# Beam based calibration of a Rogowski coil used as a horizontal and vertical Beam Position Monitor

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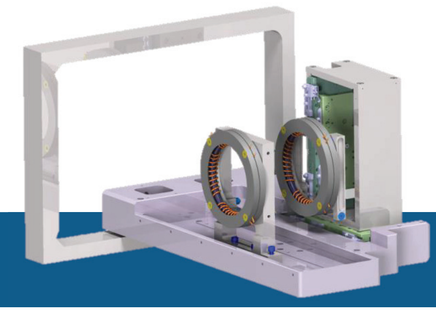
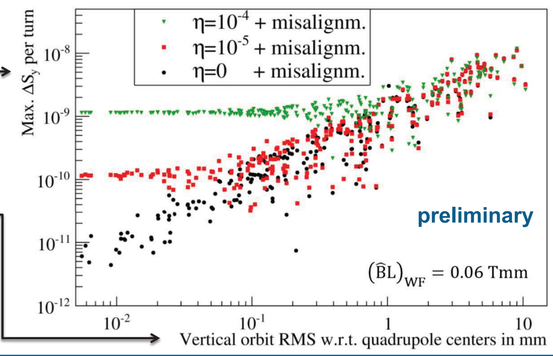
**for the JEDI Collaboration**



## Motivation

- Measure Electric Dipole Moment (EDM) of charged hadrons at COSY
- Use **RF Wien Filter** build up a EDM signal
- EDM $\eta$ **rotates spin** out of horizontal plane $\Rightarrow \frac{\Delta S_y}{\text{turn}}$
- Study **systematic effects**, like misalignments of magnets by controlling the **orbit** of the beam
  - **Improve** Beam Position Monitor (BPM) system, including new BPMs
    - Magnetostatic pick-ups based on Rogowski coil design

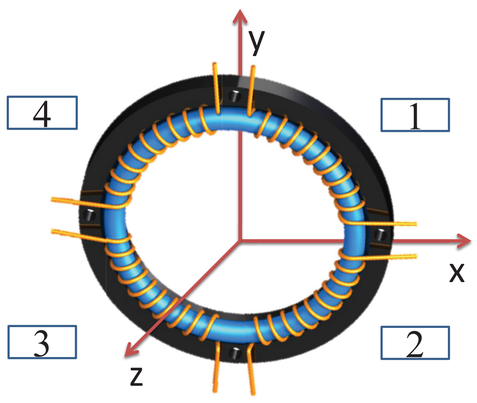



Vertical polarization build-up

Simulation result from [3]

## Design of Rogowski Pick-Up Coil for a SQUID-BPM

- Torus with:
  - Major radius $R = 40\ mm$
  - Minor radius $a = 5\ mm$
  - Winding with cooper wire $N = 350$



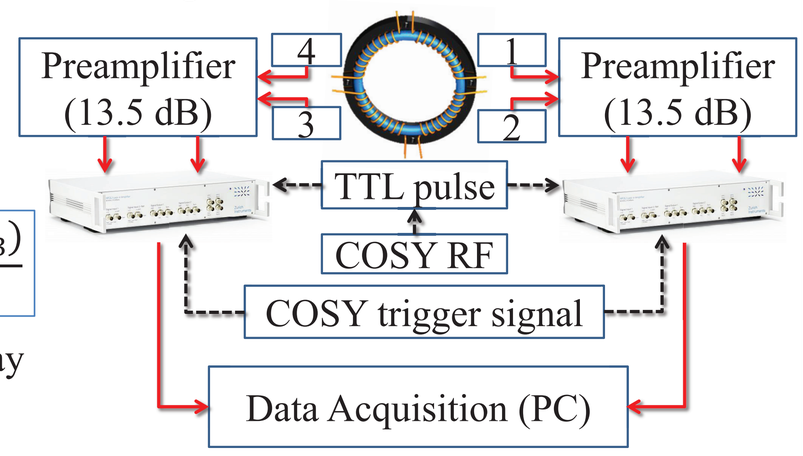

BPM in x- and y-direction (horizontal & vertical)

- Voltage induced by magnetic field $\vec{B}$ of a bunched particle beam $(x_0, y_0)$ in $z$-direction:
  - $U_{ind} = -\frac{d}{dt}\int \vec{B}\cdot d\vec{A} = -\frac{d}{dt}\iiint B_\varphi dr dz R d\varphi$
- Beam position determination in dependency of induced voltages:

$$x = m\cdot\frac{(U_1+U_2)-(U_3+U_4)}{U_1+U_2+U_3+U_4} \qquad y = m\cdot\frac{(U_1+U_4)-(U_2+U_3)}{U_1+U_2+U_3+U_4}$$

  - The arrangement of the segments is chosen in such a way that the BPM sensitivity is linear
  - Theoretical prediction for sensitivity $m = \frac{\pi\sqrt{R^2-a^2}}{2}$ depends only on tube and torus parameters

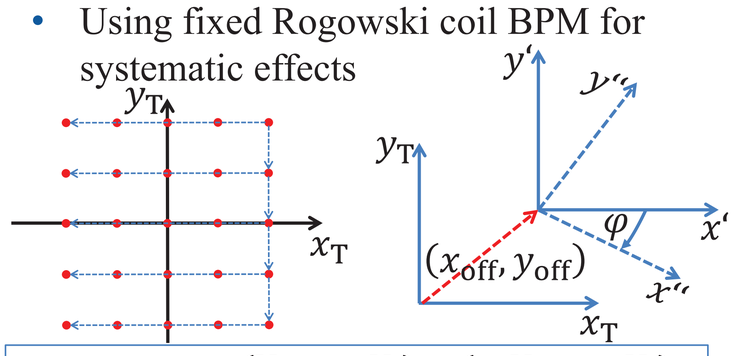
- Readout diagram for position determination of one Rogowski coil BPM:




- Cycle length of 210 $s$, sending each 5 $s$ a trigger signal for position measurement

## Measurements at COSY

- Installation of two Rogowski coil BPMs:
  - Performing a grid measurement with the piezo table and measuring the beam positon with the moved coil
  - Using fixed Rogowski coil BPM for systematic effects




$$x' = m_x\cdot m\cdot\frac{(U_1+g_2U_2)-(g_3U_3+g_4U_4)}{U_1+g_2U_2+g_3U_3+g_4U_4}$$

$$y' = m_y\cdot m\cdot\frac{(U_1+g_4U_4)-(g_2U_2+g_3U_3)}{U_1+g_2U_2+g_3U_3+g_4U_4}$$

- Weighting factors $(g_2, g_3, g_4)$
- Offset $(x_{\text{off}}, y_{\text{off}})$ and rotation $(\varphi)$ to electrical centre
- Sensitivity scaling factors $m_x$ and $m_y$

- Applying calibration algorithm to the data of the moved Rogowski coil BPM
  - Minimize $\chi^2$ in dependency calibration factors

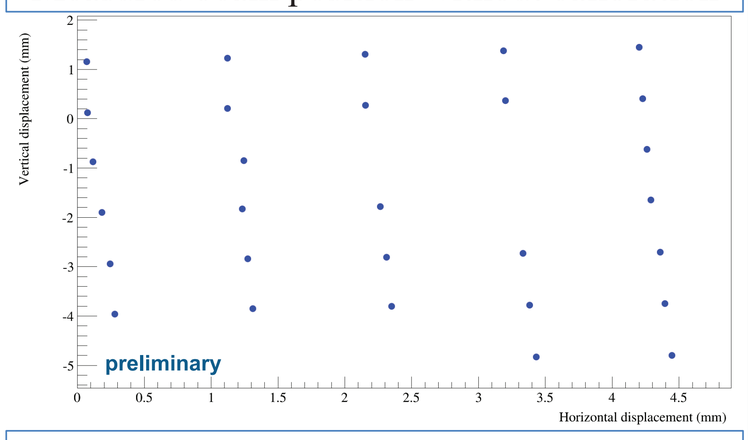
$$\chi^2 = \chi_x^2 + \chi_y^2$$

$$\chi_x^2 = \frac{(x'\cdot\cos(\varphi) - y'\cdot\sin(\varphi) - x_T - x_{\text{off}})^2}{(\sigma_{pos_x}\cdot\cos(\varphi))^2 + (\sigma_{pos_y}\cdot\sin(\varphi))^2 + (\sigma_{x,\text{fluc}})^2}$$

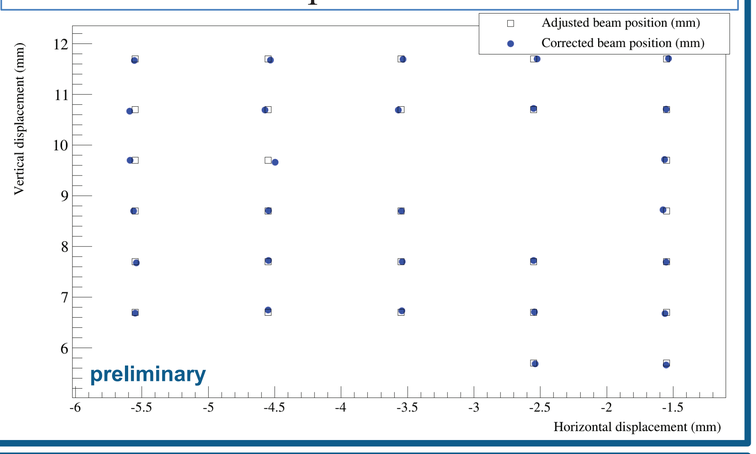
$$\chi_y^2 = \frac{(x'\cdot\sin(\varphi) + y'\cdot\cos(\varphi) - y_T - y_{\text{off}})^2}{(\sigma_{\text{pos}_x}\cdot\sin(\varphi))^2 + (\sigma_{\text{pos}_y}\cdot\cos(\varphi))^2 + (\sigma_{y,\text{fluc}})^2}$$

  - Calibrating out systematic effects of the BPM itself like different numbers of windings for each segment, rotation of the torus or deviations of the radii
  - $\sigma_{\text{x,y fluc}}$ respects cycle fluctuation of the horizontal and vertical beam positon $(\sigma_{\text{x,fluc}} = 22\,\mu\text{m}, \sigma_{\text{y,fluc}} = 32\,\mu\text{m})$

Measured beam position without calibration




Measured beam position with calibration




## Summary & Outlook

- The presented Rogowski coil BPM **measures the beam position in horizontal and vertical direction** in accelerator environment
- Successful installation of a moveable and fixed Rogowski Coil BPM in an accelerator environment
- The used minimization algorithm results in calibration factors
- The adjusted and measured beam position are in excellent agreement after calibration with the applied table positions
- Starting with cooling a Rogowski Coil BPM towards a SQUID-BPM

## References

[1] F. Rathmann et al., Journal of Physics: Conference Series **447** (2013)

[2] W. Morse, Y. Orlov, Y Semertzidis, Phys. Rev. ST Accel. Beams **16** (2013)

[3] M. Rosenthal, A. Lehrach, Conference Proceedings, IPAC15 (2015)

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[5] F. Hinder et al., Conference Proceedings, , IBIC2015 (2015)

[6] M.Tejima, Conference Proceedings, IBIC2015 (2015)