FROM RESEARCH TO INDUSTRY

ALIGNMENT AND TOLERANCES

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EuroCirCol
A key to New Physics

OUTLINE

- Definition of the errors and correction scheme
- Evaluation of the results
- Dependency of various observables on the errors
- Conclusions and perspectives

ERRORS DESCRIPTION

- FCC will be subject to various errors that will perturb its normal activity
  ⇒ important to study and to correct them

- Two types of errors contributing to beam misalignment are studied: position error and field error (both static)

- Position error is defined for all ‘MQ’ quadrupoles, in arc and in dispersion suppression (DIS) regions:
  - $0 < \sigma_{\delta x} < 0.5$ mm
  - $0 < \sigma_{\delta y} < 0.5$ mm

- Field error (random b1) is defined for all ‘MB’ dipoles (in arcs and DIS) and ‘MBS’ dipoles (in DIS), in relative units:
  - $0 < \sigma_{\delta B/B} < 0.5$ %

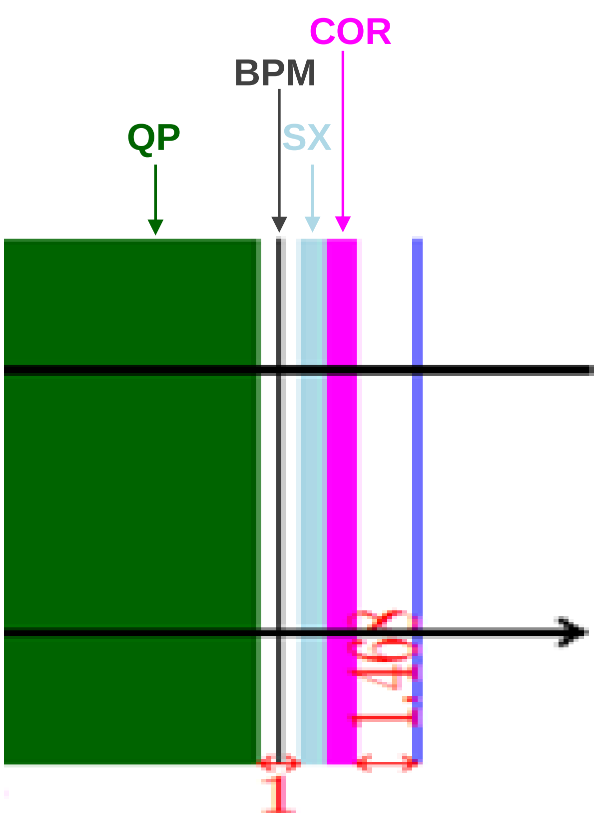
- All errors are Gaussian distributed, truncated at 3-σ values

- No errors are applied in the straight (insertion) regions

- The error generator seed is user defined, and different for each of the 500 runs

CORRECTION SCHEME

- The complete FCC ring lattice is used, at collision energy (50 TeV)
- All quadrupoles of the arc and DIS sections have a BPM and a corrector (L = 0.647 m) next to them, with the same polarity (BPMs are used on the corresponding plane only).
  - **Exception:** the first quadrupole of the DIS before each arc section (no BPM), and the last quadrupole of the DIS after each arc section (no corrector).



- Same number of BPMs (parameters) and correctors (variables)
- Optimization using the CORRECT command of MADX (SVD mode)
- The errors are evaluated only for the arcs
- IR orbit correction done in parallel

→ talk of A. Seryi (next session)

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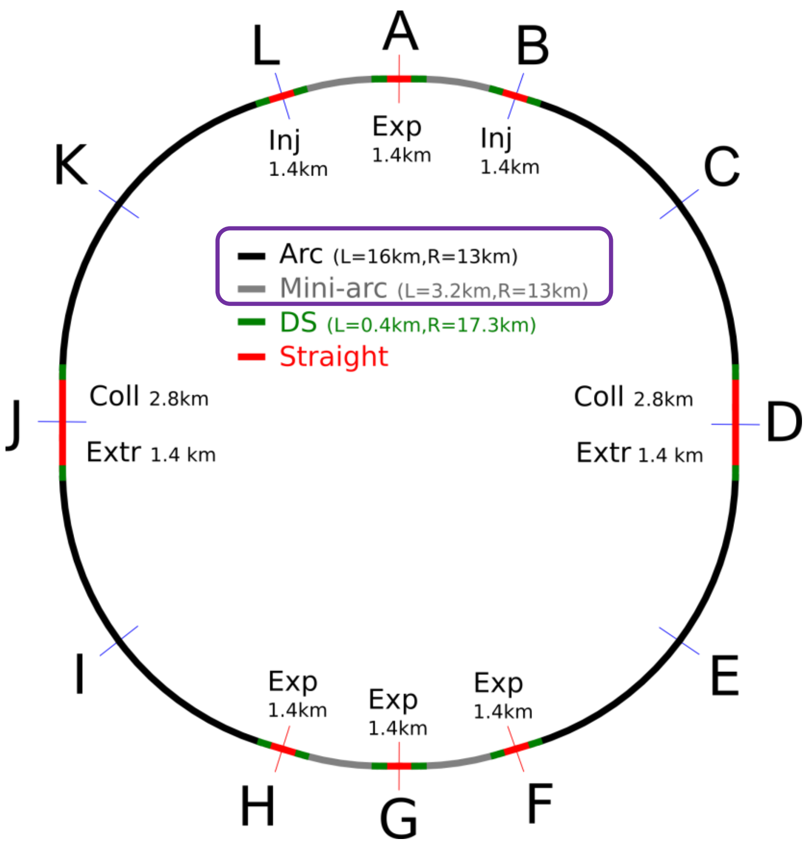

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EVALUATION OF THE RESULTS

- For each run, calculation of the RMS and maximum values for the corrector strengths and the following observables over all elements of the arcs:
  - residual orbit
  - residual angle
  - beta-beating $\Delta\beta/\beta_{ref}$
  - parasitic dispersion or dispersion beating $\Delta D/\sqrt{\beta_{re}}$

→ see LHC Project Report 501 for more details

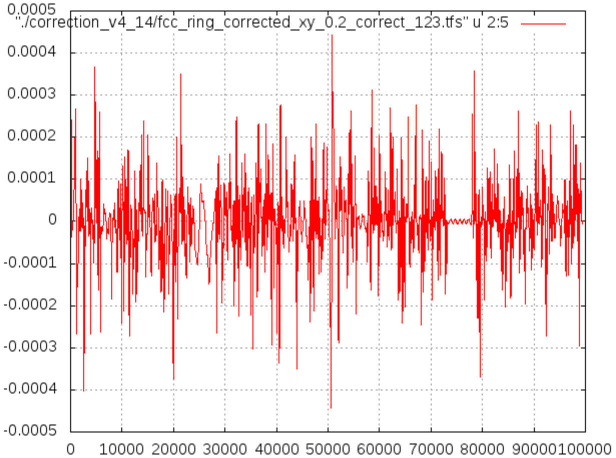
- From the distribution of the maximum values the 90-percentile (value for which 90% of the distribution is included) is calculated over all runs

- The dependency on each main error contribution is studied with:
  - Quadrupole alignment error. The RMS error is assumed identical in both planes (x and y).
  - Dipole field errors. The relative RMS error is assumed to be identical for the two types of magnets (MB and MBS).

- When one error contribution is varied, the other contribution is fixed with the reference values of **0.35 mm** for the quadrupole misalignment and **0.1%** for the dipole field errors, resp.

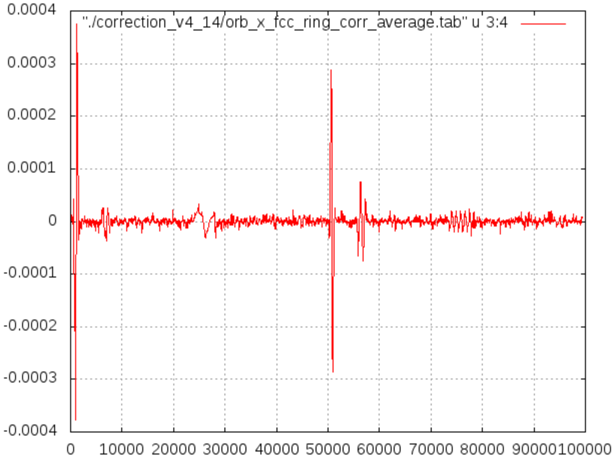
SAMPLE RESULTS

Case 0.35 mm, 0.1 %

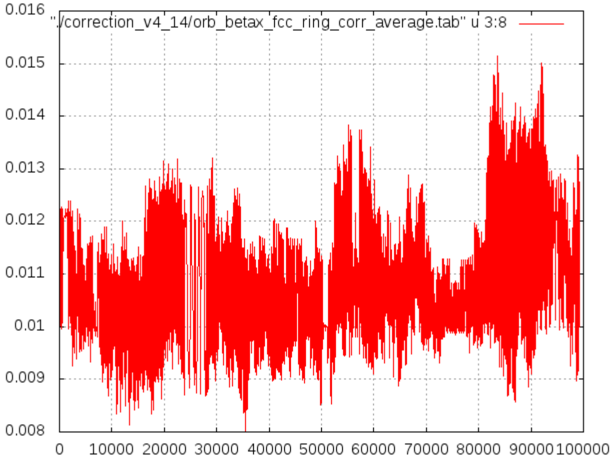


Vertical residual orbit for each element in one run

* 500 runs =>

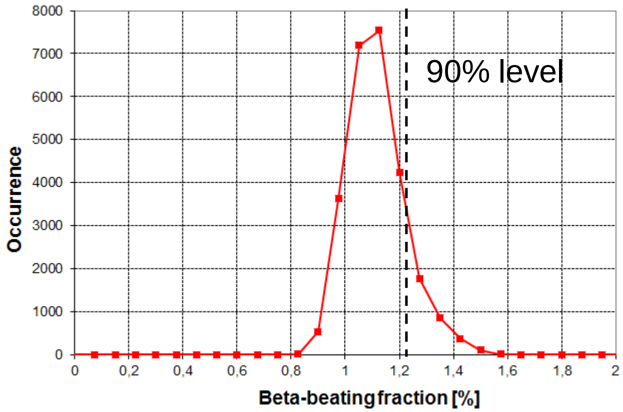


Mean value of the vertical residual orbit for each element over the 500 runs



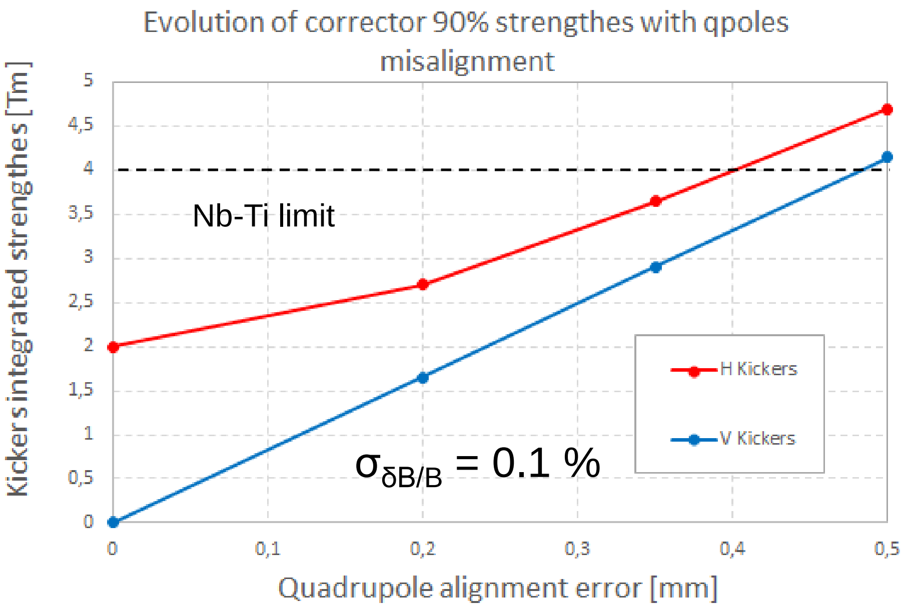
Maximum value of horizontal beta-beating over the 500 runs

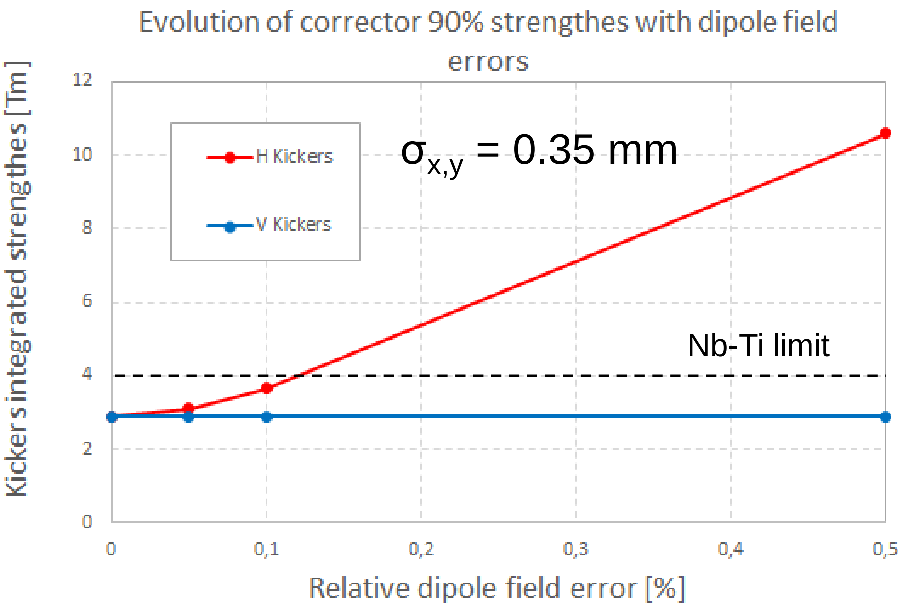
Histogram =>



Distribution of the maximum value of horizontal beat-beating

CORRECTOR STRENGTHS





Horizontal correctors always stronger

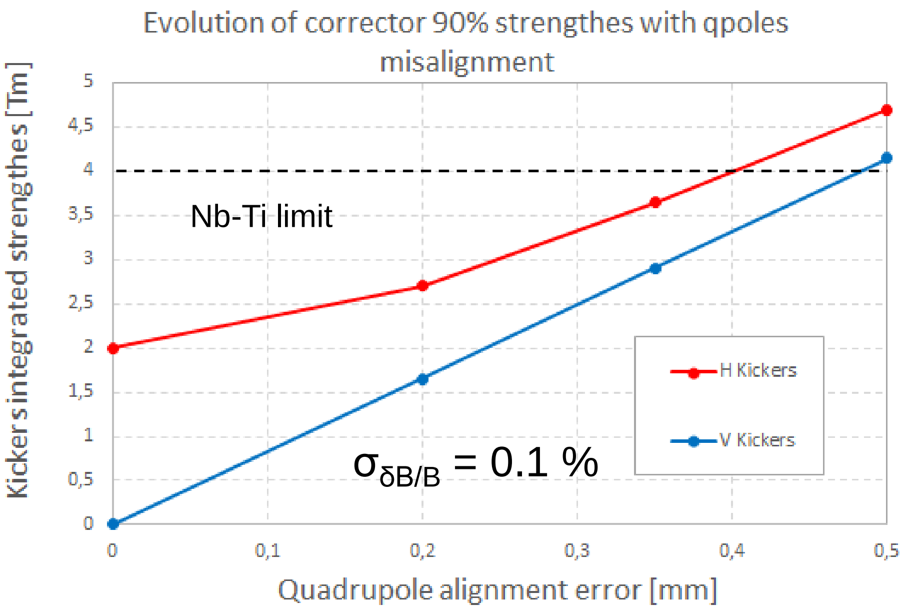
Strong dependency in x plane
Constant in y plane

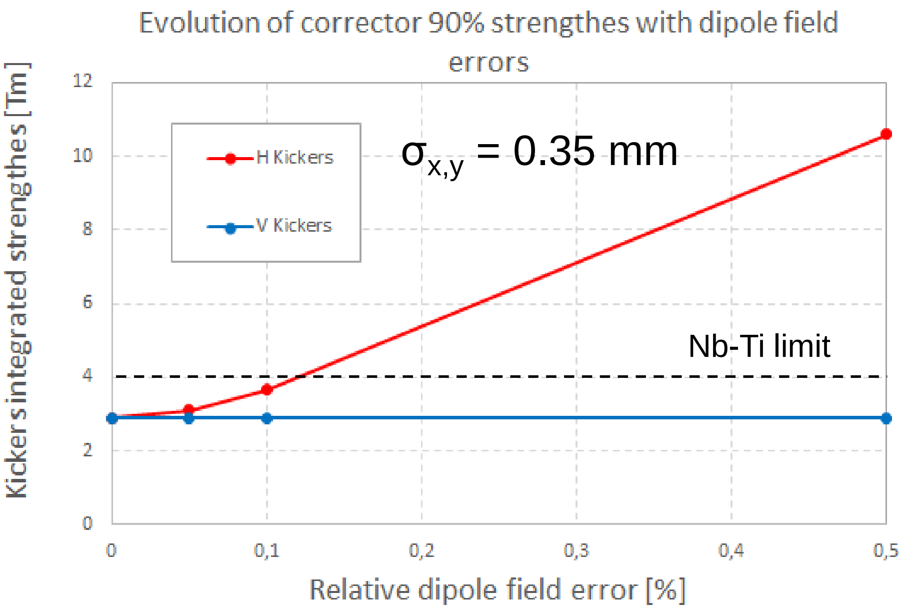
Integrated corrector strengths @ 0.35 mm, 0.1 % (90-percentile):

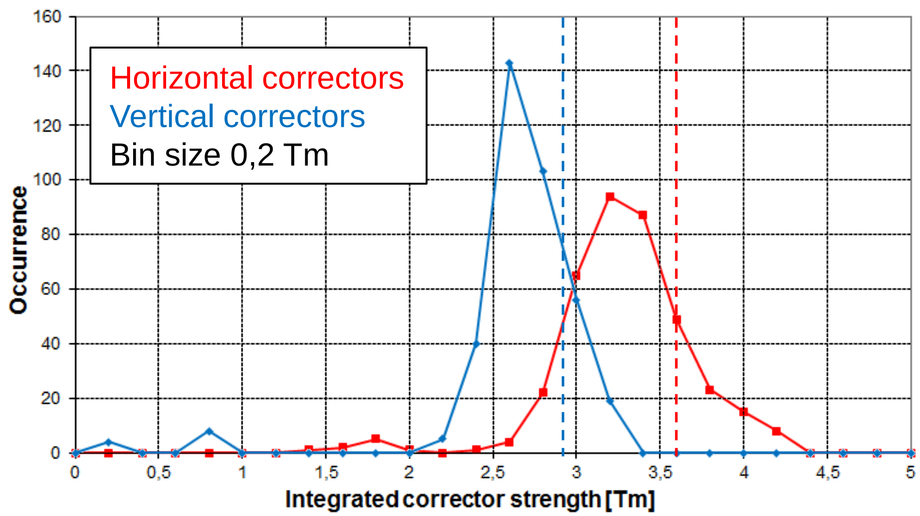
B_x*L = 3.6 Tm
B_y*L = 2.9 Tm

Compatible with the Nb-Ti technology (4 Tm) → talk of E. Todesco (Thursday)

CORRECTOR STRENGTHS

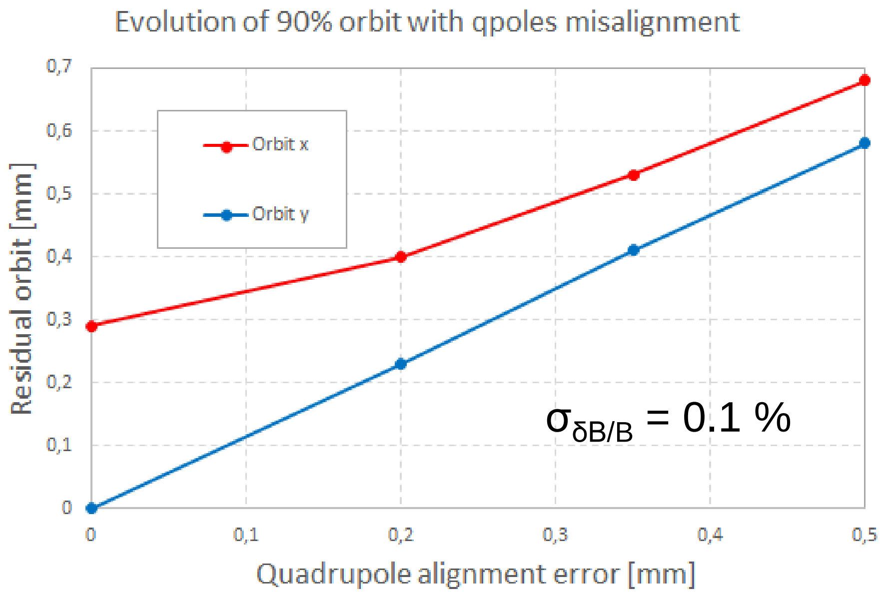


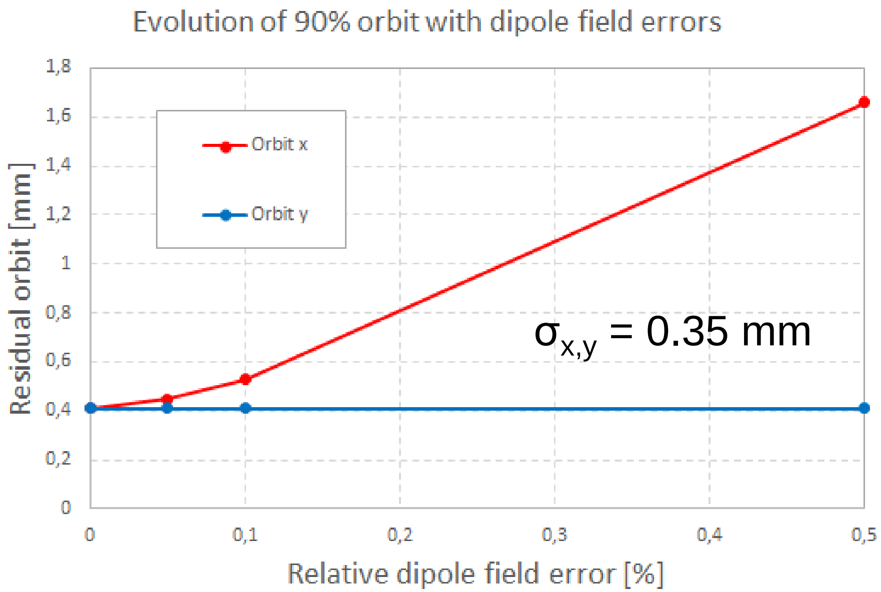




Histogram of the maximum value of the integrated correctors strengths

CLOSED ORBIT





Linear trend in both planes

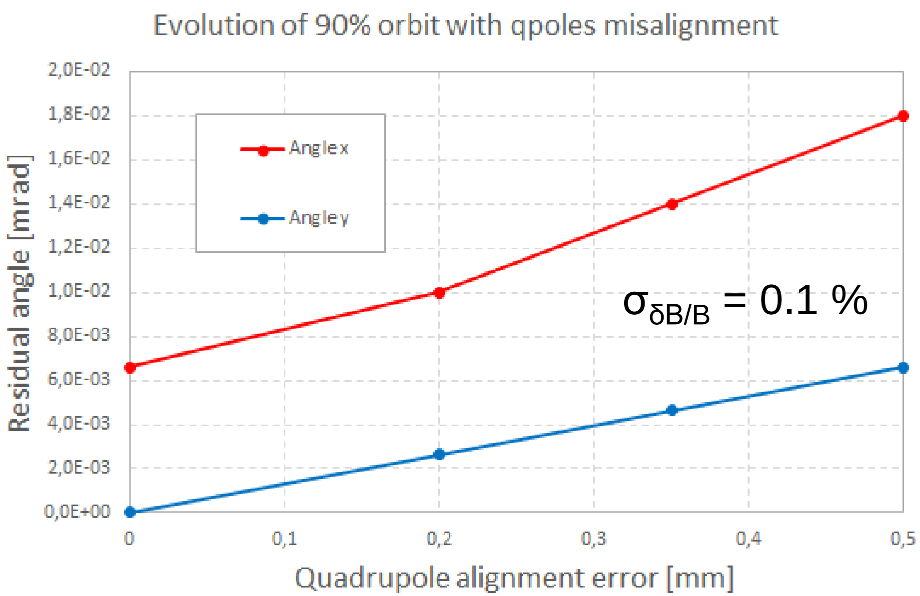
x always superior to y

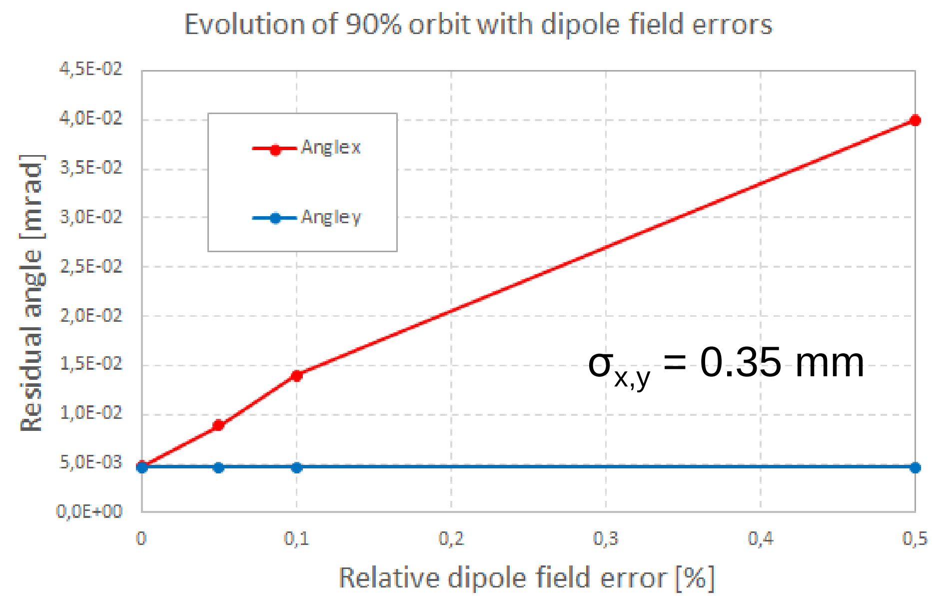
Strong dependency in x plane

Constant in y plane

Residual orbit @ 0.35 mm, 0.1 % (90-percentile)
X = 0.53 mm
Y = 0.41 mm

RESIDUAL ANGLE





Linear trend in both planes

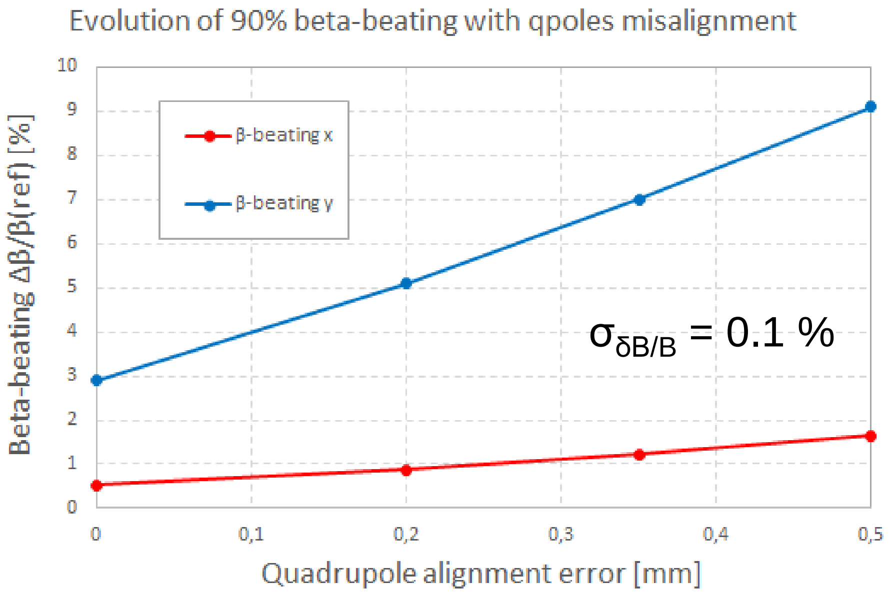
x always superior to y

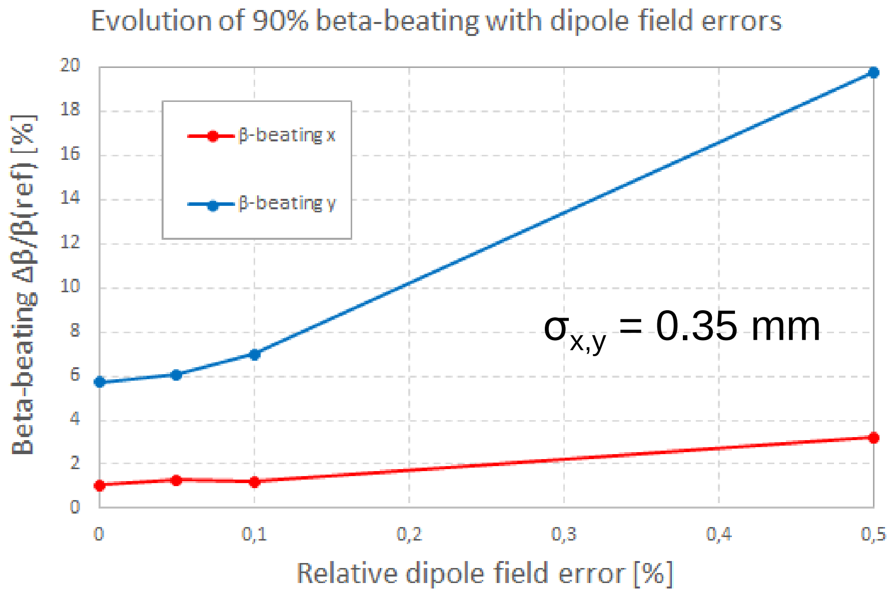
Strong dependency in x plane

Constant in y plane

Residual angle @ 0.35 mm, 0.1 %
X' = 14 μrad
Y' = 5 μrad
Should not influence beam screen design

BETA-BEATING





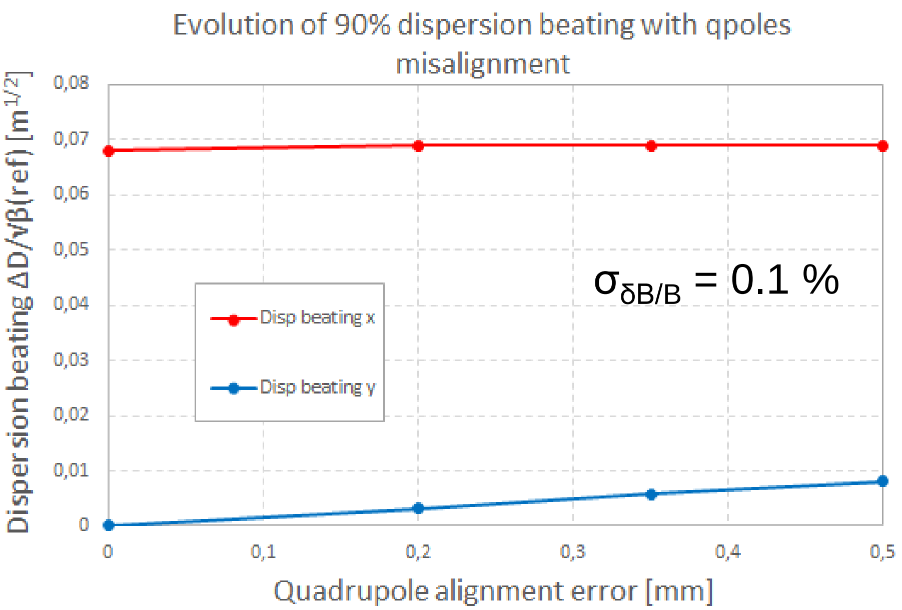
Strong beta-beating in y plane, even without quadrupole errors
=> sextupole contributions

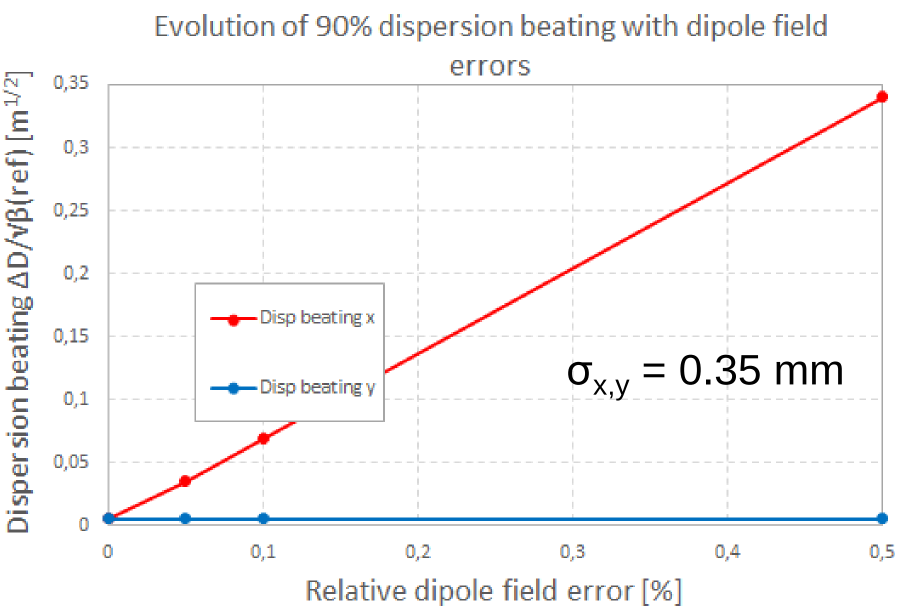
Strong beat-beating in y plane

$\Delta\beta y/\beta y > 10\%$ for $\sigma_{\delta B/B} = 0.5$ %

Beta-beating @ 0.35 mm, 0.1 % (90-percentile)
$\Delta\beta_x/\beta_x = 1.2$ %
$\Delta\beta_y/\beta_y = 7.0$ %

DISPERSION BEATING





Constant in x plane, strong
Small dependency in y plane

Strong dependency in x plane
Constant in y plane

Dispersion beating @ 0.35 mm, 0.1 % (90-percentile)

$\Delta D_x/\sqrt{\beta_x} = 6.9\text{x}10^{-2}\ m^{1/2}$

$\Delta D_y/\sqrt{\beta_y} = 5.7\text{x}10^{-3}\ m^{1/2}$

CONCLUSIONS AND PERSPECTIVES

- Corrections of the closed orbit have been performed for all arcs of the FCC ring with various sets of errors
- For a configuration with 0.35 mm quadrupoles alignment errors and dipole relative field errors of 0.1% the correctors have an integrated strength up to +/- 3.6 Tm @ 90-percentile level
- The case of quadrupole errors above 0.4 mm or dipole errors of 0.5 % would require a new technology
- To be done:
  - Include additional error contributions (BPM read error, roll angle plus field error in the dipoles)
  - Test more errors combinations (different x and y for quadrupoles)
  - Test 'clustering' of errors (as the alignment of a group of magnets is done in real world)
  - Use a different correction scheme (remove 1/n correctors/BPMs, integrate IR region?)
  - Comparison with LHC scheme