The timing upgrade project of the TOTEM RP detectors

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Abstract

We describe the upgrade project developed by the TOTEM Collaboration to measure the time of flight (TOF) of the protons in the vertical Roman Pot detectors. The physics program that the upgraded system aims to accomplish will be addressed. Simulation studies allowed to define a geometry of the sensor such that the detection inefficiency due to the pile-up of the particles in the same electrode is low even with a small amount of read-out channels. The measurement of the protons TOF with \(\sim \) 50 ps time resolution requires the development of several challenging technological solutions. The arrival time of the protons will be measured by scCVD diamond detectors, for which a dedicated fast and low-noise electronics for the signal amplification has been designed. Indeed, while diamond sensors have the advantage of higher radiation hardness, lower noise and faster signal than silicon sensors, the amount of charge released in the medium is lower. The sampling of the waveform is performed at a rate up to 10 GS/s with the SAMPIC chip. The sampled waveforms are then analysed offline where optimal algorithms can be implemented to reduce the time walk effects. The clock distribution system, based on the Universal Picosecond Timing System developed at GSI, is optimized in order to have a negligible uncertainty on the TOF measurement. Finally an overview of the control system which will interface the timing detectors to the experiment DAQ is given.

Keywords: TOF, Timing detectors, Diamond detectors

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1. The Totem RPs upgrade with diamond detectors

The TOTEM upgrade programme \cite{1} focuses on improving the experiments capability to explore and measure new physics in Central Diffractive (CD) processes: \(p + p \rightarrow p + X + p\). The installation of proton Time-Of-Flight (TOF) detectors in the TOTEM Roman Pots allows to reconstruct the longitudinal vertex position and thus to assign the proton vertex to the proper vertex reconstructed by the CMS tracker, even in presence of event pileup. Common CMS-TOTEM data taking are foreseen during the LHC Run 2, with a special LHC-optics configuration for which the proton acceptance is optimal (all \(\xi = \Delta p/p\) for \(|t| > 0.04\ \text{GeV}^2\)). Ultimately, 100 \(\text{pb}^{-1}\) can be collected in runs with a pile-up \(\mu = 50\%\). Among the many Physics channels that can be studied with CD, the upgraded system aims to measure with an unprecedented sensitivity low mass resonances (with particular emphasis to Glueball candidates), exclusive CD dijets, charmonium states and events with missing mass signatures. Even at very low pileup, for inclusive CD events and in particular for events with missing momentum the association of the protons to the CMS vertex by using only the tracking variables is problematic. Here, as well as in all CD events measured at moderated pileup, the TOF measurement is crucial. As an example, at \(\mu = 50\%\), a factor \(\sim 5\) enhancement on the inclusive CD purity can be obtained from the installation of the TOF detector in the RP, assuming a time resolution of 50 ps. The TOF is based on scCVD diamond detectors. Four TOF planes will be installed in each of the four vertical RPs. One plane is composed of eight 4.5x4.5x0.5 mm\(^3\) sensors, provided by Element 6 LTD. Diamond detectors have been chosen thanks to their proved radiation hardness and their fast response. Moreover, by using diamonds, it is possible to design a compact TOF that can be easily placed inside the existing vertical RP, without increasing the material budget for the LHC beam. After an extensive R&D on the Front End electronics a time resolution of the single sensor of the order of 100 ps has been proved. Therefore a TOF consisting of 4 diamond planes will have a time resolution of \(\sim 50\) ps, which means a resolution on the longitudinal interaction vertex \((Z_{\text{INT}} = c\Delta t/2)\) of \(\sigma_Z \sim 1\ \text{cm}\). To minimize the probability of particle pile-up in the same diamond pixel the design has been optimized in order to guarantee an uniform occupancy of the detector \cite{2}. At \(\mu = 50\%\) the inefficiency introduced by the pile-up is \(\sim 0.6\%\).

2. TOTEM RD on diamond detectors

The measurement of the protons TOF with 50 ps time resolution requires the development of several challenging technological solutions. Indeed, while diamond sensors have the advantage of higher radiation hardness, lower noise and faster signal than silicon sensors, the amount of charge released in the medium is lower. By introducing a SiGe BJT preamplifier with low-C feedback at less then 1 cm from the diamond
electrode the input impedence are increased to few kΩ (therefore enhancing the S/N) while the straight capacitance seen by the signal is still small (which is important to keep the signal fast). This solution, already developed by HADES[3], was then further elaborated by TOTEM by introducing an amplification chain which is able to keep the time resolution of the order of 100 ps also for the electrodes with larger capacitance (2pF). The BJT-based amplification chain consists of the preamplifier followed by each amplification channel is about 0.3 W. Both metalizations provided by GSI (Cr-50 nm + Au-150 nm) and by PRISM (100 nm of TiW 10%90%) have been successfully tested. Detec
tion efficiency was found >98% in the bulk of the crystal with a negligible effect introduced by the unmetallized area between the strips (see Fig. 1). Depending on the electrode capacitance, a S/N ratio between 20-25 and a risetime of 1.5-1.8 ns were found. The measurement of the time resolutions has been obtained from the difference of the arrival time of MIP particles (5.6 GeV electrons) in two aligned electrodes of two diamonds plane. An offline constant fraction discriminator have been applied to reduce the time walk effects. The measurements have been performed with the Agilent DSO9254A oscilloscope (8 bits, 20 GSa/s). A time resolution 80 < \sigma_T < 108 ps was found for electrodes capacitance 0.29 < C < 2 pF. The analog signals will be digitized with the SAMPIC chip. SAMPIC is a waveform TDC developed in Saclay[4]: it acquires the full waveform shape of the detector signal, by sampling it through a 64 cell Delay Line Loop (DLL) based TDC and an ultrafast analog memory for fine timing extraction. Each channel has an input bandwidth of 1.5 GHz, an ADC precision of 11 bits and will operate with a sampling frequency up to 10 GHz. The sampled waveforms can be therefore analysed offline where optimal algorithms can be implemented to reduce the time walk and jitter effects. Measurement performed at the test beam shown that the time resolution obtained with the SAMPIC, is compatible with the ones obtained with the high bandwidth oscilloscope.

2.1. Clock distribution and DAQ

In order to precisely measure the difference of the arrival time of the protons in the two sides of the interaction point, the crucial problem to be solved is to distribute common time signals to spatially separated detectors, with picosecond range precision. For this purpose TOTEM is adopting a clock distribution system based on an optical network, using dense wavelength division multiplex (DWDM) technique, transmitting two reference clock signals from the counting room to a grid of receivers in the tunnel. The system monitors the delays in the propagation of the signal, to control all the transmission systematic effects that will affect the signal jitter. The TOTEM clock distribution is adapted from the “Universal Picosecond Timing System”, developed for FAIR at GSI [5]. The digitized signal of the TOF detectors have to be interfaced to the existing hardware, already used for the DAQ of the RP silicon detectors [6]. To this purpose, a dedicated board, hosting the radiation tolerant Microsemi Soc FPGA M2S150-FCG1152, has been designed in order to interface the TOF signal to the hardware already existing for the silicon detectors DAQ. Initially TOTEM will not trigger on the timing detectors, the expected trigger rate from the silicon sensors is < 100 KHz.

3. Conclusions

In this contribution we described the upgrade of the TOTEM vertical Roman Pots with TOF diamond detectors. The sensors performance have been characterized in several test beams and satisfactory results on time resolution and detection efficiency have been achieved. The digitization of the signal has introduced a negligible deterioration of the time resolution. The solutions that will be adopted for the TOF clock distribution and for DAQ have been finally summarized.

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References