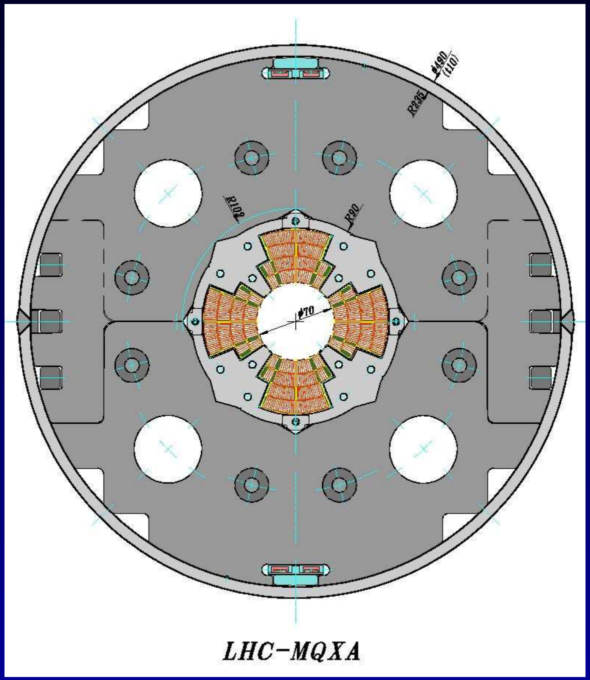

β-Beating, dispersion and coupling correction in the LHC

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Magnetic measurements and allocation

- Realistic assessment of the beta-beating correction needs of realistic b2 errors in the machine
- Magnetic measurements available in official databases
- Information on both magnetic measurements plus slot allocation (MEB activity) are required
- A code was developed in AT/MAS-MA by P. Hagen, J.-P. Koutchouk & E. Todesco. This code deals with all type of magnetic errors (multipoles)
- Output: MAD-X file with magnetic errors. In case a magnet is already assigned to a certain slot its magnetic errors are assigned to this slot. Otherwise, errors are drawn from measured distributions.

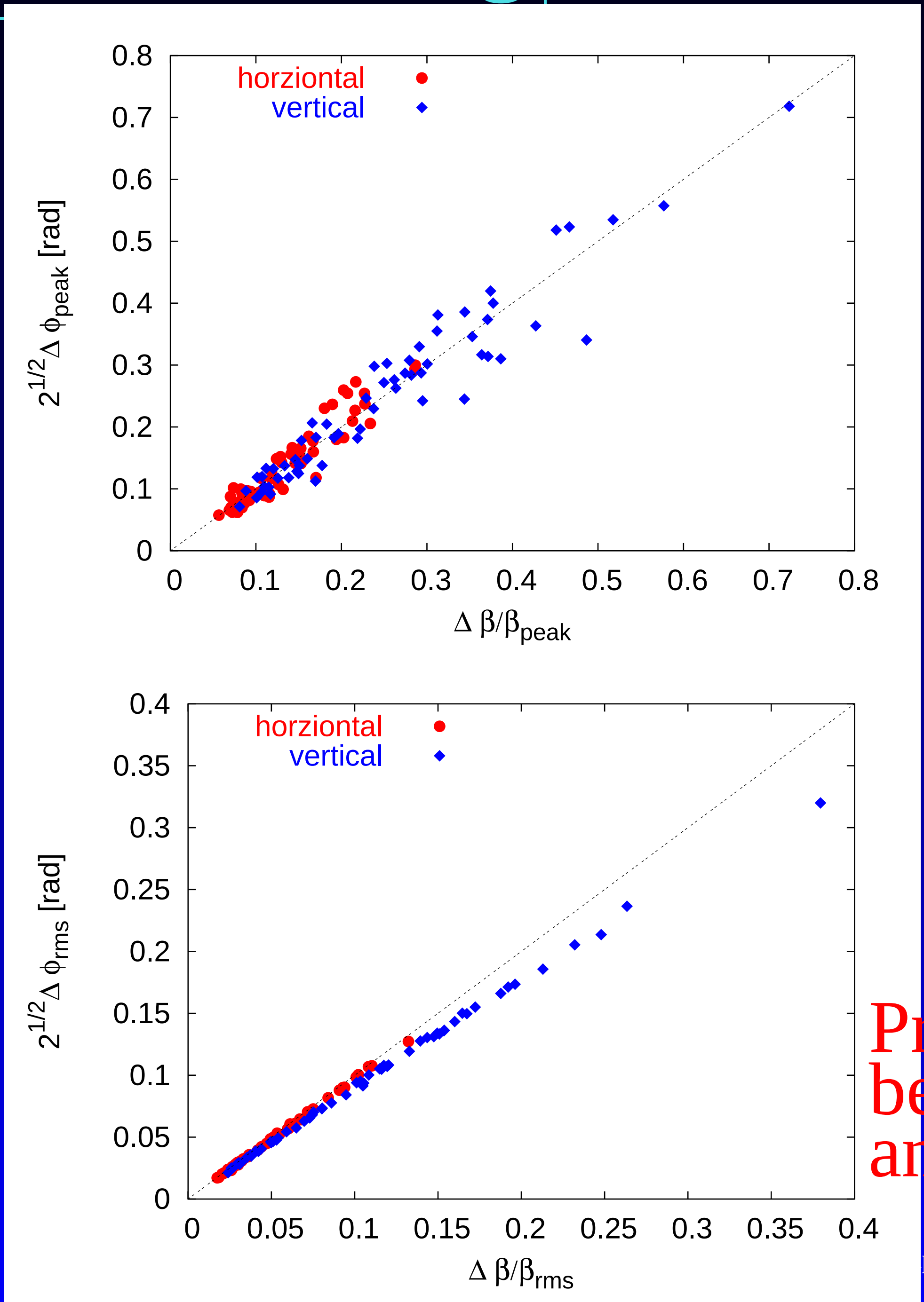
β-beating observable

- The measurement of β-functions needs good BPM calibration or good knowledge of focusing properties $\rightarrow$ Not suitable for commissioning
- Phase advance between nearby BPMs is a robust observable independent of BPM calibration, offset and tilt and focusing errors, thus phase-beating:

$$\Delta\phi_{n+1} = \phi_{n+1}^{meas} - \phi_{n}^{meas} - (\phi_{n+1}^{mod} - \phi_{n}^{mod})$$

- ϕ_n^{meas} is measured with standard FFT or SVD techniques of kicked data
- Synergy with J. Wenninger's LOCO?

ϕ-beating Vs β-beating



Precise relation between $\Delta\phi_{rms}$ and $\Delta\beta/\beta_{rms}$

Dispersion observable

- Dispersion is normally measured using radial steering and BPM readings.
- Best BPM calibration error: $\pm 4\%$ (LHC-BPM-ES-0004)
- BPM resolution (pilot bunch): 200μm
- Specification on Dispersion [Rep. 501]:

$$\left|\frac{\Delta D}{\sqrt{\beta_x}}\right| < 0.013\sqrt{m}, \qquad \left|\frac{\Delta D}{D}\right|_{QF} < 30\%,$$

- In [EPAC 02, F. Zimmermann et al.] the pilot bunch BPM resolution was not enough to measure dispersion in the range $\delta = \pm 5\ 10^{-4}$

β-beating & dispersion correction

- We compute the non-square matrix **R** from ideal MADX model as

$$(\Delta\vec{\phi}, \Delta\vec{D}, \Delta Q_x, \Delta Q_y) = \mathbf{R}\Delta\vec{k}_1$$

k_1 are all quad circuits in MADX (210 per ring).

- we invert **R** using the SVD so the correction is

$$\Delta\vec{k}_1 = -\mathbf{R}^{-1}(w_\phi\Delta\vec{\phi}, w_D\Delta\vec{D}, \Delta Q_x, \Delta Q_y)$$

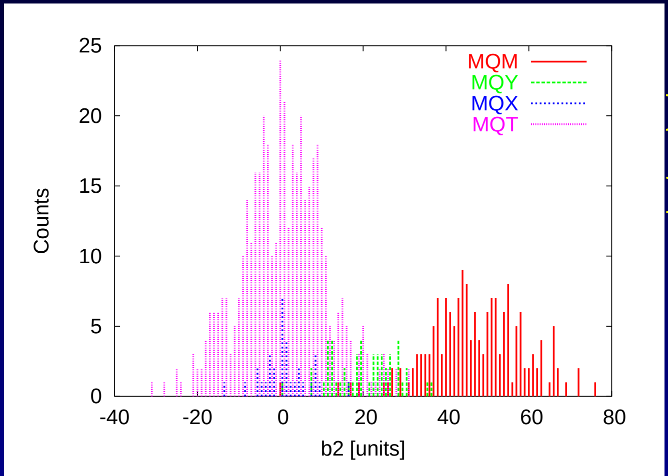
$w_{\phi,D}$ are weights used to choose beta-beating or dispersion correction.

- However correction is not guaranteed
- Simulations are needed to prove correction and to assess performance.

Simulation ingredients I

- All b_2, a_2, b_3, ... errors from measurements:

b_2 example

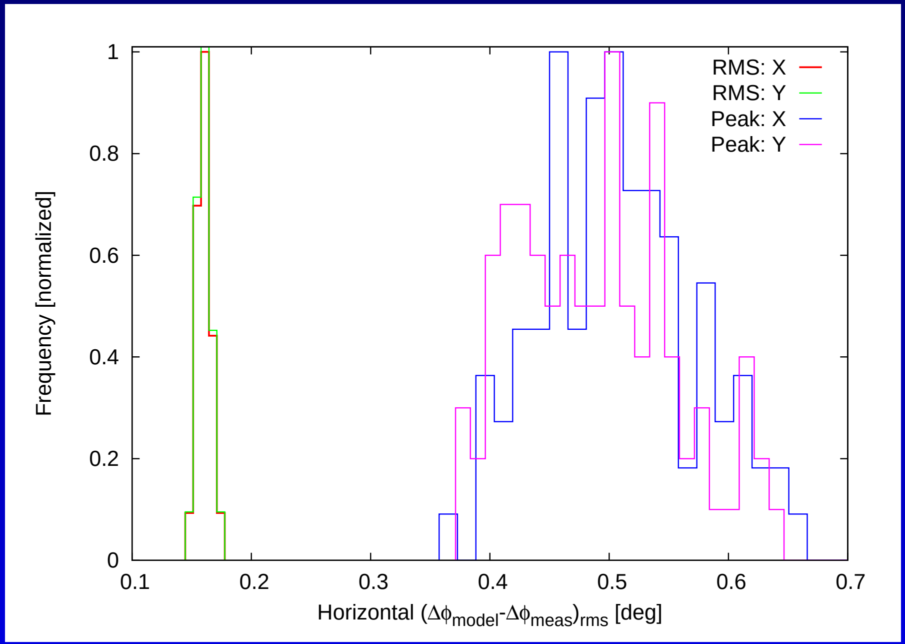


not really Gaussian
not centered

- Extra Gaussian noise of 5 units added to quad b_2
- rms misalignments of chromaticity sextupoles, $\sigma_{x,y} = 2$mm
- rms misalignments of MCS, $\sigma_{x,y} = 0.5$mm

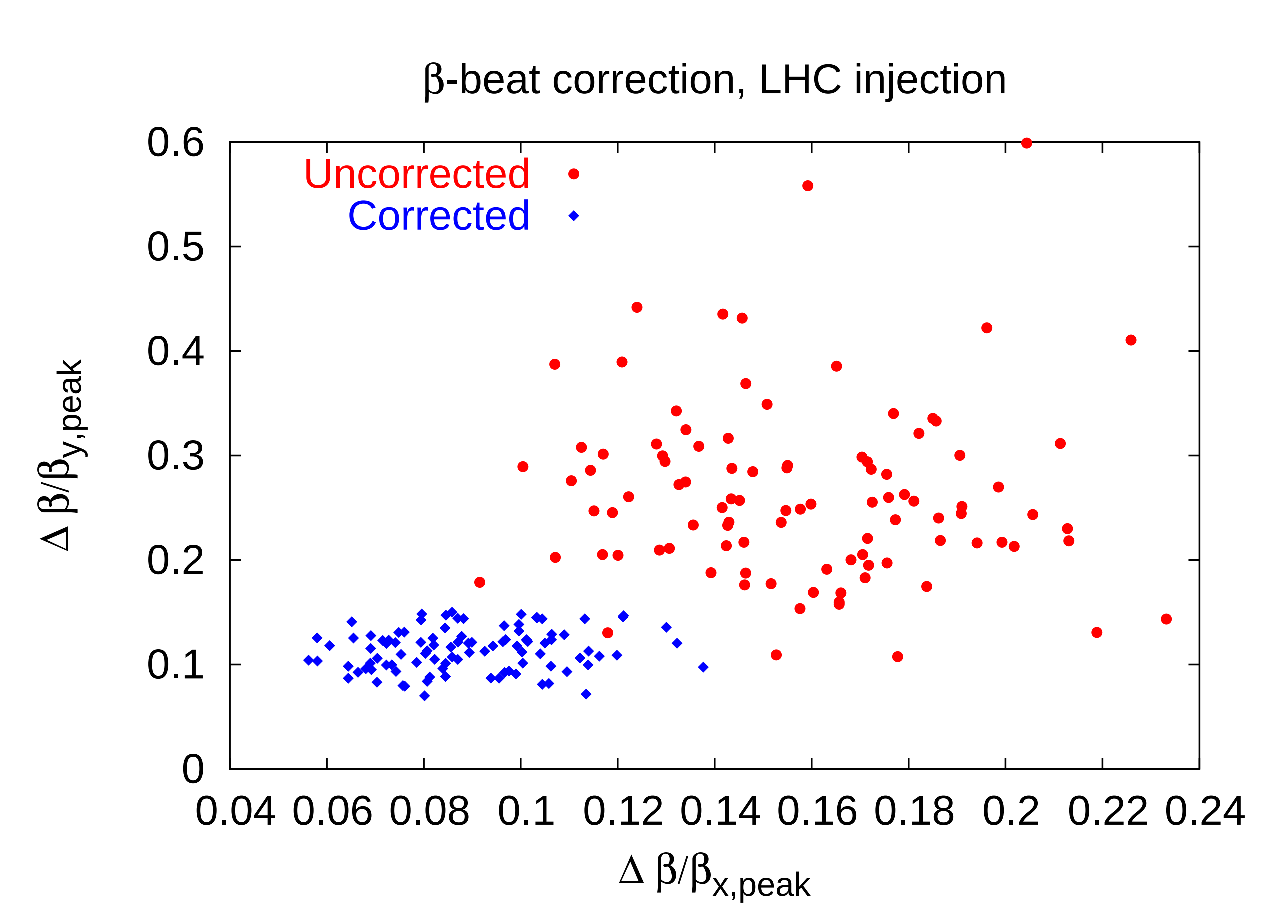
Simulation ingredients II

- Gaussian noise, σ_ϕ, added to the MADX phase to account for error measurements. σ_ϕ depends on BPM noise ($\sigma_{noise} = 200\mu$m), decoherence time (N=400 turns) and kick amplitude (a=4 mm).
- From tracking simulations the error on the phase:



To be on the pessimistic side we take $\sigma_\phi = 0.25°$.

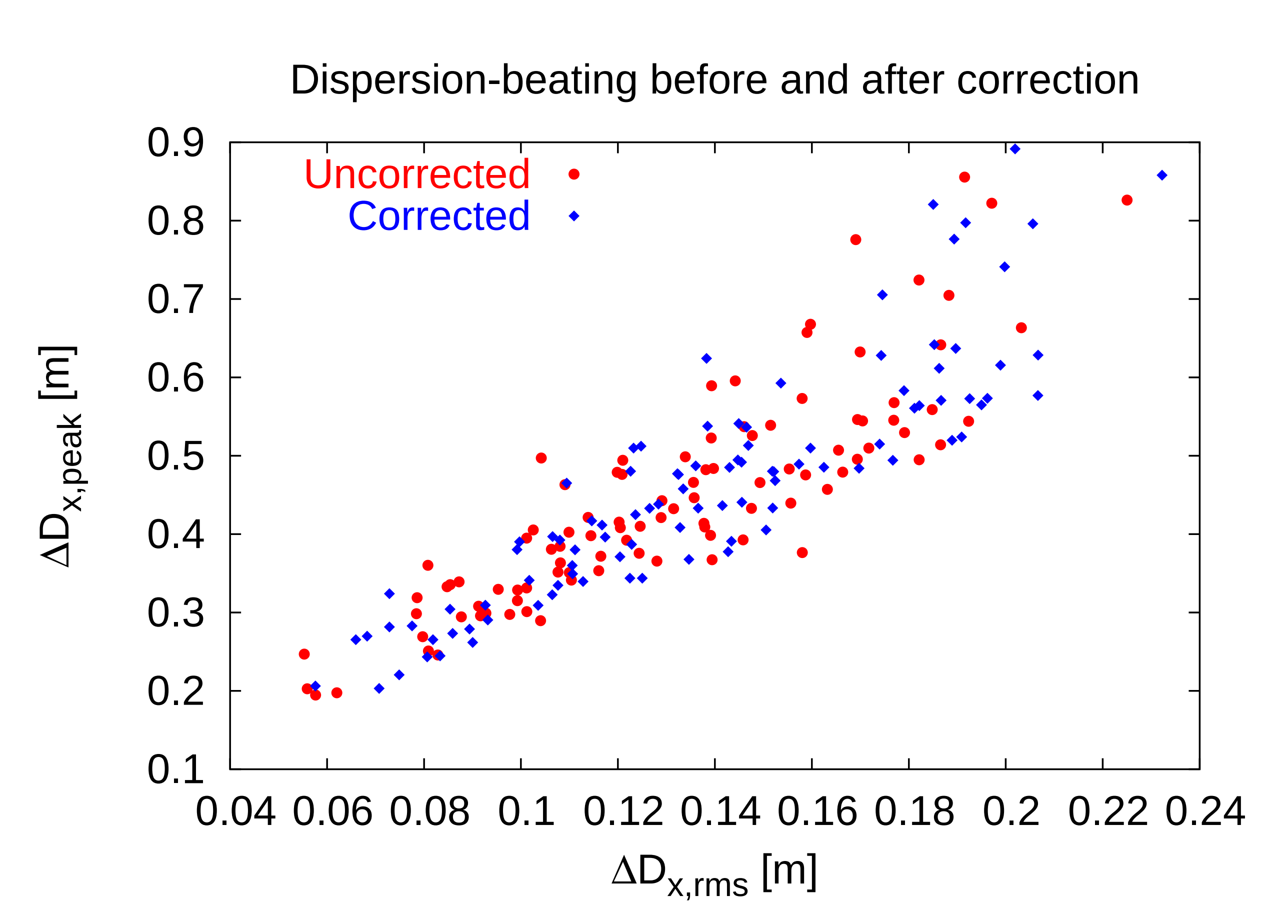
β-beating correction ($w_D = 0$)



→ β-beating correction works!

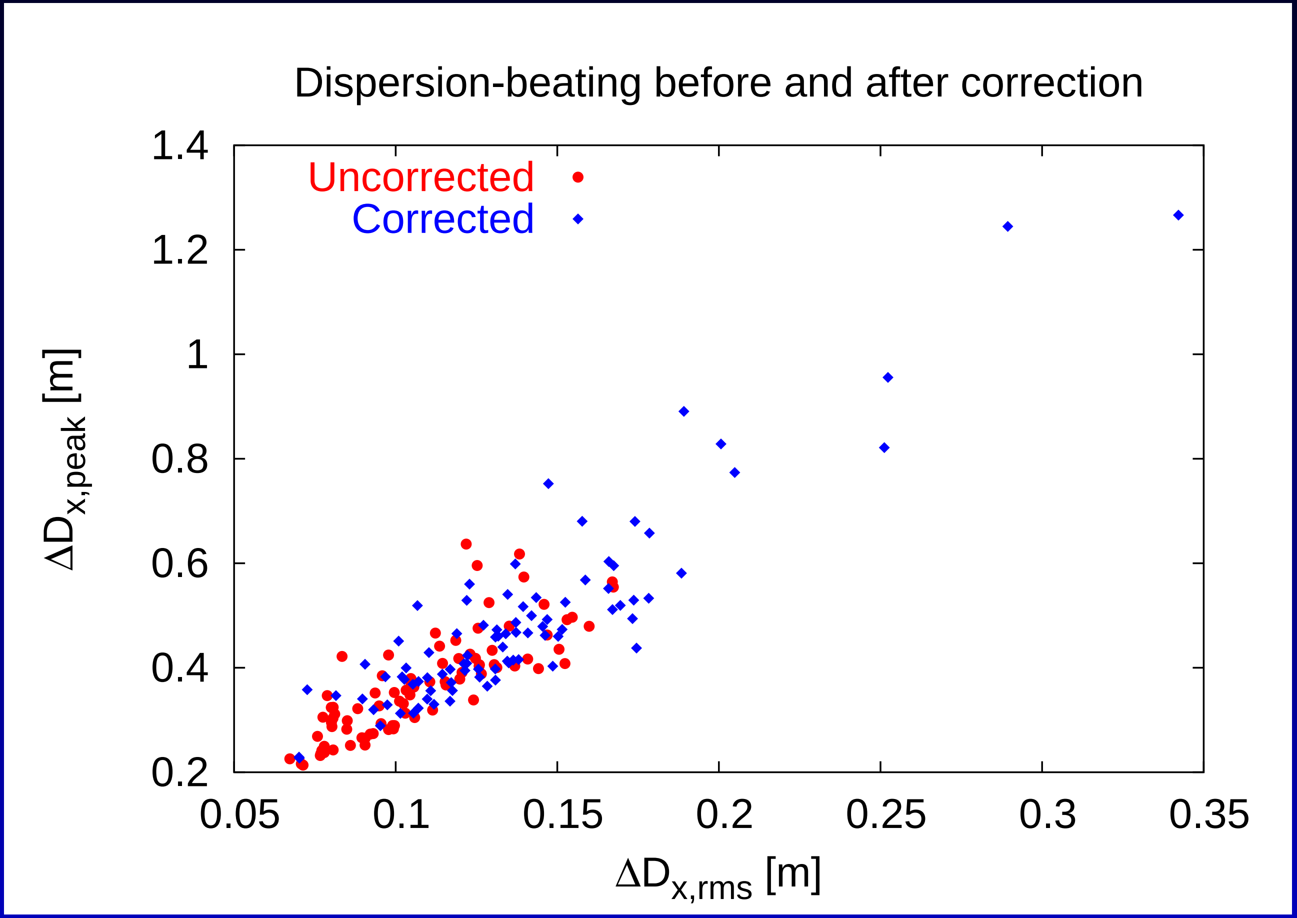
→ Best peak corrections in the 5% level

What happens to dispersion? ($w_D = 0$)



→ Dispersion remains unchanged (better than not considering dispersion at all)

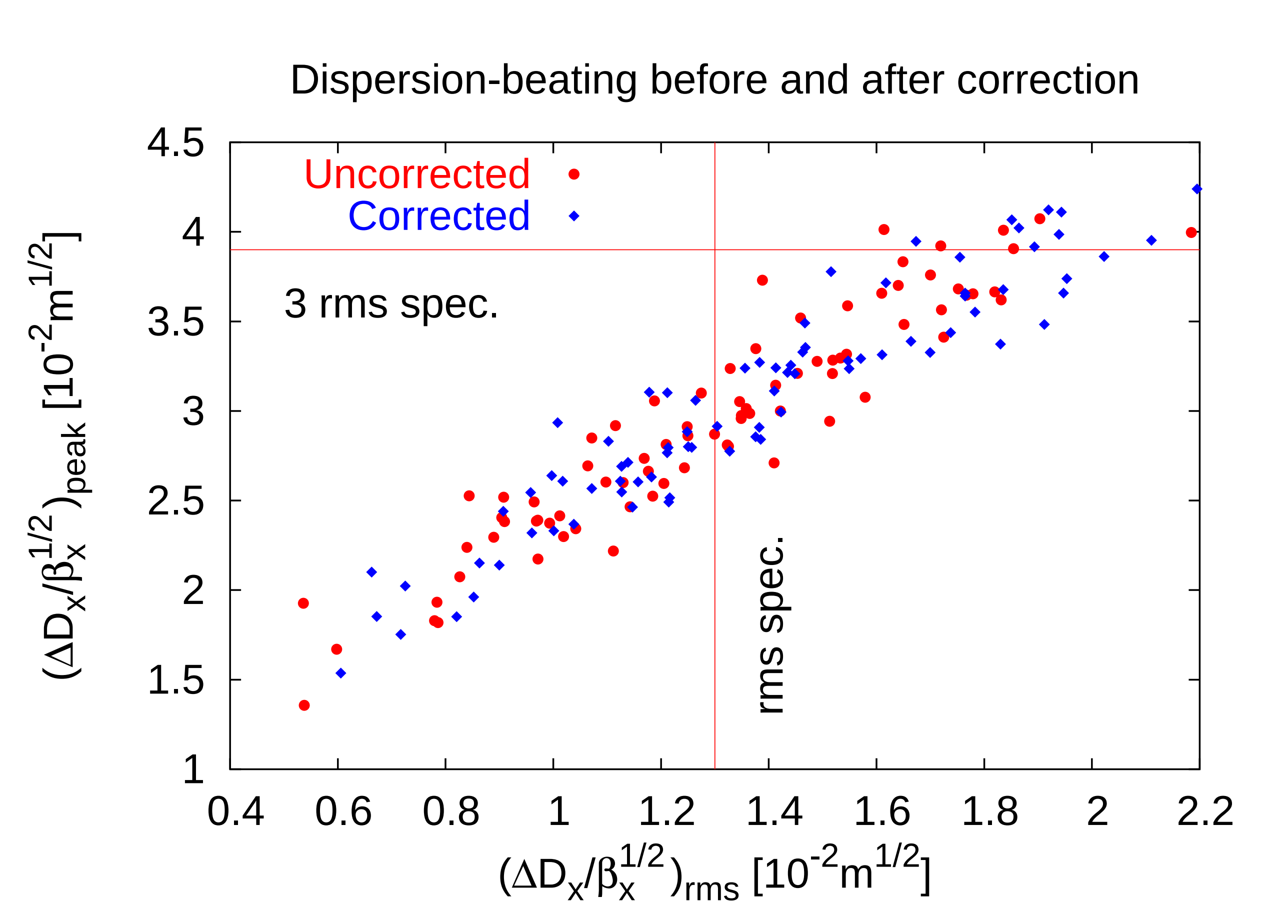
Not considering dispersion (old b_2 table)



$\rightarrow$ Dispersion gets spoiled

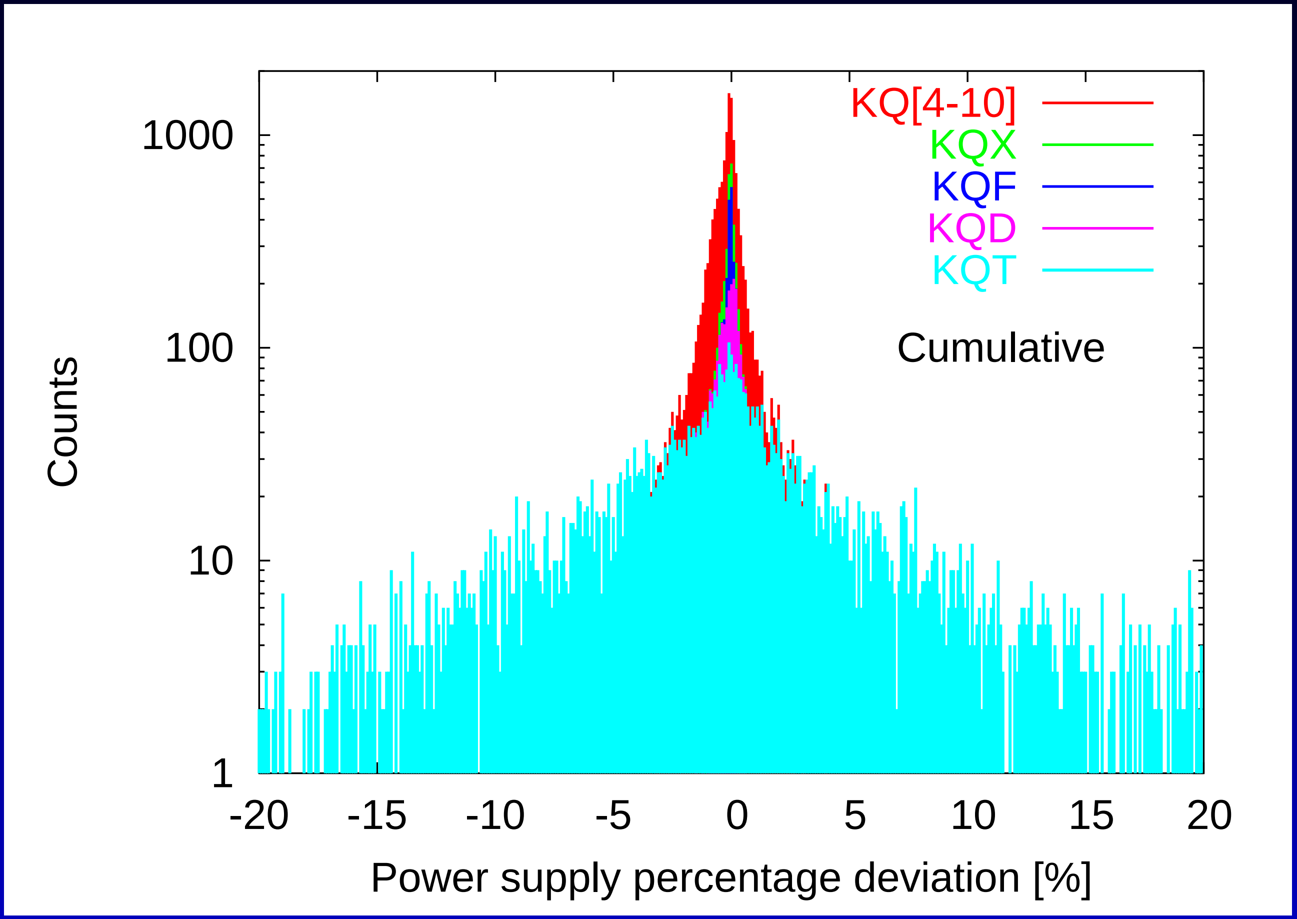
$\rightarrow$ β-beating correction must consider dispersion

Comparing dispersion to specs. ($w_D = 0$)



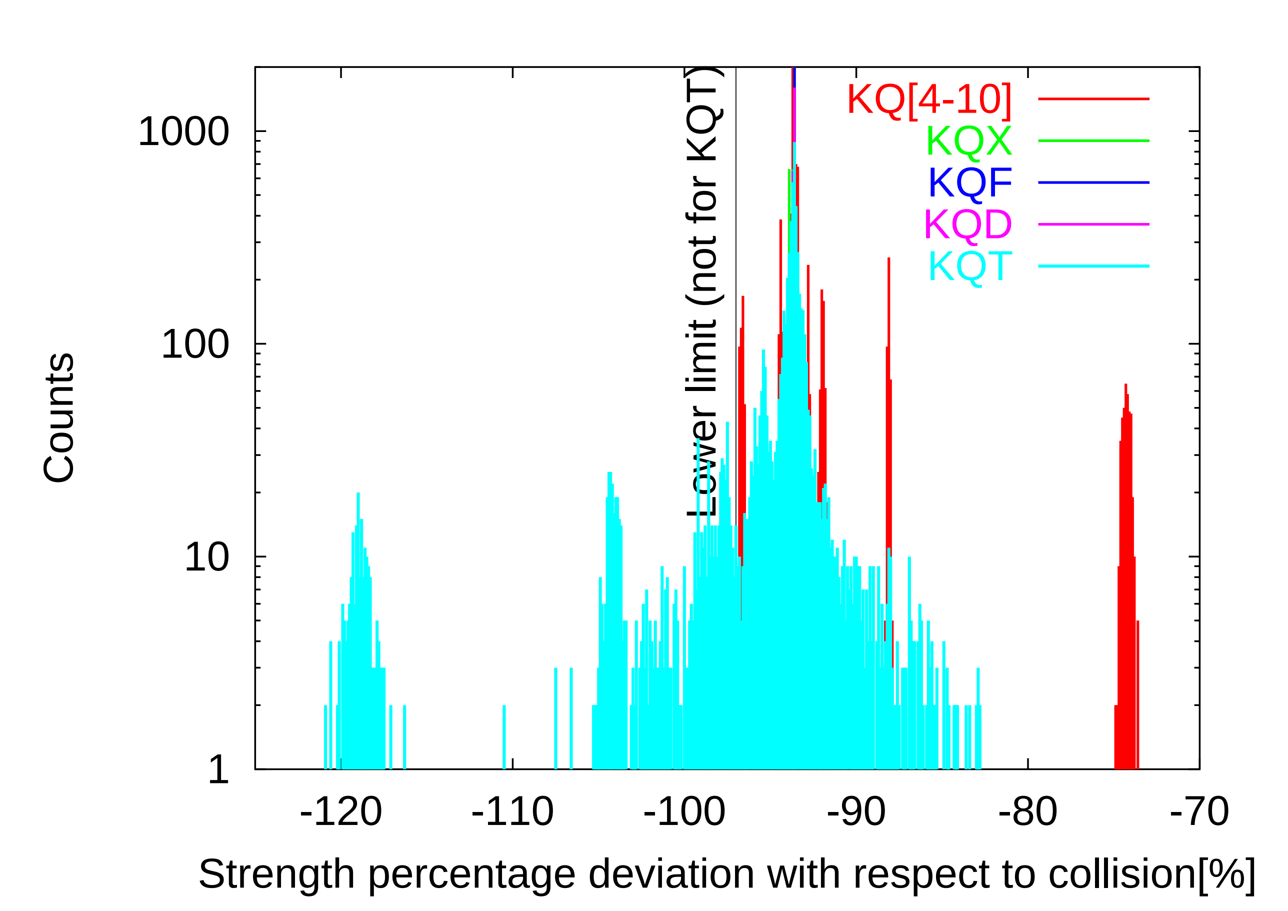
$\rightarrow$ Peak specification is met for most of the seeds but not the case for the rms specification.

Strengths of quadrupoles ($w_D = 0$) I



$\rightarrow$ Variation in the percent level with respect to nominal setting at injection

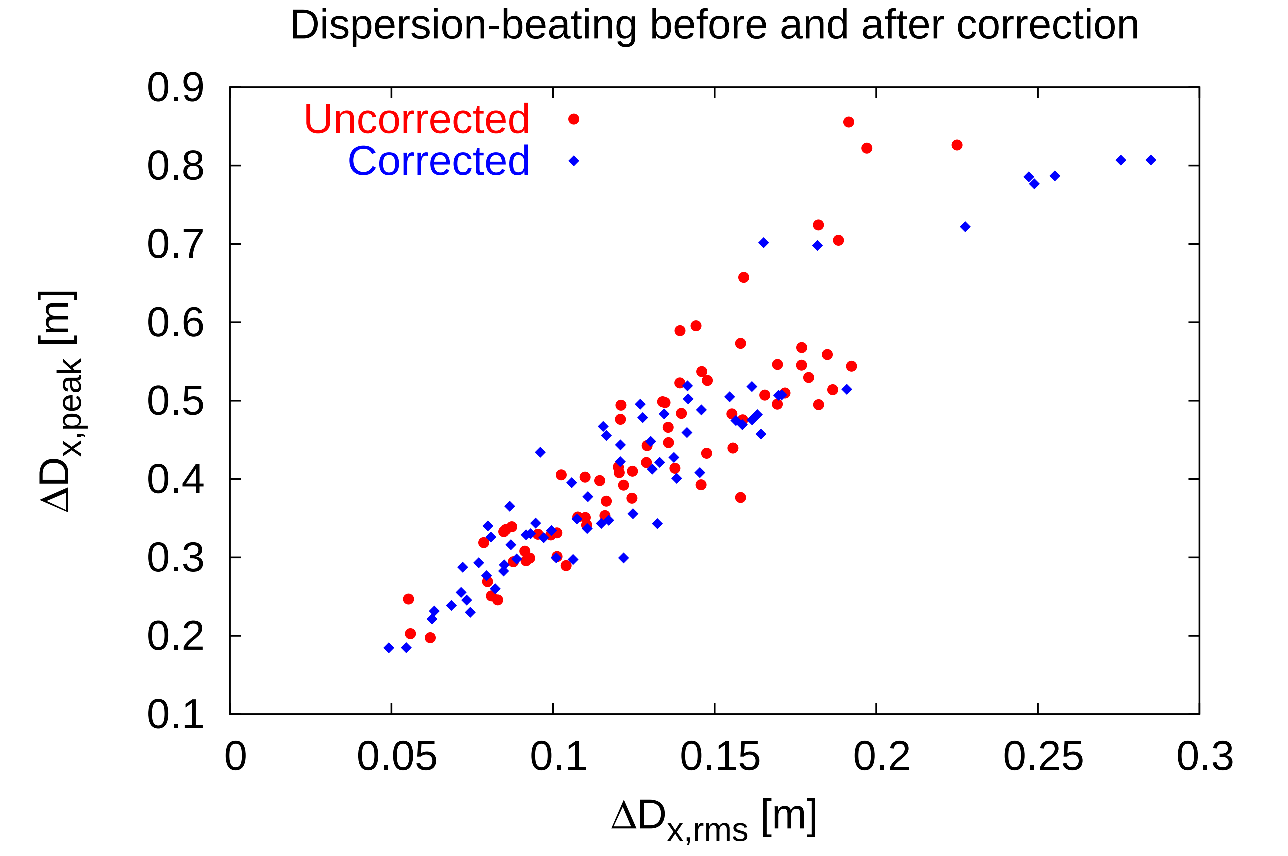
Strengths of quadrupoles ($w_D = 0$) II



$\rightarrow$ Strengths are within good limits

Can we correct dispersion only? ($w_\phi = 0$)

No BPM calibration error has been assumed



$\rightarrow$ Some seeds' dispersion-beating not correctable!

$\rightarrow$ Probably due to misuse of Q[7-7], to be clarified

Coupling

- A robust global coupling correction is presented at: R. Jones et al, CERN-AB-2005-083 BDI0
- Local coupling is also measurable from the secondary spectral lines of BPM data around the ring:

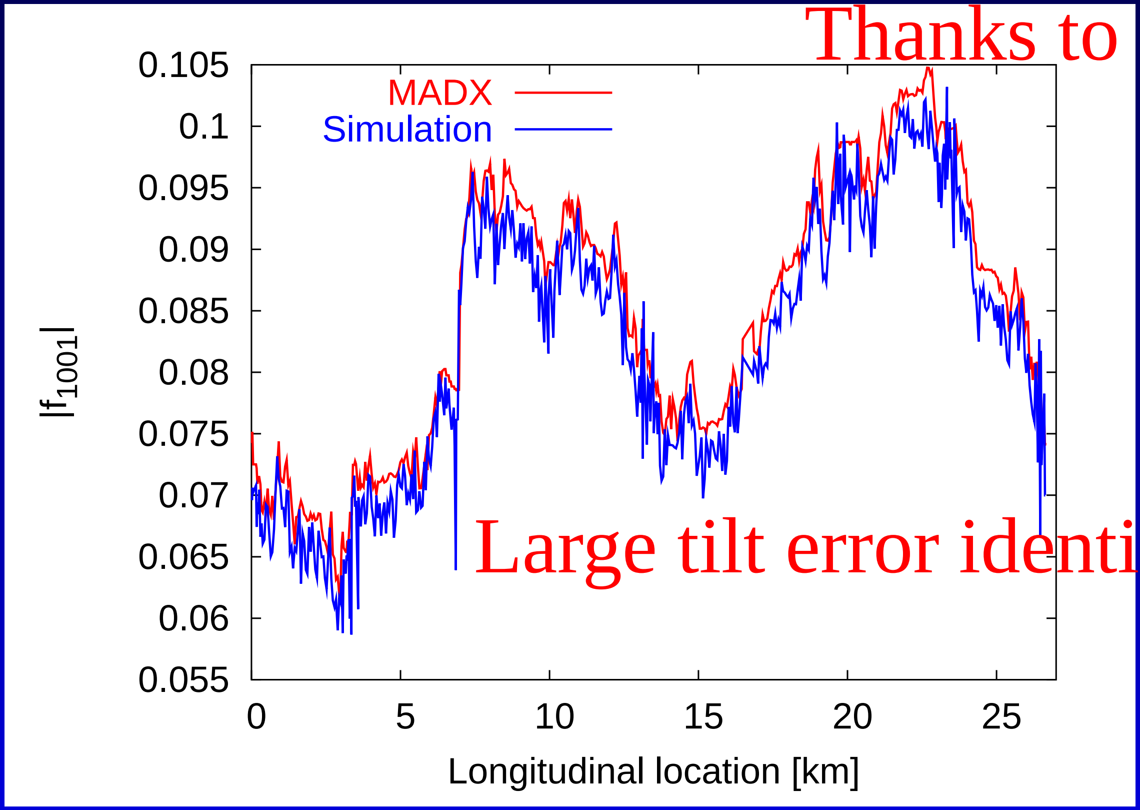
$$f_{1001} = \frac{1}{2}\sqrt{\frac{H(0,1)}{V(0,1)}\frac{V(1,0)}{H(1,0)}}$$

- Independent of BPM calibration errors and succesfully used at SPS and RHIC.
- What about LHC? The BPM data comes for free with the β-beat correction

Local coupling measurement simulation

Random quad tilts and rms orbit are assumed plus a large tilt error (15mrad) at $\approx$6km. BPM resolution=200μm, BPM tilts=2mrad, 400 turns.

Thanks to A. Franchi

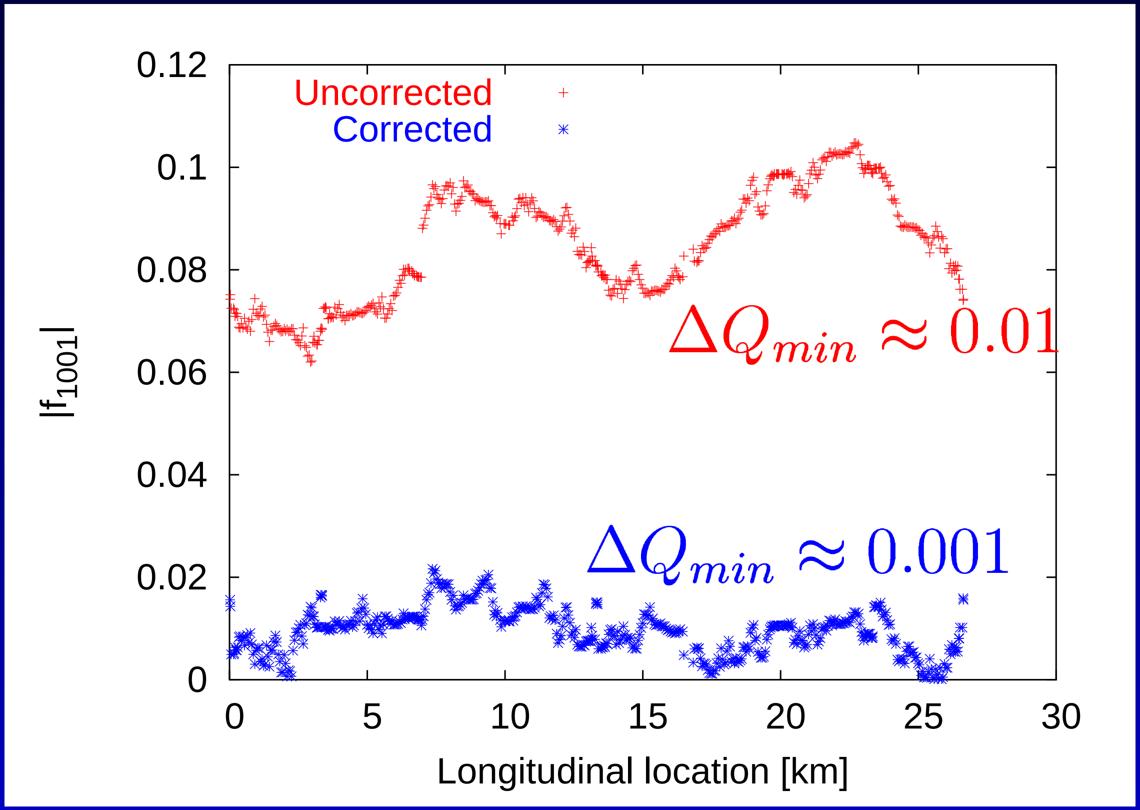


Large tilt error identified

$\rightarrow$ Measurable under realistic conditions

Local coupling correction

Using all the skew quadrupole correctors:



→ Satisfactory local correction

→ Not perfect due to the particular distribution of errors/correctors. Best local correction is realignment

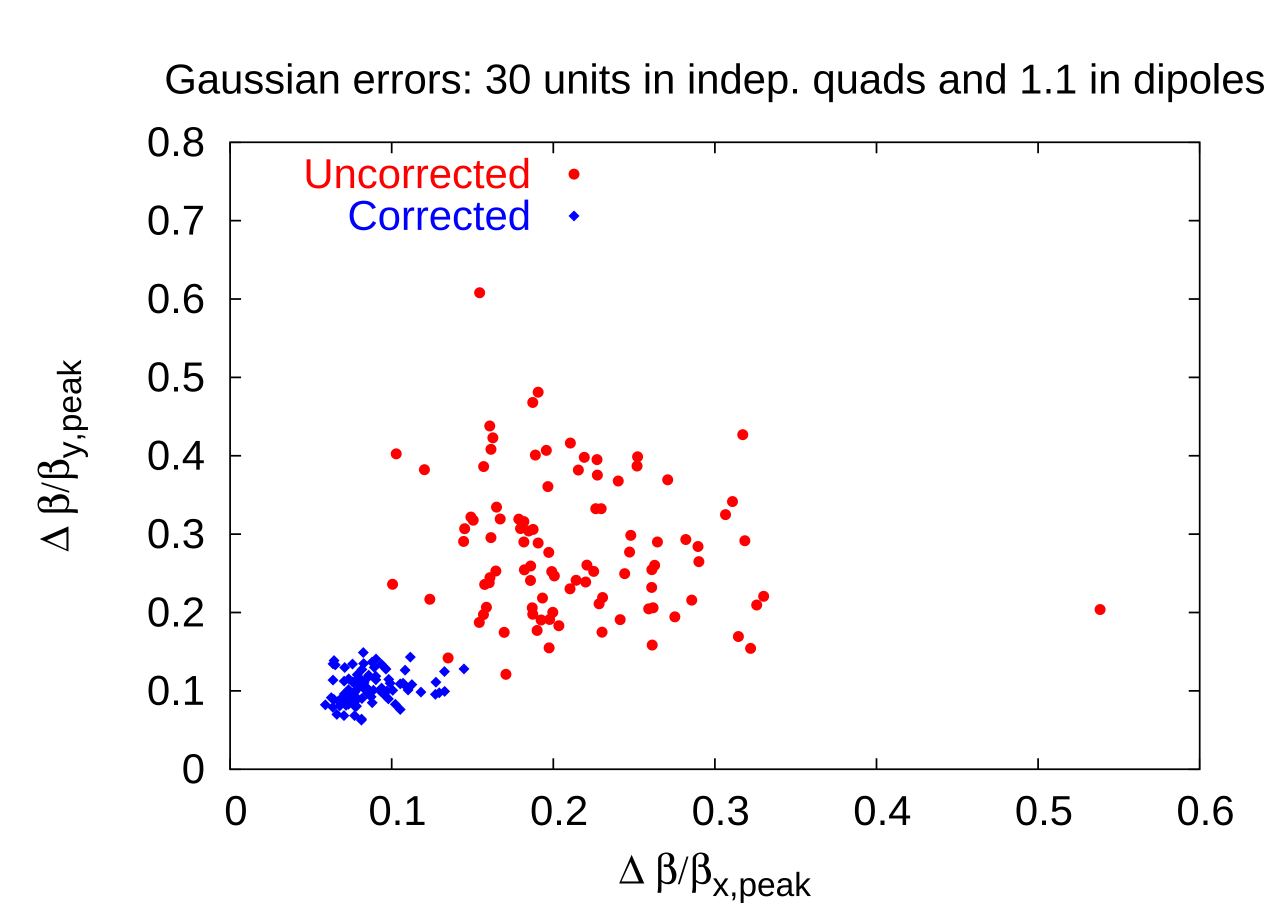
Questions

- Required facilities: BPM system in turn-by-turn mode (good synchronization is crucial)
- How long does it take?
  5 iterations are enough for β-beat correction. An iteration consists of: Data acquisition, analysis, change quad strenghts and probably injection and chromaticity re-optimization.
- Who will do it?
  Studies: I am very interested
  Software applications: Also interested but resources needed (LARP, KEK?)
  Commissioning: Again, I am very interested in taking part

Conclusions & outlook

- β-beat correction can be achieved without spoiling dispersion-beat
- Dispersion-beat correction does not seem robust yet
- Important coupling sources identifiable from the same BPM data used for β-beat

Gaussian errors: β-beat



Gaussian errors: Dispersion-beat

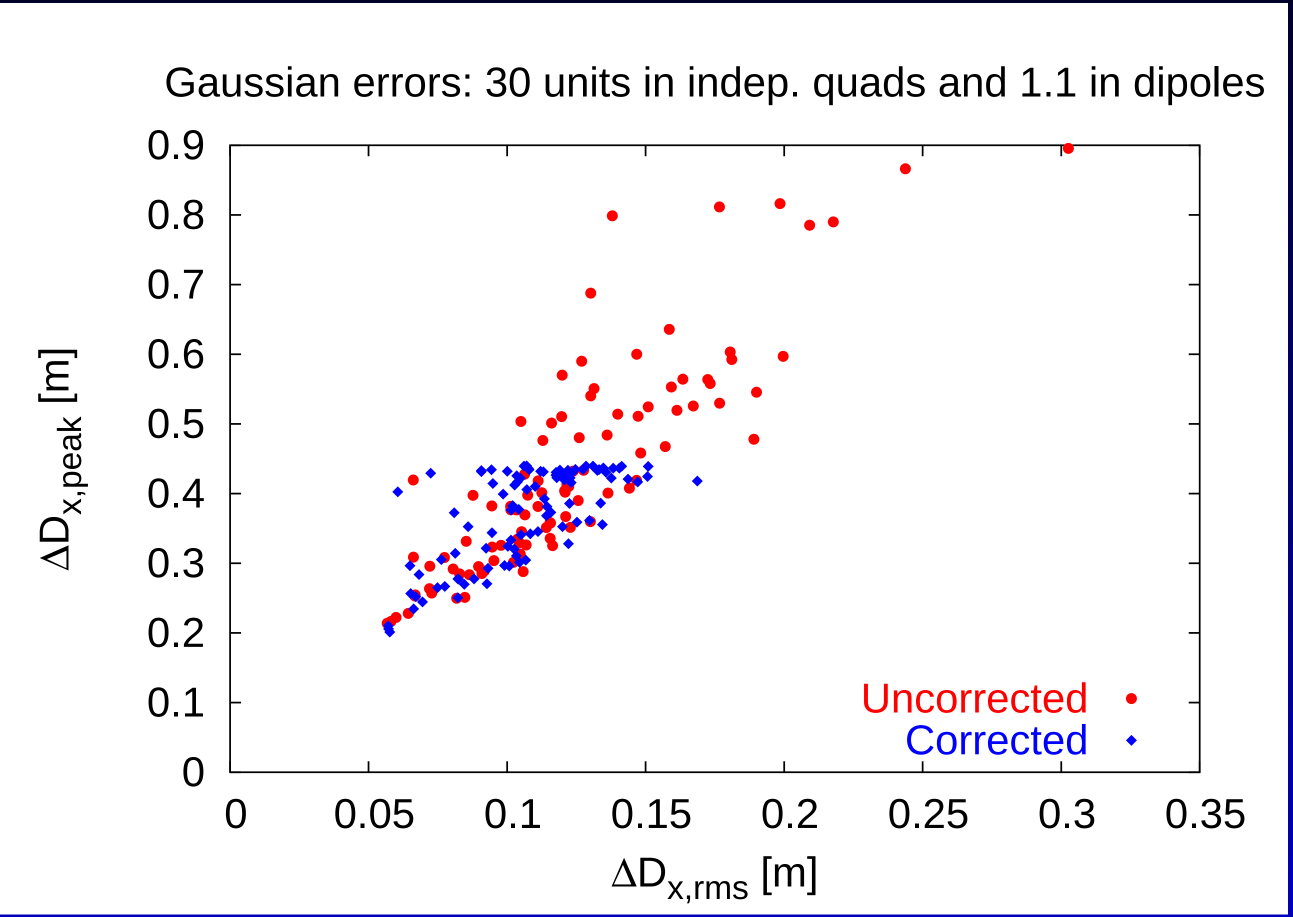


Illustration of β-beat at the BPMs

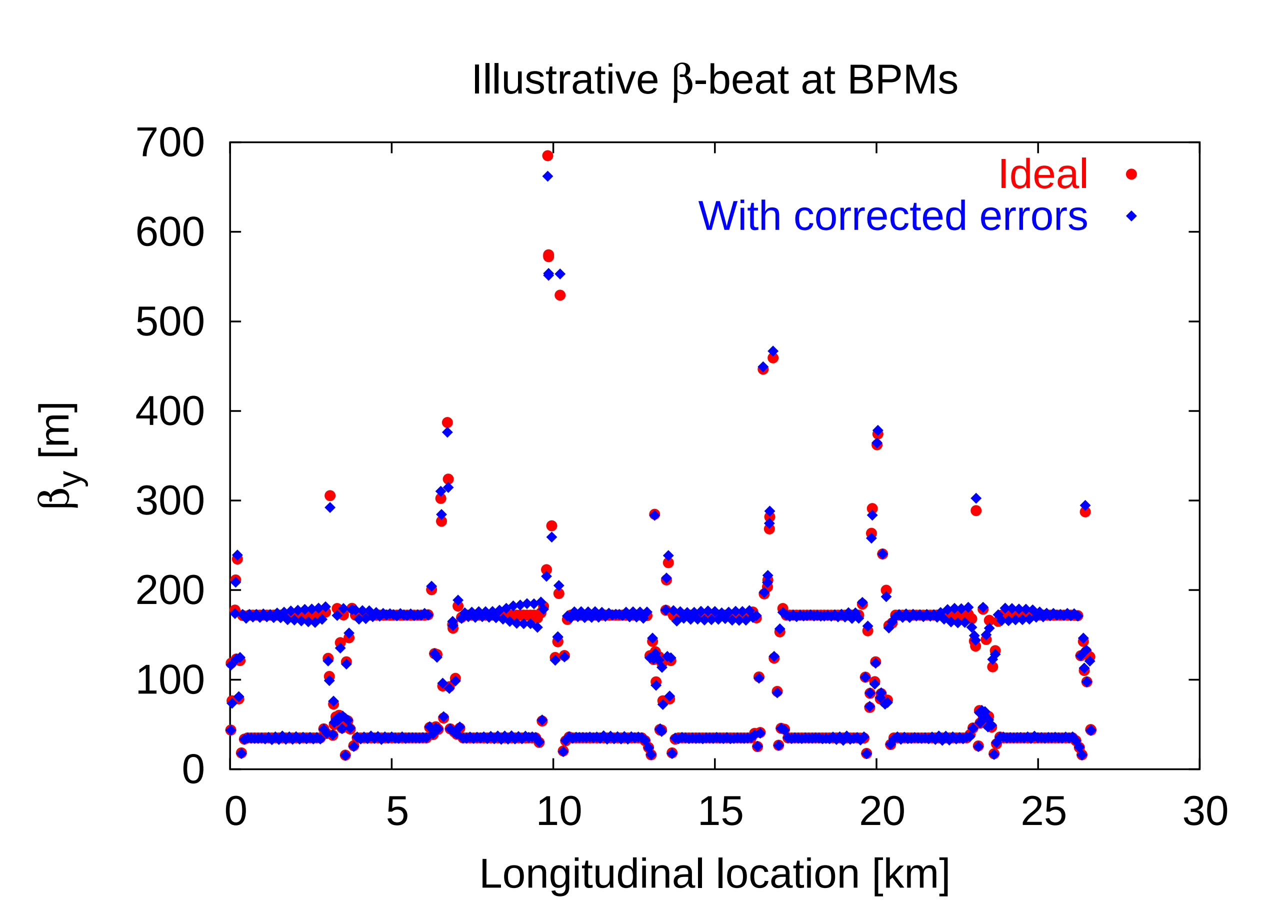
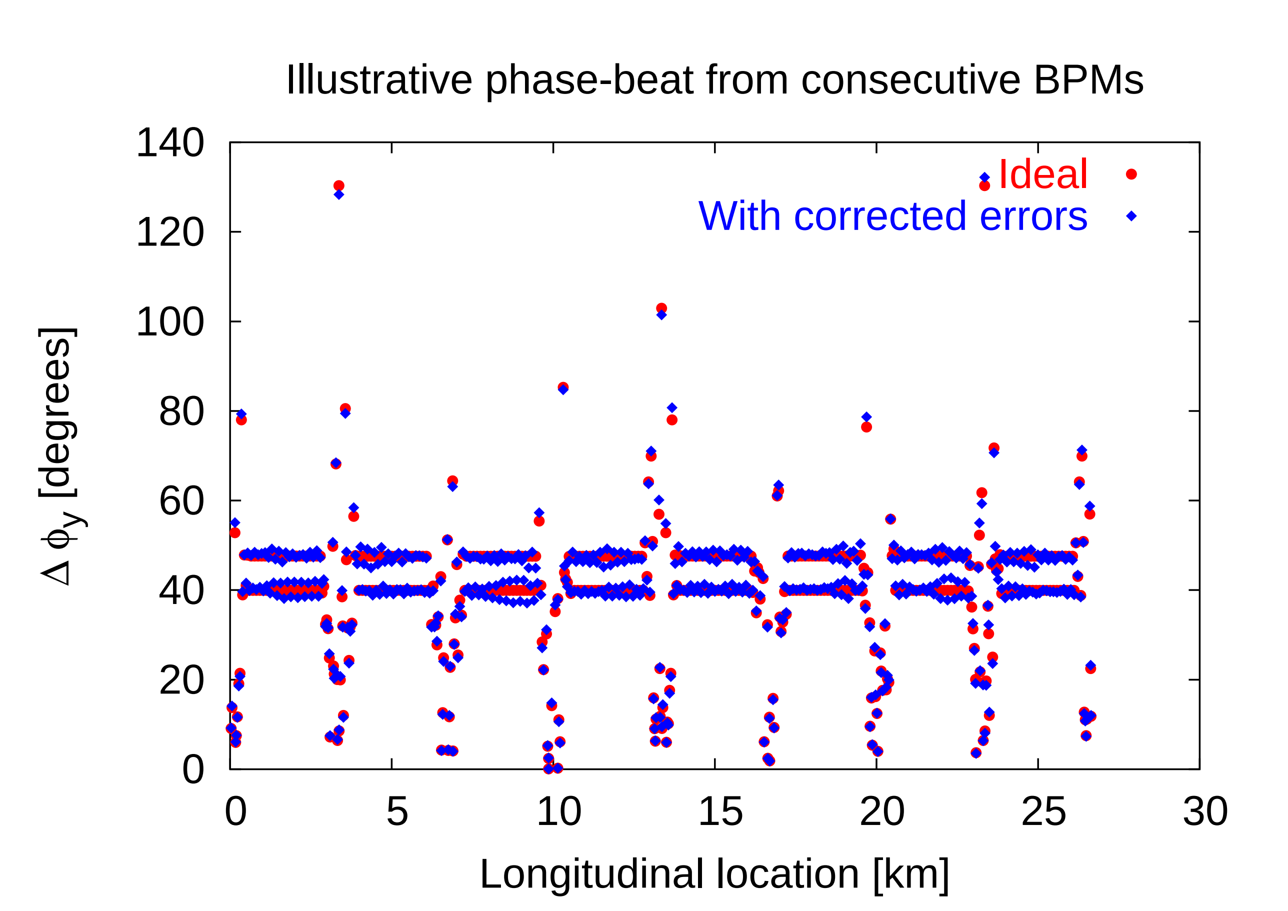


Illustration of phase-beat at the BPMs



Measurement of f_{1001}

Thanks to A. Franchi