

IP Tuning



- 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...

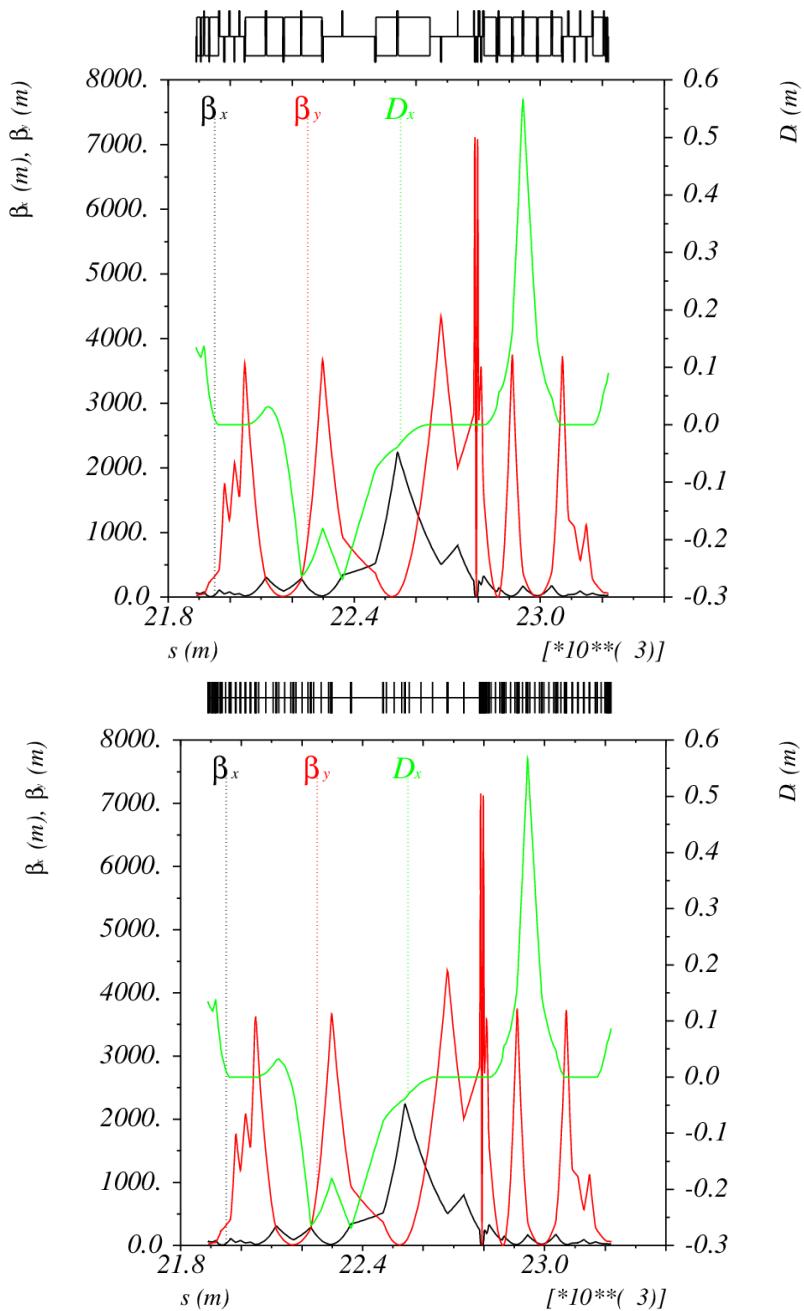
Segment-by-segment

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

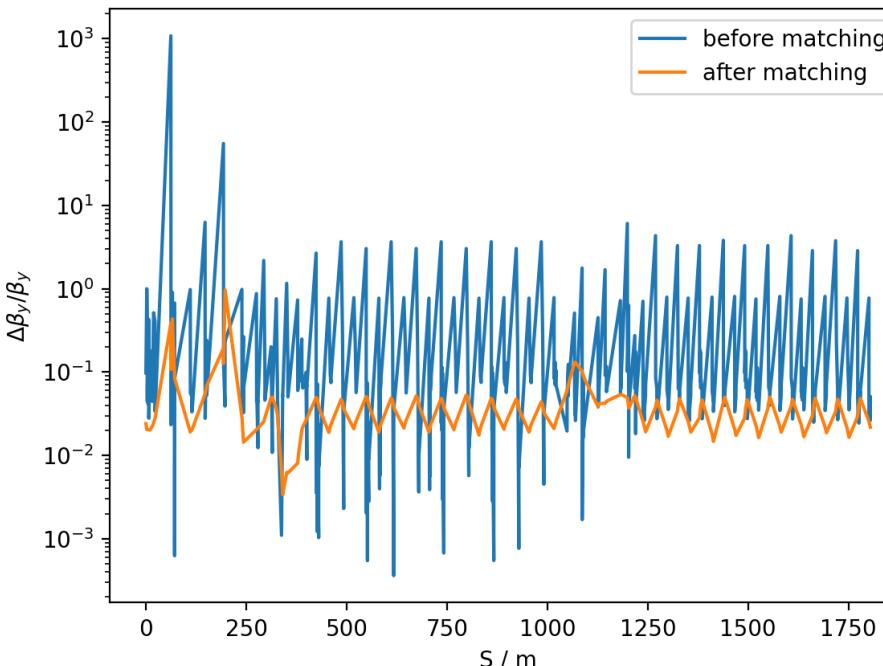
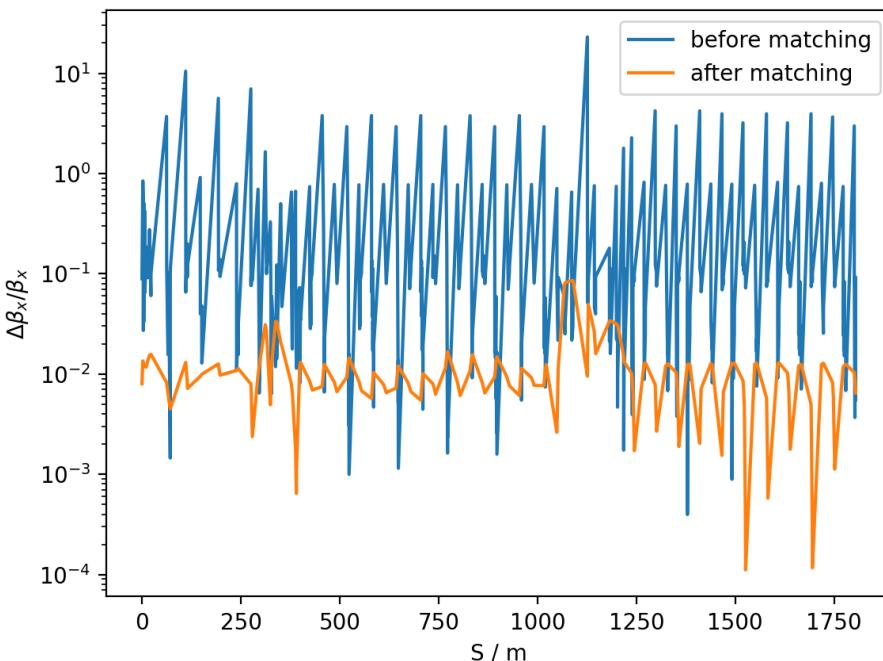
- Scripts for this written in **MADX**
- Tested for systematically and randomly **perturbed optics**
 - **Recover design strengths** and optics
- Applied to recover optics after **slicing** of lattice
 - Aim to be able to **reduce number** of slices to speed up simulations
 - Correct optics even with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

- Often **linear changes** in multiple **quadrupole strengths proportional** to the target value of a parameter
 - $\Delta k = k_{knob} \times \Delta \text{parameter}$
- 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
- Tested on CDR lattice
 - **Z Lattice** (lowest β^*)
 - Applicable to other lattices

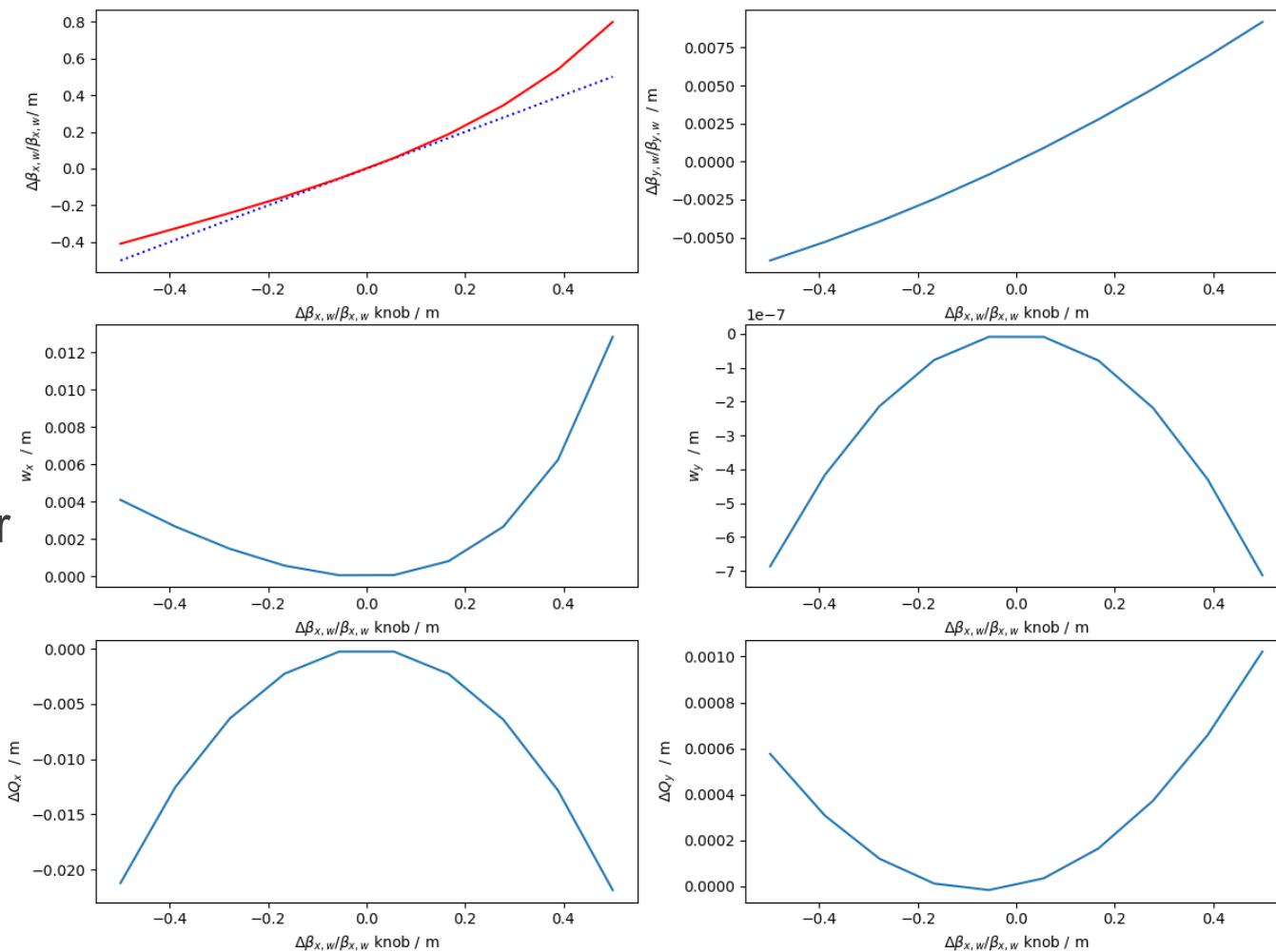
Knobs from Fitting

- 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, β_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

- 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**, M
 - **Change setting** of individual magnets, k_i
 - **Monitor changes** in observables o_j
 - $$o_j = M_{ji} k_i \approx \frac{\partial o_j}{\partial k_i} k_i$$
- Construct **pseudo inverse** of M using SVD decomposition
 - $M = USV^T$
 - Pseudoinverse $M^{-1} = VS^{-1}U^T$
 - Can be used to find the **correct setting** k_i for a **desired Δo**
 - Can **suppress small singular** values to avoid linear codependency

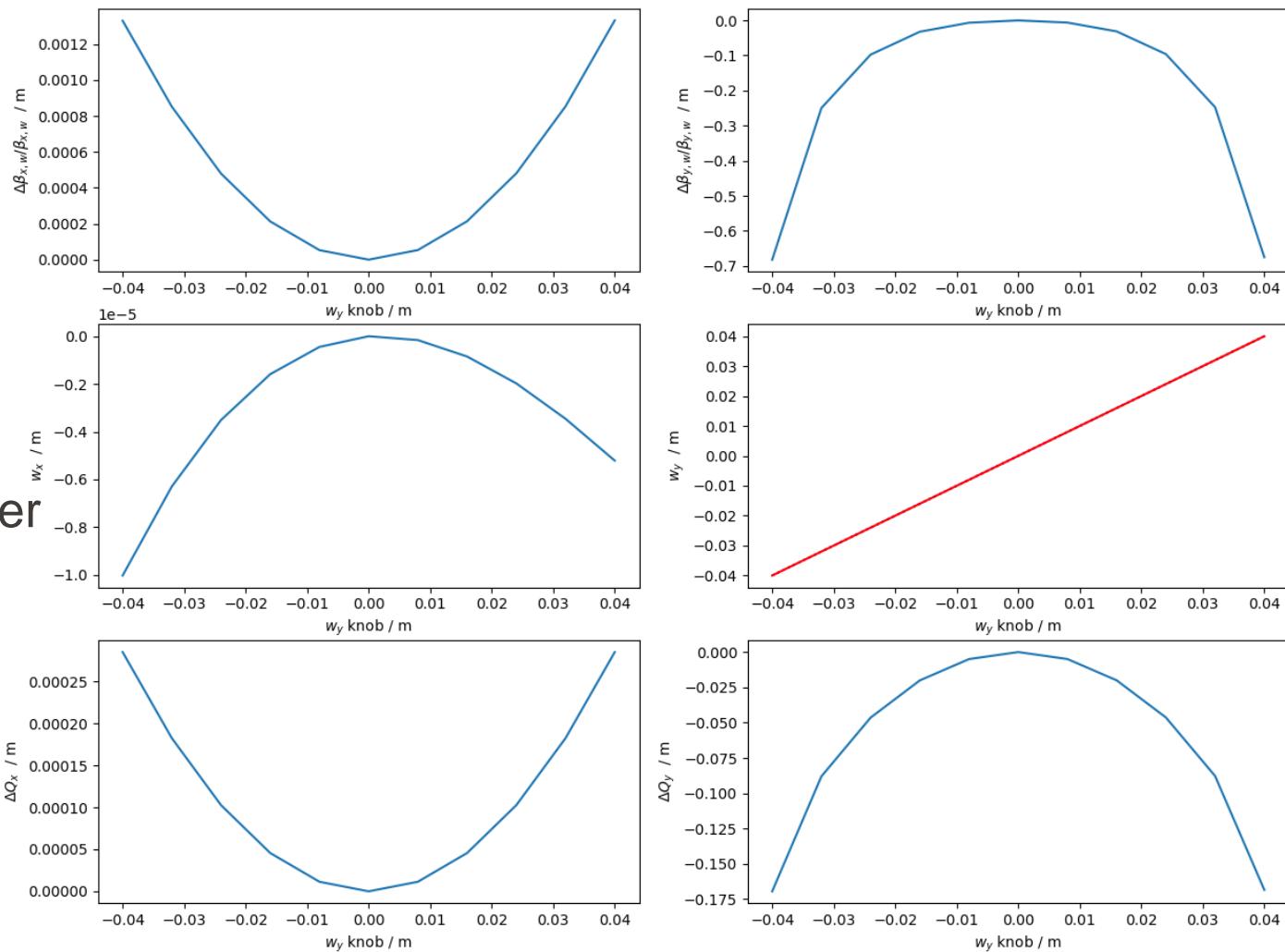
Knobs via SVD

- **Effective** for creating knobs where linear fitting fails
 - β_w control
 - Still not very linear but better than fit
 - Vertical β waist shift
- Seems to be **more effective** than linear fit
- Aberrations are **quadratic**



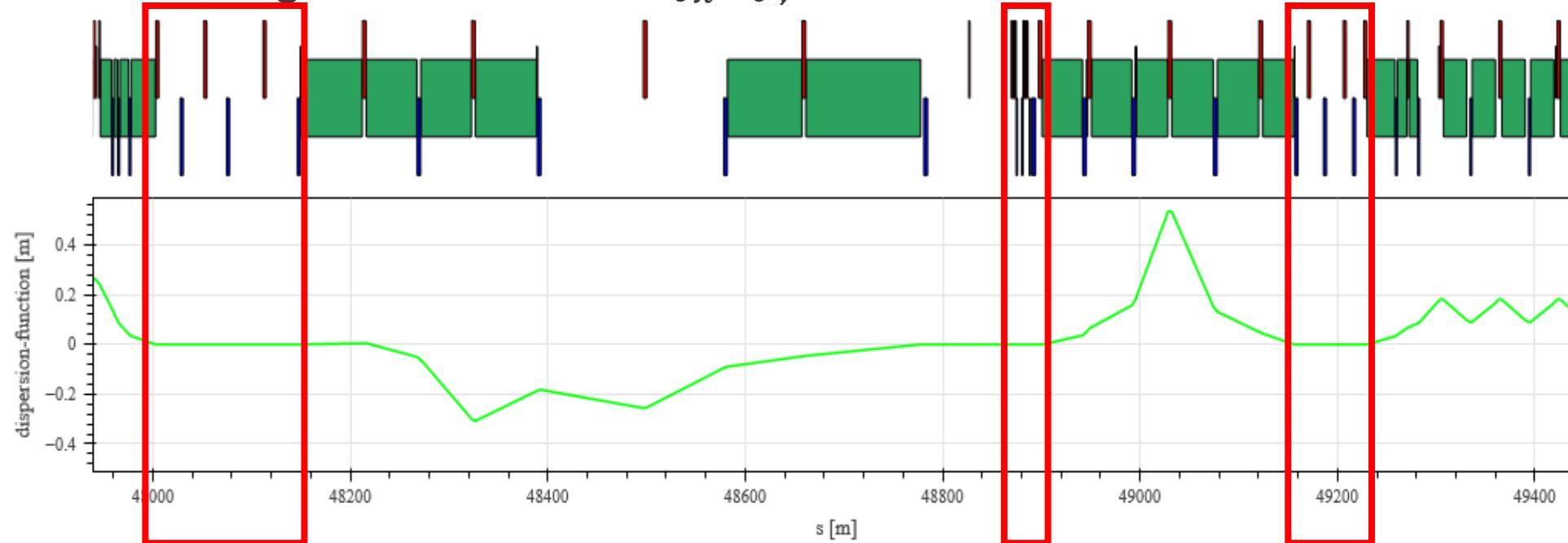
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IP Beta Knobs

- Using Doublet magnets (QC[1,2]) and matching section (Q[A,B][1-6])
 - Dispersion free region
 - Intrinsically no dispersion beating
- Knobs for
 - Waist position, w (in m)
 - β at waist, β_w (measured as % from nominal)
- Constraining machine tune, Q_x, Q_y



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Knob	Range	Perturbation over Range (Quadratic)					
		$\Delta\beta_{w,x}/\beta_{w,x}$	$\Delta\beta_{w,y}/\beta_{w,y}$	w_x	w_y	ΔQ_x	ΔQ_y
$\Delta\beta_{w,x}/\beta_{w,x}$	40 %	-	< 1 %	~12 mm	< 1 μ m	~0.02	~0.001
$\Delta\beta_{w,y}/\beta_{w,y}$	20 %	< 1 %	-	< 100 μ m	< 100 μ m	~0.0004	~0.03
w_x	40 cm	~30 %	~2 %	-	~10 μ m	~0.04	~0.03
w_y	3 cm	<0.1%	~30%	< 100 μ m	-	~0.0002	~0.1

Horizontal/Vertical Dispersion Knobs

▪ Horizontal dispersion

- Using all quadrupoles in IR
 - **Doublet** magnets (QC[1,2]) and **matching section** (Q[A,B][1-6])
 - Include quadrupoles in **dispersive region** (QCL*[3-6]) and **dispersion suppressor** (Q[L,S][1-4])
- **Constrain** w , β_w , Q , $\frac{\partial Q}{\partial \delta p}$
- **Results:**
 - Dispersion $D_x \approx \pm 2 \text{ mm}$
 - Rate of change of dispersion $D_{px} \approx \pm 0.01$

▪ Vertical dispersion

- Include **skew trims** on these magnets
- **Constrain** w , β_w , Q , $\frac{\partial Q}{\partial \delta p}$, D_x , D_{px} ΔQ_{min}
- **Results:**
 - Dispersion $D_y \approx \pm 0.6 \text{ mm}$
 - Rate of change of dispersion $D_{py} \approx \pm 0.1$

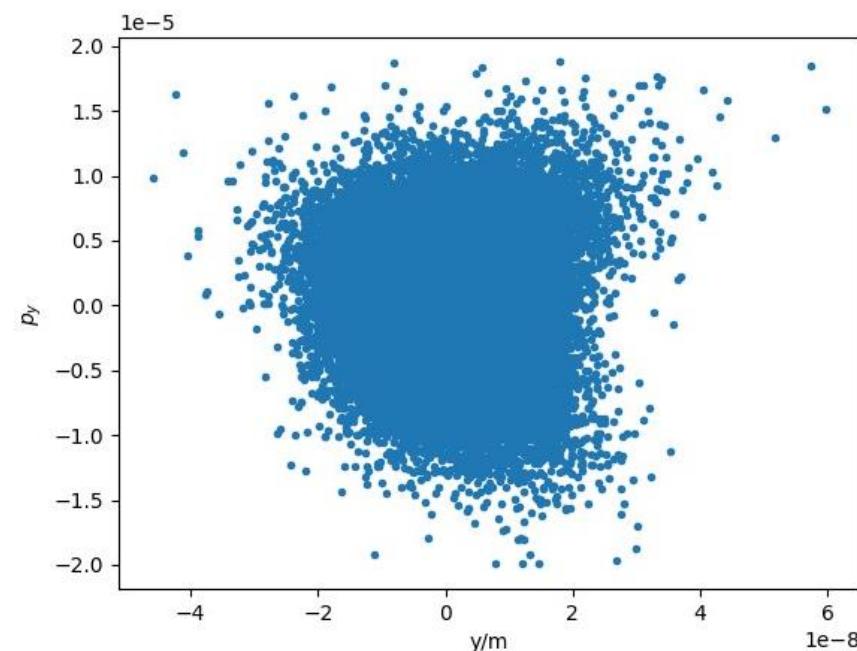
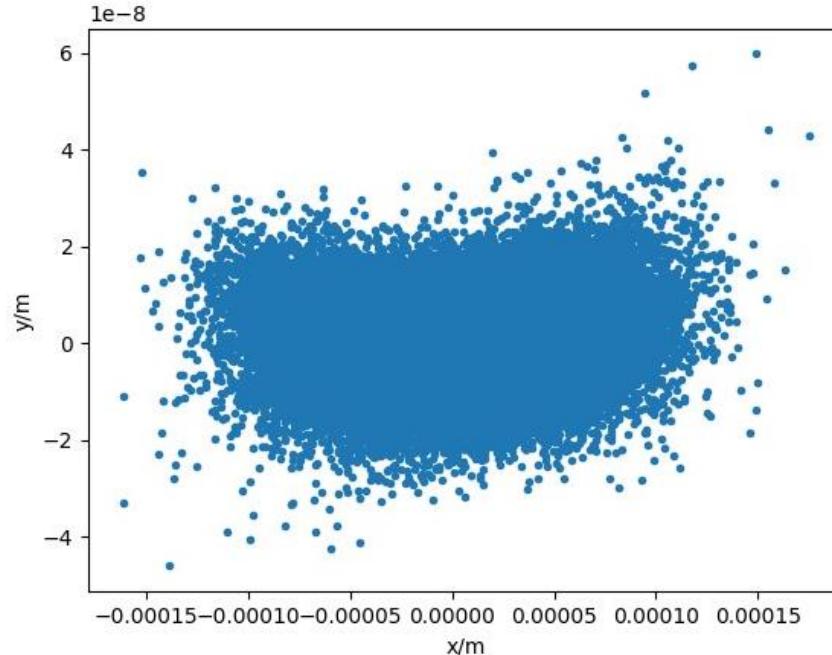
Extending Knobs

- SVD easily **extendable**
 - Further **observables**
 - Further **variables**
- Allows for extension of method to create knobs to control further parameters (at the IP)
 - Whilst keeping more observables constant
- Need to identify
 - **Which magnets** and perturbations to probe
 - **Which observables** to measure
- Allows to gain **insights** in the behaviour of the machine
 - Also useful for **alignment tolerances**

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

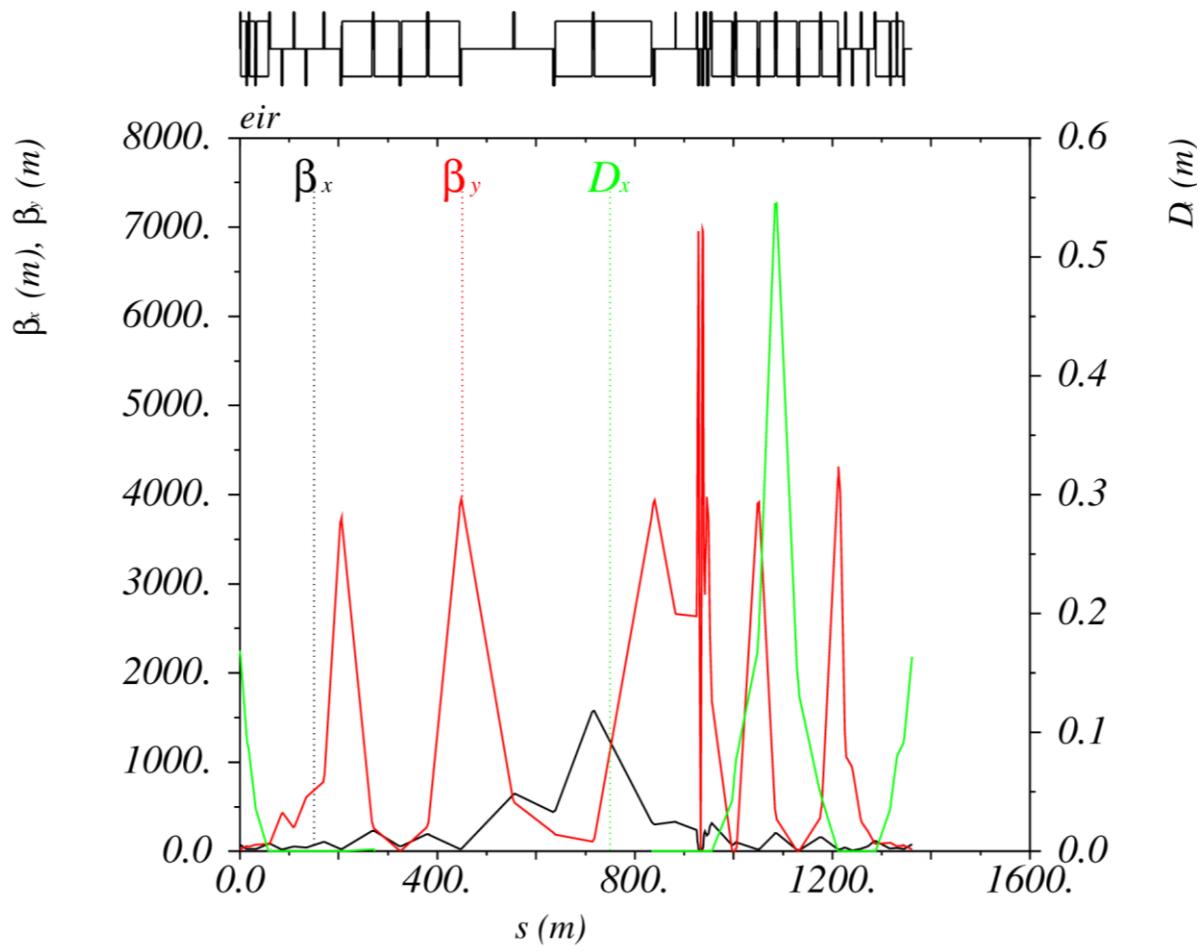


Equilibrium beam shape at IP from tracking with skew errors.

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 β 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**



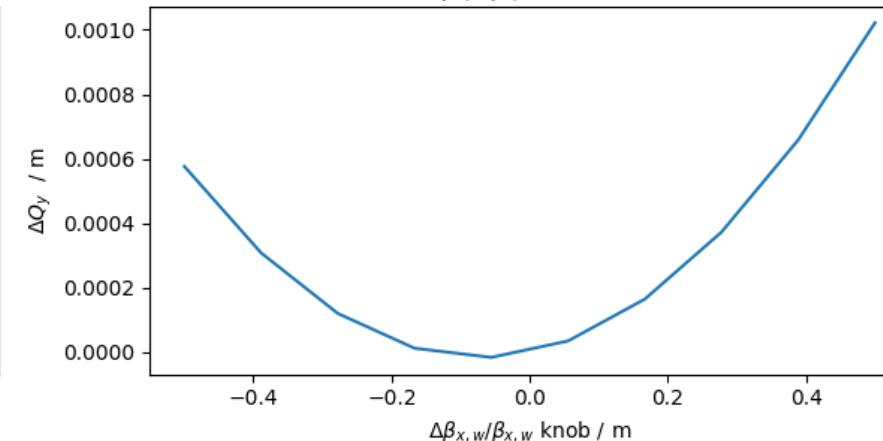
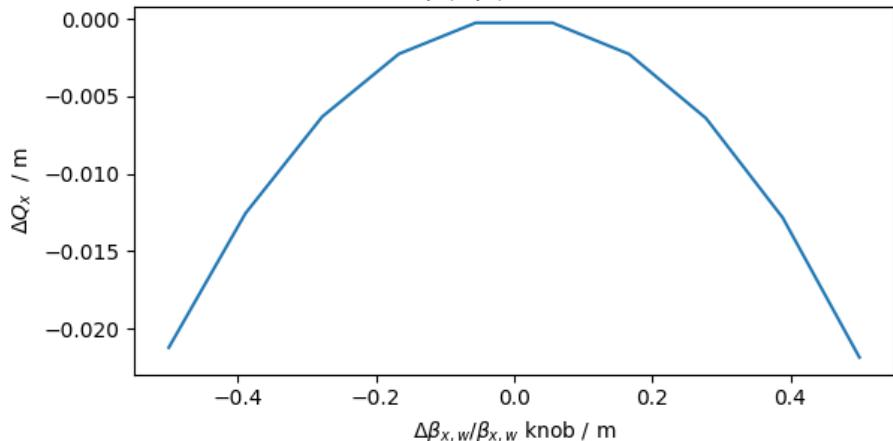
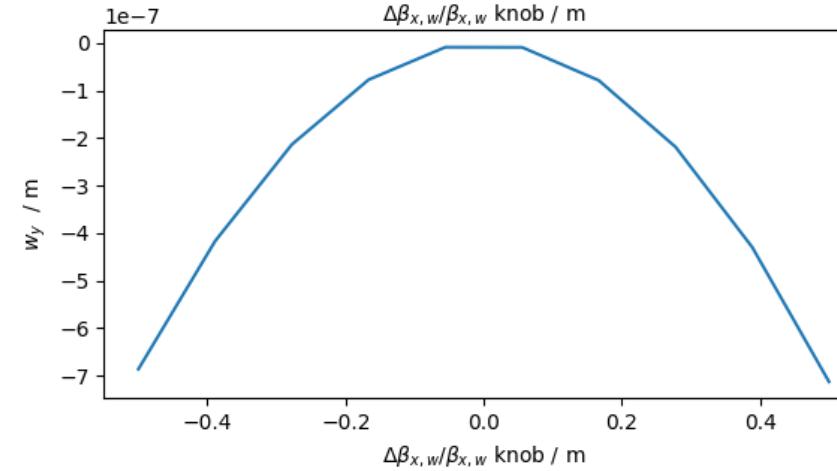
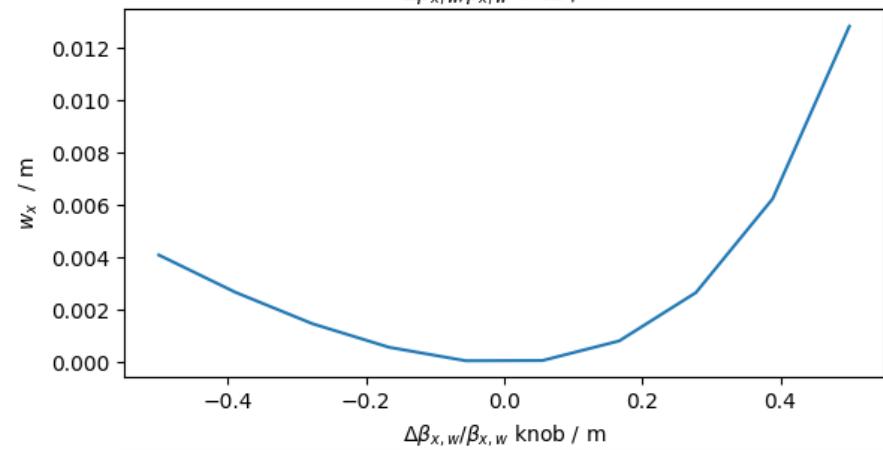
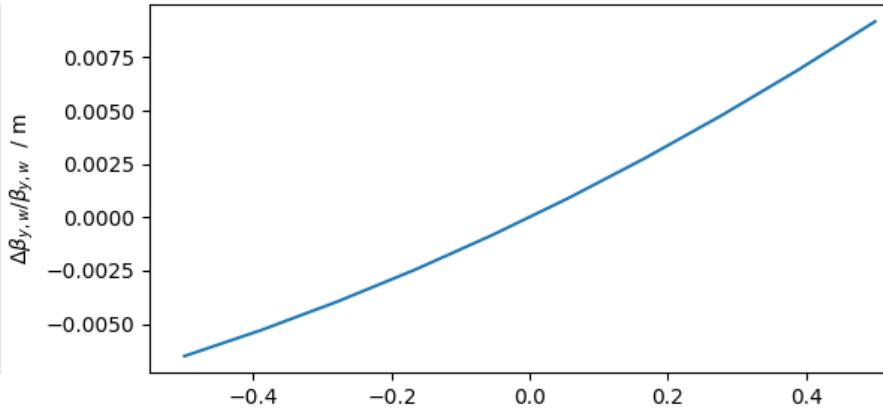
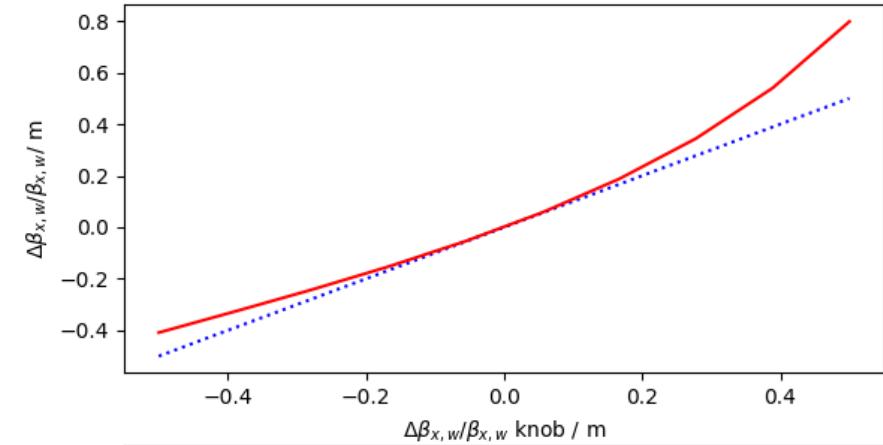
Conclusion and Outlook

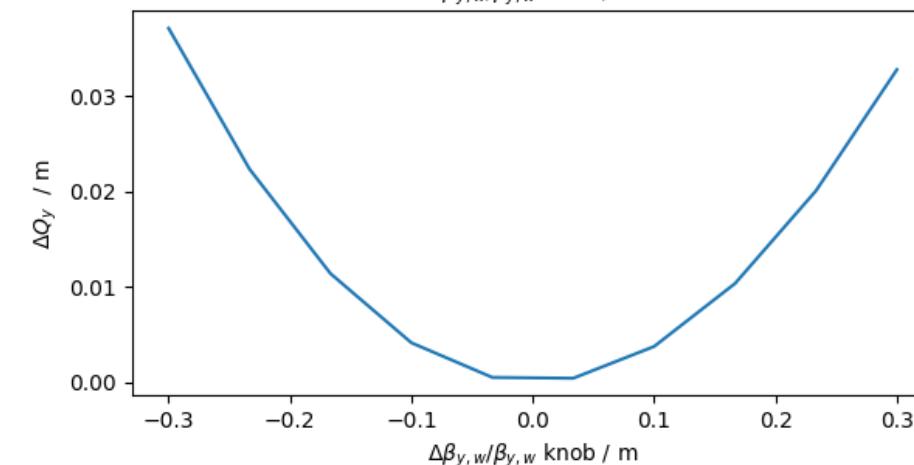
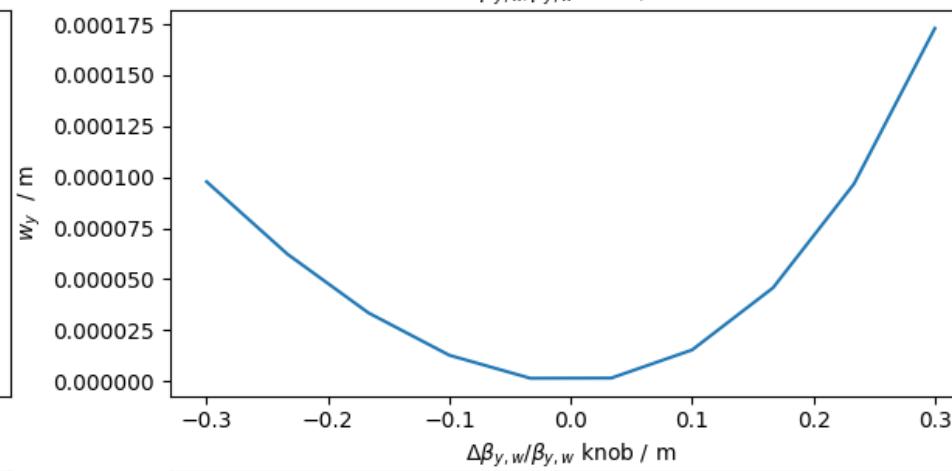
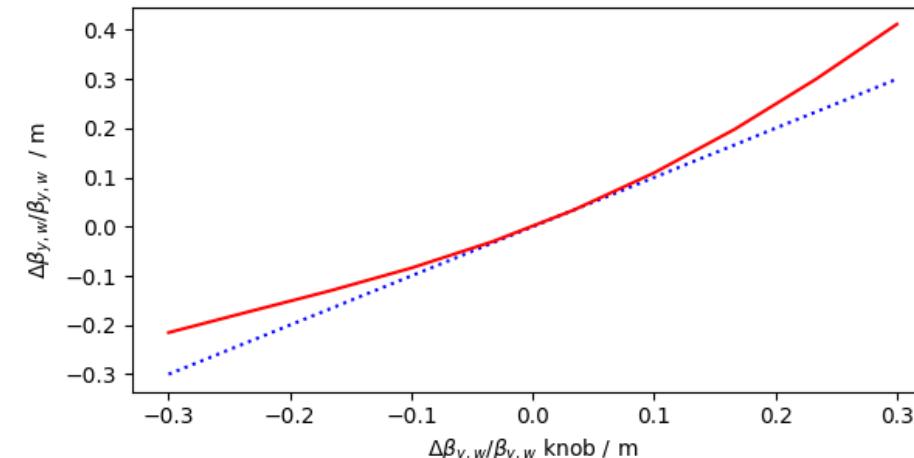
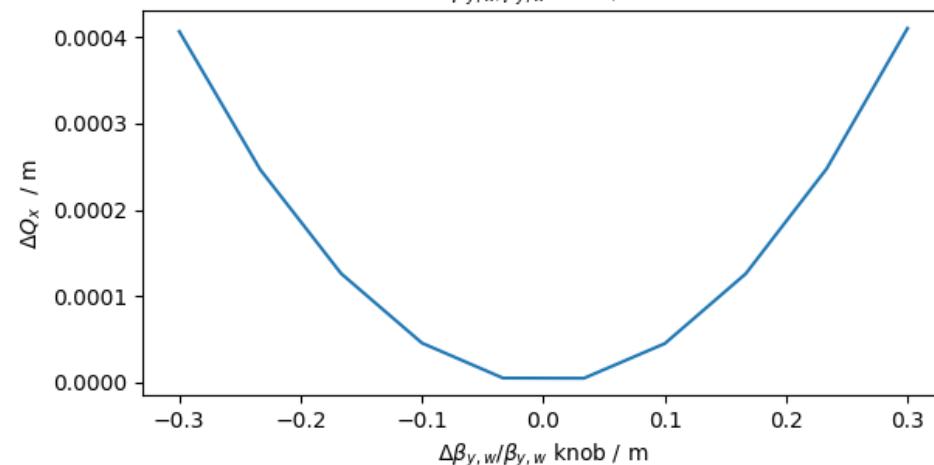
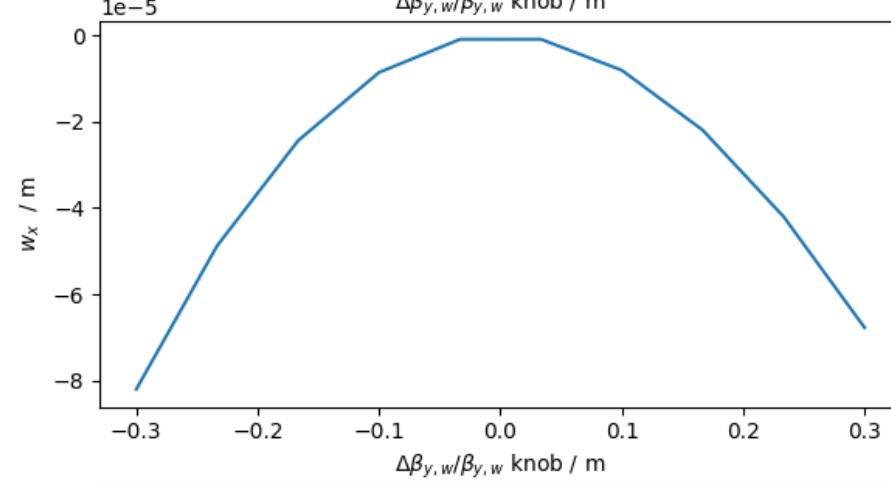
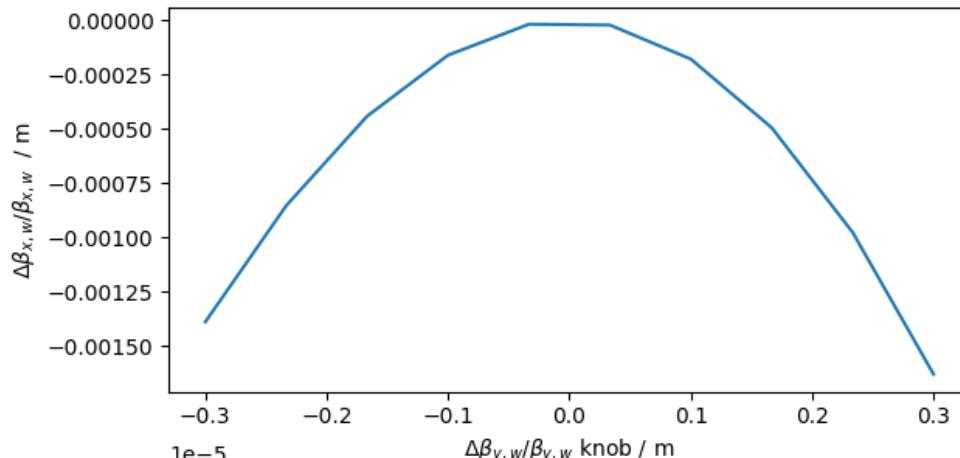
- **Segment-by-segment** style matching
 - Useful for recovering **linear optics** for conversion and **simulated** corrections
 - Do not take into account **non-linear errors**
- **Knob creation**
 - **SVD method** more effective than linear interpolation
 - Demonstrated **effectiveness** for some knobs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

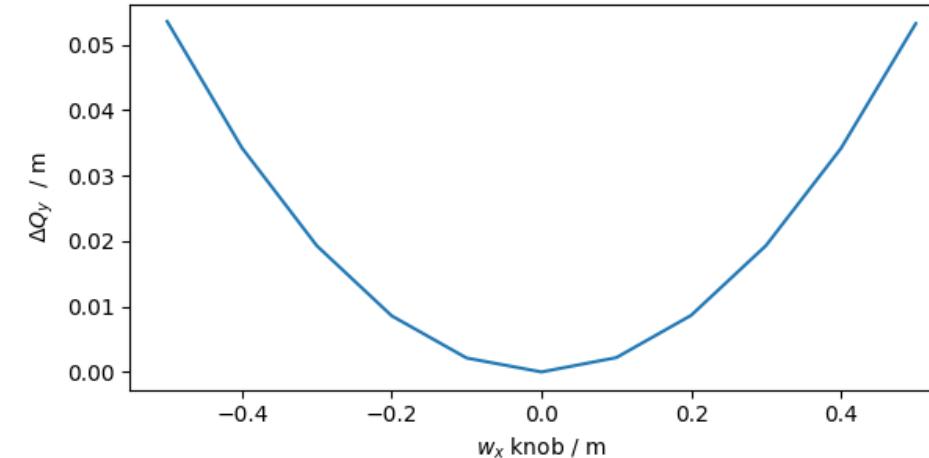
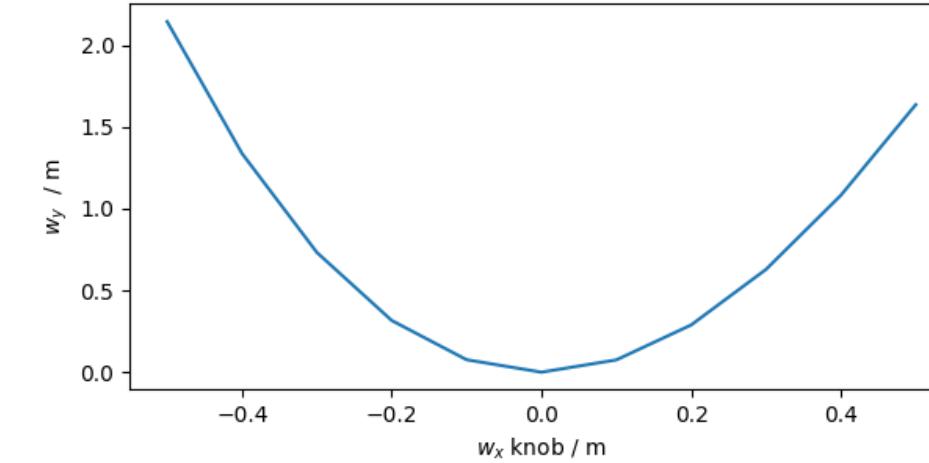
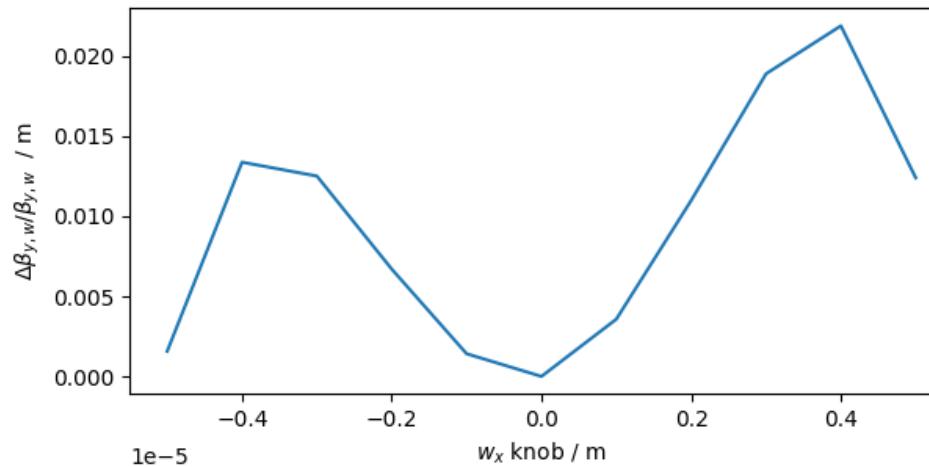
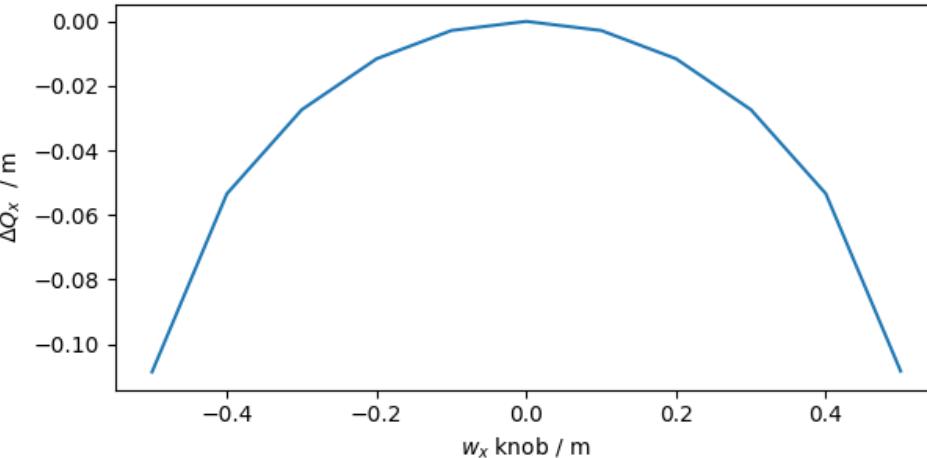
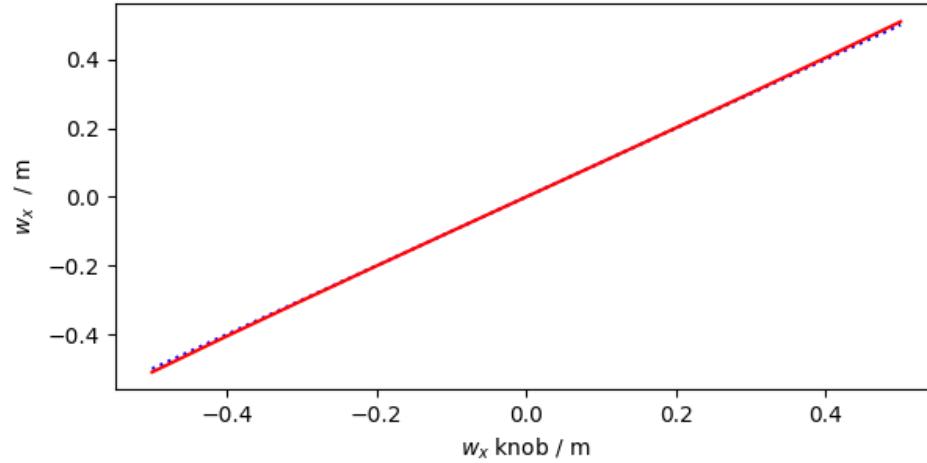
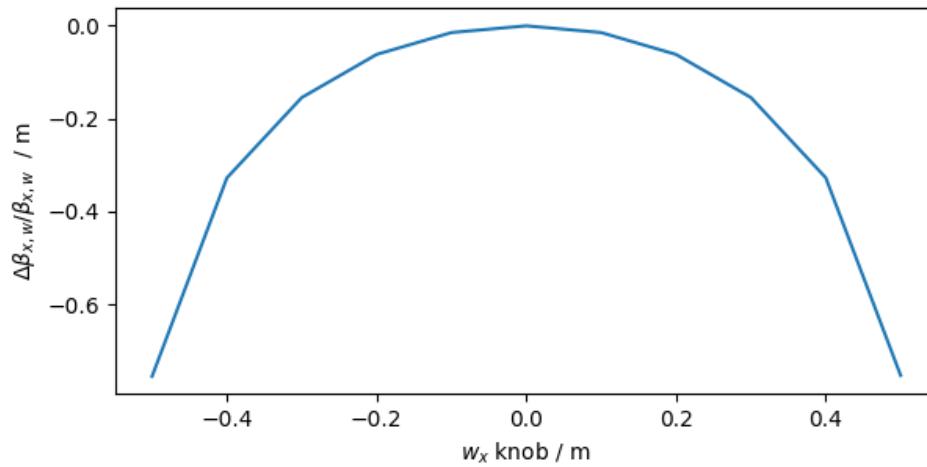
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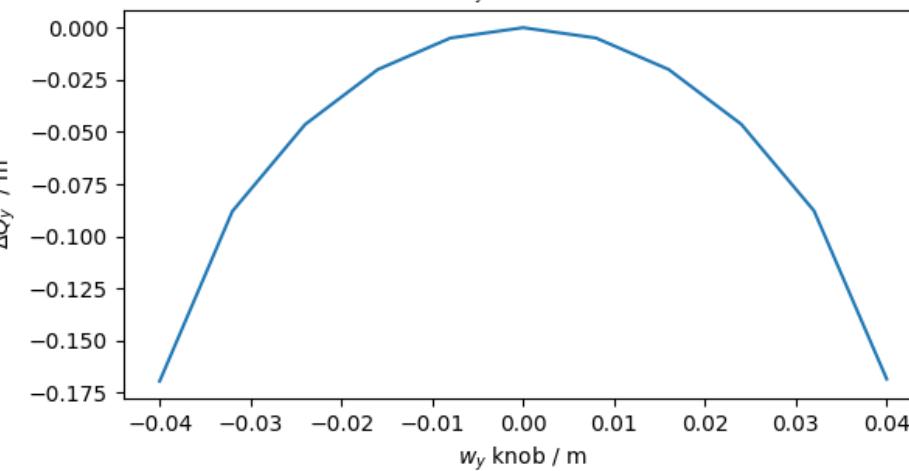
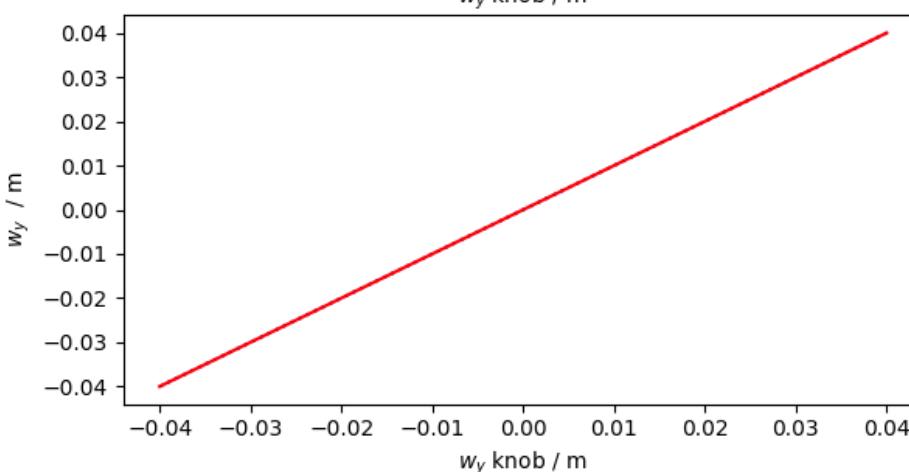
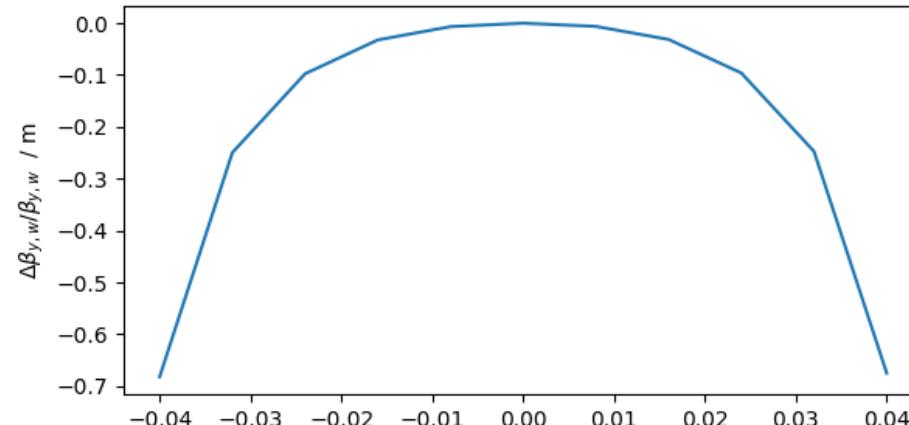
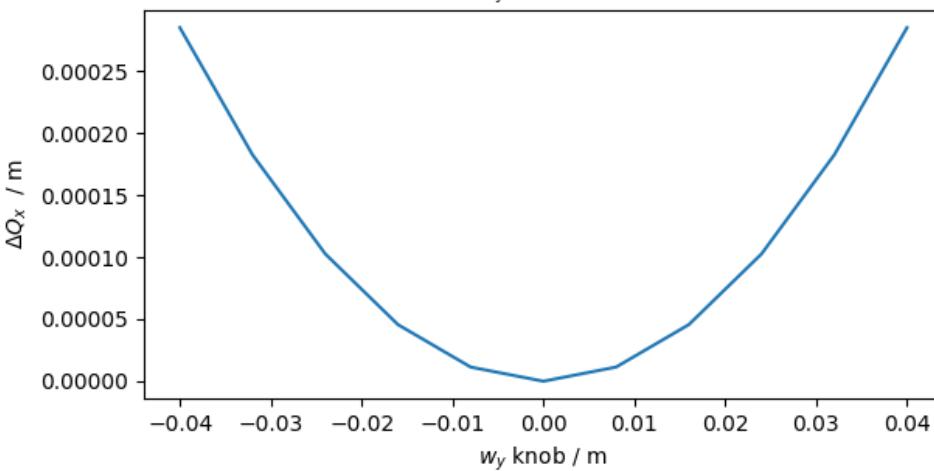
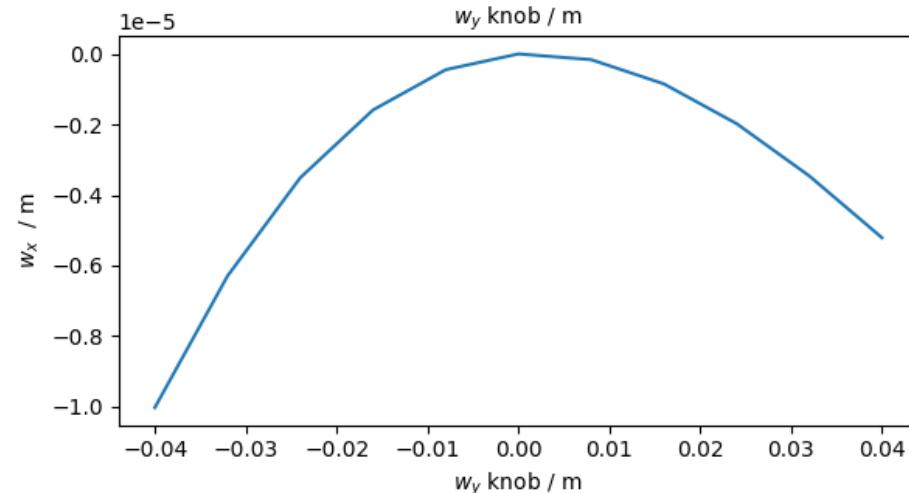
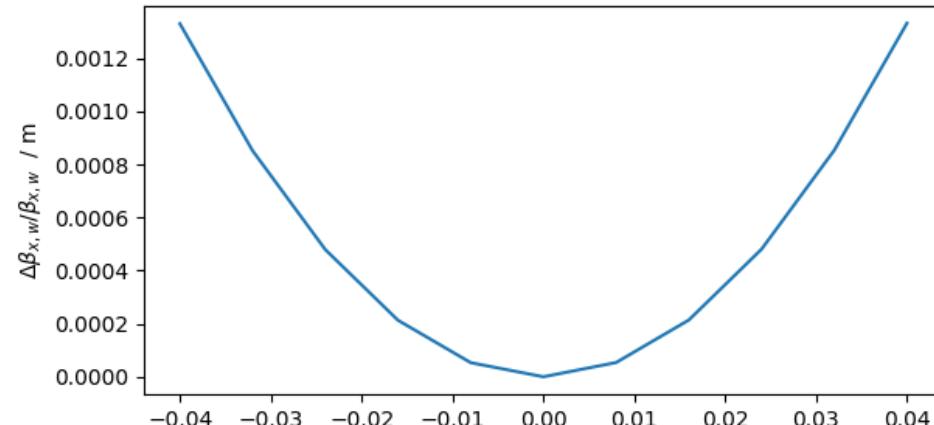
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 - Dispersion free region
 - Intrinsically no dispersion beating
- Knobs for
 - Waist position, w (in m)
 - β at waist, β_w (measured as % from nominal)
- Constraining machine tune
- Response matrix constructed using these properties and machine tune

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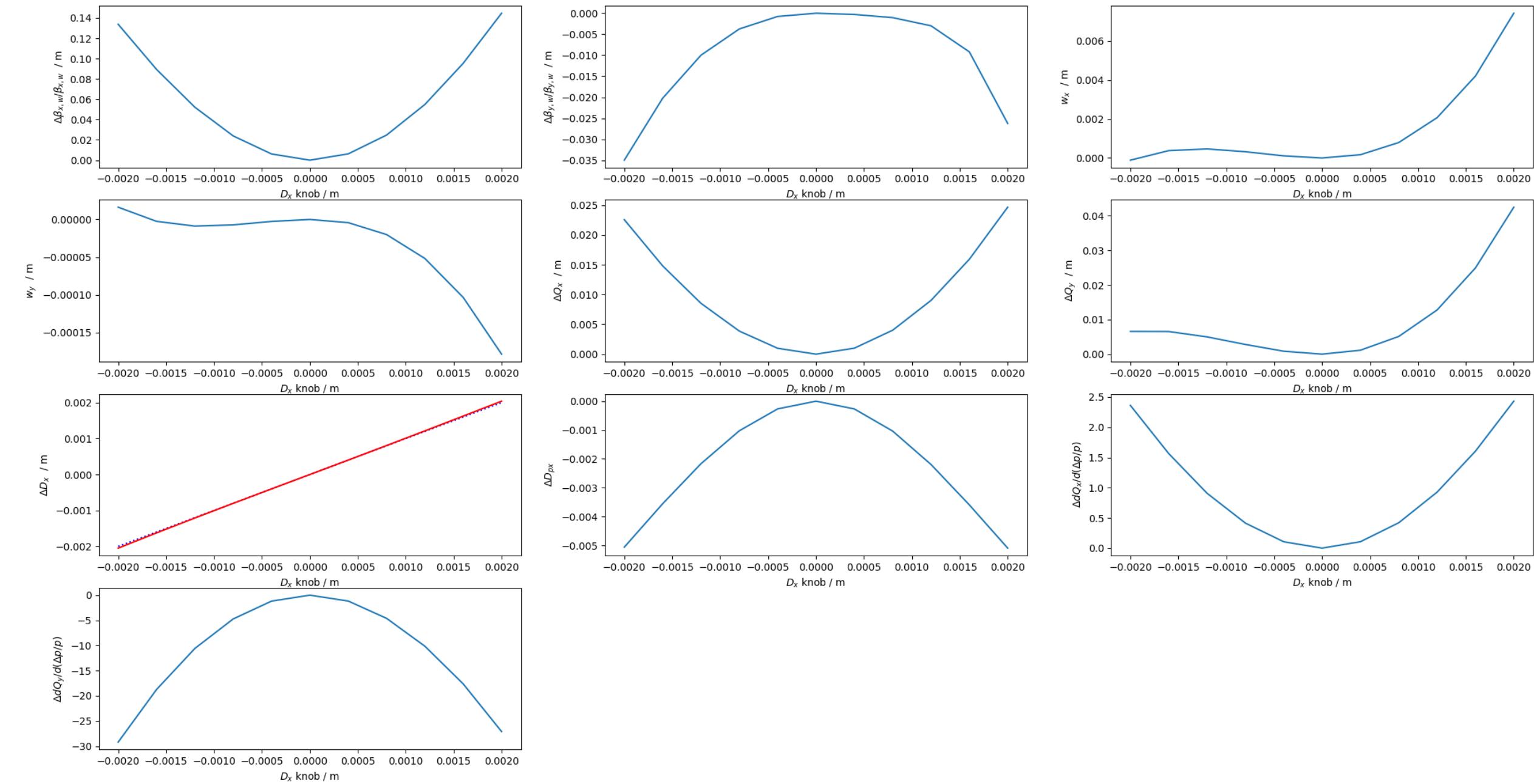


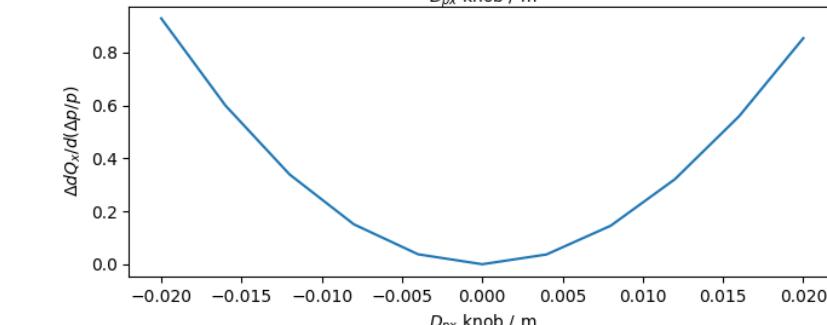
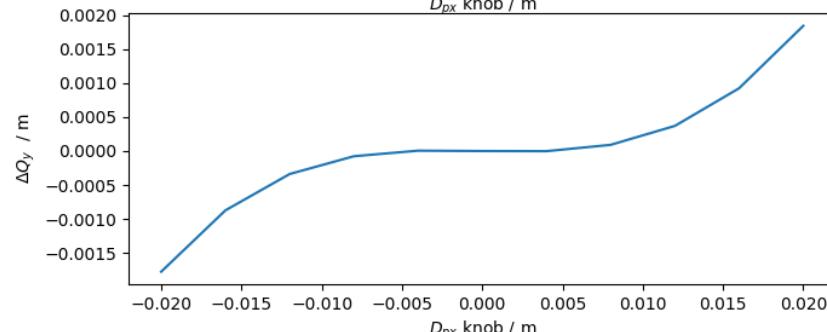
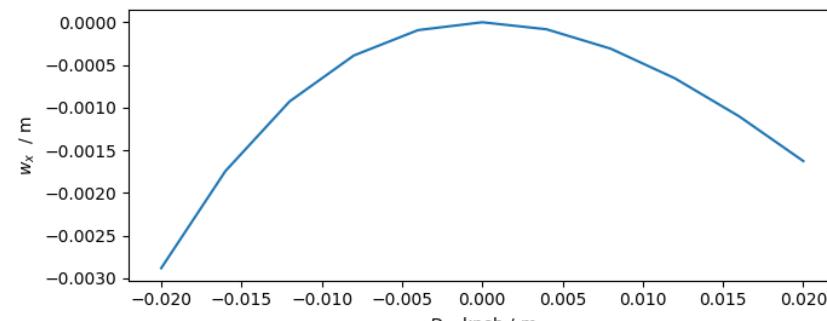
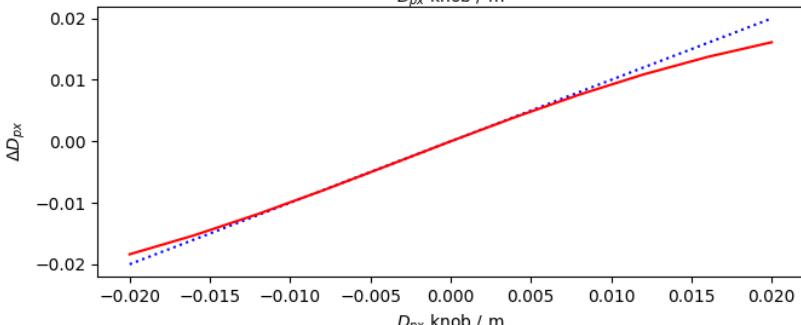
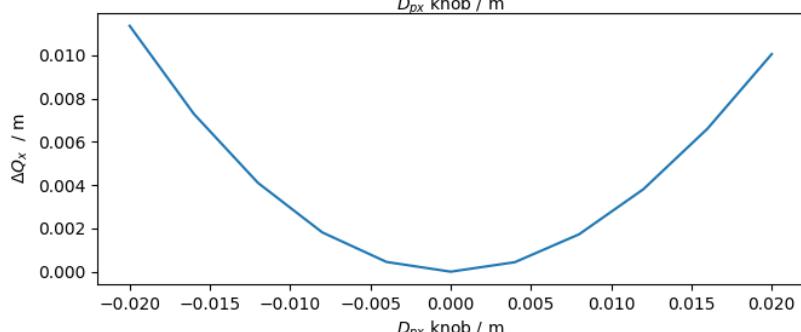
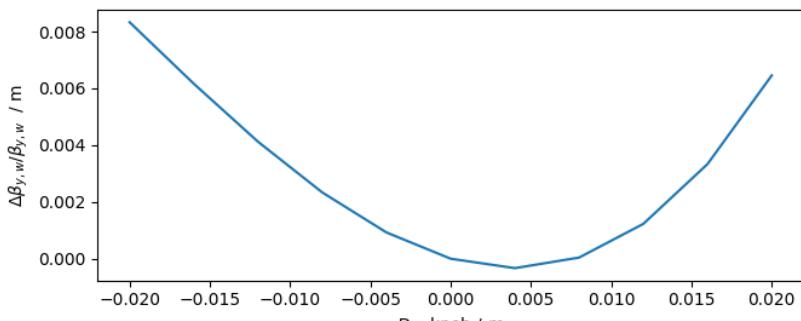
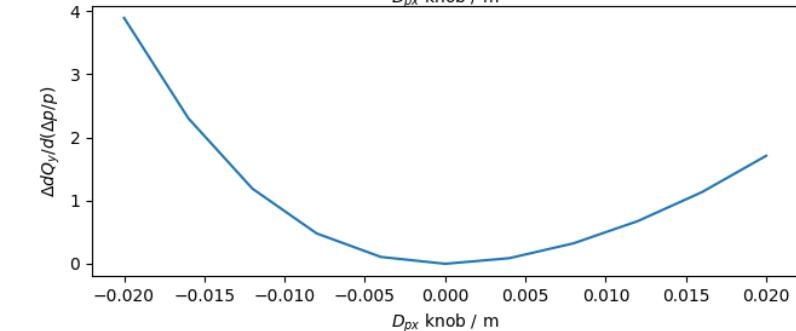
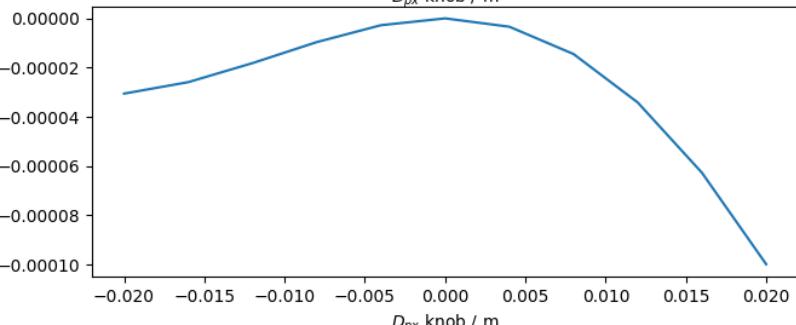
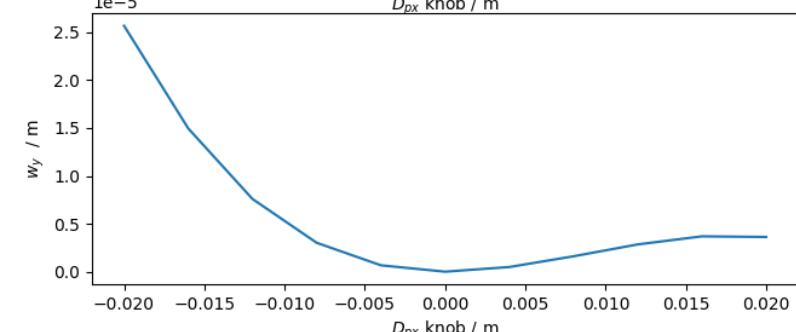
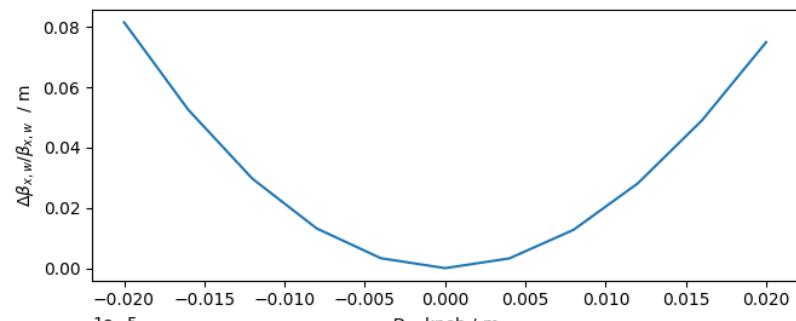




Horizontal Dispersion Knobs

- Using same dispersion free region quads
 - Doublet magnets (QC[1,2]) and matching section (Q[A,B][1-6])
- Include quadrupoles in dispersive region (QCL*[3-6]) and dispersion suppressor (Q[L,S][1-4])
- Knobs for
 - Dispersion $D_x \approx \pm 2$ mm
 - Rate of change of dispersion $D_{px} \approx \pm 0.01$
- Constrain w , β_w , Q , $\frac{\partial Q}{\partial \delta p}$





Vertical Dispersion Knobs

- Using same magnets are horizontal dispersion
 - Doublet magnets (QC[1,2]), matching section (Q[A,B][1-6]), dispersive region (QCL*[3-6]) and dispersion suppressor (Q[L,S][1-4])
- Include skew trims on these magnets
- Knobs for
 - Dispersion $D_y \approx \pm 0.6$ mm
 - Rate of change of dispersion $D_{py} \approx \pm 0.1$
- Constrain w , β_w , Q , $\frac{\partial Q}{\partial \delta p}$, D_x , D_{px} ΔQ_{min}

