Optics Correction and Emittance Performance for FCC-ee at 175 GeV

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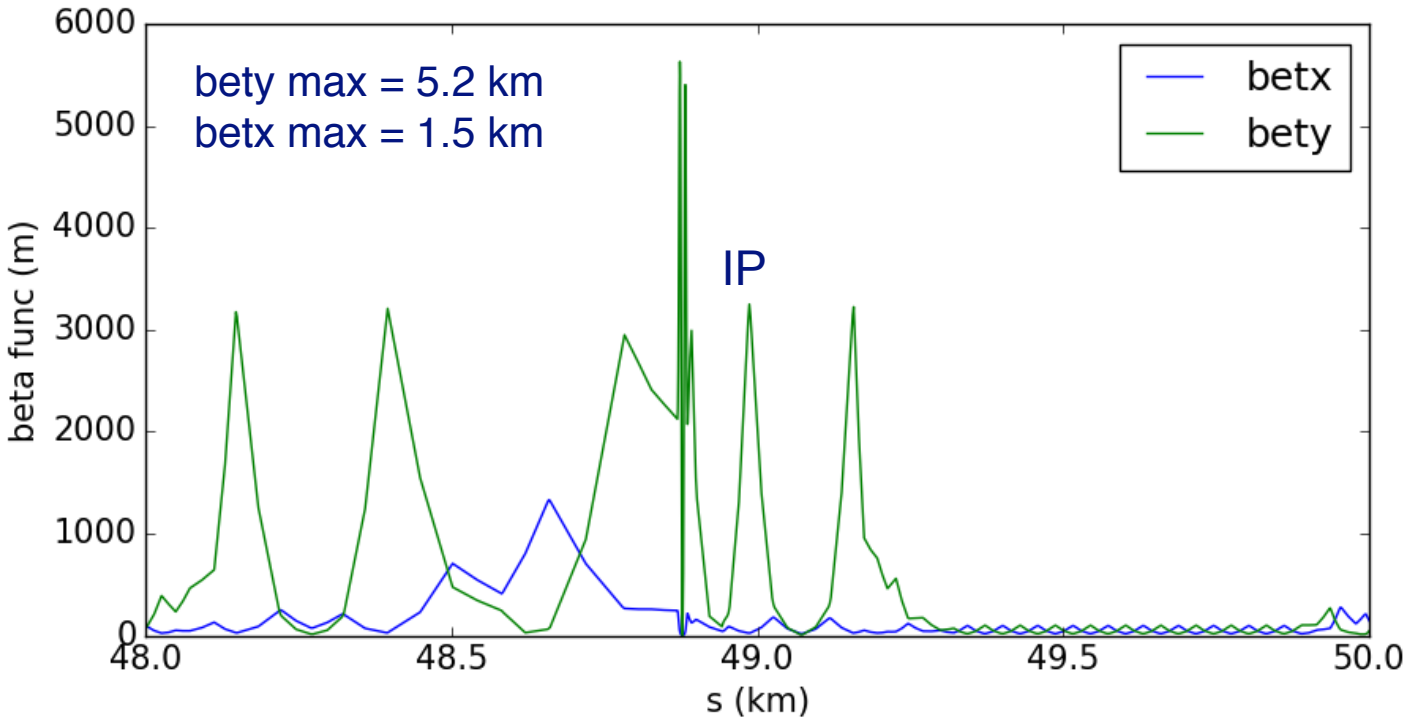
Presented by Tessa Charles

Acknowledgements to Bernhard Holzer, Katsunobu Oide, Bastian Haerer, Tobias Tydecks

Challenges & constraints for FCCee emittance tuning

Small beta* values implies large beta max



Small beta* functions:

- make lattice sensitive towards FF misalignments
- require strong sextupoles

Large emittance ratio, $\varepsilon_y/\varepsilon_x$ = 0.201 %

Vertical dispersion & betatron coupling dominate ε_y growth

- Horizontal emittance:

$$\epsilon_x = \frac{C_g}{J_x}\gamma^2\theta^3 F \qquad F_{FODO} = \frac{1}{2\sin\psi}\frac{5+3\cos\psi}{1-\cos\psi}\frac{L}{l_B}$$

L: cell length
l_B: dipole length
ψ : phase advance/cell

- Vertical emittance:

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

- Sources of vertical emittance growth:
  - vertical dispersion Dy
  - betatron coupling
  - opening angle ~ $1/\gamma$ (here negligible)

Correction methods used:

- **Orbit correction:**
  - MICADO & SVD from MADX
    → Hor. corrector at each QF, Vert. corrector at each QD
    1600 vertical correctors
    1590 horizontal correctors
    → BPM at each quadrupole
    1600 BPMs vertical / 1590 BPMs horizontal

- **Vertical dispersion and orbit:**
  - Orbit Dispersion Free Steering (DFS)

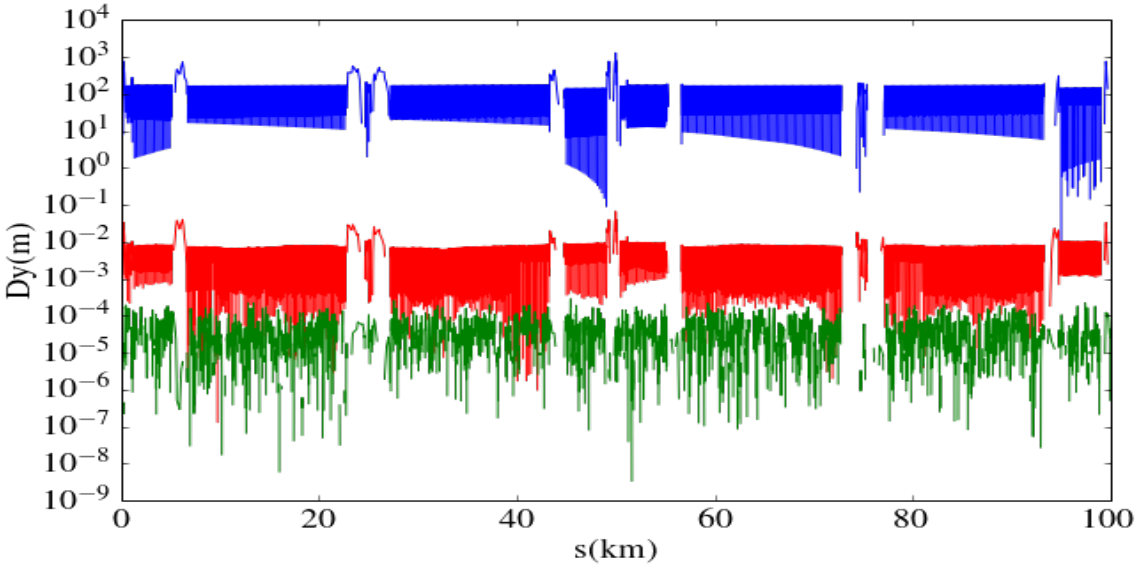
- **Linear coupling:**
  - Linear Coupling resonant driving terms (RDT)
    → 1 skew at each sextupole + skews correctors at the IP

- **Beta beating correction & Horizontal dispersion via Response Matrix:**
  - Rematching of the phase advance at the BPMs
    → 1 trim quadrupole at each sextupole

$$(\Delta\phi_{xy}, \Delta D_x, \Delta Q_x, \Delta Q_y) = \mathbf{R}\Delta k_1$$

Correction methods applied to Vertical Quadrupole Misalignments

Sextupoles turned off:



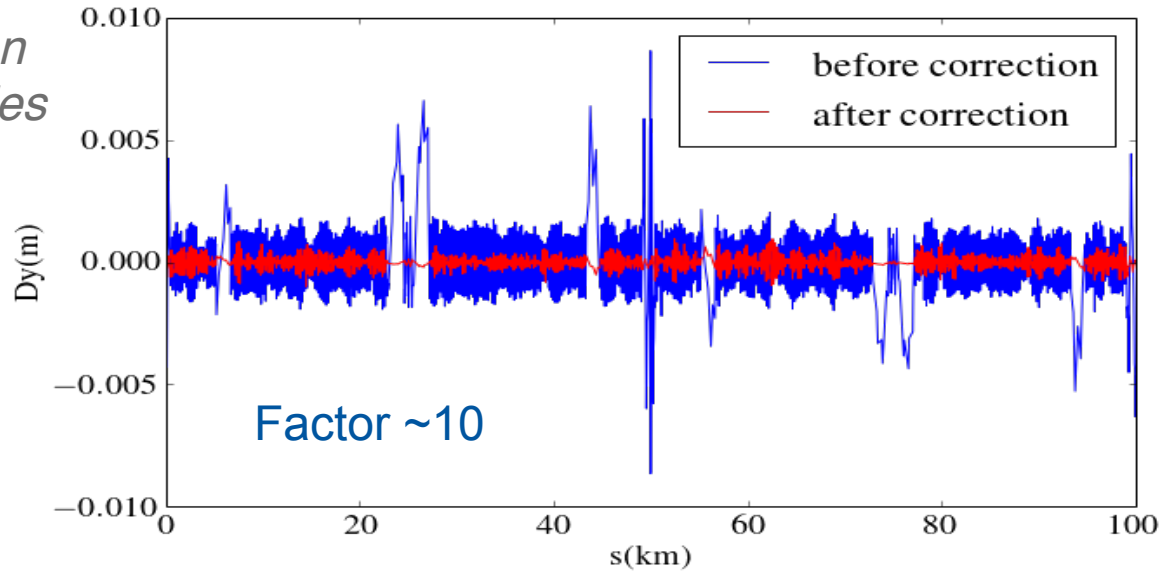
Initial D_y

After CO-correction
factor 2e4 improvement

DFS
factor 50 improvement

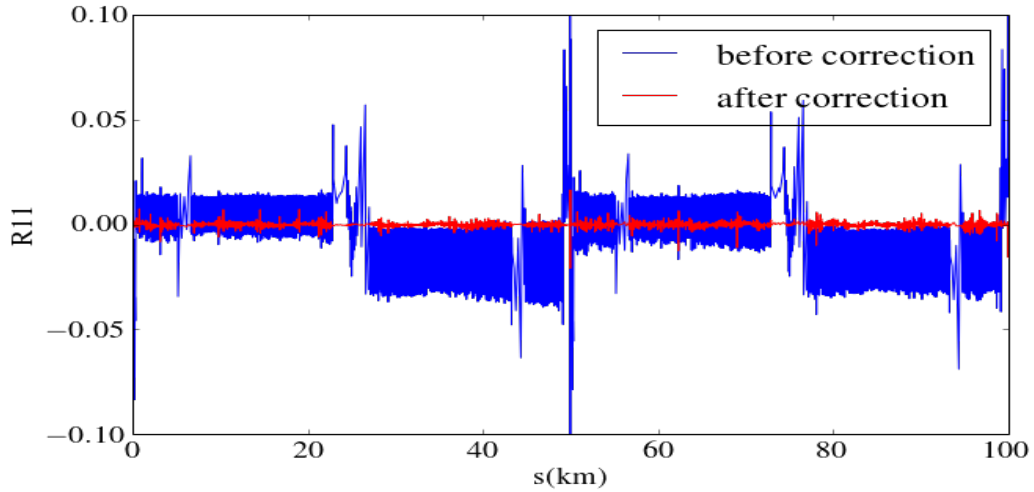
Switch on sextupoles

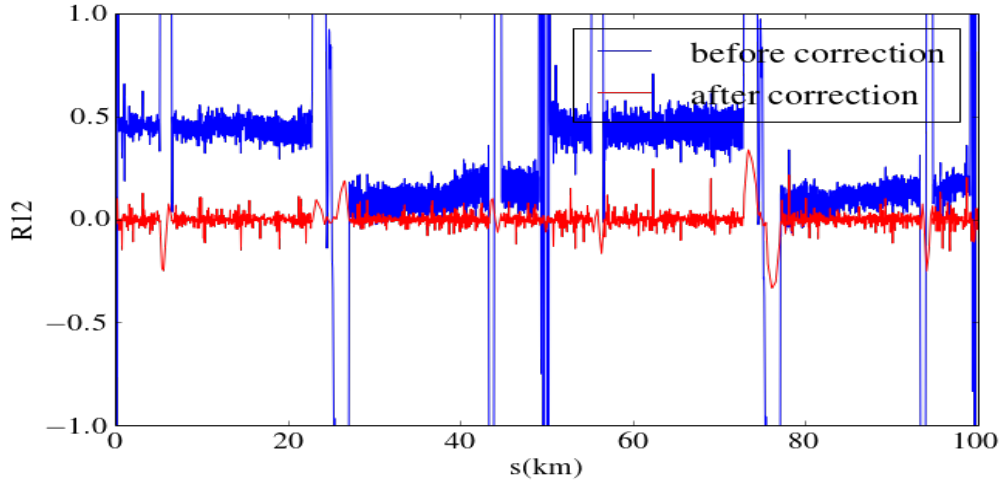
Dispersion correction during the coupling correction (coupling due to sextupole)

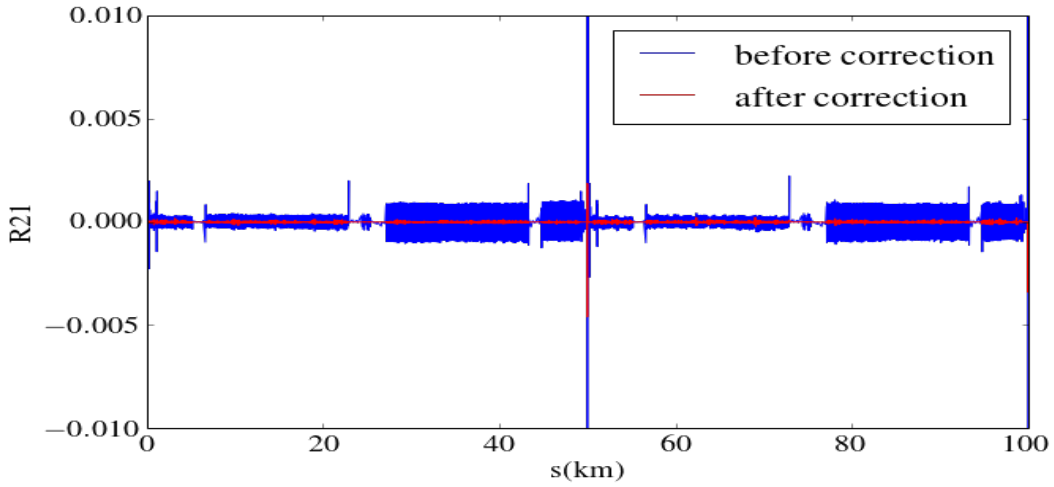


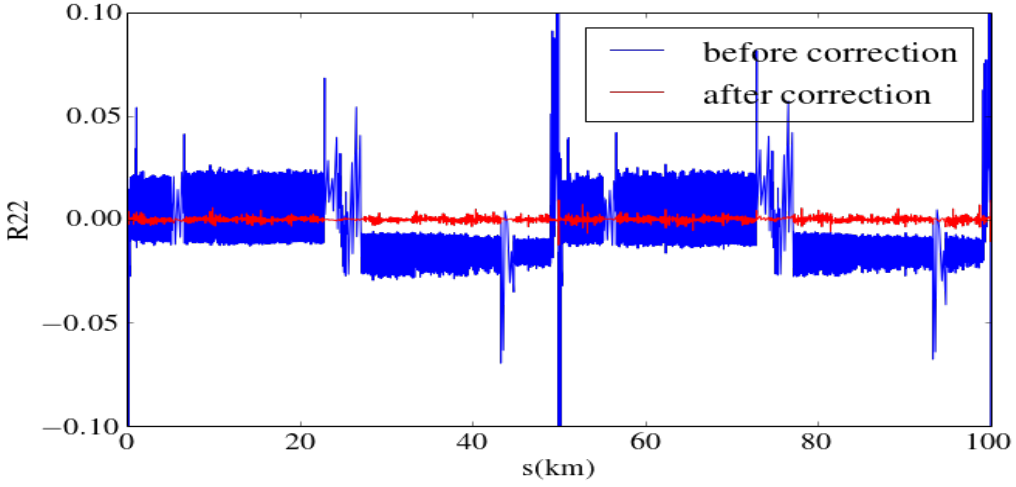
Vertical Quadrupole Misalignments

Coupling matrix elements









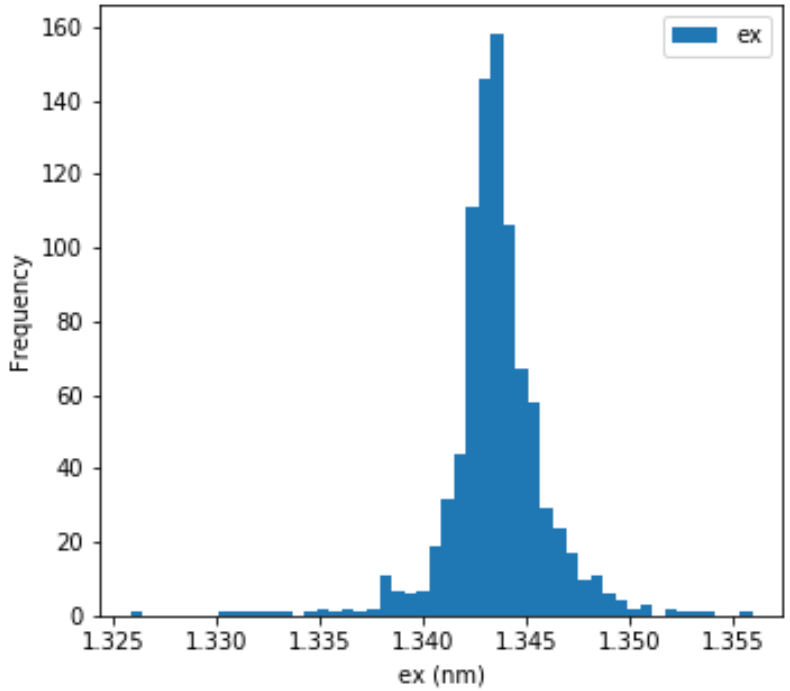
Sextupole Vertical Misalignments

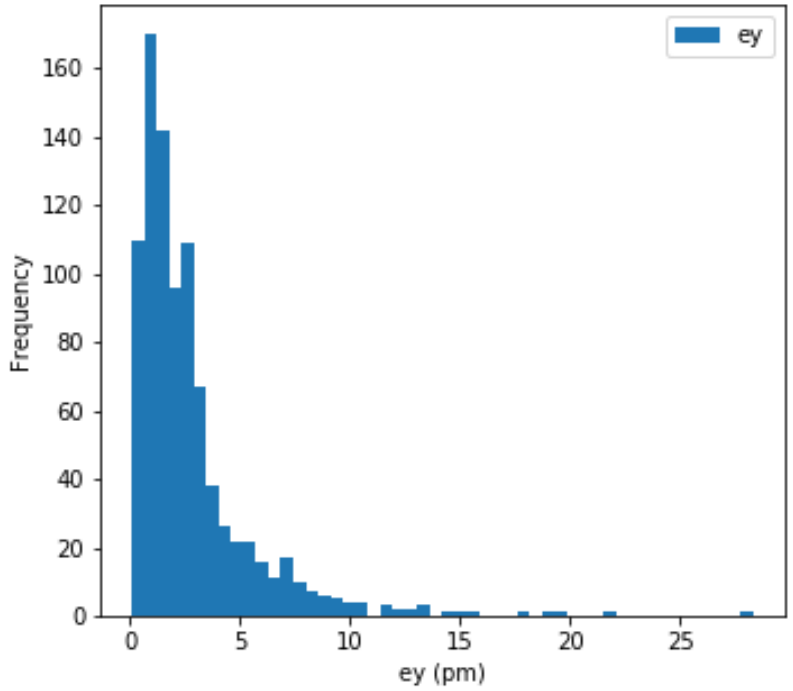
Consider Δy=10 μm RMS gaussian distributed truncated at 2.5 sigma

Before correction:

$\epsilon_y = 2.1\ pm, \epsilon_x = 1.26\ nm, \epsilon_y/\epsilon_x\ 0.0017$

2.7 pm vertical emittance design value!





Strategy for misaligned arc quads & sextupoles & dipoles

- Errors introduced**, no strength in sextupoles**
- x-y orbits correction
- Coupling correction
- Correct the horizontal dispersion

Loop 20 times

- 1 step Dispersion Free Steering w/o sextupole (Dy correction)
  +
  1 step coupling correction
- Save x,x',y,y' at the beginning of the machine

- **Switch on sextupoles** to +10% of their design current
  - orbit corrections
  - coupling correction, tune matching
  - beta beat correction, Dx correction
  - coupling + Dy correction
  - increase by 10% the sextupole strength

This avoid the tunes run of to resonance and maximize the number of successful seeds

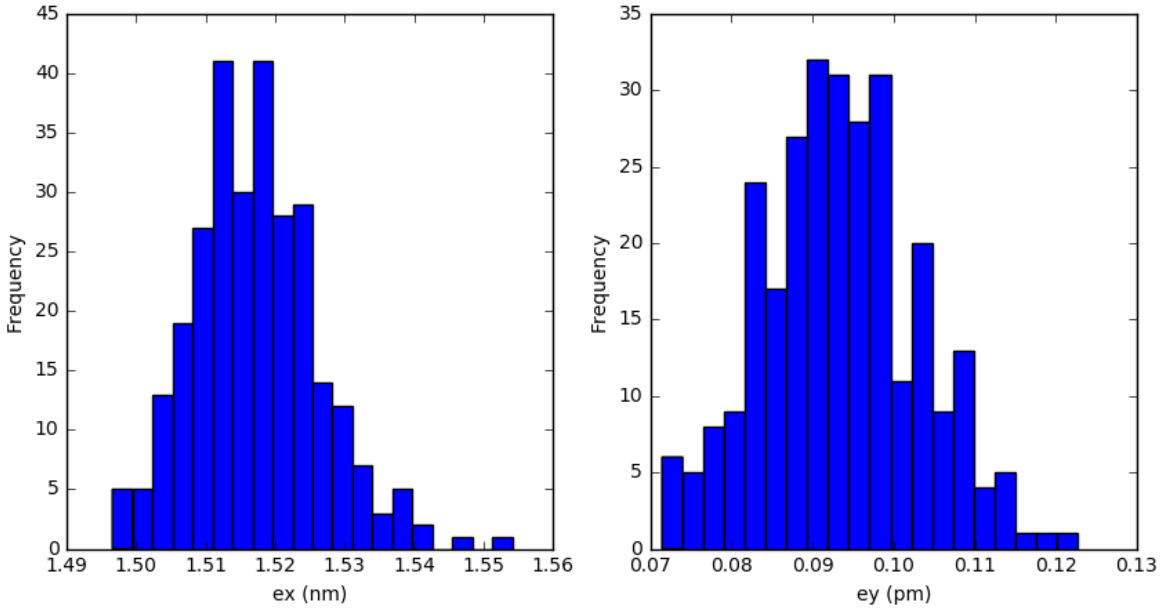
- Emittance computation

7-8h up to one day of simulation/seed

Misaligned arc quads & sextupoles

IP quads perfectly aligned (for now)

	σ_x (μm)	σ_y (μm)	σ_θ (μrad)
Arc quads	100	100	100
Sextupoles	100	100	
IP quads	0	0	0



436 out of 500 seeds converged

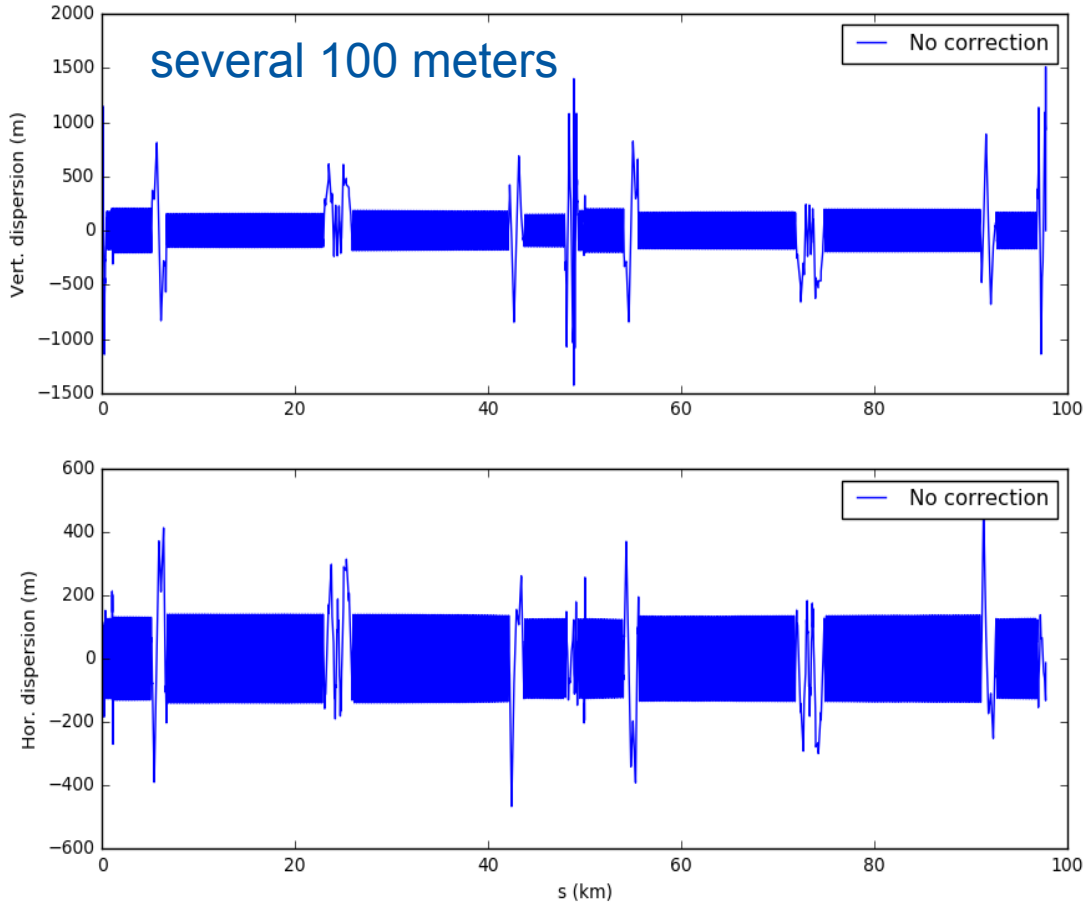
ε_y = 0.093 pm +/- 0.01
ε_x = 1.520 nm +/- 0.009
$\varepsilon_y/\varepsilon_x$= 0.006% (limit 0.2%)

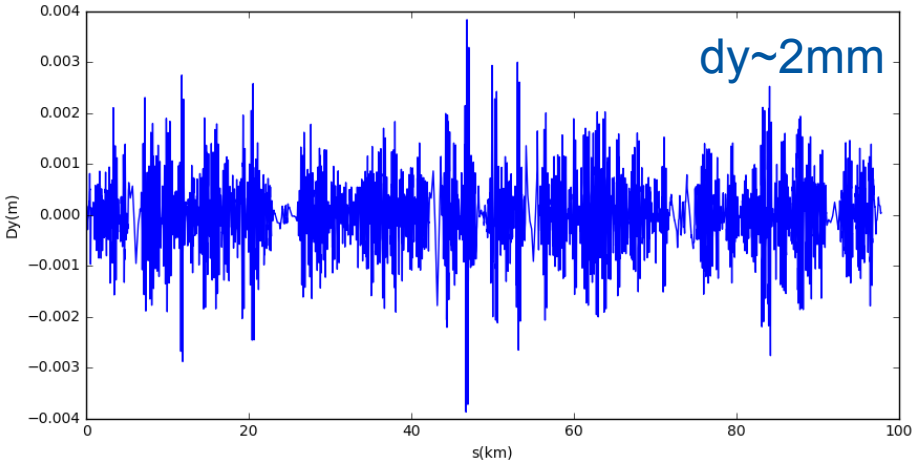
Vertical dispersion susceptible misalignments

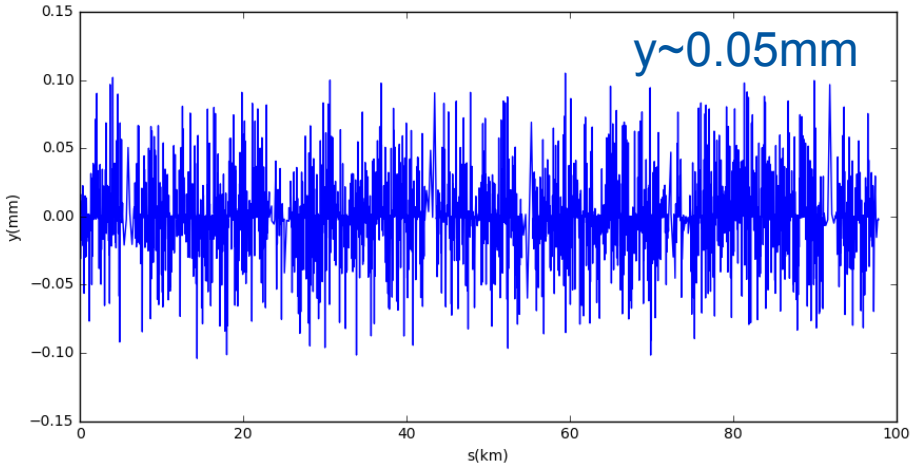
Misalignments:

Arc quads $\Delta x = 100\ \mu m$, $\Delta y = 100\ \mu m$, $\Delta\theta = 100\ \mu m$, **IP quads** perfectly aligned (for now)

Sextupoles: $\Delta x = 100\ \mu m$, $\Delta y = 100\ \mu m$

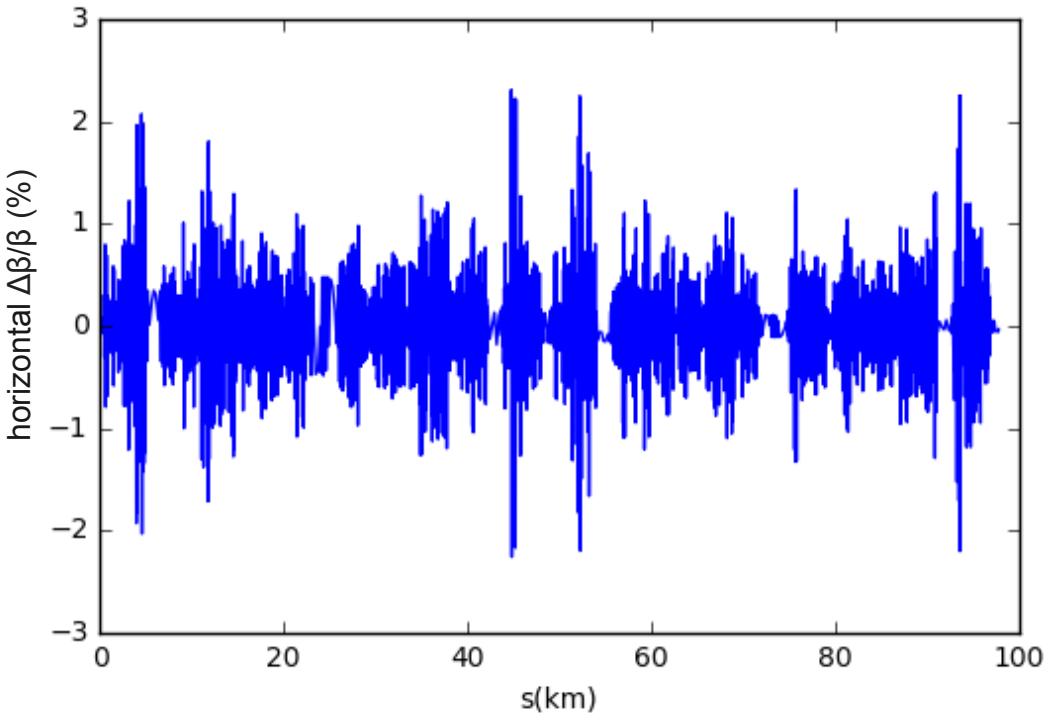


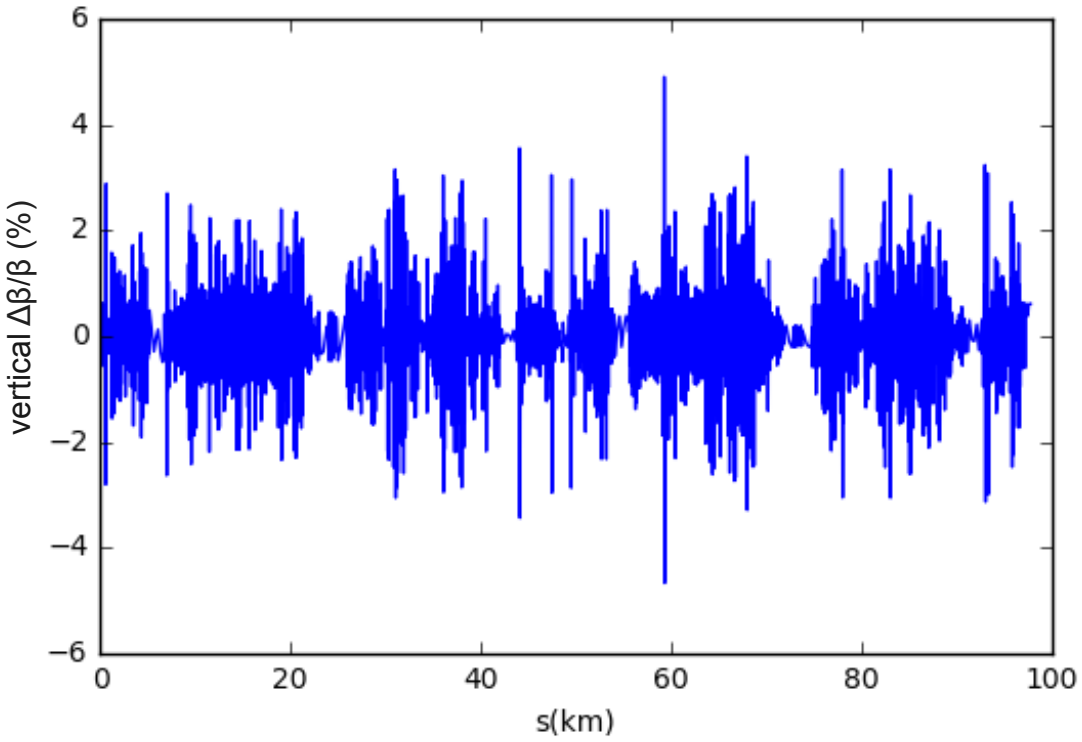




Misaligned arc quads & sextupoles

Beta beat after correction

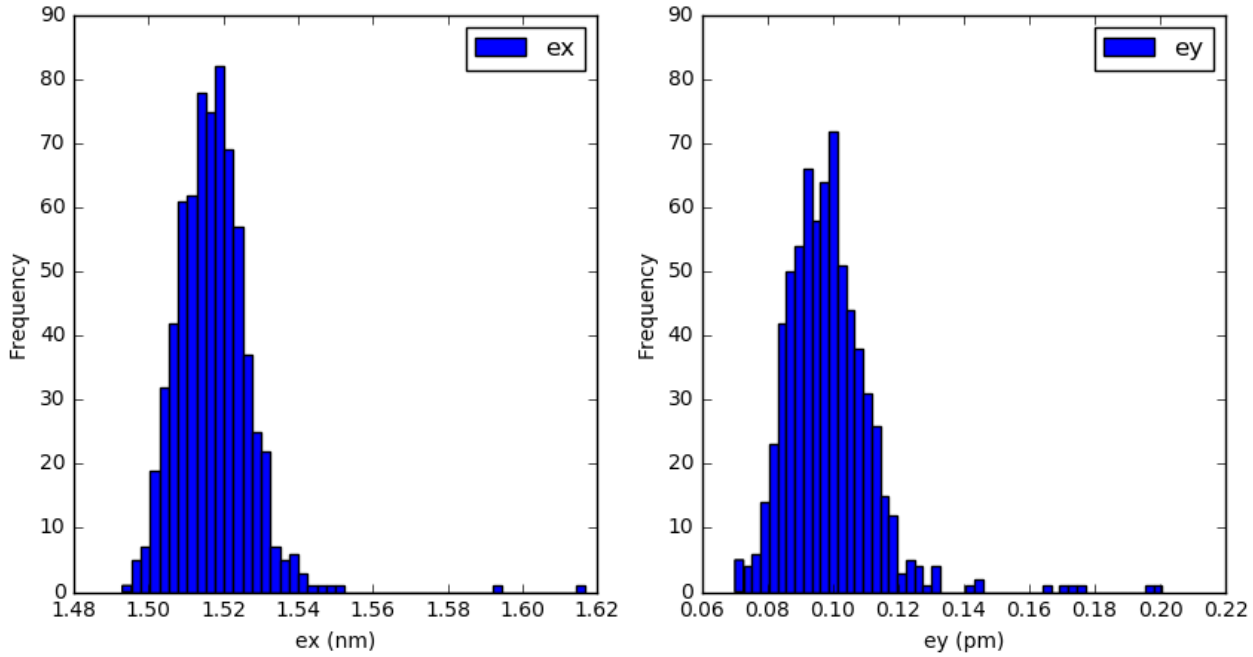




Misaligned arc and IP elements

IP quads misalignments to 50 μm and 50 μrad :

	σ_x (μm)	σ_y (μm)	σ_θ (μrad)
Arc quads	100	100	100
Sextupoles	100	100	
IP quads	50	50	50



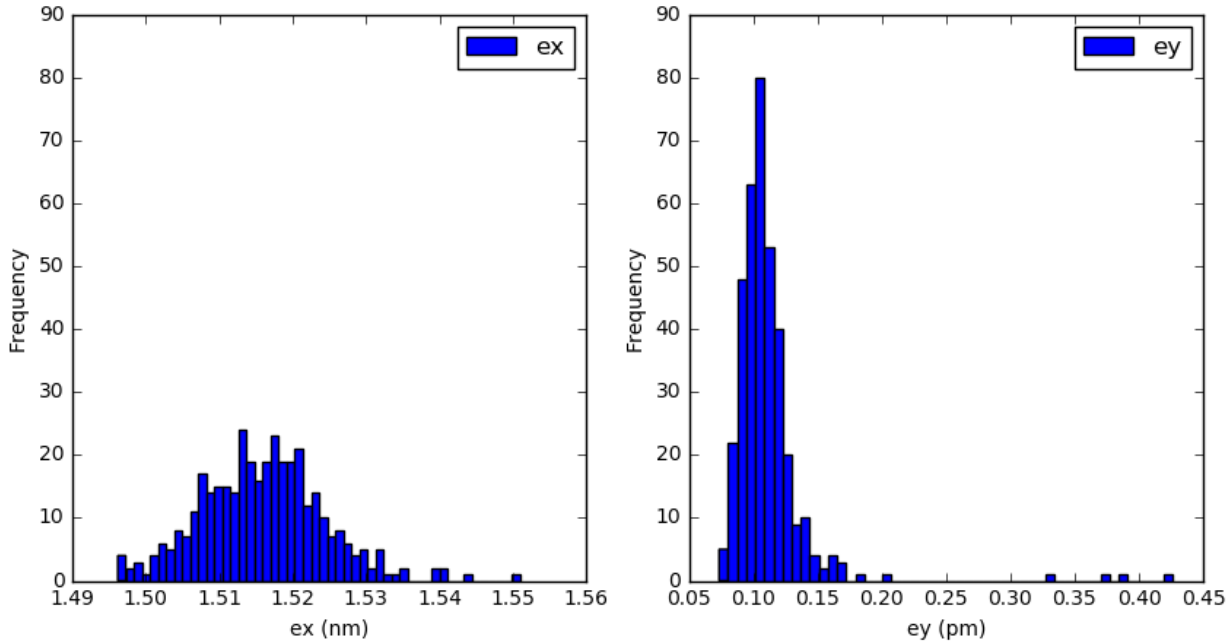
700 out of 1000 seeds converged

ε_y = 0.099 pm +/- 0.013
ε_x = 1.52 nm +/- 0.01
$\varepsilon_y/\varepsilon_x$ = 0.0065% (limit 0.2%)

Misaligned arc and IP elements

Increasing IP quads misalignments to 100 μm and 100 μrad :

	σ_x (μm)	σ_y (μm)	σ_θ (μrad)
Arc quads	100	100	100
Sextupoles	100	100	
IP quads	100	100	100



369 out of 1000 seeds converged

ε_y = 0.11 pm +/- 0.03
ε_x= 1.52 nm +/- 0.01
$\varepsilon_y/\varepsilon_x$= 0.0073% (limit 0.2%)

Conclusions & next steps

- With 100 µm, 100 µrad misalignments in arc quads & sextupoles and 50µm and 50 µrad misalignments in IP quads, the mean vertical emittance achieved after correction schemes applied is ε_y = 0.1 pm
- For 50 µm and 50 µrad misalignments in IP quads, 700 out of 1000 seeds converged. For 100 µm and 100 µrad misalignments in IP quads, 369 out of 1000 seeds converged.

Some next steps include:

- Include BPM errors
- Inclusion of field and gradient errors
- Attempt to reduce the number of BPMs.

Thank you

Back up slides

Dynamic aperture & Momentum ccceptance with Errors

Tracking done by Tobias Tydecks

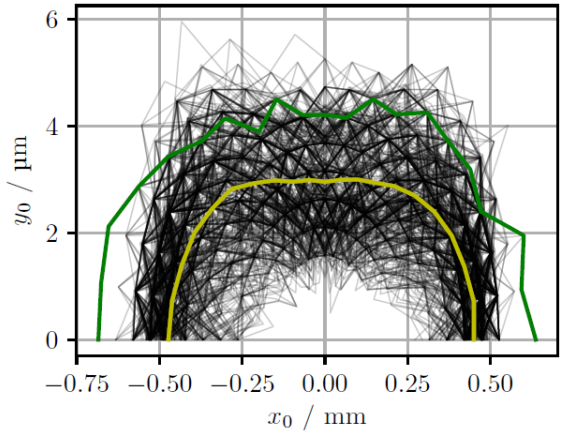


Figure 4: Dynamic aperture with (grey) and without (green) misalignment errors including radiation damping and quantum excitation for 574 out of 995 seeds. Average for seeds indicated in yellow.

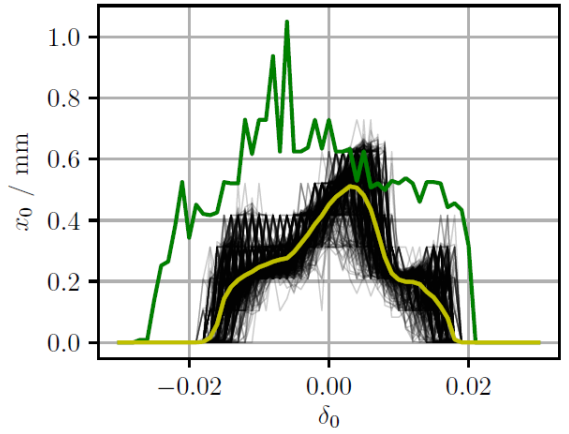


Figure 5: Momentum aperture with (grey) and without (green) misalignment errors including radiation damping and quantum excitation for 580 out of 995 seeds. Average for seeds indicated in yellow.

See Tobias' talk *"Dynamic Aperture, ideal and with errors"* on 11 Apr 2018, 09:25