# The new magnetic field optimisation procedure of the nEDM experiment at PSI

Elise Wursten
On behalf of the nEDM collaboration

Probing Fundamental Symmetries with UCN workshop, Mainz
April 11, 2016

KU LEUVEN

# Contents

- Introduction
- Magnetic field knowledge
  - CsM
  - Field maps
  - Variometer
- Optimisation procedure
- Results
  - Homogeneity of $B_z$
  - Ramsey visibility of 2015
- Conclusion

KU LEUVEN

# Goal

To optimise the magnetic field such that we gain in nEDM sensitivity

$$\sigma(d_n) = \frac{\hbar}{2\alpha E T \sqrt{N}}$$

by improving the visibility of the Ramsey curve

$$\alpha = \alpha_0 \, e^{-\frac{T}{T_2}}$$

$\alpha_0$: Initial polarisation (86%)
$T_2$: Transverse depolarisation time

while keeping systematic effects under control.

# Introduction

What do we know?

- The transverse depolarisation time $T_2$ is mainly dependent on the homogeneity of the longitudinal component $B_z$
- whereas systematic effects are related to the transverse component squared of the magnetic field $\langle {B_T}^2 \rangle$

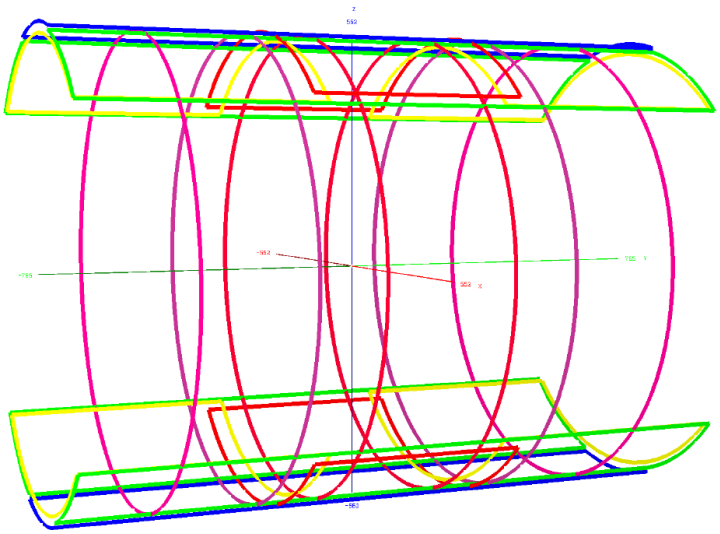
So we want to homogenise $B_z$ while keeping $\langle {B_T}^2 \rangle$ small

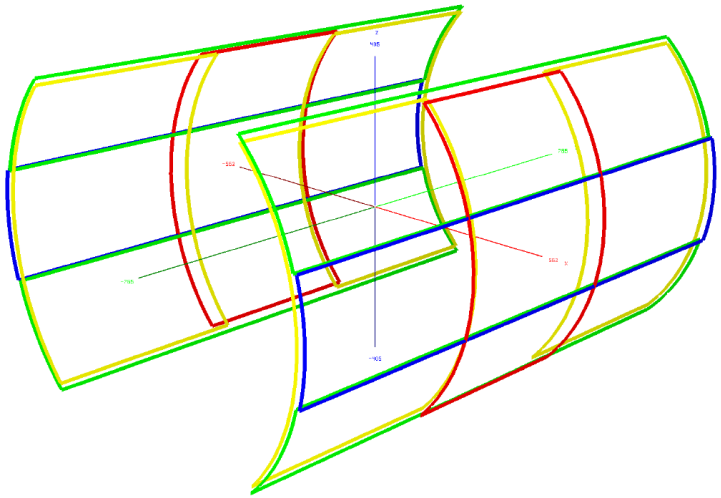
KU LEUVEN

# Introduction

## What do we need?

- ✓ Coils to trim the field





# Introduction

What do we need?

- ✓ Coils to trim the field
- ? Vector information about the magnetic field shape

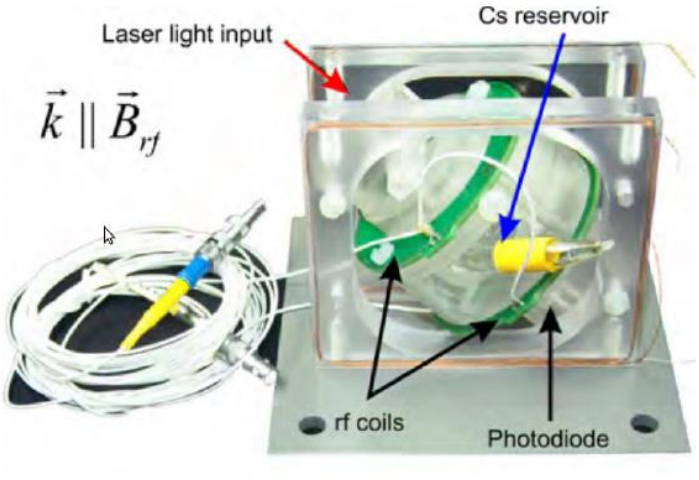
This would we easy if we had vector magnetometers, but we don’t have vector magnetometers… Or do we?

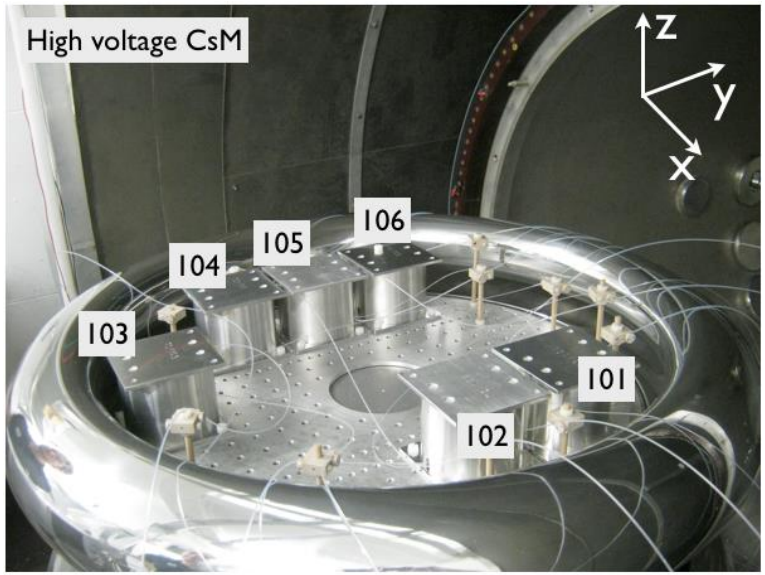
# Magnetic field knowledge

We have 16 **Cs magnetometers** installed above and below the precession chamber**:**

See talk M. Kasprzak

- Probe the field locally
- Scalar sensors



# Magnetic field knowledge

We have 16 **Cs magnetometers** installed above and below the precession chamber**:**

- Probe the field locally
- Scalar sensors

$$\left\|\vec{B}\right\| = B_z + \frac{{B_T}^2}{2B_z} + \cdots \approx B_z$$

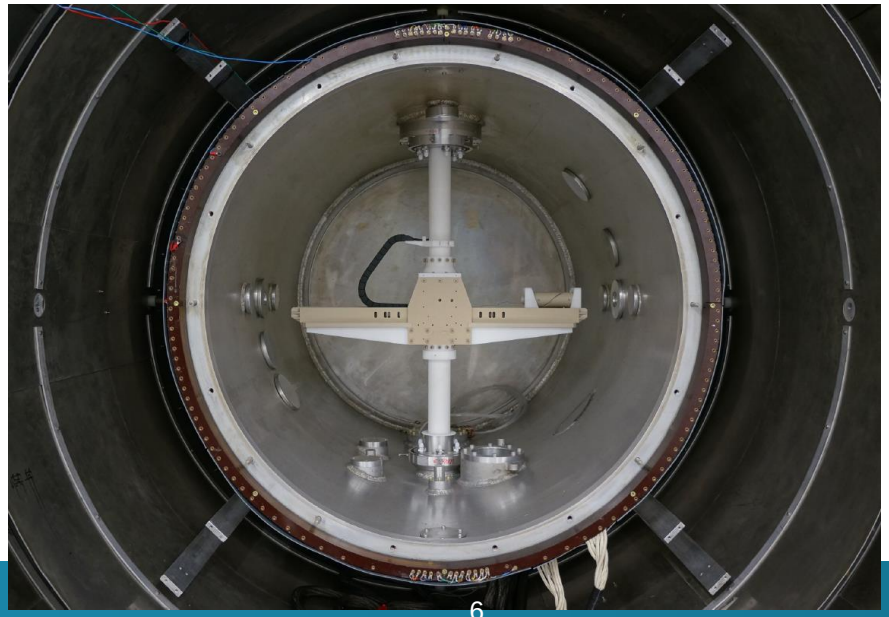
Homogenisation using only CsM was not really successful:

- No control over $B_T$

# Magnetic field knowledge

**Field maps** from mapping campaign in 2014:

- Vector fluxgate magnetometer mounted on a mapping device
- Maps of main field $\vec{B}_0$, trimcoils,…





KU LEUVEN

# Magnetic field knowledge

**Field maps** from mapping campaign in 2014:

- Vector fluxgate magnetometer mounted on a mapping device
- Maps of main field $\vec{B}_0$, trimcoils,…

Homogenisation using only maps was not really successful:

- Accuracy is not high enough to get a reliable estimate of $B_{0z}$

# Magnetic field knowledge

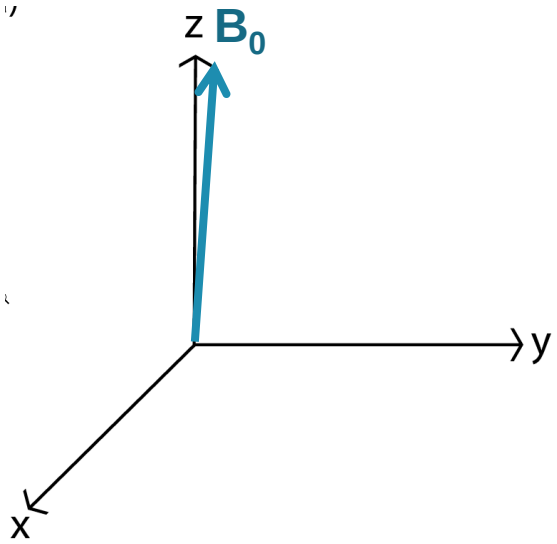
Combine CsMs and field maps:

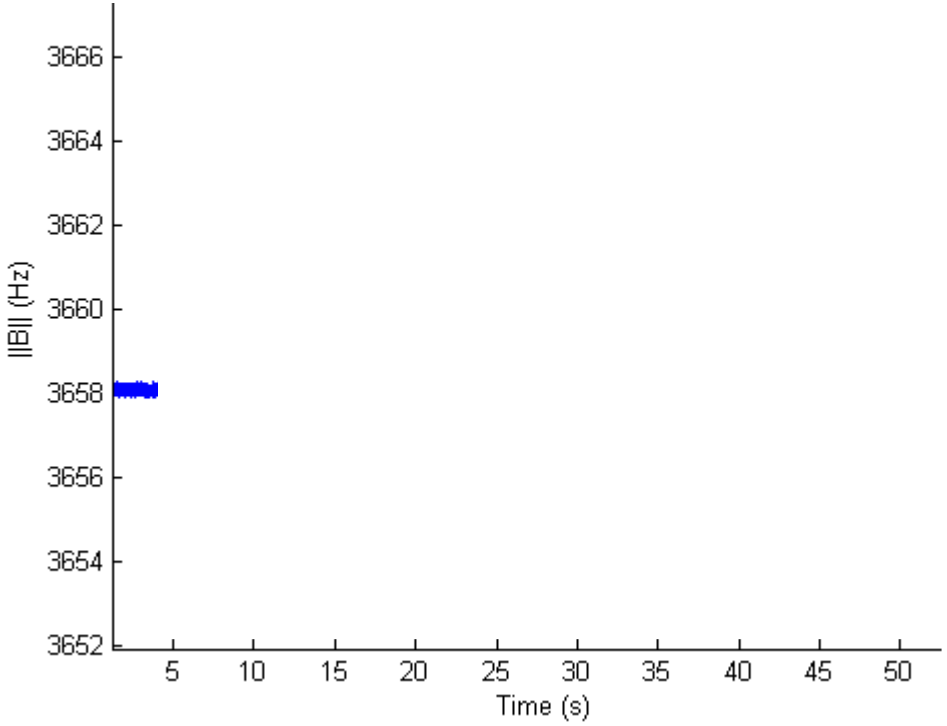
**variometer mode**

Apply a known transverse field additional to the main field and measure the response in the magnitude of the CsMs

# Magnetic field knowledge

## Variometer mode:

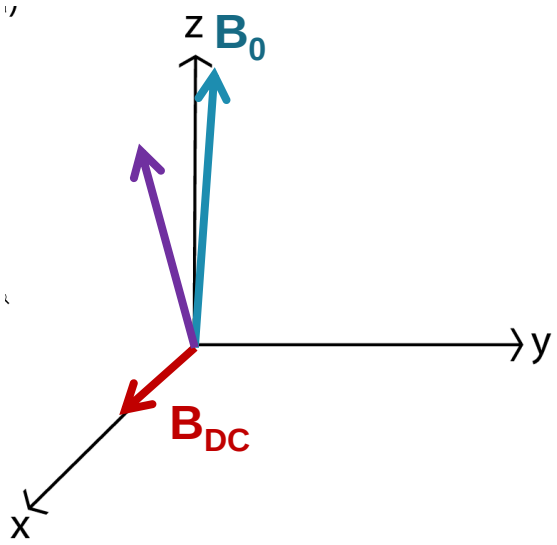


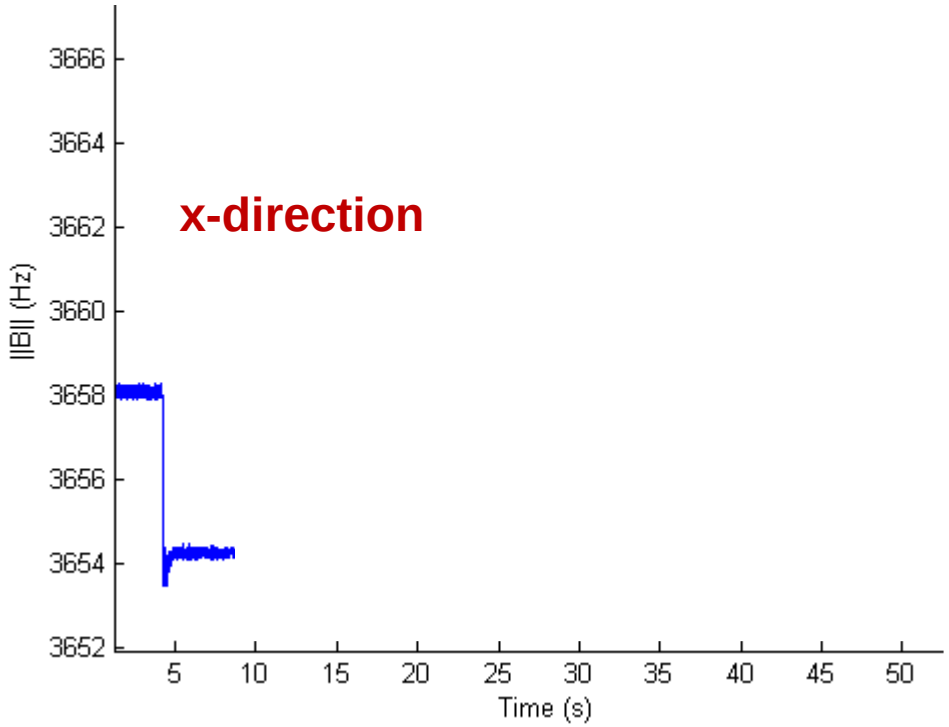




$$\|\vec{B}_0\|^2$$

# Magnetic field knowledge

## Variometer mode:

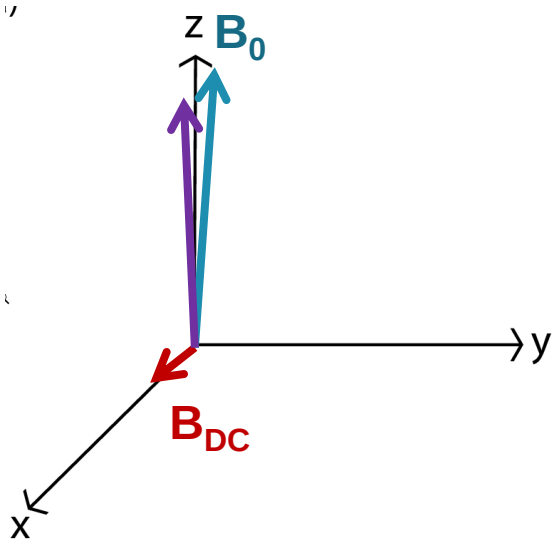


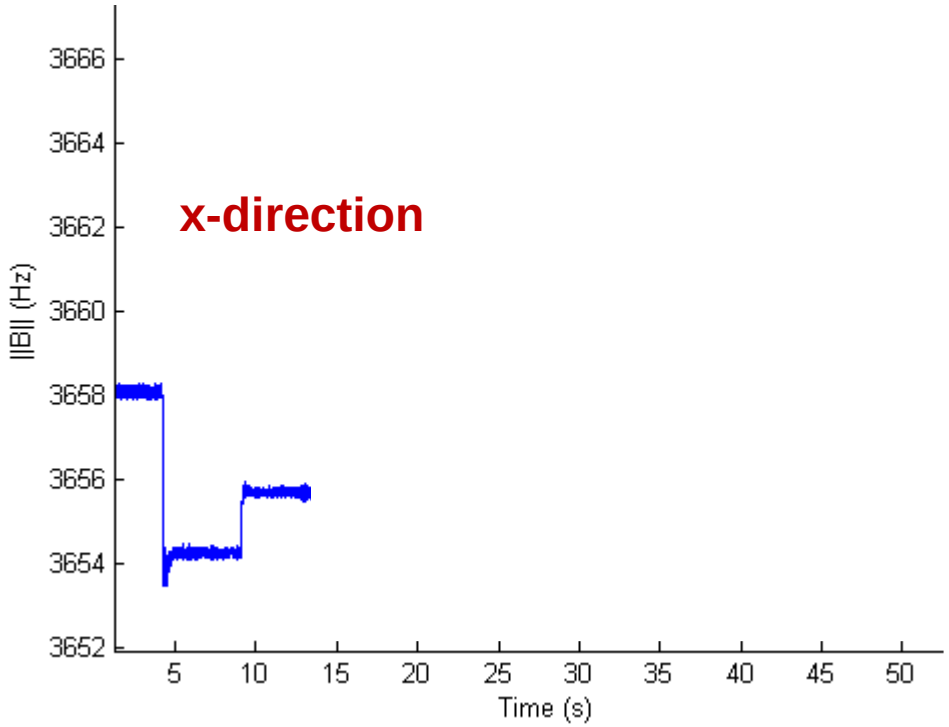




$$\|\vec{B}_0 + I\vec{B}_{\mathrm{DC}}\|^2 = \|\vec{B}_0\|^2 + 2I\vec{B}_0 \cdot \vec{B}_{\mathrm{DC}} + I^2\|\vec{B}_{\mathrm{DC}}\|^2$$

# Magnetic field knowledge

## Variometer mode:

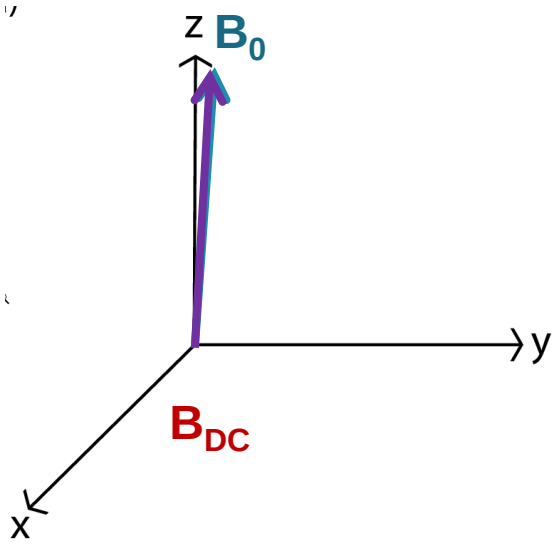


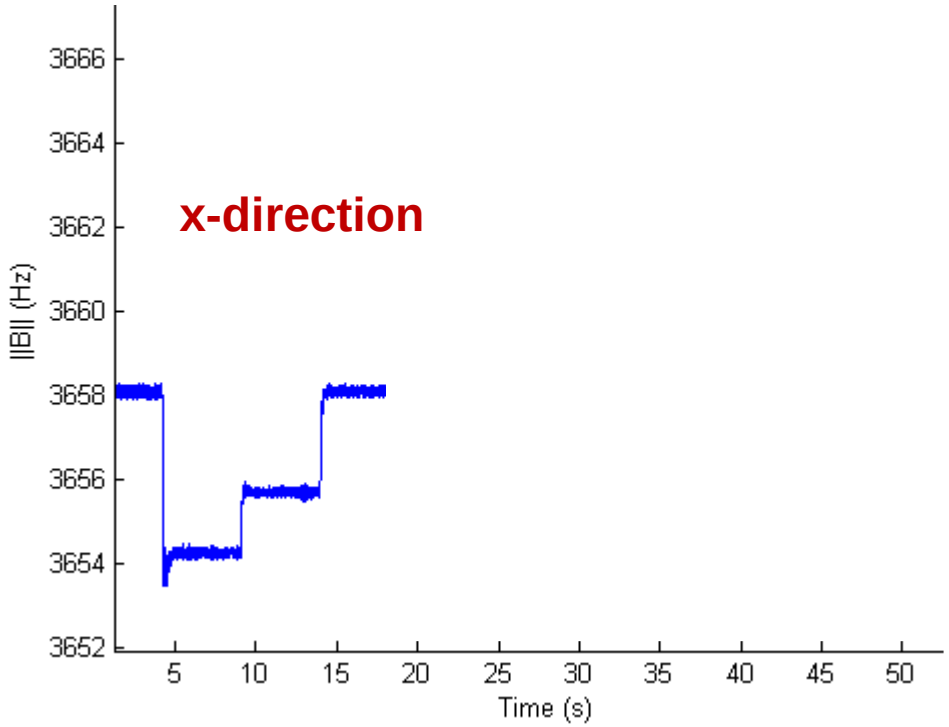




$$\|\vec{B}_0 + I\vec{B}_{\mathrm{DC}}\|^2 = \|\vec{B}_0\|^2 + 2I\vec{B}_0 \cdot \vec{B}_{\mathrm{DC}} + I^2\|\vec{B}_{\mathrm{DC}}\|^2$$

# Magnetic field knowledge

## Variometer mode:

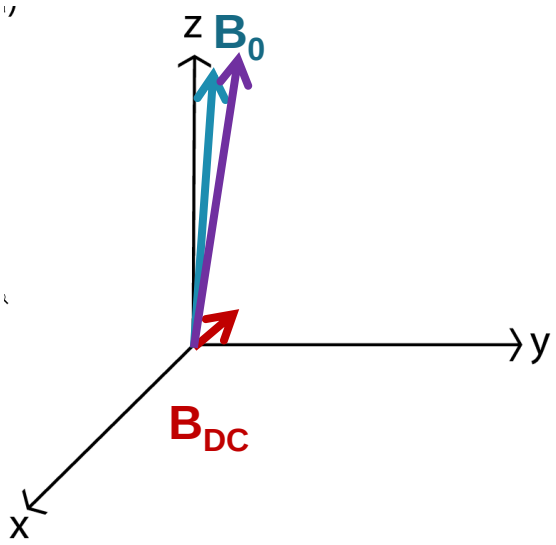


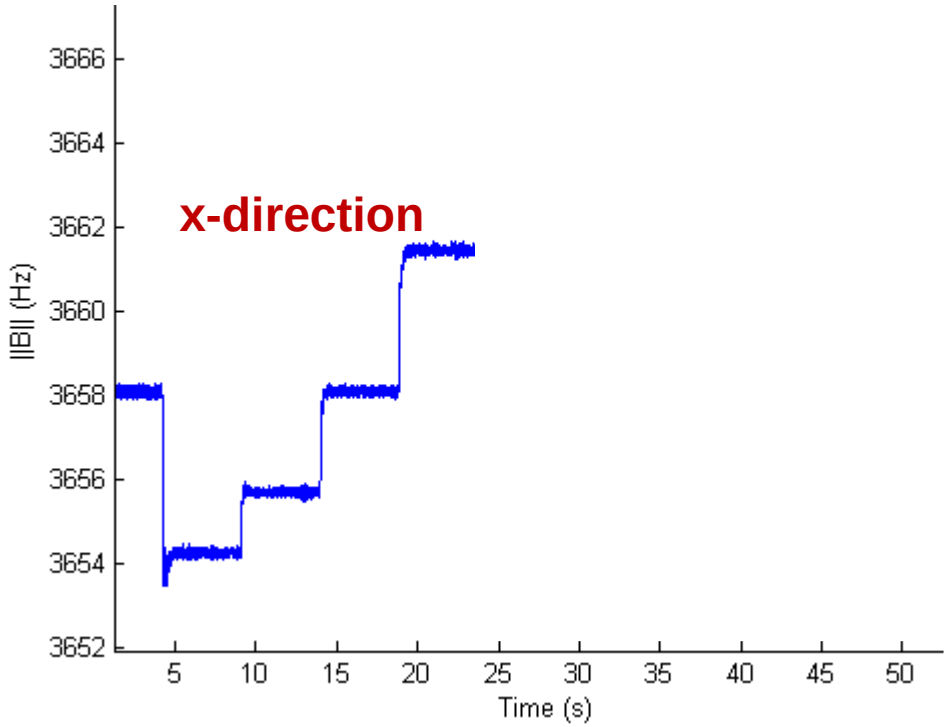




$$\|\vec{B}_0 + I\vec{B}_{\mathrm{DC}}\|^2 = \|\vec{B}_0\|^2 + 2I\vec{B}_0 \cdot \vec{B}_{\mathrm{DC}} + I^2\|\vec{B}_{\mathrm{DC}}\|^2$$

# Magnetic field knowledge

## Variometer mode:

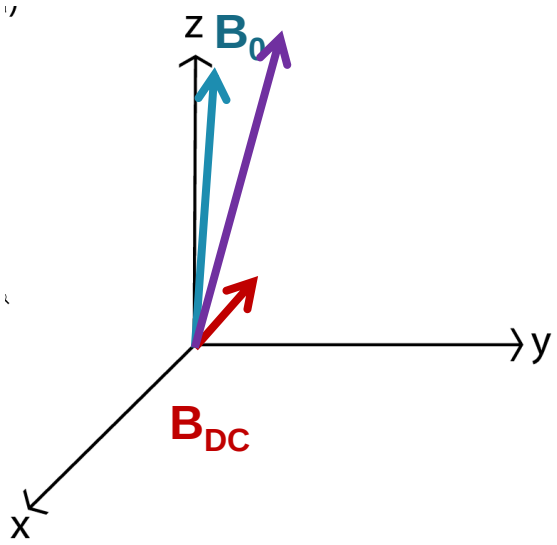


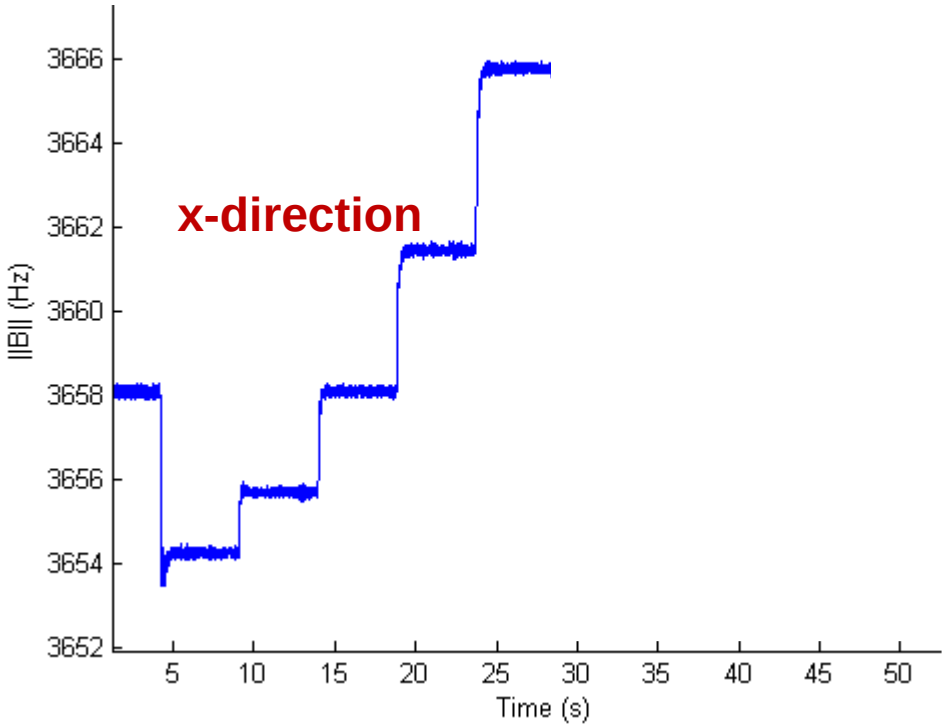




$$\|\vec{B}_0 + I\vec{B}_{\mathrm{DC}}\|^2 = \|\vec{B}_0\|^2 + 2I\vec{B}_0 \cdot \vec{B}_{\mathrm{DC}} + I^2\|\vec{B}_{\mathrm{DC}}\|^2$$

# Magnetic field knowledge

## Variometer mode:

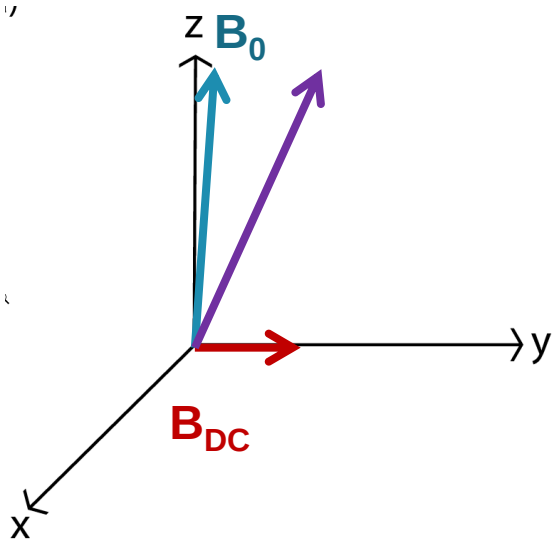


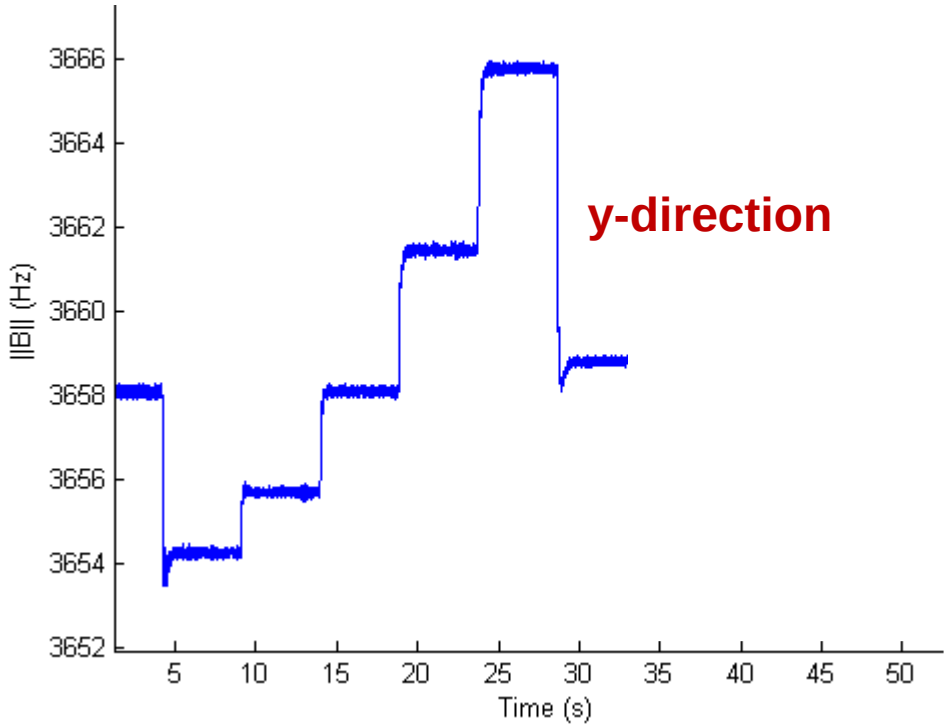




$$\|\vec{B}_0 + I\vec{B}_{\mathrm{DC}}\|^2 = \|\vec{B}_0\|^2 + 2I\vec{B}_0 \cdot \vec{B}_{\mathrm{DC}} + I^2\|\vec{B}_{\mathrm{DC}}\|^2$$

# Magnetic field knowledge

## Variometer mode:

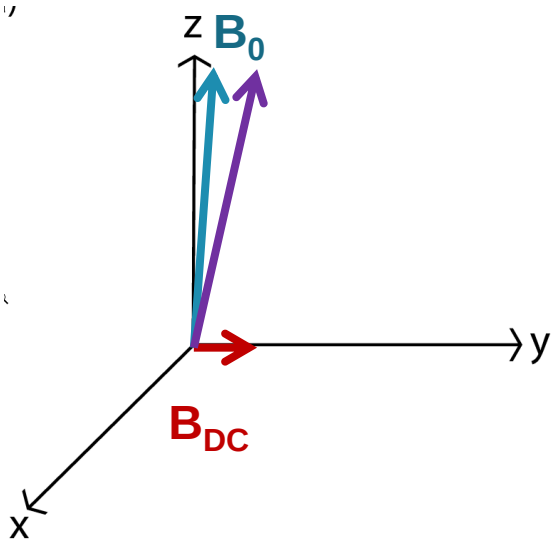


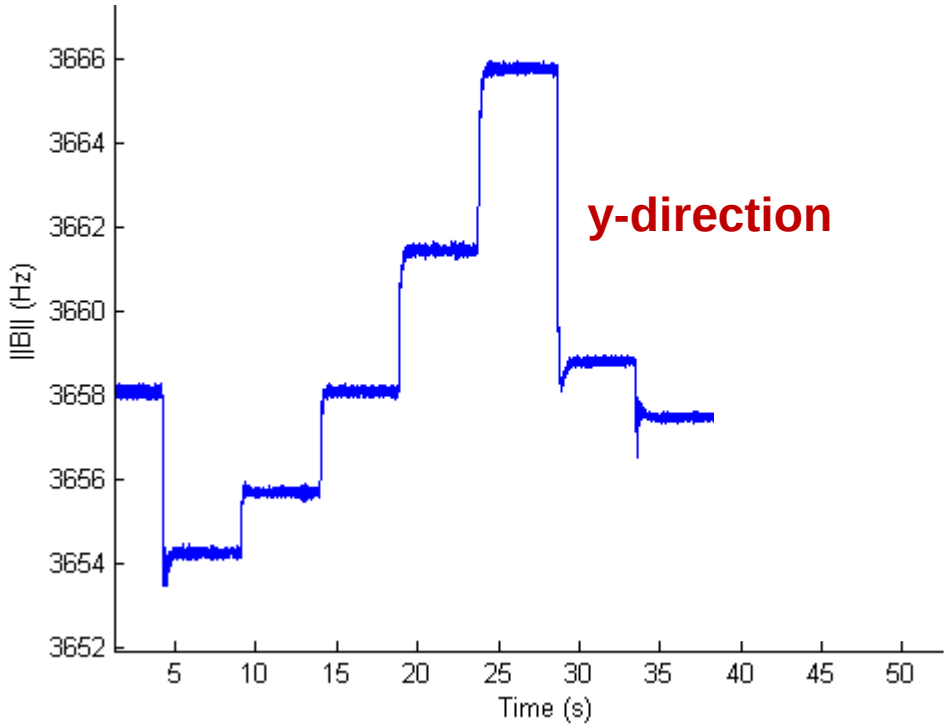




$$\|\vec{B}_0 + I\vec{B}_{\mathrm{DC}}\|^2 = \|\vec{B}_0\|^2 + 2I\vec{B}_0 \cdot \vec{B}_{\mathrm{DC}} + I^2\|\vec{B}_{\mathrm{DC}}\|^2$$

# Magnetic field knowledge

## Variometer mode:

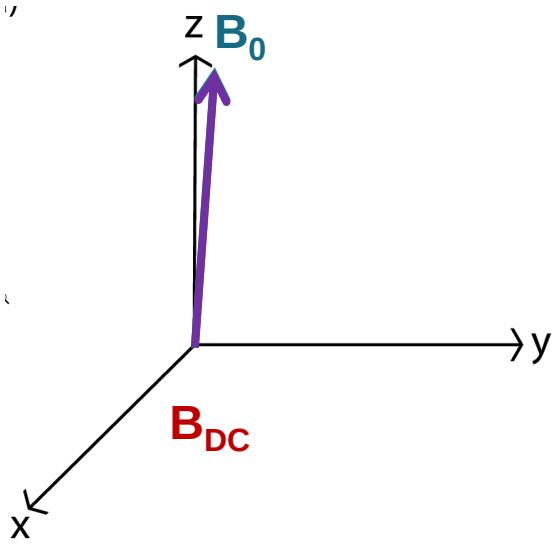


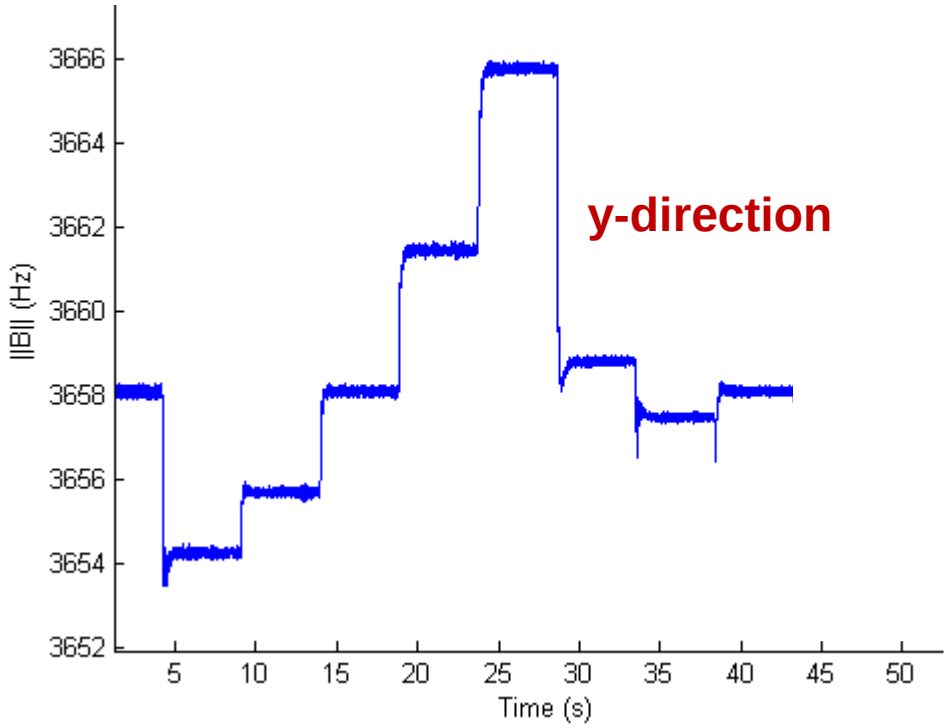




$$\|\vec{B}_0 + I\vec{B}_{\mathrm{DC}}\|^2 = \|\vec{B}_0\|^2 + 2I\vec{B}_0 \cdot \vec{B}_{\mathrm{DC}} + I^2\|\vec{B}_{\mathrm{DC}}\|^2$$

# Magnetic field knowledge

## Variometer mode:

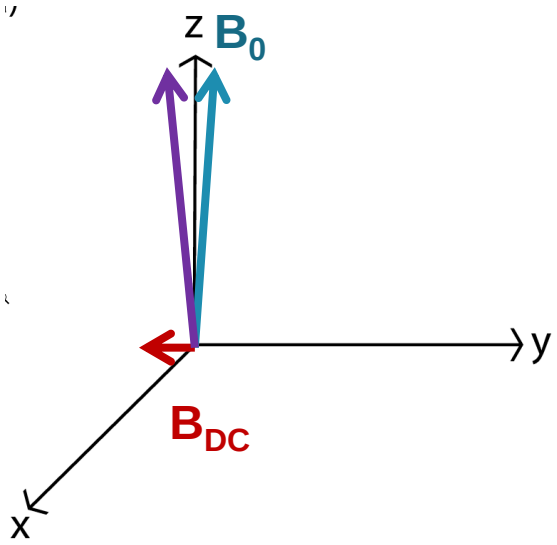


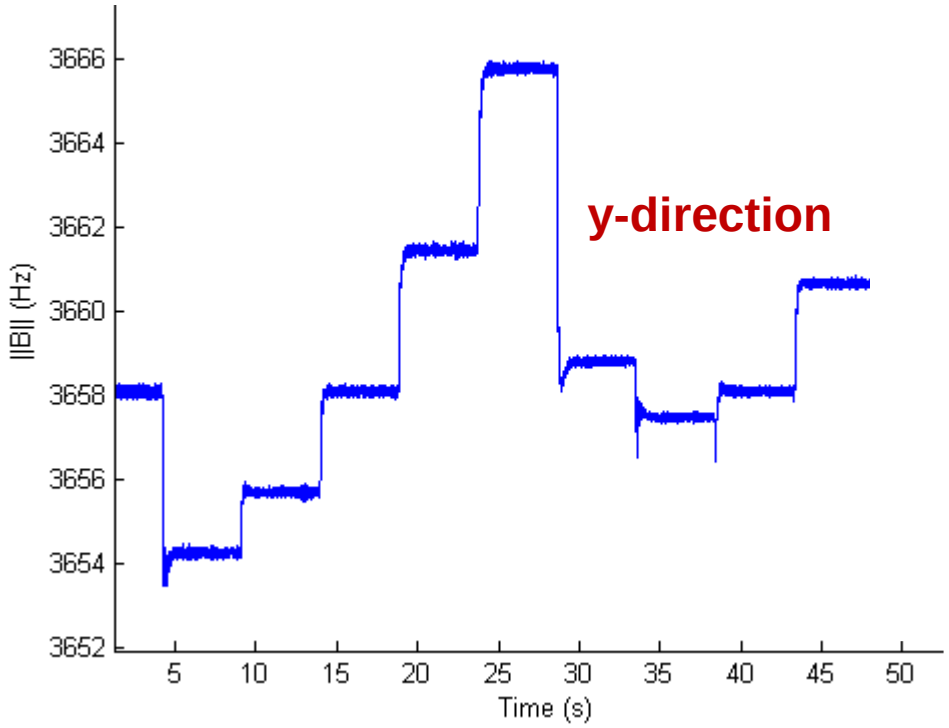




$$\|\vec{B}_0 + I\vec{B}_{\mathrm{DC}}\|^2 = \|\vec{B}_0\|^2 + 2I\vec{B}_0 \cdot \vec{B}_{\mathrm{DC}} + I^2\|\vec{B}_{\mathrm{DC}}\|^2$$

# Magnetic field knowledge

## Variometer mode:

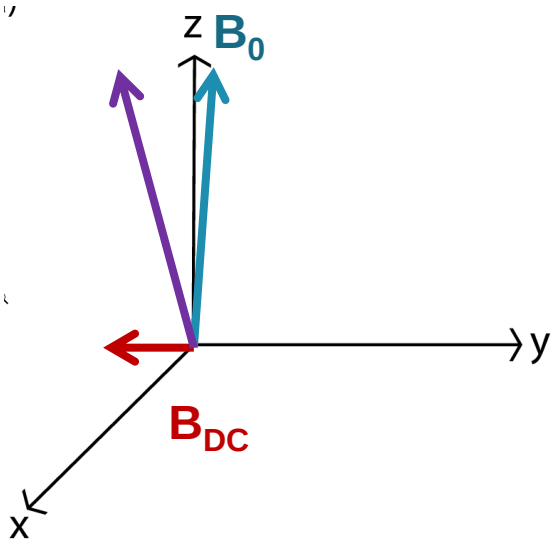


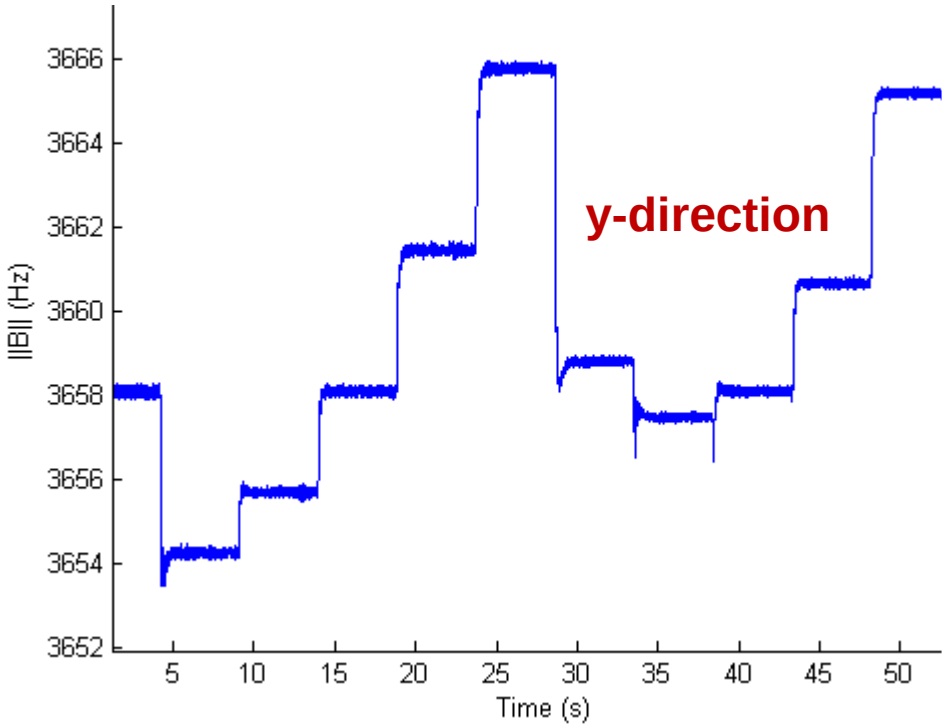




$$\|\vec{B}_0 + I\vec{B}_{\mathrm{DC}}\|^2 = \|\vec{B}_0\|^2 + 2I\vec{B}_0 \cdot \vec{B}_{\mathrm{DC}} + I^2\|\vec{B}_{\mathrm{DC}}\|^2$$

# Magnetic field knowledge

## Variometer mode:




$$\|\vec{B}_0 + I\vec{B}_{\mathrm{DC}}\|^2 = \|\vec{B}_0\|^2 + 2I\vec{B}_0 \cdot \vec{B}_{\mathrm{DC}} + I^2\|\vec{B}_{\mathrm{DC}}\|^2$$

Fit function: Parabola!

# Magnetic field knowledge

Fit function is a simple parabola

$$\|\vec{B}_0 + I\vec{B}_{\mathrm{DC}}\|^2 = \|\vec{B}_0\|^2 + 2I\vec{B}_0 \cdot \vec{B}_{\mathrm{DC}} + I^2\|\vec{B}_{\mathrm{DC}}\|^2$$

Extract $B_{0x}$ and $B_{0y}$ from $\vec{B}_0 \cdot \vec{B}_1$ and $\vec{B}_0 \cdot \vec{B}_2$

- Using $B_{0z} = \|\vec{B}_0\|$ from CsM
- $\vec{B}_1$ and $\vec{B}_2$ from field maps

$$B_{0x} \approx \frac{\vec{B}_0 \cdot \vec{B}_1 - B_{0z}B_{1z}}{B_{1x}}$$

# Magnetic field knowledge

## Variometer mode

**Precision:**

- Ranges from 5pT to tens of pT for 30s measurement time

**Accuracy**:

- Limited by knowledge of the fields produced by the two coils
- Absolute values could be off by tens of nT

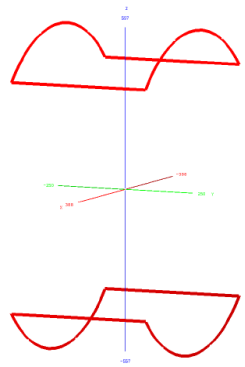
$$\delta B_{0x} \approx \frac{B_{0z}\,\delta B_{1z}}{B_{1x}} \approx \frac{1000\,\delta B_{1z}}{50} = 20\,\delta B_{1z}$$

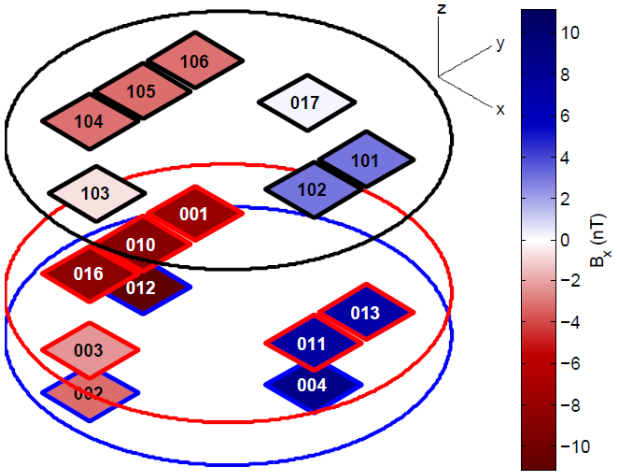
- But differences (with common $\vec{B}_0$) are accurate up to a few %

KU LEUVEN

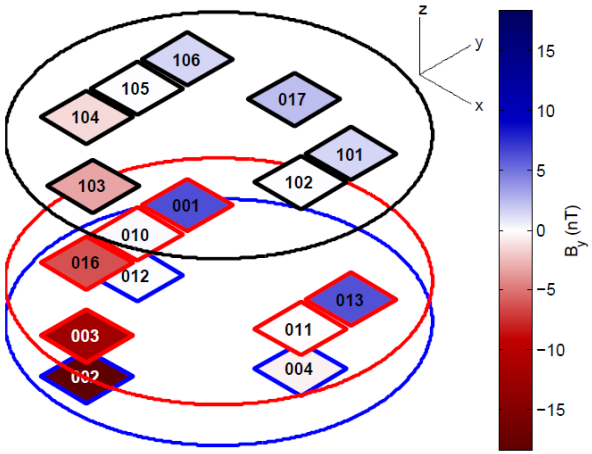
# Magnetic field knowledge

## Measure the field of the trimcoils: example BTC

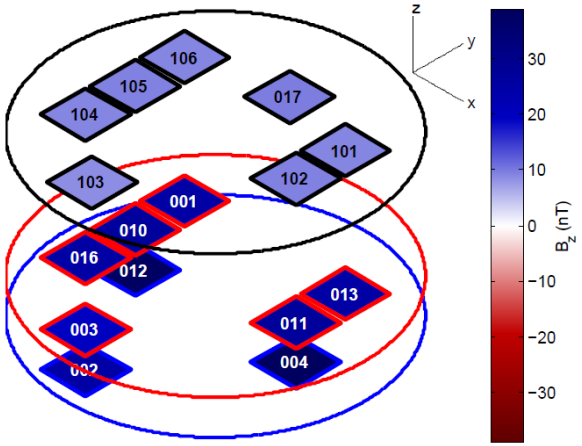





$B_x$ (nT)




$B_y$ (nT)




$B_z$ (nT)

# Optimisation procedure

Measure the field of each trimcoil with the variometer mode as in the previous example => response matrix

1. Measure the instantaneous field

# Optimisation procedure

Measure the field of each trimcoil with the variometer mode as in the previous example => response matrix

1. Measure the instantaneous field
2. Minimise least squares function such that
   a) $B_z \rightarrow B$
   b) $B_x \rightarrow 0$ and $B_y \rightarrow 0$
   c) and the trimcoil currents are regulated.

Calculate $\langle {B_T}^2 \rangle$ based on the fluxgate maps of 2014

# Optimisation procedure

Measure the field of each trimcoil with the variometer mode as in the previous example => response matrix

1. Measure the instantaneous field
2. Minimise least squares function such that
   a) $B_z \rightarrow B$
   b) $B_x \rightarrow 0$ and $B_y \rightarrow 0$
   c) and the trimcoil currents are regulated.

   Calculate $\langle {B_T}^2 \rangle$ based on the fluxgate maps of 2014
3. Assign a large weight to the Bz term, fix the regularisation parameter and scan over (small) weights for the Bx and By

# Optimisation procedure

Measure the field of each trimcoil with the variometer mode as in the previous example => response matrix

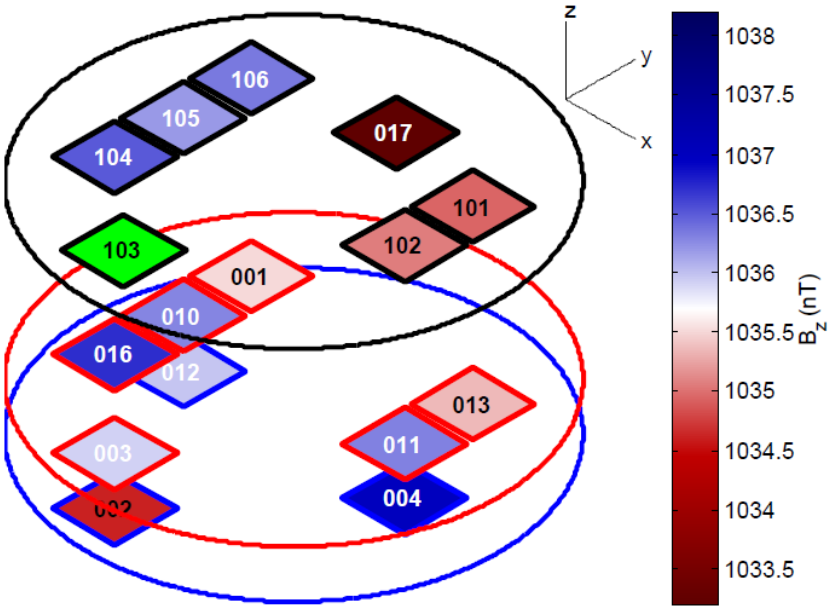
1. Measure the instantaneous field
2. Minimise least squares function such that
   a) $B_z \rightarrow B$
   b) $B_x \rightarrow 0$ and $B_y \rightarrow 0$
   c) and the trimcoil currents are regulated.

   Calculate $\langle {B_T}^2 \rangle$ based on the fluxgate maps of 2014
3. Assign a large weight to the Bz term, fix the regularisation parameter and scan over (small) weights for the Bx and By
4. Select a solution with low $\langle {B_T}^2 \rangle$ and small predicted spread in Bz.

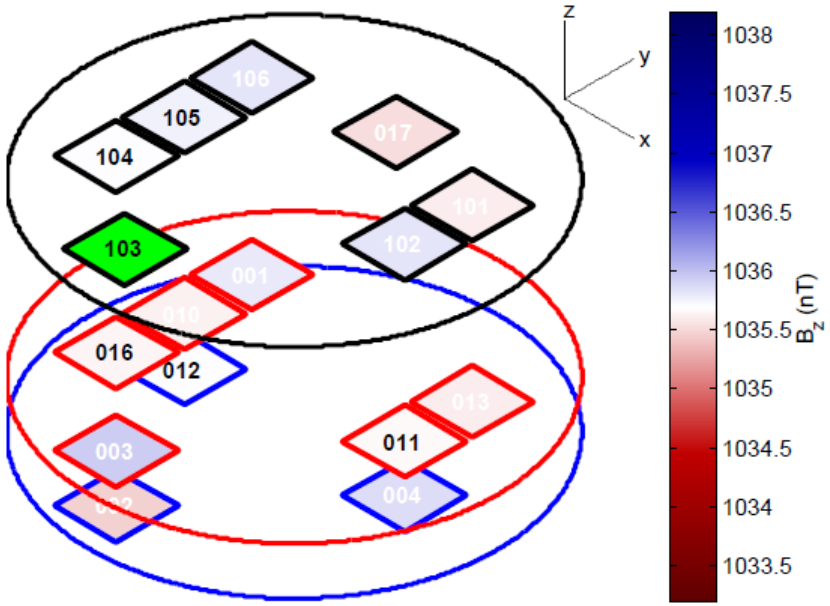
KU LEUVEN

# Results

## $B_z$ before

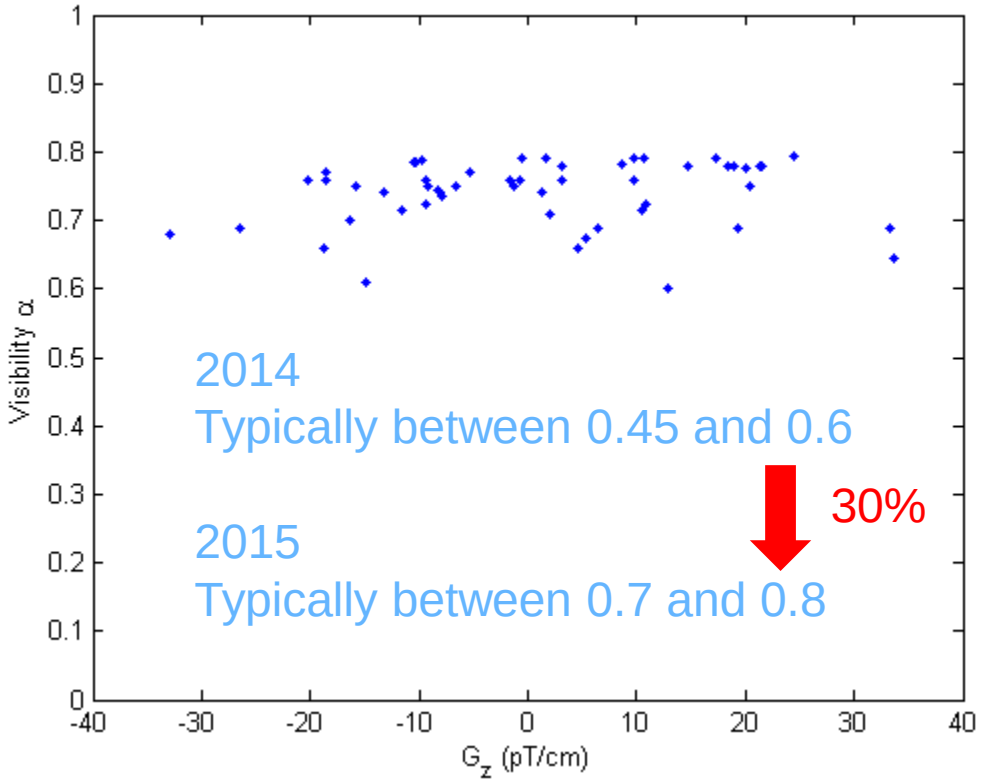



## $B_z$ after



# Results

Visibility of nEDM runs of 2015:



# Conclusion

- Vector information from CsM in variometer mode
- We have a successful routine to homogenise $B_z$ while keeping $\langle {B_T}^2 \rangle$ under control
- We report an increase of 30% in nEDM sensitivity!


KU LEUVEN