

CT-PPS data taking and physics programme

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on behalf of the CMS and TOTEM Collaborations

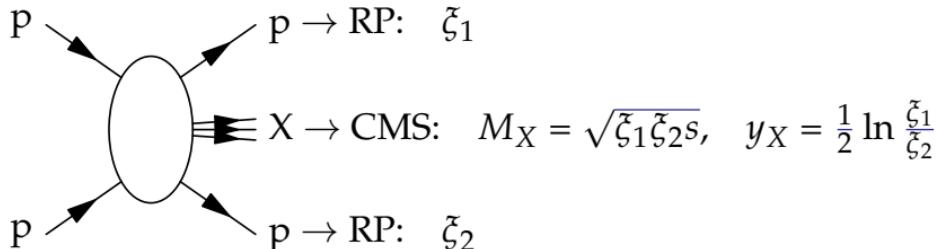


Forward Physics WG, Trento
27 September, 2016

- CMS-TOTEM Precision Proton Spectrometer
 - “accelerated” programme using TOTEM Si strip detectors
- performance of Si strips
- alignment studies
- optics studies
- proton reconstruction – control plots

(work in progress – report from the last two weeks)

- study of central exclusive production:

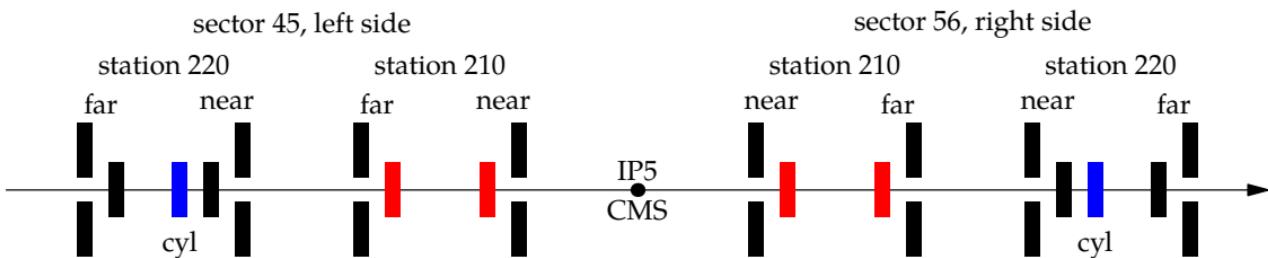


- system X : $\mu\mu, \gamma\gamma, H, WW, ZZ, jj, \dots$
- exchange of colour singlets with vacuum quantum numbers \Rightarrow selection rules for system X : $J^{PC} = 0^{++}, 2^{++}, \dots$
- large rapidity gaps between forward protons and central system
- double kinematics determination: CMS and protons \Rightarrow exclusivity

- proton tagging

- beam pockets - need good RF behaviour, base-line: RPs
- tracking detectors - need to reconstruct multiple tracks, base-line: 3D Si pixels
- timing detectors - need to suppress pile-up background, solutions: diamond, ultrafast silicon, Cherenkov

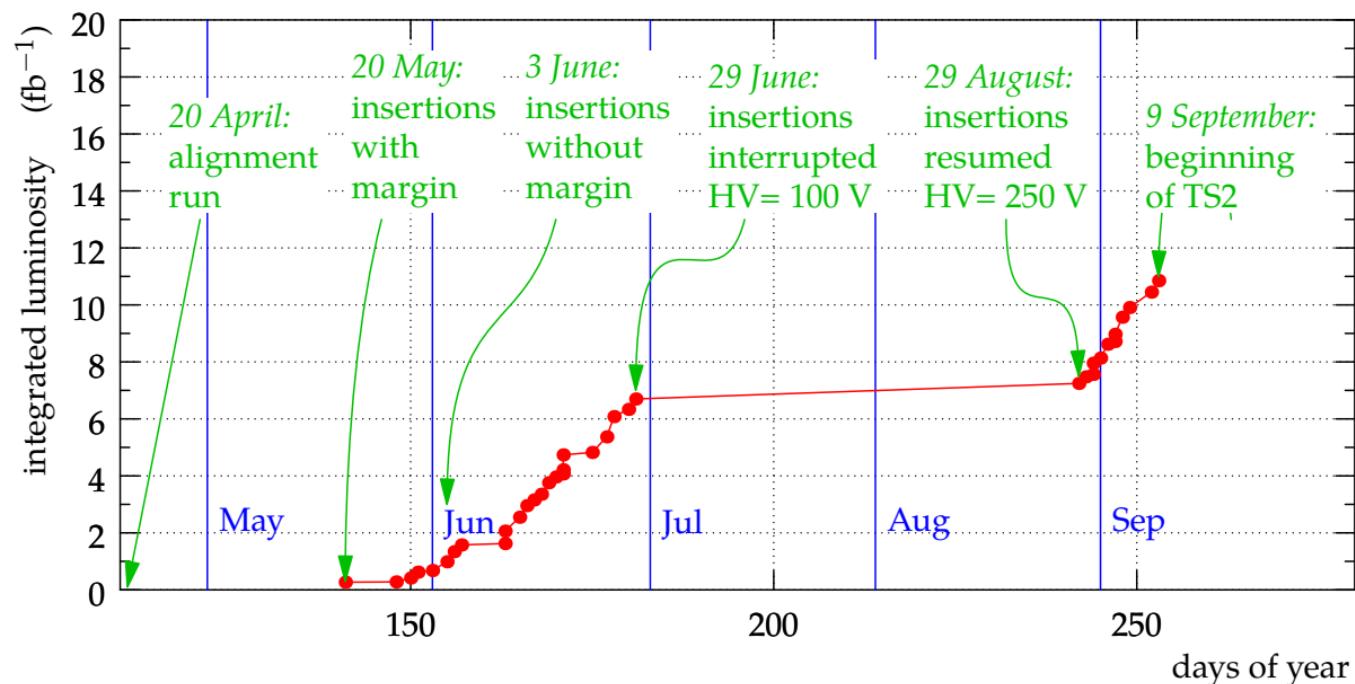
- motivated by the “750 GeV excess” (end 2015)
- use existing/advanced development technology
 - beam pockets: TOTEM RPs (with RF shields)
 - tracking detectors: TOTEM Si strips
 - timing detectors: TOTEM diamonds (with coarse tracking too)
- existing RPs around IP5 (view from the ring centre, not to scale)



- red: TOTEM RPs used for CT-PPS
- black: other TOTEM RPs
- blue: cylindrical RPs (for timing, good RF properties)

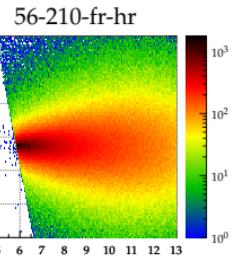
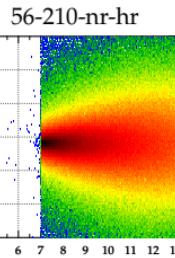
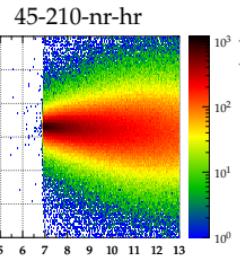
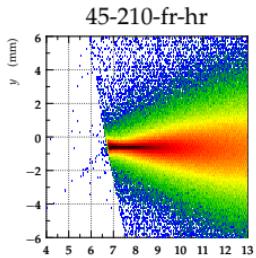
RP insertion summary

- luminosity delivered in fills with RPs inserted and read out
 - each dot = 1 fill
 - total delivered luminosity almost 11 fb^{-1}

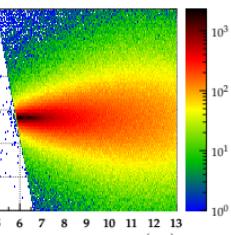
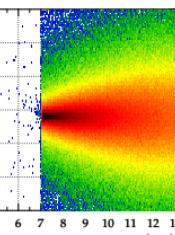
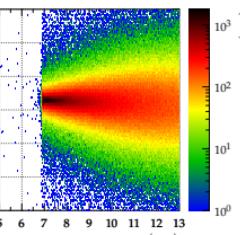
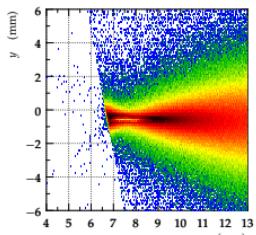


Radiation damage : Before HV increase

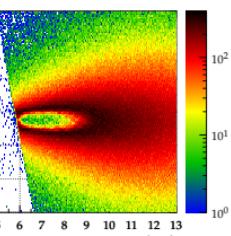
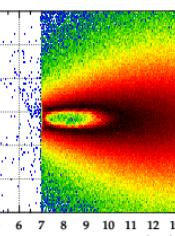
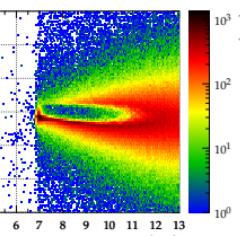
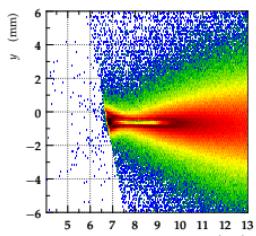
fill 4947
20 May
 $\mathcal{L}_{\text{int}} < 0.5 \text{ fb}^{-1}$



fill 4985
3 Jun
 $\mathcal{L}_{\text{int}} \approx 1 \text{ fb}^{-1}$



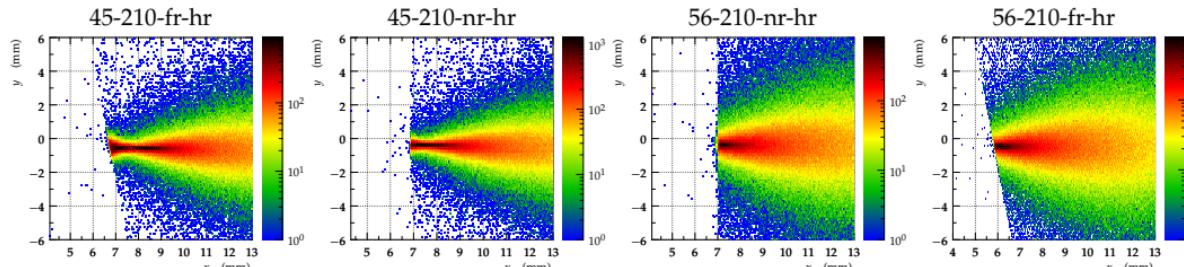
fill 5052
29 Jun
 $\mathcal{L}_{\text{int}} \approx 6 \text{ fb}^{-1}$



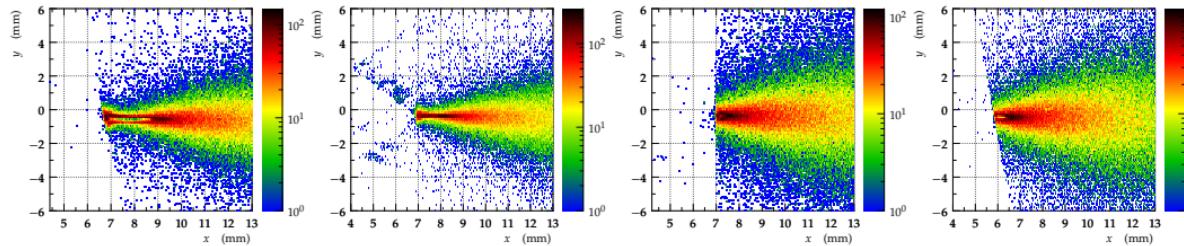
radiation damage visible in all 4 RPs

Radiation damage : After HV increase

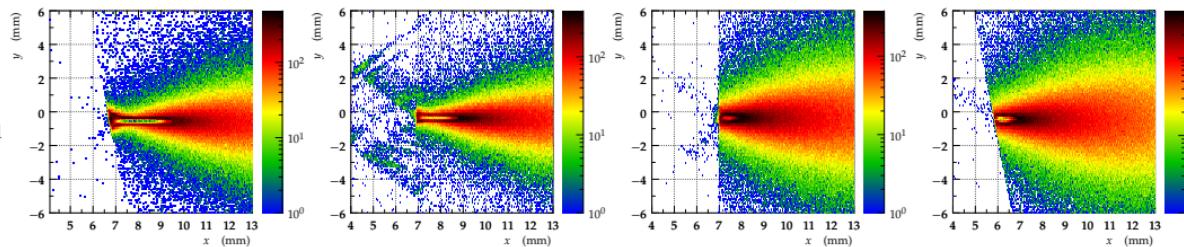
fill 5261
29 Aug
 $\mathcal{L}_{\text{int}} \approx 7 \text{ fb}^{-1}$



fill 5275
3 Sep
 $\mathcal{L}_{\text{int}} \approx 9 \text{ fb}^{-1}$



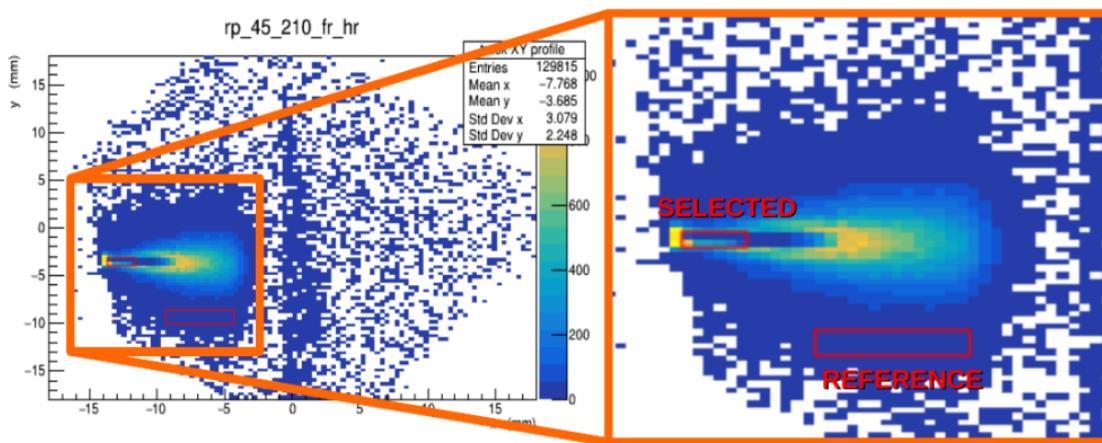
fill 5288
9 Sep
 $\mathcal{L}_{\text{int}} \approx 11 \text{ fb}^{-1}$



increased HV recovered the performance in the beginning

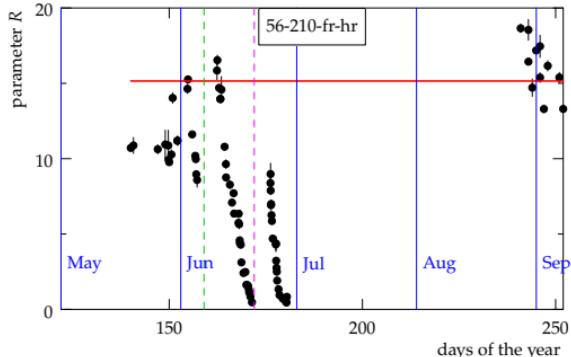
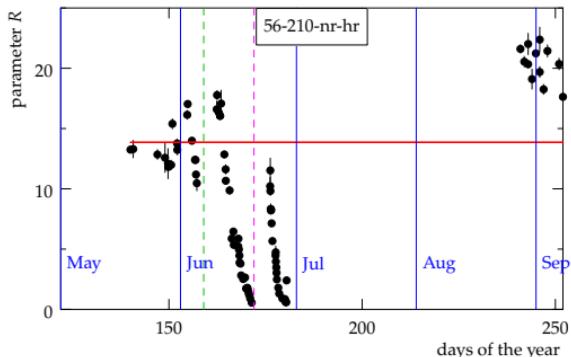
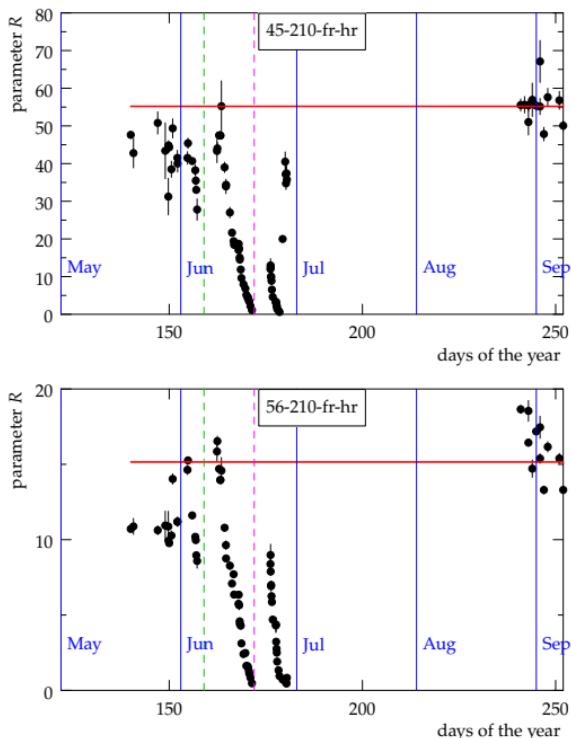
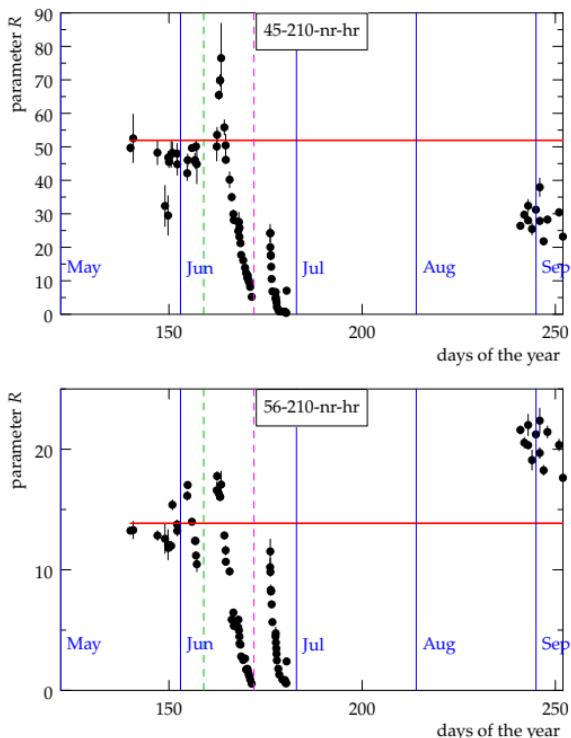
- parameter R - a simple measure of damage:

$$\text{Parameter} = \frac{\text{\# of hits in the selected area}}{\text{\# of hits in the reference area}}$$



Systematic damage monitoring

- green dashed line: TS1, magenta dashed line: 4 days without beam



performance recovered with rest time and increased HV

- transport equation (horizontal plane): IP5 → RPs

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

- x^* : vertex, θ_x^* scattering angle, ξ : fractional momentum loss
- $v_x x^* \approx 4 \cdot 10 \mu\text{m} \approx 40 \mu\text{m}$
- $L_x \theta_x^* \approx 8 \text{ m} \cdot 25 \mu\text{rad} \approx 200 \mu\text{m}$
- $D_x \xi \approx 8 \text{ cm} \cdot 10 \% \approx 8 \text{ mm}$

⇒ dispersion term dominant

- reconstruction pre-requisites

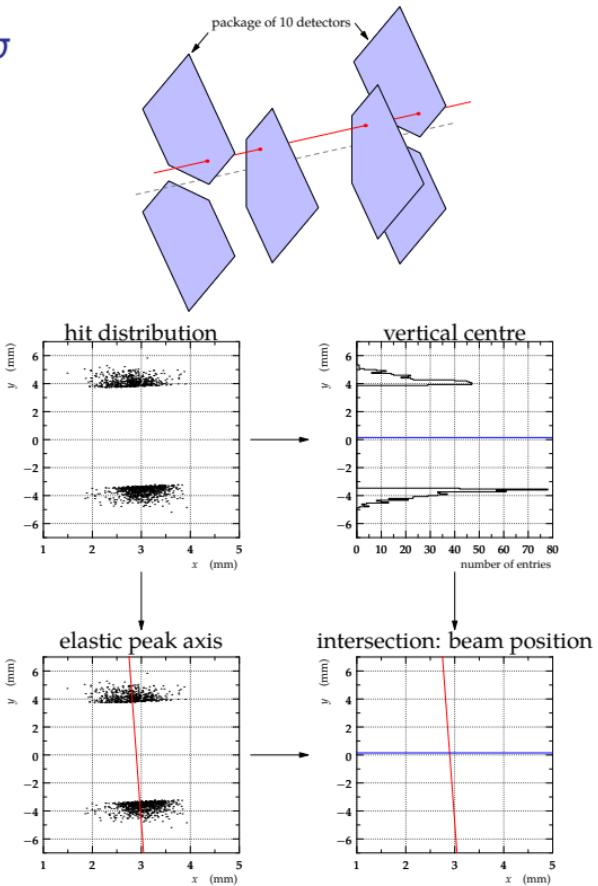
- *alignment*: offset to x
- *optics*: value of D_x , etc.

Alignment strategy : Step 1

- *alignment run*: horizontal RPs at $\approx 5 \sigma$
- *standard TOTEM alignment*

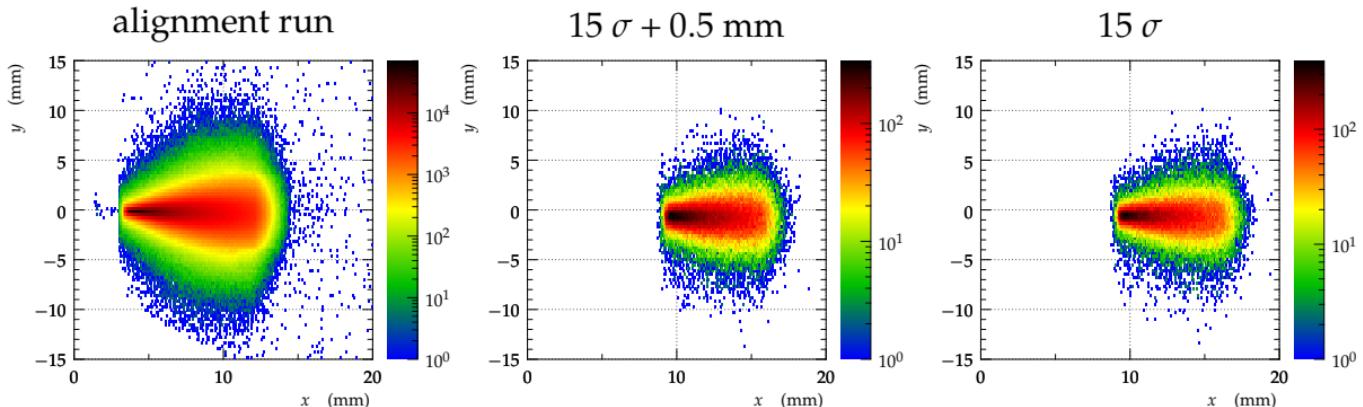
- **track-based**: relative alignment among RPs of each unit

- **elastics in vertical RPs**: alignment of units wrt. beam



Alignment strategy : Step 2

- *physics runs*: horizontal RPs at 15σ (or $15\sigma + 0.5\text{ mm}$)
- *match hit distributions (per RP)*: $\text{alignment} \leftrightarrow \text{physics run}$
 - example: hit distributions at L-210-fr-hr

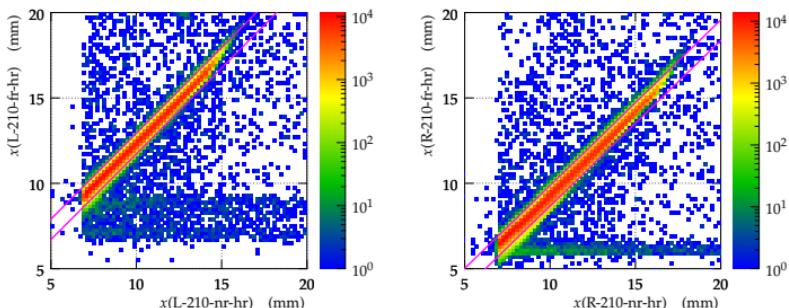


- challenges:
 - need to find appropriate match definition (bias, robustness, ...)
 - need to match “physics” only – suppress background
- assumptions: constant conditions
 - optics
 - apertures

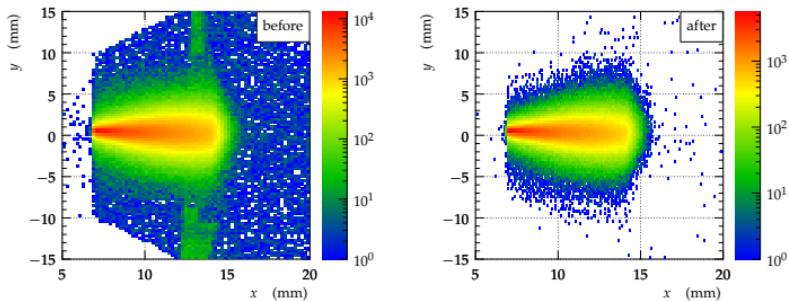
Background suppression

- x correlation near vs. far RP

- dominant term in proton propagation: $x \approx D_x \xi$



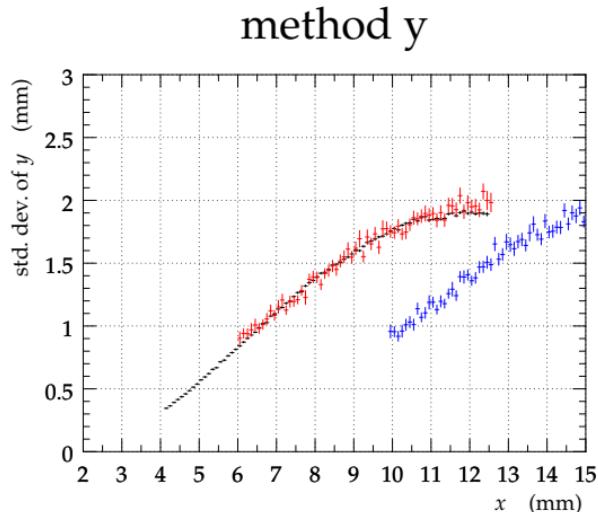
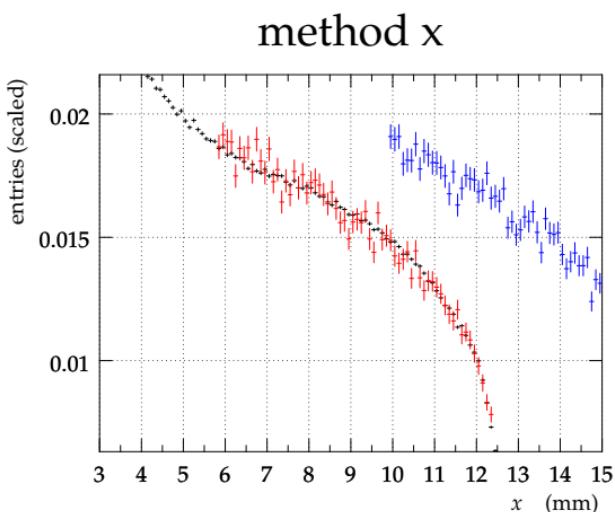
- effect (in L-210-nr-hr):



- another possible cut: near vs. far correlation in y

- more complicated as L_y depends on ξ

- simplifications (for the time being)
 - match 1D distributions
 - optimise only horizontal position, i.e. alignment in x
- 2 methods

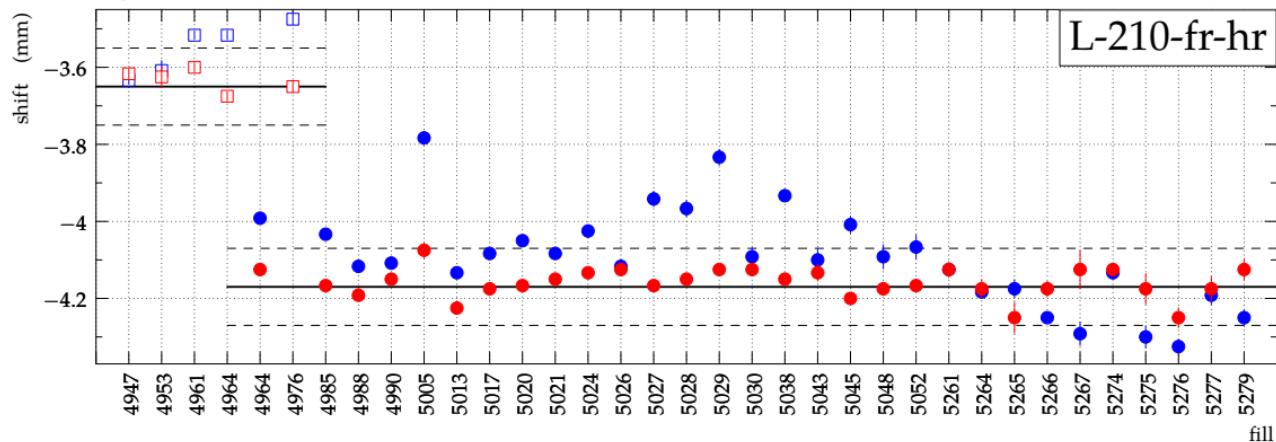


- alignment run: black
- physics run: blue (before), red (after matching)

- “method x”
 - acts on x distributions – x directly related to ξ
 - need to adjust normalisation of each dataset
 - sensitive only to shape differences
 - low x (often) unavailable due to radiation damage
 - need to use high x influenced by apertures
- “method y”
 - no normalisation needed
 - sensitive to different emittances (beam divergence same order as physics), thus also to fill-to-fill variations
 - higher x : systematic discrepancies between alignment and physics run
 - needs removal

Alignment : Matching results

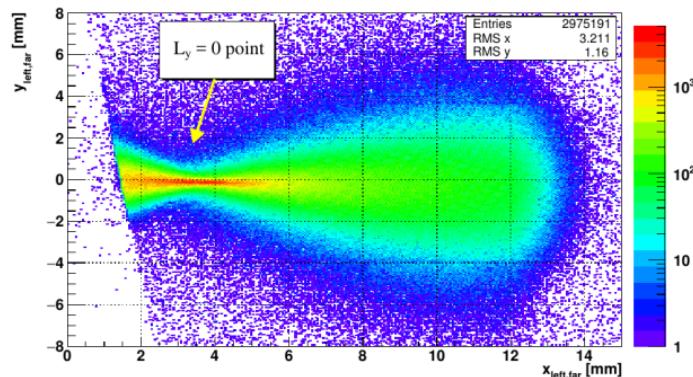
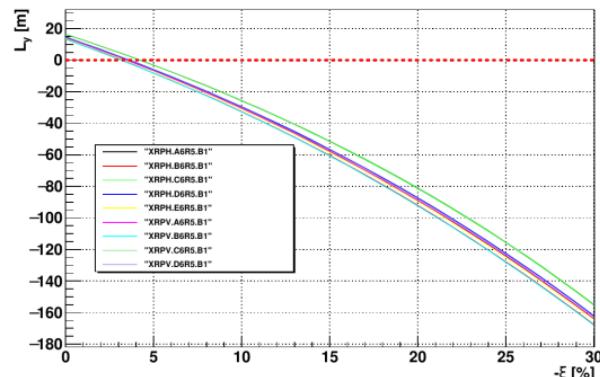
- applied to almost all fills with RPs
- example for 45-210-fr-hr



- red = method x, blue = method y
- hollow squares = runs with margin, filled dots = runs without margin
 - expected 0.5 mm difference in results
- 45-210-nr-hr: unexpected results, investigations ongoing
- “method x” more stable → preferred

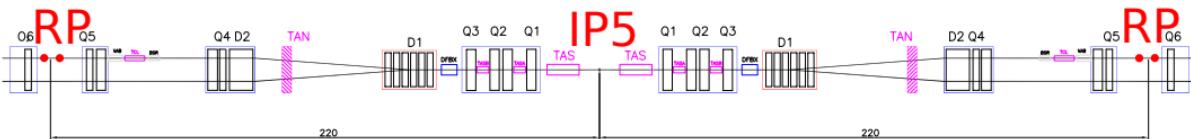
- “ L_y method” (applied to the alignment-run data)

- from optics model: ξ_0 where $L_y(\xi) = 0$
- from data: x_0 where waist in y distribution



- dispersion: $D_x = x_0/\xi_0$
 - left arm (beam 2): $D_x \approx 10$ cm
 - right arm (beam 1): $D_x \approx 7$ cm
- uncertainty $\approx 5\%$
 - $\sigma(x_0) \approx 0.15$ mm (alignment and waist determination)
 - $\delta(\xi_0) < 0.6\%$ (after matching)
 - method bias (MC study) $< 2\%$

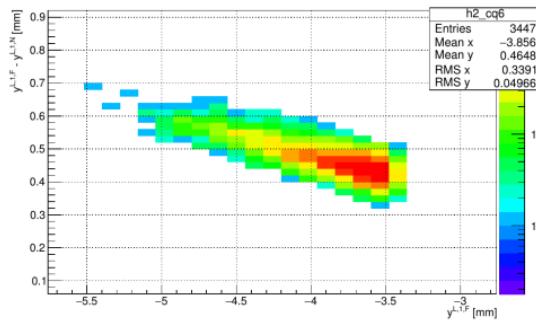
- *optics matching* = tuning of magnetic model within LHC tolerances to match with the RP observables and BPM measurements



- split into two steps (complexity reduction)

- step 1 (as in New J. Phys. 16 (2014) 103041):

- matched LHC parameters: quadrupole magnet strength
- measured constraints: derived from elastic events

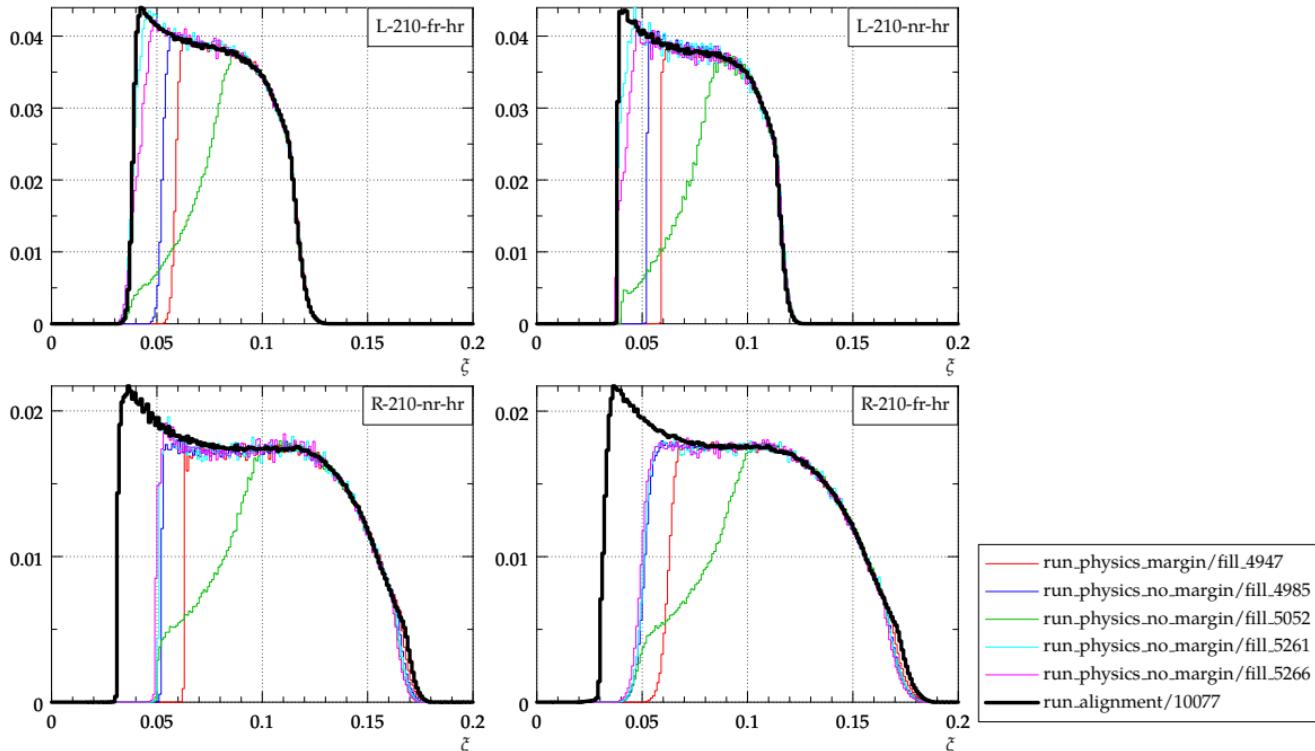


- step 2:

- matched LHC parameters: horizontal crossing-angle, quadrupole positions, kicker strength
- measured constraints: 3 BPM (22 m, 58 m, 199 m), beam position at RP 210m near vertical, 2 measured dispersions D_x

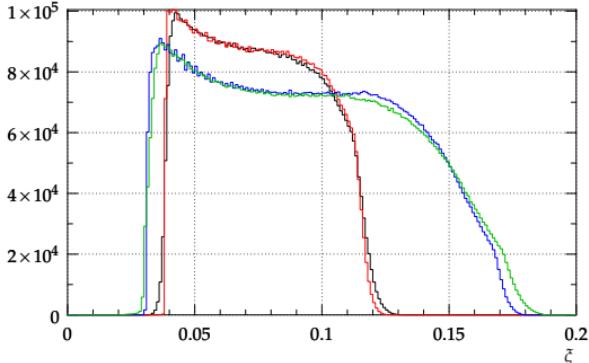
- physics is fill and RP independent → compare ξ distributions from
 - different fills
 - different RPs

Control plots for proton reconstruction : Comparison fill to fill

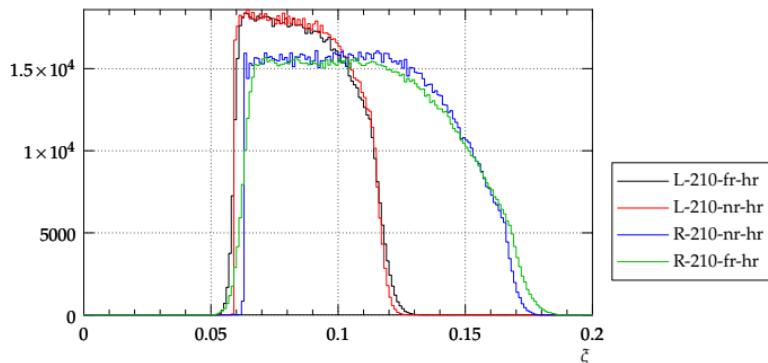


- more recent runs: radiation damage \rightarrow acceptance loss at lower ξ
- right arm: (acceptance ?) effects at lower ξ
- otherwise: good agreement

run_alignment (10077)



run_physics_margin (fill_4947)



- “alignment run”: shape well compatible for $0.04 < \xi < 0.08$
- physics run: extremely short common ξ range with no acceptance effects

- use of RPs
 - routine insertions and data taking from May to September
 - delivered luminosity almost 11 fb^{-1}
- radiation damage: observed in all 4 RPs
 - performance improved: with rest time and increased HV
 - systematic performance monitoring
- alignment (horizontal)
 - presented two alignment methods – “method x” is preferable
 - analysed almost all fills with RP inserted and read out
 - 3 RPs expected results, RP L-210-nr-hr: unexpected results (investigating)
- optics
 - asymmetric D_X values measured in beam 1 and 2, uncertainty $\approx 5\%$
 - optics model improved by the matching procedure
- ξ distributions
 - comparison fill to fill: compatible
 - comparison RP to RP: shape well compatible in alignment run
- *alignment and optics in initial phase but well under control*
- outlook
 - TS2: detector packages exchanged (no radiation damage)
 - beam-based alignment + calibration data: done on 23 Sep
 - diamond detectors installed, read-out in commissioning