Status of CMS-PPS timing detectors

PPS spectrometer

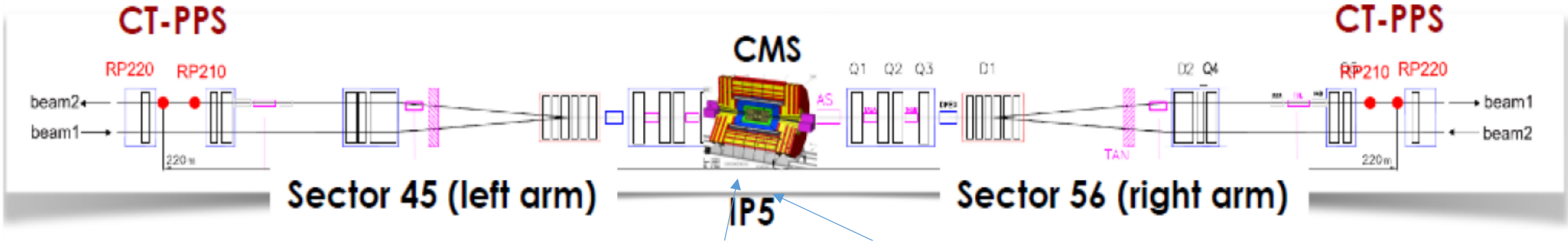
Pixel detectors

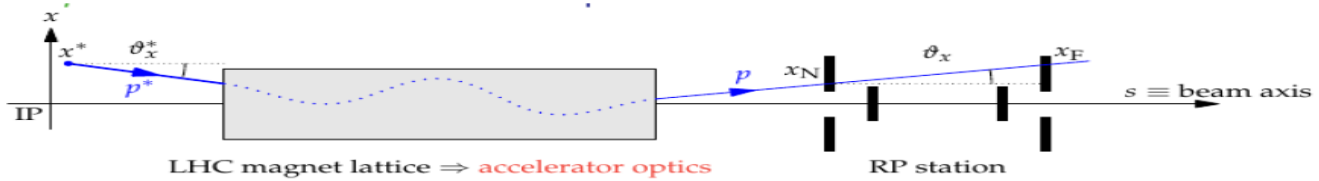
Timing detectors

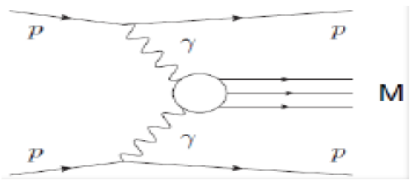
Summary and conclusions

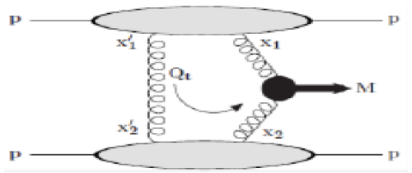
CMS-TOTEM Precision Proton Spectrometer [1],[2]

- The **CMS-TOTEM Precision Proton Spectrometer** (CT-PPS) allows the measurement of **protons in the very forward regions** on both sides of CMS in **standard LHC running conditions**, taking advantage of the machine magnets to bend the protons.
- **Tracking and timing detectors** are installed in Roman pots between 205 and 220 m from the CMS/TOTEM IP.





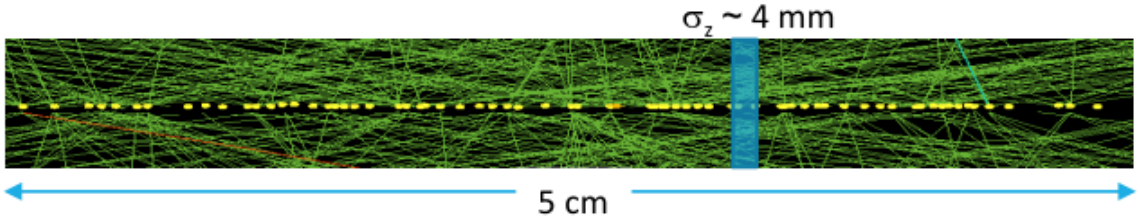




Timing detector

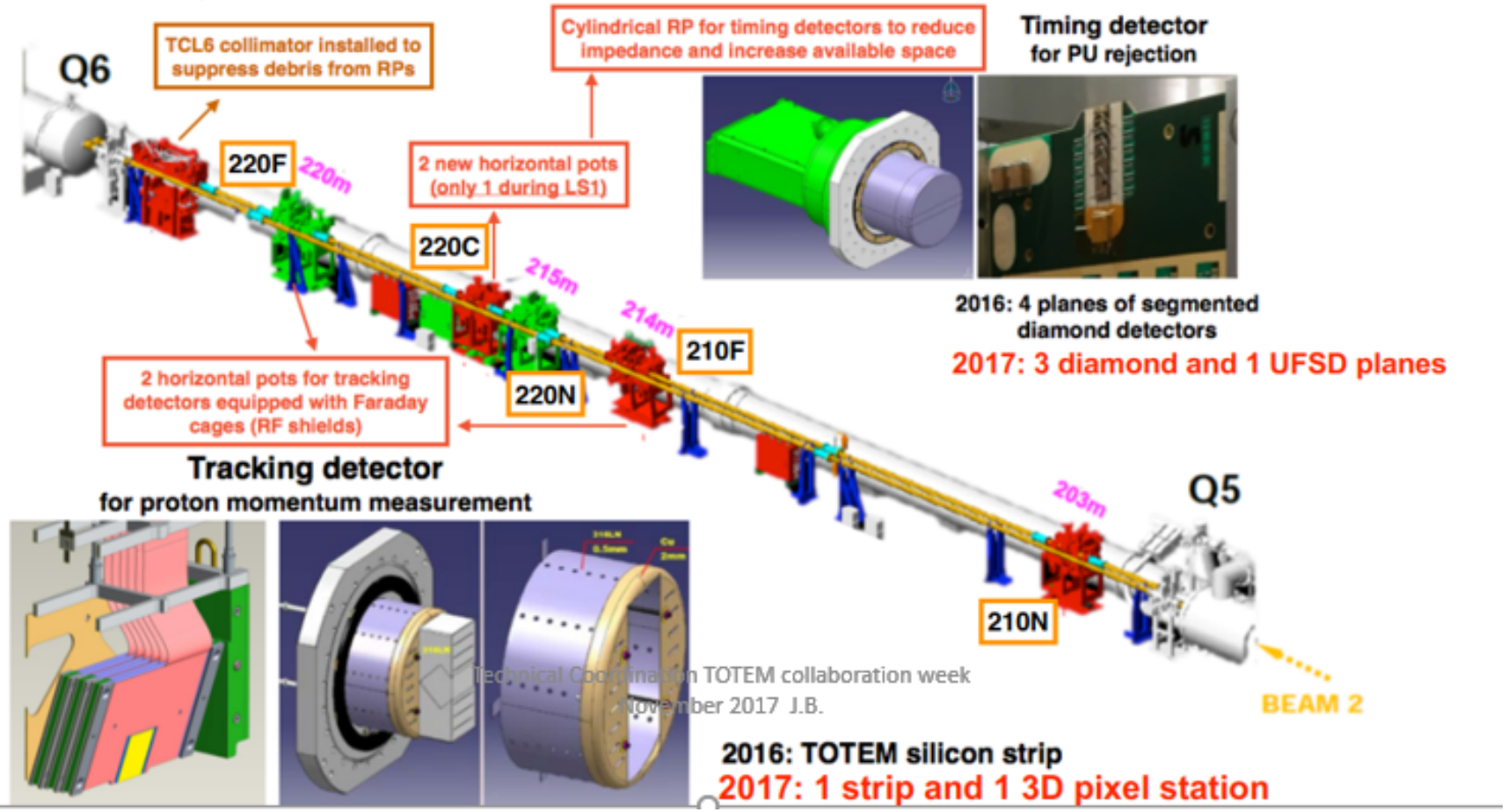
➢ Aim: disentangle primary vertex from pileup

$\sigma_{time} \sim 20$ ps $\rightarrow \sigma_Z \sim 4$ mm



Tracking detector:
proton dp/p &
pointer to timing detector

CMS PPS spectrometer



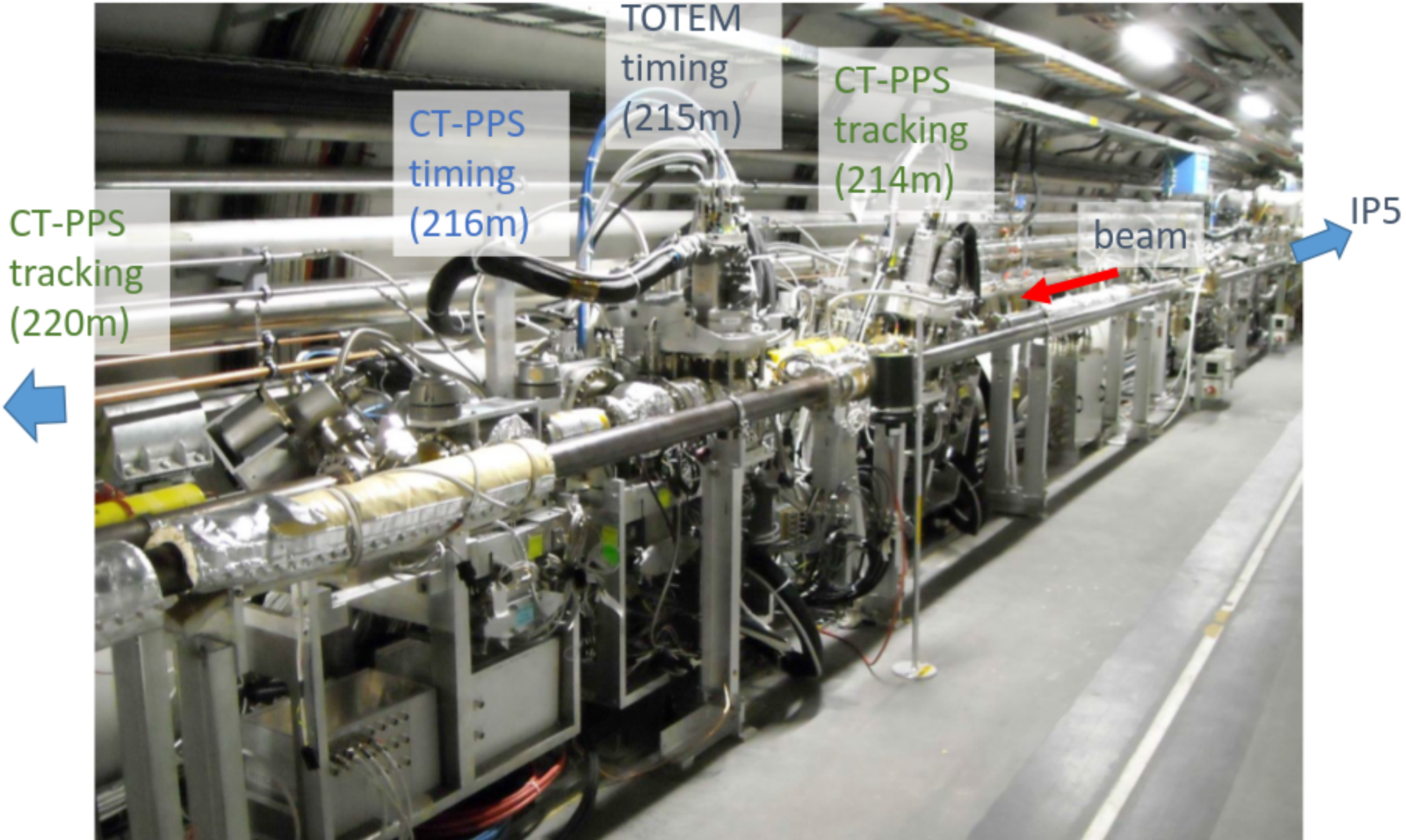
Technical Coordination TOTEM collaboration week
November 2017 J.B.

2017:
1 3D pixel station
1 Si strip station
3 Diamond planes
1 UFSD plane

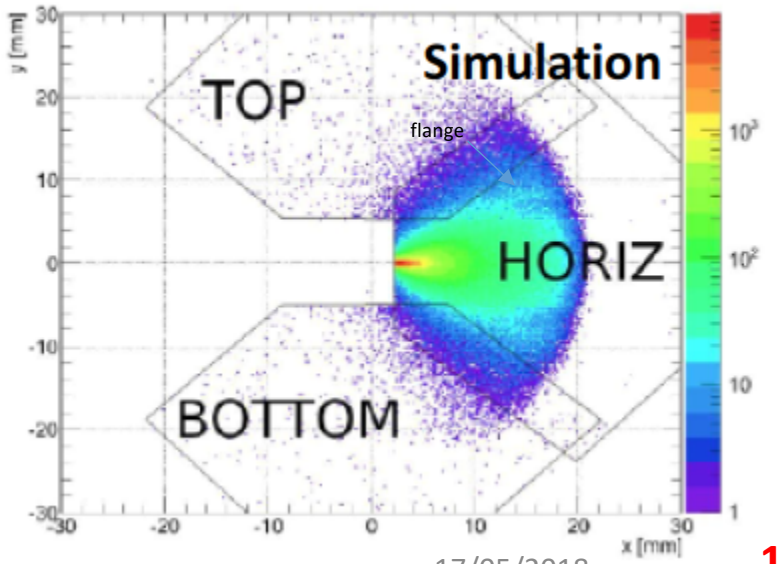
2018:
2 3D pixel stations
4 Diamond planes (2 double)

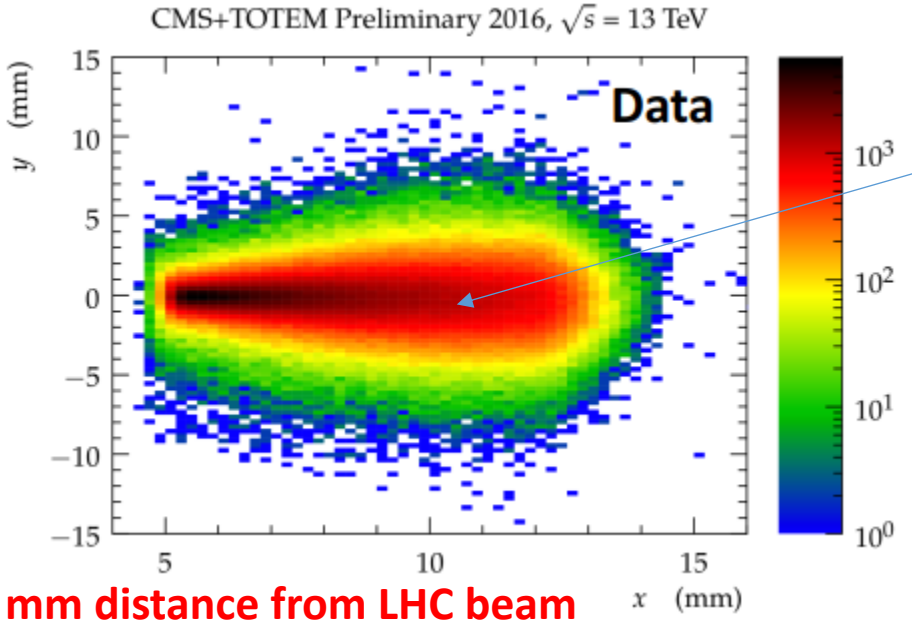
26 Roman Pots installed in LHC tunnel at ip5
PPS (standard optics) & TOTEM (special optics)

View in LHC tunnel



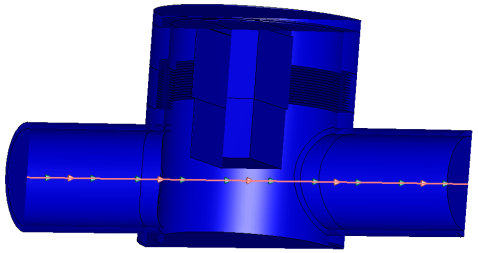
PPS -> Extreme conditions to operate detectors close to the beam of LHC

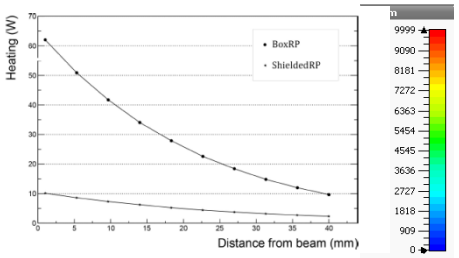




Significant irradiation gradient
~ $5*10^{15}$ p/cm^2 for 100 fb^{-1}

1.5 mm distance from LHC beam in 2017





Beam optics defines the irradiation profile
RP Impedance -> LHC acts as heater
Secondary particles by RP material interaction

LHC and CT-PPS operation during 2017

CT-PPS horizontal RPs were inserted on a regular base:
RP210 far – RP cylindrical – RP220 far
-> closest distance to LHC beam ~ 1.5 mm

During all insertion (2017) 1 single beam dump was initiated by RP movement/interlock system before TS1

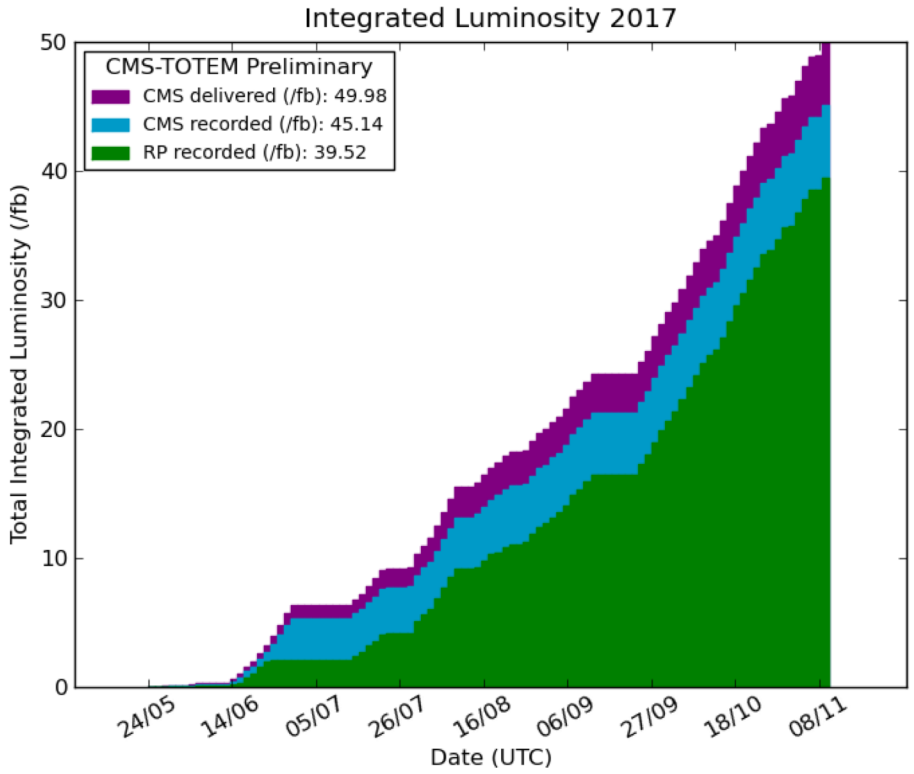
2017 ATS v. 22_ctpps2 (30 cm) and TCT = 8.5 σ: Optics and Acceptance Parameters

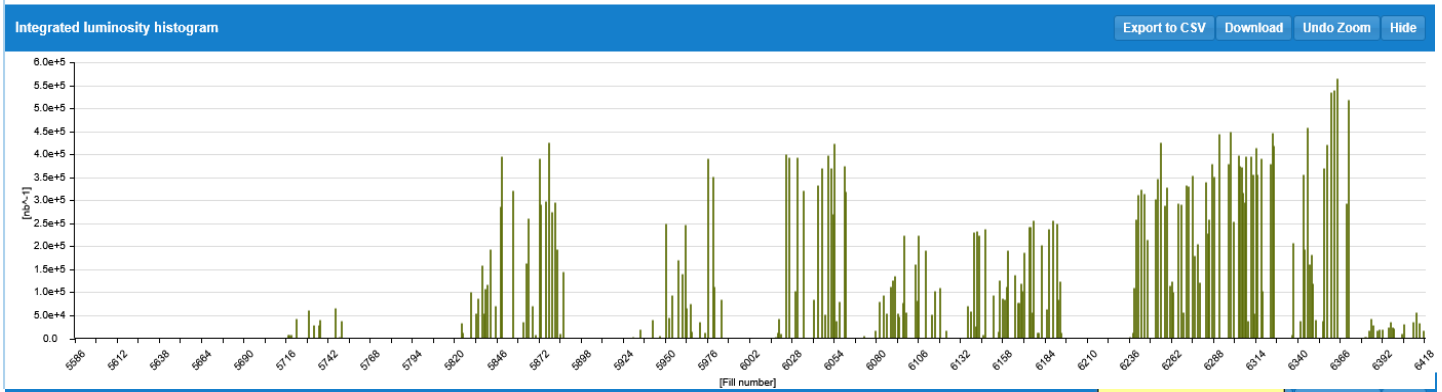
$\sqrt{s}$ = 13 TeV, β^* = 0.3 m, $\alpha_x / 2$ = 175 μrad, ε_n = 3.5 μm rad
XRPs @ TCT + 3 σ + 0.3 mm = 11.5 σ + 0.3 mm

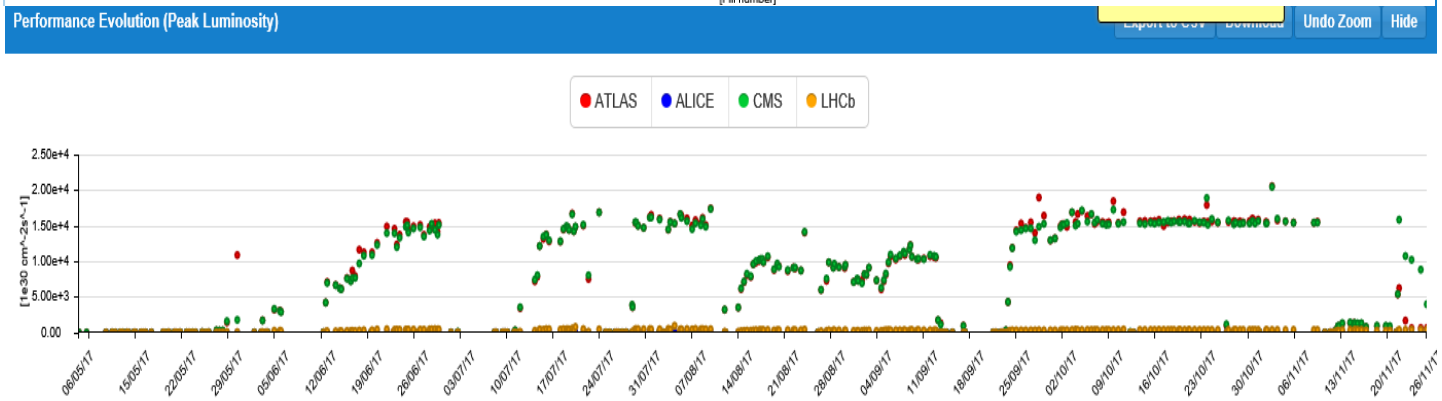
Sector 5-6 (Beam 1):

Horiz. RP	$\sigma_{x,beam}$	XRP pos. max(11.5 σ + 0.3 mm, 1.5 mm)	Det. pos. = XRP pos. + window + gap (+ 0.3 or 0.5 mm)	D_x	ξ_{min}	$\xi_{min}\sqrt{s}$
210-N	0.241 mm	3.072 mm = 12.7 σ	3.372 mm	−70.1 mm	0.0481	625 GeV
210-F	0.160 mm	2.140 mm = 13.4 σ	2.440 mm	−68.8 mm	0.0355	461 GeV
220-C	0.132 mm	1.818 mm = 13.8 σ	2.318 mm	−68.4 mm	0.0339	441 GeV
220-F	0.099 mm	1.500 mm = 15.2 σ	1.800 mm	−67.8 mm	0.0265	345 GeV
TCL4	0.748 mm	–	–	−62.0 mm	$\xi_{max} = 0.181$	$\xi_{max}\sqrt{s}$ = 2353 GeV

tracking
timing
tracking





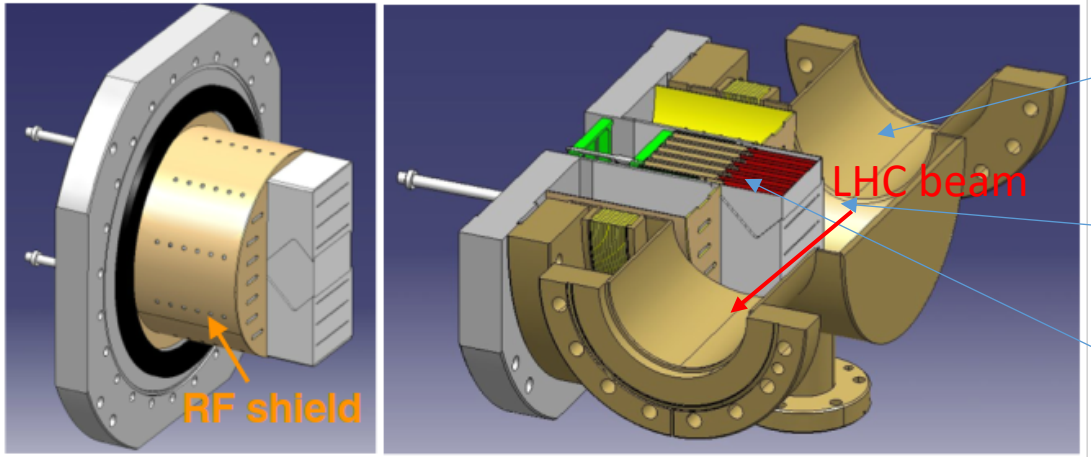


Precision Proton measurement at LHC forward physics -> main components:

- Tracking detector 4 planes (housed in Tracking RP close to LHC beam)
  -> proton trajectory -> pointer to timing detector & dp/p of proton
  -> small pixel size (~ 0.015 mm^2) track resolution < 30 um
- Timing detector (housed in Timing RP close to LHC beam)
  -> proton time of arrival with 4 detector planes
  -> bigger pixel size several mm^2 optimized for occupancy + time resolution per plane ~ 90 ps (test beam)
- Timing electronics for PPS ->NINO [6]+HPTDC[7] (in LHC tunnel close to RPs)
- Clock -> synchronization of timing electronics installed at each side of CMS - two arms ~ 500 m distance (USC55 and LHC tunnel)
  -> jitter < 2ps

RP for tracking stations

RP pixel detector integrated in RP box type [2]



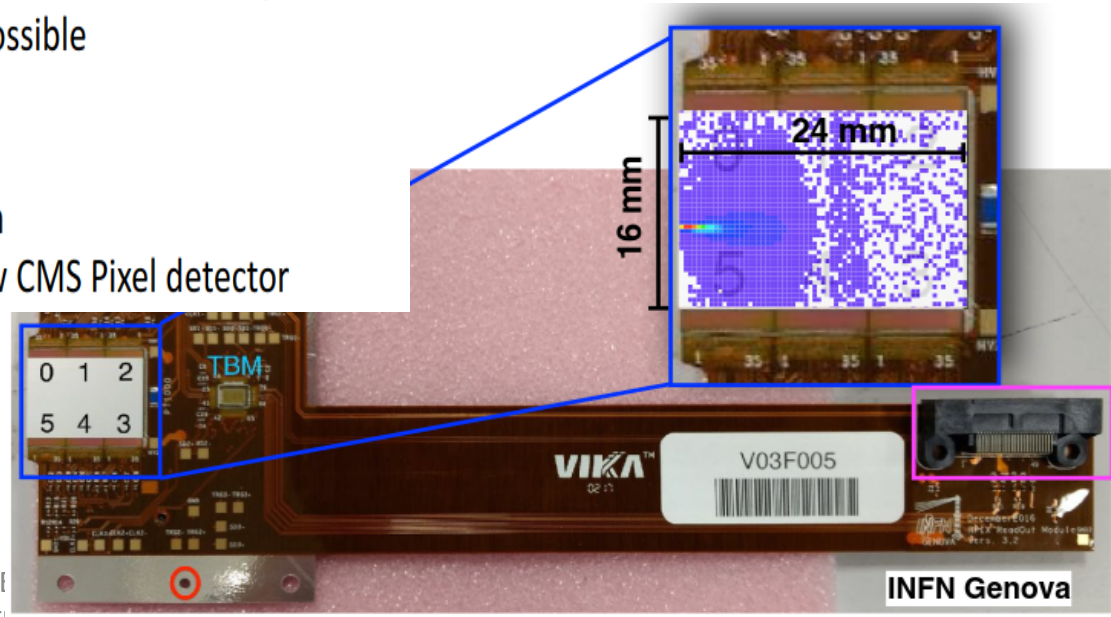
LHC vacuum

thin window (~ 150 um) to separate detectors from LHC vacuum

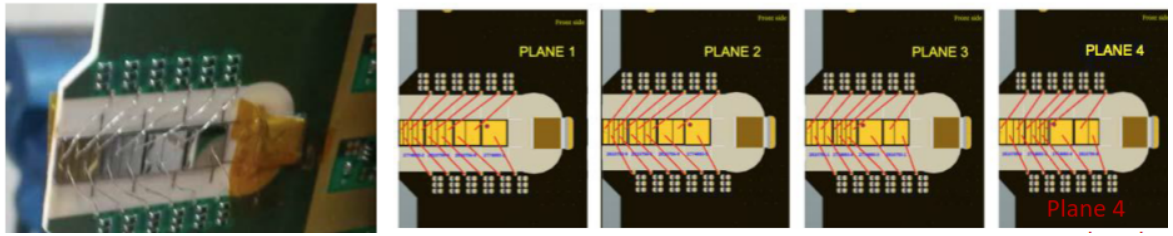
Detector package operated at 10 mbar(a), -20 C^0

3D sensor technology

- Intrinsic radiation hardness → to withstand overall integrated flux of $5x10^{15}$ p/cm^2
- 200 µm slim edge → to approach the beam as much as possible
- Pixel dimensions: 100x150 µm^2 → very high granularity
- Resolution < 30 µm
- Planes tilted by 18.4^o to optimize efficiency and resolution
- Front-end chip: latest version of PSI46dig, same as for new CMS Pixel detector

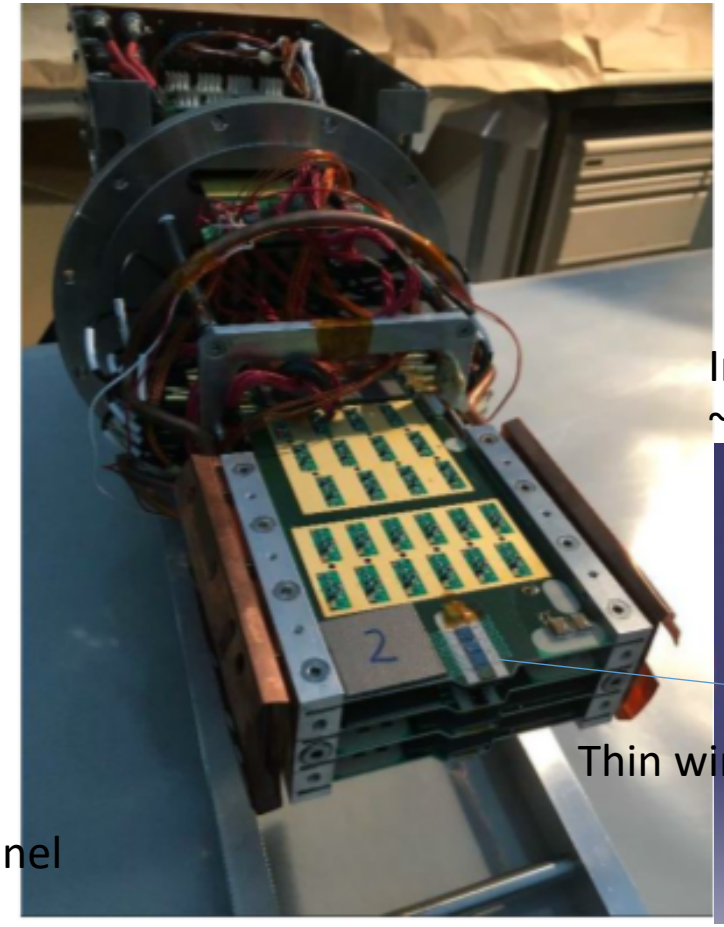


Timing detector: Diamond detector [3],[4]

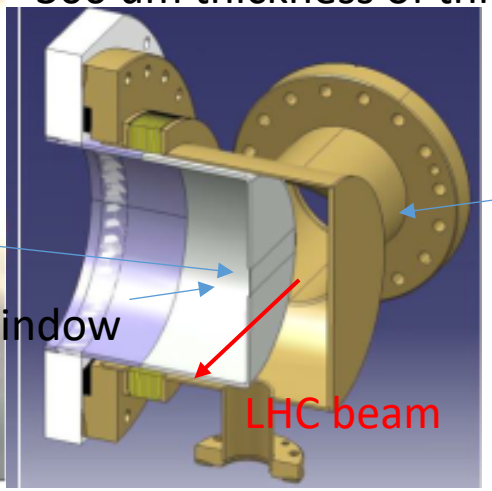


scCVD diamond = 500 um thickness
Radiation hard ~ $5*10^{15}$ p/cm^2
Area: 2.5 - 16 mm^2
Spatial resolution ~ 150 um
C varies from 0.2 to 2 pF
Time resolution/plane ~ 90 ps at test beam [4]

FE electronics integrated in RP :
3 stage amplification chain adopted from HADES collaboration amplifier.
Rise time ~ 1.7 ns
Vmax ~ 2.7 V [3]



Integrated in low imp. cylindrical RP [1]
~ 300 um thickness of thin window



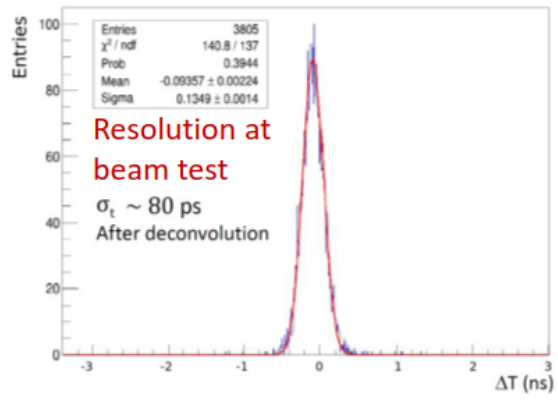
Timing electronics
NINO+HPTDC [5],[6]
~ 2m distance
to detector in LHC tunnel

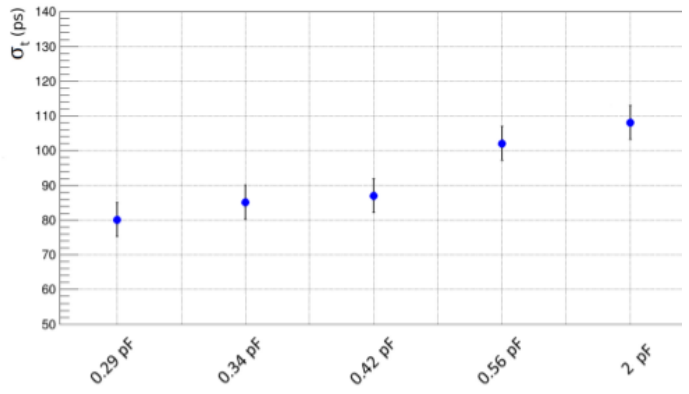
Pixel size optimized to obtain
~ equal rate per pixel
sensor is ~ 50 um close to thin window

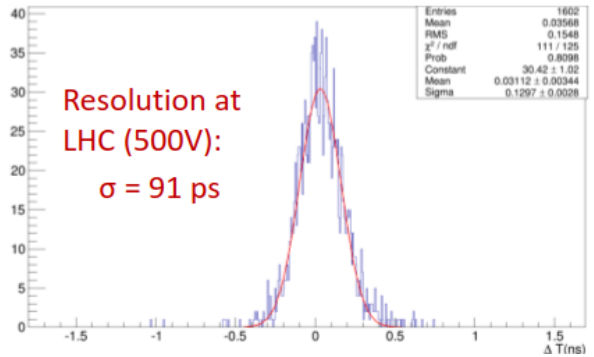
Detector package operated at 100 mbar(a), +5 C^0

Single plane diamond detector [4]

Timing performance in Beam tests and at the LHC







- Weak dependence on capacitance
- Optimal HV~700V at beam test
  - ➢ 80 ps resolution
- Resolution of 90ps confirmed at the LHC

Measurement at LHC with RP in parking position with SAMPIC chip

Double layer diamonds of CT-PPS [5]

installed in RP timing during YETS2017 -> operational with start of LHC runs 2018

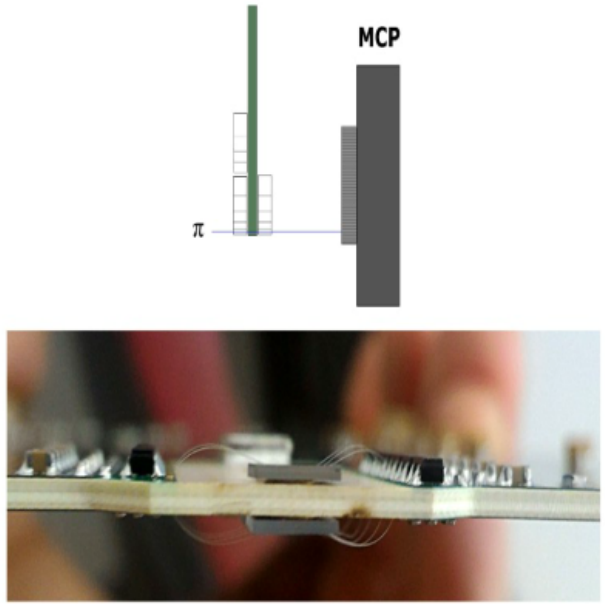
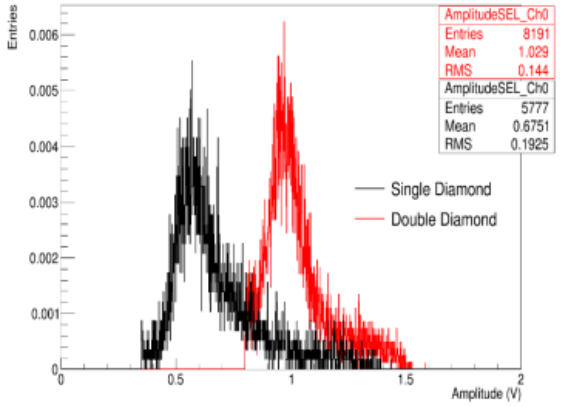
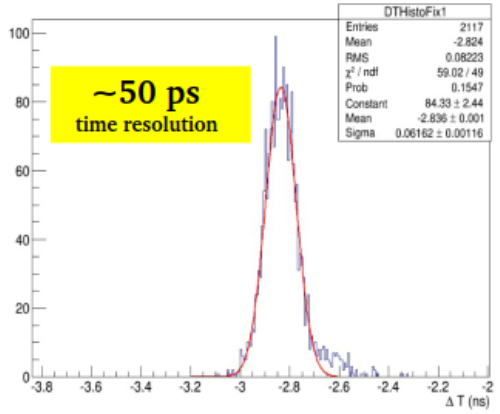


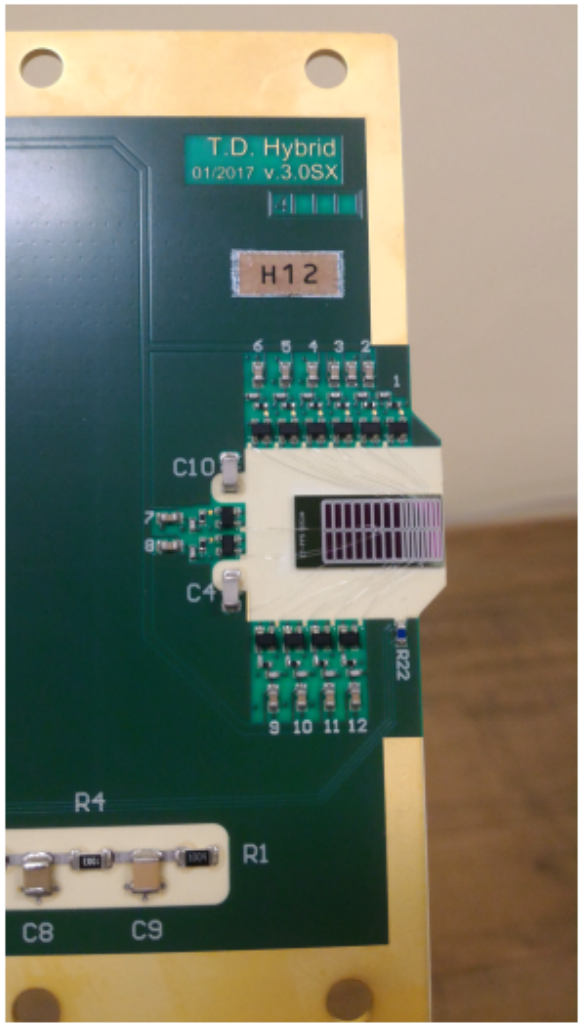
Fig. 2 Top: sketch of the test beam setup showing the prototype board (hosting the DD and a single diamond) and a Micro Channel Plate. Bottom: a picture of the edge of the prototype, the connections of the DD electrodes on the same amplifier are clearly visible.





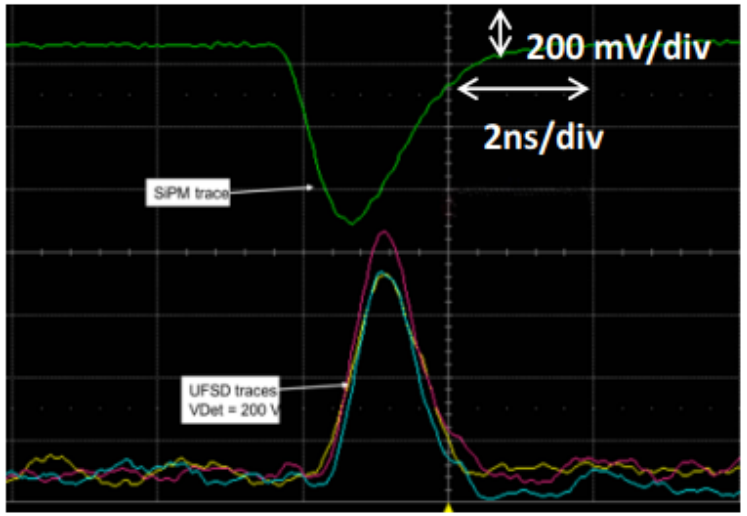
Timing Detector - UFSD

1 plane installed in RP timing (2017)



1 plane of UFSD (first installation in HEP)

- Eight 0.5x6mm^2 pads, four 1x3mm^2 pads
- Radiation hardness still an issue → in RP environment expected lifetime ~ 10^{14} p/cm^2 (R&D to improve rad-hardness still ongoing)
- Allow for high granularity (wrt to, e.g., quartz)
- Time resolution ~ 35 ps per plane
- Amplification with modified TOTEM hybrid[1]
- Readout with NINO chip[2] + HPTDC[3]

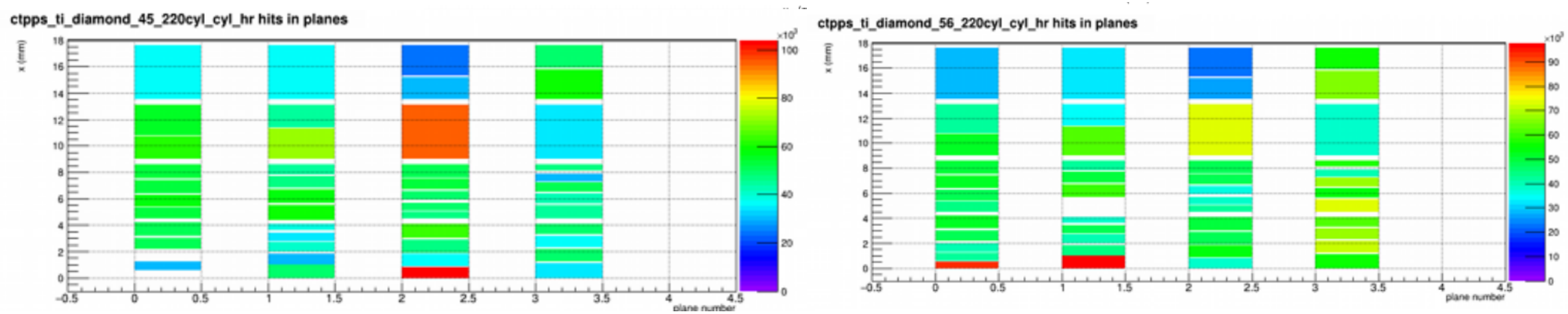


Timing Resolution [ps]		
Vbias [V]	200V	240V
N=1 :	34.6	25.6
N=2 :	23.9	18.0
N=3 :	19.7	14.8

[N. Cartiglia et al., NIM A 850 (2017) 83]

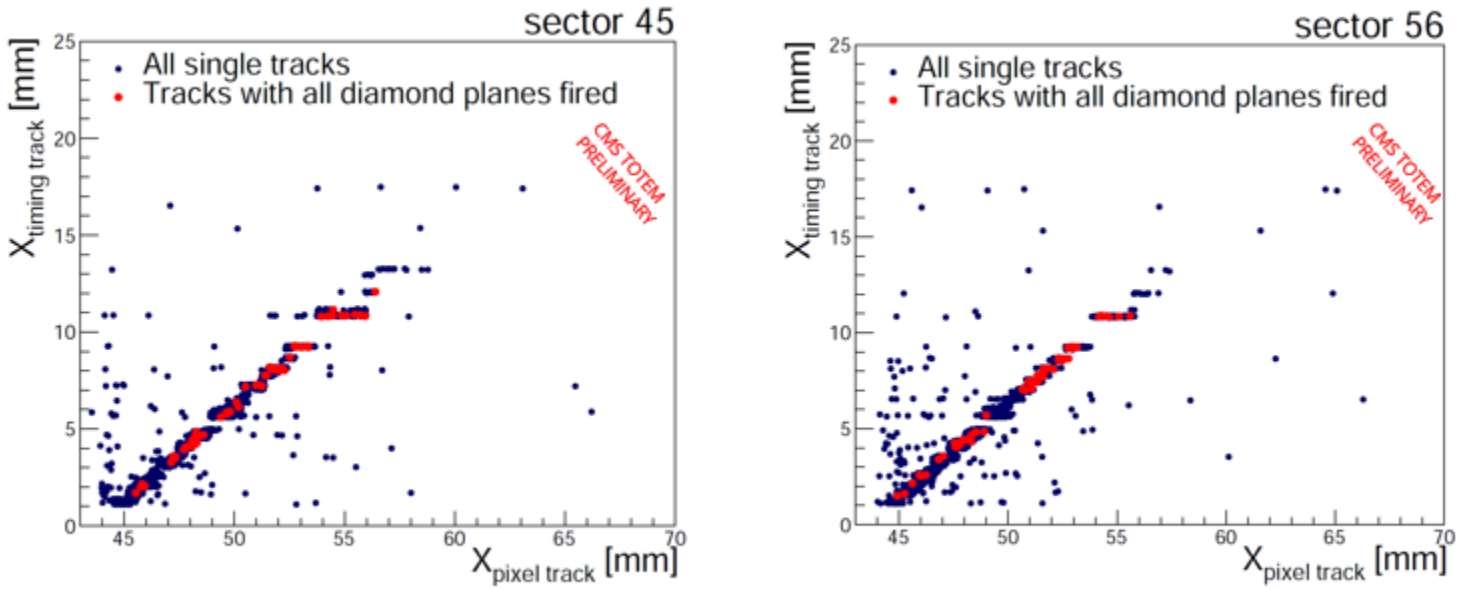
Hit Distribution in the Timing Detector (LHC standard optics)

- The geometry of the timing detector was optimized to have a uniform occupancy and a good spatial precision with a limited number of channels



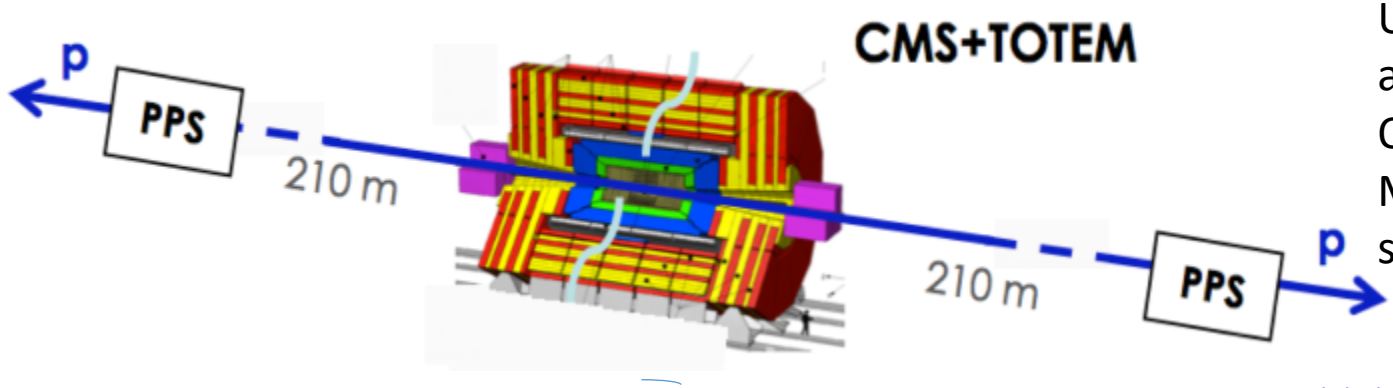
Track reconstruction of Timing Detectors

The horizontal position of the reconstructed tracks in the Timing Detector can be correlated with the tracks reconstructed in the Pixel Detector



Low pileup data (<PU> ~ 0.8) requiring 1 vertex in CMS, 1 track (per arm) in Pixel Detector, 1 track (per arm) in Timing Detector, single hit per plane in the Timing Detectors

Timing at CMS-PPS -> clock distribution



Universal Pico Second Timing System [8] adopted to CT-PPS [2],[3]
Optical clock: Dense Wavelength Division Multiplexing technique (DWDM) via single mode fiber

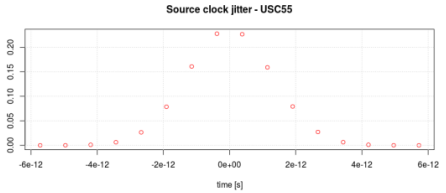
Timing Detectors operated with three different Clock configurations:

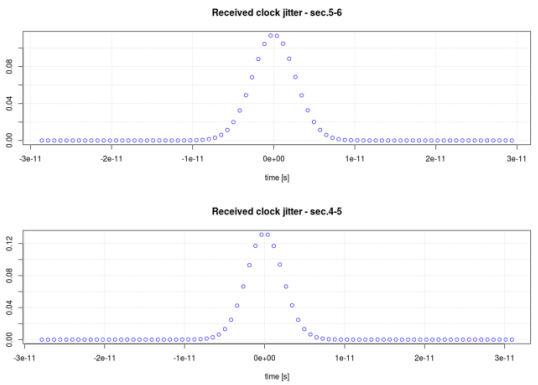
- Internal Clock (LHCC clock from CCUM +Precision PLL)
- RF Clock (locks the two arms but absolutely tied to one arm internal clock) [Before TS2] [2]
- Optical Clock (absolute, taken from the Beam 1 CMS source and sent from counting cavern to the two arms very precisely) [After TS2]

- Optical clock commissioning
  - Check of fibers attenuation **3-4dB**
  - RMS jitter at source **~1ps**
  - RMS jitter at receivers **~2ps**

LHC's tunnel

CMS USC55





Summary and conclusions:

- The CMS - PPS timing and tracking detector system integrated in the Roman Pots at ip5 fully operational with more than 40 fb^{-1} collected data during 2016 and 2017 LHC operation.
- 3 planes of diamond detectors and 1 plane of UFSD (2017) (per arm)

  4 planes of diamonds -> 2 planes with double layer (2018)(per arm)
- Efficiency -> based on matching with Si-pixel detector show 90 % efficiency for timing detectors
- Time resolution per plane single layer diamond ~ 90 ps and 50 ps per plane with double layer (test beam)
- Jitter of optical clock installed in LHC tunnel and CMS ~ 2 ps
- Specific irradiation profile on sensor due to LHC optics ~ 10^{15} p/cm^2 for 100 fb^{-1}

References:

[1]TOTEM upgrade proposal
https://cds.cern.ch/record/1554299?ln=en

[2]CT-PPS TDR
https://cds.cern.ch/record/1753795/files/TOTEM-TDR-003.pdf

[3]TOTEM Timing measurement in the vertical RP of the TOTEM exp.

http://cds.cern.ch/record/1753189?ln=en

[4]Diamond detectors for the TOTEM timing upgrade
http://iopscience.iop.org/article/10.1088/1748-0221/12/03/P03007

[5]Timing performance of a double layer diamond detector

http://iopscience.iop.org/article/10.1088/1748-0221/12/03/P03026

[6]] NINO : an ultrafast low-power front-end amplifier discriminator for the time-of-flight detector in the ALICE experiment

http://cds.cern.ch/record/818530?ln=en

[7] HPTDC High Performance Time to Digital Converter

https://cds.cern.ch/record/1067476?ln=en

[8]Universal Pico Second Timing System
https://journals.aps.org/prab/abstract/10.1103/PhysRevSTAB.12.042801

… Slides from CT-PPS presentations: M.Berretti, M. Deile, N. Minafra, T. Naaranoja, F. Ravera, V.Sola, M. Quinto, ….

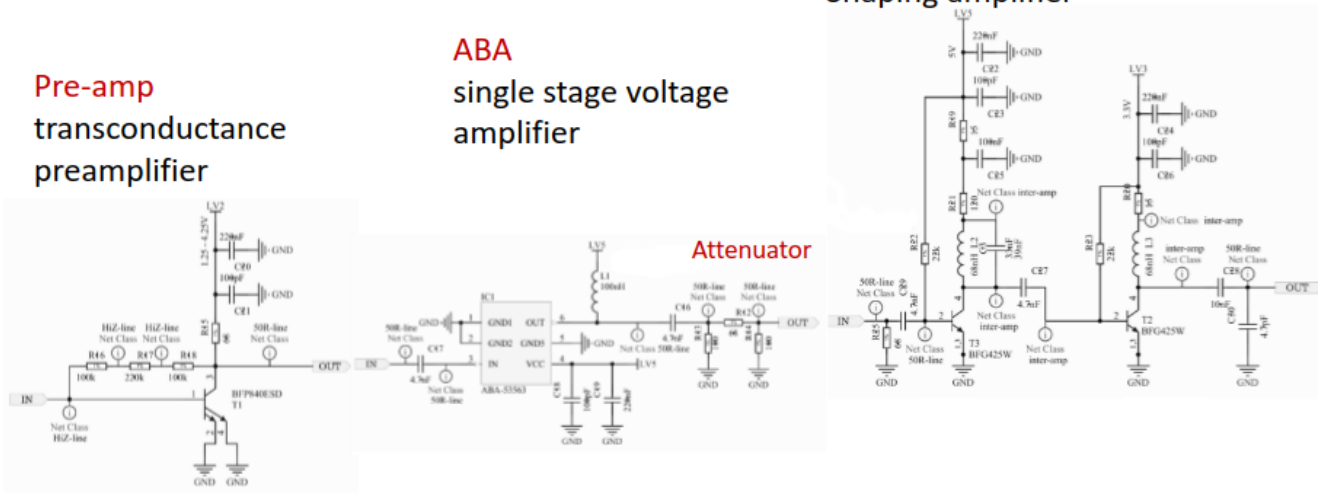
Electronics: The hybrid board

Pre-amp
transconductance
preamplifier

ABA
single stage voltage
amplifier

Attenuator

Booster
Shaping amplifier



3-stage amplification chain adapted
from the HADES Collaboration amplifier
Risetime ~1.7ns