Electron beam dynamics simulation for beam matching from bunch compressor to LCLS-I undulator magnet

PITZ Physics Seminar (PPS)

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HELMHOLTZ

DESY.

Introduction

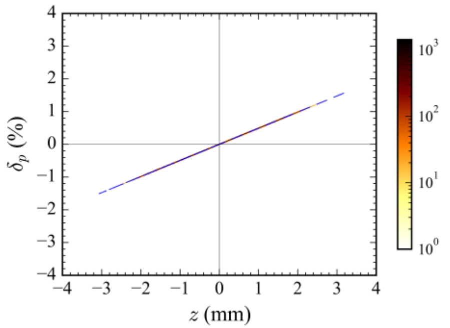
Motivation, Initial beam setup

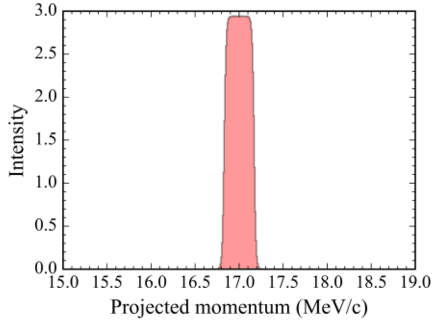
Beam momentum 17 MeV/c

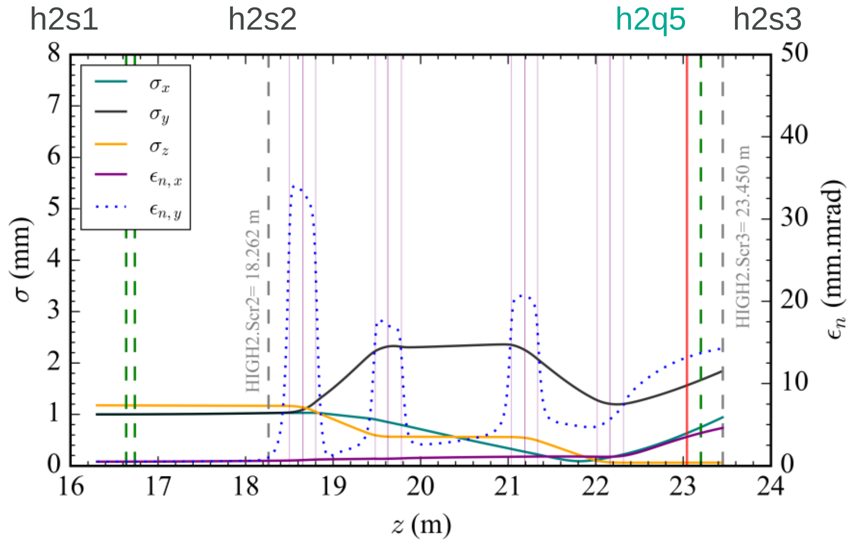
Beam with **chirp**

Energy spread 0.6%

Bunch charge 250 pC





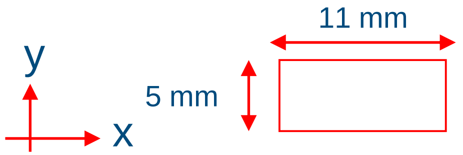


Challenges

- Only one quadrupole to focus beam after BC
- Increasing of the transverse emittance (vertical) after BC
- Strong space charge force field due to low energy electron beam, compressed beam, and high bunch charge (up to 1.5 nC for SASE)
- Match beam to small vertical pipe of an undulator magnet

Matching parameters (transverse phase space)

- Twiss-parameters : $\beta_x, \beta_y, \alpha_x, \alpha_y$
- Transverse beam emittance : ϵ_x, ϵ_y



Undulator chamber cross-section

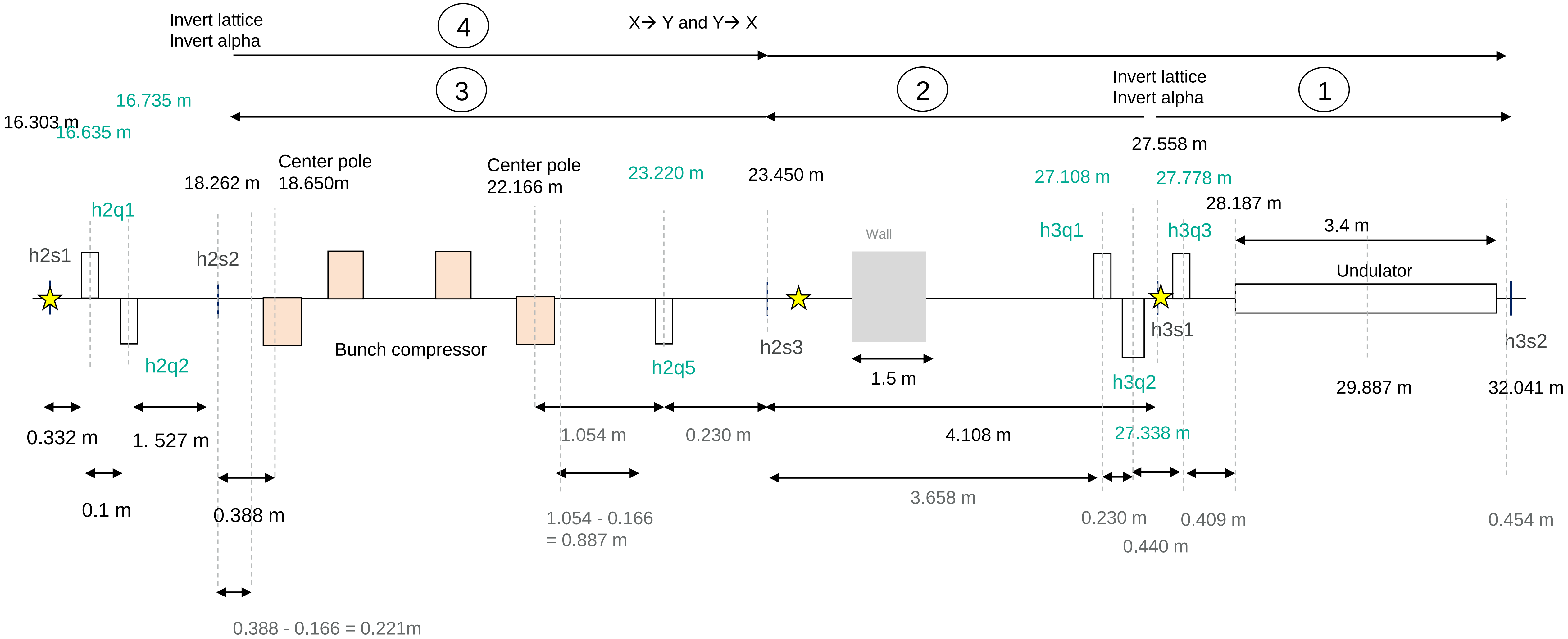
Beam matching using ASTRA and OCELOT

Motivation, Initial beam setup

Effective length of dipole magnet : 0.333047 m

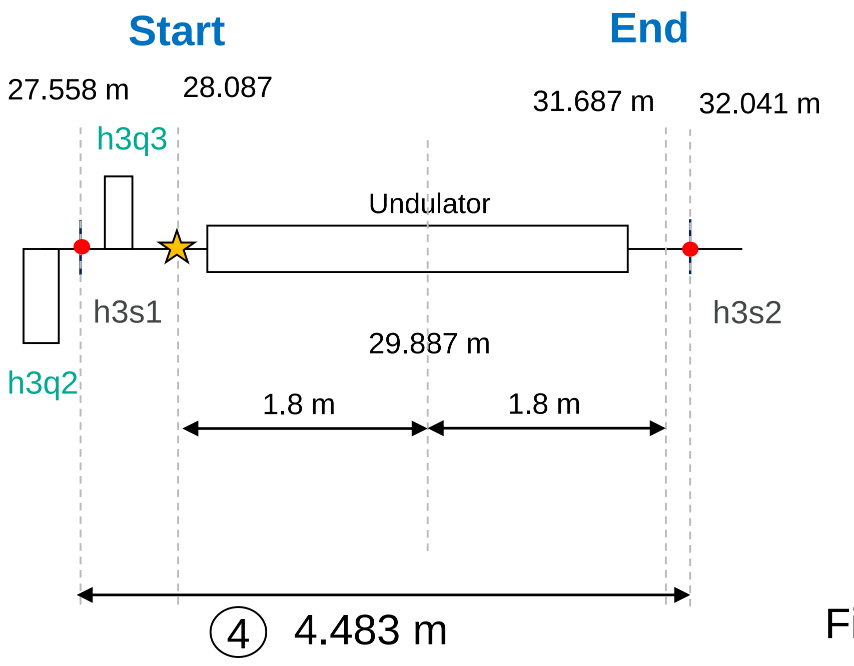
Effective length of QD : 0.04 m

Maximum strength : 8.4 T/m



Beam matching to undulator using ASTRA

Finding Twiss-parameters before undulator magnet



Simulation setup

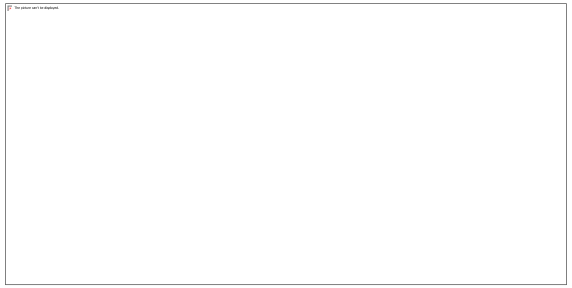
- Using ASTRA + 3D magnetic field of undulator magnet
- Optimized parameters
- Beam momentum 17 MeV/c, Bunch charge 250 pC
  - Transverse beam size $F_x = |\sigma_{xf} - \sigma_{xi}| \rightarrow 0$ $F_y = |\sigma_{yf} - \sigma_{yi}| \rightarrow 0$
  - Correlation

$$\sigma_x^2 = \frac{\beta_x \epsilon_{n,x}}{\beta\gamma}$$

$$cor_{px} = -\frac{\alpha_x}{\beta_x[m]}\sigma_x[mm]$$

Fixed transverse emittance !

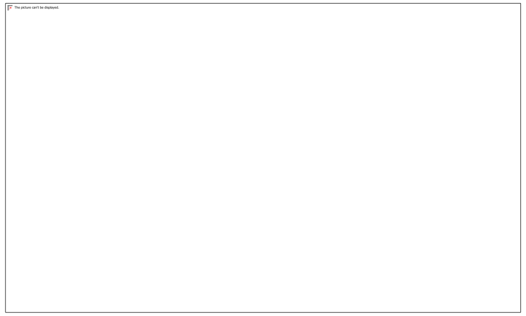
Norm. emit_x, Norm. emit_y = 1, 1 mm.mrad

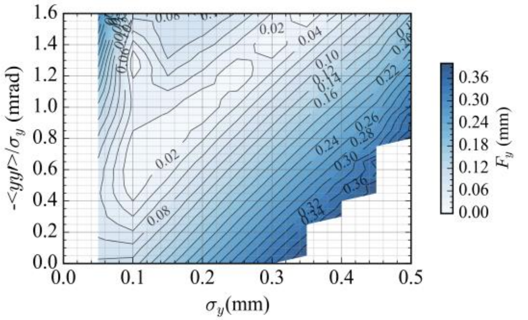


- Xemit = Yemit = 1 um
- Std_x = 0.55 mm
- Std_y = 0.15 mm
- Xx'/std_x = 0.25 mrad
- Yy'/std_y = 0.8 mrad

→

- Beta_x = 10 m
- Beta_y = 0.75 m
- Alpha_x = 4.6→6 m
- Alpha_y = 4 m



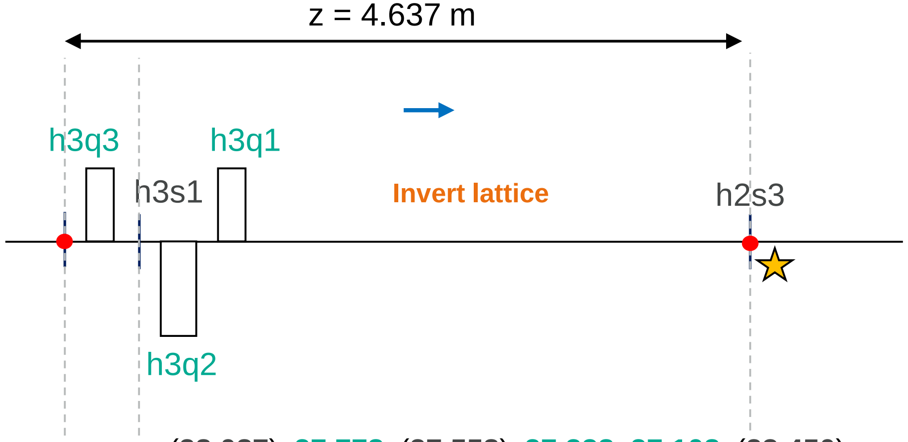


Backward tracking using OCELOT

Quadrupole scan to get round beam transportation

Invert the lattice

Invert alphas

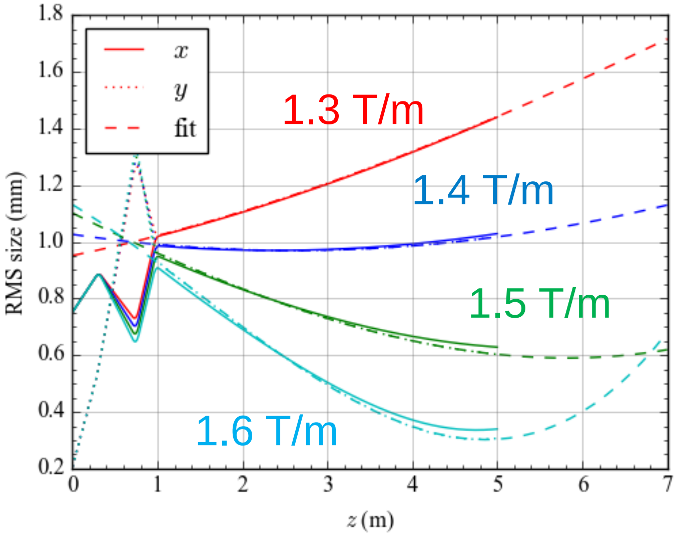


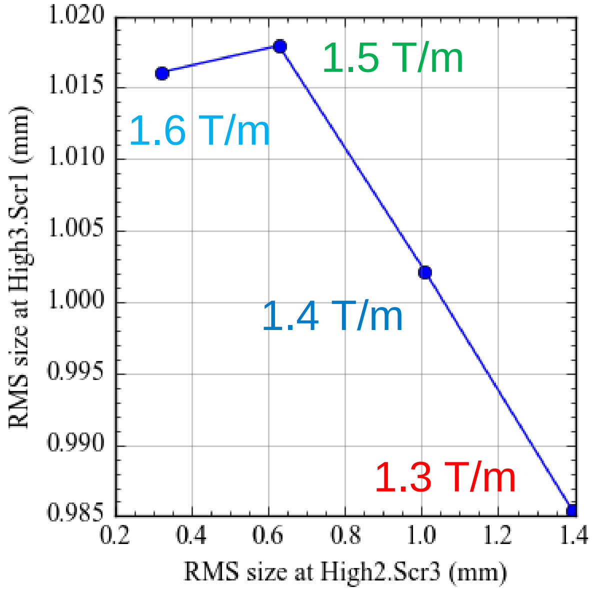
(28.087), **27.778**, (27.558), **27.338**, **27.108**, (23.450)

Positions in beamline

(0), **0.309**, (0.529), **0.749**, **0.979**, (4.637)

Positions in simulation **backward tracking**

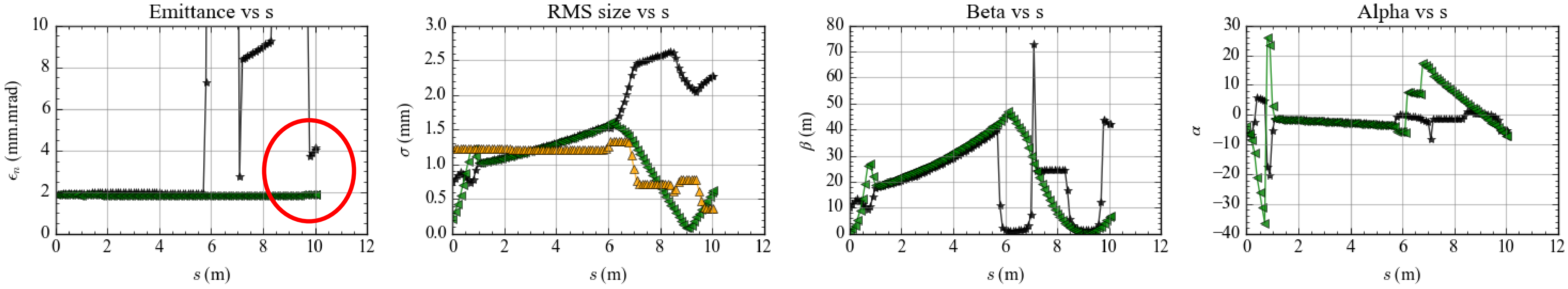




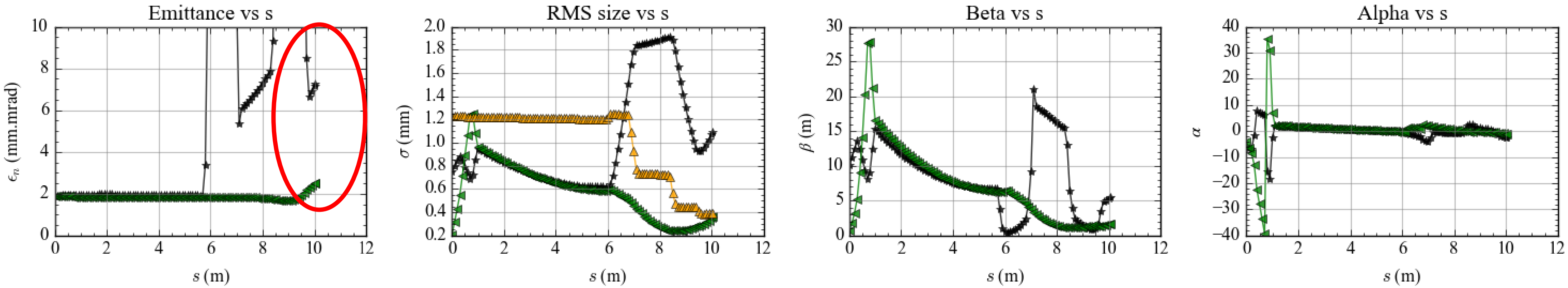
Backward tracking using OCELOT

Tracking to the entrance of the BC

HIGH3.Q3 = 1.3 T/m



HIGH3.Q3 = 1.5 T/m

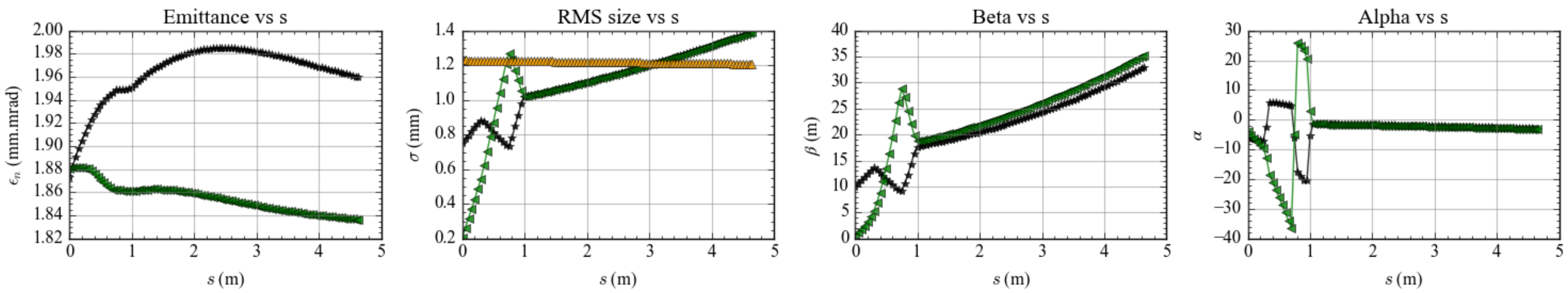


Backward tracking using OCELOT

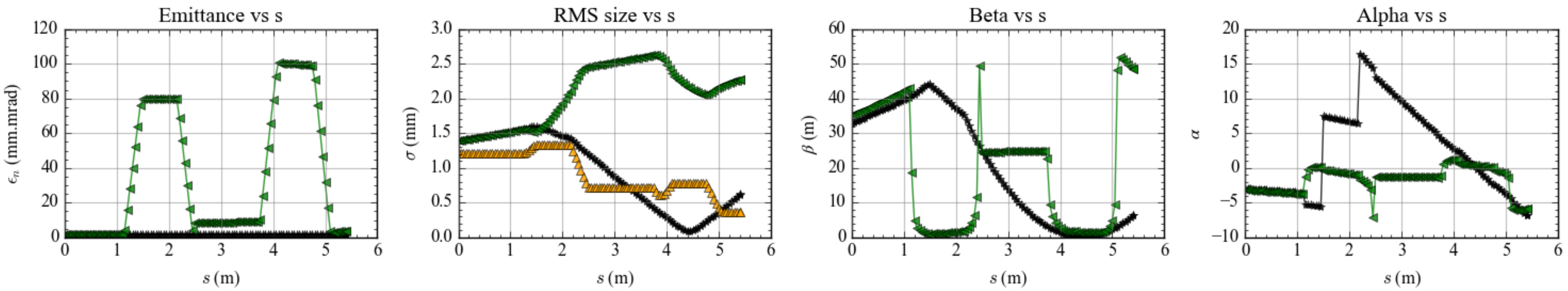
Tracking to the end off the BC, switch x and y axis and tracking further to BC entrance

1st Iteration, HIGH3.Q3 = 1.3 T/m

Green color→ Vertical **Black color**→ Horizontal



X ← → Y



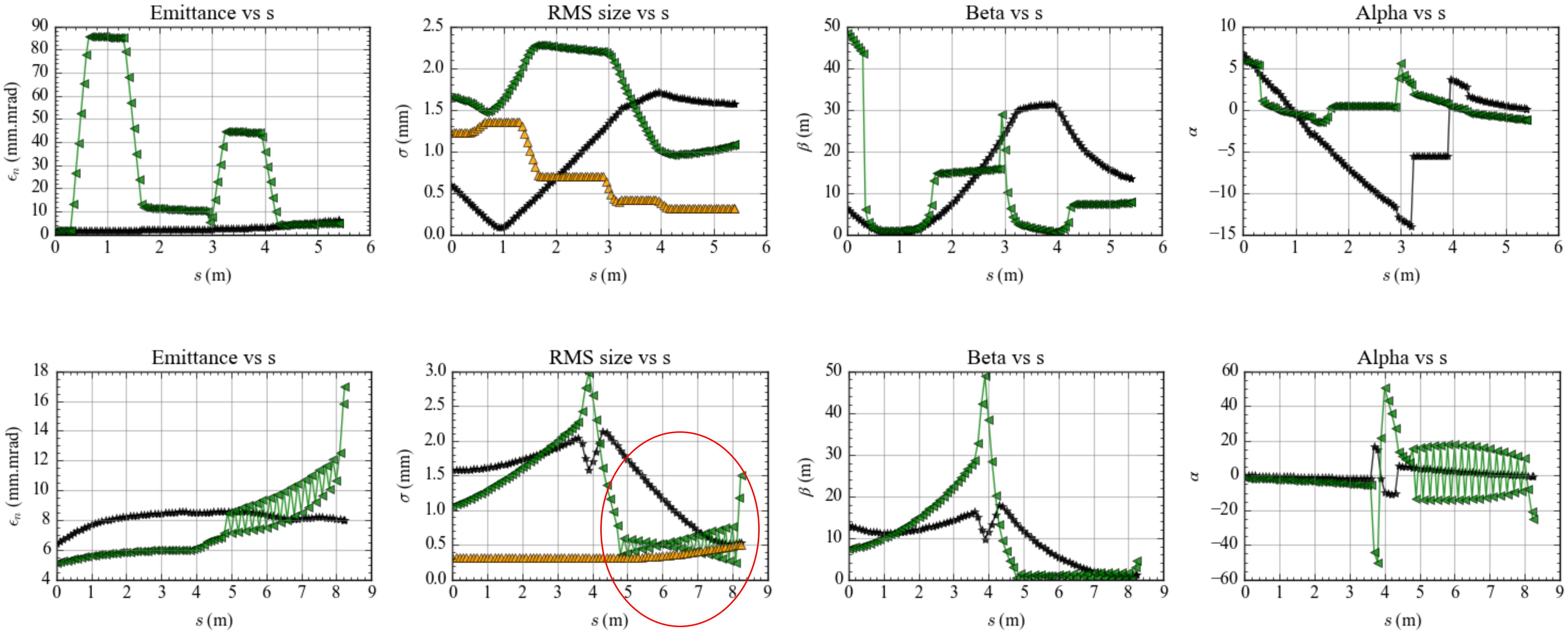
Forward tracking using OCELOT

Invert alpha (twiss-parameter), tracking beam the end of the undulator magnet

Green color→ Vertical **Black color**→ Horizontal

1st Iteration, HIGH3.Q3 = 1.3 T/m

X ← → Y

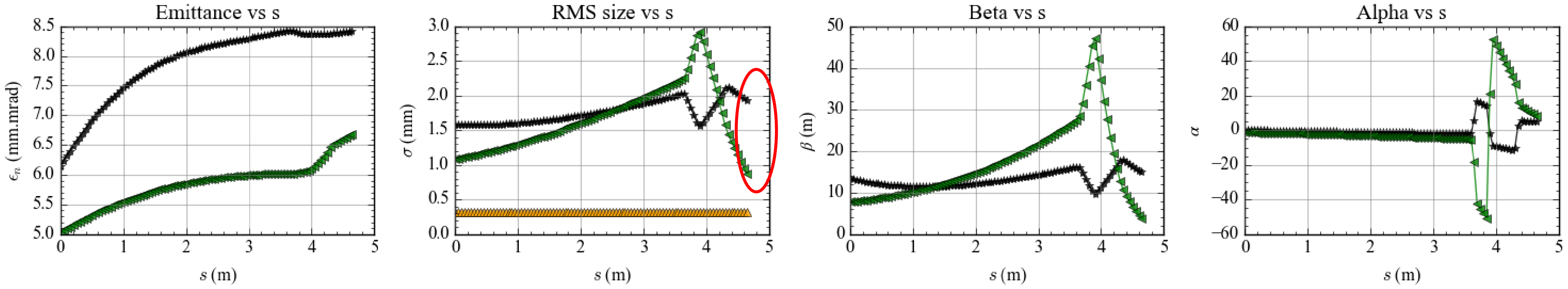


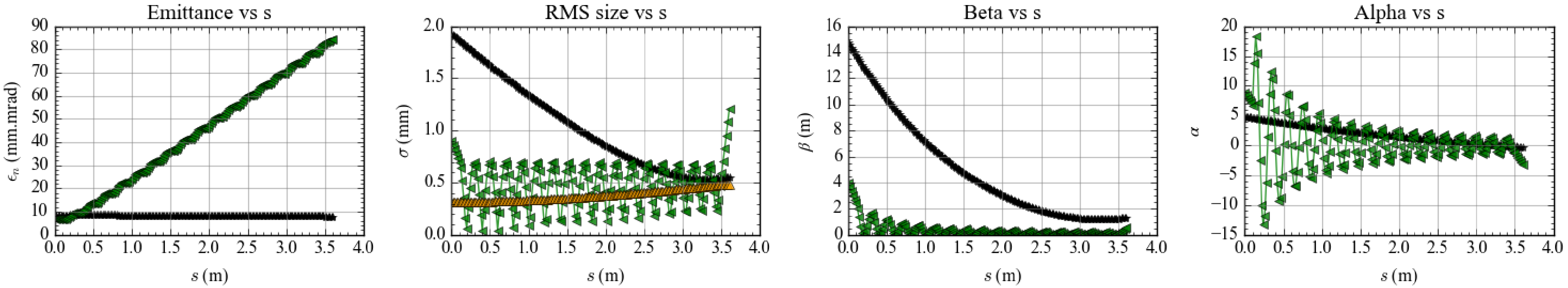
2nd Iteration

Using beam at the entrance of the undulator magnet and scale twiss-paramters to matnching condition

1st Iteration, HIGH3.Q3 = 1.3 T/m

Green color→ Vertical **Black color**→ Horizontal





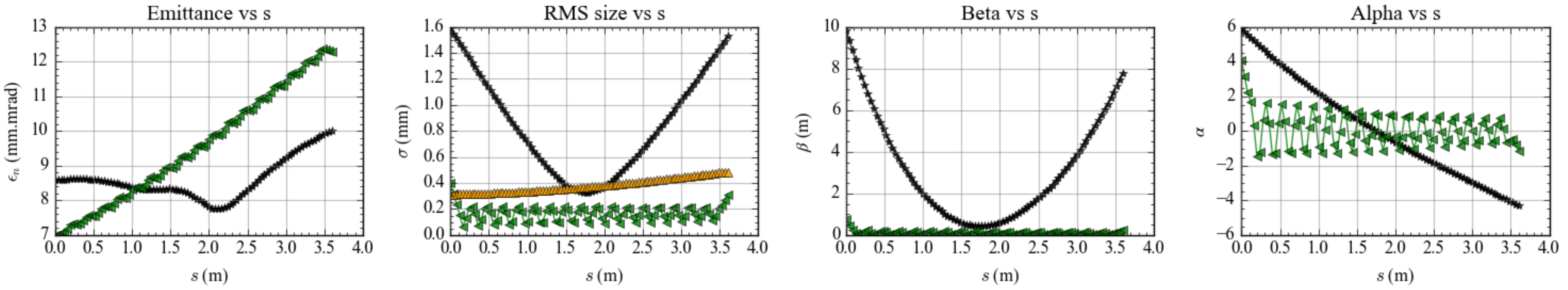
Undulator section

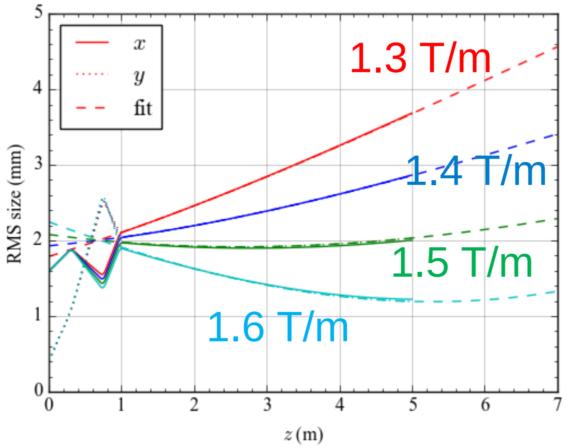
2nd Iteration

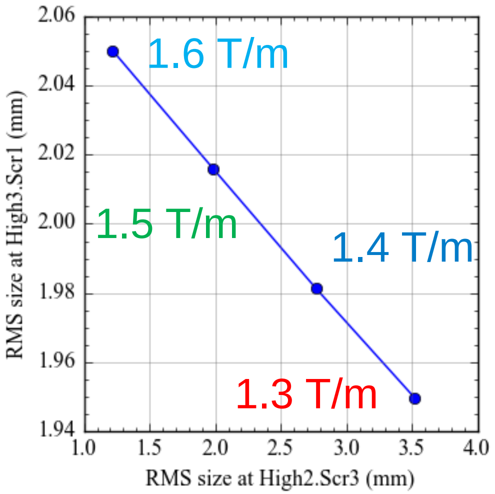
Scale beam to matching condition

1st Iteration, HIGH3.Q3 = 1.3 T/m

Scale beam to matching condition, where : betax, betay, alphax, alphay = 10 m, 0.75 m, 6, 4





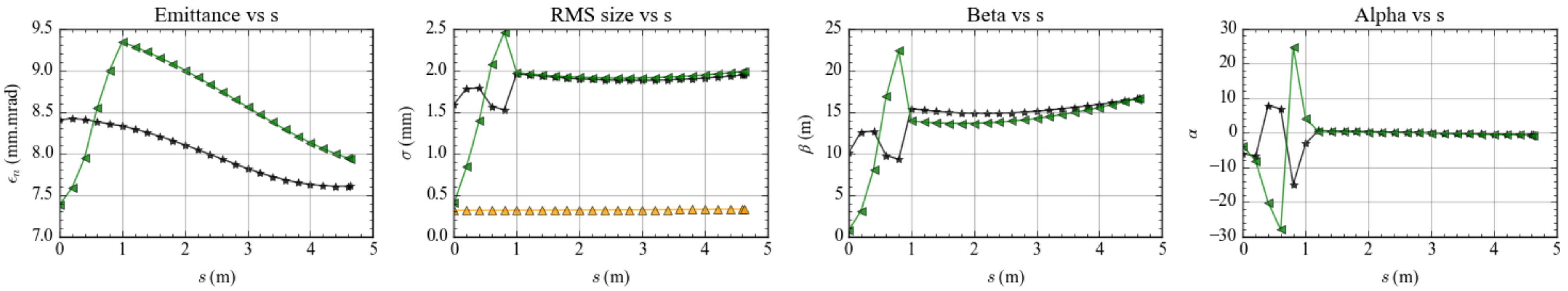


2nd Iteration

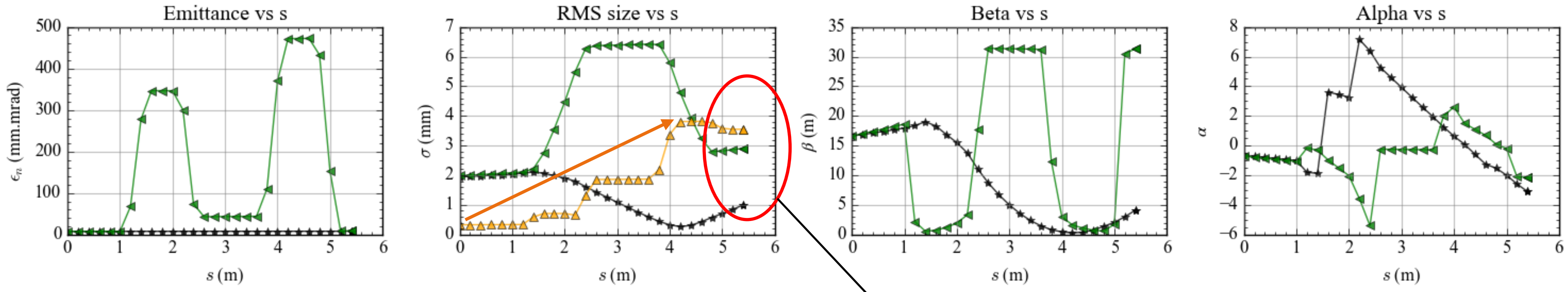
Backward tracking to the BC entrance

1st Iteration, HIGH3.Q3 = 1.3 T/m

2nd Iteration, HIGH3.Q3 = 1.5 T/m



X ←→ Y



De-compression in longitudinal

- Beam distribution
- Twiss-parameters

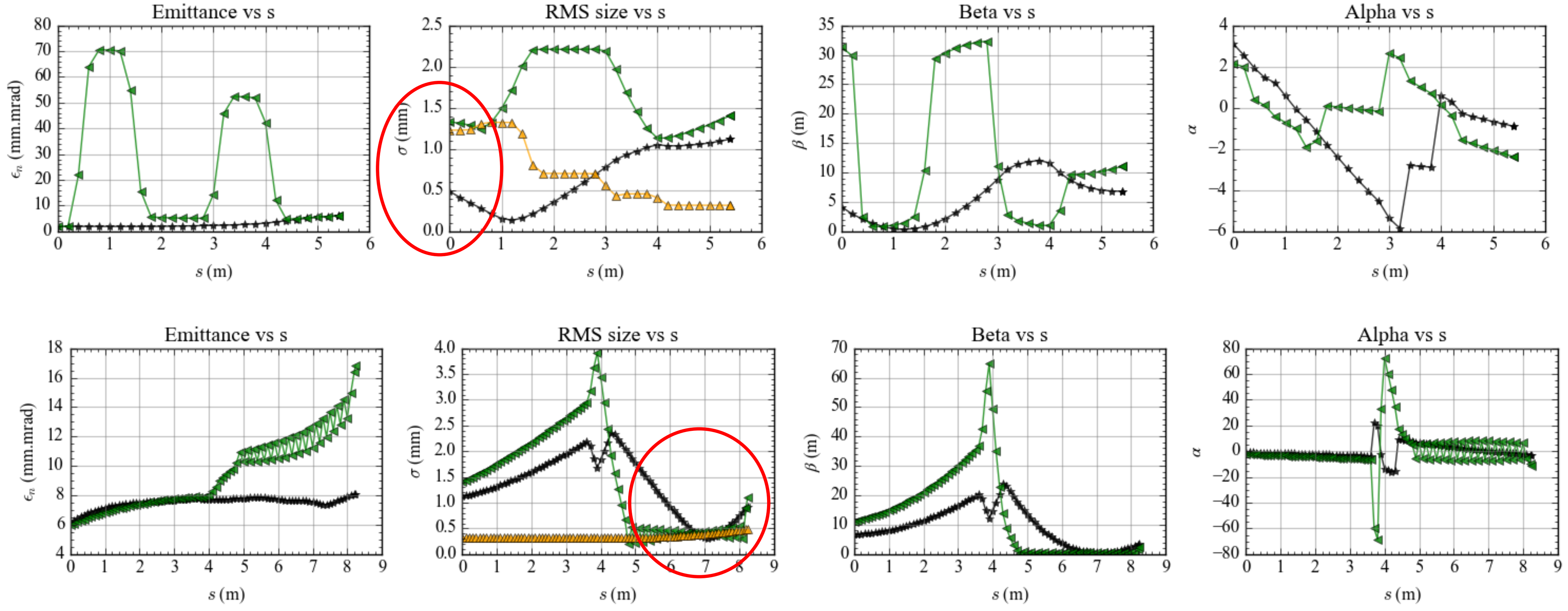
2^{nd} Iteration

Forward tracking to the end of the undulator magnet (using beam from S2E simulation)

1^{st} Iteration, HIGH3.Q3 = 1.3 T/m

2^{nd} Iteration, HIGH3.Q3 = 1.5 T/m

X ← → Y



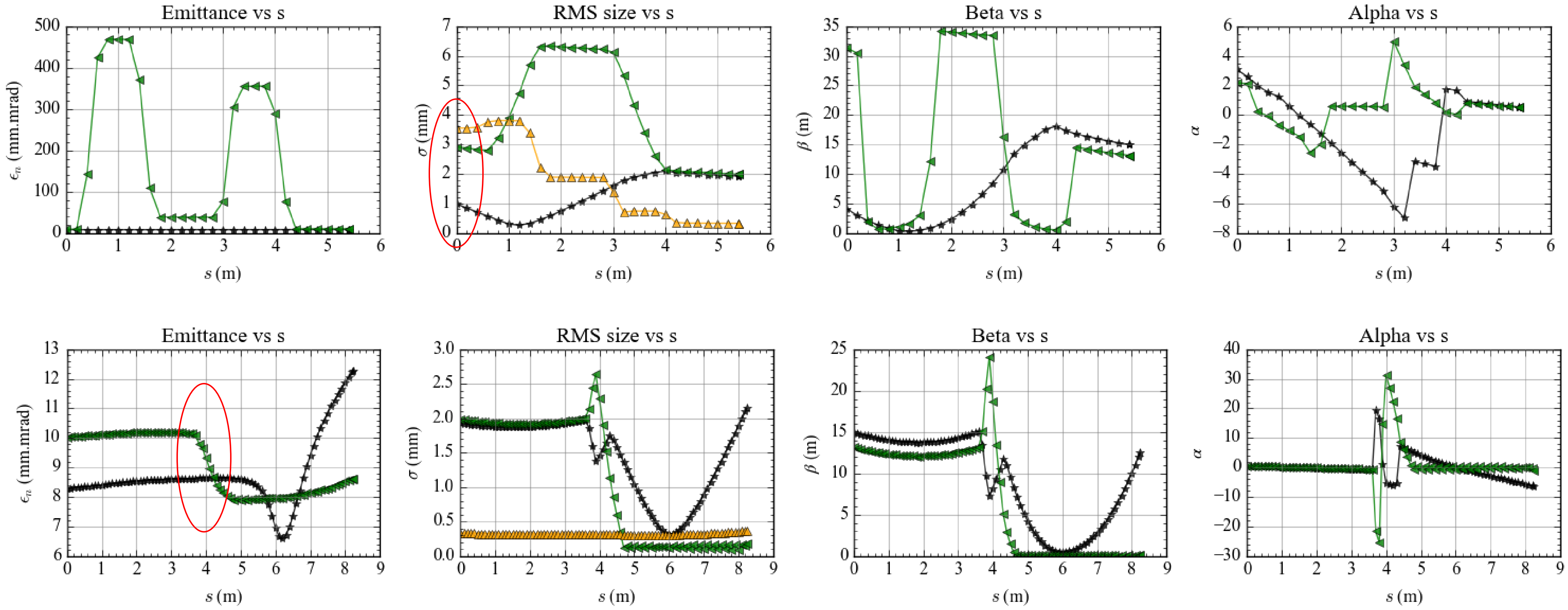
2nd Iteration

Forward tracking to the end of the undulator magnet (using beam from backward tracking)

1st Iteration, HIGH3.Q3 = 1.3 T/m

2nd Iteration, HIGH3.Q3 = 1.5 T/m

X ← → Y



Conclusion and Outlook

- Good beam transportation from BC to undulator can be achieved in 2 iterations! In the simulation.
- Matching the compressed beam require considering the longitudinal beam properties.
- The best setup parameters for beam transportation from the BC to the undulator section involves having beam symmetry in the horizontal plane, possible to get the Twiss parameters before entering the BC in the experiment, and ensuring no beam loss during transportation.

Next..

- Using HIGH2.Q5 in the matching procedure in order to optimize beam between BC and undulator magnet (for the case of using beam from S2E).
- Using difference bunches charges to test the procedure e.g., 50 pC, 1.5 nC
- Matching beam from BC entrance to booster.
- Including dispersion effect to the beam transportation.
- Including CSR effect to the beam transportation.
- Beam preparation and machine setup parameters for FEL production for low and high bunch charge.

Thank you for your attention