Swiss Accelerator Research and Technology

IP Tuning

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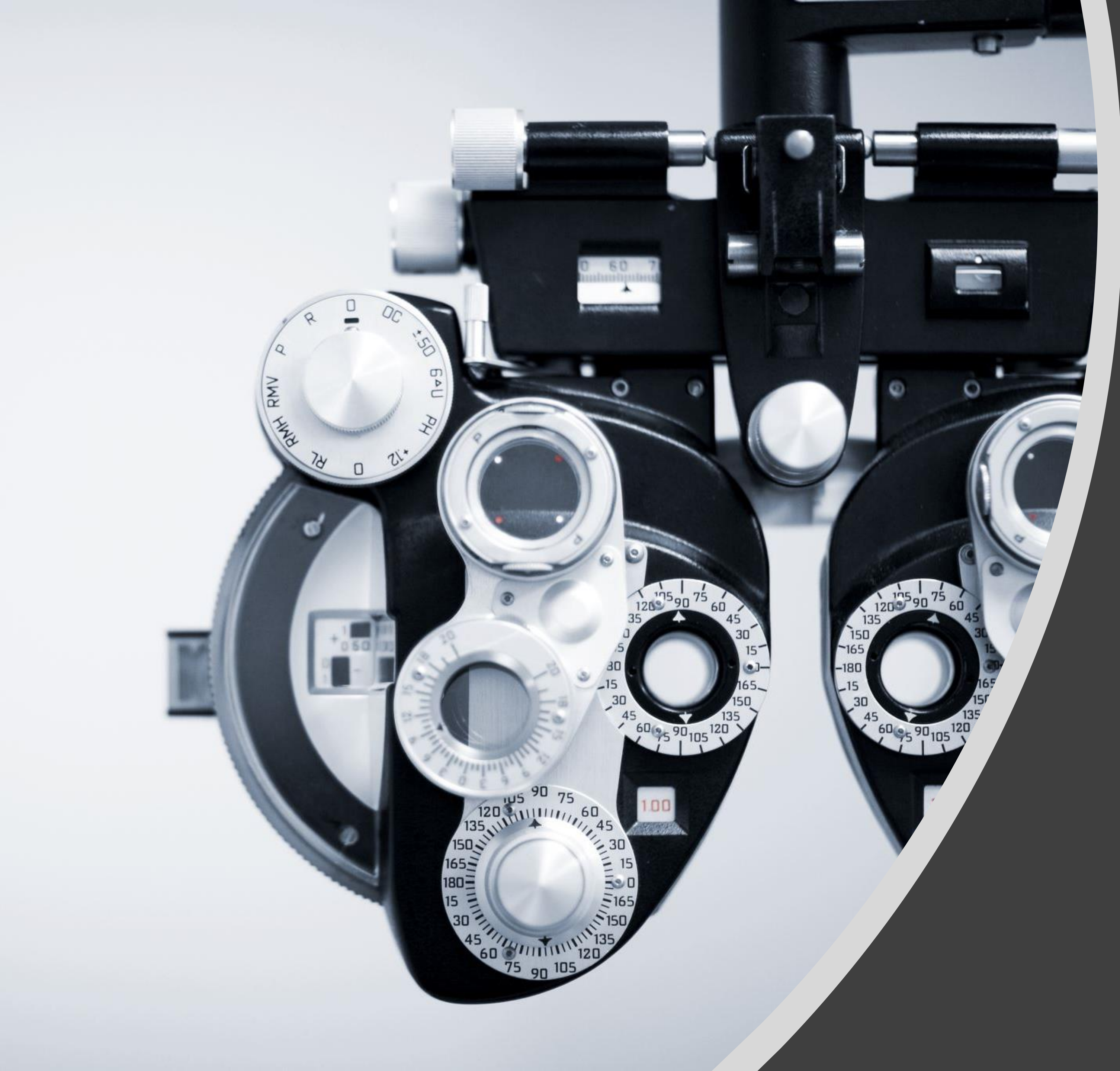
WORK SUPPORTED BY THE SWISS ACCELERATOR RESEARCH AND TECHNOLOGY (CHART)

Overview

- Optics **Matching**
  - For **conversion**
    - More robust **tracking** studies
    - Made **available to users**
  - As **“realistic” local correction**
    - Potential extra layer of **correction**
- **Knob** creation
  - Through **matching**
  - **Exploiting** linear behavior
    - Understanding **physical limitations**



Optics Matching

Motivation

- Work originally motivated by **optics distortions** after lattice conversion (**EPFL Software Framework**), for example due to:
  - Different physics in **element definitions**
  - **Slicing**
  - **Numerical errors**
- Long-term goal is to put **optics definitions/constraints** into general **lattice definition**
  - Optics matching after **every conversion** – either using wrapper in converter or directly in target code
- First prototyping done in **MAD-X** using **matching in MAD-X**
  - Immediate applications for **current studies**
    - Corrections for **sliced lattices**
    - Extra **optics corrections** in “realistic” lattices with errors and global correction (by T. Charles)

Overview

- Targeted **local matching**
  - Aim to match optics precisely at **key points**
    - Instead of global matching
    - Recover **key optics properties**
  - Use **small amount of local** magnets
  - Largely **speeds up** matching and makes **convergence** more likely
- Applied to **one section** at a time
  - Match optics around **the entire ring**
- **Segment-by-segment** style correction

Key Optics Parameters

- Key optics parameters identified from **discussion with experts**
- Focus on properties essential for **luminosity, DA etc.**
  - β^*, α and dispersion at collision point
  - Phase advances to and between crab sextupoles
  - Zero dispersion after dispersion suppressor
  - Correct phase advance to arc sextupoles
  - Phase advance in arc FODO cells
- Further **input welcome**

Implementation in MADX

- Currently implemented in MADX for a range of uses

Strategy

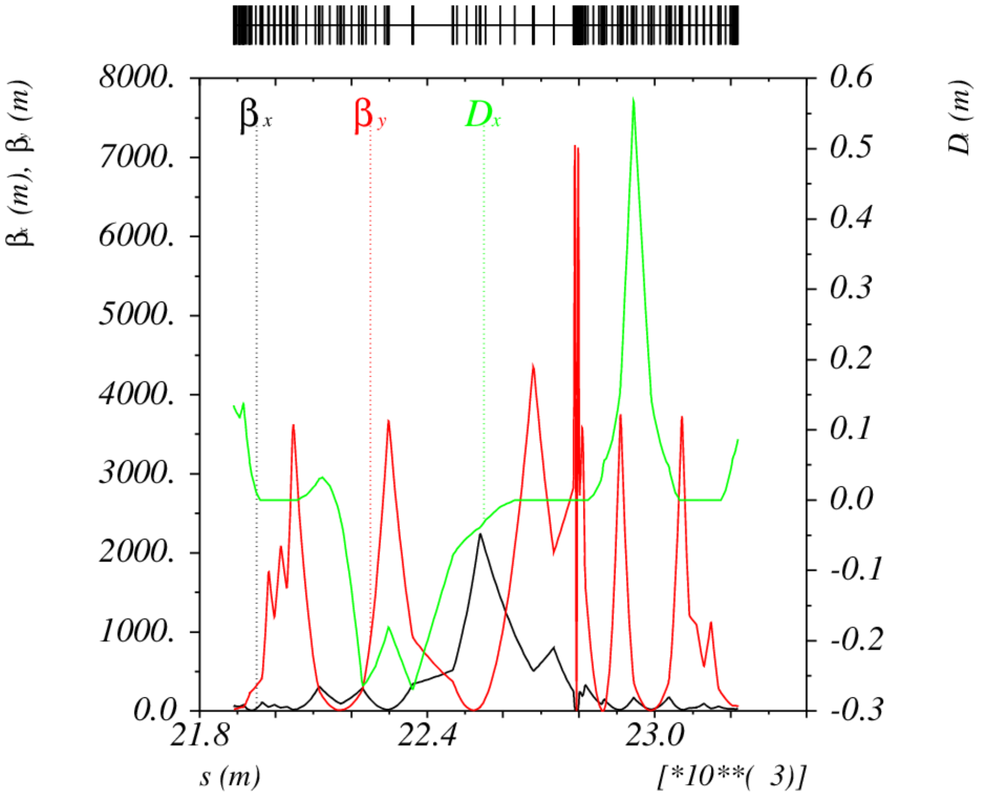
1. Identify **groups of magnets** and their **common purpose**
2. **Install markers** at the end of identified groups (or use existing ones)
3. **Save optics** at markers in “ideal” machine
4. **Perturb** lattice (e.g. slicing, conversion)
5. **Match** like an insertion starting from one location, adding **one group** of magnets **at a time**

Example – Perturbed Quadrupole Strengths

- First **artificial test case**
  - Representative of changes in **quadrupole definition**
- Apply errors to the **strengths** of the **quadrupoles**
  - **Systematic** 1% error
  - **Random** error with 1% standard deviation
- Check
  - **β-beating** reduced to numerical precision
  - Original **strengths recovered**

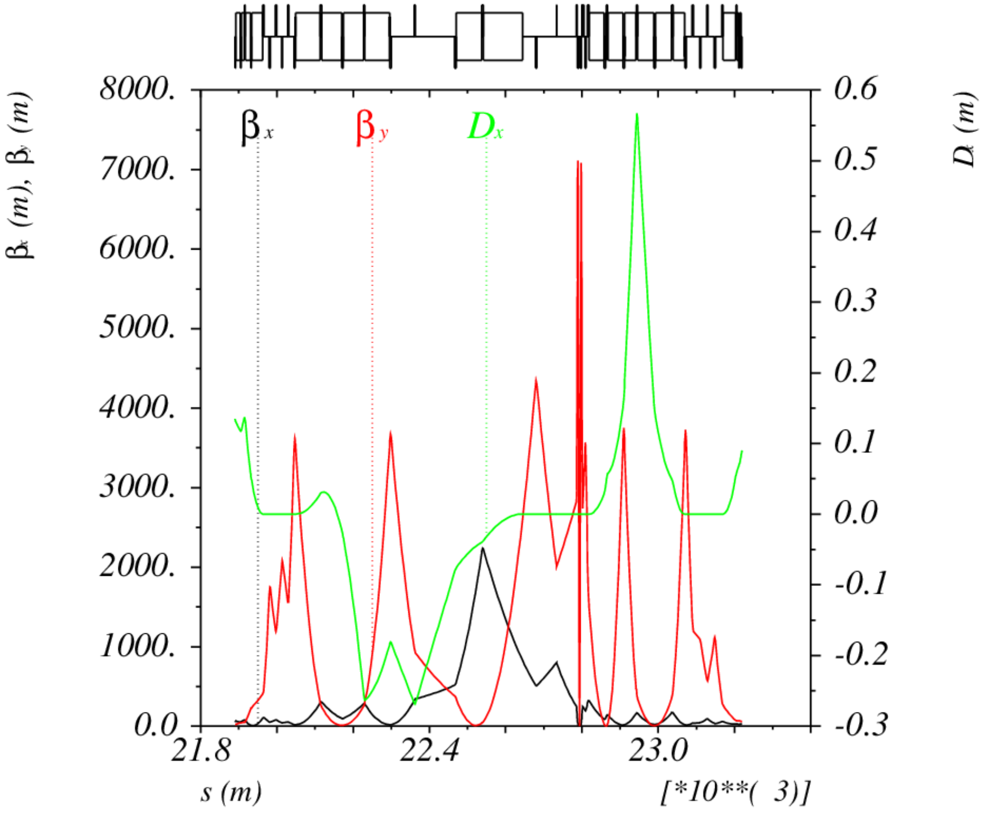
Example – Sliced Lattice

- **Slicing** required various studies (e.g. tracking)
- **Large number** of slices needed to **keep optics** close to original
  - Especially in the insertion region
  - Required to even find a **stable orbit**
  - **Slows down simulations**
- By **matching** one can recover correct optics even with **low number of slices**
  - **Speed** up simulations

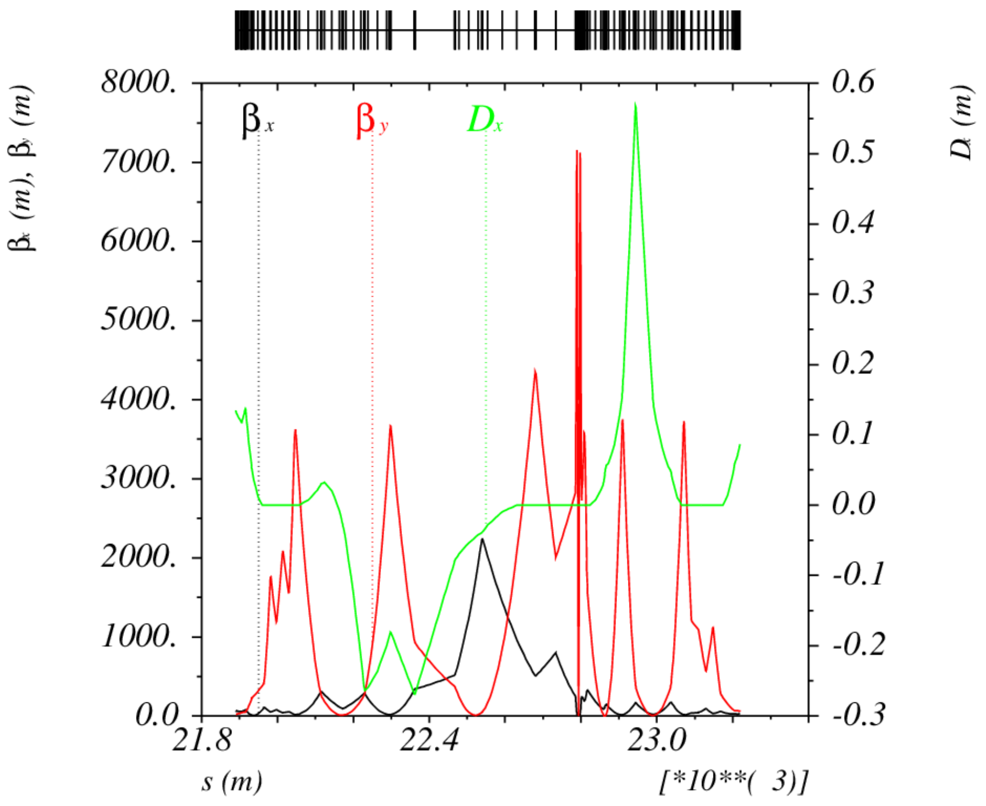


IR Twiss obtained with three slices and matching

Example – Sliced Lattice



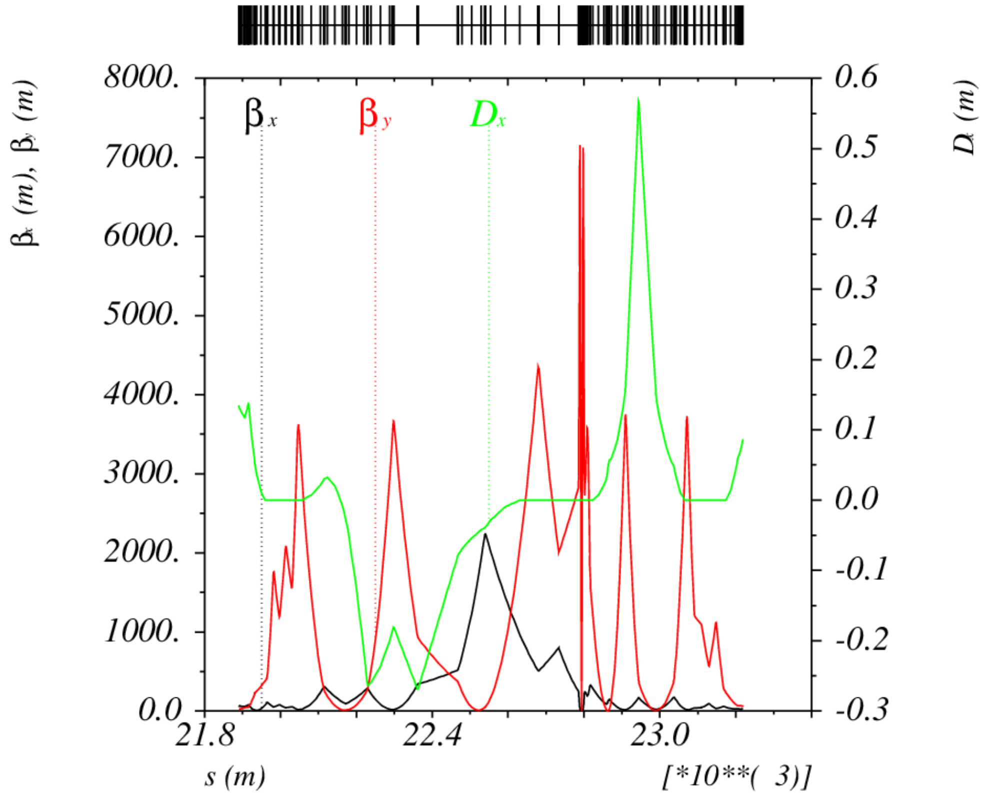
IR Twiss obtained with unsliced lattice



IR Twiss obtained with three slices and matching

Example – Sliced Lattice

- Slicing and matching algorithm uploaded in FCC-ee git repository
  - Courtesy of R. De Maria and M. Hofer
  - Made available to more colleagues
- Matching not robust for all modes
  - Different magnet families
  - Small changes in matching parameters to achieve convergence
  - Provisional fix by checking lattice version and adjusting matching accordingly
- More robust methods underway

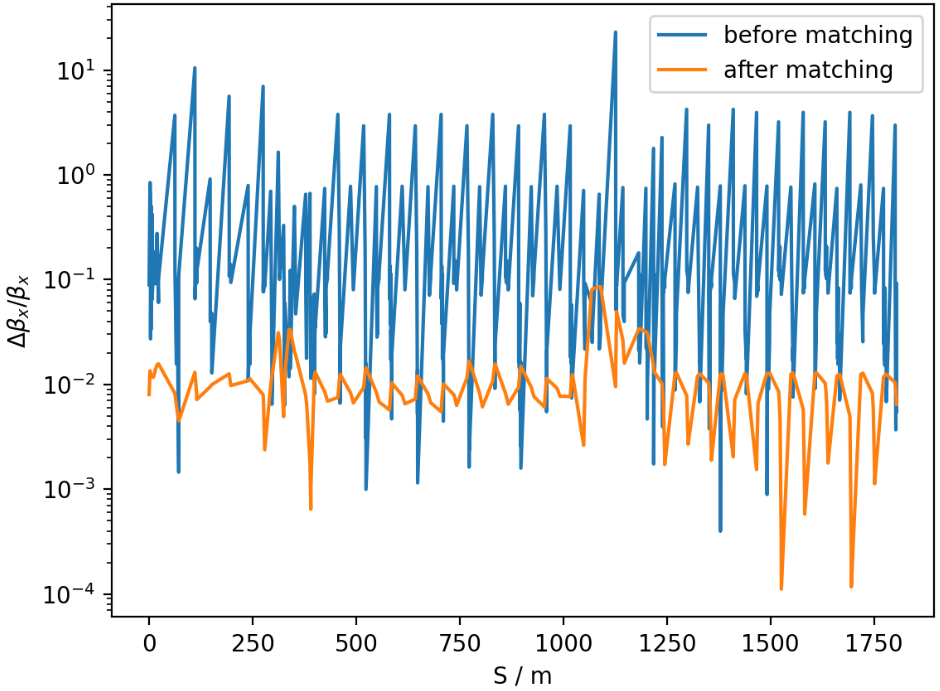


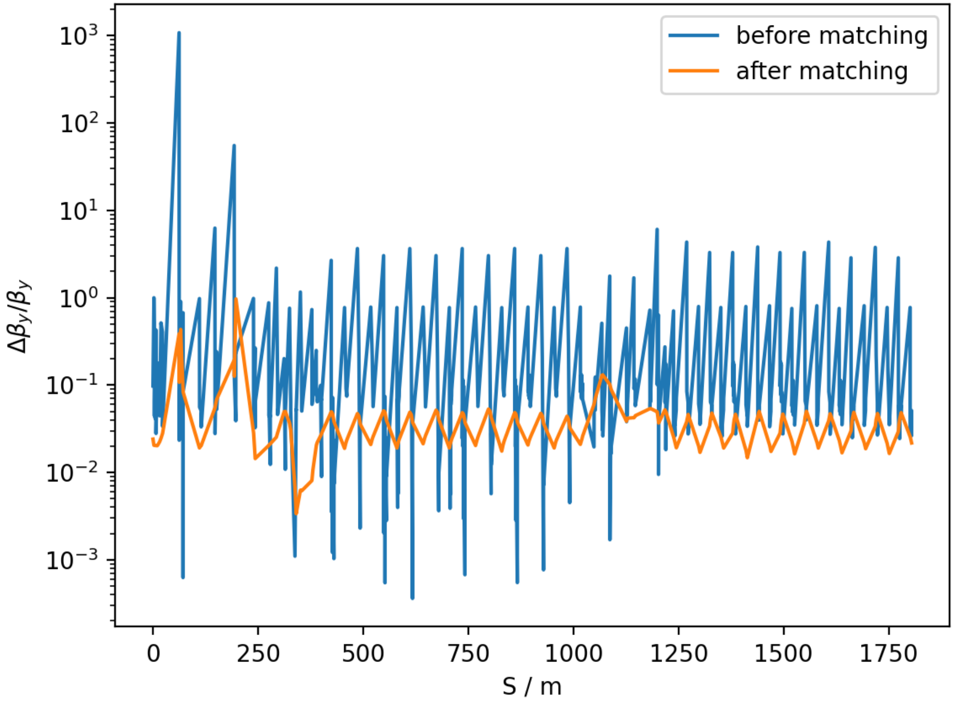
IR Twiss obtained with three slices and matching

EPFL

Optics Matching in Lattices with Errors

- Apply additional optics matching to **globally corrected lattices** with errors
  - Requested by **D. Shatilov**
  - Corrected lattices provided by **T. Charles**
- Scripts changed to **correct and save each quarter separately**
  - **Decouple** common strengths in quarters
- Insertion style **correction does not consider** non-zero **closed orbit**
  - Small **residual beating** when simulating closed machine
  - **Closed matching requires individual powering** of machine quarters
- 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**





Next Steps

- Implement matching in **sequence converter**
  - Store **constraints** and **variables** in **sequence definition**
  - Match after every **conversion** either by
    - Generating **matching scripts** in accelerator code
    - Performing **matching in python**, calling accelerator code for twiss
- Improve matching code in **MAD-X for users**
  - **Adjust constraints** in consultations with users
  - Produce (a method that creates) scripts for **all lattice versions**
- Improve **realism** of matching scripts for users
  - Understand **how precisely** different optics properties can be **measured** in various locations
  - Artificially **reduce accuracy of matching** to reflect realistic scenarios

Tuning Knobs

Motivation and Background

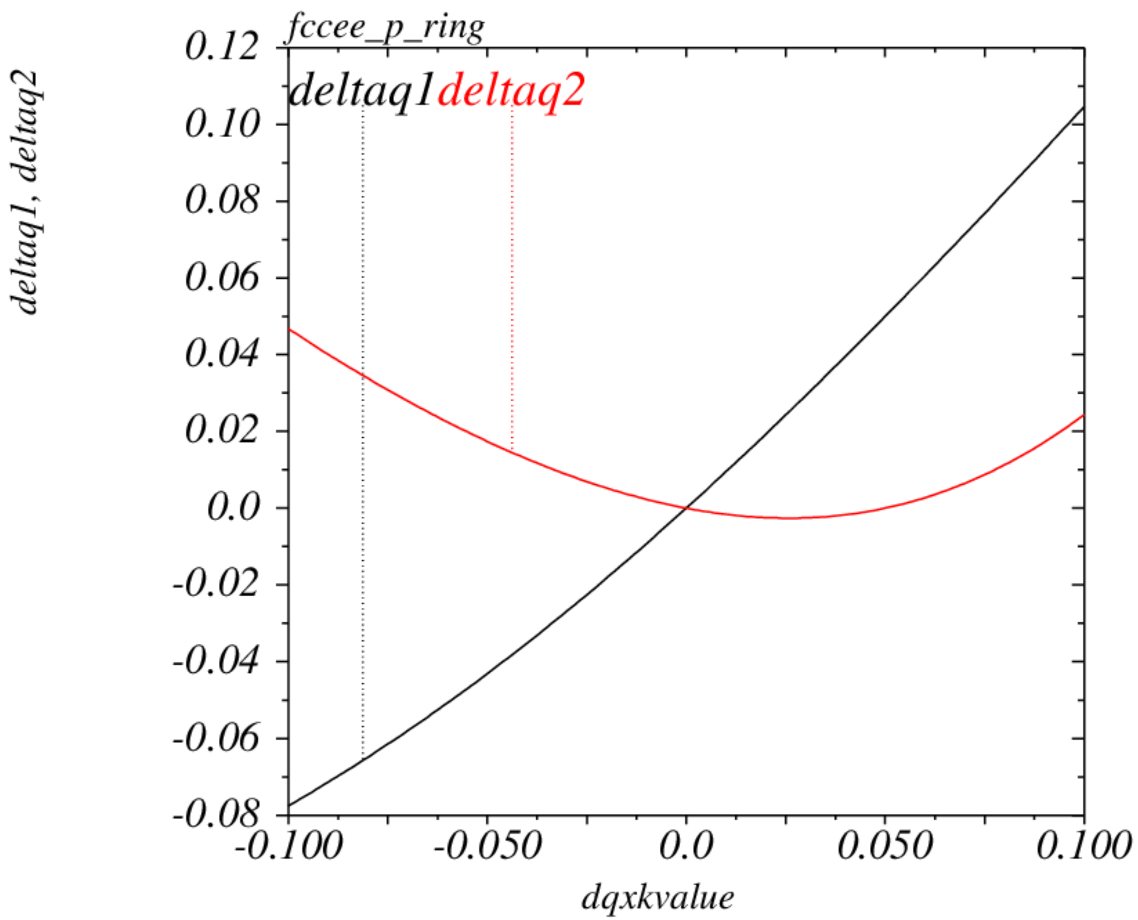
- Often **linear changes** in multiple **quadrupole strengths proportional** to the target value of a parameter
  - $\boldsymbol{\Delta k} = \boldsymbol{k_{knob}} \times \Delta parameter$
  - Match parameter at one value and **interpolate/extrapolate linearly** for other values
  - This allows the **creation of knobs** in many machines
- Can often define knobs for **many properties**
  - Tune, β waist shift, β^*, dispersion, coupling…
  - Knobs can often be added linearly without much interference
  - Allows easy **tuning of machine** without always matching
- Perform a **first investigation** of how readily IR tuning knobs can be created

Summary of Findings

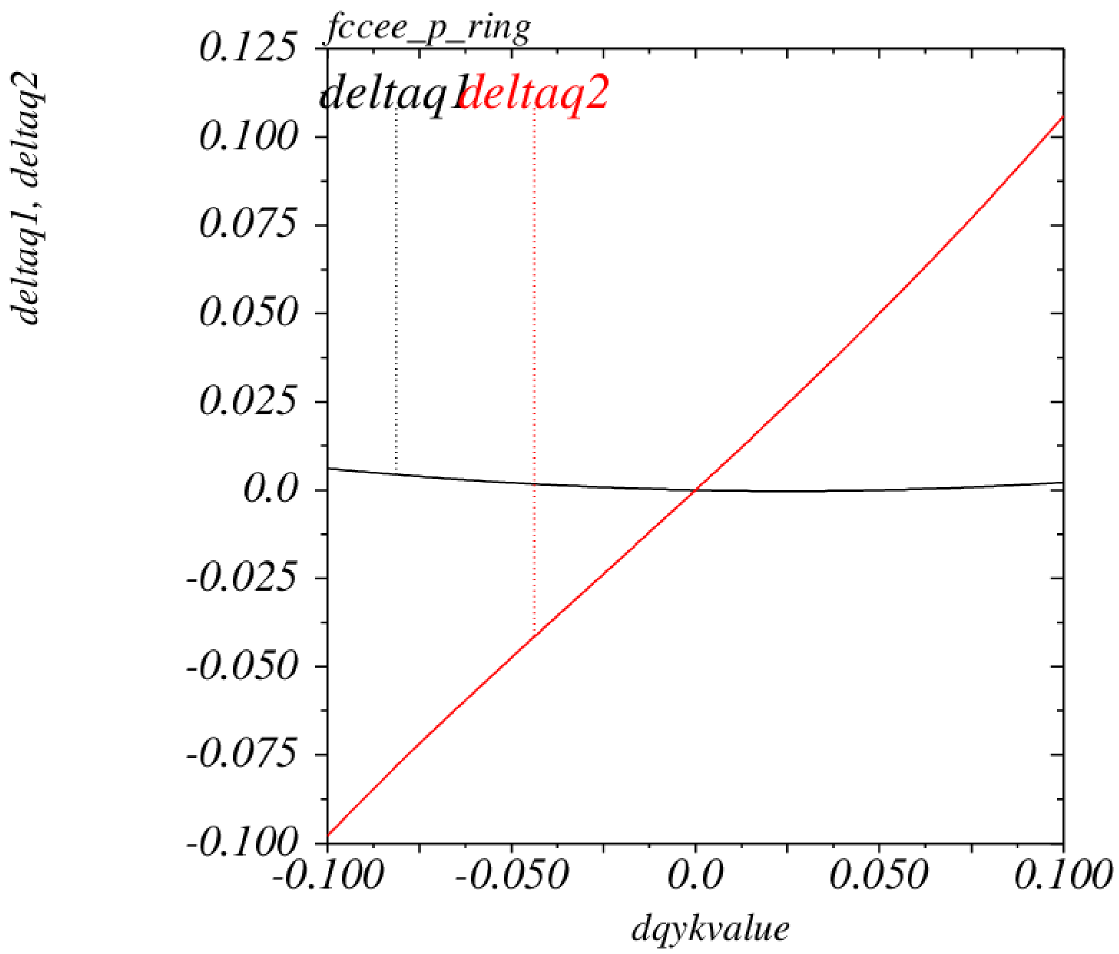
- **Certain parameters** can be varied **very linearly** without distorting other parameters too much
  - **Machine tune** using RF insertion

Change in Tune

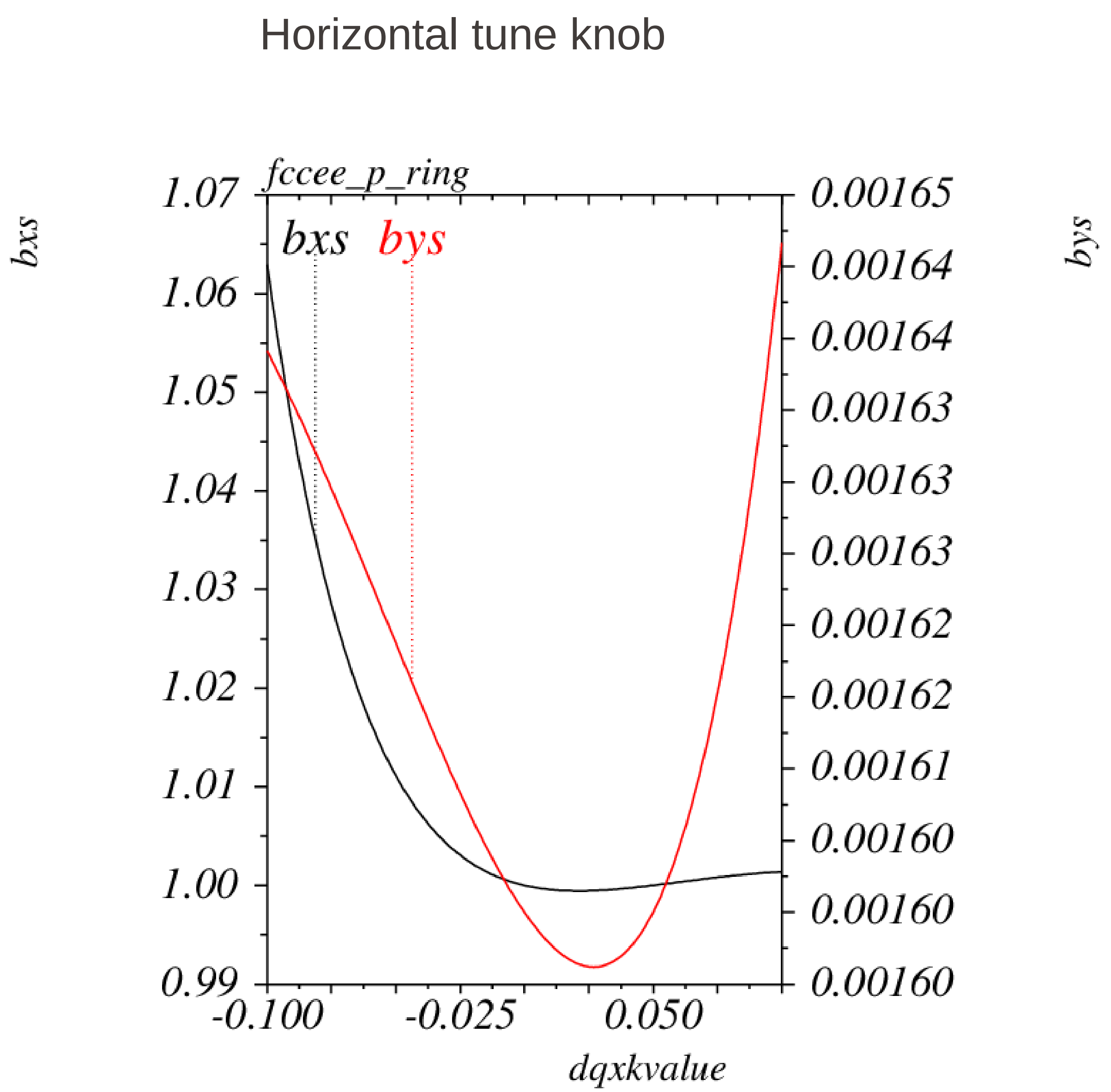
Horizontal tune knob

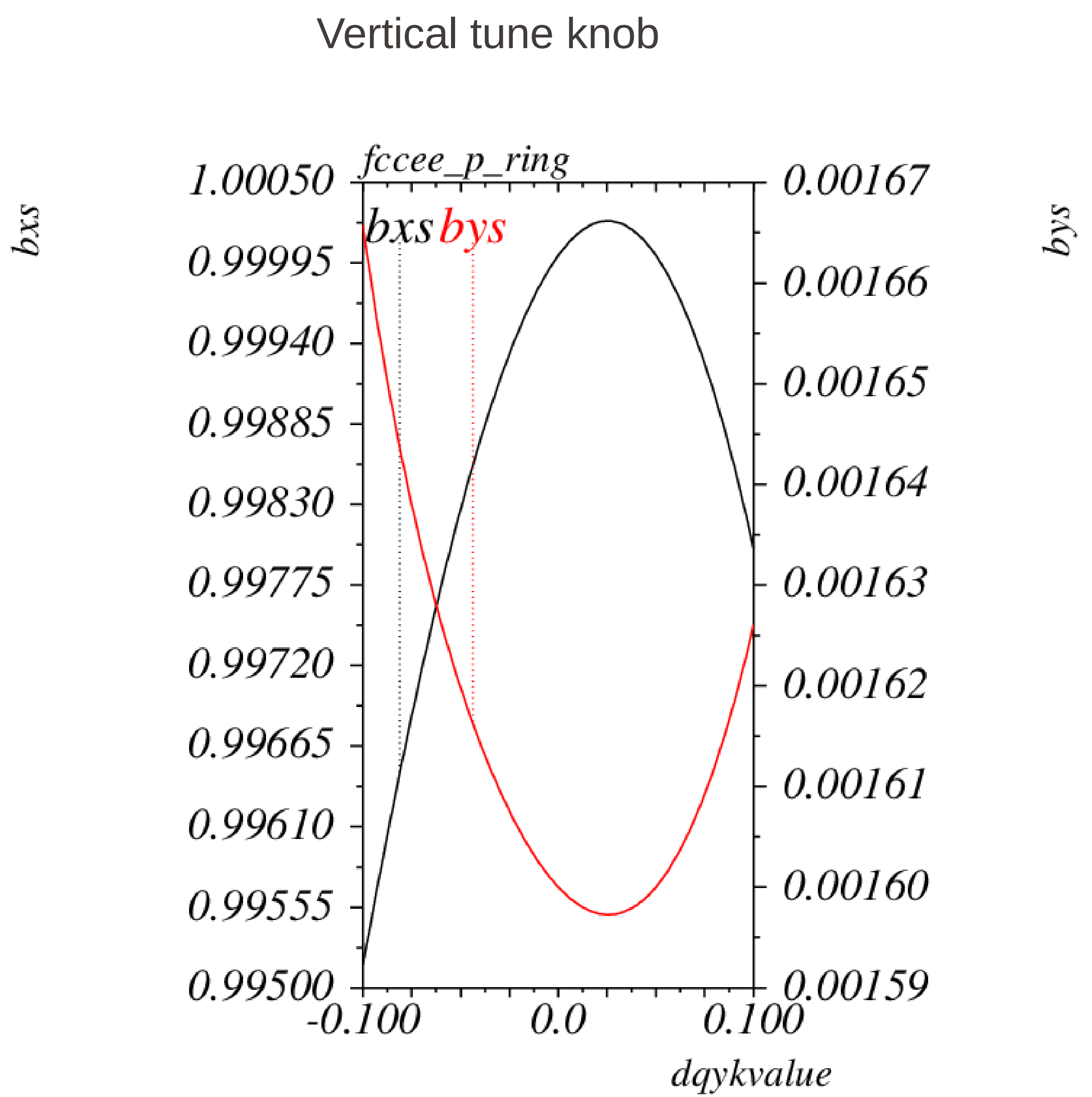


Vertical tune knob



Change in IP β





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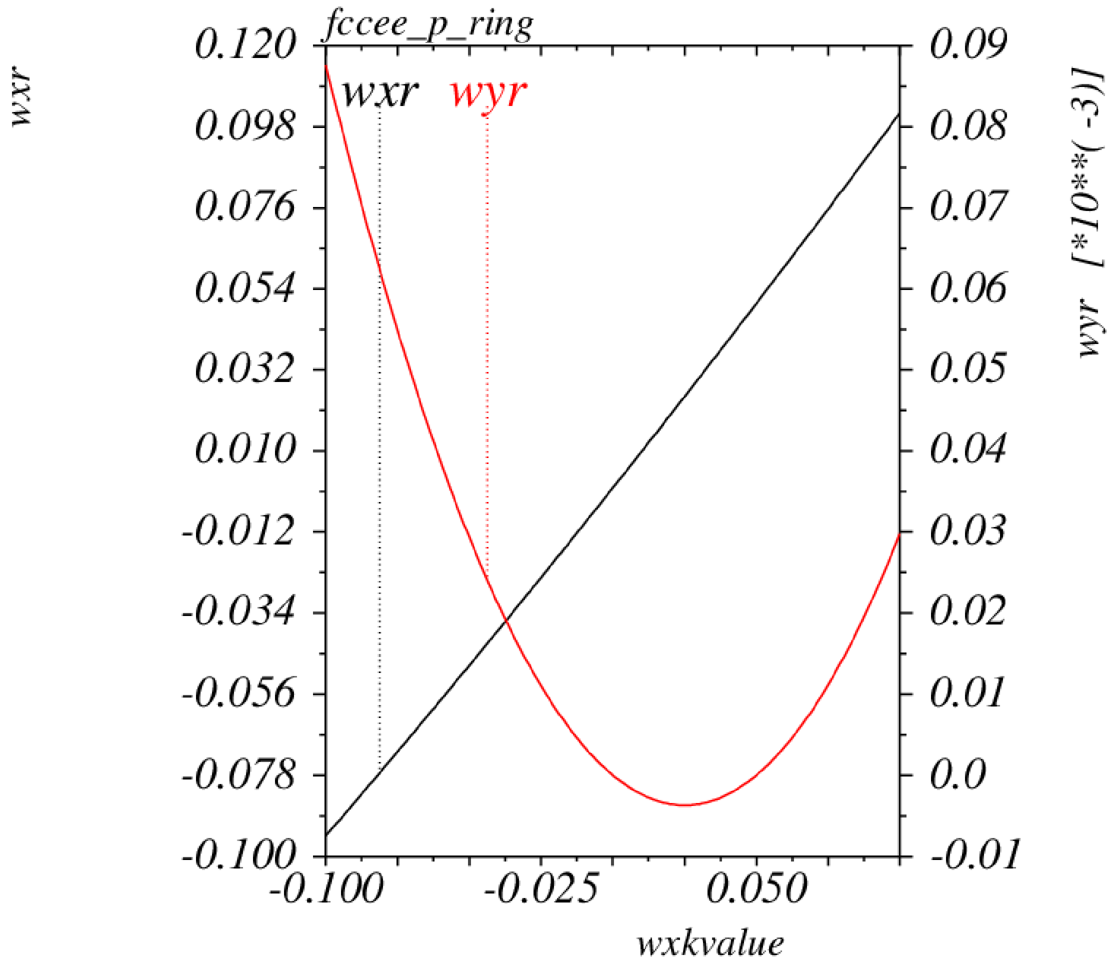
  - **Machine tune** using RF insertion
  - **Horizontal β^* waist** in IP

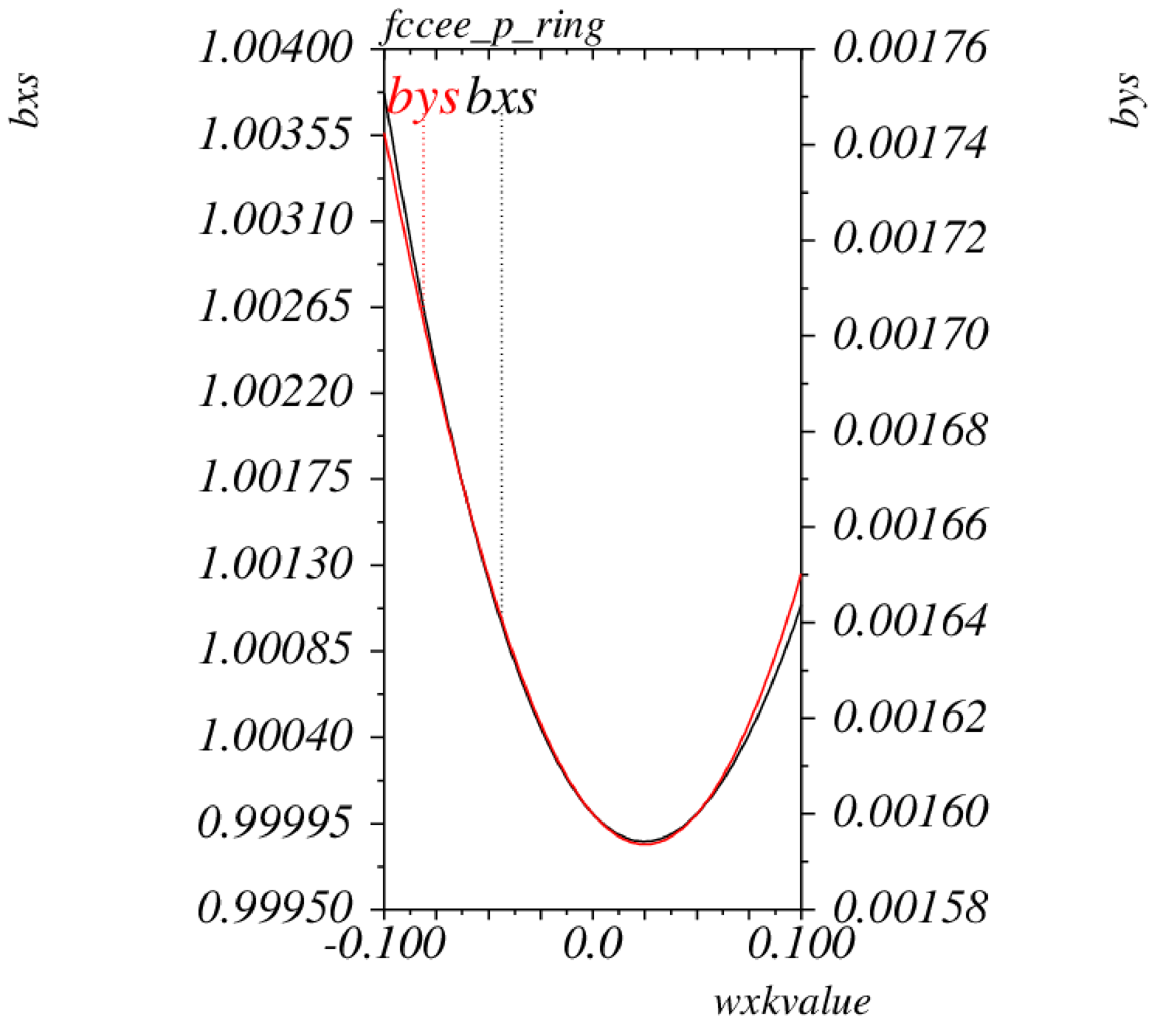
Waist Shift



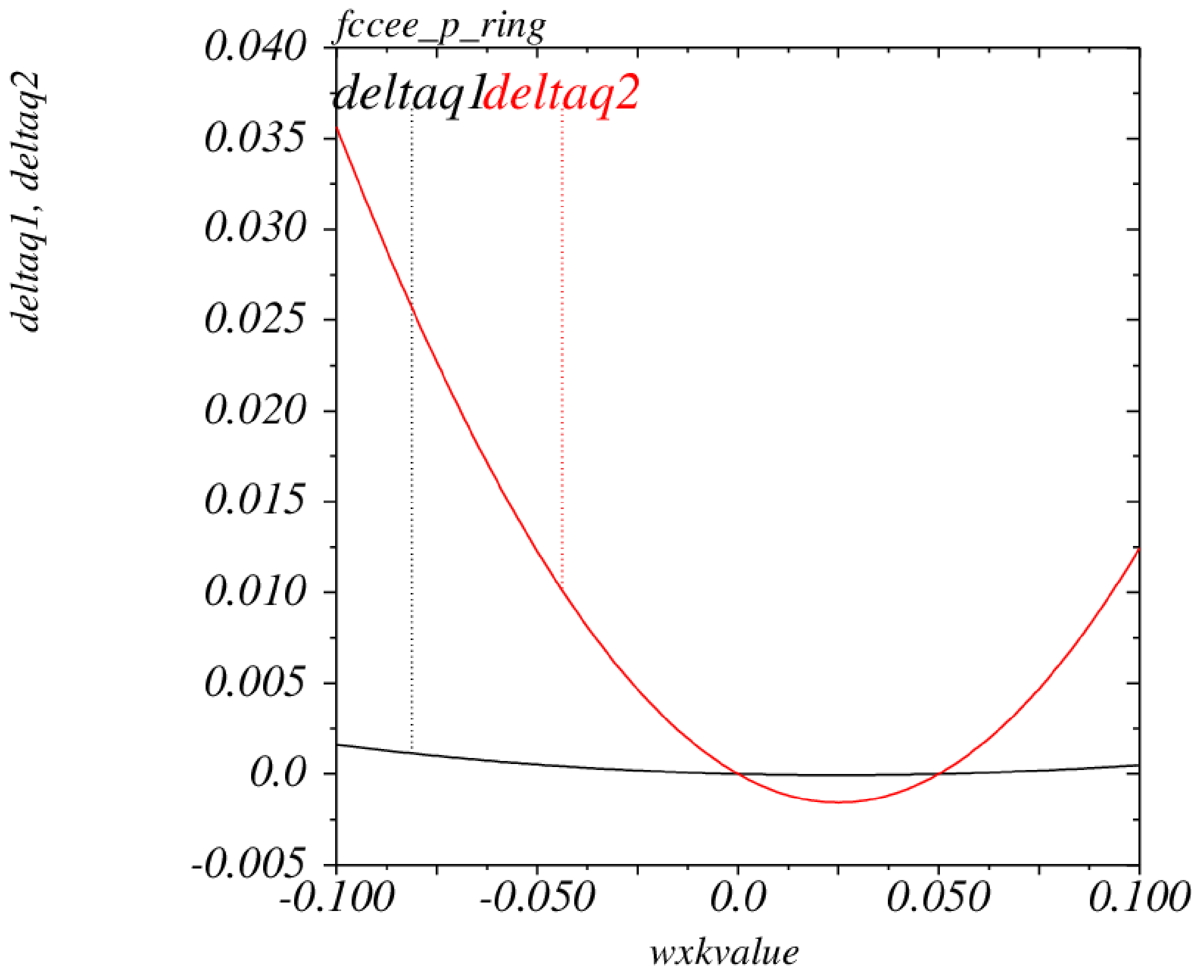
fccee_p_ring
wxr
wyr
0.120
0.098
0.076
0.054
0.032
0.010
-0.012
-0.034
-0.056
-0.078
-0.100
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.0
-0.01
wyr [*10**(-3)]
-0.100
-0.025
0.050
wxkvalue

EPFL

β^* value



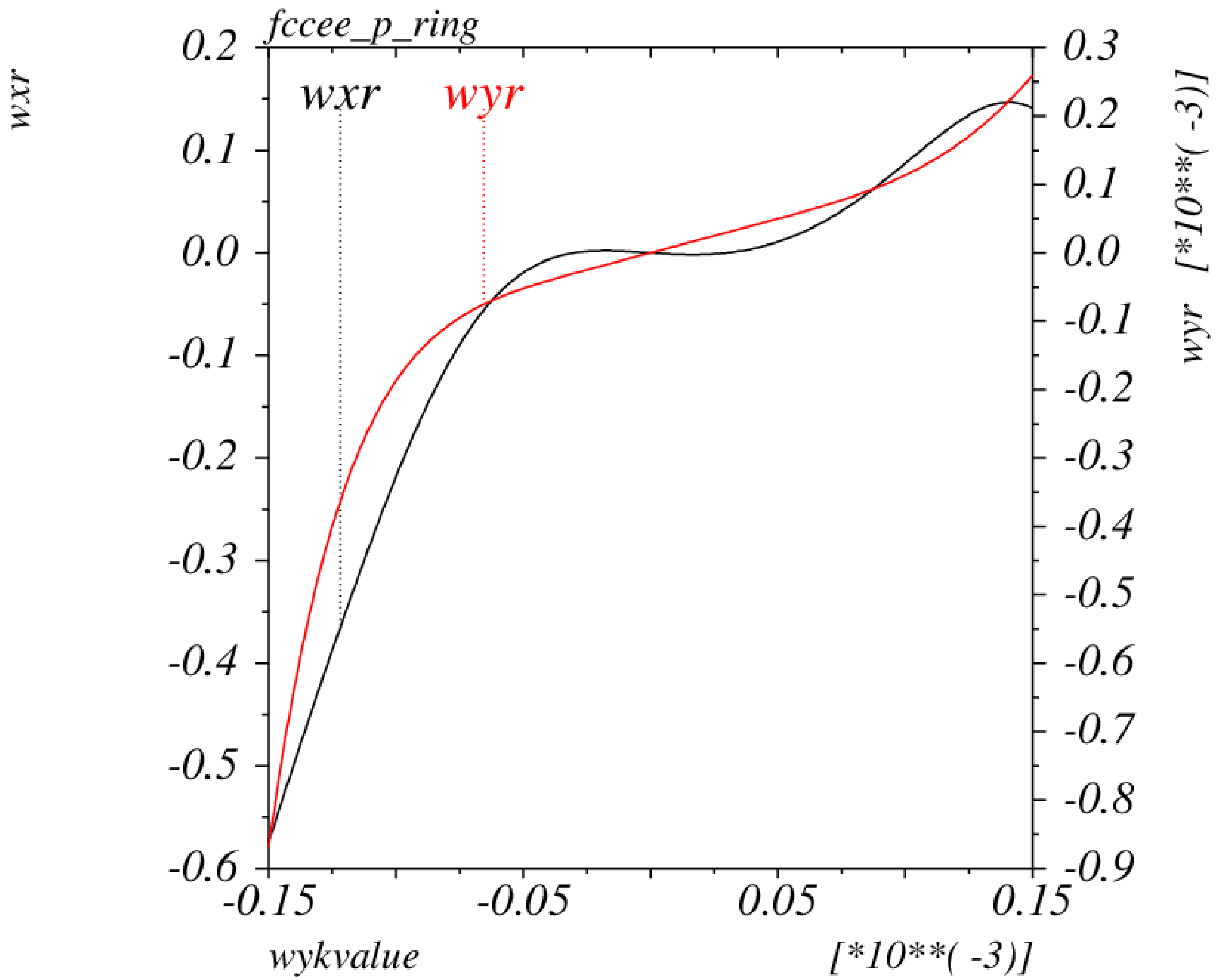
Change in Tune



Summary of Findings

- **Certain parameters** can be varied **very linearly** without distorting other parameters too much
  - **Machine tune** using RF insertion
  - **Horizontal** β**-waist** in IP
- More complex **quadratic knobs** can be defined to reduce unwanted changes in other parameters
  - Might be **harder to implement** in real machine
- Knobs for many other parameters much harder to define
  - Change other parameters more than the desired parameter
  - **Vertical** β**-waist,** $\boldsymbol{\beta}^*$ in both planes…

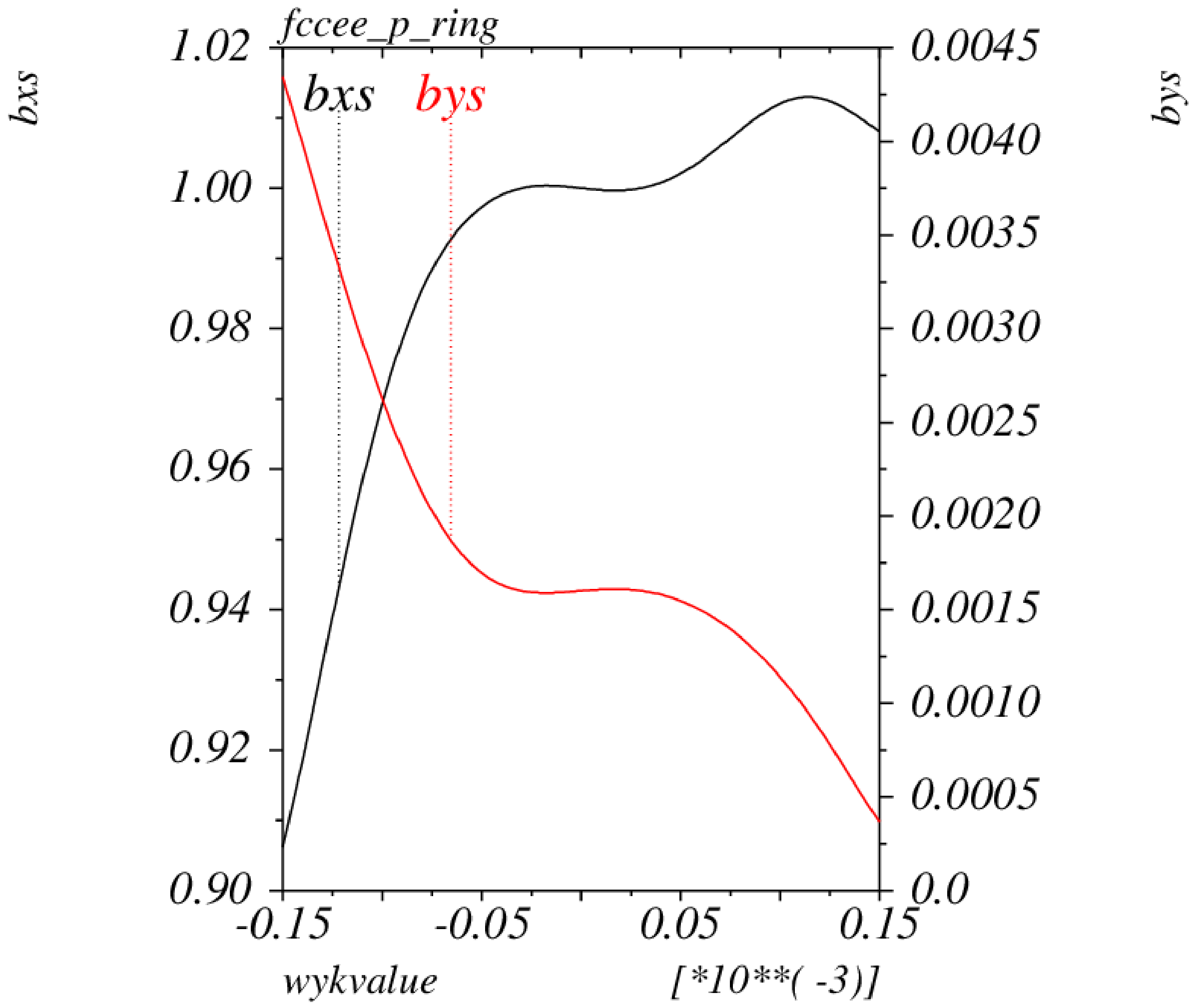
Waist Shift



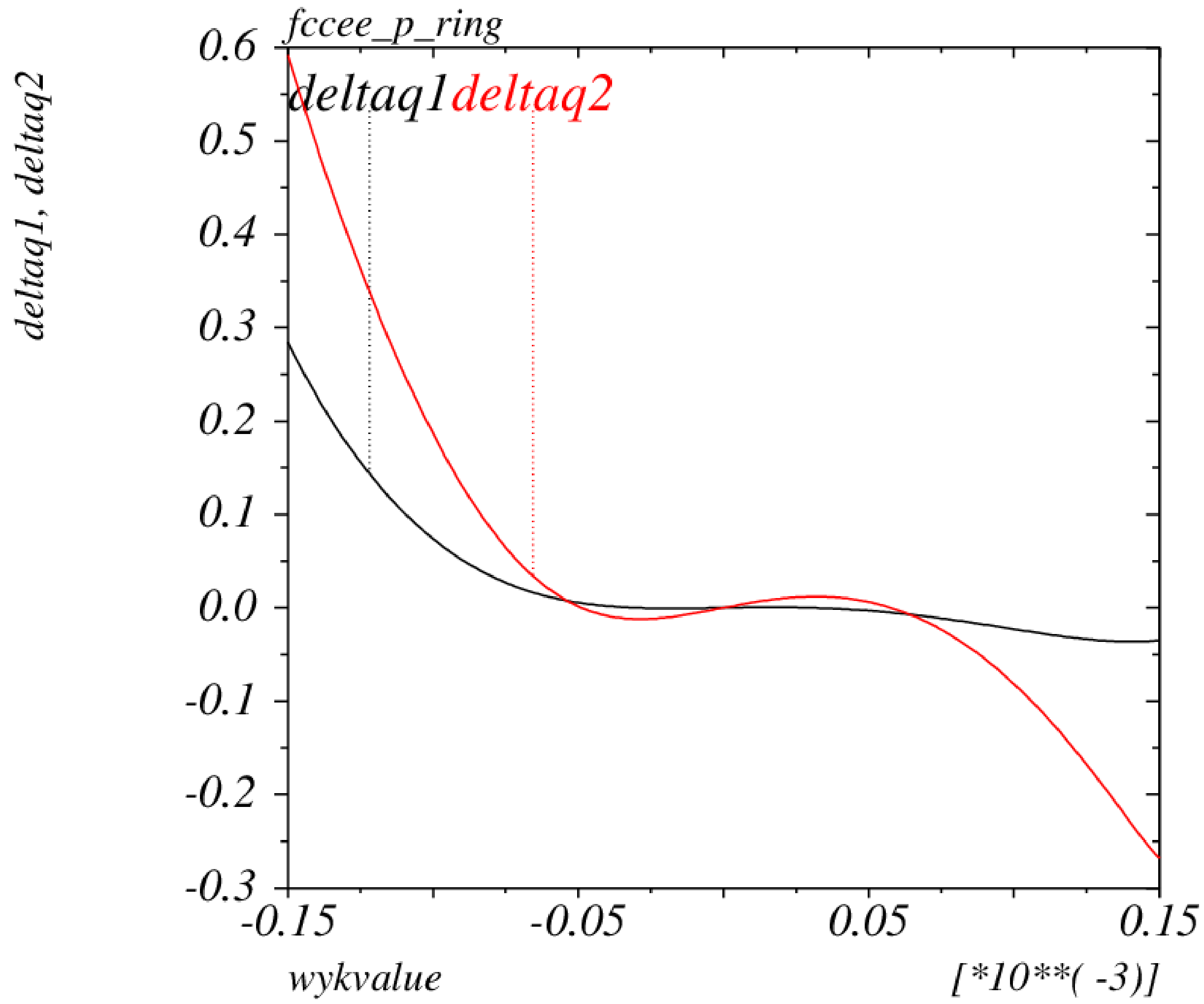
fccee_p_ring
wxr
wyr
0.2
0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
0.3
0.2
0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
-0.7
-0.8
-0.9
[*10**(-3)]
-0.15
-0.05
0.05
0.15
wykvalue
[*10**(-3)]

EPFL

β^* value



Change in Tune



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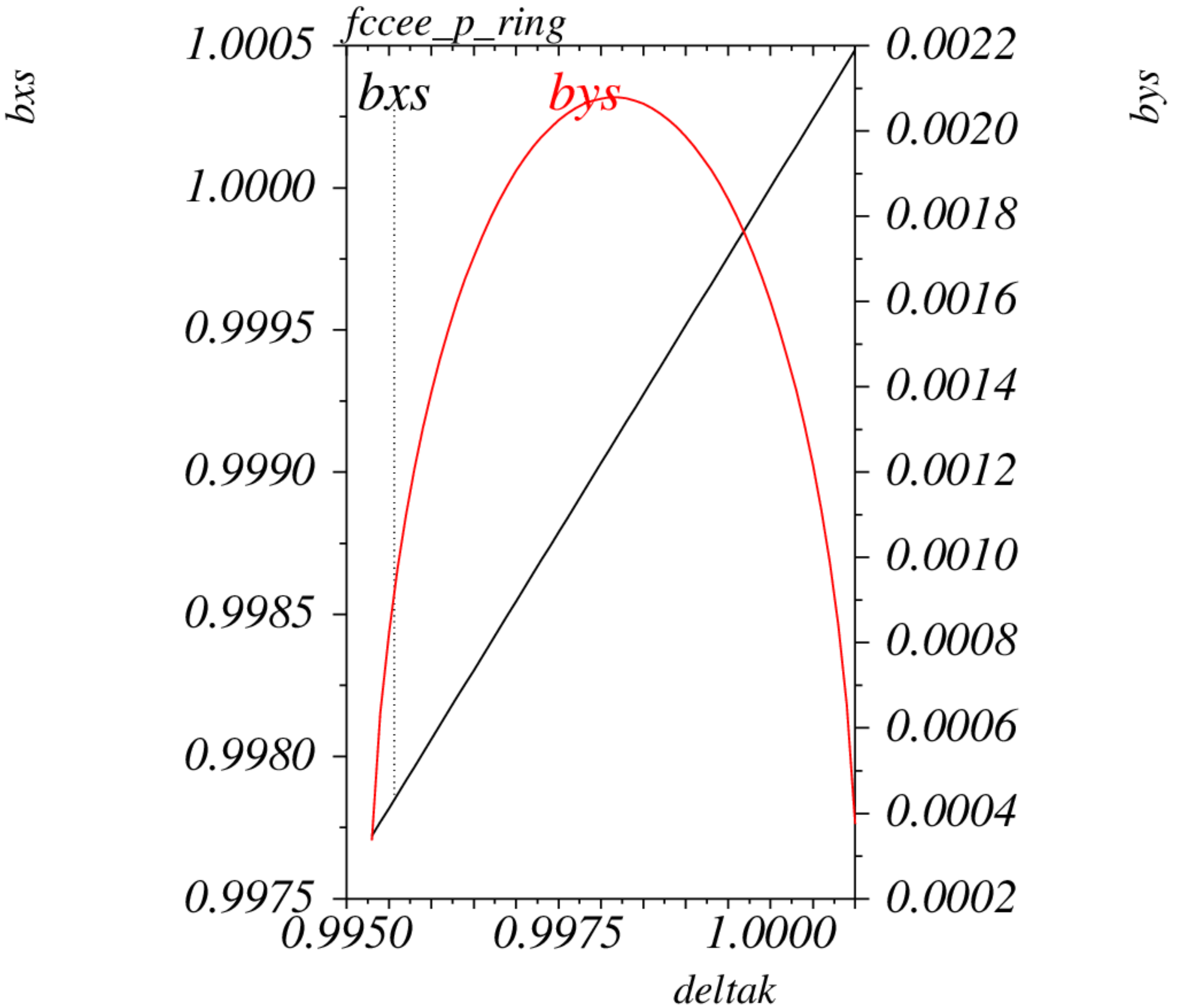
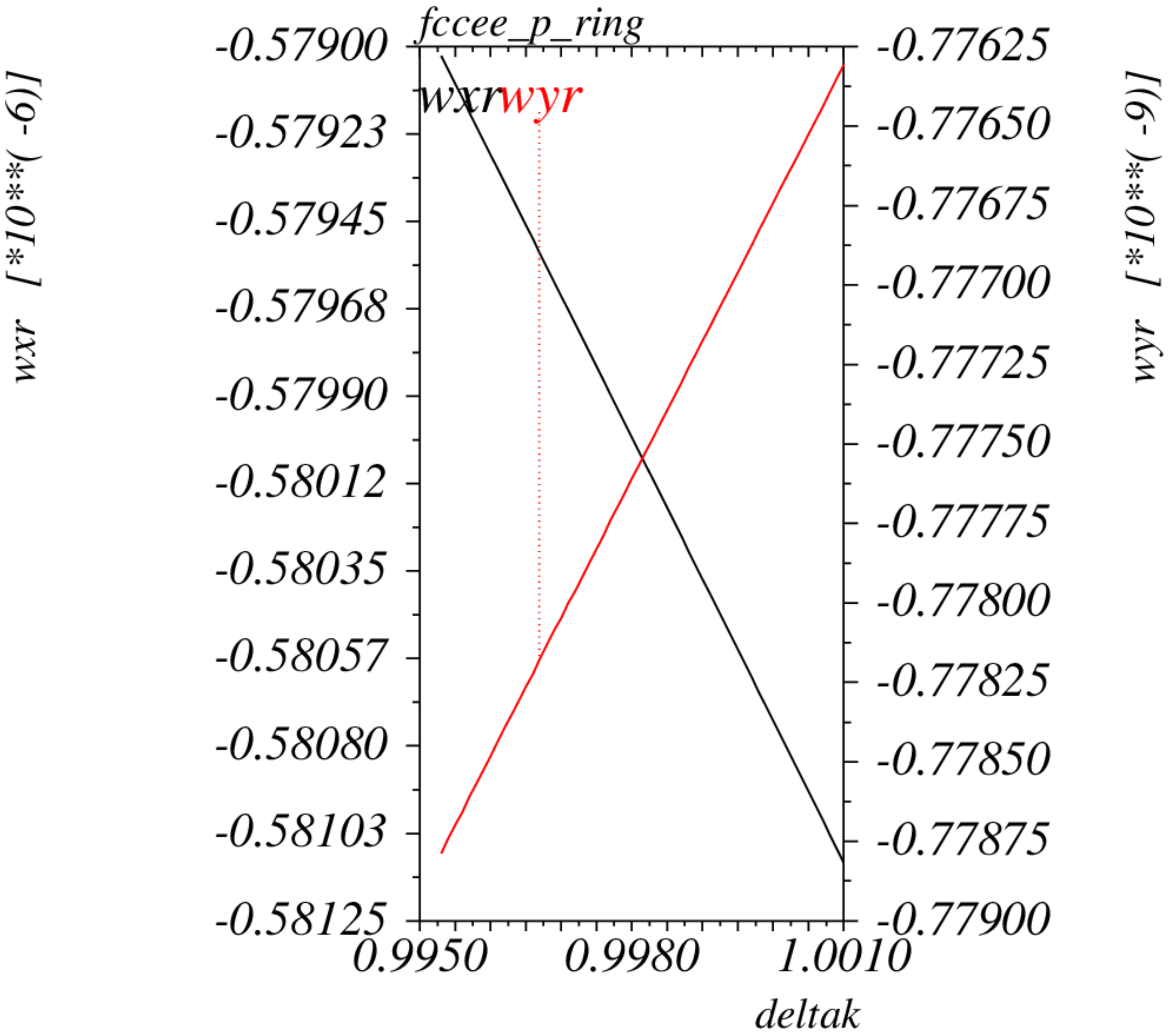
Further Investigation

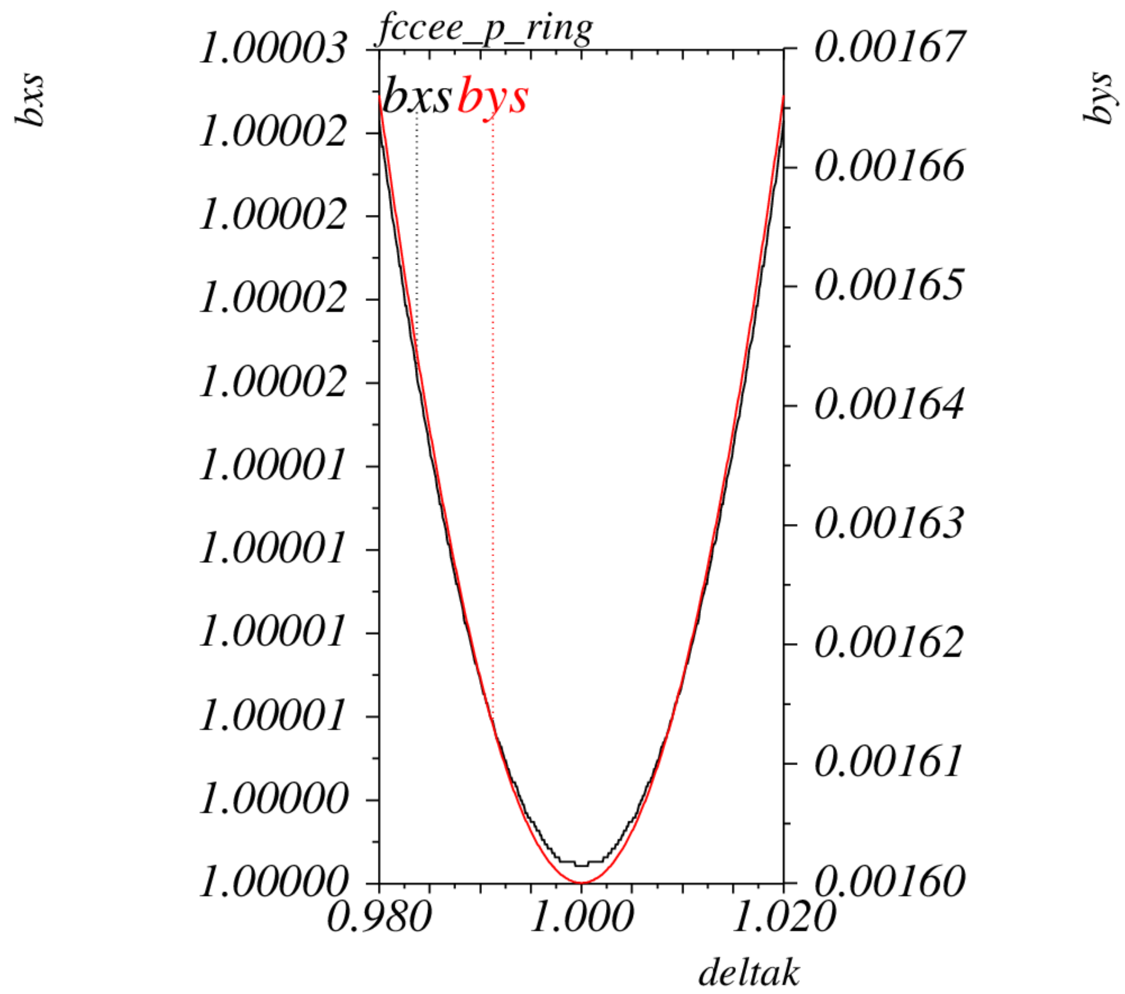
- More investigation required
- Exploit **symmetries in doublet**:
  - **Symmetric** changes to **change $\boldsymbol{\beta}^*$** at (almost) constant waist
  - **Anti-symmetric** changes to **change waist** at (almost) constant β^*

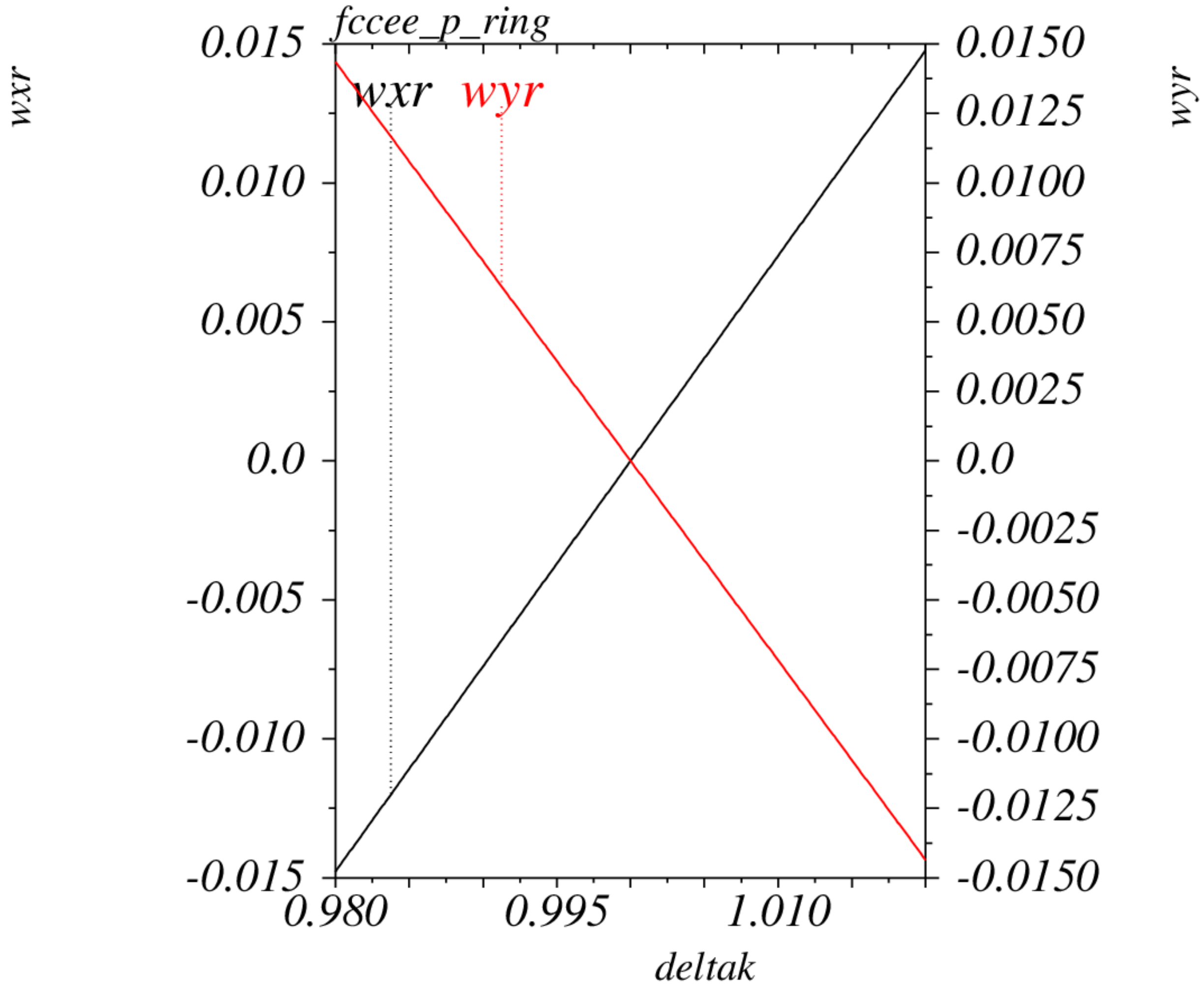
Symmetric Change in First Quadrupole





Anti-symmetric Change in First Quadrupole





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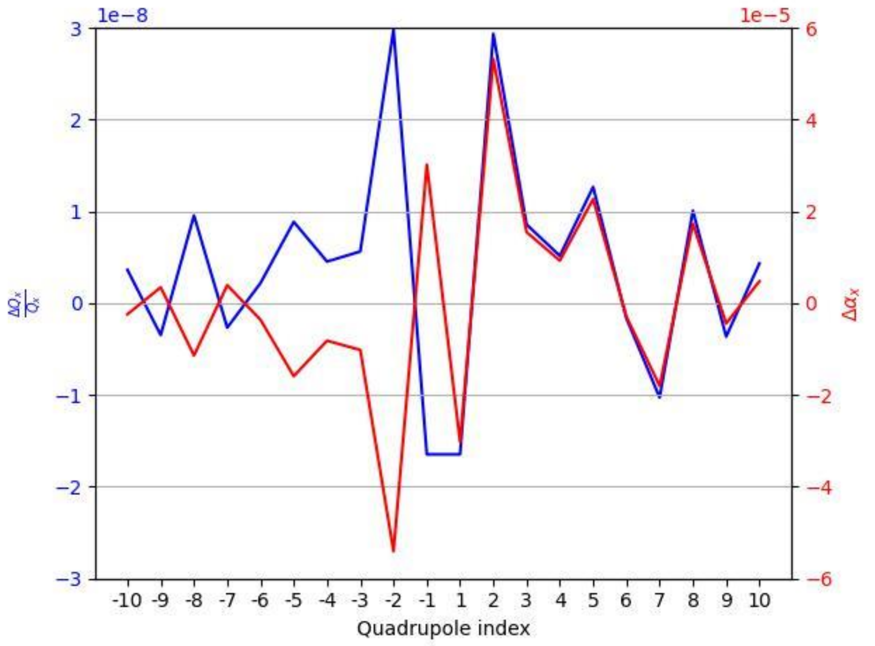
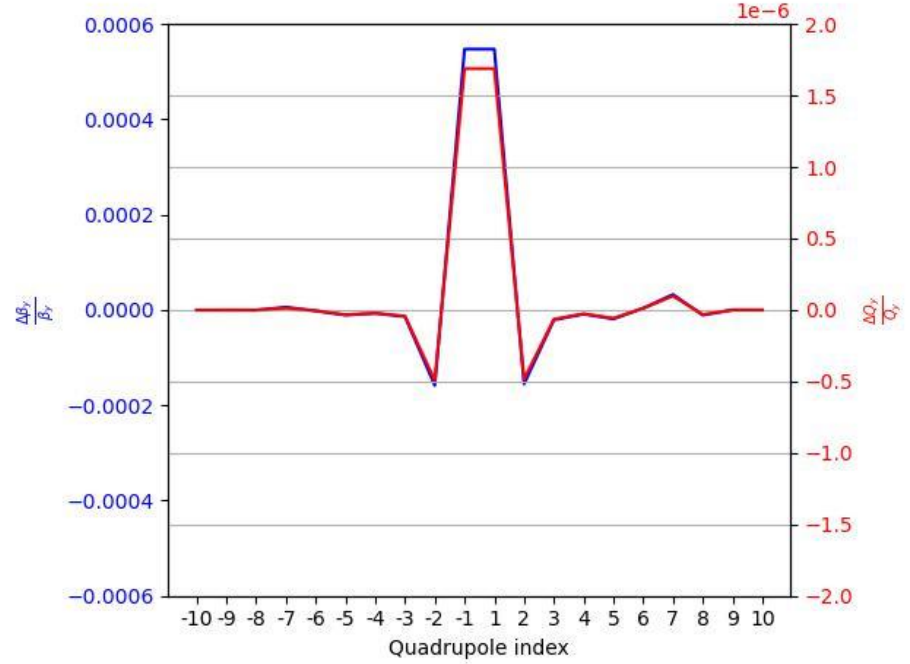
- Exploit **symmetries in doublet**:
  - **Symmetric** changes to **change $\boldsymbol{\beta}^*$** at (almost) constant waist
  - **Anti-symmetric** changes to **change waist** at (almost) constant β^*
- Systematic Δk scans to understand
  - **Interdependencies** of parameters
  - **Linearity** in response to simultaneous changes in multiple quadrupoles

Interdependencies of Parameters (G. Doat)

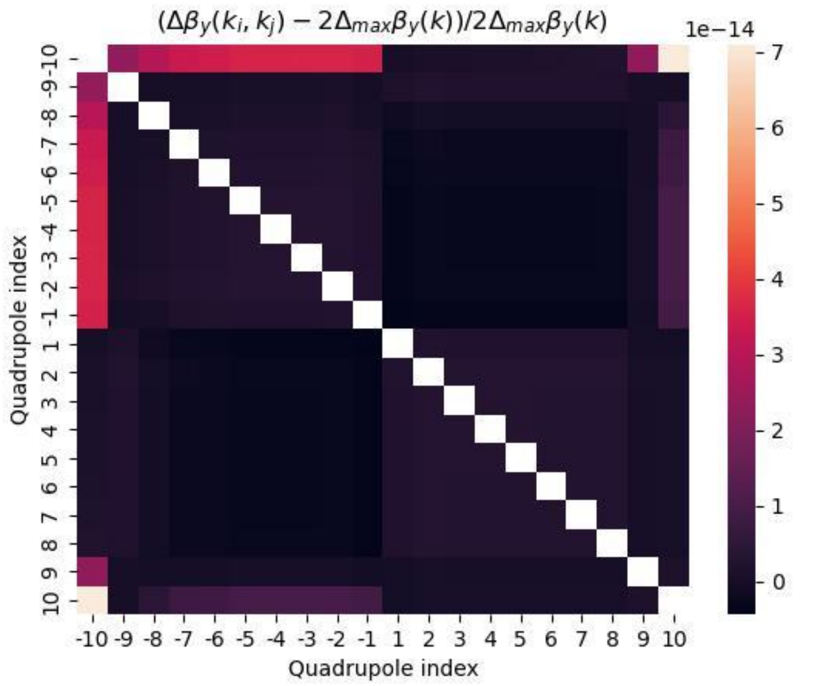
- Change Δk of first 10 quadrupoles either side of the interaction point and observe change in optics parameters
  - Some parameters very decoupled e.g. tune and α^* (waist shift)
    - Can create knobs that change one but not the other
  - Others strongly coupled e.g. tune and β^*
    - No independent knobs possible
- Bare dependencies in mind when creating knobs
  - No convergence when matching and expect no linearity
  - Need to recover change elsewhere

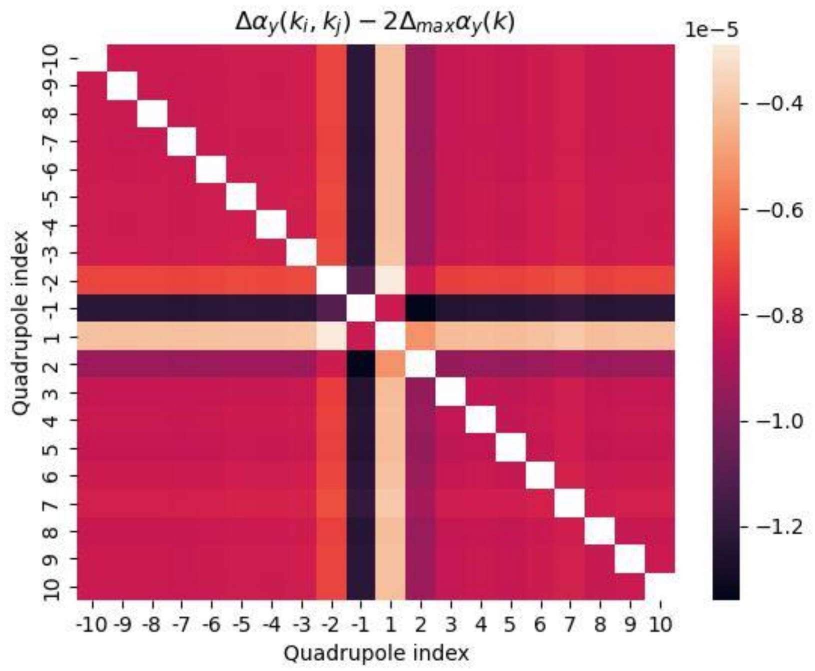




Linearity in Response (G. Doat)

- Understand how linearly perturbations add
  - Compute optics due to perturbations of individual quadrupoles
  - Compute optics due to perturbations of pairs of quadrupoles
  - Compare difference for all quadrupole pairs
- Allows to identify which magnet combinations might be more non-linear and less good for knob creation





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- Systematic Δk scans to understand
  - **Interdependencies** of parameters
  - **Linearity** in response to simultaneous changes in multiple quadrupoles
- Overall leads to more systematic choices of quadrupoles and constraints for knobs
  - Helpful approach to create knobs for this very complex IR

Conclusions

- Optics correction scripts created for local optics corrections
  - Including IR optics matching
  - Work well for ideal lattices
    - Useful after slicing
  - Should be repurposed for realistic corrections
    - First iteration of use case and feedback
- Tuning knobs as possible solution for easy corrections
  - Few knobs readily matched
  - Many parameters very touchy
  - Detailed study underway
    - Understand limitations of knobs
    - Help construct effective knobs