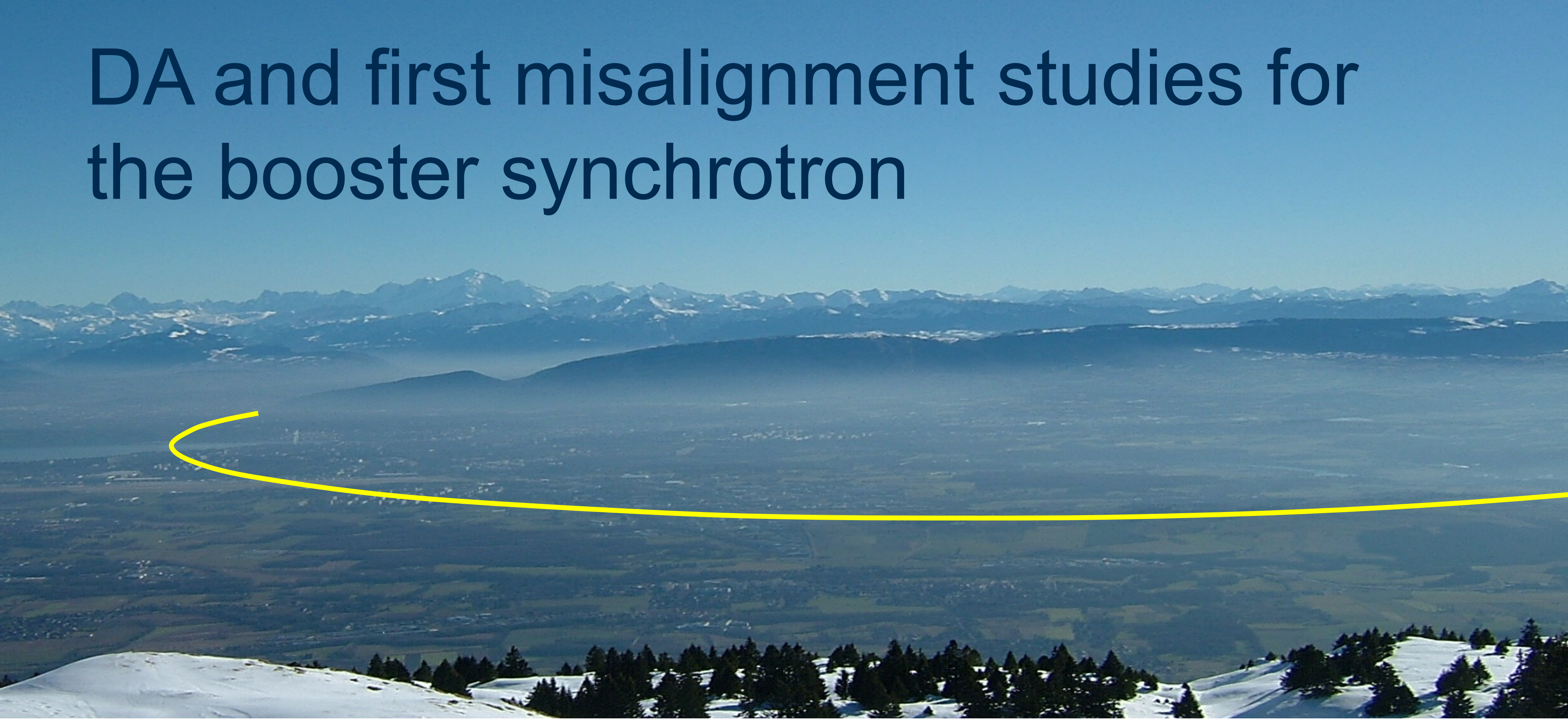
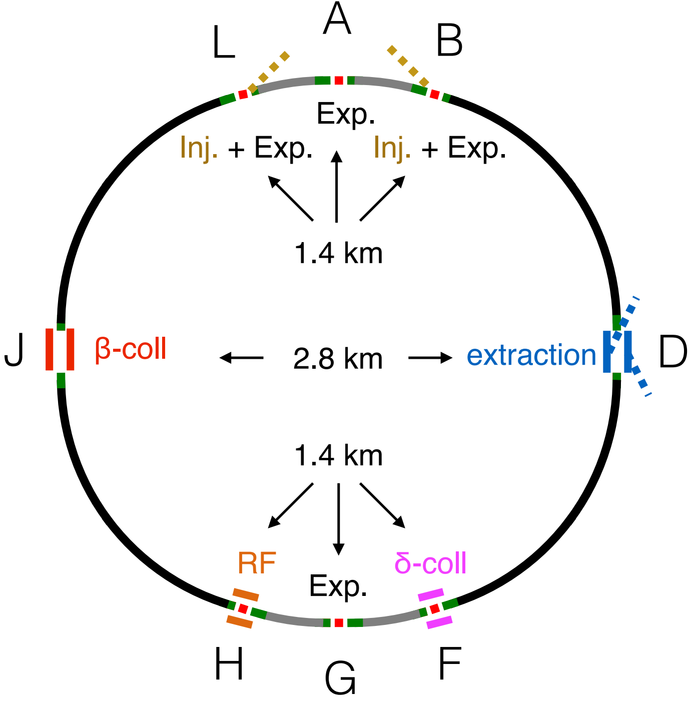
DA and first misalignment studies for the booster synchrotron



Bastian Haerer (CERN)
for the FCC-ee lattice design team

15th FCCee Injector Meeting
06 October 2017

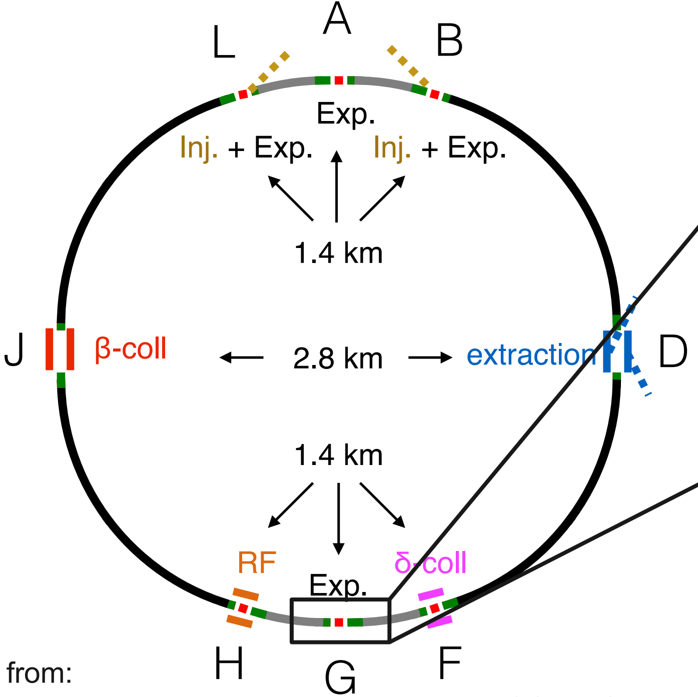
FCC Layout

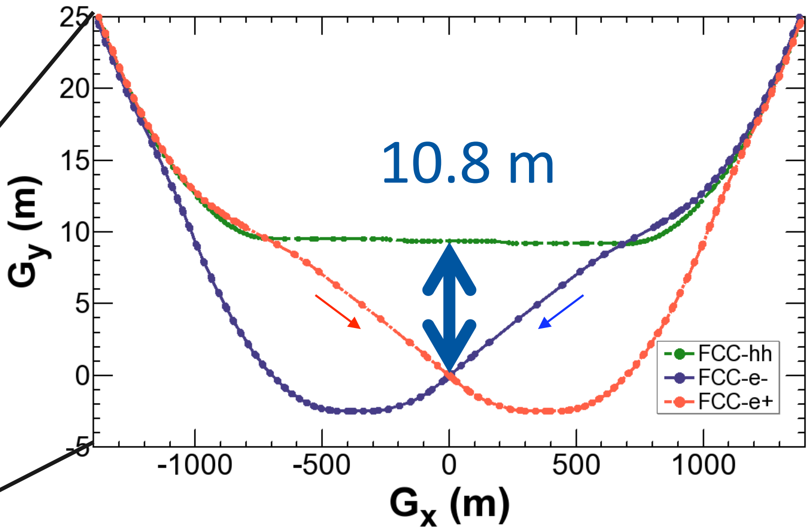


Circumference: C = 97.75 km
Bending radius: ρ = 10.5 km

2 experimental straight sections (A & G)
2 RF sections in points D and J

FCC Layout





The layout of the booster follows the footprint of FCC-hh

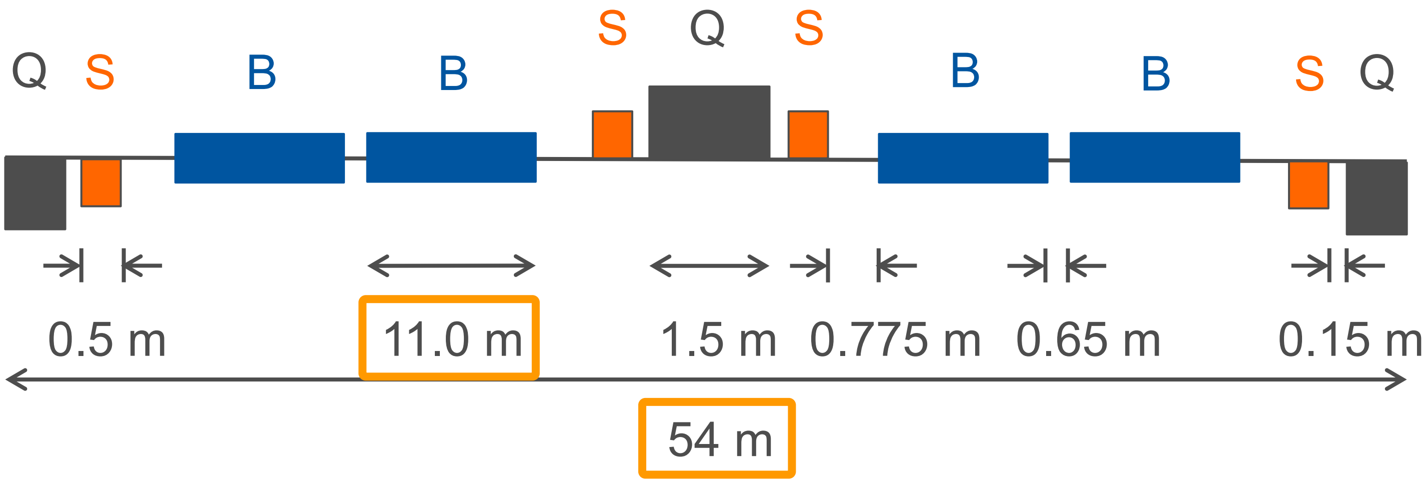
→ inside the experiments

Images from:
D. Schulte, “New layout,” Presentation in the FCC-hh General Design Meeting, Sep. 2016.
K. Oide *et al.*, "Design of beam optics for the future circular collider *e+e−* collider rings," Phys. Rev. Accel. Beams, vol. 19, p. 111005, Nov 2016.

Fields of progress

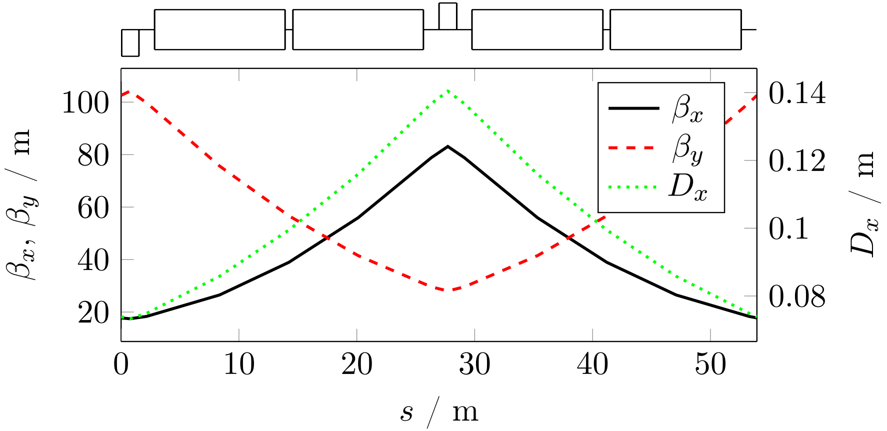
- Longer FODO cell layout in the arcs
- Three optics are investigated
- Three sextupole schemes & DA
- Transverse misalignments of quadrupoles

FODO cell of the FCC-ee booster



B = bending magnet, Q = quadrupole, S = sextupole

First optics for 80-175 GeV

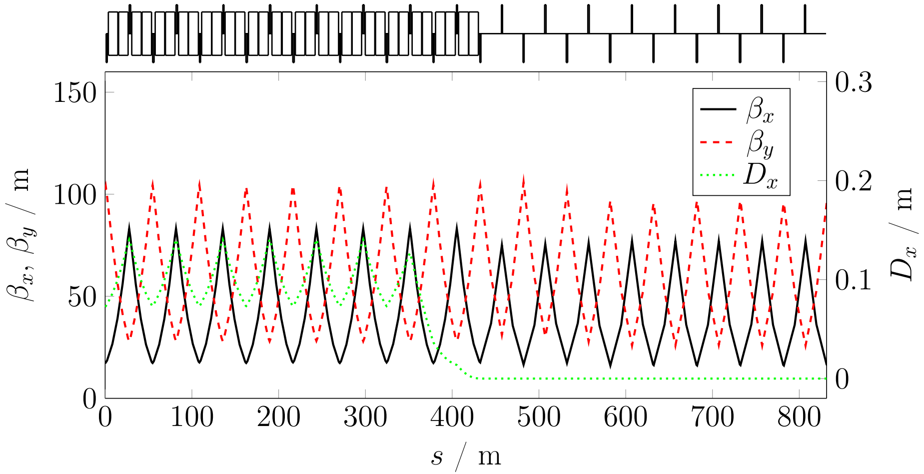


FODO cell:

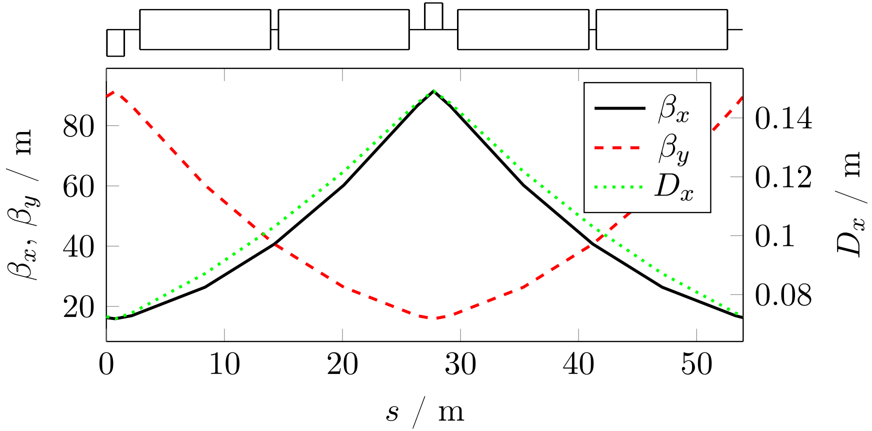
L = 54 m

φ = 90°/60°

2-cell half-bend dispersion suppressor



Second optics for 80-175 GeV

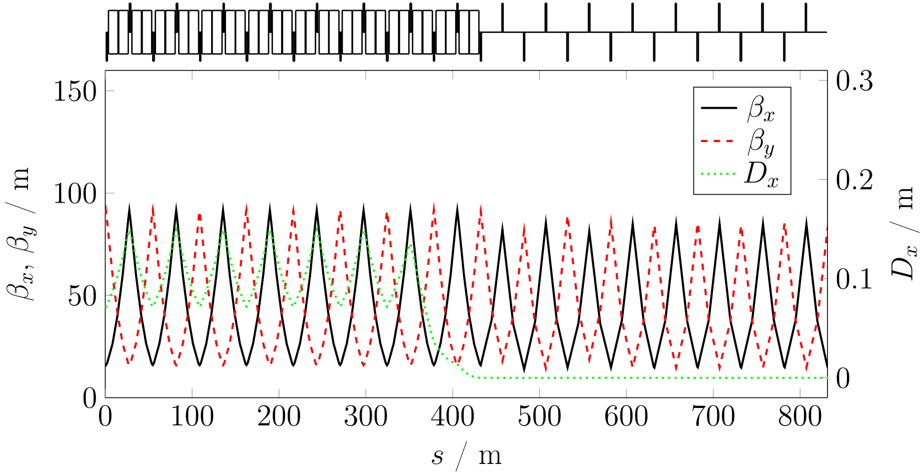


FODO cell:

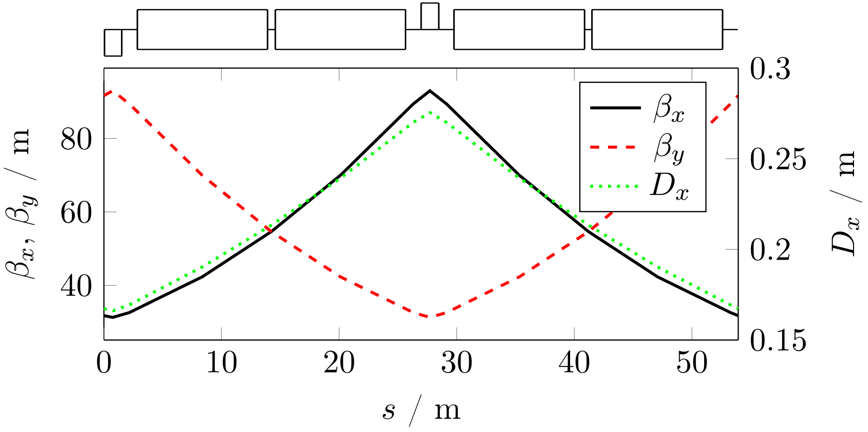
L = 54 m

φ = 90°/90°

2-cell half-bend
dispersion suppressor



Optics for 45 GeV

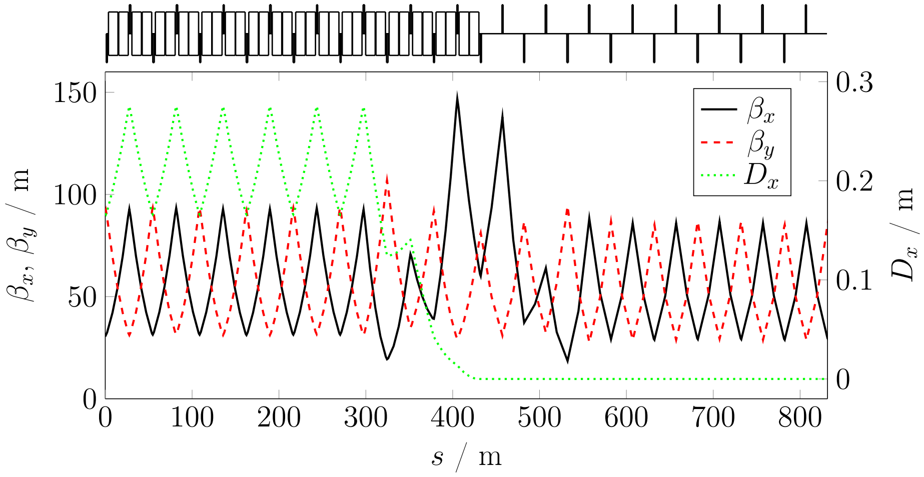


FODO cell:

L = 54 m

φ = 60°/60°

Dispersion suppressor supported by quadrupoles



Parameters

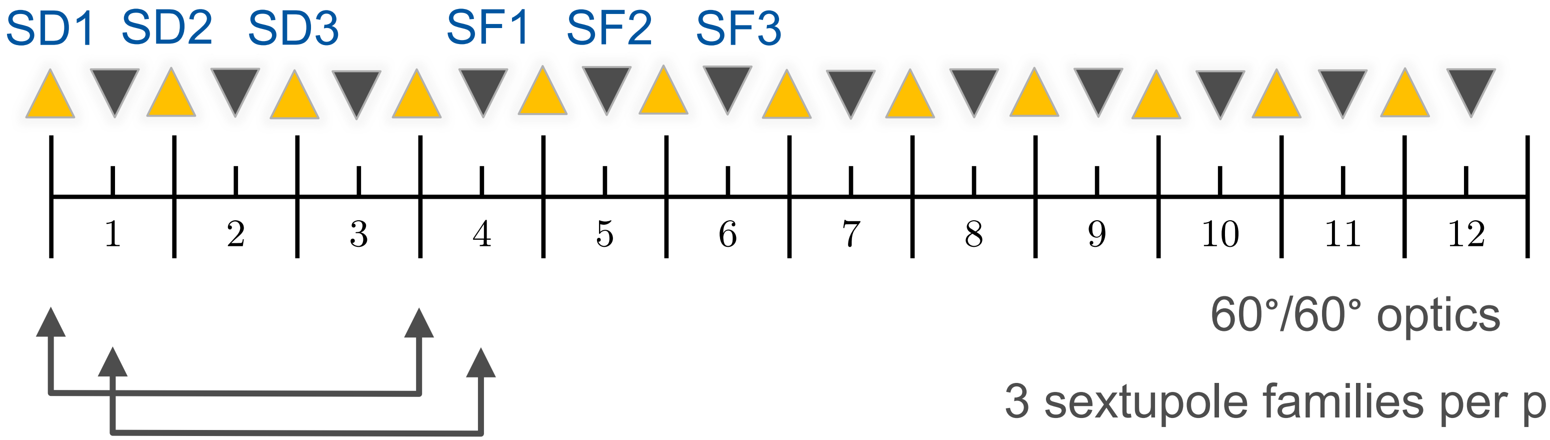
	L = 50 m **90°/60°**	**L = 54 m** **90°/60°**	**90°/90°**	**60°/60°**
Q_x	487.08	457.225	459.225	306.225
Q_y	327.14	304.290	457.290	304.290
ξ_x	-542.010	-507.658	-584.643	-338.778
ξ_y	-450.449	-420.928	-582.910	-336.455
$\alpha_c / 10^{-6}$	5.6	6.5	6.7	13.7
ε_x (20 GeV)/nm rad	0.012	0.015	0.015	0.045
ε_x (45.5 GeV)/nm rad	0.062	0.075	0.078	0.235
ε_x (175 GeV)/nm rad	0.918	1.124	1.172	3.540

Dynamic aperture

- All sextupoles in one plane are powered equally
- Only linear chromaticity corrected

- Different sextupole schemes:
  → interleaved
  → “partially” non-interleaved
  → “completely” non-interleaved

Interleaved sextupole scheme

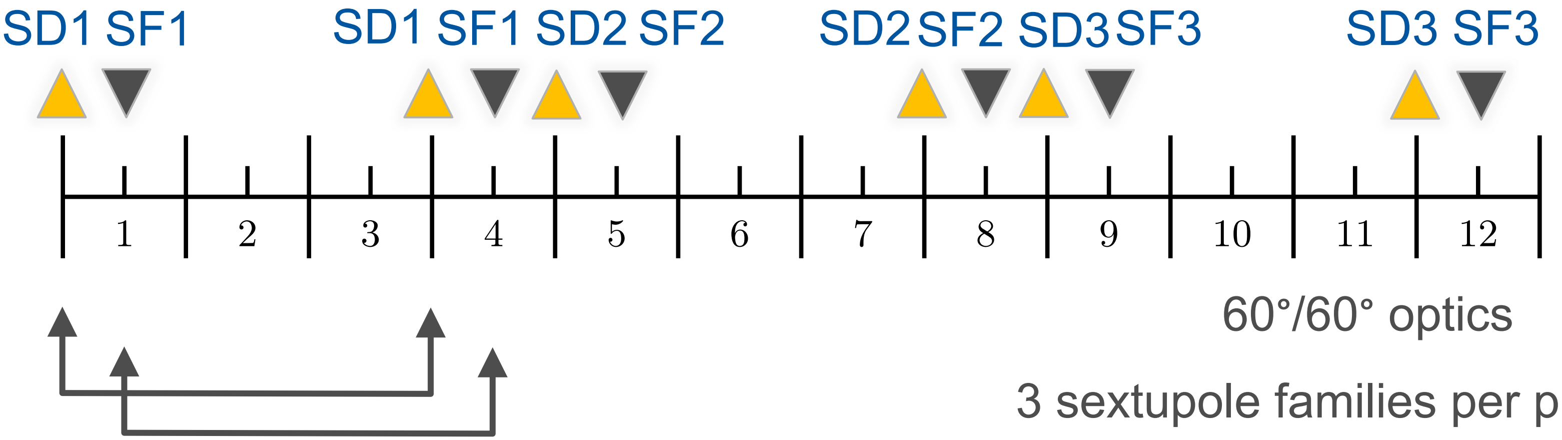


60°/60° optics

3 sextupole families per plane

$\mu_x = \mu_y = 180°$ (→ -I transformation)

Partly non-interleaved sextupole scheme

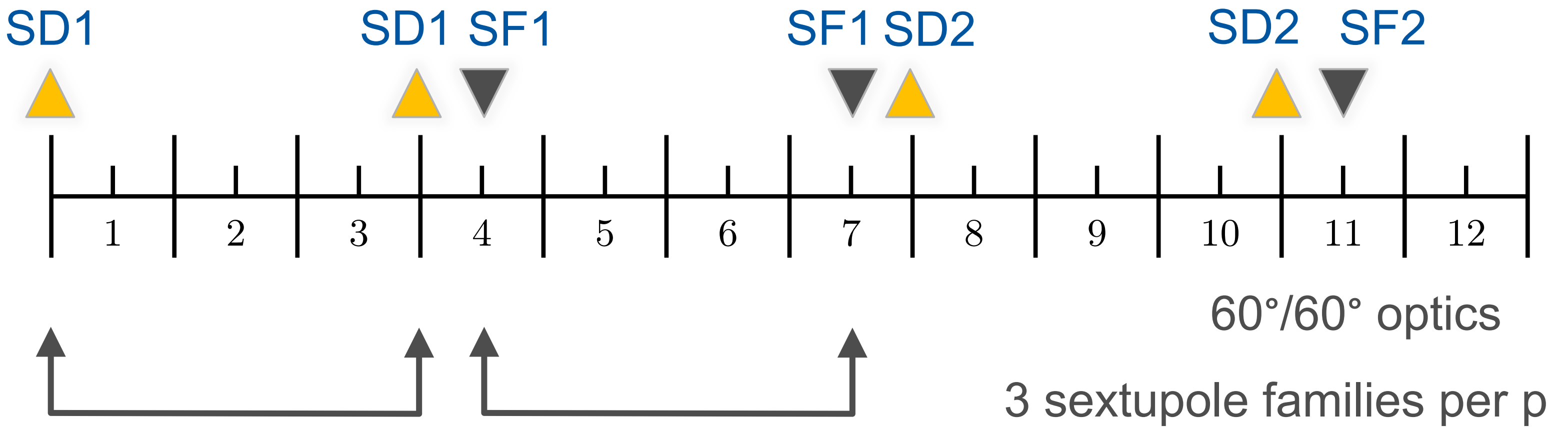


60°/60° optics

3 sextupole families per plane

$\mu_x = \mu_y = 180°$ (→ -I transformation)

Non-interleaved sextupole scheme



60°/60° optics

3 sextupole families per plane

$\mu_x = \mu_y = 180°$ (→ -I transformation)

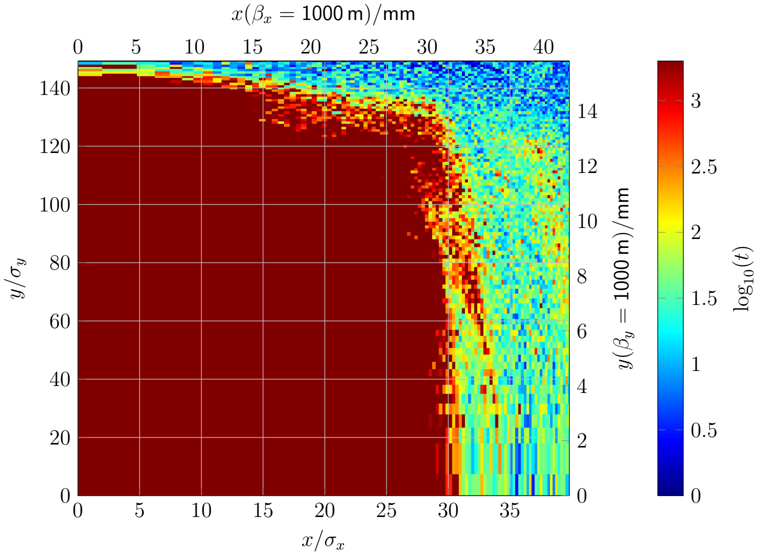
Dynamic aperture

- Obtained through tracking with PTC
  → survival after 2000 turns
- No radiation, no damping

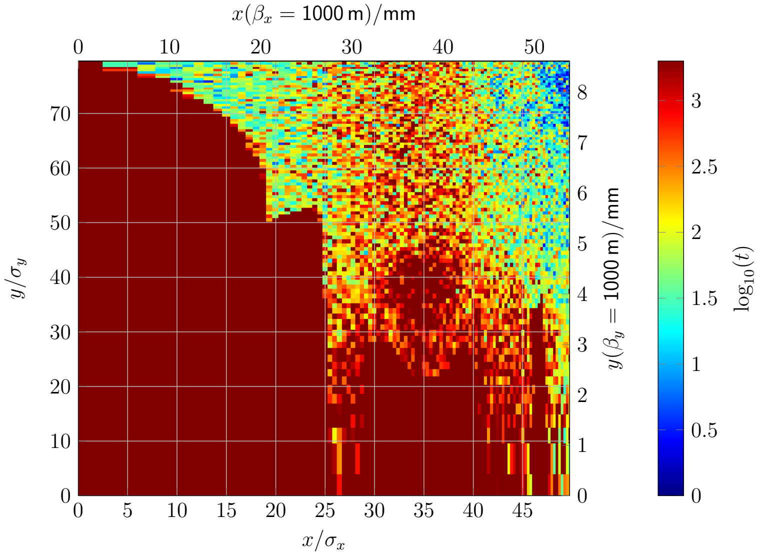
- Which sextupole scheme gives the best DA performance? → “completely” non-interleaved
- How large is the obtained DA?

Dynamic aperture (175 GeV)

Non-interleaved sextupole scheme, only linear chromaticity is compensated



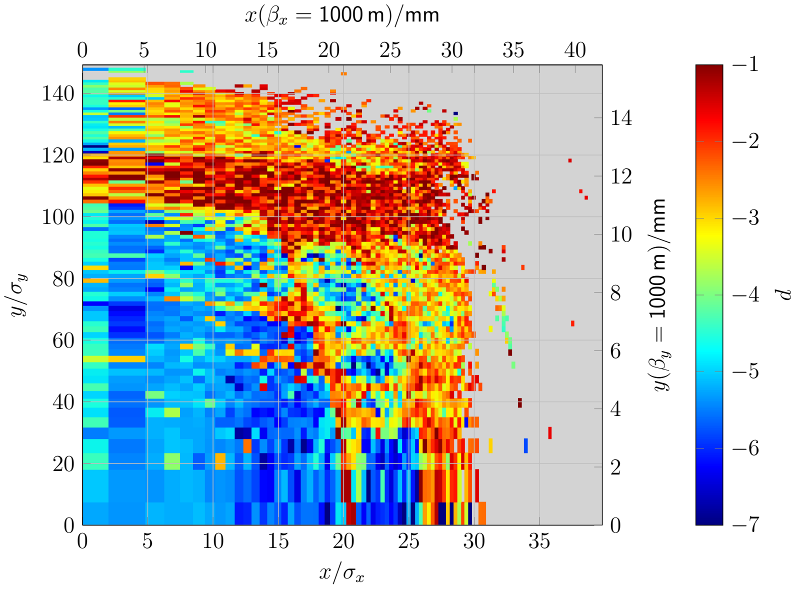
90°/60°



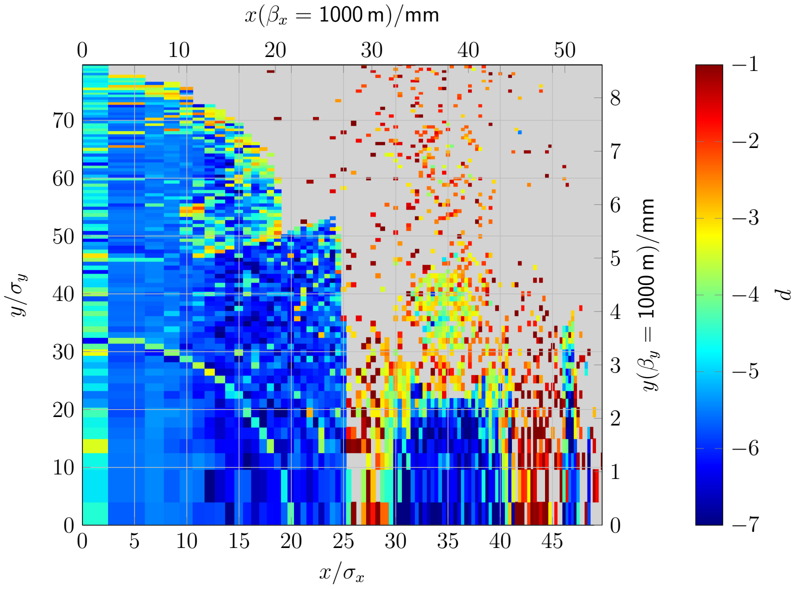
90°/90°

Diffusion rate

$$d = \log_{10}\left[\sqrt{\left(\nu_x^{(2)} - \nu_x^{(1)}\right)^2 + \left(\nu_y^{(2)} - \nu_y^{(1)}\right)^2}\right]$$

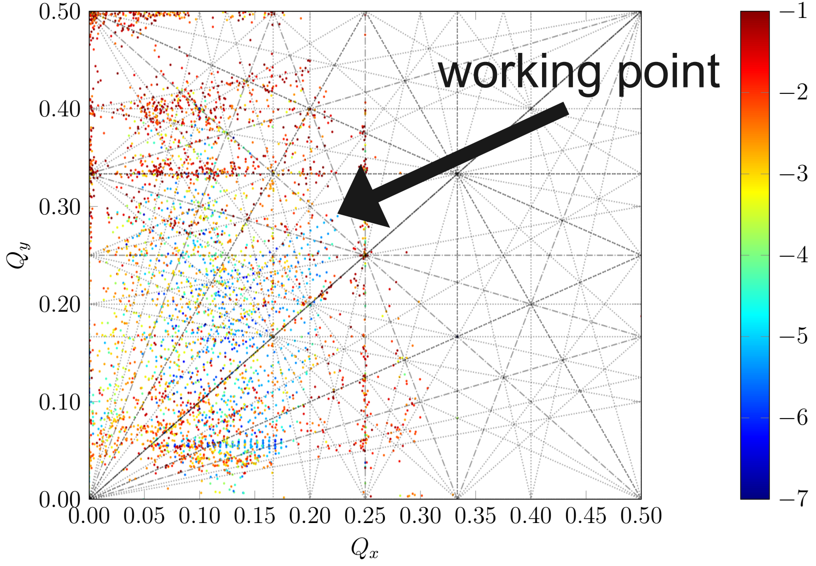


90°/60°

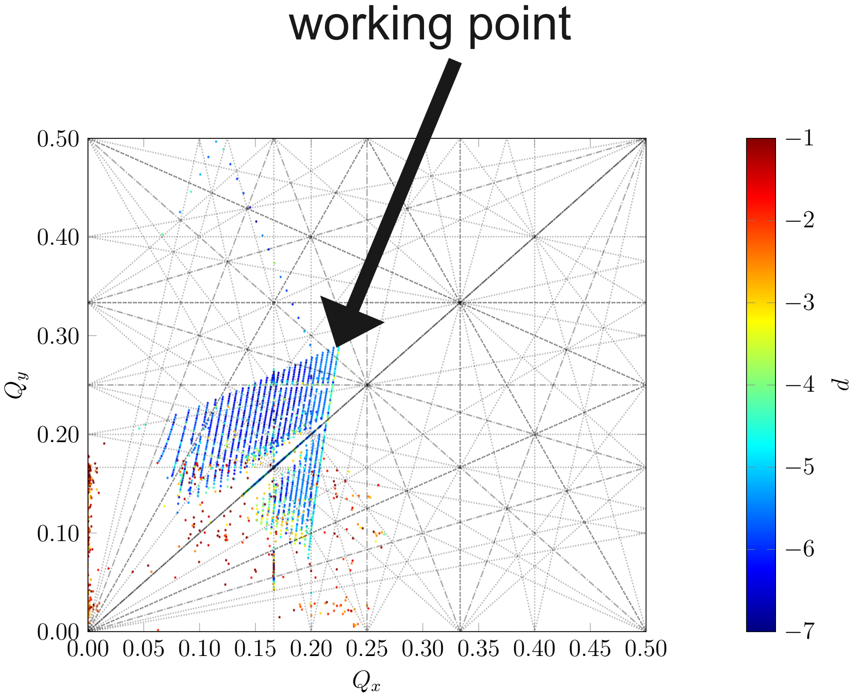


90°/90°

Tune footprint



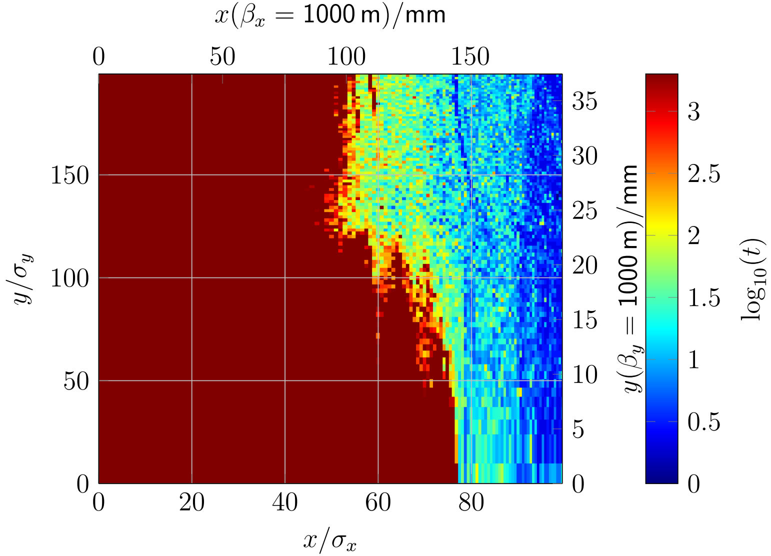
90°/60°

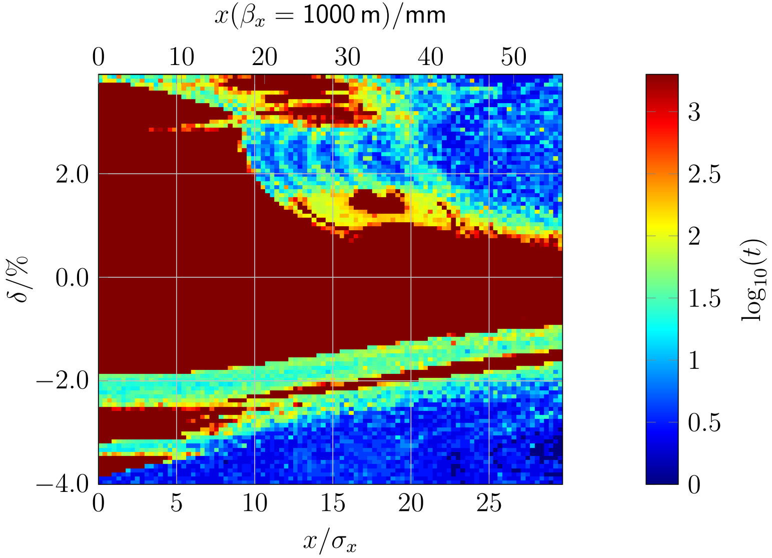


90°/90°

Bastian Haerer
bastian.harer@cern.ch

Dynamic aperture 60°/60° optics

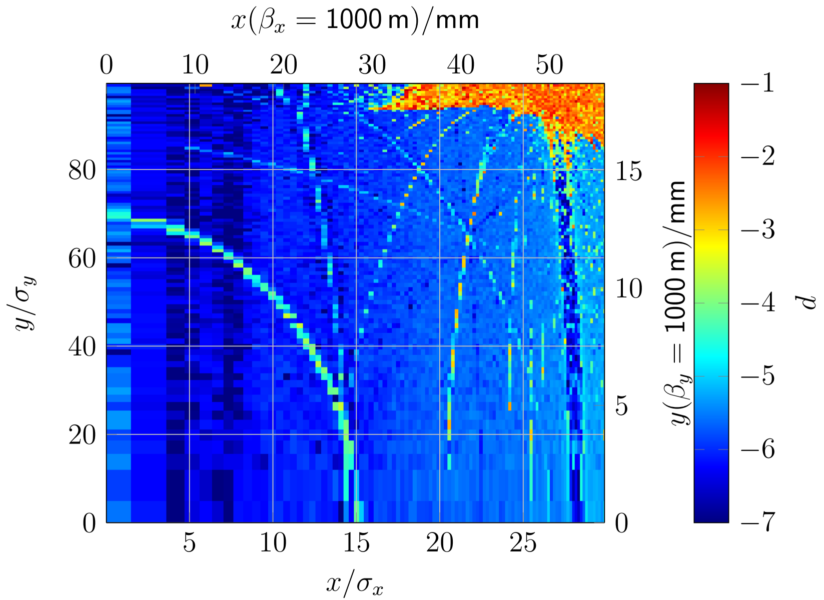




Non-interleaved sextupole scheme
Only linear chromaticity is compensated

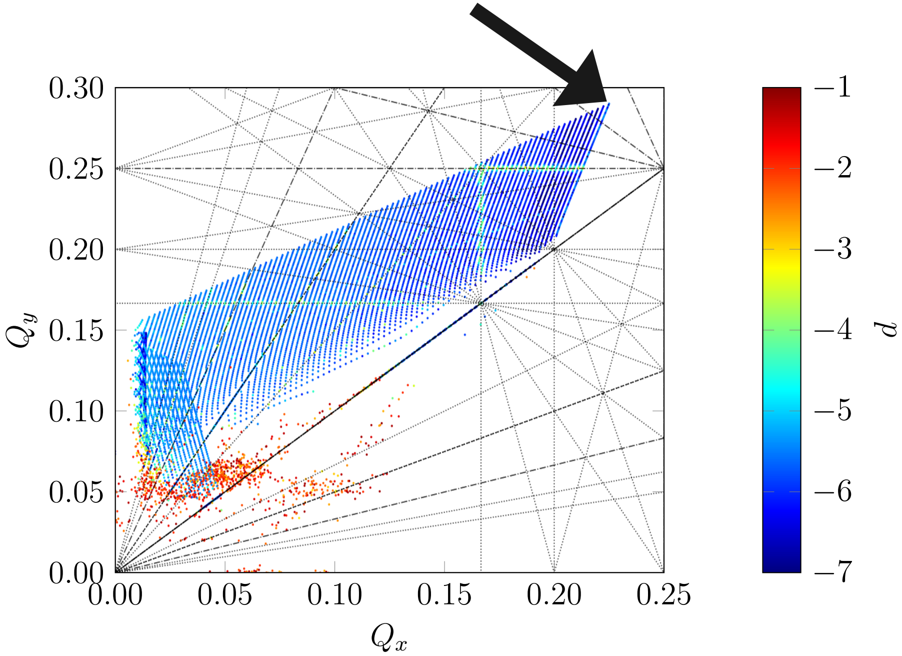
175 GeV

60°/60° optics



$$d = \log_{10}\left[\sqrt{\left(\nu_x^{(2)} - \nu_x^{(1)}\right)^2 + \left(\nu_y^{(2)} - \nu_y^{(1)}\right)^2}\right]$$

working point



tune footprint

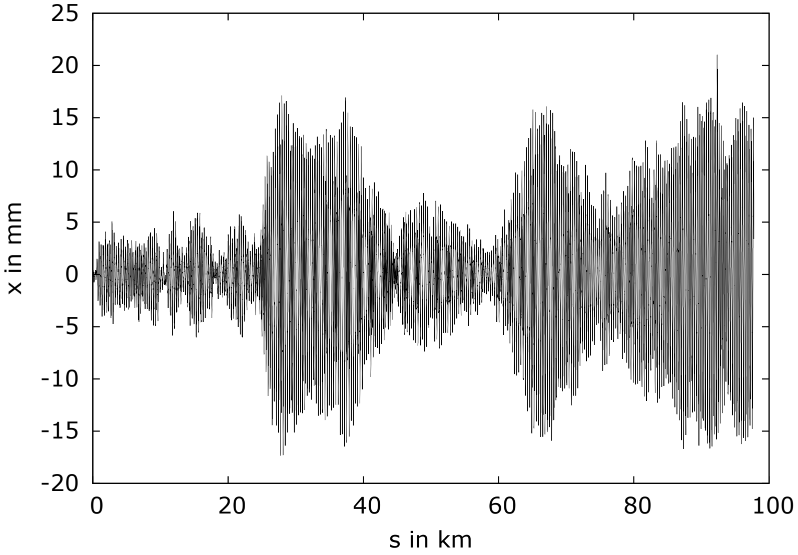
Transverse misalignments of quadrupoles

- Gaussian distributed, truncated at 3 σ
- 10 µm, 50 µm, 100 µm & 150 µm
- 100 seeds each
- Orbit correction in two iterations (SVD, micado)

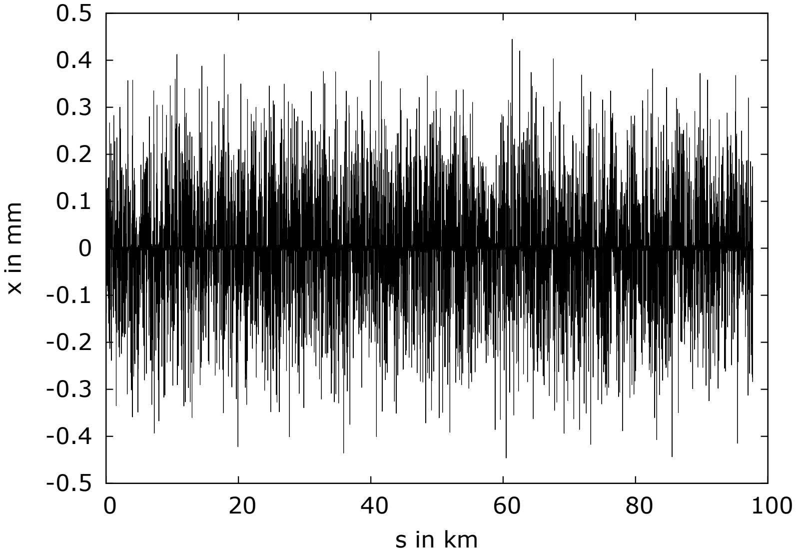
- 60°/60° and 90°/90° optics with non-interleaved sextupole scheme

Horizontal orbit

150 µm, seed 1000

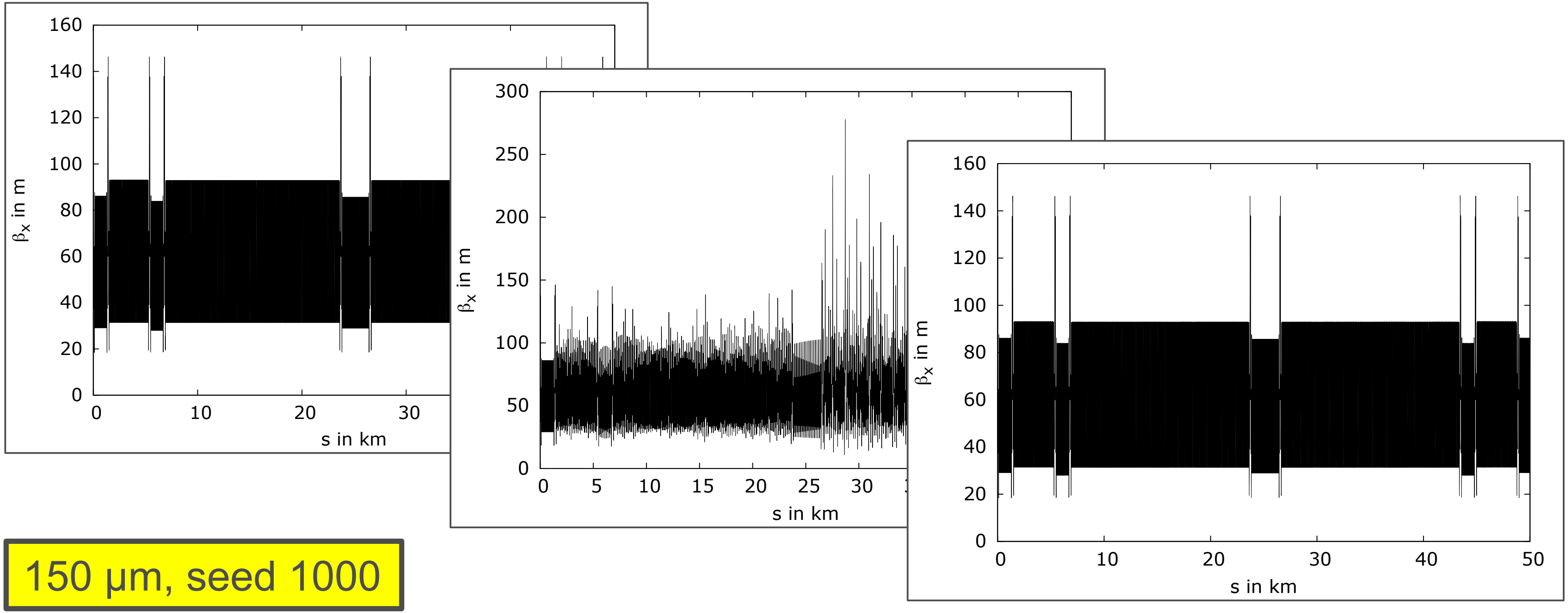


before orbit correction



after orbit correction

Optics distortions (60°/60°)



150 µm, seed 1000

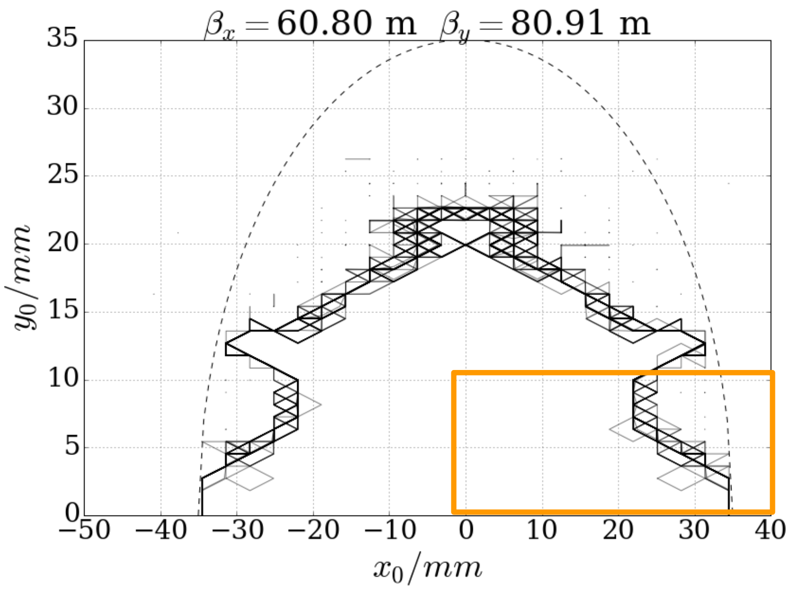
Emittances (60°/60°)

	Ideal ε_x /nm rad	**Misaligned** ε_x /nm rad
20 GeV	0.045	0.045
45 GeV	0.230	0.230
175 GeV	3.642	3.640

	Misaligned ε_y /nm rad	$\varepsilon_y / \varepsilon_x$
20 GeV	4.4×10^{-7}	9.8×10^{-6}
45 GeV	2.3×10^{-6}	9.9×10^{-6}
175 GeV	4.0×10^{-5}	1.1×10^{-5}

- No coupling from sextupole misalignment or roll angles considered yet

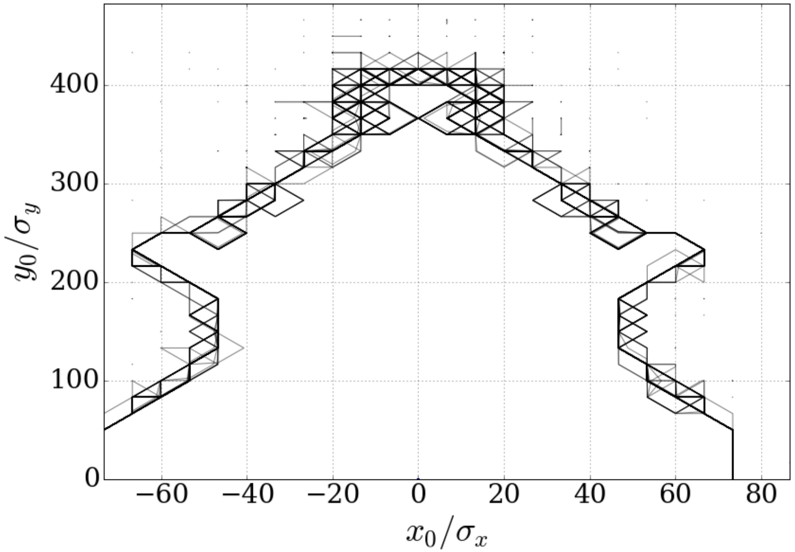
DA with misalignments



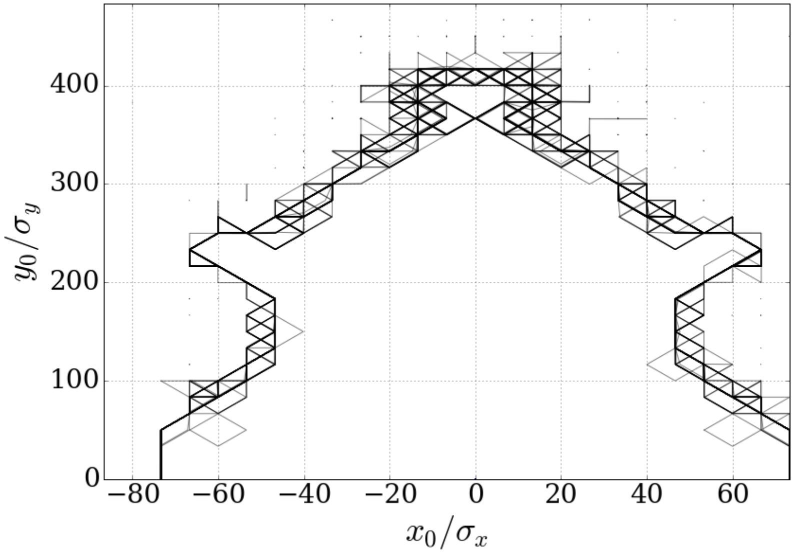
- 60°/60° optics
- 150 µm
- 100 seeds

Previously shown part:
→ No reduction of DA because of transverse misalignments

DA with misalignments

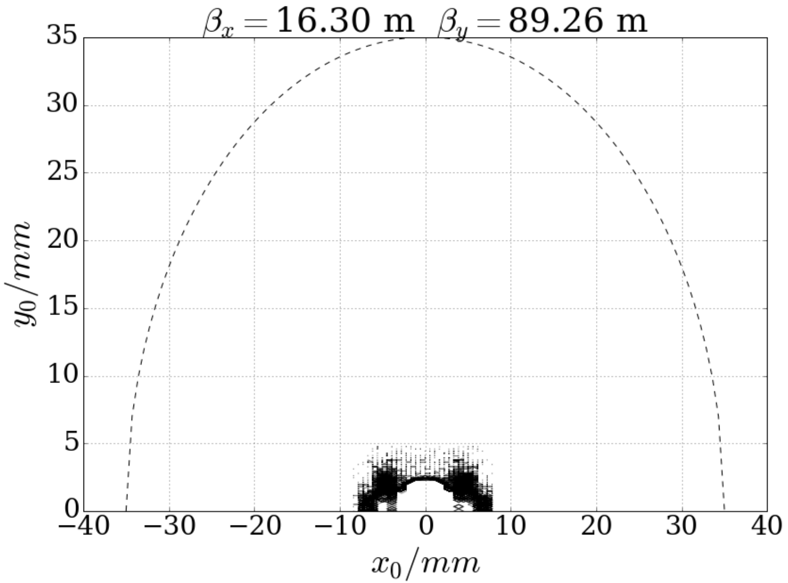


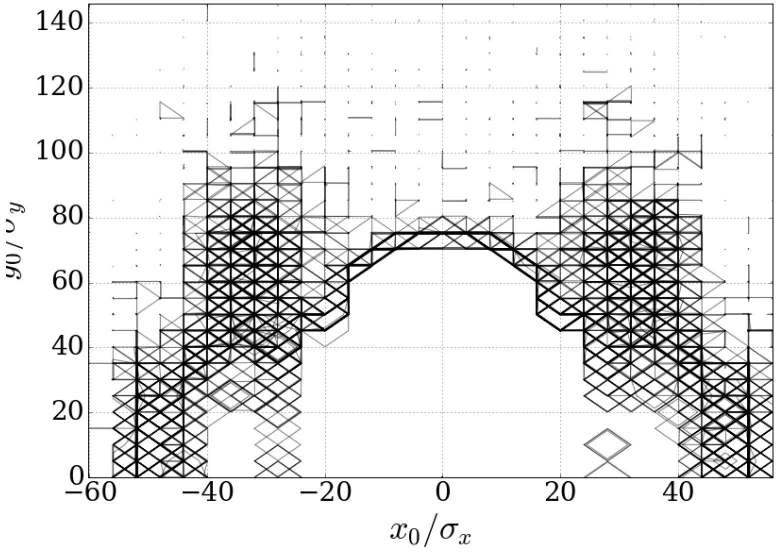
10 µm, 100 seeds



150 µm, 100 seeds

DA with misalignments II





- 90°/90° optics: 150 µm, 100 seeds

Summary

- Lattice with 54 m cell length in the arcs provides larger momentum compaction factor
- Three different optics are considered: 90°/60°, 60°/60° & 90°/90°
- 25-75 σ dynamic aperture for all optics

  → Multi-family sextupole scheme allows to modify higher orders of chromaticity and detuning with amplitude, if needed
- Transverse misalignments of quadrupoles create no considerable optics distortions

Next steps

- Contribution to coupling from roll angles and sextupole misalignments
- More realistic RF scheme

  → are there news?

- Estimation of instabilities due to low beam energy and small vertical emittance

  → Touschek effect, what else?

Thank you for your attention!

Acknowledgements:

Thanks to T. Tydecks for the tracking calculations!

Detuning with amplitude

- Detuning in first order given by

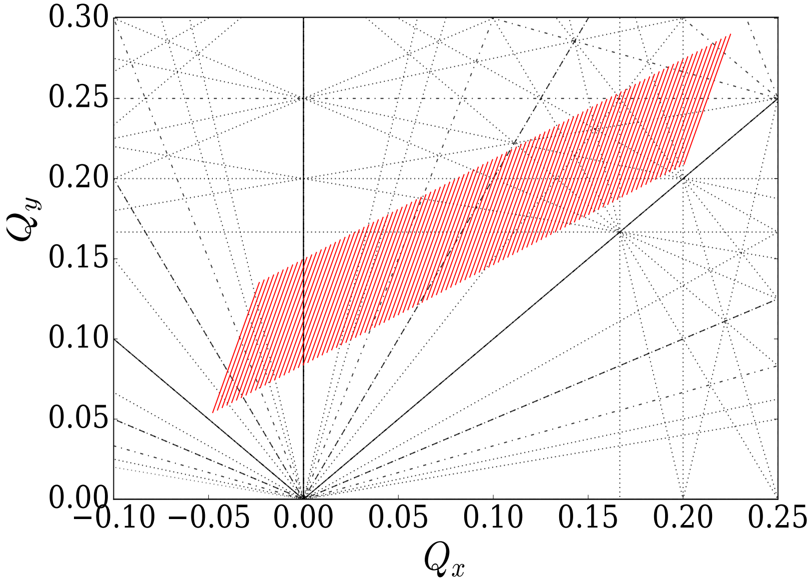
$$Q_x = Q_{x,0} + \alpha_{xx} J_x + \alpha_{xy} J_y$$

$$Q_x = Q_{x,0} + \alpha_{yx} J_x + \alpha_{yy} J_y$$

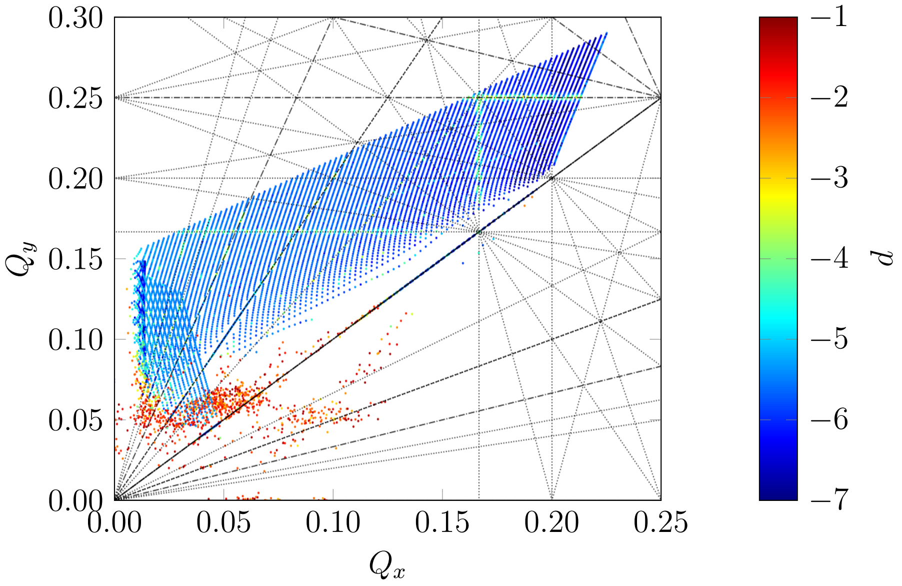
- $\boldsymbol{\alpha}_{ij}$ are the detuning coefficients, *J* the action

- Detuning coefficients (also higher orders) can be quickly calculated with PTC_normal

Tune footprints of 60°/60° optics



Analytic calculation based on first order PTC_normal results



Tracking results