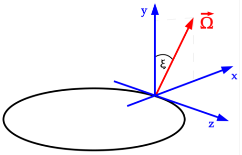
An RF-$E \times B$-Dipole for Spin Manipulation at COSY

Prototype Commissioning and First Measurements

March 31, 2014 | Sebastian Mey for the JEDI Collaboration | Forschungszentrum Jülich

Content

Proposed Measurements



- Goal: disentanglement of EDM signal from false rotations induced by ring imperfections
- comparison of transverse rotations of invariant spin axis
  - solenoid field rotates spin axis in x-y-plane
  - radial dipole field rotates spin axis in y-z-plane, but transverse beam excitation $\Rightarrow$ compensation with vertical E-field

- RF-B-field, $\int \hat{B}_x \, \mathrm{ds} = 0.3\,\mathrm{T\,mm}$, RF-E-field, $\int \hat{E}_y \, \mathrm{ds} = 46\,\mathrm{kV}$
- spin-tune-frequency $f_0 = f_{\mathrm{rev}} |k + \gamma G|; \; k \in \mathbb{Z}$
- d at 970 MeV/c: $\gamma G = -0.16098$; $f_{\mathrm{rev}} = 750\,\mathrm{kHz}$:

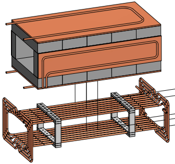
k	0	1	-1	2	-2
$\nu_0 /$ **kHz**	120	629	871	1380	1621

Content

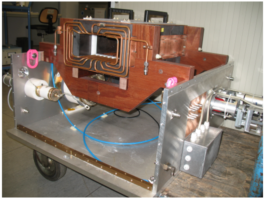
The RF-ExB-Dipole

RF-B-Dipole

ferrite blocks

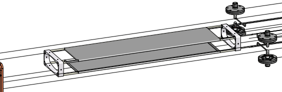


coil: 8 windings, length 560 mm

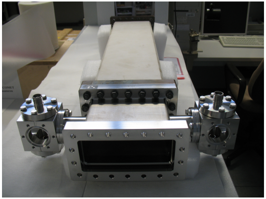


RF-E-Dipole

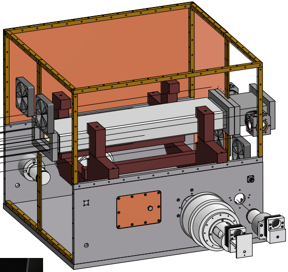
two electrodes in vacuum camber



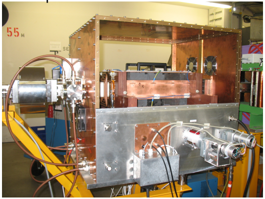
distance 54 mm, length 580 mm



Shielding Box

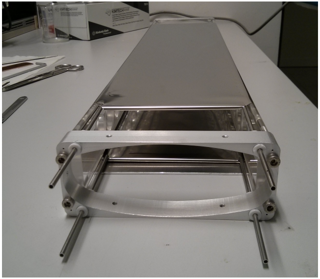


ceramic beam chamber
two separate resonance circuits

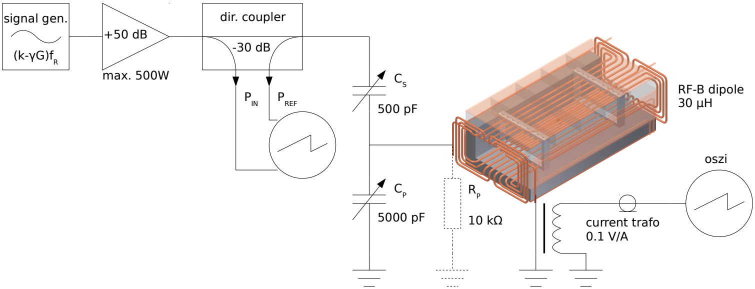


The RF-ExB-Dipole

- RF-B:
  - watercooled copper tubing, $r = 3\,\text{mm}$
  - ferrite blocks in window frame configuration $\mu_r = 240@1\,\text{MHz}$
- RF-E
  - electrodes 50 µm stainless steel foil
  - spanned over glass rods, $r = 3\,\text{mm}$
  - feedthroughs and leads mounted symmetrically

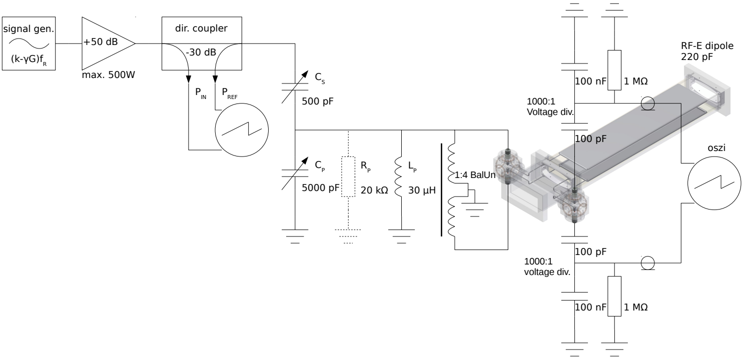


RF-B-Circuit



- parallel resonance circuit
- amplitude limited by losses $\Rightarrow \hat{I}_{max} \approx 5\,\mathrm{A}$
- tuning to $50\,\Omega$ with bidirectional coupler
- current in coil directly available via current transformer

RF-E-Circuit



- resonance circuit coupled to load by high ohmic balun transformer
- $\hat{U}_{\max} \approx 5\,\mathrm{kV}$ limited by high-voltage feedthroughs
- electrode voltage directly available via capacitive voltage divider

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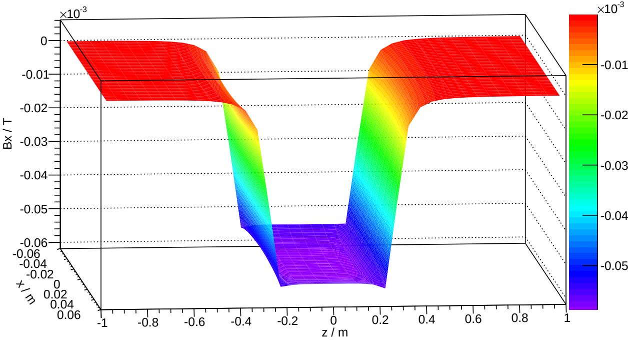
Magnetic Flux Density

$$\hat{I} = 1\,\mathrm{A}$$

$$\hat{B}_x = 0.058\,\mathrm{mT}$$

$$\int \hat{B}_x\,dz = 0.035\,\mathrm{T\,mm}$$



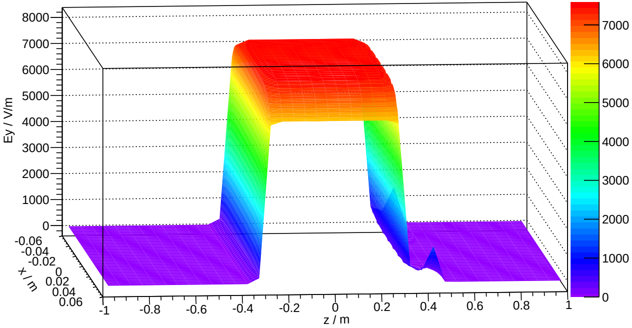
- distribution of radial component of magnetic flux density
- fields shown in central beam plane at $y = 0$

Electric Field

$$\hat{U} = 395\,\mathrm{V}$$

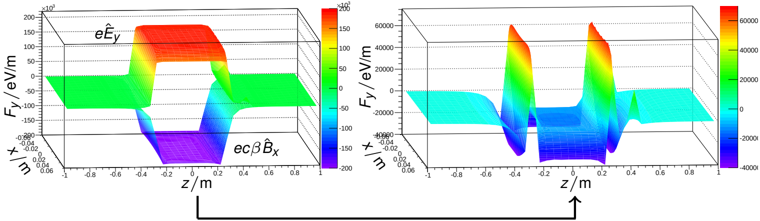
$$\hat{E}_y = 7594\,\mathrm{V/m}$$

$$\int \hat{E}_y\,\mathrm{d}z = 4818\,\mathrm{V}$$



- distribution of vertical component of electric field

Lorentz Force



$$F_y = e\left(\hat{E}_y + c\beta\hat{B}_x\right)$$

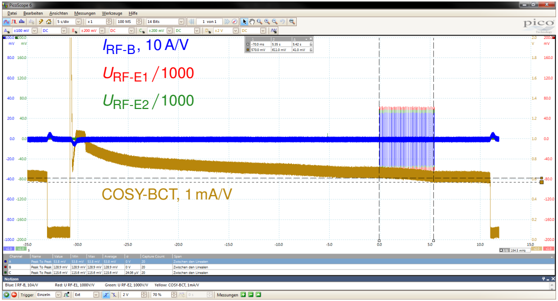
- $\beta \equiv \beta_z = 0.459$; $\hat{I} = 1\,\mathrm{A}$; $\hat{U} = 395\,\mathrm{V}$
- optimization for integral compensation along beam path

$$\int \hat{F}_y \, \mathrm{d}z = 0\,\mathrm{eV/m}$$

Content

First Measurement of Field Compensation

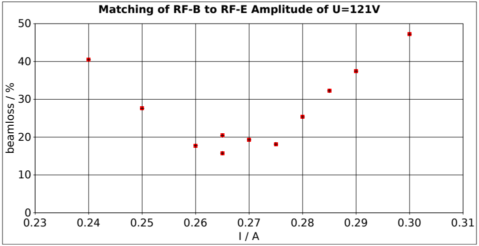
$$f_{\text{RF-ExB}} = f_{\beta_Y} = 1186\,\text{kHz}$$
$$\hat{I} = 0.27\,\text{A}$$
$$\hat{U}_1 = 129\,\text{V}$$
$$\hat{U}_2 = 116\,\text{V}$$

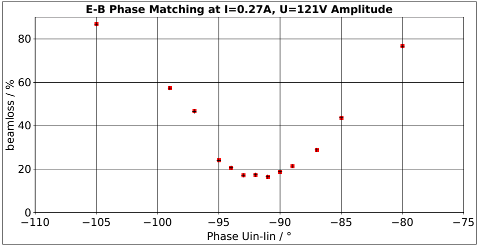


- measurement exactly on betatron frequency for max. sensitivity
- diagnosis with COSY beam current transformer
- pulsed mode of operation, 38 pulses, each 10 ms long
- compensation observed, minimum of 7 % beam-loss achieved
- fringe fields and transient time behaviour have to be further studied

First Measurement of Field Compensation

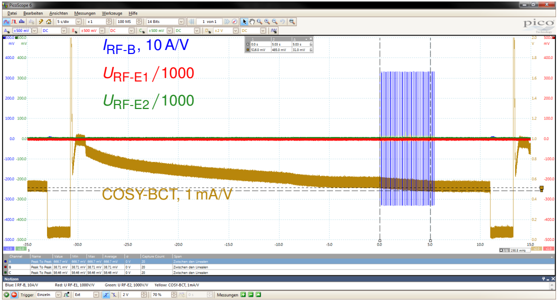
- set up well cooled beam
- orbit correction in the RF-dipole
- tune measurement
- fix one setting for the amplitude of RF-E-part
- vary amplitude and phase offset of RF-B-part to reach minimum beam loss





Measurement at Spin Resonance Frequency

$$f_{\text{RF-ExB}} = 871\,\text{kHz}$$
$$\hat{I} = 3.38\,\text{A}$$



- $f_{-1} = f_{\text{rev}} |-1 + \gamma G|$
- relatively low current in RF-B-part already induces beamloss
- fields at $\hat{I} = 3.38\,\text{A}$: $\hat{B}_x = 0.2\,\text{mT}$; $\int \hat{B}_x\,\text{d}z = 0.12\,\text{T mm}$
- required power $\approx 120\,\text{W}$

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Conclusion

To Do

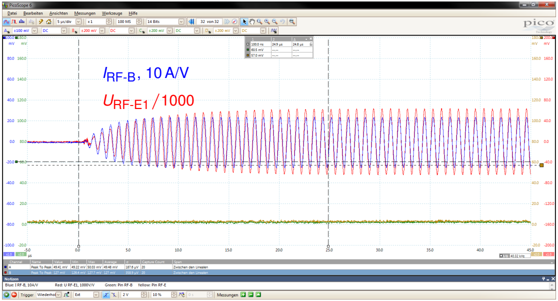
- Simulations
  - simulations with true RF-fields to better understand losses due to eddy-currents
  - verify simulations with precise field measurements in the lab
- Measurements
  - spin dynamic measurements planned for September 2014 in JEDI-beam-time with polarized d-beam
- Hardware Development
  - prototype development for an upright, high-power RF-ExB-dipole based on a stripline design already under way

Thank You for Listening!

In case of additional questions contact s.mey@fz-juelich.de.

Transient Time Behaviour

$$\Delta t = 45\,\mu\text{s}$$
$$\hat{I} = 0.27\,\text{A}$$
$$\hat{U}_1 = 129\,\text{V}$$



- Wien-Filter condition not fulfilled during first $\approx 15\,\mu$s of each pulse
- complete transient time lasts ≈ 100 ms

$\Rightarrow$ rework of resonance circuit required

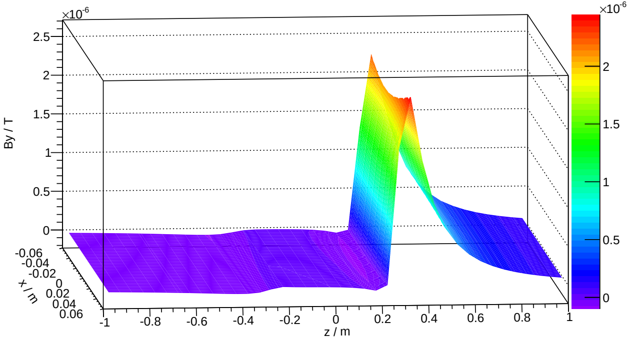
$\Rightarrow$ ultimate precision needs feed forward control during activation cycle

B_y

$\hat{I} = 1\,\text{A}$

$\hat{B}_y \approx 10^{-3} \hat{B}_x$

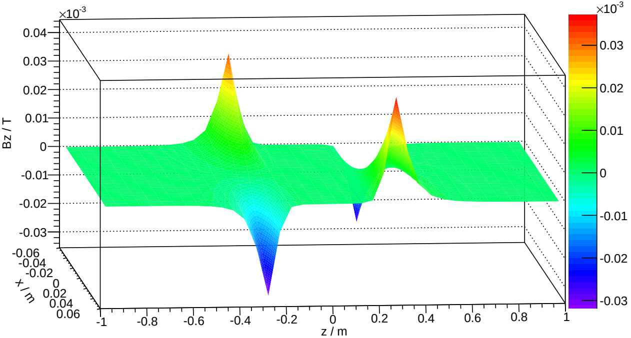
in central field region



- vertical component dominated by fields from leads to the coil

B_z

$\hat{I} = 1\,\mathrm{A}$



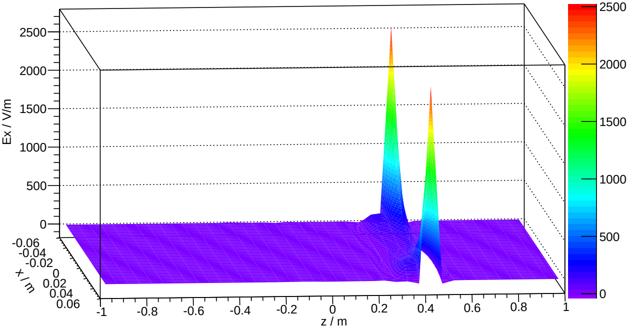
- longitudinal component dominated by fields from the coil going around the beam chamber

E_x

$\hat{U} = 395\,\mathrm{V}$

$\hat{E}_x \approx 10^{-3}\hat{E}_Y$

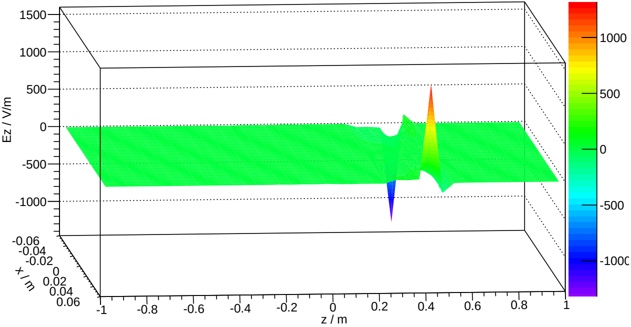
in central field region



- distribution of radial component of electric field dominated by fields from leads to the electrodes

E_z

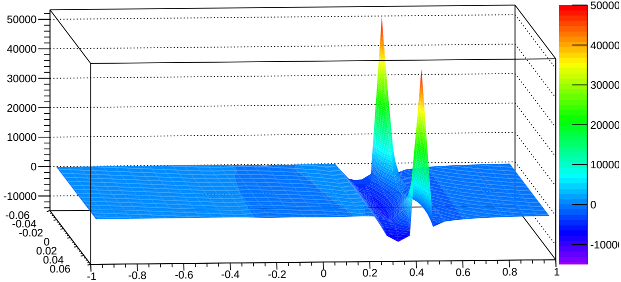
$\hat{U} = 395\,\mathrm{V}$



- distribution of longitudinal component of electric field dominated by fields from leads to the coil

F_x

$$\beta \equiv \beta_z = 0.459$$
$$\hat{I} = 1\,\mathrm{A}$$
$$\hat{U} = 395\,\mathrm{V}$$

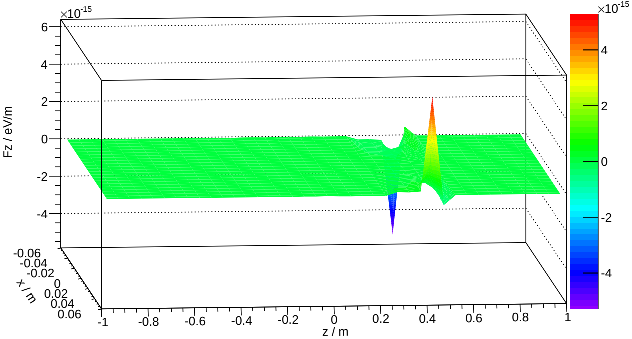


- $F_x = e\left(\hat{E}_x + c\beta\hat{B}_y\right)$

F_z

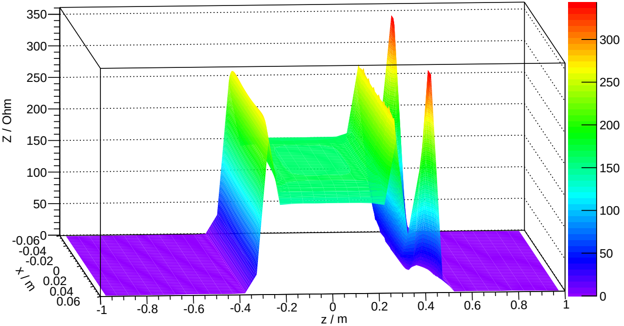
$\hat{I} = 1\,\mathrm{A}$

$\hat{U} = 395\,\mathrm{V}$



Wave Impedance

$$\hat{I} = 1\,\text{A}$$
$$\hat{U} = 395\,\text{V}$$
$$Z_{\text{theory}} = 173\,\Omega$$

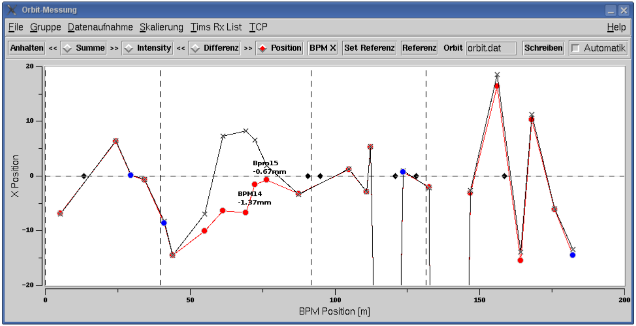


- $Z = \frac{\hat{E}_x}{\hat{H}_y} = -\frac{\hat{E}_y}{\hat{H}_x} = \beta_z Z_0$

Orbit Corrections

$\Delta x = 0.7\,\text{mm}$

$\Delta x' = 0.06\,\text{mrad}$

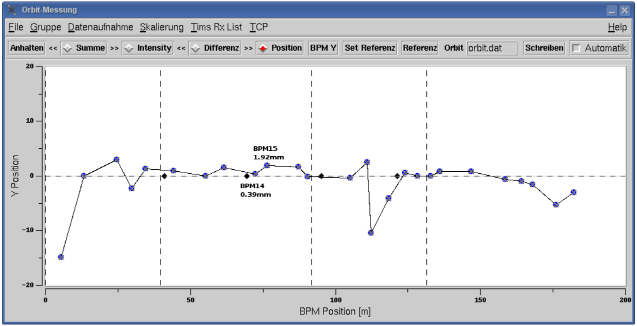


- corrected orbit with closed bump at RF-Dipole
- BPM 14 and 15 at Dipole before and after RF-ExB
- distance $\Delta z = 4.2\,\text{m}$

Orbit Corrections

$\Delta x = 1.53\,\mathrm{mm}$

$\Delta x' = 0.13\,\mathrm{mrad}$



- corrected orbit with closed bump at RF-Dipole
- BPM 14 and 15 at Dipole before and after RF-ExB
- distance $\Delta z = 4.2\,\mathrm{m}$