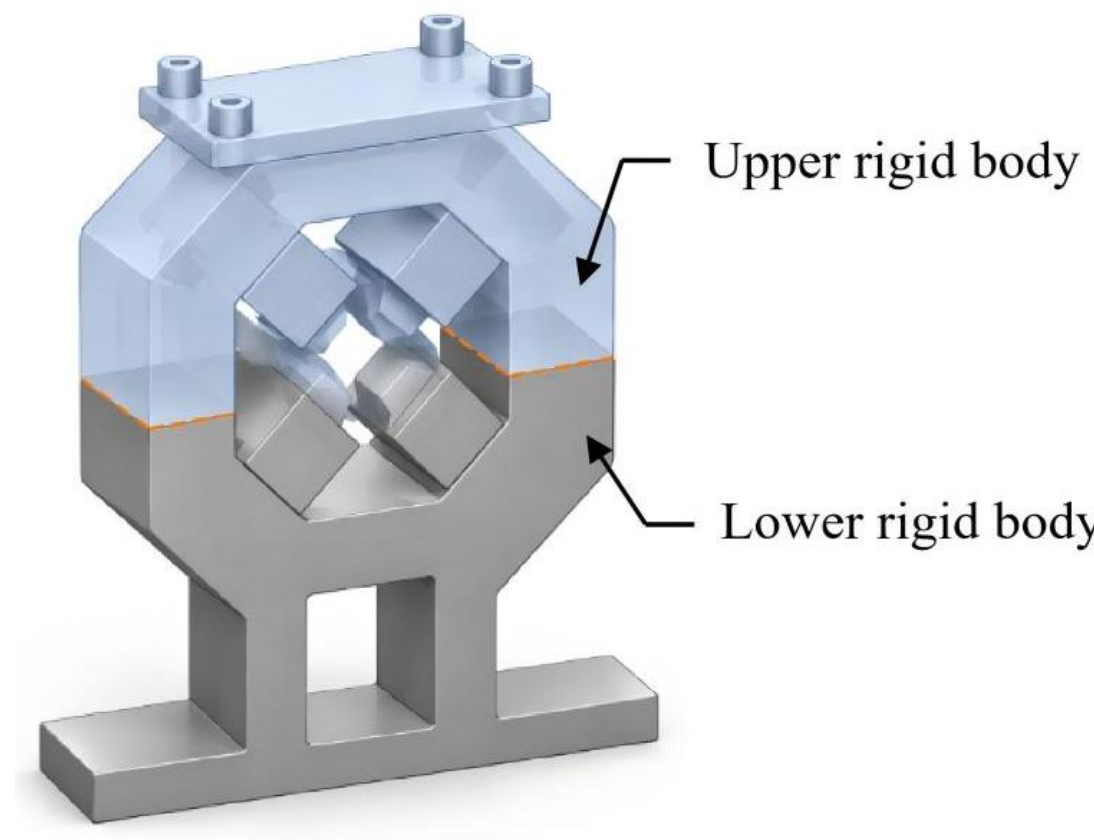


1. Introduction: opening and reassembly of accelerator magnets

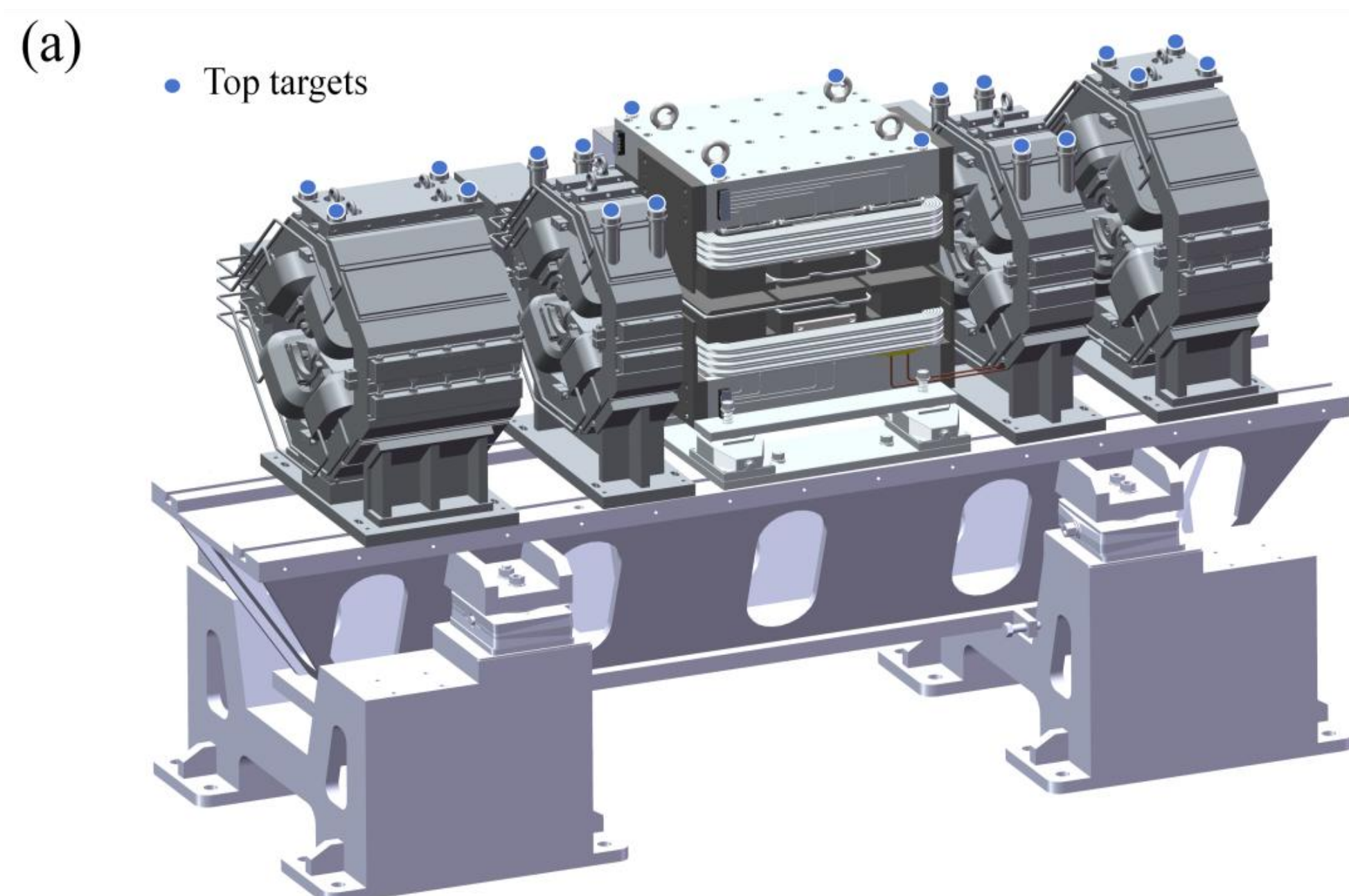
Accelerator magnets may need to be opened and subsequently reassembled during installation, maintenance, or inspection. In conventional alignment practice, restoration can be evaluated by registering accessible targets on the magnet top surface. This provides a practical assessment of the restored top-target configuration.



Key question:

Does successful restoration of accessible top targets guarantee restoration of the internal magnet geometry?

2. Geometric pre-study: what does the top-target criterion represent?



Model and target configuration

Top-target restoration is evaluated by rigid registration to the pre-opening configuration, with

$$\max(\text{RMSX}, \text{RMSY}, \text{RMSZ}) < 10 \mu\text{m}$$

A five-magnet simulation was used to test whether this criterion also constrains the internal relative pose.

At a 30 μm perturbation limit

Motion mode	Accepted
Translation only	29.47%
Translation + rotation	20.74%
Rotation only	11.45%

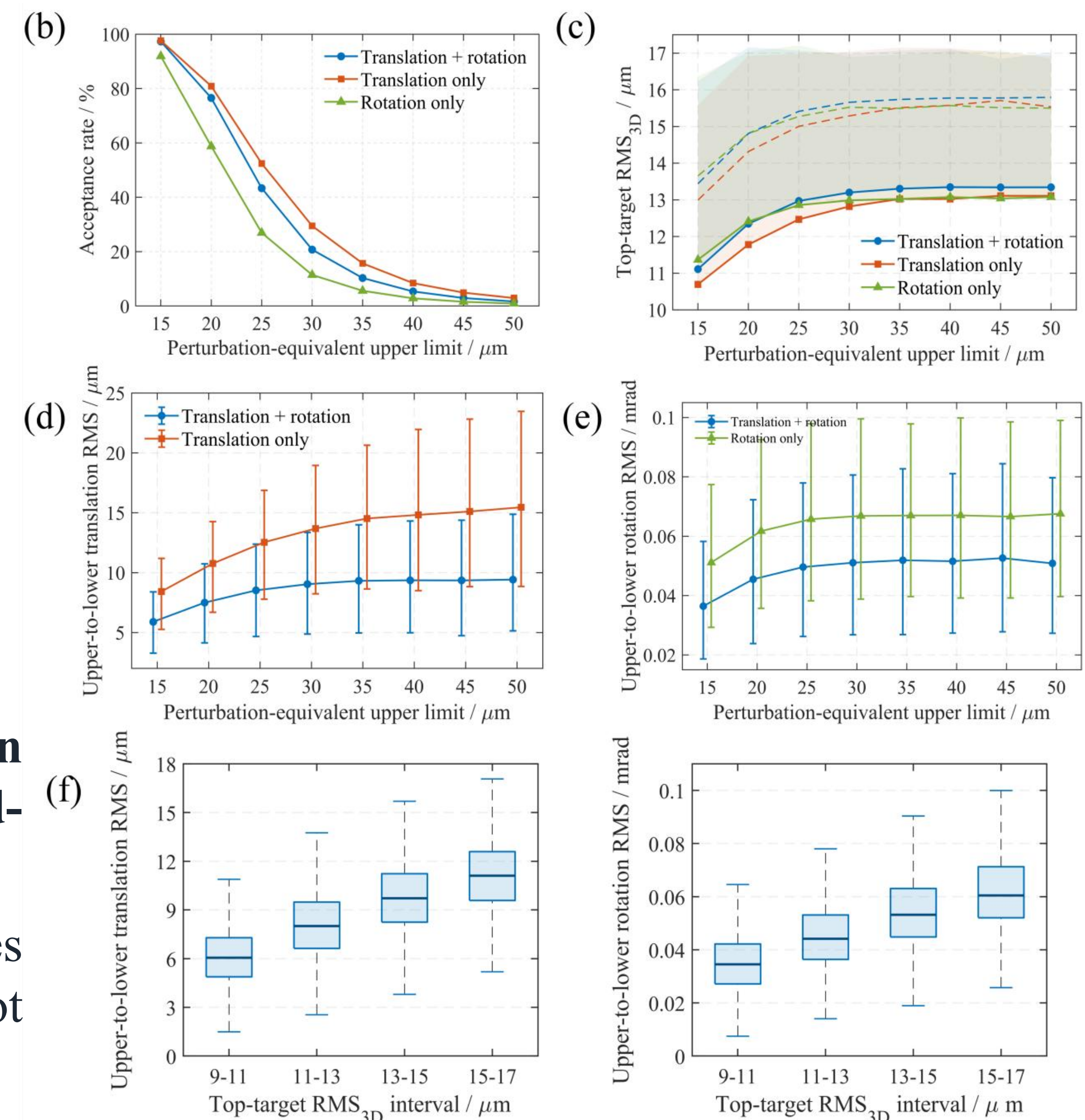
For accepted combined-motion states

$$\mathbf{T}_{\text{RMS}} = 4.87\text{--}13.36 \mu\text{m}$$

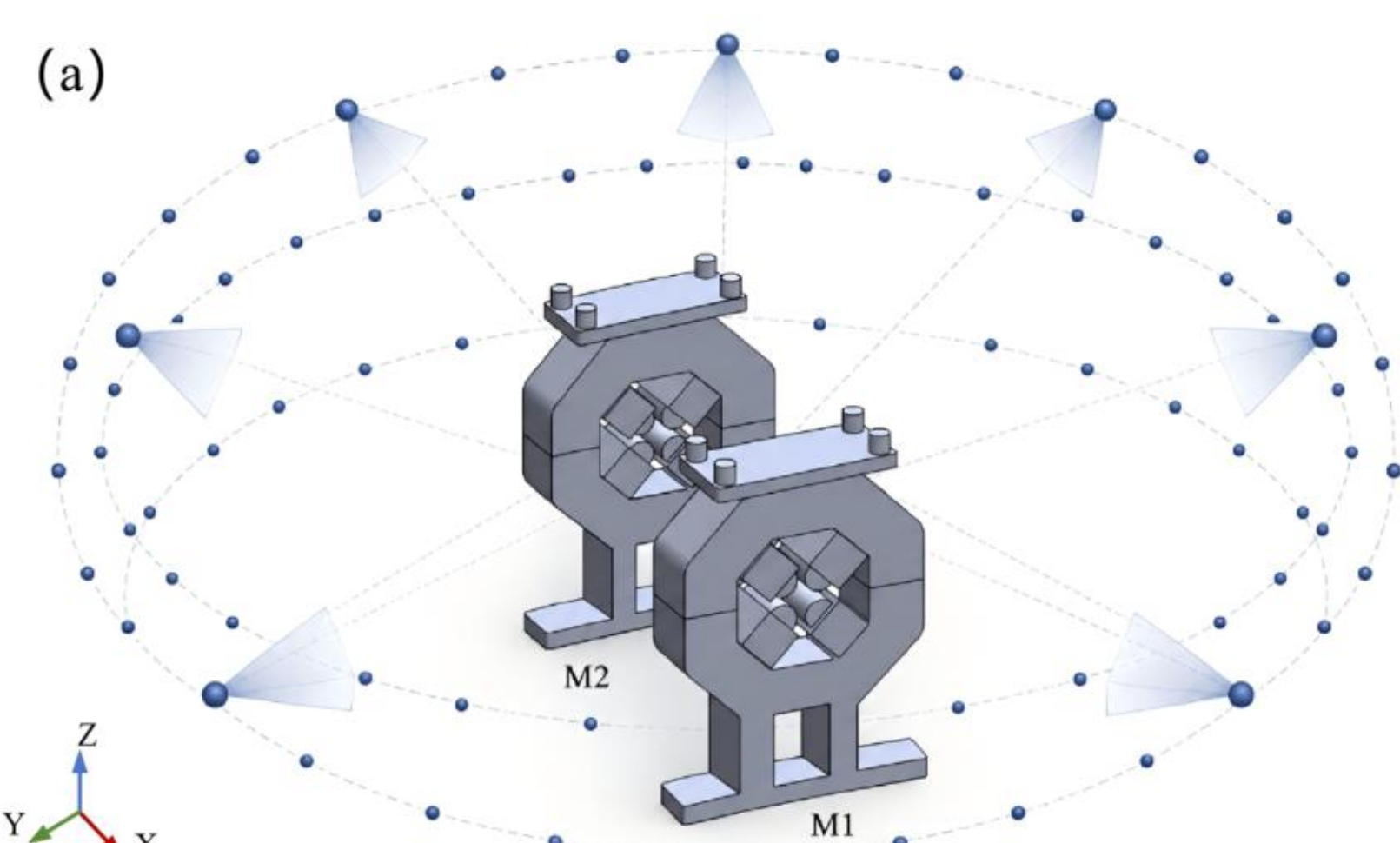
$$\Omega_{\text{RMS}} = 0.0268\text{--}0.0806 \text{ mrad}$$

Similar top-target residuals can correspond to different internal rigid-body states.

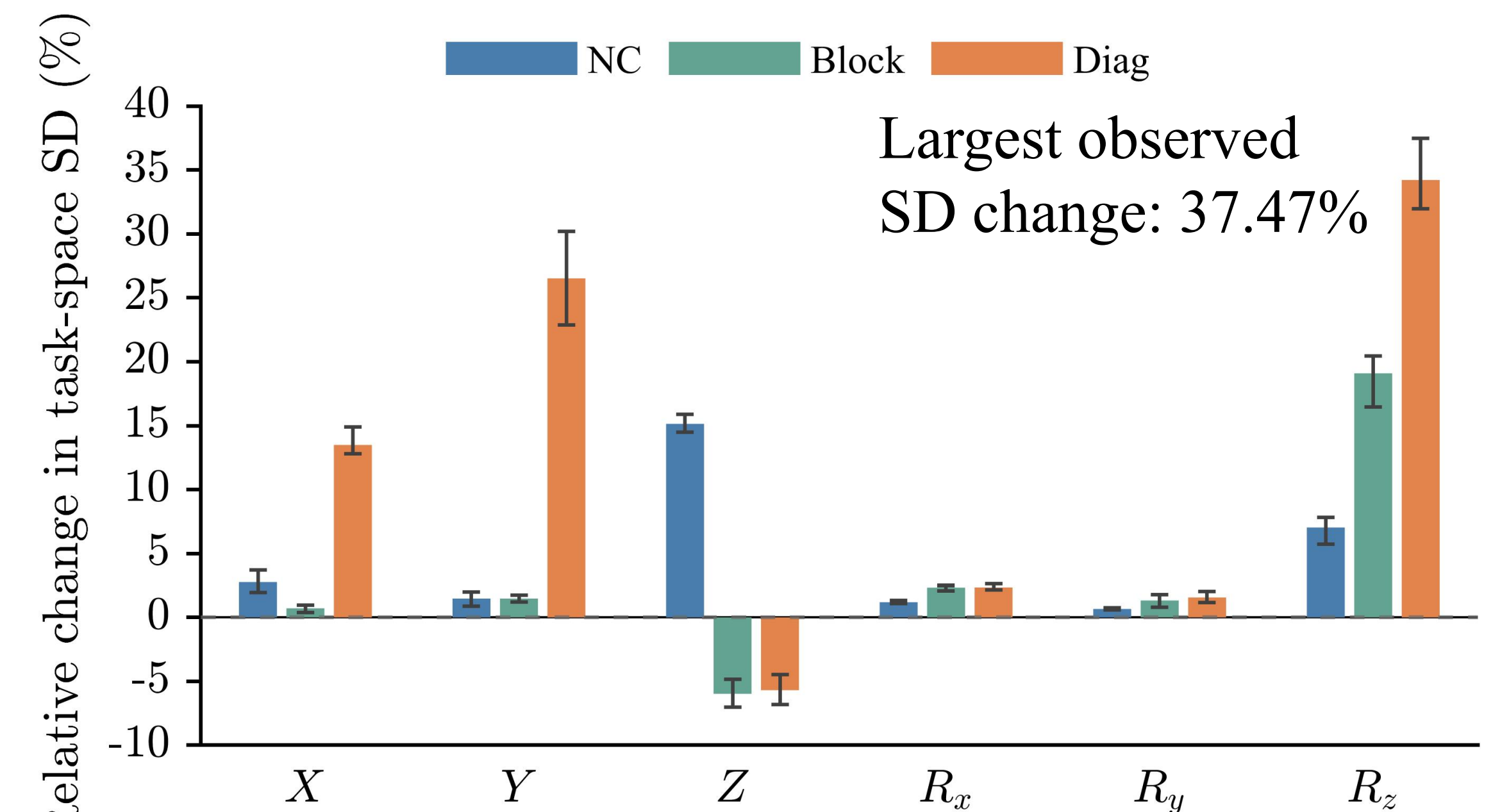
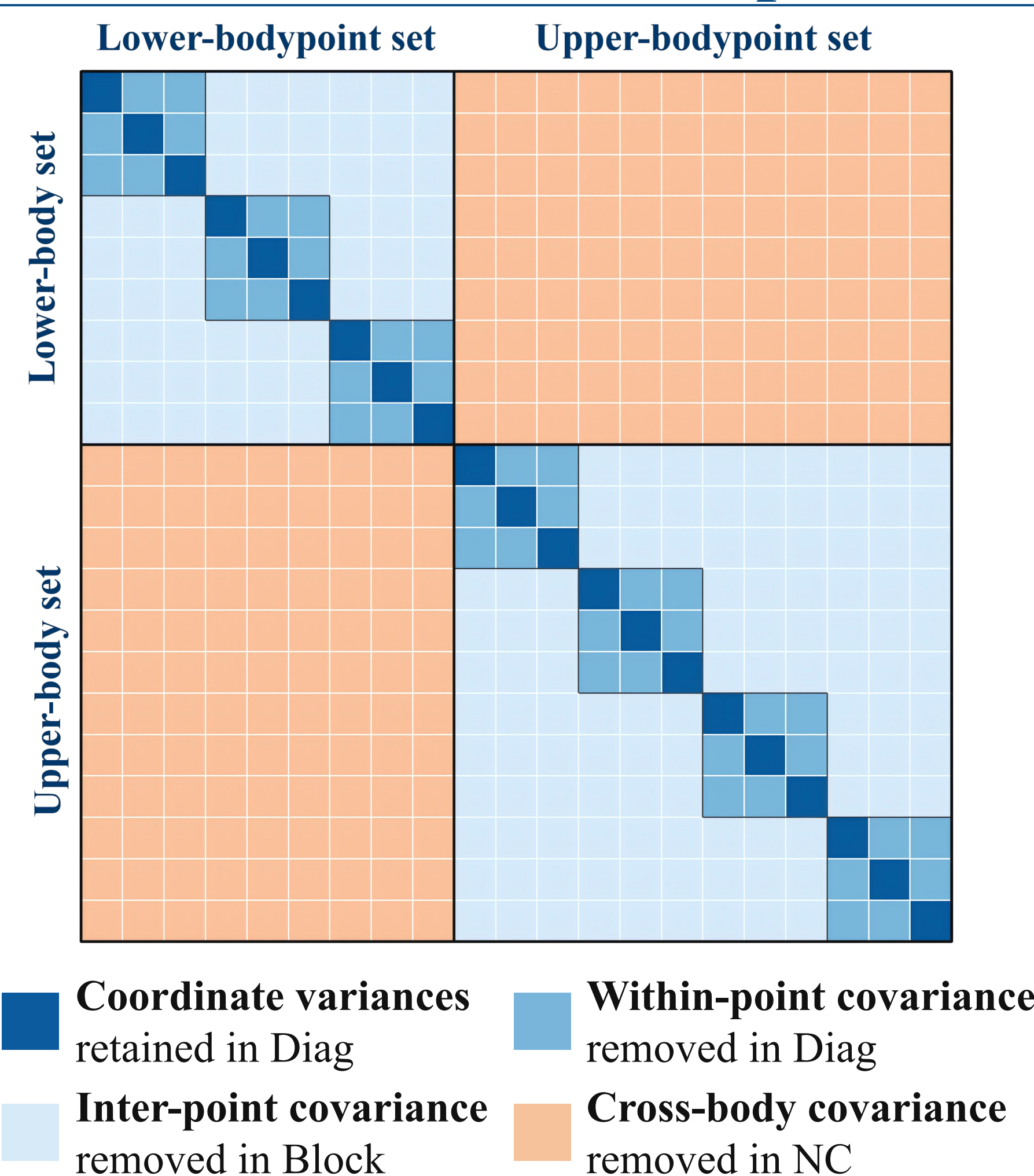
The criterion therefore evaluates restoration of the observed top region, not the upper-to-lower rigid-body pose.



3. Why does the full joint covariance matter for relative-pose uncertainty?



Upper- and lower-body task points are estimated simultaneously within the same self-calibrating bundle adjustment. Their reconstructed coordinates therefore form a full joint covariance matrix.

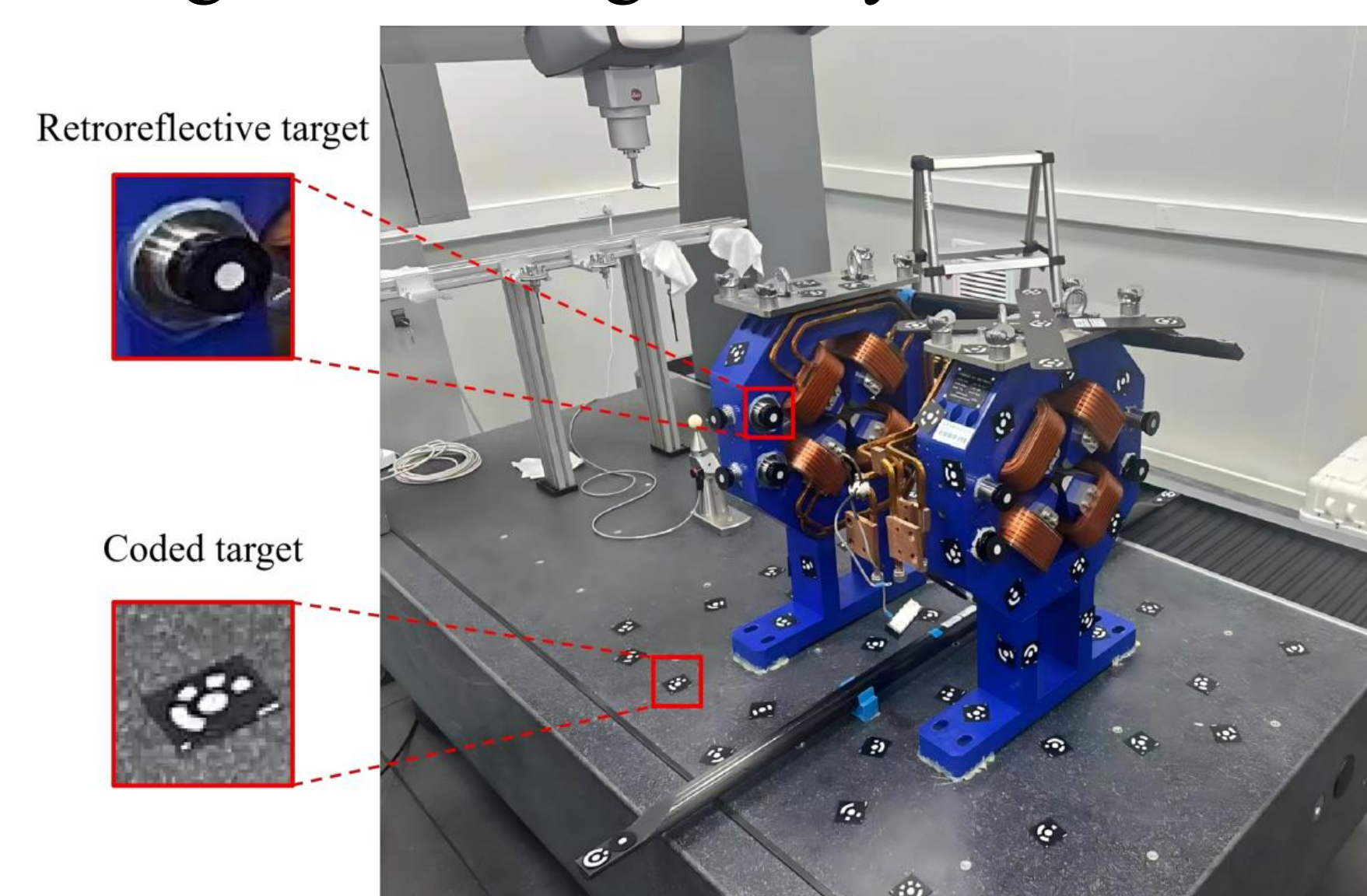


NC: no cross-body, Block: 3×3 point blocks only, Diag: variances only

Covariance simplification affects pose components differently rather than uniformly rescaling the uncertainty.

4. Opening–reassembly experiment: top-target pass and internal relative-pose change

Five independent photogrammetric networks were acquired before opening and after closing. The corresponding task points were also measured by CMM using identical rigid-body definitions.



$$\max(\text{RMSX}, \text{RMSY}, \text{RMSZ}) = 9.71 \mu\text{m} < 10 \mu\text{m}$$

The top-target criterion is satisfied — but what changed in the internal relative pose?

Relative pose change after opening and reassembly

Component	CMM	Photogrammetry	Photo – CMM
Translation components (μm)			
X	7.131	10.744	+3.613
Y	−2.969	−3.646	−0.677
Z	19.453	18.148	−1.305
Rotation components (mrad)			
R _x	0.00930	−0.01494	−0.02423
R _y	0.02392	0.09542	+0.07150
R _z	−0.00414	0.06630	+0.07044

Engineering interpretation

Translation-change agreement

3.90 μm Photogrammetry–CMM vector difference

Rotation-change difference

0.103 mrad difference between rotational-change vectors, mainly associated with R_y and R_z

Combined spatial effect at top targets (RMS)

Photogrammetry **26.04 μm**
CMM **22.30 μm**

Displacement-field difference: 14.54 μm

Unlike the 9.71 μm rigid-registration RMS, this mapping retains both relative translation and rotation.

Passing the top-target restoration criterion does not necessarily imply restoration of the internal relative pose.

Full-covariance task-space photogrammetry provides a direct 6-DOF assessment of magnet reassembly.