

# Considerations on tolerance studies for FCC-ee

Sandra Aumon, CERN, Geneva  
for the FCC-ee study group  
Thanks to Yannis and Javier

# Content

---



- Motivations
- Optics at the Interaction region
- Current strategy for alignment tolerance studies
- Results at 45 GeV
- Results at 120 GeV
- Results at 175 GeV
- Conclusions – Next steps

# Motivations



	Z	W	H	tt
Beam energy [GeV]	45.5	80	120	175
Beam current [mA]	1450	152	30	6.6
Bunches / beam	16700	4490	1330	160
Bunch population [ $10^{11}$ ]	1.8	0.7	0.46	0.83
<b>Transverse emittance <math>\epsilon</math></b>				
- Horizontal [nm]	29.2	3.3	0.94	2
- Vertical [nm]	0.06	0.007	0.0019	0.002
Momentum comp. [ $10^{-5}$ ]	18	2	0.5	0.5
<b>Betatron function at IP <math>\beta^*</math></b>				
- Horizontal [mm]	500	500	500	1000
- Vertical [mm]	1	1	1	1
Energy loss / turn [GeV]	0.03	0.33	1.67	7.55
Total RF voltage [GV]	2.5	4	5.5	11

Lattice design for 4 different energies.

Ratio  $\epsilon_y/\epsilon_x = 10^{-3}$

- Small vertical  $\beta^*$
- Strong impact on misalignments errors.
- Challenging chromaticity correction scheme.  
(Bastian Haerer , Anton)

# Motivations - suite



- Introduction of multiple misalignments of various elements (quads, sextupoles, rolls, etc.)

$$y_{co}(s) = \theta_0 G(s, s_0)$$

$$G_0 = \frac{\sqrt{\beta_0 \beta(s)}}{2 \sin(\pi\mu)} \cos(\pi\mu - |\psi(s_0) - \psi(s)|)$$

Orbit distortion due to a misaligned quadrupole  
Max beta-function 5km

- Dispersion and coupling from chromaticity correction can compromise the emittance, in particular the vertical one.

$$\epsilon = \left( \frac{dp}{p} \right)^2 (\gamma D^2 + 2\alpha D D' + \beta D'^2)$$

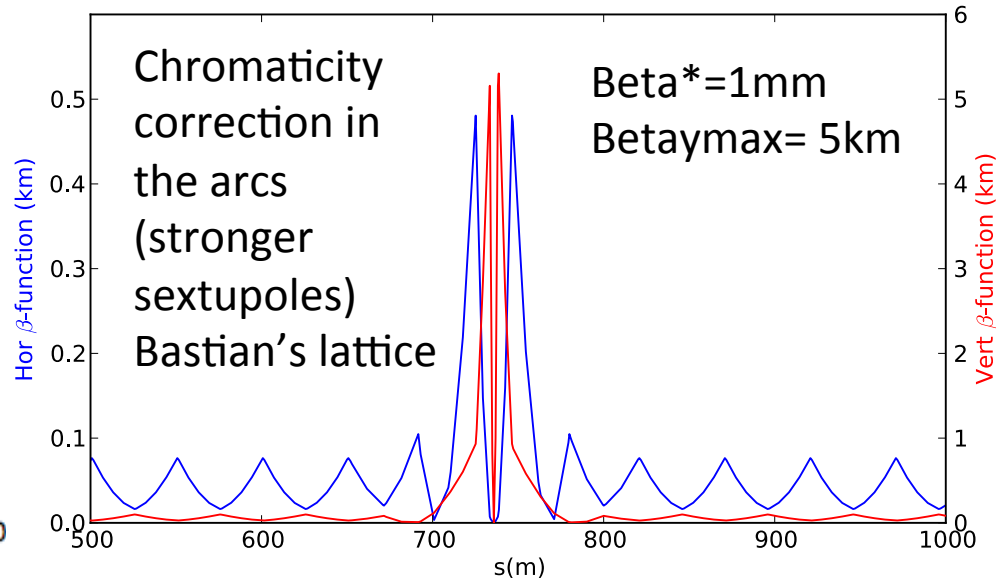
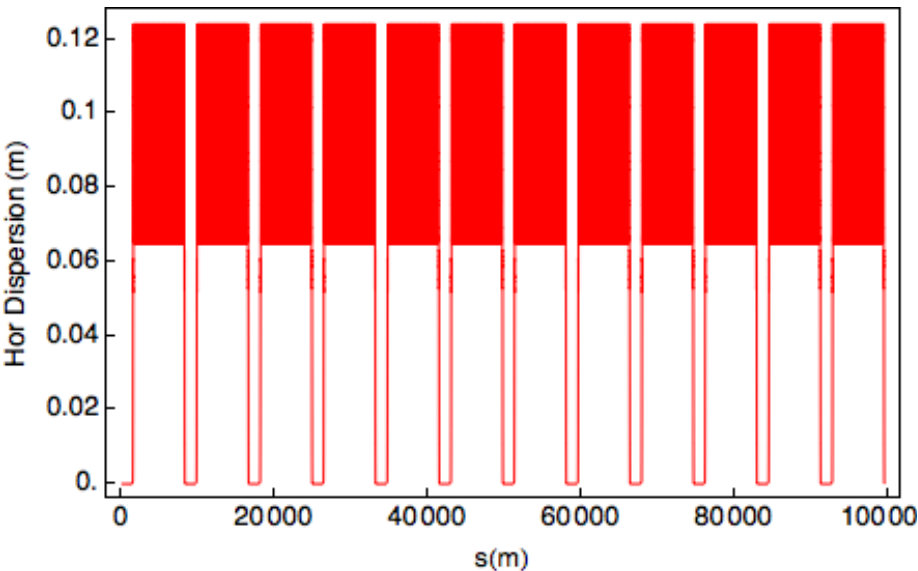
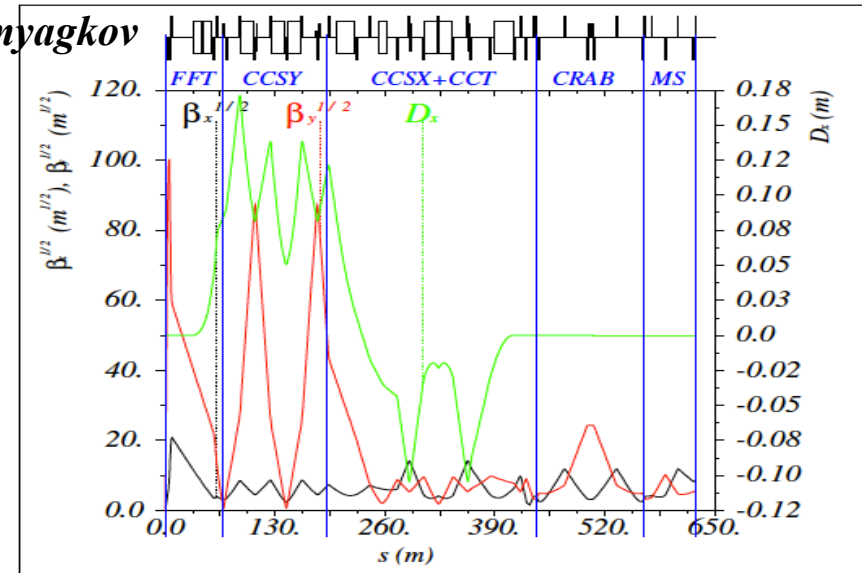
$$\hat{D} = \frac{L_{cell}^2}{\rho} \left( 1 + \frac{1}{2} \sin \left( \frac{\psi_{cell}}{2} \right) \right) / \sin^2 \left( \frac{\psi_{cell}}{2} \right)$$

- Aim: orbit tolerance study and coupling correction scheme to preserve the ratio 1/1000 in emittance.

# Optics at the IR

A.  
Bogomyagkov  
et al

- Optics for 120GeV (H) and 175GeV (ttb)
- From Bastian Haerer's presentation, tuning of the cell length and phase advance to get the correct emittances.
- 2 lattices with 2 scheme of chromaticity correction (in the arc or around the IPs)



# Current strategy



Misalignment all quads  
(150micro or less)

Orbit correction (SVD+Micado)

Chromaticity correction

Switch on the Synchrotron light:  
large sawtooth effect

Emittance ? Orbit ?

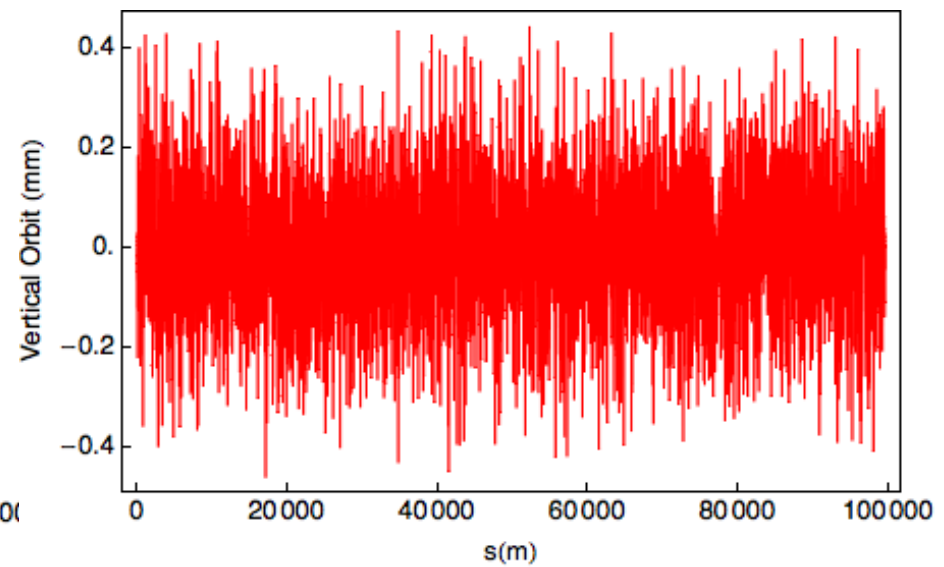
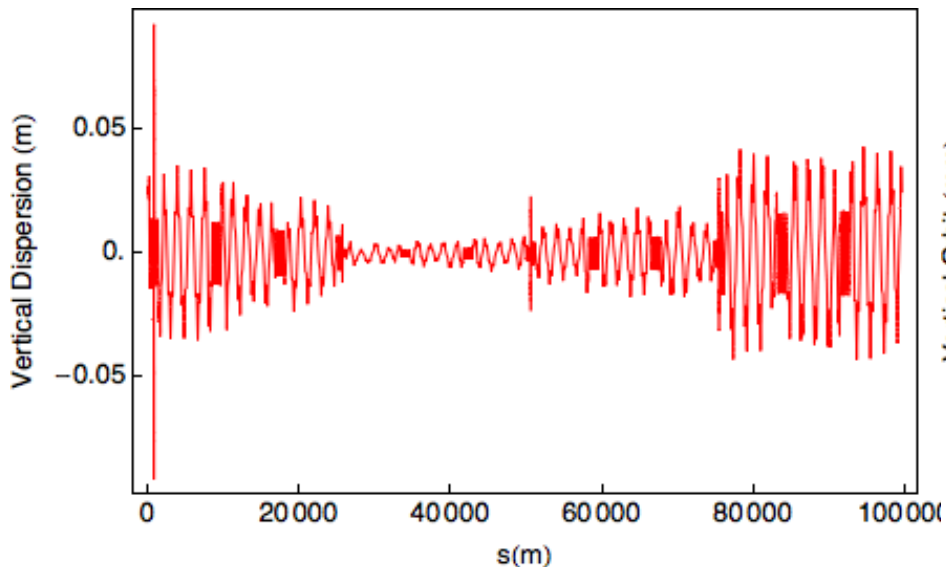
- Tool : MADX (most appropriate ?)  
-> Andreas Doblhammer
- Bastian lattice
- Only quadrupole misalignments at the moment.
- Correction of the linear lattice before switching the radiation.
- Standard misalignment 150 micrometers (Injectors and LHC standard).
- Which max misalignment is acceptable for TLEP for the different energies?

# Results 45GeV

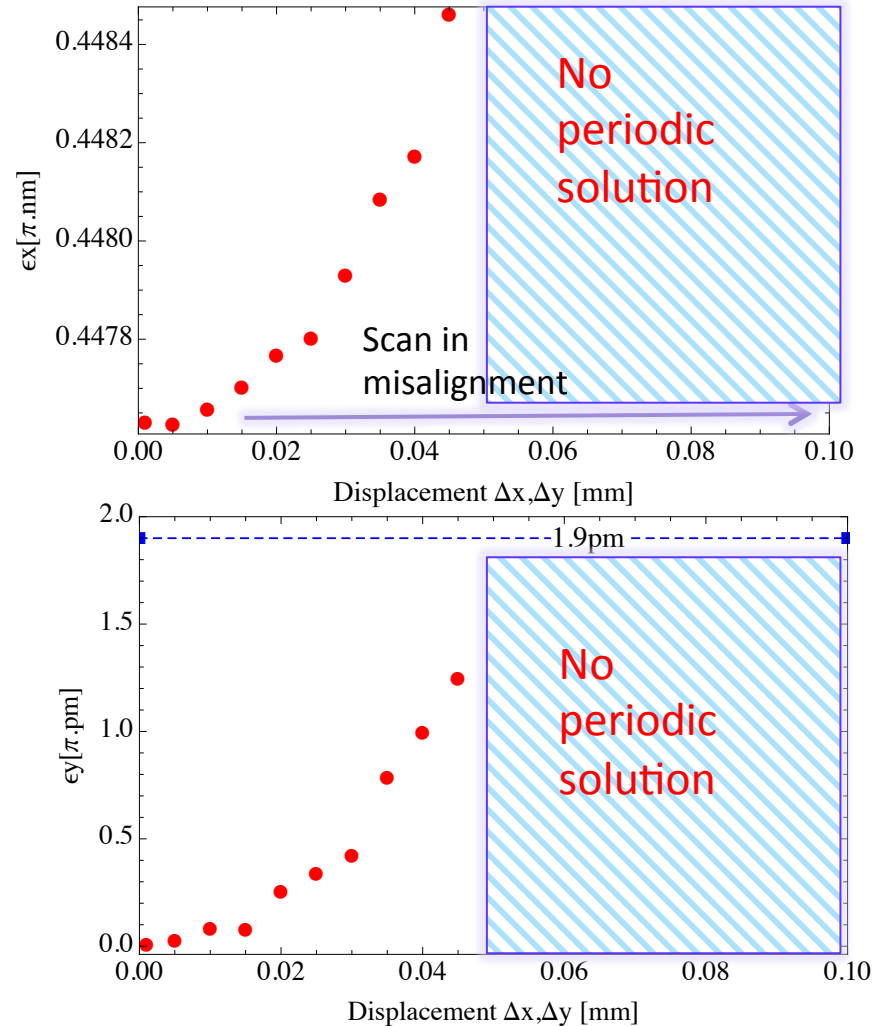


- Bastian's lattice 45 GeV (Chromaticity correction in the arcs) – 300m cell length phase adv=90/60deg.
- Gaussian distribution misalignments 150 micrometers RMS in x/y , quads only.
- FCC-ee baseline emittances: 29.2nm/60pm -> [MADX Emit 14nm/0.4pm](#)

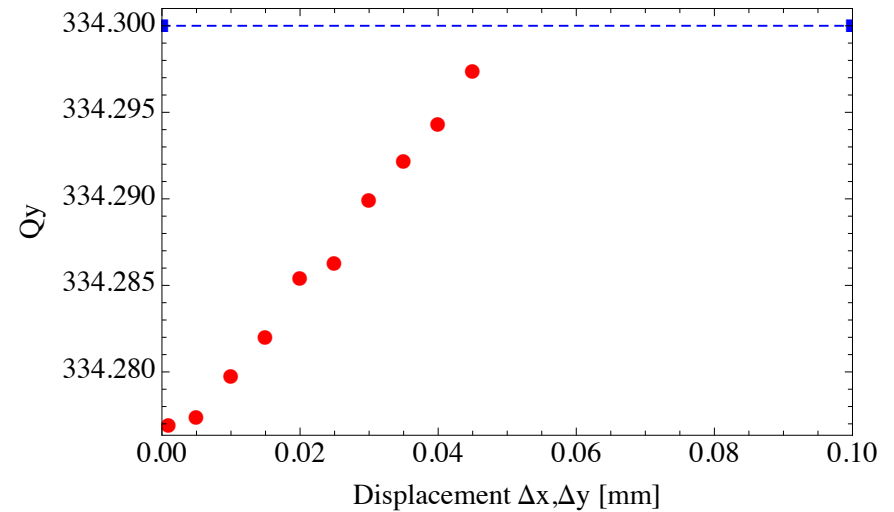
After Orbit Correction – Chromaticity correction and synchrotron radiation



# Results 120GeV

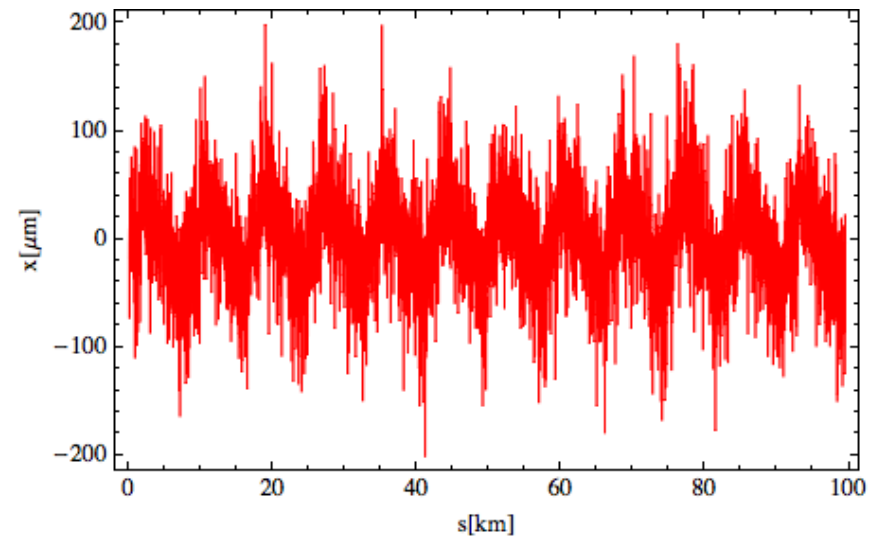
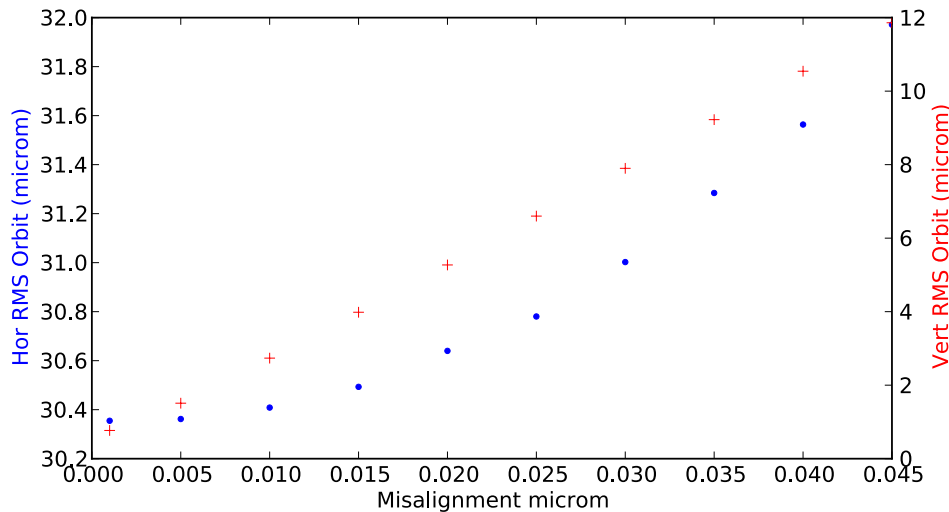
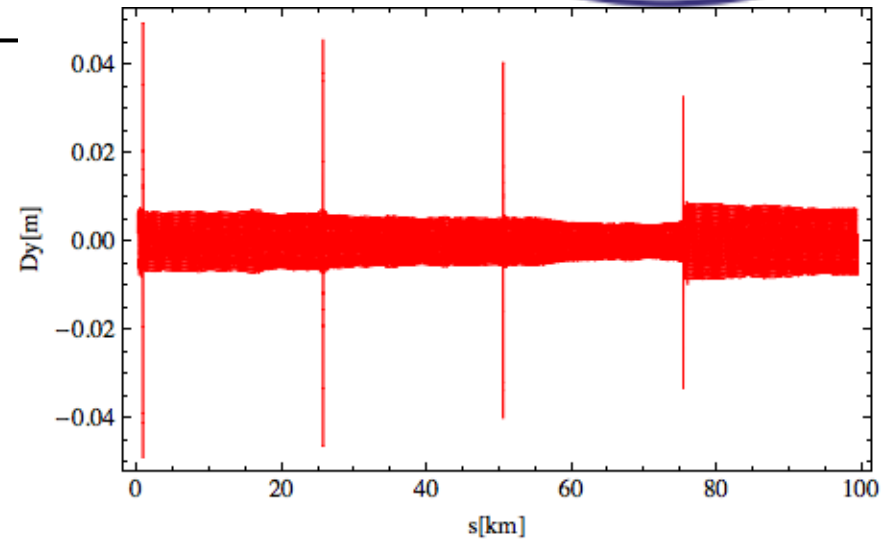


- No periodic solution with synchrotron light for **misalignments > 45micro.m** after orbit and chromaticity correction.
- Strong sextupoles strength.  
**Strong beta-beating, optics spoiled > 200%.**
- Simulations for several SEEDS on going. (10micro.m are already ok.)



# Results 120GeV

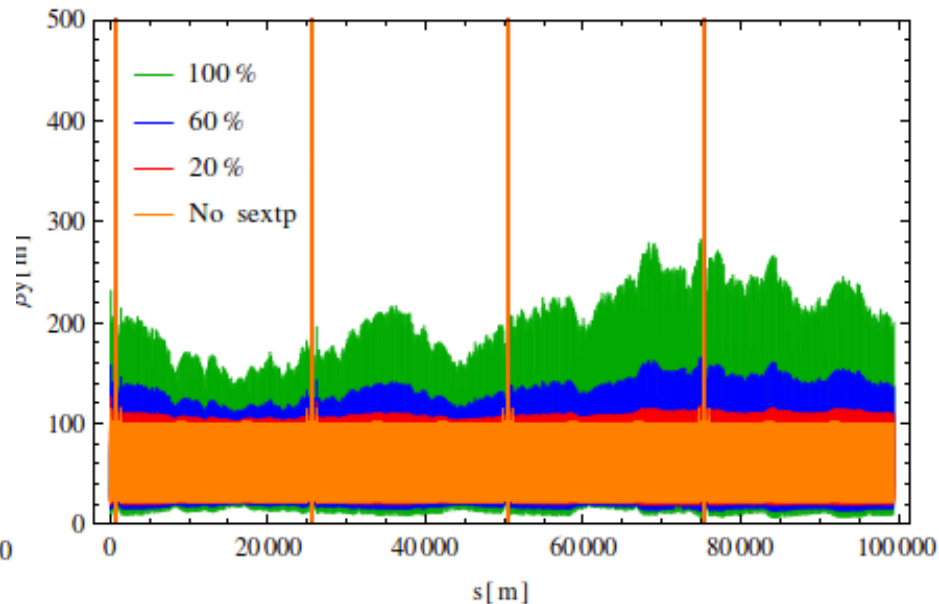
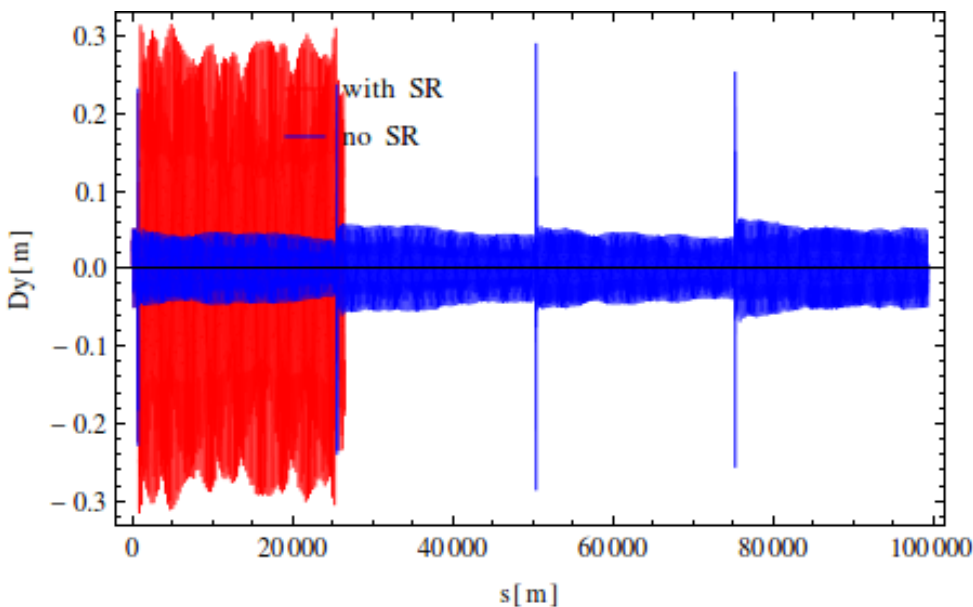
- Large vertical dispersion, here with 45microm misalignment.
- From our DR colleagues: need to correct this vertical dispersion.



# Results for 175GeV



- Very complex case: no closed orbit found for any misalignment (1 SEED) with SR. Even as a line, TWISS failed.
- Strong beta-beating already before switching the synchrotron light (200%)
- Strong sextupole field (2 order of magn. LEP)+large vertical dispersion, coupling
- **Next steps: correction of the dispersion function with skews, correction beta-beating, starting from low misalignments and larger beta\***



# Conclusions – Next steps

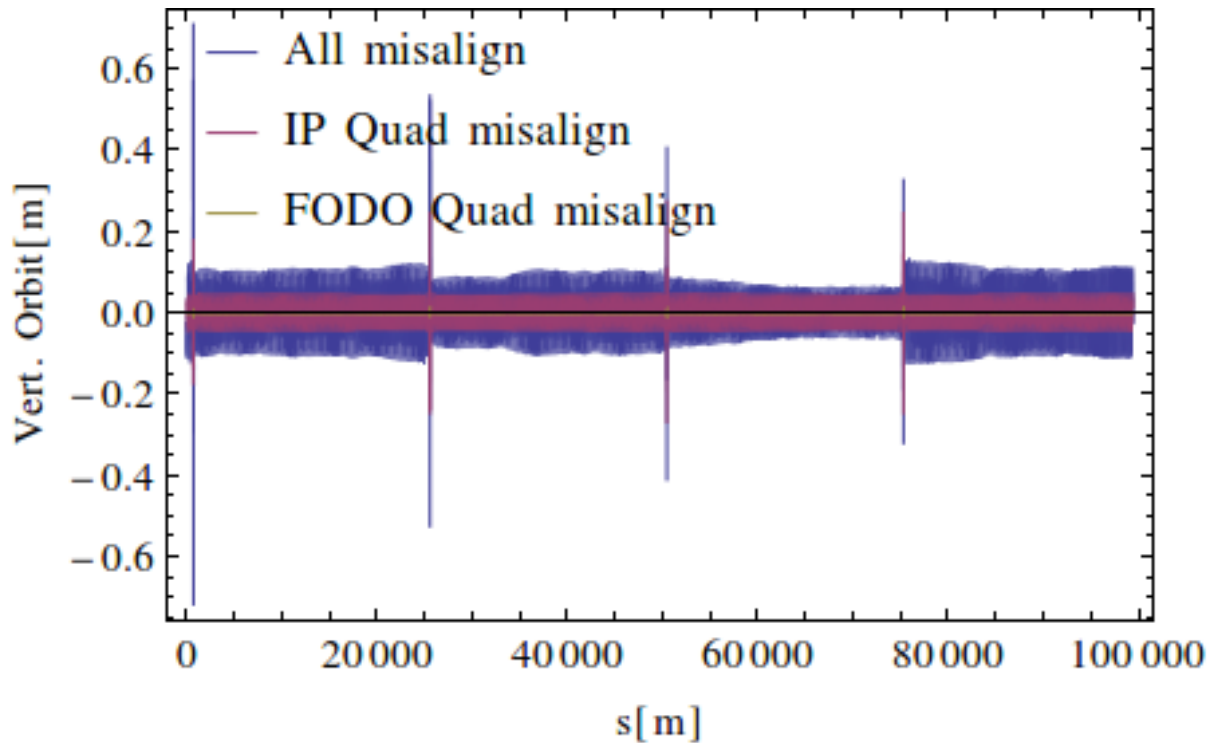
---



- 120/175GeV are the most problematic energies. (beta-beating, large vertical dispersion)
- *Include in the process, vertical dispersion/coupling correction with skew quadrupoles, and tunes matching in an iterative way starting from larger beta\*, low misalignments.*
- **Problem: re-matching of 100km machine means having separate power supplies for the different quads etc..**
- Is MADX the most appropriate tool ? (Synchrotron radiation)
- Alternative lattice with local chromaticity correction at the IR (Anton Bogomyagkov) at 45GeV.
- 45GeV/120GeV more SEEDs.

# Influence quadrupoles of IPs

---



# Sawtooth effect

Larger dispersion  
@ 45GeV (6m)

Dispersion  
12cm

