Electron and X-ray steering using pulse front tilts in laser-plasma accelerators

Erik Löfquist[1,*], Cornelia Gustafsson[1], Andrea Angella[1], Anders Persson[1],
Claes-Göran Wahlström[1], and Olle Lundh[1]
[1]Department of Physics, Lund University, Sweden. *erik.lofquist@fysik.lth.se

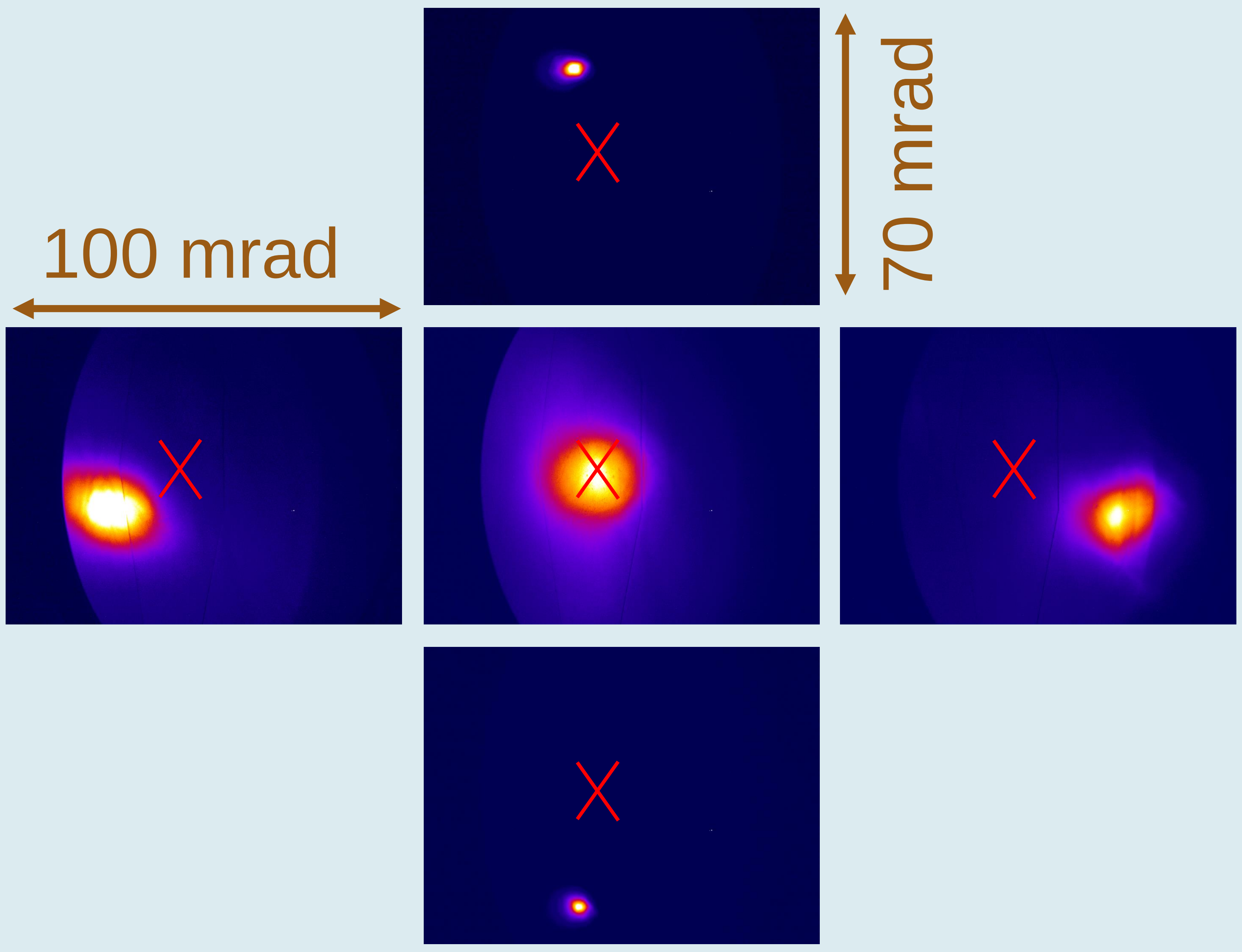
LUND UNIVERSITY

LLC
LUND LASER CENTRE

Significant steering from small laser modifications

A laser-plasma accelerated electron beam can substantially deviate by tens of milliradians from the laser's optical axis when the laser exhibits a pulse front tilt [1-3]. Here we present a method for controlling the pulse front tilt to reliably steer the electron beam to a desired angle. The control is shown to also extend to the generated X-ray radiation. The scheme can be used to stabilize the electron pointing over time, or for scanning of the electron beam without changing the optical axis in vacuum.

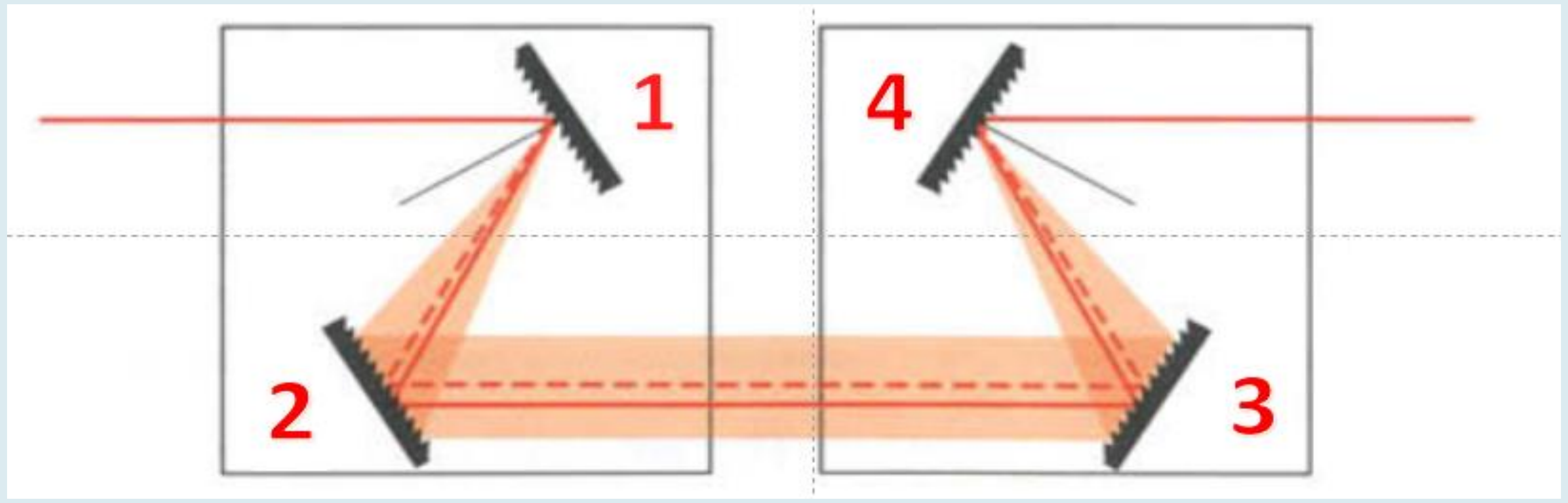
Electron beam profiles



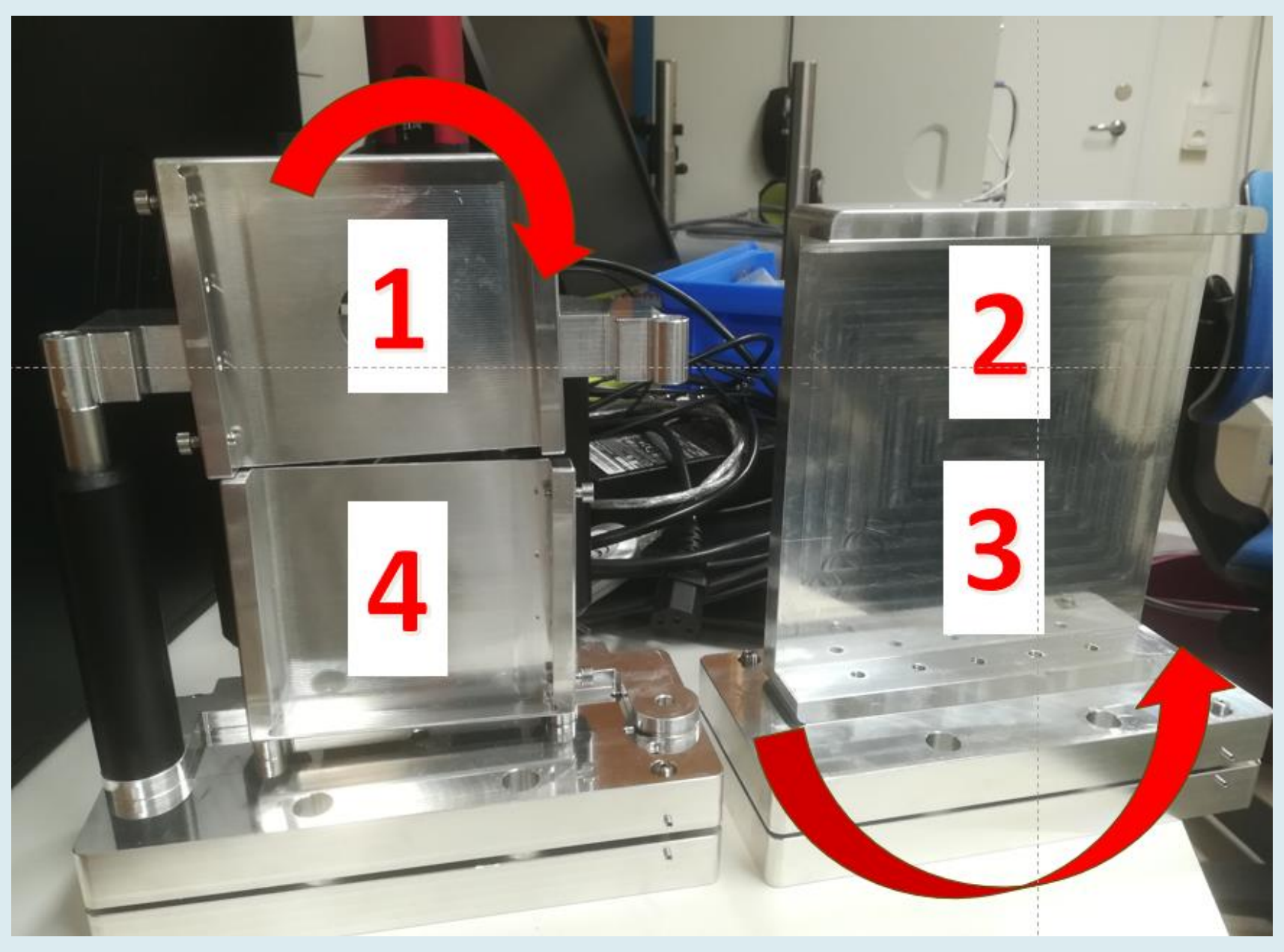
Electron beam profiles for five different laser pulse front tilts are shown above, displaying the impressive range of ~50 mrad within which the electron beam can be steered both horizontally and vertically. The red cross indicates the optical axis in vacuum.

Creating arbitrary pulse front tilts

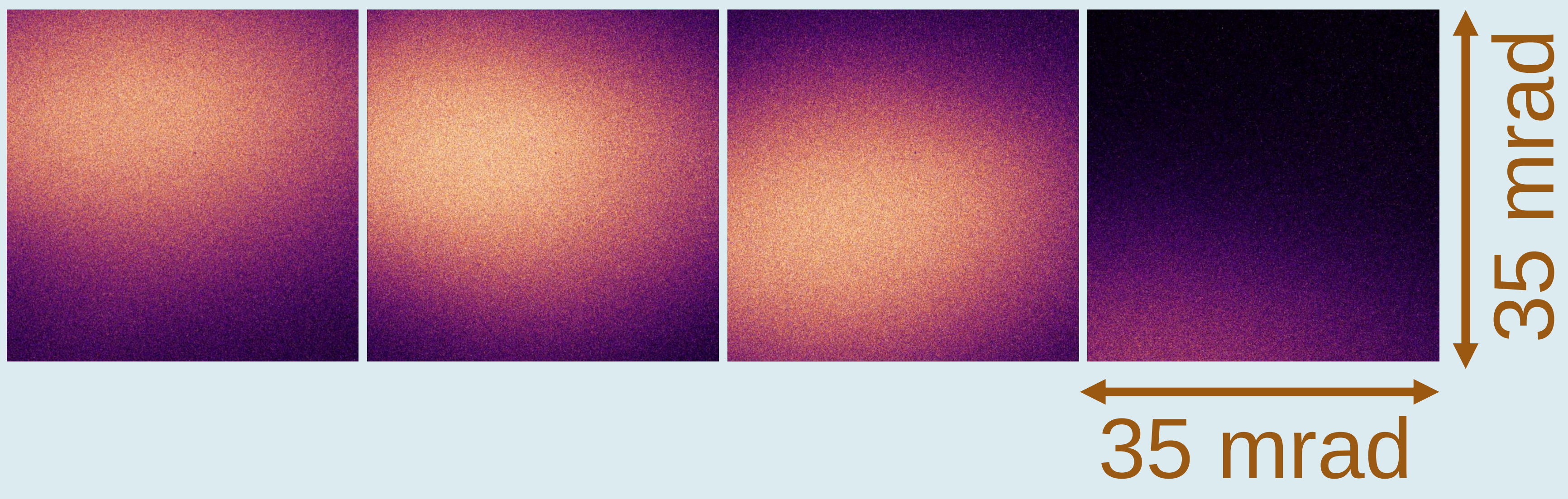
The pulse-front tilt is introduced with angular chirp in a double-pass grating compressor (1200 lines/mm) by deliberately misaligning the gratings. Rotating the gratings in the dispersion plane or in the grating plane one introduces horizontal and vertical angular chirp, respectively. Combined it allows the creation of pulse front tilts at arbitrary angles. The laser pointing is corrected with mirrors downstream to maintain a fixed optical axis to the plasma.



Schematic of a double-pass compressor drawn in the dispersion plane (top). The grating holders (right) and their rotation possibilities are indicated. The order of the laser bounces is shown by the red numbers.

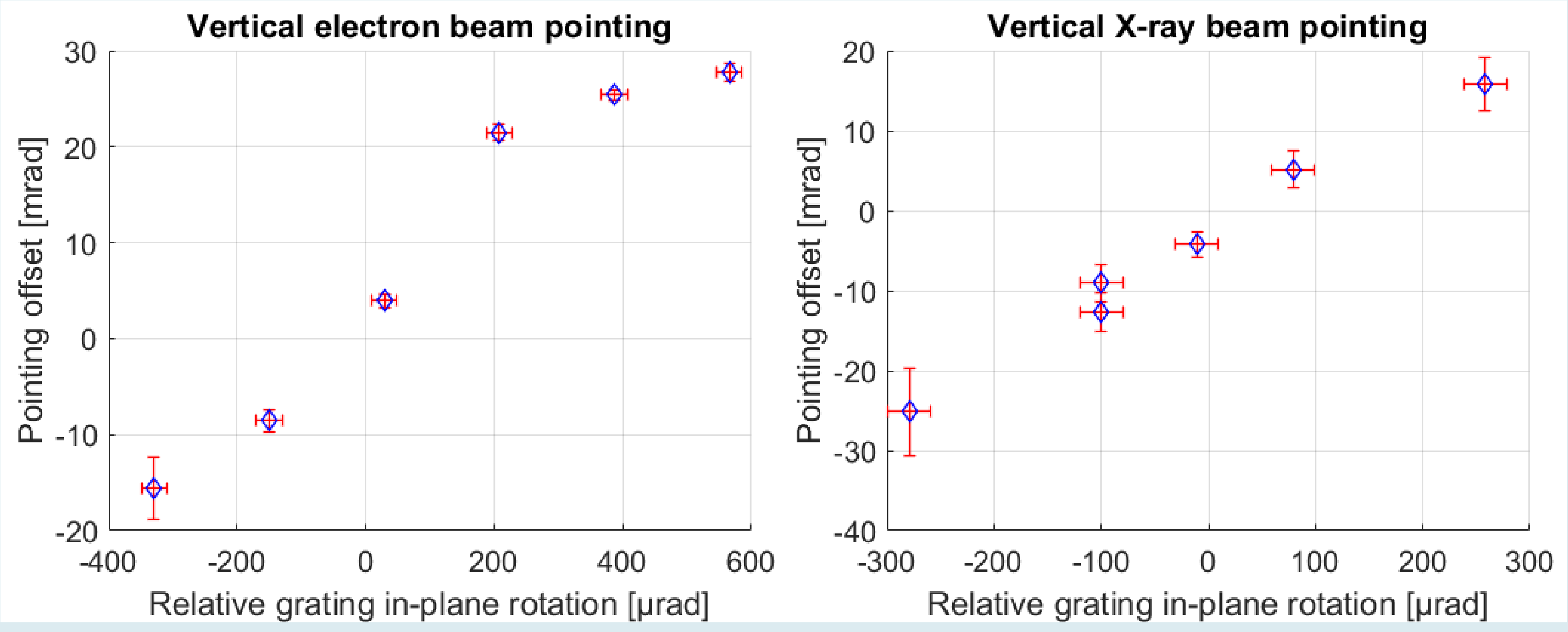


X-ray beam profiles



In the four X-ray beam profiles above, a similar steering with pulse front tilt as in the electron beam is seen. The pointing is estimated by fitting a Gaussian profile, even in the extreme case where the centroid misses the camera.

Pointing stable shot to shot



Vertical steering of electron (left) and X-ray (right) beam pointing. Data points are averages of 10 shots and vertical error bars indicate the standard deviation, which is approximately 600 µrad – small compared to the steering possible (~50 mrad). The laser pointing fluctuations into the plasma (~5 µrad) are negligible in comparison.

Why steering?

The asymmetric intensity excites an asymmetric wakefield and thus the wake-line (where the transverse force on the electrons cancels) is tilted [2-3]. A pulse front tilt rotates in focus, and the wake-line and the electrons follow. The resulting steering also depends on the laser deflection and pulse front tilt evolution in the plasma as well as the electrons' betatron motion.

References

[1] A. Popp *et al.*, PRL **105**, 215001 (2010)
[2] M. Thévenet *et al.*, Phys. Rev. Accel. Beams **22**, 071301 (2019)
[3] D. E. Mittelberger *et al.*, Physical Review E **100**, 063208 (2019)