# Top-up Injection
# Status and Next Steps*

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06.29.2021
FCC Week 2021

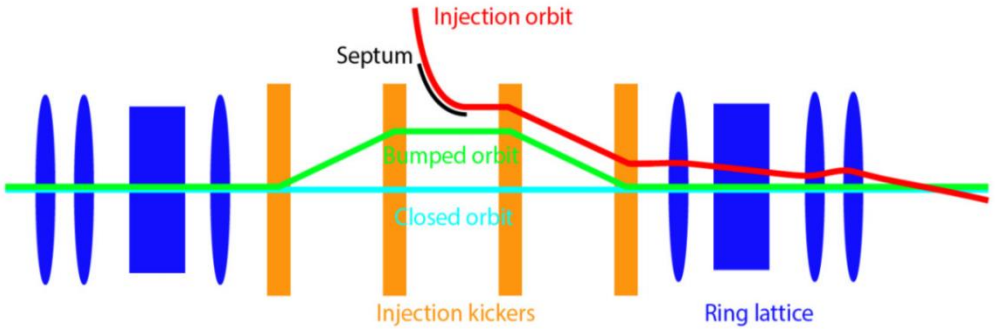
* This project has received funding from the European Union's Horizon 2020 Research and Innovation programme under Grant Agreement No 730871.

# Status

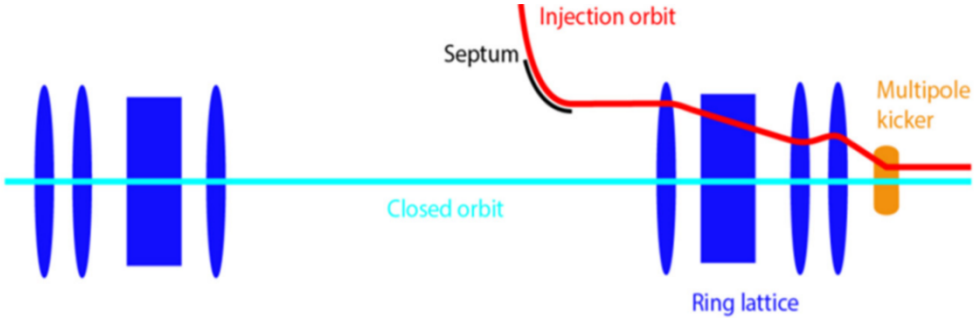
- Two injection schemes selected among many options
  - Conventional injection (CI) using kicker bump
  - Multipole/Nonlinear kicker injection (MKI)
- Remarks
  - On-axis (off-energy) injection is preferable to minimize injected beam loss at IPs
  - Need to determine which injection scheme to be implemented
  - Filling scheme proposed/discussed, need further investigation
  - Elaborated failure scenario required: highest stored energy ever in the lepton collider, ~20 MJ at Z!
  - Decision on the septum technology not yet made
  - Still many ‘next steps’ to finalize the design

# CI and MKI

Conventional injection:
Septum + Kicker bump




Multipole kicker injection:
Septum + Multipole kicker




Both injection scheme can be on-axis with finite dispersion at septum for CI and at kicker for MKI

# CI or MKI –Pros and cons

| | Conventional injection | Multipole kicker |
|---|---|---|
| Kicker technology | Normal kicker, no R&D | Need a light R&D |
| Kicker alignment | Larger tolerance | BBA is essential |
| Optics at kicker | Arbitrary (should not be very low) | Operation mode dependent |
| Beam disturbance | Dipole oscillation | Emittance growth |
| Cure for disturbance | Additional kicker(s) and tunings | Compensation kicker (Backup slide) |
| In case of failure | Stored beam loss not excluded | Only injection beam loss |

Measure: Pros, Weak pros/cons, Cons

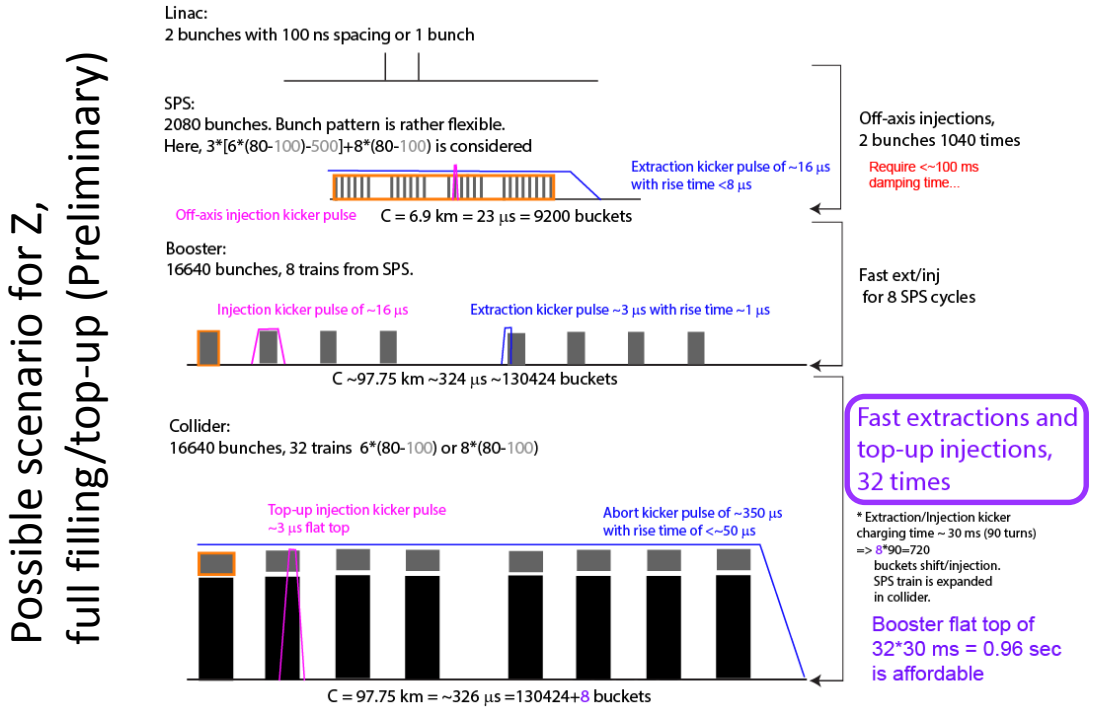
We have been discussed which one to be implemented but haven't converged…
Why not implementing both?

# Energy stored in the beam

| | |
|---|---|
| PEP II | 70 kJ |
| LEP II | 130 kJ |
| SuperKEKB | 180 kJ |
| FCC-ee at Z | 20 MJ |

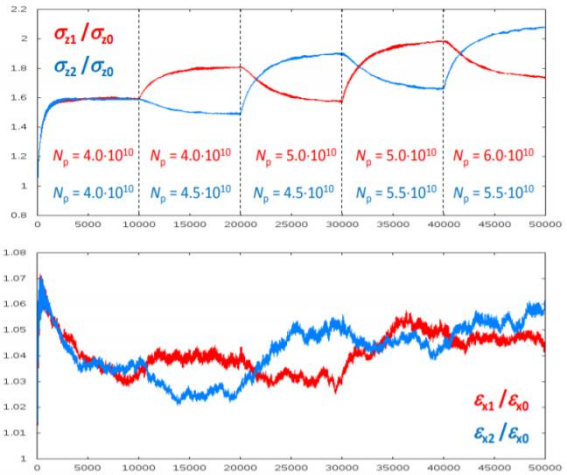
- FCC-ee will be the first lepton collider, where the energy stored in the beam is far above the damage threshold

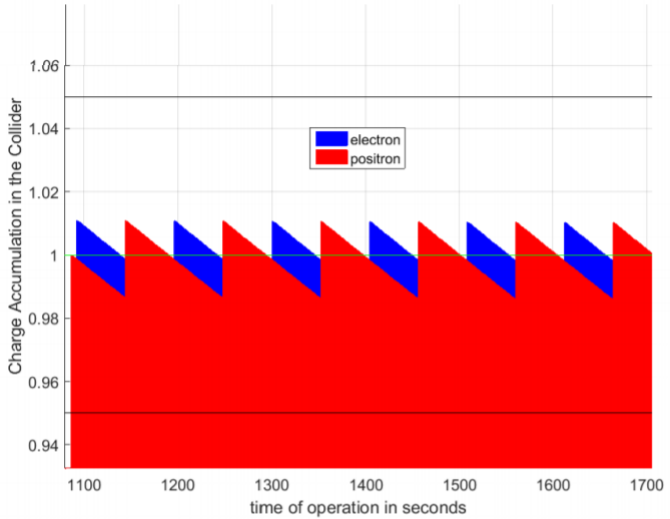
# Filling scheme




- Scheme considered in 2018 (update needed)
- The number of injections from the main booster to the collider ring is important parameter for the machine protection

# Bootstrapping and top-up




9th International Particle Accelerator Conference IPAC2018, Vancouver, BC, Canada JACoW Publishing
ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-MOPMF001

**BUNCH SCHEDULES FOR THE FCC-ee PRE-INJECTOR**

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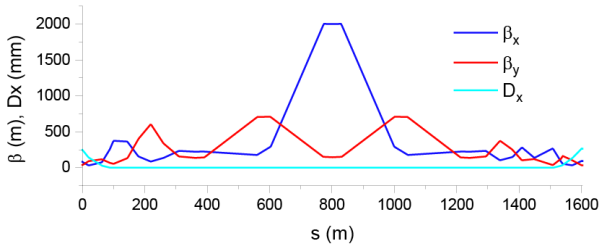
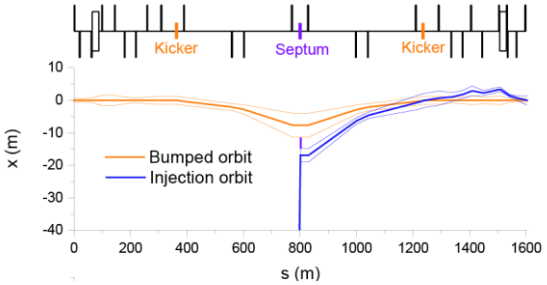
D. Shatilov, BINP SB RAS, Novosibirsk, Russia

# Optics integration (1)

- Figures from CDR
  - This optics can be used for off-axis CI and MKI
  - First dynamic aperture check (K. Oide) showed marginal deterioration as far as the phase advances over the straight section was kept (no sextupole in the straight section)
  - More flexibility, dispersive straight section to enable on-axis injection, etc. Work in progress.



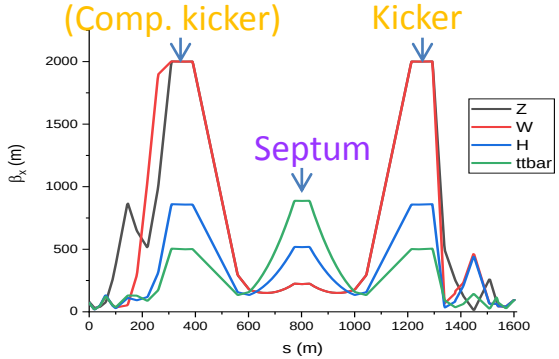




- This work is definitely an important/urgent next step

# Optics integration (2)

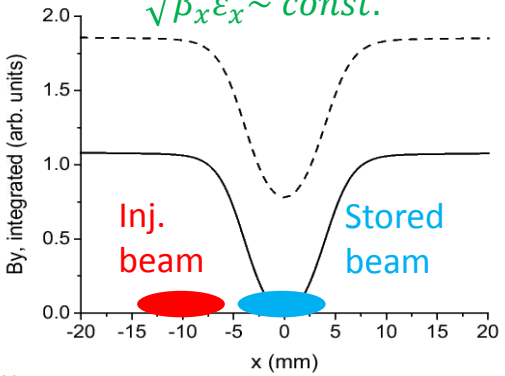
- Different operation mode → Different beam emittance
  - For off-axis CI, only need to adjust bump height
  - For off-axis MKI, need to change optics, adjusting stored and injection beam sizes to fit a fixed kicker transverse profile

Horizontal beta for 4 operation modes (MKI)




Approx. beam dimensions

$\sqrt{\beta_x \varepsilon_x} \sim const.$




  - For on-axis CI and MKI, need to change optics to introduce Dx

Off-energy (on-axis) injection is applicable to ttbar and possibly to Higgs while not to Z and W because of limited off-energy dynamic aperture

# Tracking study

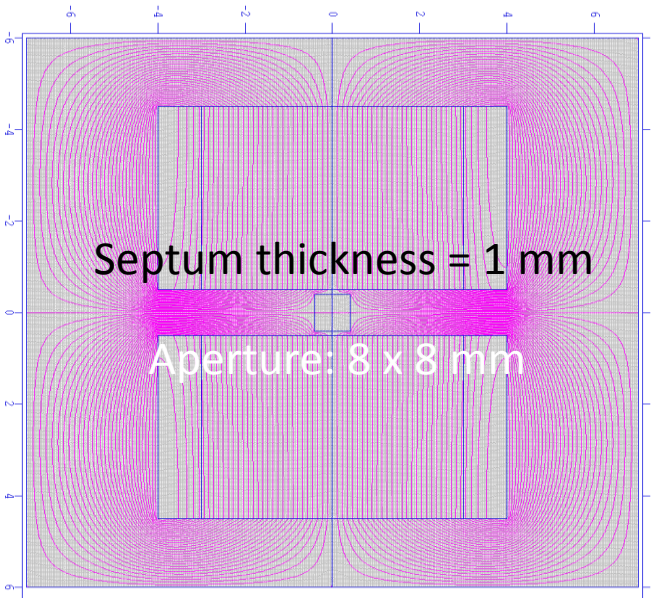
- The strategy to design the injection has been
  - Using linear lattice parameters
  - Determine the parameters such that the injection beam fits the dynamic aperture separately computed
  - Tracking for dynamic aperture search includes all possible errors
- Tracking study (by P. Hunchak, CLS) is planned to confirm ‘no bad surprise’

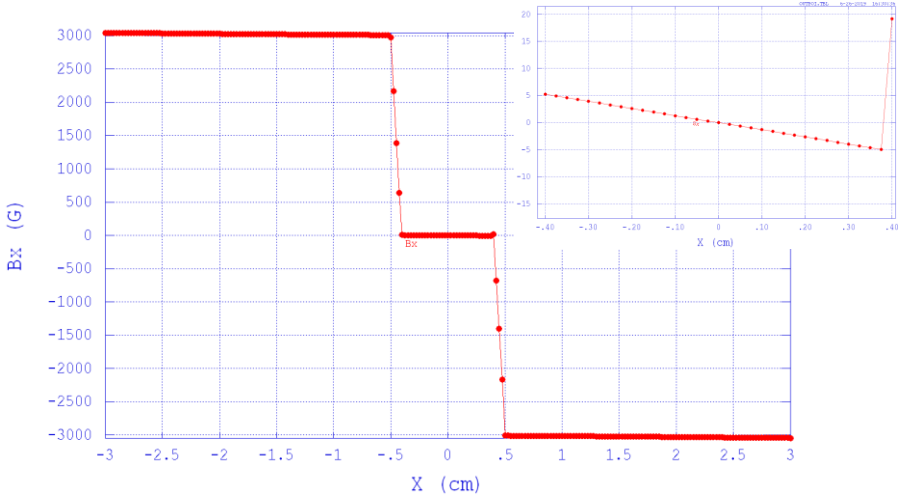
# Septum (1)

- Two types assumed in the previous study
  - Widely used eddy-current septum: ~3-mm blade thickness → Reliable but a larger DA/beta required
  - Very thin electro-static wire septum: 0.1 mm blade thickness → DA/beta requirement relaxed but never used in lepton machines
- Note that the effective thickness is thicker than the actual thickness (misalignments etc.)

# Septum (2)

- 1-mm septum ?
  - A la ALS septum (1.5 mm): Eddy-current septum with short pulse might be a choice if the pulse length can be compatible with filling scheme; Skin depth of copper ~0.2 mm at 100 kHz (10 us pulse)
  - Low field Lambertson septum seems attractive choice



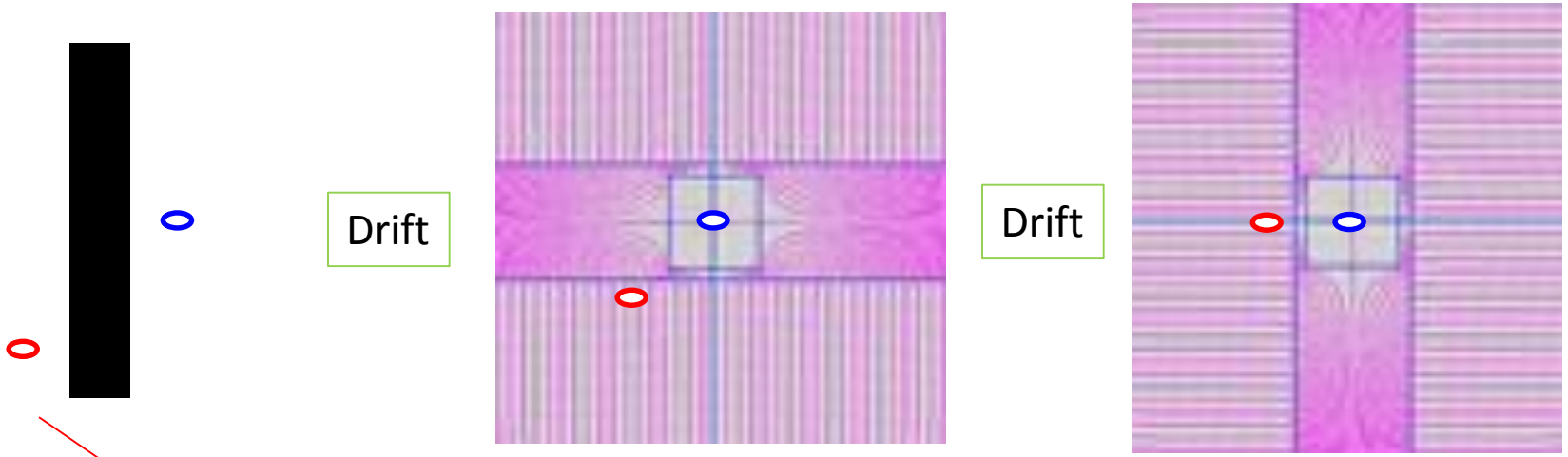

Symmetrised/linearlised leak field:
B~0.3 T for injection beam
B'~0.1 T/m for stored beam

# Septum (3)

Thick septum (H)

Thin septum (H)

Final thin septum (V)




Vertical deflection at the end of transfer line may be advantageous, or at least harmless; Booster ring mid plane is lower or higher than that of storage ring

# Summary and Next steps

- Previous studies revealed that top-up injection into FCC-ee collider is feasible
- Next steps
  - Optics integration
  - Tracking study
  - Further investigation needed to establish failure scenarios
  - Filling scheme update, etc.

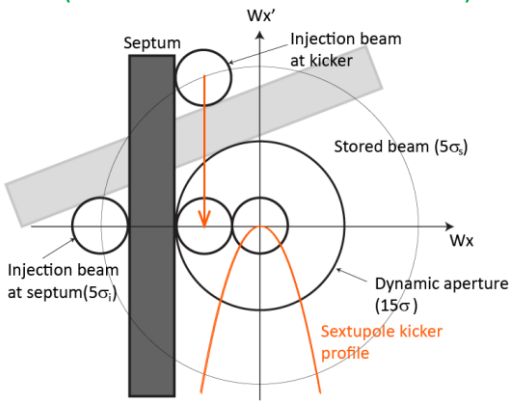
# Thank you for your attention.

Acknowledgement:
B. Balhan, W. Bartmann, J. Borburgh, Y. Dutheil, M. Hofer, P. Hunchak, R. Ramjiawan, F. Zimmermann

# “Compensation kicker”

- MKI increases beam emittance transiently, and it can be significant when the dynamic aperture is limited (left figure)
- An identical kicker placed upstream with -π phase advance in H and V planes, affecting only circulating beam, can suppress the emittance growth (Right figure)
- This concept may apply to most types of kickers, since it is actually based on the well known –I transformation

Beams “packed” into limited DA
(15σ DA and 5σ clearance case)




This figure is not very correct;
beams are distorted by kicker!