Modelling Tapering

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MADX vs SAD for FCC-ee

- FCC-ee lattice designed in SAD
  - Many tools for lattice optimisation already available e.g.:
    - Tapering
    - DA optimisation with sextupoles
  - Results benchmarked with lepton collider – SKEKB
- Long-term goal of (also) using MADX
  - A lot of experience in CERN and accelerator community
    - Several FCC-ee studies use MADX and rely on translation
  - Developed and maintained in CERN
  - Good to have a second code to verify simulations
- Overall already shown good agreement between MADX and SAD in many aspects:
  - Linear optics, amplitude and momentum detuning (presentation)
  - Emmittance (presentation) and radiation integrals (presentation)

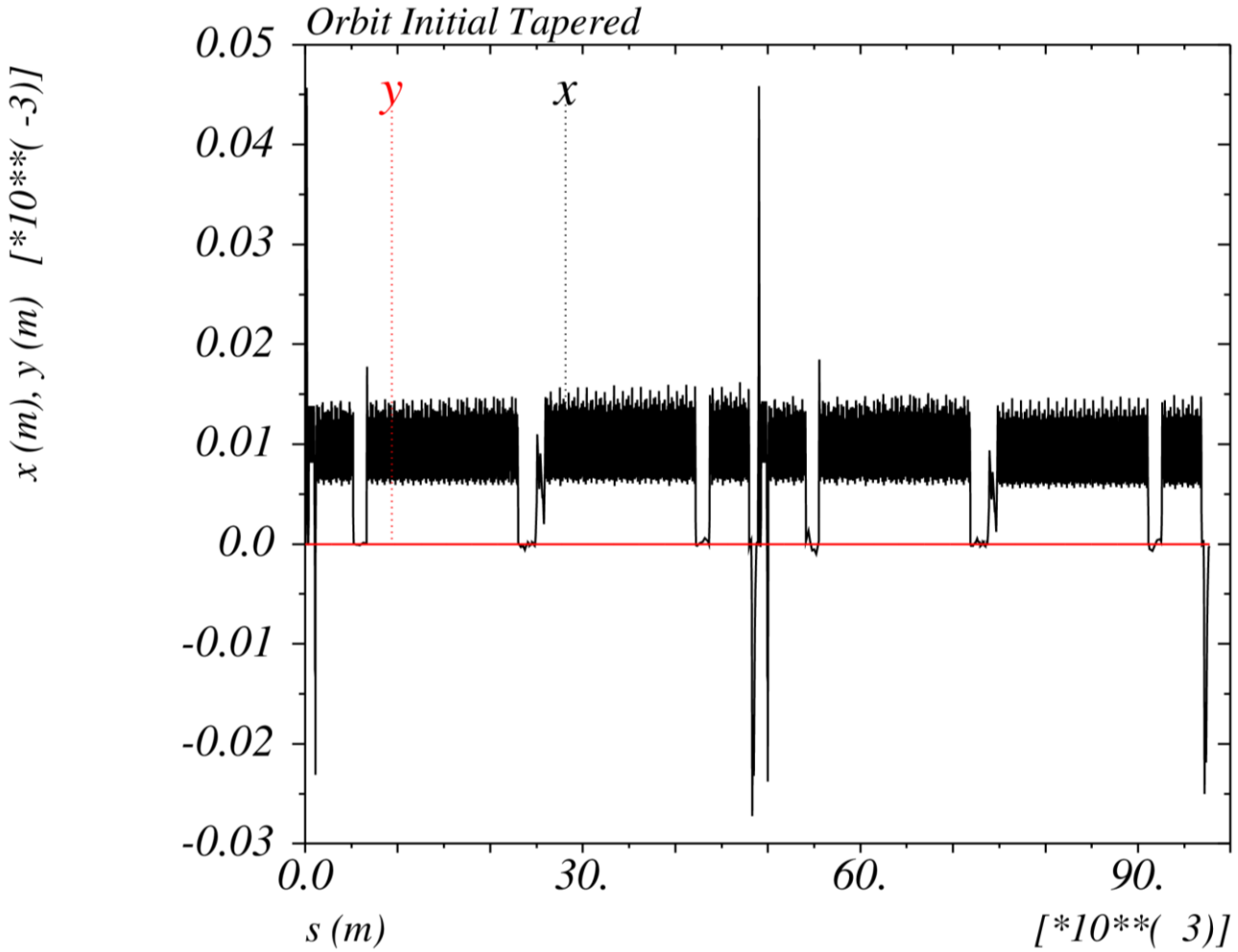
Tapering

- The concept of locally adjusting magnet strengths to compensate for local beam energy
- Not needed in hadron machines as energy loss to radiation is negligible
- SAD implementation of tapering
  - Tapering turned on using global flag
  - All magnet strengths perfectly adjusted during closed orbit search
- Some form of tapering certainly needed in FCC
  - Large energy loss per turn
  - Large saw-tooth in orbit would result in beam loss
- Tapering strategies
  - Tapering all magnets individually results in almost same orbit/optics as without radiation
    - This is very expensive
  - Would be significantly to adjust currents of several magnets simultaneously
    - Effect on orbit, optics, emittance, luminosity etc. to be determined

Tapering Strategy for MADX

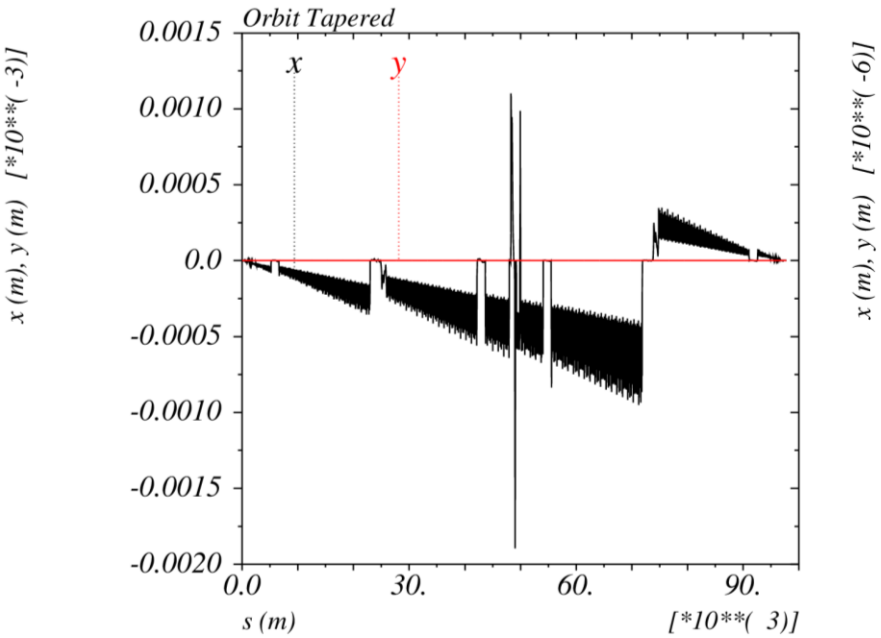
1. Perform initial Twiss without radiation
   I. Predict energy in every element using analytical formula and compute tapering and RF lag
   II. Record Twiss in IP
2. Perform Twiss as line with radiation
   I. Match RF lag
   II. Read out local energy at entrance and exit of elements, average and compute tapering
   III. Iterate I. and II. until convergence
3. Perform closed Twiss with radiation
   I. Match RF lag
   II. Read out local energy at entrance and exit of elements, average and compute tapering
   III. Iterate I. and II. until convergence

Step 1: Results with “initial estimate”

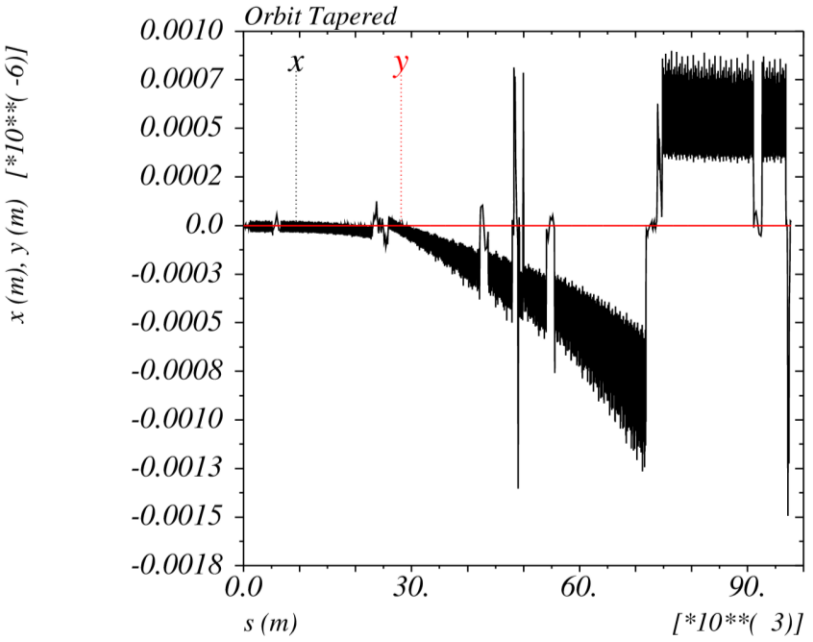


Step 2: Iterations With Twiss as Line

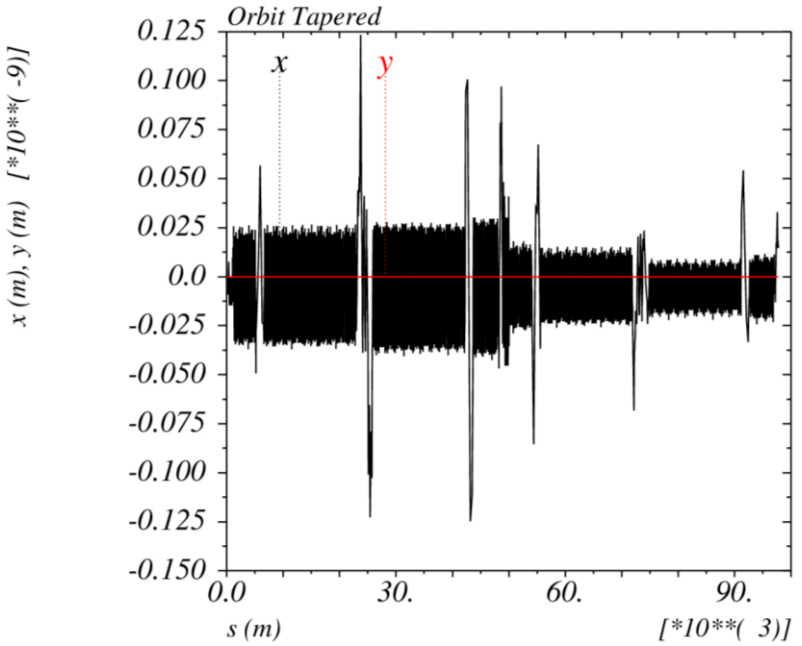
Iteration: 1



Iteration: 3

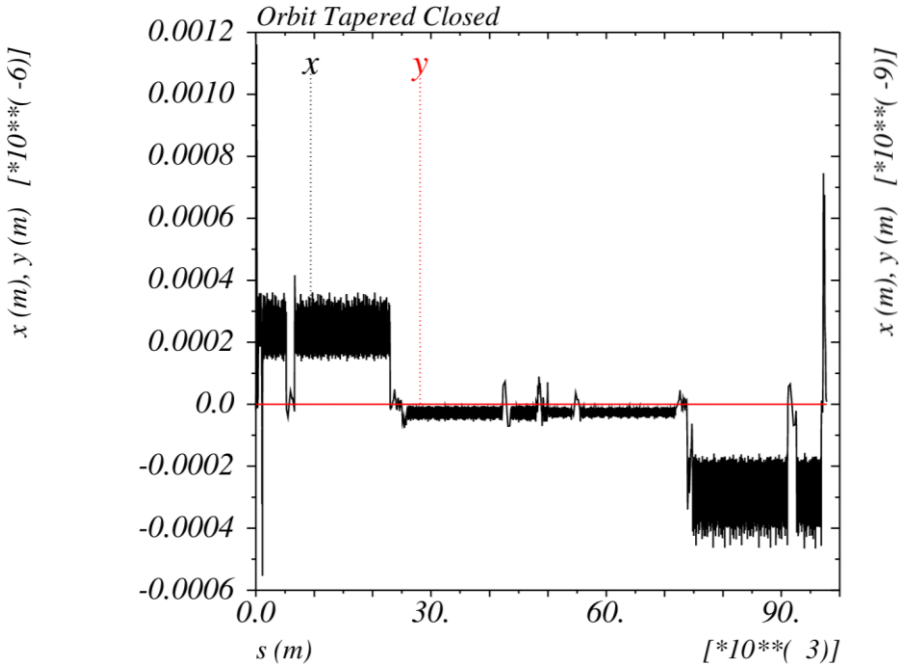


Iteration: 6 (Converged)

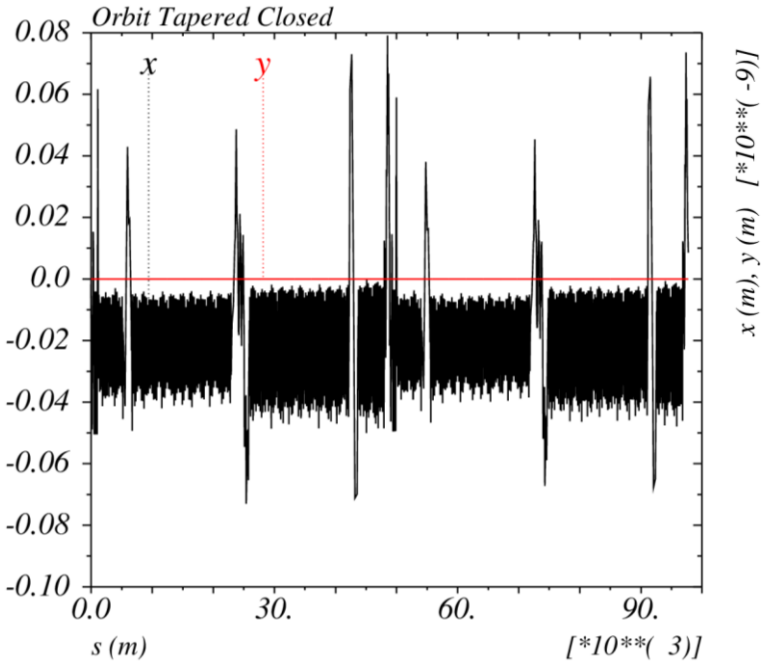


Step 3: Iterations with Closed Twiss

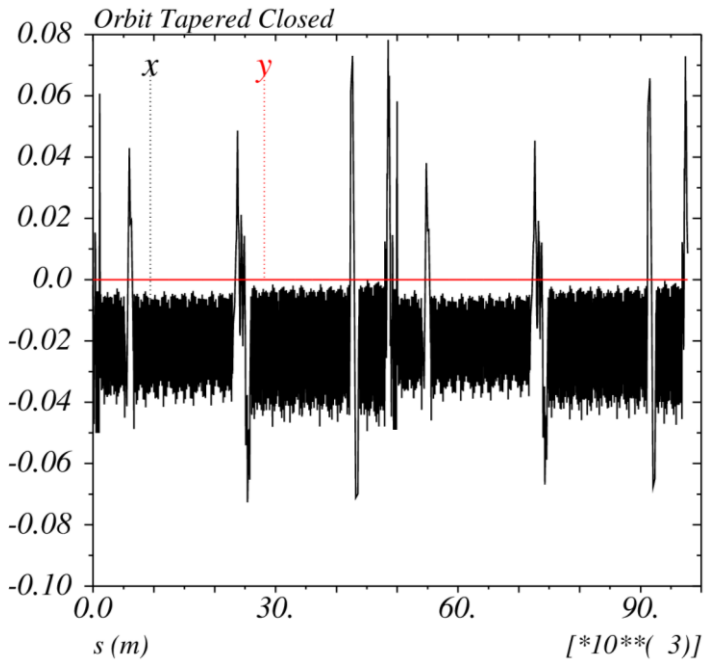
Iteration: 1



Iteration: 3 (Converged)



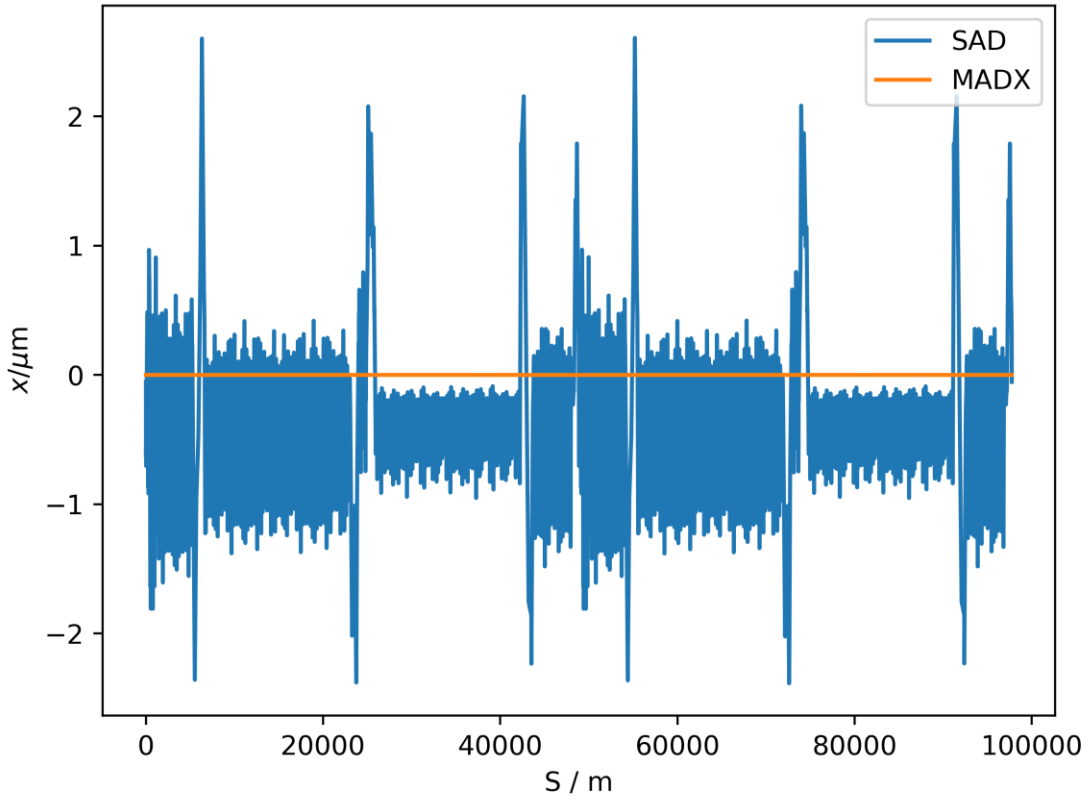
Iteration: 6 (Converged)

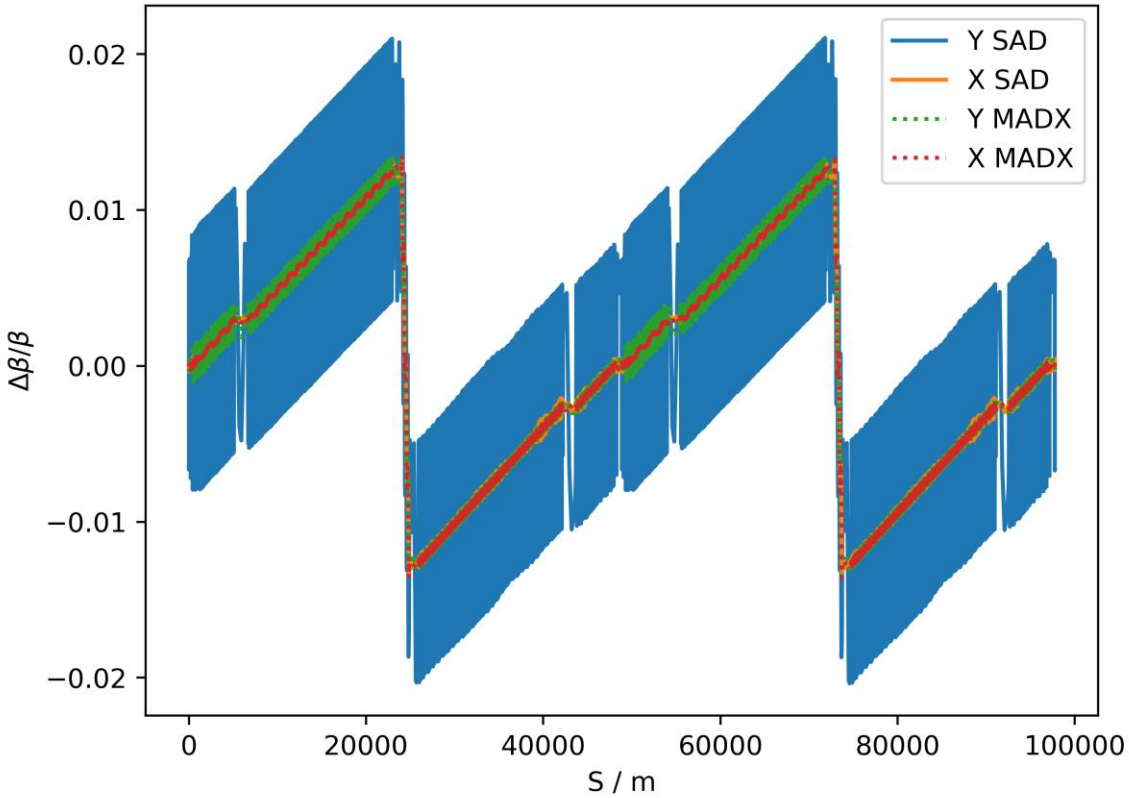


Implementation in MADX

- Implemented in MADX by Tobias Persson for MADX team (link)
- Ideal tapering of all magnets
  - Called by using “TWISS, TAPERING=TRUE”
  - Using strategy described above
- Tapering strengths saved as properties of elements
  - ANGLE -> K0, KN -> KNTAP
  - Untapered strengths not lost
  - Can later adjust KNTAP and K0 for non-ideal tapering
  - Tapered strengths sequence can be written to file
- Tapered strengths inherited in MAKETHIN

Twiss Optics Comparison (link)



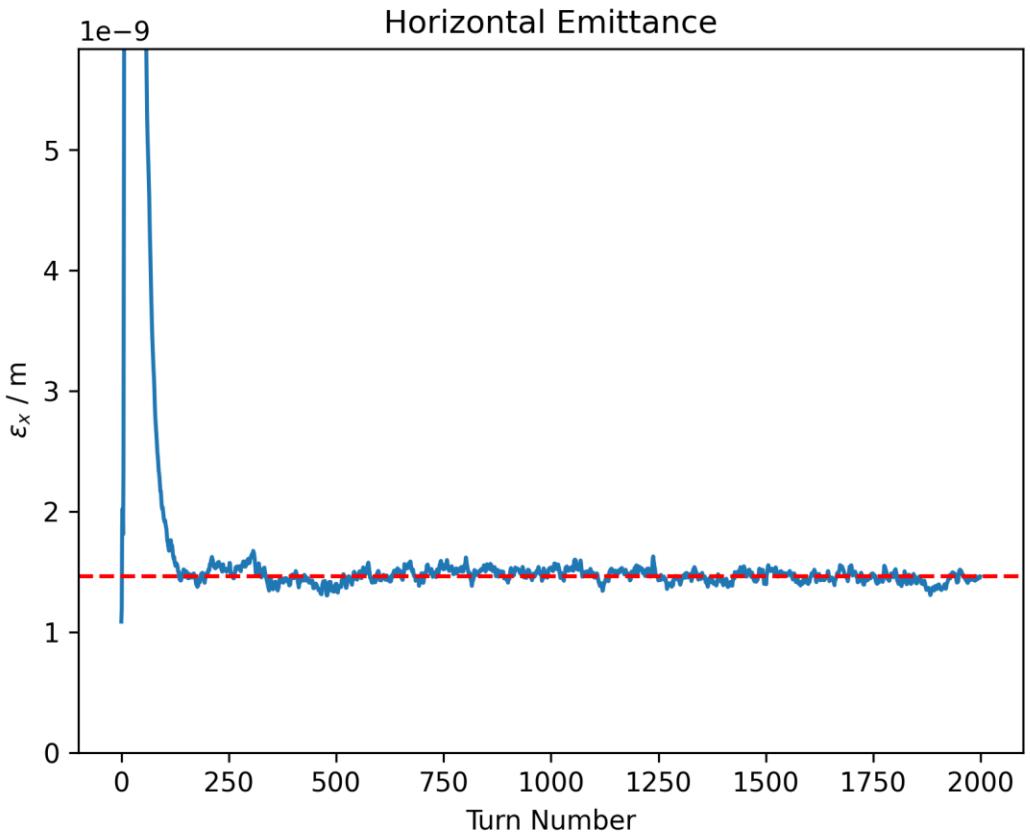


Tracking in MADX with Tapered Lattice

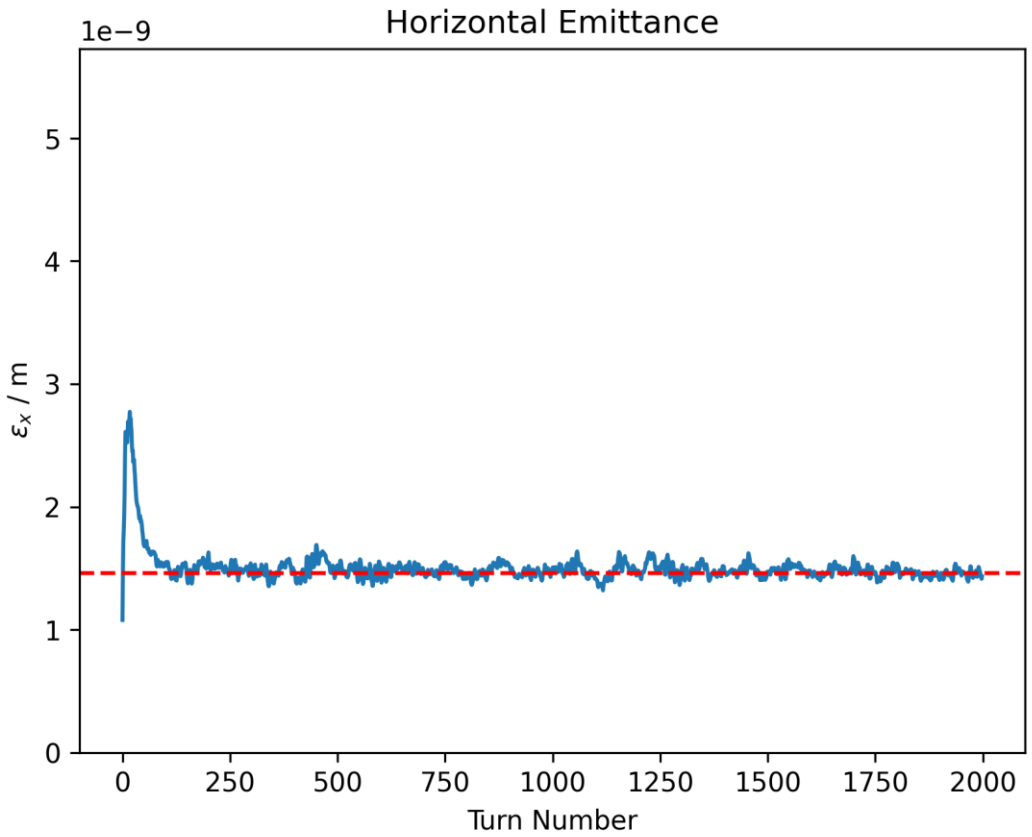
- Two main tracking options in MADX
  - PTC tracking
    - KNTAP not fully translated to PTC yet
  - MADX tracking
    - Using MAKETHIN
- Recipe for tracking tapered lattice
  - MAKETHIN
  - Re-match RF lag
  - MADX Track using DAMP = TRUE, QUANTUM = TRUE;

Horizontal Emittance

MADX

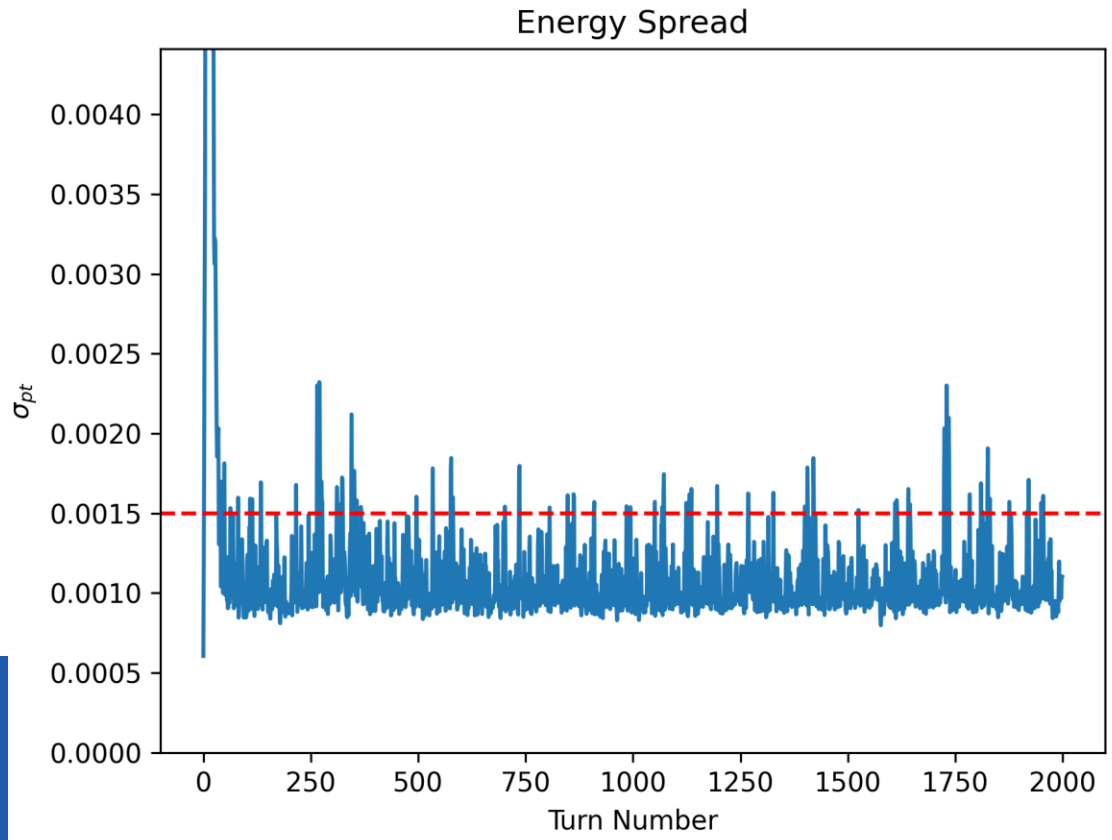


SAD



Energy Spread

MADX



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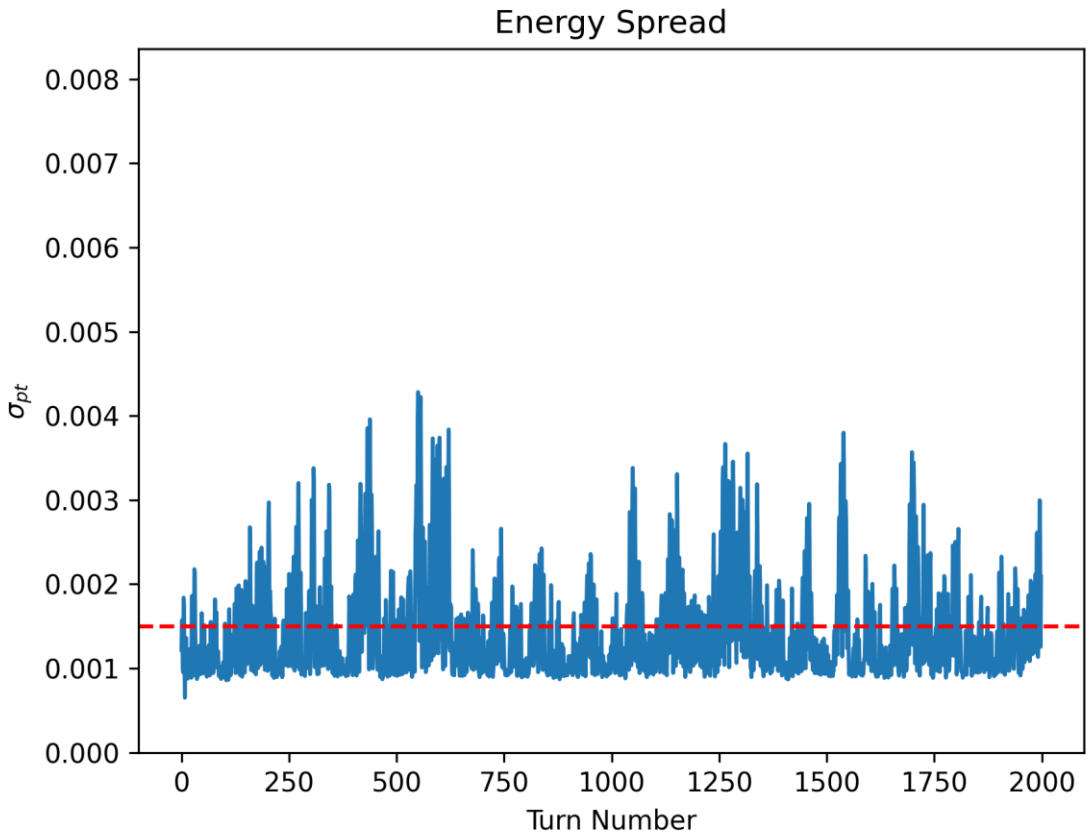
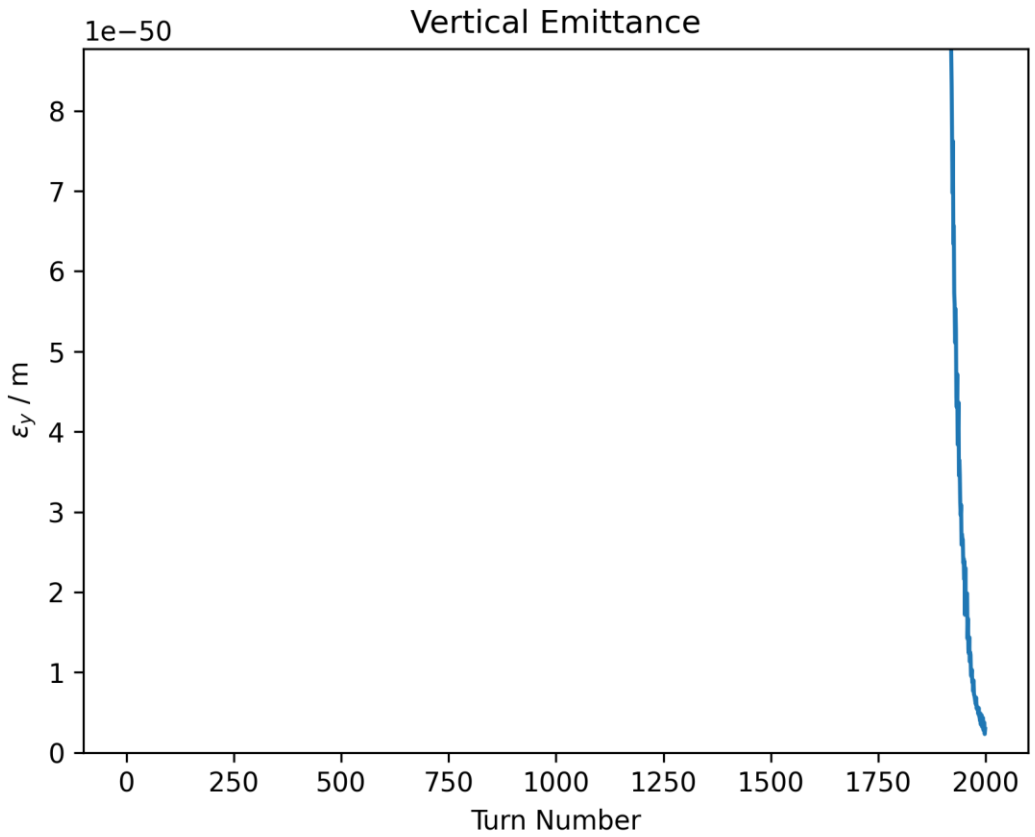
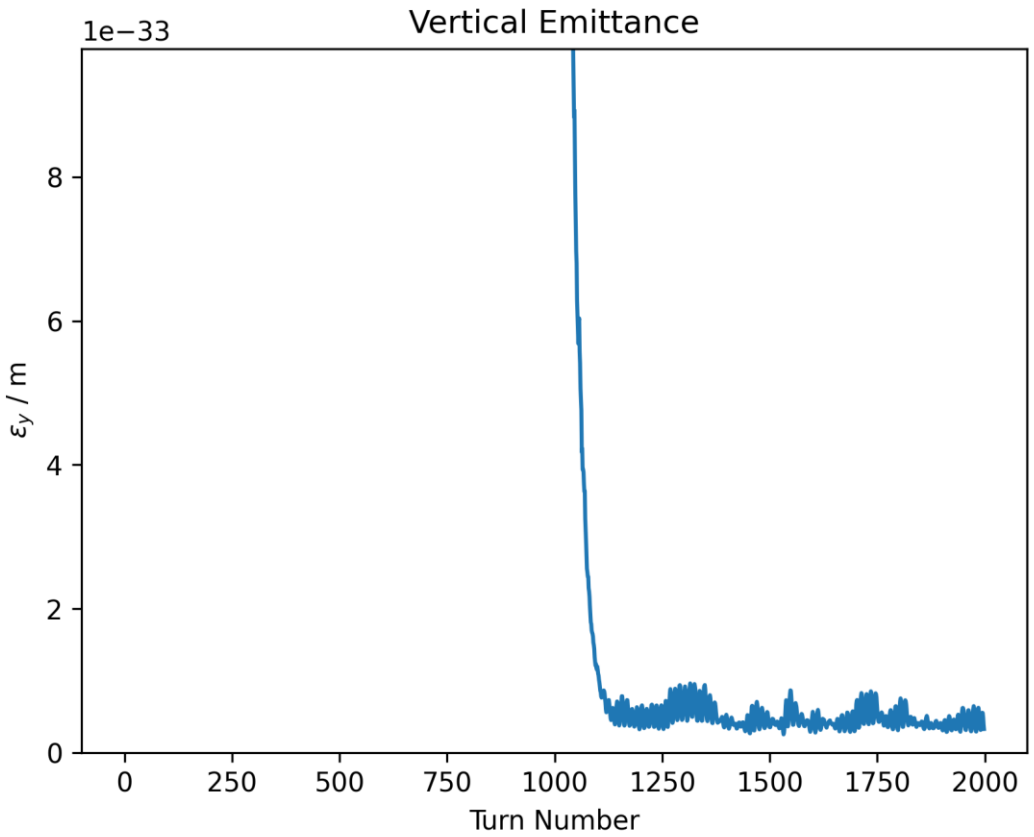


Vertical Emittance (Damping)

MADX



SAD



Summary

- Tapering strategy successfully implemented in MADX
  - Very good results when used with TWISS
  - Tracking results in good agreement with SAD
- MADX implementation
  - Easy to call
  - Can be saved to file
  - Designed to be compatible with alternative tapering schemes

Future Requirements

- Tapering and EMIT module
  - Currently bad results when using with tapered lattice
  - Somewhat independent from twiss
- Non-ideal tapering command
  - Add tapering circuits to lattice for tapering
  - Could also be done using macros or external scripts
- Possibility of implementation to MADX PTC
  - Second, well benchmarked program for studies
  - Many tools developed for PTC

Future Goals

- Work on all future requirements
- Extensive studies comparing MADX and SAD for tapered lattices with radiation
  - Linear optics, detuning, emit etc
- Attempt to implement some optimisations currently performed in SAD in MADX
  - E.g. Dynamic aperture + chromaticity optimisation
- Exploit MADX tapering flexibility
  - Develop method for non-ideal tapering
  - Examine impact of non-ideal tapering on design parameters
  - Find a suitable compromise between cost and usefulness
- MADX studies including other new features
  - Tilted solenoid
  - Tracking with deltap

Backup

Predicting Energy from Initial Twiss

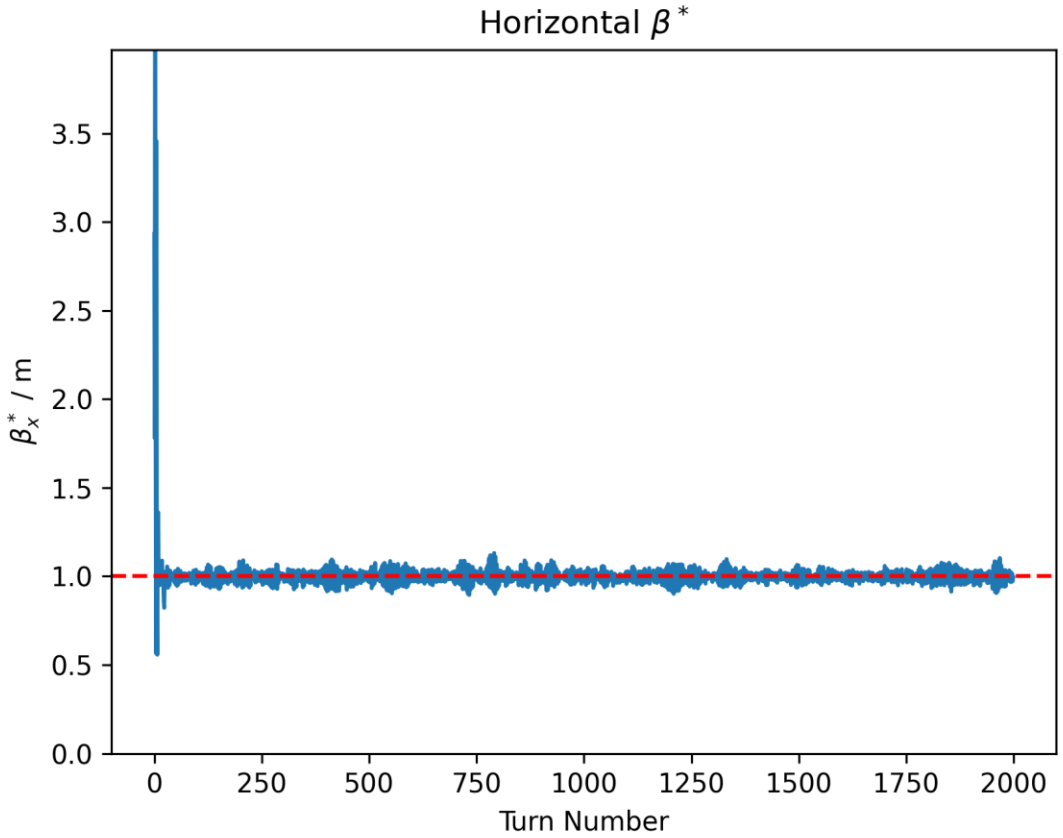
- Start with $p_t = 0$ at IP
- Cycle through elements and compute energy as $p_t(i) = p_t(i-1) - \frac{e^2\gamma^4}{3\epsilon_0\rho}\left(p_t(i-1)\right)^3 \frac{\theta}{2\pi}$
  - Energy lost around entire ring
  - Adjust for decrease in γ and weaker angle
  - Fraction of total energy loss
- Increase p_t through cavities as $V_0\cos(\phi)$
  - Evaluate p_t at exit, adjust ϕ so that $p_t = 0$ and repeat

Emittance From Track

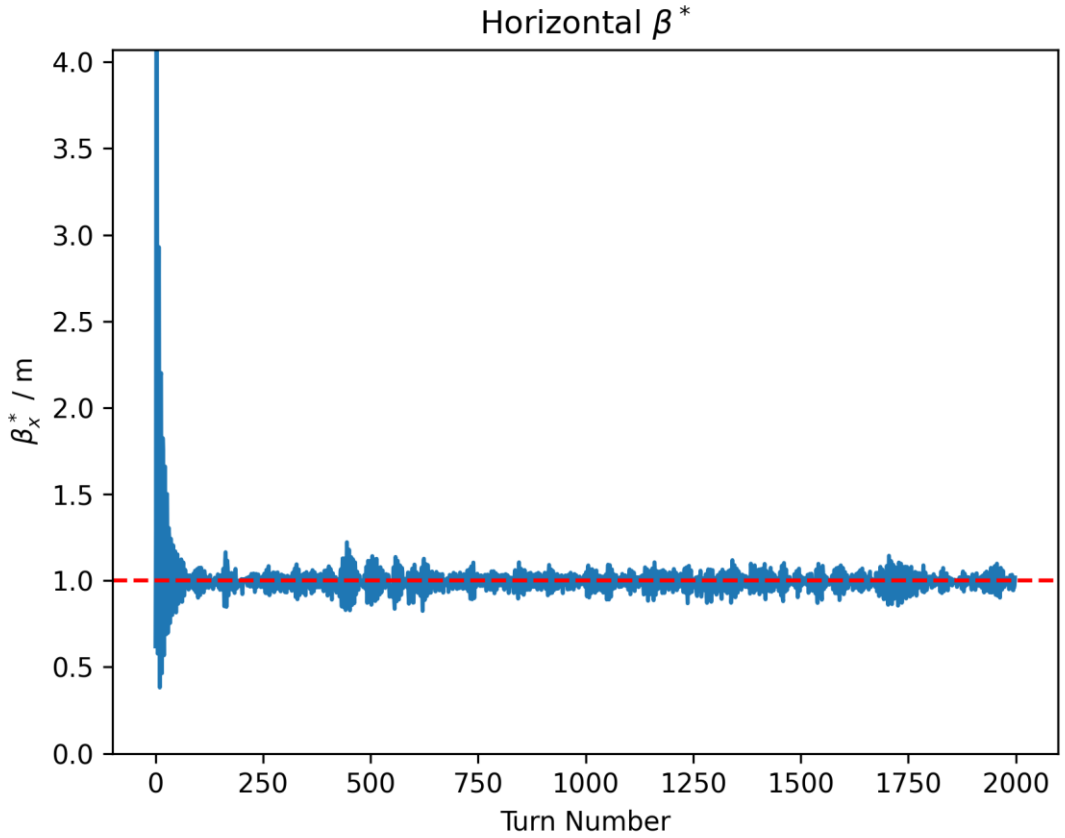
- Done for “Ideal” ttbar lattice (no solenoid)
- Initiate 5000 Gaussian particles
- Track for 2000 Turns
- Determine emittance and optical functions at IP
  - $\epsilon_x = \sqrt{< x^2 >< x'^2 > - < xx' >^2}$
  - $\beta_x = < x^2 > / \epsilon_x$
  - No coupling, so no need for beam matrix method
- Also compare to value from EMIT at 1 GeV scaled

Horizontal IP Beta

MADX

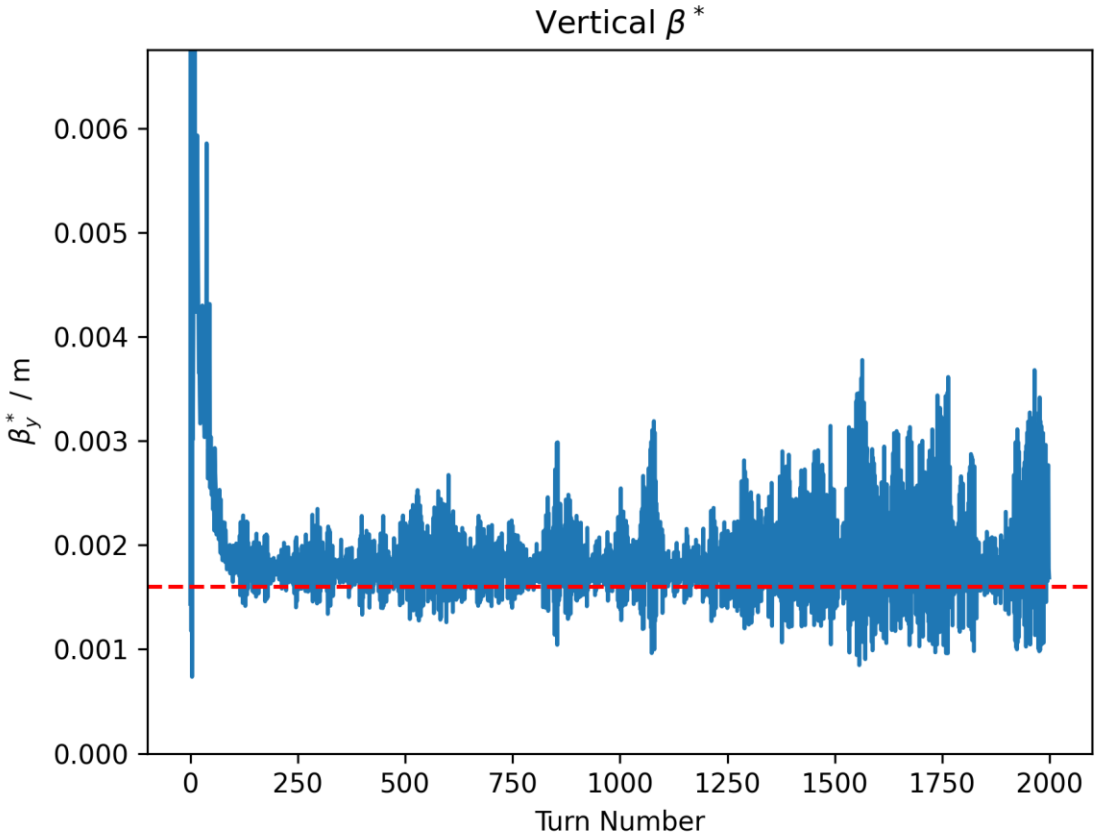


SAD

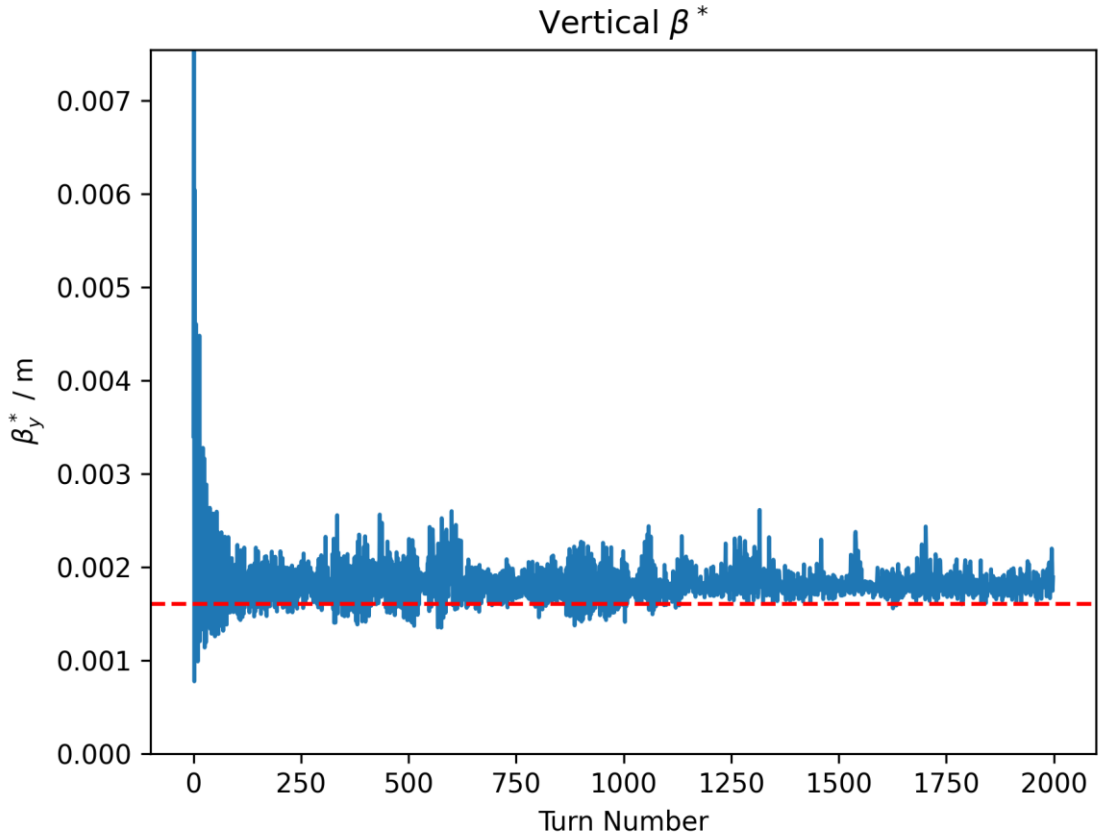


Vertical IP Beta

MADX

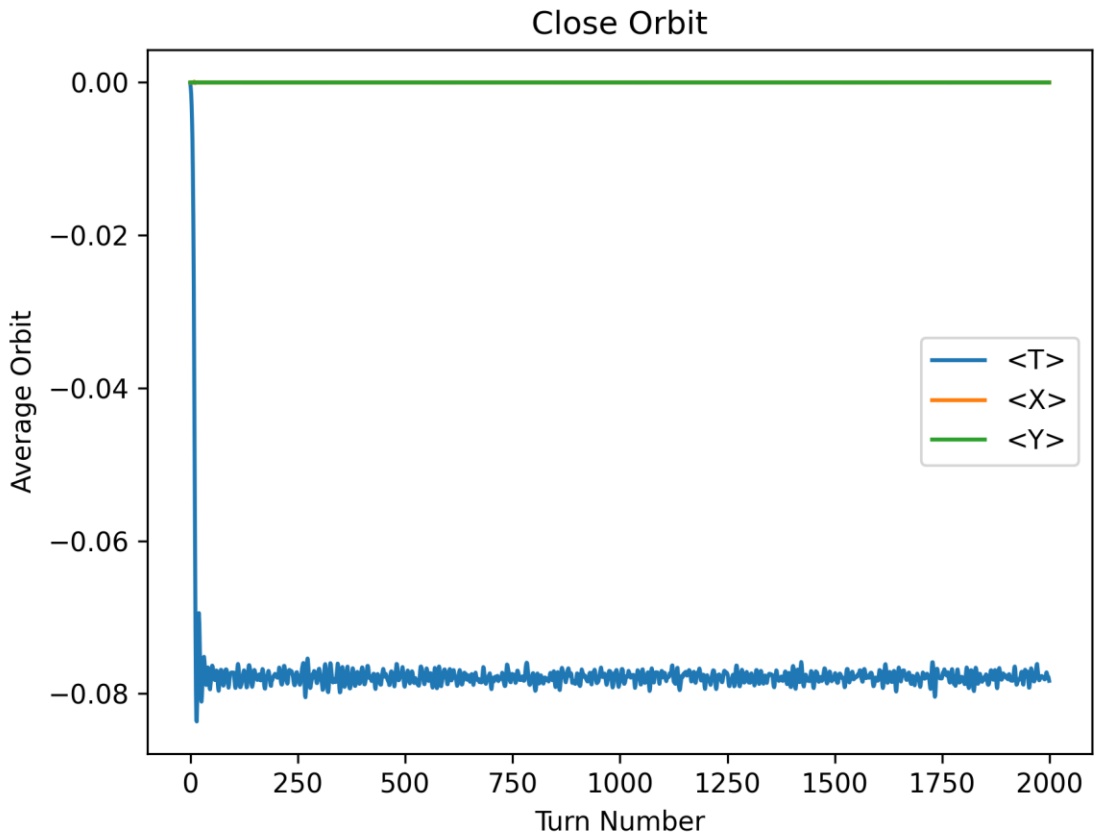


SAD



Closed Orbit

MADX



SAD