Diamond Timing Detector for TOTEM

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on behalf of the TOTEM collaboration

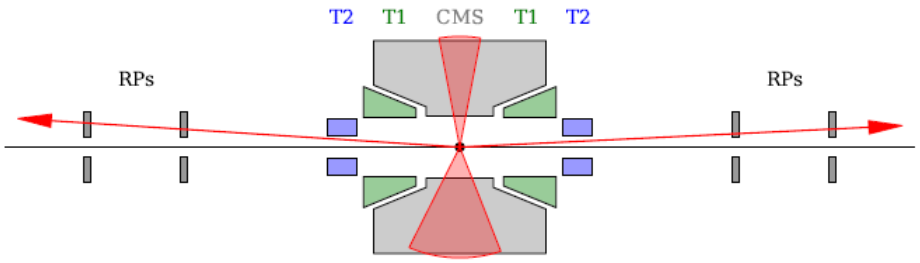
QCD at LHC: forward physics and UPC collisions of heavy ions, Trento, 2016

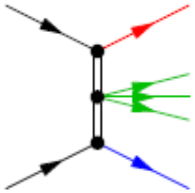
Motivation for timing

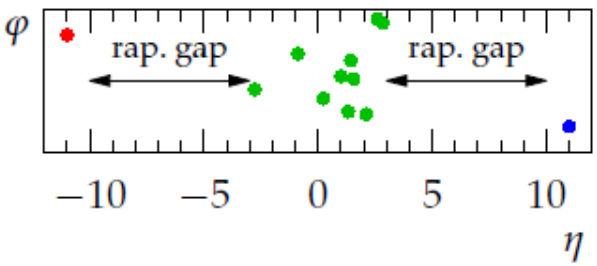
Central Diffraction (in high β* runs):

$p + p \longrightarrow p + X + p$

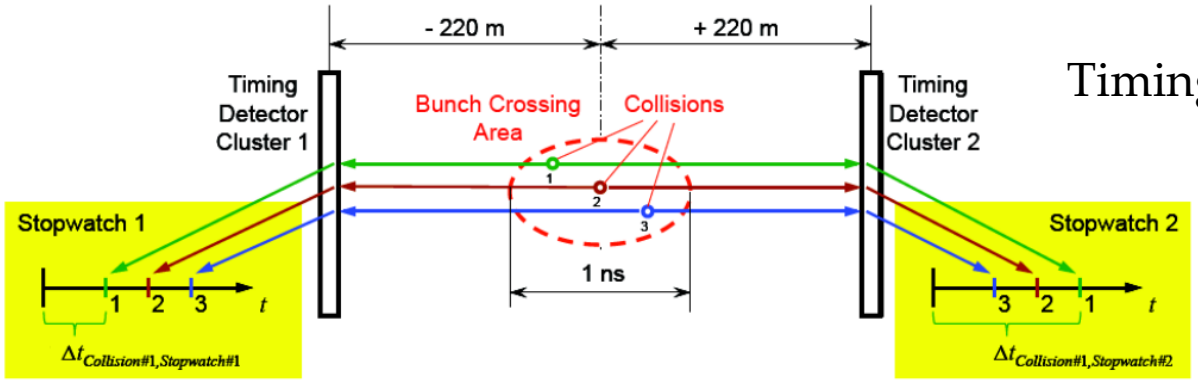
- Longitudinal vertex reconstruction at IP5
  $\sigma_z \approx 1\text{cm}, \ \Delta t \approx 50$ ps
- Pile-up reduction







CT-PPS project
(See earlier talk by Jan Kaspar)



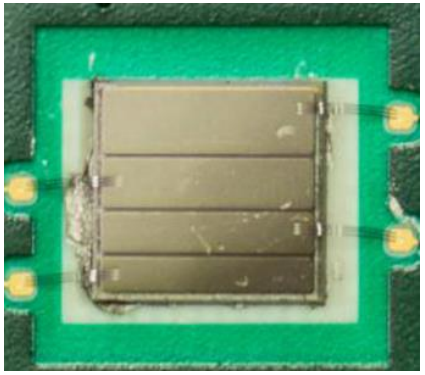
Timing scheme

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
  - Maximize preamplifer rise time
  - Maximize S/N



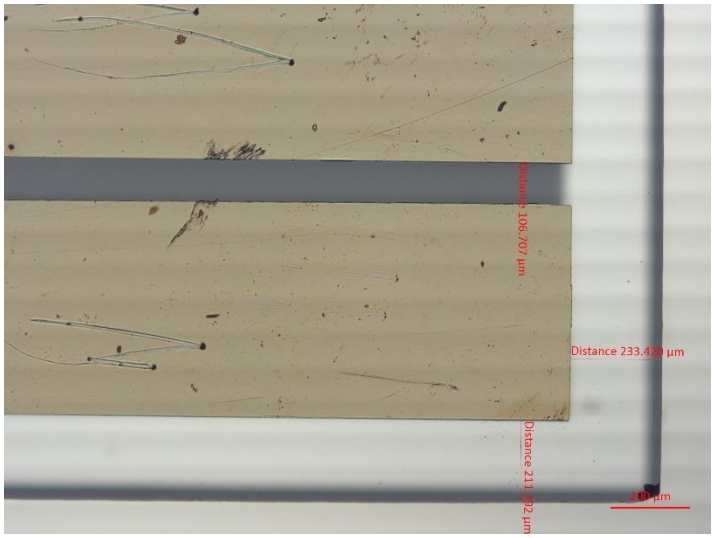
High purity, electronic-grade scCVD crystals from Element6 with <100> orientation (4.5x4.5x0.5 mm) were used

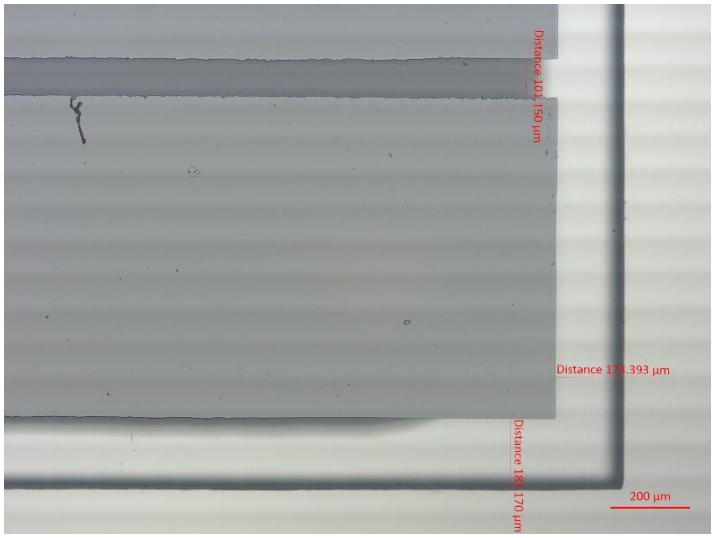
Reference: M. Berretti, The diamond time of flight detector of the TOTEM experiment, VCI2016 - The 14th Vienna Conference on Instrumentation, 15-19 Febr. 2016

Diamond 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)

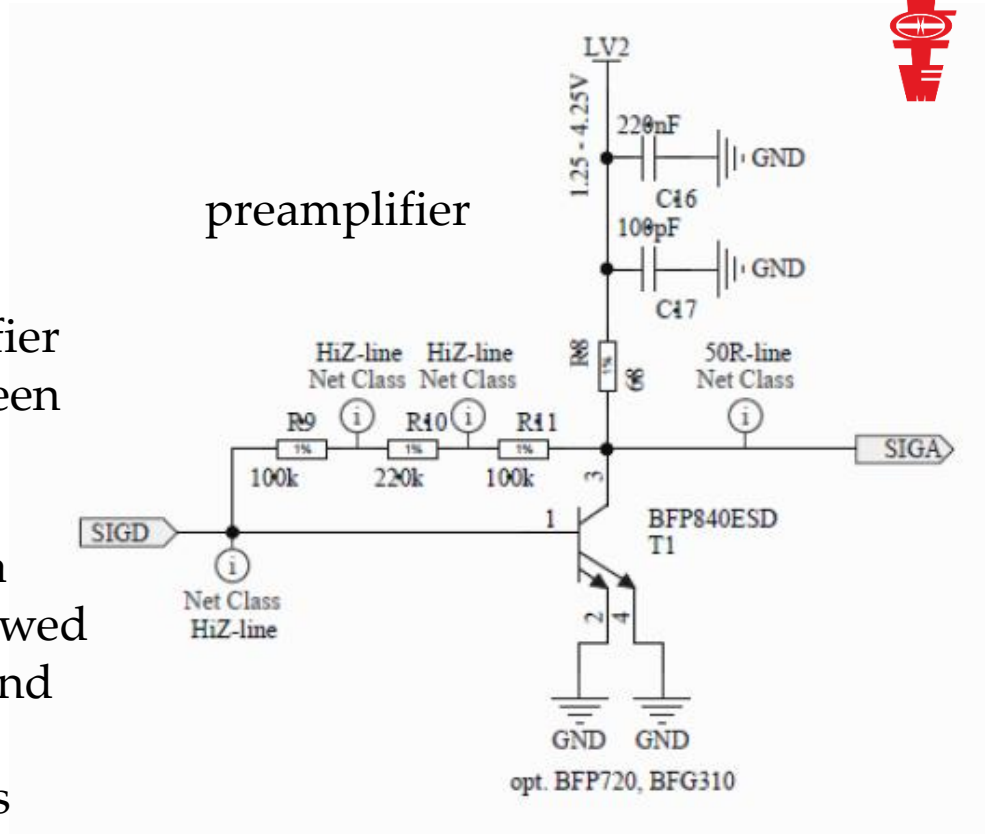


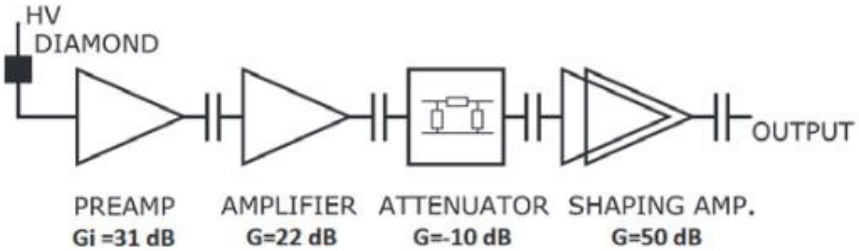


Front End Electronics

- 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



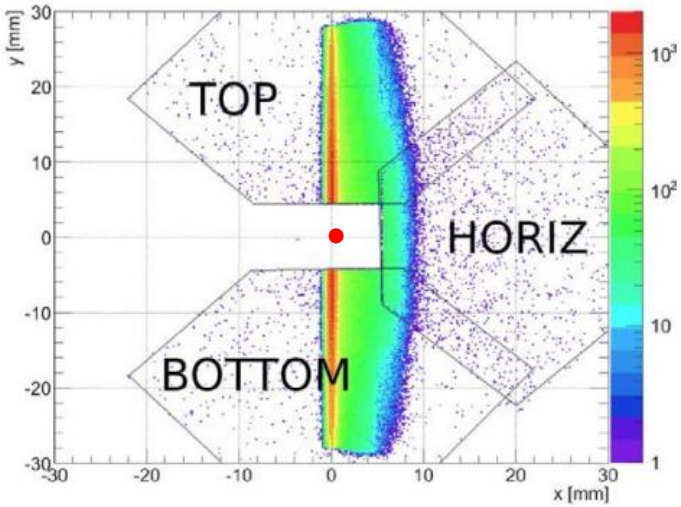


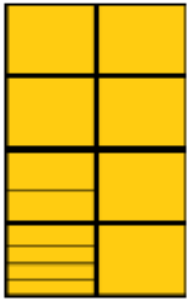
Reference: M. Ciobanu et al: In-Beam Diamond Start Detectors, IEEE Transactions on Nuclear Science, Vol. 58, No 4, August 2011

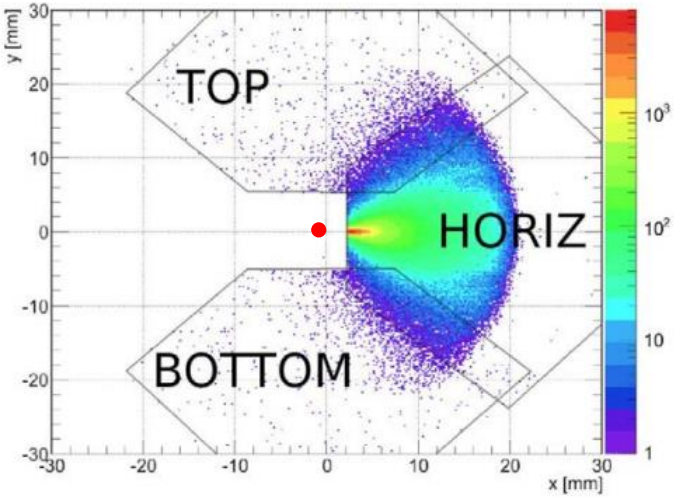
Diamond pixel layouts

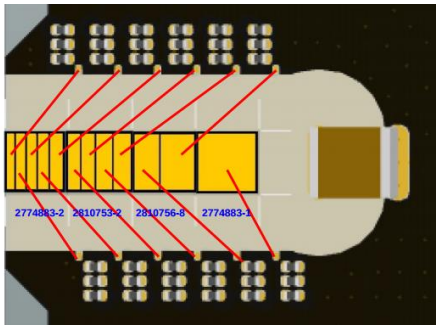
- High β*, low luminosity
- TOTEM standalone runs
- Vertical Diamond Detector
- Read-out with SAMPIC

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

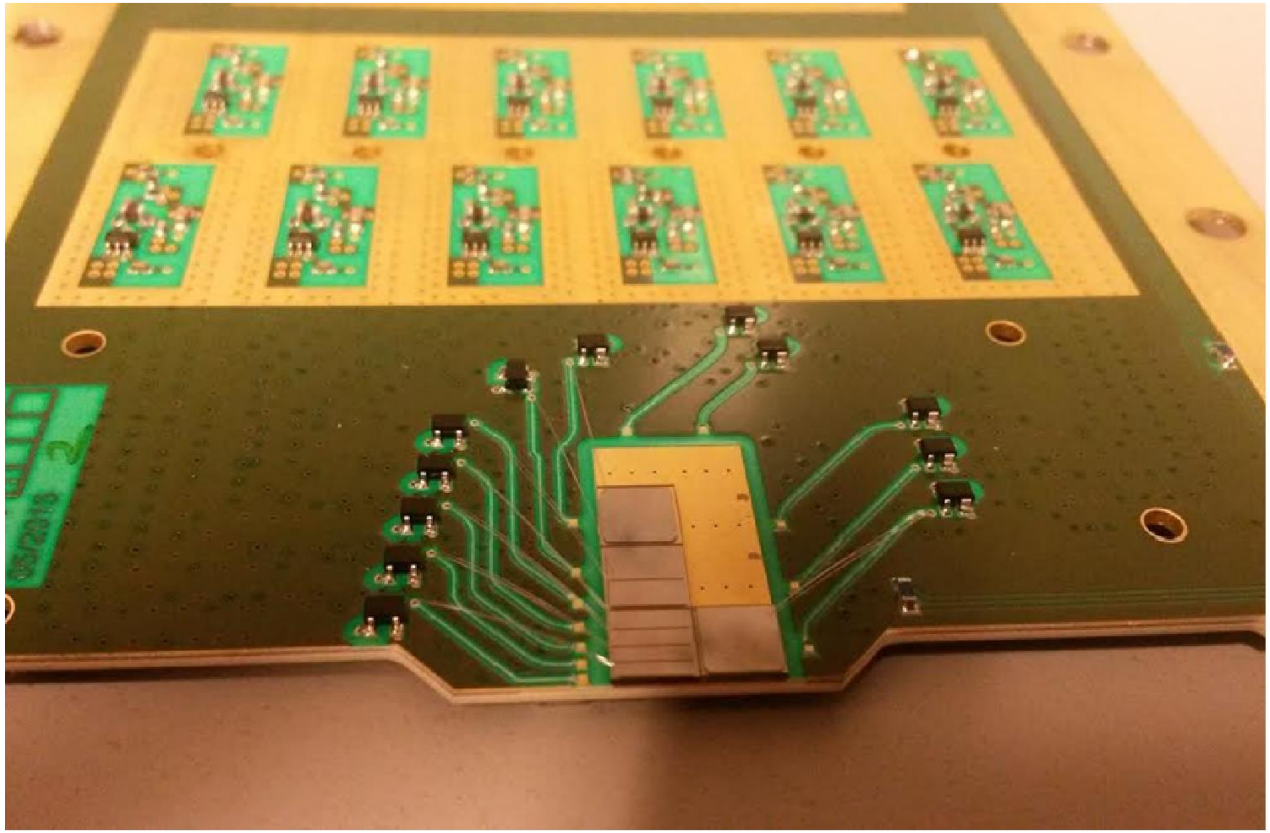


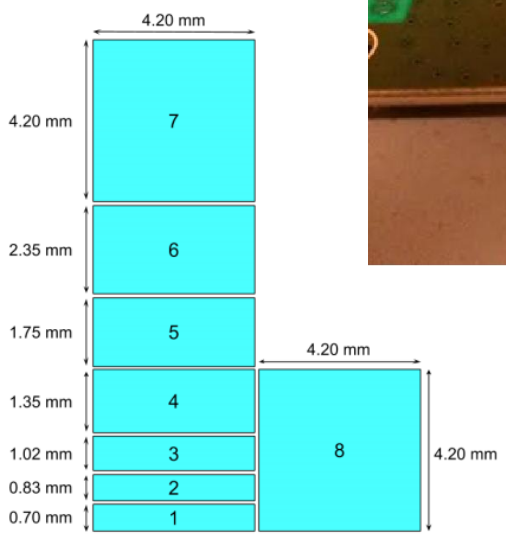






Vertical Board Prototype

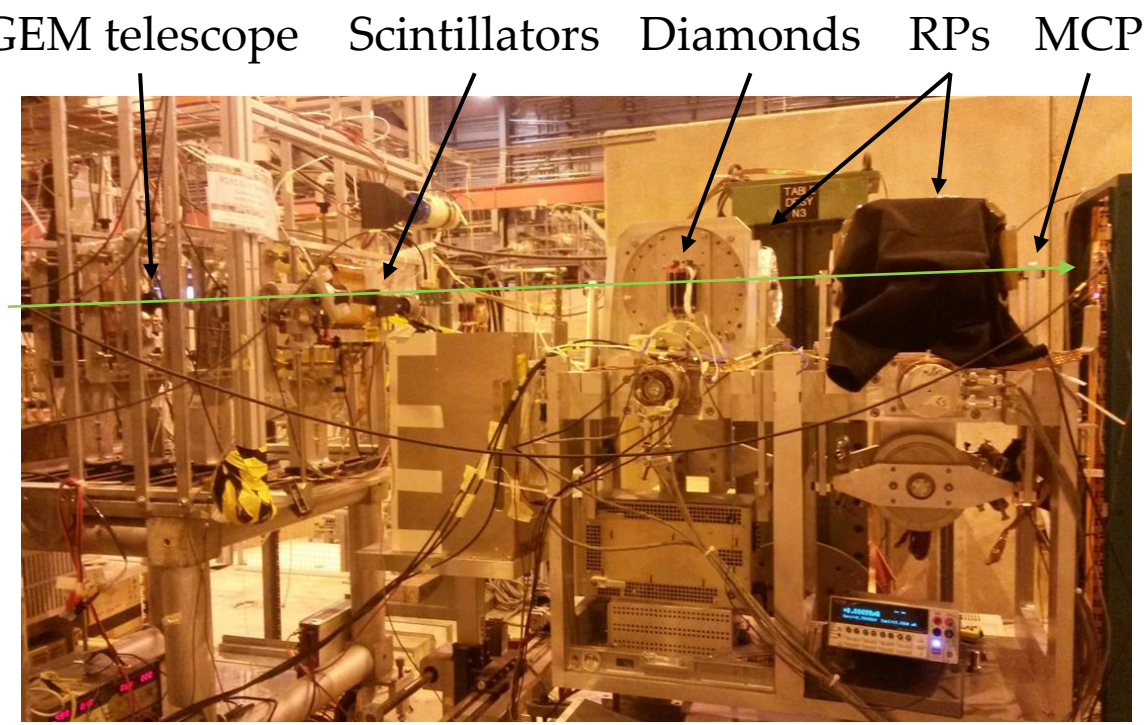




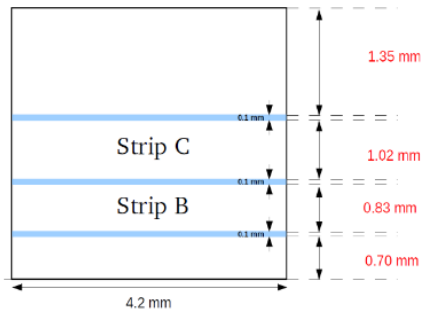
Test Beams: DESY and SPS H8

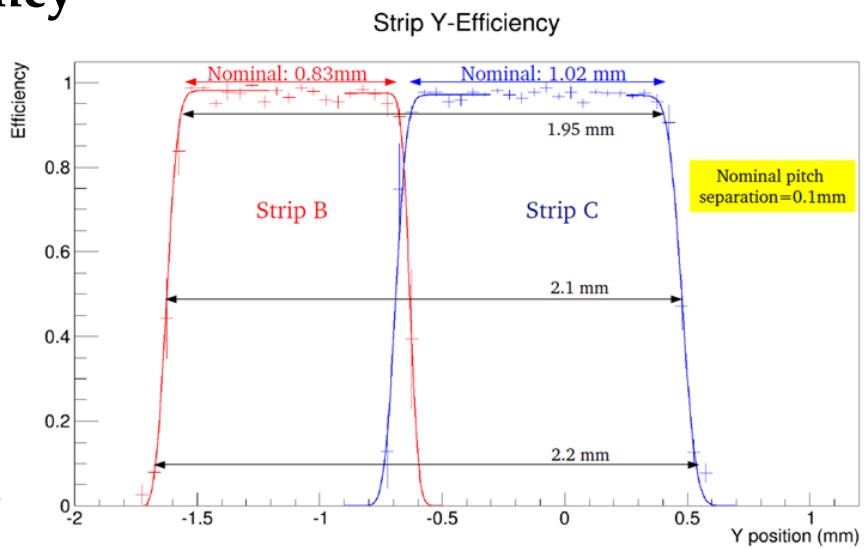
Test Beam at DESY:

- 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)

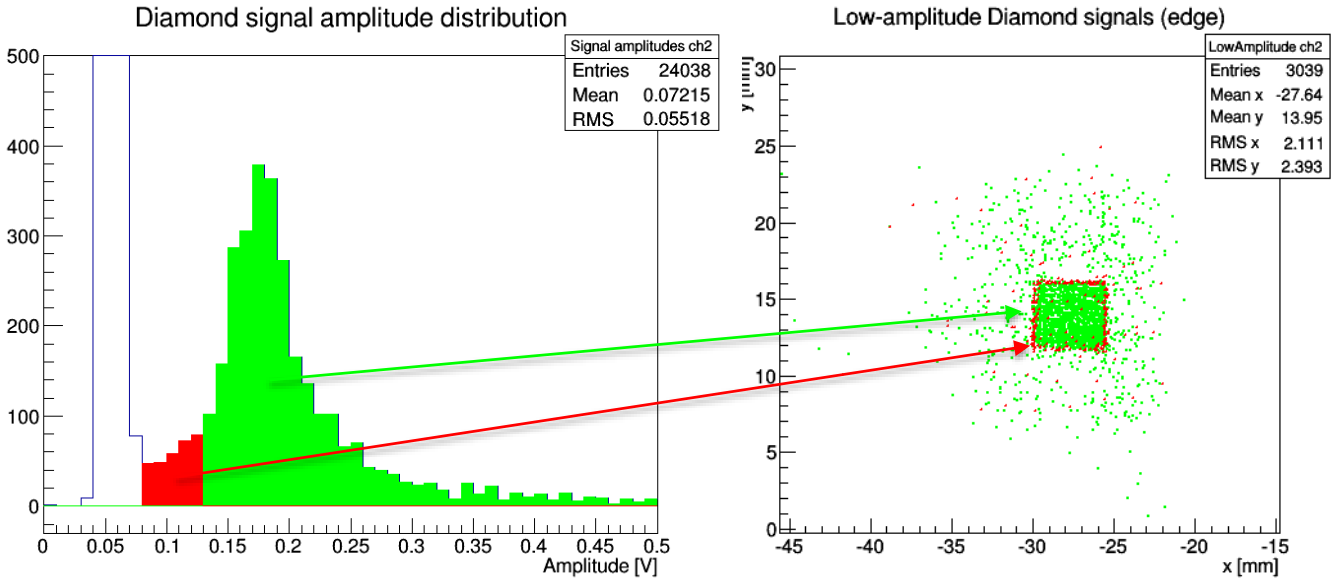


Test Beam results: Efficiency





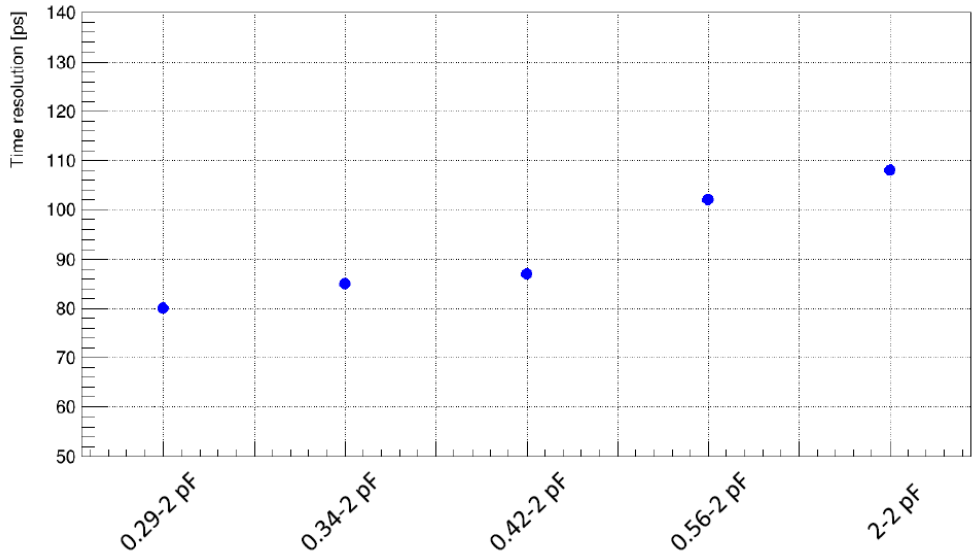
- >98% uniform efficiency
- No eff. Loss due to pattern
- Low S/N signal



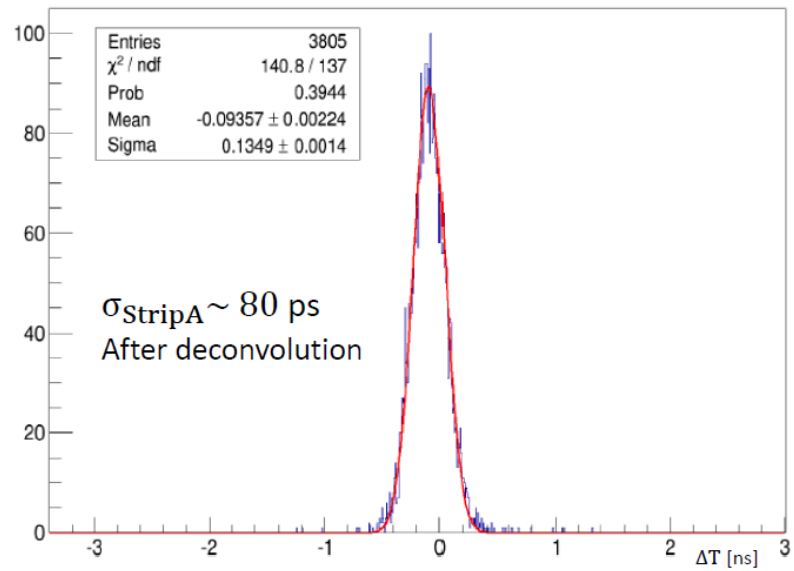
Test Beam results: Timing performance

- 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

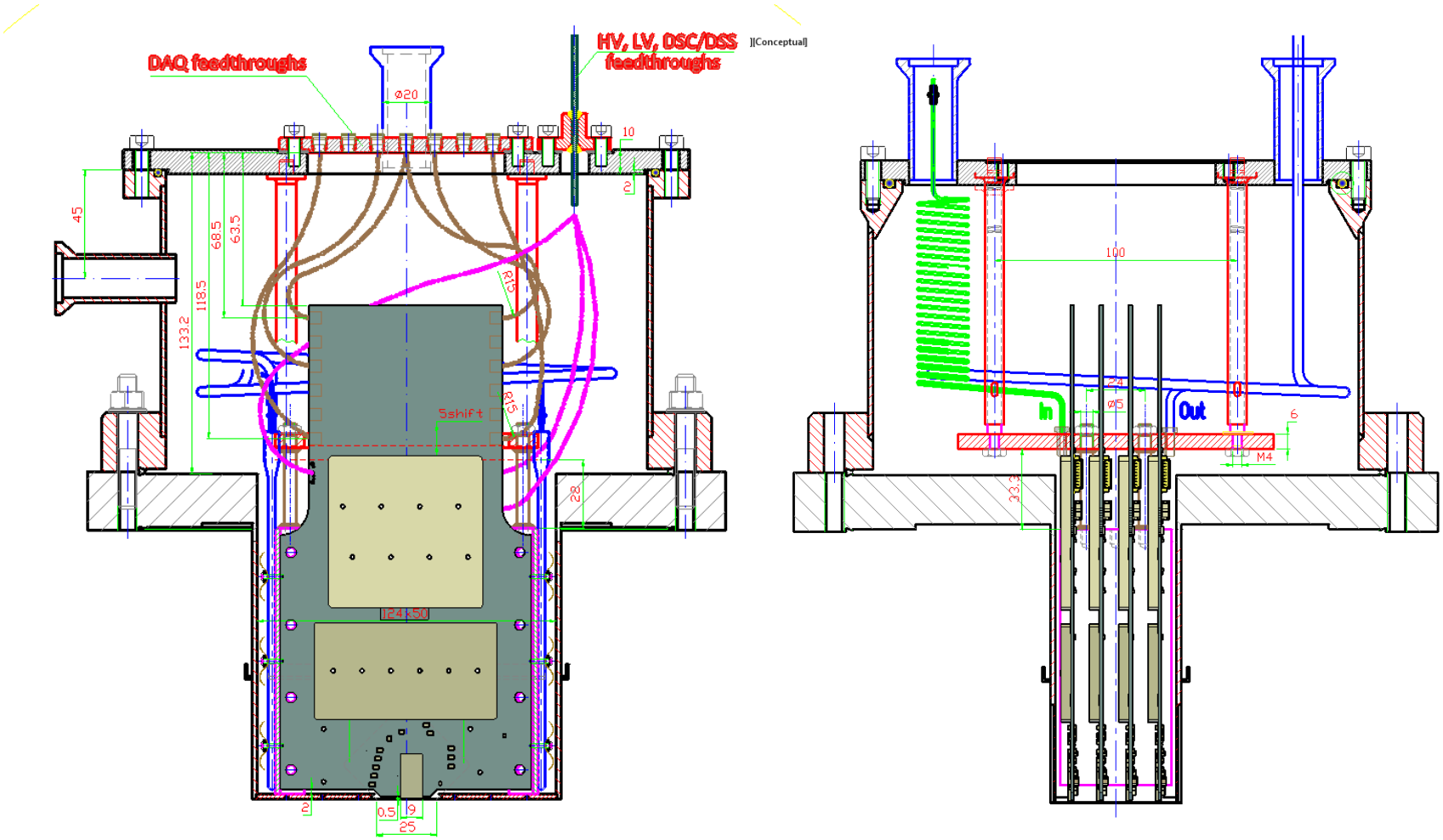


Time res. of one single sensor



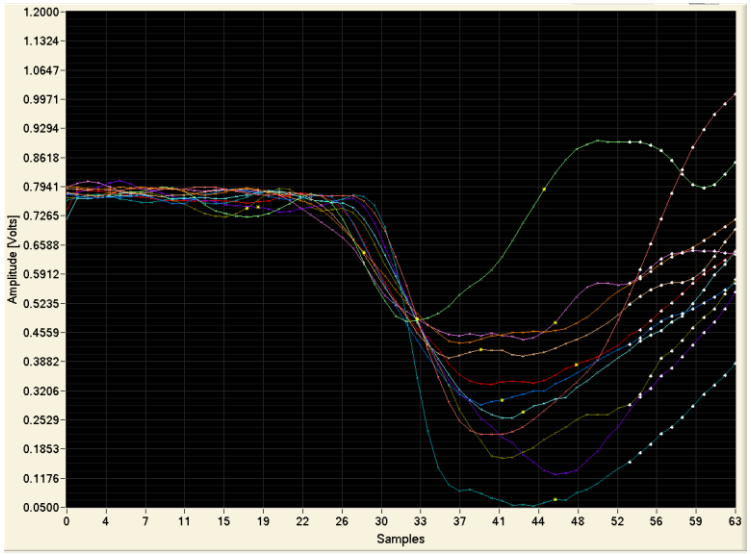
- Time res. has not been degraded due to SAMPIC waveform digitizer, but it has been degraded due to NINO chip (by ~20 ps)!

Vertical Detector Package inside RP



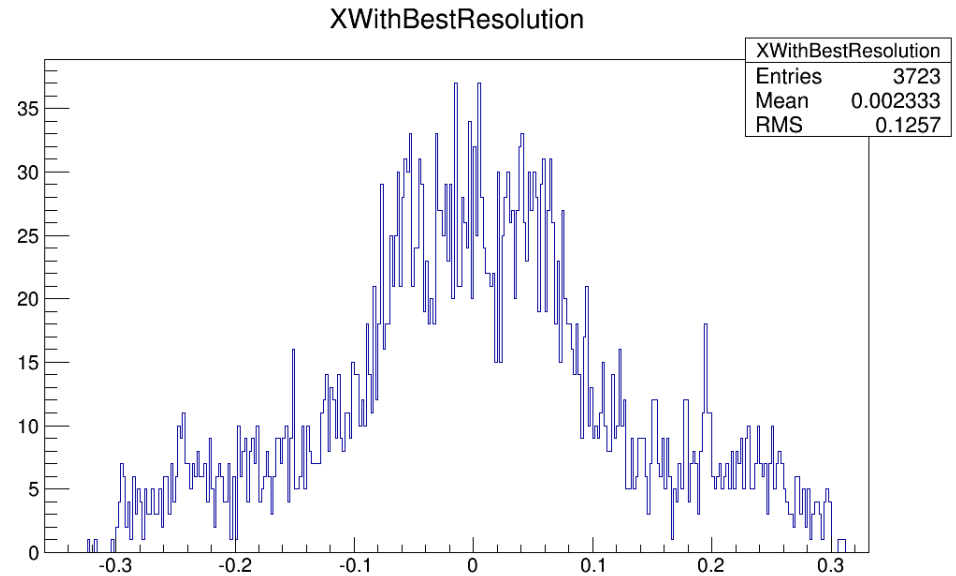
Installation at LHC, 2015 November

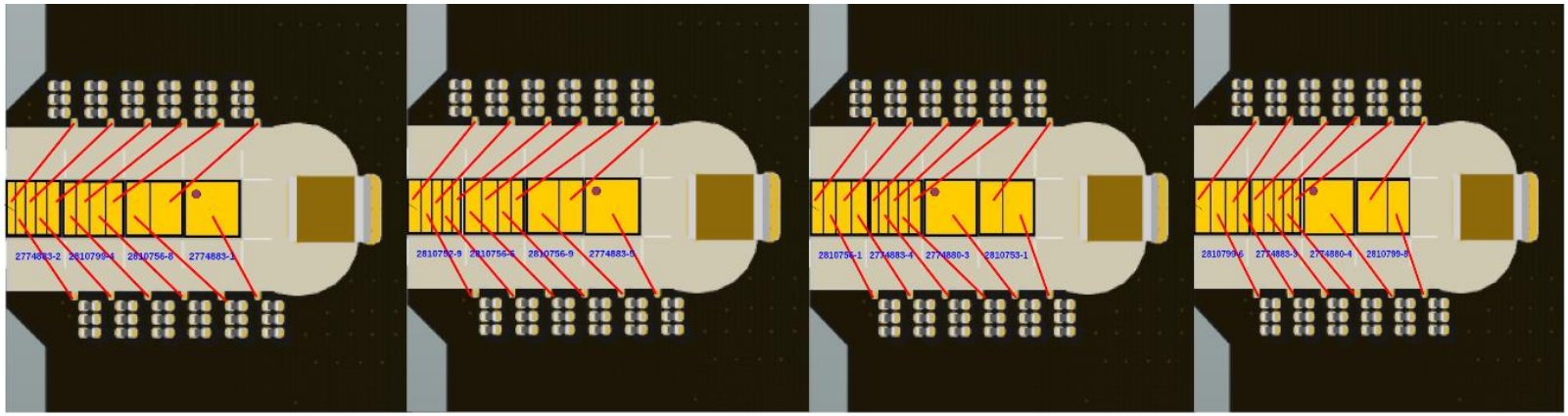
- Operation for 48 hours during an LHC pp runs at 5 TeV
  - RPs were in the ”garage” position
  - signal rate was 10-100 Hz/electrode.
  - It was operated at 500 V
  - With a SAMPIC unit the time res. of the smallest capacitance pixels was ~90 ps
  - The noise of the electronic board at T=25°C was 15-28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



Horizontal Board Geometry - coarse tracking

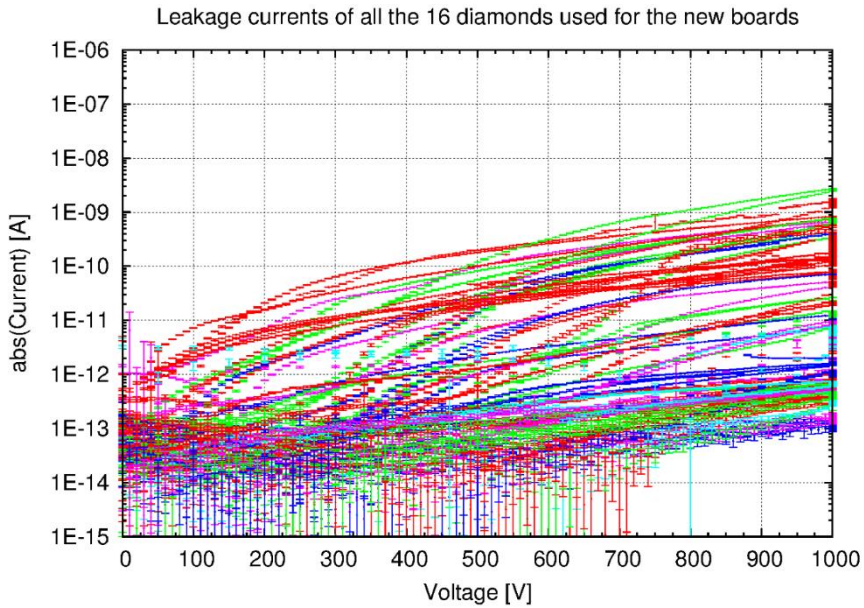
- We increased the granularity provided by each detector to enhance the tracking capability
- Geometry configuration has been studied with the goal to optimize the x-resolution for M = 750 GeV - 1 TeV
- Space resolution of 150 μm can be reached
- Occupancy is almost the same for all pixel

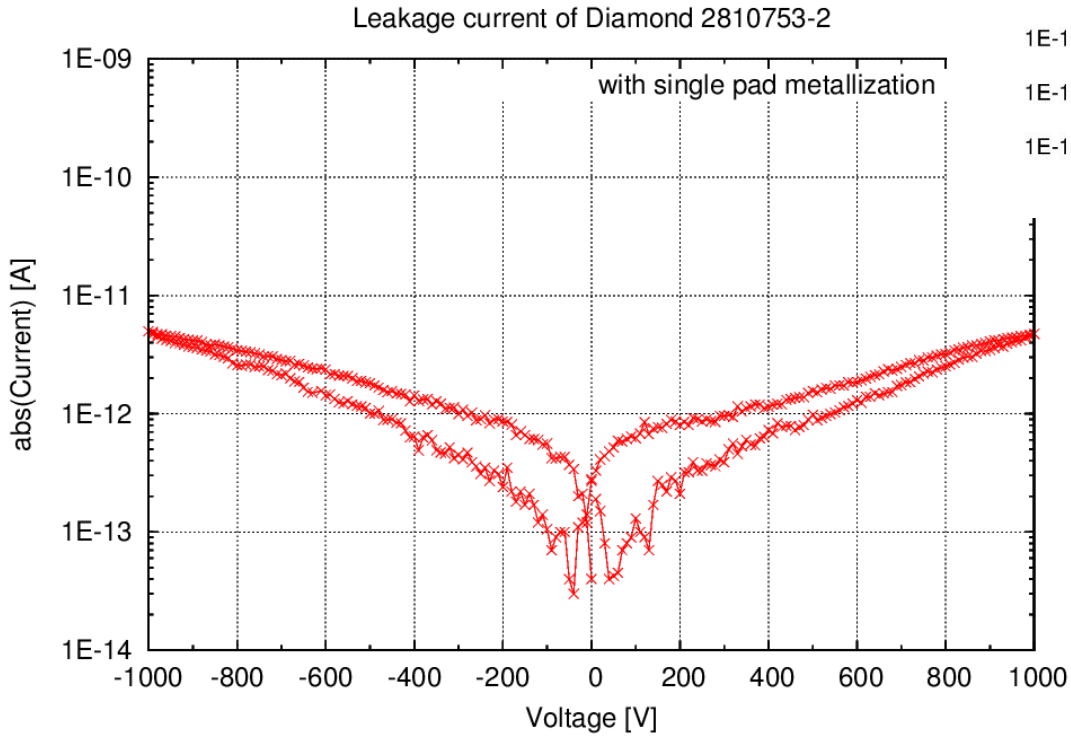




Diamond quality: leakage current

- 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

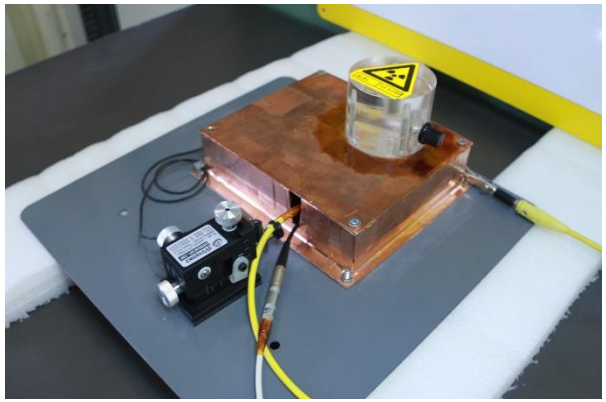


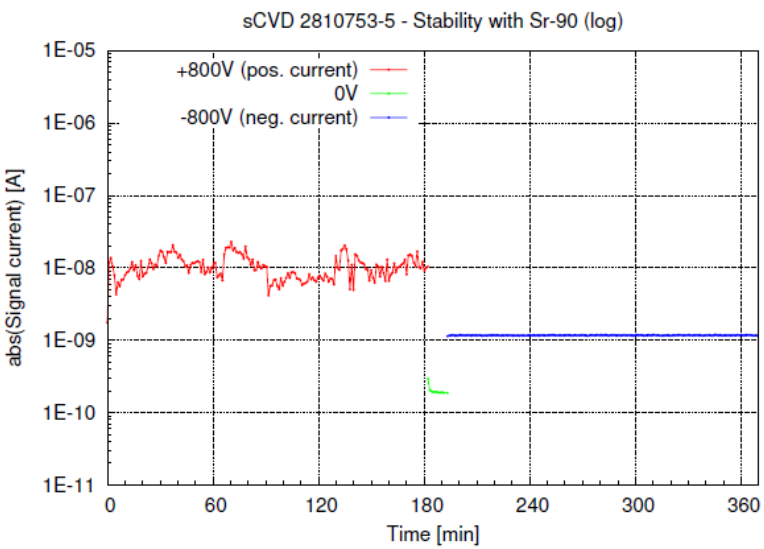


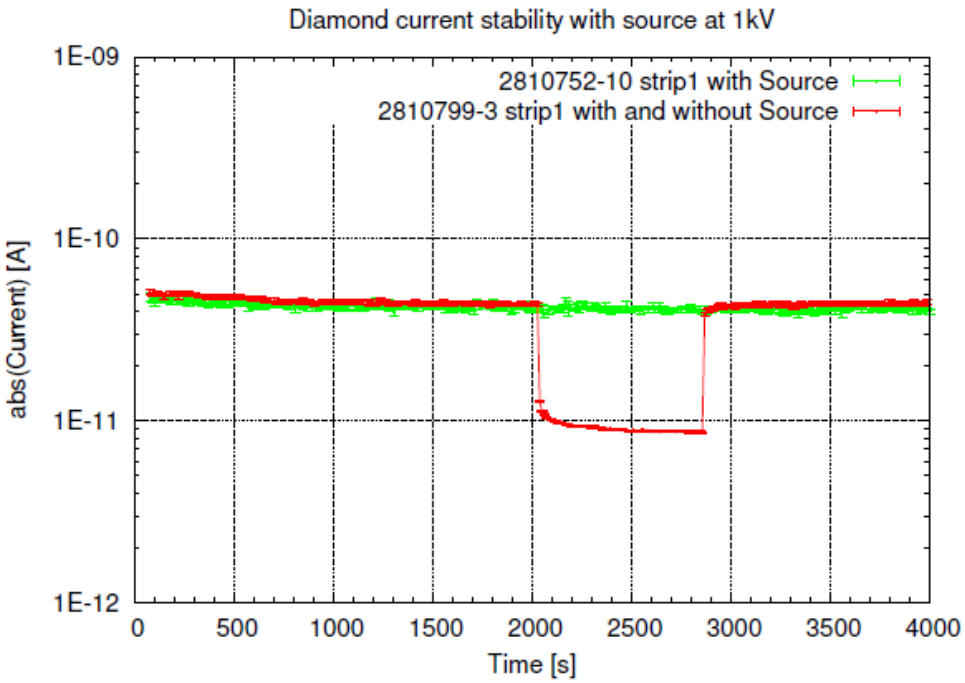
- Presence of air and water vapor increase surface conduction, so in vacuum their performance can be more better!
- Vacuum chamber for tests is under desgin

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

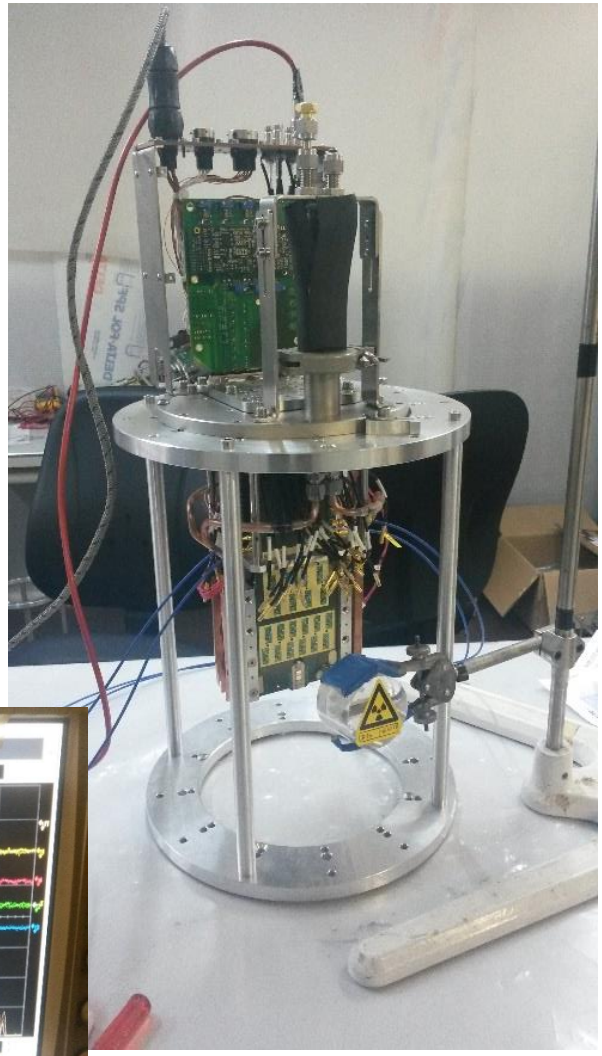


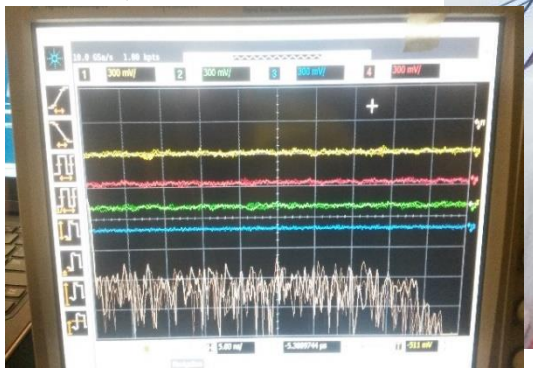




Detector performance

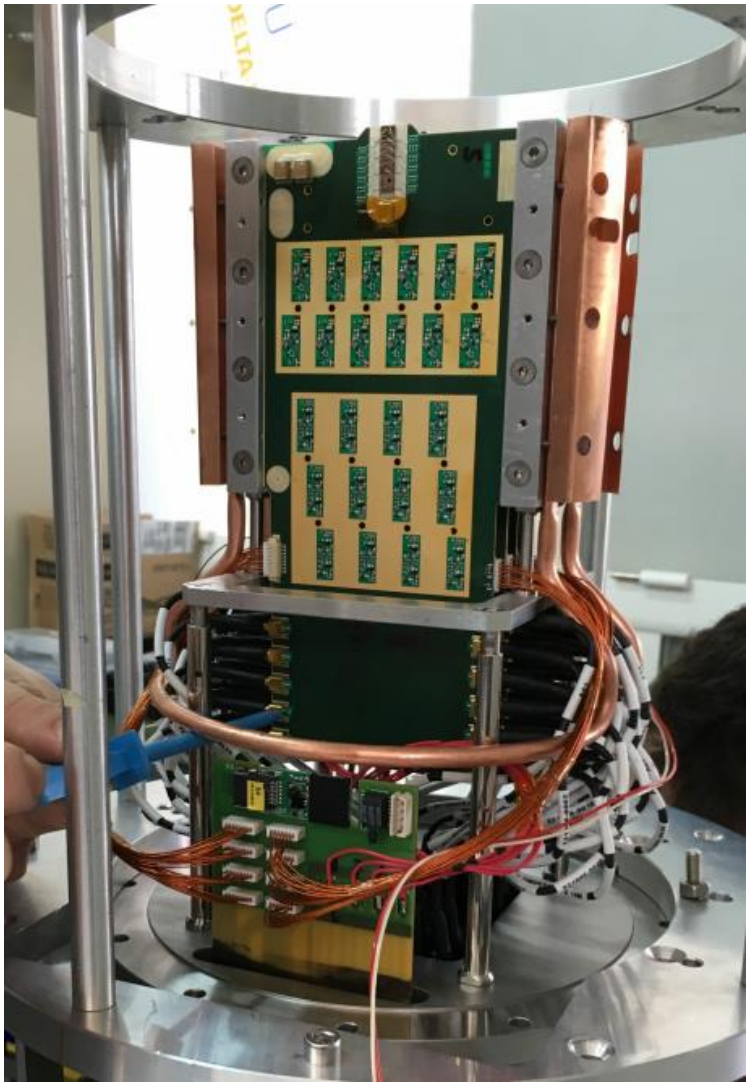
- Minor modifications on the electronics were necessary to adapt the board to the new pattern and to make it HV safe
- Each board has been tested separately in vacuum to assure that the coating procedure was done correctly
- Each channel has been tested with a β source
- Some noise was picked up when 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 RP with horizontal detector packages have been successfully installed at LHC during TS1 (June 2016)

Read-out of the new Horizontal packages

- The readout 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 will be finished nowadays.

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 package tested in the operational T and p 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!