The FLUKA geometry of the TOTEM Roman Pot detector system at the LHC  
(Version 2012)  

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Abstract  
During the design phase of the TOTEM experiment, several Roman Pot detector models were simulated in FLUKA to address radiation damage and radiation protection issues as well as to define specific accidental scenarios involving beam losses in the Roman Pot components. These FLUKA models, often implemented “ad-hoc” for a given calculation and with the best knowledge of the detector at a given time, lack consistency and nowadays do not properly reflect all final detector components installed at the LHC. In this note, we describe a new FLUKA geometry built in the framework of the FLUKA accelerator generator and based on the most updated version of the integration model of the TOTEM Roman Pot detector.
1 Introduction

The TOTEM experiment measures the total \( pp \) (proton-proton) cross section and studies elastic scattering and diffractive processes at the LHC \([1]\). The Roman Pots (RP) sub-detectors of TOTEM are movable beamline insertions allowing detection of very forward protons which are scattered out of the LHC beams by a very small angle after their collision in the Interaction Point 5 (IP5). RP stations are located in the LHC tunnel on each side of IP5: at \( \pm 220 \)m and at \( \pm 147 \)m distance from it. Each RP station is composed of two units separated by a distance of a few meters as shown in Fig. 1 (left). Units are identified as near and far with respect to their distance to the IP. A RP unit is equipped with three sets of micro-strip silicon detectors (three detector packages with 10 tracking planes each) inserted in corresponding three vacuum vessels (the “pots”): two approaching the outgoing beam vertically (top and bottom) and one horizontally. This allows a partial overlap between horizontal and vertical detectors within the LHC aperture.

The pot provides a volume with secondary vacuum, where the silicon detectors and their services are enclosed. It has the shape of a rectangular box of 5.0cm\( \times \)12.5cm with a 0.2cm thick wall made of SS-316LN steel as shown in Fig. 2. An UHV flange is welded to the box. The bottom side of the flange is connected to the bellows, to tighten the machine vacuum volume. The opposite side is connected to the second flange equipped with the silicon detectors (the detector package - Fig. 1 (right)), which tighten the secondary vacuum volume. In order to allow the silicon detectors to approach the LHC beams as close as possible, a “thin window” made of SS-316L steel is welded on the pot as visible in Fig. 2 \([2]\).

![Fig. 1. Left: mechanical drawing of the Roman Pot units - 2 RP units = RP station. Right: a sketch of the RP detector package with the stack of ten silicon detectors integrated in the secondary vacuum flange.](image)

In total, 24 RP detectors are installed at the LHC since 2010. The RP detectors are moved to very small distances from the beams, during LHC runs with special optics designed to have high \( \beta^* \). With these conditions, the RPs operate with few bunches of very small emittance.
During the LHC runs at high luminosity with normal (low $\beta^*$) optics the RPs remain for most of the time in their “garage” position, with detectors about 4cm away from the beams.

![Image](image-url)

**Fig. 2.** A picture of the pot as seen from its bottom side (pointing into the LHC vacuum chamber). The rectangular box, together with the “thin window” separating the detector edges from the LHC beam, is visible. The lateral sides of the window are 0.5mm thick, while the bottom foil is 0.15mm. The black collar of ferrites (2mm) used to reduce the RF beam coupling is also visible here.

A set of FLUKA [3] Monte Carlo simulations involving the TOTEM RP geometry have been performed in the past, during the validation phase of the RP detector design (2005-2006). These calculations assessed prompt radiation levels and field composition around the RP, residual contact doses, and studied specific accident scenarios involving beam losses in the RP components. The geometries used in such studies, often implemented “ad-hoc” for a given calculation and with the best knowledge of the detector at a given time, lack consistency and, sometimes, do not reflect the detector components installed at the LHC with their final geometrical shape and material composition.

Moreover, these preliminary studies consider only “nominal” operational parameters or use as input particle distributions independently simulated in regions of the LHC close to the RP location. Both these situations do not allow a full control of the boundary conditions and make difficult any update, extrapolation and comparison among the different simulated data sets.

Nowadays, new and more reliable FLUKA simulations are required mainly to:

1. Perform in-depth studies of the detector background by comparing the simulated data with measurements from dedicated radiation monitors [4];
2. Contribute to the risk assessment involving the standard RP operation, as well as possible accidental scenarios such as point losses or local quenches of the cryogenic magnets which sit in the LHC downstream the RP detector stations [5] (e.g. machine protection studies).
The above reasons trigger the realization of a new FLUKA model based on the final production drawings of the RP unit at the LHC as well as the most updated integration model of the RP detector assembly. The new model is built in the framework of the FLUKA accelerator generator [6], which is composed of a set of Python scripts (Line Builder) and a database of the accelerator machine element models (Fluka Element Data Base - FEDB). The Line Builder uses the accelerator TWISS file to position correctly the replicas of the accelerator components - taken from the FEDB - and includes all the relevant details (materials, tunnel walls, shielding, etc.… in the FLUKA input file.

The aim of this technical note is to give, in the first part, a brief summary of the previous FLUKA calculations performed for the TOTEM RP and their related geometrical models. In the second part, we describe instead all relevant features implemented in the new FLUKA model realized in 2012.

2 Review of the previous RP models and calculations

During the design phase of the TOTEM RP detector, a series of FLUKA Monte Carlo calculations were performed in order to optimize its design and to evaluate possible radiation damage and radiation protection constraints.

Here follows a list of the previous works available in literature and related to the TOTEM RP (list compiled to the best knowledge of the authors):

1. Preliminary calculations performed in 2002 for the design of the high luminosity insertions of the LHC are available in Ref. [7]. In this work, the geometrical model of the RP detectors is inspired by the RP previously designed at FERMILAB as shown in Fig. 3 (left). A more detailed set of calculations focusing on the TOTEM locations at the LHC is also available in Ref. [8].

Fig. 3. Sketch of the previous generations of RP detector geometries used in FLUKA Monte Carlo simulations. The left-hand side picture shows a XY cross section of the RP model from Ref [8] (2002), while the one on the right-hand-side shows a 3D view of the model from Ref. [11] (2006).
2. “Energy Deposition in the Window of the TOTEM Roman Pot for the nominal TOTEM run”. This work, described in Ref. [9], studies the effect of a deflected proton bunch hitting the RP thin window. The geometry implemented in FLUKA consists only of the RP rectangular box with its thin window (as shown in Fig. 2). The material implemented in the model geometry and the dimensions of the box differ from the one chosen in the final design of the Roman Pots.

3. “Radiation Levels at the TOTEM Roman Pot detectors”. This work, described in Ref. [10], improves the results of the previous study of Ref. [7]. The geometry implemented in FLUKA consists of the beam pipe, the RP vessels and a few structural elements.

4. “Nuclear Zoning and Dose Calculation for TOTEM RP”. This work, described in Ref [11], contains a fairly detailed description of the RP setup, namely: one RP unit (with its three Roman Pots), the cryostat behind the RP unit, cooling pipes, the concrete floor and 30cm of concrete simulating the tunnel wall around the detector as shown in Fig. 3 (right). The design of the detector package and its related services is only preliminary and does not include the inner part containing the detector hybrids with the silicon sensors integrated in the vacuum vessel. Moreover, the three detector packages are solidly build in the RP units at an arbitrary distance from the beam axis.

More in general, the approach used in the old LHC FLUKA calculations was based on a monolithic input file containing all the geometries of the different components and had to be updated manually each time a new component was added, removed or modified. The FLUKA accelerator line generator allows now a new dynamic approach in which the optics, the geometry and the physics parameters are decoupled from each other. To achieve this new FLUKA input file structure the Fluka Team performed a rework of all LHC, SPS and injection line elements, including the TOTEM RP model described in this document. The available RP model closest to reality was the one described in Ref. [11]. However, this model was based on old preliminary drawings and was too simplified to enable the execution of precise and reliable calculation (i.e. suitable for machine protection studies). For these reasons, the FLUKA model of the RP geometry described in the following sections has been implemented from scratch.

3 Background information and reference material

The reference data used for the implementation of the new RP FLUKA model are based on the drawings belonging to the following series archived in the CERN Drawing Directory (CDD) [12]:

- `\LHC\XRP__0\LHCXRP__0xxx.dwg`: for the RP unit, support structures and vacuum equipments. Moreover, Ref. [13] details all drawings which are related to the manufacture of the Roman Pot structure integrated with the beam vacuum chamber.
- `\LHC\XRD__0\LHCXRD__0xxx.dwg`: for the RP silicon detector assembly (detector package), including cooling and vacuum equipments.
Useful information about the choice of the materials used for the RP is available also in Ref. [14]. Moreover, during the modelling process, we also referred to the full TOTEM RP 3D CAD model available on the Catia SmartTeam database [15] as an additional crosscheck.

The drawings contained in the following folder refer instead to the different TOTEM detector prototypes used during validation experiments, therefore they were not considered for the present work.

- \LHC\XRPD__0\LHCTRDPD__0xxx.dwg

4 Description of the FLUKA model/input file

In the *FEDB* each element has a unique name (defined at most by 8 characters), which follows the LHC/SPS components naming scheme. Each element is defined using 3 different files, which contain the FLUKA bodies, the regions and the material assignment and whose extensions are “.bodies”, “.regions”, “.assignmat” respectively.

**Near RP ASSEMBLY (Section - Top View)**

*Fig. 4*. XY cut of the *near* RP ASSEMBLY (top view). The red line delimits the portion of space defined by the *near* RP unit (XRAtBODY), while the green lines identify the portion of space defined by the detector package + pot model (XRpdBODY). The three pots (only two are visible in the figure) can be positioned around the beam axis according to the opening of the RPs. Dimensions in the pictures are in cm.
In the FLUKA accelerator generator framework the TOTEM RPs are classified as dynamic elements (called ASSEMBLY) which are, as a matter of fact, complex elements composed of two or more simpler elements.

The RP ASSEMBLIES are therefore composed of a RP unit and three detector packages as shown in Fig. 4. As the near and far RP units are not identical, the creation of two models has been required. The base file names were called XRAtBODY and XRbtBODY for the near and far unit respectively. Both models of the RP unit include a simplified description of the BPM which is positioned aside the vertical pots. The vacuum bellow (SS-316L) connecting the beam pipe in between the vertical pots module and the horizontal one is also present. The detector package inserted in its pot vessel, which is the same repeated three times in each unit, was implemented as a separate model named XRPdBODY. Using this approach, each of the pots can be moved independently and positioned separately toward (or away from) the beam.

The FLUKA Line Builder provides the automatic generation of the complete input files of all the components for a given beam line. An alternative to create the complete RP unit model was to include separately the models of the unit and of the detectors to create LATTICES (i.e. replicas) of the object and finally to move them in place with ROT-DEFI transformations. An example of the FLUKA input file to perform this task is shown in Sec. 5.

3D pictures of the RP detector package (inserted in its vacuum vessel, e.g. the “pot”) and of one RP ASSEMBLY are shown in Fig. 5.

Fig. 5. Left-hand side: model of the TOTEM RP detector assembly inserted in the pot. The ferrite collar (brown colour) and the thin window are visible. Right-hand side: 3D view of the near RP ASSEMBLY. The transversal cut through the beam pipe shows the inner part containing the 10 detector hybrids.
The relevant details implemented for the RP detector assembly (XRPdBODY model) are:

- The pot (rectangular box made of SS-316LN) and the vacuum flange which is connected to it (see Fig. 5 (left)). On the pot, the “thin window” has been modelled in detail as it appears in Fig. 2, together with the 2mm-thick ferrite collar;
- The second flange, which mounts the detector hybrids (made of CE7) and holds the silicon detectors. The stack of 10 hybrids is modelled with minimal approximations: along the beam direction, the 10 plates are assembled two-by-two (back-to-back) and properly spaced inside the pot according to the mechanical integration drawings. On the transversal plane, a nominal distance of 0.2mm separates the silicon detector edge from the thin window of the RP;
- The “coulisse” (moveable support structure) made of lightweight Al alloy 6082 which allows the movement of the full detector assembly;
- The RP motherboard (front-end electronics PCB made of FR4) together with its encasing box, made of Al alloy 6082, which sits outside the LHC vacuum, on the top of the second flange.

The piping of the evaporative cooling system, together with the reference frames that support the stack of detector hybrids are not included in the simulated model. The vacuum bellow (thin layer of SS-316L) which connects the pot to the remaining part of the vacuum vessel, integrated in the LHC beam pipe, was also omitted in this version of the TOTEM RP model.

5 Appendix – FLUKA Roman Pot Template file

The Roman Pot FLUKA model can be generated as a standalone input file for debugging and testing with a simple FLUKA input file:

```plaintext
****START of the FLUKA input file
TITLE Test element
GLOBAL 1.0 1.0
* ..+....1....+....2....+....3....+....4....+....5....+....6....+....7...
DEFAULTS
BEAM
BEAMPOS
* ..+....1....+....2....+....3....+....4....+....5....+....6....+....7...
GEOBEGIN
0 0
* Black body
SPH blkbody 0.0 0.0 0.0 10000000.0
* Void sphere
SPH void 0.0 0.0 0.0 100000.0
* Bodies from the include file
```
$start_translat 400. 0. 0.
## include [PATH_TO_FEDB]/bodies/lhc_XRAtBODY.bodies
$end_translat
*

$start_transform -XRAt1
$start_translat 400. 0. 0.
RPP XRAt1BDY   -14.1 60.0 -80.0 60.0 -31.4 72.5
* Hollow space for upper vertical detector
*RPP XRPdBDYb   -14. 16. 7.88 46.5 -15.5 15.5
RPP XRAt1VPu   -14.05 16.25 7.65 50.0 -16. 16.
RPP XRAt1VPd   -14.05 16.25 -50.0 -7.65 -16.0 16.
RCC XRAt1VVi   0.0 -10.0 0.0 0.0 20.0 0.0 7.5
* Hollow space for horizontal detector
RPP XRAt1HP    7.65 50.0 -14.05 16.25 29.6 61.
RCC XRAt1HVi   -5.4 0.0 45.0 15.4 0.0 0.0 7.5
$end_translat
$end_transform
*

$start_translat 500. 0. 0.
## include [PATH_TO_FEDB]/bodies/lhc_XRPdBODY.bodies
$end_translat
$start_transform -XRPd1vu
$start_translat 500. 0. 0.
RPP XRPd1vuA   -6.6 6.6 0.0 13.43 -2.9 2.9
RPP XRPd1vuB   -14. 16. 7.88 46.5 -15.5 15.5
$end_translat
$end_transform
$start_transform -XRPd1vd
$start_translat 500. 0. 0.
RPP XRPd1vdA   -6.6 6.6 0.0 13.43 -2.9 2.9
RPP XRPd1vdB   -14. 16. 7.88 46.5 -15.5 15.5
$end_translat
$end_transform
$start_transform -XRPd1h
$start_translat 500. 0. 0.
RPP XRPd1hA    -6.6 6.6 0.0 13.43 -2.9 2.9
RPP XRPd1hB    -14. 16. 7.88 46.5 -15.5 15.5
$end_translat
$end_transform
END
*
Black hole
BLKBODY       5 +blkbudy -void
* Void around

VOID         5 |void     -XRAtBODY -XRPdBODY
- XRAt1BDY
* Lattice of the RP tank
XRAt1lat     5 |+XRAt1BDY -XRAt1VPu - XRAt1VPd - XRAt1VVi - XRAt1HP - XRAt1HVi
* Holes in the RP tank
XRAt1air     5 |+XRAt1BDY +XRAt1VPu -XRAt1VVi -XRPd1vuB
|+XRAt1BDY +XRAt1VPd -XRAt1VVi - XRPd1vdB
|+XRAt1BDY +XRAt1HP -XRAt1HVi -XRAt1hB
XRAt1vac     5 |+XRAt1BDY +XRAt1VVi -XRPd1vuA -XRPd1vuB -XRPd1vdA -XRPd1vdB
|+XRAt1BDY +XRAt1HVi -XRPd1hA -XRAt1hB
* Lattices of the RP vessel
XRPd1lvu    5  | +XRPd1vuA | +XRPd1vuB
XRPd1lvd    5  | +XRPd1vdA | +XRPd1vdB
XRPd1lh     5  | +XRPd1hA  | +XRPd1hB
* Region from the include file
#include [PATH_TO_FEDB]/regions/lhc_XRAtBODY.regions
#include [PATH_TO_FEDB]/regions/lhc_XRPdBODY.regions
END
* ...+....1....+....2....+....3....+....4....+....5....+....6....+....7...
LATTICE     XRAt1lat                      XRAt1lat                    XRAt1
LATTICE     XRPd1lvu                     XRPd1llvu                    XRPd1vu
LATTICE     XRPd1lvd                     XRPd1llvd                    XRPd1vd
LATTICE      XRPd1lh                      XRPd1llh                    XRPd1h
GEOEND
FREE
* tank of the roman pot
ROT-DEFI     1.0  0.0  0.0  0.0  0.0 100.0  XRAt1
ROT-DEFI   201.0  0.0  90.0  0.0  0.0  0.0    XRAt1
ROT-DEFI     1.0  0.0  0.0 400.0 -0.0   0.0   XRAt1
* Vertical detector up
ROT-DEFI     2.0  0.0  0.0  0.0  0.0 100.0  XRPd1vu
ROT-DEFI   202.0  0.0  90.0  0.0  0.0  0.0   XRPd1vu
ROT-DEFI     2.0  0.0  0.0 500.0 -0.0   0.0   XRPd1vu
* Vertical detector down
ROT-DEFI     3.0  0.0  0.0  0.0  0.0 100.0  XRPd1vd
ROT-DEFI   203.0  0.0  90.0  0.0  0.0  0.0   XRPd1vd
ROT-DEFI     3.0  0.0  0.0 500.0 -0.0   0.0   XRPd1vd
* Horizontal detector
ROT-DEFI     4.0  0.0  0.0  0.0  0.0 100.0  XRPd1h
ROT-DEFI   204.0  0.0  90.0  0.0  0.0  0.0   XRPd1h
ROT-DEFI     4.0  0.0  0.0  0.0  0.0 -45.0  XRPd1h
ROT-DEFI   304.0  0.0 270.0  0.0  0.0  0.0   XRPd1h
This file relies only on the FEDB, which can be obtained contacting the EN/STI-EET section (FLUKA Team) of the Engineering department at CERN [16]. The expand.sh tool in the FEDB ([PATH_TO_FEDB]/Tools/expand.sh) allows to replace all the #include lines with the actual contents of the files.

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References


[16] Access to the FLUKA Element Data Base and the FLUKA Line Builder SVN repositories is available on request to the EN/STI-EET section (FLUKA Team).