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Updated Radiation Protection studies for the AION100 experiment at LHC Point 4: evaluation of different shielding options

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Summary

This note summarizes the Radiation Protection studies conducted in the context of the AION-100 experiment at CERN. AION100 is a proposal for an experiment to be possibly installed in the LHC Point 4 PX46 shaft. FLUKA Monte Carlo simulations of the full loss of a 7 TeV beam on a RF element in the LSS4 were conducted to evaluate the ambient dose equivalent field in the PX46 shaft. Preliminary Radiation Protection recommendations were given in a previously released HSE-RP Technical Note EDMS 2333747. This updated Technical Note provides new results considering different shielding options in TX46 or directly in PX46.

Contents

1 Introduction

The AION collaboration is aiming at ultralight dark matter searches with ion interferometers, and is currently developing a 10 meters long version of the interferometer. In parallel they are evaluating different options for the location of a proposed 100 meters long ion interferometer. With the support of the Physics Beyond Colliders study – Technology WG, the AION collaboration is investigating the possibility of installing the AION-100 interferometer (a 100 m height detector) in the PX46 pit at CERN [1, 2].

A first study was produced with the following working conditions/assumptions desired:

- Use pre-existing shaft;
- Need approximately 100 m long column, with a minimum requirement of 80 m;
- Plan to build in many small modules: presently 5 m modules but could be up to 10 m sections;
- Assume a minimum of 3 laser sources but could be more: up to one per module;
- Assume crane operation during access to the experiment;
- Keep option of an assembly hall at top or bottom of the shaft: build from the bottom (down from top is difficult for crane);
- Assume progressive testing as the system is assembled.

One of the key points highlighted above, is the need to access the detector during beam operation, using a dedicated platform. Figure 1 shows the possible platform alternatives that might be used to access the detector, depending on the diameter of the shaft.

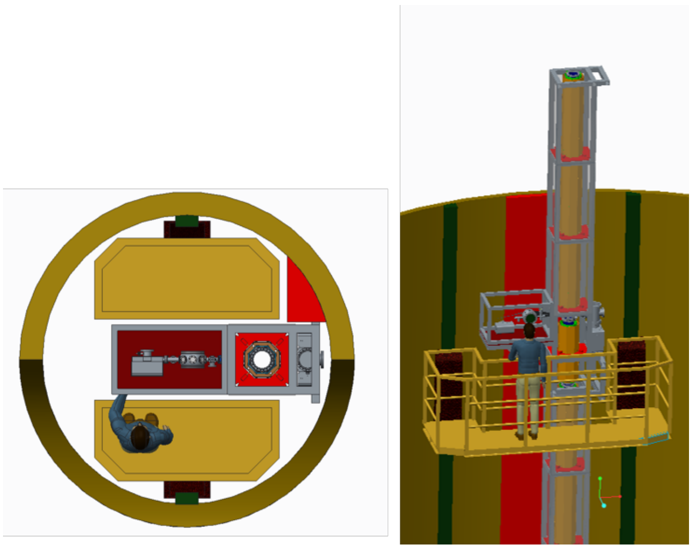


Figure 1: Example of possible platforms used in a small (2.4 m diameter, left) or large (20 m diameter, right) shaft.

The project is therefore evaluating the possibility to install the AION100 detector in the PX46 shaft, at LHC Point 4. The PX46 is currently used for ventilation, release of smoke in case of fire and transport (RF cavities) purposes and it fits the height requirement set by the project, thanks to its ~ 146 m depth as detailed in EDMS 2682927 v.1 . However, accessing the shaft during LHC operation poses a set of Radiation Protection (RP) problems that need to be addressed, such as the classification of the area, the ambient dose rate during operation and the maximum effective dose in the shaft in case of accident.

At the time of this note, the main references for RP studies at LHC Point 4 are EDMS 2333747 [3] and EDMS 1822274 [4]. EDMS 1822274, by I. Brunner and S. Roesler, provides the original shielding calculations for the machine tunnel crossing the UX45 cavern. EDMS 2333747 provides the first RP evaluation conducted within the AION100 project by considering no shielding in the PX46 shaft and the loss of the full HL-LHC 7 TeV proton beam in one of the RF elements of the LSS4. The recommendation given in the EDMS 2333747 was not to exceed a maximum depth of 90 m, to withstand with the design goal of maximum 1 mSv effective dose.

This Technical Note (TN) aims to update EDMS 2333747. Indeed, the project is now exploring the possibility to further extend the experiment depth by evaluating different shielding options and to reduce further the radiation levels in PX46. Two shielding options were studied:

1. **Option 1** consists on a 80 cm thick concrete wall in TX46;

2. **Option 2** consists on a 40 cm thick concrete slab in PX46.

The different options are shown in Figure 4 [5]. For both options, the shielding blocks are removable in order to enable access to the area reserved for handling/transport of heavy objects (Figure 2). This study updates the EDMS 2333747 by considering the accidental scenario for the above shielding options.

With regard to the ventilation, the air flow comes from UX45, then goes into the TU46 and it is finally extracted from the PX46. In addition, as mentioned above, the PX46 is used for smoke extraction in case of fire. Therefore, the ventilation layout might need to be revised by EN-CV in the future depending on safety constraints and the final configuration of the experiment.

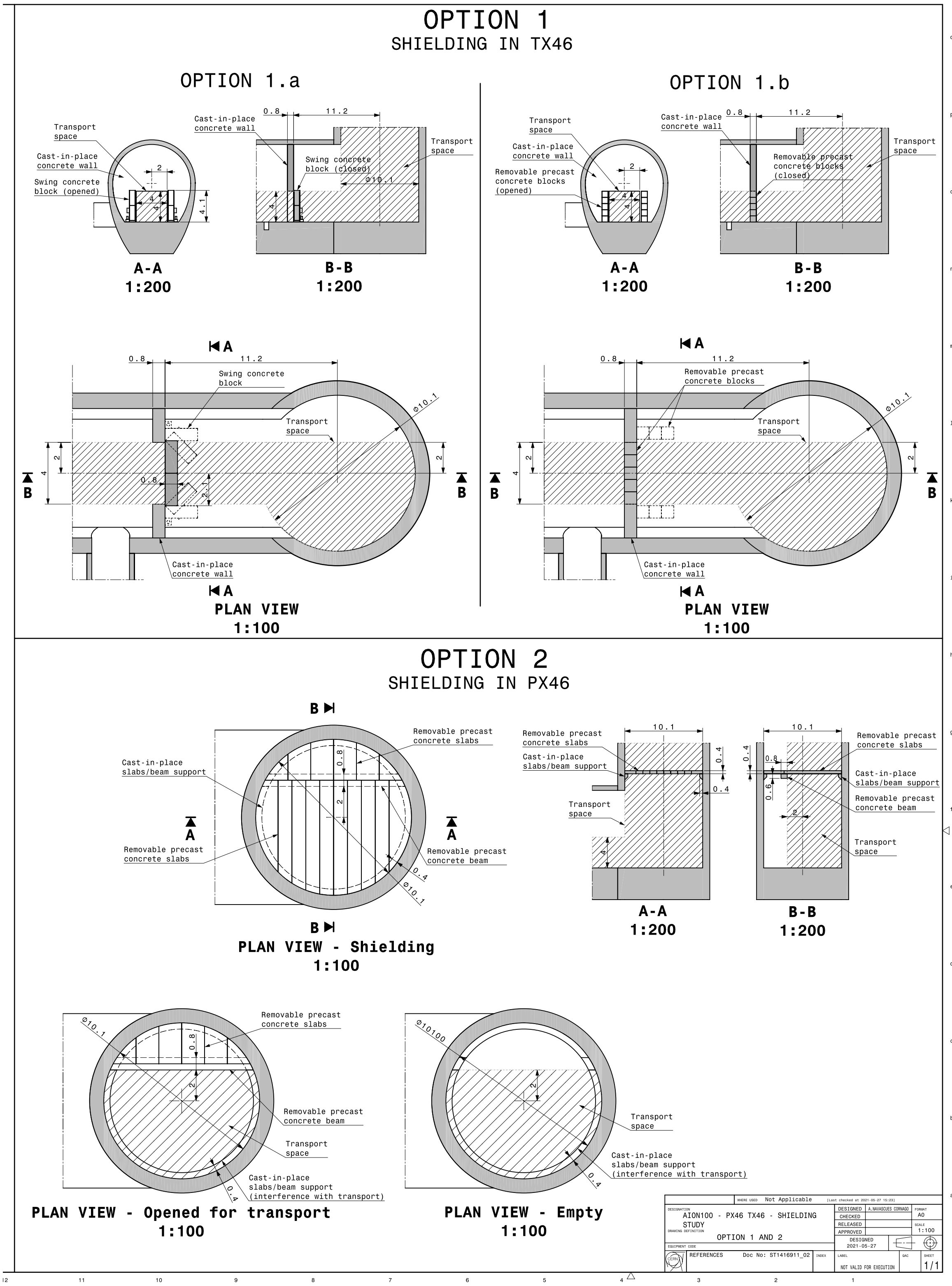


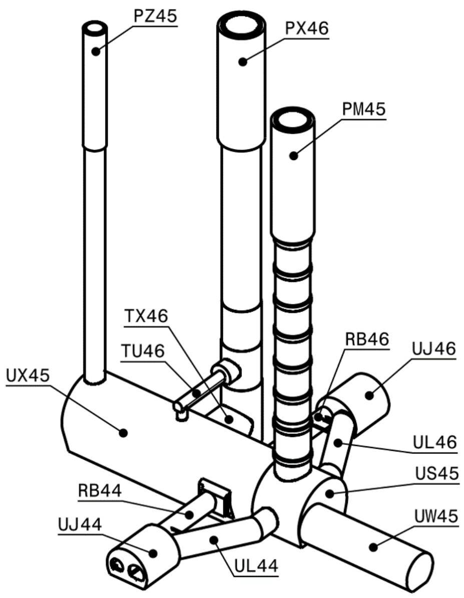
Figure 2: Technical drawings of the different shielding options. Courtesy of Kincso Balazs (SCE-DOD).

2 FLUKA simulations

2.1 Geometry of LHC Point 4 infrastructure

The FLUKA geometry used in EDMS 2333747 (Figure 3) was modified to include the new shielding options. The model now includes:

- the UX45 cavern;
- the PX46 shaft;
- the TX6 and TU46 tunnels;
- 80 cm thick concrete wall in TX46 (**option 1** - Figure 4a) - NEW;
- 40 cm thick concrete wall in PX46 (**option 2** - Figure 4b) - NEW.



(a) Isometric view

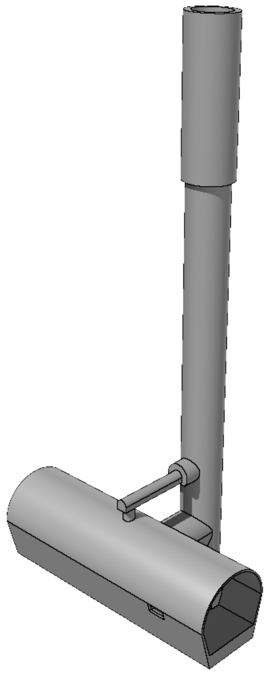
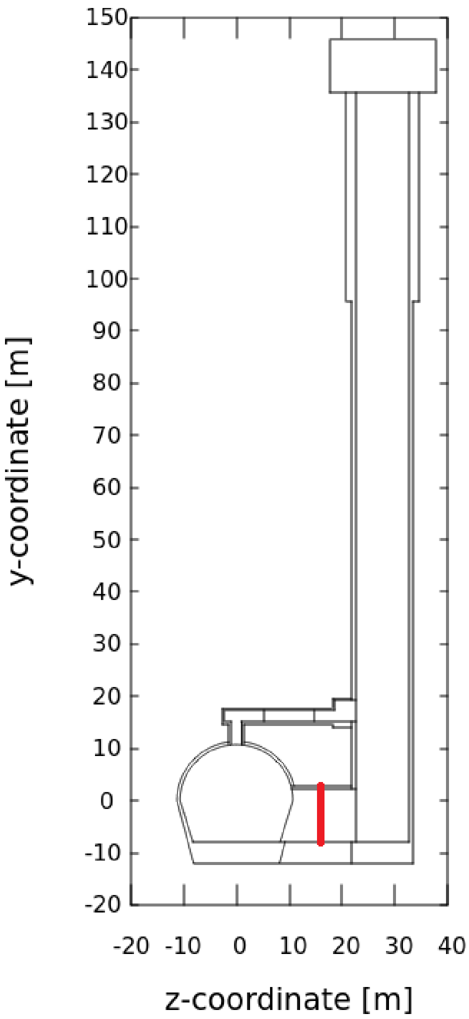

(b) FLUKA model

Figure 3: Isometric view of LHC Point 4 infrastructure compared to the implemented FLUKA model.

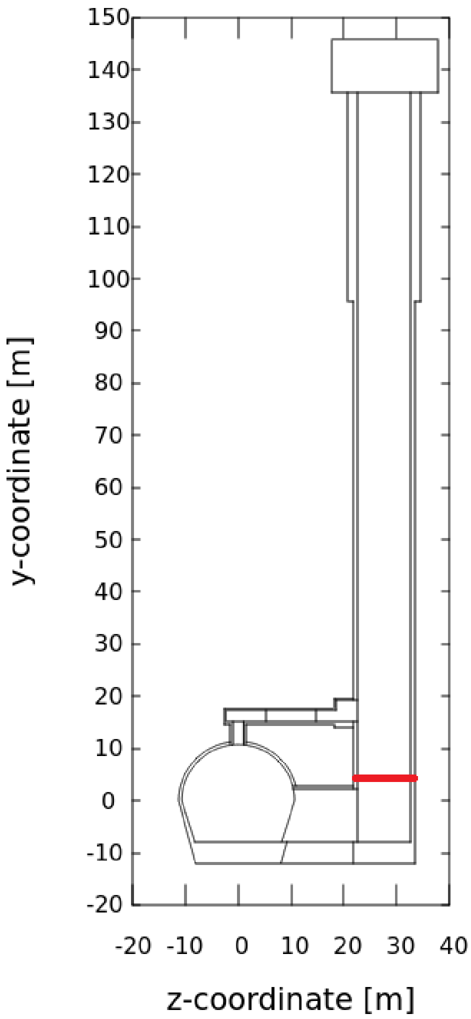
The detailed description of the main FLUKA model is reported in EDMS 2333747 while in the following only the changes related to the new shielding options will be described.

2.2 Transport settings and scoring

At the time of this note, the timescale of this project is not yet known, i.e. it is not known when the detectors might be ready for installation. Therefore, the RP evaluation



(a) Option 1



(b) Option 2

Figure 4: FLUKA geometries of the two shielding options (highlighted in red).

reported in this TN takes into account HL-LHC operation conditions/beam intensity, which are considered as a conservative scenario. The accidental scenario considered in EDMS 2333747 and in the present note takes into account the loss of the full HL-LHC 7 TeV proton beam on one of the element of the LSS4: to simulate this situation, a tungsten target of 100 cm length and 10 cm diameter was used since, at the time of this note, a detailed FLUKA model of the RF cavities in LSS4 is not available. Due to the shape of the penetrations in the machine tunnel, it was decided to simulate the loss of the beam on each side of the tunnel, by moving accordingly the target. Although no specific optics was used, the two beams were called accordingly to the nomenclature used in the LHC Design Report [6]:

- Beam 1 (clockwise): proton beam directed along $z > 0$;
- Beam 2 (anti-clockwise): proton beam directed along $z < 0$.

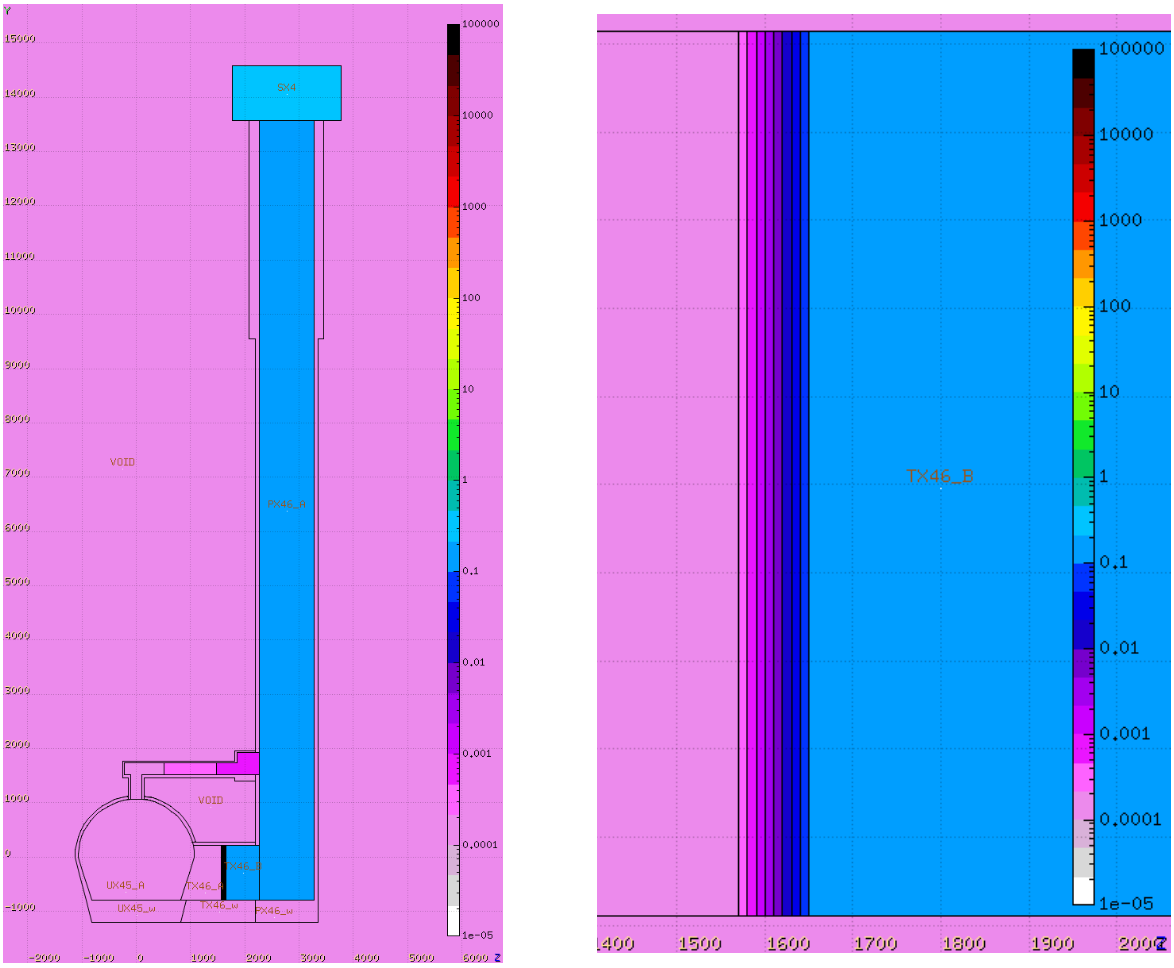
`EMF` production and transport threshold were set to 1 MeV for e^+/e^- and 100 keV for γ. Neutrons were followed down to thermal energies while the transport threshold for all other particle was set to 10 MeV. These thresholds were set under the assumption that neutrons are the most contributing particle to the prompt dose field in the PX46 shaft. To confirm this assumption, simulations in EDMS 2333747 were carried out with and without electromagnetic (EM) transport, with minor differences found. This approach was used also in the present note. However, only results with `EMF` enabled are reported in Section 3, since these provide the most accurate prediction of the ambient dose equivalent field.

Multiplicity biasing on low-energy neutrons, hadrons and muons (`WHAT(2)=0.2`) as well as EM leading particle biasing (> 1 GeV) were used. In addition, importance bias was used within the shielding wall as shown in Figure 5. It consists in dividing the wall in layers of 10 cm thickness. For each layer, the biasing factor increased by a power of two. Surrounding regions of the wall are also biased such that the ratio of the bias between two adjacent regions is < 5.

The prompt ambient dose equivalent $H^*(10)$, neutron and charged hadron fluence were scored via dedicated `USRBIN` Cartesian meshes covering both the cavern and the shaft, as in EDMS 2333747.

2.3 Normalization

As mentioned in Section 2.2, the HL-LHC beam was considered for this study, i.e. 2748 bunches with an intensity of 2.3×10^{11} protons per bunch (ppb). For comparison purposes, the LHC normalization factor was also applied considering a bunch population of 1.7×10^{11} ppb.



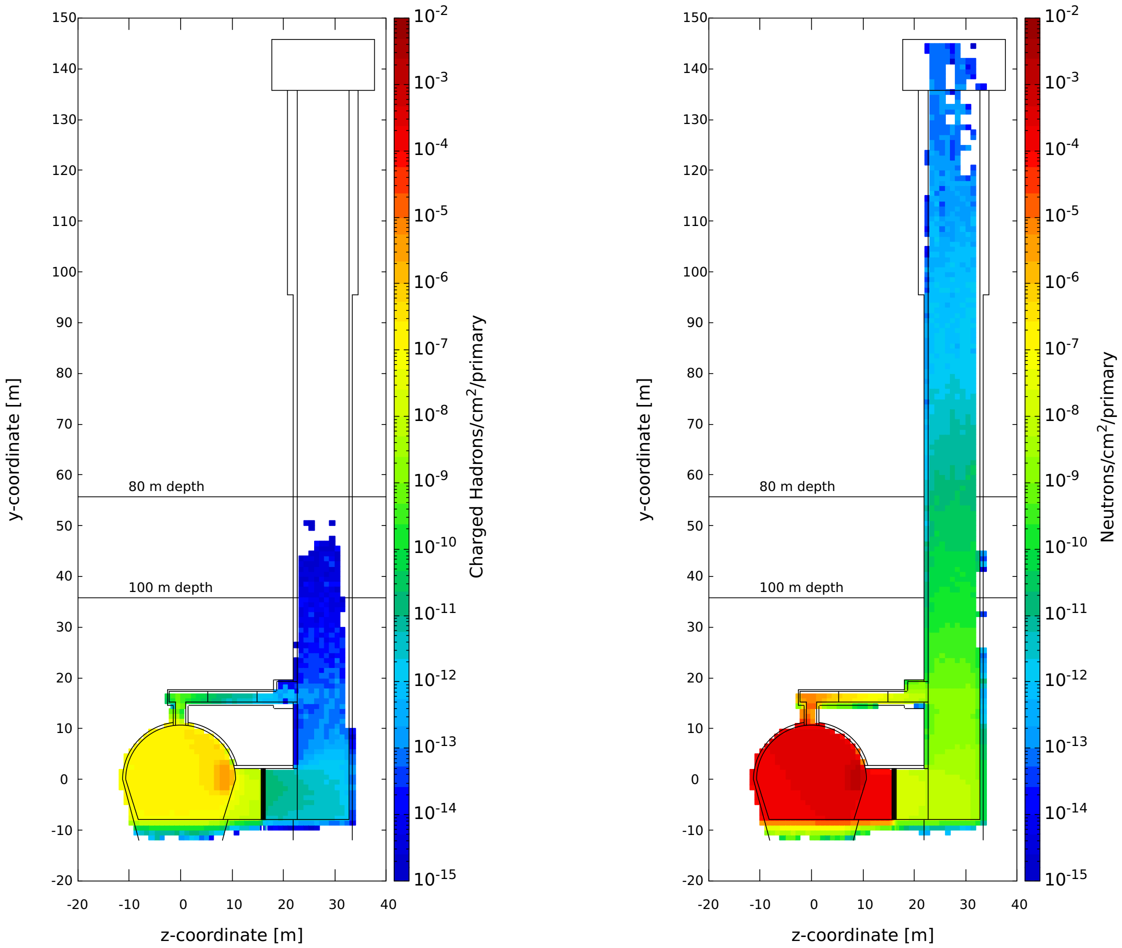
(a) View of the full geometry.

(b) Zoom on the wall biasing.

Figure 5: Importance biasing for Option 1. A similar approach was used in Option 2 were values were adapted to the geometry.

3 New shielding options

Figure 6 and Figure 7 show the comparison between the charged hadron and the neutron distribution in the PX46 shaft when the EM transport is enabled. Within the PX46 shaft, the radiation field is dominated by neutrons, whose fluence is several orders of magnitude higher than for charged hadrons.



(a) Charged Hadrons

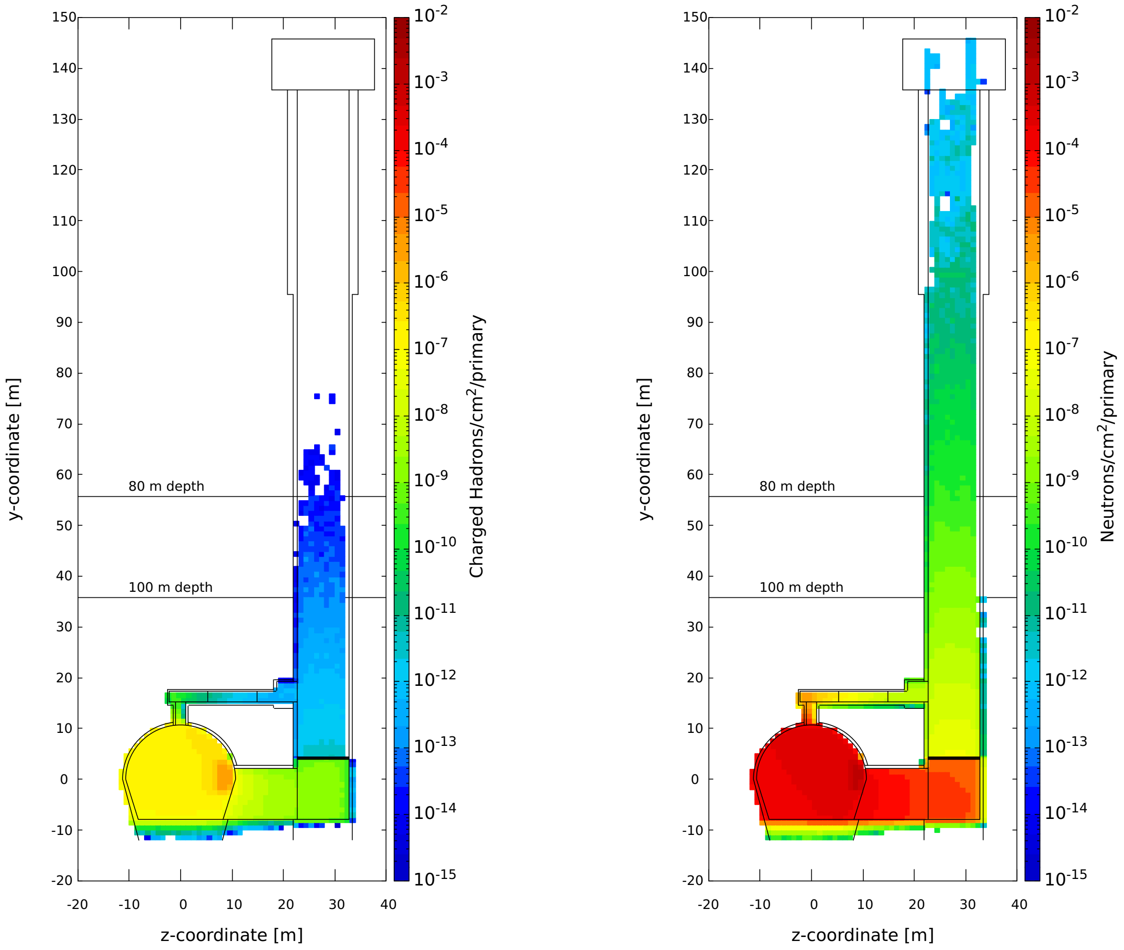
(b) Neutrons

Figure 6: Option 1. Charged hadron and neutron spatial distribution in the PX46 shaft when beam 1 is lost in LSS4. Similar results were found for the loss of beam 2. EM transport enabled.

Figure 8 and Figure 9 show the ambient dose equivalent in UX45 and at the bottom of PX46 when the beam is lost in one of the RF elements in LSS4. The different penetrations, and their orientation, play a role on the spatial distribution of the dose field in UX45/PX46.

Figure 10 and Figure 11 show the iso-dose contours, for $H^*(10)$ equals 1, 6 and 20 mSv[1], in the PX46 shaft when the beam is lost in LSS4: these values were chosen accordingly to

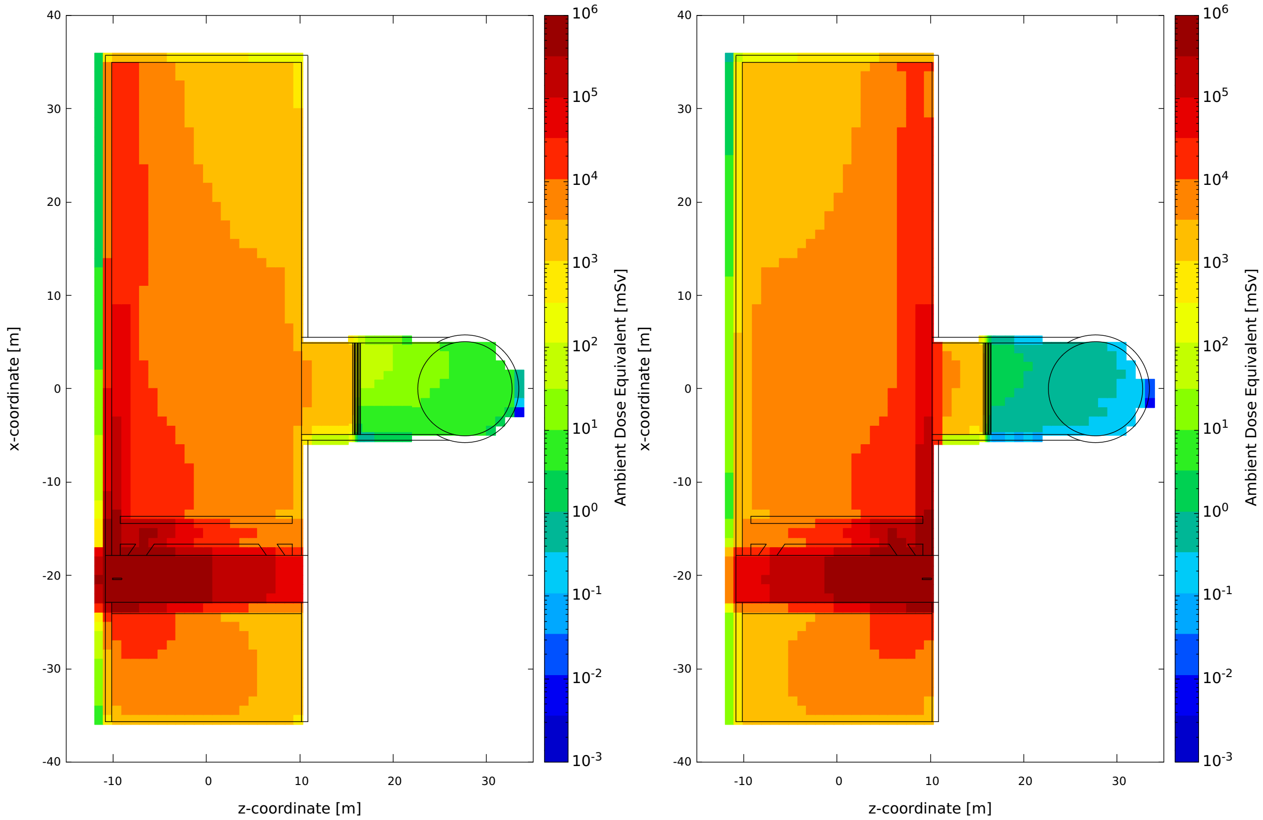
[1] Yearly Effective Dose limits for different Radiaiton Area classification as in place at CERN [7].



(a) Charged Hadrons

(b) Neutrons

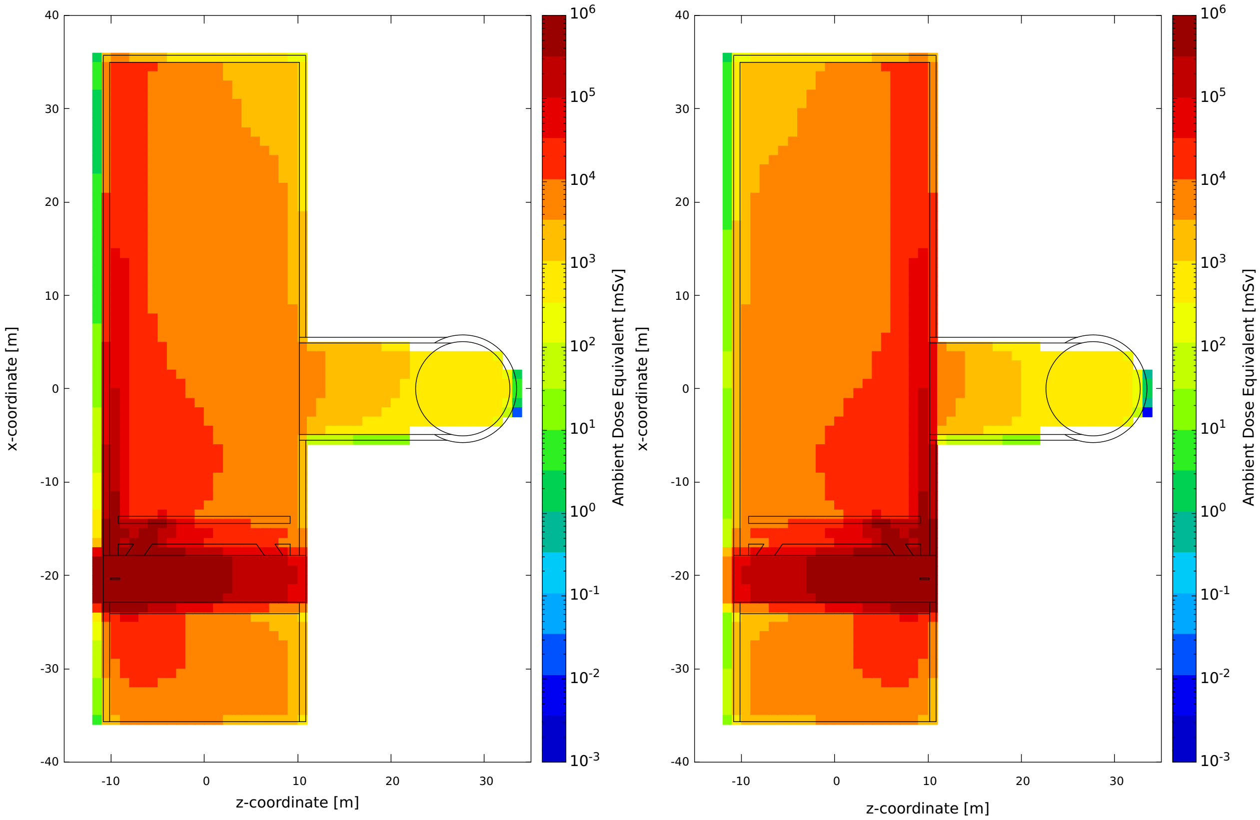
Figure 7: Option 2. Charged hadron and neutron spatial distribution in the PX46 shaft when beam 1 is lost in LSS4. Similar results were found for the loss of beam 2. EM transport enabled.



(a) Beam 1

(b) Beam 2

Figure 8: Ambient dose equivalent in the UX45 cavern when the beam is lost in one of the RF elements in LSS4 for option 1. EM transport enabled.

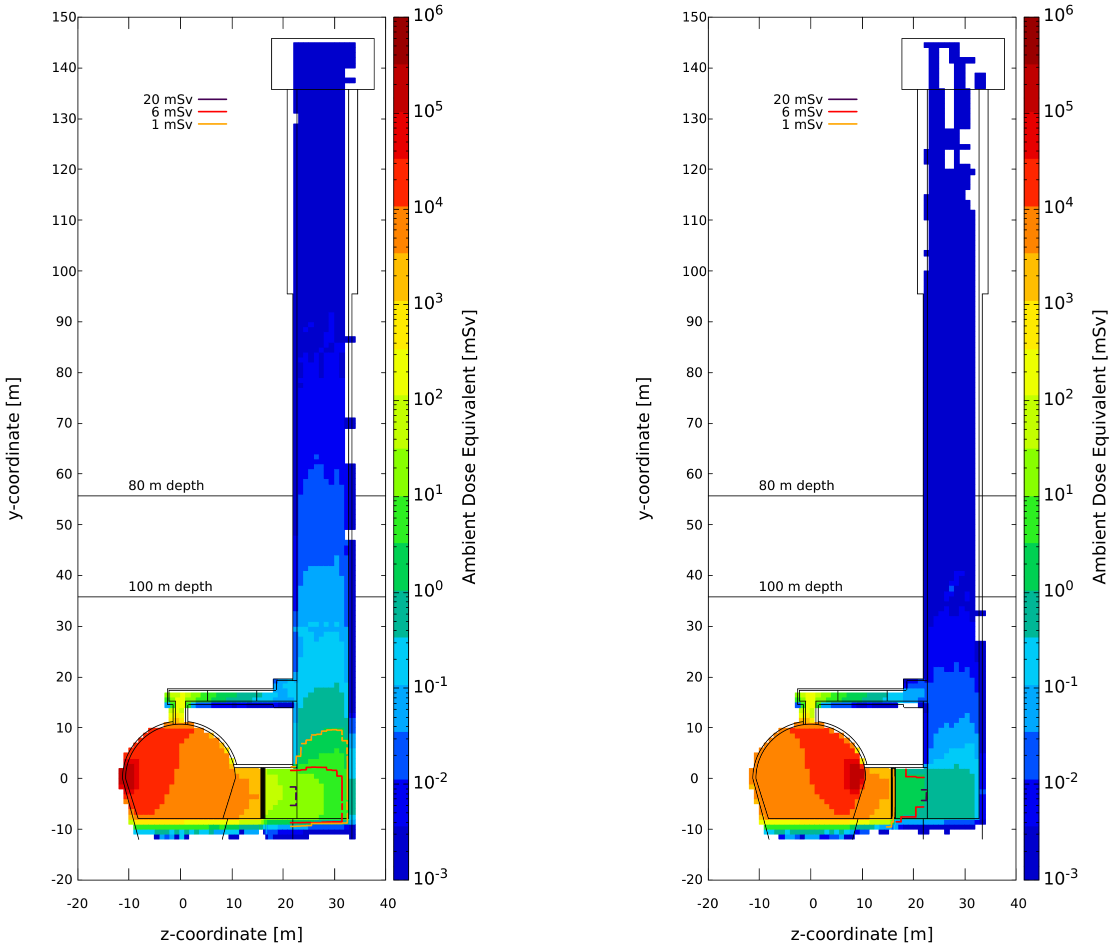


(a) Beam 1

(b) Beam 2

Figure 9: Ambient dose equivalent in the UX45 cavern when the beam is lost in one of the RF elements in LSS4 for option 2. EM transport enabled.

the Effective Dose limits for area classification, as reported in the EDMS 810149 [7]. The exposure limitation in terms of effective dose is ensured by limiting correspondingly the operational quantity ambient dose equivalent $H^*(10)$. The lines representing the minimum and the first project goal's depth, i.e. 80 m and 100 m (see Section 1), were included in the Figures for a better reading of the results: this representation provides already a qualitatively overview of the depth where the reference dose limits are reached.



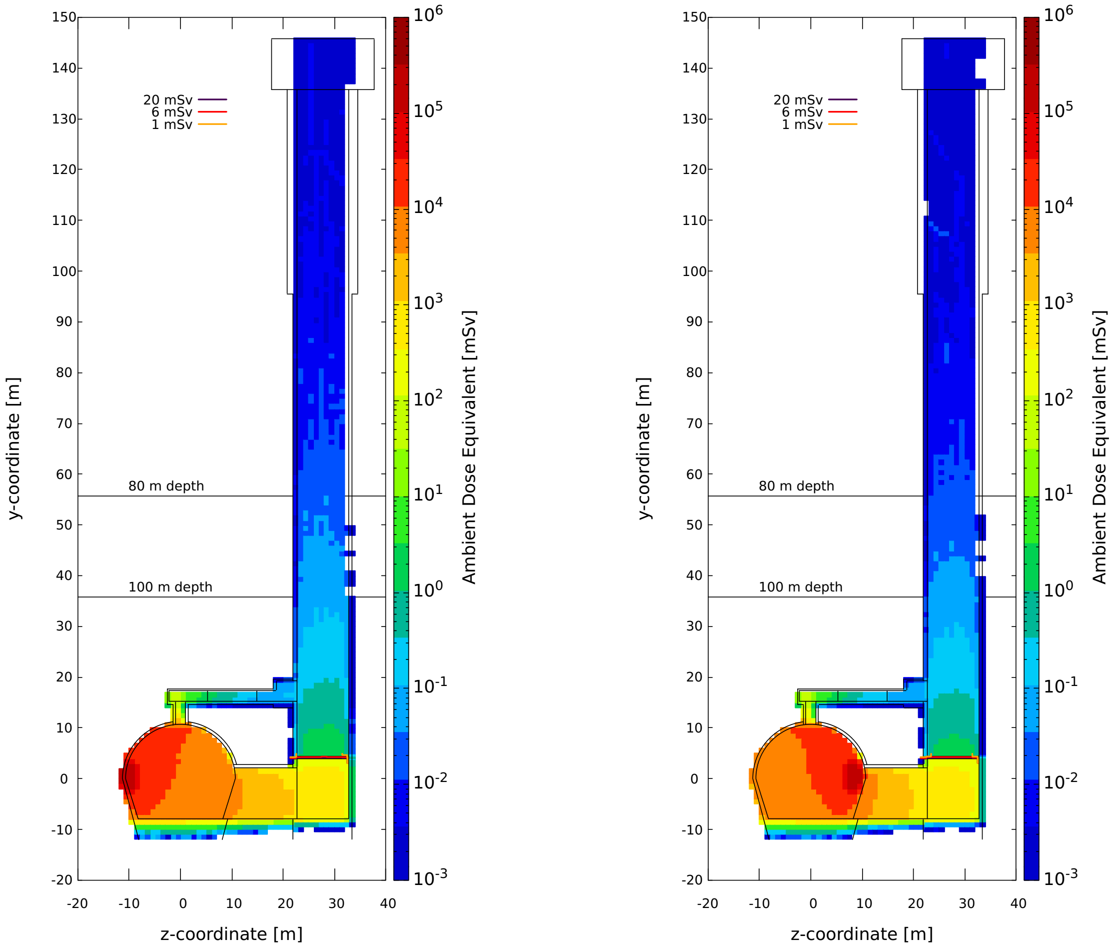
(a) Beam 1

(b) Beam 2

Figure 10: Ambient dose equivalent in the PX46 shaft when the beam is lost in one of the RF elements in LSS4 for option 1. EM transport enabled.

In Figure 11 it appears that iso-dose contours are contained within the shielding whereas in Figure 10 it would be necessary to increase the thickness of the wall to be completely below 6 mSv at the bottom of the shaft. This result is even more appreciable in Figure 12 and Figure 13, where the 1D profiles in TX46 and PX46 are presented.

Figure 12 and Figure 13 show the ambient dose equivalent profile along the UX45/TX46 cavern, at the level of the machine tunnel, and in PX46 respectively. In Figure 12 the difference position of the maximum dose peak is due to the different beam loss location simulated for beam 1 and beam 2. In both Figure 12 and Figure 13 it can be observed a



(a) Beam 1

(b) Beam 2

Figure 11: Ambient dose equivalent in the PX46 shaft when the beam is lost in one of the RF elements in LSS4 for option 2. EM transport enabled.

significant decrease of the ambient dose equivalent just after the shielding for option 1. With regard to option 2, being the shielding in the PX46 shaft, the ambient dose equivalent profile is initially overlapping the results found in EDMS 2333747 (no shielding) while decreasing below 6 mSv after the shielding. Therefore, option 2 limits the accessibility of the PX46 shaft to ∼120 m depth[2]. With regard to option 1, the full depth of the PX46 shaft is potentially accessible although, depending on the beam loss scenario, the dose limit of 6 mSv might be locally exceed at the bottom of the pit: therefore, the shielding thickness shall be increased accordingly to fully match the dose limit.

Figure 12 and Figure 13 compare the 1D profiles by considering LHC and HL-LHC beam conditions: the main difference is due to the different bunch population assumed in the two cases, providing a ∼ 35% difference.

It is important to note that the simplified model used in this evaluation includes uncertainties, which are difficult to quantify at this stage, such as the absence of "real" beam line elements in the LSS, the absence of additional equipment in the UX45 cavern. Moreover, possible margins for beam intensity increases in future operations are not included.

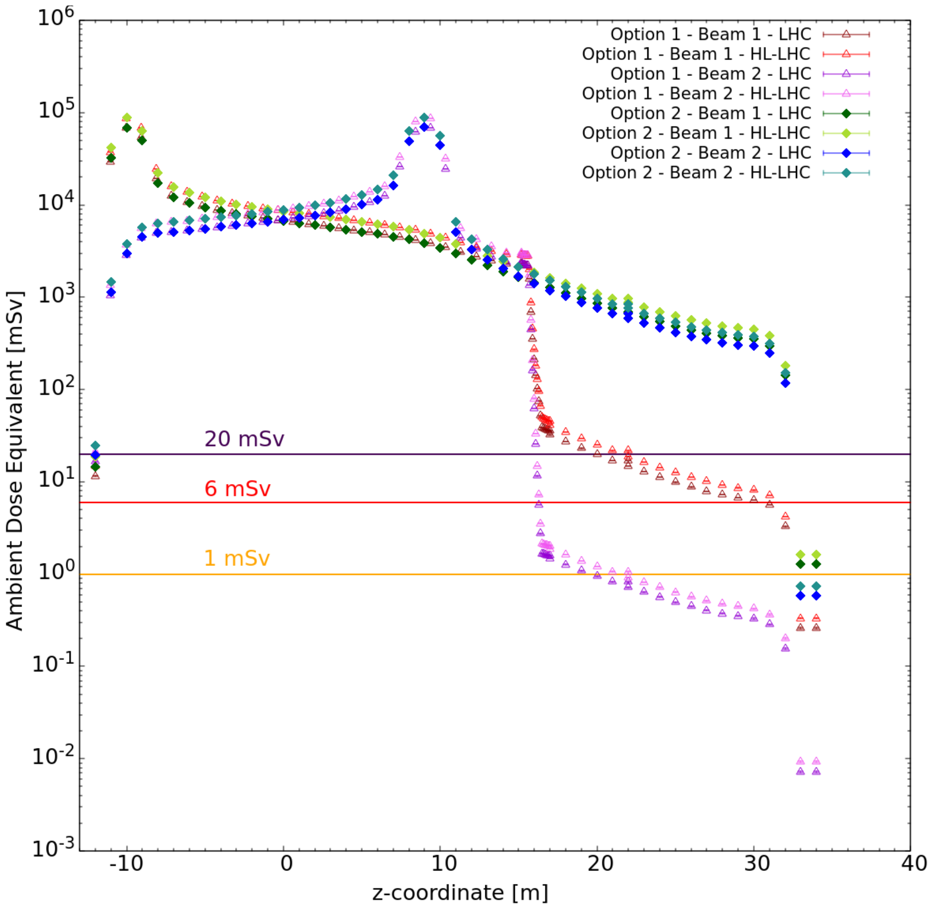


Figure 12: Ambient dose equivalent along the TX46 tunnel.

[2]value rounded to include a safety margin.

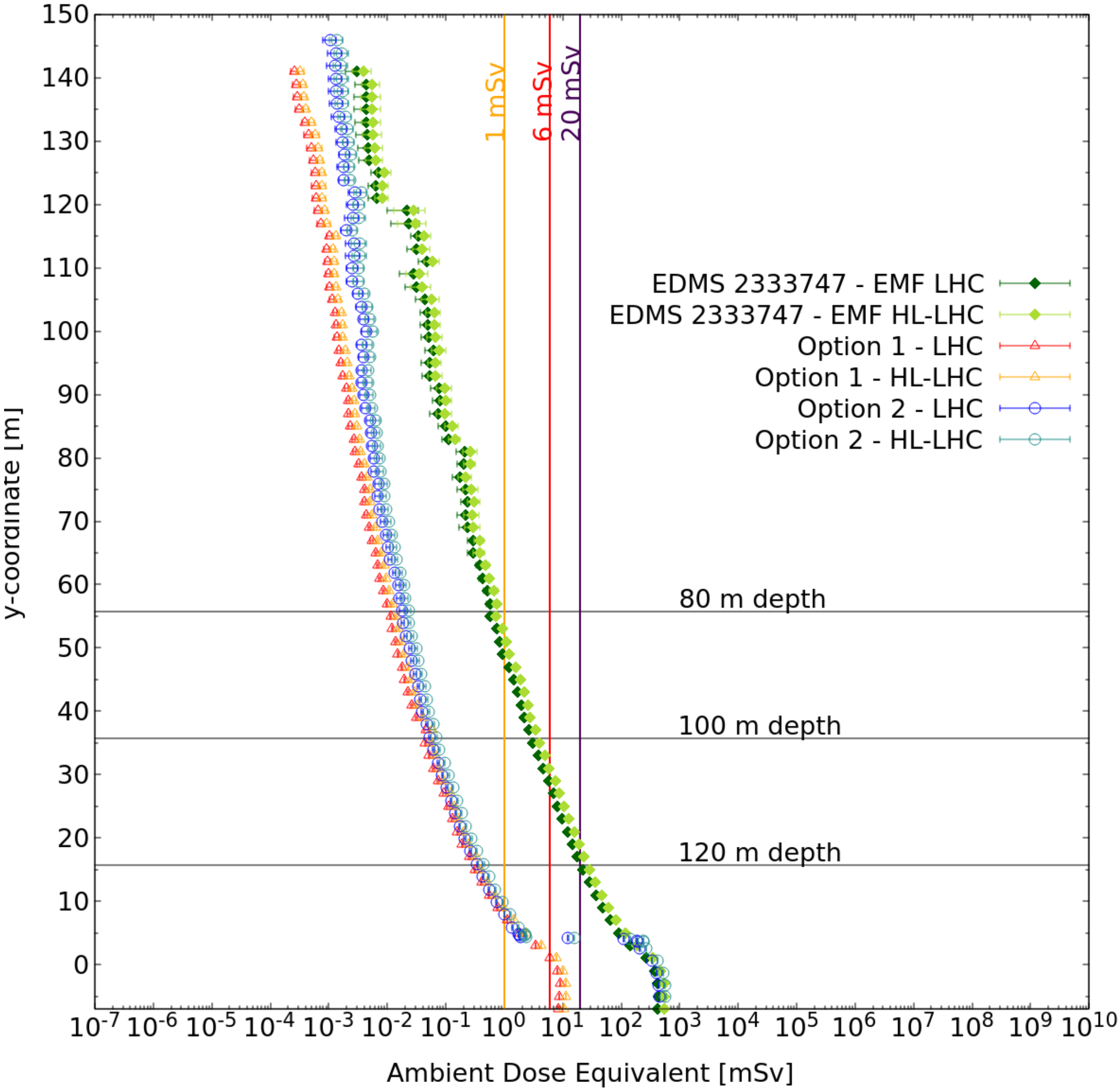


Figure 13: Comparison LHC/HL-LHC, ambient dose equivalent 1D profile along the PX46 shaft for beam 1.

4 Conclusions

This Technical Note summarizes the updated RP study conducted in the context of the AION-100 project, to possibly be installed in the PX46 shaft at LHC Point 4. The loss of the full 7 TeV HL-LHC proton beam in LSS4 is considered as reference scenario (accidental scenario) to evaluate possible RP constraints as well as the accessibility of the experiment during LHC/HL-LHC operation.

In the previously released EDMS 2333747, no shielding in PX46 was considered. To guarantee an effective dose below 6 mSv in the accidental scenario, the initial recommendation was to not exceed 90 m depth.

To extend the useful depth of the experiment, two shielding options were proposed and studied in this note: Option 1 consists on a 80 cm thick concrete wall in TX46 while Option 2 consists on a 40 cm thick concrete slab in PX46. Based on the results presented in Section 3, the following RP recommendations are provided:

- Option 1 allows to use almost the full depth of the PX46 shaft, depending on the beam loss conditions assumes. To guarantee to match the 6 mSv dose limit in any condition it is recommended to increase the thickness of the shielding wall. Depending on the shielding option that will be selected a more refined calculation will be performed.
- Option 2 allows for a recommended maximum depth of 120 m from the surface.
- The PX46 shall be classified as Supervised Radiation Area, therefore any person accessing the shaft must wear a personal passive dosimeter and need to follow the dedicated online training for working in Supervised Radiation Areas.
- Delimit the access area on the surface with a locked fence/grid to avoid unauthorized accesses.
- Foreseen dedicated RP monitoring in PX46 (currently not present).

Based on available studies and measurements, the operation scenario is negligible with respect to the accidental scenario, as taken into account in EDMS 2333747.

Besides pure RP considerations, other possible constraints such as general safety, ventilation, access, etc. must be accounted to provide a global overview on the possible installation of the AION-100 experiment in PX46 shaft: these considerations go beyond the scope of this note and of the HSE-RP group and should be discussed in dedicated integration meetings.

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