Challenges of a low emittance electron beam in a high energy booster synchrotron

7th low emittance rings workshop
17 January 2018

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for the FCC-ee lattice design team

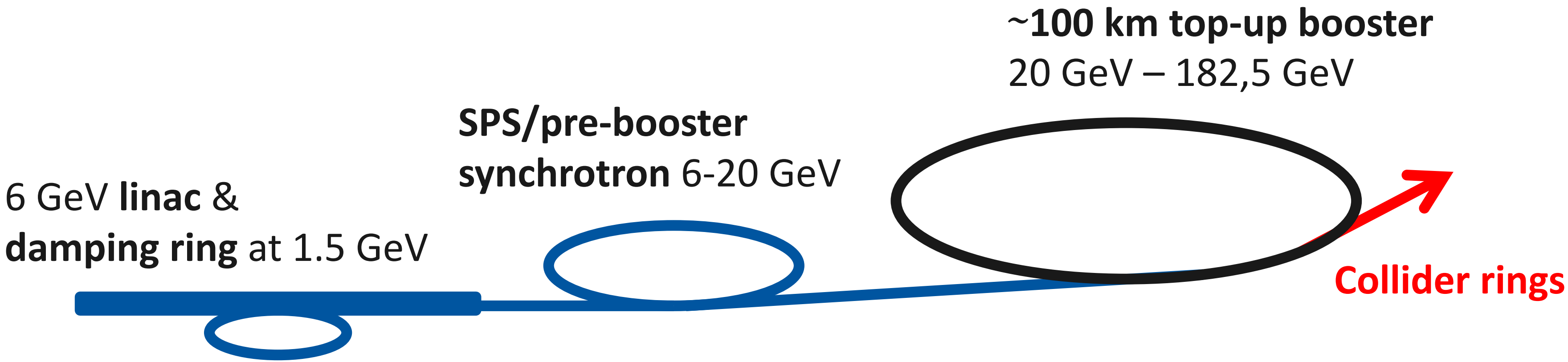
FCC-ee operation modes

100 km electron-positron collider for operation at four different centre-of-mass energies:

- Z pole: 90 GeV, $\mathcal{L} = 200 \times 10^{34}\ \mathrm{cm^{-2}s^{-1}}$
- W threshold: 160 GeV, $\mathcal{L} = 30 \times 10^{34}\ \mathrm{cm^{-2}s^{-1}}$
- ZH production mode: 240 GeV, $\mathcal{L} = 7 \times 10^{34}\ \mathrm{cm^{-2}s^{-1}}$
- ttbar threshold: 365 GeV, $\mathcal{L} = 1.3 \times 10^{34}\ \mathrm{cm^{-2}s^{-1}}$

High luminosity and constant beam losses due to radiative bhabha scattering and beamstrahlung require continuous top-up injection

FCC-ee accelerator chain



Top-up booster parameters

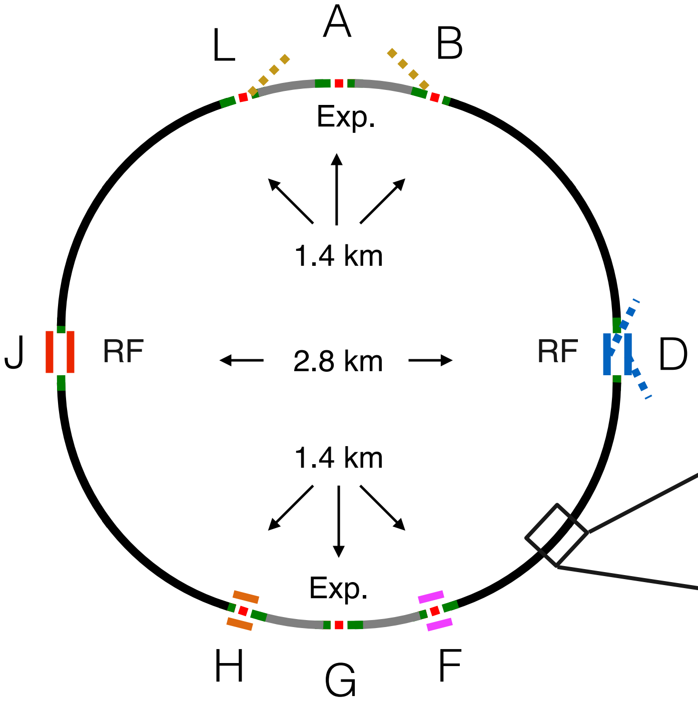
- Constraint: max. 20 min filling time
- Most challenging for 45.6 GeV

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	15.1	219.6	11.0
Injected bunch population [10^{10}]	3.3	0.16	6.0	0.12	8.0	0.16	16.9	0.34
Injected bunch charge [nC]	5.3	0.3	9.6	0.2	12.8	0.3	27.1	0.5

Full parameter table: LINK

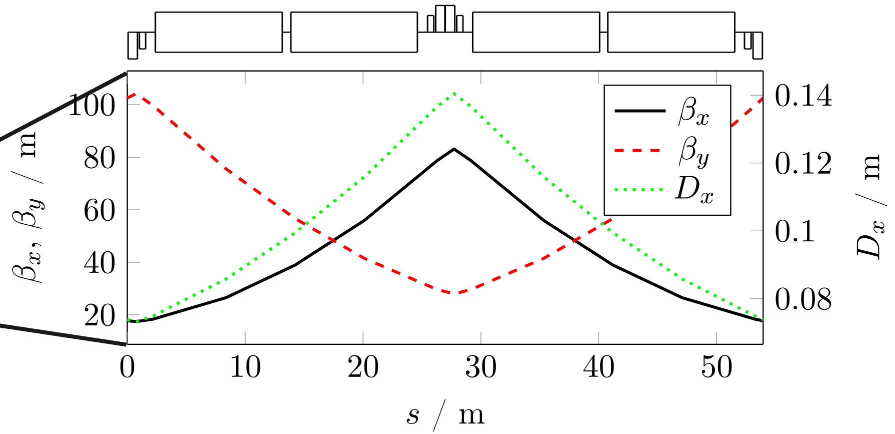
Y. Papaphilippou

FCC-ee top-up booster synchrotron



Circumference: C = 97.75 km

Bending radius: ρ = 10.5 km



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Why low emittance?

FCC-ee is designed for low emittances at high energies

- large bending radius (ρ = 10.5 km)
- small dispersion function ($D_{x,max}$ = 0.14 m)
- booster has a large energy range (20 – 182.5 GeV)

E (GeV)	U_0 (MeV)	ε_x (nm rad)	τ_x (s)
182.5	9.057.1	1.301	0.01
45.5	34.7	0.235	0.85
20.0	1.3	0.012	10.05

Issues

coming from small emittance and large damping time:

- Technical challenge: low field bending magnets (B = 6 mT)
- Long time necessary to reach equilibrium
- Strong intra-beam scattering (IBS) (max. bunch charge: 27.1 nC)
- Single-bunch instabilities?
- Wakefield effects?

First IBS study

- Start with emittances of injected beam coming from the pre-booster

$\varepsilon_{x,0}$ = 10 nm rad

$\varepsilon_{y,0}$ = 0.1 nm rad

- Iterative calculation of emittances with MAD-X IBS module for 7 damping times and 40 steps

Result

Emittances of injected beam:

$\varepsilon_{x,0}$ = 10 nm rad

$\varepsilon_{y,0}$ = 0.1 nm rad

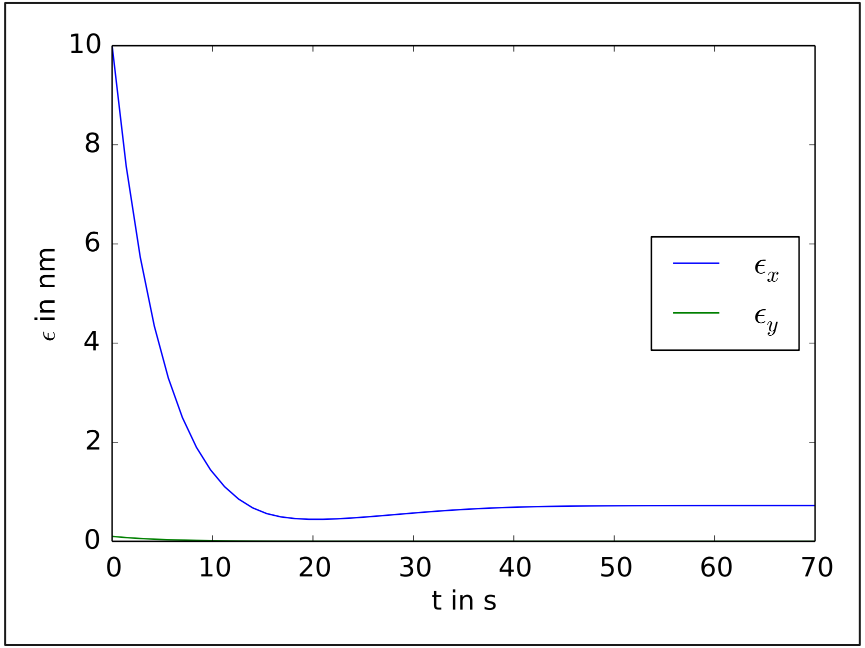
Emittances after 7 damping times:

ε_x = 722 pm rad

≈ 48 × ε_x without IBS (12 pm rad)

ε_y = 0.21 pm rad

≈ 1.4 × ε_y without IBS* (0.12 pm rad)



* assuming 1 % coupling

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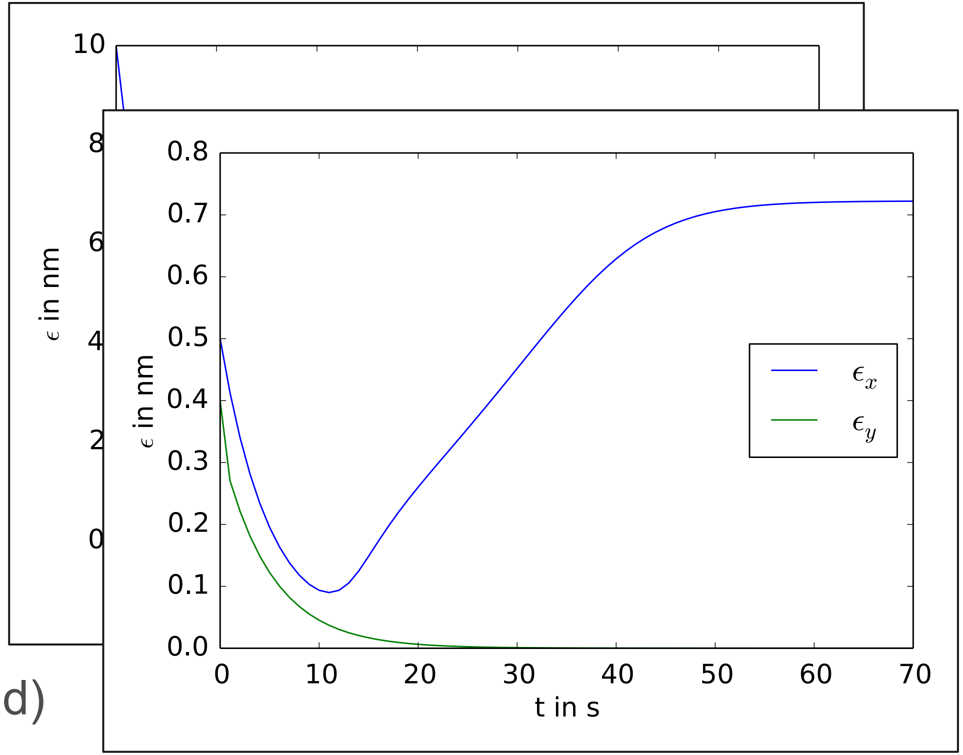

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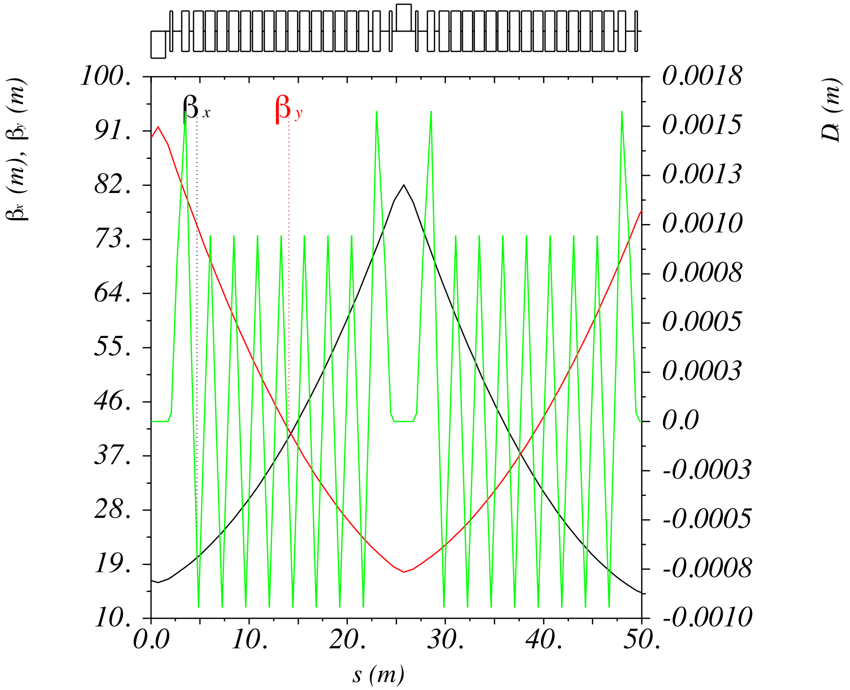
Normal conducting wiggler design



Two purposes:

1. Decrease the damping time
2. Increase the equilibrium emittance

Wiggler length:	22.6 m
Magnetic field:	0.36 T
Number of poles:	19
Pole length:	1 m
Number of wigglers:	112

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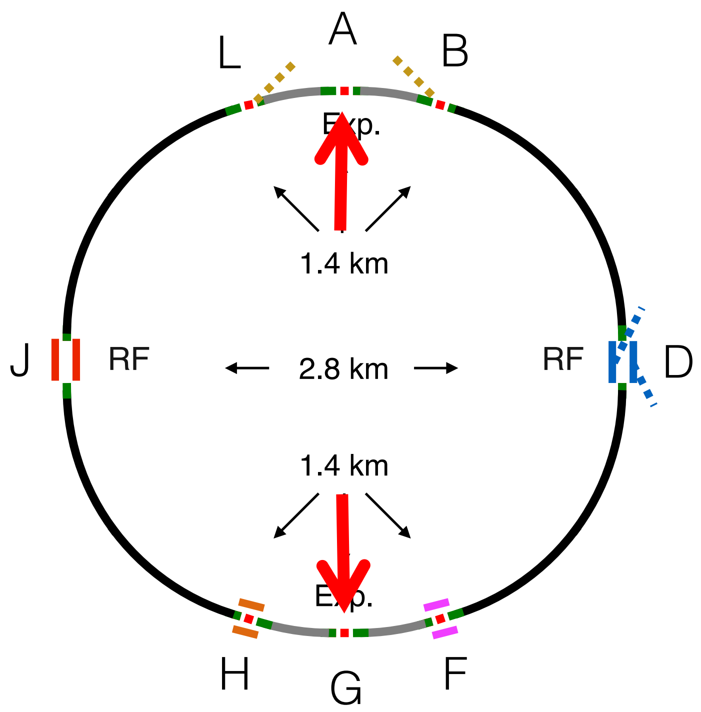

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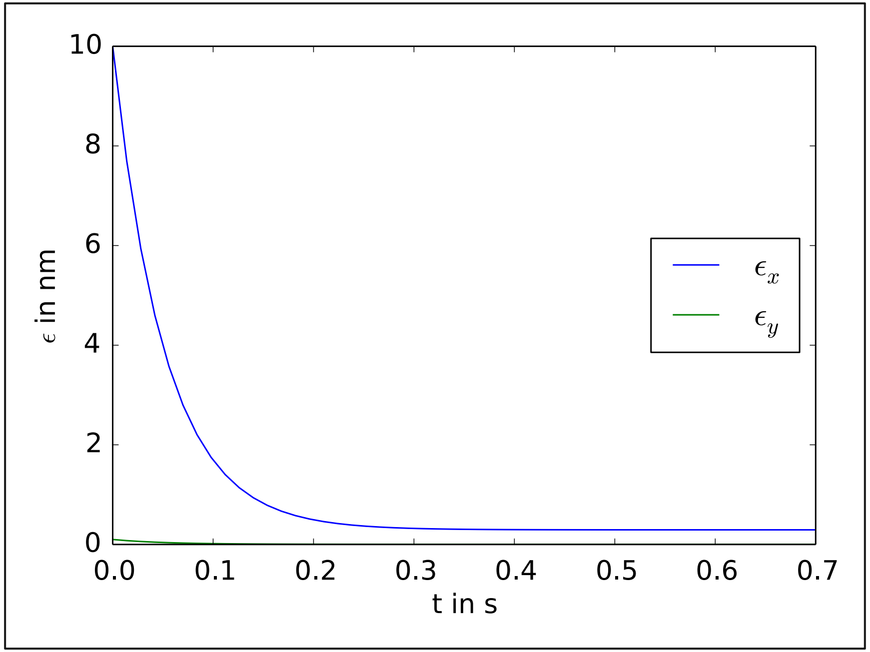
Emittance evolution with wigglers



New damping time: τ_x = 104 ms

New eq. emittance: ε_x = 292 pm rad

Emittances after 7 damping times:

ε_x = 293 pm rad

≈ 1.005 × ε_x without IBS

ε_y = 2.93 pm rad

≈ 1.000 × ε_y without IBS*

* assuming 1 % coupling

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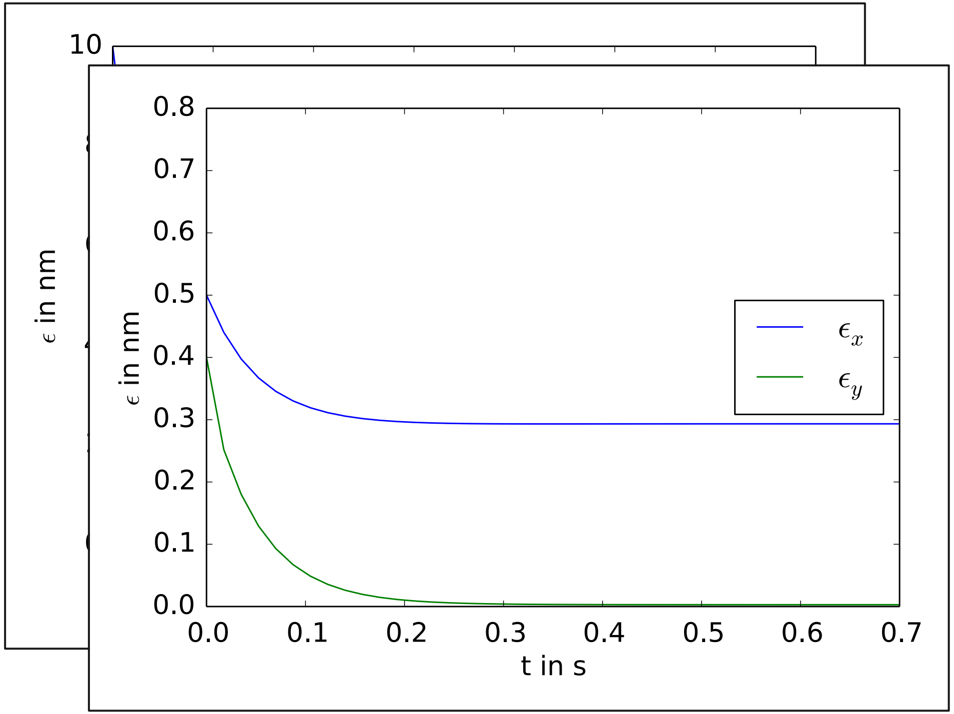

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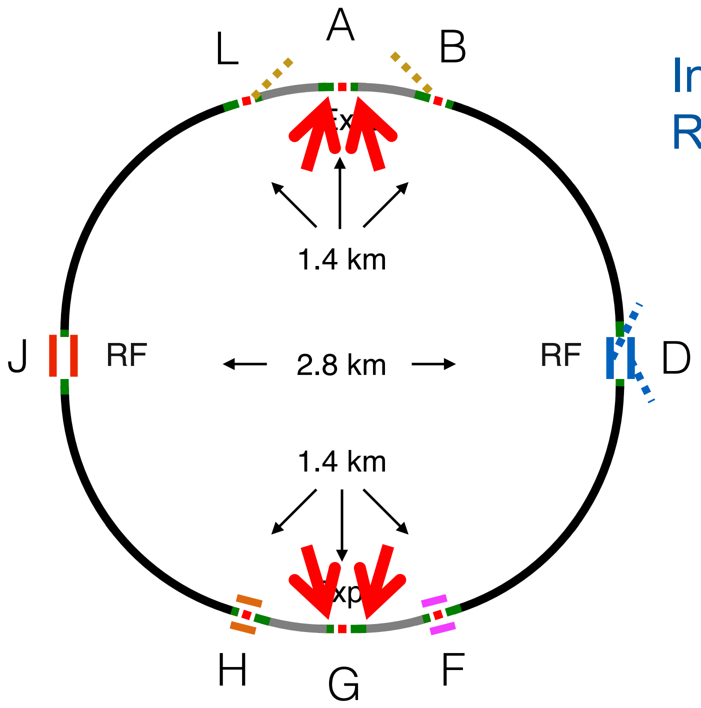
Issues of first wiggler design

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	✗

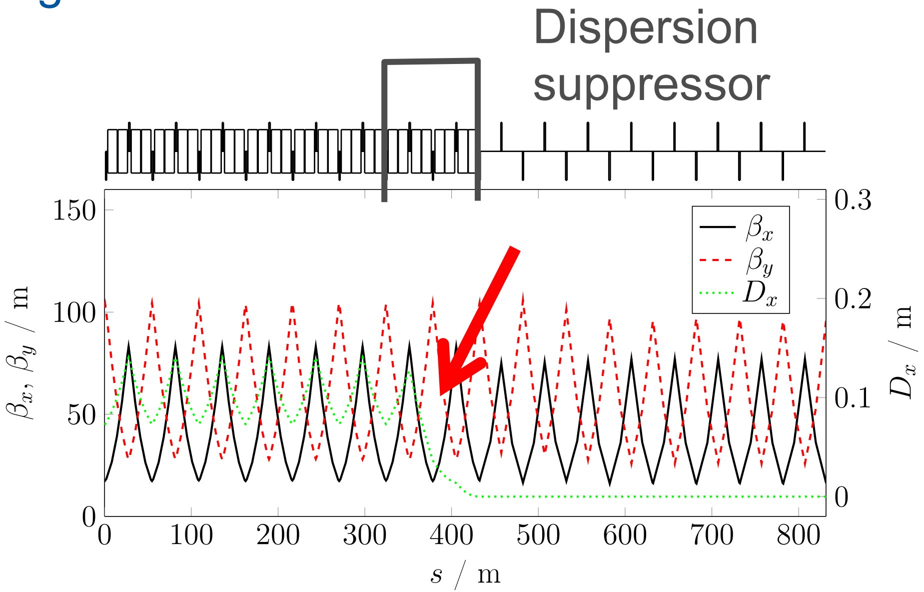
- Wigglers need to be ramped down during the acceleration process
- The number of wigglers (112) should be reduced

→ Magnetic field can be increased

Superconducting wiggler proposal



Increase magnetic field: B = 3 T
Reduce length: L ≈ 5 m



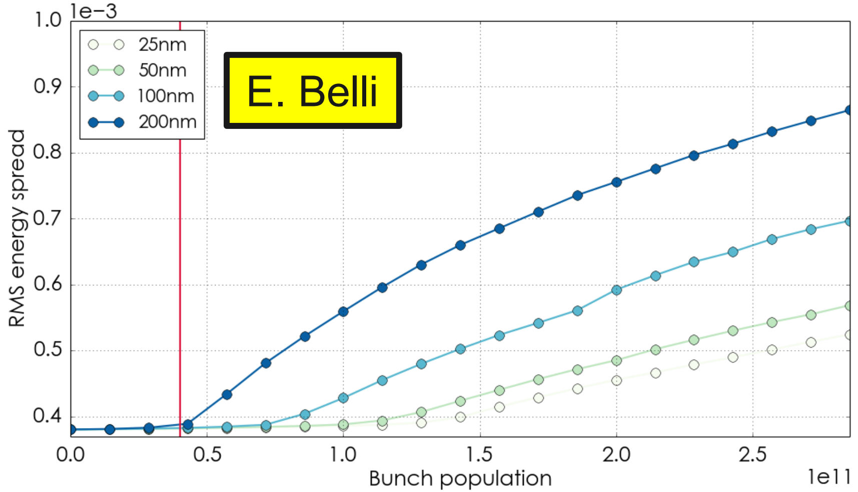
Next step: single-bunch instabilities

To be investigated soon:

Longitudinal microwave instability

Keil-Schnell-Boussard criterion:

$$\left|\frac{Z_{||}(n)}{n}\right| \leq \frac{2\pi^{3/2}E}{ce^2}\alpha_c\frac{\sigma_z}{N_p}\sigma_{dp}^2$$



RMS energy spread for different thickness of NEG-coating (main collider rings)

Needs to be checked for 20 GeV injection energy
Update of RF scheme is under way

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Summary

- FCC-ee is designed for low emittances
  → Booster with its high energy range reaches 12 pm rad
- Damping time needs to be decreased
- Horizontal emittance need to be increased to avoid emittance blow-up due to IBS
- First excitation wiggler design successfully tested
- SC wiggler design under investigation in order to reduce number of insertion devices

Thank you for your attention!

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