‘Characterization of a Non-linear Kicker at BESSY II’

O. Dressler, P. Kuske

Advanced Low Emittance Rings Technology Workshop, Valencia, Spain, 5 - 6 May 2014

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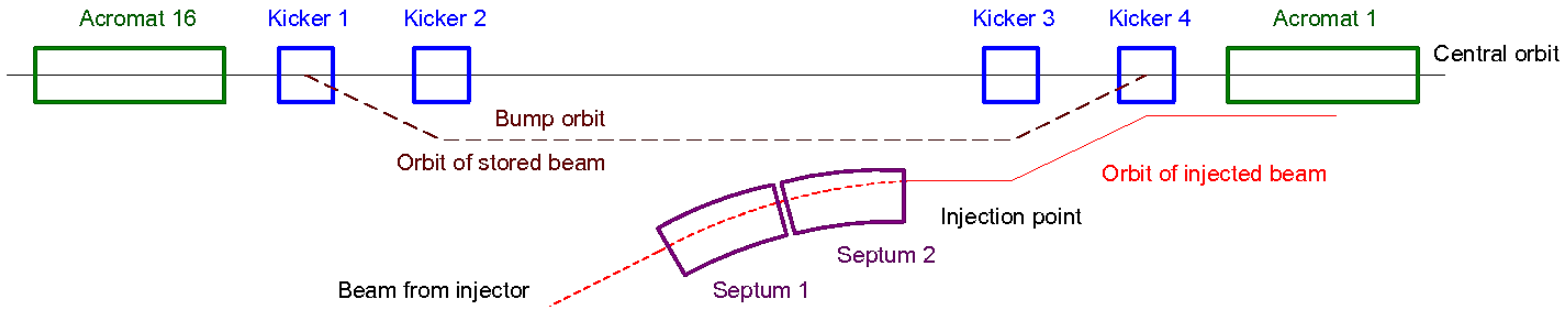
- Non-conventional Injection vs. 4 Kicker Bump,
- Undisturbed Injection with Vanishing On-Axis Field,
- **Characterization of Kicker System in BESSY II Storage Ring,**
- Field Measurements of Non-linear Kicker Magnet in Laboratory,
- Summary and Outlook.

Non-conventional Injection vs. 4 Kicker Bump

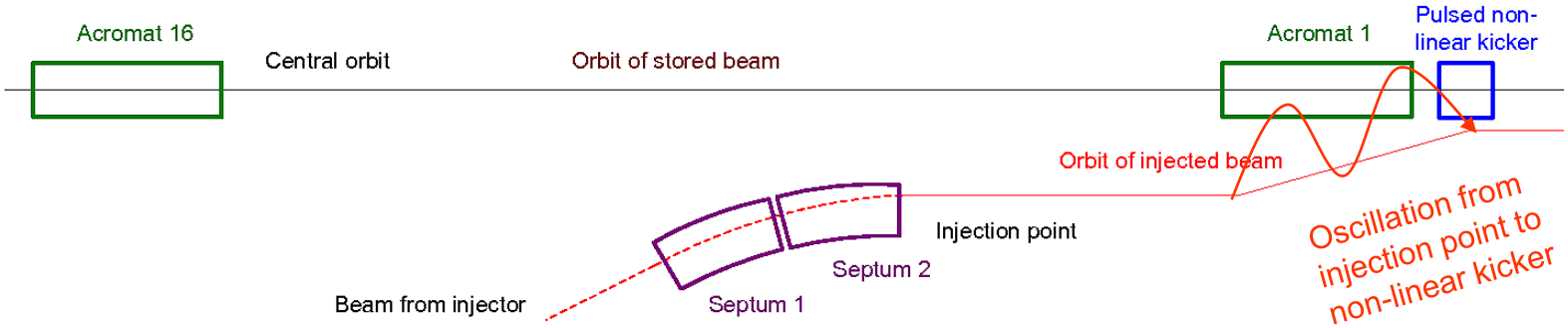
Conventional layout of BESSY II Storage Ring Injection

Two injection septa and four injection kickers in one (long) straight section, were two kicker magnets are powered in series by one pulse power supply respectively.



Non-conventional injection with one single non-linear kicker

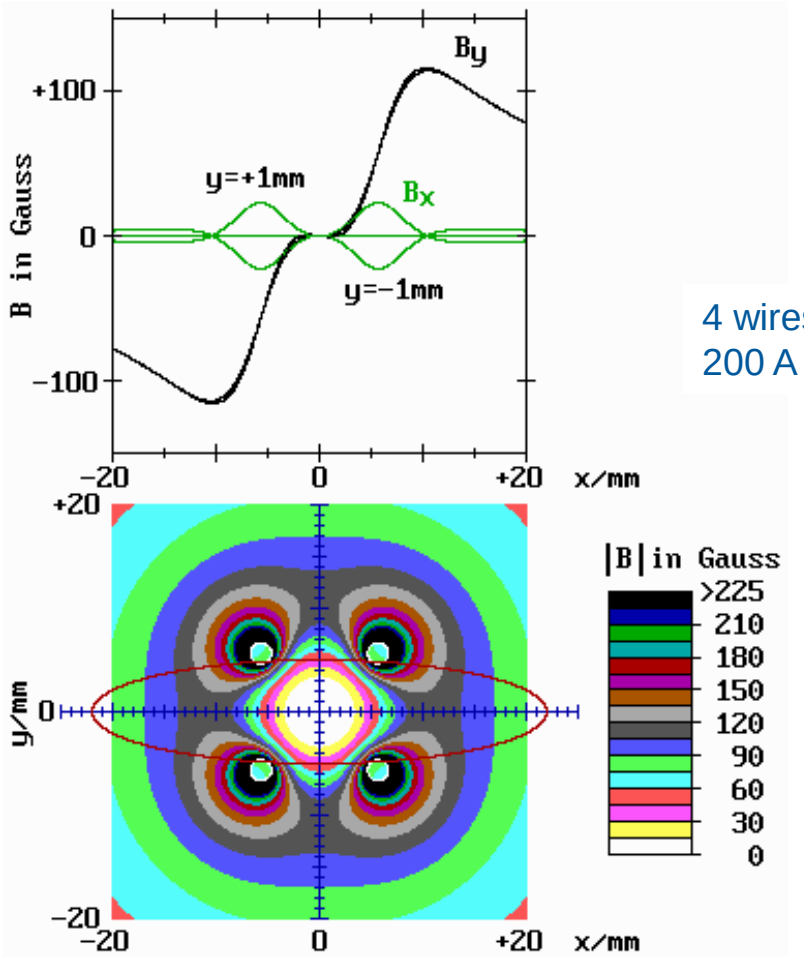
Application of the two injection septa and one single pulsed non-linear kicker magnet outside the injection straight for special injection procedure in top-up-mode *.



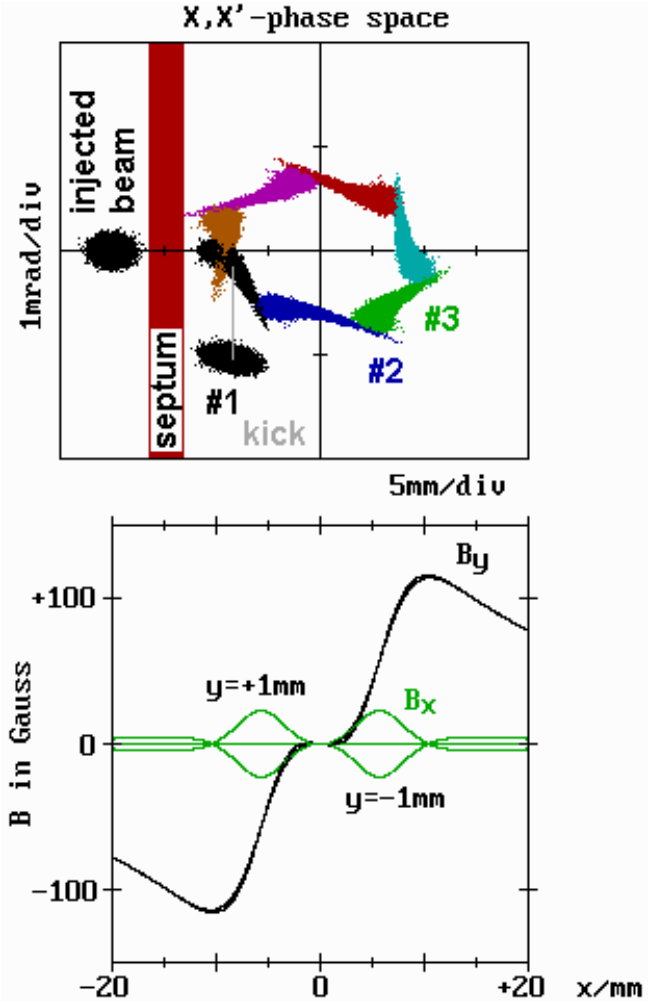
*Phys. Rev. ST Accel. Beams 10, 123501, 'New injection scheme using a pulsed quadrupole magnet in electron storage rings', K. Harada, Y. Kobayashi, T. Miyajima, S. Nagahashi, *Photon Factory*, 2007.

Single Kicker Injection with Vanishing On-Axis Field

In-vacuum stripline-type design

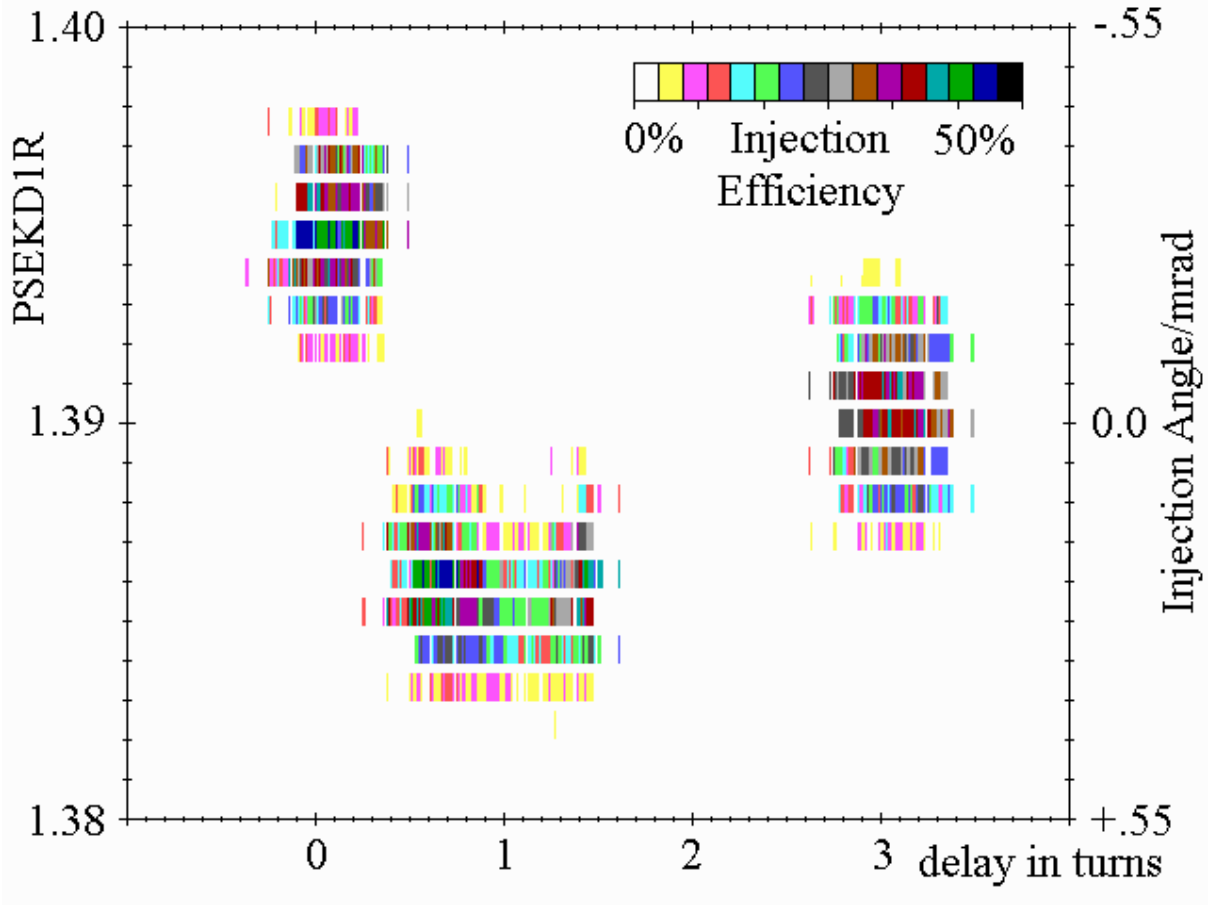


4 wires with
200 A each



P. Kuske, et al, XX1 ESLS Workshop, Karlsruhe, 21-22, November 2013

Variation of the horizontal injection angle and kicker delay



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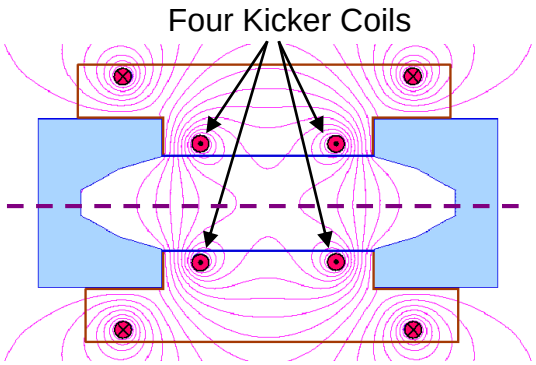
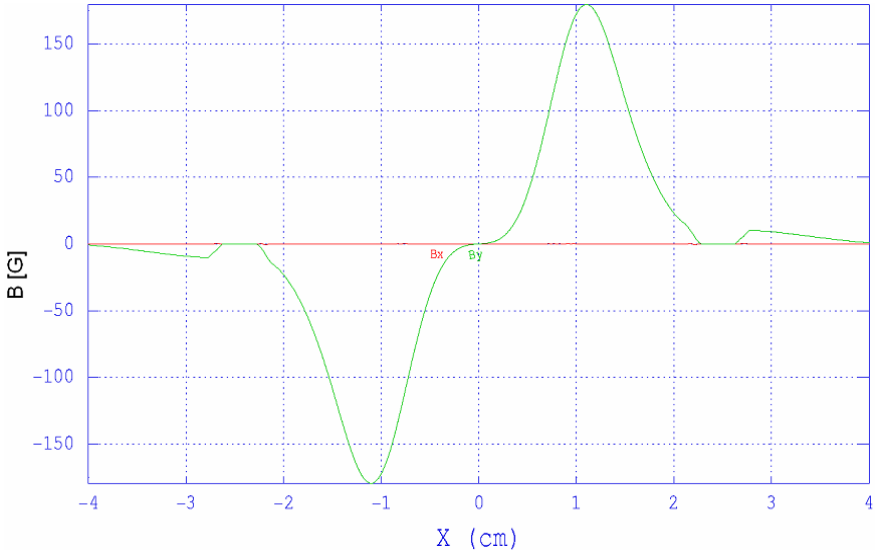
Efficiency up to 60% with chosen optics and kicking the injected beam at later turns also.
Magnet works as expected.

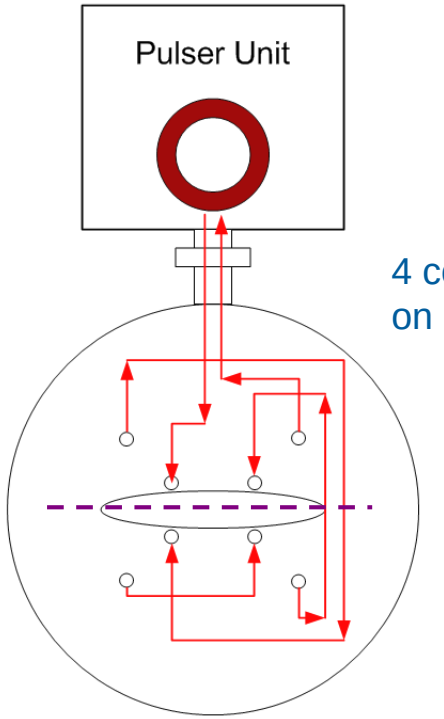
Field Distribution in Magnet and its Symmetry

2D Magnet Model





Schematics of Electrical Connections



4 coils in series
on 1 transducer

Specification

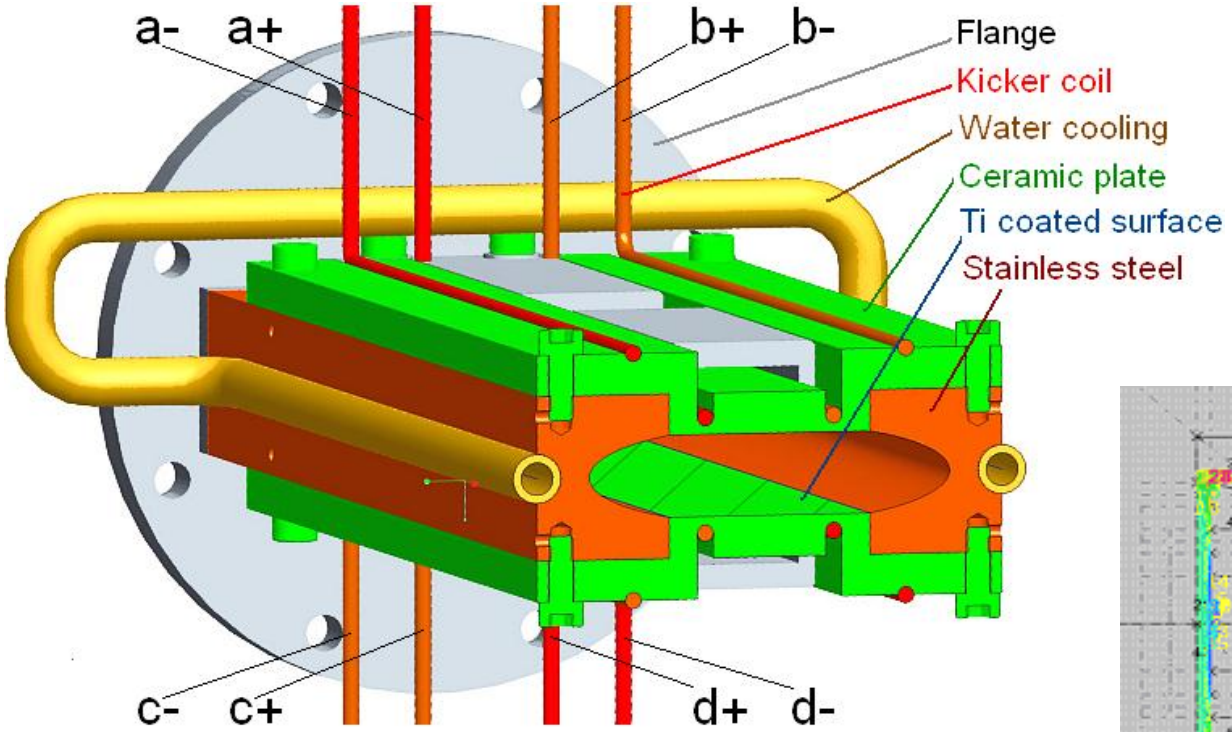
$B_{y\ max.} \geq 25$ mT, depiction in [G],
(1 G = $1 \cdot 10^{-4}$ T)

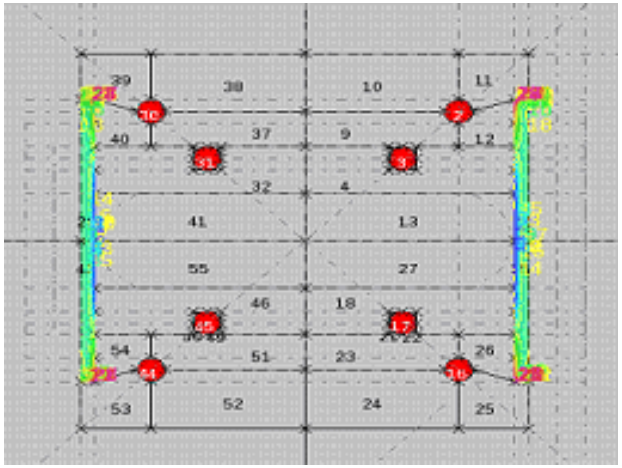
$B_{y\ max.}$ at y = 0 and x = +12 mm

$B_{y\ min.}$ at y = 0 and x = -12 mm

$B_x = 0$ along y = 0

Sectional View 3D Magnet Model

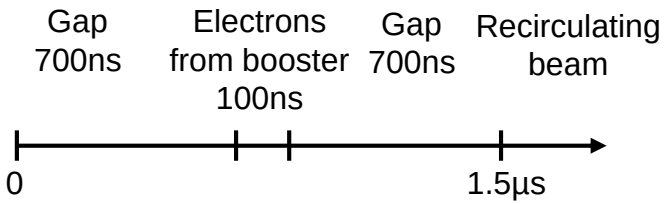




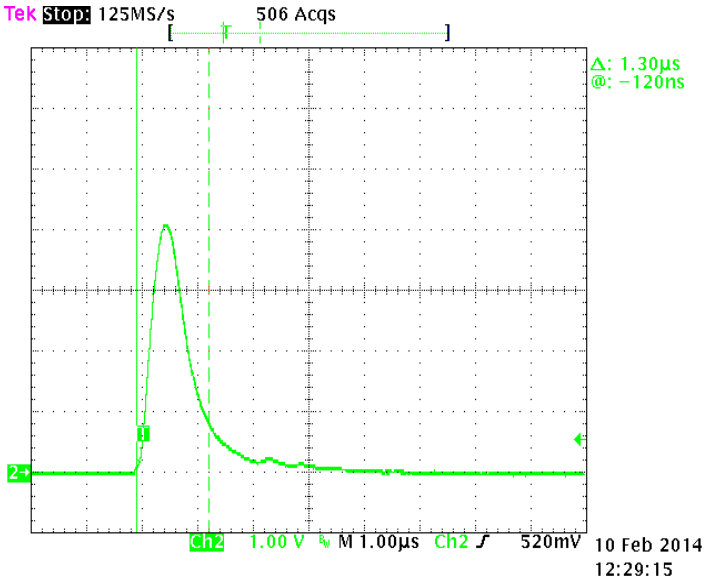
Calculation of eddy currents in neighboring surfaces of simple geometry by P. Lebasque, SOLEIL

Excitation Pulse Length

Time Scale for BESSY II Storage Ring with Circumference of 240 m



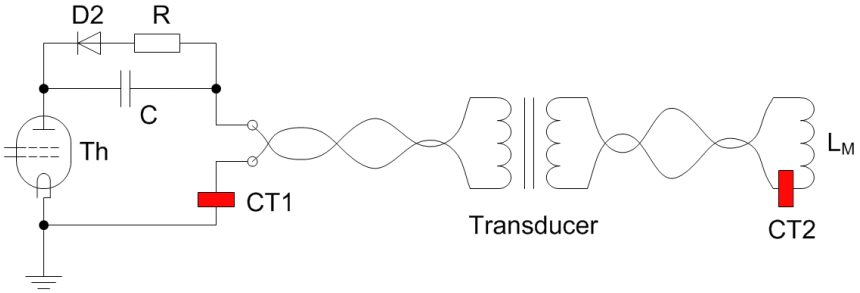
Assume possible pulse current duration (hence pulsed B-field duration) **up to 1.5 µs.**



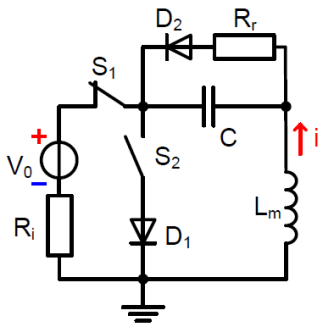
Measured pulse curve on pulse power supply CT1.

Set up the pulse power supply for a pulse length of 1.3 µs for characterization measurements. Because of the discrete components and limiting 15kV charging voltage, the maximum current was 300 A, approx. Î = 200 A were used for measurements.

Pulser / Transducer / Magnet (previously shown)



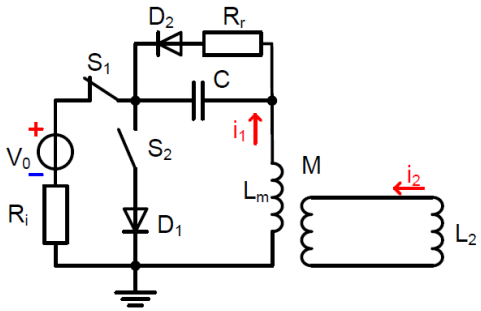
Realistic Network of Pulsed Power Circuit

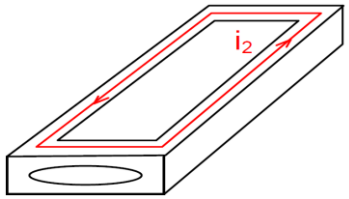


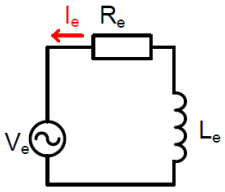
L_m - Magnet inductance

Simplified pulser circuit
→ Pulser network without transducer to concentrate on magnet properties only.

Simplified pulser circuit plus secondary loop
caused by magnet structure
Remember: frame support structure
→ Possible current path, but not under suspicion anymore since no significant asymmetries are noticeable.







Effects of eddy currents in to coils adjacent metallic surfaces are investigated because of their excitation current independent, much longer time constant.

$$\tau = \frac{L_e}{R_e}$$

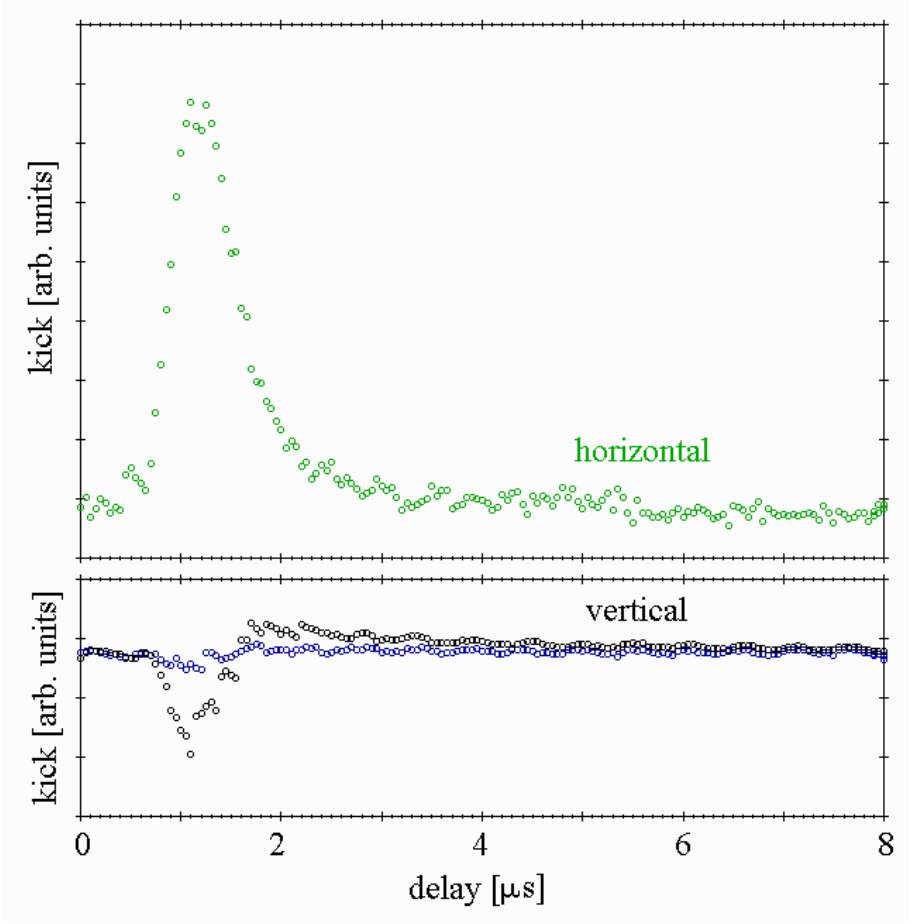
Methodology:

- Small single bunch current was injected through the NL-kicker onto a screen monitor which is located 5 m behind the magnet,
- CCD-camera and image analysis delivers beam position and beam size,
- Shift of the beam was monitored when the kicker was fired,
- Delay between bunch arrival time and the kicker pulse was varied,
- Vary horizontal and vertical position in the kicker,

But, measurement uncertainties in the horizontal plane due to 9 pulsed extraction and injection magnets in injector chain.

Temporal Field Distribution (1)

Temporal variation of the field at about dx~-11 mm and dy~2mm



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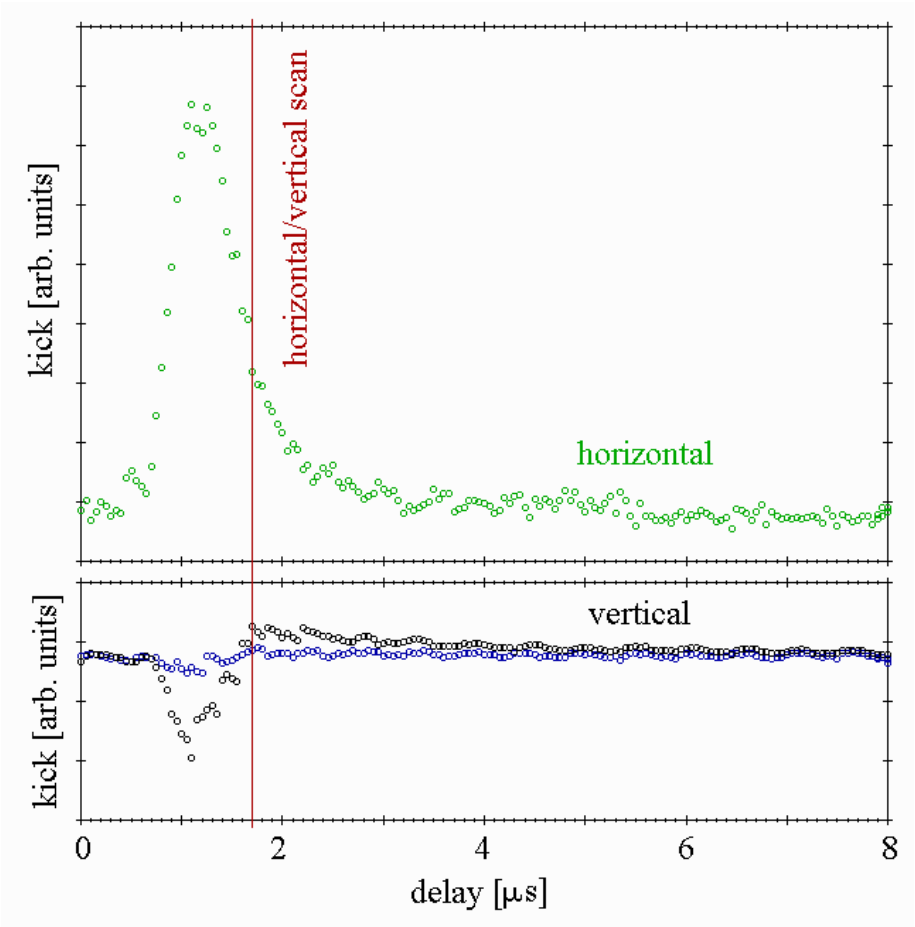
Off-axis beam experiences fields dominated by eddy currents at later times.

Temporal Field Distribution (2)

Temporal variation of the field at about dx~-11 mm and dy~2mm



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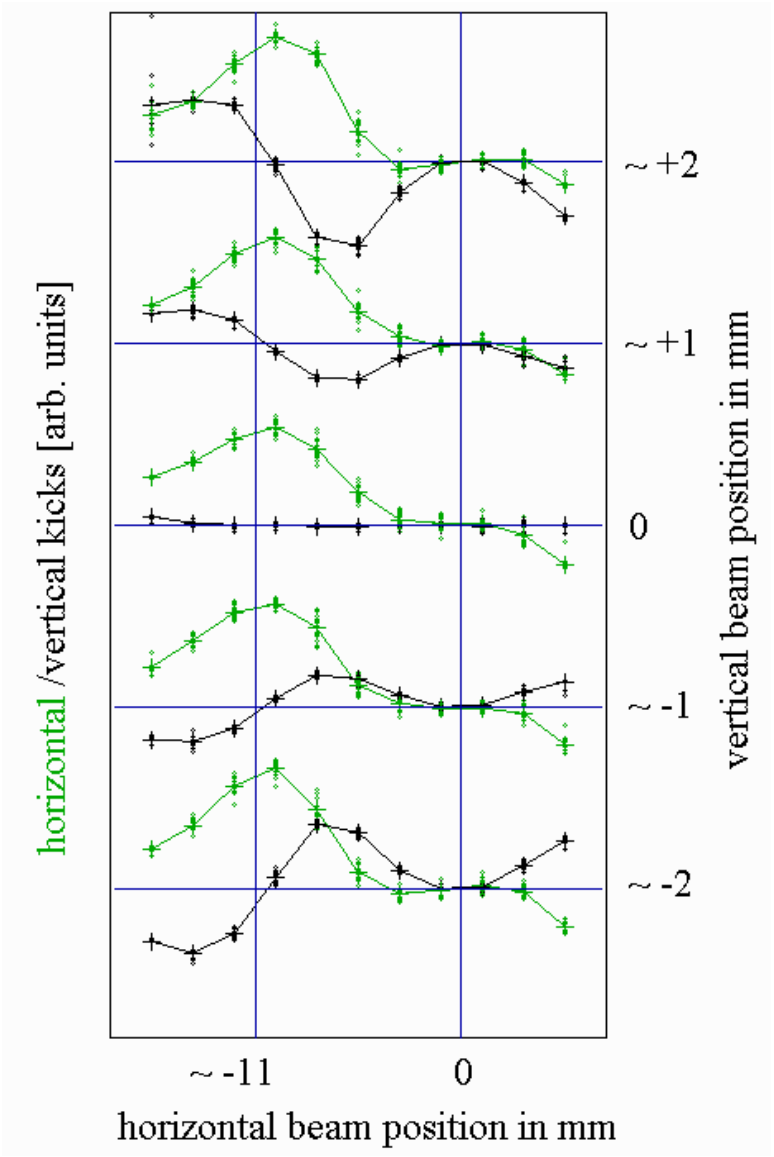
For red delay variation of the beam position inside the kicker.

Spatial Field Distribution Inside Kicker Magnet



- Flat, zero horizontal and vertical fields close to zero (location of the stored beam),
- 'Flat' field in the mid-plane ~11 mm off-axis (position of the injected beam),
- The off-axis vertical kick contains large eddy current field contributions (polarity change).

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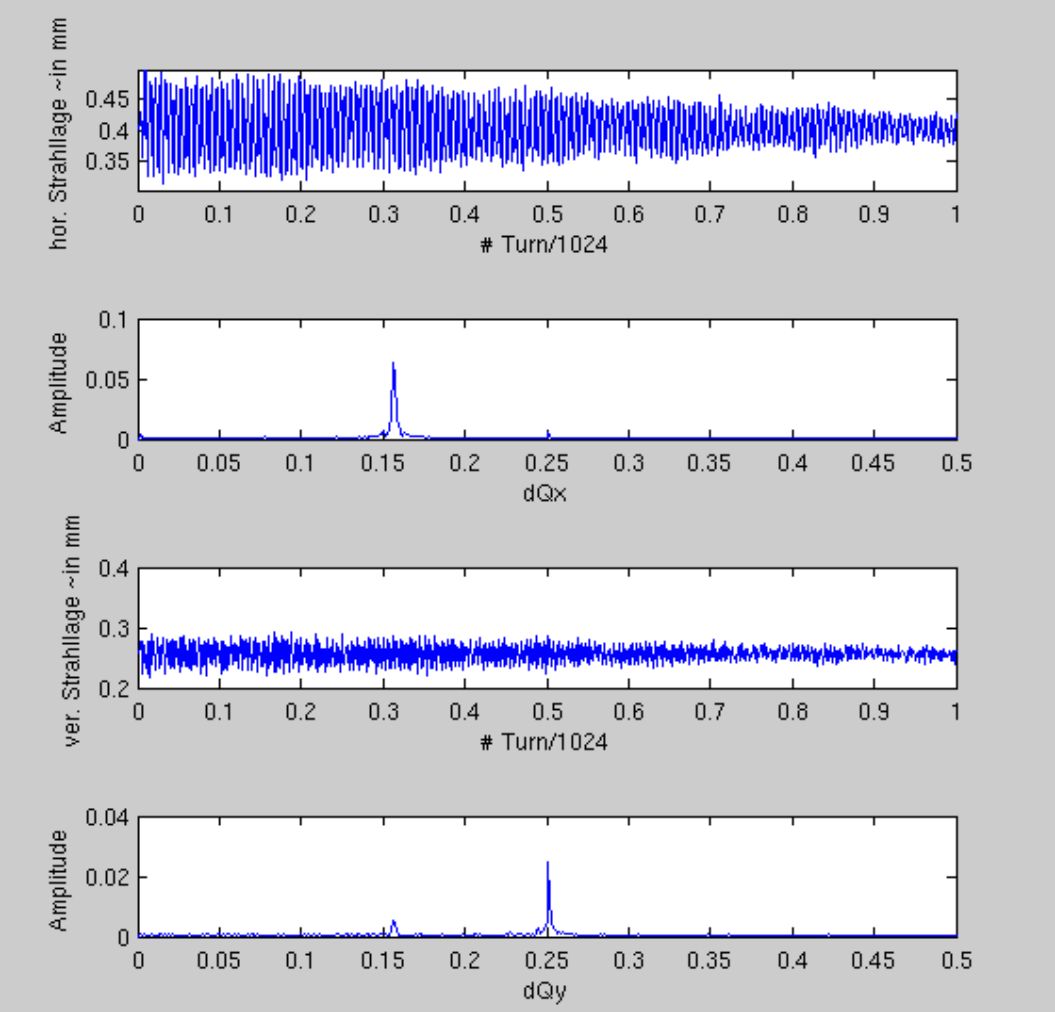
Methodology:

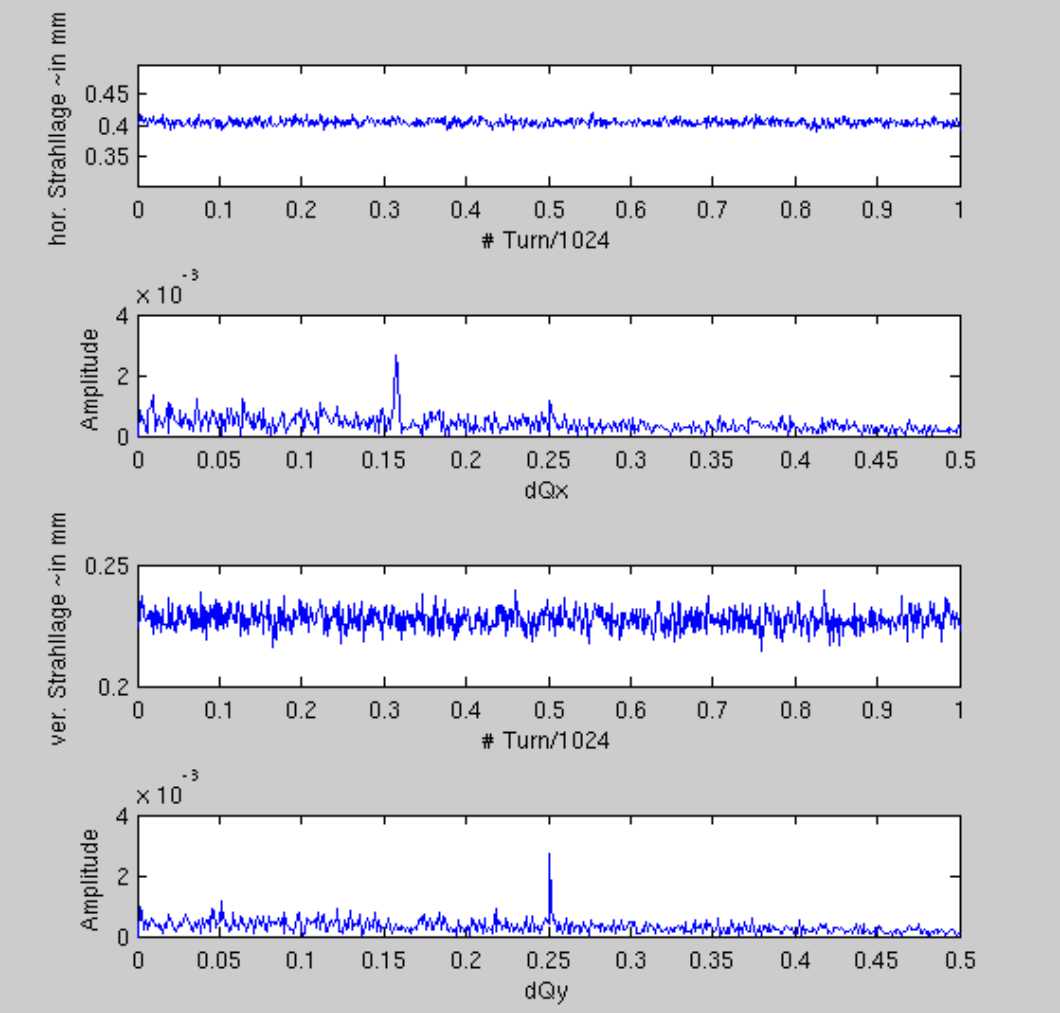
- Short bunch train, small beam current, chromaticities set to zero,
- Horizontal and vertical closed orbit bumps inside the kicker magnet,
- Kicker fired and dipole motion detected turn-by-turn with Libera-Brilliance electronics,
- FFT of the data delivers amplitude of beam motion at the tunes: sub μm-resolution achieved,
- Measurements performed as a function of the kicker timing (for short kicker pulses only).

Kicker-Induced Beam Motion (1)



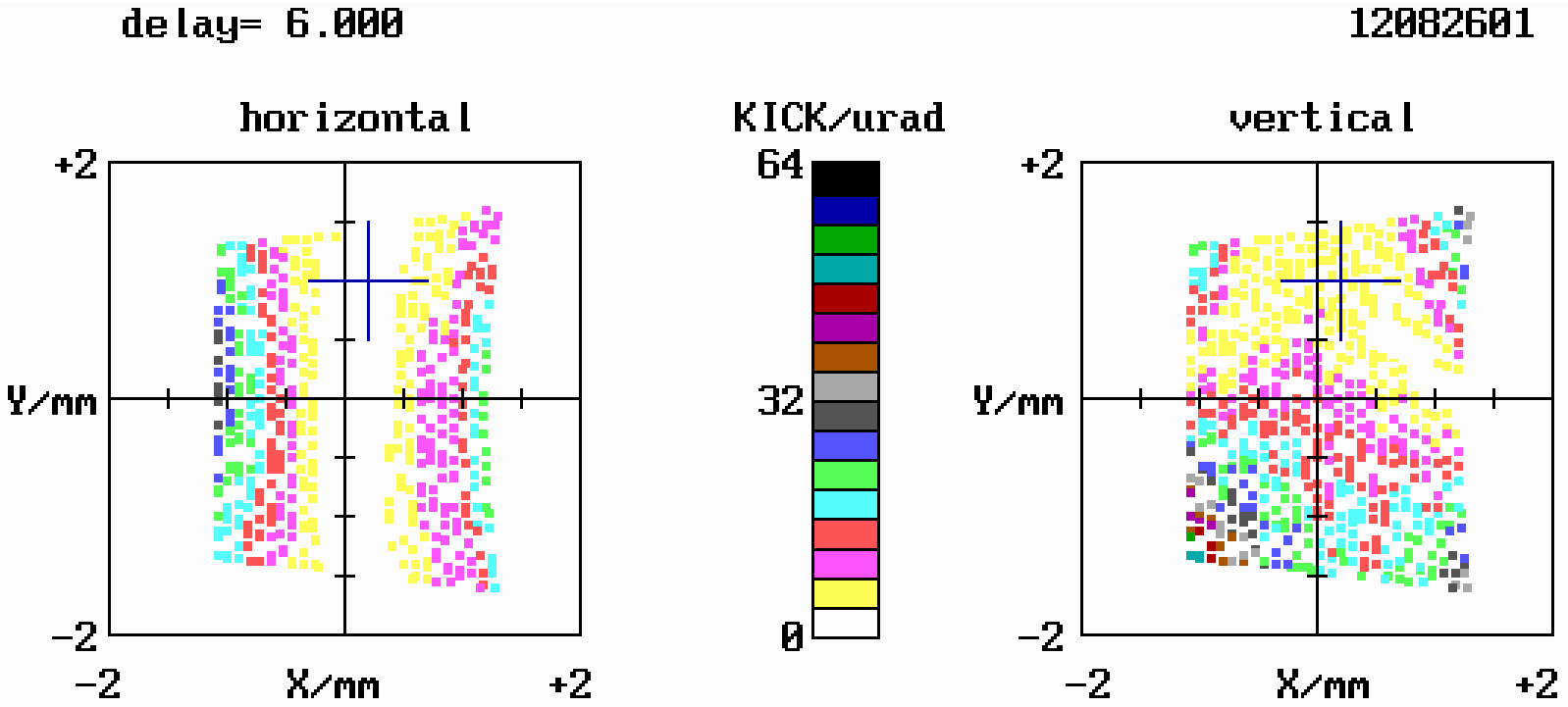
Libera-Brilliance BPM-Electronics + MatLab analysis of turn-by-turn data.

Kicker-Induced Beam Motion (2)



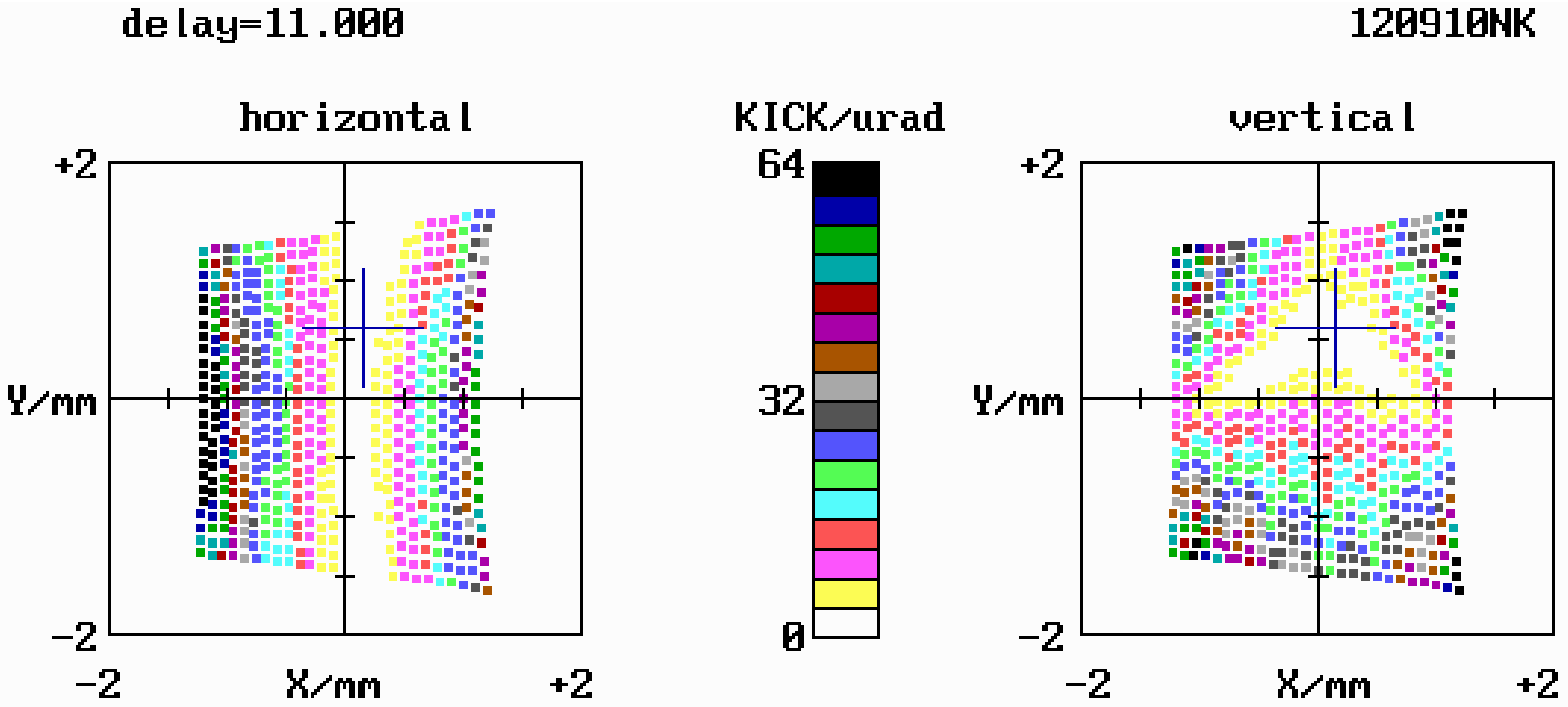
Libera-Brilliance BPM-Electronics + MatLab analysis of turn-by-turn data.

Spatial Variation of the Fields (1)



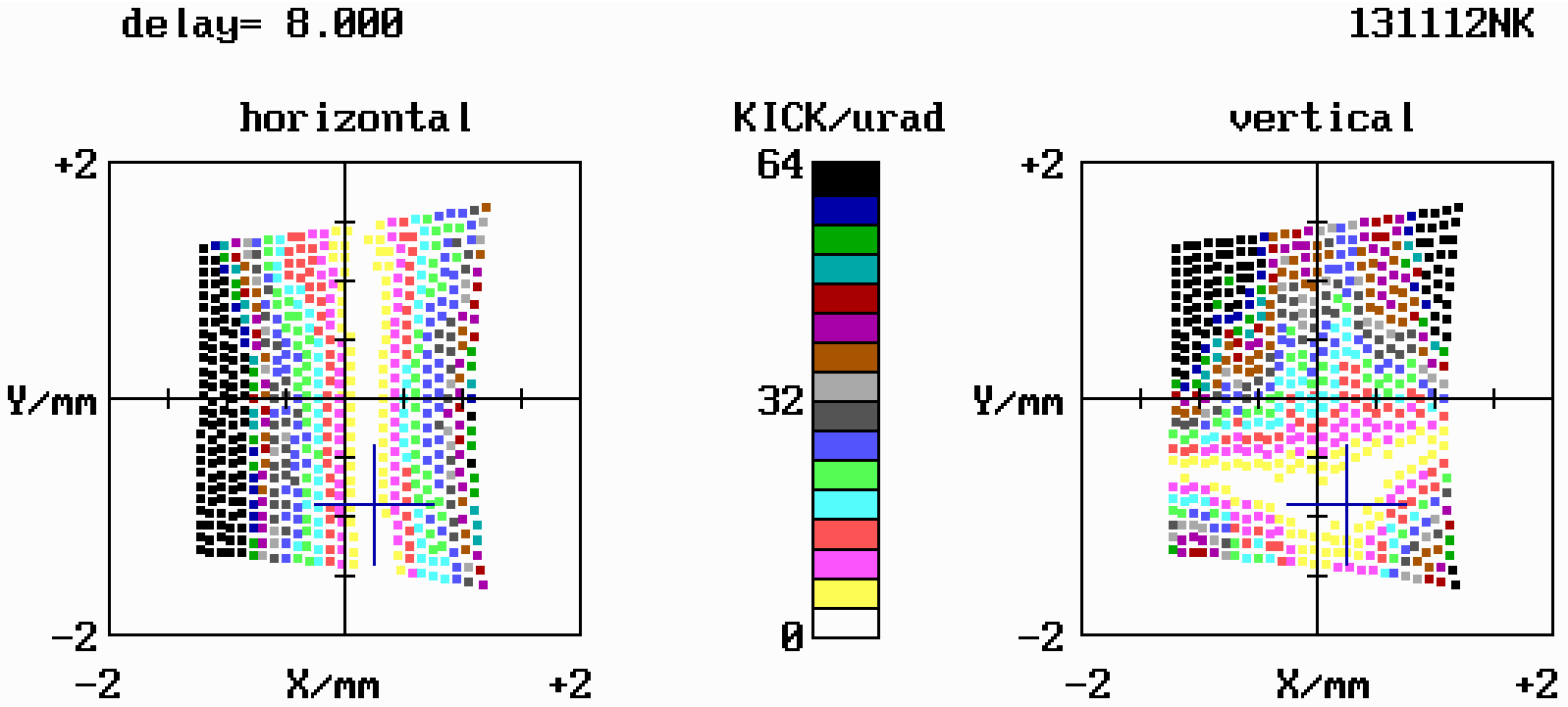
Top and bottom coils powered serially in pairs – poor adjustment of current pulses (a few percent different).

Spatial Variation of the Fields (2)



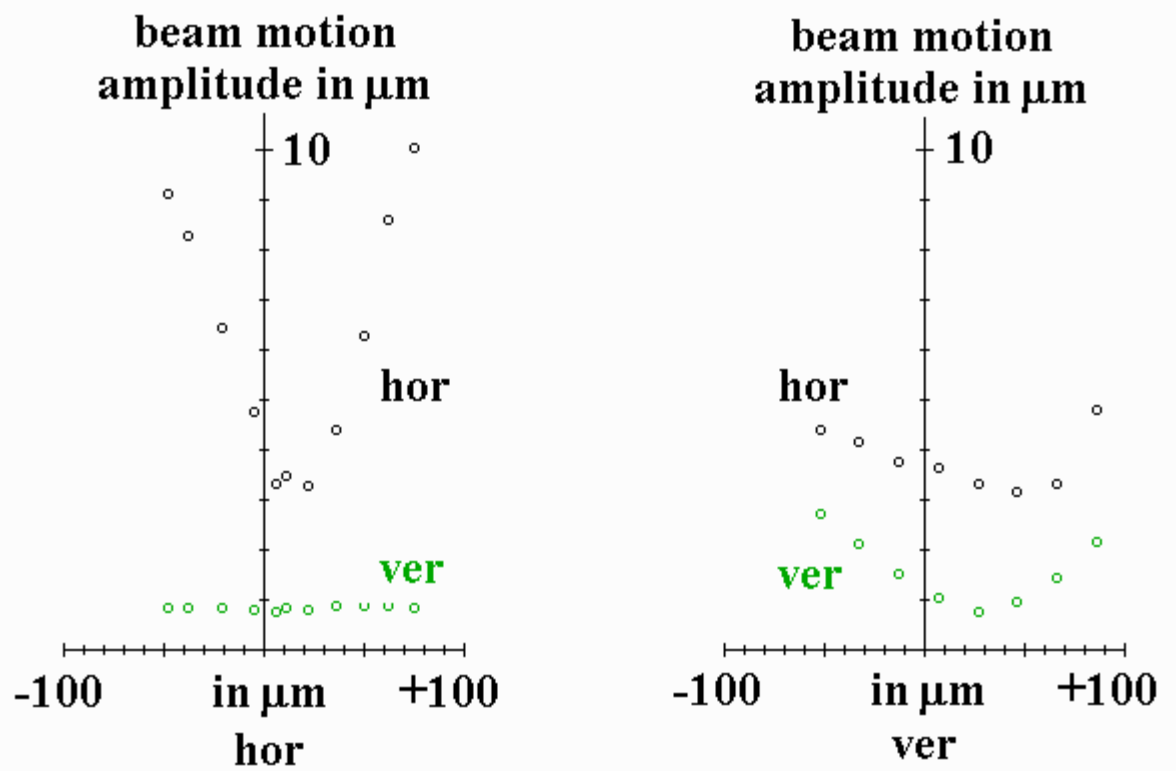
Top and bottom coils powered serially in pairs – adjustment of current pulses better (as good as possible identical).

Spatial Variation of the Fields (3)



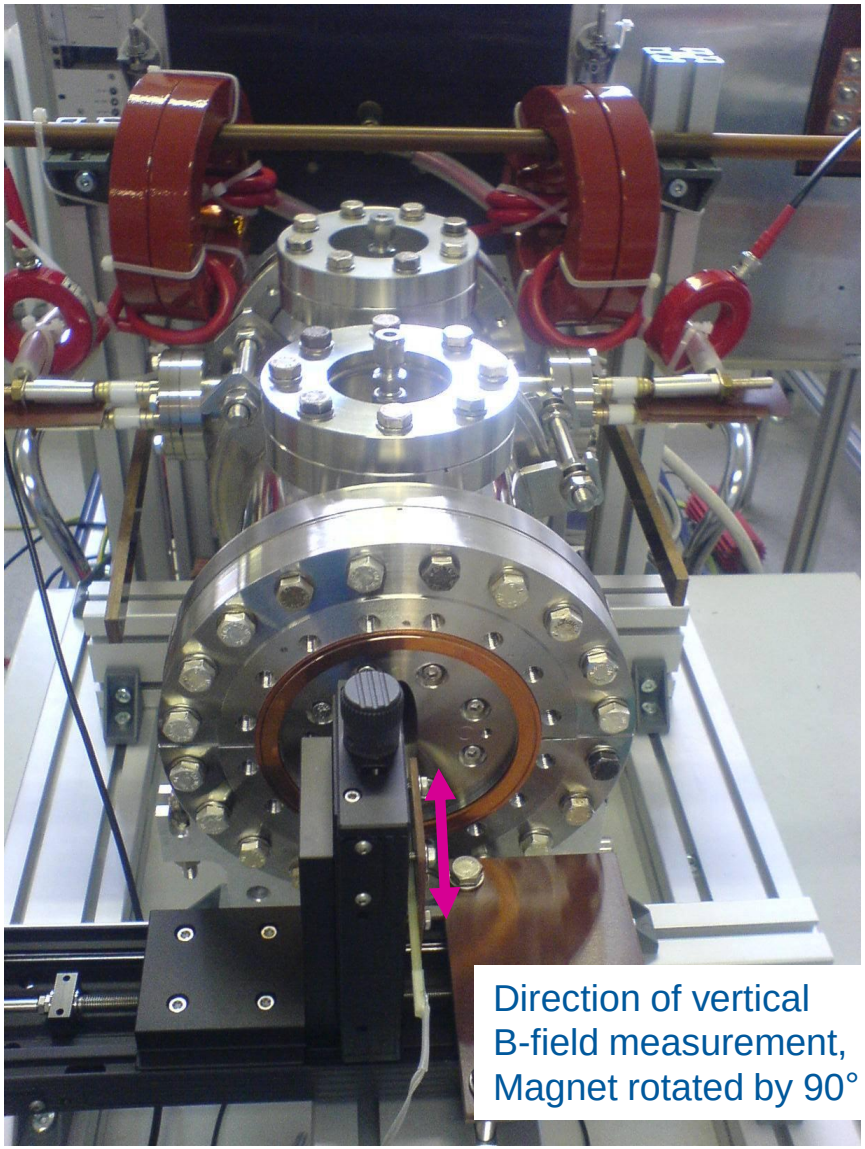
Top and bottom coils powered in series – the 4 currents are identical.

Line Scan Close to Smallest Orbit Perturbations



Vertical perturbations: can be made vanishingly small in the vertical plane: < 1 µm,
Horizontal perturbations: ~3 µm is the minimum, in a quite small area,
Linear dependence could be related to a quadrupolar field component .

Laboratory Set-up for Magnetic Field Measurements



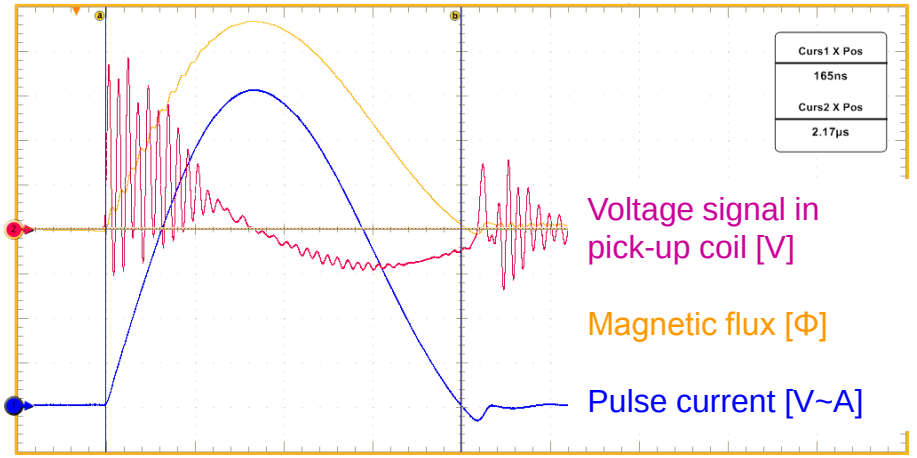
Direction of vertical B-field measurement, Magnet rotated by 90°

Procedure for Magnetic Field Measurements:

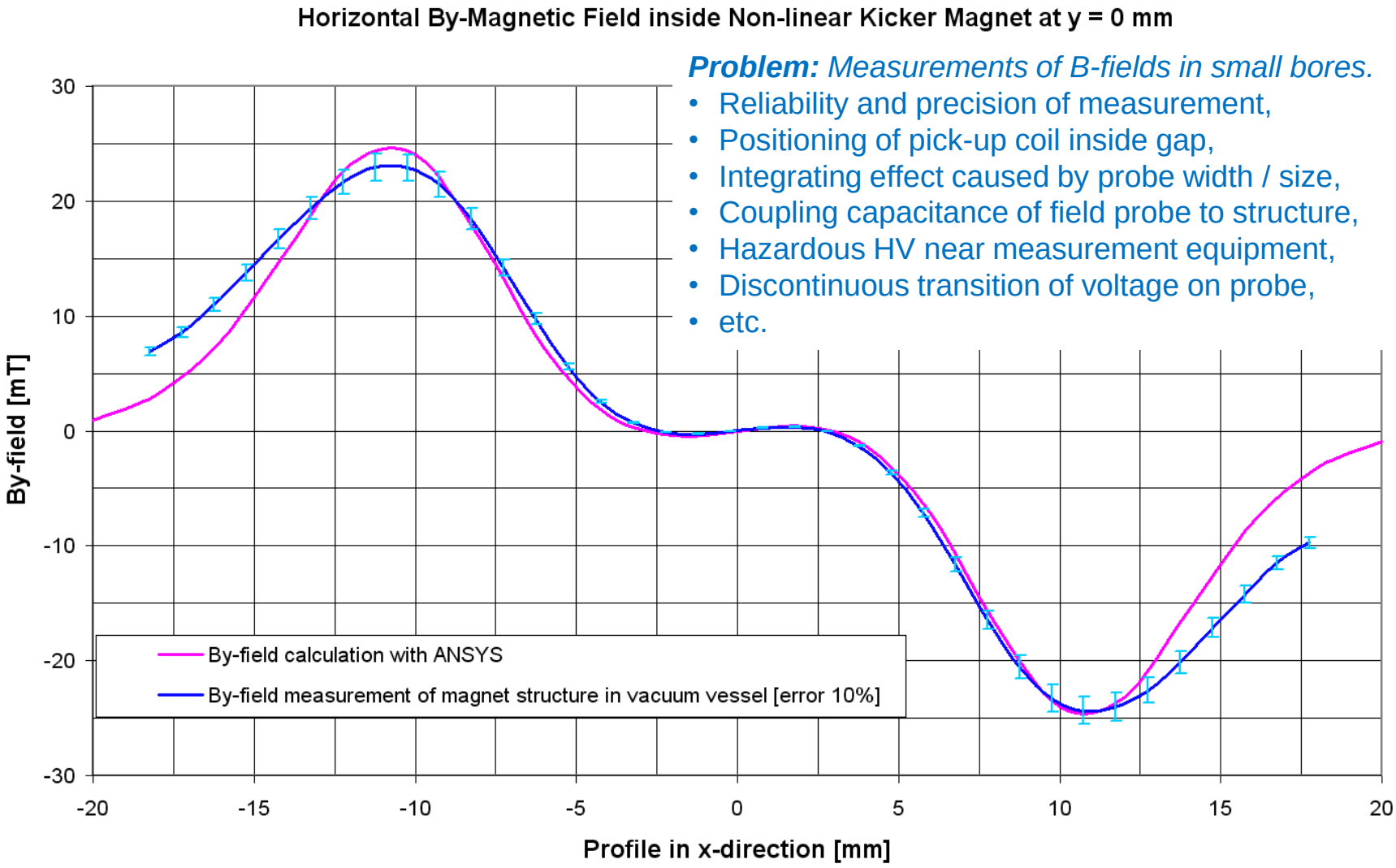
- Measurement of in long straight coil induced voltage v(t) at succeeding horizontal positions.
- Instantaneous calculation of magnetic flux φ(t) out of voltage trace with the storage oscilloscope.
- Readout of max. value Φ_{max} from oscilloscope for actual position, division by known coil area.
- Plot points into diagram.

$$\varphi(t) = -\int v(t)dt \qquad B_{0max} = \frac{\Phi_{max}}{A}$$

Typical scope picture of B-field measurement



Magnetic Field Measurement vs. ANSYS Calculation



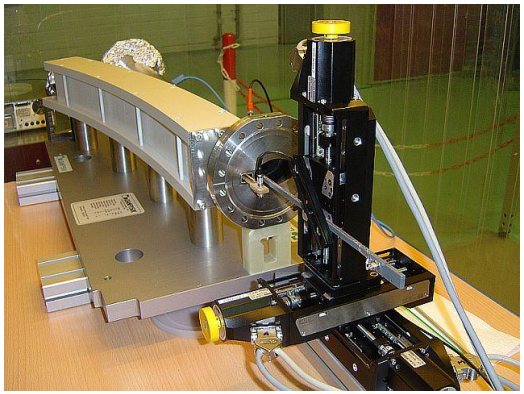
Problem: *Measurements of B-fields in small bores.*

- Reliability and precision of measurement,
- Positioning of pick-up coil inside gap,
- Integrating effect caused by probe width / size,
- Coupling capacitance of field probe to structure,
- Hazardous HV near measurement equipment,
- Discontinuous transition of voltage on probe,
- etc.

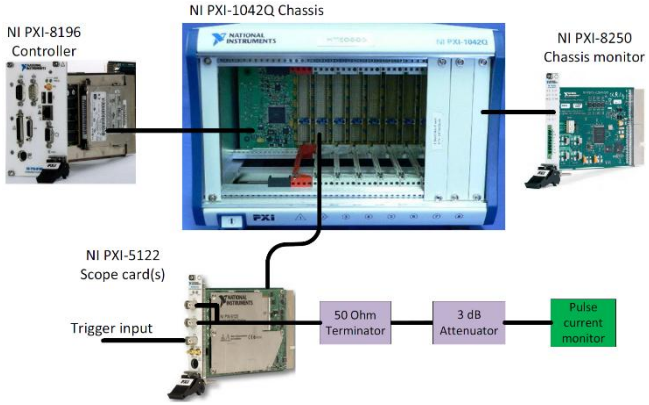
Proposal: Automatized Magnetic Field Mapping

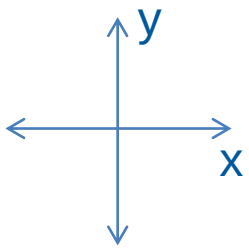
HZB Helmholtz Zentrum Berlin

Example: B-field measurements on septum magnet

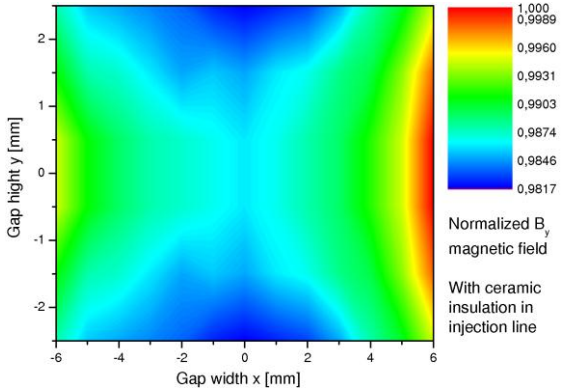


Proposed set-up for automatized B-field measurements on NL-Kicker





Normalized B_y-field map of septum magnet



O. Dressler, M.v. Hartrott, N. Hauge, 'Determination of the Magnetic Characteristics in the Injection Septum for the MLS', proceedings of the IPAC10, p. 1773, Kyoto, Japan, 2010.

Technical details:

National Instruments technology and Labview programming:

- PXI NI-1042Q or PXIe NI-1062 chassis,
- Embedded controller PXI NI-8108 or PXIe NI-8196,
- Oscilloscope card PXI NI-5122,
- Two stepper motors and control cards,
- Measuring table and x/y supports,
- Pick-up coils according to measurement task (long coil 1 winding, short coil x windings),
- Labview program for measurement control and automatic measurement analysis.

Summary and Outlook

- **Kicker magnet and pulsed PS work fine:**
  → No thermal problems and kicker serves as back-up solution for BESSY II,

- **Injection Efficiency:**
  → All kicker (interconnection) configurations have shown 80 % efficiency; without much optimization, could be further improved,
  (80% with $\beta_{xinj}=\beta_{xkicker}$, 60% with $\beta_{xinj}=2\cdot\beta_{xkicker}$),

- **Orbit perturbations:** < 1 μm vertically and ~3 μm horizontally,

- **Field distributions:**
  → Were determined experimentally with reduced pulse duration,

- Investigation of impact of eddy currents will continue,

- And we will continue our collaboration with