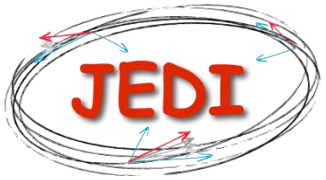


JÜLICH
FORSCHUNGSZENTRUM

Development of new Beam Position Monitors at COSY

DPG Frühjahrstagung

March 12, 2015 | Fabian Hinder on behalf of the JEDI collaboration

Content

- Motivation
- Magnetostatic BPM ⇒ Rogowski Coil
- Results from laboratory measurements
- Outlook

Introduction

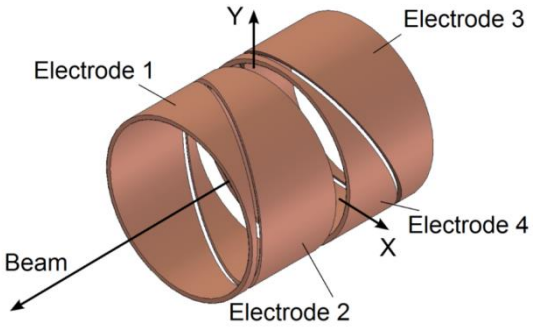
Aim of Jülich Electric Dipole moment Investigations collaboration:

- Measure the EDM of charged particles (p, d)
- Use a modified storage ring:
  - Horizontally polarized beam
  - RF Wien Filter running in phase with spin precession
  - EDM leads to a polarization build-up
  - Challenge:
    - Disentangle EDM from systematic effects
    - ➢ Improve orbit and Beam Position Monitors

Beam Position Monitor (BPM)

- BPM measures transverse beam position (x_0, y_0)

- Standard at COSY: Electrostatic BPM
  - Length: $\approx 20\ cm$



New development:

- Magnetostatic BPM
  - Length: $\approx 1\ cm$

Rogowski Coil

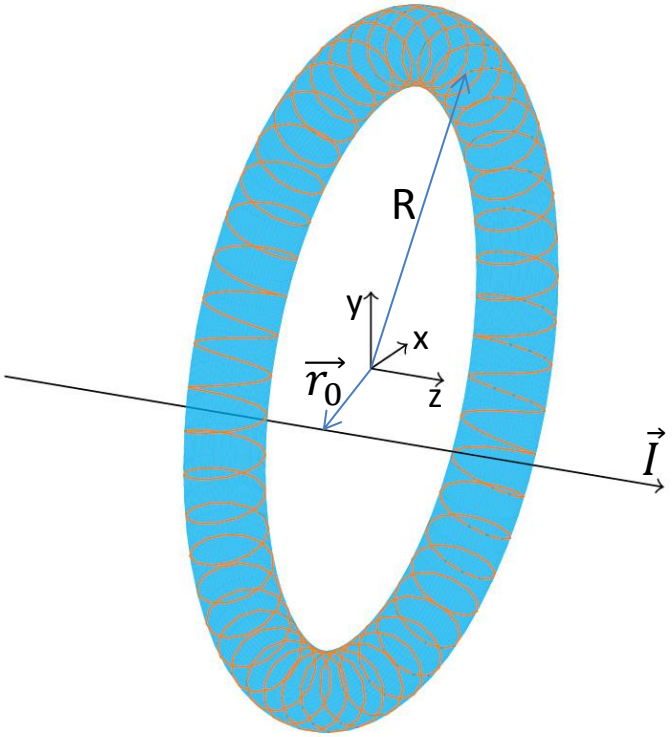
Pickup-Coil to measure the magnetic flux:

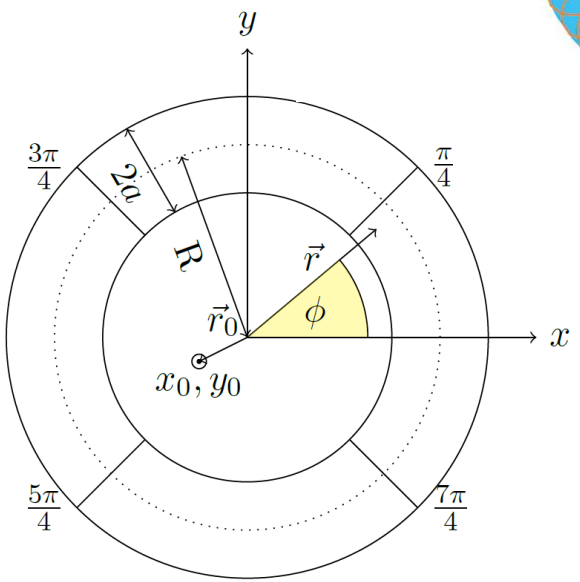
Standard application to measure AC currents

Torus with:

- Major radius $R = 40\ mm$
- Minor radius $a = 5\ mm$
- Winding with copper wire $N = 1400$

- Divided into
  - One segment (BCT)
  - Two segments
    (BPM in one dimension)
  - Four segments
    (BPM in two dimensions)





Magnetic Field of Particle Beam

Simple Model:

Point-like charge with constant velocity at position (x_0, y_0):

Particle Beam:

Current: $\vec{I} = I_0 \cdot \overrightarrow{e_z}$

Position: $\overrightarrow{r_0} = \begin{pmatrix} x_0 \\ y_0 \\ 0 \end{pmatrix}$

Pickup-Coil:

Position: $\vec{r} = \begin{pmatrix} x \\ y \\ z \end{pmatrix}$

Magnetic Field:

$$\vec{B} = \frac{\mu_0}{2\pi} \vec{I} \times \frac{\vec{r} - \overrightarrow{r_0}}{|\vec{r} - \overrightarrow{r_0}|^2}$$

Induced Voltage in one Segment

$$U_{ind} = -\frac{d}{dt}\int \vec{B}\cdot d\vec{A} = -\frac{d}{dt}\iiint B_\varphi dr dz R d\varphi$$

Taylor of B_φ to $\mathcal{O}(r_0^2/R^2)$ leads to:

$$U_{ind,1/1} = \frac{dI_0}{dt} N\mu_0 (R - \sqrt{R^2 - a^2})$$

$$U_{ind,1/2} = \frac{dI_0}{dt} N\mu_0 (R - \sqrt{R^2 - a^2}) \left(1 - \frac{2}{\pi\sqrt{R^2-a^2}} x_0\right)$$

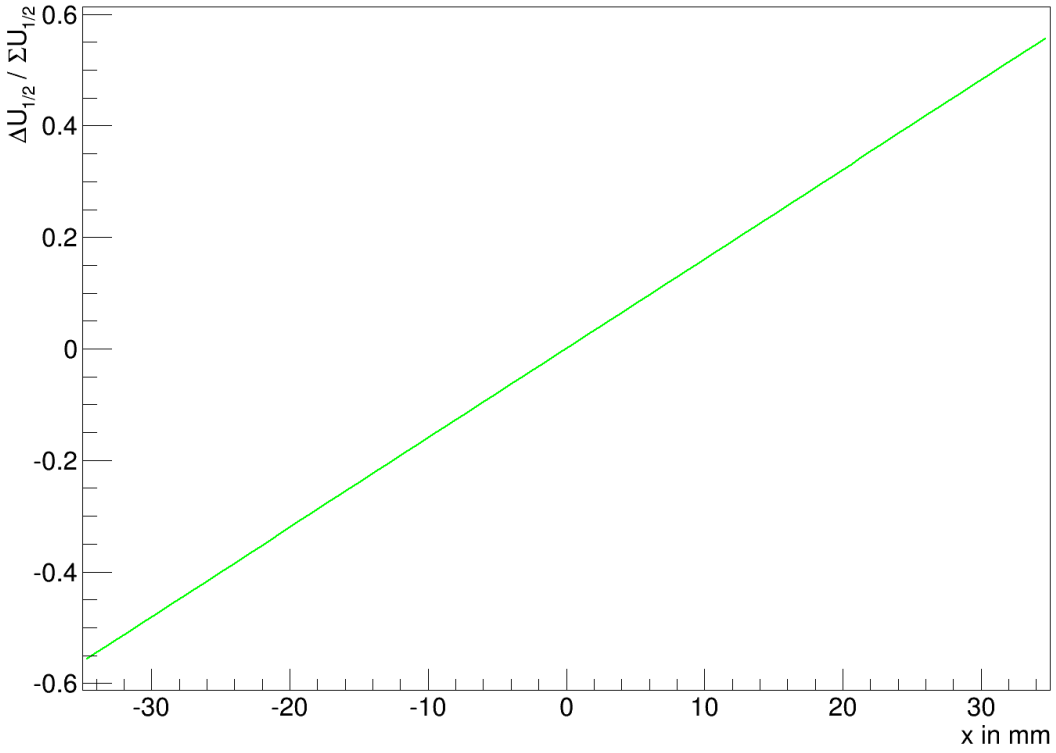
$$U_{ind,1/4} = \frac{dI_0}{dt} N\mu_0 \left(R - \sqrt{R^2 - a^2}\right) \left(1 - \frac{2\sqrt{2}}{\pi\sqrt{R^2-a^2}} x_0 - \frac{r_0^2 \sin(2\Psi - 2\varphi)\, a^2}{\pi(R^2 - a^2)^{3/2} \cdot (R - \sqrt{R^2 - a^2})}\right)$$

Position Determination I

By using two halves of one Rogowski-Coil BPM:

Measuring the voltage difference and the voltage sum:

$$\frac{\Delta U_{1/2}}{\Sigma U_{1/2}} = \frac{2}{\pi\sqrt{R^2 - a^2}} x_0$$



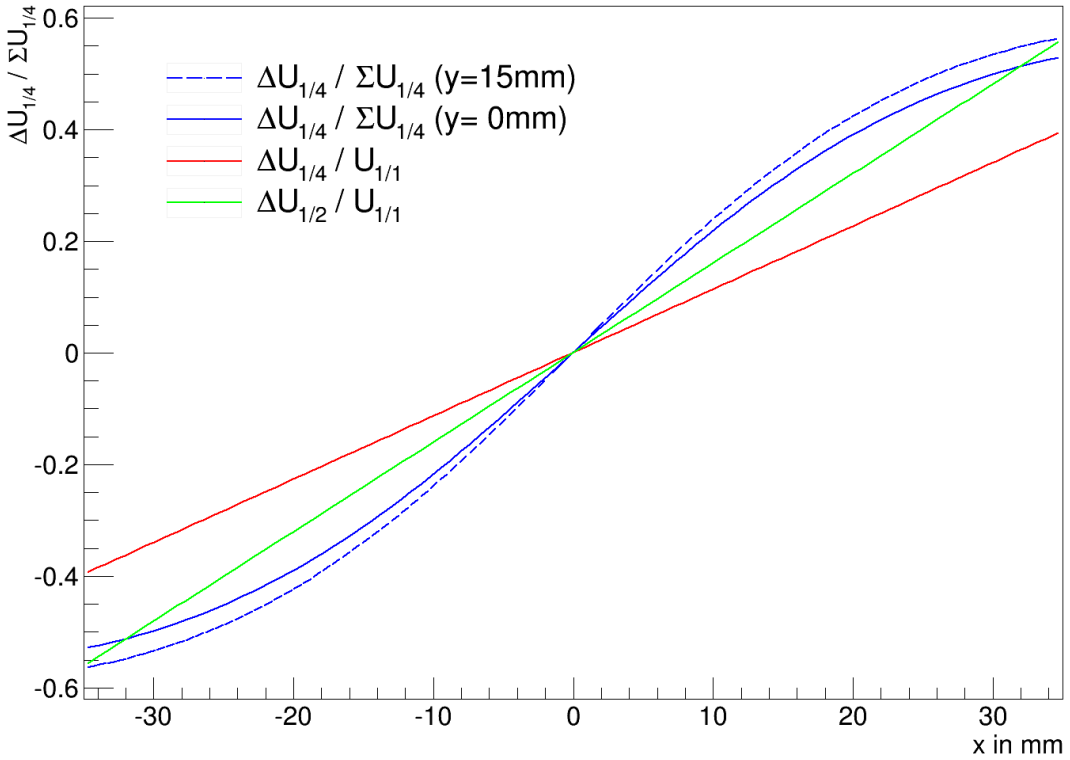
Position Determination II

By using two quarters of one Rogowski-Coil BPM:

Two approaches are possible:

1. $$\frac{\Delta U_{1/4}}{\Sigma U_{1/4}} = \frac{2\sqrt{2}}{\pi\sqrt{R^2-a^2}} x_0 + \mathcal{O}(x_0 y_0, x_0^2, y_0^2)$$

2. $$\frac{\Delta U_{1/4}}{\Sigma U_{1/1}} = \frac{\sqrt{2}}{\pi\sqrt{R^2-a^2}} x_0$$



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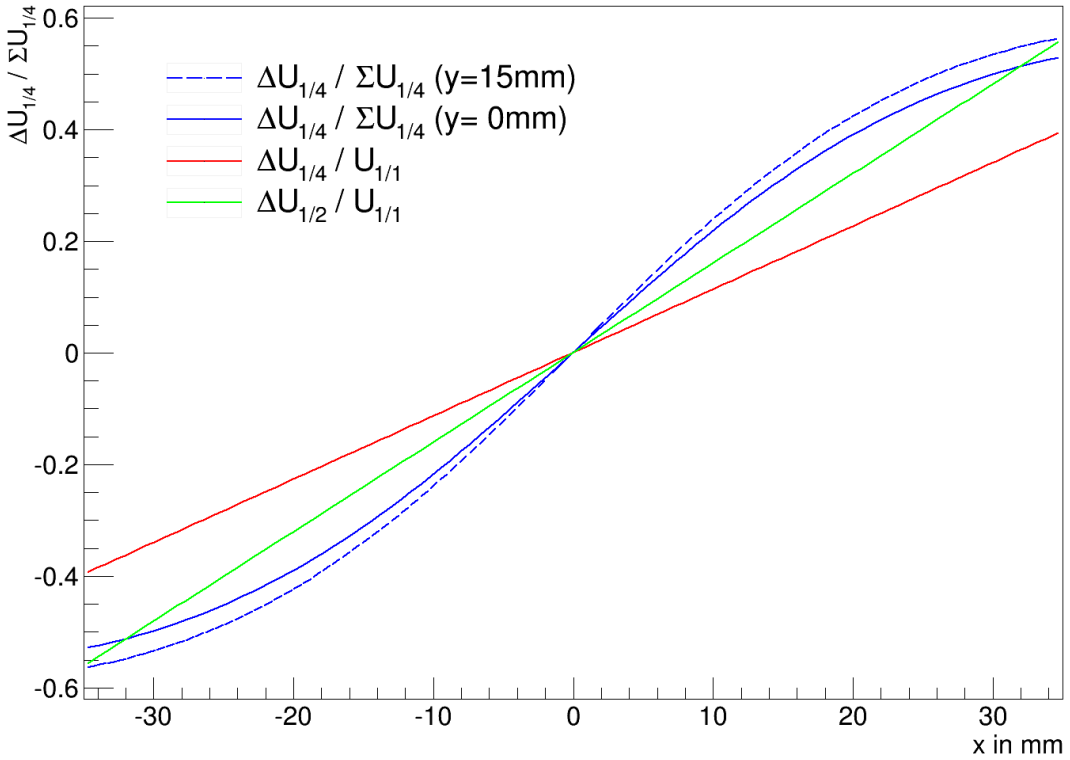
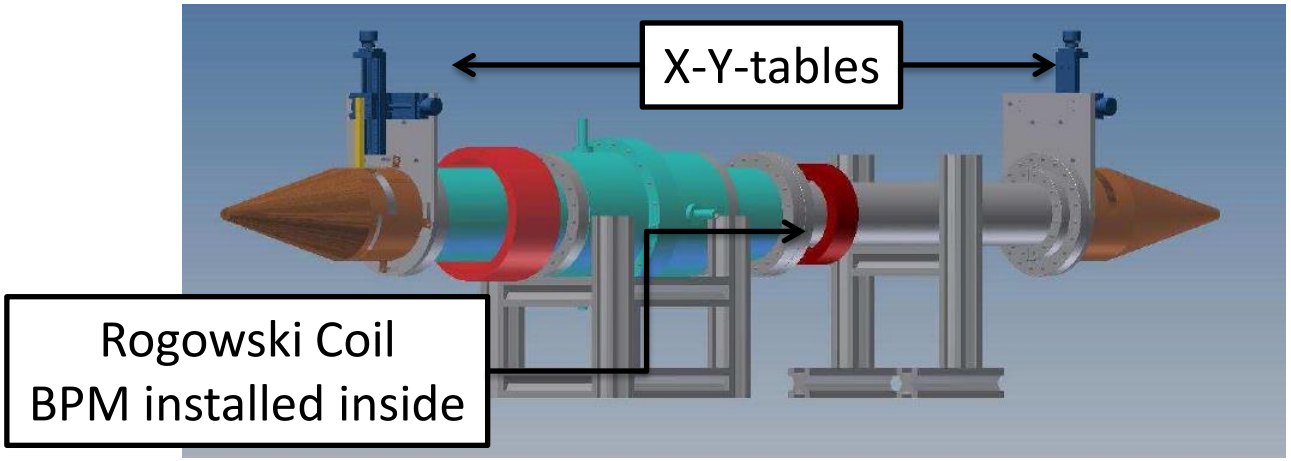
2. $$\frac{\Delta U_{1/4}}{\Sigma U_{1/1}} = \frac{\sqrt{2}}{\pi\sqrt{R^2-a^2}} x_0$$

- Maximum Sensitivity with $\frac{\Delta U_{1/4}}{\Sigma U_{1/4}}$ but not linear
- Linear with $\frac{\Delta U_{1/4}}{\Sigma U_{1/1}}$ but lower sensitivity

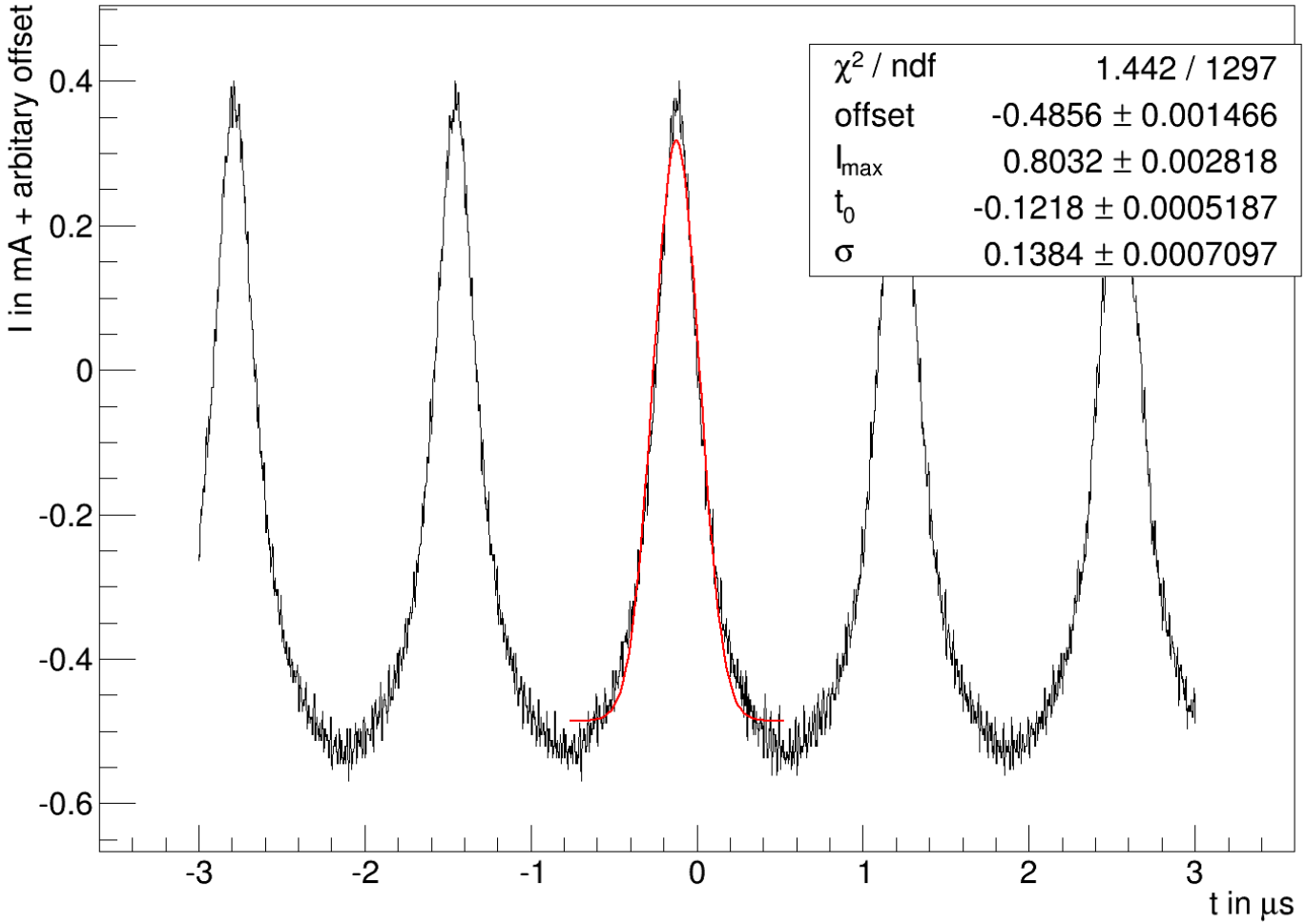


Measurement at Testbench



- Installation of one quartered Coil at test bench
- Movable wire inside
- Simulated Gaussian beam with parameters like a cooled beam in COSY
  - $f = 750\,kHz, N \approx 10^{10} particles, \frac{\Delta T}{T} \approx 0.1$

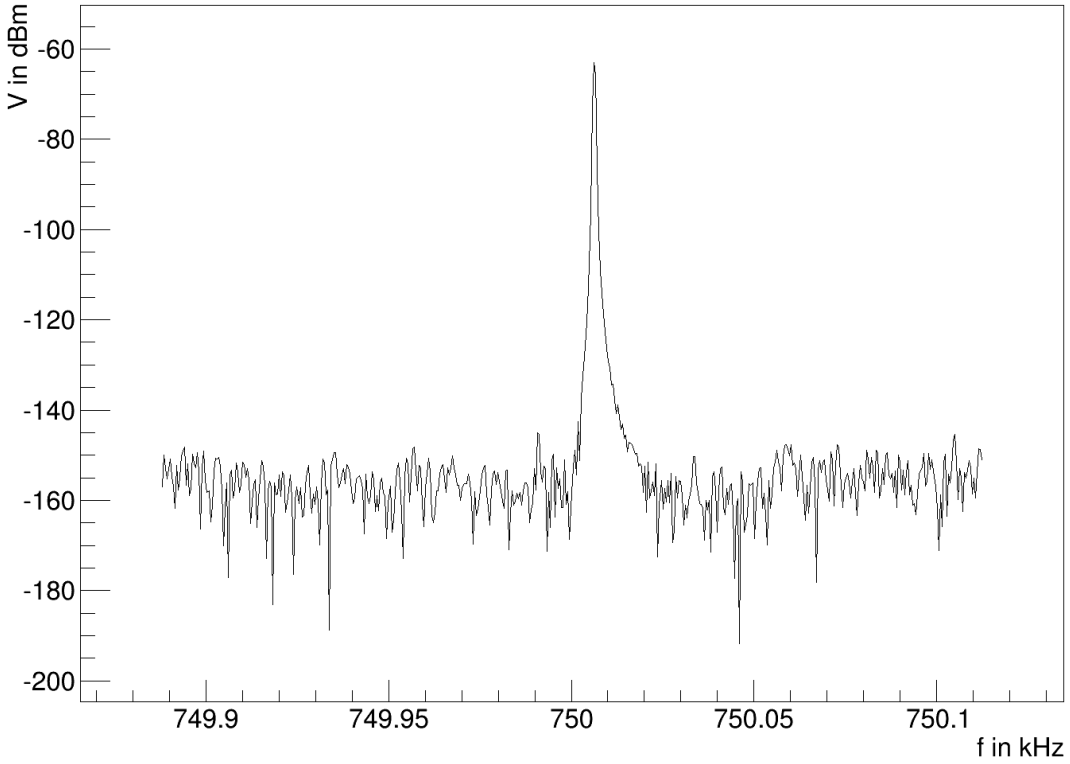
Current Distribution



- $f = 750\ kHz, N \approx 10^{10} particles, \frac{\Delta T}{T} \approx 0.1$

Position Measurement

- Vary position of wire:
  - $y_0 = 0\,mm,\ x_0 = -30\,mm\ to\ 30\,mm$
- Measure voltage of all four quarters with Lock-In Amplifier:



$x_0 = 0\,mm, y_0 = 0\,mm$

$SNR \approx 1500$

U= $62.40\mu V \pm 0.03\mu V$

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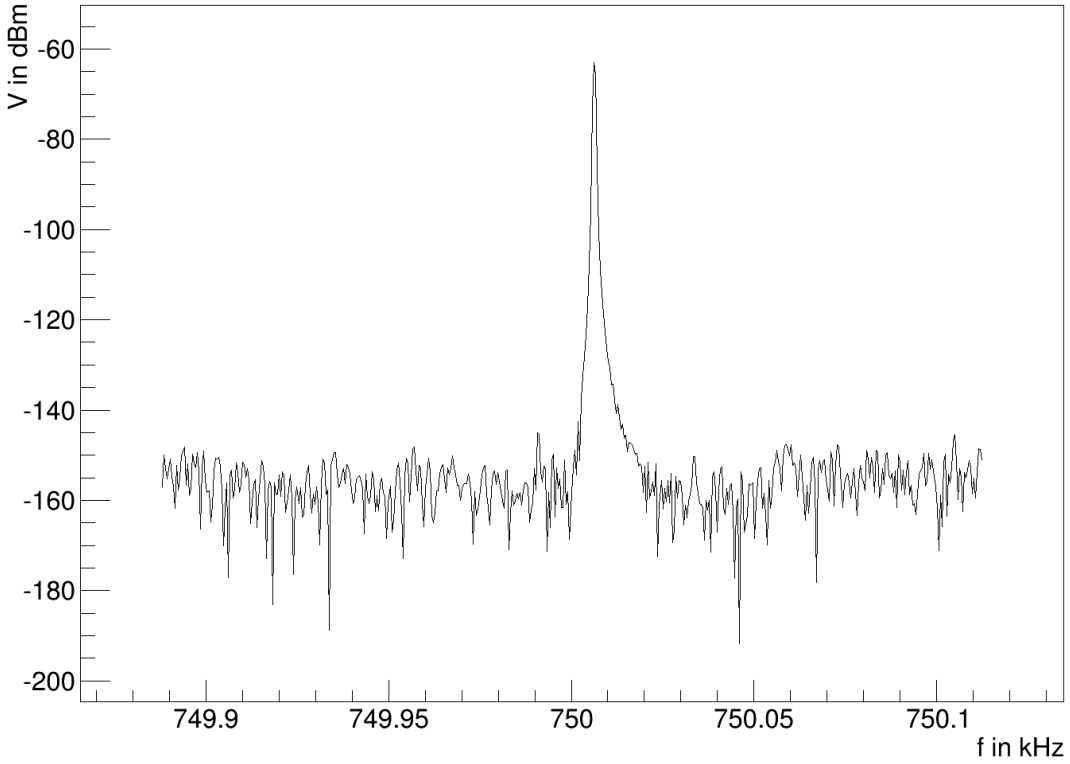

$x_0 = 0\ mm, y_0 = 0\ mm$

$SNR \approx 1500$

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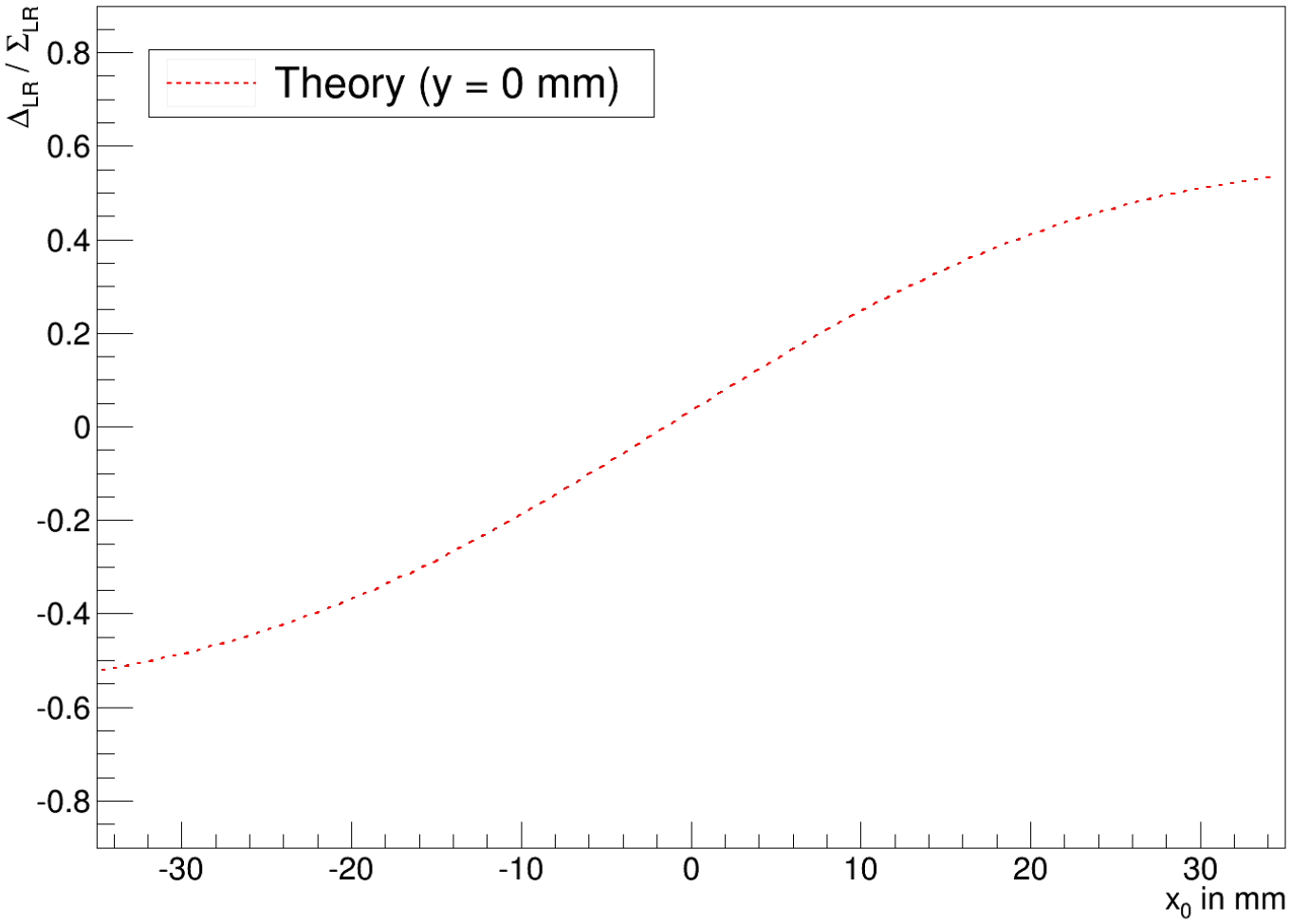
Calculate:

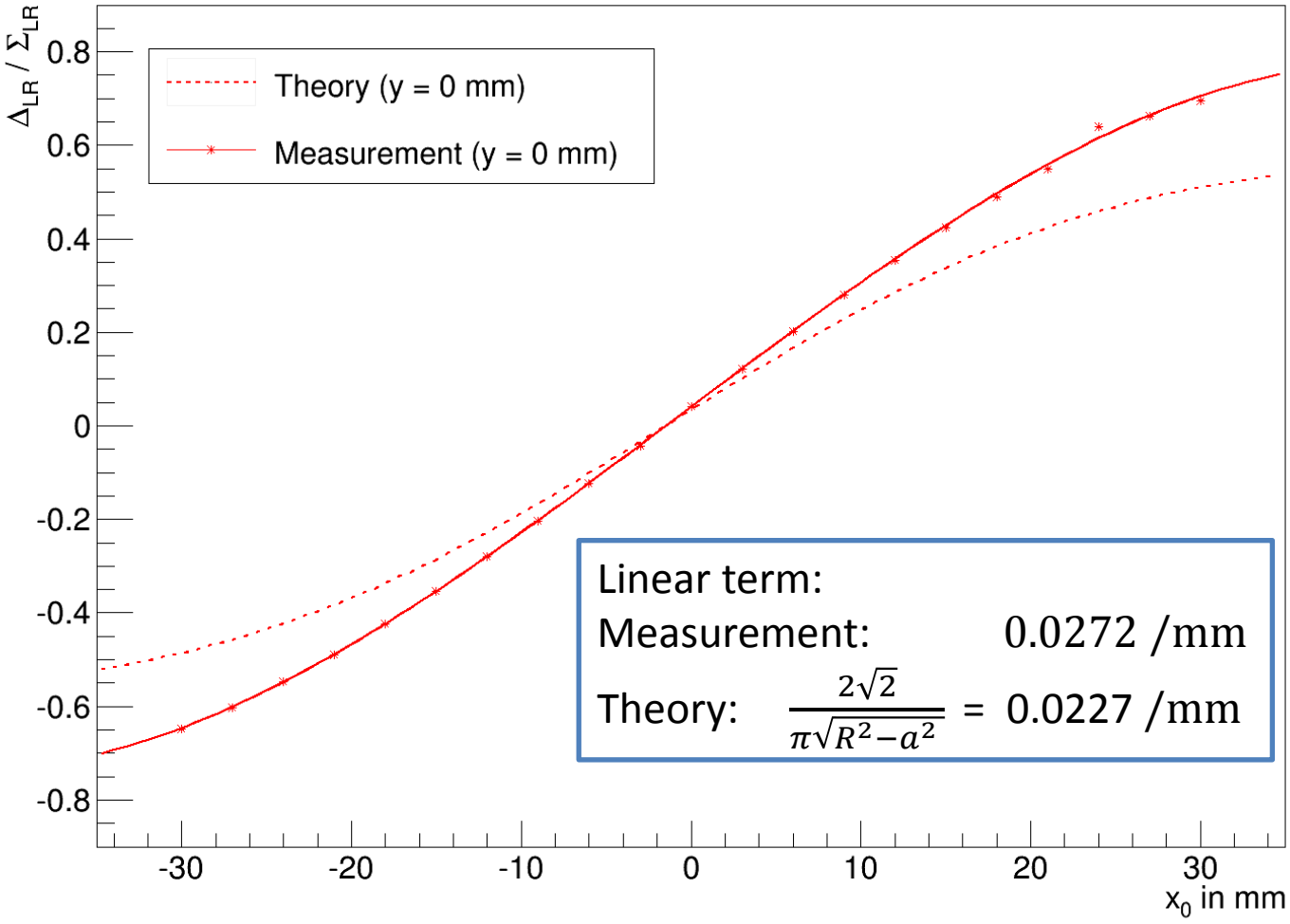
$\Delta U_{1/4}$

$\Sigma U_{1/4}$

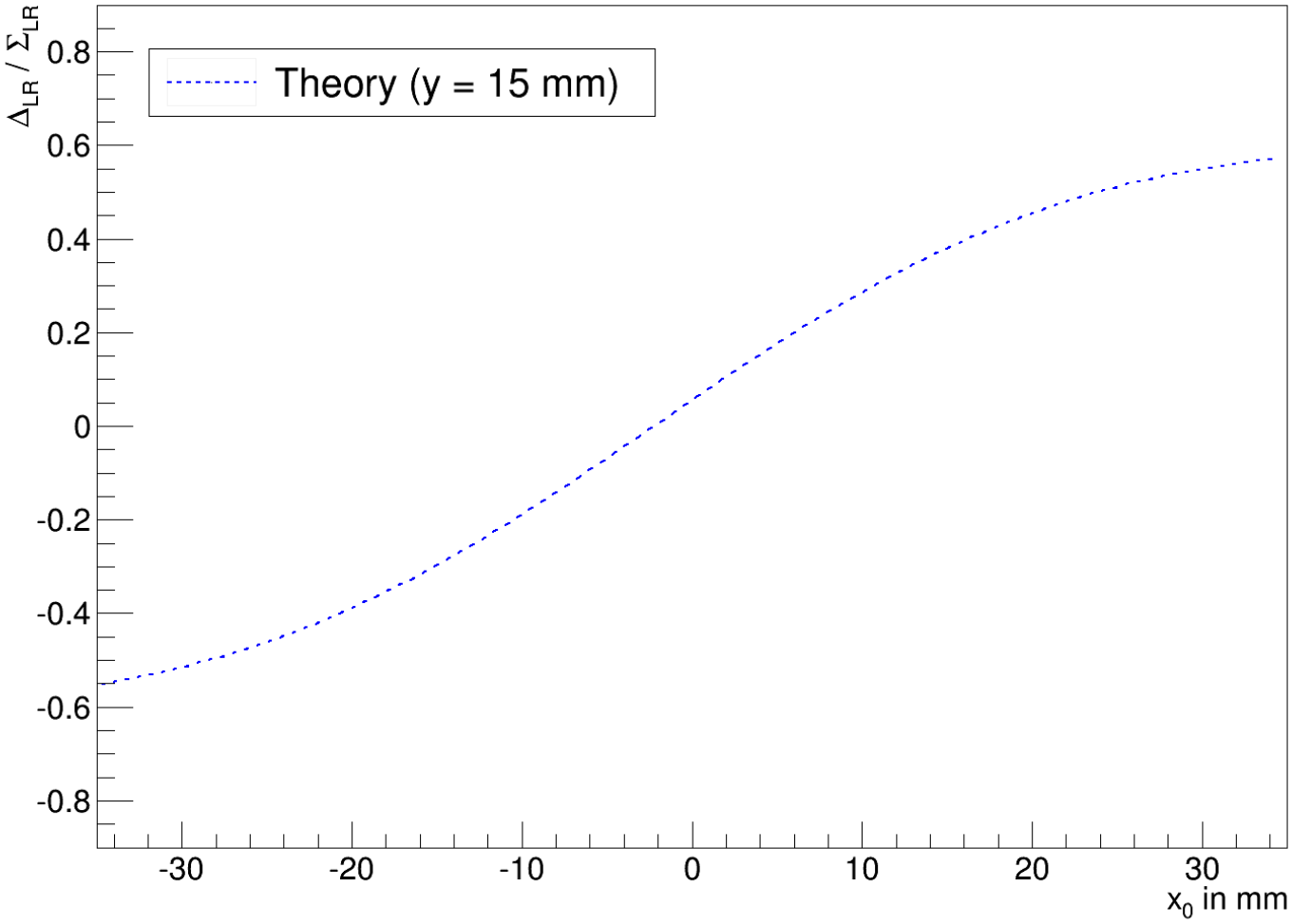
Measurement Results I



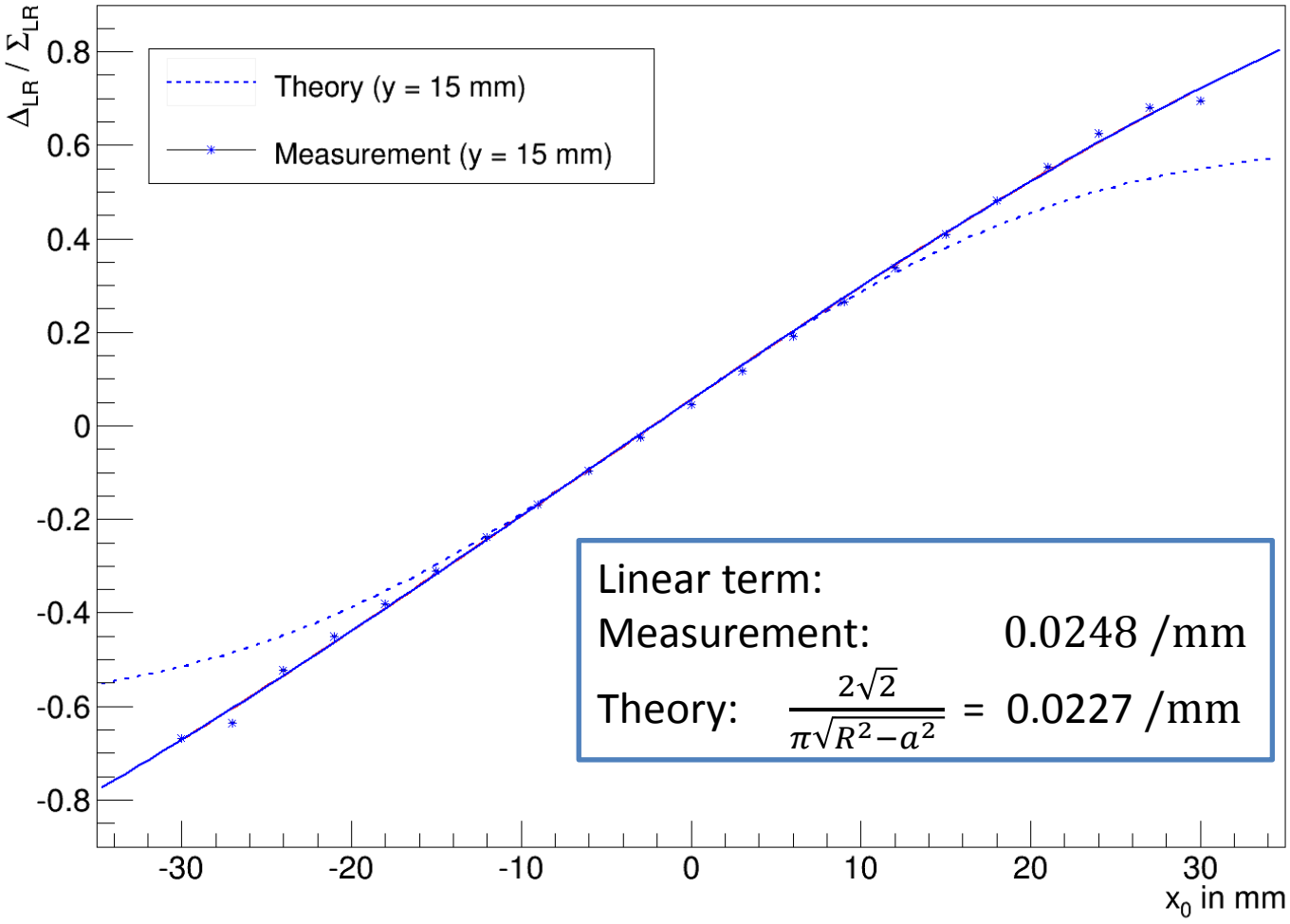
Measurement Results I



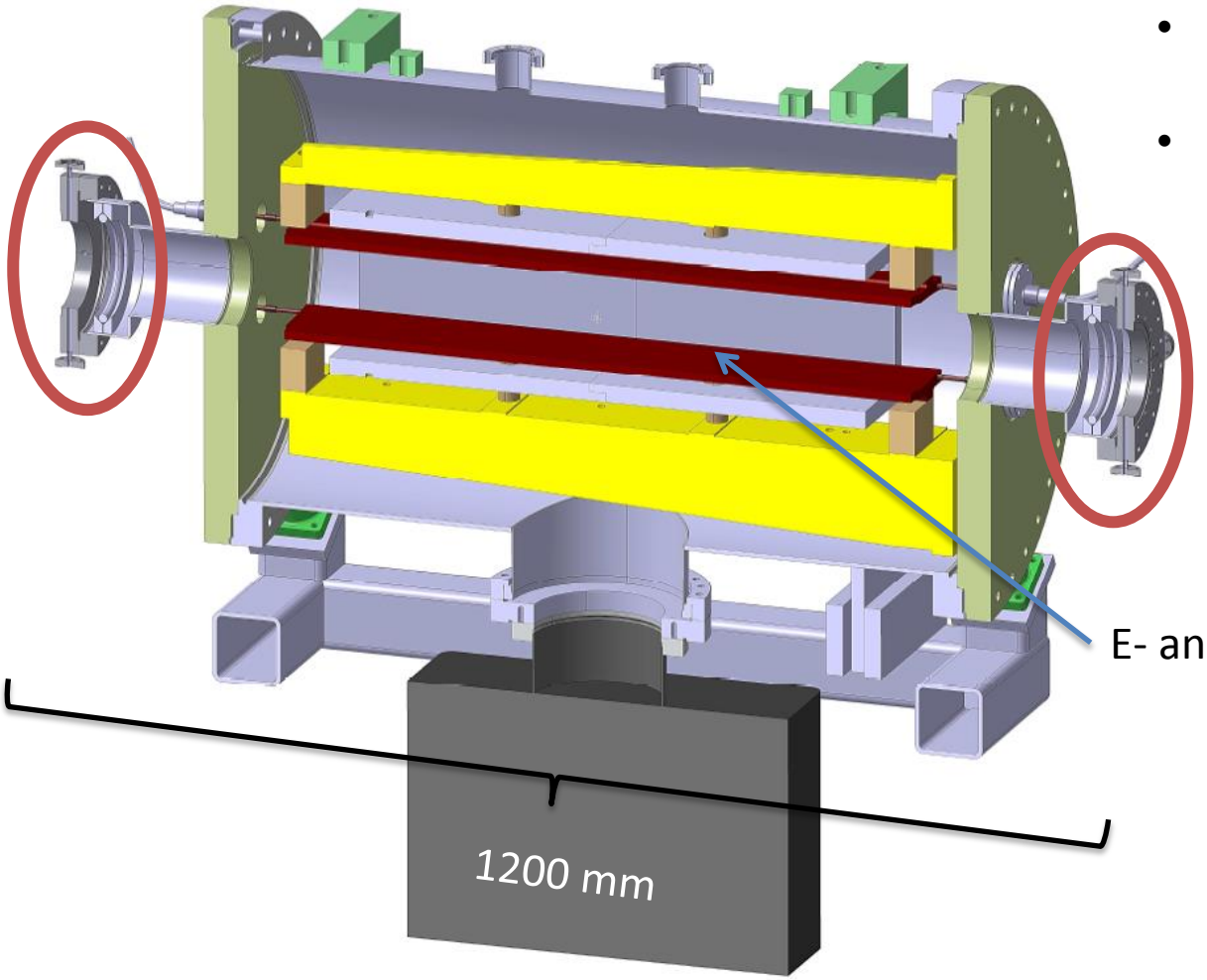
Measurement Results II



Measurement Results



RF Wien Filter

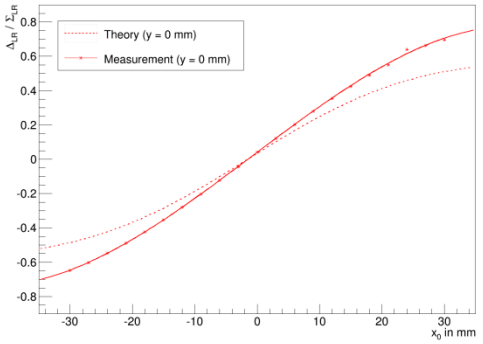


Installation between quadrupoles

- No COSY BPM next to it
- Installation of Rogowski Coil BPMs at both ends
  - Position beam in center and parallel to Wien Filter

E- and B- Field region

Outlook



- Improve theoretical prediction
- Installation of a system at COSY in May 2015
  - Comparison between electrostatic BPM and magnetostatic BPM
- Calibration of measurement system for Wien Filter