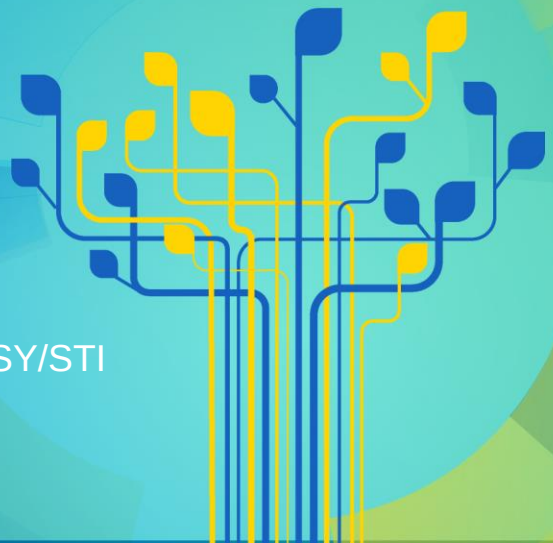
HSE
Radiation Protection

Radiation Protection studies for the Forward Physics Facility project: prompt ambient dose equivalent

Presentation given at the **5th Forward Physics Facility Meeting** https://indico.cern.ch/event/1196506/



L. Elie, A. Infantino, H. Vincke HSE/RP

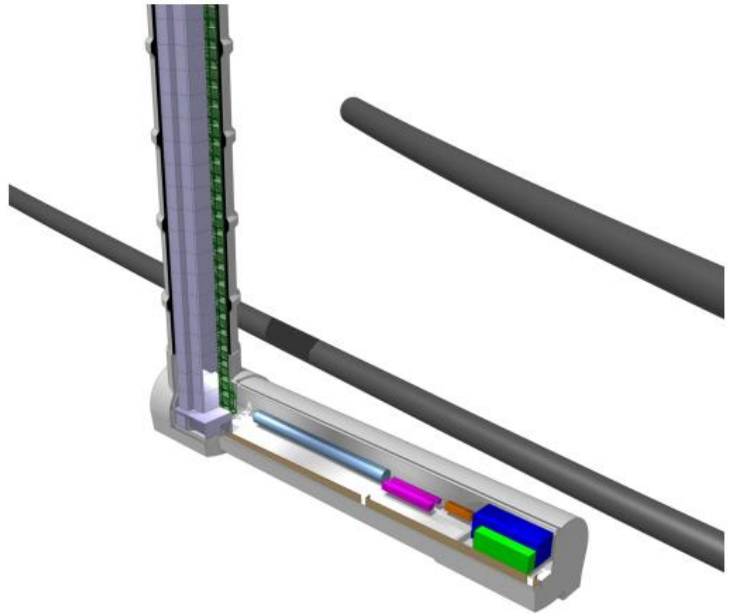
With input from: Marta Sabate Gilarte, Francesco Cerutti SY/STI

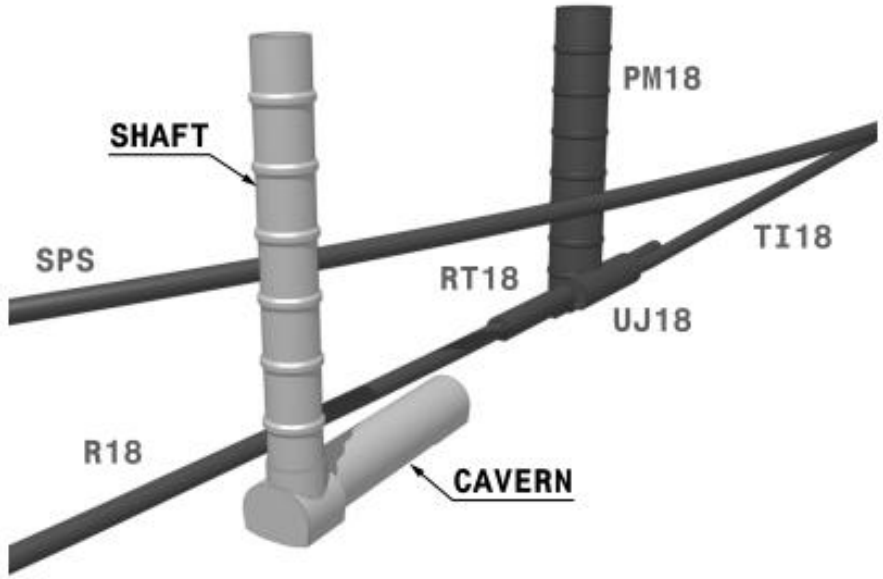
15.11.2022

EDMS 2797521

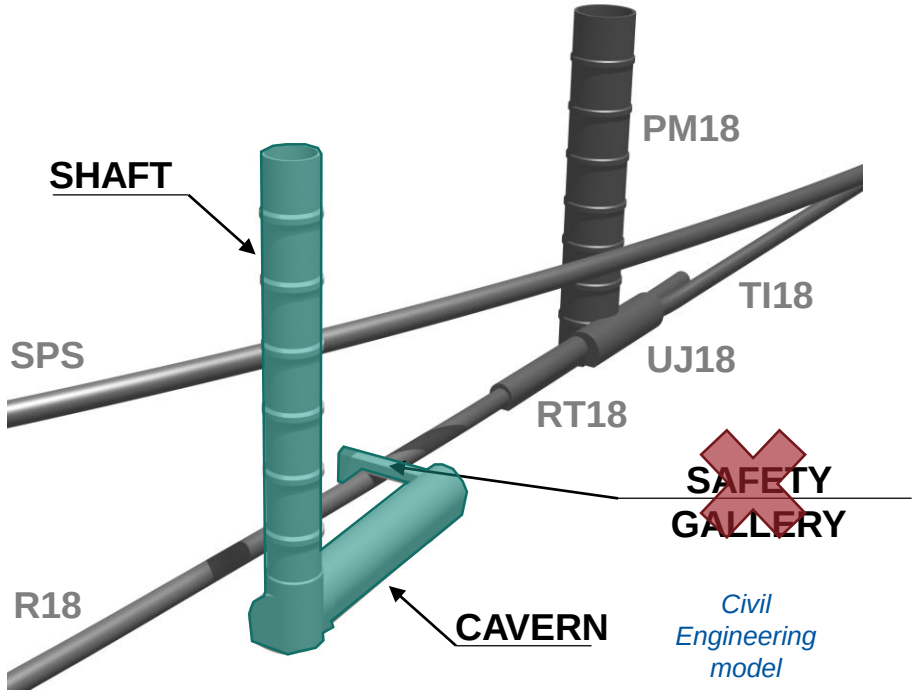
Context

- Access of the experimental cavern during LHC operation.
- RP constraints verified via FLUKA (CERN v4-2) simulations.
- HSE-RP created a model of FPF infrastructure → complex modelling
- Safety tunnel + chicane (3x80cm thick concrete walls) now suppressed.
- Several source of radiations to be considered:
  - **beam-gas interactions** during operation
  - **accidental scenarios** (e.g. loss of LHC/SPS beam)
  - **direct muon contribution** from IP1/LSS1

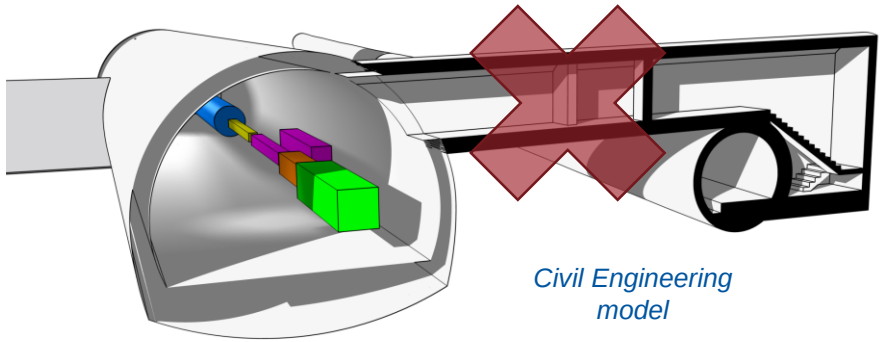




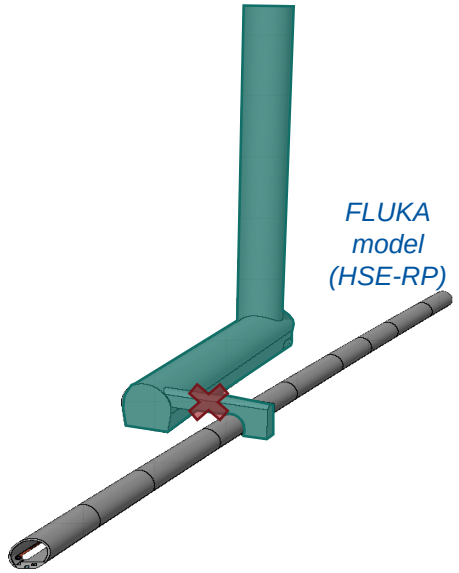
Context



Civil Engineering model

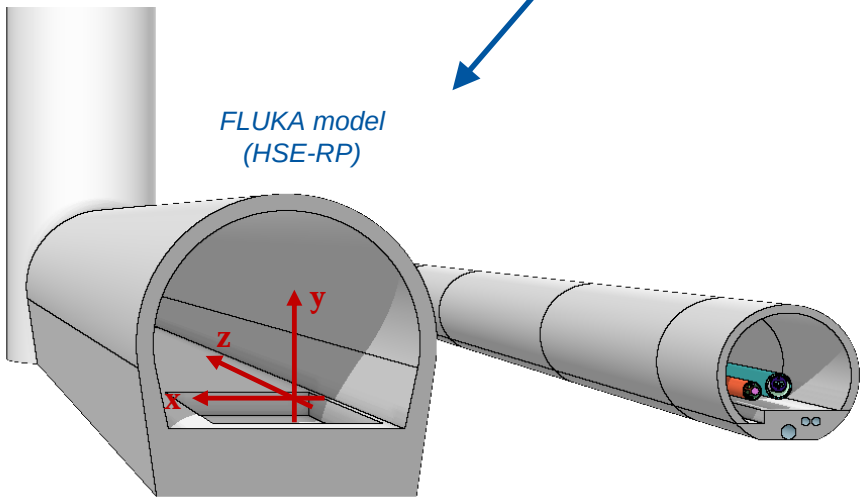


Civil Engineering model



FLUKA model (HSE-RP)

FLUKA model (HSE-RP)



FLUKA

Aim

- The RP-FLUKA simulations aim to:
  - Determine the prompt radiation levels in the new experimental cavern and in the shaft for different scenarios (source terms)
    - → Verify the accessibility of the experimental cavern/shaft during LHC (and SPS) operation
- Several presentations already published in EDMS and a dedicated HSE-RP Technical Note under finalization (EDMS 2771345)
- FLUKA model:
  - FLUKA CERN v4-2.2
  - LHC beam line (ARC) + FPF infrastructure, as provided by CE (Sep. 2021)
  - Different transport setting used for fine tuning the simulations → most accurate particle transport reported here (EMF-ON, lower transport thresholds, and more)
  - Scoring of particle fluence spatial distribution (muons) and prompt ambient dose equivalent
  - Muon source term (scored at ~350 m from IP1) from the FLUKA team (SY-STI) to simulate the RP-2nd step for assessing the muon contribution (See references 1 & 2)

Source terms

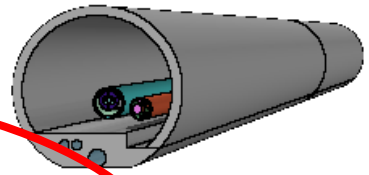
Not anymore relevant without safety tunnel

OPERATION

COMPLETED

Beam-gas interactions

1E15 H_2/m^3 for 100h beam lifetime (LHC design report). Recent R2E study indirectly determined lower residual-gas densities over Run 2 operation.



(first studies) COMPLETED

Direct muon component

Prompt dose from muons coming from IP1/LSS1. Muon phase space calculated from SY-STI and integrated into HSE-RP simulations.

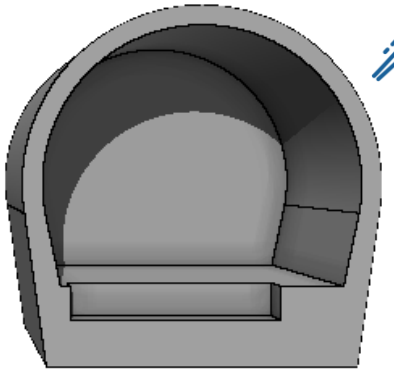
μ

ACCIDENT

COMPLETED

Loss of LHC beam

Loss of the full 7 TeV proton beam on the MB.B15R1 (dipole in front the connecting tunnel entrance)



COMPLETED

Loss of SPS beam

Loss of the full 450 GeV proton beam in the SPS tunnel (relevant for the shaft). Negligible since the distance between the shaft and the SPS tunnel is >35m.

HL-LHC ultimate conditions used as scaling/normalization factor

Radiation Areas classification

EDMS 810149

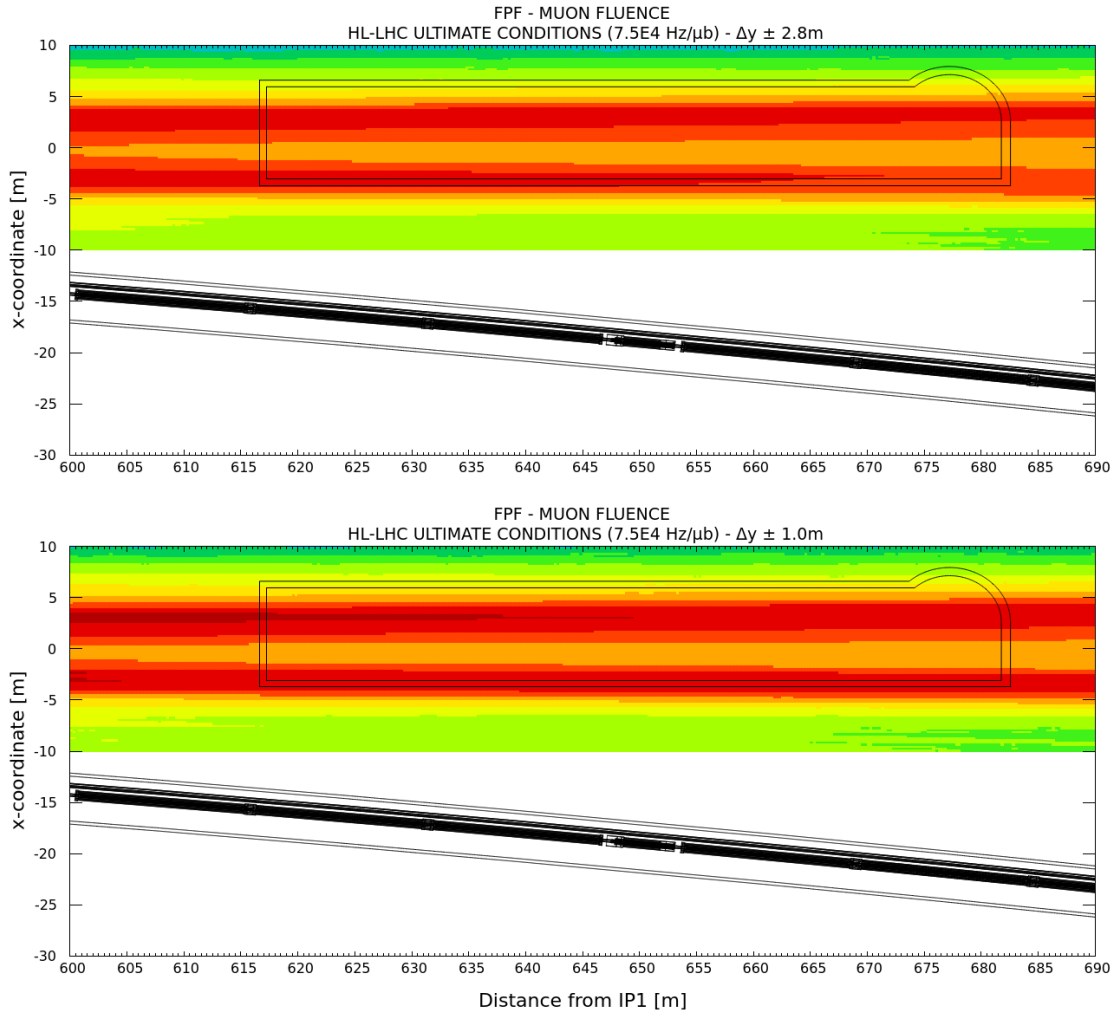
	Area	Annual dose limit (year)	Ambient dose equivalent rate		Sign
			permanent occupancy	low occupancy	
	Non-designated	1 mSv	0.5 µSv/h	2.5 µSv/h	
Radiation Area	Supervised	6 mSv	3 µSv/h	15 µSv/h	Dosimeter obligatory / *Dosimètre obligatoire*
Radiation Area	Simple Controlled	20 mSv	10 µSv/h	50 µSv/h	SIMPLE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

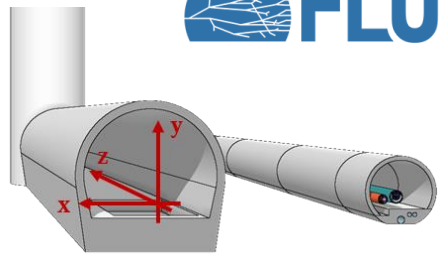
Controlled Area

Low-occupancy: < 20% working time

✓ CERN objective: **< 3 mSv** / 12 consecutive months; highest dose during LS2 **2 mSv** / 12 consecutive months

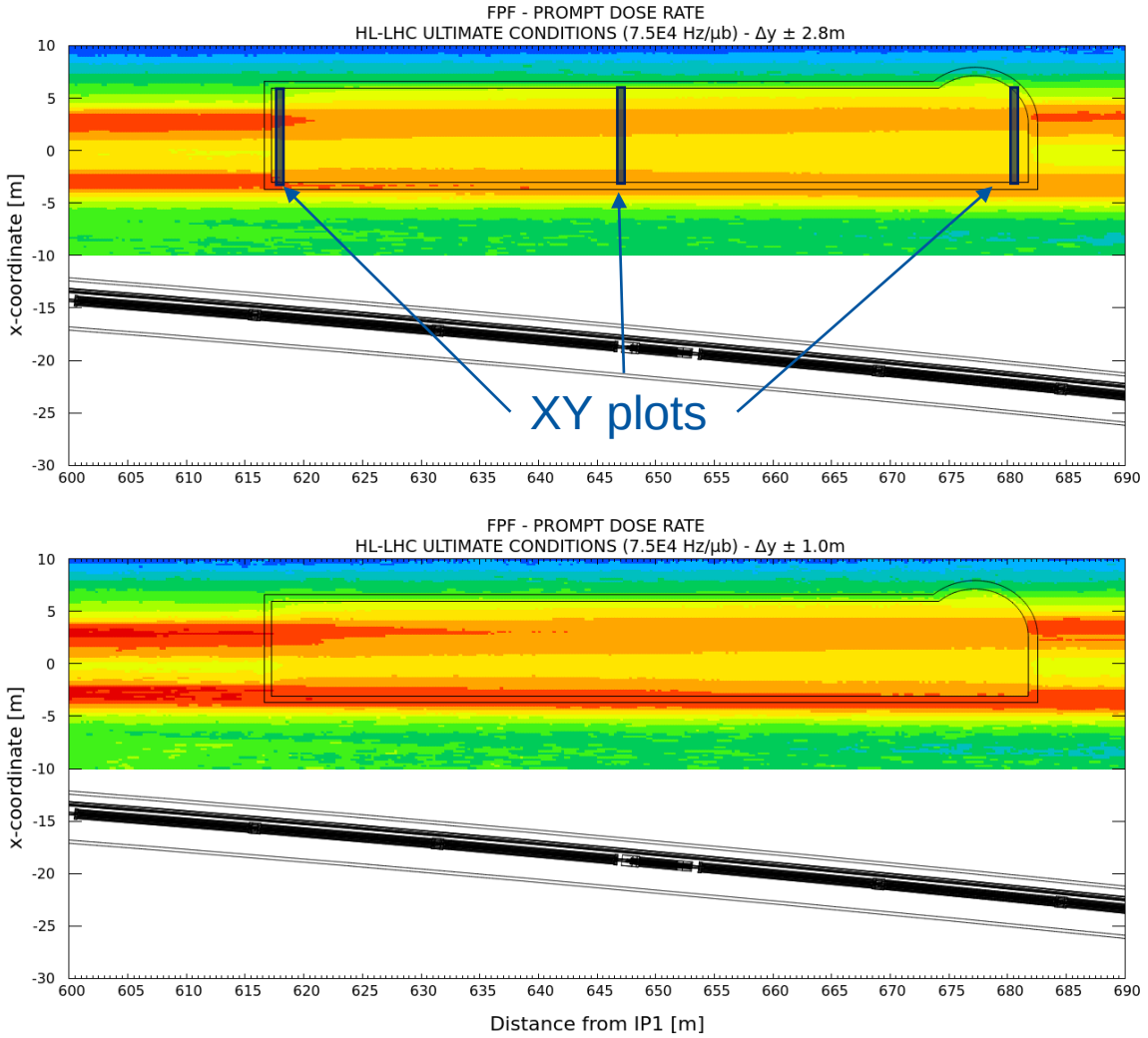
Muon fluence 2D maps

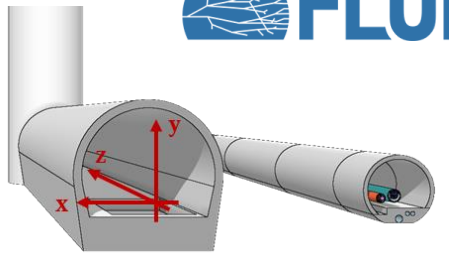


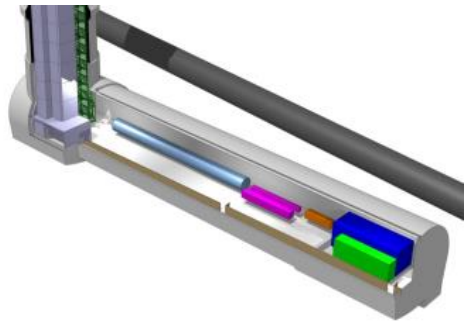


Muon source term from the FLUKA team (SY-STI)

$H^*(10)$ 2D maps



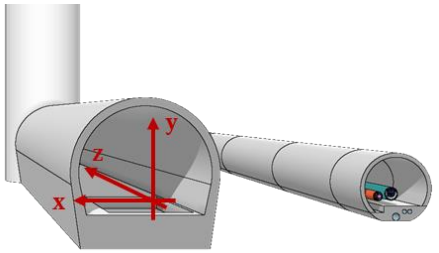




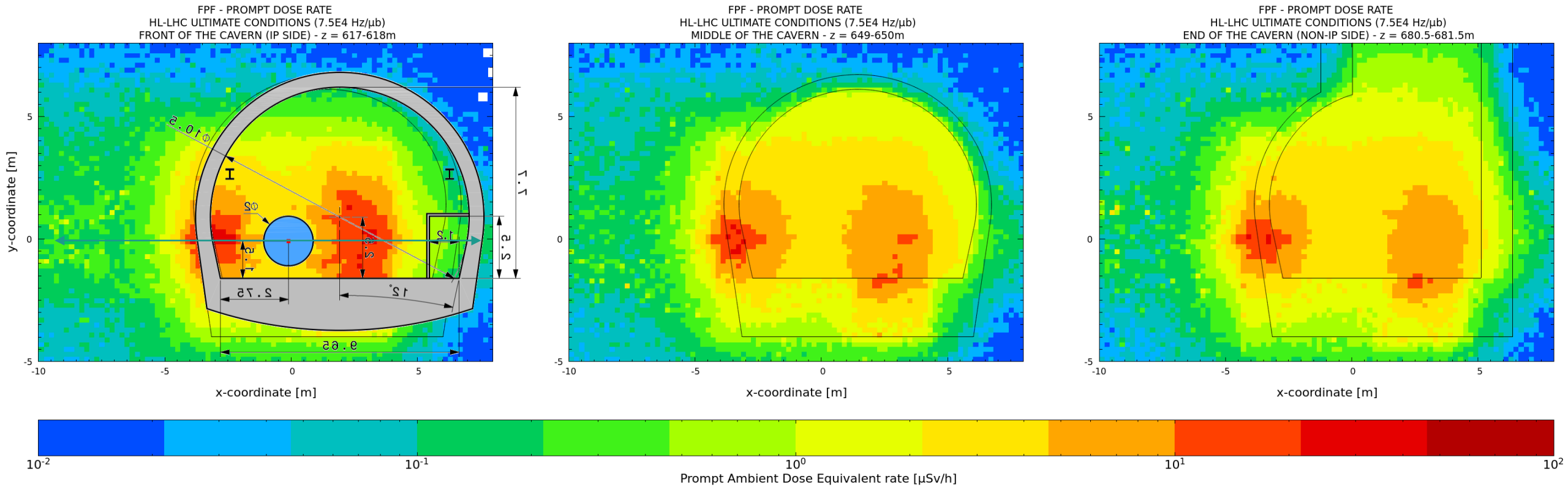
COMMENT:

"Empty cavern": Detectors not included in simulation; 'secondary' particles will increase H*(10) … to be studied later

$H^*(10)$ 2D maps

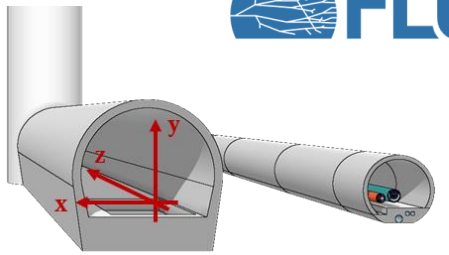


FLUKA

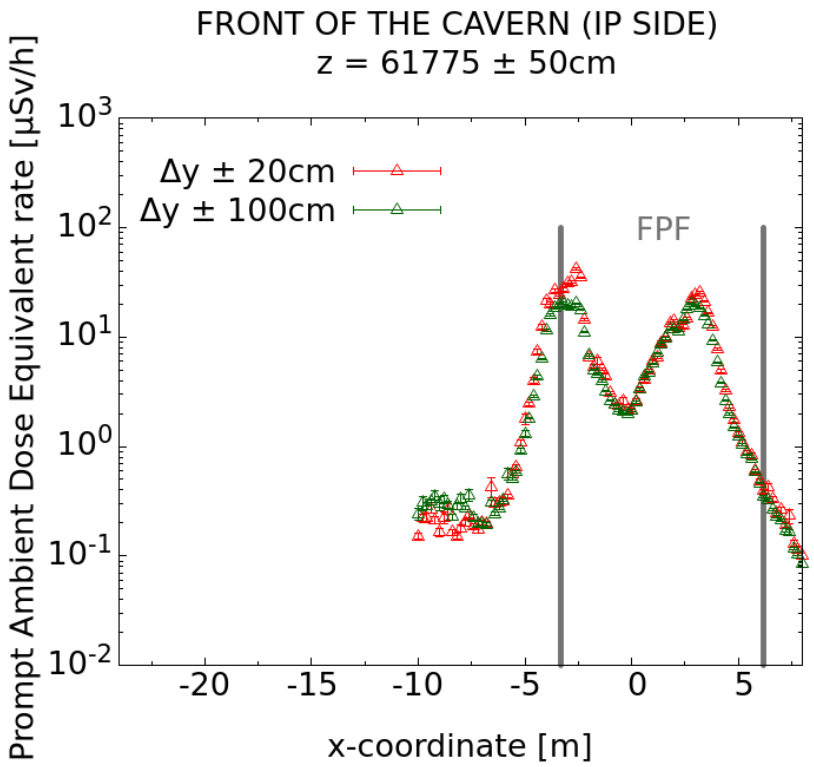


Note that the shape of the cavern has changed due to the suppression of the safety tunnel. Nevertheless, the general outcome is still valid.

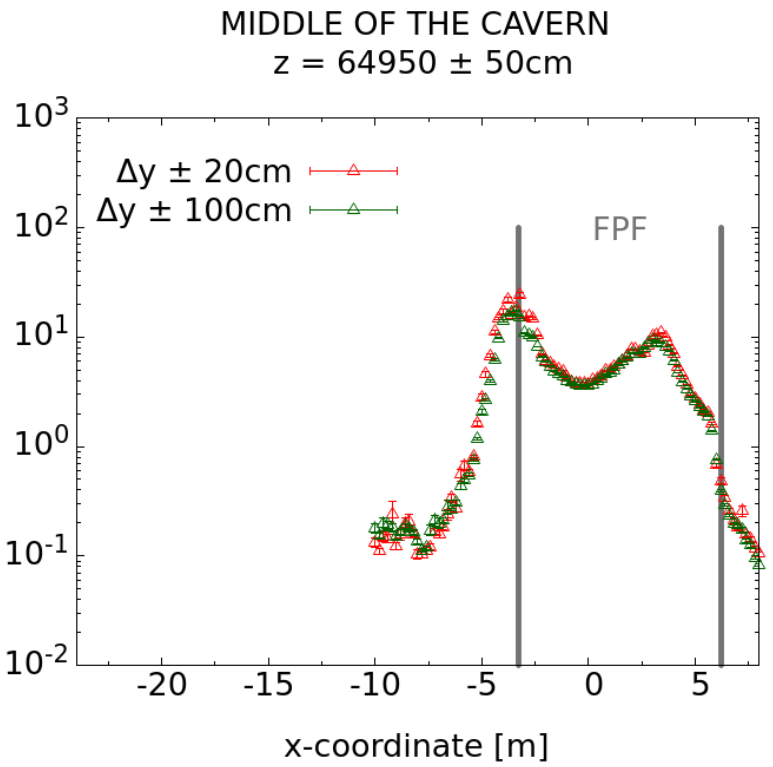
$\dot{H}^*(10)$ profile



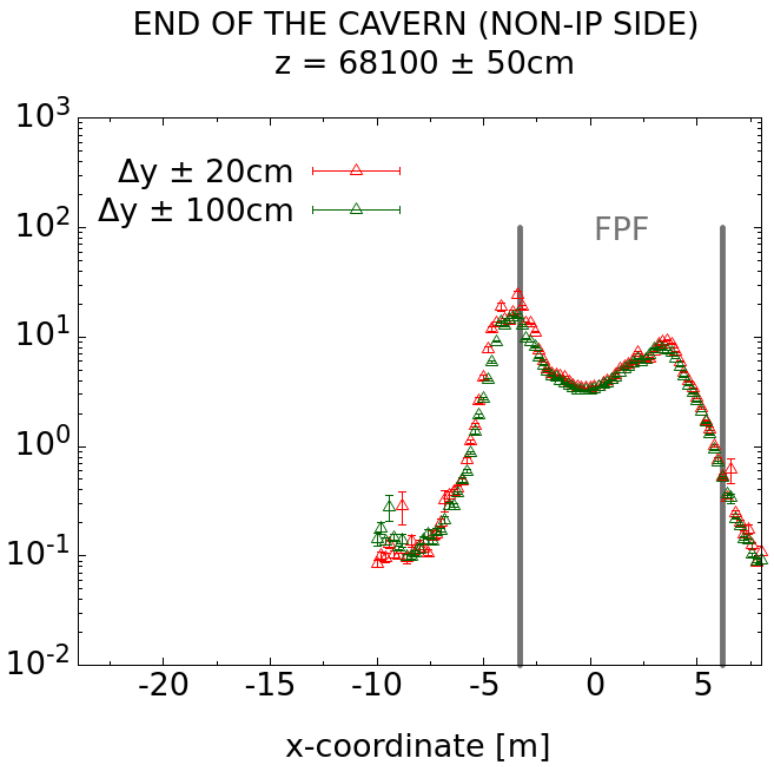
FPF - HL-LHC ULTIMATE CONDITIONS (7.5E4 Hz/μb)



Simple Controlled Radiation Area
< 50 μSv/h

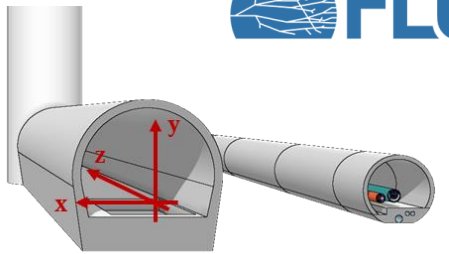


Supervised Radiation Area
< 15 μSv/h

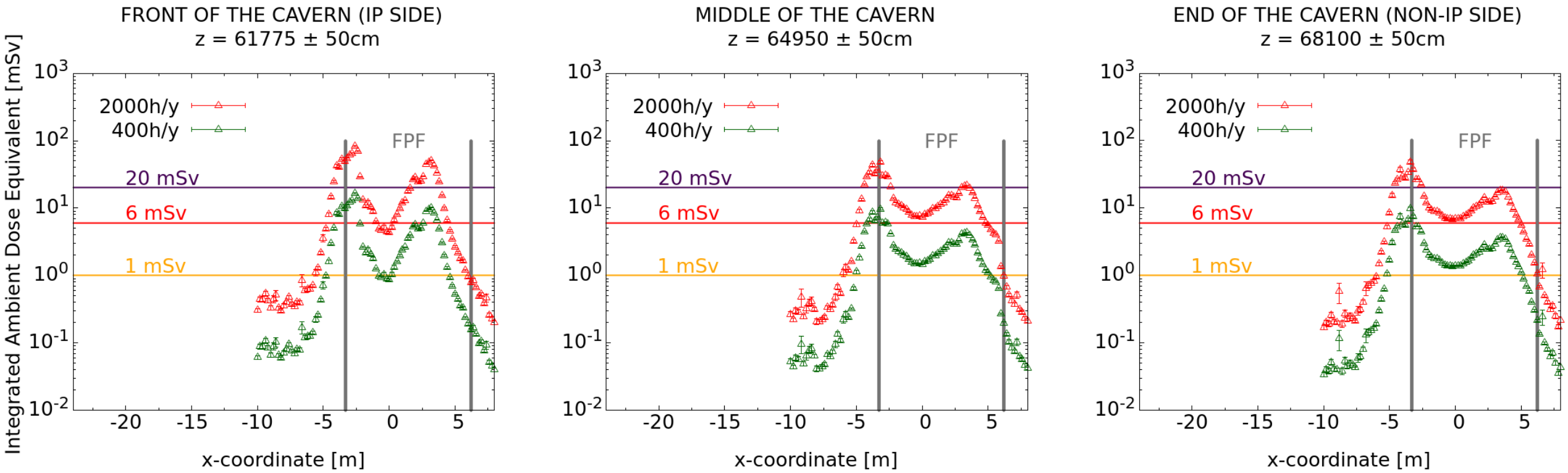


Supervised Radiation Area
< 15 μSv/h

$H^*(10)$ profile



FPF - HL-LHC ULTIMATE CONDITIONS (7.5E4 Hz/μb) - Δy ± 20cm



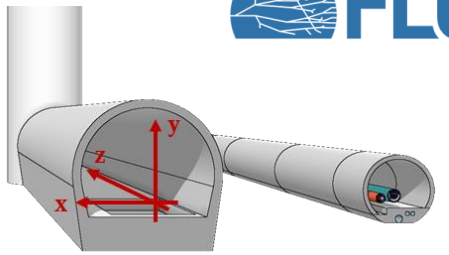
Summary

- ✓ Accessibility of the experimental cavern during LHC operation requires the evaluation of different source terms: beam-gas interactions, direct muon contribution to prompt dose, loss of the LHC and SPS beam
- ✓ Operational scenario:
  - ✓ **From previous studies:** prompt dose rate from beam-gas interaction below 2.5 μSv/h (limit for non-designated areas), dose from accidental LHC and SPS beam loss negligible.
  - ✓ **From this study:** Direct contribution from muons coming from IP1/LSS1 can limit the accessibility to the cavern during LHC operation, i.e. > 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.
  - ✓ No permanent control rooms are foreseen underground. Nevertheless, "*During installation and commissioning, there maybe people in the cavern for an extended period, but this will be only for a short period and not routine operation*" → time to be quantified.
  - ✓ Final study to be done with 'detectors/equipment installed/integrated in the FLUKA model'
  - ✓ Excavation to be performed outside LHC operation → external personnel involved in the excavation (of the cavern and the lower part of the shaft) have to be classified as "Radiation Workers"

HSE
Occupational Health & Safety
and Environmental Protection unit

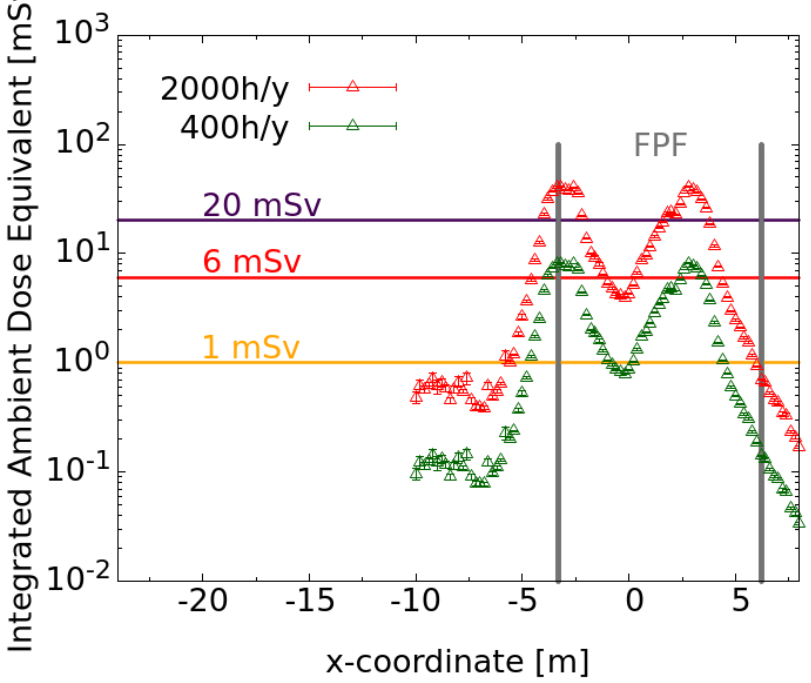
BACKUP SLIDES

$H^*(10)$ profile

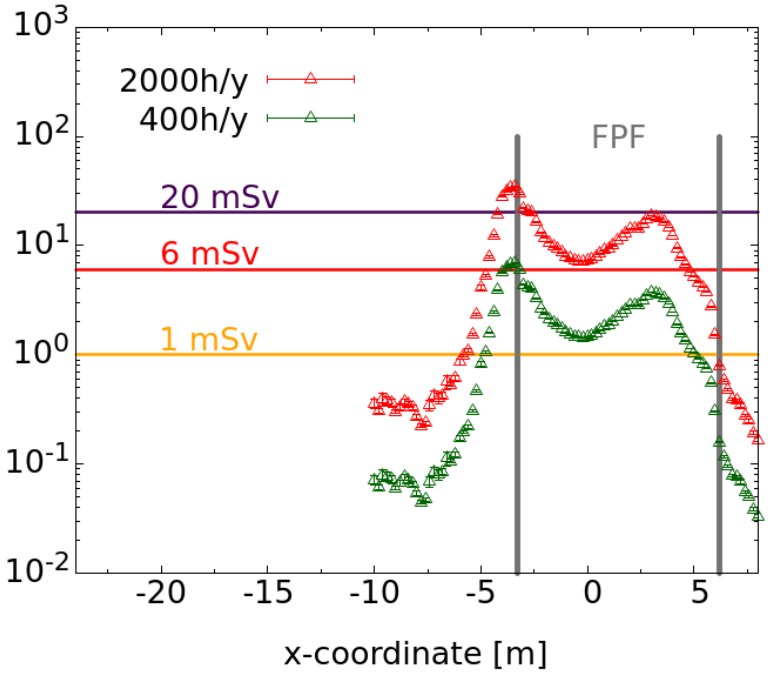


FPF - HL-LHC ULTIMATE CONDITIONS (7.5E4 Hz/μb) - Δy ± 100cm

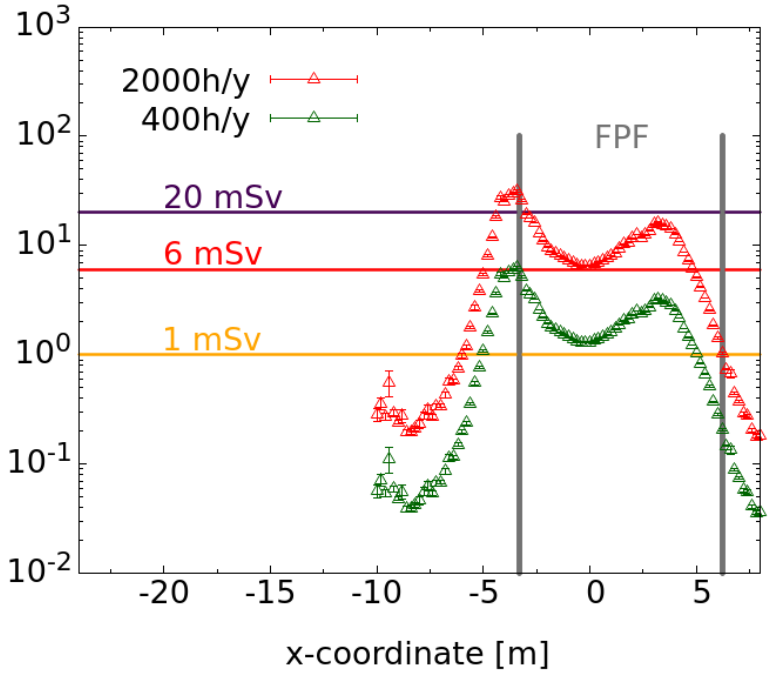
FRONT OF THE CAVERN (IP SIDE)
z = 61775 ± 50cm



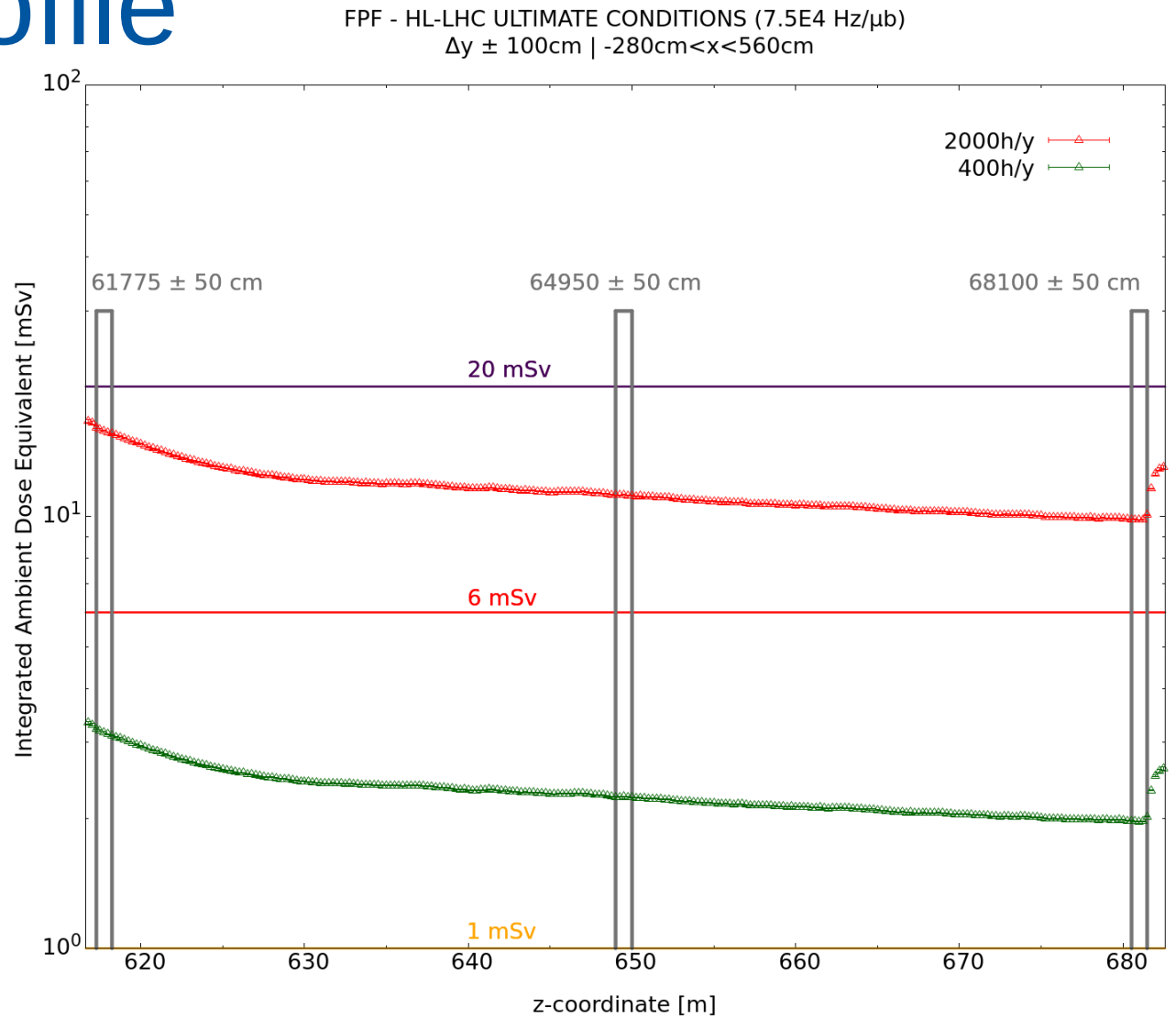
MIDDLE OF THE CAVERN
z = 64950 ± 50cm

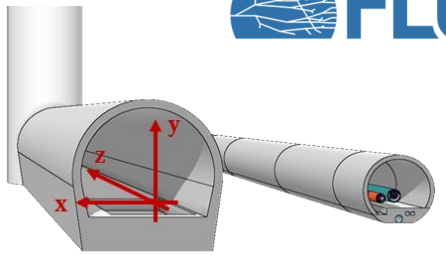


END OF THE CAVERN (NON-IP SIDE)
z = 68100 ± 50cm

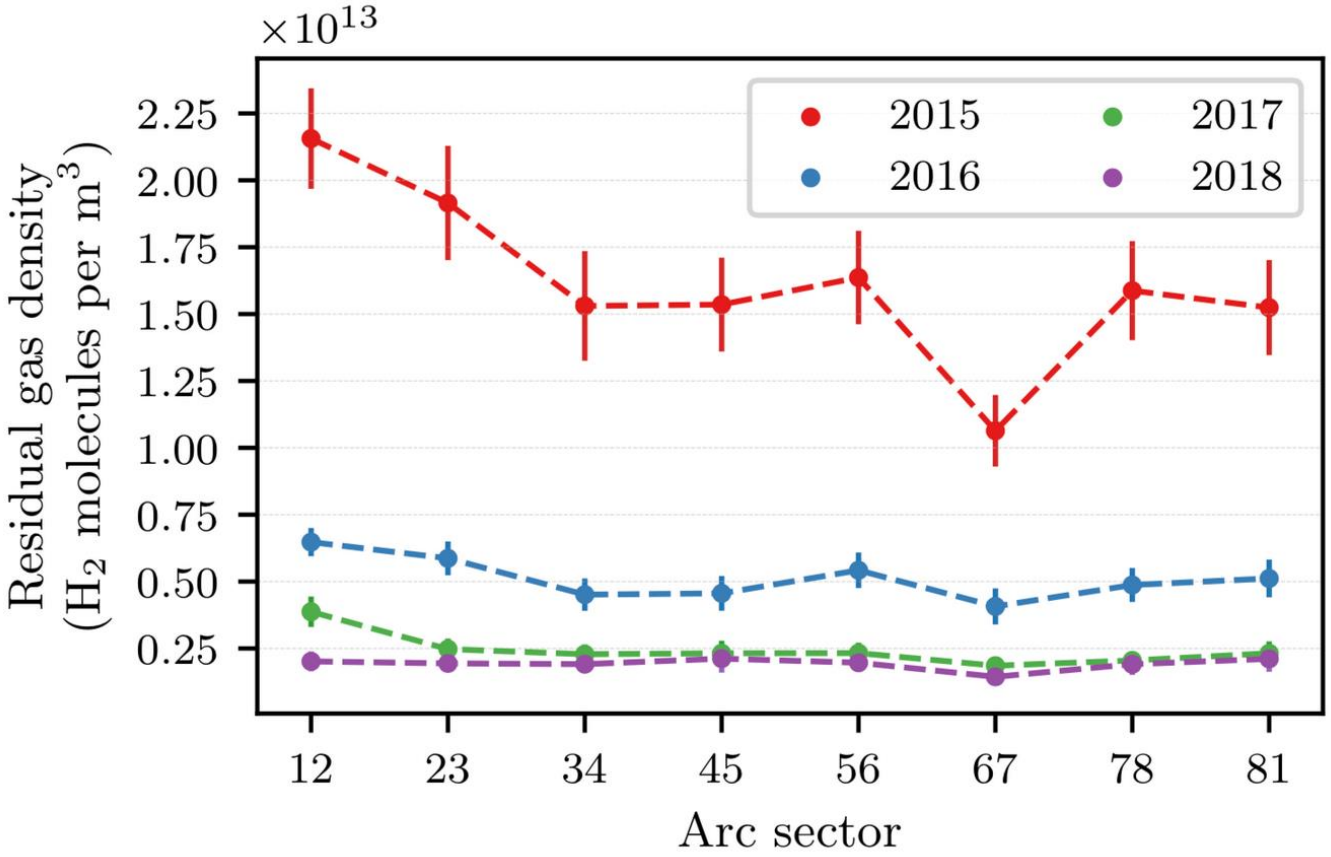


$H^*(10)$ profile


FPF - HL-LHC ULTIMATE CONDITIONS (7.5E4 Hz/μb)
Δy ± 100cm | -280cm<x<560cm
2000h/y
400h/y
61775 ± 50 cm
64950 ± 50 cm
68100 ± 50 cm
20 mSv
6 mSv
1 mSv
Integrated Ambient Dose Equivalent [mSv]
z-coordinate [m]
10^2
10^1
10^0
620
630
640
650
660
670
680


y
z
x

Source term: Beam-gas interactions



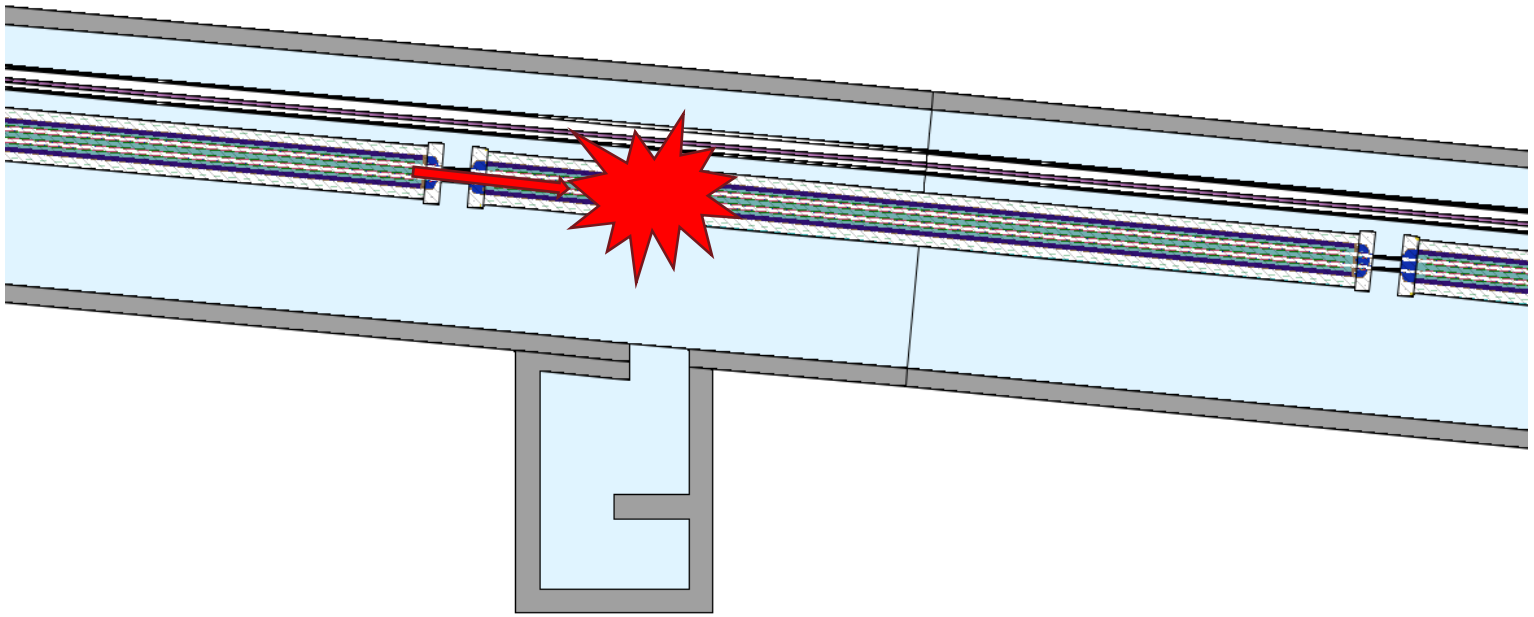
Residual gas density:

- LHC design max 1E15 H_2/m^3 for 100h beam lifetime (LHC design report)
- R2E studies on Run 2 shows that the residual gas-density can be better than 2.25E13 H_2/m^3
- However:
  - Difficult to predict Run 3 (and beyond) performance
  - Machine can undergo through a conditioning, i.e. higher gas-density at the beginning of a Run
- This work: conservative assumption of 1E15 H_2/m^3

K. Biłko et al. Radiation Environment in the LHC Arc Sections during Run 2 and FutureHL-LHC Operations.IEEE, Transactions on Nuclear Science, DOI 10.1109/TNS.2020.2970168.

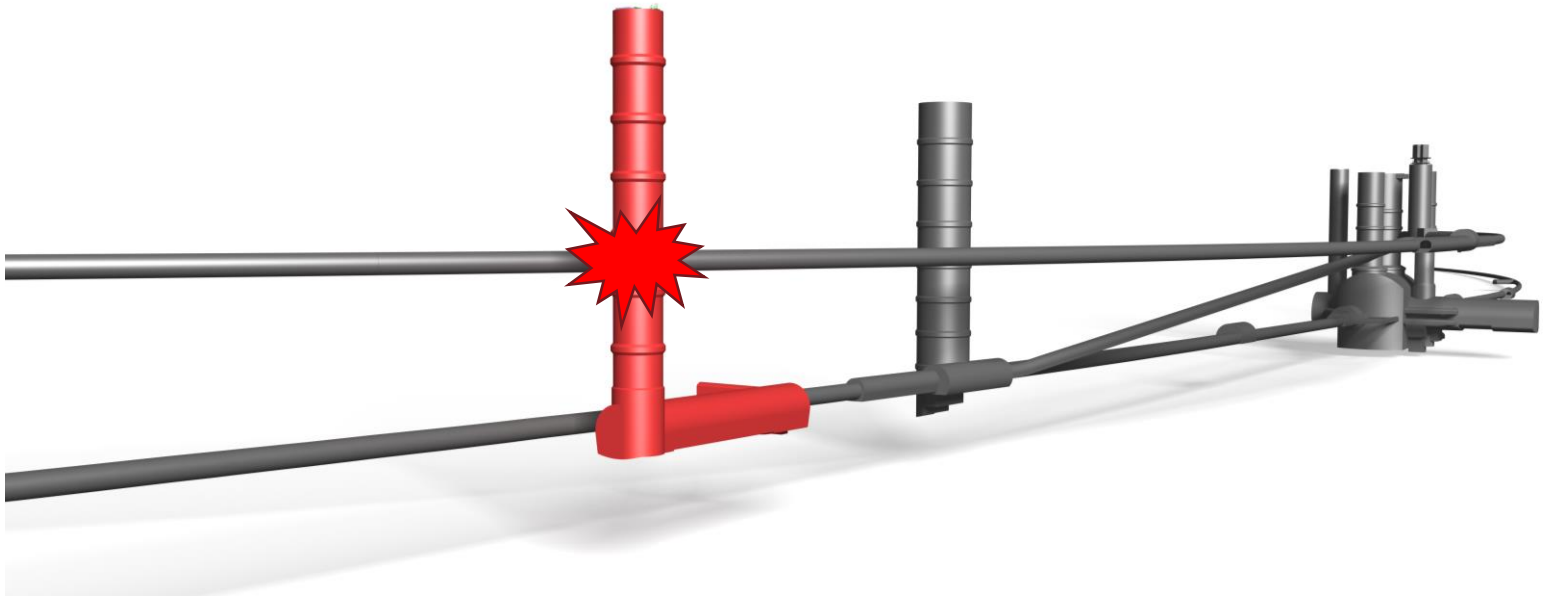
Source term: Loss of LHC beam

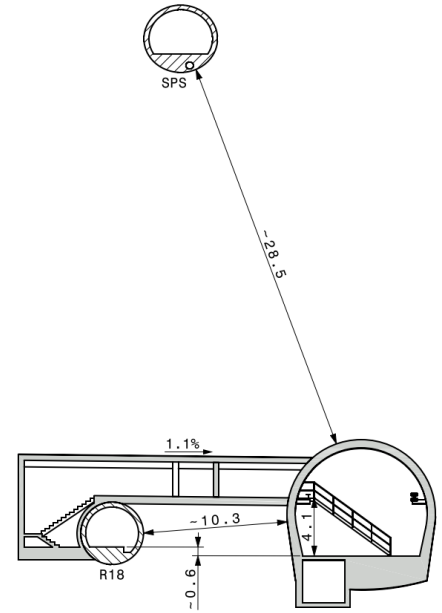
- Loss of the 7 TeV LHC beam on the MB.B15R1
- Check the streaming through the safety gallery/chicane
- Sensitivity analysis to check the effect of the loss point → worst case scenario loss in front the safety gallery entrance
- Normalization: HL-LHC conditions, i.e. 2748 bunches and 2.3E11 ppb

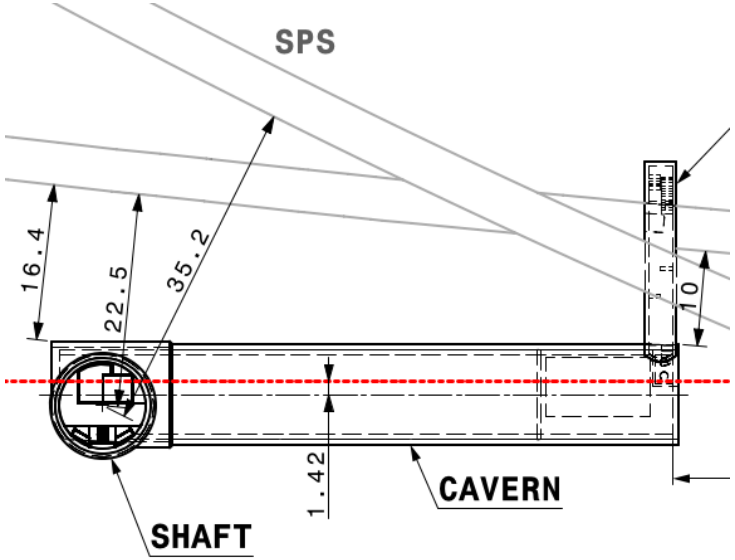


Source term: Loss of SPS beam

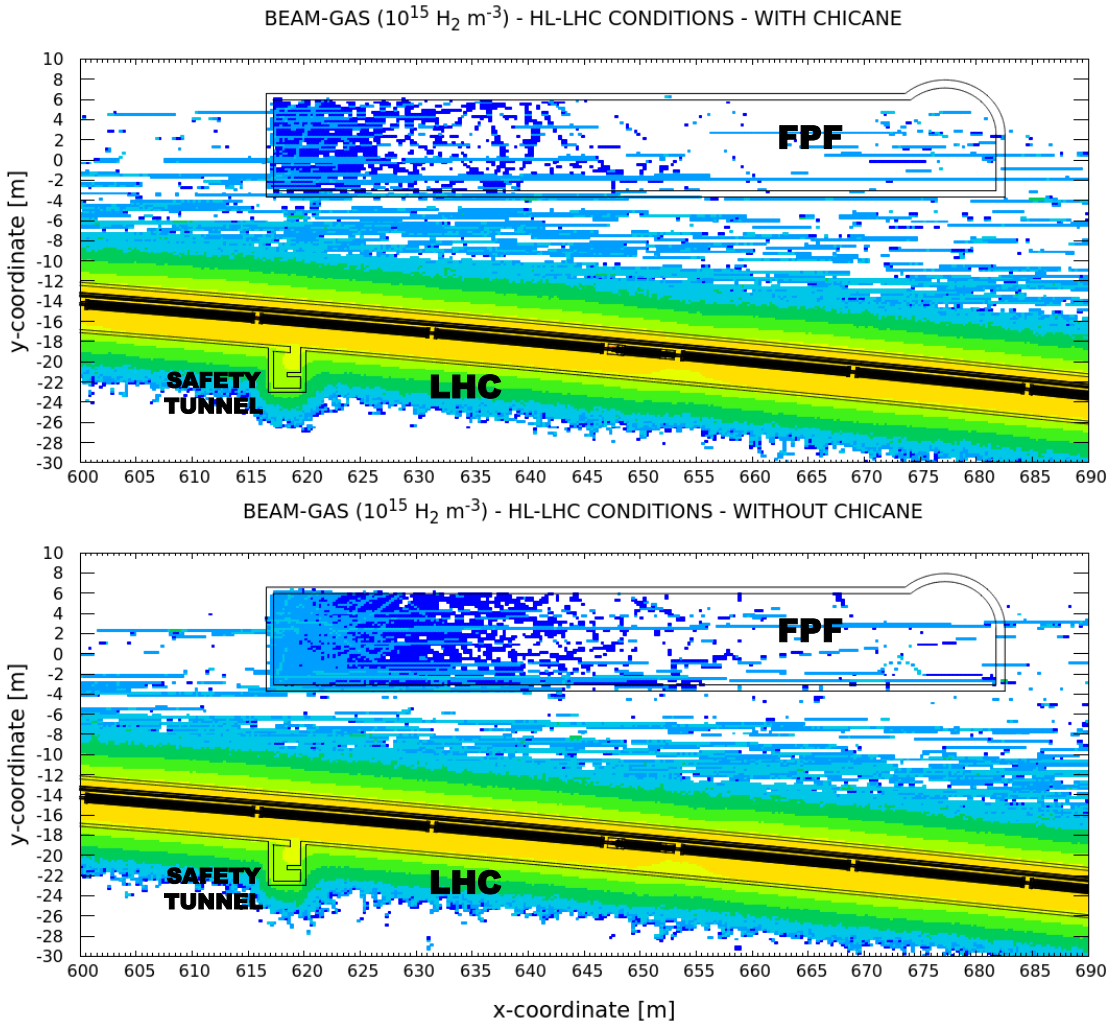
- Loss of the 450 GeV SPS beam in the SPS tunnel
- Mainly critical for the shaft
- Distance of the SPS tunnel from the shaft > 35m
- Radiological impact in the shaft due to beam loss in SPS can be neglected

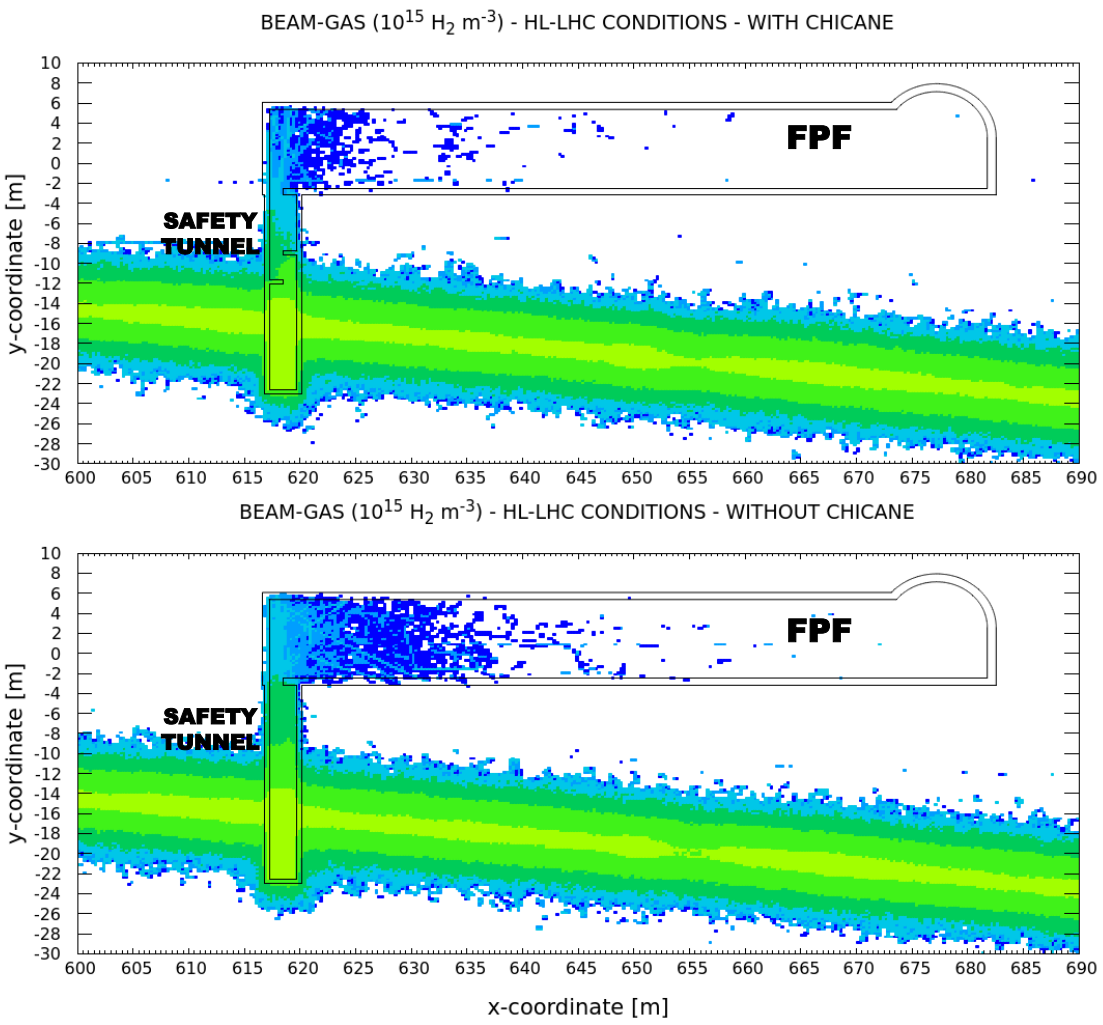


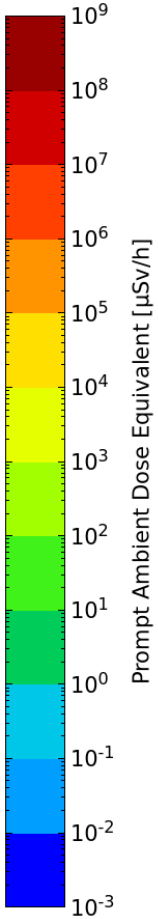




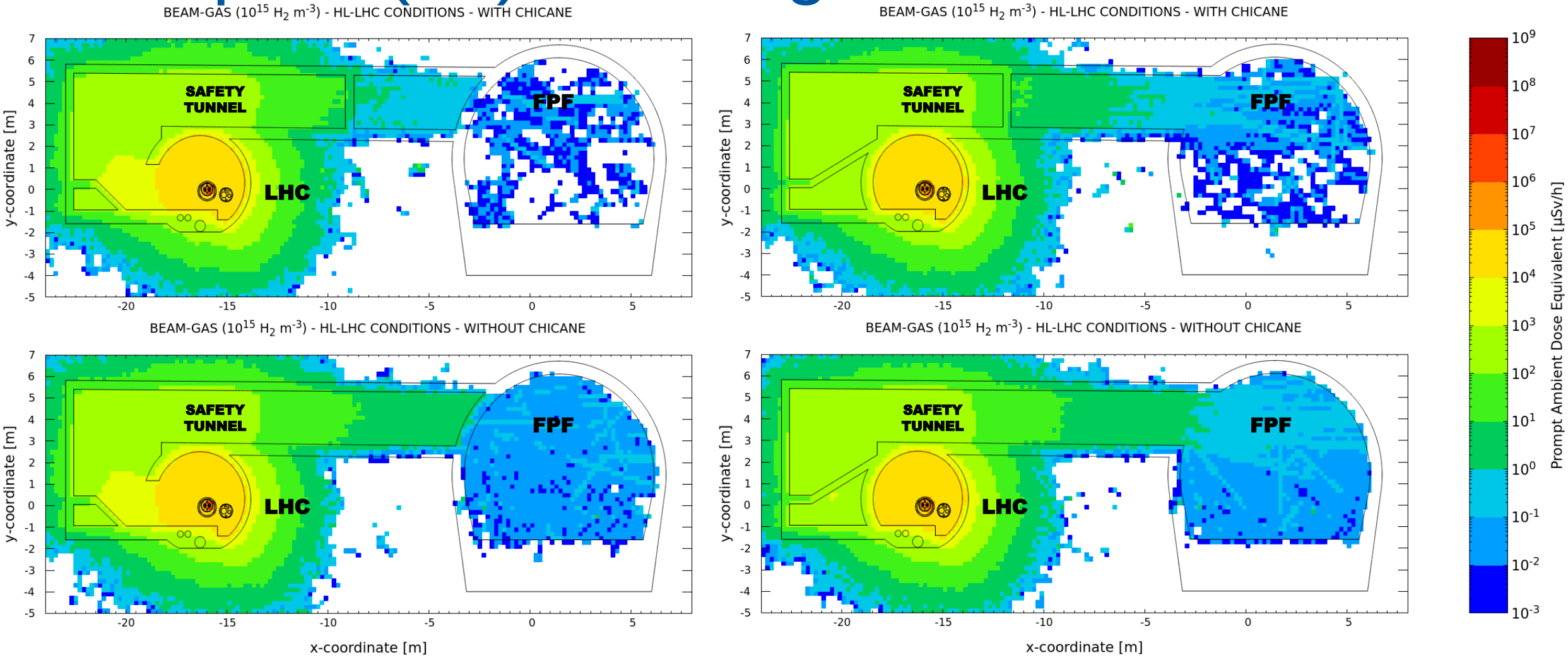
Prompt H*(10): beam-gas



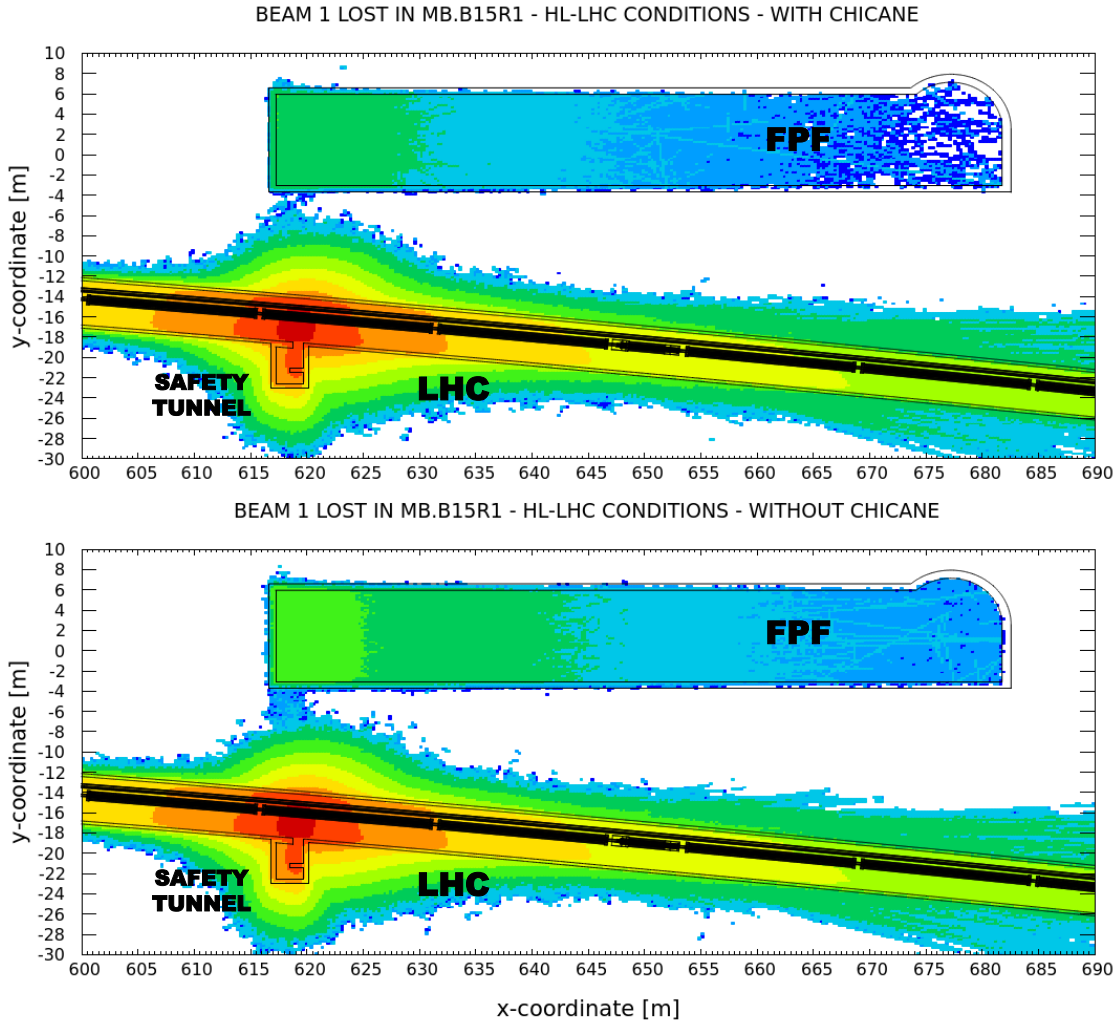


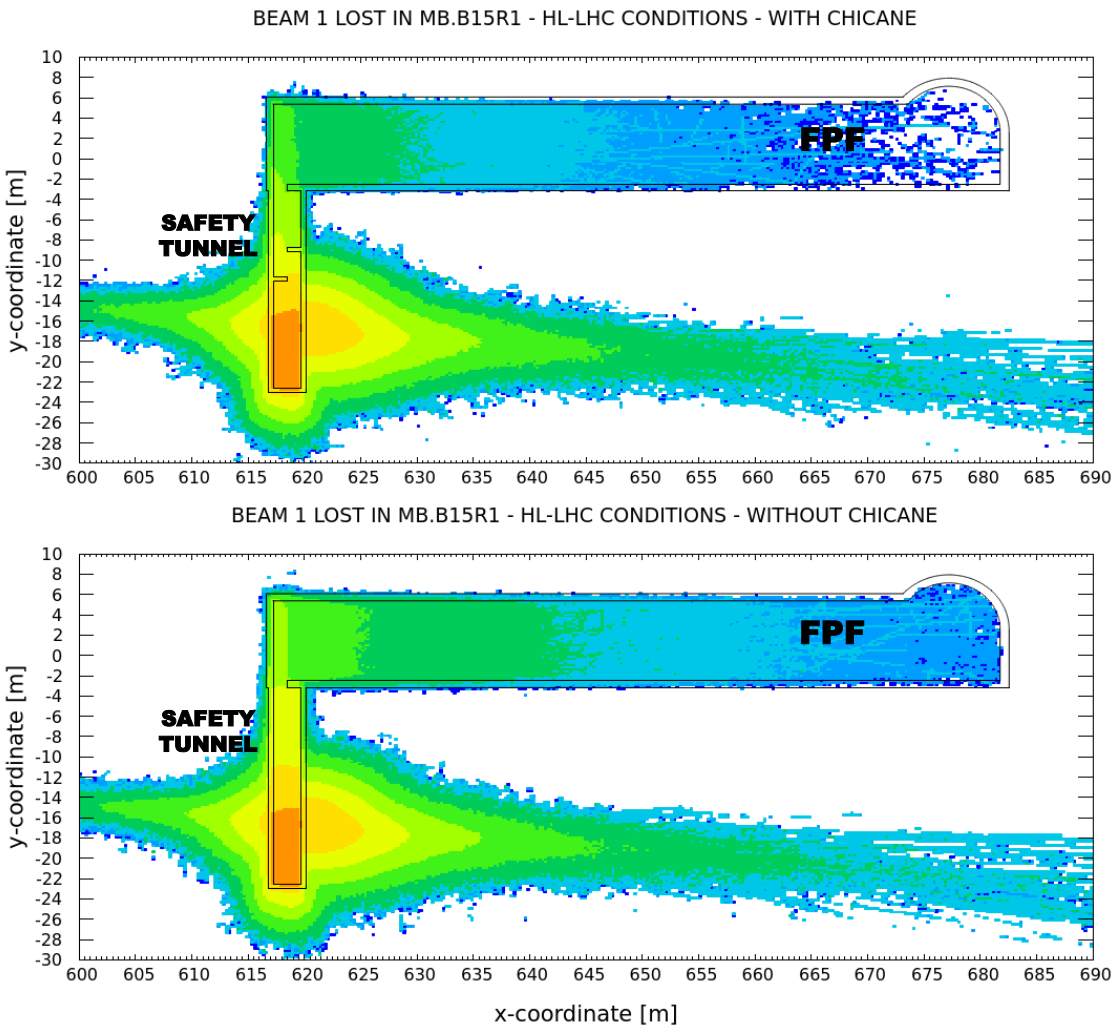


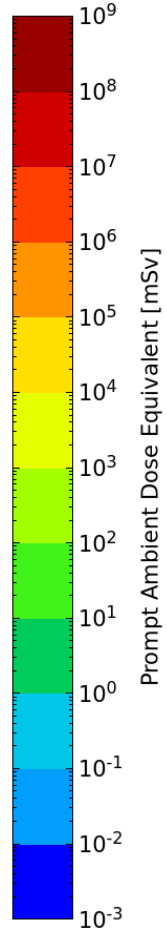
Prompt H*(10): beam-gas



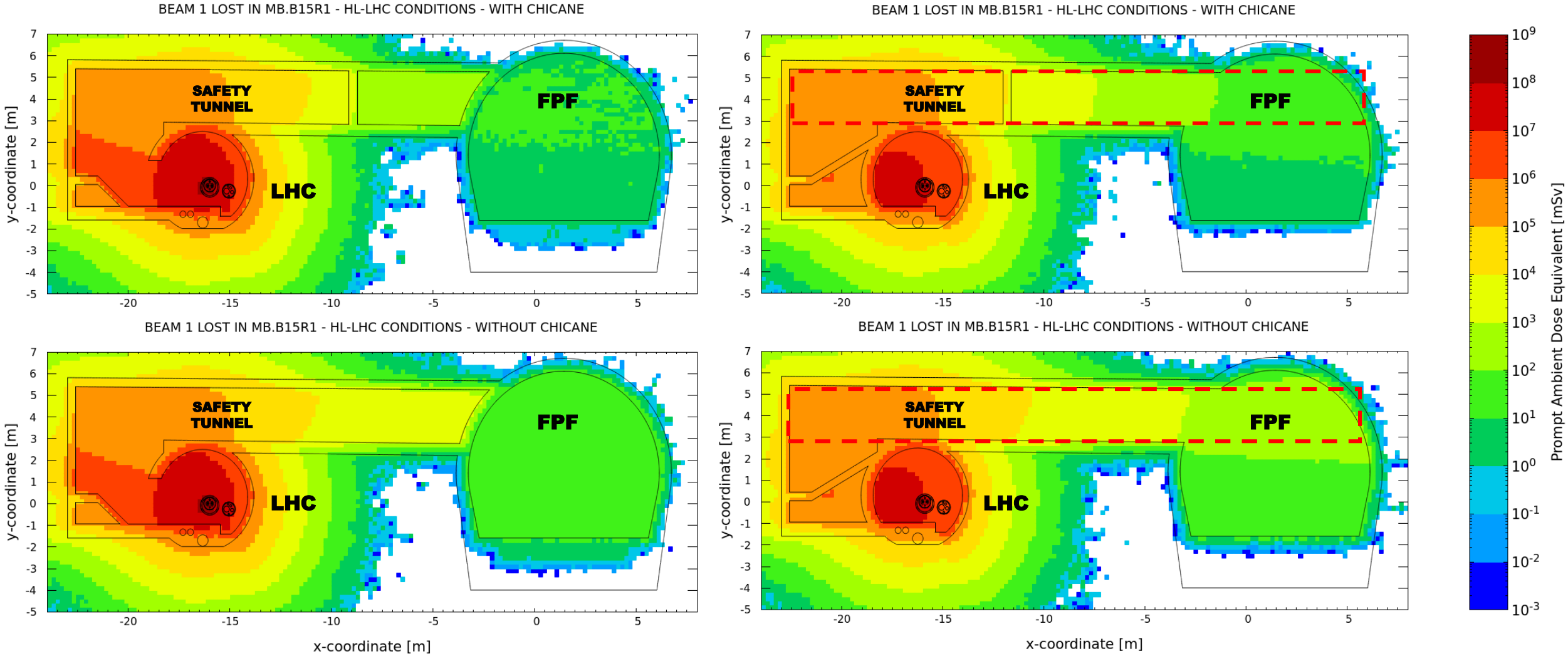
Prompt H*(10): loss of the LHC beam



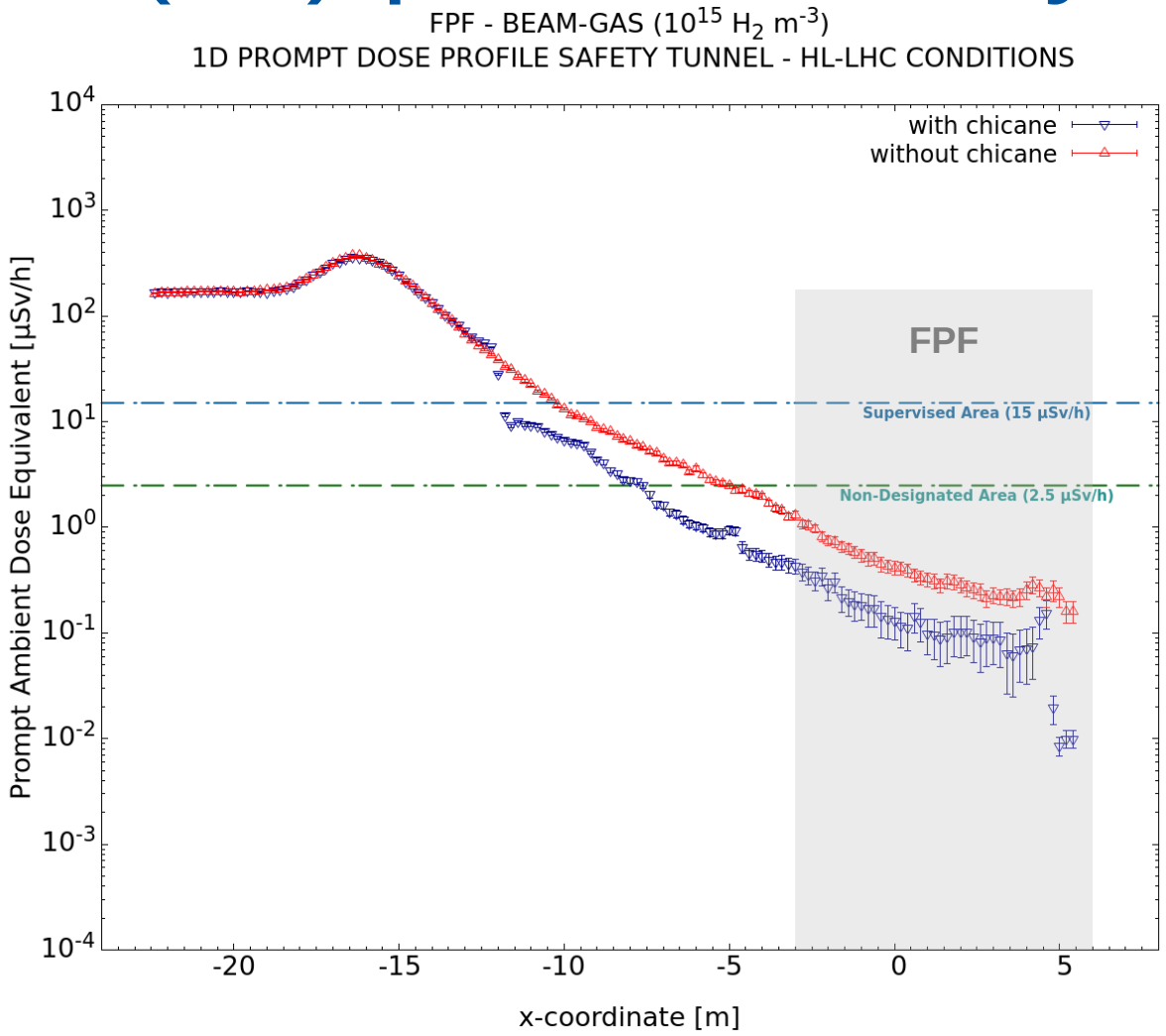


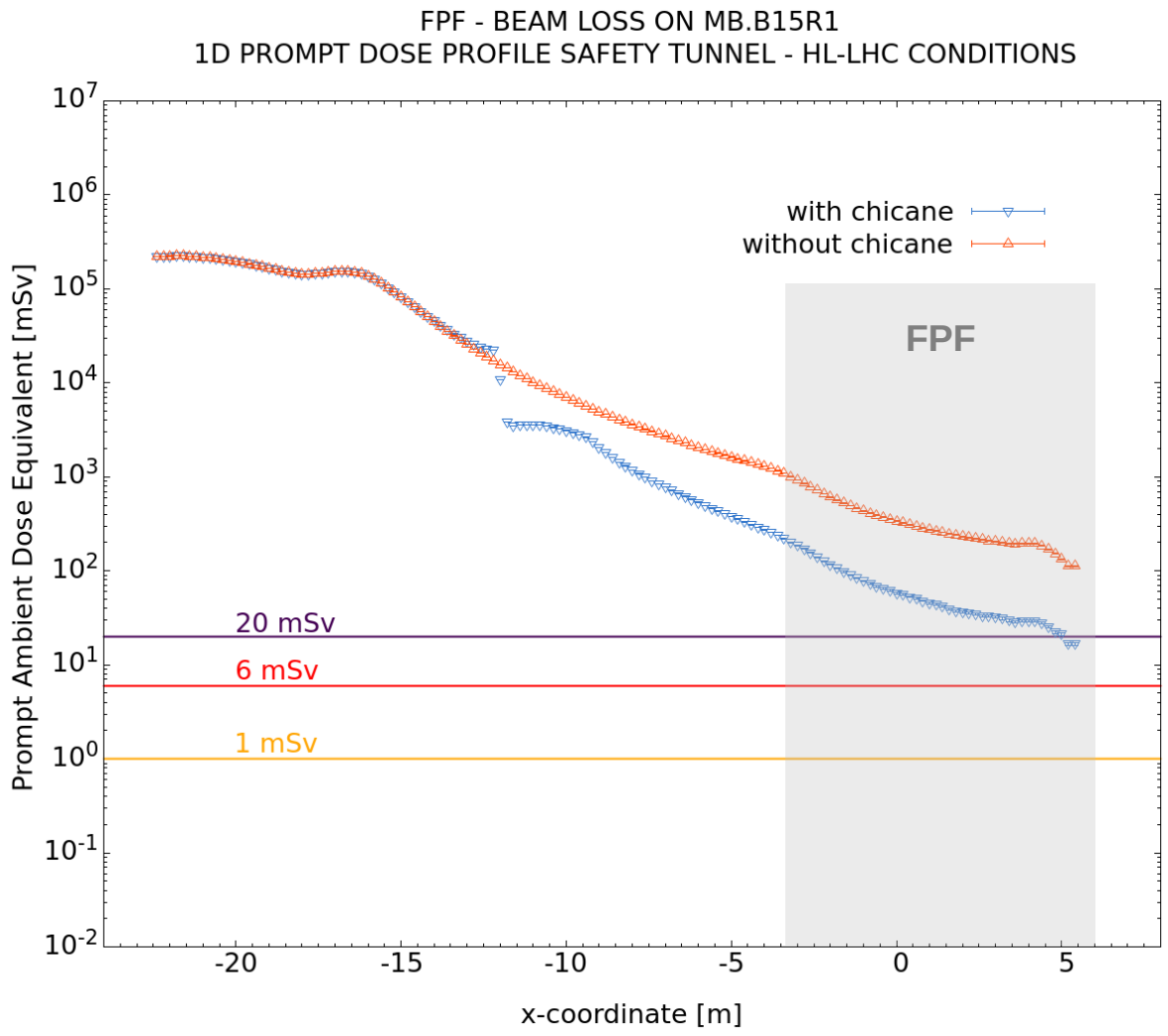


Prompt H*(10): loss of the LHC beam



H*(10) profile: safety tunnel





H*(10) profile: safety tunnel