PROCEEDINGS OF SCIENCE

The TOTEM Roman Pot Detector System at the LHC: Status, Operation and Performance

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At the TOTEM Experiment, very forward charged particles from pp scattering at IP5 in the LHC are detected with silicon sensors which are equipped with a terminating structure which is sensitive within 50µm from its physical end and are housed in Roman Pots presently operating down to 3mm from the centre of the beam. In this work, I will introduce the Roman Pot experimental apparatus and then discuss its status, operation and performance with recent results. Emphasis will be also given to the alignment procedure which is a crucial part of the operation of this detector.

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1. Introduction: The TOTEM Experimental Apparatus and the Roman Pots System

The TOTEM experiment [1][2] is an LHC experiment dedicated to forward hadronic phenomena. The tree pillars of its physics program are: an accurate measurement of the total pp cross section, a measurement of elastic scattering in a wide kinematic range and studies of diffractive processes. All these processes are characterized by the presence of forward particles in the final state. This feature brings special requirements for the detector apparatus. In particular, large pseudorapidity coverage – to detect most fragments from inelastic collisions and provide appropriate acceptance for outgoing diffractive and elastic protons. To accomplish these tasks, TOTEM comprises three sub-detectors: the telescopes T1 and T2 to detect inelastic collision products and a system of Roman Pots (RP) for forward proton detection.

The Roman Pots are placed symmetrically around the interaction point 5 (IP5). To measure protons scattered at very small angle they have to be far away from the IP and are therefore distributed in stations at 147 and 220 m at each side of the IP (see Figure 1). Each Station is made of two units, with each unit containing one top, one horizontal and one bottom pot.

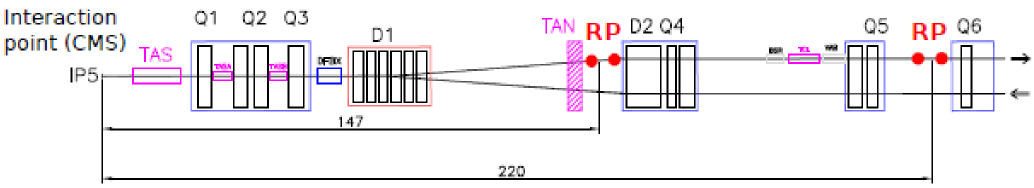

Figure 1 Scheme of the Roman Pot system (only the part on the right side of IP5 is shown). The black lines represent the beam-pipes of incoming and outgoing beams (see the arrows on the r.h.s.). The two RP stations are marked in red, each unit is drawn as a red dot.

The Pot is a beam pipe insertion device housing one detector package. In total there are 24 detector packages each of them is made of ten tracking planes with silicon microstrip sensors. All the sensor lay in the plane orthogonal to the beam and have strips oriented alternately at ±45° wrt. the edge facing the beam. A very thin window (150μm) separates the sensors from the primary LHC vacuum. Its low material budget is extremely important to keep the interaction rate at a bearable level. For data taking, in conditions of stable beams, a reliable movement system drives the pots from the garage position which is outside the beam pipe to a position (IN) where the sensors are close to the beam. When the pots are IN, the sensors approach the beam envelope within a few sigmas. In these conditions their overlap (Figure 2 right) is crucial for the alignment.

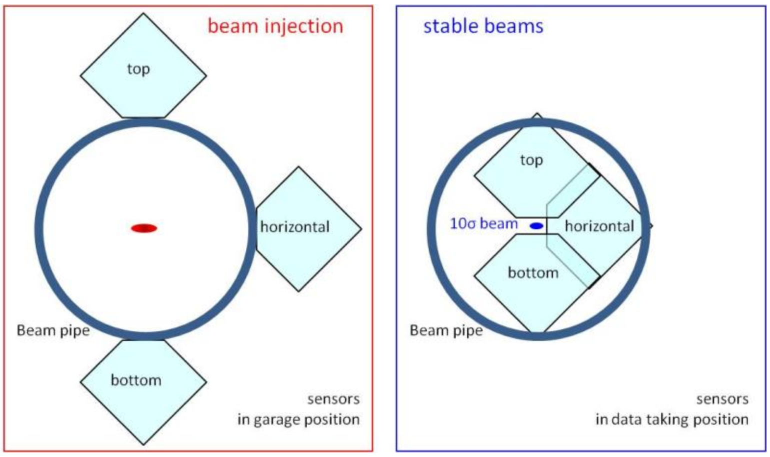

Figure 2 Positioning of the Silicon sensors in the top, horizontal and bottom pots with respect to the beam pipe before (left) and after (right)the declaration of stable beams.

To maximize the acceptance for forward protons, the sensors have the particular feature of being almost edgeless. In fact, these sensors developed recently employing the principle of the “current terminating structure” have an insensitive edge on the side close to the beam of only 50µm [3][4], which is more than one order of magnitude smaller than the ones used in the other LHC silicon trackers.

The assemblies of the Roman Pot Detector Packages have followed the requirement of a very compact design due to the space constraints in the LHC Tunnel. The sensors are mounted on hybrids which also contains the frontend chip VFAT2 is present (see Figure 3). This rad-hard ASIC chip is provided with digital storage, data transmission and a fast-OR to produce trigger information from segments of the sensor. A block of 10 hybrids makes the detector package and connects to a motherboard, which receives and distributes the HV, LV, the Slow Control, the clock, the fast commands and L1A to the frontend chips and the sensors. The motherboard also converts data frames and triggers into optical signals and then transmits to the counting house which is located in IP5. The motherboard also acts as a feed-through from the secondary vacuum of the sensor to the LHC tunnel ambient and hosts several temperature and pressure gauges as well as radiation monitors.

With the Si sensors and chips in the vacuum, a cooling system based on two phase evaporative cooling keeps the temperature of the assembly at ≤-15° C. The heat transfer is made via support plates and bars in CE07 (Ospray®) in tight contact with capillary pipes where cooling liquid (C_3F_8) flows. The mounting of the assembly has required precision jigs to pile up hybrids in a stack with tolerances of a few tens of micrometers.

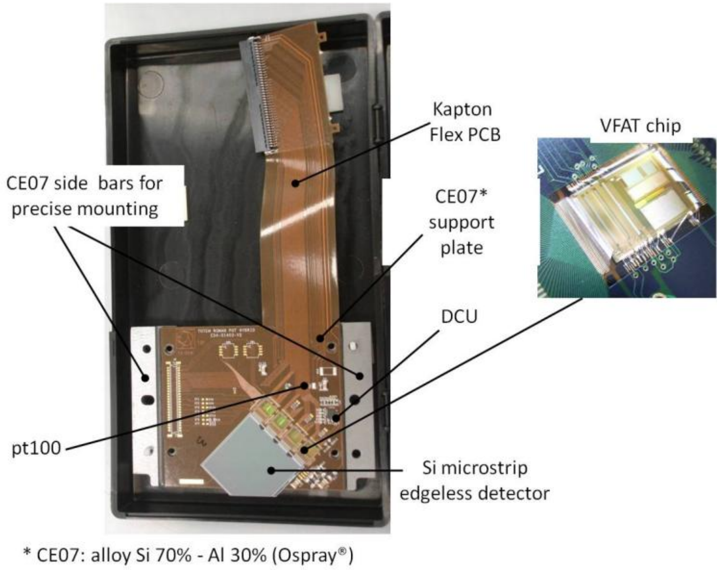

Figure 3 Roman Pot Hybrid with details

2. The Roman Pot Detector Status

The Roman Pot System is now complete. After the installation and the commissioning of the Roman Pot Detectors in the stations at 220m from IP5 happened starting from 2008 to end of 2009, while the stations at 147m have been installed during the technical stop of 2010 and are now operational. A picture of a Roman Pot Detector Package and the Station at 147 in sector 45 is shown below in Figure 4

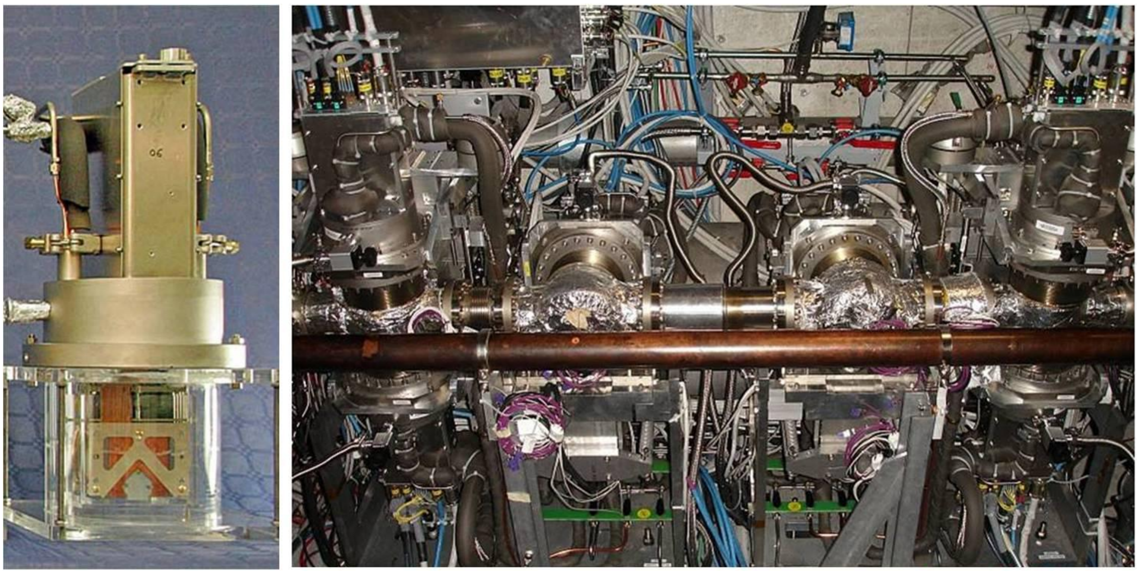

Figure 4 A Roman Pot Detector Package (left) and a complete Roman Pot Station (right)are shown above.

To avoid stress on the thin window separating the detector from the vacuum of the machine, a secondary vacuum is always present and the cooling runs continuously, apart from short interruptions during maintenance operations happening in technical stops. The performance of the cooling system has been so far excellent with the temperature of the hybrids always below -15°C during data taking (see Figure 5).

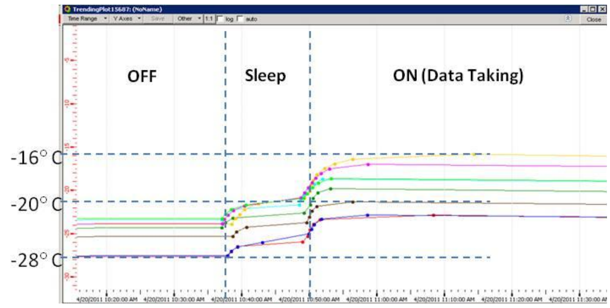

Figure 5 Snapshot from the DCS monitors with temperature trends in different detector packages, while everything is OFF (left), while the readout chips are in "Sleep" mode (centre) and then when it is all powered and taking data (right).

The sensors and the F/E chips are only powered up for the operation of the detector. The sensors are for now being powered with 100V and so far no evidence of damage due to radiation has been experienced. The sensitive edge current and the bulk current are both regularly monitored via a DCU chip sitting on the hybrid and no change in the current values has been seen so far (see Figure 6).

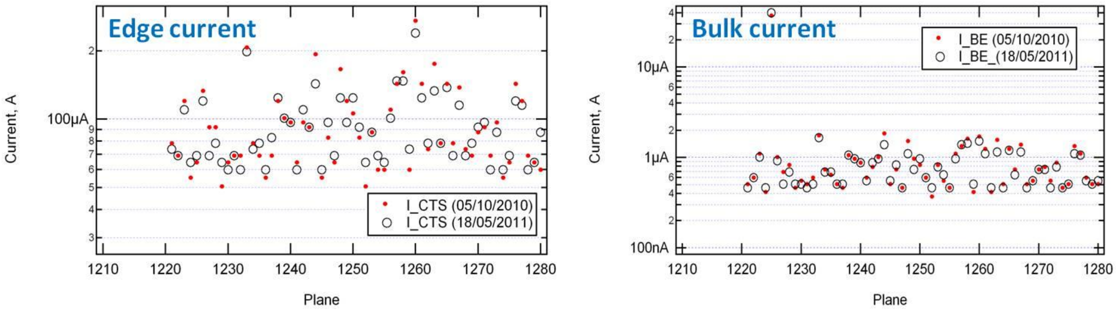

Figure 6 Comparison of the edge current (right) and the bulk current (left) for the same sensors measured in October 2010 (dots) and in May 2011 (circles).

The overall status of the detector is also monitored with regular checks of channel noise and counting of bad channels. The channel noise is about 900 el. rms with a rate of too noisy or dead channels of about 2% over the whole Roman Pot System.

3. Operation and Performance

The Roman Pot Detectors are movable devices and can represent a risk for the machine. Their movement is controlled from the LHC CCC and the insertion is allowed only after stable beam is declared. Although the Roman Pot setup can operate well during normal LHC runs, for LHC machine safety reasons the pots cannot approach the beam closer than ~15 σ. To align the Roman Pot system to the beam, special calibration LHC runs have been dedicated to TOTEM. In these runs, which have low luminosity, the Roman Pot envelope approaches the beam down to 5σ (~1mm). These runs are crucial to the

Roman Pot operation and need to be repeated for every change in beam energy and optics. Moreover for the TOTEM experiments are foreseen special physics run with high beta optics for parallel to point focusing, low intensity, to approach the beam to ~10σ.

3.1 Roman Pot Alignment

The alignment is a crucial process of Roman Pot measurements. The alignment of the Roman Pots means: to measure the boundaries of the beam and define with a precision of few tens of microns where the beam centre at the location of the Roman Pots is. It is made in three steps, first with a scraping exercise, where the pots envelopes approach the beam with a precision of ~10µm until the beam is scraped (a schematic representation of the exercise is shown below in Figure 7) to centre the Roman Pot envelops with respect to the beam. Then, tracks of particles resolved with a precision of 10µm and crossing the two RP units in the horizontal and vertical pots (either top or bottom), define the relative position of the sensors in the different pots as well as the absolute distance between the top and the bottom pots. Finally, the beam centre information and the position of the sensors are linked together by using the data from metrology surveys (~10µm precision) made during the detector assembly and installation.

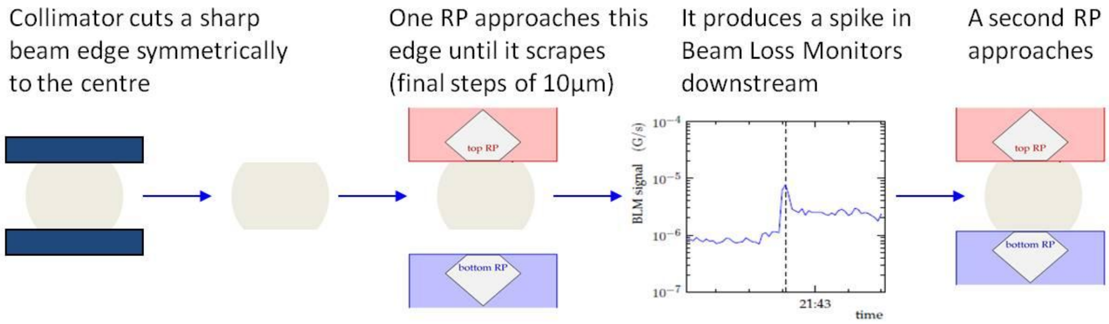

Figure 7 Schematic representation of the scraping exercise where, with the help of the information from the Beam Loss Monitors downstream the Roman Pots, the beam edges are detected.

3.2 Protons, background and radiation dose

The distribution of the hits in all the silicon sensors is highly non uniform as it is shown in Figure 8. As well, locally, in the horizontal pots the rate of particles can be more than an order of magnitude higher than in the neighbouring vertical pots. Moreover, by measurement made with RadMons [5], it has been shown that the average radiation dose accumulated in the silicon sensors at the Stations at 147 is more than ten times higher than in the ones from the stations at 220m [6].
Finally, depending on whether the detectors are operated at close distance to the beam or are kept in the stand-by garage position during normal LHC runs, their exposition to radiation changes drastically. Therefore it is very hard, as of now, to establish what the lifetime of the sensors will be.

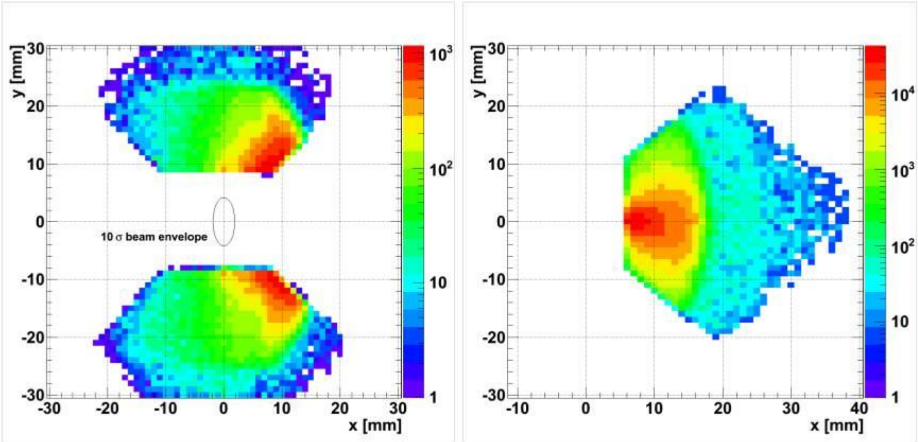

Figure 8 Intercepts of reconstructed tracks in sensors from Top and Bottom Pots (left) and Horizontal Pots (right) in one station at 220 m. The higher hit density in the horizontal pot is due to the diffractive protons.

4. Conclusions

The TOTEM Experiment with its Roman Pot Detectors has been brought to life in a fairly short time. Its experimental apparatus completion happened this year will allow us to explore the full discovery potential of the TOTEM Experiment.
For now, the overall performance of the Roman Pot Detector with its edgeless silicon detectors has been excellent. The effort spent in the development and construction of the experiment has started to pay off with the first physics results. With the fundamental contribution of data from the Roman Pots, the first measurements of the elastic scattering [7] and the total cross-section [8] at the LHC, which are central measurements of the TOTEM program, have recently been published.

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