FCC-ee INJECTION AND EXTRACTION

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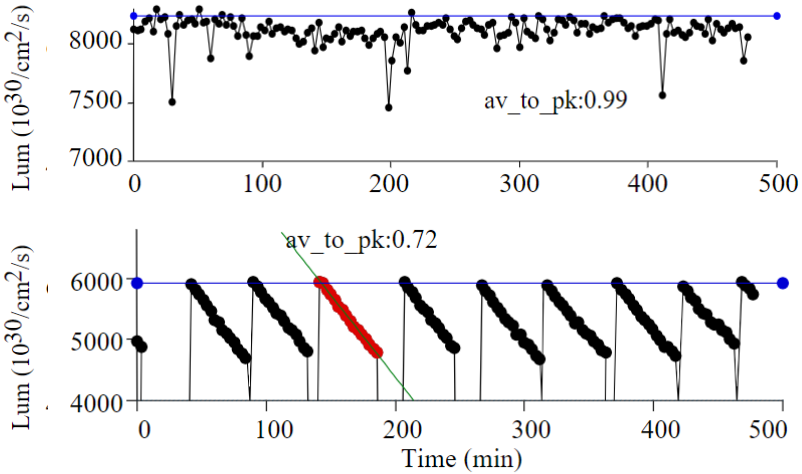
Introduction

- To maximize time in collision, and thereby integrated luminosity, FCC-ee is foreseen to use top-up injection
  - Full energy beam from booster injected close to stored beam with either transverse or momentum offset, merge via SR damping
  - Injection interval ranging from $23s\ (H)$ to $60s\ (W)$ [ref]
  - To avoid flip-flop instability, charge imbalance below $\pm 5\%$ (Z) - $\pm 3\%$ (other modes)
- Used in operation in SKEKB and PEP-II and many light sources



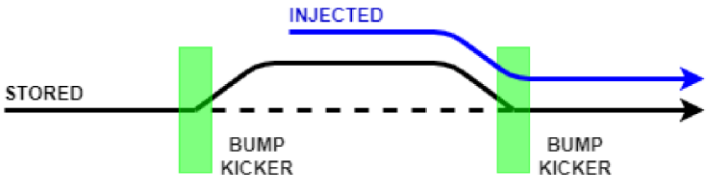
Wienands, U. "Lepton Collider Operation with Constant Currents". Proceedings of the 2005 Particle Accelerator Conference. doi:10.1109/pac.2005.1590385

Injection schemes

- Different injection schemes have been evaluated during CDR phase, with two general schemes deemed viable for FCC-ee

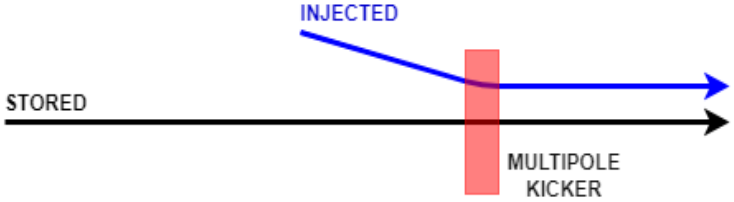
Conventional orbit bump injection

- Dipole kicker magnets creating a one turn closed orbit bump to bring stored beam close to septum



Multipole Kicker injection

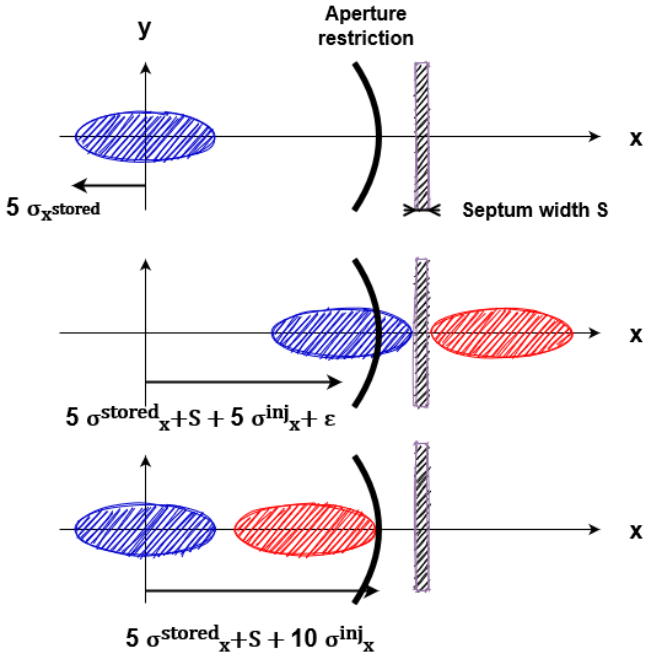
- Use of a special kicker magnet with special field shape
- Small on-axis field for minimal effect on stored beam, while significant kick for injected beam



- Both modes allow separation via transverse offset (x) or momentum offset ($D_x\delta_p$)
- Beam injection is performed in the horizontal plane

Conventional orbit bump injection

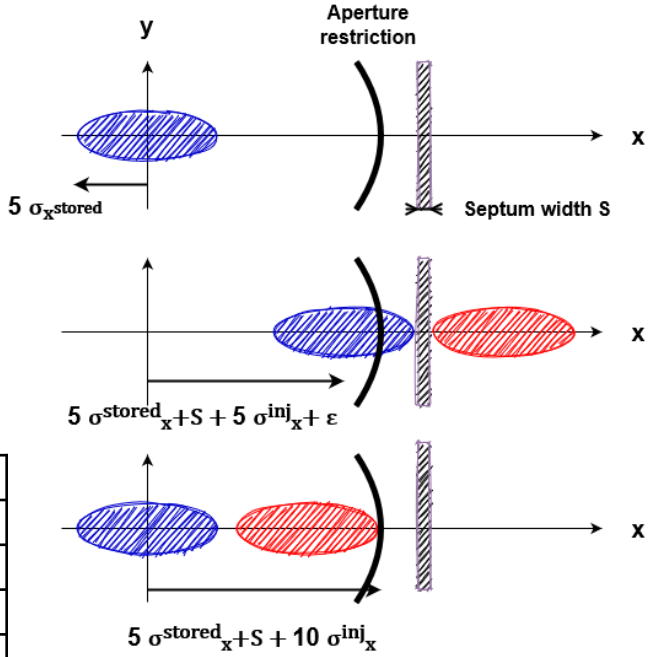
- Requires physical aperture and DA above $5\sigma_x^{stored} + S + 10\sigma_x^{injected}$ to store both beams
  - For off-momentum injection, DA above $5\sigma_x^{injected}$ for given δ_p
  - Accounting for hor. emittance from booster [ref], $\sigma_x^{injected} \Big/ \sigma_x^{stored}$ ranging from 0.5 (Z) to 0.9 ($t\bar{t}$)
  - Optics of the TL can be adjusted to optimize phase space coverage
    - For current injection optics, $\beta_x^{stored} \approx 4\beta_x^{injected}$ [ref]



- Septum aperture larger by safety margin ε wrt primary collimator for safety, need to account in bump height

Conventional orbit bump injection

- With orbit bump closed, beams still separated by septum width S, including alignment tolerances
  - Benefits from thin electrostatic septum with $S = 200\mu m$ under study ($S = 200\mu m \triangleq 0.3\sigma_x$)
    - R&D at CERN planned to investigate sparking rates as function of electric field



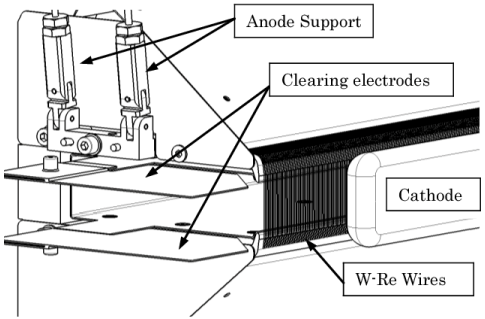


Fig. 1. ZS electrostatic septum used for SPS slow extraction

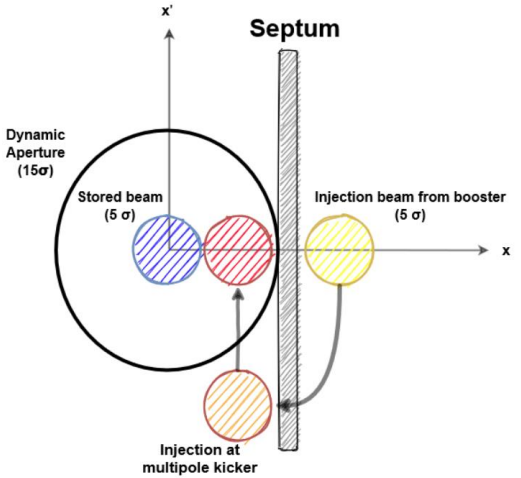
Preliminary - still under study

Septum

Parameter	Value
Deflection angle	65 µrad
Int. field ($\bar{t}\bar{t}$)	11.2 MV
Electric field	1.87 MV/m
Potential difference	37.4 kV
Septum thickness	200 µm
Gap width	20 mm
Length	2×3 m

Multipole kicker injection

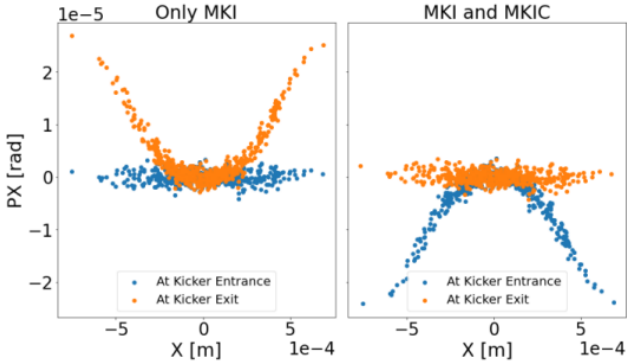
- Special kicker permits to kick an off-axis beam, while stored beam remains (relatively) unaffected
  - Unlike conventional bump injection, septum width plays secondary role
    → magnetic eddy current septum with 3mm septum width
  - So far, only 2D design for MKI exist, further R&D and 3D design required
- Aperture requirement of $5\sigma_x^{stored} + 10\sigma_x^{injected}$
  - Septum aperture affects strength of kicker and thereby stored beam distortion

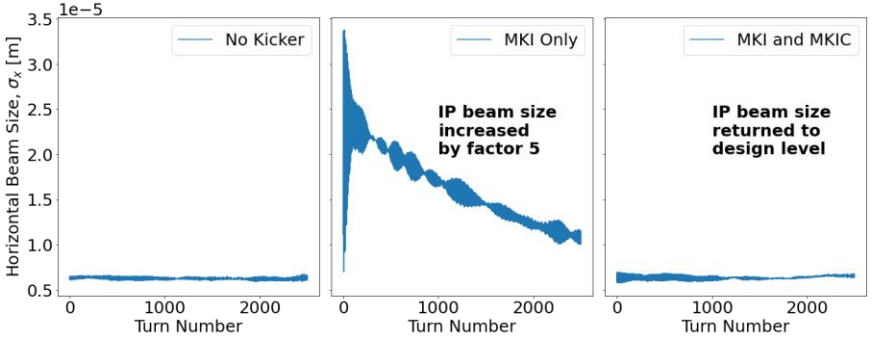


M. Aiba et al. "Top-up injection schemes for future circular lepton collider"

Multipole kicker compensation

- Non-zero on-axis field of the MKI results in distortion of stored beam
  - Temporary increase of beamsize at IP by factor 5
  - Compensation kicker upstream to cancel effect on stored beam
    - Phase advance of 180° and same optics allows for –I transformation

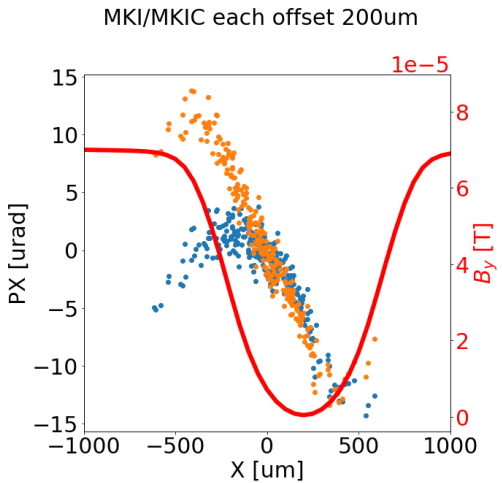




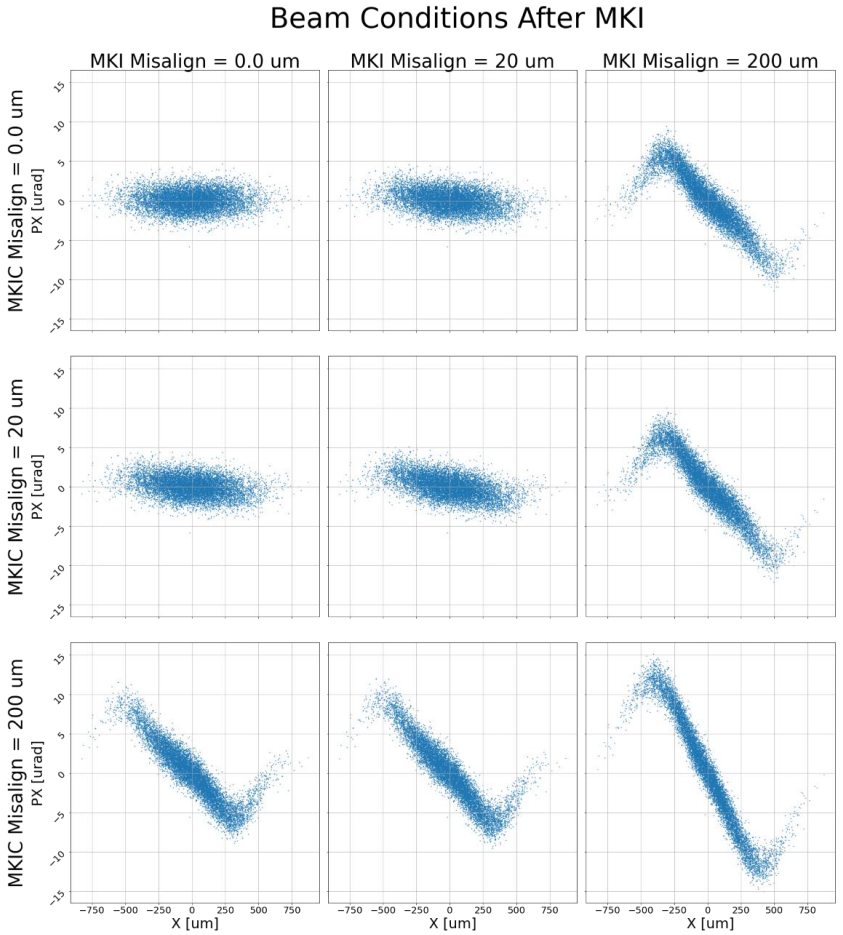
P. Hunchak

Alignment tolerances

- Off-center passage of stored beam through either one or both MKI results in distortion
  - For case of both MKI fields shifted by $200\mu m$, ε_x increase by factor 1.75



At MKI



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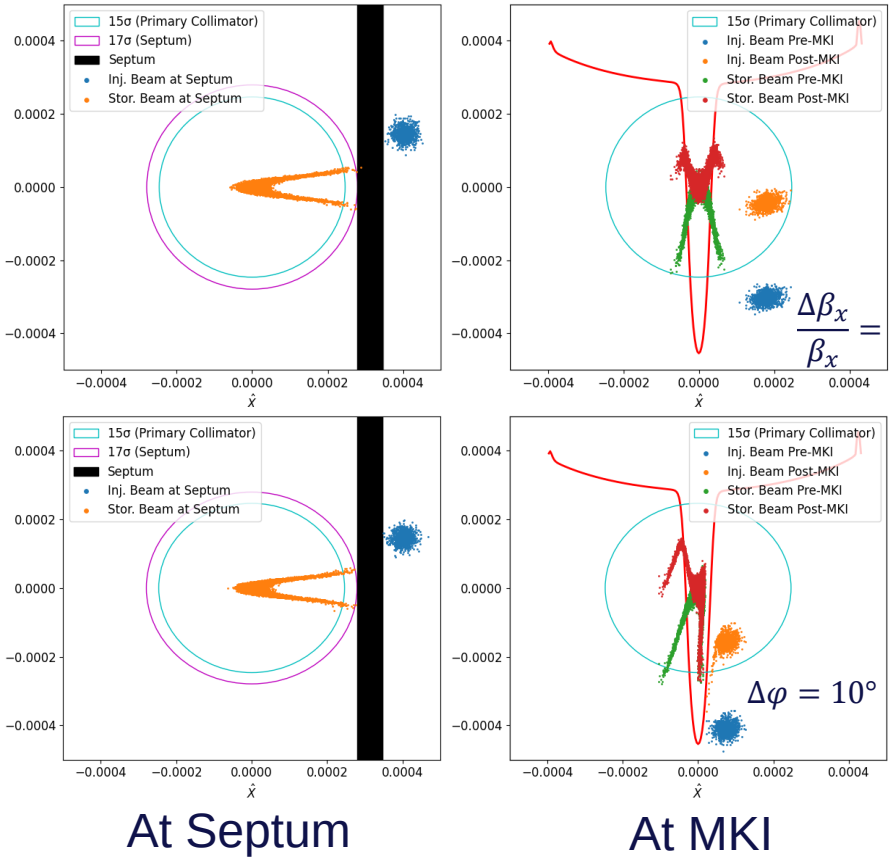
Impact of optics errors

- Similarly, optics errors resulting in distortion of stored beam and reduced injection efficiency

- Tolerable distortions to be studied with tracking studies, including beam-beam



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Failure scenarios

- Stored beam energy in FCC-ee between ~20MJ (Z) and 0.3 MJ ($t\bar{t}$)
  - Stored energy of injected beam factor ~10 below

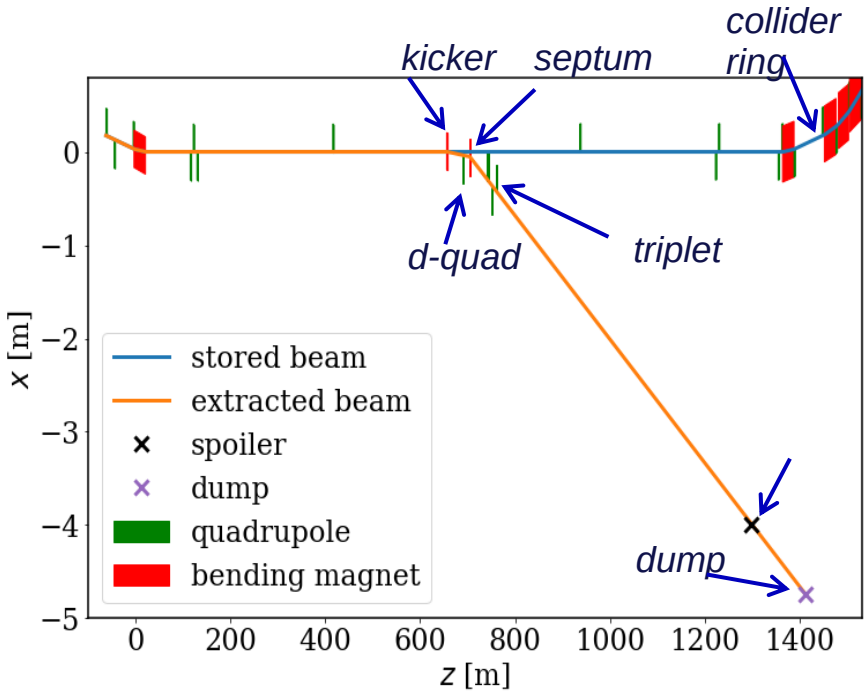
- Multipole Kicker Injection has the advantage that beam centroid is (minimally) affected in case of no trigger or mistrigger
  - Erratic turn-on: emittance blowup of stored beam
  - No trigger: injected beam hitting absorber

- In conventional bump injection, failure of one kicker may result in stored beam loss at septum or downstream aperture
  - Injected beam to be absorbed by downstream protection

- Septum failure considered as slow process and active protection is considered
  - Tolerable variation in septum strength dictates beam abort time

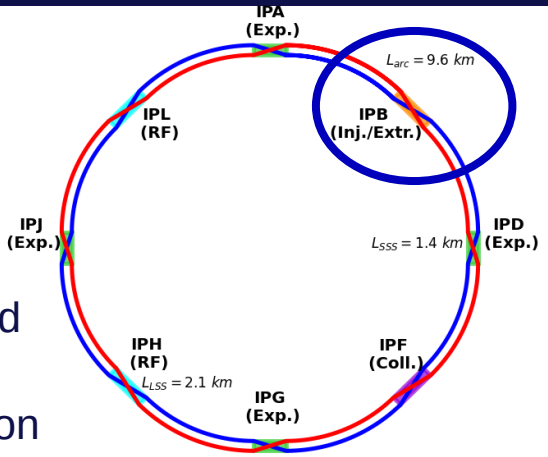
Extraction

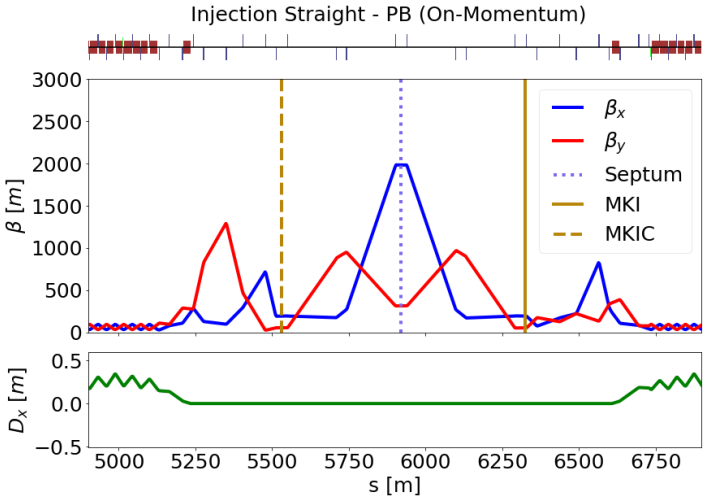
- First study on layout of extraction and requirements presented last workshop [ref]
- After extraction, defocusing triplet to blow up beamsize, propagating for ~700m before hitting spoilers and finally beam dump
- Hardware parameter achievable
  - Kicker: $1\ mrad$ deflection, $3\ \mu s$ rise time, $300\ \mu s$ flat top
  - Septum: $5\ mrad$ deflection, $5\ cm$ separation
- Based on SKEKB experience with “crazy beam”, proposal to install extraction upstream of each IP

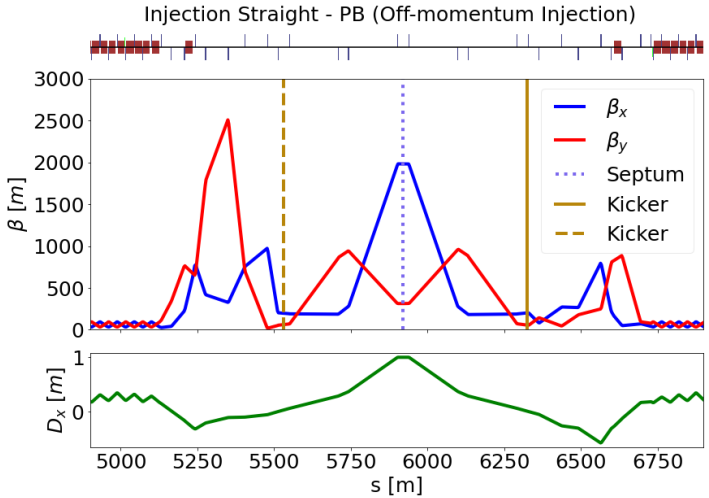


Integration into collider

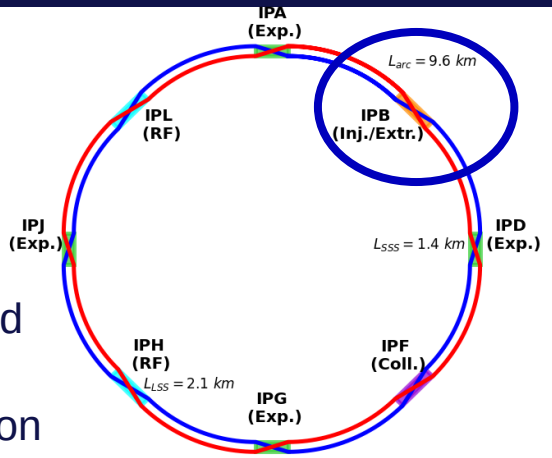
- One dedicated straight section (PB) for injection (& extraction)
- For 2-IP lattice, a layout for an injection insertion has been devised by M. Aiba
  - Compatible with both conventional and Multipole kicker injection



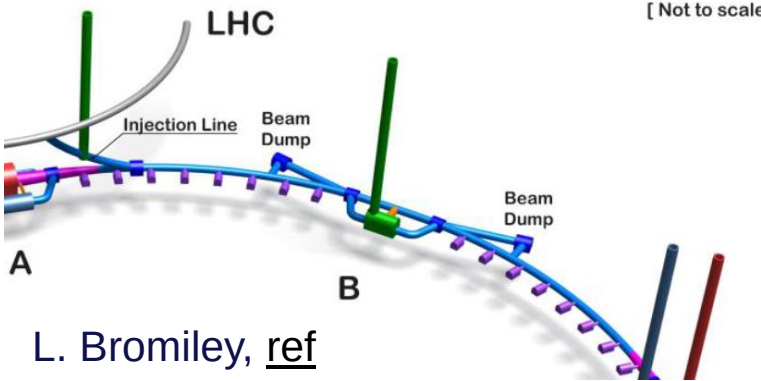




Integration into collider



- One dedicated straight section (PB) for injection (& extraction)
- For 2-IP lattice, a layout for an injection insertion has been devised by M. Aiba
  - Compatible with both conventional and Multipole kicker injection
- For 4-IP lattice, layout under study
  - Combining both injection and extraction in one 2.1km long insertion, requires beam crossing
  - Integration of transfer line from booster to collider and extraction line
    - FCC-hh dump at the same location



L. Bromiley, ref

Conclusions

- Top-up injection key ingredient in reaching luminosity goal
  - Proven technique used in other e^+e^- collider and light sources
- Two feasible injection schemes (with on- and off-momentum variants) identified
  - Studies on tolerances and impact on performance being performed
  - R&D needed for multipole kicker, thin electro static septa
- High stored beam energy requires special attention
  - Slight preference towards MKI for Z-operation mode as failures only lead to stored beam blow-up
- Integration in latest 4-IP lattice started
  - Necessity for extraction/dump upstream of each experiment to be looked into

Thanks for your attention!