CERN-RRB-2010-046

20 April 2010

The Status of TOTEM

Progress Summary Report for the April 2010 RRB

The TOTEM Collaboration

1. Introduction

Since the last RRB in October 2009 the commissioning of the TOTEM Roman Pot (RP) and T2 detectors continued successfully. However before taking data in December 2009 two problems appeared. The Roman Pot detectors encountered a low voltage (LV) and a high voltage (HV) problem. The control of one half of the T2 telescope was lost a few days before the run. Thus only a part of the detectors were able to take data.

In collaboration with the collimation group, an absolute position calibration of some Roman Pots was obtained by moving them slowly out of the collimator shadow (i.e. to a distance of only a few beam sigma from the beam centre), while monitoring the signal of the beam loss monitor downstream of the RP. Under these conditions, tracks with the Roman Pot detectors were recorded. Furthermore, one arm of the very forward T2 telescope took several thousand tracks at a centre-of-mass energy of 2.36 TeV, resulting in a first preliminary rapidity distribution (without correction). In summary, we gained useful experience during the first LHC run.

During the shutdown the LV and the HV problems of the RP detectors were successfully solved such that at the beginning of this year's run all Roman Pot detectors at 220 m from IP5 were fully functional. In addition, the RP motors were calibrated, and their movement was tested with the interlock box together with the CCC. For T2, the faulty card in one telescope arm was exchanged, so that the full telescope is now ready to take data.

Since the beginning of the 2010 running period, TOTEM is performing extensive trigger studies, which will lead to understanding the backgrounds, to the tuning of the alignment algorithms and to the optimisation of the trigger tracking efficiency. This should allow soon the setting up of a physics trigger to take data.

One half of the more central forward telescope T1 is ready to be inserted into CMS; the second one will be ready in summer after the beam test.

During the shutdown some installations of T1 services were done on one side of CMS. Important steps were the welding of the fixing blocks and the truss installation test and survey, showing that all positions are within 5 mm from the nominal position. During 2010 the second T1 telescope has to be completed and tested. Both telescopes must be installed during the technical stop at the end of the year.

The RP detectors for the 147 m stations will also be assembled and tested this year before being installed either in short technical stops or at the end of the year.

2. The Roman Pots

Since November 2009 the commissioning of the Roman Pots System has continued. After completion of the connectivity, the whole system has been tested, starting from the services to the DCS and the DAQ. The data taking for the Roman Pot system was conditioned by the permission from the machine to move the Roman Pots towards the beam. The first displacement of one Roman Pot during "stable beams" (with detector OFF) was allowed the 29th of November and the activity on the BLM adjacent to the moving pot was monitored. The second occasion to move a pot was given the 15th of December during a run specially agreed by the machine for TOTEM. At this occasion, the edge of the pot was lowered down to 4 mm from the beam centre (~4.4σ), and data were taken with the LV1 trigger from the bunch crossing signals distributed by the machine at IP5. A collection of reconstructed tracks from different events of this run is shown in Figure 1.

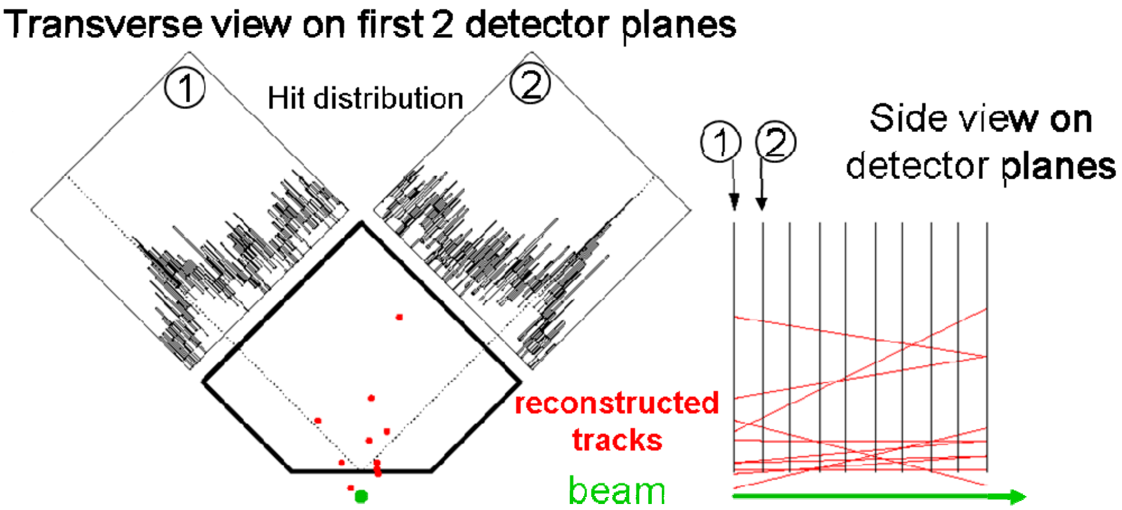

Figure 1: Transverse and side view of reconstructed tracks from overlaid events in one single pot.

During the 2009 running period it was found that several silicon sensors belonging to different pots were in contact with the thin window of the pot. These contacts were shorting the HV, not allowing to power up the HV of the sensors.

This issue was addressed and solved during the shutdown of January. In fact, an intensive program of consolidation was organised and completed during this period. New spacers increasing the distance of the sensors from the thin window by 250 μm were produced and replaced in all the 12 pots. Moreover, to improve the stability of the front-end electronics and data transmission, the LV distribution was reinforced with additional power channels. These actions required the extraction and the re-insertion of all the detector packages. Consequently, the final calibration of the motors with the laser tracker, which could not be completed before the start of the 2009 LHC runs, was made in early 2010.

After this phase of consolidation, the commissioning tests on the readout continued, showing the full functionality of the 99% of the VFAT chips. Presently we are implementing and testing the active trigger. The first data taking with active trigger is expected to happen soon.

Regarding the equipment of the Roman Pot stations at 147 m, the production of the detector packages is continuing, but at a low rate. So far, two additional detector packages have been assembled and ready to be tested with particles in H8.

The TOTEM interlock system contributes to the safe LHC operation by providing Injection Permit and User Permit signals to the central Beam Interlock Controller (BIC). Specifically, injection is inhibited if not all Roman Pots are in retracted position. Furthermore, if any Roman Pot is found to be outside its beam-mode dependent position limits as defined by the collimation database (LSA), the TOTEM interlock system will automatically retract all Roman Pots and dump both LHC beams by withdrawing the User Permit. Technically, this interlock logic is implemented on a custom-designed circuit board.

Already during the 2009 running period, the vital features of the TOTEM beam interlock system were functional and performing according to the specifications.

During the winter shutdown, further improvements and advanced features were implemented:

- A key-secured override switch allows Roman Pot movements outside stable beam mode. This is needed for special calibration runs together with the collimation system.
- An emergency Roman Pot retraction button was installed in the TOTEM control room with a hardware link to the motor control.
- A key-secured movement inhibit switch prevents undesired non-emergency Roman Pot movements by the operator.

Before the restart of the machine, a comprehensive interlock test has been successfully carried out. All functionalities showed the intended behaviour [2].

Furthermore, a new calibration of the LVDT-based Roman Pot position measurement system was performed, as well as a geometrical survey relating the Roman Pots to the Beam Position Monitors nearby.

3. The T1 CSC Telescope

The arm of the T1 telescope installed on the H8 test beam line in the North Area has been extensively tested in two running periods in November and December 2009. Front-end electronics, data acquisition chains, HV, LV and gas distribution were in their final configurations. The data acquisition system was capable of reading out the whole system, for a total of nearly 9000 channels, at rates up to 200 Hz. Data have been taken with both a pion beam interacting with a Cu target in a relative position roughly corresponding to the interaction point in CMS, and a muon beam crossing all layers of a given sextant. In the first case, multi-track events resulting from pion scattering on the target have allowed to reconstruct interaction vertices: the distributions of the vertex coordinates (Figure 2) are centred around the target location, with radial and longitudinal standard deviations of about 3 cm and 85 cm, respectively (with no alignment).

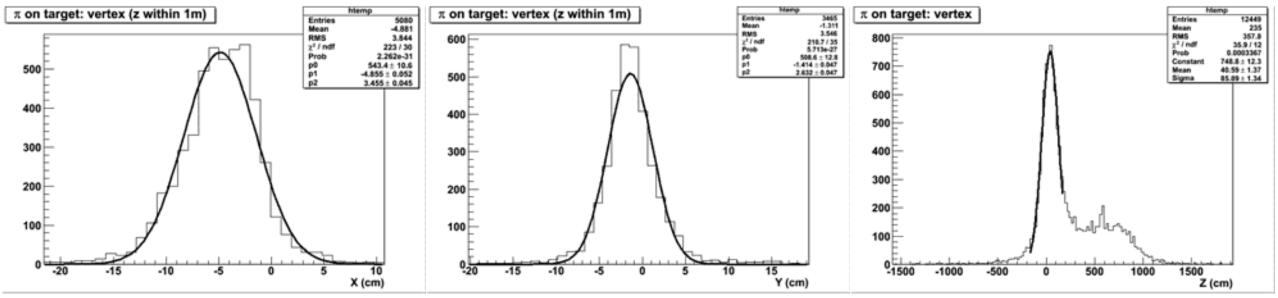

Figure 2: Distributions of the three coordinates of vertices reconstructed from pion test beam data.

In the second case, the efficiency of the hit chambers has been measured as a function of the HV applied (Figure 3): values are as expected, with efficiency approaching 100% around 3.45 kV with the current threshold settings.

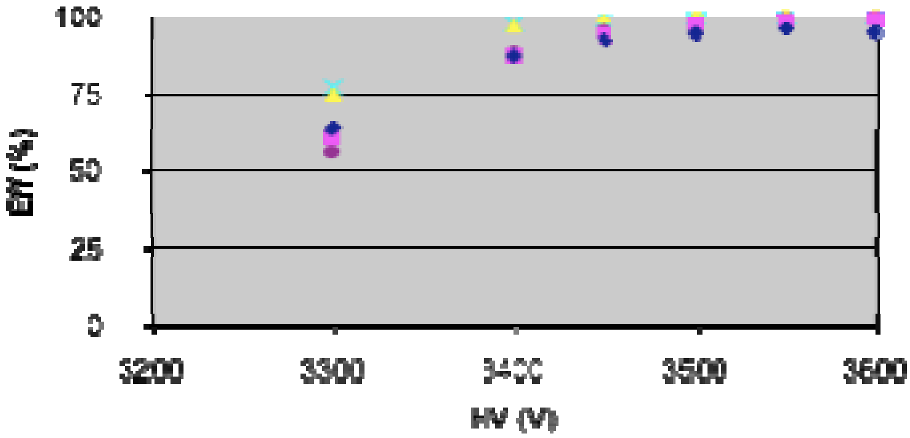

Figure 3: Hit reconstruction efficiency (using 3-coordinate coincidences) in the CSC of one sextant as a function of applied HV, from muon test beam data.

Due to the delicacy of the procedure of installation of T1 inside the CMS end-cap, around the beam pipe, and the substantial interference with planned CMS maintenance operations, it has not been possible to install the telescope arm during the latest winter shut-down, despite the fact that all services on the '–' side of the detector were ready.

In the meanwhile, the second arm of the telescope has been assembled in the laboratory at building 188 in Meyrin (Figure 4). The cabling and mounting of front-end electronics modules is being completed on the last half-arm. All chambers, including spare ones, have been equipped with the additional protection circuit to preserve the VFAT chips from damages due to occasional sparks.

All parts of the support structure of T1 and the installation tools are ready. A test installation of the support truss has been performed during the winter shut-down on the '+'

side of CMS: survey measurements have shown deviations from the truss nominal position within 5 mm (without correction shimming).

Regular meetings are being held with CMS in order to devise detailed installation plans for T1, with the aim of establishing safe and time-wise optimised sequences for different scenarios of the next LHC technical stops.

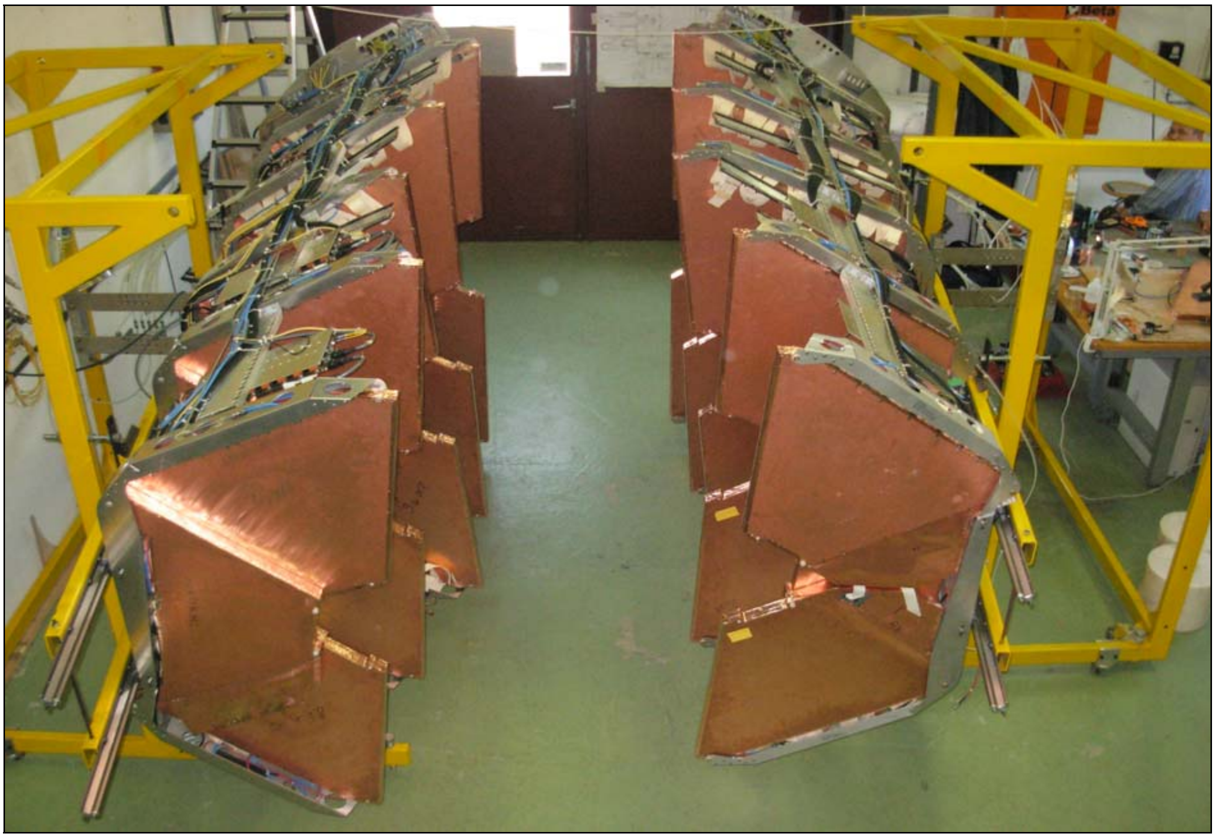

Figure 4: The two halves of the second arm of T1, assembled in the lab at building 188

4. The T2 GEM Telescope

The detector has been fully installed in the UXC55 cavern during the summer 2009. The commissioning of all the services and electronics has been performed in autumn. In the months before the CMS closure one half detector showed erratic fatal errors in the control chain. Due to the limited access, it has not been possible to change the front-end card responsible for the failure before the December run.

Hence the 2009 runs were taken without the "minus"-half detector. We took data with a minimum-bias trigger, resulting in event rates compatible with the other experiments in the LHC.

The tracks reconstructed from the data showed consistency with the simulation; the primary vertex of each collision has been measured together with the pseudo-rapidity η (Figure 5).

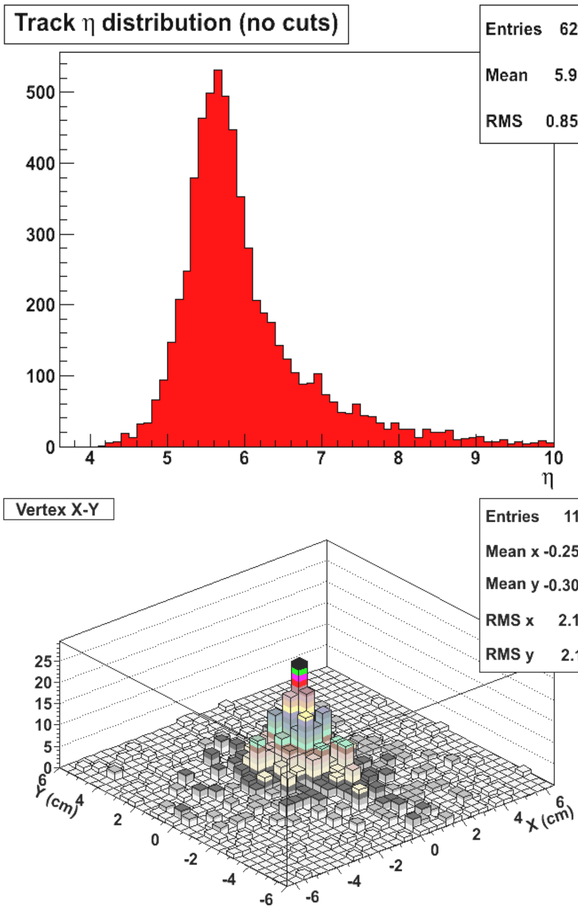

Figure 5: Data from T2 taken in December 2009. Top: pseudo-rapidity distribution, bottom: transverse vertex distribution.

CMS opened the detector during the Christmas shut-down, and the HF platforms, hosting the T2 detectors, have been put in the garage position.

The opening allowed the replacement of the faulty front-end card on the minus end side of T2 and also an upgrade on the mechanics for a smoother and faster opening procedure.

The new commissioning started end of January and before mid February the detector has been fully tested.

The trigger chain has been also upgraded and the detector could start taking data at the first LHC collisions. The Minimum Bias events collected since now shows the same behaviour as the December data. Both arms are working as expected.

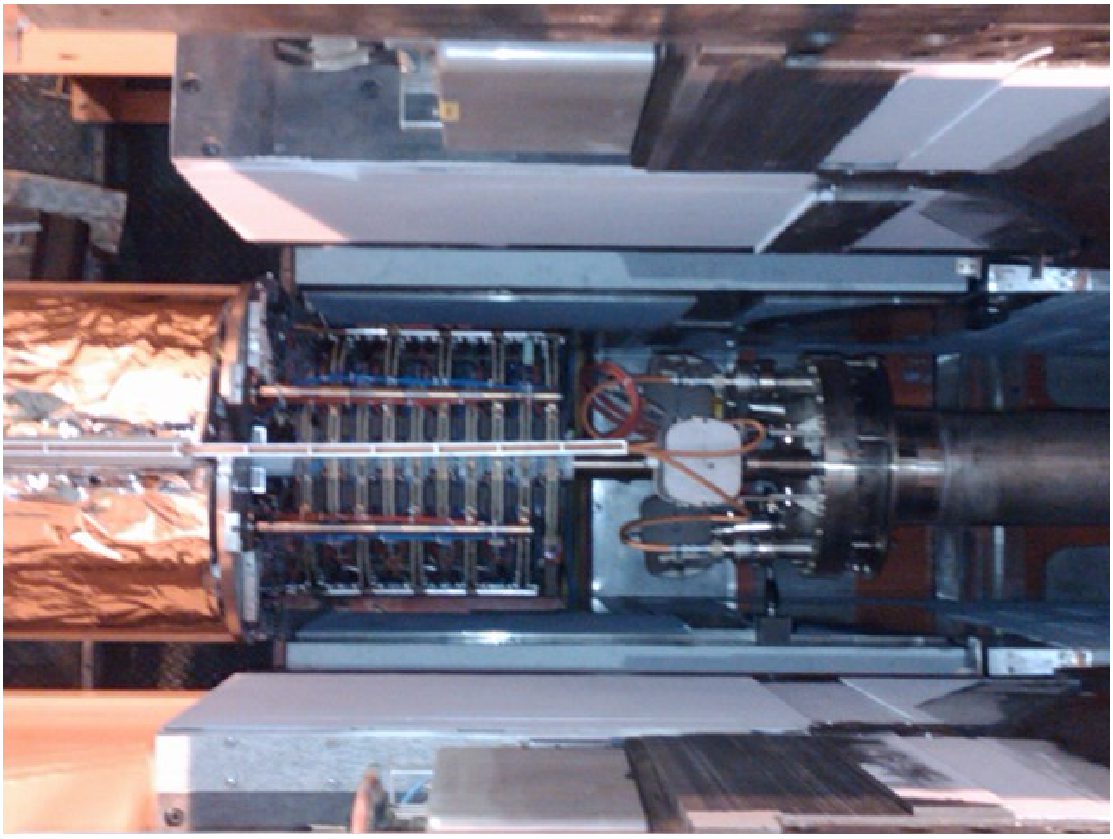

Figure 6: Top view of the T2 telescope inside the CMS shielding.

5. The Electronics System

After the completion of the installation of T2 and the Roman Pot stations at 220 m, commissioning started and valuable experience about the electronics behaviour was gained using the detectors. A severe problem was detected with the reset procedure of the optohybrids used for data transmission from the detector to the counting room, which – if not executed rapidly – destroys these optohybrids (GOH or Gigabit Opto Hybrids).

To fix this problem, the reset procedure was automated to guarantee its timely completion. Unfortunately, the problem, detected too late, caused some damage: about 10 optohybrids had to be replaced on the Roman Pots in the tunnel. This repair was carried out in record time under difficult conditions with very limited access to the tunnel, as the machine was in the start-up phase.

These optohybrids are rare items, and TOTEM was already relatively short of spares on the optical components. Steps are now being taken to try to consolidate the number of spares of optohybrids and optoreceivers, primarily through contacts with CMS, which has a very limited number as well, but still large compared to the TOTEM needs. In some cases, a small number of new parts will be fabricated from existing components (the optical components on these optohybrids and receivers are obsolete and can no longer be procured from industry).

Progress was made as well on DSS and DCS: emergency buttons were installed in the TOTEM control room and connected. Tests on DSS were carried out, and we still would like to carry out some further improvements. Some progress was also made on the infrastructure for T1: connections for the low voltage and high voltage systems were finalised and tested. During these tests one power module failed (this module has been known to have some problems, and some additional protection has been implemented for it, but the failure occurred even with these additional protections in place. This is now under investigation). This incident triggered an effort to verify that the latest updates in terms of hardware and firmware were implemented on our system with corrective action where necessary.

We are slowly making progress on our important production problems with some printed circuit boards. After the successful discussion with the manufacturer of our Roman Pot and gas detector hybrids a first batch of new Roman Pot detector hybrids has been delivered, which is now being mounted. A final production of gas hybrids is to be received from them by the end of this month.

It was agreed that to complete the HOST board production (the main 9U VME card for data acquisition and trigger) new components would be ordered for the remaining production instead of recovering the components. This will hopefully be finalised soon (some components are difficult to obtain), so that mounting of the remaining part of the new production can proceed.

6. Data Acquisition

During the last six months the DAQ group has targeted several issues: new infrastructure at Point 5, firmware, and software.

A new network link has been installed at Point 5. It allows data transport from the UXC cavern (where the DAQ front-ends are located) to the TOTEM Control Room at the surface on a private data link, therefore off-loading the CMS Technical Network from the task of transporting the TOTEM raw data. The new network link provides enough bandwidth for present use and possible future upgrades.

A new centralised infrastructure for the distribution of Trigger and Timing signals has been implemented. This new system allows any TOTEM sub-detector both to run independently or to join a unified data taking without need of cable reconfiguration. This new system is also used by the DAQ firmware to perform the functions of trigger throttling and dead-time calculation. The global timing of the system w.r.t. the LHC machine signals has been studied and understood during the first run in December.

The effort on firmware development has proceeded steadily with consolidation of the performance achieved in autumn 2009, better handling of abnormal conditions, easier configuration and reset procedures. In the next period the firmware development will target remote reprogramming of the FPGAs, integration of the TTC system in the on-the-fly consistency checks of data frames from the VFATs. This kind of checks is a pre-requisite for future possible inter-operability with the CMS DAQ system.

Although the accent is still on firmware development, effort on software has concentrated on better user friendliness via the gradual introduction of simplified panels for controlling the data taking. This effort is ongoing and will continue during the next months.

7. Offline Software and Computing

The current TOTEM Offline Software Release (3.3) includes the simulation (Geant4 + digitisation) and the reconstruction (clustering, tracks) in all TOTEM detectors, the simulation of the Coincidence Chip, the simulation of the L1 Trigger response and a package for the forward proton transport in the LHC lattice.

The work in the last months was focussed on the final developments and optimisation of packages related to the detector commissioning and first collision data.

In detail:

- Data unpacking: compliant with the new data structure.

- Mapping and Calibration: finalise procedures to analyse calibration data and produce results to be used in the simulation/reconstruction package.

- Alignment: test the algorithms with collision data and produce alignment constants.

- Event Display: work still in progress. Optimisation of the graphic rendering.

- LHC Data Monitor and Logging: a custom C++ program receives the LHC data during the data taking, monitor them and archive them for offline use. This has been successfully tested with BPM and BLM data during the runs with the Roman Pots.

- Implementation of the final optics (in progress)

The production of simulated data is following the LHC conditions (optics, energy).

The simulated data are used to test the software performance, to compare with data, to refine on the analysis tools and to define the trigger strategy.

8. Physics

TOTEM took several runs of data at $\sqrt{s}$ = 2.36 TeV (as well as some data at $\sqrt{s}$ = 0.9 TeV) with half of the T2 telescope operational in December 2009. The reconstructed hits and tracks in one event are shown in Figure **7.**

These data have been used for checking the offline reconstruction and developing a global alignment strategy for T2. After a residual-based internal alignment of the 10 GEM planes in a quarter, each quarter is globally aligned using particle tracks measured by T2 that are required to originate from a common vertex compatible with the proton-proton interaction point as shown in Figure **8.**

This way global horizontal and vertical tilts and offsets of a quarter can be estimated from the data. A good global alignment is important for a detailed separation of primary and secondary particle tracks and for a precise determination of the particle pseudo-rapidity η.

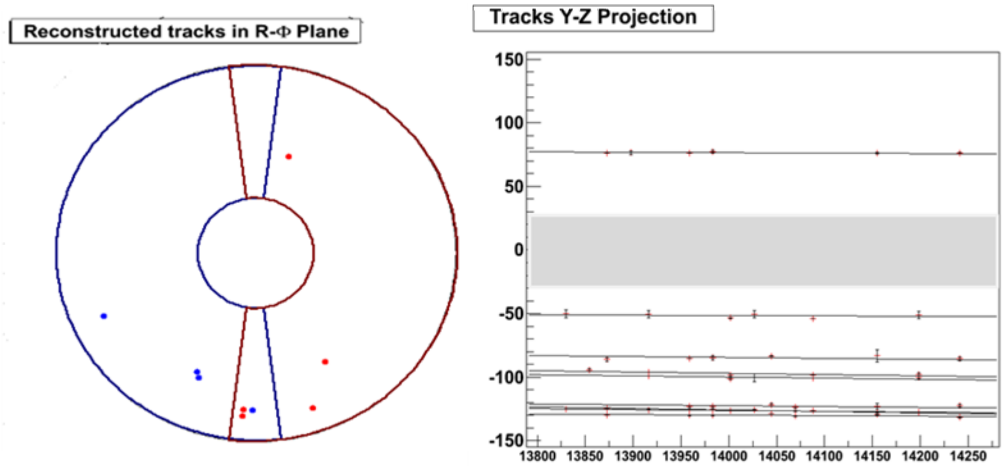

Figure 7: The xy-view and Rz-view of T2 for an event taken at √s = 2.36 TeV in December 2009.

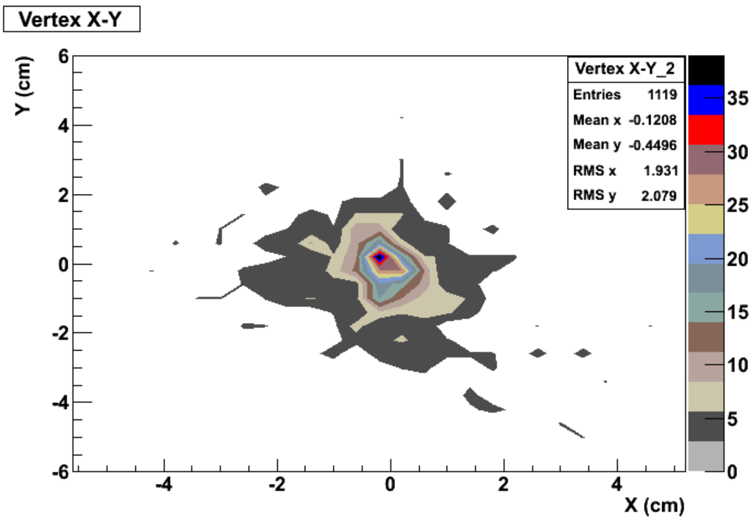

Figure 8: The transverse distribution of the reconstructed event vertices using T2 tracks in √s = 2.36 TeV data.

In close collaboration with the offline software group, the preparation work for the physics analysis of the TOTEM data is continuing.

This work includes a more detailed study of the first physics measurements in terms of expected precision and physics relevance as well as making sure that sufficient suitable data samples will be collected for making detector alignment and determining necessary efficiencies and backgrounds for the first physics analyses.

In the upcoming months, the LHC will run with beams of reduced number of bunches and bunch intensities at an energy of 3.5 TeV per beam. Under these conditions, TOTEM will have the opportunity to make its first physics measurements covering large-|t| elastic scattering and high-mass central and single diffraction as well as the measurement of event topologies in inelastic events.

References

[1] M. Dutour et al.: TOTEM Roman Pots Control System -- Use Case Specification, EDMS 937276.

[2] M. Deile et al.: Results from the TOTEM Interlock Tests in February – March 2010, EDMS 1066465.