… riding the wave

A Stretched Wire Tomography System at Kyma

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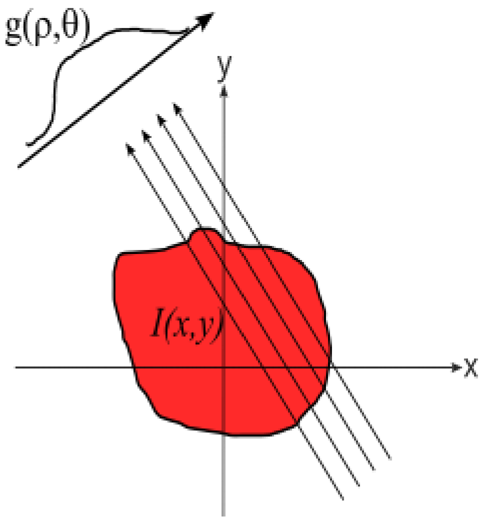
Introduction

- Technique of SW tomography first proposed and demonstrated by ESRF at IMMW19 in Grenoble in 2019
- Kyma already has a Small Stretched Wire Bench
  - *for characterization of single magnets and small modules*
- Adaptation of the SW Bench to a SW Tomography system
  - *Addition of only one rotary stage necessary*

Radon Transform and Field Integrals



Radon transform is a path integral along the line $L(\rho,\theta)$ of the function $I(x,y)$.

$$L(\rho,\theta) = \{(x,y) \in \mathbb{R} \times \mathbb{R}: xCos(\theta) + ySin(\theta) = \rho\}$$

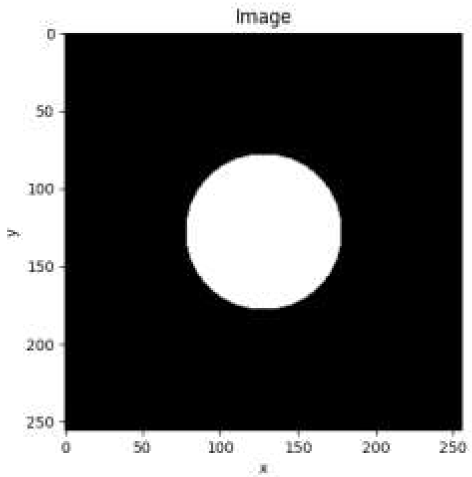
$$g(\rho,\theta) = \int_L I(x,y)ds$$

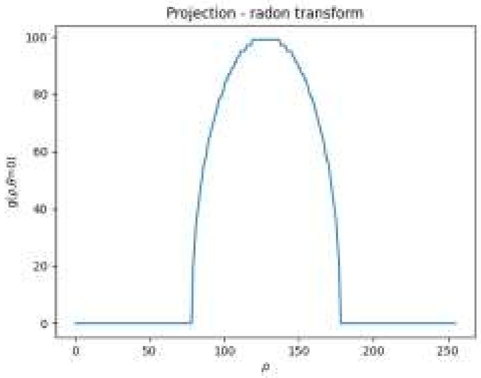
Field integral is a path integral of the magnetic field density along a specific line.

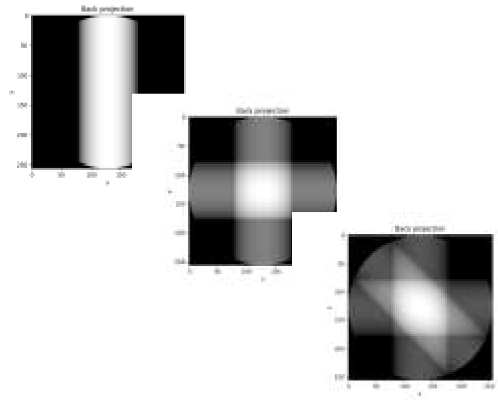
$$Iz_L(\rho,\theta) = \int_L Bz(x,y)ds$$

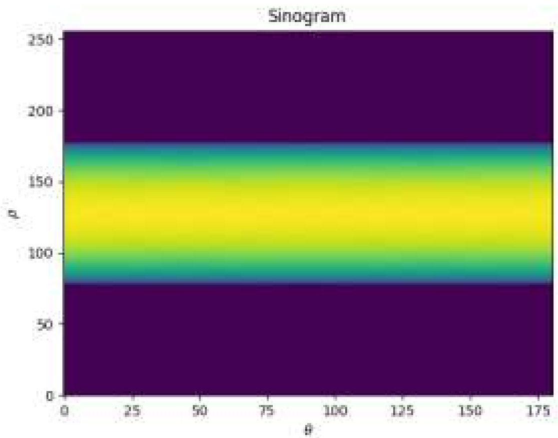
- Field integral over a line L is equivalent to the Radon transform of the magnetic field along the line L.
- From field integral measurements scans at different angles we can reconstruct a 2D map of the magnetic field density.
- A stretched wire bench with a rotary stage can be used to measure 2D magnetic field map.

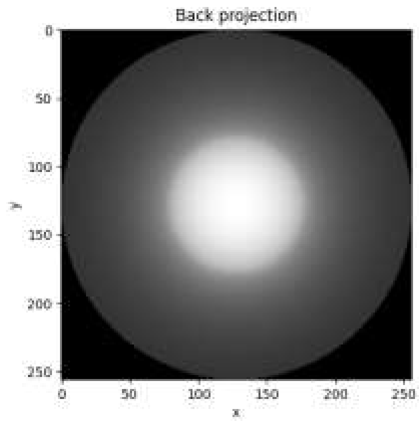
A Simple Back Projection - Laminograms

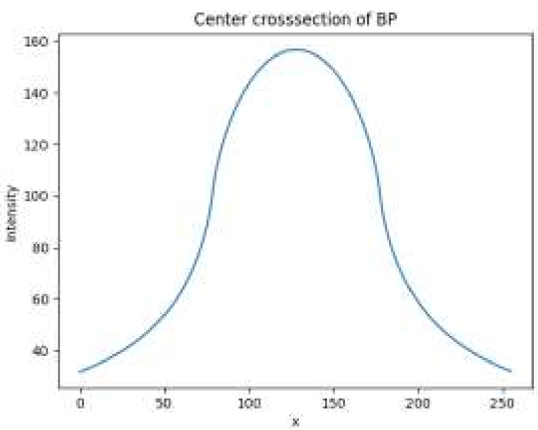












Inverse Radon T. and Fourier Slice Theorem

$$g(\rho,\theta) = \iint I(x,y)\delta(x\cos(\theta) + y\sin(\theta) - \rho)dxdy$$

A projection function

$$G(\omega,\theta) = \int_{-\infty}^{\infty} g(\rho,\theta)e^{-i2\pi\omega\rho}\, d\rho$$

Fourier transform of a projection function

$$G(\omega,\theta) = \iint_{-\infty}^{\infty} I(x,y)e^{-i2\pi\omega(xCos(\theta)+ySin(\theta))}dxdy = \iint_{-\infty}^{\infty} I(x,y)e^{-i2\pi\omega(ux+vy)}dxdy$$

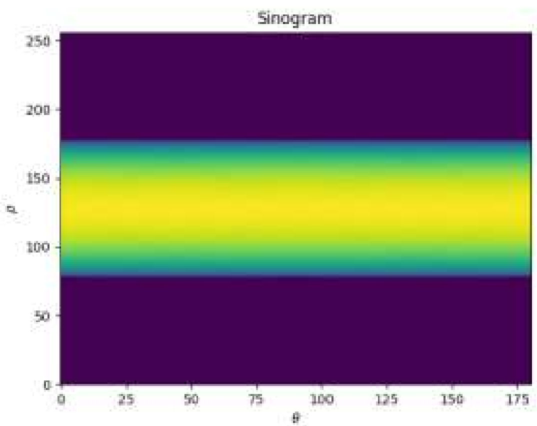
$$v = \omega\, Sin(\theta)$$

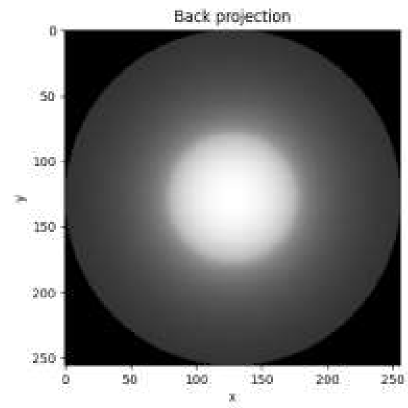
$$u = \omega\, Cos(\theta)$$

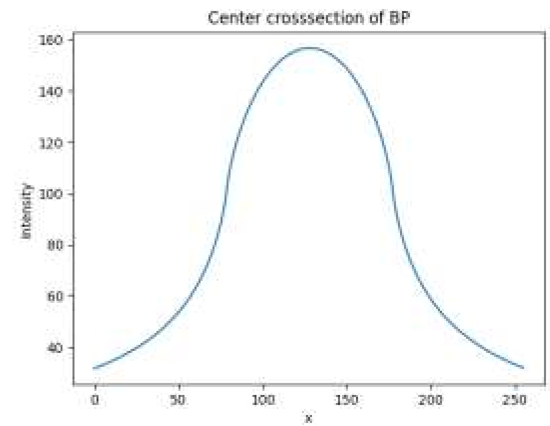
$$I(x,y) = \int_{-\infty}^{\infty} |\omega| G(\omega,\theta)e^{-i2\pi\omega\rho}\, d\omega$$

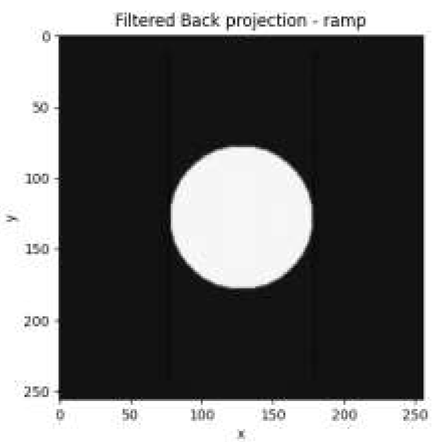
Inverse radon transform is a Fourier transform of a $G(\omega,\theta)$ multiplied by a filter function $|\omega|$.

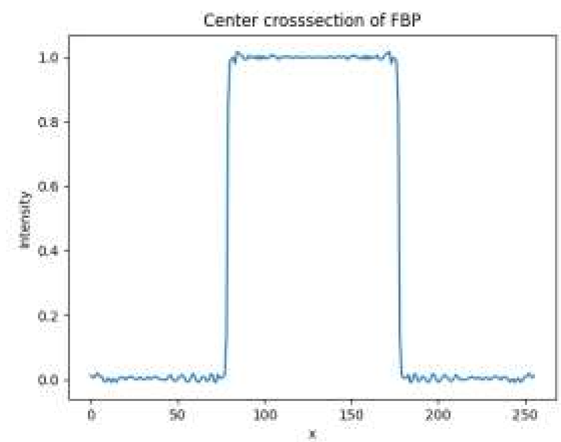
Filtered Back Projection

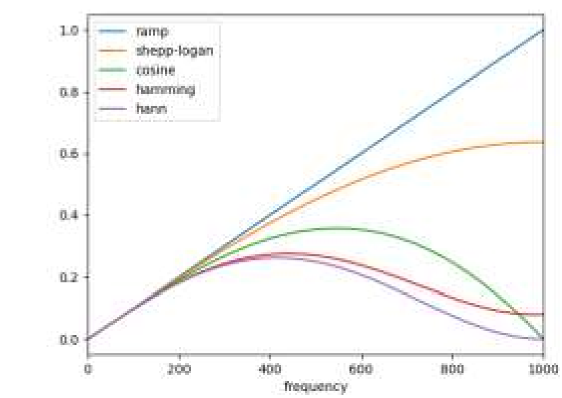










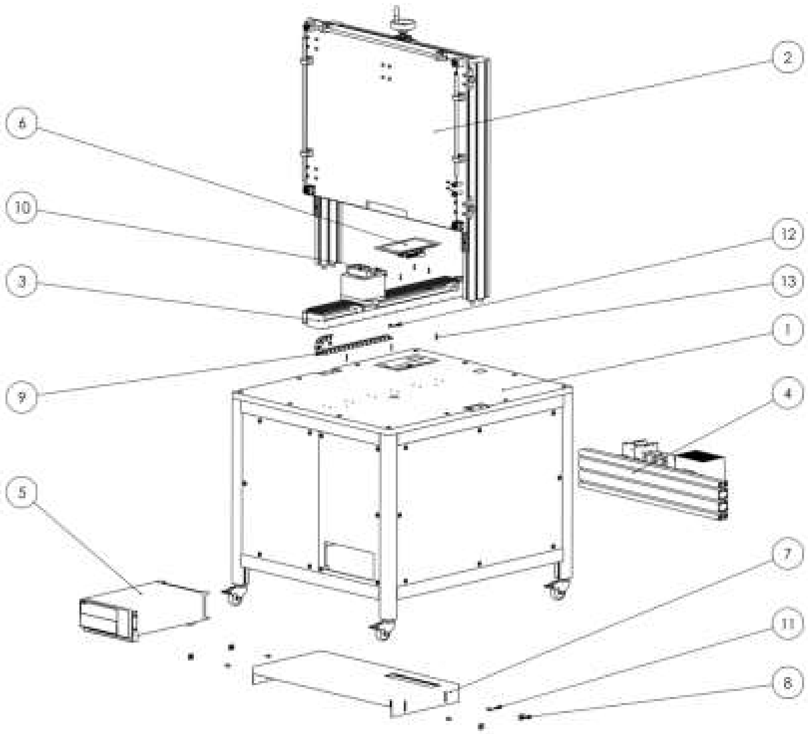


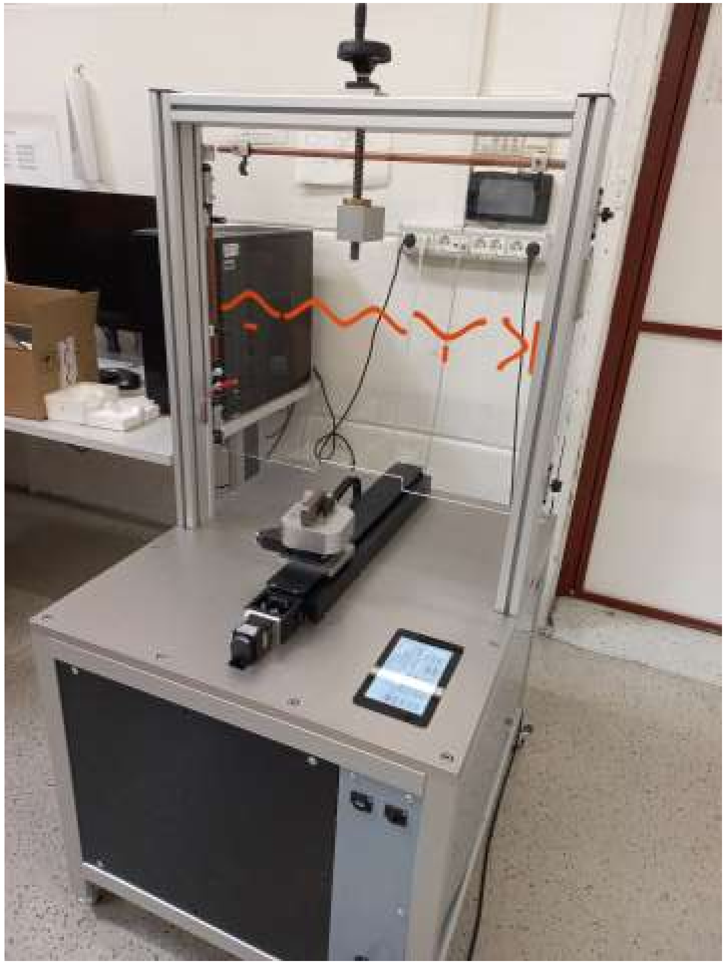
Small Stretched Wire Bench

- **Basic design parameters**
  - ***Small size convenient to transport.***
  - ***Control by Raspberry Pi (SBC)***
  - ***Routines written in Python for ease of use***
  - ***Keithley Nanovolt 2182A meter***

Stretched Wire Bench - Construction

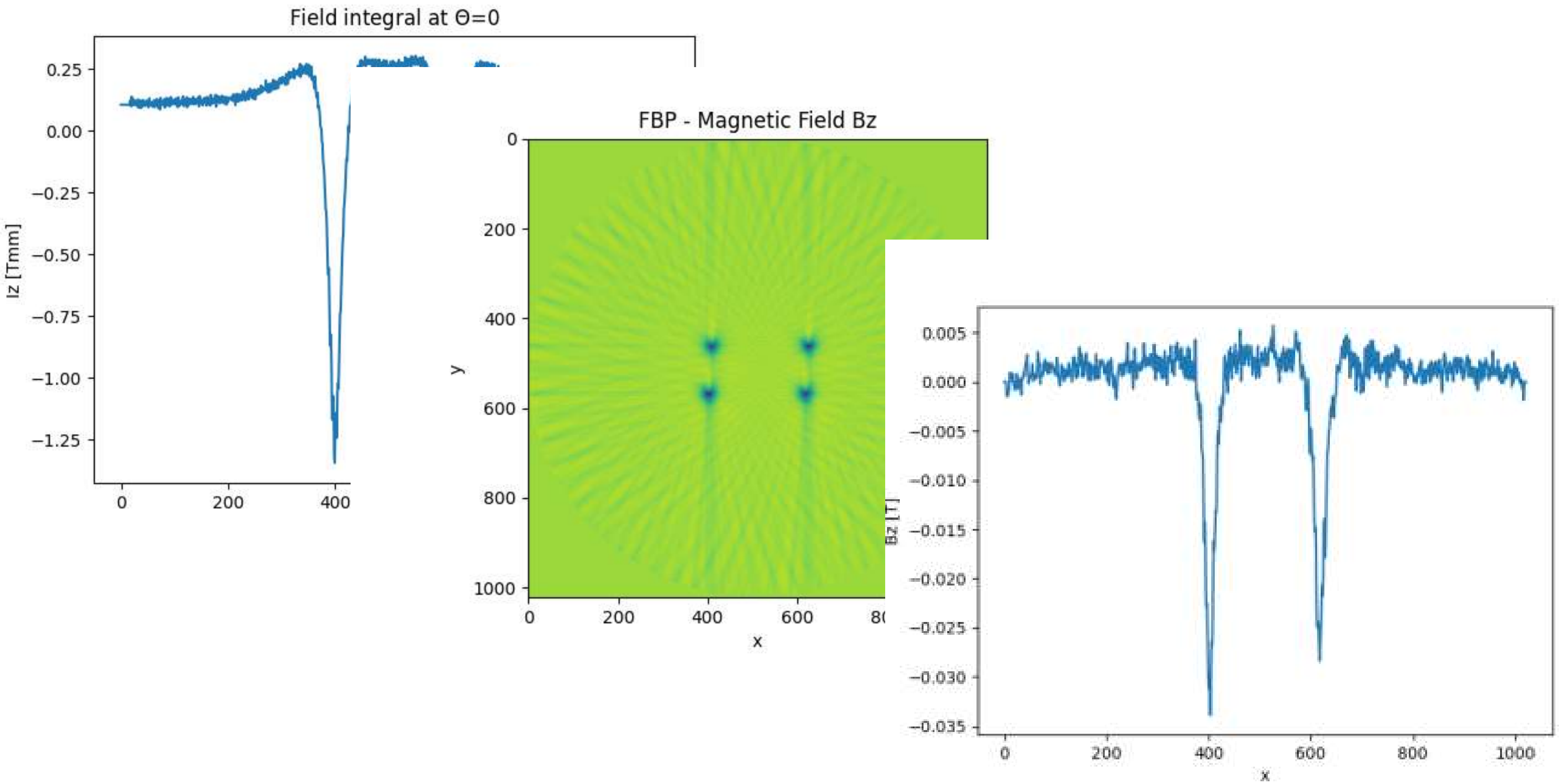
- Fixed single strand wire loop
- Linear translation stage
- Rotary stage





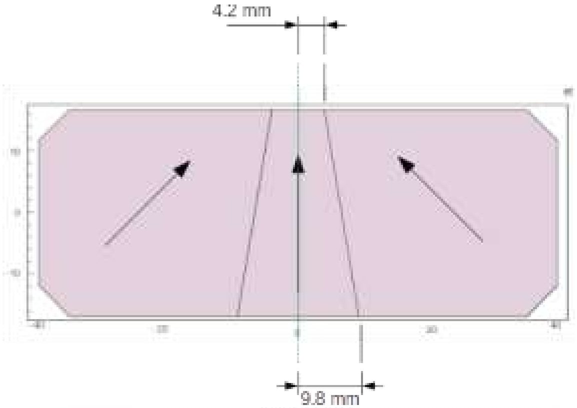
First Measurements

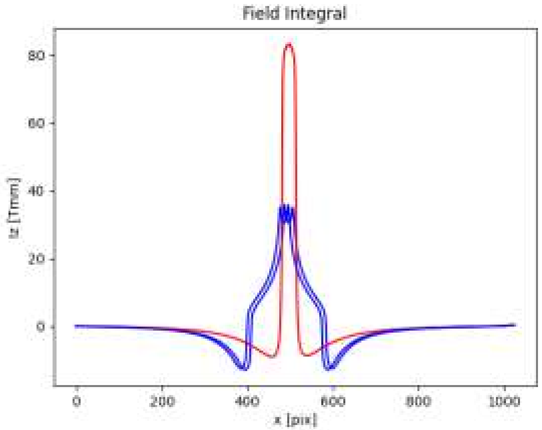
- A set of 4 cylindrical magnets was used for the first measurements.

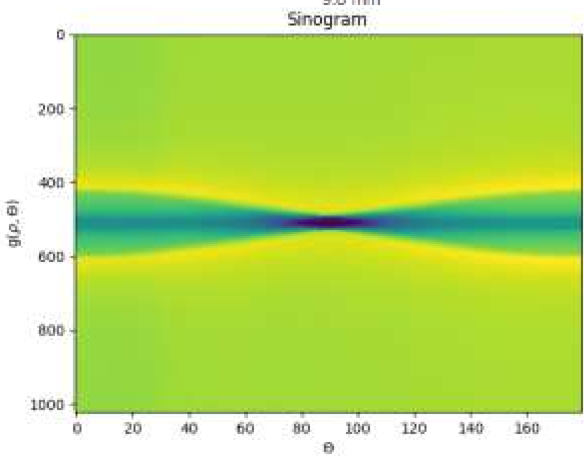


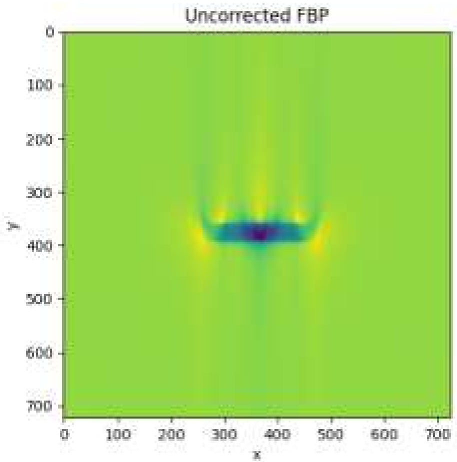
Measurements of a magnet block

- A segmented magnet block made from 3 glued pieces was used for tests.



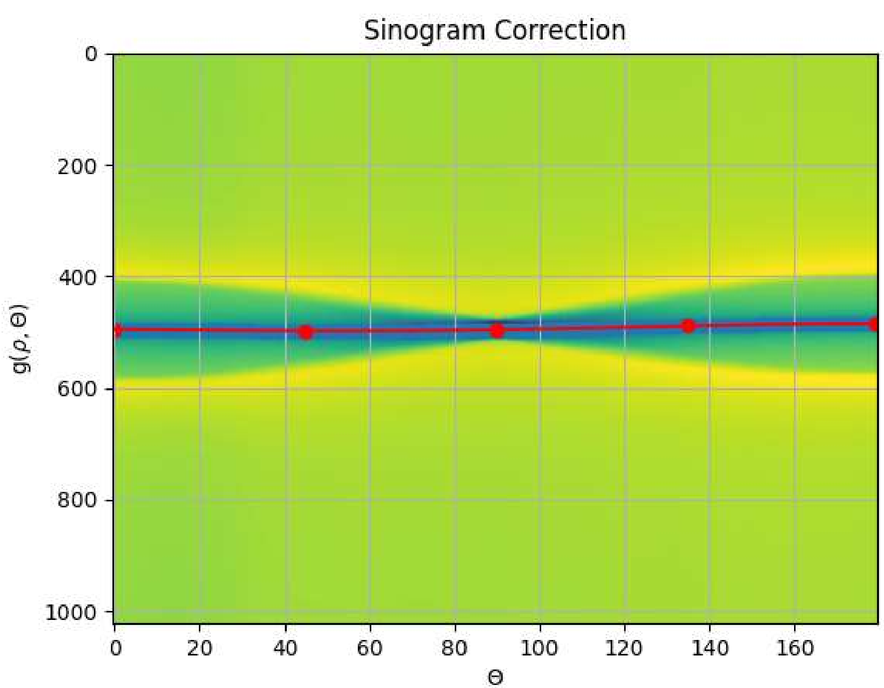


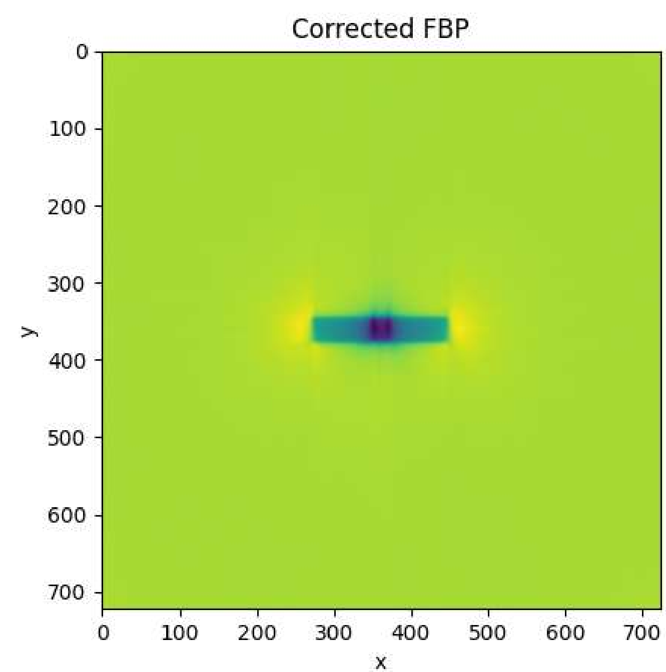




Axis shift correction

- Each point in an image follows a sinus curve on a sinogram.
- Misalignment of the rotation axis can be corrected by removing a sinus fit from a sinogram.

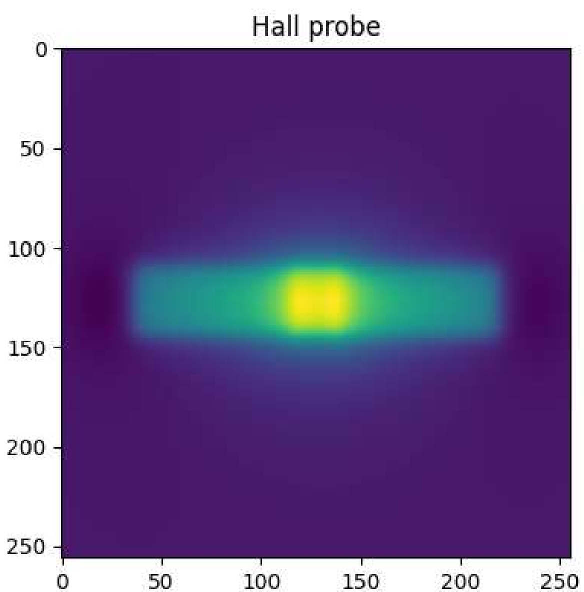


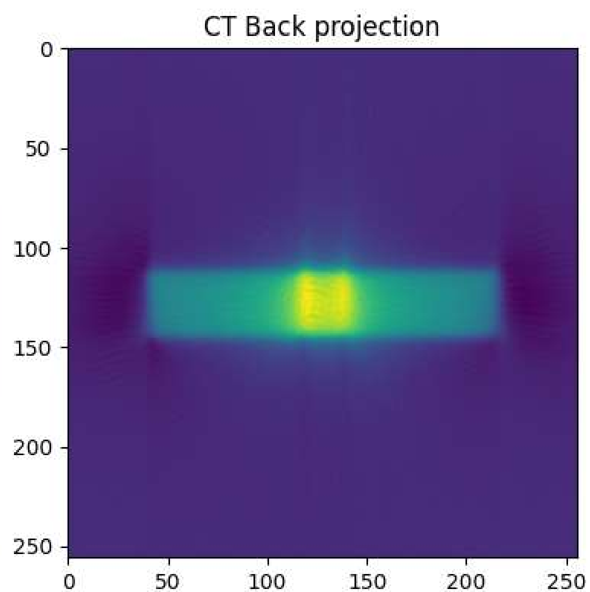


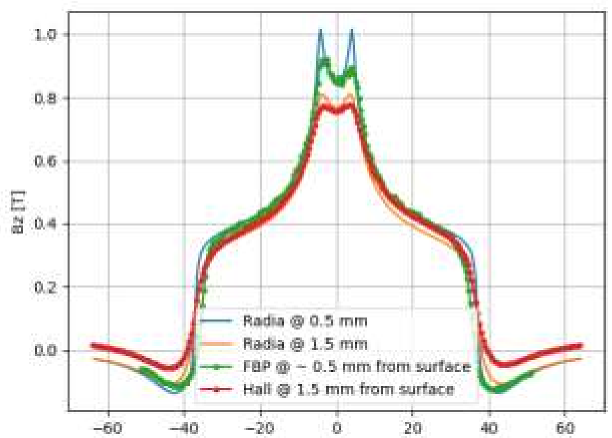
Jun K, Yoon S. Alignment Solution for CT Image Reconstruction using Fixed Point and Virtual Rotation Axis. Sci Rep. 2017 Jan 25;7:41218. doi: 10.1038/srep41218. PMID: 28120881; PMCID: PMC5264594. **https://arxiv.org/ftp/arxiv/papers/1605/1605.04833.pdf**

Comparison with a Hall probe

- **2D Hall probe field map**
  - *Distance from surface 1.5 mm*
  - *Longitudinal and horizontal step 0.5 mm/point*
  - *128 x 128 point field map was created*
- **SW Tomography**
  - *Distance from surface was ~ 0.5 mm*
  - *Field integrals measured at 180 angles*
  - *Horizontal step was 0.4 mm/point*







Conclusions

- **A dedicated SW Tomography bench was designed and assembled**
- **First tests are very promising.**
- **Advantages:**
  - ***Magnetic field very close to the surface can be measured.***
  - ***A dedicated bench can be used for magnet quality control***
  - ***Data could be used for further optimizations***
- **Open questions:**
  - ***Can we measure absolute values of magnetic field?***

Thanks to the Team!

Special thanks to Andrej Nabergoj and Žan Mahnič