Status Report of TOTEM
and the CT-PPS Roman Pot Operations

LHCC Open Session
23rd September 2015

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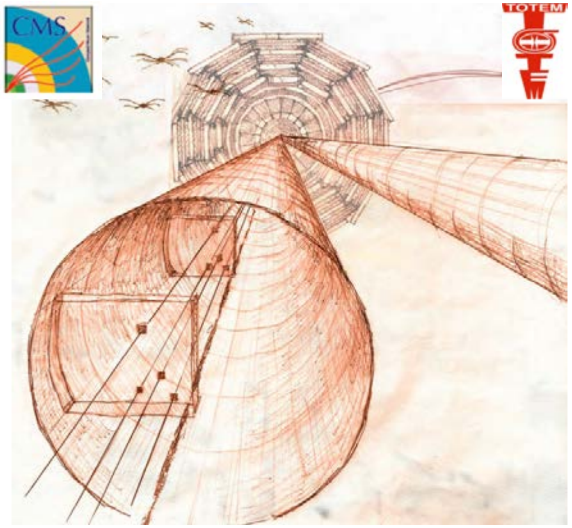
(CERN)

on behalf of

The TOTEM Collaboration

and

The CT-PPS Project



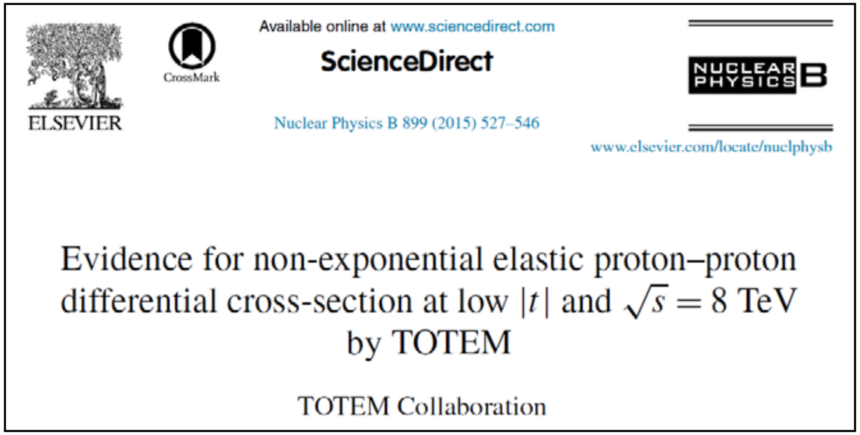
Overview

1. Recent and upcoming physics publications

2. Beam operations in 2015
   - VdM fills at $\beta^* = 19$ m — done
   - Special run at $\beta^* = 90$ m — October
   - RP test insertions for CT-PPS at $\beta^* = 0.8$ m — ongoing

3. Timing detector development
   and testbeam characterisation

Recent and Upcoming Physics Publications



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NUCLEAR PHYSICS B

Nuclear Physics B 899 (2015) 527–546

www.elsevier.com/locate/nuclphysb

Evidence for non-exponential elastic proton–proton differential cross-section at low $|t|$ and $\sqrt{s} = 8$ TeV by TOTEM

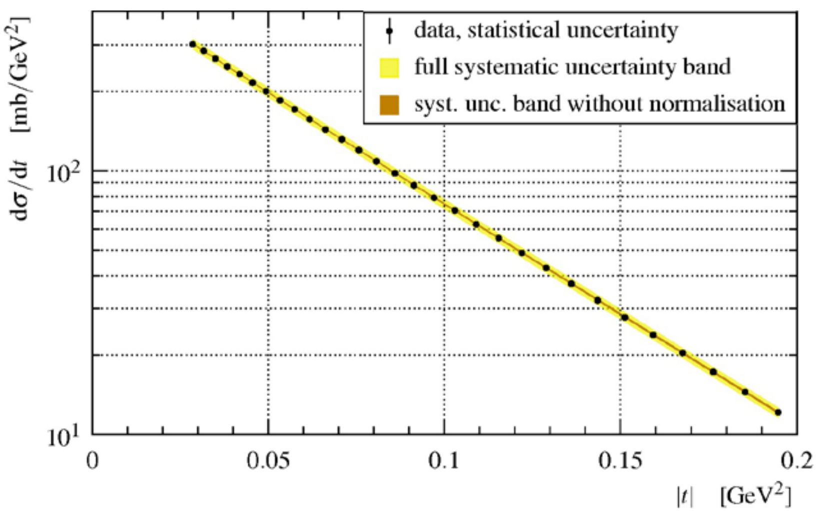
TOTEM Collaboration

Nucl. Phys. B899 (2015) 527

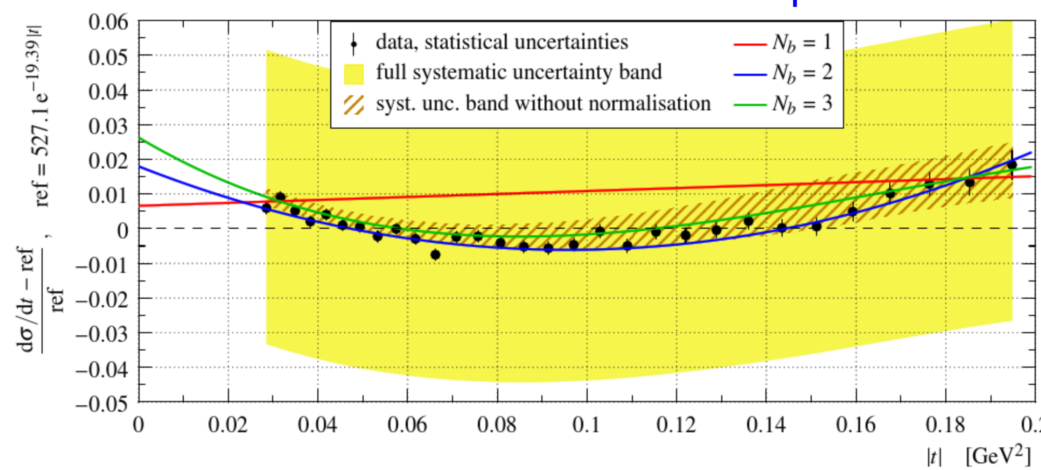
High statistics data set (β^*=90m, 2012): 7 M elastic events

0.027 GeV^2 < |t| < 0.2 GeV^2 dominated by hadronic interaction (Coulomb interaction neglected)

Differential Cross-Section dσ/dt



Relative deviation of dσ/dt from exponential



Pure exponential form excluded at 7.2 σ significance.

Recent and Upcoming Physics Publications

Upcoming: Elastic pp scattering in the Coulomb-Nuclear Interference Region

Measurement down to $|t| \sim 6 \times 10^{-4}$ GeV^2:

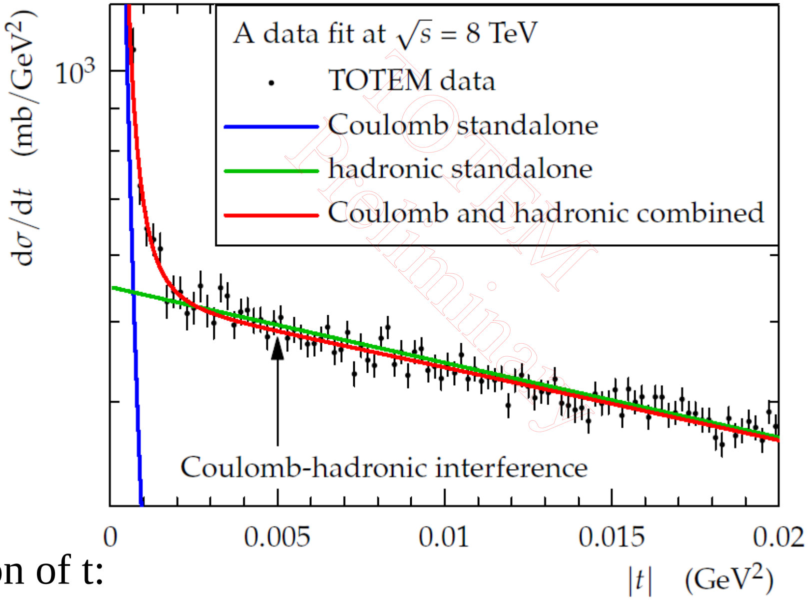
- $\beta^* = 1000$ m optics
- Roman Pot approach to 3 σ from the beam centre

$$F^{C+H} = F^{C} + F^{H} e^{i\alpha\Psi}$$

$$|F^H| \quad \arg(F^H)$$

$A\, e^{-B(t)\,|t|}$

hadronic phase as function of t:
implications on behaviour of elastic scattering in impact parameter space:
preferentially central or peripheral ?



Combined β^*= 1km & 90 m data

- exclude Simplified West & Yennie interference formula (requiring purely exponential hadronic ampl.)
- have constraining power on:
  - hadronic amplitude
  - hadronic phase → impact parameter picture

→ measurement of $\rho = \cot \arg F^{H}(t=0)$

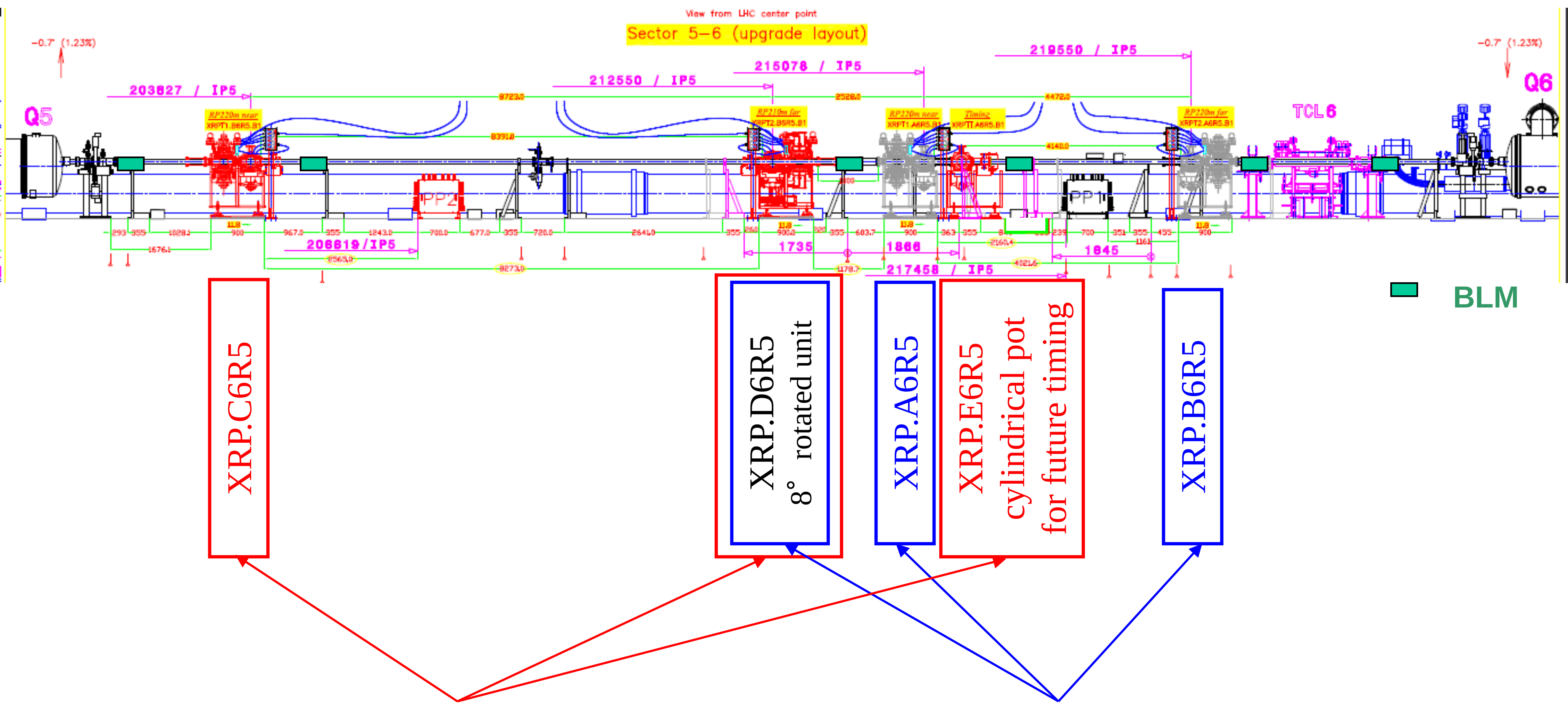
→ previous σ_{tot} measurements (that neglected CNI) are confirmed.

Results blessed, article in progress

Beam Operations in 2015

The Roman Pot System after LS1 and its Usage at High and Low β*
(Example: Sector 5-6)

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



Operation at low β* (0.8 m): CT-PPS
14 individual pots (both sectors together)

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

Runs at β^* = 19 m: LHCf Run and Van der Meer Scans

June: LHCf Run

Data taken with T1, T2 (minimum bias) → performance as in Run 1

August: VdM Scans

RPs inserted during all fills, even during IP5 scans:

Vertical RP: 12 σ

Horizontal RP: 15 σ

Successful data-taking with RPs, T2, and combined with CMS:

Trigger:

- RP single arm, T2 in veto
- RP double arm
- bunch crossings (zero bias)
- T2 minimum bias
- CMS: dijets, double muons

Pileup: μ = 0.05 and 0.4, Luminosity from 9×10^{28} to 3×10^{30} cm^{-2} s^{-1}

DAQ consolidation: 25 kHz rate measured: factor 25 w.r.t. Run 1

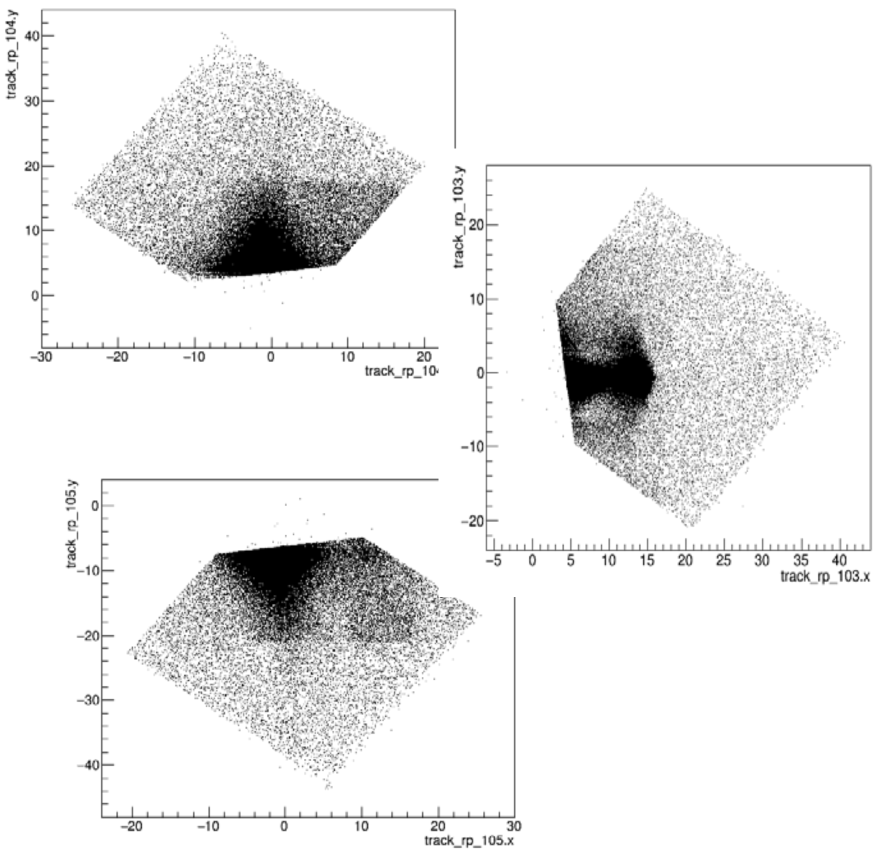
Total integrated luminosity taken: ~ 40 nb^{-1}

Offline data synchronisation and combination CMS+TOTEM in progress.

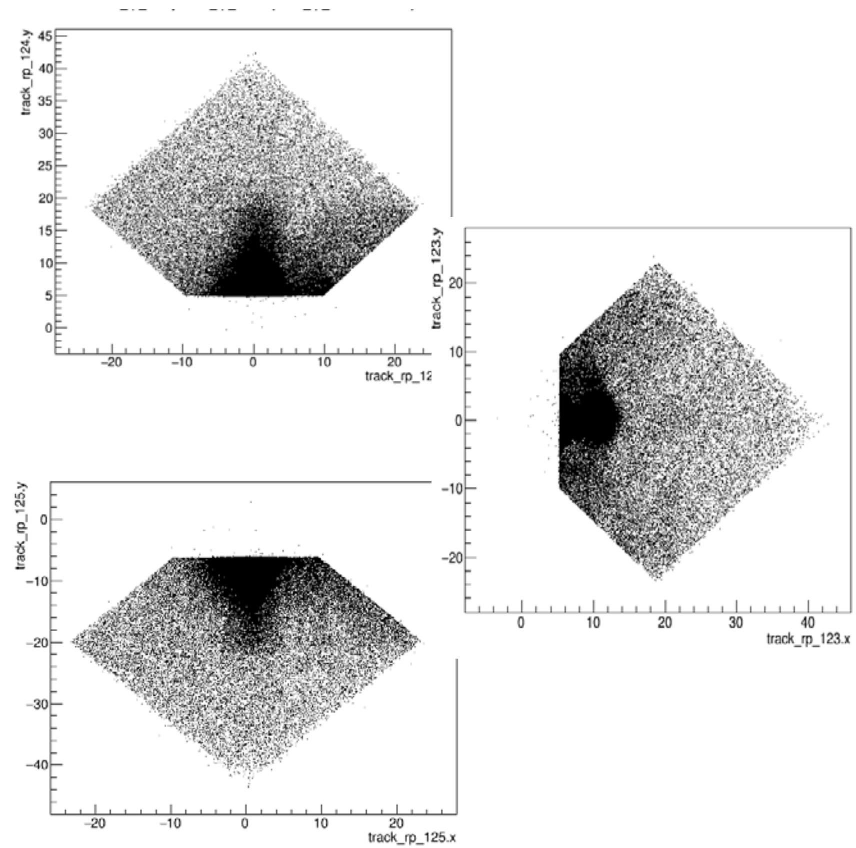
All TOTEM detectors operational and ready for the β^* = 90 m run in October.

RP Hit Maps from the Van der Meer Runs ($\beta^* = 19$ m)

56 RP 210 far
(8º rotated unit)



56 RP 220 far

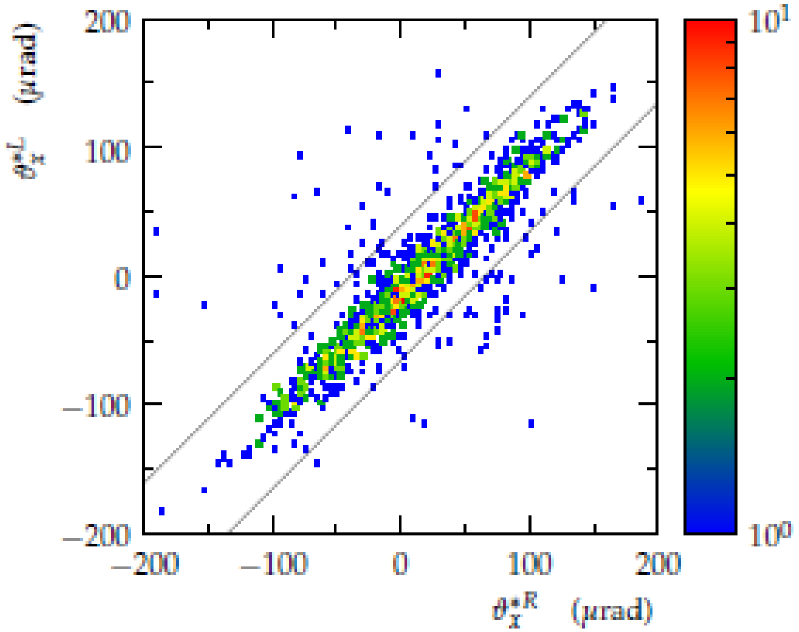


Van der Meer Runs (β* = 19 m): Elastic Events

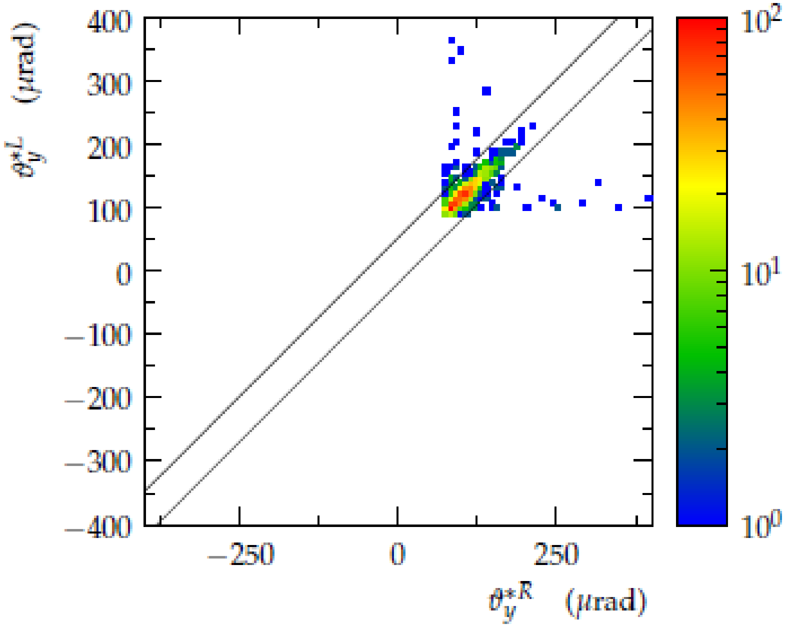
Diagonal double-arm selection: 45 bottom – 56 top

Correlation of scattering angles in the 2 arms:

Θ_x^* (45) vs. Θ_x^* (56)



Θ_y^* (45) vs. Θ_y^* (56)

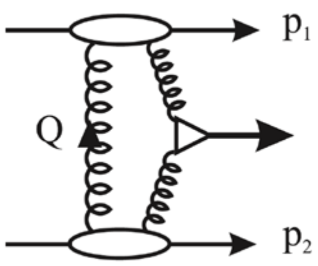


Scheduled for October: β* = 90 m Run

[see CERN-LHCC-2014-020 (TOTEM-TDR-002)
and CERN-LHCC-2014-024 (TOTEM-TDR-002-ADD-1)]

a) Low-Luminosity Programme
- for elastic scattering, total cross-section
- needs RPs very close to the beam (~ 5 – 6 σ)
→ use RP alignment fill (few hours of data taking after alignment)

b) High-Luminosity Programme
- low-mass central diffractive spectroscopy, glueball searches
- missing mass searches
in a joint run with CMS



100 ns bunch spacing → up to 702 bunches
~700 bunches to be reached after intensity ramp-up: 1 fill of 3–4 hours at ~50 and ~250 bunches

→ needs new version of 90 m optics with crossing angle (~ ±50 μrad):
First optics commissioning step successfully completed on 12 September !
Second commissioning shift planned for today.

bunch population (6 – 7) x 10^{10} p/b, emittance ε_n ~ 2.5 μm rad
→ pileup μ ~ 0.1
→ $\mathcal{L}$ = (0.6 – 0.8) pb^{-1} / 24 h

Common Request by CMS and TOTEM in the LPC: $\mathcal{L}_{int} \geq 1\ pb^{-1}$

RP Insertions in Regular Fills at Low β*

Objective:

Establish Roman Pot insertions for physics operation in all regular fills from 2016 on

Problems during first Insertion Tests in 2012:

Impedance heating combined with outgassing:

- measured temperature rise on electronics cards inside RPs despite active cooling
- traces (black spots) of metal overheating on bellow next to a ferrite fragment
- ferrite (Ferroxcube 4S60, not baked out at 1000 ºC) outgassing
  → vacuum deterioration
  → amplification of collision debris showers → dumps on BLMs

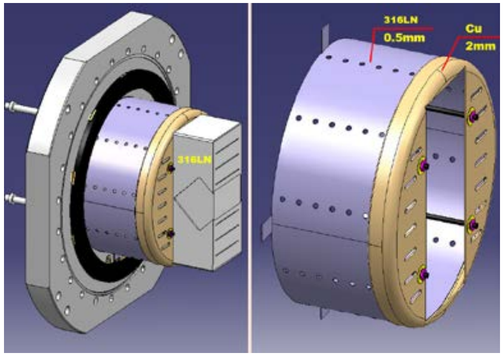
But no beam instabilities observed

RP Insertions in Regular Fills at Low β*

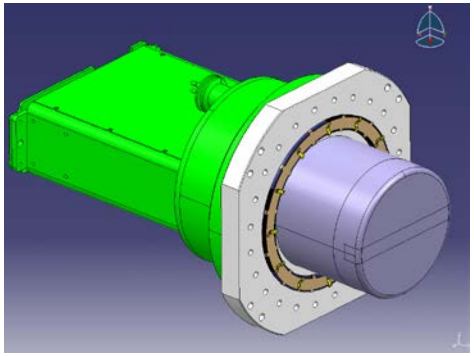
Technical Improvements during LS1

[see e.g. LHC-XRP-EC-0010, LHC-XRP-EC-0011]

- New ferrite material for all RPs (Transtech TT2-111R) like for collimators
  → higher Curie temperature
- Ferrite bake-out at 1000 °C
  → less outgassing
- Installation of RF shields in horizontal RPs for high-lumi operation,
  new ferrite geometry
  → significant impedance reduction



- Cylindrical RP geometry for new timing RPs
  → significant impedance reduction
  → but more material along the beam
  (12 cm for cylindrical pot instead of 5 cm for old box-shaped pot)



- TCL6 to intercept showers from RPs

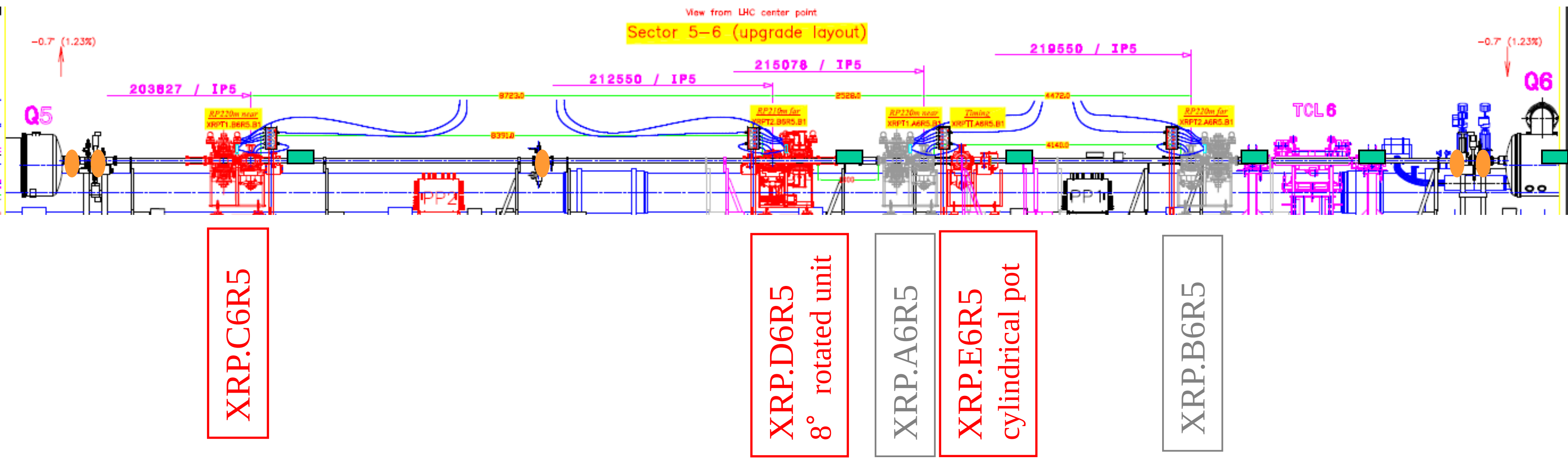
→ 2015: test effectiveness of modifications by inserting RPs in all steps of intensity ramp-up

RP Insertions in Regular Fills at Low β*

Commissioning Programme Philosophy:

- Study beam losses / showers and interplay with TCL collimator system
  extended BLM system: 1 monitor after **almost each RP unit**,
  after TCL6 and at the quadrupole Q6

- Study RP impact on impedance:
  - heating: temperature sensors on/in RPs
  - vacuum: 5 gauges in RP sector: DCS monitoring
  - beam orbit stability: monitored by impedance group



Beam Loss Monitor (BLM)

Vacuum Gauge

Operation at low β*

Operation at high β*

RP Insertions in Regular Fills at Low β*

3 – 4 July: Beam-based alignment of all 14 low-beta RPs in 1½ hours,
afterwards 45 minutes of diagnostic data taking in quiet beams with pots @ 6–8 σ

5 – 14 July: RP insertions in all intensity steps of 50 ns intensity ramp-up
still nominal TCL configuration: TCL5 in, TCL6 out,
very conservative RP positions due to orbit uncertainties: **~ 30 σ horizontally, ~ 20.5 σ vertically**
3, 50, 152, 296, 476 bunches per beam → lumi up to 1.3 x 10^{33} cm^{-2} s^{-1}

13 – 21 August: RP insertions in first part of 25 ns intensity ramp-up
final TCL configuration: TCL5 out, TCL6 @ 25 σ
closer RP positions: **~ 25 σ horizontally, ~ 19.5 σ vertically**
2, 86, 157, 219, 315 bunches per beam → lumi up to 0.7 x 10^{33} cm^{-2} s^{-1}

Technical Stop 2: Installation of Aluminium bar in cylindrical pot in 5-6
mimicking the material of a Cherenkov Quartz bar

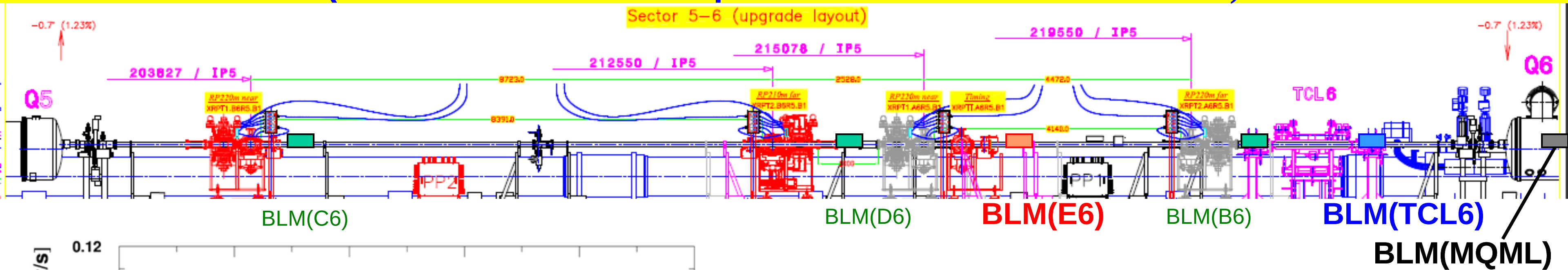
Since 5 Sept (ongoing): RP insertions in second part of 25ns intensity ramp-up
So far: 2, 49, 219, 459, 745, 1033, 1177 bunches per beam → lumi up to 2.3 x 10^{33} cm^{-2} s^{-1}

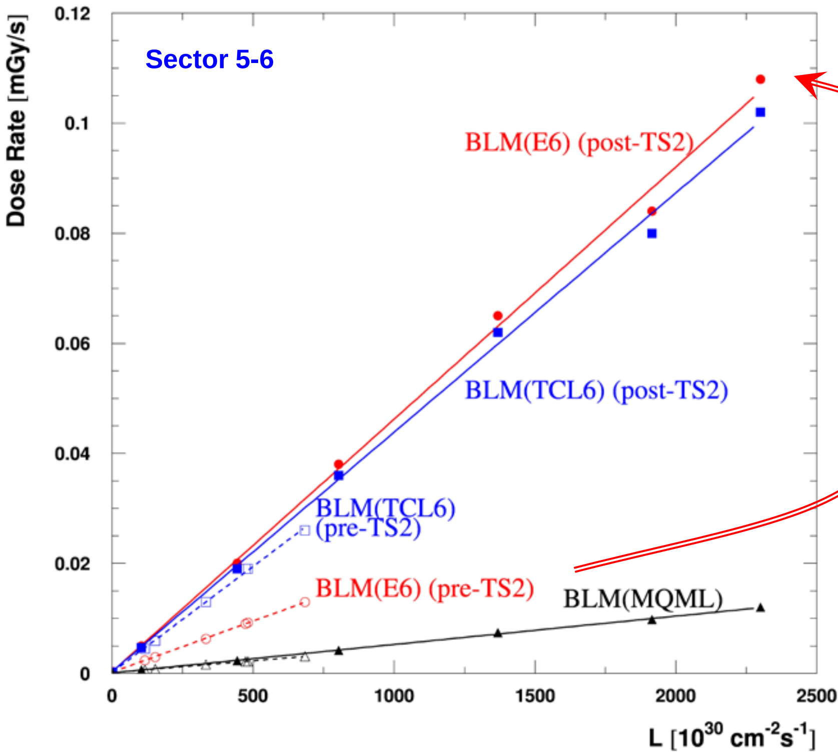
So far: no beam instabilities due to RP insertions observed.

Aim for RP positions later this year if all insertions successful:
20.7 σ horizontally, 18.2 σ vertically

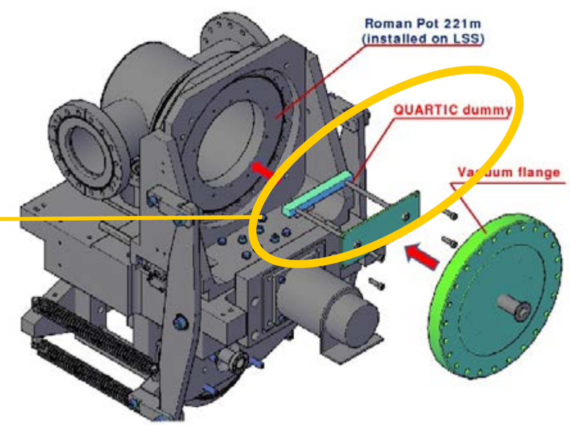
Beam Loss Monitor Response to RP Insertions

(Insertion of horizontal pots to ~25 σ from beam centre)





Installation of Al bar (Quartic dummy) in the pot

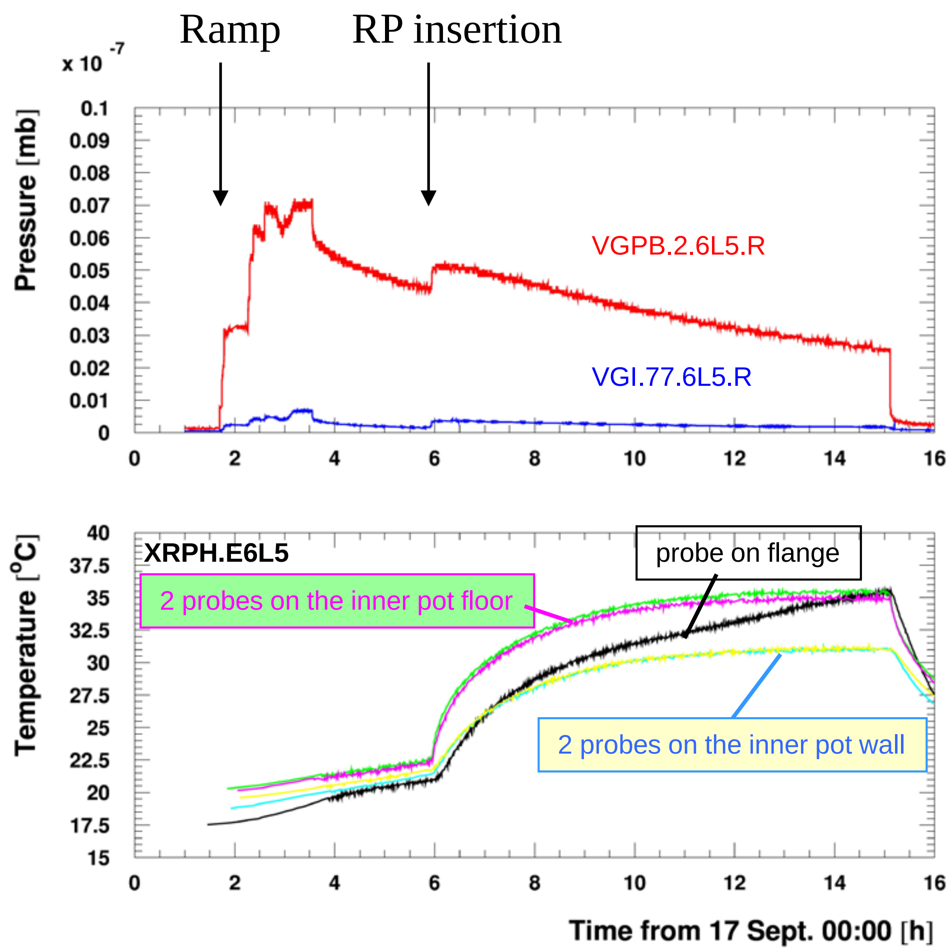


- Dose rates proportional to luminosity → showers = collision debris, not single-beam halo
- RP generating strongest shower dose rate: cylindrical pot (E6): most material
- Installation of dummy QUARTIC bar → dose rate in BLM(E6) increases by ~ factor 2
- Linear Extrapolation to $L=10^{34}$ cm^{-2} s^{-1} : BLM(E6) = 0.47 mGy/s = 0.07 Thresh. → **no problem from BLMs expected**
- Strong dose rate in BLM(TCL6), very small signals in quadrupose BLMs → **TCL6 is effective**

Vacuum and Temperature Response

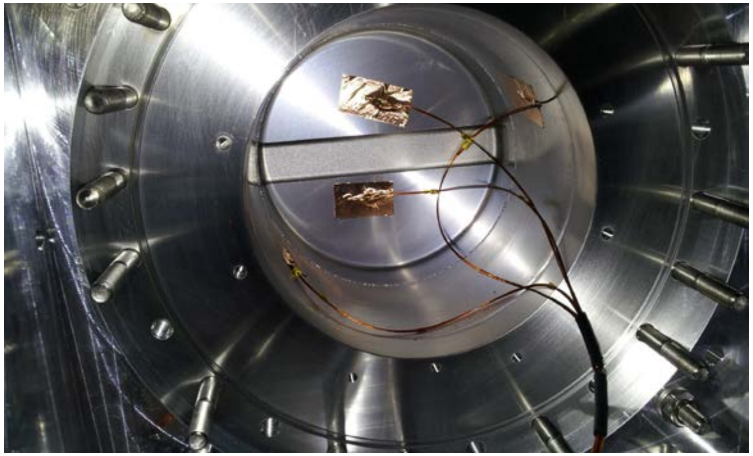
Example fill: **horizontal pots @ ~25 σ from beam centre, L ~ 1.9 x 10^{33} cm^{-2} s^{-1}**

Time evolution of pressure and temperature:



Vacuum gauges near the most upstream RP:
significant but unproblematic pressure rise

Temperature sensors on cylindrical pot:
hottest spot = pot floor (towards beam) !



Slow temperature increase approaching an equilibrium value,
moderate magnitude: up to 36 ºC at RP floor 3 mm from beam centre without cooling
Comparison: 2011 in a fill without cooling: 41 ºC on RP electronics card with pot retracted (4 cm from beam)

Timing detector development and testbeam characterisation

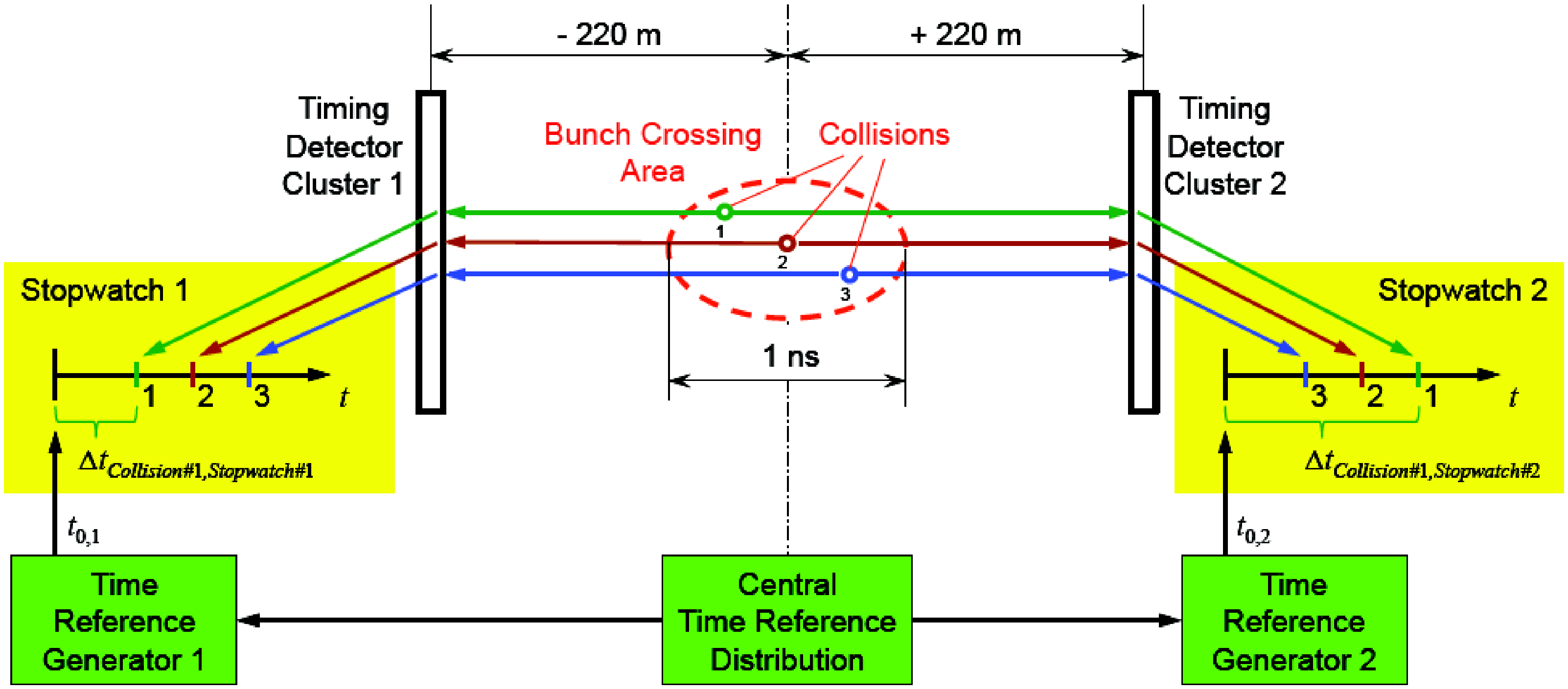
Longitudinal Vertex Reconstruction by Time Measurement

Pileup problem:

High luminosity → multiple events in 1 bunch collision !

- CMS tracker can separate multiple vertices longitudinally,
- leading proton tracks have angles in μrad range → insufficient vertex precision

→ for double-arm events (CD) reconstruct vertex from time-of-flight difference



Position of Collision 1 ~ $\Delta t_{Collision\#1,Stopwatch\#1} - \Delta t_{Collision\#1,Stopwatch\#2}$

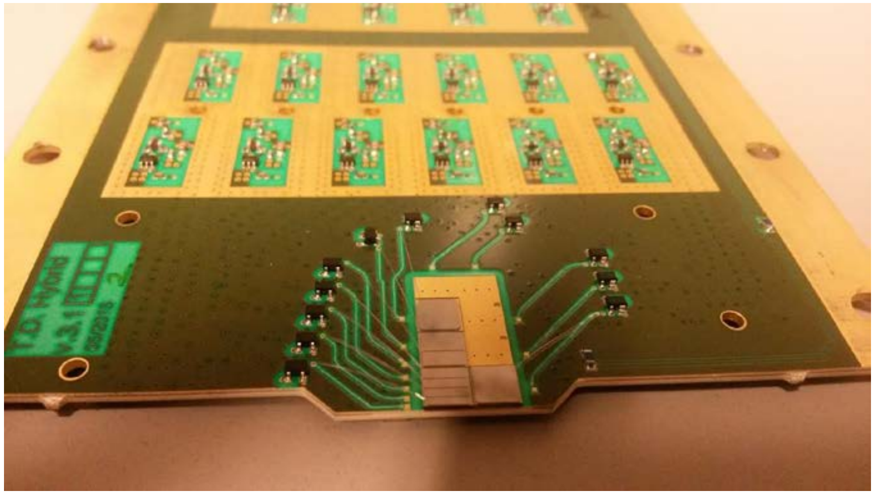
Timing Detector Development for Medium Pileup (β^* = 90 m Runs)

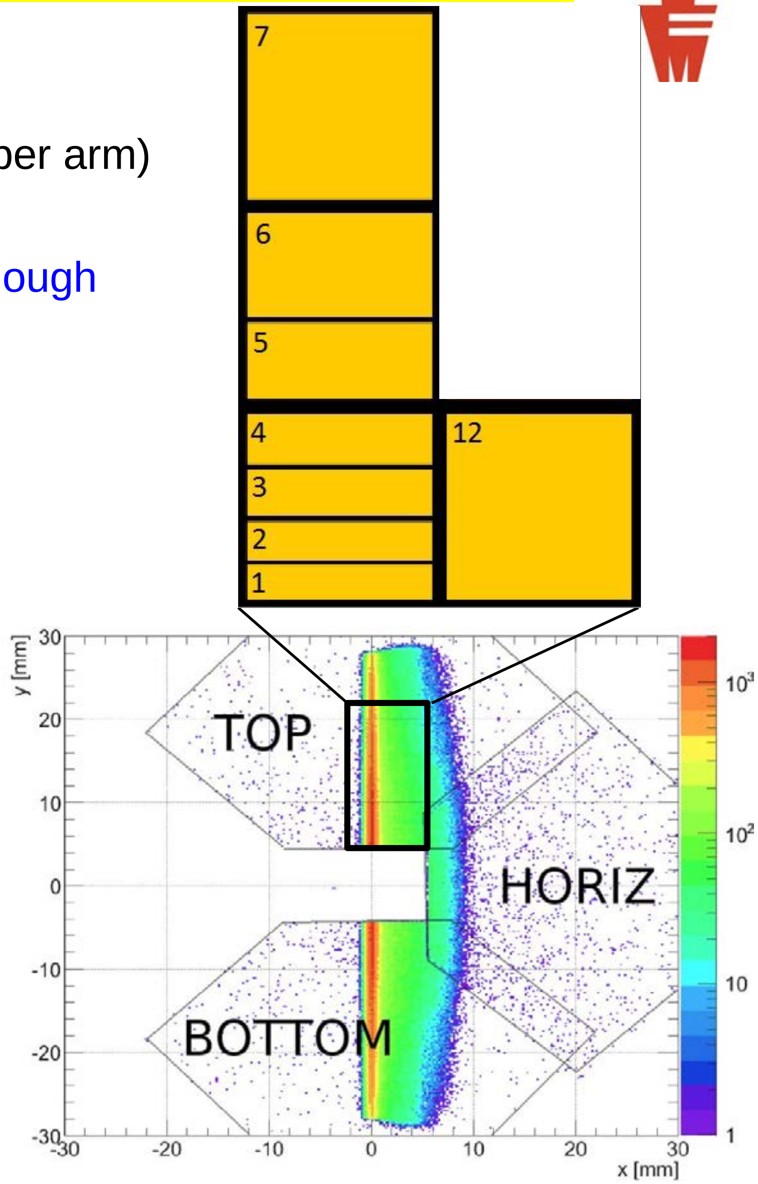
Objective:

- 3 timing detector planes in 4 vertical RPs (1 pot pair per arm)
- Detector installation in Technical Stop 3 – YETS
- ~ 60 ps resolution per arm (~ 100 ps per detector) enough since at 90m the pileup $\mu < 0.6$
  (different for CT-PPS: β^*=0.8m: $\mu \leq 50$!
  → needs time resolution ~ 10 ps)

Development of Diamond Detectors:

Segmentation follows the diffractive hit distribution: almost constant occupancy per pixel

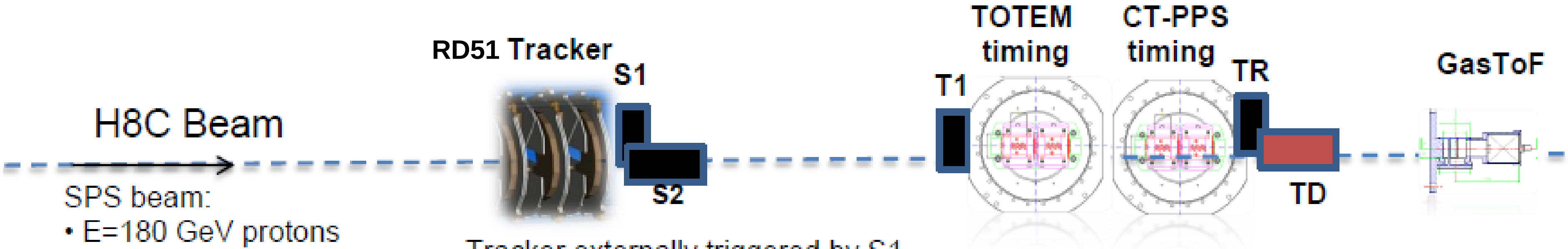




Testbeam Characterisation of Diamond Detectors

TOTEM + CT-PPS test beam, timing detectors inside Roman Pots

- TOTEM: diamonds
- CT-PPS: QUARTIC Cherenkov detectors



SPS beam:
- E=180 GeV protons
- Divergence: 40-250 mrad
- Rate 5-10KHz/cm²/spill

Tracker externally triggered by S1 and S2 (trigger area ~2x2 cm²)

Average time resolution as function of the pixel size

~100 ps goal reached for all the sizes

Room for improvement:

- diamond selection
- noise shielding
- LV optimisation

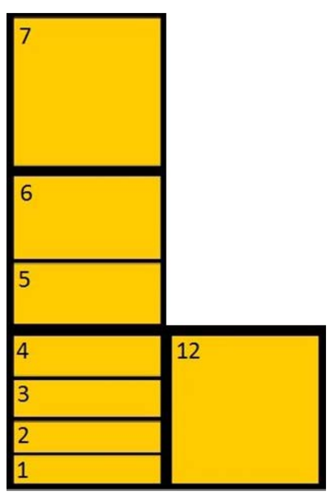
TS3: 3 planes in 1 pot → system test

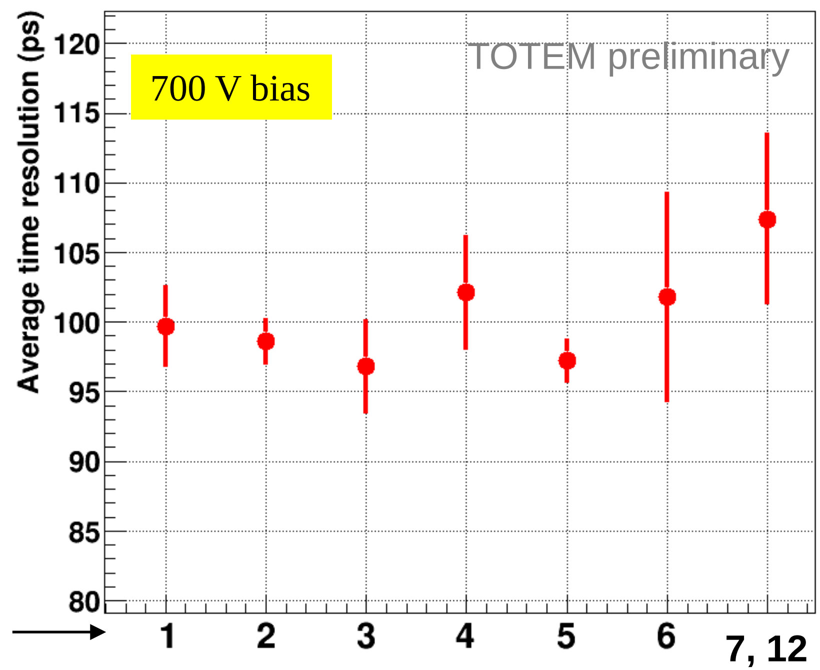
Winter 2015-16 (YETS):

3 planes in 4 pots for physics in 2016

→ expected 60 ps time resolution

→ few cm vertex resolution





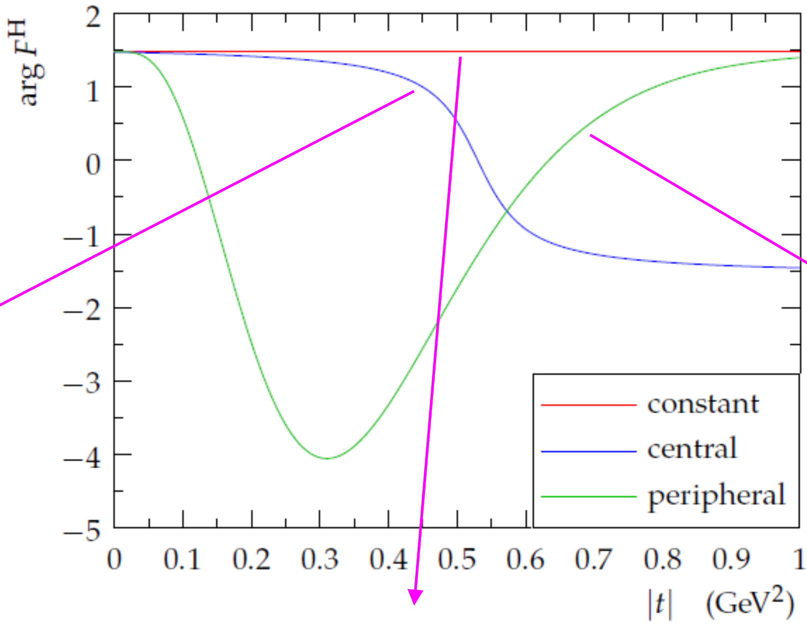
Conclusions, Outlook

- Several publications from run 1 upcoming (only partly covered here)
- All TOTEM detectors are operational
- Successful data taking during the VdM scans
- RP insertions in regular low-β^* fills ongoing: so far very promising
- We are ready for the special run at $\beta^* = 90$ m in October
- 2016: first LHC operations with timing detectors in RPs

The End

Elastic Scattering in the Coulomb-Nuclear Interference Region

Different options for the unknown nuclear phase:



"central phase":
profile function in impact parameter picture:
Elastic scattering preferentially central

$$\arg F(t) = \frac{\pi}{2} - \operatorname{atan} \frac{\cot p_0}{1 - \frac{t}{t_d}}$$

constant phase:
also central behaviour

$$\arg F(t) = p_0$$

"peripheral phase":
profile function in impact parameter picture:
Elastic scattering preferentially peripheral

$$\arg F(t) = p_0 + \zeta_1 \left|\frac{t}{t_0}\right|^{\kappa} \exp(\nu t), \quad t_0 = 1\,\mathrm{GeV}^2$$

Result for $\rho = \frac{\Re F^H(0)}{\Im F^H(0)} = \cot \arg F^H(0) = \cot p_0$ is model dependent

Analysis of the CNI Region

Fit models retained for final analysis:

Hadronic Slope	Constant Phase (representative for all central phases)	Peripheral Phase
$N_B = 1$ (pure exponential)	excluded	disfavoured
$N_B = 3$ (parabolic exp. slope)	possible	possible

Impact parameter picture: profile functions