HZB BESSY II Light Source

OVERVIEW OF TECHNOLOGIES FOR INJECTIONS

Olaf Dressler - I.FAST Workshop 2024 on Injectors for Storage Ring Based Light Sources

6-8th March 2024, KIT, Karlsruhe, Germany

(Pulsed) Magnet Systems for Injections into Storage Rings

- *DC dipole magnets, with reasonably small gaps, highly stable power supplies required,*
- *Permanent material dipole magnets, 'samarium cobalt vs. neodymium iron boron magnets' especially with DC 'offset current coil' for magnetic field adjustment,*
- *Slow pulsed or ramped dipole magnets,*
- *(Fast) pulsed magnets like conventional septa and fast pulsed kicker magnets, typically C-yoke or window frame magnets, with laminated iron or ferrite core,*
- *Non-linear field kicker magnets, sometimes named multi-pole kicker magnets, characteristics is coil without an iron core, profile of beam pipe maintained,*
- *Traveling wave kicker magnets, called stripline kicker structures, inside vacuum system, full metal, focus on feed throughs for excitation current.*

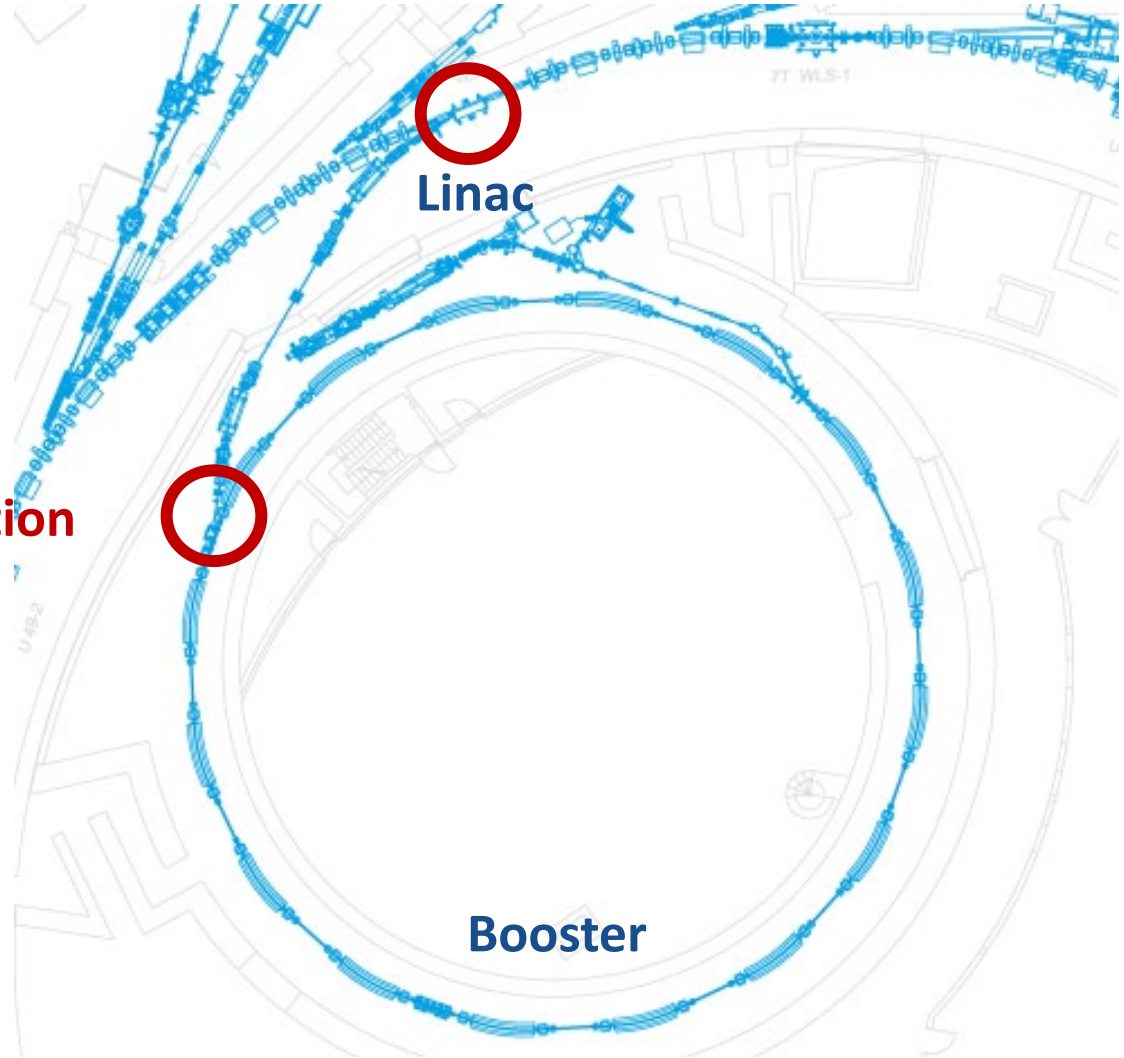
Purpose of (Pulsed) Injection Systems

Injection into, and, beam accumulation in storage rings in dedicated operational modes, e.g. top-up, with very high injection efficiencies (>95%).

High demands on:

- *Deflection angle, therefore magnetic field strength,*
- *Magnetic field homogeneity inside magnet gap; but avoid undesired stray field on stored beam outside,*
- *Properties of the desired pulse shape: Sinusoidal or rectangular, pulse length, flat top, rise and fall times,*
- *Magnetic field stability, e.g. specification for repetitive pulse-to-pulse stability $1x10^{exp-4}$ pp,*
- *Electro-magnetic interference (EMI) in regard with other neighboring devices,*
- *24/7 operability, easy or better no maintenance,*
- *Interaction of the pulser technology which is used to energize the pulsed magnets with the accelerator.*

Exemplary Overview of the BESSY Injector

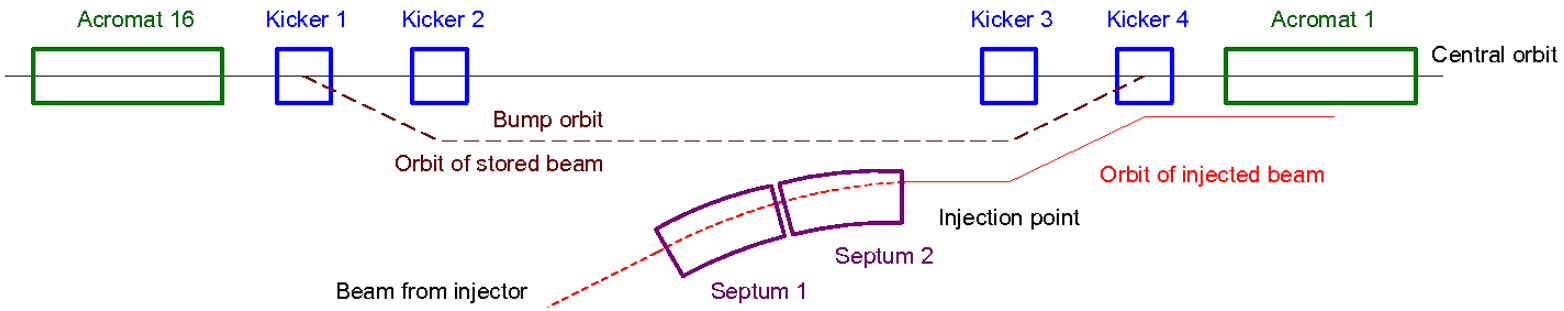


Horizontal plane

The Conventional Storage Ring Injection

Conventional Layout of BESSY II Storage Ring Injection

Two similar injection septa and four injection kickers in one (long) straight section.

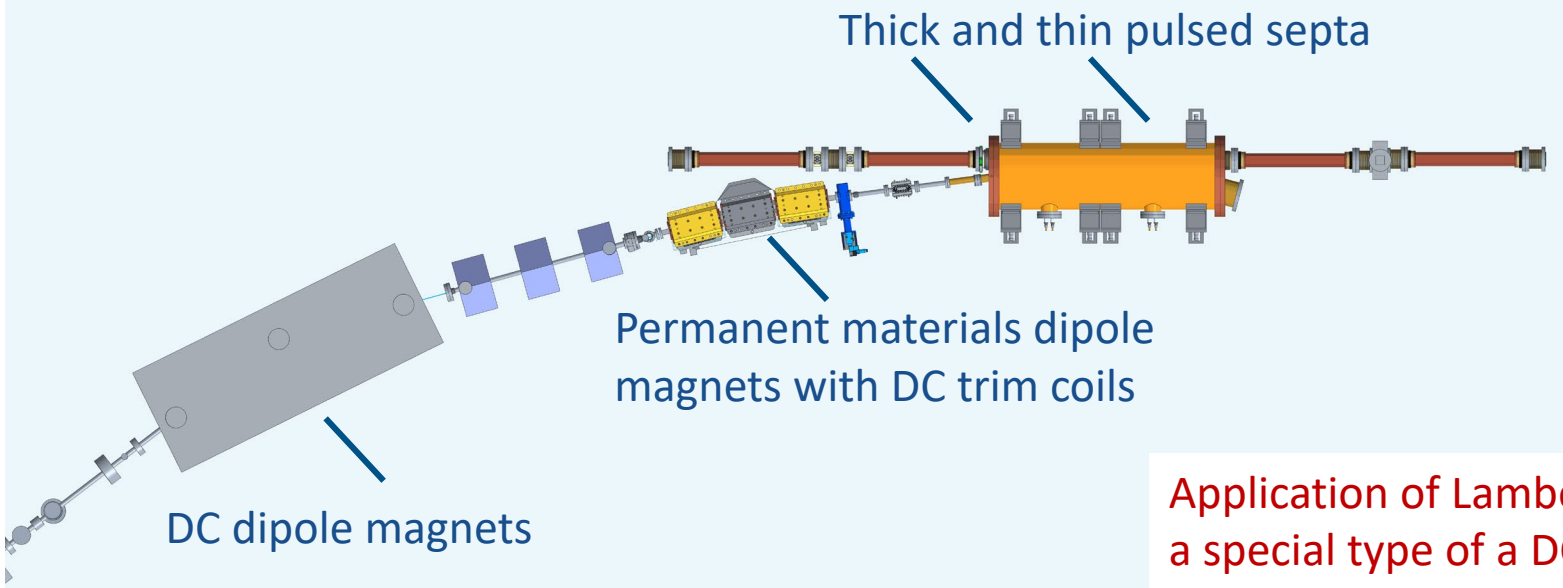


Two different challenges:

1. Development of the injection path, e.g. DC / permanent material dipole magnets and pulsed septa for optimal injection,
2. Kicker magnets for beam injection and accumulation into the storage ring.

DC Dipole Magnets, Permanent Materials Dipole Magnets, Thick and Thin Pulsed Septa

Scheme of the proposed upgrade of BESSY II injection



Application of Lambertson septum, a special type of a DC septum, possible?

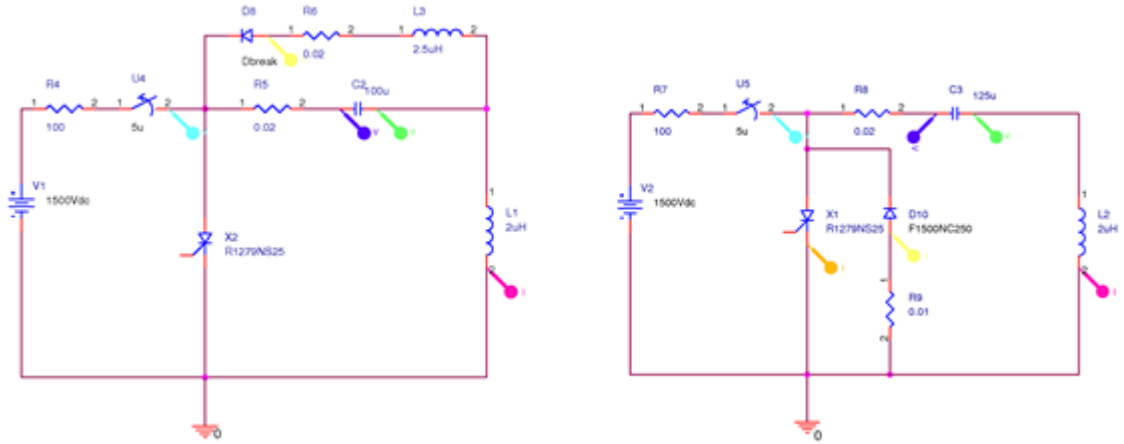
DC Dipole Magnets, Permanent Materials Dipole Magnets, **Thick and Thin Pulsed Septa**

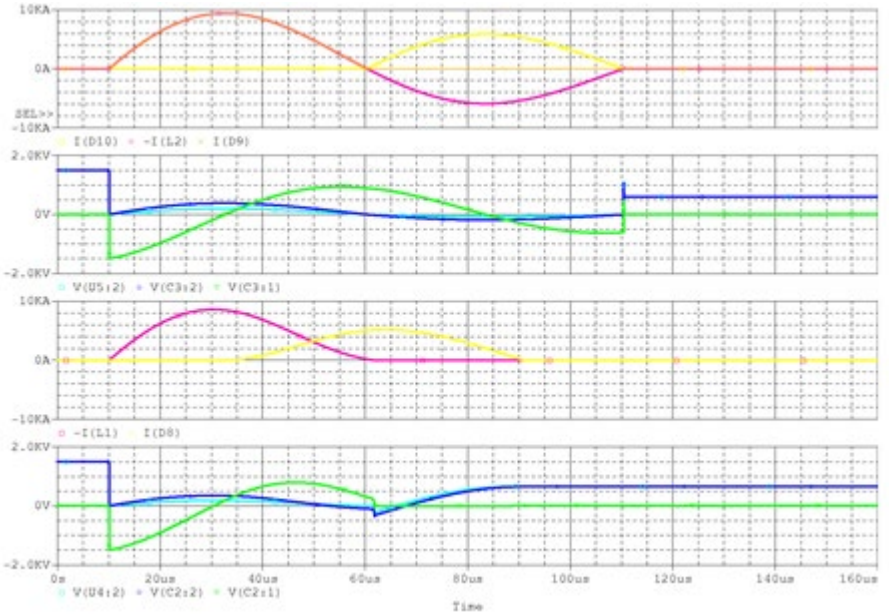
Two major design issues for pulsed septa:

1. Reduce the septum blade thickness for smaller injection distances / angles.
2. Magnet excitation with full sine current pulse for eddy current reduction.

*D. Shuman et al., 'Stray Field Reduction of ALS Eddy Current Septum Magnets', Proc. of 2005 PAC, Knoxville, TN, U.S.A., 2005, pp. 3718-3720.

PSpice schematics for **half-sine pulser (left), full-sine pulser (right**





Full sine current

Full sine voltages

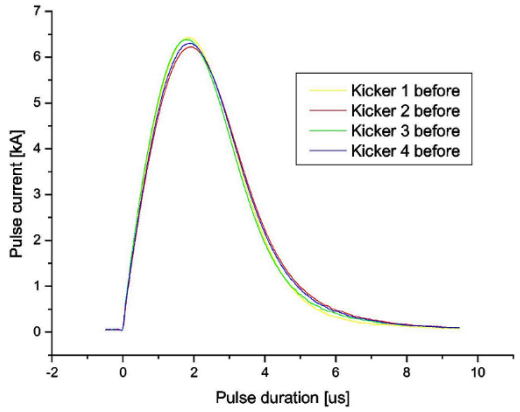
Half sine current

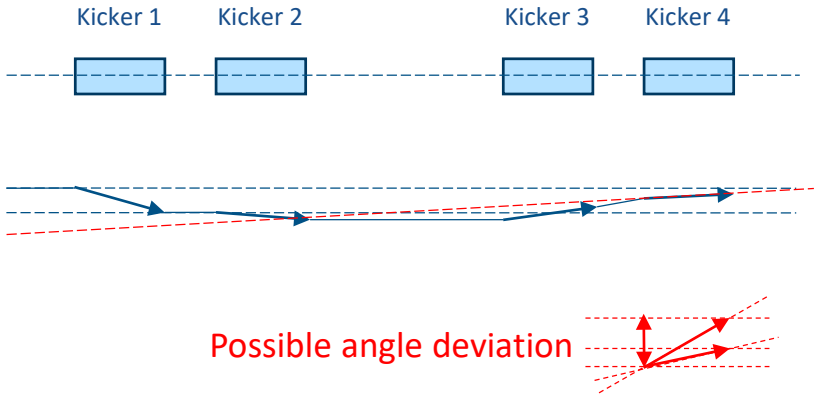
Half sine voltages

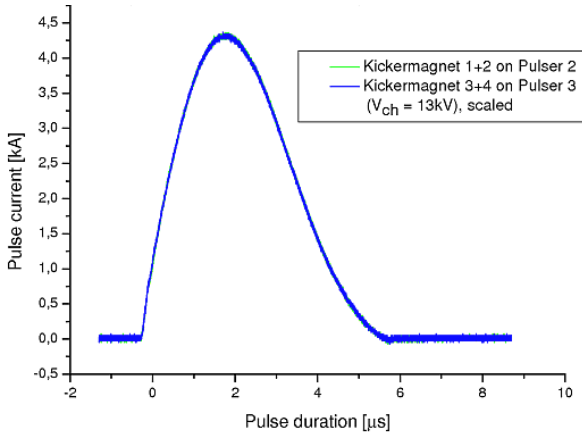
Current and voltage curves of the PSpice simulations (left).

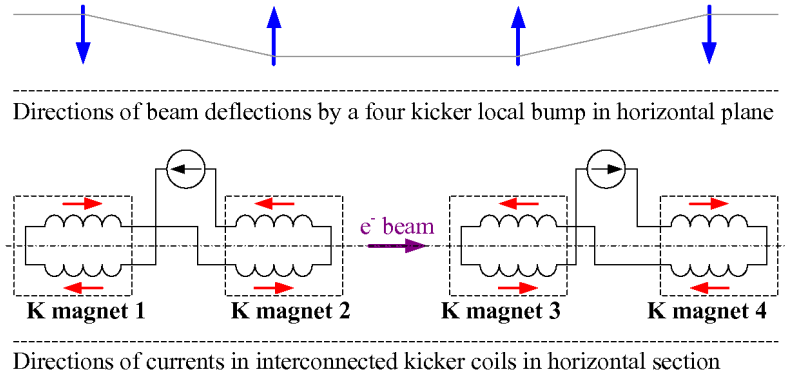
Conventional Kicker Magnets, Non-Linear Kickers, Stripline Kickers

Four Conventional Kicker Magnets









Matching and stabilizing of four similar transient kicker magnetic fields / driving pulse currents is a huge challenge.

Deviations in pulse shape and also in pulse start timing jitter cause different angle and position deviations for successive electron bunches in the bunch train.

First idea for mitigation:
Drive all kicker magnets with one pulse power supply.

*Stover, G. D. 'Analysis and design modifications for upgrade of storage ring bump pulse system driving the injection bump magnets at the ALS', PAC'95; Dallas, TX, U.S.A., 1995.

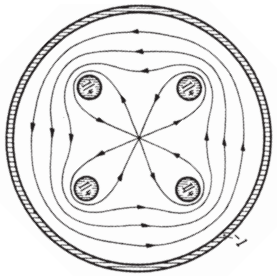
Second idea:
Adjustment of the kicker magnet inductances and powering them in groups, series connection of two kicker magnets on one pulser unit each side of septum magnet.

*Dressler, O. et al., 'Matching Pulse Shapes of the BESSY II Storage Ring Injection Kicker System / High Precision Pulse Measurements', PPC05, Monterey, CA, U.S.A., 2005.

Now, the angle and position dependence has changed into a position dependence, e.g. a parallel shift of the target path.

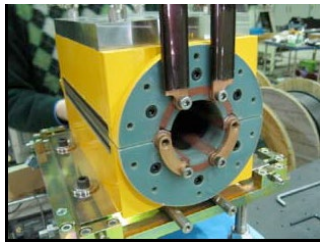
Conventional Kicker Magnets, Non-Linear Kickers, Stripline Kickers

‘Star Quad’



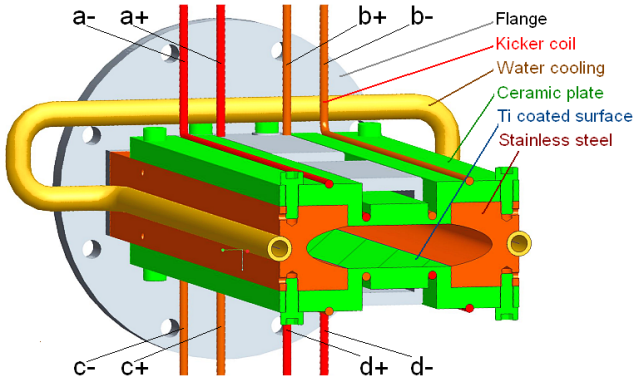
*H. Kaden, ’Eddy Currents and Shielding in Communications Technology’, Springer-Verlag Berlin Heidelberg GmbH, 1959.

Pulsed quadrupoles, sextuples, octupoles



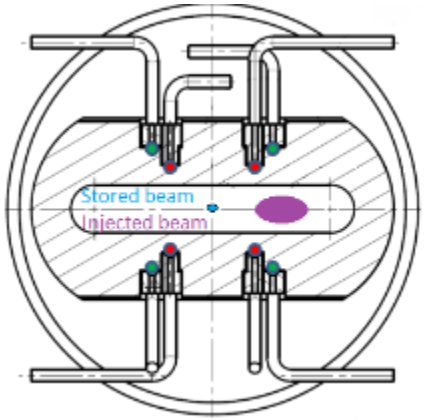
*Phys. Rev. ST Accel. Beams 10, 123501, ‘New injection scheme using a pulsed quadrupole magnet in electron storage rings’, K. Harada, Y. Kobayashi, T. Miyajima, S. Nagahashi, Photon Factory, 2007.

Non-Linear Kicker - 3D Model



*Dressler, O., 'Development of a Non-Linear Kicker System to facilitate a new Injection Scheme for the BESSY II Storage Ring', Proc. of IPAC2011, San Sebastian, Spain, 2011, pp. 3394-3396.

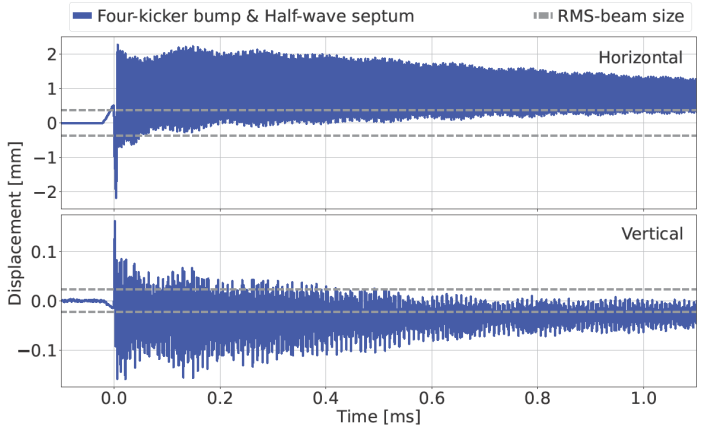
Multipole Injection Kicker



*J. Da Silva Castro, P. Alexandre, R. Ben El Fekih, T. S. Thoraud, 'Multipole Injection Kicker (MIK), a Co-operative Project SOLEIL and MAX IV', in Proc. 10th Mechanical Engineering Design of Synchrotron Radiation Equipment and Instrumentation Int. Conf. (MEDSI’18), Paris, France, Jun. 2018, pp. 48–49.

Solution – Full Sine Excitation for Septa and Non-Linear Kicker?

1



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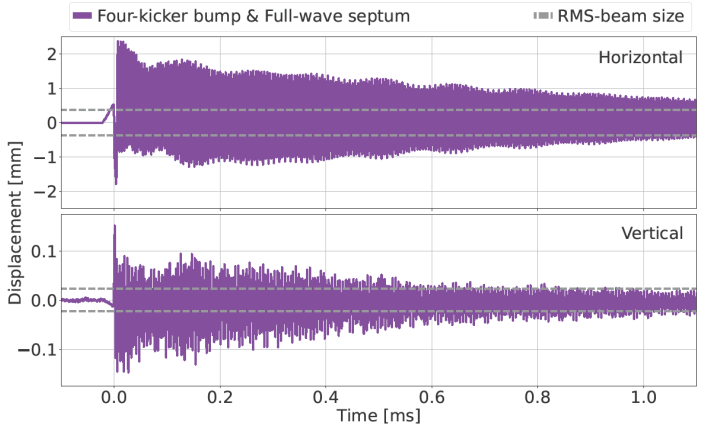

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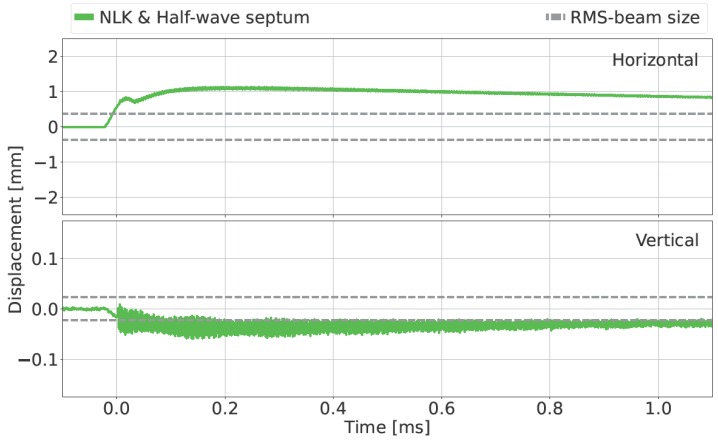

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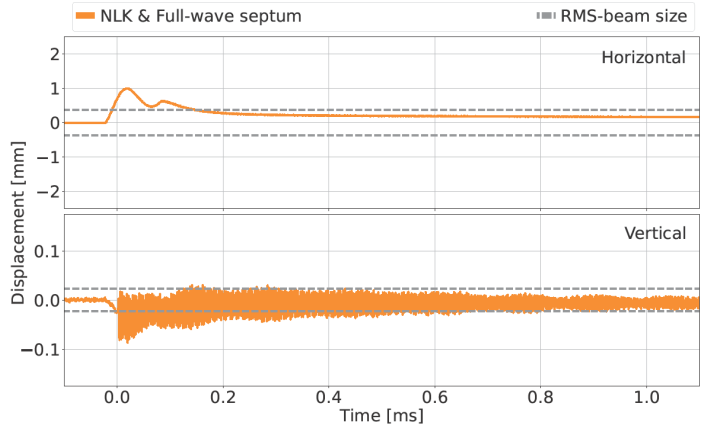
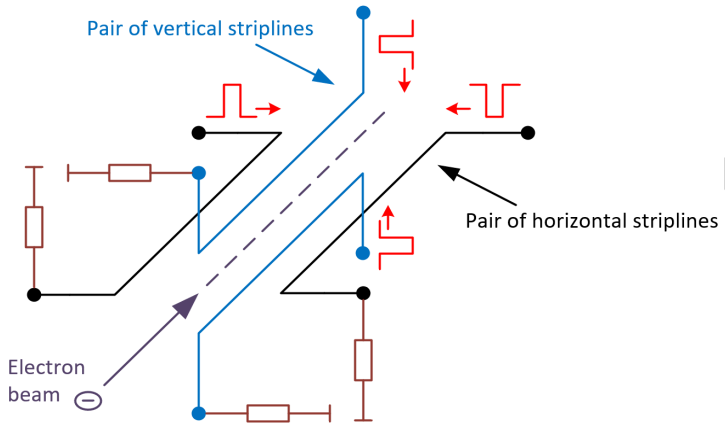


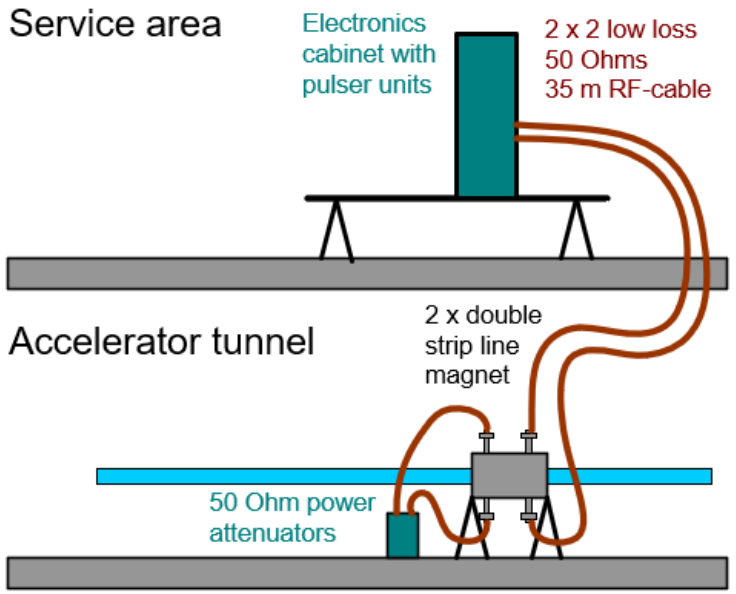
*A. Gora et al., 'Beam-Based Characterization of a Non-linear Injection Kicker at BESSY II', Proc. IPAC'23, Venice, Italy, May 2023, pp. 1156–1158.

Real measurements with electron beam in a storage ring:
Combination of full wave septum and non-linear kicker injection shows the least beam displacement or excitation during the injection process.

Conventional Kicker Magnets, Non-Linear Kickers, **Stripline Kickers**

Developments of stripline kickers **and** pulsers as pulse power systems to facilitate on-axis injection for single bunches and multi bunch trains, and for swap out injections of those.





Schematics of a hor. and vert. strip line kicker

Pulsers for stripline kickers are:

1. Traveling wave pulsers,
2. Blumlein structures,
3. Inductive adders,
4. Marx generators,
5. etc.

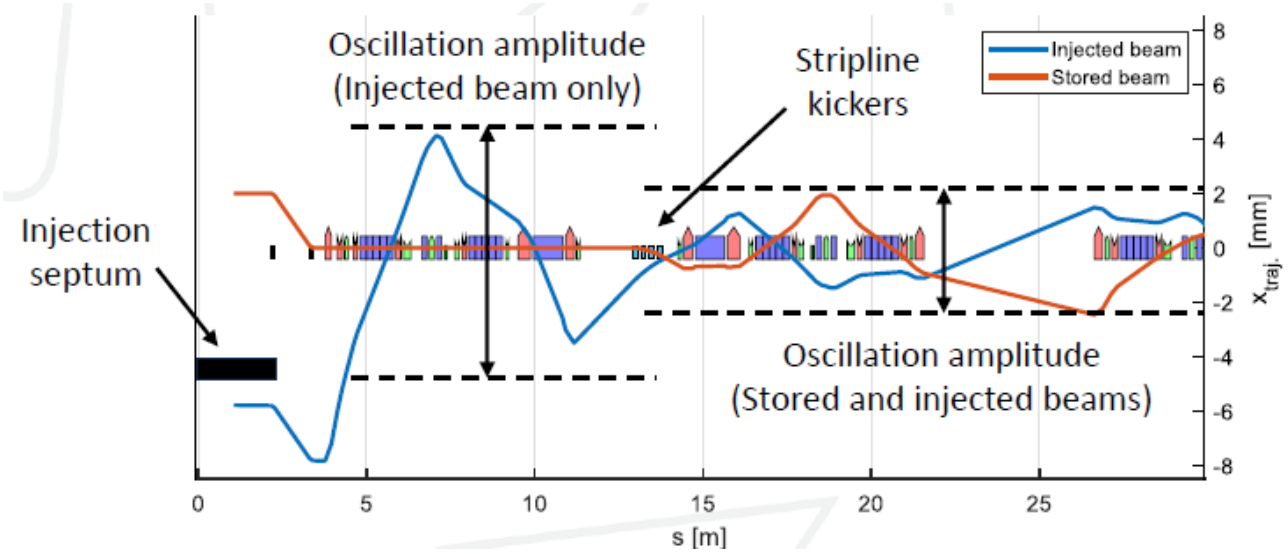
With thyratrons or matrixes of solid state switches.

*C.Belver-Aguilar, 'Stripline design for the extraction kicker of Compact Linear Collider damping rings', Phys. Rev. ST Accel. Beams 17, 071003 (2014),

*William L. Waldron, James E. Galvin, William B. Ghiorso, and Chris Pappas, 'The Design and Testing of an Inductive Voltage Adder for ALS-U Kicker Magnets', LBNL Berkeley, CA, U.S.A. 2016, 978-1-5090-2354-7/16/$31.00 ©2016 IEEE

*G. Loisch et. al., 'Stripline Kickers for Injection into PETRA IV', Proc. of IPAC2021, Campinas, SP, Brazil, pp.2863-2865.

Aperture sharing for highest efficiency injection into storage rings



'Trajectory of injected- and stored bunch centroids through the first achromat during single-bunch aperture sharing. Chicanes are set to a 2 mm static bump.'

*J. Kallestrup et. al., 'Aperture Sharing Injection for DIAMOND-II', Proc. of IPAC2022, Bangkok, Thailand, 2022, pp. 2606-2609. ISBN: 978-3-95450-227-1

Question after all:

Does the developed technology fit to the physics requirements?

Summary

Very different technologies available for conventional injections:

1. DC dipole magnets – incl. Lambertson septa, for a special geometry of the injection trajectory,
   Permanent materials dipole magnets, consideration of samarium cobalt vs. neodymium iron boron magnets,
   Thick and thin pulsed septa, describing the thickness of the septum blade, half or full sine current excitation,

2. Conventional kicker magnets – four kicker bump
   Non-linear kickers - special magnetic field distribution,
   Stripline kickers - 50 Ohms electro-magnetic field for deflection,
   for both above - single or multiple devices,

3. In general: Pulser devices to drive the pulse currents for the above mentioned technologies,

4. Beam optics feature - Aperture sharing for highest efficiency injection,

5. Operability, stability and longevity.
   Finally: Does the developed technology fit to the physics requirements?