Accelerator Toolbox Workshop

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This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 871072

ESRF, 2-3 Oct. 2023

Minimizing the Fluctuation of Resonance Driving Terms for Storage Ring Dynamic Aperture Optimization and its Implementation on AT

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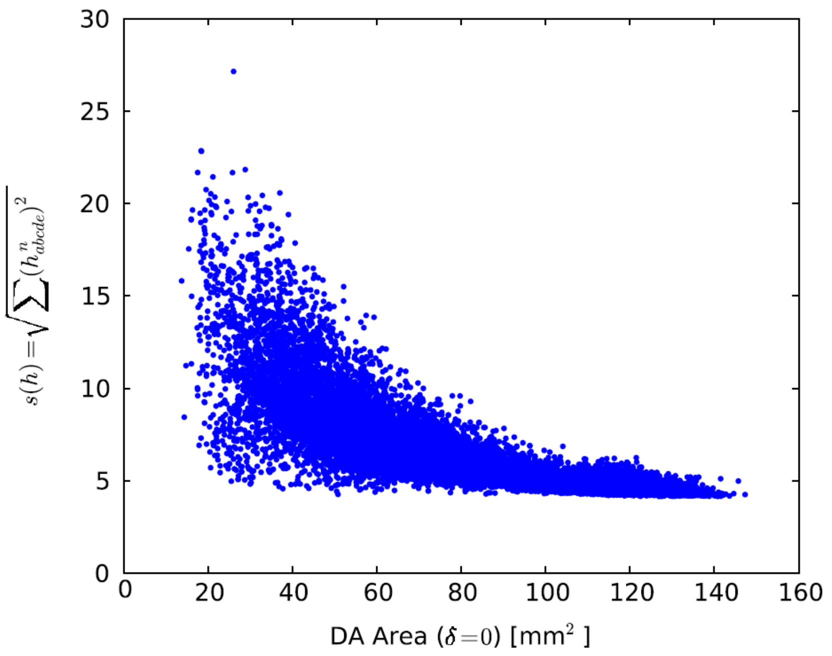
Outline

- ❑ Introduction
- ❑ Analyzing and optimizing dynamic aperture based on minimizing RDT fluctuations
- ❑ Computing RDT fluctuations on AT
- ❑ Conclusion

Dynamic aperture optimization

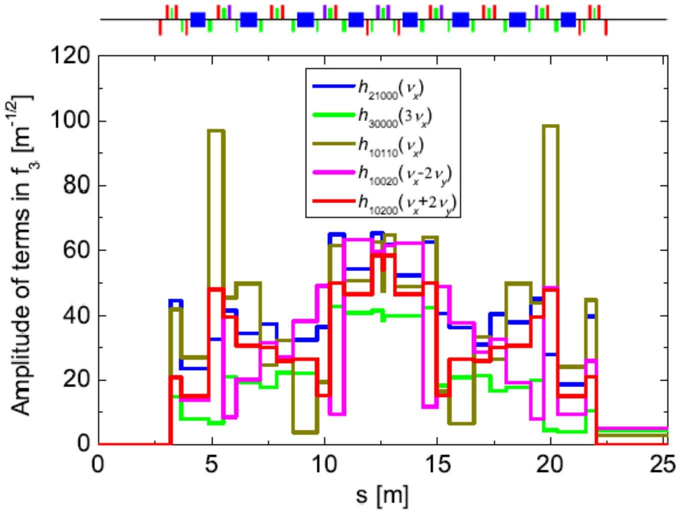
- Two widely-used approaches for dynamic aperture (DA) optimization
  1. Minimization of resonance driving terms (RDTs)
  2. Tracking based direct optimization with evolutionary algorithms
- The 1st analytical approach:
  - Small RDTs is a necessary but not sufficient condition for large DAs (see the figure);
  - Fast optimization, physical analysis.
- The 2nd numerical approach:
  - In principle, the largest DA can be found;
  - Very time-consuming, basically no physics.
- For better DA optimization:
  - Powerful analytical approach (to be further developed) + powerful numerical approach.



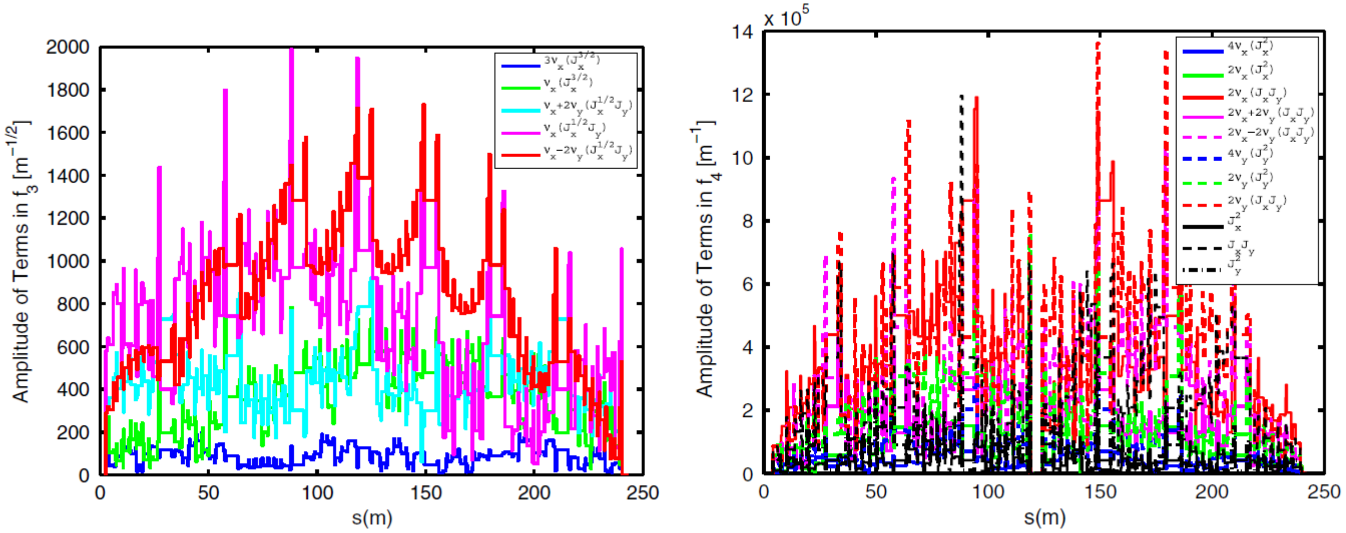
Correlation between DA area and RDTs.
L. Yang, et al., PRST-AB, 14, 054001 (2011).

Control of the variation or fluctuation of RDTs

- Nonlinear dynamics cancellation
  - The nonlinear cancellation within a lattice cell (left figure) is more effective than the cancellation over some cells (right figure) in enlarging the DA.
  - The variation or fluctuation of RDTs along the longitudinal position in the former is smaller than that in the latter, which inspires us that reducing the RDT fluctuations could be very beneficial for enlarging the DA.



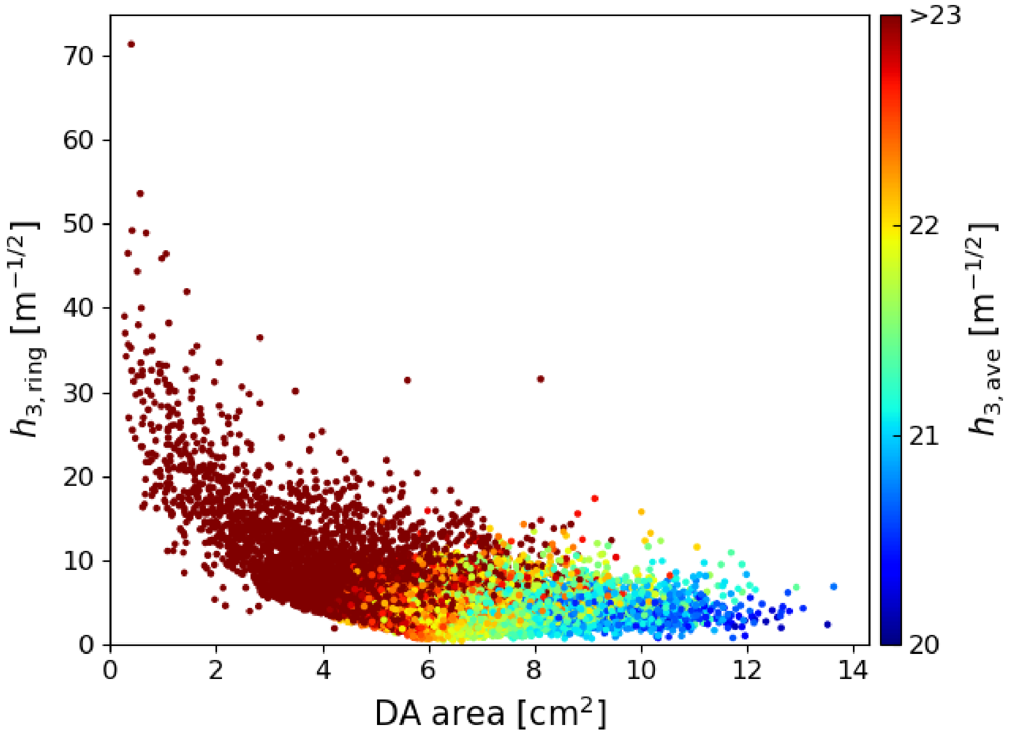
The variation of 3rd-order RDTs along a lattice cell.



The variation of 3rd- and 4th-order RDTs along 8 lattice cells.
Y. Cai, et al., PRST-AB, 15, 054002 (2012).

Correlation between RDT fluctuations and DA

- Lattice example:
  - SSRF double-bend achromat lattice
  - 8 families of sextupoles, 10000 nonlinear solutions
- The RDT fluctuations are quantitatively represented by the average RDTs at nonlinear magnets.
  - The same order RDTs have the same weight;
  - 4th-order RDTs have smaller weight than 3rd-order RDTs.
- Minimizing the RDT fluctuations is more effective than minimizing the commonly used one-turn RDTs in enlarging the DA.



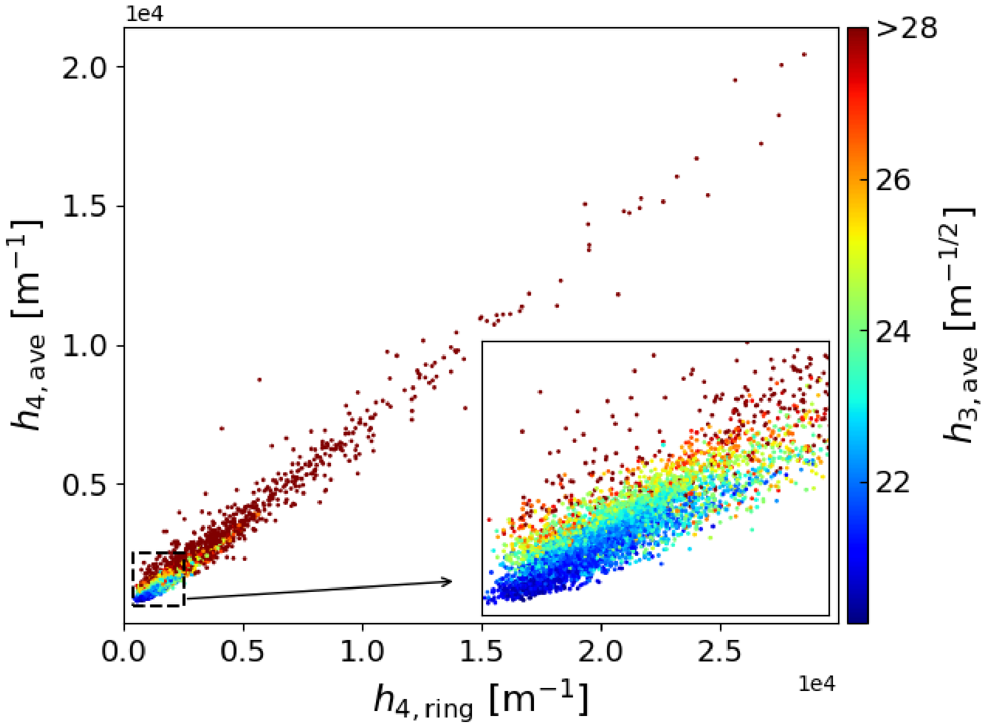
Correlation between DA area, 3rd-order one-turn RDTs ($h_{3,\ ring}$) and 3rd-order RDT fluctuations ($h_{3,\ ave}$) . B. Wei, et al., PRAB, 26, 084001 (2023).

Correlation between low- and higher-order RDTs

- ➢ As we know, for the commonly used one-turn RDTs, if the 3rd-order one-turn RDTs are smaller, the 4th-order one-turn RDTs can be larger.

- ➢ Reducing 3rd-order RDT fluctuations can help reduce both 4th-order RDT fluctuations and 4th-order one-turn RDTs, as well as amplitude dependent tune shifts.

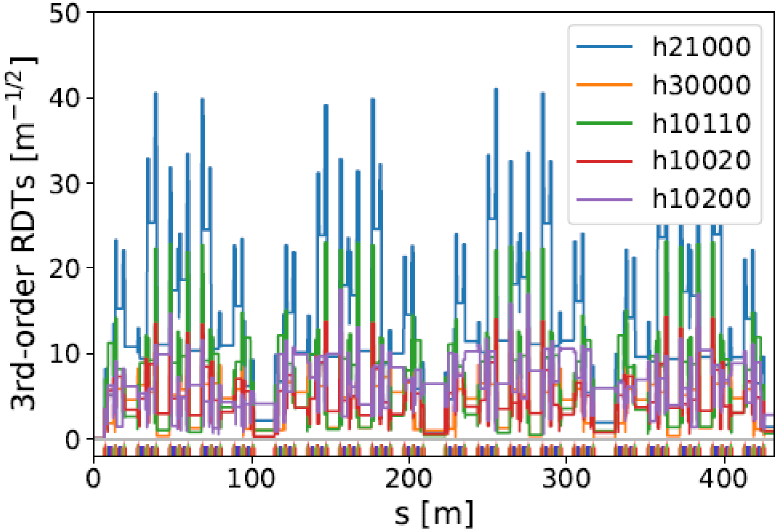
- ➢ How about 5th-order RDTs if 3rd-order RDT fluctuations are reduced?
  - Demonstrated using frequency map analysis.

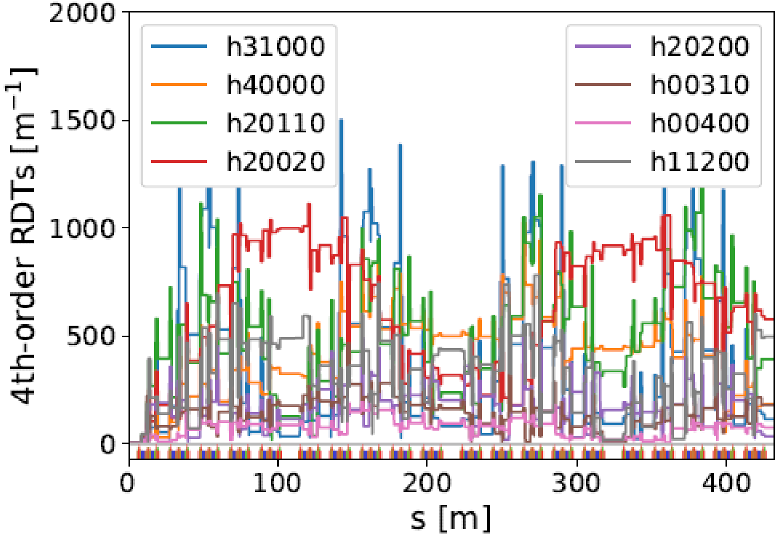


Correlation between low- and higher-order RDTs.

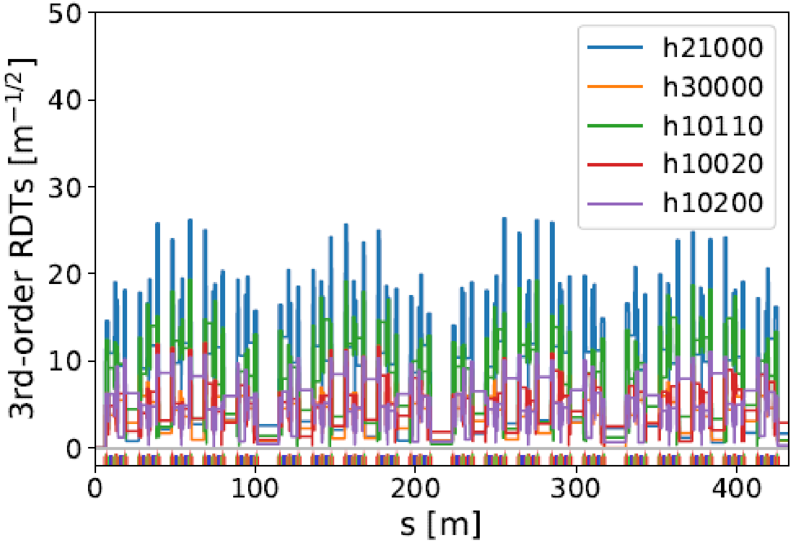
Correlation between low- and higher-order RDTs

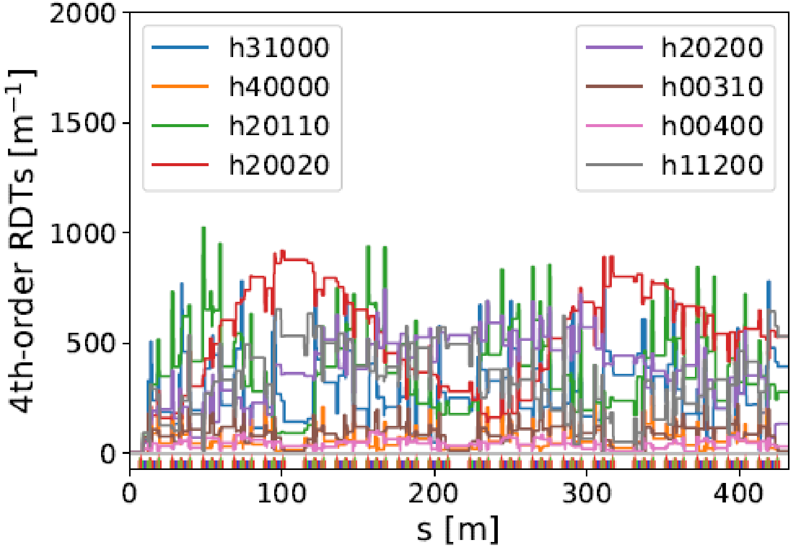
1st nonlinear solution: larger RDT fluctuations





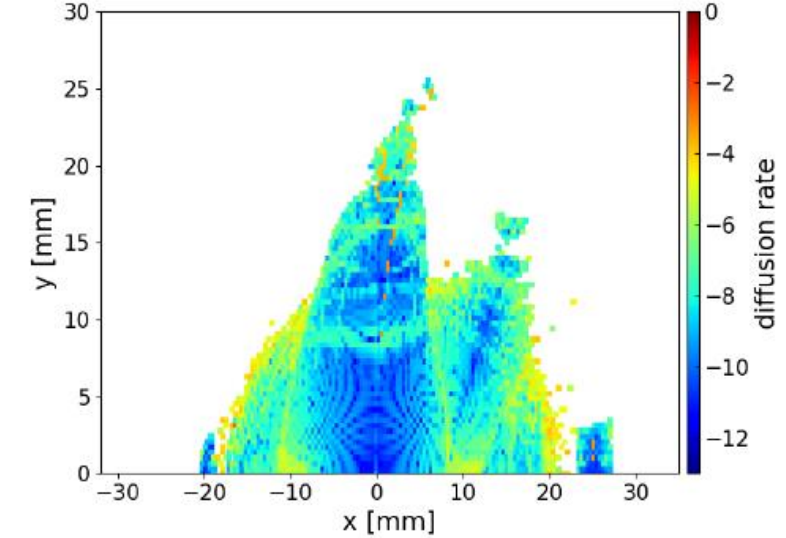
2nd nonlinear solution: smaller RDT fluctuations

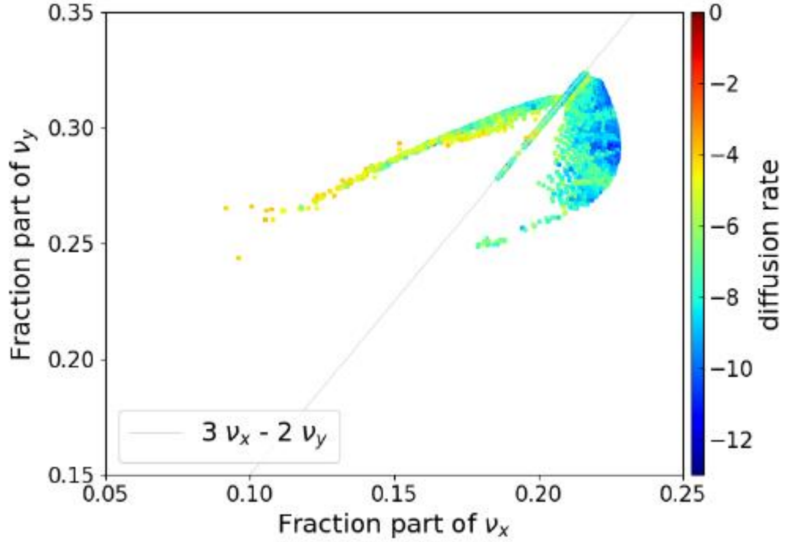




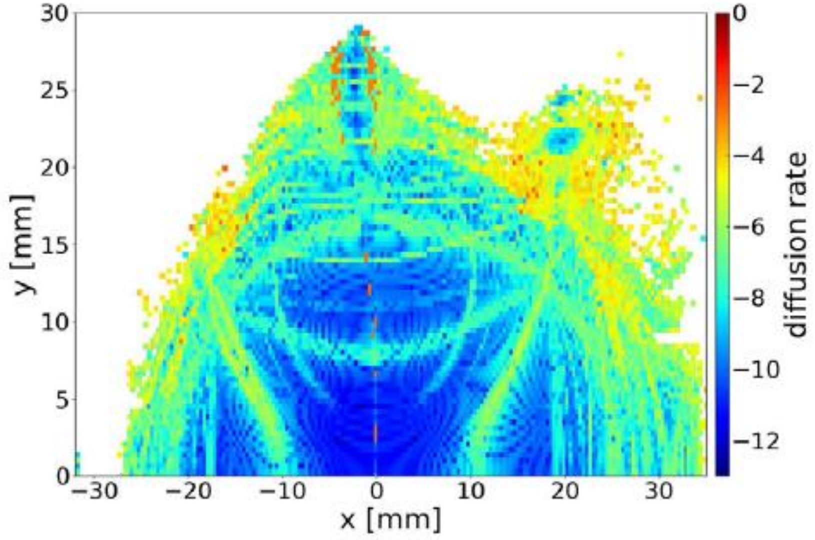
Correlation between low- and higher-order RDTs

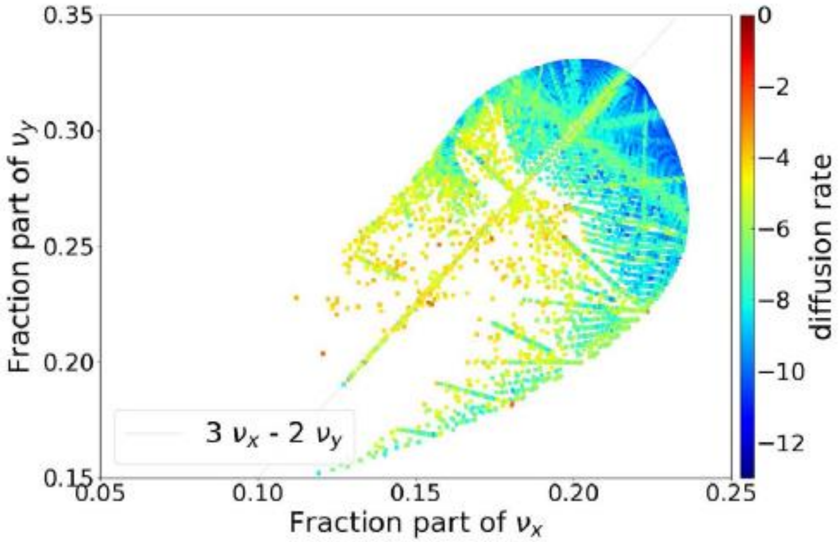
1st nonlinear solution: larger RDT fluctuations





2nd nonlinear solution: smaller RDT fluctuations

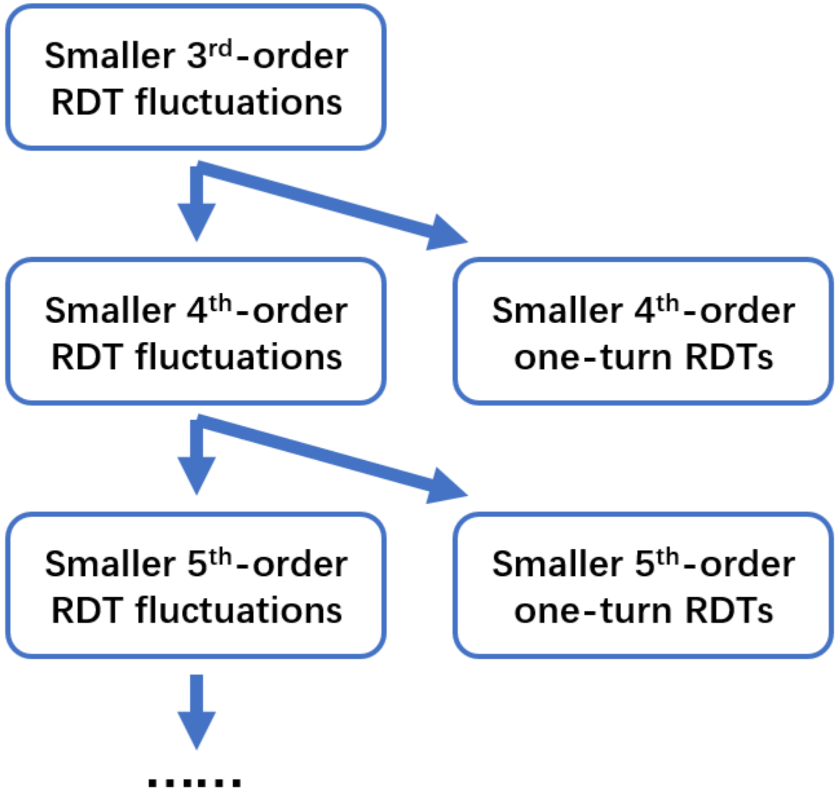




Physics behind minimizing RDT fluctuations

- Reducing low-order RDT fluctuations can help reduce higher-order and even higher-order RDTs.

- Based on minimizing RDT fluctuations, it would not be necessary to calculate higher-order RDTs in DA optimization.
  - For RDTs higher than 4th-order, they are not only more computationally complicated but also more numerous.



Schematic of the correlation between low- and higher-order RDTs.

Optimizing DA based on minimizing RDT fluctuations

- Lattice example:
  - SOLEIL II TDR lattice
  - Tens of sextupole and octupole families

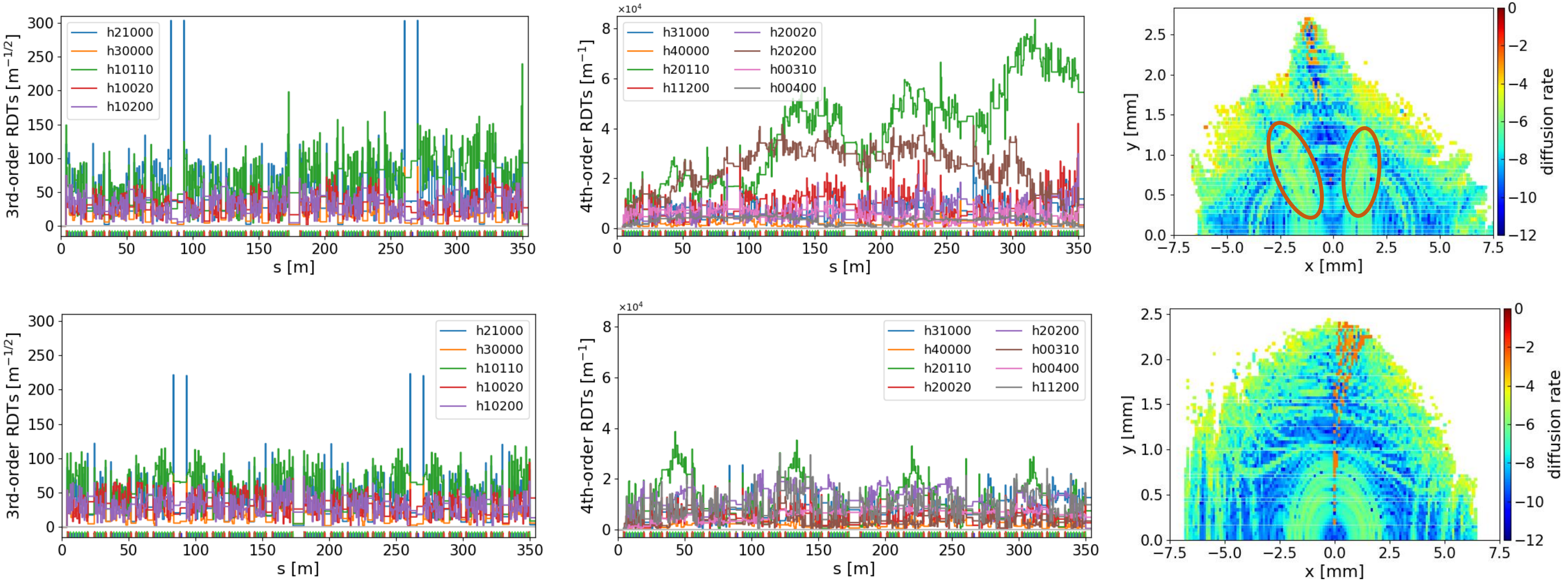
- The on-momentum DA was preliminarily optimized based on numerically minimizing RDT fluctuations using genetic algorithms.

- The optimization was performed very fast as compared to the tracking-based numerical approach.

- Compared to the reference solution, the optimized solution has smaller RDT fluctuations and its horizontal DA is larger in the negative direction, where the beam is injected; and the optimized solutions also has lower diffusion rates.

Optimizing DA based on minimizing RDT fluctuations

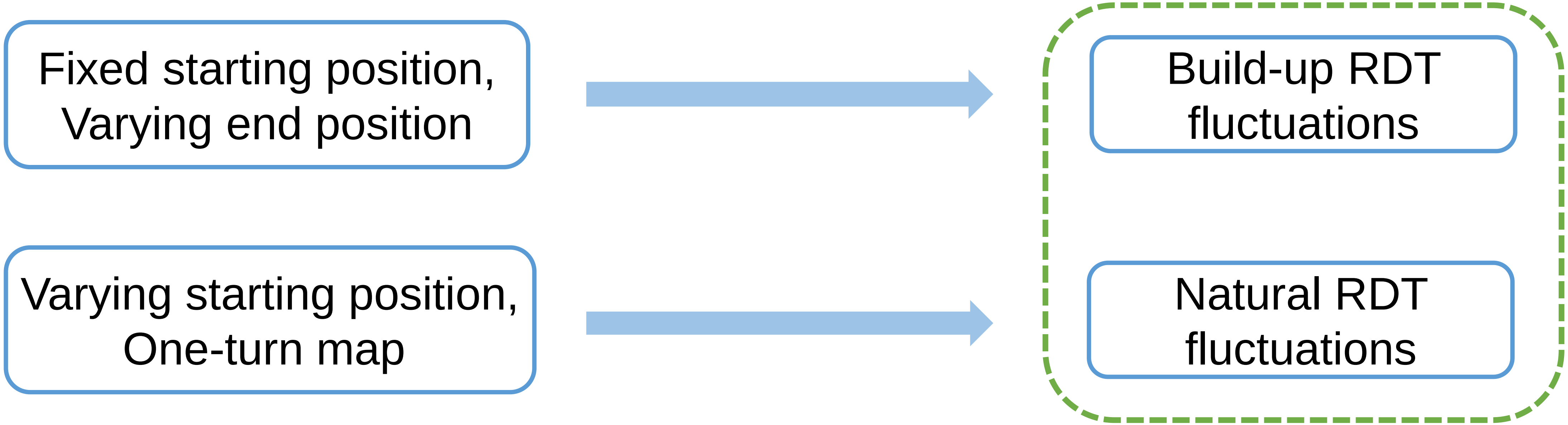
- Reference solution (top) & optimized solution (bottom)



3rd- and 4th-order RDT fluctuations and on-momentum DAs of the reference and optimized solutions.
Z. Bai, et al., FLS2023, TU1B4.

Computing RDT fluctuations on AT

- The above computation of RDT fluctuations is based on our Python code: SimpleStorageRing. Recently we implemented it on AT.



The build-up RDT fluctuations and the natural RDT fluctuations are related; both can be used in the nonlinear optimization (B. Wei, et al., PRAB, 26, 084001 (2023)).

Computing RDT fluctuations on AT

[RDT, buildup_fluctuation, natural_fluctuation] = computeRDTfluctuation(ring, varargin)

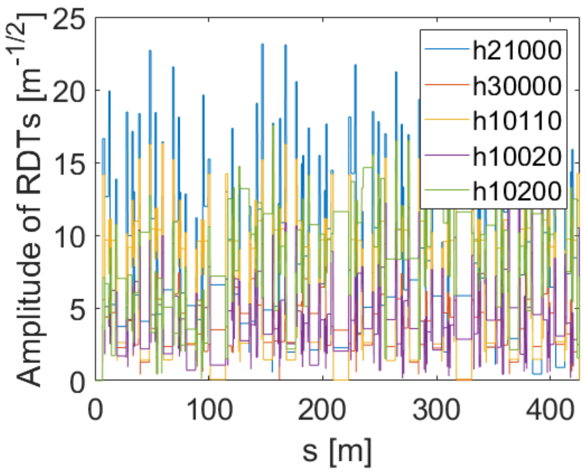
The additional arguments:

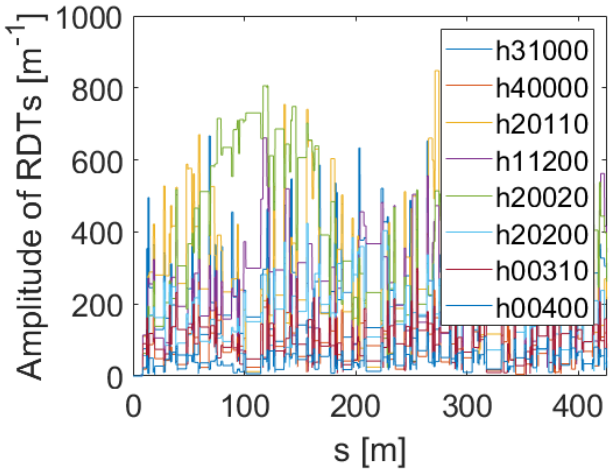
  nslices: number of slices of each sextupole, which affects the crossing terms.

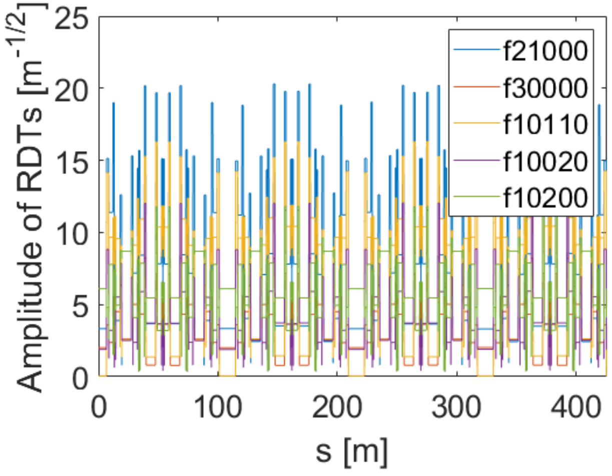
  nperiods: number of periods, which is used to compute multi-period RDTs.

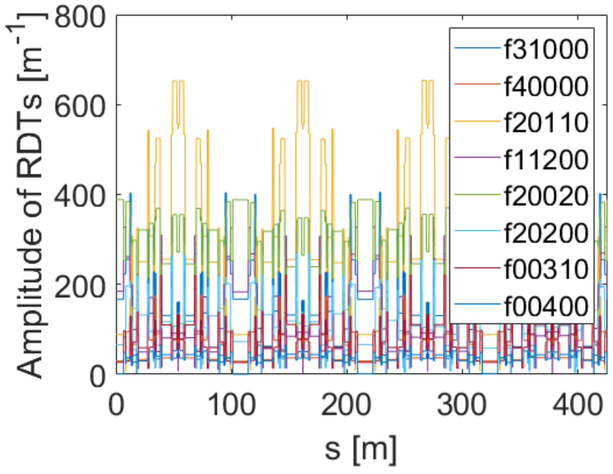
RDT: struct, one-turn RDT and ADTS terms.

buildup_fluctuation and natural_fluctuation: a struct of arrays.



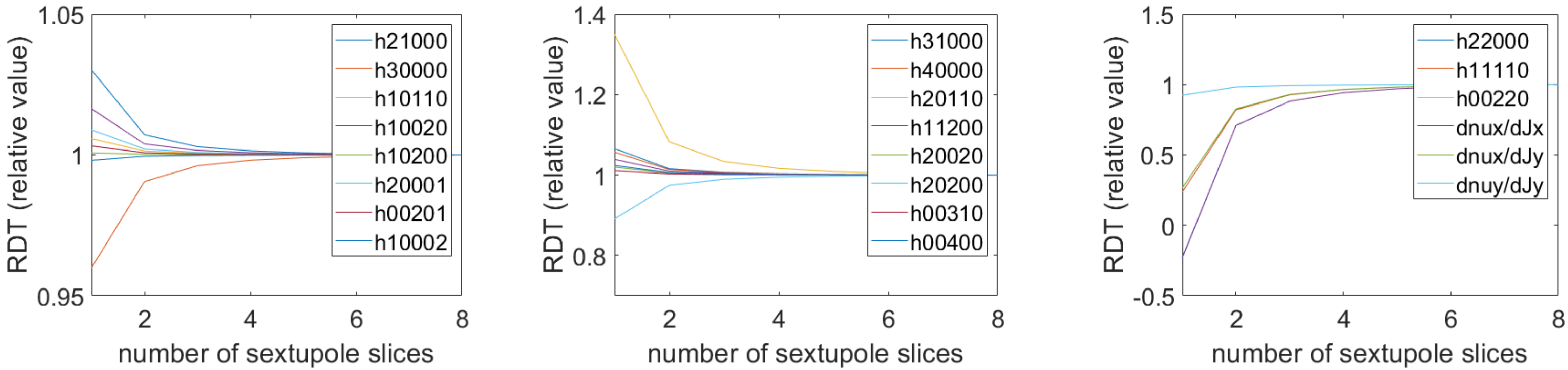






Computing RDT fluctuations on AT

- The number slices significantly affects the result of crossing terms.



- After slicing sextupoles, the number of magnets become large. In our computation, the 3rd-order RDT fluctuations are recorded, which can much reduce the computation of 4th-order RDT fluctuations.

$$\sum_{j>i=1}^{N}[\hat{V}_i,\hat{V}_j] = \sum_{j=2}^{N}\left[\sum_{i=1}^{j-1}\hat{V}_i\,,\hat{V}_j\right]$$

Conclusion

- Minimizing the fluctuation of RDTs along the longitudinal position is much more effective than minimizing the commonly-used one-turn RDTs in enlarging the DA.

- Based on minimizing RDT fluctuations using genetic algorithms, large DA solutions with low diffusion rates can be found very fast.

- The computation of RDT fluctuations was recently implemented on AT, which can be combined with genetic algorithms to optimize the DA.

Thank you for your attention!