TOTEM & CT-PPS installation and status

Joachim Baechler

Outline:

- CT-PPS & TOTEM spectrometer in the LHC tunnel
- Status and experience of operation in 2015 & 2016
- Status of upgrade project
- Summary and conclusions

Main goals of TOTEM consolidation and upgrade project after LS1 LHC

- Measurement of total cross section

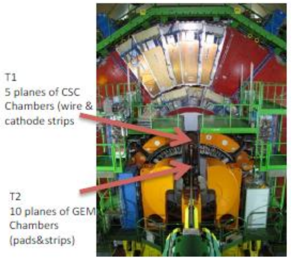
$$\sigma^2_{TOT} = \frac{16\pi(\hbar c)^2}{1+\rho^2} \cdot \left.\frac{d\sigma_{EL}}{dt}\right|_{t=0}$$

Using luminosity from CMS

$$\frac{d\sigma_{EL}}{dt} = \frac{1}{L} \bullet \frac{dN_{EL}}{dt}$$

$$\sigma_{TOT} = \frac{16\pi(\hbar c)^2}{1+\rho^2} \cdot \frac{\left.\frac{dN_{EL}}{dt}\right|_{t=0}}{N_{EL} + N_{INEL}}$$

Luminosity independent



TOTEM detectors integrated in CMS (T1, T2)

TOTEM detectors integrated in LHC (RP)

- Forward multiplicity
- Diffractive physics (soft & hard diffraction, jets)

TOTEM (stand alone)
TOTEM&CMS at low / highβ*, special runs } consolidation

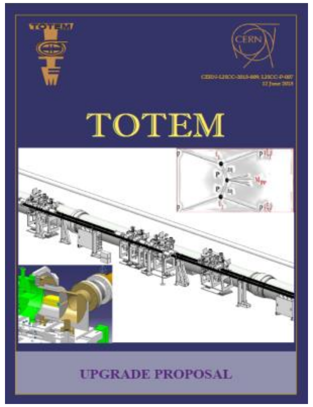
TOTEM&CMS at low β* and high luminosity -> CT-PPS

consolidation & upgrade

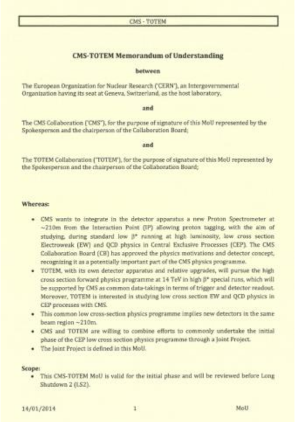
ROMAN POT: Milestones reached from March 2013 until September 2016

L H C C

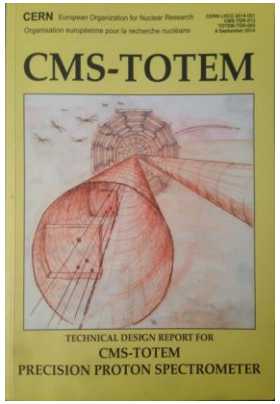
March 2013

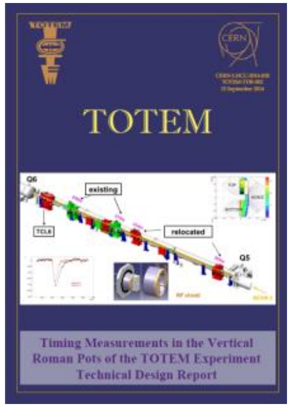


June 2013 consolidation & upgrade



January 2014 CMS-TOTEM MoU





September 2014 TOTEM timing TDR CT-PPS TDR

November 2014

March-December 2015 Restart LHC Run 2 Roman Pot insertions at end of fill

March- 2016 Insertion of RP 210 near /far RP cylindrical.

June 2016

RP approved for insertion at design luminosity of LHC

LHC LS1 access for RP installation

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

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

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 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].

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

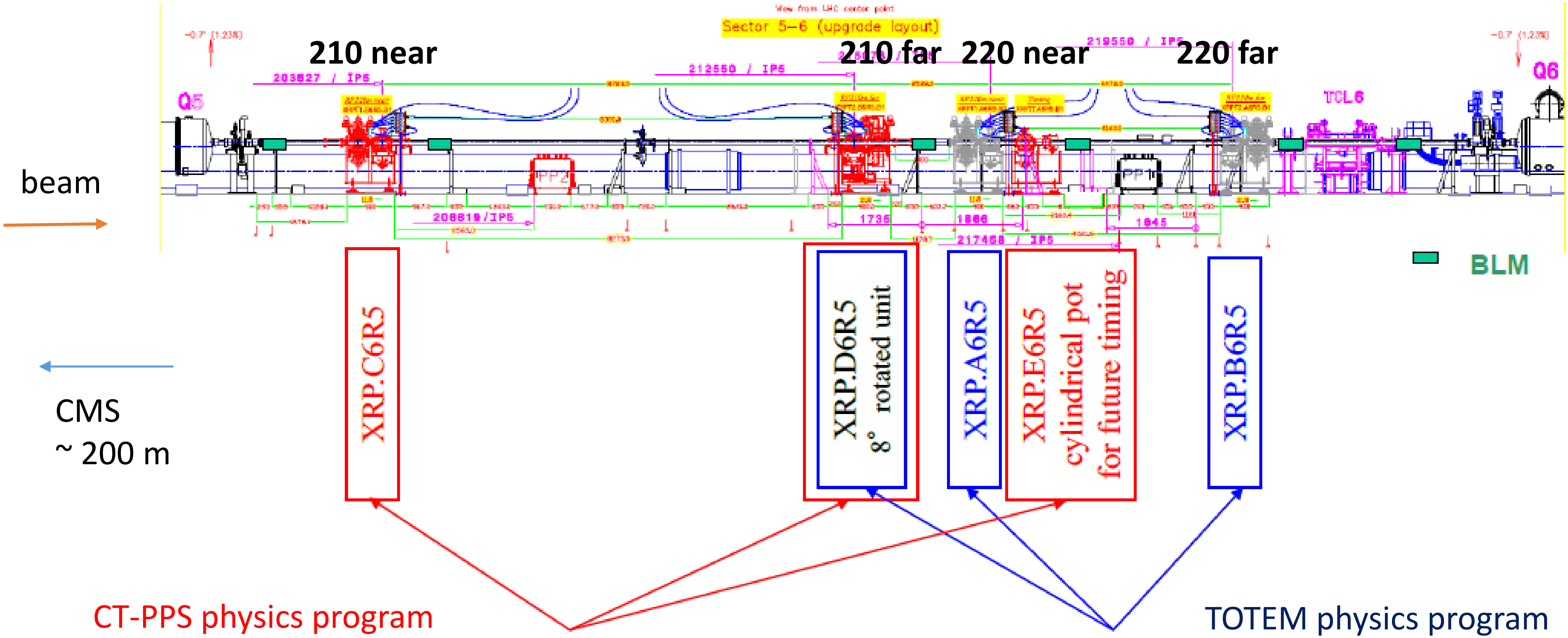
June/September 2016 TS 1/TS2

Installation of :
Diamond detectors in RP-cylindrical for tracking g& timing
Clock distribution (RF & LASER)

TOTEM Si strip readout fully integrated in CMS DAQ 100kHz
More 10 fb^{-1} recorded at nominal RP position
(15σ distance to beam)

TOTEM & CT-PPS

26 Roman Pots: the largest Roman Pot system ever operated at a collider

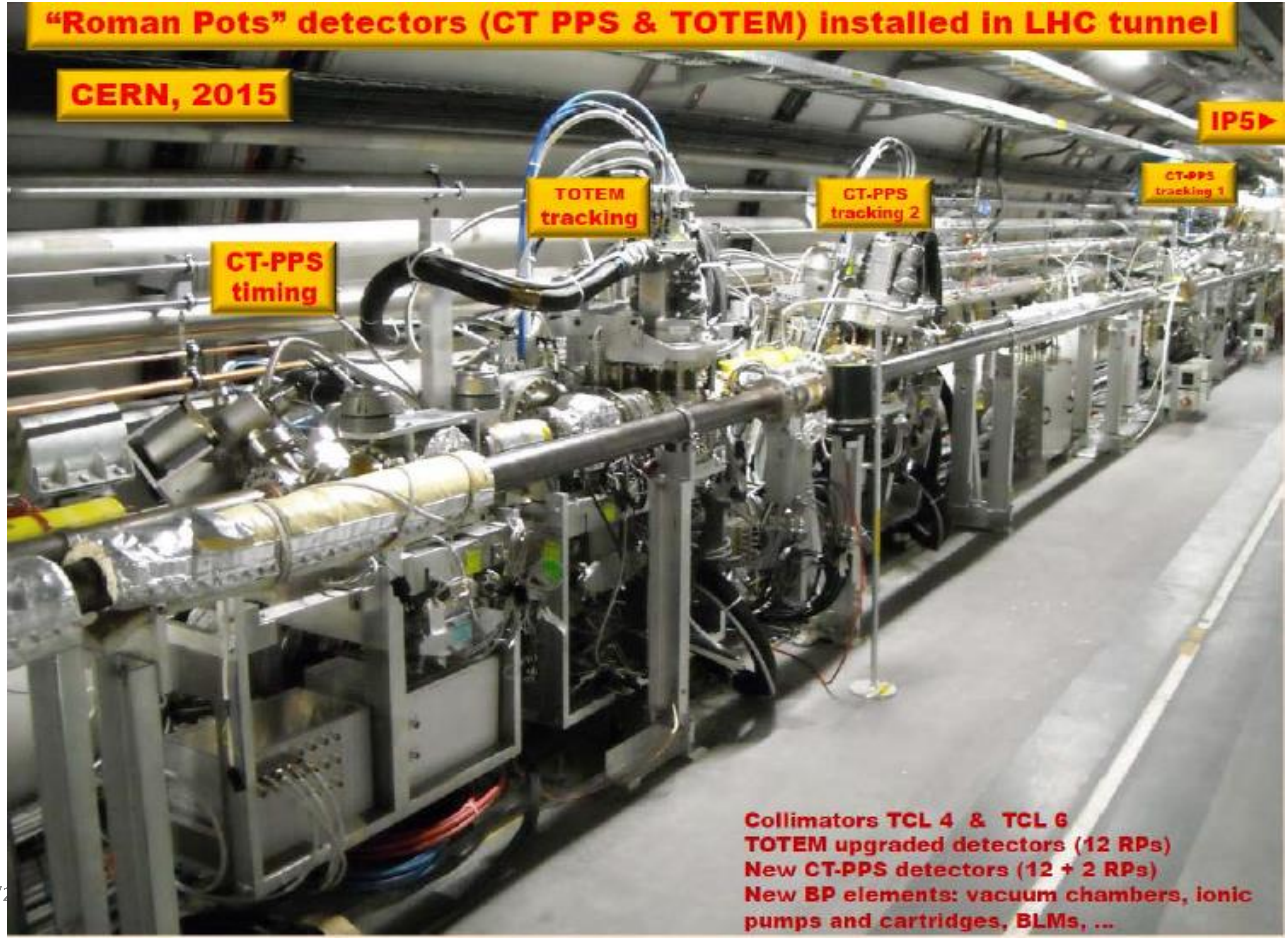


CT-PPS physics program

Operation at low β* 0.4m CT-PPS
14 individual pots (both sectors together)

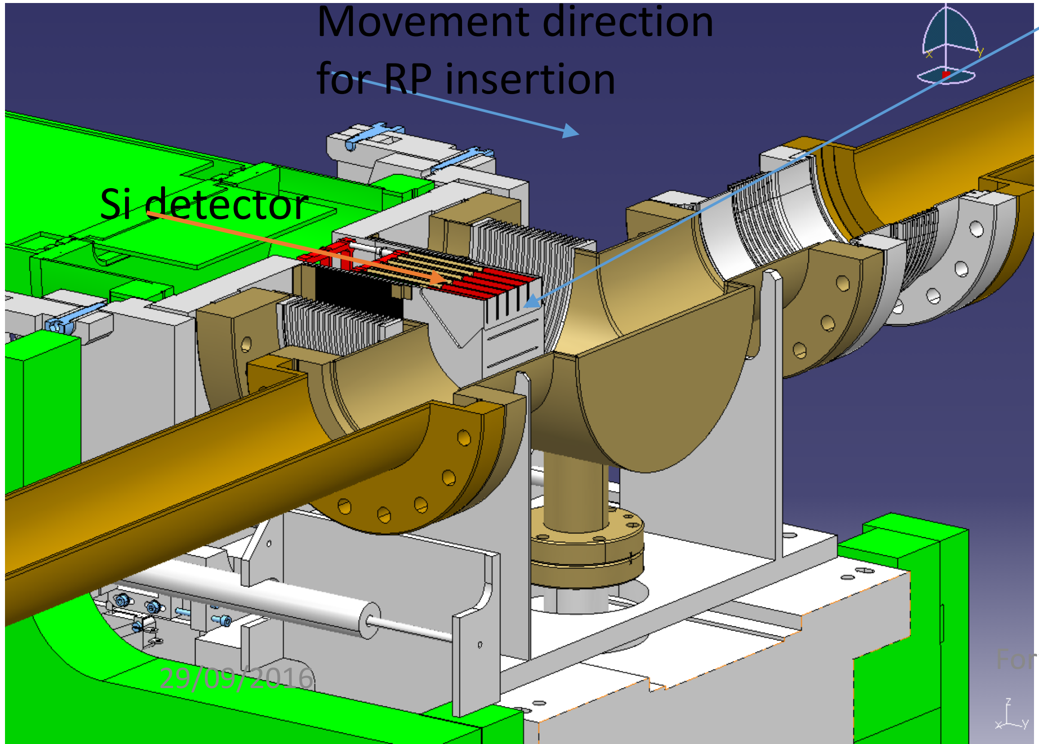
TOTEM physics program

Operation at medium/high β* (19 m, 90 m) 2.5 km
18 individual pots (both sectors together)


"Roman Pots" detectors (CT PPS & TOTEM) installed in LHC tunnel
CERN, 2015
IP5►
TOTEM tracking
CT-PPS tracking 2
CT-PPS tracking 1
CT-PPS timing
Collimators TCL 4 & TCL 6
TOTEM upgraded detectors (12 RPs)
New CT-PPS detectors (12 + 2 RPs)
New BP elements: vacuum chambers, ionic pumps and cartridges, BLMs, ...

Physics requirements (standard LHC optics)

Horiz. RP	$\sigma_{x,beam}$	15 σ	… + window + gap (0.3 or 0.5 mm)	D_x	ξ_{min}	$M_{min} = \sqrt{\xi_1 \xi_2 s}$
210-N	213 µm	3.195 mm	3.495 mm = 16.4 σ	–80.0 mm	0.044	572 GeV
210-F	144 µm	2.160 mm	2.460 mm = 17.1 σ	–76.3 mm	0.032	416 GeV
220-C	120 µm	1.800 mm	2.300 mm = 19.2 σ	–75.0 mm	0.031	399 GeV



Extreme requirements on RP spectrometer and LHC beam performance:

Reproducibility of insertion position from fill to fill better than 50 µm
LHC beam orbit stability better than 100 µm
Impedance impact mitigation of installation -> RF shield – Ferrite geometry
Radiation hard detectors
Separated with thin window of 150 µm from LHC vacuum

Fully automatized RP insertion steered by LHC CCC
More than 30 RP insertions this year !

Roman Pot insertions in 2016

Main Goals (2016):

Validate Roman Pots for insertions at physics position 15σ at design luminosity of LHC

Integrate the detectors in CMS DAQ global run to assure physics data taking in combination with CMS

Calibration of RP Si detectors in combination with LHC optics

4 different insertion periods:

1. **Intensity ramp-up before 3rd June:**
   Insertions with margin: $15\ \sigma + 0.5$ mm
   Up to 1824 bunches ($L \leq 6.4 \times 10^{33}$ cm^{-2} s^{-1})

   End-of-fill tests with removal of the 0.5 mm margin: → $15\ \sigma$

2. **from 3rd June until TS1:**
   Insertions to $15\ \sigma$
   Up to 2040 bunches ($L \leq 7.3 \times 10^{33}$ cm^{-2} s^{-1})

3. **after TS1 (installation of diamond detectors)**
   - Realignment of the units E6L5, E6R5, C6L5, C6R5
     → alignment from April reproduced within 100 μm
     → pre-TS1 $15\ \sigma$ settings unchanged without further loss maps
   - Insertions resumed: **2040 bunches ($L \leq 8.2 \times 10^{33}$ cm^{-2} s^{-1})**

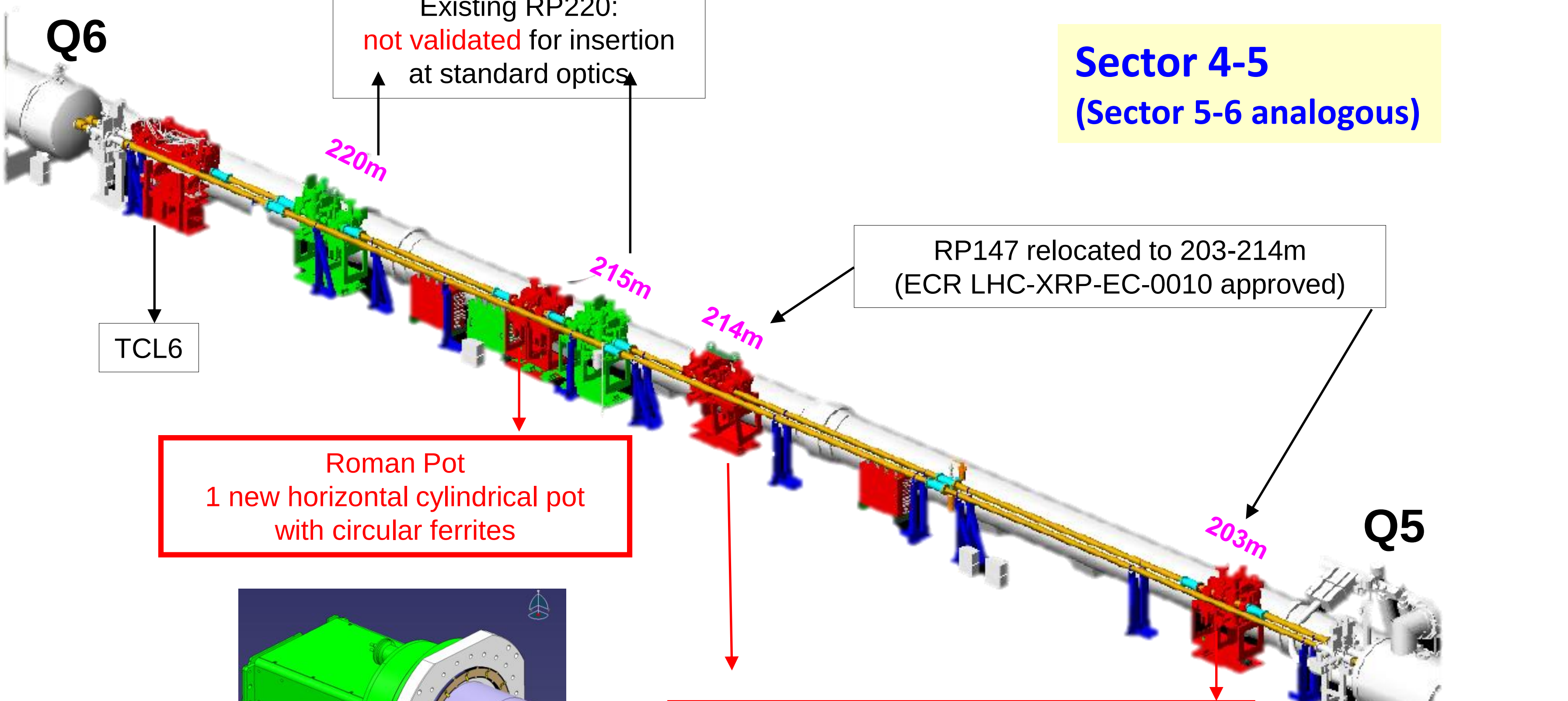
   29 June: insertions suspended due to radiation damage in Si detectors

4. **from 28 August until TS2**
   Insertions resumed ($15\ \sigma$) with only Si detector XRPs (units C and D)
   2220 bunches ($L \leq 12.4 \times 10^{33}$ cm^{-2} s^{-1})

The upgraded Roman Pot Spectrometer
-> Three horizontal RPs are validated for insertions at LHC standard optics

Sector 4-5
(Sector 5-6 analogous)

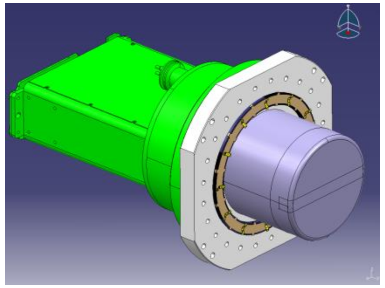
Existing RP220:
not validated for insertion
at standard optics



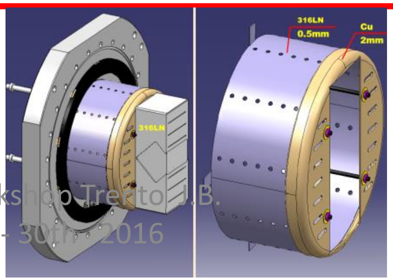
TCL6

RP147 relocated to 203-214m
(ECR LHC-XRP-EC-0010 approved)

Roman Pot
1 new horizontal cylindrical pot
with circular ferrites



Roman Pot upgrade :
horizontal pots at 203 m and 214 m
equipped with **Faraday cages** (RF shields)
and circular ferrites



timing detectors:
integrated diamond detectors
during TS1

IMPACT OF LHC BEAM ON ROMAN POT and Si Detector TEMPERATURE & IMPACT of ROMAN POTS ON LHC BEAM STABILITY

IMPACT of LHC BEAM ON ROMAN POT TEMPERATURE:

Flange temperature (close to Ferrites) below + 60 C°

OPERATIONAL TEMPERATURE OF Si detectors always below -14 C°

IMPACT of ROMAN POTS ON LHC BEAM STABILITY:

Conclusion (B.Salvant LHC) on

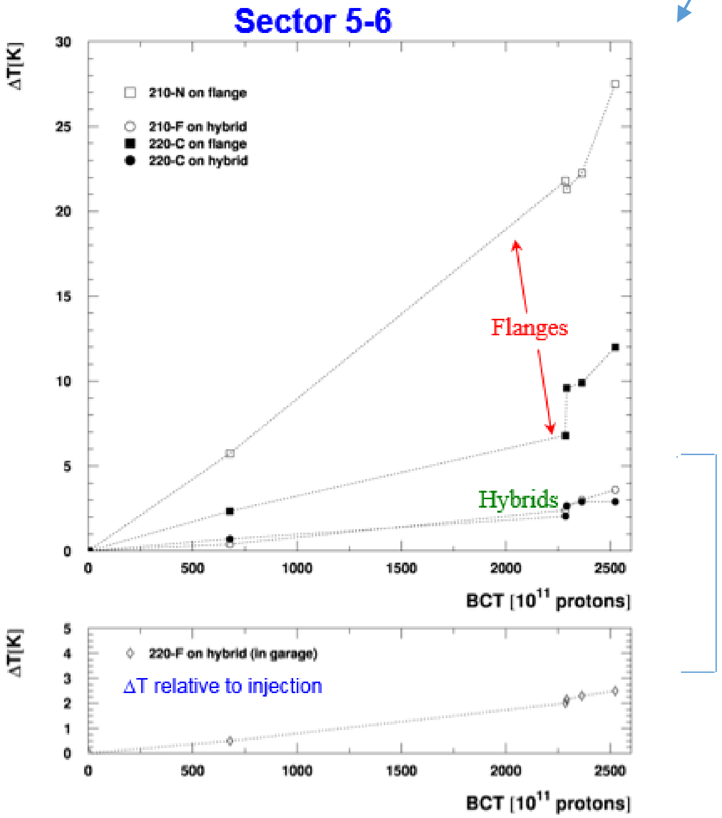
3rd Elba Workshop on Forward Physics @ LHC energy (June 2016):

"… no observations on BBQ (amplitudes, tunes) and synchronous phase error during RP insertion of 15 σ "

Temperature reach of new Roman Pots after insertion to 15 σ

ΔT relative to injection

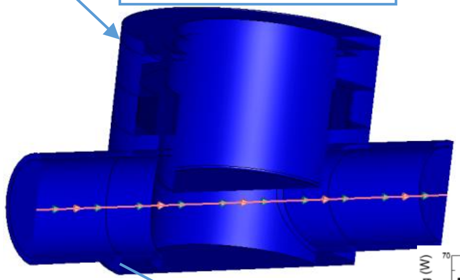
3rd September 2016



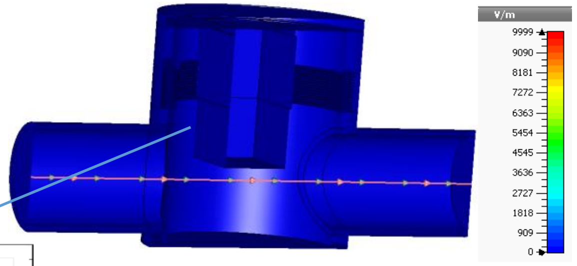
Hybrid Old design (in garage position)

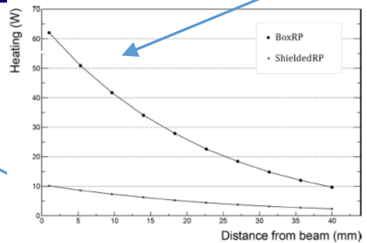
New design
Cylindrical RP or RF shield
Circular ferrites

flange



Old box design without RF shield and old Ferrite geometry



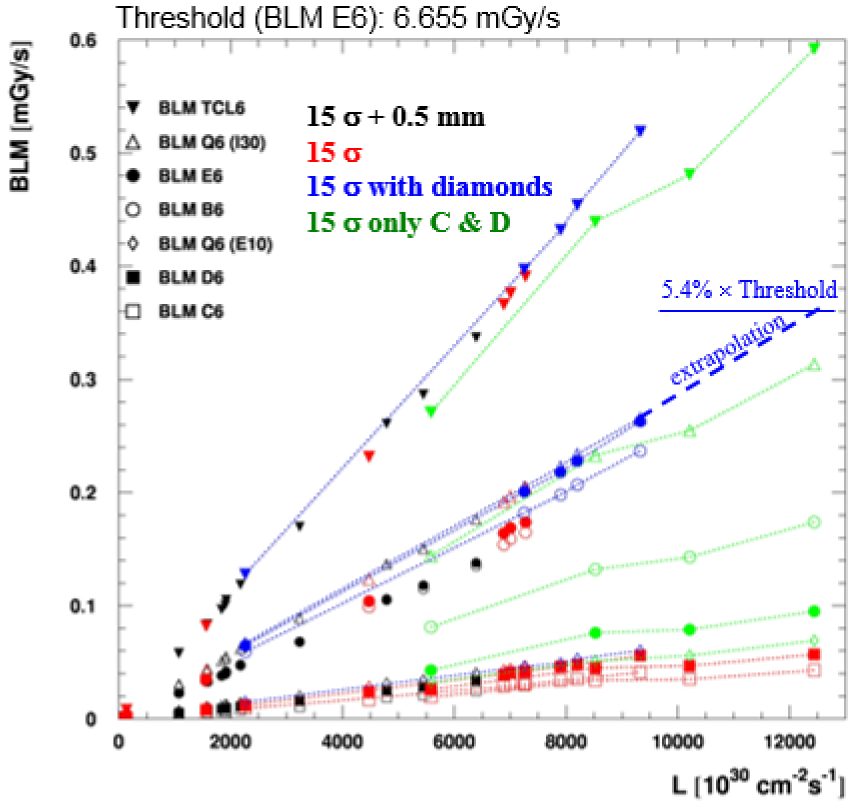


IMPACT of Roman Pots on Beam loss monitors & LHC vacuum

In total there are 7 BLMs and 5 LHC vacuum sensors installed in each sector

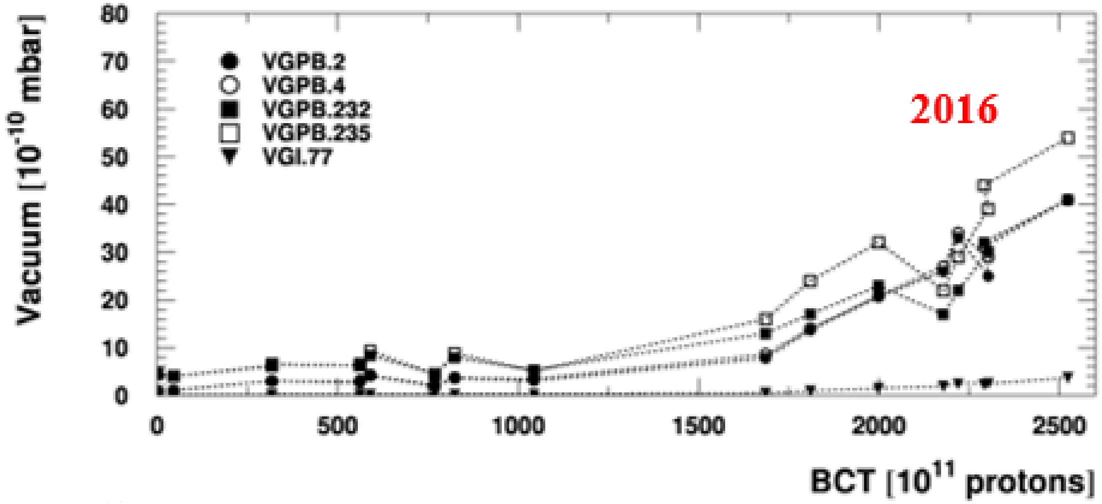
Sector 5-6

3rd September 2016



Most critical BLM

LHC vacuum in 220 m region



- BLM signals were much below threshold for beam dump
- no particular UFO activity was created by RP in the 220 m region
- no beam dump was initiated by Roman Pot insertions up to design luminosity of LHC

→ BLMs show linear increase with Luminosity

→ BLM_signal
~ particle rate x material budget (pot, LHC vacuum)

DAQ integration: project timeline

Feb 9th
- 1st meeting with CMS DAQ
- Documentation opened
- System requirements identified

Apr 6th
- 1st MiniDAQ readout test at 10Hz with emulated data
- Files available to offline/dqm

Apr 27th
- 1st MiniDAQ high rate test ok w. emulated data
- Slink data transfer error identified and fixed
- ReSync fast-command test
- ~90kHz rate limit reached w/o errors

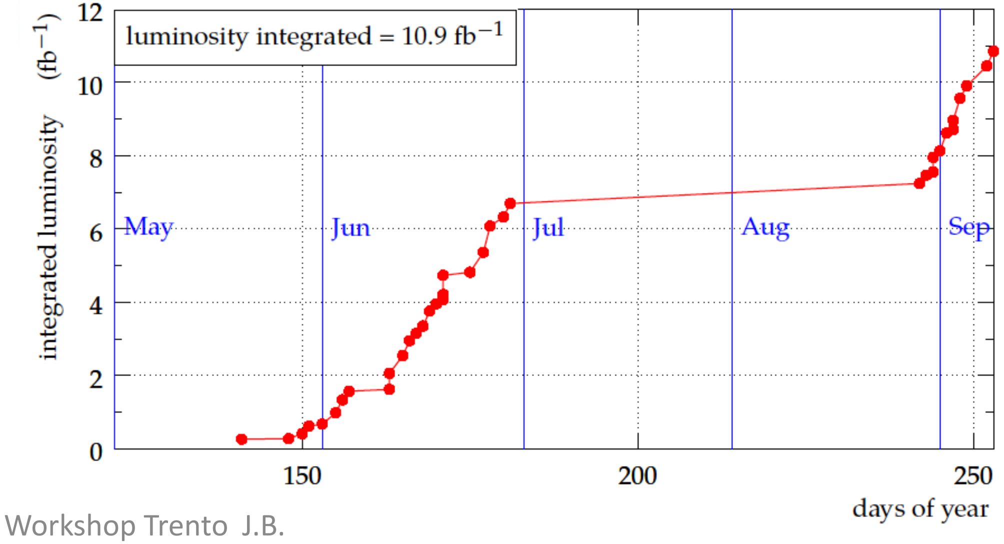
May 2nd
- 1st MiniDAQ test with Si-Strip ON
- ReSynch fast-command test OK
- RAW data mode tested
- Zero-suppr. mode

May 4th
- Si-Strip in global running with CMS
- Stress test 90k rate w. periodic ReSync OK

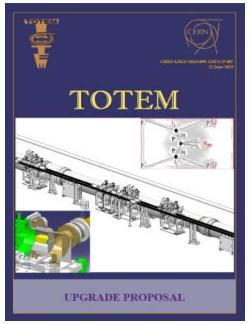
May 18th
- Si-Strip timed w/ LHC beam and CMS global trigger

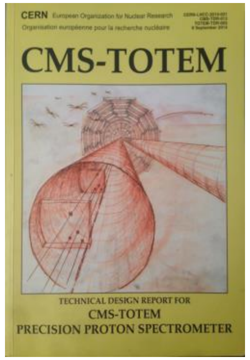
September 10th

RP Strip operation integrated in CMS global run: ~ 11 fb^{-1}



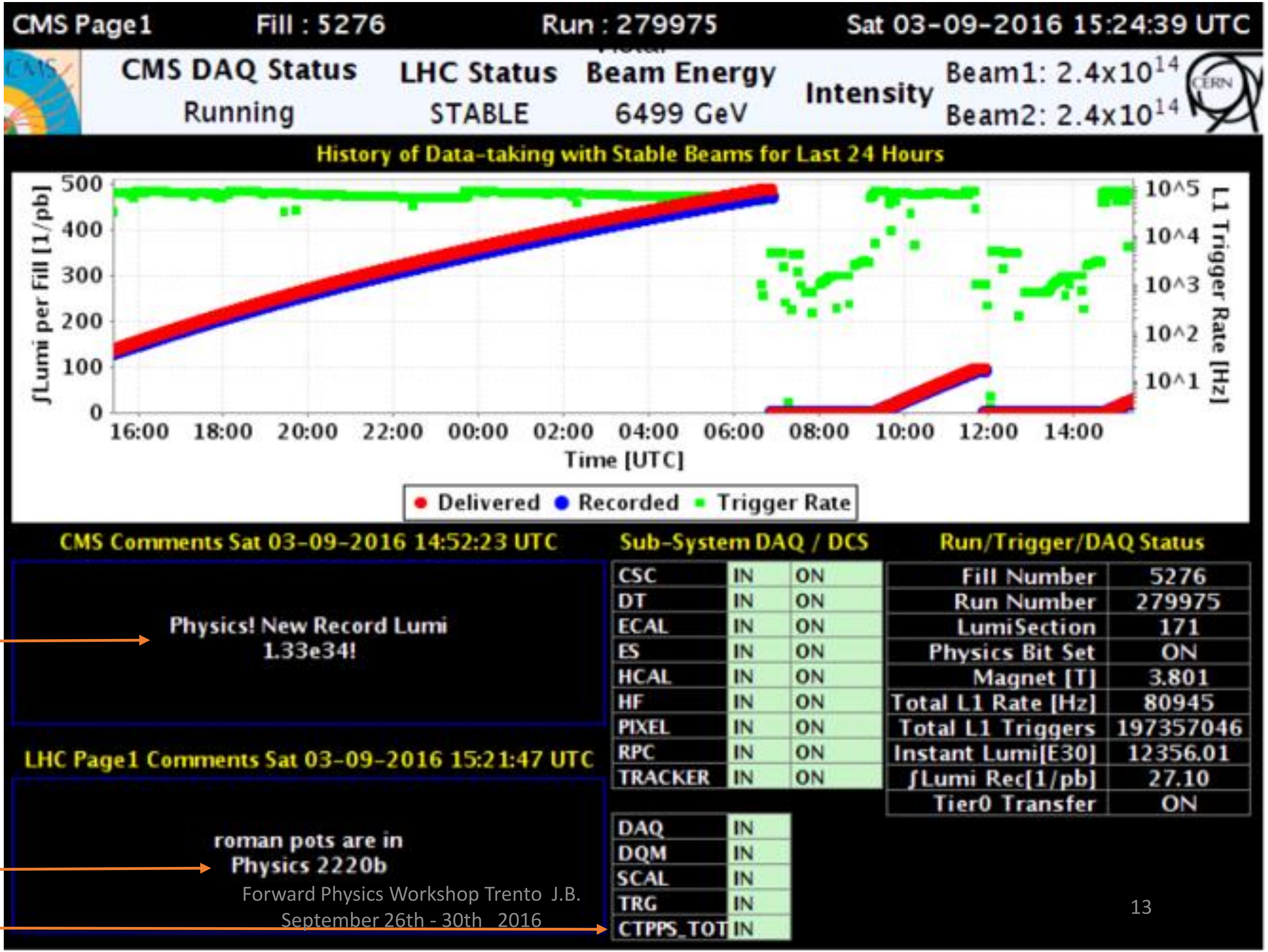
Important goals reached





Roman Pots inserted at standard LHC operation luminosity record
(so far)

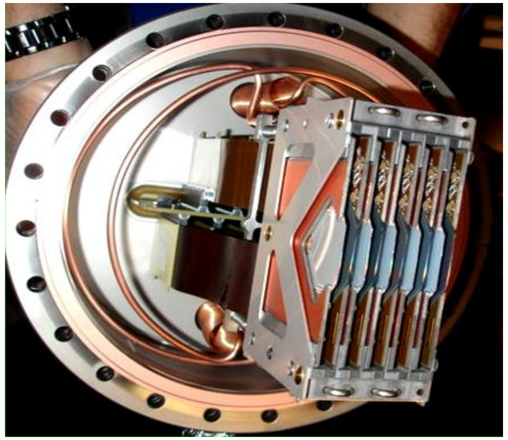
Readout of RP Si detectors fully integrated
in CMS DAQ Global run

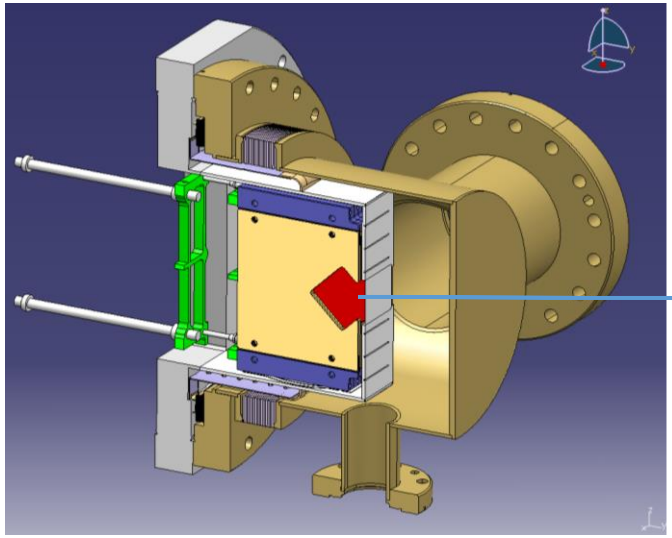


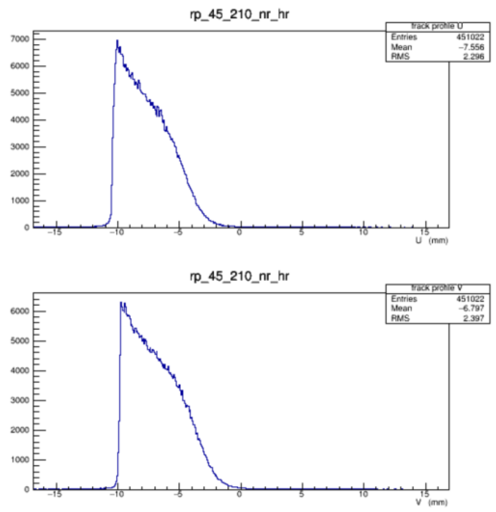
Si strip operation in horizontal Roman Pots at 15 σ

28 August 2016

Fill 5261 : L ~ 0.5/fb



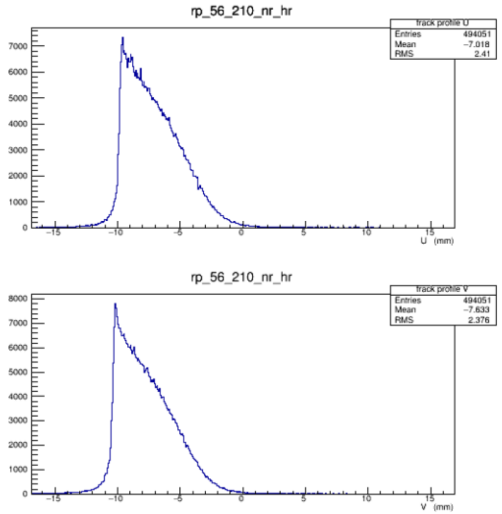


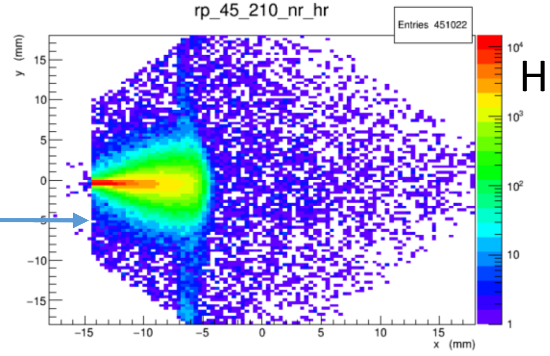


Run279766

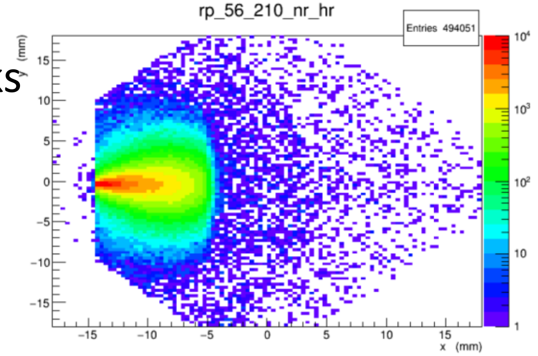
L~268/pb

IP5





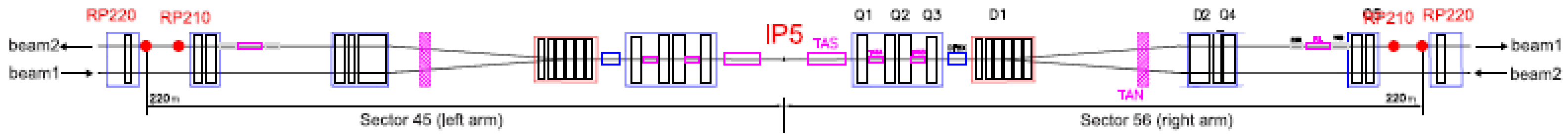
HIT MAP of tracks



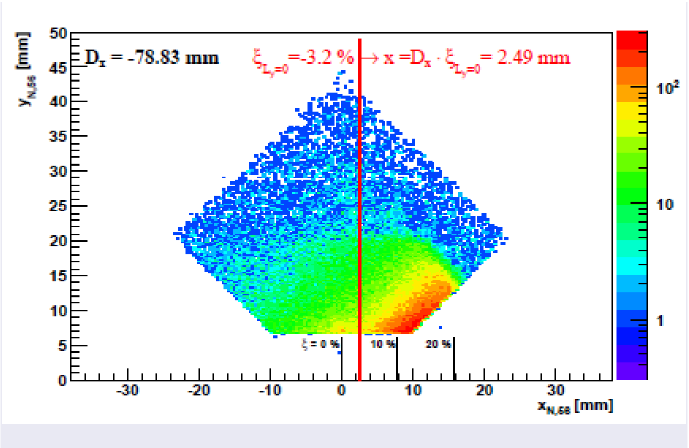
detector edge collimator

detector edge collimator

Optics functions & calibration

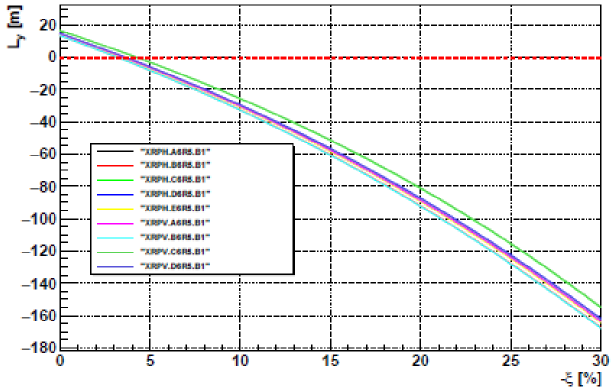


Alignment run standard optics (5σ horizontal)
RP (verticals & horizontal in partial overlap)

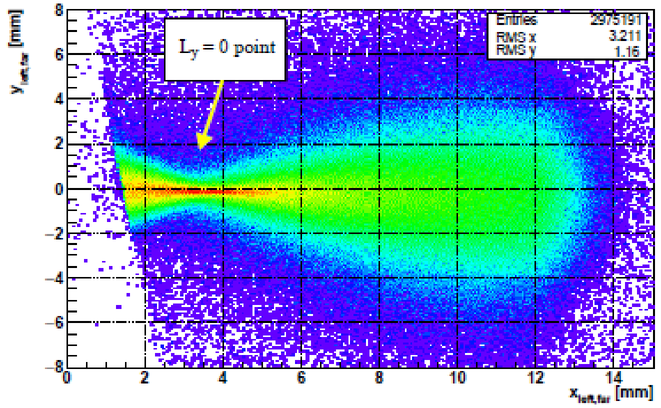


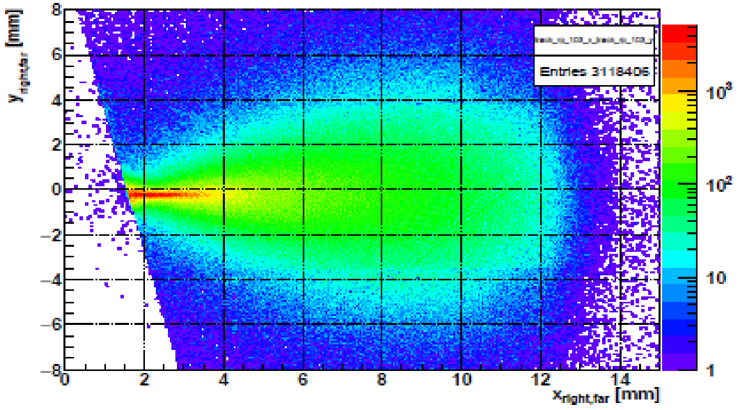
$L_y(\xi)$ from LHC optics model (MAD-X) at the RPs:

$L_y = 0$



Use of vertical and horizontal RPs
(tracks in overlap)
during alignment run at lowβ*.
Elastic scattered protons in vertical RP
constraint the precision in the x-position





$$y = v_y \cdot y^* + L_y \cdot \theta_y^*$$

$$x = v_x \cdot x^* + L_x \cdot \theta_x^* + D_x \cdot \xi$$

TOTEM (high β* 2.5 km)

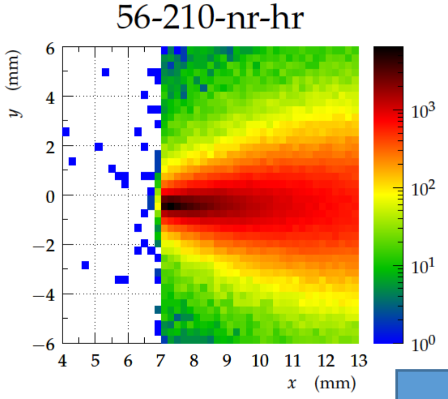
- High beta optics was successful setup
- The vertical RPs were aligned and then inserted to 3 σ
- The horizontal RPs were aligned and then inserted to 9 σ

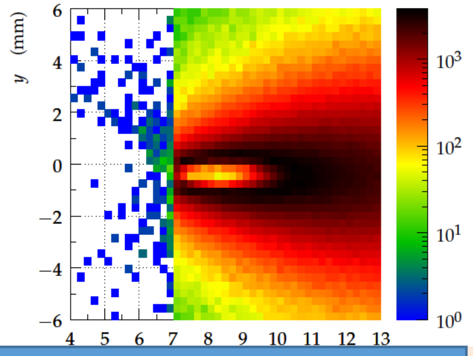
……. the run started on 19.9.2016

	$3\ \sigma_{y,beam}$	$3\ \sigma_{y,beam}$ + 0.3 mm	$\lvert t_y\rvert_{min}$	$5\ \sigma_{x,beam}$	$5\ \sigma_{x,beam}$ + 0.3 mm	$\lvert t_x\rvert_{min}$	ξ_{min}
210-N	0.375 mm	0.675 mm	5.0×10^{-4} GeV^2	4.255 mm	4.555 mm	0.088 GeV^2	0.056
210-F	**0.381 mm**	**0.681 mm**	**3.1×10^{-4} GeV^2**	**3.585 mm**	**3.885 mm**	**0.120 GeV^2**	**0.070**
220-N	**0.384 mm**	**0.684 mm**	**2.9×10^{-4} GeV^2**	**3.390 mm**	**3.690 mm**	**0.136 GeV^2**	**0.077**
220-C				3.340 mm	3.640 mm	0.141 GeV^2	0.079
220-F	**0.405 mm**	**0.705 mm**	**2.5×10^{-4} GeV^2**	**3.045 mm**	**3.345 mm**	**0.182 GeV^2**	**0.096**

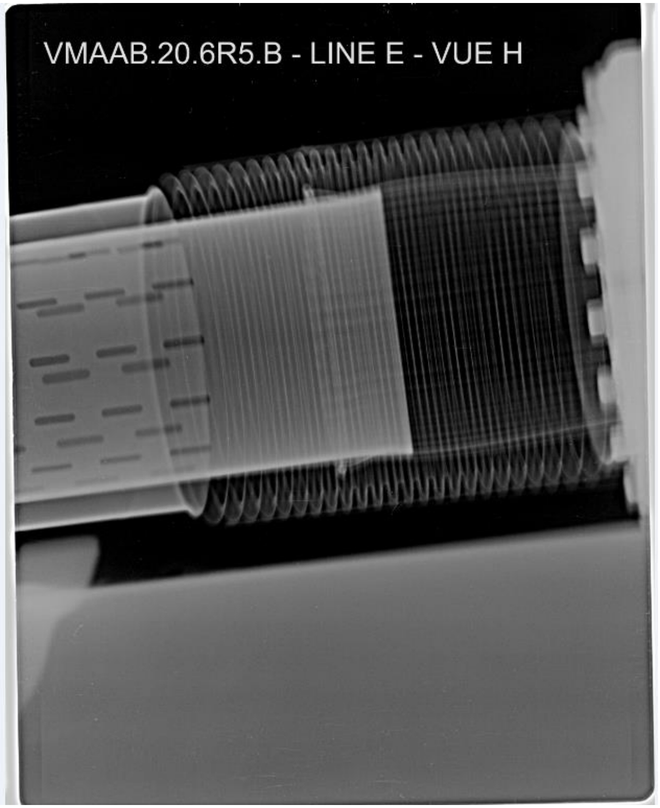
reach of $|t| \sim 6*10^{-4}$ GeV^2
measurement of elastic scattering in the Coulomb-Nuclear interference region
(same conditions as with 1 km optics and lower energy)
Precision measurement of ρ parameter (+/- 0.01) (energy dependent)

Radiation damage of sensor in horizontal RP very local
-> change of vertical position of RP unit to enlarge detector lifetime



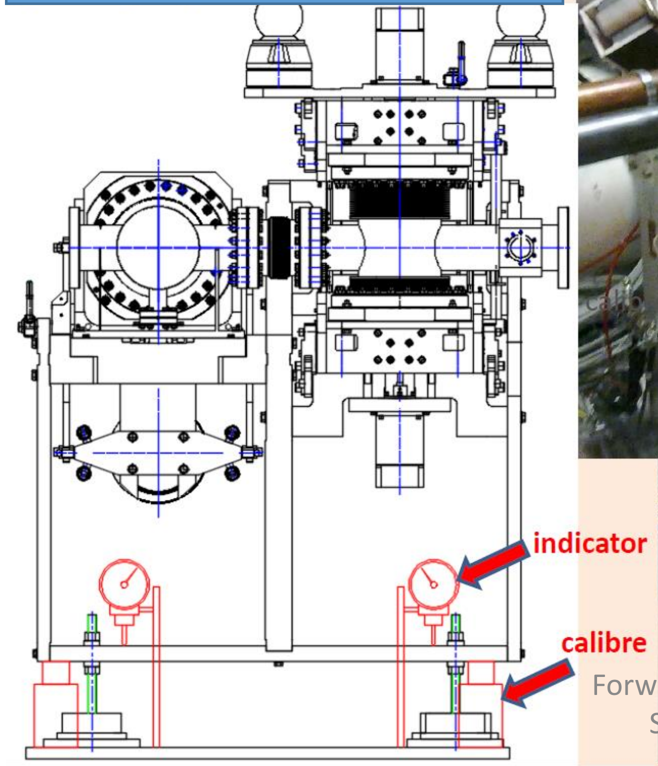


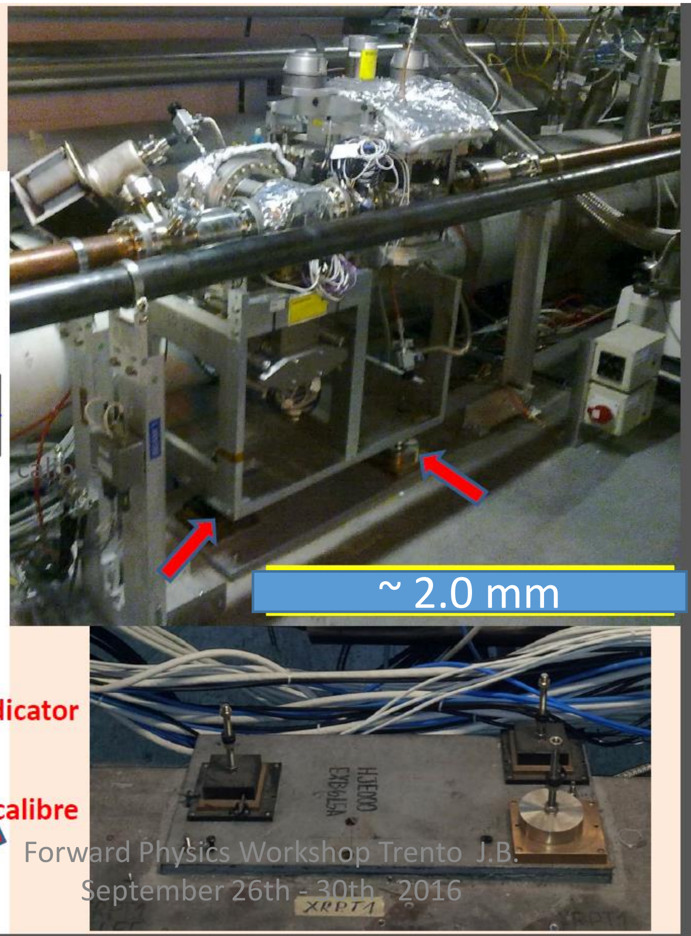
x-ray campaign of RF finger during TS1



Shift of RP unit vertically

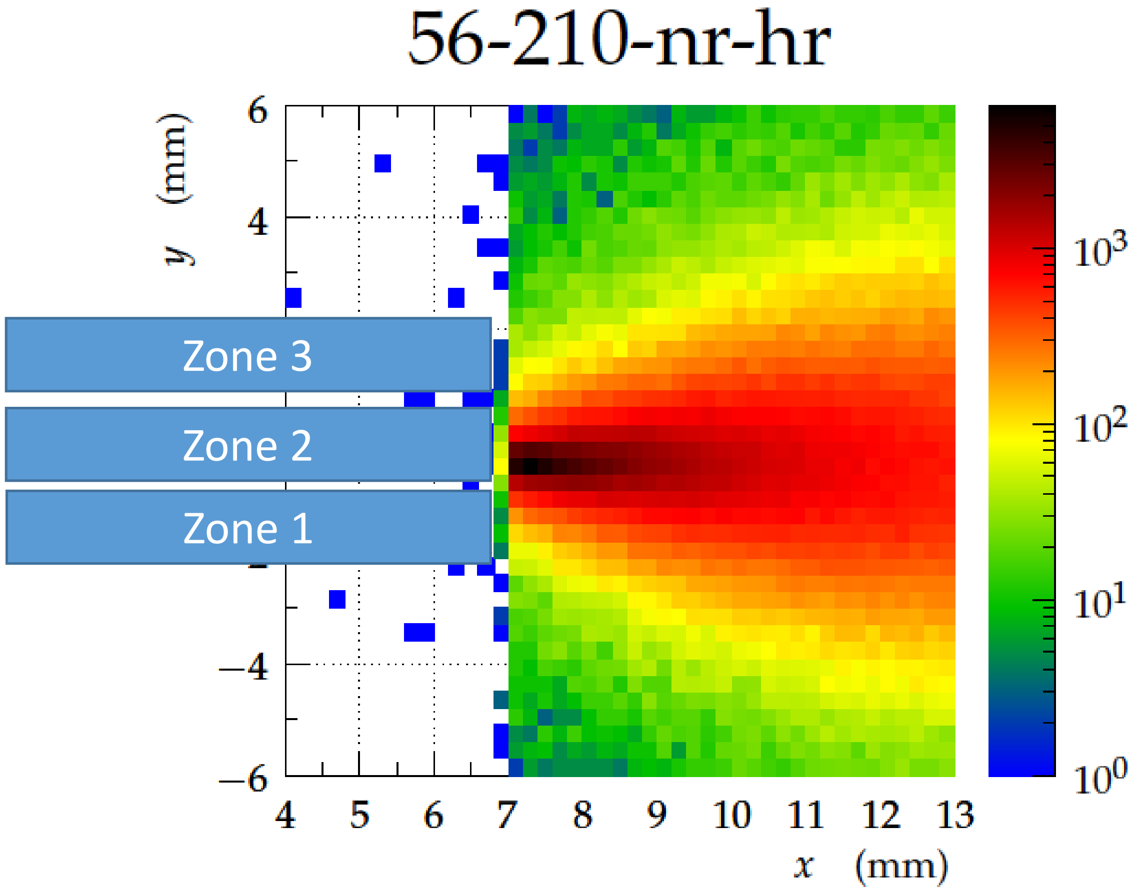
Procedure was approved by LHC vacuum group





x-ray analysis allow shift of ~ 2mm

Three different position of detector relative to beam allow extension of life time (zone 1,2,3)



Re-alignment necessary
after change of RP unit position

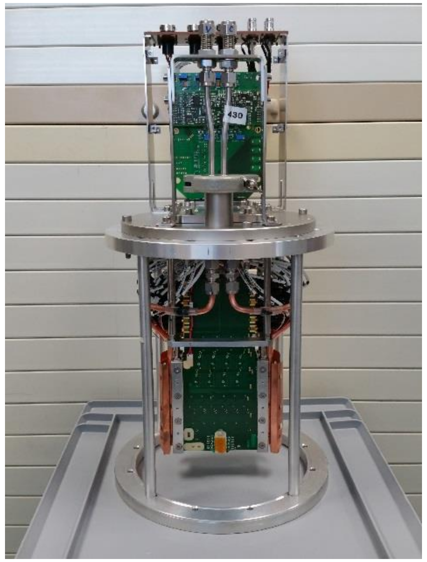
Upgrade installation work during TS1 and TS2

TS1

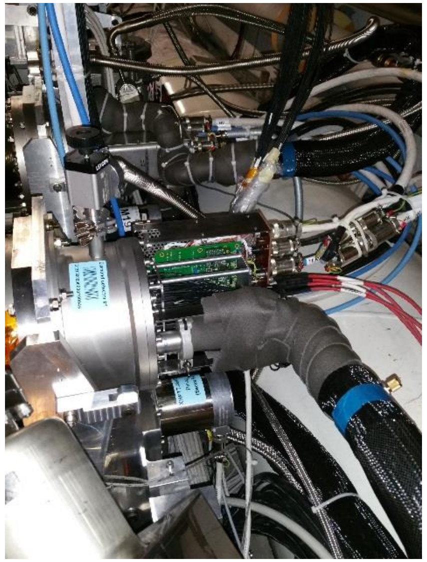
- Installation of diamond detectors in cylindrical RPs
- Installation of precision clock components

TS2

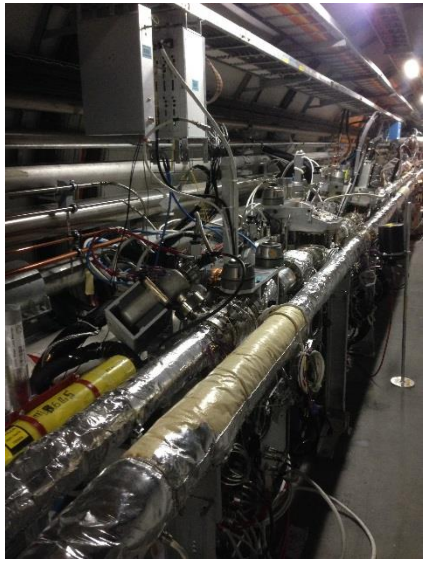
- Installation of timing electronics & precision clock components
- Exchange of detector packages in horizontal RPs 210 m near/far



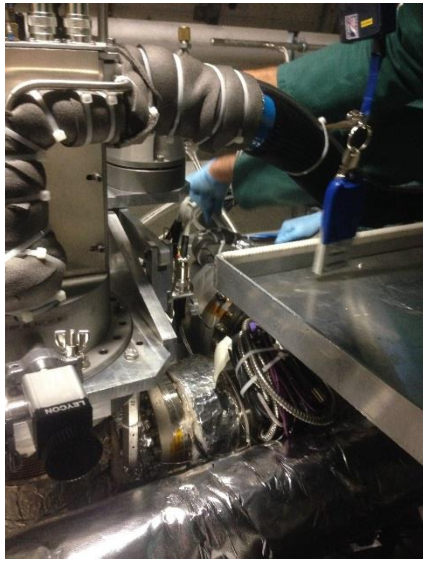
Diamond detector package with champignon



Diamond detector – champignon integrated in cylindrical Roman Pot



Timing detector electronics and clock distribution components (RF & LASER based)



Exchange of horizontal Si strip detector

Summary and Conclusions (1)

- **Detector upgrade**

- ❑ Diamond detectors (tracking & timing) were integrated in cylindrical Roman Pots during **TS1**
- ❑ Readout firmware uploaded and clock distribution components were installed during **TS2**

- **Detector service**

- ❑ 4 Si strip detector packages exchanged (TS2) in horizontal RPs of 210m for efficient data taking after TS2
- ❑ RF finger x-ray campaign during TS1 -> Preparation for RP unit vertical shift by 2.0 mm during EYETS

- **Special Runs at high β* (2.5 km optics)**

- ❑ Beam was successfully setup with β* = 2.5 km - the vertical RPs aligned at only 3 σ beam distance
- ❑ reach of $|t| \sim 6*10^{-4}$ GeV^2
- ❑ elastic scattering in the Coulomb-Nuclear interference region
- ❑ high precision measurement of ρ parameter

Summary and Conclusions (2)

- **Runs at standard optics of LHC -> Roman Pot (new development) insertions and data taking**

- automatic Roman Pot insertions (15σ)
- insertions were validated for the design luminosity of LHC (L= 10^{34} cm^{-2} s^{-1})
- no perturbations of the LHC machine were observed due to RP insertions
- total number of 14 RPs (6 horizontals, 8 verticals) were inserted at low β*
- Roman Pot readout is fully integrated in CMS DAQ (100 kHz, CMS global runs)
- 11 fb^{-1} were recorded in CMS global runs with RPs in 15σ position
- RP-detector calibration & LHC optics calibration was performed
- dispersion measured with precision of 5 % - asymmetry in dispersion (sectors 4-5 & 5-6)
- event matching with CMS achieved and data analysis started

Common effort by LHC, CMS and TOTEM

Upcoming activities -> 2016 to 2017

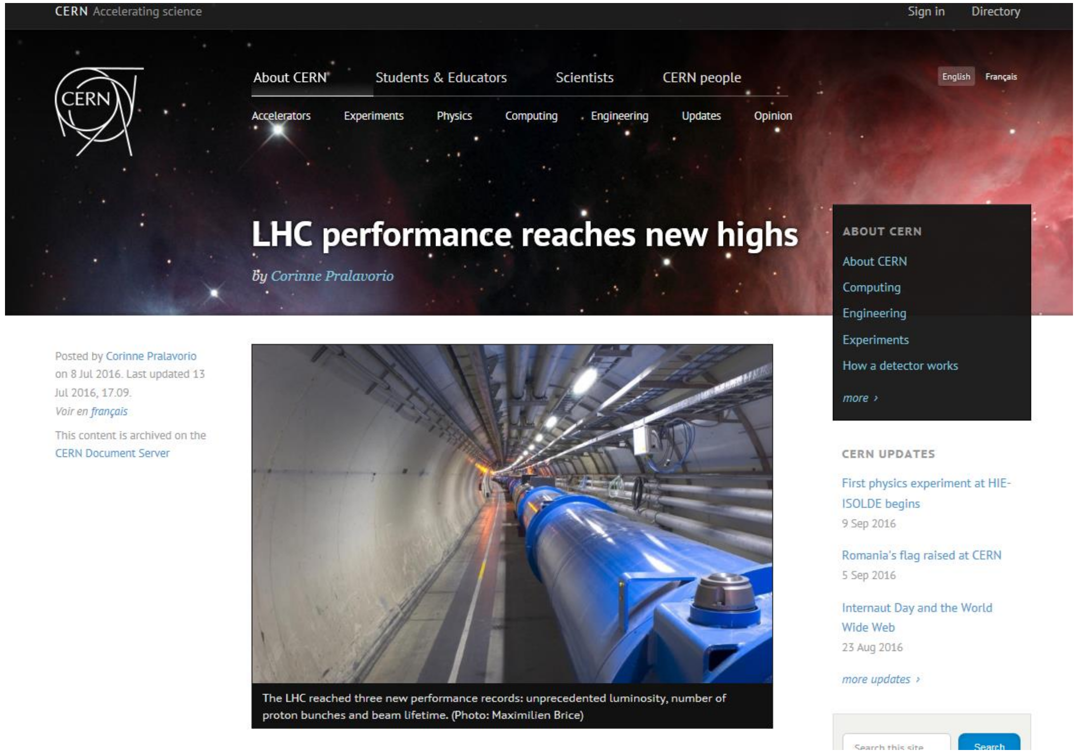
- Continue data taking with new crossing angle after TS2
  data taking with RP cylindrical diamond detector measurements
  & RP 210 (Si strip)

- EYETS and TS – 2017

  Under discussion: possibility to exchange the RP220 m horizontals

  -> equip with RF shields

- Si-Pixel for tracking
- Further R&D on timing detectors



The LHC reached three new performance records: unprecedented luminosity, number of proton bunches and beam lifetime. (Photo: Maximilien Brice)

It's full speed ahead for the Large Hadron Collider (LHC), as it shatters its own records one after the other, achieving record luminosity, record numbers of bunches and a record beam lifespan.

Some 2076 bunches of 120 billion protons are currently circulating in the ring in each direction. At the end of June, beams were maintained in the accelerator for a record 37 consecutive hours! But the main indicator of success for the operators is luminosity, the measurement of the number of potential collisions in a given time period. On 29 June, peak luminosity (the number of potential collisions per second and per surface unit) exceeded 10^{34} cm^{-2} s^{-1}. This number may not mean much to most of us, but it made the LHC operators very proud as it corresponds to the ultimate objective defined by those who originally designed this huge machine!

The result is a torrent of data for the experiments. "At present, we are providing an integrated luminosity of 2 inverse femtobarns of data per week," says Jorg Wenninger, who is in charge of the LHC operations team. The inverse femtobarn (fb^{-1}) is the unit of measurement for integrated luminosity, indicating the cumulative number of potential collisions. One inverse femtobarn corresponds to around 80 million million collisions.

Rapidity Reach versus Dispersion