The TOTEM T2 Detector at LHC: Track Reconstruction Algorithm and Preliminary Measurements

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Abstract – TOTEM is an experiment designed to perform total cross section, elastic scattering, and diffractive dissociation measurements at the LHC. It is made up of elastic detectors set in the tunnel (Roman Pots) and two inelastic telescopes: T1 and T2, located in the same cavern as the CMS experiment.

The T2 telescope is placed at the very forward region of the CMS’s detector, in a high radioactive environment, as revealed by measurements performed using radiation sensors. The amount of particles produced in the interaction with material in front of and around the detector was found to be particularly challenging for both detector performances and physics analysis. The offline software developed for the reconstruction of inelastic events tracks is briefly described. Internal and general alignments of the telescopes have been another complex issue: the strategy to correct the misalignment biases are explained.

A preliminary measurements of the forward charged particle $\eta$ distribution performed by T2 is also presented.

I. THE TOTEM EXPERIMENT AND THE T2 DETECTOR

The TOTEM experiment is dedicated to the measurement of total cross section, elastic scattering and diffractive processes at the LHC \cite{1}.

The experimental apparatus, shown in Fig. 1, is made up of three sub-detectors: Roman Pots are used for the elastic scattered and diffractive protons measurement, while two inelastic detectors (T1 and T2) are employed for the forward charged particle flow and inelastic rate measurements. The Roman Pots host edgeless silicon detectors and are set in the tunnel at distances of 220m and 147m from the interaction point (IP5). T1 and T2 are located in the same cavern as the CMS experiment, in the forward regions of its detector.

The T2 telescope, in particular, is placed at about 14 meters from the interaction point, after the CMS’s hadron forward (HF) calorimeter. It covers the pseudo-rapidity region between 5.3 and 6.5. There are two T2 telescopes (Fig. 2), one for each side of the IP, consisting of 2 quarters which comprise 10 planes. The planes are made up of semi-circular triple-GEM (Gas Electron Multipliers) chambers \cite{2}, each one with an azimuthal acceptance of 192°\cite{3}.

The T2 Read-Out (RO) foil is divided into 1560 pads (having an area $\Delta\eta \times \Delta\phi = 0.06 \times 0.018$) and 2 columns of 256 strips (pitch: 400$\mu$m, width: 80$\mu$m). The signal generated by the front end electronics is digital, which means that only the list of the activated pads and strips is saved.

![Fig. 1 The TOTEM experimental apparatus.](image1)

![Fig. 2 One quarter of a T2 telescope.](image2)

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II. T2 RADIATION BACKGROUND

The T2 telescope is placed in the forward region with respect to the interaction point, at the two edges of the CMS detector. The environment in that area is high radioactive so it is important to monitor the radiation level.

Both radiation dose and neutron fluence are continuously measured by radiation monitor sensors set inside the detector. Four active units are used, two per arm. Each unit is made up of two different and independent sensors: a CMRP diode and a BPW diode. The first one is very sensitive to low radiation, but it reaches soon a saturation level; the second one on the contrary is resistant to contamination, but not responsive under a certain threshold.

A remarkable asymmetry in the distribution of the particle fluence between the two arms has been detected. The explanation of such results lies in the geometrical asymmetry of the two edges of the CMS detector (Minus and Plus side). On the Minus side a Cherenkov calorimeter, CASTOR, is placed next to the T2 telescope: more precisely, by moving from the center to the extreme of CMS, one meets the hadron forward calorimeter, then T2 and finally CASTOR. The interaction of the particles produced by the pp collisions with all the material in the CASTOR detector determines a huge back emission of neutrons.

The high level of radiation measured by the CMRP diode on the Minus side made it saturate in April 2011: since then, the BRW diode has taken over the measurement.

A detailed description of the devices used and of the measurements performed, as well as plots of the results, are available in the IEEE-NSS-MIC 2011 Conference Record: F. Ravotti, “First Radiation Background Studies for the TOTEM Roman Pots and T2 detectors”.

III. T2 DETECTOR SIMULATION

The main program used to simulate the T2 detector triple GEM is Garfield. A precise definition of the electrostatic configuration inside the detector is obtained by interfacing Garfield with Maxwell 2D SV, a finite-elements based software. The simulation of the transport and ionization properties in gas mixtures is done using Garfield’s interface with Magboltz, Imonte and HEED. These dedicated software tools allow to study the response of the detector in terms of spatial charge distribution and signal induced on the electrodes. Unfortunately this detailed simulation cannot be used to study the detector response on proton-proton (pp) Monte Carlo (M.C.) events, since it would take too much CPU-time. Therefore, a parametrized simulation allowing to reproduce the detector response both on data and on the detailed simulation is needed [4].

In order to tune the model with the data, two free parameters are needed: the effective strip area and the equivalent chip-threshold. The former is needed in order to tune the cluster size of the strips, the latter is used to properly simulate the efficiency of each RO chip. Single particle event simulation has been utilized in order to convert the chip efficiency measured on data in an equivalent threshold of the chip to be applied in the simulation. The results on the comparison between data and tuned simulation for the pad efficiency and cluster size are shown in fig. 2. Similar comparison have been obtained for the strip read-out.

![Plane Pad Efficiency](image1)

![Pad Cluster Size](image2)

Fig. 3 Comparison between Monte Carlo (Pythia) and 7TeV data for inelastic events: plane pad efficiency (top) and cumulative pad cluster size (bottom) for one T2 quarter.

IV. TRACK RECONSTRUCTION IN T2

The amount of particles produced by the interaction of primary particles with the material in front of and around T2 was found to be particularly challenging both for the detector performances and for the physics analysis.

The modelization of the forward region has been simulated with GEANT4 and properly tuned with the data. A large amount of secondary particles (which roughly constitute 90% of the signal in T2) is produced mainly in the vacuum chamber walls in front of the detector, in the Beam Pipe (BP) cone at $\eta=5.53$ and in the lower edges of the CMS HF calorimeter. Secondaries are the main responsible of high-track multiplicity events in T2, producing a strip occupancy larger than 40% for about 10% of the events. The local magnetic field being weak and almost collinear with the track direction, the T2 detector has no selecting power for the lowest energy particles. The track finding algorithm is composed by three sub-procedures:
1. **Road Finding**: by using pad clusters (preferred on the strip clusters since they have smaller occupancy, smaller noise, and higher efficiency, and because they offer the possibility to measure X,Y,Z position at the same time) the algorithm looks for 3D collinear cluster tubes (pad-roads) through the 10 planes of each quarter. The algorithm is inspired to a seedless Kalman Filter technique, where noise and multiple scattering sources can be assumed negligible.

2. **Track Finding**: for every pad road, the overlapping strips are associated to each pad cluster and all the possible combinations of strip and pad cluster hits are generated. The best combinations are chosen by a minimum $\chi^2$ criteria. Simulation studies have shown that a minimum of 4 pad clusters (with at least 3 overimposed strip clusters) can be required as a quality criteria for the road.

3. **Track Fitting**: the hits in a road are fitted, the geometrical and quality track parameters are computed and outliers reduction is eventually performed.

By using the algorithm described above, the primary tracks hitting T2 are reconstructed with an efficiency of about 95%. The $\eta$ resolution obtained is 0.07 in the central acceptance region, assuming a vertex constraint.

V. **ALIGNMENT CORRECTION**

Misalignment biases, dominated by global T2 quarter displacements respect to the IP, were found to affect the measurement performed by the T2 telescope. Consequently, particularly effort has been put in correcting the alignment of each quarter.

The internal misalignments are mainly due to shifts of the planes in the X and Y directions. Two different methods have been developed in order to correct for such displacements: the iterative and the MILLEPEDE ones.

The relative alignment between the two quarters of an arm has been obtained using tracks reconstructed in the overlap regions.

For what concerns the global alignment, studies on the expected symmetries in the track parameters distributions and the position on each T2 plane of the “beam pipe shadow” (very low track efficiency radial zone due to primary particles absorbed by the $\eta=5.53$ beam pipe cone) have been used as a reference.

VI. **ANALYSIS OF THE $dN_{CH}/d\eta$**

A preliminary measurement of the forward charged particle $\eta$ distribution has been performed by using the data taken in special 2011 runs at low luminosity with an inclusive T2 trigger.

Secondary track rejection has been derived from data analysis, while primary track efficiency and smearing effects correction have been obtained from MC studies. The results are reported in fig. 3. The black points show the experimental measurements with the uncertainties related to statistical effects. The red band represents the overall systematic uncertainty, mainly related to the estimation of the track efficiency, to the effect of detector misalignment and to the secondary track contribution subtraction.

Work is in progress for the determination of the residual systematic related to the MC modeling of the forward particle energy spectrum and to the simulation of magnetic field effects. These latter (less relevant) uncertainties are expected to give an additional contribution at the level of few percent units.

**REFERENCES**


