
CERN

FCCee top-up injection

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Outline

- Context
- What is top-up injection ?
- PB layout and optics
- Dynamic aperture
- Baseline scheme
- Conclusion

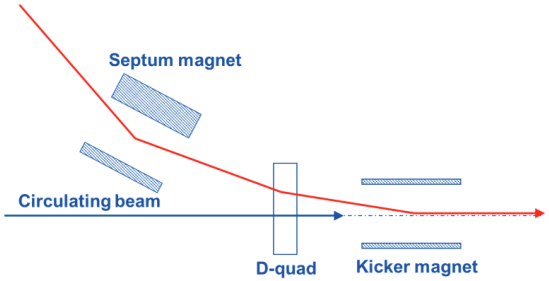
Context

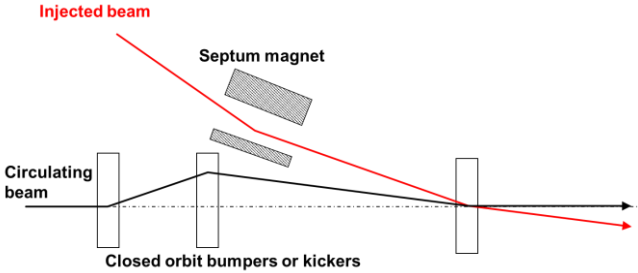
- The FCCee collider high luminosity also causes a small beam lifetime ~10-20 min [1]
  - The collider operates at constant energy and continuously receives injections from the full energy booster
  - Further constraints of the intensity imbalance between colliding bunches < 3-5% [2]
- Requirements
  - Injection efficiency goal established at 80% for the sizing of the injector chain [3]
  - High reliability and high repetition rate (every ~3s in Z-mode)

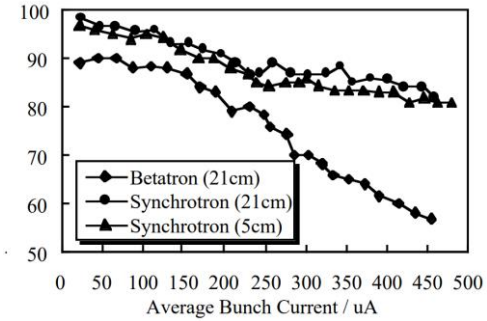
[1] K. Oide, GHC optics and collider parameters, FCCweek 2024
[2] D. Shatilov, How to increase the physics output per MW.h for FCC-ee?, 10.1140/epjp/s13360-022-02346-x
[3] H. Bartosik, meeting series FCCee injectors parameters

What is top-up injection ?

- Fast injection : used by high energy hadron synchrotrons where bunches are transferred into empty buckets
- Top-up injection : bunches are injected besides the circulating beam and rely on synchrotron radiation damping to merge with the main bunch
- Challenges of top-up injection
  - Fast bump uses kicker magnets to move the circulating beam close to the injection septum for a single turn
  - Very small beams -> sensitive to leak fields and requires small septum blade
  - The process is never 100% efficient and typically becomes less efficient as the circulating intensity increases
  - The injection efficiency is the critical parameter, depends on the beam dynamics in the whole ring far from the closed orbit -> comprehensive physics model is needed



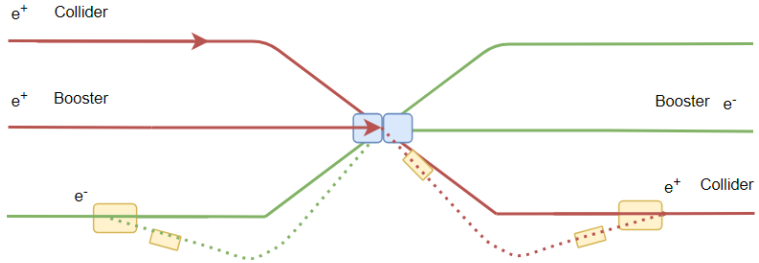


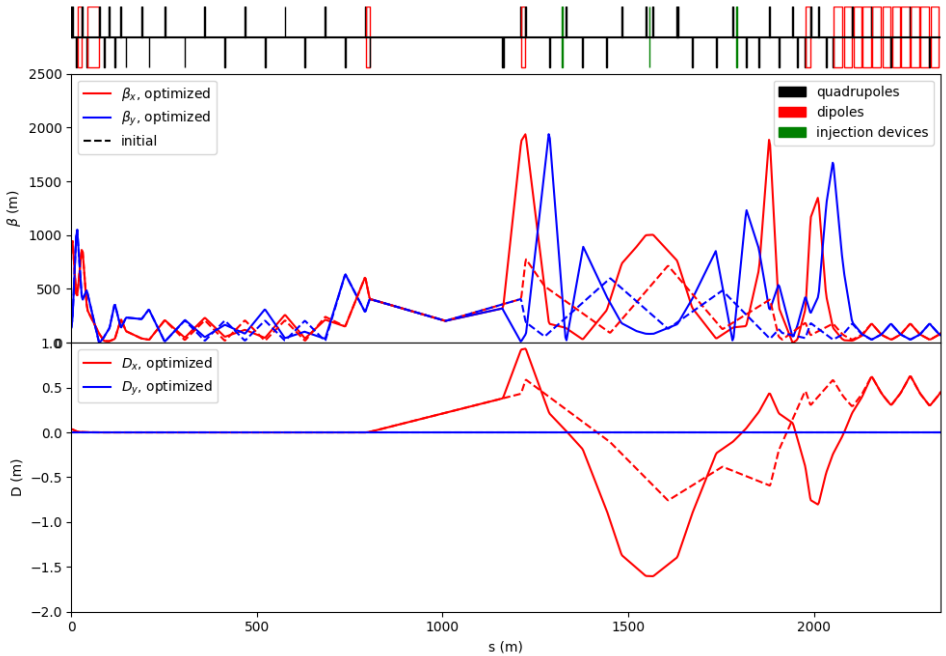


[1] Collier, Paul. "Synchrotron phase space injection into LEP." Proceedings Particle Accelerator Conference. Vol. 1. IEEE, 1995.

Top-up injection optics

- Optics constraints at the injection point
  - $\boldsymbol{D_x} = 1.4$ m and $\beta_x = 1000$ m
  - Makes use of the dispersion created by the separation dipoles at the center of the straight section
- Optics matching to the ring lattice
  - Twiss parameters are matched on both sides of the straight section
  - Phase advance across the straight section matched
  - No matching of the W function
- Large D_x and β_x
  - Reducing the requirement on energy offset
- $\boldsymbol{\pi}$ mode bump
- Effects in ring dynamics
  - No significant effect observed in late 2023 on GHC lattice (MR59) **(not true anymore !)**
  - Systematic validation of the injection optics is required

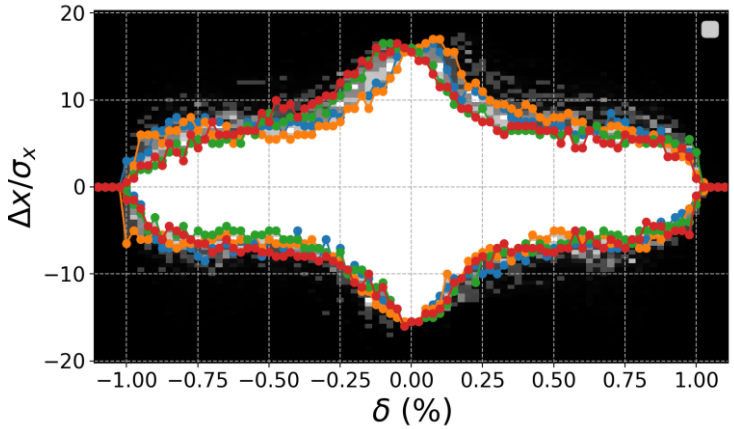




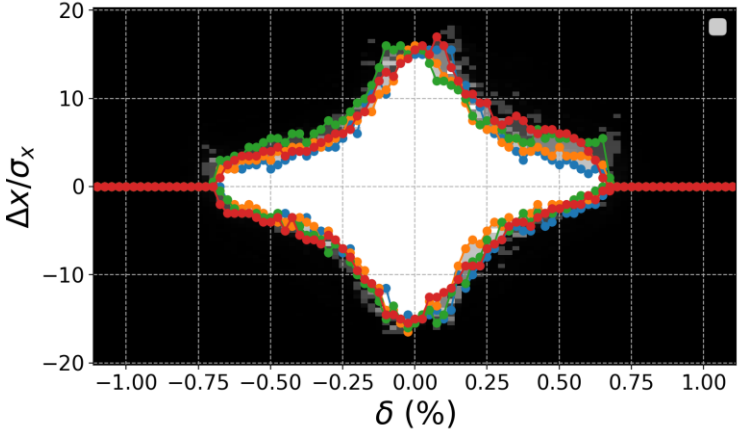
Dynamic aperture (DA)

- Initial concept aims at on-axis injection with 1% energy offset
  - On axis injection injects on the chromatic closed orbit an minimizes the injected beam offset around the experiments -> favored scheme
  - Off-axis scheme injects besides the circulating beam, with a betatron offset
- Not possible due to the significant reduction of DA with the present injection optics

DA without injection optics



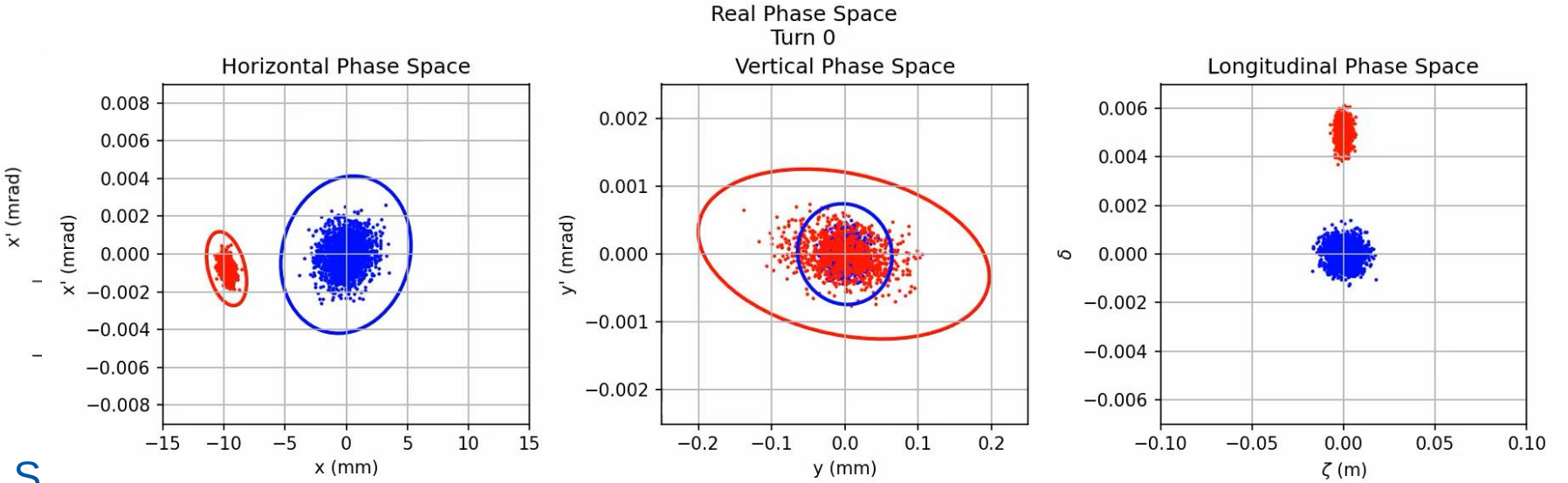
DA with injection optics



- Status
  - Ongoing discussions with K. Oide for the injection optics design
  - Baseline scheme switched to hybrid on-off axis with lower injection energy offset

Baseline scheme

- Due to limited momentum acceptance of the lattice with injection optics, feasibility of hybrid on-off axis injection was studied.
- On the hybrid injection scheme, injected beam has an energy offset as well as a horizontal offset with respect to off-energy orbit: $\boldsymbol{\Delta x_{offset}} = 5\sigma_{cir} + S + 5\sigma_{inj} - |D_x\delta|$



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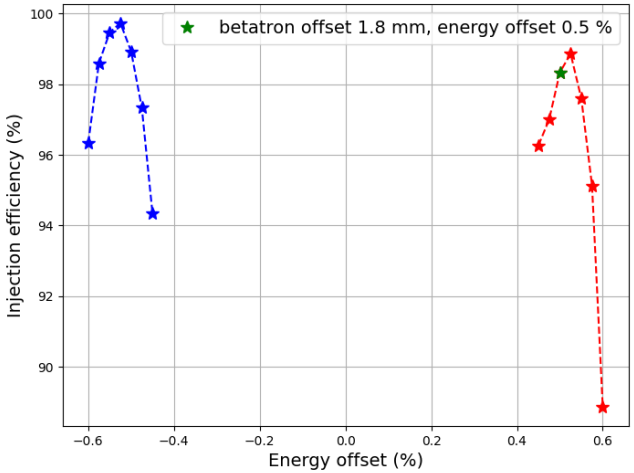
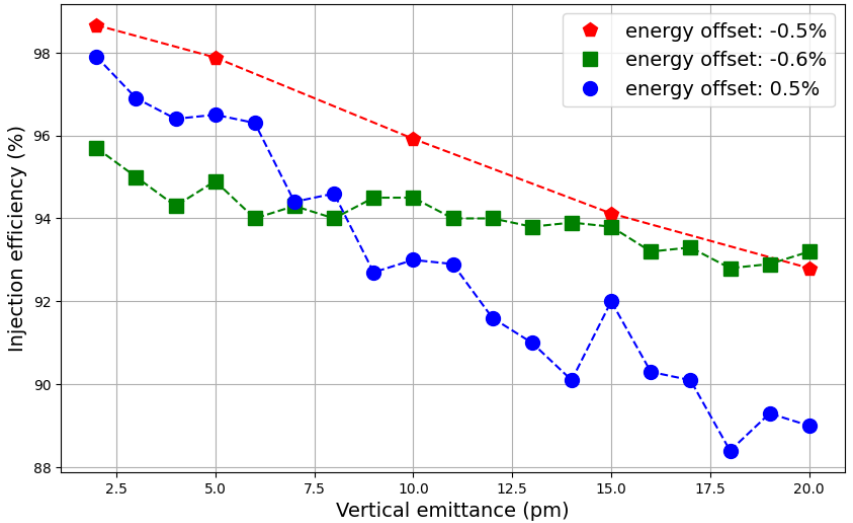
Baseline scheme : injection efficiency simulations

- Present tracking ignores errors and collective effects (beam-beam, impedance, …)
- Scanning of the injection efficiency versus various parameters



Energy offset scan



Vertical emittance scan

Timeline

- 2024 :
  - baseline injection scheme and hardware identified
  - first simulation for Z-mode on GHC lattice
- 2025
  - Simulation of optics and injection process at every mode, with GHC & LCC lattices
  - Review of the baseline injection scheme
- 2026-2027
  - Injection process modelling with collective effects, including beam-beam
  - Injection process efficiency and collimation scheme [1]
  - Machine protection mitigation measures and failure cases modelling
- 2027 : Pre-TDR

[1] R. Versteegen, Design, commissioning and operation of the collimation for the ESRF-EBS, Low emittance rings workshop 2024

Conclusion

- Challenges
  - Fast bump of the circulating beam close to the injection septa
    - Machine protection questions in case of fast kicker failure -> partially addressed already with
    - Local halo cleaning may be needed since the circulating beam is bumped within 5σ of the injection septa
  - High reliability is required for injection every 3s and maintain the bunch population balanced
  - Injection efficiency
    - Losses at injection need to be controlled for machine protection and detector background
    - High efficiency relies on well controlled beam dynamics at the highest intensities
- Status
  - Present injection optics has strong impact on the dynamic aperture
  - A hybrid injection scheme is the present baseline for the FSR
- Prospects
  - A working group on top-up injection with ring dynamics, hardware and injection experts is needed
  - Closer collaboration with other storage rings and collider using top-up injection will be beneficial
  - Review of the baseline injection scheme by an international panel will be conducted