Set-up, characterization & mitigation of cross-talk between PM-based & ferrite-enforced appliances for FLASH 2020

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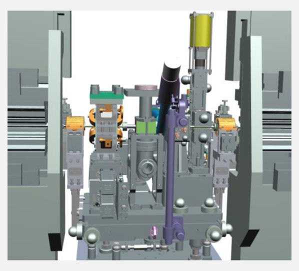
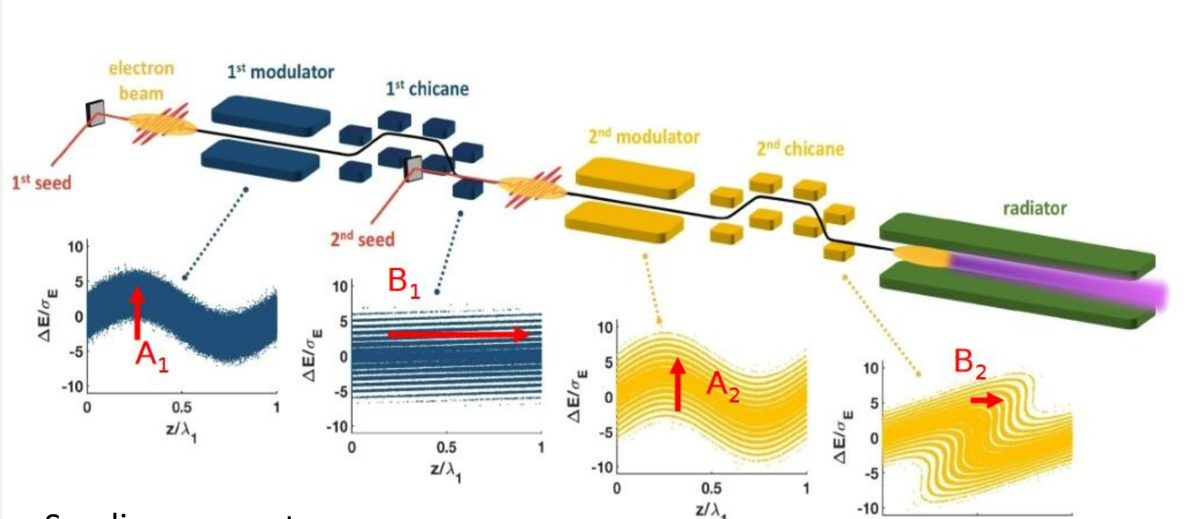
Seeding line with radiators – Upgrade of FLASH1 to a seeded FEL

- 6 variable polarisation undulators (APPLE III) of 2.5m length each, with intersections of about 0.8m length between the undulators.
- Intersection contains various e-beam diagnostics, vacuum instrumentation, a quadrupole magnet, **corrector coils** and a **phase shifter chicane magnet**.
- The phase shifters are used to **delay the electron beam trajectory** to phase the **radiation of the adjacent undulators** which shall **interfere constructively and radiate coherently**.
- Longitudinal space in the intersections is constrained: a **compact, permanent magnet-based** phase shifter was developed to replace larger EM phase shifters and a **series of ten PSs** was built.

Seeding beamline.

Intersection with phase shifter, corrector coils, BPM and quadrupole magnet. ►





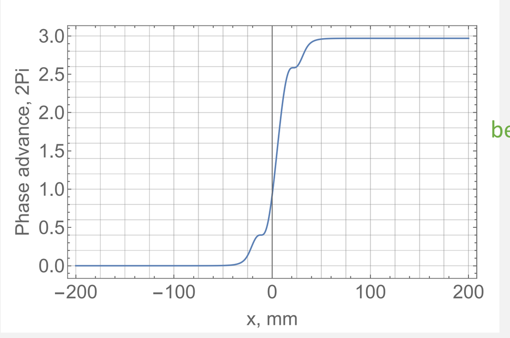
Seeding concept.

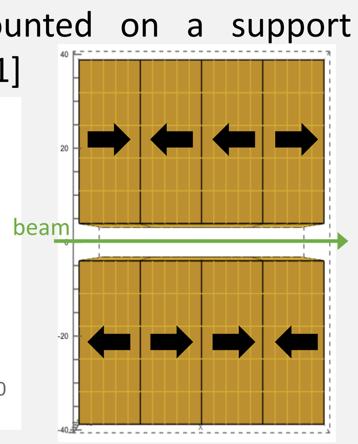
● Phase range of 2.8*2π for 20nm@1.35GeV ● Series of 10 phase shifters ● Compact, permanent magnet-based design ● Pre-sorting allows for using lower quality, low price magnets ● <0.02Tmm on-axis kick remaining ● novel tuning method for meticulous and individual correction ● high uniformity within series

Permanent-magnet based phased phase shifters

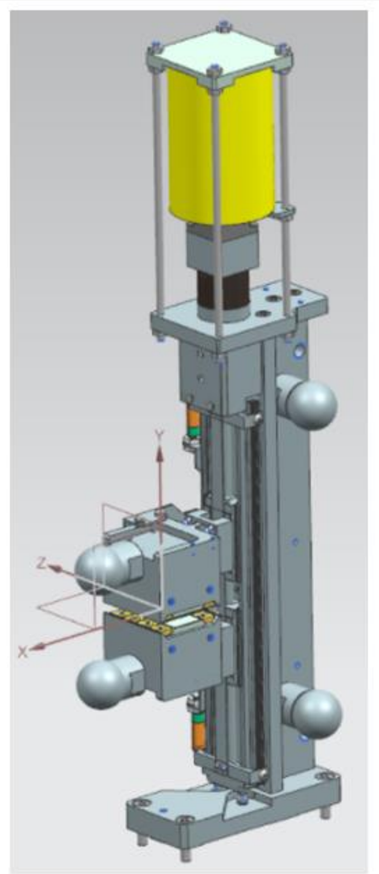
Magnetic set-up

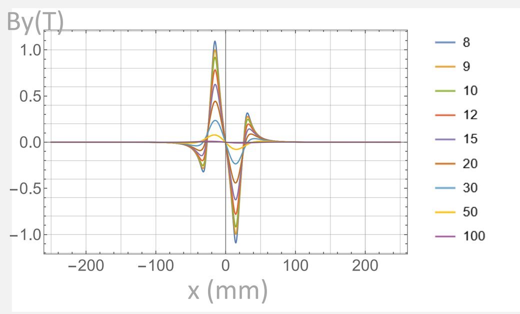
Each phase shifter consists of **eight equal permanent magnet blocks** (four in the top and four in the bottom keeper) mounted on a support structure with **movable gap.** [1]





L: Phase advance along the beam direction for 8mm gap. R: Magnet configuration, black arrows indicate the direction of magnetization.





By(T) on axis for different gaps.

Magnet blocks. Size: 35x35x15mm^3

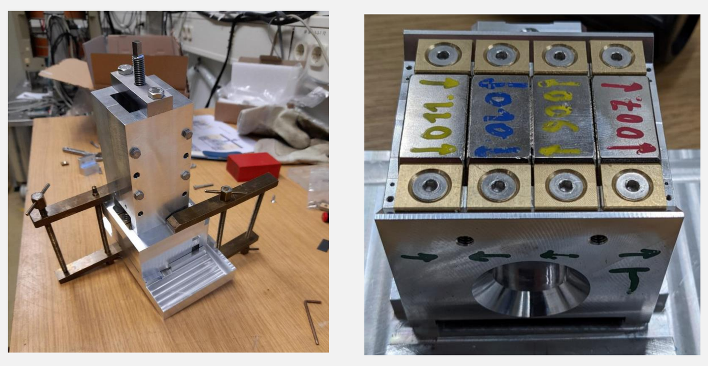
Table 1. Specified design parameters.

E	1.35	GeV
λ_u	30	mm
Gap	8	mm
$\Delta\phi$	>1.5x2π	rad
L_{mag}	<100	mm

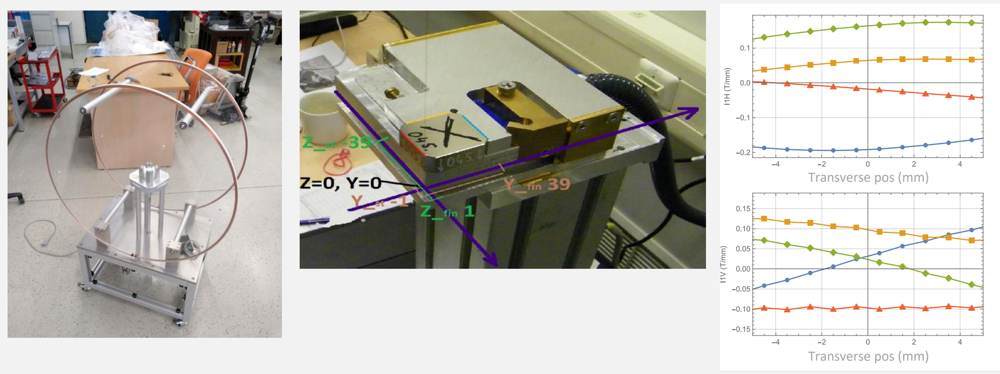
Assembly

Large forces of >700N: **dedicated frame** that allows for a **safe and accurate mounting** of the magnets into their keepers.

Process can be **reversed** to take magnets out safely.



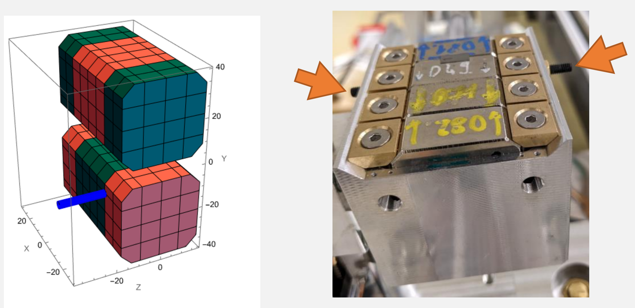
Magnet characterization and sorting

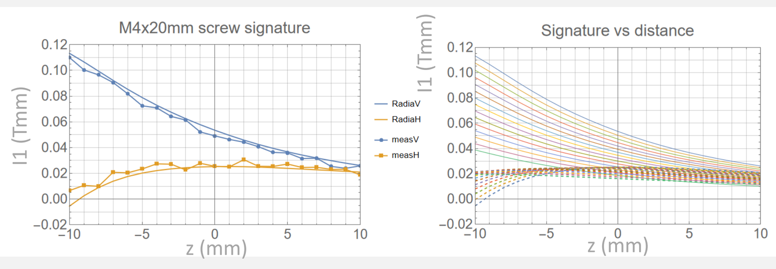


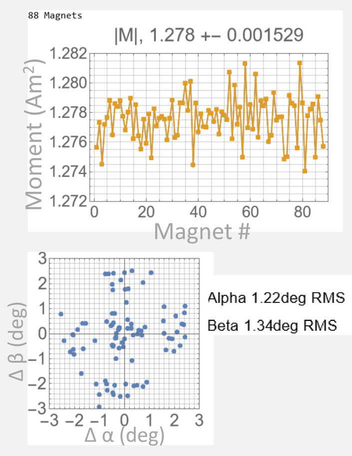
88 magnets were characterized by **Helmholtz coil** (L) and **stretched-wire** (centre). Example for hor (top R) and vert (bottom R) first field integral of the four sides of one magnet.

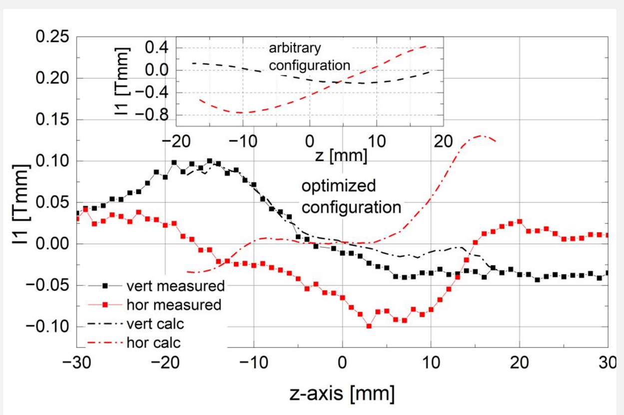
Characterization and tuning

Characterization by **Hall probe and stretched wire measurements**. **Remaining on-axis field integrals** compensated by **inserting magnetic screws** acting as a shunt on the side of the keepers. **Magnetic signature** of one screw at different distances to the magnets was **first calculated in Radia** (below). Specific screw configuration (number of screws, position and distance to magnets) was computed for the remaining field integral of each PS.



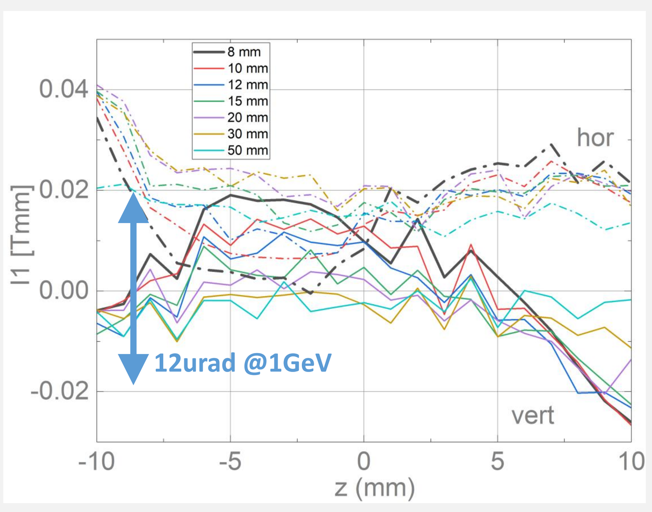


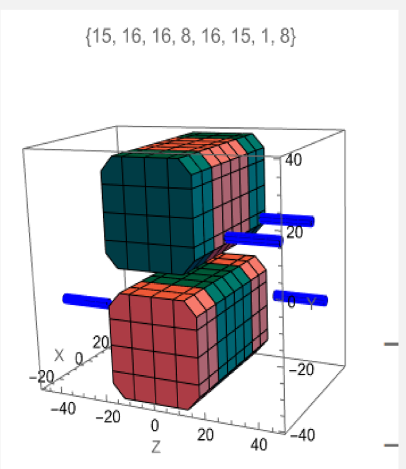




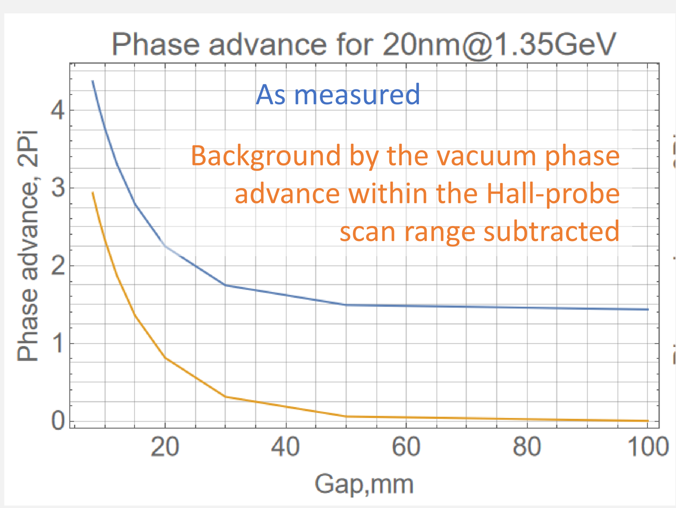
L: Total magnetic moment and angular distribution of the moment for 88 magnets. R: Inset: Vert and hor 1st field integral of a phase shifter with **arbitrarily picked magnets**. A **sorting process** would start with an arbitrary starting configuration and would rotate and swap magnets randomly in each position, keeping only more favourable configurations. After 50'000 iterations, the total field integral close to the beam was reduced to **<0.05Tmm**. **Off-sets** in the measured data (symbols) result from **small misalignments** during the mounting process.

Final parameters





L: Remaining **vertical and horizontal first field integral after screw correction** (centre) for different gaps between 8 and 100mm. Signal at 100mm gap was subtracted at smaller gaps as a background.



Phase advance as a function of gap. The technical specifications asked for a minimum phase range of 1.5*2π ,all phase shifters achieve at least **2.8*2π.**

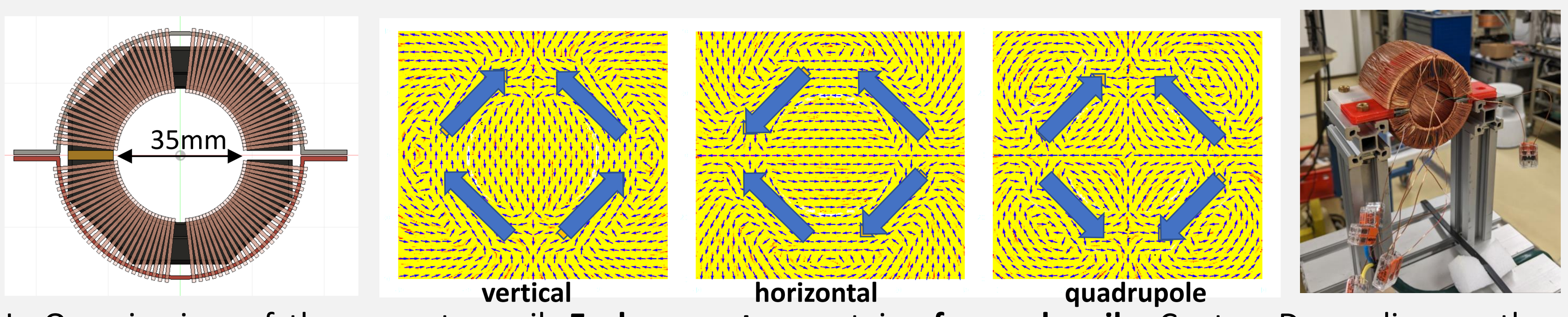
Corrector coils with variable field direction

(Usually **gap dependent**) **kicks to the electron beam that remain after undulator tuning** have to be corrected with the help of steerer coils. Small, **resistive coils** are placed **upstream and downstream of an undulator** and by varying the strength and direction of the generated magnetic field, they allow to **deflect the beam** by a small angle and to consequently **correct its trajectory**.

● Ferrite-based. ● 0.55Tmm at 1A. ● AC capability. ● Air-cooled ● Compact and cost-efficient design ● Series of 40 coils manufactured

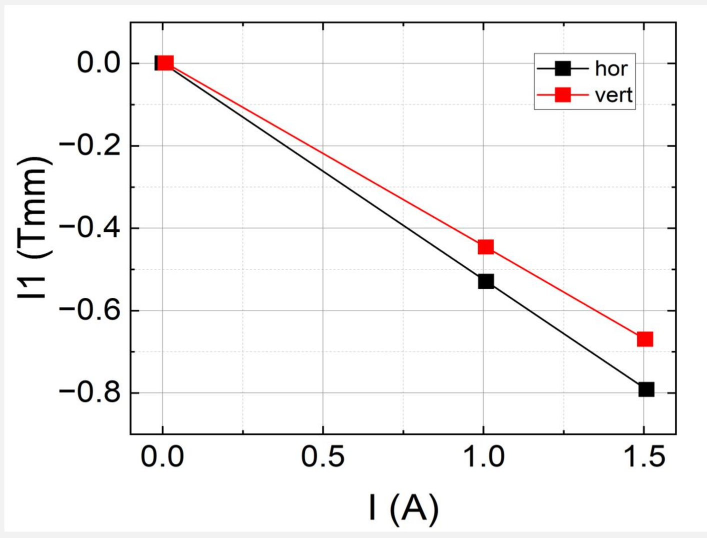
Set-up and operation

Steerers/corrector coils will be mounted around a 34mm CF16 flange of the vacuum chamber on an **adjustable holder**. The **ferrite core enhances** the coil strength by **more than 50% compared to previous design** (air coils). The ferrite **is suitable for HF use (>10MHz)**, however, for practical purpose the ramp rate will be limited and the coils are **part of a slow feedback system**.



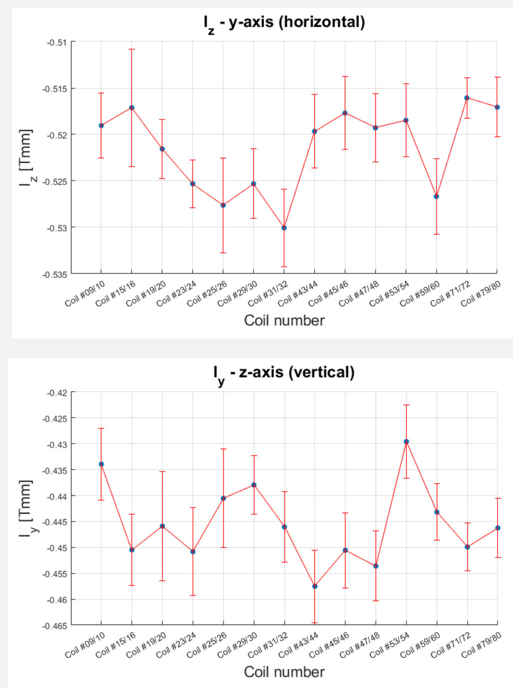
L: On-axis view of the corrector coil. **Each corrector** contains **four sub-coils**. Centre: Depending on the polarity, **vertical, horizontal or quadrupole fields**, or any linear combination can be generated when powered independently. An integrated quadrupole of 30mT@1A could be used as an alignment quadrupole for undulators, if both were measured and aligned together in the lab before installation in the tunnel. R: Coil in lab set-up.

Characterisation by stretched wire



◄**On-axis first field-integral** provided by the corrector coil as a **function of current** (black: hor field, red: vert field).

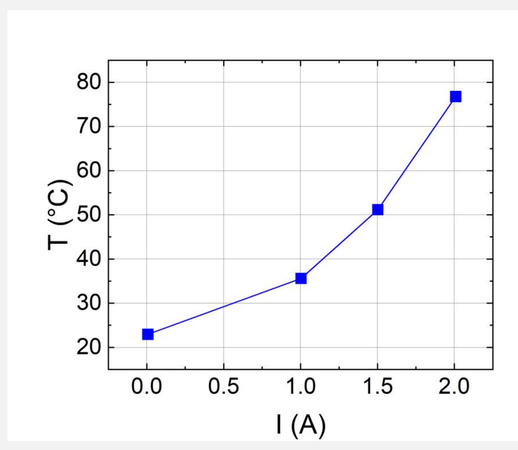
Maximum value of **first field integral** for some arbitrarily selected coils from the **series (all at 1A).**►

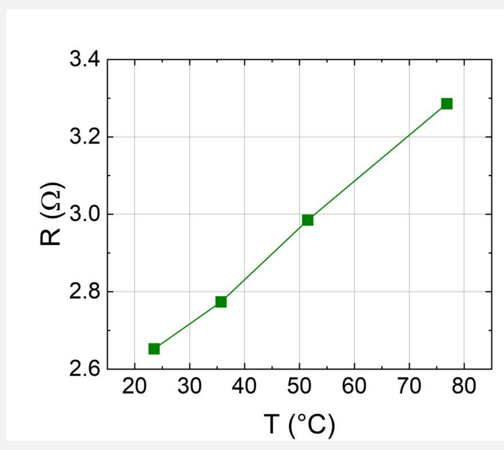


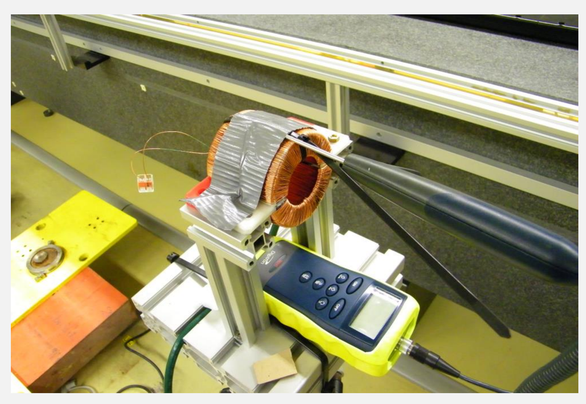
Heating effects

Both coil halves powered with the same current. Resistance of **one half** of the coil: **3.3 Ohm.**

2A * 2A * 3.3Ohm * 2coils ~ **26W Max and 75°C**, (incl. resistance increase due to temperature)







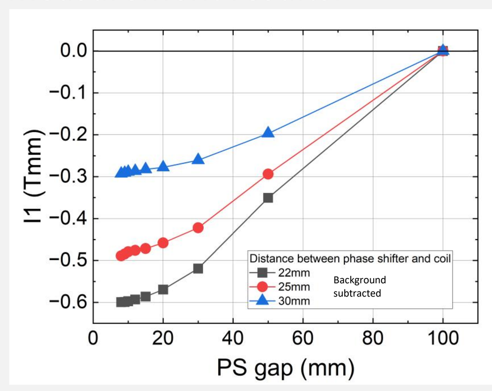
Measurement set-up.

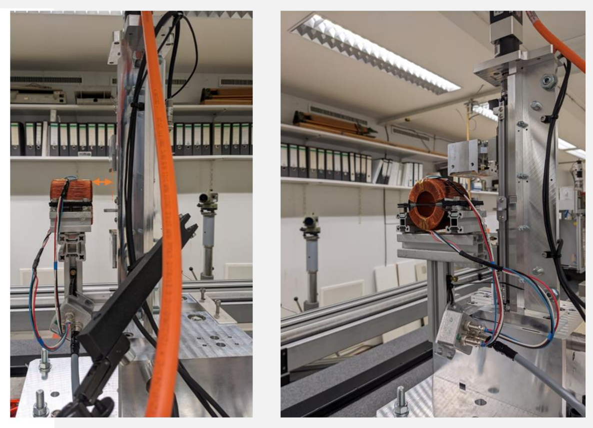
Mitigation of cross-talk

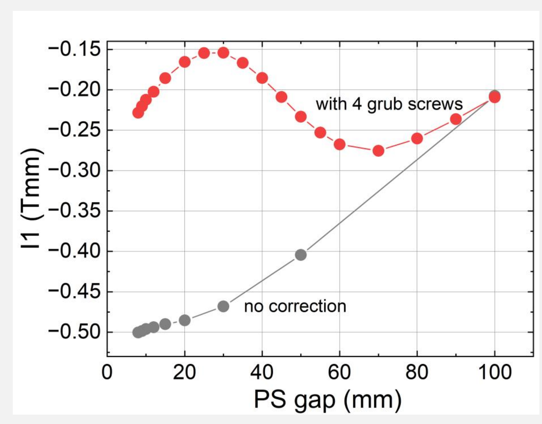
Due to spatial constraints: only **30mm space between the phase shifter and the correction coil.**

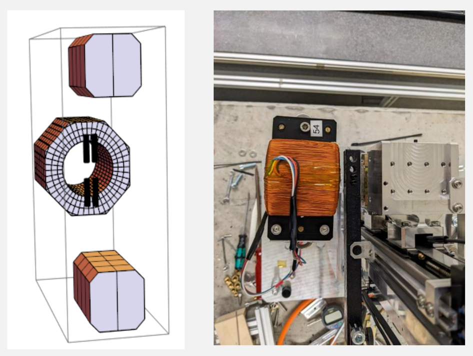
Leads to significant **cross-talk** resulting in a **dampening of the phase shifter fringe field**. Unwanted vertical kick of **0.5Tmm** at smallest gap.

Solution: Installation **of two sets of ferromagnetic screws** above and below the beam pipe, respectively. Exact position and size of the screws calculated beforehand in RADIA and refined based on stretched-wire measurement results.









Remaining kick reduced to **0.2Tmm** with a **±0.06Tmm gap-dependent variation** in vertical direction (red data points). Varying part is small enough to be forward-corrected by the steerer itself, DC part can be corrected by a small displacement of the neighboring quadrupole sitting on a motorized mover.

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References

[1] P. N'gotta *et al* 2022 *J. Phys.: Conf. Ser.* **2380** 012007