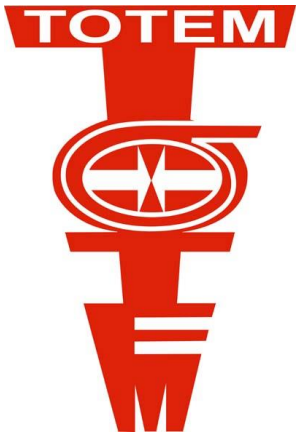
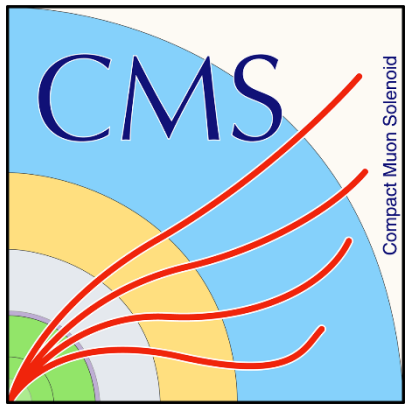




Diamond Timing Detectors in TOTEM and CT-PPS at the LHC

Tiina Naaranoja,

Helsinki Institute of Physics

on behalf of the CMS and TOTEM collaborations

6th ADAMAS workshop, Zagreb, Croatia, 27.-28. November 2017

Introduction

The Compact Muon Solenoid (CMS) is a general purpose LHC experiment

TOTEM is a smaller special purpose LHC experiment

- Specializes in very forward region
- Shares interaction point with CMS

The CMS-TOTEM Precision Proton Spectrometer (CT-PPS)

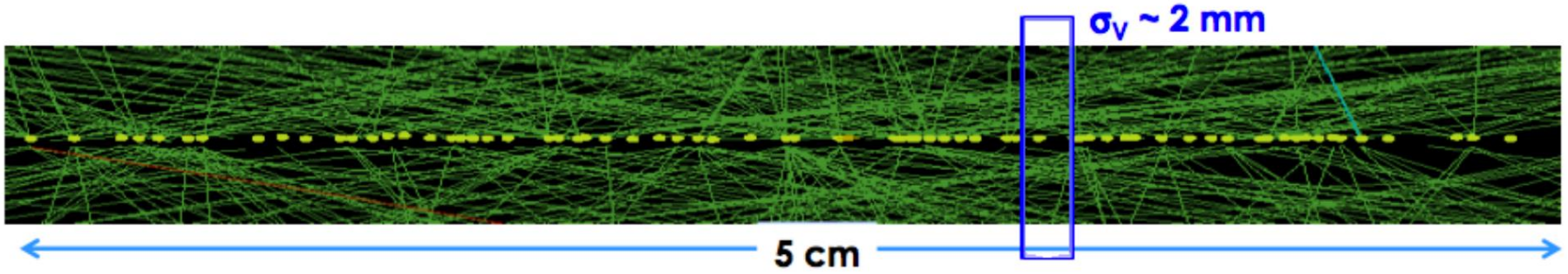
Two upgrade projects with timing detectors

- Many similarities (Motivation, technology, people)
- Some differences (Acceptance, requirements, beam optics)

The basic R&D for TOTEM upgrade

Focus will be on the CT-PPS

Timing measurement



Vertex measurement by timing: σ_t=10ps ⟶ σ_v=2mm

Needed time resolution depends on magnitude of **pile-up,**

Depending on beam optics needed resolution ranging from 10ps to 50ps

Note: Requirements for time precision are for detector package. Diamond timing detector package consists of 4 planes. This gives requirement of 40 ps per plane.

A Brief History of the TOTEM and CT-PPS Diamond Timing Detectors

2013 Proposal for TOTEM timing detectors

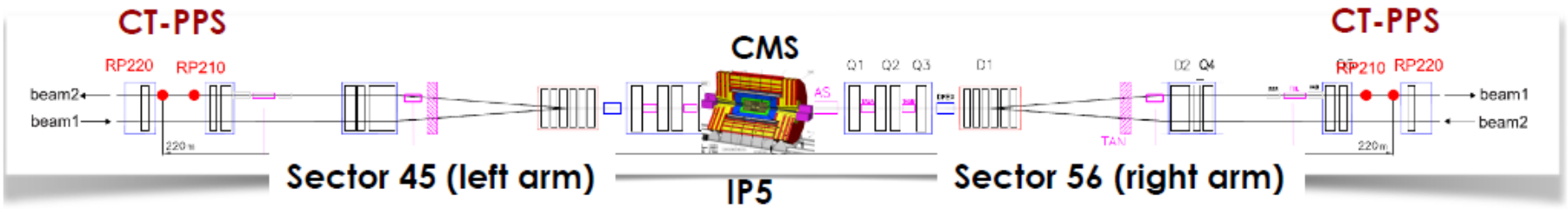
2014 Technical Design Reports for CMS-TOTEM Precision Proton Spectrometer (CT-PPS) and TOTEM timing upgrade

2015 Installation of first diamond package in TOTEM timing detectors (already removed)

2016 Installation of diamonds in CT-PPS timing stations, operated as tracking device for comissioning

2017 One plane out of four diamond planes replaced with Ultra-Fast Silicon Detectors, both operated as timing detectors

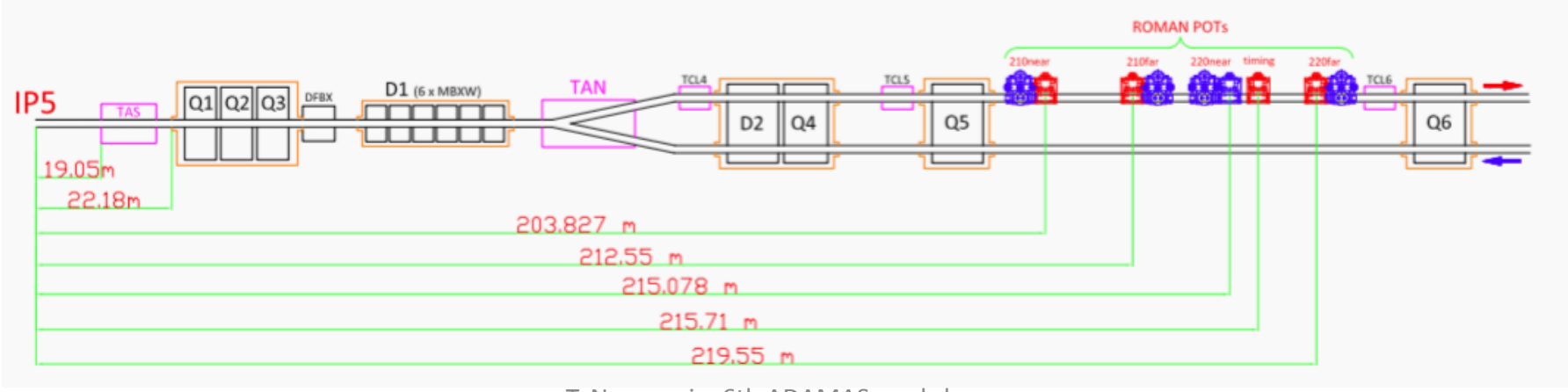
CT-PPS apparatus



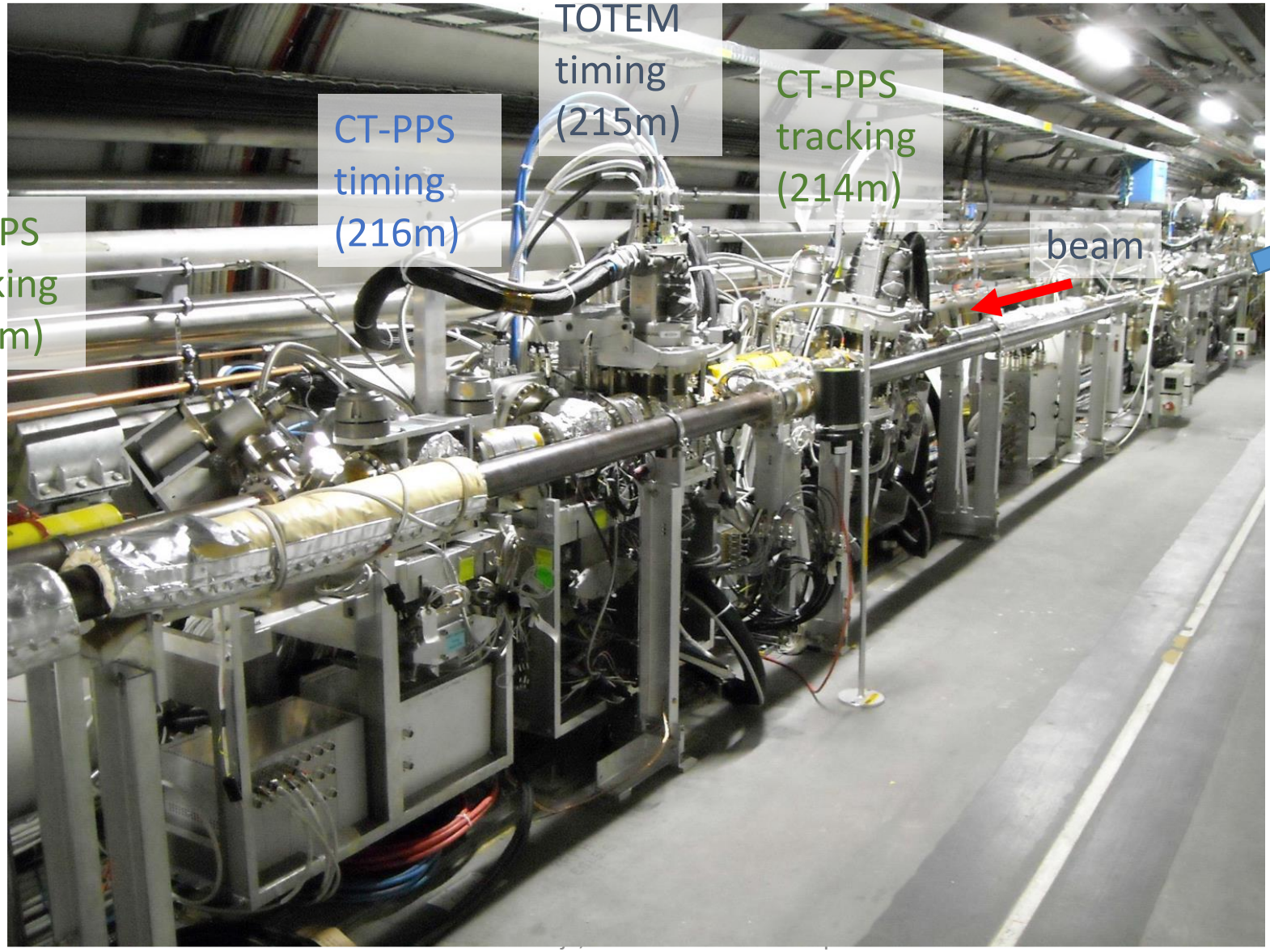
In each arm:

2 stations of tracking detectors: Precise measurement of proton trajectory

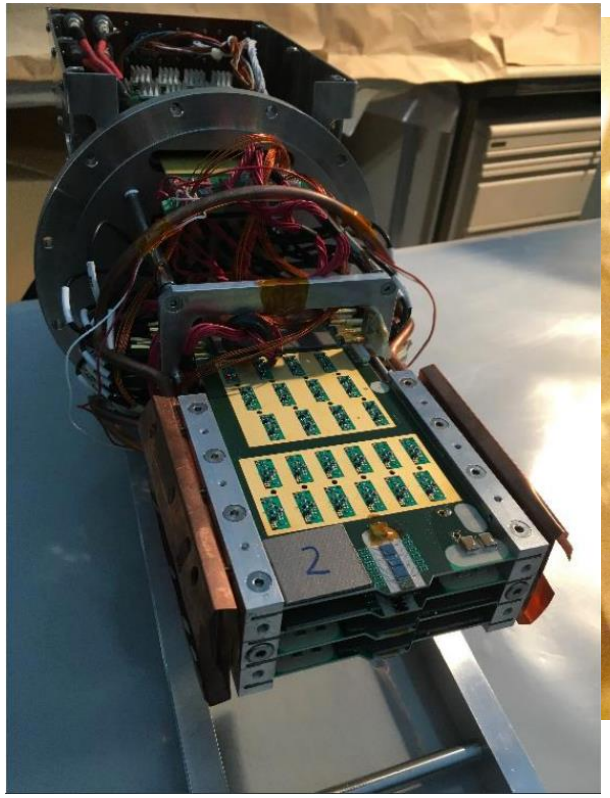
2 timing stations: Time-of-Flight of proton

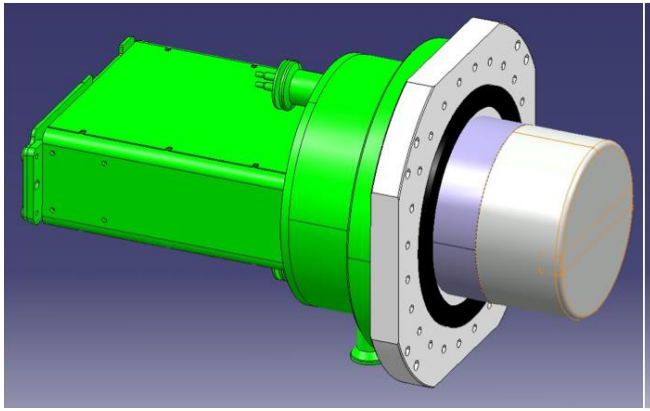


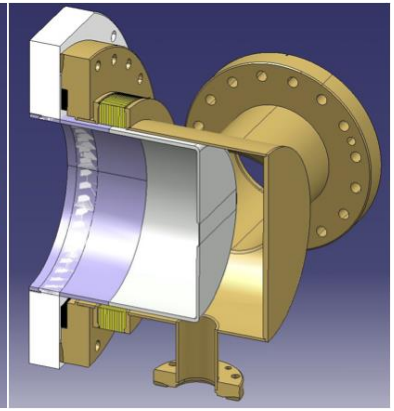
CT-PPS apparatus



Roman pots (RP)



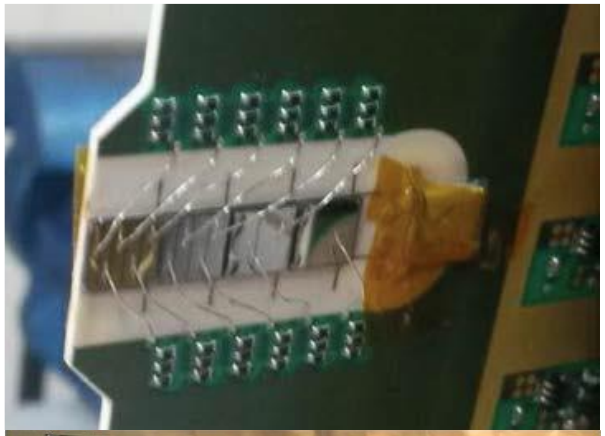


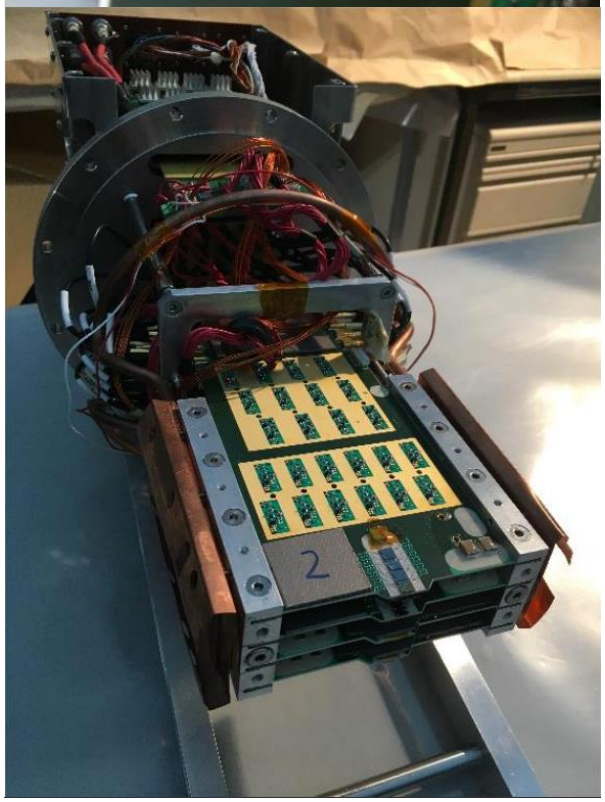


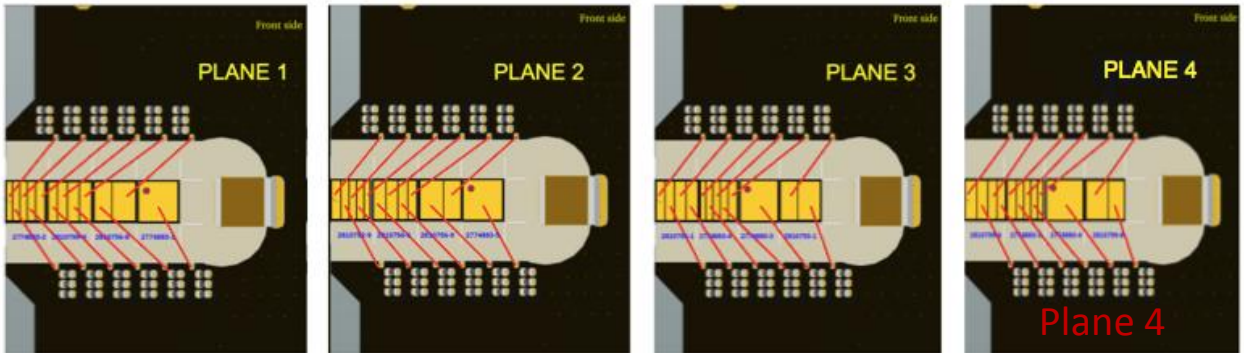
Vacuum vessel, separated from vacuum in beam pipe by thin window

Detectors ~2mm from beam

The diamond sensors in CT-PPS







Plane 4 Replaced with UFSD in 2017

4 planes of 4 scCVD diamond sensors

- Detector grade scCVD from e6
- TiW-metallization by Princeton
- Cr/Au-metallization by Applied Diamond, Inc

Optimization of pixel arrangement gives ~150 µm spatial resolution

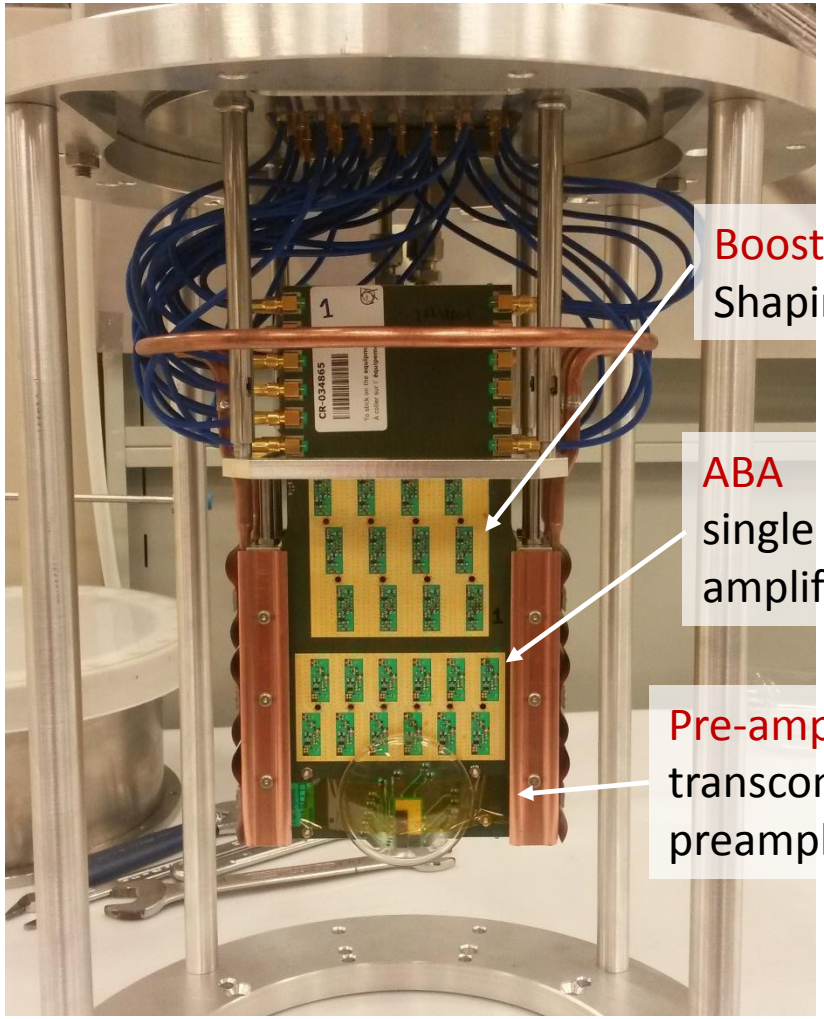
Electronics

Front-end: TOTEM hybrid board[1]

Readout: Digitized with NINO[2] + HPTDC[3]

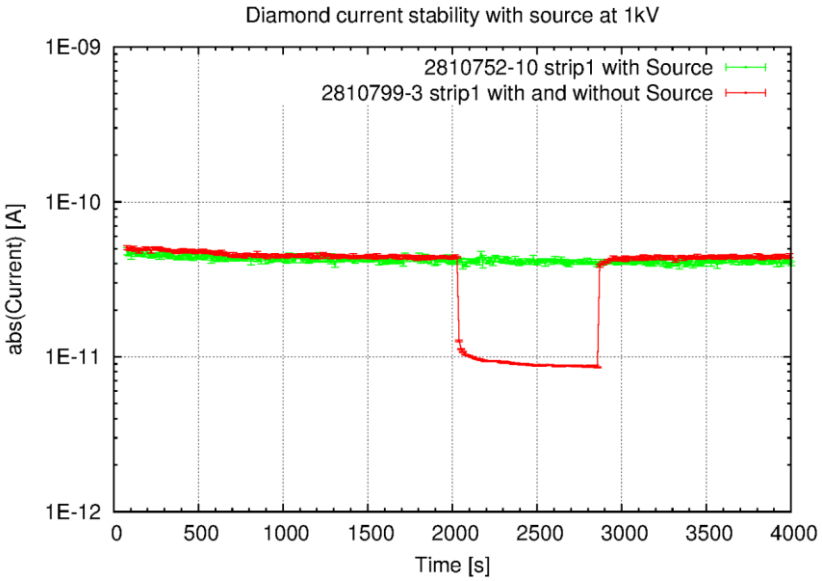
[1] TOTEM Coll., JINST 12 (2017) P03007
[2] F. Anghinolfi et al., NIM A 533 (204) 183
[3] M. Mota and J. Christiansen, IEEE JSSC 34 (1999) 1360

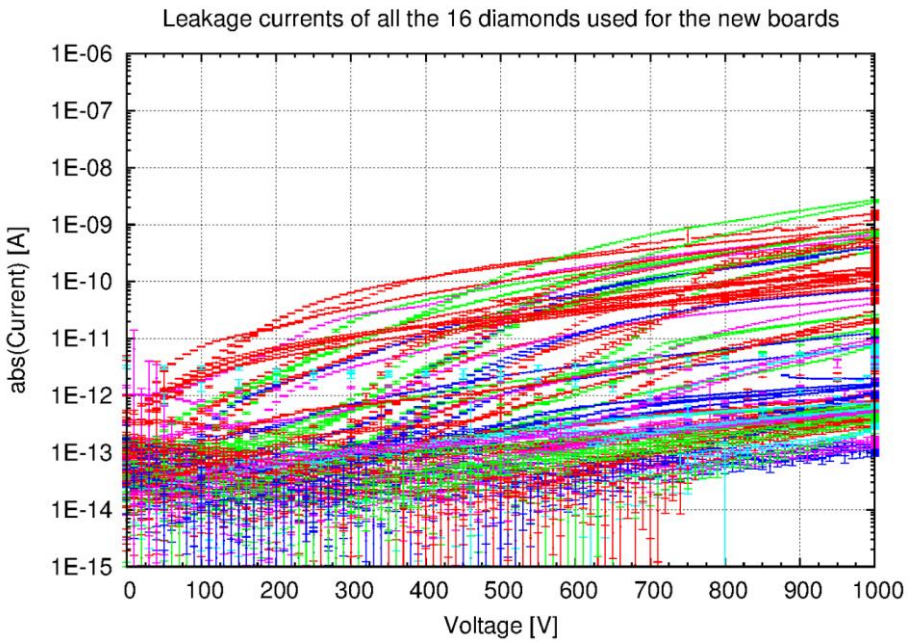
Electronics: The TOTEM hybrid board



3-stage amplification chain designed by TOTEM for the needs of diamond sensors operated in roman pots (adapted from HADES Collaboration amplifier)
Risetime ~1.7ns

Sensor Characterization





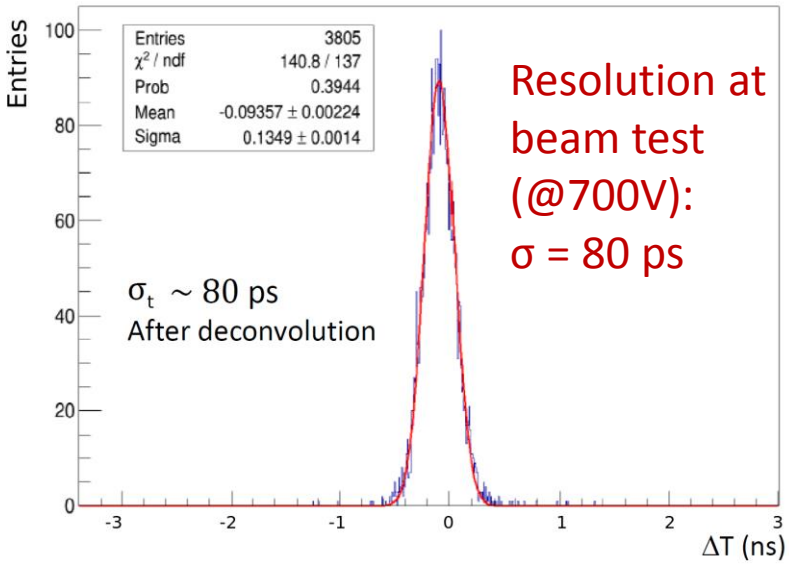
Requirements

Microscope examination

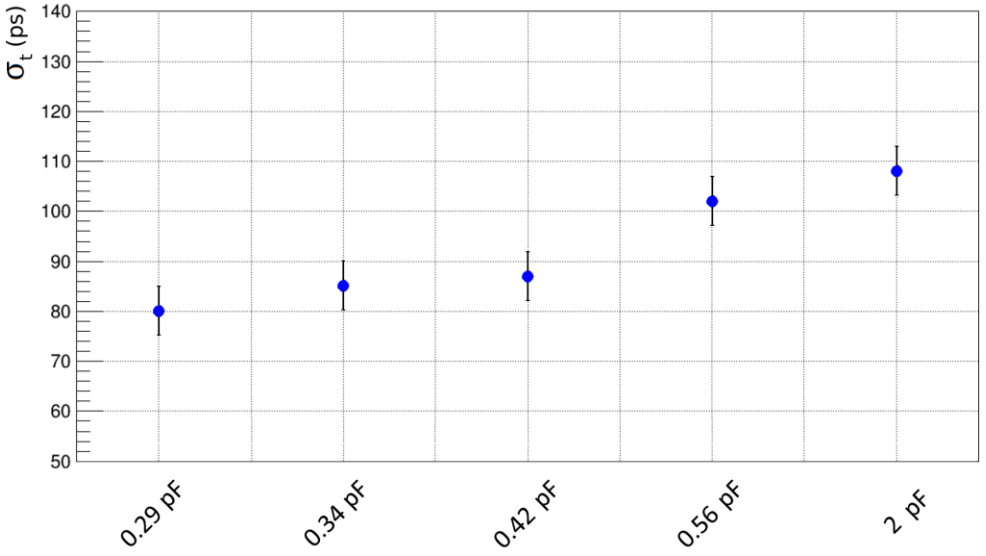
Leakage current below 10nA

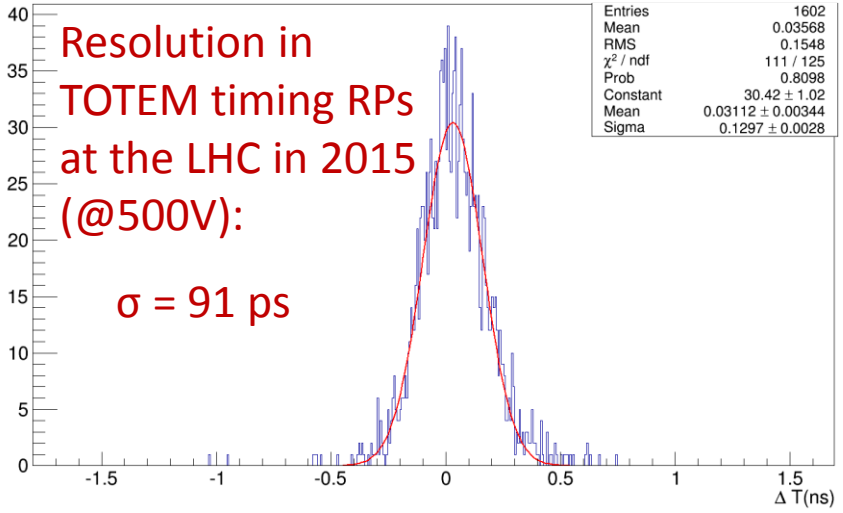
Stable signal (40MBq ^{90}Sr source)and dark current over time

Timing performance in Beam tests and at the LHC



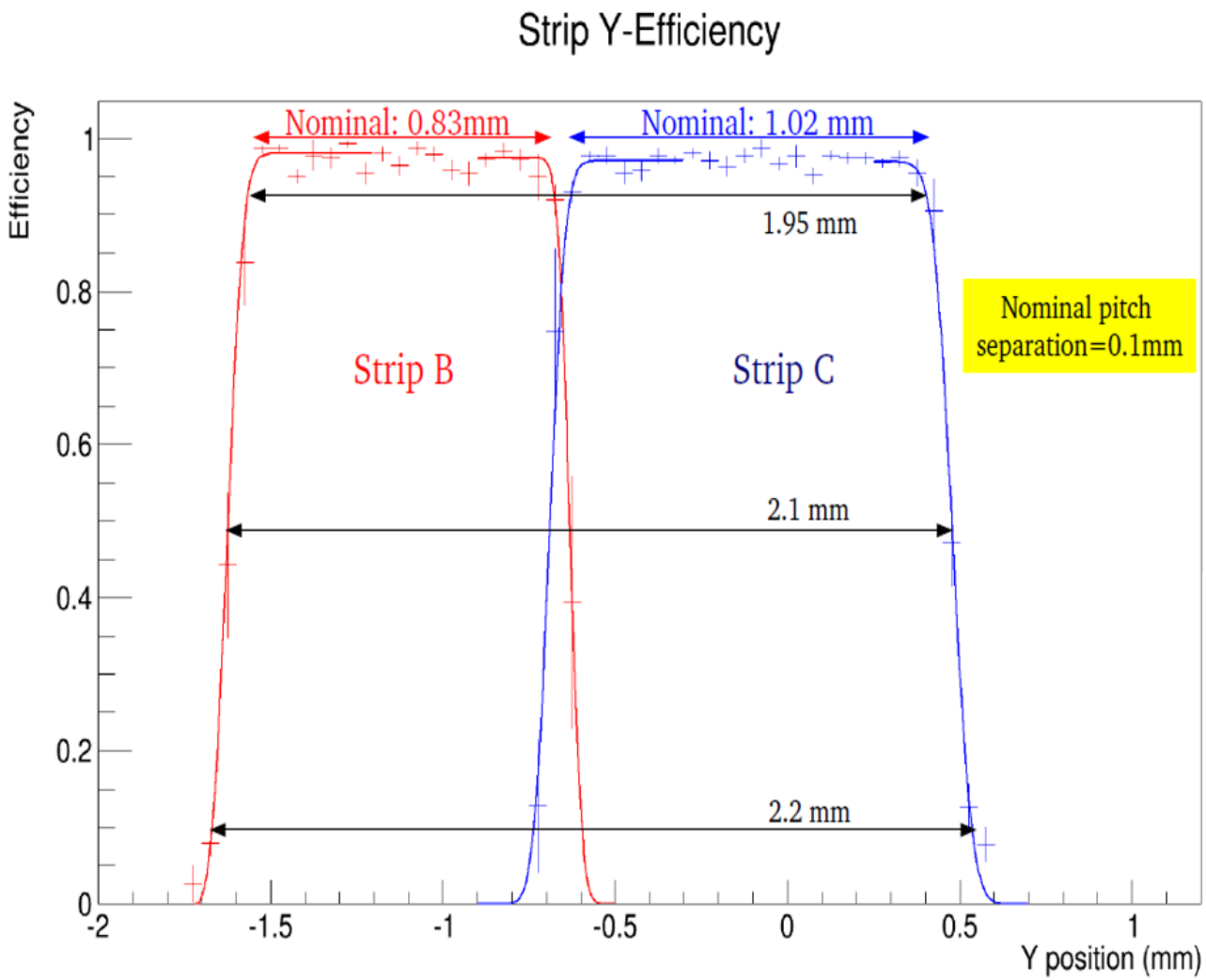
[TOTEM collaboration, 2017 JINST 12 P03007]





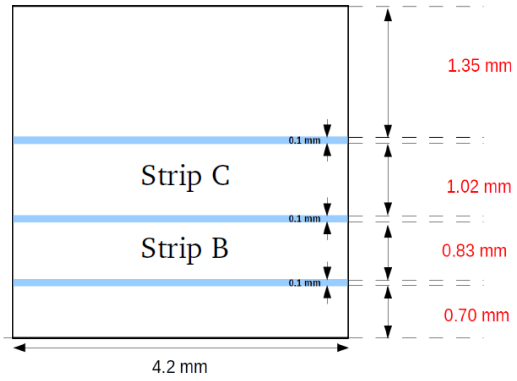
- Weak dependence on capacitance
- Optimal HV=700V at beam test
  - ➢ 80 ps resolution
- Resolution of 90ps confirmed at the LHC in 2015 (note: current operation in CT-PPS is much improved)

Detection efficiency



>98% on strip

>80% between strips



Operation in the LHC

Adaptations to operating HV in vacuum

- Operation in reduced pressure (30 mbar) requires potting (Silicone coating compound) to prefent discharge
- Re-design PCB: smaller HV-pads, proofing HV-vias

Improvement of charge collection

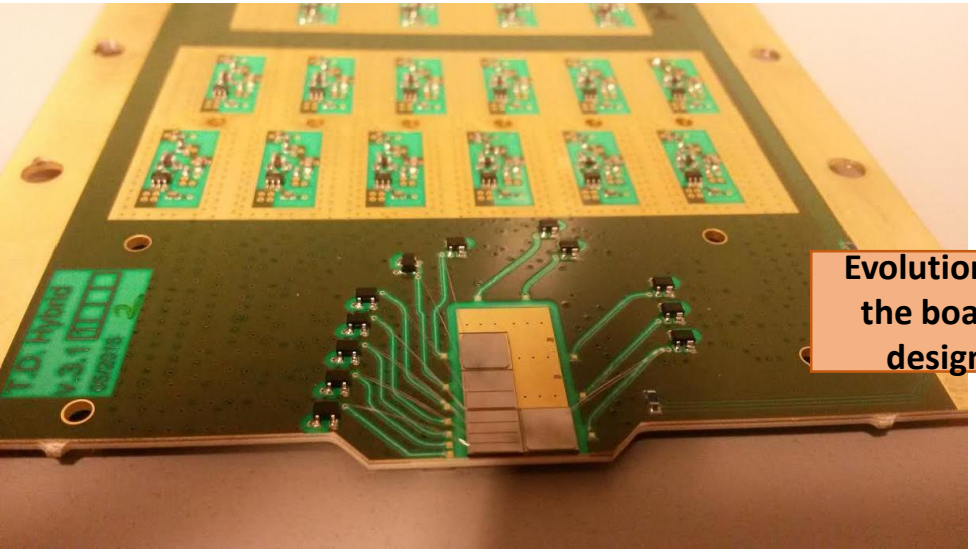
- Pre-amplifiers as close to sensor as possible
- 150 µm wire bonding

Proximity of boards leads to feedback between them

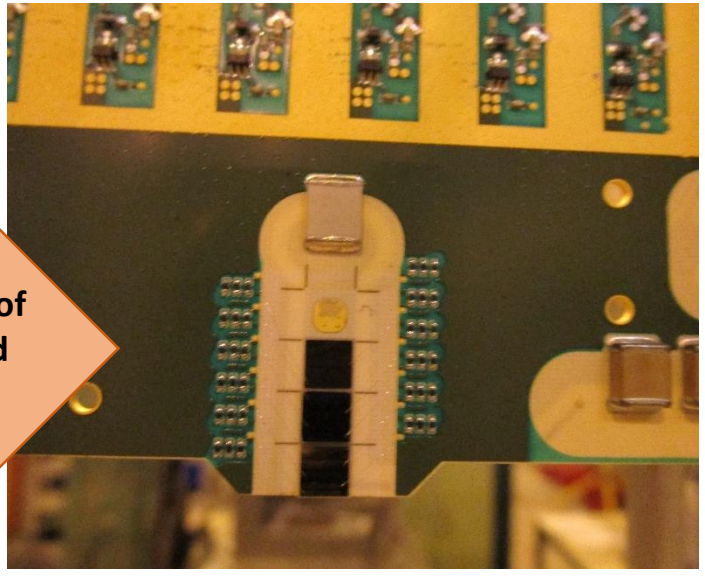
- EMI shielding

Since diamonds installed in CT-PPS 2016

- 2.5 fb^{-1} taken as tracking device in 2016
- ~40 fb^{-1} as timing detector in 2017

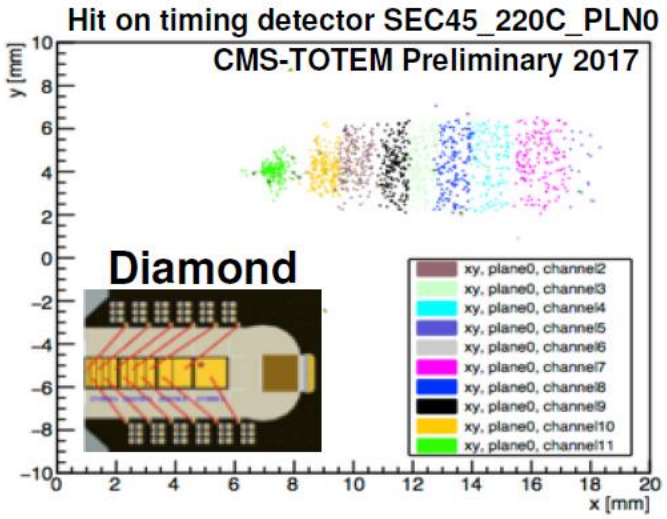


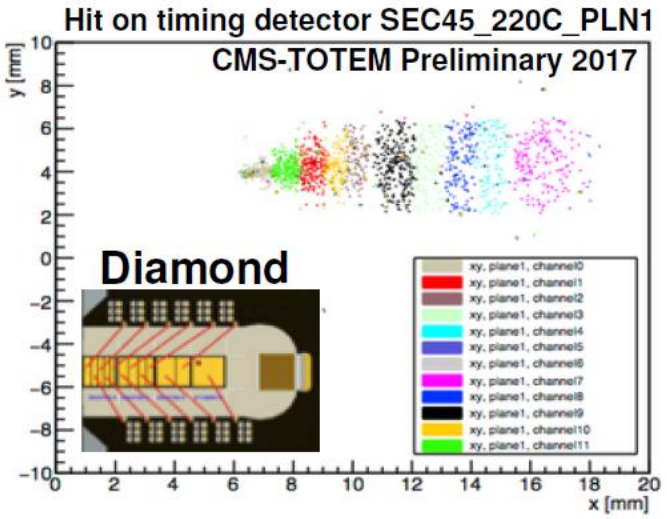
Evolution of the board design

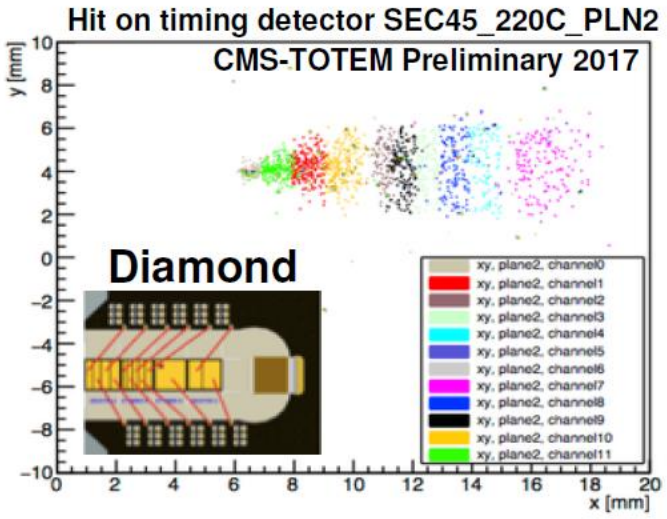


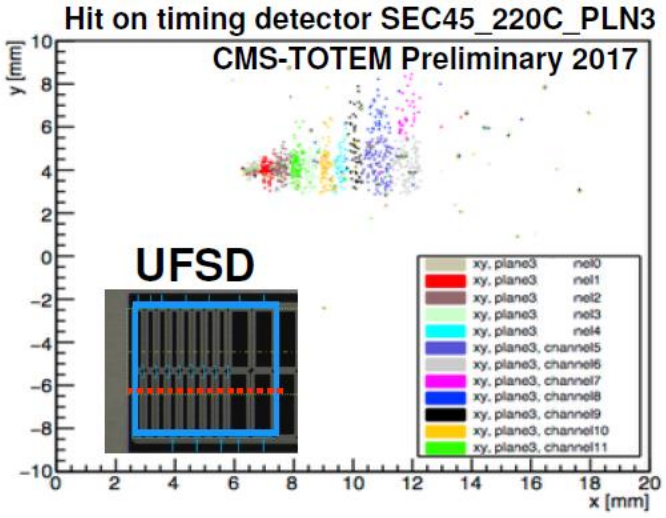
Current Operation in CT-PPS

Commissioning in final phase. Below position measurement in tracking RPs, when hit present in timing detectors. Clear correlation to timing detector geometry.





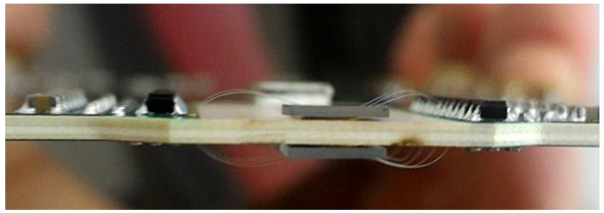


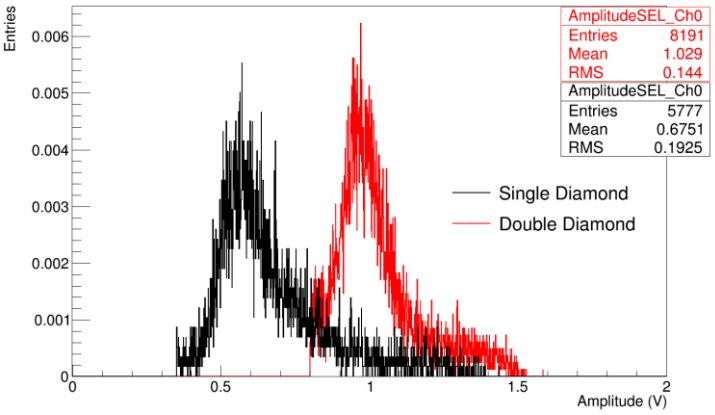


Next steps: Double diamond

Project to improve the time resolution

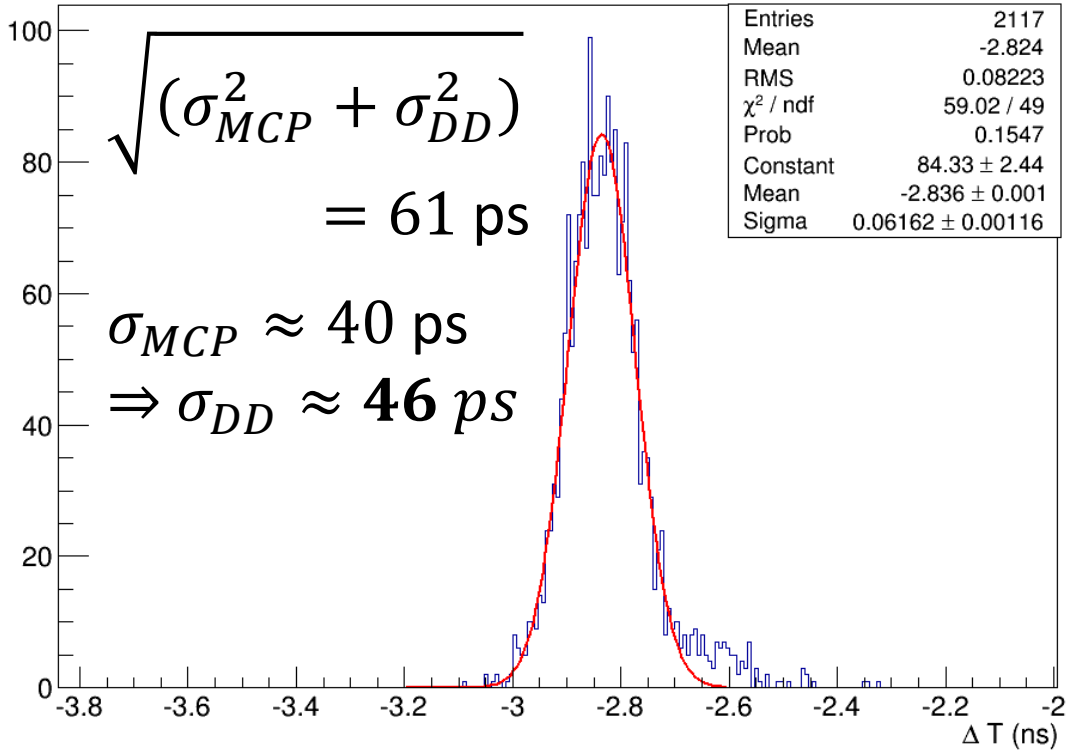
Time precision of plane below 50 ps in beam test





Signal amplitude distribution

Time difference distribution between double diamond detector and MCP



$$\sqrt{(\sigma_{MCP}^2 + \sigma_{DD}^2)} = 61 \text{ ps}$$

$$\sigma_{MCP} \approx 40 \text{ ps}$$

$$\Rightarrow \sigma_{DD} \approx \mathbf{46}\ ps$$

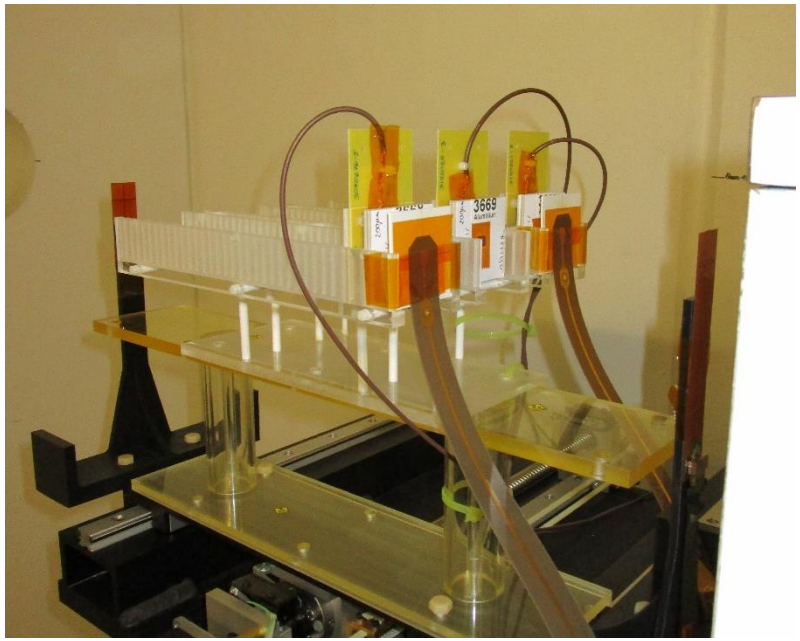
2017 JINST 12 P03026

Next steps: Radiation hardness

No problems observed so far and are not expected during the detector lifetime

To confirm the radiation hardness, diamonds have been irradiated at CERN IRRAD both with front end electronics and without

Resolve contributions to radiation hardness from different sources



24 GeV protons

Fluences ~10^{14} protons/cm^2

~$5*10^{15}$ protons/cm^2

Summary

Diamond detectors have been developed for timing measurements

Time resolution of 50 ps or below for each detector package has been achieved

Diamonds are installed and taking data in CT-PPS

Double diamond project to enhance time resolution

Thank you for your attention!

References

TDR for CT-PPS:

LHCC-2014-021; TOTEM-TDR-003; CMS-TDR-13, https://cds.cern.ch/record/1753795

TDR for TOTEM timing upgrade:

CERN-LHCC-2014-020 ; TOTEM-TDR-002, https://cds.cern.ch/record/1753189

Addendum: https://cds.cern.ch/record/1968585

Diamond detectors for the TOTEM timing upgrade:

2017 JINST 12 P03007, https://doi.org/10.1088/1748-0221/12/03/P03007

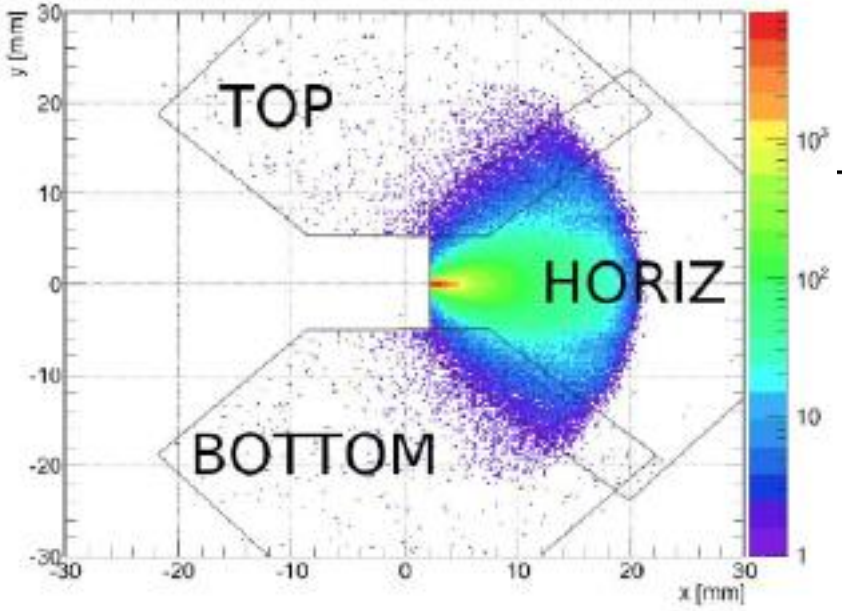
Double diamonds :

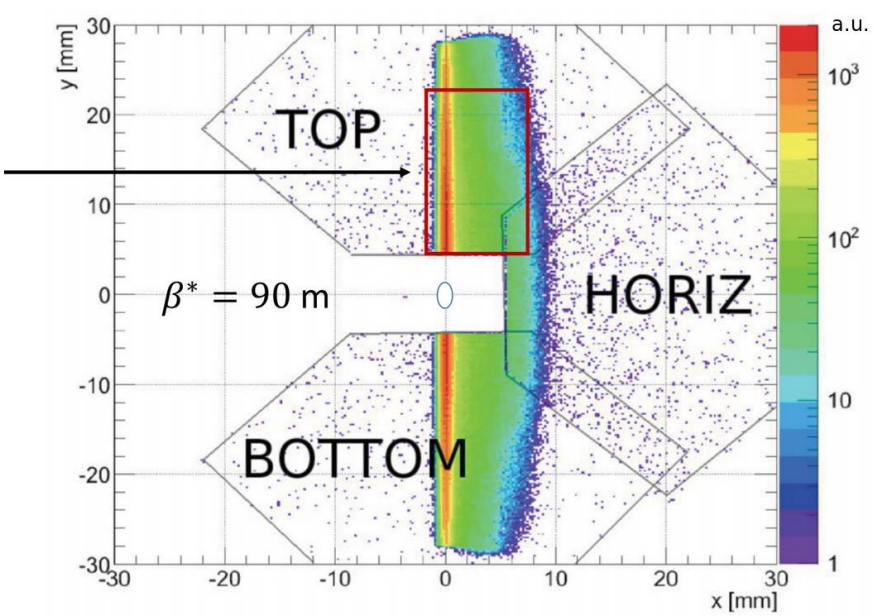
2017 JINST 12 P03026, https://doi.org/10.1088/1748-0221/12/03/P03026

Back up

Hit density in different Roman Pots depends on beam optics

Below simulated hit-maps for TOTEM strip detectors





High luminosity run

- standard run
- High pile-up
- High level fluences

CT-PPS timing acceptance

β*=90 run

- special run
- Low pile-up
- Moderate level fluences

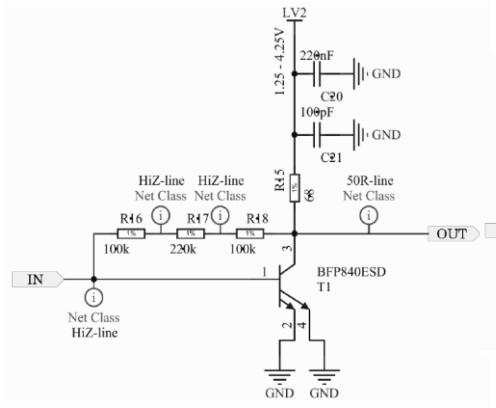
TOTEM timing acceptance

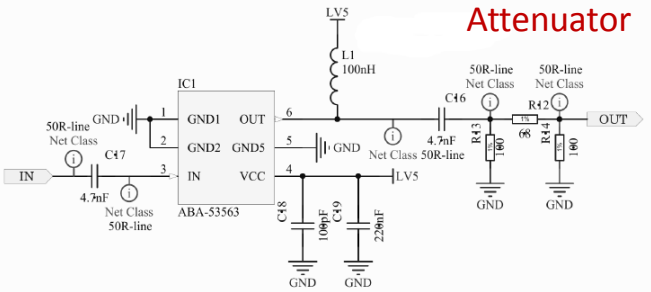
Electronics: The TOTEM hybrid board

Pre-amp
transconductance preamplifier

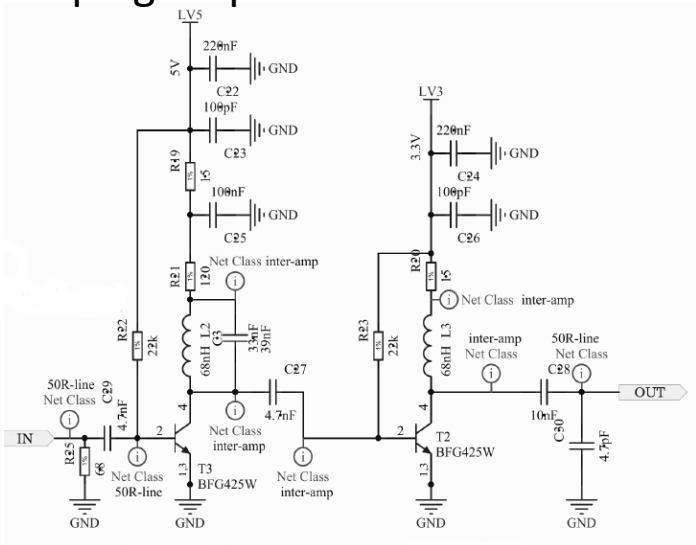
ABA
single stage voltage amplifier

Booster
Shaping amplifier





Attenuator



3-stage amplification chain designed by TOTEM for the needs of diamond sensors operated in roman pots (adapted from HADES Collaboration amplifier)
Risetime ~1.7ns