Benemérita Universidad
Autónoma de Puebla

Development of online software tools for the TOTEM-CMS Data Acquisition System

Presentation by **Nadia Mariana Leal Reyes**

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XVIII Mexican Workshop on Particles and Fields | November 23rd 2022.

Overview

- Experimental Apparatus
- Objective
- DAQ
- Electronics and Online System
- Control Software for new T2
- Outlook and Conclusion

Experimental Apparatus

TOTEM

The TOTal cross section, Elastic scattering and diffraction dissociation Measurement (TOTEM) is one of the LHC experiments.

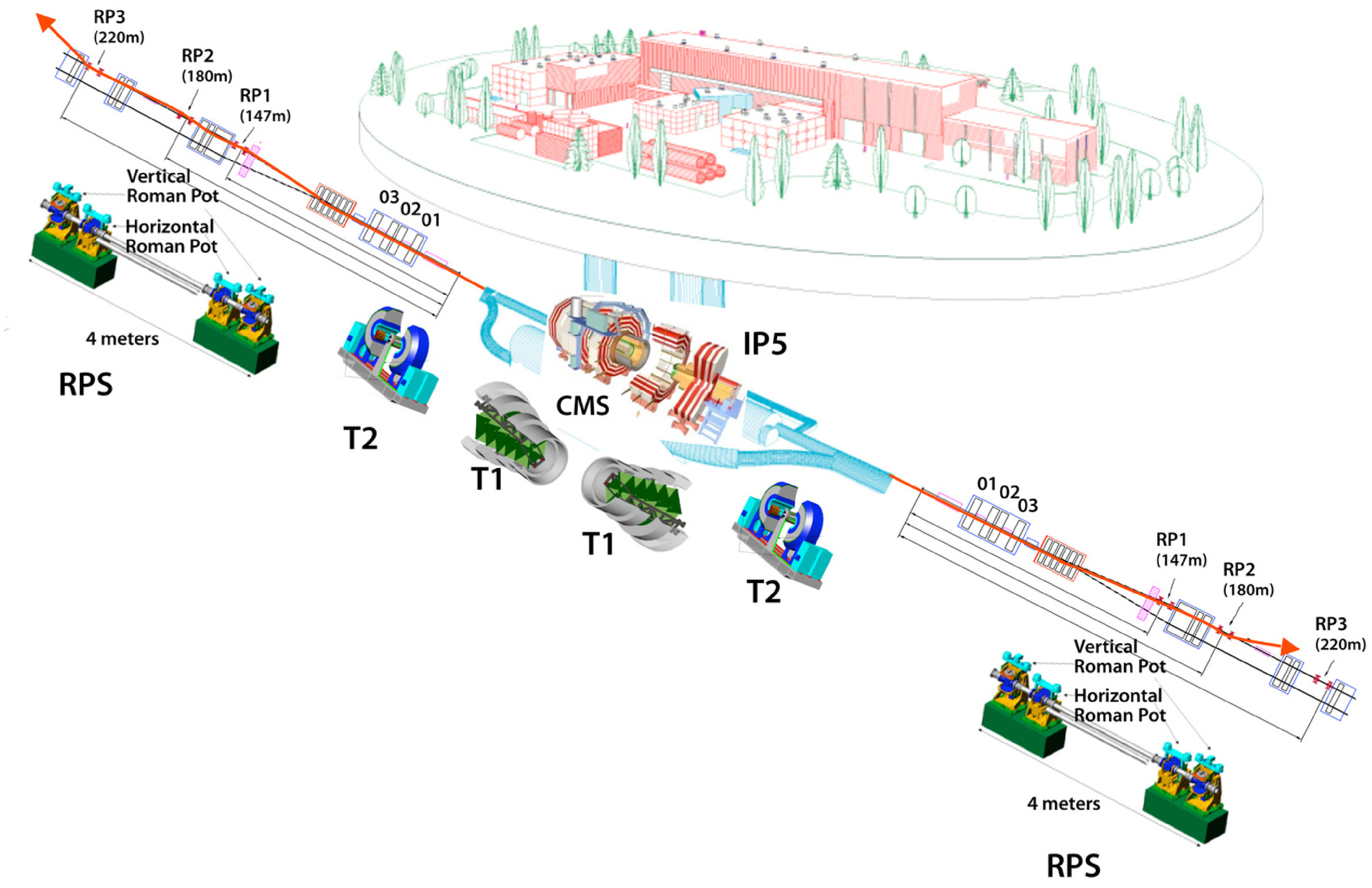


Fig. 1: Schematic diagram of TOTEM's detectors.

“TOTEM and LHCf: refinements for the restart. TOTEM et LHCf: peaufiner le redémarrage”. In: (Aug. 2009), p. 4. url: https://cds.cern.ch/record/1201831

Fig. 2: LHC/HL-LHC Plan of upgrades.

The HL-LHC project | High Luminosity LHC Project.
url:https://hilumilhc.web.cern.ch/content/hl-lhc-project.

During the LS2:

- A new beam pipe was designed and installed on the IP5.
- CMS and TOTEM have upgraded the Roman Pot and moving system, as well as the Telescope 2 (now new T2).

This work focuses on the development of control software for the new T2 detector, which is part of the TOTEM experiment and will be discussed.

new T2

The new Telescope 2 (new T2) is under commissioning. The technology employed for the new T2 is different from the previous detector which was based on GEMs.

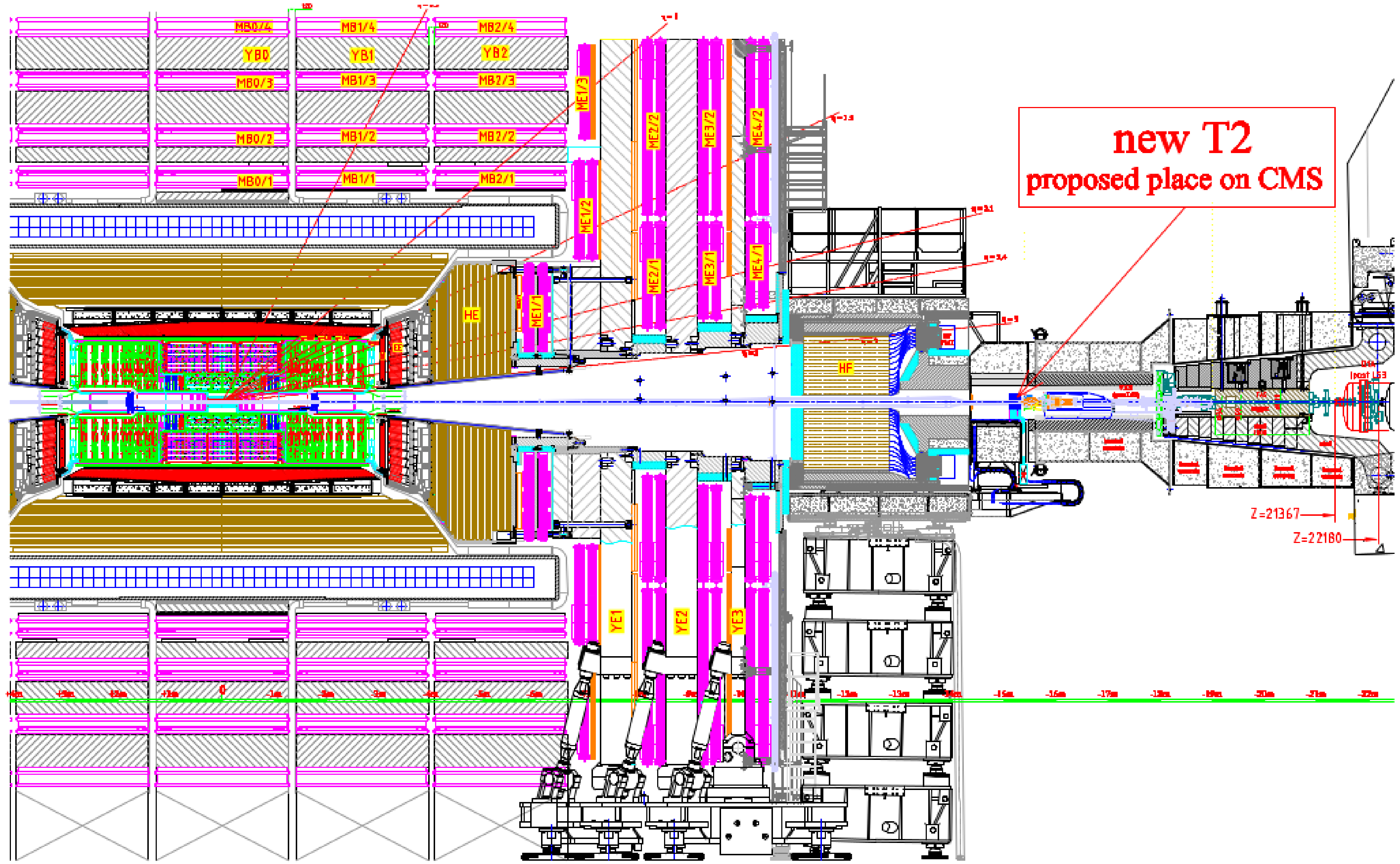


Fig. 3: The CMS experiment longitudinal section indicating the new T2 detector location.

TOTEM Collaboration. Upgrade of the TOTEM T2 Telescope, Technical Design Report. Tech. rep. Geneva: CERN, June 2019. url: https://cds.cern.ch/record/2677468.

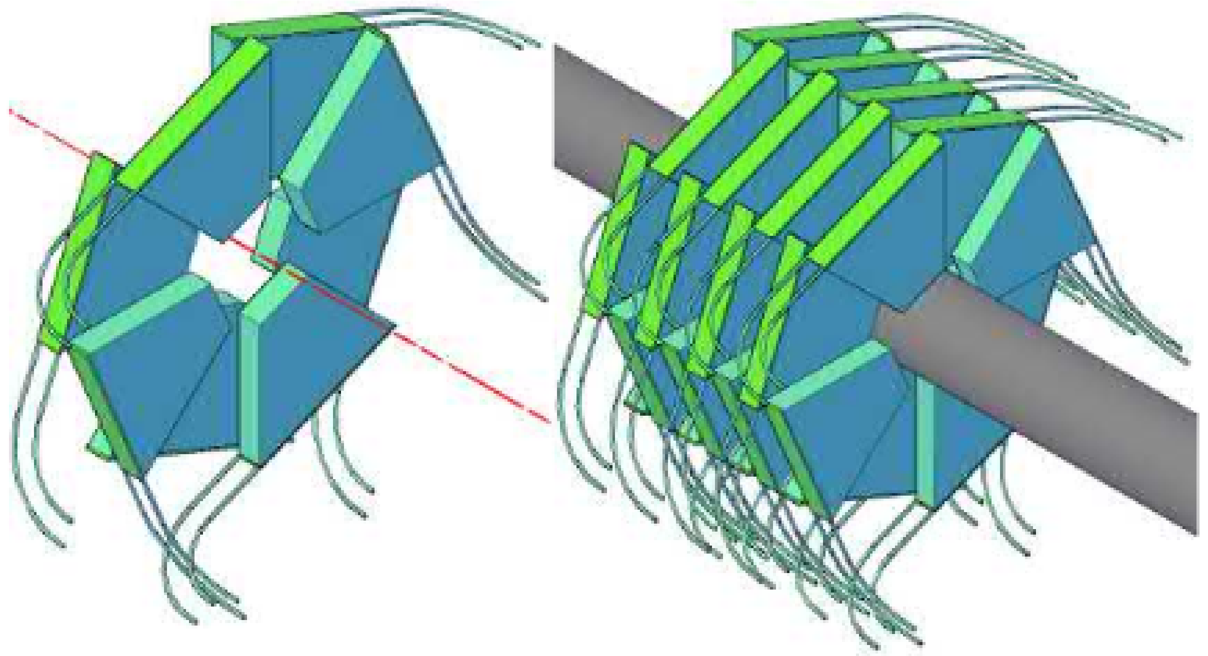


Fig. 4: Scheme of the new T2 single plane of scintillators (left) and the set of scintillators around the beam pipe (right)

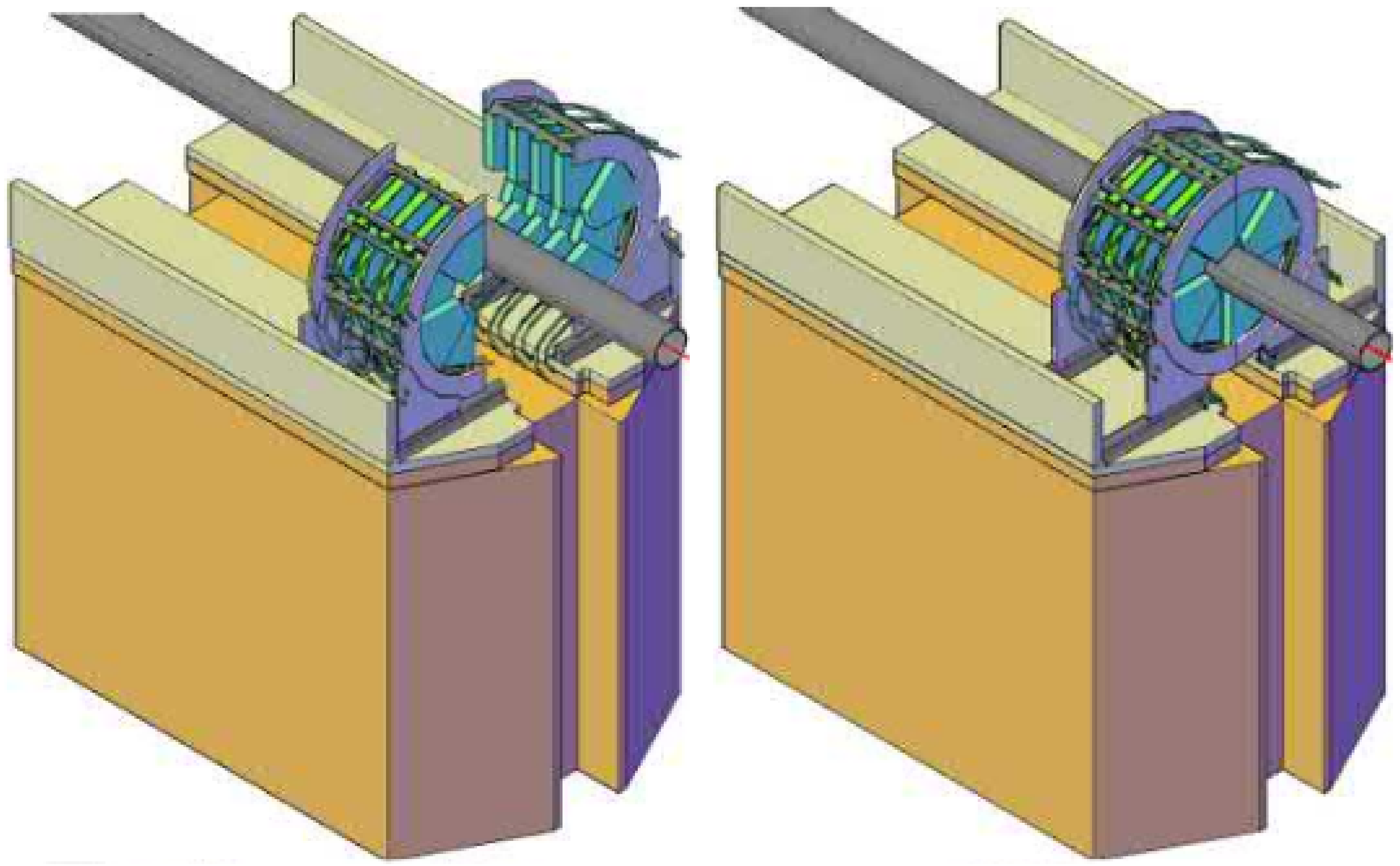


Fig. 5: Scheme of the new T2 detector in its open and closed positions.

TOTEM Collaboration. Upgrade of the TOTEM T2 Telescope, Technical Design Report. Tech. rep. Geneva: CERN, June 2019. url: https://cds.cern.ch/record/2677468.

DAQ

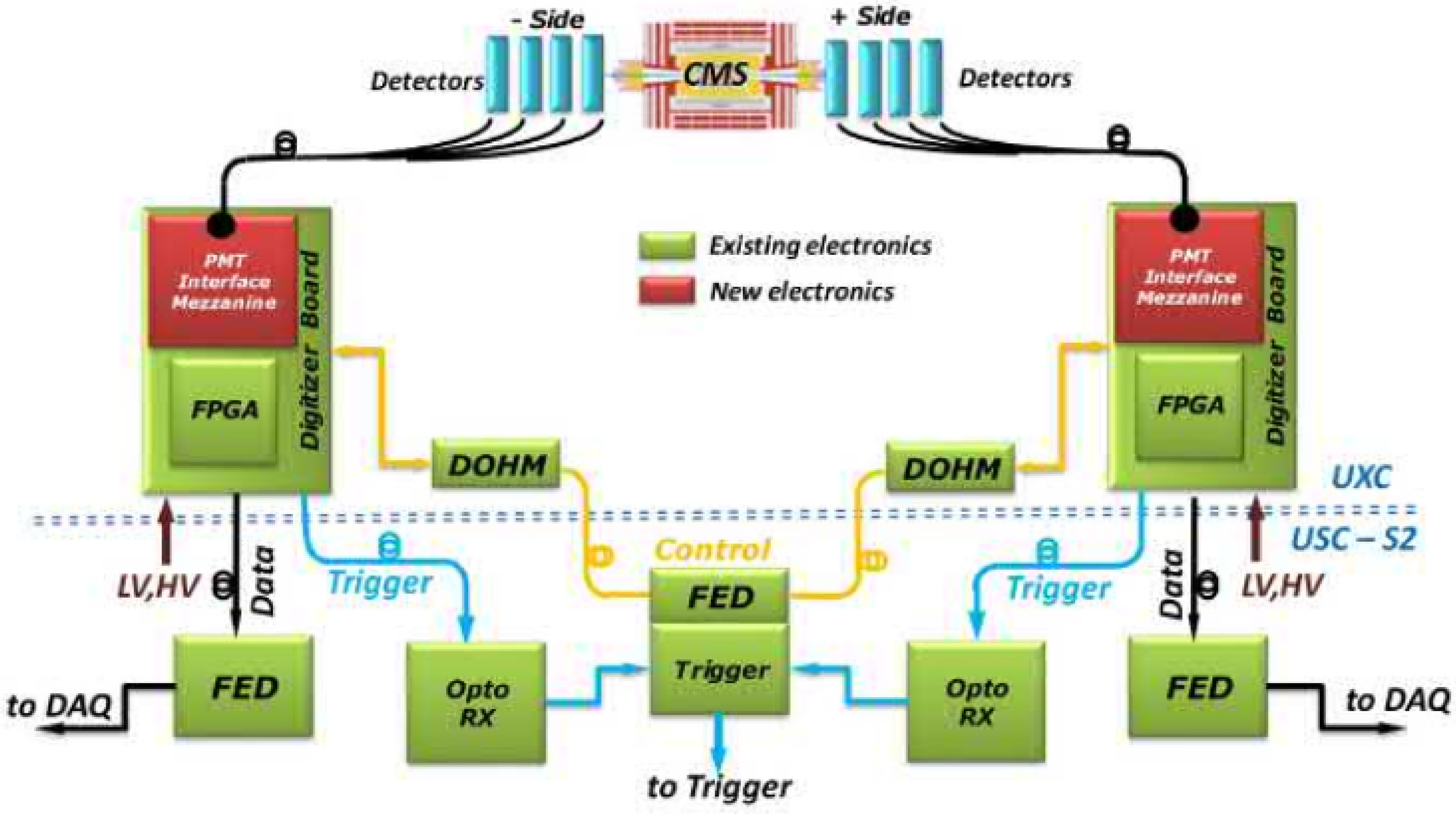


Fig. 6: Schematic representation of the Electronic chain that shows the two quarters and the communication with the Counting room.

TOTEM Collaboration. Upgrade of the TOTEM T2 Telescope, Technical Design Report. Tech. rep. Geneva: CERN, June 2019. url: https://cds.cern.ch/record/2677468.

Roman Pots

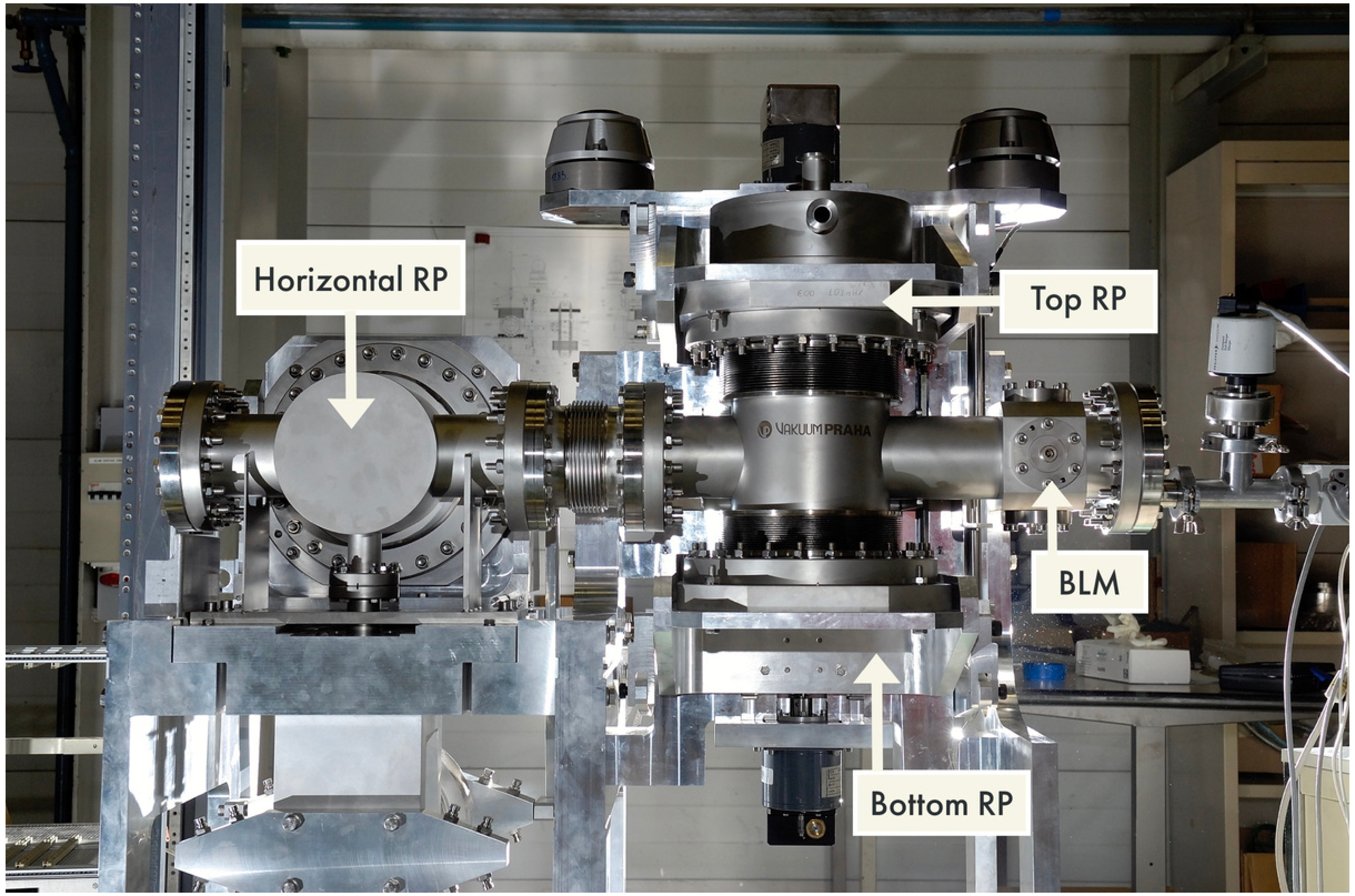


Fig. 7: Photograph of the Roman Pot unit before installation, the three RPs are signaled.

Maximilien Brice. “The Roman Pot for the TOTEM experiment”. Nov. 2006. url: http://cds.cern.ch/record/1001240.

Physics motivation

TOTEM is dedicated to the measurements of the total proton-proton cross-section and the study of elastic and diffractive proton-proton scattering at the Large Hadron Collider.

The inelastic events make relevant contributions to the total cross section. However, the CMS detector only has a coverage of $|\eta| < 4.7$, which is why a complementary inelastic detector like the new T2 with an $\eta = 5.3 - 6.5$ range is really important.

Objective

The development of an online software utility, written in an object-oriented programming language, which controls the new T2 detector through a slow control optical link.

Electronics and Online System

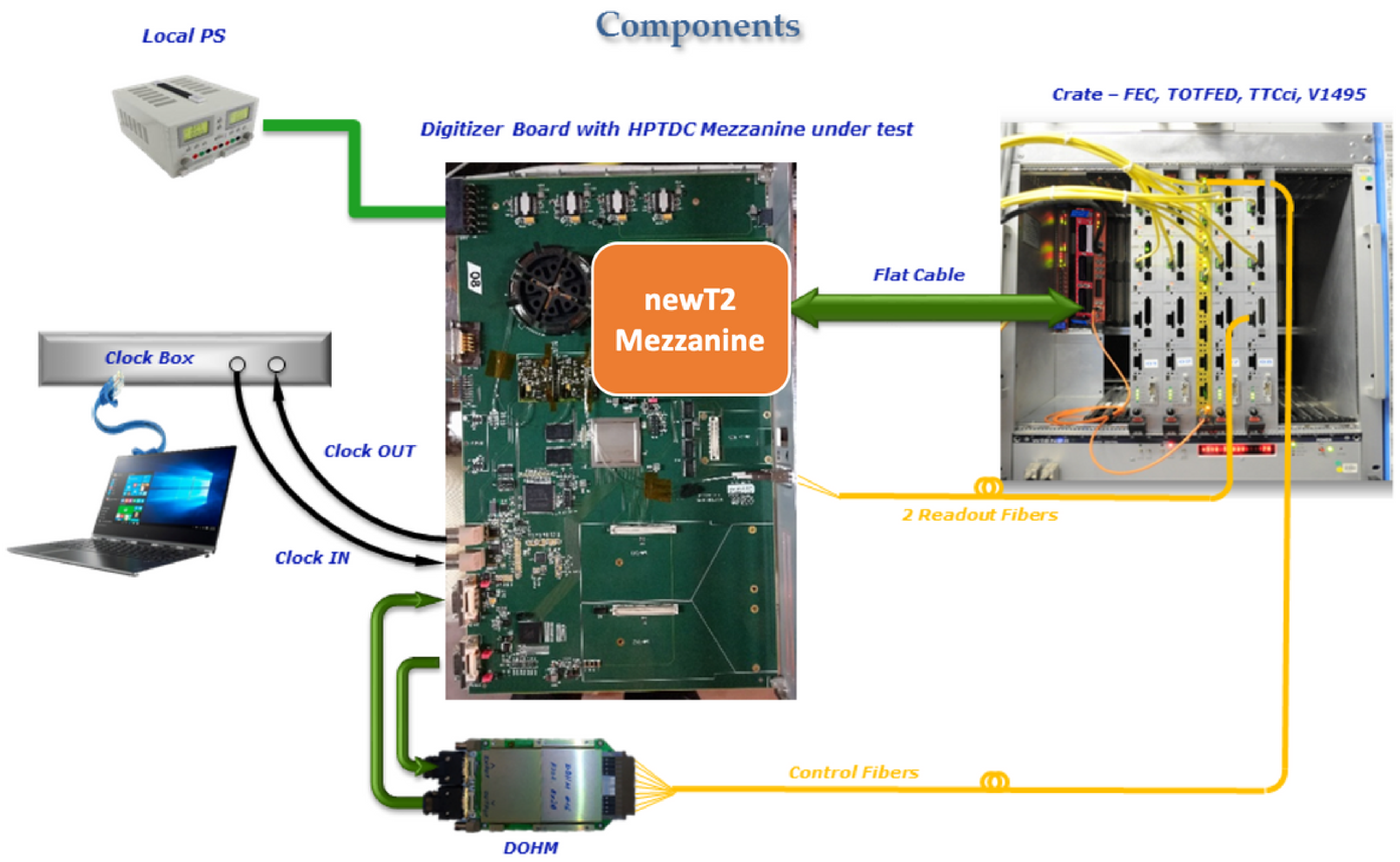
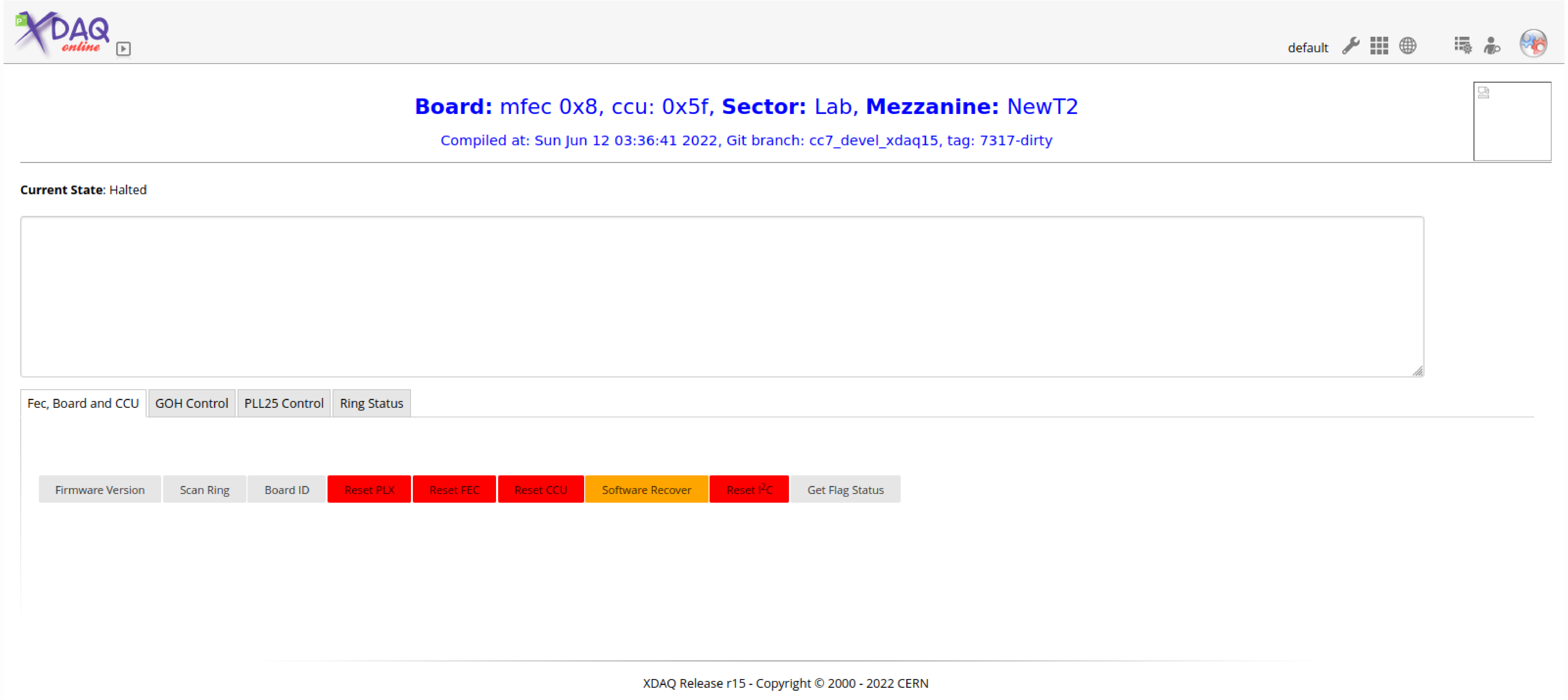


Fig. 8: Scheme of the batch setup for the new T2 software development. The digitizer board is hosting the new T2 mezzanine. The board is controlled through the slow control (an optical link between the FEC VME backend and the DOHM). The commands are sent by a computer to the VME crate controller (Credit: G. Antchev).

The new T2 detector Readout Box is set up in the Radiation Protected Zone in CMS. In this zone, the system can always be powered up and stay non-attended given that the infrastructure against fire and other safety requirements are met.

Control Software for new T2



XDAQ online

default

Board: mfec 0x8, ccu: 0x5f, **Sector:** Lab, **Mezzanine:** NewT2

Compiled at: Sun Jun 12 03:36:41 2022, Git branch: cc7_devel_xdaq15, tag: 7317-dirty

Current State: Halted

```
SCAN RING DEVICE

Probing on FEC 6 ring 8 CCU 0x5f channel 16 address 0x0
Probing on FEC 6 ring 8 CCU 0x5f channel 16 address 0x1
Probing on FEC 6 ring 8 CCU 0x5f channel 16 address 0x2
Probing on FEC 6 ring 8 CCU 0x5f channel 16 address 0x3
Probing on FEC 6 ring 8 CCU 0x5f channel 16 address 0x4
Probing on FEC 6 ring 8 CCU 0x5f channel 16 address 0x5
Probing on FEC 6 ring 8 CCU 0x5f channel 16 address 0x6
Probing on FEC 6 ring 8 CCU 0x5f channel 16 address 0x7
```

Fec, Board and CCU | GOH Control | PLL25 Control | Ring Status

Firmware Version | Scan Ring | Board ID | Reset PLX | Reset FEC | Reset CCU | Software Recover | Reset I²C | Get Flag Status

daq@ttf43:~ | daq@ttf43:~/newt2/controlsoftware/ThirdParty/APIConsoleDebugger

```
bin  command  configure_board  GUIDigitizerBoard.py  images  include  lib  Makefile  newt2_conf.xml  README  ReadoutVMEAnalyzer.py  src
[daq@ttf43 APIConsoleDebugger]$ ./bin/linux/x86_64/ntest.exe --ccu 0x5f --ring 0x08 --slot 0x06 --option scanRingDevice
test, as integer, ccu: 95
ccu: 0x5f
ring: 0x8
slot: 0x6

------------------------
F E C   F U N C   T E S T
------------------------
ATTENTION: GOHRESET for digitizer board version 2.

C O N F I G U R E   D E V I C E

CRATE: vme2818
FecAccess::FecAccess 3
FecAccess::FecAccess adapterslot 0 configurationFile /home/daq/newt2/controlsoftware/generic/config/FecAddressTable.dat vmeBaseAddresses 0x7fff5c96a370 strBusAdapter CAEN2718LinuxPCIBusAdapter numberOfRing 8
FecVmeRingDevice::configureHardBaseAddress (after mutex): returned from createBusAdapter and busAdapter_ is 0x1f80820 (should not be null)
FecAccess::setInitFecAccess
The status register 0 of the FEC 6, ring 7 is not correct 2d44c0
The status register 0 of the FEC 6, ring 6 is not correct 244c0
The status register 0 of the FEC 6, ring 5 is not correct 44d8
VME Fec has been configured
                Scanned Ring Device



S C A N   R I N G   D E V I C E

Probing on FEC 6 ring 8 CCU 0x5f channel 17 address 0x70 ==> Found a register
Probing on FEC 6 ring 8 CCU 0x5f channel 17 address 0x71 ==> Found a register
Probing on FEC 6 ring 8 CCU 0x5f channel 17 address 0x72 ==> Found a register
Probing on FEC 6 ring 8 CCU 0x5f channel 17 address 0x73 ==> Found a register
Probing on FEC 6 ring 8 CCU 0x5f channel 20 address 0x72 ==> Found a register
Probing on FEC 6 ring 8 CCU 0x5f channel 22 address 0x0 ==> Found a register
Probing on FEC 6 ring 8 CCU 0x5f channel 22 address 0x1 ==> Found a register
Probing on FEC 6 ring 8 CCU 0x5f channel 22 address 0x2 ==> Found a register
```

Board: mfec 0x8, ccu: 0x5f, **Sector:** Lab, **Mezzanine:** RPStrip

Compiled at: Sat May 21 08:23:41 2022, Git branch: master, tag: 5575-dirty

Current State: Halted

Fec, Board and CCU | CCU 0x5f | CCU 0x6f | CCU 0x7f | CCU 0x8f | Ring Status

GOH 1	GOH 2	GOH 3			
0	0	0	Set Laser	Read Laser	Reset GOH (V2)

PLL Phase Invert Bit	PLL Phase (0-11)			
0	0	Set PLL Phase	PLL status	PLL reset

Outlook and Conclusion

Coding with a parsing method for controlling the hardware components and then migrating the methods to XDAQ resulted in the new T2 XDAQ interface. The development of an online software utility that controls the new T2 through a slow control optical link, the new T2 XDAQ interface, was presented.

Thank you!

BACKUP

Activities

- Configuring a virtual machine (VM)
- Programming in C++ language, mainly with the use of a parsing method of commands and instructions.
- Parsing parameters from the command line, as well as from a JSON file.
- Migrating the methods for the XDAQ control software.
- Configuring a SSH tunnel to access from outside CERN GN.

Precision Proton Spectrometer (PPS)

CMS subsystem designed for measuring scattered protons.

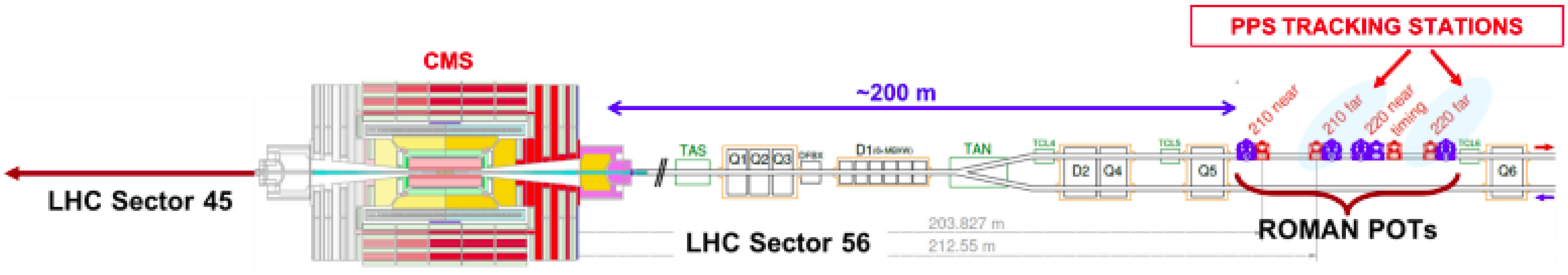
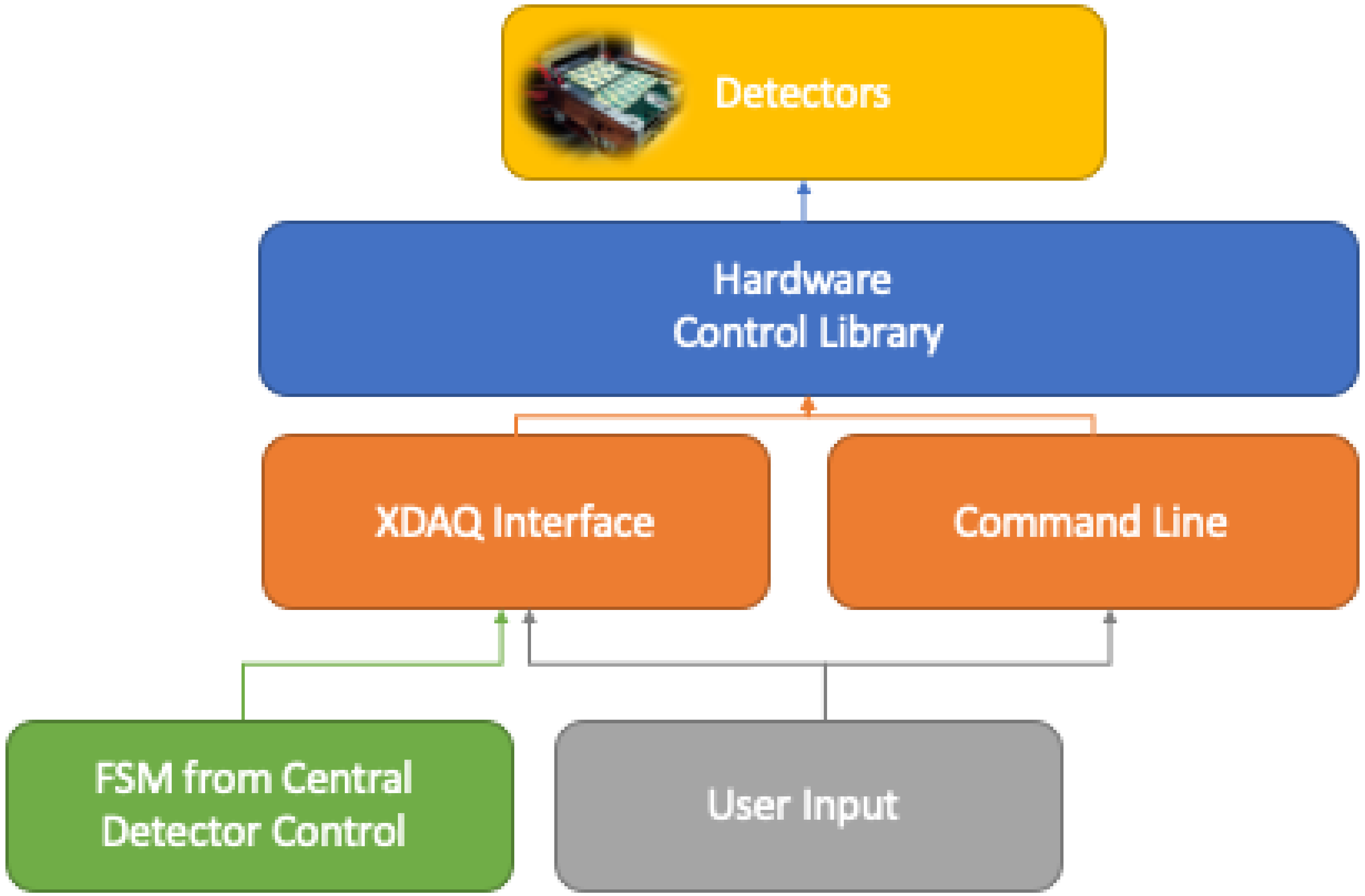


Fig.6: Schematic diagram of one of the LHC sectors where PPS is installed. The timing station is placed between two tracking stations.

E. Bossini. “The CMS Precision Proton Spectrometer timing system: performance in Run 2, future upgrades and sensor radiation hardness studies”. In: JINST 15 (2020).

Option	Action
ScanRingDevice	Scans the ring devices and returns as an output the detected components.
CheckFPGA	Checks the registers.
SetBoardId	Tags a digitizer board with a fixed ID number. The desired Id number needs to be included in the input.
BoardId	Gets the board id.
Configure	Configures the Fec access.
StartRun	Starts the Data acquisition.
StopRun	Stops the Data acquisition.
PLLStatus	Gets the the digitizer board PLL status.
PLLReset	Resets PPL.
PLLPhaseInvert	Inverts the rising edge of the LHC clock.
writeReg	Writes to a specific register. An additional value parameter is needed as input.
readReg	Reads the register.
sendTrigger	Sends a L1A Trigger.
RingReconfigure	Reconfigures the ring (or the slow control).
CCUReset	Resets the CCU and generates a new token.
FecReset	Resets the Fec.
GOHReset	Resets GOH digitizer. PLL lock of GOH.
CheckPowerGOH	Checks the intensity of the GOH.
SetPowerGOL	Sets the GOL power. Additional parameters are needed as input for this option: first and second values.
GetPowerGOL	Reads the intensity of the GOL.
FullGOLProcedure	Additional parameters are needed as input for this option: first and second values.
GetFirmwareVersion	Gets the digitizer board firmware version.
GetFlagStatus	Gets flag status of the digitizer board.
GetGOHStatus	Gets the GOH status.
GetCounters	Gets the counters: trigger, event orbit, and bunch number.
GetConfig	Gets the full board configuration.
SetConfig	Sets the new t2 configuration from a configuration file.
ResetI2C	Releases all the I^2C bus devices communication on the board.


Detectors
Hardware
Control Library
XDAQ Interface
Command Line
FSM from Central
Detector Control
User Input

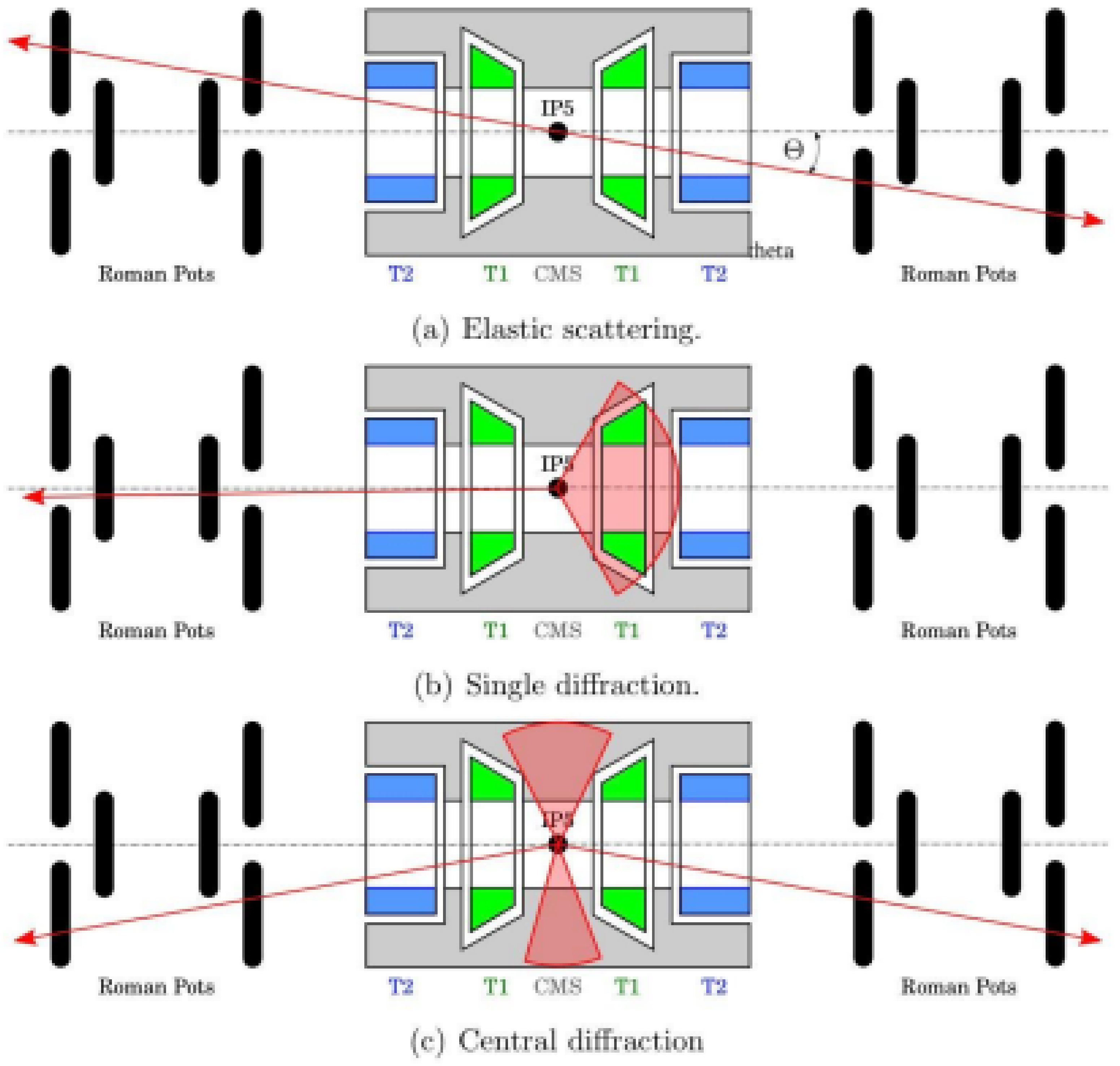
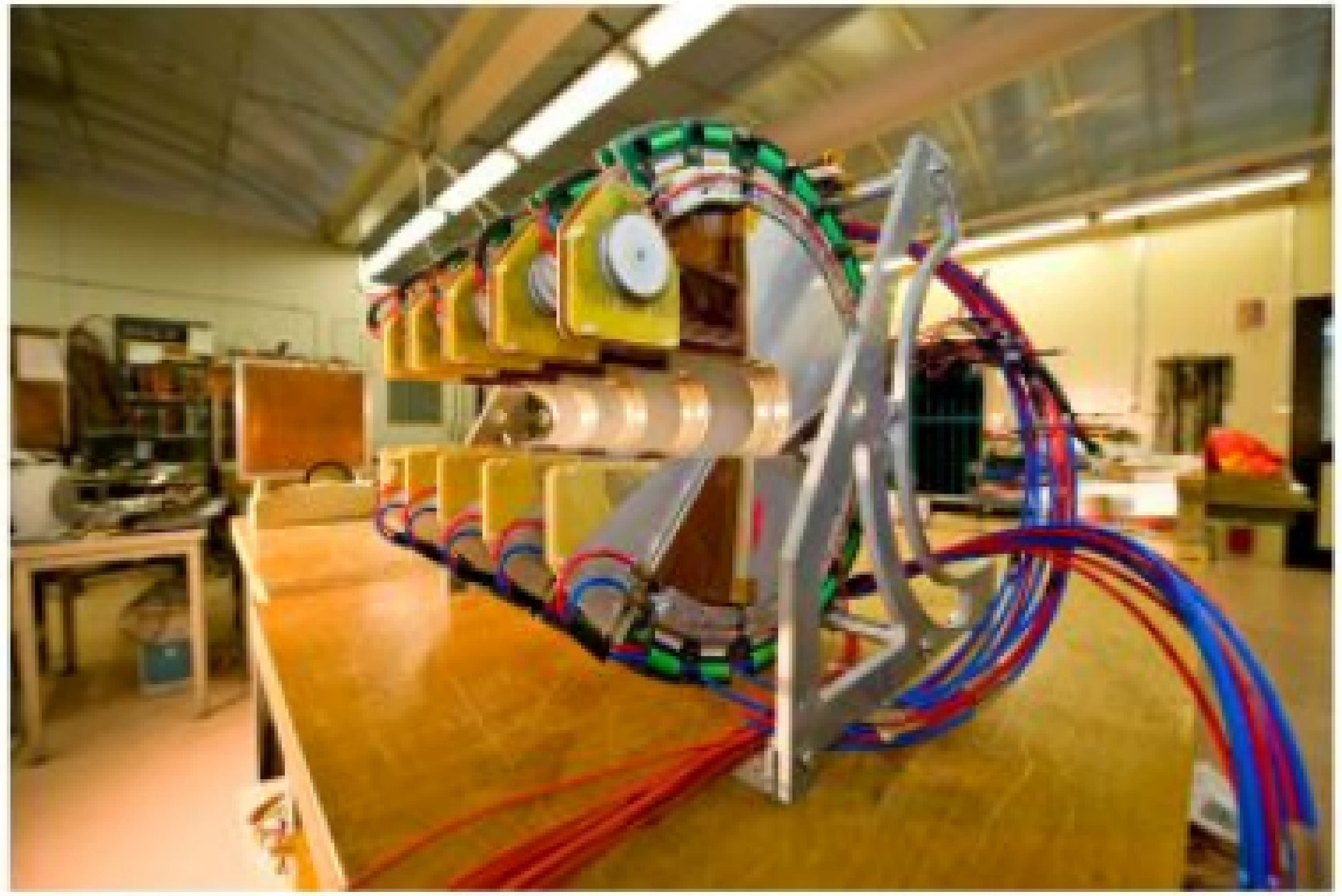


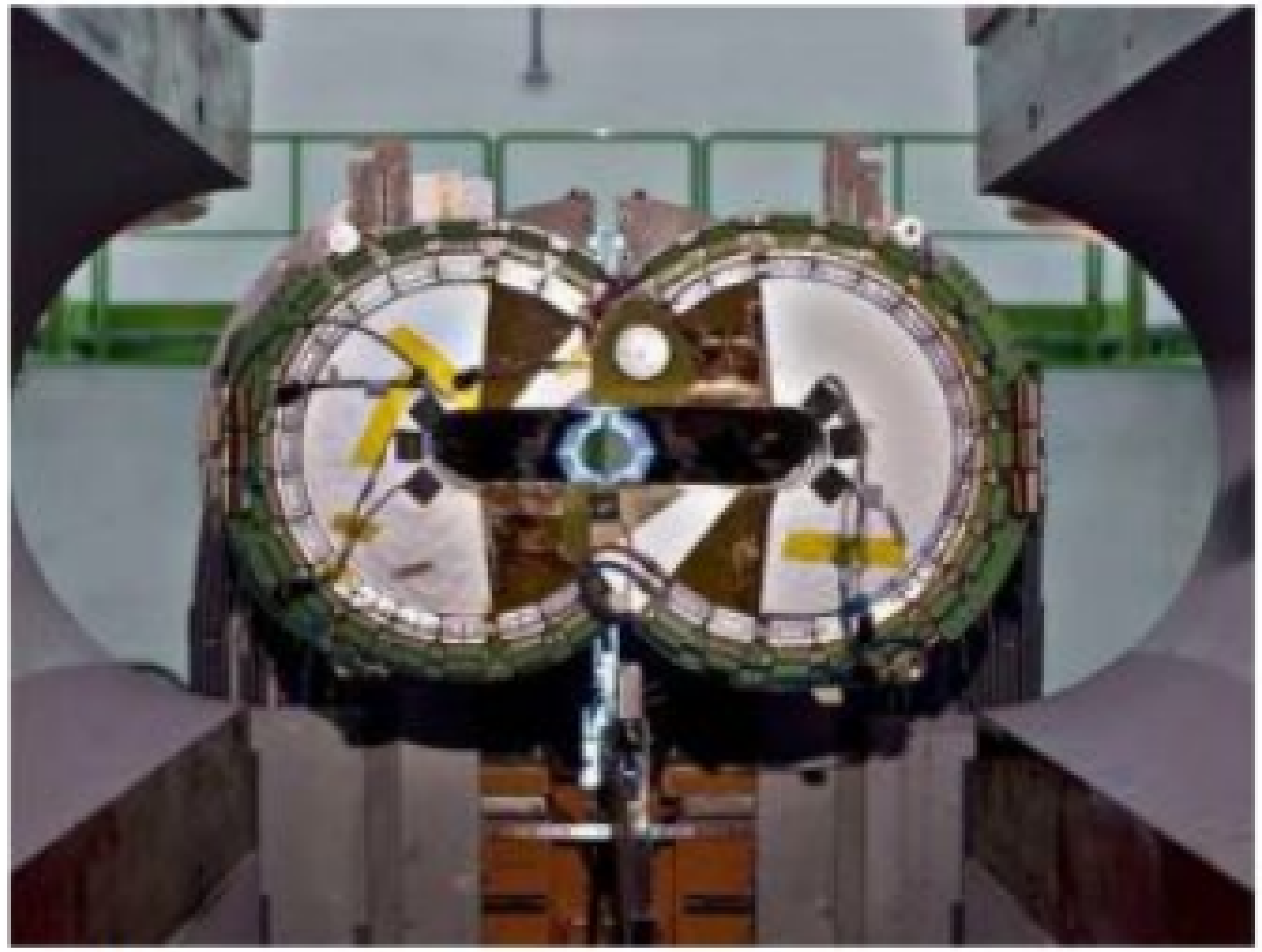
Fig. : Schematic diagram of three types of measurement scenarios conducted by TOTEM

Josef Kopal. “Development of the TOTEM Trigger System”. Presented 04 Mar 2015. 2014. url: https://cds.cern.ch/record/2688184.

T2 detector



(a) One quarter of the T2 detector on a laboratory table. All five planes are made of a single piece of Gas Electron Multiplier (GEM) detector.

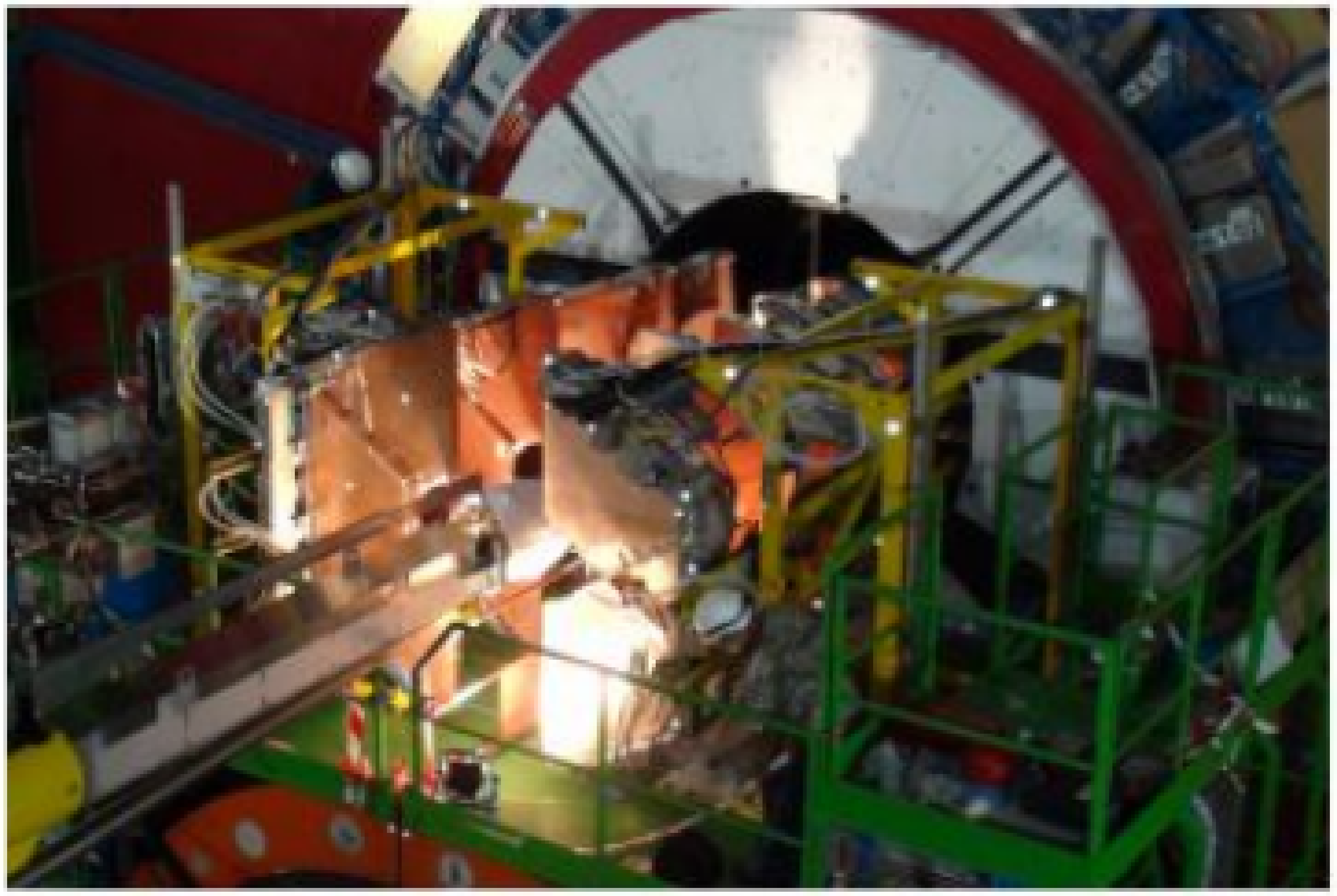


(b) Two quarters of one arm of T2 before closing at the end-cap of CMS. In the middle, there is the beam pipe.

Josef Kopal. "Development of the TOTEM Trigger System". Presented 04 Mar 2015. 2014. url: https://cds.cern.ch/record/2688184.

T1 detector

(a) One quarter of the T1 detector stored in the laboratory waiting for its installation. You can see 5 detectors planes surrounded by the read out electronics. All five planes are made of three individual Cathode Strip Chamber (CSC) detectors.



(b) The Telescope 1 during its installation to the end-cap of CMS. The two quarters of the telescope are opened. The beam pipe is visible in the middle.

Josef Kopal. "Development of the TOTEM Trigger System". Presented 04 Mar 2015. 2014. url: https://cds.cern.ch/record/2688184.

Tracking RPs

Strips: This technology is still used in the vertical RPs that only operate during the alignment or during special low luminosity runs. The strip detectors are conformed by 10 planes of edgeless silicon strip sensors, each plane is made up by 512 strips and have a pitch of 66 m. Five of the planes are oriented at a +45° angle and the other five at -45° thus forming five "double-planes" as they are placed orthogonally back-to-back.

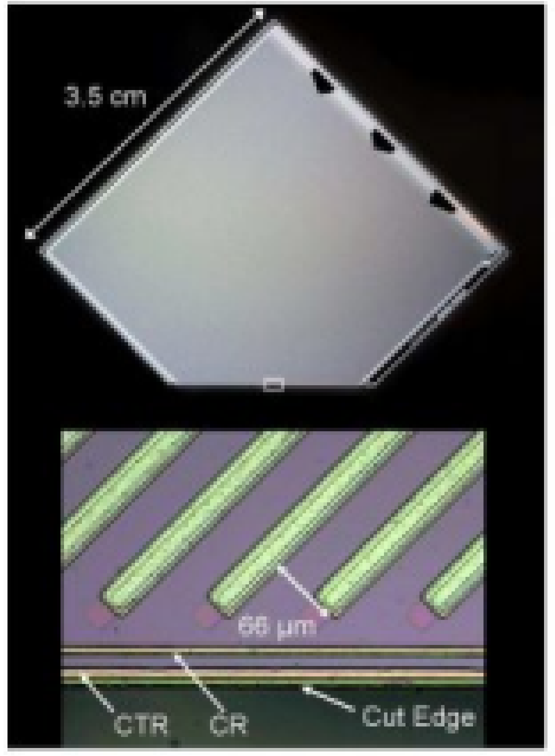
3D Pixels: Throughout the years the strips on the horizontal detectors were replaced by 3D pixel sensors in the horizontal RPs. The 3D pixel sensors where chosen as the main technology for tracking due to their radiation hardness and the prospect to minimize the insensitive edge area by implementing slim edges.

RP Timing system

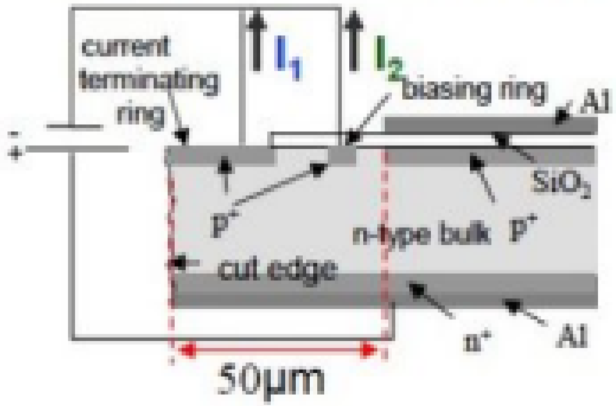
For the timing system two detector technologies have been used for pile-up rejection: artificial single-crystal diamonds (scCVD) and Ultra Fast Silicon Detectors (UFSD). The pile-up rejection is important as the Precision Proton Spectrometer has to operate in a high luminosity environment with up to 60 pile-up interactions per bunch crossing. This system allows PPS to correlate the protons measured with the vertex CMS reconstructed.

Diamond detectors were used for data-taking in 2016 and in 2017, they were used along UFSDs, of the four detector planes that are in each timing station three planes consisted of diamonds and one of UFSDs. In the 2018 data-taking period the diamond detectors were used again and the use of this technology has been confirmed for the upcoming Run 3. As these detectors present intrinsic radiation hardness they are expected to withstand well the conditions they are going to be exposed to in PPS.

Tracking detector - Silicon strips



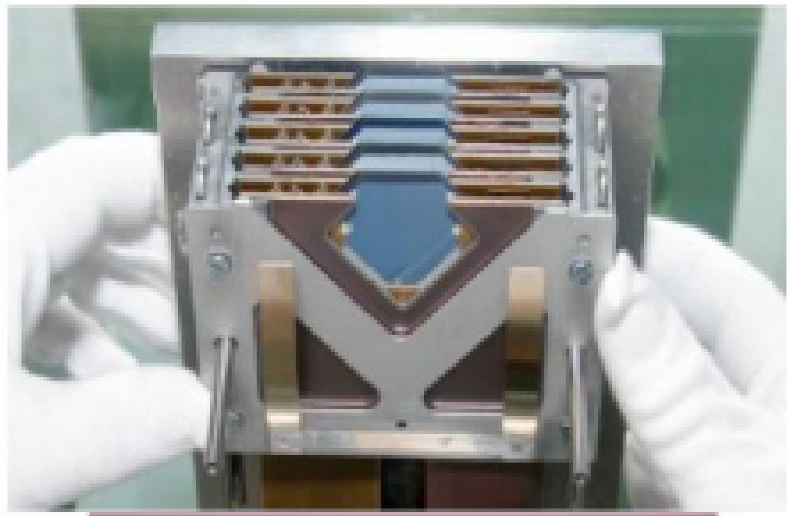
Planar technology + CTS
(Current Terminating Structure)

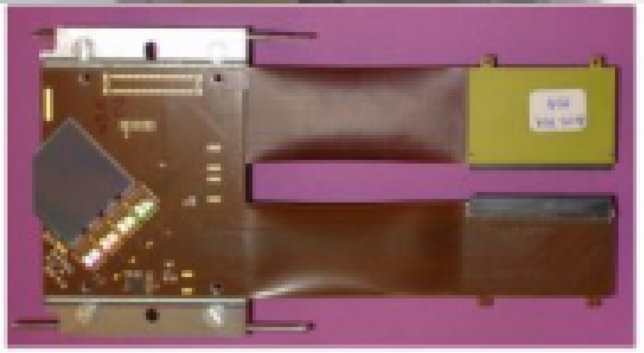


Same detectors used by the TOTEM experiment[*]

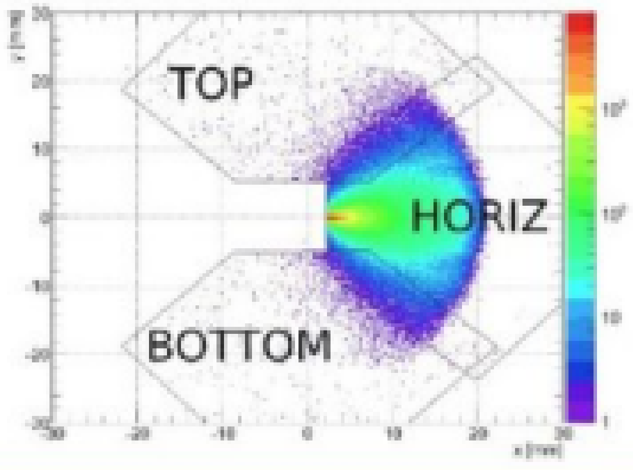
10 planes per pot of silicon strip detectors

- Micro-strip silicon detectors with edgeless technology (inactive edge ~50 µm)
- 512 strips at ±45°
- Pitch: 66 µm
- Digital readout provided by VFAT2 chips
- Lifetime up to an integrated flux of 5×10^{14} p/cm^2
  - → too low for PPS requirements, detector pushed to its limit
- Hit/track reconstruction using consolidated TOTEM algorithms (software fully integrated in CMS official software)
- No multitrack capability
- Track resolution ~12 µm

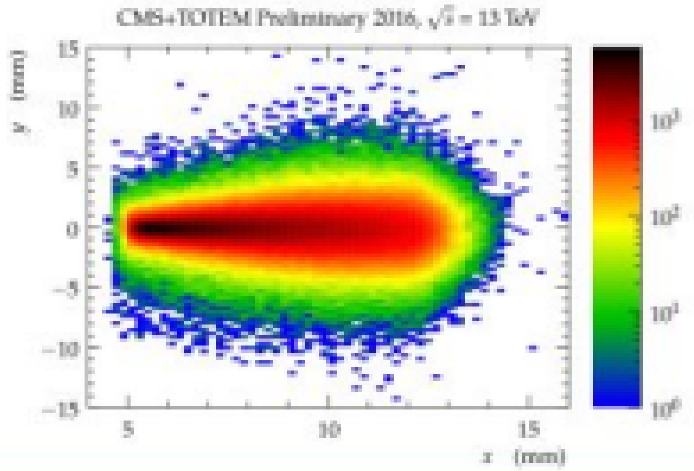




Simulation

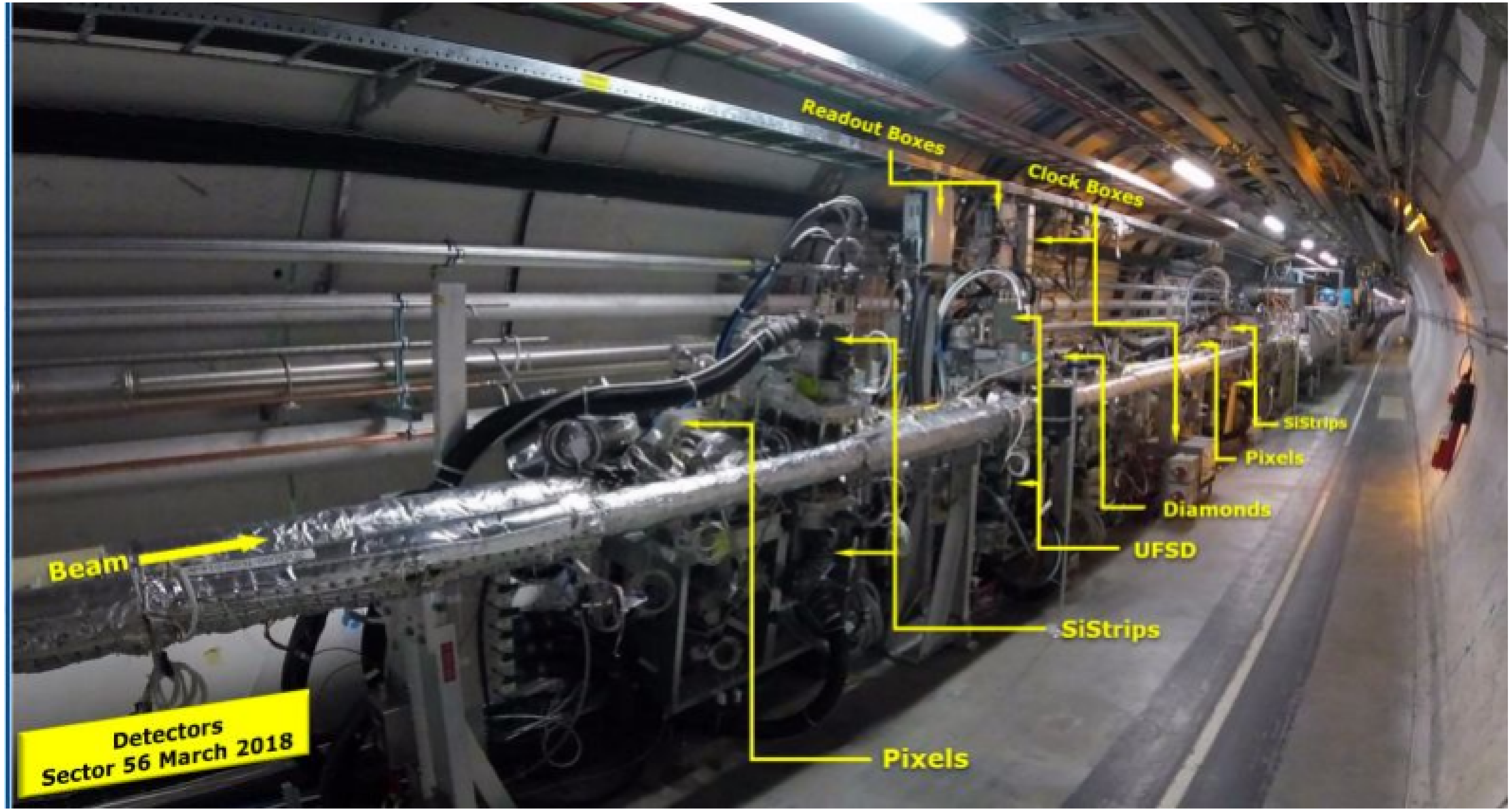


Data



[*] TOTEM Coll., JINST 3 (2008) S08007

A. Solano. “The Precision Proton Spectrometer of CMS: Performance in Run2 and prospects for Run3”. LOWX 2021. URL: https://indico.cern.ch/event/713101/contributions/3102240/attachments/1705601/2748103/Solano-PPS_DIFLOWX2018.pdf



Credit: D. Figueiredo

Coincidence Chip

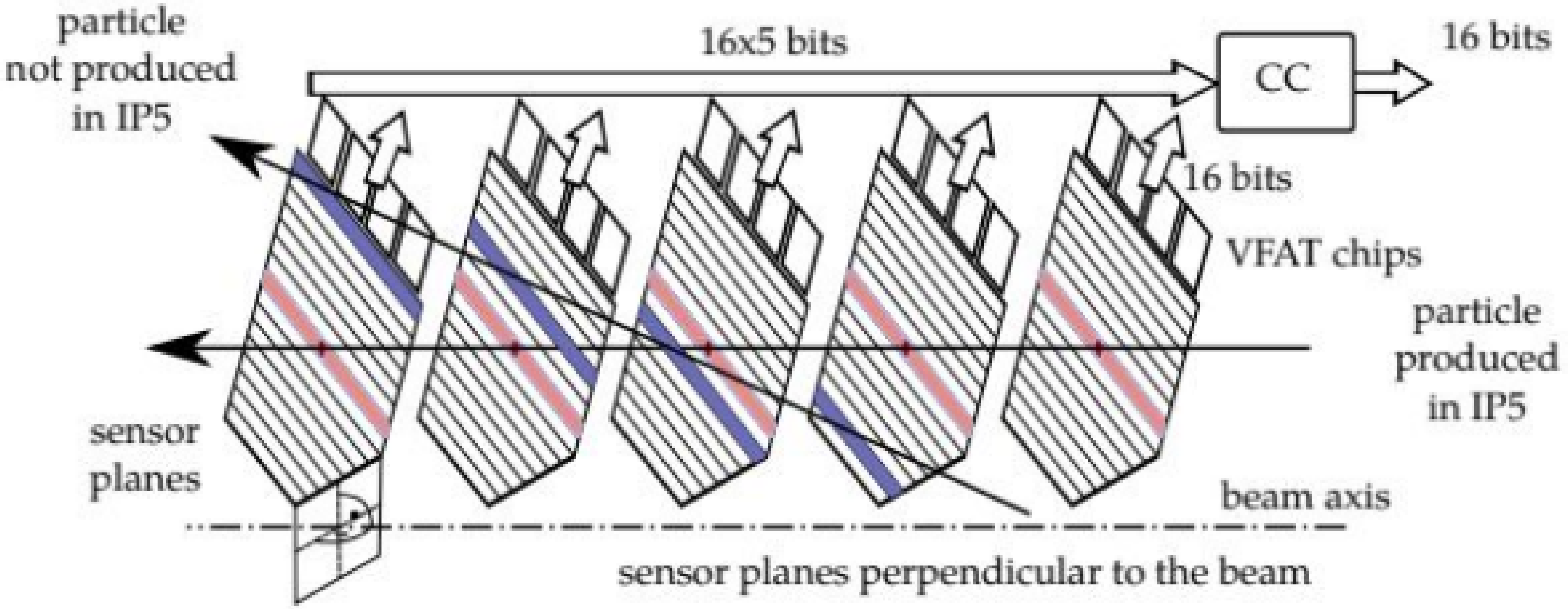


Figure 2.4: Function of the coincidence chip. The Coincidence Chip takes into account positions of activated areas in the set of planes. If a predefined number of active sectors corresponding to the same row in the plane set is found then the trigger signal is propagated.

Josef Kopal. “Development of the TOTEM Trigger System”. Presented 04 Mar 2015. 2014. url: https://cds.cern.ch/record/2688184.