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U.S. DEPARTMENT OF ENERGY

Nonlinear optics from hybrid dispersive orbits

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Outline

- Motivation: optics correction order-by-order
- Review existing methods and expansion to harmonic sextupoles
- Simulations and preliminary beam studies
- Summary

Motivations

- After orbit and linear optics correction, measured dynamic aperture is smaller than simulation
- Nonlinear optics are not corrected, relying on online optimization
- Sext settings are based on on-bench PS calibration
- Not ready for sext correction? in-series PS scheme

Order-by-order optics corrections

0th order: closed orbit correction using dipole kicks

1st order: beta-beat (phase advance) correction using quads

2nd order: chromatic function correction using sexts

3rd order: correction using octupoles ?

Existing methods

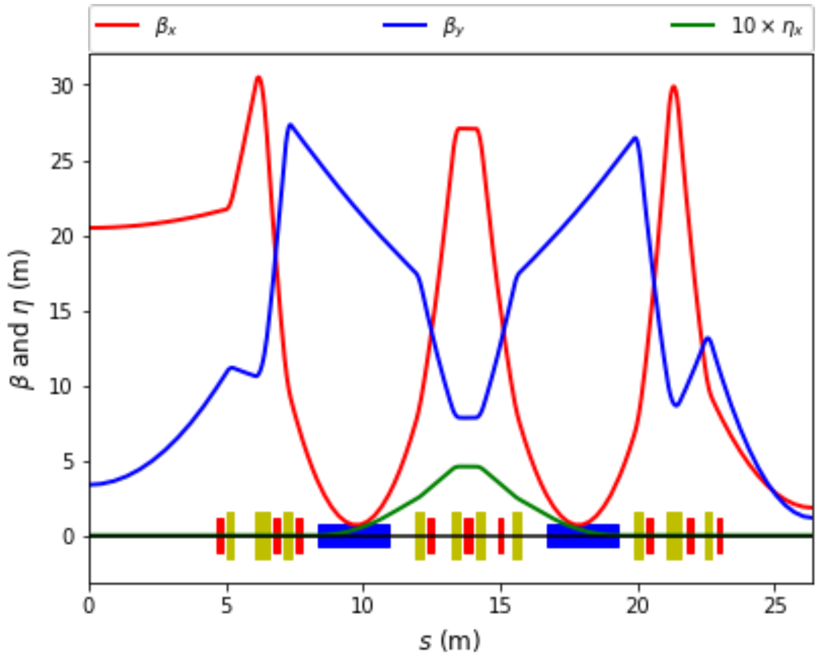
- Correction of multiple nonlinear resonances in storage rings, R. Bartolini, et al., PRST-AB, 2008
- First simultaneous measurement of sextupolar and octupolar resonance driving terms in a circular accelerator from turn-by-turn beam position monitor data, A Franchi, et al., PRST-AB, 2014
- Nonlinear optics from off-energy closed orbits, D. Olsson et al., PRAB, 2020
- …

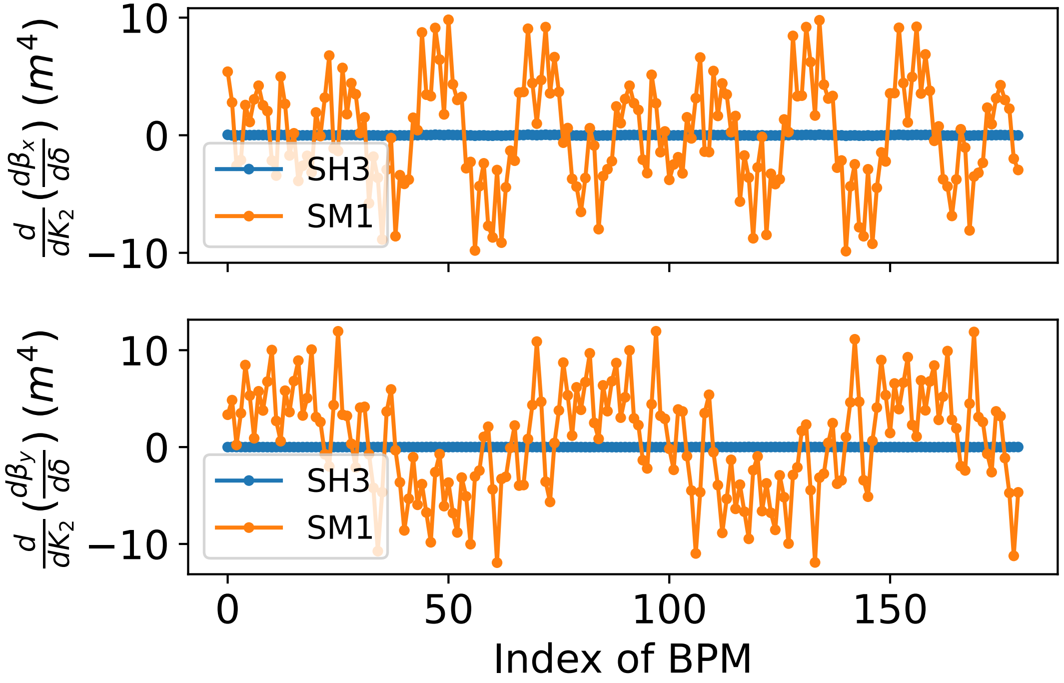
$$\frac{\Delta\beta(z)}{\beta_0} = \frac{\delta}{2\sin 2\pi\nu_0}\int_z^{z+L} \beta(k - m\eta)\cos[2\nu_0(\varphi_z - \varphi_\zeta + 2\pi)]\mathrm{d}\zeta\ ,$$

m: sext's strength, *η*: dispersion

How about harmonic sextupoles (HS)?

- Some 4th generation light source rings (ALS-U) and colliders (EIC) have HS





$$\frac{\Delta\beta(z)}{\beta_0} = \frac{\delta}{2\sin 2\pi\nu_0}\int_z^{z+L} \beta(k - m\eta)\cos[2\nu_0(\varphi_z - \varphi_\zeta + 2\pi)]d\zeta \,,$$

Chromatic SM1 is measurable, Harmonic SH3 is not.

Possible solutions

- Creating horizontal dispersion or local bump for HS

Pros: easy to understand

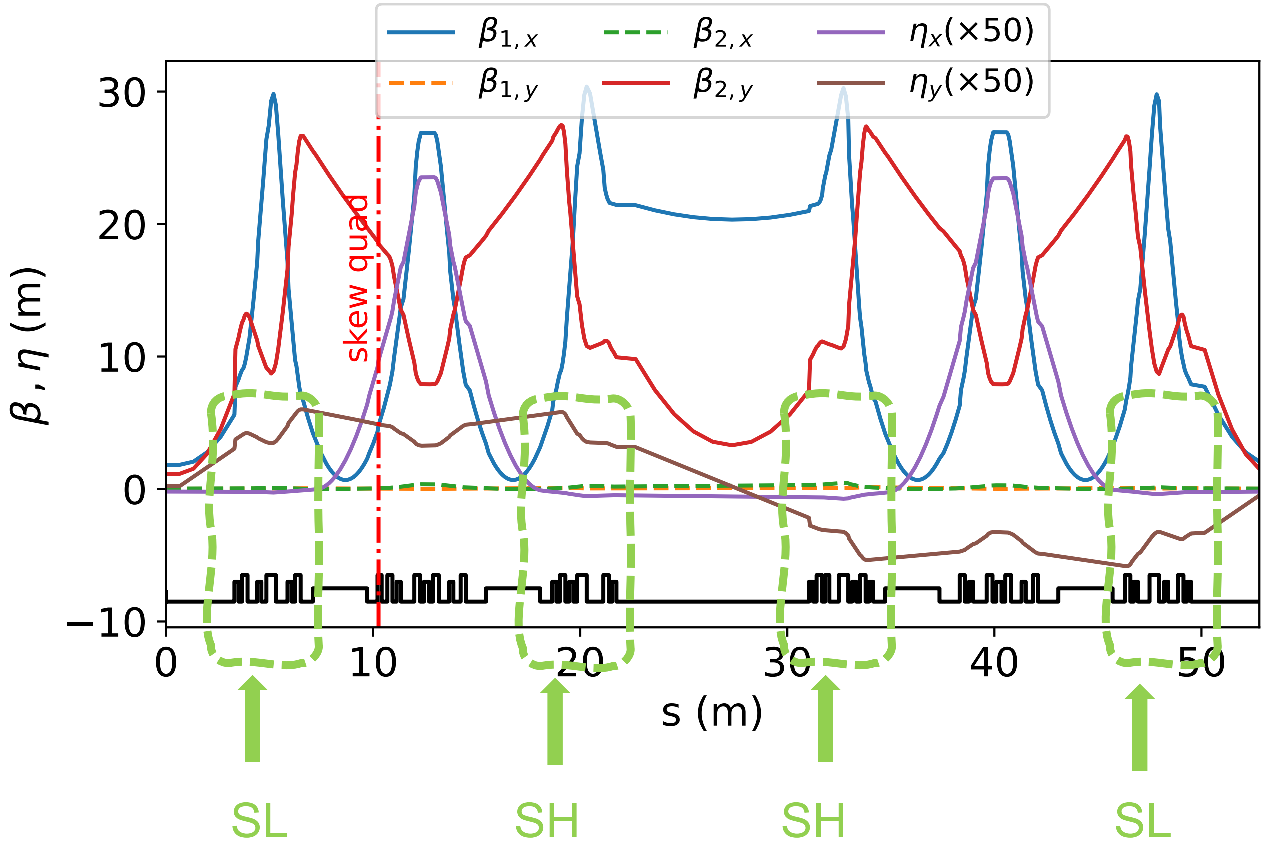
Cons: sophisticated implementation, time-consuming

- **Measuring with hybrid dispersive orbits** (this talk)

Pros: easy to implement, fast

Cons: some requirements on hardware

Hybrid dispersive optics using skew quads

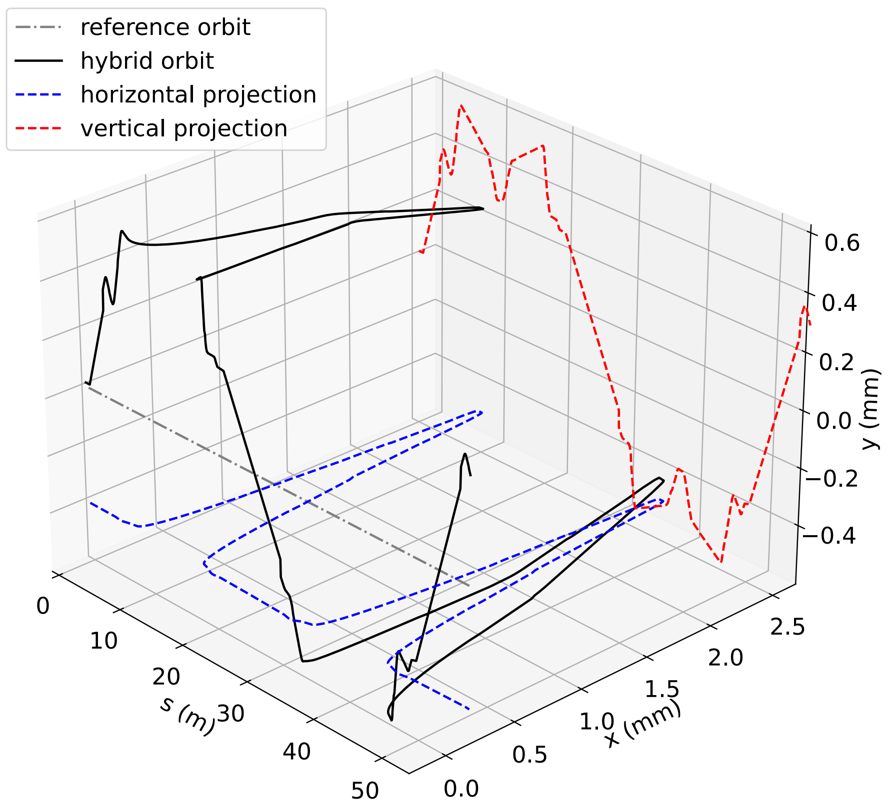


~3% of normal quad

Choosing SQM's $K_1 = 0.07\ m^{-2}$
g = 0.7 T/m

See hardware requirements later:
to produce measurable dependency

Hybrid dispersive orbit (dp=0.5%)



- Measuring optics with different energies
- Computing chromatic function

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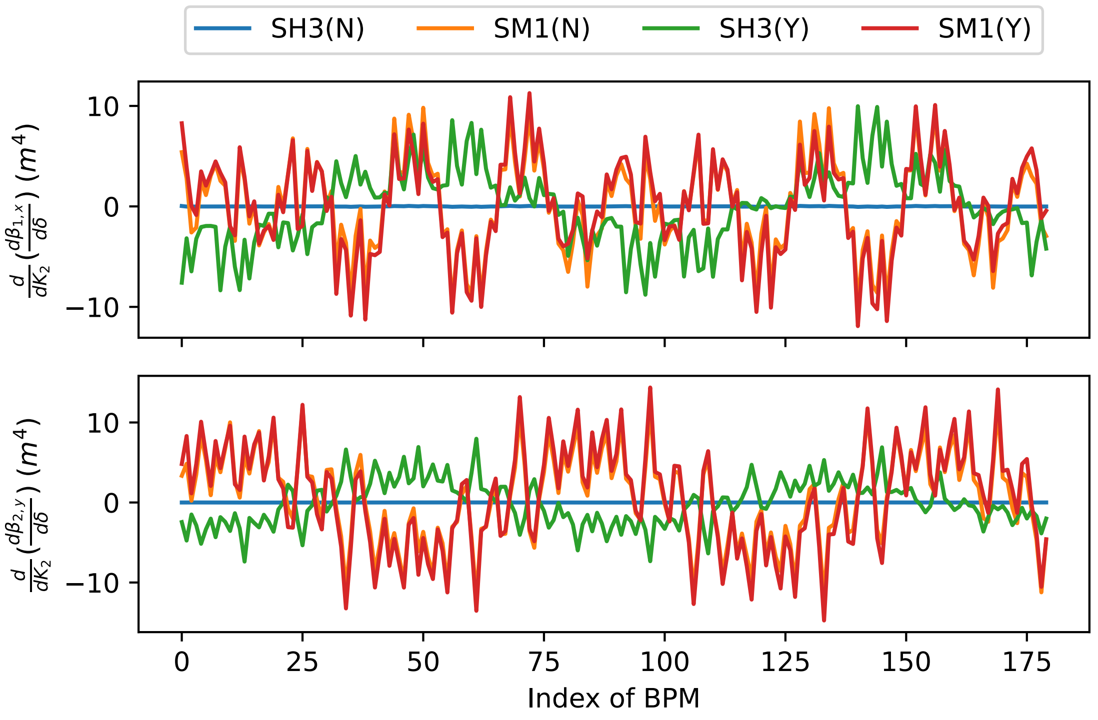
Measurable dependency for harm. sext.



N: No, without vertical offset
Y: Yes, with vertical offset

SM1: Chromatic sext
SH3: Harmonic sext

Not too much change for SM1,
While SH3 is measurable

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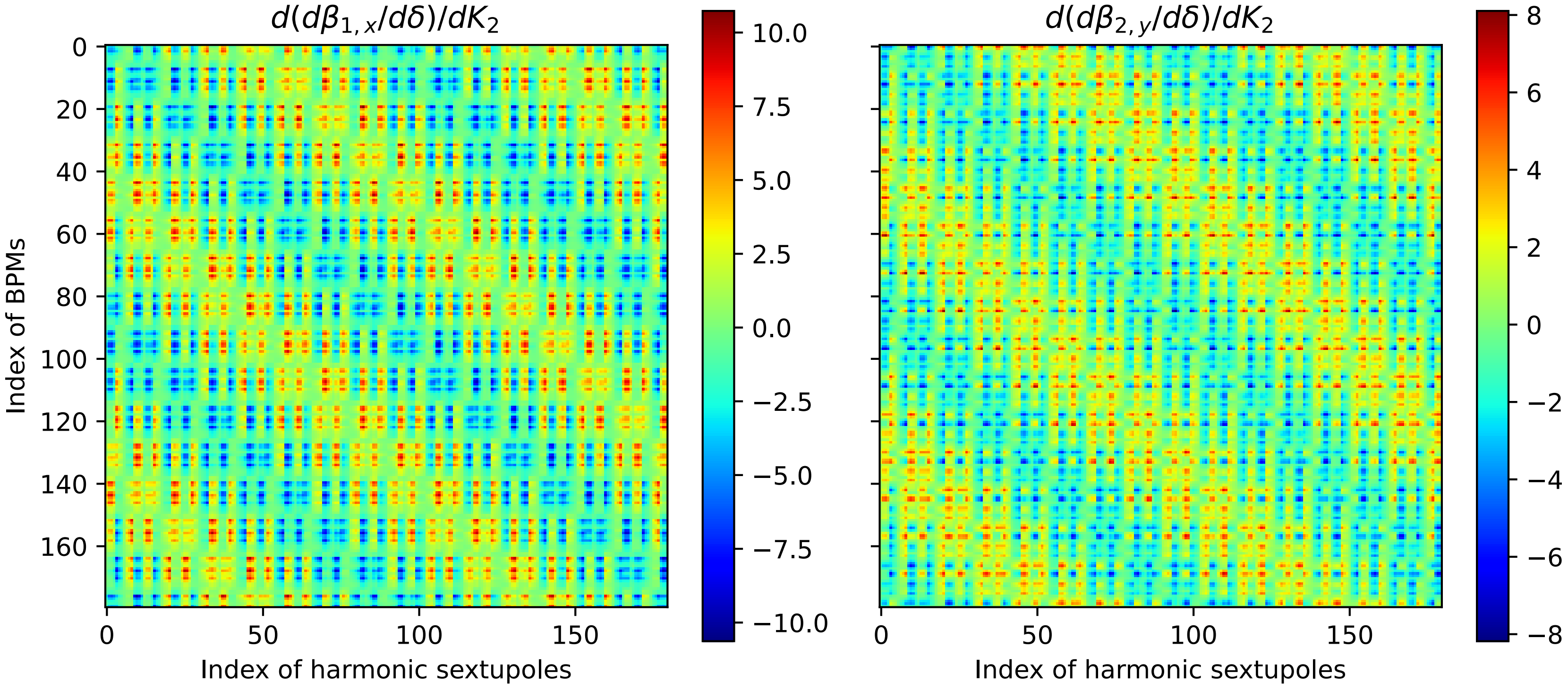
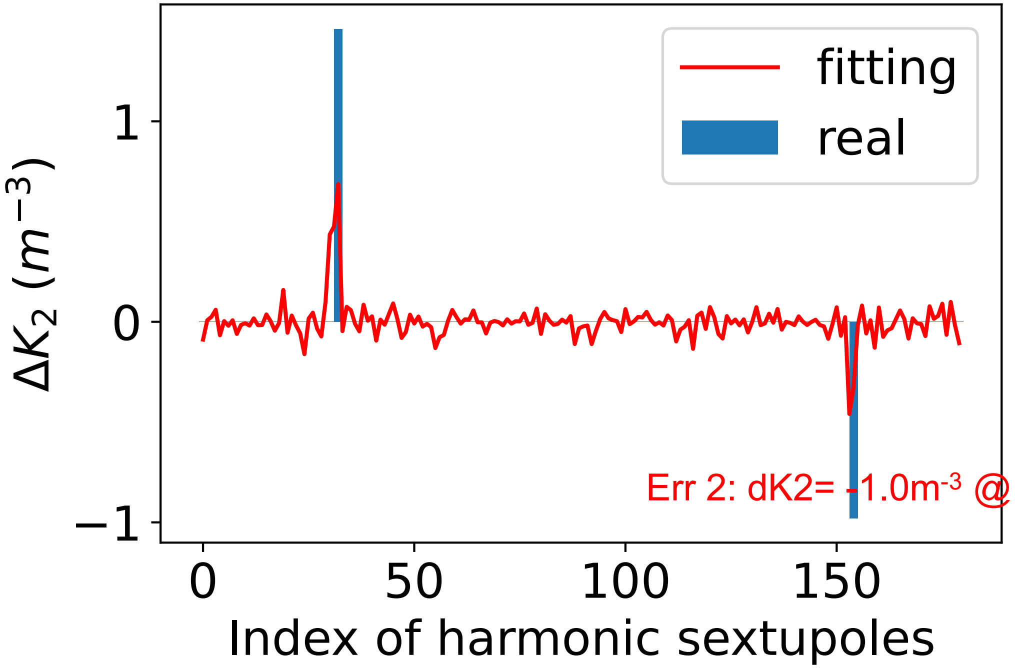
Full resp. matrix for all harm. sexts



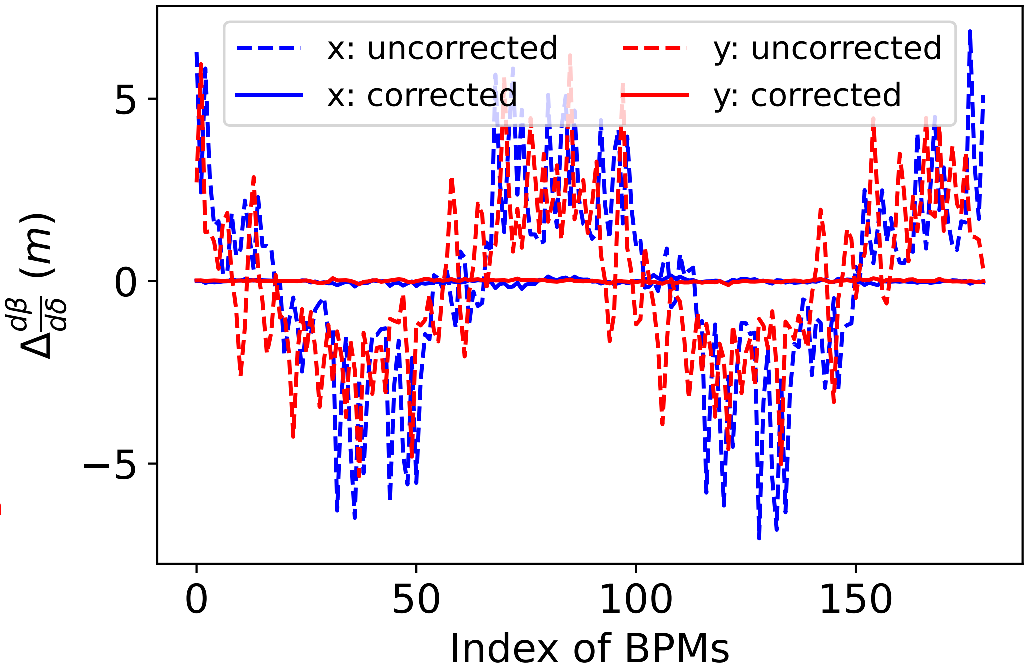
Computed with MAD-X's PTC module

Simulation 1: two isolated errors

Err 1: dK2= +1.5m^{-3} @ 32th sext

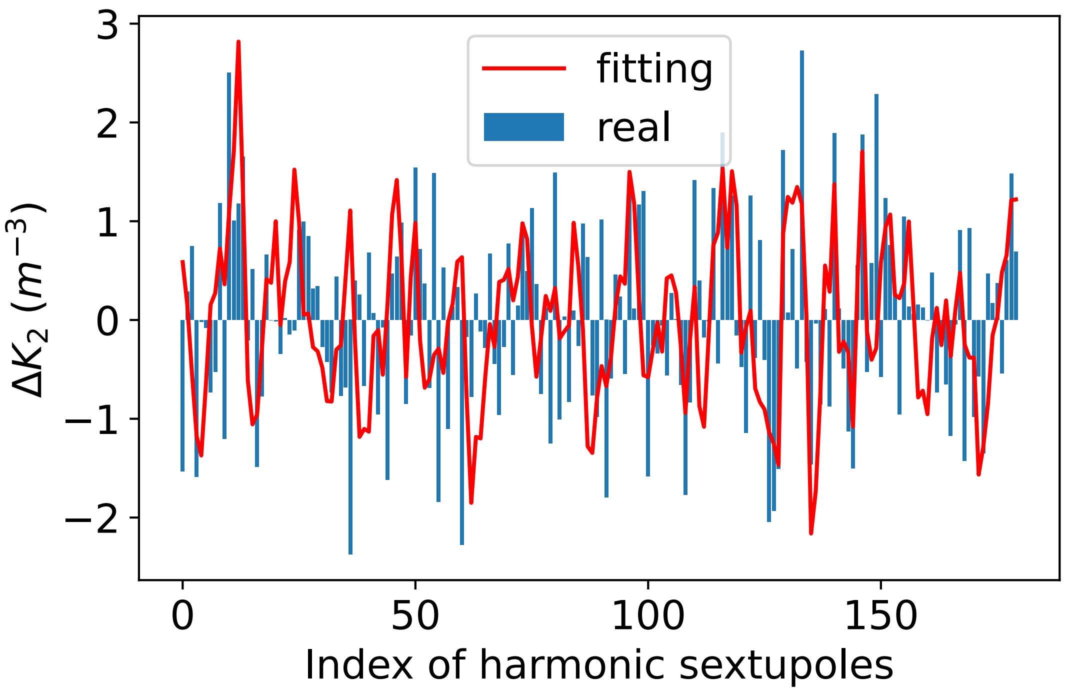


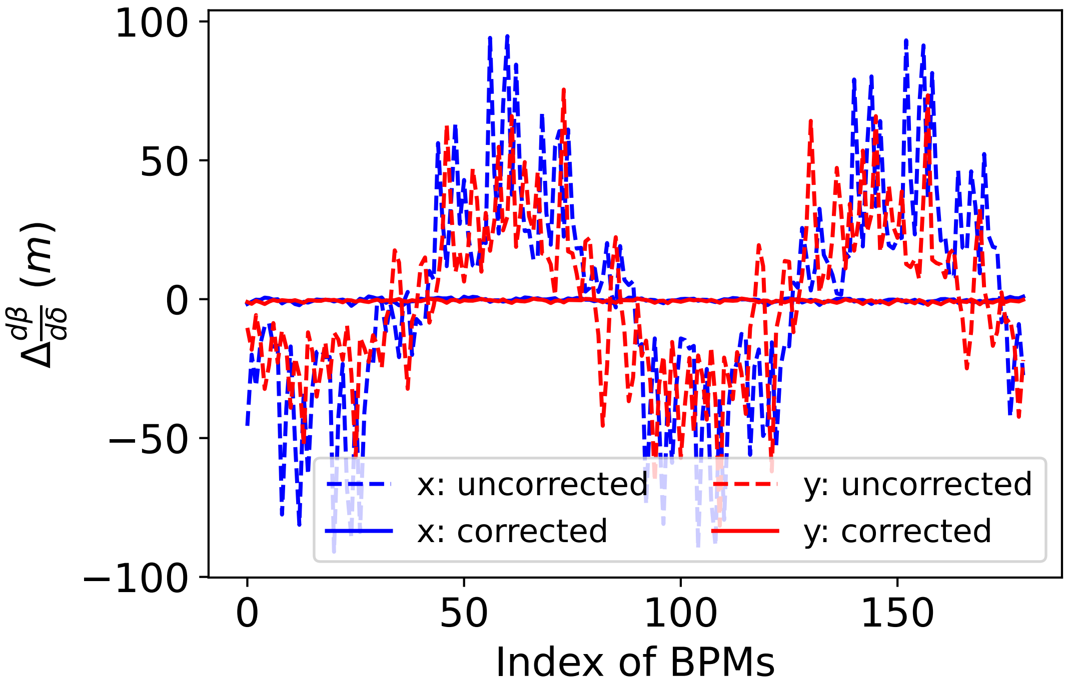
Err 2: dK2= -1.0m^{-3} @ 154th



High degeneracy was found among harm. sexts
Although can not exactly reproduce errors, the optics distortion can be corrected well

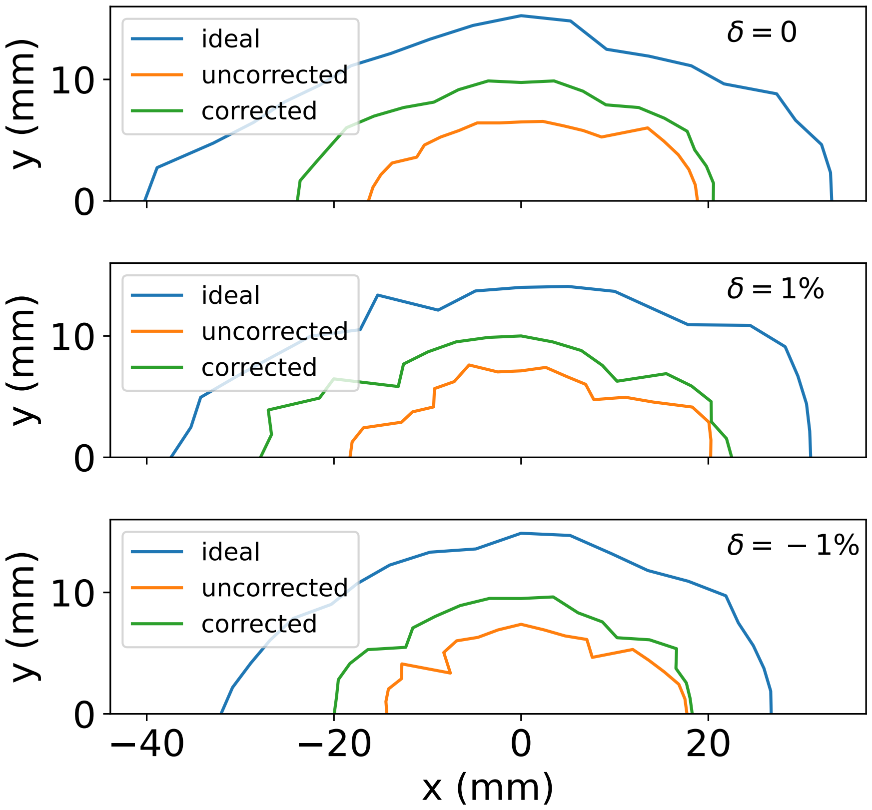
Simulation 2: random errors





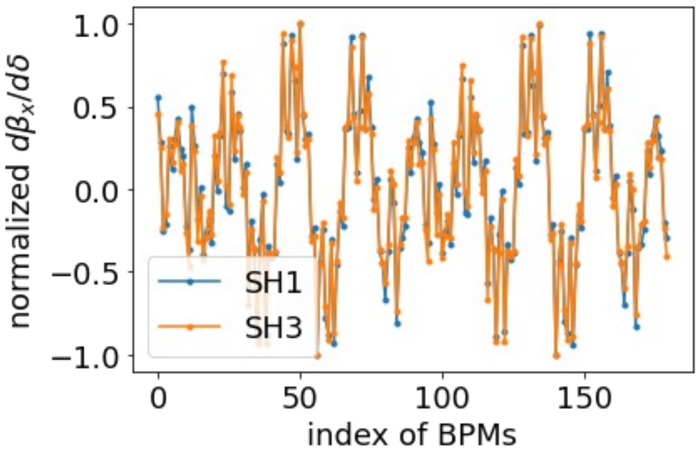
Still with high degeneracy, but the optics distortion can be corrected well

Dynamic aperture for simulation 2



On- and off-momentum DAs before/after correction

- Modest improvement on dynamic apertures
  - Sexts are close, strong degeneracy exists
  - Only first order $(d\beta/d\delta)$ has been corrected



Degeneracy of two adjacent sexts

Beam studies: a two-stage calibration

Stage one: calibrate chromatic sexts (similar idea as MAX-IV, but using TbT data) – from horizontal dispersive orbits

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Incorporating chromatic sext errors into model and using it reference

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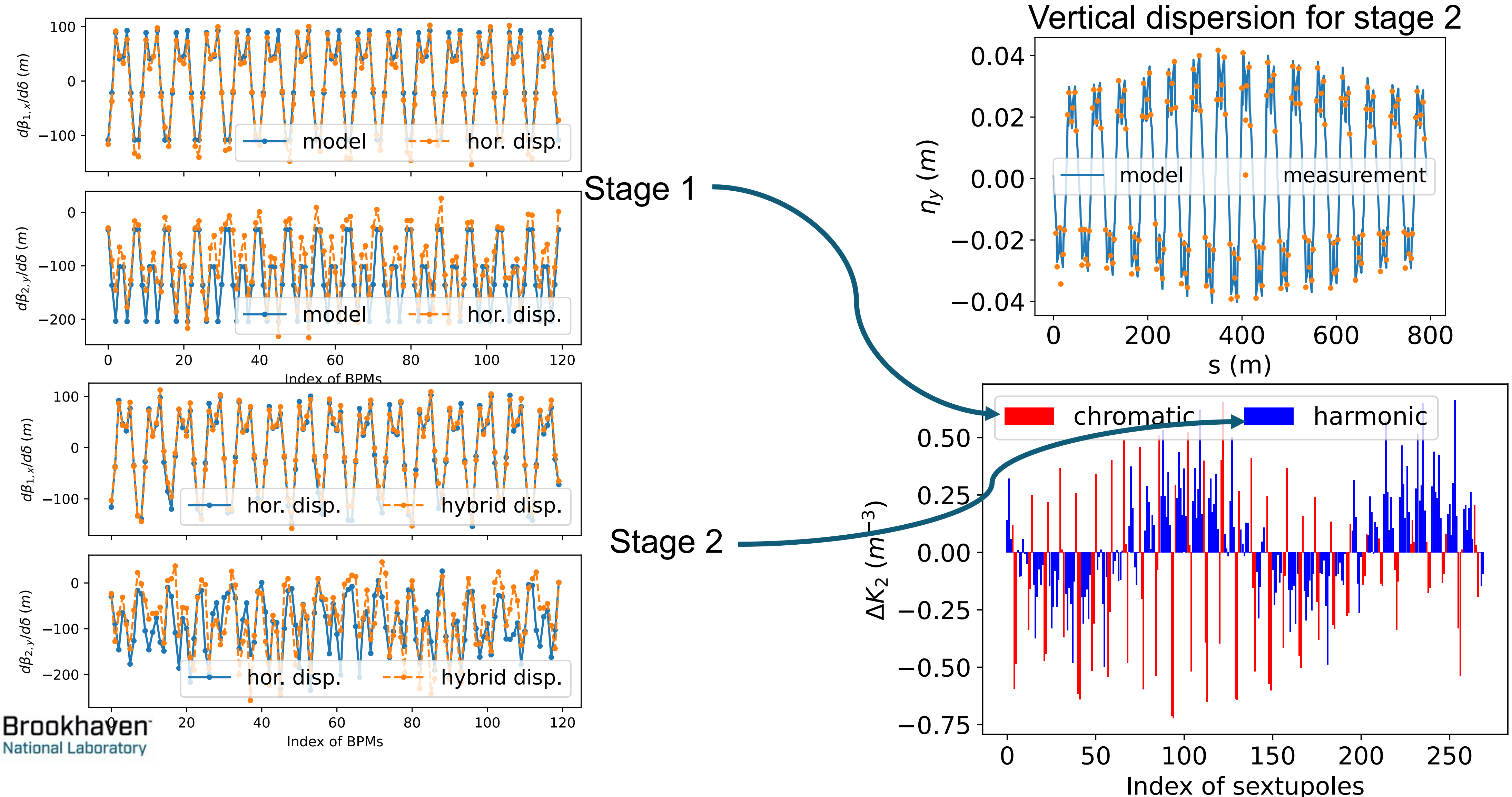
Stage two: calibrate harmonic sexts, using the first stage result as reference – from hybrid dispersive orbits

Two-stage online calibration results



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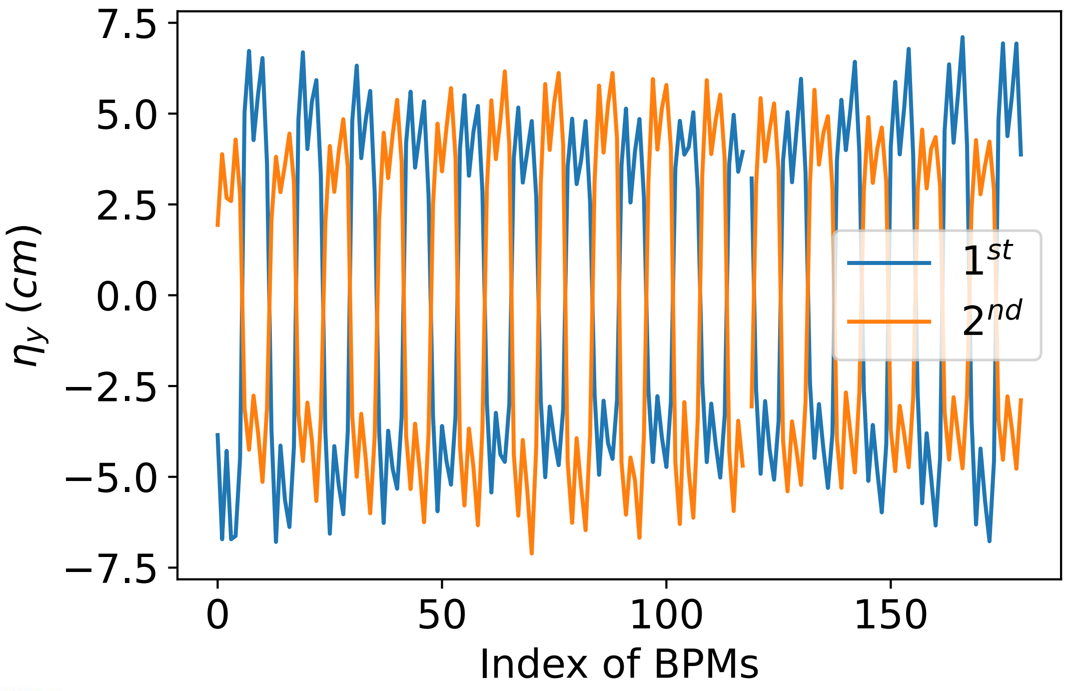
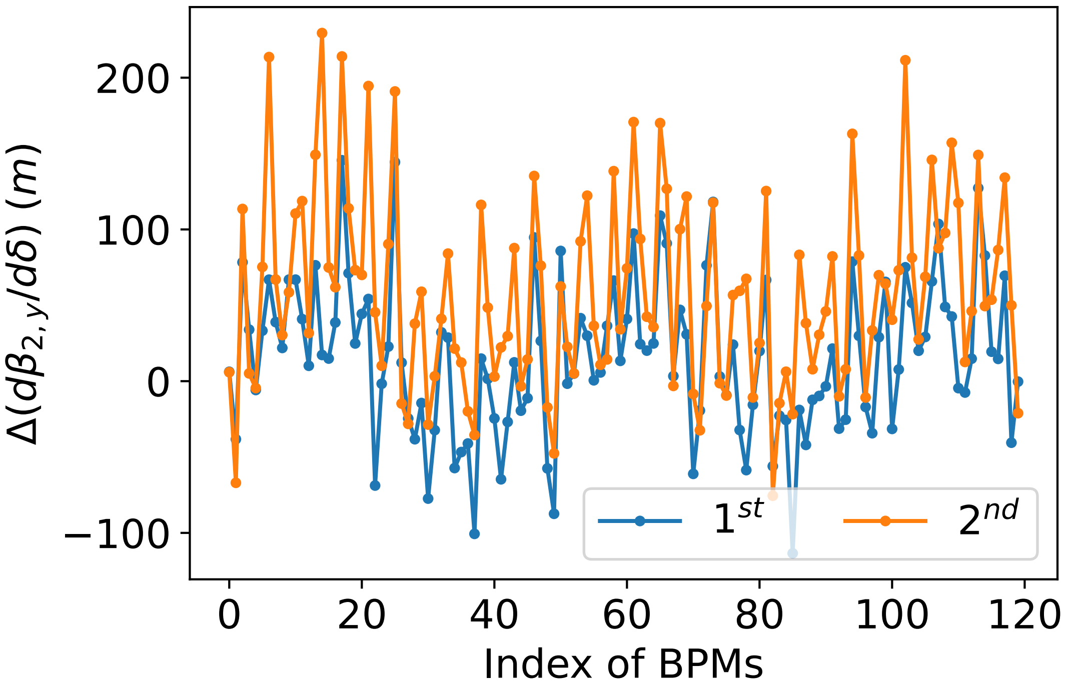
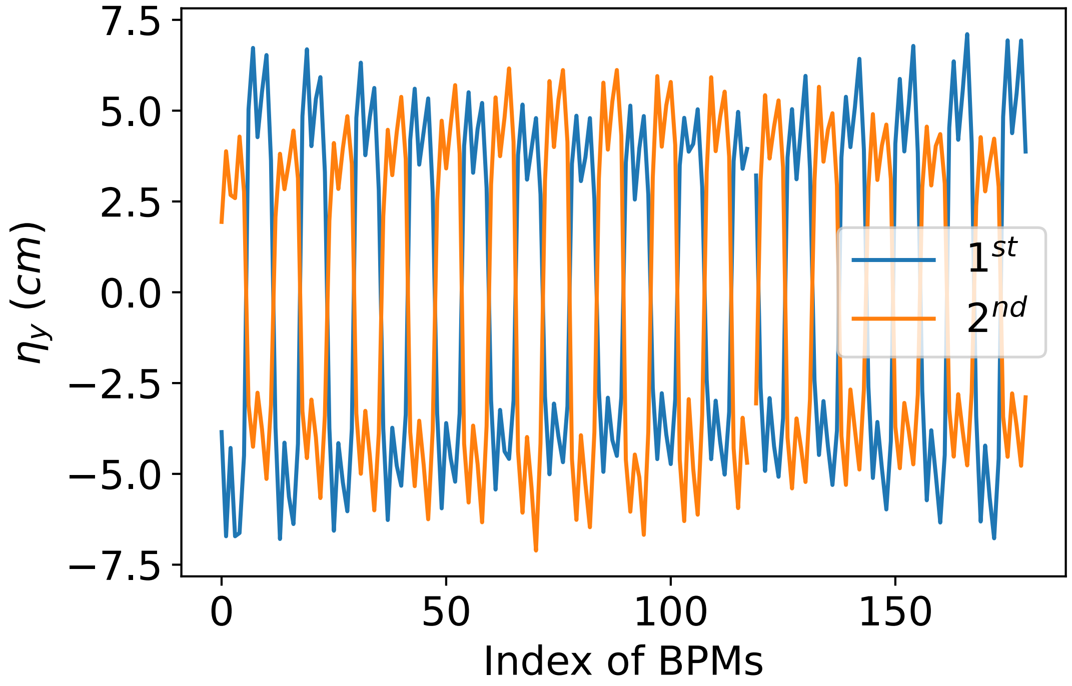
Validation by flipping v-dispersion

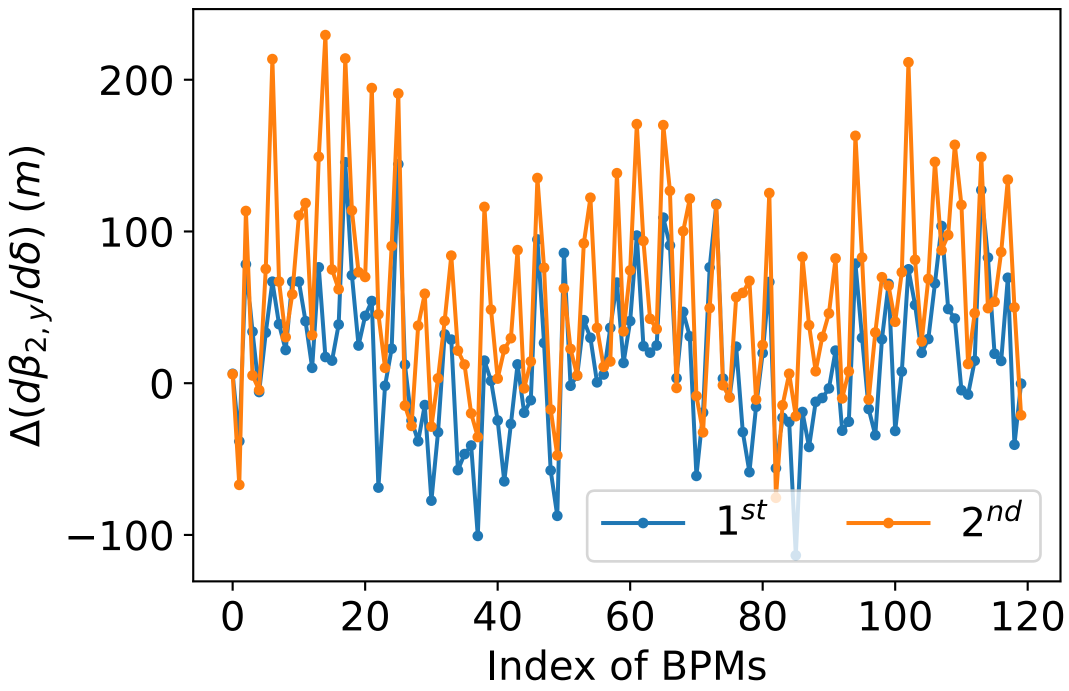
switch all skew quads from K_1 to $-K_1$, vertical dispersion will be flipped as well, nonlinear chromatic optics remains same





Measurements





Similar tendency

Requirements on hardware

Sexts: Powered independently ✗

Skew quads: capable to generate desired vertical dispersion ✗

BPMs: sufficiently accuracy ✓

Summary

- Chromatic function on hybrid dispersive orbits for calibrating harmonic sexts

- New facilities with HS might need independently powered sexts and strong skews