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The CMS – TOTEM Precision Proton Spectrometer

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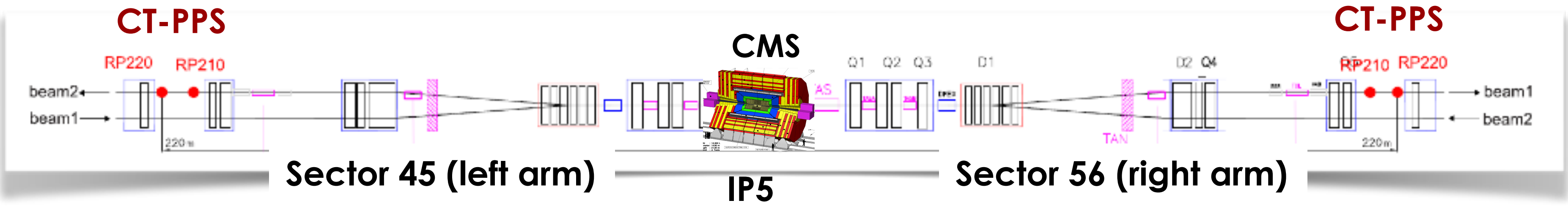
on behalf of the CMS and TOTEM collaborations

Outline

- **Project Overview**
- **Physics Motivation**
- **Experimental Apparatus**
  - ✓ Tracking detectors (Silicon Strips and 3D Silicon Pixels)
  - ✓ Timing detectors (Diamonds and UFSD)
- **2016 and 2017 data taking conditions**

Forward Proton Tagging@LHC: CT-PPS

The **CMS-TOTEM Precision Proton Spectrometer** (CT-PPS) allows **precision proton measurements in the very forward regions** on both sides of CMS during **standard LHC running.**



- Two stations for **tracking detectors** and one station for **timing detectors** installed between 200 and 220 m from the common CMS-TOTEM interaction point (IP5) on both sides of the central apparatus

- LHC magnets between IP5 and the detector stations used to bend out of the beam envelope protons that have lost a small fraction of their initial momentum in the interaction

→ **proton fractional longitudinal momentum loss (ξ) between 2% and 10%**

A Bit of History

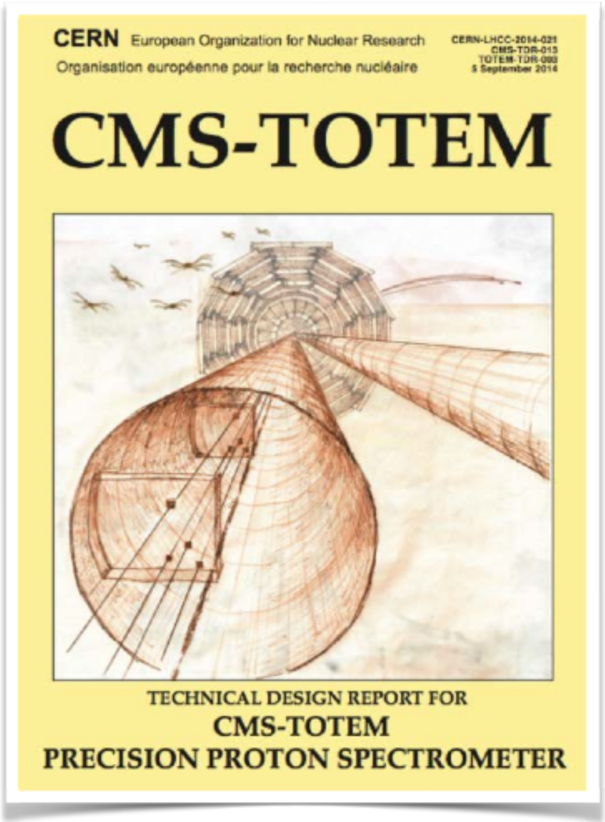
- Project TDR[1] **approved in Dec. 2014** by LHCC and CERN Research Board

- **First data taking period in 2016 with an 'accelerated program' configuration**
  - ▻ Si strip detectors from TOTEM experiment used
  - ▻ Diamonds for timing

  First $\gamma\gamma \rightarrow \mu^+\mu^-$ observation (one protons intact) based on 10 fb^{-1} [2]

  Details in L. Lloret Iglesias's talk

- **Data taking with the baseline detector configuration started in May 2017**
  - ▻ 3D Silicon Pixels & Strips for tracking
  - ▻ Diamonds + UFSD for timing



[1] CT_PPS TDR, CERN-LHCC-2014-021
[2] CMS PAS PPS-17-001
TOTEM NOTE 2017-003

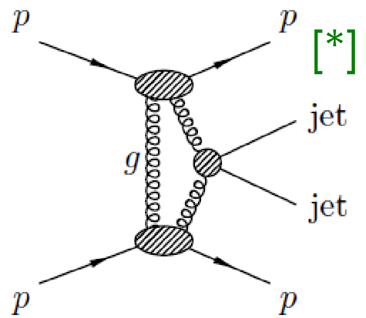
Physics in LHC-Run2 with CT-PPS

The main goal of CT-PPS is to study central exclusive production (CEP) processes:

pp → ppX

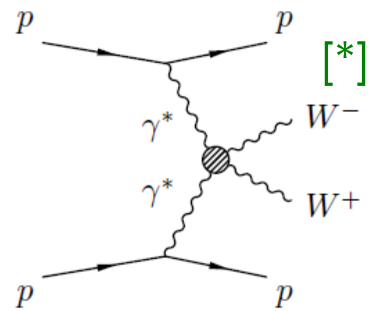
QCD: **LHC as gluon-gluon collider with tagged proton**

- Exclusive two and three jet events
- Test of pQCD mechanism of exclusive production
- Gluon jet samples with small component of quark jets



EWK: **LHC used as photon-photon collider**

- Measurement of $\gamma\gamma \rightarrow$ W+W-, $\gamma\gamma$, e+e-, $\mu+\mu$-, $\tau+\tau$-
- Search for anomalous quartic gauge couplings (AQGCs) with high sensitivity

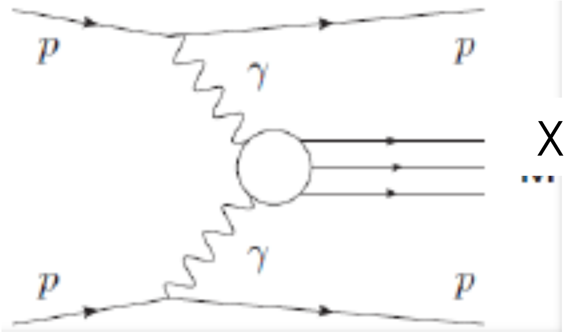


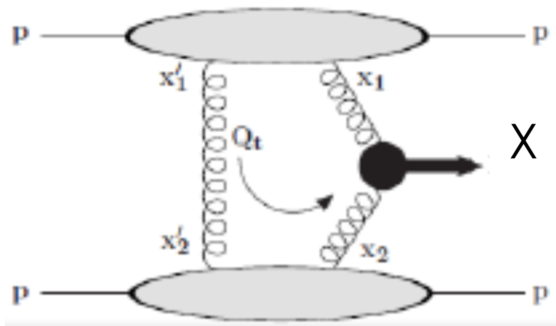
Beyond Standard Model:

- Clean events (no underlying event)
- Independent mass measurement by pp system
- J^{PC} quantum numbers 0++, 2++

[*] CEP PROCESSES **pp → p X p** STUDIED IN DETAIL FOR THE CT-PPS TDR

Experimental Strategy





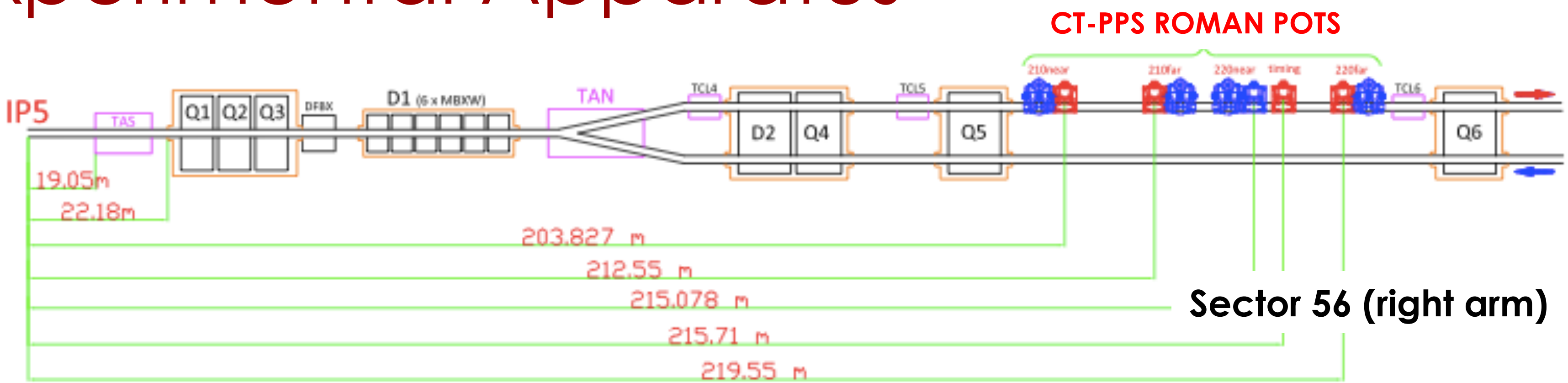
- High-p_T system (X) detected by the CMS central detector, scattered protons detected by CT-PPS
- The measurement of the two scattered protons fully determines the kinematics of the central system X, irrespective of its decay mode.
- Central system mass is measured via the momentum loss of the two protons:

$$M_X = \sqrt{s \cdot \xi_1 \cdot \xi_2}$$

ξ: fractional momentum lost by the proton

Main challenges:
- Operate as close as possible to the beam line without preventing LHC stable operation
- Cope with high pile-up of standard LHC running
- Run detectors in high radiation environment

Experimental Apparatus



Proton position and angle measurements, combined with the beam magnets, allow to **determine the momentum of the scattered protons**

- Position resolution of ~10 μm
- Angular resolution of ~1-2 μrad

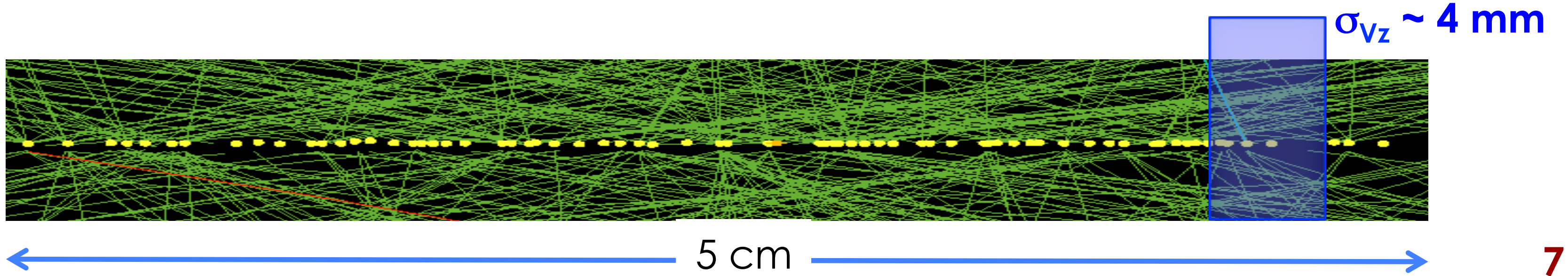
→ **$\Delta p/p \sim 2\cdot10^{-4}$**
Mass resolution: ~5 GeV/c²

Proton timing measurement from both sides of CMS allows to **determine the primary vertex**, correlate it with that of the central detector and **reject pile-up**

- Time resolution ~20 ps

→ **Vertex z-by-timing: ~4 mm**

$$\sigma_{Vz} = \frac{c}{2}\sqrt{2\sigma^2_{\Delta t}}$$



Detector Configuration in 2016

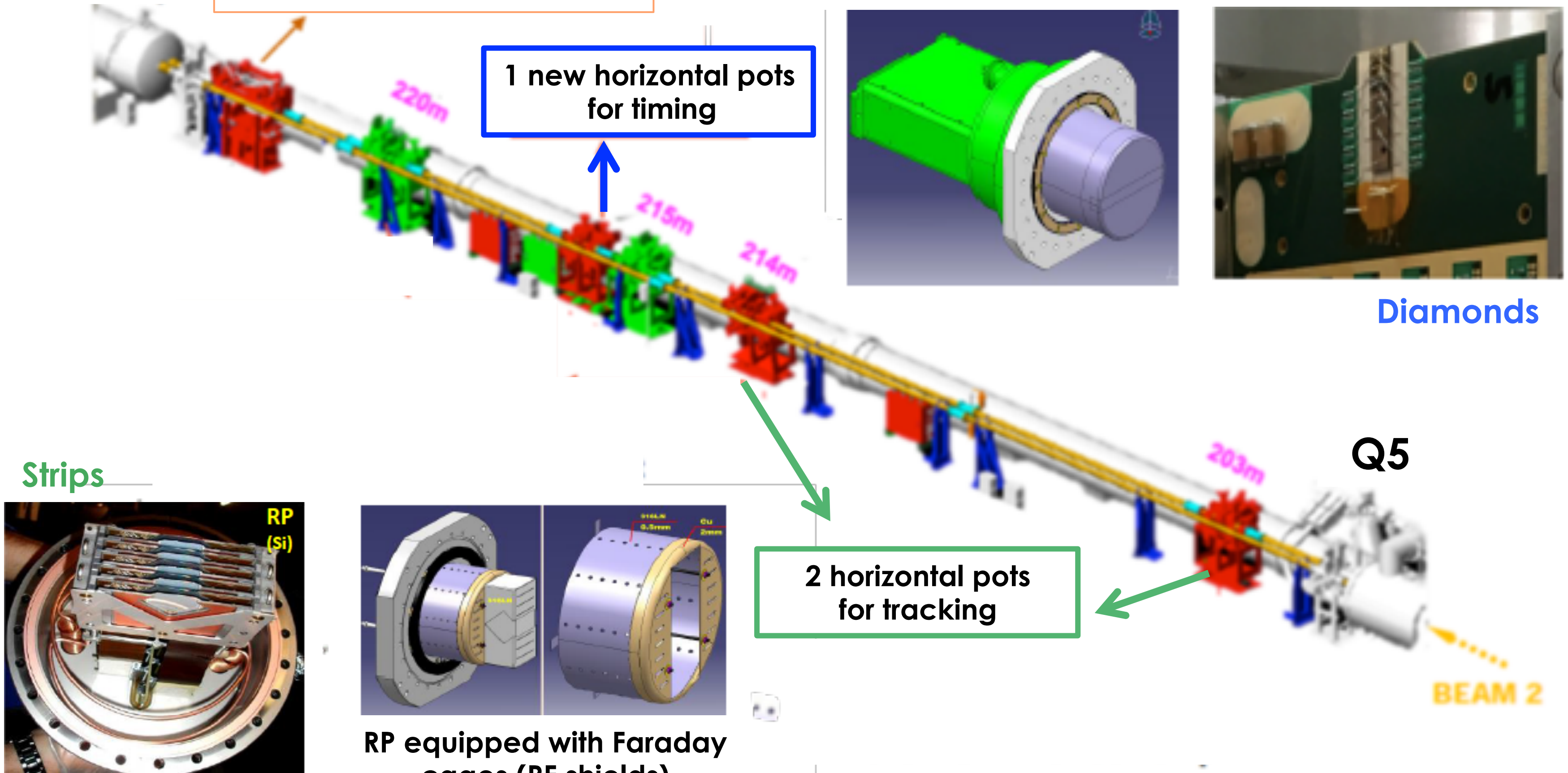
Tracking and timing detectors installed in Roman pots (RP):

- 2 horizontal pots at 203 m and 214 m for tracking
- 1 horizontal pot at 216 m for timing

Collimator (TCL6) to suppress debris from RPs

1 new horizontal pots for timing

Cylindrical RP for timing detectors to reduce impendance and increase available space



Diamonds

2 horizontal pots for tracking

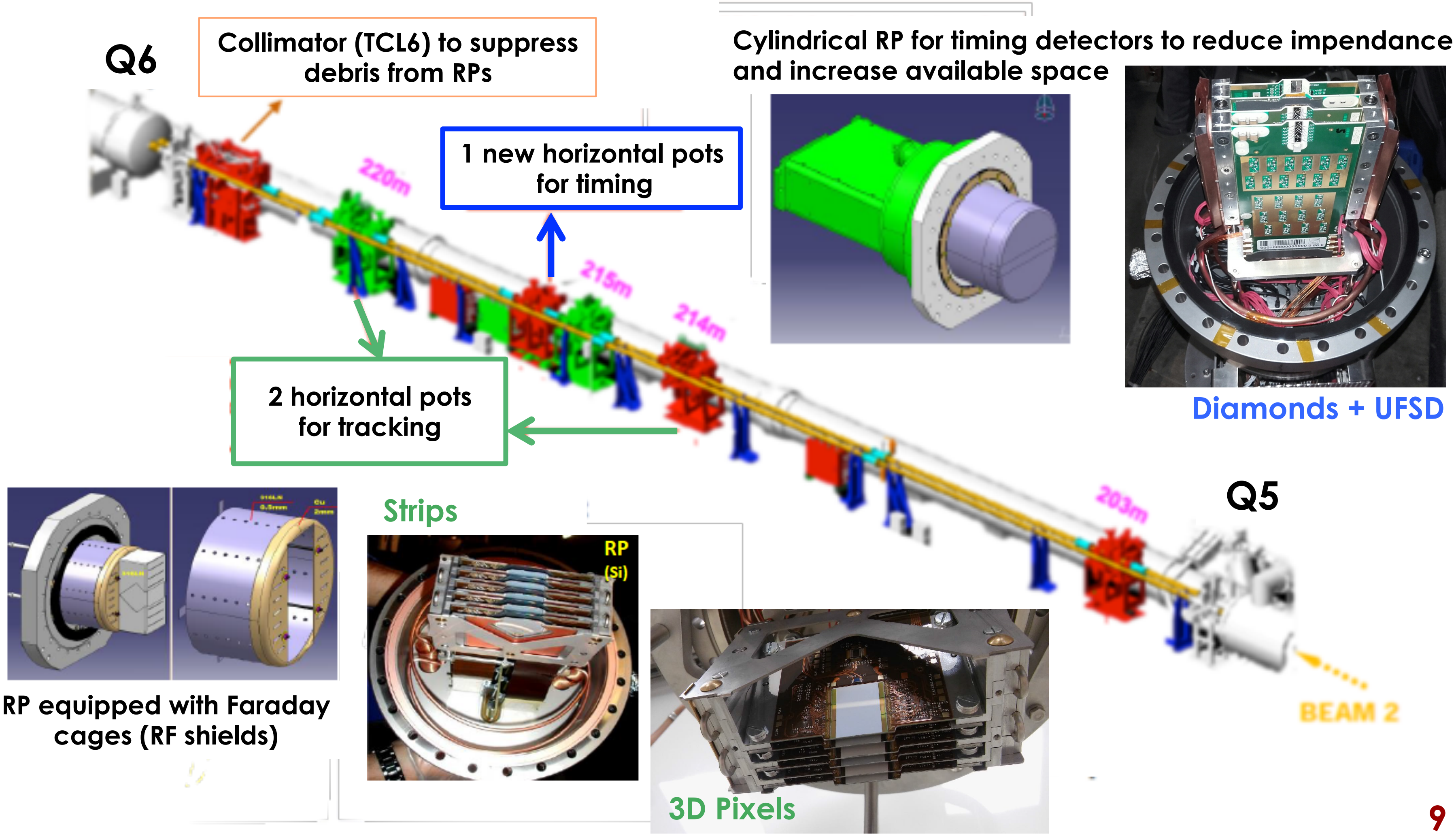
Strips

RP equipped with Faraday cages (RF shields)

Detector Configuration in 2017

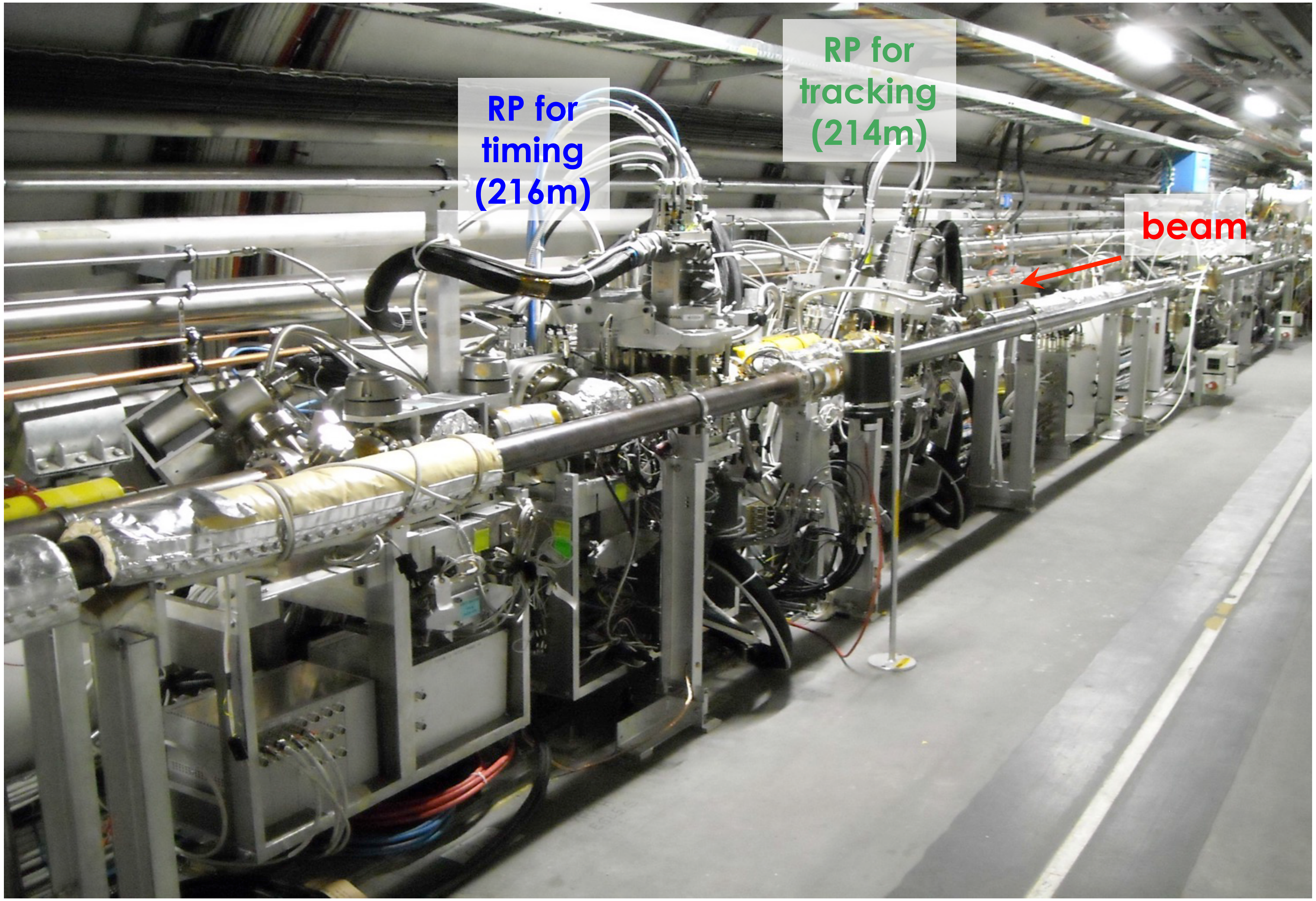
Tracking and timing detectors installed in Roman pots (RP):

- 2 horizontal pots at 214 m and 220 m for tracking
- 1 horizontal pot at 216 m for timing



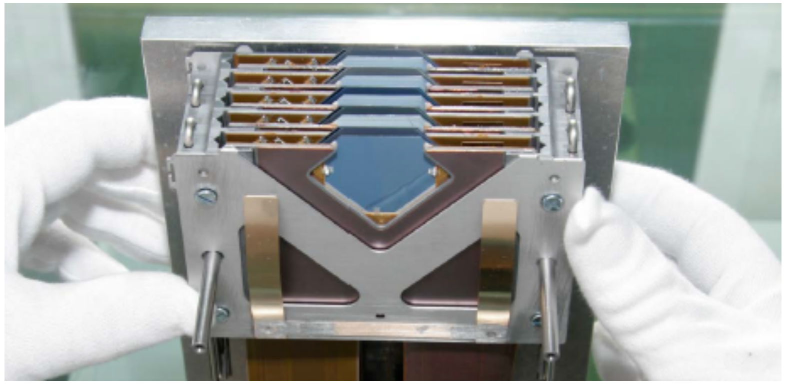
Experimental Apparatus and LHC Tunnel

RP for
tracking
(220m)



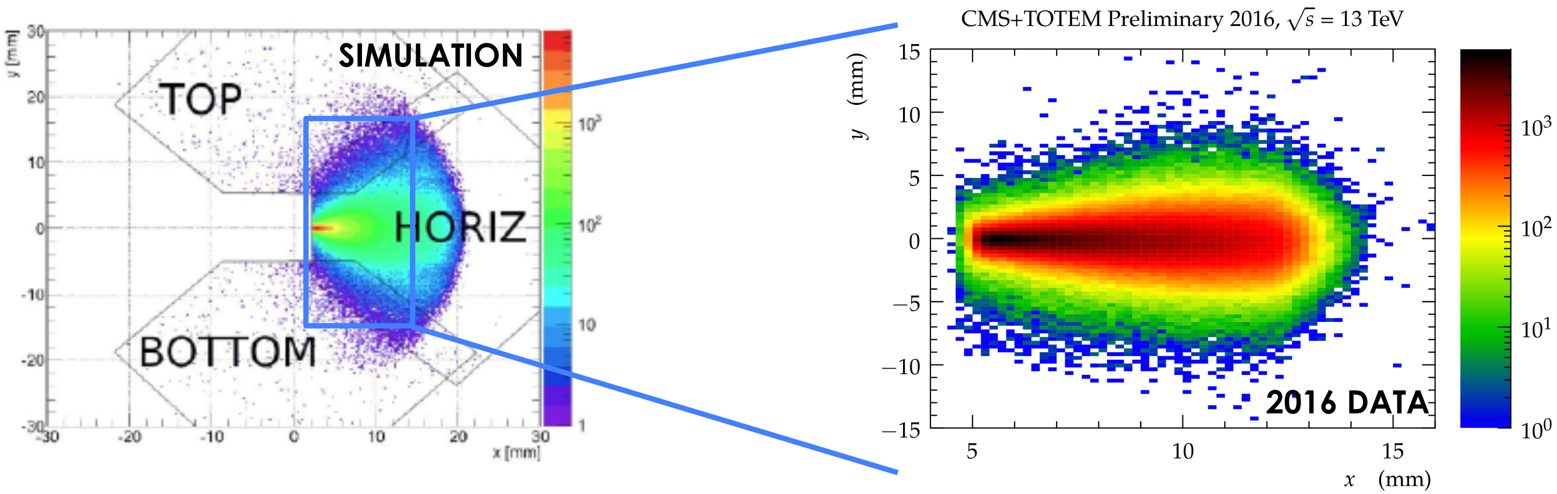
Tracking Detector - Silicon Strips

Micro-strip silicon detectors with edgeless technology - inactive edge 50 μm



- 10 planes per station
- 512 strips per plane, tilted by +/-45°
- Pitch: 66 μm
- Resolution: ~20 μm
- Lifetime up to an integrated flux of $5 \cdot 10^{14}$ p/cm^2

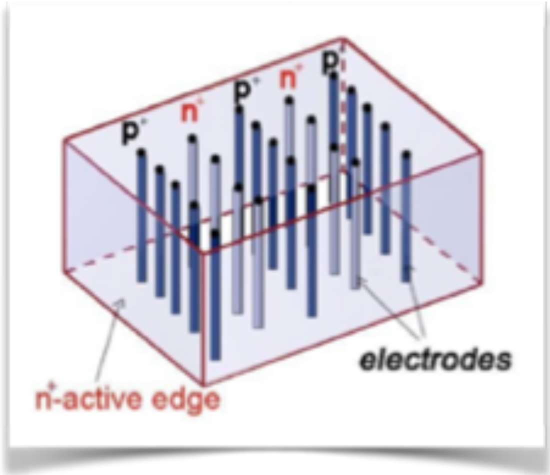
Hit/track reconstruction using consolidated TOTEM algorithms (fully integrated in the CMS official software)

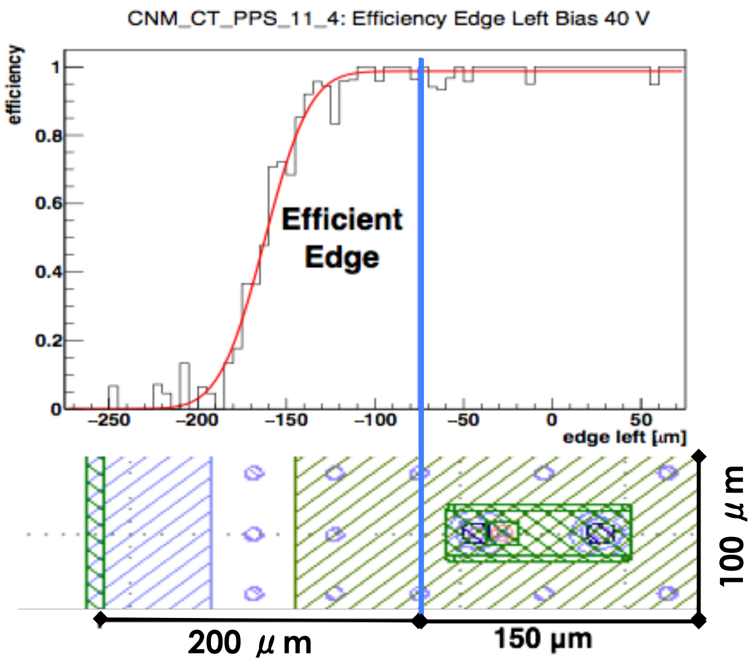


Tracking Detector - Silicon 3D Pixels

3D sensor technology

- Intrinsic radiation hardness → to **withstand** overall integrated flux of **$5 \cdot 10^{15}$ p/cm^2**
- Pixel dimensions: 100x150 μm^2 → **very high granularity**
- Front-end chip: latest version of PSI46dig, same as for new CMS Pixel detector
- Planes tilted by 18.4° to optimize efficiency and resolution
- **Resolution per plane < 30 μm**

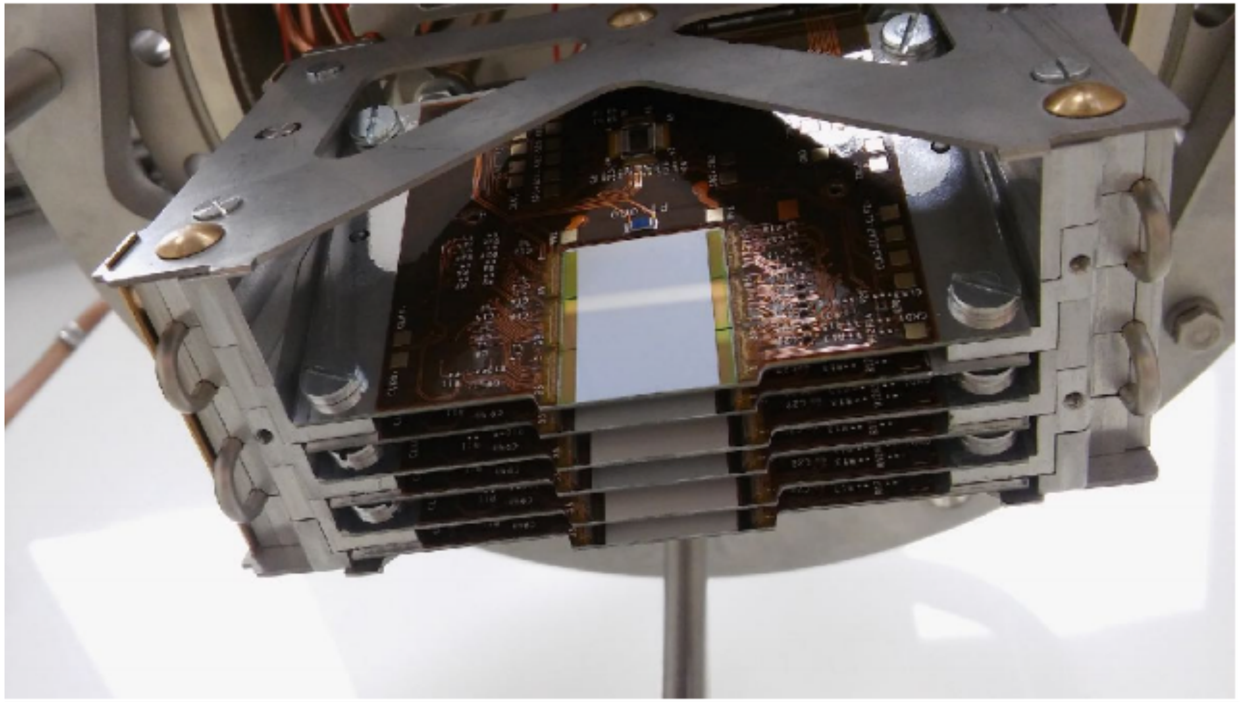


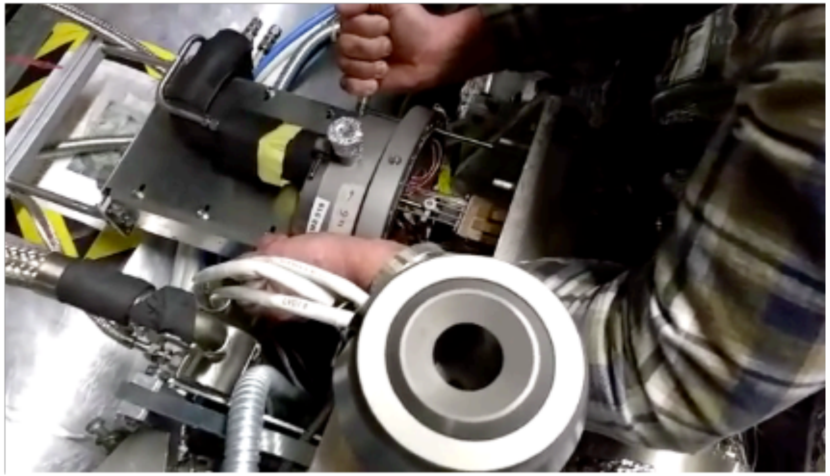


- **200 μm slim edge** → to approach the beam as much as possible

  Up to 150 μm can be gained at the edge of the sensor by increasing bias voltage .

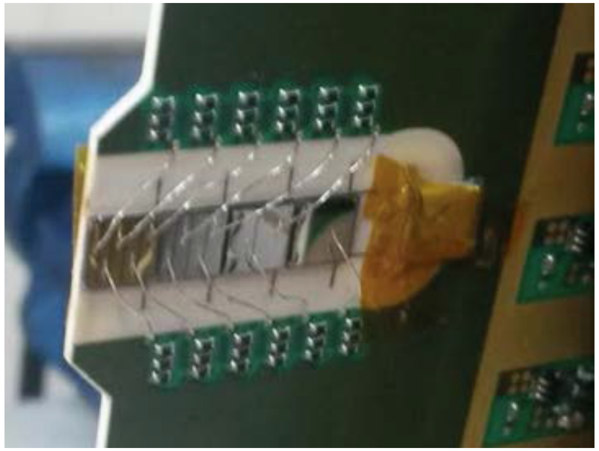
Silicon 3D Pixels Installation in 2017



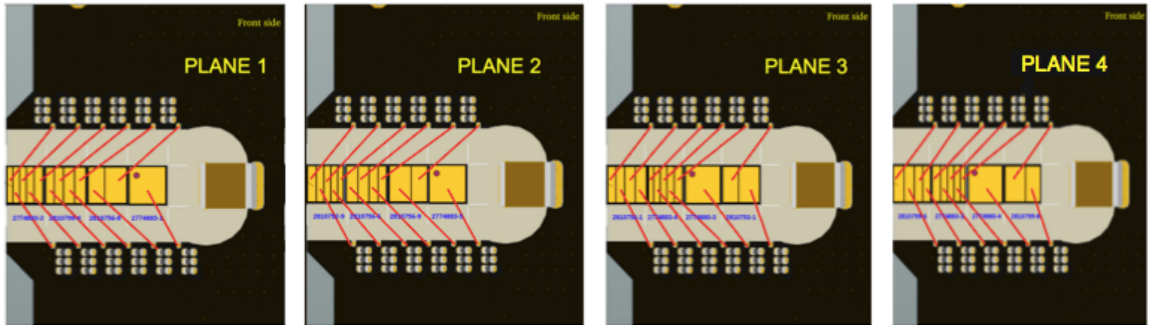


The detectors were installed in the Roman pots along the LHC at the end of March

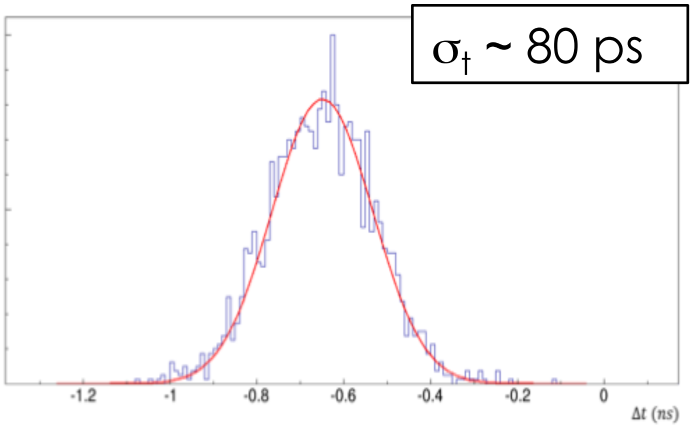
Timing Detector - Diamonds



- 4 planes (3 in 2017) of scCVD Diamonds
- 4 4x4mm^2 diamond sensors per plane, with different pad patterns



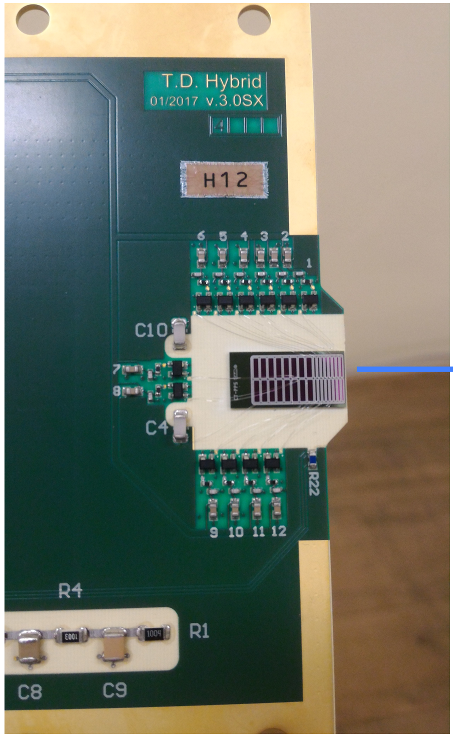
- ▹ Amplification with TOTEM hybrid[1]
- ▹ Digitization with NINO chip[2] + HPTDC[3]
- ▹ Intrinsic radiation hardness → to withstand overall integrated flux of $5{\cdot}10^{15}$ p/cm^2



▹ **Time resolution ~ 80 ps per plane**

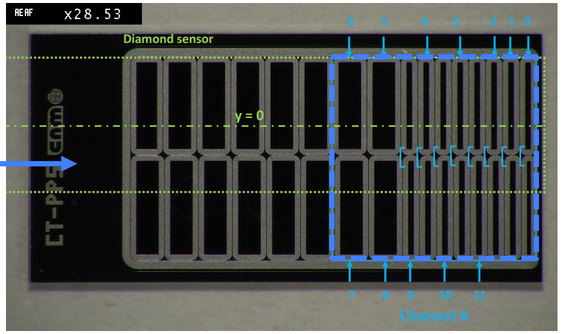
[1] TOTEM Coll., JINST 12 (2017) P03007
[2] F. Anghinolfi et al., NIM A 533 (204) 183
[3] M. Mota and J. Christiansen, IEEE JSSC 34 (1999) 1360

Timing Detector - UFSD



1 plane of UFSD (Ultra Fast Silicon detector, based on 50 μm thick low gain silicon sensors)

→ First installation in HEP



12 read-out channels:

- 8 0.5x6mm² pads
- 4 1x3mm² pads

▹ Amplification with adapted TOTEM hybrid

▹ Digitization with NINO chip + HPTDC

▹ **Time resolution ~ 30 ps per plane**

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

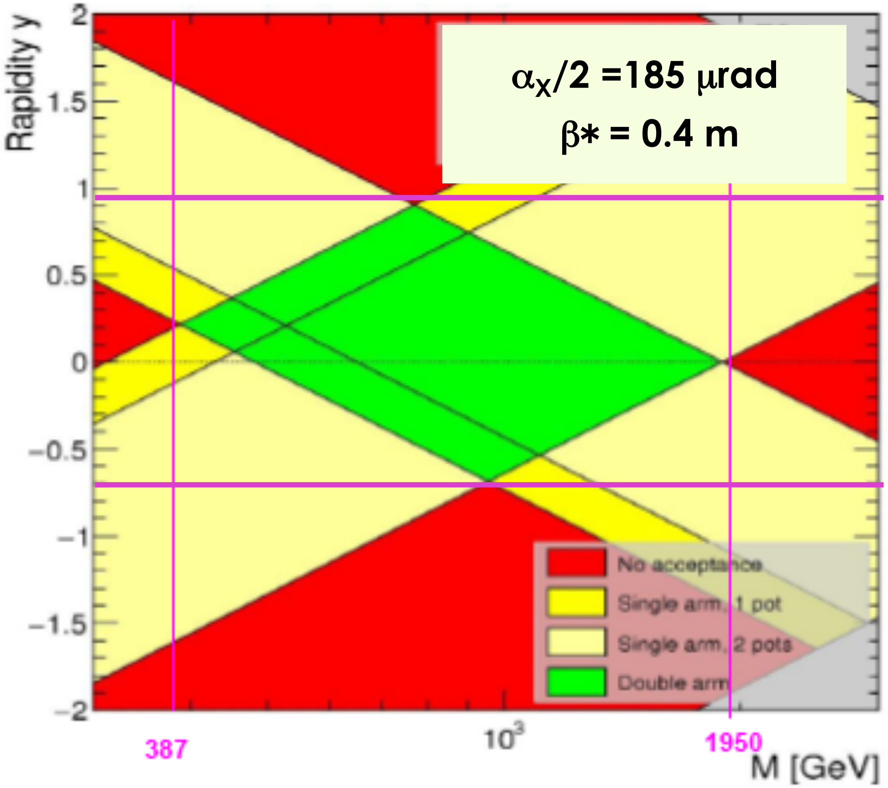
Number of planes

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

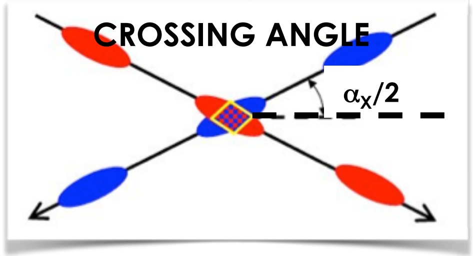
▹ In RP environment expected lifetime ~ 10^{14} p/cm²
(R&D to improve rad-hardness still ongoing)

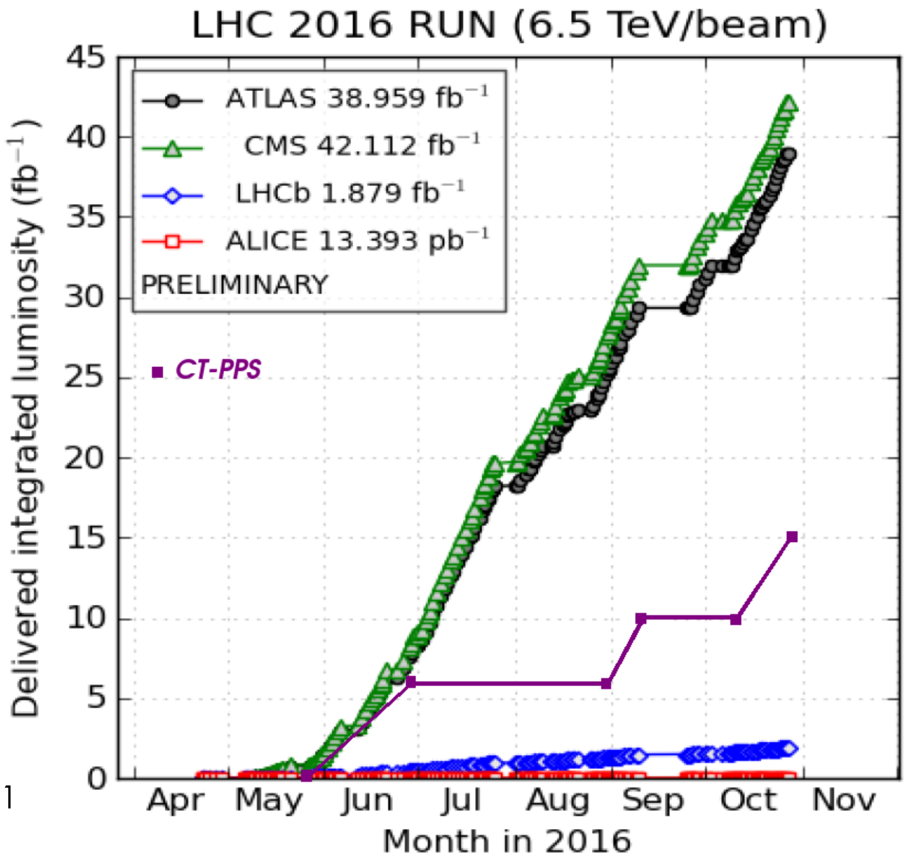
2016 Data Taking

$$y = \frac{1}{2}\ln\frac{\xi_1}{\xi_2}$$



$$M^2 = \xi_1 \xi_2 s$$





Data collected with:

- Silicon Strips only: first 12.5 fb^{-1}
- Silicon Strips & Diamonds: last 2.5 fb^{-1}

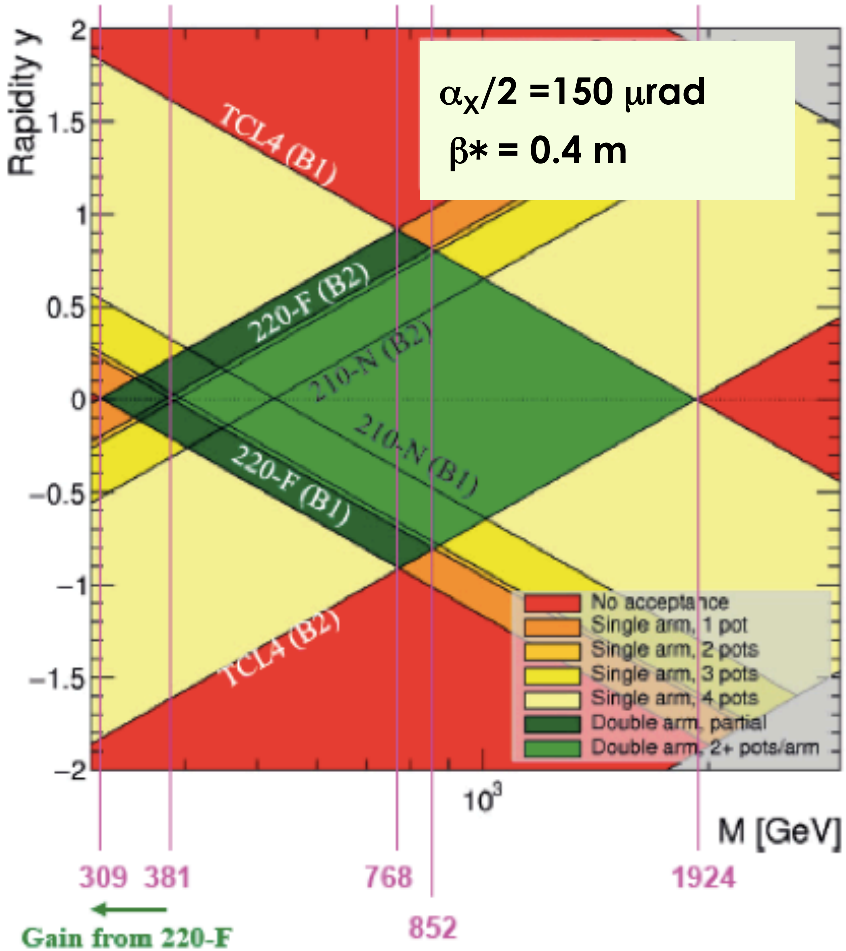
- **Minimum distance** of approach to the beam: **$15\sigma_{beam}$**

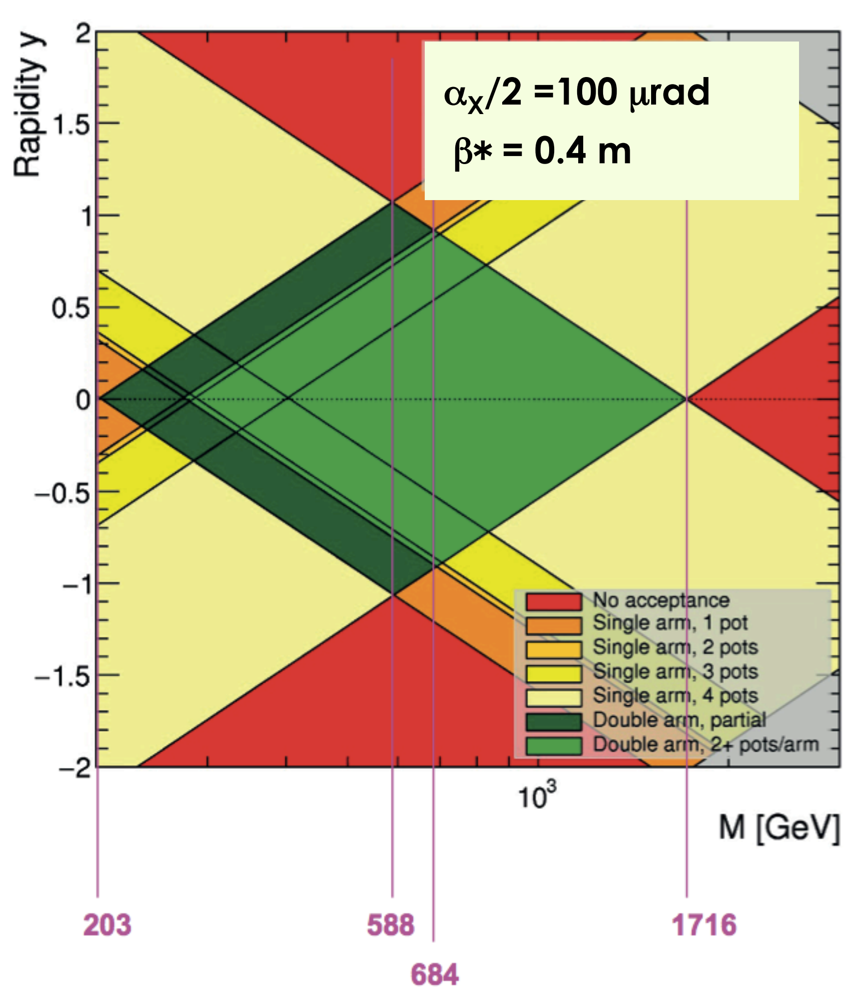
2017 Data Taking

In 2017 Roman Pot operation foreseen at 4 crossing-angles

- $\alpha_X/2$: 150, 140, 130, 120 μrad

→ **CT-PPS kinematic acceptance strongly affected by the LHC optics**





- **Minimum distance** of approach to the beam: $\mathbf{12\sigma_{beam} + 0.3\ mm}$

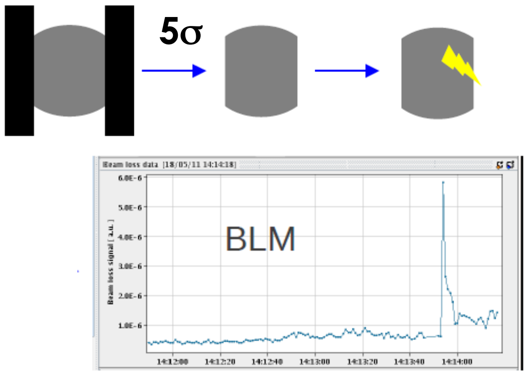
RP Detector Alignment Run

The kinematic quantities of the proton at the IP determined from the reconstructed proton track parameters by using the beam-transport matrix between the interaction point and CT-PPS.

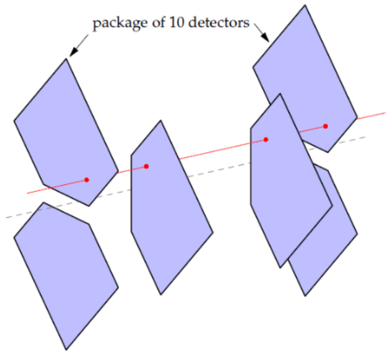
A **precise determination of the position of the detectors** (with an accuracy of a few μm) with respect to the beam is crucial

The alignment of RPS among themselves and with respect to the beam done in **dedicated low intensity run** where all (horizontal and vertical) RPs approach the beam.

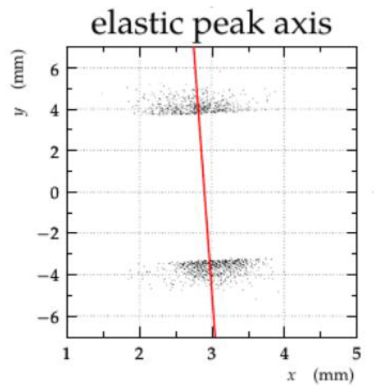
A 3-step procedure[1] developed and extensively used by TOTEM is applied



1. Alignment wrt the collimators



2. Relative RP alignment

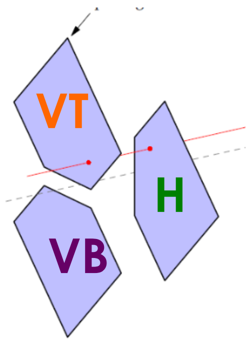


3. Global alignment wrt the beam

For each physics run the RP position is determined by comparing the measured shape of the distribution of the track-impact-point x with the one obtained in the alignment run.

[1] CERN-TOTEM-NOTE-2017-001/002

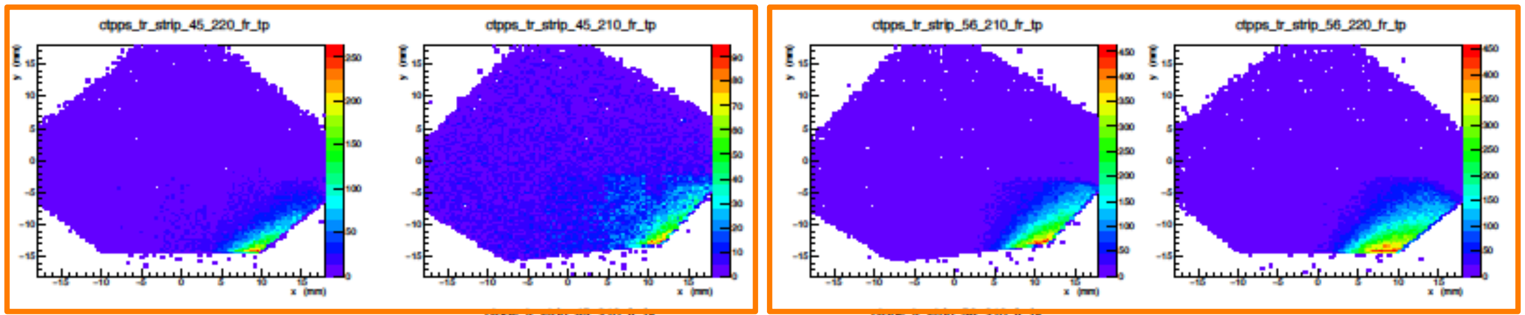
2017 Data - Silicon Strips



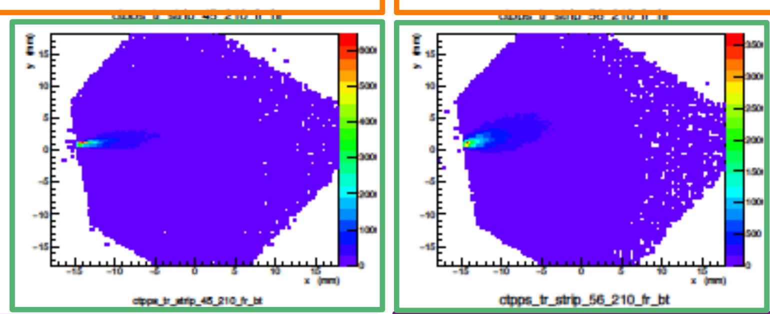
CT-PPS DQM Plots from 20-21 May 2017 Alignment Run

Sector 45 | Sector 56

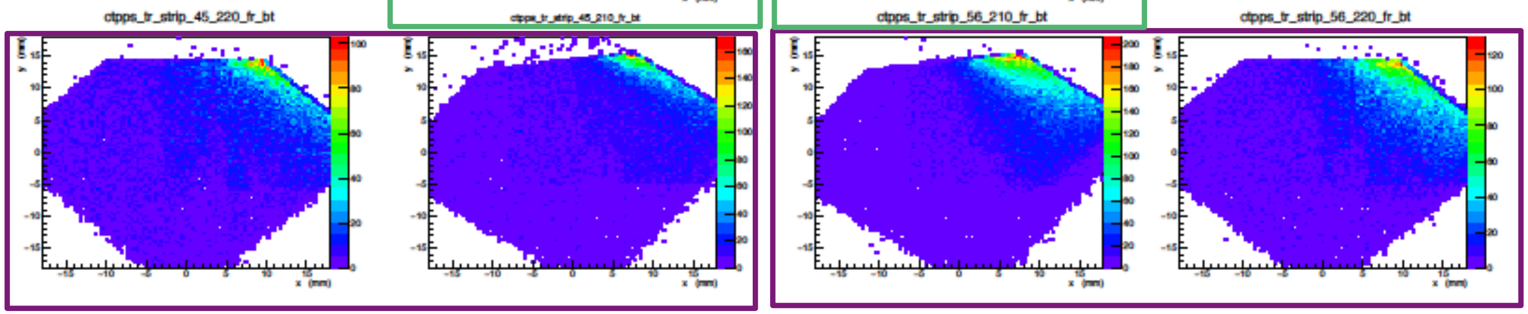
TOP VERTICAL POTS



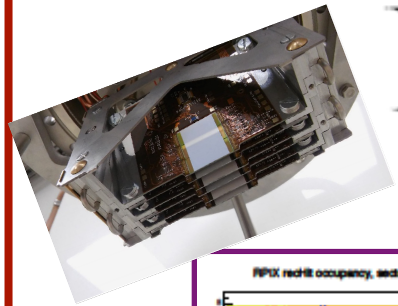
HORIZONTAL POTS



BOTTOM VERTICAL POTS



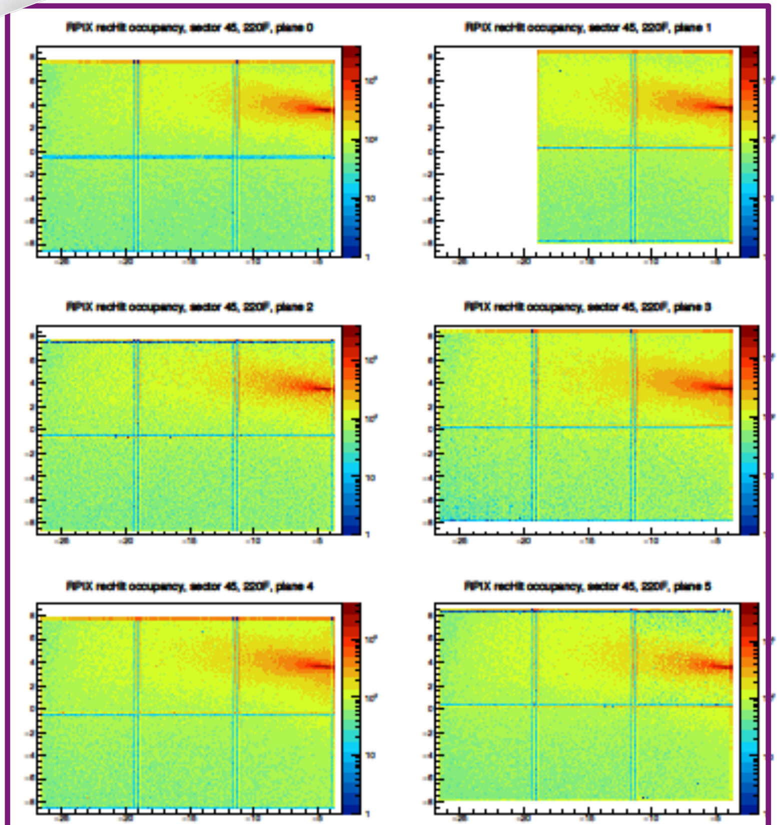
2017 Data - 3D Silicon Pixels



CT-PPS DQM Plots from 20-21 May 2017 Alignment Run

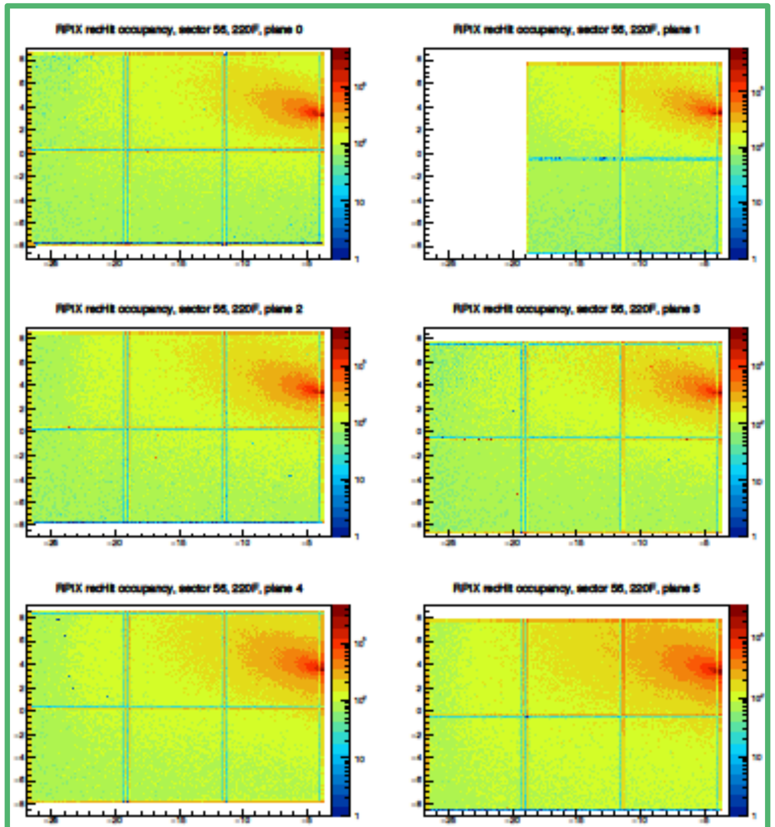
Logarithmic
Z scale

Sector 45



6 planes

Sector 56



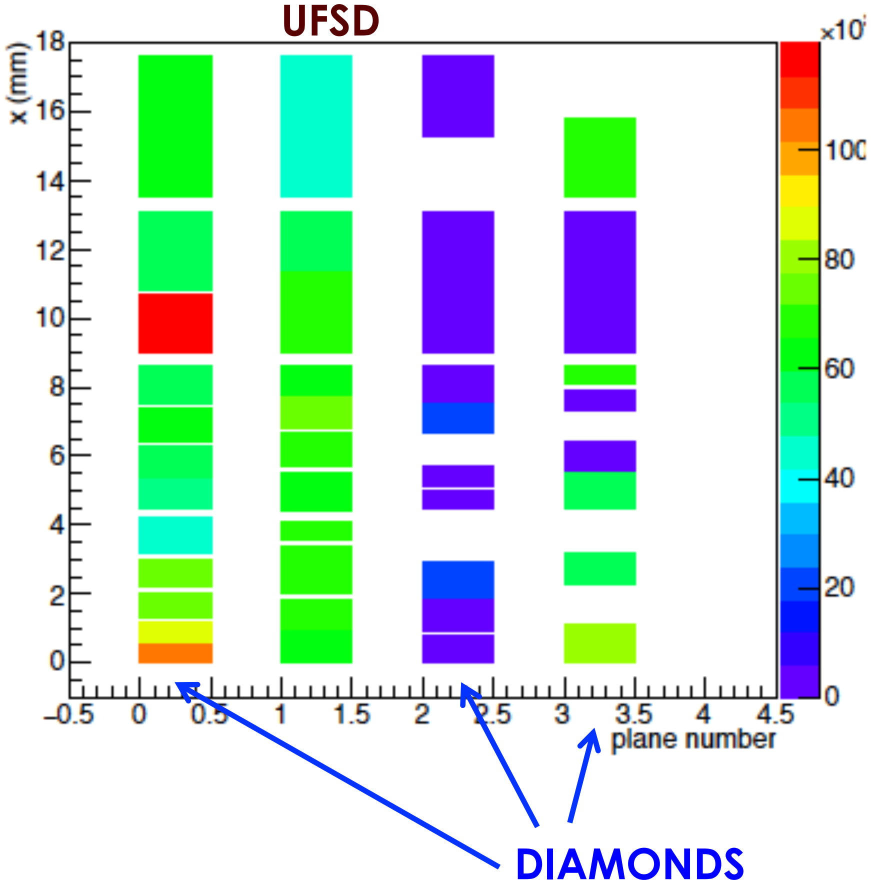
6 planes

<0.05% bad/noisy pixels

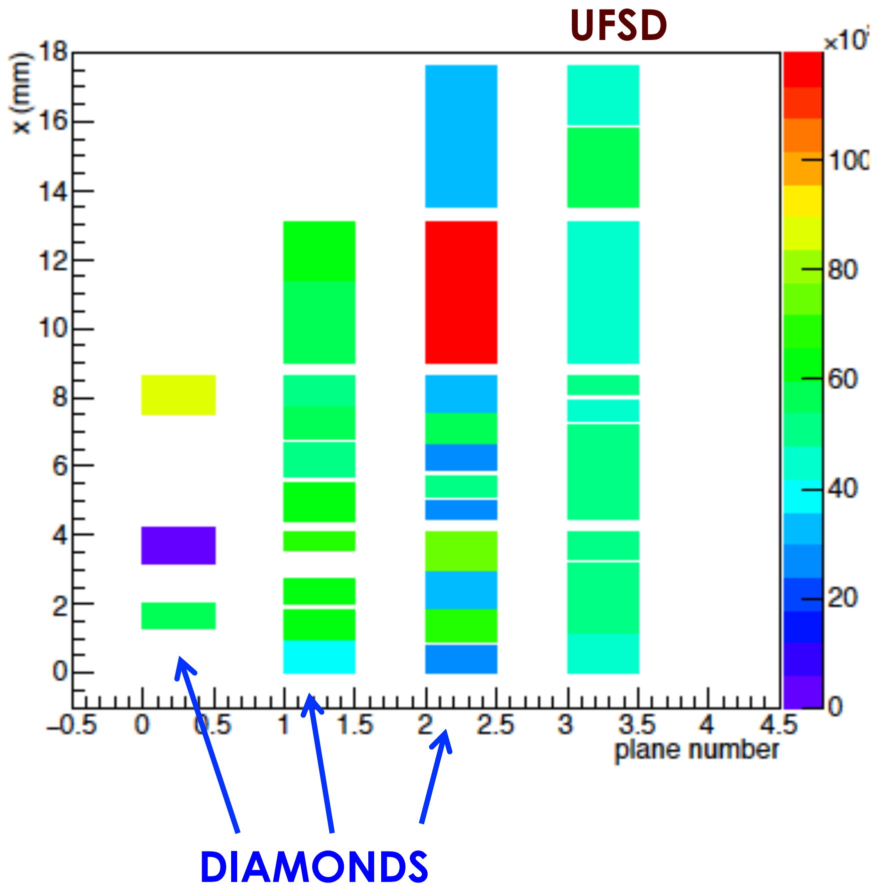
2017 Data - 3 Diamonds + 1 UFSD

CT-PPS DQM Plots from 20-21 May 2017 Alignment Run

Sector 45



Sector 56



Summary

- CT-PPS R&D phase completed; now running
- 2016 CT-PPS installation with an 'Accelerated Program'
  - ✓ Silicon Strips + scCVD Diamond Detectors
  - ✓ The ability to operate detectors close to the beam-line at high luminosity proved
  - ✓ 15fb^{-1} of data @ $\sqrt{s}$ = 13 TeV collected
  - ✓ First result presented here by L. Lloret Iglesias
- 2017 CT-PPS installation completed in April
  - ✓ 4 different detector technologies
    - Silicon Strips and 3D Silicon Pixels for tracking
    - scCVD Diamonds and UFSD for timing
  - ✓ All detectors successfully installed and integrated in the CMS central DAQ.
  - ✓ Regular RP insertions following beam intensity ramp
    → 2nd fill after 2 h, 3rd fill full time
  - ✓ Final commissioning almost completed

Lots of high quality data at $\sqrt{s}$ = 13 TeV expected