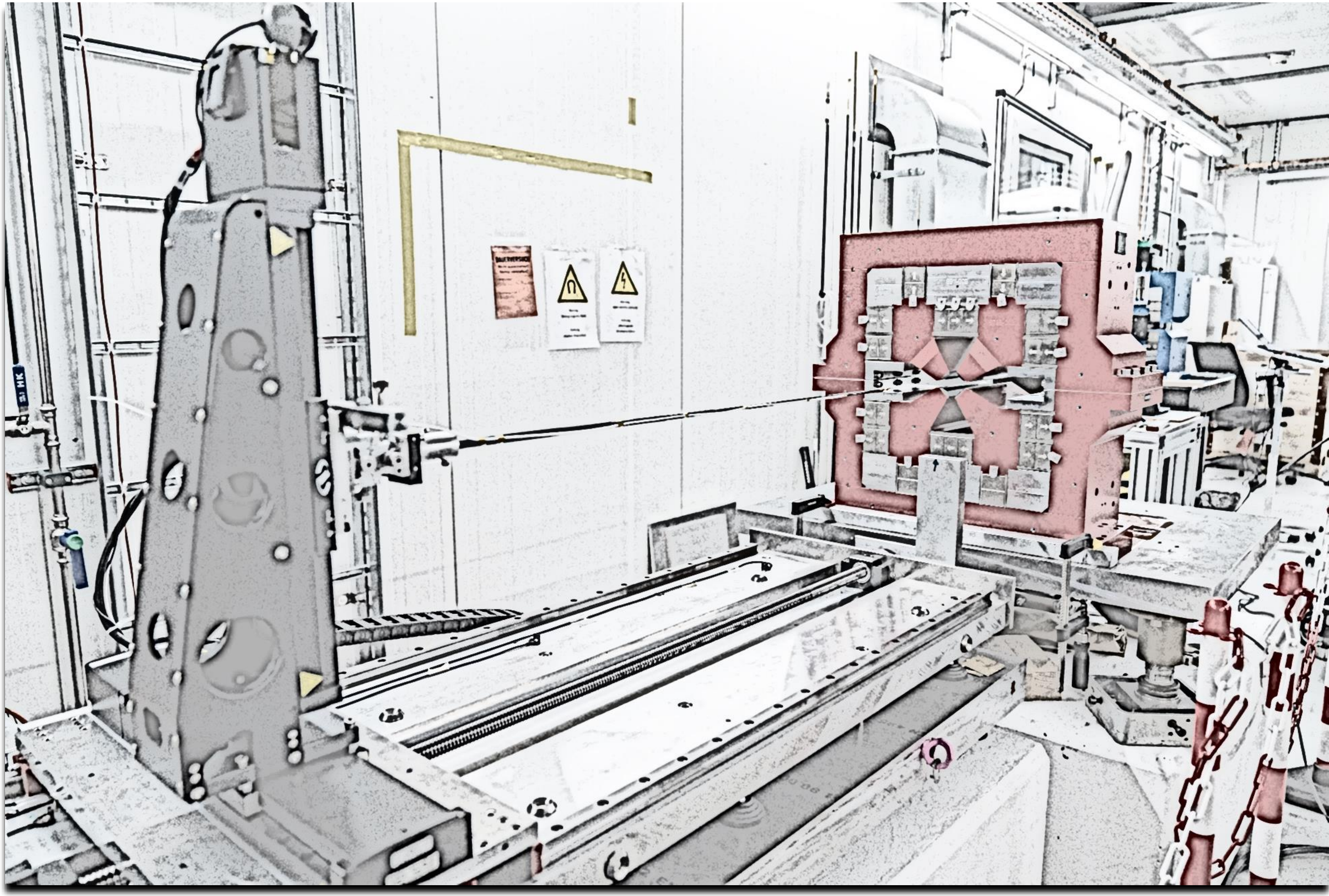
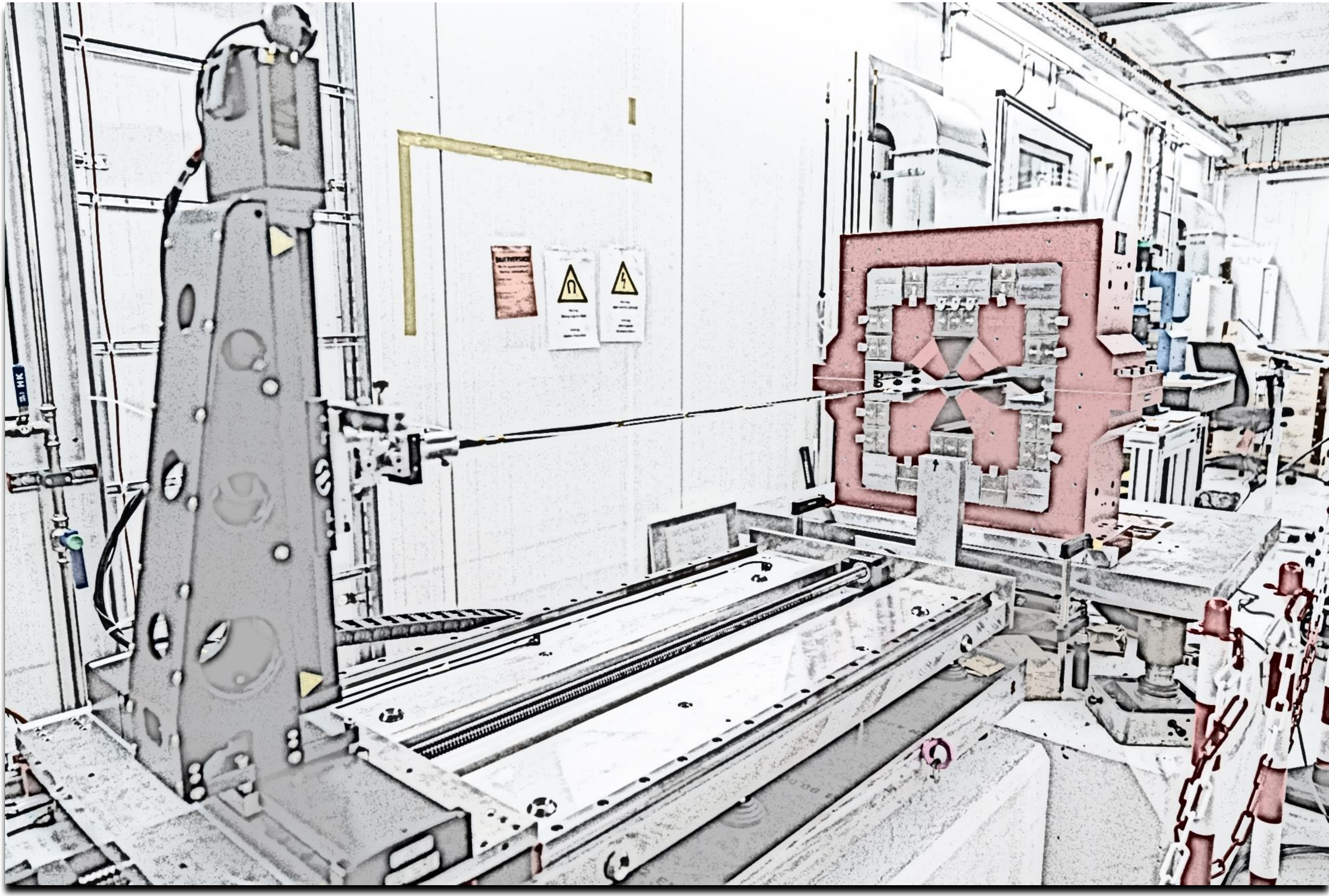
Magnetic coupling measurements on permanent magnets with hall probe for the upgrade of the Swiss Light Source (SLS2)

R. Riccioli, M. Aiba, C. Calzolaio, T. Ernst, G. Montenero, S. Sanfilippo
IMMW23, Bad Zurzach, 08 October 2024

Outline



Outline

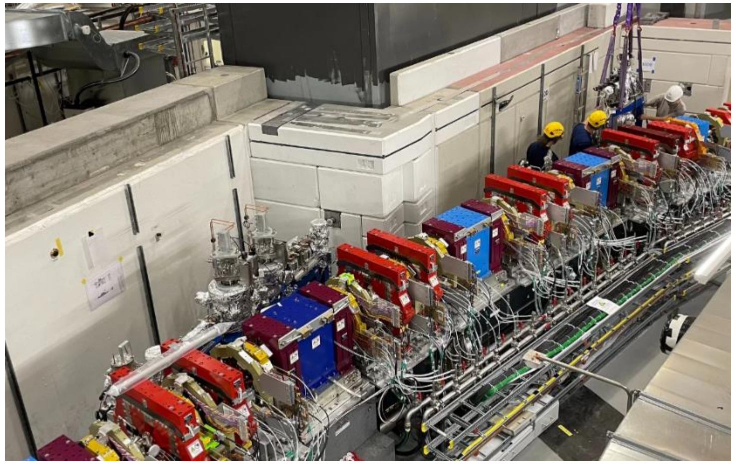


Introduction

PSI

Swiss Light Source upgrade: SLS2.0 project

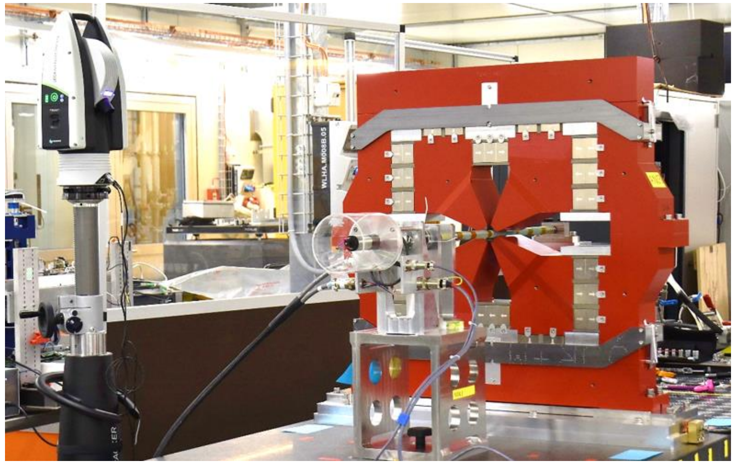
- Goal: Increase photon flux and beam brilliance
- High magnet density: from 388 to 1270 with same storage ring dimensions
- Use of 327 permanent magnets (PMs)
- See oral ‘Summary of Projects and Challenges in the Magnet Section at the Paul Scherrer Institute’ by S. Sanfilippo



Installation of the first two front ends for the SLS2.0 completed | Photonics Instrumentation | PSI

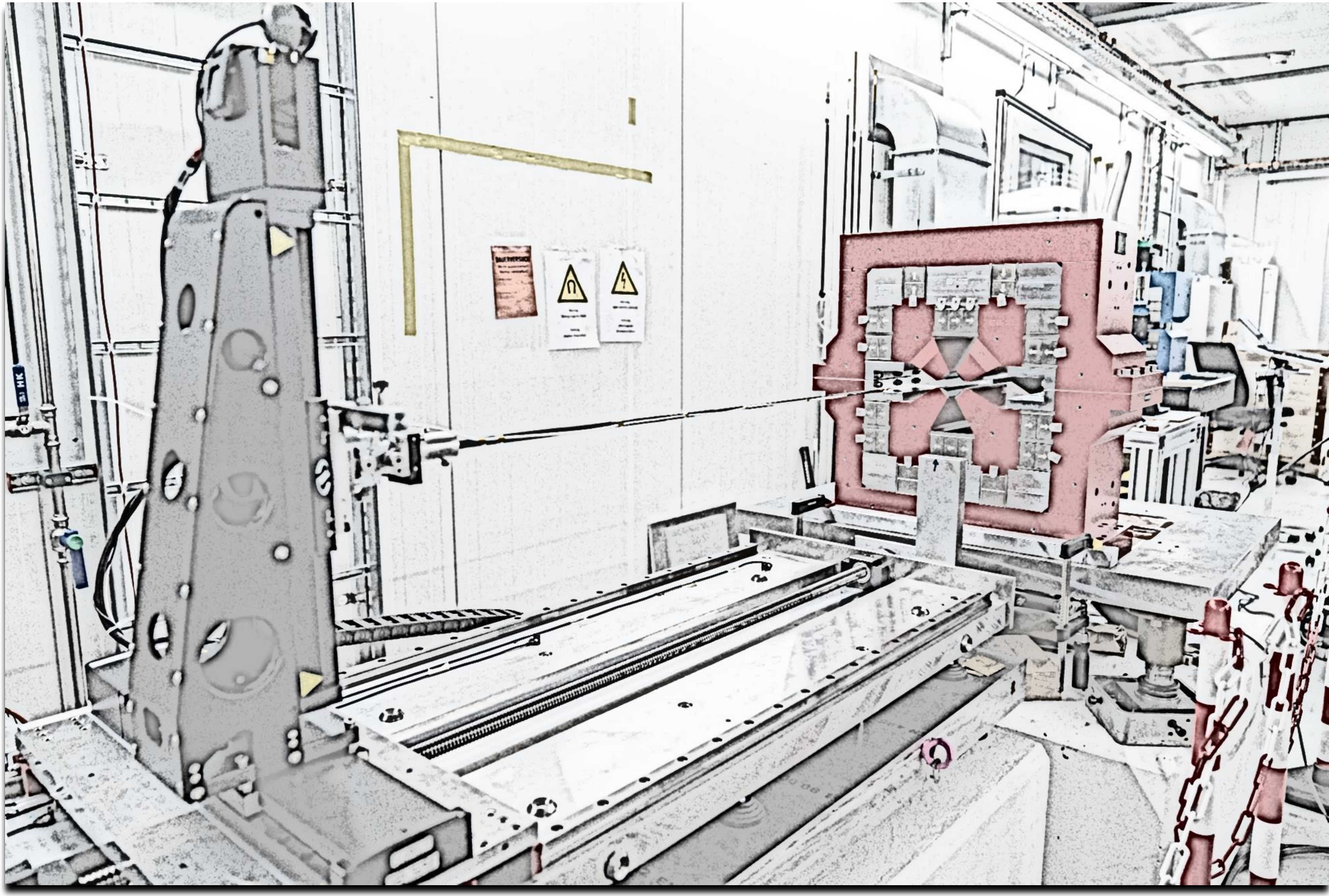
Permanent magnets tuning

- All the permanent magnets were tuned by adding shims and adjusting the moderator plates (see C. Zoller’s talk)
- All the quadrupoles (VEs, ANs, ANMs, VBs, VBXs) were tuned with the rotating coil measurement system
- The dipoles were tuned with hall probe mapping system and moving wire system (see G. Montenero’s talk)

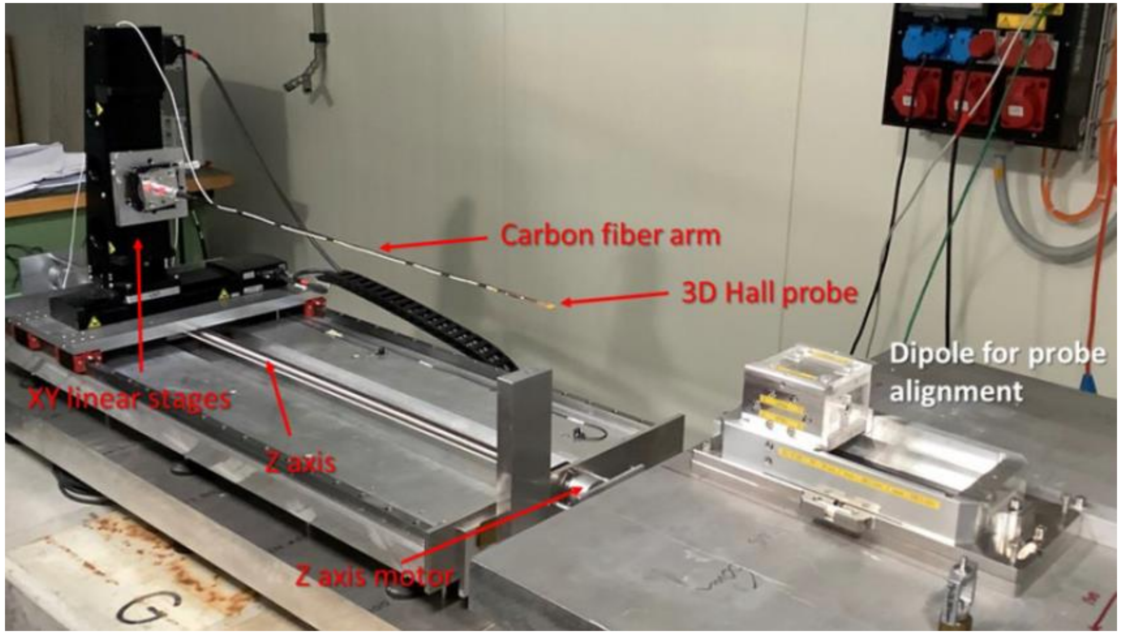


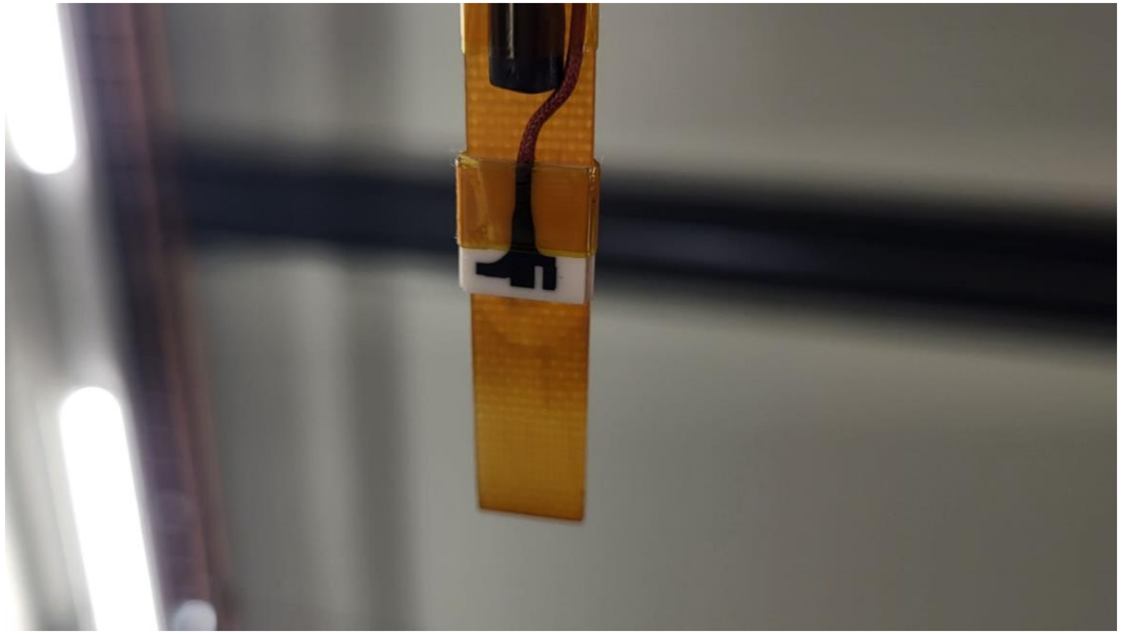
Tuning of Permanent magnets with rotating coil measurements

Outline



Compact field mapper





Compact field mapper

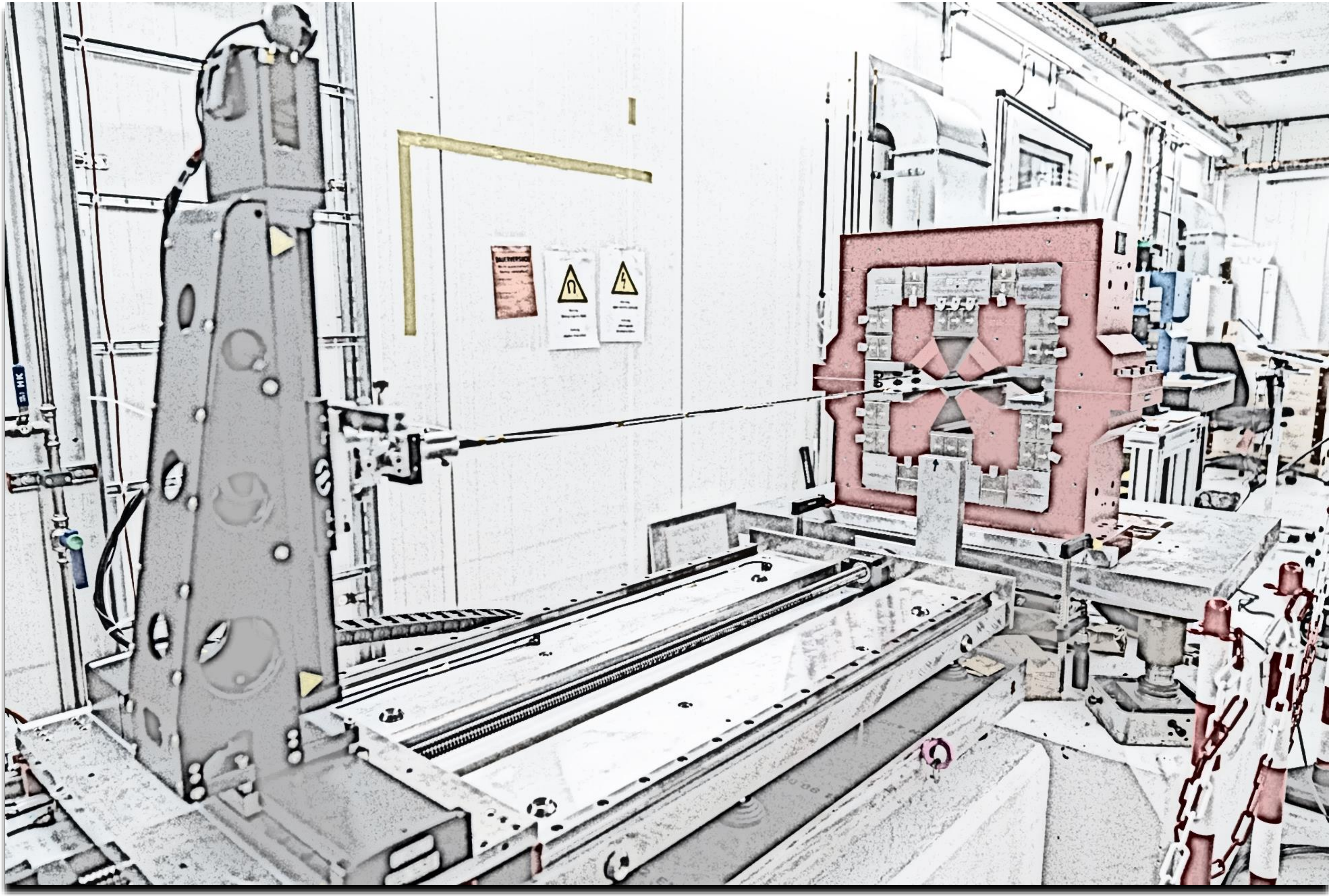
- XY motion range: ± 125 mm
- Z motion length: 925 mm
- Probe positioning with reference dipole
- See ‘Design and construction of a high accuracy field

mapper for longitudinal gradient bending magnets’ by P. La Marca

SENIS 3D Hall probe type S

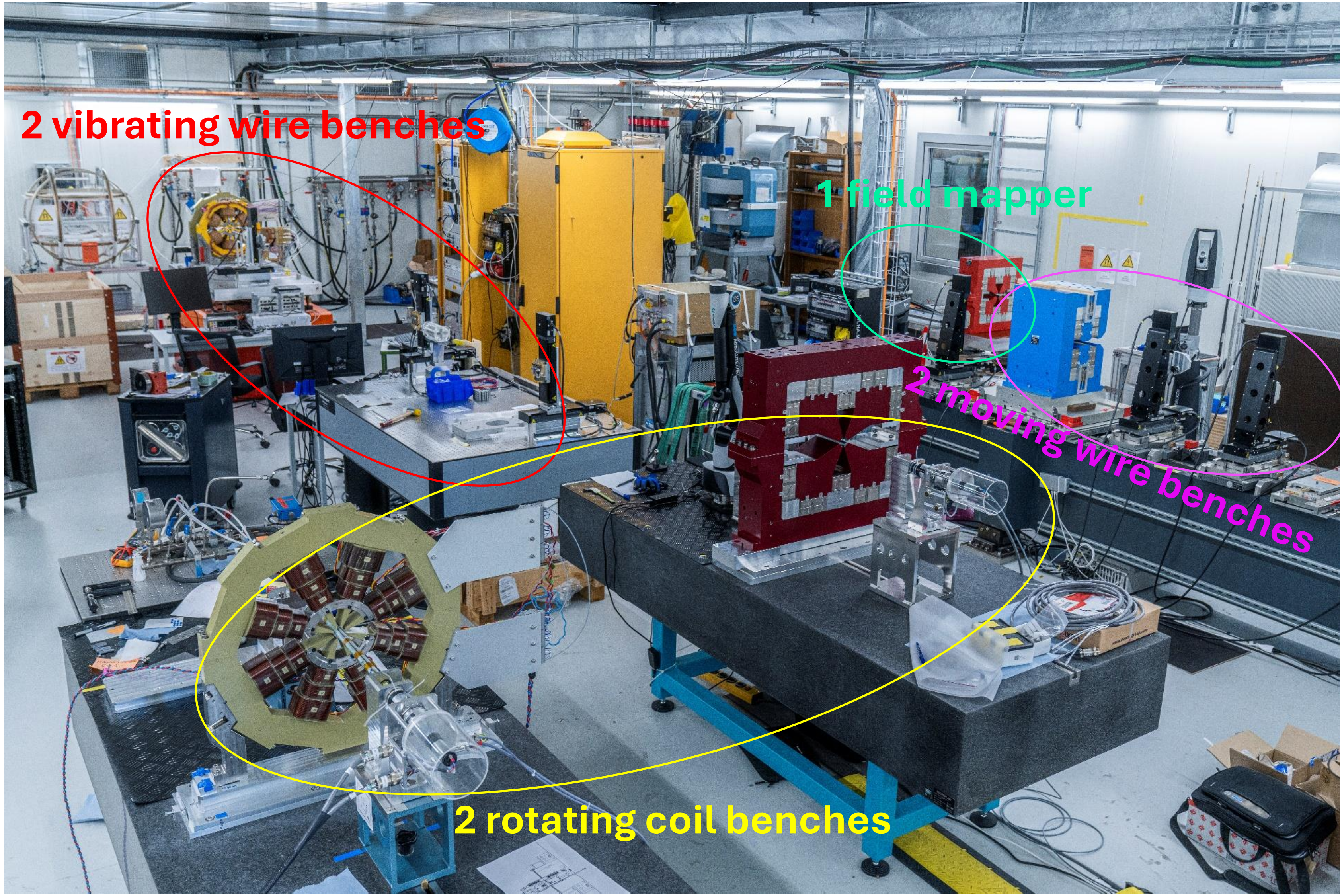
- Sensitive volume 150x150x1 μm^3
- Probe dimension 10mm x 1.4mm x 10mm
- Max measured field: ± 2 T
- Probe sensitivity: 5 V/T
- Probe maximum accuracy: ± 25 units of maximum field

Outline

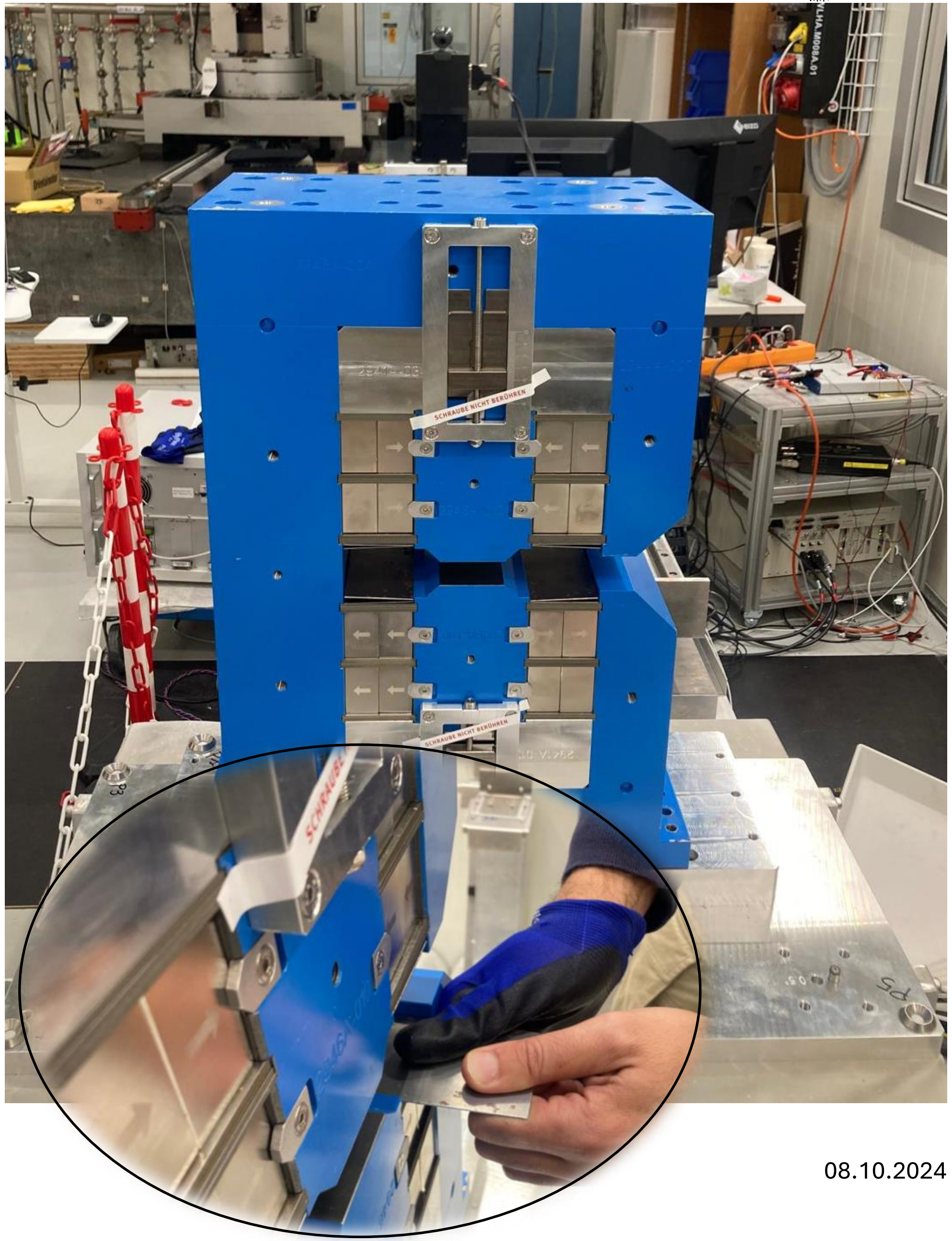


Single magnets tuning

- The compact field mapper (CFM) system was not foreseen for series measurements
- Due to the huge number of magnets to be measured (>1000) in a limited amount of time, seven measurement benches were running in parallel
- The Hall probe system was then used for tuning 24 permanent dipoles



Single magnets tuning



Permanent bending dipoles tuning

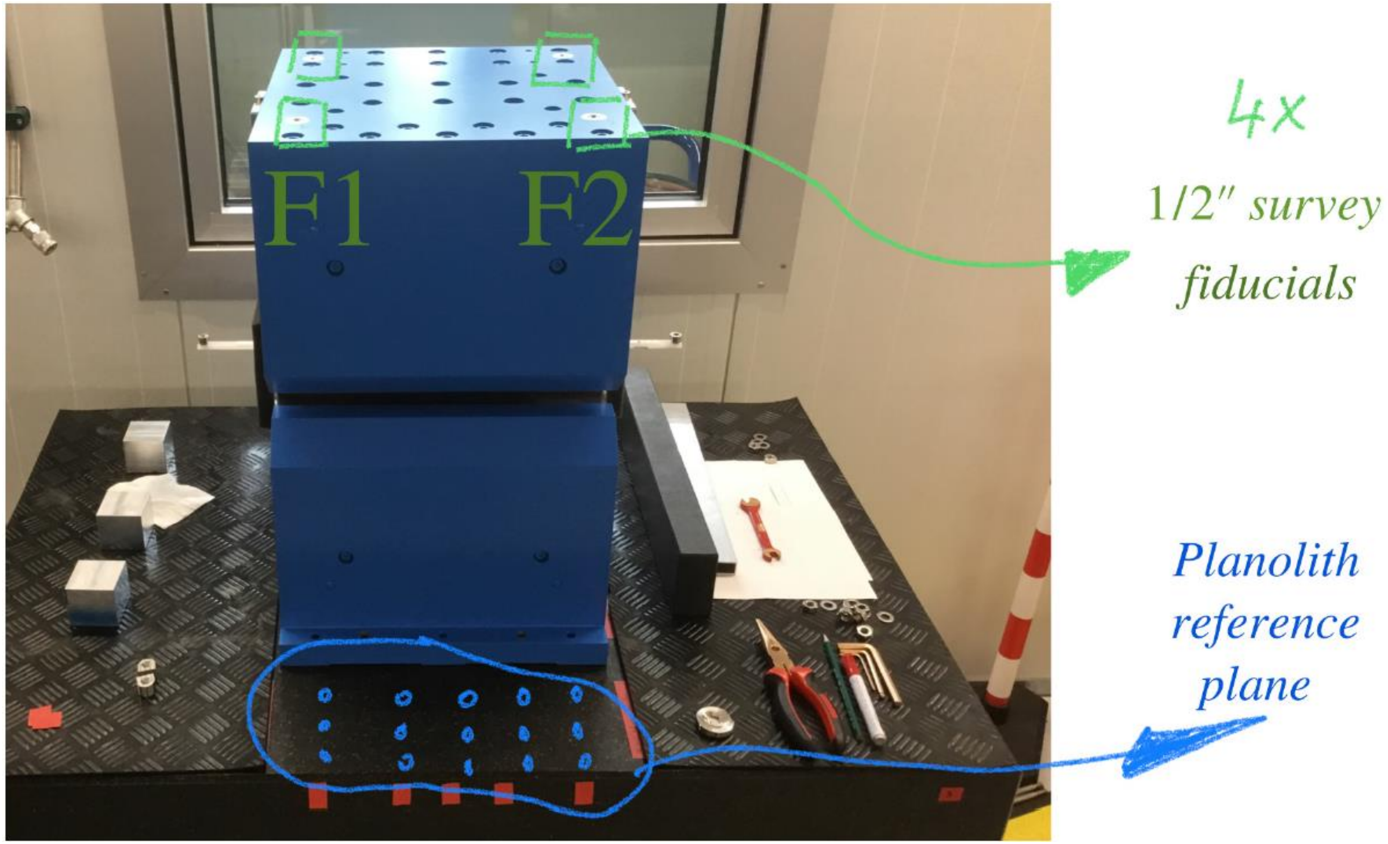
- The BEs needed to be tuned at the optimized integrated target value defined by simulations over a length of 720 mm:
    - BEIs: -0.30419 Tm
    - BEOs: -0.29621Tm
- Measurement performed on the mechanical axis
- The tuning was done by shimming and moderator plates closure, similar to the procedure presented by C. Zoller
- Compared to MW measurement: ± 10 units
- The magnets are tuned at 1 unit close to target value

Single magnets tuning

PSI

Mechanical axis definition

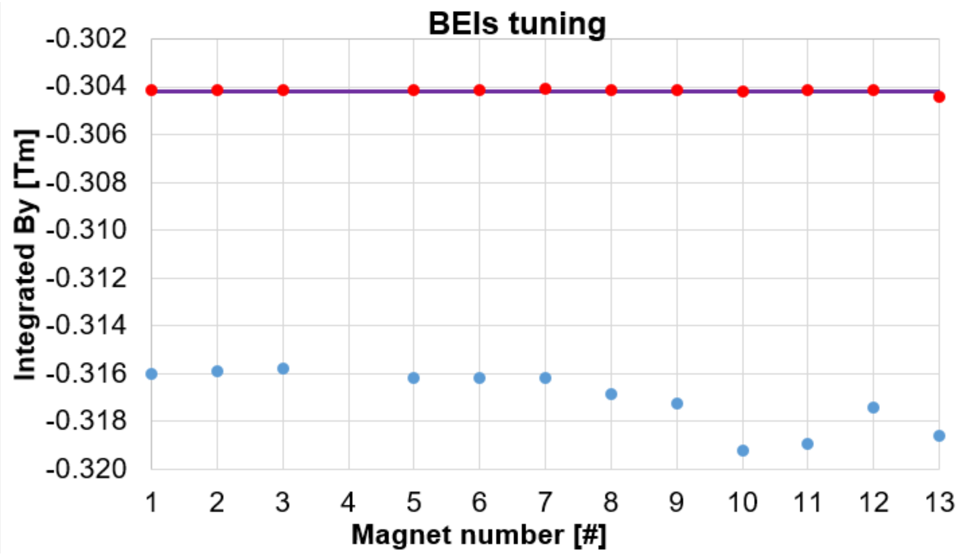
- The dipoles are first measured mechanically on a reference surface defined by a granite table with planarity below 2 µm
- X and Z coordinates of the centre found with the use of a AT960 Laser tracker, while Y coordinate is found based on CMM (Coordinate Measuring Machine) measurements

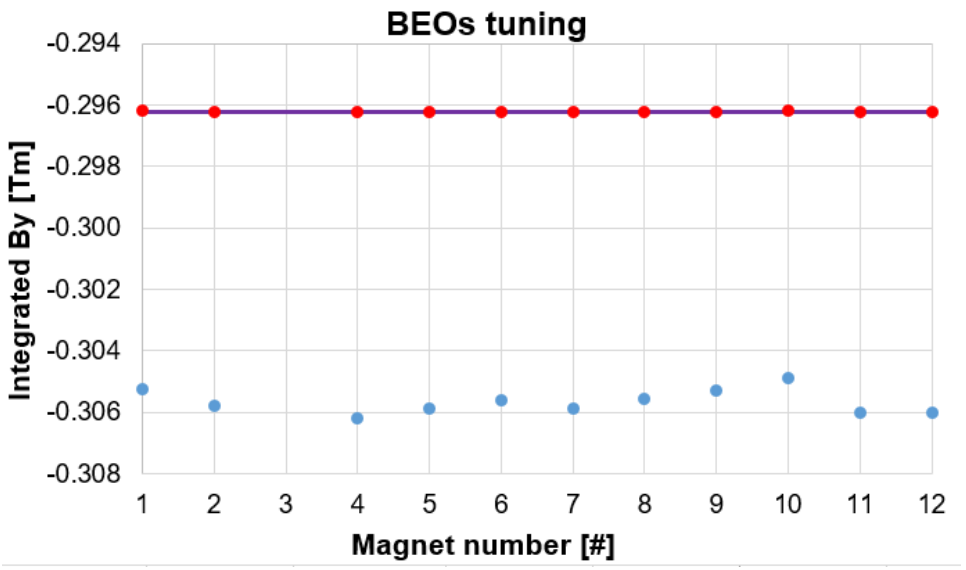


Single magnets tuning

Permanent bending dipoles tuning

- The magnet is then measured pristine first and then it is tuned following the moderators curve
- The pristine values change over a range of 100 units for the BEIs and over 40 units for BEOs
- The magnets are tuned in order to be below 1 unit from the target value





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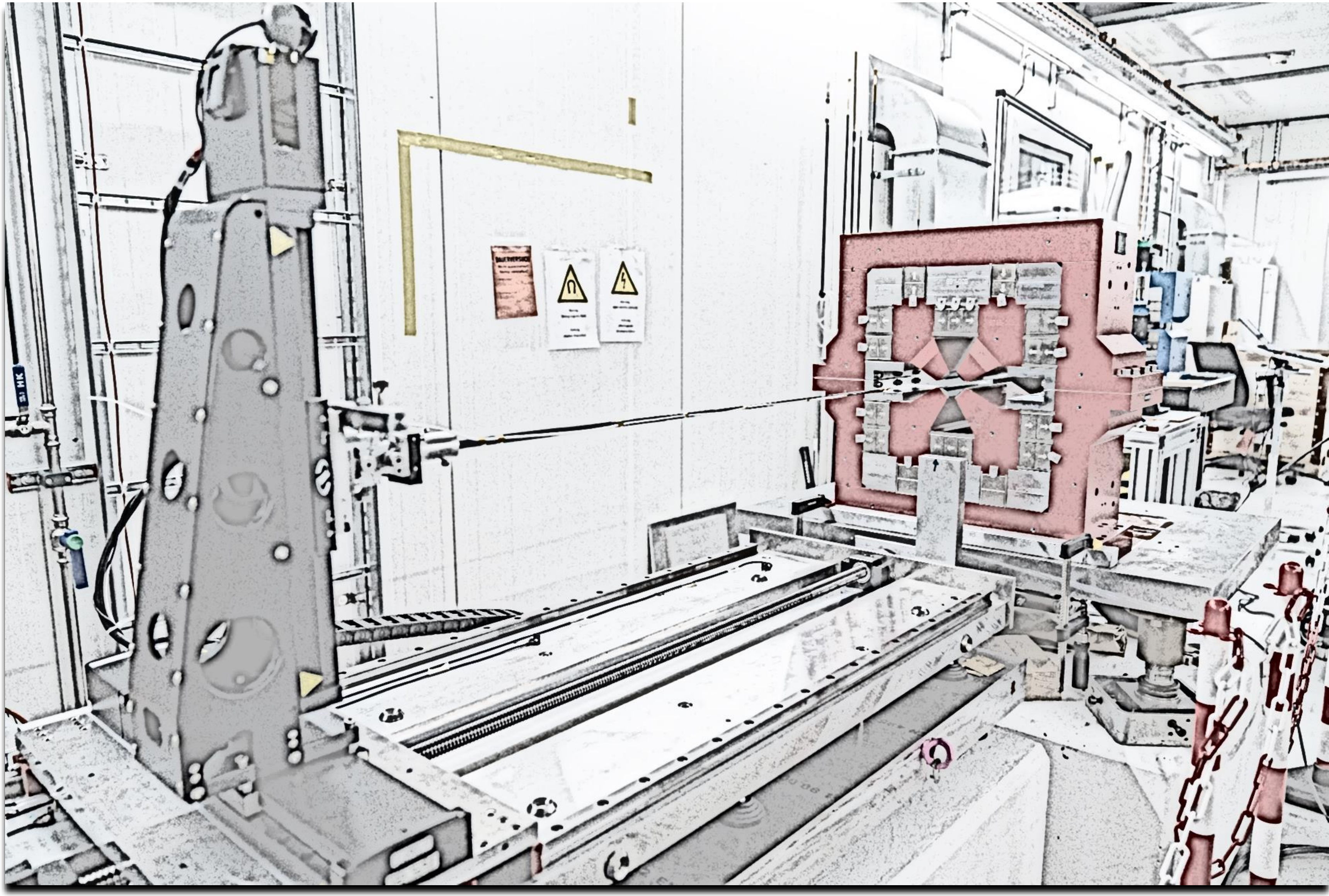
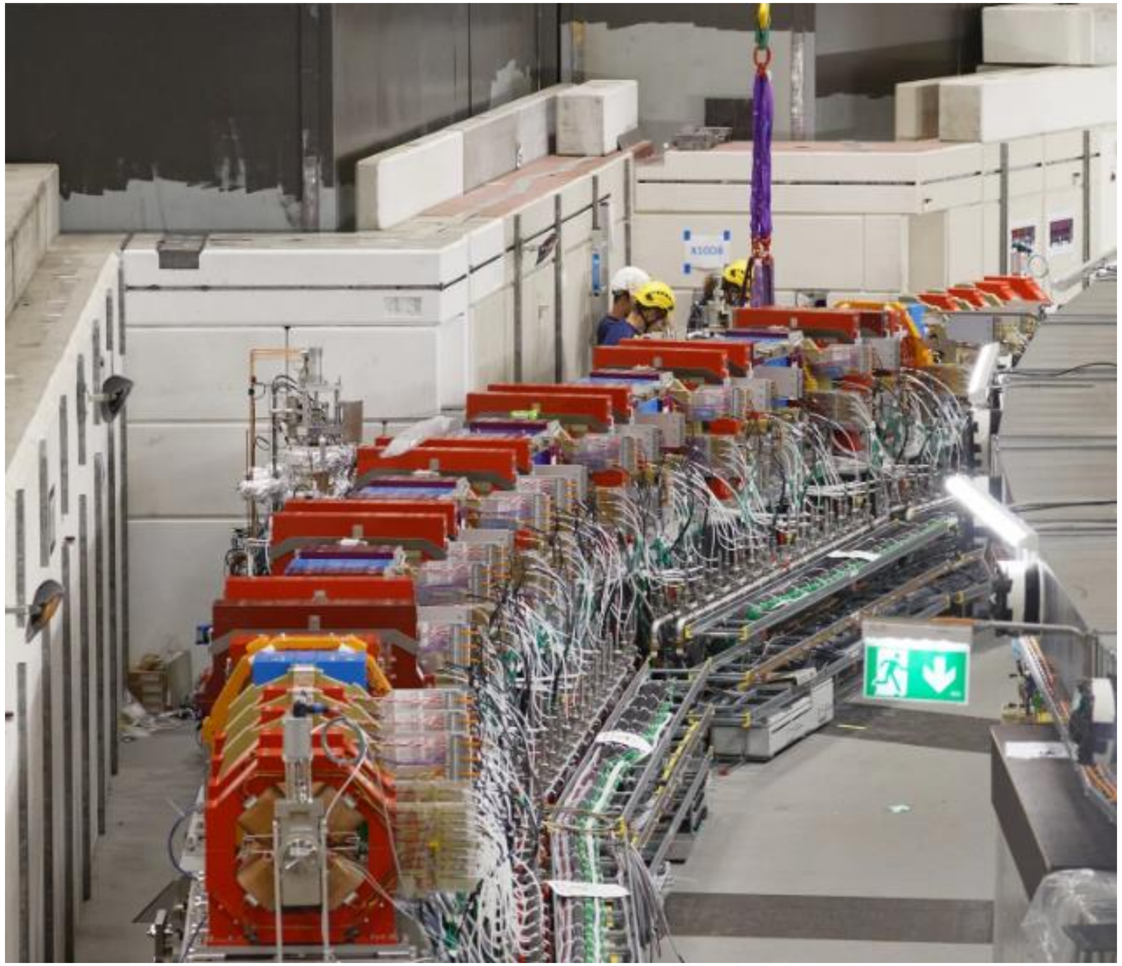


Crosstalk scenarios

PSI

- The high proximity (below 5 cm) of the electromagnets to the permanent ones weakens the PMs strength
- The permanent magnets tuning is *simulation-oriented*: the target values used for the beam optics come from optimization with the simulations



Crosstalk scenarios

- The simulations are also the ones proving the attenuation of the PMs due to electromagnets
- The accuracy of the simulations in reproducing the magnetic coupling effect may not be sufficient to fulfill the beam optics requirements (+/-20 units)
- Eight scenarios were investigated in order to **assess the relative difference of the attenuation between simulation and measurement**

Scenario	Magnet sequence	Crosstalk attenuation [%]
1	BEI-SXQ	3.84
2	SXQ-VEI	2.2
3	ANMI-HS2G-OS2A	2.28
4	HS2G-OS2A-ANO1-CHS	3.11
5	ANI2-HS2K-OS2E	2.45
6	HS2K-OS2E-ANO3-CHS	3.15
7	ANI4-HS2K-OS2E	2.84
8	HS2K-OS2E-ANO5-CHS	3.16
9	ANI6-OS2F-HS2L	2.87
10	OS2F- HS2L-ANO7-CHS	3.20
11	ANI8-OS2F-HS2L	2.86
12	OS2F- HS2L-ANO9-CHS	3.12
13	ANI10-OS2B-HS2H	2.79
14	OS2B-HS2H-ANMO-CHS	2.83
15	VEO-SXQ	2.18
16	SXQ-BEO	3.49

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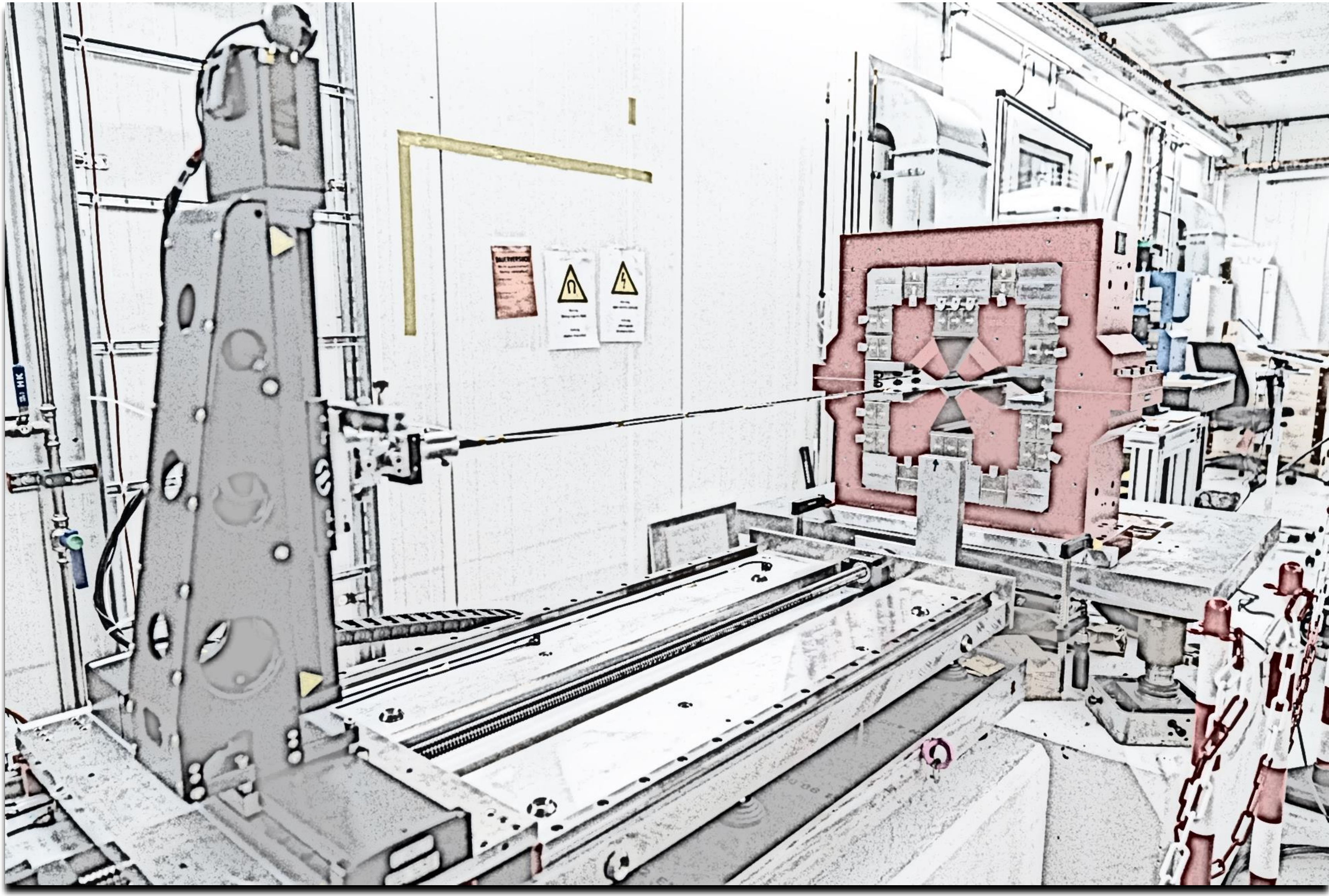


Measurements approach overview

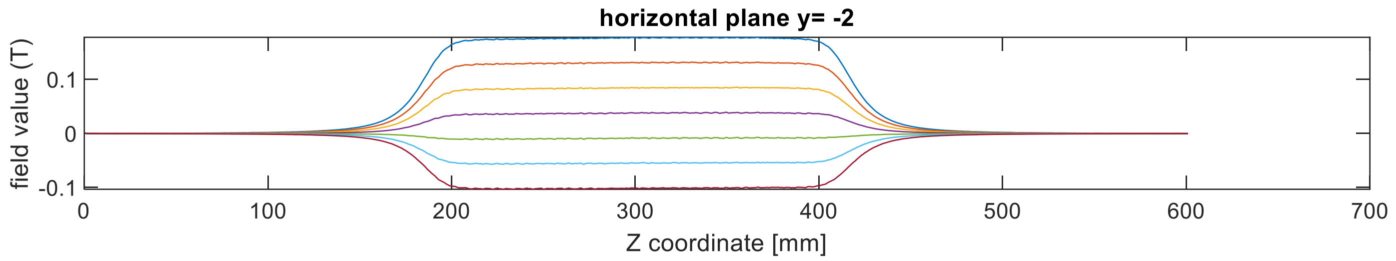
- Specific base plates were designed for each scenario in order to reproduce the machine installation
- The magnets are aligned with a AT500/AT960 Laser tracker based on the theoretical positioning of the magnets within a precision of 30 µm

Measurements approach overview

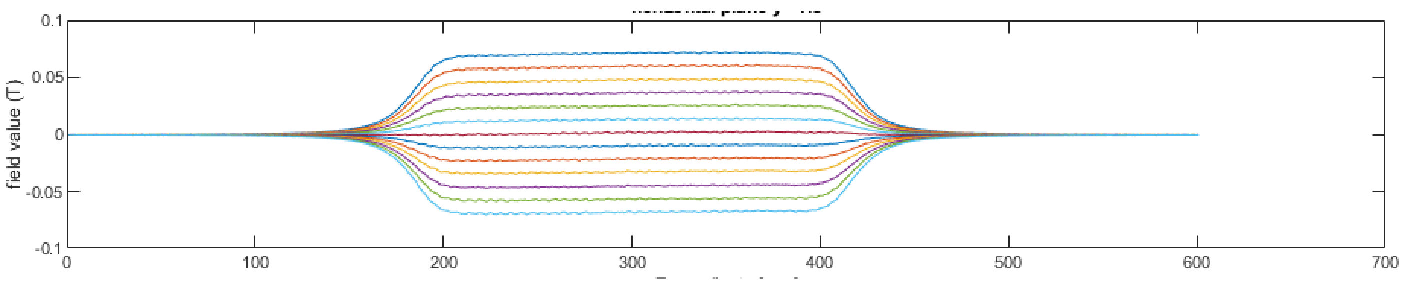
Stand-alone measurement

- A first measurement considers the magnetic axis found with the RC
- Due to uncertainties related to the axis transfer and the hall probe positioning, the probe needs to be re-centered for a better estimation of the gradient with a coarse volume (x/y=±3mm, step=1mm)
- After finding the measurements centre, a small and fine volume (x/y=±1.5, step=0.25mm) is scanned to minimize field error effects on the gradient assessment

Measurement with coarse volume



Measurement with fine volume after re-centering



Measurements approach overview

PSI

Crosstalk measurement

- The PMs are measured first stand-alone and the value is then validated against the RC measurement
- The magnet is then measured with the corresponding neighbours
- The magnetic axis moves with the magnetic coupling, but we always use the stand-alone one
- Only the integral value over the yoke length is compared to the simulated one

VEO-Field integral	VEO Alone	VEO & SXQ	Attenuation
Computed (T)	9.869	9.648	2.2 %
Measured (T)	9.852	9.671	1.8 %
Δ [units]	17	-24	**–40**

ANO7-Field integral	ANO Alone	CHS_ANO7_HS2L_OS2F	Attenuation
Computed (T)	-10.114	-9.790	3.2 %
Measured (T)	-10.115	-9.753	3.6 %
Δ [units]	-1	38	**37**

Measurements approach overview

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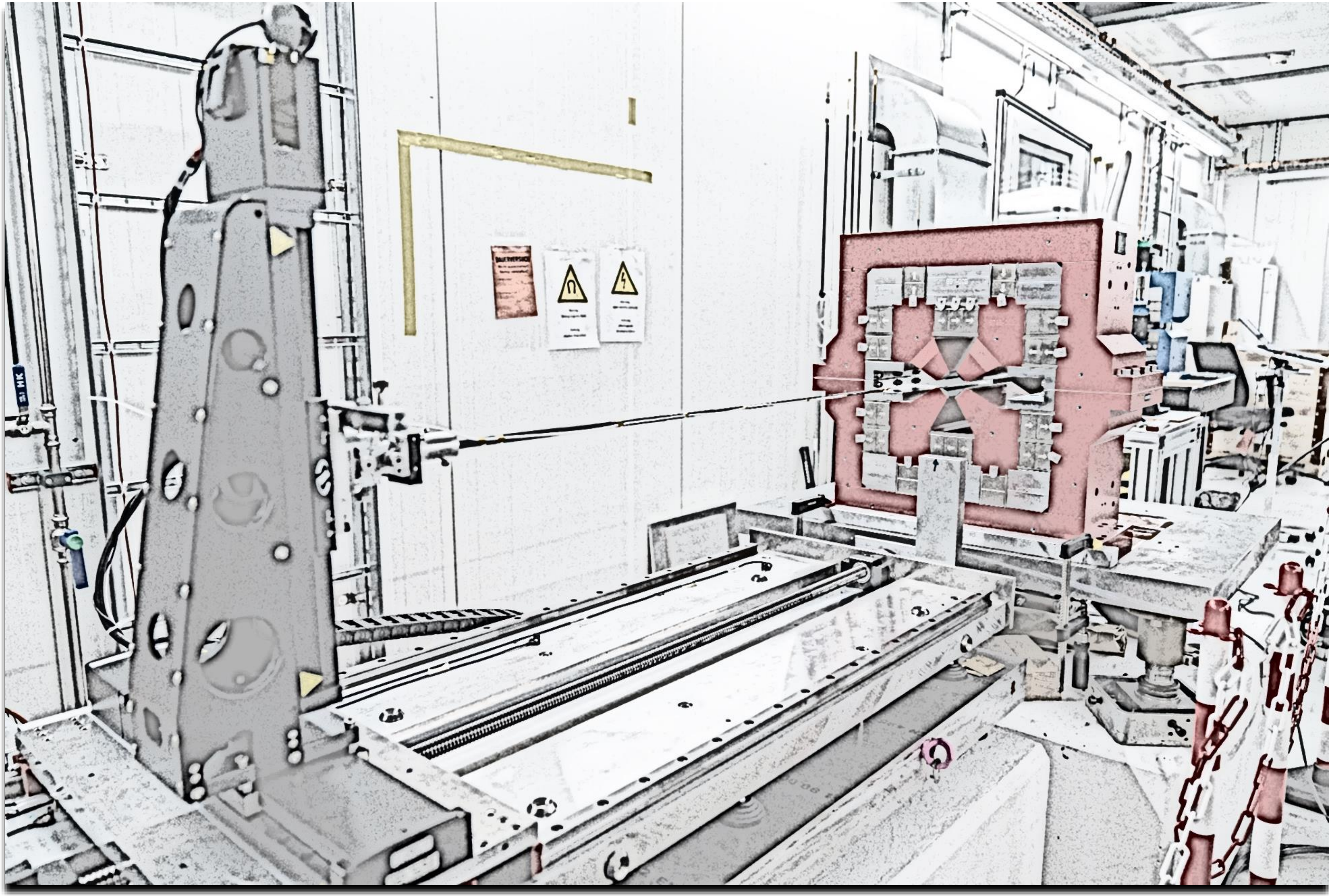
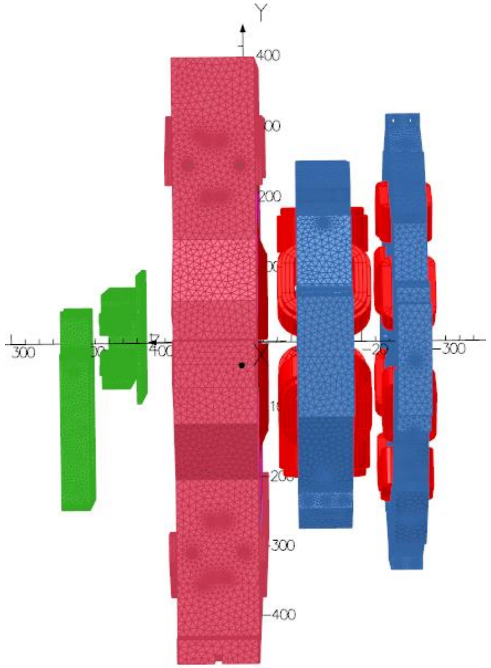
What matters for the re-tuning of the magnets is the relative difference between simulations and measurements

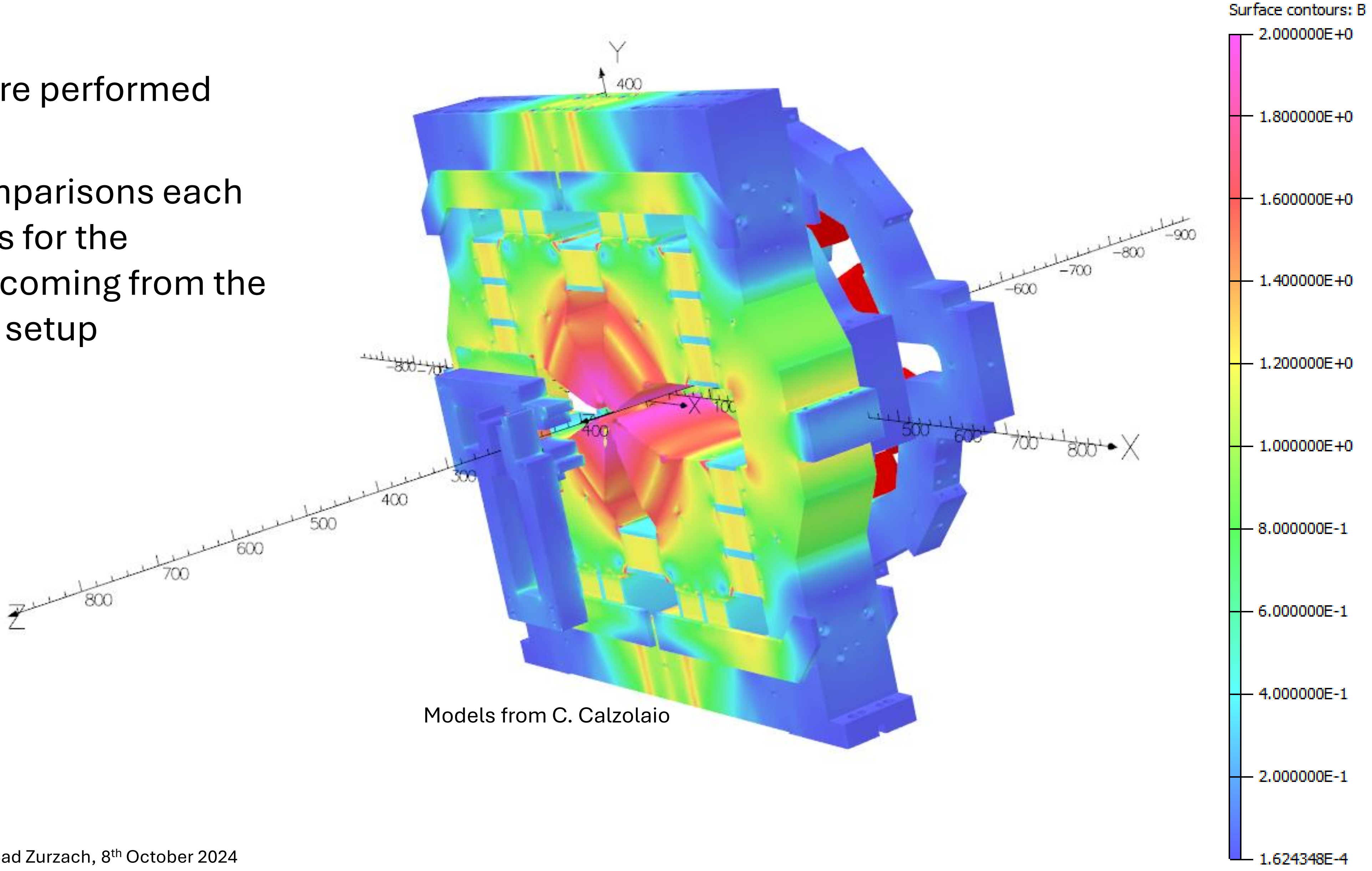
Outline



Simulations

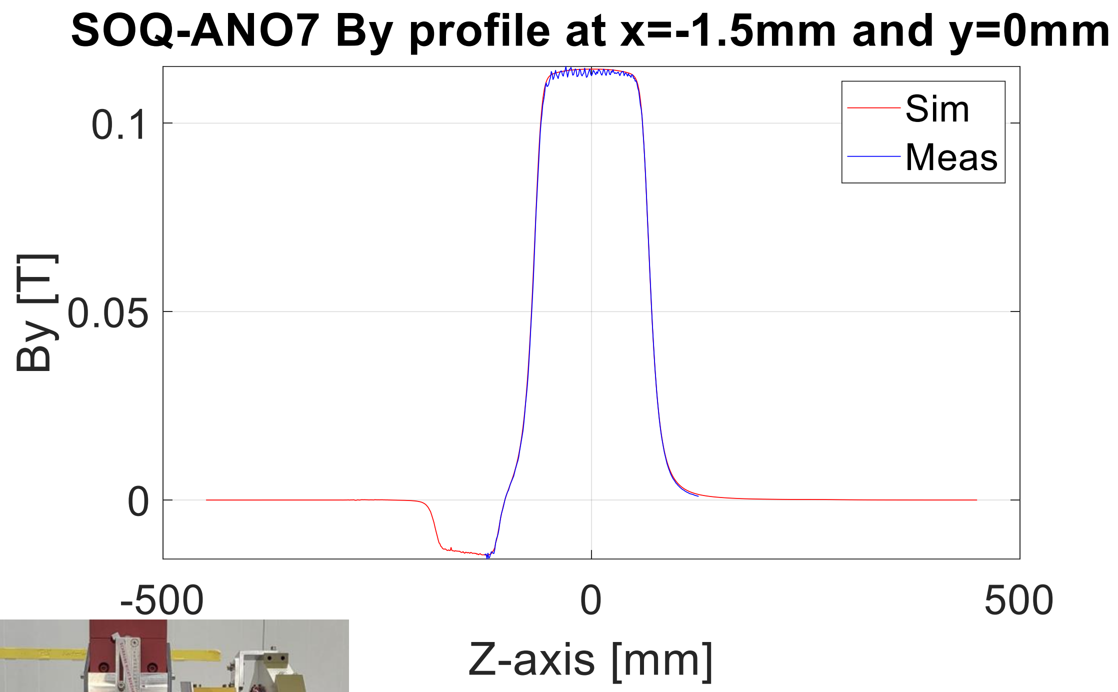
- Simulations were performed with Opera
- To have fair comparisons each model accounts for the misalignments coming from the measurements setup

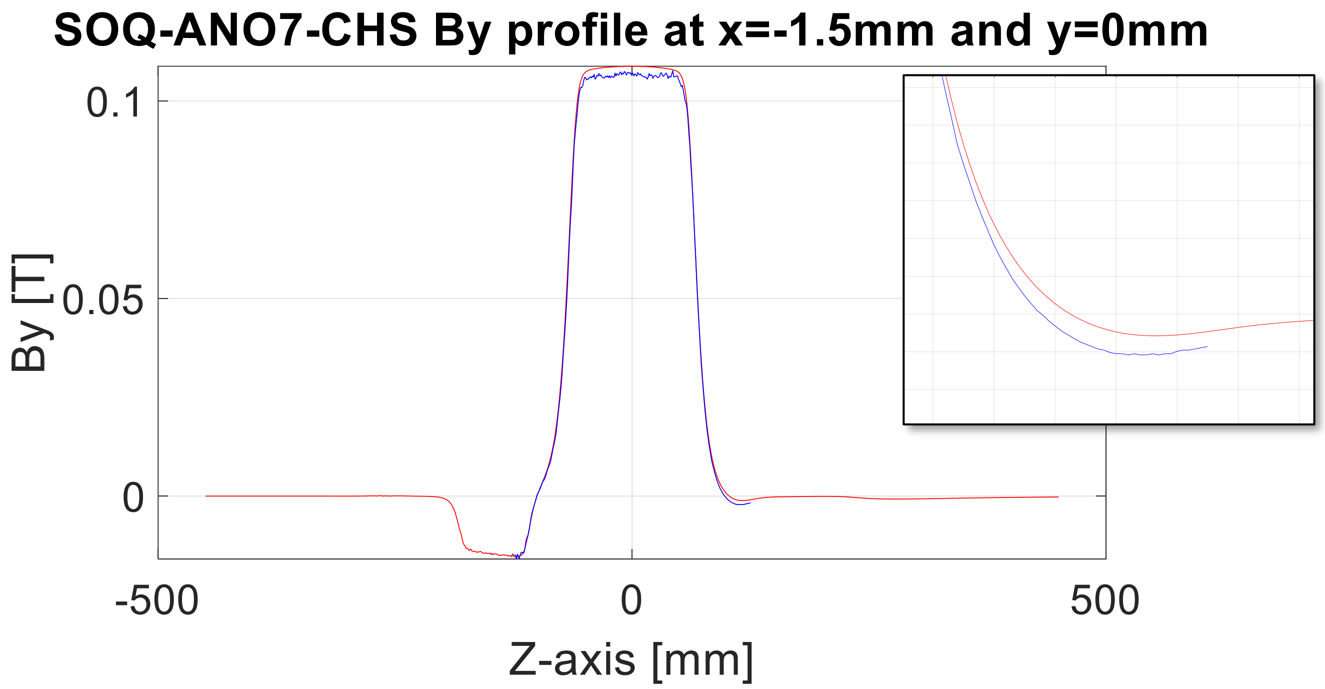




Models from C. Calzolaio

Simulations

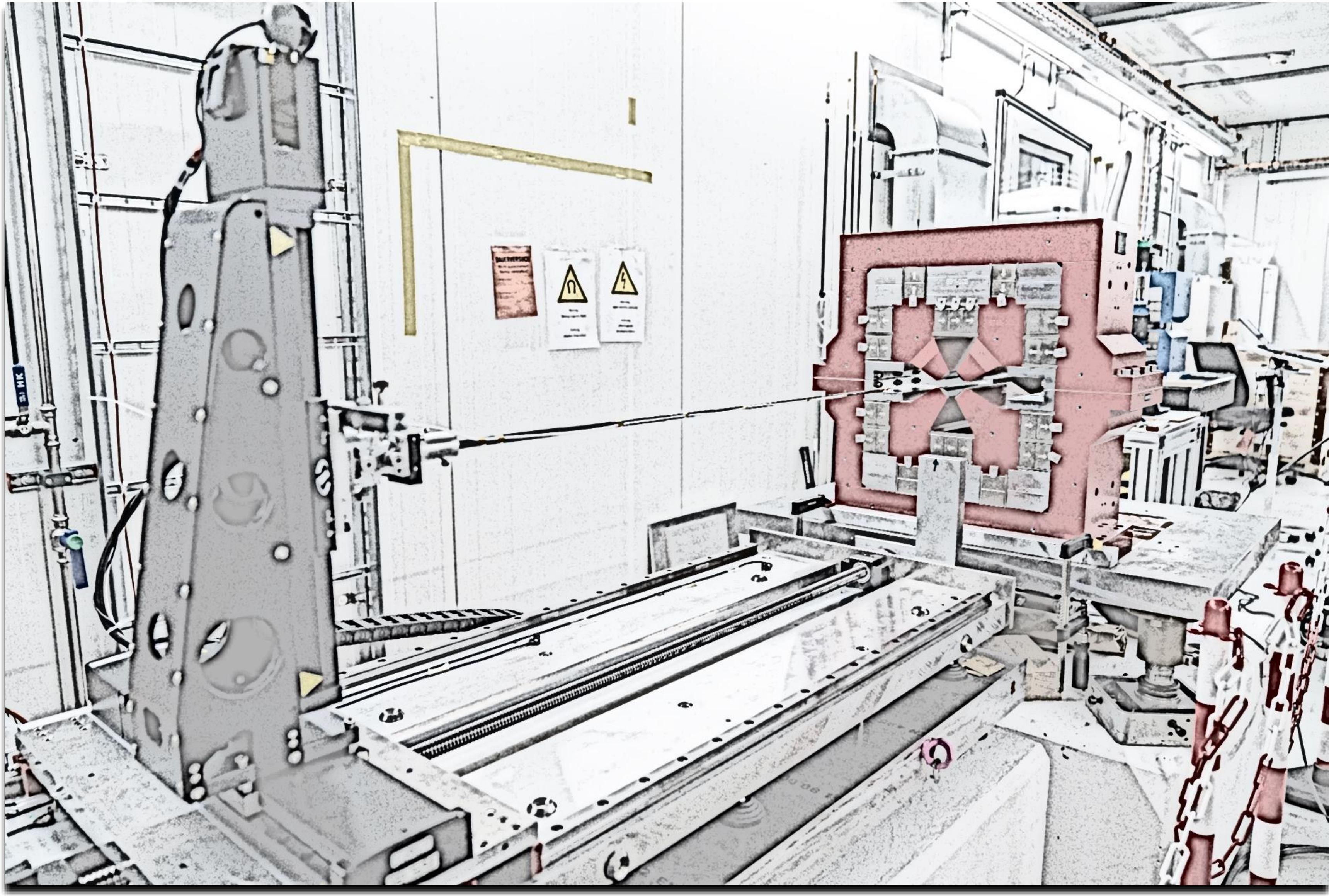




- The field profile is well represented by the models

- The measurement-simulation difference is not always understood and if it comes from measurement uncertainties or models
- The BH curve used for the magnets could be the responsible for these differences

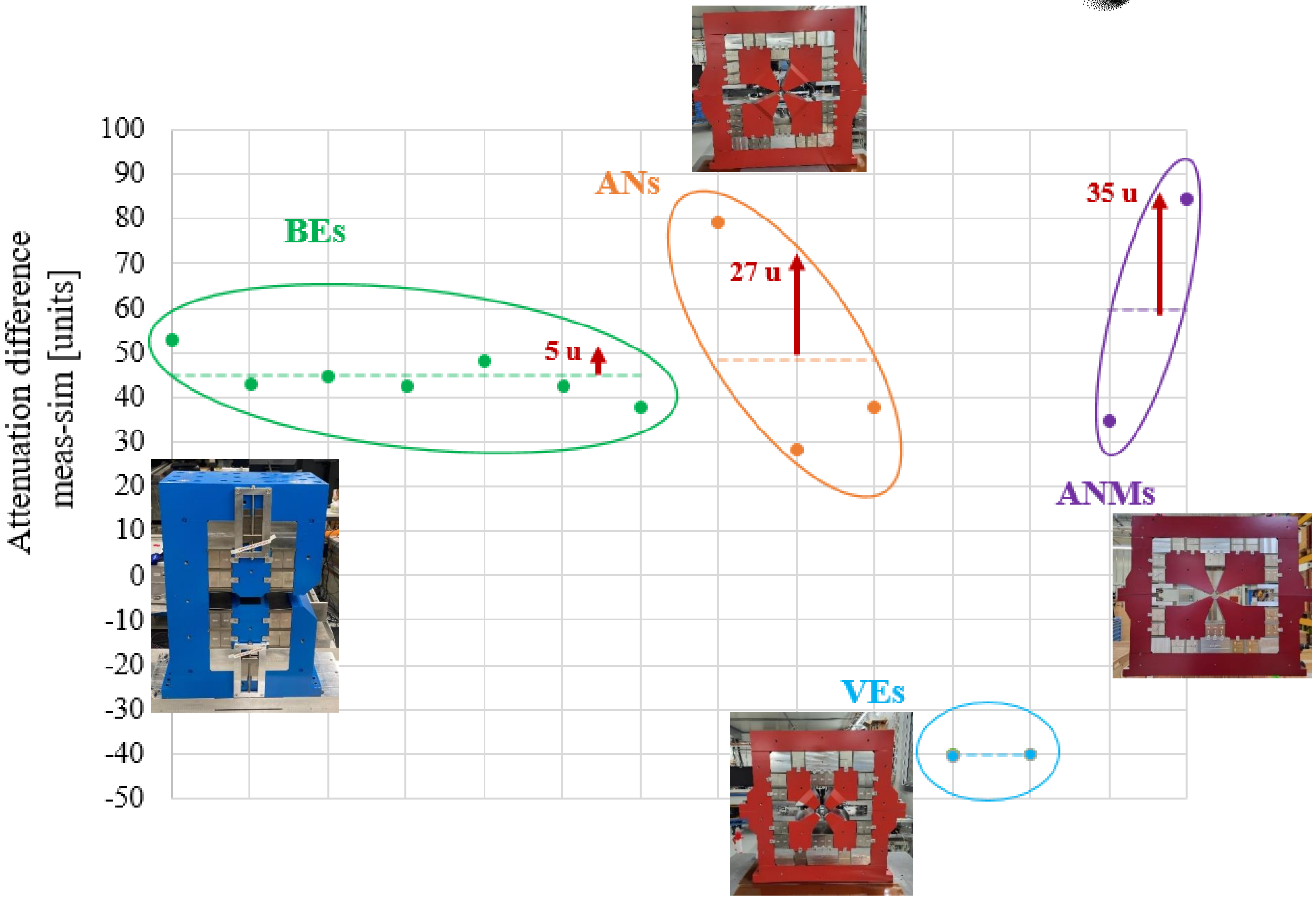
Outline



Results

Key-points

- The measurement-simulation difference can be grouped into three main families

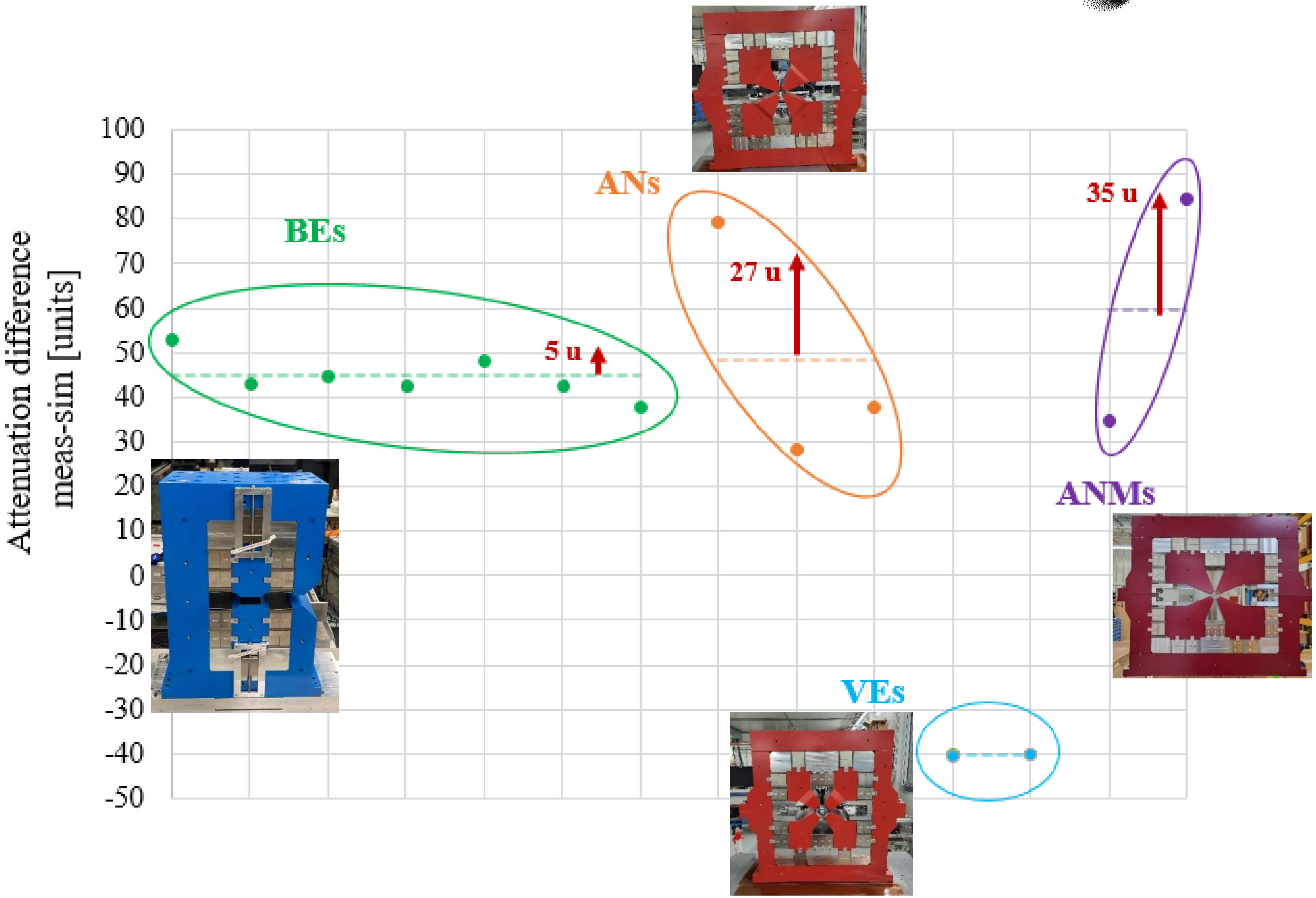


Results

PSI

Key-points

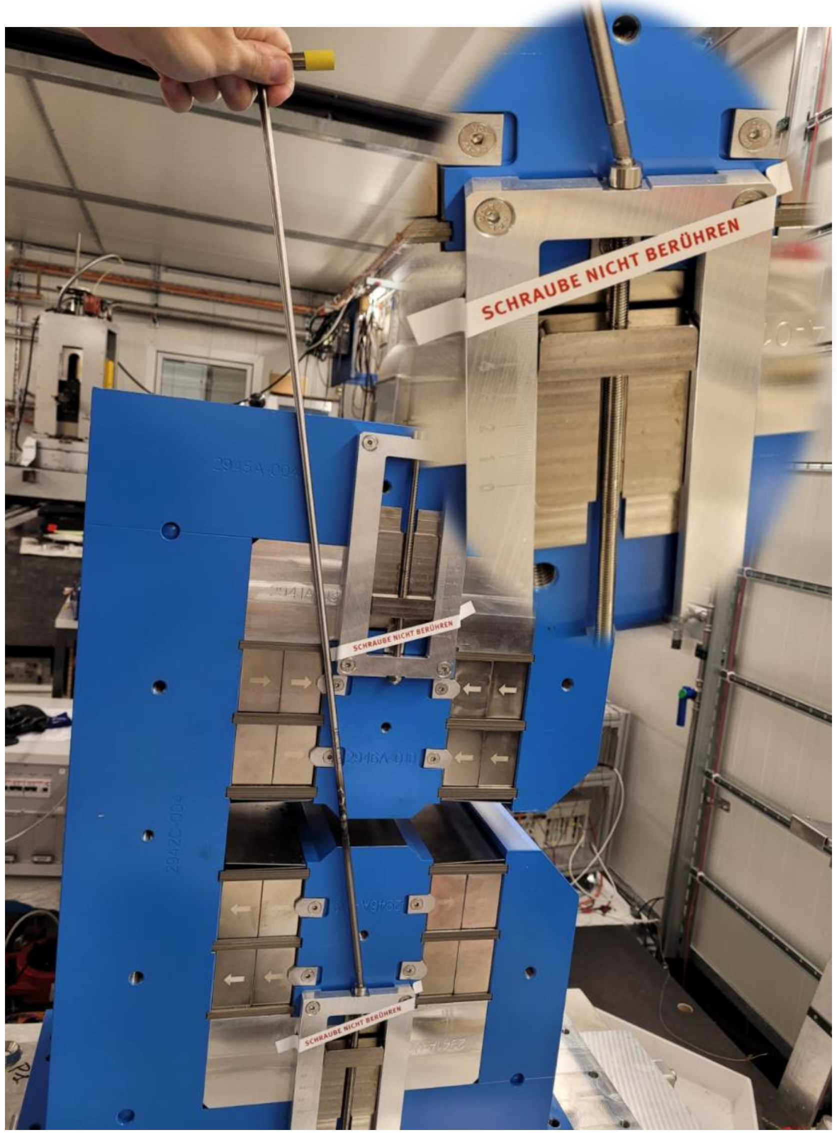
- The ANs and ANMs families show a quite similar behaviour with a spread of about 30 units
- More scenarios are going to be studied during the machine commissioning to better understand the crosstalk effect
- General trend, no matter which scenario is analysed: the CHS decrease the measured strength of 60-70 units and 40-50 units in the simulations



Results

Implemented strategies

- The average difference per family has been considered for a fine re-tuning
- The magnets are now being retuned directly on the girder after installation → special tool is used for adjusting with Ti tip



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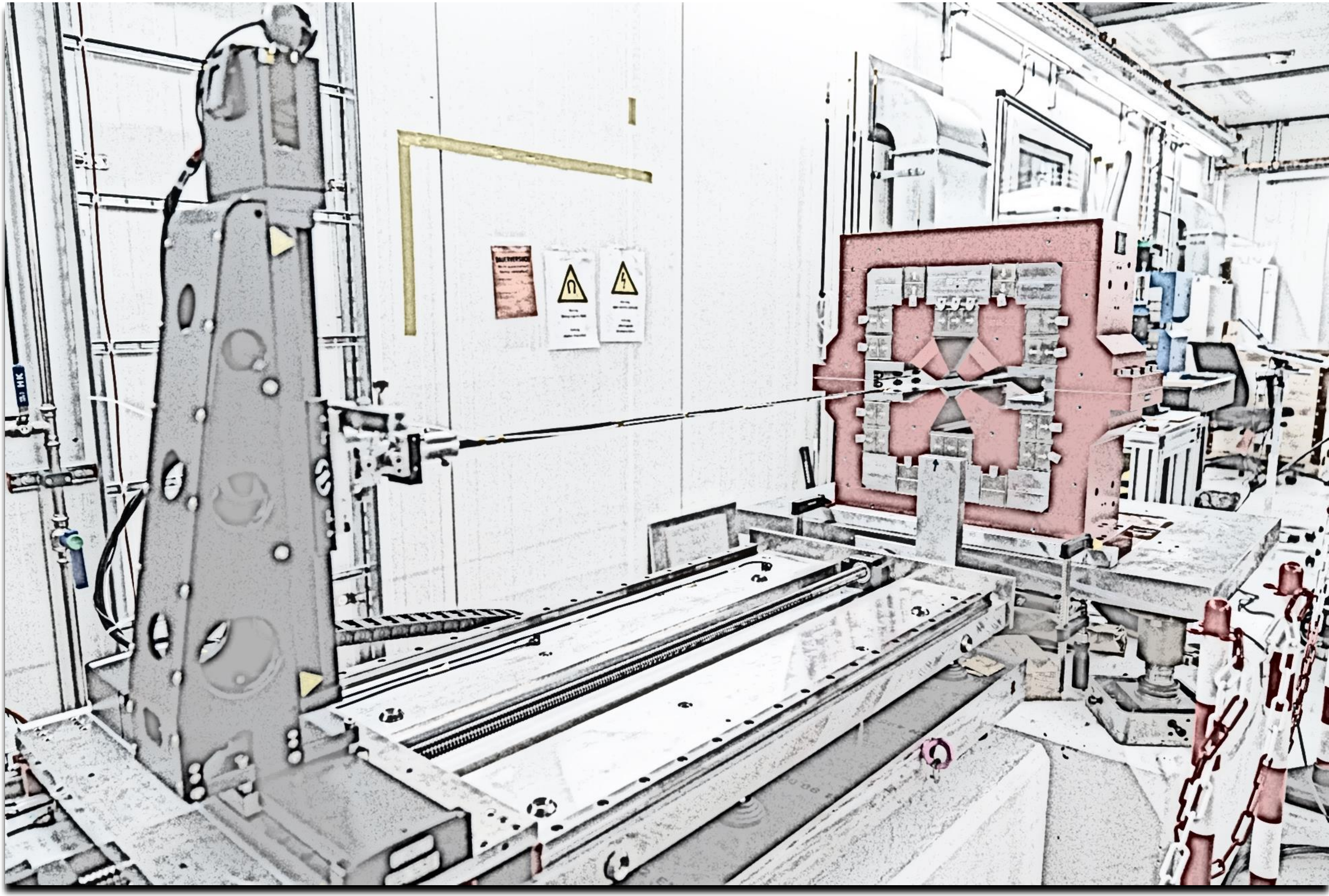
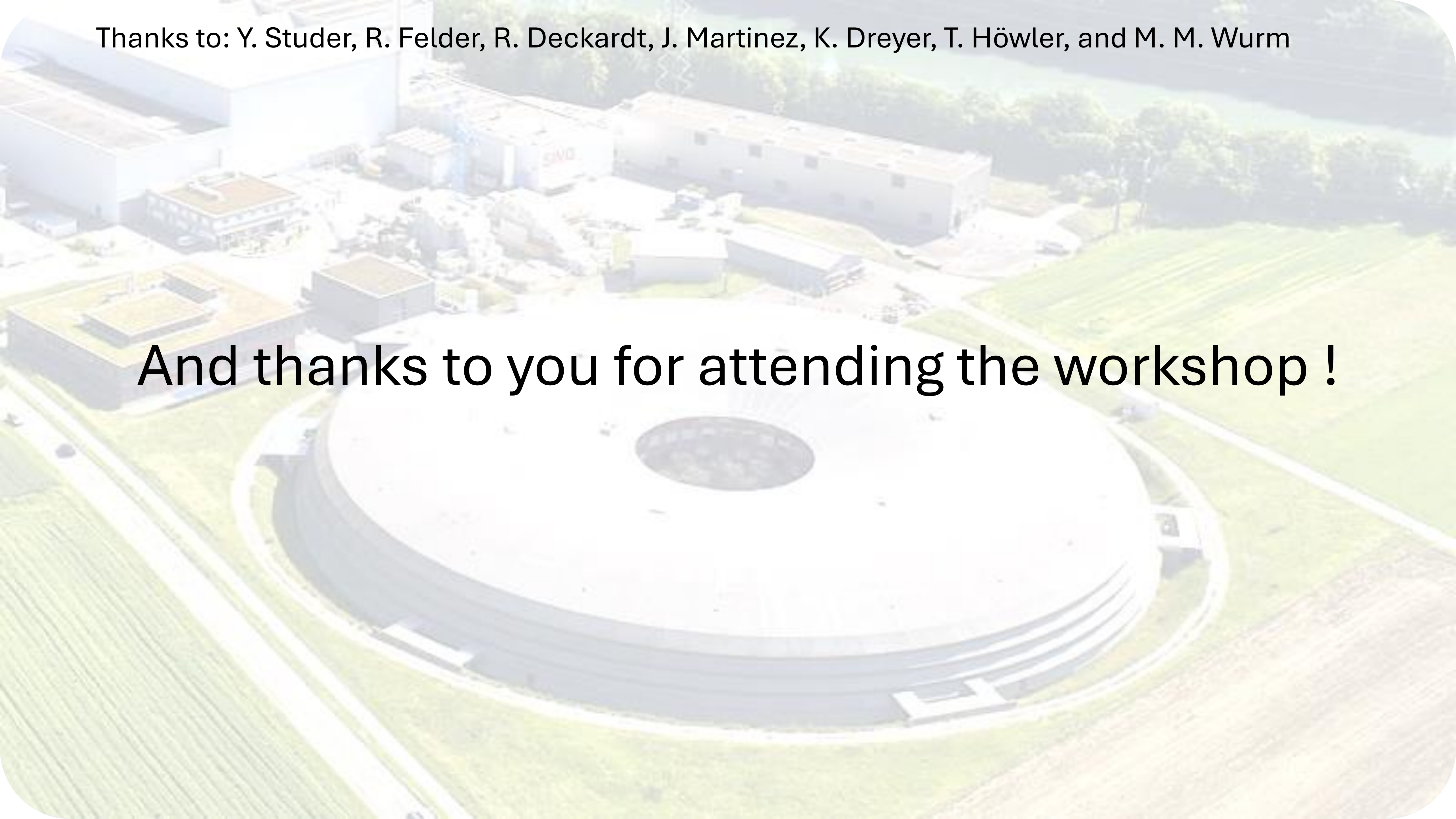


Conclusions

- The **compact field mapper** was successfully used **for permanent dipoles tuning** during the SLS2.0 magnets qualification
- Thanks to the **Hall probe**, it was possible **to scan a volume within the yoke** of the permanent magnets **for assessing the magnetic coupling effect**
- For each crosstalk scenario, the **measurement procedure** requires several steps including alignment each magnet between two and three times plus several scanned volumes → **full measurement time: min 3 days**
- Thanks to the reproducible difference for the **dipoles BEs and the quadrupoles VEs**, it is possible to extrapolate a **systematic attenuation to be used for fine re-tuning**
- In the case of the **quadrupoles ANs and ANMs** the **difference between simulated attenuation and measurement** has a spread of about 30 units (**bigger than the instrument accuracy**)
- Up to now, the spread of the **measurement-simulation difference** in **some cases** is not yet understood and therefore **not fully predictable** → **more measurements will come with spare magnets during commissioning**



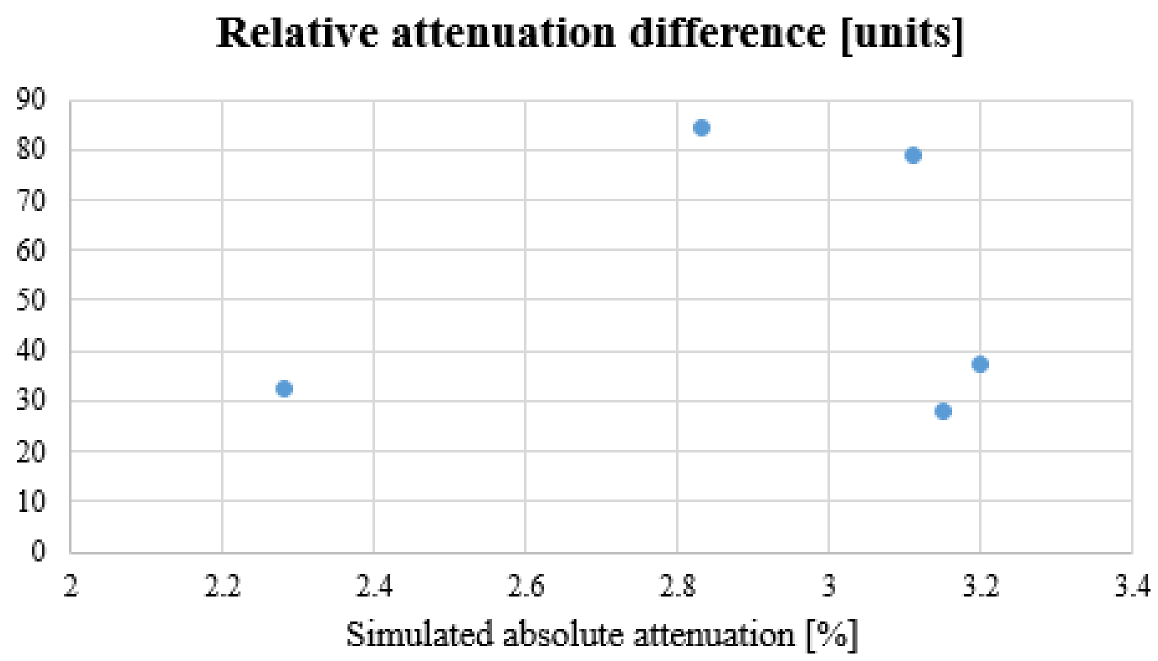
Thanks to: Y. Studer, R. Felder, R. Deckardt, J. Martinez, K. Dreyer, T. Höwler, and M. M. Wurm

And thanks to you for attending the workshop !

Annexes

Attenuation difference correlations ?

Type	Tilt angle [°]	Shims [mm]	x-shift [mm]	z-shift [mm]	Sim absolute attenuation [%]	Current Sx [A]	Current Oc [A]	ATTENUATION DIFFERENCE [units]
ANO1	0.12	0	-3.132	-245.999	3.11	35.5	0.75	79.10480292
ANO3	0.12	0	-3.133	-245.999	3.15	38.5	1.8	28.15322829
ANO7	0.12	0	-3.367	-146	3.2	28	1.75	37.59433765
ANMI	0.13	4	-3.07	-150	2.28	35.5	0.75	32.52595816
ANMO	0.13	0	-3.147	-151	2.83	35.5	0.75	84.34663083



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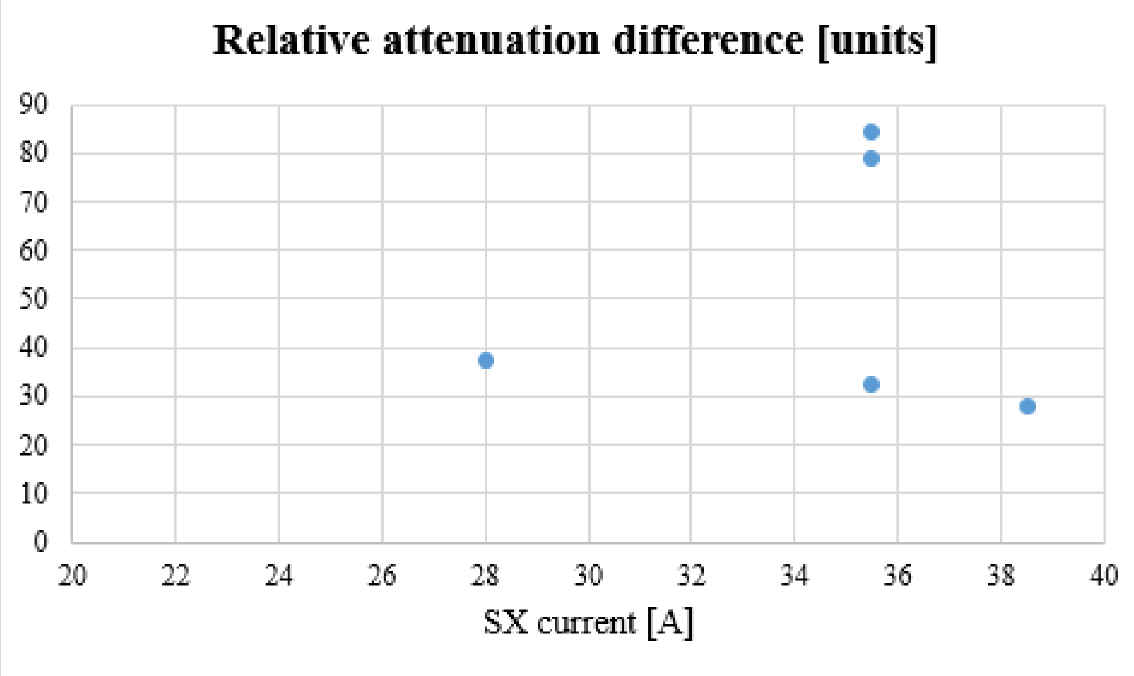

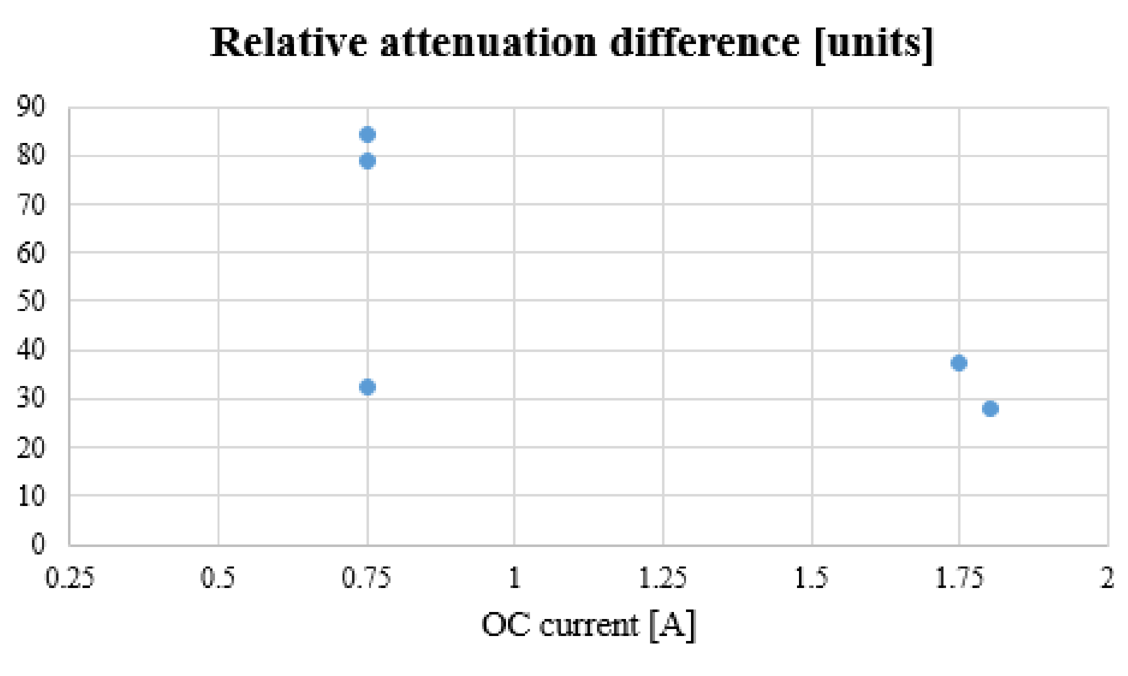

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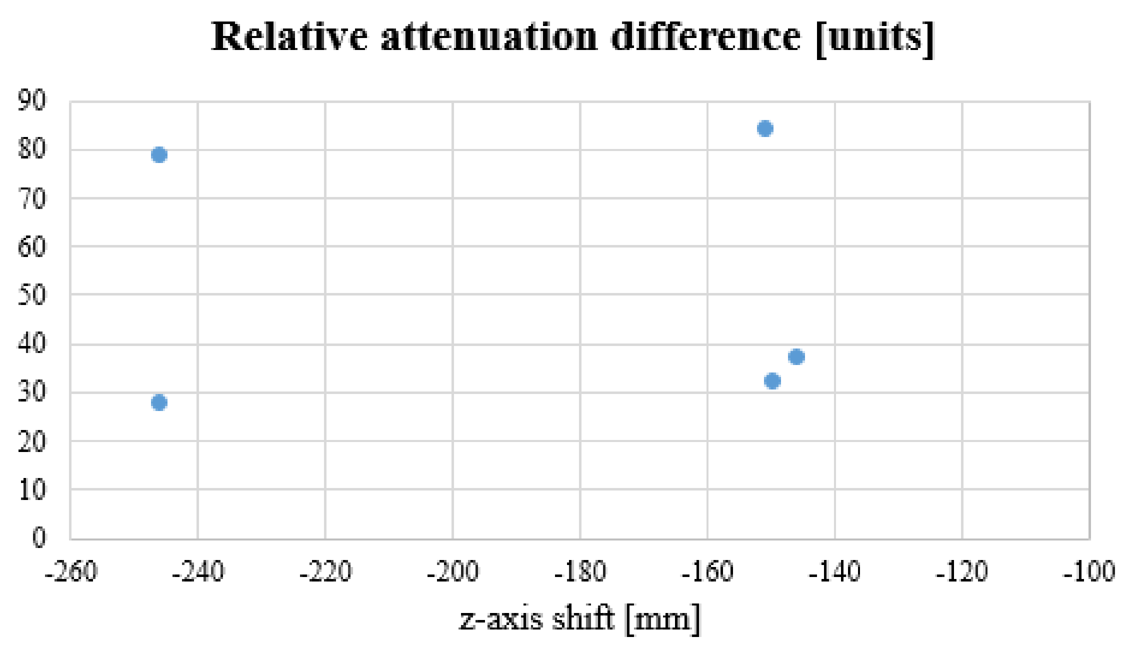
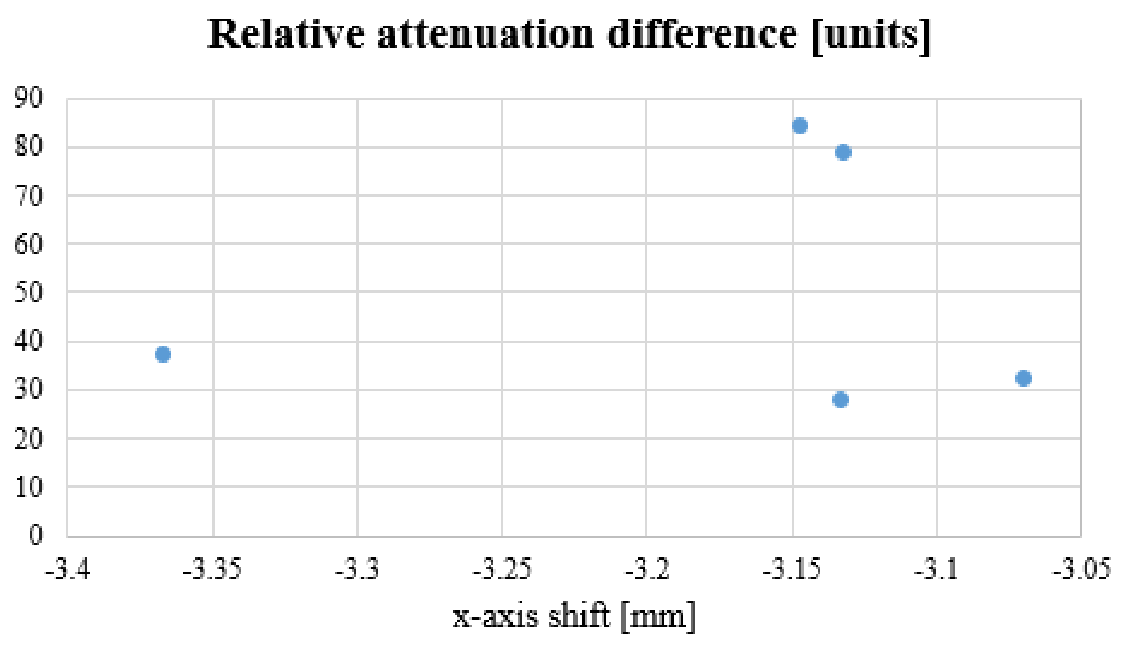




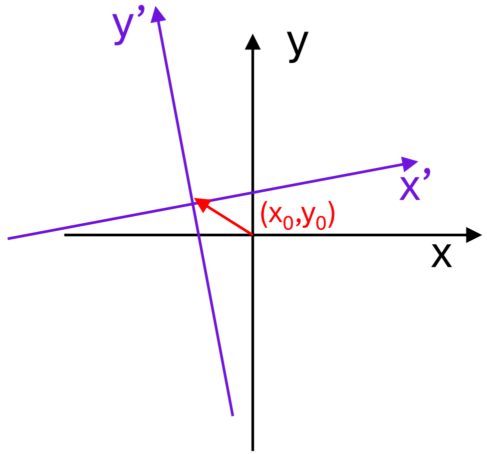
Quadrupole magnetic axis

In the mapper frame x'Oy'

$$B_{x'}(x',y') = -g\sin 2\theta_r\, x' + g\cos 2\theta_r\, y' - g\sin\theta_r\, x_0 + g\cos\theta_r\, y_0$$

$$B_{y'}(x',y') = +g\cos 2\theta_r\, x' + g\sin 2\theta_r\, y' + g\cos\theta_r\, x_0 + g\sin\theta_r\, y_0$$

Roll angle contribution quad — **Dipole feed-down contribution with roll**



$$\boldsymbol{B_y(x') = 0}\ ? \quad \boldsymbol{B_x(y') = 0}\ ?$$

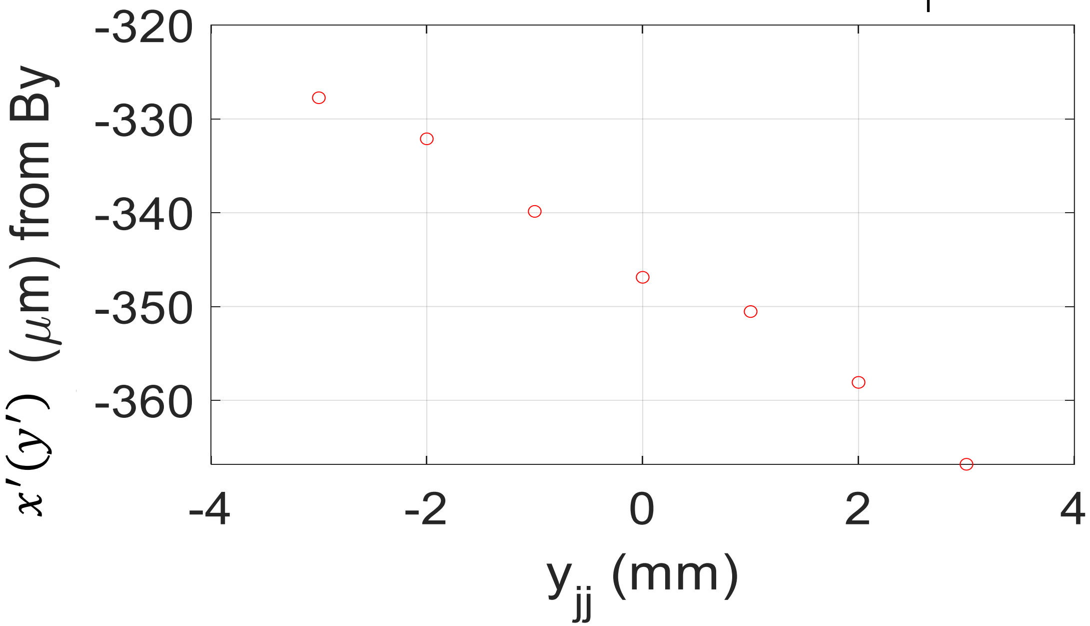
$$0 = -\sin 2\theta_r\, x' + \cos 2\theta_r\, y' - \sin\theta_r\, x_0 + \cos\theta_r\, y_0$$

$$0 = \cos 2\theta_r\, x' + \sin 2\theta_r\, y' + \cos\theta_r\, x_0 + \sin\theta_r\, y_0$$

Assuming $\theta r << 1$

$$x'(y') \approx -(2\theta_r y' + x_0)$$

$$y'(x') \approx -2\theta_r x' + y_0$$



Line functions of x' and y' allow estimating the roll angle (linear fit) and the axis coordinates