Yellow Report

Chapter 9
Detectors

J. Baechler - LHC Physics WG meeting,
Madrid 22.4.2015

CONTENT – Chapter 9 (1)

CONTENT – Chapter 9 (2)

Introduction (1)

Chapter 9

Detectors

The following paragraphs describe the detector systems of the different LHC experiments optimized for the forward physics program as outlined in previous chapters of this report. Already existing detectors are described shortly, or a reference to the detailed articles [1] is given. The newly developed components that have been integrated during the long shutdown 1 (LS 1) and the ongoing R&D activities are described in more detail with possible reference to the corresponding technical design reports (TDRs) or upgrade proposals. The forward detector systems can in general be separated in two different types, the movable beam inserts with detectors and the standard detectors that are integrated in the central detector or installed in the LHC tunnel.

Movable beam inserts with detector sensors

The detector carriers which are integrated in the LHC beam tube and enter into the LHC beam vacuum are generically called “movable beam inserts”. These beam inserts carry the detector sensors for tracking or timing and allow the approach of the sensor to a distance down to a millimetre from the beam center. The movable beam inserts have to comply with LHC requirements in view of impedance, ultra high vacuum and safety. The material budget plays an important role, as a fraction of the secondary particles which are generated by interaction of high energy particles with the material of the movable beam inserts are scattered in the material of the supra conducting LHC magnets close by. The beam insert design is universal and can be used in the different corresponding locations of the LHC machine.

The specific LHC optics generates a specific particle occupancy pattern in the sensors integrated in the movable beam inserts, depending on both, the distance of the sensor relative to the corresponding interaction point and the location in the tunnel (experiment). For each experiment and location, the size and pixelization of the sensor is specific and optimized accordingly and differs strongly for the high and low β^* optics. The insertion of the beam inserts is a complex procedure requiring the close collaboration with the LHC collimator experts and the operators in the LHCC control room. In this sense the movable beam inserts become an integral element of the LHC machine.

The movable beam inserts are also present in the parking position during the standard runs and interfere with the LHC machine mostly due to their impedance. The beam-induced heating of the movable beam device can lead to local vacuum degradation and thus create perturbations of the machine operation during the energy ramp-up phase and the later stable operation of the LHC machine.

Introduction (2)

Standard detectors

The standard detector for LHC forward physics can be either integrated in the central detector of an LHC experiment, or in the tunnel of LHC, outside of the vacuum beam pipe. The operation of these detectors is in the autonomy of the experiment.

Considerations for the Design and Operation of Forward Detectors at LHC with High and Low β^* Optics

Certain physics observables require that the forward detector information is combined with that of the corresponding central detector. In this case the synchronisation of the specific forward detector systems with the central detector needs to be considered in the design of the trigger and data acquisition. The distance of up to 250 m from the forward detectors to the central detectors requires fast signal transmission and precision clock distribution systems. An important impact on the detector design and general layout is given by the machine settings. The physics programme outlined in Chapter?? of this report specifies

the different LHC beam optics, beam parameters and instantaneous luminosity for the measurement of a given physics variable. The requirements for the operation of detectors and movable beam inserts at low and high β^* are quite different.

The LHC beam intensity setting and instantaneous luminosity for the special runs (high β^*) will be defined by the forward physics community in agreement with the LHC operation group, while the integral time for these special runs is subject to negotiation with the LHC scientific management of CERN.

For high β^* runs, the integral luminosity per run and the integral beam time per year is much lower with respect to the standard runs, leading to significantly lower instantaneous and integral radiation exposure to ionizing and non-ionizing radiation of the dedicated detectors and carriers. However, forward tracking detectors optimized in view of radiation hardness and multi-track resolution combined with

ATLAS ALFA

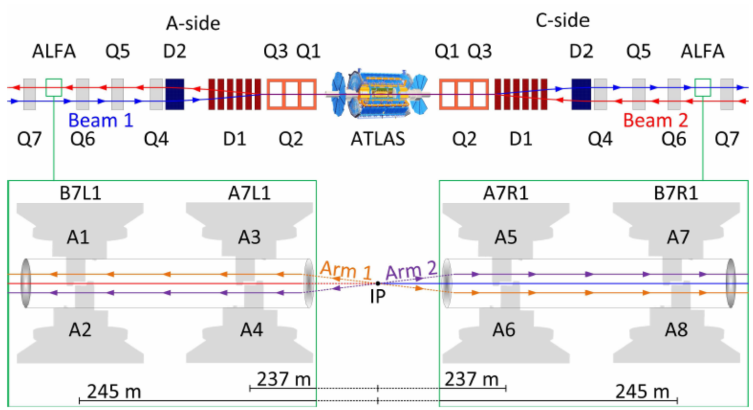


Fig. 9.2: A sketch of the experimental set-up, not to scale, showing the positions of the ALFA Roman Pot stations in the outgoing LHC beams, and the quadrupole (Q1–Q6) and dipole (D1–D2) magnets situated between the interaction point and ALFA. The ALFA detectors are numbered A1–A8, and are combined into inner stations A7R1 and A7L1, which are closer to the interaction point, and outer stations B7R1

Fig. 9.3: Three of the main modifications implemented to minimise the effect of RF. From left to right: the RP filler with the copper contacts for proper grounding, the ferrites distributed as a ring on the flange of the station and the HDS (heat distribution system) in copper with the temperature probes attached to it.

Roman Pot
consolidation & upgrade strategy

CONSOLIDATION -> LS1

- Remove RP147 m stations & patch panel (allows installation of TCL4)
- Relocation of RP147 m stations (including Si strip detectors) in +/- 210 m region
- Exchange of ferrites of all RPs, Integration of ferrite support spring

Consolidation RP147&RP220 -> during LS1

UPGRADE - Roman Pot station –> LS1

- Installation of additional new RP stations (horizontal) in +/-220 m region (1 RP stations in each sector (4/5), (5/6))
- Integration of RF optimized horizontal Roman Pots in relocated horizontal stations in +/- 210 m region

Upgrade Roman Pot station -> during LS1 or **In end of year technical stops after LS1** (break of vacuum)

UPGRADE – new movable beam pipe devices –> after LS1

- Development of new movable beam pipe devices

Upgrade movable beam pipe devices -> after LS1 (break of vacuum)

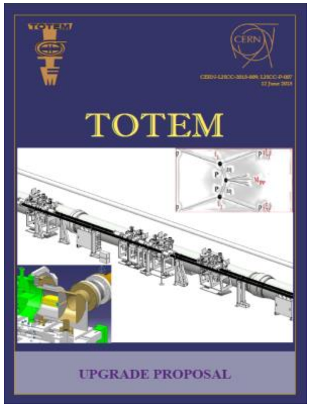
UPGRADE detector -> after LS1

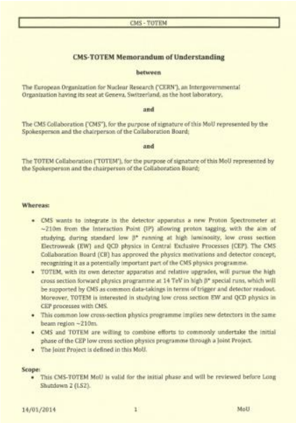
- Integration of new pixel detectors in the (relocated RP147m) RPs in 210 m region
- Integration of new timing detectors in the new horizontal RPs

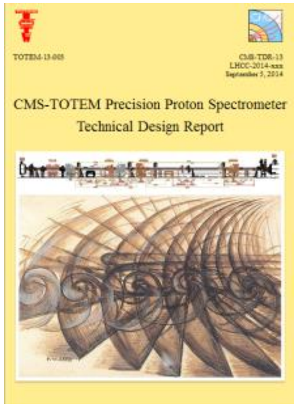
Upgrade Roman Pot detector -> during LS1 or in short technical stops **after LS1**

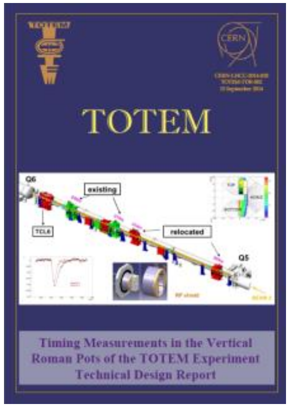
ROMAN POT: Milestones during LS1

LHCC









March 2013

June 2013
consolidation
& upgrade

January 2014
CMS-TOTEM
MoU

September 2014
TOTEM timing TDR
CT-PPS TDR

November 2014

March 2015
Restart LHC
Run 2

LHC LS1 access for RP installation

August 2014

DP Si operation
& RP movement &
calibration & interlock LHC

Cooling & vacuum
tests

RP operation with DAQ

RP operation from CCC

commissioning

Timing detector R&D
Test beams at CERN (PS,SPS) & PSI

All Components integrated in the LHC beam line by August 2014

ENGINEERING CHANGE REQUEST

Installation and Renaming of Absorbers for Physics Debris (TCL type collimators) on both sides of IP1 and IP5 in front of D2/Q4

BRIEF DESCRIPTION OF THE PROPOSED CHANGE(S):

It is proposed to install TCL4 (TCL type) collimators in the forward regions of IR1 and IR5, in front of D2/Q4 cryostats. These collimators were built as part of the present LHC collimation system and their installation was delayed to allow the operation of the "close" TOTEM Roman pot stations in IR5.

ENGINEERING CHANGE REQUEST

Installation of Physics Debris Absorbers (TCL) on both sides of IP1 and IP5 in front of the Q6 Quadrupole

BRIEF DESCRIPTION OF THE PROPOSED CHANGE(S):

It is proposed to install TCL, physics-debris collimators, on both sides of IP1 and IP5 in front of the Q6 Quadrupole (TCL6). This request follows the ECR EDMS Doc. 1283867 where the preparation of the TCL6 infrastructure was proposed and approved. This proposal to install the TCL6 is now brought forward taking into account the latest information on collimator production schedule and results of simulations that were deemed necessary before taking the final decision.

ENGINEERING CHANGE REQUEST

TOTEM Consolidation Project

BRIEF DESCRIPTION OF THE PROPOSED CHANGE(S):

The TOTEM Roman Pot (RP) stations that were installed on the outgoing beam at a distance of 147m on both sides of IP5 have been de-installed. TOTEM proposes to move these stations to 210 m (between Q5 and Q6) on both sides of IP5, so that after LS1 the TOTEM setup will contain a new 210 m station with a near and far unit in addition to the existing 220m station. The new 210 m far unit will be rotated by 8° around the axis of the beam. To foresee the later addition of timing detector units, TOTEM proposes to add one piece of dummy beam pipe between the existing near and far units of the 220m station.

ENGINEERING CHANGE REQUEST

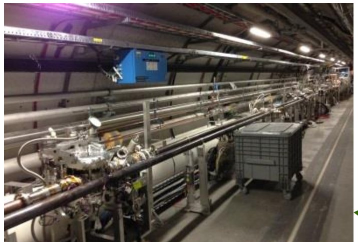
TOTEM Upgrade Project

BRIEF DESCRIPTION OF THE PROPOSED CHANGE(S):

The TOTEM Upgrade Proposal [1] foresees the installation of additional horizontal Roman Pots (RPs) between the existing RP units at 215 and 220 m from IP5. These new RPs, intended to house time-of-flight detectors for elastically or diffractively scattered protons, have been designed in cylindrical geometry minimising the beam impedance and offering enough space for 12 cm long Cerenkov detectors, one of the technologies being explored for the time measurement.

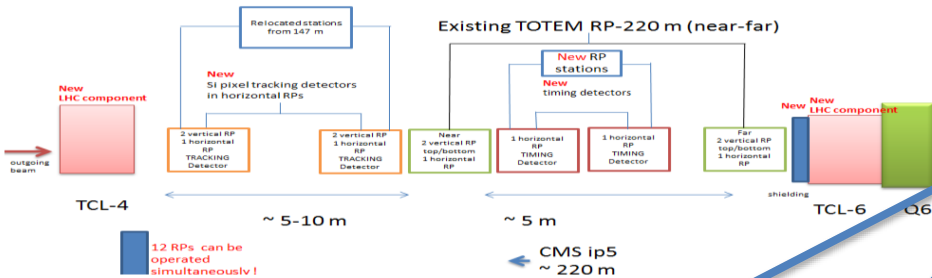
Furthermore, the existing horizontal RPs of the units at 203 and 213 m will be equipped with Faraday shields to reduce their impedance.

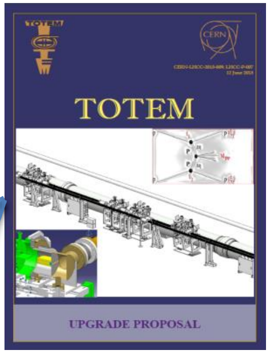
This ECR elaborates on the technical details of the new RP elements and their integration in the LHC. It thus complements the already approved consolidation ECR [2].



ECRs related to consolidation & upgrade @LHC ip5

Roman Pot consolidation & upgrade overview (schematic)





LHC

EDMS NO.	REV.	VALIDITY
1283826	1.0	RELEASED

ENGINEERING CHANGE REQUEST

Installation and Renaming of Absorbers for Physics Debris (TCL type collimators) on both sides of IP1 and IP5 in front of D2/Q4

BRIEF DESCRIPTION OF THE PROPOSED CHANGE(S):

It is proposed to install TCL4 (TCL type) collimators in the forward regions of IR1 and IR5, in front of D2/Q4 cryostats. These collimators were built as part of the present LHC collimation system and their installation was delayed to allow the operation of the "close" TOTEM Roman pot stations in IR5.

TOTEM

EDMS NO.	REV.	VALIDITY
1314925	1.0	RELEASED

ENGINEERING CHANGE REQUEST

TOTEM Consolidation Project

BRIEF DESCRIPTION OF THE PROPOSED CHANGE(S):

The TOTEM Roman Pot (RP) stations that were installed on the outgoing beam at a distance of 147m on both sides of IP5 have been de-installed. TOTEM proposes to move these stations to 210 m (between Q5 and Q6) on both sides of IP5, so that after LS1 the TOTEM setup will contain a new 210 m station with a near and far unit in addition to the existing 220m station. The new 210 m far unit will be rotated by 8° around the axis of the beam. To foresee the later addition of timing detector units, TOTEM proposes to add one piece of dummy beam pipe between the existing near and far units of the 220m station.

LHC

EDMS NO.	REV.	VALIDITY
1357736	0.1	DRAFT

ENGINEERING CHANGE REQUEST

Installation of Physics Debris Absorbers (TCL) on both sides of IP1 and IP5 in front of the Q6 Quadrupole

BRIEF DESCRIPTION OF THE PROPOSED CHANGE(S):

It is proposed to install TCL, physics-debris collimators, on both sides of IP1 and IP5 in front of the Q6 Quadrupole (TCL6). This request follows the ECR EDMS Doc. 1283867 where the preparation of the TCL6 infrastructure was proposed and approved. This proposal to install the TCL6 is now brought forward taking into account the latest information on collimator production schedule and results of simulations that were deemed necessary before taking the final decision.

CMS-TOTEM

EDMS NO.	REV.	VALIDITY
1361537	0.1	DRAFT

ENGINEERING CHANGE REQUEST

TOTEM Upgrade Project

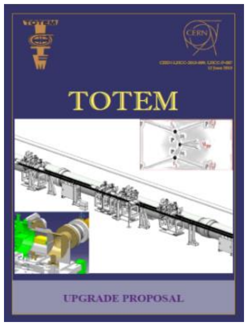
BRIEF DESCRIPTION OF THE PROPOSED CHANGE(S):

The TOTEM Upgrade Proposal [1] foresees the installation of additional horizontal Roman Pots (RPs) between the existing RP units at 215 and 220 m from IP5. These new RPs, intended to house time-of-flight detectors for elastically or diffractively scattered protons, have been designed in cylindrical geometry minimising the beam impedance and offering enough space for 12 cm long Cerenkov detectors, one of the technologies being explored for the time measurement.

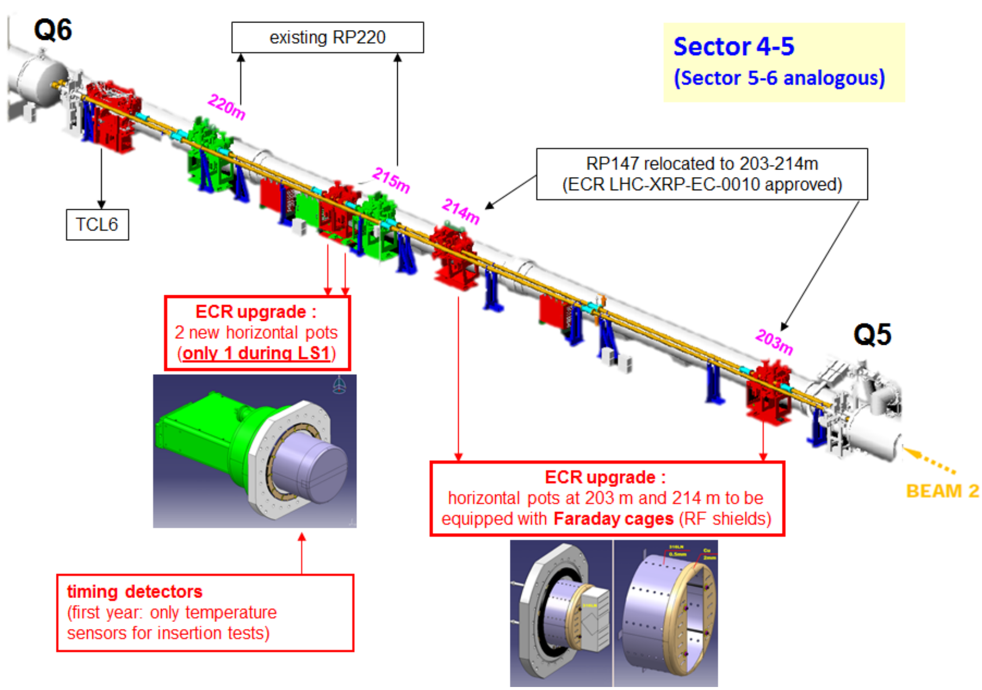
Furthermore, the existing horizontal RPs of the units at 203 and 213 m will be equipped with Faraday shields to reduce their impedance.

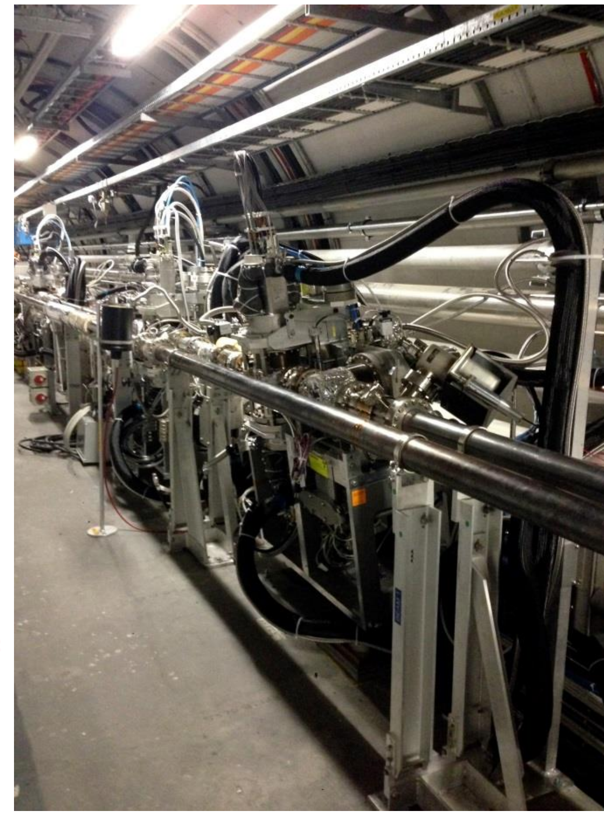
This ECR elaborates on the technical details of the new RP elements and their integration in the LHC. It thus complements the already approved consolidation ECR [2].

Roman Pot and TCL installation in LHC tunnel completed (consolidation & upgrade) during LS1



The Upgraded Roman Pot Spectrometer
ECR upgrade (scheduled for LS1)



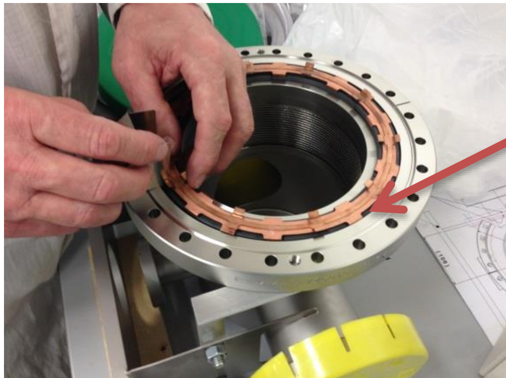


November 2014

R&D of new ROMAN POT (2013-2014)

RF test of new Roman Pot design with thin window of 300 µm

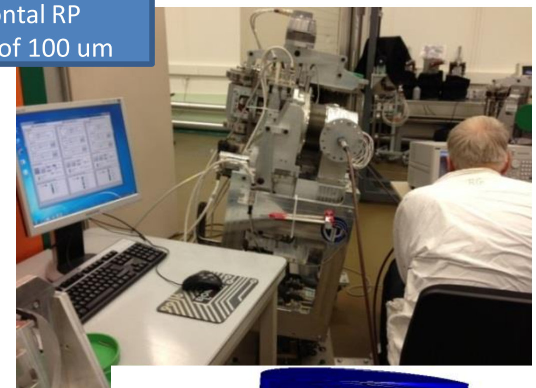
combination of new bellow & beam pipe & circular ferrite with new cylindrical RP or RF shield



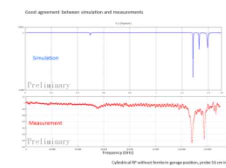
New bellow & beam pipe with circular ferrites & ferrite support ring –> integrated in horizontal RP test station

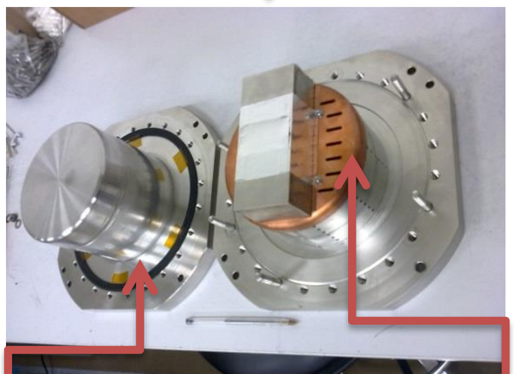
Horizontal RP test station

Movement of horizontal RP in steps of 100 um

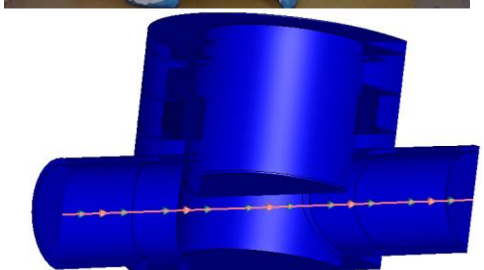


Measurements with and without ferrites
Results show good agreement with simulation

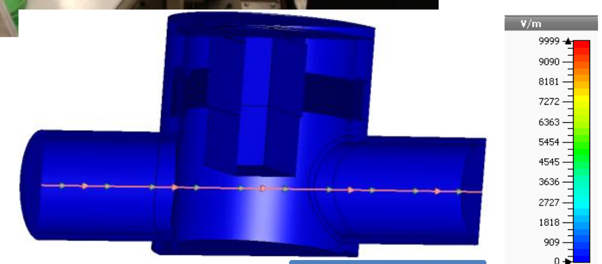




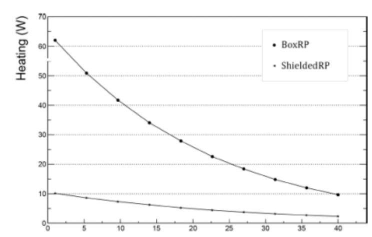
New cylindrical Roman Pot & RF shield for box Roman Pot



New design Cylindrical or RF shield



Old box design without RF shield



TOTEM and TOTEM consolidation & upgrade

T! & T2

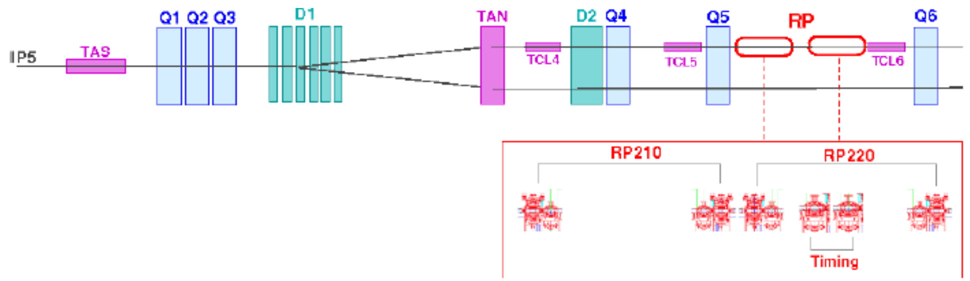


Fig. 9.5: The LHC beam line on one side of interaction point IP5 after LS1: the TOTEM Roman Pots are installed at distances of 210-220 m.

Timing for vertical RP

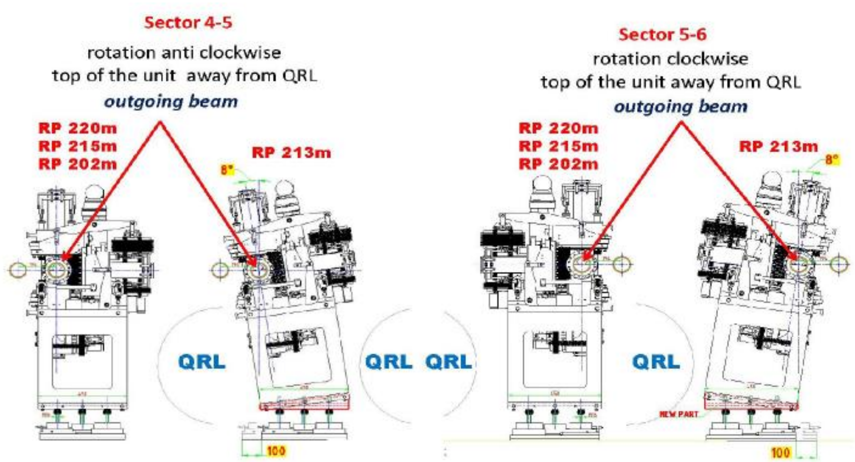


Fig. 9.9: Drawings of the rotated RP units. The view is directed along the outgoing beam.

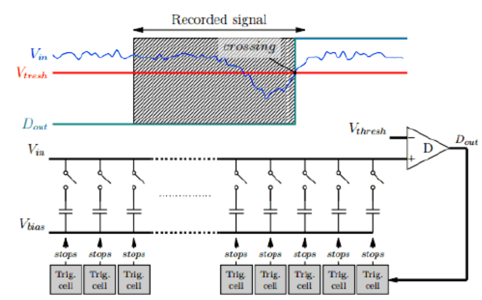


Fig. 9.12: Inside the SAMPIC, the input signal is continuously sampled in a ring analog buffer. In internal trigger mode, the signal is compared to a programmable threshold to stop the sampling and start the ADC conversion.

CT-PPS

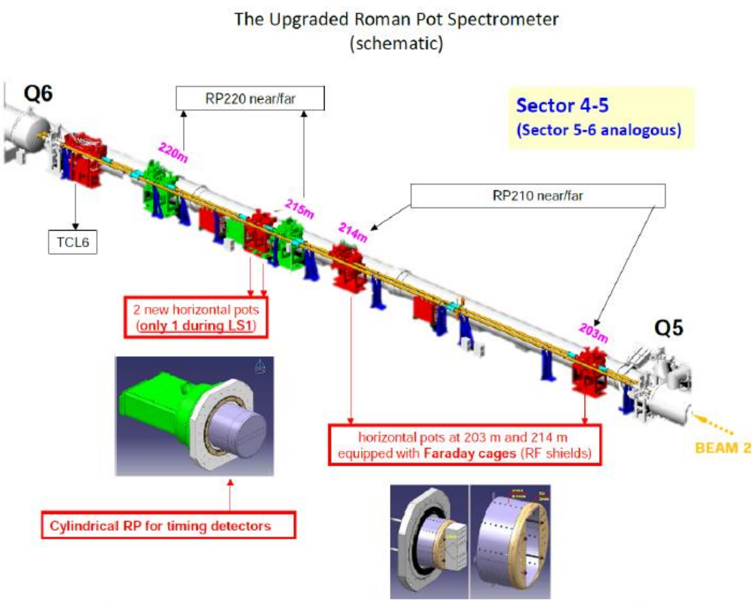


Fig. 9.19: The layout of the beam line in the 200 m region after LS1

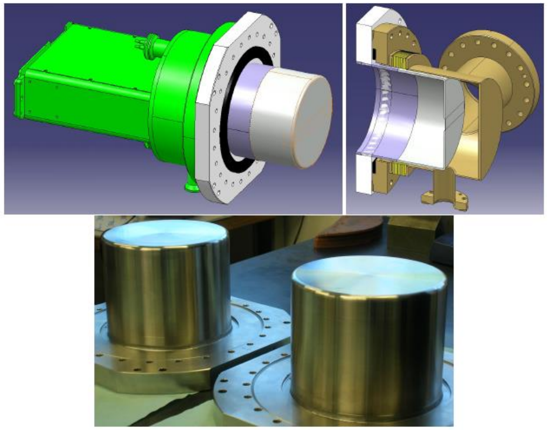


Fig. 9.21: Top: drawings of the cylindrical detector housing for the new RPs designed to accomodate timing detectors. Bottom: the manufactured pots.

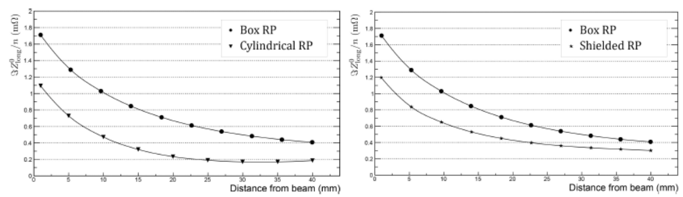


Fig. 9.26: Effective longitudinal impedance as a function of the RP distance from the beam, for the three RP designs.

	Distance from the beam [mm]	$\frac{\Im Z^{0}_{long}}{n}$ [mΩ]	fraction of $(\frac{\Im Z_{long}}{n})^{eff}_{LHC}$ (90 mΩ)	$\overline{\Im Z^{driving}_{trans}}$ [MΩ/m]	fraction of $\Im(Z_x)^{eff}_{LHC}$ (25 MΩ/m)	Heating [W] I=0.6 A
Box RP	1	1.7	< 1.9 %	0.15	< 0.6 %	62
	5	1.3	< 1.4 %			52
	40 (garage)	0.41	< 0.45 %			10
Cylindrical RP	1	1.1	< 1.2 %	0.11	< 0.5 %	13
	5	0.73	< 0.81 %			11
	40 (garage)	0.18	< 0.20 %			4
Shielded RP	1	1.2	< 1.3 %	0.2	< 0.8 %	10
	40 (garage)	0.30	< 0.33 %			2

Table 9.1: Main results of the simulation of the present box RP (Box RP), the cylindrical RP (Cylindrical RP), and the Box RP with Shield. Longitudinal and transverse impedances are compared with the total values estimated for the present LHC effective impedances.

CT-PPS

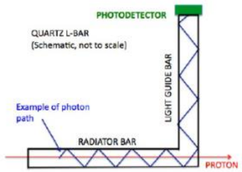
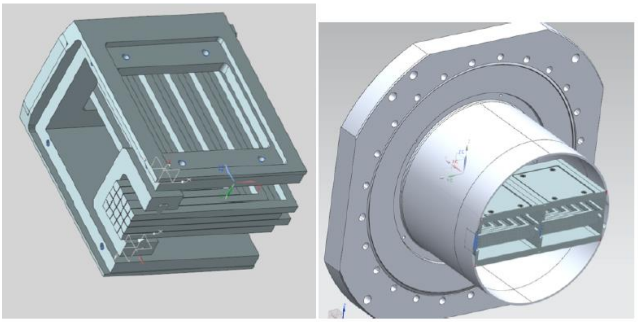
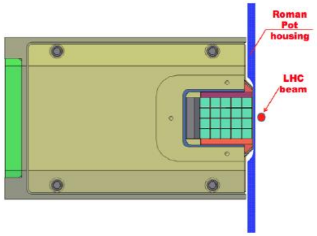


Fig. 9.27: Cherenkov light rays in the radiator and light guide bar, for $n = 1.48$, in the plane of the 'L' ($\phi_{ch} = 90°$).



ig. 9.29: Left:Design (B. Ellison, FNAL) of module for insertion in Roman Pot (two in one pot). Right: ssembly of two Quartic modules in Roman Pot. The beam comes from the left.



ig. 9.30: "Particle eye view" of bar array in pot. This is a modified design (D. Druzhkin) reducing the naterial close to the beam.

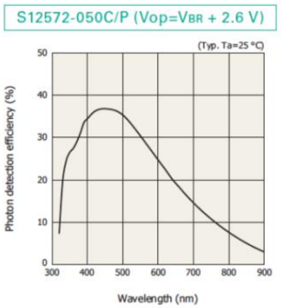


Fig. 9.31: Photon detection efficiency of Hamamatsu S12572 SiPM. This is the product of the quantum efficiency and the fill factor (50 μm pixels).

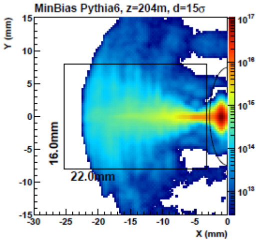


Fig. 9.34: Simulated proton fluence in the tracking station at 204 m from the IP for the integrated luminosity of 100 fb^{-1}. The rectangle indicates the detector surface transverse to the beam assuming a detector tilt angle of 20°. The ellipse shows the 15 sigma beam contour. In the detector edge a value of the order of 5×10^{15} p/cm^2 is obtained. This value is compatible with the extrapolation from TOTEM data.

CMS forward shower counter

9.3 Forward Shower Counters in CMS

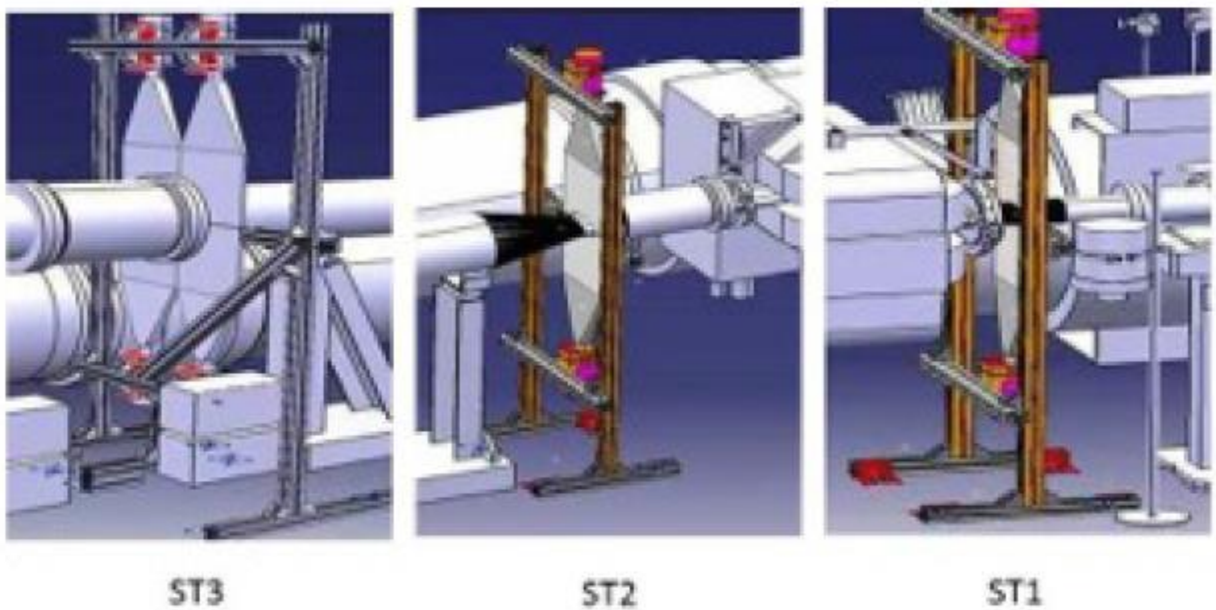


Fig. 9.17: The layout of three FSC stations in CMS. The fourth station is identical to ST3.

AFP

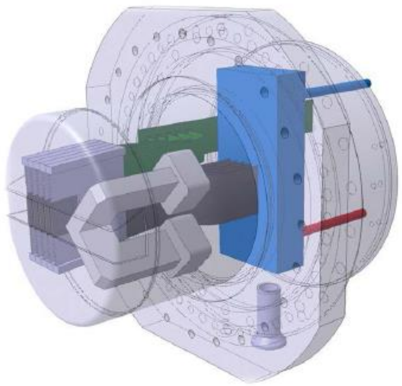


Fig. 9.37: The design of the AFP Roman Pot with a 5-plane Silicon 3D Pixel tracker and a double LQbar Time-of-Flight detector. Note the cold-air heat exchanger near the top flange (dark blue) which is using cold air from a vortex 'aircooler' apparatus.

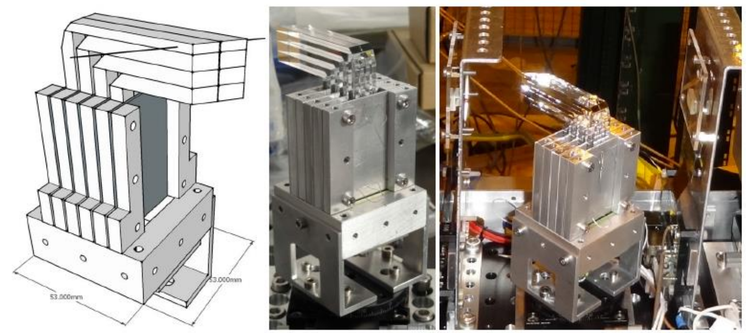


Fig. 9.39: Left: the design of the AFP Time-of-Flight Detector (LQbar). The straight line is an example of a diffractive proton entering one of the quartz radiator bars from the right. Middle: The LQbar detector before test beam installation in November 2014. Note the quartz radiator bars with the 45° Aluminized mirrors. Right: the LQbar ToF installed in the beam test. Two 3D Silicon tracker planes are also visible.

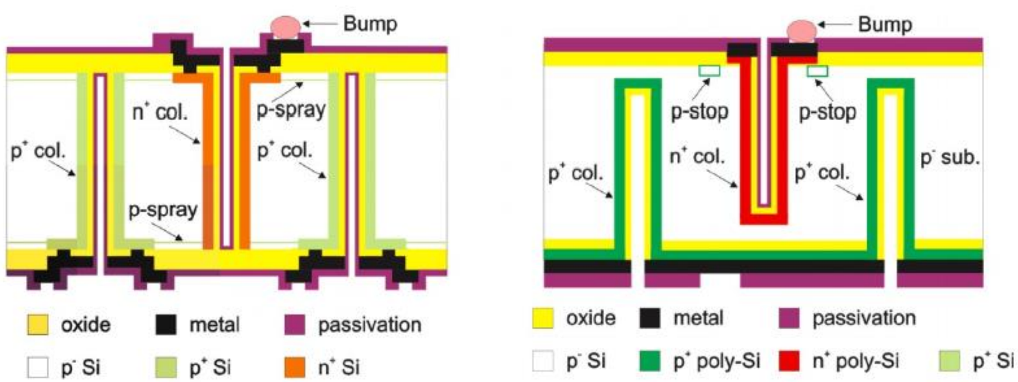
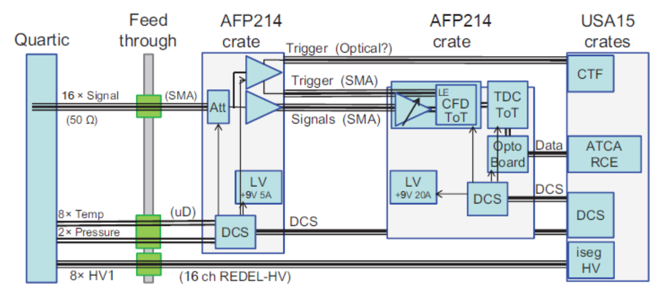


Fig. 9.38: **Design of the columns of the FBK (left) and CNM (right) 3D sensors.**



AFP Ultrafast Timing Electronics System – Block Diagram

Fig. 9.40: A schematic diagram of the components of the fast timing electronics chain described in the text, together with their physical locations in the LHC tunnel.

LHCb Experiment

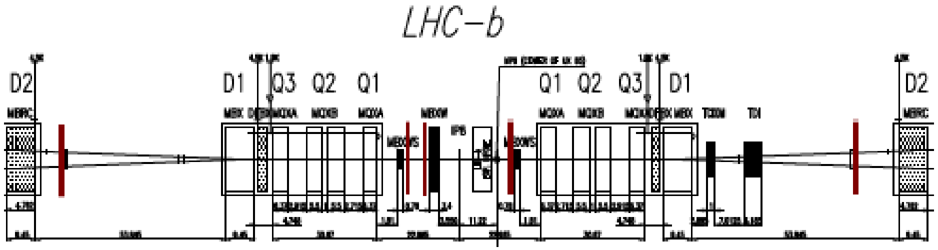
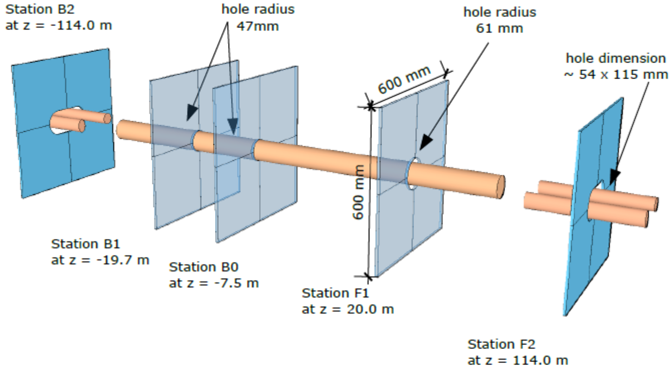


Fig. 9.43: Layout of IR8. The positions of the shower counter stations are indicated by the red arrows.



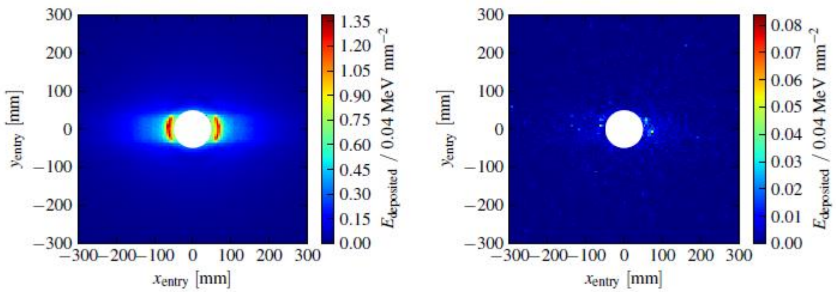


Fig. 9.45: Simulated energy deposited in the innermost backward Herschel counter (B0) for inelastic collisions (left) and for events mimicking a CEP-like physics event with a disassociated proton (right)

Fig. 9.44: Schematic overview of the scintillator configuration. The z scale has been compressed and the long section of the beam pipe between the B/F1 and B/F2 stations omitted.

The Alice Diffractive Detector

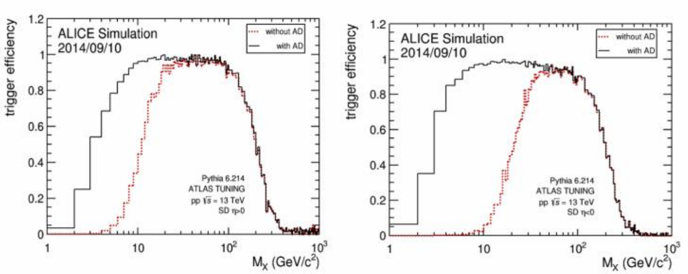


Fig. 9.48: Trigger efficiency for single diffractive events (SD) for $\eta > 0$ (right) and $\eta < 0$ (left). In both cases the efficiency of the trigger given by AD increases considerably at low diffractive masses

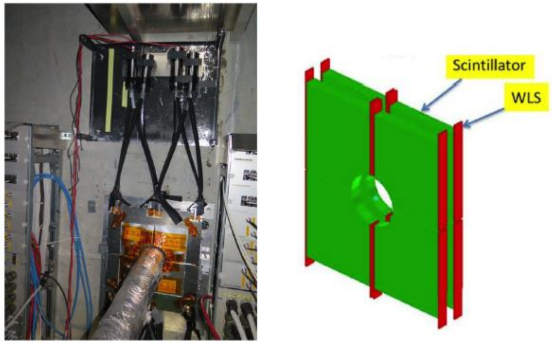


Fig. 9.49: Picture of one AD station installed inside the ALICE' cavern (left). Drawing of one AD station (right) showing eight scintillator cells (green) and two WLS bars per cell (red)

ADA/ADC layer positions

Station	Inner radius (cm)	η_{min}	η_{max}	Z (cm)
ADC layer 0	3.7	-6.96	-4.92	-1955.75
ADC layer 1	3.7	-6.96	-4.92	-1953.05
ADA layer 2	6.2	+4.77	+6.30	+1693.65
ADA layer 3	6.2	+4.77	+6.30	+1696.35

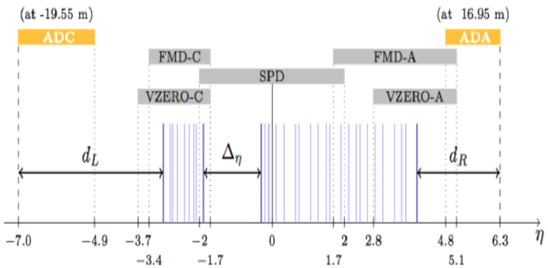


Fig. 9.50: Pseudorapidity coverage of the AD system. The diffractive trigger will be generated by AD, VZERO and SPD systems.

LHCf Detectors

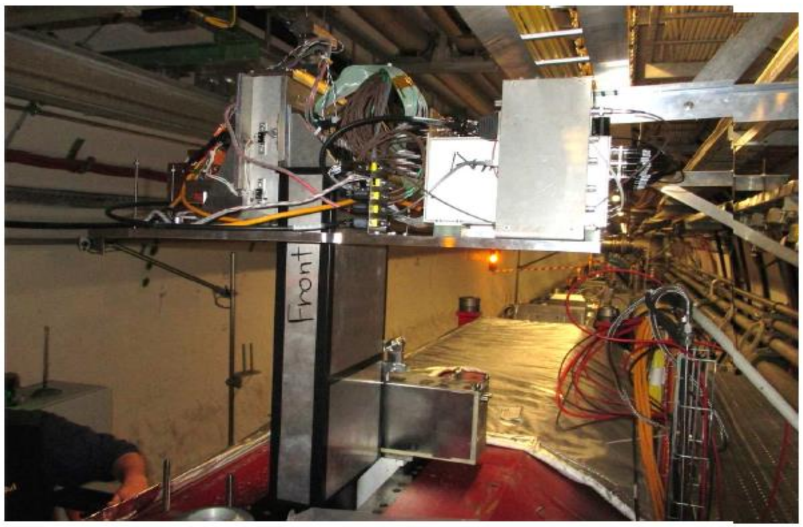


Fig. 9.52: LHCf Arm1 detector and its front-end electronics being installed into the TAN instrumentation slot.

9.8 LHCf Detectors

The Large Hadron Collider forward (LHCf) experiment installed two independent detectors at either sides of IP1 (ATLAS) [93] . The detectors are installed in the instrumentation slots of the TAN absorbers 140 m away from the IP. The detector at the IP8 (LHCb) side is called Arm1 and the other at the IP2 (ALICE) side is called Arm2. This location allows the detection of neutral particles with $\eta > 8.4$. Photons, predominantly decay products of π^0, and neutrons are dominant particles arriving at the detectors. The detectors to be used in Run-II are essentially the same used in Run-I except some upgrades described below.

Each of the LHCf detectors consists of two small calorimeters with a double tower structure [94]. The dimensions of the towers transverse to the beam direction are 20 mm×20 mm and 40 mm×40 mm for Arm1 and 25 mm×25 mm and 32 mm×32 mm for Arm2. The longitudinal structure of the towers is a stack of 44 radiation lengths of Tungsten interleaved with 16 sampling scintillators. Plastic scintillators were used during Run-I but they have been replaced with Gd_2SiO_5 scintillators for Run-II [95] to make the calorimeters radiation harder. Four X-Y pairs of strip sensors, SciFi in Run-I [96] and GSO-bar bandles in Run-II [97] for Arm1 and Silicon strip sensors for Arm2 [98], are inserted to measure the lateral distribution of the showers. The longitudinal locations and the readout circuit of the Silicon strip sensors have also been updated in Run-II to optimize the energy determination ability using the Silicon sensors. Thanks to the double tower structure and position sensitivity, invariant mass of photon pairs hitting each calorimeter can be estimated. By selecting $\pi^0 \to \gamma\gamma$ events, momenta of π^0 are obtained

conclusions

- Contributions from
  - ATLAS, CMS , TOTEM
  - ALICE, LHCb, LHCf
- All chapters are complete
  final corrections ongoing
- Link of detector chapter to physics chapter