# SLHC-PP

# DELIVERABLE REPORT

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The Preparatory Phase of the Large Hadron Collider upgrade (SLHC-PP) is a project co-funded by the European Commission in its 7th Framework Programme under the Grant Agreement n° 212114. SLHC-PP began in April 2008 and will run for 3 years.

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## EXECUTIVE SUMMARY

Studies of the impact of ionising radiation on workers and the environment for planned facilities rely heavily on results of radiation transport calculations with Monte-Carlo programs.

Whenever the range of applications of a well-tested Monte-Carlo programme is extended – e.g. for higher particle energies – it is reasonable to verify that the predictions of the programme coincide with experimental measurements of the same observables.

Simulations of the radiation impact of the sLHC concern to a significant extent the effects in of proton beams accelerated to energies of 7 TeV. Presently, there are no experimental data to which to compare estimations for LHC and one relies exclusively on the validity of the underlying physical effects and their parameterisation at very high energies.

Predictions of Monte-Carlo programs for the sLHC proton beam energy of 7 TeV can be validated with data from LHC.

In the sLHC-pp project it had been planned to expose various dosimeters to the first beams with energy *E*=7 TeV in LHC during 2009, in order to compare their indication to predictions of prompt radiation effects. Good performance of a particular code in this area would greatly enhance the confidence one can have in it.

Due to the incident with one of the magnets in LHC in September 2008 and the ensuing long stop of more than one year, the planned work programme could not be realised in the planned lapse of time. For the LHC run 2009/2011, numerous dosimeters have been placed in LHC and in the experiments ATLAS and CMS. While the accelerator will run at an energy of only 3.5 TeV (50% of the nominal energy), the evaluation of the dosimeters will still yield precious data on the validity of Monte-Carlo models in unchartered energy regions.

The present report is describing the types and locations of radiation monitors placed in LHC and the experiments. Evaluation of the experiments will begin after an interruption in the 2009/2011 LHC-run at the beginning of 2011 and the results will be reported elsewhere.

# 1. INTRODUCTION

Studies of the impact of ionising radiation on workers and the environment for planned facilities rely heavily on results of radiation transport calculations with Monte-Carlo programs. These programs allow to address the effects of radiation fields of complex nature (broad energy and particle spectra, distributed sources of radiation) in civil engineering structures (the so-called “geometry”) of near-arbitrary shape, extension and materials.

Monte-Carlo radiation transport programs are in use for all applications involving the emission and absorption of ionising radiation and they have been extensively tested, benchmarked and subsequently improved. Examples of use of radiation transport programs are the nuclear industry, medical applications and Dosimetry of external radiation and intcorporated radionuclides.

Whenever the range of applications of a well-tested Monte-carlo programme is extended – e.g. for higher particle energies – it is reasonable to verify that the predictions of the programme coincide with experimental measurements of the same observables.

Simulations of the radiation impact of the sLHC concern to a significant extent the effects in of proton beams accelerated to energies of 7 TeV. This energy exceeds the present world record of proton energies, achieved at Fermilab, by a factor of 7. Presently, there are no experimental data to which to compare estimations for LHC and one relies exclusively on the validity of the underlying physical effects and theuir parametrisation at very high energies.

For sLHC, the situation is in principle better: the 10-fold increase of luminosity, accompanied with a proportional increase in radiation levels, does not entail an energy increase. Therefore it is possible to validate predictions of Monte-Carlo programs for the sLHC proton beam energy of 7 TeV with data from LHC.

Predictions of interest for radiation protection can be divided in two types:

1.) Effects of prompt radiation during accelerator operation: dose (equivalent) (rates)

2.) Effects of activation and decay radiation from activated material: activation and dose (equivalent) (rates)

To produce reliably measurable activation in samples, in particular of long-live species of high relevance for radiation protection, requires higher beam intensities as LHC was supposed to deliver during 2009. In the sLHC-pp project it has been planned to expose various dosimeters to the first 7 TeV beams in LHC during 2009, in order to compare their indication to predictions of prompt radiation effects. Good performance of a particular code in this area would already greatly enhance the confidence one can have in it.

Due to the incident with one of the magnets in LHC in September 2008 and the ensuing long stop of more than one year, the planned work programme could not be realised in the planned lapse of time. For the LHC run 2009/2011, numerous dosimeters have been placed in LHC and in the experiments ATLAS and CMS. While the accelerator will run at an energy of only 3.5 TeV (50% of the nominal energy), the evaluation of the dosimeters will still yield precious data on the validity of Monte-Carlo models in unchartered energy regions.

The present report is describing the types and locations of radiation monitors placed in LHC and the experiments. Evaluation of the experiments will begin after an interruption in the 2009/2011 LHC-run at the beginning of 2011 and the results will be reported elsewhere.

# 2. PASSIVE DOSIMETERS IN LHC

For an in-depth characterisation of the various types of passive radiation detectors, the reader is referred to the reference [Fue09a], and to the extensive bibliography contained therein.

## 2.1. PASSIVE DOSIMETERS IN ATLAS

Passive detectors have been installed in the experimental and in the service caverns. An overview of the installed detectors and their location is given in Table 1. More information about the precise detector positions can be found in the corresponding references. In Table 2, the already performed MC-simulations are listed. The calculated quantities and the areas for which they results have been obtained can be found in the table as well.

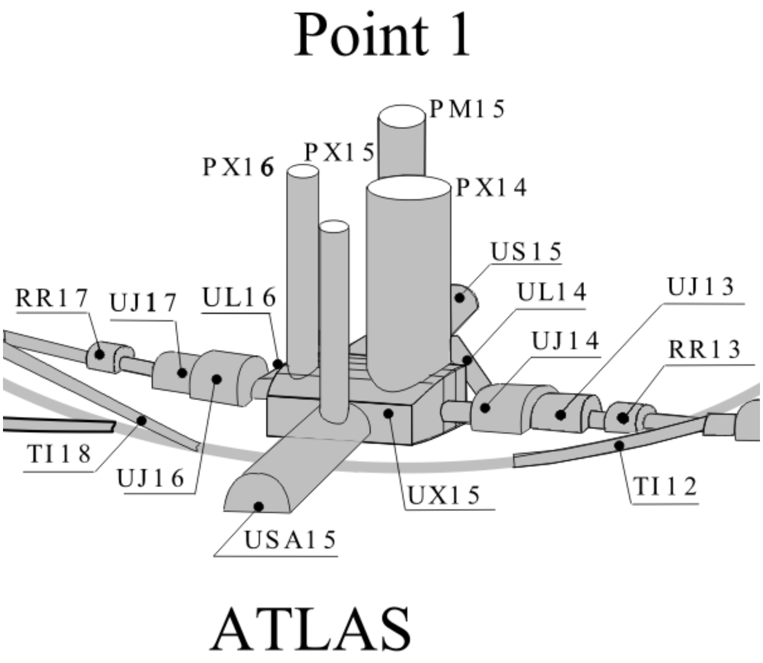

*Figure 1 General underground layout of point 1.*

*Table 1 Summary of the installed passive detectors at point 1.*

| Detector Type | Ref. | Number | Location | Supplier |
|---|---|---|---|---|
| CR-39 | [Fue09] | 114 | UX15, USA15 | PSI |
| TLD | [Ott09] | 20 | UX15, USA15, ULX16, US15, TE14 | CERN |
| RPL | [Zaj10] | 12 | UX15 | CERN |
| Alanine | | 12 | | |
| Activation sample sets | | 37 | | |
| Activation samples | [Dix09] | 24 | ATLAS detector | IPN Orsay |

## 2.2. PASSIVE DOSIMETERS IN CMS

The numbers of passive detectors per cavern are listed Table 3. Further information about the precise position can be found in the corresponding references. A summary of the documented MC-simulations in the experimental cavern can be found in Table 4. The calculated quantities in the different reports are listed in the second column.

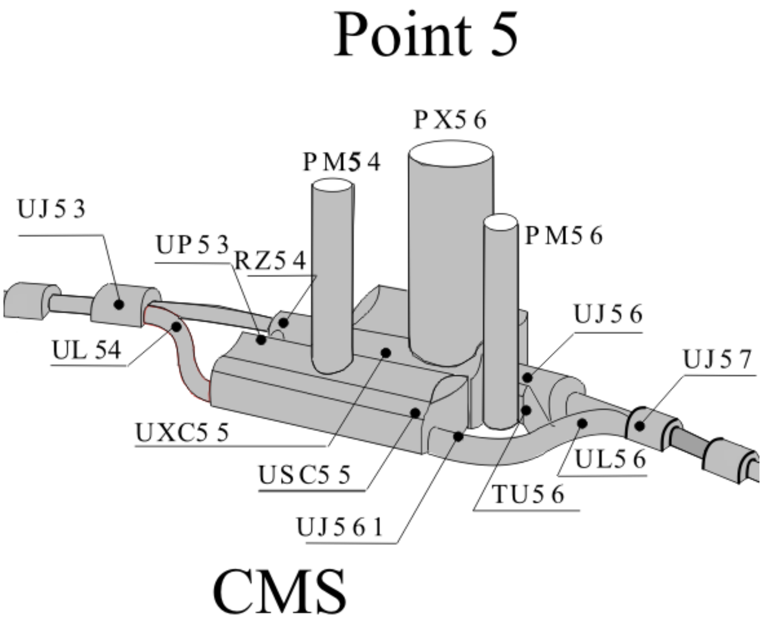

*Figure 2 General underground layout of point 5.*

*Table 2 Summary of the installed passive detectors at point 5.*

| Detector type | Ref. | Number | Location | Supplier |
|---|---|---|---|---|
| Alanine | [Roe09] | 28 | UXC55 | CERN |
| RPL | | 28 | UXC55 | CERN |
| Activation samples | | 28 | UXC55 | CERN |
| TLD | [Mue09] | 160 | UXC55, USC55 | DESY |
| CR-39 | [Fue09] | 166 | UXC55, USC55 | PSI |

## 2.3. PASSIVE DOSIMETERS IN LHCB

A list of the installed passive detectors, which are installed at the same positions at the active ones, is given in Table 7

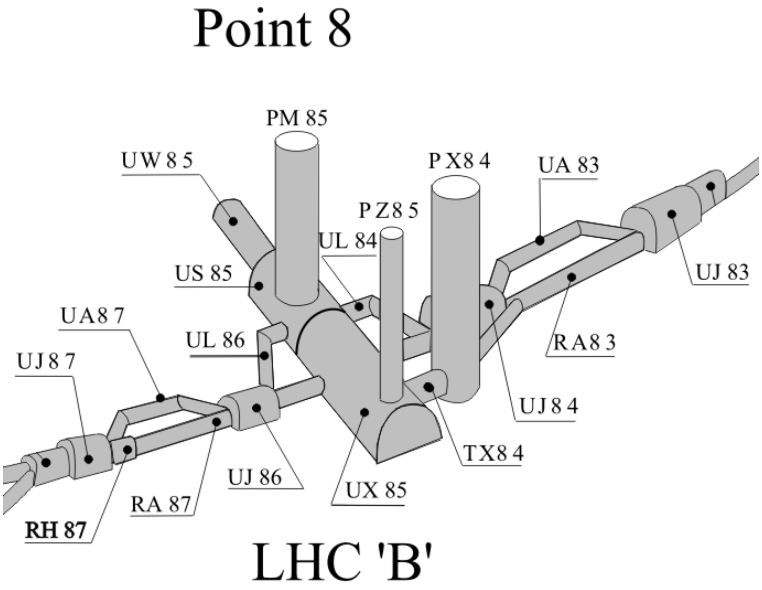

*Figure 3 General underground layout of point 8.*

*Table 3 Summary of the installed passive detectors at point 8.*

| Detector Type | Ref. | Number | Location | Supplier |
|---|---|---|---|---|
| RPL | [Cor09] | 125 | UX85B | CERN |
| Alanine | | 125 | | CERN |
| TLD | | 125 | | IJF |
| BPW34 | | 32 | | CERN |

## 2.4. PASSIVE DOSIMETERS IN TOTEM

The TOTEM experiment will measure the total pp cross section and study elastic scattering and diffractive dissociation at the LHC [TOT08]. TOTEM consists of three sub-detectors: the Roman Pot (RP) silicon detectors located in the very forward direction of the beam interaction point 5 (IP5) and two inelastic telescopes, T1 and T2. These detectors, together with some of the related readout electronics, are located in LHC areas where high radiation levels are expected [Mok03]. Two Roman Pot stations are installed symmetrically on either sides of the IP5. They are installed in a distance of 147 m and 220 m from IP5. In Table 9 the installed passive detectors are listed and in Table 10 the already performed MC-Simulations. For the location at 147 m distance from the IP5 results in terms of ambient dose equivalent can be found in the work from Mokov et al. [Mok03]. The prompt dose rates are in the Sv range, where as the residual dose rates vary strongly due to lower statistical significance results outside the beam line elements.

*Table 4 Summary of the installed passive detectors at the TOTEM experiment.*

| Detector Type | Ref. | Number | Location | Supplier |
|---|---|---|---|---|
| RPL | [Rav09] | 72 | LSS5<br>Romen pots at 147 m and 220 m from IP5 and at the T1 and T2 | CERN |
| Alanine | | 108 | | CERN |
| TLD | | 144 | | IJF |
| BPW34 | | 36 | | CERN |
| CR-39 | [Fue09] | 16 | Inner triplet, Romen pots at 147 m | PSI |

## 2.5. PASSIVE DOSIMETERS IN THE LHC ACCELERATOR

Passive detectors have been distributed by the radiation to electronics R2E taskforce in the LHC machine (see Table 11) [Bru09]. The supplier of the TLDs is the Institute of nuclear physics IJF, Krakow, Poland. In addition, the R2E taskforce established a comprehensive database of published MC-simulations in the tunnel and experiments [Web4]. A query on this website performed on Nov. 30, 2009 regarding radiation levels returned 102 references to publications, web links and talks. This database offers as well the possibility to apply filters in order to refine the listed results. In Table 12, a summary of the technical notes containing MC simulations in the LHC machine is given.

*Table 5 Passive detectors in the LHC tunnel distributed by the R2E taskforce.*

| Area | Total per area | Type | Area | Total per area | Type |
|---|---|---|---|---|---|
| UJ13 | 1 | TLD | RR57 | 4 | TLD |
| UJ14 | 2 | TLD |  | 1 | Act. sample |
| UJ16 | 3 | TLD | UPS54 | 1 | TLD |
| RR13 | 4 | TLD | UPS56 | 1 | TLD |
|  | 1 | Act. sample | USC55 | 1 | TLD |
| RR17 | 4 | TLD | UX65 | 3 | TLD |
|  | 1 | Act. sample |  |  |  |
| UPS14 | 1 | TLD | US65/UX65 | 2 | TLD |
| UPS16 | 1 | TLD | UA63 | 2 | TLD |
| US15 | 1 | TLD | UA67 | 19 | TLD |
| UJ23 | 4 | TLD | UD62 | 2 | TLD |
|  | 1 | Act. sample |  |  |  |
| RA27 | 1 | TLD | UD68 | 2 | TLD |
| PZ33 | 1 | TLD | UJ76 | 4 | TLD |
| UJ32 | 2 | TLD | RR73 | 3 | TLD |
|  | 1 | Act. sample |  | 1 | Act. sample |
| UJ33 | 3 | TLD | RR77 | 3 | TLD |
| RE38 | 2 | TLD | US85 | 7 | TLD |
| US45/UX45 | 2 | TLD | UX85 | 3 | TLD |
| UX45 | 4 | TLD | UJ87 | 4 | TLD |
| UJ56 | 6 | TLD |  | 1 | Act. sample |
| RR53 | 4 | TLD | UA83/87&RB83/87 | 6 | TLD |
|  | 1 | Act. sample |  |  |  |

## 3. CONCLUSIONS

A dense network of passive dosimeters has been installed in the LHC accelerator and in four experimental areas.

Monte-Carlo radiation transport calculations of the respective areas yield as a result particle fluences and/or doses, from which the hypothetical response of the dosimeters will be inferred. The existing calculations must still be updated to the lower energy of the LHC beam in 2010/2011, $E$ = 3.5 TeV (instead of 7 TeV).

Once sufficient dose is accumulated by the various dosimeters, they will be collected and evaluated.

The comparison of predicted and measured dosimeter signal is an important contribution to the validation of the radiation transport codes employed in the assessment of radiation impact of sLHC. .

## 4. REFERENCES

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