# FIRST THOUGHTS ON FCCee DEPOLARIZER KICKER

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Acknowledgements:
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# Motivation

Several needs identified in FCCee for RF transverse kickers with sufficient bandwidth for acting selectively on bunches

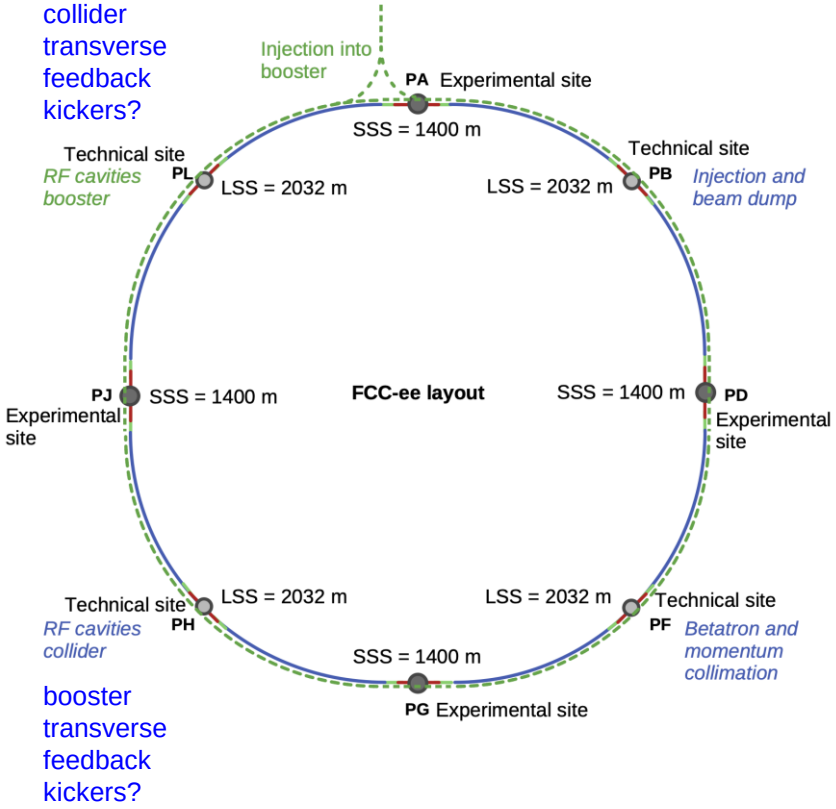
- *Transverse feedback:* (in particular at Z-pole with high total beam current), but also at WW
  - collider ring: 25 ns bunch spacing (minimum to be considered currently 20 ns)
    - very fast instability driven by resistive wall needs mitigation (… 3-7 turns)[1]
  - booster ring: 25 ns bunch spacing (minimum to be considered 20 ns)
    - at booster injection energy: additional functionality for *injection oscillation damping*
- *Depolarizer kicker:* transverse excitation as part of the system to measure the mean energy of the beam by resonant depolarization in regular intervalls during Physics at Z-pole and WW energies at least
- Similar bandwidth requirements due to the same need for bunch selectivity
  - motivates to look for synergies and hence for a universal kicker design
- Cohabitation of the systems for excitation and feedback need further study
  - situation in FCCee much different from LEP due to the very high number of bunches and the need for a strong transverse feedback (at Z-pole) at FCCee
    - nota bene: motion of bunches couples through the impedance of the accelerator

1. See talks by D. Teytelman and M. Migliorati (Wed)

# Placement options in ring

**Discussions on possible placement options starting**

- from the technical sites, locations where RF is located offer (some) space
  - PL: booster RF, collider transverse FB
  - PH: collider RF, booster transverse FB
- advantages of PL and PH:
  - free from space and optics constraints of experimental points, and the other technical sites with extraction, injection and collimation
- collider RF and transverse kickers expected to be both larger scale systems than the respective systems for the booster → have these in different points



# Depolarizer kicker

**Basic functional requirements (for operation at the Z-pole and WW)**

- The depolarizer is a powerful set of transverse electromagnetic kickers needed in FCCee as part of the system to provide a calibrated beam energy measurement at the Z-pole and WW energies via resonant depolarization, a technique already extensively used at LEP
  - 100 to 160 lower intensity witness bunches can be placed in 10 -16 of the total of 20 gaps of the filling pattern for the Z-pole energy run; these bunches are specifically dedicated to the energy measurement, placed at 100 ns in both beams such that they do not collide in any of the experiments[2]
  - bunch selective excitation with the depolarizer at 100 ns bunch spacing is required in the form of a swept or stepped excitation across the spin resonance
  - for Physics bunches the same type of kicker system shall be used to continuously or on demand shake the beam locally, i. e. apply a modulated (closed) orbit bump to prevent polarization build up

2. See talk by H. Bartosik on filling patterns (Tue)

# Transverse Feedback Kickers

**Requirements**

- bunch-by-bunch operation calls for +/- 20 MHz minimum for 25 ns bunch spacing
- high gain required, not necessarily high kick strength
- low noise electronics
- prefered to provide feedback kicks in a band at a multiple of the bunch repetition frequency, nx40 MHz or nx50 MHz depending on bunch spacing
  - lowest betatron frequency is very low in frequency (~660 Hz)
- possibilities to distribute kicker system over several collider points considered before but seems at present not required[1]
- fast damping rates required for low order modes only
- have a set of kickers available at different phase advances is an advantage (if fractional tune options close to 0.5 or integer, it is a must)
- highest beta function for given aperture, low dispersion for associated set of pick-ups
- additional synergy to be explored for applications as in LHC (AC-dipole for optics measurements …)

1. See talk by D. Teytelman (Wed)

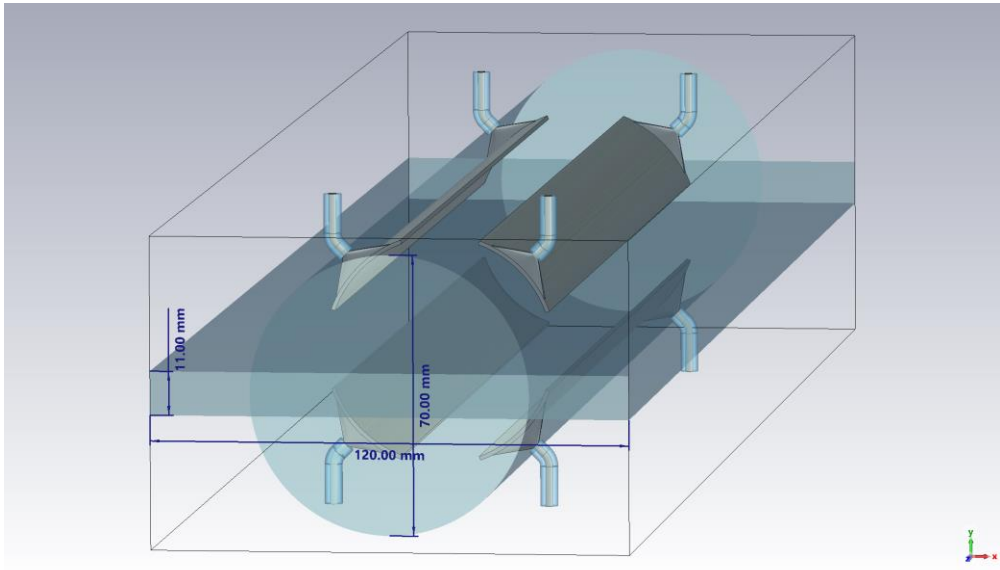
# Let’s look what can be achieved with striplines

- start with a design suitable also for arc locations, compatible with the standard vacuum chamber diameter
- explore option for straight technical section with larger vacuum chamber diameter adjacent to cryo modules
- reminder: staying as close as possible to beam with striplines will give the highest kick

# Stripline kicker: arc compatible version

## Characteristics

- 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
- 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

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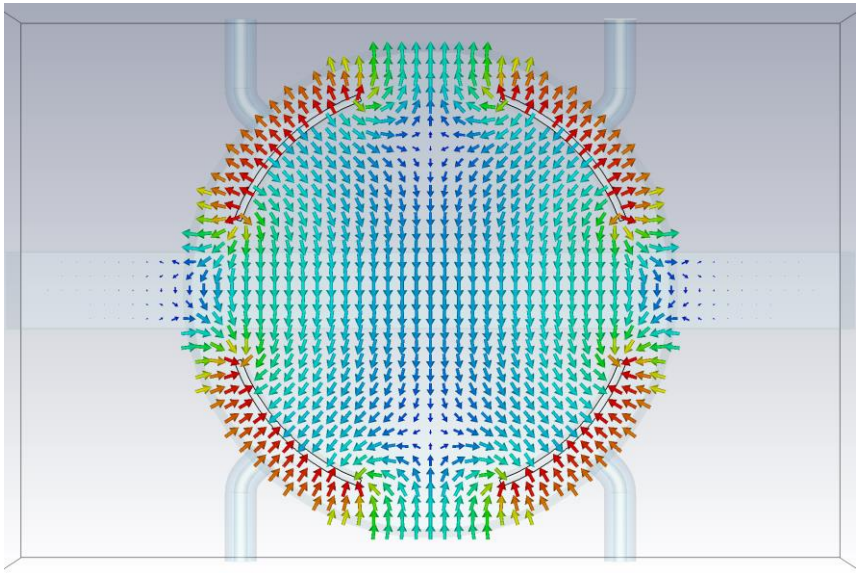
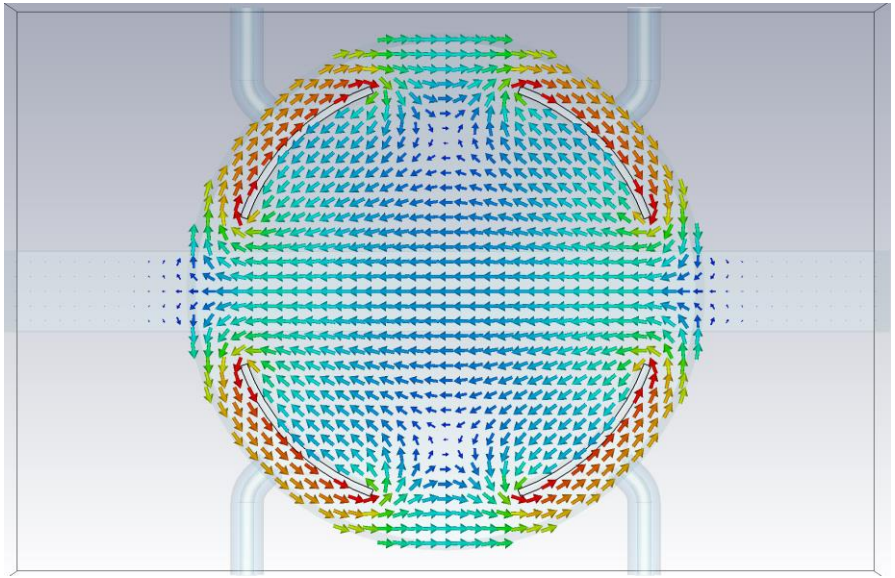
# Stripline kicker: field plots (example)



**Electric field (vertical)**



**Magnetic field field (horizontal)**

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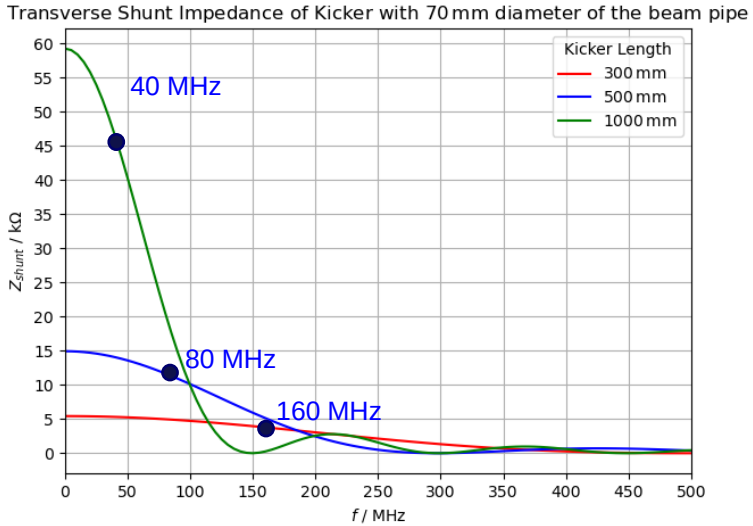
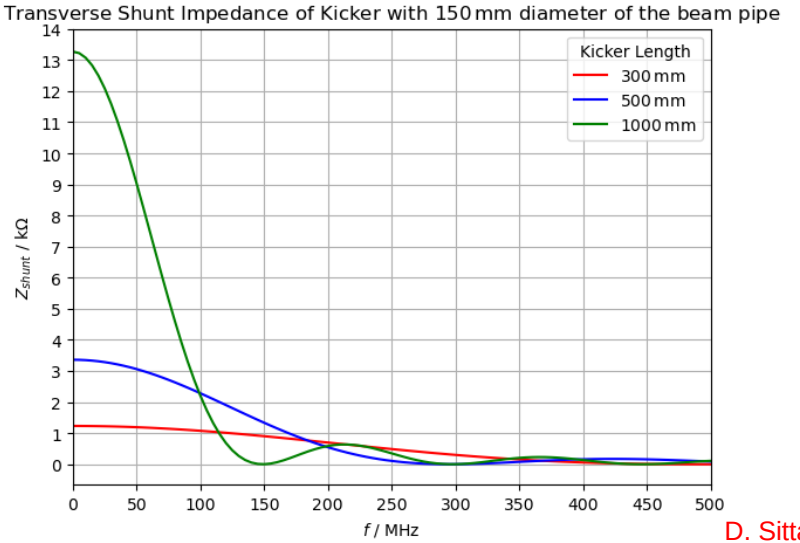
# Shunt impedance

**Adaptation of length to bandwidth (as example for two possible diameters)**

70 mm vacuum chamber diameter (arc compatible)




150 mm diameter (as next to collider RF cavity modules)

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integrated transverse kick: $V_T = \sqrt{2PZ\_T}$

small diameter kicker and splitting over several kickers helps keeping required power level “acceptable”

# Kick voltage and kick angle

**Needed for depolarizer for Z-pole (45 GeV beam)**

- 10 μrad at 45 GeV → 450 keV/c transverse momentum kick needed, at minimum two locations for implementing a closed bump with modulated amplitude

  - option: 1 m long kickers (RF matched to 50 Ω):
  - 45 kΩ transverse shunt impedance per kicker at 70 mm diameter
  - clearly having only one such kicker of 1 m would require excessive power
    - 560 kW pulsed per electrode
    - gain factor 10 in shunt impedance by reducing diameter by factor 3
    - splitting over four kickers (4 x 1 m long)
    - 3.5 kW amplifiers (4 per kicker, i.e. 16 per beam) for the RDP kicker
  - Will be a challenge to design such striplines compatible with high bunch intensities at short bunch length; PEP II experience at SLAC shows how elements in vacuum can be easily damaged → design and test in existing electron machine?

# Summary

- Transverse feedback and depolarizer require electromagnetic kickers with bunch selective capabilities and modulation bandwidths of several tens of MHz
- Given the high kick strength needed for the depolarizer a set of long striplines installed as close as possible to the beam seem a feasible option
- To keep the needed RF power reasonable the kick needs to be distributed over several elements
- As several meters of installation space will be required at at least two locations, the integration and the design of a suitable optics needs to be given priority
- Point L of FCCee and an adjacent arc seem a logical choice
- The requirement to implement the depolarizer kickers in a way to form a modulated closed local bump with dipoles in between needs confirmation

# Thank you
# for your attention.

# Spare

## 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 μrad at 450 GeV/c)
- full amplitude not as bunch selective as needed for FCCee
- due to resonances not (readily?) suitable for short electron bunches

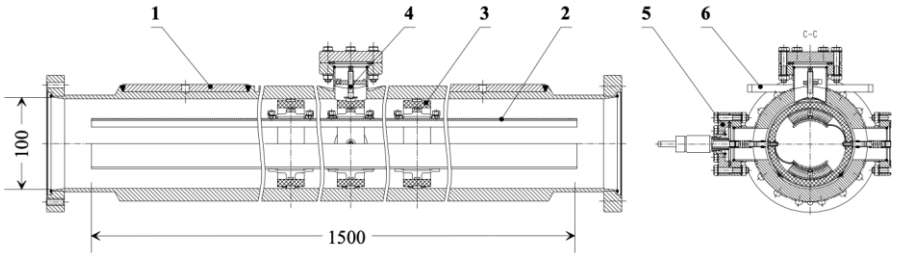


Table 1: Beam Parameters and Requirements

| | | |
|---|---|---|
| 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 | $\pm 7.5$ | kV |
| kick per turn at 450 GeV/c up to 1 MHz | 2 | $\mu$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 $\sigma_{\mathrm{beam}}$ | |

W. Hofle et al. PAC 2001