The TOTEM Experiment Consolidation and Upgrade

G. Antchev [*]

On behalf of the TOTEM Collaboration

[*] INRNE-BAS, Sofia, Bulgaria

Gueorgui.Antchev@cern.ch

Abstract

The TOTEM experiment has three sub-detectors: Roman Pots (RP) with silicon strips, the T1 detector with Cathode Strip Chambers (CSC) and T2 with Gas Electron Multiplier detectors (GEM). The Roman Pot detectors are located in the straight sections of the LHC tunnel on both sides of the CMS experiment at IP5. Between 2009 and 2012 data at $\sqrt{s}$ = 7 and 8 TeV was collected in special runs at reduced luminosity. The TOTEM experiment consolidation and upgrade program and the possibilities of resolving event pileup and multiple tracks in the proton detectors will be described briefly in this paper.

I. Introduction and TOTEM Detectors

TOTEM [1] is an experiment dedicated to the measurement of total cross section, elastic scattering and diffractive processes at the LHC. The full TOTEM detector is composed of Roman Pot stations (RP), Cathode Strip Chambers T1 (CSC) and Gas Electron Multipliers T2 (GEM). The T1 and T2 detectors are located on each side of the CMS interaction point in the forward region, but still within the CMS cavern, see Figure 1.

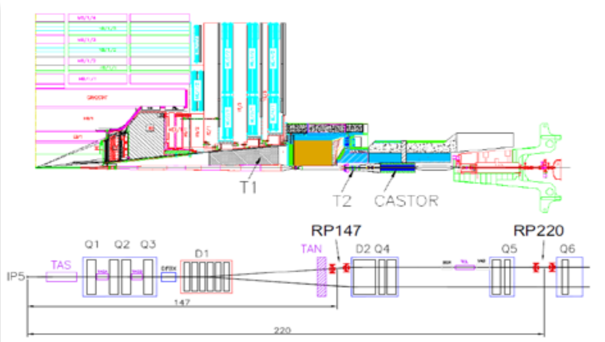

Figure 1: Top: The TOTEM forward detectors T1 and T2 embedded in the CMS detector. Bottom: The LHC beam line and the Roman Pots at 147 m and 220 m sector 5-6

II. Roman Pot

Two Roman Pot stations are installed in the straight section of the LHC tunnel on each side of the interaction point at 220 m and 147 m. Each station consists of two groups of three Roman Pot separated by a few meters to obtain a sufficiently large lever arm for the track angle reconstruction. Three Roman Pots were designed in one group to approach the beam with detector stacks from three different sides (top, bottom and the one horizontal side to which the diffractively scattered protons are deviated by the machine dispersion). Each Roman Pot contains 10 silicon strip detectors with 512 strips. Figure 2 shows the TOTEM Roman Pot unit (example of sector 5-6 at 220 m near unit).

Figure 2: The TOTEM Roman Pot Unit

The silicon strip detectors are mounted on a hybrid together with the VFAT2 readout chip [2]. The strips on the detector form a 45 degrees angle with the edge close to the beam. Flipping the detector hybrid and mounting it face-to-face with the next one results in orthogonal strips giving the U and V coordinate information. The stack of 10 hybrids forms a so-called detector package. A picture of it is shown on Figure 3.

Figure 3: The Detector Package

III. CONSOLIDATION

In the following section, the TOTEM consolidation program will be described.

A. Motivation

During LHC Phase I, TOTEM collected data at √ s = 7 and 8 TeV in special runs at reduced luminosity. This allows analysis of large cross-section processes like elastic scattering and soft diffractive channels, and also the measurement of the total pp cross-section and the pseudo rapidity distribution of charged particles. The results were published in EPL journals **[3][4][5][6][7][8]**. To repeat those measurements at the new LHC energies of √ s = 13 and 14 TeV is one of the goals of the TOTEM collaboration. Another one is to combine the TOTEM and CMS detectors with common triggers of high flexibility.

B. Strategy

Due to the background created by pileup events it was difficult to collect a pure sample of central diffractive events. The contamination of events with the right signature (e.g. two leading protons and central dijets) can be larger than 60% due to the pileup of a soft central diffractive event (or two single diffractive events) with a central non-diffractive dijets event. Therefore the strategy for the future is to:

- Upgrade the detector apparatus for resolving the pileup of multiple events in the same bunch crossing.
- Operate at higher luminosities by increasing the luminosities of special runs and later by exploiting standard LHC fills.

C. Multiple tracks - ambiguity

An example of multiple tracks is schematically shown in Figure 4.

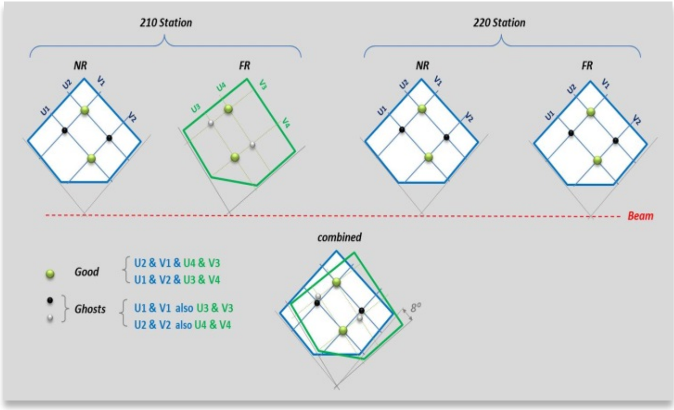

Figure 4: Vertical Pots – for each unit a single plane is shown

D. Experimental Setup

To resolve the event pileup and multiple tracks in the proton detectors TOTEM proposes the following:

- Relocate the 147 m stations to 210 m (the region between quadropole Q5 and 220 m stations).
- Tilt half of the station (far unit) by 8 degrees around the beam axis.
- Installation of two new horizontal Roman Pots to accommodate timing detectors for reconstructing the longitudinal vertex position of the leading protons in central diffractive events.

A drawing of the experimental setup layout is shown in Figure 5.

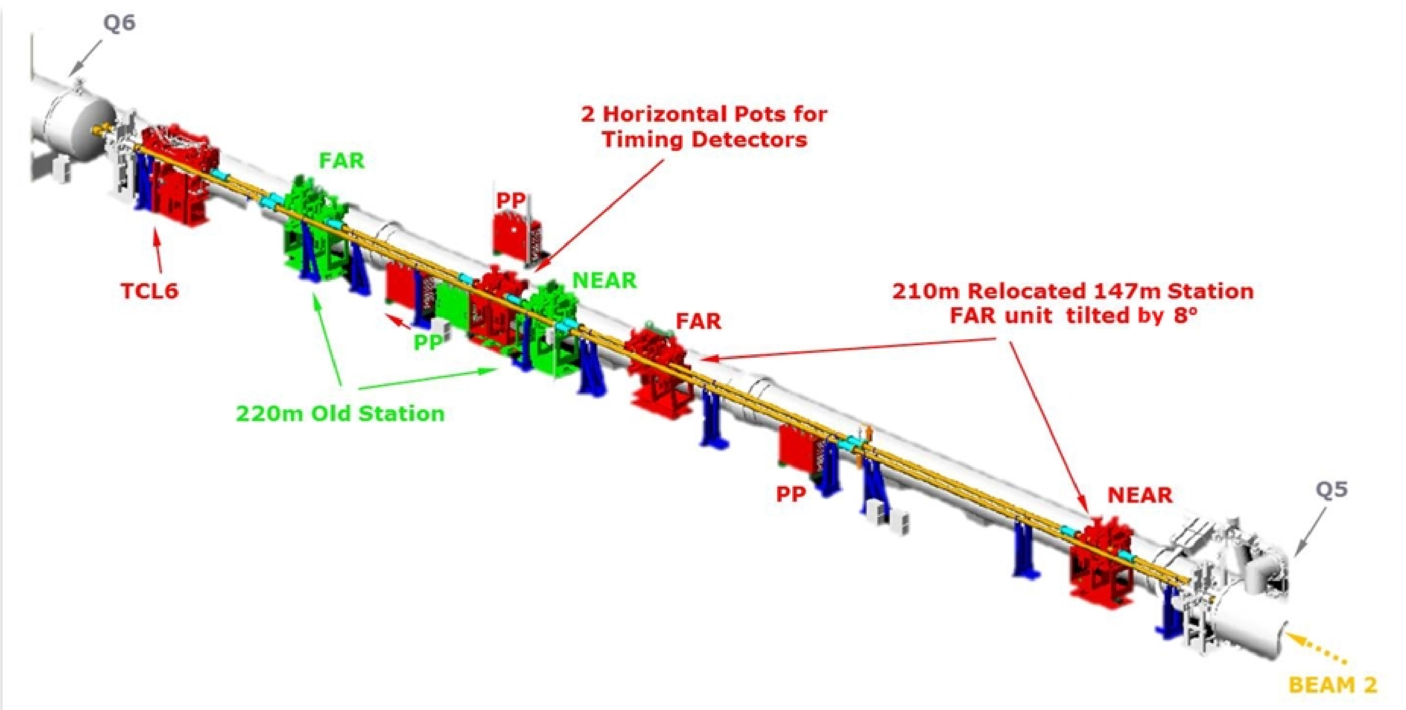

Figure 5: Experimental Setup Layout – the sector 4-5 is shown

The stations at 220 m will remain unchanged as before LS1. The former station at 147m is removed from cell 4 to make space for the new collimator TCL4 and relocated into the free space between the quadrupole Q5 and the station 220 m (i.e. at 210 m).

The entire far unit is rotated by 8^{o} around the beam axis in order to introduce two additional track projections for resolving multi-track events. To achieve this rotation new mechanical support has been designed. The drawings of the rotated and non-rotated units on sector 5-6 are shown in Figure 6.

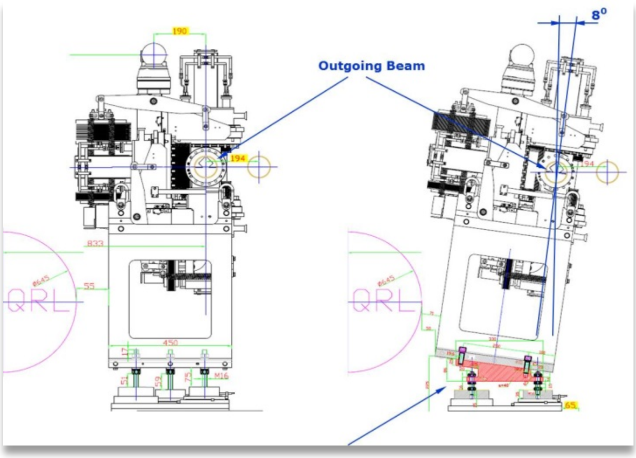

Figure 6: Non-rotated and Rotated Units – sector 5-6

All pots of the 210m and 220m stations are initially equipped with the existing edgeless silicon strip detectors. This will enable immediately after LS1 the continuation of the low-luminosity physics program at β* = 90m, using the unmodified 220 m stations with their well-established performance. These early runs will at the same time offer the opportunity to successively insert the 210 m stations and gain experience with their properties. Adding the 210 m near unit will provide an extended lever arm for precise elastic scattering-angle measurements.

Moving on to the luminosity-enhanced β* = 90 m scenario with crossing-angle and about 1000 bunches; the tilted 210 m far unit will contribute its stereo effect for resolving multiple tracks.

IV. Upgrade

The upgrade proposal foresees during LS1 the installation of an additional horizontal Roman Pot – intended to house timing detectors for operation at low β* – between the near and far units of the 220m station. The new Roman Pots have been designed with a cylindrical rather than rectangular pot geometry providing sufficient space to accommodate quartz Cerenkov bars, one of the possible technologies for timing detectors. The high material budget of the quartz bars and the longer beam-facing Roman Pot window will result in multiple scattering of the signal protons and in showers, precluding the usage of the downstream tracking 220 far unit simultaneously with the timing Roman Pot. In the very first stage the new pots will be equipped with only temperature sensors which will give way to timing detectors as soon as they become available. In addition to Cerenkov detectors, other technologies with less material budget will be investigated.

New Roman Pot

In order to provide the necessary space for timing detectors and reduce the beam coupling impedance several options have been considered. Cylindrical detector housing has been selected. Future impedance reduction can be done by adding cooper coating of the cylindrical surface. The pictures of the new cylindrical Roman Pot are shown on Figure 7.

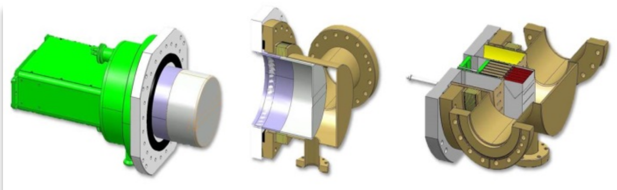

Figure 7: New Cylindrical Roman Pot

V. Integration with CMS DAQ

TOTEM operated mostly in stand-alone mode but compatibilities with CMS was always a prime requirement for the systems **[9]**. The Trigger system is able to provide the trigger to CMS within the required latency and also is able to receive the trigger signal from CMS and include it to global trigger generation algorithm. To comply with the required latency the electrical trigger signals are transferred to the central trigger system using LVDS repeaters. Each Roman Pot is able to send electrical triggers using VFAT2 readout chip and coincidence chip.

The main part of the DAQ and Trigger systems is the TOTEM Front End Driver, so-called TOTFED **[10]**. It receives and handles trigger building and tracking data from the detectors, and interfaces to the global trigger and data acquisition systems. It has been designed as modular device and compatible with CMS DAQ system.

The TOTFED main interface to the CMS DAQ is the CMC Transmitter based on the S-Link64 protocol. This transmitter is plugged on the optical receiver card OptoRX12 which receives data and trigger information. Processing and data formatting is applied inside programmable logic devices (FPGA's) on OptoRX12 before sending data via CMC Transmitter. On the other side of the transmitter is the Front-end Readout Link – FRL **[11]**. The FRLs are Compact PCI boards with an internal PCI bus hosting a commercial Myrinet network interface card. To comply with the new requirements for CMS DAQ data transfer after LS1 this interface will be replaced by the Gigabit Ethernet interface.

The block diagram of the Roman Pot DAQ system is shown in Figure 8.

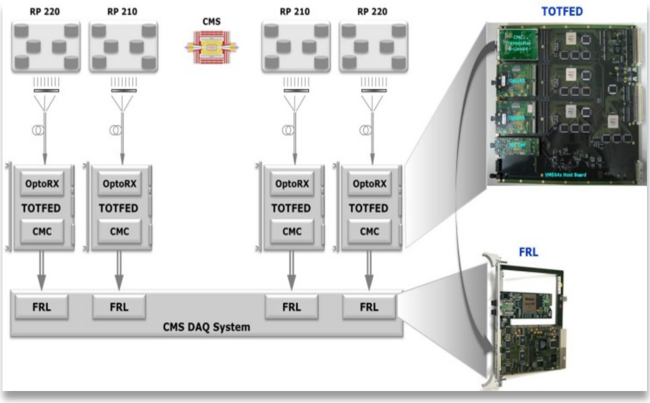

Figure 8: The Roman Pot DAQ System – block diagram

Each Roman Pot station is read by one TOTFED device equipped with two OptoRX12 receivers and two CMC transmitters. Then the CMC transmitters are connected via copper cable to the FRL devices located in the nearby rack. The maximum data transfer rate for each CMC transmitter is about 480 MB/s. From the FRLs data are transferred via Gigabit Ethernet interface to the CMS DAQ system. Integration with the CMS DAQ system required also several changes in the software configuration in order to comply with the CMS XDAQ system.

VI. Services

For the consolidation the Roman Pot stations from 147 m are moved to 210 m and of course their infrastructure has to follow. It consists of low voltage, high voltage supplies, and optical data transmission connections from the counting room. Also the sensors for slow control and safety systems and motorisation have to be connected.

This infrastructure is generally applicable, and it has been decided to use it for the new Roman Pot stations foreseen for installation of precise timing detectors. High voltage cables up to 2 kV will be added and additional fibres dedicated for a timing reference signal will be installed during LS1. This early preparation of the infrastructure enables the installation of the new detectors during short technical stops.

Other important parts of the infrastructure are the interlock and DSS systems, DCS system and cooling and vacuum systems. Relocation of all those systems is also required to complete the consolidation program.

VII. Summary

The TOTEM experiment consolidation and upgrade during technical stop LS1 are an on-going process. Several work packages are carried out in parallel, such as: production of new cylindrical Roman Pots, ferrite elements, calibration and movement system tests in the laboratory. The relocation of the 147 m stations to 210 m on both sides needs production of new beam pipe elements and bellows. It also required production of new cables and displacement of the patch panels. The consolidation and upgrade program also relies on the extensive help from different CERN groups and external collaborators.

VIII. References

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