Rogowski beam position monitors

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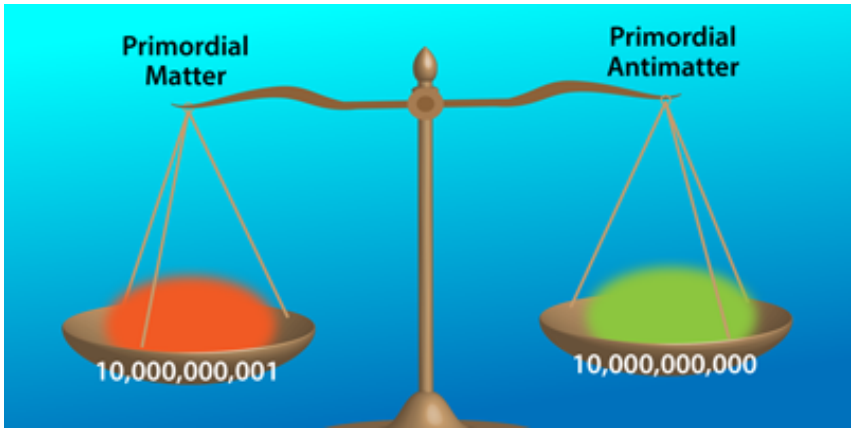
PANIC 2021 Conference

8 September 2021

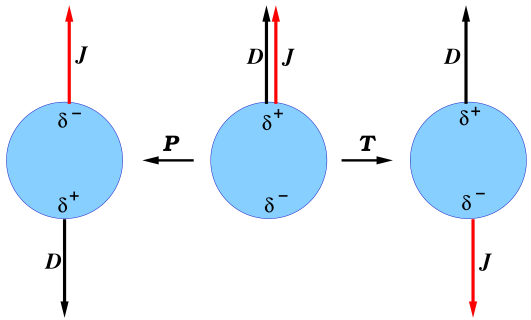
Overview

Motivation

- Freez-out stage: 10^9 antimatter vs. $10^9 + 1$ matter
- A surplus of 1 matter particle $\Rightarrow$ the today's universe!
- Why did matter survive?



- Sakharov's (1967) conditions for baryogenesis (one of them is CP violating processes)
- Electric dipole moment (EDM) violates P and T (hence CP)



- Current EDM investigatins carried by JEDI using the COoler SYnchrotron COSY
- Define beam transverse coordinates $\Rightarrow$ beam position monitors (BPMs)

Principle of Rogowski coil

- Toroidal helical wire (magnetic induction)

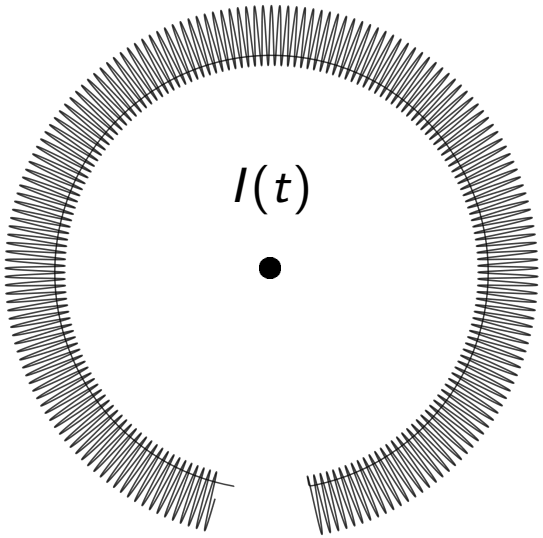


Figure 1: Rogowski winding.

Principle of Rogowski coil

- Toroidal helical wire (magnetic induction)
- Segmented into four parts (link to beam coordinates):
  - $\frac{\Delta_x}{\Sigma} = \frac{\text{right}-\text{left}}{\text{right}+\text{left}}$
  - $\frac{\Delta_y}{\Sigma} = \frac{\text{up}-\text{down}}{\text{up}+\text{down}}$

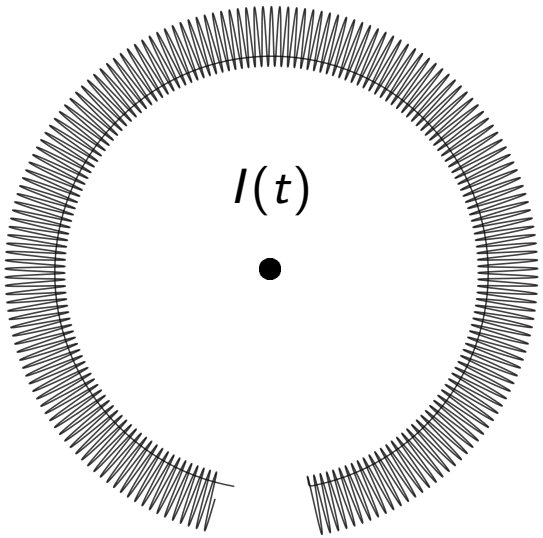


Figure 1: Rogowski winding.

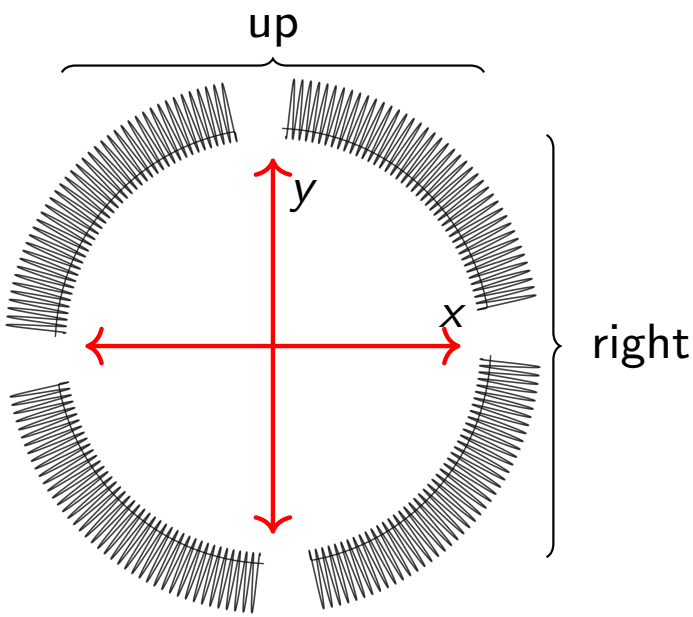


Figure 2: Rogowski BPM winding.

Assembly

Figure 3: Core-winding combination.

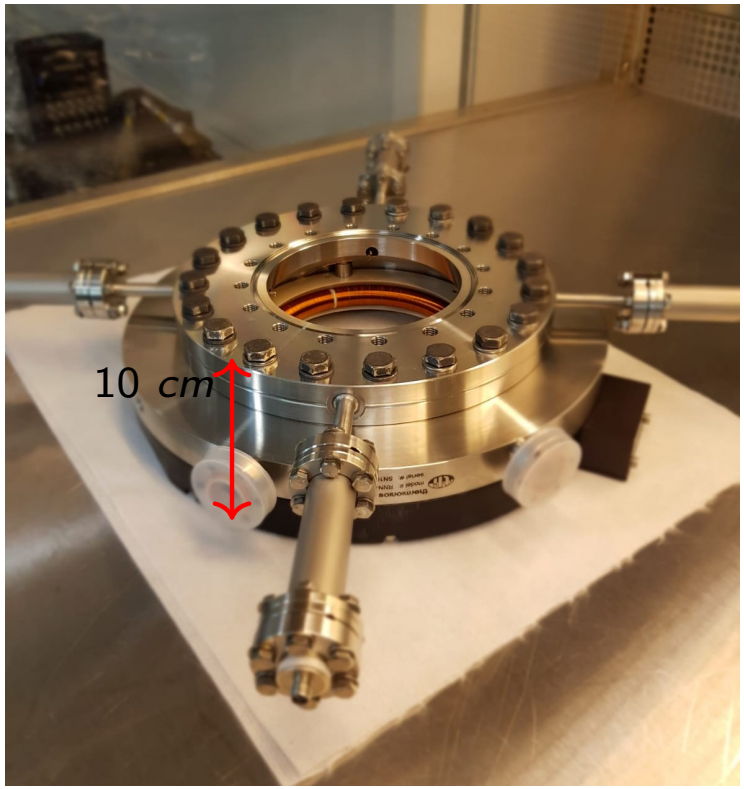
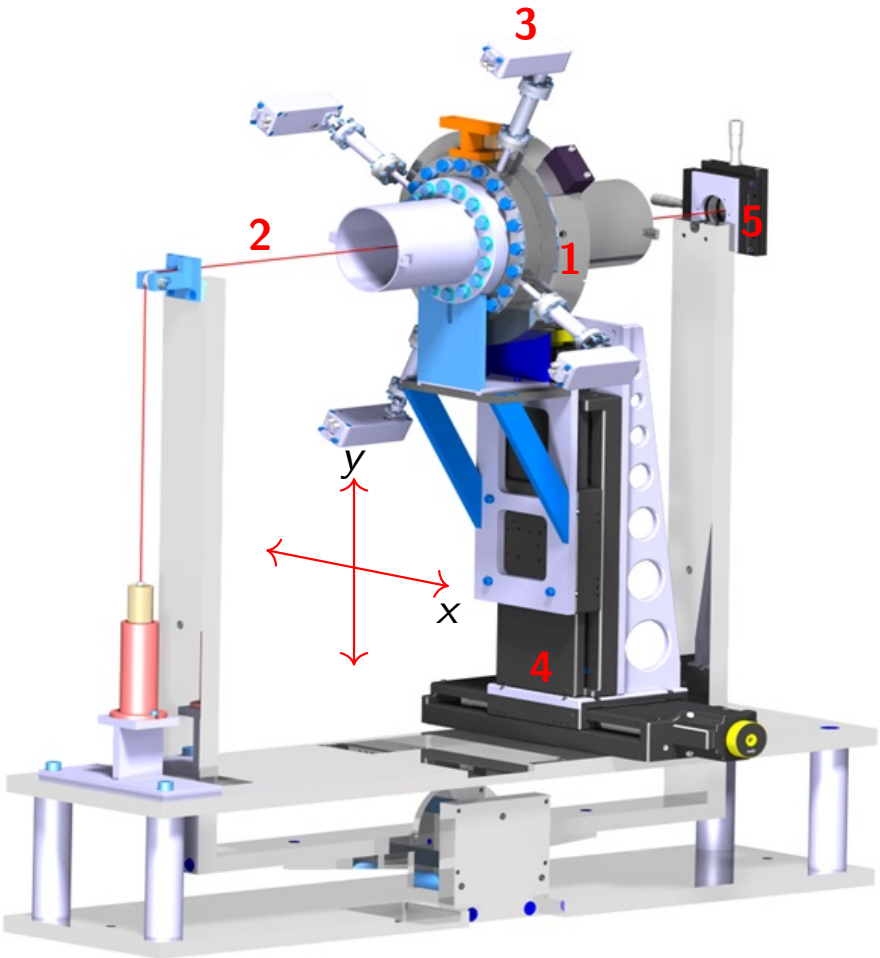


Figure 4: Rogowski BPM.

Calibration measurement



- **1**: Rogowski BPM
- **2**: Copper wire (beam) $\vec{z}$
- **3**: Pre-amplifier
- **4**: Stepping drives
- **5**: Manual tables
- For signal processing: Lock-in amplifiers

Figure 5: Laboratory test-stand.

Theoretical background

- Each coil has $\Delta\psi < \frac{\pi}{2}$
- The response of quadrant 1 is governed by eq. 1.

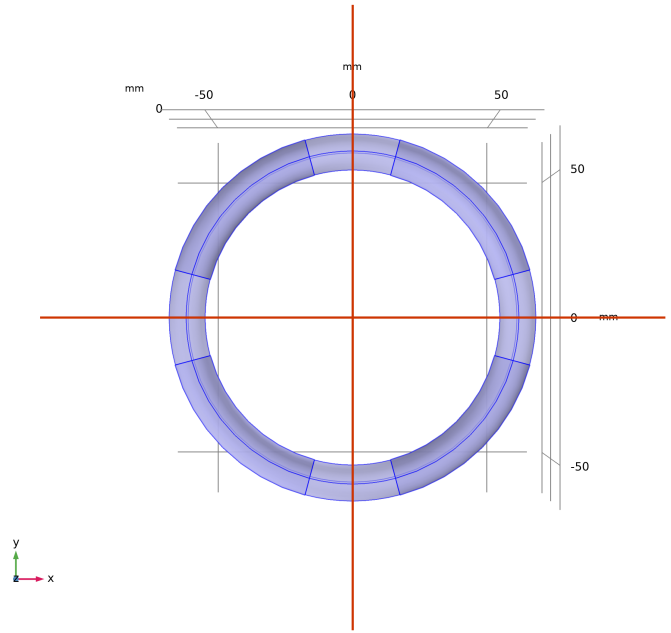


Figure 6: Winding configuration.

$$
\begin{aligned}
U_{out1}(x,y,\omega) = \; & \omega\gamma_1(\omega_0,\omega_1,\omega) n\mu_0 c_0^{\dagger} I \Bigg[\Big(1 + c_1^{\dagger}(x+y) + c_2^{\dagger}(xy) \\
& + c_3^{\dagger}(-x^3 - y^3 + 3yx^2 + 3xy^2) \\
& + c_4^{\dagger}(-x^4 - y^4 + 6x^2y^2) \\
& + c_5^{\dagger}(x^5 + y^5 - 10x^3y^2 - 10y^3x^2 + 5y^4x + 5x^4y) + \ldots \Big) + \ldots \Bigg]
\end{aligned}
\tag{1}
$$

Calibration example

Calibration example ($\Delta\psi < \frac{\pi}{2}$)

- ⋆ Rogowski BPM with winding range $< \frac{\pi}{2}$ was calibrated
- ⋆ Sine wave with $f = 750$ kHz, and a square map of range(-10,10,1) mm

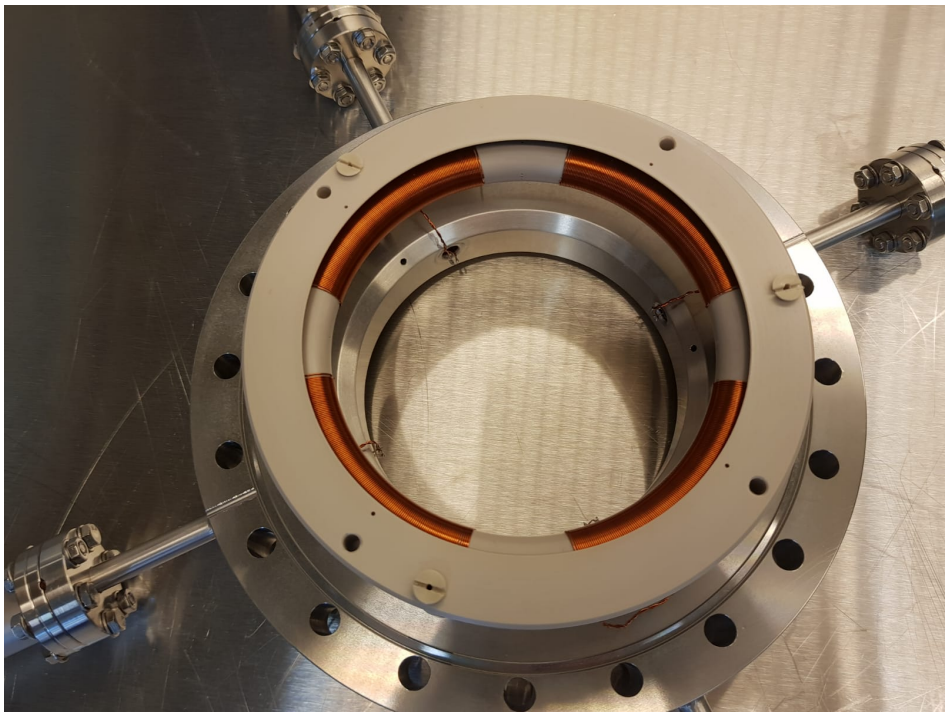


Figure 7: Rogowski BPM winding with incomplete angular range.

Calibration example

Calibration exampl ($\Delta\psi < \frac{\pi}{2}$)

- ⋆ Measurement data was used to verify the theoretical model (see eq. 1)
- ⋆ Well agreement between measurement and model (residuals in the order of 1 µV)

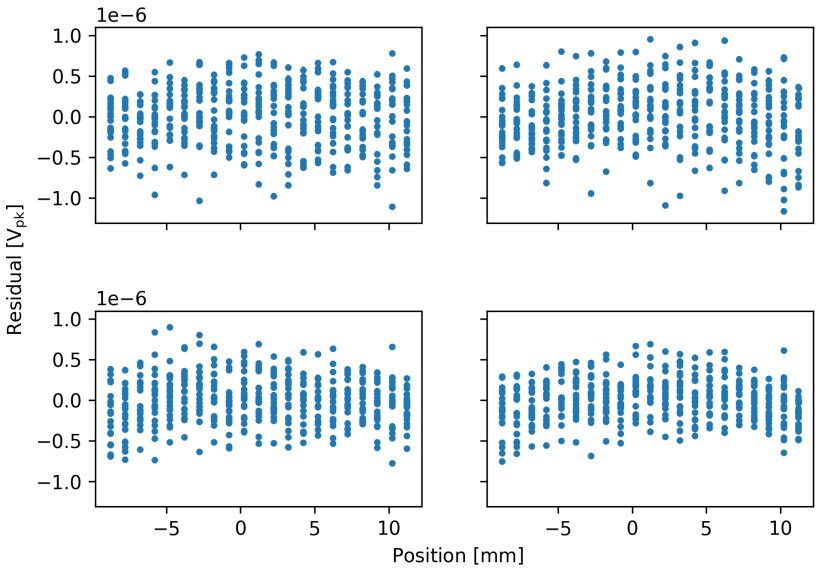


Figure 8: Measured − expected (voltages).

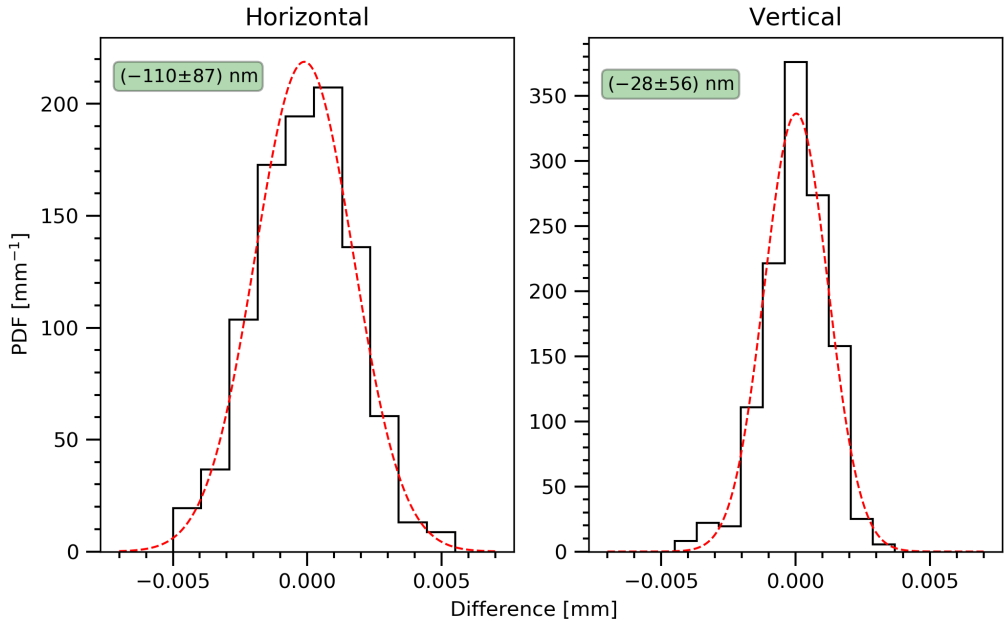


Figure 9: Measured − expected (positions).

Evaluations

SNR

The signal to noise ratio from Rogowski BPM can vary depending on:

- operational frequency
- beam current amplitude
- electronics (filter bandwidth and other relevant settings)

But in general it can reach a value of few thousands.

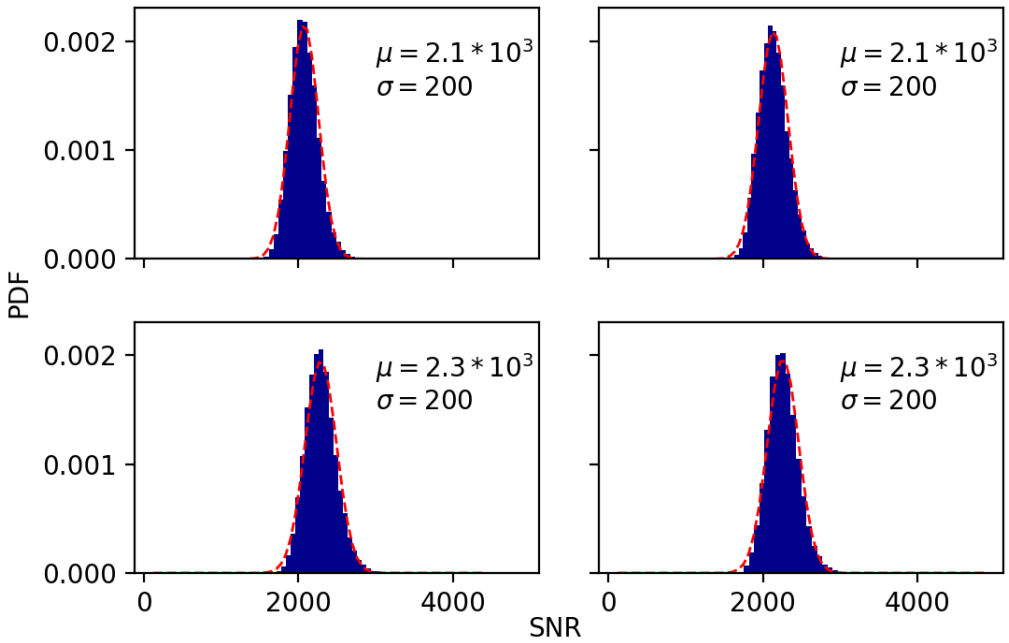


Figure 10: An example for the SNR from the four quadrants of Rogowski BPM.

Evaluations

Resolution

An estimate for the spatial resolution, neglecting the differences between individual coils (for simplicity) and assuming that beam position is some where around the center where linear position dependence is just sufficient:

$$\delta_x = \frac{1}{2c_1 \times SNR} \,. \tag{2}$$

A resolution of few µm for one single measured beam position (averaged over a second) is reachable.

Accuracy

An estimate for the accuracy considering errors from the stepping motors and errors introduced by temporal changes of electrical signal is about 20 µm.

Installation and use in COSY (COoler SYnchrotron)

Installation

Two Rogowski BPMs were successfully installed in COSY.

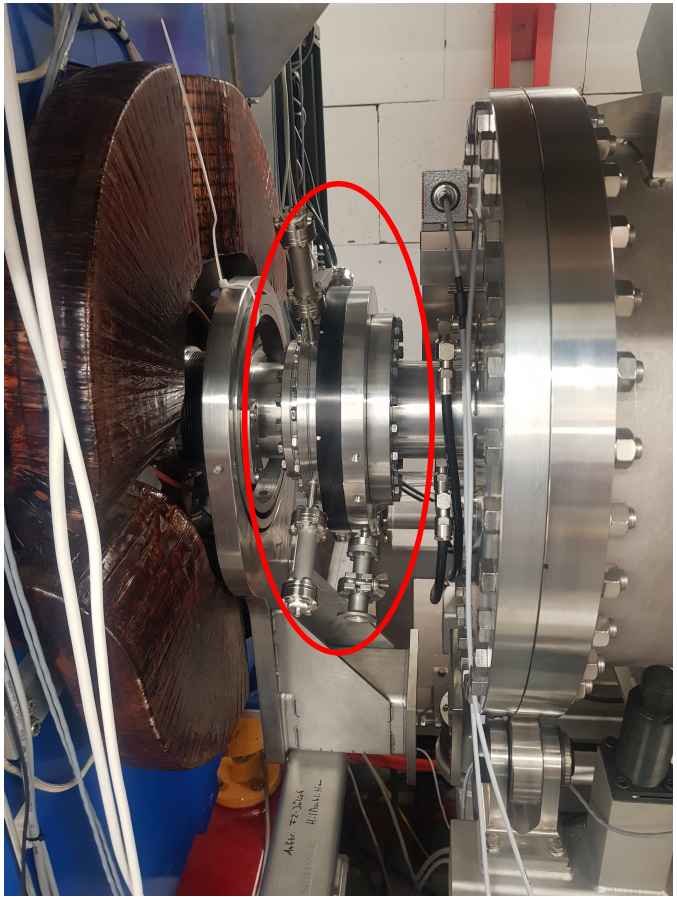


Figure 11: A photo for one Rogowski BPM installed in COSY.

Installation and use in COSY

Local orbit bump:

- fixed horizontal orbit
- apply vertical bumps (range$(5, -5, 1)$ mm)

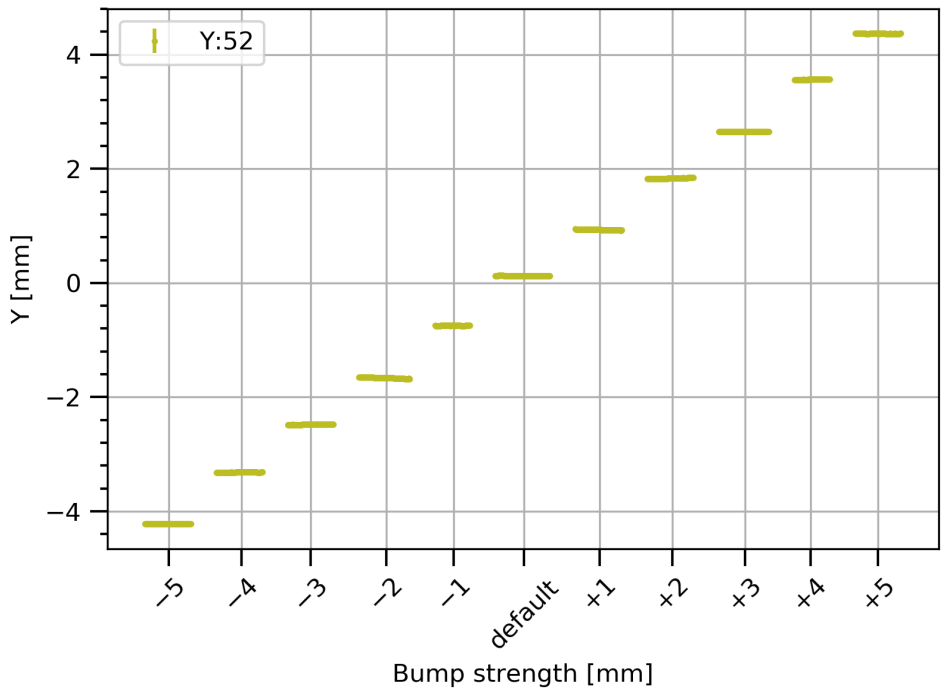


Figure 12: Vertical orbit measured by Rogowski BPM after applying a local orbit bump.

Installation and use in COSY

Positional resolution:

- resolution in the sub-micro meter regime was reached
- for a coil with system SRF around 3.229 MHz
- single bunch mode (measured at a frequency of 750 kHz)
- beam current in the range $0.6 - 1$ mA

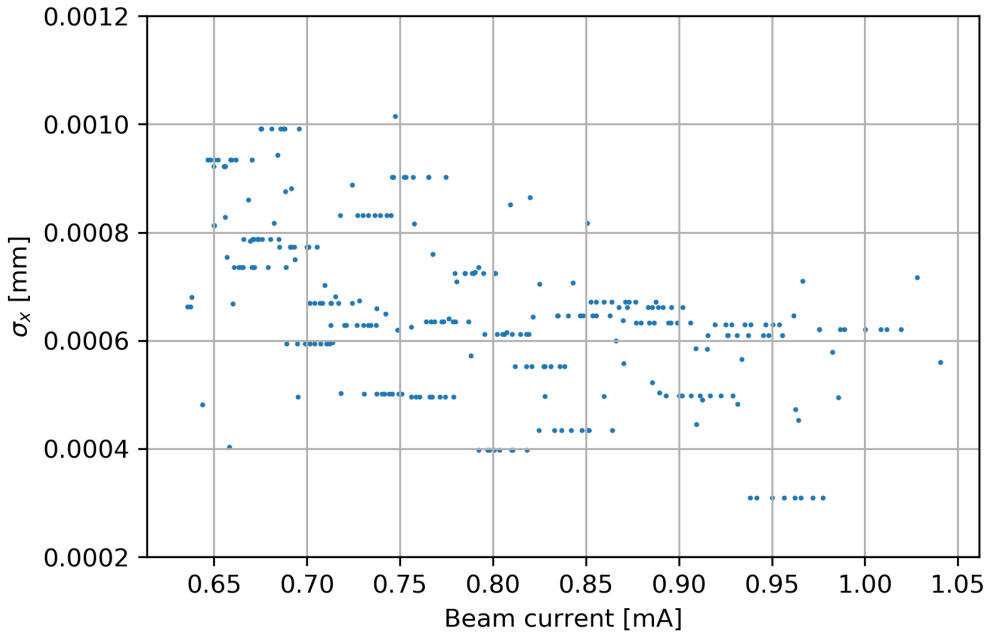


Figure 13: Positional resolution.

Summary

- New types of compact, non-destructive BPMs based on Rogowski coil have been built
- Agreement between theoretical model and experimental data from calibration measurement
- Successful installation and operation in COSY

The End