ROMAN POT INSERTIONS IN HIGH-INTENSITY BEAMS FOR THE CT-PPS PROJECT AT LHC

M. Deile* on behalf of the CMS and TOTEM Collaborations;
D. Mirarchi†, R. Bruce, A. Mereghetti, S. Redaelli, B. Salvachua, B. Salvant,
G. Valentino, CERN, Geneva, Switzerland

Abstract

In 2015 the Roman Pots (RPs) of the CMS-TOTEM Precision Proton Spectrometer in the LHC Interaction Region 5 successfully approached the 6.5 TeV beam in regular fills ($\beta^* = 0.8$ m) to distances of 25 beam width sigmas at all intensity steps reached during that running season, i.e. up to 2244 bunches producing a luminosity of 4.8×10^{33} cm^{-2}s^{-1}. Given that earlier insertion tests at low β^* before the Long Shutdown 1 (LS1) had suffered from impedance heating at the RPs, this first-time achievement proves the effectiveness of the impedance mitigation actions undertaken in LS1 and represents an important milestone towards physics production at distances as small as 15 sigmas. This contribution reviews the diagnostic measurements assessing debris showers and beam impedance effects, i.e. the data from Beam Loss Monitors, beam vacuum gauges and temperature sensors. The dependences of the observables on luminosity or beam current are shown. Extrapolations to higher luminosities and smaller distances to the beam do not indicate any fundamental problems. Finally the plans for 2016 are outlined.

INTRODUCTION

The Roman Pots (RPs) on both sides of the Interaction Point 5 (IP5) were originally developed and built by the TOTEM collaboration. In the first years of LHC operation they served mainly for dedicated beam time with special high-β^* optics and low beam intensities and luminosities, exploring elastic and soft diffractive physics with large cross-sections. Neither collision debris showers nor impedance effects were an issue. In 2012 the scope of RP-based physics was extended to standard low-β^* fills giving access to high luminosities and hence high-mass diffractive processes with low cross-sections. First RP insertion tests to distances of 3.3 – 4.4 mm (25 – 30 σ, where σ is the betatron beam width) in standard fills at 4 TeV beam energy, intensities of about 1.5×10^{14} protons per ring and luminosities up to 3×10^{33} cm^{-2}s^{-1} suffered from impedance heating, resulting in ferrite outgassing and vacuum degradations that finally generated losses leading to beam dumps by the Beam Loss Monitors (BLMs).

In 2014, during LS1, the CMS-TOTEM Precision Proton Spectrometer (CT-PPS) [1] project was founded, aiming at the exploration of diffractive physics at high luminosity. The physics performance goals will finally require a beam approach distance of 15 σ (i.e. 1.8 – 3.2 mm) or closer. For this project the RP and physics debris collimator (TCL) systems underwent a major consolidation and upgrade programme [2–4]. The old RP units at ~ ±150 m from IP5 were relocated to ±(203 − 213) m (XRP.C6R5 and XRP.D6R5 in Fig. 1), just upstream of the unchanged 215 m units (XRP.A6R5), making space for the new collision debris collimator TCL4 [5]. Since proton acceptance for CT-PPS physics requires the existing TCL5 collimator to stay wide open (~ 35 σ), another debris collimator, TCL6 [6], was added just downstream of the last RP unit (XRP.B6R5). TCL6 also intercepts showers created by the RPs. To complement the tracking detectors in the existing RPs by time-of-flight detectors for proton vertex identification, an additional RP (XRP.E6R5) was added on each side of IP5. For impedance and outgassing mitigation, all RP ferrites were replaced with a new material (TransTech TT2-111R), baked out at 1000° C. Furthermore, all horizontal RPs intended for high-luminosity use (red in Fig. 1) were geometrically optimised [7–9]: the old RPs were equipped with RF shields minimising cavity resonances, whereas the newly added pots already have a cylindrical shape avoiding any cavities.

The objective of the 2015 RP operation was to demonstrate the effectiveness of these improvements by inserting the RPs in all LHC beam intensity steps.

RP INSERTIONS IN 2015

The RP insertion series discussed here was performed for 6.5 TeV beams with up to 2244 nominal bunches (each with a population of ~ 1.15×10^{11} protons) separated by 25 ns. The maximum luminosity reached in this study was 4.8×10^{33} cm^{-2}s^{-1}. All RPs of the units XRP.[C,D,E]6R5 (Beam 1) and XRP.[C,D,E]6L5 (Beam 2) were inserted simultaneously, typically 2 hours after declaration of stable beams. Just before the RP insertions the TCL4/5/6 collimator configuration was changed from (15 σ/15 σ/out) to (15 σ/35 σ/25 σ). The RP distances to the beam centre were defined as 20.7 σ, i.e. retracted by 7 σ relative to the tertiary collimators (TCT), plus a fixed margin of 0.5 mm accounting for orbit uncertainties. Considering the different beam widths at different RPs, the total distances lay in the range of 2.7 – 3.9 mm, corresponding to about 25 σ.

During each insertion the debris shower development and impedance effects were monitored.

Debris Shower Measurements

The showers generated by the interactions of collision debris with the RP material can – if too intense – quench superconducting magnets downstream of the RP system.

* Mario.Deile@cern.ch
† presenter

ISBN 978-3-95450-147-2

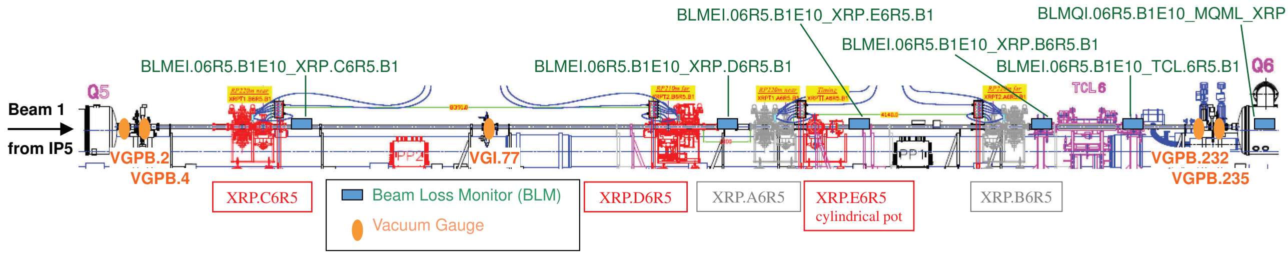

Figure 1: TOTEM / CT-PPS RP system in Sector 5-6 after LS1 (Sector 4-5 is symmetric relative to IP5). The red RP units are used for the low-β^* operations described in this article whereas the grey units are reserved for special high-β^* runs. The RP units XRP.[A,B,C,D]6R5 consist of a pair of vertical pots and a single horizontal pot, whereas XRP.E6R5 has only a horizontal pot.

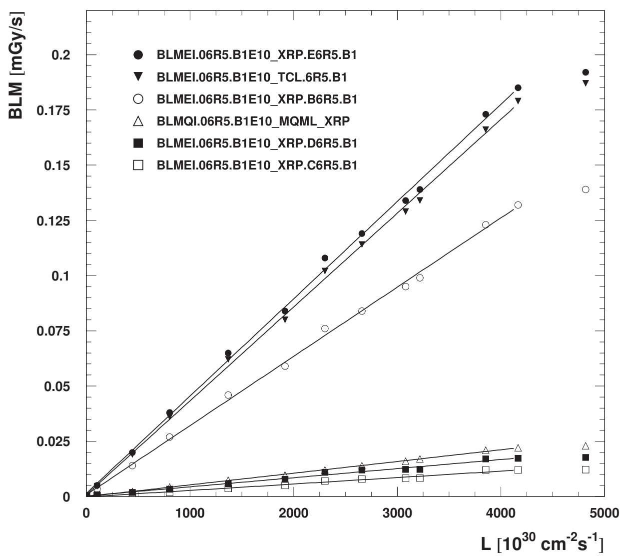

Figure 2: Dose rates in Sector 5-6 after RP insertion in Beam 1 measured by the BLMs behind the RP units (BLMEI.06R5.B1E10_XRP.[B,C,D,E]6R5.B1), the collimator TCL6 (BLMEI.06R5.B1E10_TCL.6R5.B1), and inside Q6 (BLMQI.06R5.B1E10_MQML_XRP) as a function of the luminosity. The integration time of the BLM data is 1.3 s. The interlock thresholds of the BLMs behind E6 and TCL6 are 6.655 and 0.838 mGy/s, respectively.

Therefore each RP unit as well as TCL6 are followed by dedicated interlocked BLMs. Furthermore, several BLMs are placed inside the quadrupole Q6 to create an interlock before the deposited energy reaches the quench level of the magnet.

Figure 2 shows the dose rates in the relevant BLMs after RP insertion as a function of the luminosity. While the shower development is difficult to understand quantitatively without detailed simulations, the following conclusions can be drawn:

- The highest dose rates are observed after the elements exposing most material to the beam halo: the new cylindrical RP with 12 cm of steel along the beam and the collimator TCL6. The old box-shaped RPs (5 cm material) show a lower shower production. The radiation seen in Q6 is low and does not constitute any quench risk.
- The BLM belonging to the XRP.B6R5 unit (not inserted) registers the small-angle part of the shower from the XRP.E6R5 unit.
- The dose rates are in good approximation linear with the luminosity. This is expected since the single-beam halo components are mostly removed by three collimator stages upstream, and the remaining halo consists of collision debris from IP5. The measurements at the highest luminosity are outliers with significantly low dose rates. They suffer from unknown systematic effects and have not been included in the linear fits shown in the figure.
- Linear extrapolations to a future luminosity of $10^{34}\,\mathrm{cm^{-2}s^{-1}}$ yield dose rates that stay below the interlock thresholds: the BLMs behind the XRP.E6R5 unit and TCL6 are expected to reach 7 % and 50 % of the thresholds, respectively. This remains to be confirmed in operation with different optics.

An important aspect for future operation is the behaviour of the loss rates at insertions closer to the beam. This could not be measured directly because in 2015 a closer approach was not considered to be safe. However, inserting the RPs individually and in small steps to their nominal positions, the BLM rates were measured as a function of the approach distance. This dependence was observed to be linear over a wide range (Fig. 3). In the absence of any beam structures, e.g. edges of collimator shadows, a continuation of the linear behaviour can be expected for smaller distances as long as the RP does not move closer to the beam than the preceding collimator, i.e. the TCT. This gives hope that from the beam-loss point of view there should not be any fundamental obstacle to a 15 σ approach, where according to the simple linear model the dose rate would reach only about 10 % of the interlock threshold.

Measurements of Impedance Effects

Impedance effects of RP insertions have two aspects: (a) perturbations of the longitudinal and transverse beam stability via complex tune shifts, and (b) local heating that may result in outgassing at the RPs.

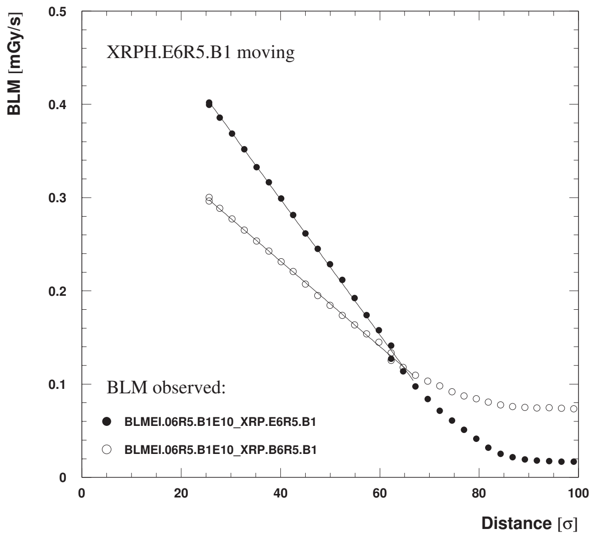

Figure 3: Dose rate at two BLMs, extrapolated to $\mathcal{L} = 10^{34}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$, as a function of the insertion distance of the XRP.E6R5 unit. For this study all other RPs are in retracted position.

During the RP insertions no effects on the real transverse tune were observed.

To measure impedance heating, temperature sensors were installed in the new cylindrical horizontal RP in sector 4-5 (XRPH.E6L5.B2): two PT100 probes were glued on the inner cylinder barrel wall, and two others on the flat floor facing the beam and hence closest to the main heat source. Possible outgassing effects are assessed by monitoring the beam vacuum in several gauges (see Fig. 1 for their locations). Figure 4 shows the time evolutions of the temperatures measured in the RP and of the beam vacuum in cell 6L5 during a fill with $\mathcal{L} = 1.9 \times 10^{33}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$ and a total beam intensity of 1.0×10^{14} protons. At RP insertion time the temperature starts rising steeply and then tends towards a saturation value at thermal equilibrium. As expected, the probes on the RP floor, closest to the beam, show the strongest effect. The pressure reacts to RP insertion mainly at the gauges VGPB.2 and VGPB.4, and slightly at VGI.77. The pressure increase at RP insertion time is immediate and does not follow the further temperature rise. It may be related to debris-shower bombardment rather than impedance heating.

The gauges VGPB.232 and VGPB.235 are only sensitive to the TCL6 movements, occurring a few minutes before the RP insertions. RP movement effects are compensated by pumps between the RPs and these gauges.

The temperature and pressure increase due to RP insertion as a function of the beam intensity is shown in Fig. 5. While the functional dependences do not become evident from these data, and other systematic effects seem to be important, in particular for the vacuum, no problematic values are expected to be reached for the beam intensities envisaged for 2016 ($\leq 3.5 \times 10^{14}$ protons per beam).

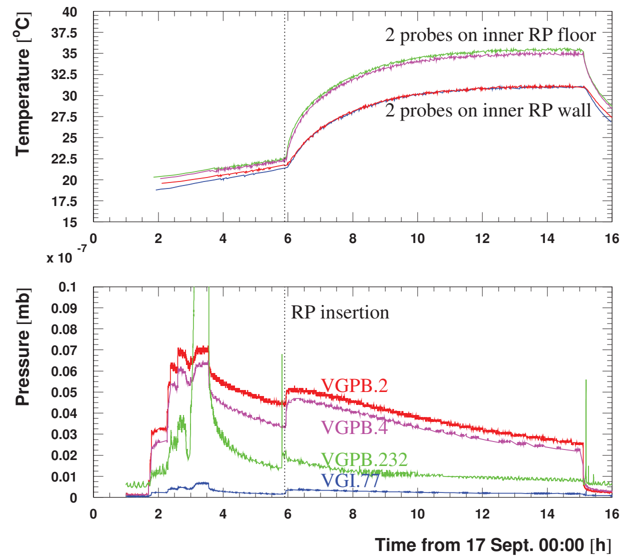

Figure 4: Time evolutions during a fill: (top) the temperature in the cylindrical RP unit XRPH.E6L5.B2 (with cooling switched off) measured by probes on the inner cylinder barrel wall and on the floor facing the beam; (bottom) the beam vacuum pressure at some of the gauges in cell 6L5 (see Fig. 1).

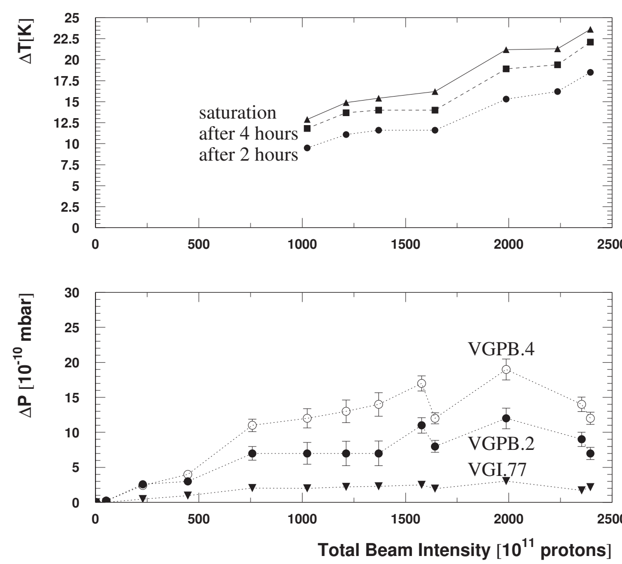

Figure 5: Temperature increase (RP floor facing the beam) and pressure rise induced by the RP insertions as a function of the total beam intensity.

PLANS FOR 2016

Given that experience from 2015 did not indicate any principal problems, the RP insertions will continue in 2016 with more agressive RP positions: initially $15\,\sigma + 0.5$ mm, later to be reduced to $15\,\sigma$ if careful approach tests are successful and if the beam orbit is stable enough. First physics data taking is foreseen.

ISBN 978-3-95450-147-2

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ISBN 978-3-95450-147-2