Optics measurement prospects for the FCC-ee

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FUTURE
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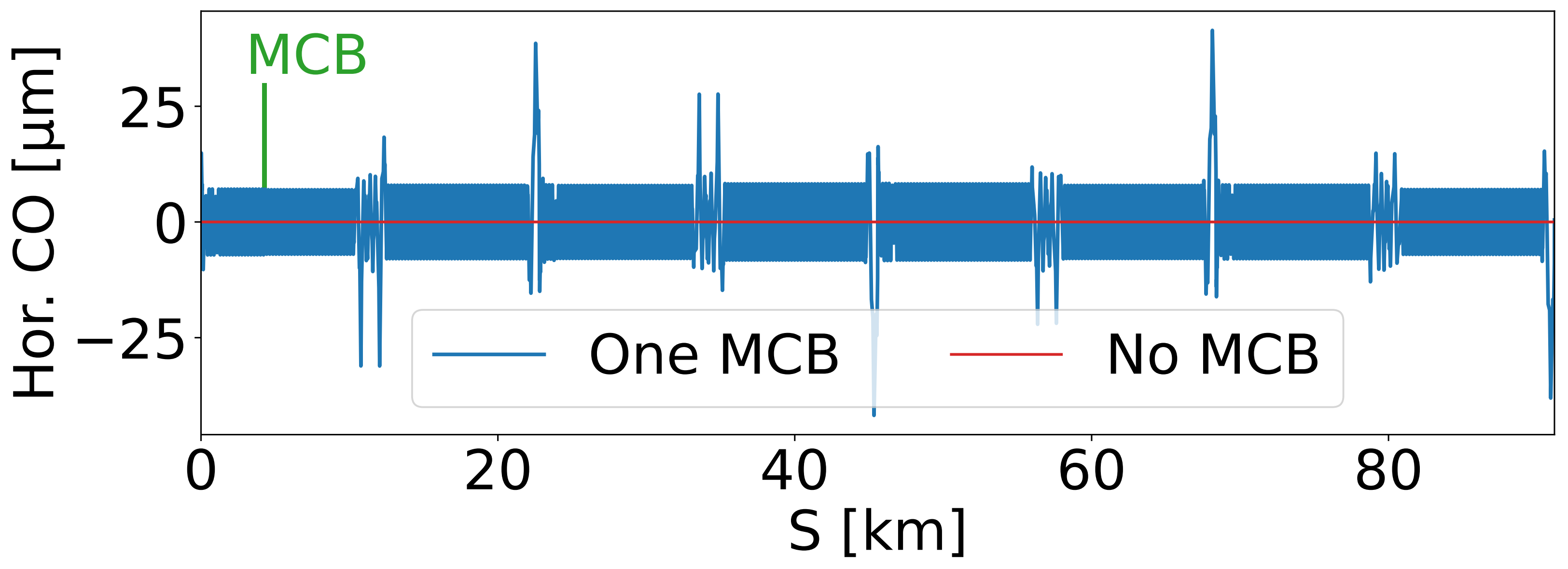
Abstract

Within the framework of the Future Circular Collider Feasibility Study, the design of the electron-positron collider FCC-ee is optimised. Polarized low intensity pilot bunches are foreseen at the first energy stages to determine the beam energy, and thus sufficient level of polarization must be achieved which can be limited by alignment and optics errors. Additionally, strong synchrotron radiation damping at the highest beam energy and its impact on the beam dynamics will demand optimized beam measurements to control the optics at the desired level. Various techniques to measure the optics in the FCC-ee are explored, including the orbit response matrix approach and turn-by-turn measurements.

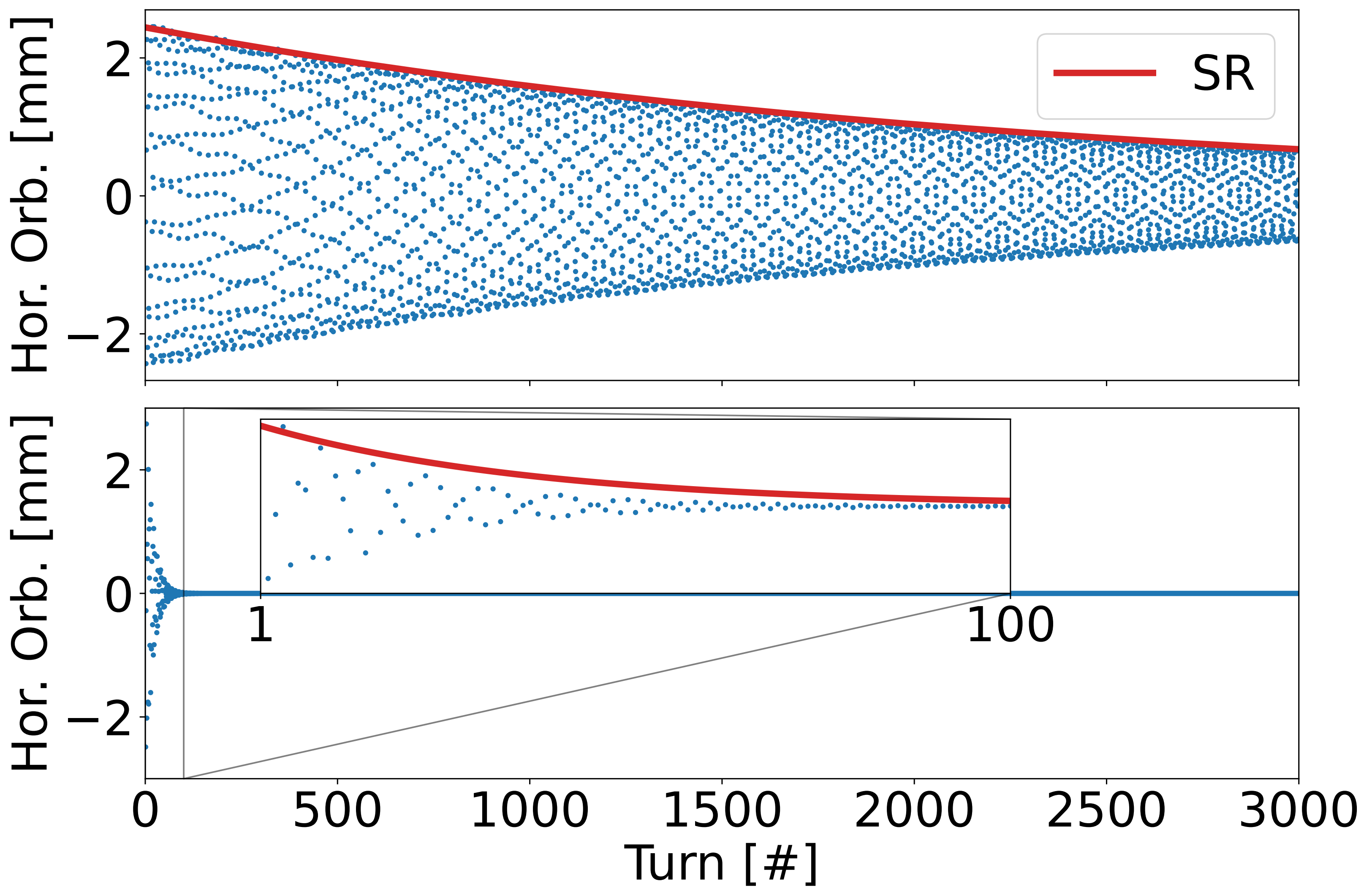
Orbit Response Matrix

For Orbit Response Matrix (ORM) measurements dipole kickers (MCB) distort the orbit one after the other and the average orbit is recorded at Beam Position Monitors (BPMs). The time required for ORM increases with the size of a storage ring and is thus expected to be rather time consuming for the FCC-ee. Especially at the top beam energy of 182.5 GeV, where synchrotron radiation losses within one revolution are about 10 GeV, the damping of the beam orbit should be included. An example of a closed orbit with one dipole kicker is shown in the figure below for the tapered $t\bar{t}$-lattice using MAD-X.



Turn-by-Turn Optics Measurements

To perform turn-by-turn (TbT) measurements the beam needs to be excited first. For lepton storage rings a single kick applied to a particle beam is a non-destructive method since synchrotron radiation damps the amplitude until the equilibrium emittance is reached. The horizontal and vertical damping times are approximately 0.710 s and 0.012 s, respectively at the Z- and $t\bar{t}$-mode, corresponding to 2335 and 41 turns, as shown in the figure below for single particle tracking in SAD with and initial kick of 10 times the horizontal (σ_x) and vertical beam size (σ_y). In addition to radiation damping the amplitude of a particle bunch is affected by e.g. decoherence, as recently investigated in [1] for leptons. While the damping is sufficiently slow for single kick excitation at the Z-pole, at top energy the orbit is damped too fast and thus a continuous excitation using, e.u. using the transverse feedback or an AC-dipole, must be used.



Disclaimer

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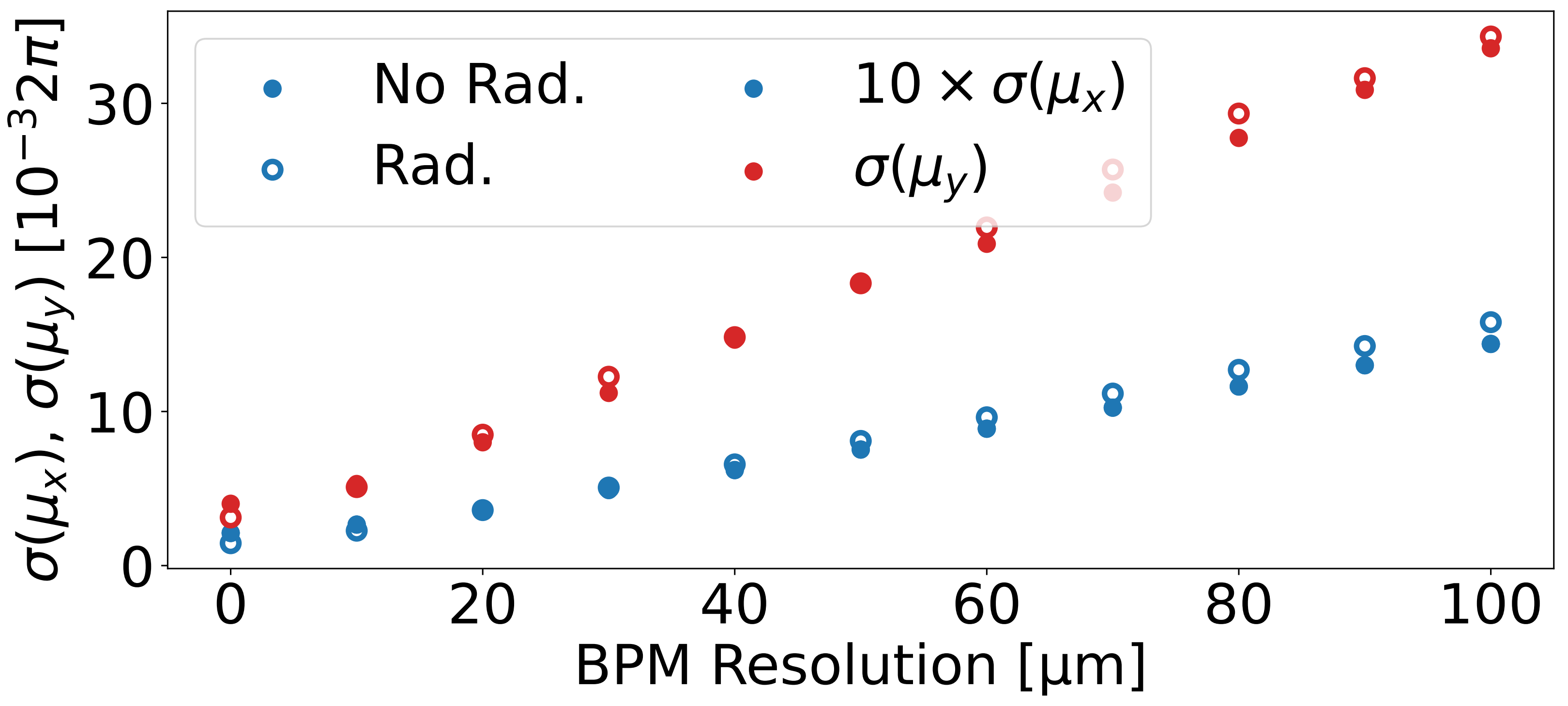
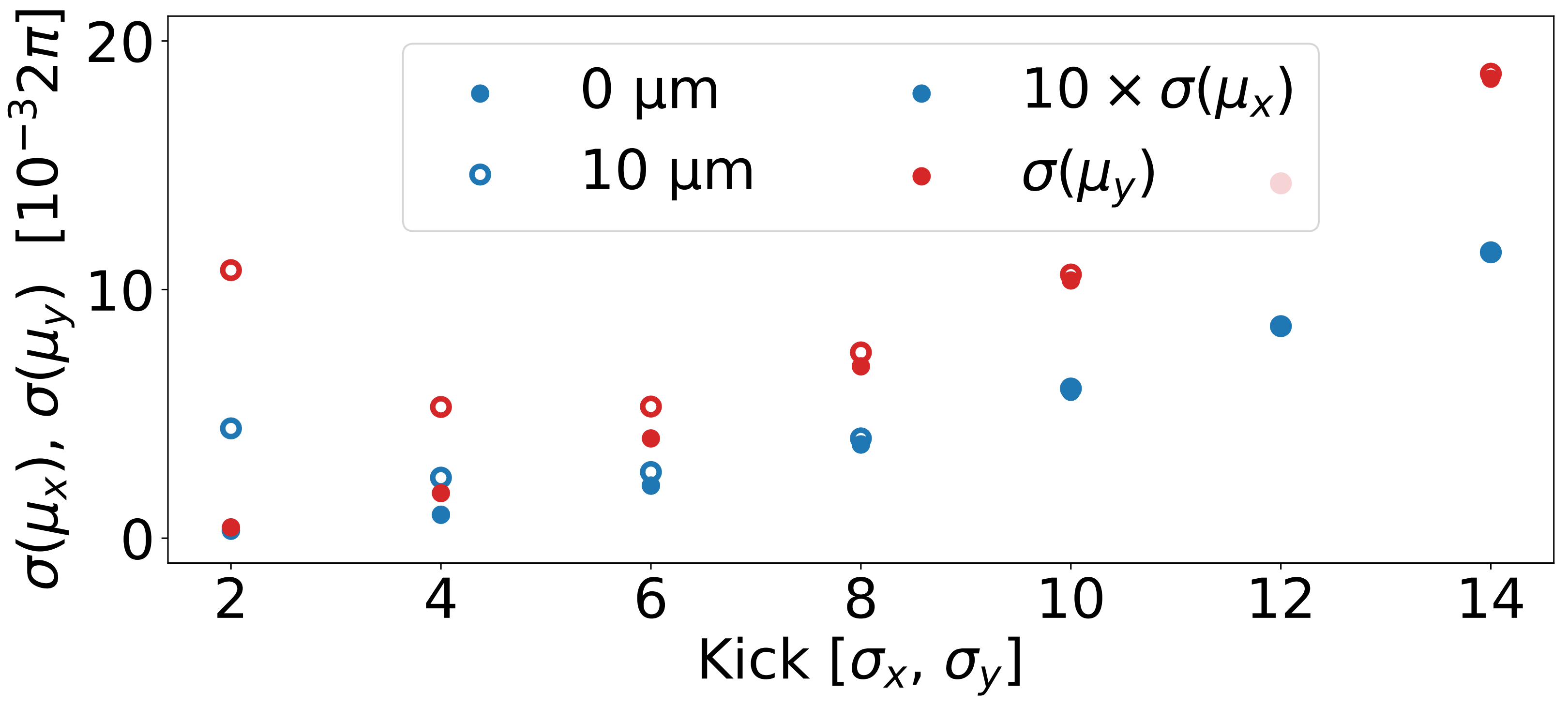
Phase Advance Error

To evaluate the impact of BPM noise on optics measurements, a random Gaussian distributed noise with a rms of up to 100 μm is included to the TbT single particle tracking data for the Z-lattice. The initial kick of $6\sigma_x$ and $6\sigma_y$ is applied at IP1 and the orbit is recorded for 500 turns at about 360 virtual BPMs. As a figure-of-merit the rms phase advance error with respect to the ideal model, $\sigma(\mu_{x,y}) = \mathrm{rms}(\mu^{\mathrm{err}}_{x,y} - \mu^{\mathrm{mdl}}_{x,y})$, is used. It can be seen in the figure below that with increasing BPM noise $\sigma(\mu_{x,y})$ increase linearly. Radiation damping marginally impacts the result.



Scans of the initial kick amplitude are performed for both transverse planes. If no BPM noise is considered the relative errors with respect to the model increase with increasing driving amplitude. However, by including a BPM noise of 10 μm $\sigma(\mu_x)$ and $\sigma(\mu_y)$ first decrease with increasing oscillation amplitude, since the excitation of the kick is greater than the noise. In this example the minimum horizontal and vertical errors of, respectively, $0.24\times10^{-3}(2\pi)$ and $5.28\times10^{-3}(2\pi)$ are achieved with $4\sigma_{x,y}$. Increasing the driving amplitude further increases the relative error, since non-linearities, here caused by sextupoles only, are enhanced.



Conclusion

Due to its unprecedented size and the strong synchrotron radiation damping at $t\bar{t}$ running, the applicability of existing methods needs to be re-evaluated, whereby first promising simulations for ORM and TbT measurements are performed. In future studies several other optics and misalignment errors will be included and their impact on the measurement quality evaluated. Also the excitation with an AC-dipole will be studied in detail. Complementarily, the impact of synchrotron radiation on the ORM measurements must be studied. More details are given in [2].

References
[1] J. Keintzel, PhD thesis, CERN-THESIS-2022-018, 2022.
[2] J. Keintzel *et al.*, in Proc. IPAC'22, TUOZSP1.