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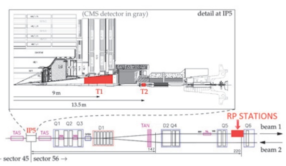
The diamond time of flight detector of the TOTEM experiment

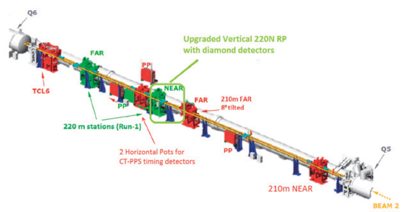
The Totem RPs upgrade and its Physics motivation

The TOTEM upgrade programme [1],[2] focuses on improving the experiment's capability to explore and measure new physics in Central Diffractive (CD) processes: p+p -> 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 one 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 $|t|>0.04$ GeV²).

TOTEM in Run2:

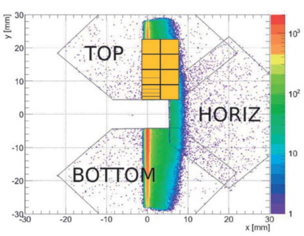




Experimental advantages of CD:

- Exclusive CD: quantum number filter on $J_{(Z)}^{PC}$.
- Presence of rapidity forbidden/allowed regions.
- The CMS/TOTEM P_T balance further increases the experimental sensitivity in exclusive events.
- Production from a high-purity gluonic system (exclusive dijets or low mass resonances).
- $M^2_{pp}=\xi_1\xi_2 s$ vs M^2_{CMS} comparison allows missing mass searches.

A diamond TOF detector:



Track distribution in the 220F RP, for events with 2 protons in the final state. The golden picture on the TOP shows the diamond detector surface. The diamond detector in the BOTTOM RP is not reported for clarity.

Diamond detectors have been chosen due to their:
- Proven radiation hardness and fast response.
- Small and safe enough to be placed inside a RP.

After an extensive R&D on the FE electronics a time resolution < 100 ps has been proved.
- 4 diamond planes per arm -> 50 ps per arm will be achieved ($\sigma_z \sim 1$ cm).

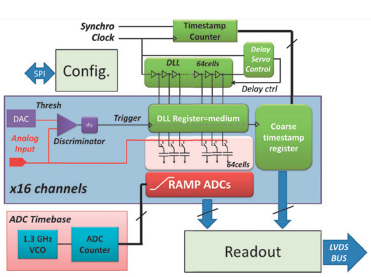
To minimize the pileup probability in the same diamond pixel the design has been optimized in order to guarantee an uniform occupancy [3].

Background Reduction:

- The measurement of the protons TOF adds an independent variable ($Z_{VTX} = c\Delta t/2$) that can be used in together with the track-based variables to reduce the background.
- For exclusive events, the TOF information is used to better understand the background (S/B enhancement)
- For inclusive events, or events with missing momentum the association of the proton to the CMS vertex by using only the tracking variables is more problematic. Here timing detectors are even more crucial.
- **IN GENERAL, an additional factor 5 on the CD sample purity can be obtained from the installation of a timing detector in the RP with 50 ps time resolution per arm.**

Waveform digitization with the SAMPIC

- Waveform TDC developed in Saclay[5], used to acquire 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.*
- Sparse mode self-triggering (only the triggering channels will send data).



	Measure
Channel number	16
Input bandwidth	1.5 GHz
Sampling frequency	1 - 10GHz
ADC precision	11bit
Noise	1mV
Range	1V
Conversion time	1μs
Readout clock	400MHz max. (* not verified)
Readout time	2.5ns/word+ header x nb of channels

- Test beam measurements confirmed a negligible worsening of the time resolution due to the SAMPIC.

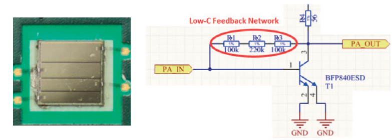
References

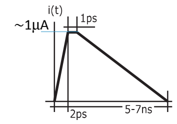
[1],[2] The Totem Collaboration: CERN-LHCC-2014-020, CERN-LHCC-2014-024
[3] M. Berretti: CERN-TOTEM-NOTE-2014-001
[4] M. Ciobanu et al: IEEE TRANSACTIONS ON NUCLEAR SCIENCE, VOL. 58, NO. 4, AUGUST 2011
[5] E. Delagnes et al: 2014 IEEE NSS/MIC; in2p3-01082061; http://hal.in2p3.fr/in2p3-01082061
[6] J. Varela, J. Baechler et al: CERN-LHCC-2014-021 ; TOTEM-TDR-003 ; CMS-TDR-13

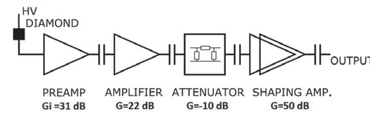
TOTEM R&D on diamond detectors

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 transconductance amplifier at less than 1 cm from the diamond electrode the input impedence can be increased to few kΩ (therefore enhancing the S/N) while the straight capacitance seen by the signal is still small (important to keep the signal fast).
- This solution, already developed by HADES[4], was then further elaborated by TOTEM who introduced an amplification chain which is able to keep the time resolution at ~100 ps also for the pixel with the larger capacitance (~2pF).
- Effort was spent to optimize the bias network of the 1st stage amplifier in order to obtain un-distorted phase and gain response.



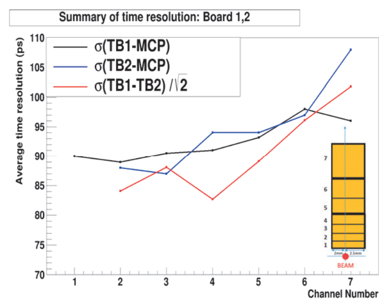




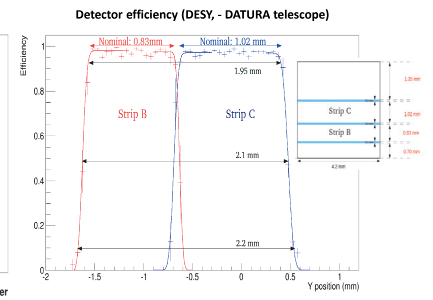
Top: Diamond with 4 strips and the preamplifier layout
Left: Expected primary current from a MIP
Bottom: The full amplification chain

Only electronic graded scCVD sensors (bought from Element6) provided enough efficiency and time resolution. Both metallizations Cr-50nm + Au-150nm and TiW-100nm have been successfully tested.

Detector performance with MIP particles



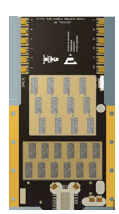
Average time resolution σ_T as a function of the channel number, obtained with 2 diamond planes (B1,B2). Blue and black curves are obtained by using a MCP (with σ_T ~30 ps).



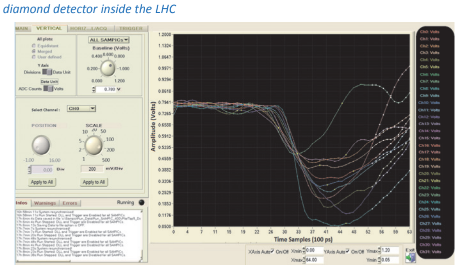
Detection efficiency as a function of the particle position. The efficiency is found >98% in the bulk of the crystal with a negligible effect introduced by the unmetallized area between the strips.

Installation and operation of diamond TOF in the LHC

- The first package (out of 4) of the diamond TOF detector has been installed in the LHC tunnel during November 2015.
- The system has been tested with a secondary vacuum of 200mb and T~15 °C. Heating produced by the electronics (~25W) was efficiently cooled by the evaporative cooling system.
- An higher secondary vacuum pressure and a lower (490V) diamond bias voltage has been used in order to minimize corona arcs that may be produced around the diamond.
- A coating procedure has been studied in order to safely operate the diamonds in lower vacuum and at nominal HV (700V).

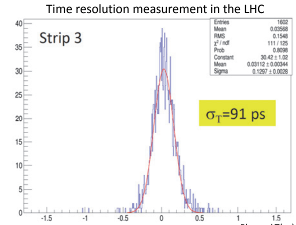


Top: The first TOF detector consisting of 4 diamond planes, installed in the TOTEM RP.
Left: One diamond detector plane. The three amplification stages are visible in the golden squared area. The fast analogic signal is brought outside the RP by using SMP connectors (on the top sides)



Bottom: Event display from the SAMPIC DAQ control showing a shower of particles hitting the diamond detector inside the LHC

Time resolution measurement in the LHC



Conclusions and Outlook

- In 2015 the TOTEM Collaboration built, tested and installed inside a RP in the LHC the first timing detector for high energy protons.
- The desired timing performance has been achieved.
- Intense work is ongoing in order to have a detector which can operate at even larger HV for June 2016.
- A set of diamond detectors are also expected to be installed in the CT-PPS horizontal RPs [6] for operations at high luminosity.