Challenges and status of the rapid Cycling Top-up Booster for FCC-ee

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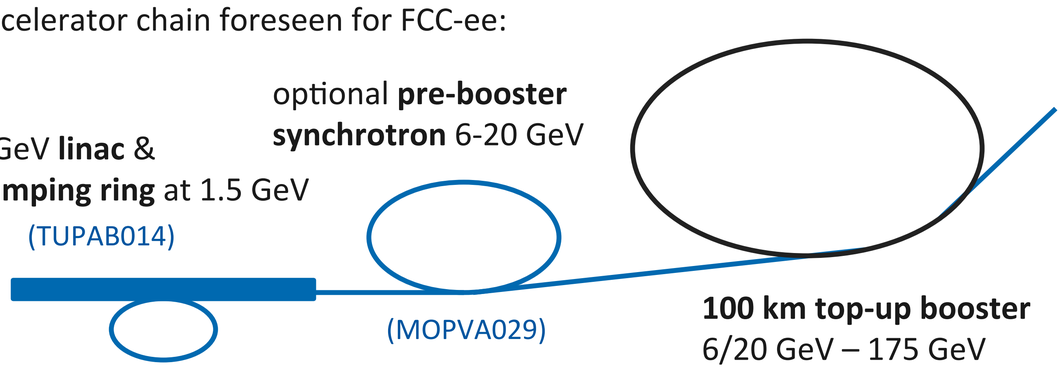
Abstract

FCC-ee is a 100 km e^+e^- collider, which is being designed within the Future Circular Collider Study (FCC) for precision studies and rare decay observations in the range of 90 to 350 GeV centre-of-mass energy. The beam lifetime will be limited to less than one hour, because of radiative Bhaba scattering and beamstrahlung. In order to keep the luminosity on the high level of 10^{35} $cm^{-2}s^{-1}$ continuous top-up injection is required. Therefore, besides the collider, that will operate at constant energy, a fast cycling booster synchrotron will be installed in the same tunnel. The injection energy to the booster synchrotron will be around 6 to 20 GeV. Such small energies together with the large bending radius not only create an ultra-small beam emittances, but also requires very low magnetic fields close to the limit of technical feasibility.
This poster focuses on the challenges and requirements for the top-up booster design arising from low magnetic fields and collective instabilities and present the status of the lattice design.

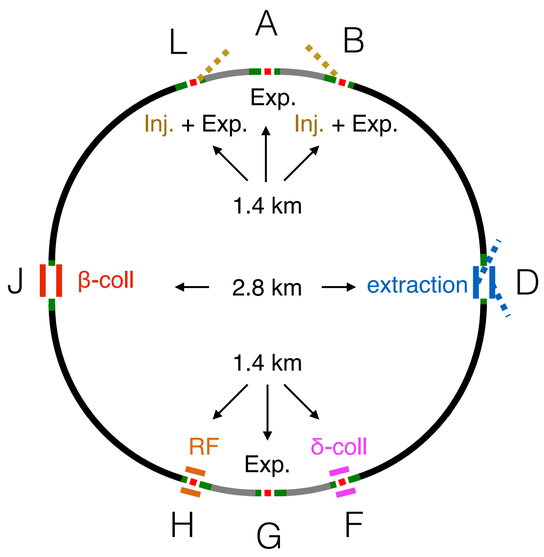
FCC-ee injector chain

Accelerator chain foreseen for FCC-ee:

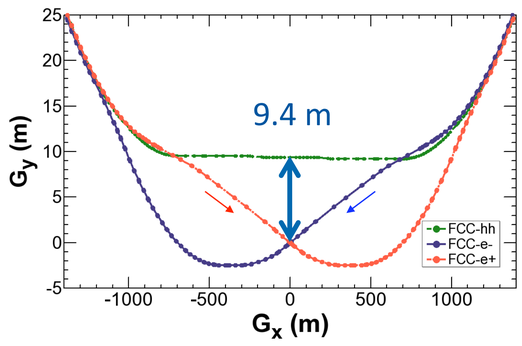


Top-up injection every 10 (14) s for electrons (positrons)

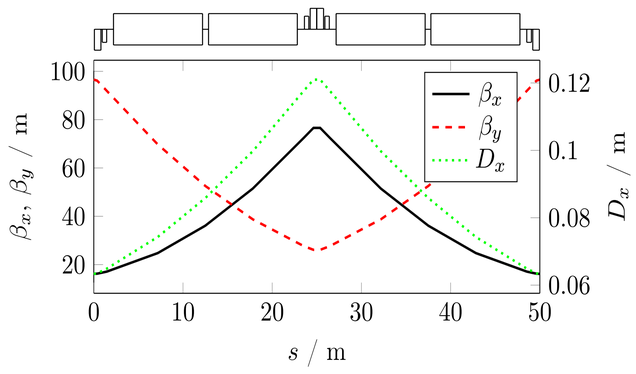
Layout and lattice



- Layout must be compatible with FCC-hh shown on the left
- **Circumference: 97.6 km**
- RF will be installed in Points D and J

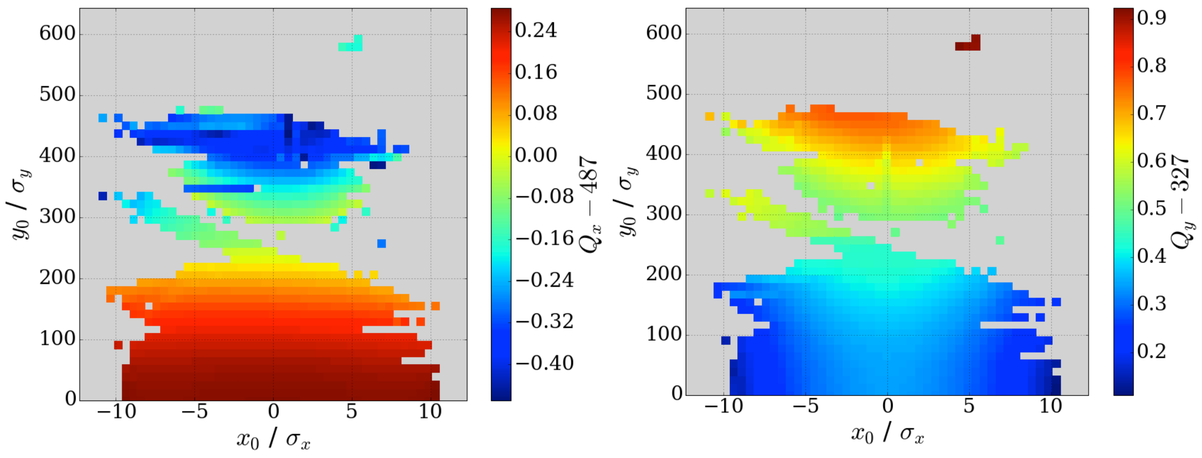


- Bypasses around the detector will follow the footprint of FCC-hh



- 50 m FODO cell with Ψ = 90°/60° phase advance
- Sextupoles on each side of the quadrupoles

First tracking studies



First tracking studies:

- 175 GeV beam energy
- 512 turns (20 damping times)
- no misalignments
- no momentum offset

- **Dynamic aperture** determined by survival of particles:
  ±10 σ in horizontal plane
  ±200 σ in vertical plane
- In horizontal plane limited by vertical tuneshift with amplitude

Challenges for the booster design

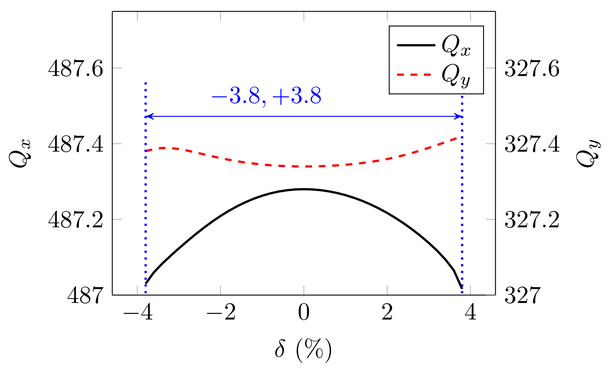
E(GeV)	B (Gs)	ε_x (nm rad)	τ (s)
6.0	19	0.001	368
20.0	63	0.012	9.94
45.5	145	0.194	0.84
175	556	0.959	0.02

- Stable beam dynamics required for a **large range of beam energies**
- **Small bending fields** require special low field magnets
  6 GeV: 19 Gs or 20 GeV: 63 Gs
- **Small beam emittances** might lead to strong intra-beam scattering and single-bunch instabilities
- **Large synchrotron radiation power (50 MW)** and **high high critical energy (~1 MeV)** require sophisticated absorber design and radiation protection
- Low number or RF stations makes the adjustment of the magnet strengths to the local beam energy to avoid sawtooth orbit necessary
- Different injection schemes are under investigation [1]

Tunes and chromaticity

- Tunes are adjusted by FODO cell phase advance in the straight sections D and J
- **Horizontal tune: Qx = 487.28**
- **Vertical tune: Qy 327.34**

- Chromaticity matched to zero with **one sextupole family per plane**
- **Momentum acceptance: δ ± 3.8 %**



Conclusions

A first lattice for the FCC-ee Top-Up Booster Synchrotron was set up following the footprint of the main collider including bypasses around the experiments. A FODO cell layout similar to the one in the collider storage rings was chosen in order to obtain the same beam parameters. First tracking studies indicate sufficient dynamic aperture for short beam storage. Very small bending fields and potential single-bunch instabilities suggest to include a pre-booster synchrotron to increase the injection energy from 6 GeV to 20 GeV. Next steps in the design process will focus on the evolution of the beam emittance during the acceleration process and the investigation of instabilities at low energies.

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References:
[1] M. Aiba, Á. S. Hernándey, F. Zimmermann, " Top-up injection for FCC-ee",
CERN internal note CERN-ACC-2015-065, Geneva, Switzerland, July 2015