PSB orbit correction

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From the the minutes of the APC Meeting 14.09.2007, in the frame of the machine studies to be done at the 2008 start-up, M. Chanel proposed

→ The partial realignment of the PSB

a) The present orbits have to be measured for different energies and working points

b) A compensation is calculated based on the displacements and tilts of the 16 QDs (at most)

c) The corrections will be applied to the machine during the shut-down and their results are measured during the first week of start up.

d) Start up measurements can be taken in the evenings with 1-2e12 p over one cycle. On the following day, the machine is stopped and the corrections, based on the over night calculations of a code previously validated, can be applied.

Orbit measurements on the 01.11.2007 and 06.11.2007

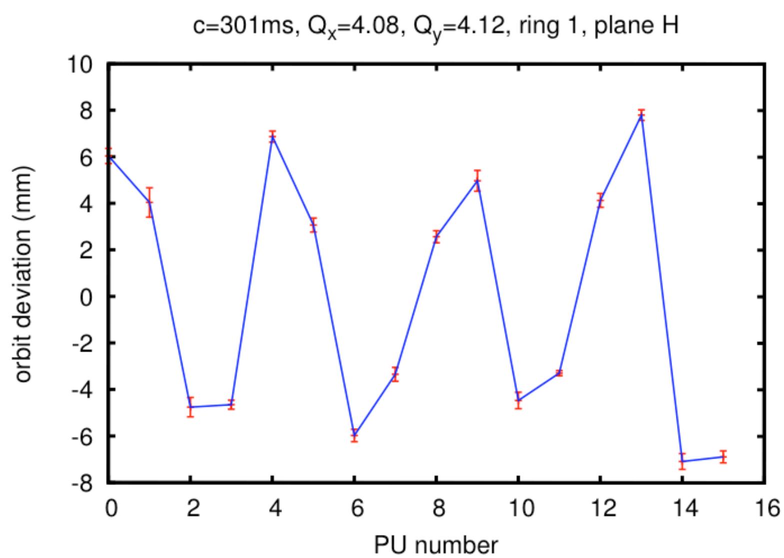
⇒ **User:** NORMHRS; special archive for orbit measurements (sieve, 5e11 p/ring, vertical correction dipoles = 0, flat C02/C04 functions at measurement points)

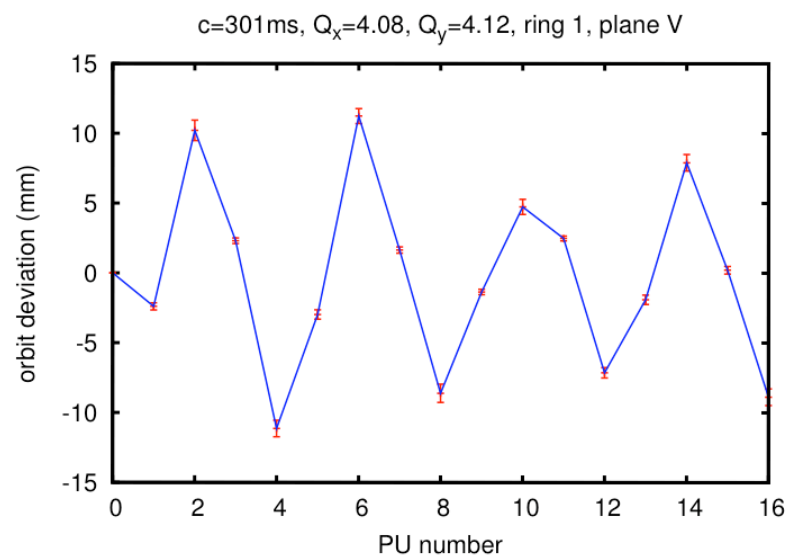
⇒ 6 measurement sets

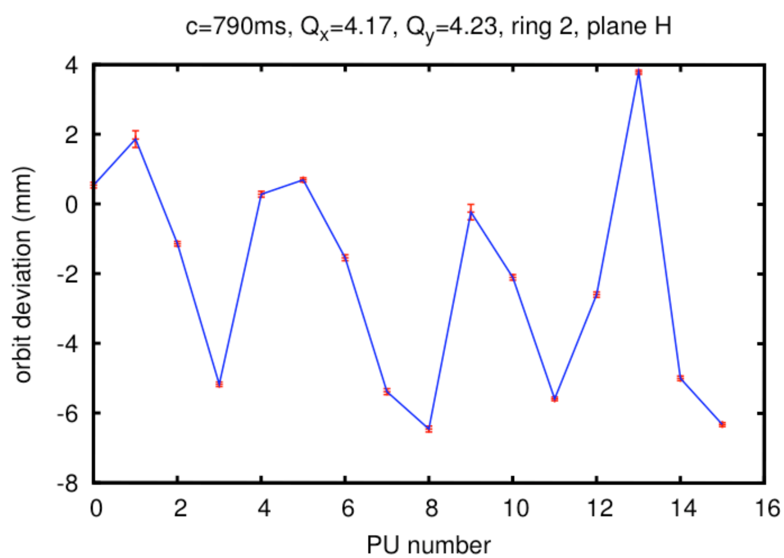
	Energy (MeV)	Q_x	Q_y
301WP1	63	4.172	4.230
301WP2	63	4.083	4.131
301WP3	63	4.212	4.304
301WP4	63	4.279	4.583
500WP1	403	4.163	4.234
790WP1	1377	4.169	4.255

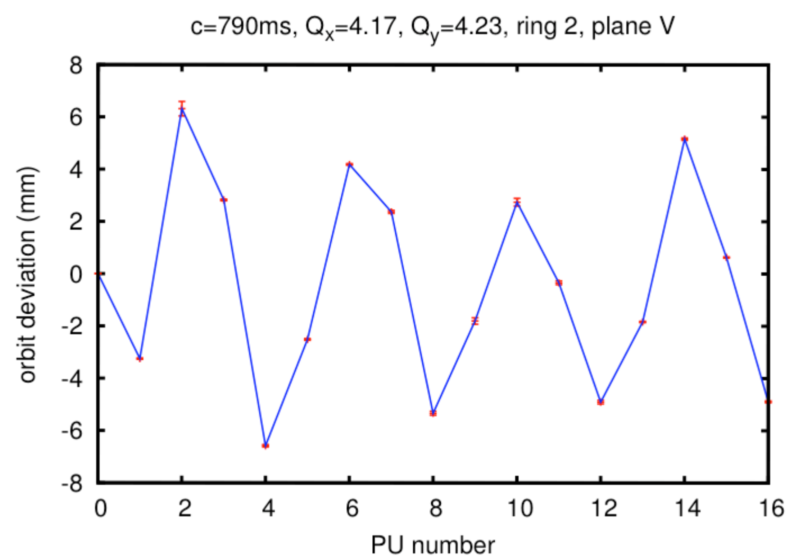
Orbit measurements on the 01.11.2007 and 06.11.2007

⟹ Examples of measured orbits









Correction algorithm

⇒ **R** is the response matrix that relates the ring by ring displacements of the QDs (Δx_i, Δy_i) to the orbit measured at the PUs locations (Δx_{oi}, Δy_{oi}).

⇒ It is re-calculated for each of the measurement sets, after matching the measured tunes.

⇒ It is applied to all four rings, assuming they are identical

$$\begin{pmatrix} \vec{\Delta x}_{o1} \\ \vec{\Delta y}_{o1} \\ \vec{\Delta x}_{o2} \\ \vec{\Delta y}_{o2} \\ \vec{\Delta x}_{o3} \\ \vec{\Delta y}_{o3} \\ \vec{\Delta x}_{o4} \\ \vec{\Delta y}_{o4} \end{pmatrix} = \begin{pmatrix} \bar{\mathrm{R}} & \bar{0} & \bar{0} & \bar{0} \\ \bar{0} & \bar{\mathrm{R}} & \bar{0} & \bar{0} \\ \bar{0} & \bar{0} & \bar{\mathrm{R}} & \bar{0} \\ \bar{0} & \bar{0} & \bar{0} & \bar{\mathrm{R}} \end{pmatrix} \cdot \begin{pmatrix} \vec{\Delta x}_{1} \\ \vec{\Delta y}_{1} \\ \vec{\Delta x}_{2} \\ \vec{\Delta y}_{2} \\ \vec{\Delta x}_{3} \\ \vec{\Delta y}_{3} \\ \vec{\Delta x}_{4} \\ \vec{\Delta y}_{4} \end{pmatrix} = \bar{\mathcal{R}} \cdot \begin{pmatrix} \vec{\Delta x}_{1} \\ \vec{\Delta y}_{1} \\ \vec{\Delta x}_{2} \\ \vec{\Delta y}_{2} \\ \vec{\Delta x}_{3} \\ \vec{\Delta y}_{3} \\ \vec{\Delta x}_{4} \\ \vec{\Delta y}_{4} \end{pmatrix}$$

Correction algorithm

⇒ The ring by ring displacements of the QDs (Δx_i, Δy_i) are not independent in the PSB, because all the QDs share the same support. The independent variables are the displacement and tilt angle of the manifold (Δx, Δy, α).

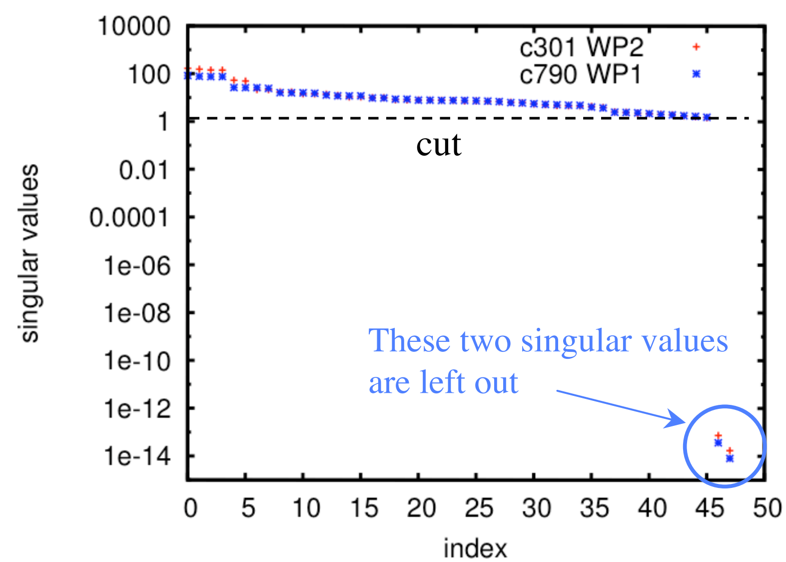
$$\begin{pmatrix} \vec{\Delta x}_1 \\ \vec{\Delta y}_1 \\ \vec{\Delta x}_2 \\ \vec{\Delta y}_2 \\ \vec{\Delta x}_3 \\ \vec{\Delta y}_3 \\ \vec{\Delta x}_4 \\ \vec{\Delta y}_4 \end{pmatrix} = \begin{pmatrix} \bar{0} & \bar{I} & \bar{0} \\ \bar{0} & \bar{0} & \bar{I} \\ \bar{I} & \bar{I} & \bar{0} \\ \bar{0} & \bar{0} & \bar{I} \\ 2\bar{I} & \bar{I} & \bar{0} \\ \bar{0} & \bar{0} & \bar{I} \\ 3\bar{I} & \bar{I} & \bar{0} \\ \bar{0} & \bar{0} & \bar{I} \end{pmatrix} \cdot \begin{pmatrix} \Delta L \cdot \vec{\alpha} \\ \vec{\Delta x} \\ \vec{\Delta y} \end{pmatrix} = \bar{K} \cdot \begin{pmatrix} \Delta L \cdot \vec{\alpha} \\ \vec{\Delta x} \\ \vec{\Delta y} \end{pmatrix}$$

Correction algorithm

⇒ The corrections are calculated by pseudo-inversion of the previous expression.

⇒ If we assume to use all the 16 QDs as correctors, SVD is used, applying a singular value cut of 1%

$$\begin{pmatrix} \Delta L \cdot \vec{\alpha} \\ \vec{\Delta x} \\ \vec{\Delta y} \end{pmatrix} = -\left(\bar{\mathcal{R}} \cdot \bar{\mathrm{K}}\right)^{-1} \cdot \begin{pmatrix} \vec{\Delta x}_{o1} \\ \vec{\Delta y}_{o1} \\ \vec{\Delta x}_{o2} \\ \vec{\Delta y}_{o2} \\ \vec{\Delta x}_{o3} \\ \vec{\Delta y}_{o3} \\ \vec{\Delta x}_{o4} \\ \vec{\Delta y}_{o4} \end{pmatrix}$$



Correction algorithm

The correction software allows:

⇒ To remove energy errors (clean the data from the average)

⇒ To take out from the analysis the reading of one or more PUs, which may be considered faulty for some reason (e.g., PU5 and PU9)

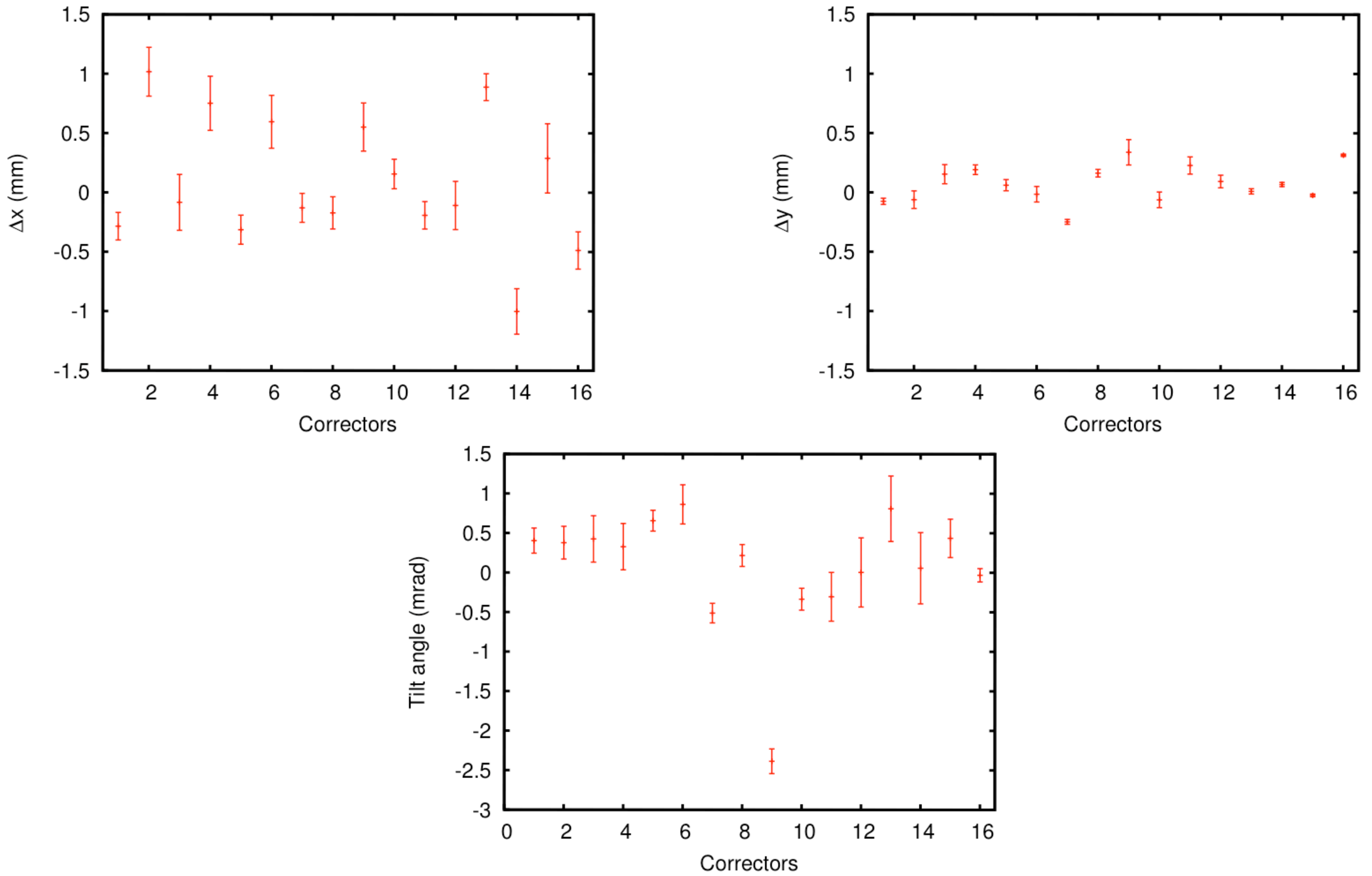
⇒ To remove the data from one or more rings, which may be considered less reliable because of some additional ring-specific problem (e.g., data from Ring 3 appeared to be dominated by some local error)

⇒ A Mikado-like algorithm has been implemented to test correctors one by one, then by pairs and so on, keeping at each iteration the strongest corrector and probing the remaining ones.

⇒ The correction can be made globally using data from horizontal and vertical orbits together, or separately in the two transverse planes.

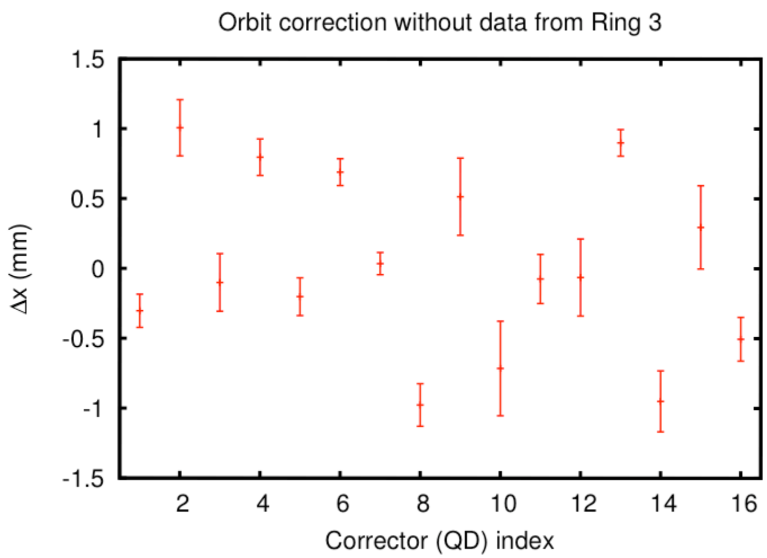
Application to the PSB

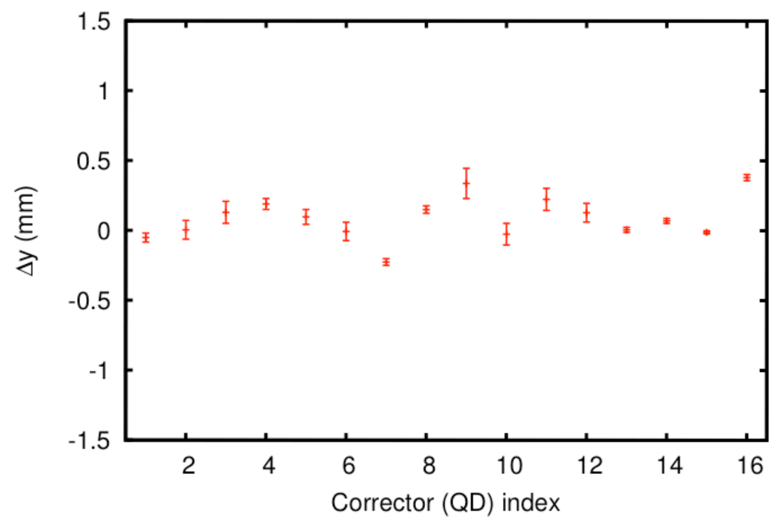
Global correction using data from all rings and all correctors

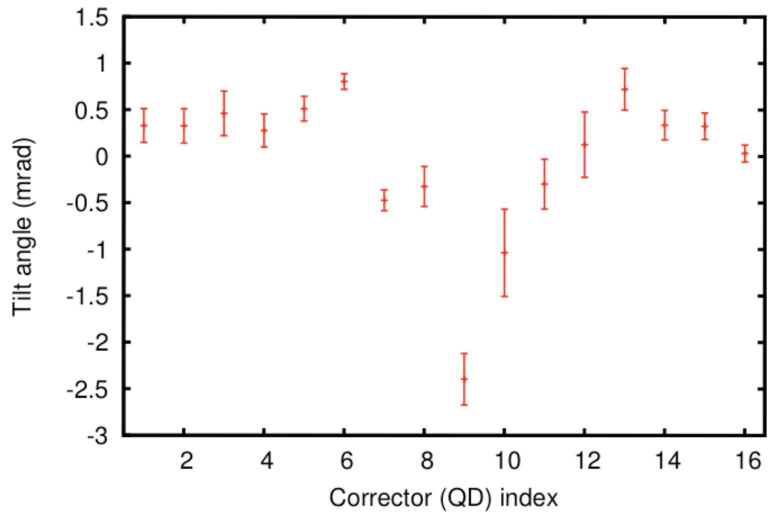


Application to the PSB

Global correction using all correctors but removing data from Ring 3

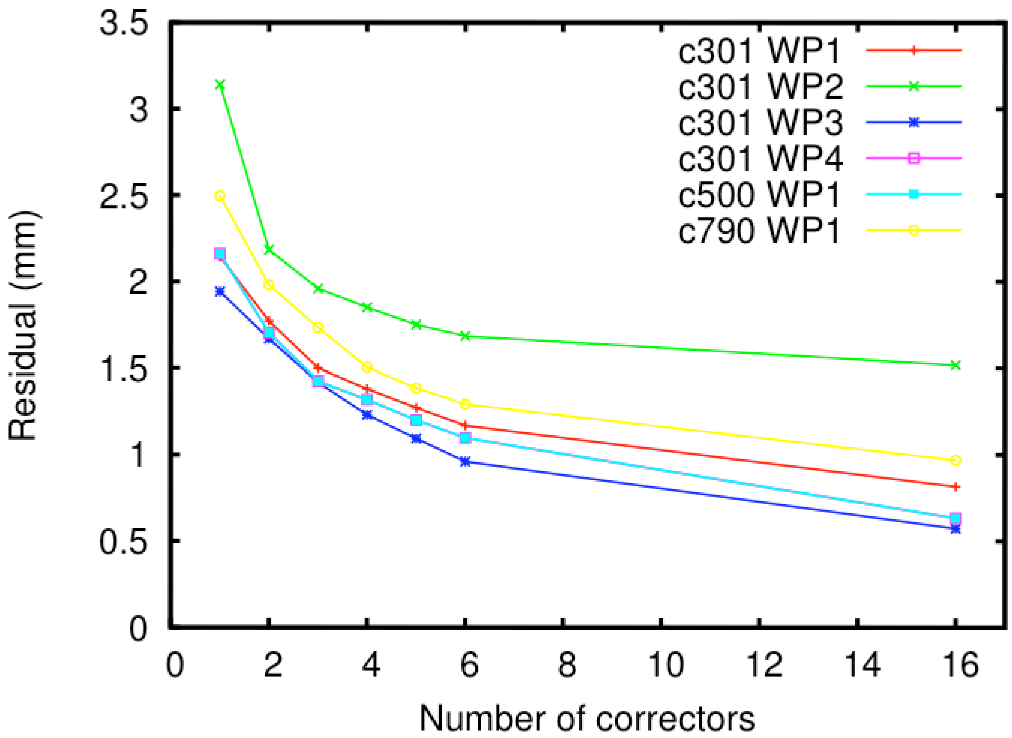






Application to the PSB

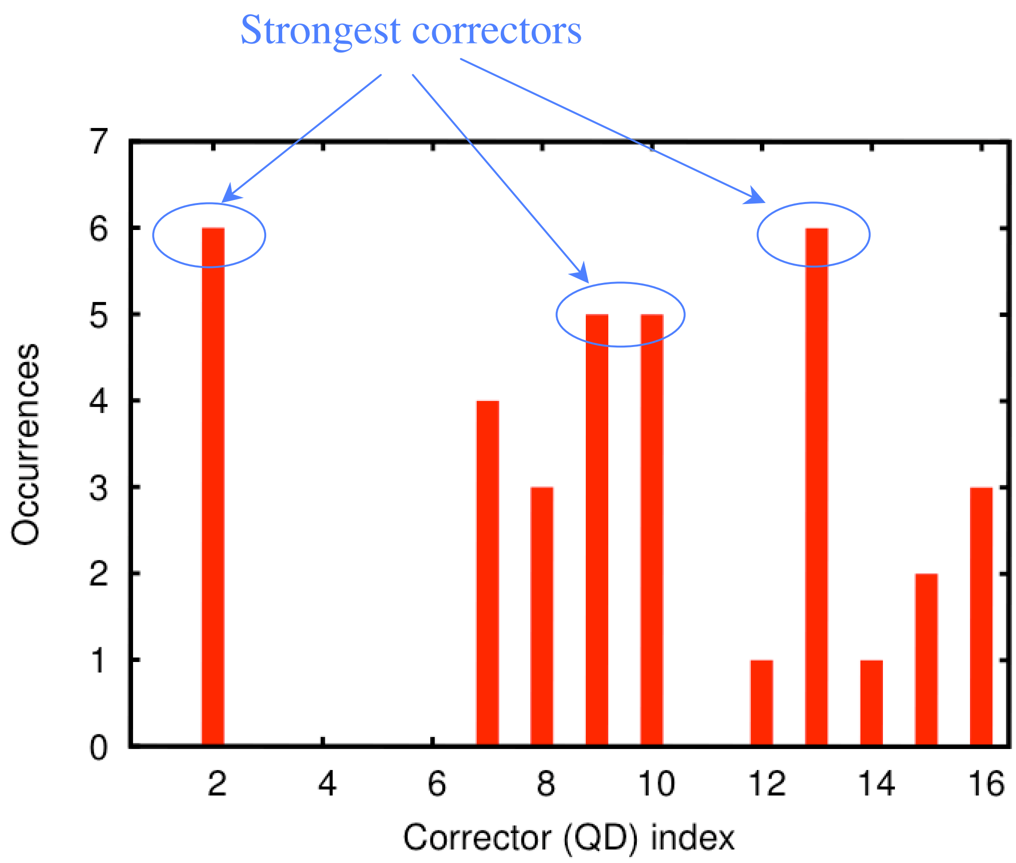
Looking at the global orbit residual (i.e., rms orbit after correction) for different numbers of correctors, we decide that 4-6 correctors could be enough to have an acceptable correction



Application to the PSB

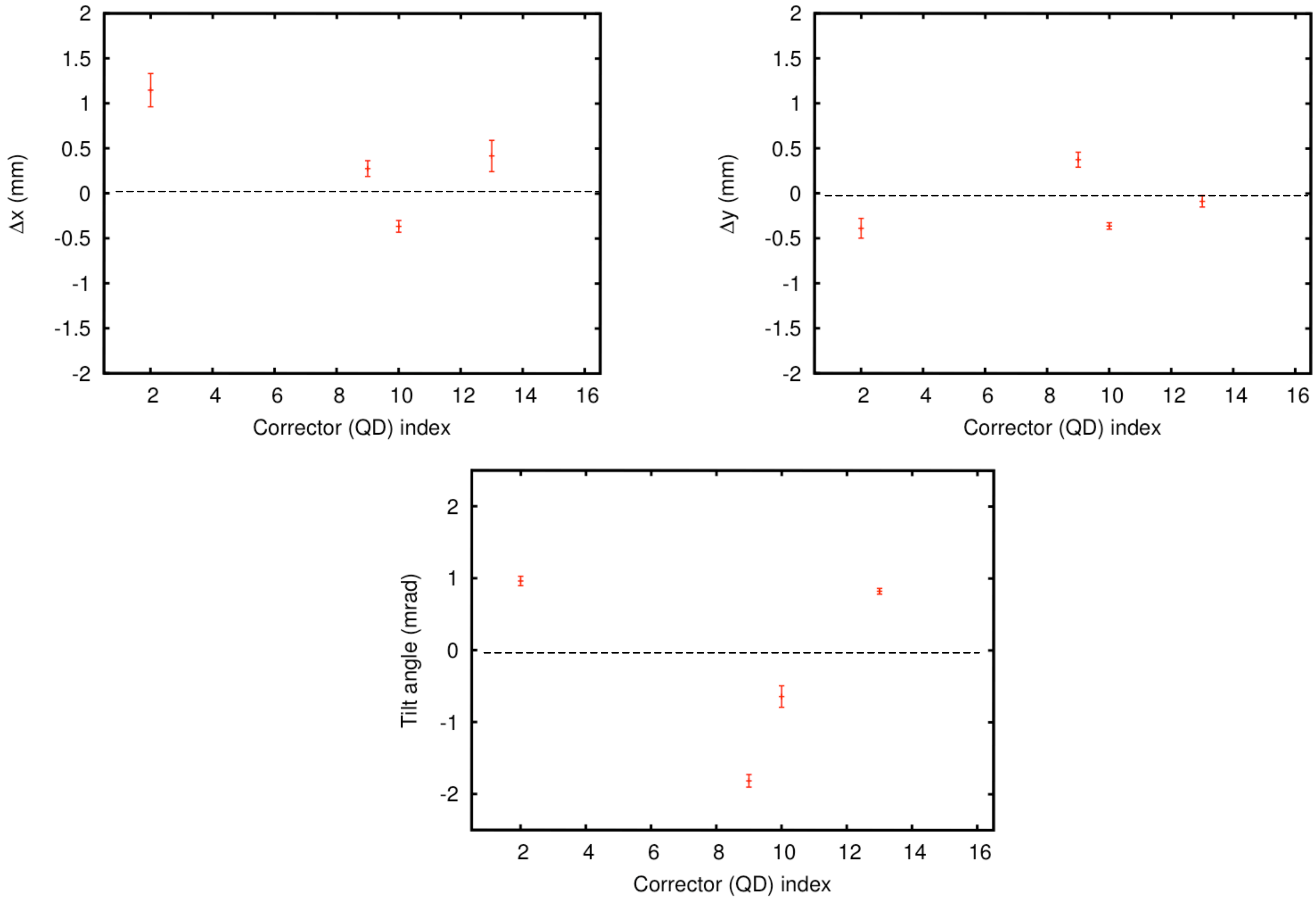
→ To decide which correctors should be chosen, we have done a Mikado analysis up to 6 correctors for each of the 6 measurement sets.

→ The correctors with the highest number of occurrences (0 to 6) are considered to be the strongest



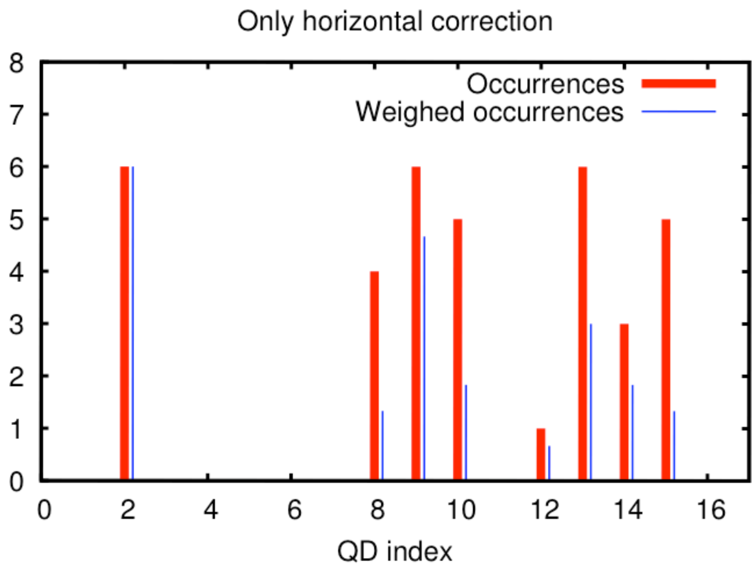
Application to the PSB

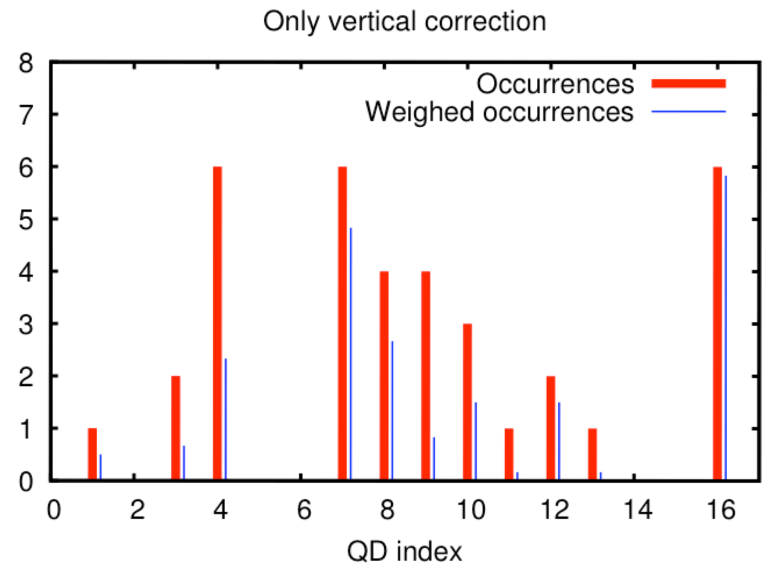
→ Corrections required for the 4 chosen correctors



Application to the PSB

→ We can try to correct separately in horizontal and vertical plane



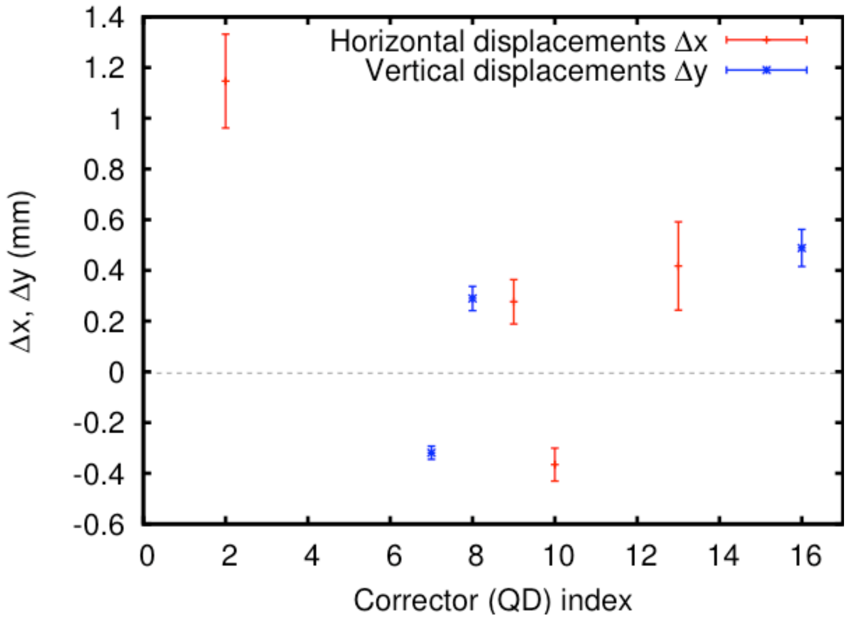


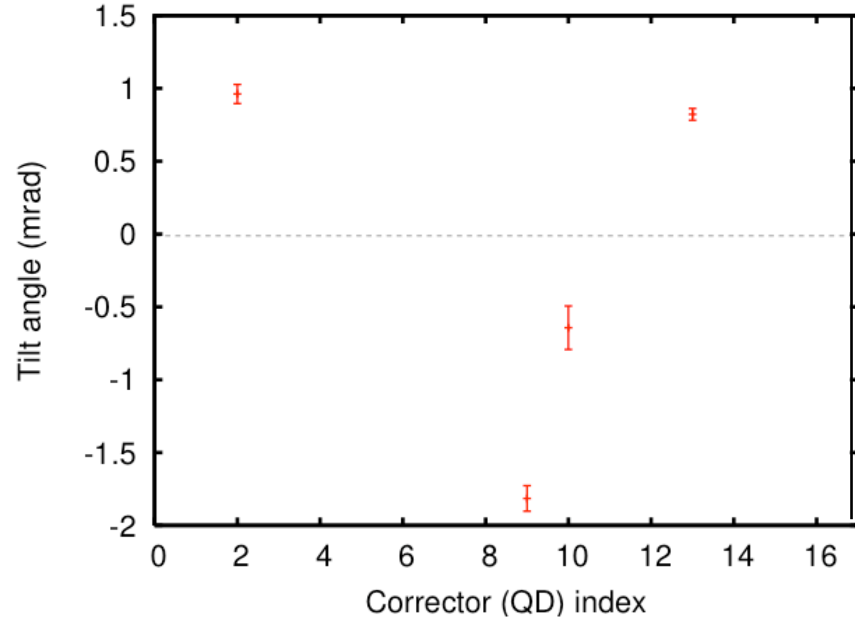
→ It turns out that the four correctors for the global correction (**QD2, QD9, QD10, QD13**) are the strongest ones for the horizontal correction. The 4 strongest ones for the vertical correction are **QD4, QD7, QD8, QD16**.

→ Probably because of the needed tilt of QD9, the precise localization of the horizontal correctors is more critical than for the vertical ones.

Application to the PSB

→ Corrections using the best correctors separately in H (4 correctors) and V (3 correctors)



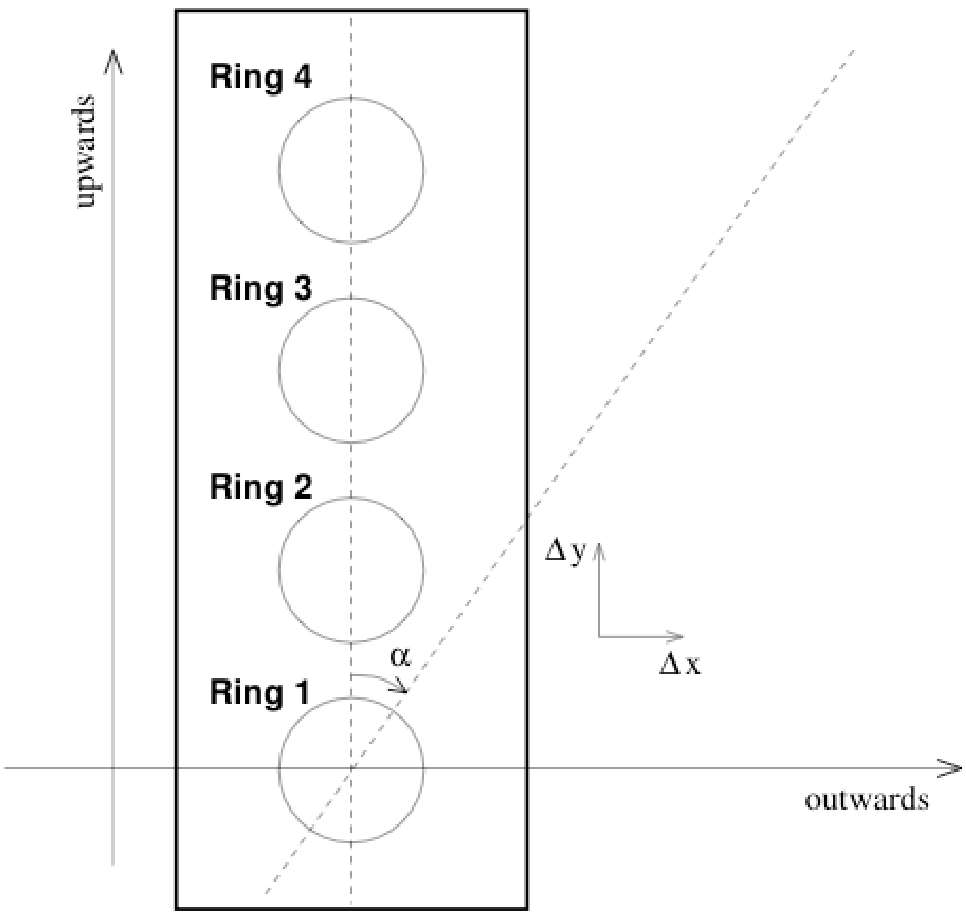


→ The required horizontal displacements and tilt angles of QD2, QD9, QD10, QD13 **do not change much** wrt the previous analysis.

→ The vertical displacements of the QDs are similar to those obtained by using QD2, QD9, QD10, with the signs consistently reversed where there are 180° phase advances. **The residues obtained with these correctors are ~15% lower than those obtained with QD2, QD9, QD10**

Application to the PSB

→ Remark on the signs of the displacements/tilt angles



→ The MADX convention is left-handed in the direction of the beam. Therefore, **positive Δx is inwards and positive Δy is upwards** (beam in PSB goes counterclockwise)

→ Data from the PUs have **positive Δx_o outwards and positive Δy_o upwards**.

→ Therefore: the **required positive displacements Δy are upwards**, but the **required positive displacements Δx and tilt angles are outwards** (see Figure)