Diamond Timing Detector for TOTEM experiment

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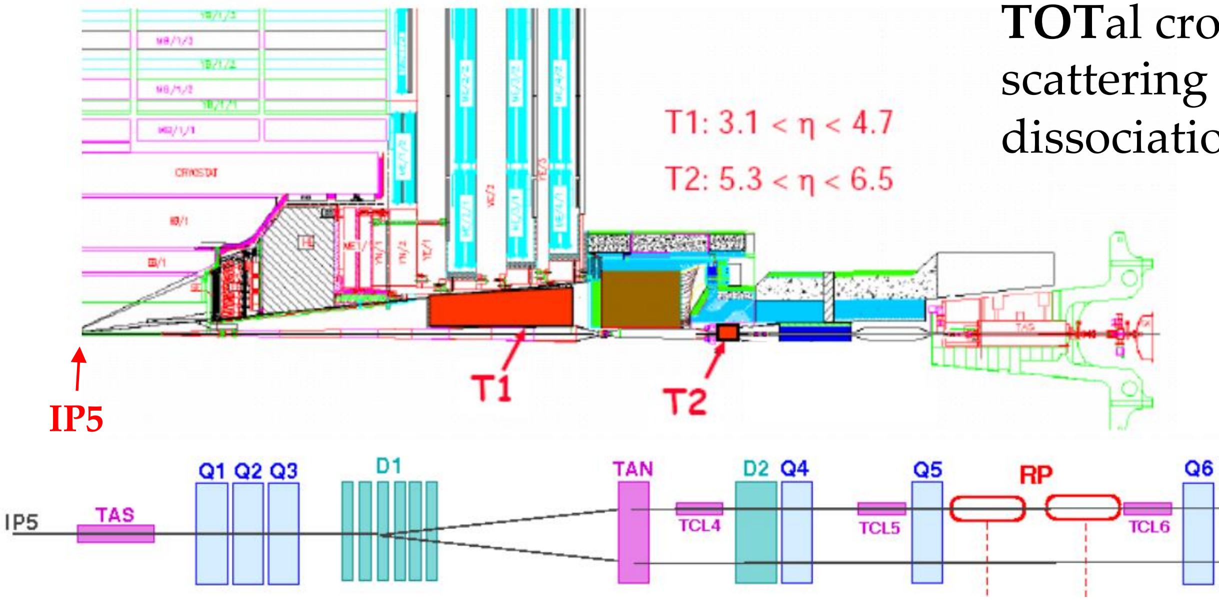
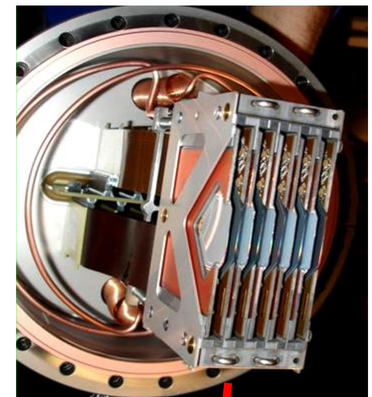
on behalf of the TOTEM collaboration

Day of Femtoscopy,
Gyöngyös, 2016

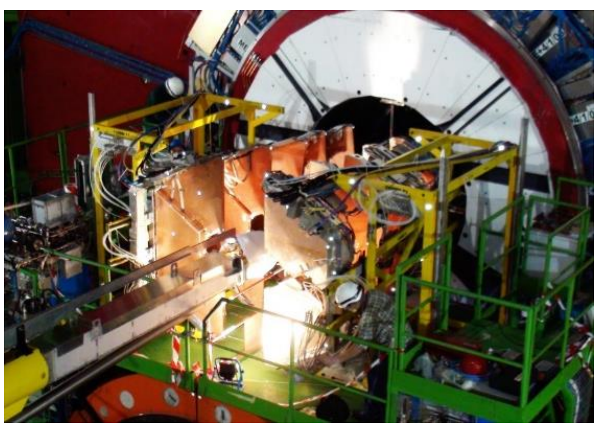
CERN LHC TOTEM experiment

TOTal cross section, **E**lastic scattering and diffraction dissociation **M**easurement

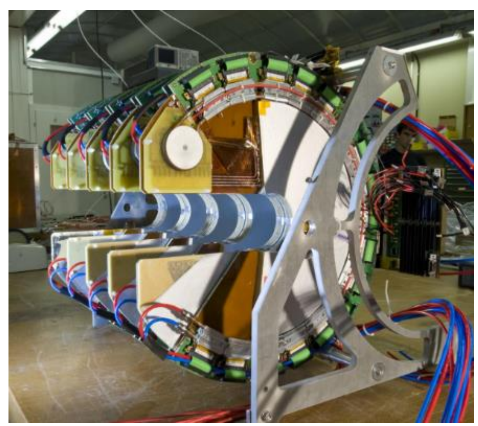




T1 telescope



T2 telescope



3 Roman Pots

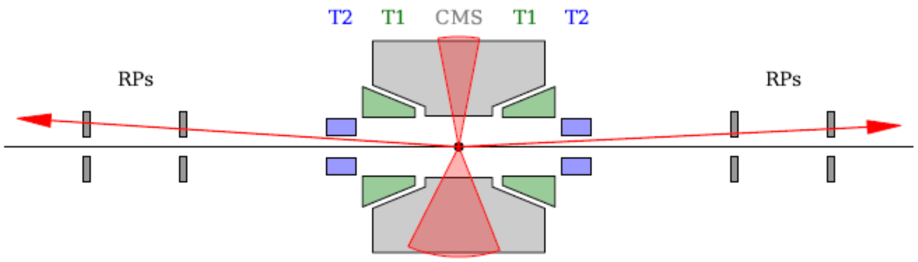
Motivation for timing

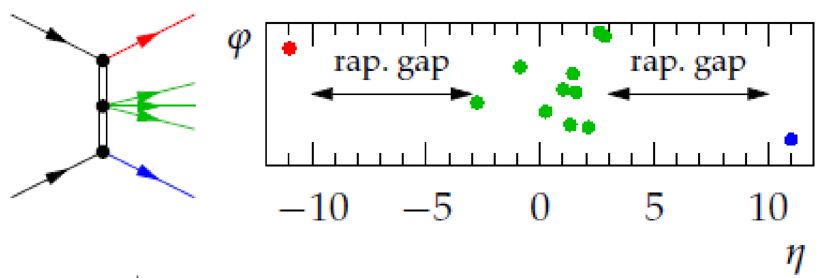
Central Diffraction (in high β* runs):

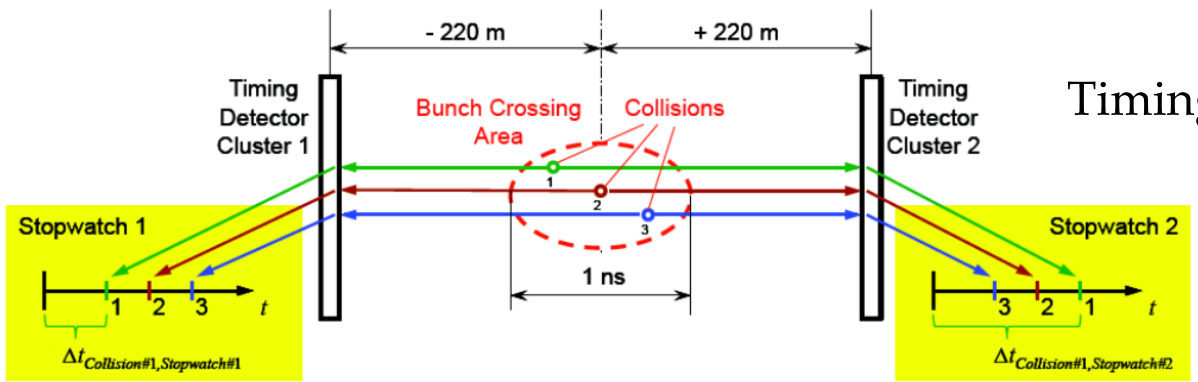
p + p ⟶ p + X + p

- Longitudinal vertex reconstruction at IP5
  $\sigma_z \approx 1\text{cm},\ \Delta t \approx 50$ ps
- Pile-up reduction

CT-PPS project







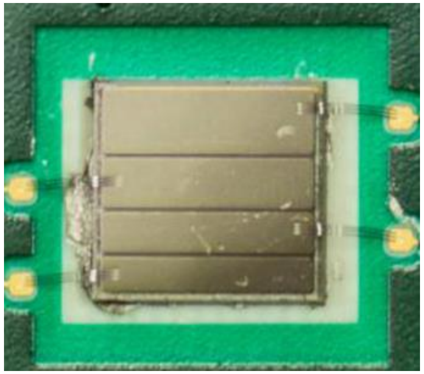
Timing scheme

References: TDR - Timing Measurements in the Vertical Roman Pots of the TOTEM Experiment: CERN-LHCC-2014-020, CERN-LHCC-2014-024

scCVD diamond as a detector

- Fast and good charge collection
- Pixel pattern is easy to implement
- Low material budget
- Radiation hardness
- Low noise

- Large capacitance
- Low signal (~12000 e)
  - Impedance adaptation
  - FEE bandwidth optimization
  - Maximized preamplifer rise time
  - Maximized S/N



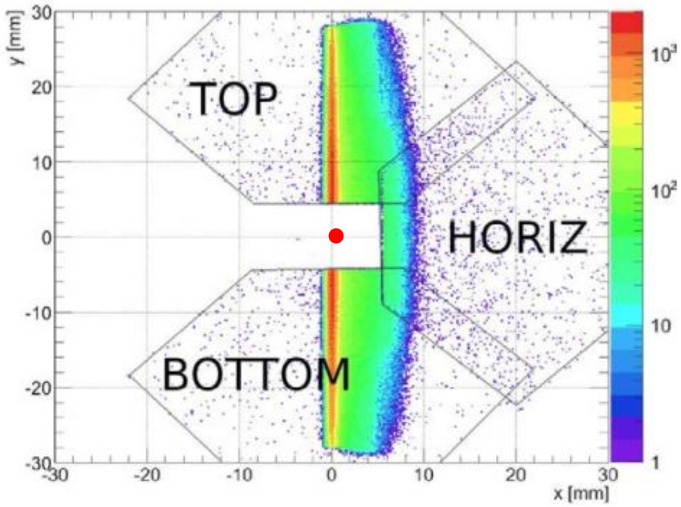
High purity, electronic-grade scCVD crystals from Element6 with <100> orientation (4.5x4.5x0.5 mm) were used

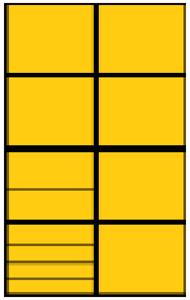
Reference: M. Berretti, The diamond time of flight detector of the TOTEM experiment, VCI2016 - The 14th Vienna Conference on Instrumentation, 15-19 Febr. 2016

Diamond pixel layouts

Vertical Diamond Detector

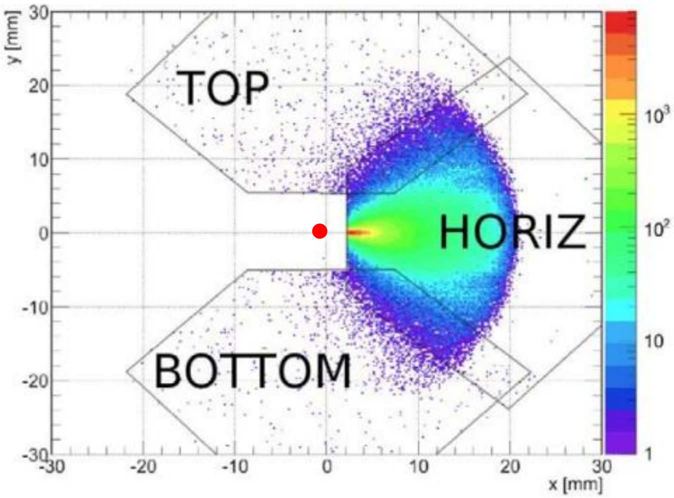
- TOTEM standalone runs
- High β*, low luminosity
- Read-out with SAMPIC

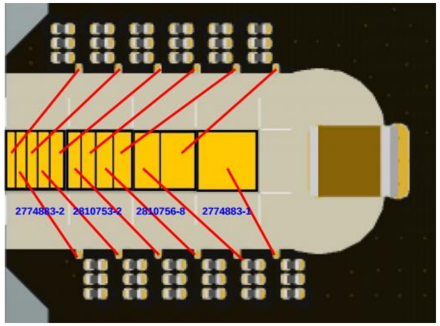




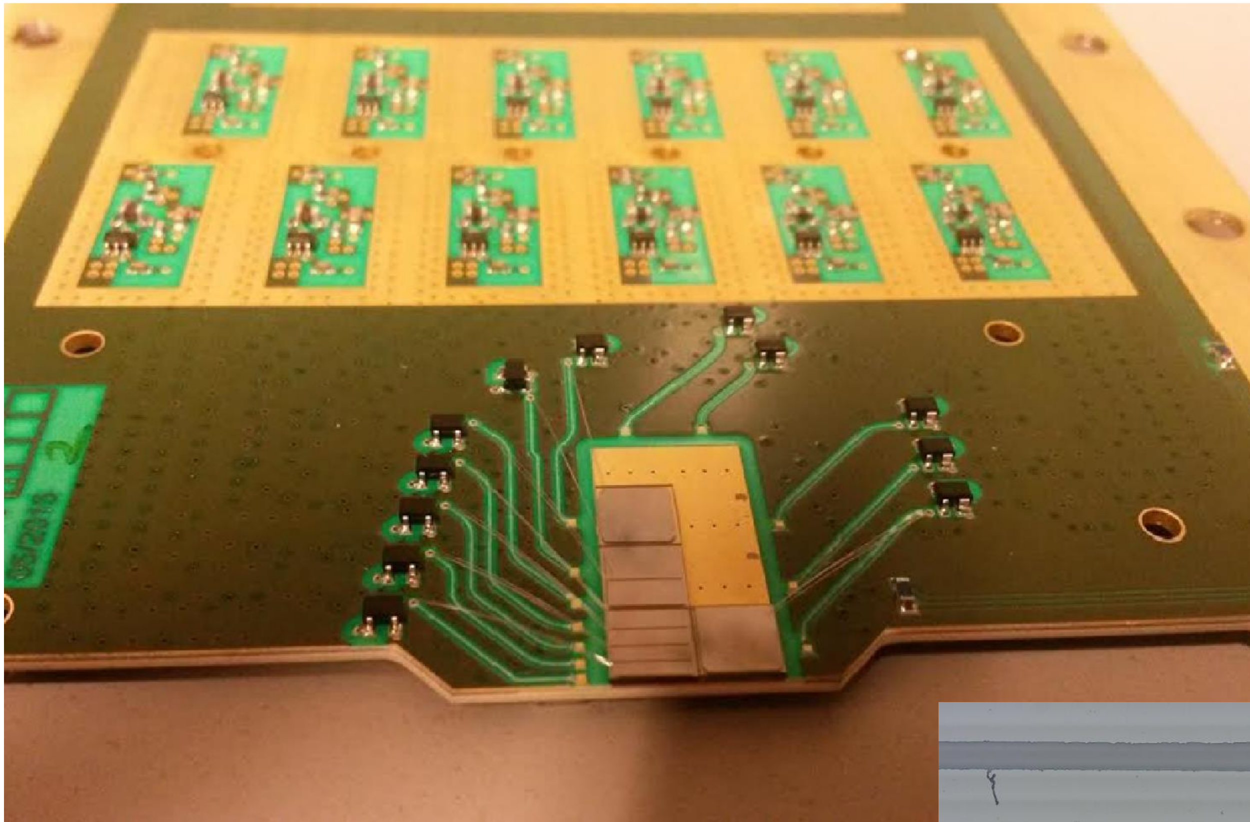
Horizontal Diamond Detector

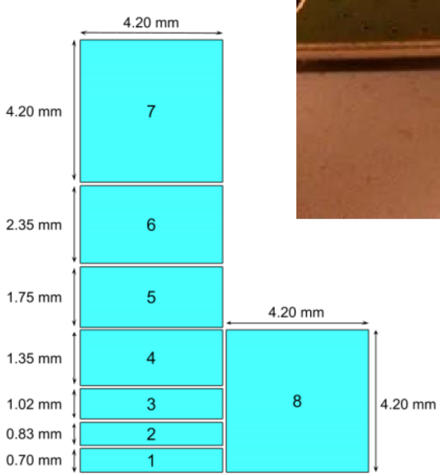
- CT-PPS runs
- Low β*, high luminosity
- Read-out with NINO





Vertical Board Prototype



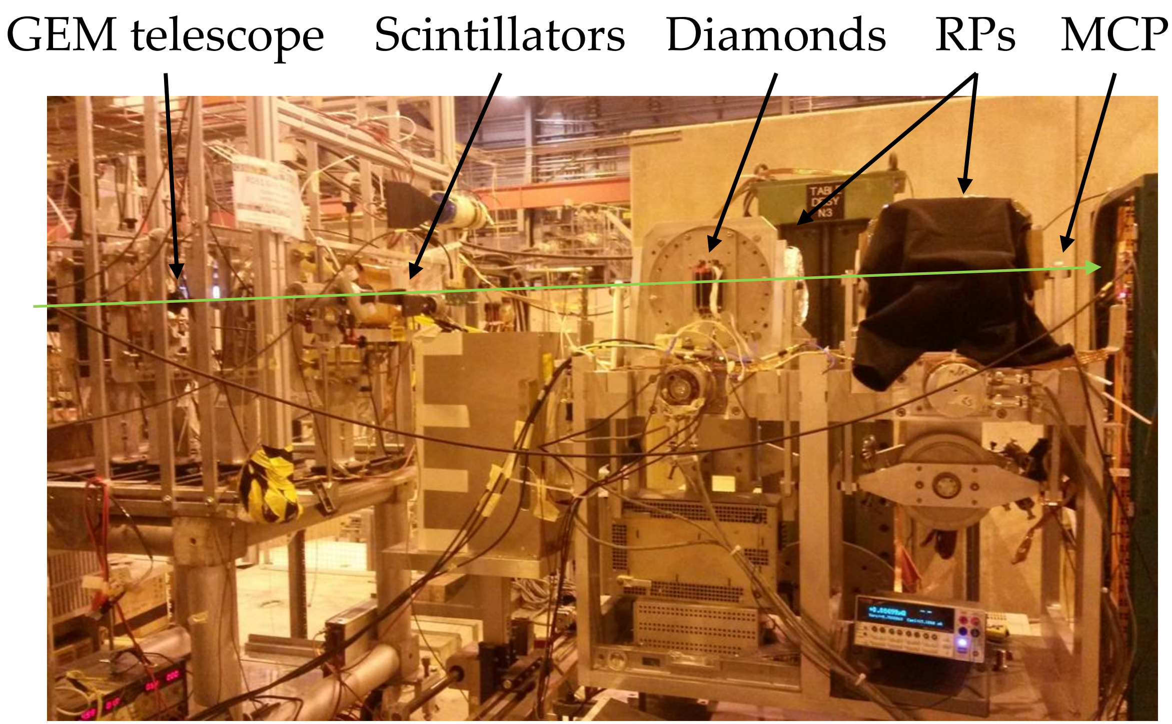


Test Beams: DESY and SPS H8

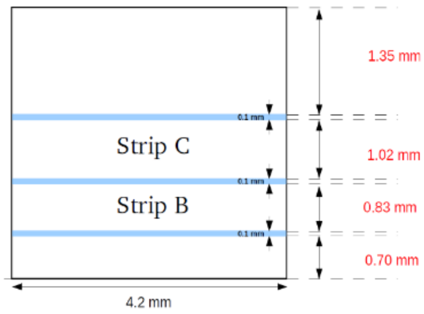
Test Beam at DESY:

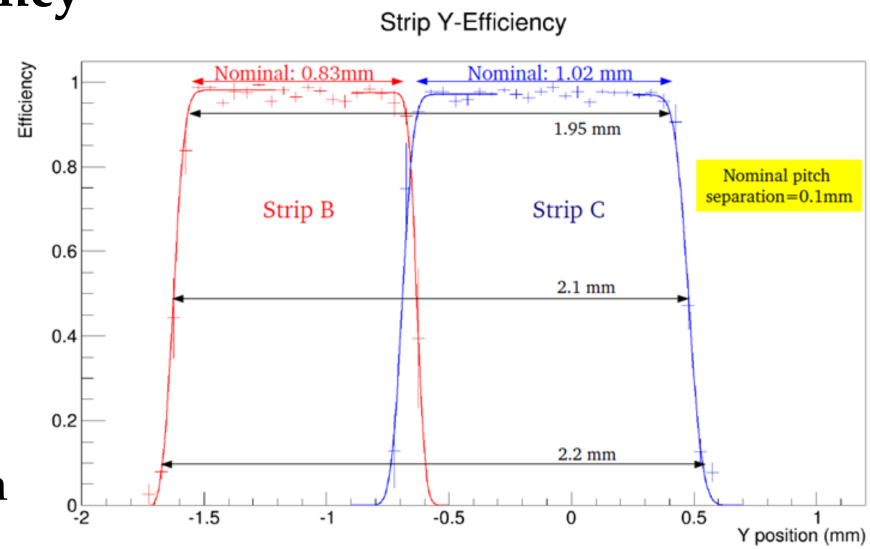
- a mixed pion and electron beam
- To measure the efficiency the tracks have been reconstructed with the DATURA tracking telescope (6 Si pixel detector planes)

Test Beam at H8 →

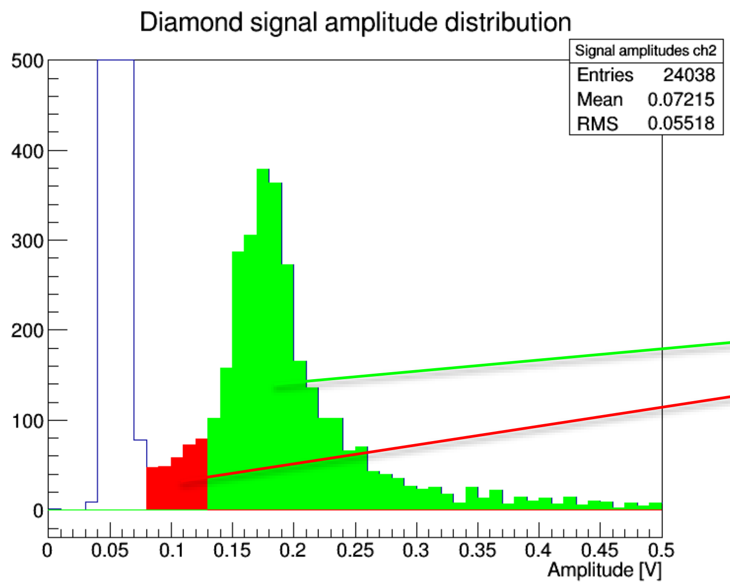


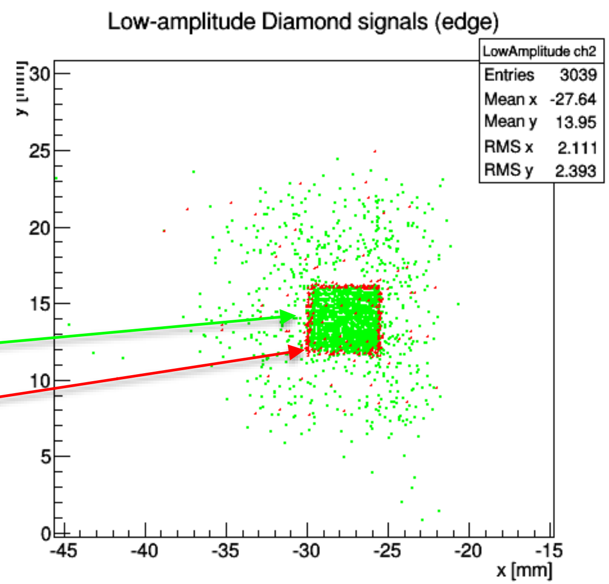
Test Beam results: Efficiency





- >98% uniform efficiency
- No eff. Loss due to pattern
- Low S/N signal

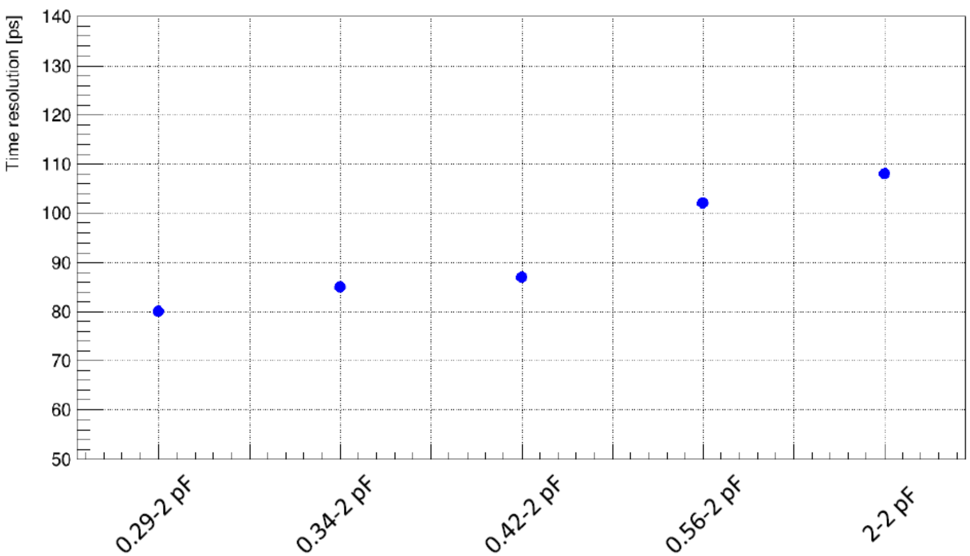




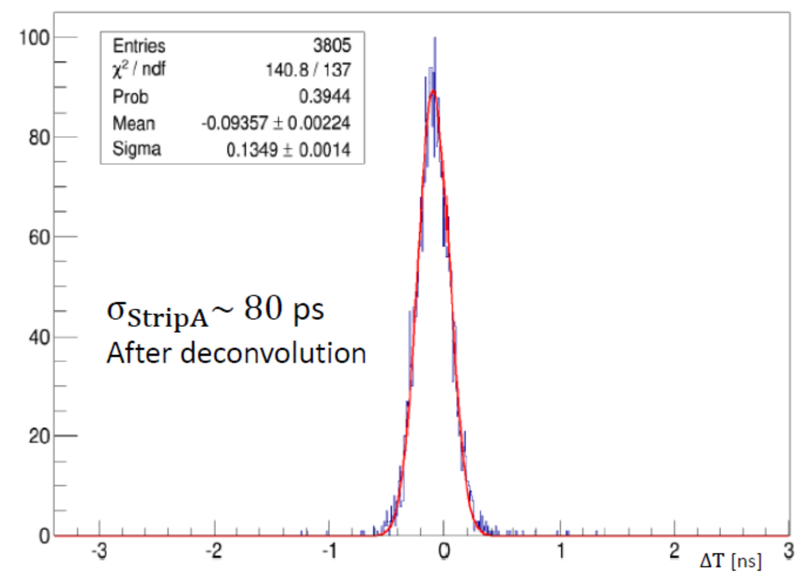
Test Beam results: Timing performance

- Average Rise time: 1.4 - 1.7 ns
- Average S/N: 40 - 50
- Time resolution is found to slightly increase with the capacitance
- S/N > 25 for strips, S/N > 18 without strips

Time res. vs. capacitance

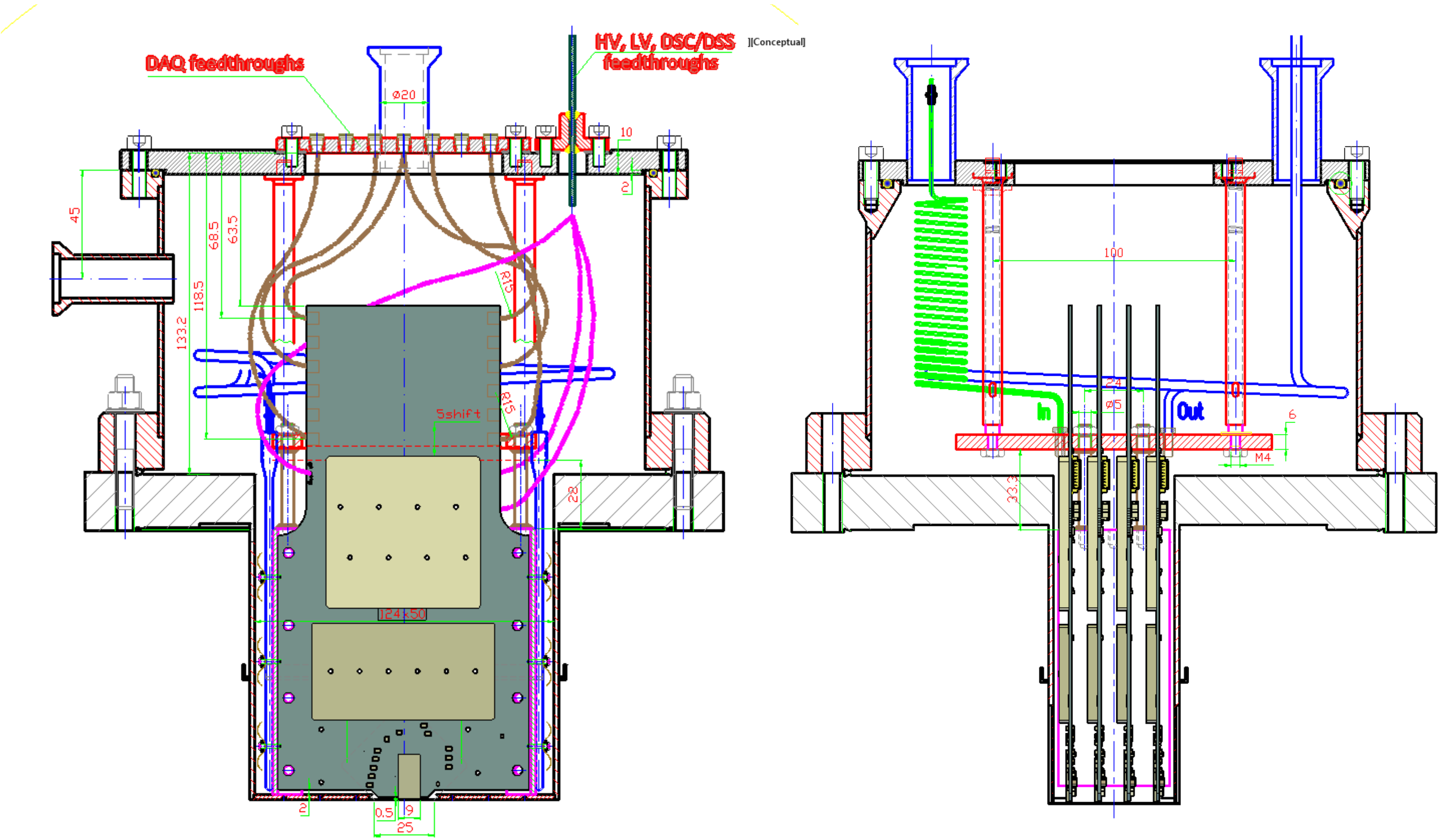


Time res. of one single sensor



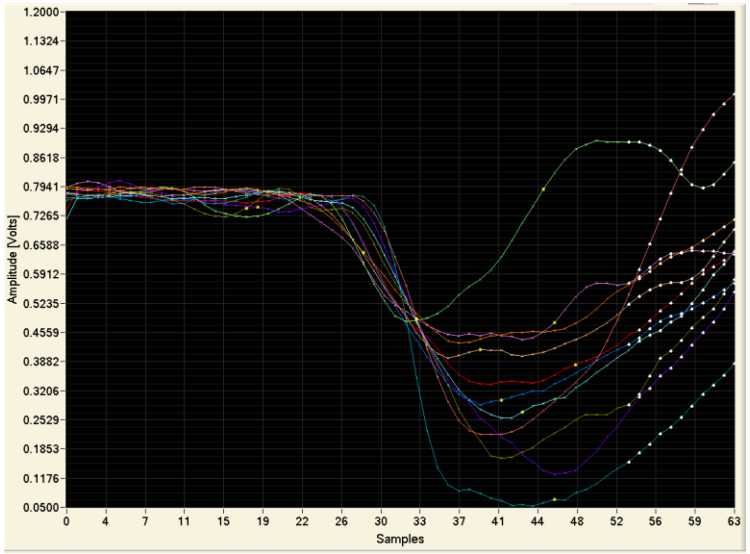
- Time res. has not been degraded due to SAMPIC waveform digitizer, but it has been degraded due to NINO chip (by ~20 ps)!

Vertical Detector Package inside RP



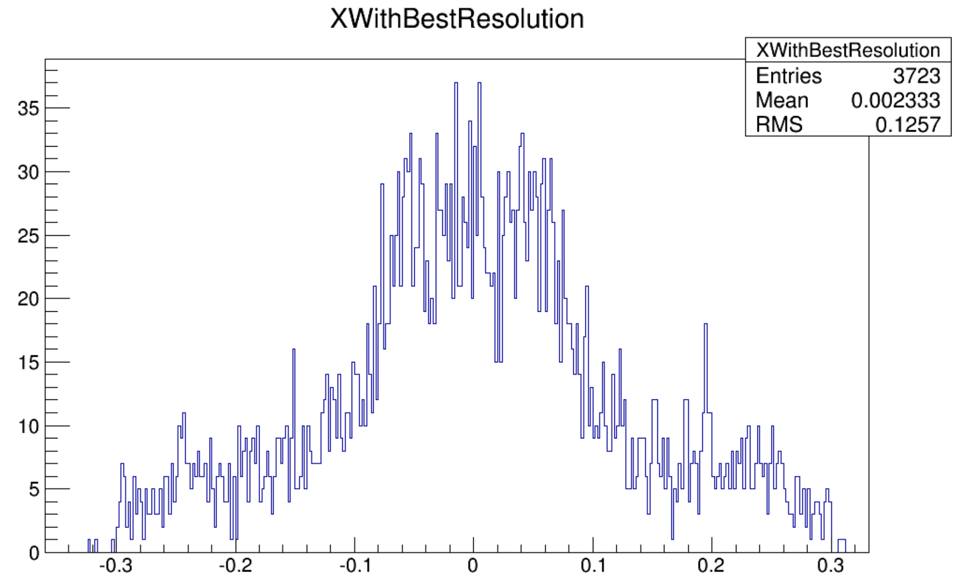
Installation at LHC, 2015 November

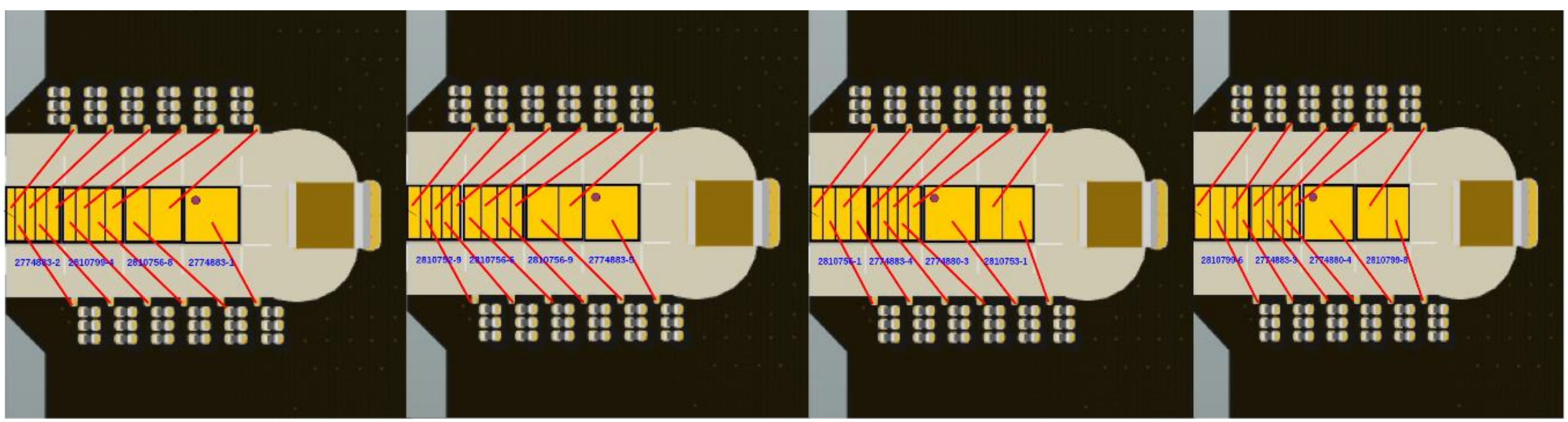
- Operation for 48 hours during an LHC pp runs at 5 TeV
  - RPs were in the "garage" position
  - signal rate was 10-100 Hz/electrode.
  - It was operated at 500 V
  - With a SAMPIC unit the time res. of the smallest capacitance pixels was ~90 ps
  - The noise of the electronic board at T=25°C was 15-28 mV RMS



Horizontal Board Geometry - coarse tracking

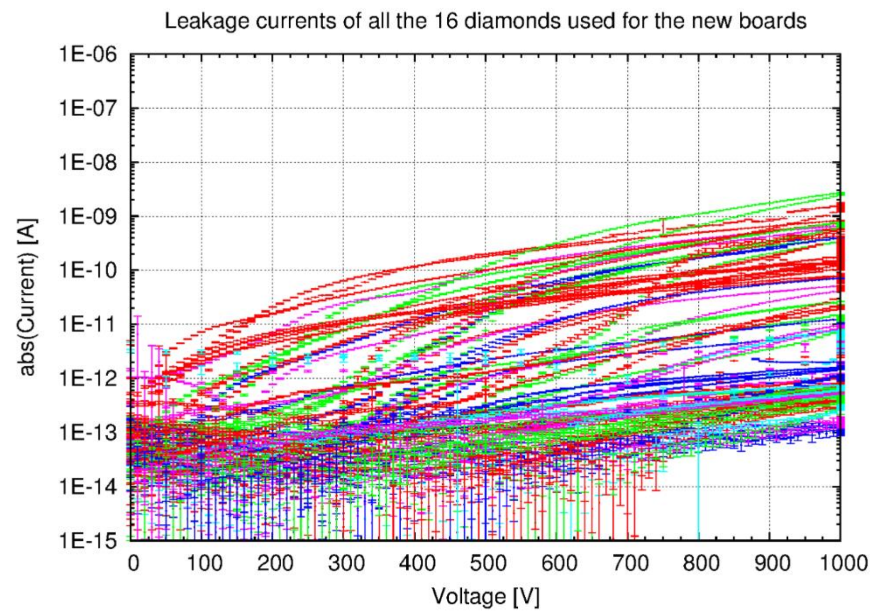
- We increased the granularity provided by each detector to enhance the tracking capability
- Geometry configuration has been studied with the goal to optimize the x-resolution for M = 750 GeV - 1 TeV
- Space resolution of 150 μm can be reached
- Occupancy is almost the same for all pixel

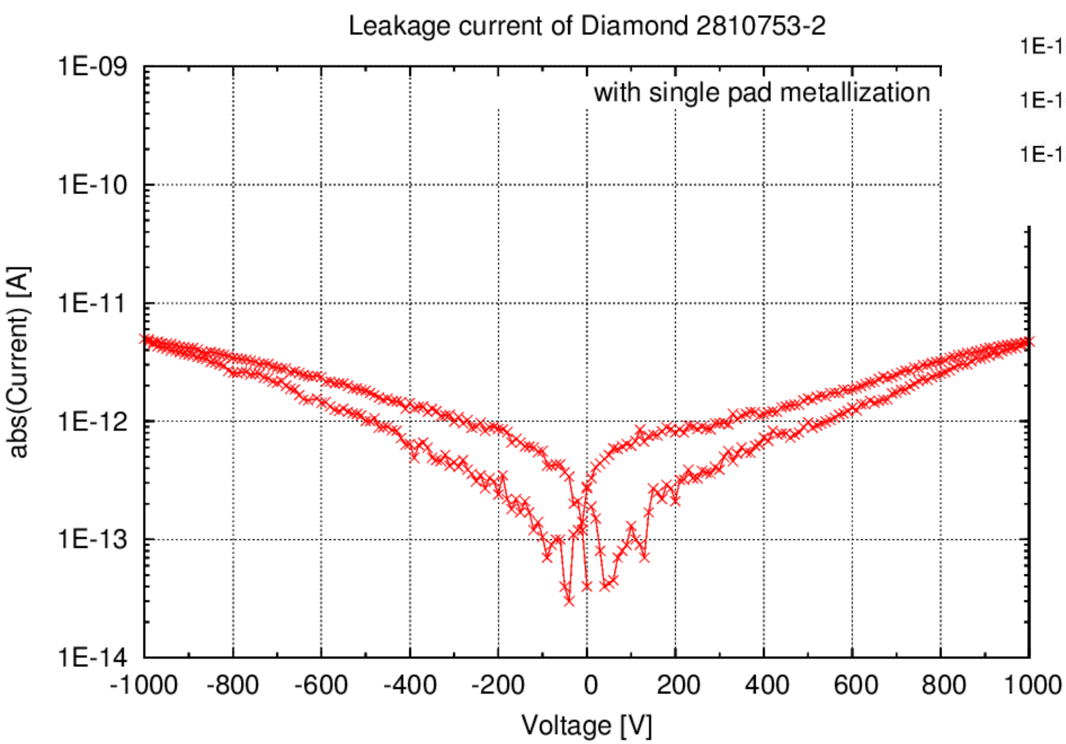




Diamond quality: leakage current

- Each strip of each diamond has been tested in term of leakage current and its stability over time
- The 2x16 best diamonds were selected with current < 1 nA @ 1 kV

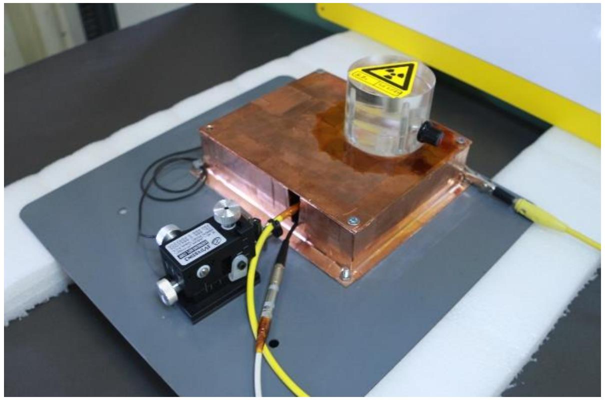


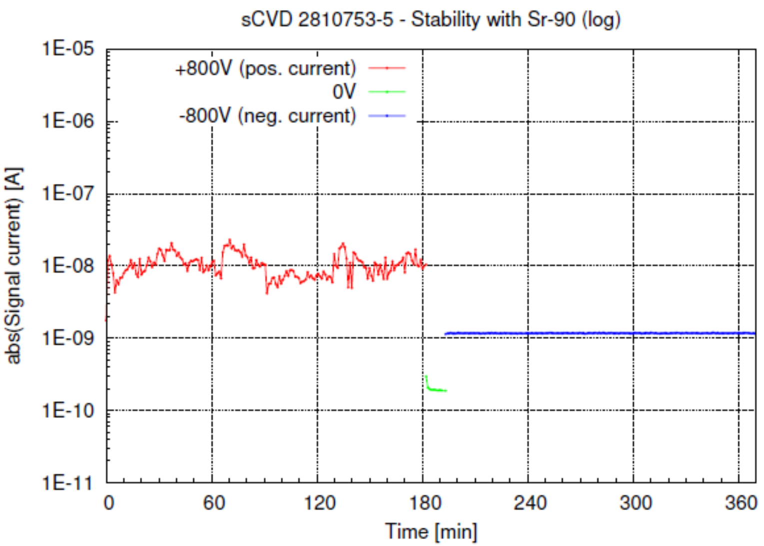


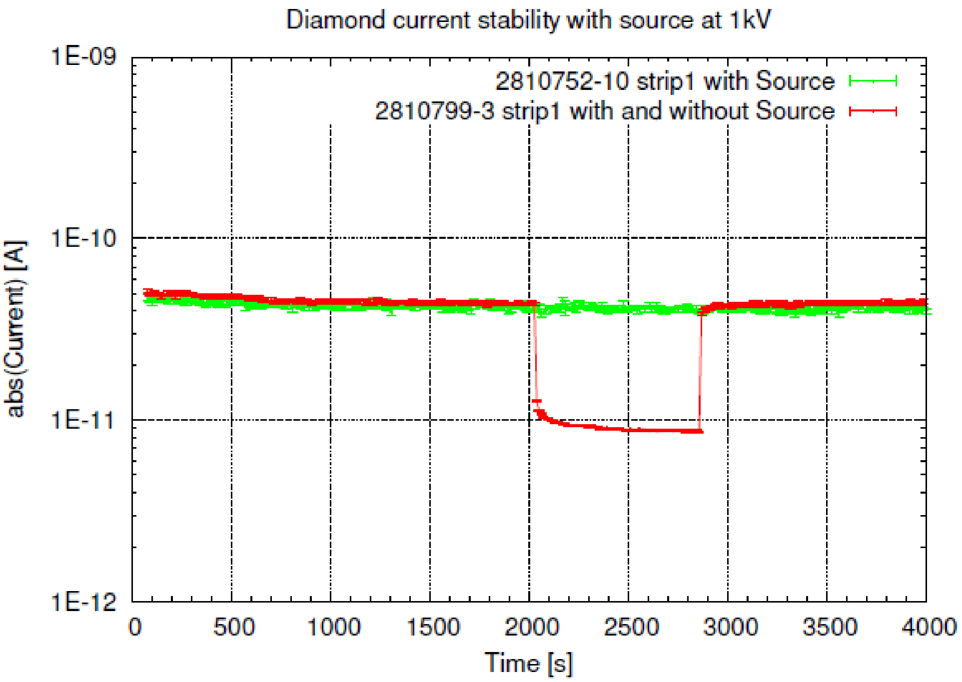
- Presence of air and water vapor increase surface conduction, so in vacuum their performance can be more better!
- Vacuum chamber for tests is under desgin

Diamond quality: Charge collection stability

- Charge collection (signal current) stability over time has been also tested for each diamond with a β radioactive source (~36 MBq)
- Sometime strange asymmetric behaviour were found





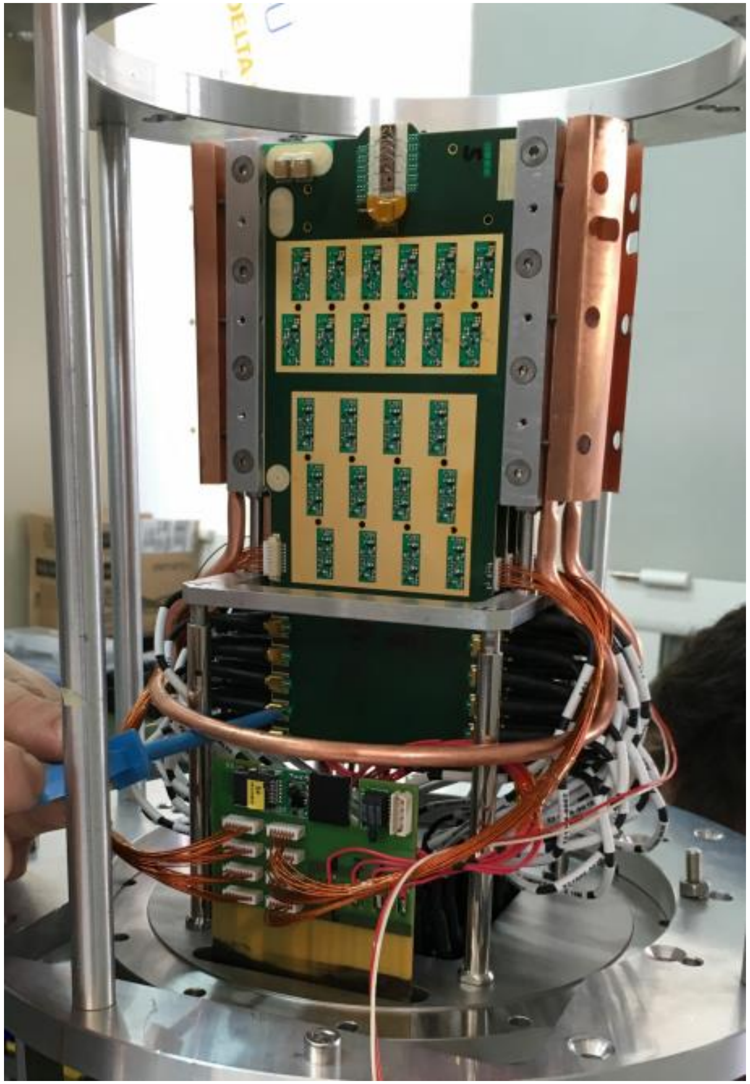


Detector performance

- Minor modifications on the electronics were necessary to adapt the board to the new pattern and to make it HV safe
- Each board has been tested separately in vacuum to assure that the coating procedure was done correctly
- Each channel has been tested with a β source
- Some noise was picked up when boards were put together with a common power source
  - RF shielding was necessary
  - Most effective solution: reduction of amplifier gain (without any loss in efficiency or time resolution)

Horizontal detector package

- Pressure and cooling tests of the RP packages in SPS H8
  - Operational T for electronics: 30°C (cooling: 10-15 °C).
  - Operational p: ~40 mb
  - T/p stability also have been proved (including overpressure test and T down to -25 °C).



2 RPs with horizontal detector packages have been successfully installed at LHC during TS1 (June 2016)

Summary

- TOTEM has made a great effort in the R&D of Diamond Time-Of-Flight detectors to reconstruct longitudinal vertex position and reduce pile-up
- First vertical prototype installed at LHC worked well in Nov 2015
- We have successfully reached the required timing performance, furthermore the detector was also optimized for tracking purpose
- Each channel and board has been tested and quality is assured in terms of HV and signal stability, both RP packages tested in the operational conditions and passed all the safety tests
- Two new horizontal Diamond Timing Detector with 4-4 boards have been installed in LHC tunnel during TS1 and will be operational soon

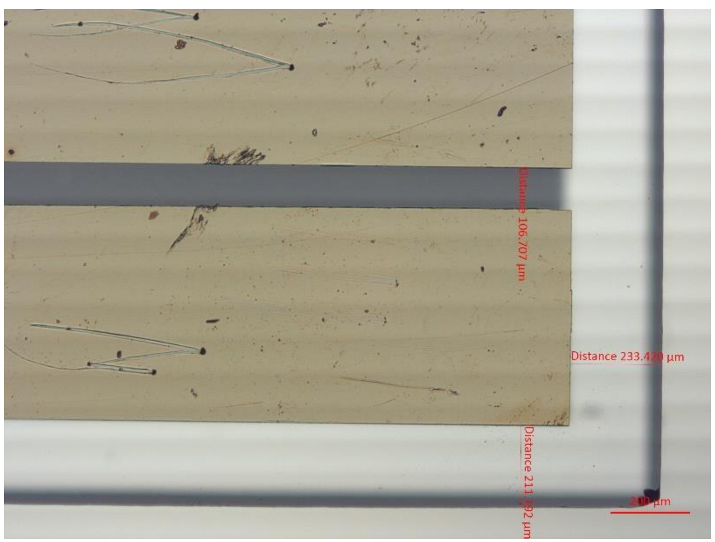
Thank you for your attention!

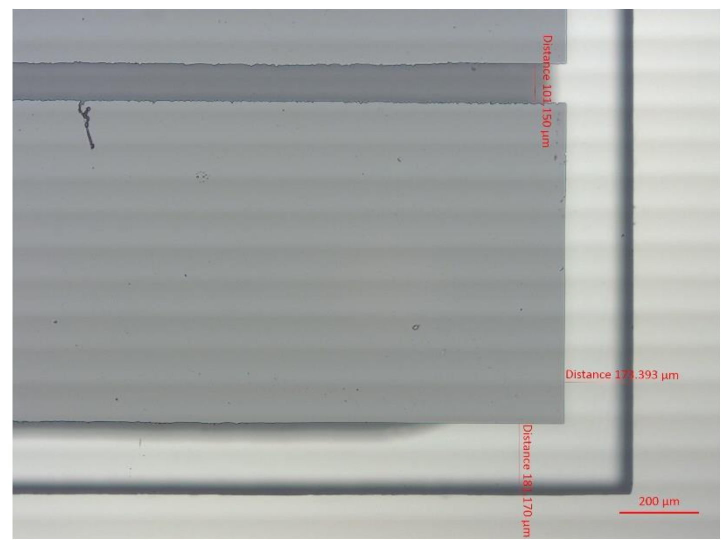
Backup slides

Diamond metallization

- Electrodes are needed to be created on the surface of the crystals
- The metallization processes are company specific
  - Main steps: Laser polishing and PVD
- We have tested different metallization types. They were made by:
  - GSI (Cr-50 nm + Au-150 nm)
  - PRISM (100 nm of 10% Ti and 90% W alloy)
  - Applied Diamond Inc. (Cr-50 nm + Au-150 nm)
- Non-metallized region on the edge is 150 µm, strips are separated by 100 µm

Smallest strips on a crystal with 5 strip (Cr+Au) and 4 strip (Ti-W)

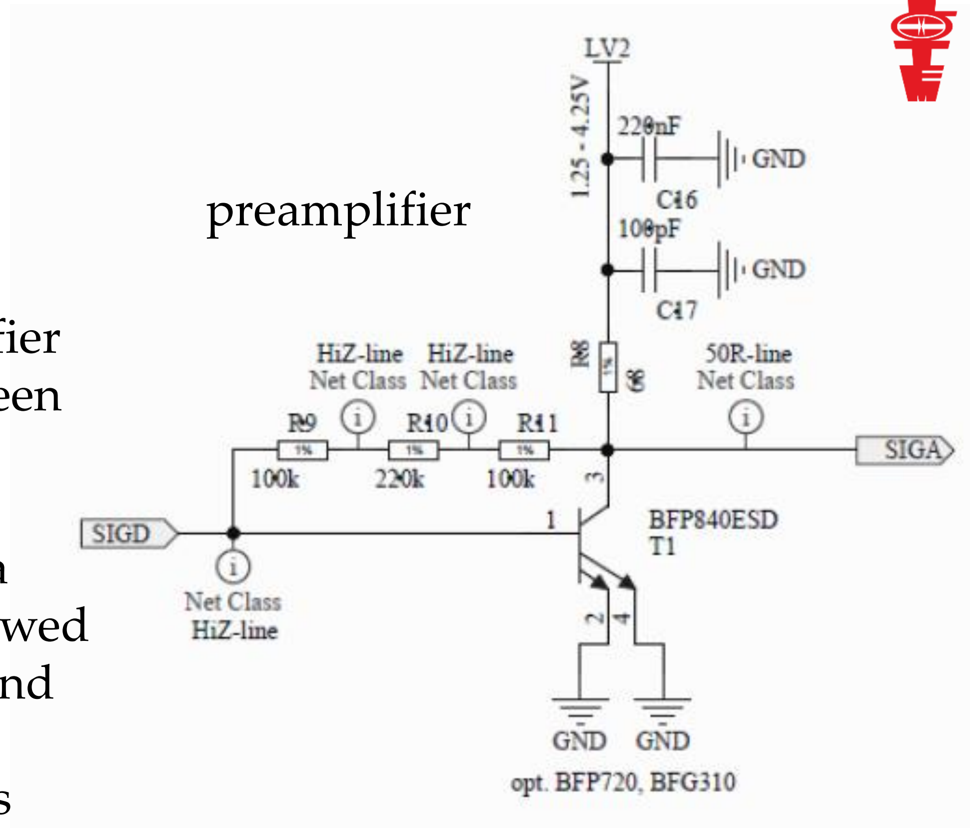


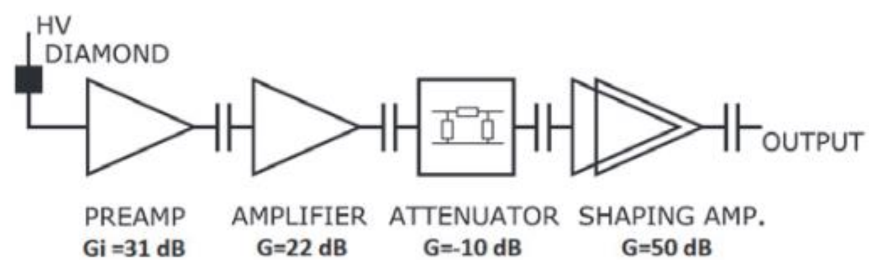


Front End Electronics

- Only 2.9 fC charge are released by a MIP in a 500 µm diamond plate
- Main noise source: first stage amplifier
- FEE design must compromise between speed and low noise

- The amplification chain consists of a transconductance preamplifier followed by a single stage voltage amplifier and by a booster who also shapes the analogue voltage output signal. This design has been adapted from the HADES collaboration.
- Total input capacitance: 0.2 - 2 pF
- Low-C feedback





Reference: M. Ciobanu et al: In-Beam Diamond Start Detectors, IEEE Transactions on Nuclear Science, Vol. 58, No 4, August 2011

Read-out of the new Horizontal packages

- The read-out electronics is based on the Digitizer board
  - FPGA based (Microsemi SmartFusion)
  - NINO discriminators (Leading and trailing edges measured)
    - Optimization (attenuation and capacitance)
  - HPTDC as a Time to Digital converter
  - GOH (Totem Opto Hybrid data Transfer) Or POH (New CMS Opto hybrid for data Transfer)

- Firmware
  - Data packing (Totem Si Strip data Format)
  - Buffering at any L1
  - I^2C configuration registers

Commissioning of the Read-out has just finished.