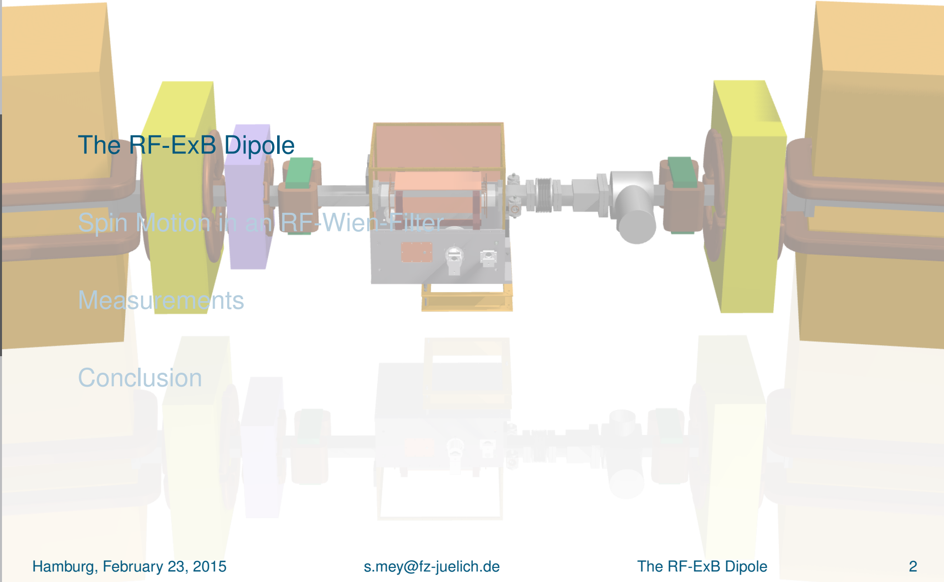
An RF Wien Filter as Spin Manipulator

MT Student Retreat 2015

Hamburg, February 23, 2015 | Sebastian Mey | Forschungszentrum Jülich

JÜLICH FORSCHUNGSZENTRUM

Content

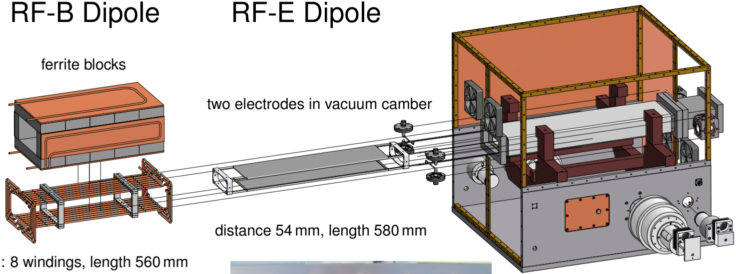


The RF-ExB Dipole

shielding Box

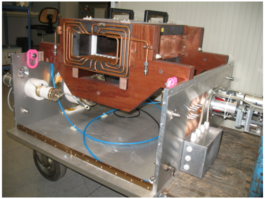
RF-B Dipole

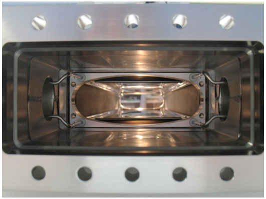
RF-E Dipole



distance 54 mm, length 580 mm

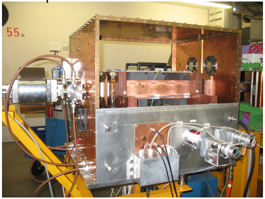
coil: 8 windings, length 560 mm



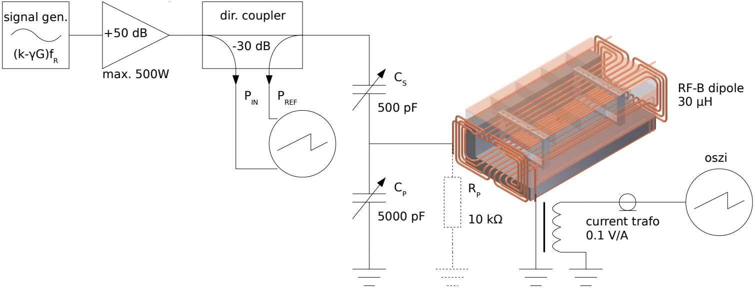


ceramic beam chamber

two separate resonance circuits



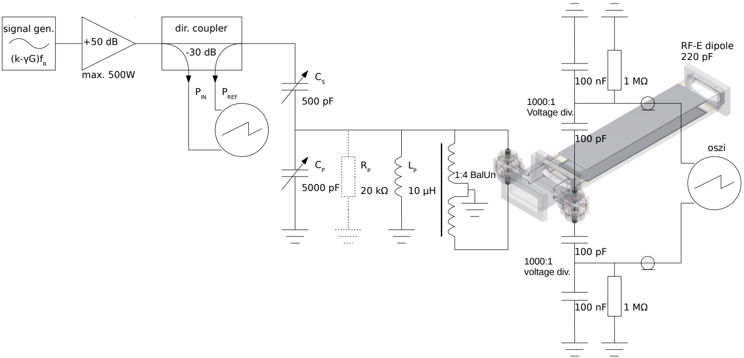
RF-B Circuit *



- amplitude limited by losses $\Rightarrow \hat{I}_{max} \approx 5\,\mathrm{A}$ @ $P_{in} \approx 90\,\mathrm{W}$
- matching to 50 Ω with bidirectional coupler
- frequency range 630 kHz - 1170 kHz
- current in coil directly available via current transformer

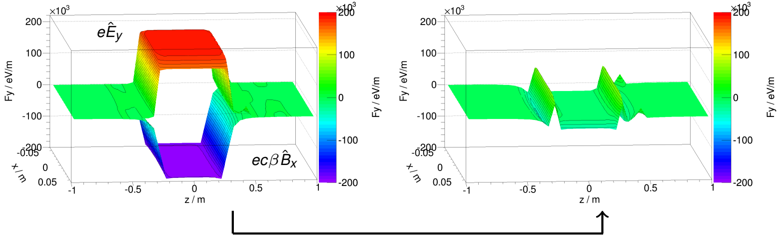
[* A. Schnase, “RF-Dipole System at COSY for spin-flipping experiments”, IKP Annual Report 2002]

RF-E Circuit



- $\hat{U}_{max} \approx 2\,\mathrm{kV}$ @ $P_{in} \approx 90\,\mathrm{W}$
- frequency range 630 kHz - 1060 kHz
- electrode voltage directly available via capacitive voltage divider

Lorentz Force Compensation



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

- $\beta \equiv \beta_z = 0.459$; $\hat{I} = 1\,\mathrm{A}$; $\int \hat{B}_x\,\mathrm{d}z \approx -0.035\,\mathrm{T\,mm}$
- $\hat{U} = 395\,\mathrm{V}$; $\int \hat{E}_y\,\mathrm{d}z = 4818\,\mathrm{V}$
- simulated optimization for integral compensation along beam path $\int \hat{F}_y\,\mathrm{d}z = 0\,\mathrm{eV/m}$

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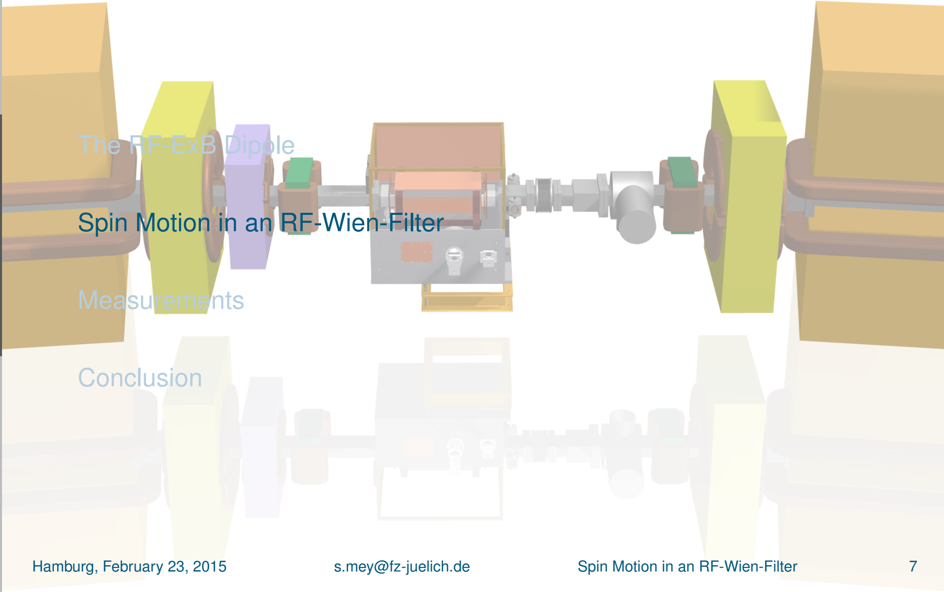
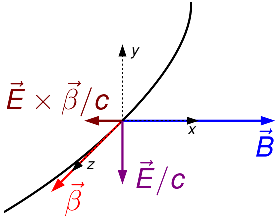


Thomas-BMT Equation in Case of a Wien-Filter

- consider device with pure radial magnetic and vertical electric field
- adjust net Lorentz force to zero
  $\Rightarrow \quad \frac{\vec{E}}{c} = -\vec{\beta} \times \vec{B}$
- Thomas-BMT Eq.: $\frac{\mathrm{d}\vec{S}}{\mathrm{d}t} = \frac{e}{m}\, \vec{S} \times \vec{\Omega}_{\mathrm{MDM}}$



- $\vec{\Omega} = (1+\gamma G)\vec{B}_\perp + \cancelto{0}{(1+G)\vec{B}_\parallel} - \left(\frac{\gamma}{\gamma+1} + \gamma G\right) \frac{\overbrace{\vec{\beta} \times \vec{E}}^{=\vec{\beta}\times(\vec{\beta}\times\vec{B})=\beta^2\vec{B}}}{c}$

  $= \left(1 - \frac{\beta^2\gamma}{\gamma+1} + (1-\beta^2)\gamma G\right)\vec{B} = \frac{1+G}{\gamma}\vec{B}$

Spin-Resonance Strength of an RF-Wien-Filter *

- particles sample localized RF field once each turn at orbit angle θ

$$\Rightarrow \; b(\theta) = \int \hat{B}\,\mathrm{d}l \cos\left(\frac{f_\mathrm{RF}}{f_\mathrm{rev}}\theta + \phi\right) \sum_{n=-\infty}^{\infty} \delta(\theta - 2\pi n)$$

- intrinsic resonance strength given by spin rotation by turn, calculate with Fourier integral over driving fields along orbit*:

$$|\epsilon_k| = \frac{f_\mathrm{spin}}{f_\mathrm{rev}} = \frac{1+G}{2\pi\gamma} \oint \frac{b(\theta)}{B\rho} e^{iK\theta}\,\mathrm{d}\theta$$

$$= \frac{1+G}{2\pi\gamma} \frac{\int \hat{B}\,\mathrm{d}l}{B\rho} \sum_{n=-\infty}^{\infty} \cos\left(2\pi n \frac{f_\mathrm{RF}}{f_\mathrm{rev}} + \phi\right) e^{i2\pi K n}$$

$$= \frac{1+G}{2 \cdot 2\pi\gamma} \frac{\int \hat{B}\,\mathrm{d}l}{B\rho} \left(\sum_n e^{\pm i\phi} \delta\left(n - K \mp \frac{f_\mathrm{RF}}{f_\mathrm{rev}}\right)\right)$$

[* S. Y. Lee, 10.1103/PhysRevSTAB.9.074001 (2006)]

Resonance Condition

- spin tune given by γG, resonance at every sideband with
  $K \stackrel{!}{=} \gamma G = n \pm \frac{f_{\text{RF}}}{f_{\text{rev}}} \Leftrightarrow f_{\text{RF}} = f_{\text{rev}}|n - \gamma G|; \ n \in \mathbb{Z}$
- d at 970 MeV/c: $\beta = 0.459$; $\gamma = 1.126$; $G = -0.142\,987$;

$\Rightarrow$ $f_{\text{rev}} = 750\,\text{kHz}$; $\gamma G = -0.16098$:

n	0	1	-1	2	-2
f_{RF} / kHz	120	629	871	1380	1621

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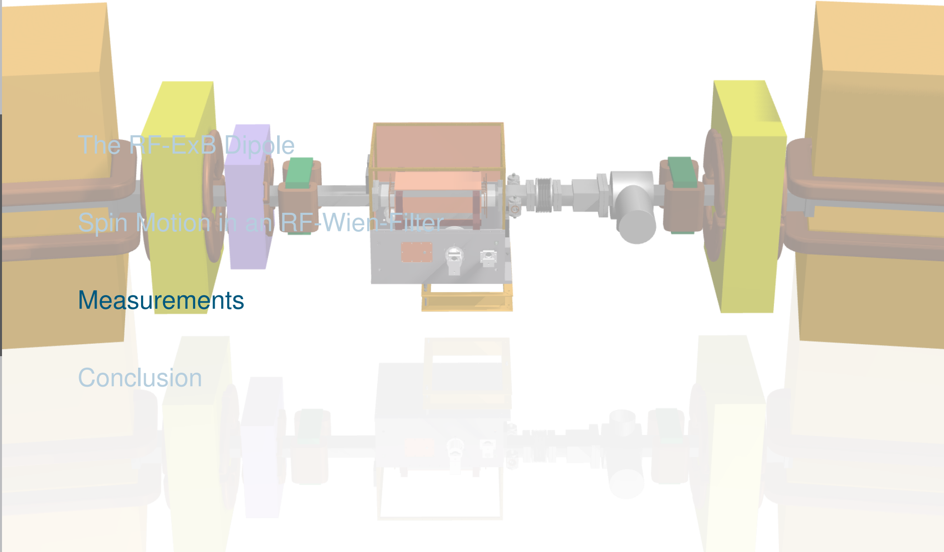
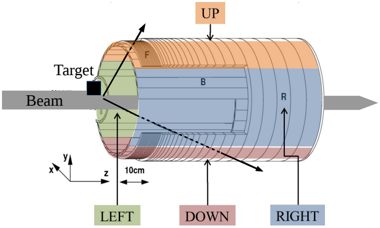
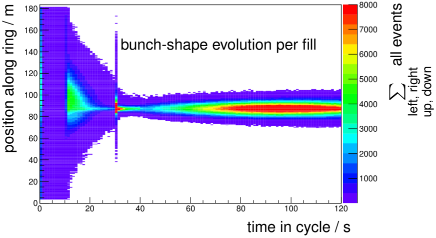


Polarimetry and Beam Setup

- massive carbon target with slow extraction
- polarization $\Rightarrow$ rate asymmetries in $^{12}\mathrm{C}(\vec{\mathrm{d}},\mathrm{d})$: $P_y \propto \frac{N_{left}-N_{right}}{N_{left}+N_{right}}$
- use Cross Ratio to suppress offset and first order systematic errors

$$CR_y = \frac{r-1}{r+1}; \quad r^2 = \frac{L(\uparrow)R(\downarrow)}{L(\downarrow)R(\uparrow)}$$





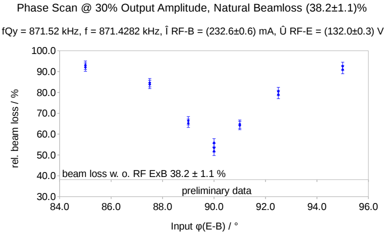
Field Compensation

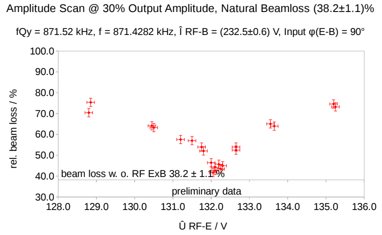
- measurement on betatron frequency for max. sensitivity
- polarimeter target directly above beam-pipe-center as defining acceptance

$\Rightarrow$ exited part of beam is removed

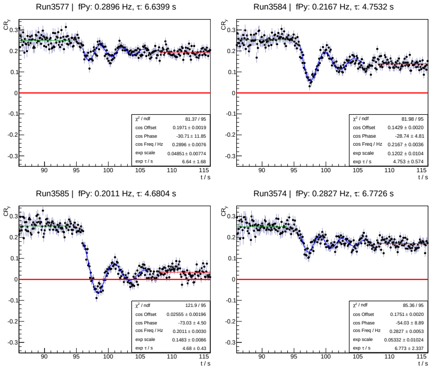
$\Rightarrow$ diagnosis with COSY beam current transformer

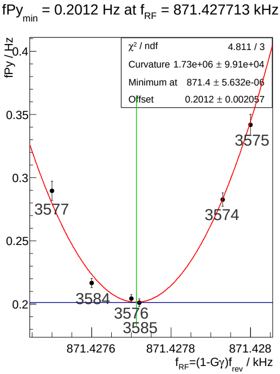
- determination of amplitudes and phase corresponding to Lorentz force compensation down to per mille!





Measurement of Resonance Strength

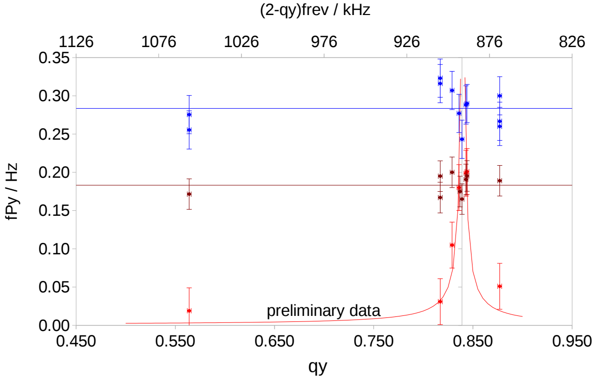




- total spin flip only on resonance $\Rightarrow$ average polarization $\rightarrow 0$
- minimum of vertical polarization oscillation frequency
- resonance strength $\varepsilon = \frac{f_{P_{y\,\mathrm{min}}}}{f_{\mathrm{rev}}}$

Preliminary result of Fixed Frequency Scans

- RF-solenoid: $f_{P_y} \propto \frac{1+G}{4\pi} \frac{\int \hat{B}_{\parallel}\, \mathrm{d}l}{B\rho}$; RF-Wien-Filter: $f_{P_y} \propto \frac{1+G}{4\pi\gamma} \frac{\int \hat{B}_{\perp}\, \mathrm{d}l}{B\rho}$
- RF-dipole: $f_{P_y} \propto \frac{1+\gamma G}{4\pi} \frac{\int \hat{B}_{\perp}\, \mathrm{d}l}{B\rho}$ + interference from beam oscillations



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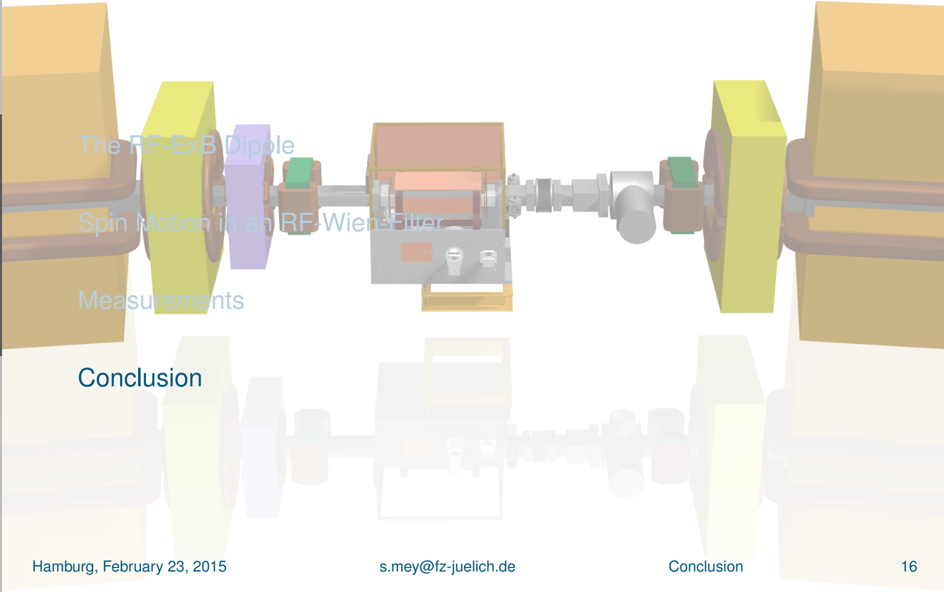

The RF-ExB Dipole

Spin Motion in an RF-Wien-Filter

Measurements

Conclusion

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Conclusion

- RF-ExB dipole acting on MDM with minimal disturbance has been successfully commissioned
  - RF-B amplitude: $\int \hat{B}_x \, dz \approx 0.18\,\mathrm{T\,mm}$ @ $\hat{I}_{\mathrm{max}} = 5\,\mathrm{A}$
  - RF-E amplitude: $\int \hat{E}_y \, dz \approx 24\,\mathrm{kV}$ @ $\hat{U}_{\mathrm{max}} = 1975\,\mathrm{V}$
  - ± 1 spin harmonics at 629 kHz and 871 kHz available for studies
- field strengths necessary for spin manipulation ($\approx 0.01\,\mathrm{T\,mm}$) available at very low input powers ($\approx 10\,\mathrm{W}$)
- Wien filter as RF spin manipulator is a concept that works
- high precision version with stripline layout scheduled for commissioning in Septermber 2015*

[* see talk given by J. Slim]

Content