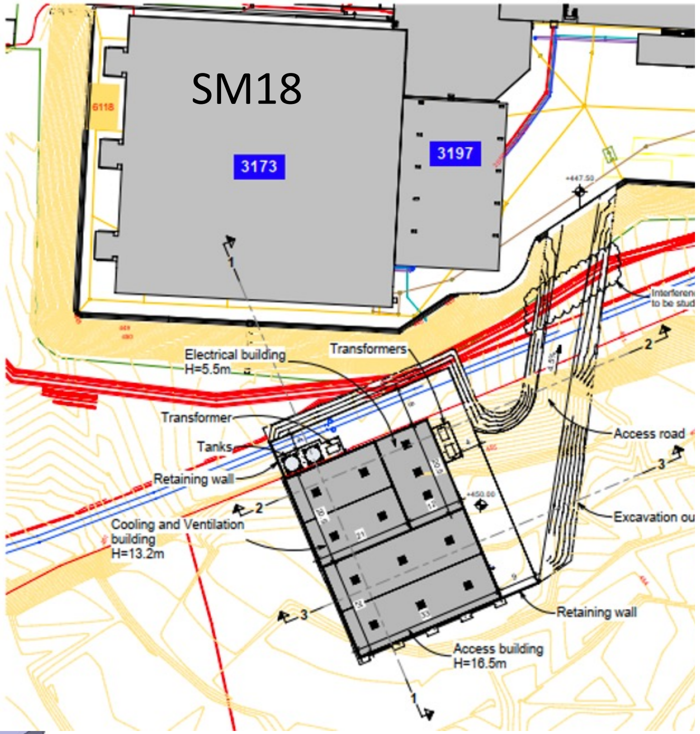
K. Balazs, J. Osborne

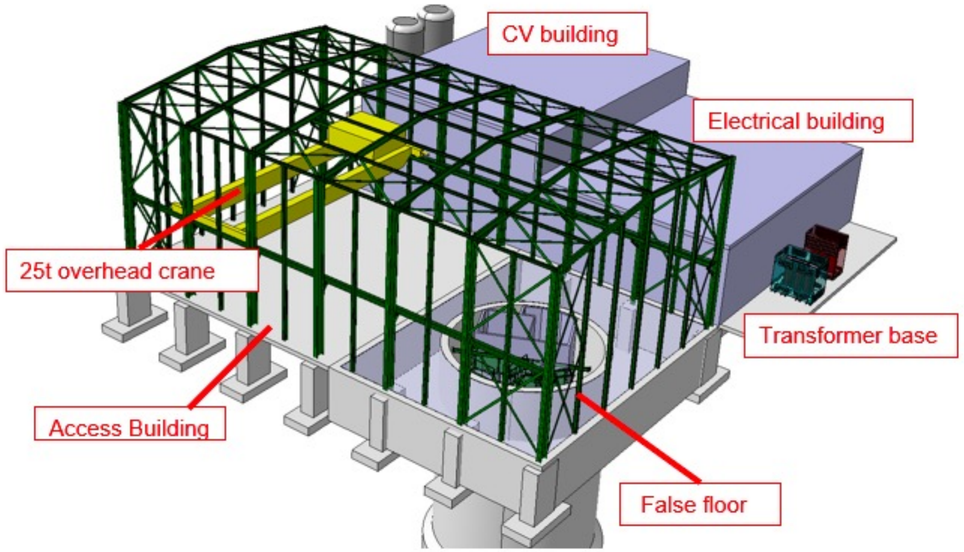


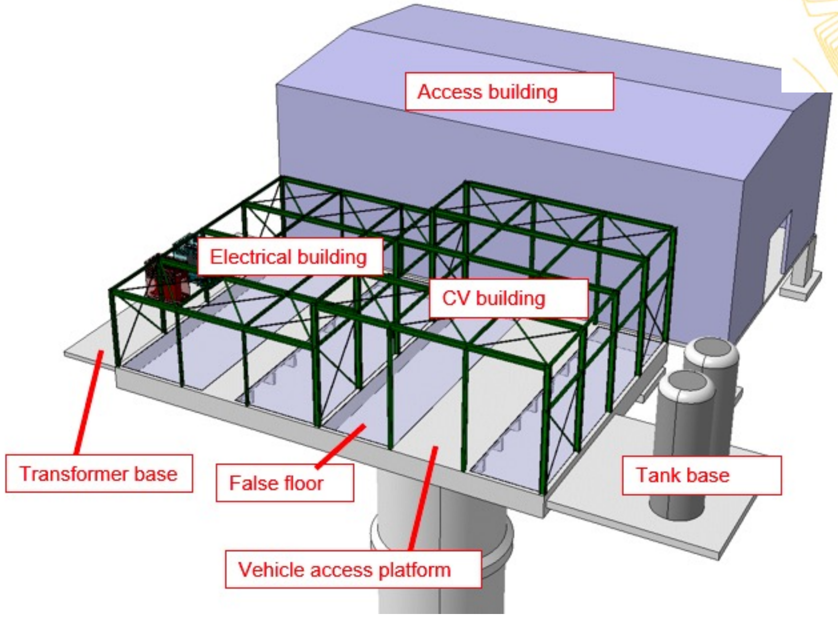
3D EXISTING



3D NEW

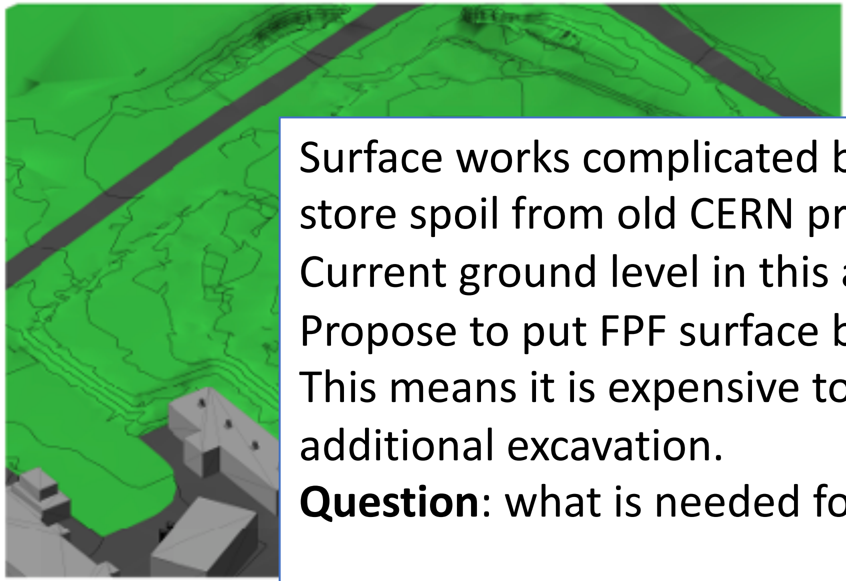




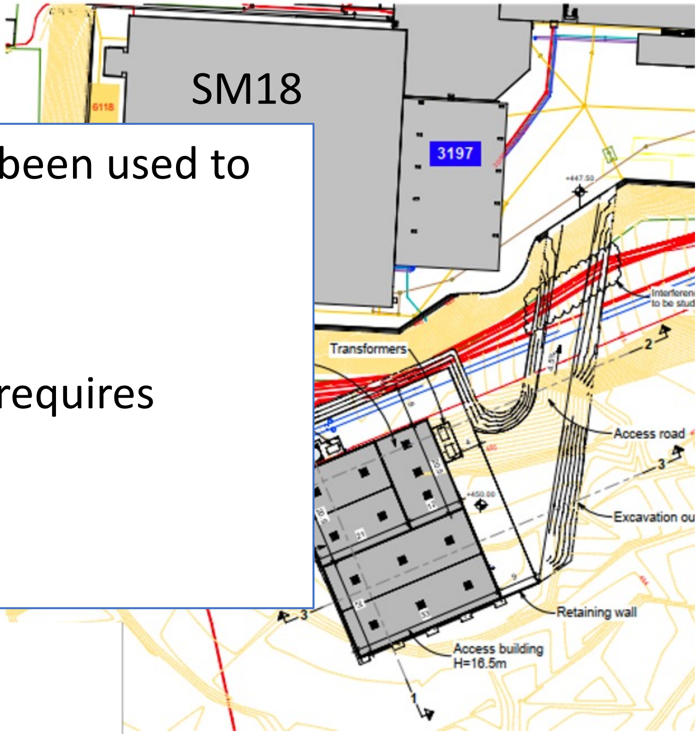


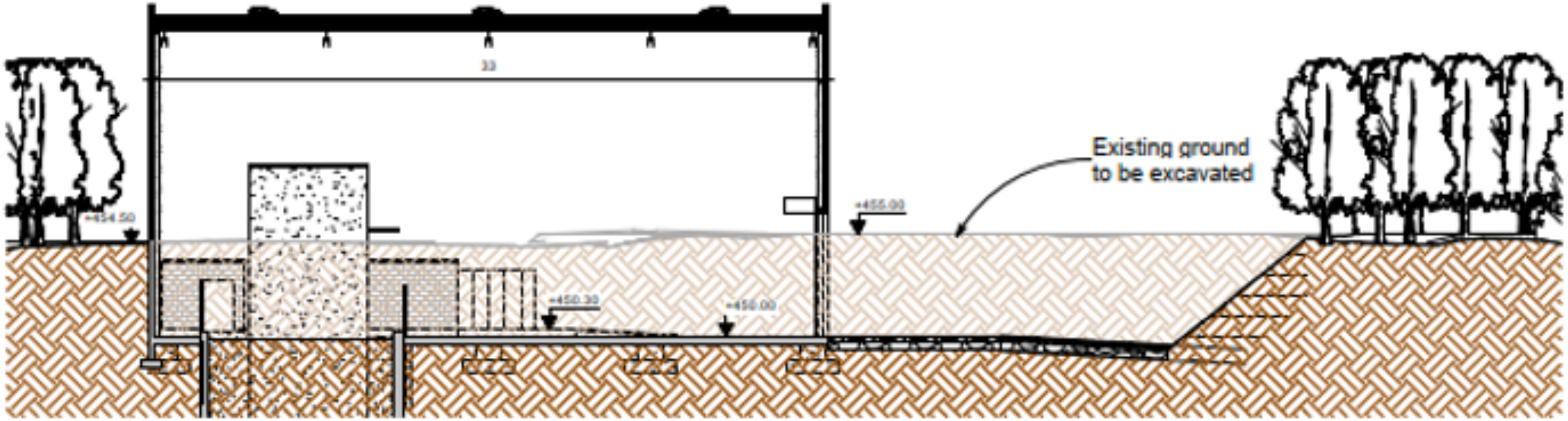
New Cavern: Surface works

K. Balazs, J. Osborne



Surface works complicated by the existing ground conditions, as this area has been used to store spoil from old CERN projects.
Current ground level in this area is at 453-457m above sea level.
Propose to put FPF surface buildings at 450m above sea level.
This means it is expensive to increase the size of the surface buildings, as this requires additional excavation.
Question: what is needed for experiment control rooms on surface?





SECTION 3-3
Sc. 1 : 200

K. Balazs, J. Osborne
CERN SCE

First costing of CE works & services

- Preliminary costing of civil engineering works for the two options
- Based on comparative costing to similar projects:
  - SPS Dump Facility Tunnel eye enlargement as reference point for UJ12 alcoves
  - 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 13MCHF for UJ12 alcoves, 23MCHF for new cavern
- Additional cost for services ~15MCHF for new cavern (see backup), much less for UJ12 alcoves
- **Total cost: ~40MCHF (new cavern), ~15MCHF (UJ12 alcoves)**

Costing of Services (New Facility)

Item	New Cavern (kCHF)	Comments / Reference
EN-EL	1,500	2MVA power EDMS 2588617 (M. Lonjon (EN-EL)) (800k added to account for civil engineering for links from SE18 (1.5m under ground))
Ventillation	7,000	Rough estimate from M. Battistin (EN-CV) based on HL-LHC installation
Access system + ODH + fire-safety + evacuation	2,500	Discussion in dedicated 'safety systems' meeting with EN-AA
Transport infrastructure	1,440	Shaft crane 25tn (570), Cavern crane 25tn(370), Lift (500) (From C. Bertone (EN-HE))
Total	**~12.5 MCHF**	

Based on previous projects these are expected to be the main cost drivers for services.

Contrasting the two options

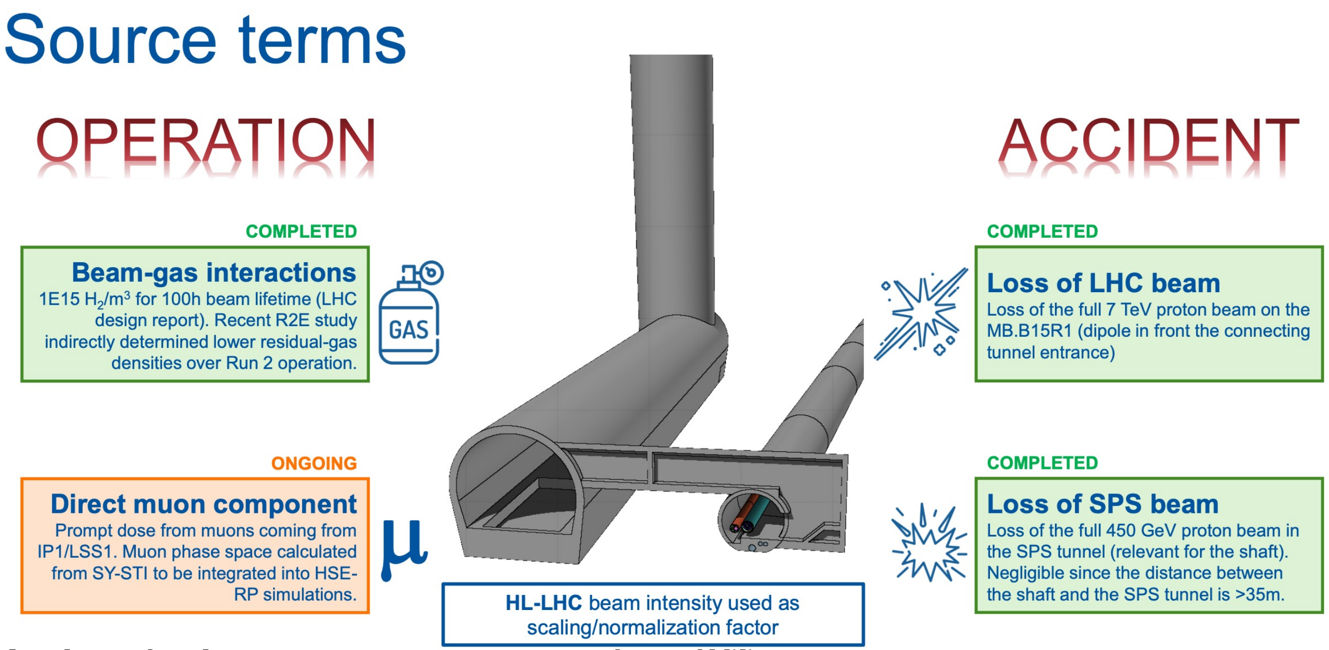
- UJ12 alcoves advantages:
  - Cost
- New Facility advantages:
  - No size constraints on the experiments
    - FASER2 physics would be much reduced if restricted to a 6m long alcove
  - New facility would allow a LAr based detector, not possible in LHC tunnel due to safety constraints
  - Access to the experimental area much easier for new facility option
    - Requirements on size/weight of apparatus for installation
    - Access for maintenance during beam operation (RP study ongoing – but looks possible)
  - Radiation and beam backgrounds negligible for separate cavern compared to UJ12 alcoves
  - Much of the excavation work and the installation of services/experiments could be done during LHC operations for the new facility – reducing possible schedule pressure during LSs

Given the only factor of ~2.5 difference in costs between the two options there is a strong preference from the physics side towards the new facility option.
This is now considered the baseline option!

L. Elie, A. Infantino, M. Maietta, H. Vincke (HSE-RP)

Radioprotecton (RP) Study

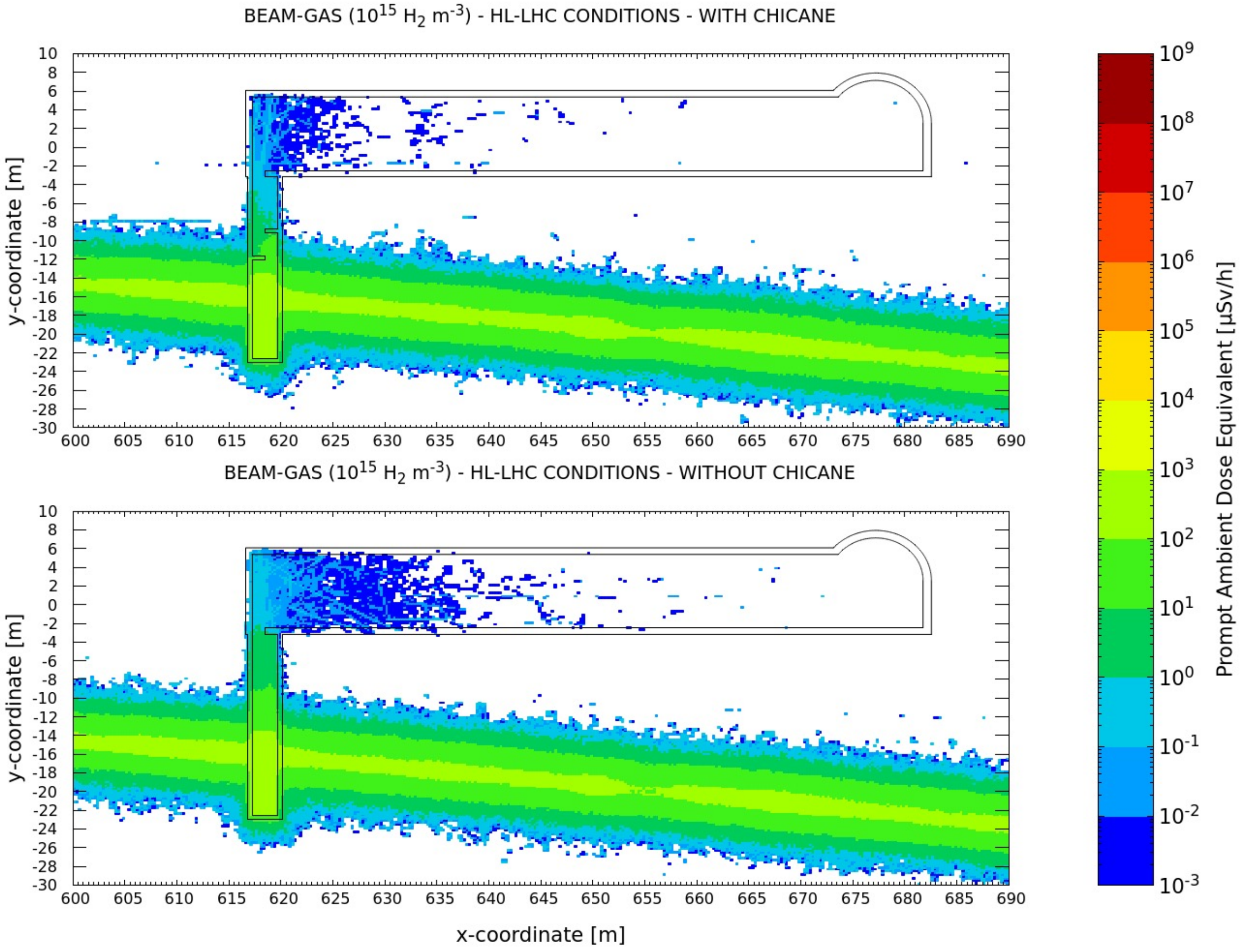
- An RP study has been carried out to assess if people can access the FPF cavern during HL-LHC operations which would be a significant benefit

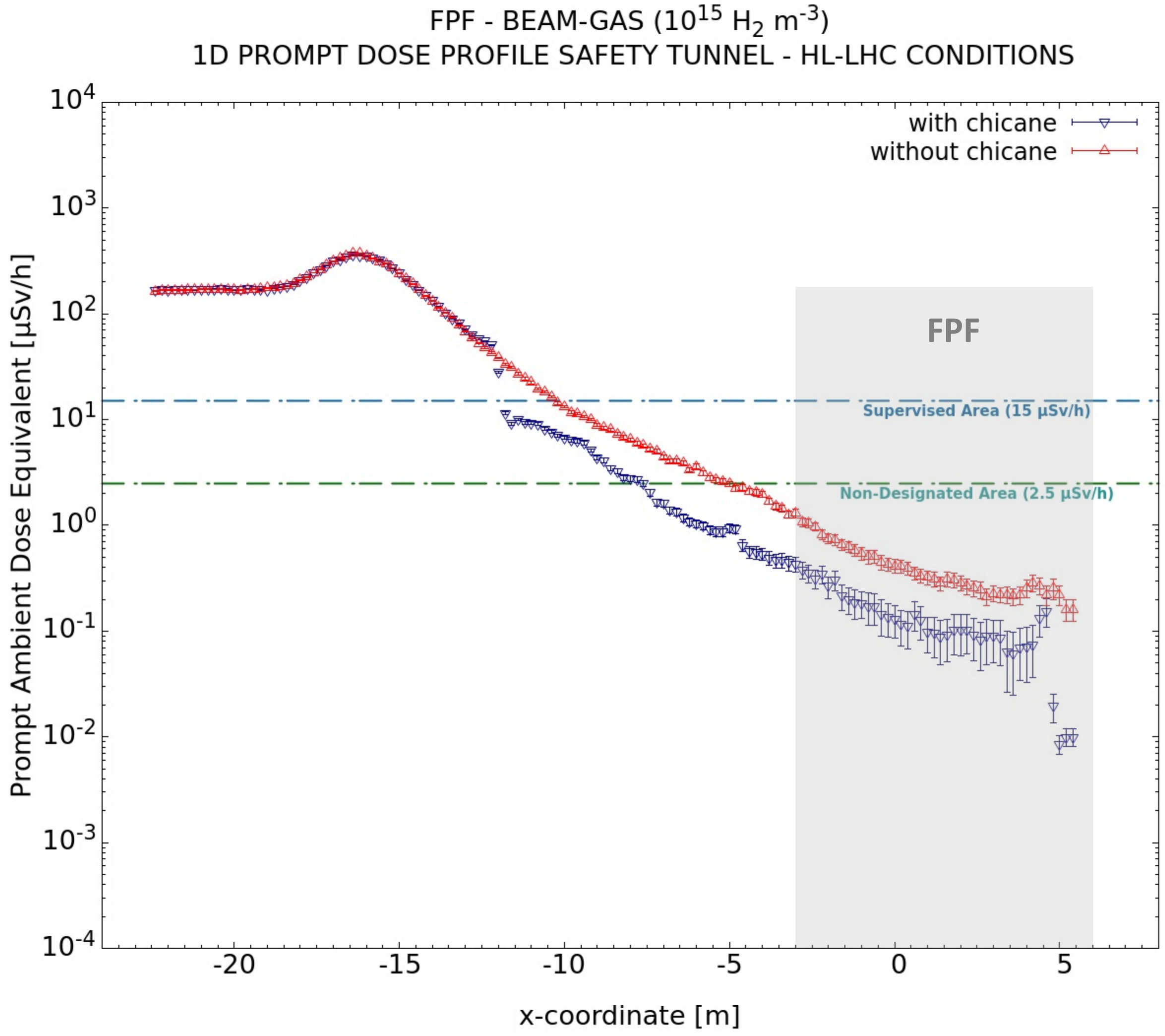


- Detailed FLUKA simulations run to assess the different components
  - SPS losses not a problem
  - Beam-gas not a problem
  - Accidental loss of full LHC beam in worst place – radiation level too high, updates to chicane in safety gallery being studied
  - Prompt muon dose – under study

L. Elie, A. Infantino, M. Maietta, H. Vincke (HSE-RP)

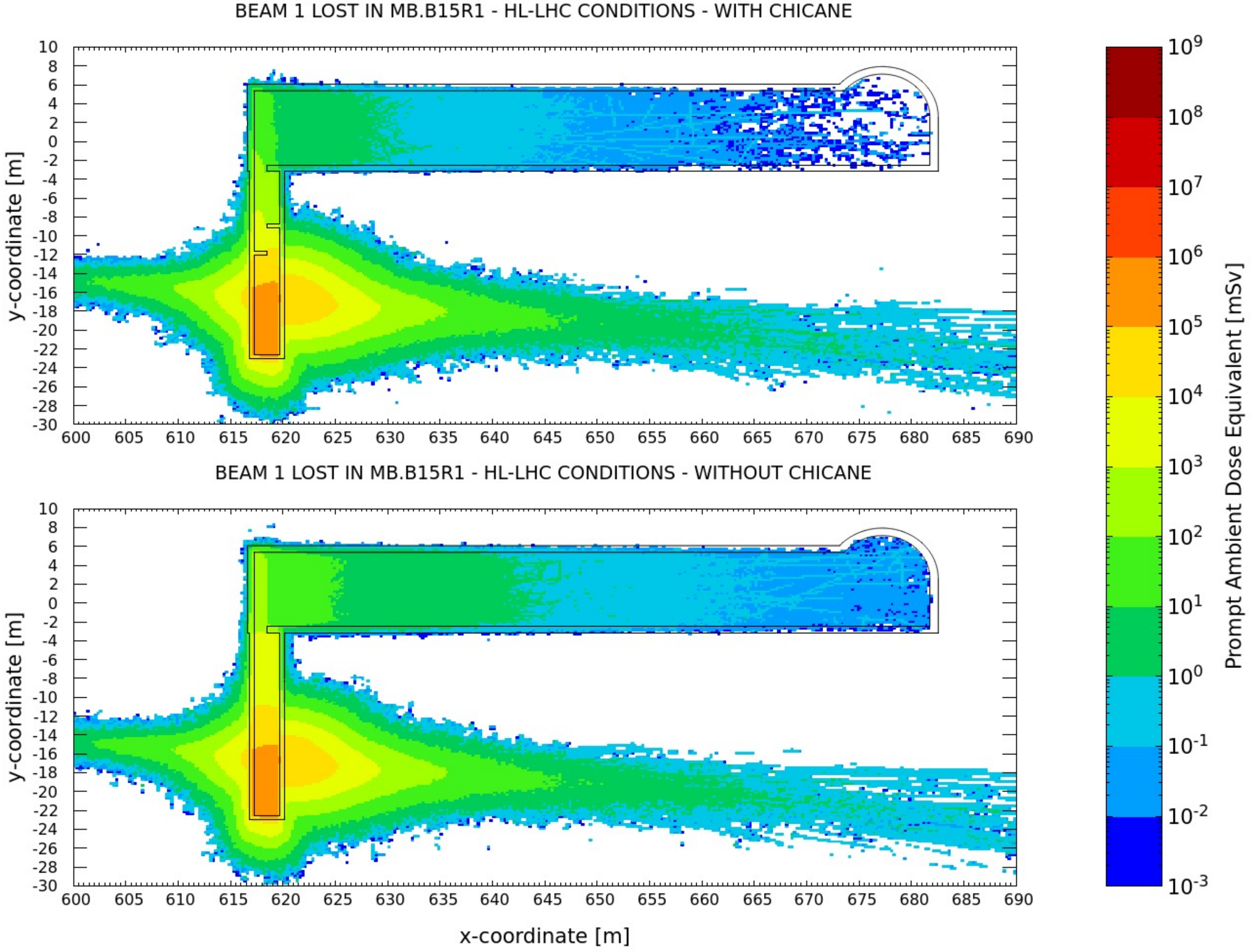
RP Study – beam gas

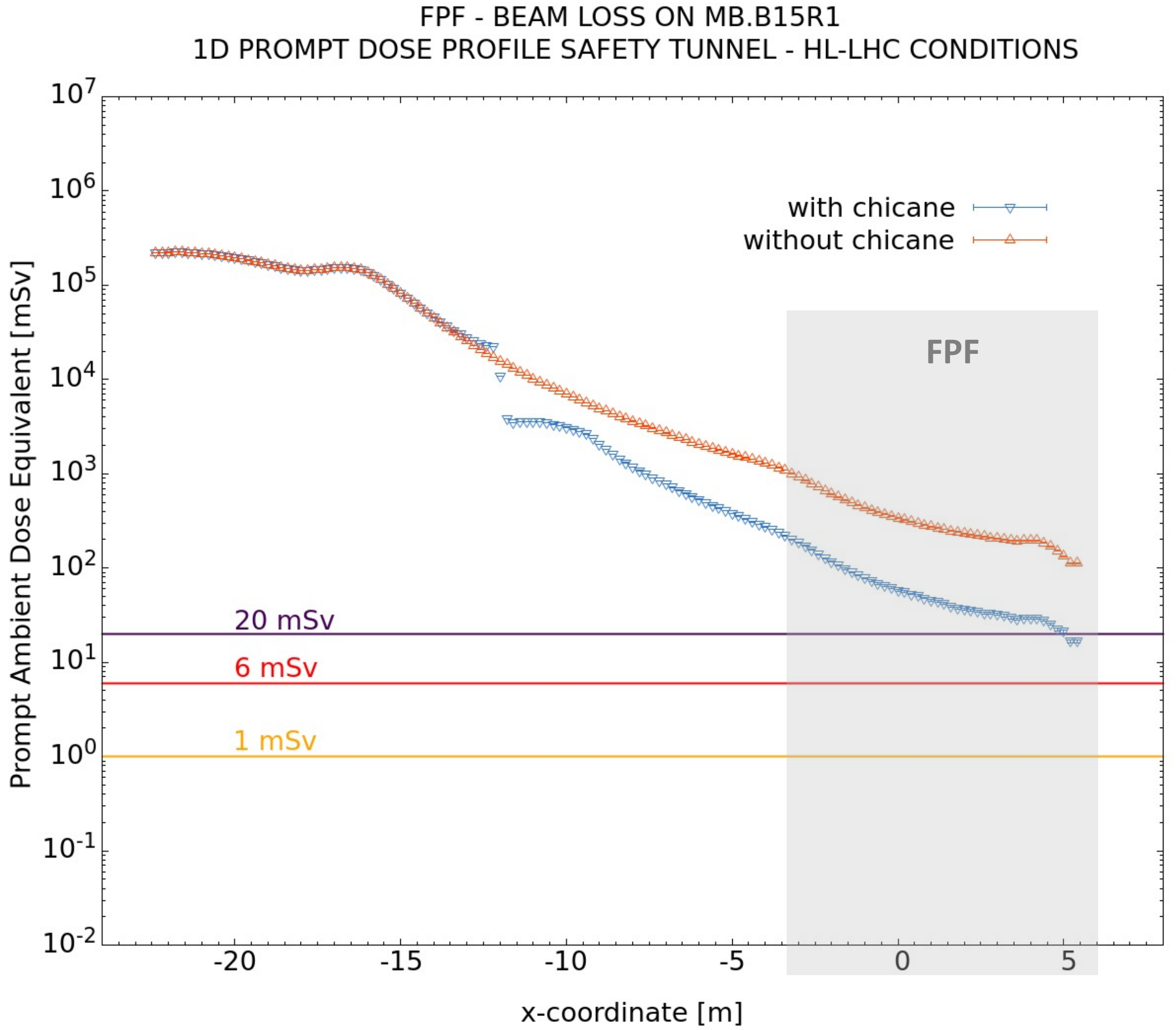




L. Elie, A. Infantino, M. Maietta, H. Vincke (HSE-RP)

RP Study – Accidental LHC beam loss



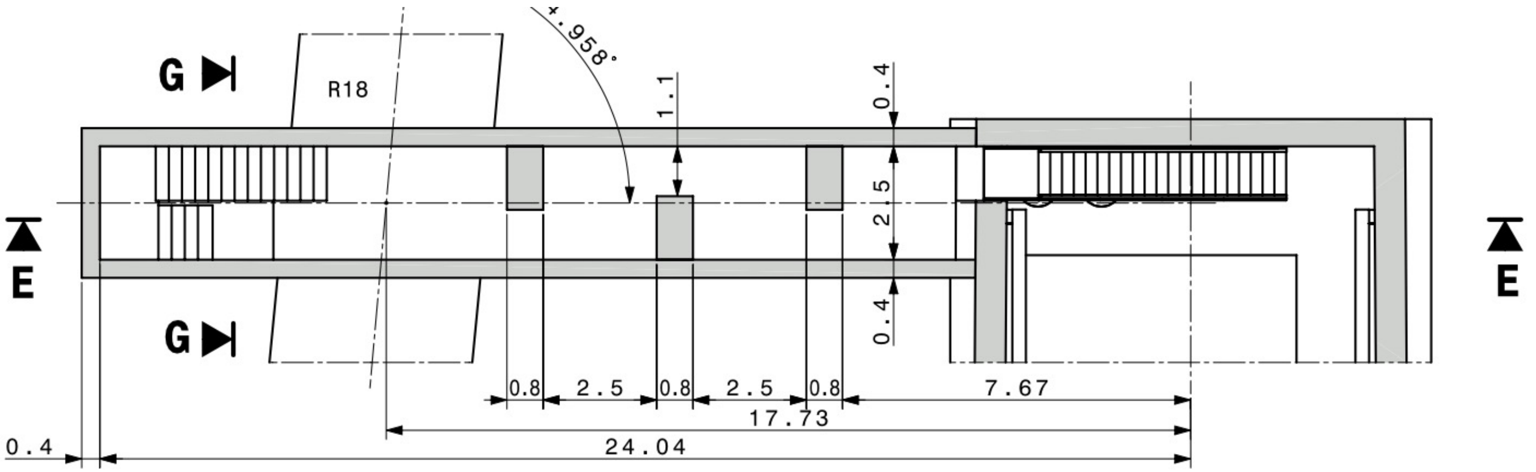


Chicane in safety gallery reduces the dose but not enough. Chicane being redesigned to address this (thicker/more walls)

M. Andreini, F. Corsanego, O. Deschamps, A. Infantino, K. Balazs, A. N. Cornago (HSE, RP, SE)

RP Study – Accidental LHC beam loss

- After a discussion with safety, CE and RP - Propose to:
  - Double thickness of walls in chicane (40cm -> 80cm)
  - Add additional wall
  - Reorder walls and increase their lengths
- RP Study to be redone with update chicane geometry to see if this will sufficiently reduce the dose in the cavern



Plan view - Safety gallery

M. Andreini, F. Corsanego, O. Deschamps, A. Infantino, K. Balazs, A. N. Cornago
(HSE, RP, SE)

RP Study – Accidental LHC beam loss

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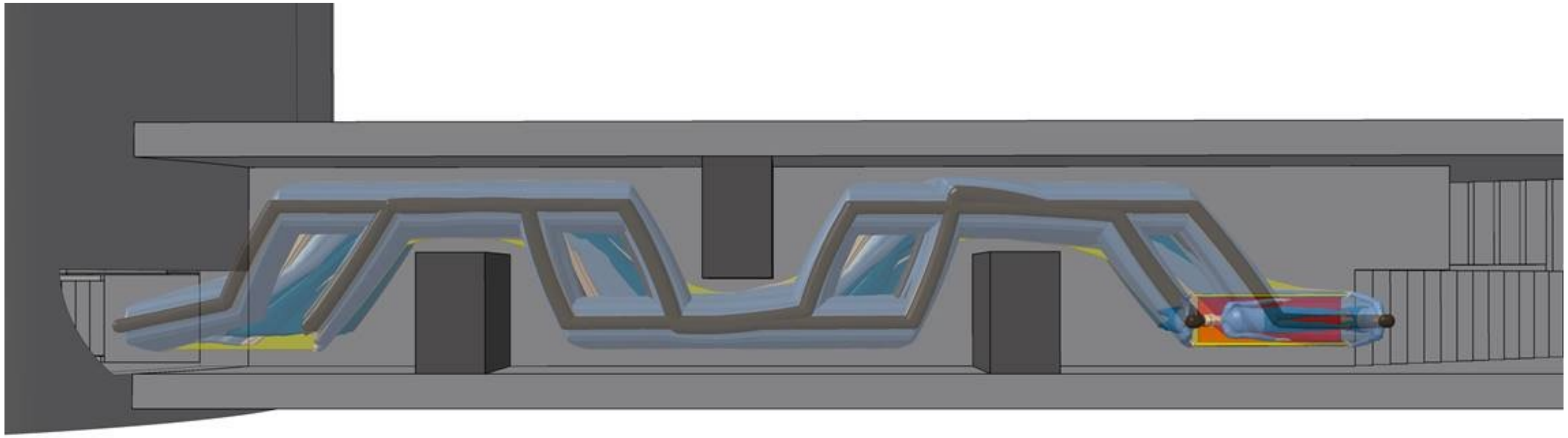
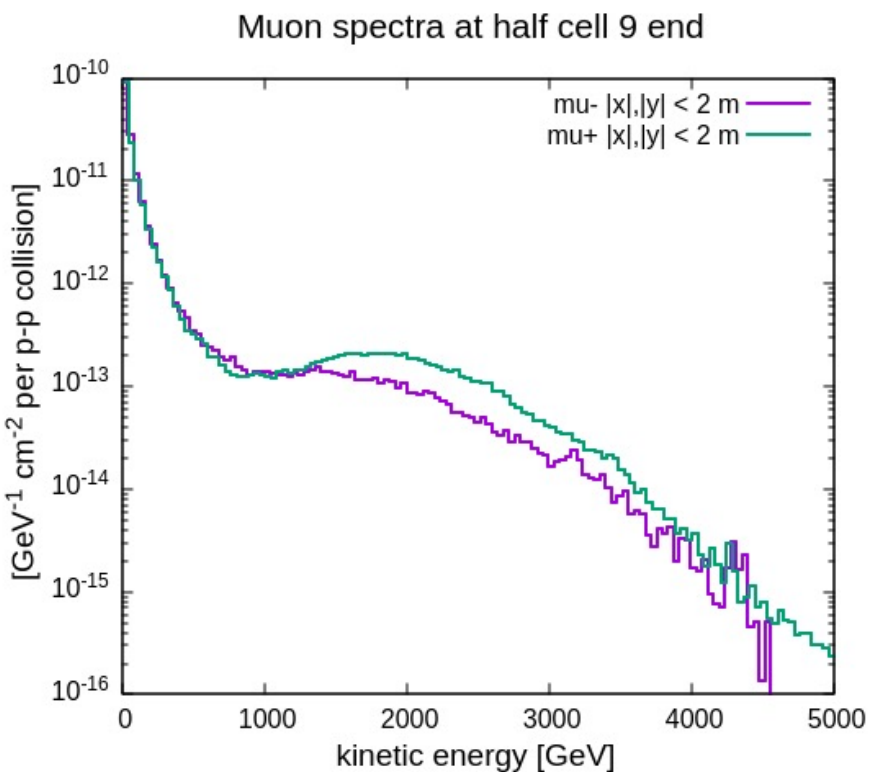


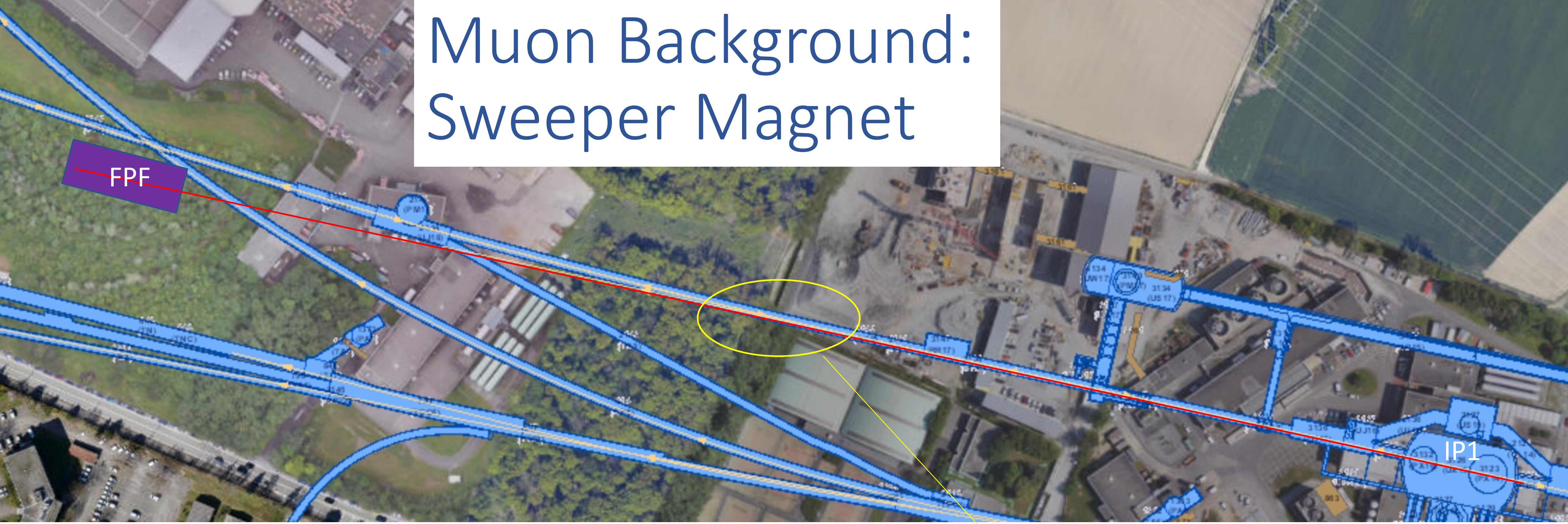
F. Cerutti, M. S. Gilarte (SY-STI)

FLUKA study of FPF background

- FLUKA team running simulations to estimate the expected (muon) background in the FPF
- Background rate important for:
  - Experiment design
  - RP study (dose from muons)
  - Study of sweeper magnet (see next slides)
- In order to study sweeper magnet ~400m from IP1, muon flux estimated in 4x4m^2 square around LOS at ~350m from IP1
- As a second step these muons will be propagated to the FPF (through ~250m of rock)
  - In progress…



Muon Background: Sweeper Magnet



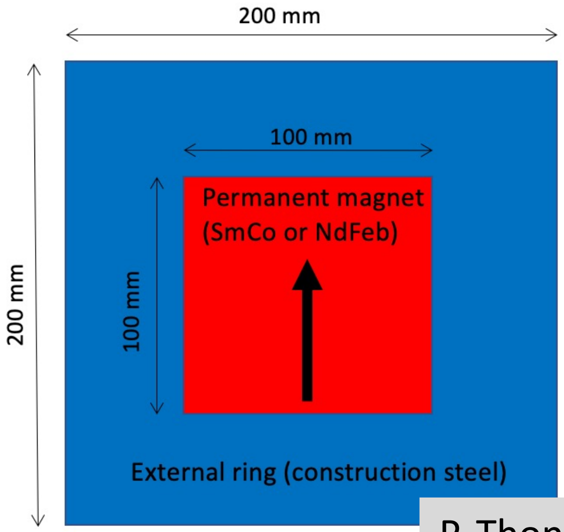
Background muons coming from IP1 collisions go through FPF (~1.5Hz/cm^2) on LOS, higher away from LOS.

Placing a sweeper magnet on the LOS can deflect these muons and reduce the background – which could be very important for physics - e.g. reducing the number of times emulsion would need to be replaced.

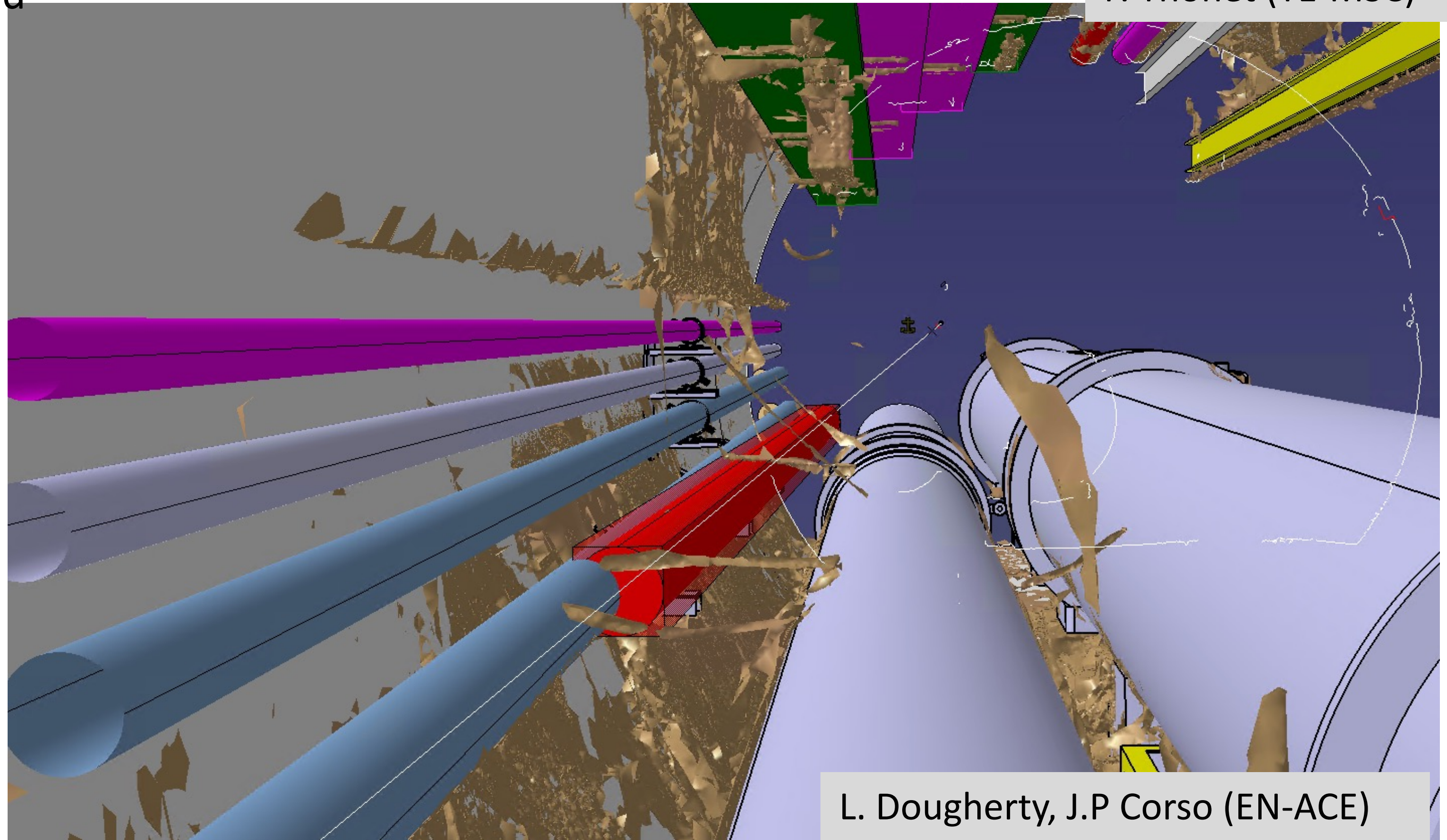
Best place for such a magnet would be between where LOS leaves LHC magnets and where it leaves the LHC tunnel (200m lever-arm for deflected muons).

Sweeper Magnet: Ongoing Studies

- Preliminary design of sweeper magnet by CERN magnet group
  - Based on permanent magnet to avoid power converter in radiation area
  - Consider 7m long (20x20cm^2 in transverse plane) magnet, 7Tm bending power
- To install such a magnet would require some modifications to cryogenic lines in relevant area
  - Possibility of modifications to be investigated with LHC cryo
  - Integration/installation aspects to be studied
- FLUKA and BDSIM studies ongoing to assess effectiveness of such a magnet in reducing the muon background in the FPF



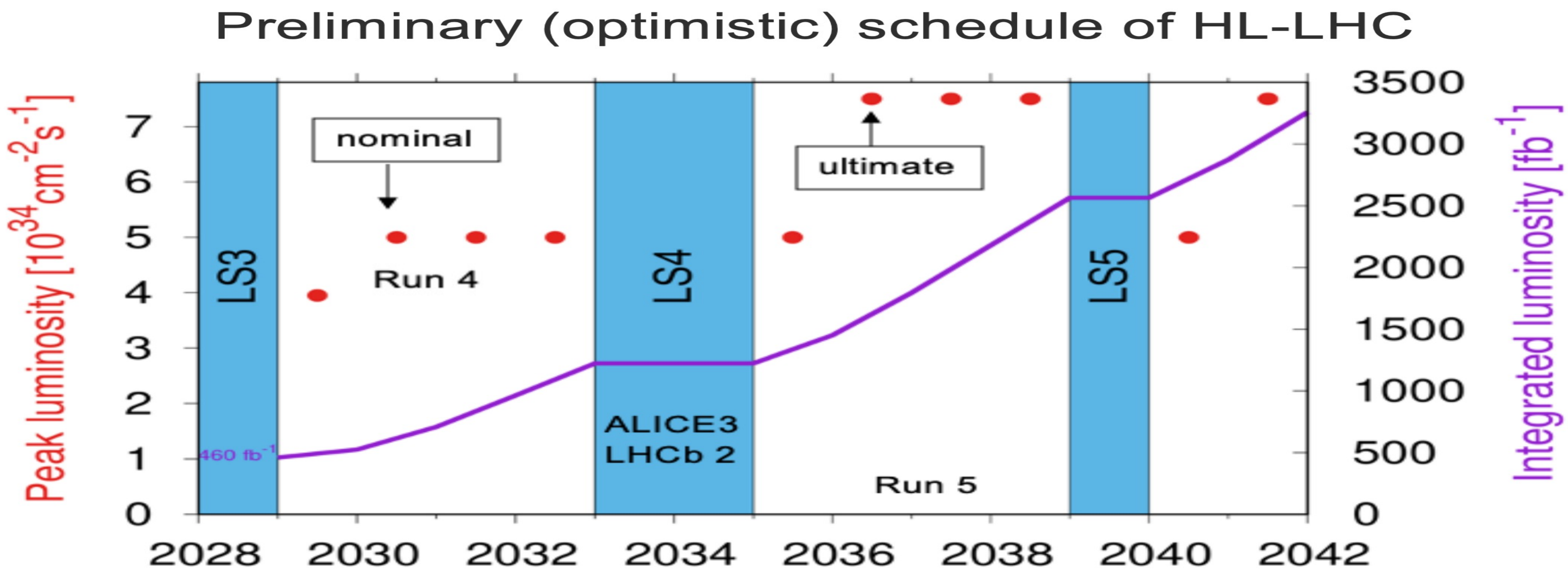
P. Thonet (TE-MSC)



L. Dougherty, J.P Corso (EN-ACE)

Possible FPF schedule

HL-LHC schedule from DG presentation, New-Year (on-line) meeting, 13/1/22



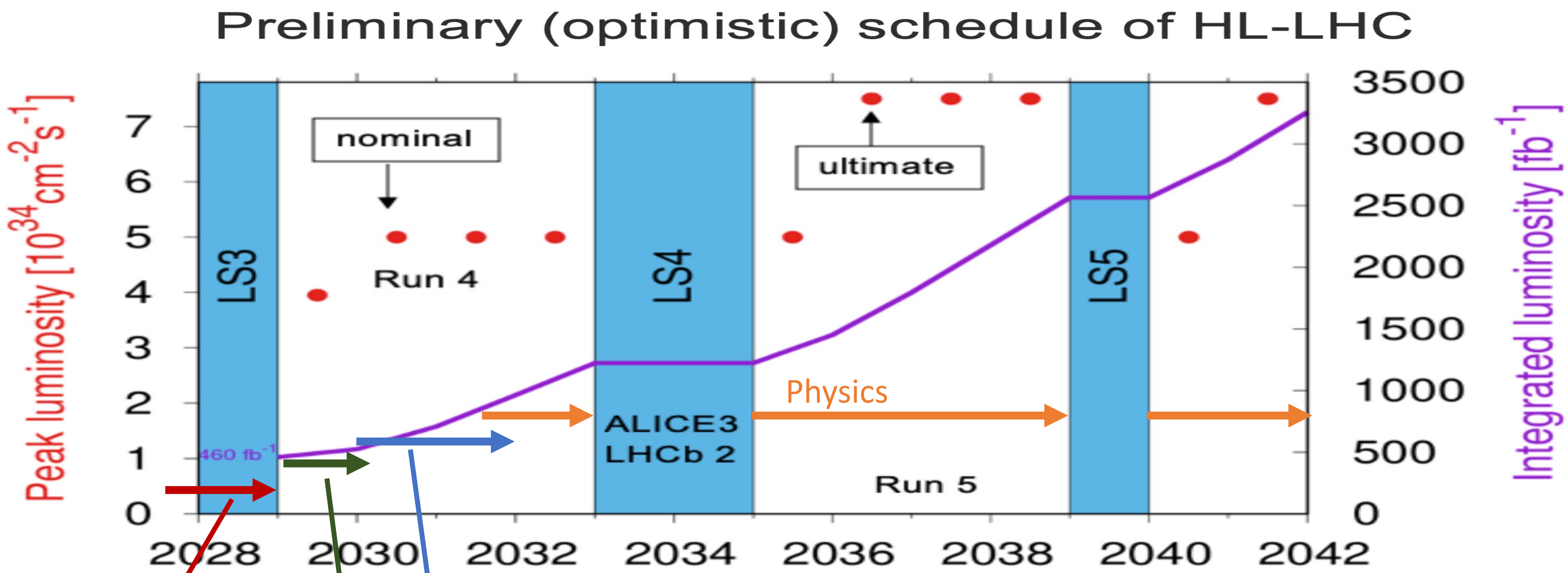
(HL)-LHC schedule recently updated to take into account time needed to prepare for HL-LHC (bot machine and experiments):

- Run 3 extended by 1 year (now 22-25)
- Long shutdown 3 (LS3) now 3 years (from 2.5) (now 26-28)

It is not yet clear if these extensions translate to extending the running period of the HLC-LHC – this would likely be decided at the next European Strategy.

Possible FPF schedule

HL-LHC schedule from DG presentation, New-Year (on-line) meeting, 13/1/22



Pure CE works (including connection to LHC)

Installation and commissioning of the experiments

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

Such a schedule would:

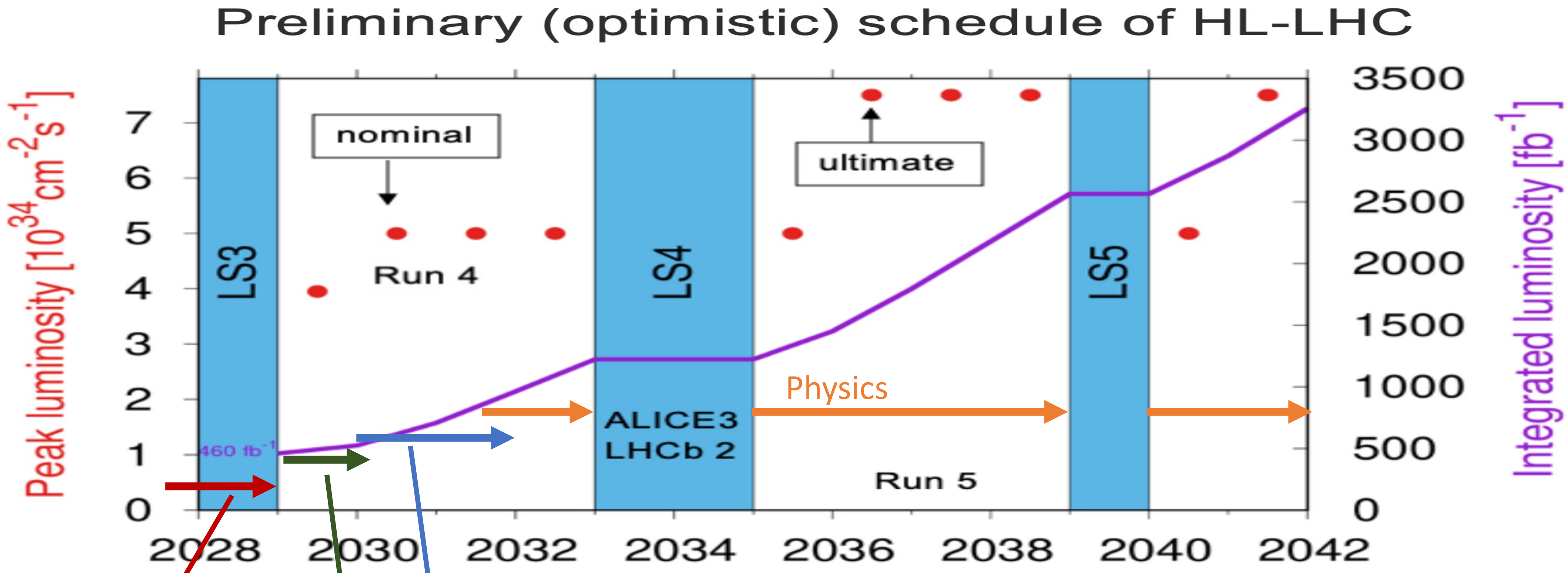
- Allow physics data taking for most of the luminosity of the HL-LHC
- Not overload CERN technical teams during LS3
- Design of facility would allow different experiments to come online at different times

Requirements:

- Can access the facility during LHC operations (RP study ongoing)
- Can complete CE works before the end of LS3

Possible FPF schedule

HL-LHC schedule from DG presentation, New-Year (on-line) meeting, 13/1/22



Pure CE works (including connection to LHC)

Installation and commissioning of the experiments

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

If the above schedule becomes unachievable we would aim to implement the facility during Run 4:

- Ongoing study within ABP to understand what digging is compatible with HL-LHC operations (significantly further from IP than UPR works, so likely much of digging can be done)
- To investigate if connection of safety gallery compatible with (E)YETS during Run 4

Crossing angle at IP1 during HL-LHC

- For HL-LHC the crossing plane at IP1 will change from vertical -> horizontal
  - Where the direction of the crossing angle will push the beam away from the LHC
- The maximum half crossing angle will be ~250urad, with changes of the order of 100urad during the physics fills
  - This means that the LOS will move by 15cm compared to nominal, and will move by ~6cm during the fill
- Although horizontal crossing is the default for IP1 for the full HL-LHC era, it was pointed out to me recently that changes to the crossing direction H->V could happen, this would lead to O(20-30cm changes in the position of the LOS at the FPF)
  - If this can effect the physics of FPF experiments, then taking this into account by moving the experiments should be considered in the deisgn

Ongoing studies and future work

- Current ongoing studies in the FPF PBS WG:
  - RP study of accidental LHC beam loss, with updated safety gallery design
  - FLUKA study of muon flux at FPF
    - => RP study on dose from prompt muons
    - => study on effectiveness of sweeper magnet in reducing the muon flux at the FPF
  - Study by CERN Beam Physics (BE-ABP) on how much of the civil engineering works can be done during (HL-)LHC beam operations (due to vibrations effecting the beam)
- And next studies:
  - (Assuming FLUKA study demonstrates sweeper magnet is useful) – Integration study (also with LHC cryo) on location of sweeper magnet, including (supports, handling, etc...)
  - More thorough civil engineering design, leading into a refined cost and time estimate for works
- In addition to this, we need to make progress in the design of the experiments, and their requirements
  - This will be fed into a refined design of the facility (including needed infrastructure and services)
  - At the moment, this is the critical path to coming-up with a technical design of the facility

Summary

- Much work carried out on the FPF facility within the context of the PBC accelerator track WG
- A preliminary conceptual design of the facility, including a rough costing, including for the services and infrastructure needs has been carried out
  - Baseline: New cavern
    - ~600m from IP1, 65m-long,8m-wide
    - ~40MCHF for CE works + services
- Next steps require input on requirements from the proposed experiments to allow a technical design, and updated costing, of the facility
- Best timeline would be to dig the cavern during LS3
  - Would need project (facility + experiments) approved and funded in the next ~3years

Backup…

Acknowledgements

Many thanks to all the CERN teams who have contributed to FPF studies:

- PBC: G. Arduini, C. Vallee, J. Jaeckel
- SCE-DOD-FS: K. Balazs, J. Osborne
- HSE-RP: L. Elie, A. Infantino, M. Maietta, H. Vincke
- SY-STI-BMI: F. Cerutti, M. Sabate Gilarte
- EN-ACE-INT: J. P. Corso
- EN-HE: C. Bertone
- EN-CV: M. Battistin, O. Crespo-Lopez
- EN-EL: M. Lonjon
- EN-AA: P. Ninin, S. Grau, T. Hakulinen, R. Nunes
- HSE-OHS: M. Andreini
- BE-ABP
- TE-MSC-NCM: P. Thonet

Currently proposed FPF experiments

- FLArE
  - $\mathcal{O}$(10tn) LAr TPC detector
  - DM scattering
  - Neutrino physics (ν_μ/ν_e)
    - Full view of neutrino interaction event
- FASERnu2
  - $\mathcal{O}$(10tn) emulsion/tungsten detector (FASERnu x10)
    - Mostly for tau neutrino physics
  - Interfaced to FASER2 spectrometer for muon charge ID ($\nu_\tau/\ \nu_\tau$ separation)
- AdvSND
  - Neutrino detector slightly off-axis
    - Provides complementary sensitvity for PDFs from covering different rapidity to FASERnu2
- FASER2
  - Detector for observing decays of light dark-sector particles
  - Similar to scaled up version of FASER (1m radius vs 0.1m)
    - Increases sensitivity to particles produced in heavy flavour decay
  - Larger size requires change in detector and magnet technology: Superconducting magnet
- FORMOSA
  - Milicharged particle detector
  - Scintillator based, similar to miliQan

No detailed design for any of these experiments yet!

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

K. Balazs, J. Osborne

UJ12 Alcoves – Very Preliminary Cost Estimate for CE works

Preliminary Cost Estimate

Ref.	Description of works	Cost [CHF]
1.	**CE Works Alcoves**	**10,866,870**
1.1	Alcove 6.4*2.9 m	2,864,902
1.2	Alcove 6.4*3.7 m	3,655,220
1.3	Alcove 6.4*4.4 m	4,346,748
2.	**Engineering and consultancy**	**1,630,031**
3.	**Minor Works**	**287,281**
3.1	Site investigation	74,524
3.2	Miscellaneous	212,757
	Total Cost	**12,784,182**

Draft

Methodology

- Comparative Costing
- SPS Dump Facility Tunnel eye enlargement as reference point
- Cost Estimate Class 4 – total could be 50% higher and 30% lower than the given estimate

Assumptions

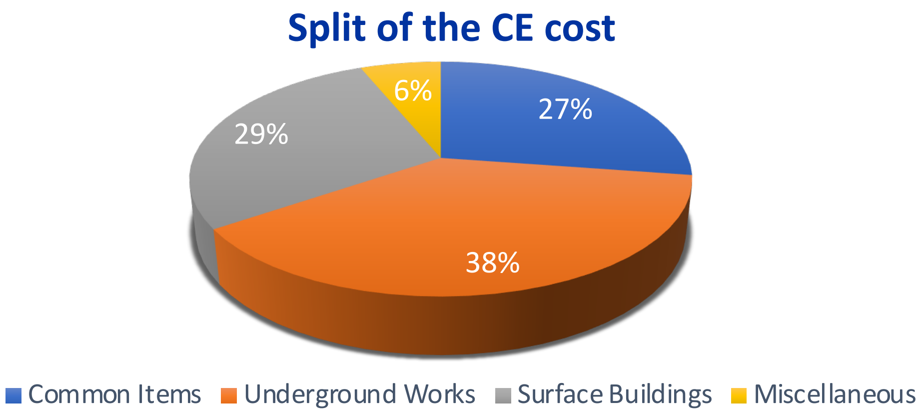
- Removal of the existing services and equipment from the UJ12 not included
- Services (CV, electricity etc.) not included

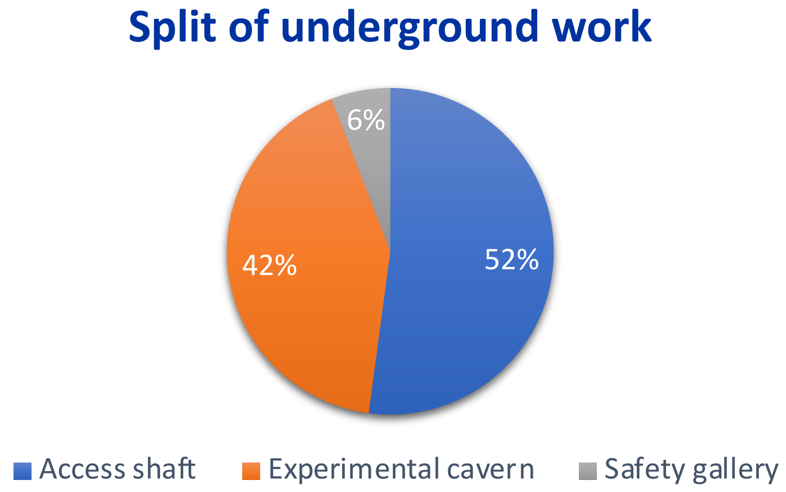
K. Balazs, J. Osborne

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**

Draft





S. Le Naour (LHC magnets) & K. Brodzinski (Cryo)

What needs to be removed from UJ12 for alcoves option

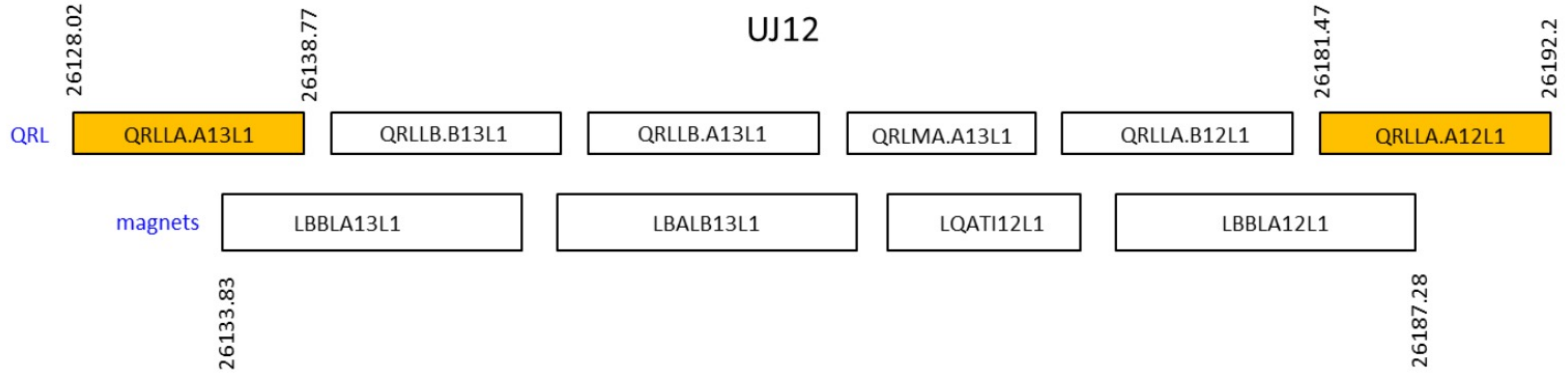
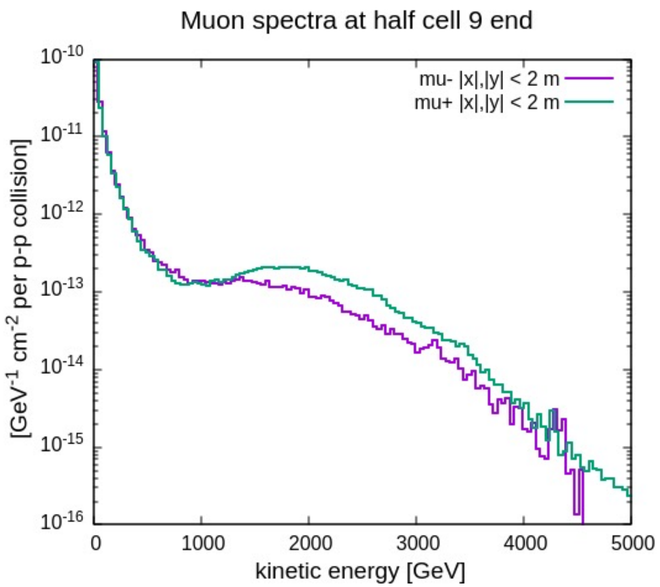


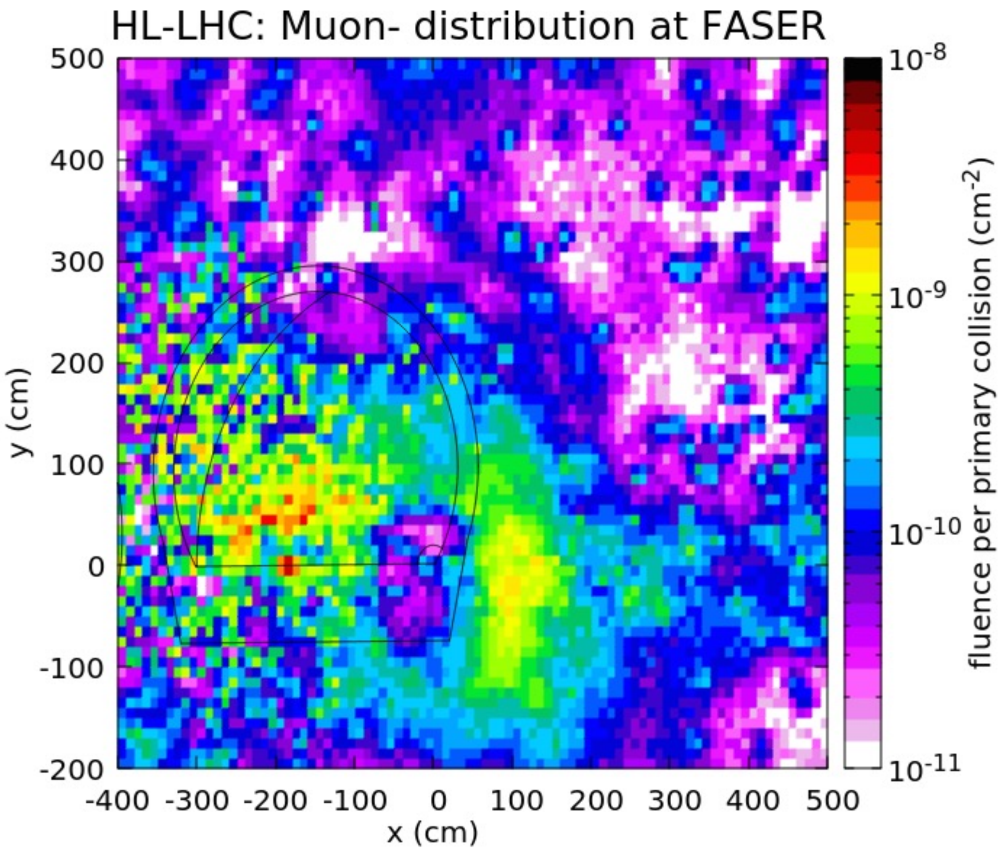
Figure 1; Sketch of UJ12 machine layout (magnets and the QRL) with main Dcum values.

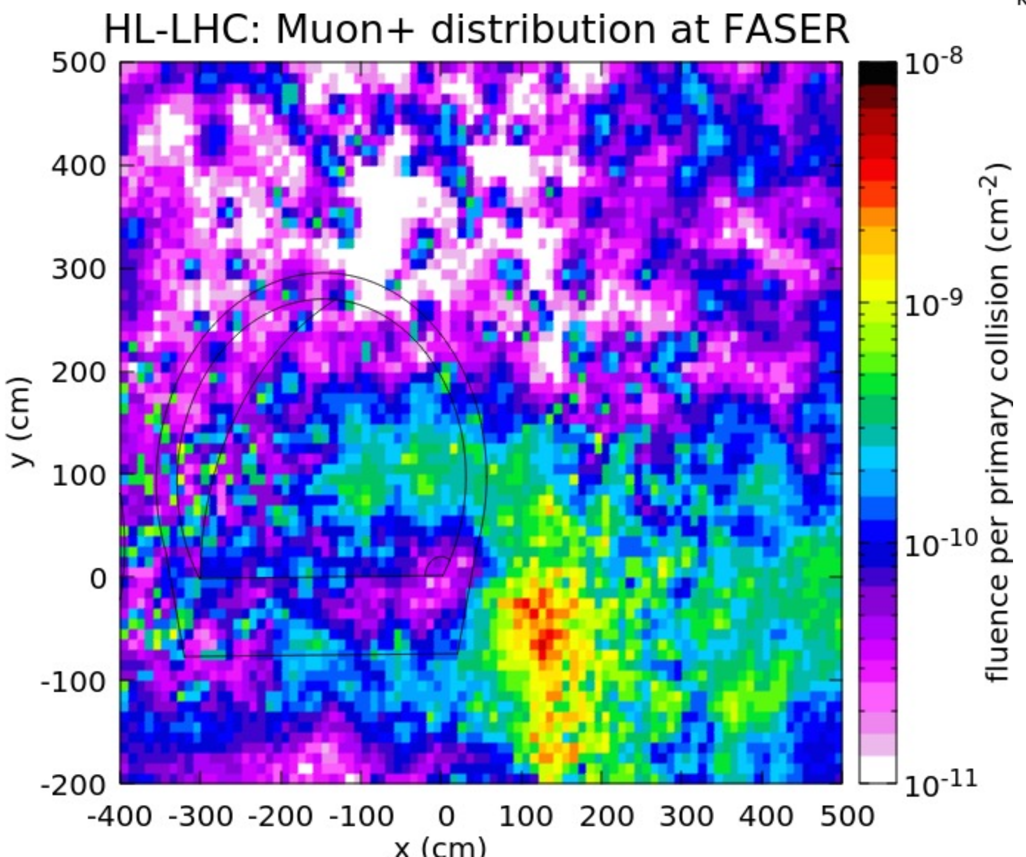
Muon Backgrounds

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



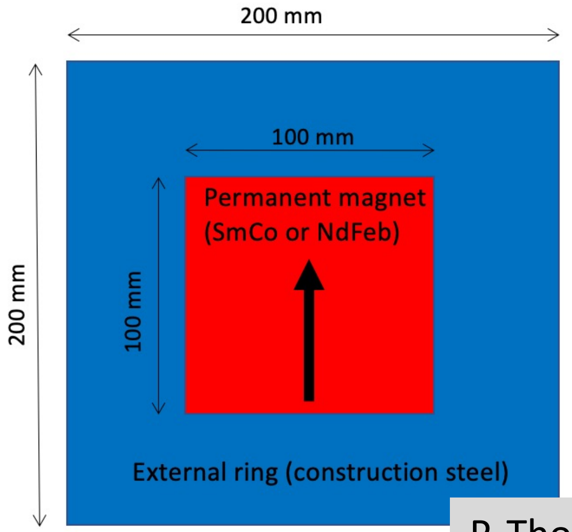
FLUKA distribution of muon flux in tranverse plane around LOS.
The flux is lowest on the LOS.





Sweeper Magnet: Ongoing Studies

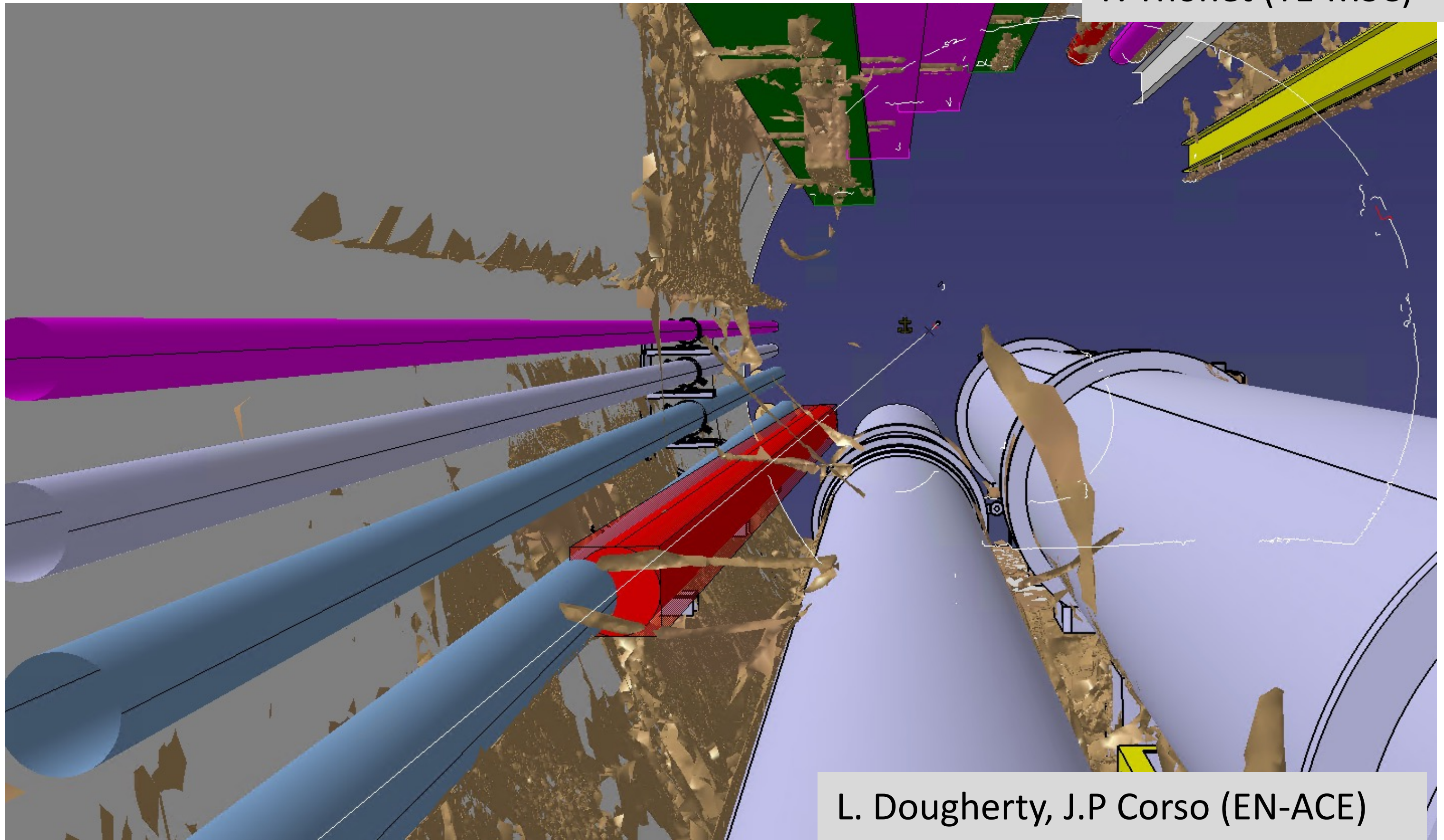
- Preliminary design of sweeper magnet by TE-MSC
  - Based on permanent magnet to avoid power converter in radiation area
  - Simple / cheap design with 1T bending power (~150kCHF)
  - Consider total length ~7m, 2.3tonnes
  - 7Tm magnet would deflect a 100 GeV muon 4.2m from the LOS at the FPF
  - Handling, support structure not yet considered



P. Thonet (TE-MSC)

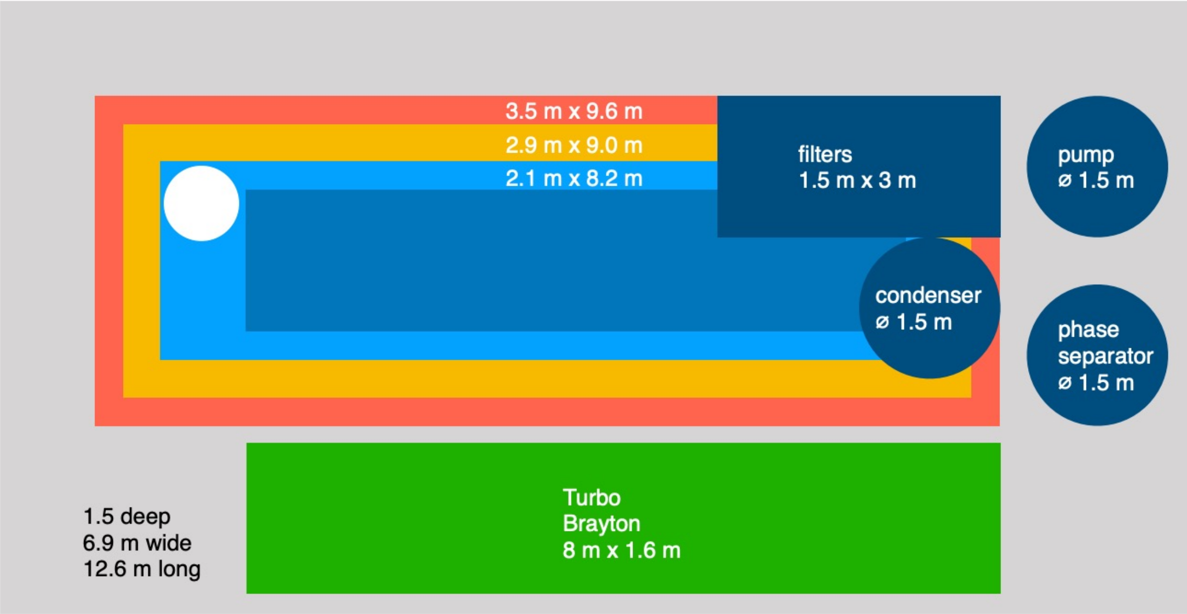
- Integration have looked at placement of sweeper magnet on the LOS in the LHC tunnel
  - Laser scan of relevant area taken in 2020
  - Would need some minor modifications to cryogenic lines (warm return line) in relevant area to allow sufficiently long magnet to be installed
  - Possibility of modifications to be investigated with LHC cryo

- FLUKA and BDSIM studies ongoing to assess effectiveness of such a magnet in reducing the muon background in the FPF

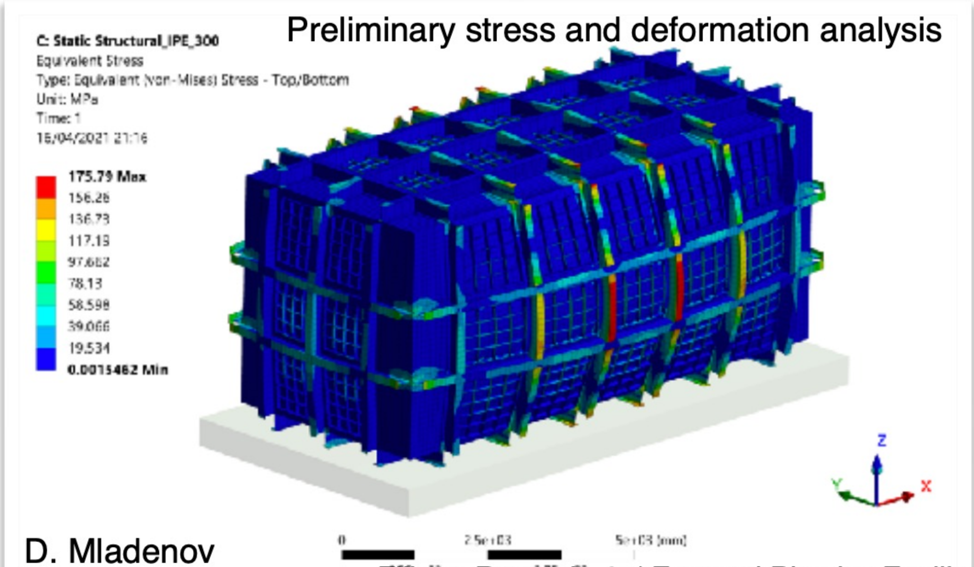

L. Dougherty, J.P Corso (EN-ACE)

LAr TPC cryogenics and cryostat

LAr TPC detector drives many aspects of services/infrastructure and safety systems.
Rough design of cryostat and cryogenics by F. Resnati based on proto-Dune experience in the neutrino platform.



- Reduced to 30 cm the non-instrumented LAr layer.
- Insulation thickness reduced to 40 cm (~increase the heat input (O(4 kW)).
- Reduce structural thickness.
- Manhole for egress added.



Dimensions (height) may need to increase after considering
- minimum gas thickness
- minimum equipment depth
- cryogenic pipes