The CT-PPS project

Nicolo Cartiglia
(with R. Arcidiacono, A. Solano)
INFN Torino

On behalf of the CMS and TOTEM Collaborations

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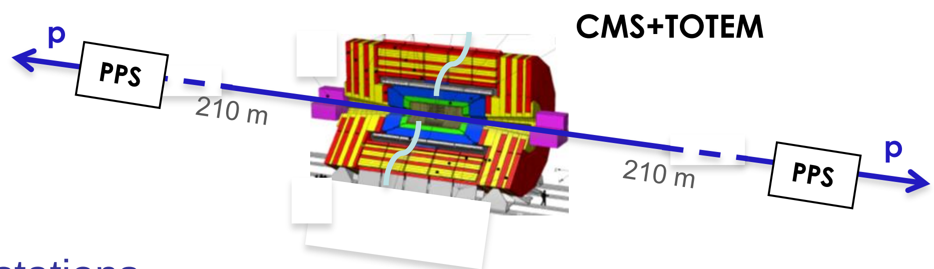
Detector concept

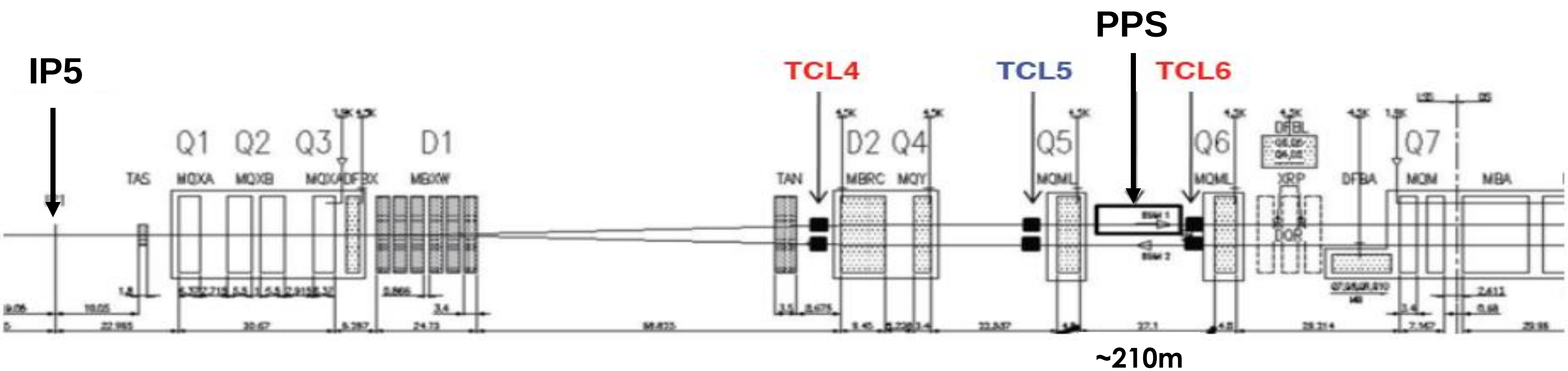
The **CMS-TOTEM Precision Proton Spectrometer** (CT-PPS) will allow precision proton measurements in the very forward regions on both sides of CMS during standard LHC running:

- Two stations for **tracking detectors** and two stations for **timing detectors** installed at ~210 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

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



LHC lattice between IP5 and CT-PPS detector stations

Detector concept

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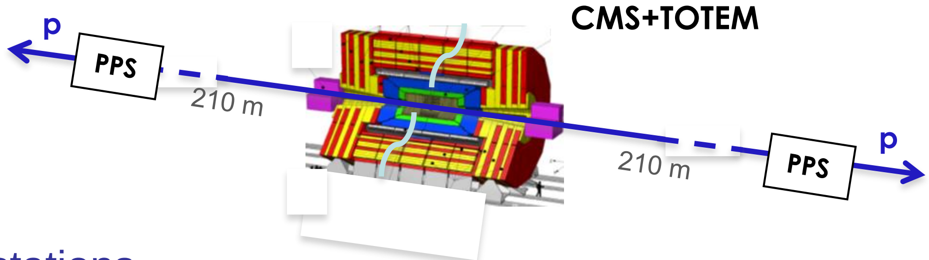

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→ **fractional longitudinal momentum loss (ξ) between 2% and 10%**

A **Memorandum of Understanding** between **CERN** and the **CMS** and **TOTEM** Collaborations for a common physics program and detector development signed in **December 2013**

The TDR is ready and approved by the two Collaborations
Now presented to the LHCC (next meeting on Sep. 23rd-25th**)**
[CERN-LHCC-2014-021, CMS-TDR-13, TOTEM-TDR-003]

Project planning

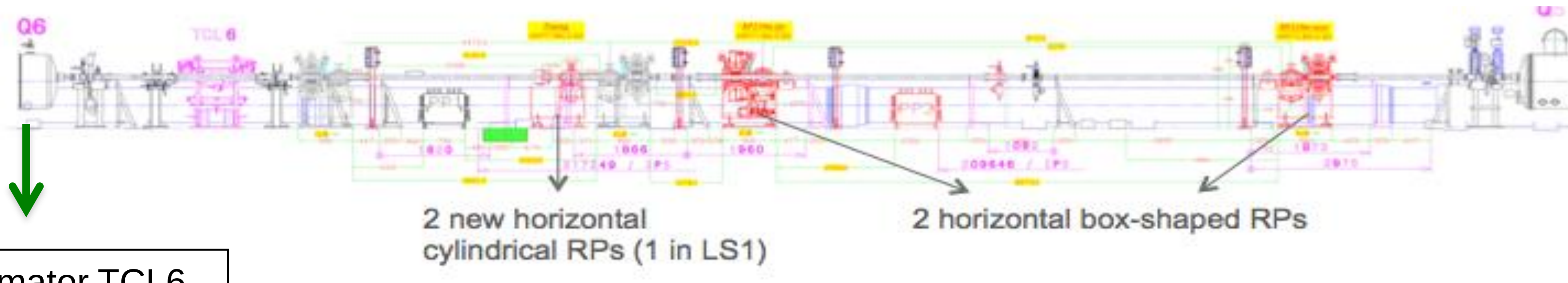
The CT-PPS project includes an **exploratory phase** in 2015-2016 and a **production phase** until LHC LS2 (2018)

- **Exploratory phase** (2015-16)
  - Prove the ability to operate detectors close to the beamline at high luminosity
    - Show that CT-PPS does not prevent the stable operation of the LHC beams and does not affect significantly the luminosity performance of the machine.
  - In 2015:
    - Evaluate RPs in the 204-215 m region
    - Demonstrate the timing performance of the Quartic baseline
    - Use TOTEM silicon strip detectors at sustainable radiation intensity
    - Integrate the CT-PPS detectors into the CMS trigger/DAQ system.
  - In 2016:
    - Evaluate the MBP option
    - Upgrade the tracking to pixel detectors
    - Upgrade the timing detectors if required/possible

- **Data Production phase**
  - Aim at accumulating 100 fb^{-1} of data before LHC LS2

Roman Pots in LHC line

RP units at: 220m ~ 215m 204m → IP5



New collimator TCL6 to protect magnet Q6

In current plan: detectors housed in Roman Pot, developed by TOTEM

In the exploratory phase of **2015-2016**:

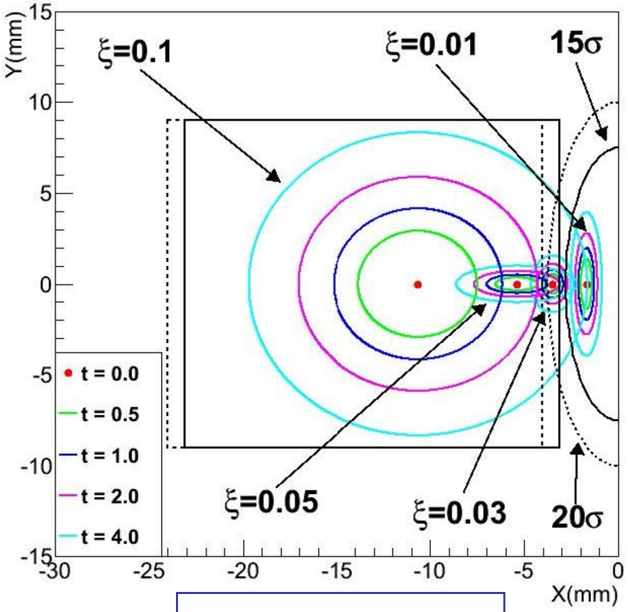
- pursue the TOTEM+CMS physics program at low/medium luminosity
- commission RP insertions during high luminosity data taking

Experimental Challenges

- Ability to operate the detectors close to the beam (15-20 σ)

Need to **sustain very high radiation levels**. For 100 fb^{-1}:
- proton flux up to $5\cdot10^{15}$ cm^{-2} in the **tracker detectors**
- 10^{12} n_{eq}/cm^2 and 100 Gy in **photosensors** and **readout electronics**

Position of scattered protons at 204m, for fixed (ξ,t)



2% < ξ < 10%

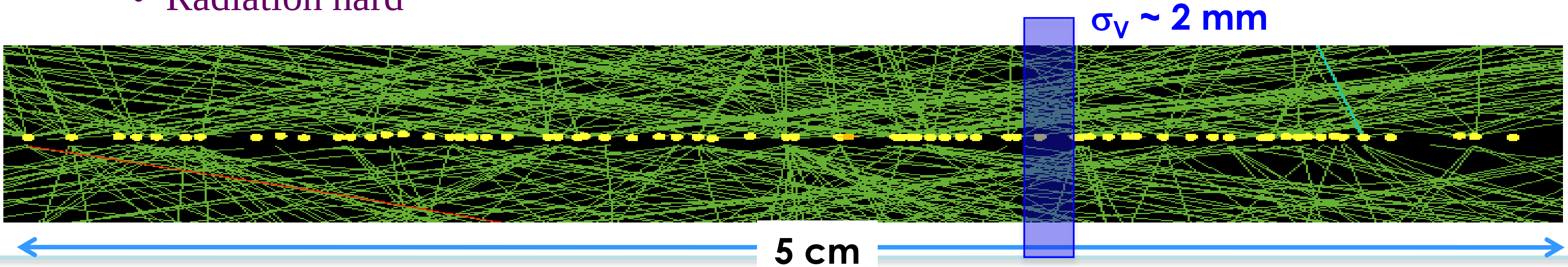
- Ability to reject background from high PU environment (μ = 50), mainly inelastic events overlapping with SD protons from the same bunch crossing

Use proton timing for primary vertex determination
Exploit the kinematical constraints of CEP events

Detector requirements

- **Measurement of scattered proton momentum: position and angle in tracking detectors, combined with the beam magnets**
  - Position resolution of 10-30 μm
  - Angular resolution much lower than beam angular spread
  - Slim edges on side facing the beam → dead region ~100 μm
  - Tolerance to inhomogeneous irradiation
    → ~$2\cdot10^{15}$ n_{eq}/cm^2 close to the beam (for 100 fb^{-1})

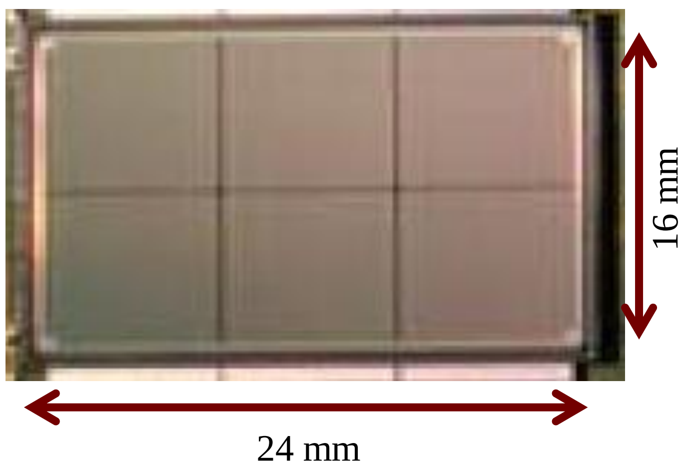
- **Measurement of CEP vertex: proton time on both sides of CMS in timing detectors**
  - Time resolution ~10 ps → Vertex z-by-timing: ~2 mm
  - Segmentation to cope with the high occupancy expected
  - Edgeless (~ 200 μm)
  - Radiation hard



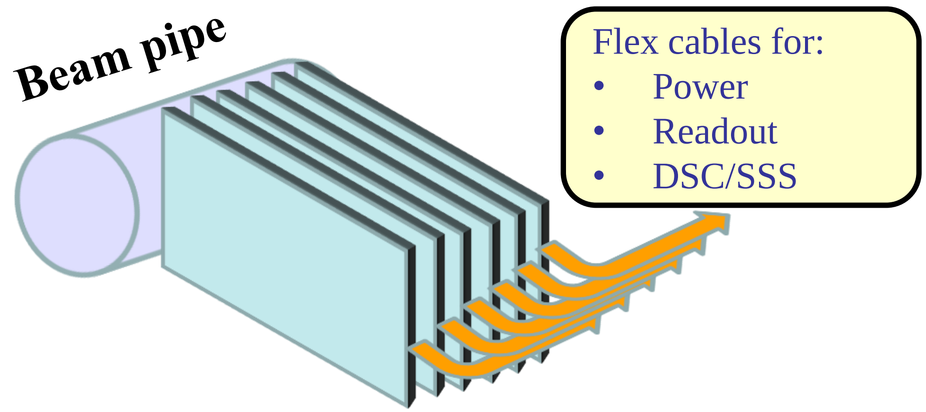
Tracking detectors

- **Baseline: 3D silicon pixel detectors**

Detector installation foreseen in 2016



- 16 x 24 mm^2 **3D silicon pixel sensors**
- 150(x) x 100(y) μm^2 pixel pattern
  same as CMS pixel detectors
- **6 PSI46dig readout chips**
  (52x80 pixels each)



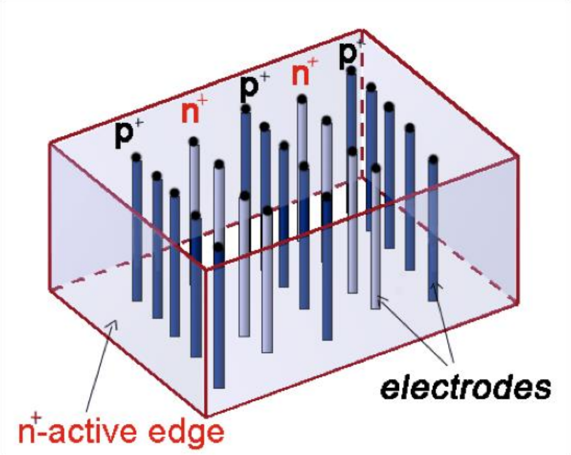
Redundancy of 6 detector planes per station

→ Same readout scheme as Phase-I upgrade of CMS Forward Pixel Tracker

3D sensors

3D sensors consist of an array of columnar electrodes

- Mature technology after 15 years of R&D and the construction of the ATLAS IBL



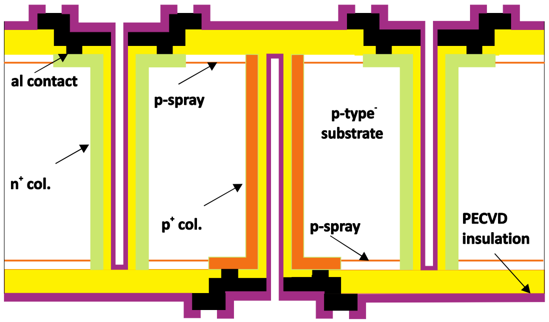
Interesting features w.r.t. planar sensors:

- Low depletion voltage (~10 V)
- Fast charge collection time
- Reduced charged trapping probability and therefore high radiation hardness
- Slim edges, with dead area of ~100-200 μm or Active edges, with dead area reduced to a few μm
- Spatial resolution comparable with planar detectors

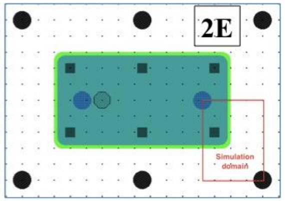
3 different 3D sensor layout tested, by FBK, Sintef and CNM: different in type of columns, sensor edge, electrode configuration

FBK 3D sensors

Preferred solution: FBK 3D



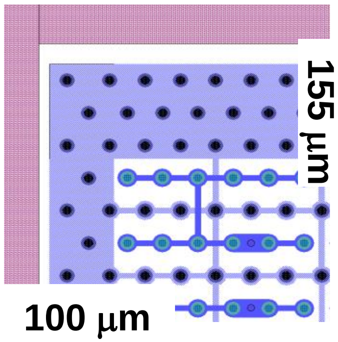
- **Passing-through empty columns**
- **Slim edges (200 μm)**
- **Inter-electrode distance 62 μm**
- **Double-sided etching**



62.5 μm

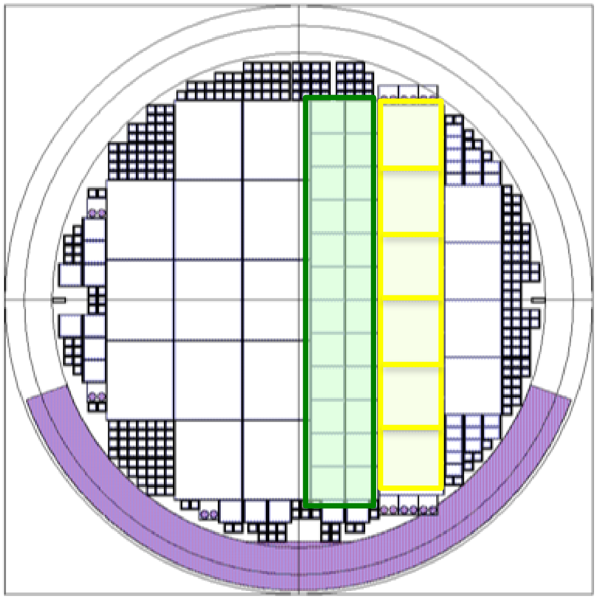
New production on the way with:

- Double sided etching
- **100 μm slim edge on one side of the sensor**



- **New 3E electrode configuration and 2x2 chip modules**

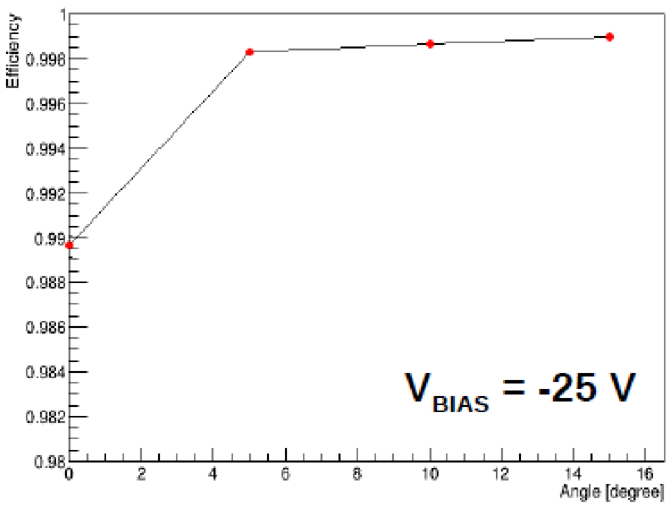
  24 0.8x0.8 cm^2 Single pixel sensors (1E, 2E, 3E, 4E) [green]
  6 1.6x1.6cm^2 Quad pixel sensors CMS (2E, 3E) [yellow]

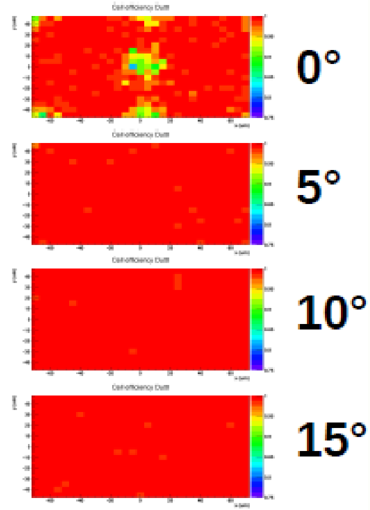


3D sensors tests

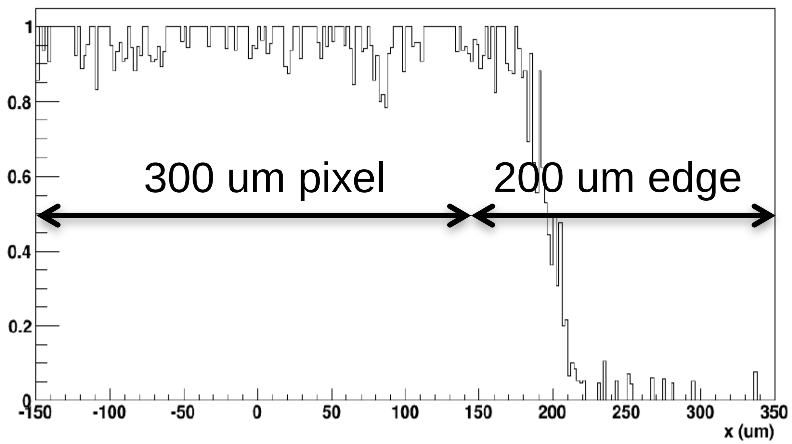
Preliminary results of un-irradiated FBK 3D sensors read out by PSI46dig ROCs, tested at Fermilab with a 120 GeV proton beam

Efficiency vs angle





Edge Efficiency



Detectors are tilted to reduce the geometrical inefficiency due to the empty electrode columns

Efficiency remains high up to 150 μm from the sensor's boundary

Efficiency > 99.5% already at 5°

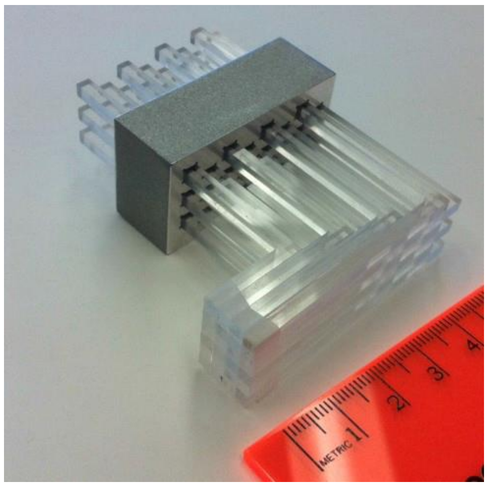
Spatial resolution for 2 pixel clusters : ~12 μm

Measurements with the same detectors, irradiated at fluences from $1\cdot10^{15}$ to $1\cdot10^{16}$ n_{eq}/cm^2, were just taken during the last two weeks at Fermilab.

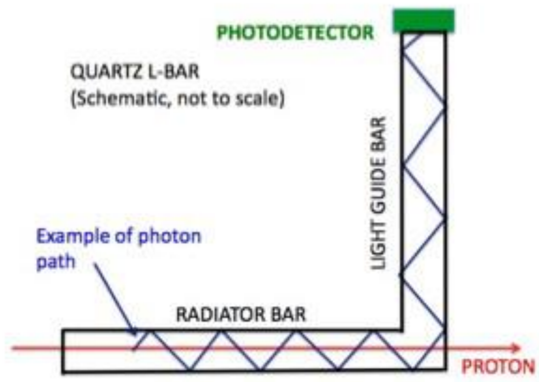
Timing Detectors

- **Baseline: L-bar Quartic**, Čerenkov detectors with sapphire and quartz radiators

Detector installation foreseen at the end 2015

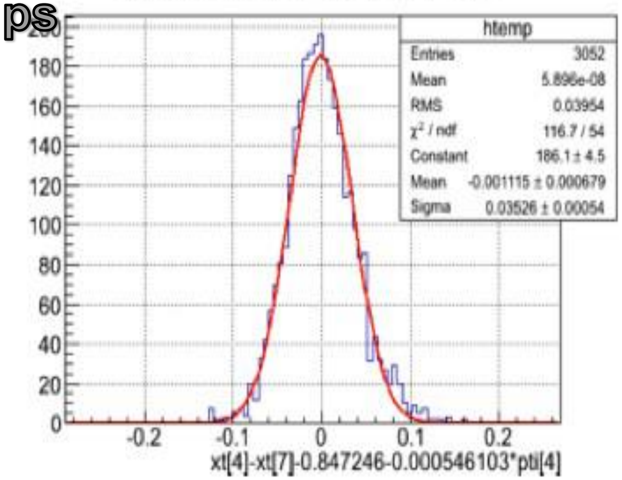


4x5=20 3x3 mm^2 bar elements

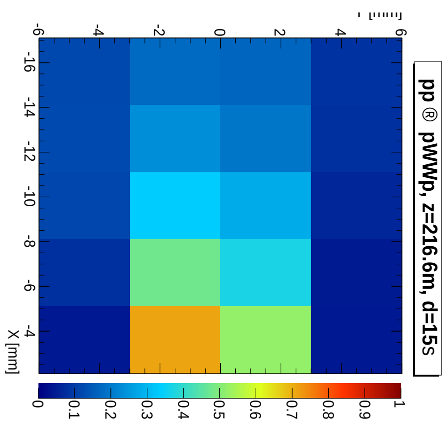


Beam test results:

Time resolution: σ(t)=33 ps



2+2 in-line modules: σ(t)~15 ps



Occupancy for μ=50 pileup

High occupancy causes inefficiency due to overlapping hits (may reach ~40%)

Timing Detectors

R&D on **solid state detectors** as future alternative solutions

Diamonds, LGADs, 3Ds

- Motivations:
  - ➢ solid state detectors may have fine segmentation reducing the channel occupancy
  - ➢ detectors are thin and light, reducing nuclear interactions and allowing a large number of layers N
    $\sigma(t) \sim 1/\mathrm{sqrt}(N)$
  - ➢ state of the art for mip measurement: s(t)~100 ps
    - requires R&D to achieve s(t)~30 ps per layer

Summary

- The joint CMS-TOTEM Proton Precision Spectrometer project will study Central Exclusive Production in p-p collisions, measuring the kinematic parameters of the scattered protons

- To cope with CT-PPS requirements and challenges, new radiation-hard, slim-edge timing and tracking detectors are under development

- Detector baseline: Čerenkov L-bar Quartic detectors for timing
  3D silicon pixel detectors for tracking
- Detector R&D:
  Solid state timing detectors: Diamonds, Low Gain Avalanche Diodes, 3D sensors