

Characterization of a Novel Multi-Functional Daily QA Device for Comprehensive Linear Accelerator Quality Assurance

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INTRODUCTION

- Radiotherapy delivery has advanced rapidly (ex. SGRT, 6DoF couches, single-iso/multi-target SRS, combined-axis deliveries) while daily QA platforms have remained largely unchanged for nearly two decades.
- Daily QA is siloed across vendors and systems: beam output, IGRT, SGRT, and isocenter checks require separate phantoms, setups, and coordinate systems, testing each subsystem in isolation rather than as the integrated chain used to treat.
- As online adaptive workflows reduce traditional patient-specific QA, machine QA carries a growing share of the quality burden: daily tests must become broader and more sensitive.
- The Daily QA 4 Pro (Sun Nuclear/Mirion) is the first major revision of the widely used DQA3 platform, integrating beam dosimetry, IGRT, SGRT, and Winston-Lutz isocenter verification into a single isocentric setup.

SPECIFIC AIM

To independently characterize the novel capabilities of a multi-functional daily QA device — detector array performance per AAPM TG-312, beam dosimetry across all diode and ion chamber detectors, IGRT and SGRT positioning performance, and the accuracy and sensitivity of its Active Measurement and Imaging Winston-Lutz isocenter tests.

METHODS AND MATERIALS

Daily QA 4 Pro (DQA4) New Features

Active Measurement (AM) W/L: after IGRT positions the phantom at isocenter, diode arrays measure radiation field centroid at each gantry angle – the phantom itself is the W/L target; no central BB.

Imaging W/L: kV/MV images of 8 off-axis BBs at 4–8 gantry angles yield imager X/Y/SID offsets, phantom 6DoF position, and per-BB field–target coincidence for gantry, collimator, and couch.

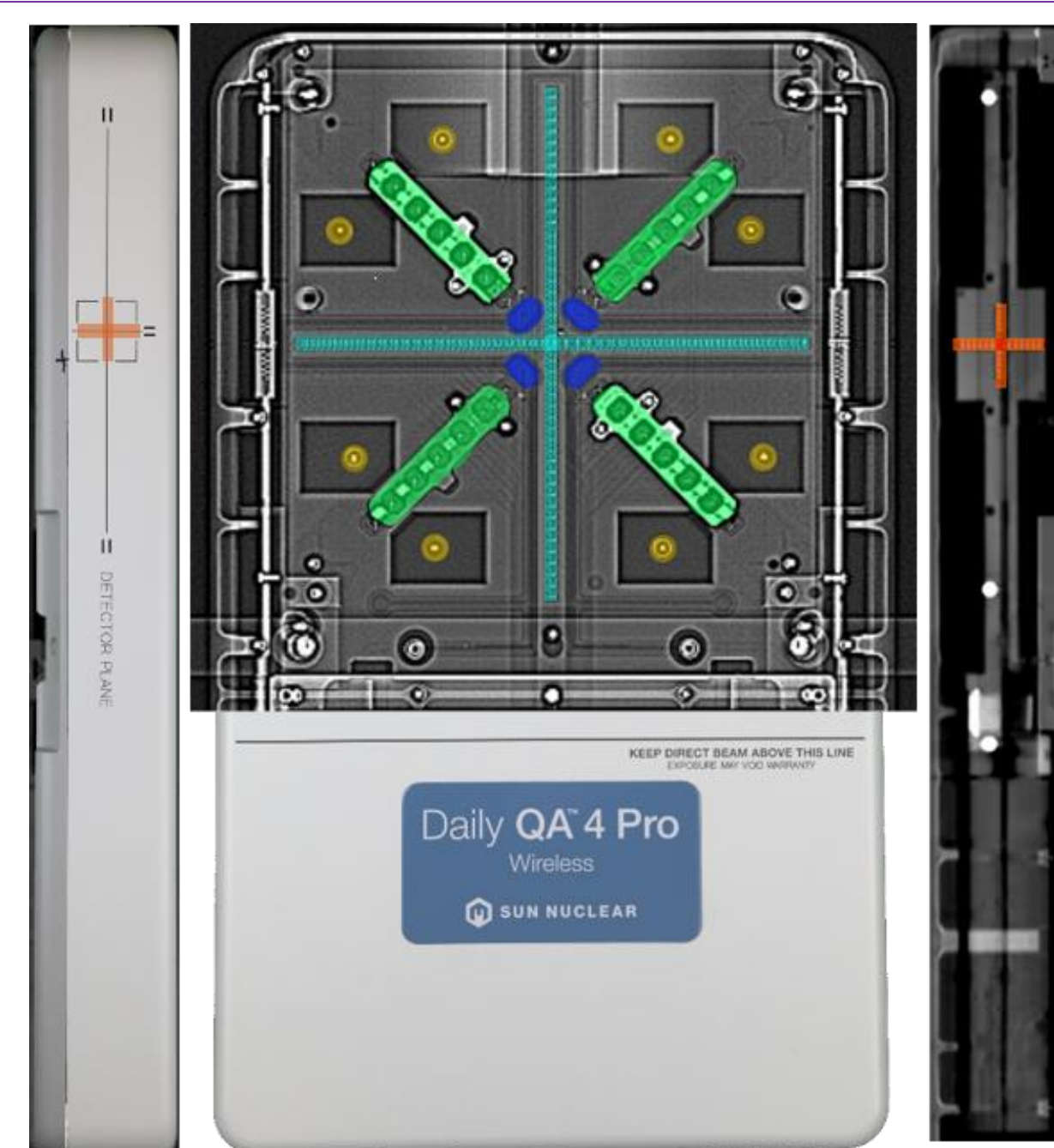


Fig. 1: Top and side view of CT scout overlaid on phantom demonstrating internal detectors and features:

- 4 centrally located **ion chambers**
- High density diode arrays along **principal axes** and **sidewalls**
- 8 tungsten **5mm BBs**
- 4 **energy wedges** covering diode arrays along diagonal axes

- ~75 msmt sessions on 6 TrueBeams over 3 months: ~30 beam dosimetry, ~30 AM W/L, ~20 Imaging W/L
- DICOM plans generated in Eclipse; TrueBeam Developer Mode XML files for automated AM (14 fields) and Imaging W/L (20 fields) delivery
- Array characterization per TG-312: linearity, dose rate, reproducibility, leakage compensation, rotation, dose calibration
- Dosimetry over 2–20 cm field sizes, jaw- and MLC-defined
- W/L sensitivity: induced couch shifts of 0.5–1.5 mm per axis; noise floor derived from variance of the non-driven axes; induced gantry rotation error and isocal bypass
- Same-session IGRT (kV, CBCT) and SGRT (AlignRT) offset positioning and residuals
- Results extracted from the SunCHECK SQL database via custom queries, analyzed independently in Python

RESULTS

IMAGING & SGRT ASSESSMENT

Fig. 2: (right) Example radar plots from software GUI demonstrating the residual IGRT shifts and SGRT positioning plotted together with AM W/L isocenter assessment. Fig. 3: (bottom) VisionRT capture and linac readout of DQA4 roll of 3° from isocenter accurately captured.



BEAM DOSIMETRY ASSESSMENT

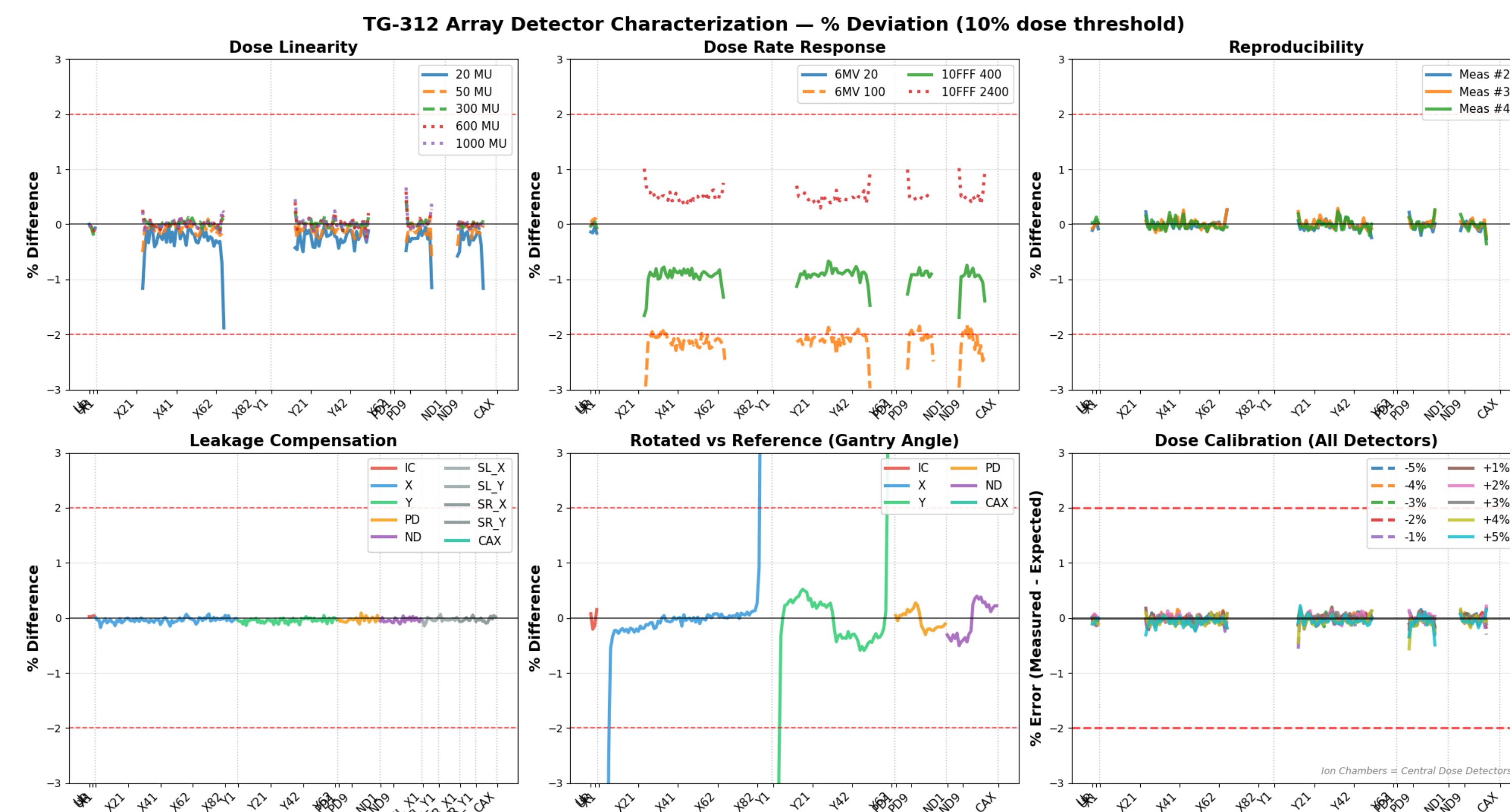


Fig. 4: TG-312 characterization of DQA4 across 6 metrics. Dose linearity, dose rate response, reproducibility, and dose calibration required measurement over a 10x10 cm² field size, leakage and array normalization irradiated all detectors. Dose rate response of diodes under responded at lower dose rates; however, ion chambers (responsible for output) were well within tolerance for dose rate.

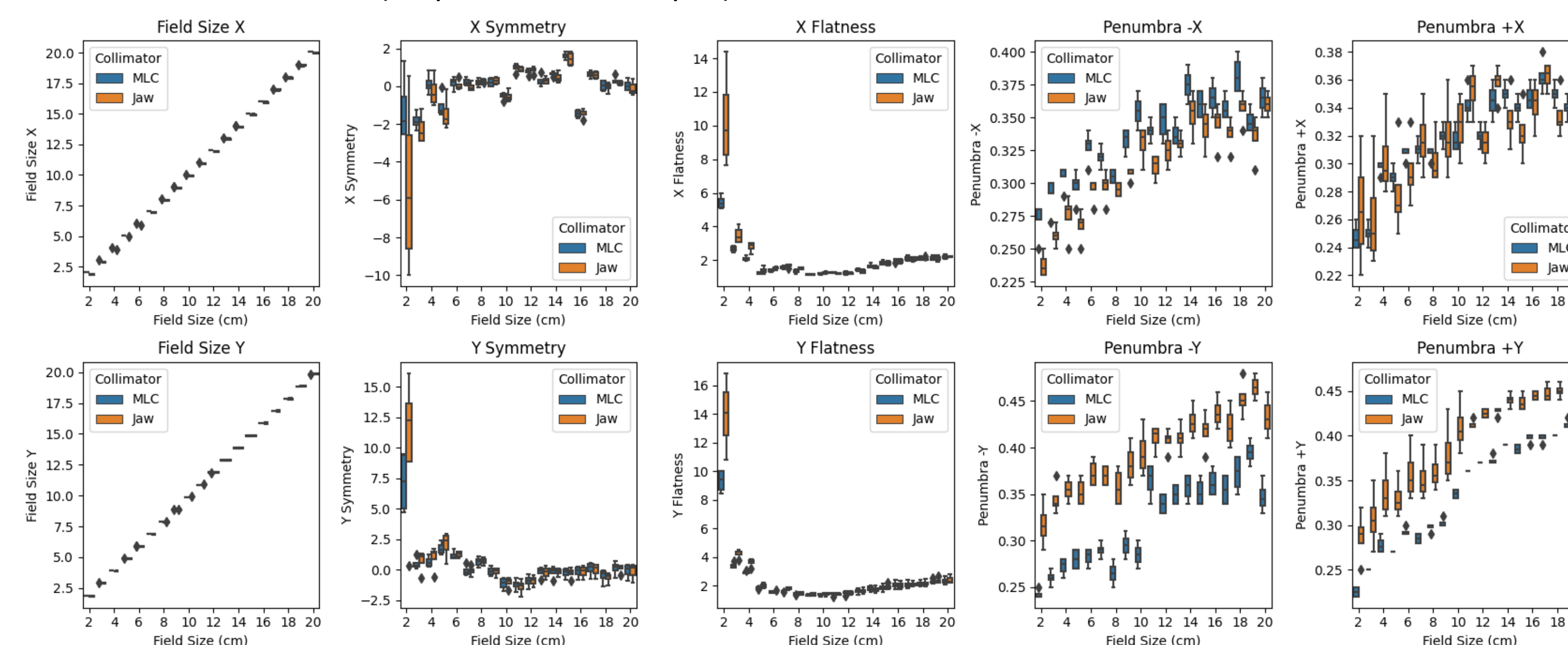


Fig. 5: Beam parameters measured against varying field size for MLC and jaw defined symmetric fields across 6 machines and 30 measurements. Variations were observed at small field sizes and Y penumbrae.

ISOCENTER ASSESSMENT – Active Measurement W/L

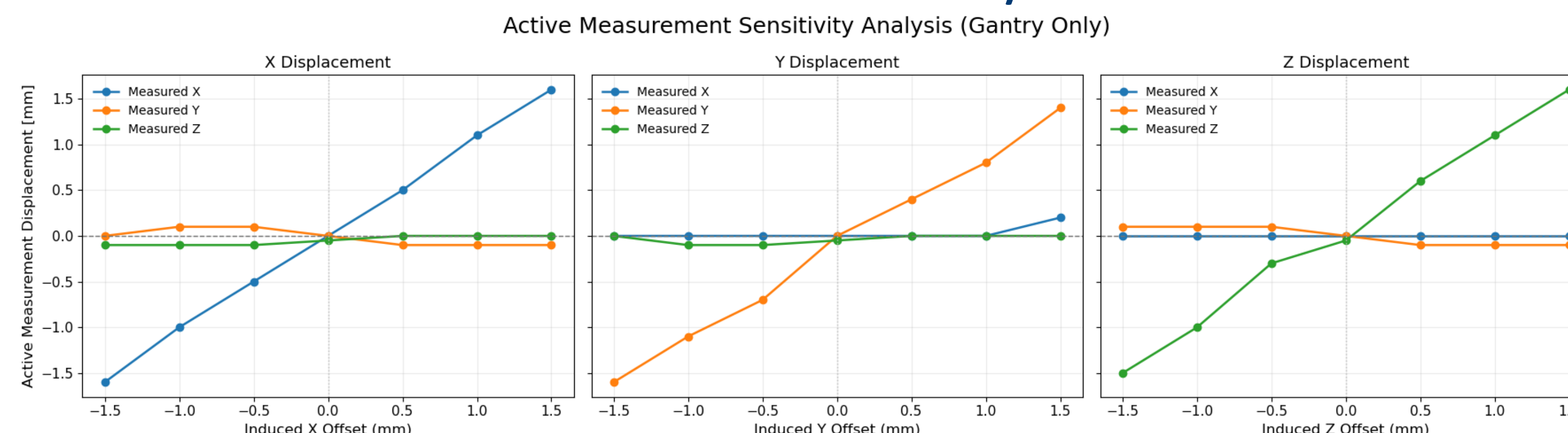
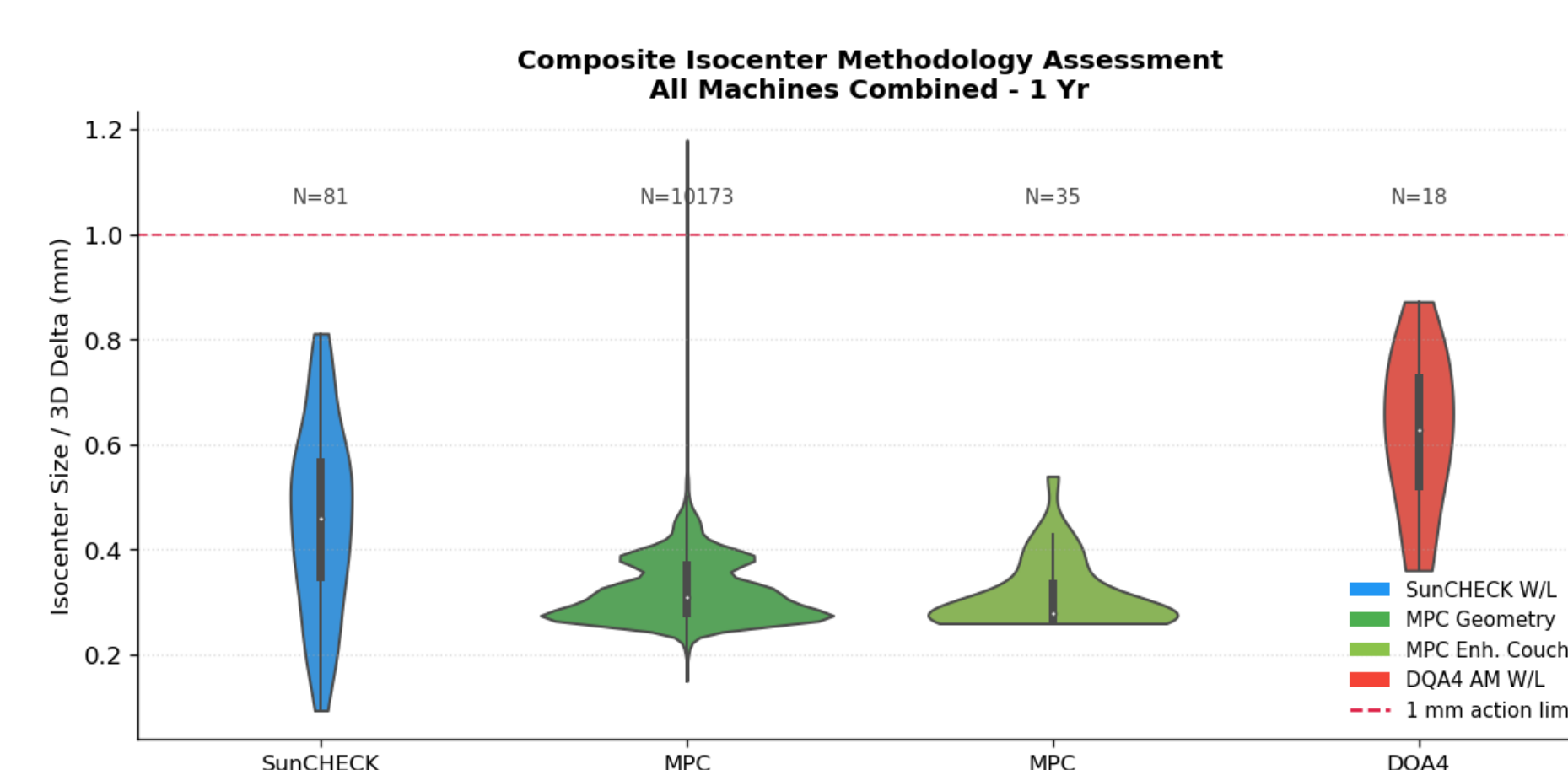


Fig. 6: (top) AM accurately tracked phantom displacement in X, Y, Z up to 1.5mm, demonstrating a noise floor of 0.10mm and minimum detectable shift of 0.21mm (95%). Fig. 7: (right) Comparison of AM W/L measurement to clinical isocentric measurements across linac fleet over a 1 year timeframe, demonstrating comparable performance to traditional W/L cube measurements and MPC.



ISOCENTER ASSESSMENT – Imaging W/L

Fig. 8: Example exposures of the 8x gantry (kV and MV), 2x couch, and 2x collimator angle Imaging W/L assessment (20 total). Each MV exposure involves MLC carriage shifts and measures in integrated mode, preventing automated delivery in TrueBeam Machine QA mode. A Developer Mode script was created fully automating acquisition in ~7.5 minutes.

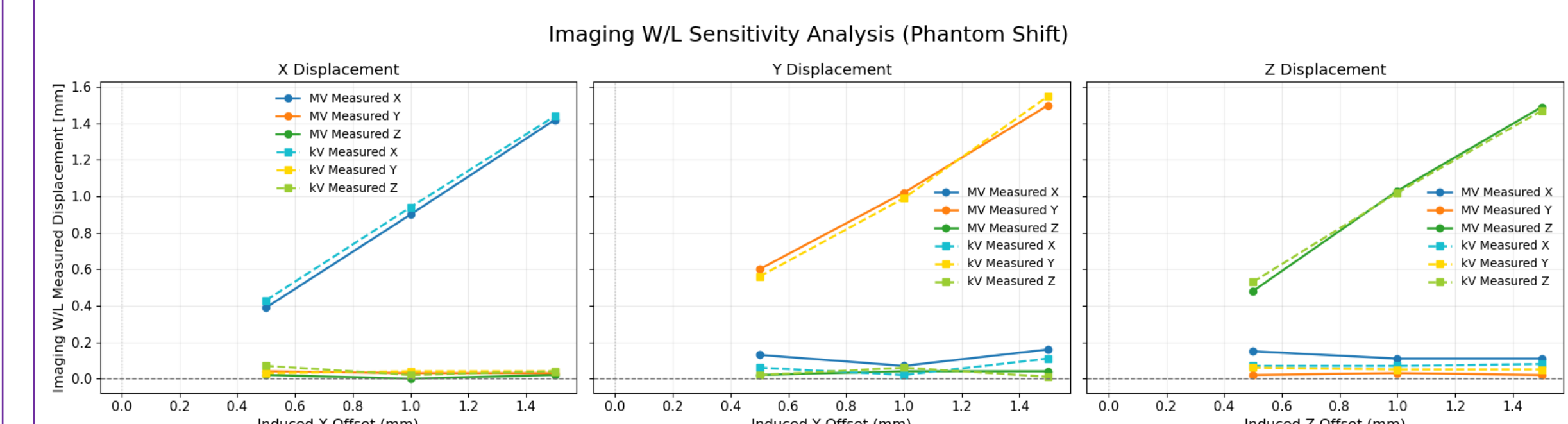
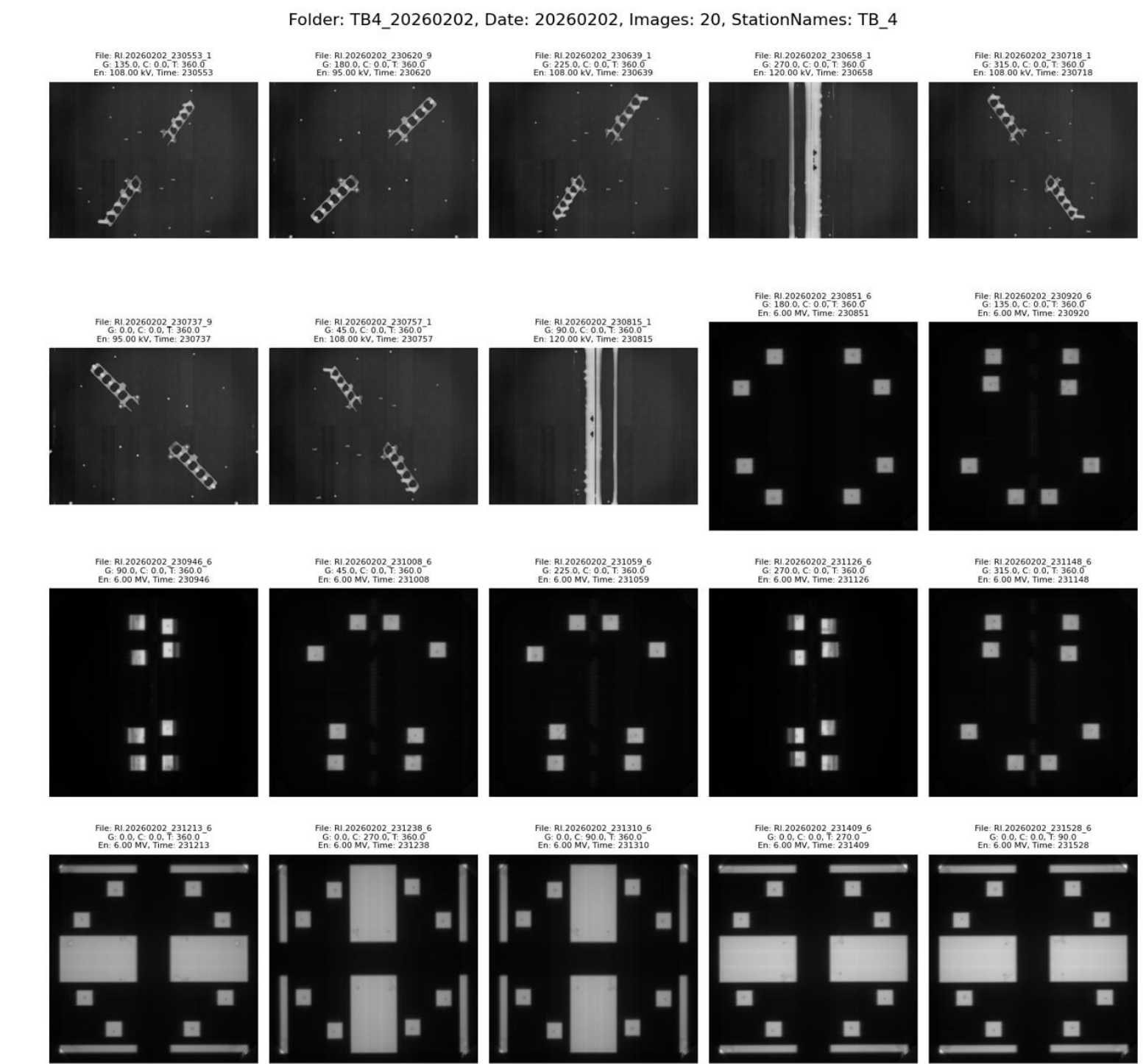


Fig. 9: Sensitivity analysis of Imaging W/L in response to phantom shift. Pooling kV & MV non-driven axes (N=36) show a noise floor of 0.05mm and minimum detectable shift of 0.10mm (95%). Mean 3D congruence between kV/MV calculated positions was 0.084mm. Random gantry deviation and turning off isocal correction yielded 3D differences of 0.22 and 0.54mm, respectively, indicating that these are detectable errors.

DISCUSSION

- Single IGRT-guided setup, one room entry** - beam, IGRT, SGRT, and radiation isocenter evaluated simultaneously in one coordinate frame, including SGRT capture at couch 90°/270° during the W/L sequence (not possible with siloed phantoms).
- AM W/L assumes accurate gantry positioning:** sideboard measurements at 90°/270° are first-order sensitive to gantry angle error (~1.7-2.6 mm per degree); central-array measurements are first-order insensitive. Sub-millimeter isocenter QA requires gantry accuracy within ~±0.2-0.3°.
- Imaging W/L software is still maturing (no couch-kick Field-Target-Coincidence or isocenter positioning, similar to MMWL yet).

CONCLUSIONS

- DQA4 Pro consolidates beam dosimetry, IGRT, SGRT, and W/L isocenter verification into a single setup and session – commissioned per TG-312 and evaluated against TG-142, MPPG 8.b, TG-179, and TG-302.
- Active Measurement W/L reliably detects sub-millimeter shifts (0.11mm noise floor; 0.21mm minimum detectable shift at 95%) and is concordant with MPC and traditional BB-based W/L across all machines.
- The device brings monthly-class profile resolution and a novel wedge-based energy index into daily QA.
- The indexed 6DoF baseplate enables true end-to-end testing at non-zero pitch/roll/yaw – clinically realistic conditions rather than idealized W/L setups.
- Automation of the 14-field AM and 20-field Imaging W/L sequences add ~5 min each; the integrated session runs ~5 min faster than the current multi-phantom program, ~15 min savings compared to MMWL measurements.
- Raw-detector transparency supports independent, TG-332-consistent verification, with IGRT/SGRT coverage that vendor self-check tools cannot assess.