

STUDIES TOWARDS A DEPOLARISER DESIGN

presented by W. Hofle
CERN SY-RF-BR

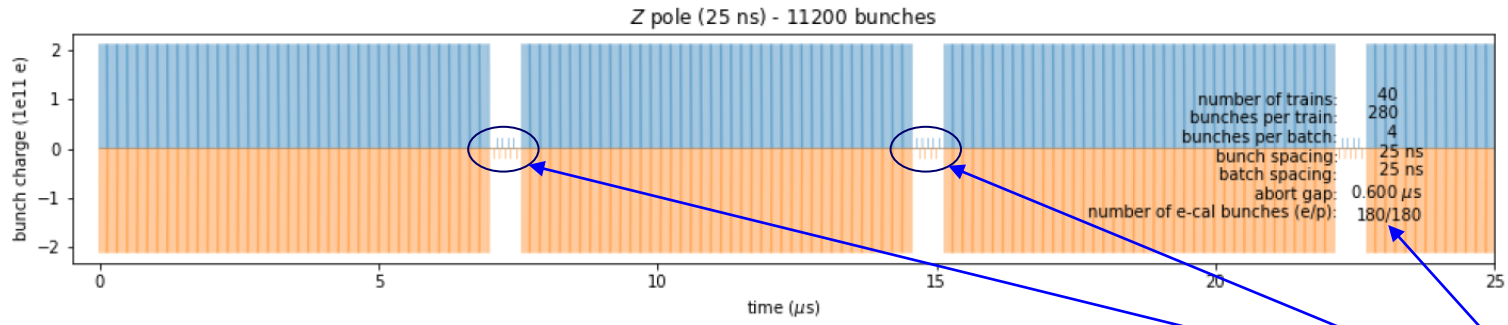
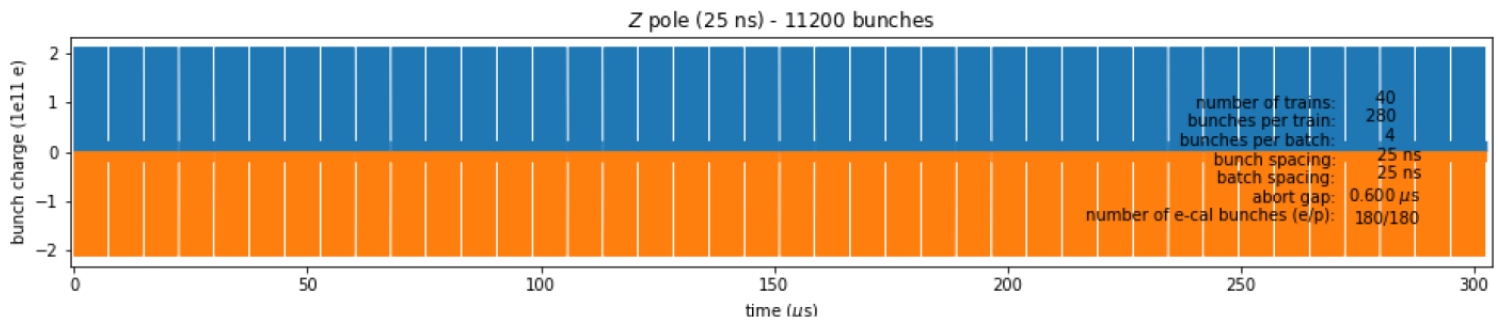
Acknowledgements:
I. Karpov, D. Sittard, L. Thiele,
Epol WG

Depolariser kickers and transverse feedback

Recapitulation

- due to similar requirements for **bandwidth** synergy between the needed kickers for the transverse feedback and the depolariser have been explored
- long, $O(m)$, stripline kickers operating at a multiple of the bunch repetition frequency offer good RF power efficiency and sufficient bandwidth
- **differences in requirements** between transverse feedback and depolarizer kickers are
 - depolarizer kicker only needed for **vertical kicks**, transverse feedback also for horizontal plane kicks
 - implementation of depolariser excitation as a **modulated local orbit bump** requires one or several sets of pairs of kickers **with bending magnets** in between
 - no perturbation on experimental points permitted, recommended to have a tuning possibility with a **third kicker** per set of kickers
 - kick strength required for depolarizer is high (**10 μ rad**) and adequate protection is needed to prevent acting on Physics bunches (loss of synchronisation with gaps)

Filling pattern Z-pole – update of 2024

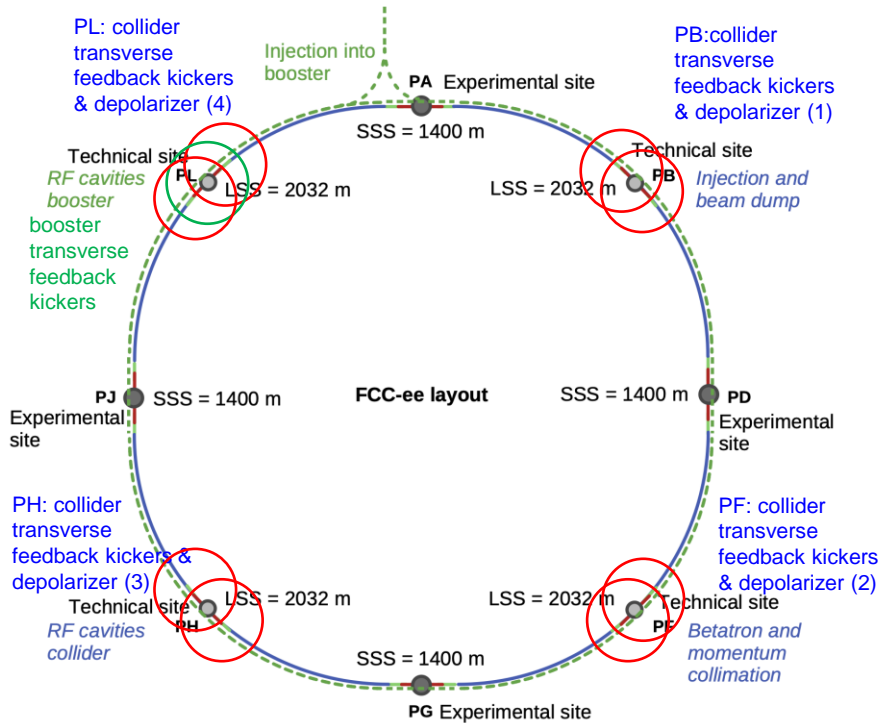


H. Bartosik, FCC week 2024
 (new alternate filling schemes
 with short trains (e-cloud
 mitigation of 5 ns spaced bunches
 need study)

Collider filling pattern for whole ring and zoom

e-cal bunches of at least one gap are affected by injection bump risetime, so effectively 175 (one beam), 176 (the other beam) useful bunches at maximum

Considerations for placement in ring



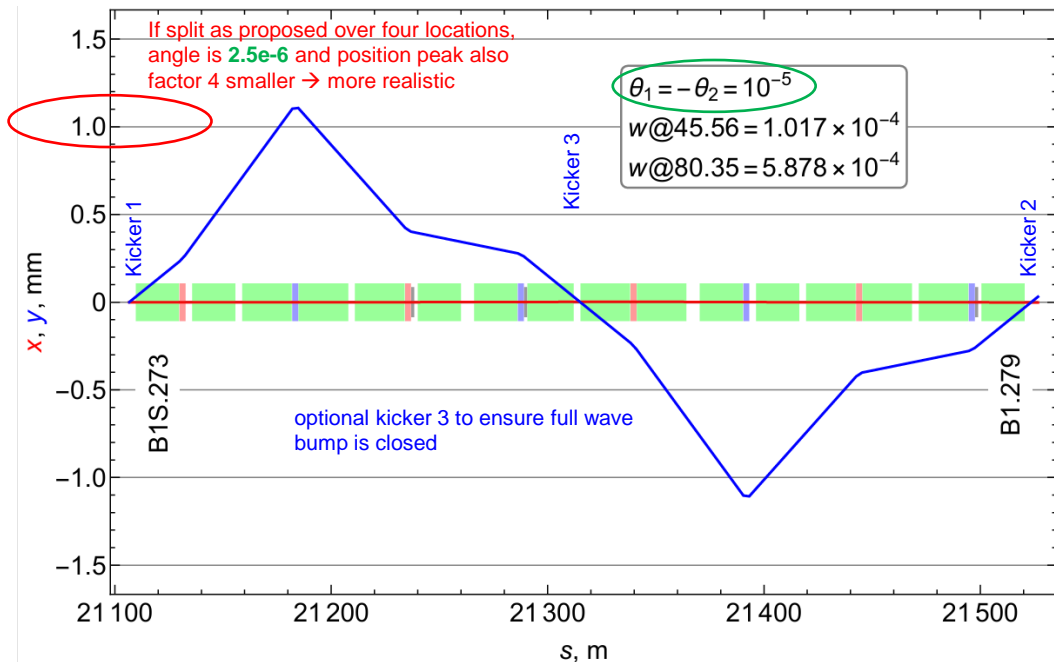
Update 2025:

- arcs adjacent to technical sites PL, PB, PF, PH now preferred
 - see [K. Oide FCC week 2025](#) for proposal for integration of kickers in GHC optics
 - assume similar possibilities in LCC optics exist, but needs check, LCC optics has somewhat lower beta functions → impacts efficiency at least for transverse feedback part
- experimental sites (PA, PG, PD, PJ)
 - spaces that were considered:
 - return arc (optics not really suited)
 - regular arc, out-going beam, still a possibility

Placement in regular arc under study

positron beam outgoing (clockwise) / right of Ips,
see also K. Oide FCC week 2025

- split system over eight **locations**, left and right of four points, four per beam
- chose kickers of lengths of 1 m
- → at least 8 kickers per beam for **four full wave bumps per beam**
- + a third kicker to ensure bump closure (another 4 kickers per beam)
- 24 kickers in total

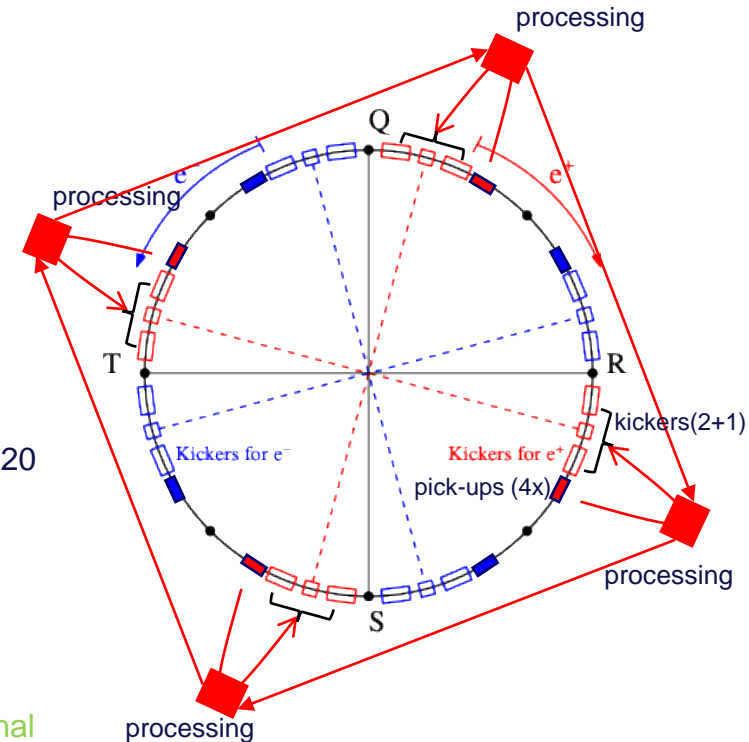


Following proposal by I. Koop, update see [K. Oide, FCC week 2025](#)

<https://indico.cern.ch/event/1471324/contributions/6220925/attachments/2963259/5212471/Koop-depolarizer%20review.pdf>

Depolariser and distributed transverse feedback

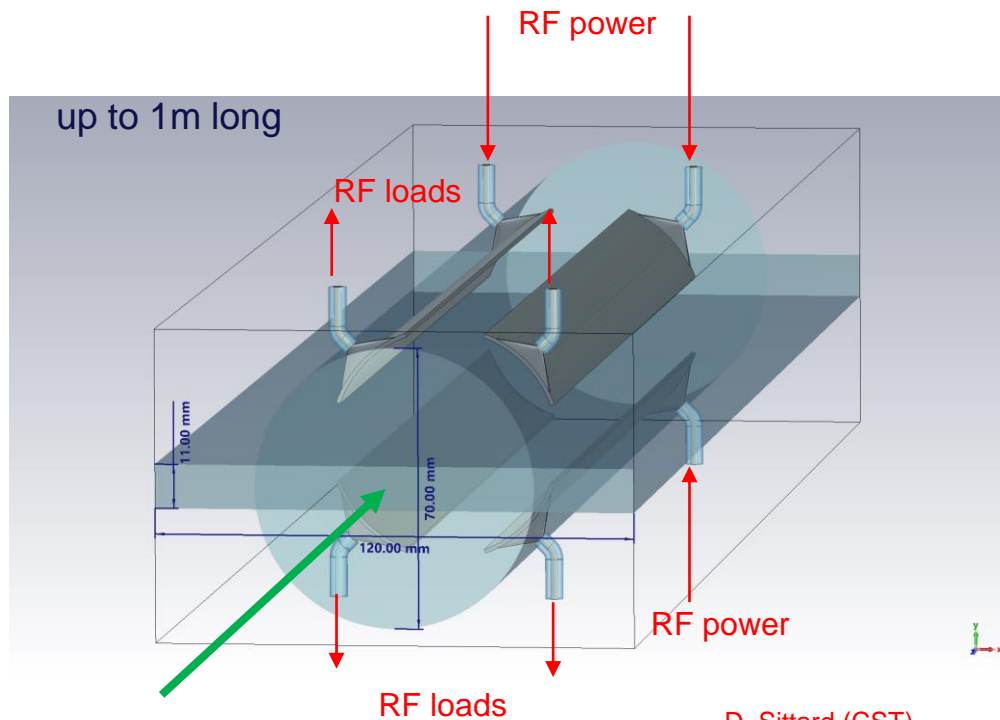
- distributed system with four-fold symmetry
- kickers and pick-ups installed at on out-going beam at start of arc
- points “Q,R,S,T” can be either experimental points or technical points
 - arcs adjacent to technical sites now preferred !
- three kickers per point and beam (12 per beam, 24 total)
 - two strong kickers (also main depolarizer bump kickers)
 - one shorter kicker (polarizer bump correction)
 - can have a higher frequency reach (100 MHz)
- four pick-ups per point and beam (16 per beam, 32 total)
 - spacial sampling, i.e. betatron phase advance between pick-ups 60-120 degrees, covering one period of betatron oscillation
 - pick-ups down stream of kickers (immediate monitoring of system malfunction, machine protection!)
- low latency data links connecting the four processing nodes per beam
 - simulations needed to determine what processing will provide additional damping to the low order coupled bunch modes using these links



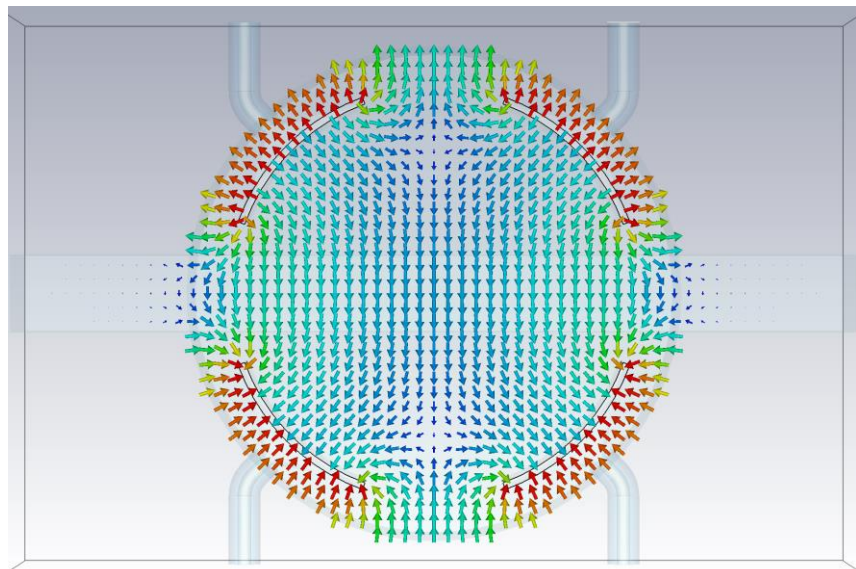
Stripline kicker: arc compatible version (1st version)

Characteristics (good for transverse feedback, but too low shunt impedance for depolariser with arc compatible diameter)

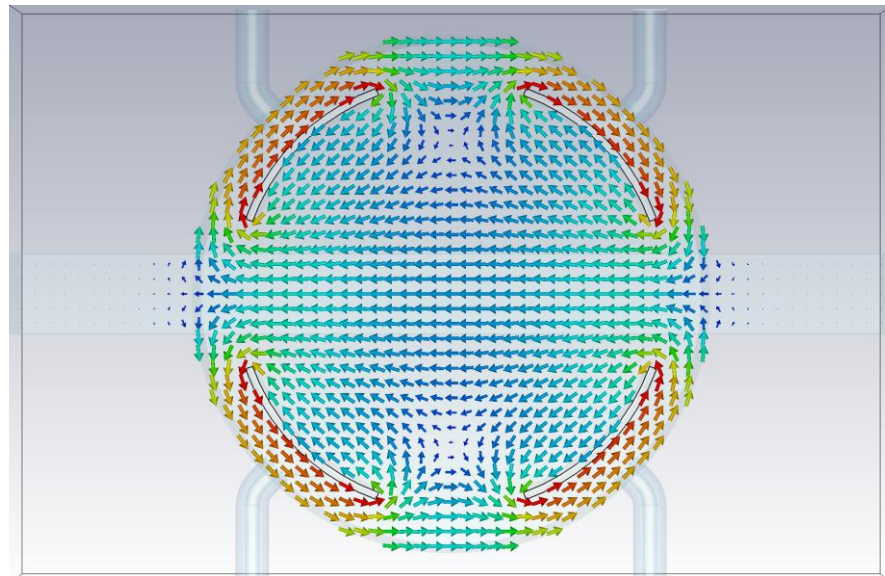
- four electrodes arranged at 45 degrees
- leaves horizontal plane free for synchrotron radiation absorbers similar as for BPM designs
- compatible with vacuum chamber diameters of 60-70 mm foreseen for arcs (initial proposal)
- small diameter also desirable for increased shunt impedance, but matching to 50 Ohm must be considered for both differential mode and common mode
- universal design that can be powered to provide vertical or horizontal kicks, even simultaneously, power can be directed to plane that needs high level kicks
- device is a backward coupler, powered at beam downstream ports and terminated at upstream ports
- action on beam provided in equal parts from magnetic and electric fields
- length can be adjusted to match actual needs for bandwidth
- total kick strength provided by set of kickers, placed at the appropriate phase advance / optics as needed



Stripline kicker: field plots (70 mm chamber)



Electric field (vertical)



Magnetic field field (horizontal)

D. Sittard

- vertical kick evenly split between electric and magnetic fields
- optimization is planned to start this year (beam impedance, details of the design compatible with short bunch length ...)

Shunt impedance kicker (four electrode version)

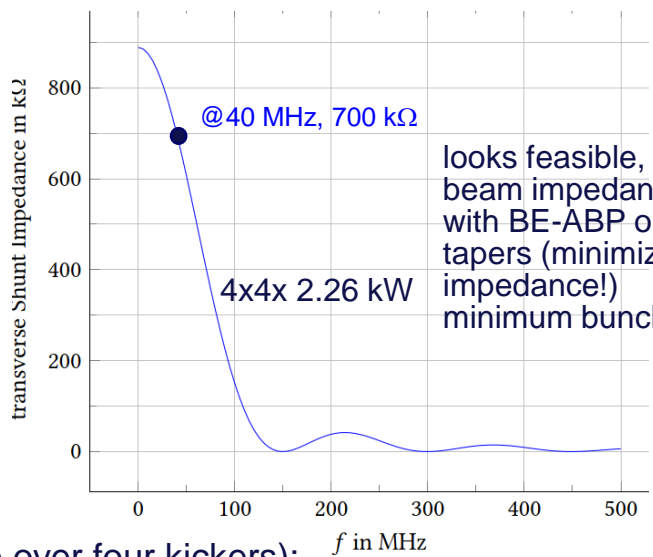
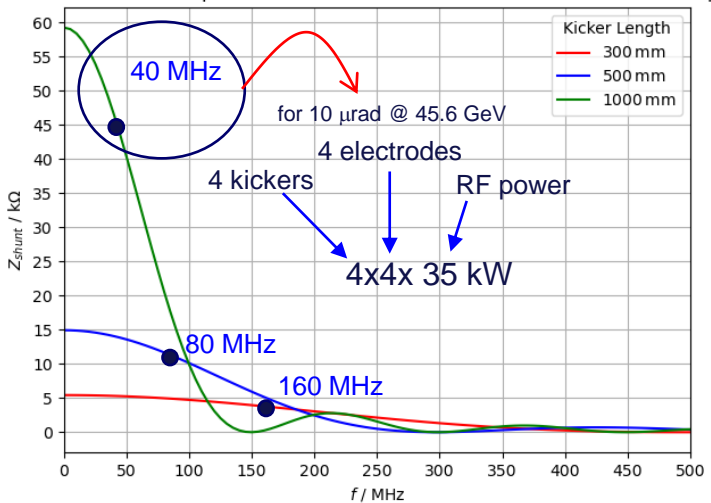
Adaptation of length to bandwidth also possible (using 1 m long kickers for 40 MHz +/- 20 MHz)

70 mm vacuum chamber diameter (directly arc compatible)

26 mm vacuum chamber (→ 18 mm between electrodes)

→ power need reduced by factor 15.6

Transverse Shunt Impedance of Kicker with 70 mm diameter of the beam pipe

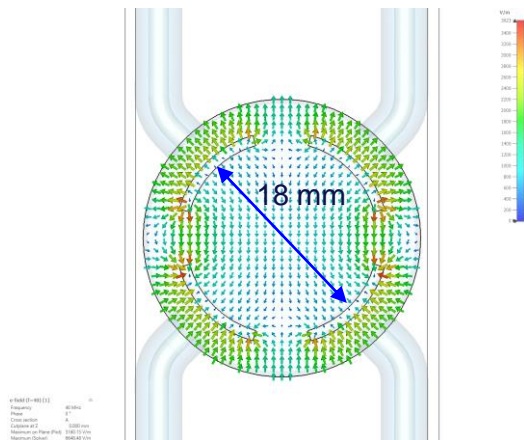


integrated transverse kick 450 kV needed (split voltage over four kickers):

$$V_T = \sqrt{2PZ_s}$$

- total length *per beam* for kickers ~10 m (+ overhead tapers)
- 3 m per location per beam (if split over four points per beam)

Stripline kicker: field plots (26 mm chamber)



Electric field (vertical)



Magnetic field field (horizontal)

- vertical kick evenly split between electric and magnetic fields
- 18 mm diameter stay clear aperture, tight tapers needed for impedance → possibly adds to installation length !

Kick voltage and kick angle summary

- **10 μrad** at 45 GeV \rightarrow **450 keV/c** transverse momentum kick needed for the **depolariser function**, several kickers needed to implement this modulated closed bump
- stripline kickers offer a viable solution
- split over four locations per beam
 - use sets of 1 m long kickers (RF matched to 50 Ω) with four electrodes for each location to create local modulated bump (2x4x2.26 kW = 18 kW RF power per bump)
 - four such systems per beam
 - 24 kickers in total for both beams combined
 - for 16 main kickers: **144 kW RF power**
 - for 8 adjustment kickers: **36 kW RF power**
 - bandwidth for adjustment kicker can be higher

Kicker lengths and powers (table is for one of four locations)

Location	Function	Length	Power
left of IP e ⁻	open bump	1.0 m	9.04 kW
left of IP e ⁻	correction	0.75 m	4.5 kW
left of IP e ⁻	close bump	1.0 m	9.04 kW
right of IP e ⁺	open bump	1.0 m	9.04 kW
right of IP e ⁺	correction	0.75 m	4.5 kW
right of IP e ⁺	close bump	1.0 m	9.04 kW

Next crucial steps – my view

- optimization of kickers with respect to having high power efficiency (shunt impedance) in operating band and acceptable beam impedance overall
 - optimization of electrode design, possible consideration of advantages of higher line impedance kicker
 - decision on minimum bunch length for design specification
- simulations with new tools available to confirm kick strength is sufficient for depolarisation as needed, see [G. Iadaorola FCC week 2025 \(Xsuite\)](#)
- move to prototyping depolariser kicker once a solid electromagnetic design is established (prototyping not before 2026), clarify where a prototype could be tested
- converging on exact installation location and optics including the space needed with tapers
- follow-up on machine protection considerations



Thank you
for your attention.

Spare

FCCee collider and booster transverse feedback

Key requirements

- need bunch-by-bunch operation at 25 ns bunch spacing → defines bandwidth
- can operate at multiple of bunch repetition frequency (short bunches) → no need to work in “base-band” as in LHC → helps as it reduces *relative* bandwidth
- sets of RF matched strip-lines with carefully chosen length as kickers seem obvious choice
- **Booster:**
 - request to also operate to damp a significant transverse injection error → defines maximum kick requirements
 - needs estimate of injection errors, filamentation time, ... to define system
 - moderate damping times only for instabilities (not beyond experience from LHC)
 - single location in ring sufficient, but also resonant depolarizer function if polarized beams are injected
- **Collider:**
 - need to damp very fast transverse instabilities → **four turns risetime**, high gain system
 - favors distributed system with multiple pick-ups and kickers
 - possibility of synergy with exciter for resonant depolarization (as in LEP)

Recapitulation TFB for FCC-ee

- FCC-ee requires a coupled bunch transverse feedback system
- fast rise times of the instability of 4 turns caused by the resistive wall impedance are predicted for the lowest order coupled bunch modes, see [M. Miglorati \(FCC week 2025\)](#)
- requires shortest possible latency (1-2 turns), short latency ensures transverse FB disentangled from orbit FB
 - use several pick-ups for “spacial sampling”, see [D. Teytelman \(FCC week 2024\)](#)
 - notch filter for closed orbit suppression
 - distributed kicker system for possibly feeding back low frequency mode with less than 1 turn delay, see [A. Drago \(FCC week 2018\)](#)
- lowest betatron frequency can be as low as 500 Hz for a tune fractional tune of 0.15
 - the feedback system should cover all unstable modes, i. e. frequencies up to half the bunch repetition frequency → 20 MHz bandwidth for baseline 25 ns bunch spacing
 - when introducing shorter bunch spacings (5 ns) at least a few feedback kickers are needed to cover frequencies up to 100 MHz, the mixed scheme proposed for electron cloud mitigation needs further scrutiny on how the bunches oscillate, and simulations with realistic feedback

Machine Protection considerations (03.10.24)

What can go wrong?

- excitations not correctly synchronized
- excitation amplitudes not correct leading to not closed depolarizing bumps
- any of the other excitations that will certainly be used (AC dipole mode etc.) need to be protected against failures
- very strong kicks possible comparable or even larger than at LHC injection

- machine protection task force working group requested examination of failure scenarios and mitigations
- from MP point of view not clear if entangling TFB and depolarizer system into one system is the optimum due to the different kick strength required for both systems and the possible failure scenario
 - possibility to have common kickers, with combination of signals before kicker (pulsed system for depolarizer, cw system for feedback function)

Mitigation

- protection with BLMs of limited or of no use due to small beam size, absence of significant halo
- monitoring of positions at appropriate distance from kickers at specific phase advance
- global monitoring of beam position required turn-by-turn, independent of pick-ups used for TFB
- interlocks need to be derived from this monitoring
 - use also down strip TFB pick-ups for monitoring
- beam stoppers?

LHC ADT kicker (LHC transverse feedback)

- high impedance tetrode amplifiers
- kicks with electric field only
- 6 m effective length split over 4 kickers twice as strong as depolarizer kicker system (2 μ rad at 450 GeV/c)
- full amplitude not as bunch selective as needed for FCCee
- due to resonances not (readily?) suitable for short electron bunches

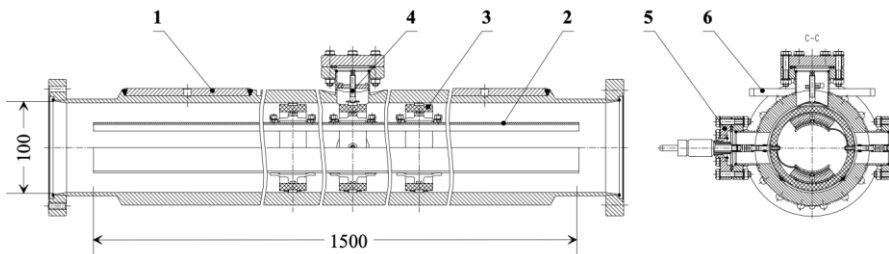


Table 1: Beam Parameters and Requirements

Injection beam momentum	450	GeV/c
Static injection errors ($\beta = 183$ m)	2	mm
ripple ($\beta = 183$ m)	2	mm
resistive wall growth time	14	ms
decoherence time	68	ms
tolerable emittance growth	2.5	%
overall damping time	4.7	ms (53 turns)
standard bunch spacing	25	ns
minimum gap between batches	995	ns
lowest betatron frequency	> 2	kHz
highest frequency to damp	20	MHz
Electro-static kickers	base band	
aperture of kickers	52	mm
number of kickers per plane and beam	4	
length of kicker plates	1.5	m
nominal voltage up to 1 MHz	± 7.5	kV
kick per turn at 450 GeV/c up to 1 MHz	2	μ rad
rise-time 10-90%, $\Delta V = \pm 7.5$ kV	350	ns
rise-time 1-99%, $\Delta V = \pm 7.5$ kV	720	ns
frequency range for gain	0.001–20	MHz
noise dominated by pick-up signal quantisation	10 bit/2 σ_{beam}	