

Survey marathon: assessing measurement repeatability of SOLEIL storage ring

Y. Delalande¹, S. Ducourtieux¹, A. Lestrade¹, M. Sebdaoui¹, B. Leluan¹, C. Bourgoïn¹, Y. Denis¹, D. Jourdain¹, E. Lazarowitz¹, M. Baklouti¹, J. Guillory², S. Durand³

¹Synchrotron SOLEIL

²Laboratoire Commun de Métrologie LNE (Cnam/LCM - EA 2367)

³Laboratoire Geomatique et Foncier (Cnam/GeF - UR 4630)

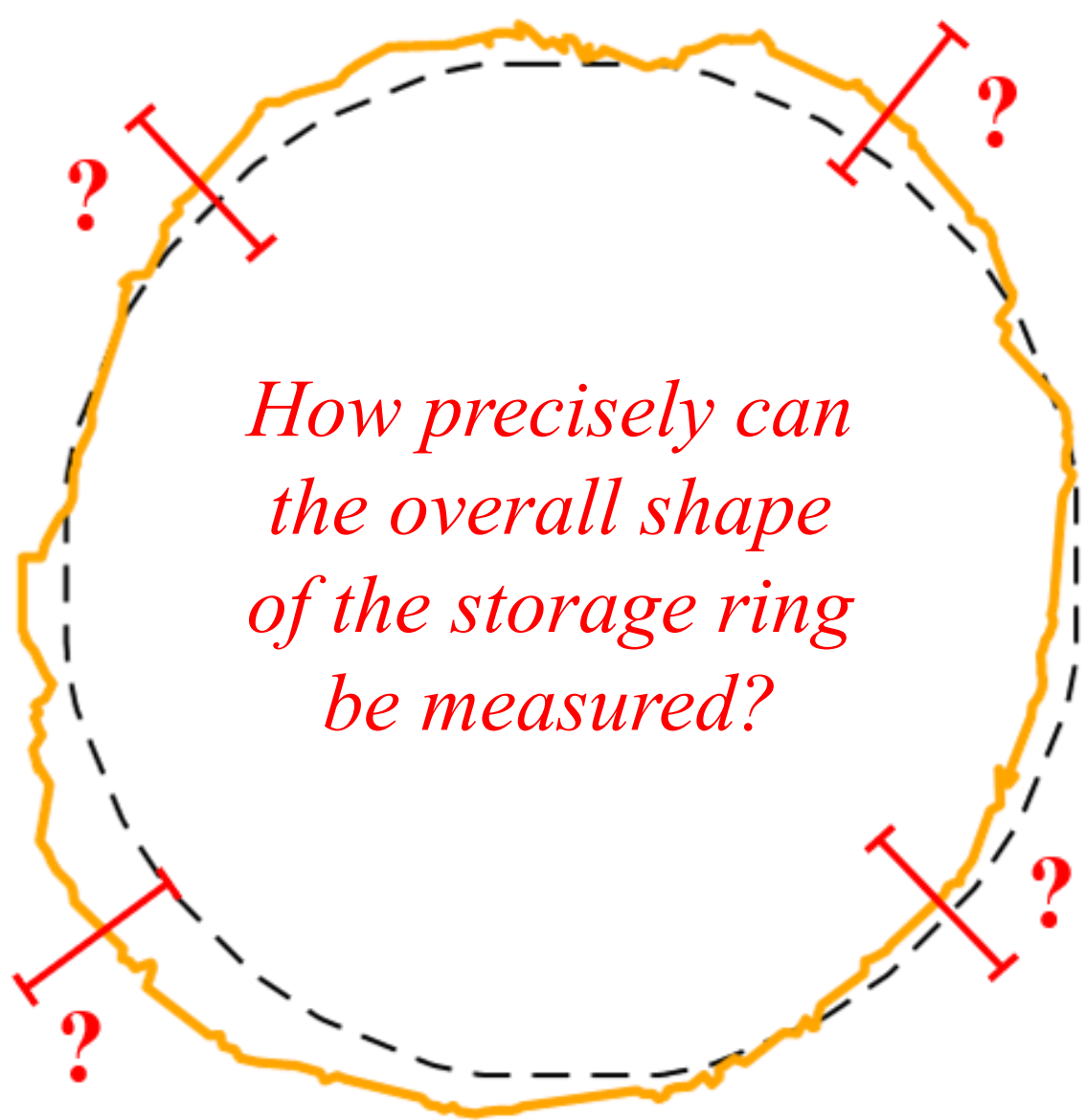
ABSTRACT

The SOLEIL II machine upgrade requires unprecedented alignment tolerances, down to +/- 20 μm for the most critical magnets of the storage ring. This specification demands full control of measurement uncertainties throughout the various steps of the alignment process. One of these steps is the survey, which aims to determine the position of the machine's components and thereby reconstruct its entire geometry. This is a critical step, as it is the final one that determines whether the components comply with the specified tolerances. If this step introduces excessive uncertainty in the position of the components, it can lead to wrong decisions, such as validating a non-conforming alignment or, conversely, rejecting an alignment that is in fact correct. As this uncertainty is difficult to estimate, an in-house model was developed to simulate complete surveys and predict it. To validate this model and, above all, to quantify the uncertainty experimentally, a measurement campaign was conducted, in which seven surveys of the storage ring were performed in succession over a period of less than three weeks. The results show that the dispersion of the machine's global shape does not exceed 30 μm in any of the three directions ($k = 1$), while the circumference of the machine is repeatable to better than 300 μm . Locally, at the level of an individual girder, the dispersion of the magnets does not exceed 2 μm in the three directions ($k = 1$).

AIM AND METHODOLOGY

Methodology

- 4 laser trackers operated simultaneously in the tunnel (2 AT930 and 2 AT960)
- Instruments compensated (ADM offset, geometry) and prisms selected for minimal optical offset
- Air conditioning turned off at each station to ensure a stable and homogeneous temperature over 3 weeks
- Standard mode (5s integration), levelled measurements, full two-face round (Face 1 outbound / Face 2 return)



KEY FIGURES

7 Complete surveys		
3	462	35,290
Campaign weeks	Stations	Measurements
537	10	30
Network points	Operators	Mean time per station (min)
4.3	7.3	1.5
Mean observations per points	Mean sight distance (m)	Max temperature variation (°C)

ADJUSTMENT

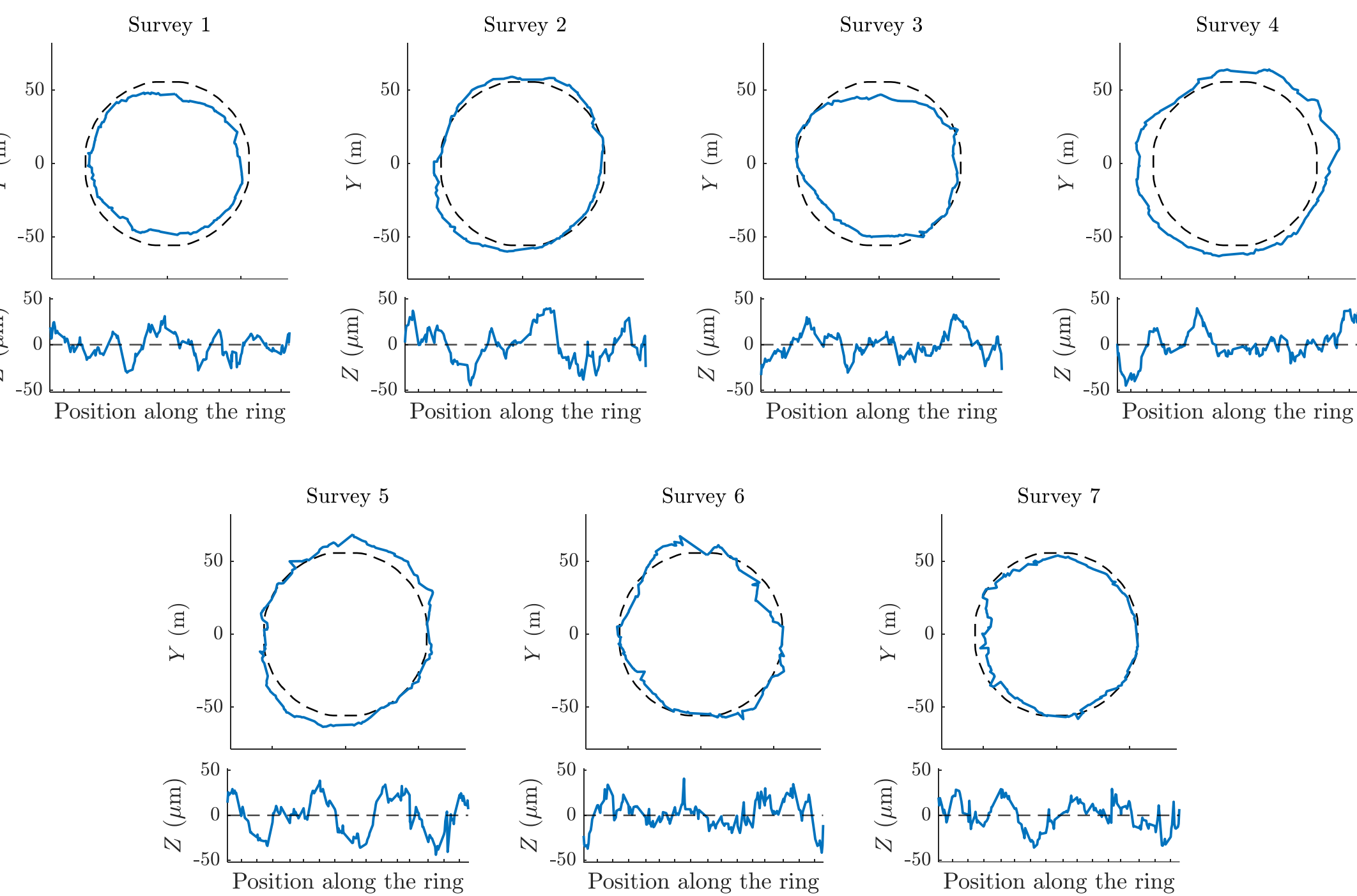
Each survey was adjusted independently using Spatial Analyzer software via USMN option.

Survey no.	Free network	4 DoF		Cartesian model	
	Global RMS (mm)	Average RMS (mm)	Hz angle residuals (")	V angle residuals (")	Distance residuals (mm)
1	0.016	0.008	0.26	0.49	0.002
2	0.017	0.009	0.26	0.55	0.003
3	0.016	0.008	0.26	0.50	0.002
4	0.019	0.01	0.38	0.55	0.004
5	0.017	0.009	0.30	0.50	0.004
6	0.022	0.012	0.33	0.71	0.006
7	0.021	0.011	0.31	0.66	0.004

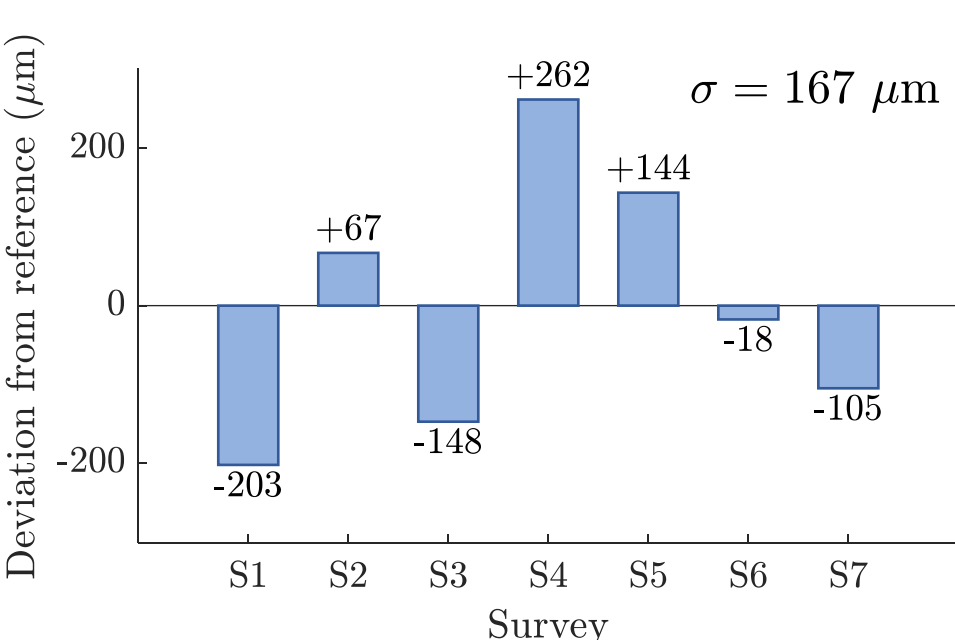
GLOBAL SHAPE

Repeatability of the planimetry and vertical global shape of the storage ring:

--- Average shape — Measured shape



Circumference repeatability:

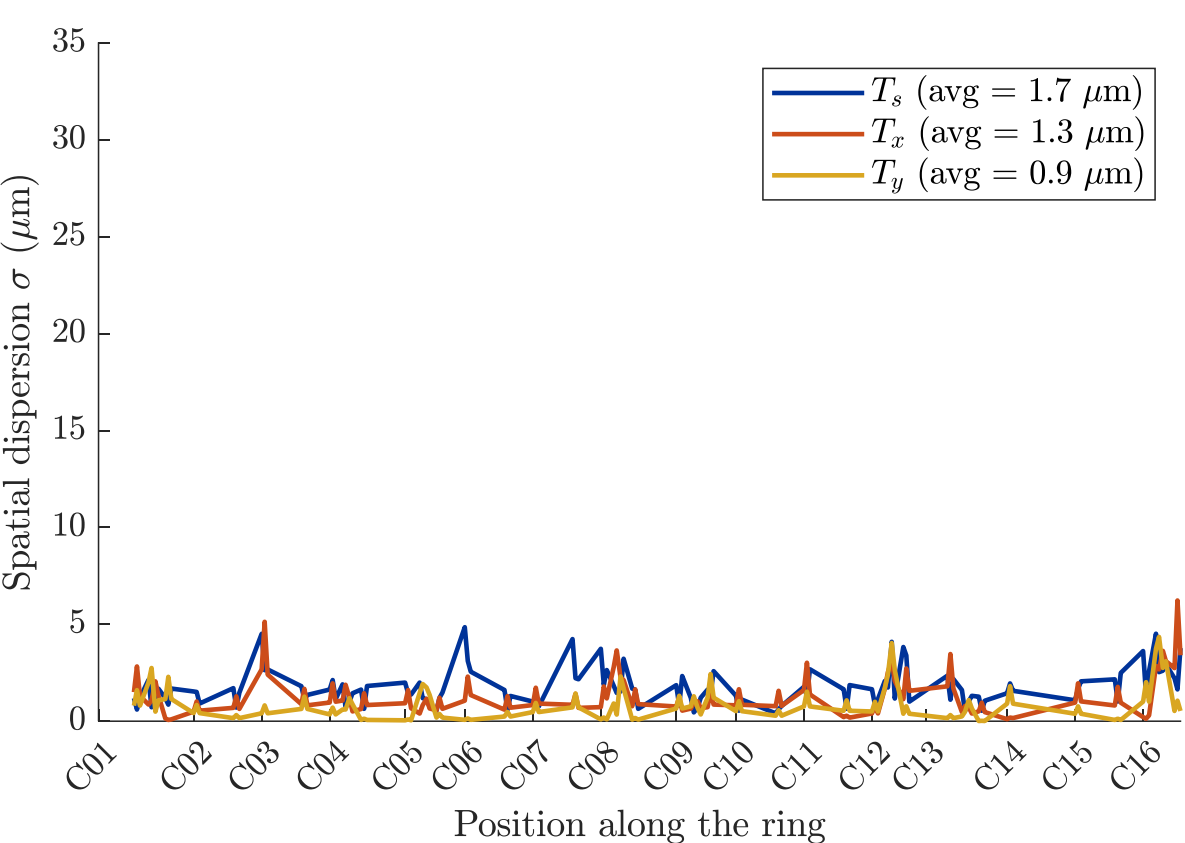


Measurements vs simulations:

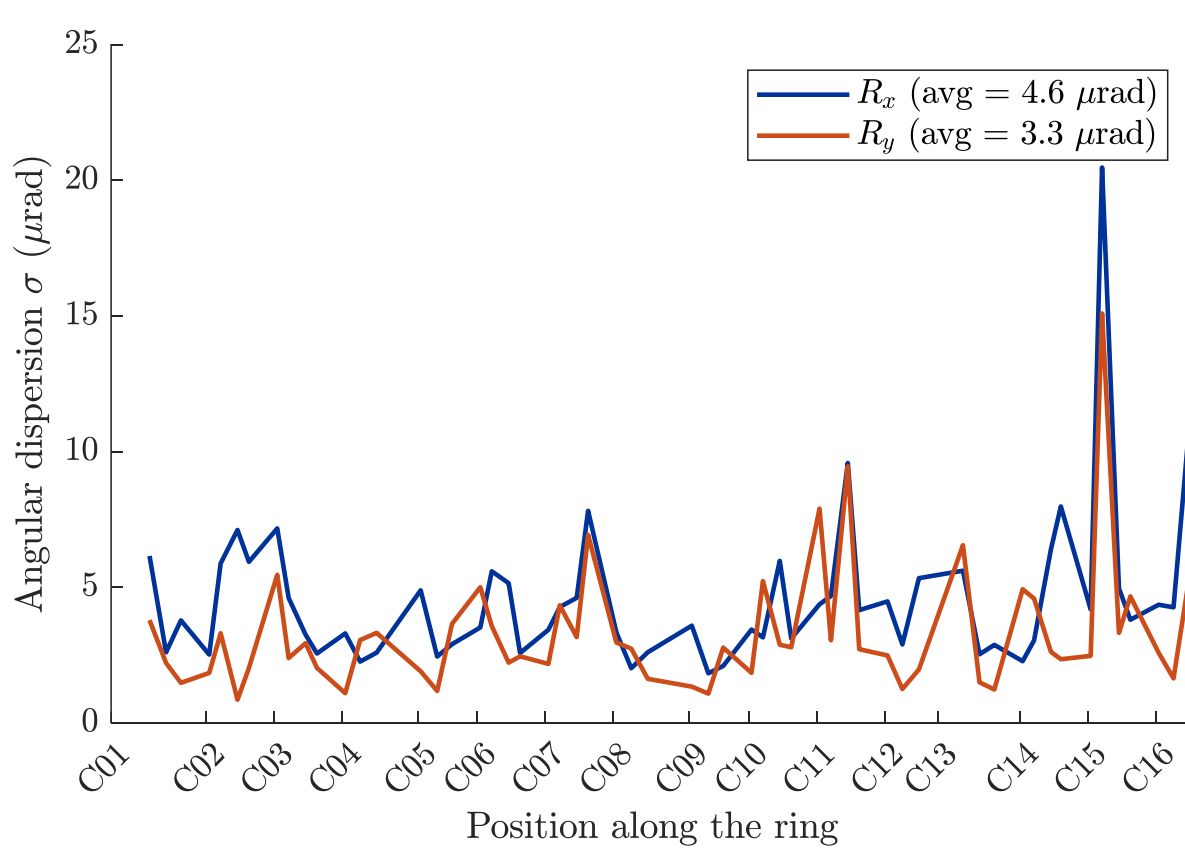
	Survey marathon	Simulations
σ_s (μm)	13	12
σ_x (μm)	30	26
σ_z (μm)	17	16
σ_c (μm)	167	50

LOCAL SHAPE

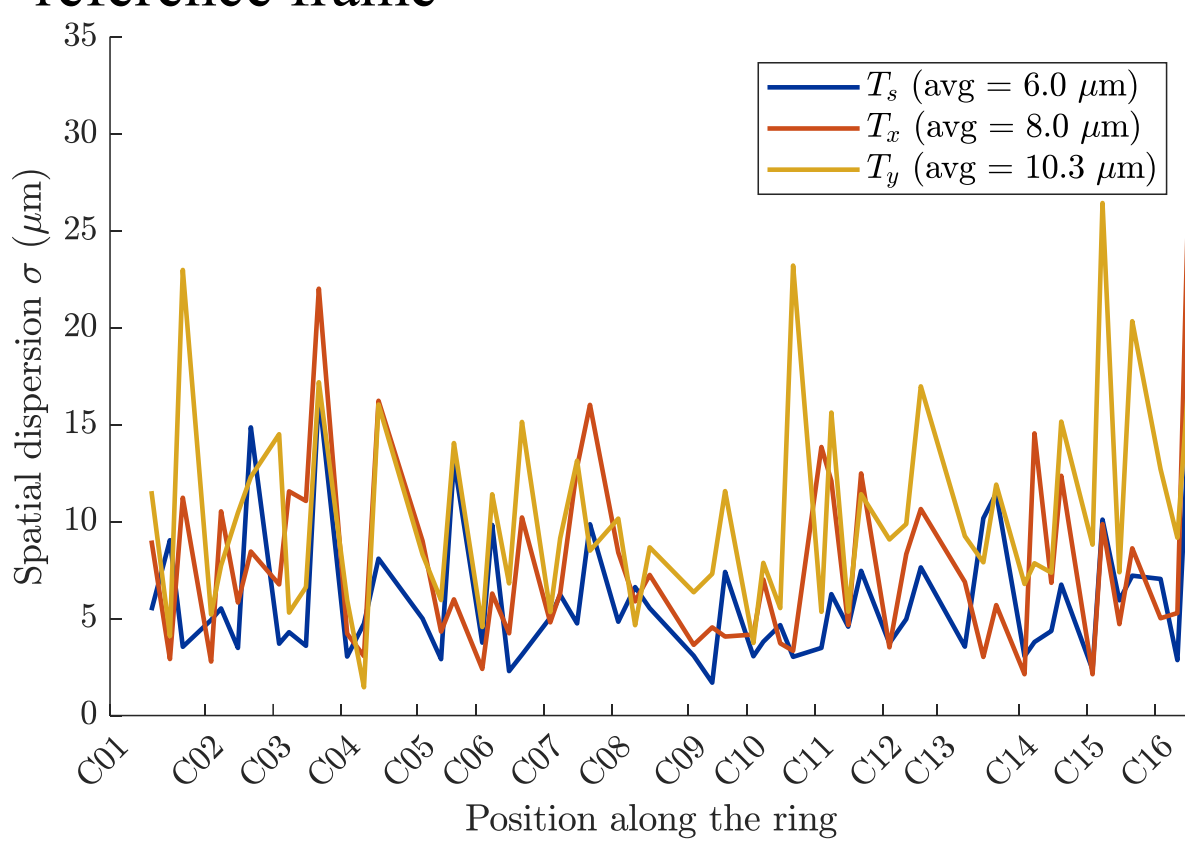
Intra-girder repeatability: relative position of the magnets within the girder's reference frame



Girder orientation repeatability: angle between a best-fit line through each girder's magnets, relative to the theoretical line orientation



Inter-girder repeatability: relative position between the last magnet of one girder and the first of the next, measured in the common reference frame

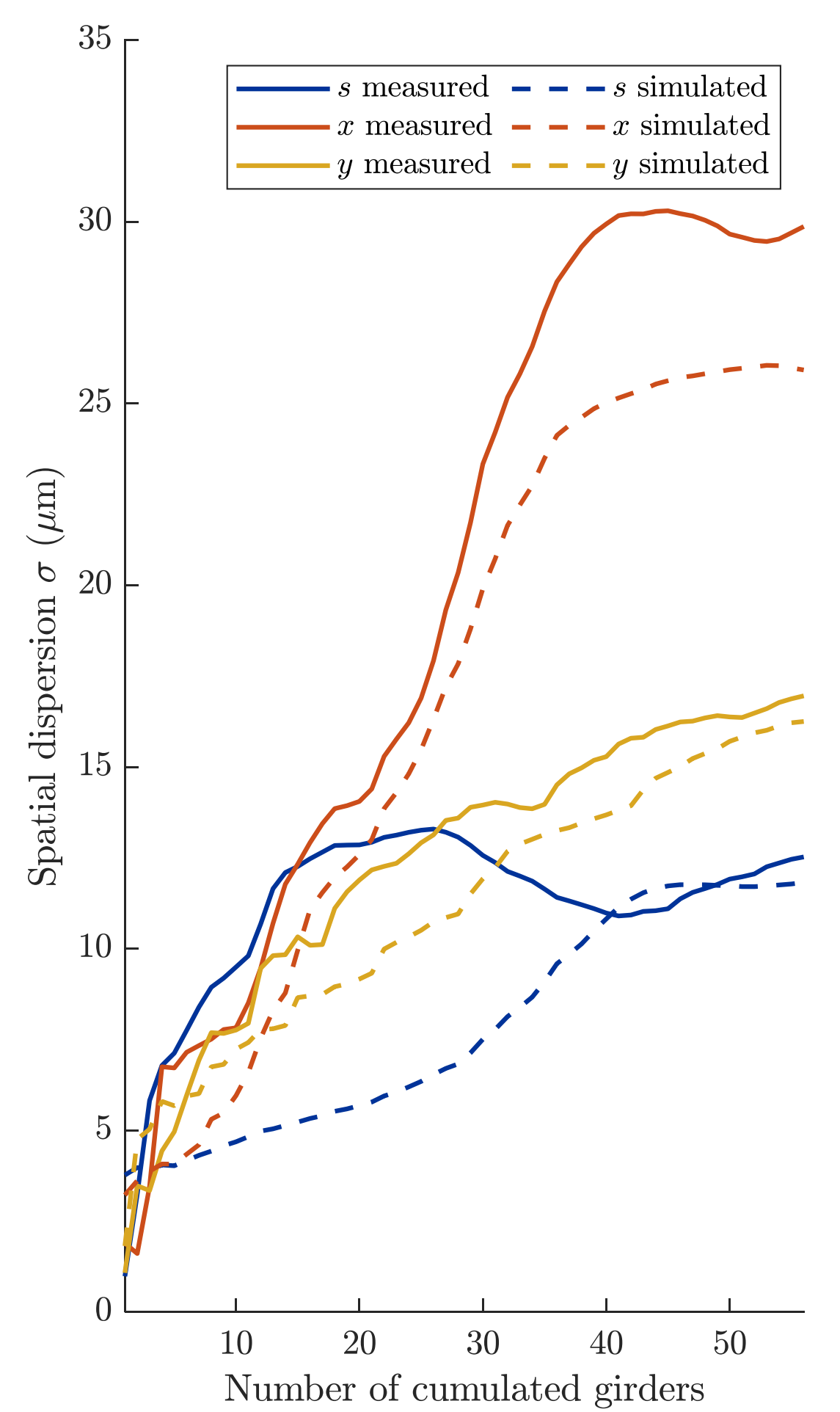


Measurements vs simulations:

		Survey marathon	Simulations
Magnets	σ_{T_s} (μm)	1.7	3.0
	σ_{T_x} (μm)	1.3	2.4
	σ_{T_y} (μm)	0.9	2.2
	σ_{T_z} (μm)	6.0	5.9
	σ_{T_x} (μm)	8.0	8.8
Girders	σ_{T_y} (μm)	10.3	11.2
	σ_{R_x} (μrad)	4.6	6.1
	σ_{R_y} (μrad)	3.3	4.2

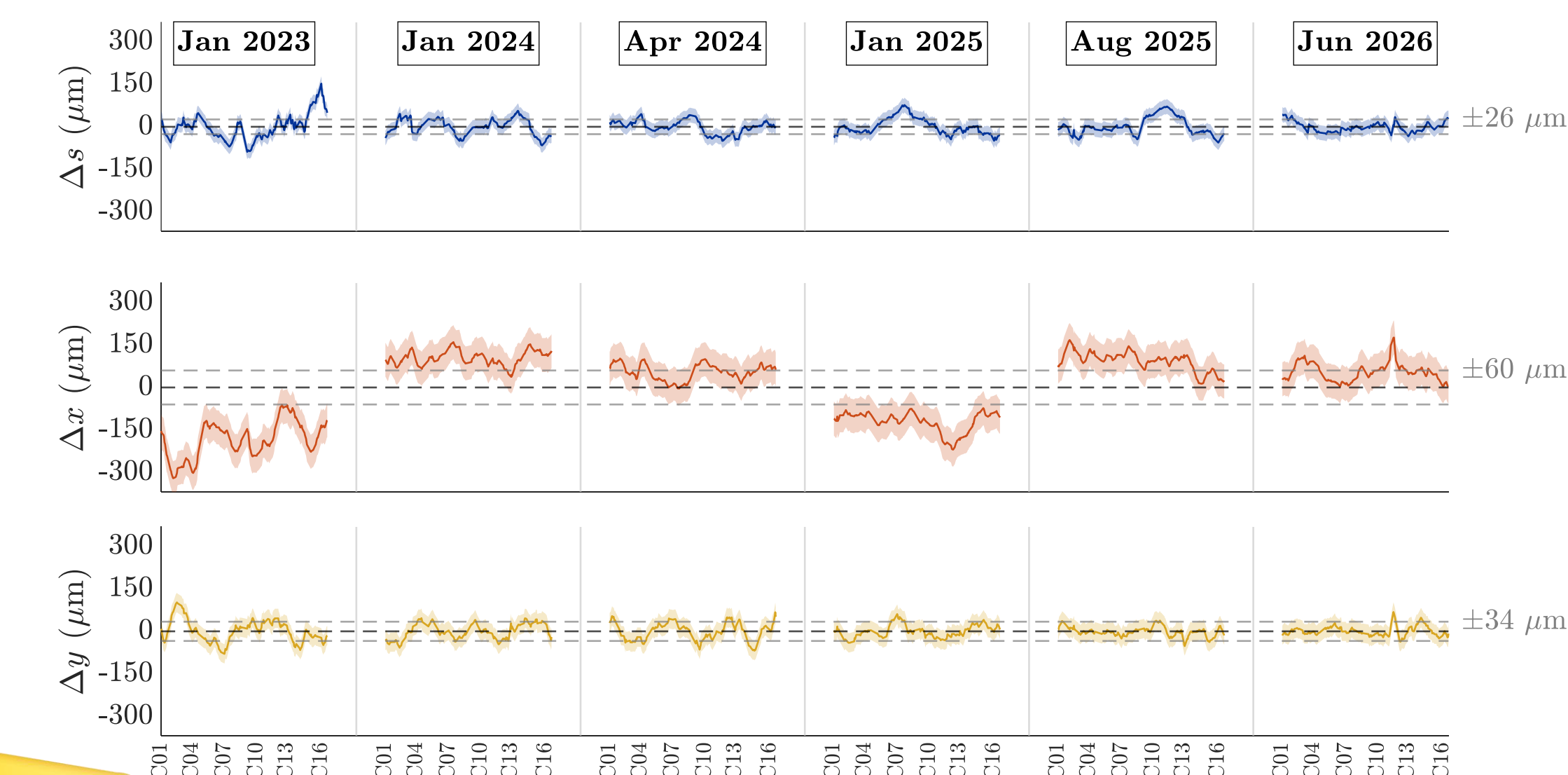
SCALE EFFECT

Spatial dispersion as a **function of the number of girders** considered, compared against simulation. The more girders are considered, the less controlled the shape becomes.

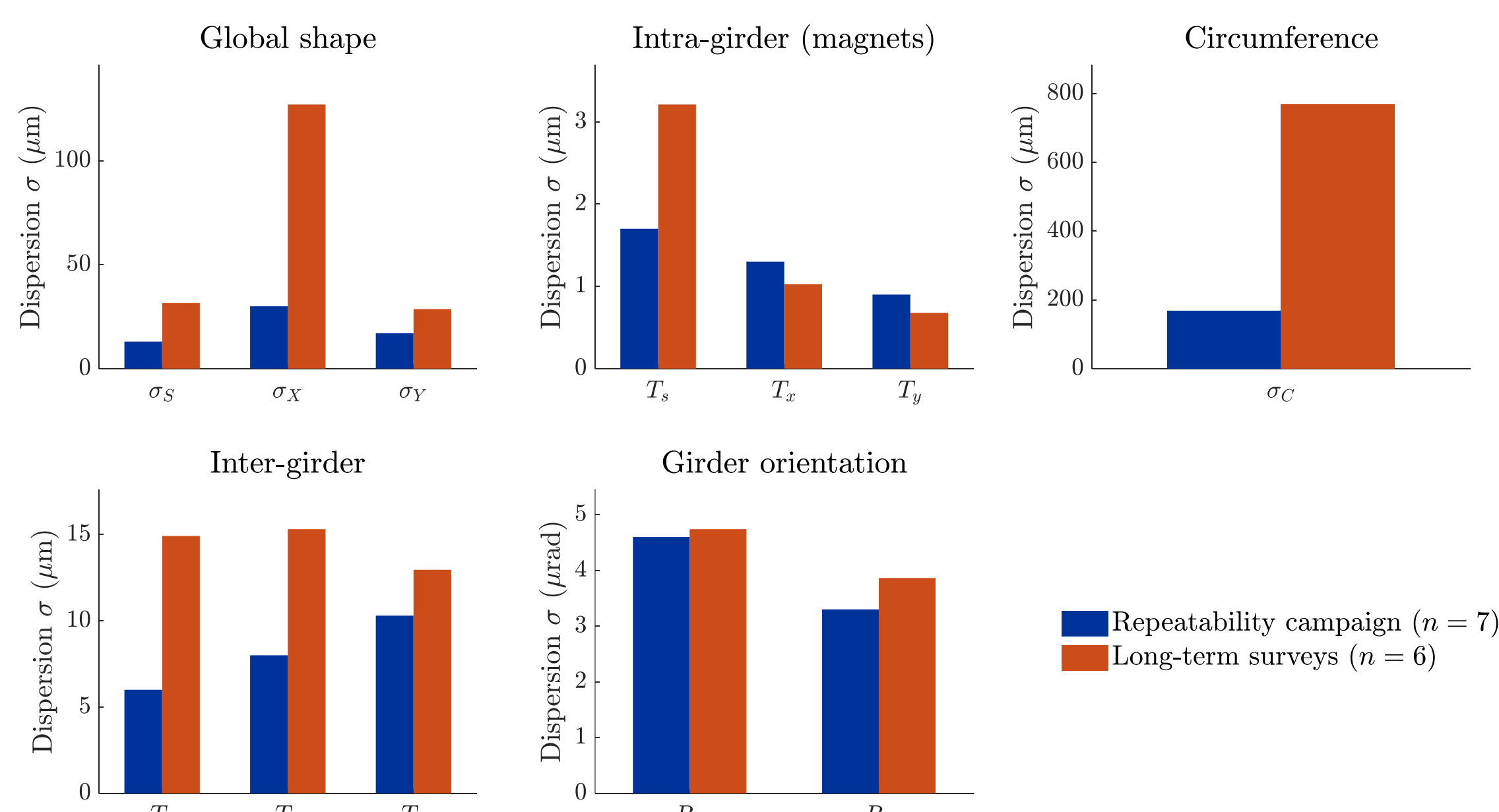


STORAGE RING EVOLUTION OVER TIME

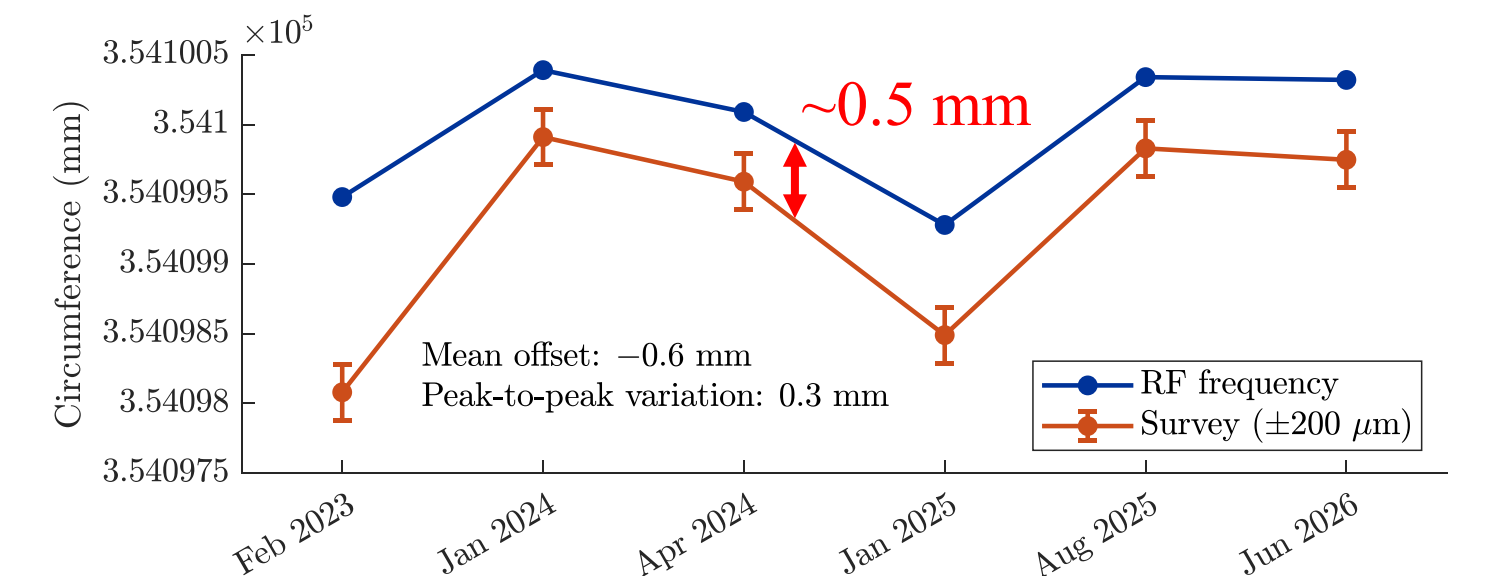
Since 2023, **six** complete surveys have tracked the storage ring over time. Combined with the repeatability uncertainty from this campaign, they let us separate real machine motion from measurement noise.



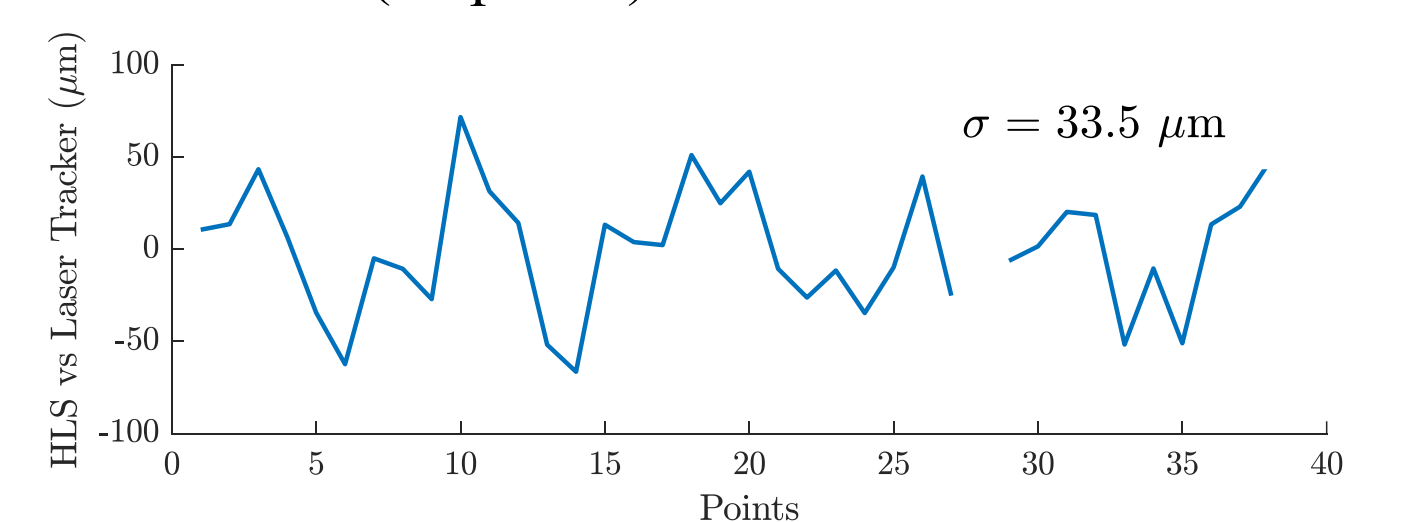
Dispersion of each indicator, campaign vs. 3-year surveys:



RF frequency vs surveys: cross-validation of the circumference measurement



HLS vs surveys: cross-validation of the vertical shape of the machine (38 points)



CONCLUSION

This work establishes, for the first time, a realistic repeatability uncertainty for every alignment indicator of the SOLEIL storage ring. Over three years, only the radial component shows a statistically significant real drift — independently confirmed by the RF-derived circumference — consistent with thermal expansion of the concrete slab supporting the machine, which would explain both the radial motion and the associated circumference variation. The close agreement between these measurements and Monte Carlo simulations validates the simulation model [1], meaning future survey strategies can now be predicted and optimised numerically. These uncertainties, assessed at this specific step of the survey, will now be incorporated into the uncertainty budget for the overall alignment strategy, making it more realistic and enabling conformity decisions to be taken with the greatest possible confidence [2].

[1] Y. Delalande *et al.* Modelling and optimization of SOLEIL II survey and uncertainty assessment of the measurement process using Monte Carlo approach. In Proc. International Workshop on Accelerator Alignment (IWAA), 2024.

[2] Y. Delalande *et al.* Optimisation of the SOLEIL II accelerator alignment strategy through the implementation of a metrological approach. Submitted to Measurement Science and Technology, September 2026