Reproducing LhARA stage 1 BDSIM results with RFTrack

WP6 LhARA meeting

16/03/2026

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Emittance considerations

- RMS emittance defined with canonical variables (x,px,...) stays constant if perfect linearity, no chromaticity, conservative forces,...
- **$\varepsilon_x * \varepsilon_y \geq \varepsilon_{4D}$** if correlation between x and y distributions

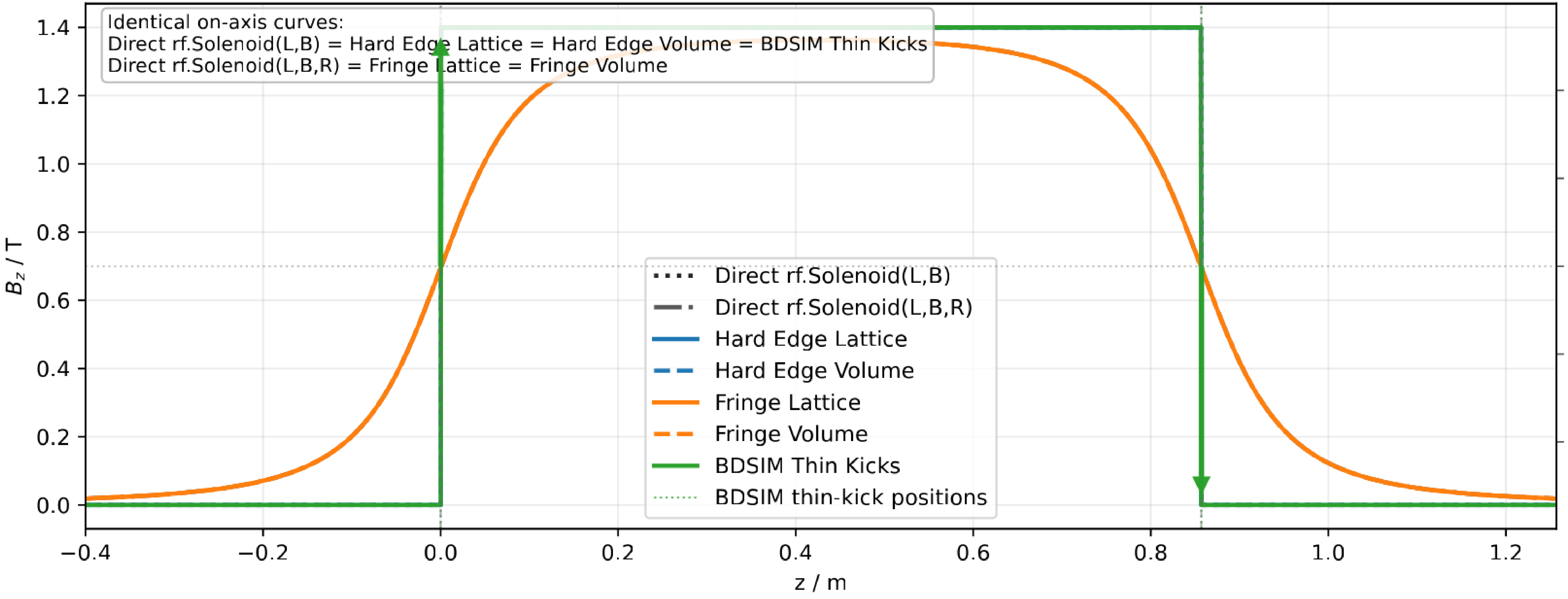
  =>**solenoid** changes x,y correlations: **artificial blowing up of ε_y=> blowing up of beta**

- Geometric and normalized RMS emittance increases in a solenoid because of the **chromaticity**: emittance increases due to **filamentation**

What I forgot to do: **–emittanceOnTheFly** when calling 'rebdsimOptics': **compute emittance on each sampler** again

Solenoid: on axis B field

- Lattice and Volume modes: continous fringe model
- Hard edge + kicks: BDSIM like for paraxial beams



Discrepancies between lattice and fringe mode in RFTrack

- Lattice with fringe and Volume with fringe have the same on axis field
- Lattice: uses a matrix element
- Volume: resolve motion equations + need to choose a fringe field length => *does it replace previous beamline element map if any?*

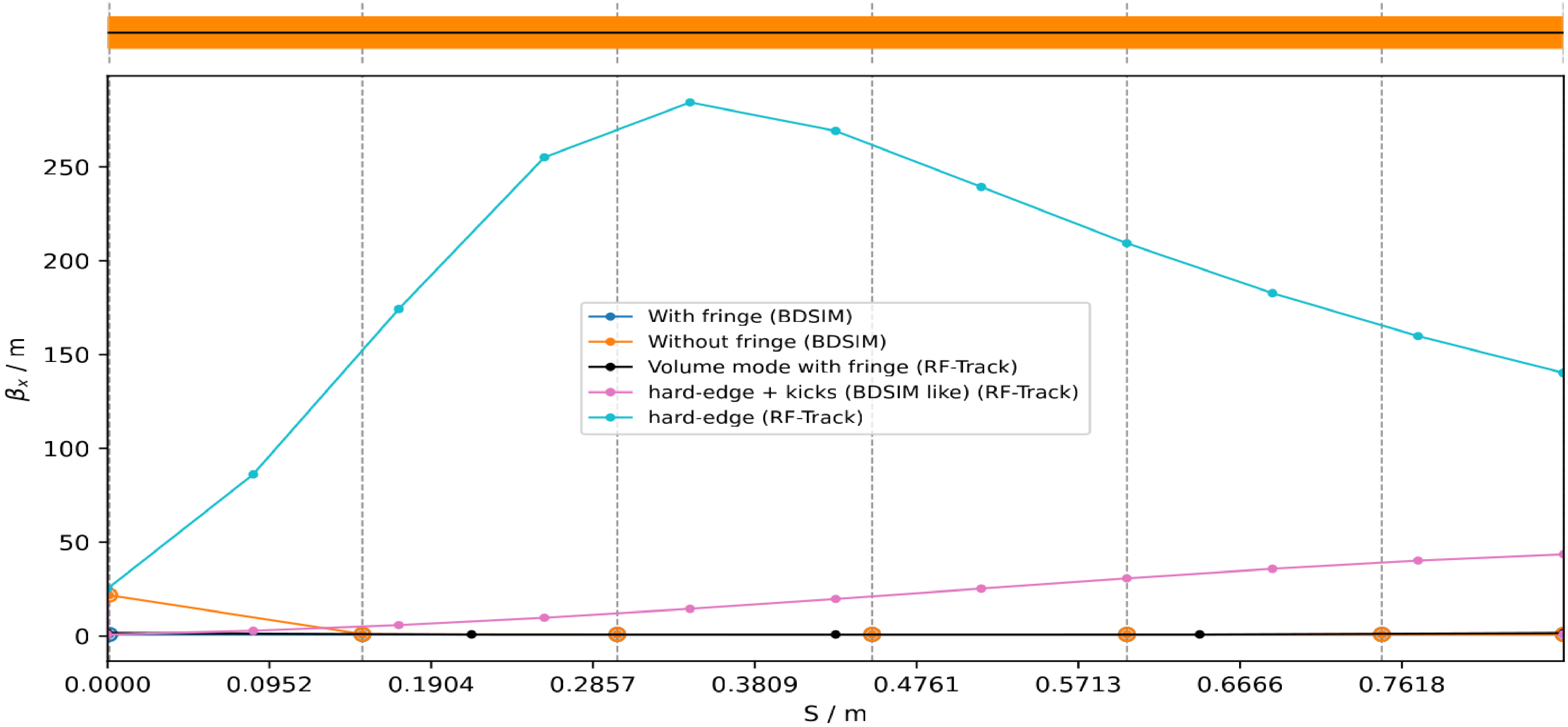
BDSIM Solenoid models

- paraxial: analytic BDSIM solenoid formula
- non-paraxial: Geant4 RK4 using the field/equation of motion
- fringe: separate thin rmatrix kicks
- In BDSIntegratorSolenoid.cc:

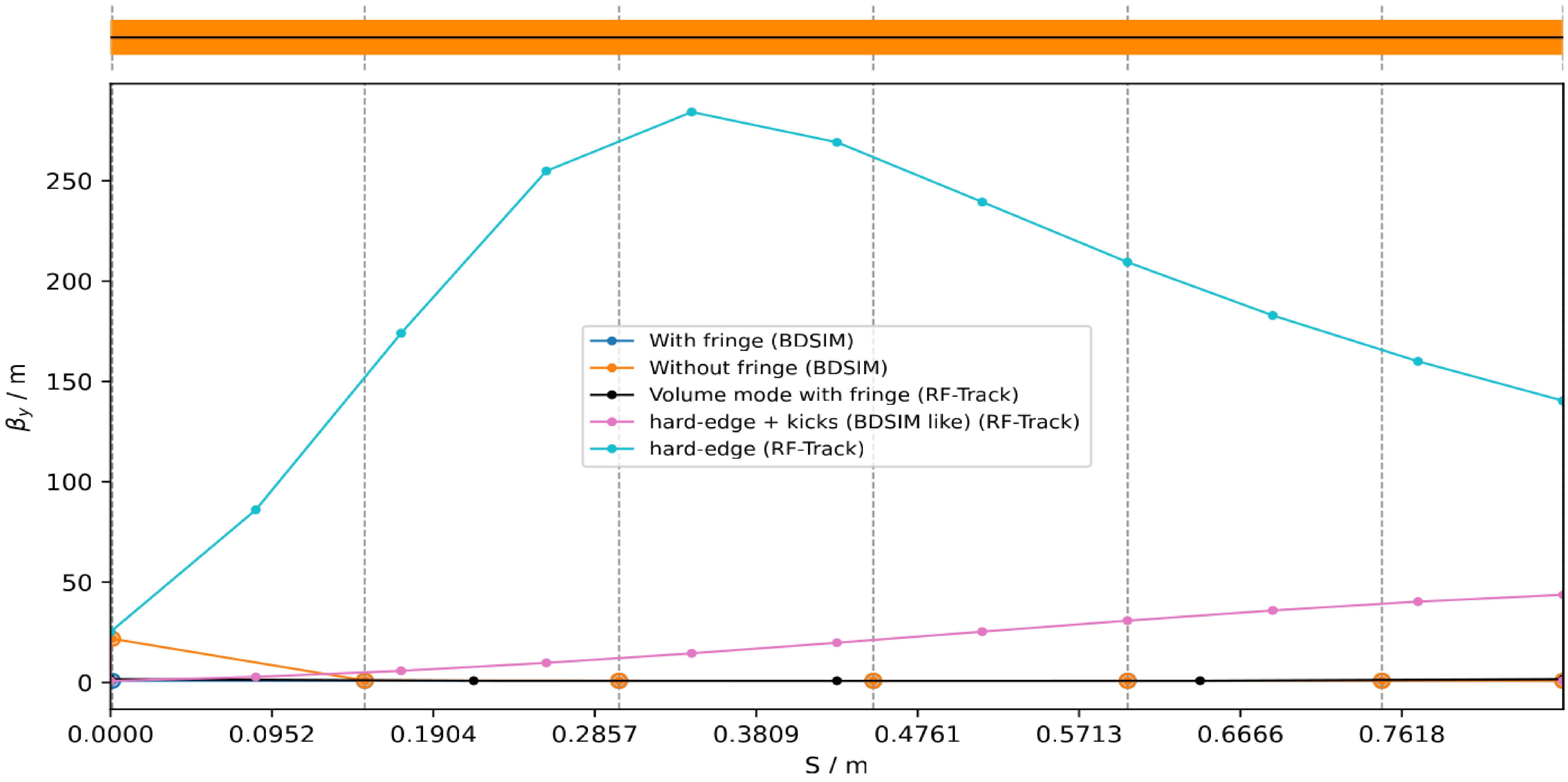
```
// only proceed with thick matrix if particle is paraxial
// judged by forward momentum > 1-limit and |transverse| < limit (default limit=0.1)
if (zp0 < (1.0-backupStepperMomLimit) || std::abs(xp0) > backupStepperMomLimit || std::abs(yp0) > backupStepperMomLimit)
  {
    backupStepper->Stepper(yIn, dydx, h, yOut, yErr);
    SetDistChord(backupStepper->DistChord());
    return;
  }
```

Solenoid simulation (without first drift)

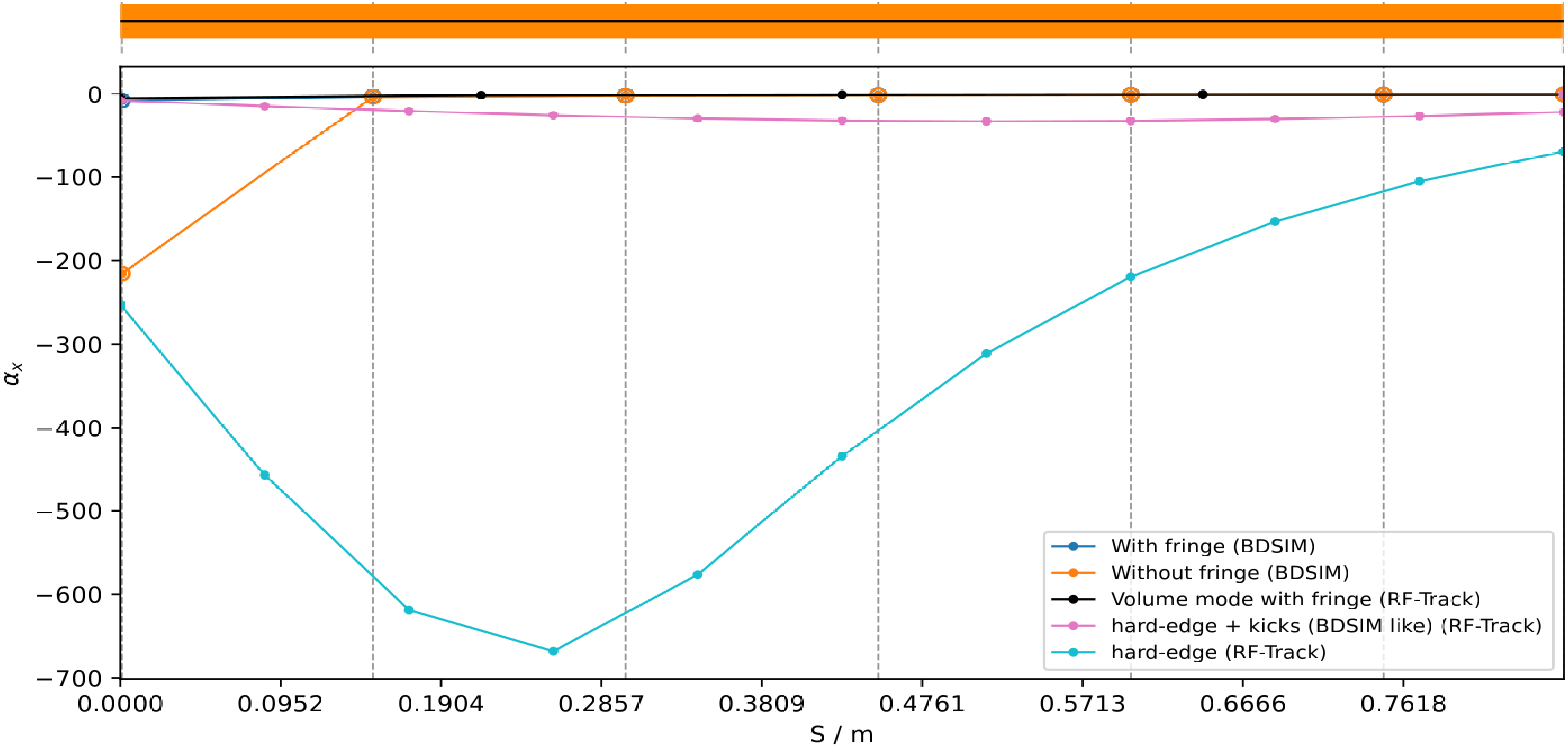
Beta x function



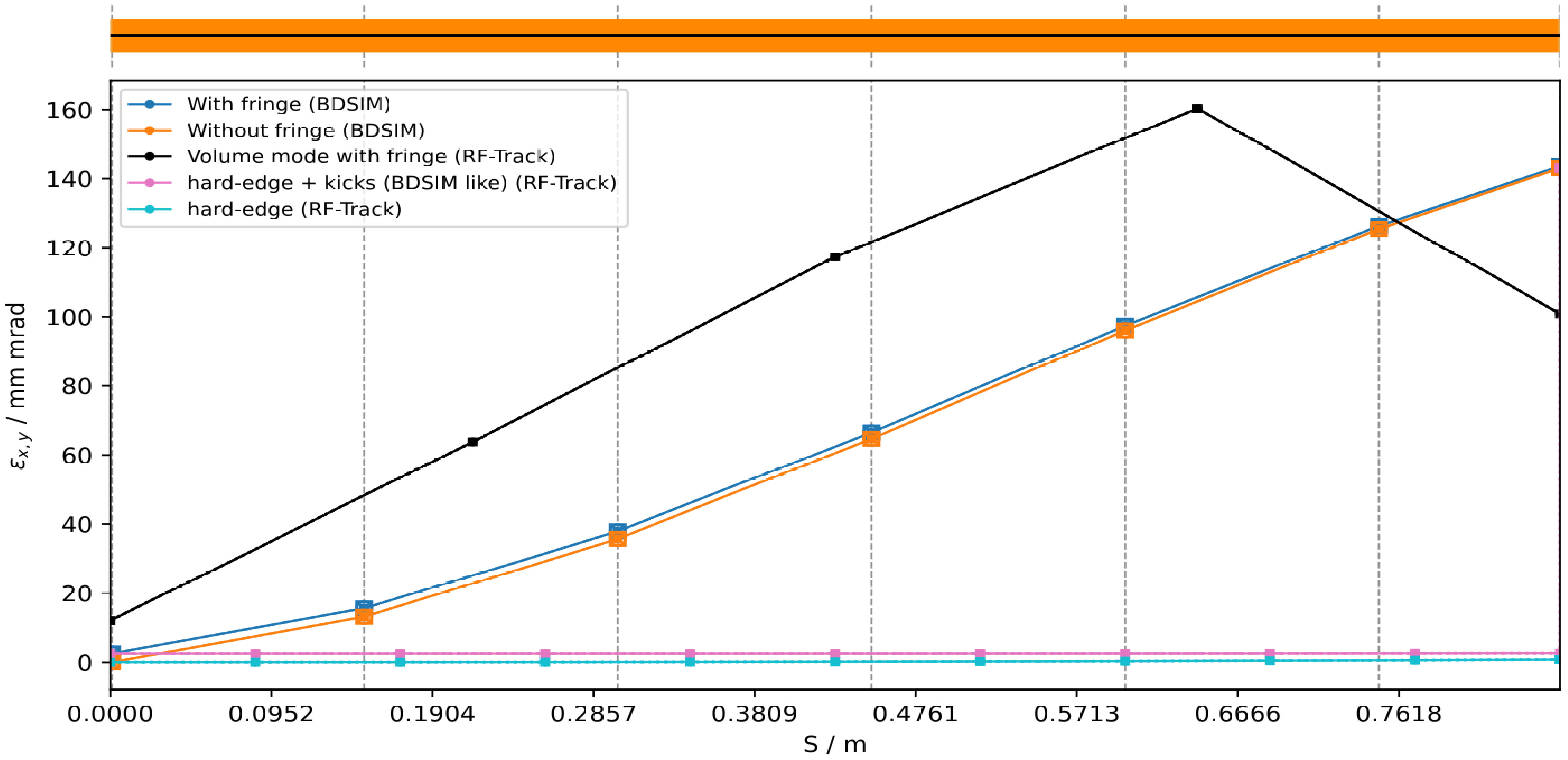
Beta y function



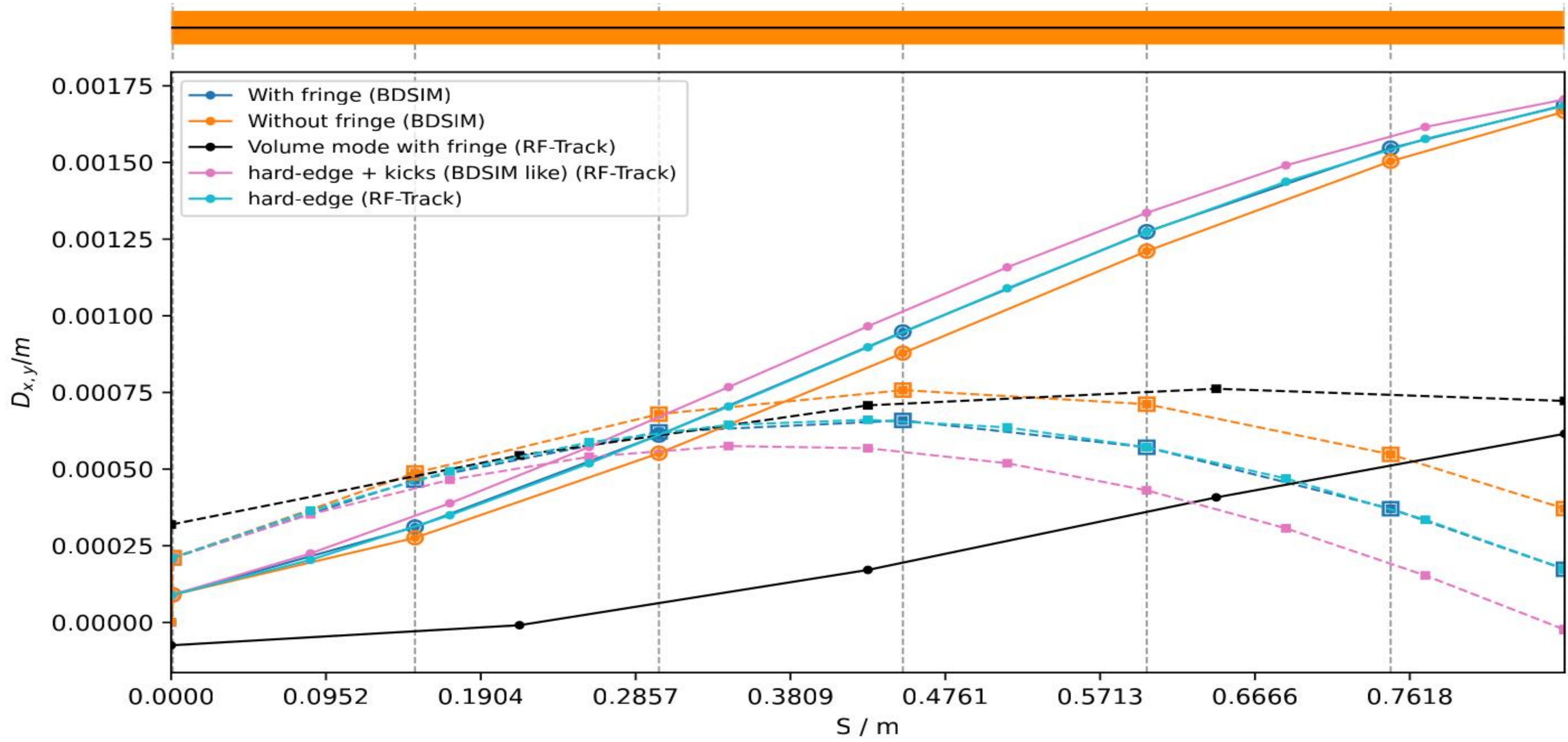
Alpha x function



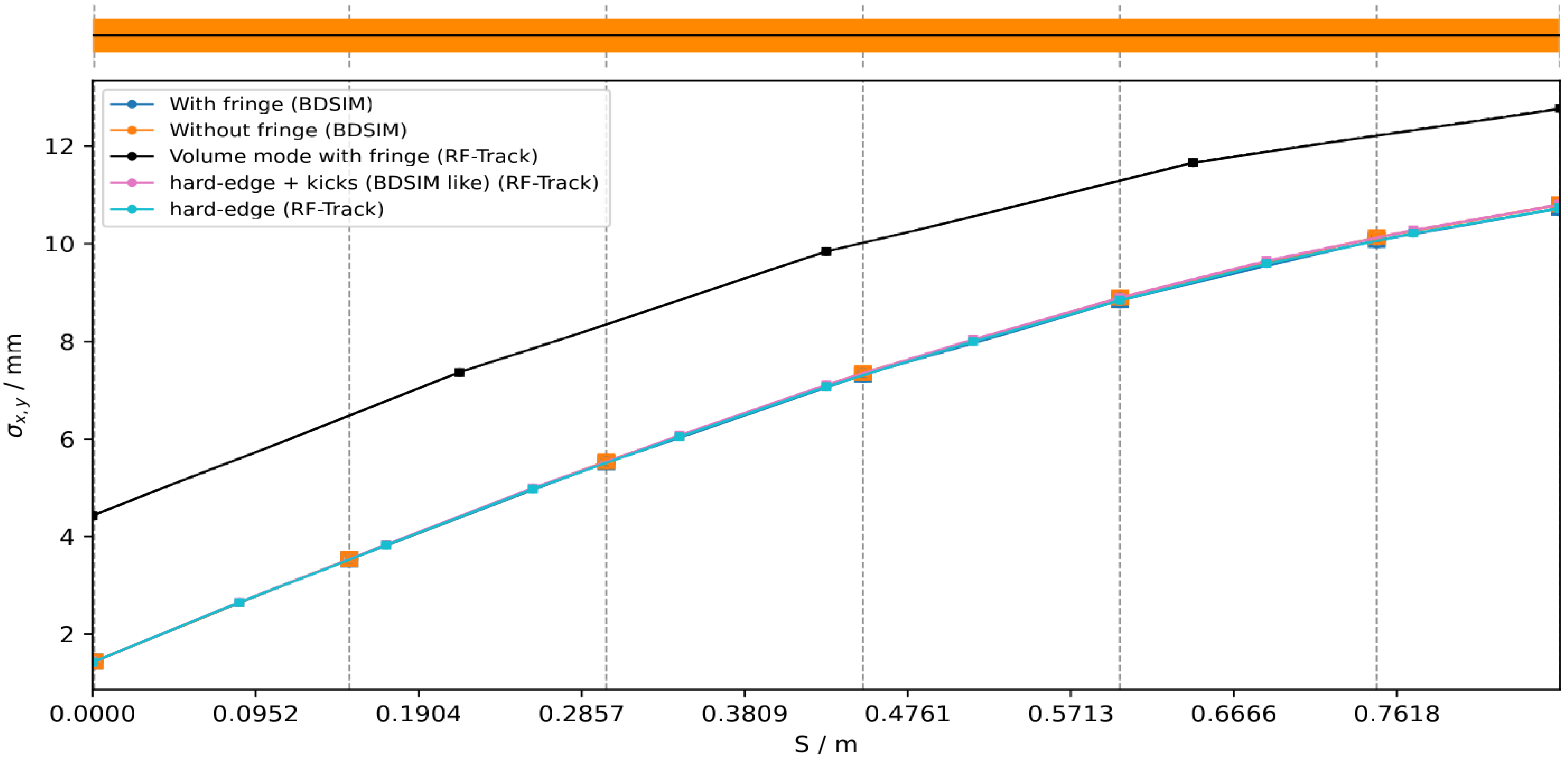
Projected Emittance



Divergence in position

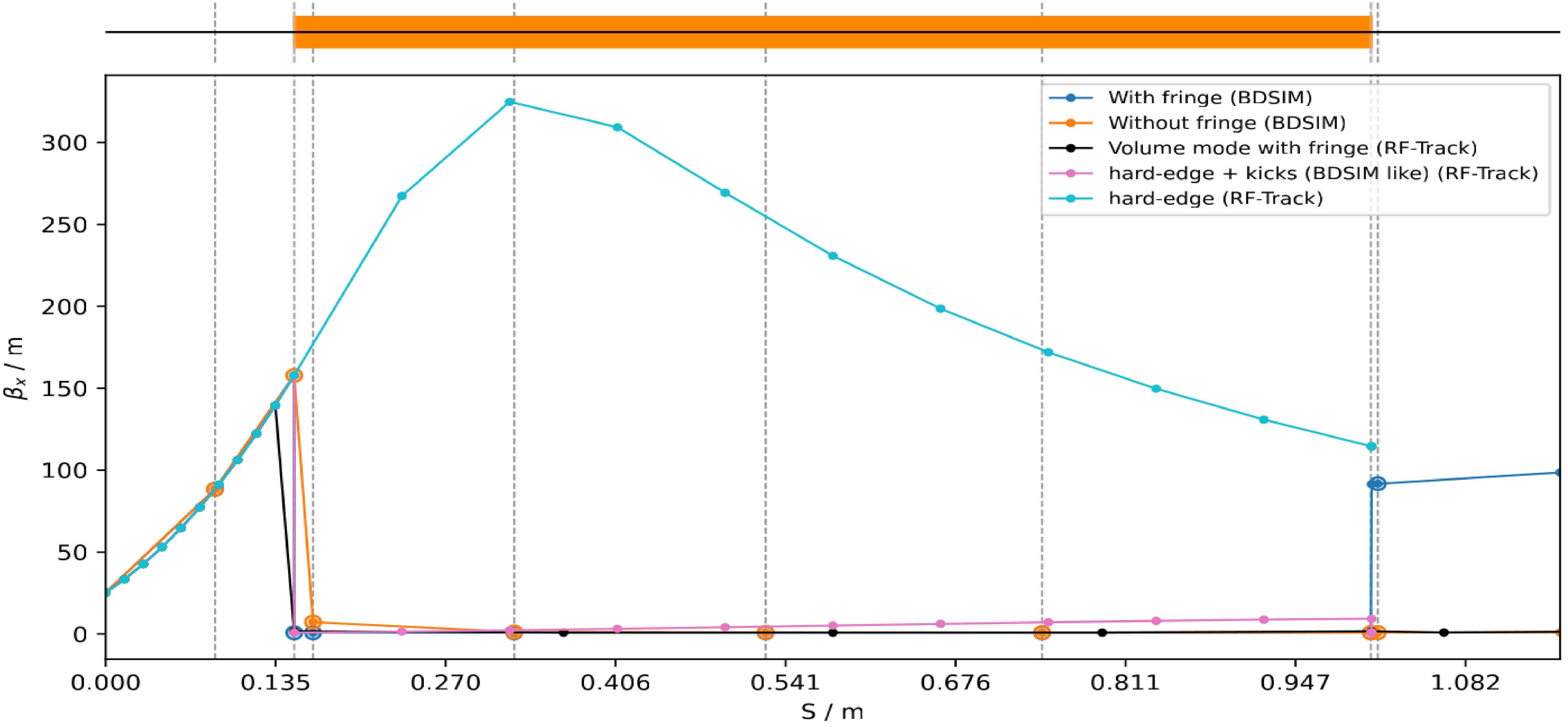


Beam size

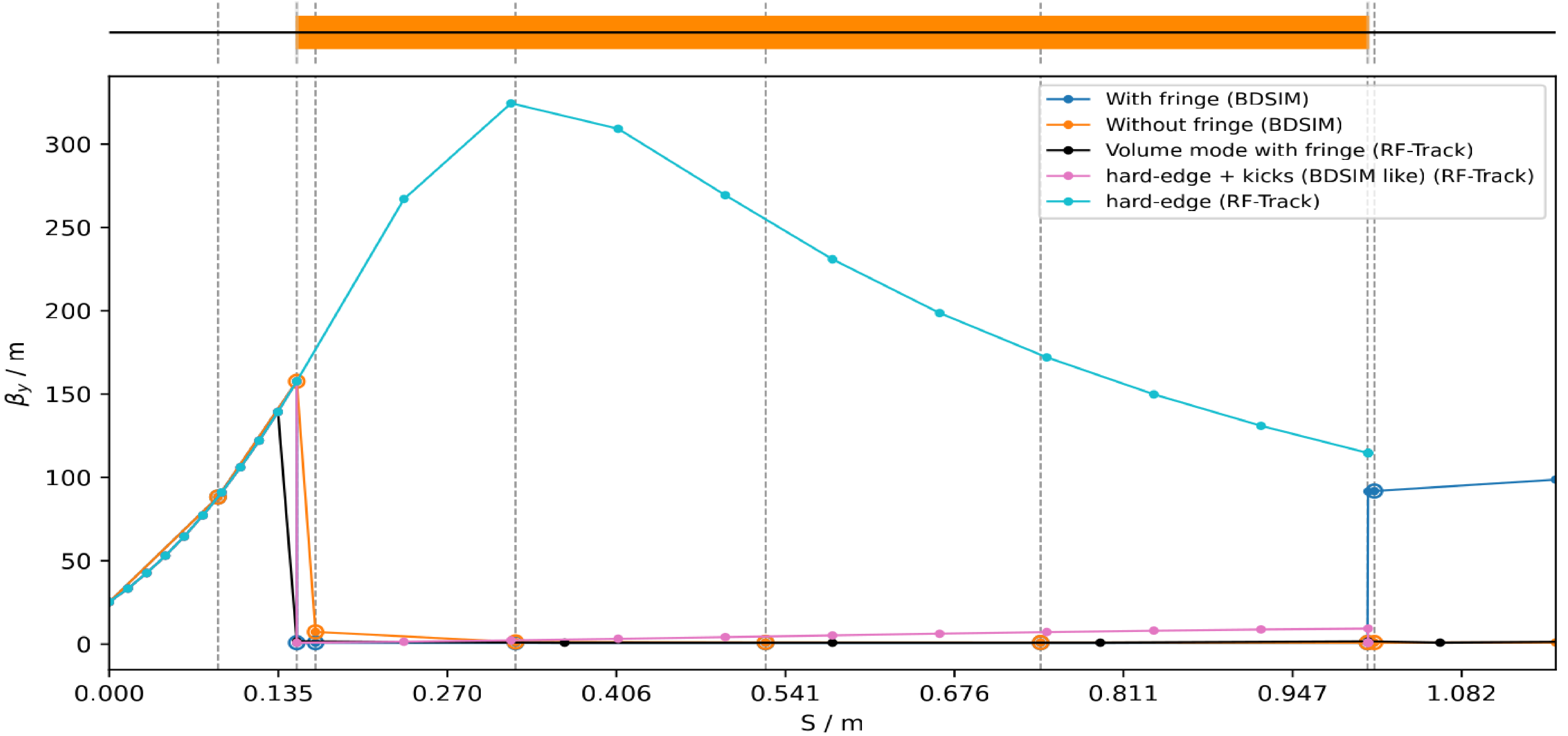

With fringe (BDSIM)
Without fringe (BDSIM)
Volume mode with fringe (RF-Track)
hard-edge + kicks (BDSIM like) (RF-Track)
hard-edge (RF-Track)
$\sigma_{x,y}$ / mm
12
10
8
6
4
2
0.0000
0.0952
0.1904
0.2857
0.3809
0.4761
0.5713
0.6666
0.7618
S / m

Drift+solenoid simulation: start of LhARA Stage 1 beamline

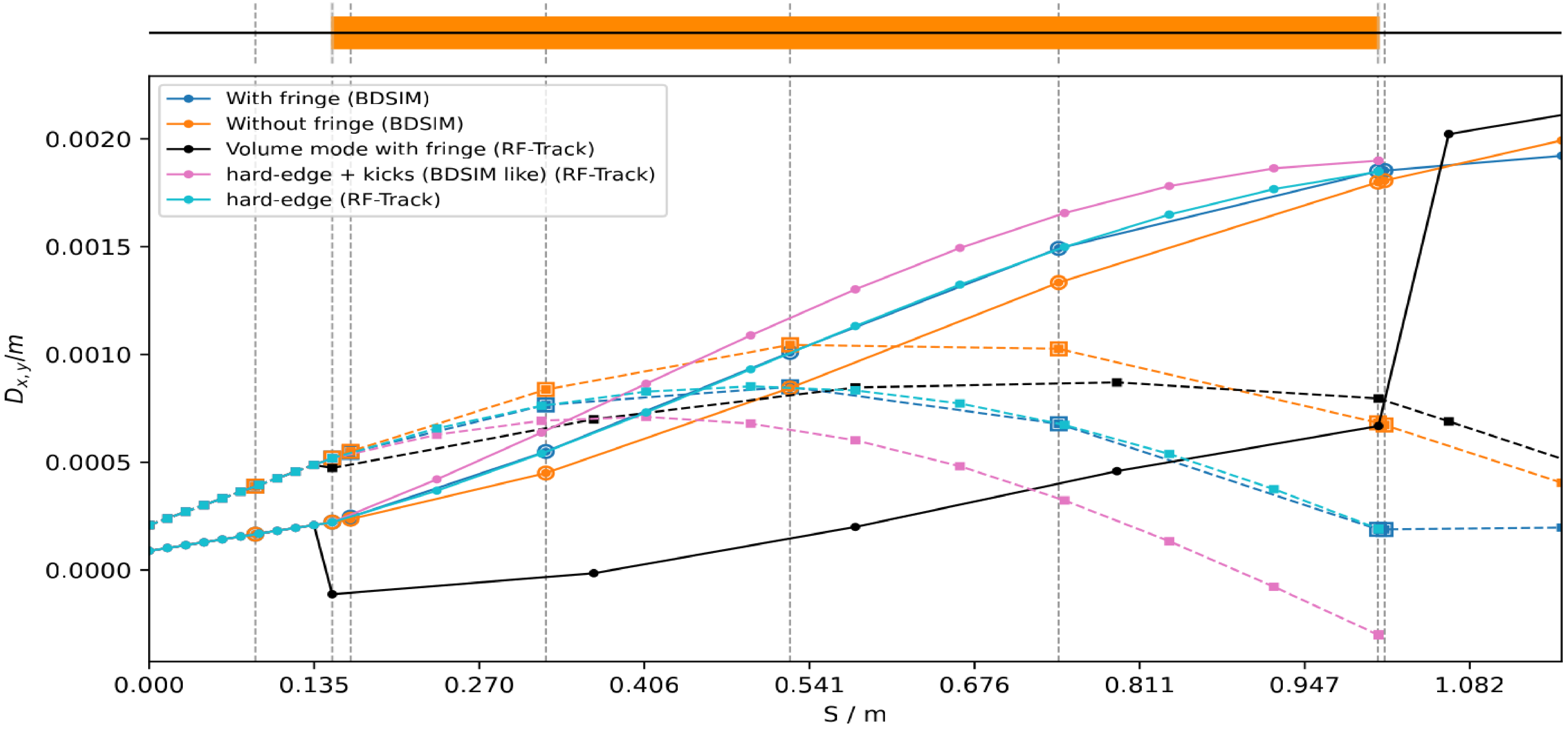
Beta x function: drift+solenoid



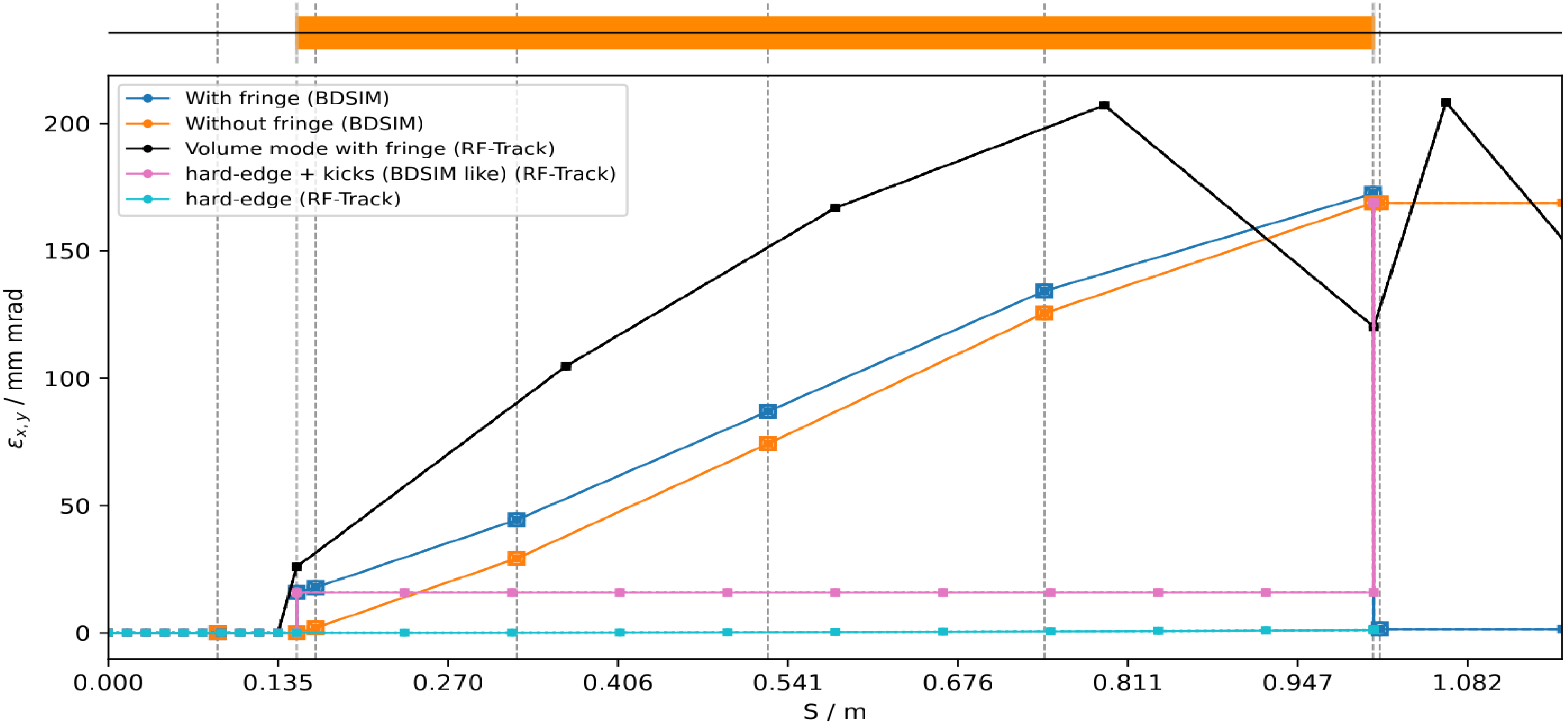
Beta y function: drift+solenoid



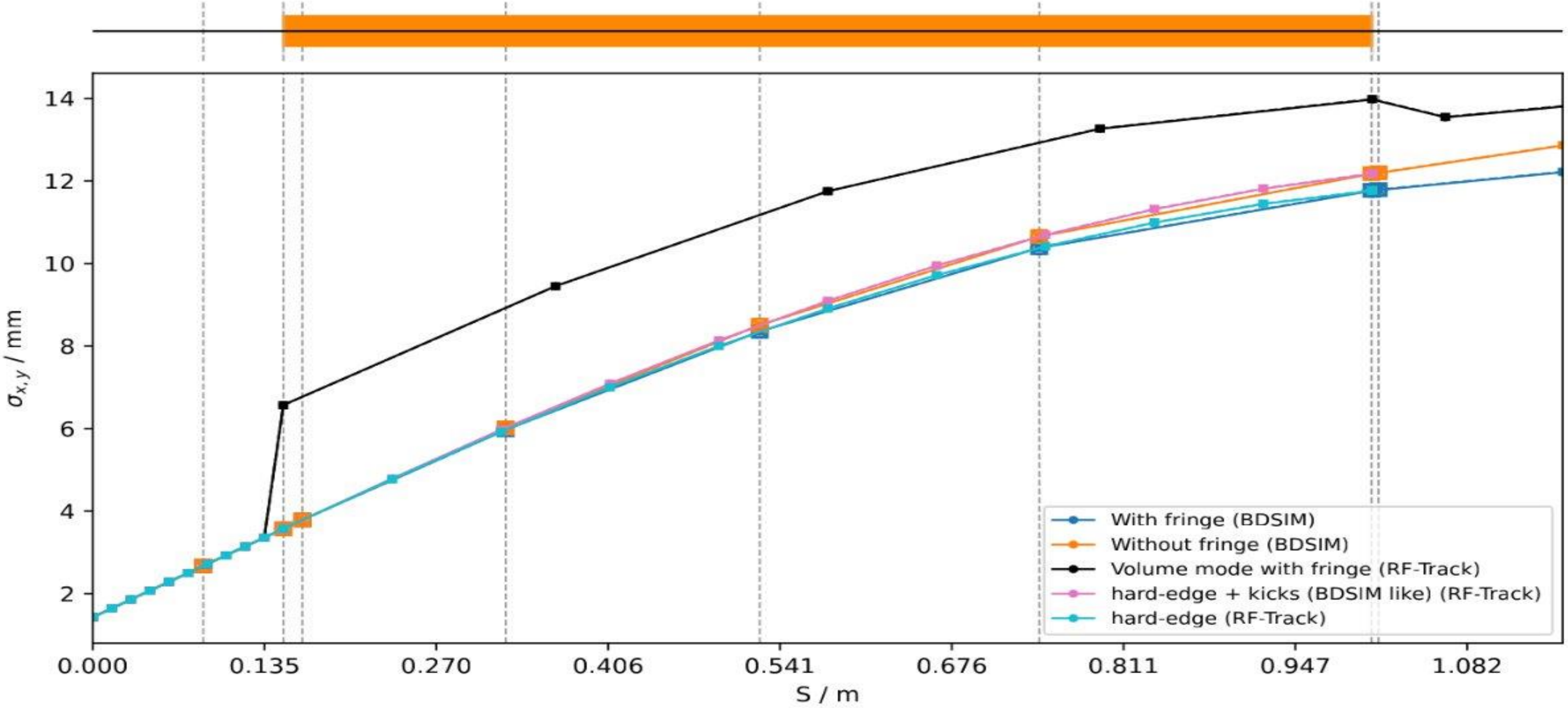
Dispersion: drift+solenoid



Projected Emittance



Beam size



14
12
10
8
6
4
2
$\sigma_{x,y}$ / mm
0.000
0.135
0.270
0.406
0.541
0.676
0.811
0.947
1.082
S / m
With fringe (BDSIM)
Without fringe (BDSIM)
Volume mode with fringe (RF-Track)
hard-edge + kicks (BDSIM like) (RF-Track)
hard-edge (RF-Track)

Beta and alpha discrepancies (while sigma are matching)

Because beta and alpha are derived quantities and computed from second moments:

- beta = $\langle x^2 \rangle$ / epsilon
- alpha = $-\langle x x' \rangle$ / epsilon

with epsilon itself also derived from the covariance matrix. So small differences in:

- angular spread, covariance x-x', coupling, dispersion subtraction, numerical noise

=> can produce noticeably larger differences in beta and alpha, even when beam sizes still agree well.