Elastic scattering and optics at the LHC

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CERN*

LHC WG on Forward Physics and Diffraction 2018

Madrid, Spain

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***Also at Wigner RCP, Budapest, Hungary**

LHC optics measurement with Roman Pots

Method developed in TOTEM:

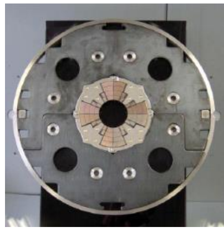
- Use **measured** proton data from RPs
- Based on kinematics of elastic candidates
- Published in New Journal of Physics
- http://iopscience.iop.org/1367-2630/16/10/103041/

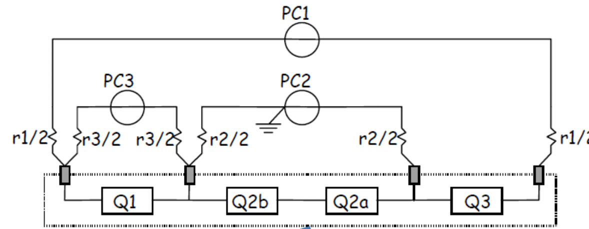
LHC optics at IP5 briefly

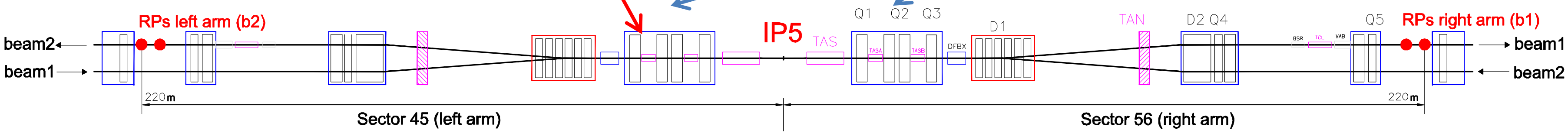
Sketch of the LHC magnet lattice at IP5:

$$k = \frac{1}{B\rho}\frac{dB_z}{dx}$$

MQXA quadrupole







s: distance from IP5 (*≡IP5)

Measured

$$\begin{pmatrix} x \\ \Theta_x \\ y \\ \Theta_y \\ \xi \end{pmatrix}_{RP} = \begin{pmatrix} v_x & L_x & m_{13} & m_{14} & D_x \\ v'_x & L'_x & m_{23} & m_{24} & D'_x \\ m_{31} & m_{32} & v_y & L_y & D_y \\ m_{41} & m_{42} & v'_y & L'_y & D'_y \\ 0 & 0 & 0 & 0 & 1 \end{pmatrix} \cdot \begin{pmatrix} x^* \\ \Theta^*_x \\ y^* \\ \Theta^*_y \\ \xi^* \end{pmatrix}$$

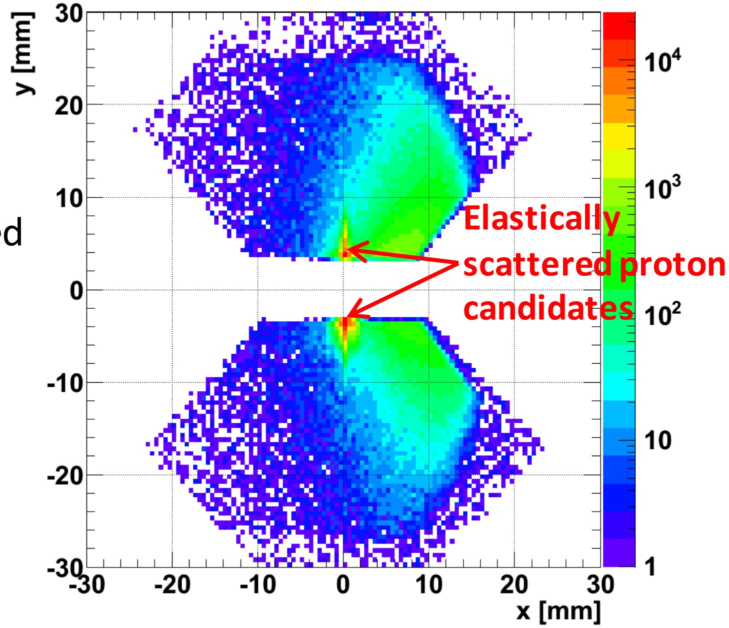
$$\sigma(\Theta) = \sqrt{\varepsilon / \beta_x(s)}$$

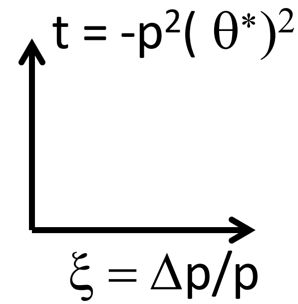
Determines angular resolution.

Elastic proton candidates and optics estimators

Scoring plane:

- At 220 m
- All the reconstructed tracks
- **Elastic candidates** highlighted





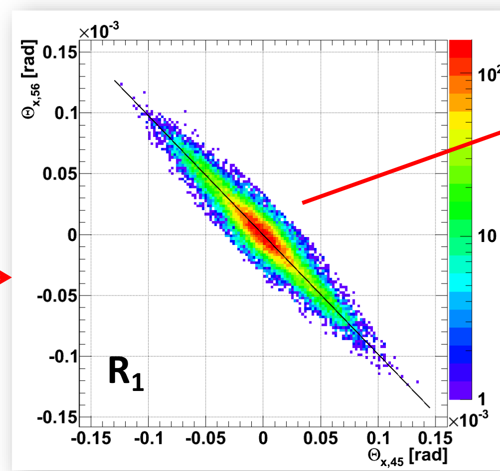
Optics estimators:

- Tag elastic events (unique “galactic disk” shape)
- Elastic scattering (**momentum conservation**) ensures that for each elastic event

$$\Theta^*_{x,b1} = \Theta^*_{x,b2}$$

Propagation...

...with real optics T+ΔT:



Optics estimator

$$R_1 \equiv \frac{\Theta_{x,b1,RP} \cdot \Theta^*_{x,b1}}{\Theta_{x,b2,RP} \cdot \Theta^*_{x,b2}} \approx \frac{\frac{dL_{x,b1,RP}}{ds}}{\frac{dL_{x,b2,RP}}{ds}}$$

β* = 3.5 m optics estimation

On the basis of constraints R_1-R_{10} the optics can be estimated:

$$\chi^2 = \sum_{i=1}^{10} \left(\left(R_{i,\text{measured}} - R_{i,\text{calculated}} \right) / \sigma(R_i) \right)^2 + \chi^2_{\text{LHC Design}}$$

Refine machine settings

- 2x6 quad. magnet strength
- 2x6 quad. rotation
- Momentum of 2 beams

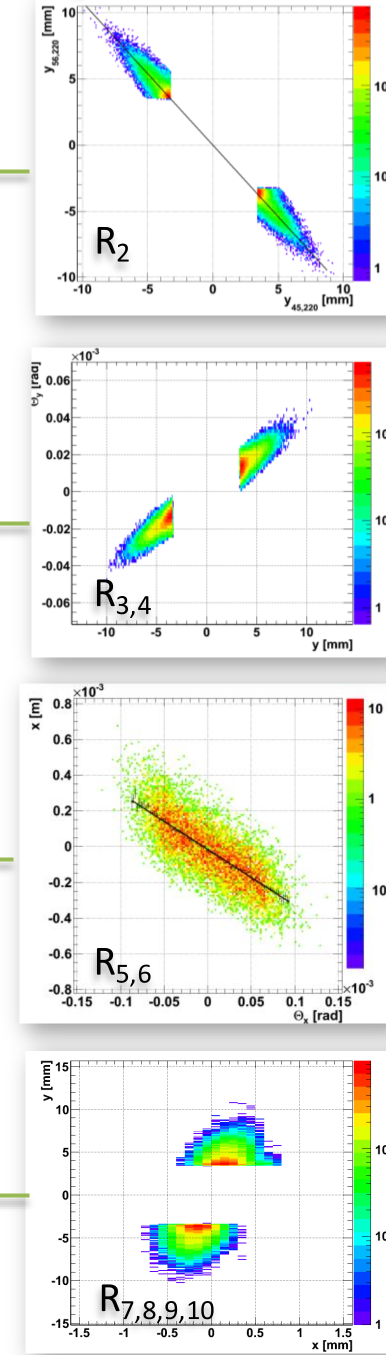
MAD-X

Calculated ratios R_1-R_{10} → Comparison ← Measured ratios R_1-R_{10}

dL_x/ds, L_y

$$R_2 \equiv \frac{y_{b1,RP}}{y_{b2,RP}} \approx \frac{L_{y,b1,RP}}{L_{y,b2,RP}} \qquad R_3 \equiv \frac{\Theta_{y,b1,RP}}{y_{b1,RP}} \approx \frac{\frac{dL_{y,b1,RP}}{ds}}{L_{y,b1,RP}}$$

$$R_7 \equiv \frac{x_{b1,RP}}{y_{b1,RP}} \approx \frac{m_{14,b1,near\_pots}}{L_{y,b1,near\_pots}} \qquad R_5 \equiv \frac{x_{b1,RP}}{\Theta_{x,b1,RP}} \approx \frac{L_{x,b1,RP}}{dL_{x,b1,RP}/ds}$$



Proton kinematics reconstruction & optics imperfections

Machine imperfections alter the optics:

- **Strength conversion error, σ(B)/B ≈ 10^{-3}**
- **Beam momentum offset, σ(p)/p ≈ 10^{-3}**
- Magnet rotations, σ(ϕ) ≈ 1 mrad
- Magnetic field harmonics, σ(B)/B ≈ 10^{-4}
- Power converter errors, σ(I)/I ≈ 10^{-4}
- Magnet positions Δx, Δy ≈ 100 µm

$$t(v_x, L_x, L_y, \ldots, p) = -p^2 \cdot \left(\Theta_x^{*2} + \Theta_y^{*2}\right)$$

→ Precise model of the LHC optics is indispensable!

Novel method from TOTEM:

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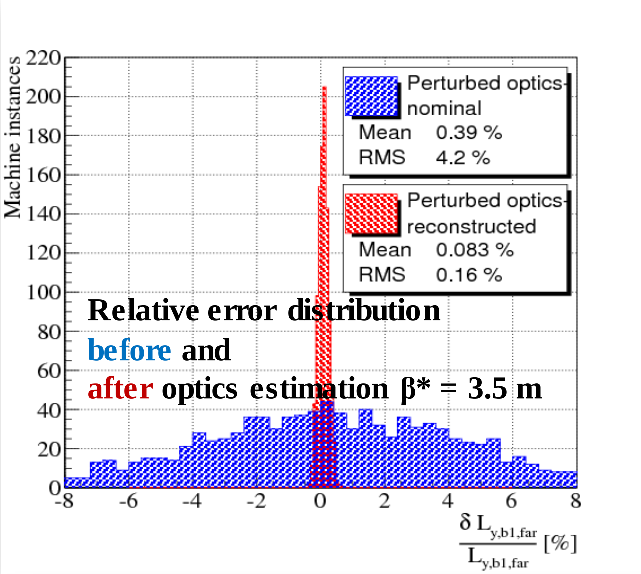
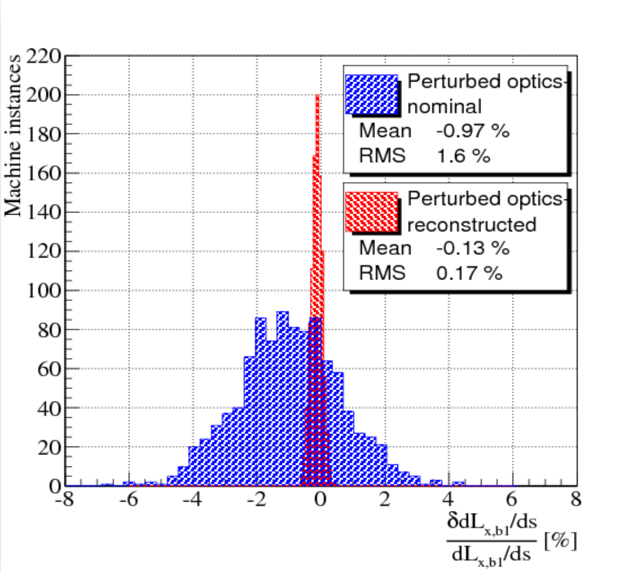
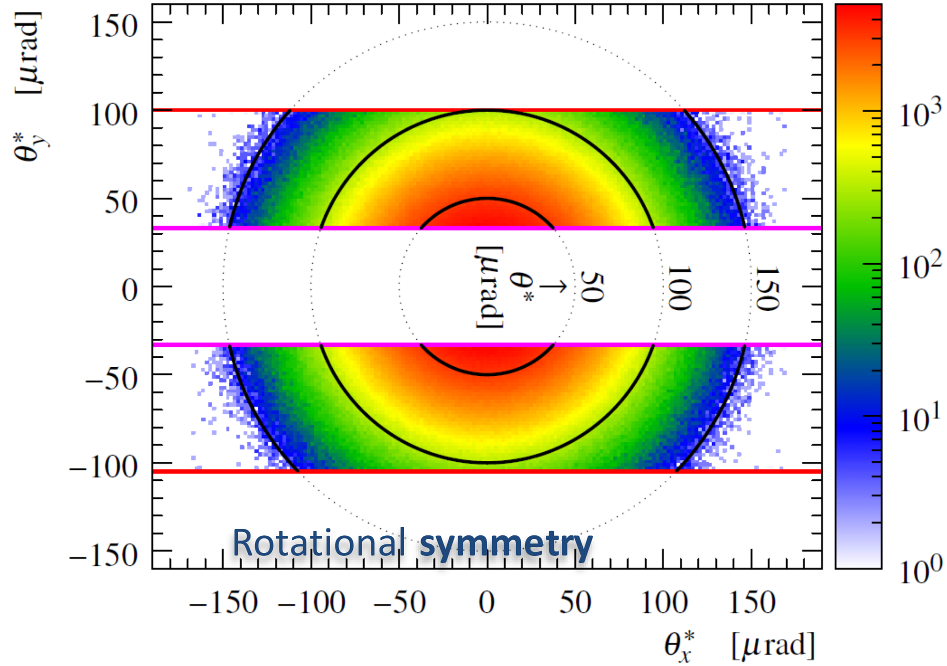




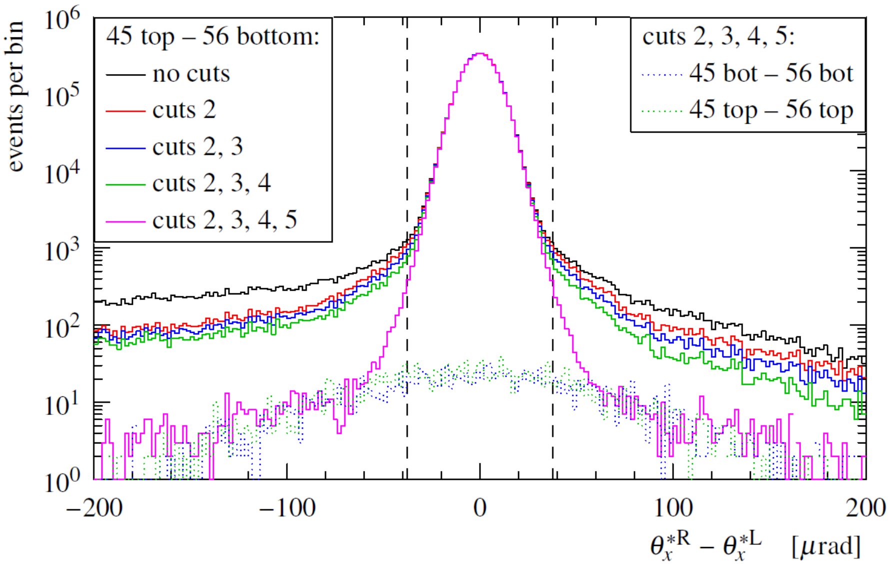
Reconstructed proton kinematics after optics estimation (β* = 90 m)

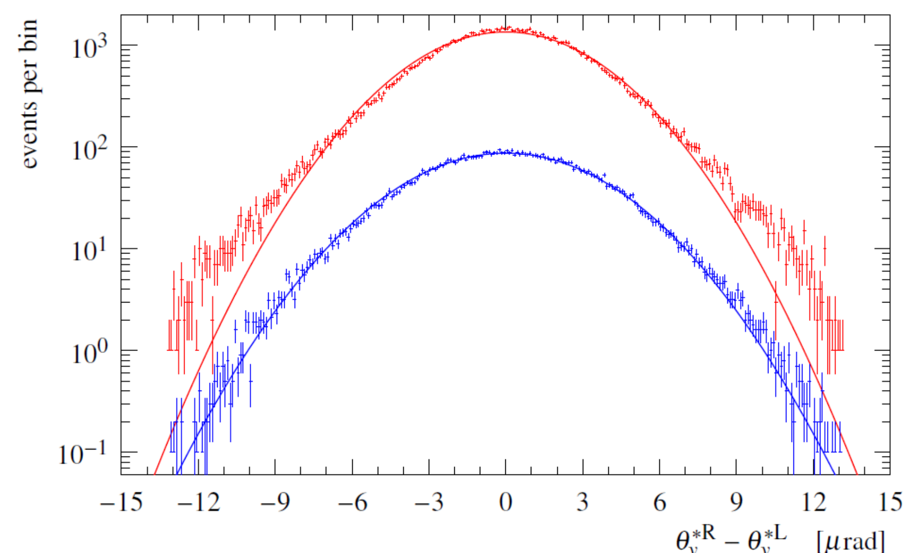
Comments:

- Optics imperfections → Would cause distortions of expected physical symmetries
- After optics estimation: **clear symmetries**



Left - right **symmetry**



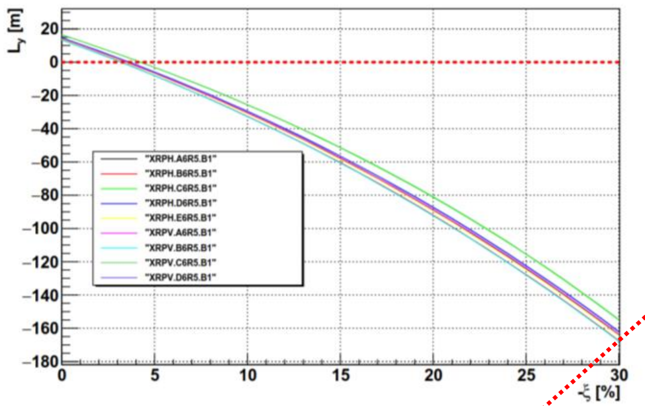


CMS – TOTEM PPS optics
√s = 13 TeV, α = 370 μrad

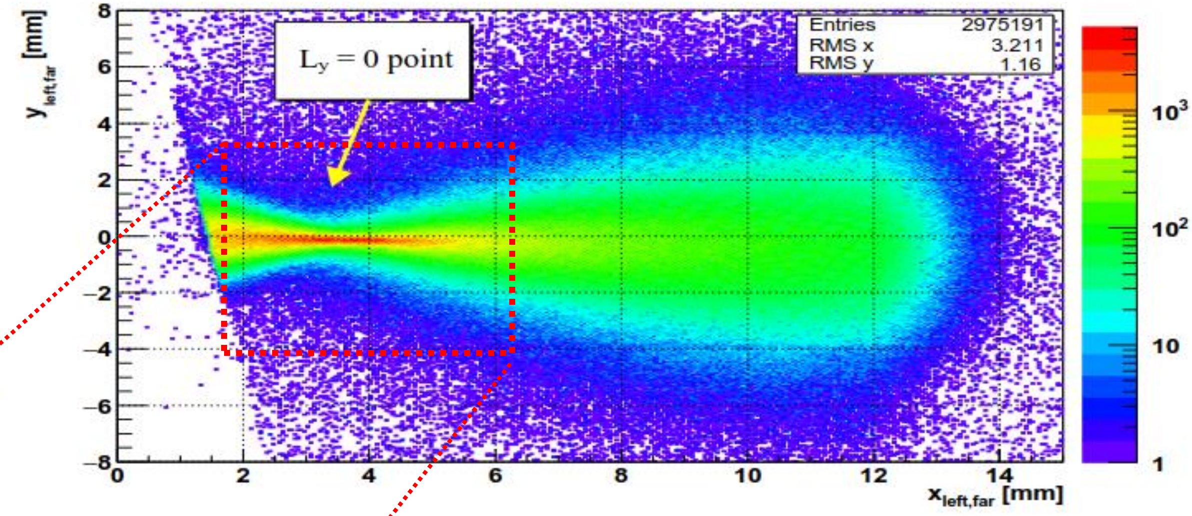
- Link to optics note

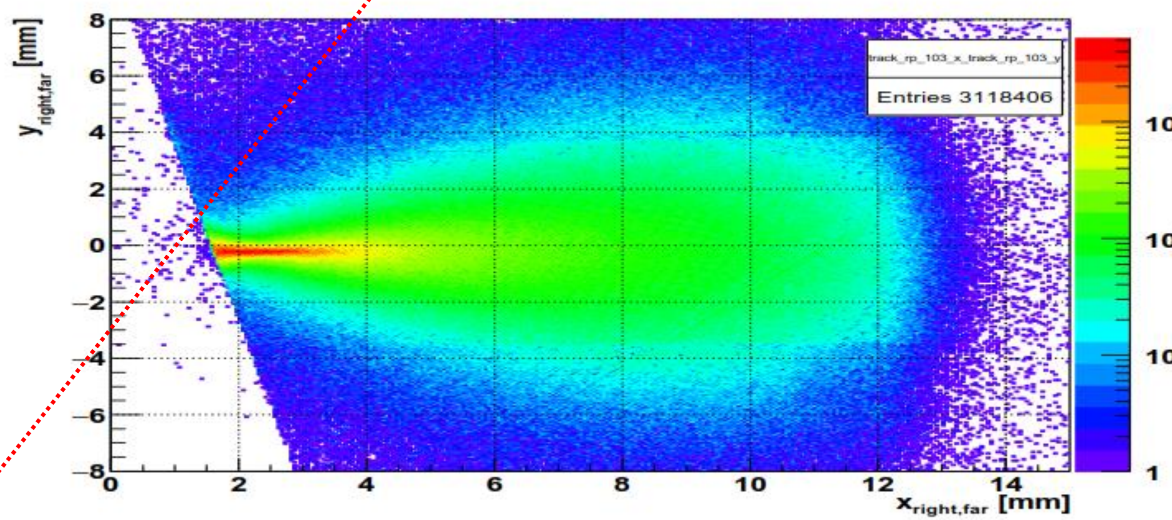
Dispersion ξ measurement at LHC

$L_y(\xi)$ shows a vertical focus at ξ_0 !

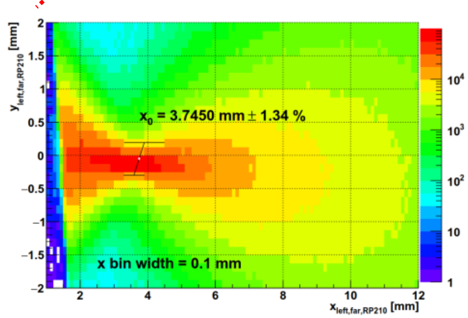


RP measurement of x_0



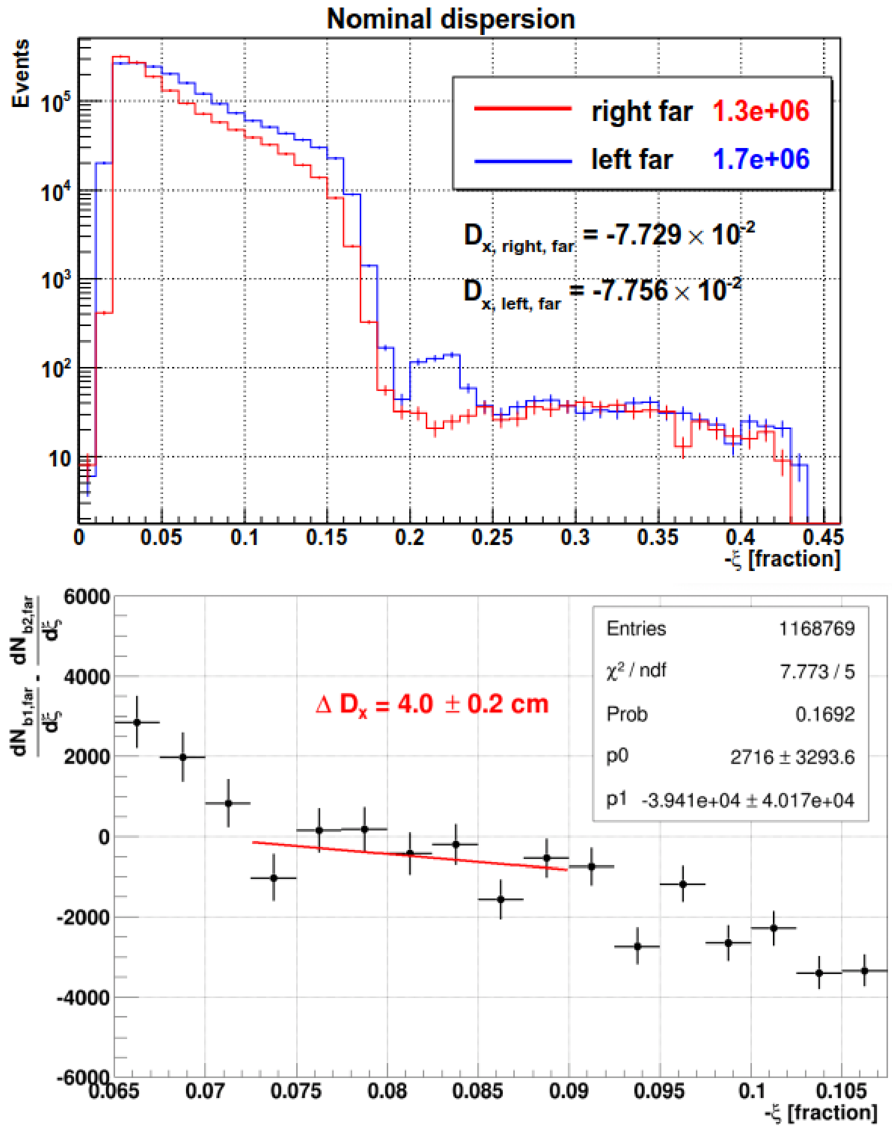


$D_x = x_0 / \xi_0$



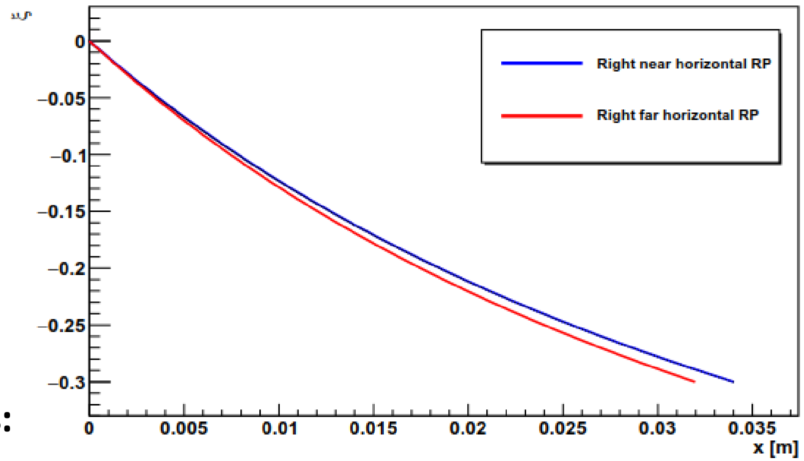
Method 2: matching the dispersions of the beams ξ_1, ξ_2

Based on left-right scattering symmetry:



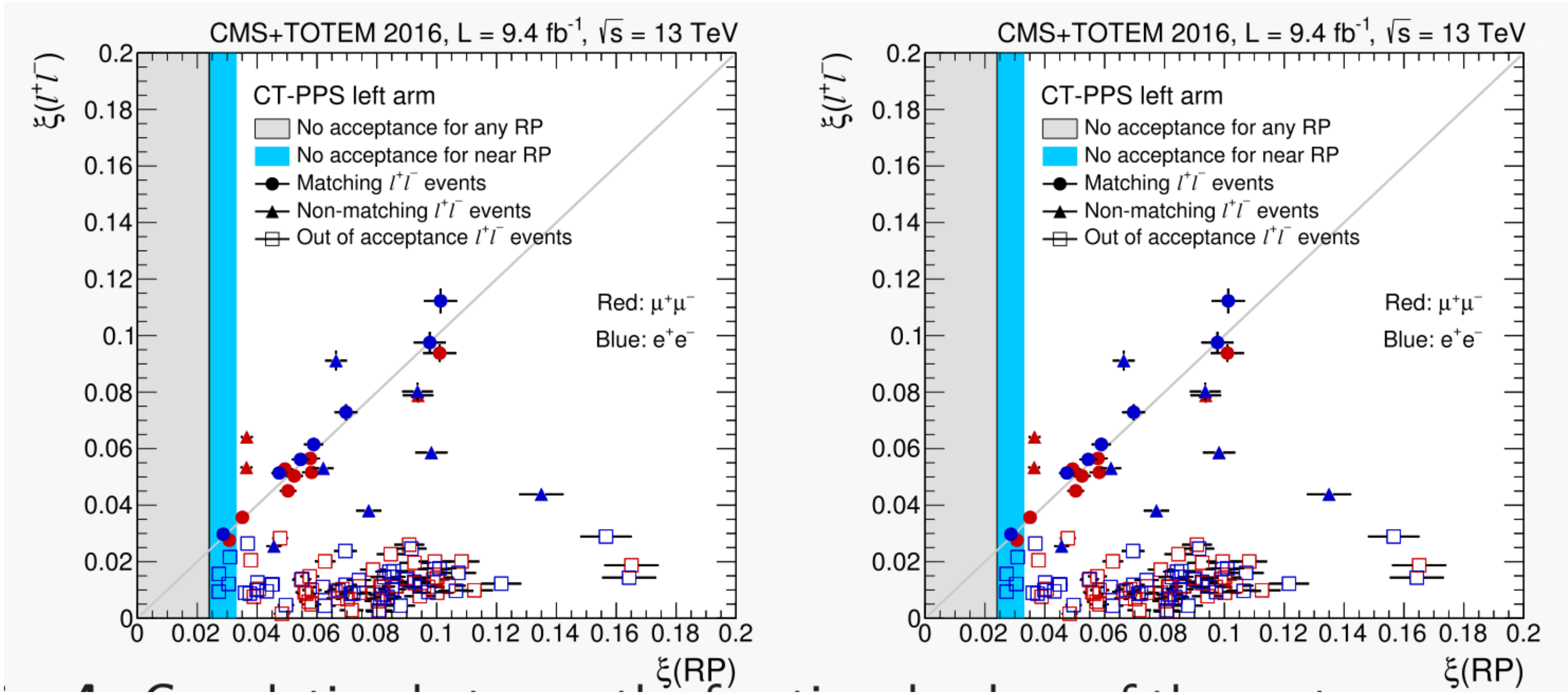
Reconstruction of ξ for $\mu^+\mu^-$ analysis

The ξ depence Results:



CMS-TOTEM ξ correlations:

Feedback & calibration



Conclusions

- CT-PPS optics methods developed
- Performs well on 2016, 2017 data
- Several crossing angles covered
- Increasing statistics and feedback from analysis (e.g. dimuon analysis)