FROM RESEARCH TO INDUSTRY

STATUS OF THE CORRECTION SCHEMES IN THE ARCS

- Reminder from Berlin
- Errors definition and correction schemes
- Evaluation of the results
- Conclusions and perspectives

The European Circular Energy-Frontier Collider Study (EuroCirCol) project has received funding from the European Union's Horizon 2020 research and innovation programme under grant No 654305. The information herein only reflects the views of its authors and the European Commission is not responsible for any use that may be made of the information.

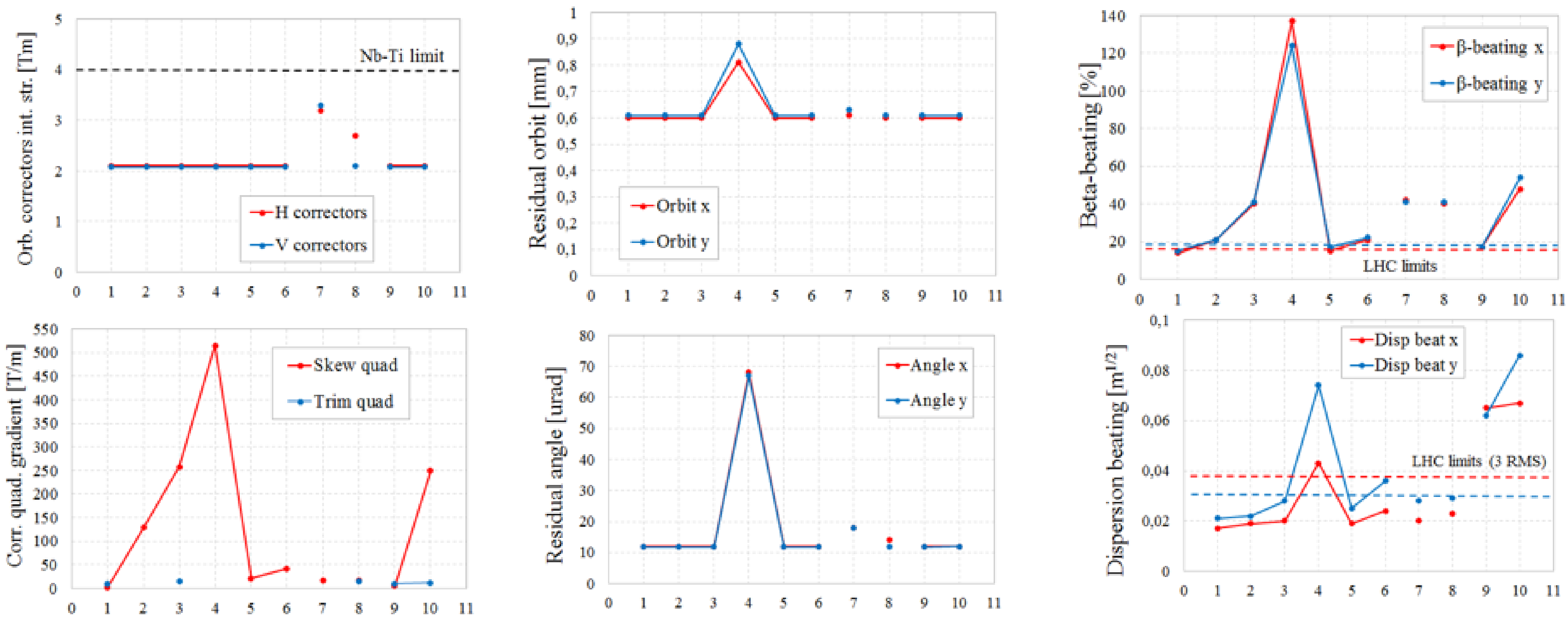
EuroCirCol A key to New Physics

David Boutin, Antoine Chance, Barbara Dalena

09 OCTOBER 2017

MAIN RESULTS DISCUSSED AT FCC WEEK 2017

- Improved correction schemes of the linear coupling and the ring tunes were implemented
- Skew quadrupoles corrector strengths were too high if a2(u) > 0.55
- Increased tolerances on the quadrupole alignment error and the dipole b1 error gave reasonable strengths for the orbit correctors
- Collision optics had higher beta and dispersion beating than injection (orbit optimization bug)



ERRORS DEFINITION

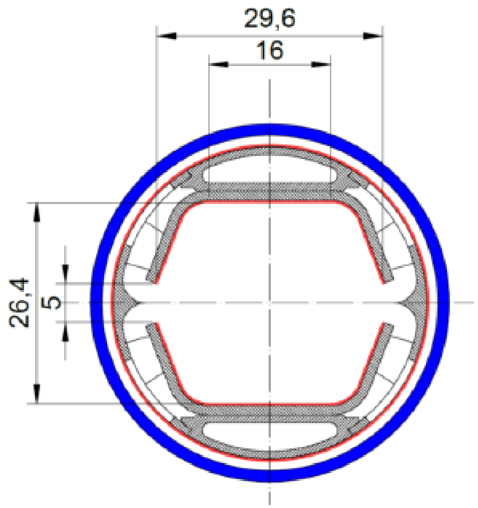
- Errors defined for main dipoles, main quadrupoles and for BPMs used in arcs and DIS sections
- Errors are Gaussian distributed, truncated at 3-σ values, with a different seed for each run
- No errors defined in the straight sections (insertions) unless specified
- Study of the variation of dipole a2 and quadrupole alignment tolerances, with 100 machines simulated for each case of study

Element	Error	Error desc.	Units	FCC	LHC	Comments
Dipôle	σ(x),σ(y)		mm	0.5	0.5	no effect on observables
	σ(ψ)	roll angle	mrad	0.5	n/a	effect in vertical plane
	σ(δB/B)	random b1	%	0.1	0.08	LHC value includes σ(ψ)
	σ(δB/B)	random a2	10-4 units	**1.1**	1.6	
	σ(δB/B)	uncert. a2	10-4 units	**1.1**	0.5	
Quad	σ(x),σ(y)		mm	**0.36**	0.36	
	σ(ψ)	roll angle	mrad	1	0.5	
	σ(δB/B)	random b2	%	0.1	0.3	
BPM	σ(x),σ(y)		mm	0.3	0.24	value relative to quad
	σ(read)		mm	0.2	0.5	accuracy

Reference values of the LHC design taken from LHC Project Report 501/370

IMPACT OF THE ERRORS ON THE BEAM SCREEN

C. Garion



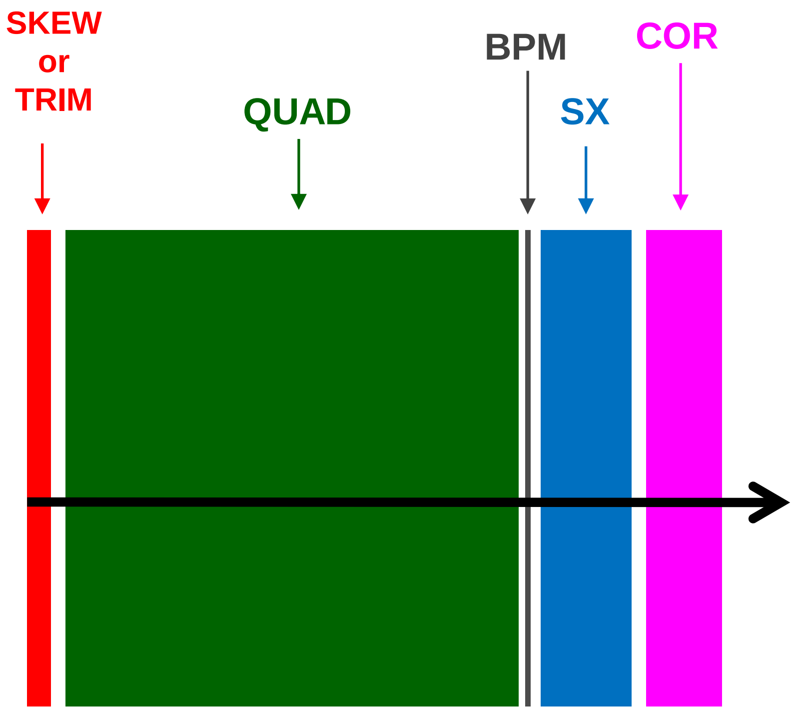
ϵ_N	2.2	μm
$\delta p/p$	6	10^{-4}
β-beating coefficient	1.05	-
Closed orbit uncertainty	2	mm
Fractional H/V parasitic dispersion	0.14	-
Peak linear dispersion	2.358	m
β_x in standard qf	355.13	m
Halo parameters	{6,6,6,6}	-

- The synchrotron radiation is evacuated through an aperture in the horizontal plane of the arc dipole chamber (total gap 5 mm as presented in FCC Week)
- The maximum drift a photon can travel in the arc sections before hitting the chamber walls is estimated to 11 m
- Position and angle misalignment of the beam can affect the evacuation efficiency, leading to heating, desorption and performances losses

CORRECTION SCHEMES OF THE ARC SECTIONS

- Optics studied at injection (3.3 TeV, β* = 4.6 m), another optics at collision (50 TeV, β* = 0.3 m) gives similar results

- All main quadrupoles units of the arc sections and DIS have a BPM and an orbit corrector included next to the quadrupole. Quadrupoles correctors ('skew' or 'trim') can also be inserted before the quadrupole unit.



- The correction is performed with the MADX code, following an iterative procedure:

  1/ analytic correction of the linear coupling
  2/ orbit correction
  3/ tune correction

- The errors are evaluated in the following only for the arc sections and any insertion added to the global correction scheme

- Most of the quadrupolar correctors in the short arc sections are reserved for the spurious dispersion correction

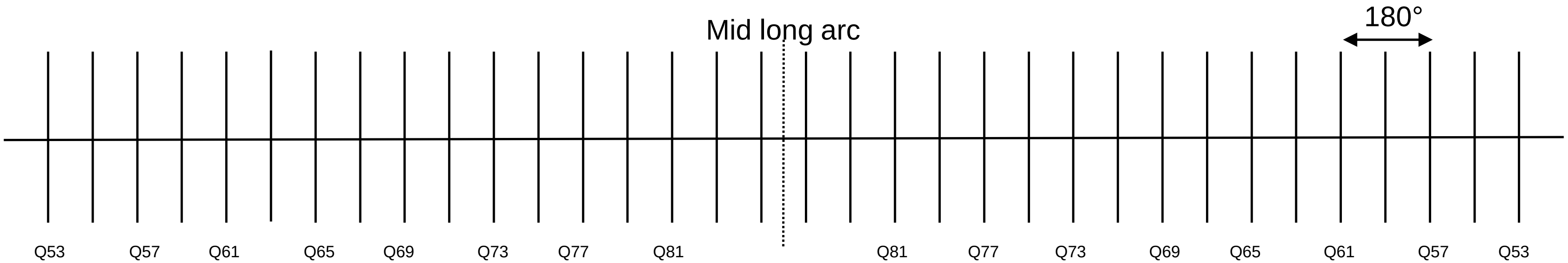
CORRECTION OF THE LINEAR COUPLING

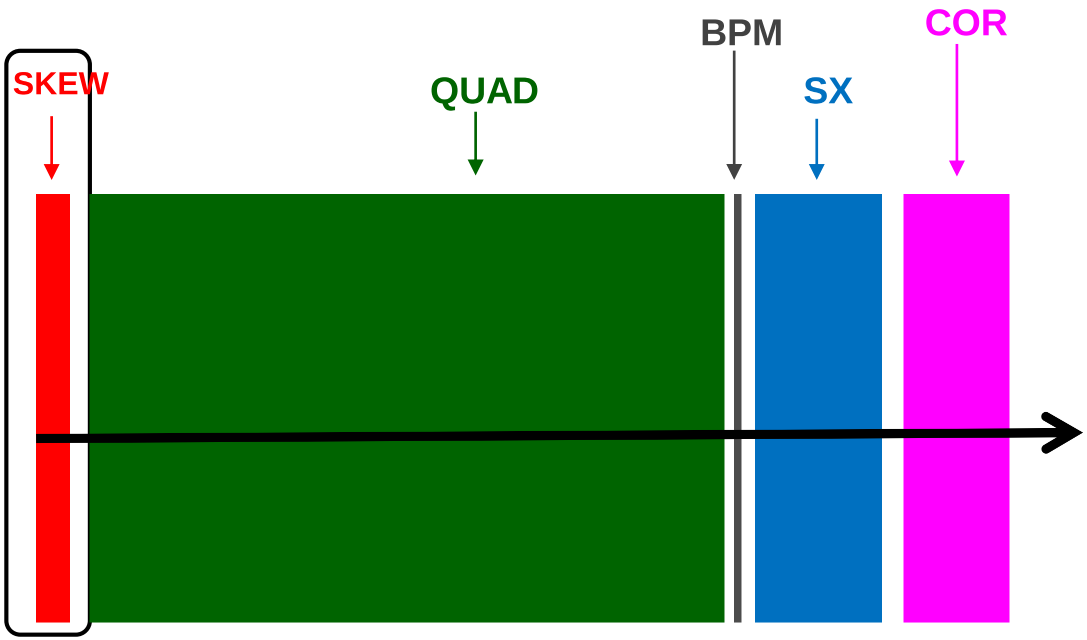
- Analytic calculation of the contribution of each magnet of the arc sections to the coupling:

$$\Delta c_-^i = \frac{1}{2\pi}\cdot\int_L ds\sqrt{\beta_x\beta_y}\cdot k_s\cdot e^{i(\mu_x-\mu_y)}$$

extract of LHC Project Report 399

- The main contribution is the a2 multipolar coefficient of the dipoles

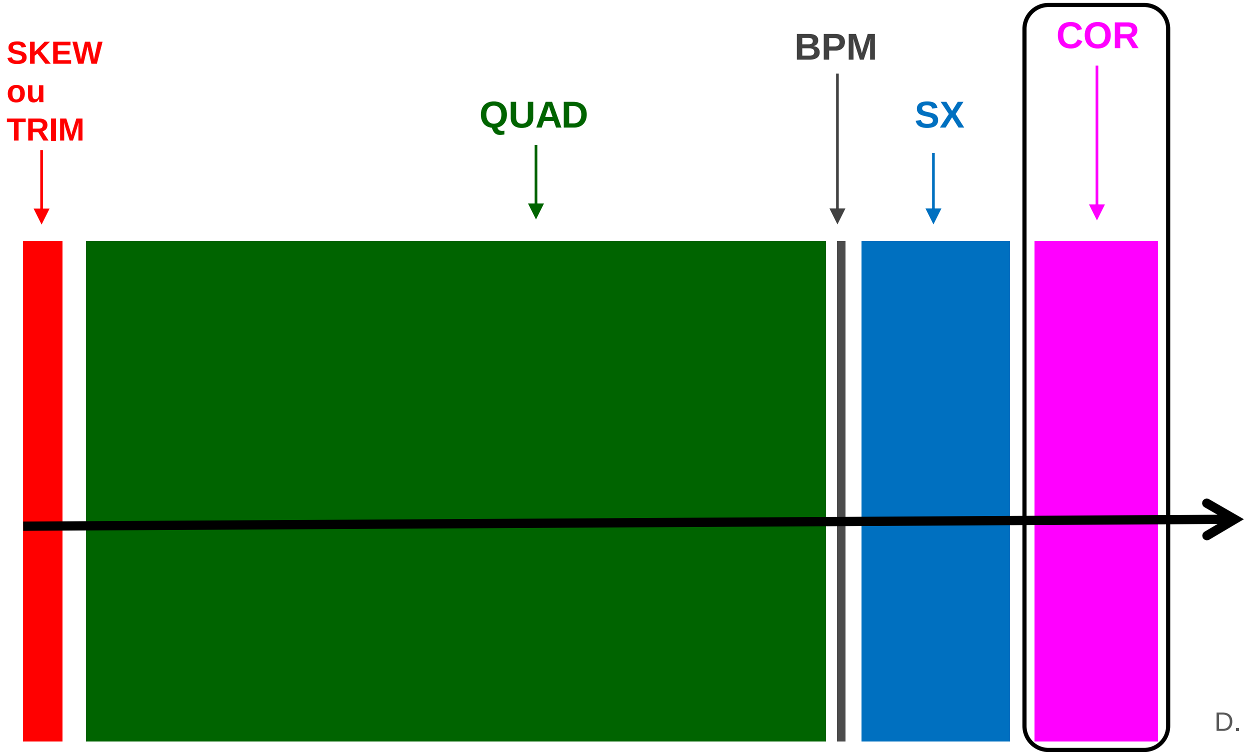




Correction applied to groups of 8 skew quadrupoles (L = 0.32 m, estimated gradient about 200 T/m) around the middle of each long arc

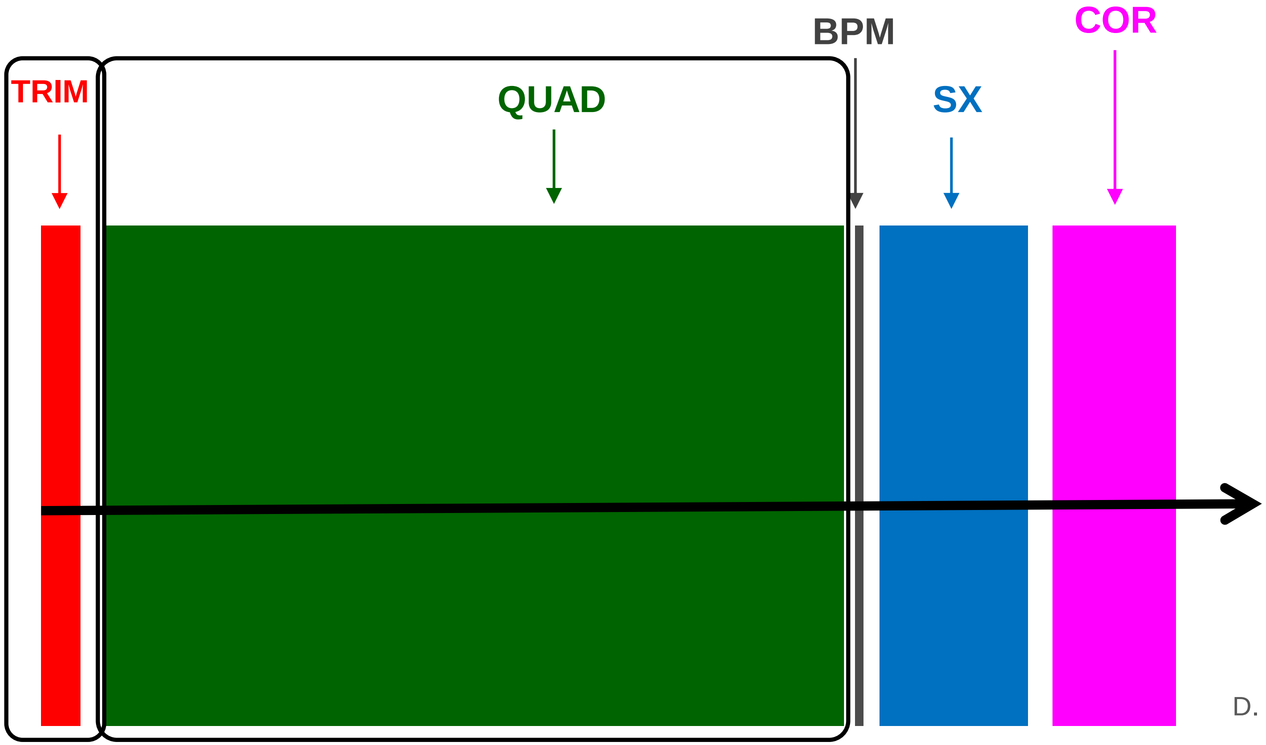
ORBIT CORRECTION

- Performed with dipolar correctors, L = 1 m, max integrated strength = 4 Tm, Nb-Ti technology
- Global correction of the residual orbit measured by BPMs (horizontal or vertical plane)
- Same number of BPMs (parameters) and orbit correctors (variables) in each plane
- In the global correction scheme, each orbit corrector is correlated with the BPM located on the 2nd next quadrupole (phase advance of 90°)



TUNE CORRECTION

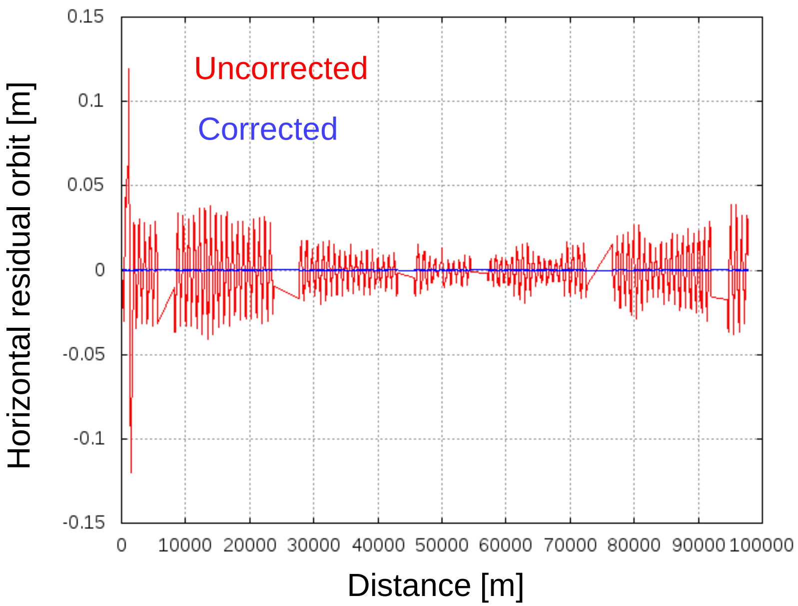
- Performed with quadrupolar correctors (L = 0.32 m, maximum gradient 200 T/m, Nb-Ti technology) or with main quadrupoles (L = 6 m, maximum gradient 400 T/m, Nb-Ti technology)
- Correction of the horizontal (Q1) et vertical (Q2) tunes
- The quadrupolar correctors present at the beginning and end of long arc sections are employed
- Since the results are similar with both methods of correction, the main quadrupoles are used in the following

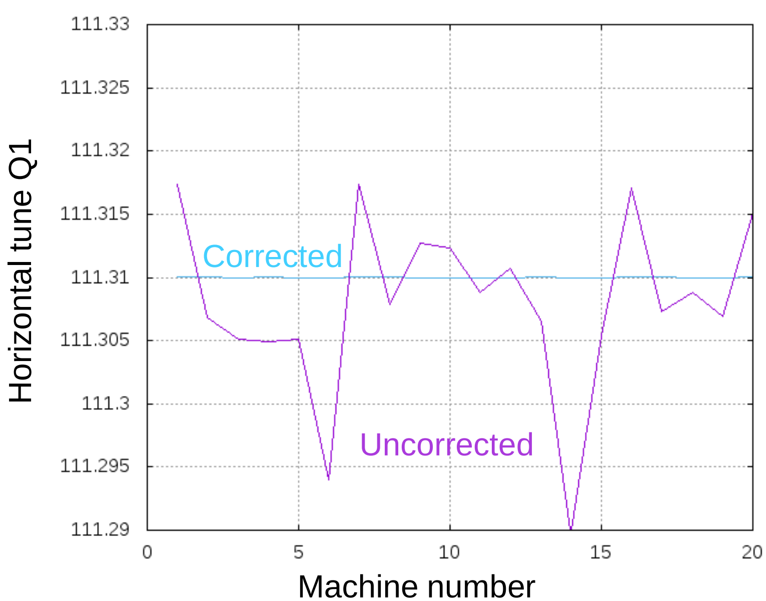


EVALUATION OF THE RESULTS

- For each machine, calculation of the mean, RMS and maximum values of the following observables for each relevant magnet of the arc sections:
  - **Corrector strengths**
  - Residual **orbit and angle**
  - Beta-beating $\mathbf{\Delta\beta/\beta_{ref}}$
  - Parasitic dispersion or dispersion beating $\mathbf{\Delta D/\sqrt{\beta_{ref}}}$
- → see LHC Project Report 501 for more details

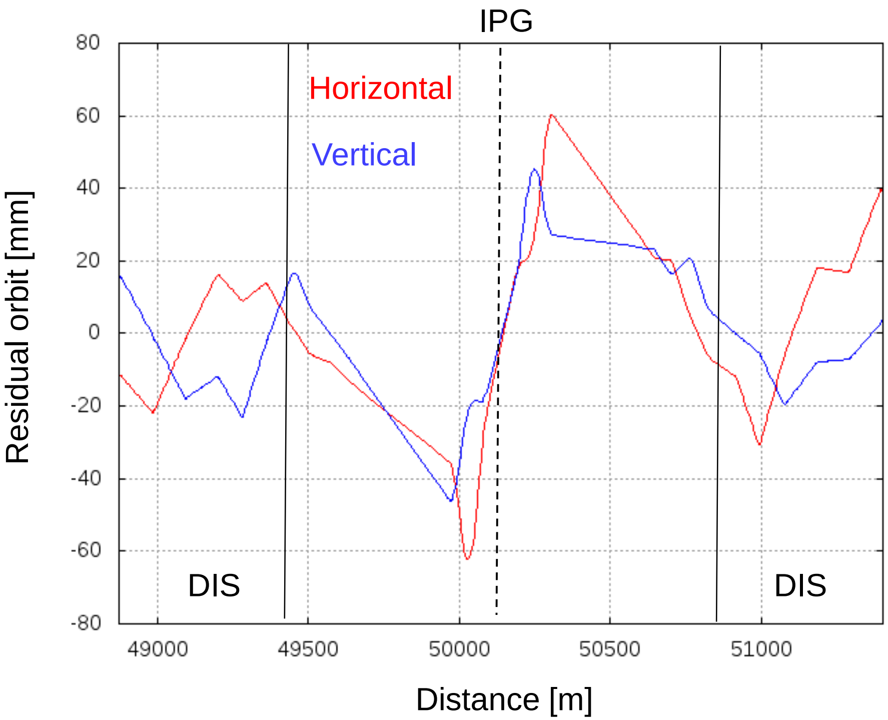
- From the maximum values distribution the 90-percentile (value for which 90% of the values of a given distribution are included) is calculated over all machines

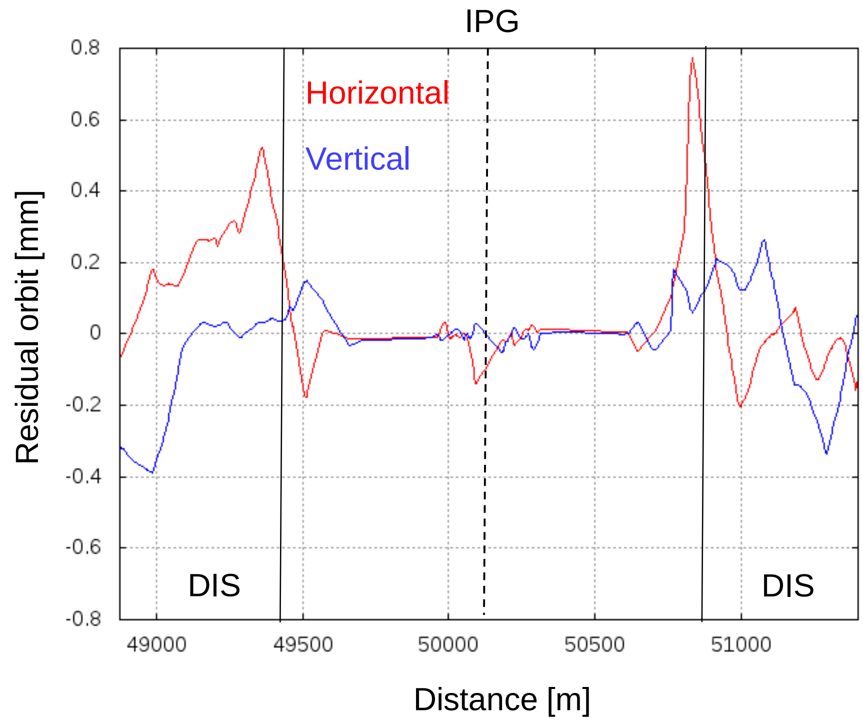




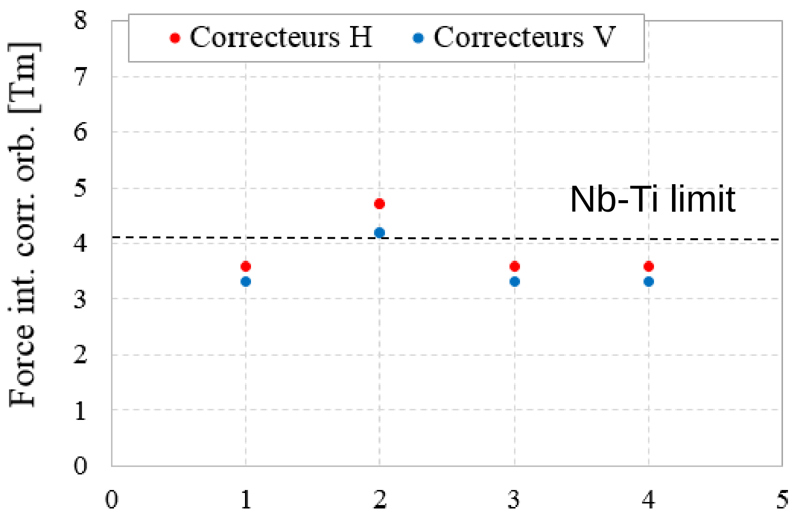
IMPLEMENTATION OF THE INTERACTION REGION

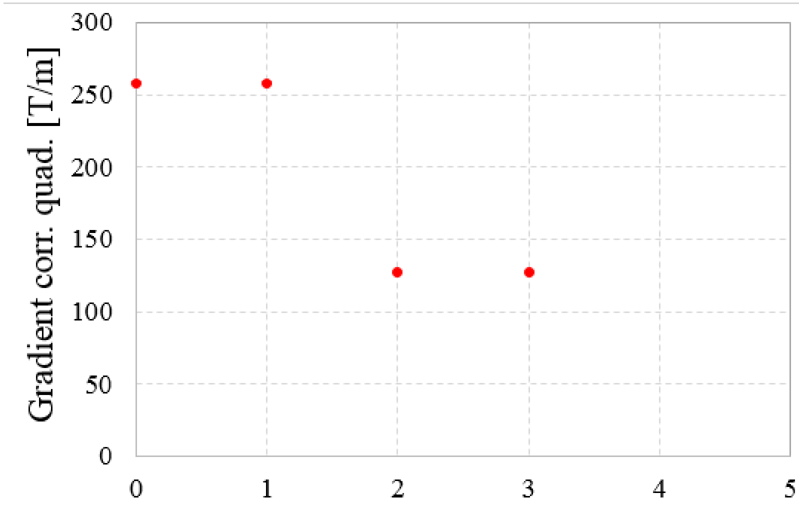
- The latest IR optics V7 are included
- Correction scheme taken from IR orbit correction (E. Cruz)
- Errors implemented for the IR elements are the quadrupole alignment errors (0.5 mm) and the dipole roll angle (2 mrad)





CORRECTOR STRENGTHS





The strengths are normalized to collision rigidity

<u>Cases of study</u>

1/ reference errors (p.3)

2/ σ(x/y) = 0.36 → 0.50 mm for quadrupoles

3/ dip a2(u) = 1.1 → 0.55

4/ dip a2(u) = 1.1 → 0.55, a2(r) = 1.1 → 2.2

σ(x/y) = 0.50 mm not compatible with Nb-Ti technology for orbit correctors

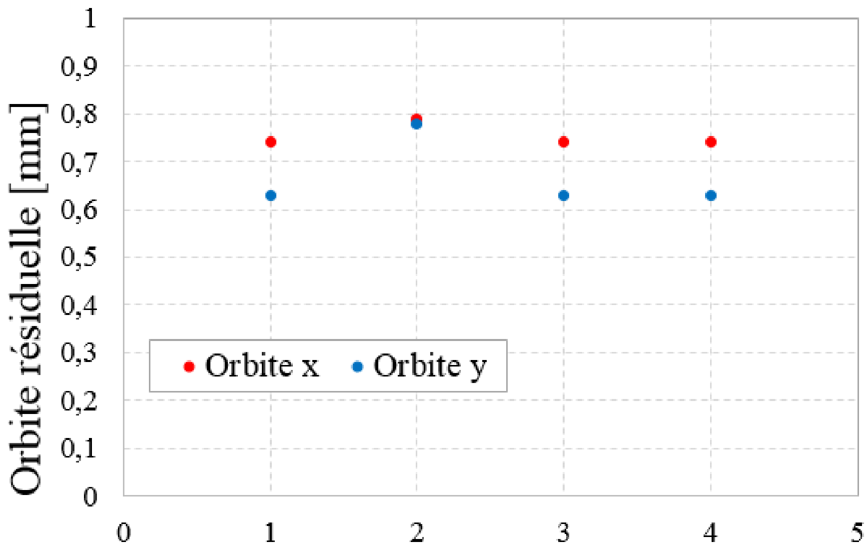
One can estimate the tolerance limit to around 0.4 mm

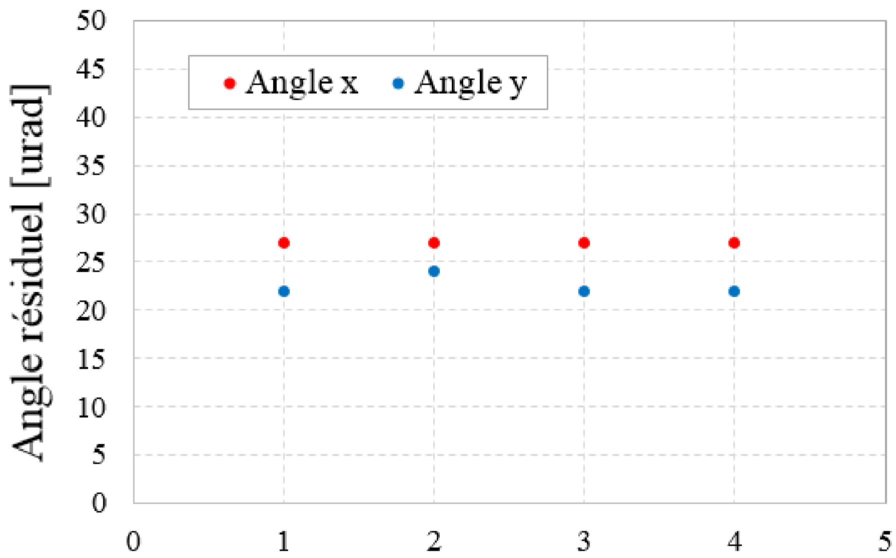
The IR orbit correctors are not included in the analysis

Skew quadrupoles are above 200 T/m in cases 1 and 2 (table V0/V2 values)

The tolerance on a2(u) should not be increased further (table V1 value)

RESIDUAL ORBIT AND ANGLE





<u>Cases of study</u>

1/ reference errors (p.3)

2/ σ(x/y) = 0.36 → 0.50 mm for quadrupoles

3/ dip a2(u) = 1.1 → 0.55

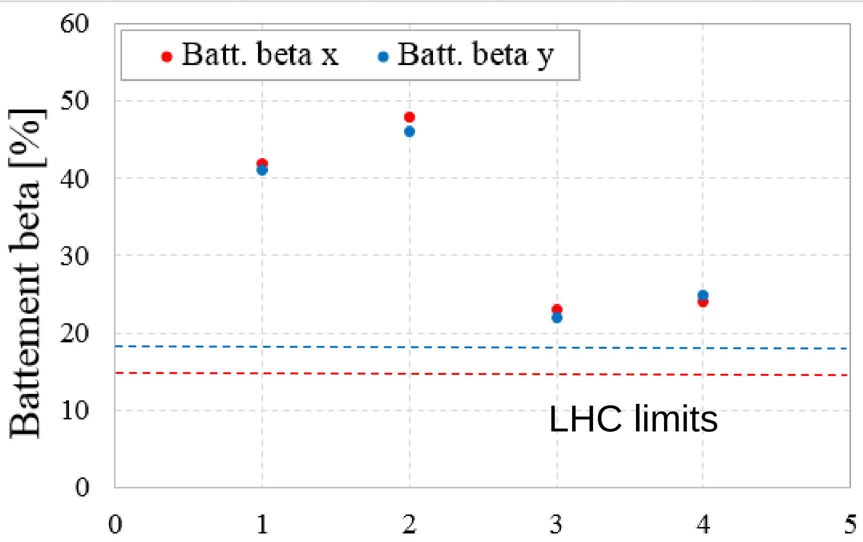
4/ dip a2(u) = 1.1 → 0.55, a2(r) = 1.1 → 2.2

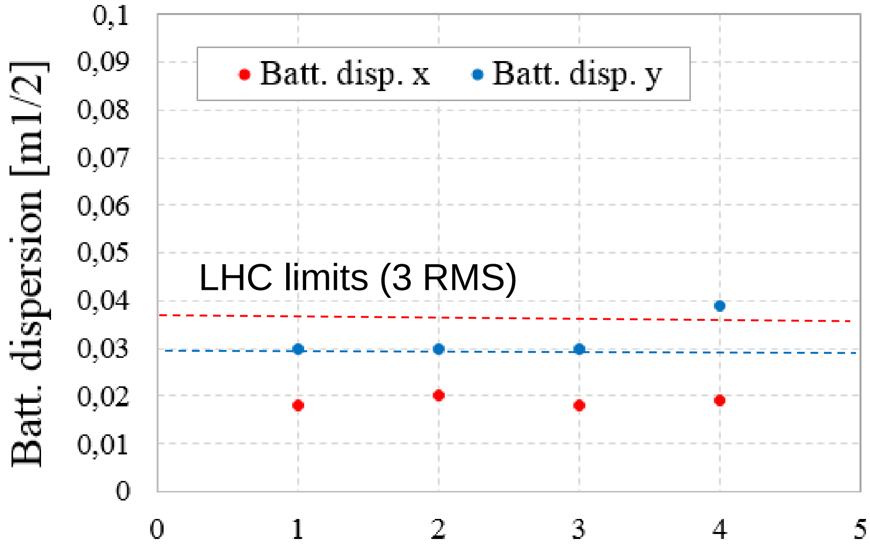
All cases have a residual orbit < 1 mm, compatible with the geometry of the dipole chamber (5 mm aperture)

Residual orbit values driven by IRs, below 0.7 mm in the arcs sections

The combined contributions of a vertical residual angle of 25 µrad and of the emission cone of photons (19 µrad) contribute to a total vertical offset of +/- 1 mm after a drift of 11 m for case 2

BETA AND DISPERSION BEATING





<u>Cases of study</u>
1/ reference errors (p.3)
2/ σ(x/y) = 0.36 → 0.50 mm for quadrupoles
3/ dip a2(u) = 1.1 → 0.55
4/ dip a2(u) = 1.1 → 0.55, a2(r) = 1.1 → 2.2

Beta-beating way too strong with a2(u) = 1.1 (cases 1 and 2)

Reducing a2(u) leads to values close to LHC limits

Beta-beating values driven by long arc sections

Dispersion beating too strong for case 4

CONCLUSIONS AND PERSPECTIVES

- A global correction scheme of the residual orbit, the linear coupling and the ring tunes for the arc section of FCC-hh has been updated with the newest optics

- The residual orbit and angle are compatible with the aperture considered for the synchrotron radiation evacuation

- Beta-beating is too high with the a2(u) value given in tables V0/V2

- At this stage of study trim quadrupoles are not used

- The reference tolerances on quadrupole alignment and on dipole b1 give reasonable orbit correctors strengths, a quadrupole misalignment of 0.5 mm can be excluded

- The IRs contribute to the residual orbit only

- Perspectives:
  - Continue the integration of the insertion regions (collimation, etc)
  - Add other systematic errors (dipole b2, alignment)
  - Discussions are ongoing to finalize the dimensioning of correctors and their occupation