Diamond timing detector for the TOTEM experiment

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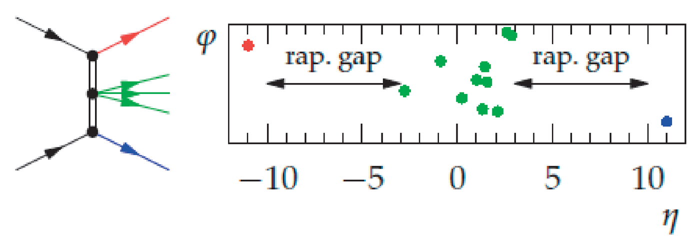
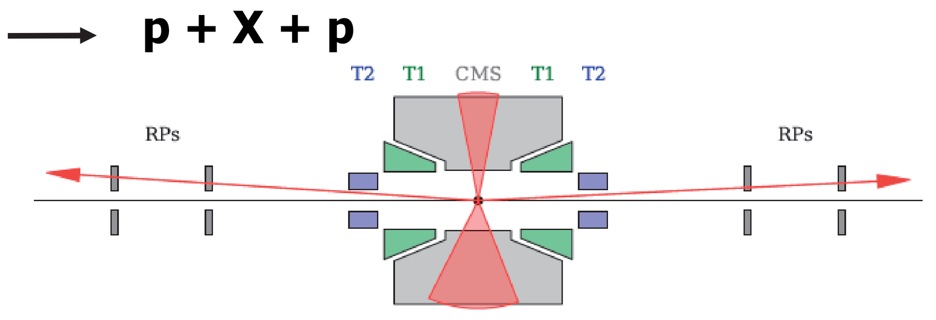
Physics motivation

The TOTEM upgrade programme [1,2] focuses on improving the experiment's capability to explore and measure new physics in Central Diffractive (CD) processes: $p + p \longrightarrow p + X + p$

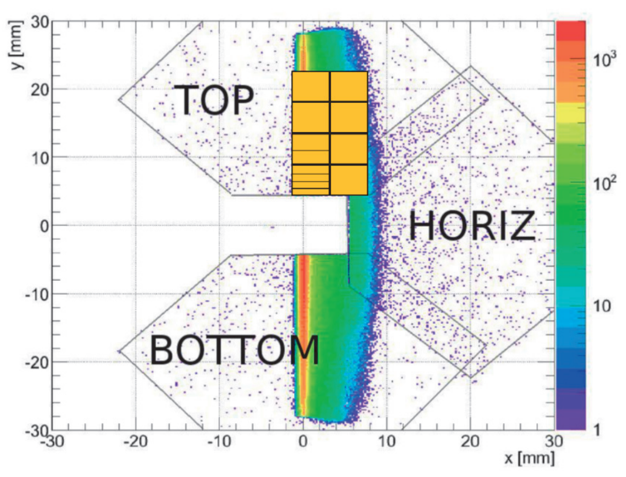




The installation of proton Time-Of-Flight (TOF) detectors in the TOTEM Roman Pots allows us to reconstruct the longitudinal vertex position and thus to assign the proton vertex to the proper one reconstructed by the CMS tracker, even in presence of event pileup.

Common CMS-TOTEM data taking are foreseen during the LHC Run2, with a special LHC-optics configuration (β^* = 90 m) for which the proton acceptance is optimal (all $\xi=\Delta p/p$ for $|t|>0.04$ GeV^2).

Diamond TOF detector



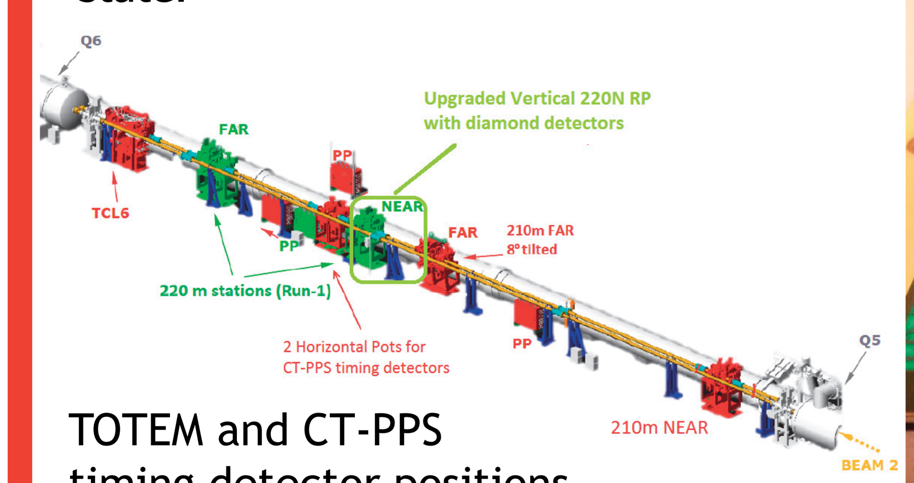
Track distribution in one RP in β^* = 90 m runs, for events with two protons in the final state.

Diamond detectors have been chosen due to their:

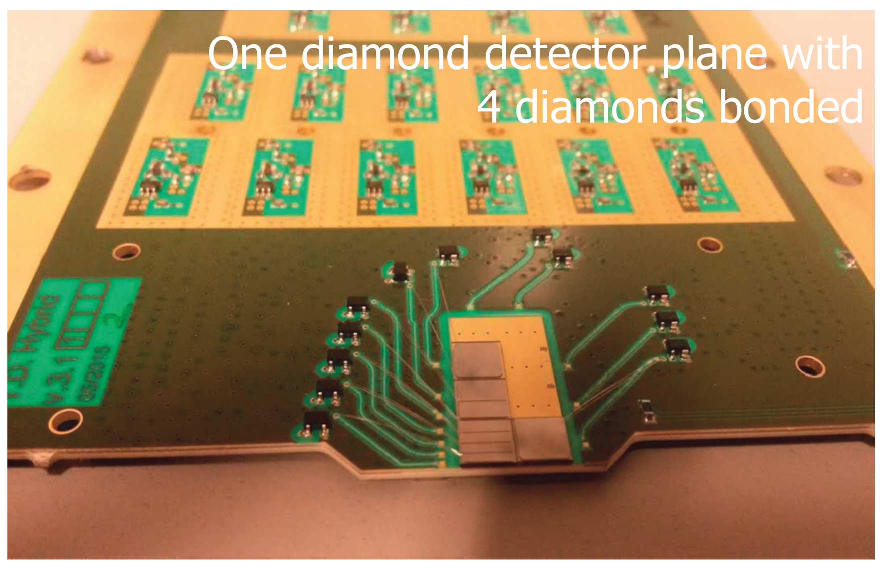
- Radiation hardness
- Fast response, low noise
- Small size

After the TOTEM R&D on the Front End electronics a time resolution <100 ps has been proved. With 4 diamond planes per arm, 50 ps time resolution will be achieved.

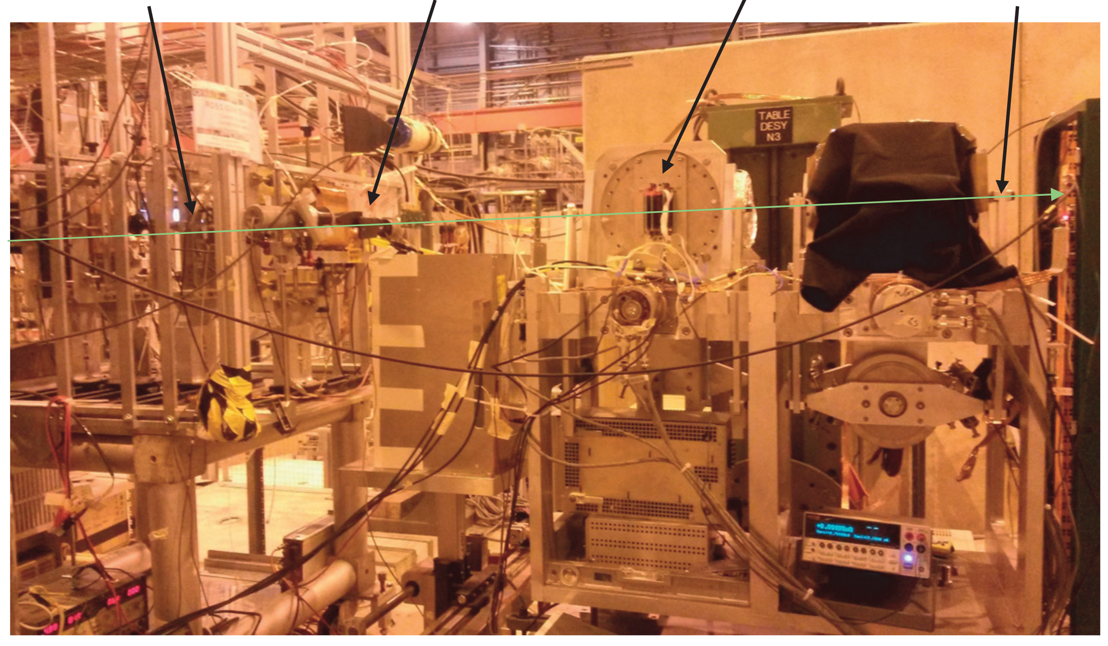
To minimize the pileup probability in diamond pixels the metallization pattern has been optimized for uniform occupancy [3].



TOTEM and CT-PPS timing detector positions



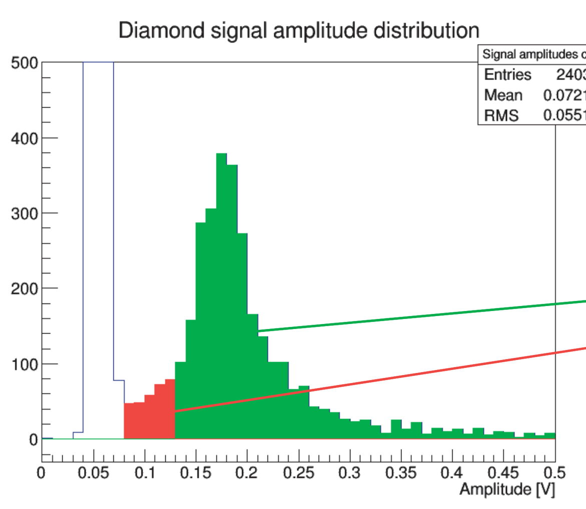
Test Beam results

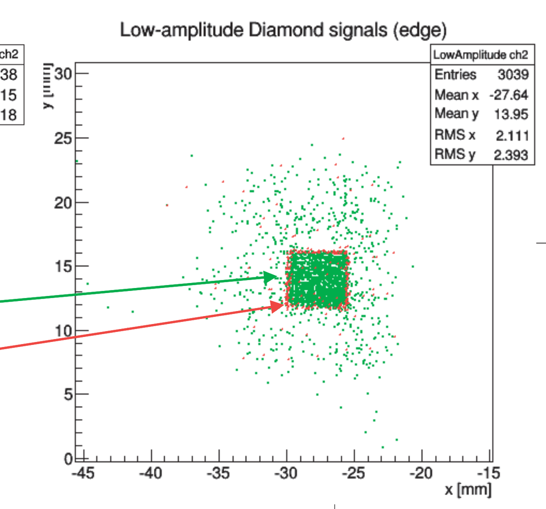


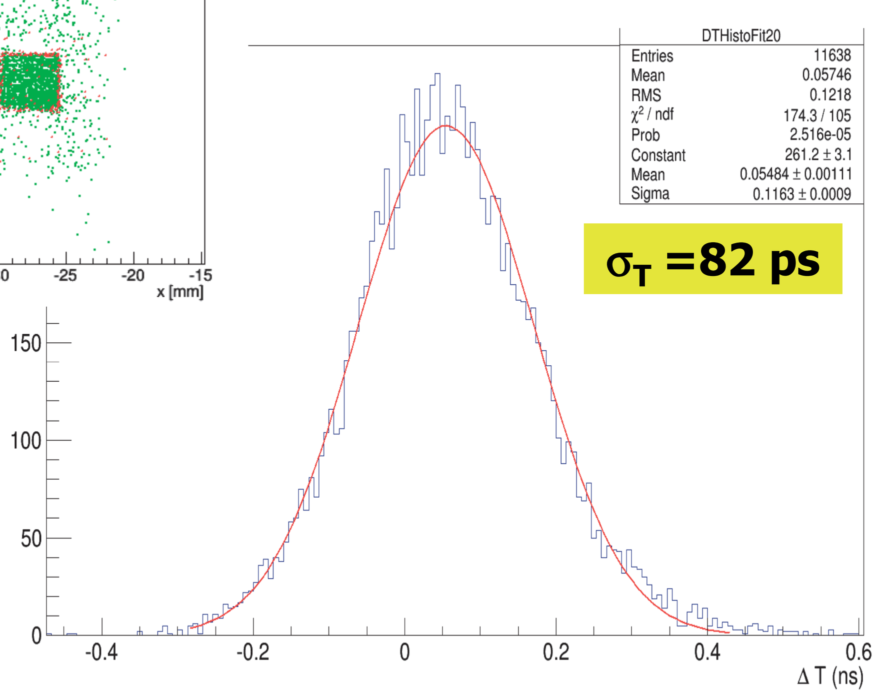
At SPS H8C test beam area we successfully tested diamond detectors' timing performance and efficiency inside a Roman Pot in their final settings (left).

For efficiency studies RD51 GEM tracker was used. Diamonds have a good (>99%) detection efficiency. Independent timing measurements were done by using also the CT-PPS MCP.

Secondary vacuum and cooling tests were also done here.







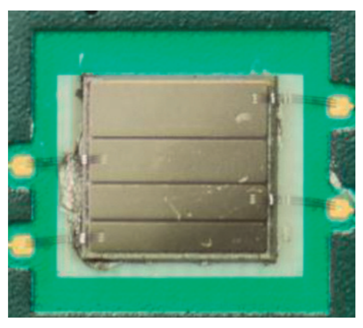
Only MIPs passing through the non-metallized region of the diamond (edge) have a lower SNR. Time resolution of two Hybrid boards with SAMPIC readout was 82 ps in 560-640V range and at p=170 mbar pressure (right).

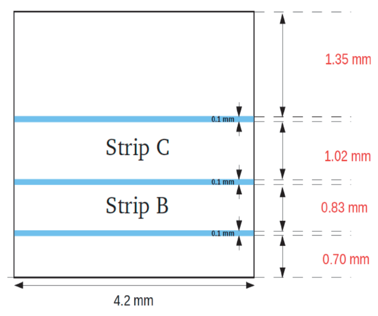
Crystals and metallization

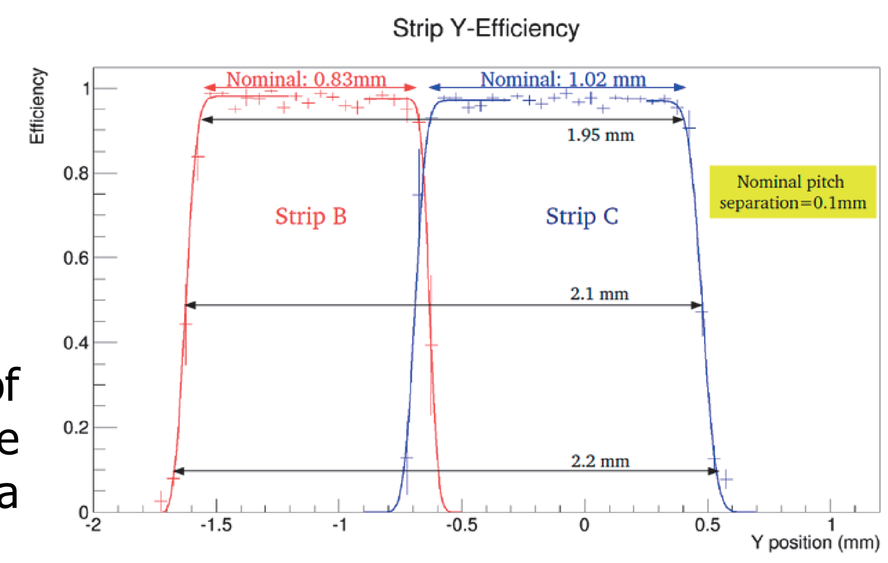
Electronic graded Single Crystal CVD diamonds from Element Six company [4] are used. So far only this material provides enough efficiency and time resolution. High purity, {100} orientation crystal contains <5 ppb Nitrogen and typically <0.03 ppb N-vacancy concentration.

It is ideal radiation detector material due to its radiation hardness, high electron mobility and charge collection efficiency (>95 %).

Diamond metallizations were done by Department of Physics at Princeton University, using TiW(100nm) pre- and final metallizations (left fig.), but Cr(50nm)+Au(150nm) was also tested.





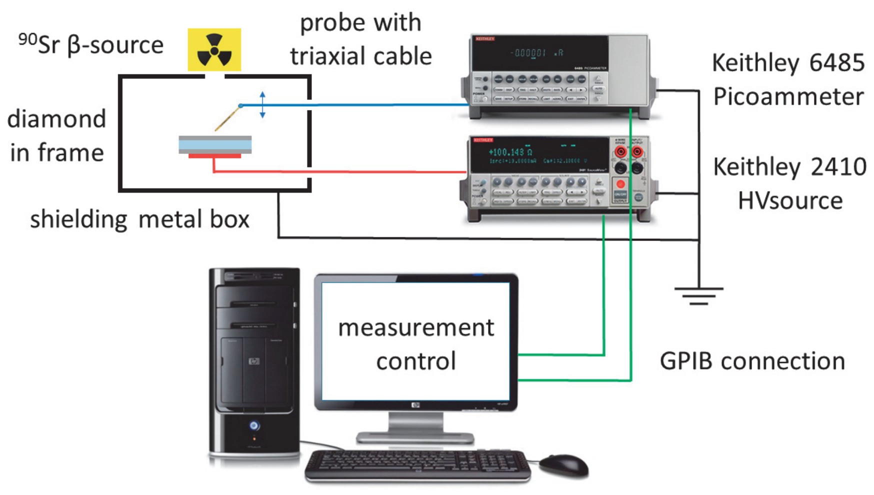


Detection efficiency as a function of the particle position (right). The efficiency loss due to unmetallized area between the strips is negligible.

Diamond characterization

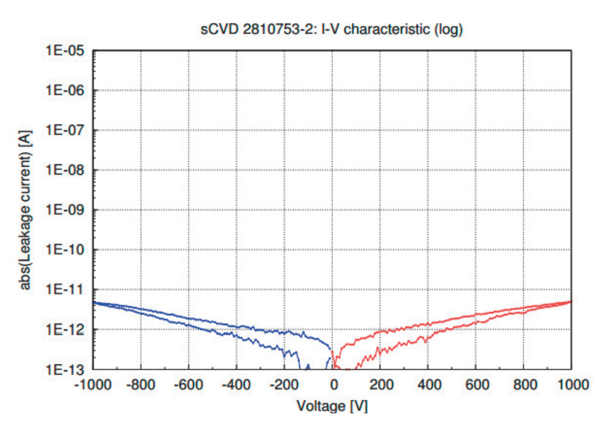
Characterization of pre-metallized diamond sensors is necessary in order to select only diamonds with low leakage current and stable signal current.

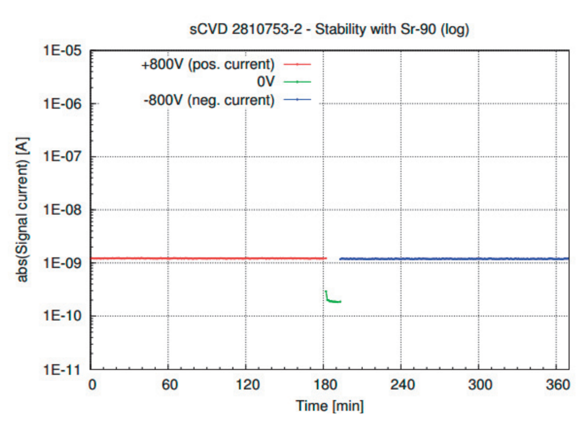
Diamonds often have an asymmetric behaviour in I-V characteristic or in signal stability, therefore decision is needed which side of crystal should be patterned.



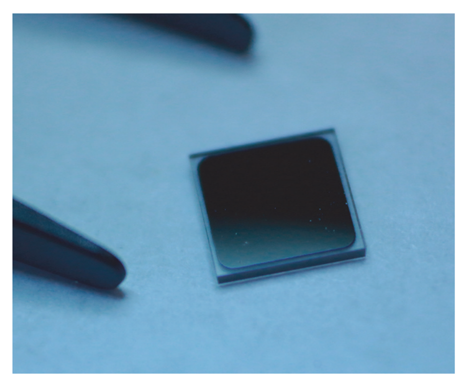
Computer controlled measurement setup was built to measure ~pA leakage currents in pre- and final metallized diamonds with movable spring probe. Leakage current depends on crystal quality (e.g. impurity concentration) and metallization process.

Signal current (~nA) stability over time can be also measured with ^{90}Sr β-source. Crystals not satisfying criteria are sent back to producer.

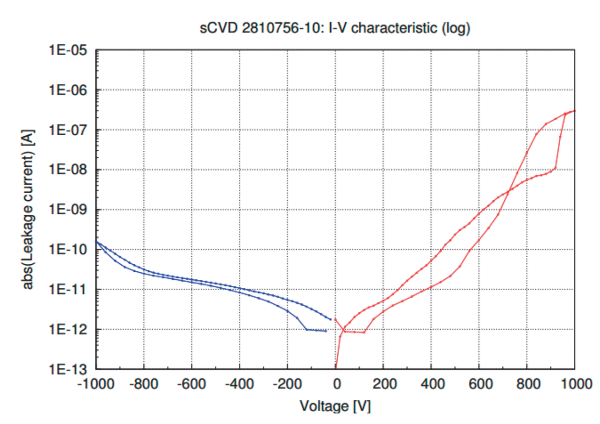


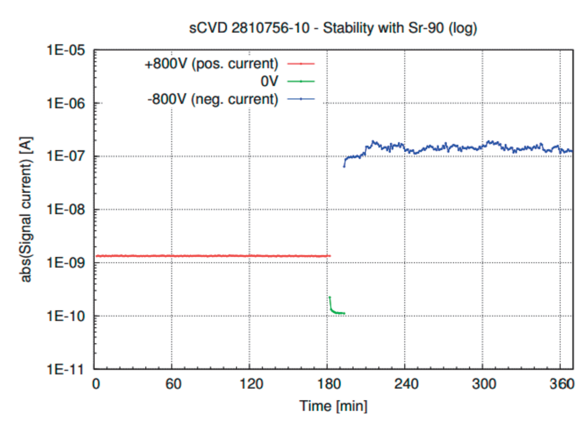


Good diamond: normal leakage current (left) and stable signal current with source as function of time (right)

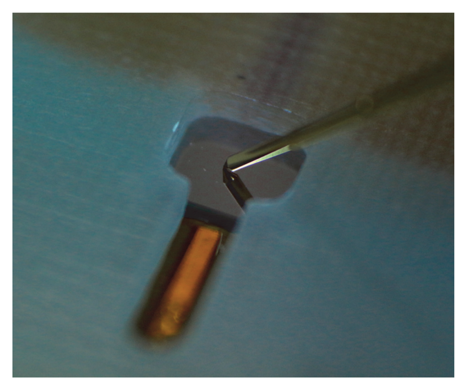


TiW(100nm) pre-metallized diamond



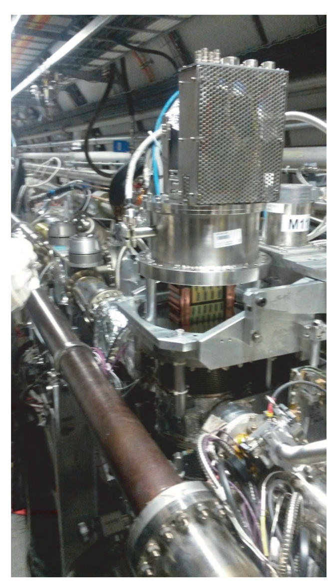


Bad diamond: high leakage current only at positive HV and unstable signal current only at negative HV



Movable spring probe

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 (left). The desired timing performance has been achieved.
- Intensive work is ongoing in order to build and test all the other detectors until June 2016.
- Diamond quality studies are still ongoing.
- A set of diamond detectors will also be installed in the CT-PPS horizontal RPs [5] for operations at high luminosity.

[1,2] The TOTEM Collaboration: CERN-LHCC-2014-020, CERN-LHCC-2014-024

[3] M. Berretti: CERN-TOTEM-NOTE-2014-001

[4] Element Six Ltd., https://e6cvd.com/

[5] J. Varela, J. Baechler, et al.: CERN-LHCC-2014-021; TOTEM-TDR-003; CMS-TDR-13

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LHC Students Poster Session

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