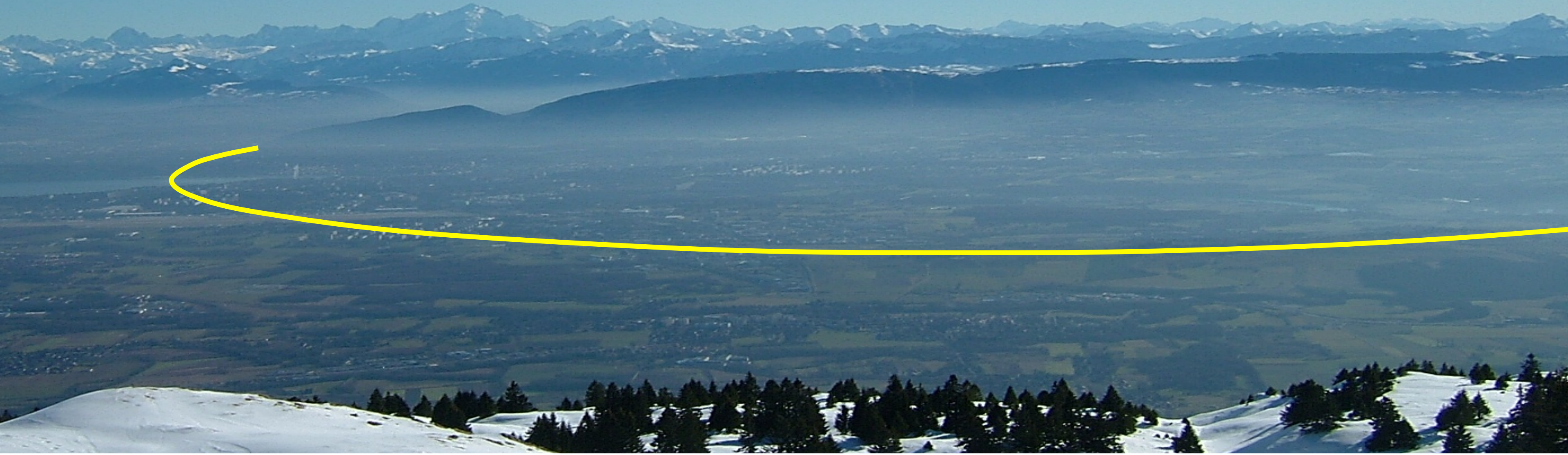
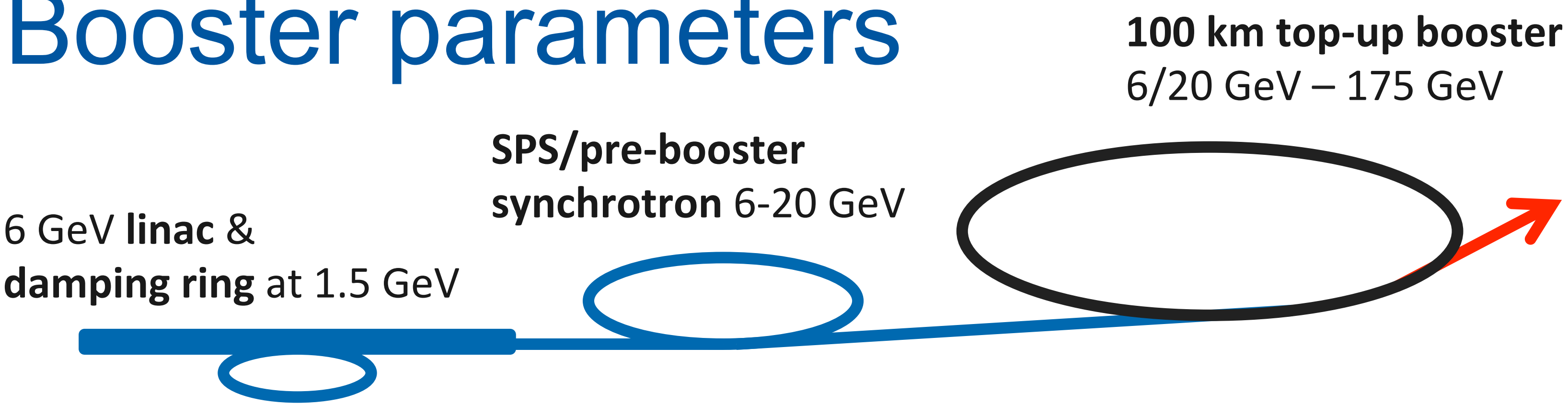
A first lattice for the FCC-ee top-up booster synchrotron



FCC Week Berlin
1 June 2017

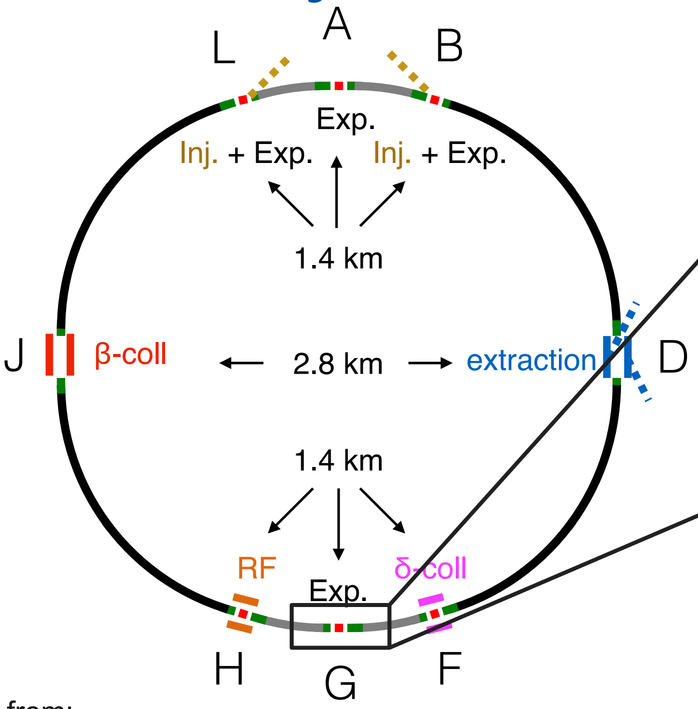
Bastian Haerer (CERN)
for the FCC-ee lattice design team

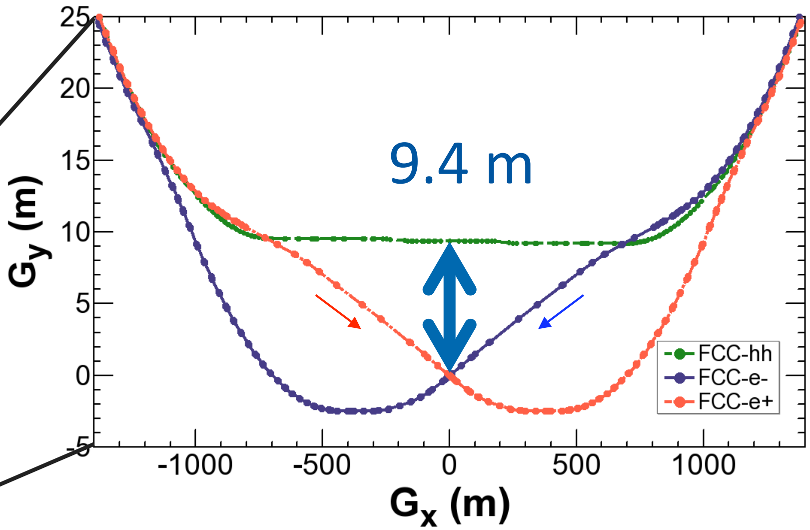
Booster parameters



Accelerator	FCCee-Z		FCCee-W		FCCee-H		FCCee-tt	
Energy [GeV]	45.6		80		120		175	
Type of filling	Full	Top-up	Full	Top-up	Full	Top-up	Full	Top-up
BR # of bunches	7100	35500	5260		60	780	62	
BR cycle time [s]	26.75	97.75	68.6		7.1	20.3	7.12	
#of BR cycles	20	2	4	1	13	1	10	1
Total number of bunches	71000		5260		780		62	
Filling time (both species) [sec]	1070	391	548.8	84.6	184.6	40.6	142.4	14.2
Injected bunch population [10^{10}]	4.3	0.21	6.0	0.12	8.0	0.16	22.1	0.44

FCC Layout

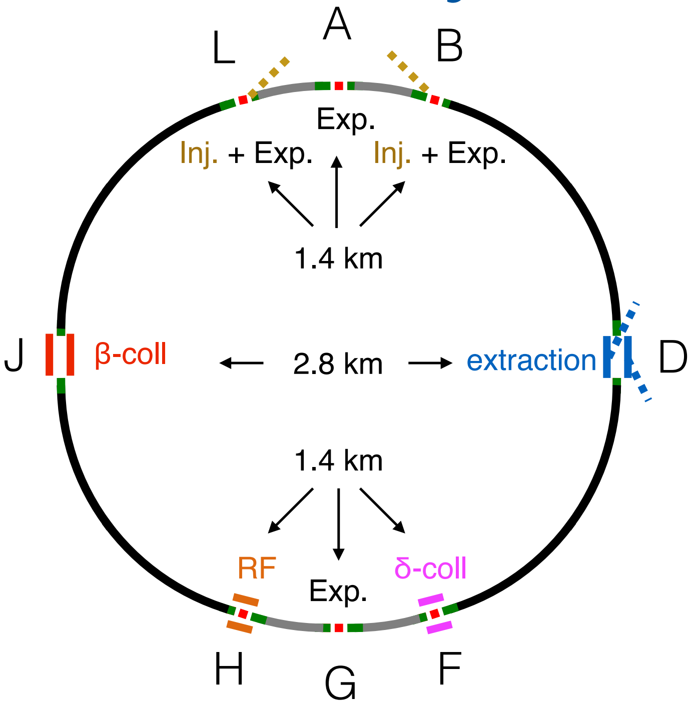




The layout of the booster follows the footprint of FCC-hh
→ inside the experiments

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.

FCC-ee Layout



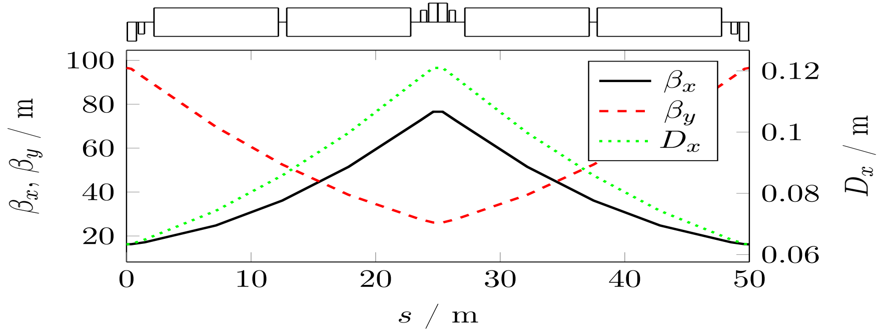
Circumference: C = 97.75 km
Bending radius: ρ = 10.5 km

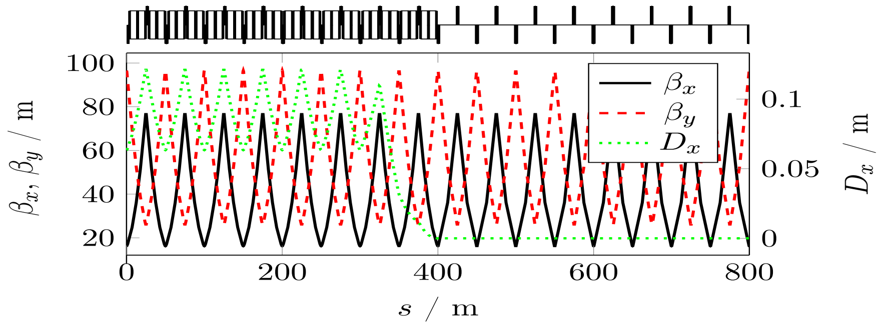
2 RF sections in points D and J
So far: 1m 5-cell cavities

→ More realistic design is coming

We would like to avoid tapering
→ To be confirmed by 6D tracking studies

Lattice





FODO cell

- L = 50 m
- φ = 90°/60°

Dispersion suppressor

- Two half-bend cells

Emittances and damping times

E(GeV)	ε_x (nm rad)	τ (s)
6.0	0.001	368
20.0	0.012	9.94
45.5	0.194	0.84
175.0	0.959	0.02

→ Very small equilibrium emittances at injection energies

→ Small emittance might lead to much intra-beam scattering

- Emittance at injection: ε_x = 0.7 nm rad
- Long damping times → will equilibrium be reached?

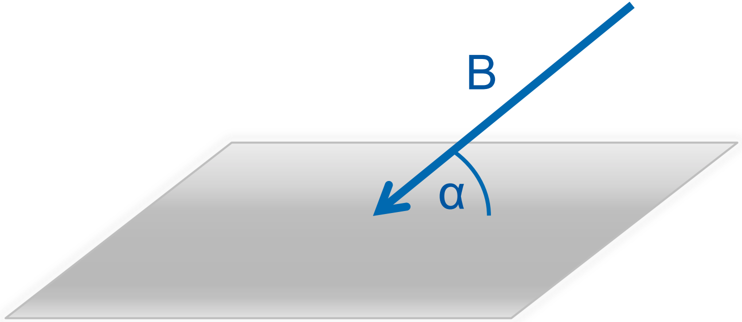
Bending fields

E(GeV)	ε_x (nm rad)	τ (s)	B (Gs)
6.0	0.001	368	19
20.0	0.012	9.94	63
45.5	0.194	0.84	145
175.0	0.959	0.02	556

- Very small bending fields feasible?
- Cross-talk between booster and collider magnets?
- How large is the effect of the earth’s magnetic field?

Earth's magnetic field

- Angle to surface: $\alpha \approx 45°$
- Magnetic field: $B \approx 0.5$ Gs



Deflection in one FODO cell (50 m):

Energy (GeV)	Deflection (mm)
6.0	4.419
20.0	1.326
45.5	0.583
175.0	0.152

→ Dedicated orbit correction system is required

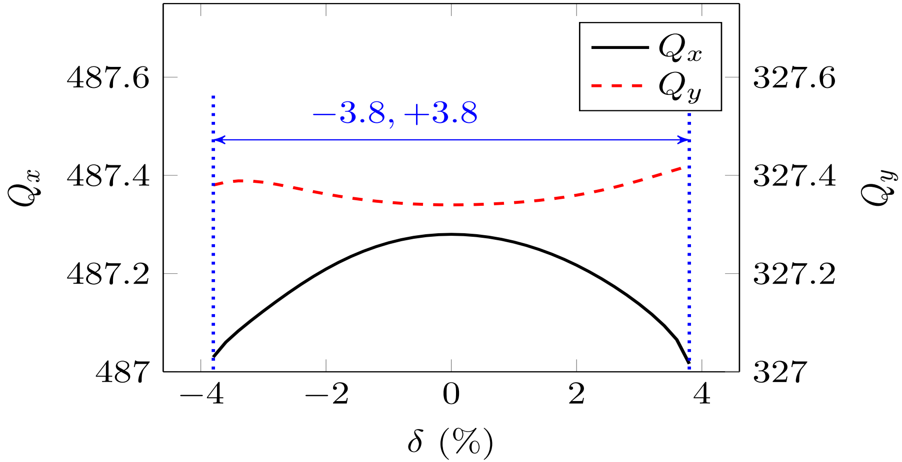
Tunes and chromaticity

Tunes (starting point):

- $Q_x = 487.28$
- $Q_y = 327.34$

Natural chromaticity

- $\xi_x = -542.01$
- $\xi_y = -450.45$



One sextupole family per plane

→ Momentum acceptance (Twiss)

[-3.8%, +3.8%]

First tracking studies

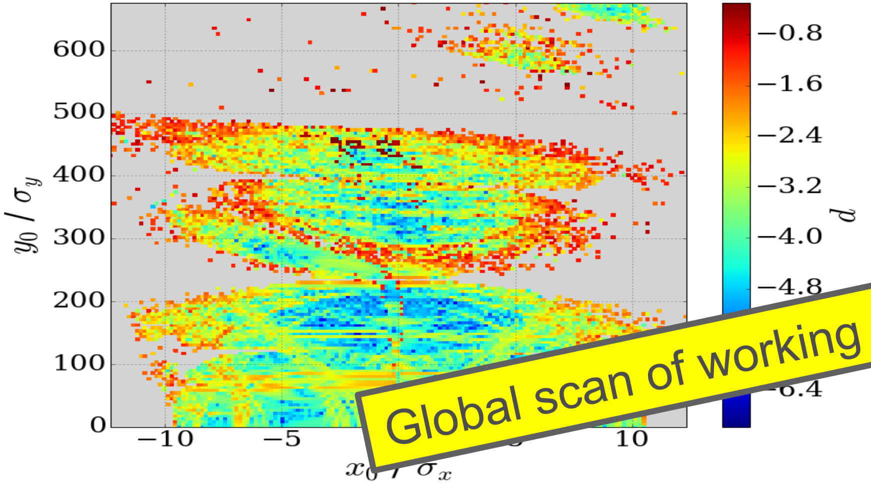
- Tracking performed together with Tobias Tydecks with PTC
  → 512 turns, 175 GeV beam energy, without synchrotron radiation & rf, without energy deviation and imperfections

- NAFF (Numerical Analysis of Fundamental Frequencies) analysis in cooperation with Panos Zisopoulos

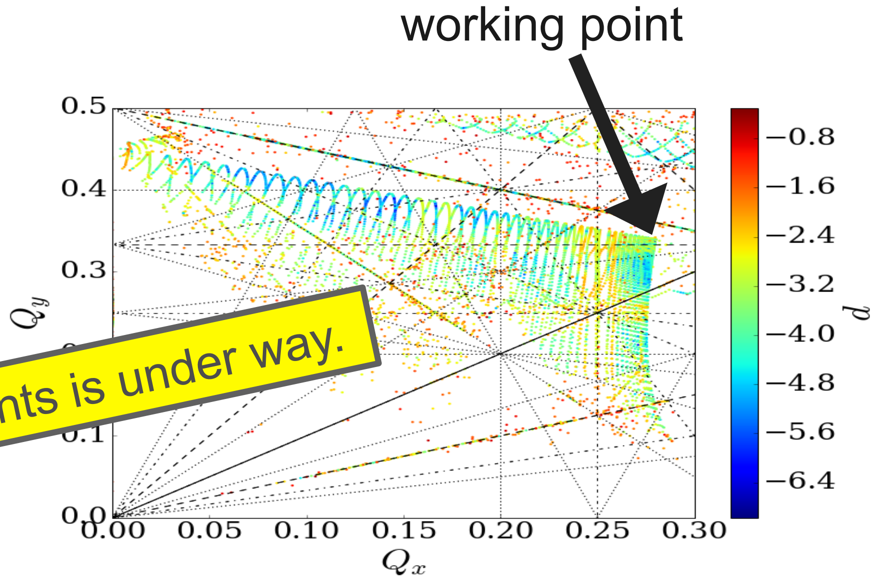
- → Calculation of dynamic aperture and optimisation of the working point

Y. Papaphilippou, Detecting Chaos in Particle Accelerators through Frequency Map Analysis Method, Chaos 24 (2014) 024412, 2014
J. Laskar, *Frequency map analysis and particle accelerators*, Proceedings of the 2003 Particle Accelerator Conference, 2003, pp. 378-382 Vol.1.

175 GeV, working point .28/.34



Diffusion rate d



Tune diagram

Global scan of working points is under way.

DA: horizontal: ±10 σ
vertical: ±220 σ

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

Future steps

- Increase dynamic aperture
  → more sophisticated sextupole scheme
- Tracking including energy deviation and imperfections

- Check technical feasibility of low-field magnets

- Evolution of the hor. emittance during the filling process
- Collective effects → intra-beam scattering
- Effects of impedances → limits to the beam current

- Prepare lattice for injection and extraction elements

Thank you for your attention!

Acknowledgements:

Thanks to B. Holzer, Y. Papaphilippou, K. Oide, T. Tydecks and P. Zisopoulos for their input!