Simulations with CSR

CSR study group:
D. Zhou, T. Yoshimoto, Y. Seimiya, M. Kikuchi, N. Iida

Acknowledgments

N. Nakamura, M. Shimada, K. Oide

Beam Injection TF meeting, Jun. 17, 2022, KEK

Status of CSR simulations

- Lots of work has been done by Y. Seimiya, T. Yoshimoto, M. Kikuchi, and N. Iida on simulations with RF wakes, CSR, and ISR (sorry that I did not follow well).
- I joined the simulations in Dec. 2021 (sorry that it was so late).

- We created a small CSR study group (N. Iida, M. Kikuchi, D. Zhou, T. Yoshimoto, Y. Seimiya) and had three meetings (and lots of collaborative work). The meetings were very effective and very fruitful discussions were done.
  - Mar. 28, 2022, https://kds.kek.jp/event/42188/.
  - Apr. 28, 2022, https://kds.kek.jp/event/42189/.
  - May. 18, 2022, https://kds.kek.jp/event/42391/.

- We achieved good agreements in benchmark simulations. Finally, we could draw conclusions on the CSR issues at the BTe.
- This talk summarizes the findings of the CSR study group.
- I also give some comments on recent progress and on future investigations.

Benchmark simulations

- ELEGANT simulations developed by T. Yoshimoto

- SAD scripts developed by T. Yoshimoto
  - Parallel-plates model for CSR
  - RF wake model (Lumped model and distributed model)

- SAD scripts developed by D. Zhou
  - CSRZ model for CSR
  - Parallel-plates model for CSR
  - RF wake model (Distributed model, WakeFunction same as Yoshimoto-san’s with his help)

- Benchmarks between SAD simulations
  - CSR wakes
  - Longitudinal bunch profile
  - Emittance growth

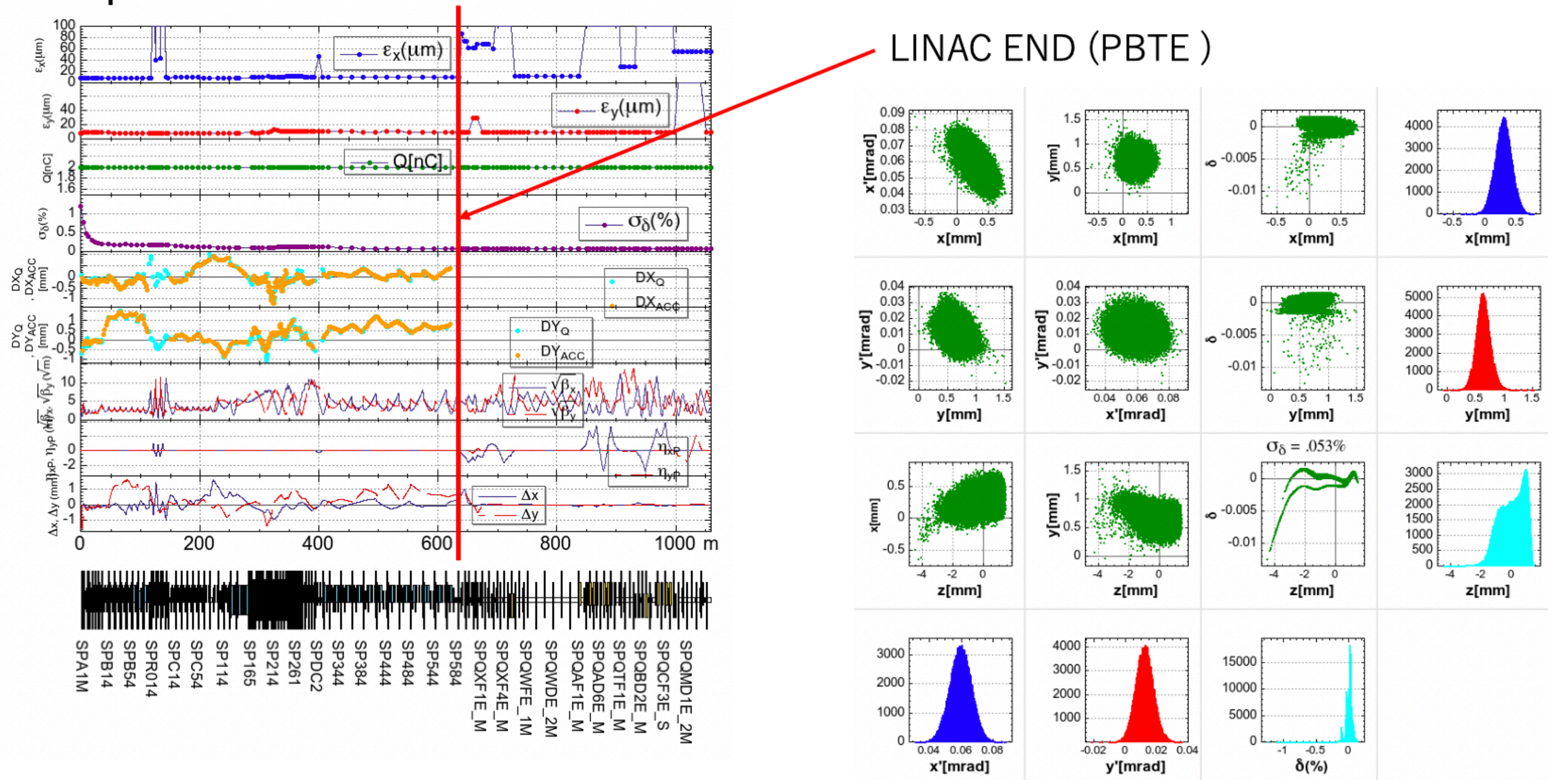
Simulations starting from PBTE

- Initial distribution at PBTE provided by Y. Seimiya

LINAC END beam particles (PBTE)

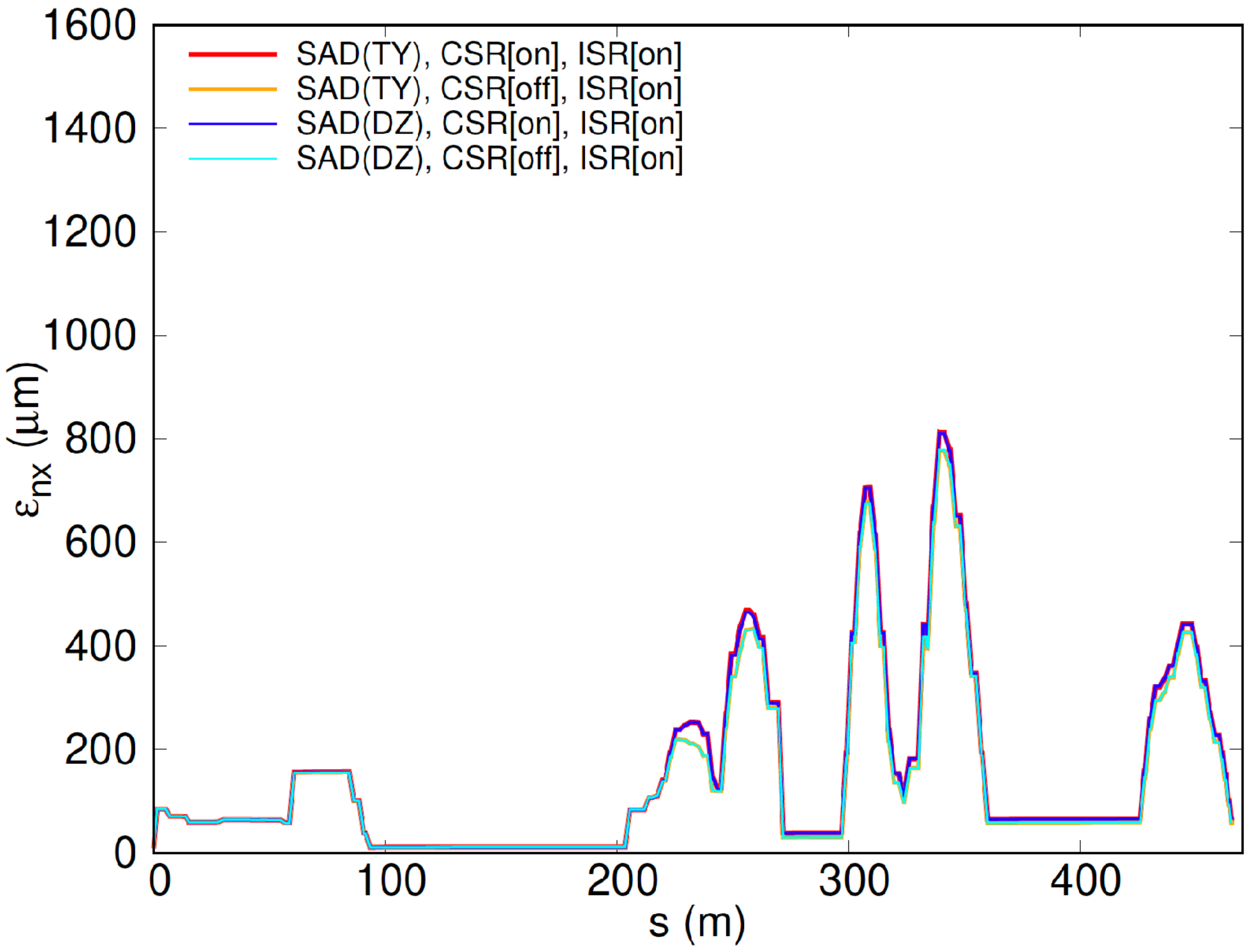
Courtesy of Y. Seimiya

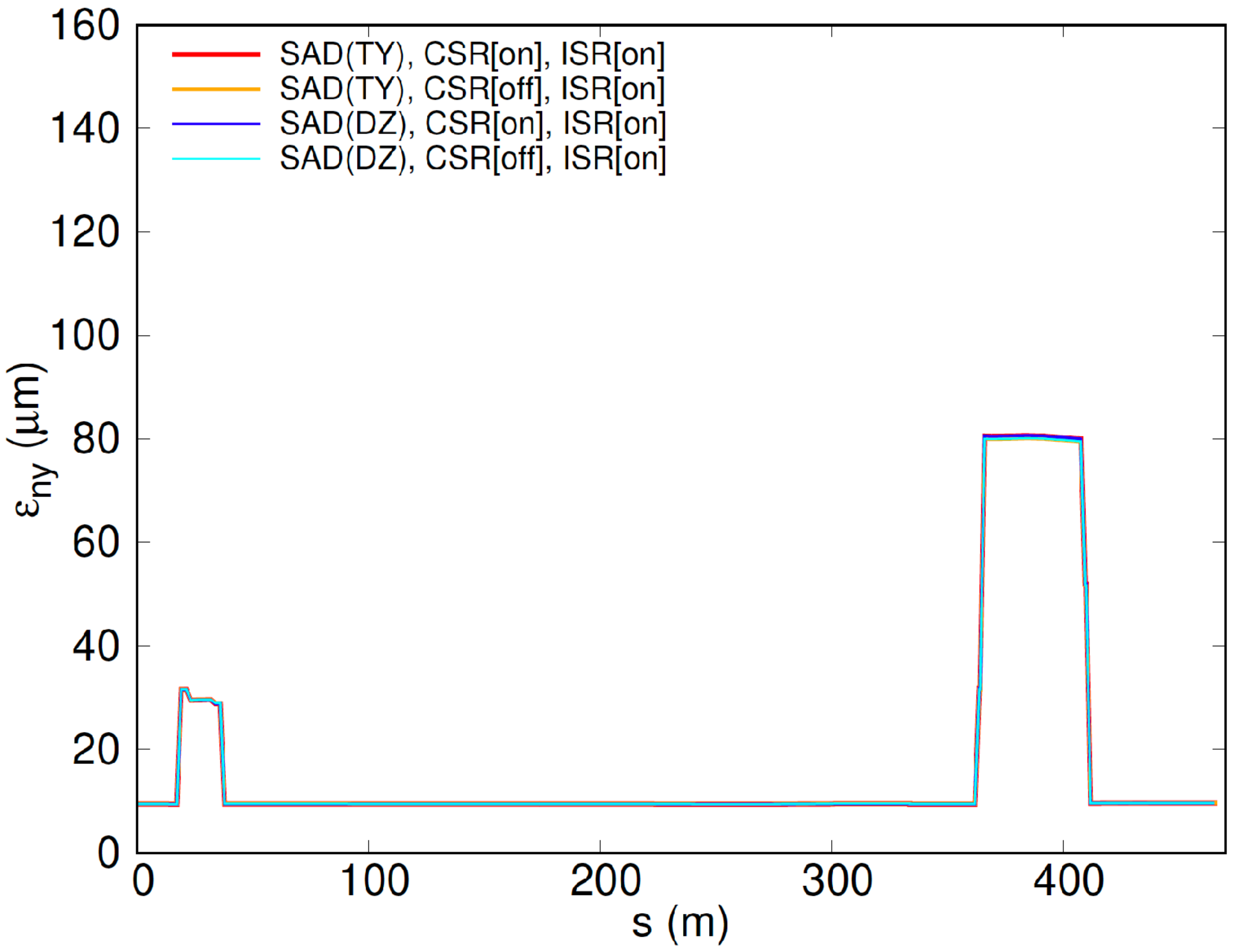
- # of particle @SPA1M = 1e5



Simulations starting from PBTE

- Tracking w/ CSR: Very good agreements in the results by D. Zhou and T. Yoshimoto
- Important conclusion:
  - CSR effects are relatively weak and depend on the initial beam distribution

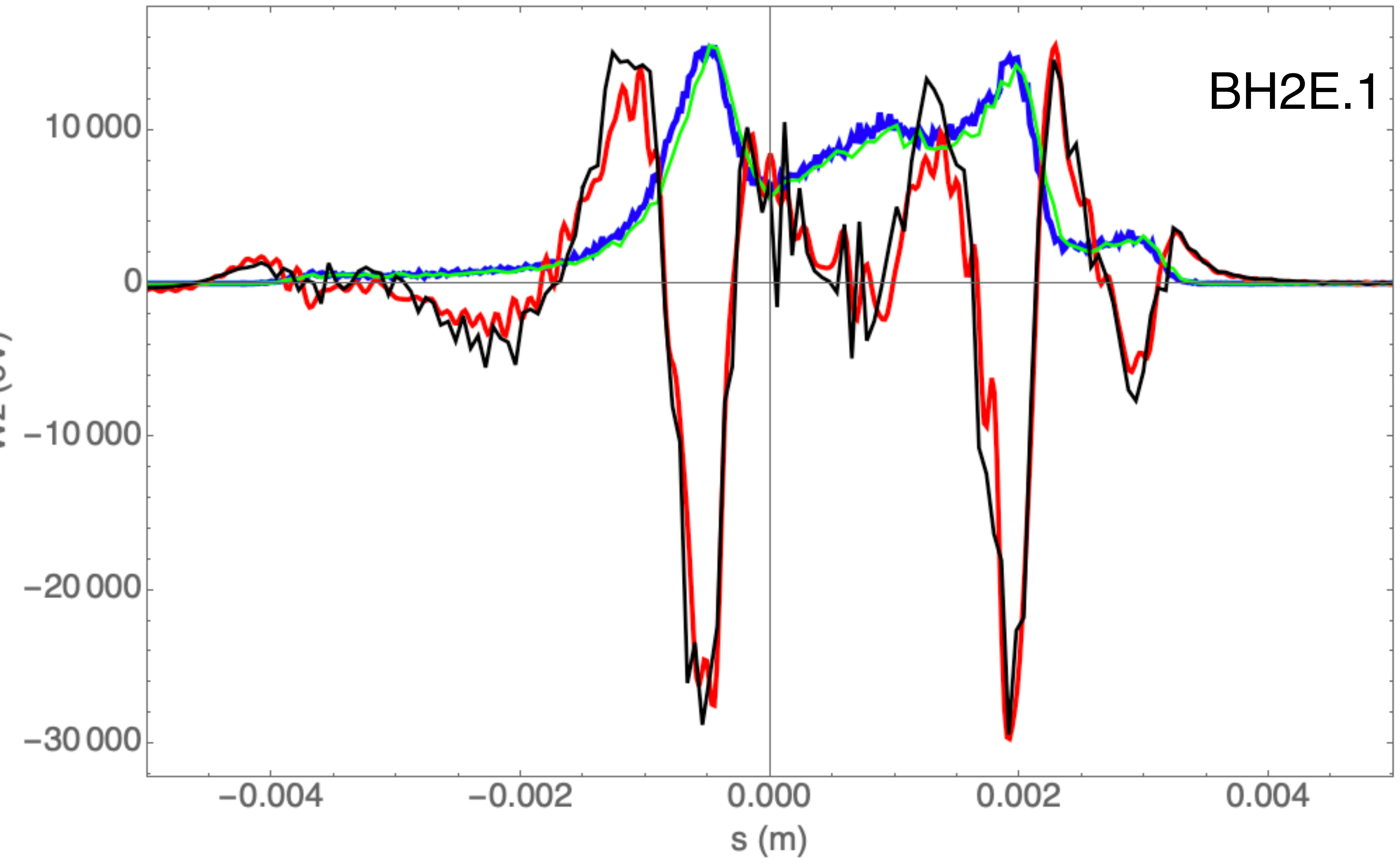


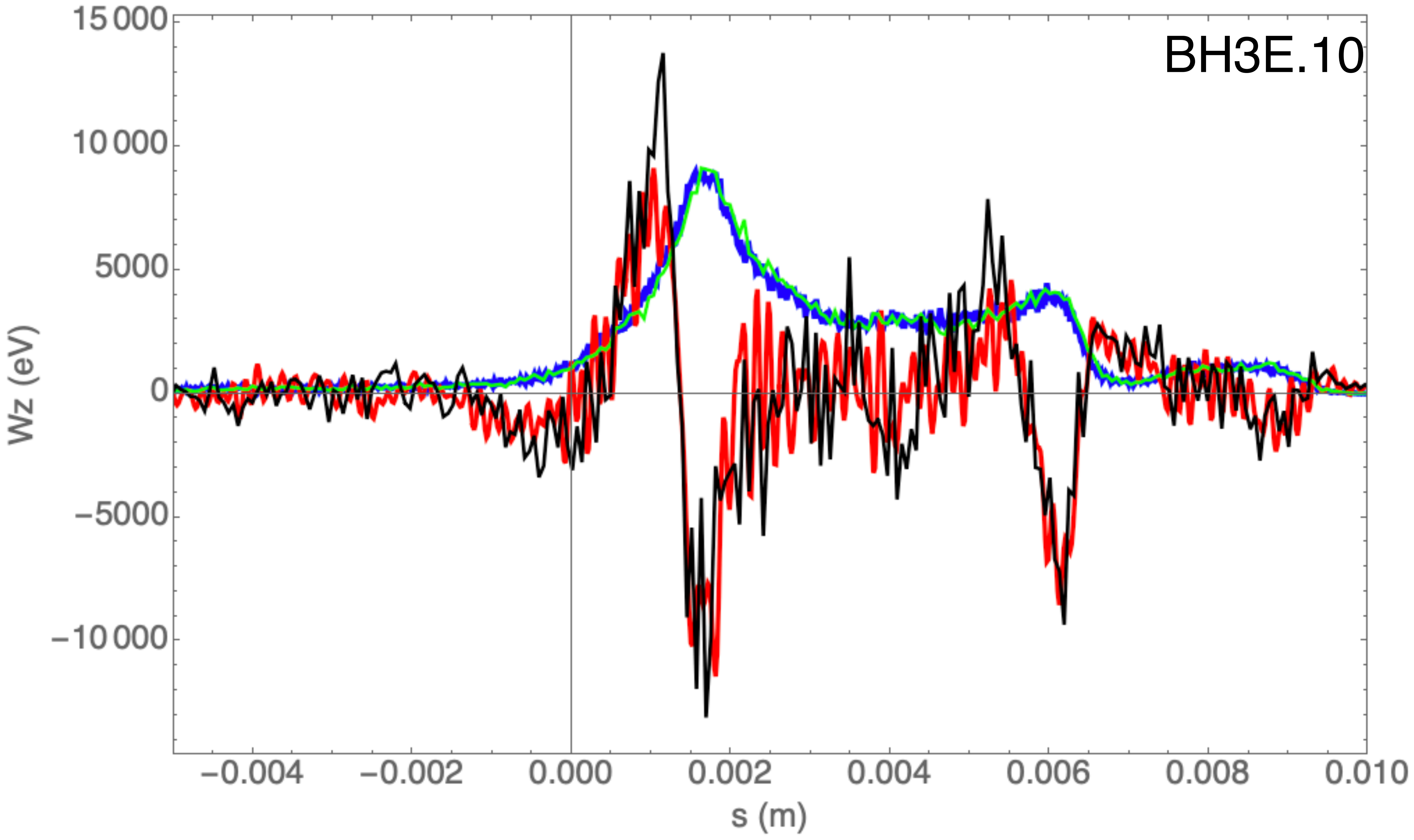


Simulations starting from PBTE

- CSR wakes at BT03 (Ebeam=7 GeV).

Blue: z-profile (DZ)
Green: z-profile (TY)
Red: CSR wake (DZ)
Black: CSR wake (TY)

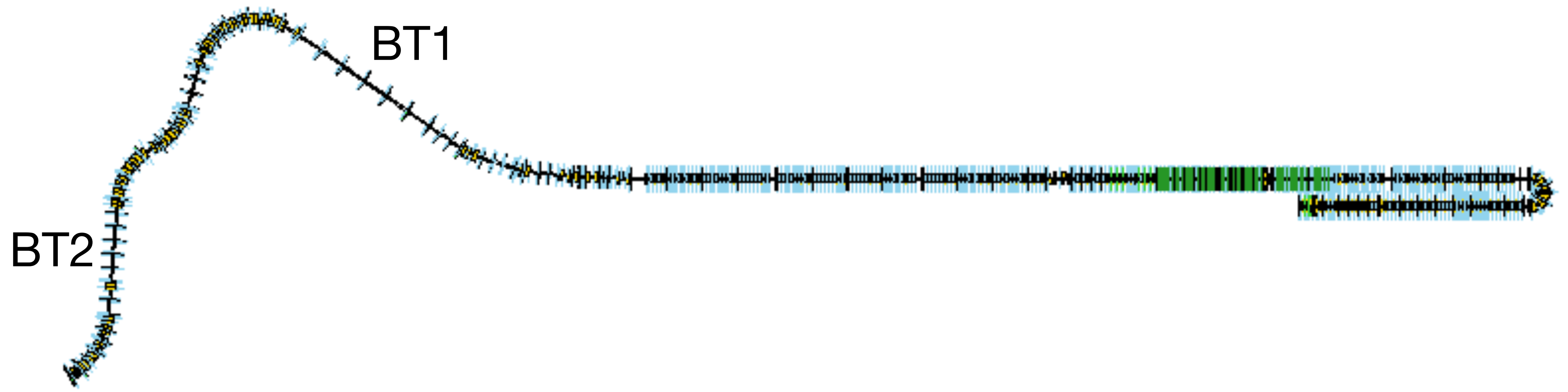


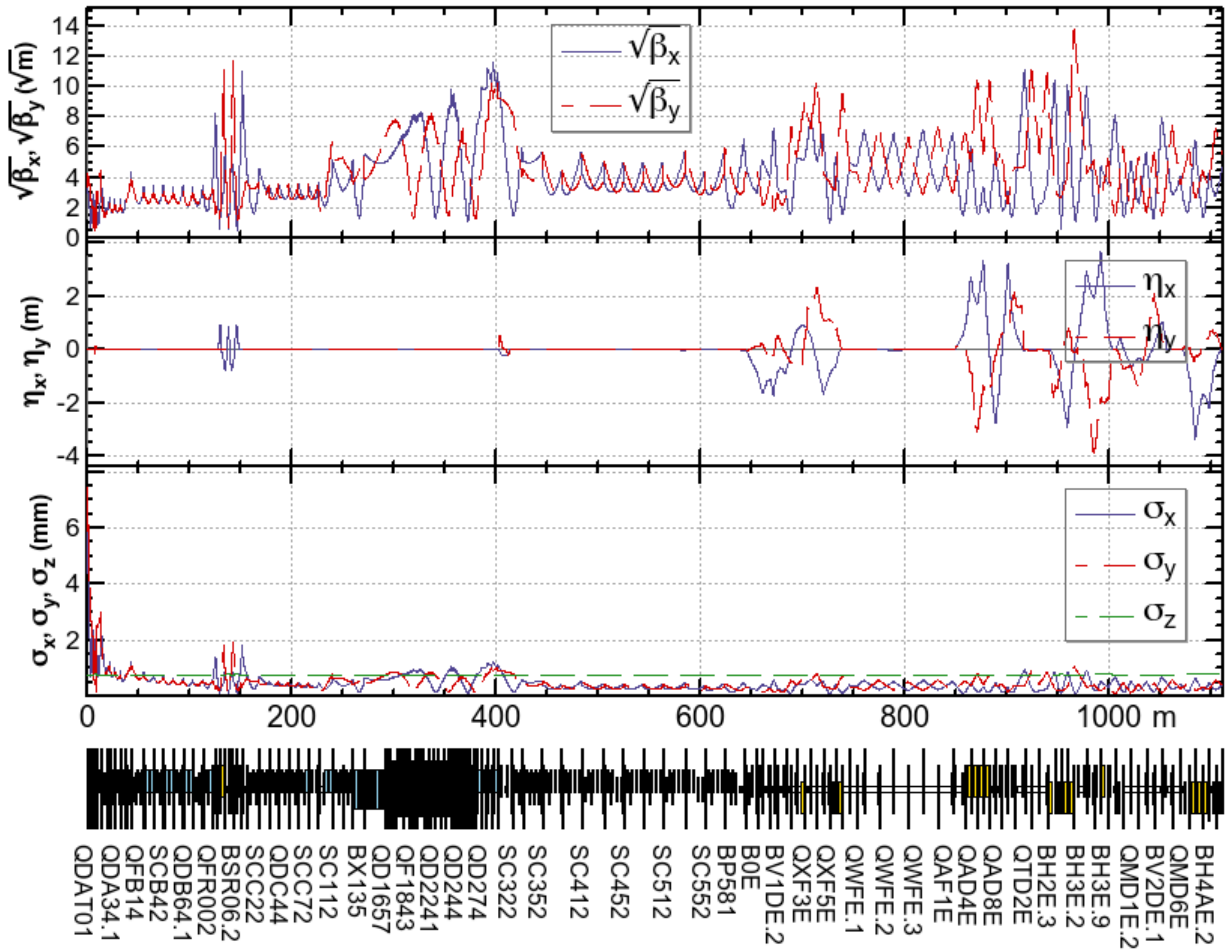


Simulations starting from PATGUN

BTe layout and initial beam parameters

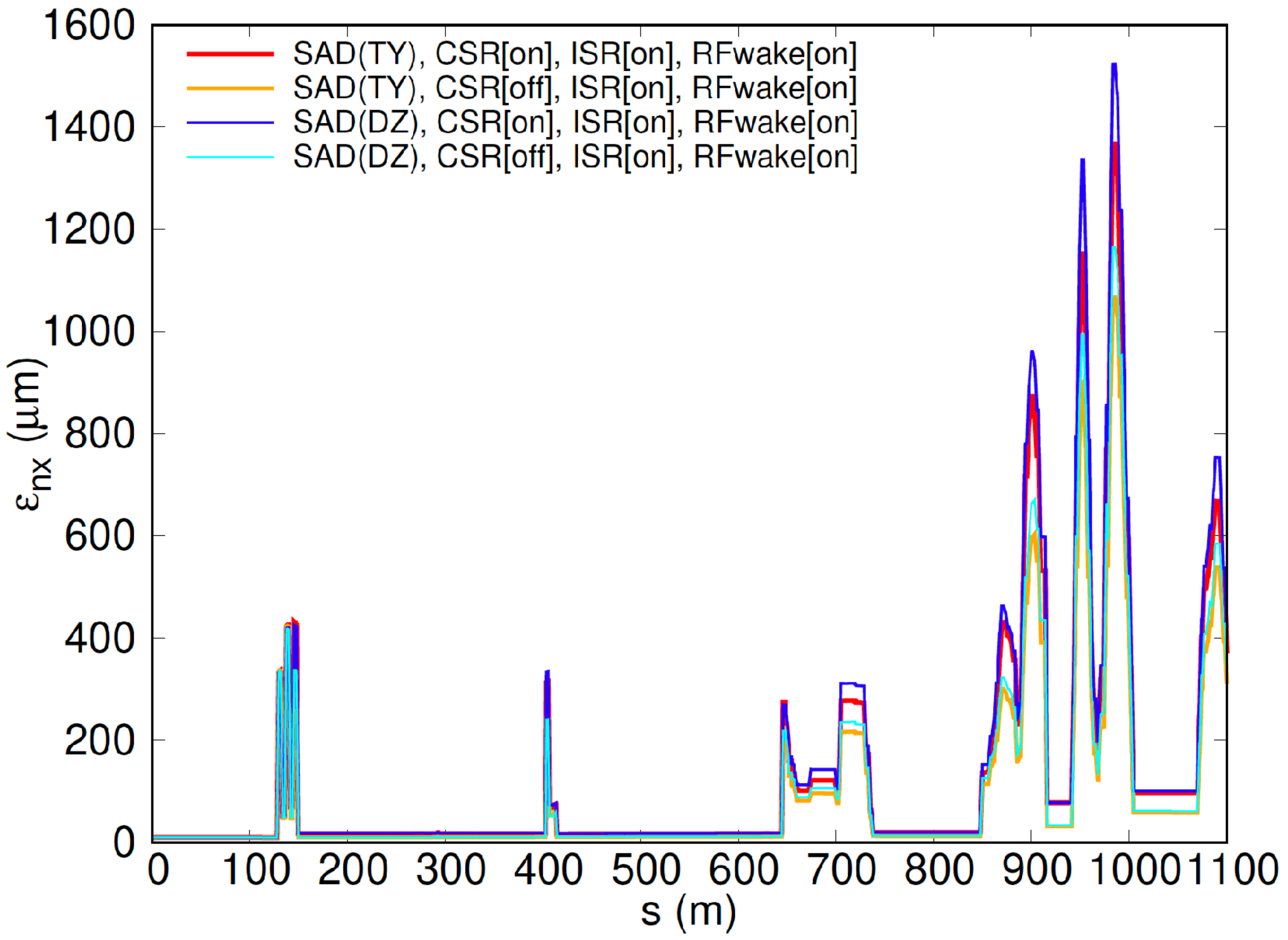
- SAD deck file from T. Yoshimoto.
- Beam line starts from PATGUN.
- Initial beam parameters (following T. Yoshimoto):
  - Initial transverse normalized emittances: $\epsilon_{xn} = \epsilon_{yn} =$ 10.e6 m.
  - Initial bunch length: $\sigma_z = 0.9$ mm.
  - Initial energy spread: $\sigma_p = 1\%$.
  - Bunch charge: 2 nC.
- Number of macro-particles 5e4 for results of following slides.

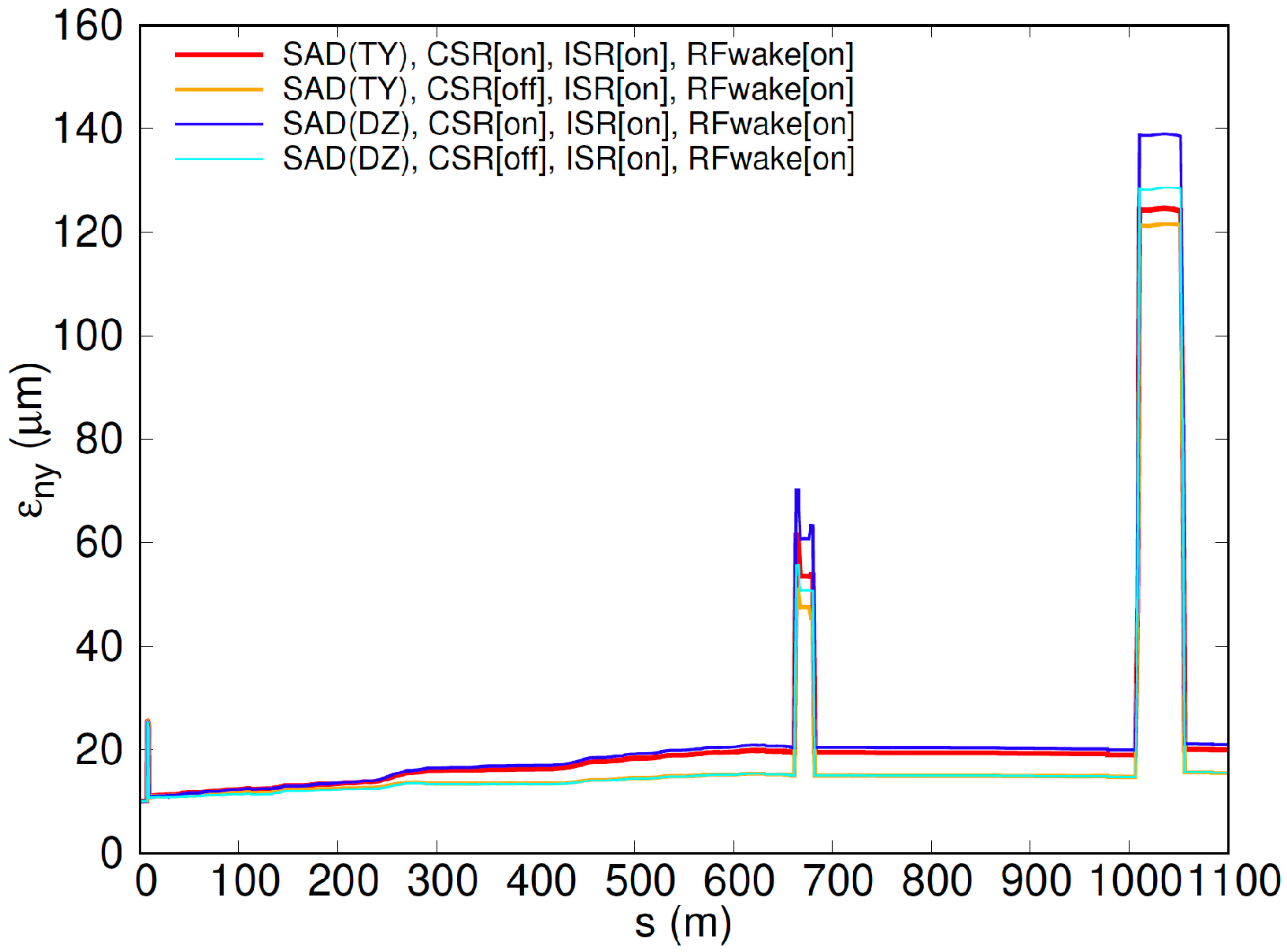




Simulations starting from PATGUN

- Tracking w/ CSR: Good agreement in the results by D. Zhou and T. Yoshimoto
- Important conclusion
  - Tracking simulations show CSR effects are strong at BTe (it was discovered by T. Yoshimoto and confirmed by D. Zhou)

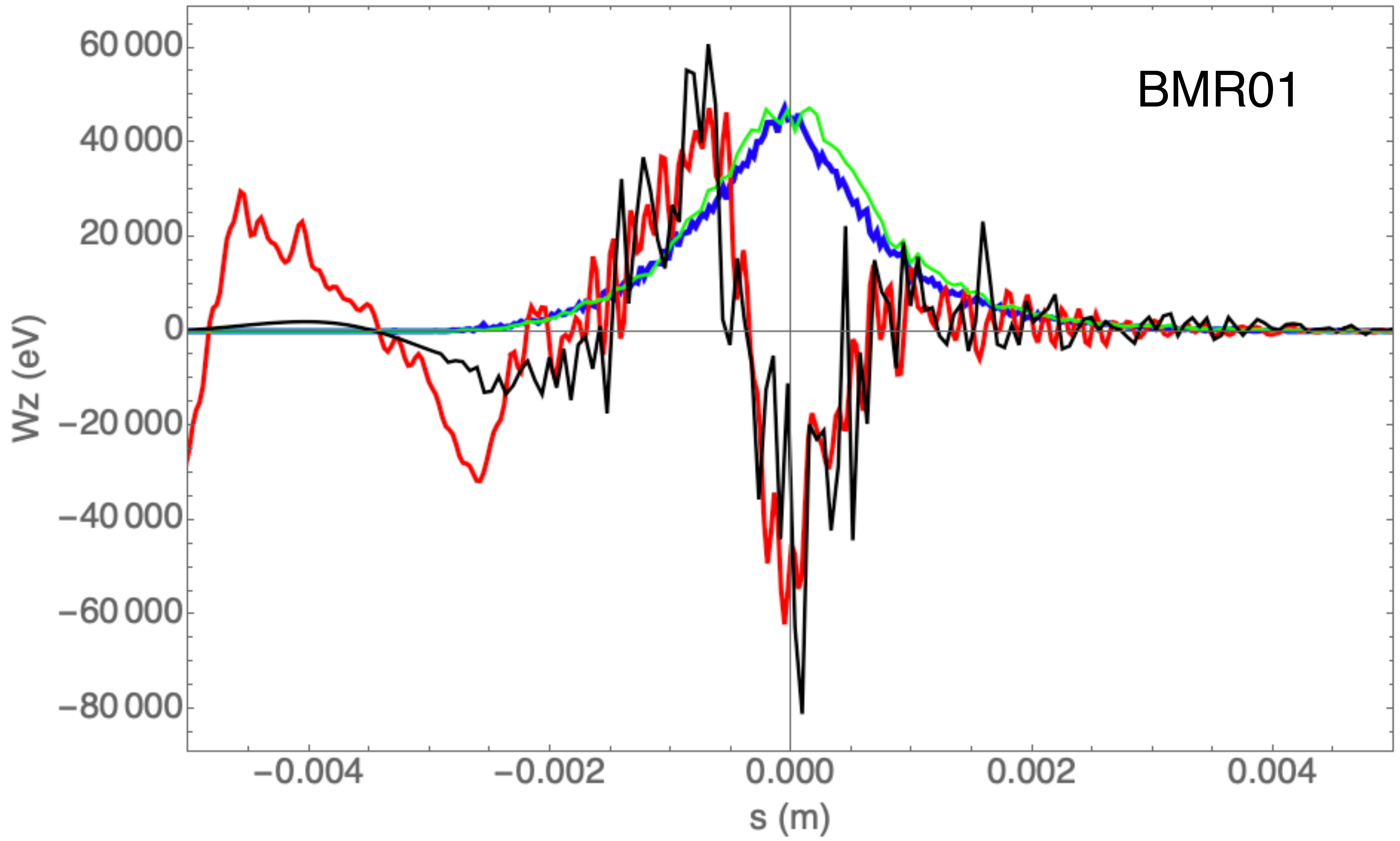


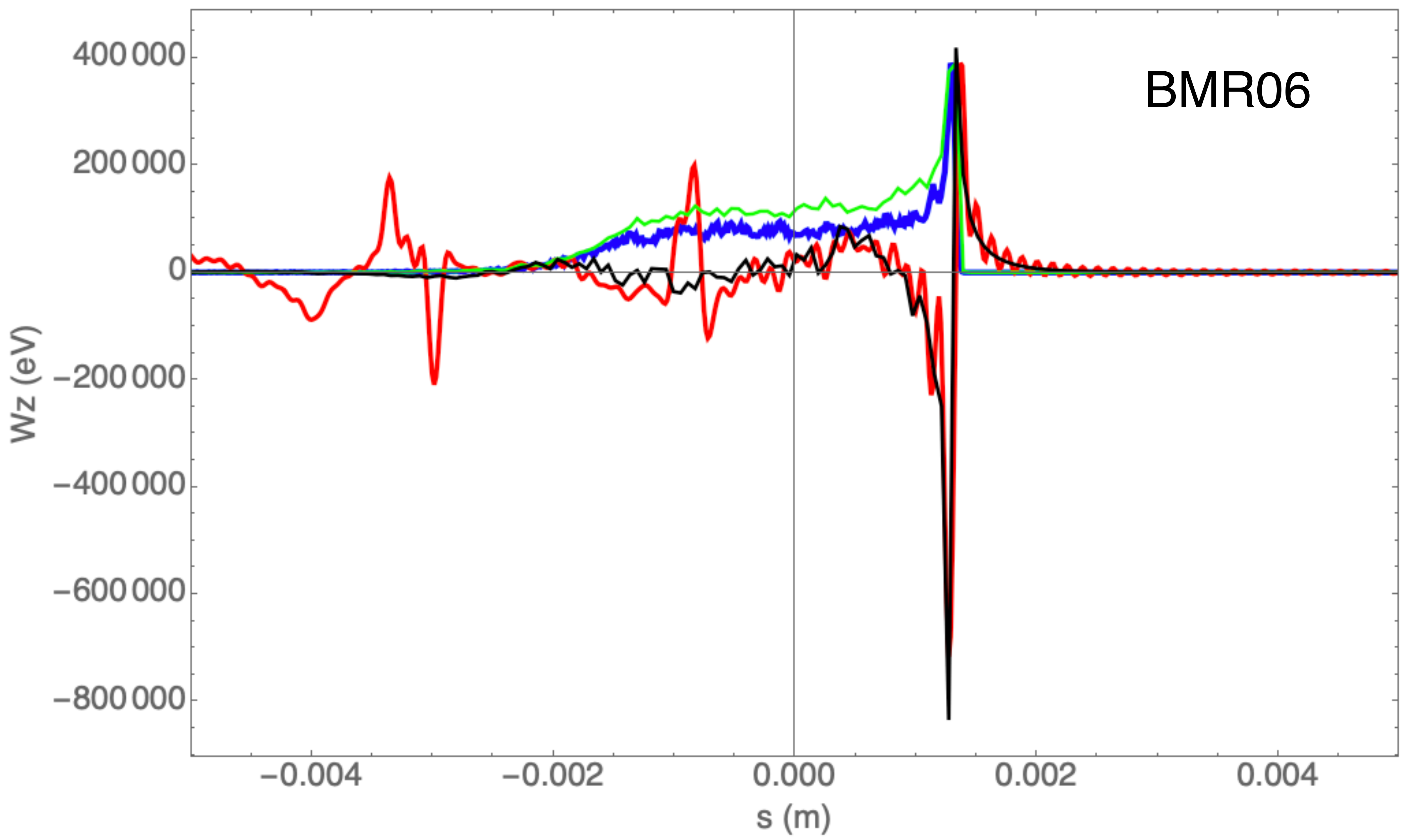


Simulations starting from PATGUN

- CSR wakes at J-ARC (Ebeam=1.5 GeV).
  - CSR effects at J-ARC looks to be strong
  - The steep slope on the head side is the main source of CSR wake at BMR06

Blue: z-profile (DZ)
Green: z-profile (TY)
Red: CSR wake (DZ)
Black: CSR wake (TY)

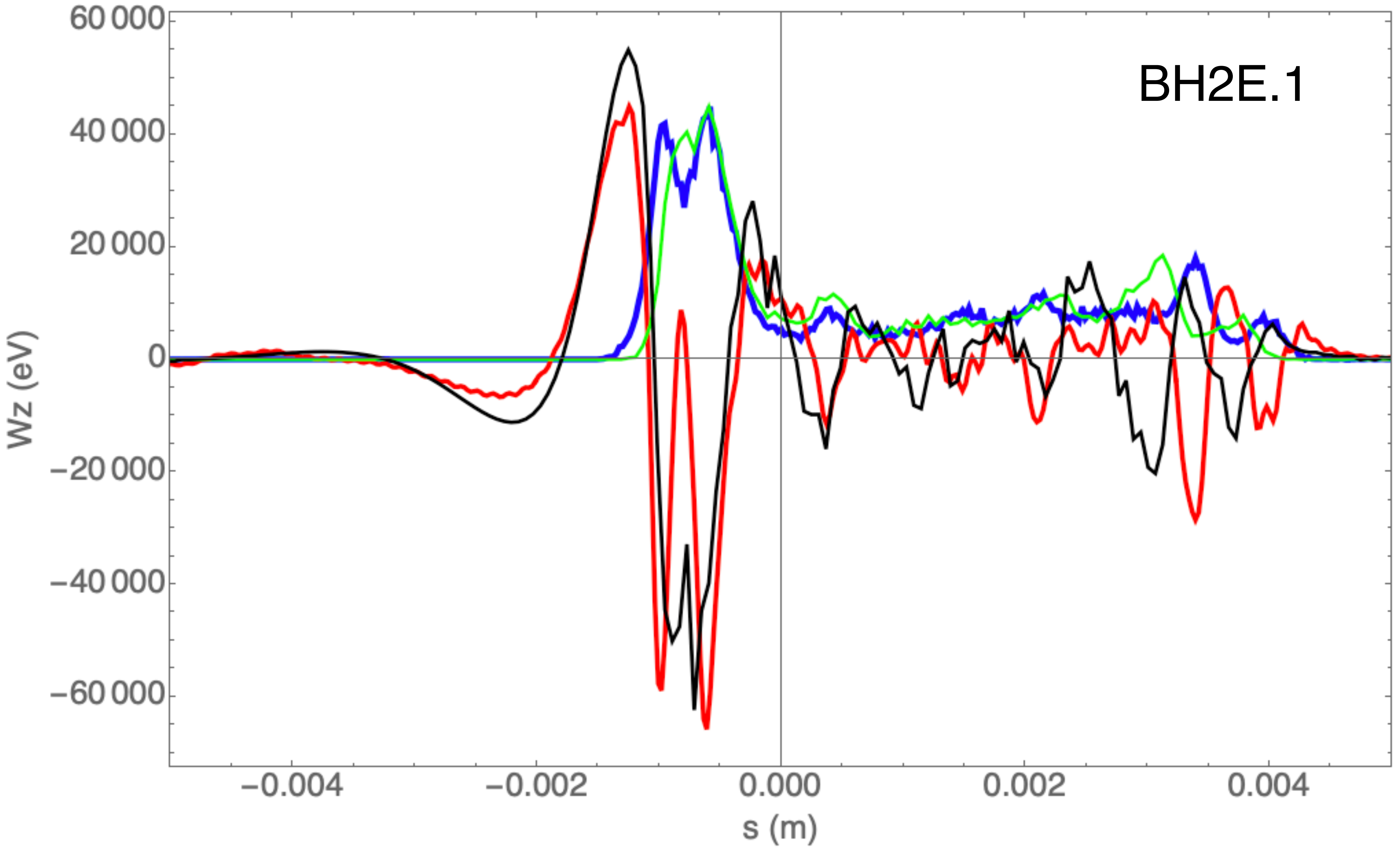


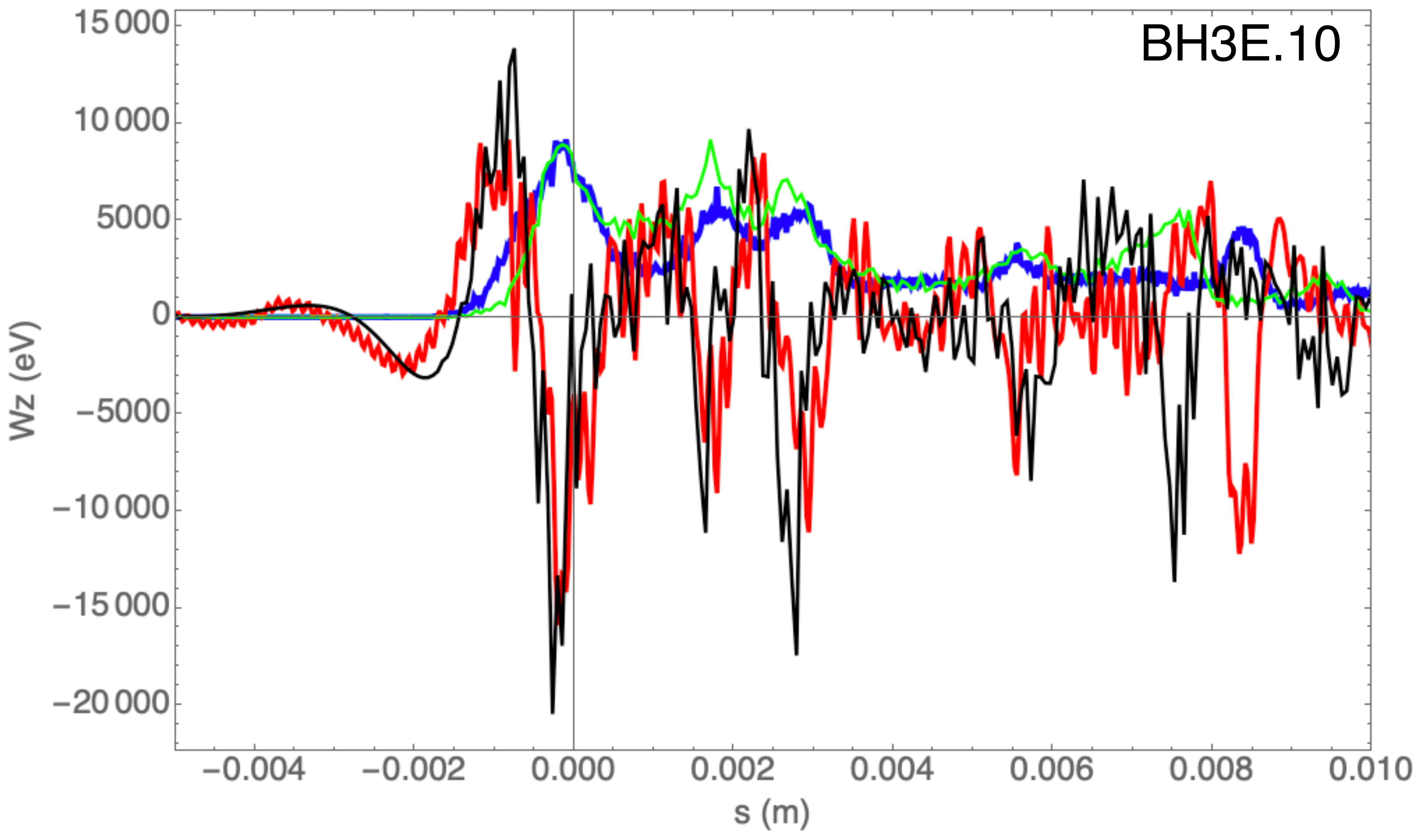


Simulations starting from PATGUN

- CSR wakes at BT03 (Ebeam=7 GeV).

Blue: z-profile (DZ)
Green: z-profile (TY)
Red: CSR wake (DZ)
Black: CSR wake (TY)

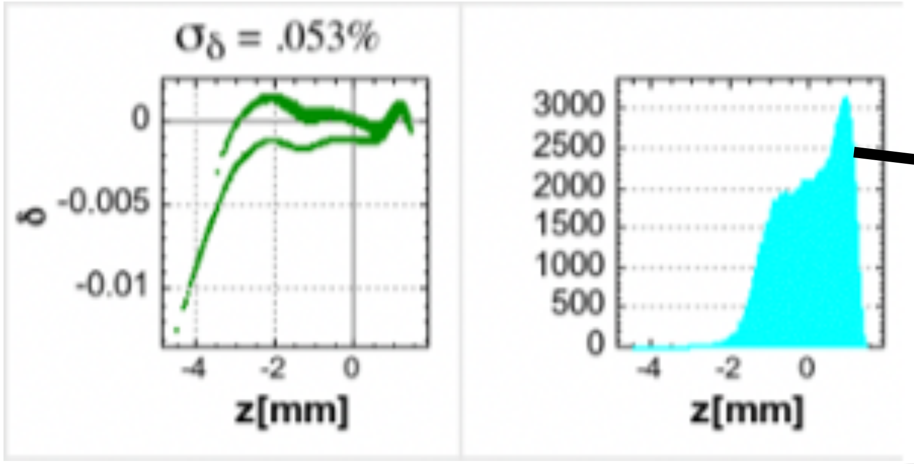




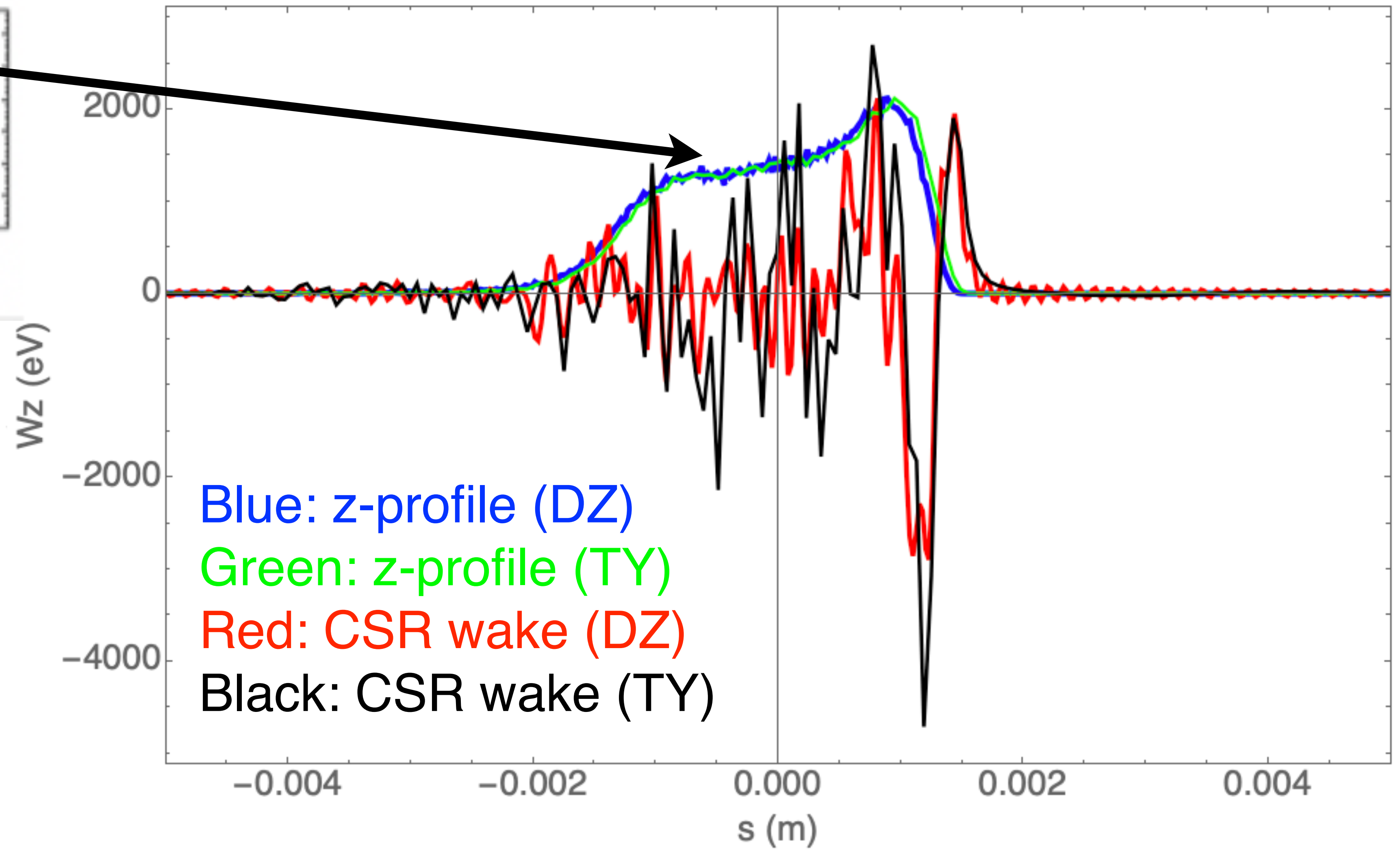
Comparison of simulations starting from PATGUN and PBTE

- CSR wakes at BHD0 (7.1 meters from PBTE, Ebeam=7 GeV).
  - Sorry that our codes do not save data at PBTE.
- The main difference between Yoshimoto&Zhou's and Seimiya's simulation:
  - Comment from Yoshimoto-san: The discrepancy between Yoshimoto&Zhou's and Seimiya-san's distributions at PBTE comes from the dpp_rms of the initial distribution (Zhou, Yoshimoto: 1%, Seimiya: 5%) @ ~10 MeV.
  - Comment from Yoshimoto-san: The realistic initial distribution at ~10 MeV is crucial.

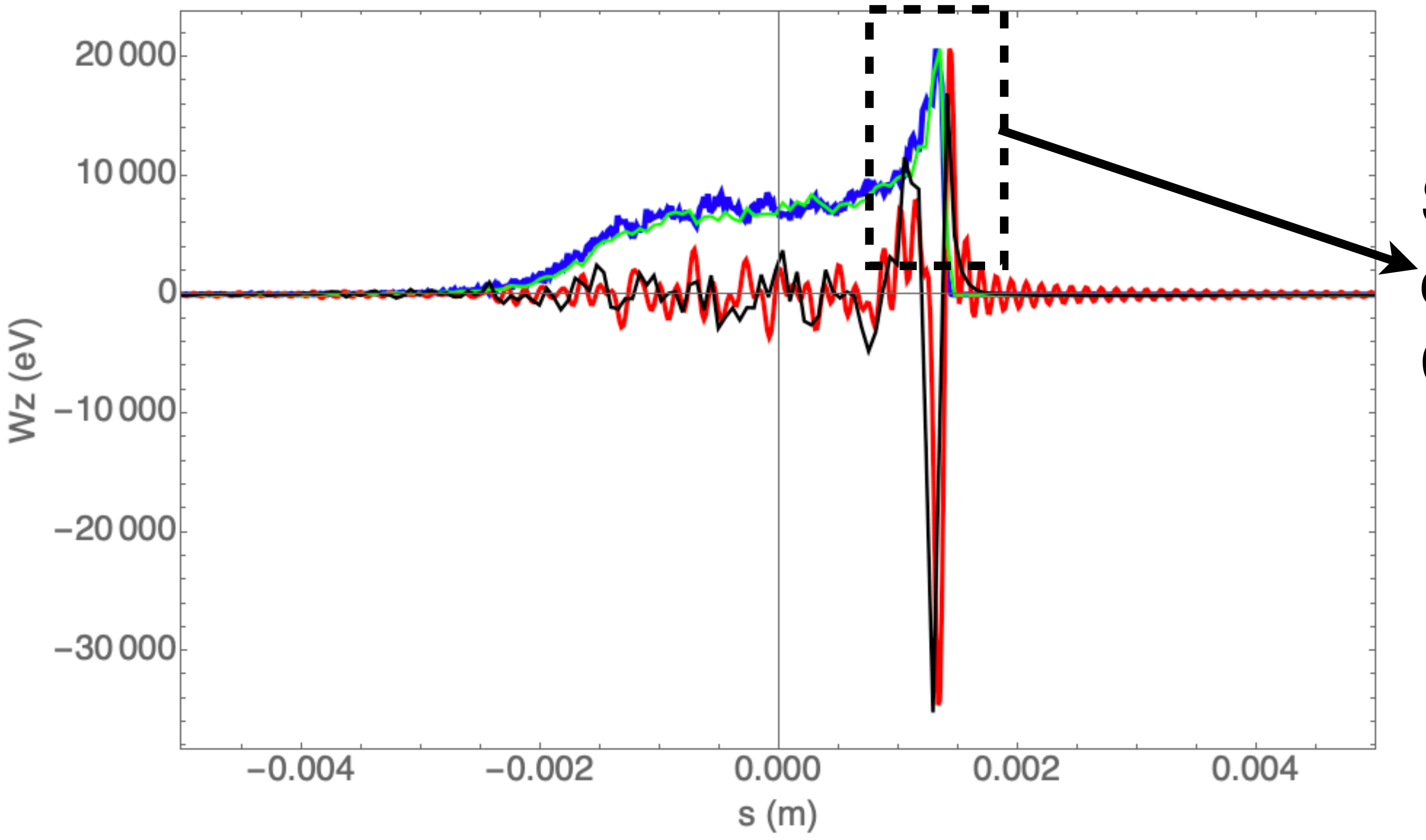
Initial distribution provided by Y. Seimiya



Starting from PBTE
CSR wake and z-profile at BHD0
Initial distribution provided by Y. Seimiya



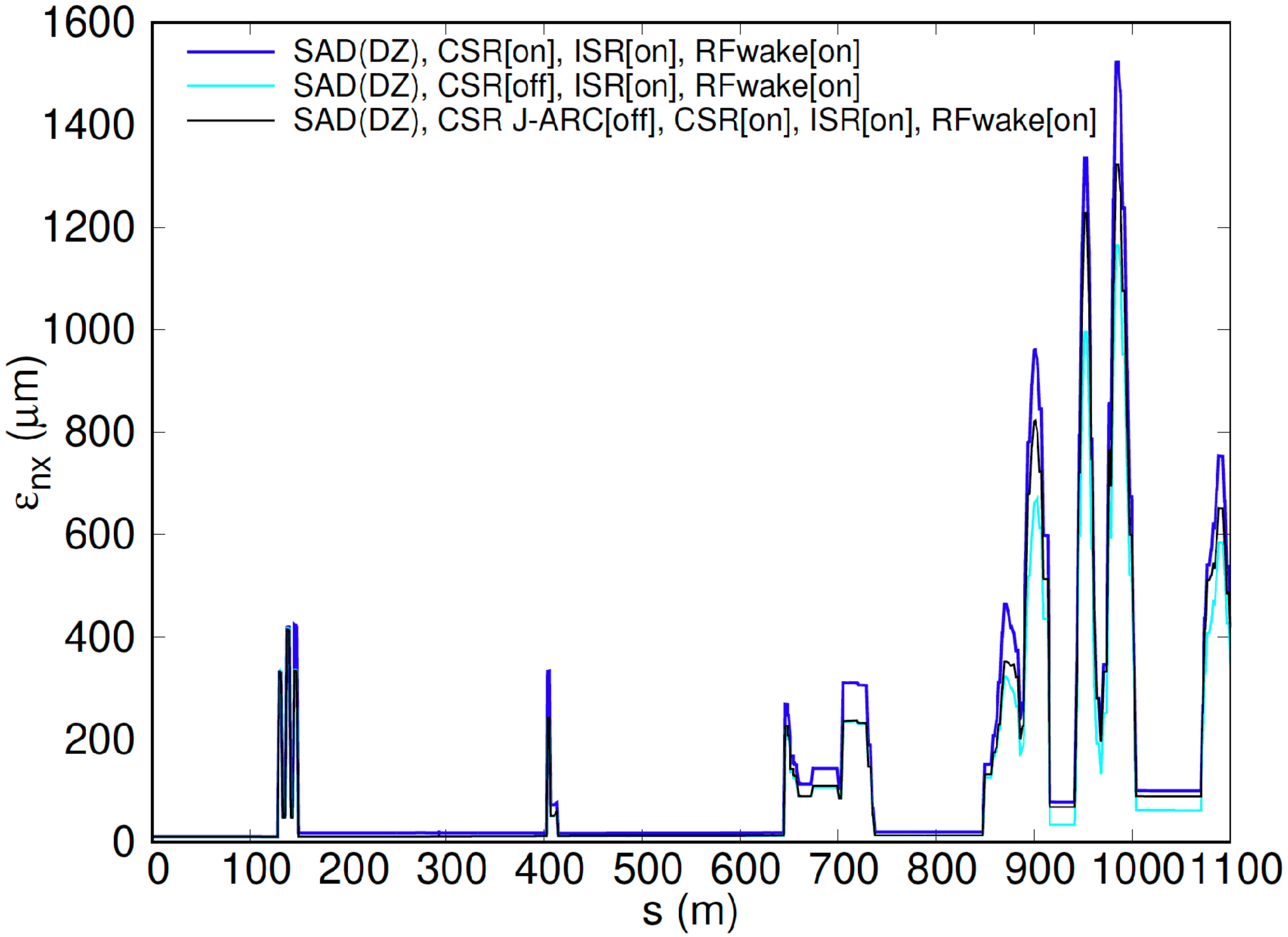
Starting from PATGUN
CSR wake and z-profile at BHD0
Initial distribution as shown on page.8 (Yoshimoto&Zhou)



Sharp shoulder causes stronger CSR

Effects of CSR at J-ARC

- Simulations start from PATGUN. Initial beam distribution is defined on page.8
- Conclusions:
  - Emittance growth at J-ARC propagates to BTe.
  - The longitudinal profile from linac is essential in determining the CSR effects at BTe.
  - The realistic initial distribution at ~10 MeV is crucial (Yoshimoto-san).



Message from Oide-san

- “the original design (of KEKB linac) was done with R56 = 0 from the beginning in 1997. Even R566 is corrected to zero using the sextupoles. Not only in the design, both R56 and R566 were measured and corrected by beam, using streak camera in 1998/1999.”
- Oide-san also pointed to APAC’98 paper by T. Kamitani et al.

BEAM OPTICS MATCHING IN THE KEKB INJECTOR LINAC

T. Kamitani, H. Koiso, N. Akasaka, A. Enomoto, J. Flanagan, H. Fukuma,
Y. Funakoshi, K. Furukawa, N. Iida, T. Ieiri, T. Nakamura,
Y. Ogawa, S. Ohsawa, K. Oide, K. Satoh, M. Suetake, and T. Suwada
KEK, 1-1 Oho, Tsukuba-shi, Ibaraki-ken, 305, Japan

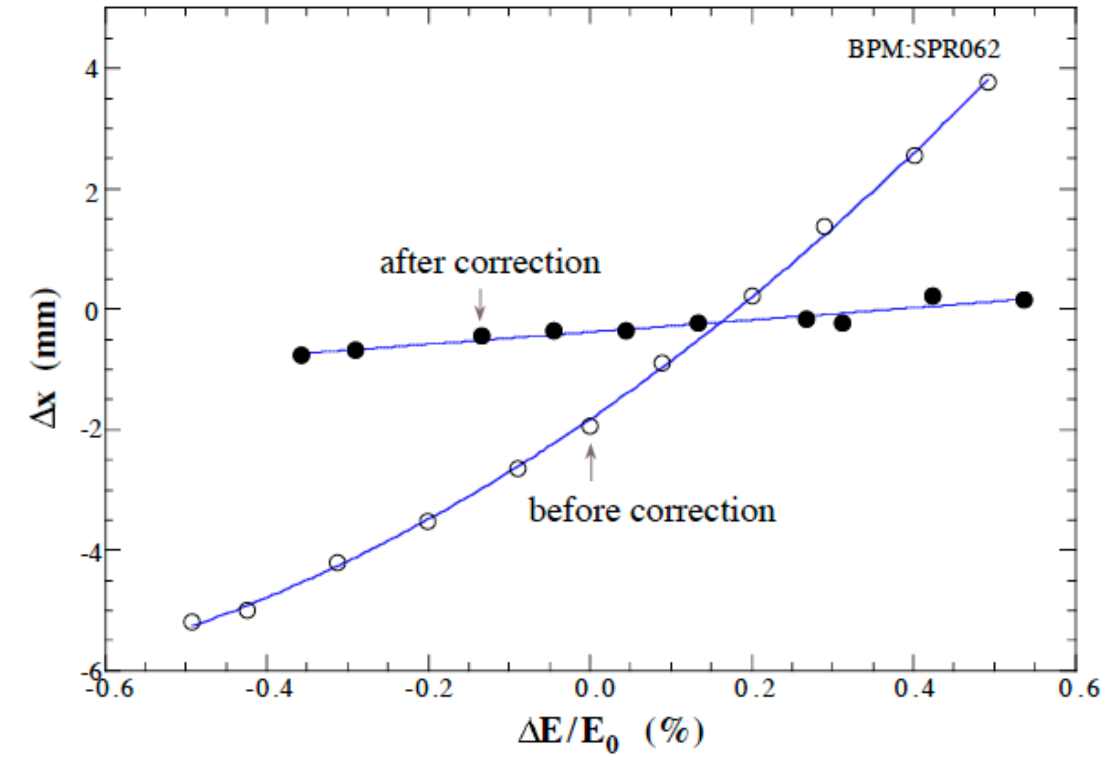


Figure: 7 Dependence of the horizontal orbit on the energy deviation. (White: before, Black: after optical parameter tuning)

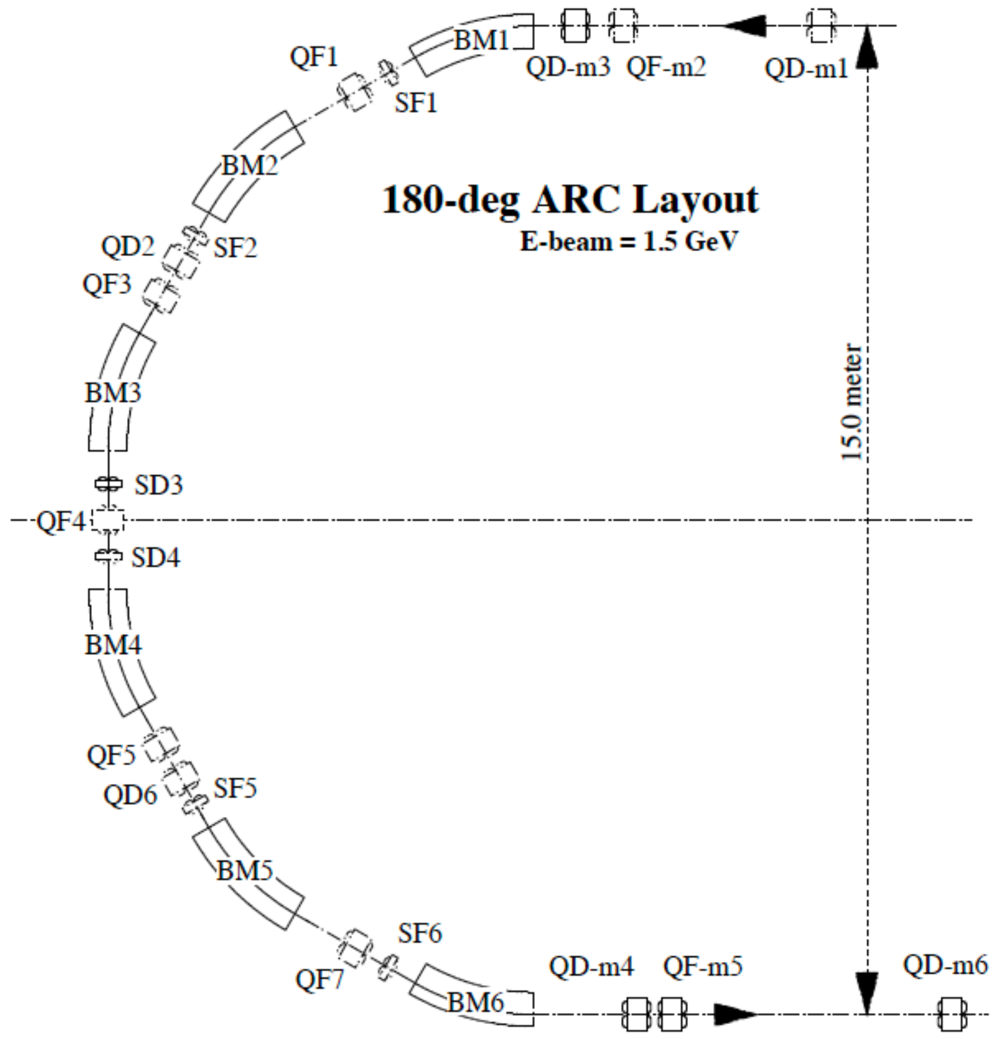


Figure: 5 Layout of the 180-deg arc.

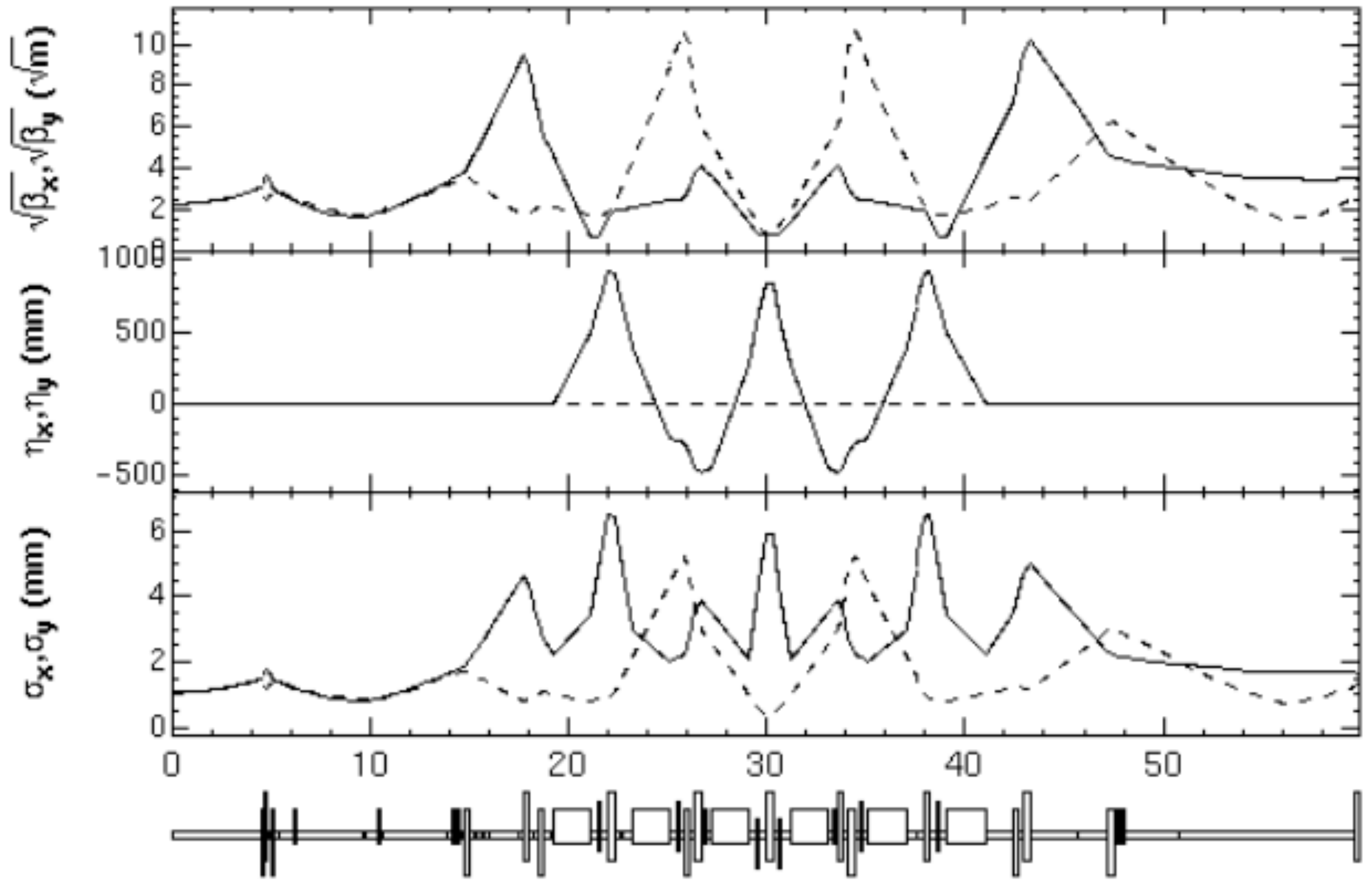


Figure: 6 First order achromatic and isochronous optics of the arc.

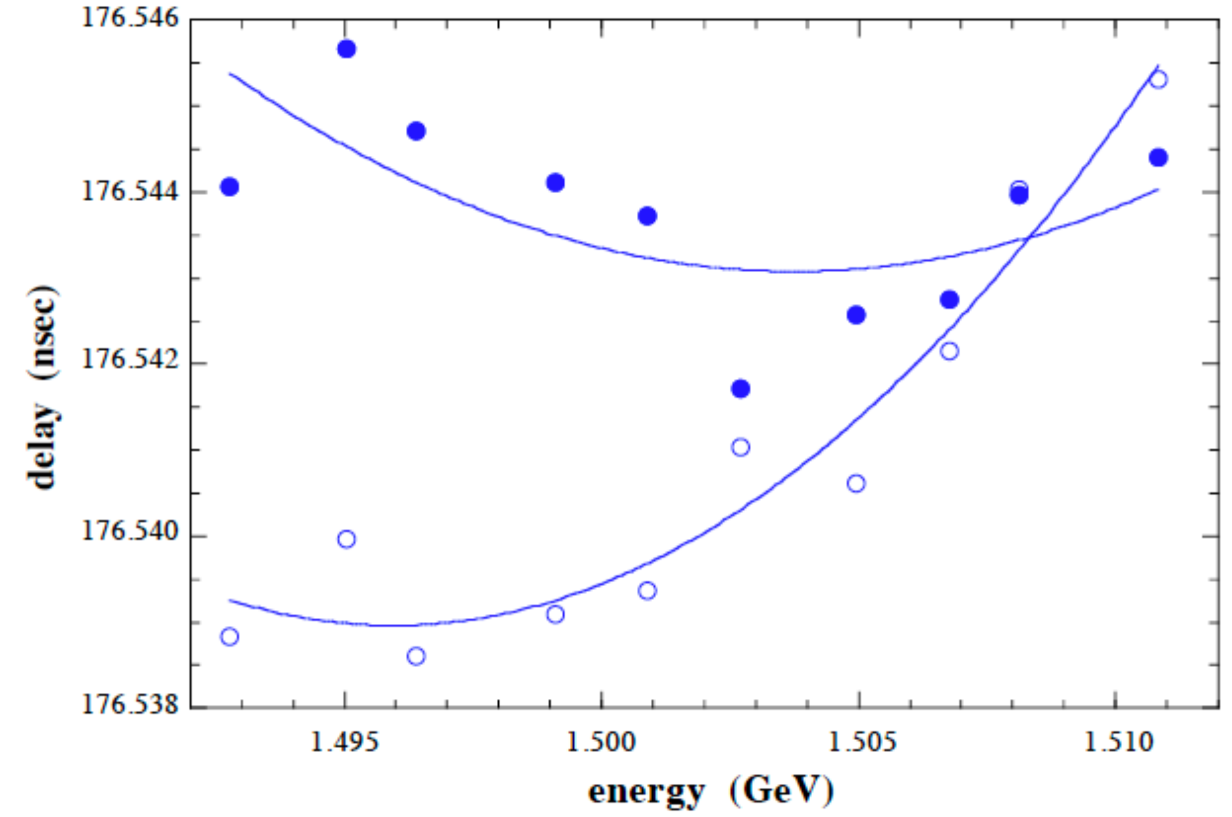


Figure: 9 Measured isochronicity just after the arc. (White: before, Black: after optical parameter tuning)

Summary

- With the initial distribution provided by Y. Seimiya, CSR effects at BTe looks to be weak
  - This suggests that the longitudinal profile (micro bunching, not rms bunch length) before BTe is essential.
  - Comment from Yoshimoto-san: The discrepancy between Yoshimoto&Zhou's and Seimiya-san's distributions at PBTE comes from the dpp_rms of the initial distribution (Zhou, Yoshimoto: 1%, Seimiya: 5%) @ ~10 MeV.
  - Comment from Yoshimoto-san: The realistic initial distribution at ~10 MeV is crucial.
- Optics design to change the longitudinal profile might be useful
  - Simulations: Understand the CSR effects; Search for mitigations.
  - Experiment: Measure emittances at BTe with various optics settings?
  - Kikuchi-san's analysis confirmed the effectiveness of adjusting optics settings.

Discussion

- Let's try to catch the important physics.
  - What is the CSR effect? CSR causes momentum kick to the beam. The longitudinal profile is essential in determining the CSR kick strength (confirmed by Kikuchi-san's longitudinal dynamics analysis). Therefore, one thing that can be done is to manipulate the R56 in the arc sections. Making the bunch length longer and avoiding the sharp micro bunches is important.
  - If we cannot manipulate R56 (=manipulating longitudinal profile), then we have to manipulate R16 (this is dispersion). This will mitigate the CSR-driven transverse emittance growth. Making isochronous optics (or CSR cancellation optics, there are many papers on this topic) is a good choice.
  - Parallel-plates model, ELEGANT model, and CSRZ model for CSR are not essential.
  - Shorter bunches or bunch profile with the sharp shoulder is not preferred from viewpoint of RF wakes (they cause energy loss and momentum spread) (personal opinion).
  - Is changing the chamber of BTe to increase CSR shielding effective?
    - We need more simulations. Before drawing a conclusion, simulations with optics changes before BTe might be more meaningful.
    - Kikuchi-san's longitudinal dynamics analysis and machine studies (N. Iida, M. Kikuchi et al.) already showed that optics changes look to be effective.

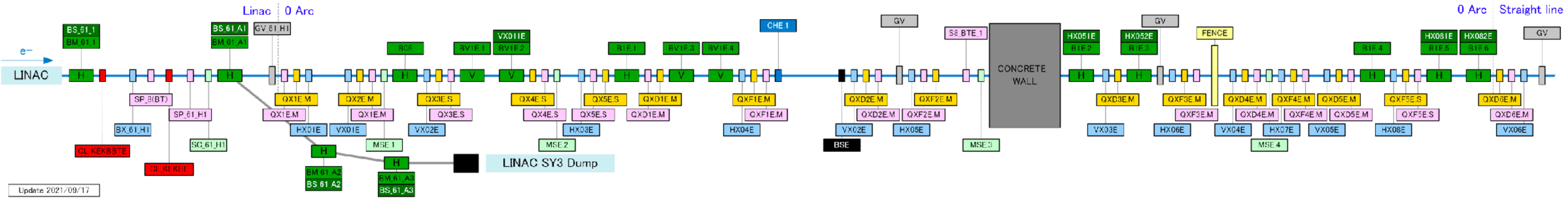
Discussion

- Future investigations
  - ISR effects (causing direct emittance growth at the BT end) should be understood better, and remedies should be investigated (if possible).
  - Currently, we are using Twiss functions to generate the initial distributions for CSR simulations. We need a reliable beam distribution from the RF gun (careful simulations and experimental measurement if possible). This is essential for a reliable tracking simulation from the linac to the BT end (so-called Start-to-End simulation).
  - The space-charge (SC) effect in low-energy sections (say, < 100 MeV) is of concern (my personal viewpoint). If possible, run simulations with SC (my SAD script has subroutines for models of longitudinal and transverse SC; GPT can be better) for low-energy sections.
  - Machine errors are another factor to be taken into account.
  - The overall design of linac+BTe should be done with a balance between single-particle dynamics and collective effects (CSR, ISR, RF wakes). This requires intensive simulation work.

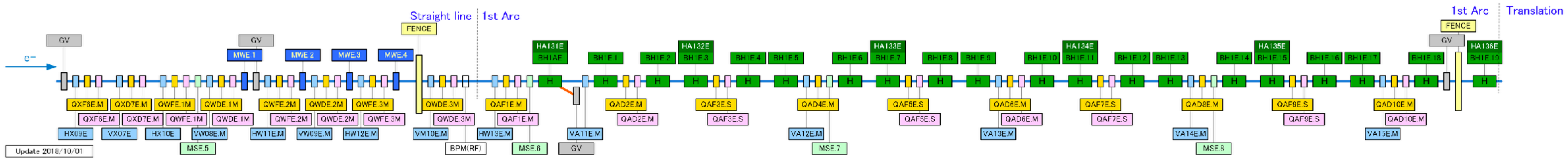
Backup

Simulations starting from PBTE

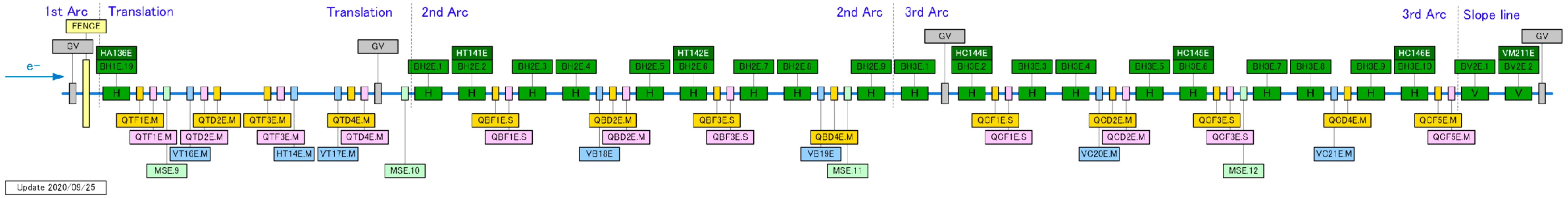
HER-BT01



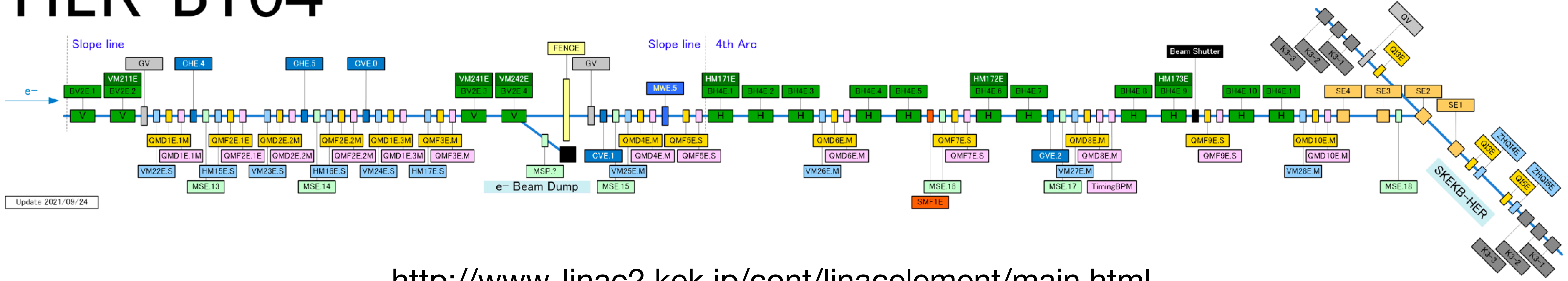
HER-BT02



HER-BT03



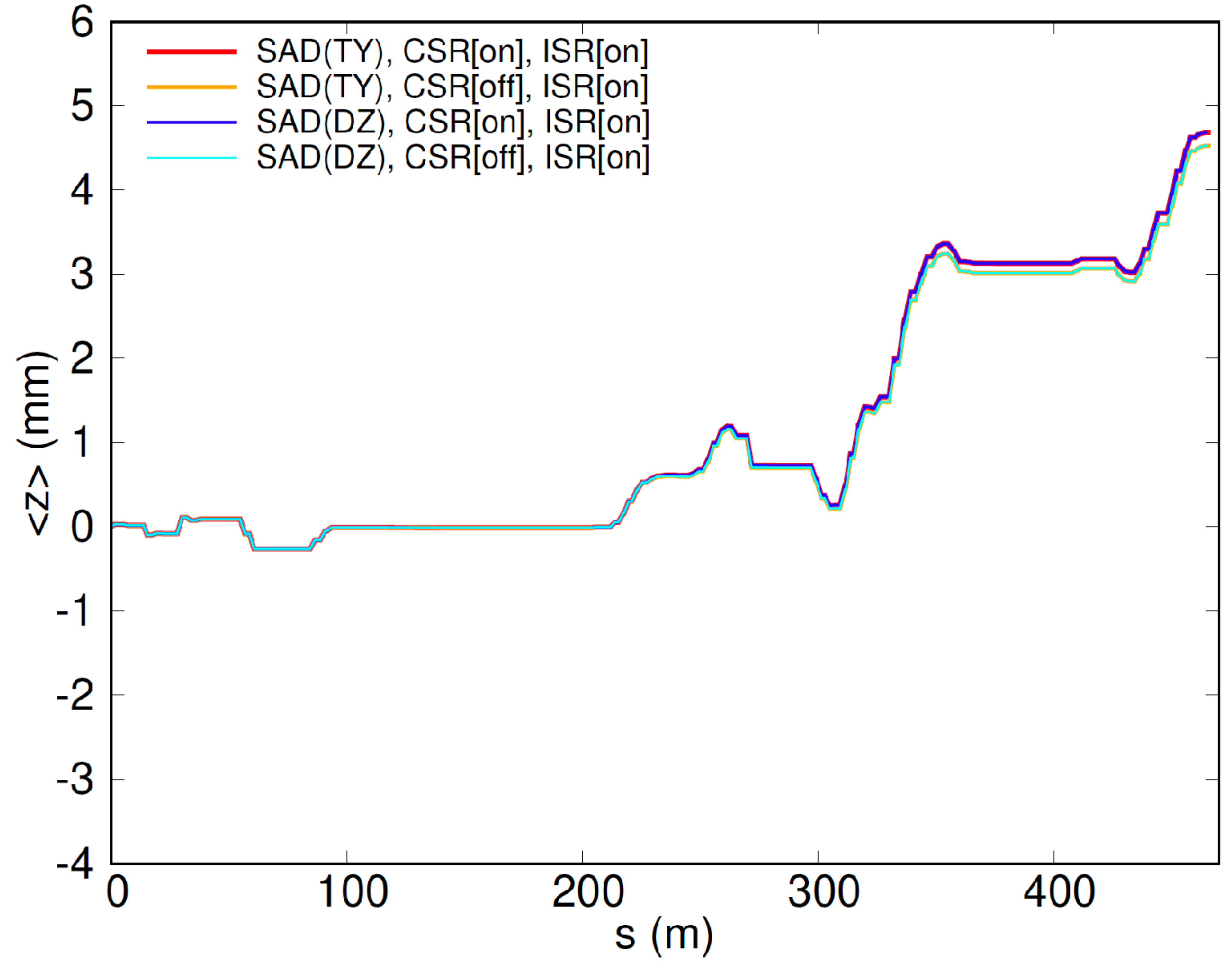
HER-BT04

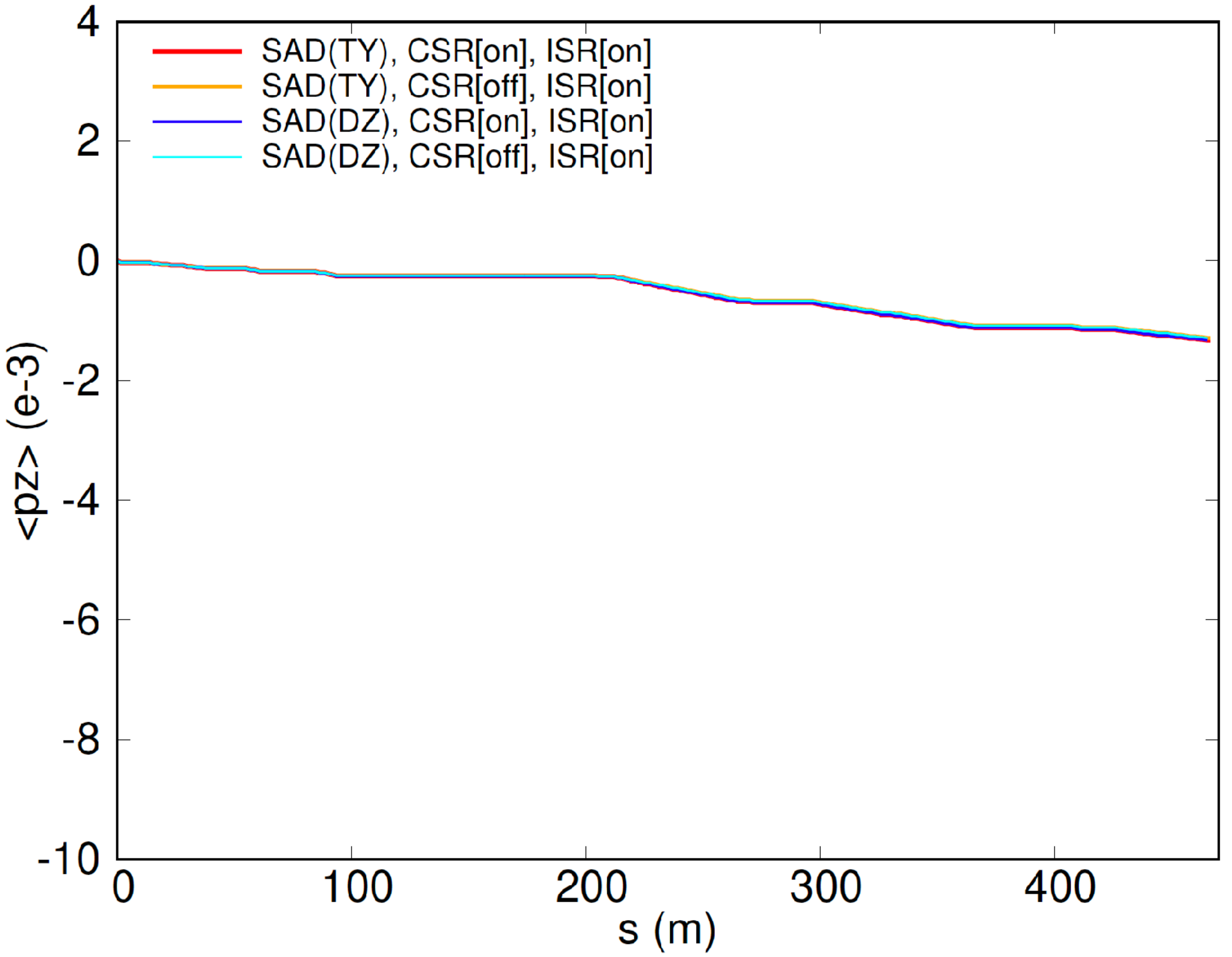


http://www-linac2.kek.jp/cont/linacelement/main.html

Simulations starting from PBTE

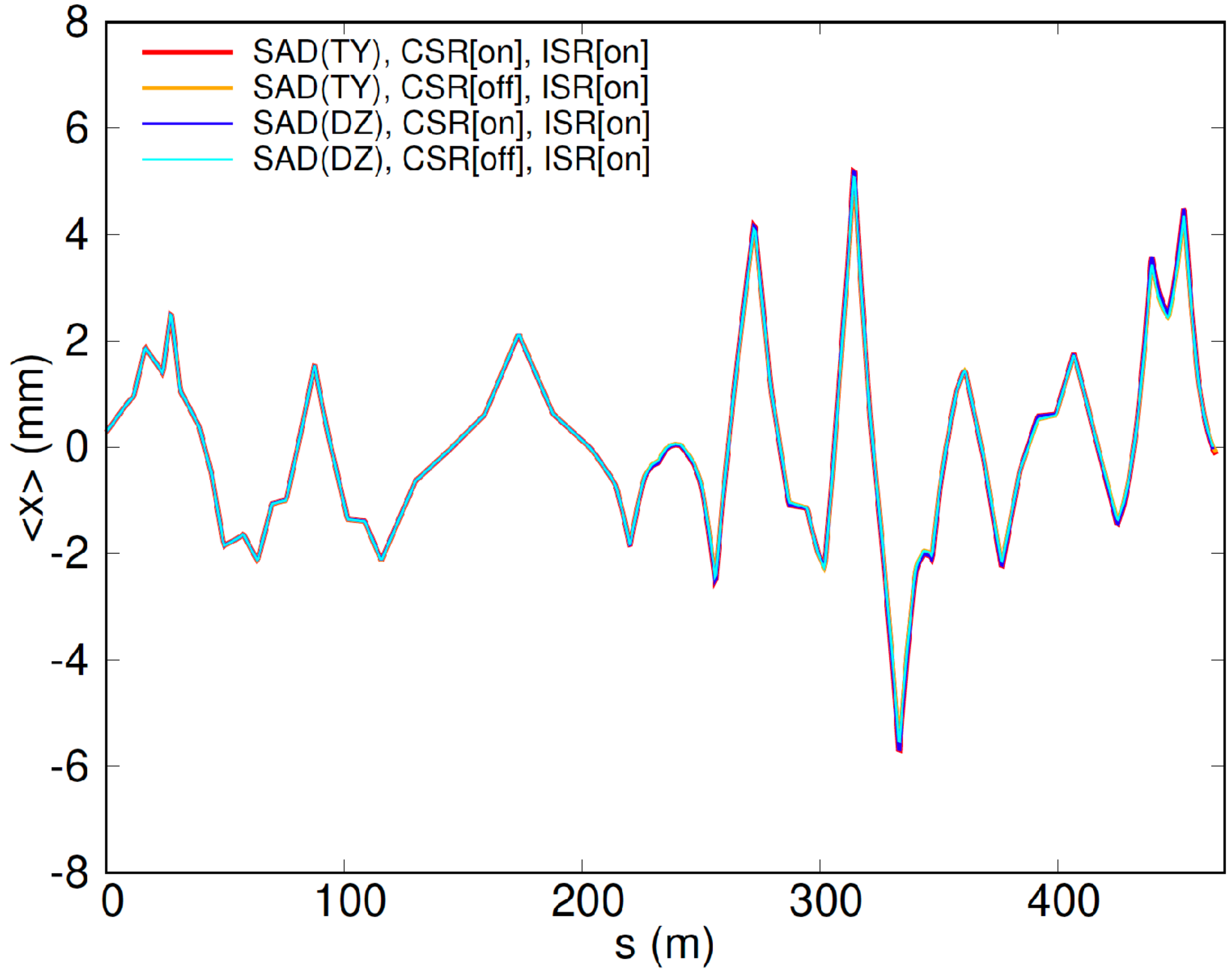
- <z> and <pz> show very good agreement. CSR effect is seen.

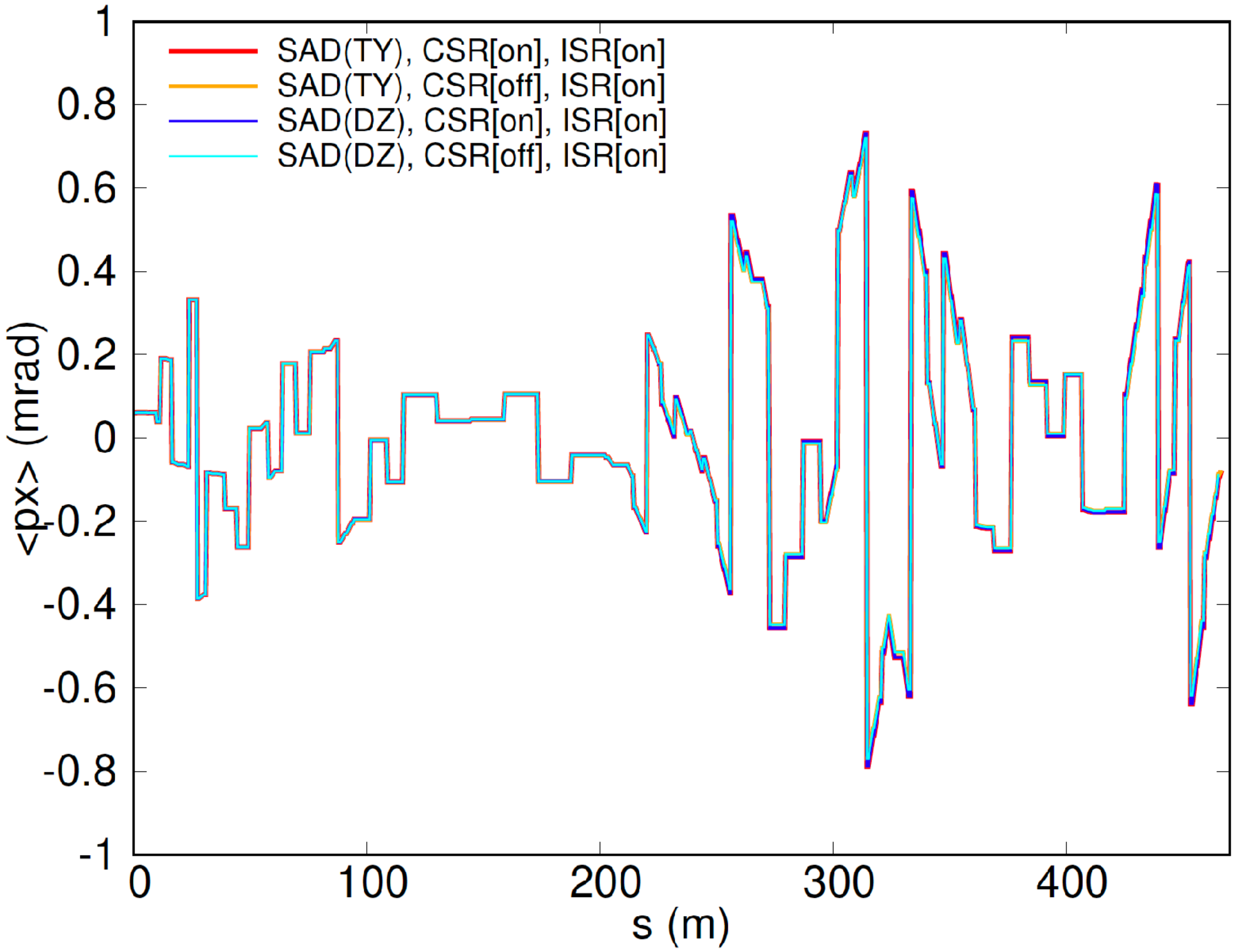




Simulations starting from PBTE

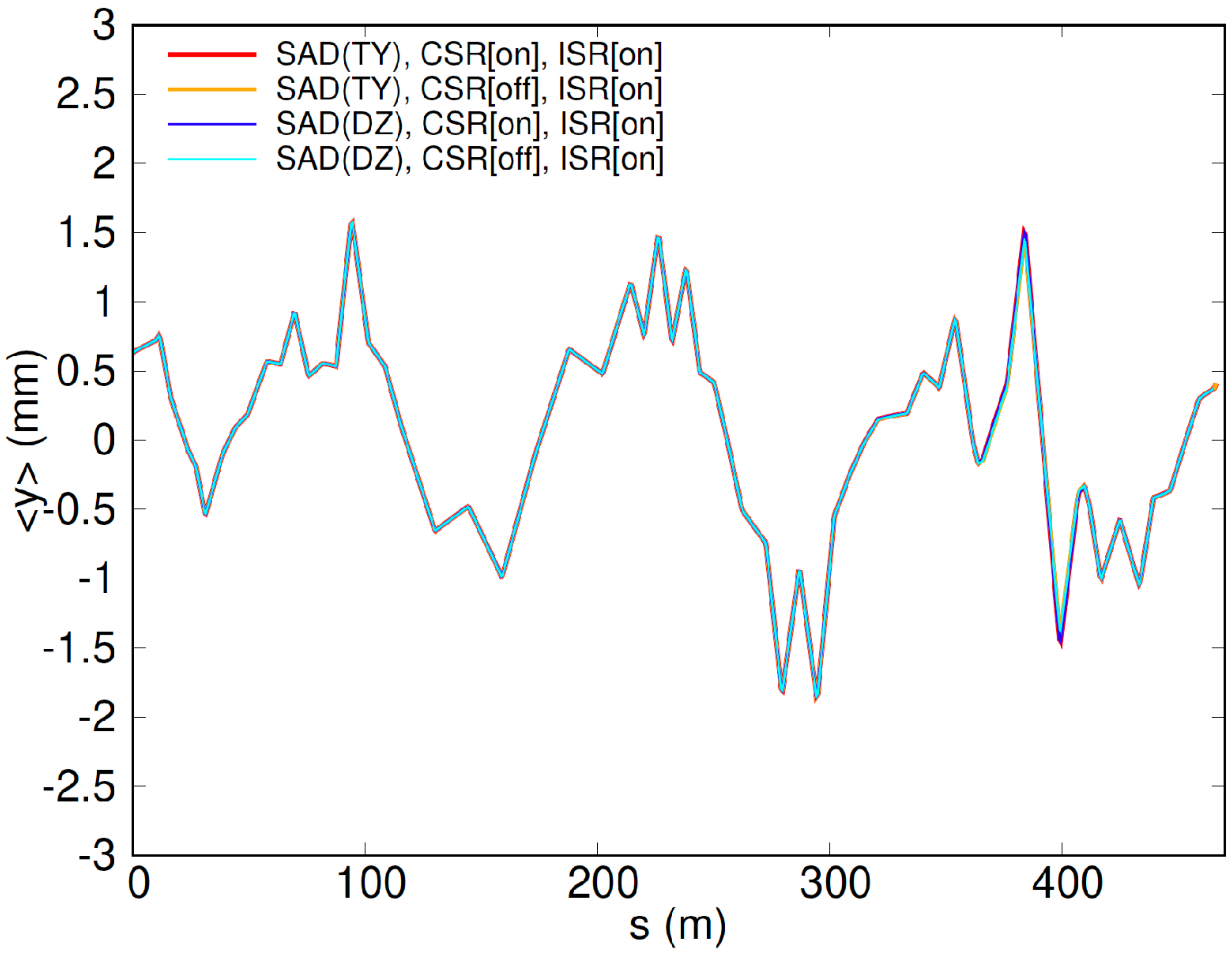
- <x> and <px> show very good agreement. CSR effect is seen.

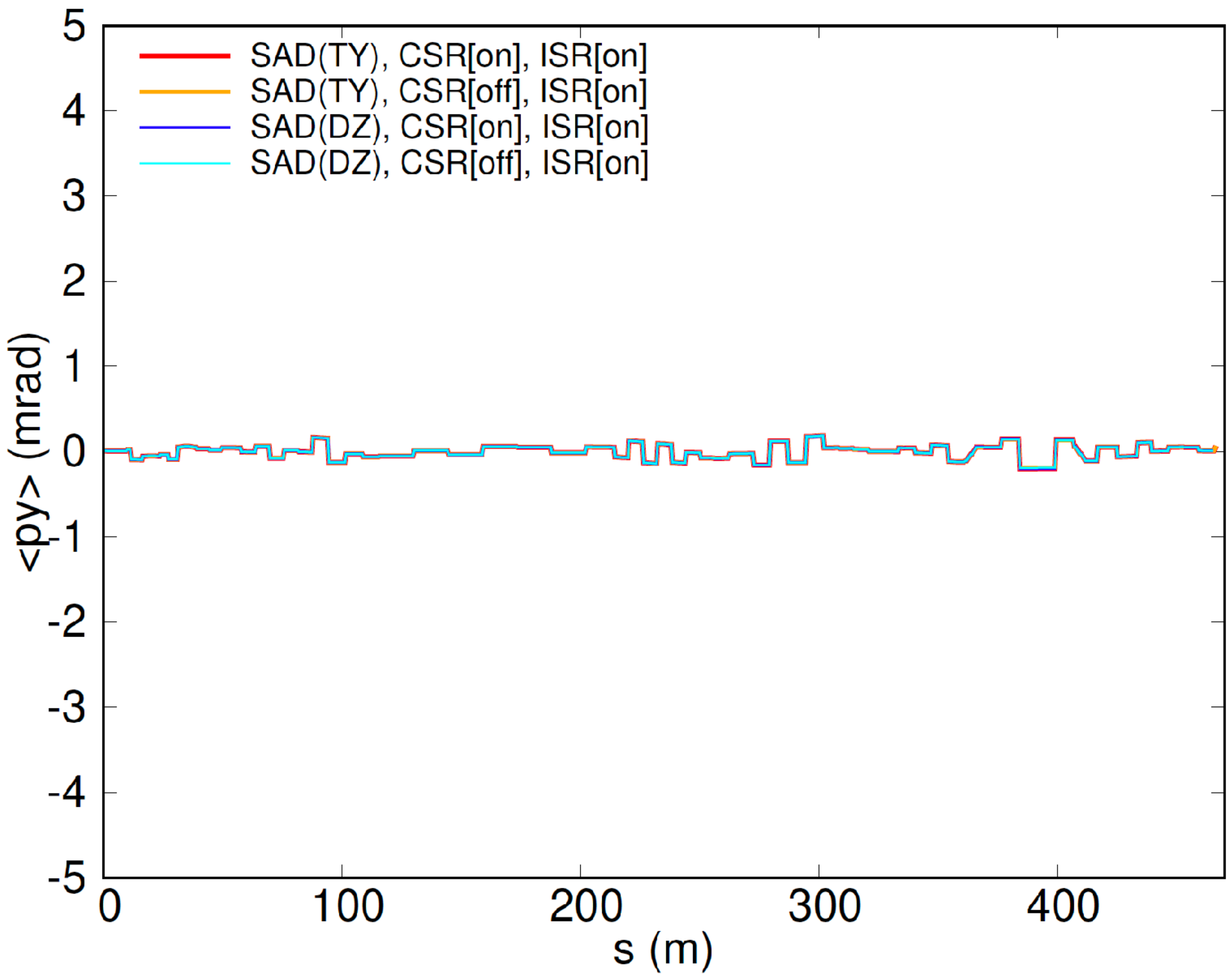




Simulations starting from PBTE

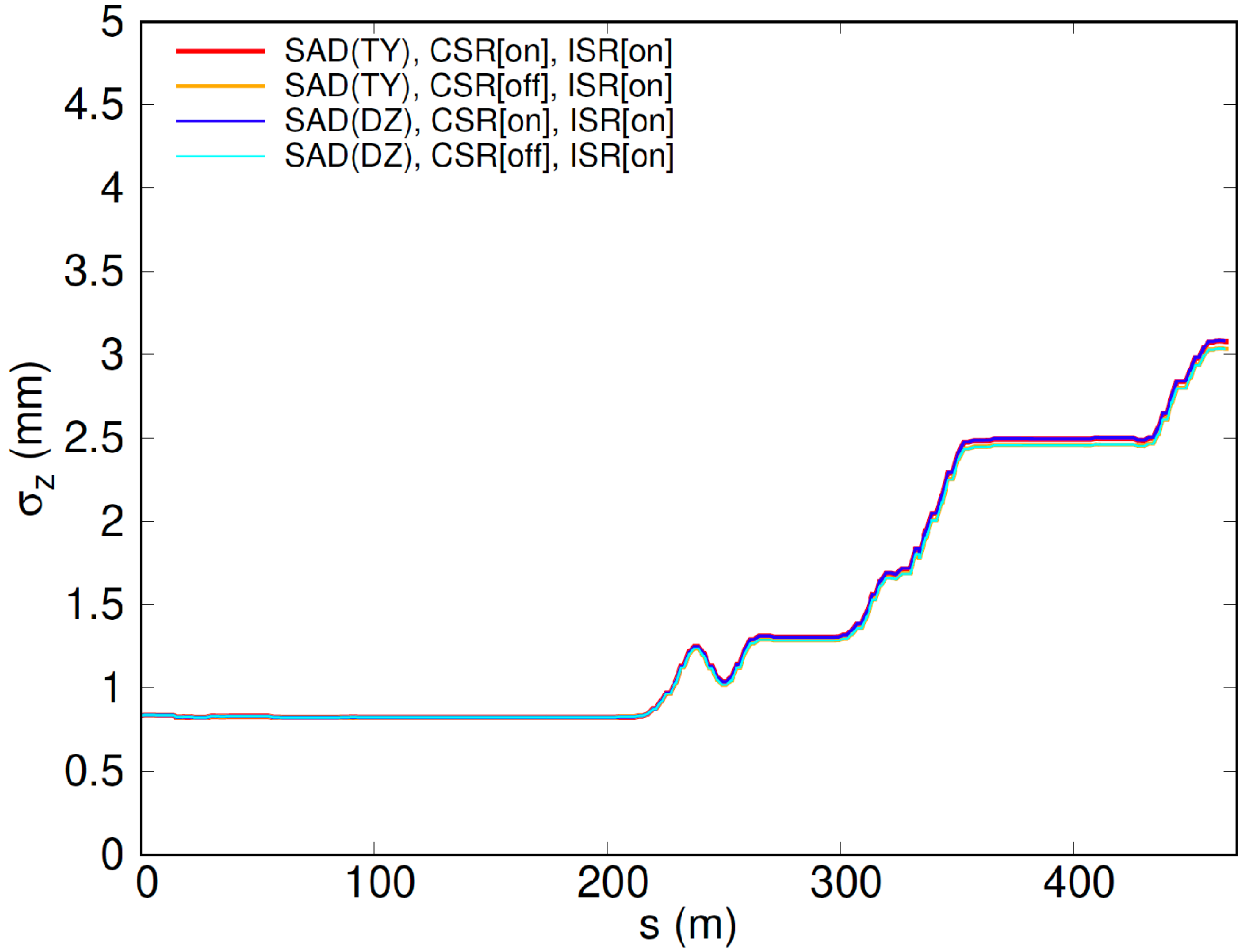
- <y> and <py> show very good agreement.

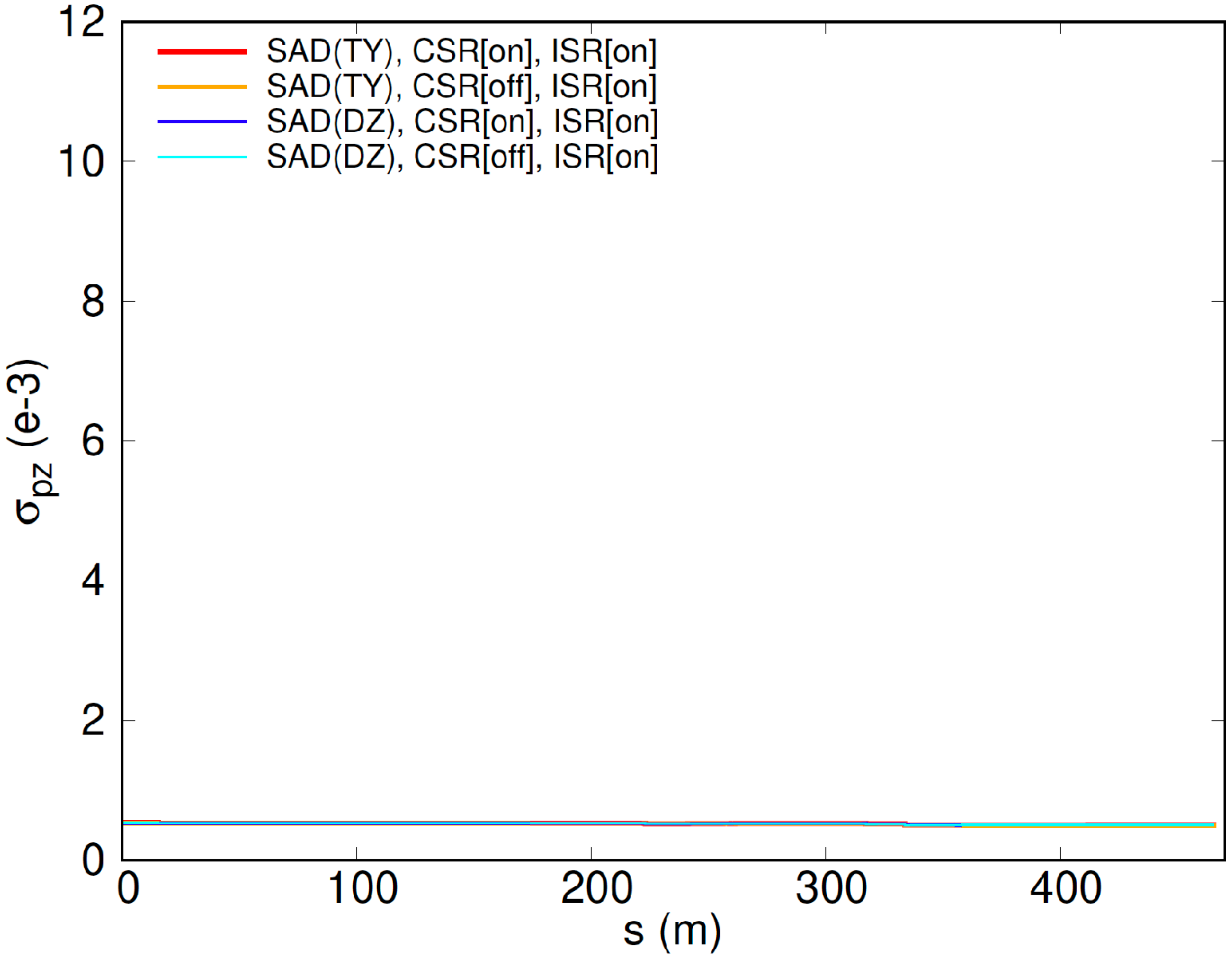




Simulations starting from PBTE

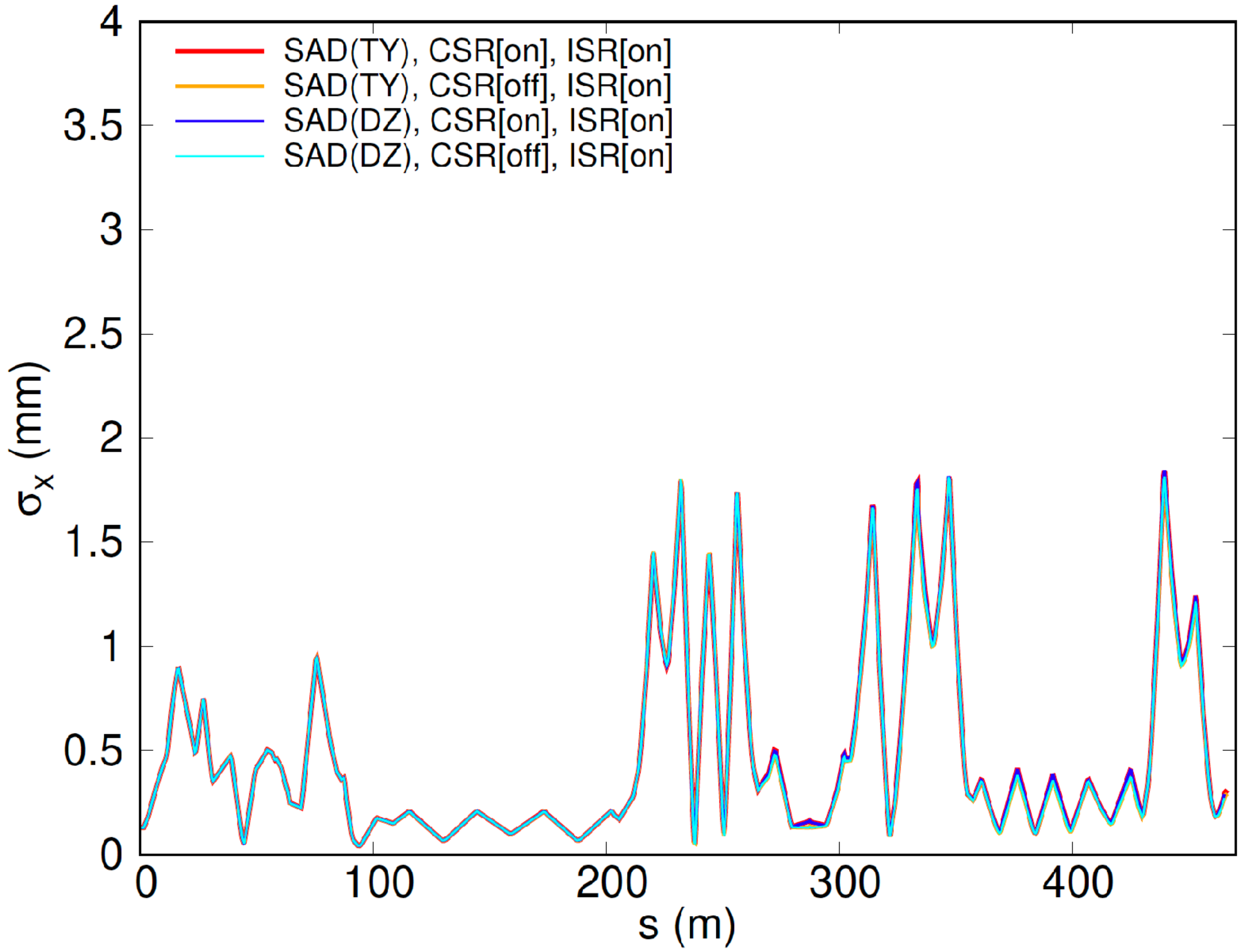
- rms σ_z and σ_{pz} show very good agreement.

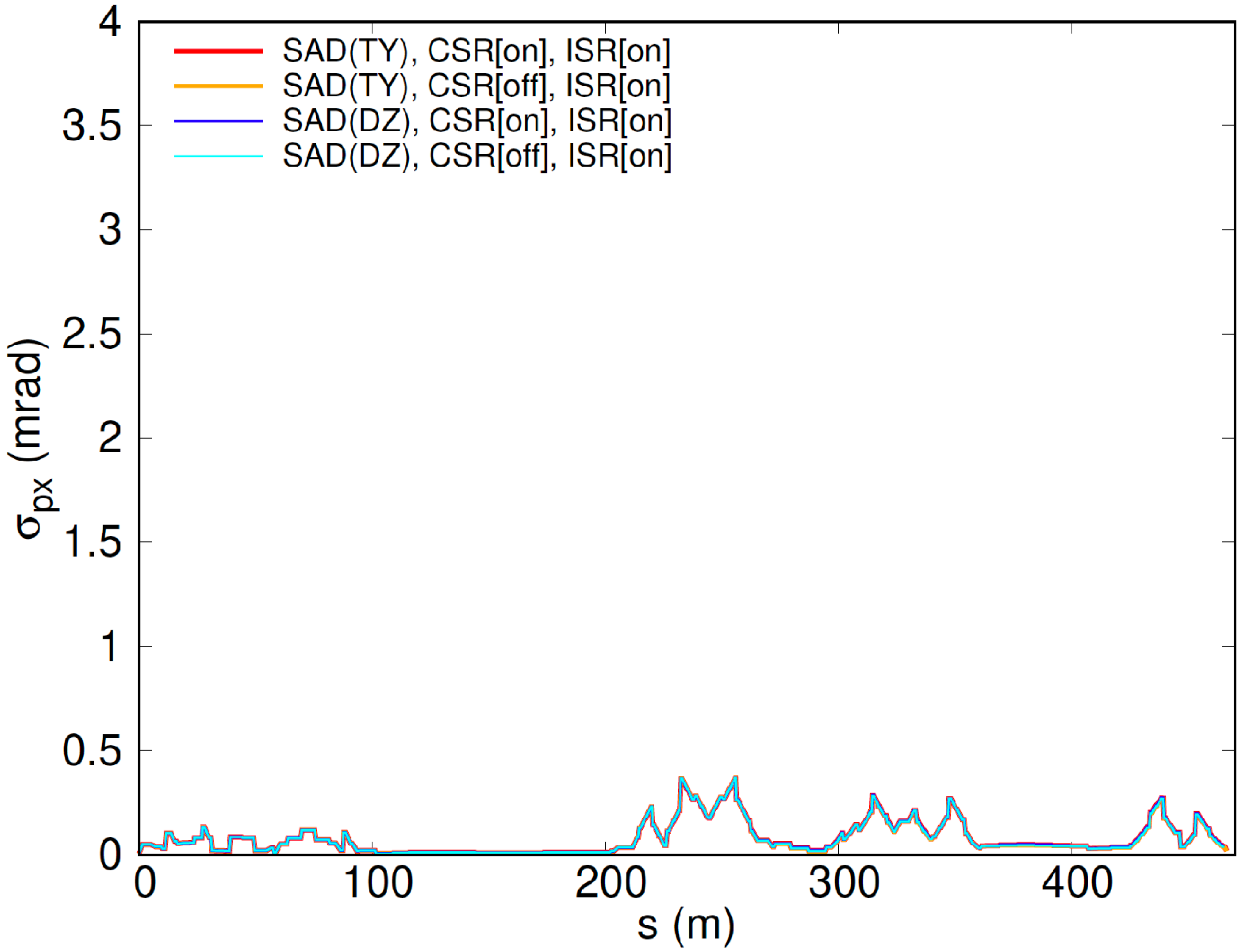




Simulations starting from PBTE

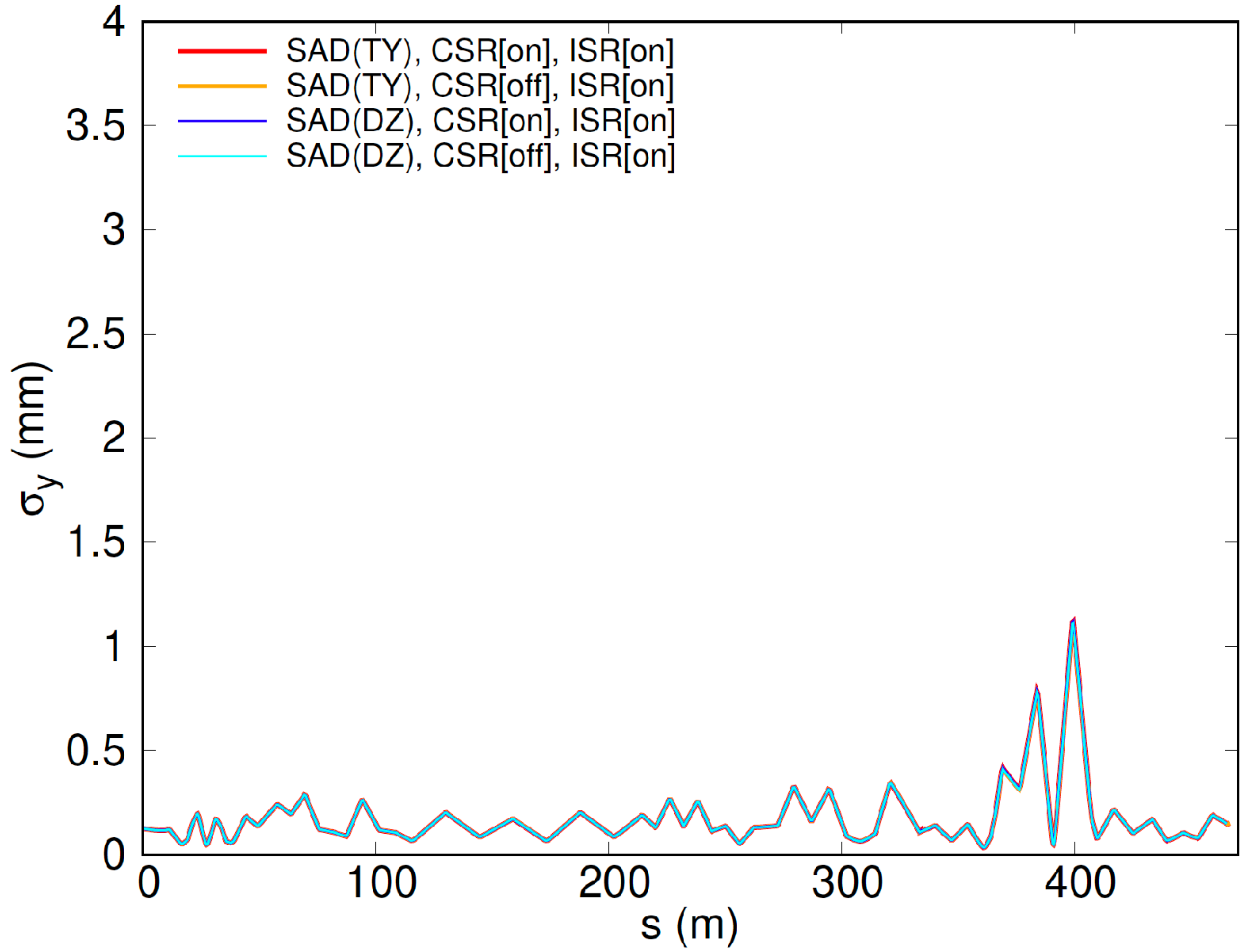
- rms σ_x and σ_{px} show very good agreement. CSR effect is seen.

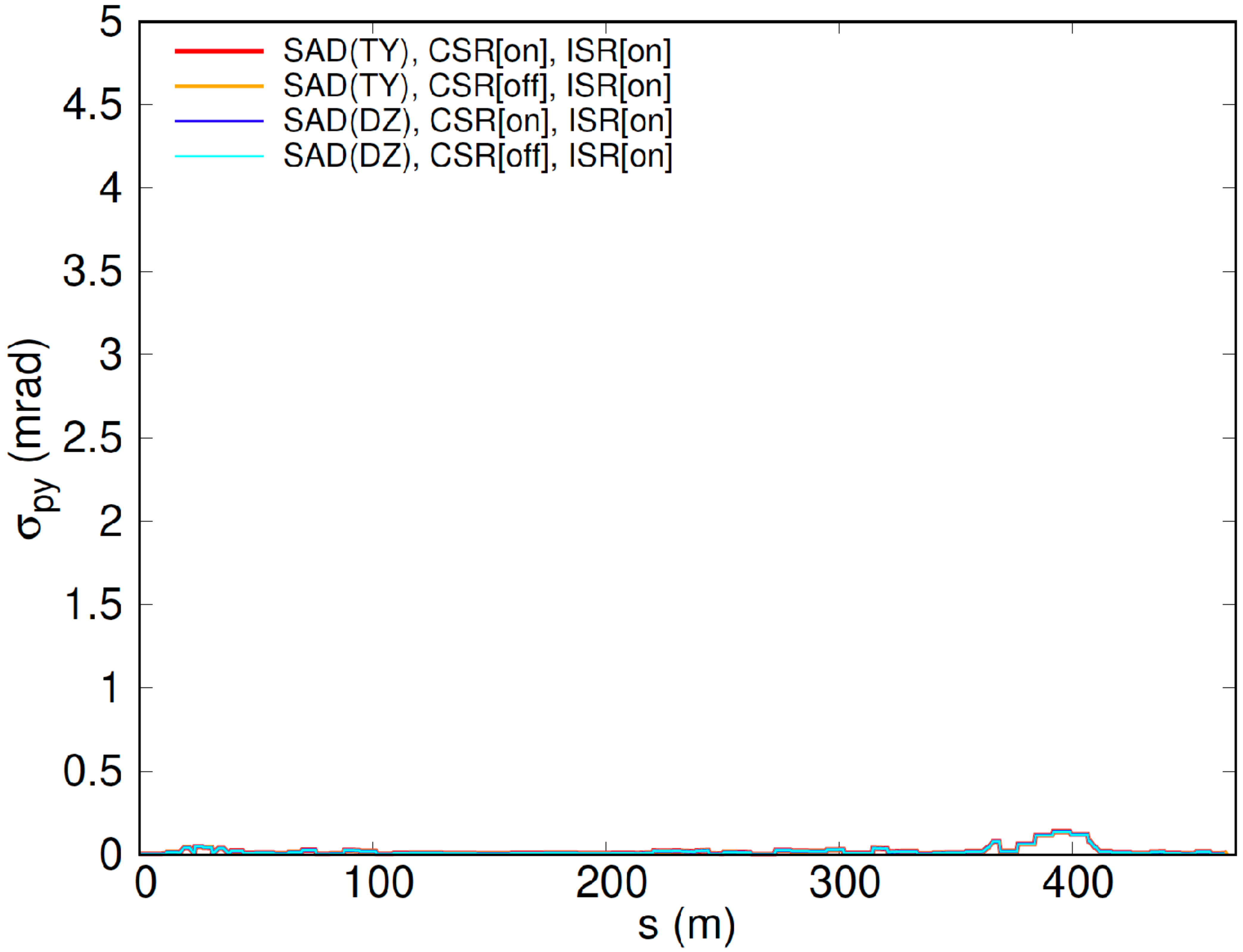




Simulations starting from PBTE

- rms σ_y and σ_{py} show discrepancy.

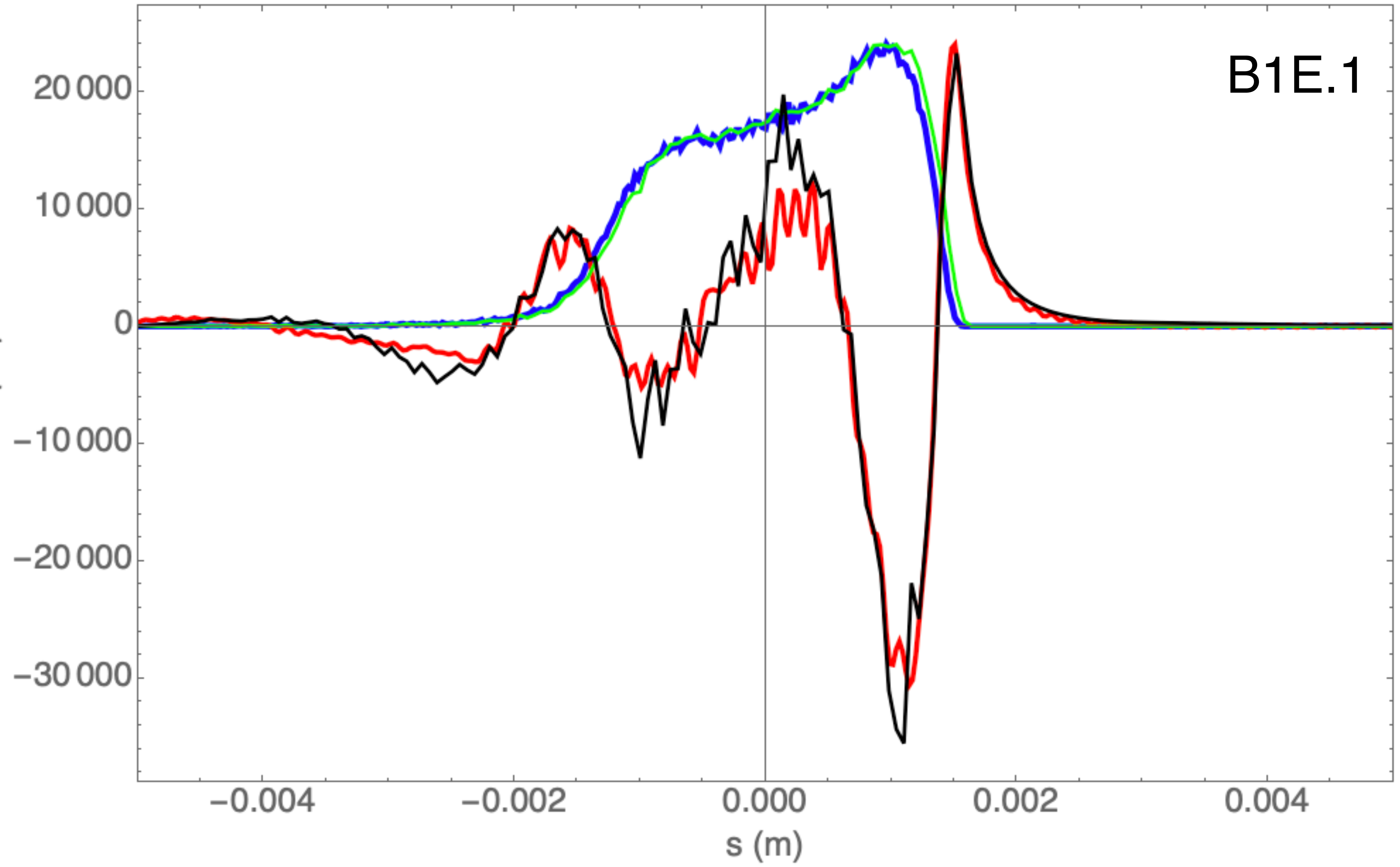


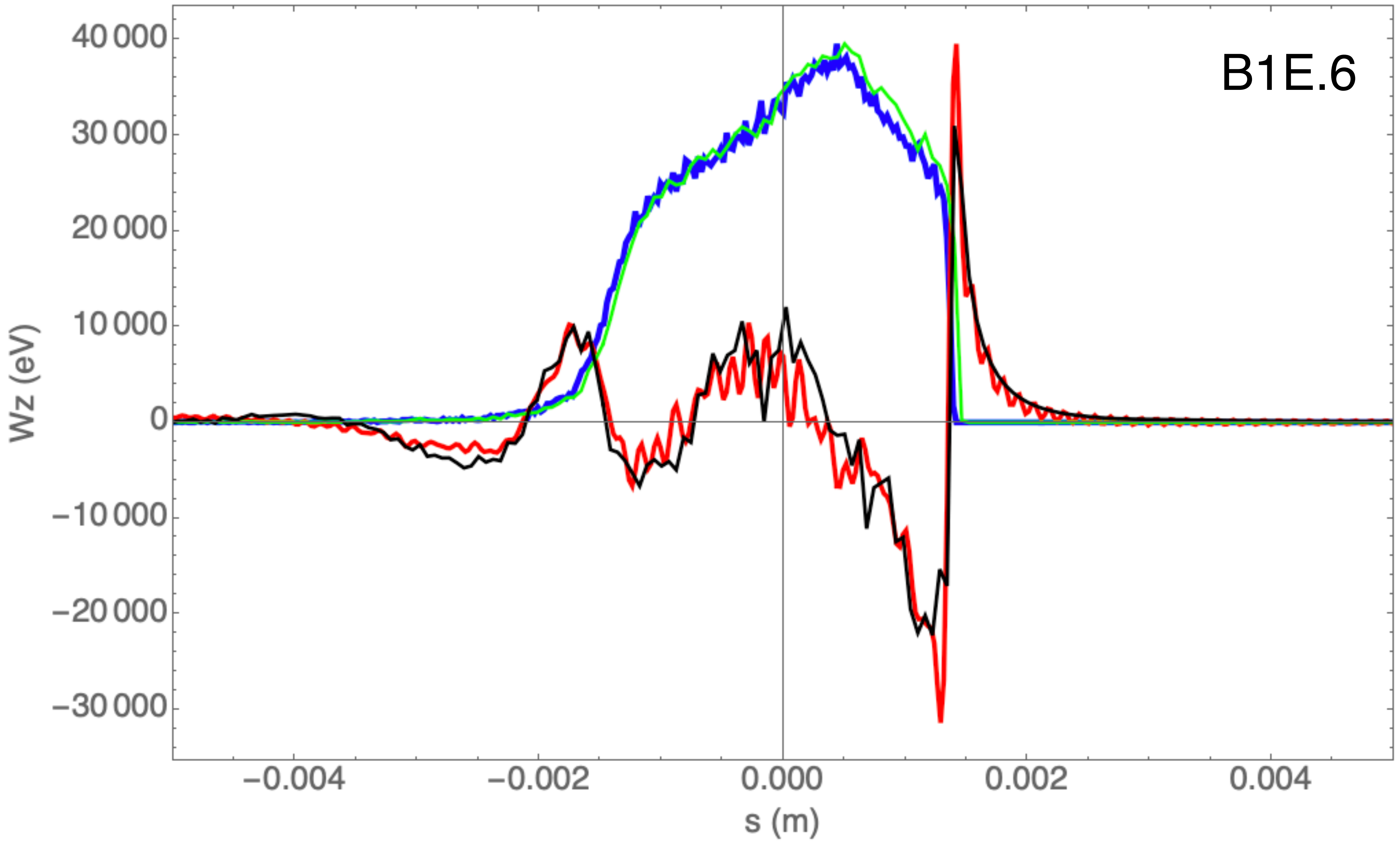


Simulations starting from PBTE

- CSR wakes at BT01 (Ebeam=7 GeV).

Blue: z-profile (DZ)
Green: z-profile (TY)
Red: CSR wake (DZ)
Black: CSR wake (TY)

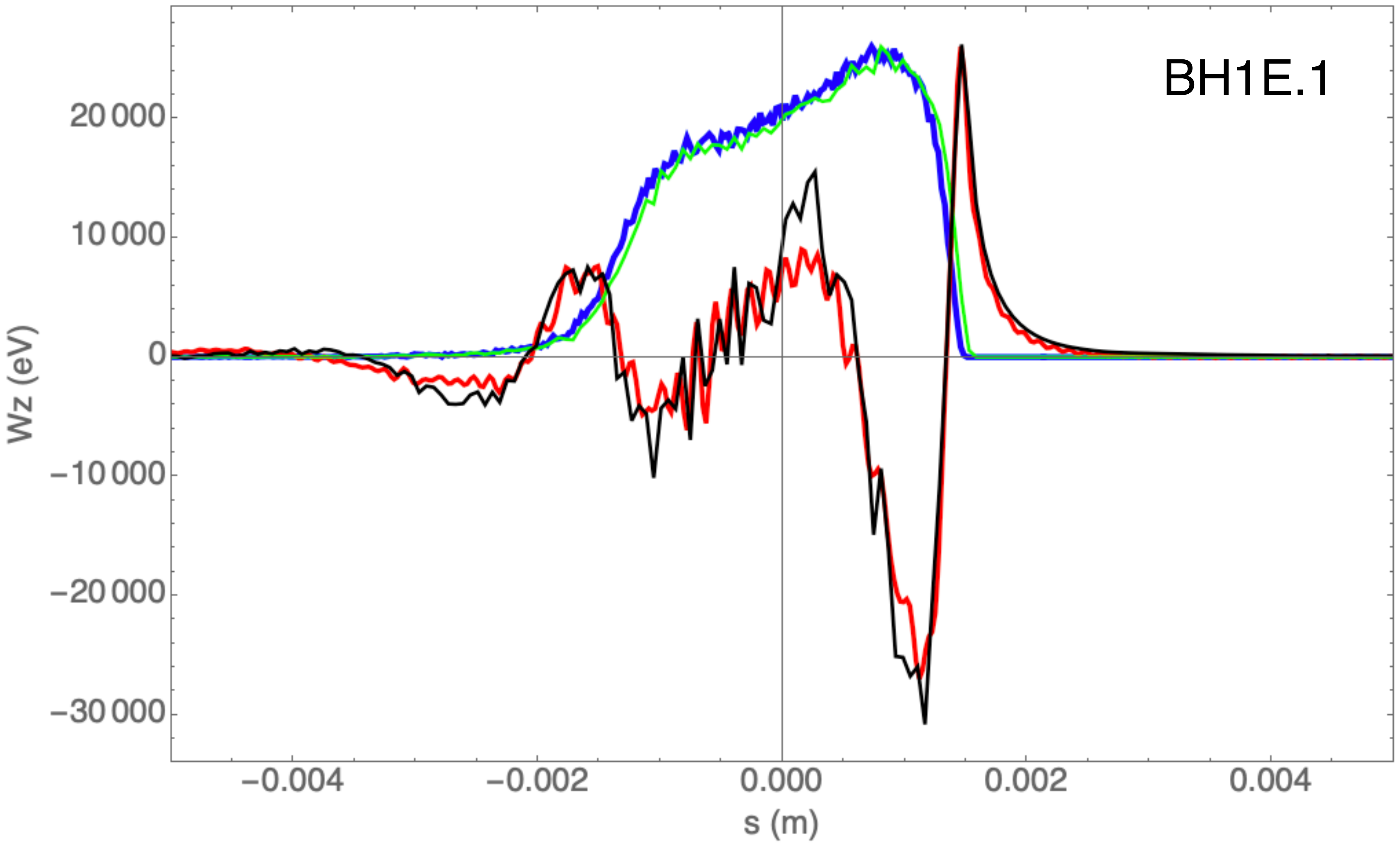


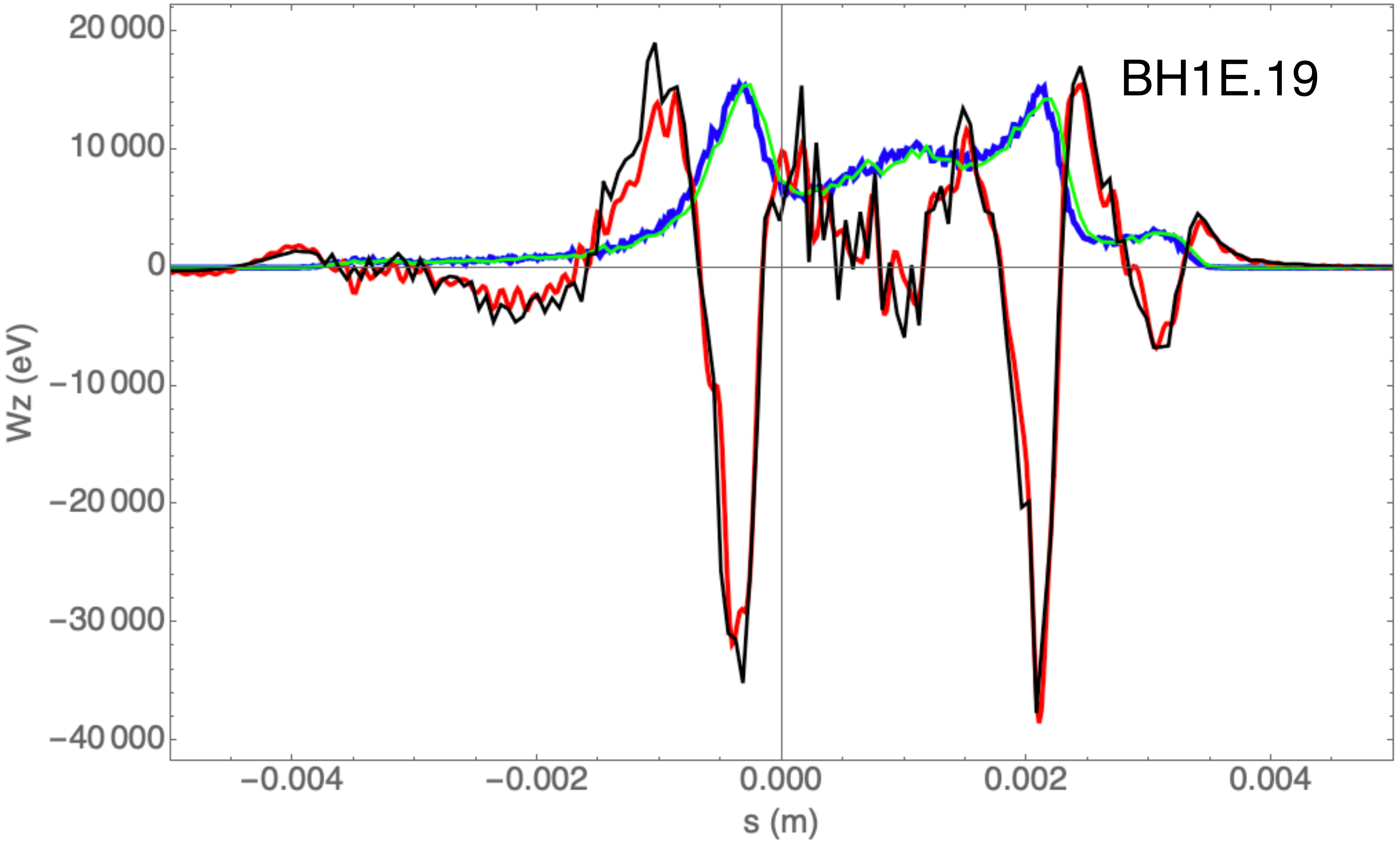


Simulations starting from PBTE

- CSR wakes at BT02 (Ebeam=7 GeV).

Blue: z-profile (DZ)
Green: z-profile (TY)
Red: CSR wake (DZ)
Black: CSR wake (TY)

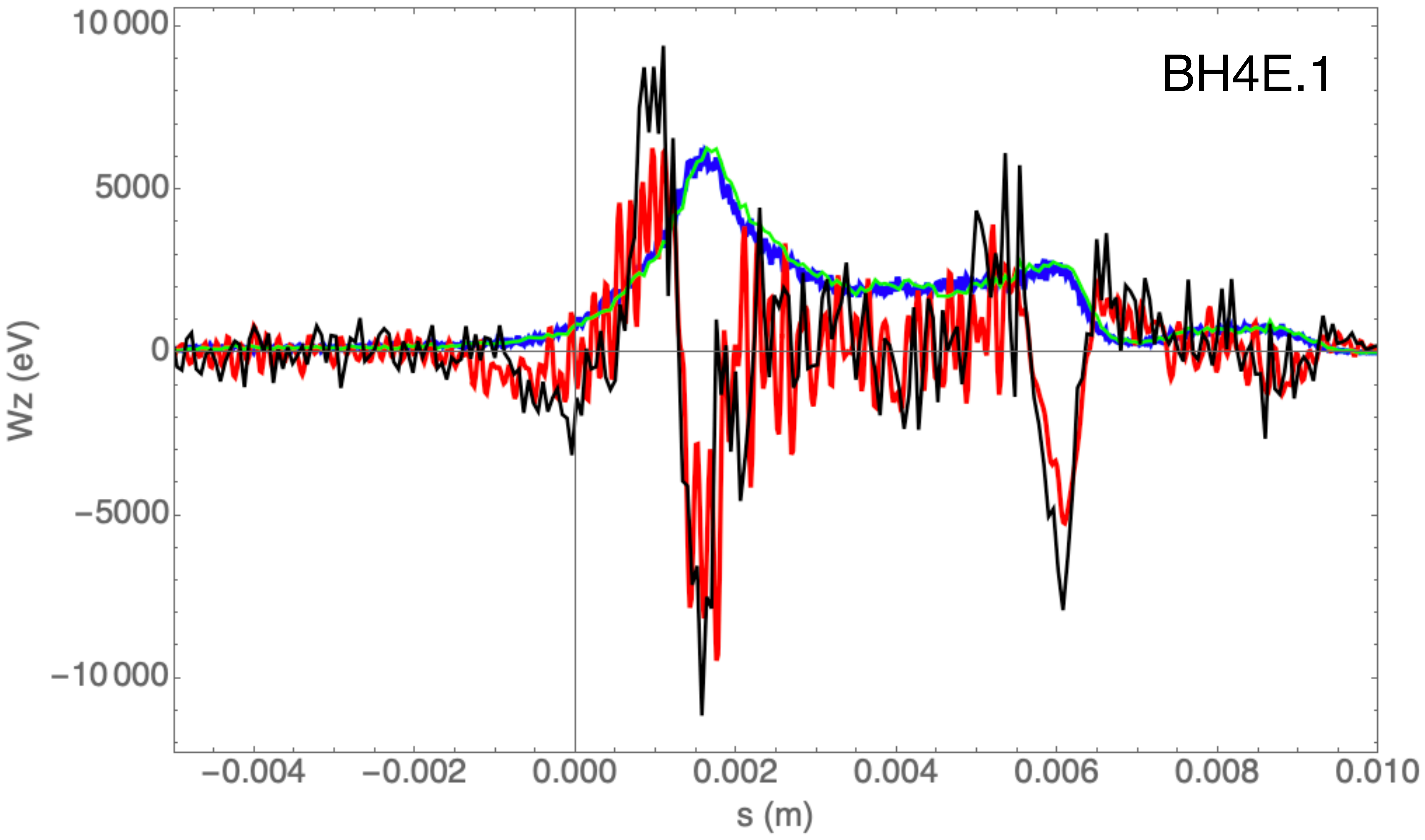


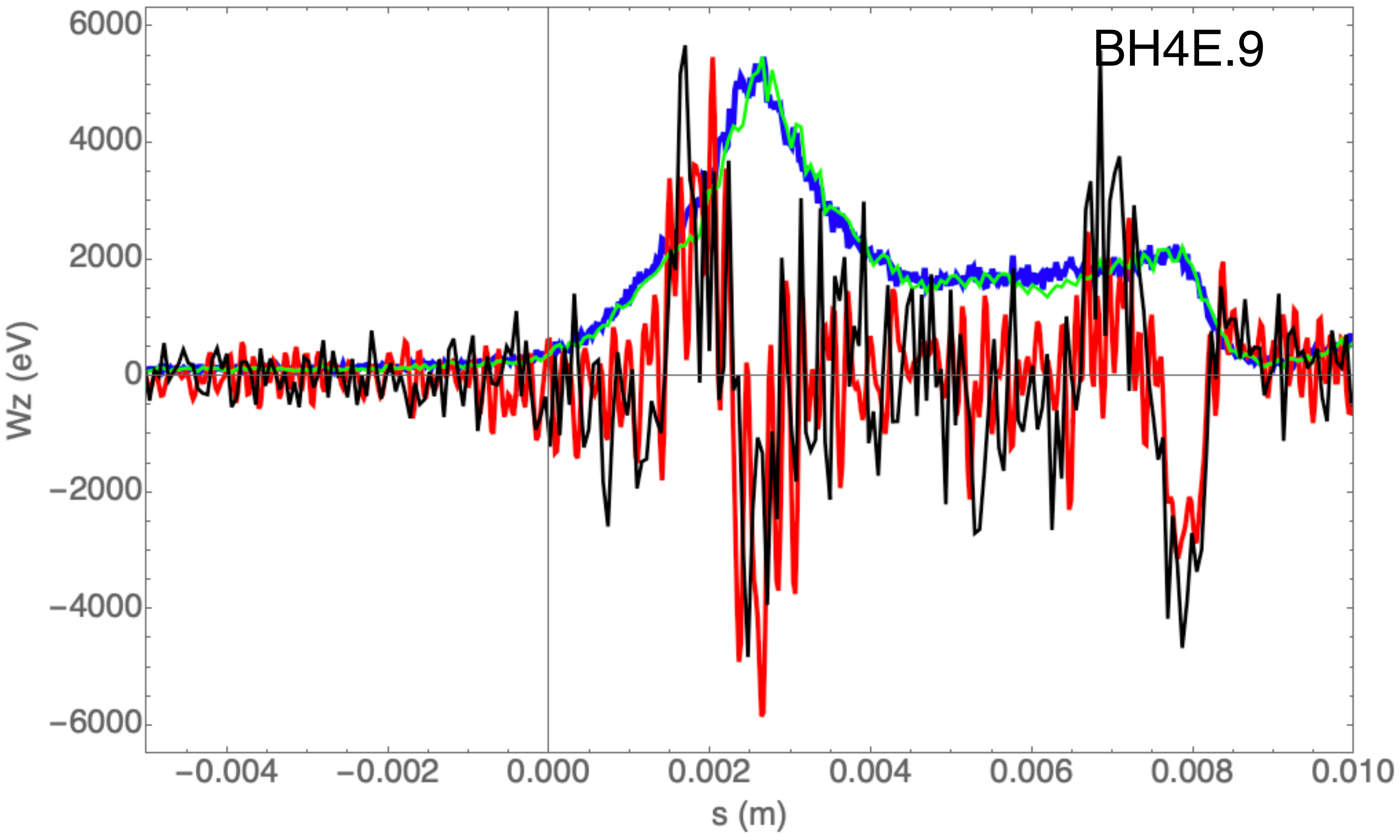


Simulations starting from PBTE

- CSR wakes at BT04 (Ebeam=7 GeV).

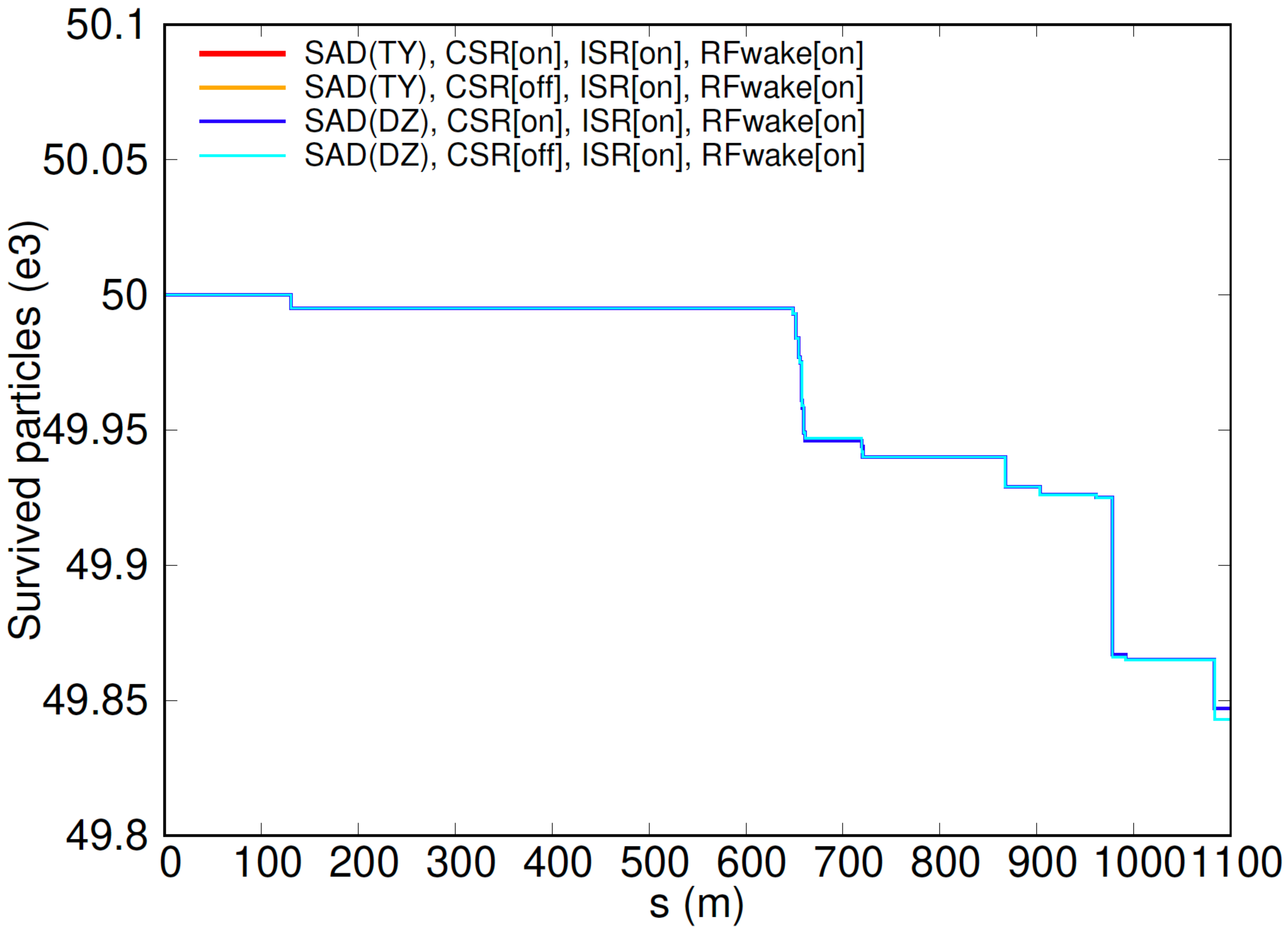
Blue: z-profile (DZ)
Green: z-profile (TY)
Red: CSR wake (DZ)
Black: CSR wake (TY)





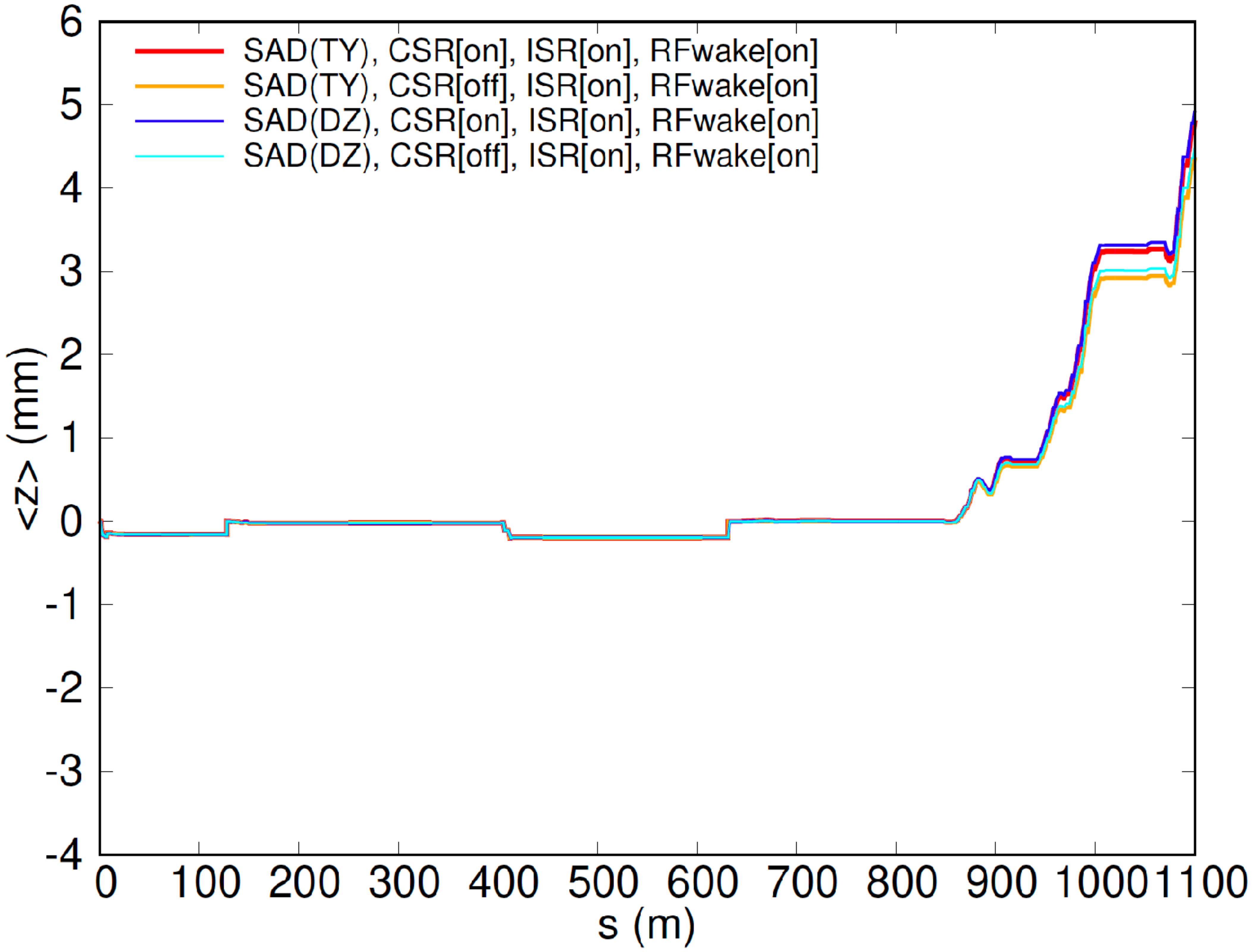
Simulations starting from PATGUN

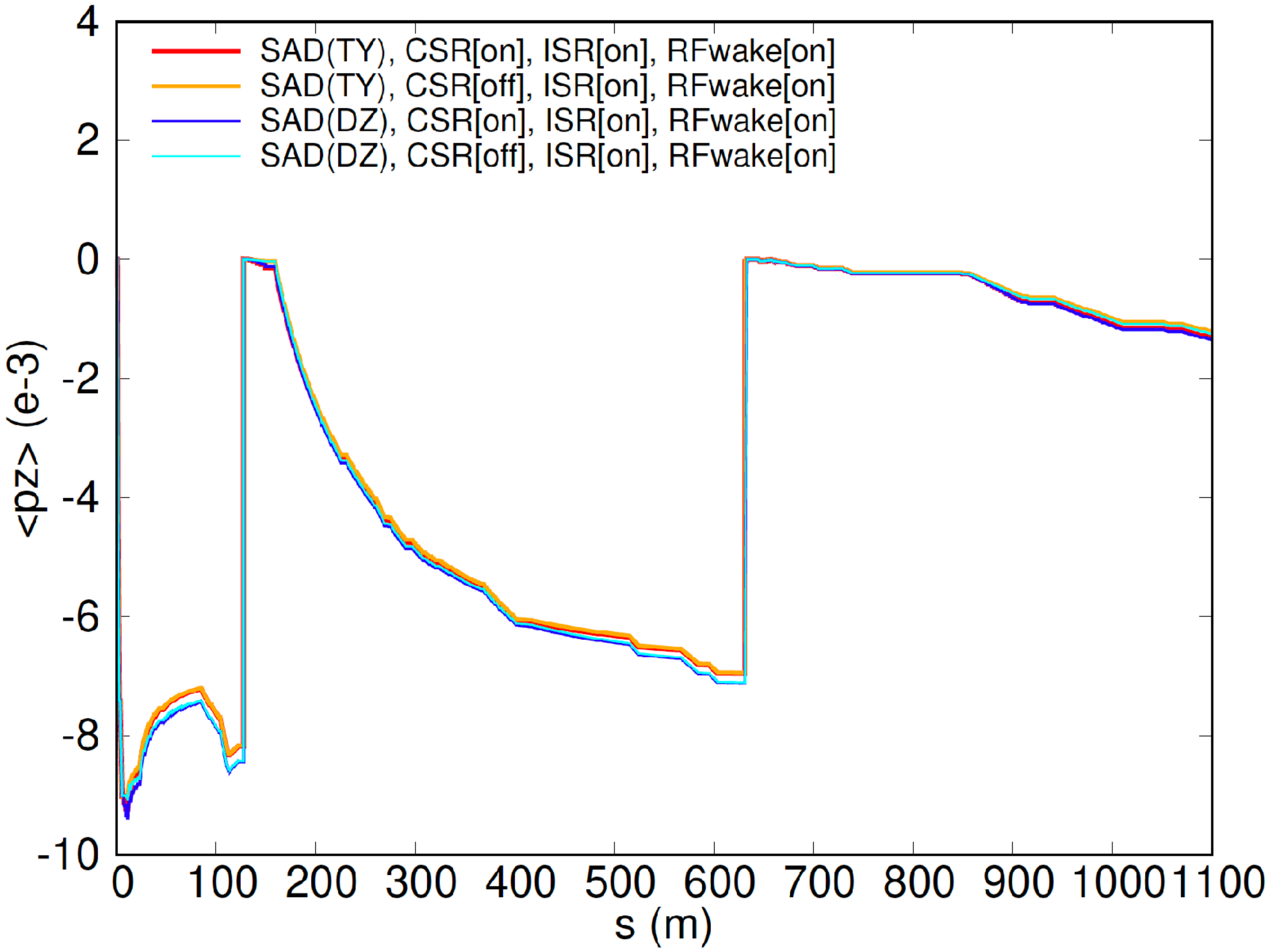
- Small particle loss is seen



Simulations starting from PATGUN

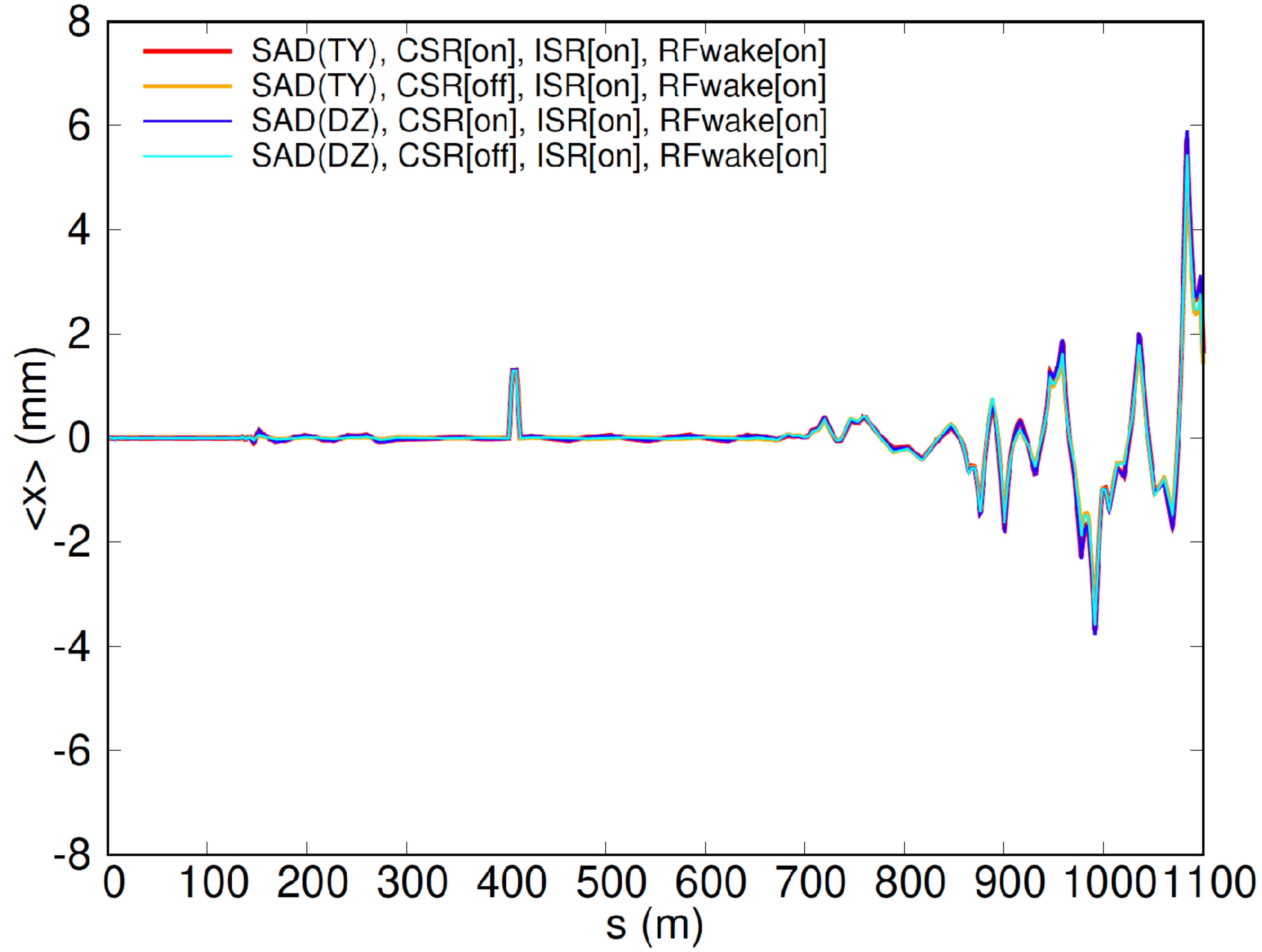
- <z> and <pz> show good agreement. CSR effect is seen.

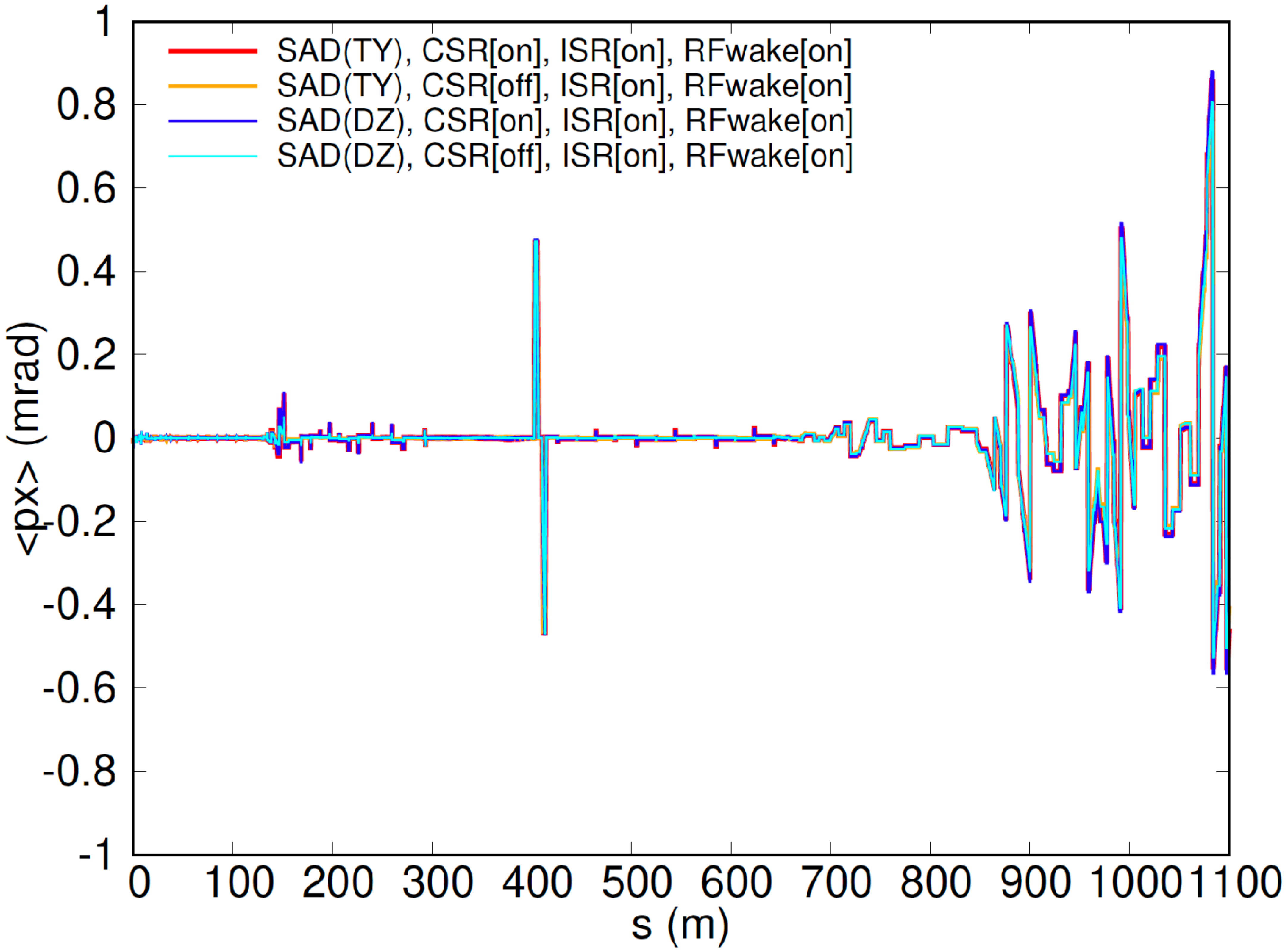




Simulations starting from PATGUN

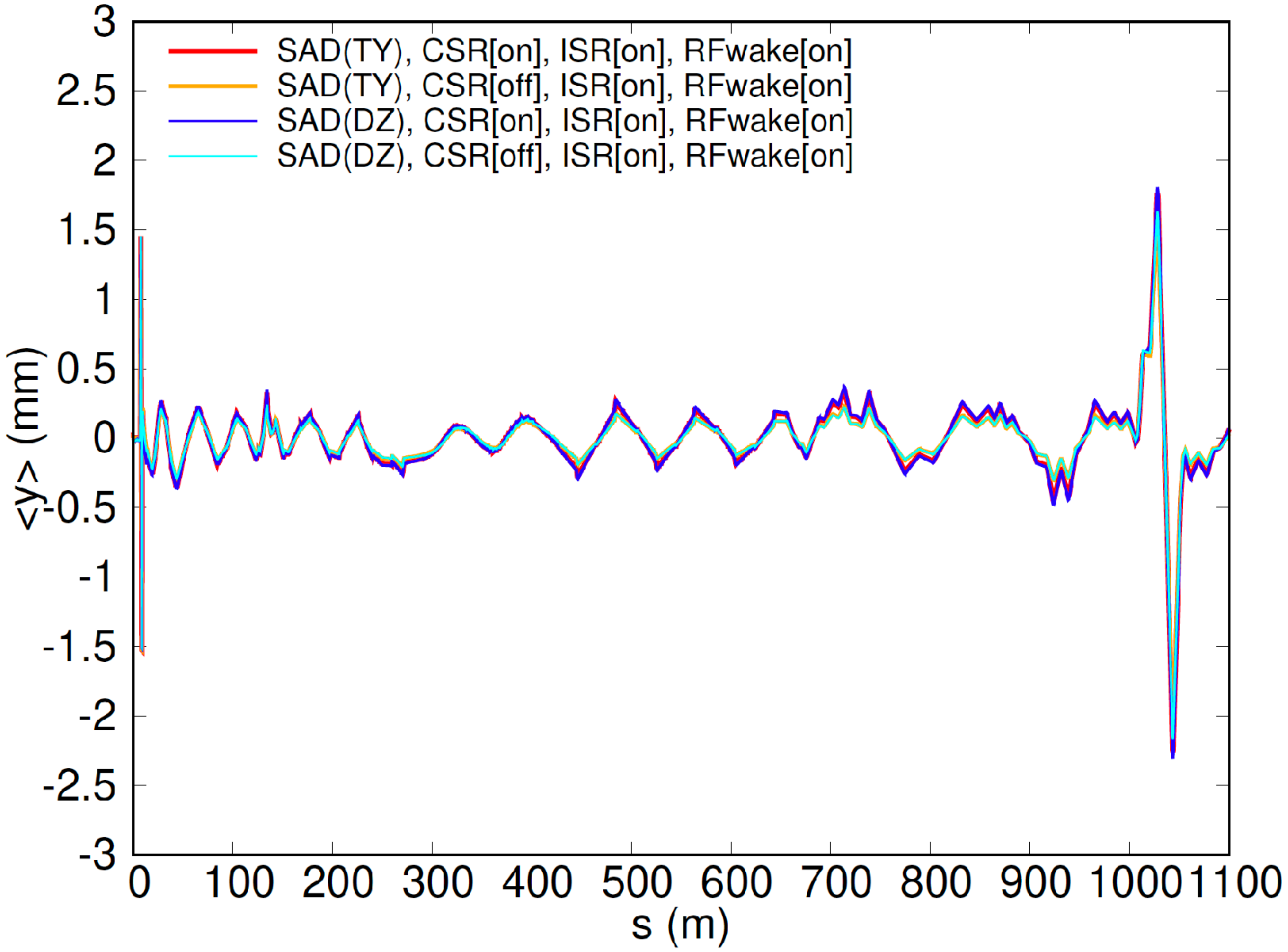
- <x> and <px> show good agreement. CSR effect is seen.

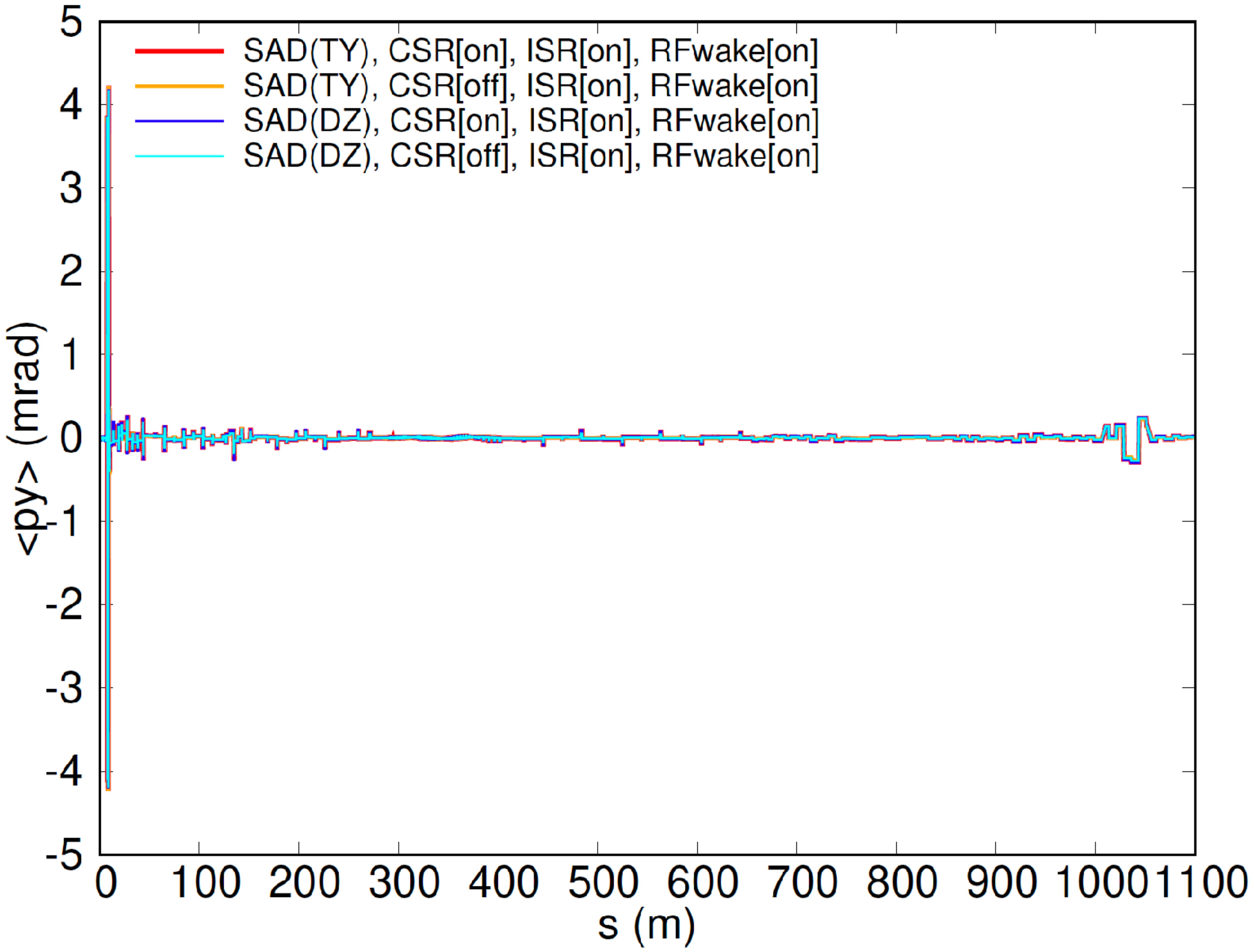




Simulations starting from PATGUN

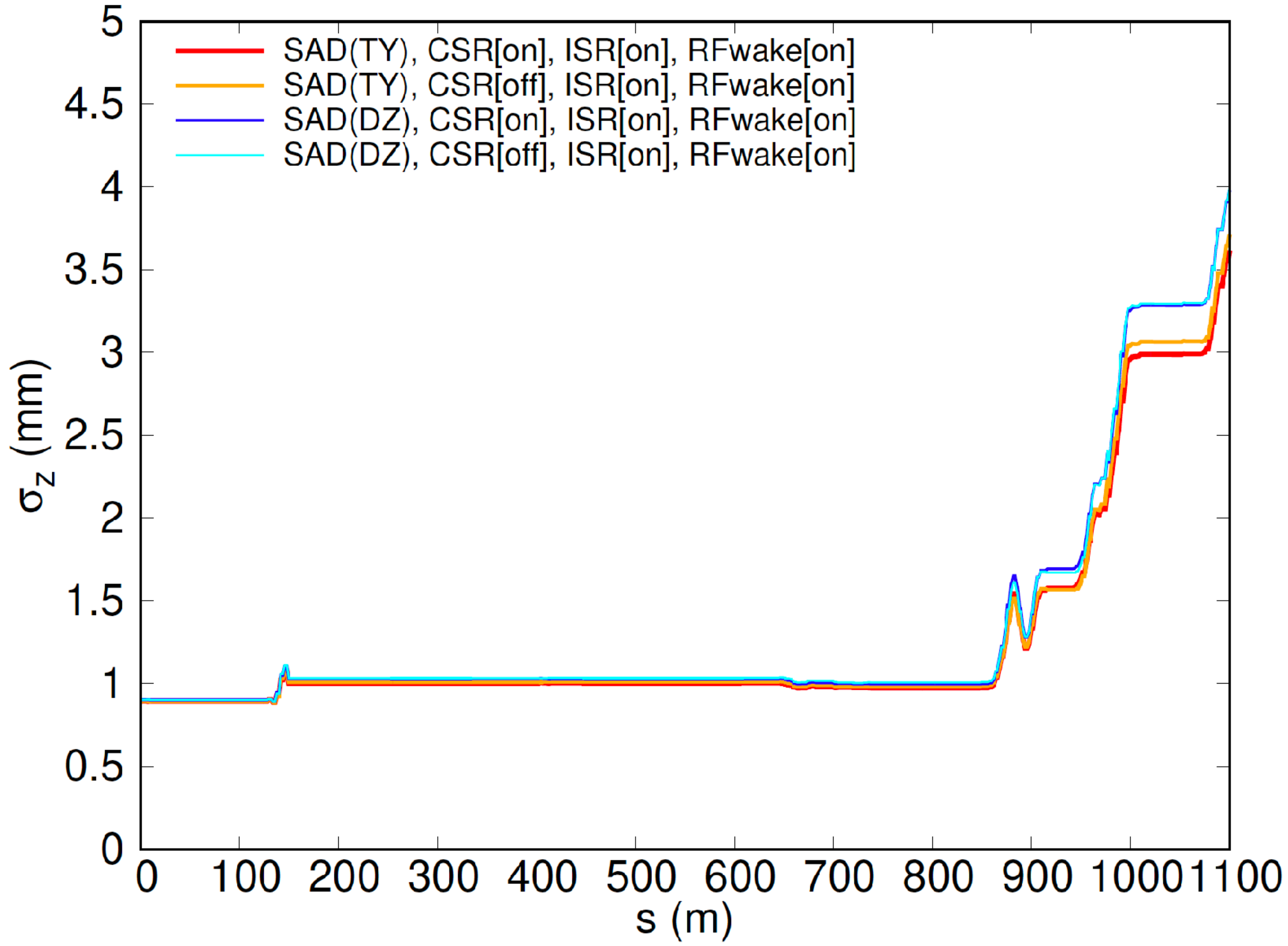
- <y> and <py> show good agreement.

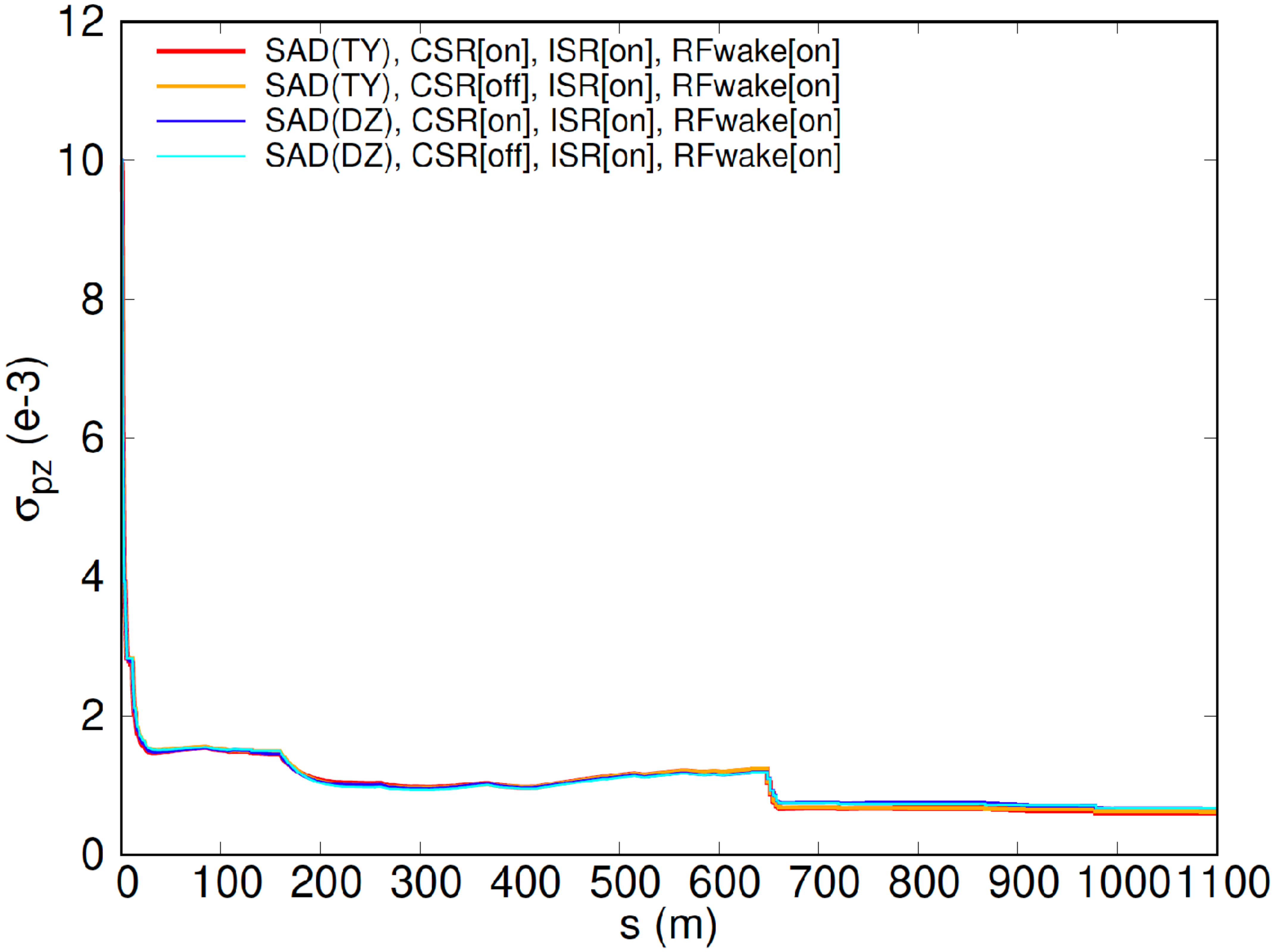




Simulations starting from PATGUN

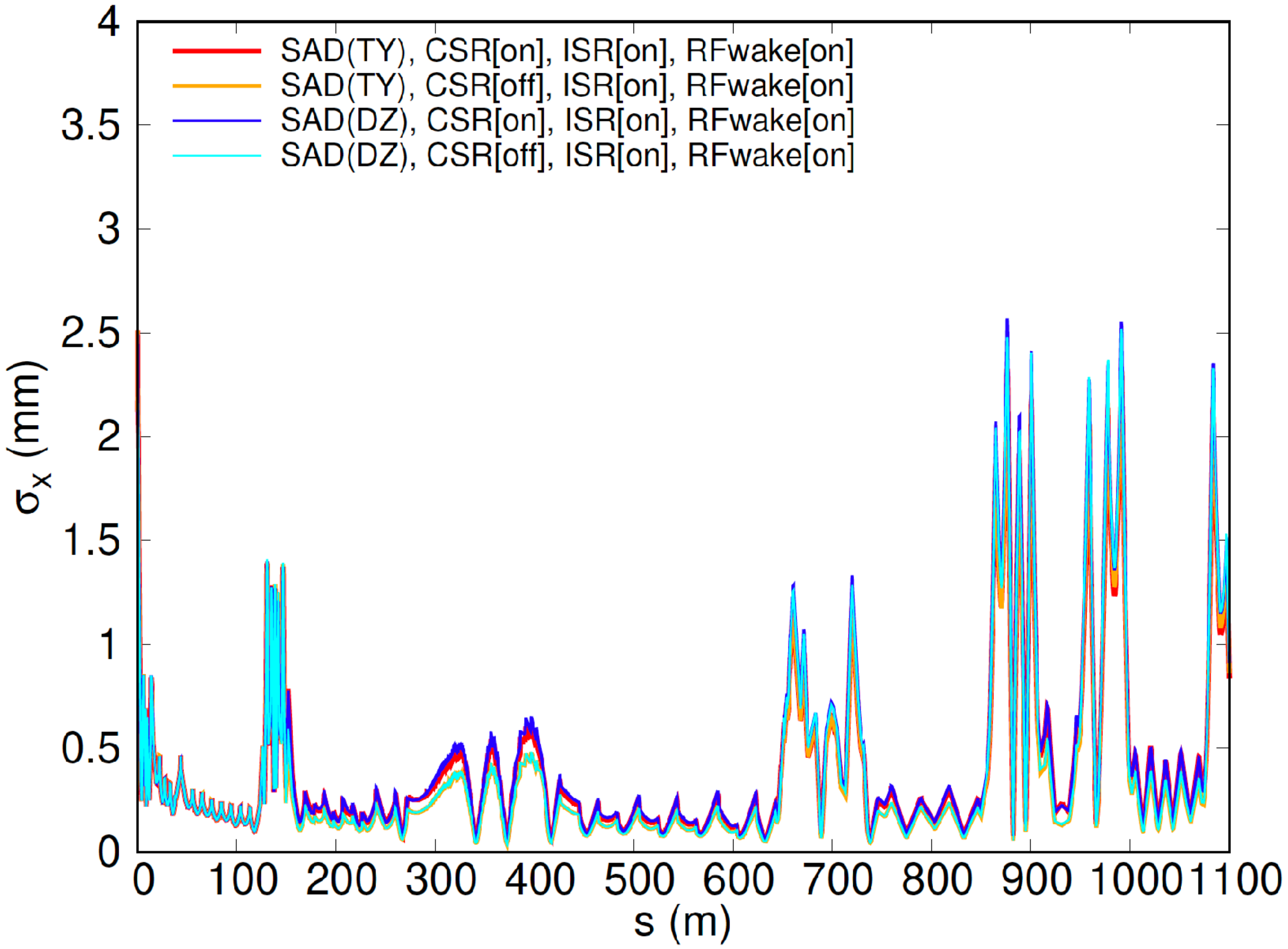
- rms σ_z and σ_{pz} show a small discrepancy. To be investigated.

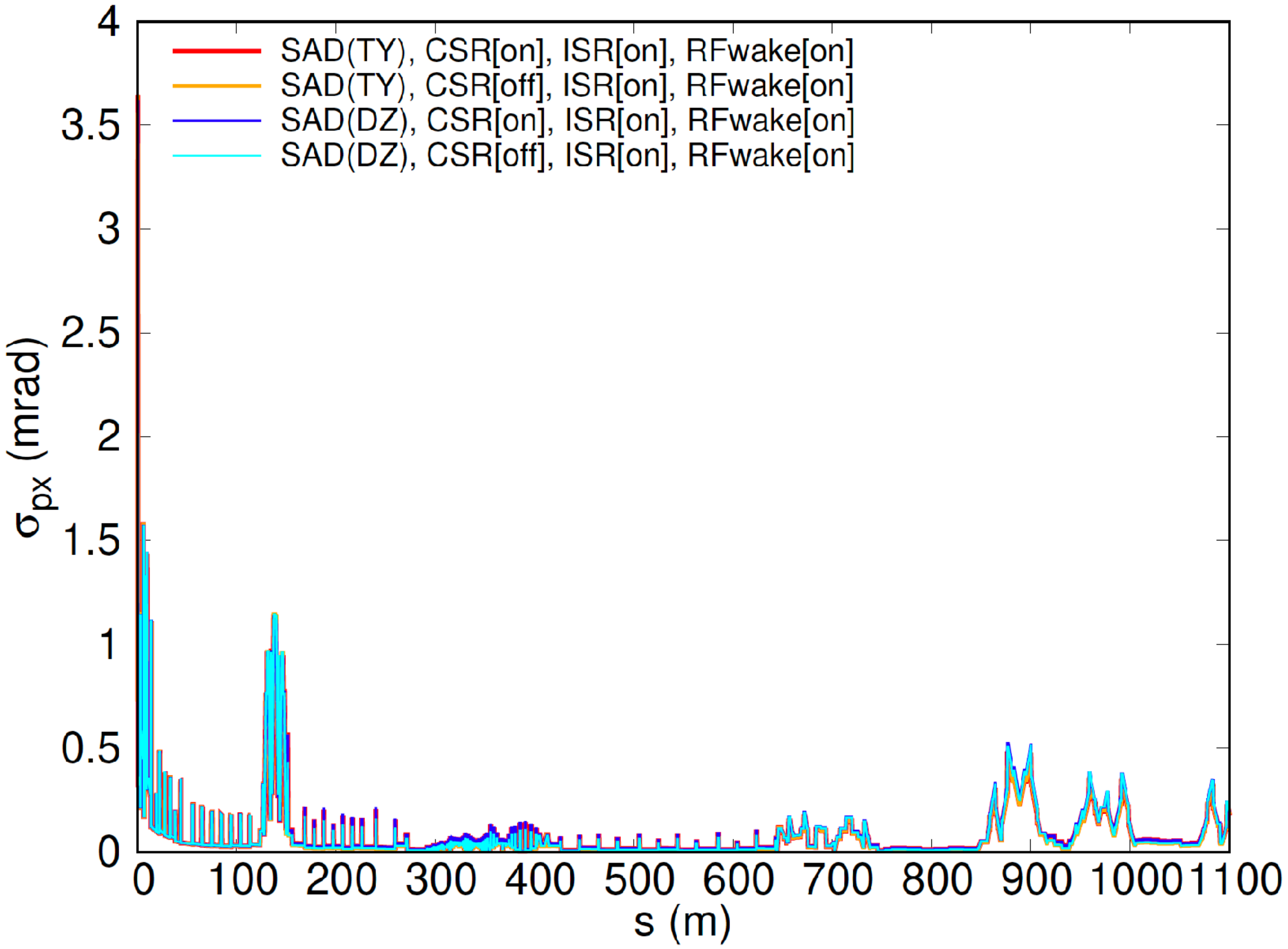




Simulations starting from PATGUN

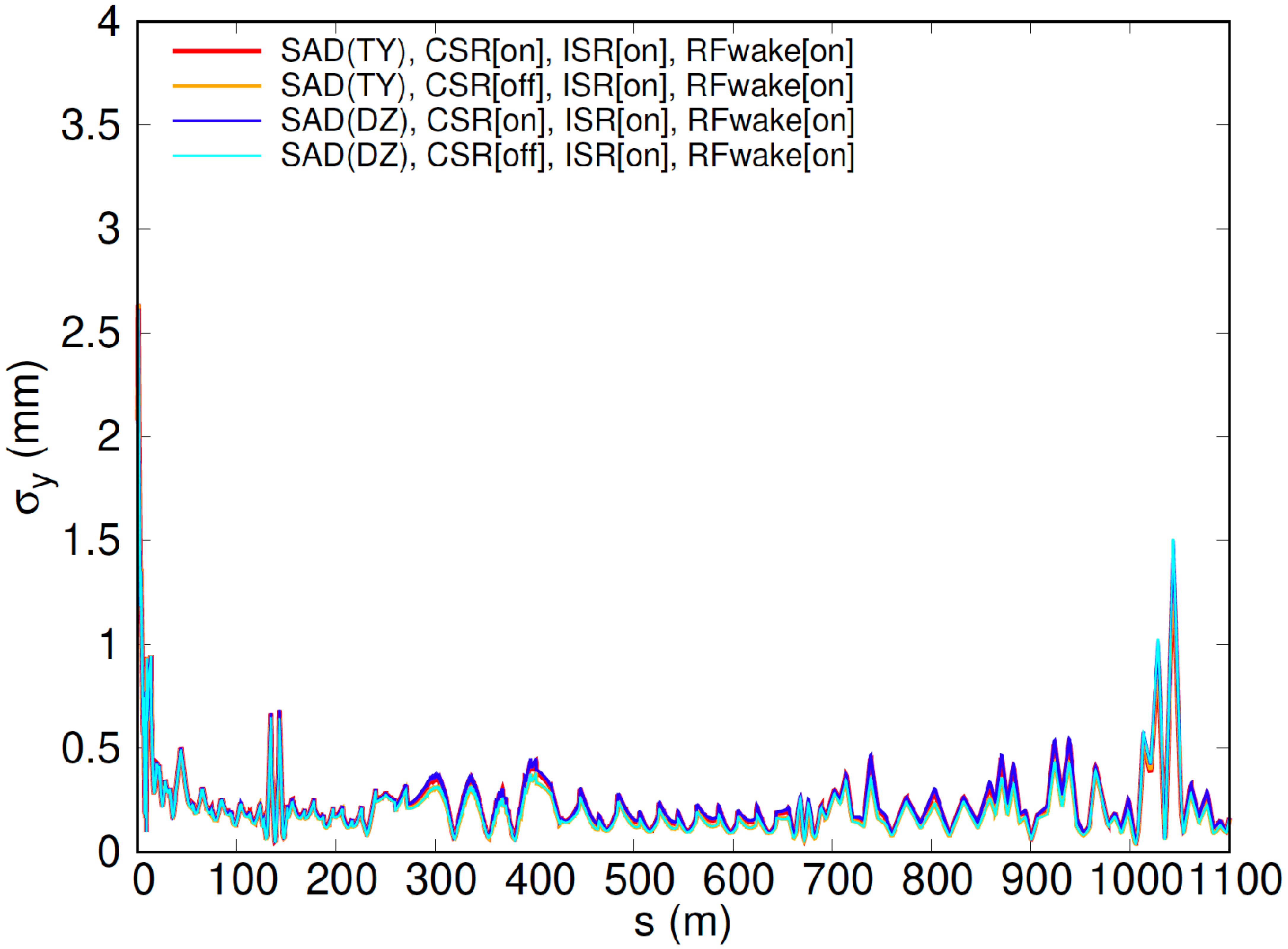
- rms σ_x and σ_{px} show good agreement. CSR effect is seen.

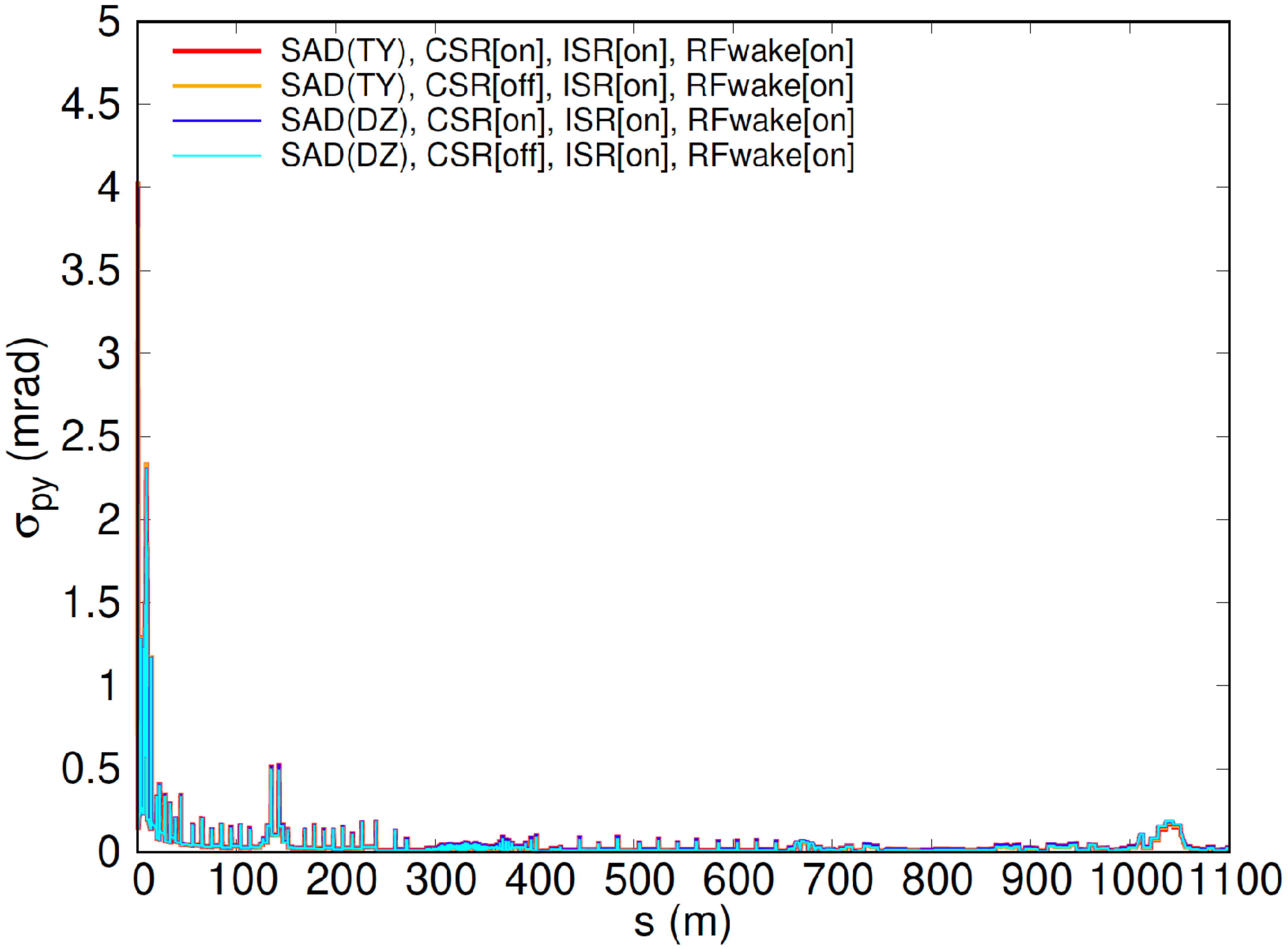




Simulations starting from PATGUN

- rms σ_y and σ_{py} show good agreement.

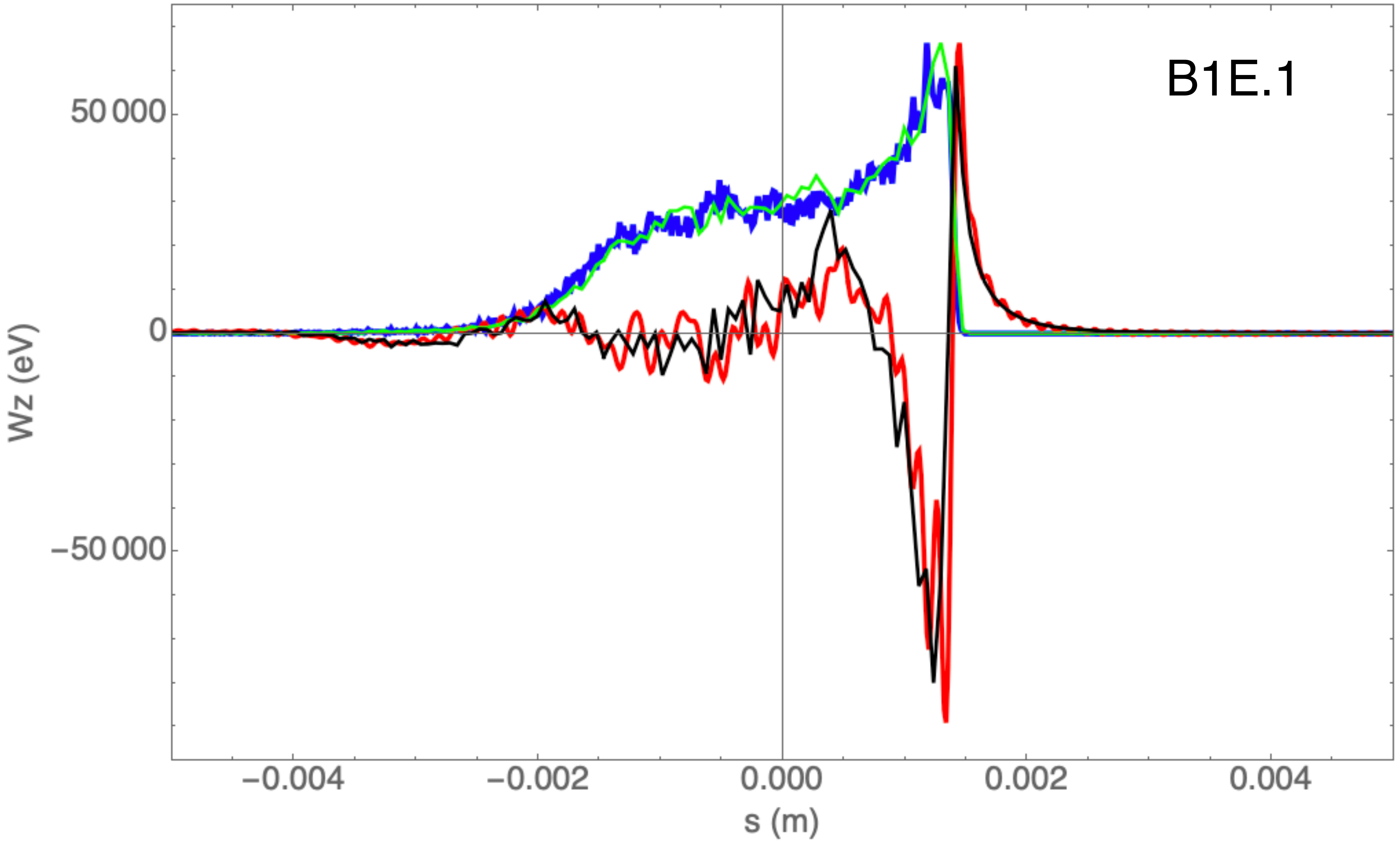


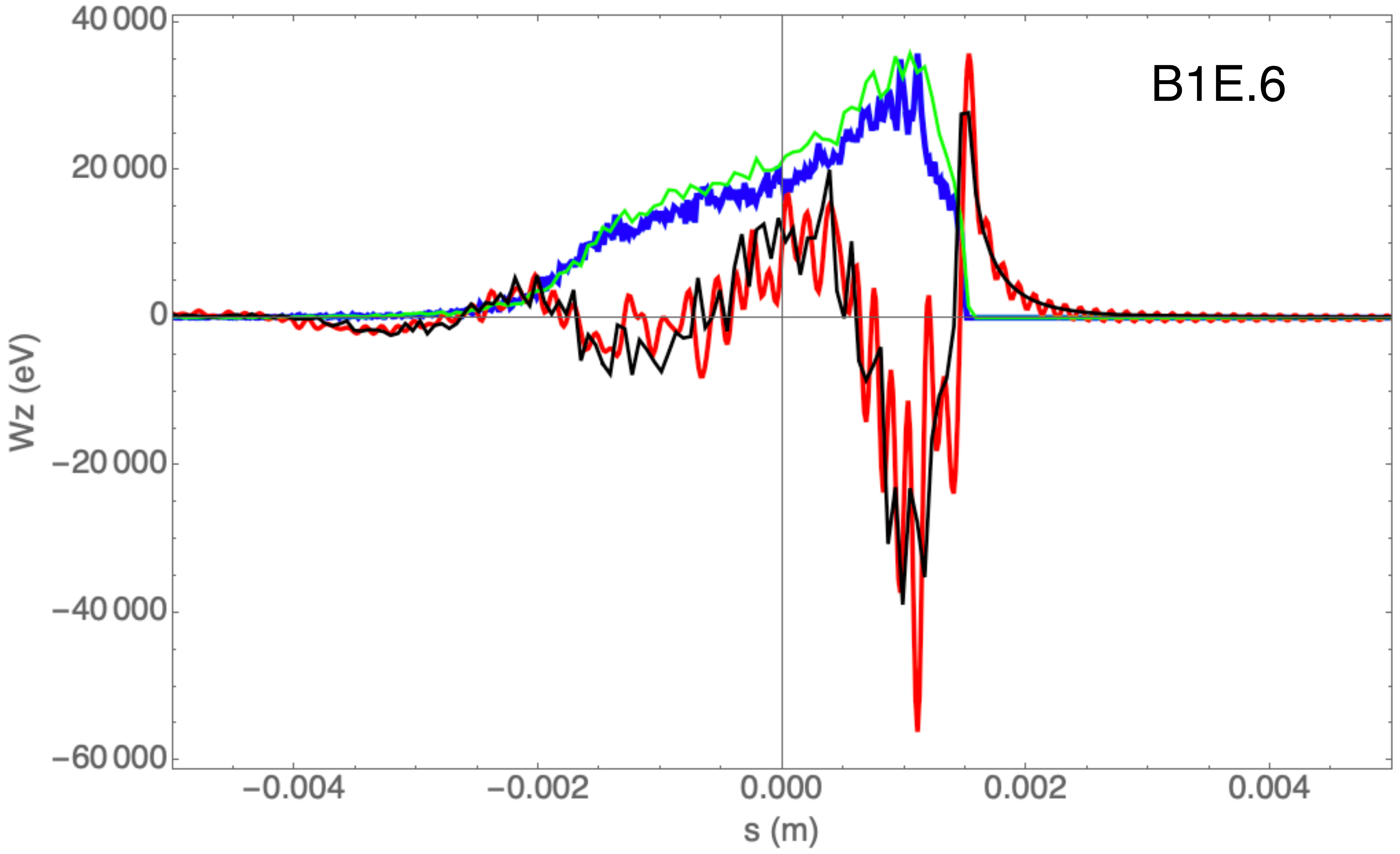


Simulations starting from PATGUN

- CSR wakes at BT01 (Ebeam=7 GeV).

Blue: z-profile (DZ)
Green: z-profile (TY)
Red: CSR wake (DZ)
Black: CSR wake (TY)

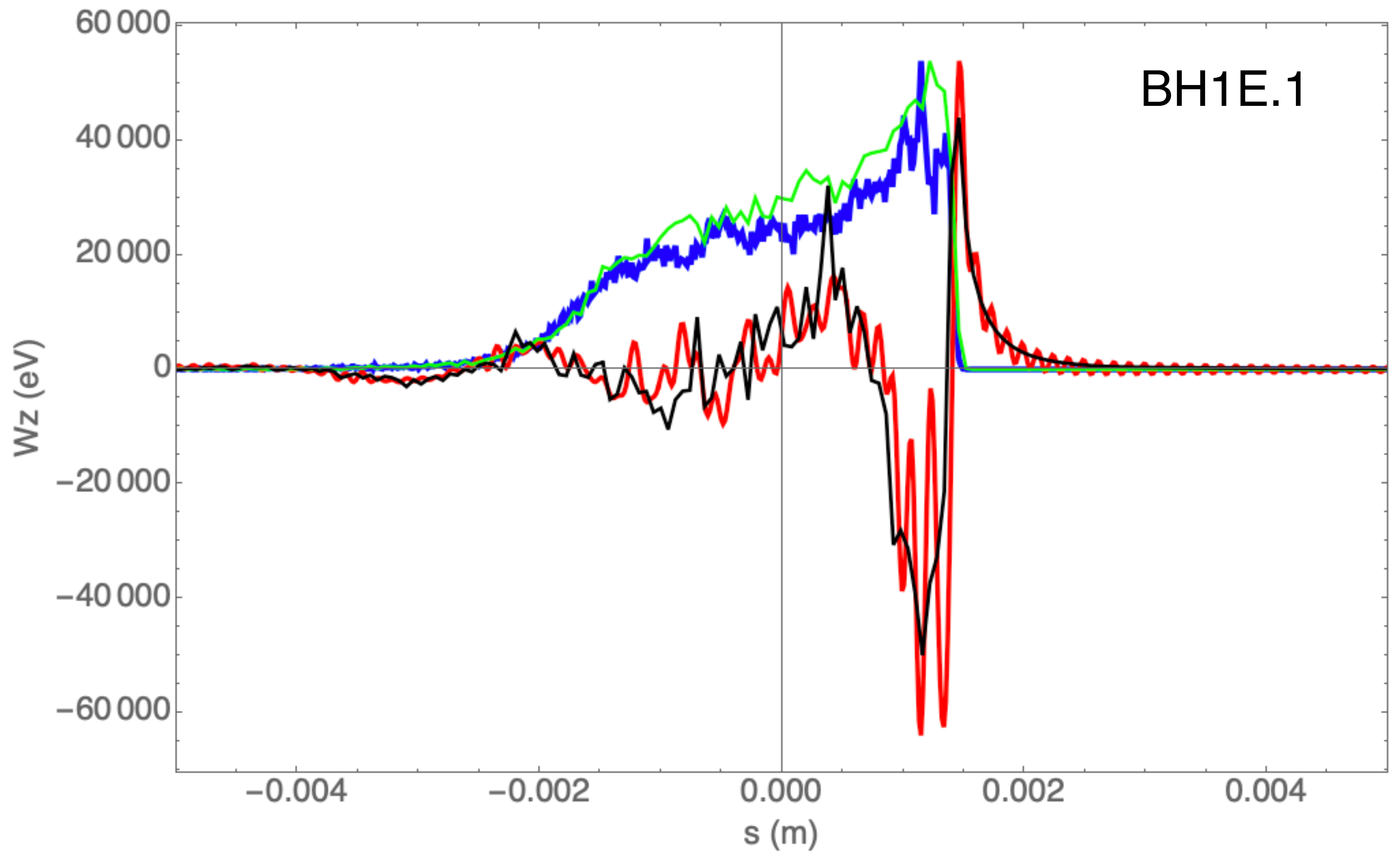


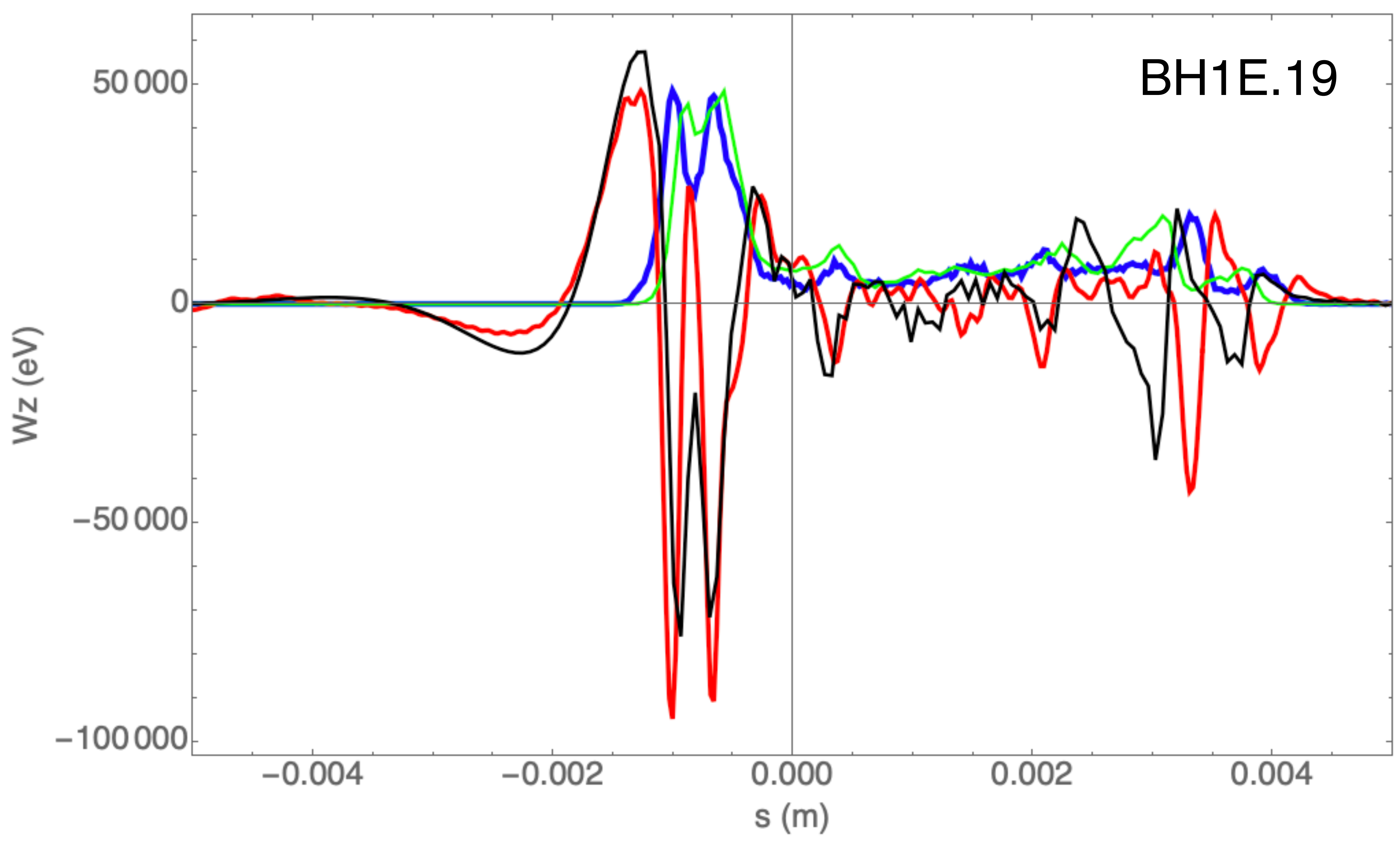


Simulations starting from PATGUN

- CSR wakes at BT02 (Ebeam=7 GeV).

Blue: z-profile (DZ)
Green: z-profile (TY)
Red: CSR wake (DZ)
Black: CSR wake (TY)





Simulations starting from PATGUN

- CSR wakes at BT04 (Ebeam=7 GeV).

Blue: z-profile (DZ)
Green: z-profile (TY)
Red: CSR wake (DZ)
Black: CSR wake (TY)