Injection from booster to collider rings
Schemes, specifications and discussions

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FCC-ee injector meeting

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- Conventional injection scheme
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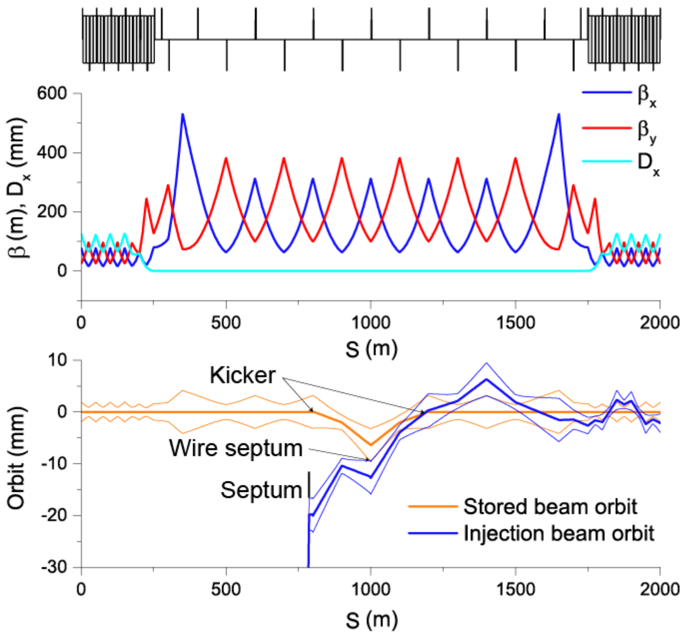
  (Booster and Collider)
- Summary

Summary from previous studies

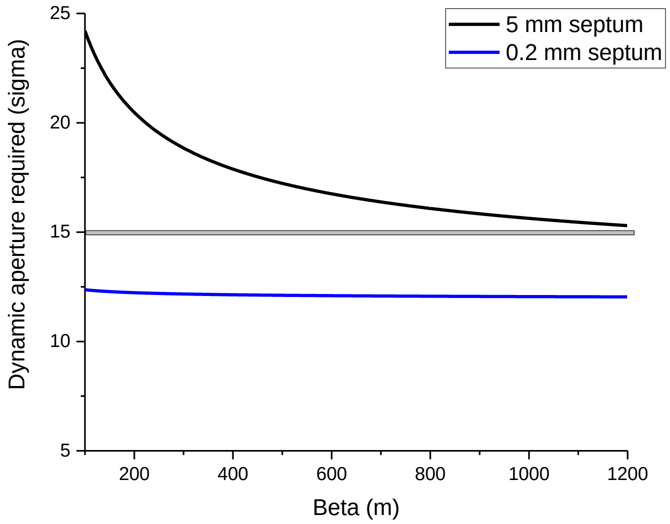
- Requirement/Assumption for top-up injection
  - Similar emittance in booster and collider (1.3 nm @ 175 GeV)
  - ~1.5 km straight section available in collider
  - 5 sigma clearance for high injection efficiency
  - (Limited) dynamic aperture: ~15 sigma for on-energy, 5 sigma up to +/- 2% off-energy
  - Septum
    - Blade thickness of 5 mm (3 mm + mechanical margin)
    - Wire septum of 0.2 mm (~20 um + mechanical margin)
- Two viable injection schemes found, but with some "weak points"
  - Conventional injection scheme (on-energy/off-energy)
    - Both on- and off-energy injection require a wire septum unless beta function at the septum is enhanced to >1 km
    - Beam disturbance (coherent betatron oscillation) due to a bump leakage in practice
  - Multipole kicker injection (on-energy/off-energy)
    - Nonlinear kicker is essential to avoid strong injection beam mismatch
    - Unavoidable emittance growth up to 30% due to the limited dynamic aperture or (normalised) dispersion

Conventional injection (1)

Optics and orbits for on-energy injection with wire septum

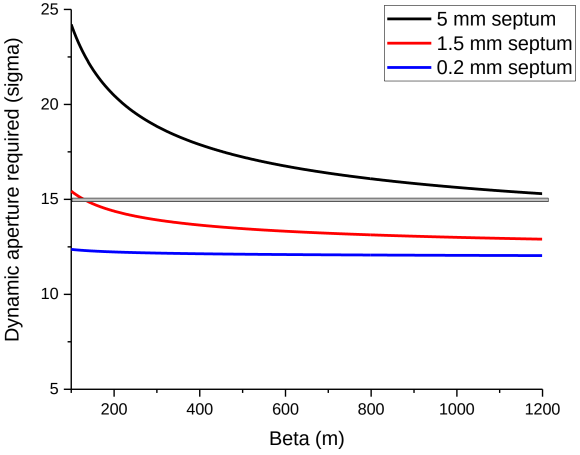


Required dynamic aperture



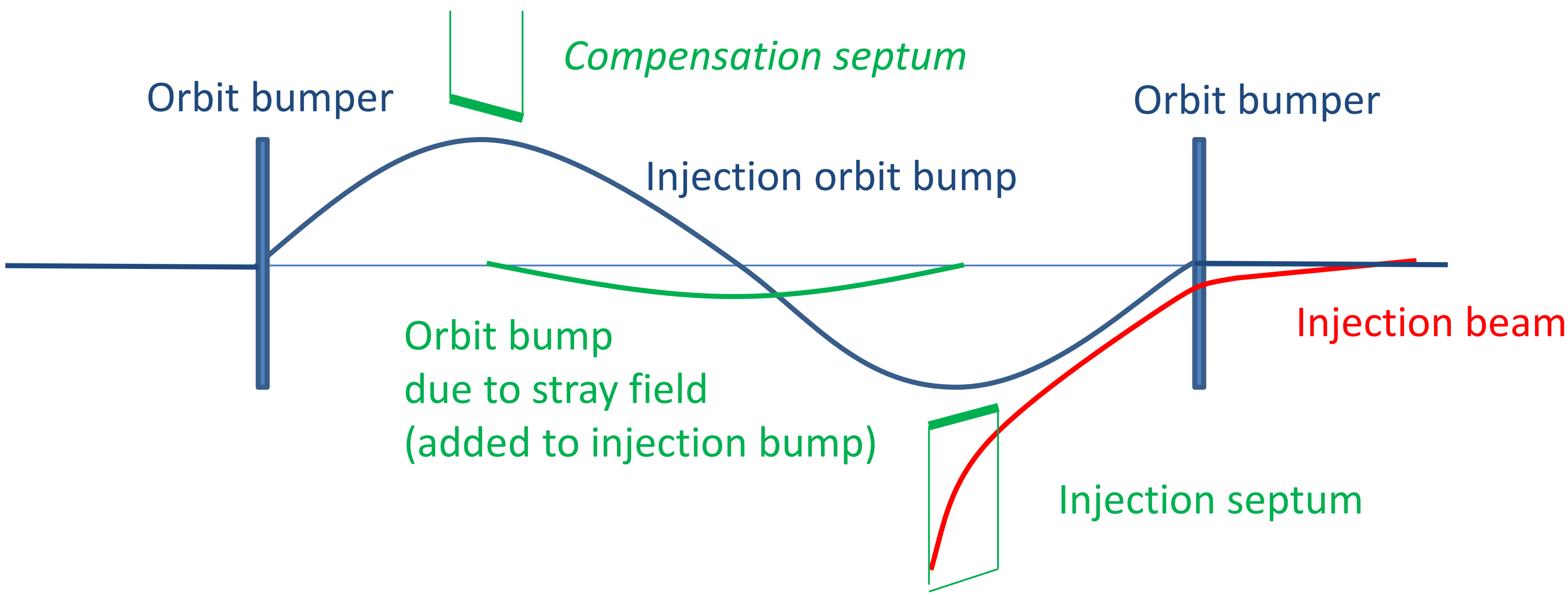
Conventional injection (2)

- Reconsideration of magnetic septum assumptions
  - Present assumption: 3 mm blade (5 mm septum thickness with margin)
    - To achieve strong enough (~0.5 T) field to inflect the injection beam
    - The blade should be thick enough to suppress stray field
  - Thinner septum?
    - Field of ~0.1 T is enough since a very long straight section is available (Also a large ring beta, >100m, helps for 90 deg. upstream thick/DC septum)
    - **Allow (some) stray field but compensate for by *other means* rather than by thick blade**
    - With a lower field and a less stringent stray field criterion, the thickness can be thinner
  - Possible revised assumption: 1.5 mm including mechanical margin
    - Easy for conventional injection scheme (e.g. no wire septum and easy-handling beta)



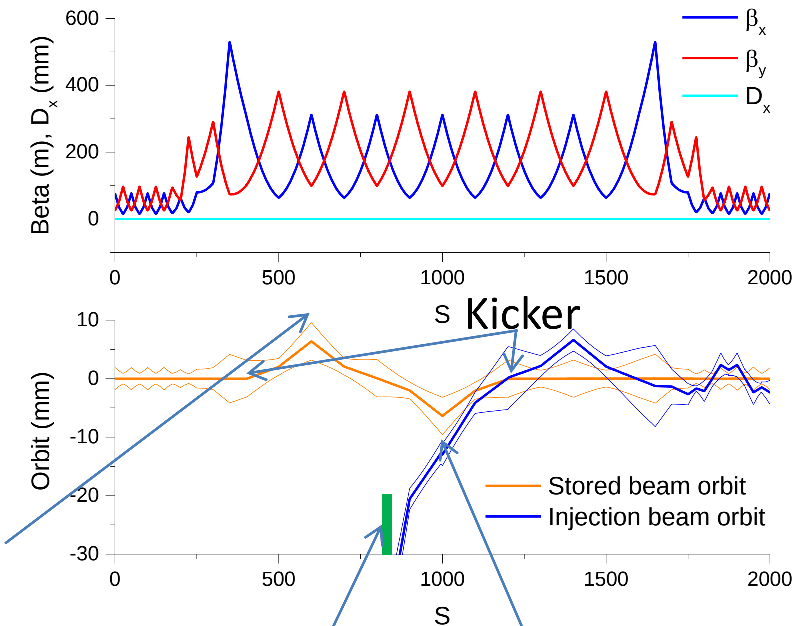
Conventional injection (3)

- “Compensation septum” (or “Dummy septum”)
  - Put another septum to compensate for the stray field disturbance
  - 2π injection orbit bump with Compensation and Injection septa at the peak of bump with a π phase advance in-between
  - Stray field generate a *closed* π bump → No bump leakage in principle when the two septa are identical
  - Note that orbit bumpers and septa do not necessarily have same pulse duration/shape



Conventional injection (4)

Optics and orbits for on-energy injection with thin septum and compensation septum



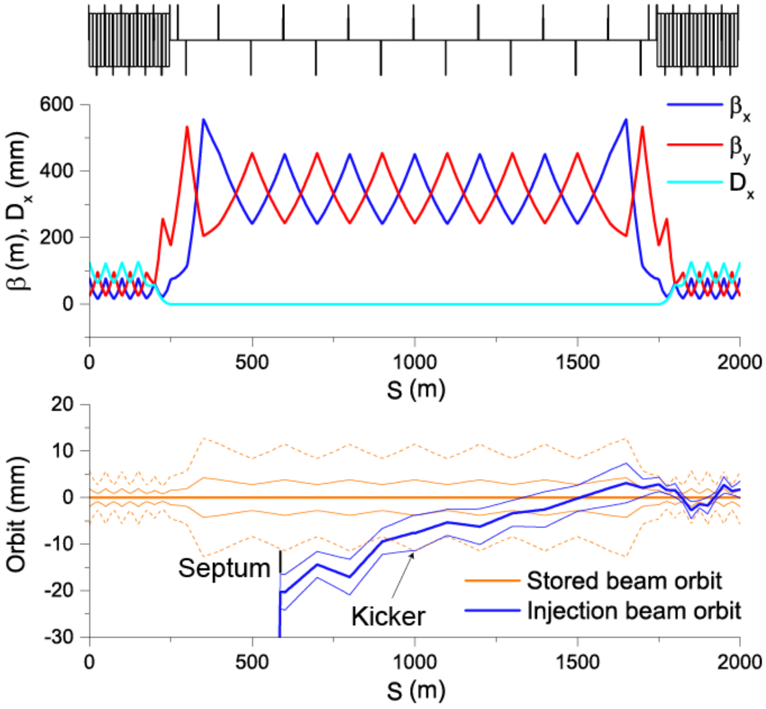
Compensation septum

Thick septum
(Can be DC magnet)

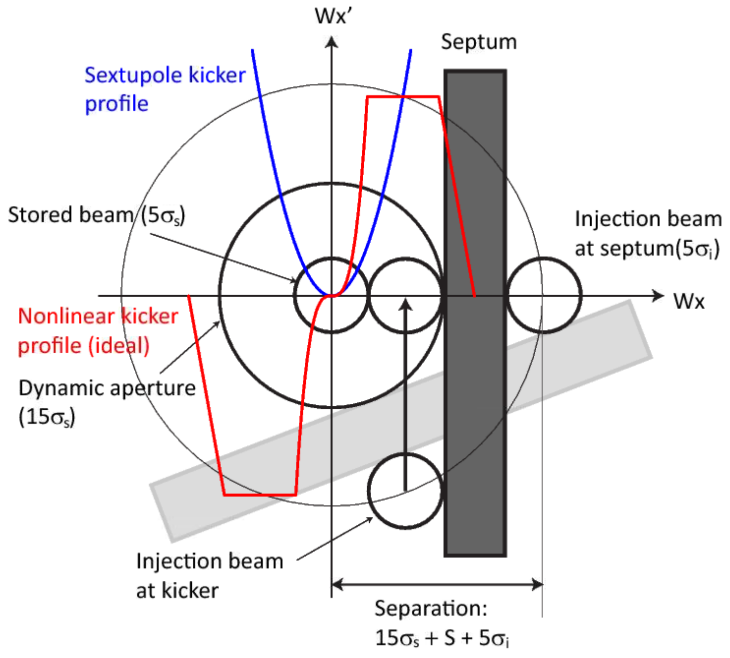
Injection septum (1.5 mm)
Integrated field = 0.1 Tm

Multipole kicker injection (1)

Optics and orbits for on-energy injection with septum (5 mm)



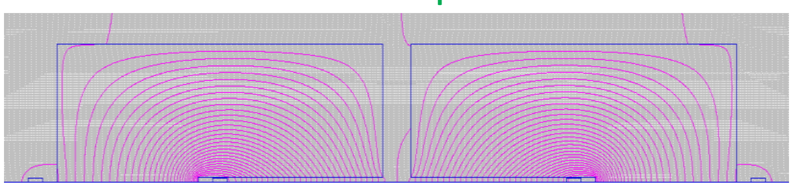
How the beams are "packed" in the phase space…



Multipole kicker injection (2)

- Similar approach to "Compensation septum"
  - Compensate for the emittance growth by another kicker, "Compensation kicker"
  - With π phase advance between two kickers, the disturbance to the beam is to be compensated for (up to any high multipole)
  - Sextupole-like nonlinear kicker:

Two C-shape kickers



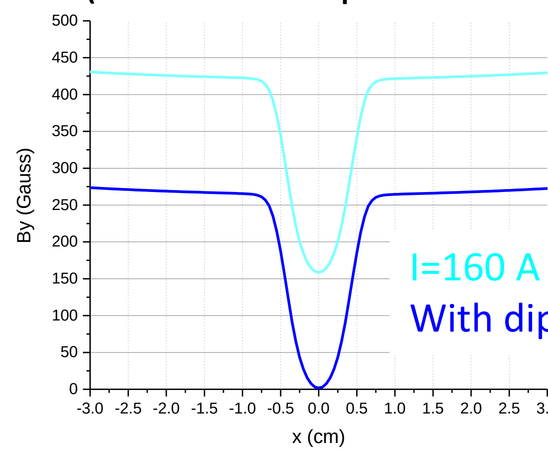
\+

Dipole kicker to cancel
the dipole component at the centre

Residual dipole kick is also compensated when two kickers are identical

Can be Quad+Octupole kicker if we accept "beta function bump"

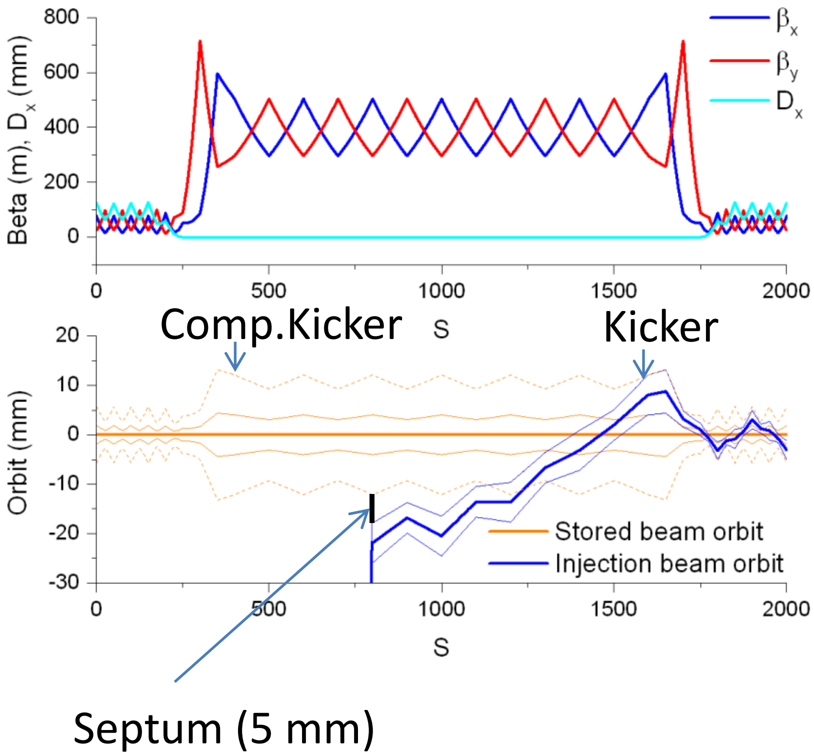
Field profile expected for on-energy inj.
(Poisson computation for static field)



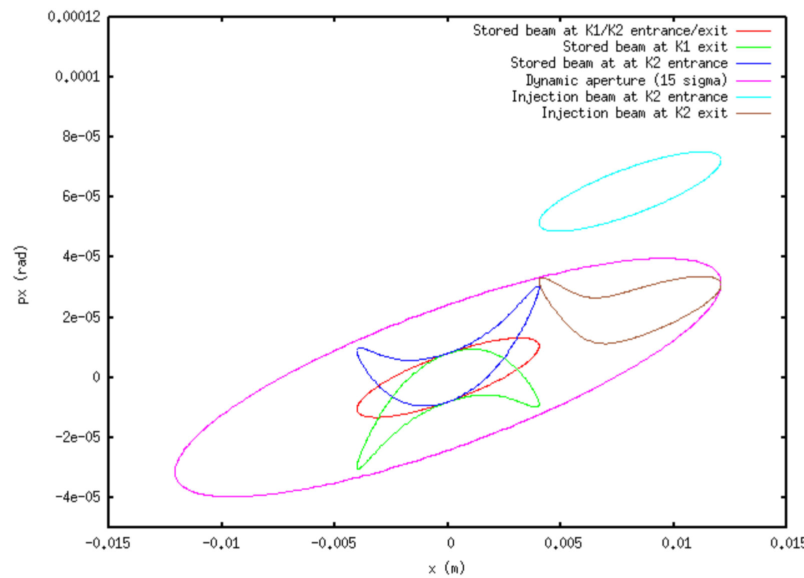
I=160 A for 4 mm full gap
With dipole kicker attached

Multipole kicker injection (3)

Optics and orbits for on-energy injection with multipole kicker and compensation kicker



Beams in phase space



Specifications

Parameters	Conventional injection (on-/off-energy)	Multipole kicker injection (on-/off-energy)
Beta at septum and kicker (m)	310/310 (or 1200/1800)	~400 m
Type of kicker	Dipole kickers	Nonlinear kicker
Integrated kicker field (Tm)	0.012/0.025 (or weaker)	0.025/0.03 (Plateau)
Type of septum	Wire septum (or 5-mm septum)	5-mm septum or wire septum
Required DA (σ)	~15/5@-1.8%	15/5@-2%

- (Tentative) specifications are found
- Similar specifications apply to the compensation kicker/septum schemes
- Kicker and septum pulse durations are still missing

Filling pattern (1)

- Collider
  - The four operation modes require very different filling patterns (number of bunches, bunch spacing)
  - Common RF scheme (with no separator) assumes only a half of collider ring to be filled (K. Oide, FCC week 2016)
  - RF beam loading study suggests rather uniform filling (with various fine structures, “by2”, “by4”, etc.)

  (D.Teytelman,https://indico.cern.ch/event/590639/contributions/2382368/attachments/1377659/2092710/dt_beam_loading.pdf)
- Booster
  - Any constraint in the filling pattern?
- Booster to Collider transfer
  - Bunch-by-bunch transfer may not be realistic because of the large number of bunches in Z mode?
  - Burst mode can adopt different bunch spacing as demanded?

Filling pattern (2)

- Long-flat-top kicker and septum may be applicable to any filling pattern
  - Single train in the booster is required… Compatible with the injector chain?
  - For the collider beam lifetime of ~1 hour, need to top-up the two collider rings by 6~8 booster cycles
  - This corresponds to 83~111 μs flat-top when the collider ring is fully filled, or 42~55 μs flat top for half filling

Summary

- Two viable injection schemes identified
- Possible improvements of these schemes are under investigation
- (Tentative) Specifications for injection found though still missing ones of pulse duration
- Long-flat-top kicker and septa may be applicable and flexible to realise various filling pattern (if it is fine for booster)