Challenges with the Permanent-magnet Delta Undulator for the Sirius Synchrotron Light Source

Low Emittance Ring – Permanent Magnets Workshop

November 2023 – Trieste, Italy

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CNPEM Brazilian Center for Research in Energy and Materials

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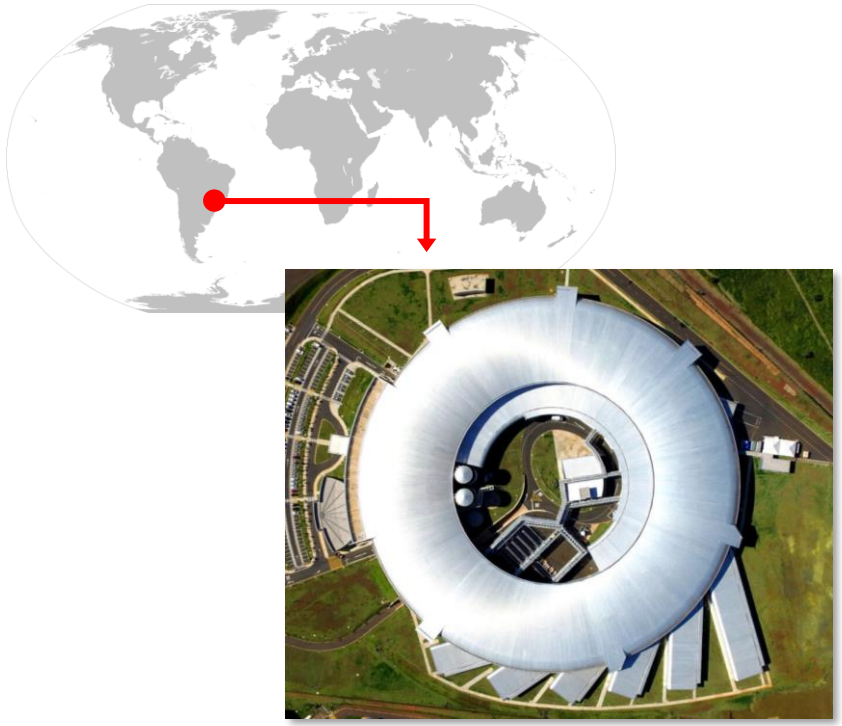
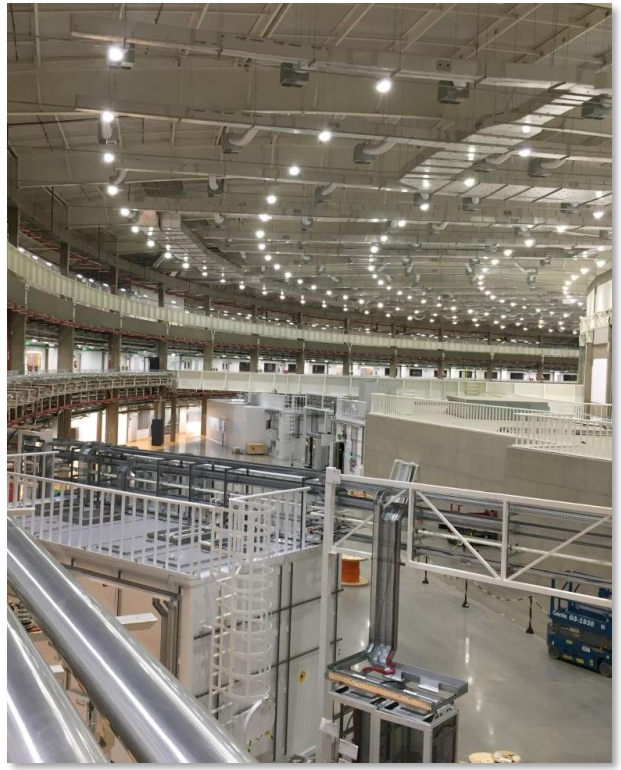
Sirius





4th generation 3 GeV synchrotron
518 m circumference S.R.
Operating at 100 mA in top-up mode
0.25 nm·rad emittance
Up to 38 beamlines

Phase 1: 14 beamlines
First opened to community in 2020
10 currently open to external users

Phase 2: 10 new beamlines
+ 3 beamlines for future BSL-4 laboratory

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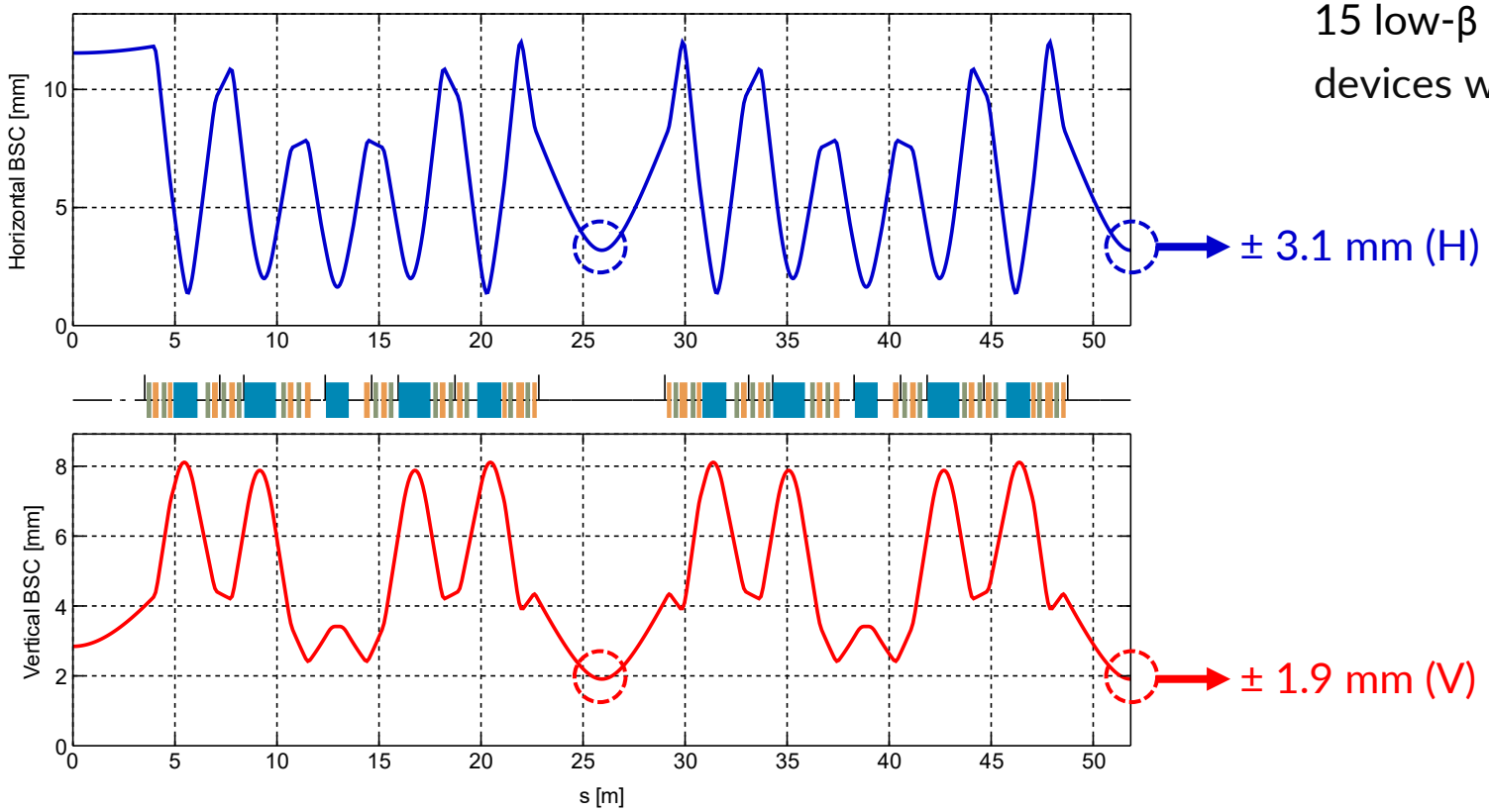
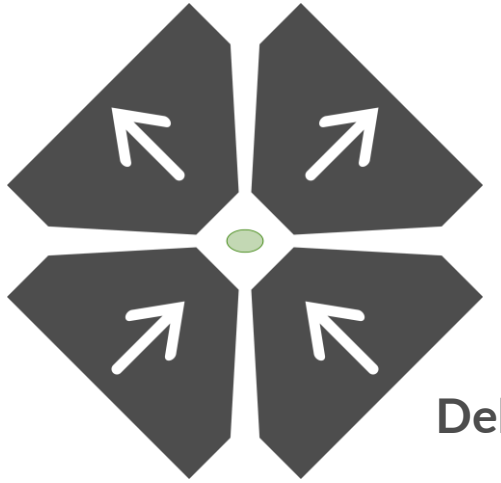
Low β beam-stay-clear



15 low-β straight sections allow for insertion devices with lower horizontal gap...



Delta design

...used for the first time in a storage ring-based light source.

Linear, circular and elliptic polarization

Symmetry in the H and V deflection parameters

Higher peak field compared to planar and APPLE-II

Less complex design compared with APPLE-X

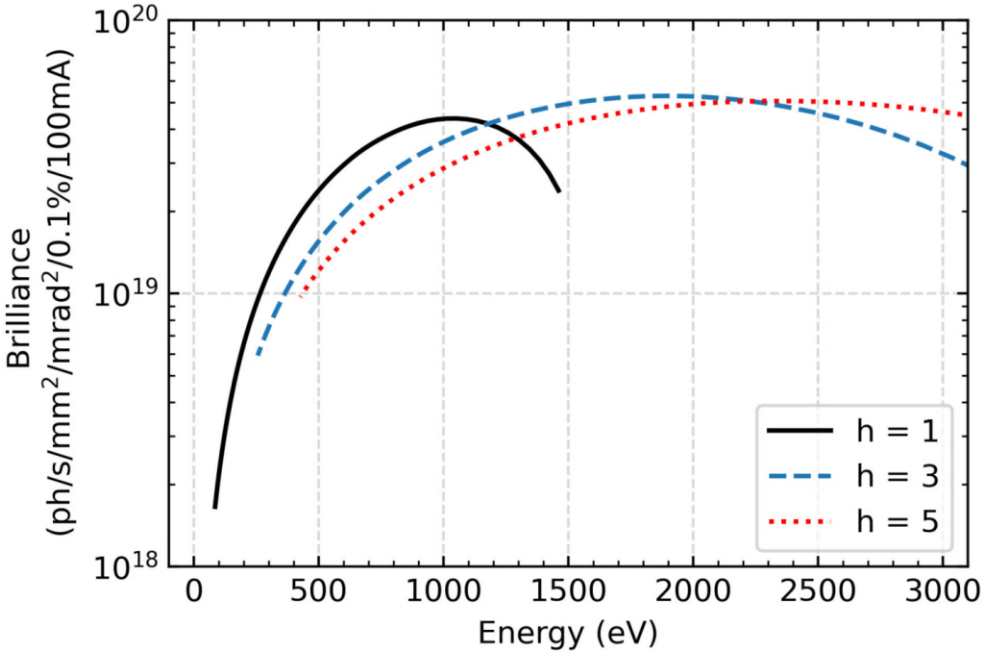
The field can be aligned with the beam axis but not eliminated

Design should allow hall probe measurements, shimming, and installation around vacuum chamber while keeping block fastening and mechanical stability in mind.

Delta Undulator for Sabiá Beamline

Soft x-rays beamline focused on x-ray absorption spectroscopy (XAS) and electron photoemission microscopy (PEEM).

Gap	13.6 mm
Number of periods	21
Period length	52.5 mm
Length	1.2 m
Energy range	0.1 – 1.6 keV
Magnets remanence (NdFeB)	1.37 T
Peak field on linear polarization	1.25 T (K = 6.1)
Peak field on circular polarization	0.88 T ($K_H = K_V = 4.3$)
Max. Transversal force on single one array	29 kN
Max. Longitudinal force on single array	33 kN



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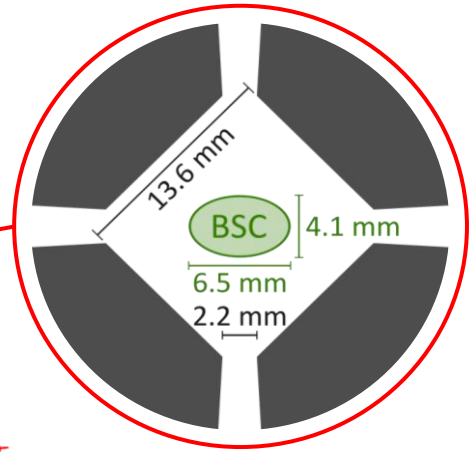
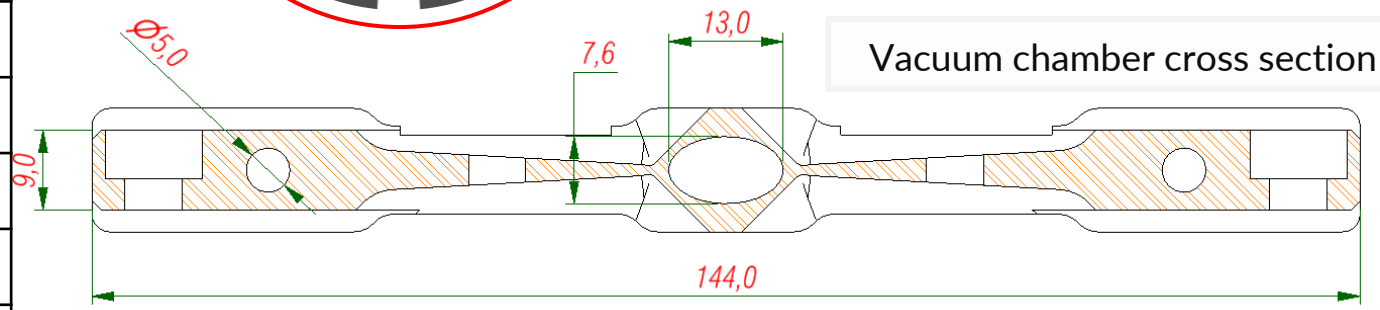
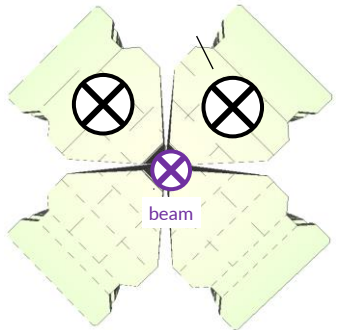
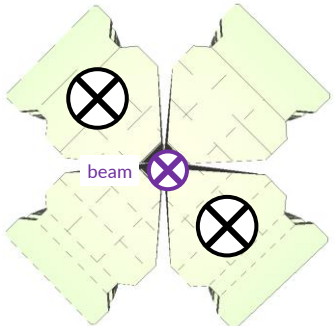




Vacuum chamber cross section



GV (vertical gain)



Phase

Cassettes movements

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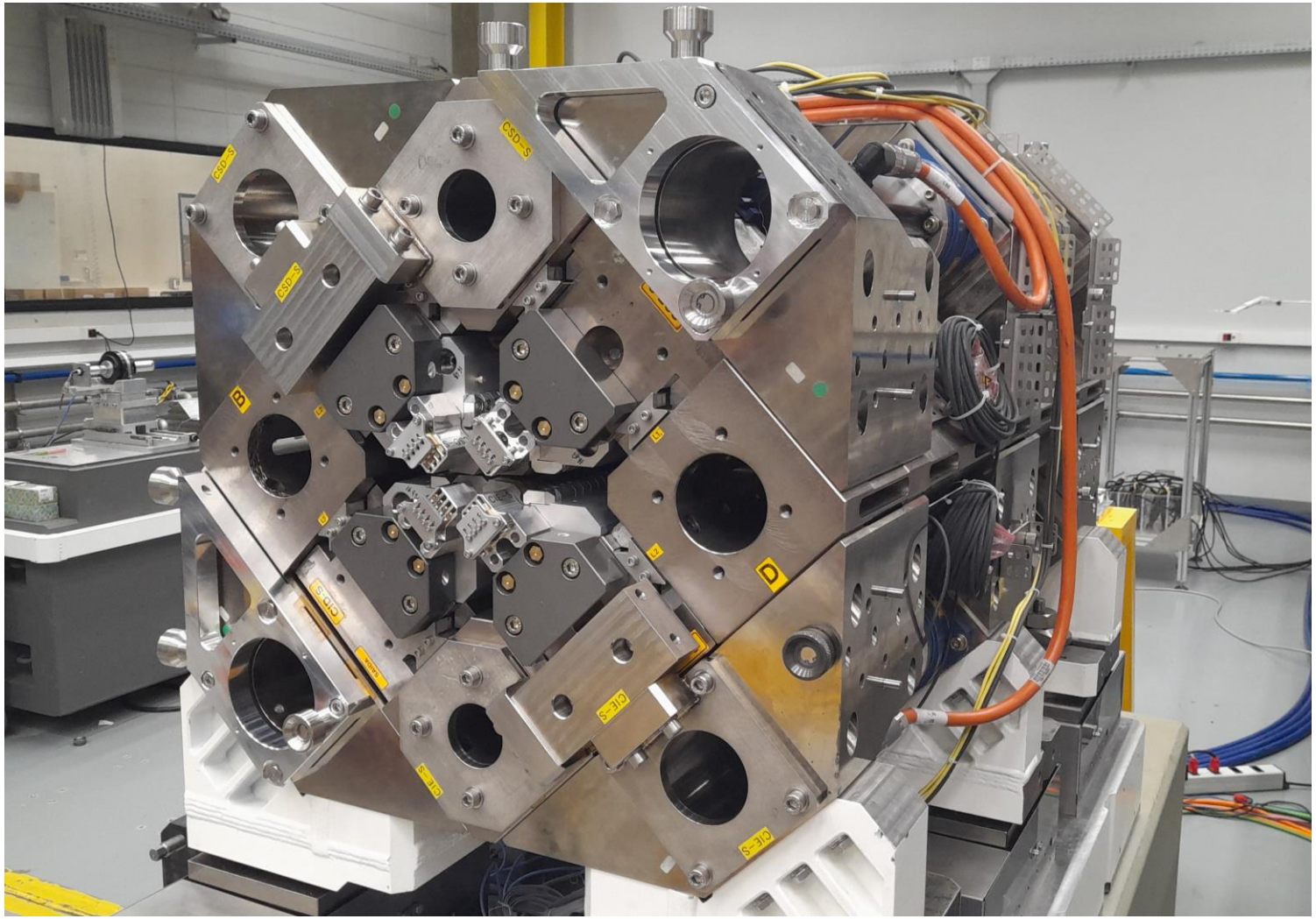
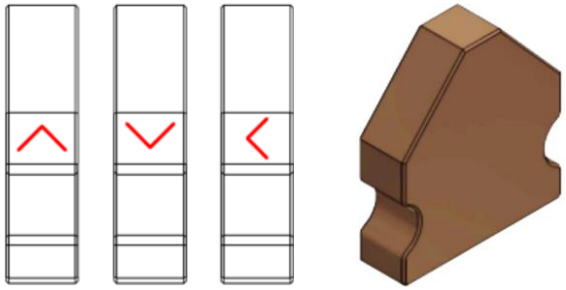
Delta Undulator for Sabiá Beamline

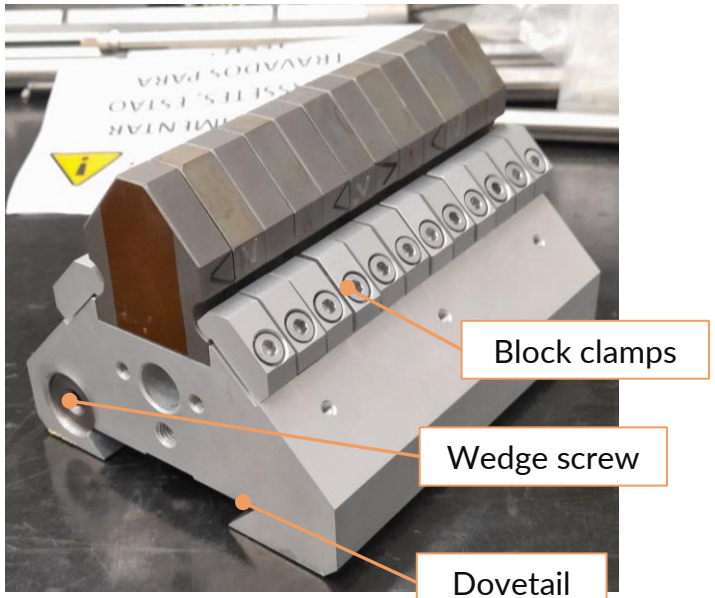


Magnet blocks and mechanical design

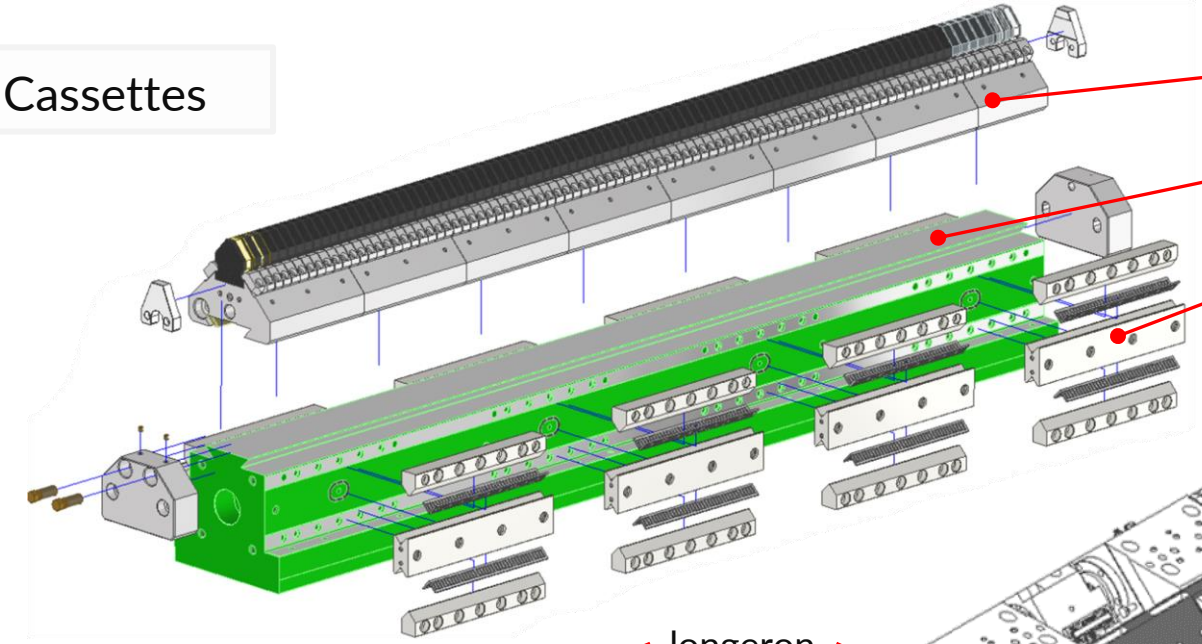
Block design



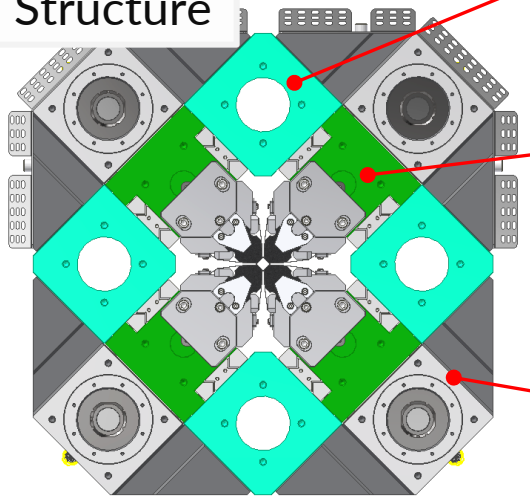
Keepers / Subcassettes

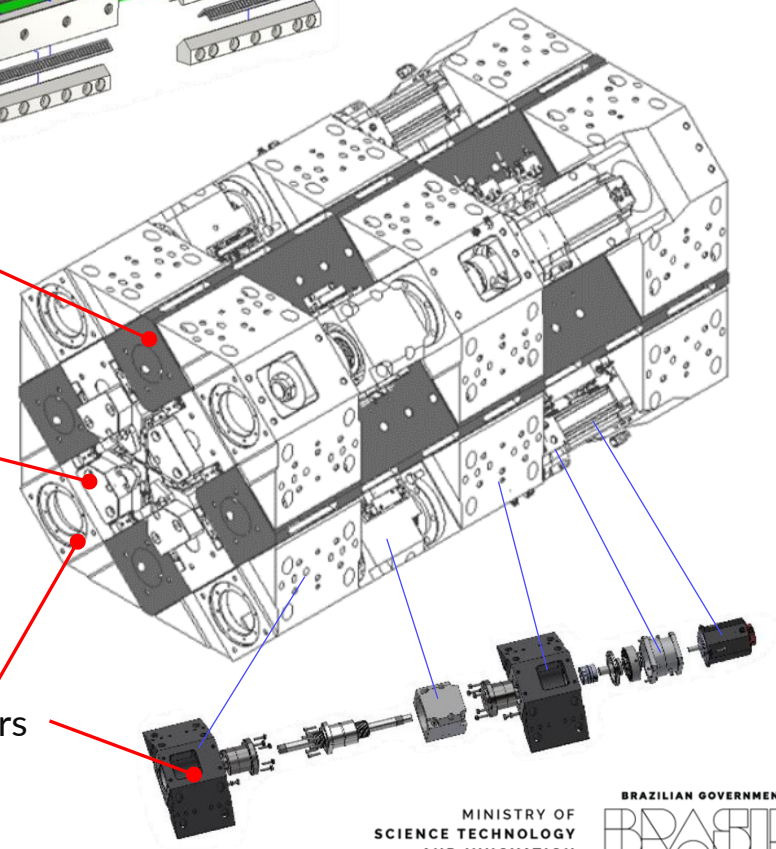


Cassettes



Full Structure





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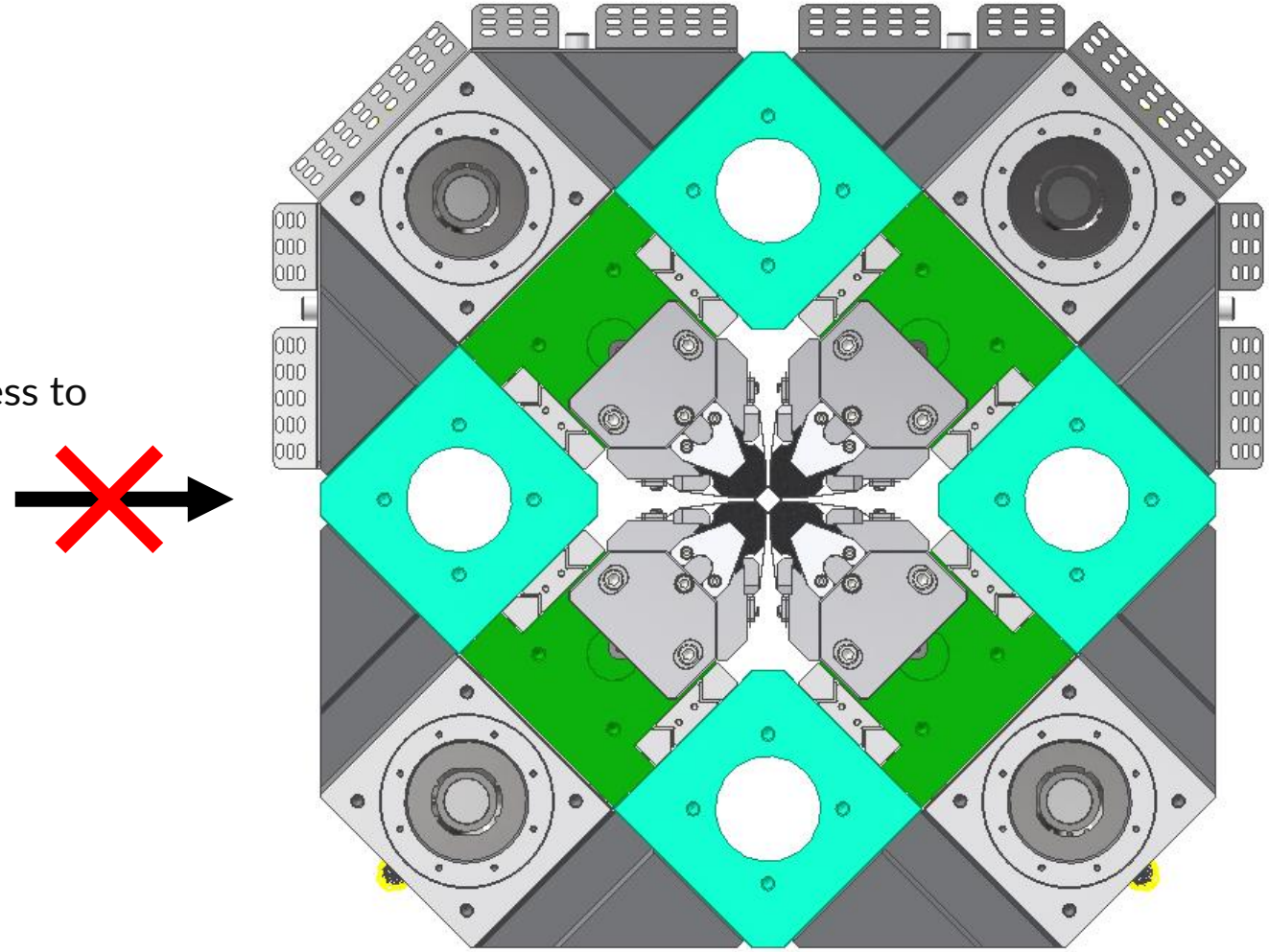
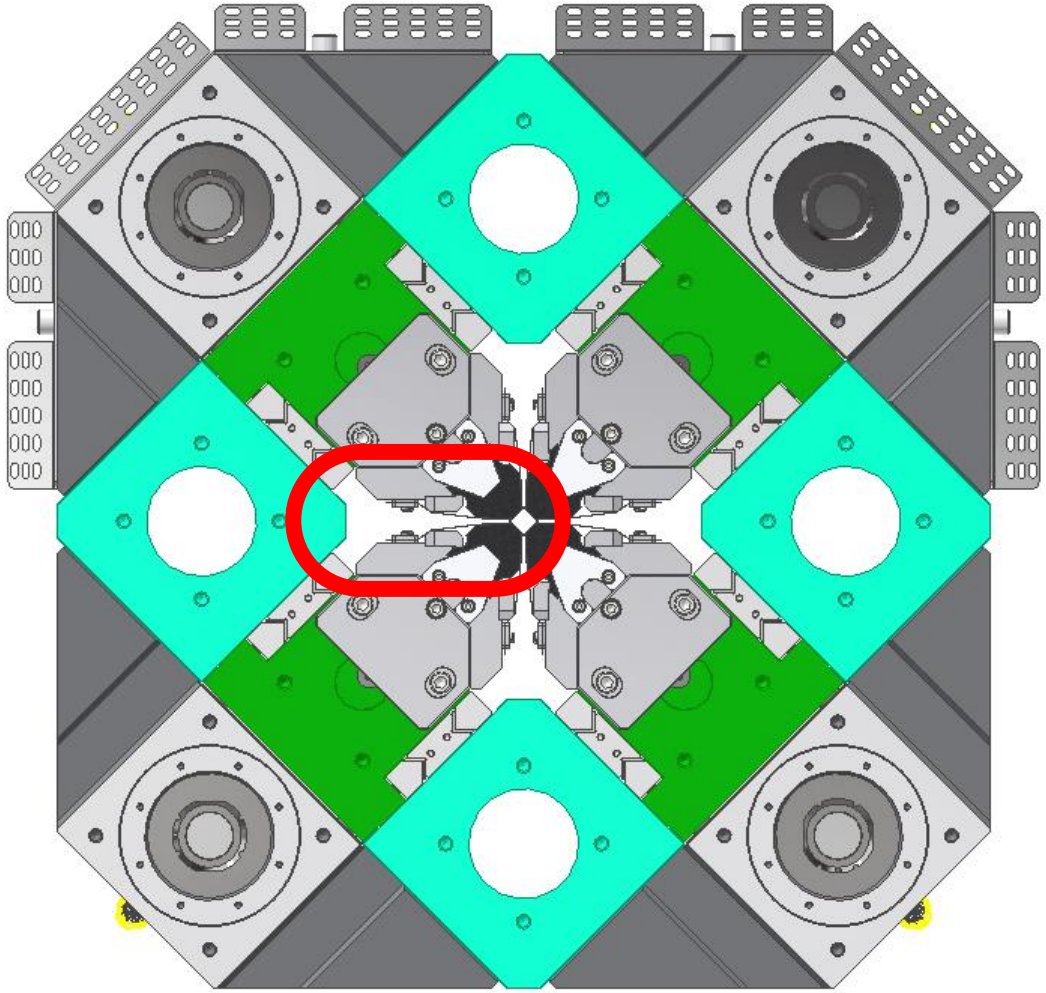
Magnetic measurement

No lateral access to magnetic gap

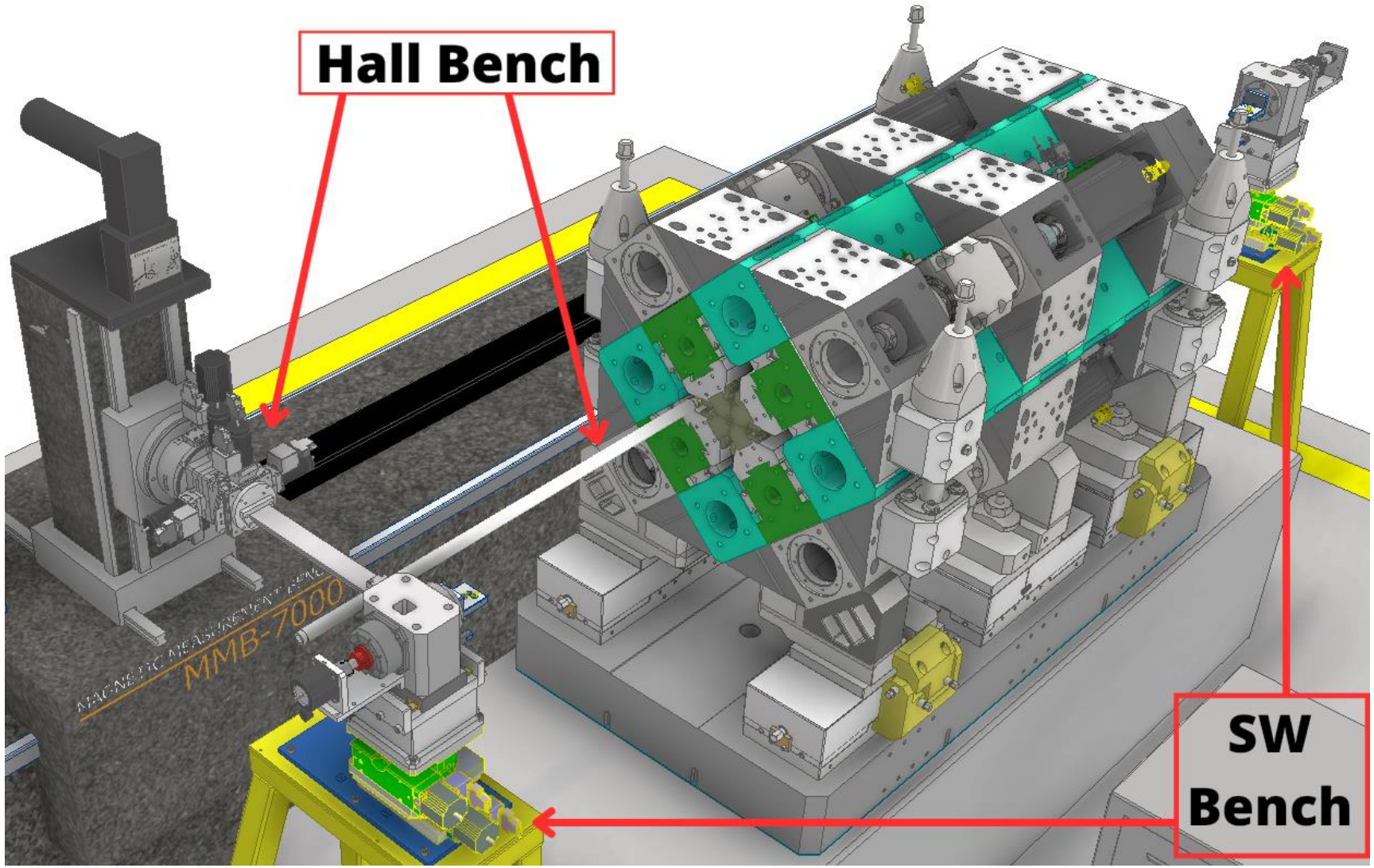


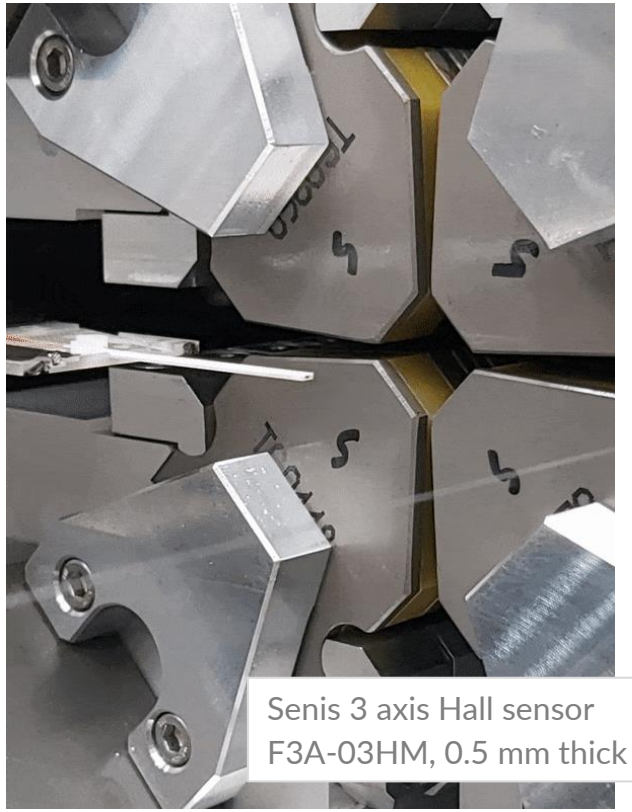
Magnetic measurement

Space between longeron and cassettes



Magnetic measurement



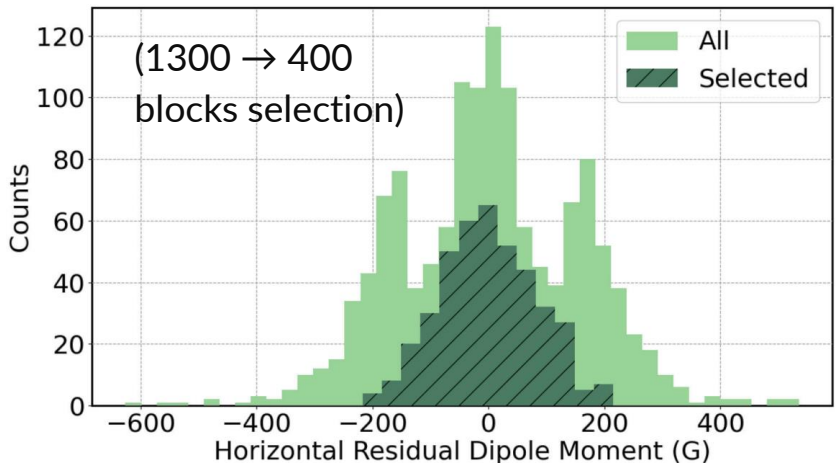


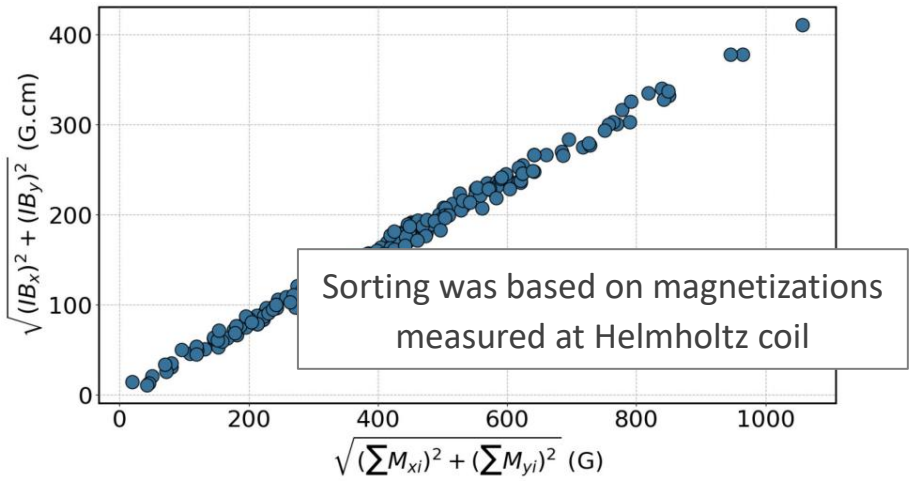
Senis 3 axis Hall sensor
F3A-03HM, 0.5 mm thick

Measurement outside central planes could not be made with Hall probe.

Magnetic assembly and optimization

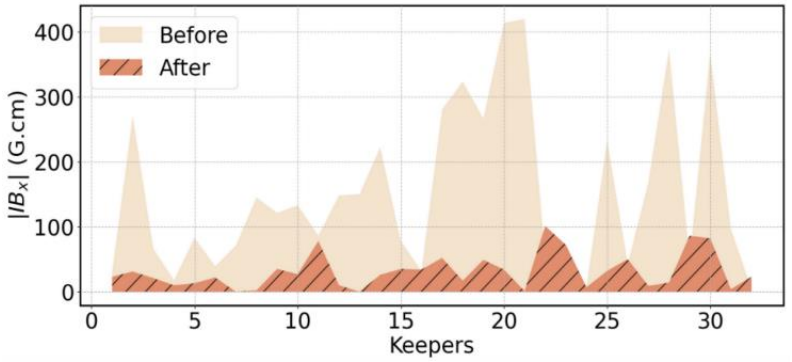
Block selection and sorting



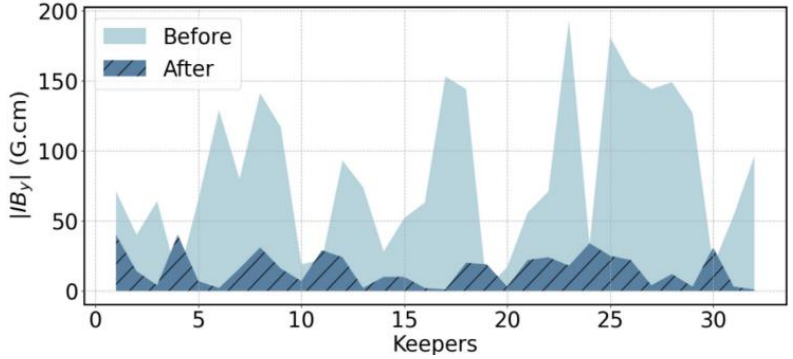


Sorting was based on magnetizations measured at Helmholtz coil

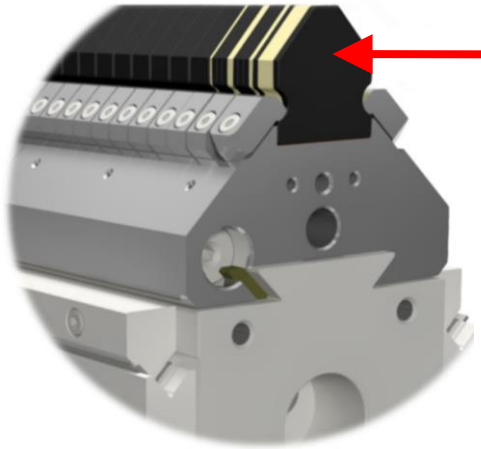
Block rotation

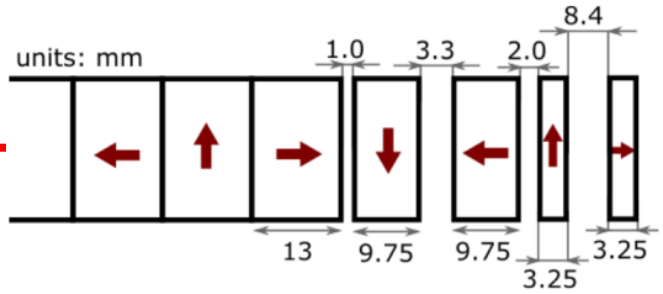


Block rotation correction



Terminations design

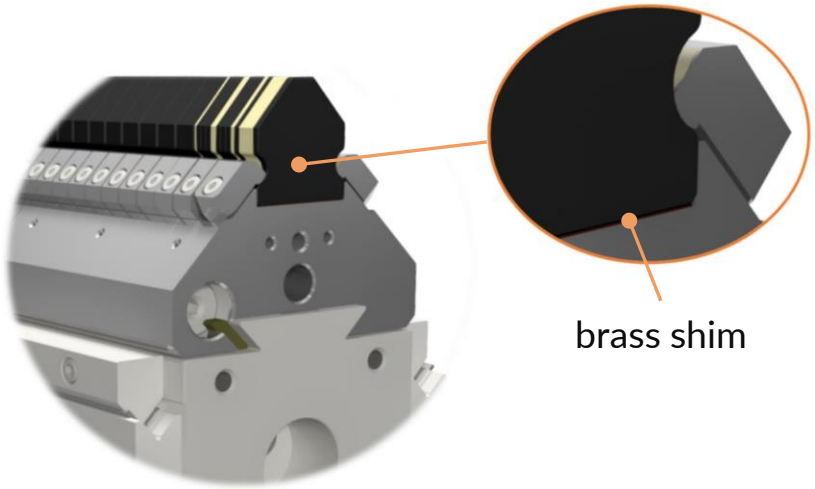


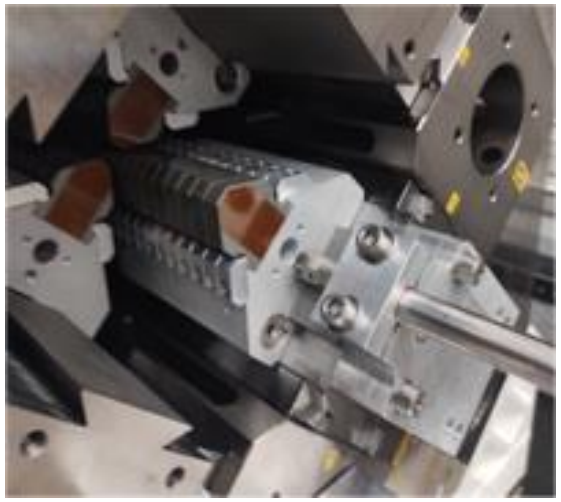


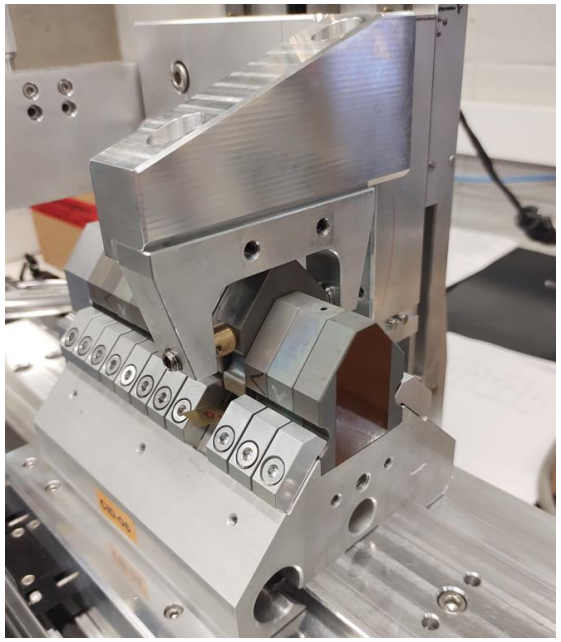
Terminations optimized only before assembly.

Magnetic assembly and correction pathways

Block shimming







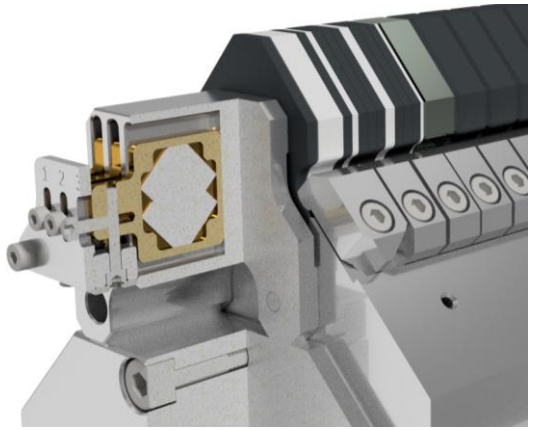
Assembly device, also used for shimming

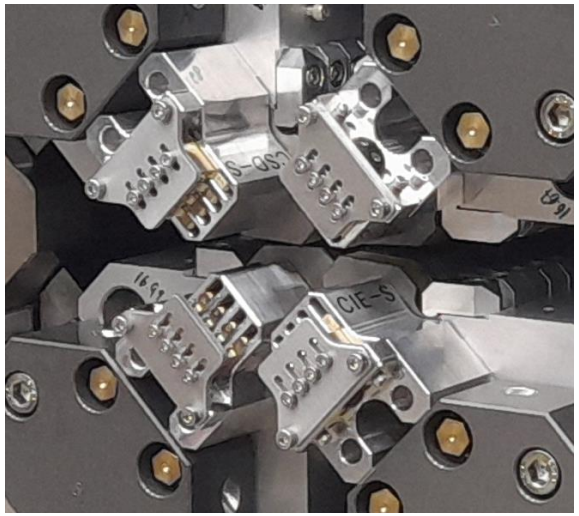
Shims from 0 to 0.5 mm in 0.05 mm steps

Initial 0.25 mm value (±0.25 mm shimming)

Keepers were disassembled and reassembled on the undulator for shimming, time-limiting the number of possible shimming iterations.

Magic fingers



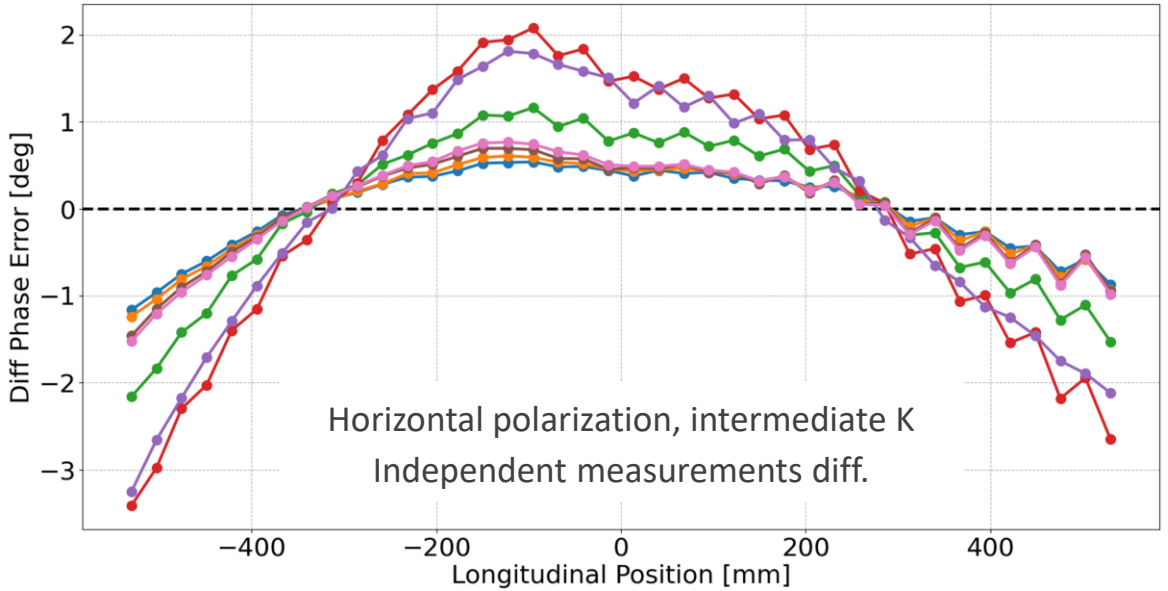


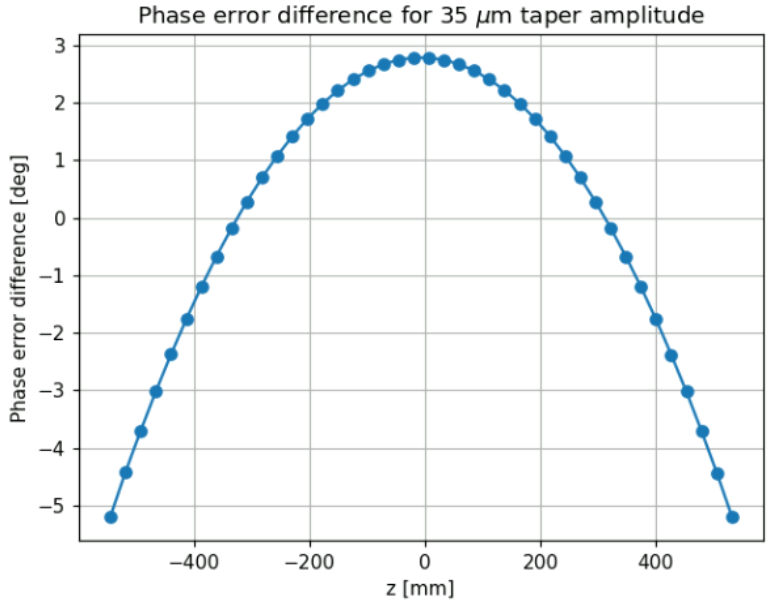
Repeatability issues

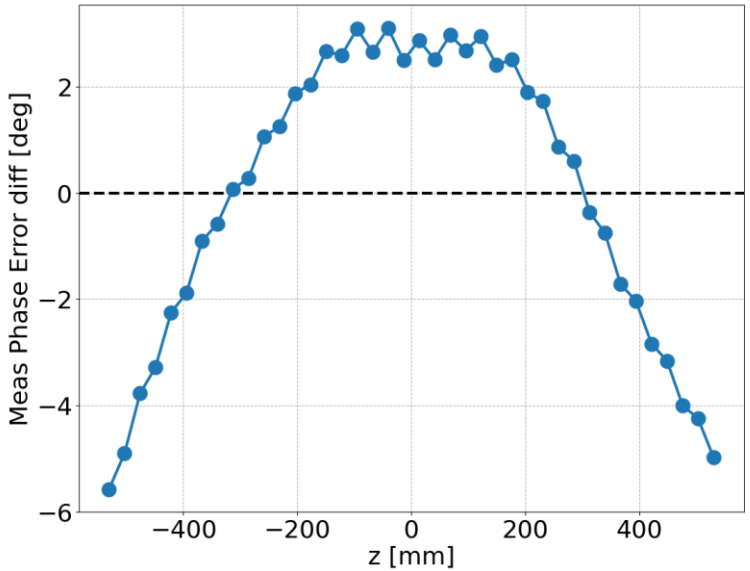
Hall probe measurements after full assembly revealed great phase error deviations among measurements separated by cassettes cycling

Radia model simulations revealed compatibility with cassette tapering

Results prompted mechanical interventions for improving cassette stability

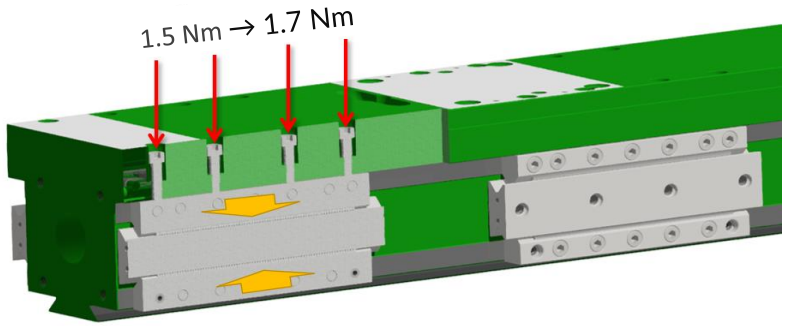




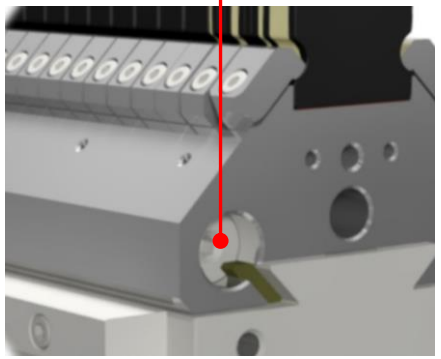


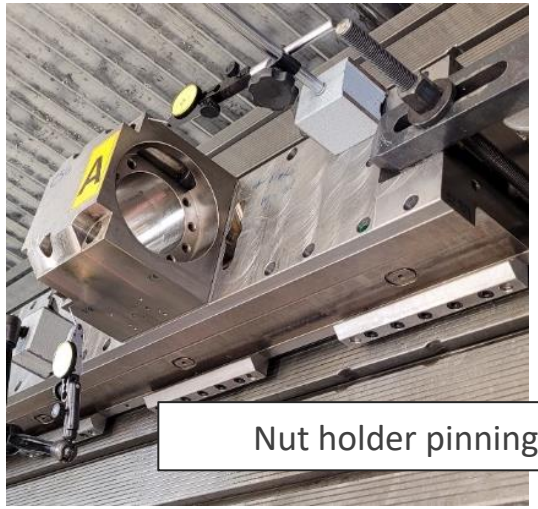
Repeatability issues – Mechanical interventions

Pre-load increase in cassettes' linear guides

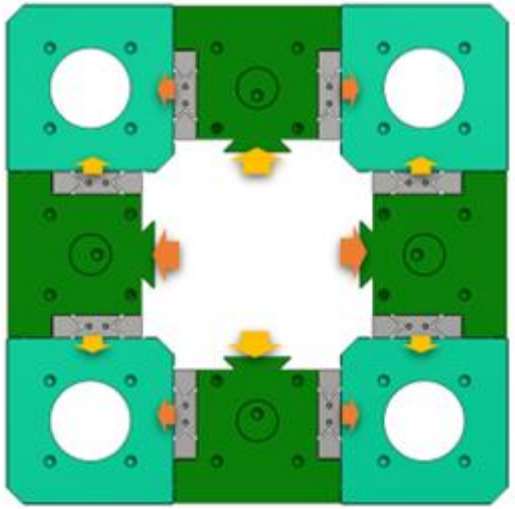


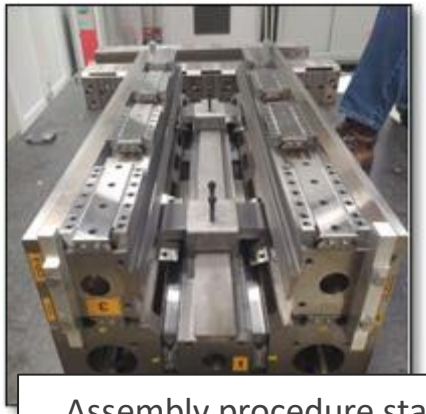
Torque increase in wedge screw (4 Nm → 15 Nm)





Nut holder pinning

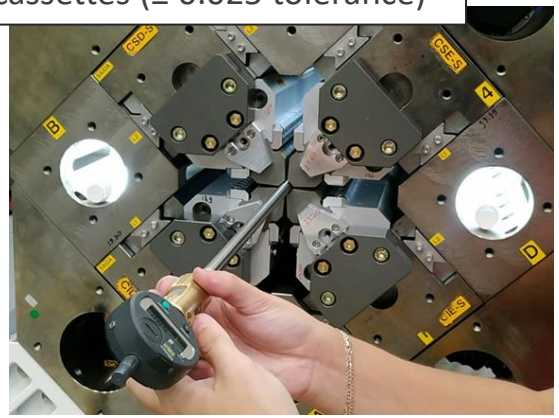




Assembly procedure standardization, including shims on linear guides

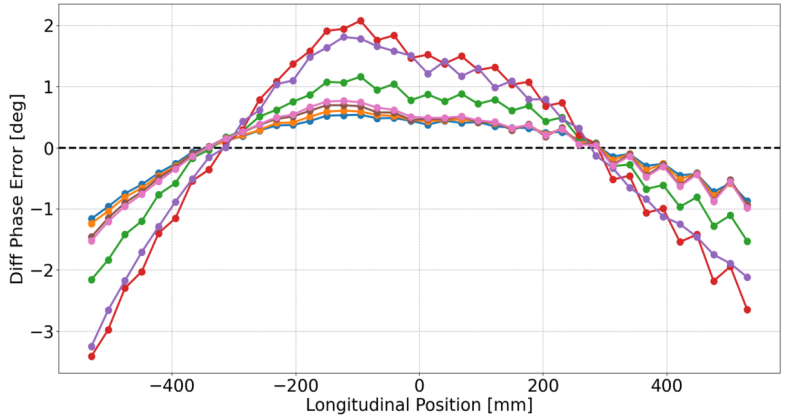
New assembly device including shims

Measurement and correction for gap between cassettes (± 0.025 tolerance)

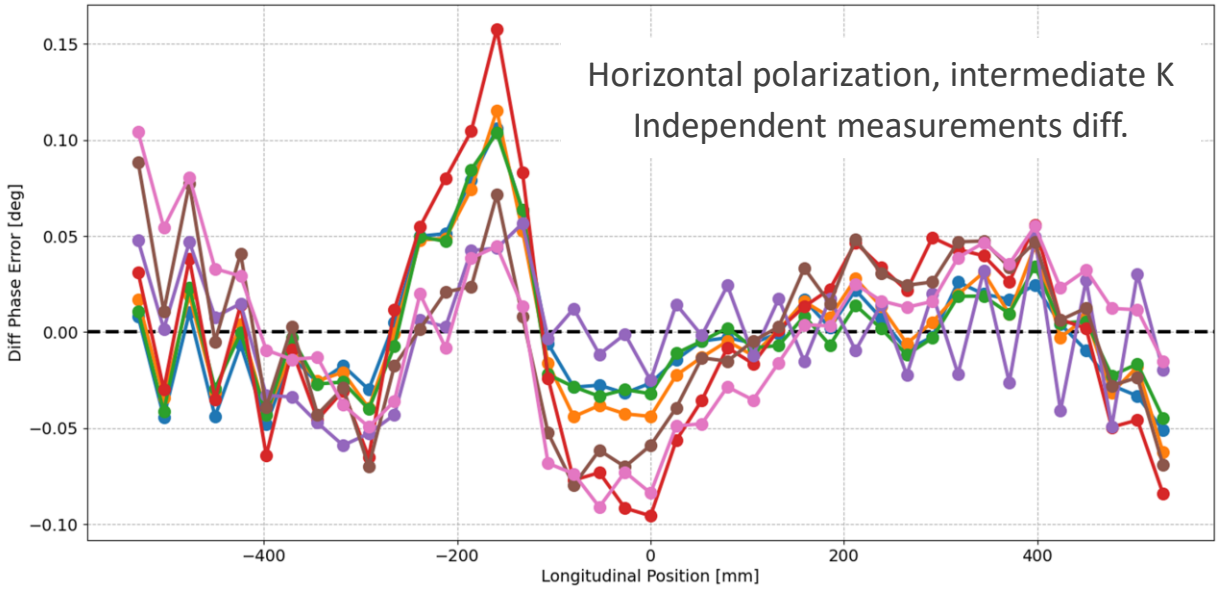


Mechanical interventions results

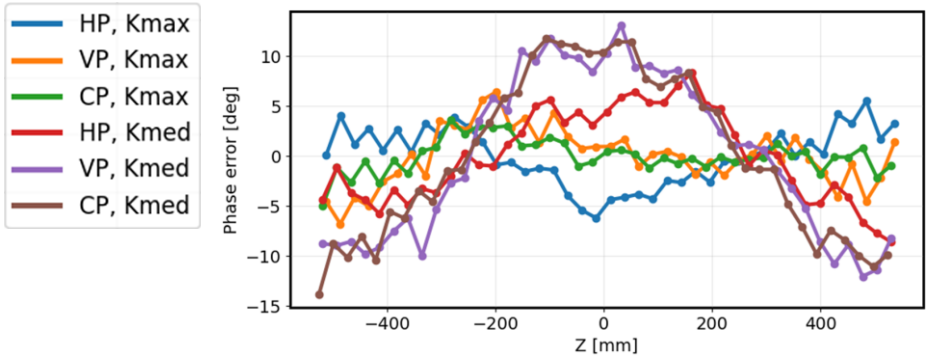
Mechanical interventions greatly improved reproducibility, as seen on phase error deviations among measurements.



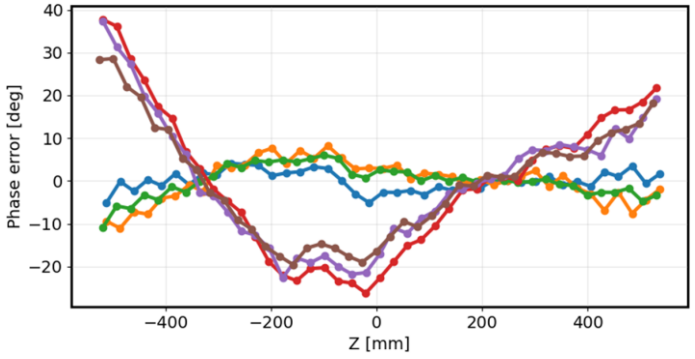
Before



After



Before



After

However, “taper-like” profile was greatly enhanced for intermediate K phases
(absolute phase error, not variation across measurements)

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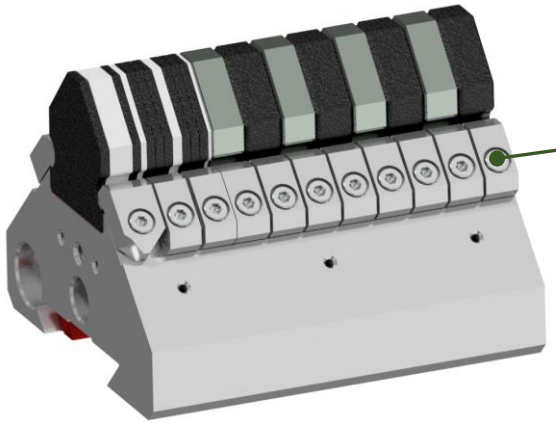
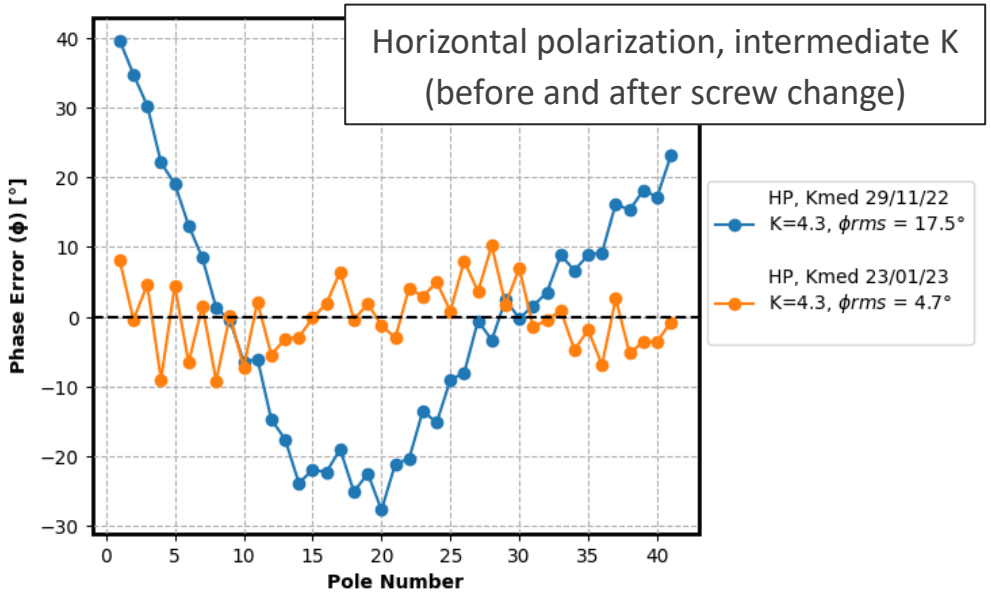
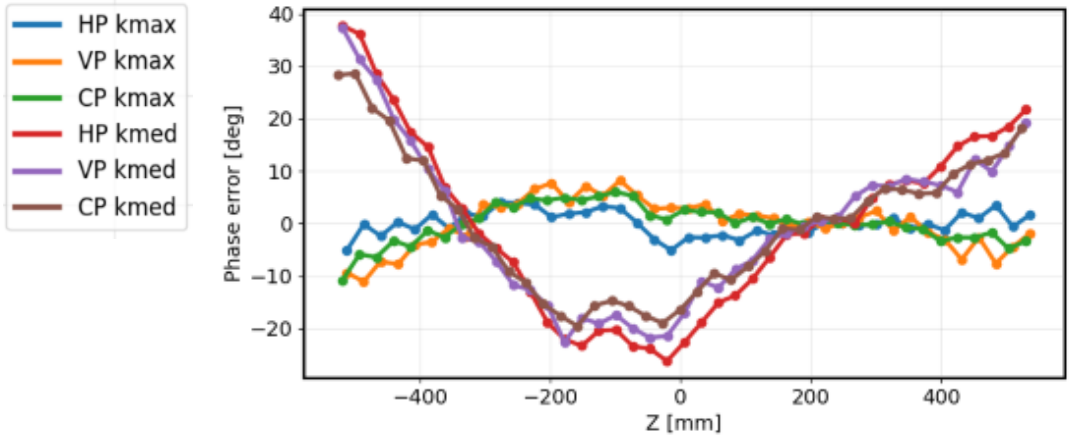
Block holding clamps screw change

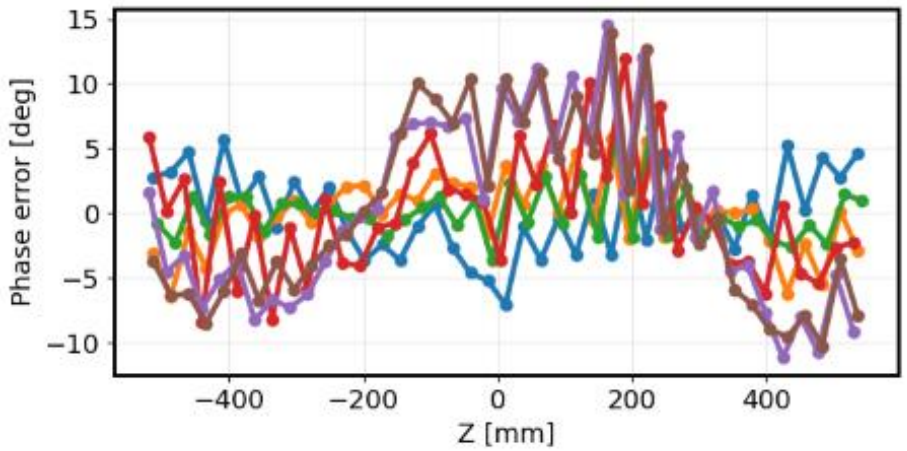


New clamp screws
Aluminium → 304 Steel
(plus, 4.2 Nm → 5.0 Nm)

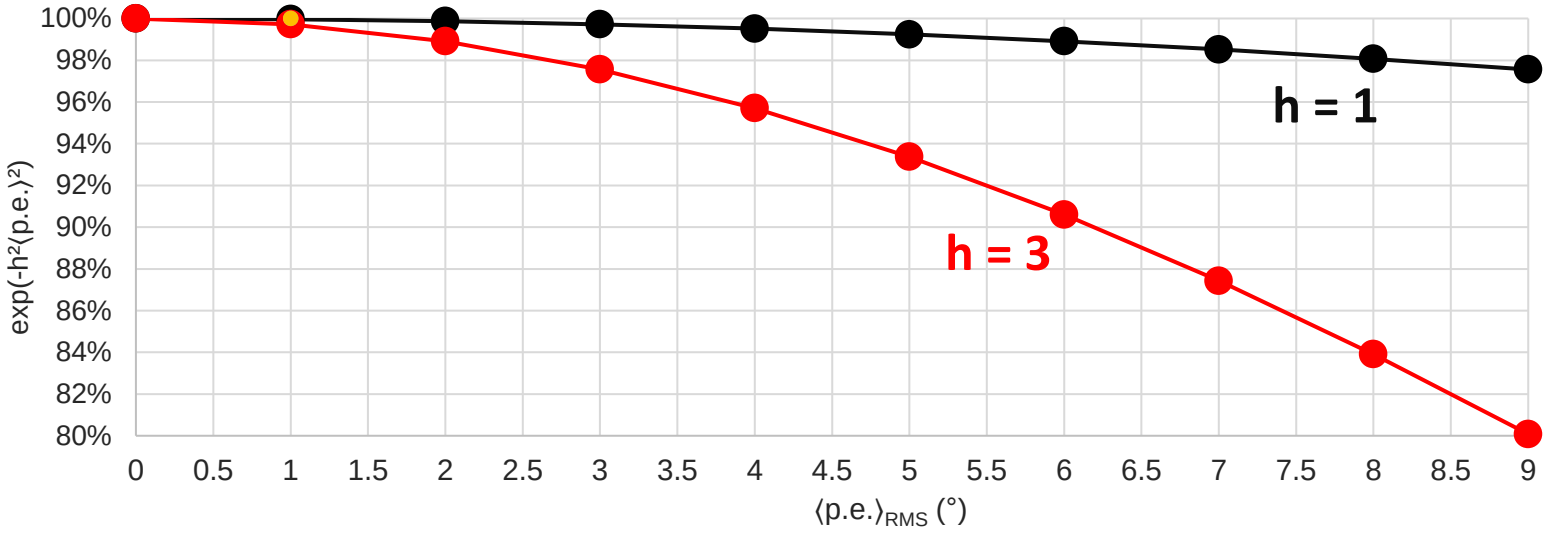
Horizontal polarization, intermediate K
(before and after screw change)

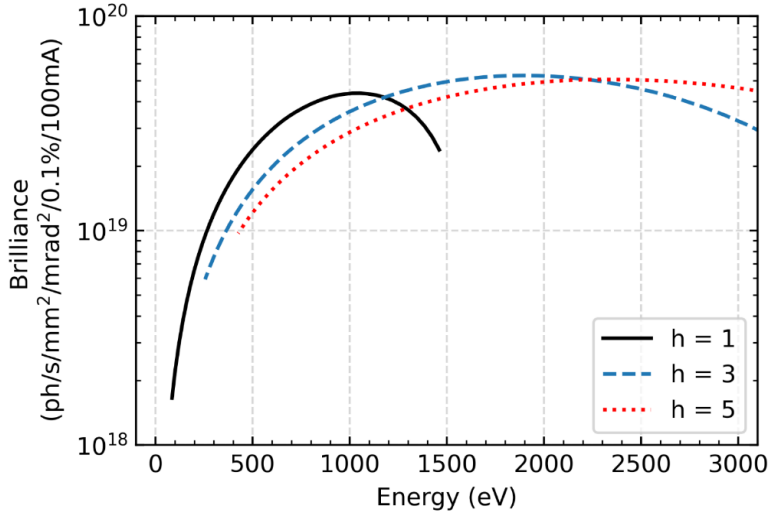






Shimming correction





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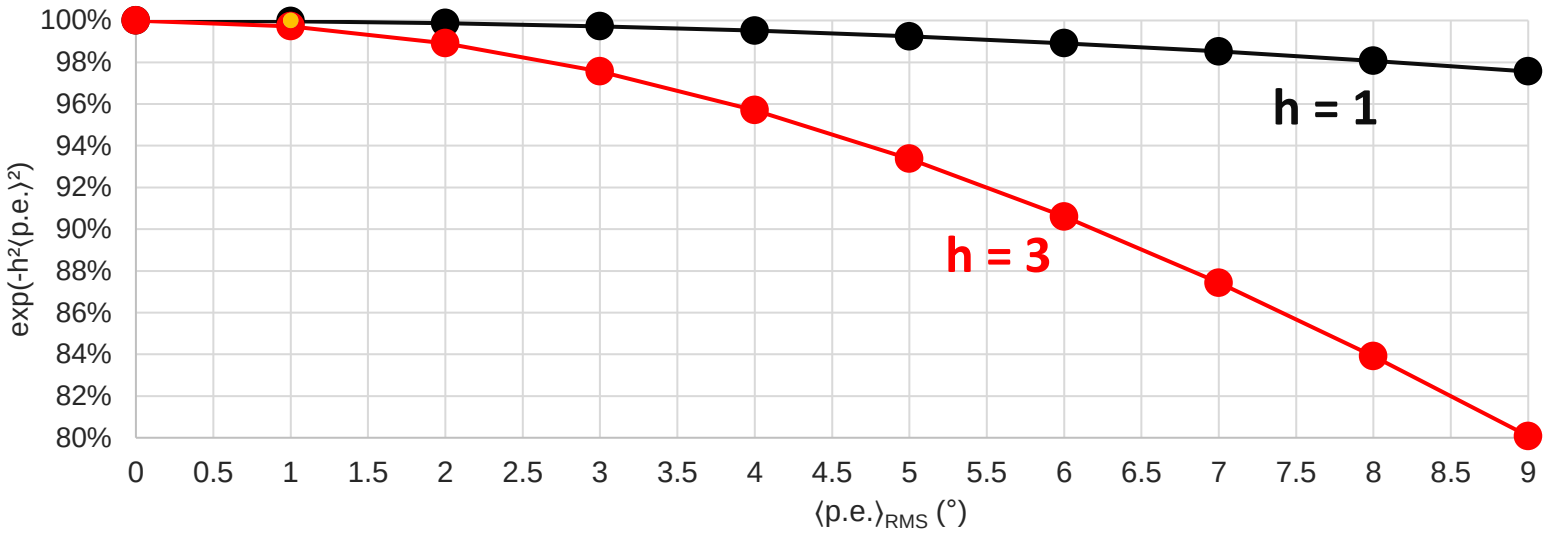
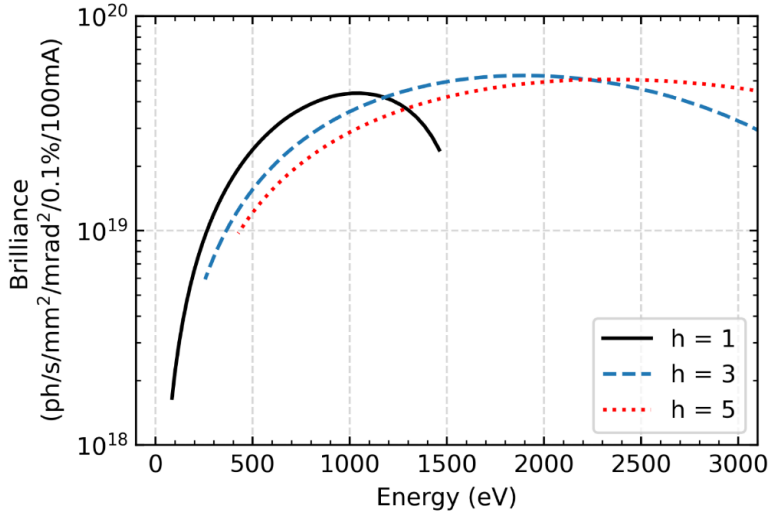




All cassettes

or

Only upper cassettes

and

Longitudinal blocks

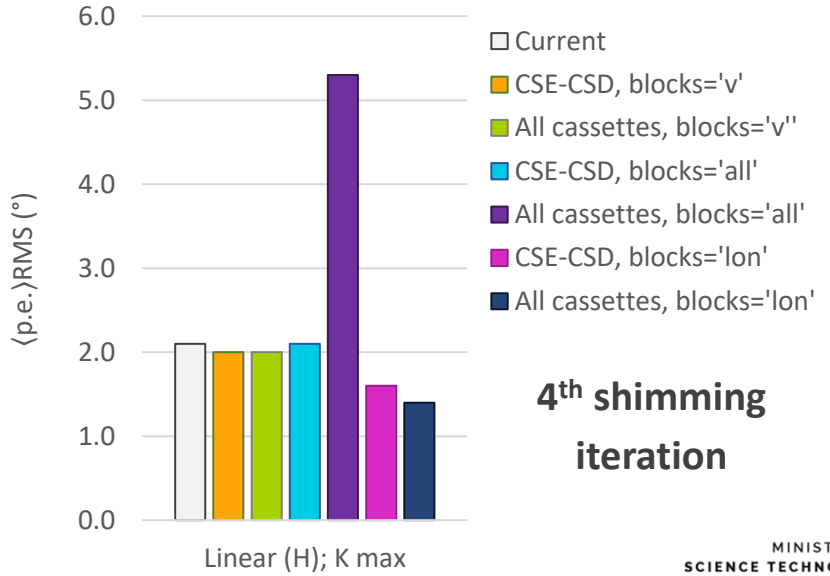
or

Vertical blocks

or

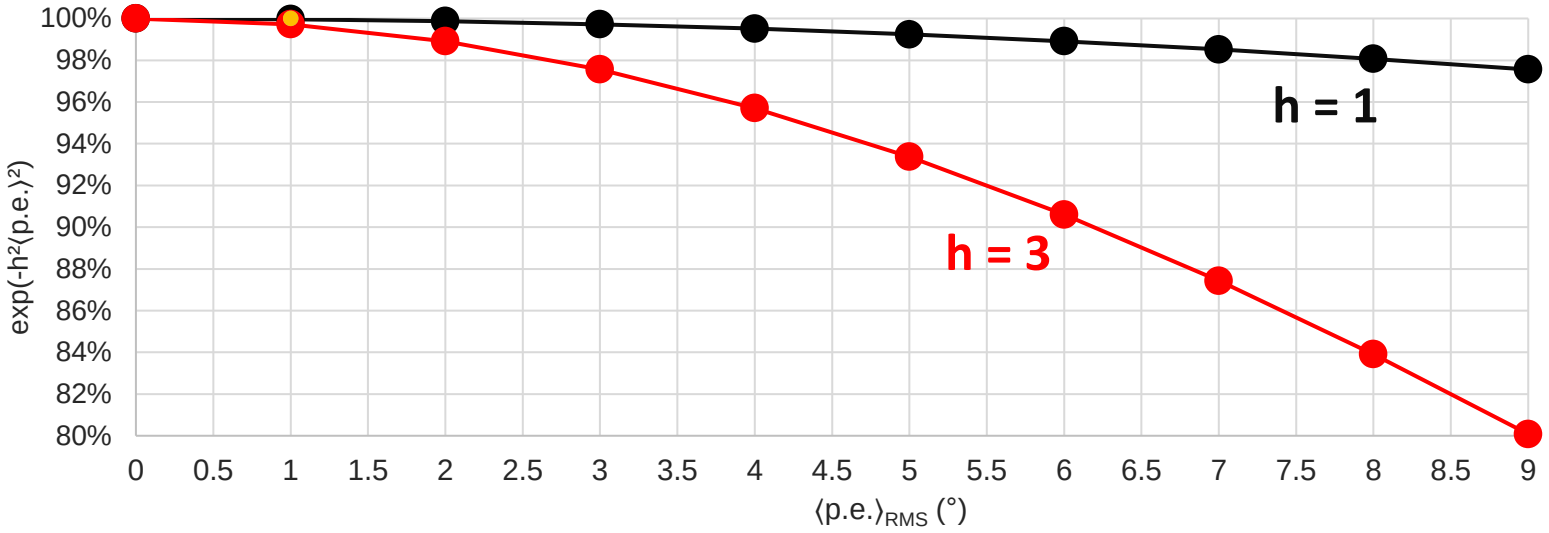
All blocks

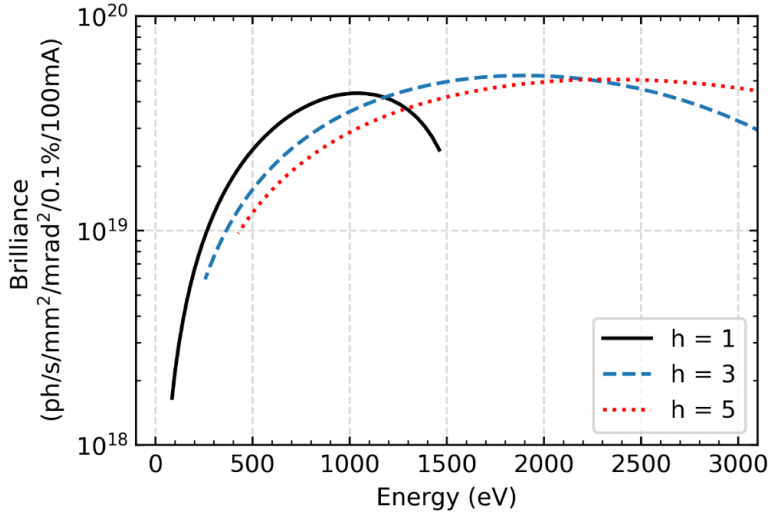
Mean shim value among all phases closer to 0.05 steps

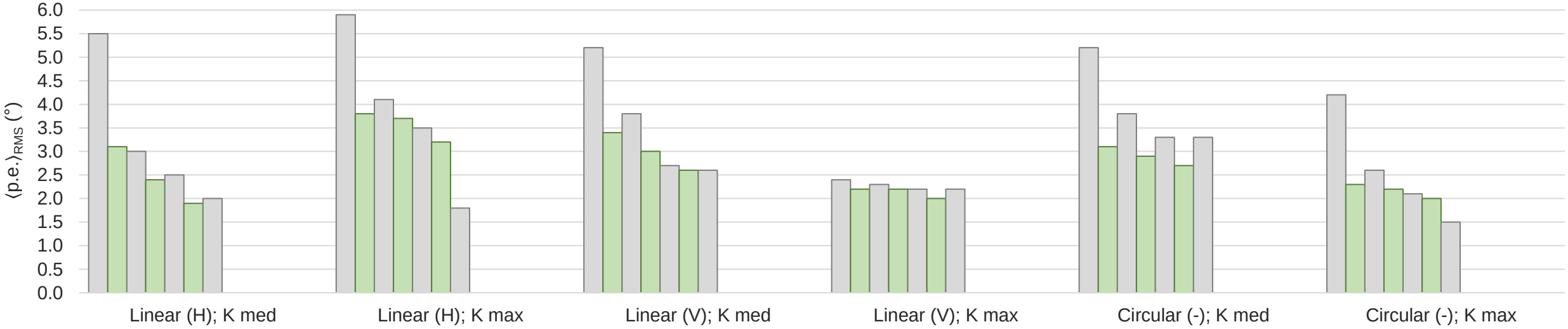


4th shimming iteration

Shimming correction





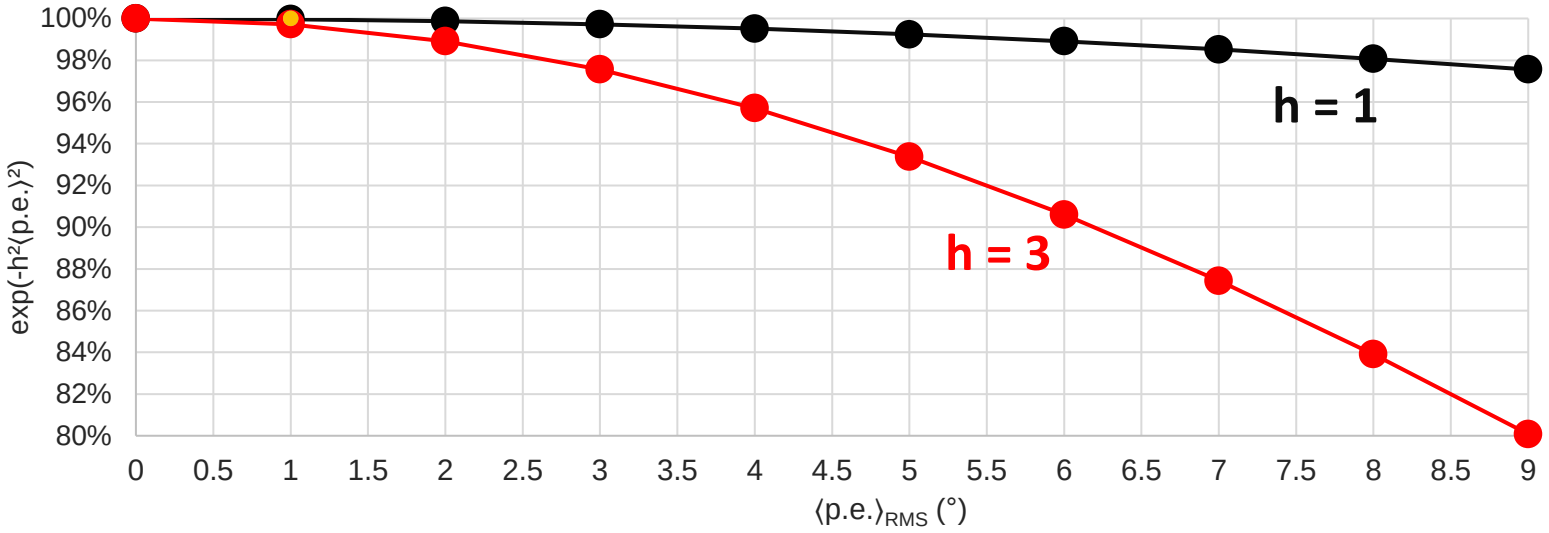


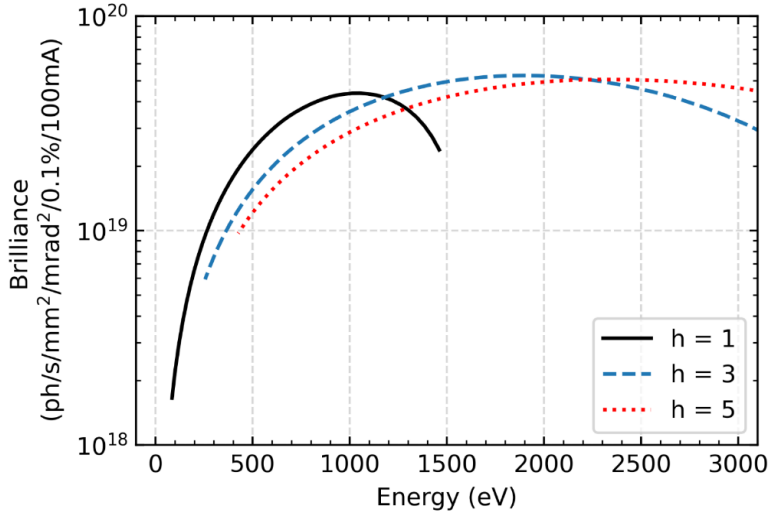
Calculated iteration **Measured after iteration (or initial)**

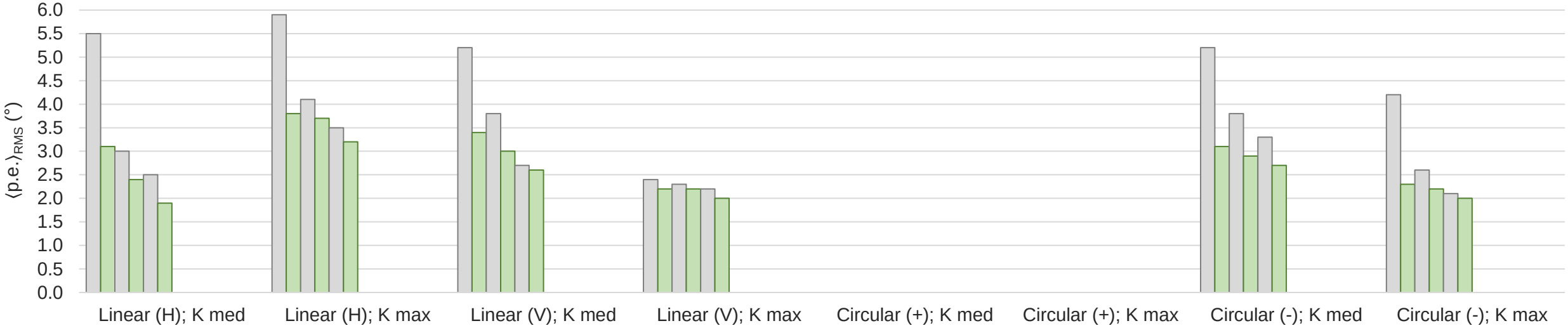
MINISTRY OF SCIENCE TECHNOLOGY AND INNOVATION

BRAZILIAN GOVERNMENT BRASIL UNITING AND REBUILDING

Shimming correction

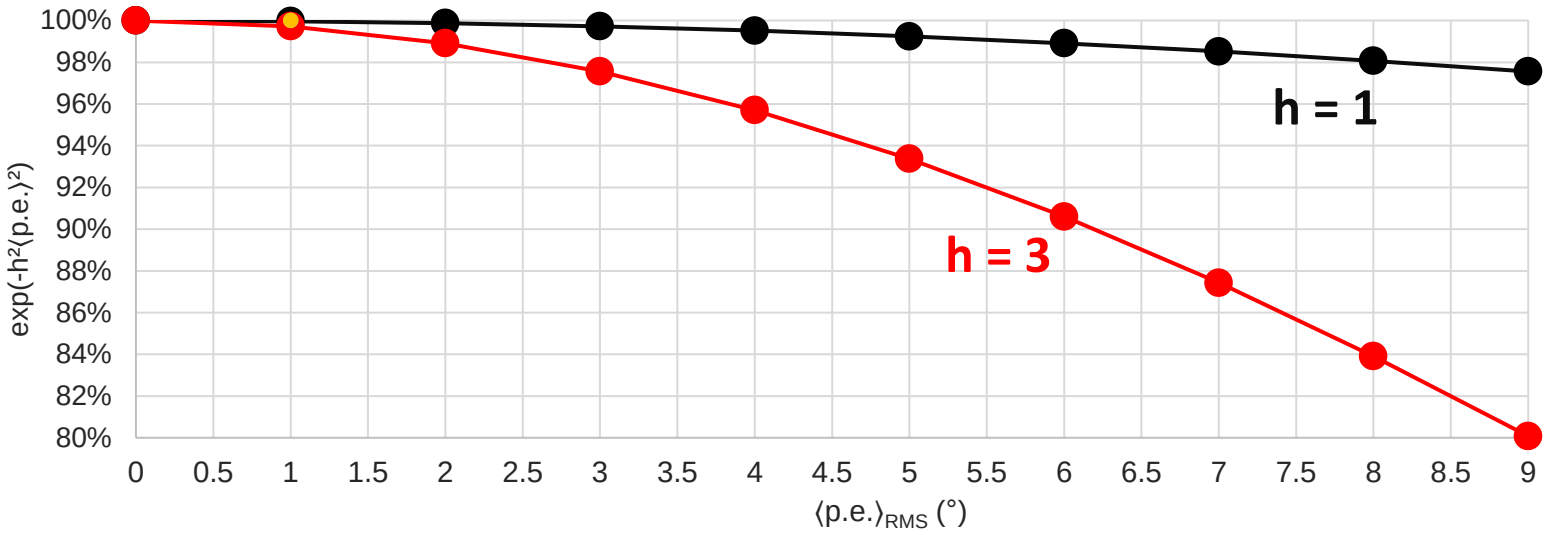


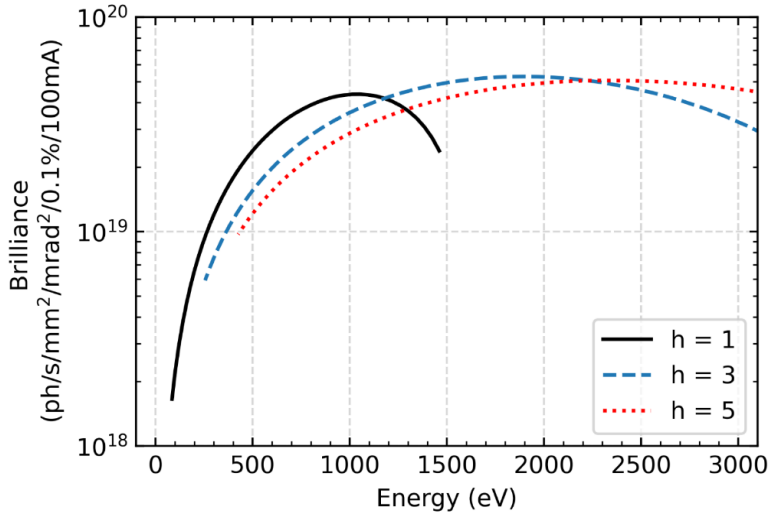


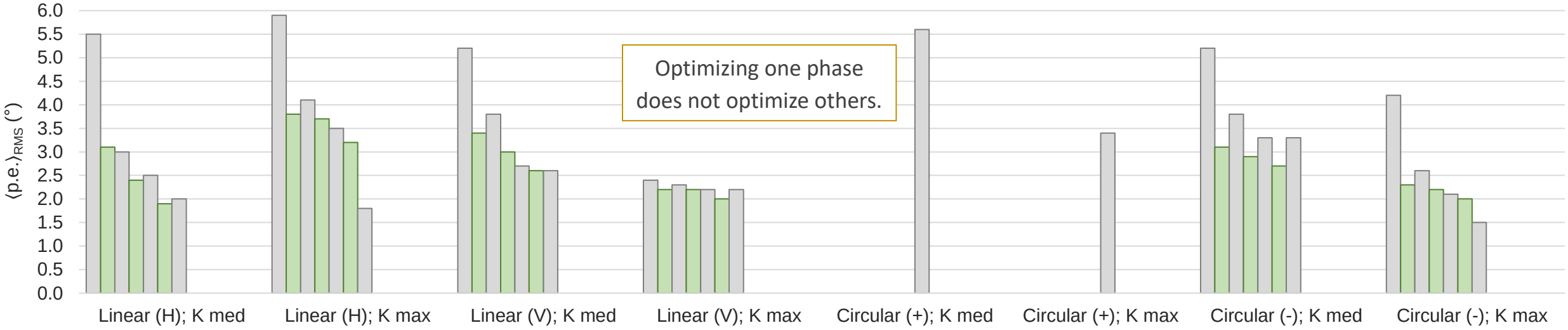


Calculated iteration **Measured after iteration (or initial)**

Shimming correction

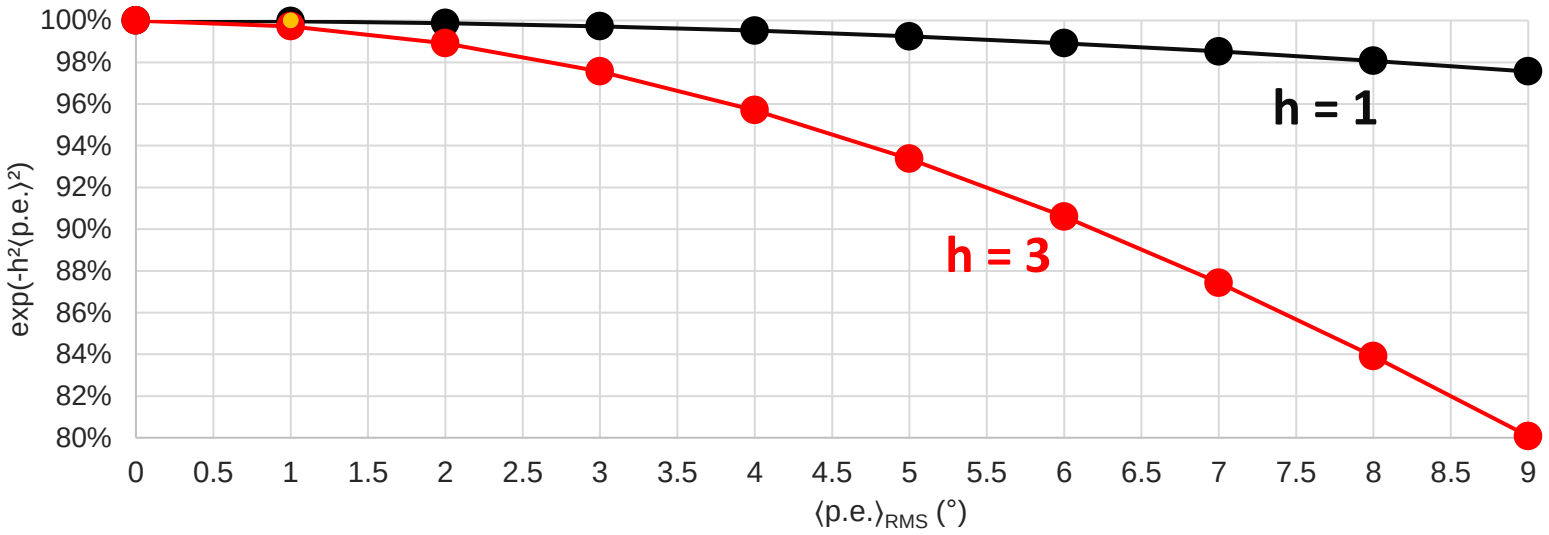


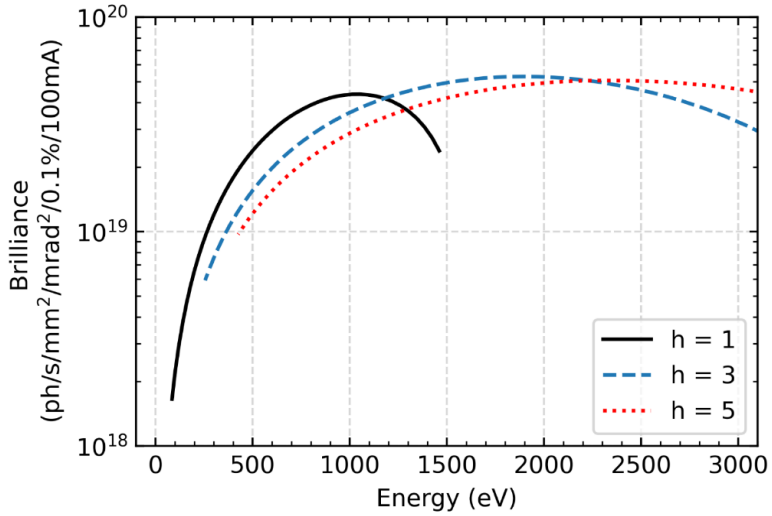


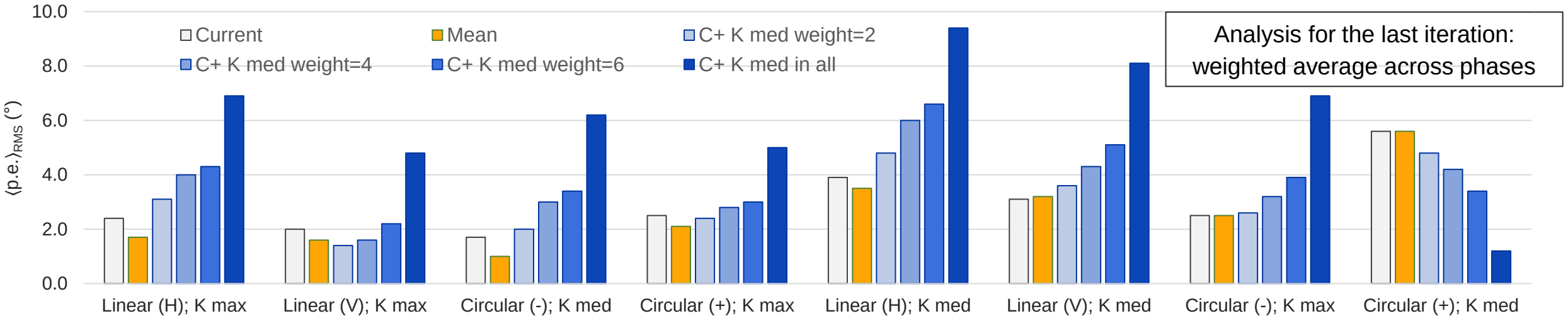


Calculated iteration **Measured after iteration (or initial)**

Shimming correction

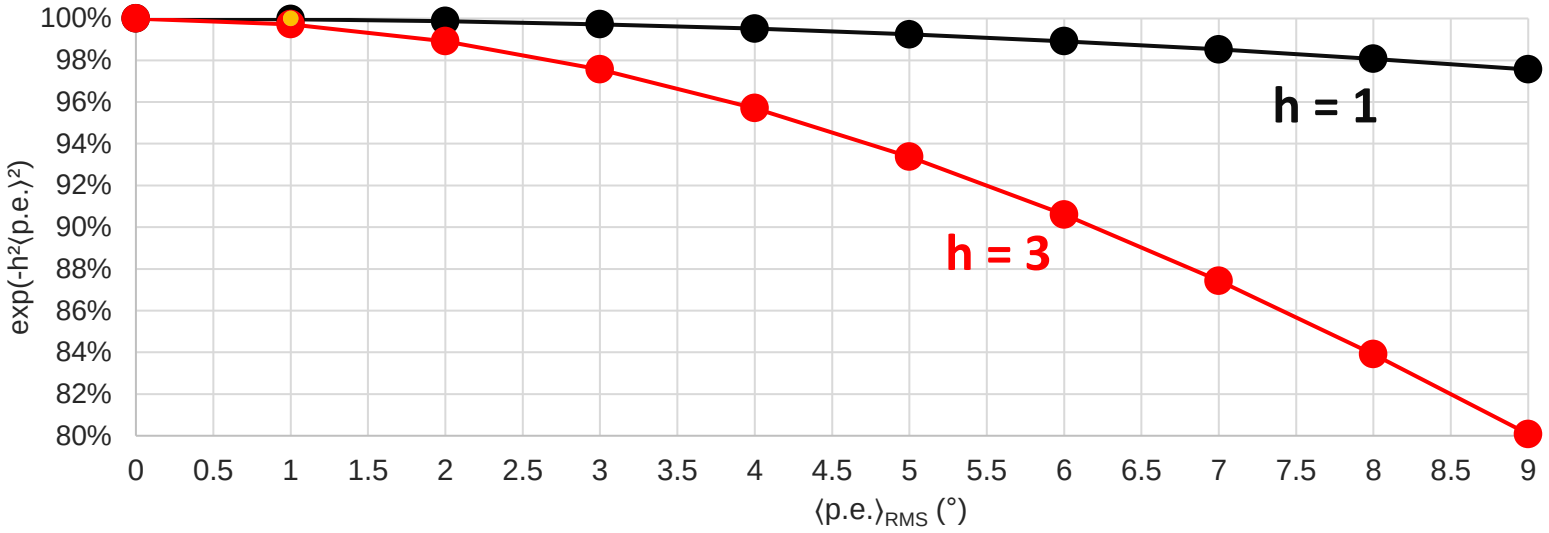


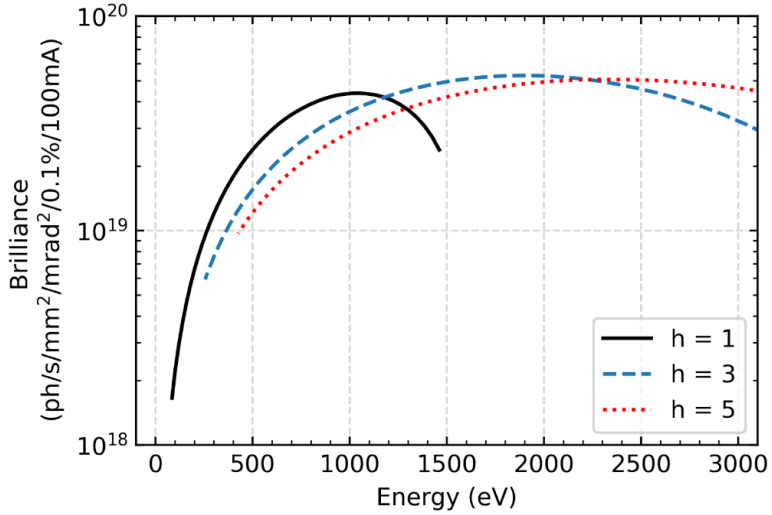


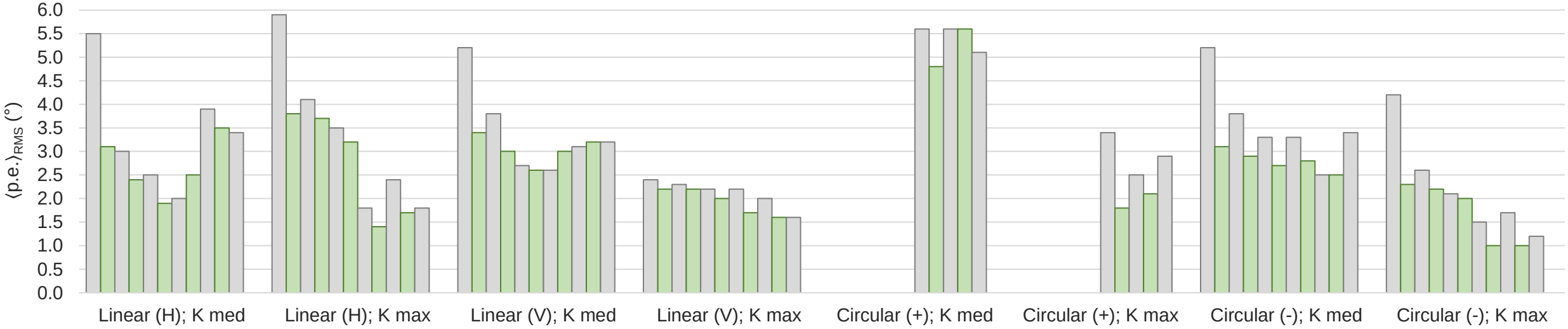


Analysis for the last iteration: weighted average across phases

Shimming correction





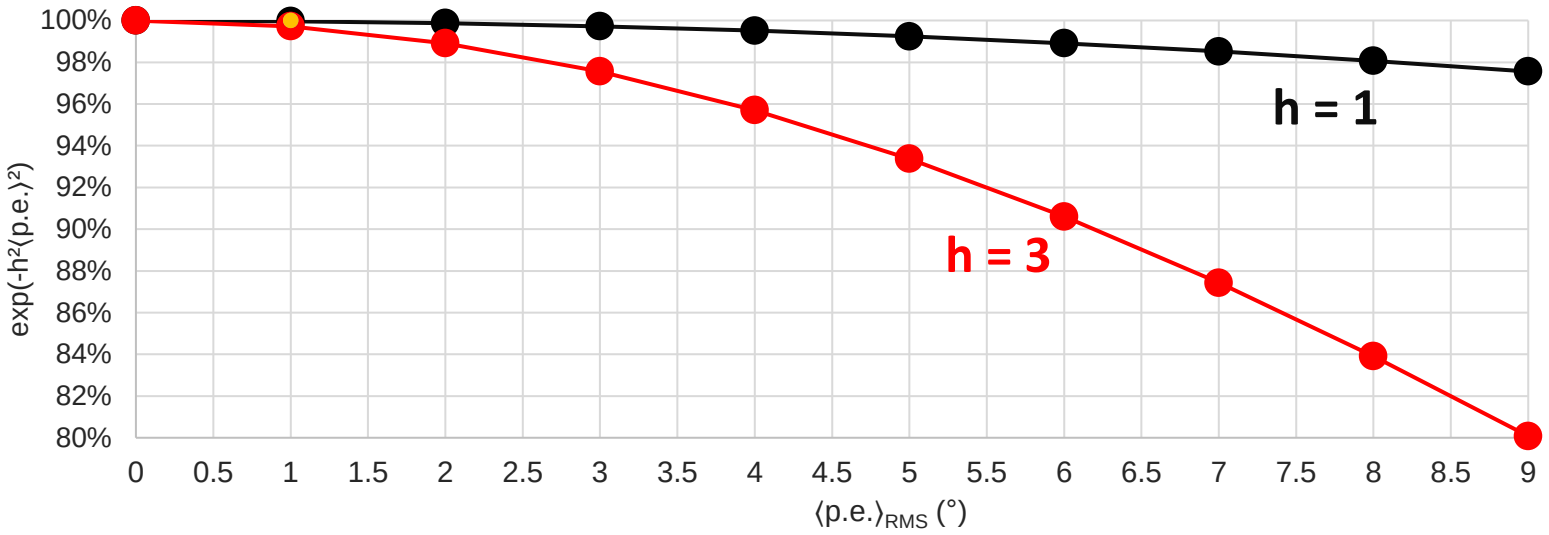


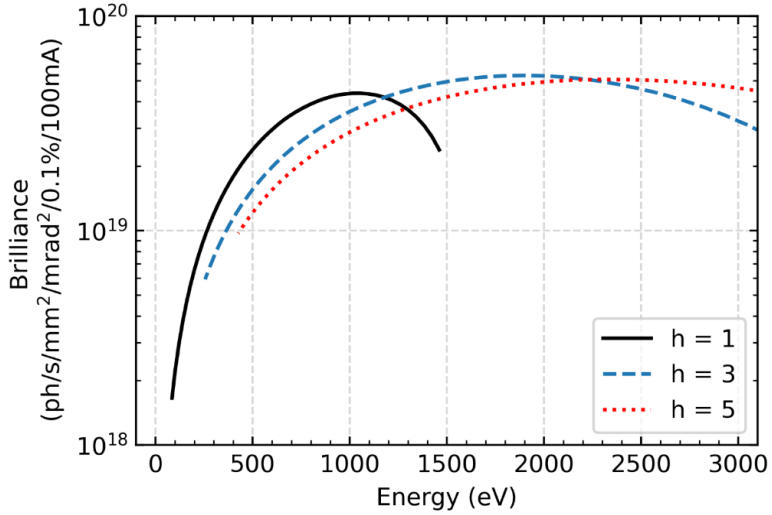
Calculated iteration **Measured after iteration (or initial)**

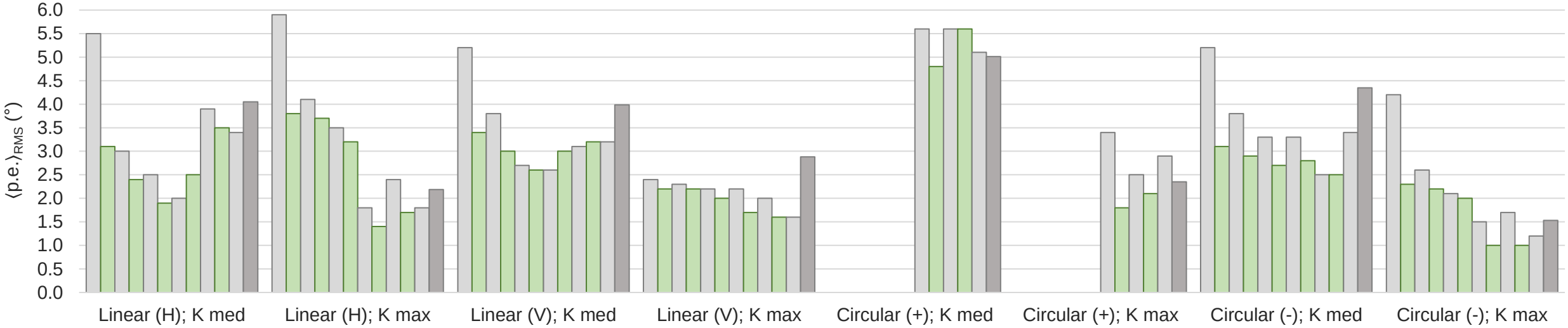
MINISTRY OF SCIENCE TECHNOLOGY AND INNOVATION

BRAZILIAN GOVERNMENT BRASIL UNITING AND REBUILDING

Shimming correction





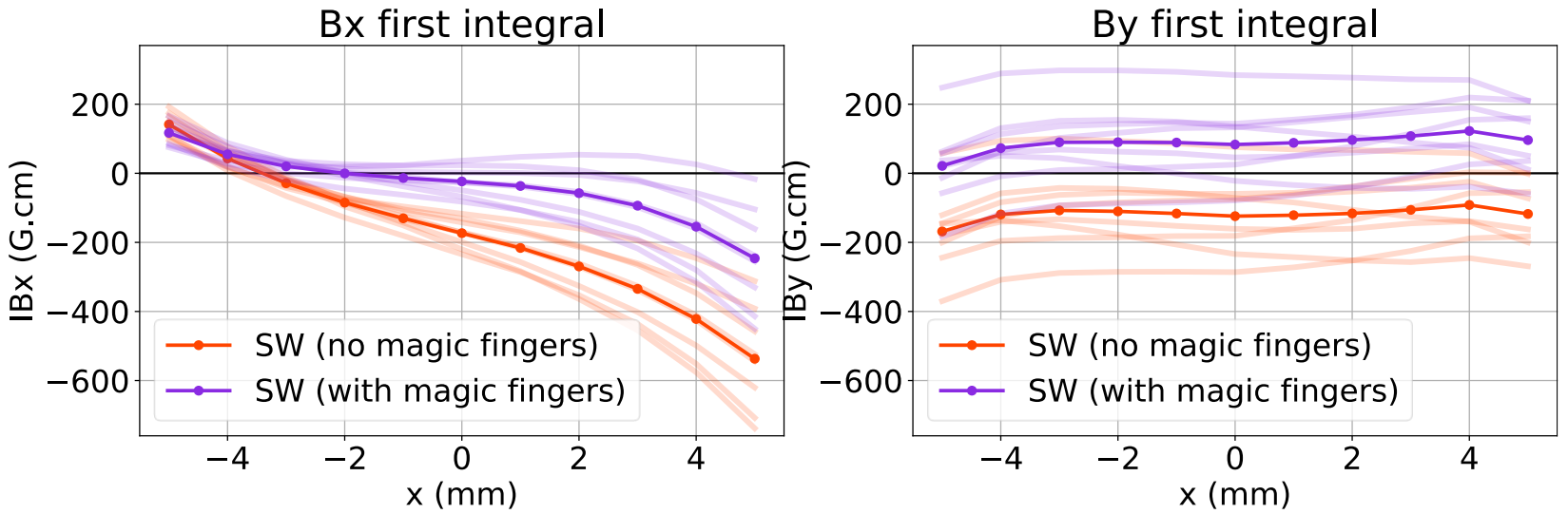


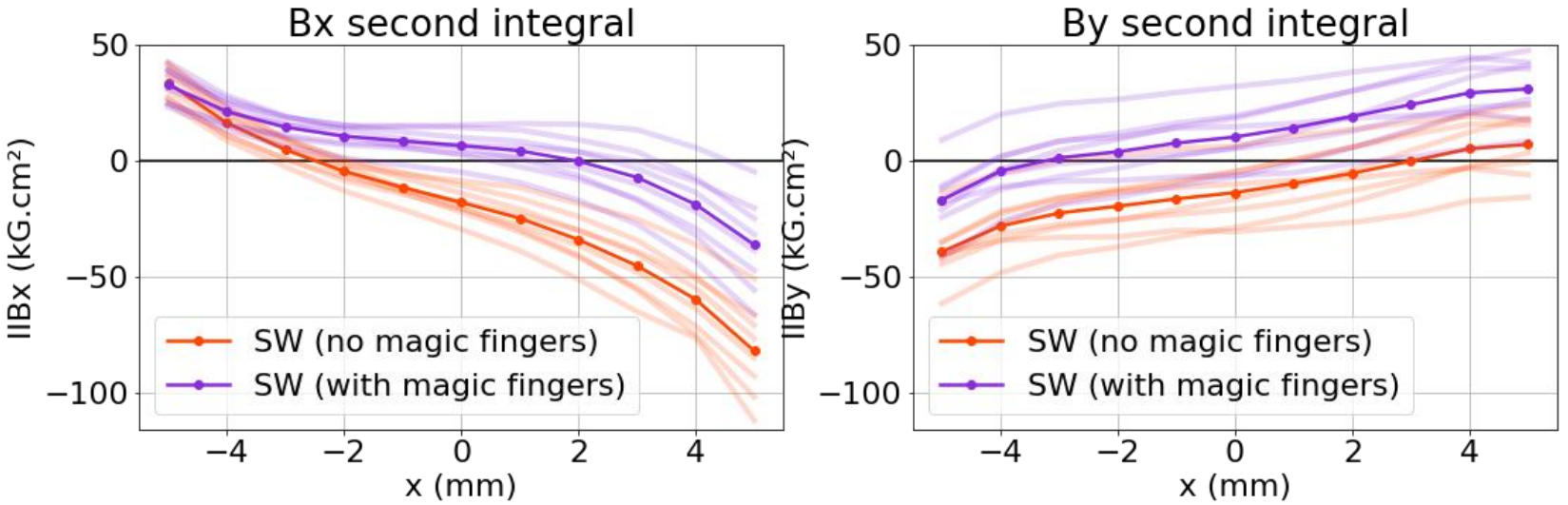
Calculated iteration **Measured after iteration (or initial)** **Final values (after magic fingers)**

MINISTRY OF SCIENCE TECHNOLOGY AND INNOVATION

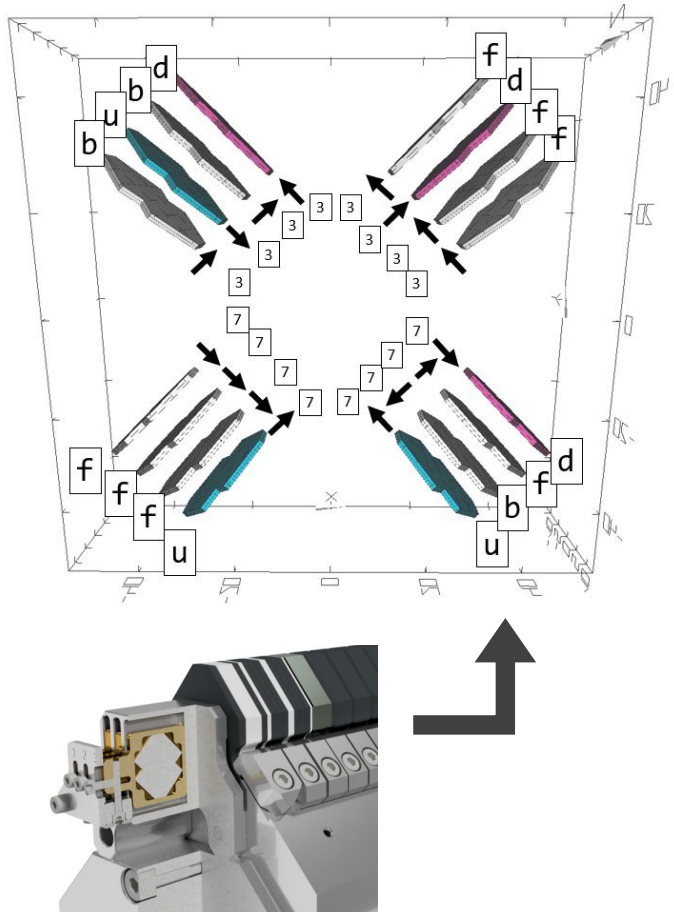
BRAZILIAN GOVERNMENT BRASIL UNITING AND REBUILDING

Magic fingers correction

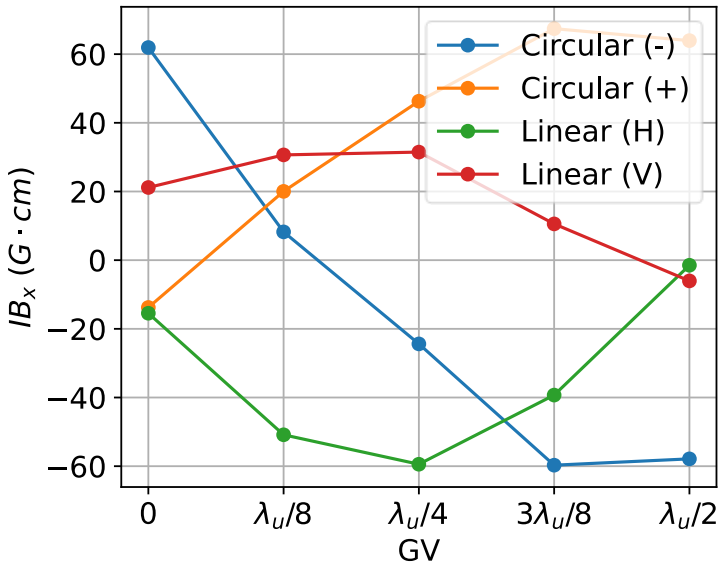


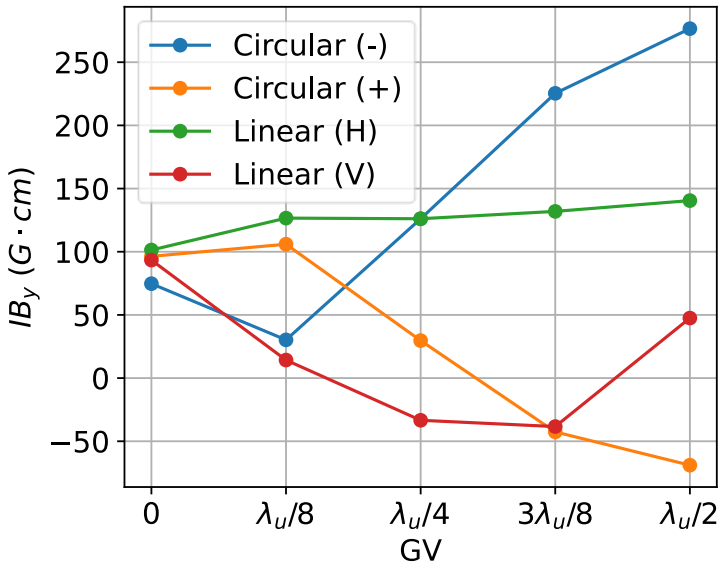


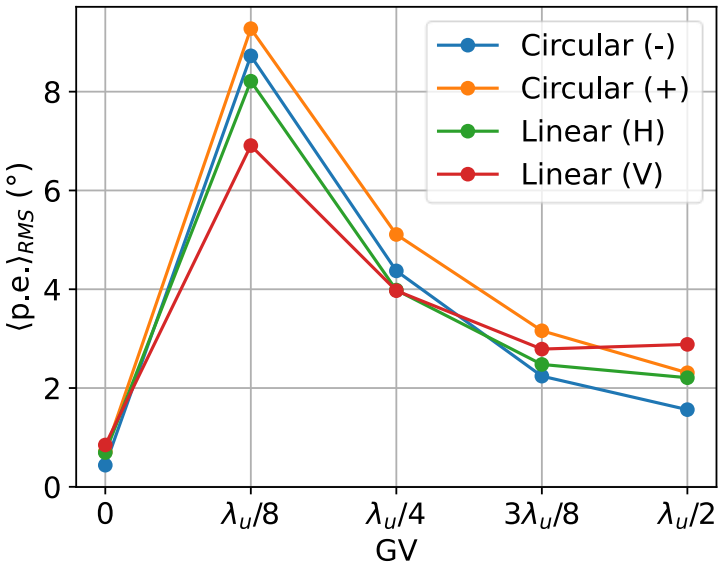
Magic fingers assembly after optimization through simulated annealing

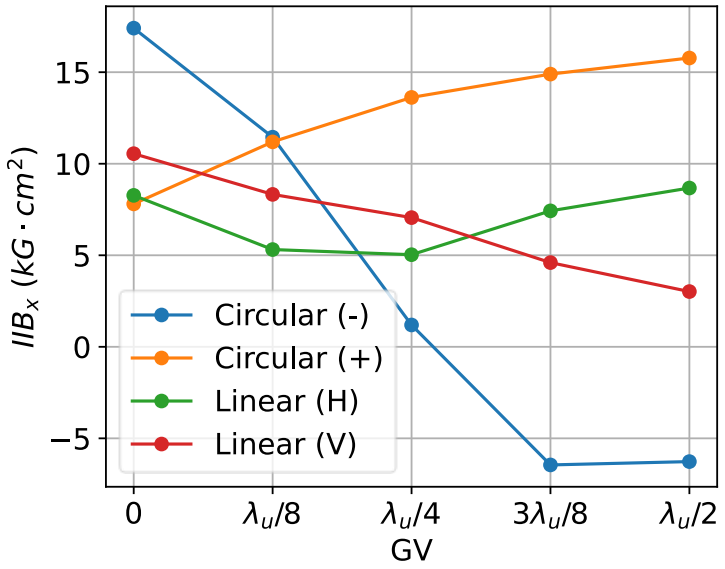


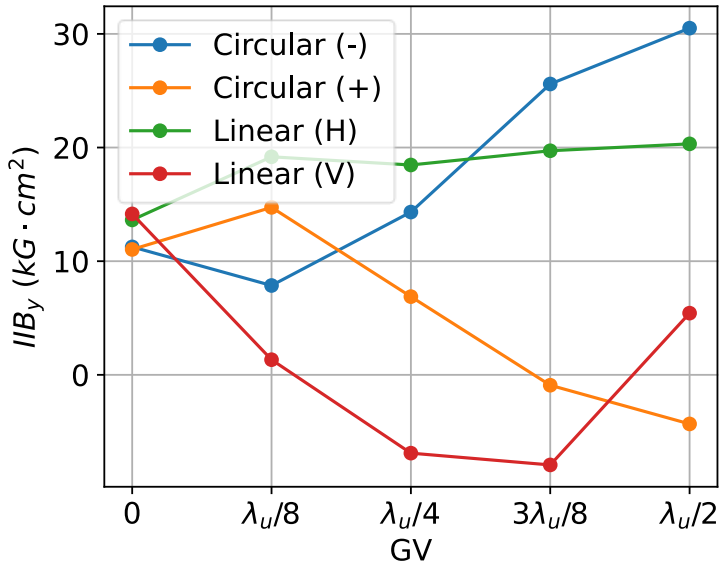
Final Characterization







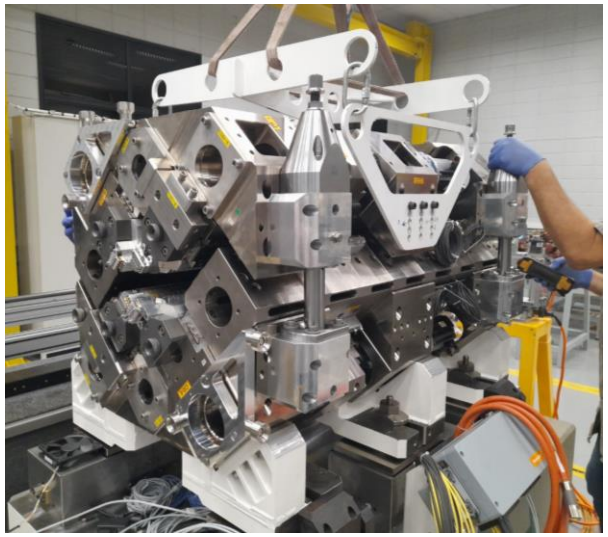




Intermediate low-K phases found to be less optimized with respect to phase error.

Feedforward correctors integrals (10 A):
Hor.: 452 G·cm (in) and 452 G·cm (out)
Ver.: 515 G·cm (in) and 506 G·cm (out)

Storage ring installation



Thank you

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lucas.francisco@cnpem.br

Some references

For Sirius:
L. Liu, M. Alves, A. C. Oliveira, X. Resende, e F. De Sá, “Sirius Commissioning Results and Operation Status”, Proceedings of the 12th International Particle Accelerator Conference, vol. IPAC2021, p. 6 pages, 1.540 MB, 2021, doi: 10.18429/JACOW-IPAC2021-MOXA03.
For the Delta Sabiá Undulator:
L. Vilela et al., “Status Report of Sirius Delta Undulator”, IEEE Trans. Appl. Supercond., vol. 32, nº 6, p. 1–5, set. 2022, doi: 10.1109/TASC.2022.3160941.

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CNPEM Brazilian Center for Research in Energy and Materials

MINISTRY OF SCIENCE TECHNOLOGY AND INNOVATION

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