Simulations of IR Tuning

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Motivation

- Work originally motivated by to **correct optics** when **converting** between codes
  - Ensure **same physics** for different studies
  - **EPFL/CHART** software framework
- **Synergies** with needs of other studies that require **optics tuning**
  - Attempt to apply **segment-by-segment** style corrections to improve IR optics
  - Attempt to create **tuning knobs** in IR for correcting perturbations without rematching
- **Relaxed optics** for easier commissioning but also for simpler benchmarking studies

Levels of Matching

- **Global corrections**
  - Tune, detuning, chromaticity, beta beating
    - **Benchmarked** in conversion
    - Not relevant to IR tuning
- **Segment-by-segment** style matching
  - Match several important optics at certain physically relevant **checkpoints**
    - Includes IP, crab sextupoles, dispersion suppressor etc.
- **Tuning knobs**
  - For **local correction** of specific parameters
    - β^* control, waist shift,
- **Non-linear** corrections
  - To be explored…

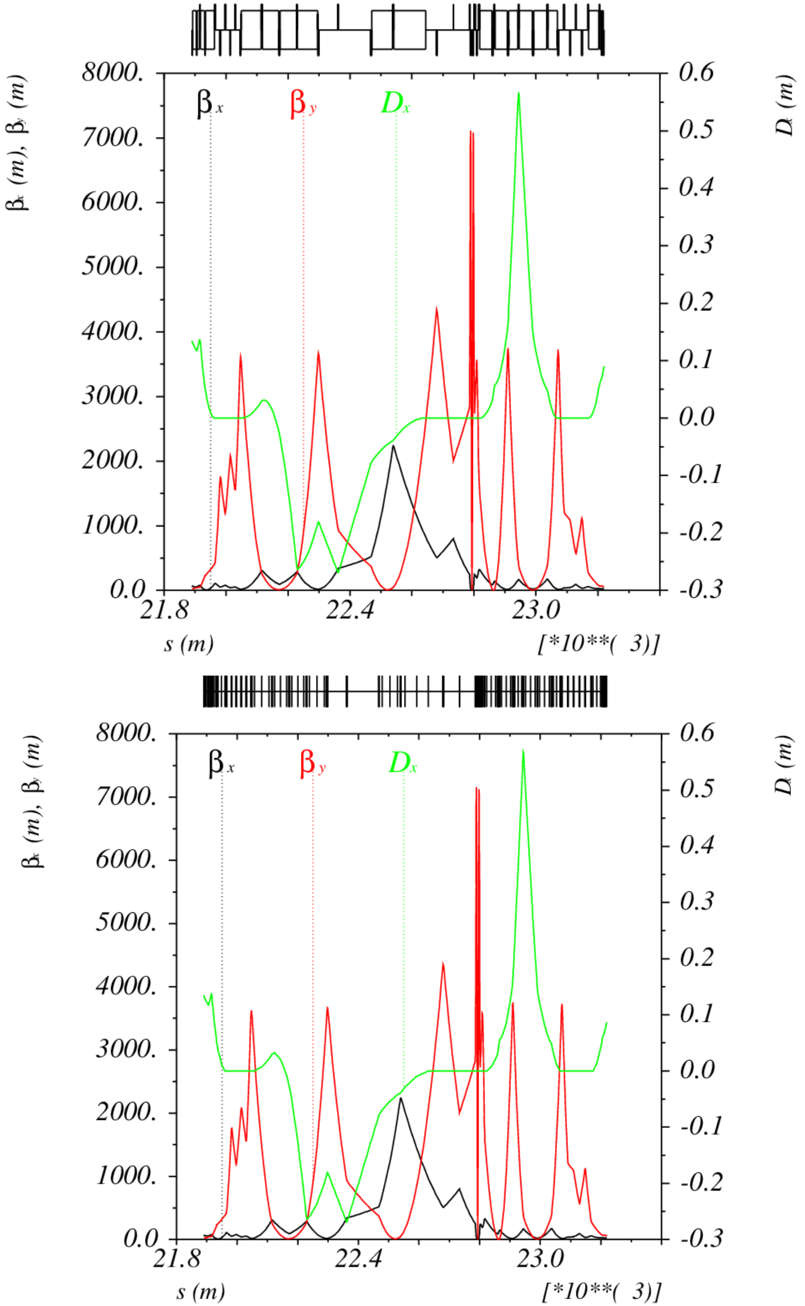
Segment-by-segment

Segment-by-segment: Strategy

- Identify **sections** based on
  - **Magnets** with common purposes
  - Important **optics properties** at specific **points**
- Compute and **save ideal** optics at these points
- **Load perturbed** lattices and match optics using segment-by-segment matching
  - **Assume ideal** optics at **entrance** of section
  - Perform **matching** to **exit** of section
- **Iterate** from one section to the next to recover correct optics

Segment-by-segment: Application

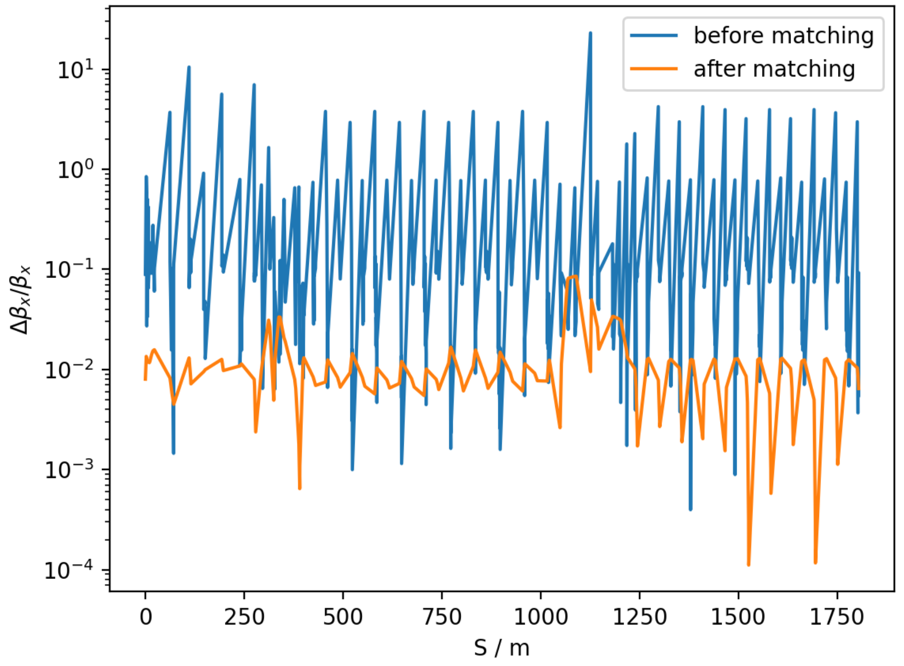
- **Scripts** for this written in **MADX**
- Tested for systematically and randomly **perturbed** optics
  - **Recover design strengths** and optics
- Applied to recover optics after **slicing** of lattice
  - Aim to be able to **reduce number** of slices to speed up simulations
  - Correct optics even with **only three slices**

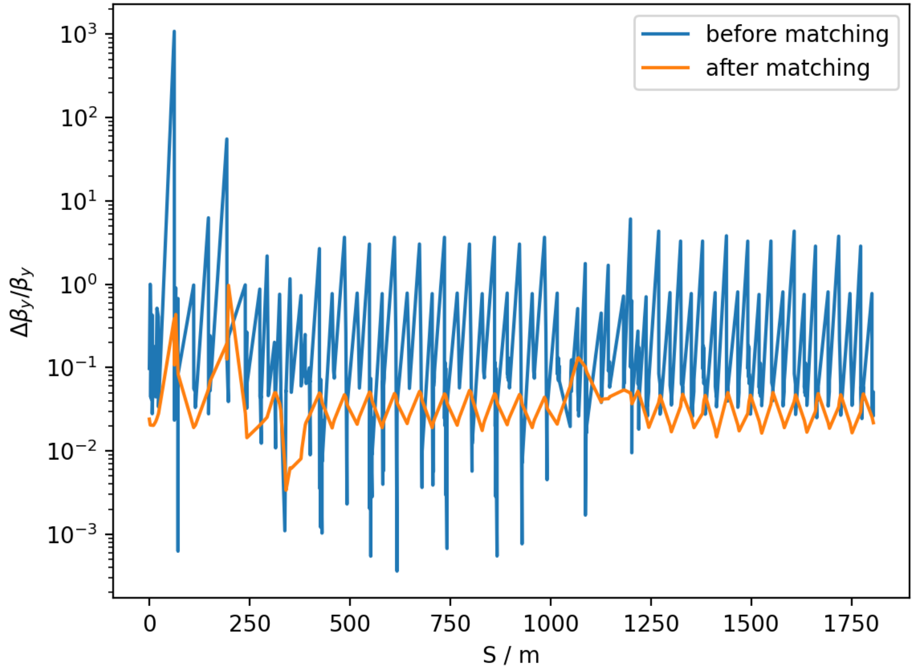


IR Twiss obtained thick elements and with three thin slices per element and matching

Segment-by-segment: Application

- Applied to globally corrected lattices
  - Corrected lattices provided by **T. Charles**
- Scripts changed to **correct and save** each **quarter separately**
- Insertion style **correction does not consider** non-zero **closed orbit**
  - Small **residual beating** when simulating closed machine
- IP β-beating reduced from ~20% to **~2% percent**
  - Need to explore how this affects other parameters
    - E.g. increased coupling, increased β-beating in certain areas
    - Coupling increase reported by **D. Shatilov**





Knobs

Knobs

- Often **linear changes** in multiple **quadrupole strengths proportional** to the target value of a parameter
  - $\boldsymbol{\Delta k} = \boldsymbol{k_{knob}} \times \Delta parameter$
- Compared to regular matching
  - More **targeted** adjustments
  - Easier and **fast** to use
  - **Less precise**, also at keeping other parameters unchanged
- **Realistic** in control room environment

Knobs from Fitting

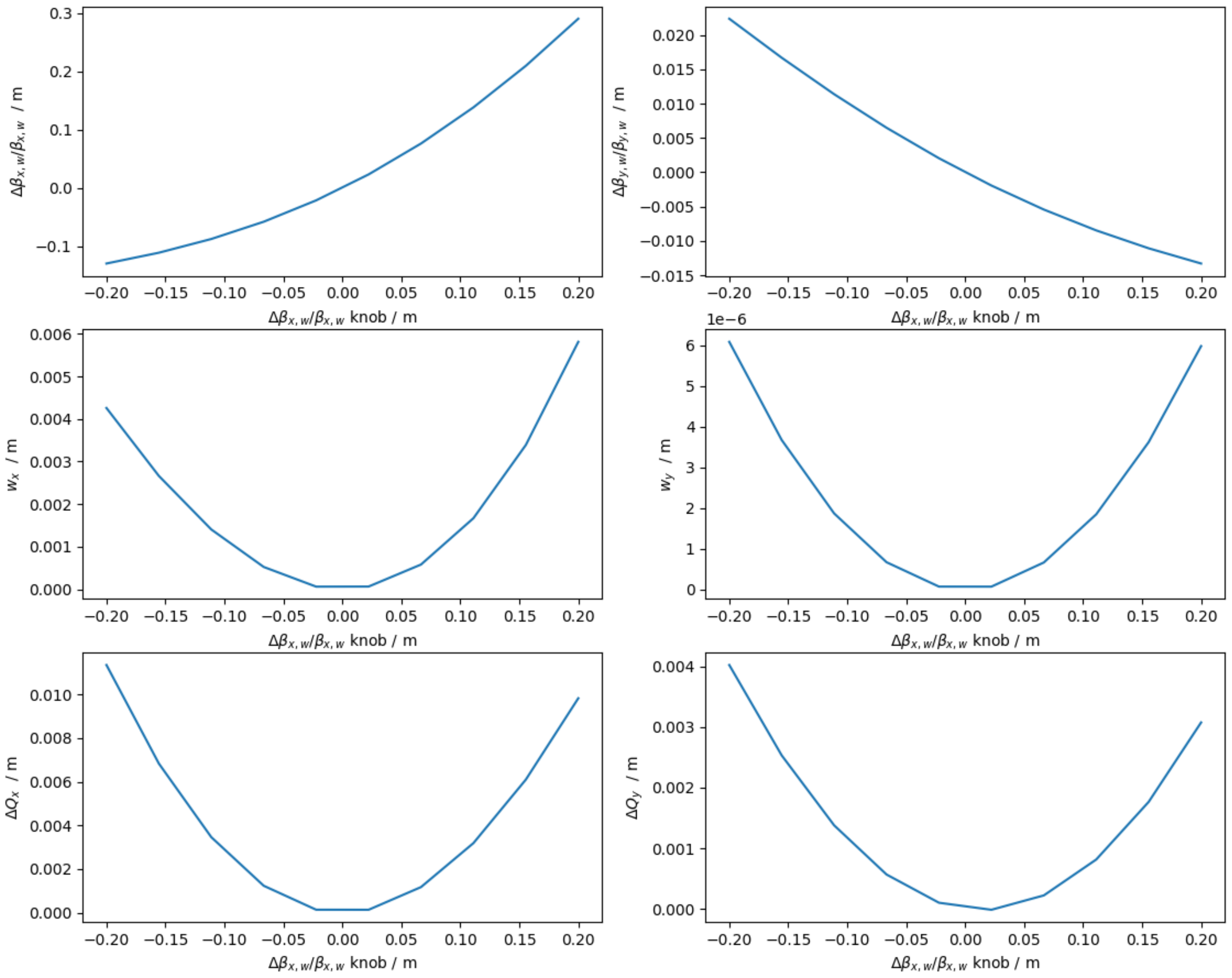
- Match one parameter to one value whilst keeping others constant and **interpolate/extrapolate linearly** for other values
- **Certain parameters** can be varied **very linearly** without distorting other parameters too much
  - **Machine tune** using RF insertion
  - **Horizontal β-waist** in IP
- Knobs for many other parameters much harder to define
  - Change other parameters more than the desired parameter
  - **Vertical β-waist, $\boldsymbol{\beta_w}$** in both planes…
- More complex **quadratic knobs** can be defined to reduce unwanted changes in other parameters
  - Might be **harder to implement** in real machine
  - Still not satisfactory results for problematic parameters

Knobs via SVD

- Method pointed out by K Hanke, T Raubenheimer and P Raimondi at FCC-IS workshop
- Alternative method of creating knobs
  - "**Reverse**" to matching method
- Generate **response matrix**, $\boldsymbol{M}$
  - **Change setting** of individual magnets, k_i
  - **Monitor changes** in observables o_j
  - $o_j = M_{ji} k_i \approx \frac{\partial o_j}{\partial k_i} \mathrm{k_i}$
- Construct **pseudo inverse** of $\boldsymbol{M}$ using SVD decomposition
  - $\boldsymbol{M} = \boldsymbol{U}\boldsymbol{S}\boldsymbol{V}^{\boldsymbol{T}}$
  - Pseudoinverse $\boldsymbol{M}^{-1} = \boldsymbol{V}\boldsymbol{S}^{-1}\boldsymbol{U}^{\boldsymbol{T}}$
    - Can be used to find the **correct setting** $\boldsymbol{k_i}$ for a **desired** $\boldsymbol{\Delta}$**o**
    - Can **suppress small singular** values to avoid linear codependency

Knobs via SVD

- **Effective** for creating knobs where linear fitting fails
  - $\boldsymbol{\beta_w}$ **control**
    - Still not very linear but better than fit
  - **Vertical $\boldsymbol{\beta}$ waist shift**
- Seems to be **more effective** than linear fit
- Allows to gain **insights** in the behaviour of the machine
  - Also useful for **alignment tolerances**



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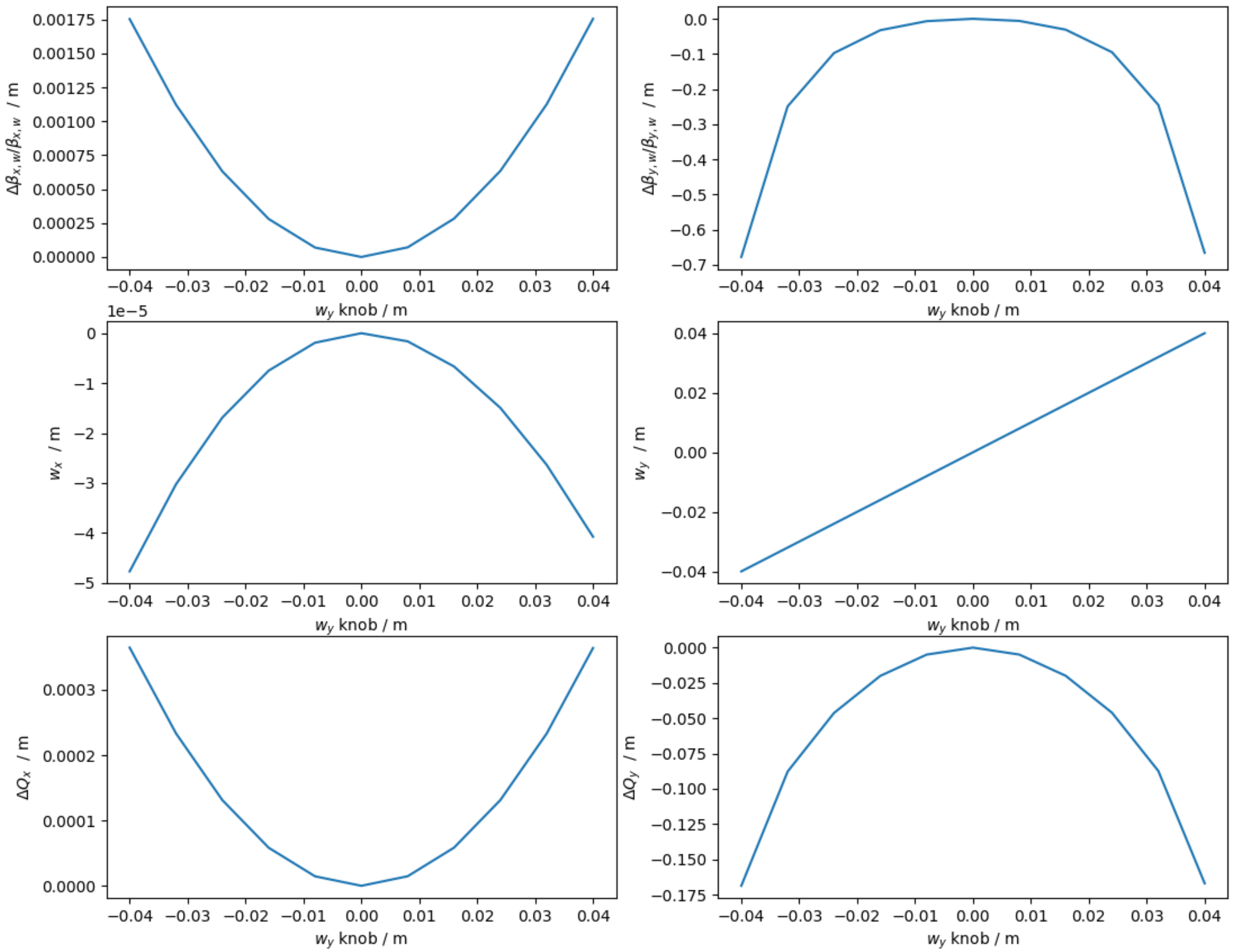


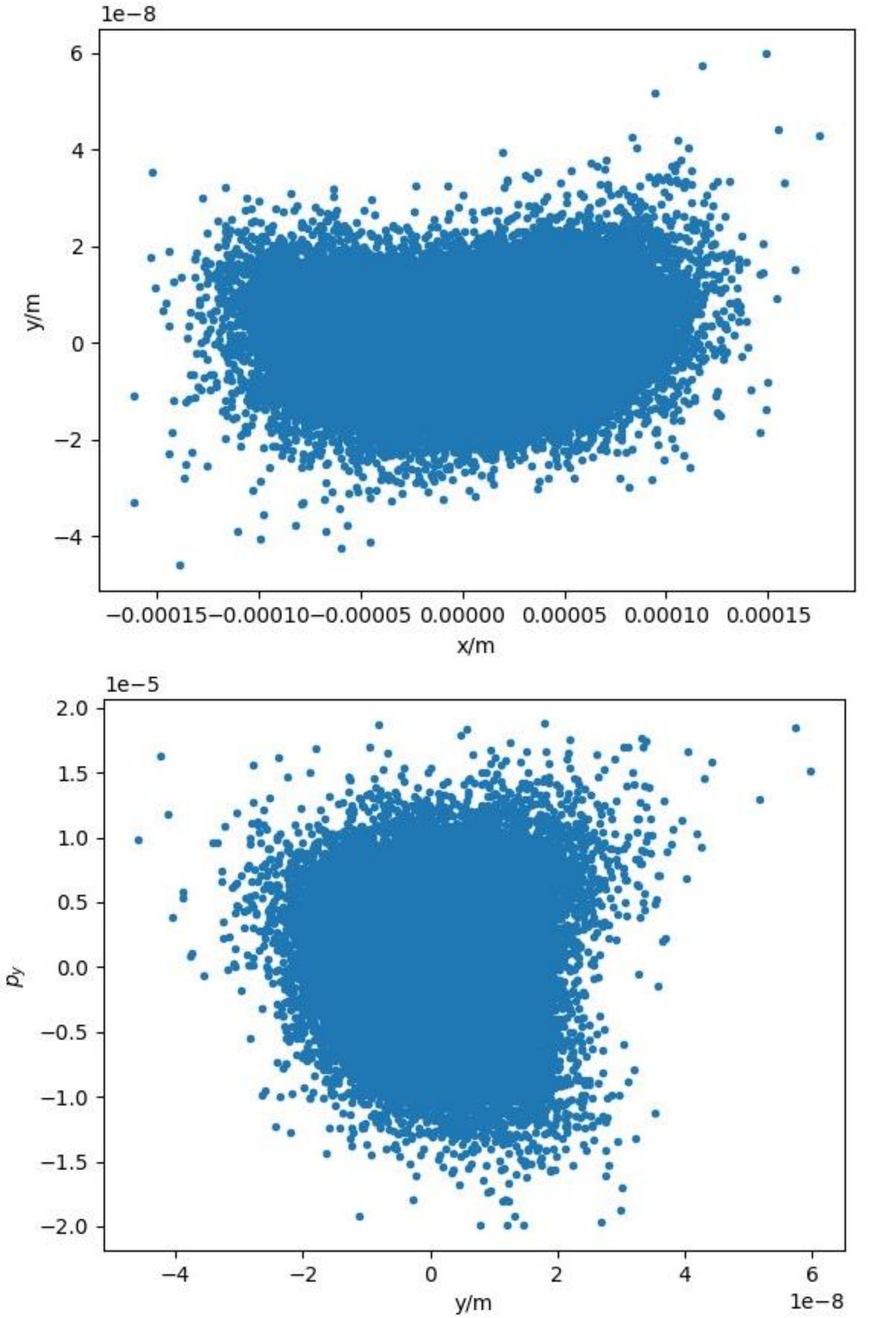
Coupling and Vertical Dispersion

- SVD **extendable**
  - Further **observables**
    - Vertical dispersion, ΔQ_{min}, chromaticity
  - Further **manipulations**
    - Vertical displacement of sextupole, rotation of quadrupole, skew quadrupole field
- Allows for extension of method to create knobs to control further parameters at the IP e.g. **vertical dispersion**
  - Whilst keeping more observables constant
- Need to identify
  - **Which magnets** and perturbations to probe
  - **Which observables** to measure

Non-linearities

Non-Linearities

- Require tuning of **non-linear** behaviour for e.g.
  - **Dynamic aperture** optimisation
  - Correcting **aberrations** in the **IP** for Luminosity
- Non-linear behaviour directly **influenced by optics tuning**
  - E.g. anharmonicities after segment-by-segment correction
- Development **robust measurement and correction strategies**
- Require **robust simulation tools** to determine non-linear behaviour

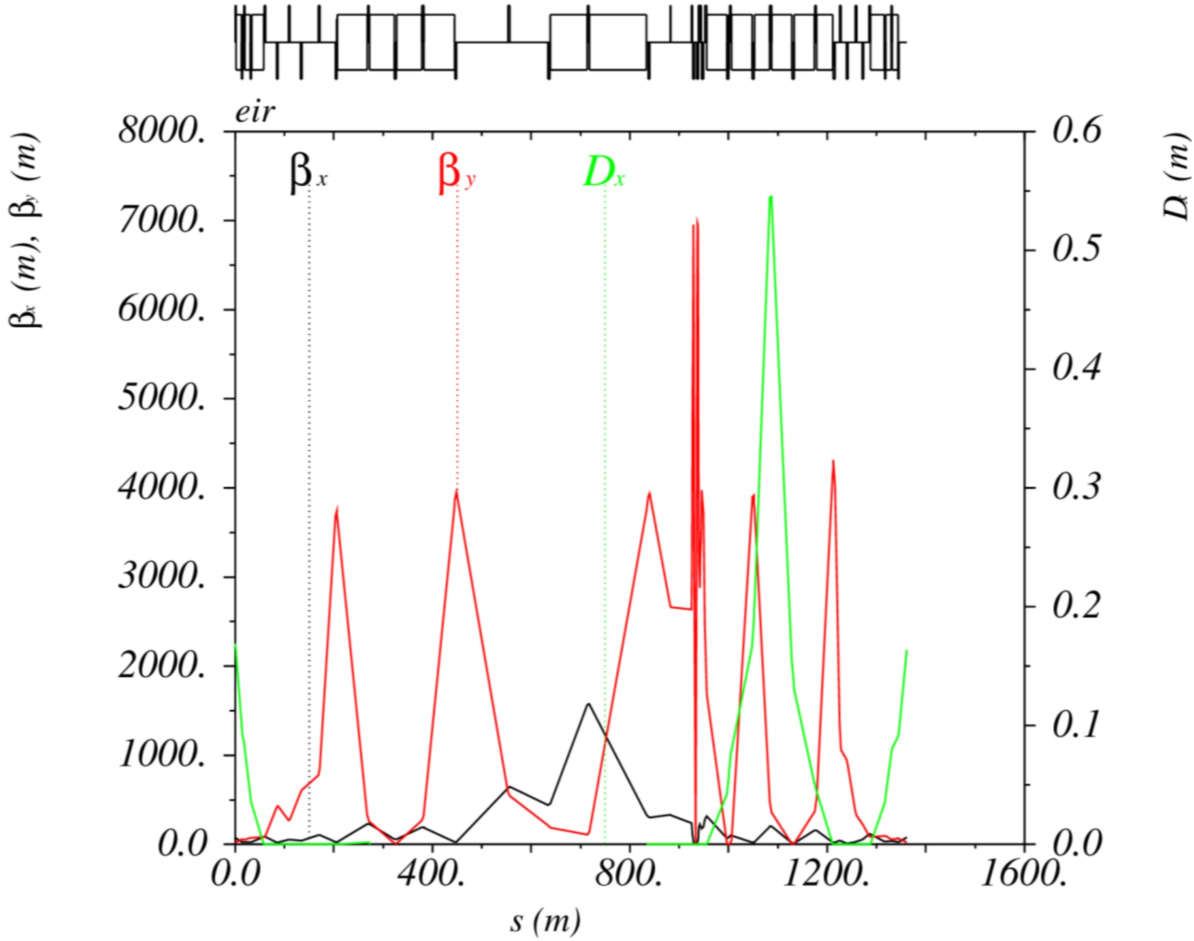


Equilibrium beam shape at IP from tracking with skew errors.

Relaxed IR Optics

Relaxed IR Optics

- **Relaxed optics** important for
  - Easier **commissioning** and correction strategies
  - **Benchmark** simulations without IR effects
- Larger β^* results in **smaller $\boldsymbol{\beta}$ in final focus** section
  - **Lower non-linearities**
  - **Less susceptible to errors**
- Scripts with madx **macros** that
  - **Save** initial **optics** at arcs
  - **Match** to a new target β^*
  - **Save** new **strengths**



Conclusion and Outlook

- **Segment-by-segment** style matching
  - Useful for recovering **linear optics** for conversion and **simulated** corrections
  - Do not take into account **non-linear errors**
- **Knob creation**
  - **SVD method** more effective than linear interpolation
  - Demonstrated **effectiveness** for some knobs
    - Need to **create comprehensive** set of knobs for users
  - **Coupling/vertical dispersion knobs** to be explored
- Need to understand **non-linear errors** and conceptualise **correction strategies**
- **Relaxed optics** matching scripts for MADX available