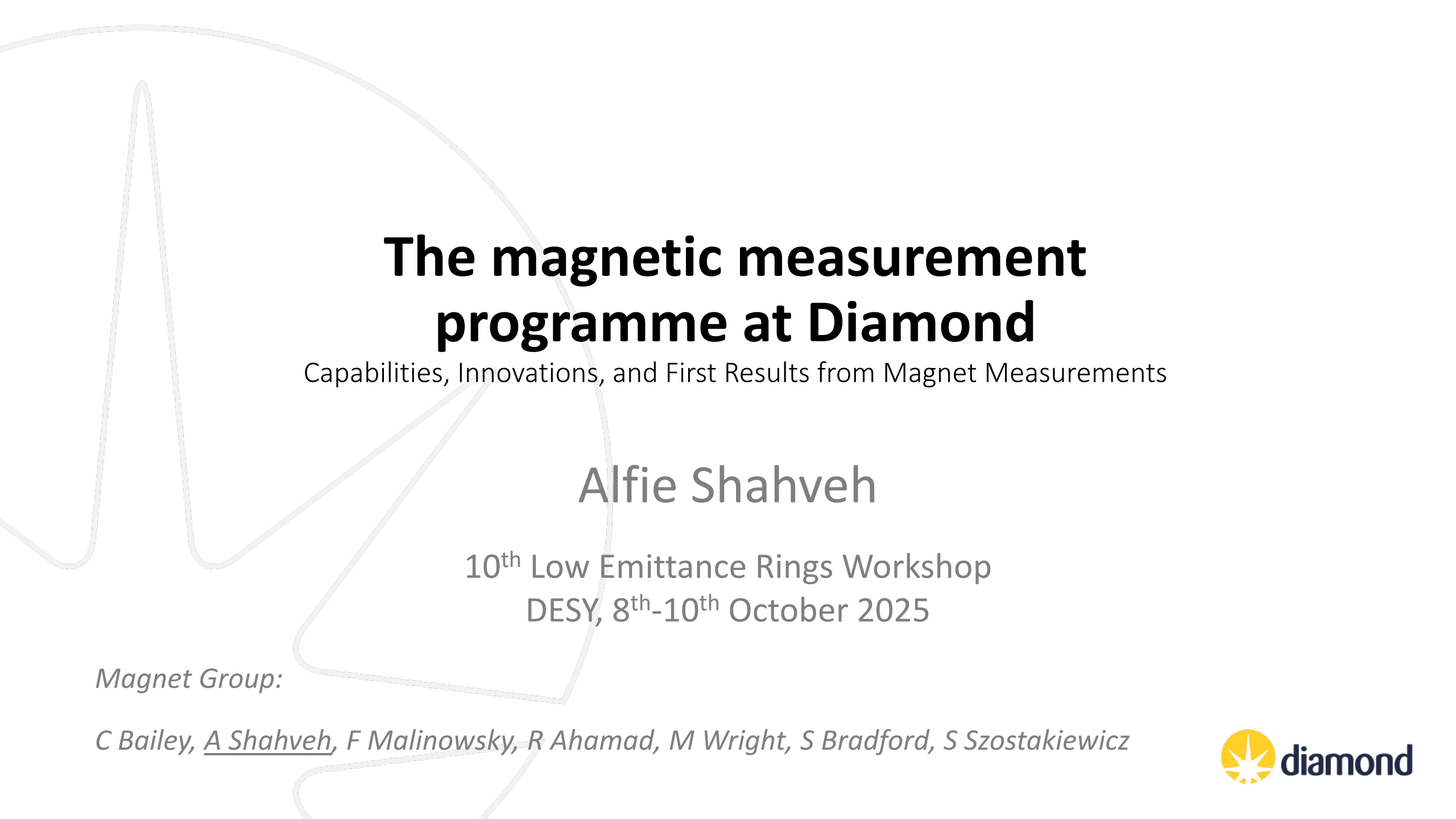




The magnetic measurement programme at Diamond

Capabilities, Innovations, and First Results from Magnet Measurements

Alfie Shahveh

10th Low Emittance Rings Workshop
DESY, 8th-10th October 2025

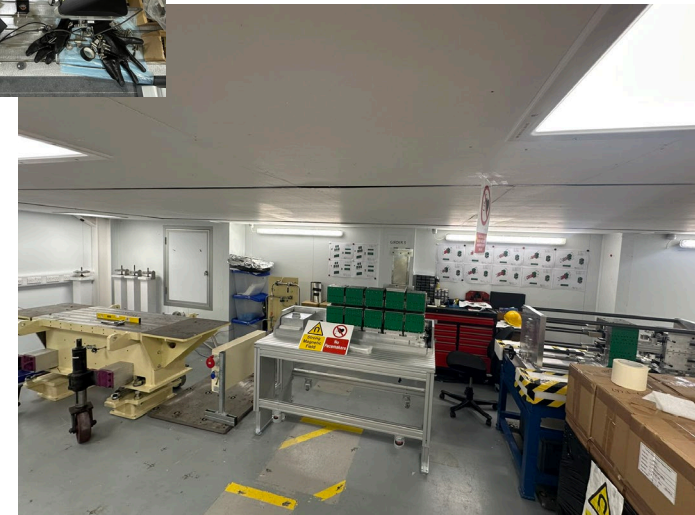
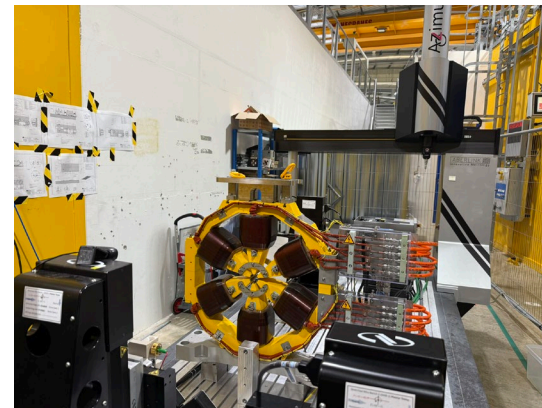
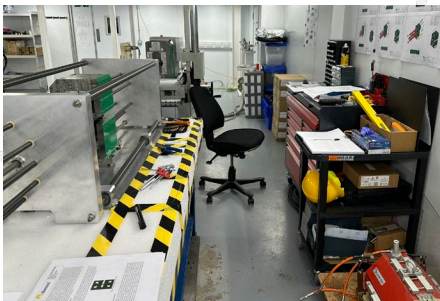
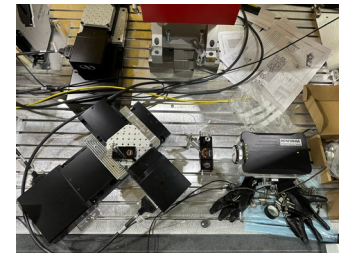
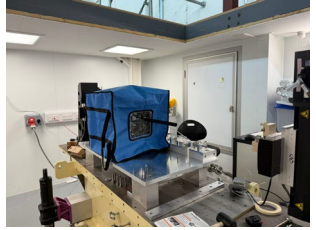
Magnet Group:

C Bailey, A Shahveh, F Malinowsky, R Ahamad, M Wright, S Bradford, S Szostakiewicz



Talk Outline

- Magnet delivery status
- Introduce the new magnetic measurement facility at Diamond and Diamond Extension Building (DEB)
- DL Magnet in-house assembly and measurements
- Show innovations such as Hall sensor and Stretched wire bench integration in the Coordinates Measuring Machine (CMM)
- Present first magnet measurement results
- Conclusion



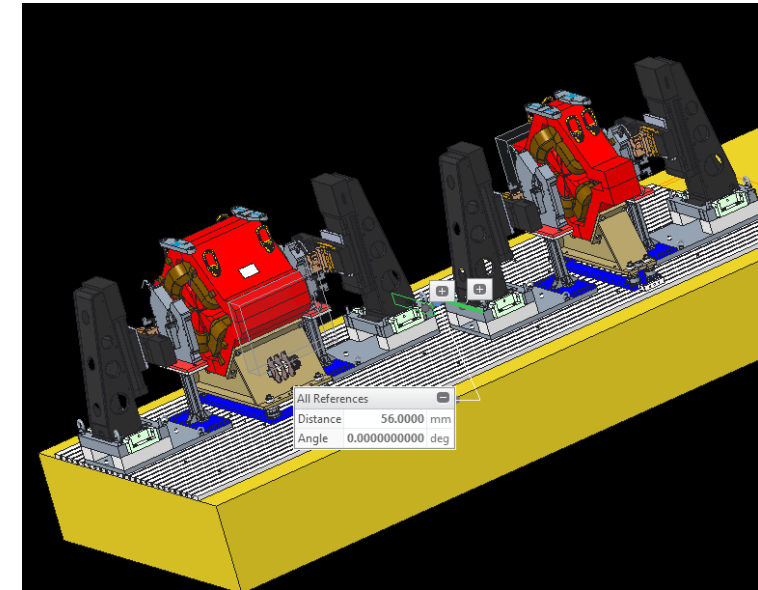
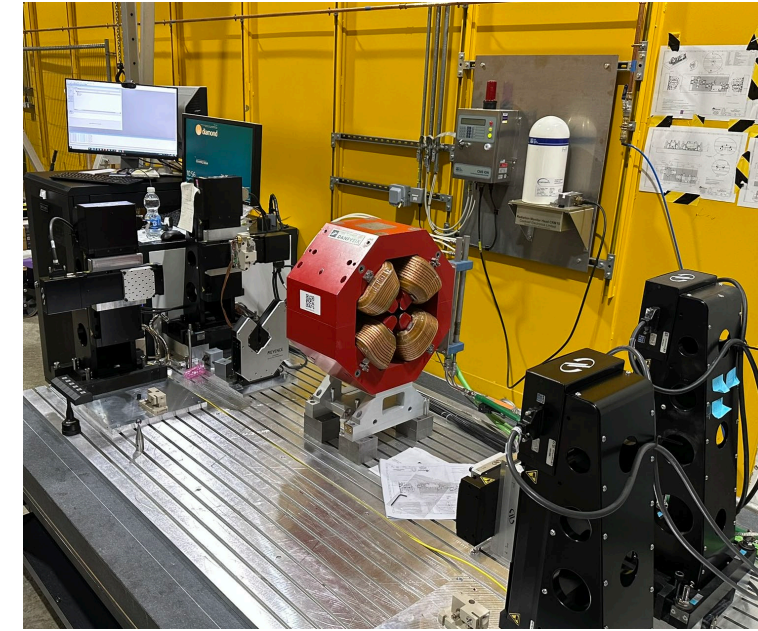
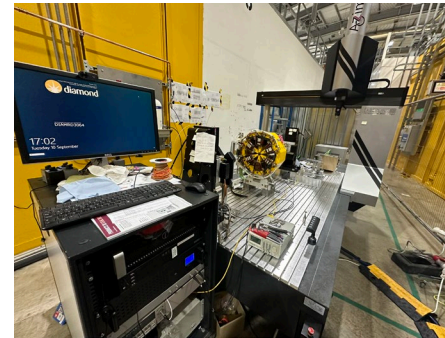
Magnet Delivery Status

Magnet	Company	Status	Date Pre-Series Here	Date 1 st Series Deliveries	Date Last Deliveries
Quadrupole	Sigma Phi	Pre-series delayed to late October, series production about 6-7 month behind the schedule as of Now!	31/07/25	10/02/26	08/04/27
Sextupole	DanFysik	Series deliveries expected to be delayed at least by 3 months	14/05/25	17/12/25	26/03/27
DQ	Tesla	Pre series delayed to late October (~3.5 months)	01/07/25	29/01/26	07/01/27
DL	PM Blocks HPMG	All on site	N/A	17/12/24	Dec 25
	Poles and Yoke RTC	First articles received and tested, some delays for series deliveries		01/03/25	Dec 26

- Various contract delays allowed the magnet group to strengthen internal capabilities.
- Measurement lab and in-house assembly/measurement line established in temporary facilities.
- Progress maintained despite delayed DEB handover.

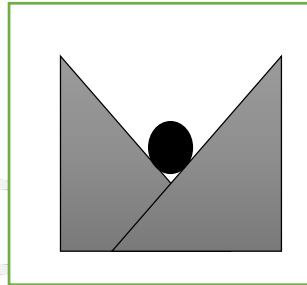
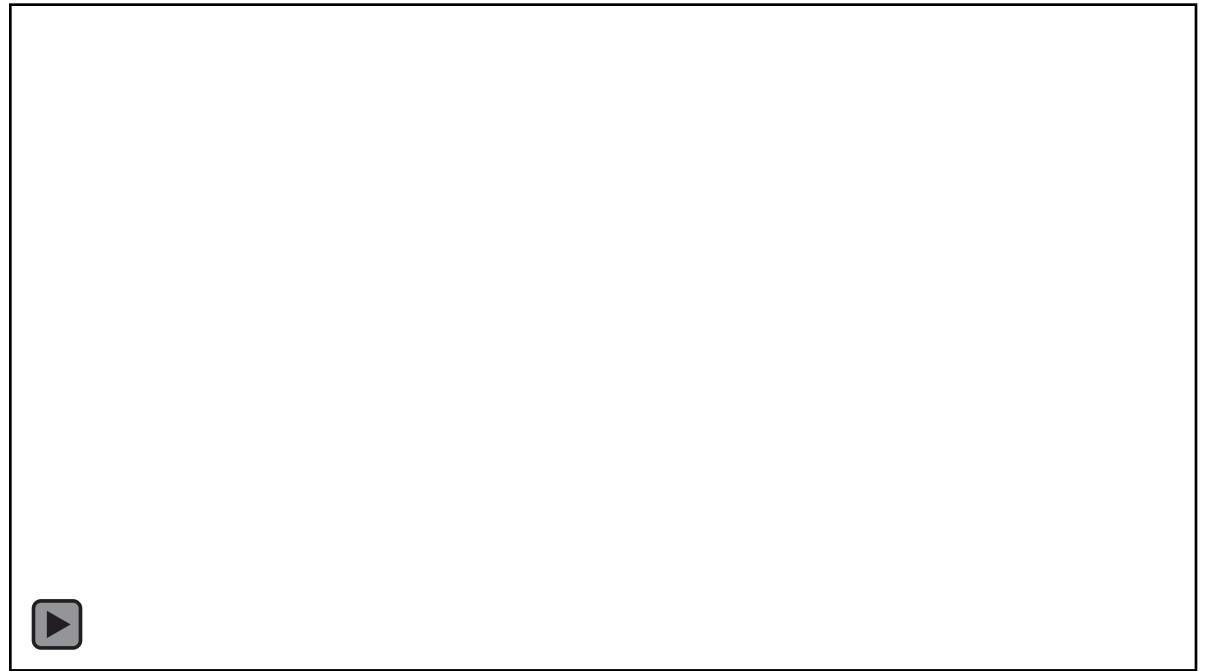
Facility Configuration

- CMM #1 hosts two Stretched Wire benches, ideal for large magnets or cross-talk measurements, and supports Hall probe integration
- CMM #2: hosts one SW bench for smaller magnets
- All benches use unified control software and data acquisition
- DL Production/Measurements
 - DL production line includes two permanent magnet insertion tools.
 - These tools feed the module assembly jig to build a complete DL with coarse alignment.
 - The assembled DL is transferred to the Stretched Wire bench on the CMM.
 - Final alignment and magnetic field tuning are performed on the CMM-integrated SW bench.



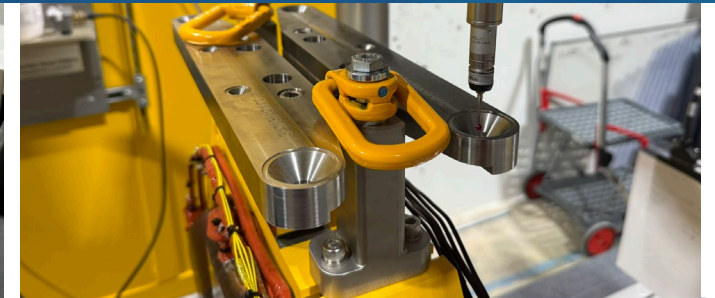
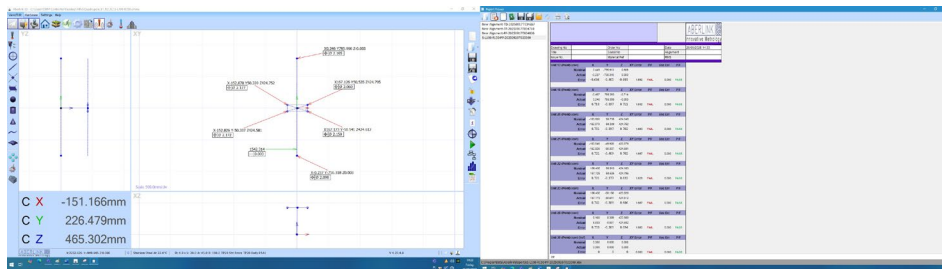
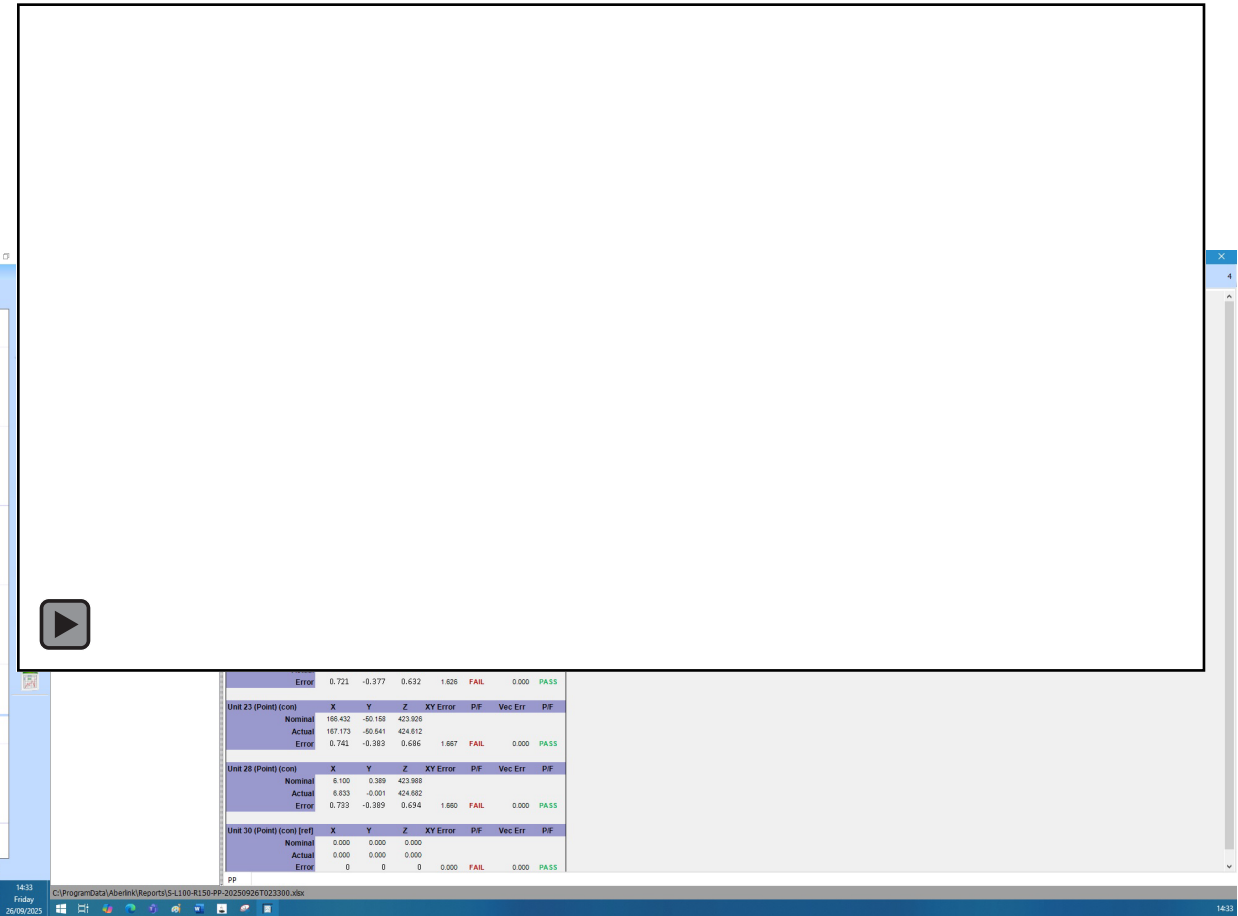
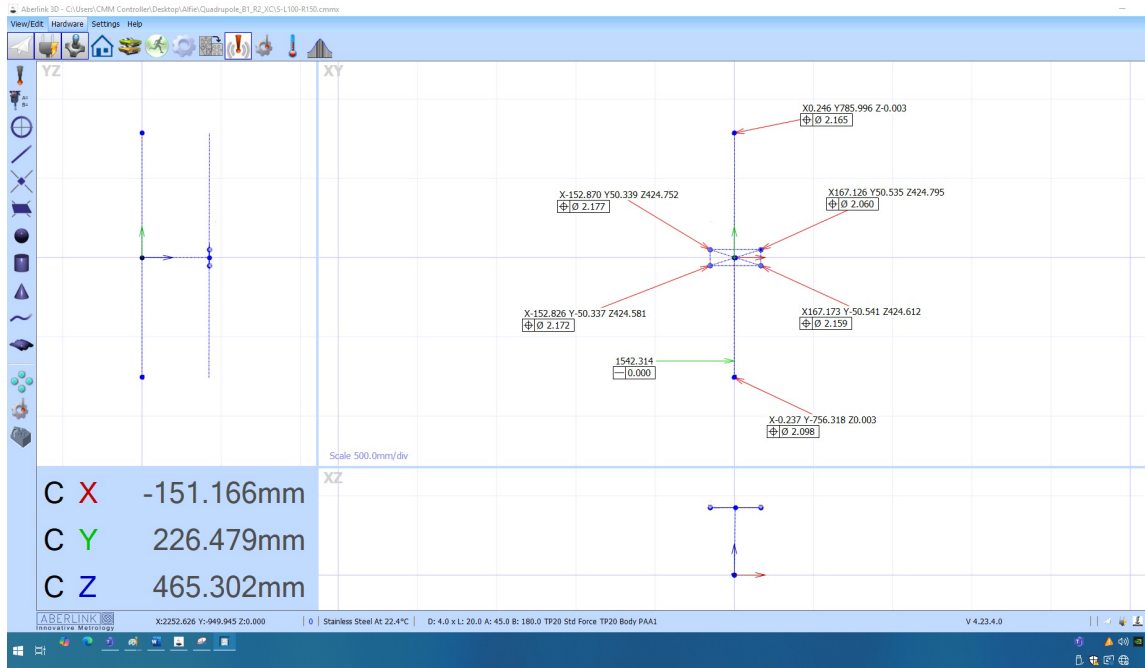
Stretched wire bench

- Three SW benches developed in-house (based on ESRF design; two newly built, one existing purchased 10 years ago).
- High precision (2×10^{-4}), stable, and compact setup integrated on a CMM bed.
- Capabilities: field integral, effective length, magnetic axis, and alignment verification.
- Wire position monitored via direct and indirect measurements to check holder wear.
- In-situ roll correction and automated fiducialisation implemented.
- Automatic data export to girder installation and survey databases.



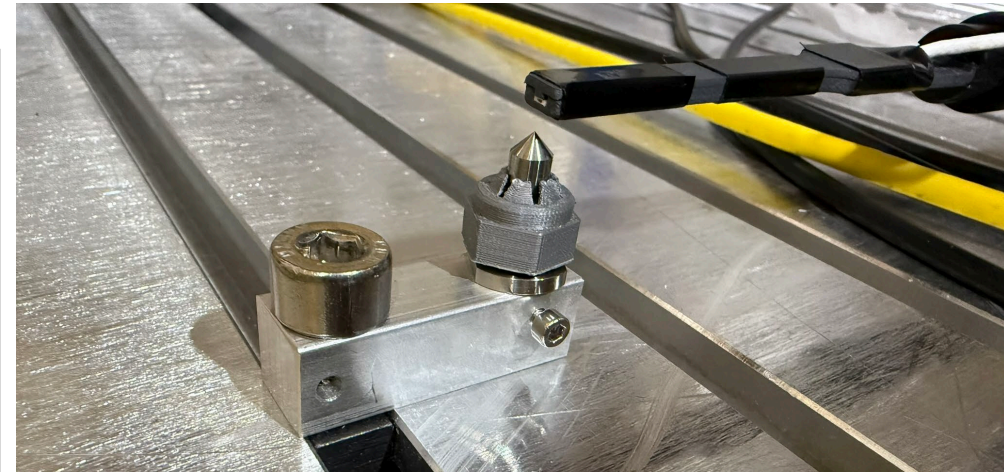
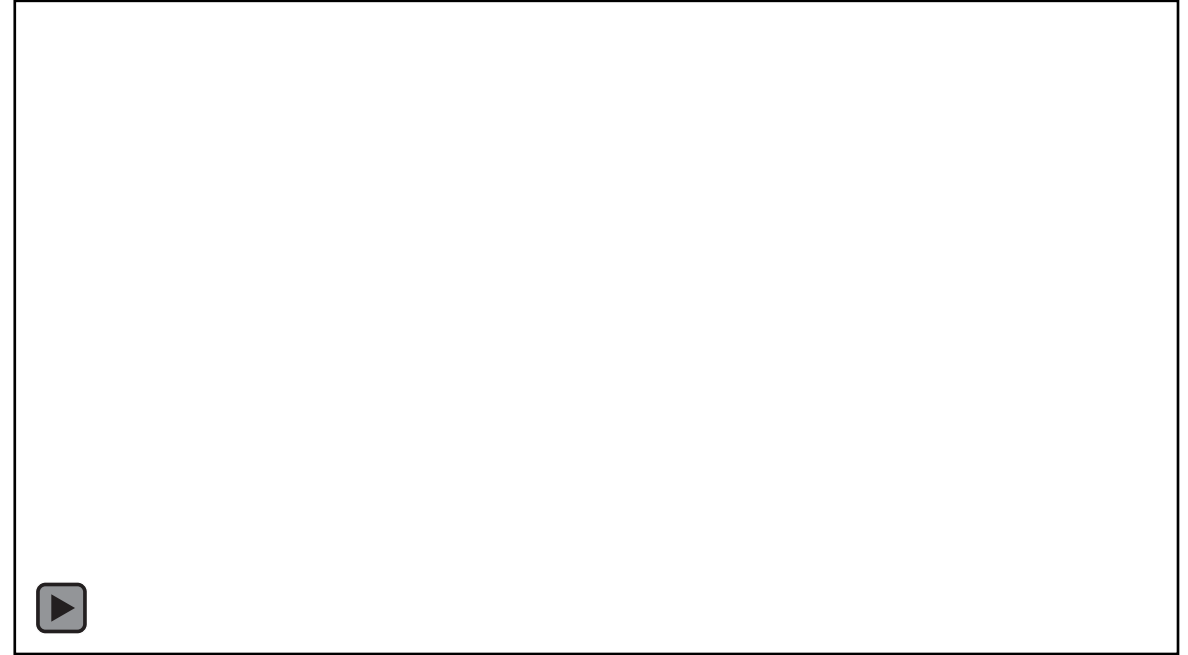
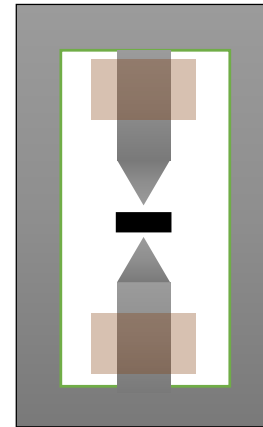
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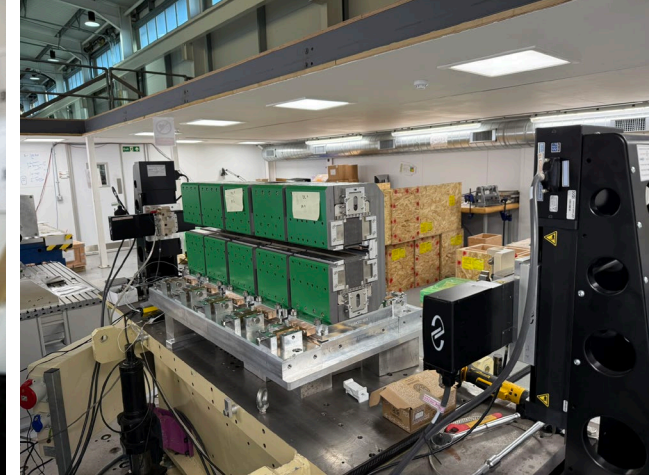
Hall Sensor Integration in CMM

- Integration of a Hall effect probe system within the CMM coordinate frame
- Enables 3D volumetric field mapping along programmable trajectories
- Directly correlates magnetic and mechanical references using a magnetic cone
- Compact setup eliminating separate positioning stages
- Custom plugin designed by the CMM manufacturer, tailored to Diamond specifications
- SENIS F3A probe is used to measure the field



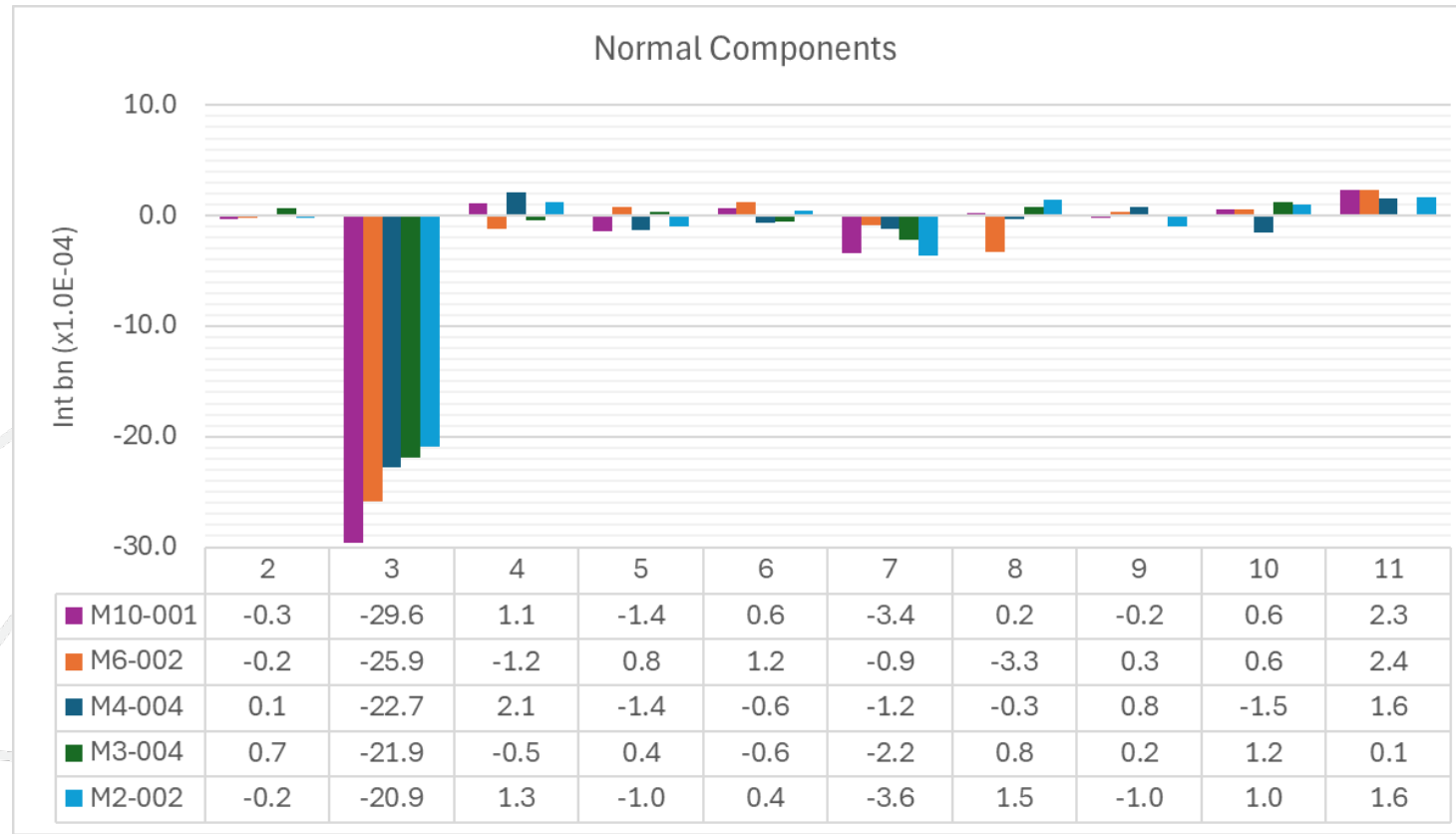
DL Magnet production and measurements

- Yokes and poles manufactured by RTC (Slovakia).
- Permanent magnet blocks: 8,424 full and 3,024 quarter blocks supplied by HPMG, pre-sorted by Diamond.
- 13 complete DL magnets delivered across 4 design variants.
- Pole tips wire-eroded with $\pm 20 \mu\text{m}$ tolerance achieved.
- Go/No-Go gauge checks performed after machining and prior to PM block loading to verify pole-to-pole gap.
- FOS measurements within specification.
- Module-level tuning and FOS verification carried out for each magnet type.
- Thermoflux material applied to reduce temperature sensitivity to $\pm 5 \times 10^{-5}$ per $^{\circ}\text{C}$.
- Series production initiated with DL1 to accelerate in-house manufacturing capability.



DL Magnet production and measurements (continue)

- Multiple tests have been conducted on FOS magnets.
- Pole tip inspections were carried out by the metrology lab.
- Magnetic measurements were performed using the stretched wire bench.
- The observed b3 component is mainly caused by fringe fields, which are significantly weaker in the full DL configuration.



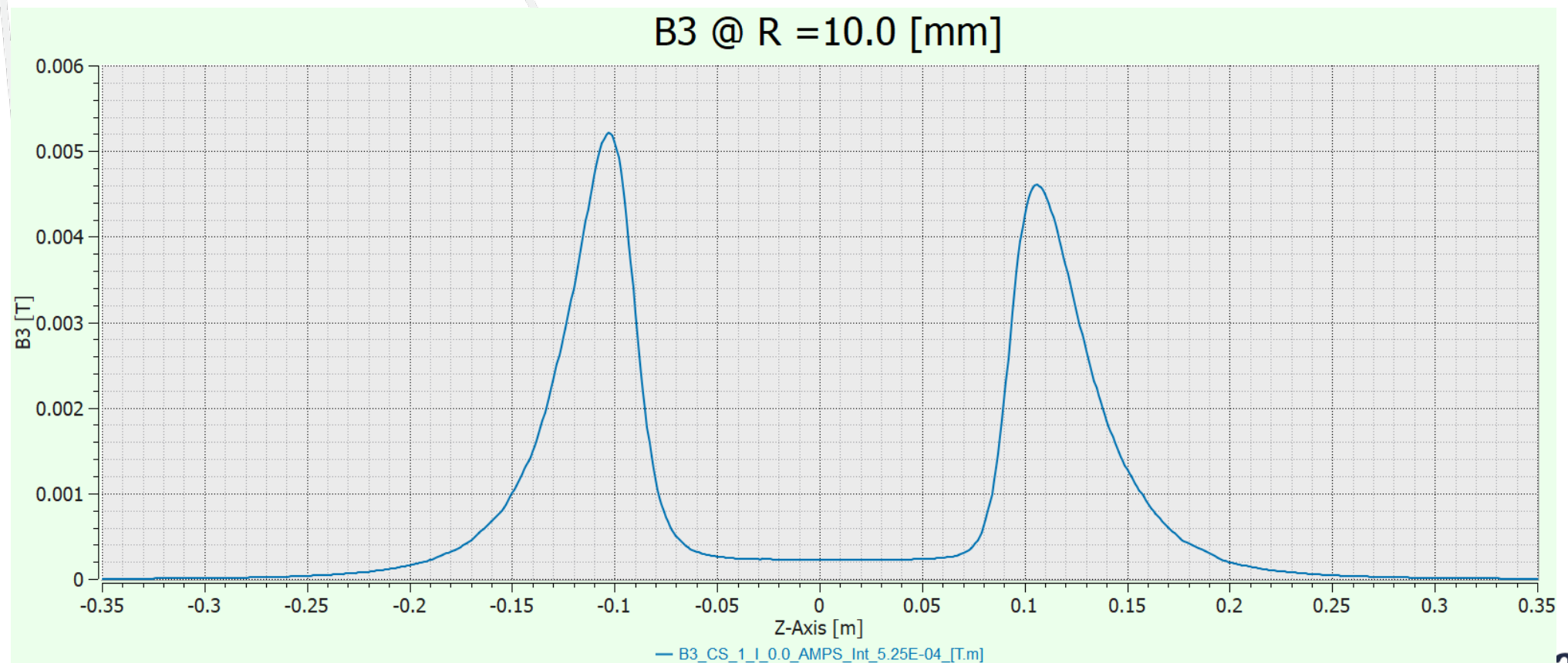
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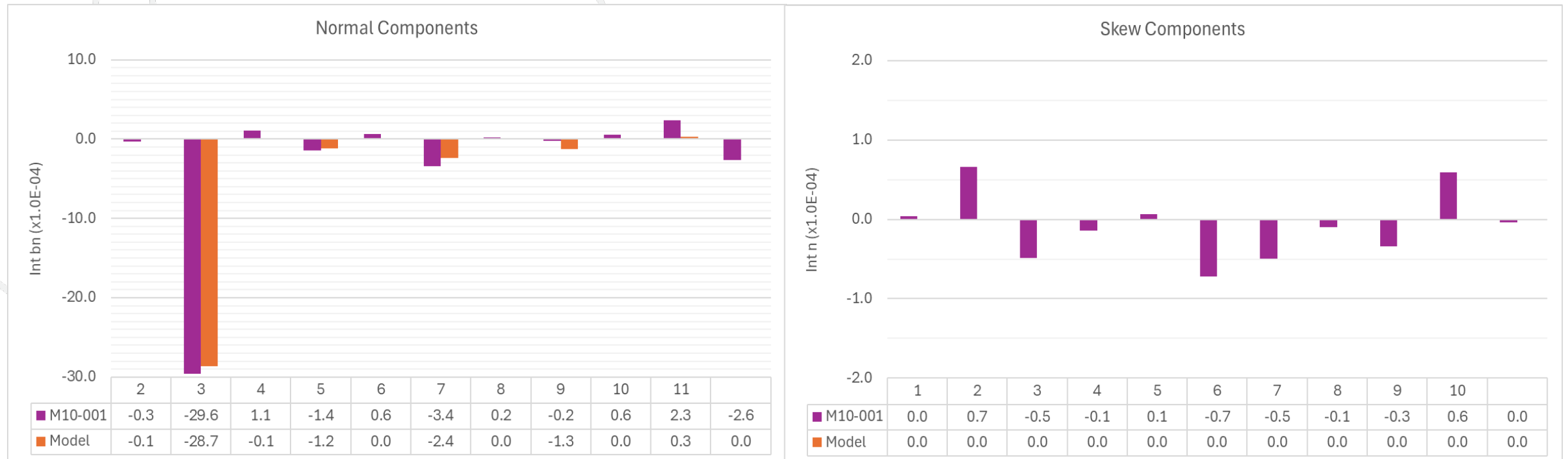
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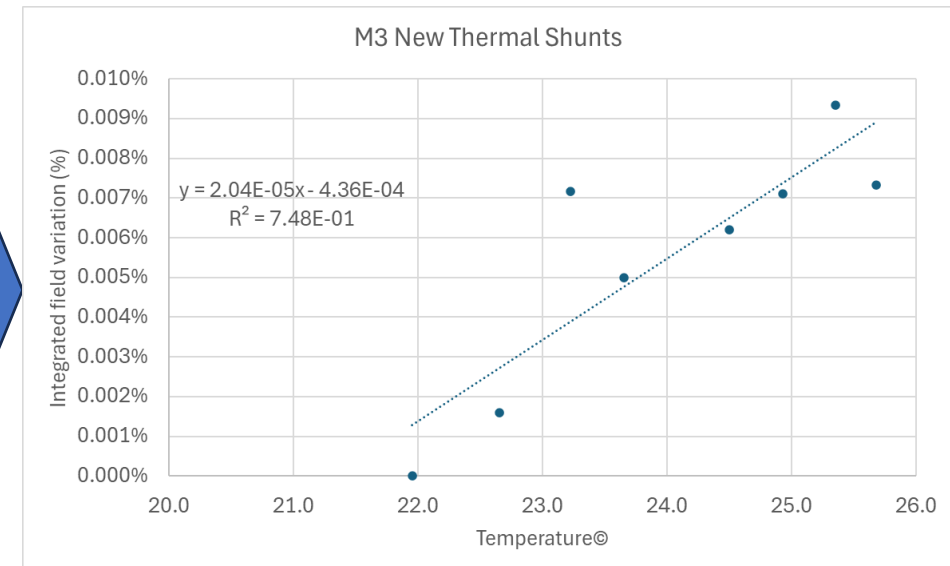
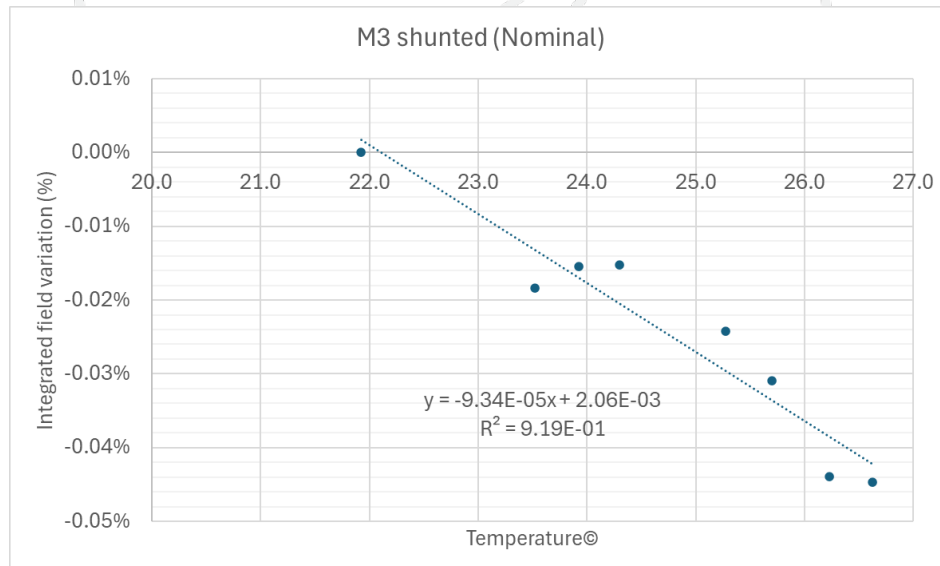
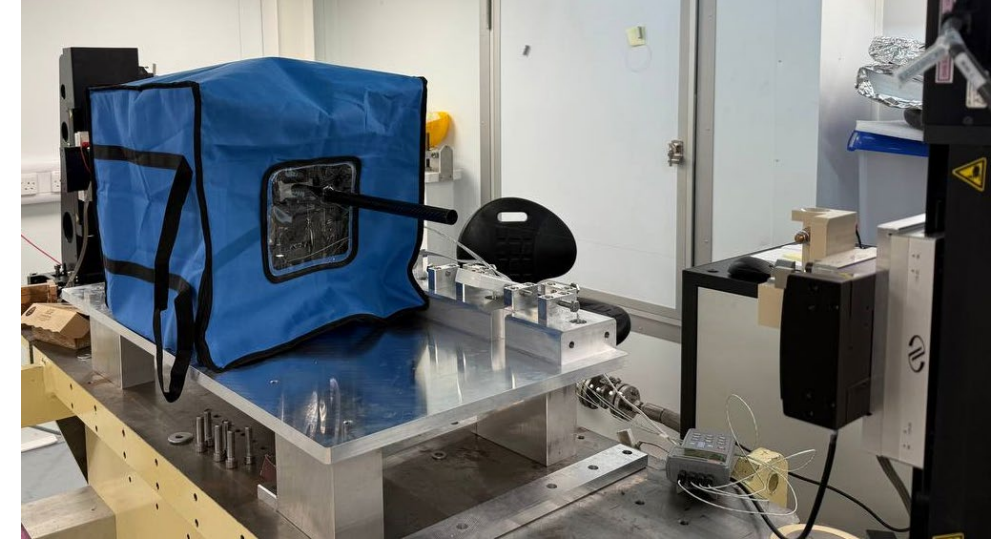
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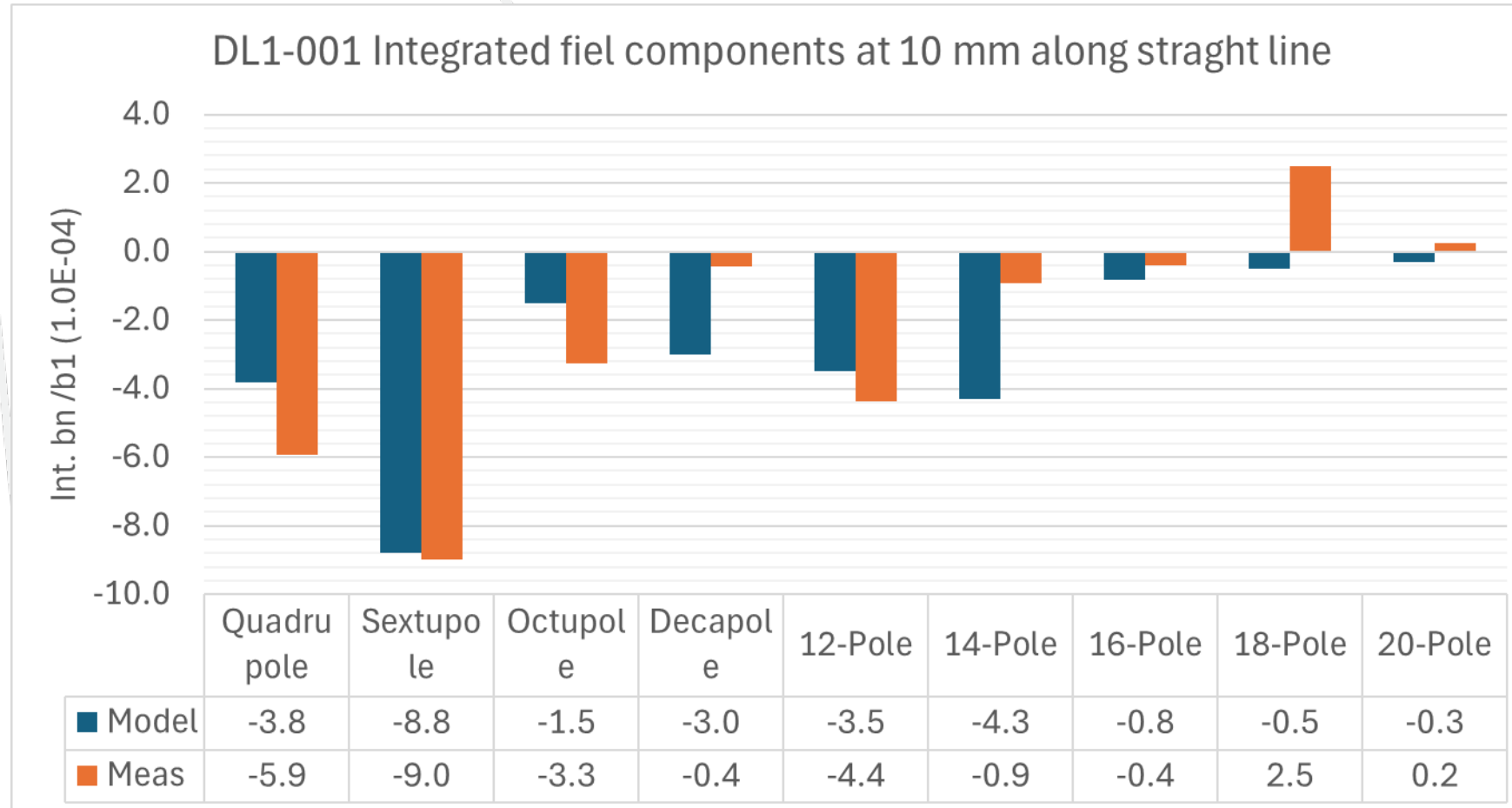
Thermal Shunt Installation & Stability

- Each module equipped with nominal-size thermal shunts
- Thermal stability with design thermal shunts: $\sim 1.5 \times 10^{-4} / ^\circ\text{C}$
- Target with additional thermal shunts installed $\rightarrow$ Better than: $\pm 5.0 \times 10^{-5} / ^\circ\text{C}$



Full DL magnet measurements

- Straight-line integration (stretched wire) shows apparent quadrupole from staggered geometry.
- Trajectory-based integration confirms no real quadrupole component.



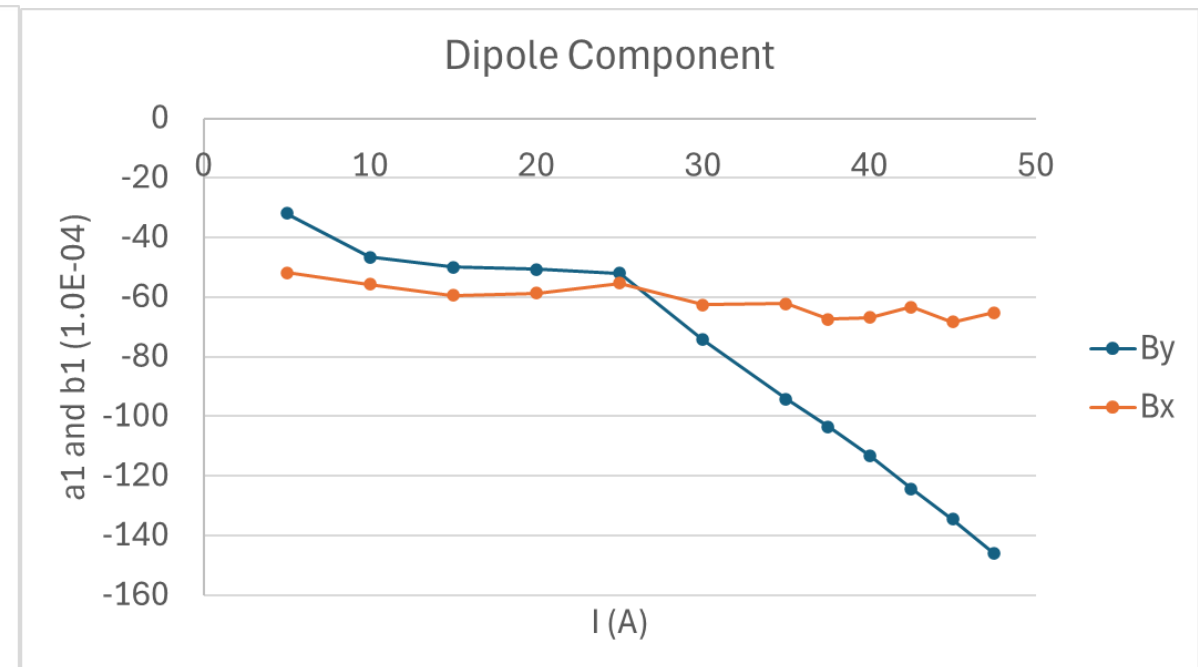
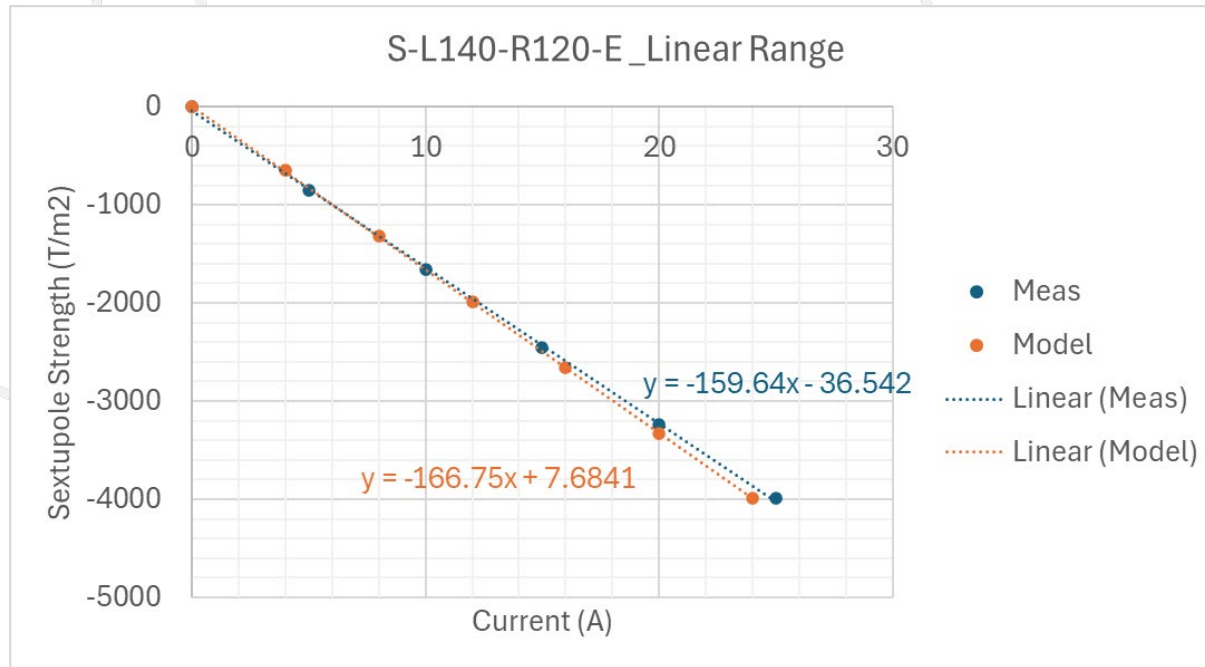
Sextupole Measurements

Danfysik Pre-series testing

- Results from FATs on pre-series ok but towards upper limit of acceptable range, so negotiated pre-series testing on 2 further examples of each type of sextupole, but possible subsequent changes agreed to be only final machining.

Comparison FAT(Danfysik) vs. SAT(Diamond) – Magnet Variants

- Comparison performed across different magnet variants
- Measurement system repeatability: $\sim 2.0 \times 10^{-4}$
- Results shown in plots below (Specs are absolute values)



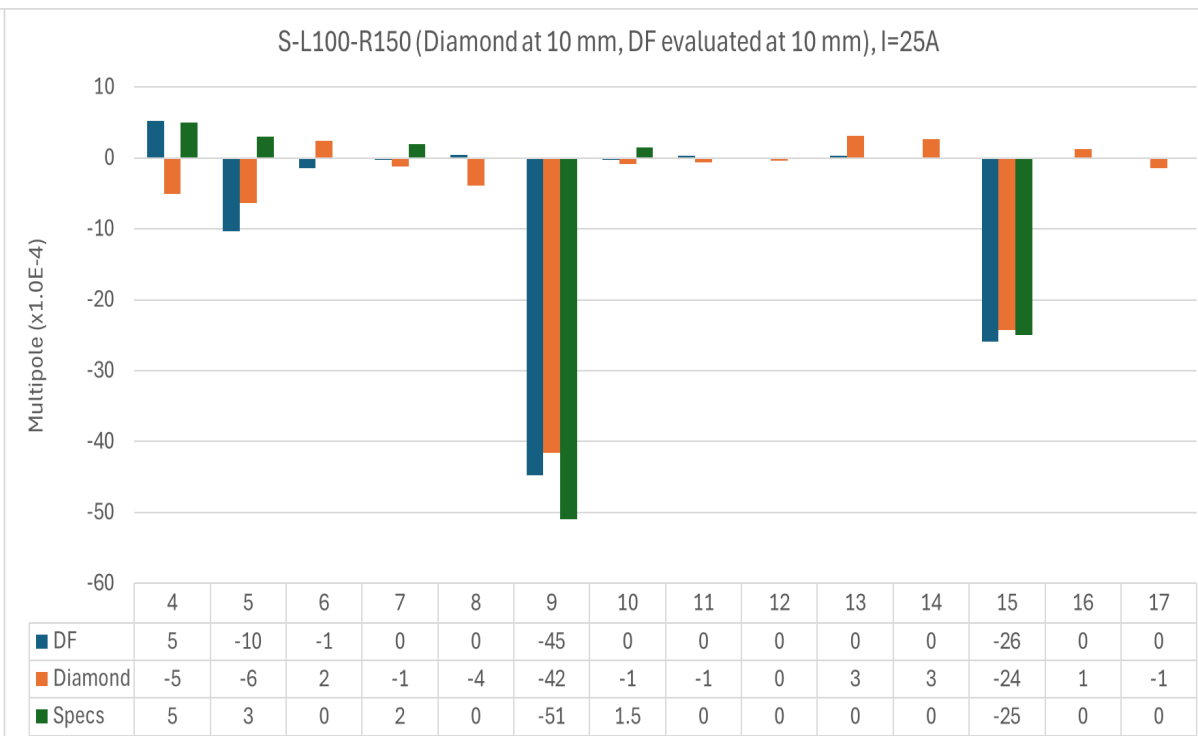
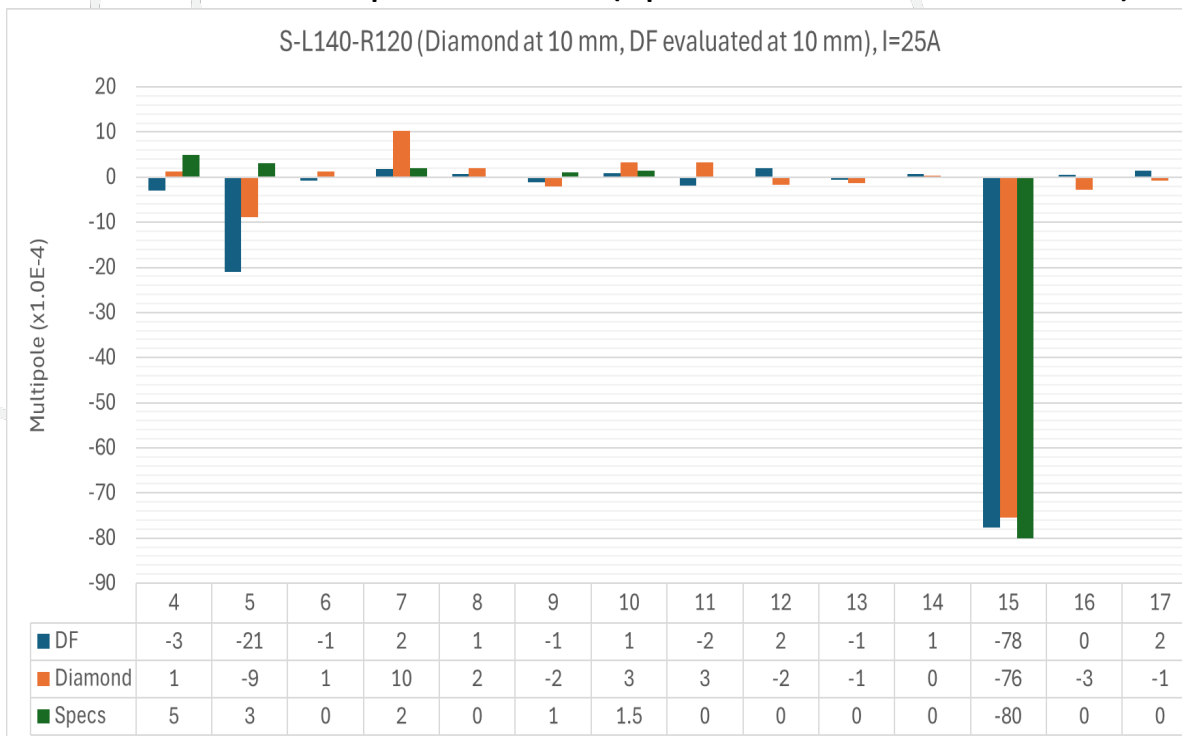
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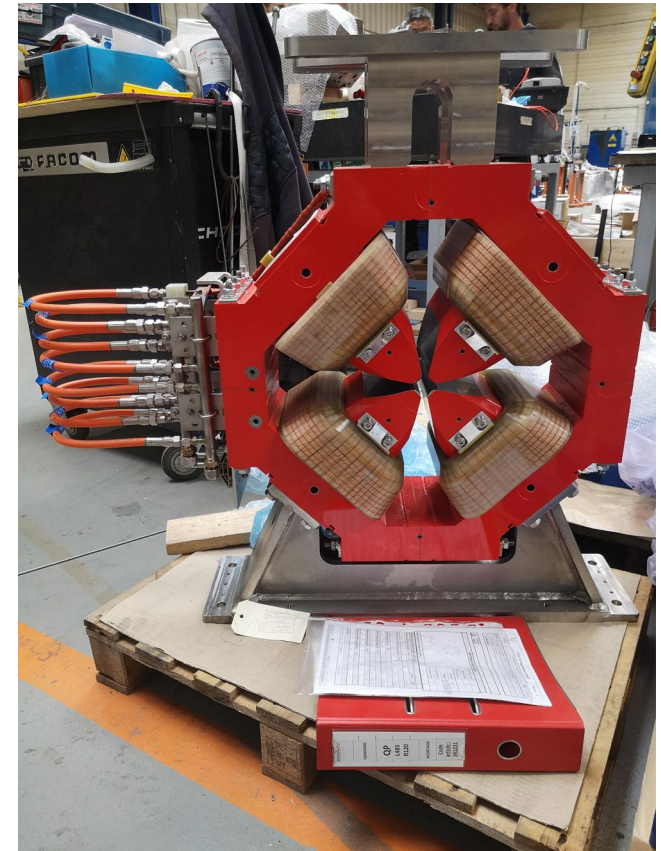
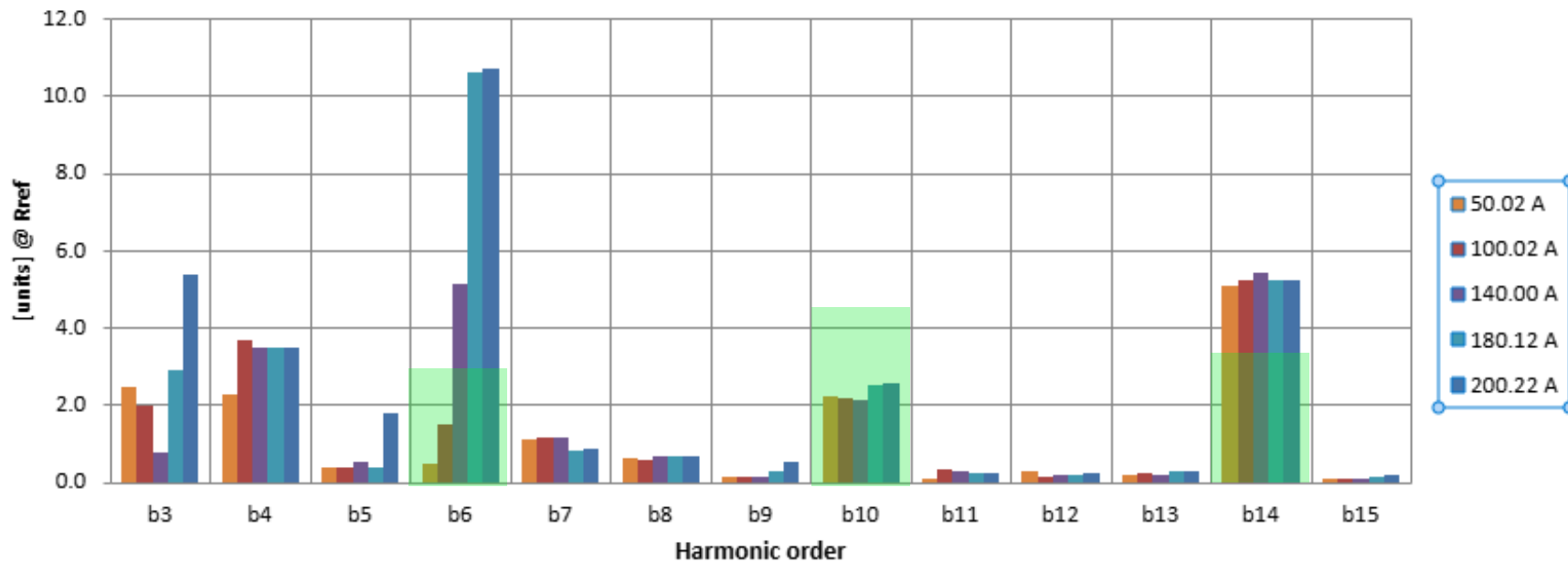


Quadrupole Measurements

Pre-series FAT Status (Sigma Phi)

- There have been delays on pre-series from July to currently in progress!
- One out of four has failed dimensional checks following machining, a replacement yoke is being machined ~1 month further delay.
- Partial results from 1st complete magnet received.

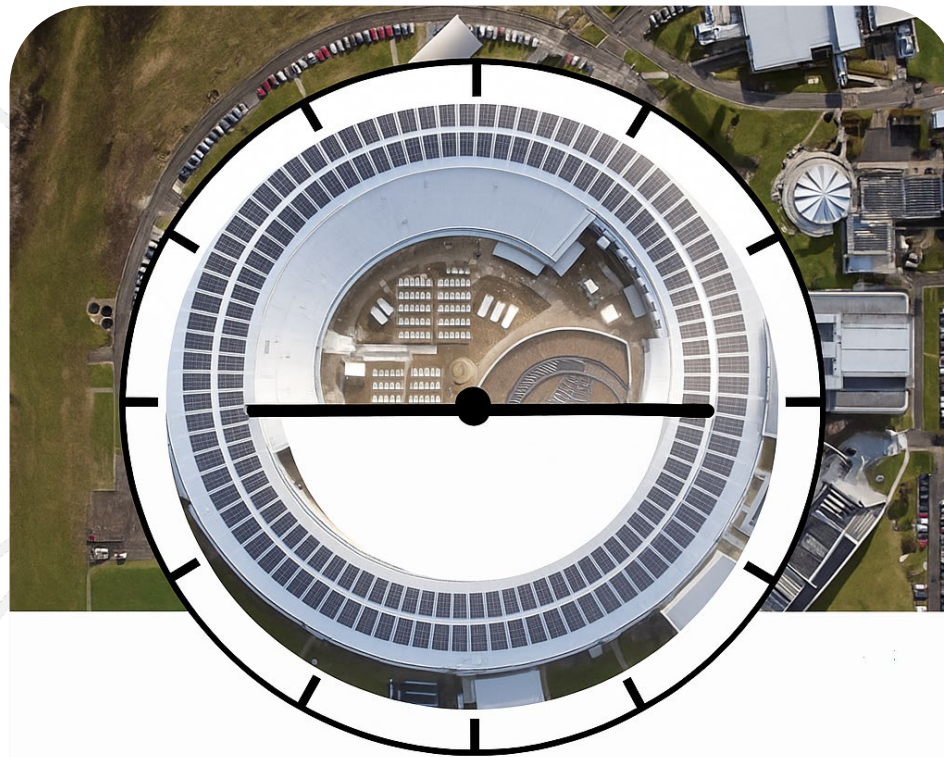
Harmonic components (bn) versus current @Rref 10mm



Conclusion

Lesson learned so far:

- Always prepare for potential delays, having a well-thought-out Plan B keeps progress on track.
- Be as specific as possible in your technical specifications, especially for the measurement plans, clarity upfront prevents confusion later.
- Review all manufacturer calibration certificates and measurement data carefully to ensure traceability and consistency.
- Attending and witnessing Factory Acceptance Tests (FAT) is invaluable, it helps align expectations and catch issues early.
- Magnet manufacturers deliver excellent work and expertise; close collaboration ensures their craftsmanship meets project intent.
- Clear definitions and repeatable measurement procedures are essential, benchmarking results across facilities can be challenging without them.



thank you for your attention

Any Questions?

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