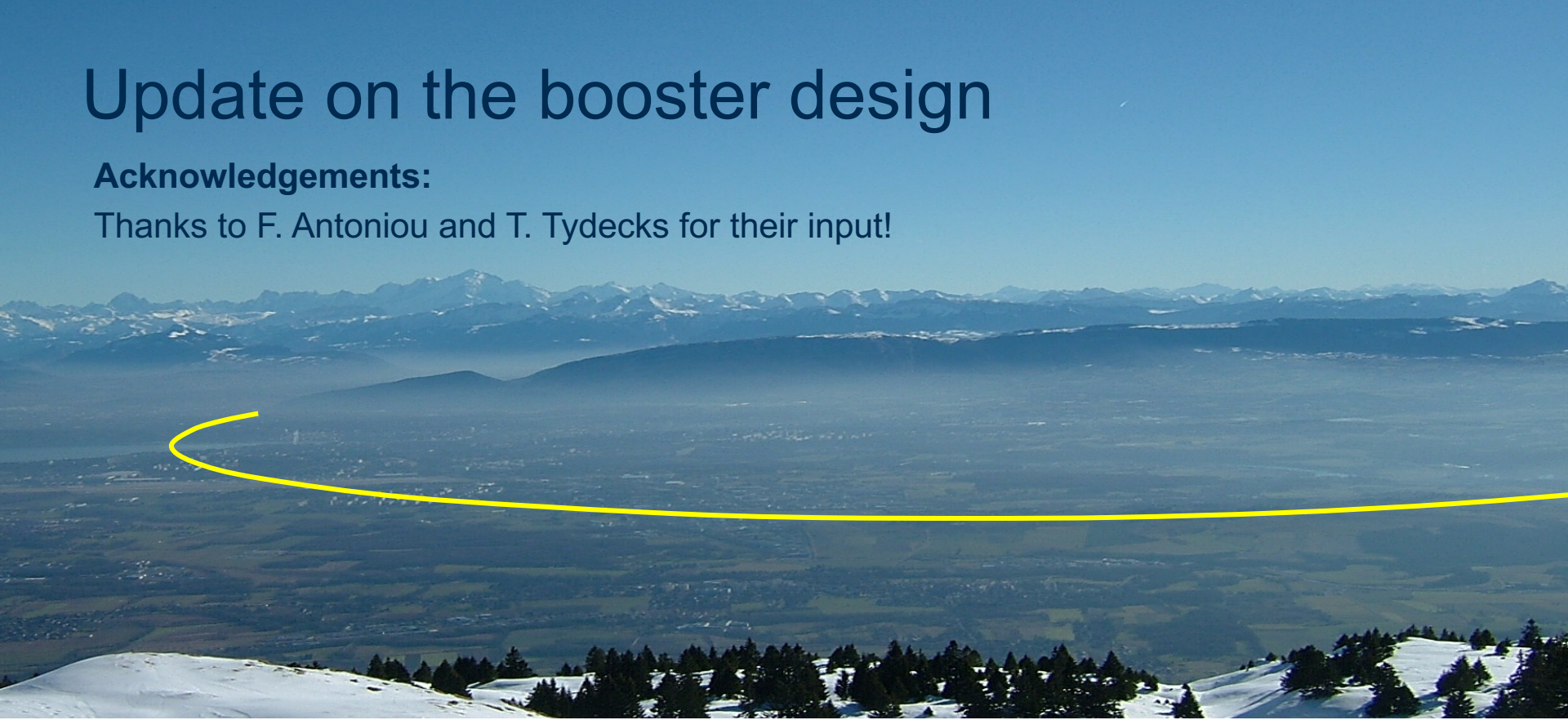
Update on the booster design

Acknowledgements:
Thanks to F. Antoniou and T. Tydecks for their input!



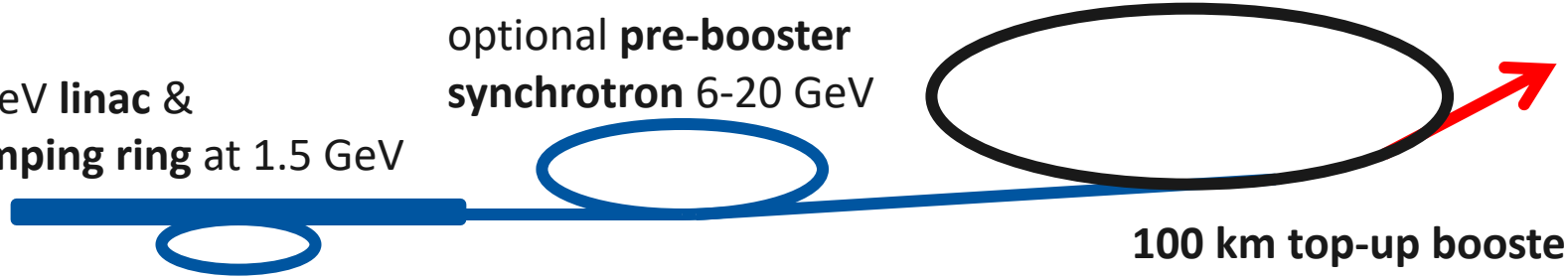
4th FCC Week Amsterdam
12 April 2018

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

What is new since Berlin?

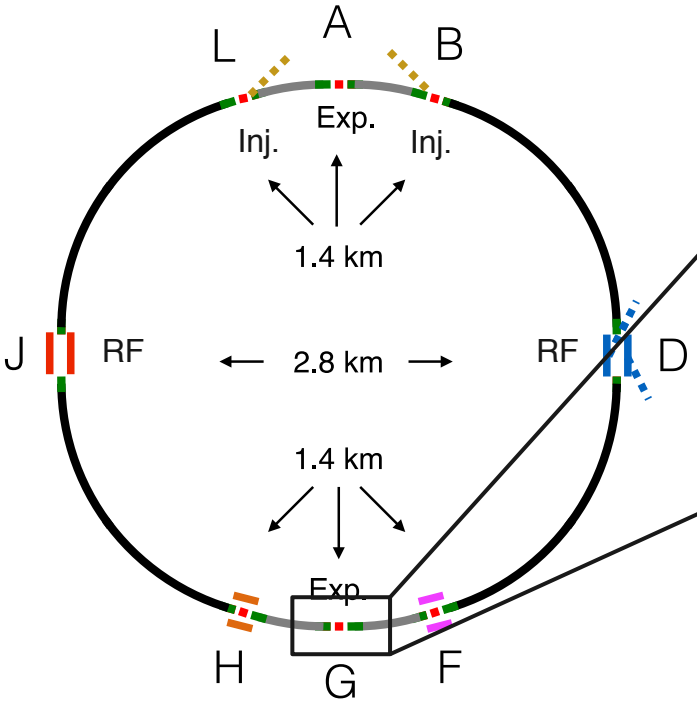
1. New parameters for injector chain
2. Lattice and optics update
3. We converged on 20 GeV injection energy
4. Wigglers were installed to mitigate IBS and decrease damping time at injection energy
5. Dynamic aperture studies

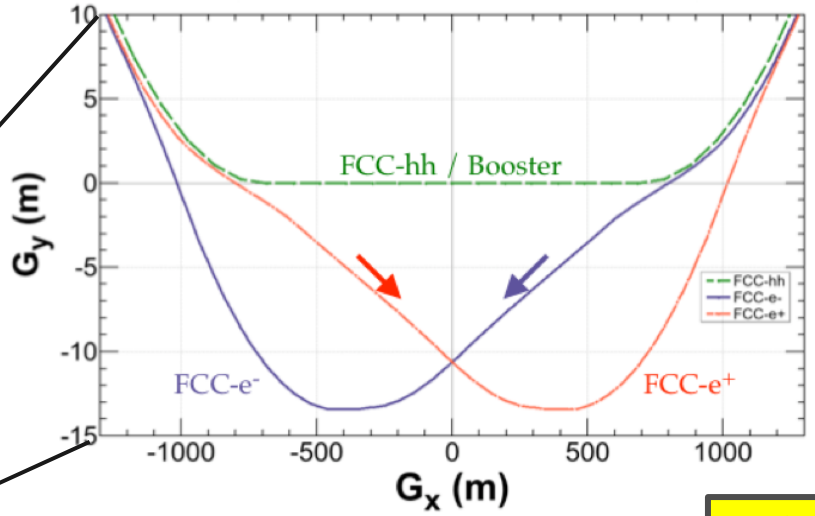
Parameter overview



Accelerator	**FCCee-Z**		**FCCee-W**		**FCCee-H**		**FCCee-tt**	
Energy [GeV]	45.6		80		120		182.5	
Type of filling	Full	Top-up	Full	Top-up	Full	Top-up	Full	Top-up
BR # of bunches	16640		2000		393		39	
BR cycle time [s]	51.74		14.4		7.53		5.49	
#of BR cycles	10	1	10	1	10	1	20	1
Filling time (both species) [sec]	1034.8	103.5	288	28.8	150.6	15.06	219.9	11.0
Injected bunch population [10^{10}]	3.3	0.16	6.0	0.12	8.0	0.16	16.9	0.34

Layout

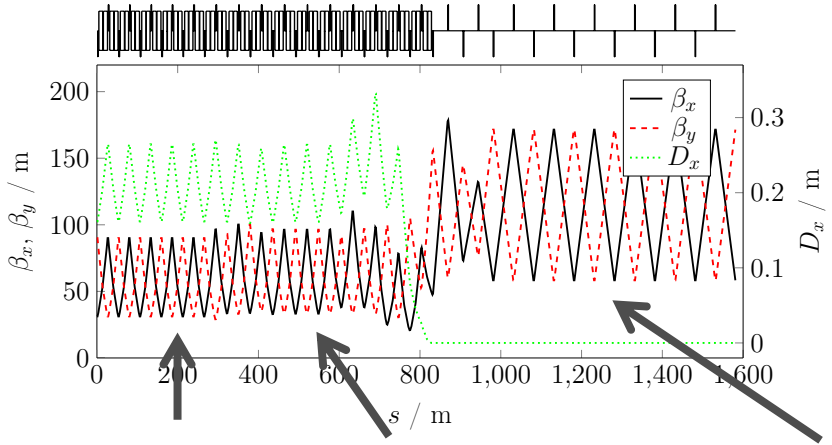




K. Oide

The layout of the booster follows the footprint of FCC-hh
→ inside of the experiments

Lattice and optics



- 90°/90° optics for *H* an *tt*
- 60°/60° optics for *W* and *Z*

- Non-interleaved sextupole scheme, 1 family per plane

Long arcs
$L_{cell} \approx 54$ m
R = 13.15 km

FCC-hh
disp. suppressor
$L_{cell} = 56.6$ m
R = 15.06 km

Straight section
with RF
$L_{cell} = 100$ m

Equilibrium emittances

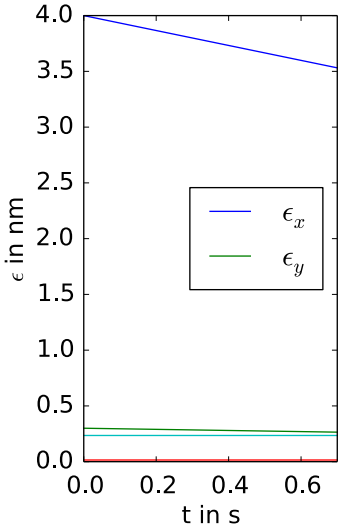
beam energy (in GeV)	emittance booster (in nm rad)	emittance collider (in nm rad)	
182.5	1.30	1.48	90°/90° optics
120.0	0.55	0.63	
80.0	0.73	0.84	60°/60° optics
45.5	0.24	0.24	

Low synchrotron radiation at 20 GeV beam energy:

→ ε_x = 15 pm rad (90°/90° optics)

τ_x = 10.05 s

Emittance with IBS

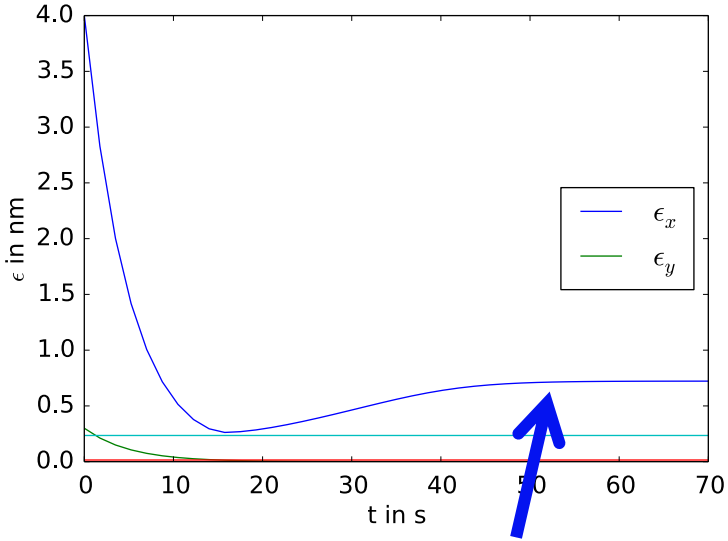


90°/90°

Hor. equilibrium emittance ε_x :

@ 45.5 GeV

@ 20 GeV



Emittances after 0.7 s

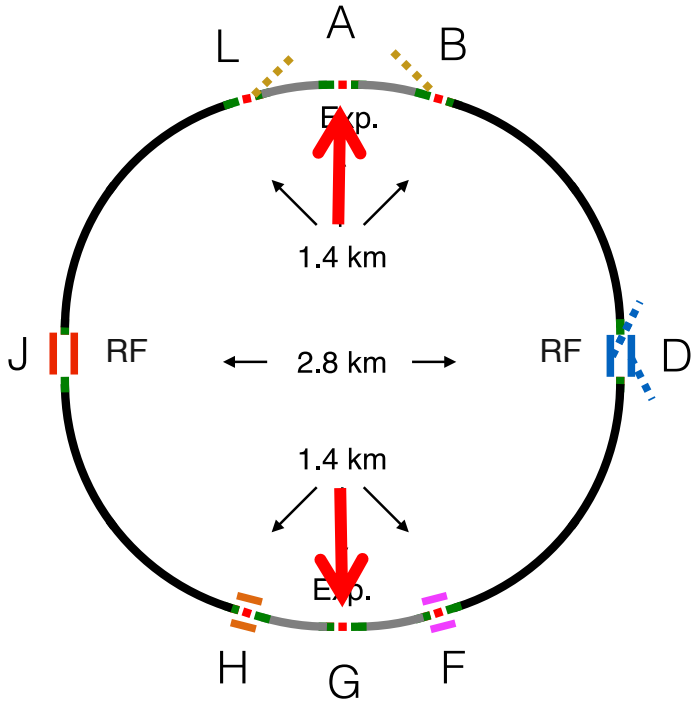
Emittance blow-up due to IBS

ε_x = 722 pm rad

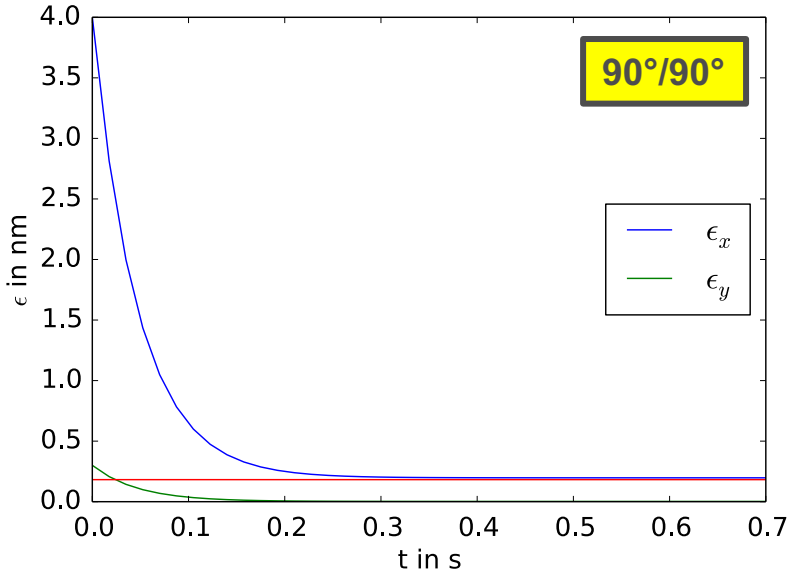
≈ 48 × ε_x without IBS

Wiggler parameters and locations

Wiggler parameters		
B_{pole}	(T)	1.8
$B_{wiggler}$	(T)	1.45
L_{pole}	(cm)	9.5
g	(cm)	5
# poles		79
L	(m)	9.065
# wigglers		16
τ_x	(s)	0.1
ε_x (60°/60°)	(pm rad)	235
ε_x (90°/90°)	(pm rad)	196



Emittance evolution with wigglers



New damping time: τ_x = 104 ms
New eq. emittance: ε_x = 196 pm rad

Emittances after 7 damping times:
ε_x = 197 pm rad
≈ 1.003 × ε_x without IBS
ε_y = 1.96 pm rad
≈ 1.000 × ε_y without IBS*

* assuming 1 % coupling

Additional synchrotron radiation

E (GeV)	U_0 (MeV)		U_0 (MeV) with wiggler	
20.0	1.3	→	126.2	✓
45.5	34.7	→	681.3	✗
182.5	9.057.1	→	19981.2	✗

- Wigglers need to be ramped down during the acceleration process
- RF voltage was increased to V_{rf} = 140 MV
- Synchrotron radiation power per wiggler: $P_w \approx 2.1$ MW (Z, full filling)

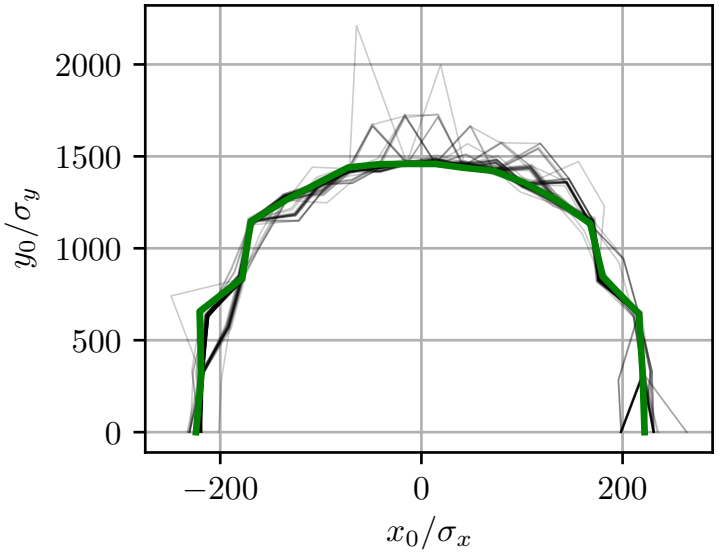
Dynamic aperture studies

The studies include

- radiation damping and quantum excitation
- 100 μm quadrupole misalignments (100 seeds)
- 55 μm resolution

and were performed for 20 GeV beam energy

DA of 60°/60° optics with misalignents



- with ε_x = 45 pm rad
  and $\beta_x = \beta_y$ = 100 m
  → x_{max} = 16.0 mm
  → y_{max} = 9.7 mm

On-axis on-energy injection foreseen.

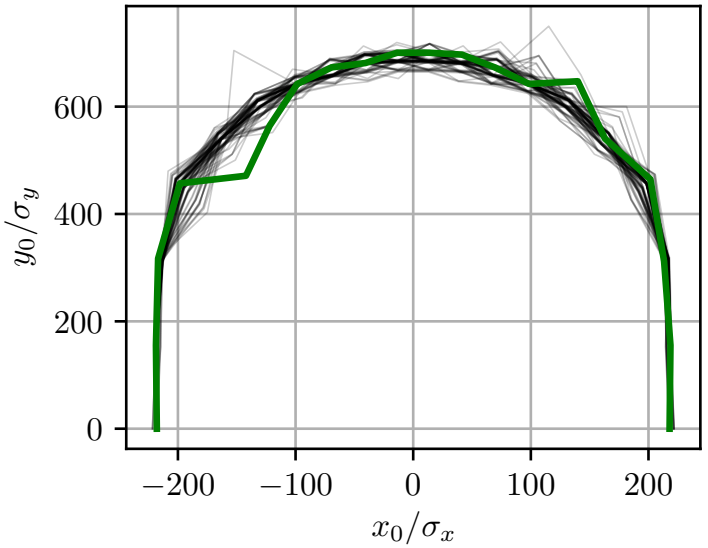
Without wigglers

Ideal lattice*

Lattice with misalignments (100 seeds)

* for 1 % coupling

DA of 90°/90° optics with misalignments



- with ε_x = 15 pm rad
  and $\beta_x = \beta_y$ = 100 m
  → x_{max} = 8.7 mm
  → y_{max} = 2.6 mm

On-axis on-energy injection foreseen.

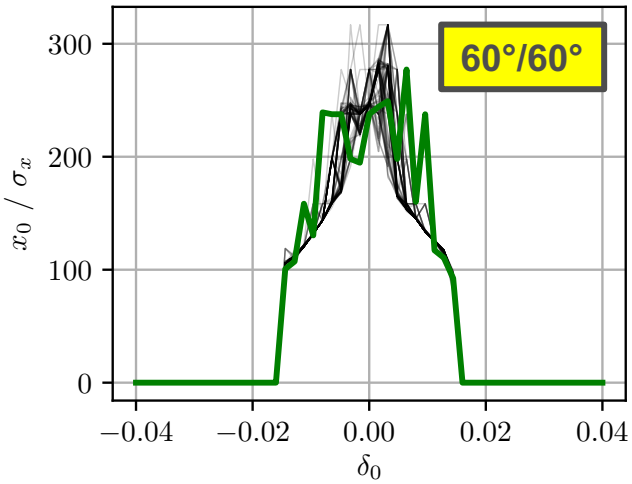
Without wigglers

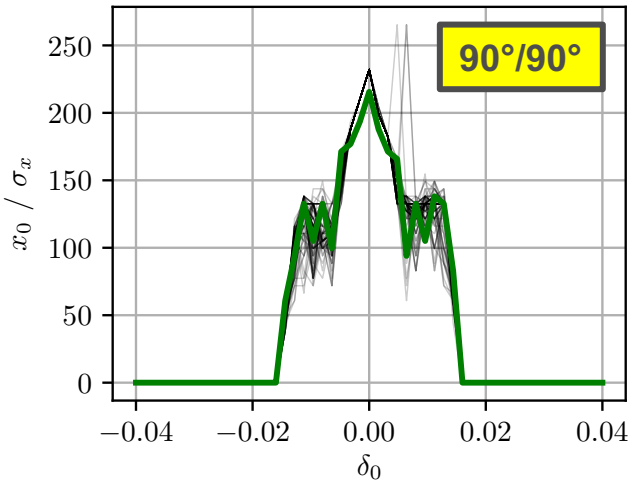
Ideal lattice*

Lattice with misalignments (100 seeds)

* for 1 % coupling

Momentum aperture





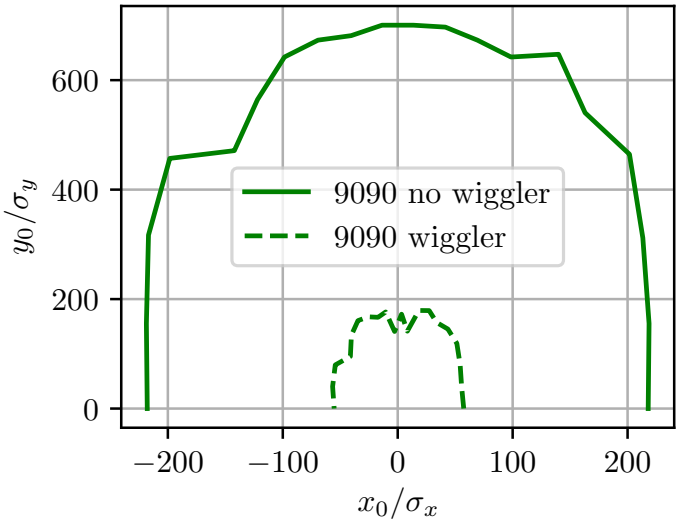
Without wigglers

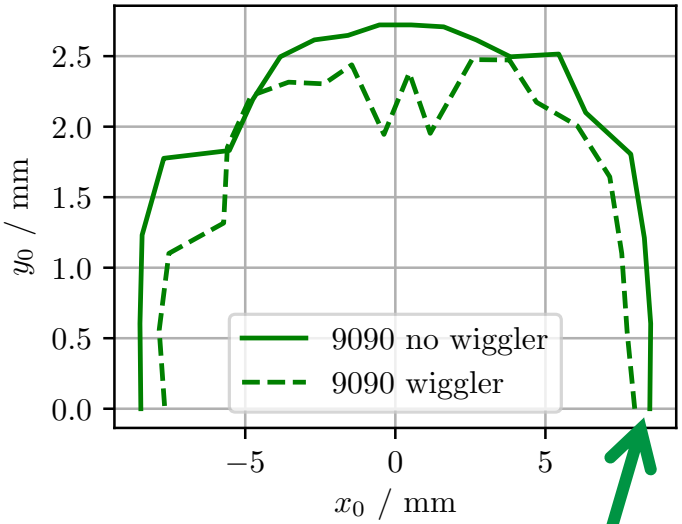
Energy spread of injected beam: σ_E/E ≈ 0.001 (pre-booster)
≈ 0.01 (linac)

DA with wigglers

Work in progress

for $\beta_x = \beta_y = 100$ m





196 pm rad (with wiggler)

Emittance ε_x = 15 pm rad (no wiggler)

0.4 mm
≃ sawtooth amplitude

Outlook

- Move wigglers to RF sections
- Finalise DA studies with wigglers
- Studies of TMCI due to resistive wall are ongoing (E. Belli)
- Tolerance studies of gradients and fields will allow to determine the minimum injection energy

Thank you for your attention!

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