FPF Sweeper Magnet

Jamie Boyd (CERN)

3rd FPF workshop - 25/10/21

Very much still a work in progress…

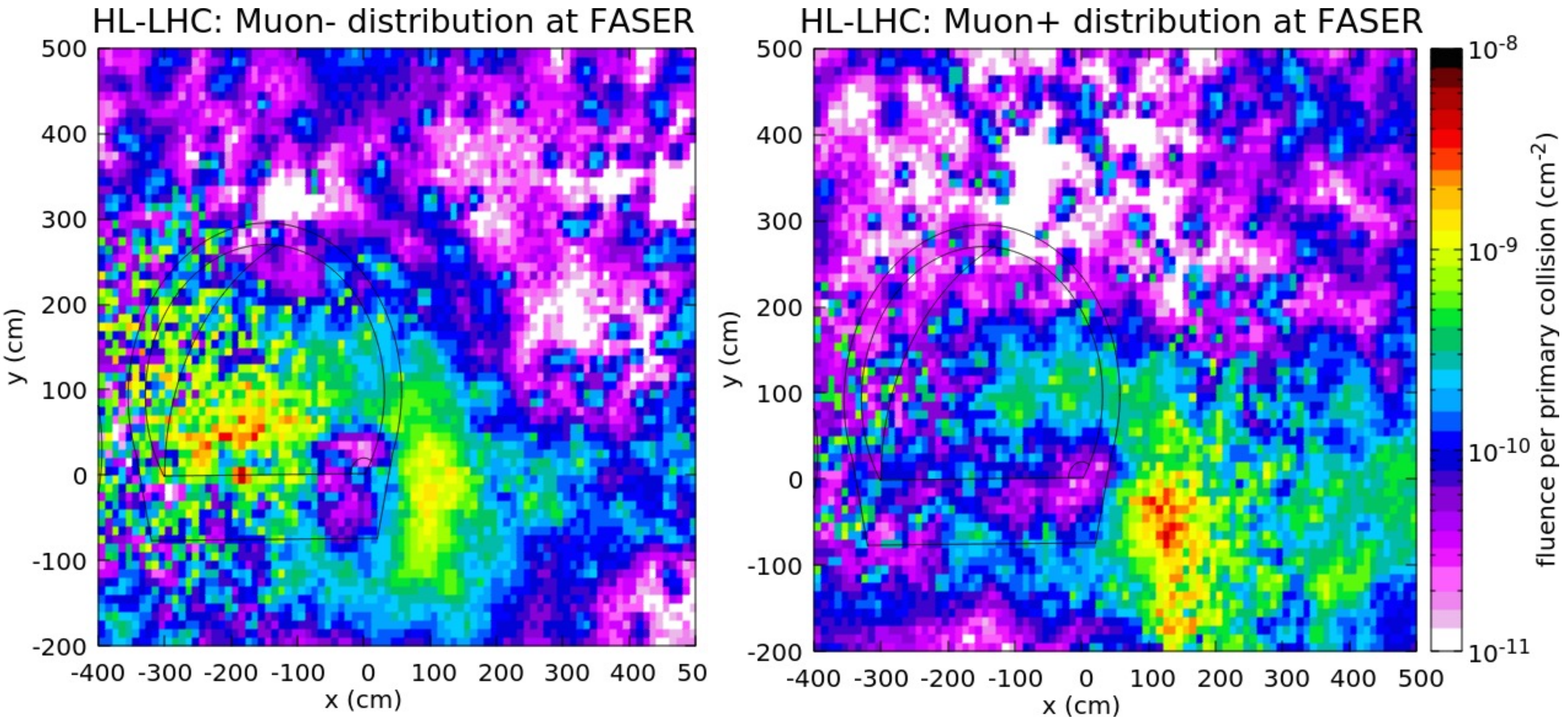
Introduction

- For many of the experiments installed in the FPF minimizing the background from muons produced in the LHC collisions in ATLAS (including decays/secondary-interactions of the collisions products) will be important
  - Would allow to exchange (expensive!) emulsion films less often
  - Would facilitate low energy measurements in FLArE LAr TPC
  - Would reduce backgrounds in FORMOSA
  - Would reduce fraction of luminosity vetoed in all FPF experiments
- The current expectation based on FLUKA studies validated with in situ measurements in 2018 LHC running is we expect a rate of 0.5Hz/cm^2 of muons on the LoS for a luminosity of 2e34cm^{-2}s^{-1}
  - For HL-LHC would scale to 2.5Hz/cm^2 (5e34cm^{-2}s^{-1}) for the baseline scenario and 3.75Hz/cm^2 (7.5e34cm^{-2}s^{-1}) for the “ultimate” luminosity scenario
  - The flux increases by up to O(1) order of magnitude as you go 1 - 2m from the LoS
- Investigating the use of a sweeper magnet to bend muons away from the FPF and reduce the flux

Expected muon flux (FLUKA)

F. Cerutti, M. Sabate-Gilarte (CERN, SY-STI)

FLUKA distribution of muon flux in tranverse plane around LOS.
The flux is lowest on the LOS.
More detailed FLUKA studies ongoing…



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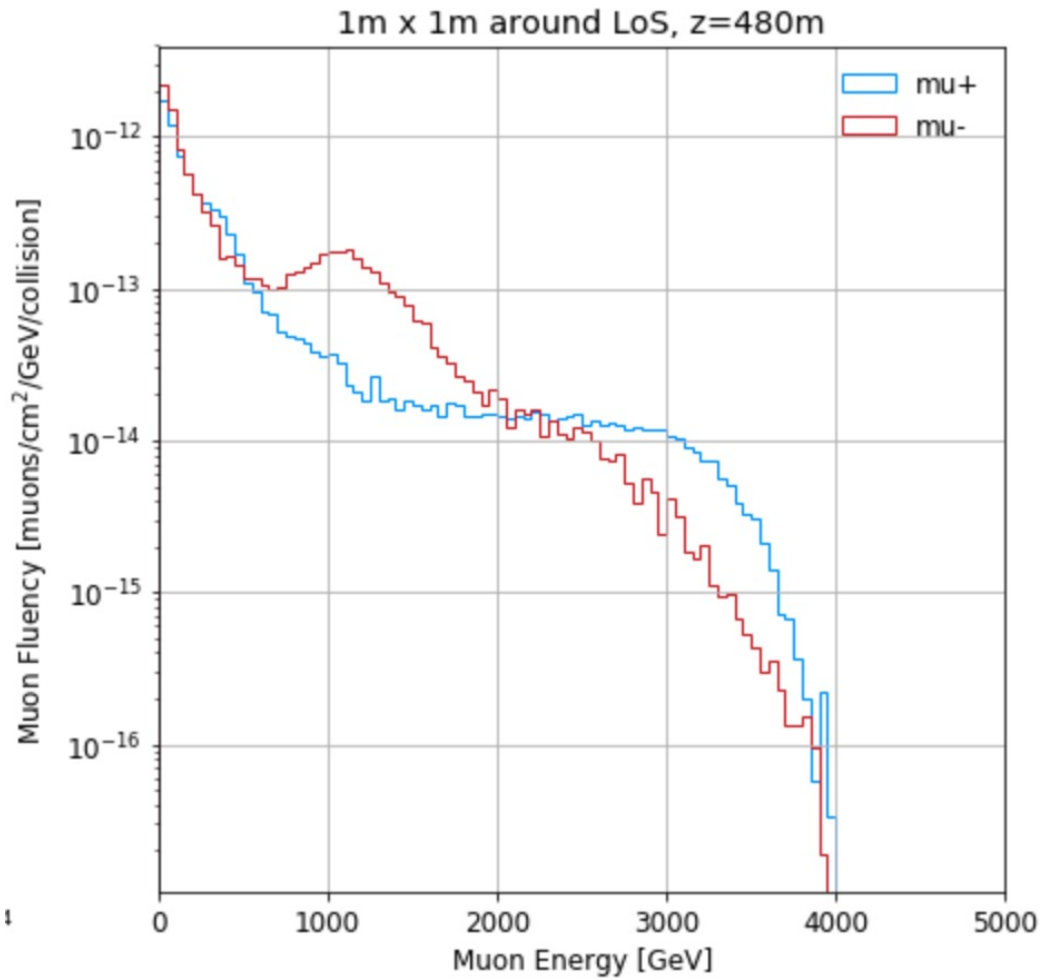
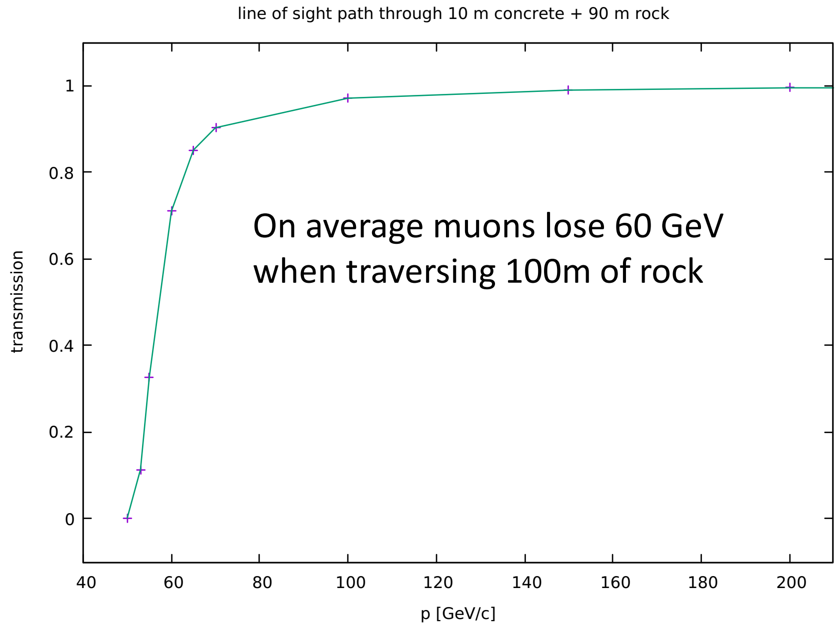


Muon flux as function of energy at 480m from IP.

Muons are very high energy – need a powerful magnet &/or big level arm to sufficiently deflect these muons.



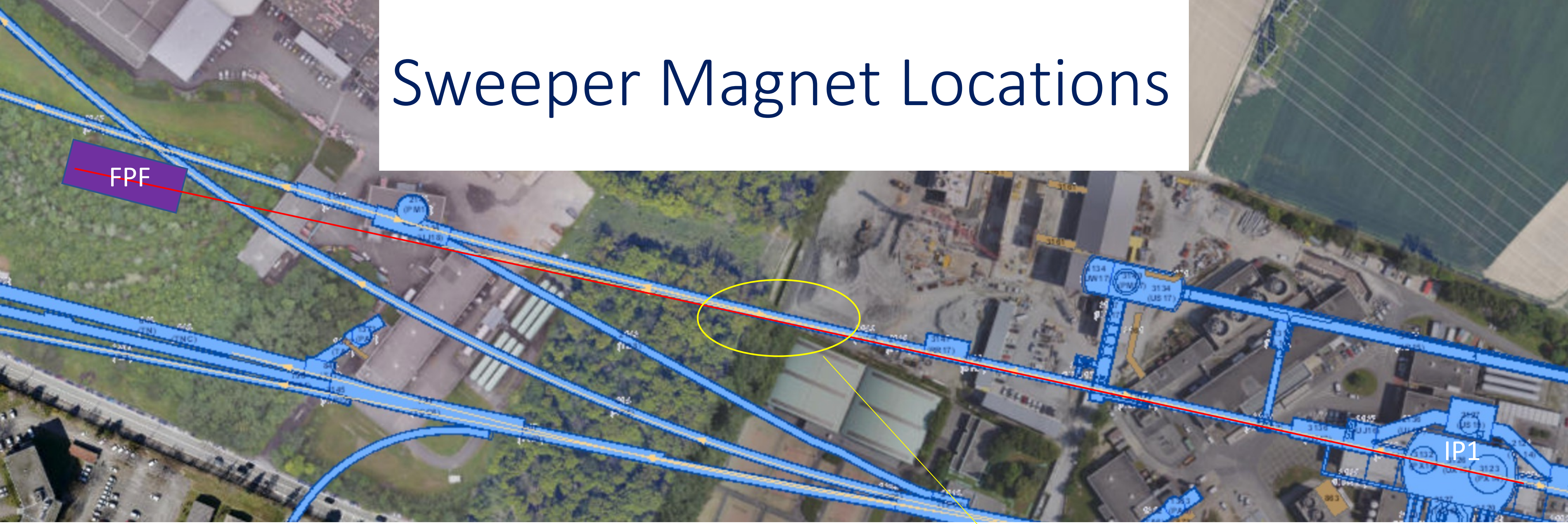
From older FLUKA study:

Energy threshold [GeV]	Charged particle flux [cm^{-2} s^{-1}]
10	0.40
100	0.20
1000	0.06

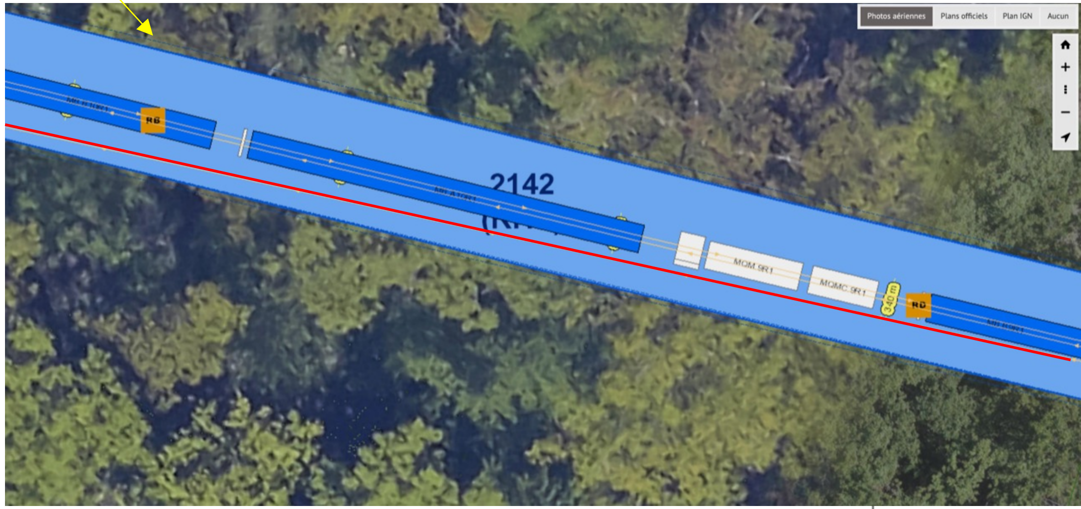
Expected charged particle rate for different energy thresholds ($2e34 cm^{-2}s^{-1}$) scale by ~2.5 for HL-LHC

F. Cerutti, M. Sabate-Gilarte (CERN, SY-STI)

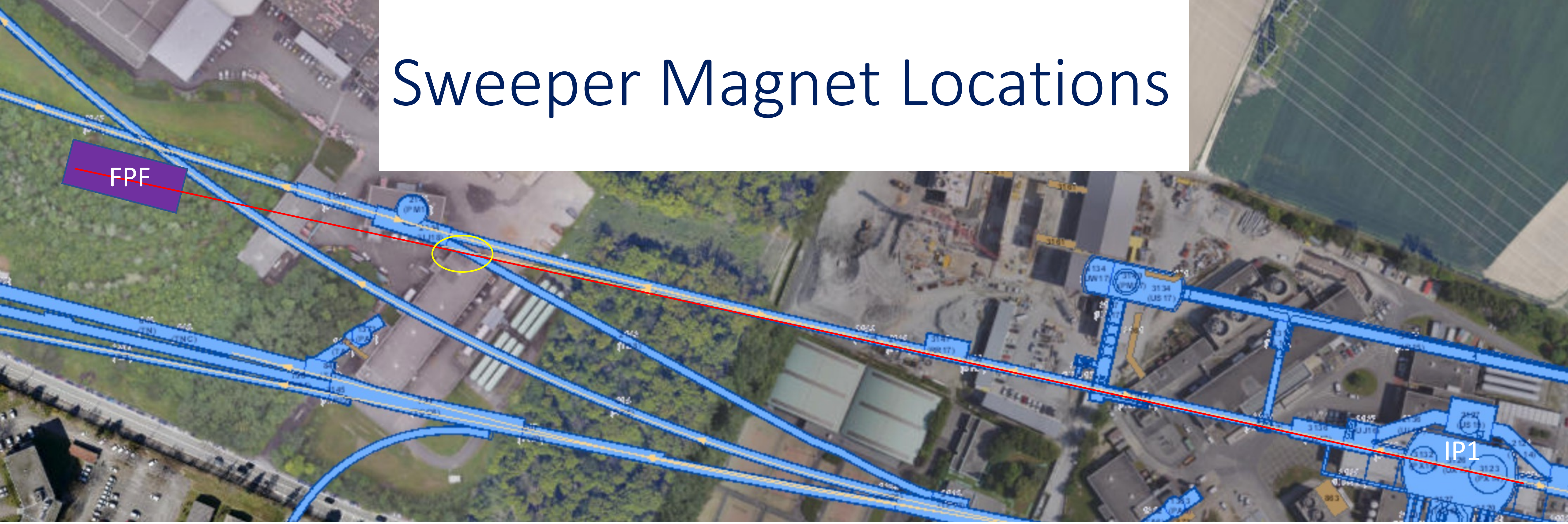
Sweeper Magnet Locations



Placing a sweeper magnet on the LOS before the FPF can deflect 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 to deflect muons). Here would need to use a permanent magnet since power supplies for an electro/super-conducting magnet would be effected by radiation in this location.

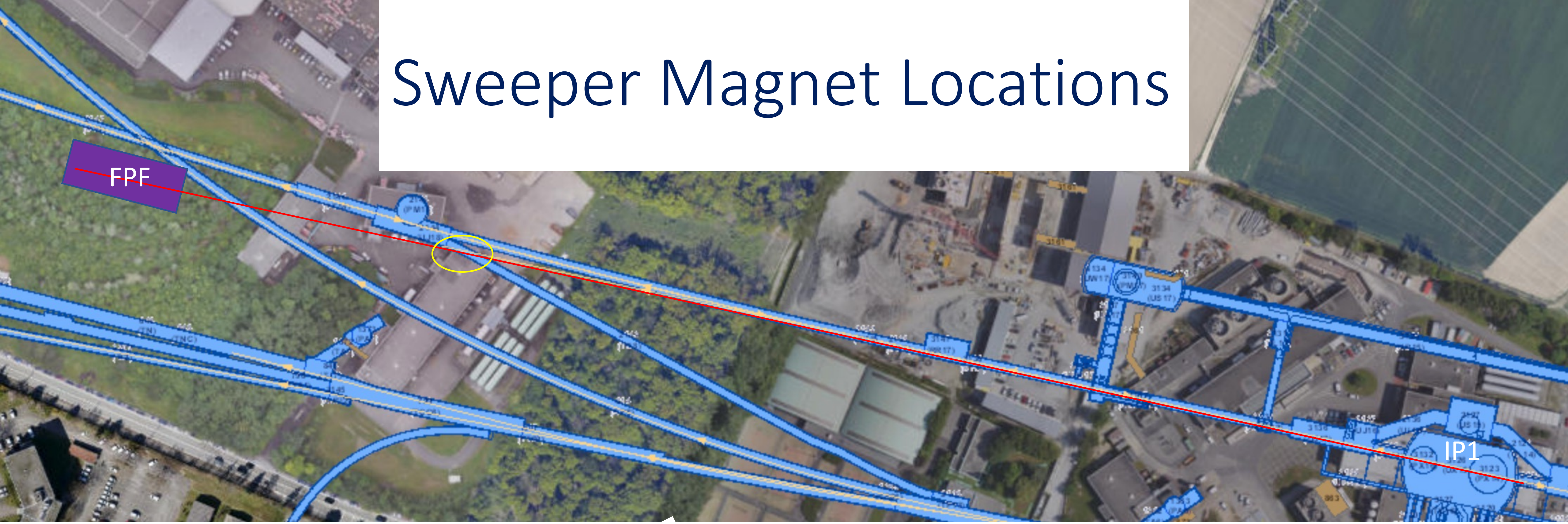


Sweeper Magnet Locations



Placing a sweeper magnet on the LOS before the FPF can deflect muons and reduce the background.
An alternative place could be in the TI18 tunnel (where SND is currently installed). This would be more difficult (would require digging to enable space on the LOS), and less effective (available length for magnet would be more limited, and lever-arm to bend muons would be less ~100m). But in principle a superconducting magnet could be used here to increase the bending power.

Sweeper Magnet Locations



Placing a sweeper magnet on the LOS before the FP… deflect muons and reduce the background.
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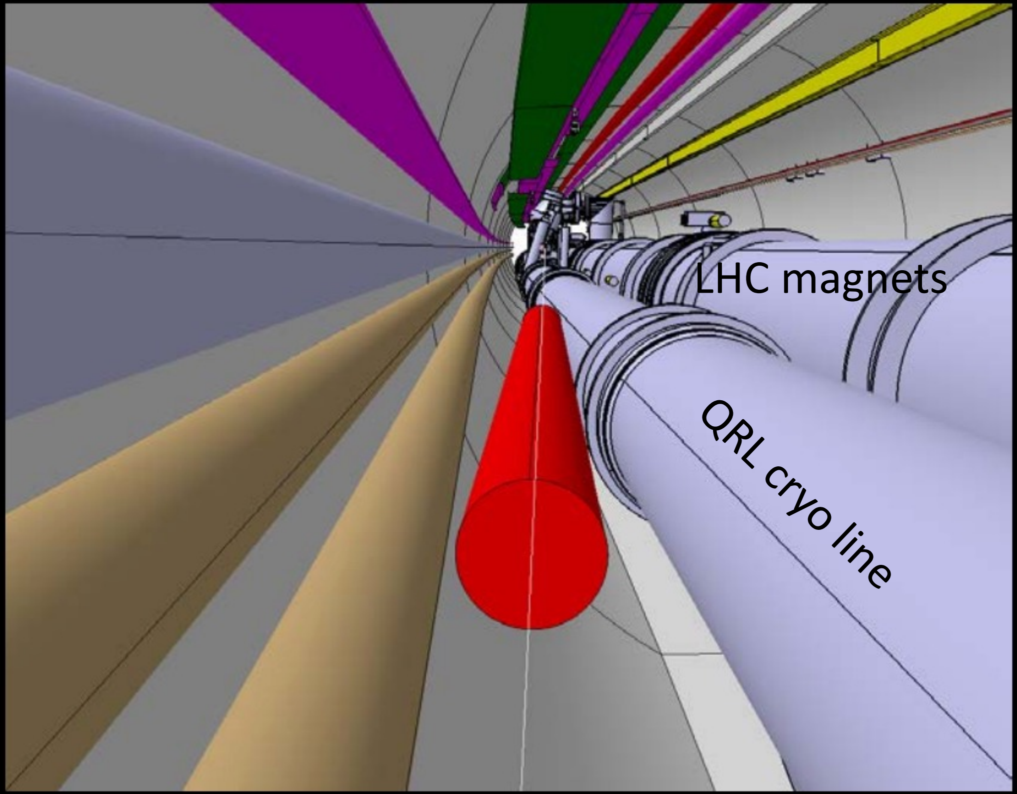
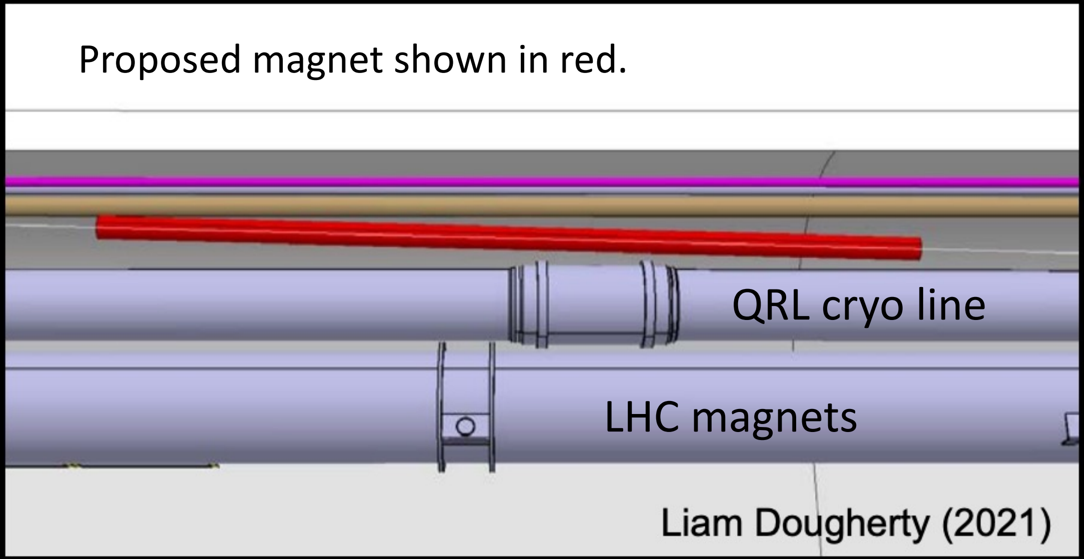
For now focus on the location in the LHC tunnel.

Initial Studies



$$h_B \approx \frac{ecd}{E_\mu} B\ell = 60\ \text{cm}\left[\frac{100\ \text{GeV}}{E_\mu}\right]\left[\frac{d}{200\ \text{m}}\right]\left[\frac{B\cdot\ell}{\text{T}\cdot\text{m}}\right]$$



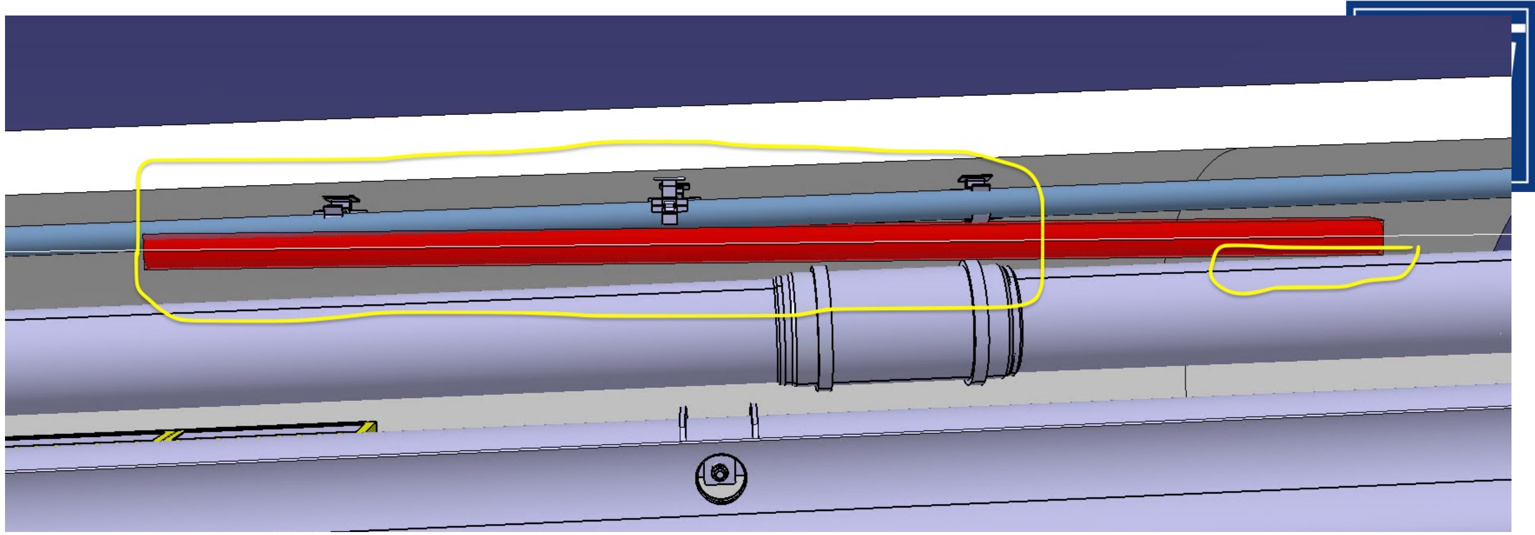
Initial studies using the integration model of the LHC, suggested that a 7m-long / 20cm-diamater magnet could be placed on the LOS in the LHC tunnel. Assuming a 1T/m this would give 7Tm of bending power with a lever-arm of 200m. Looked quite promising!

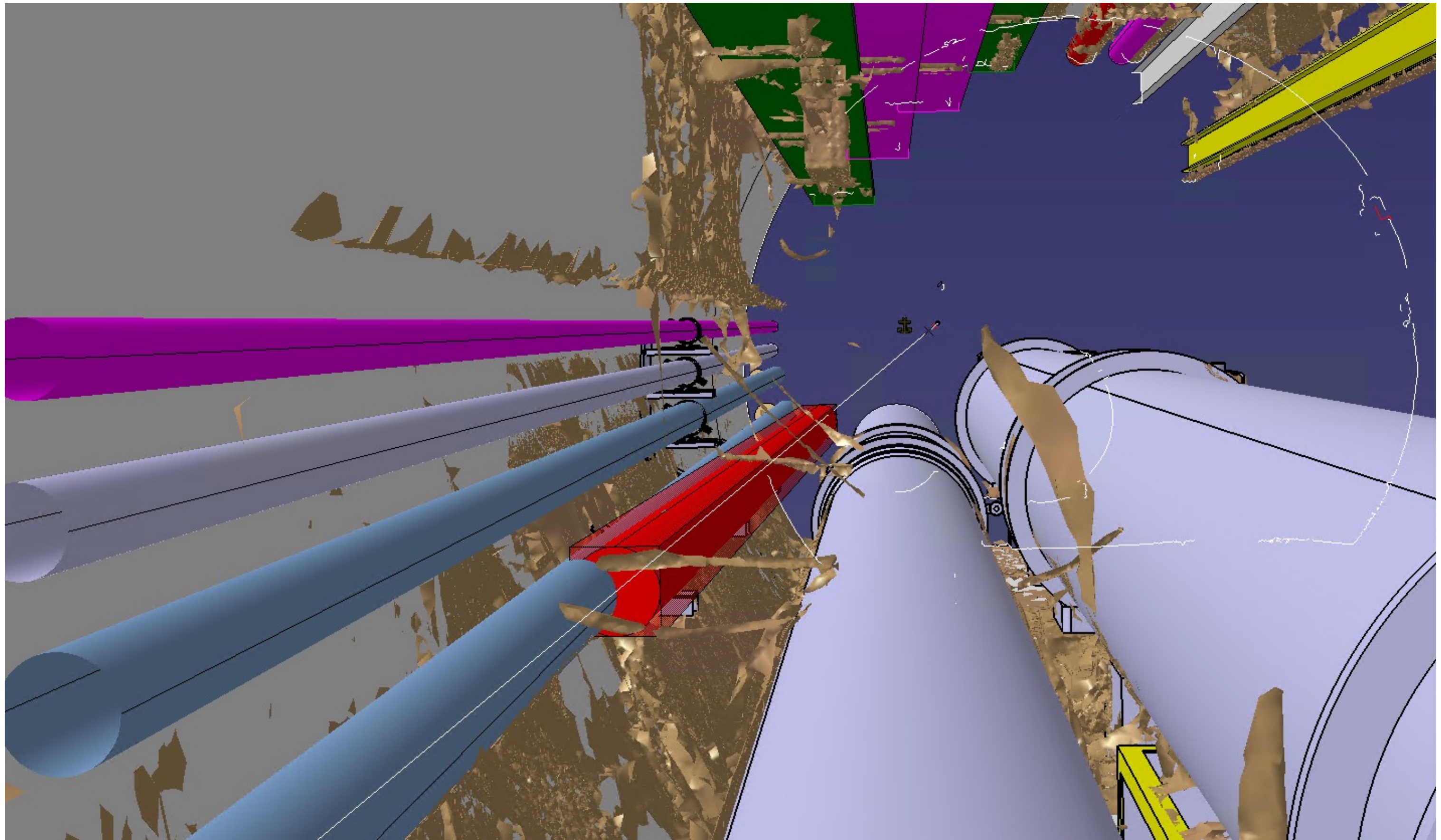
For FPF d ~ 200m
100 GeV muons would be bent ~4.2m from LOS for 7Tm field

L. Dougherty (CERN EN-ACE)

Further Studies

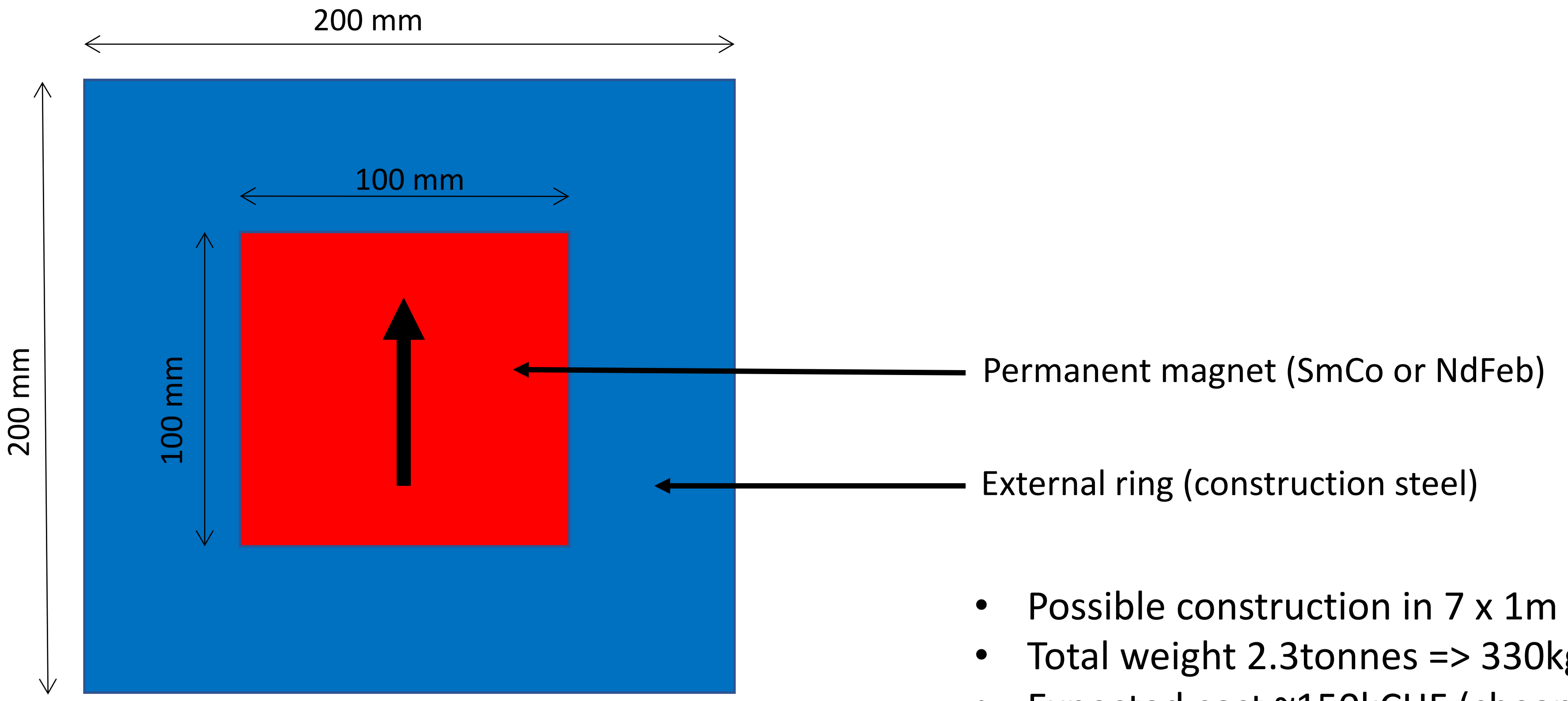
- To investigate further a laser scan was taken in the relevant region of the LHC tunnel.
- Unfortunately this revealed a number of items (pipes, infrastructure) not included in the original integration model.
- This means in the current situation 70% of the proposed magnet is clashing with installed cryogenic infrastructure (mostly the Warm Return Line (WRL)).
- We need to see with the LHC cryo team if we could modify the WRL in this area to free up space to be able to install a longer magnet.
- We also need to investigate the magnet support and handling equipment for the installation/removal.
- A further complication is the beam crossing angle which will move the LoS ~10cm towards the tunnel wall at this location.





Possible Magnet Design

- Simple design with the permanent magnetic blocks placed at the center of the assembly (no open aperture needed).
- The efficiency of the magnet is very good.
- The field homogeneity inside the window of 100 x 100 mm is very good (≈ +/- 1%).
- We could imagine to use NdFeb magnets if the radiation / energy deposit stay low at the magnet location (to be studied)



Pictured: FASER sweeping magnet

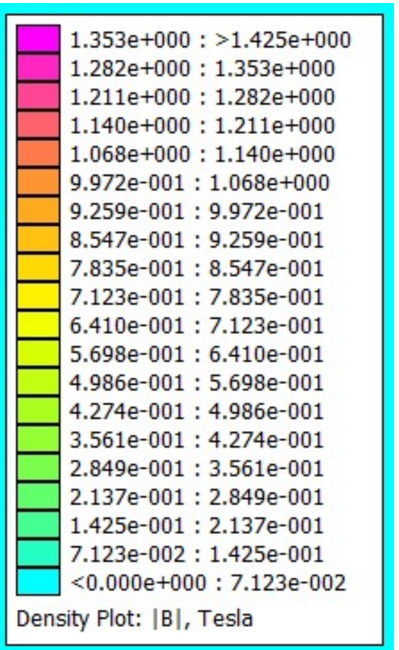
- Possible construction in 7 x 1m long sections
- Total weight 2.3tonnes => 330kg/section
- Expected cost ~150kCHF (cheap!)
  - Not including cryo changes, supports etc..
- Need to consider integration aspects (support / handling etc..)

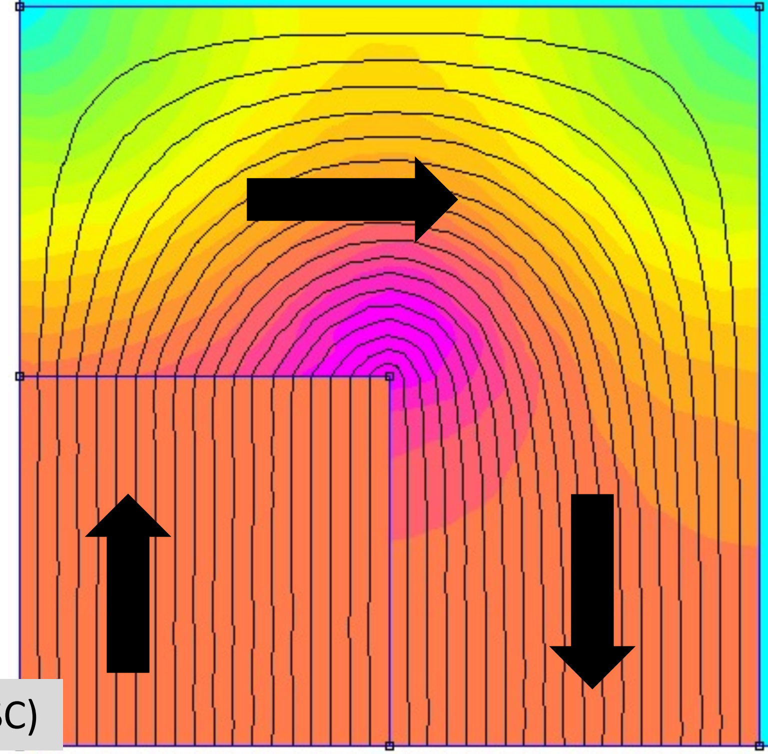
P. Thonet (CERN, TE-MSC)

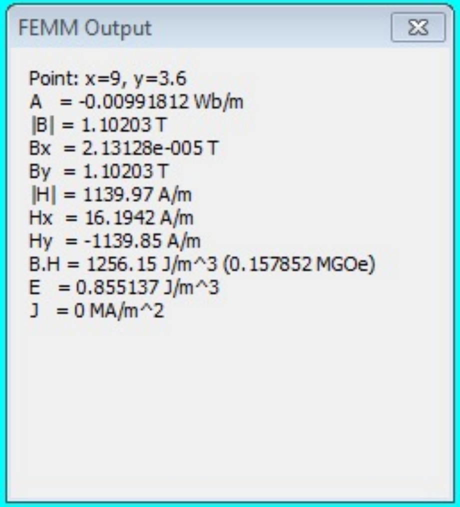
Possible Magnet Design

- Central field inside a window of 100 x 100 mm of:
  - 1.1 T with SmCo magnets.
  - 1.4 T with NdFeb magnets.
  - Studies needed to see if NdFeb an option in the LHC tunnel
- Radial stray field negligible (<0.002T 10cm from magnet)
  - Not expected to be problematic for LHC
- **The polarity is the opposite in the return yoke.**

Magnetic design with ¼ of the cross section.





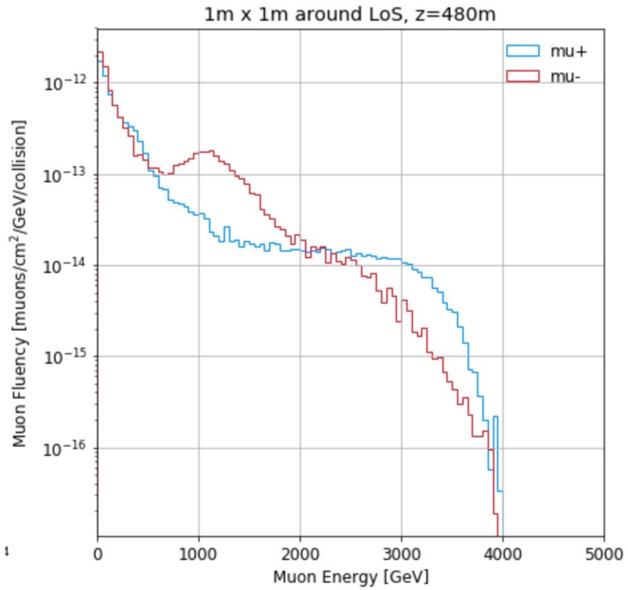


Performance: Muon Deflection

Assuming very simple (naive) model where magnet sweeps away all muons assuming perfect dipole field, and does not sweep any additional particles into FPF - then expect, these defelections at FPF.

For 7Tm field

Muon E (GeV)	FPF (d=200m)
100	4.2m
250	1.6m
500	0.8m
750	0.6m
1000	0.4m



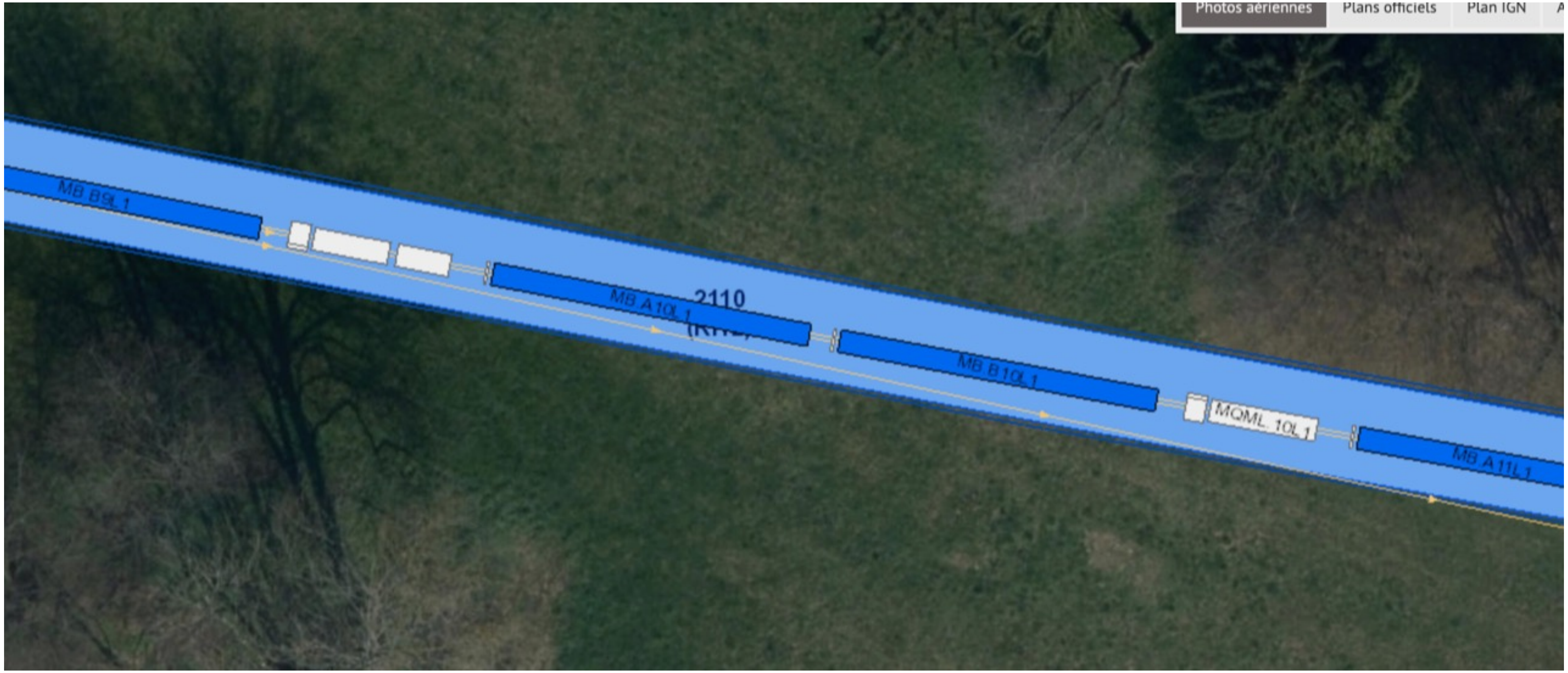
FPF: LArTPC,FASER2,FASERnu2 (r~0.75m) – Magnet would get rid of all E<0.5 TeV muons (~5-10x reduction in rate).
Performance needs to be studied with detailed simulations (FLUKA/BDSIM). Such studies are starting.
Need to consider if there is an optimal configuration of the magnetic field to minimize muon rate in FPF, and also possible effects of deflected muons on other areas (LHC operations, anything else?).

Next Steps

Next Steps:

- Need simulation studies (FLUKA/BDSIM) to demonstarte that this can work, and to estimate reduction in muon rate on LoS at the FPF location
  - Is 20cm x 20cm sufficient transverse coverage
  - Possibility to make more detailed measurements of muon flux in Run 3 (2022) to validate simulations
- Need to followup with LHC cryo/integration
  - What are minimum modifications to WRL to allow ~7m magnet to fit on LoS?
  - Can these be done in LS3?
  - What about effect of HL-LHC crossing angle?
- Installation/Handling
  - Strategy for safe installation (during LS3?), dedicated handling equipment/tooling
- Magnet support:
  - Design support for magnet. Must not interfere with existing equipment and be safe for LHC/cryo
- Need to check expected dose in this area to see if NdFeb magnet can be used as magnetic material
  - If so length could be reduced to ~5m with same performance

Many thanks to CERN Physics Beyond Colliders for their support in these studies!



LOS leaves LHC magnets around A10.L1 and leaves tunnel at B10.L1.
For HL-LHC crossing angle will move LOS by 8-10cm away from magnets.