Beta Squeeze Using a New Matching Routine in MadX

Work outline and first results

Riccardo de Maria

CERN AB-ABP-LOC

LOC Meeting, 30 August 2005

Introduction

Algorithm

Introduction

The dipole first layout for the .25m$\beta*$ LHC introduces new difficulties for the matching of the insertion region:

- $\beta*$ peak is 18km pushing the limit on the quadrupole strengths;
- the dispersion has to be different from zero before entering the triplets, giving to Q4-Q7 an additional task.

Finding a continuous path between the collision and the injection optics gets more difficult.
It needs to take the full advantage to have

- 20 variables (Q4-Q13 RL) for
- 14 constraints ($\beta_x \beta_y \alpha_x \alpha_y d_x dp_x$ right and left and $\mu_x \mu_y$)

MadX Matching Routines

Madx provides two main matching routines:

- lmdif: fast but limited to problems where $c <= v$
- simplex: slow and not suited for constrained problems (solutions get far from the starting point)

A new matching routines has been developed in order to be:

- fast;
- suited for constrained problems (find the closest solution from the starting point);
- suited for problems where $v >= c$;

After some testing the routine shows good results if:

- it exists a good solution with close constraints
- the problem is such that $v > c$ (for $v = c$ lmdif perform more reliable)

Algorithm

The algorithm is based on a simple implementation of the Newton-Raphson method.
A matching problem can be written as:

$$\mathbf{c} = \mathbf{f}(\boldsymbol{\nu})$$

where $\mathbf{c}$ is vector of the c constraints, $\boldsymbol{\nu}$ is vector of the ν variables and $\mathbf{f}$ is vector field representing the optics.
If $\mathbf{c}_0 = \mathbf{f}(\boldsymbol{\nu}_0)$ is a good solution for $\mathbf{c}_0$ close to $\mathbf{c}$ then the vector field can be approximated with :

$$\mathbf{c} = \mathbf{c}_0 + \frac{\mathrm{D}\mathbf{f}}{\mathrm{D}\boldsymbol{\nu}}(\boldsymbol{\nu}_0)\delta\boldsymbol{\nu} + \mathrm{O}\left(|\delta\boldsymbol{\nu}|^2\right)$$

and the solution found by iterations using :

$$\boldsymbol{\nu} = \boldsymbol{\nu}_0 + \delta\boldsymbol{\nu} \qquad \frac{\mathrm{D}\mathbf{f}}{\mathrm{D}\boldsymbol{\nu}} = \mathbf{J} \qquad \delta\boldsymbol{\nu} = \mathbf{J}^{-1}(\mathbf{c} - \mathbf{c}_0)$$

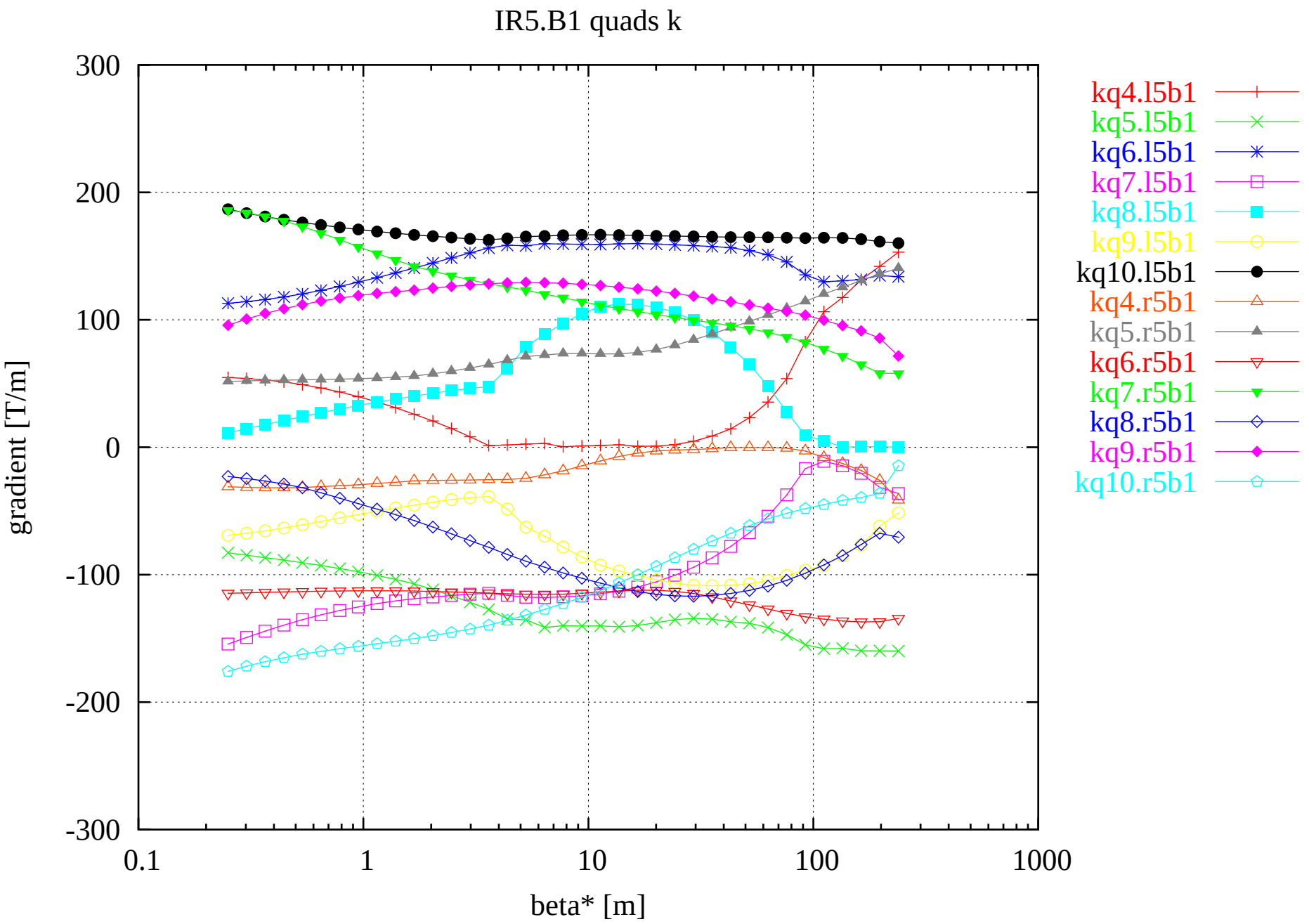
$\mathbf{J}$ has c rows and ν columns and if $\nu > c$ the problem can be solved such that $|\delta\boldsymbol{\nu}|$ be minimum with LQ decomposition.

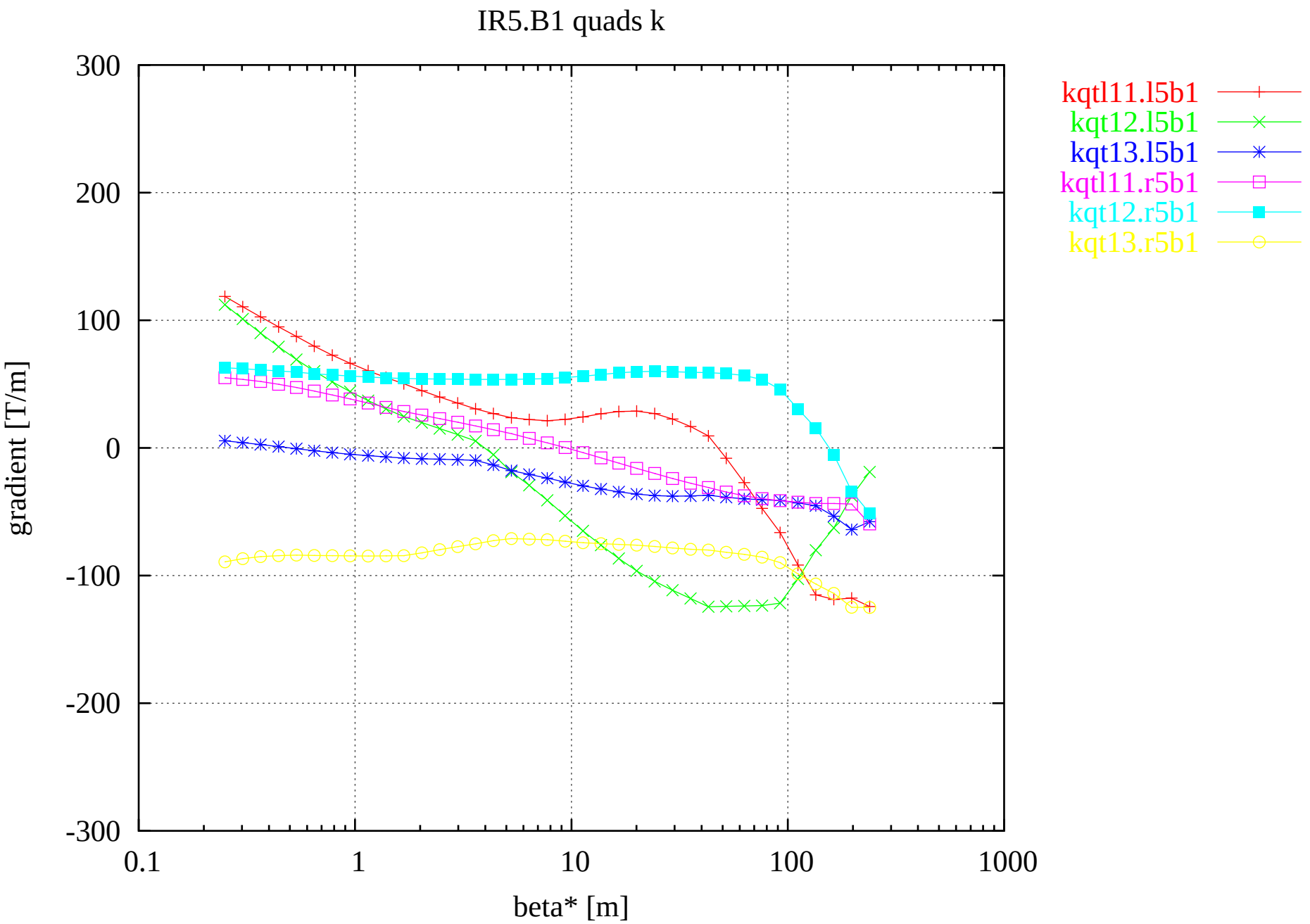
Try 1

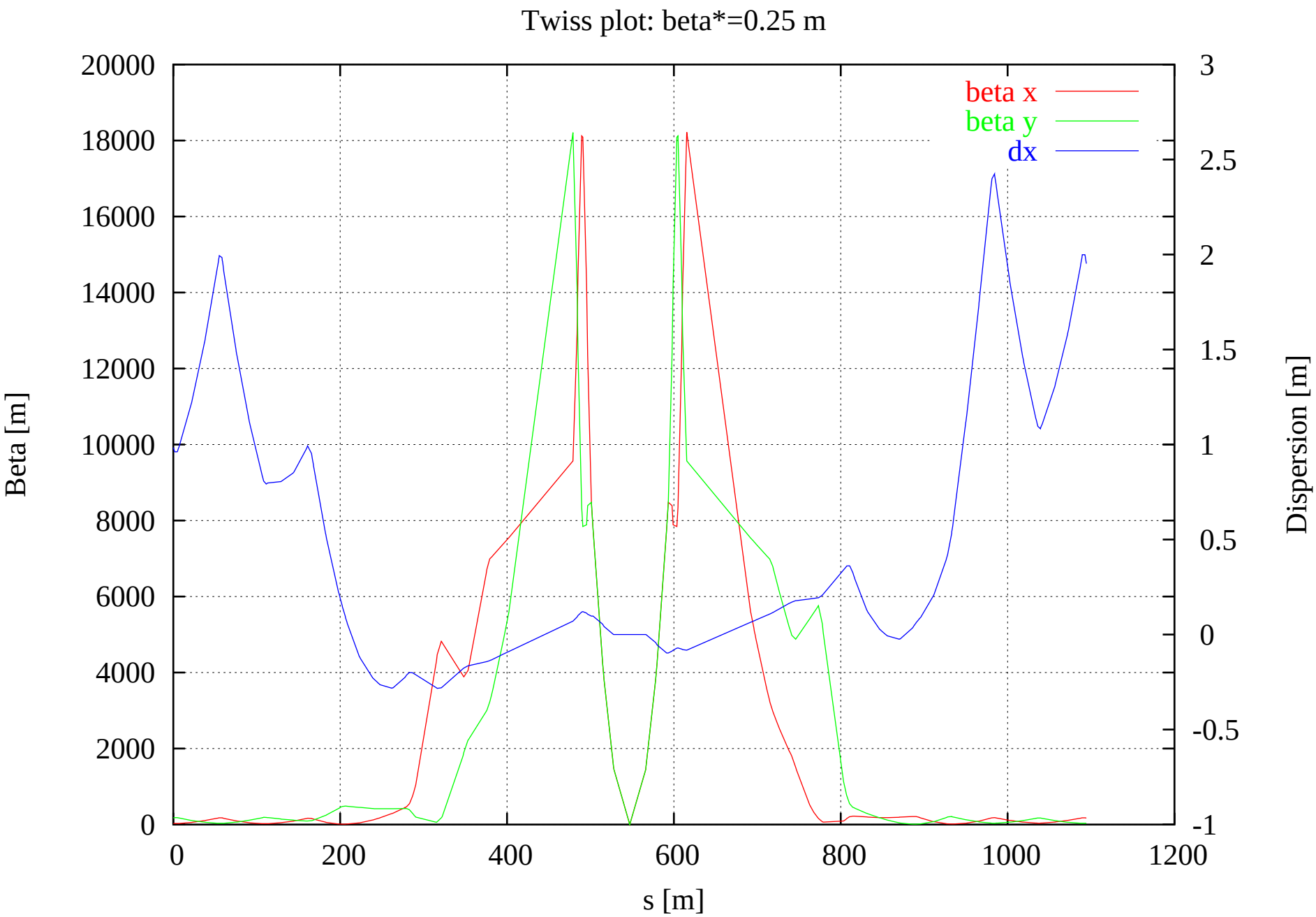
- Increase of $\beta*$ of 10%
- No additional constraints

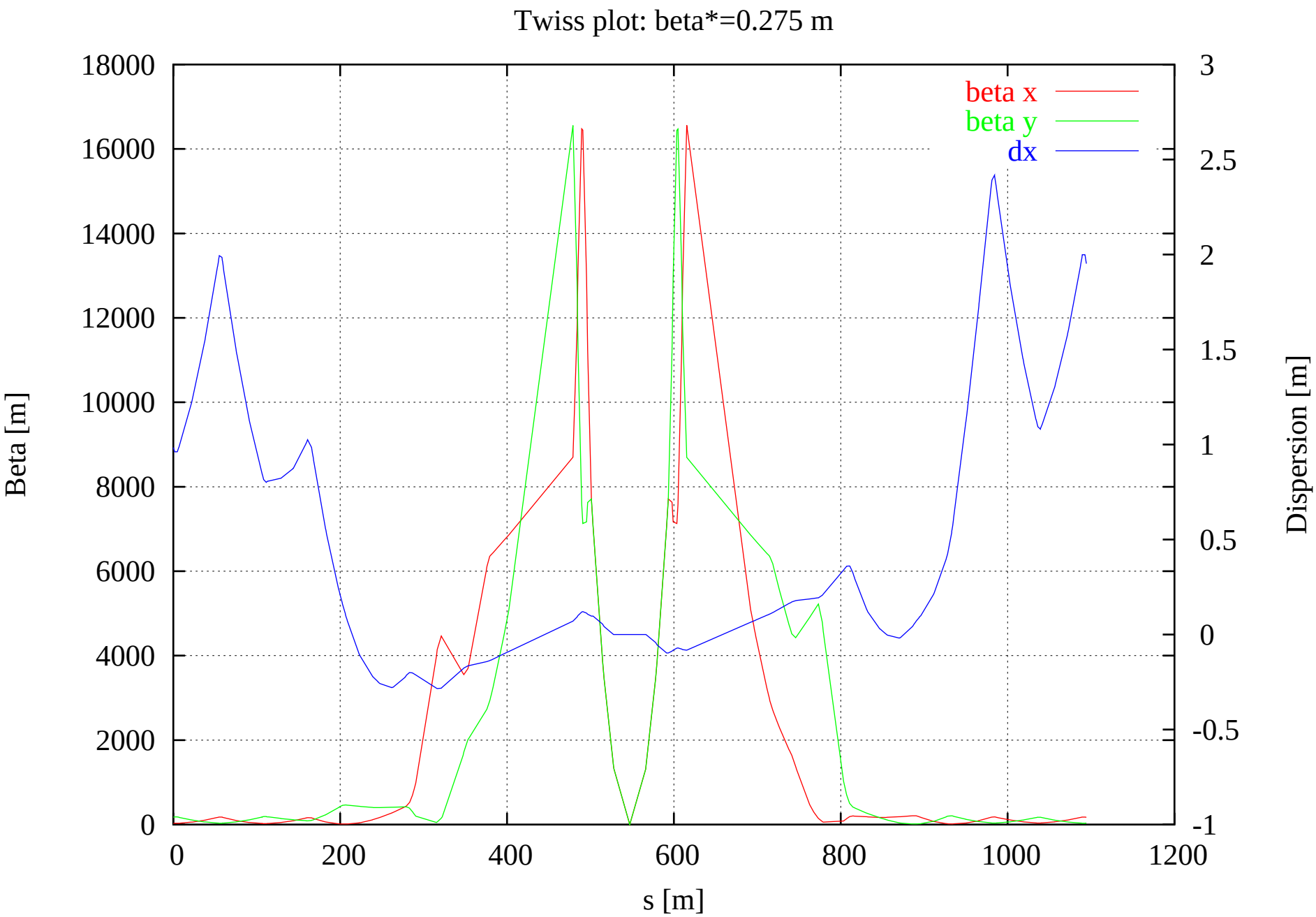
Try 2

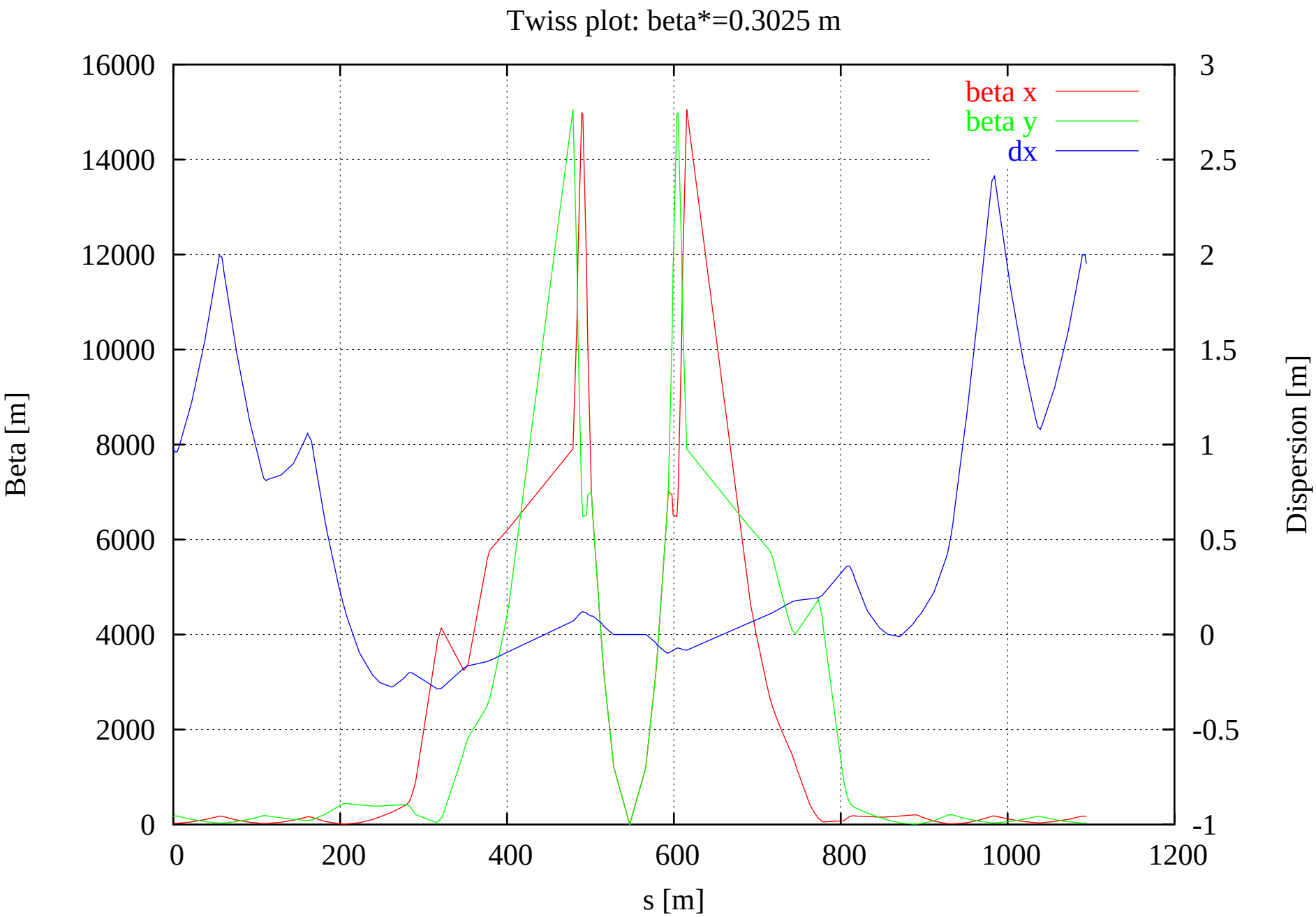
- Increase of $\beta*$ of 10%
- Slope of Q4 left and right and Q9 left fixed
- $\mathtt{beta}$ max for Q6 Q8 left and right set to be half of $\mathtt{beta}$ max in the triplet

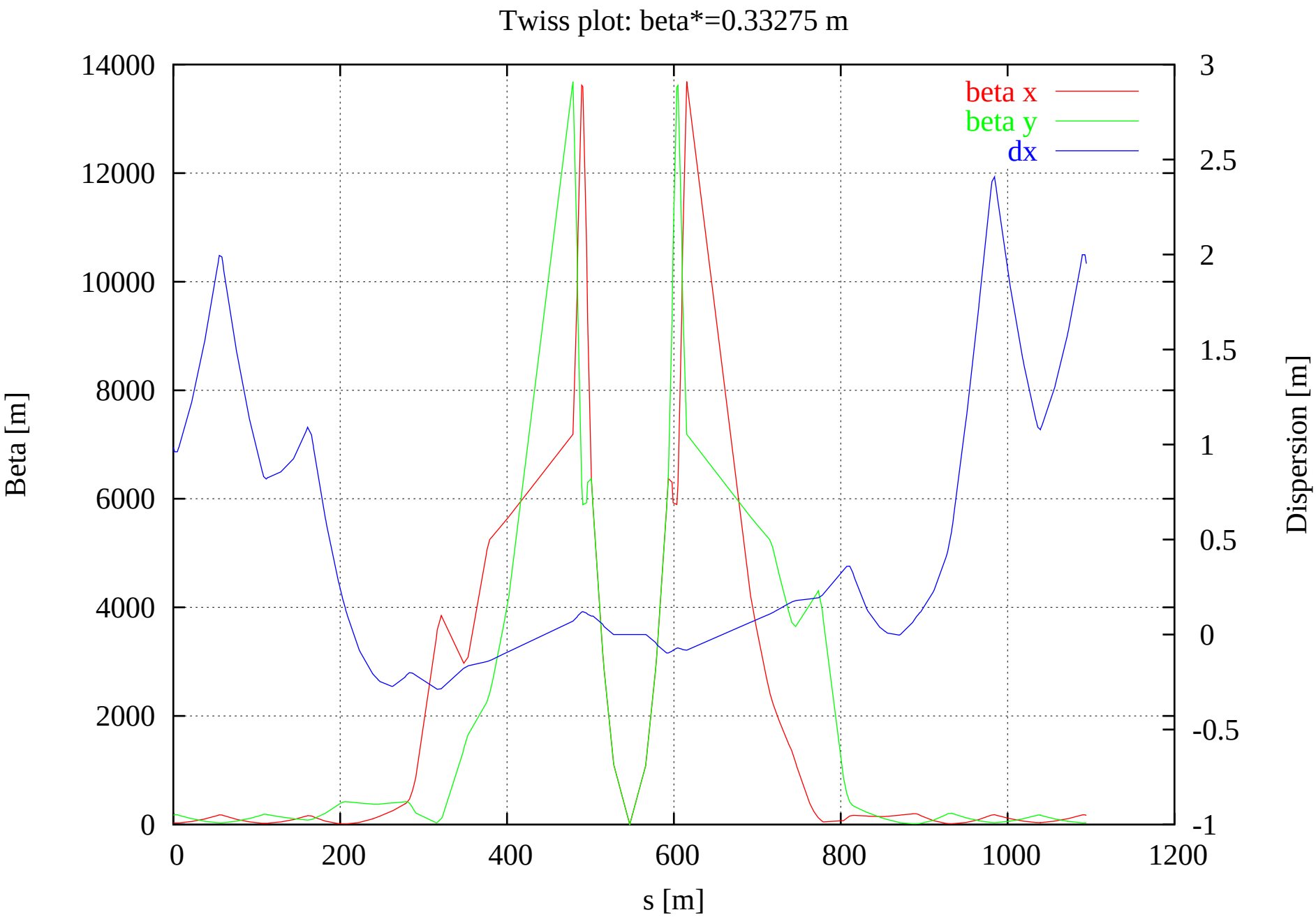

IR5.B1 quads k
gradient [T/m]
beta* [m]
300
200
100
0
-100
-200
-300
0.1
1
10
100
1000
kq4.l5b1
kq5.l5b1
kq6.l5b1
kq7.l5b1
kq8.l5b1
kq9.l5b1
kq10.l5b1
kq4.r5b1
kq5.r5b1
kq6.r5b1
kq7.r5b1
kq8.r5b1
kq9.r5b1
kq10.r5b1

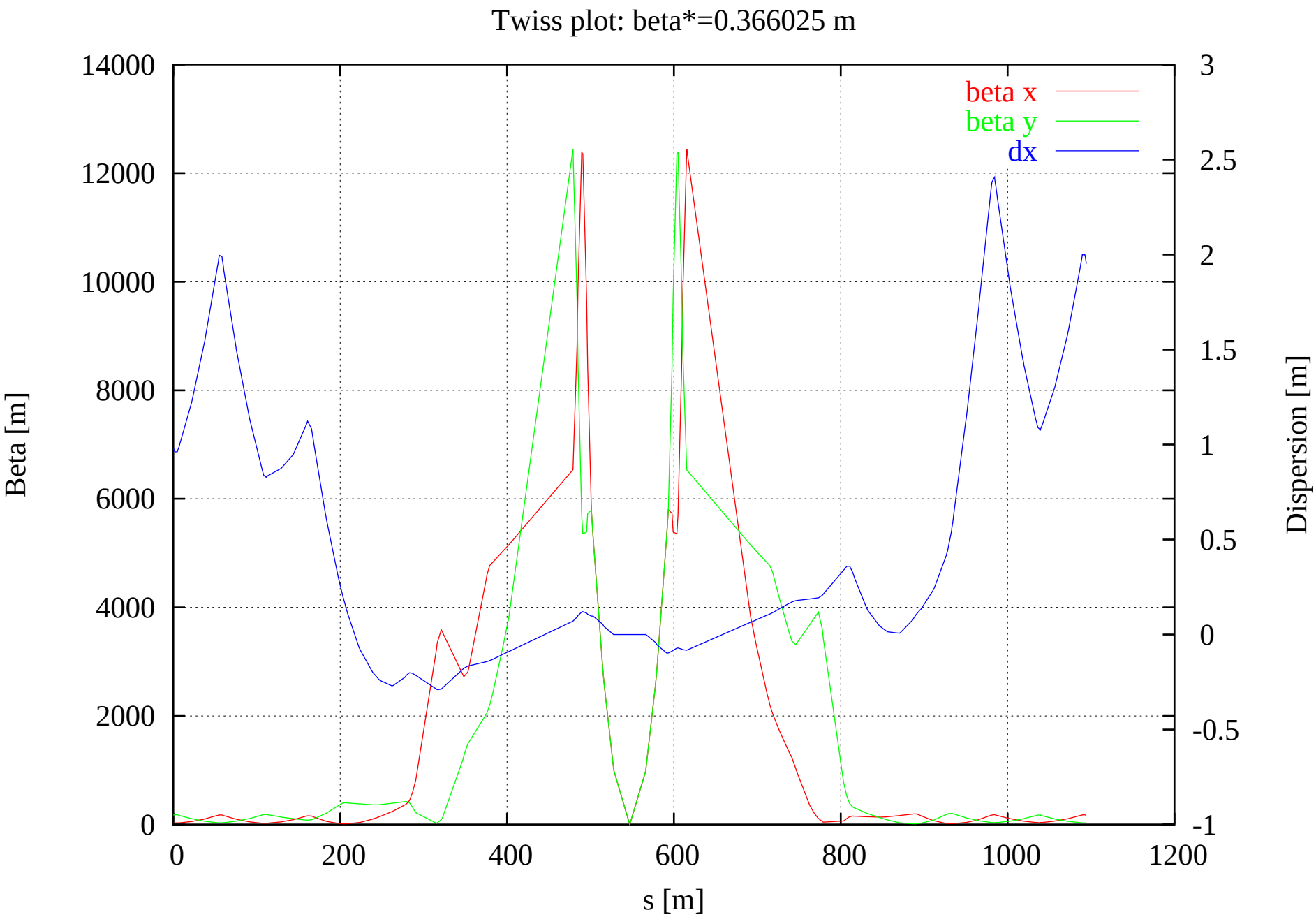

IR5.B1 quads k
gradient [T/m]
beta* [m]
300
200
100
0
-100
-200
-300
0.1
1
10
100
1000
kqtl11.l5b1
kqt12.l5b1
kqt13.l5b1
kqtl11.r5b1
kqt12.r5b1
kqt13.r5b1

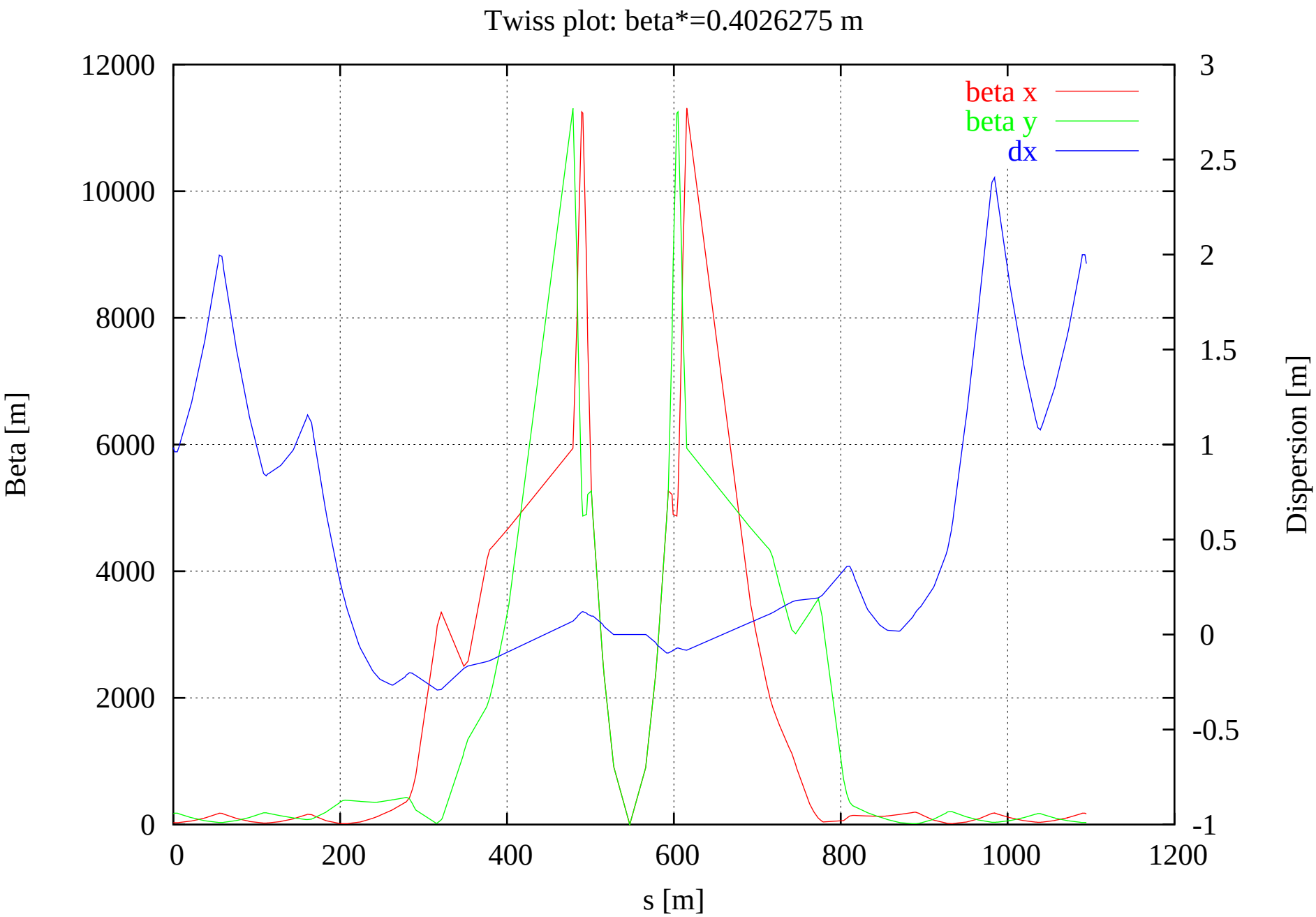

Twiss plot: beta*=0.25 m
beta x
beta y
dx
Beta [m]
Dispersion [m]
s [m]
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
3
2.5
2
1.5
1
0.5
0
-0.5
-1
0
200
400
600
800
1000
1200

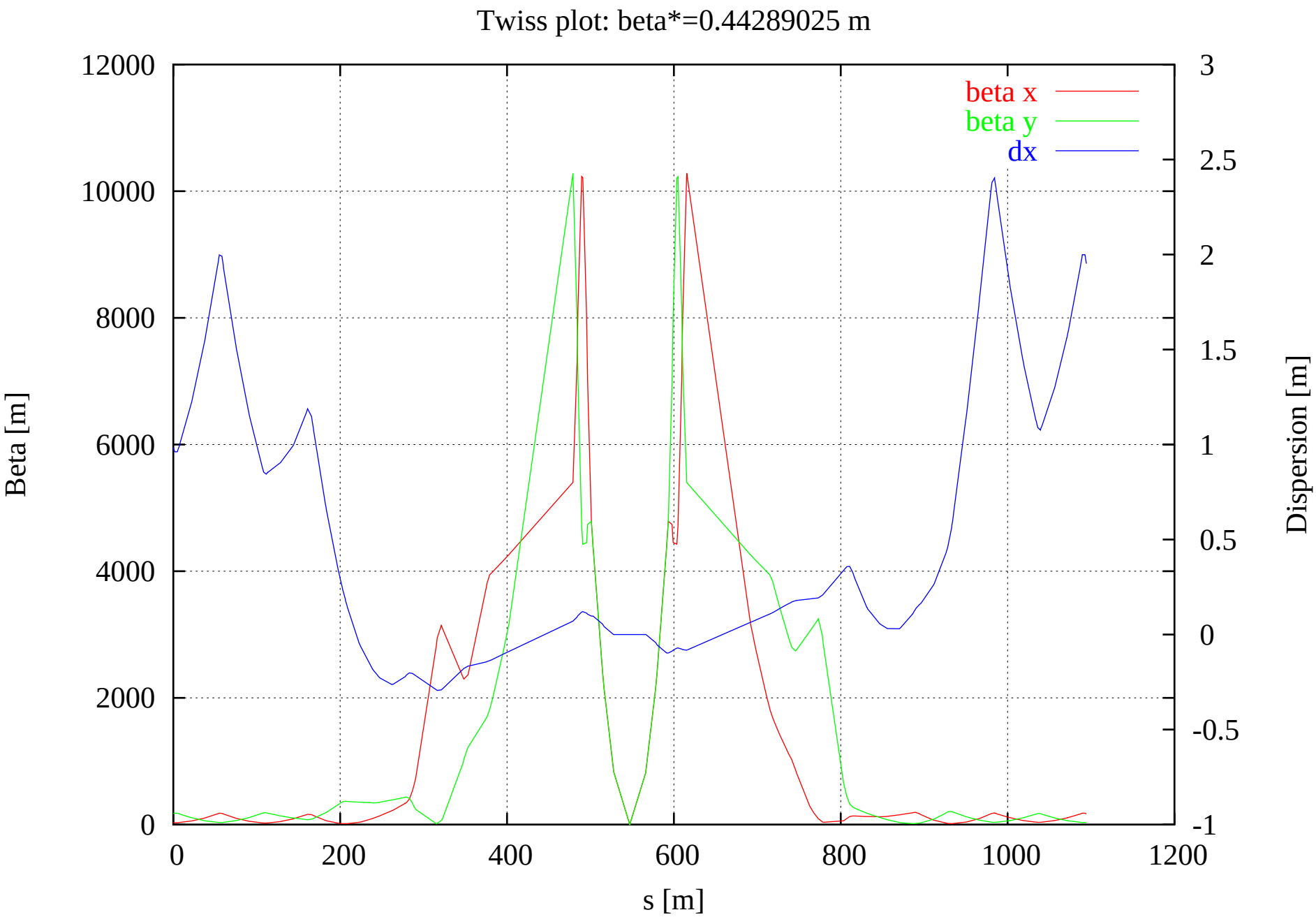

Twiss plot: beta*=0.275 m
beta x
beta y
dx
Beta [m]
Dispersion [m]
s [m]
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
3
2.5
2
1.5
1
0.5
0
-0.5
-1
0
200
400
600
800
1000
1200

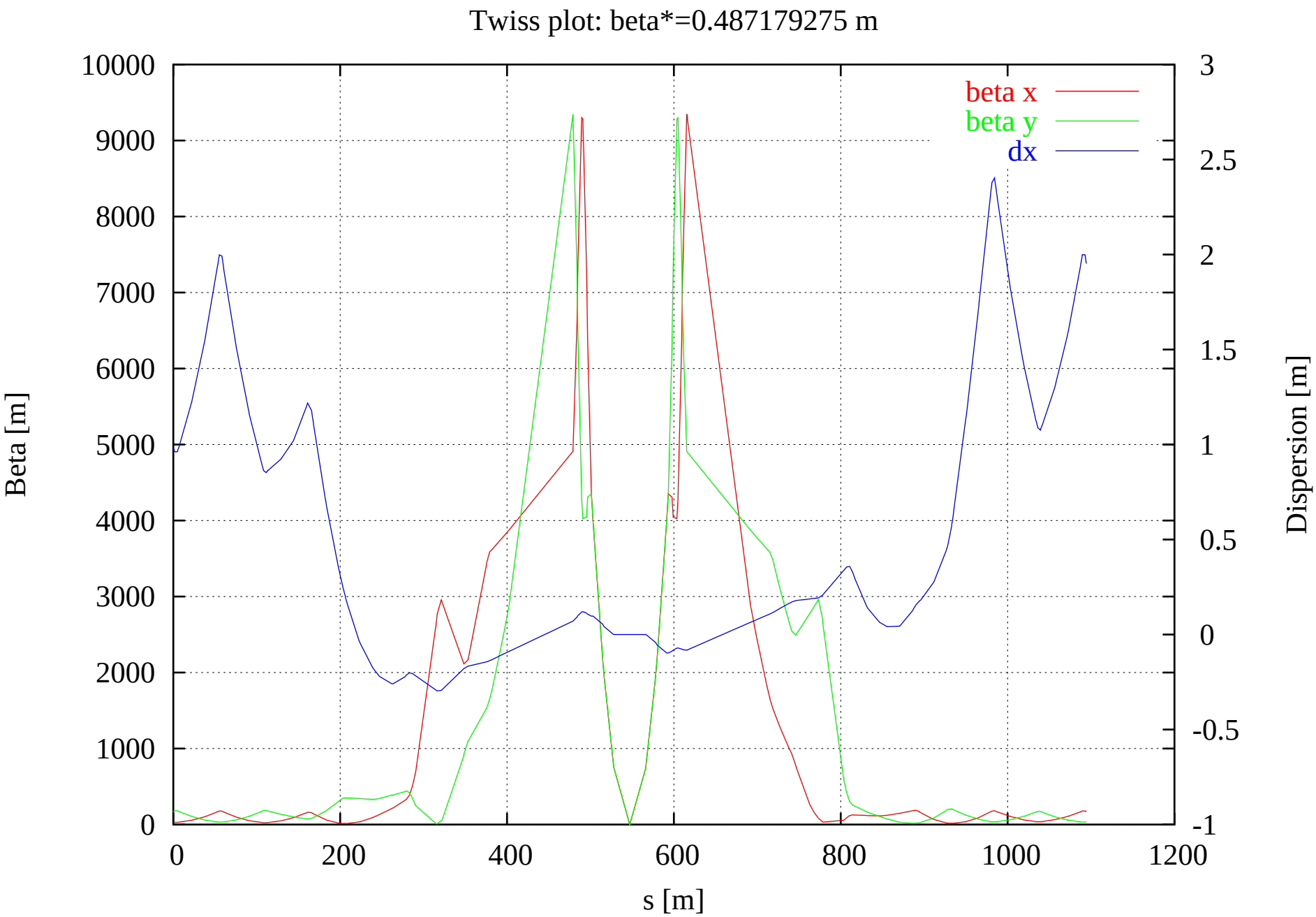

Twiss plot: beta*=0.3025 m
beta x
beta y
dx
Beta [m]
Dispersion [m]
s [m]
16000
14000
12000
10000
8000
6000
4000
2000
0
3
2.5
2
1.5
1
0.5
0
-0.5
-1
0
200
400
600
800
1000
1200

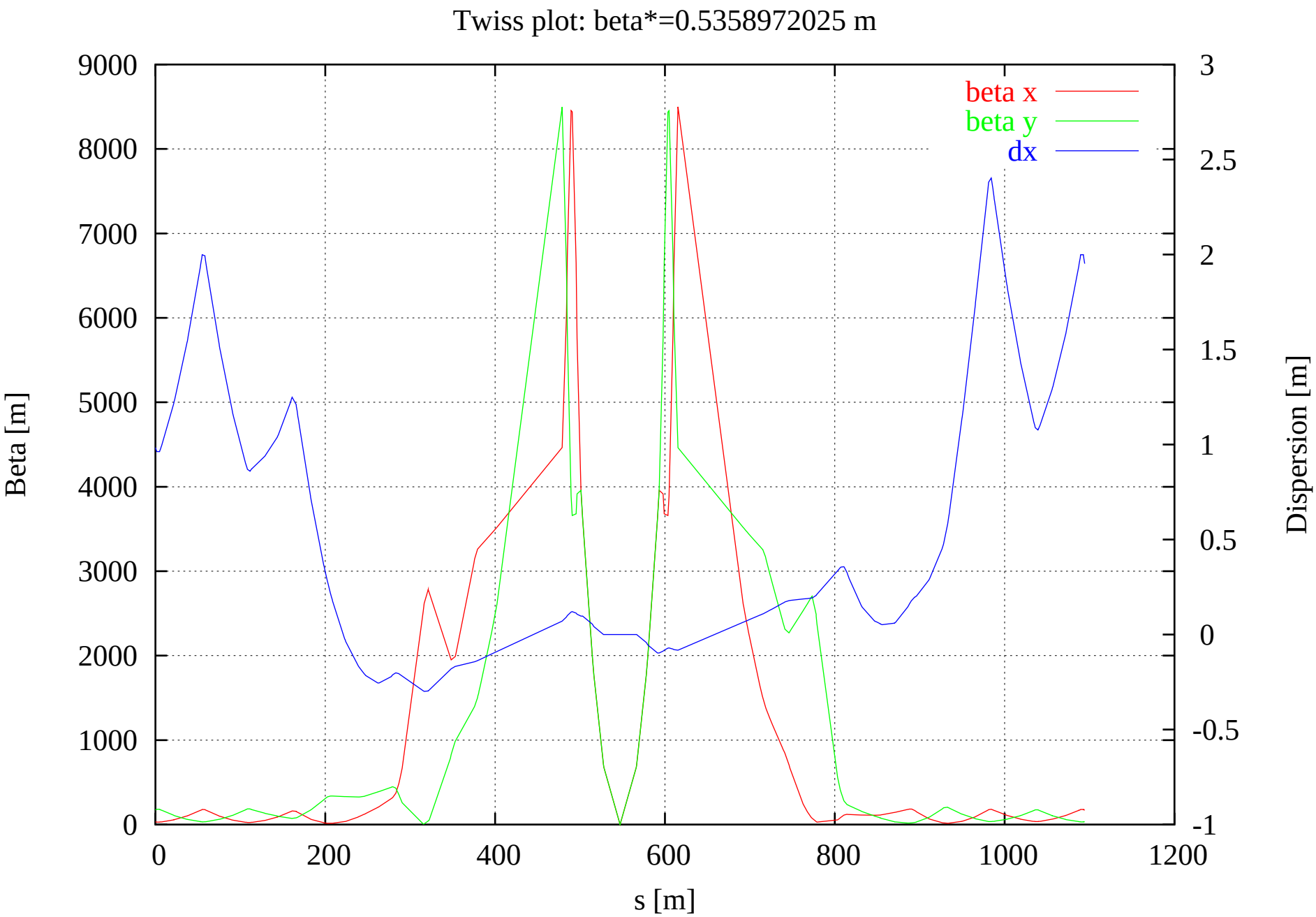

Twiss plot: beta*=0.33275 m
beta x
beta y
dx
Beta [m]
Dispersion [m]
s [m]
14000
12000
10000
8000
6000
4000
2000
0
3
2.5
2
1.5
1
0.5
0
-0.5
-1
0
200
400
600
800
1000
1200

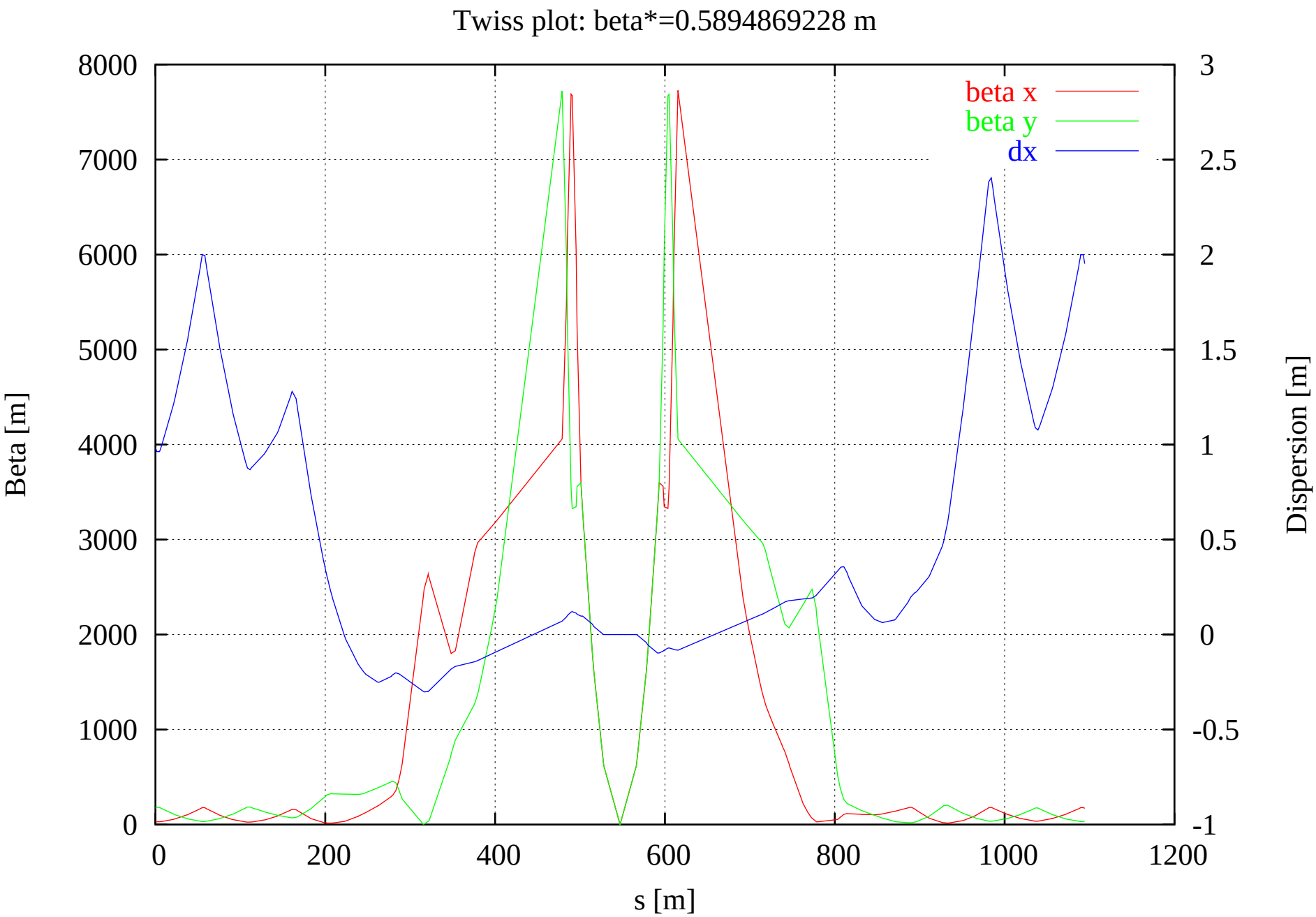

Twiss plot: beta*=0.366025 m
beta x
beta y
dx
Beta [m]
Dispersion [m]
s [m]
0
2000
4000
6000
8000
10000
12000
14000
-1
-0.5
0
0.5
1
1.5
2
2.5
3
0
200
400
600
800
1000
1200

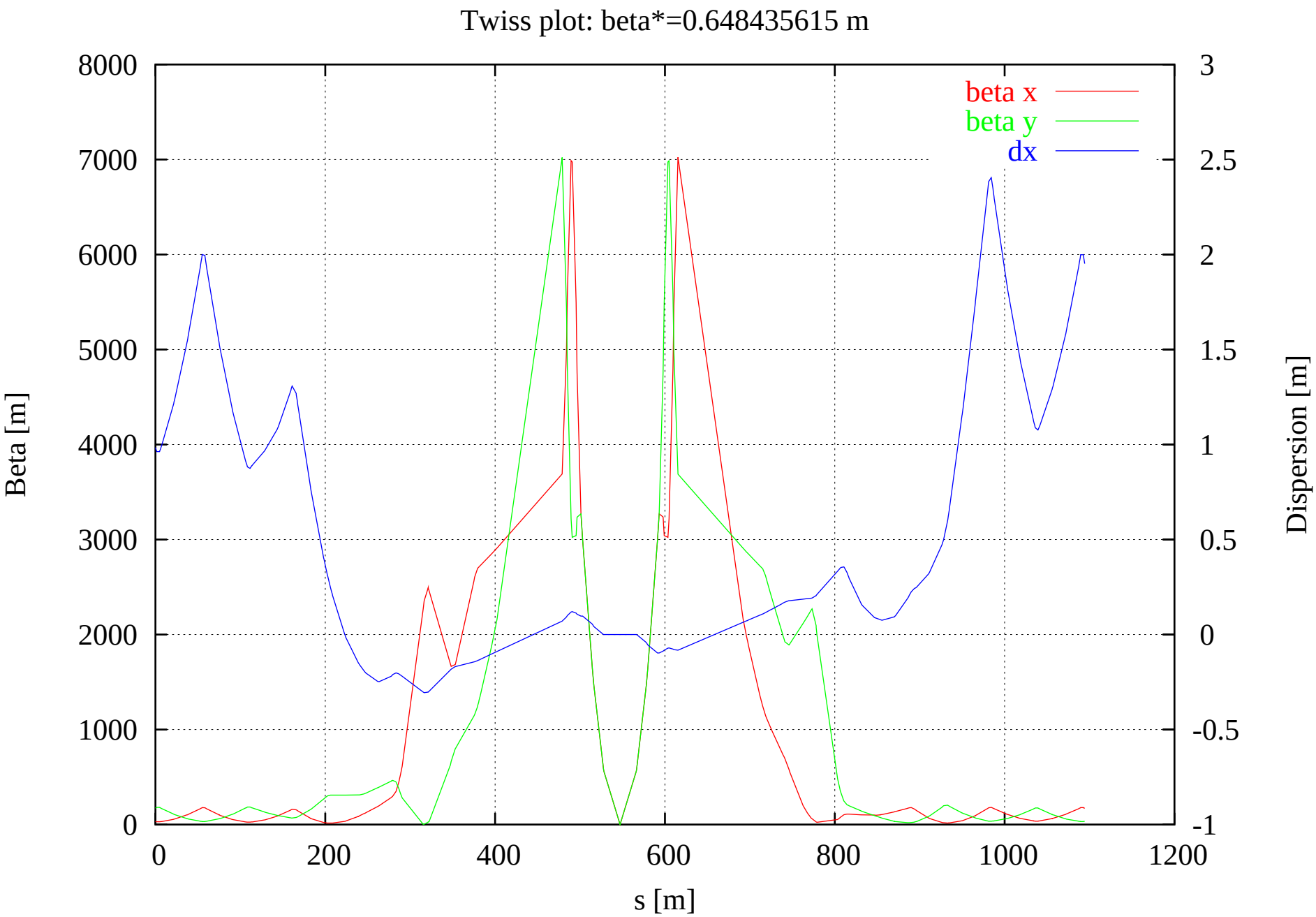

Twiss plot: beta*=0.4026275 m
beta x
beta y
dx
Beta [m]
Dispersion [m]
s [m]
12000
10000
8000
6000
4000
2000
0
3
2.5
2
1.5
1
0.5
0
-0.5
-1
0
200
400
600
800
1000
1200

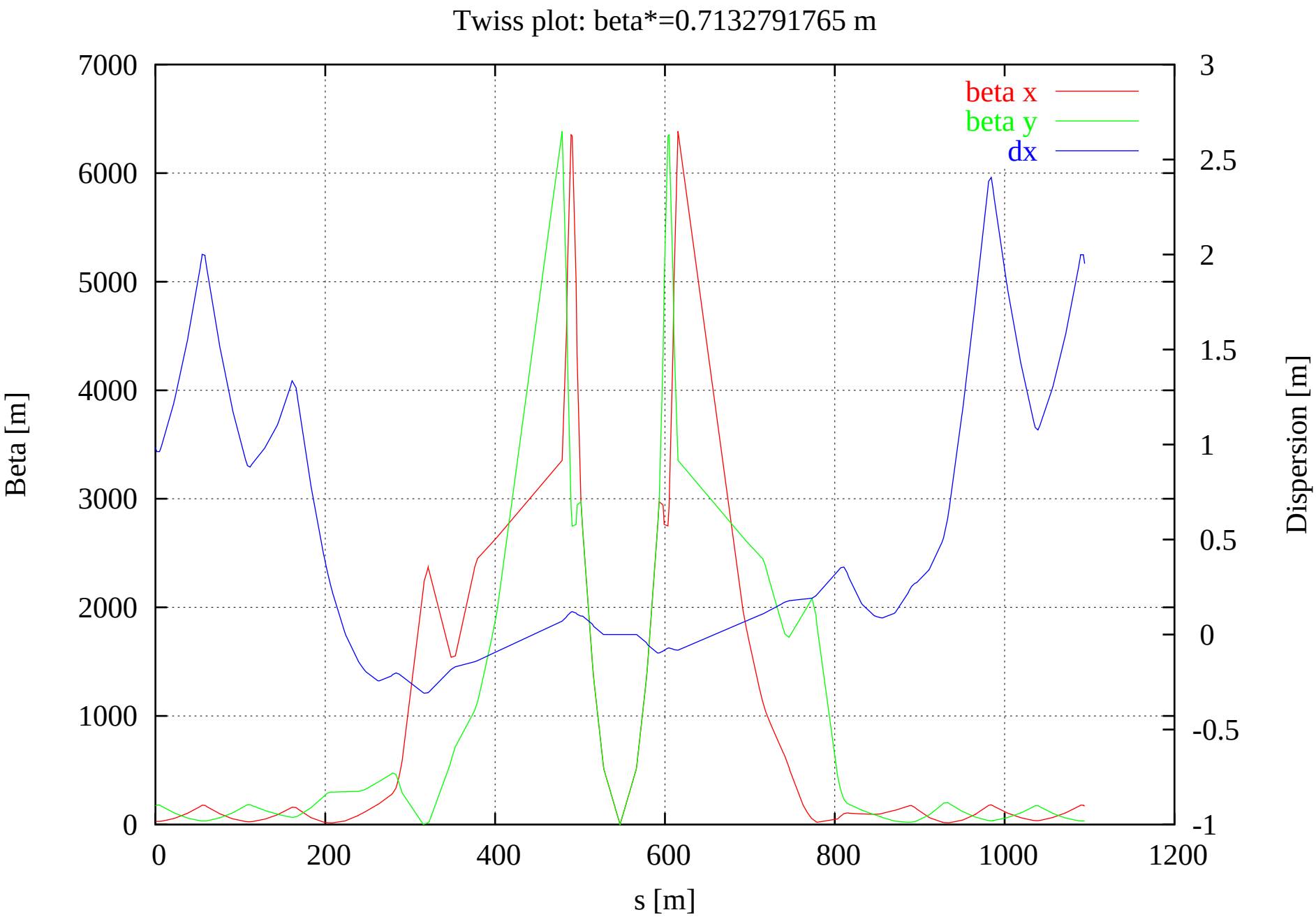

Twiss plot: beta*=0.44289025 m
beta x
beta y
dx
Beta [m]
Dispersion [m]
s [m]
12000
10000
8000
6000
4000
2000
0
3
2.5
2
1.5
1
0.5
0
-0.5
-1
0
200
400
600
800
1000
1200

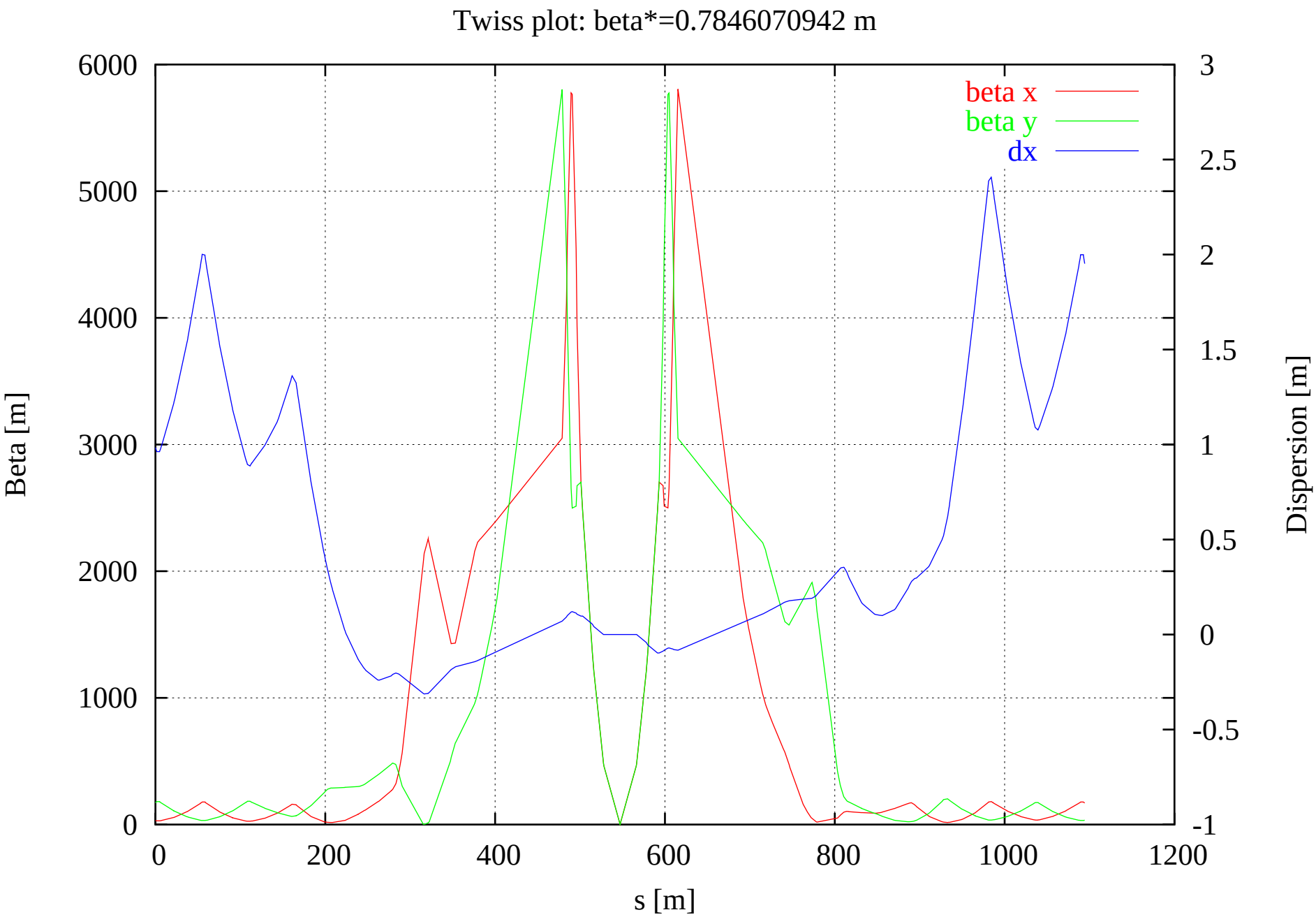

Twiss plot: beta*=0.487179275 m
beta x
beta y
dx
Beta [m]
Dispersion [m]
s [m]
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
3
2.5
2
1.5
1
0.5
0
-0.5
-1
0
200
400
600
800
1000
1200

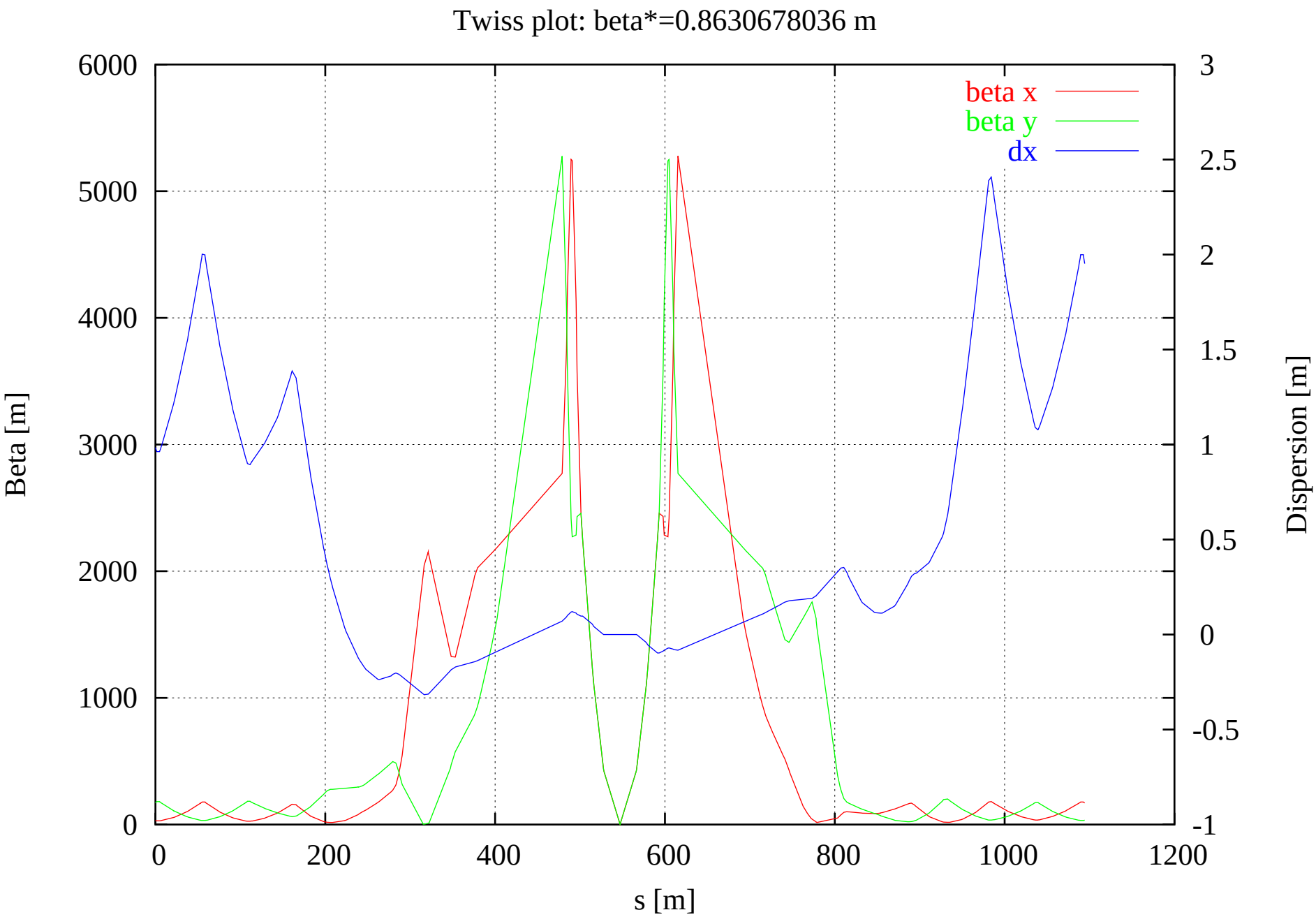

Twiss plot: beta*=0.5358972025 m
beta x
beta y
dx
Beta [m]
Dispersion [m]
s [m]
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
3
2.5
2
1.5
1
0.5
0
-0.5
-1
0
200
400
600
800
1000
1200

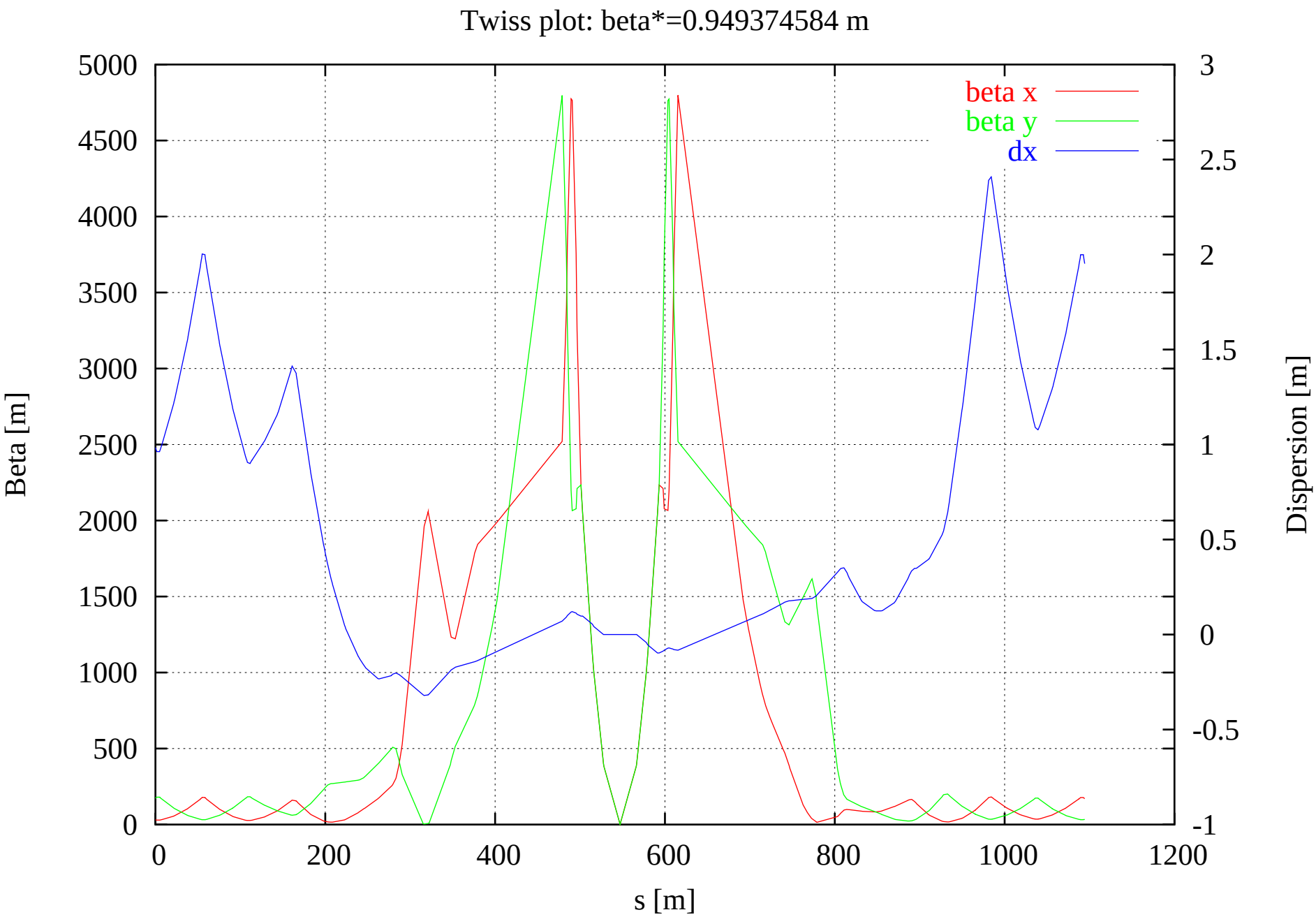

Twiss plot: beta*=0.5894869228 m
beta x
beta y
dx
Beta [m]
Dispersion [m]
s [m]
8000
7000
6000
5000
4000
3000
2000
1000
0
3
2.5
2
1.5
1
0.5
0
-0.5
-1
0
200
400
600
800
1000
1200

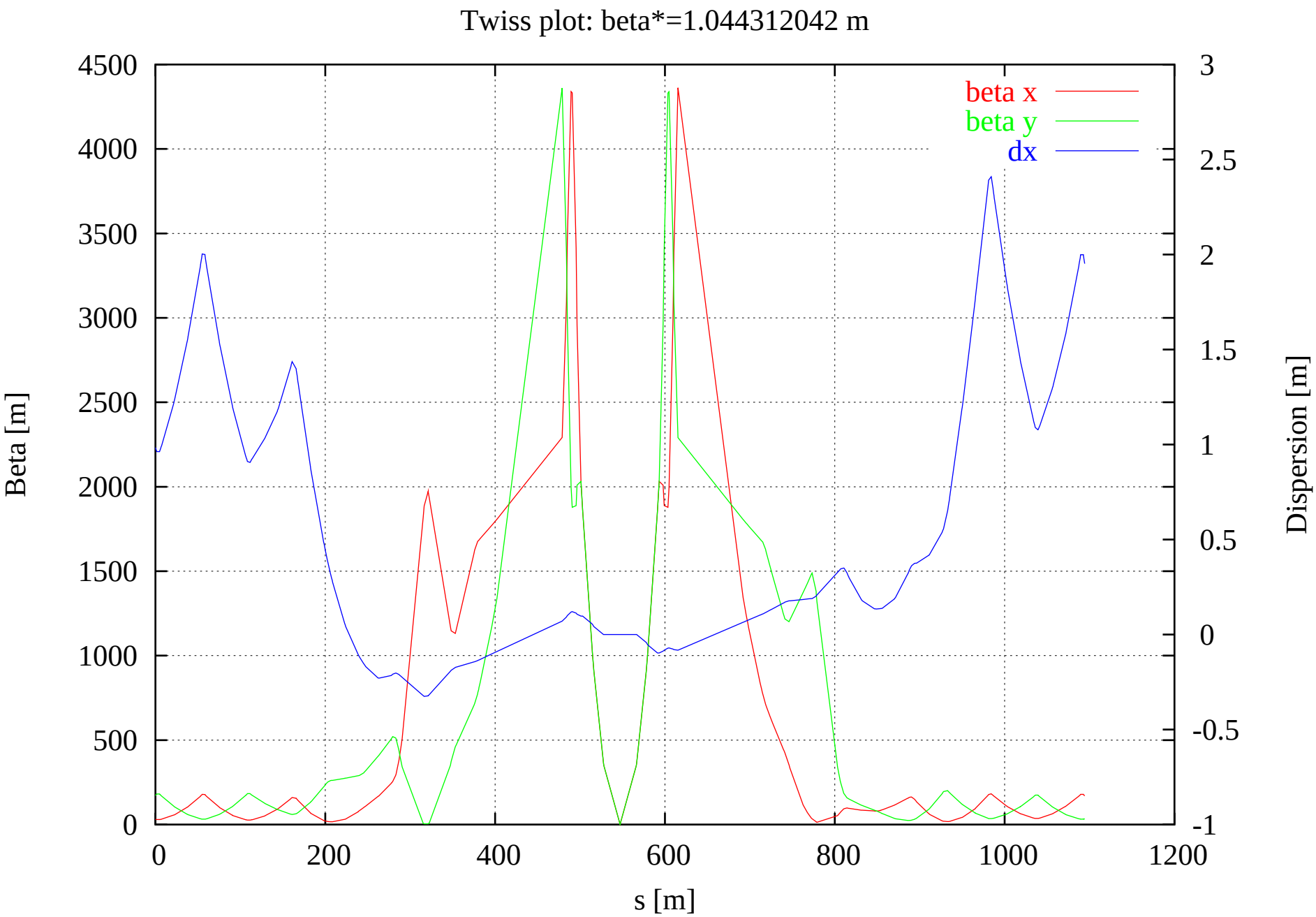

Twiss plot: beta*=0.648435615 m
beta x
beta y
dx
Beta [m]
Dispersion [m]
s [m]
8000
7000
6000
5000
4000
3000
2000
1000
0
3
2.5
2
1.5
1
0.5
0
-0.5
-1
0
200
400
600
800
1000
1200

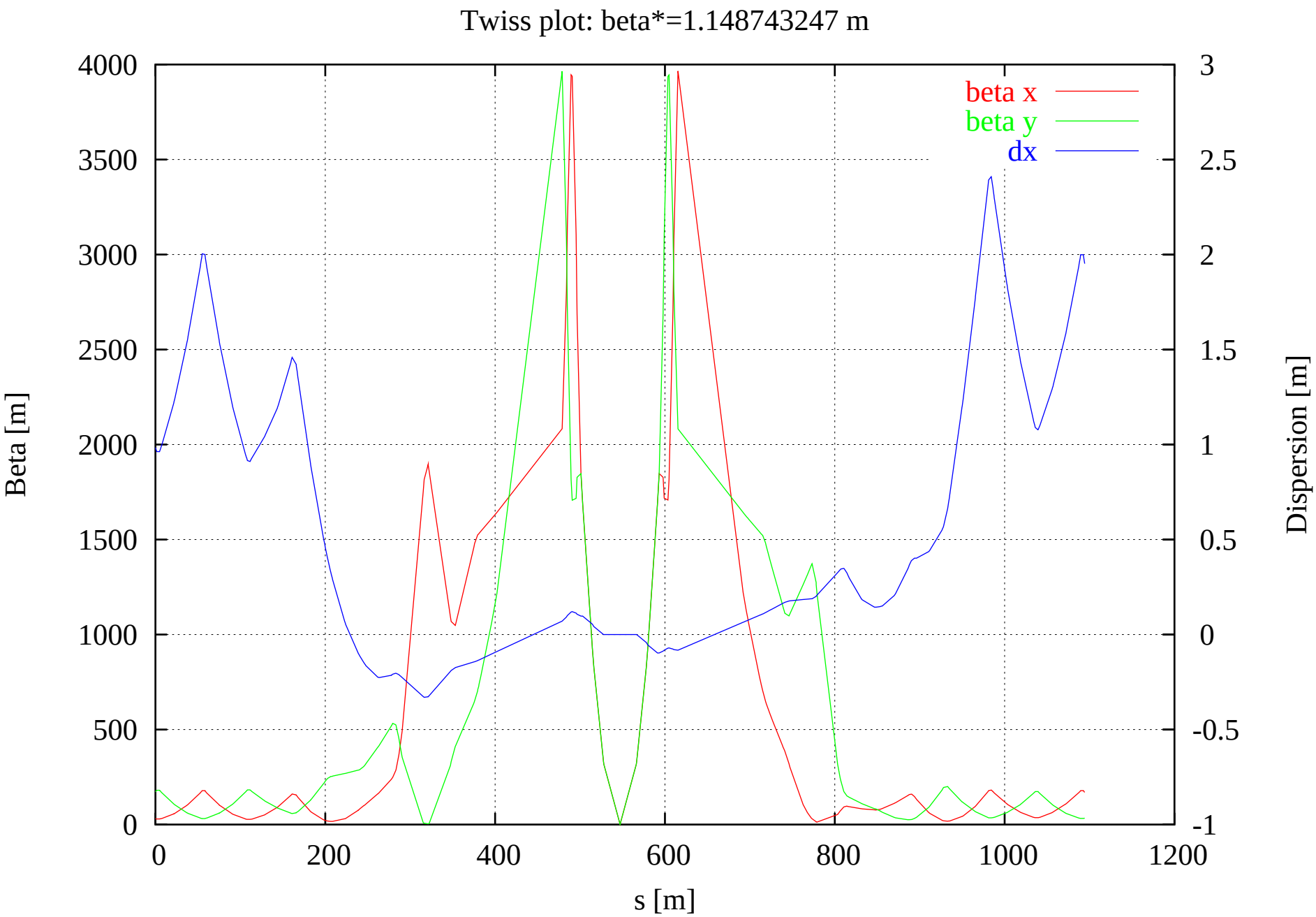

Twiss plot: beta*=0.7132791765 m
beta x
beta y
dx
Beta [m]
Dispersion [m]
s [m]
7000
6000
5000
4000
3000
2000
1000
0
3
2.5
2
1.5
1
0.5
0
-0.5
-1
0
200
400
600
800
1000
1200

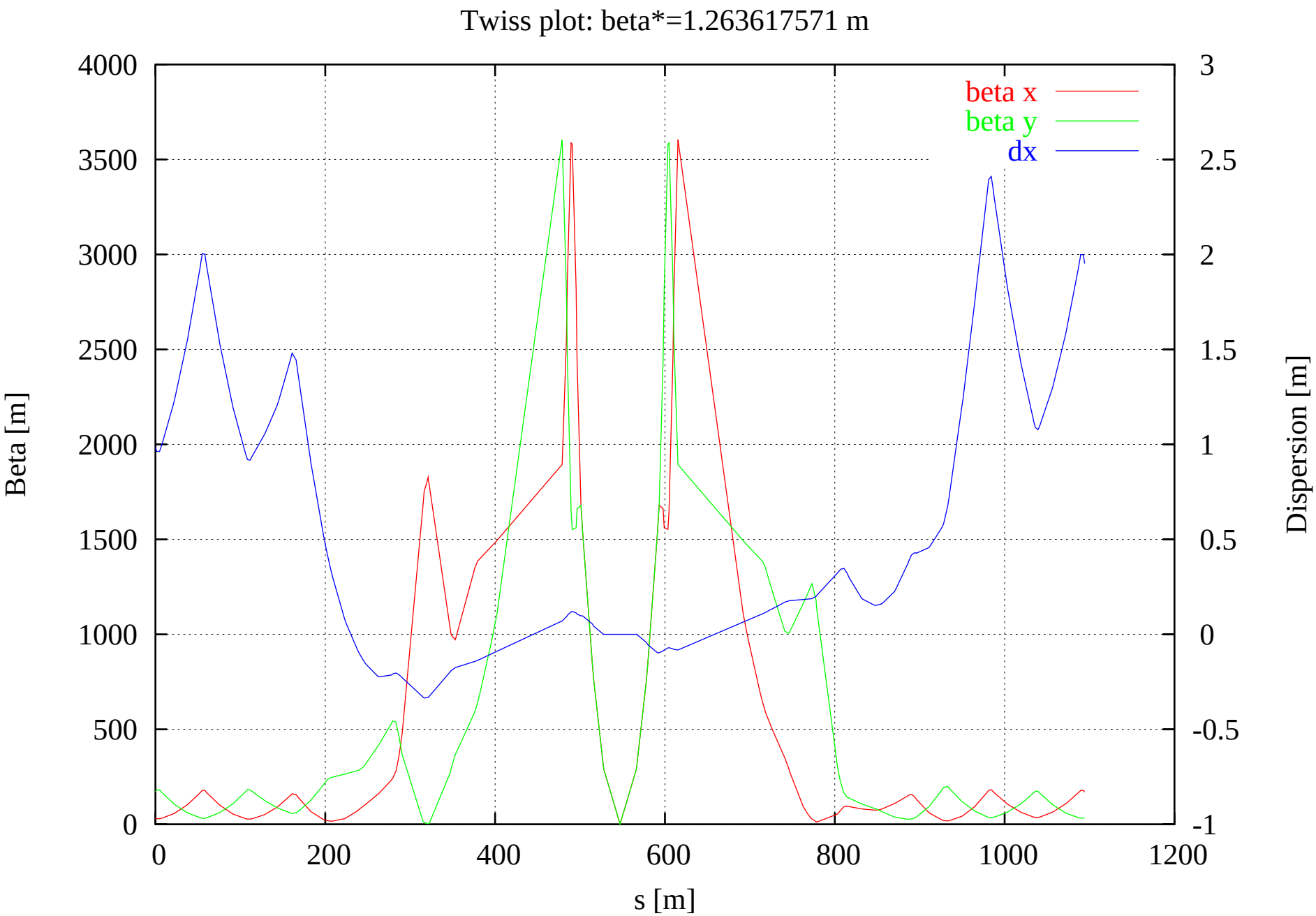

Twiss plot: beta*=0.7846070942 m
beta x
beta y
dx
Beta [m]
Dispersion [m]
s [m]
6000
5000
4000
3000
2000
1000
0
3
2.5
2
1.5
1
0.5
0
-0.5
-1
0
200
400
600
800
1000
1200

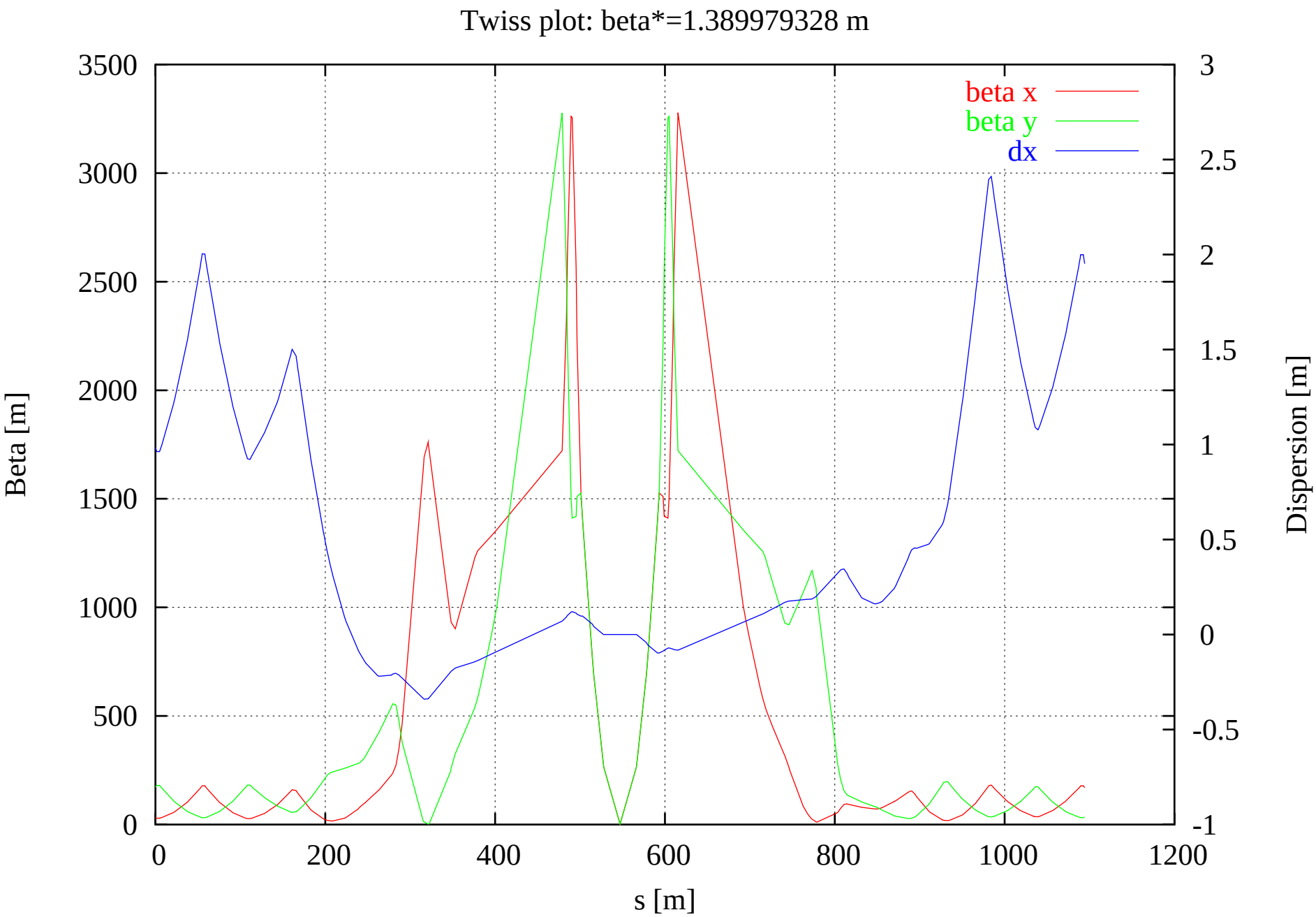

Twiss plot: beta*=0.8630678036 m
beta x
beta y
dx
Beta [m]
Dispersion [m]
s [m]
6000
5000
4000
3000
2000
1000
0
3
2.5
2
1.5
1
0.5
0
-0.5
-1
0
200
400
600
800
1000
1200

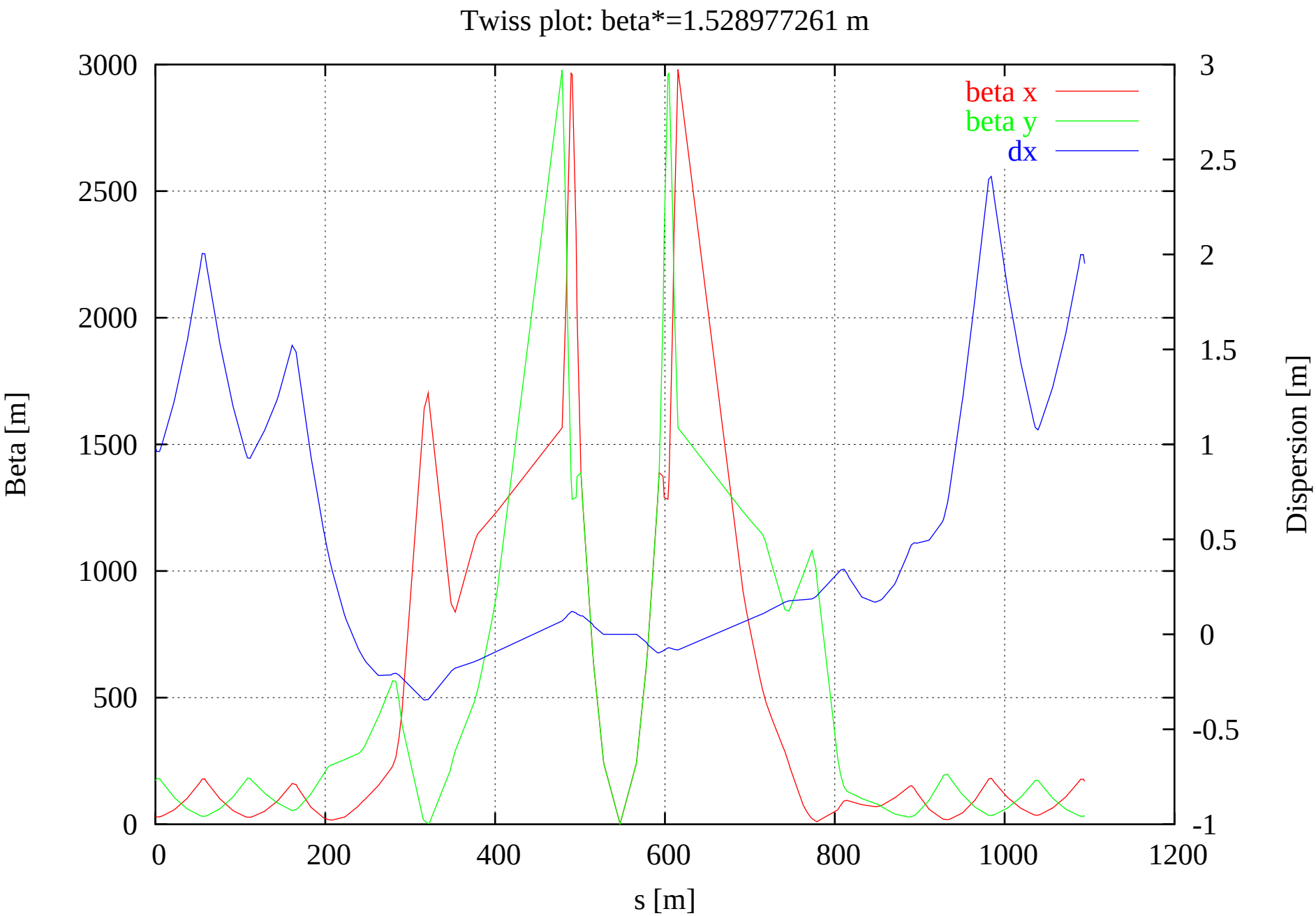

Twiss plot: beta*=0.949374584 m
beta x
beta y
dx
Beta [m]
Dispersion [m]
s [m]
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
3
2.5
2
1.5
1
0.5
0
-0.5
-1
0
200
400
600
800
1000
1200

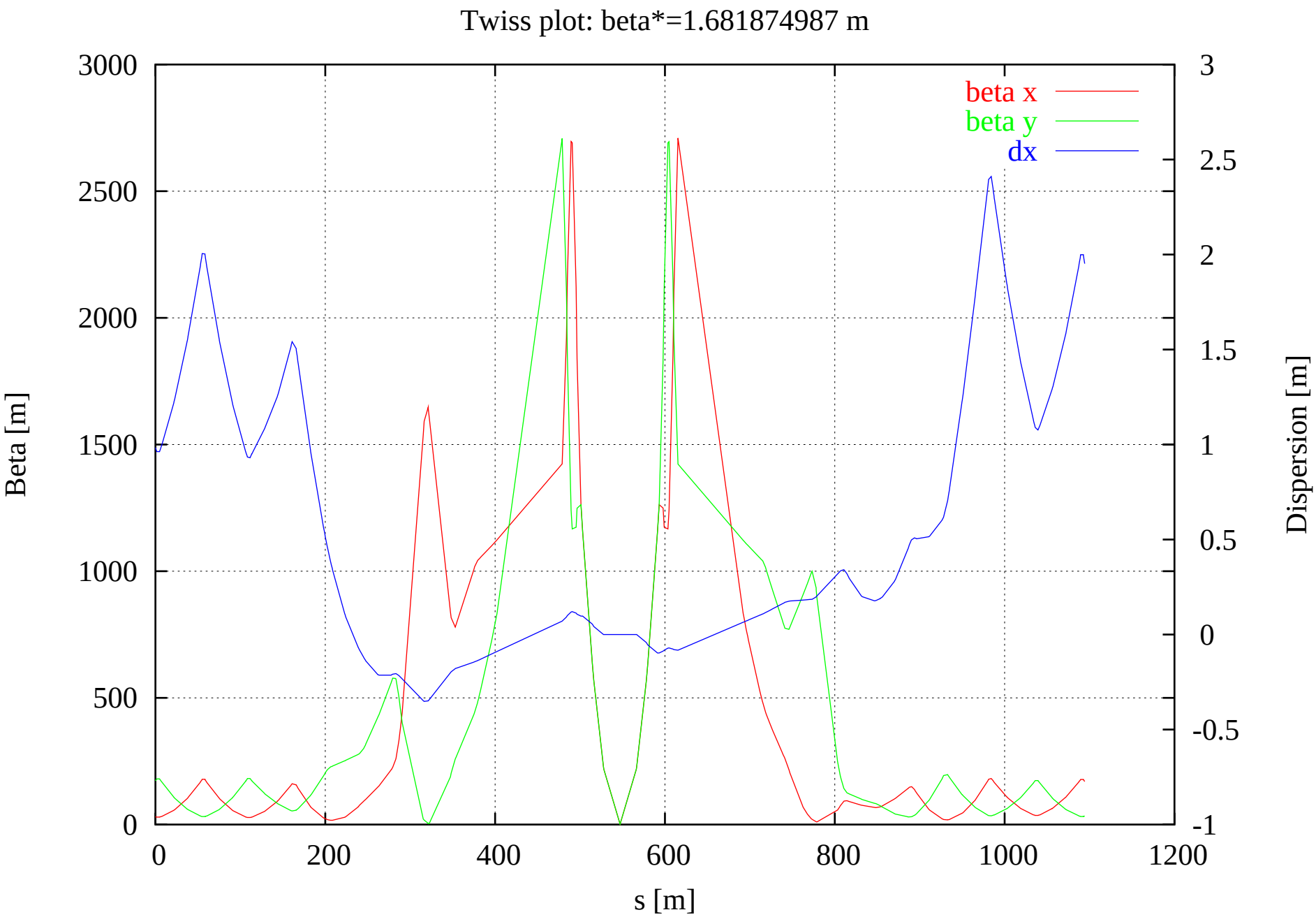

Twiss plot: beta*=1.044312042 m
beta x
beta y
dx
Beta [m]
Dispersion [m]
s [m]
4500
4000
3500
3000
2500
2000
1500
1000
500
0
3
2.5
2
1.5
1
0.5
0
-0.5
-1
0
200
400
600
800
1000
1200

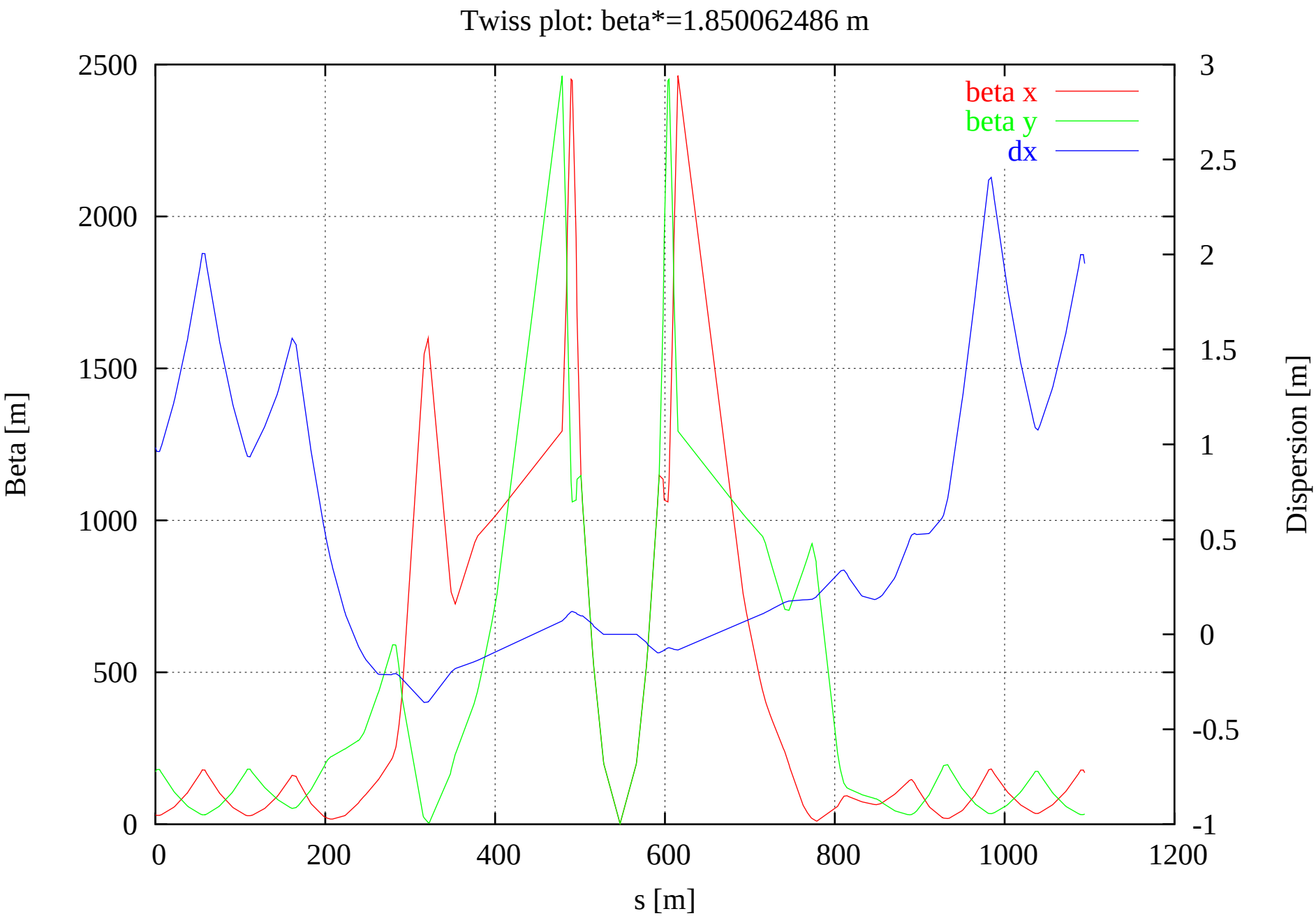

Twiss plot: beta*=1.148743247 m
beta x
beta y
dx
Beta [m]
Dispersion [m]
s [m]
4000
3500
3000
2500
2000
1500
1000
500
0
3
2.5
2
1.5
1
0.5
0
-0.5
-1
0
200
400
600
800
1000
1200

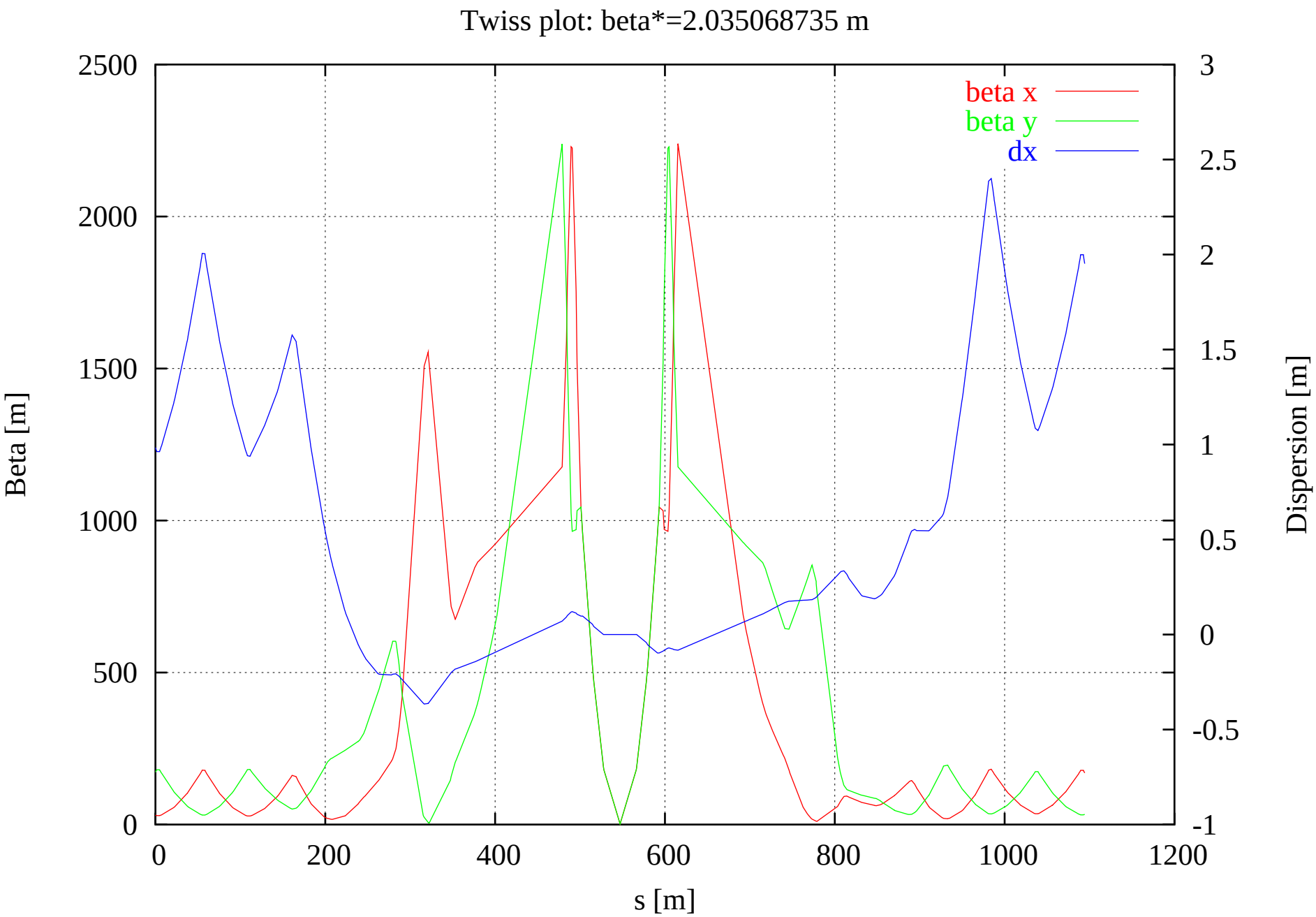

Twiss plot: beta*=1.263617571 m
beta x
beta y
dx
Beta [m]
Dispersion [m]
s [m]
4000
3500
3000
2500
2000
1500
1000
500
0
3
2.5
2
1.5
1
0.5
0
-0.5
-1
0
200
400
600
800
1000
1200

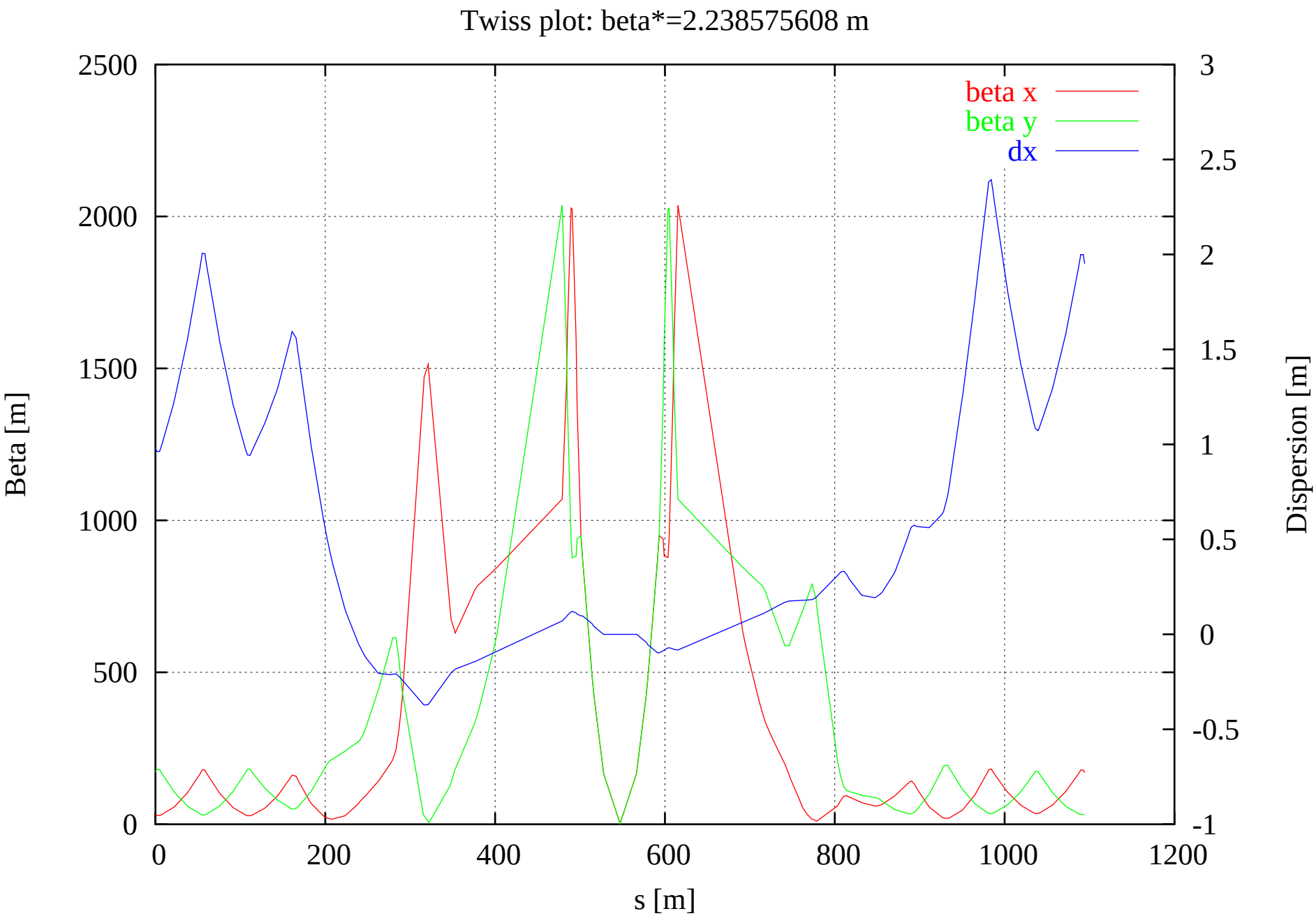

Twiss plot: beta*=1.389979328 m
beta x
beta y
dx
Beta [m]
Dispersion [m]
s [m]
3500
3000
2500
2000
1500
1000
500
0
3
2.5
2
1.5
1
0.5
0
-0.5
-1
0
200
400
600
800
1000
1200

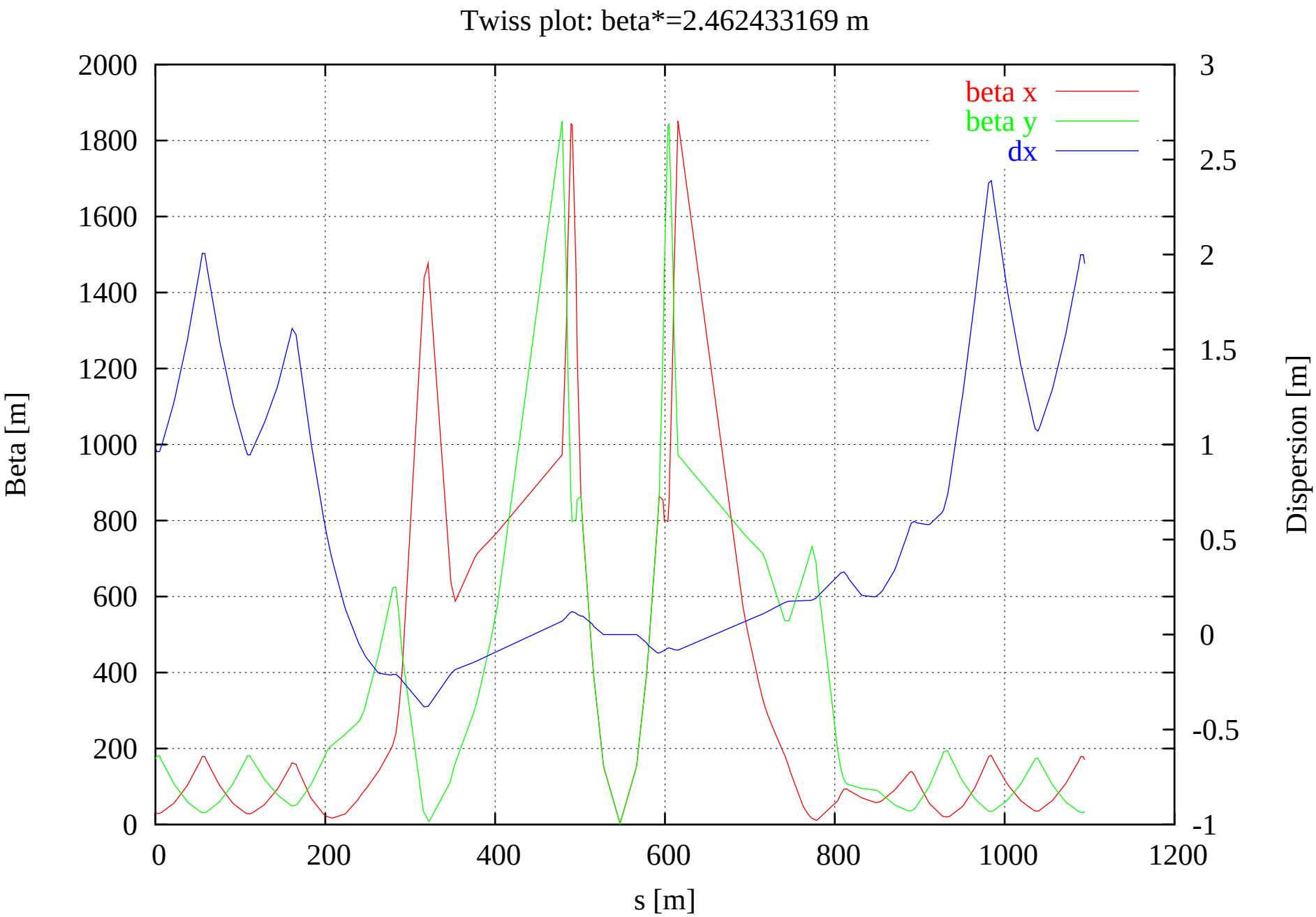

Twiss plot: beta*=1.528977261 m
beta x
beta y
dx
Beta [m]
Dispersion [m]
s [m]
3000
2500
2000
1500
1000
500
0
3
2.5
2
1.5
1
0.5
0
-0.5
-1
0
200
400
600
800
1000
1200

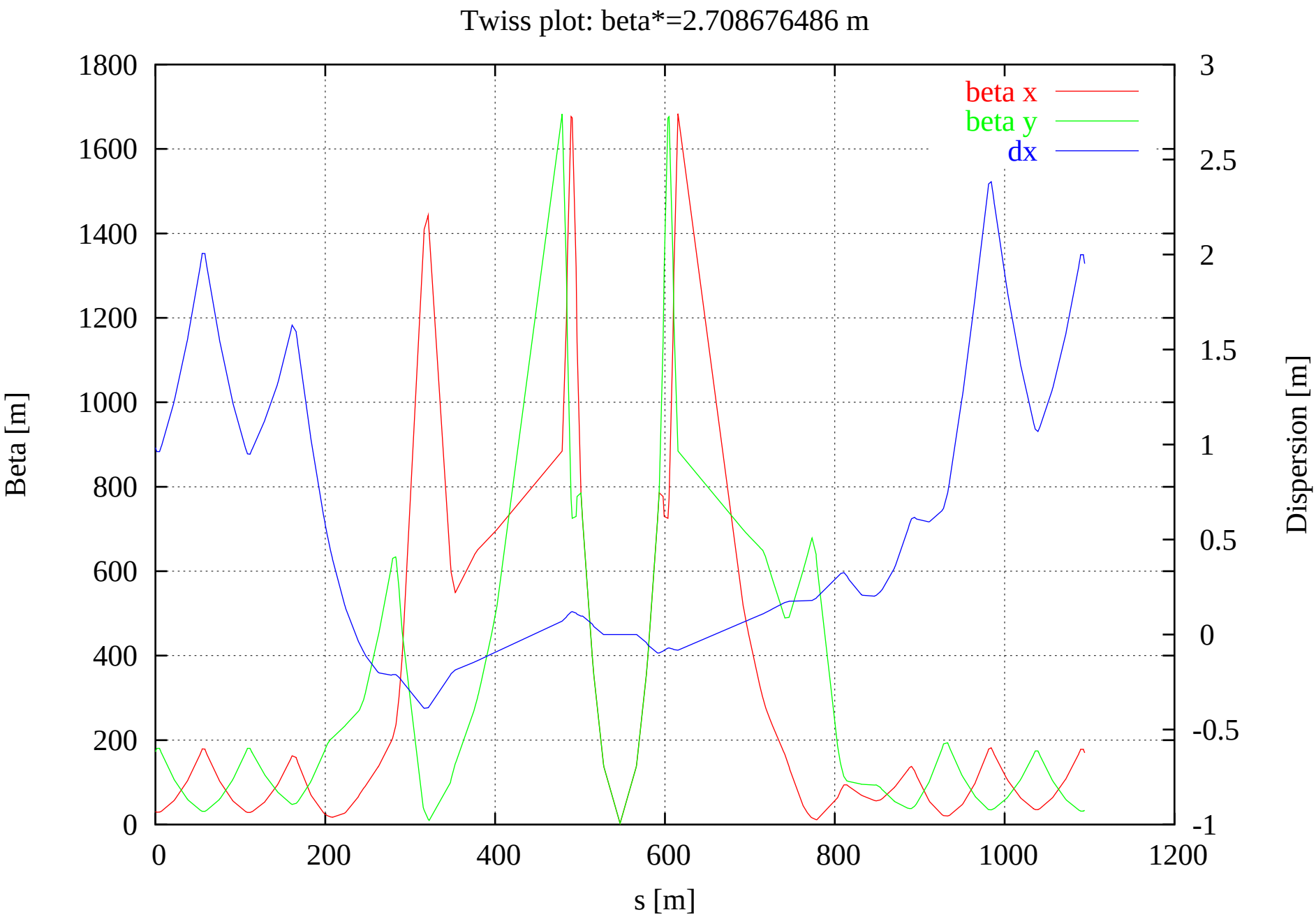

Twiss plot: beta*=1.681874987 m
beta x
beta y
dx
Beta [m]
Dispersion [m]
s [m]
3000
2500
2000
1500
1000
500
0
3
2.5
2
1.5
1
0.5
0
-0.5
-1
0
200
400
600
800
1000
1200

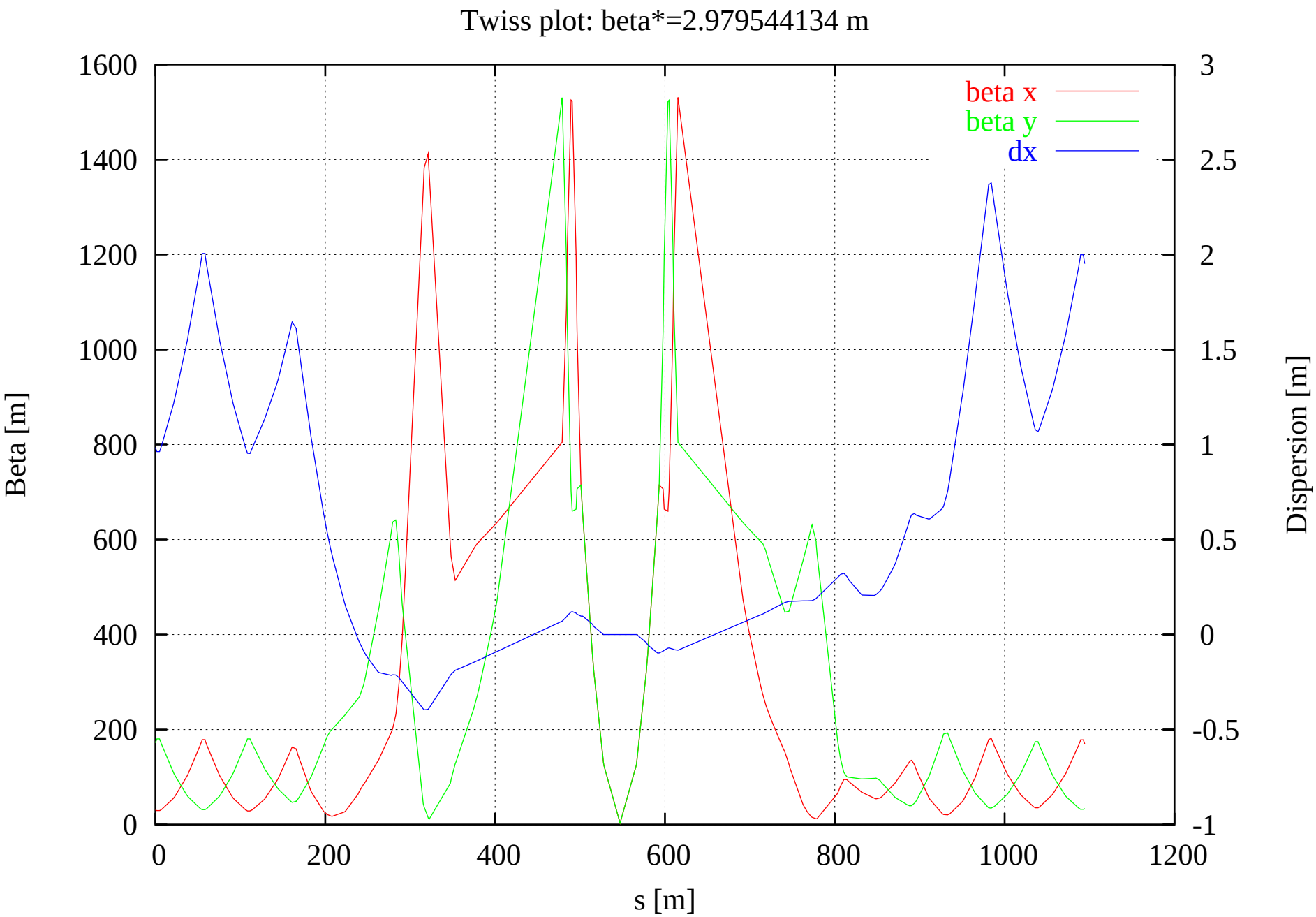

Twiss plot: beta*=1.850062486 m
beta x
beta y
dx
Beta [m]
Dispersion [m]
s [m]
2500
2000
1500
1000
500
0
3
2.5
2
1.5
1
0.5
0
-0.5
-1
0
200
400
600
800
1000
1200

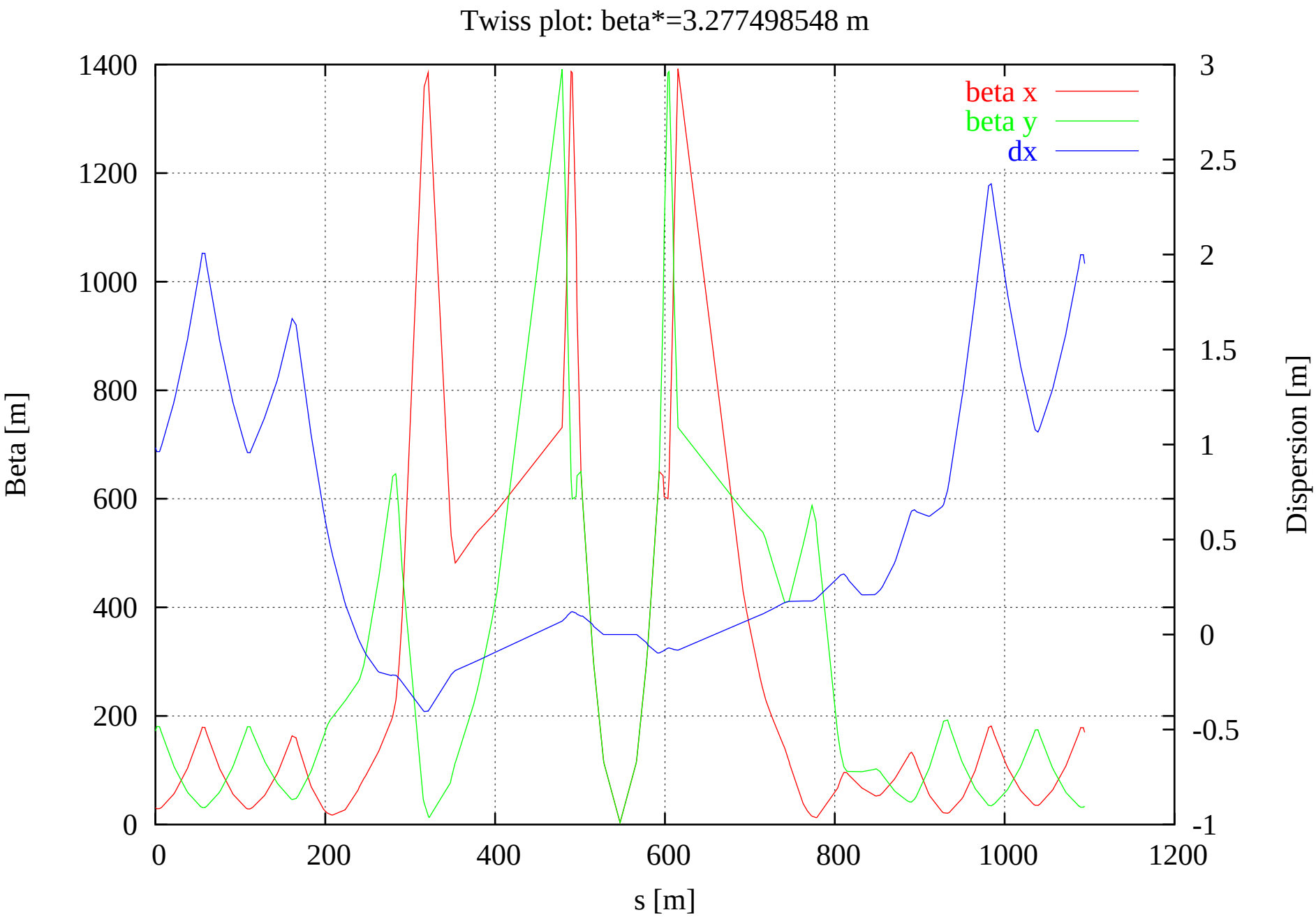

Twiss plot: beta*=2.035068735 m
beta x
beta y
dx
Beta [m]
Dispersion [m]
s [m]
2500
2000
1500
1000
500
0
3
2.5
2
1.5
1
0.5
0
-0.5
-1
0
200
400
600
800
1000
1200

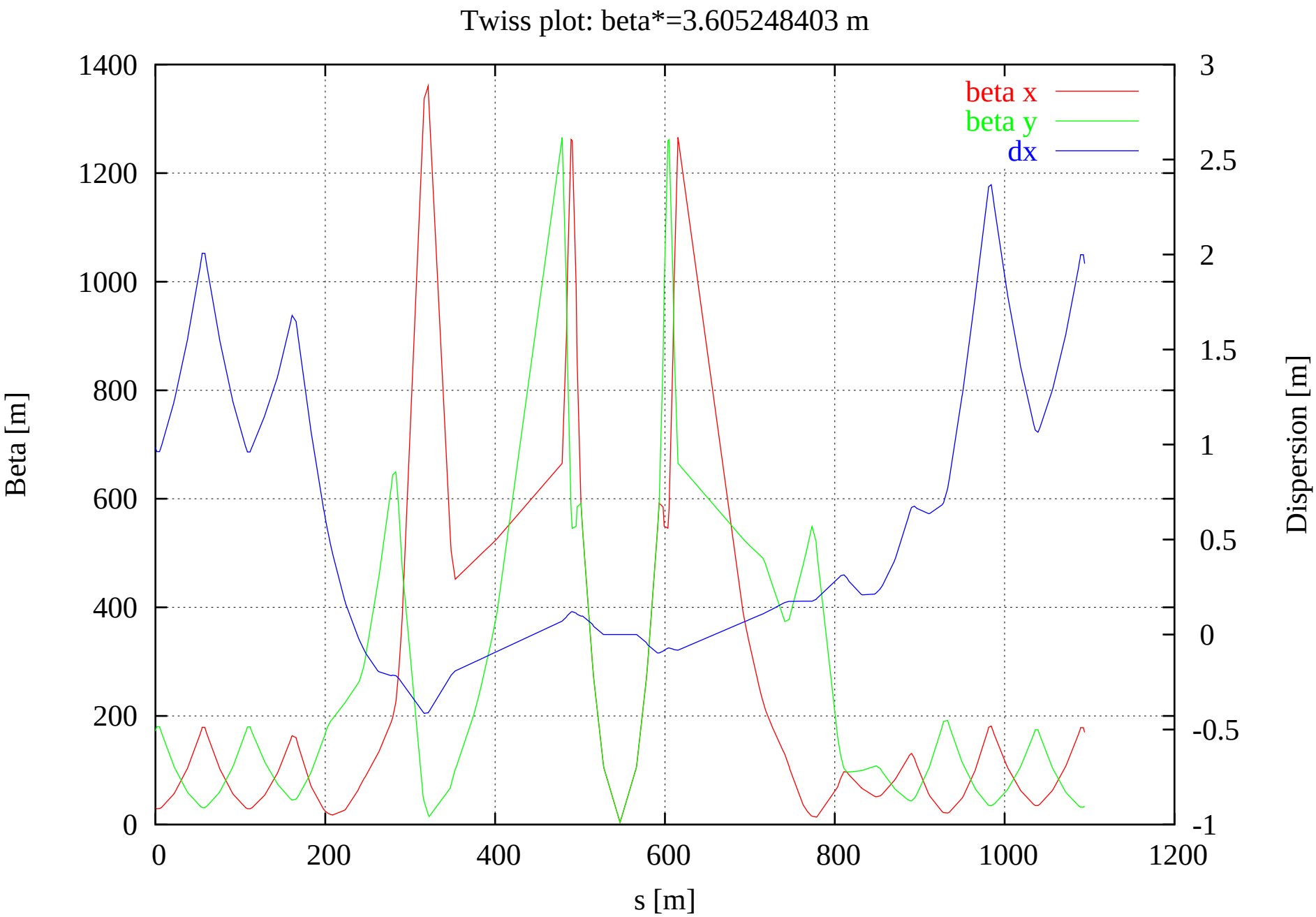

Twiss plot: beta*=2.238575608 m
beta x
beta y
dx
Beta [m]
Dispersion [m]
s [m]
2500
2000
1500
1000
500
0
3
2.5
2
1.5
1
0.5
0
-0.5
-1
0
200
400
600
800
1000
1200

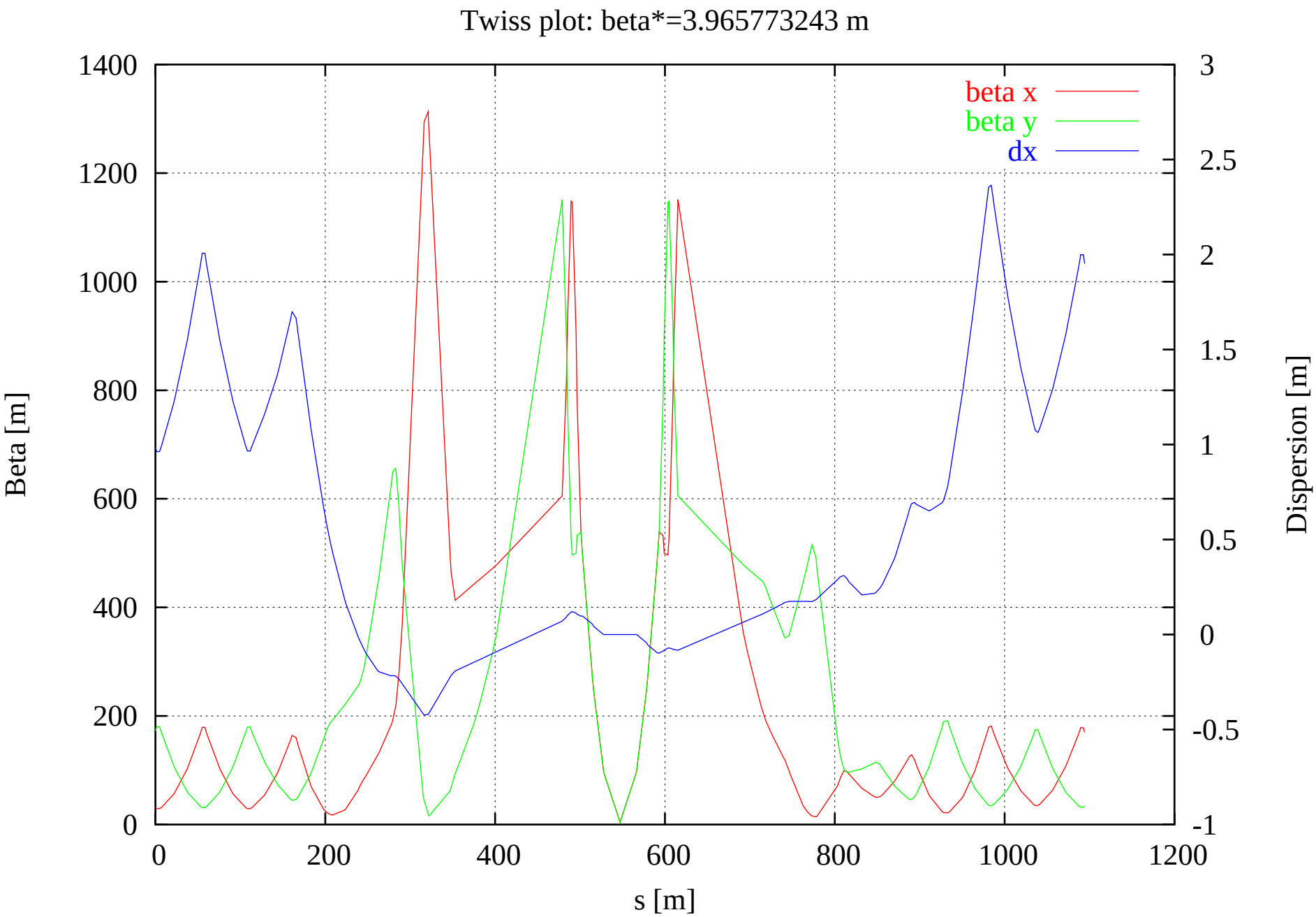

Twiss plot: beta*=2.462433169 m
beta x
beta y
dx
Beta [m]
Dispersion [m]
s [m]
2000
1800
1600
1400
1200
1000
800
600
400
200
0
3
2.5
2
1.5
1
0.5
0
-0.5
-1
0
200
400
600
800
1000
1200

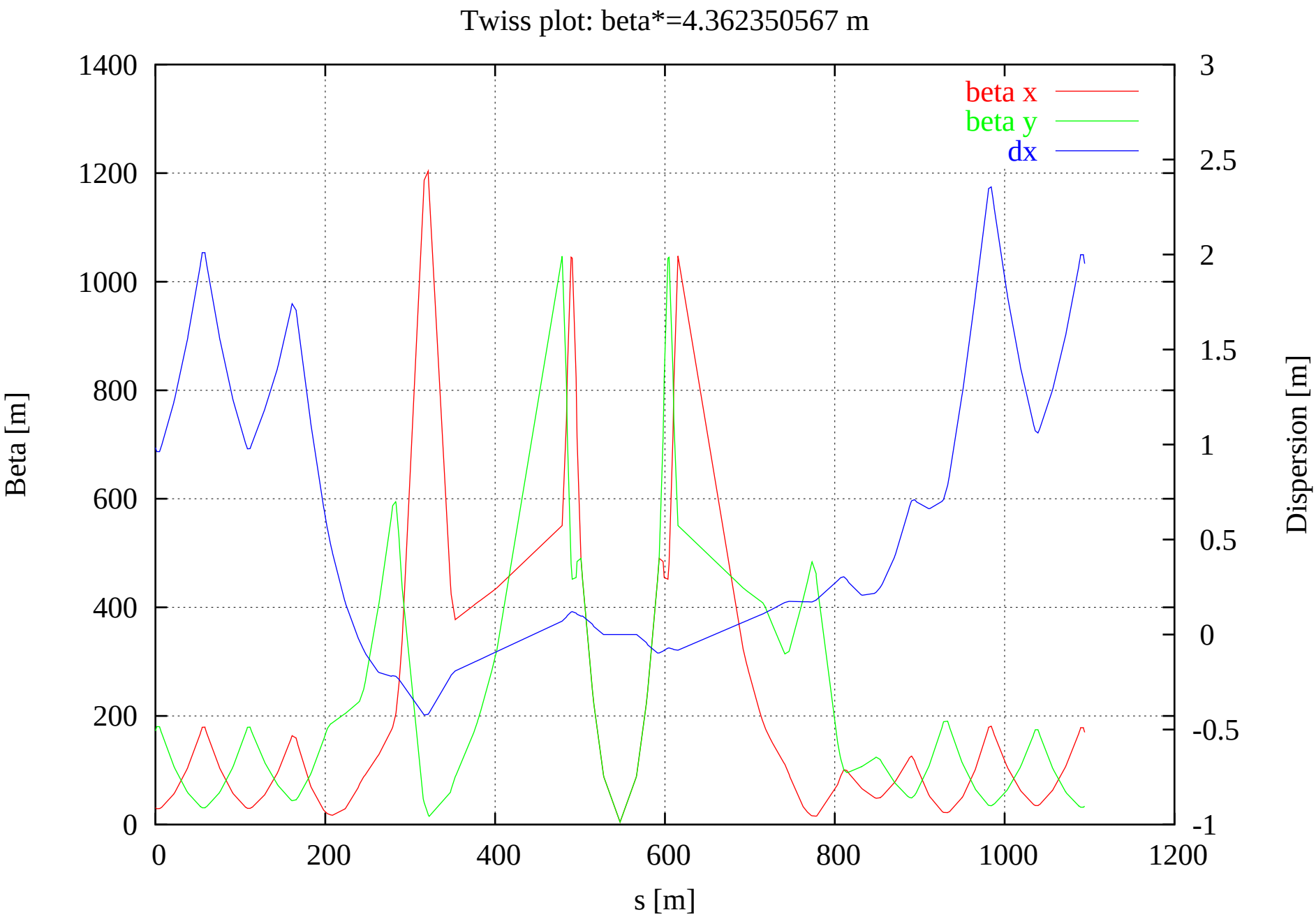

Twiss plot: beta*=2.708676486 m
beta x
beta y
dx
Beta [m]
Dispersion [m]
s [m]
0
200
400
600
800
1000
1200
1400
1600
1800
-1
-0.5
0
0.5
1
1.5
2
2.5
3

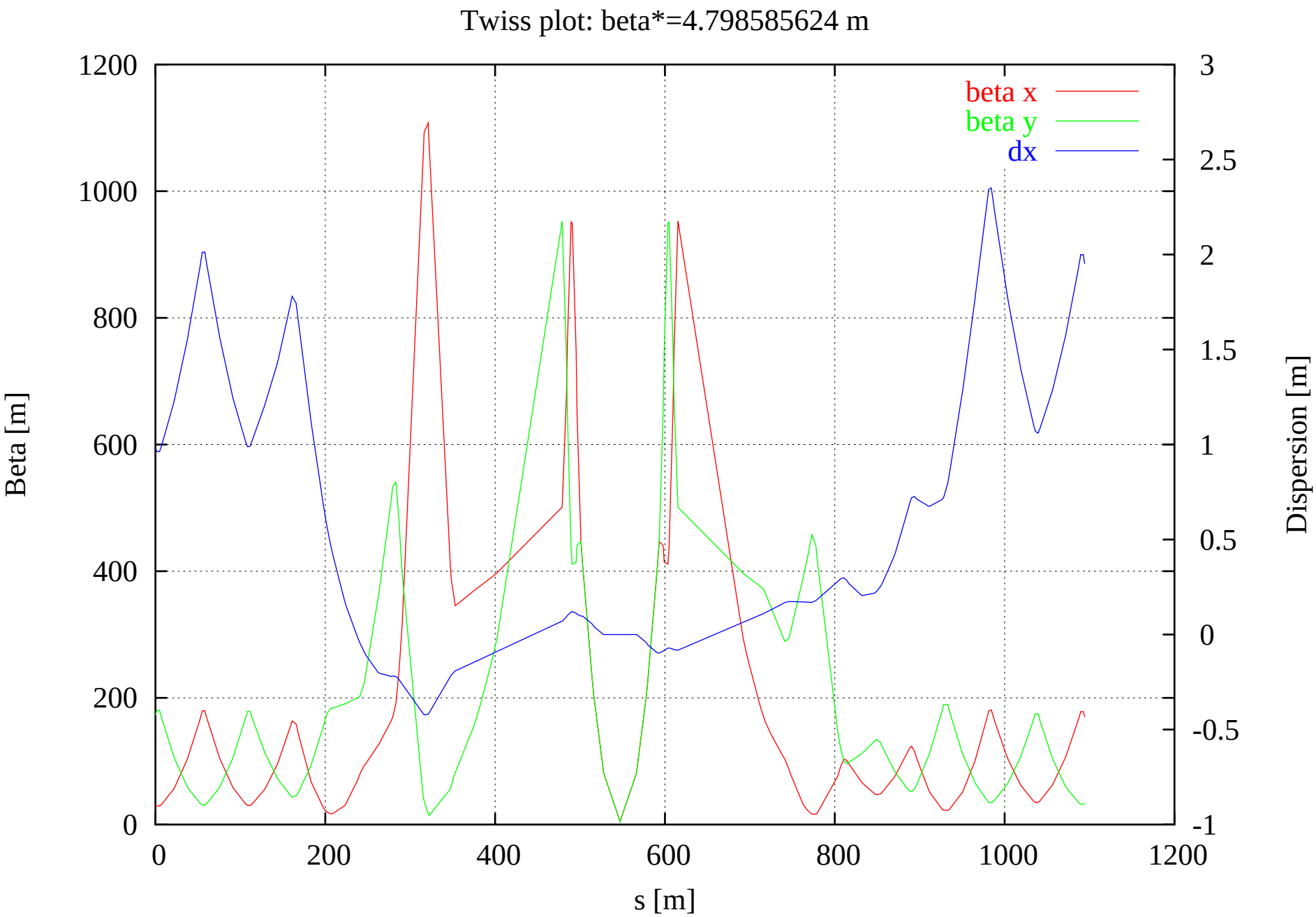

Twiss plot: beta*=2.979544134 m
beta x
beta y
dx
Beta [m]
Dispersion [m]
s [m]
0
200
400
600
800
1000
1200
1400
1600
-1
-0.5
0
0.5
1
1.5
2
2.5
3

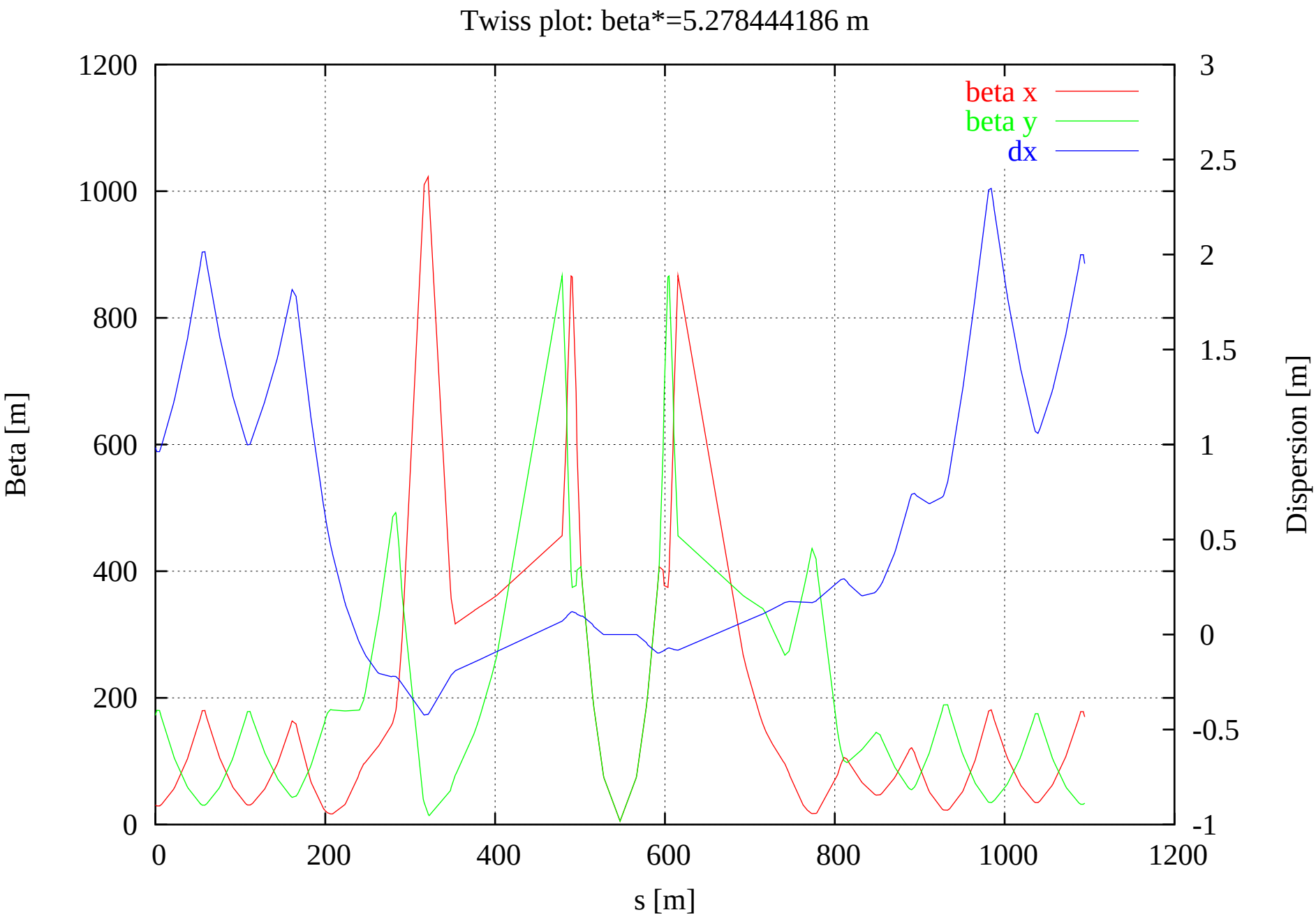

Twiss plot: beta*=3.277498548 m
beta x
beta y
dx
Beta [m]
Dispersion [m]
s [m]
0
200
400
600
800
1000
1200
1400
-1
-0.5
0
0.5
1
1.5
2
2.5
3

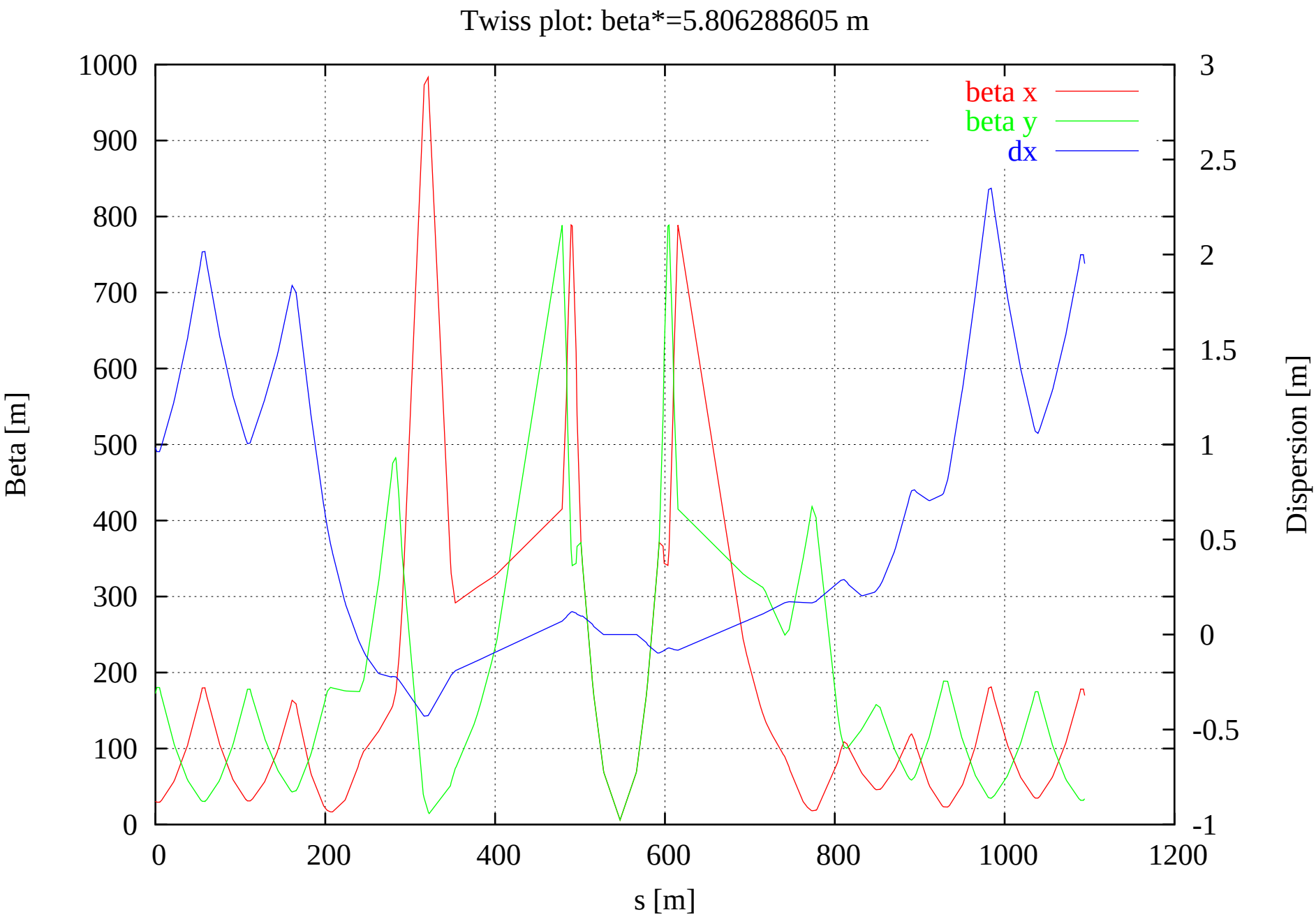

Twiss plot: beta*=3.605248403 m
beta x
beta y
dx
Beta [m]
Dispersion [m]
s [m]
0
200
400
600
800
1000
1200
1400
-1
-0.5
0
0.5
1
1.5
2
2.5
3

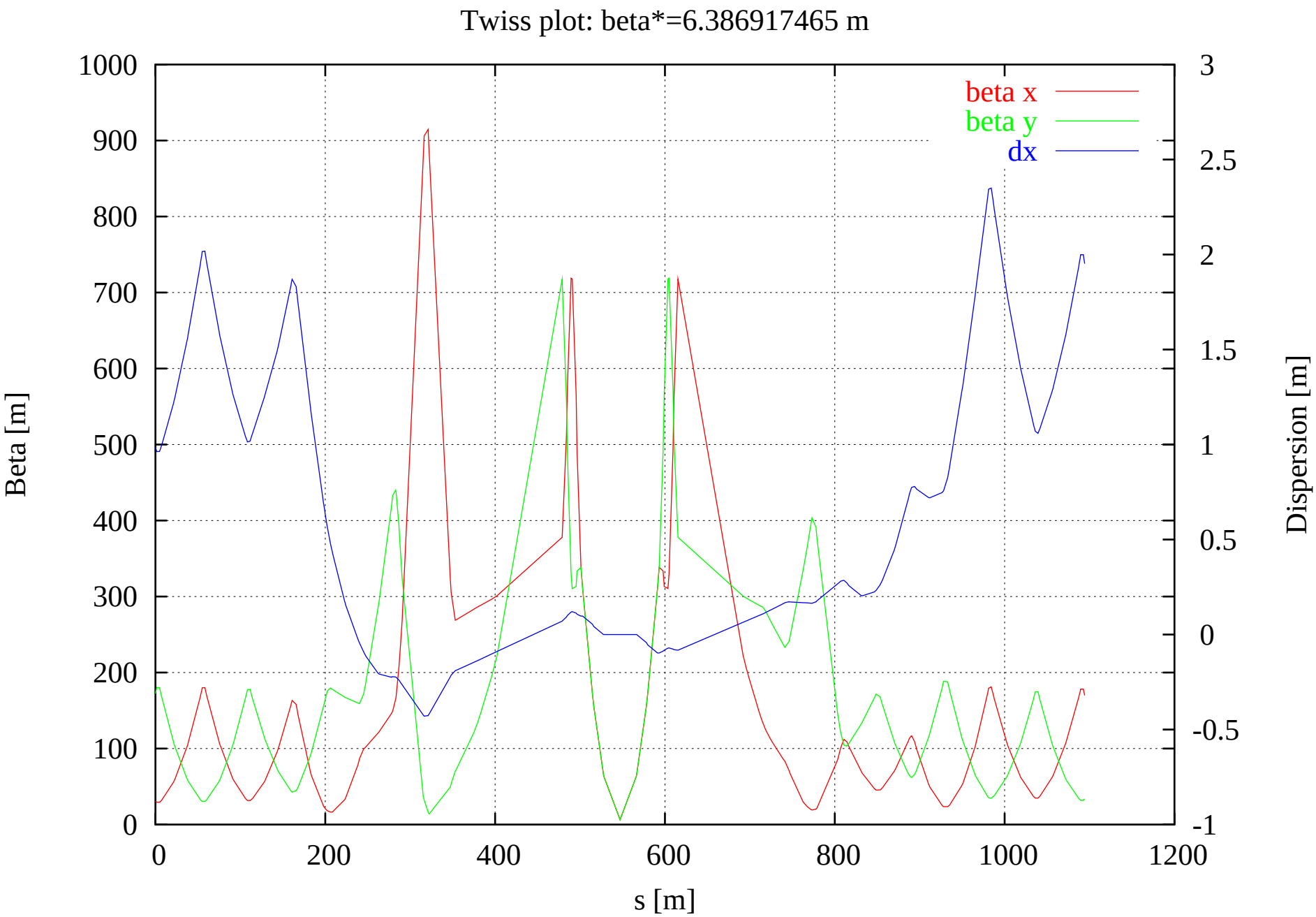

Twiss plot: beta*=3.965773243 m
beta x
beta y
dx
Beta [m]
Dispersion [m]
s [m]
0
200
400
600
800
1000
1200
1400
-1
-0.5
0
0.5
1
1.5
2
2.5
3

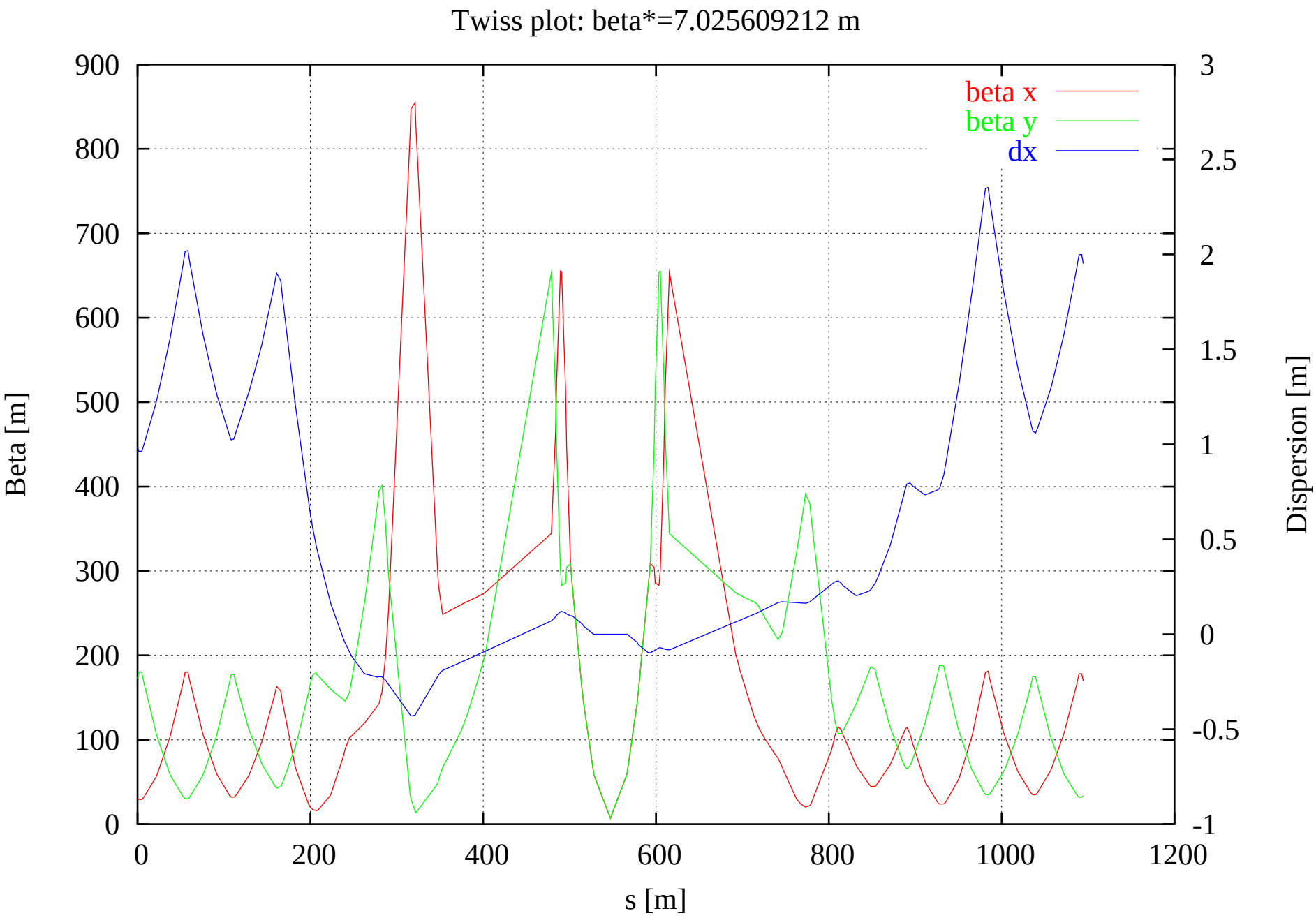

Twiss plot: beta*=4.362350567 m
beta x
beta y
dx
Beta [m]
Dispersion [m]
s [m]
0
200
400
600
800
1000
1200
1400
-1
-0.5
0
0.5
1
1.5
2
2.5
3

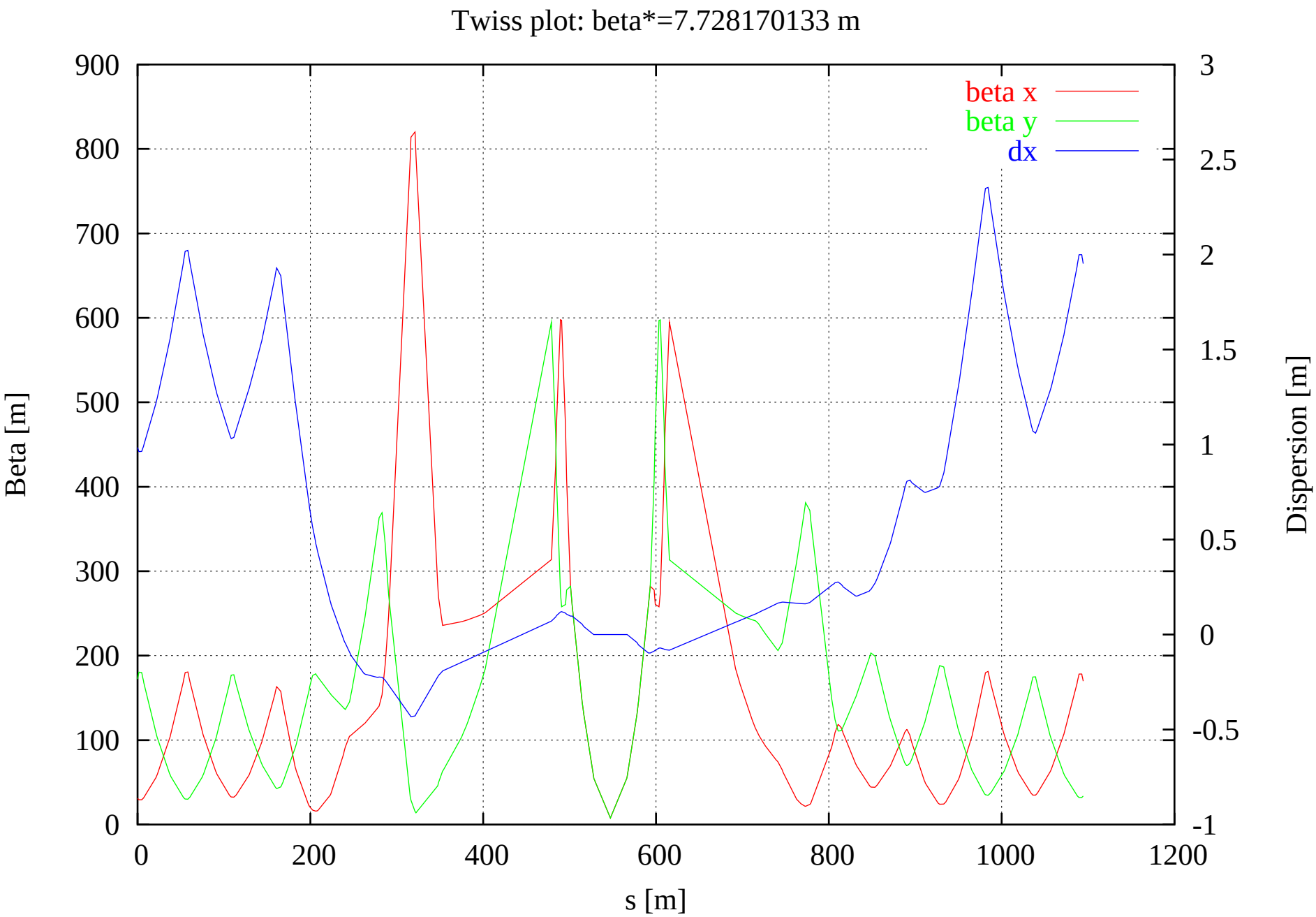

Twiss plot: beta*=4.798585624 m
beta x
beta y
dx
Beta [m]
Dispersion [m]
s [m]
0
200
400
600
800
1000
1200
-1
-0.5
0
0.5
1
1.5
2
2.5
3

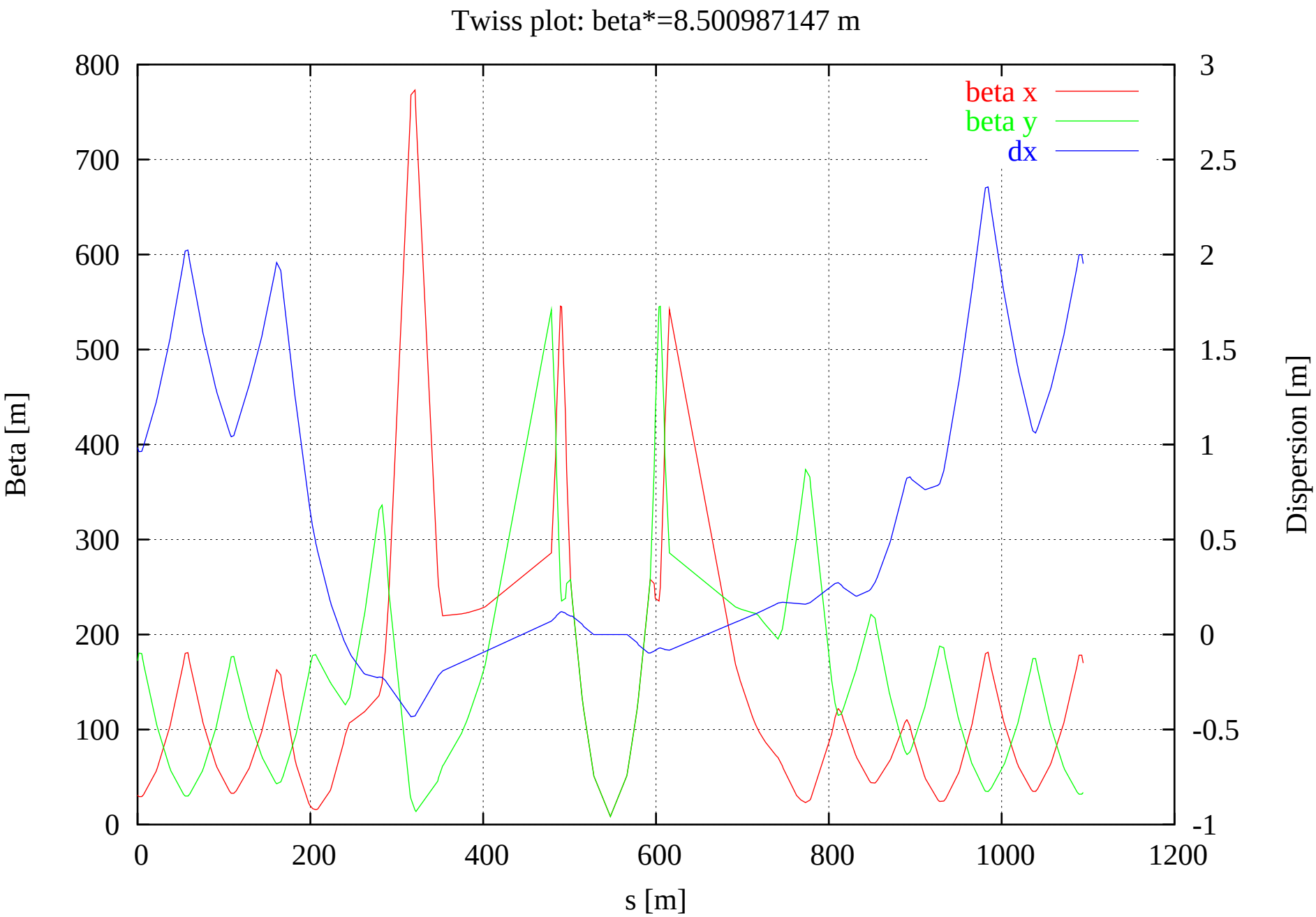

Twiss plot: beta*=5.278444186 m
beta x
beta y
dx
Beta [m]
Dispersion [m]
s [m]
0
200
400
600
800
1000
1200
-1
-0.5
0
0.5
1
1.5
2
2.5
3

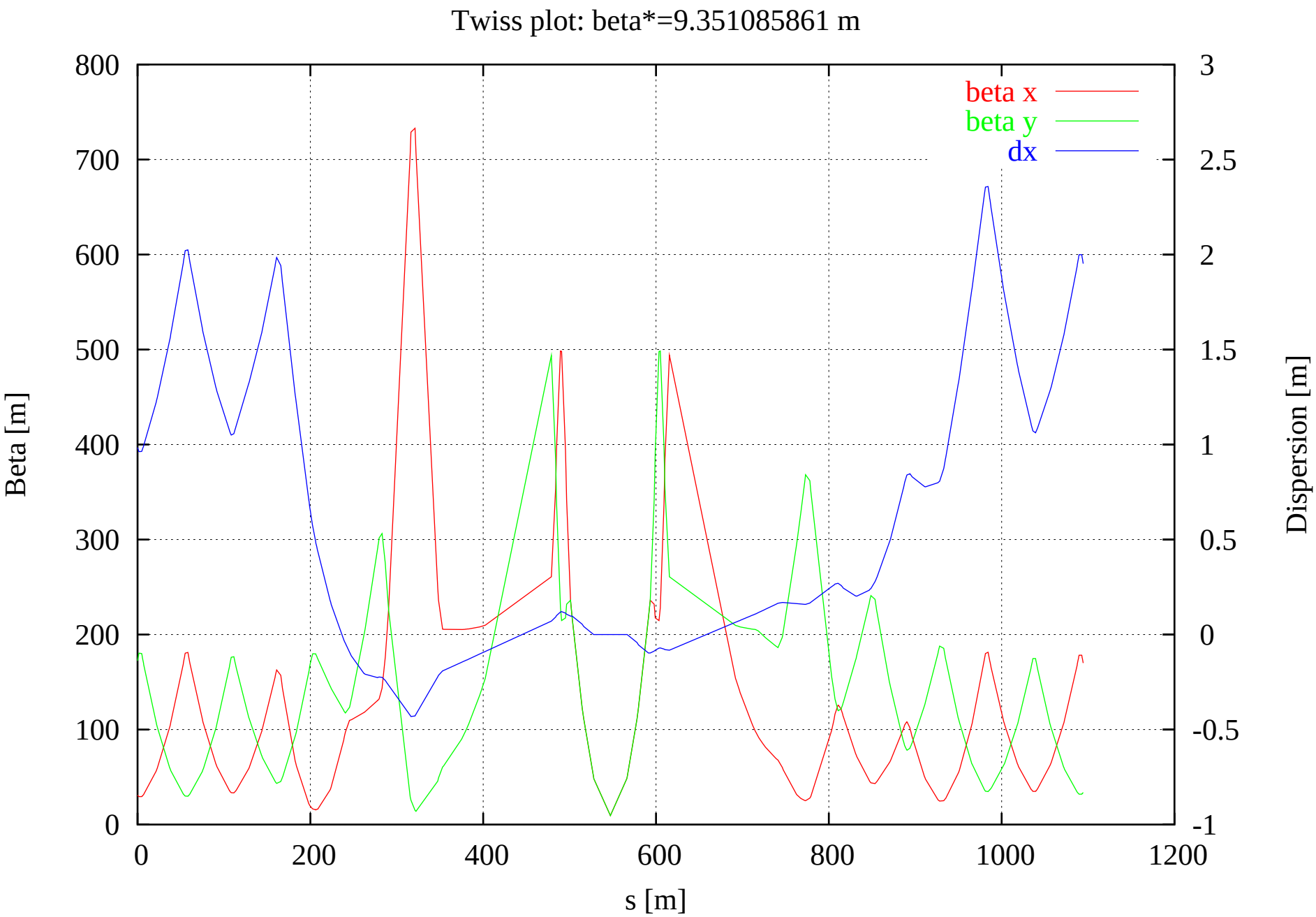

Twiss plot: beta*=5.806288605 m
beta x
beta y
dx
Beta [m]
Dispersion [m]
s [m]
0
100
200
300
400
500
600
700
800
900
1000
-1
-0.5
0
0.5
1
1.5
2
2.5
3
0
200
400
600
800
1000
1200

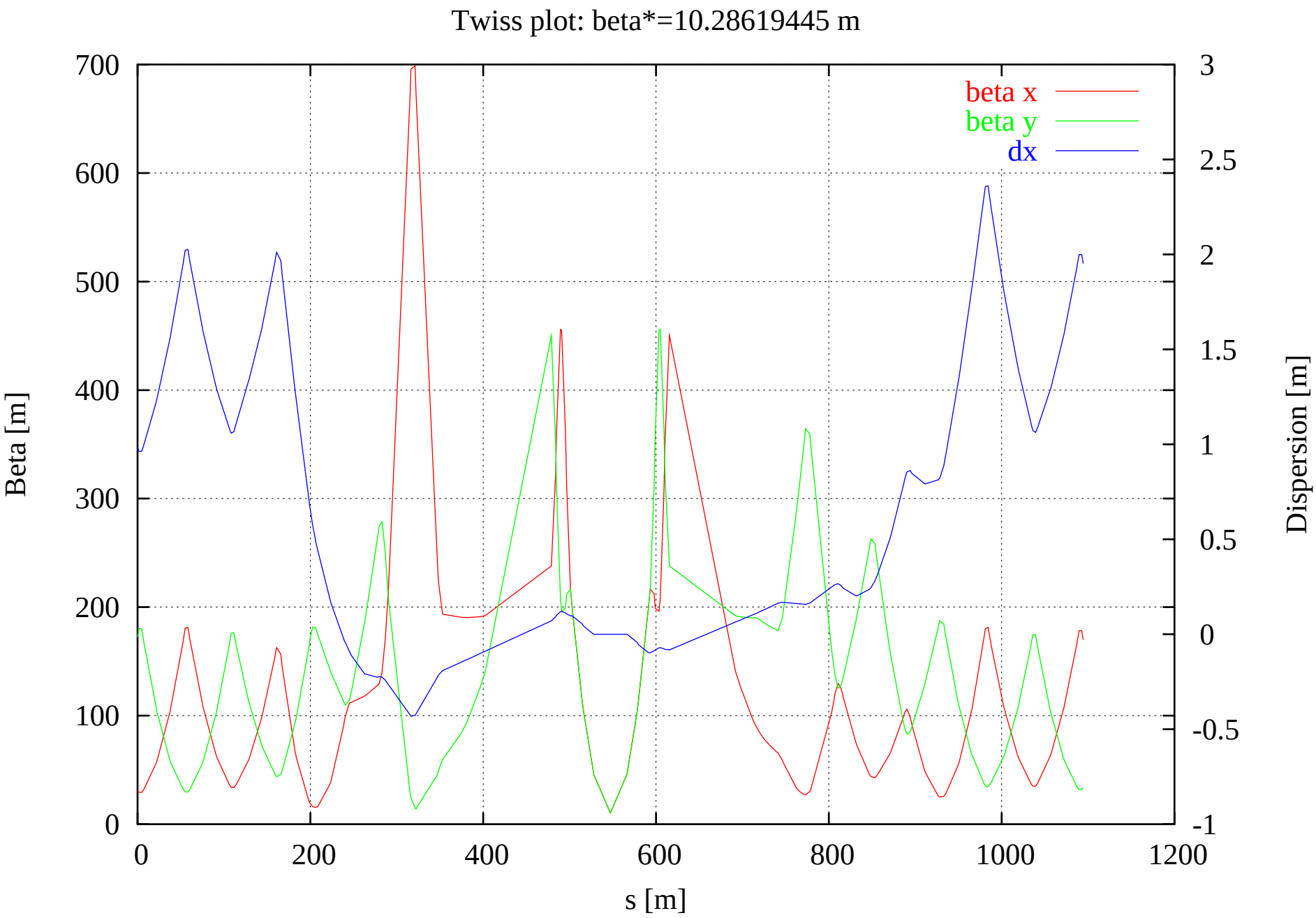

Twiss plot: beta*=6.386917465 m
beta x
beta y
dx
Beta [m]
Dispersion [m]
s [m]
0
100
200
300
400
500
600
700
800
900
1000
-1
-0.5
0
0.5
1
1.5
2
2.5
3
0
200
400
600
800
1000
1200

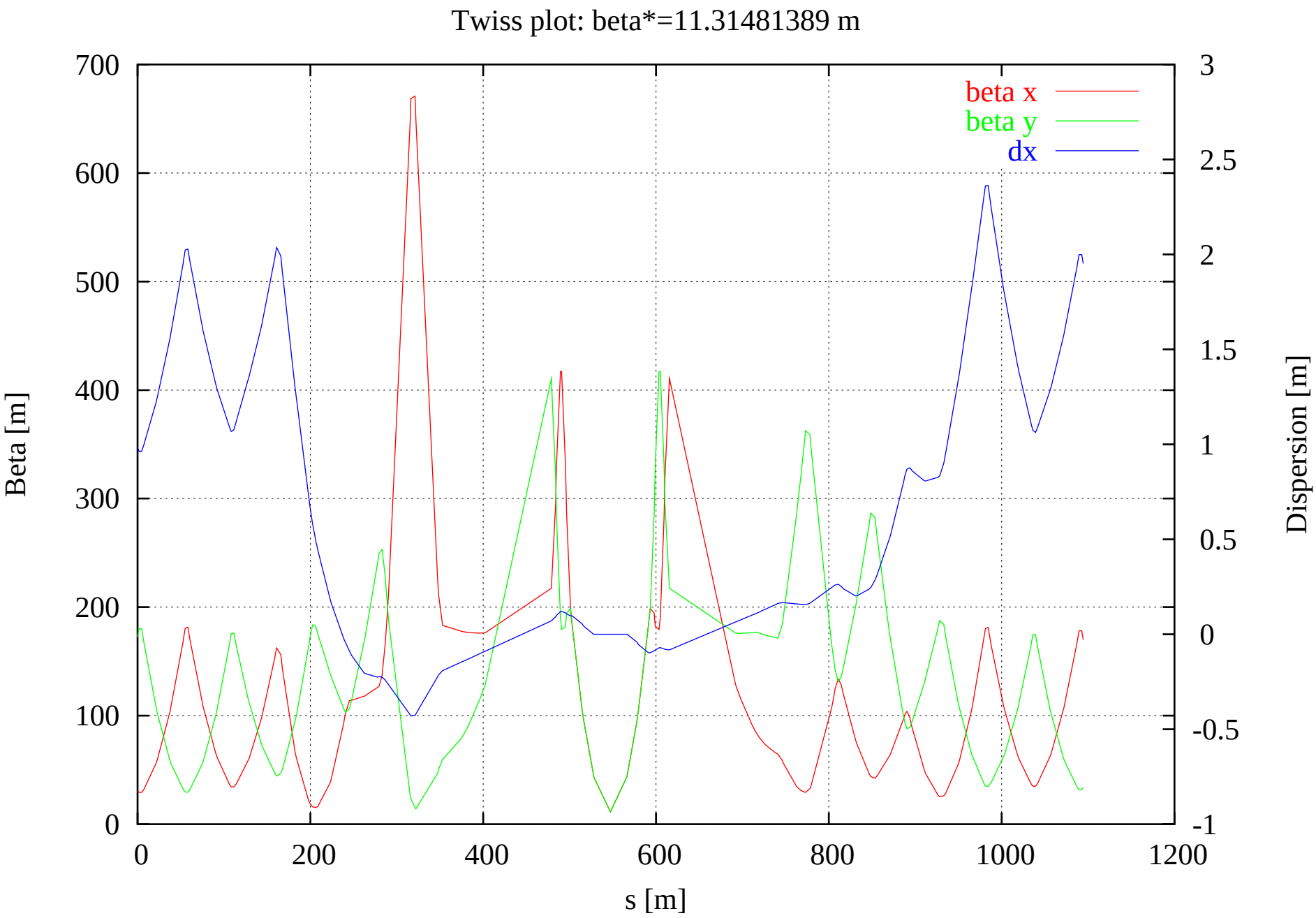

Twiss plot: beta*=7.025609212 m
beta x
beta y
dx
Beta [m]
Dispersion [m]
s [m]
0
100
200
300
400
500
600
700
800
900
-1
-0.5
0
0.5
1
1.5
2
2.5
3
0
200
400
600
800
1000
1200

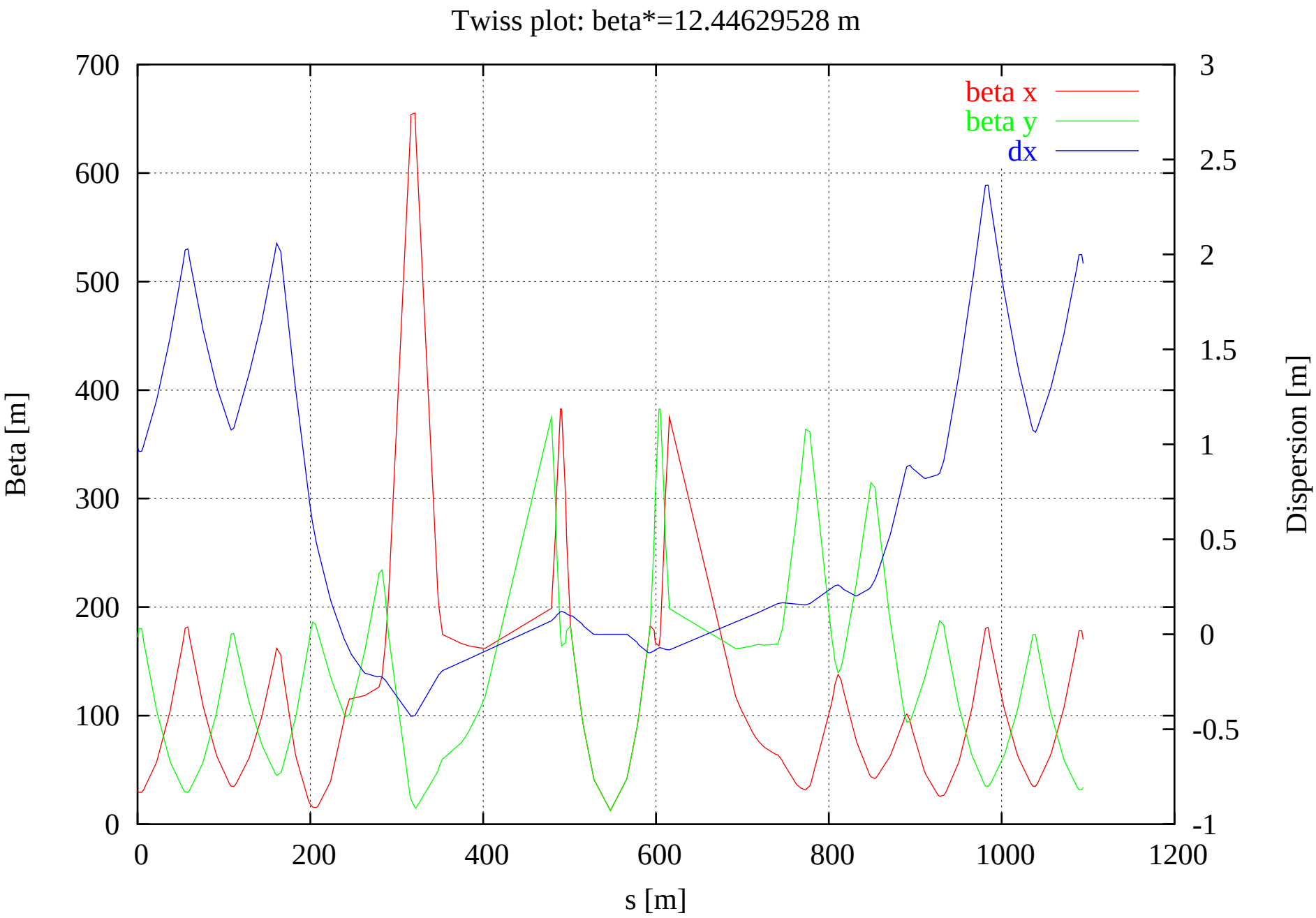

Twiss plot: beta*=7.728170133 m
beta x
beta y
dx
Beta [m]
Dispersion [m]
s [m]
0
100
200
300
400
500
600
700
800
900
-1
-0.5
0
0.5
1
1.5
2
2.5
3
0
200
400
600
800
1000
1200

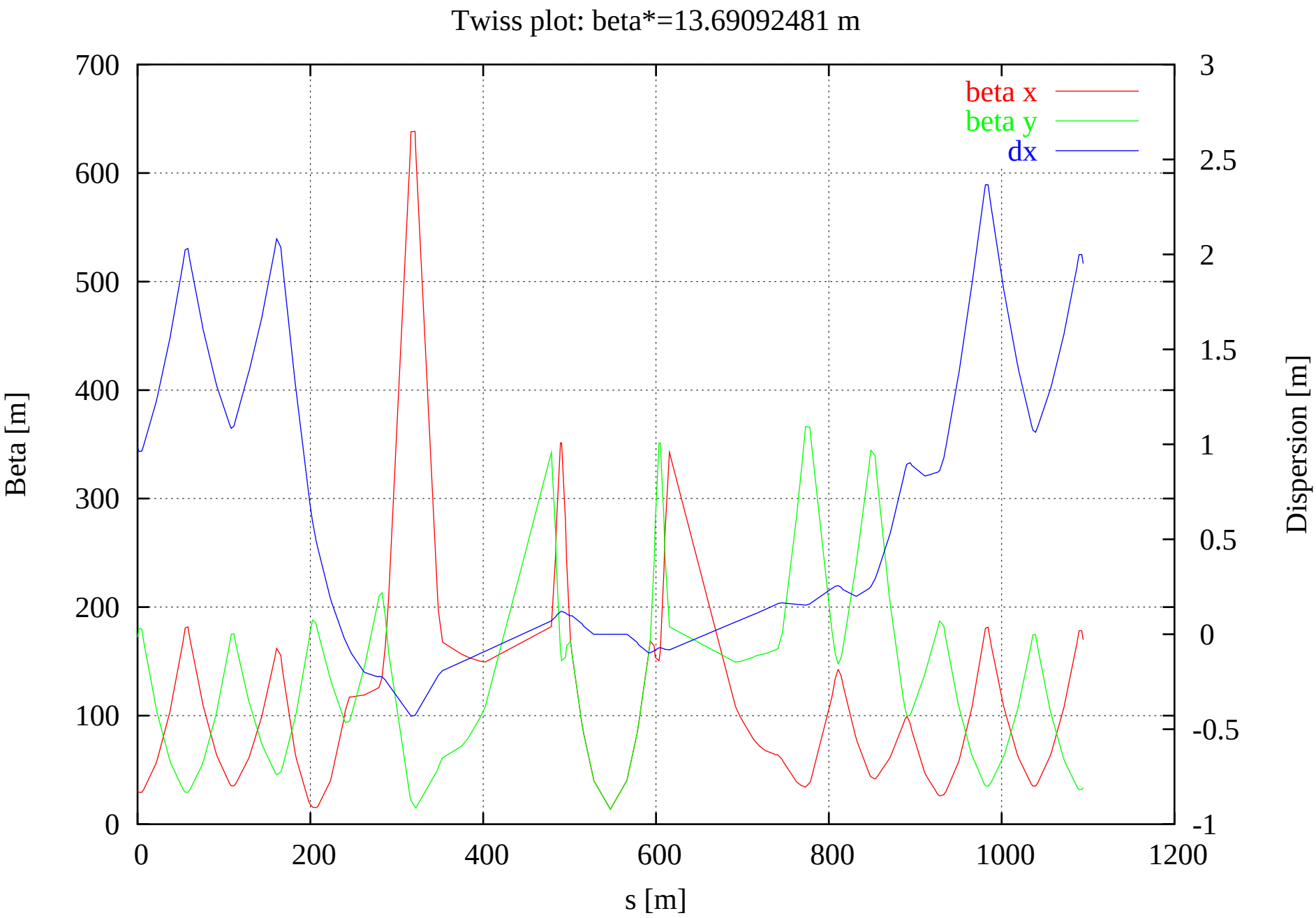

Twiss plot: beta*=8.500987147 m
beta x
beta y
dx
Beta [m]
Dispersion [m]
s [m]
0
100
200
300
400
500
600
700
800
-1
-0.5
0
0.5
1
1.5
2
2.5
3
0
200
400
600
800
1000
1200

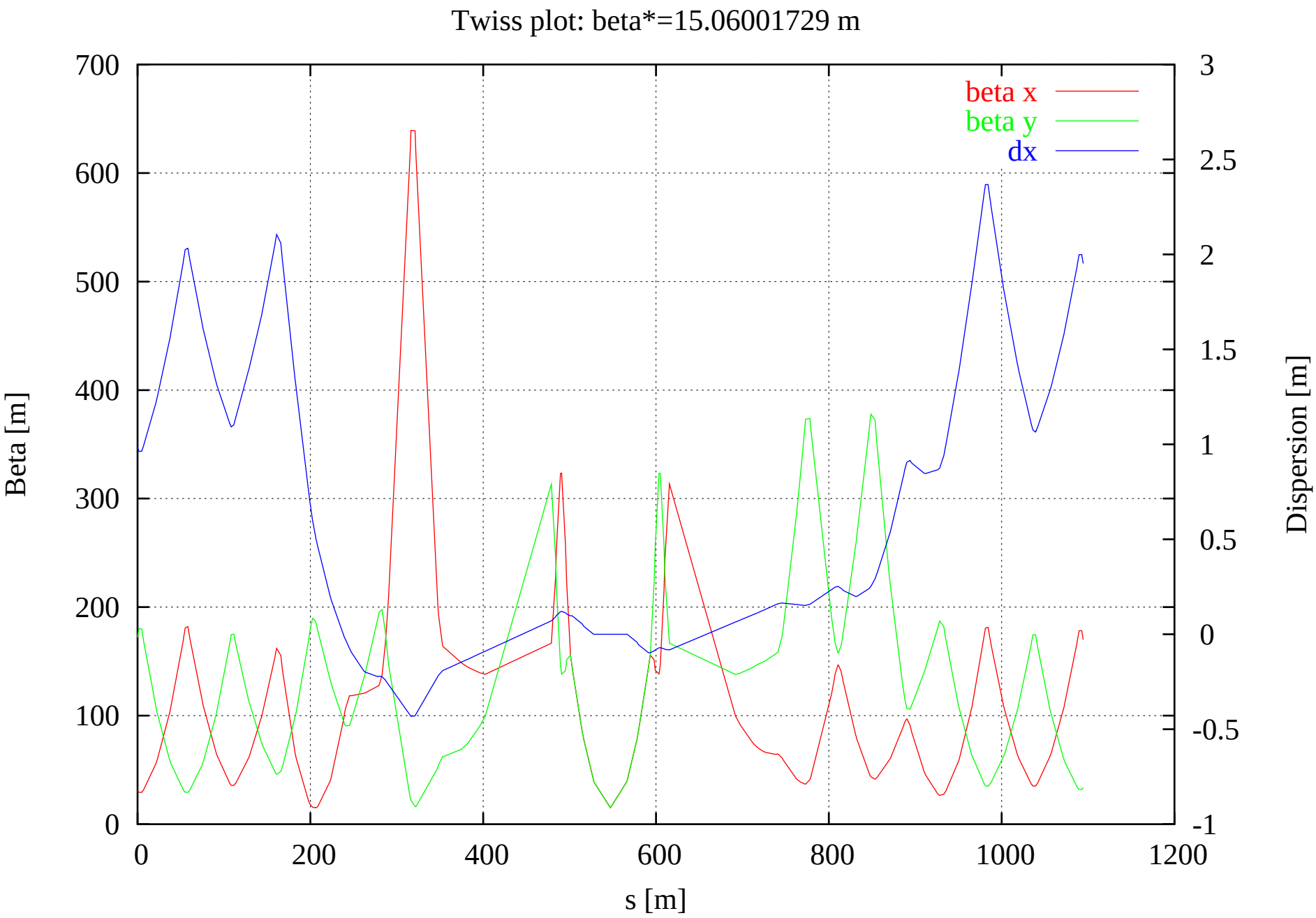

Twiss plot: beta*=9.351085861 m
beta x
beta y
dx
Beta [m]
Dispersion [m]
s [m]
0
100
200
300
400
500
600
700
800
-1
-0.5
0
0.5
1
1.5
2
2.5
3
0
200
400
600
800
1000
1200

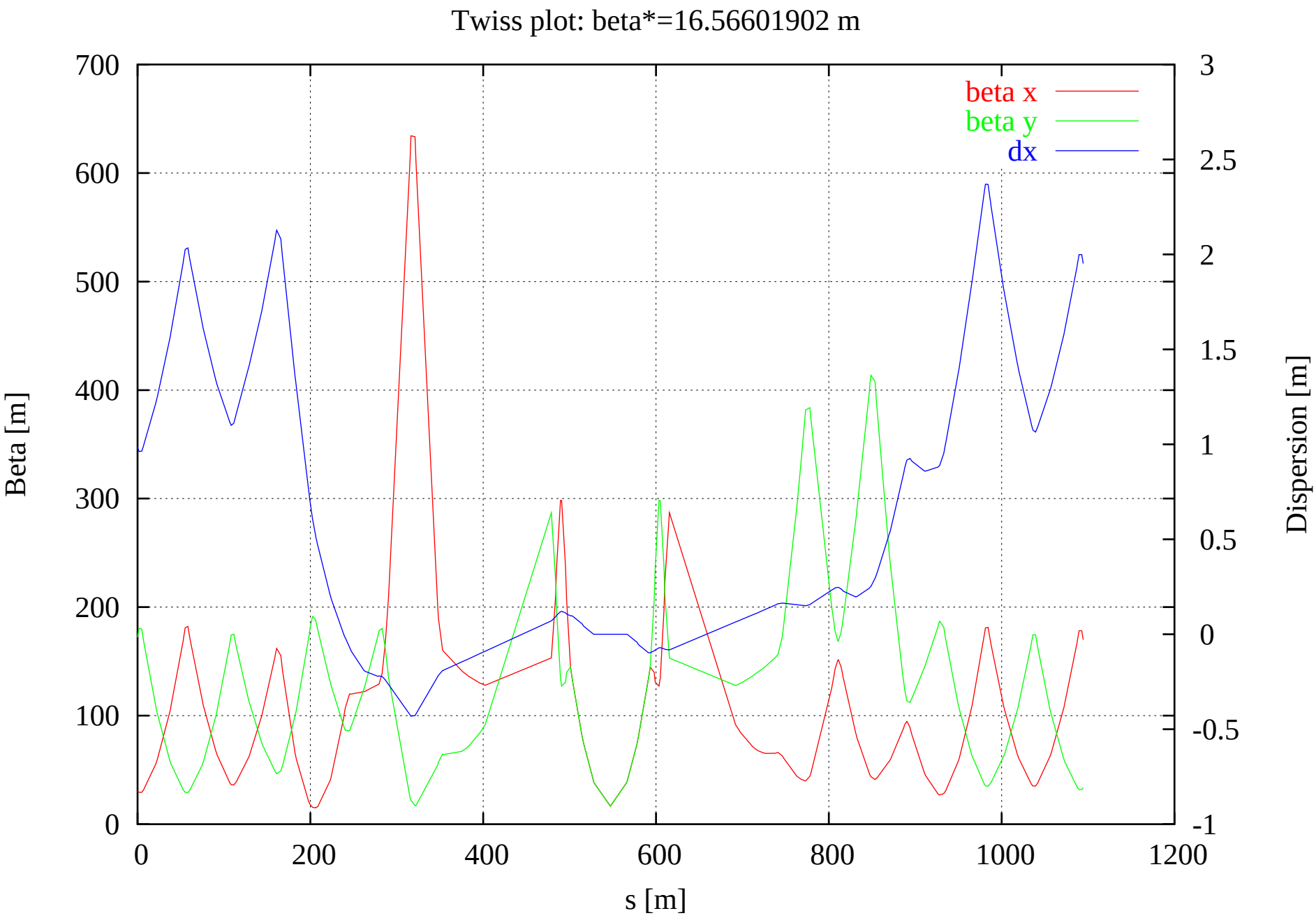

Twiss plot: beta*=10.28619445 m
beta x
beta y
dx
Beta [m]
Dispersion [m]
s [m]
0
100
200
300
400
500
600
700
-1
-0.5
0
0.5
1
1.5
2
2.5
3
0
200
400
600
800
1000
1200

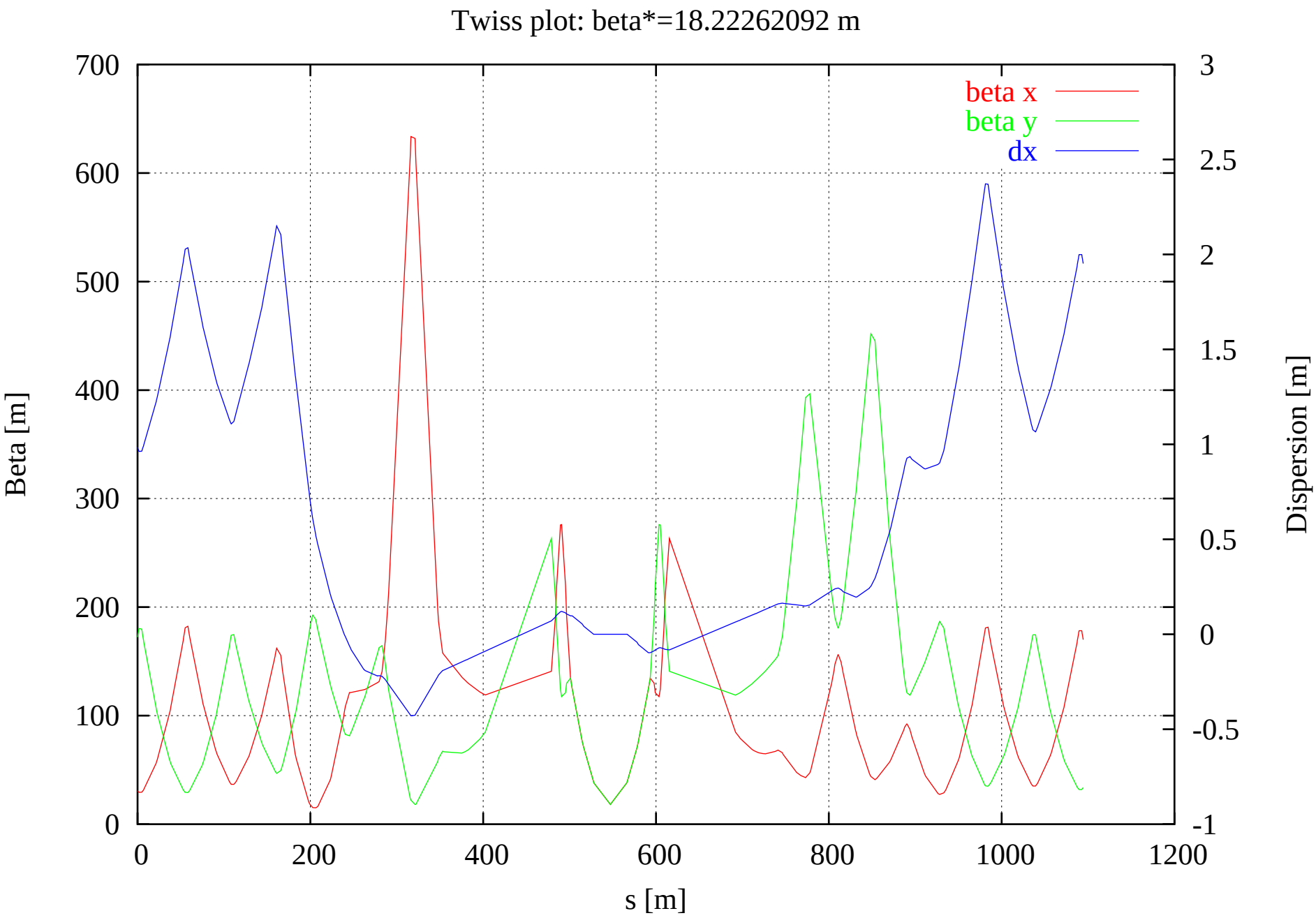

Twiss plot: beta*=11.31481389 m
beta x
beta y
dx
Beta [m]
Dispersion [m]
s [m]
0
100
200
300
400
500
600
700
-1
-0.5
0
0.5
1
1.5
2
2.5
3
0
200
400
600
800
1000
1200

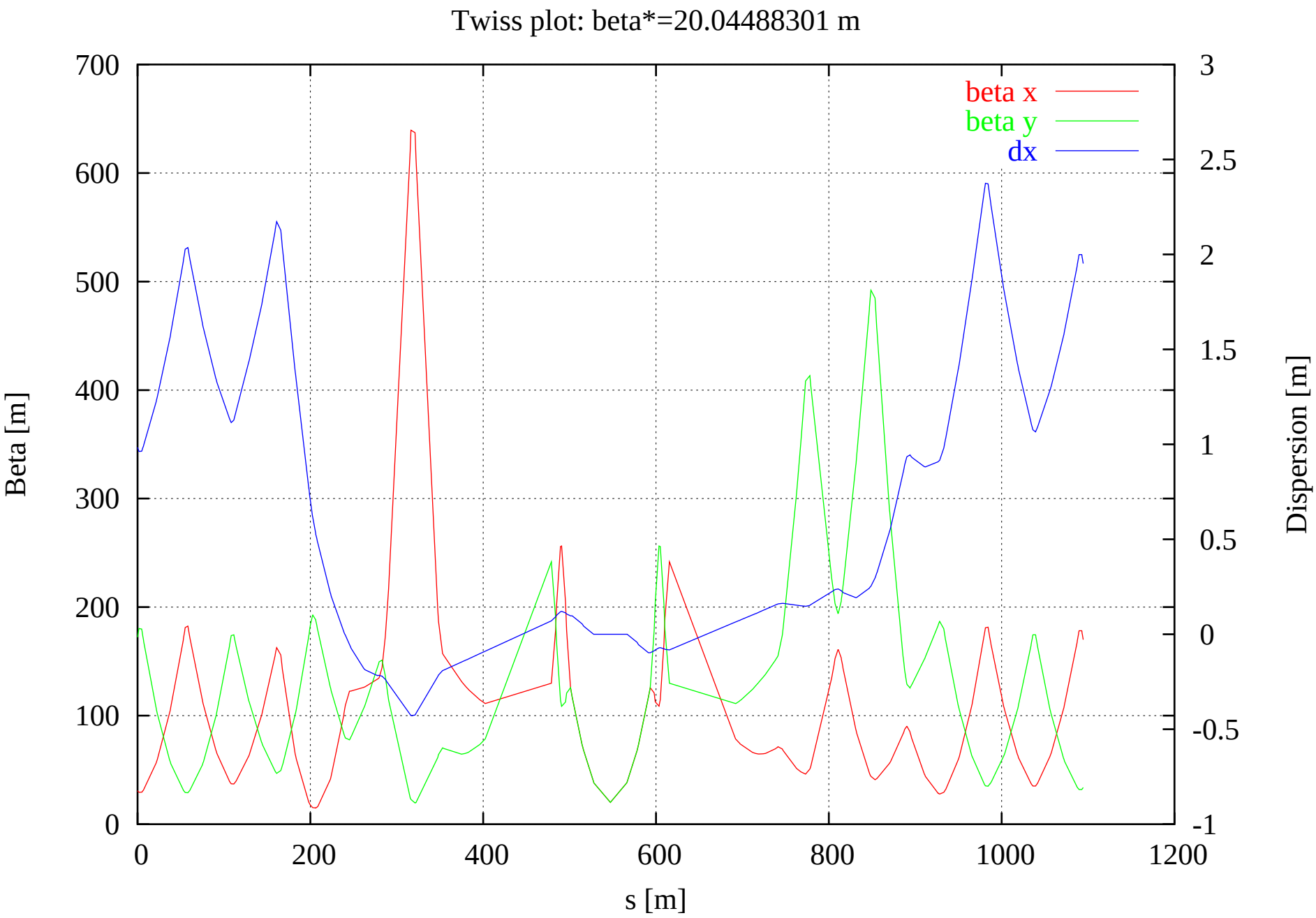

Twiss plot: beta*=12.44629528 m
beta x
beta y
dx
Beta [m]
Dispersion [m]
s [m]
0
100
200
300
400
500
600
700
-1
-0.5
0
0.5
1
1.5
2
2.5
3
0
200
400
600
800
1000
1200

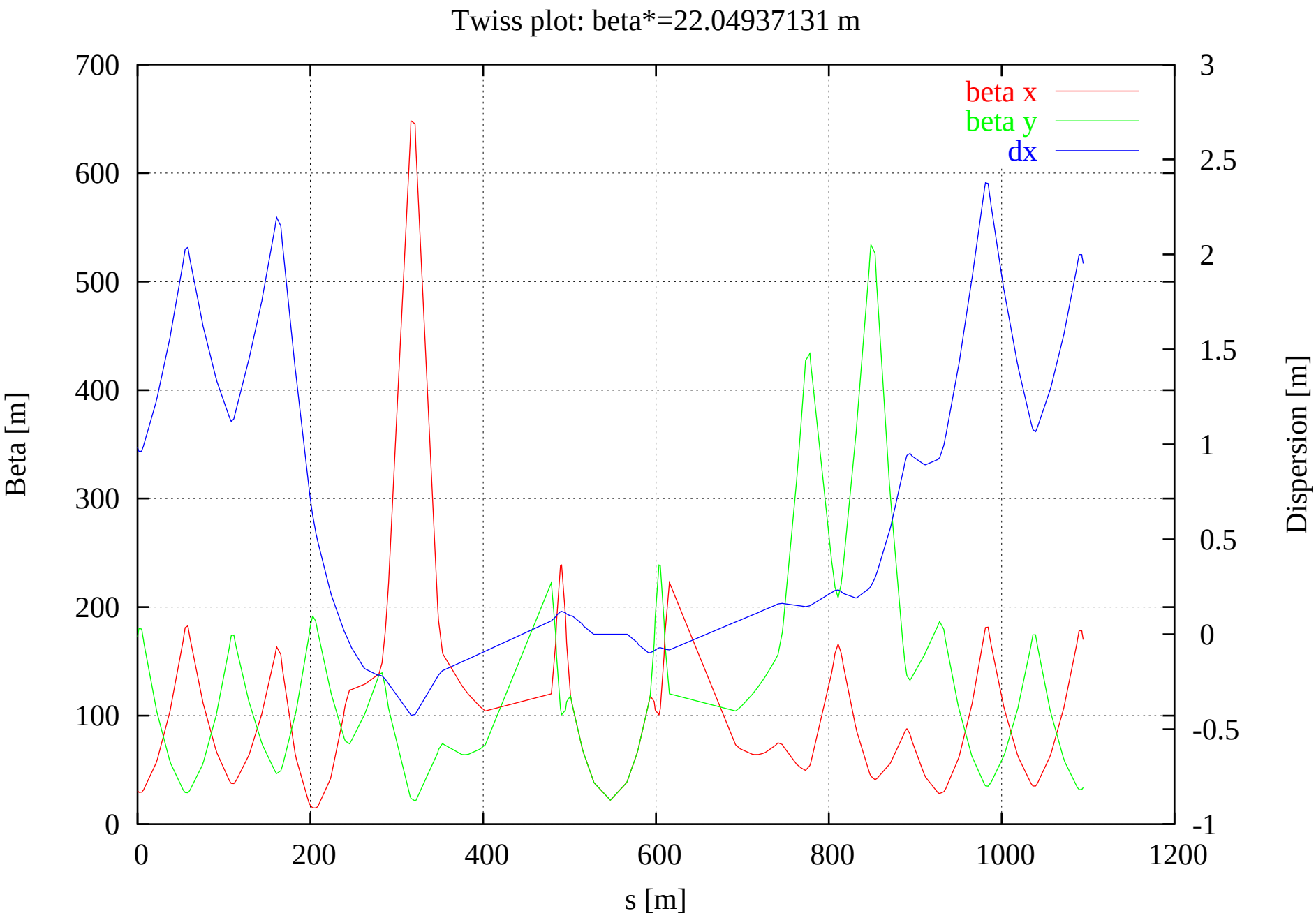

Twiss plot: beta*=13.69092481 m
beta x
beta y
dx
Beta [m]
Dispersion [m]
s [m]
0
100
200
300
400
500
600
700
-1
-0.5
0
0.5
1
1.5
2
2.5
3
0
200
400
600
800
1000
1200

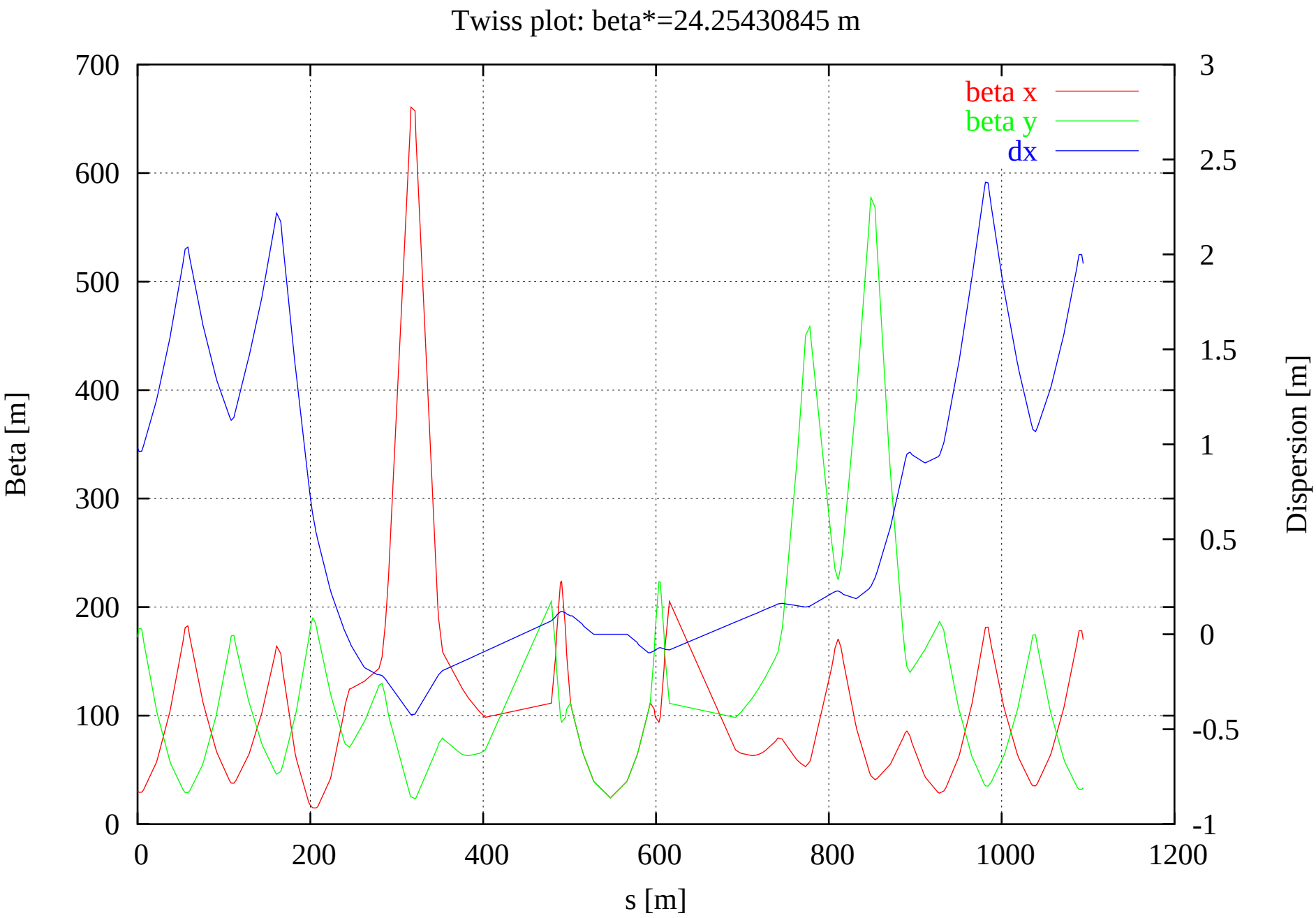

Twiss plot: beta*=15.06001729 m
beta x
beta y
dx
Beta [m]
Dispersion [m]
s [m]
0
100
200
300
400
500
600
700
-1
-0.5
0
0.5
1
1.5
2
2.5
3
0
200
400
600
800
1000
1200

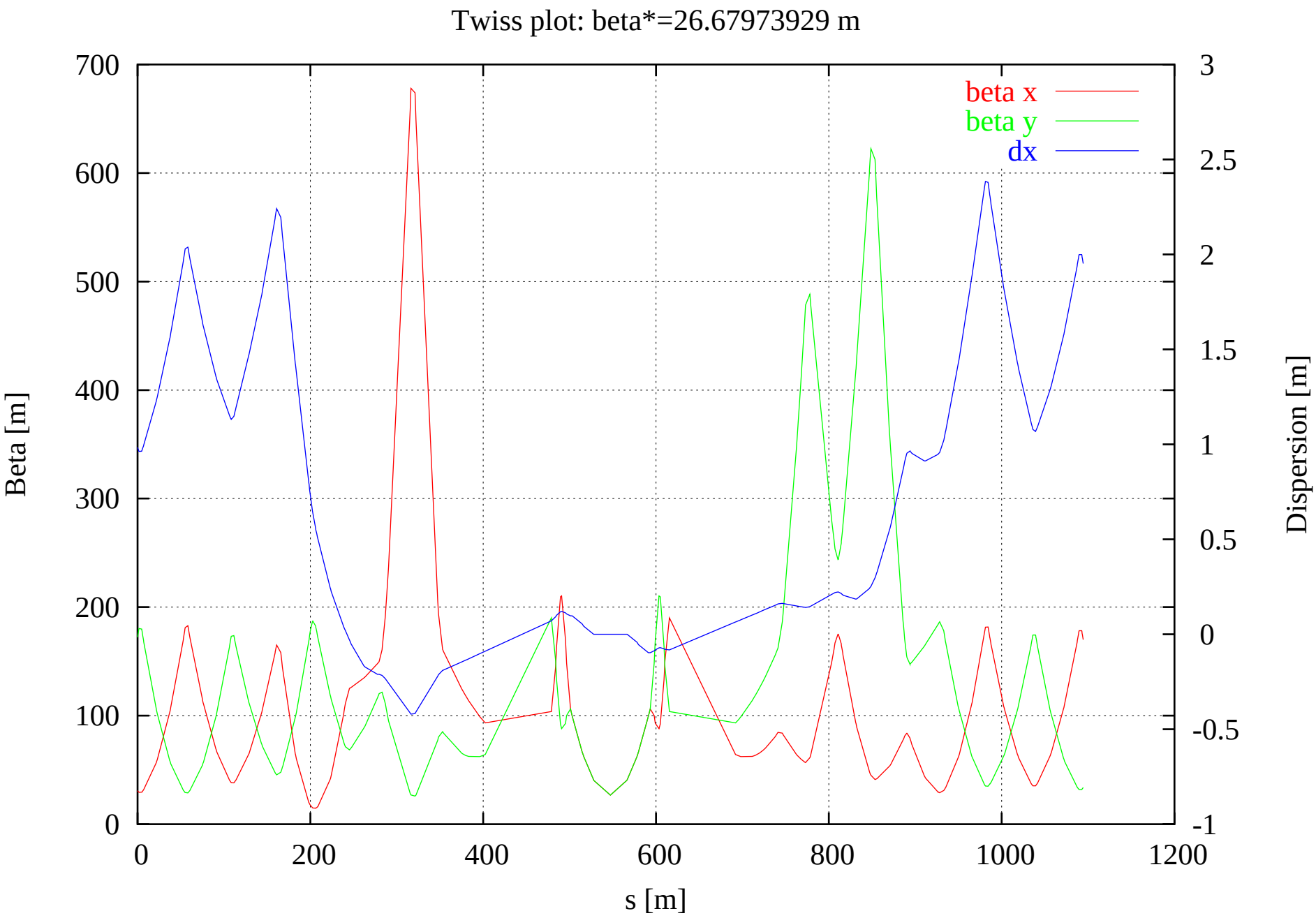

Twiss plot: beta*=16.56601902 m
beta x
beta y
dx
Beta [m]
Dispersion [m]
s [m]
0
100
200
300
400
500
600
700
-1
-0.5
0
0.5
1
1.5
2
2.5
3
0
200
400
600
800
1000
1200

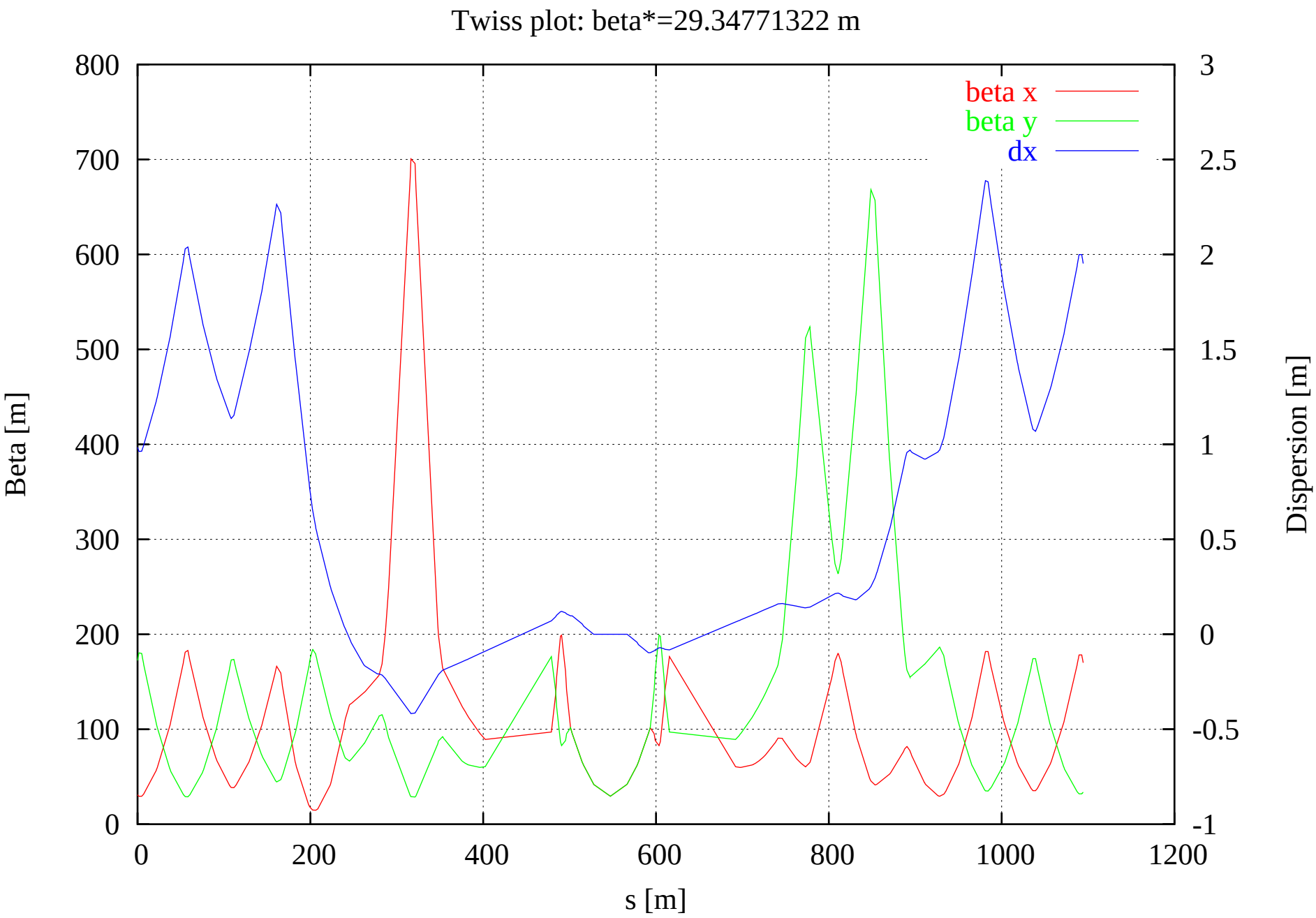

Twiss plot: beta*=18.22262092 m
beta x
beta y
dx
Beta [m]
Dispersion [m]
s [m]
0
100
200
300
400
500
600
700
-1
-0.5
0
0.5
1
1.5
2
2.5
3
0
200
400
600
800
1000
1200

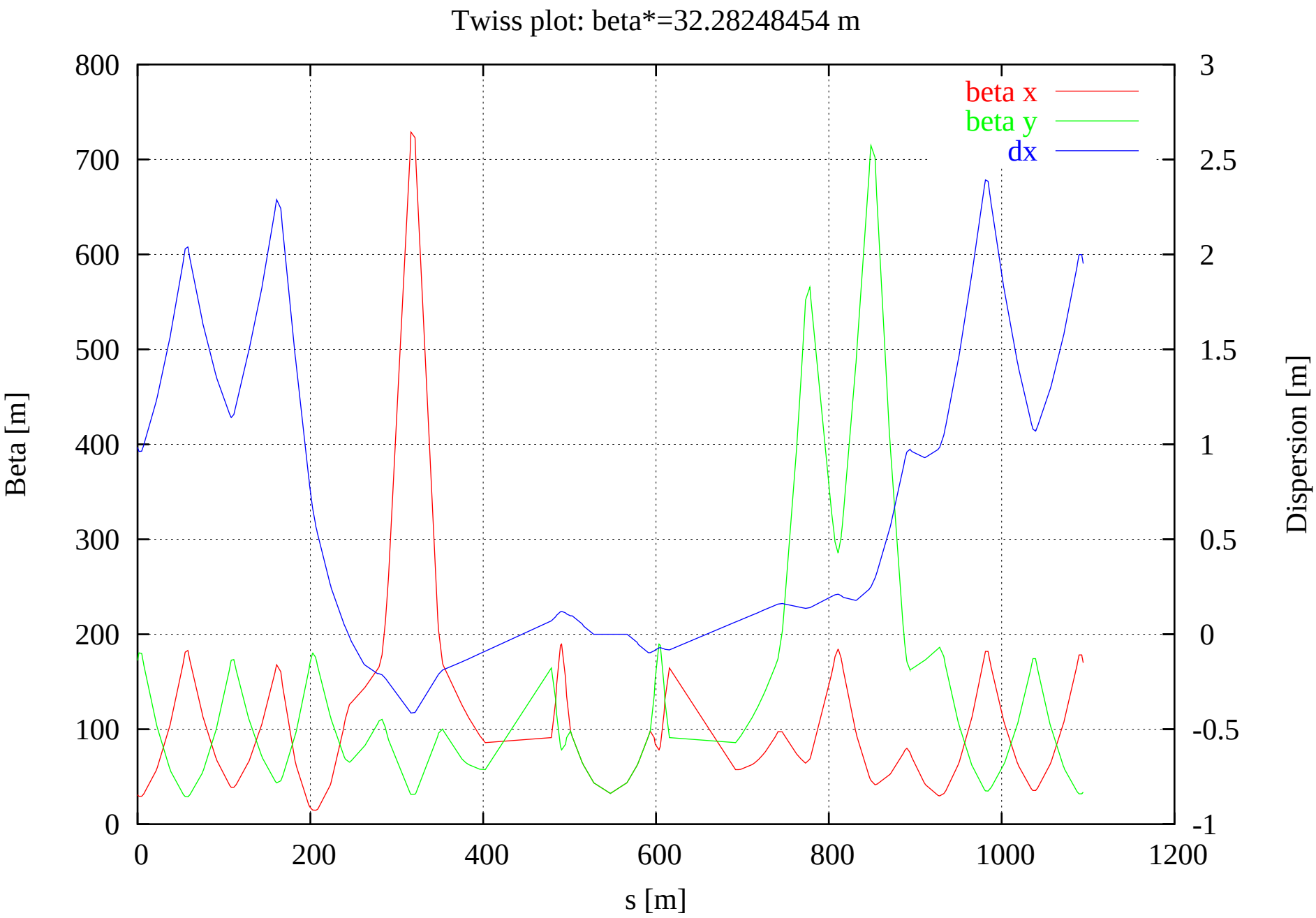

Twiss plot: beta*=20.04488301 m
beta x
beta y
dx
Beta [m]
Dispersion [m]
s [m]
0
100
200
300
400
500
600
700
-1
-0.5
0
0.5
1
1.5
2
2.5
3
0
200
400
600
800
1000
1200

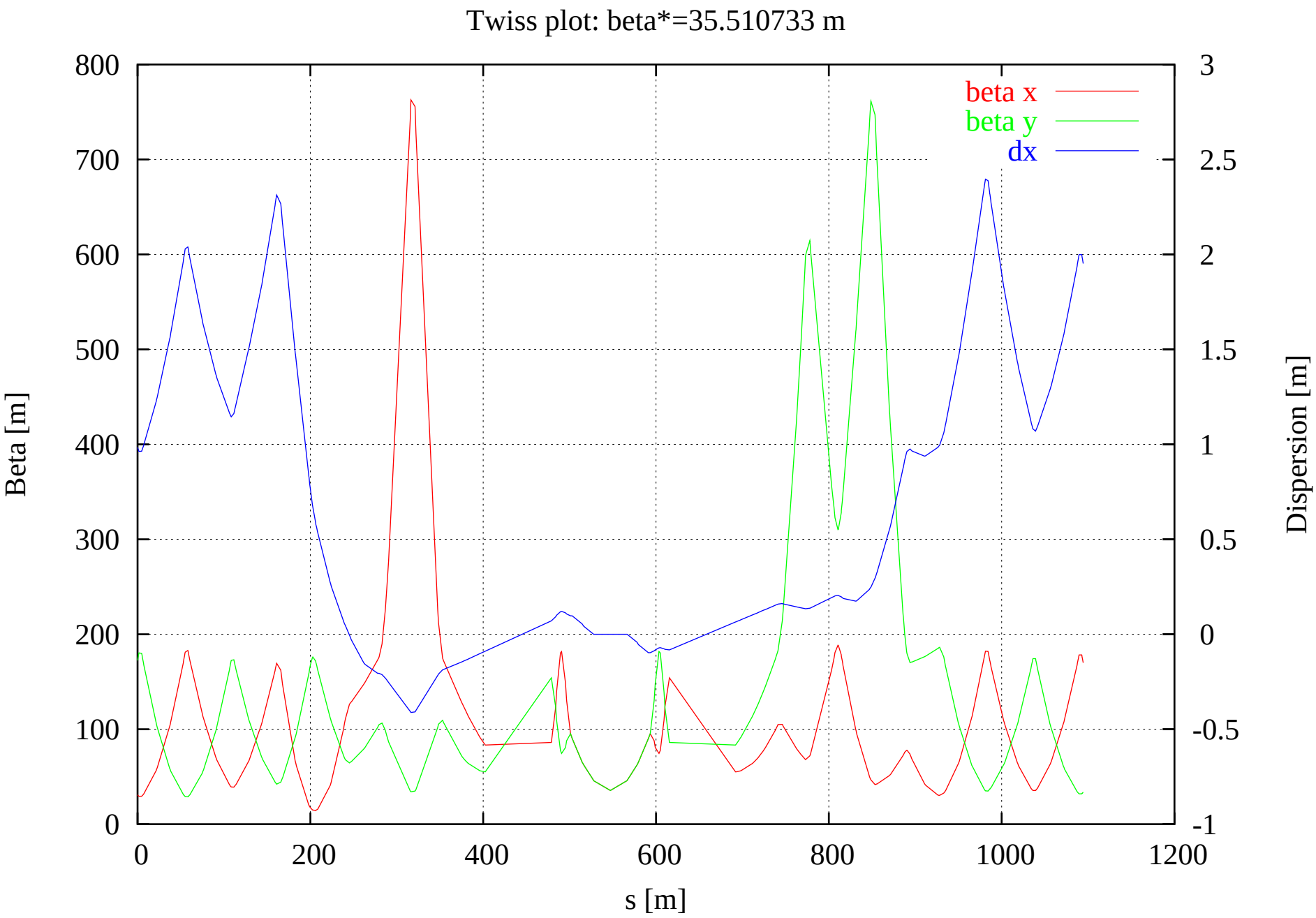

Twiss plot: beta*=22.04937131 m
beta x
beta y
dx
Beta [m]
Dispersion [m]
s [m]
0
100
200
300
400
500
600
700
-1
-0.5
0
0.5
1
1.5
2
2.5
3
0
200
400
600
800
1000
1200

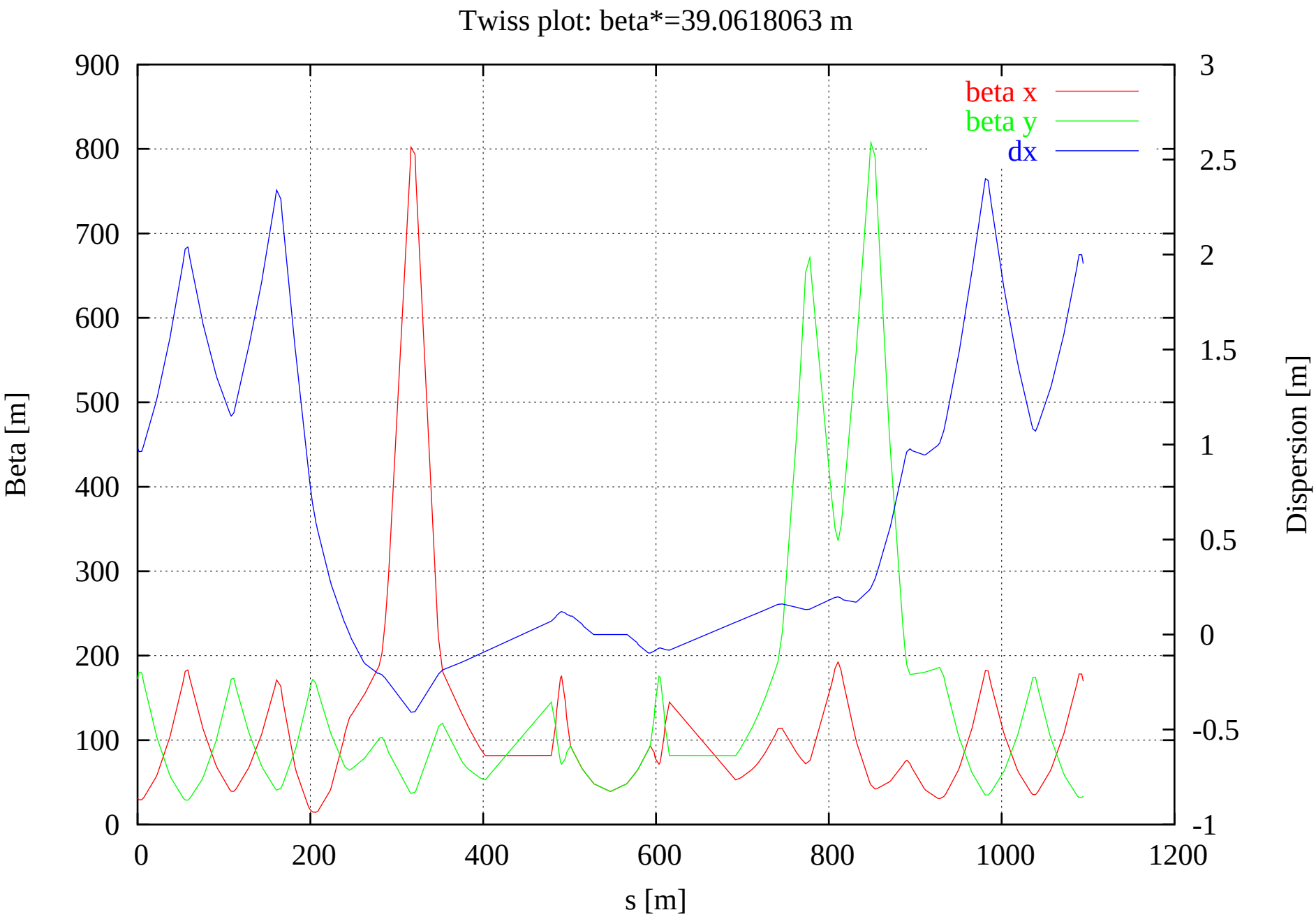

Twiss plot: beta*=24.25430845 m
beta x
beta y
dx
Beta [m]
Dispersion [m]
s [m]
0
100
200
300
400
500
600
700
-1
-0.5
0
0.5
1
1.5
2
2.5
3
0
200
400
600
800
1000
1200

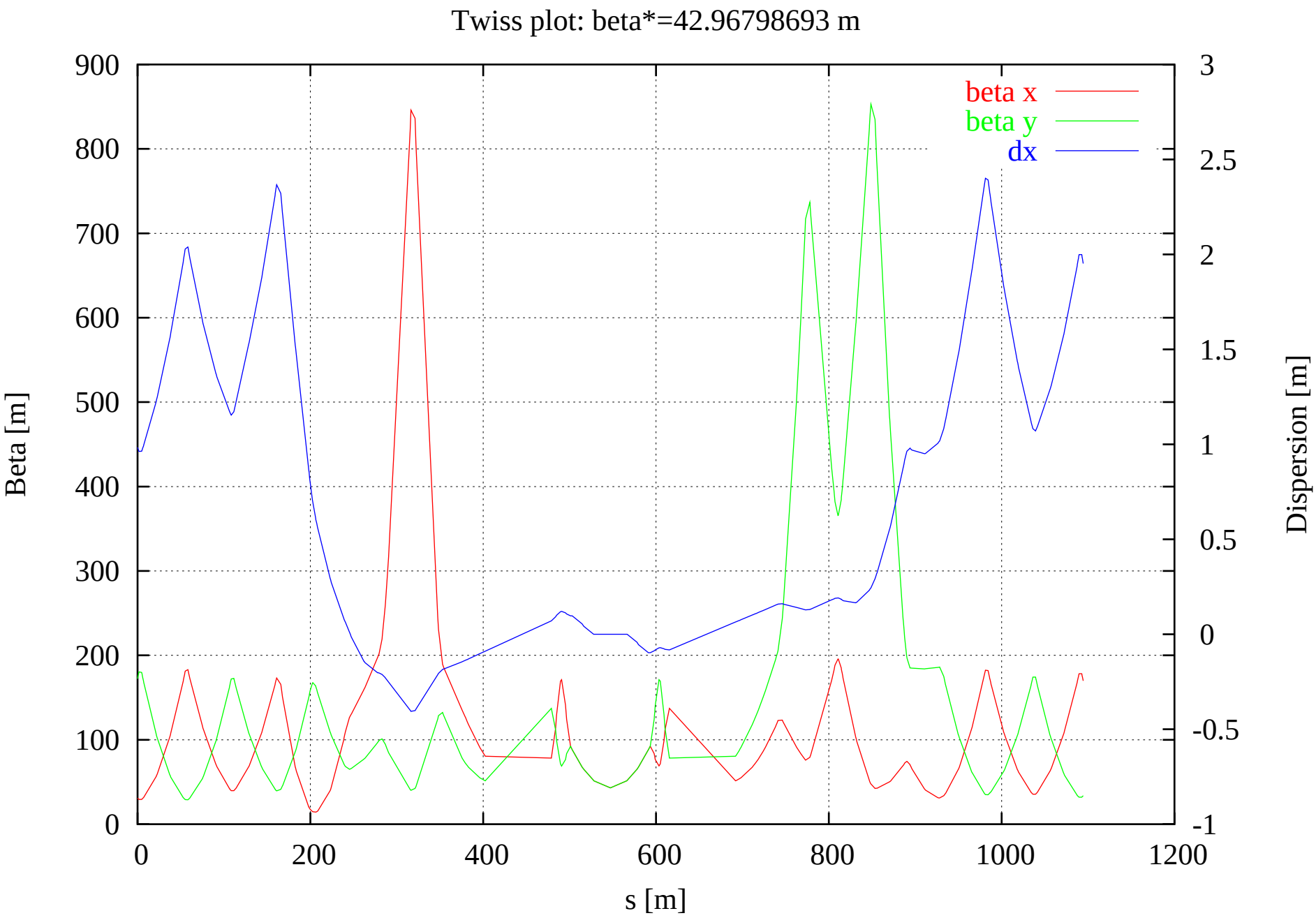

Twiss plot: beta*=26.67973929 m
beta x
beta y
dx
Beta [m]
Dispersion [m]
s [m]
0
100
200
300
400
500
600
700
-1
-0.5
0
0.5
1
1.5
2
2.5
3
0
200
400
600
800
1000
1200

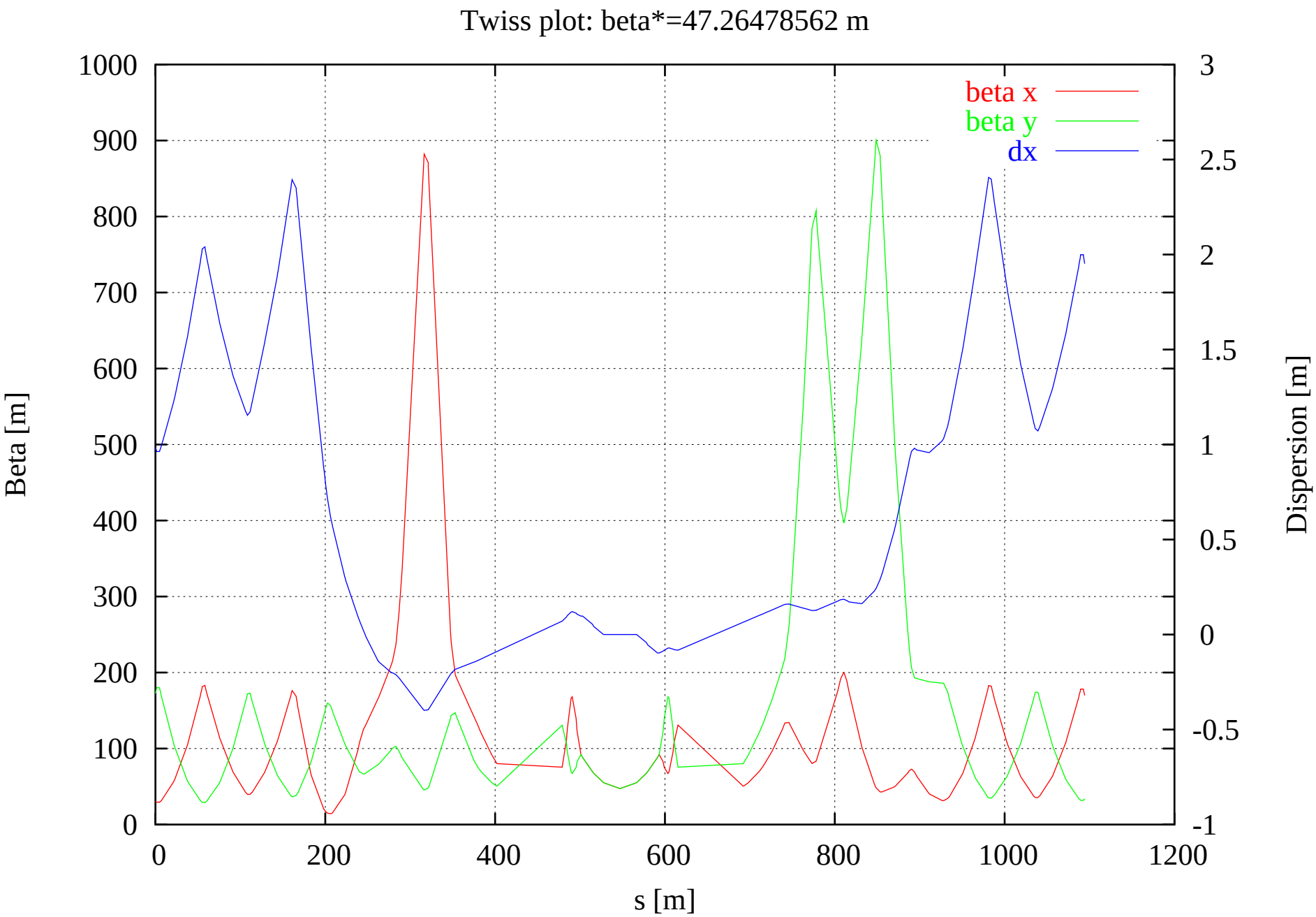

Twiss plot: beta*=29.34771322 m
beta x
beta y
dx
Beta [m]
Dispersion [m]
s [m]
0
100
200
300
400
500
600
700
800
-1
-0.5
0
0.5
1
1.5
2
2.5
3
0
200
400
600
800
1000
1200

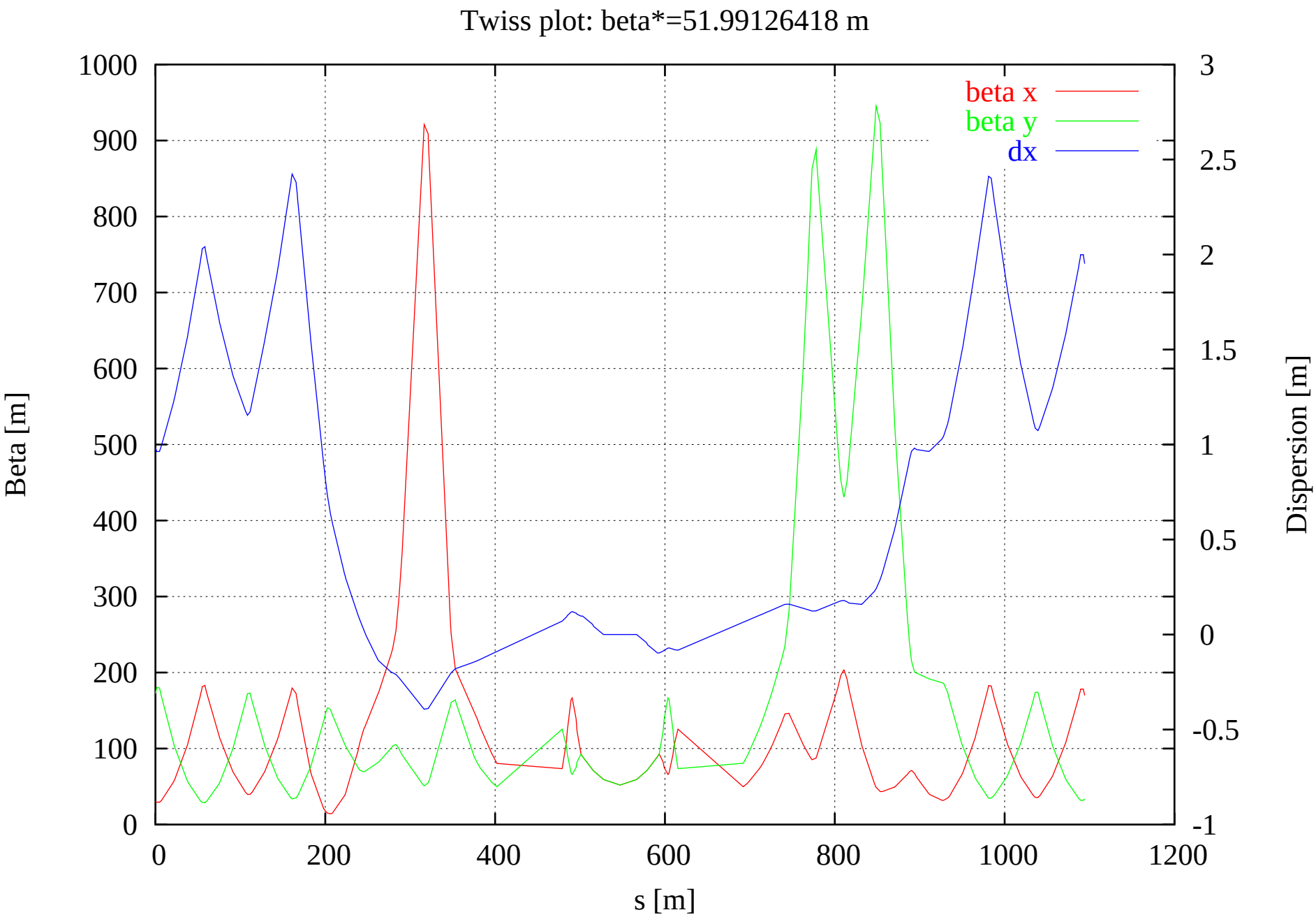

Twiss plot: beta*=32.28248454 m
beta x
beta y
dx
Beta [m]
Dispersion [m]
s [m]
800
700
600
500
400
300
200
100
0
3
2.5
2
1.5
1
0.5
0
-0.5
-1
0
200
400
600
800
1000
1200

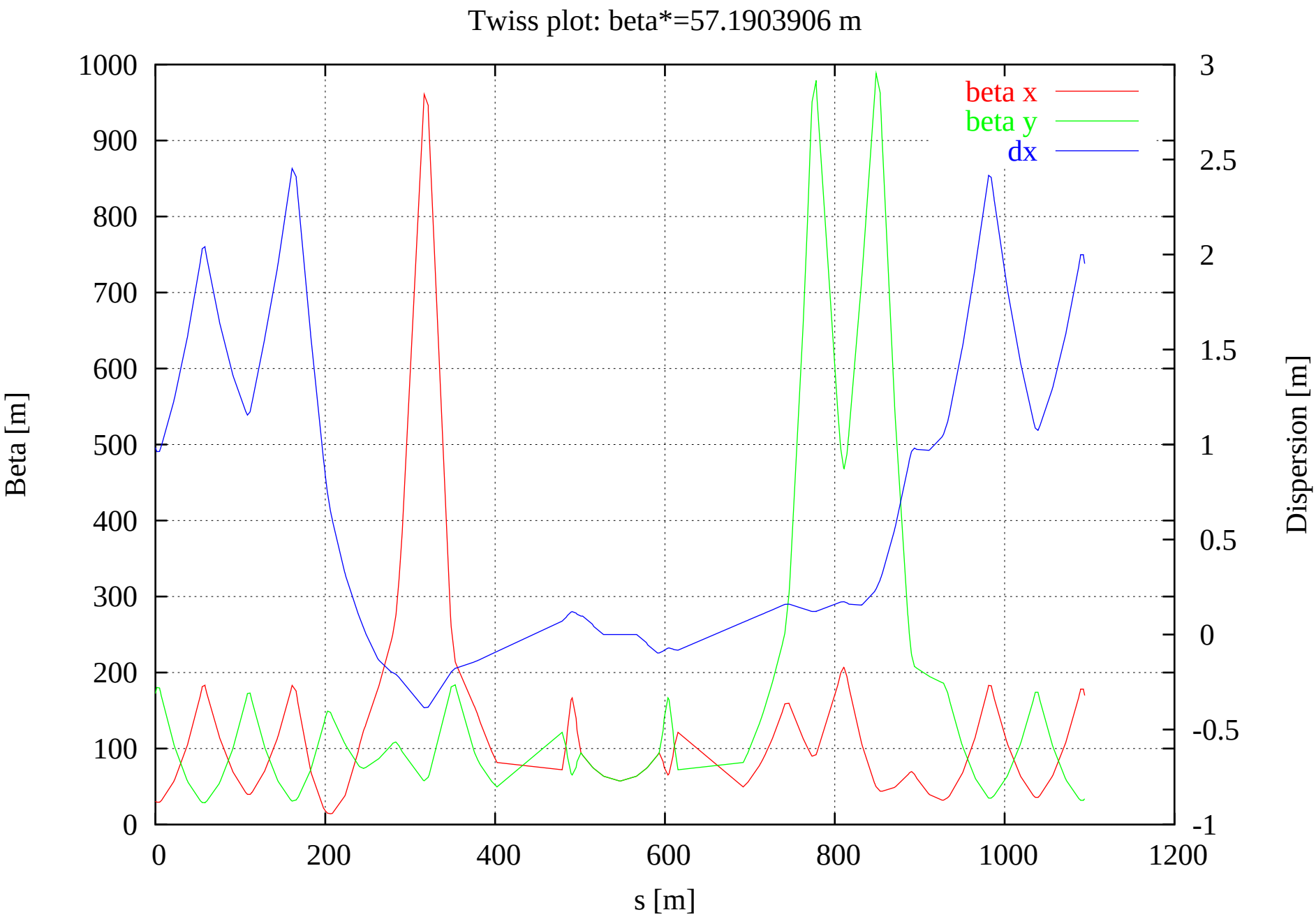

Twiss plot: beta*=35.510733 m
beta x
beta y
dx
Beta [m]
Dispersion [m]
s [m]
0
100
200
300
400
500
600
700
800
-1
-0.5
0
0.5
1
1.5
2
2.5
3
0
200
400
600
800
1000
1200

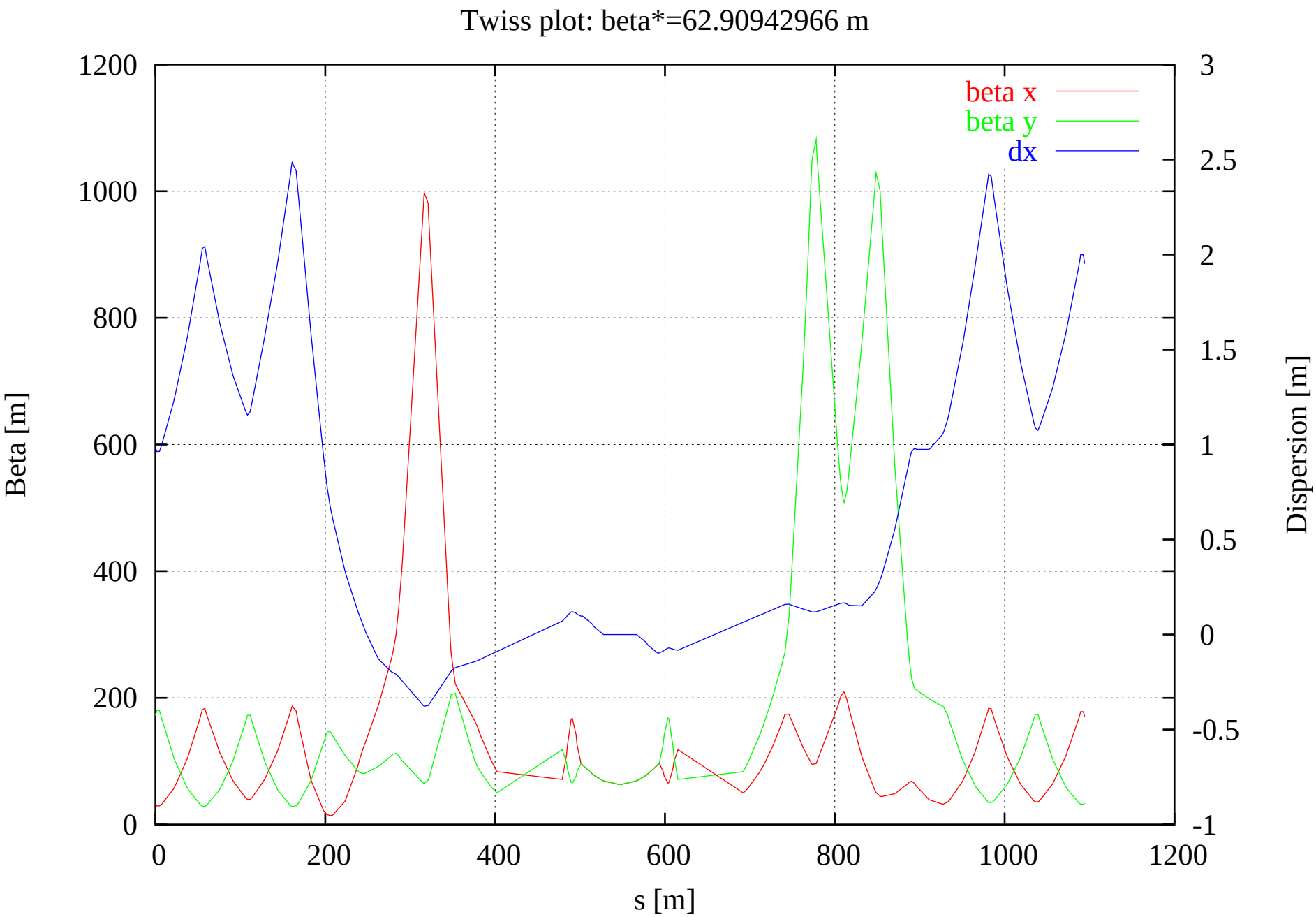

Twiss plot: beta*=39.0618063 m
beta x
beta y
dx
Beta [m]
Dispersion [m]
s [m]
0
100
200
300
400
500
600
700
800
900
-1
-0.5
0
0.5
1
1.5
2
2.5
3
0
200
400
600
800
1000
1200

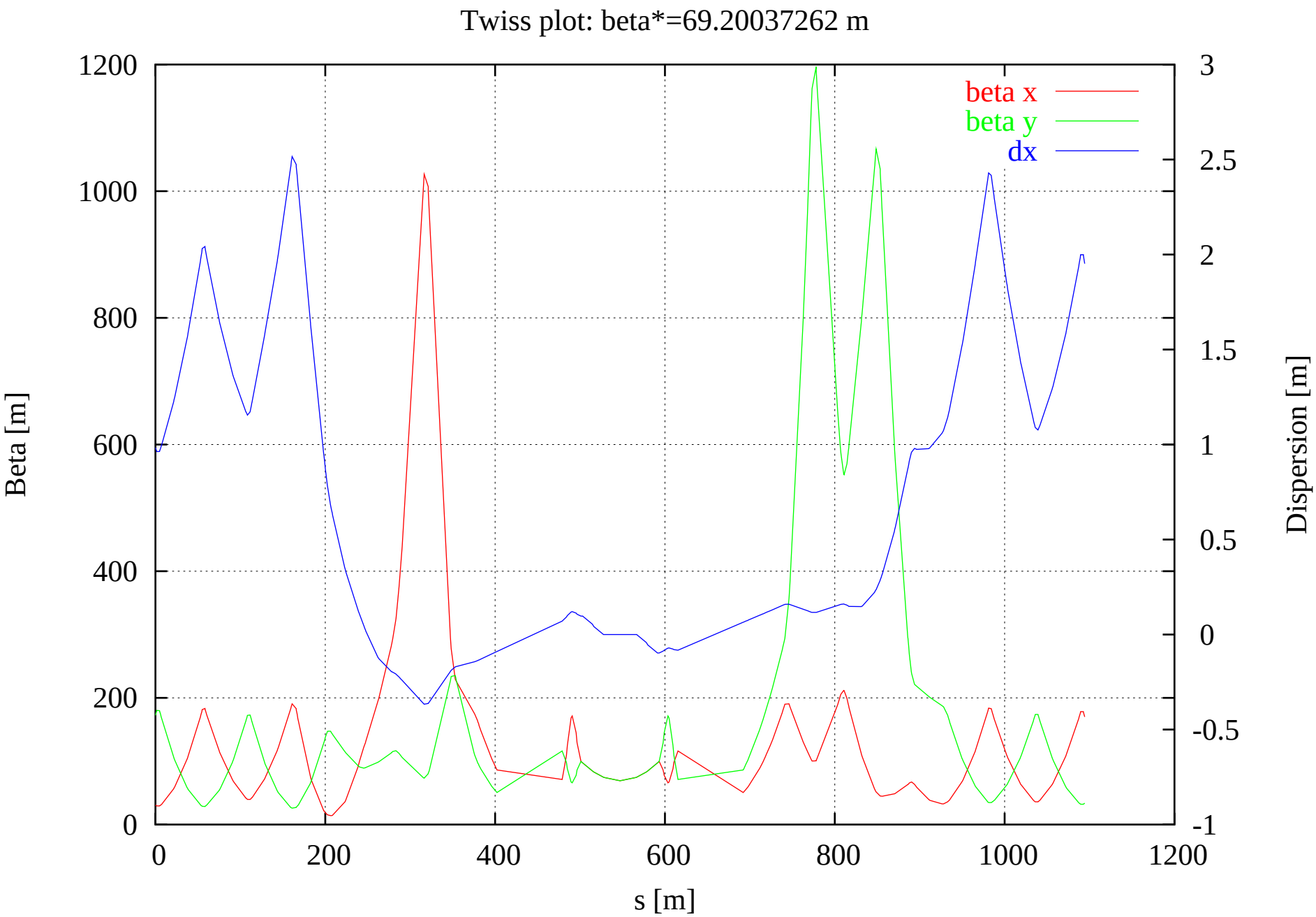

Twiss plot: beta*=42.96798693 m
beta x
beta y
dx
Beta [m]
Dispersion [m]
s [m]
0
100
200
300
400
500
600
700
800
900
-1
-0.5
0
0.5
1
1.5
2
2.5
3
0
200
400
600
800
1000
1200

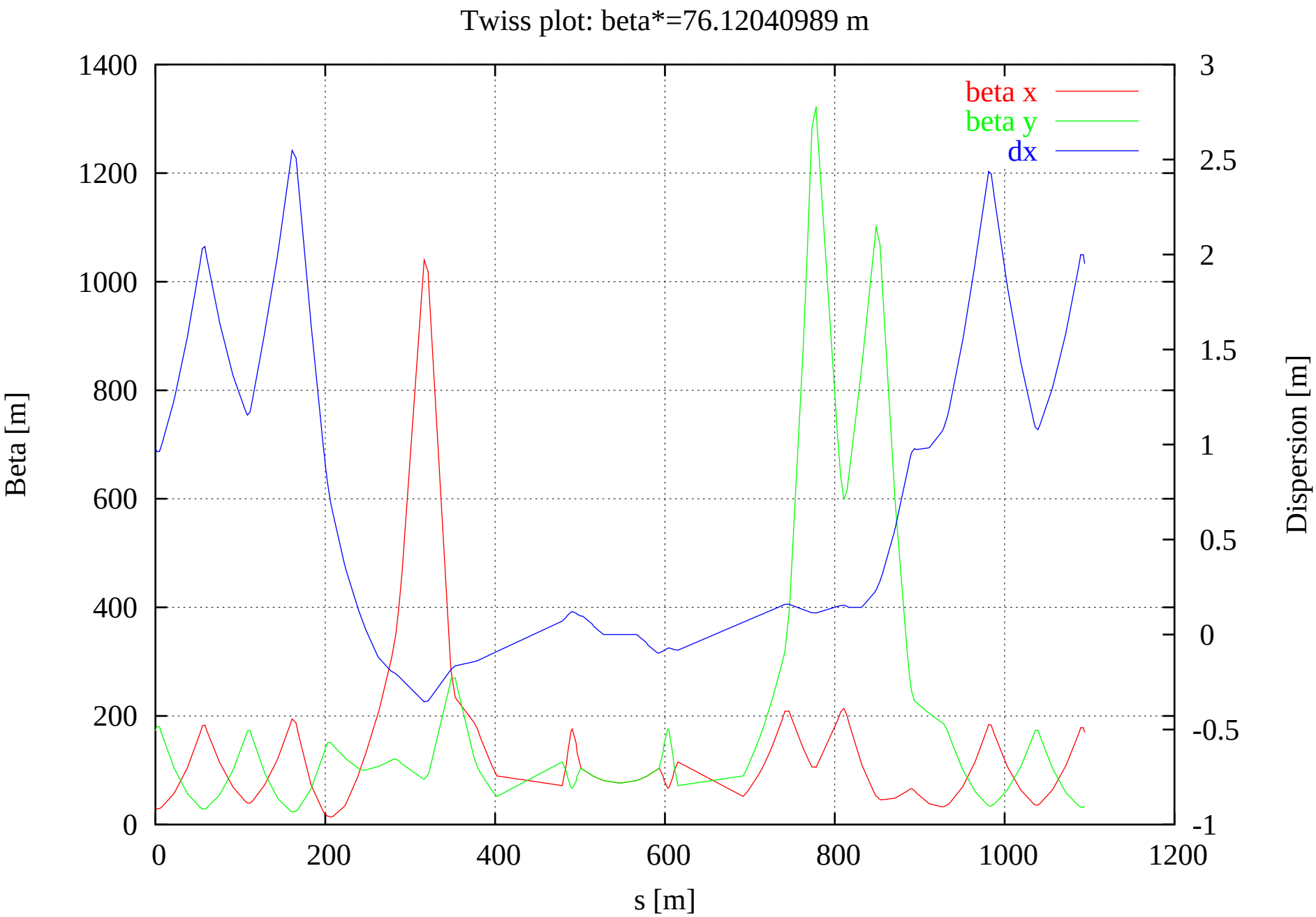

Twiss plot: beta*=47.26478562 m
beta x
beta y
dx
Beta [m]
Dispersion [m]
s [m]
0
100
200
300
400
500
600
700
800
900
1000
-1
-0.5
0
0.5
1
1.5
2
2.5
3
0
200
400
600
800
1000
1200

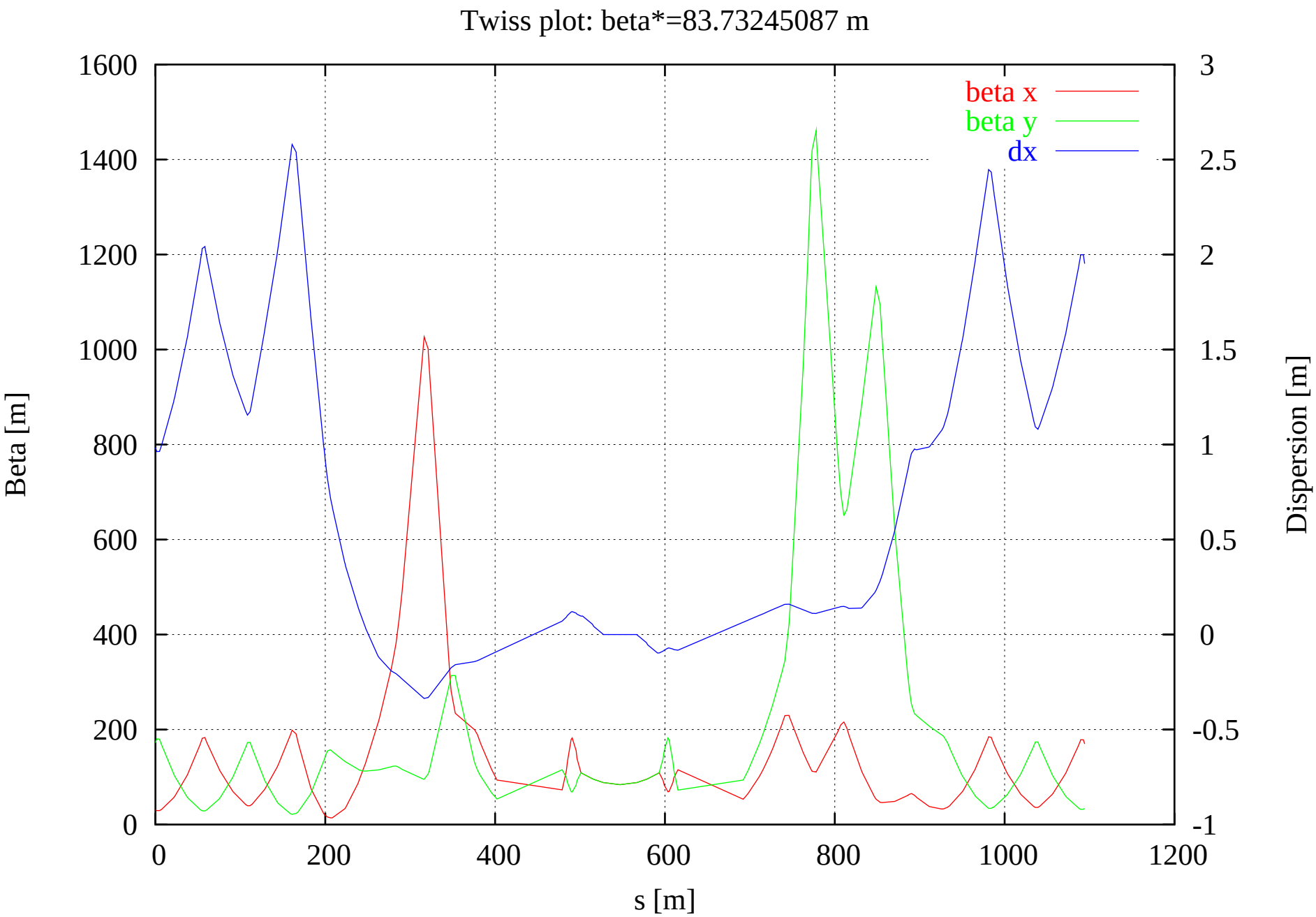

Twiss plot: beta*=51.99126418 m
beta x
beta y
dx
Beta [m]
Dispersion [m]
s [m]
0
100
200
300
400
500
600
700
800
900
1000
-1
-0.5
0
0.5
1
1.5
2
2.5
3
0
200
400
600
800
1000
1200

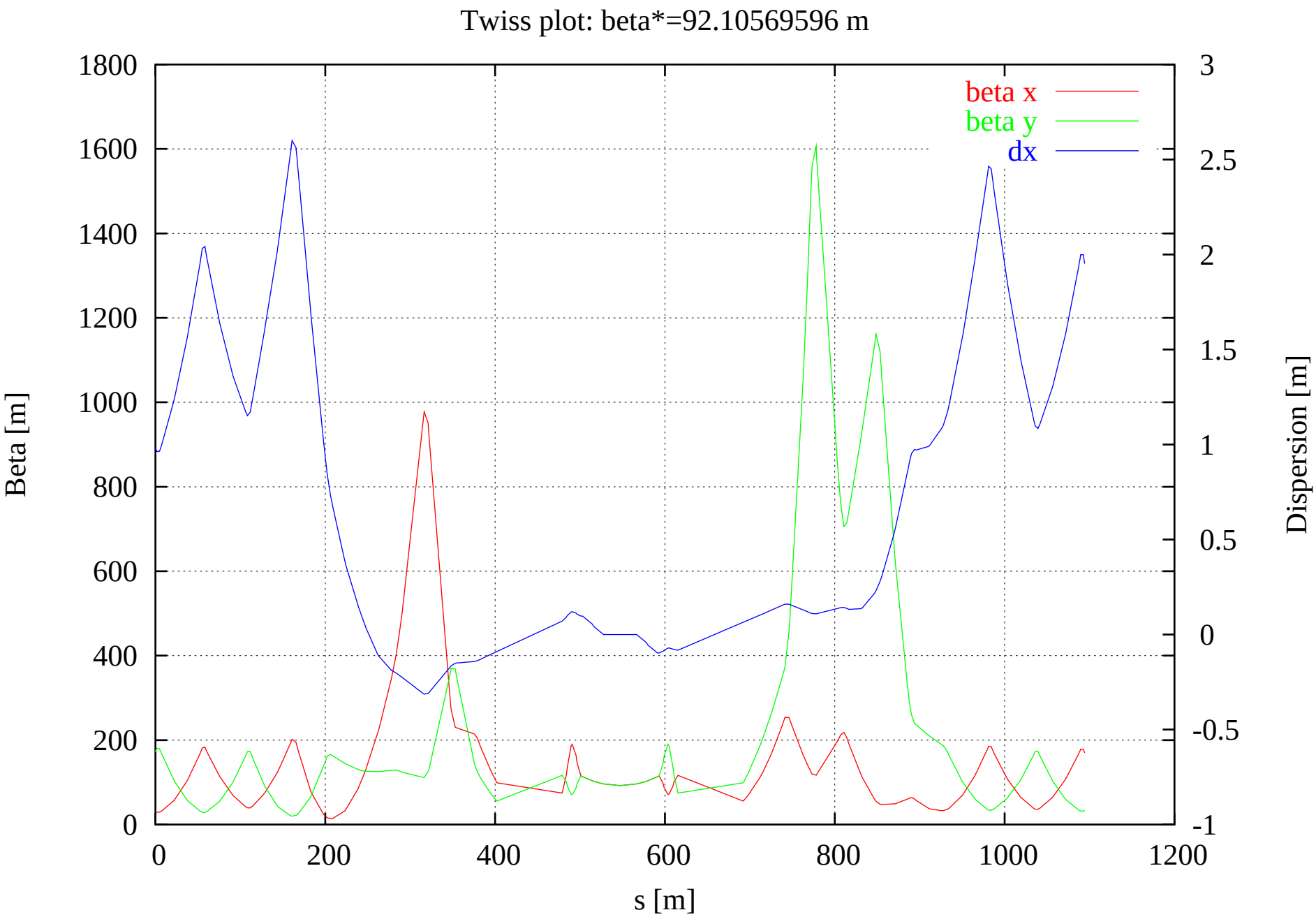

Twiss plot: beta*=57.1903906 m
beta x
beta y
dx
Beta [m]
Dispersion [m]
s [m]
0
100
200
300
400
500
600
700
800
900
1000
-1
-0.5
0
0.5
1
1.5
2
2.5
3
0
200
400
600
800
1000
1200

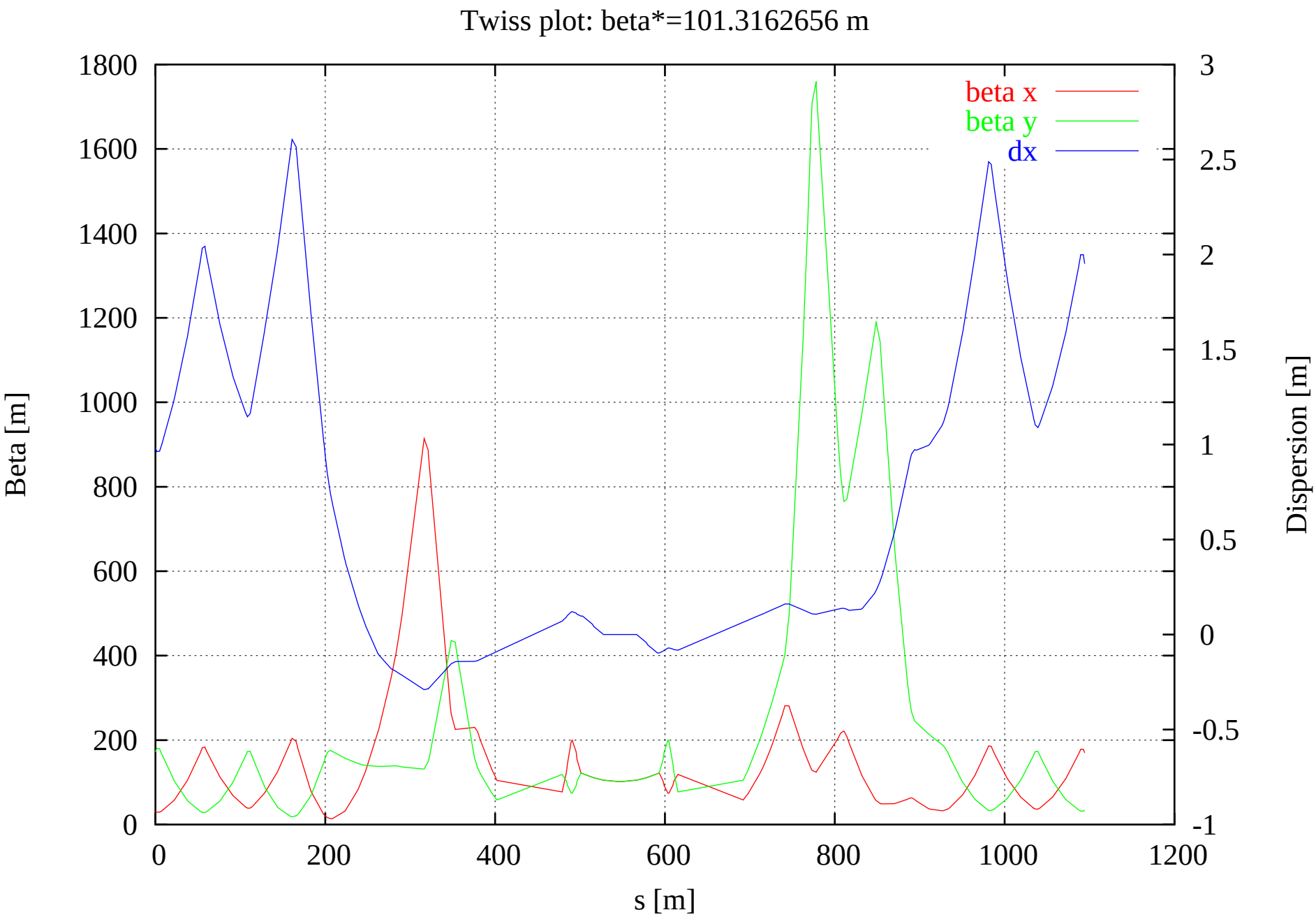

Twiss plot: beta*=62.90942966 m
beta x
beta y
dx
Beta [m]
Dispersion [m]
s [m]
0
200
400
600
800
1000
1200
-1
-0.5
0
0.5
1
1.5
2
2.5
3

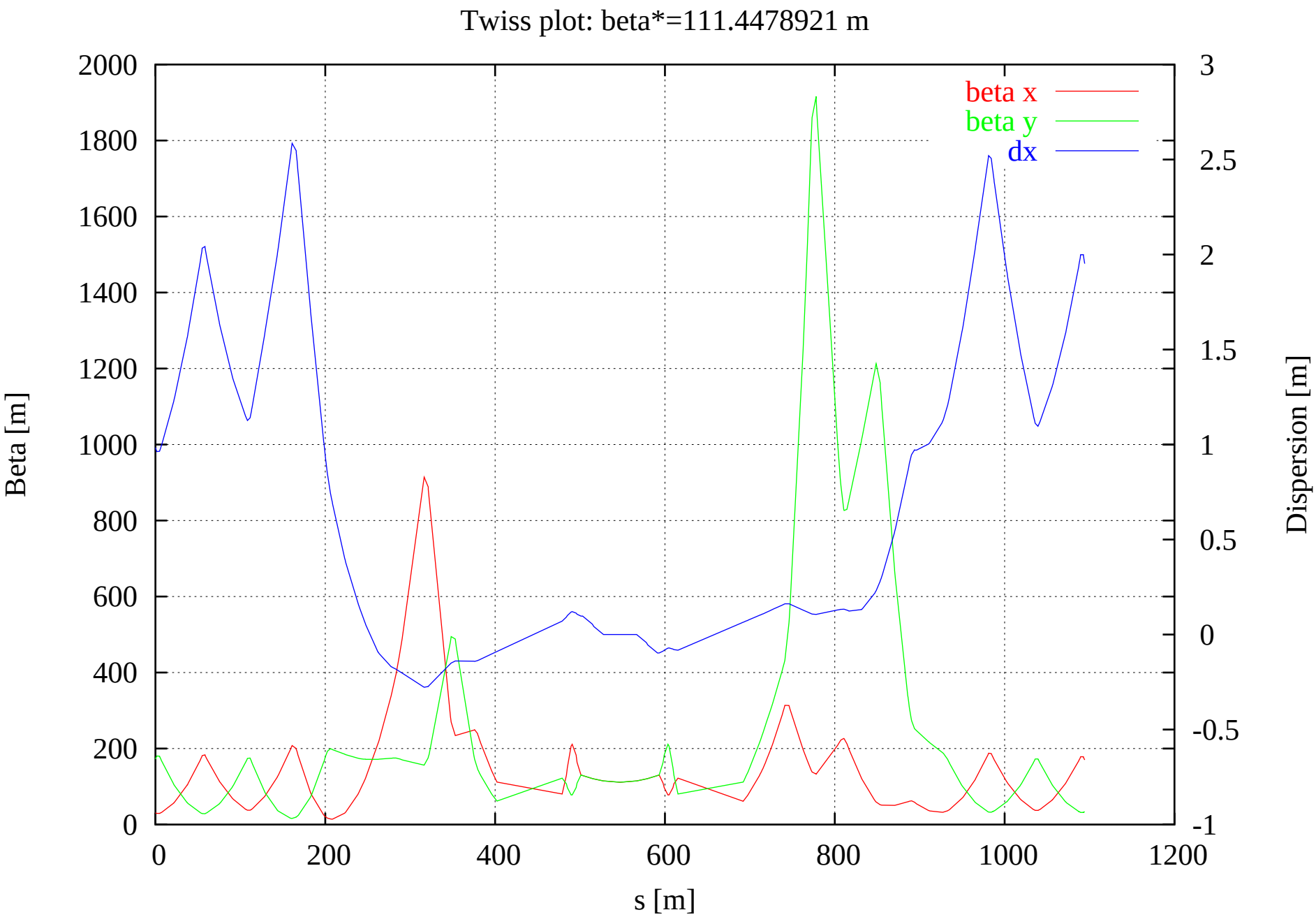

Twiss plot: beta*=69.20037262 m
beta x
beta y
dx
Beta [m]
Dispersion [m]
s [m]
0
200
400
600
800
1000
1200
-1
-0.5
0
0.5
1
1.5
2
2.5
3

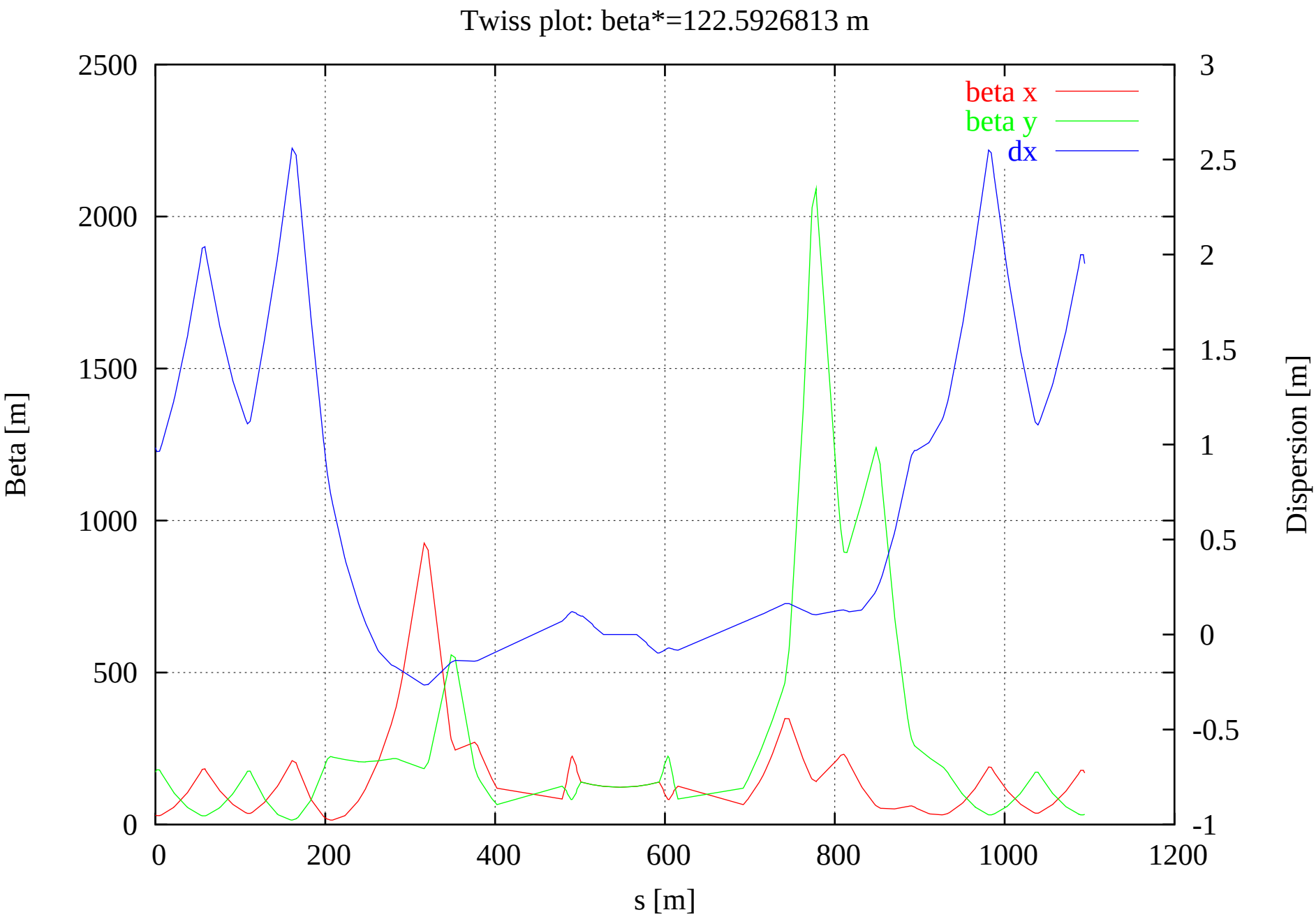

Twiss plot: beta*=76.12040989 m
beta x
beta y
dx
Beta [m]
Dispersion [m]
s [m]
0
200
400
600
800
1000
1200
1400
-1
-0.5
0
0.5
1
1.5
2
2.5
3

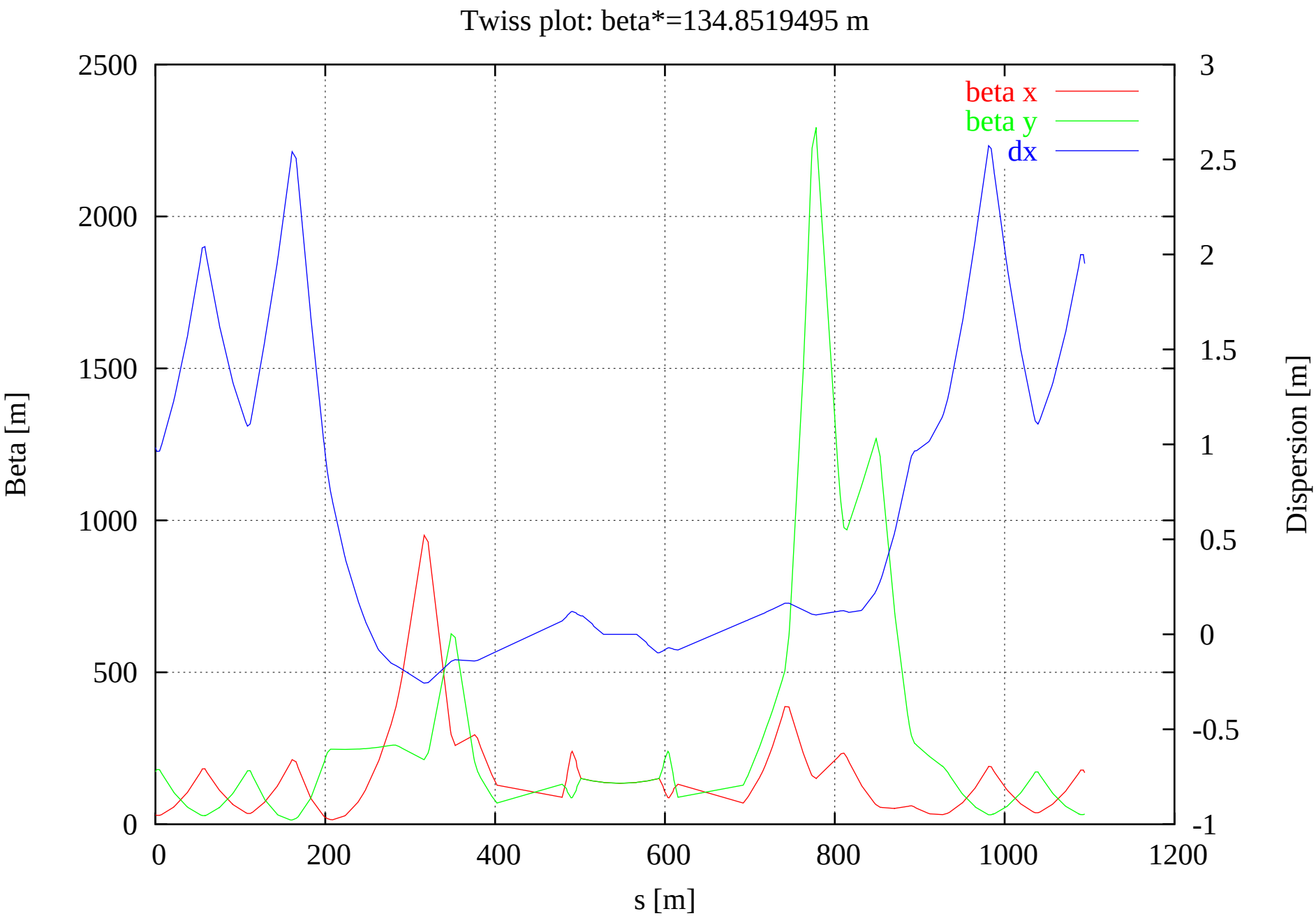

Twiss plot: beta*=83.73245087 m
beta x
beta y
dx
Beta [m]
Dispersion [m]
s [m]
0
200
400
600
800
1000
1200
1400
1600
-1
-0.5
0
0.5
1
1.5
2
2.5
3

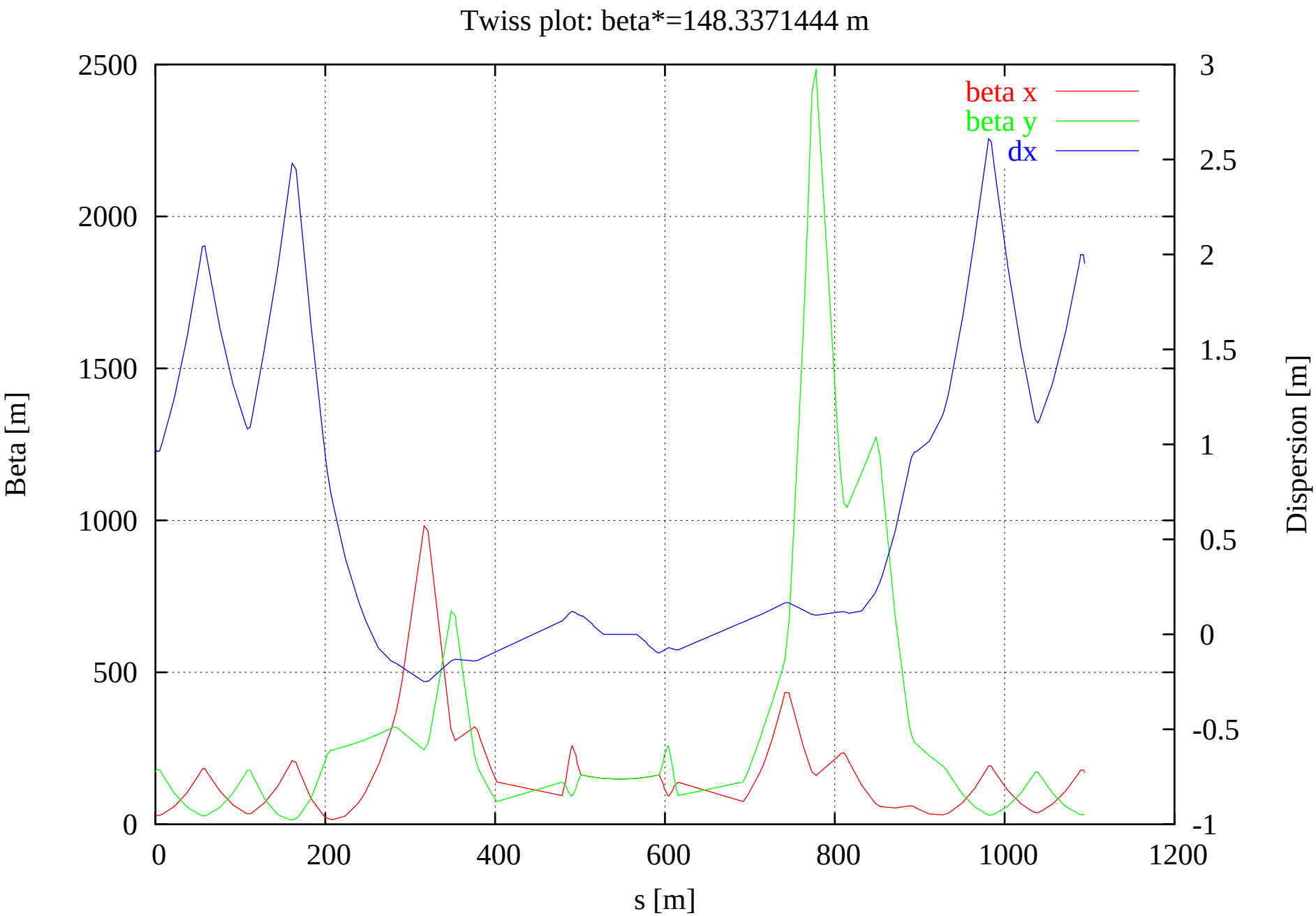

Twiss plot: beta*=92.10569596 m
beta x
beta y
dx
Beta [m]
Dispersion [m]
s [m]
0
200
400
600
800
1000
1200
1400
1600
1800
-1
-0.5
0
0.5
1
1.5
2
2.5
3

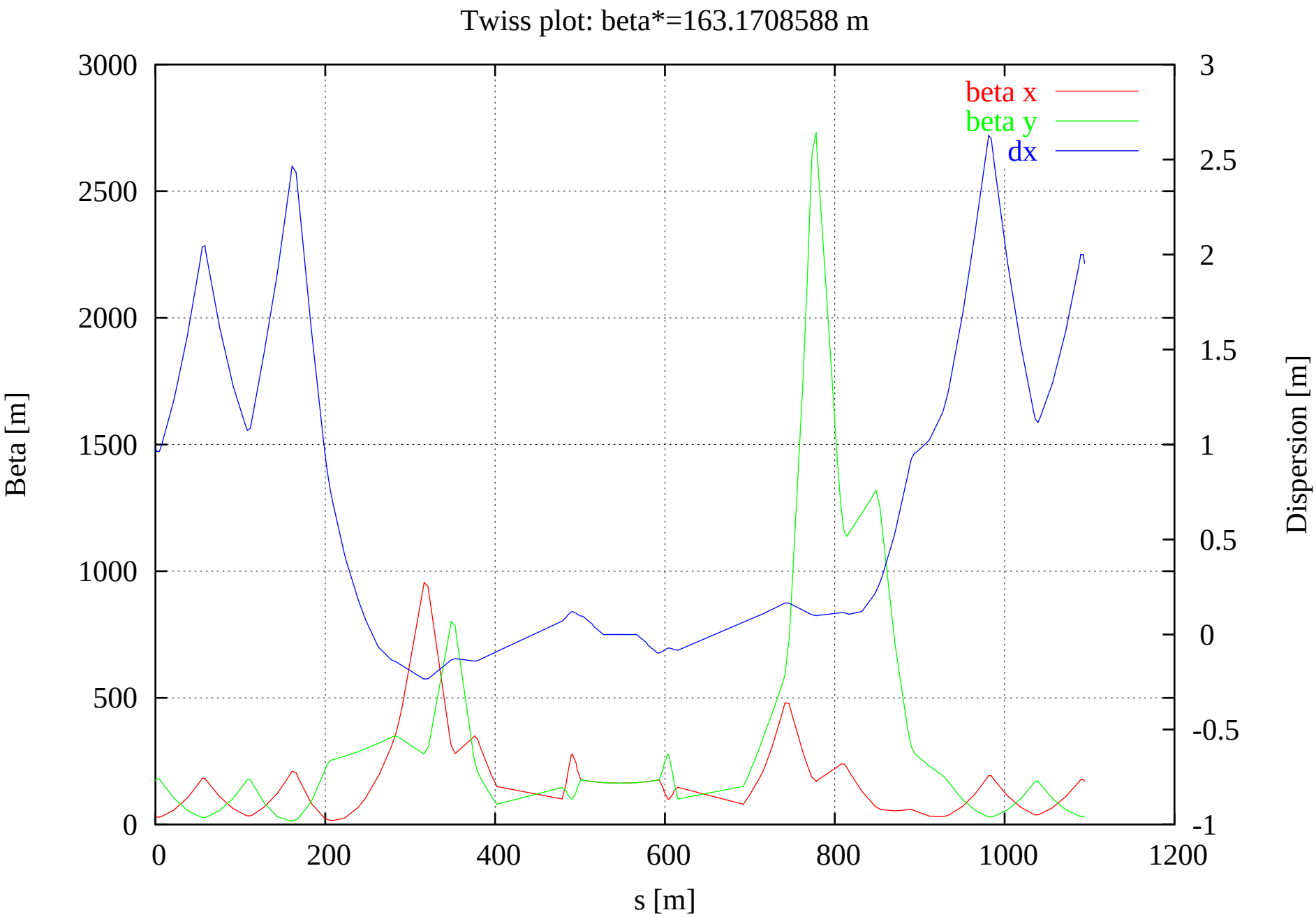

Twiss plot: beta*=101.3162656 m
beta x
beta y
dx
Beta [m]
Dispersion [m]
s [m]
0
200
400
600
800
1000
1200
1400
1600
1800
-1
-0.5
0
0.5
1
1.5
2
2.5
3

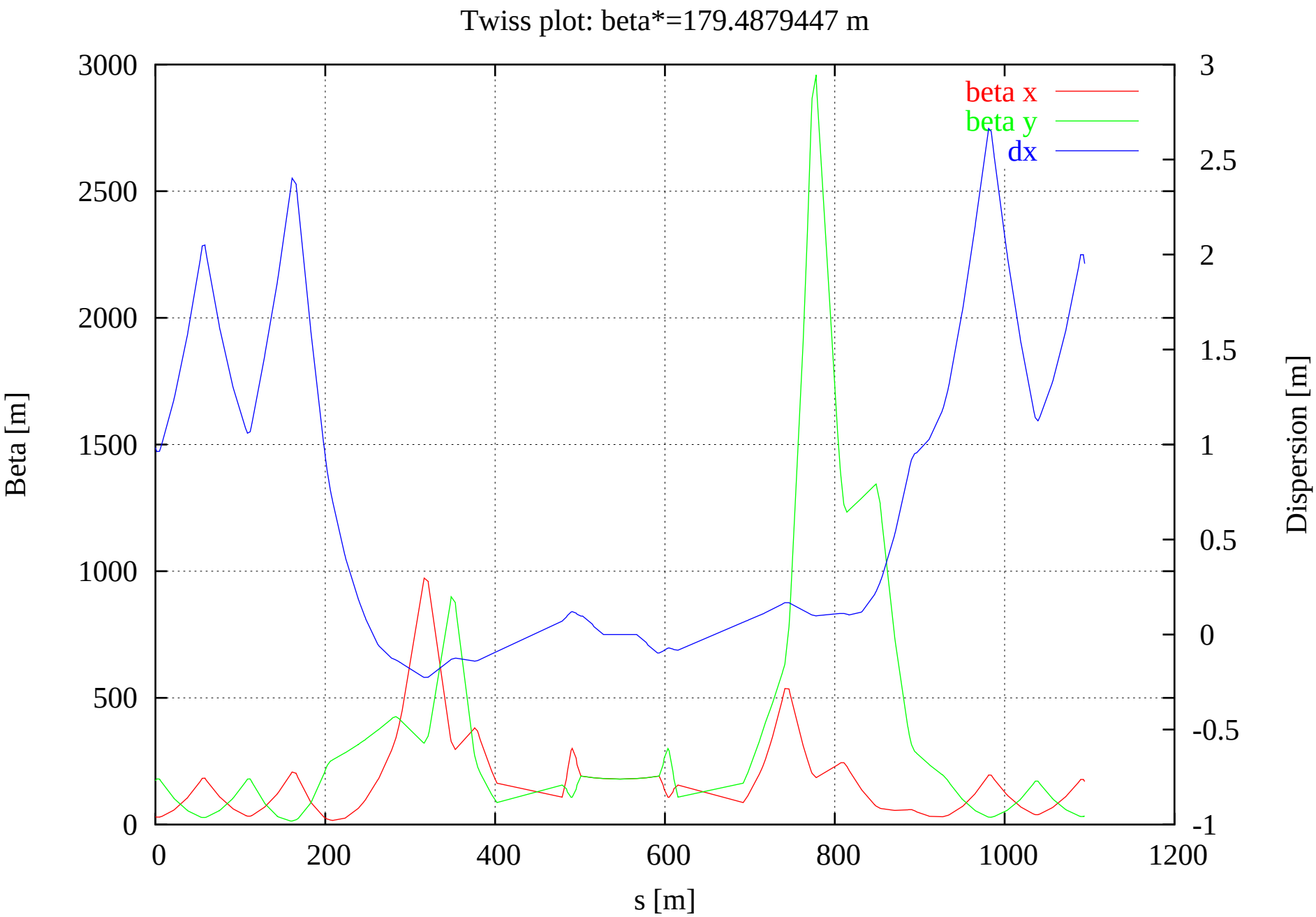

Twiss plot: beta*=111.4478921 m
beta x
beta y
dx
Beta [m]
Dispersion [m]
s [m]
2000
1800
1600
1400
1200
1000
800
600
400
200
0
3
2.5
2
1.5
1
0.5
0
-0.5
-1
0
200
400
600
800
1000
1200

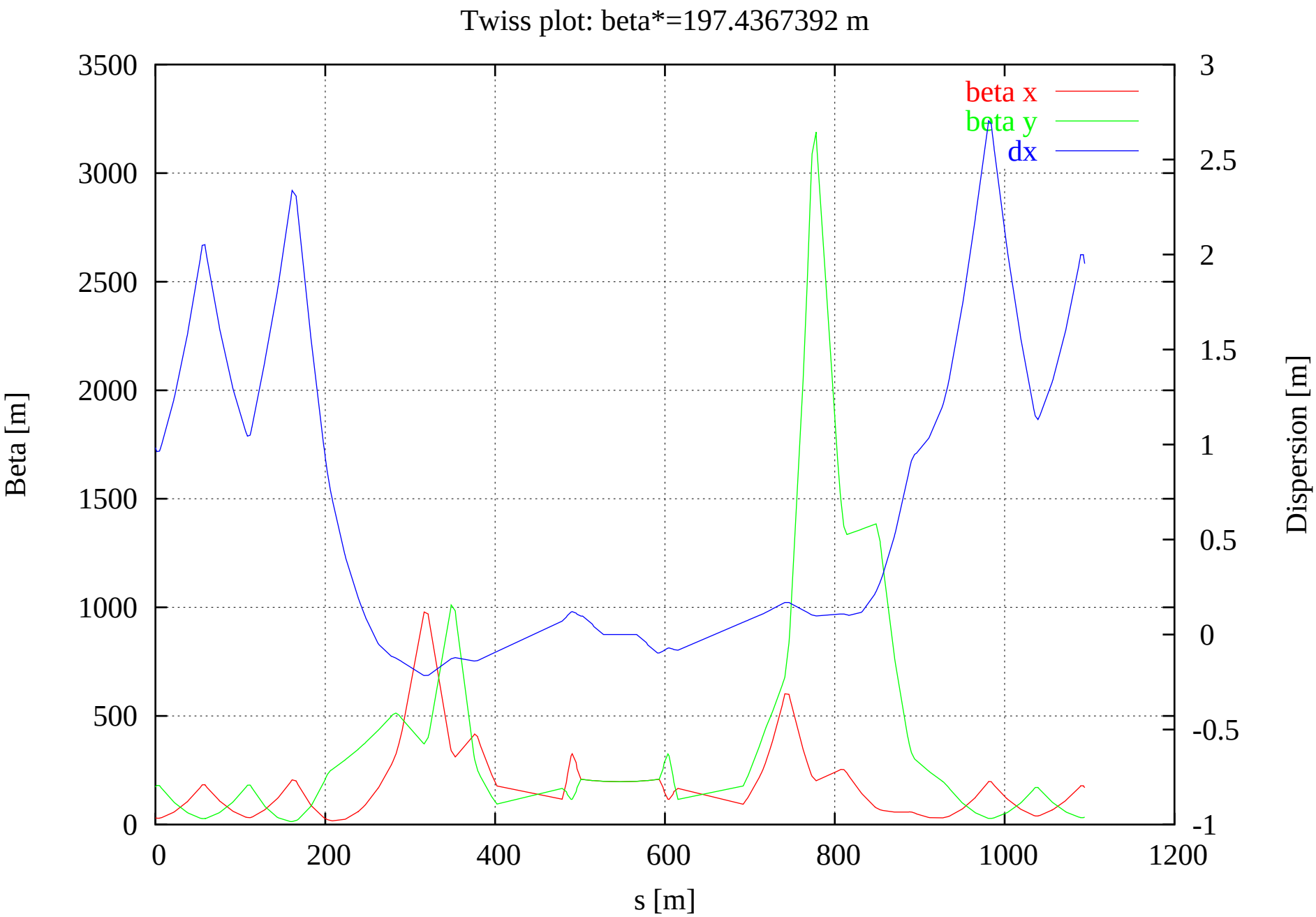

Twiss plot: beta*=122.5926813 m
beta x
beta y
dx
Beta [m]
Dispersion [m]
s [m]
2500
2000
1500
1000
500
0
3
2.5
2
1.5
1
0.5
0
-0.5
-1
0
200
400
600
800
1000
1200

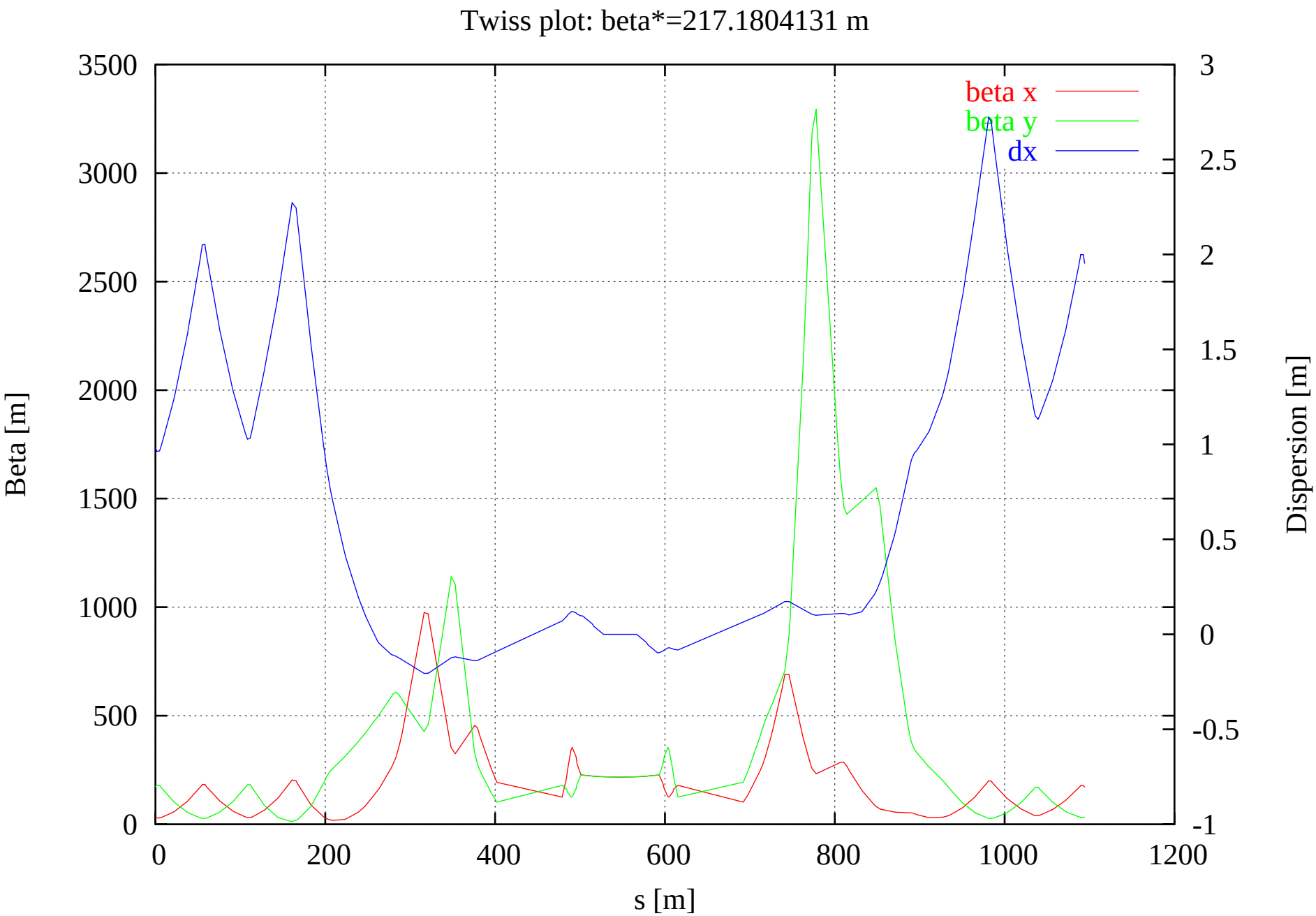

Twiss plot: beta*=134.8519495 m
beta x
beta y
dx
Beta [m]
Dispersion [m]
s [m]
2500
2000
1500
1000
500
0
3
2.5
2
1.5
1
0.5
0
-0.5
-1
0
200
400
600
800
1000
1200

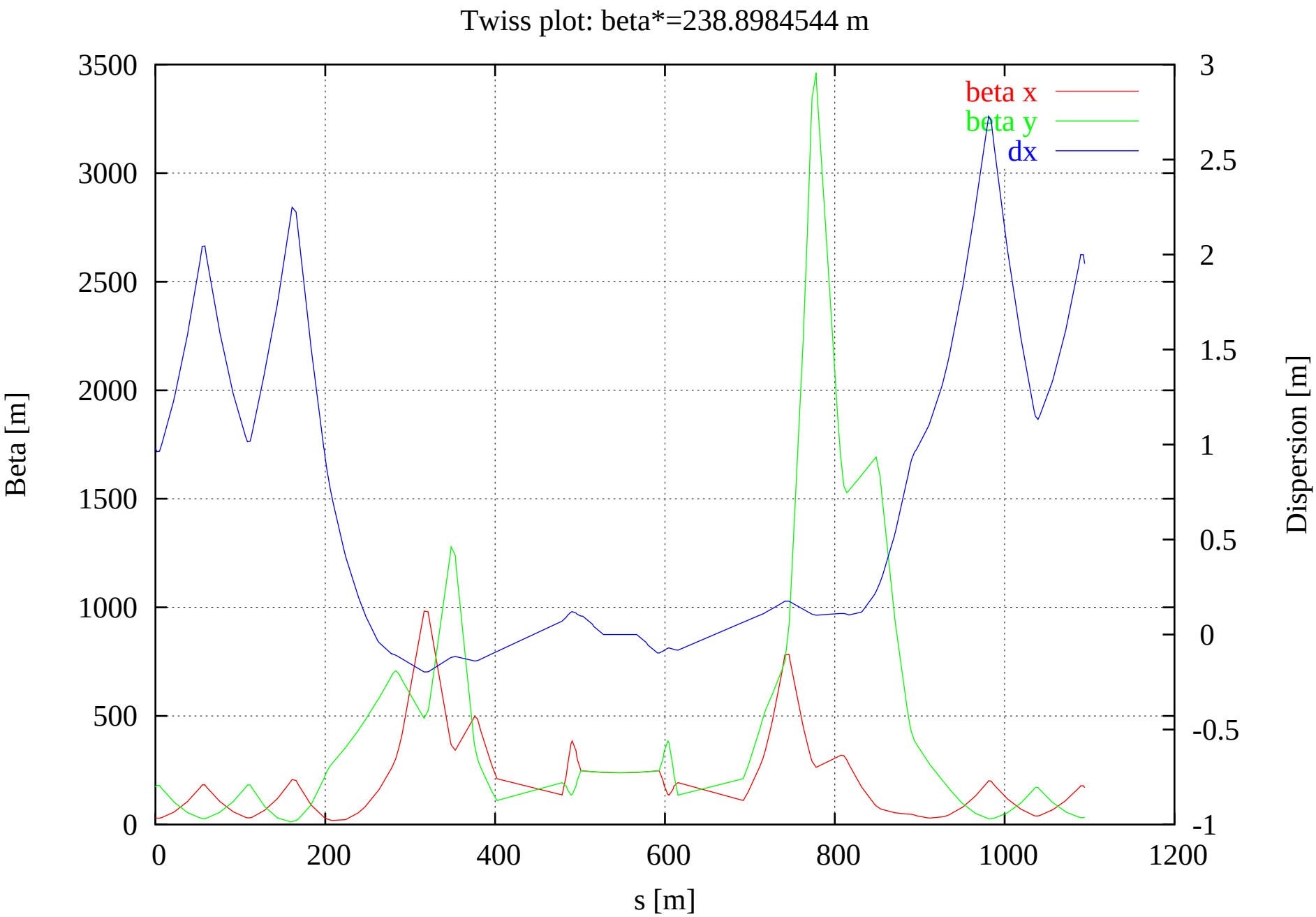

Twiss plot: beta*=148.3371444 m
beta x
beta y
dx
Beta [m]
Dispersion [m]
s [m]
2500
2000
1500
1000
500
0
3
2.5
2
1.5
1
0.5
0
-0.5
-1
0
200
400
600
800
1000
1200

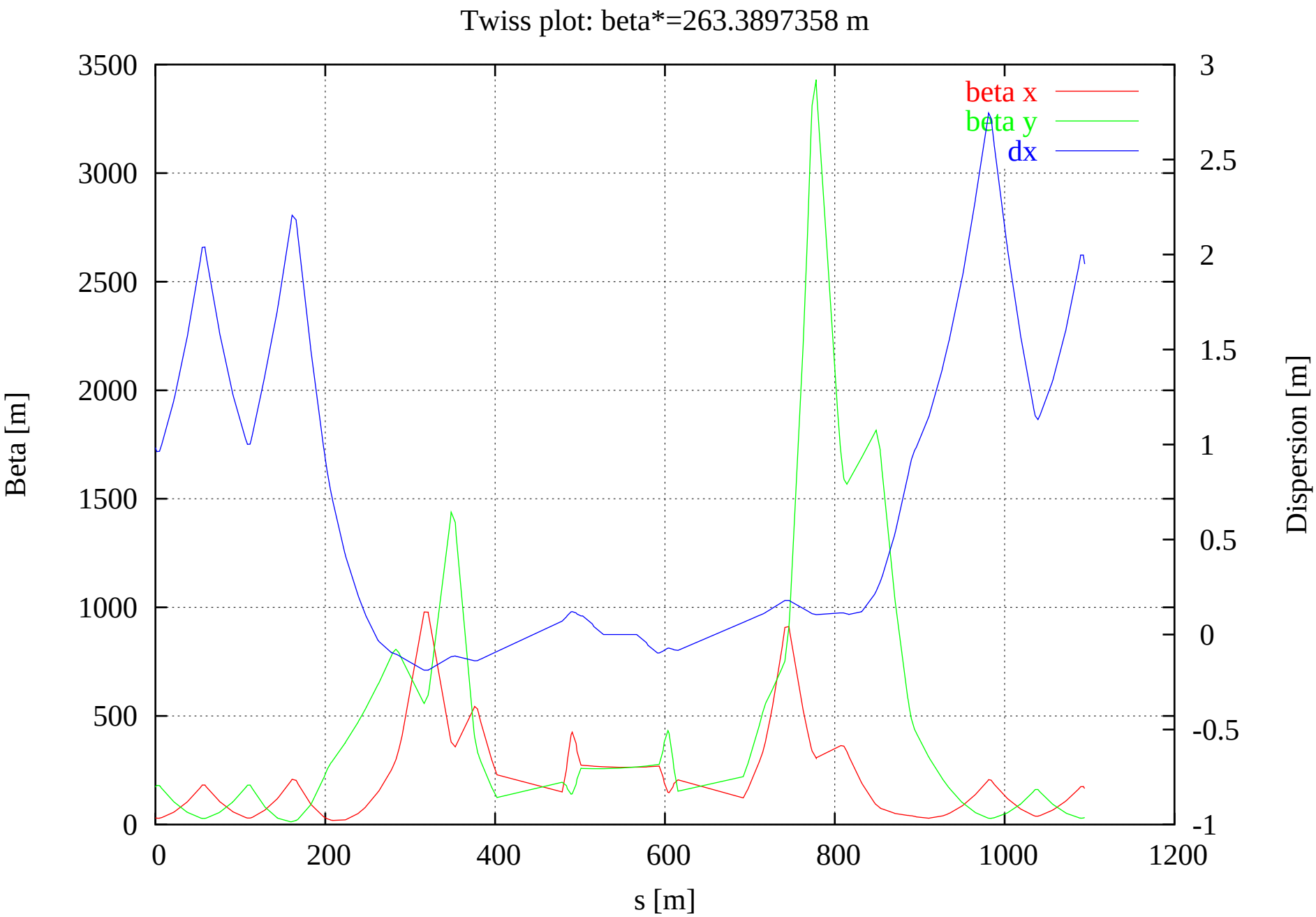

Twiss plot: beta*=163.1708588 m
beta x
beta y
dx
Beta [m]
Dispersion [m]
s [m]
3000
2500
2000
1500
1000
500
0
3
2.5
2
1.5
1
0.5
0
-0.5
-1
0
200
400
600
800
1000
1200

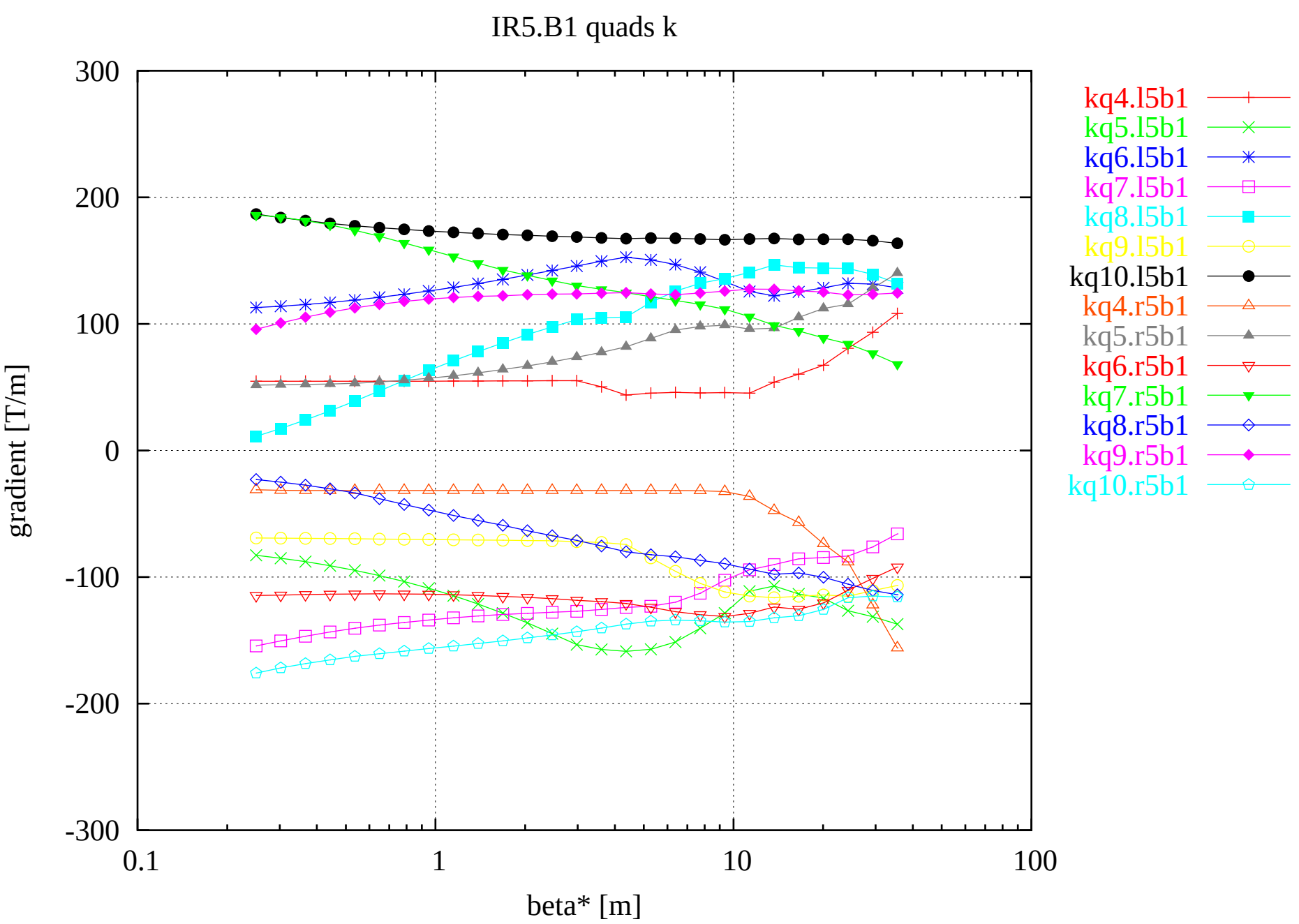

Twiss plot: beta*=179.4879447 m
beta x
beta y
dx
Beta [m]
Dispersion [m]
s [m]
3000
2500
2000
1500
1000
500
0
3
2.5
2
1.5
1
0.5
0
-0.5
-1
0
200
400
600
800
1000
1200

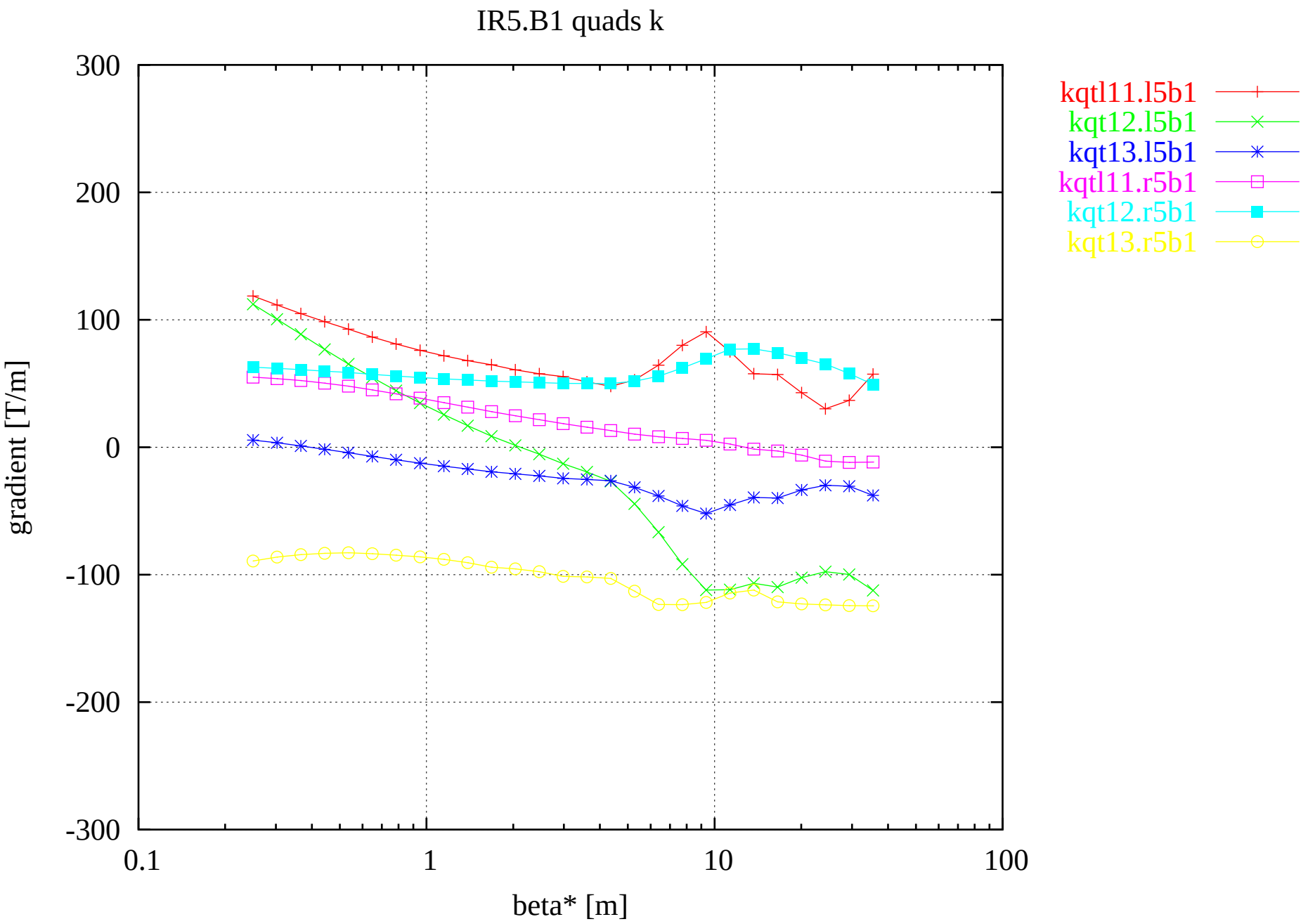

Twiss plot: beta*=197.4367392 m
beta x
beta y
dx
Beta [m]
Dispersion [m]
s [m]
0
500
1000
1500
2000
2500
3000
3500
-1
-0.5
0
0.5
1
1.5
2
2.5
3
0
200
400
600
800
1000
1200

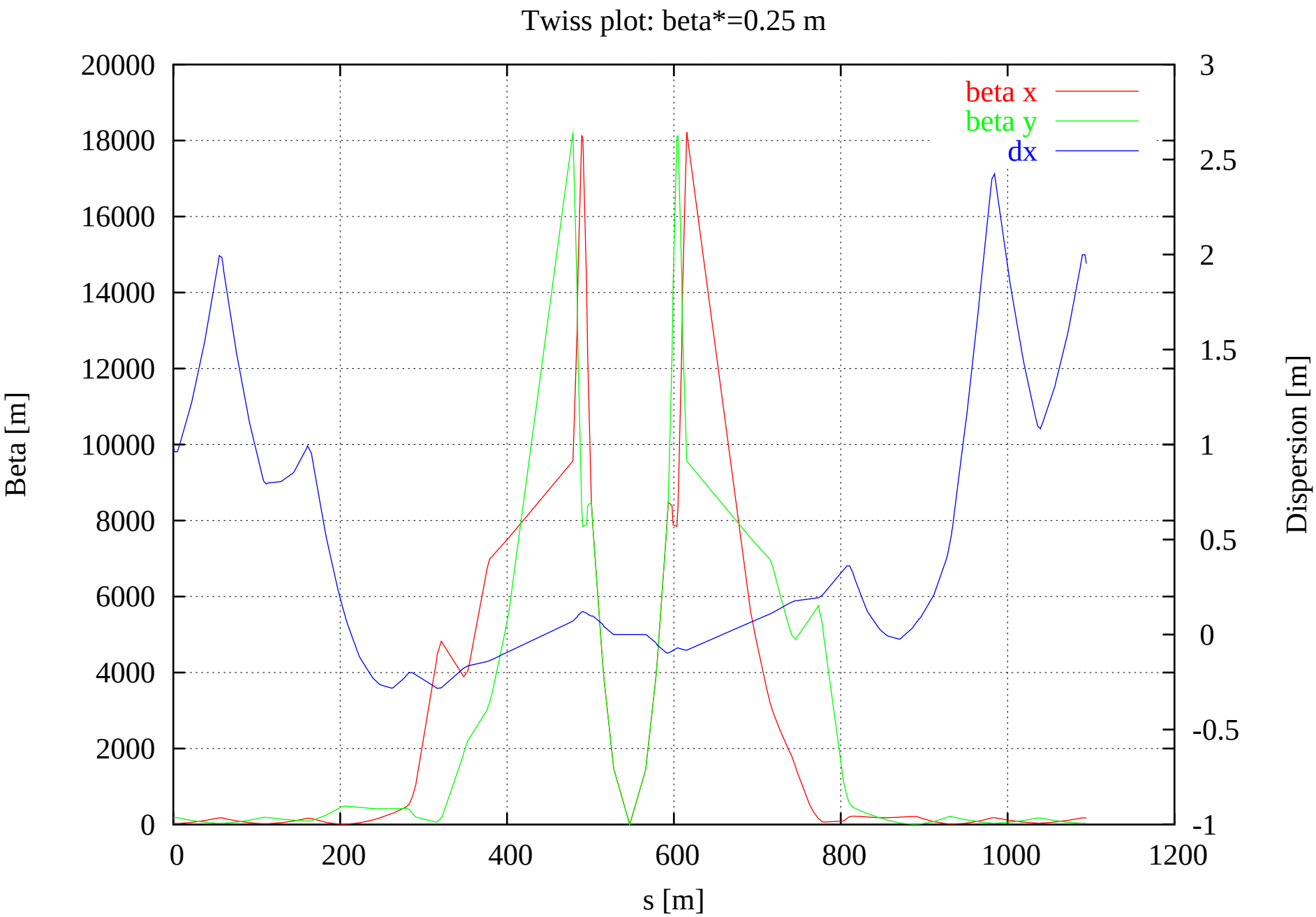

Twiss plot: beta*=217.1804131 m
beta x
beta y
dx
Beta [m]
Dispersion [m]
s [m]
0
500
1000
1500
2000
2500
3000
3500
-1
-0.5
0
0.5
1
1.5
2
2.5
3
0
200
400
600
800
1000
1200

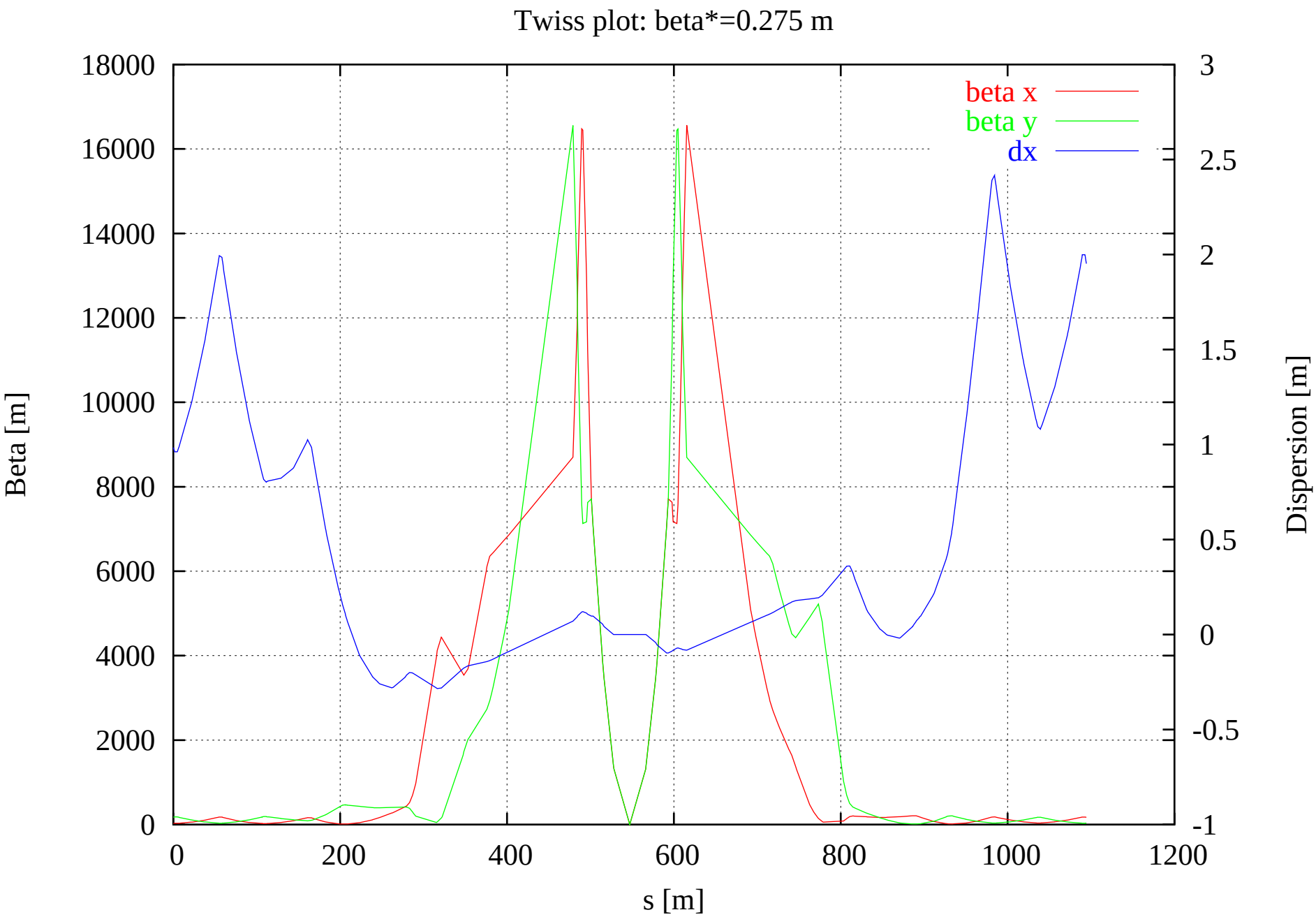

Twiss plot: beta*=238.8984544 m
beta x
beta y
dx
Beta [m]
Dispersion [m]
s [m]
0
500
1000
1500
2000
2500
3000
3500
-1
-0.5
0
0.5
1
1.5
2
2.5
3
0
200
400
600
800
1000
1200

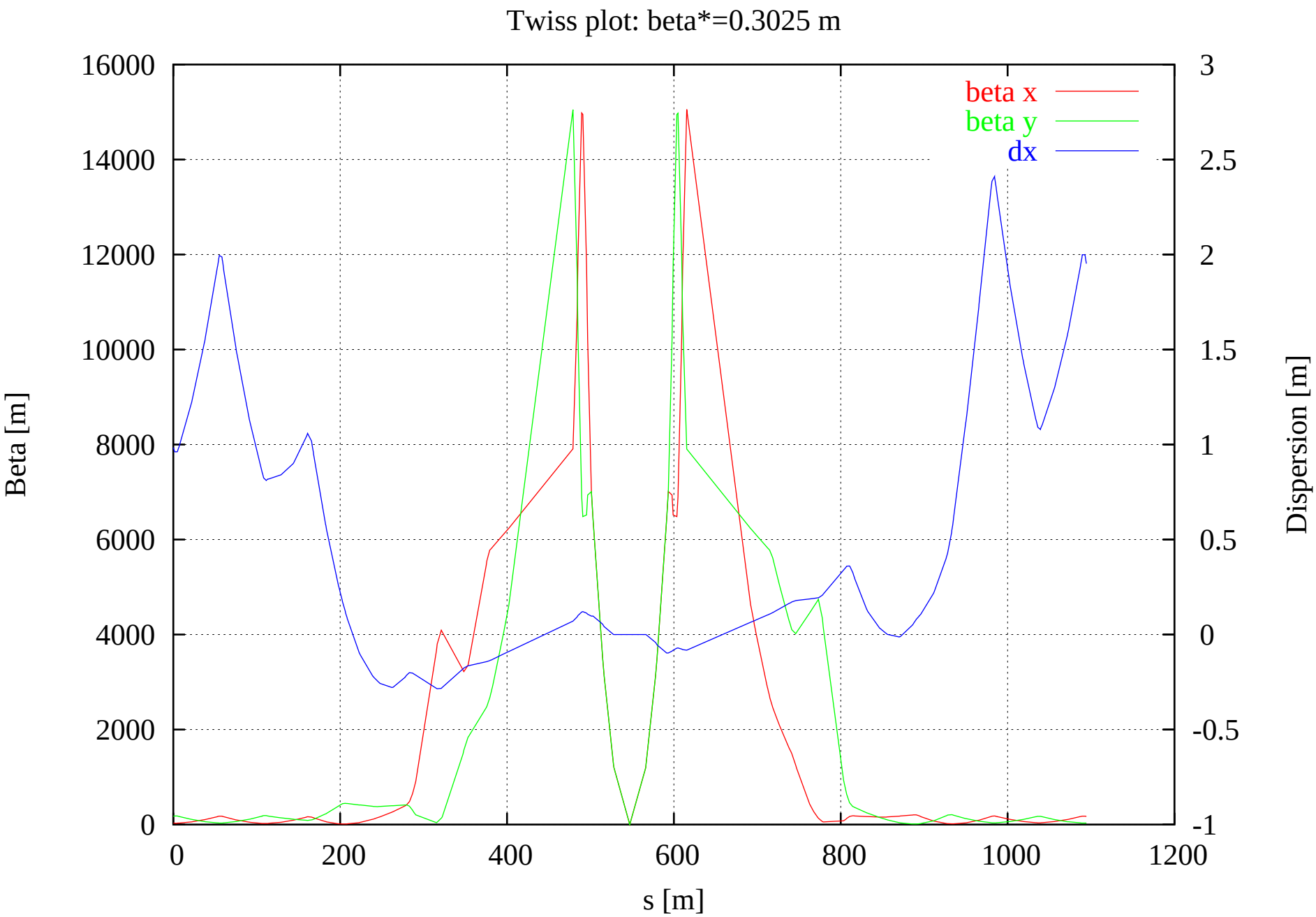

Twiss plot: beta*=263.3897358 m
beta x
beta y
dx
Beta [m]
Dispersion [m]
s [m]
0
500
1000
1500
2000
2500
3000
3500
-1
-0.5
0
0.5
1
1.5
2
2.5
3
0
200
400
600
800
1000
1200

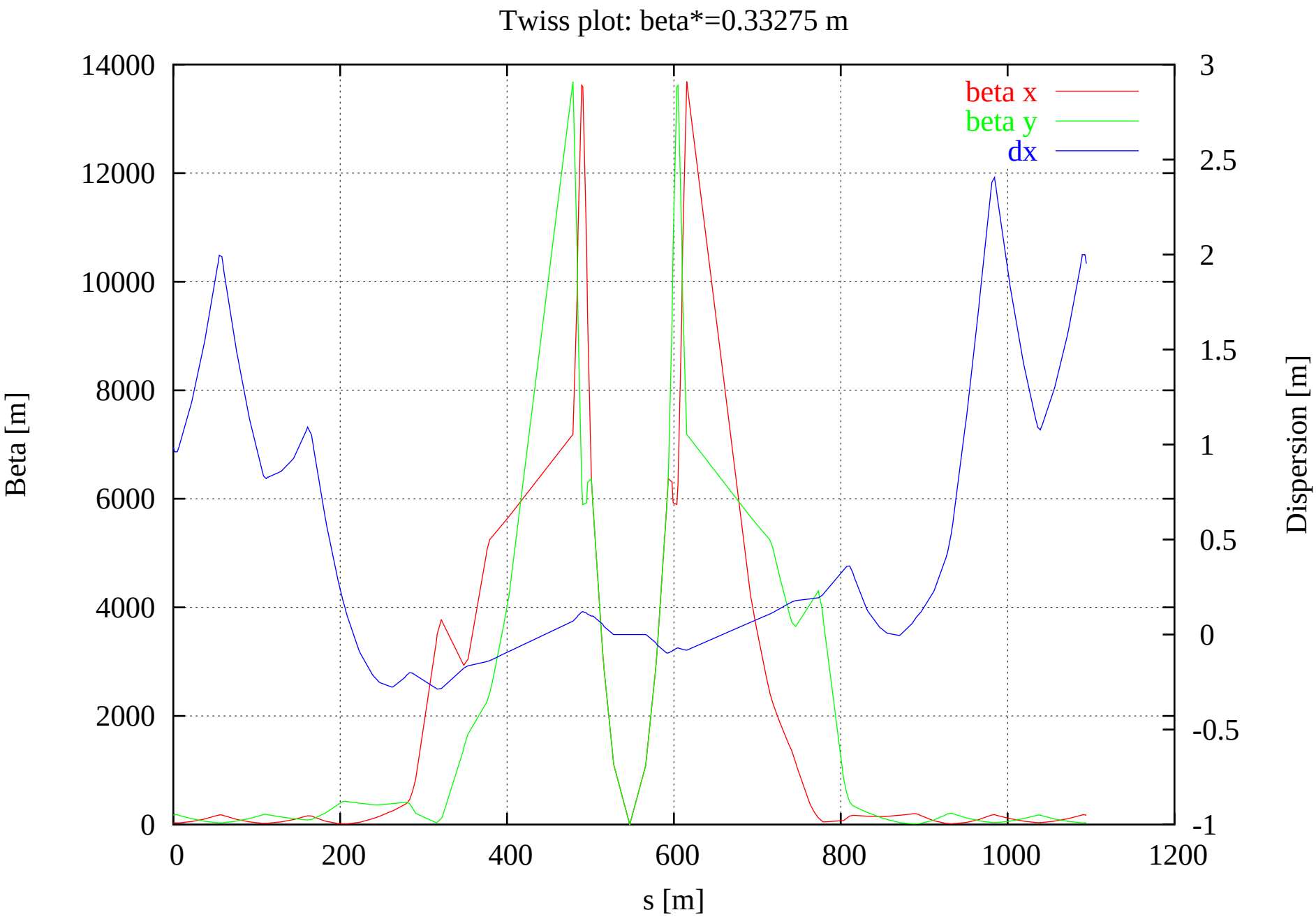

IR5.B1 quads k
gradient [T/m]
beta* [m]
300
200
100
0
-100
-200
-300
0.1
1
10
100
kq4.l5b1
kq5.l5b1
kq6.l5b1
kq7.l5b1
kq8.l5b1
kq9.l5b1
kq10.l5b1
kq4.r5b1
kq5.r5b1
kq6.r5b1
kq7.r5b1
kq8.r5b1
kq9.r5b1
kq10.r5b1

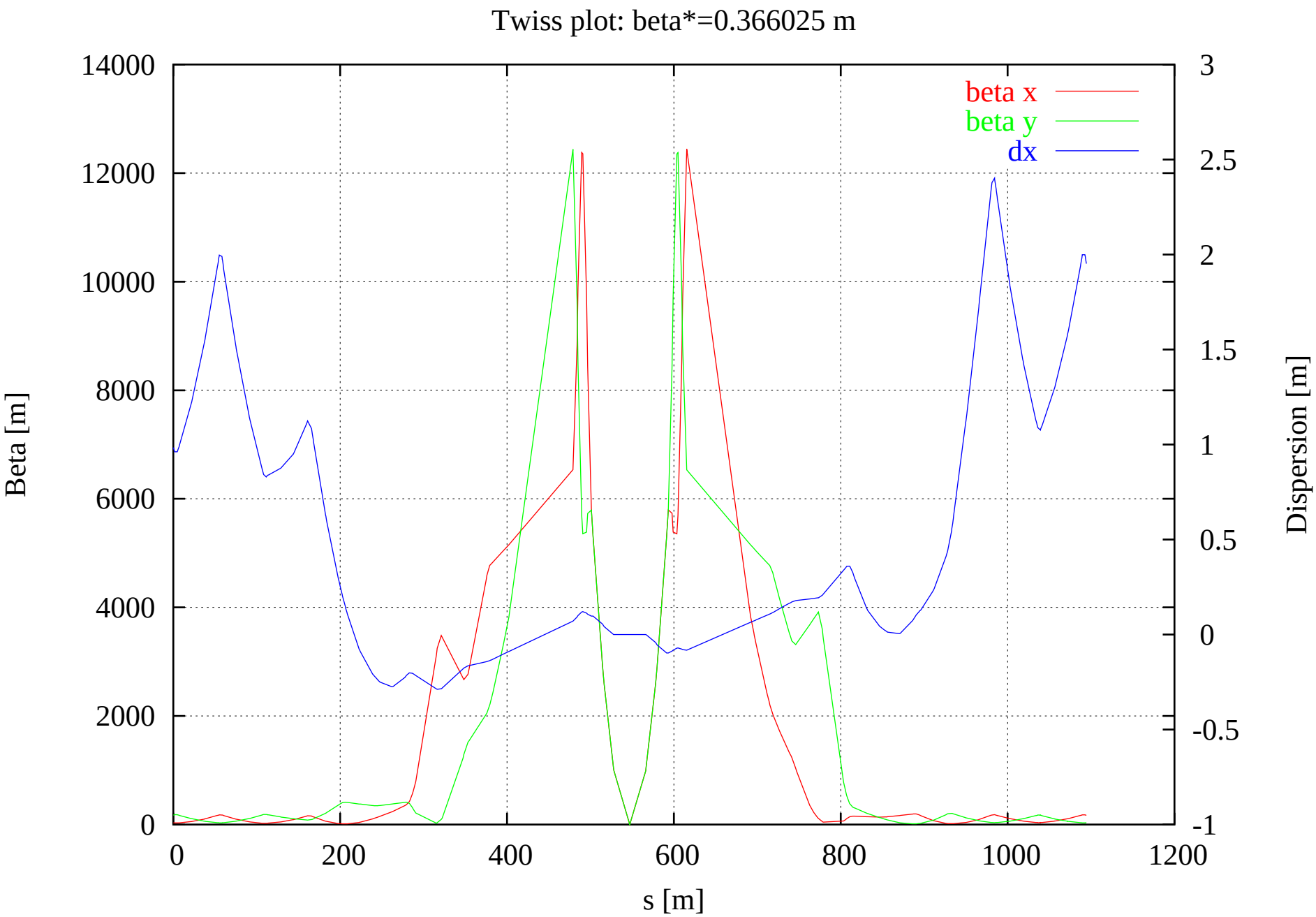

IR5.B1 quads k
gradient [T/m]
beta* [m]
300
200
100
0
-100
-200
-300
0.1
1
10
100
kqtl11.l5b1
kqt12.l5b1
kqt13.l5b1
kqtl11.r5b1
kqt12.r5b1
kqt13.r5b1

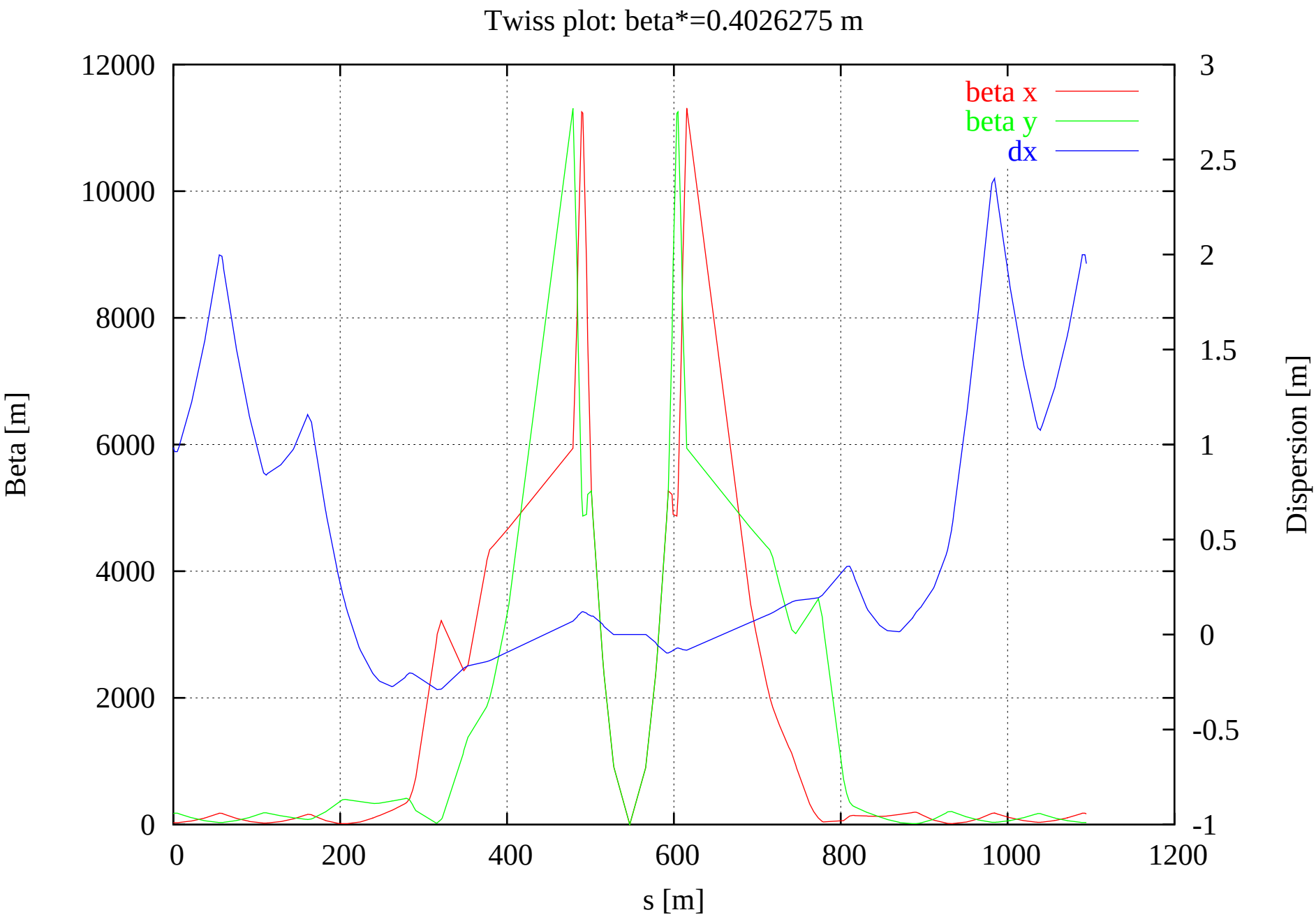

Twiss plot: beta*=0.25 m
beta x
beta y
dx
Beta [m]
Dispersion [m]
s [m]
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
3
2.5
2
1.5
1
0.5
0
-0.5
-1
0
200
400
600
800
1000
1200

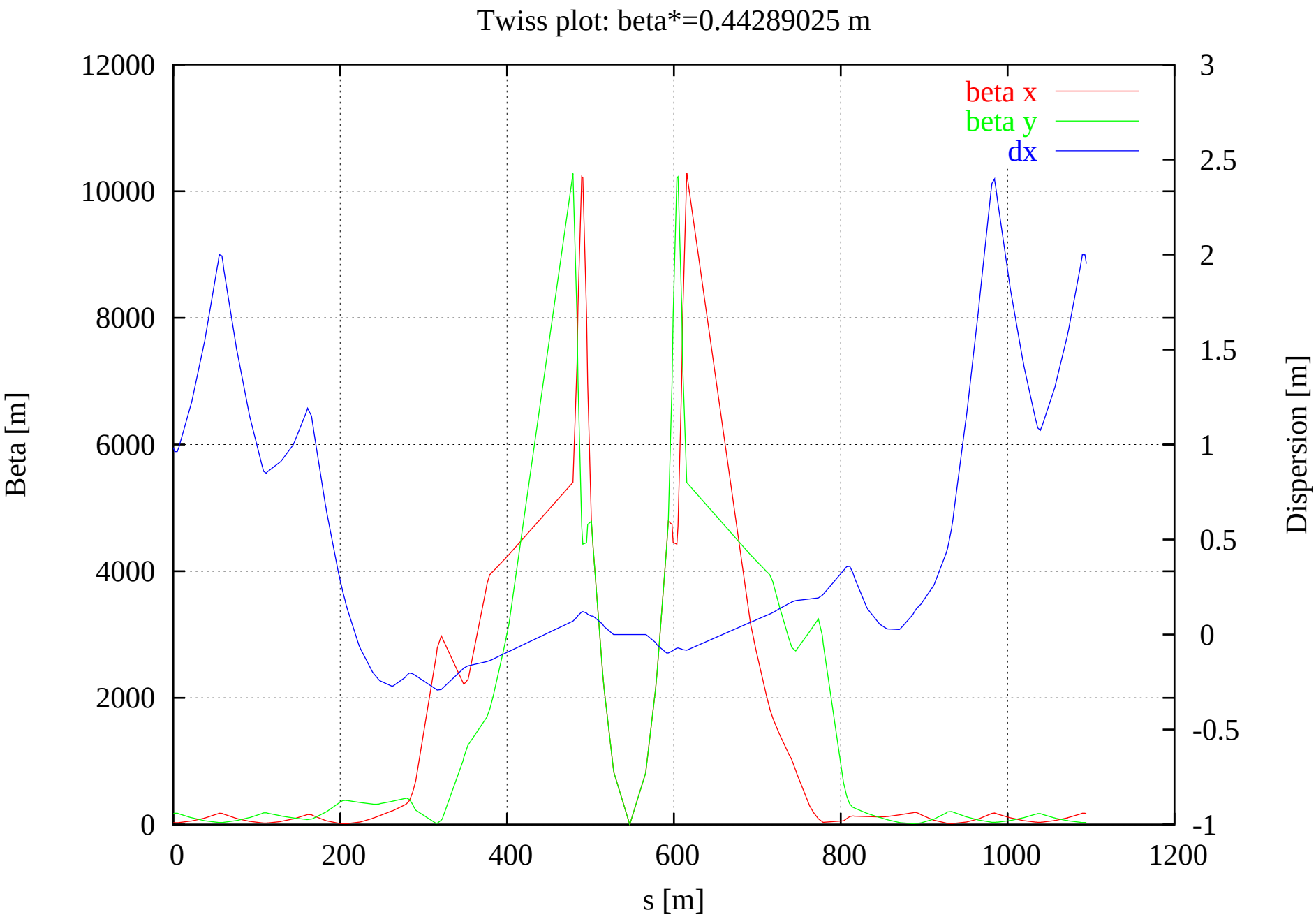

Twiss plot: beta*=0.275 m
beta x
beta y
dx
Beta [m]
Dispersion [m]
s [m]
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
3
2.5
2
1.5
1
0.5
0
-0.5
-1
0
200
400
600
800
1000
1200

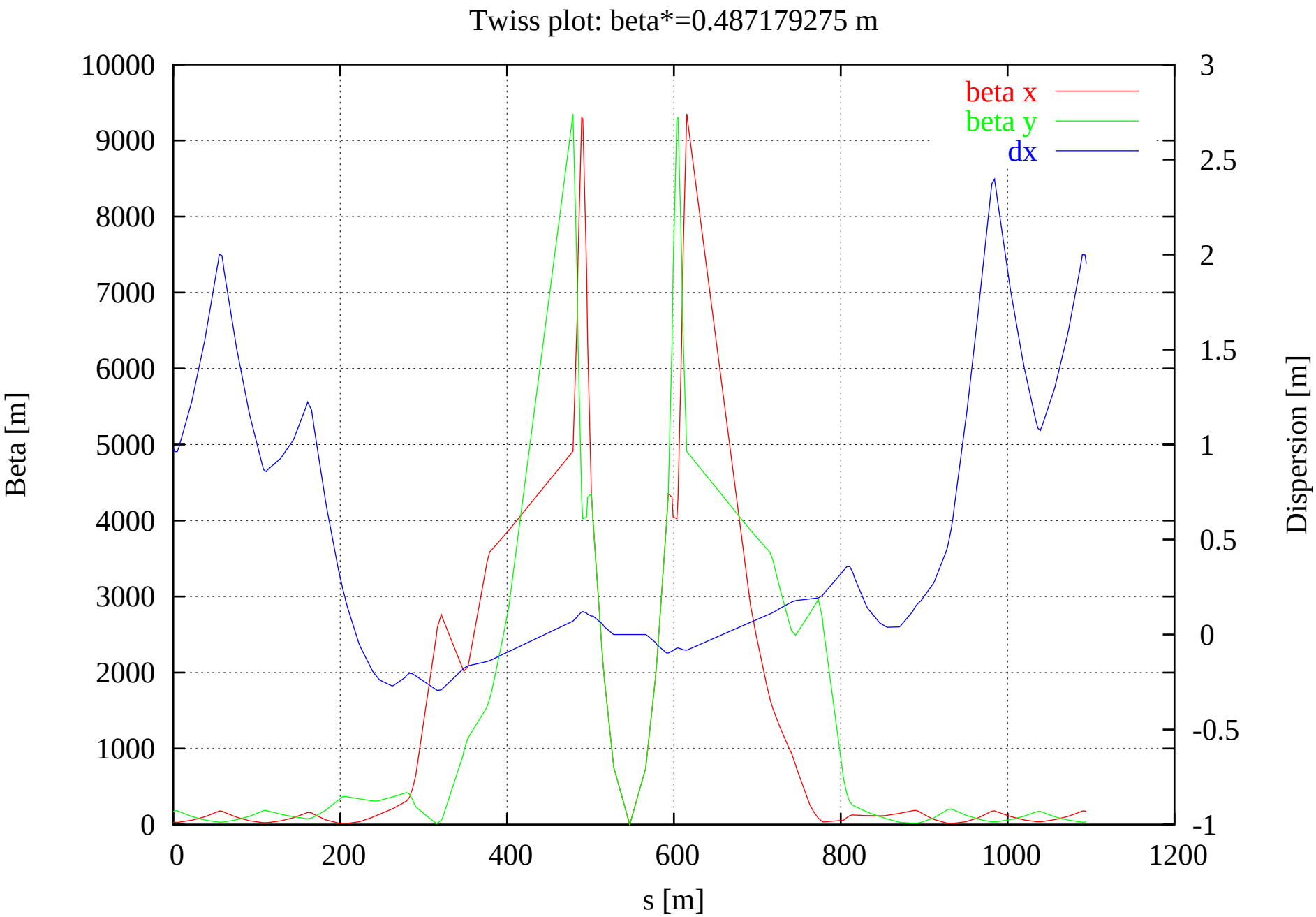

Twiss plot: beta*=0.3025 m
beta x
beta y
dx
Beta [m]
Dispersion [m]
s [m]
16000
14000
12000
10000
8000
6000
4000
2000
0
3
2.5
2
1.5
1
0.5
0
-0.5
-1
0
200
400
600
800
1000
1200

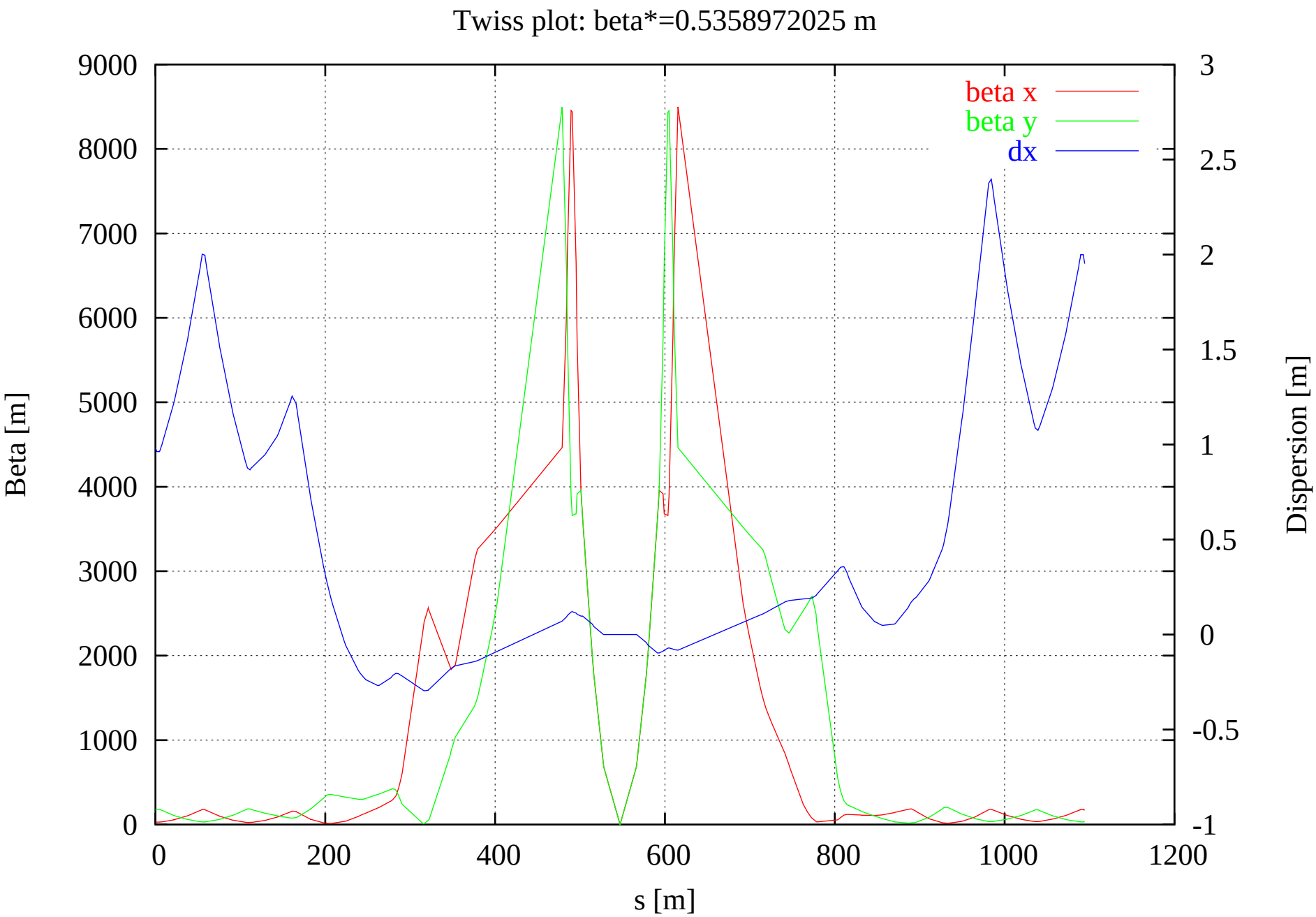

Twiss plot: beta*=0.33275 m
beta x
beta y
dx
Beta [m]
Dispersion [m]
s [m]
14000
12000
10000
8000
6000
4000
2000
0
3
2.5
2
1.5
1
0.5
0
-0.5
-1
0
200
400
600
800
1000
1200

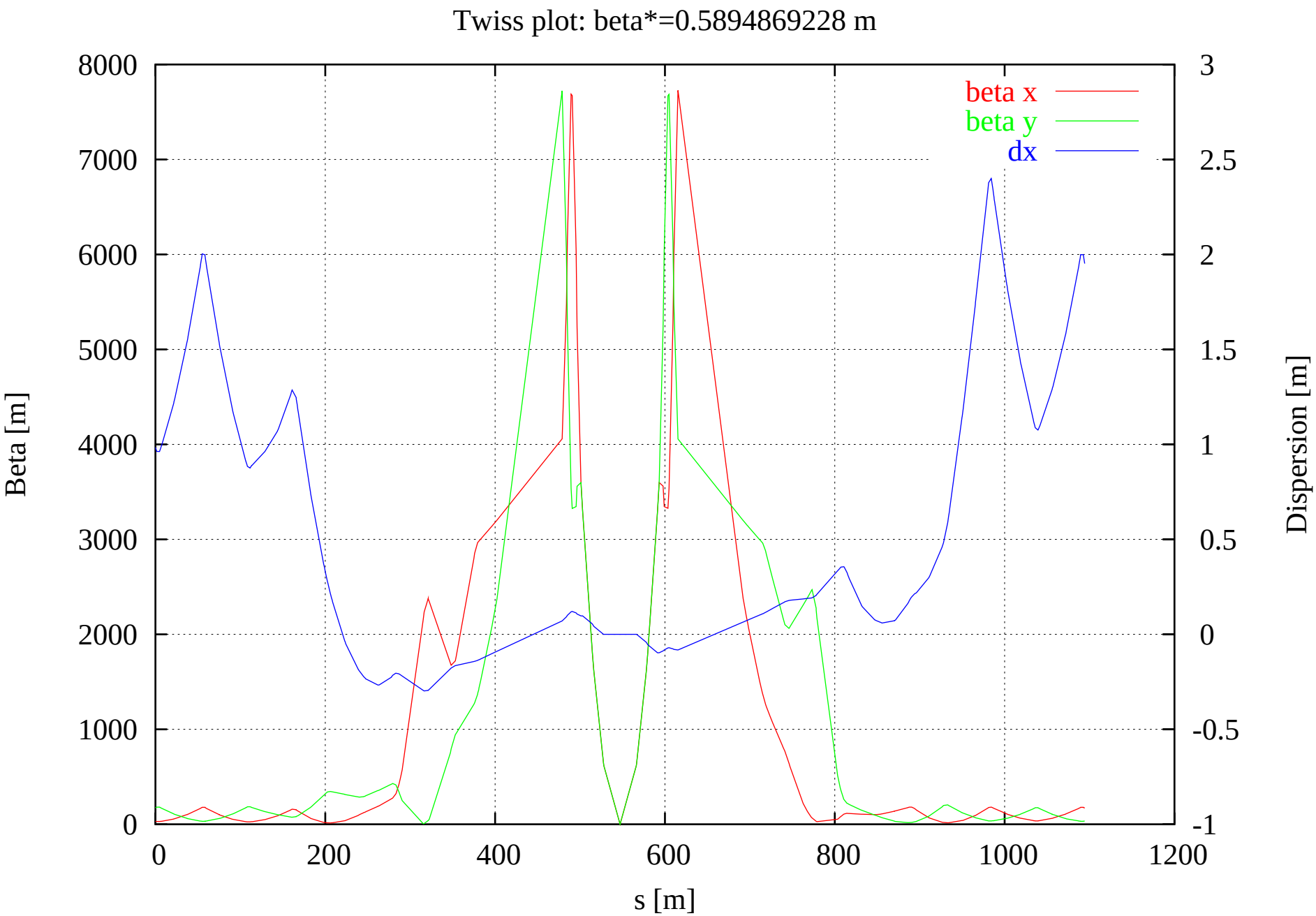

Twiss plot: beta*=0.366025 m
beta x
beta y
dx
Beta [m]
Dispersion [m]
s [m]
0
2000
4000
6000
8000
10000
12000
14000
-1
-0.5
0
0.5
1
1.5
2
2.5
3
0
200
400
600
800
1000
1200

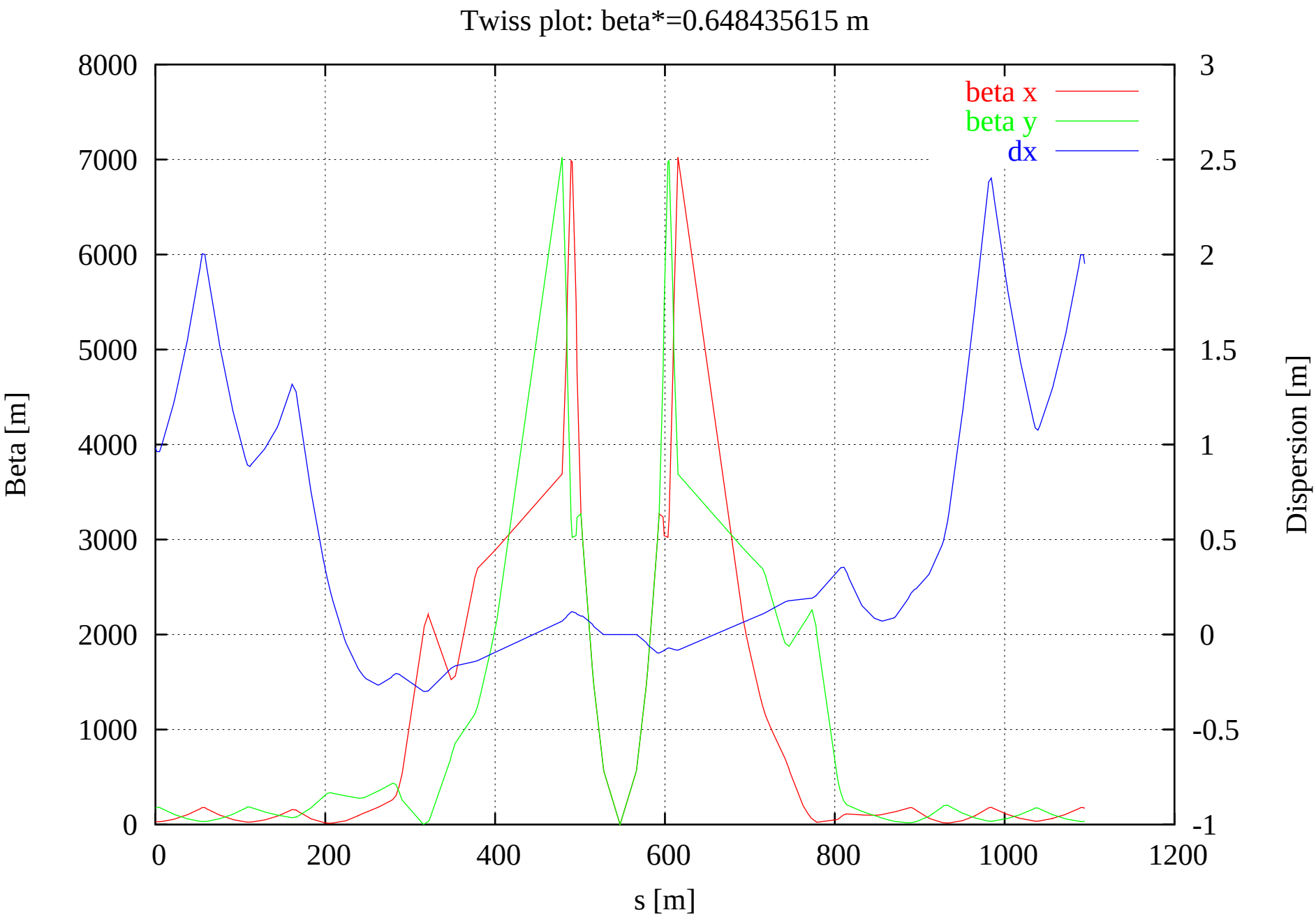

Twiss plot: beta*=0.4026275 m
beta x
beta y
dx
Beta [m]
Dispersion [m]
s [m]
12000
10000
8000
6000
4000
2000
0
3
2.5
2
1.5
1
0.5
0
-0.5
-1
0
200
400
600
800
1000
1200

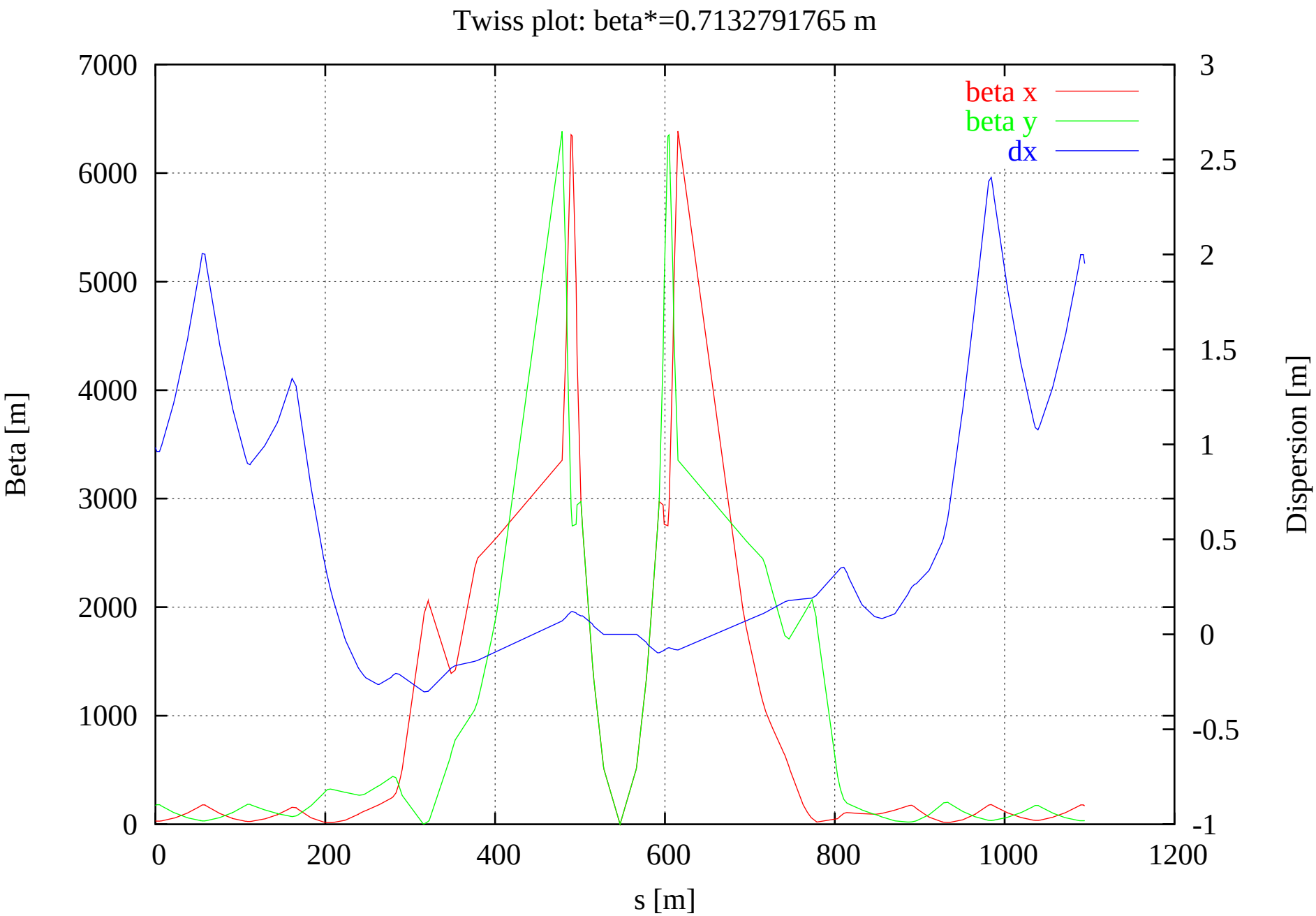

Twiss plot: beta*=0.44289025 m
beta x
beta y
dx
Beta [m]
Dispersion [m]
s [m]
12000
10000
8000
6000
4000
2000
0
3
2.5
2
1.5
1
0.5
0
-0.5
-1
0
200
400
600
800
1000
1200

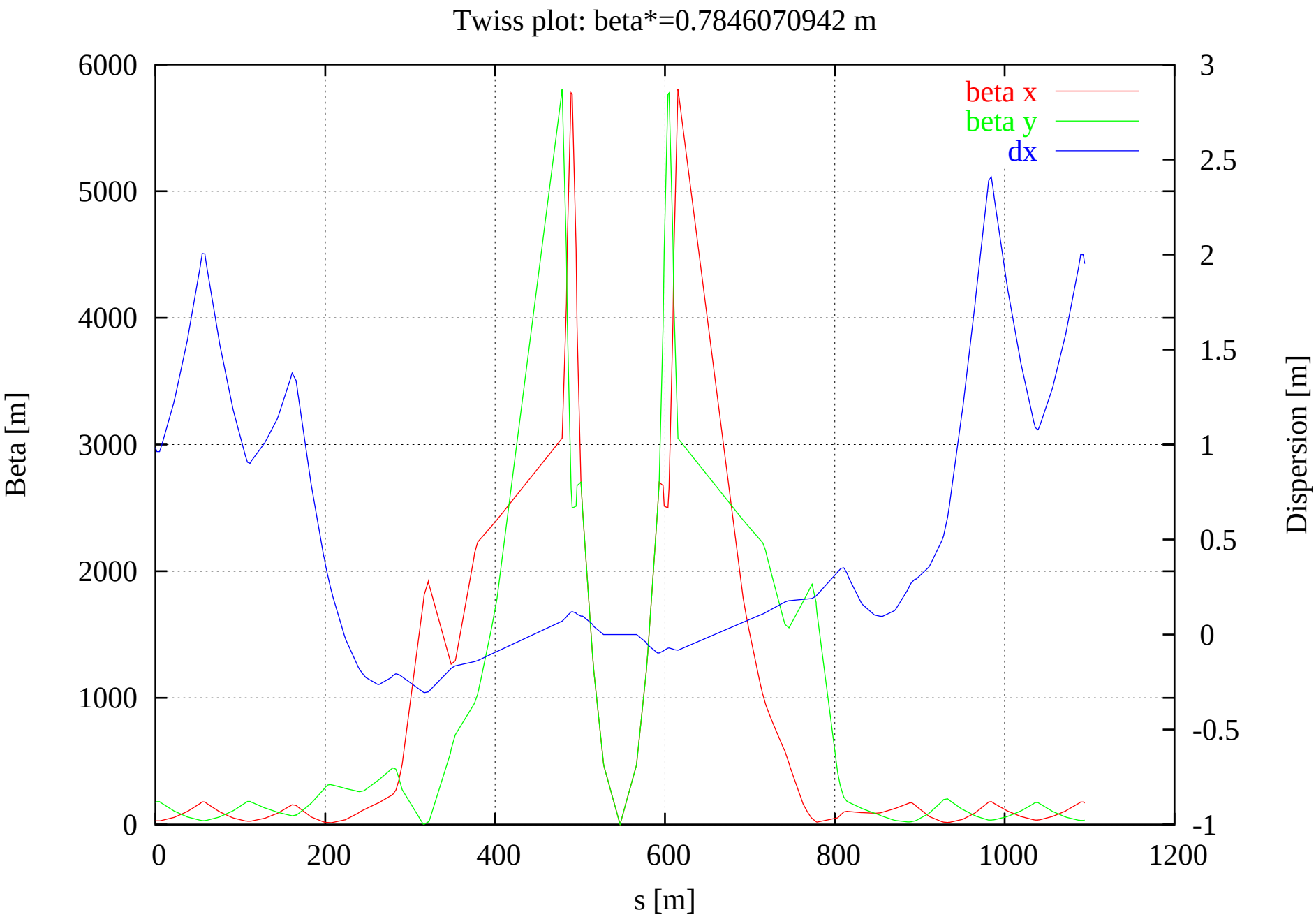

Twiss plot: beta*=0.487179275 m
beta x
beta y
dx
Beta [m]
Dispersion [m]
s [m]
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
3
2.5
2
1.5
1
0.5
0
-0.5
-1
0
200
400
600
800
1000
1200

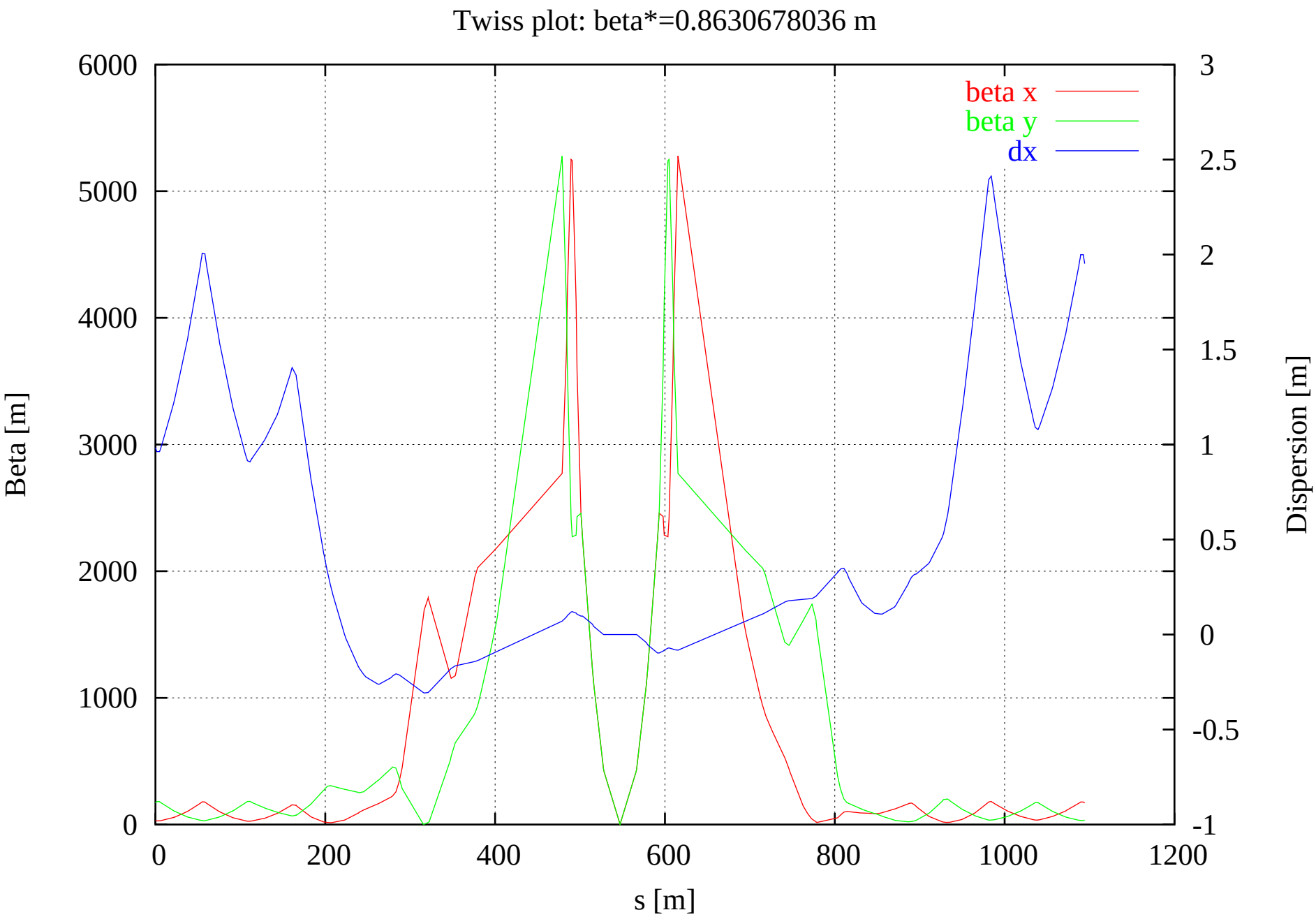

Twiss plot: beta*=0.5358972025 m
beta x
beta y
dx
Beta [m]
Dispersion [m]
s [m]
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
3
2.5
2
1.5
1
0.5
0
-0.5
-1
0
200
400
600
800
1000
1200

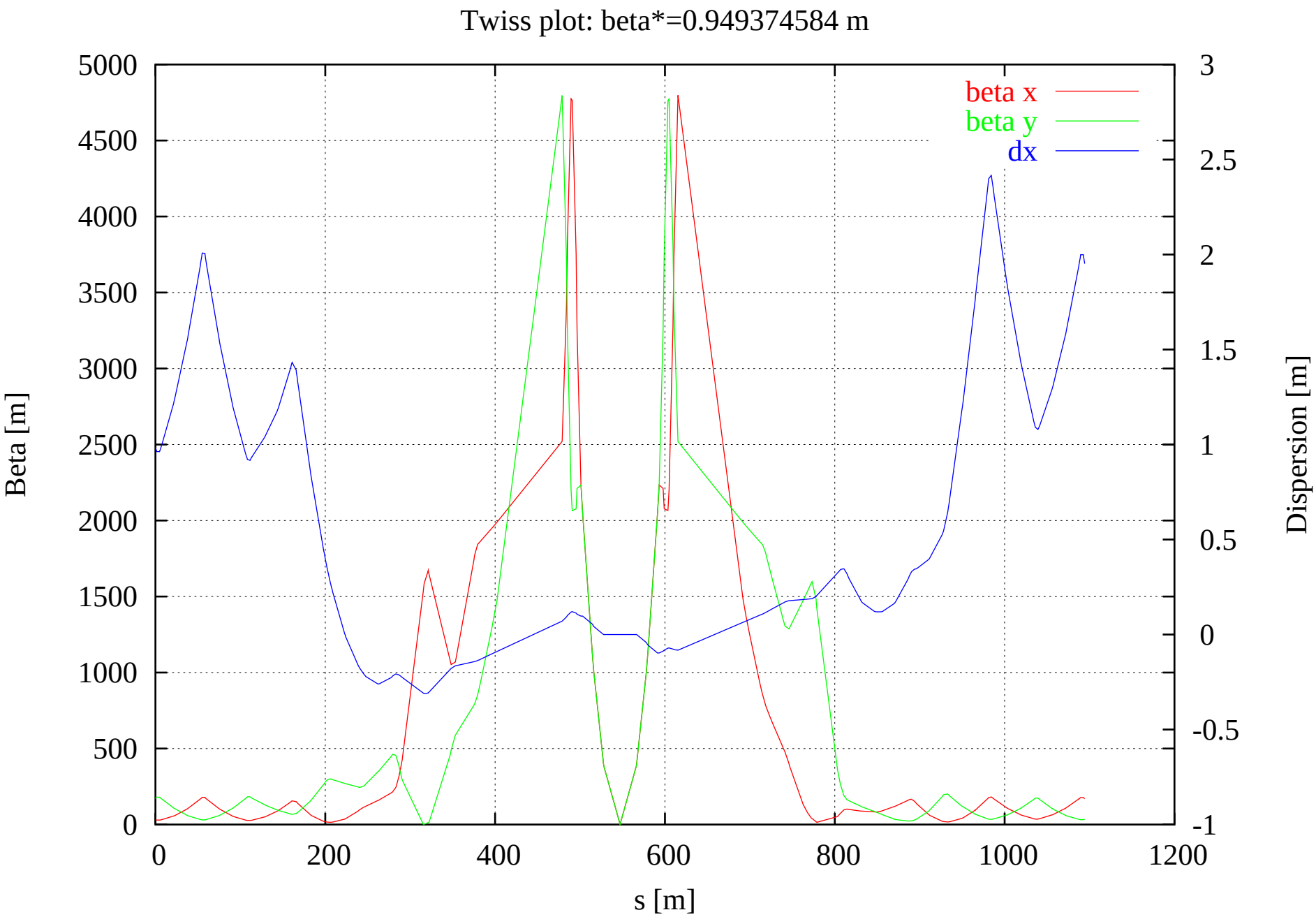

Twiss plot: beta*=0.5894869228 m
beta x
beta y
dx
Beta [m]
Dispersion [m]
s [m]
8000
7000
6000
5000
4000
3000
2000
1000
0
3
2.5
2
1.5
1
0.5
0
-0.5
-1
0
200
400
600
800
1000
1200

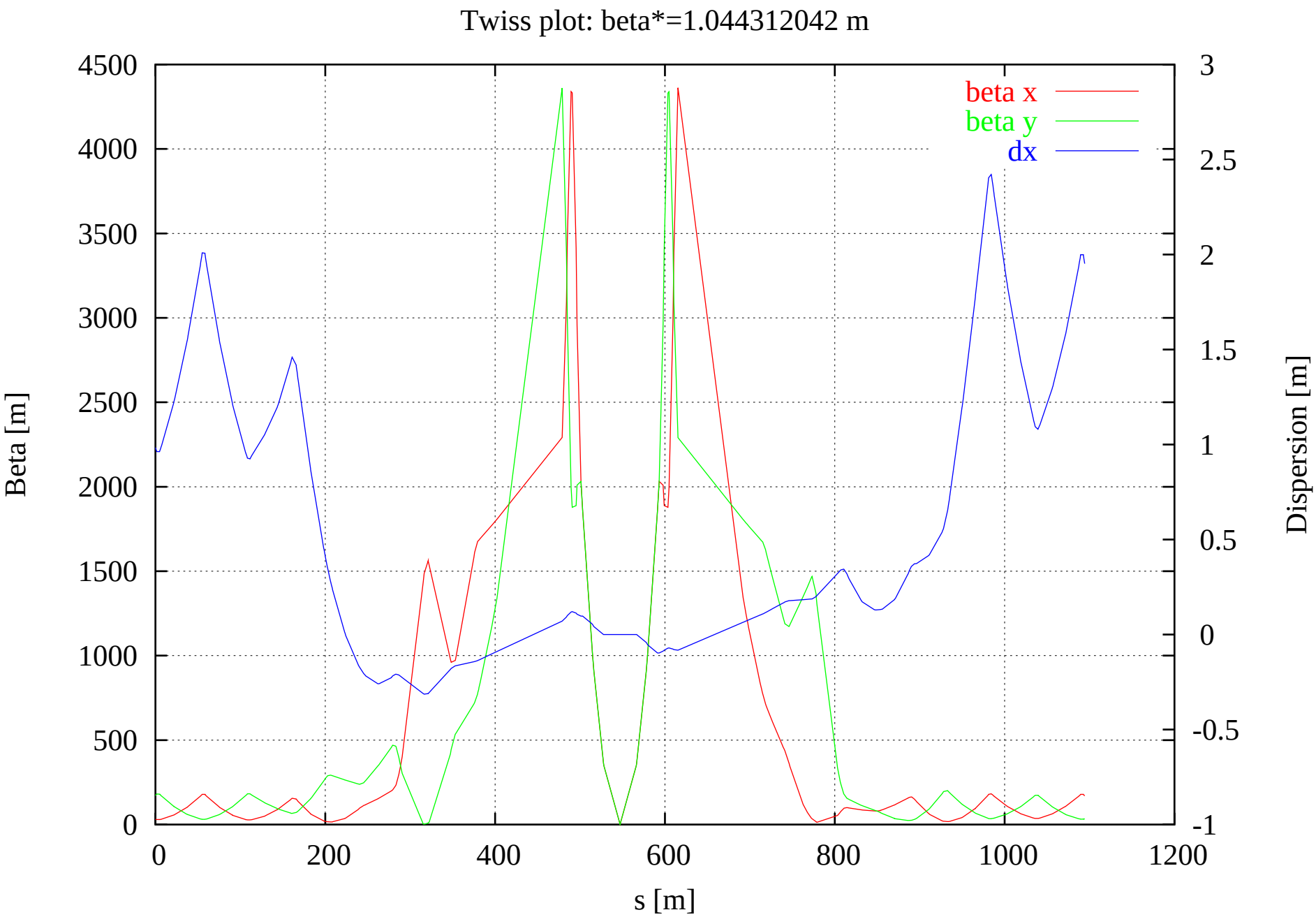

Twiss plot: beta*=0.648435615 m
beta x
beta y
dx
Beta [m]
Dispersion [m]
s [m]
8000
7000
6000
5000
4000
3000
2000
1000
0
3
2.5
2
1.5
1
0.5
0
-0.5
-1
0
200
400
600
800
1000
1200

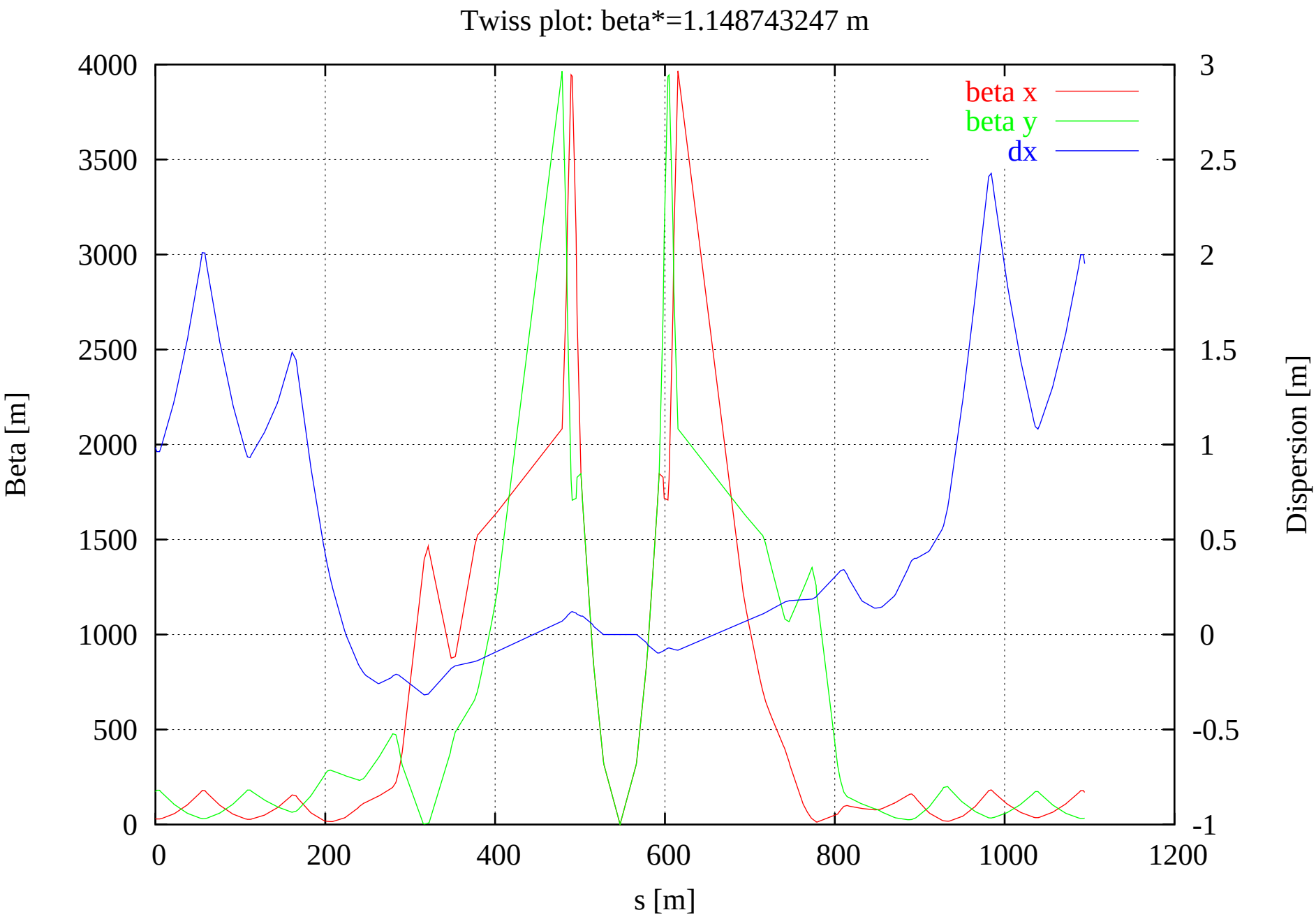

Twiss plot: beta*=0.7132791765 m
beta x
beta y
dx
Beta [m]
Dispersion [m]
s [m]
0
1000
2000
3000
4000
5000
6000
7000
-1
-0.5
0
0.5
1
1.5
2
2.5
3
0
200
400
600
800
1000
1200

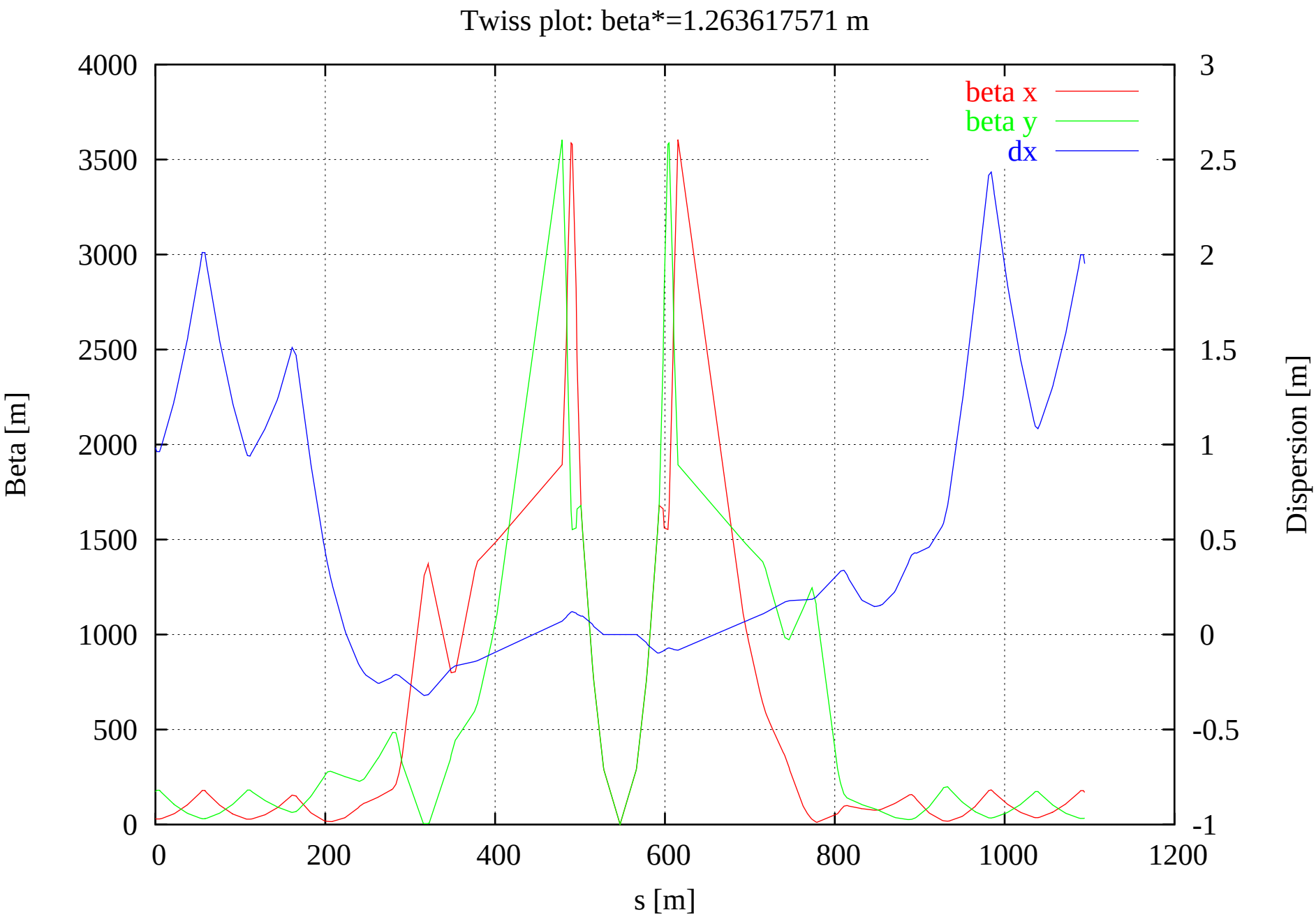

Twiss plot: beta*=0.7846070942 m
beta x
beta y
dx
Beta [m]
Dispersion [m]
s [m]
6000
5000
4000
3000
2000
1000
0
3
2.5
2
1.5
1
0.5
0
-0.5
-1
0
200
400
600
800
1000
1200

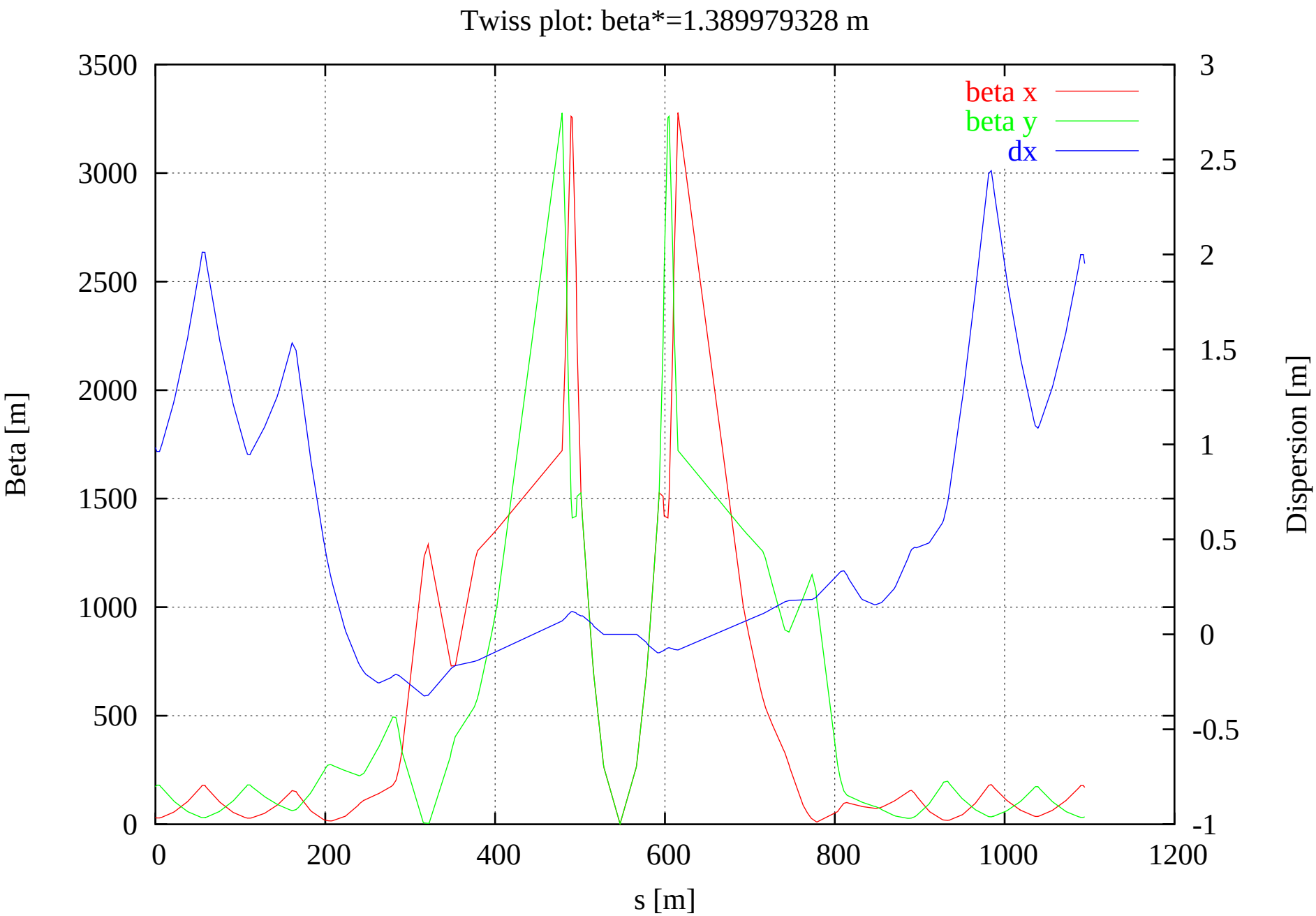

Twiss plot: beta*=0.8630678036 m
beta x
beta y
dx
Beta [m]
Dispersion [m]
s [m]
6000
5000
4000
3000
2000
1000
0
3
2.5
2
1.5
1
0.5
0
-0.5
-1
0
200
400
600
800
1000
1200

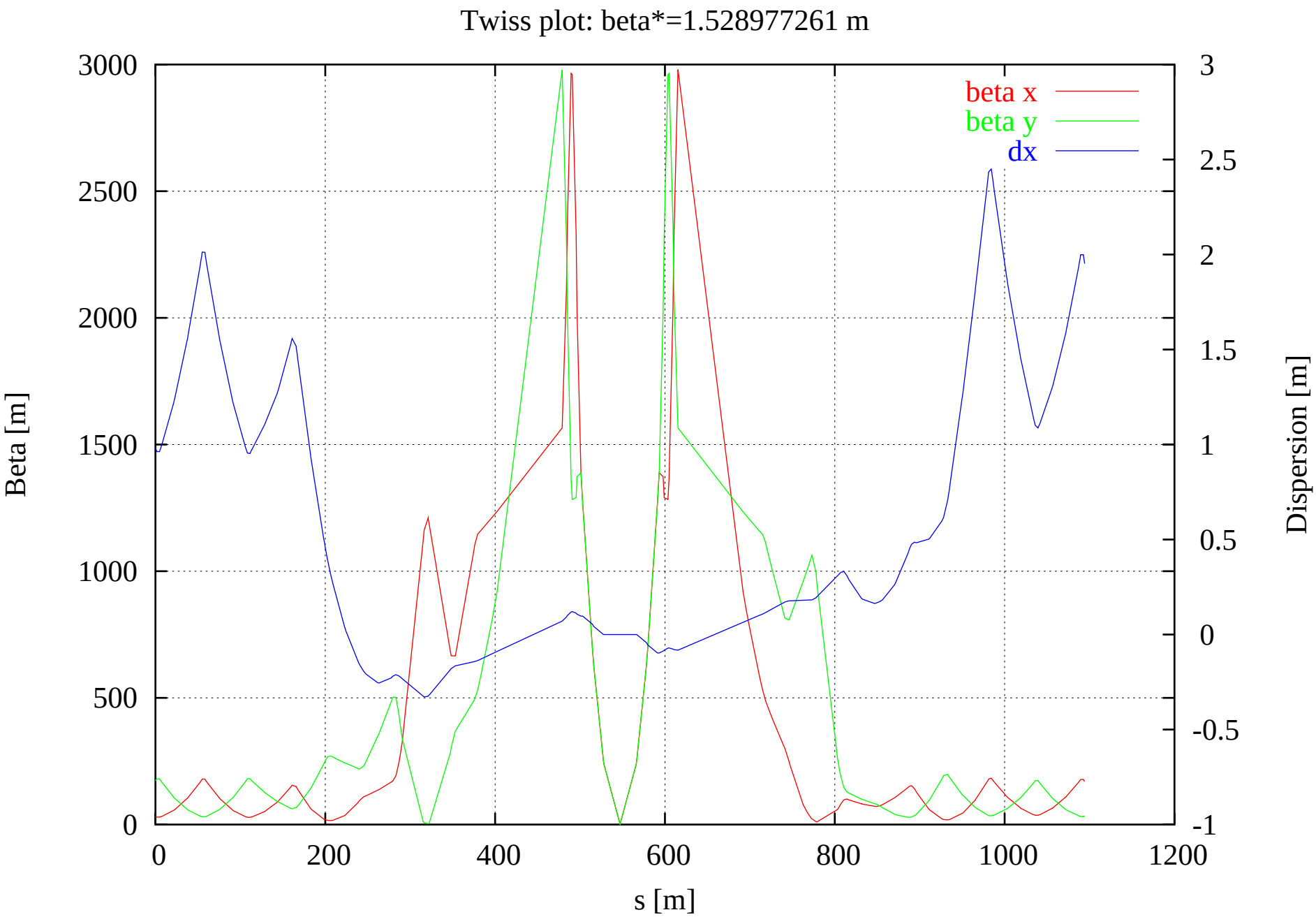

Twiss plot: beta*=0.949374584 m
beta x
beta y
dx
Beta [m]
Dispersion [m]
s [m]
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
3
2.5
2
1.5
1
0.5
0
-0.5
-1
0
200
400
600
800
1000
1200

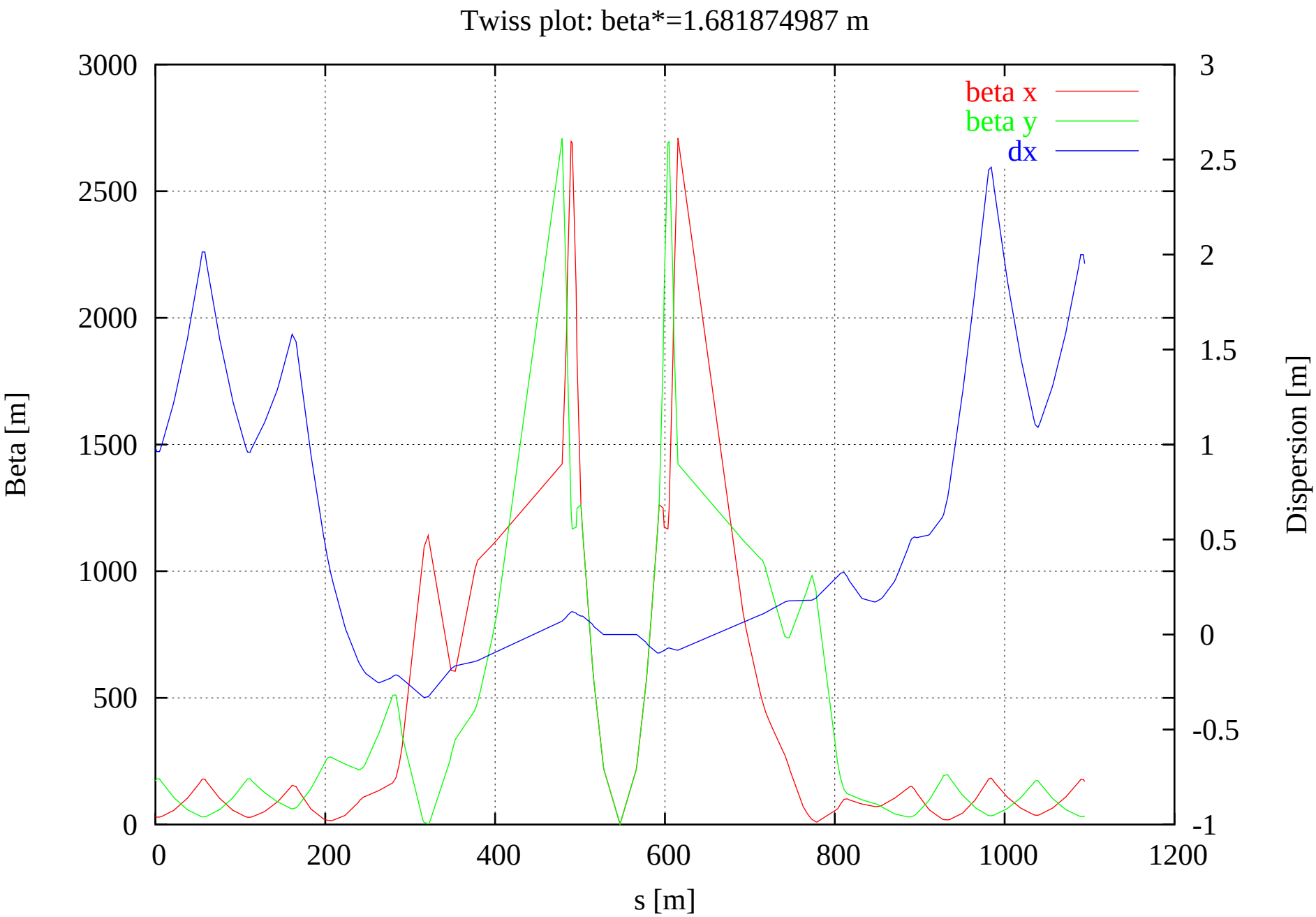

Twiss plot: beta*=1.044312042 m
beta x
beta y
dx
Beta [m]
Dispersion [m]
s [m]
0
500
1000
1500
2000
2500
3000
3500
4000
4500
-1
-0.5
0
0.5
1
1.5
2
2.5
3
0
200
400
600
800
1000
1200

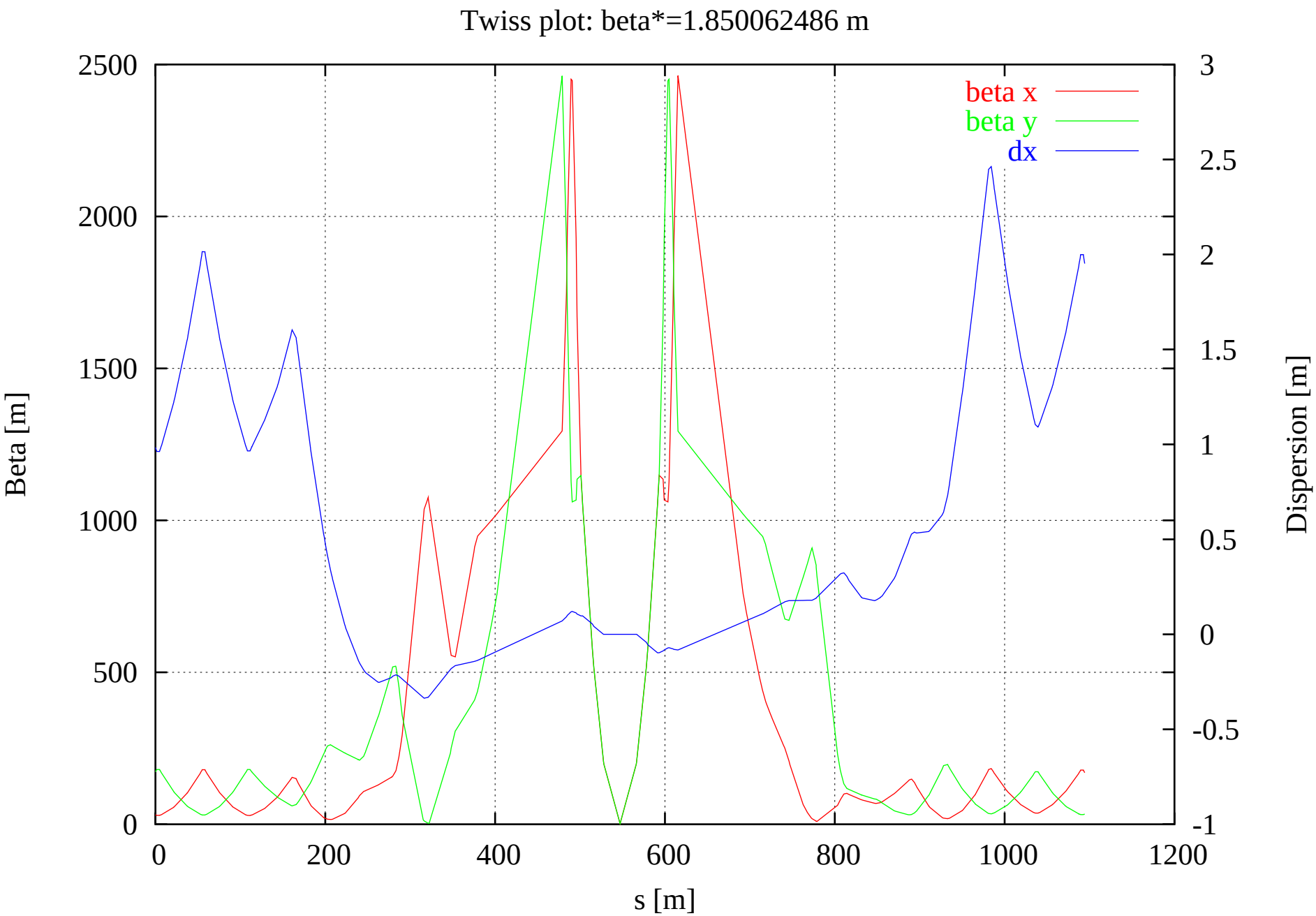

Twiss plot: beta*=1.148743247 m
beta x
beta y
dx
Beta [m]
Dispersion [m]
s [m]
4000
3500
3000
2500
2000
1500
1000
500
0
3
2.5
2
1.5
1
0.5
0
-0.5
-1
0
200
400
600
800
1000
1200

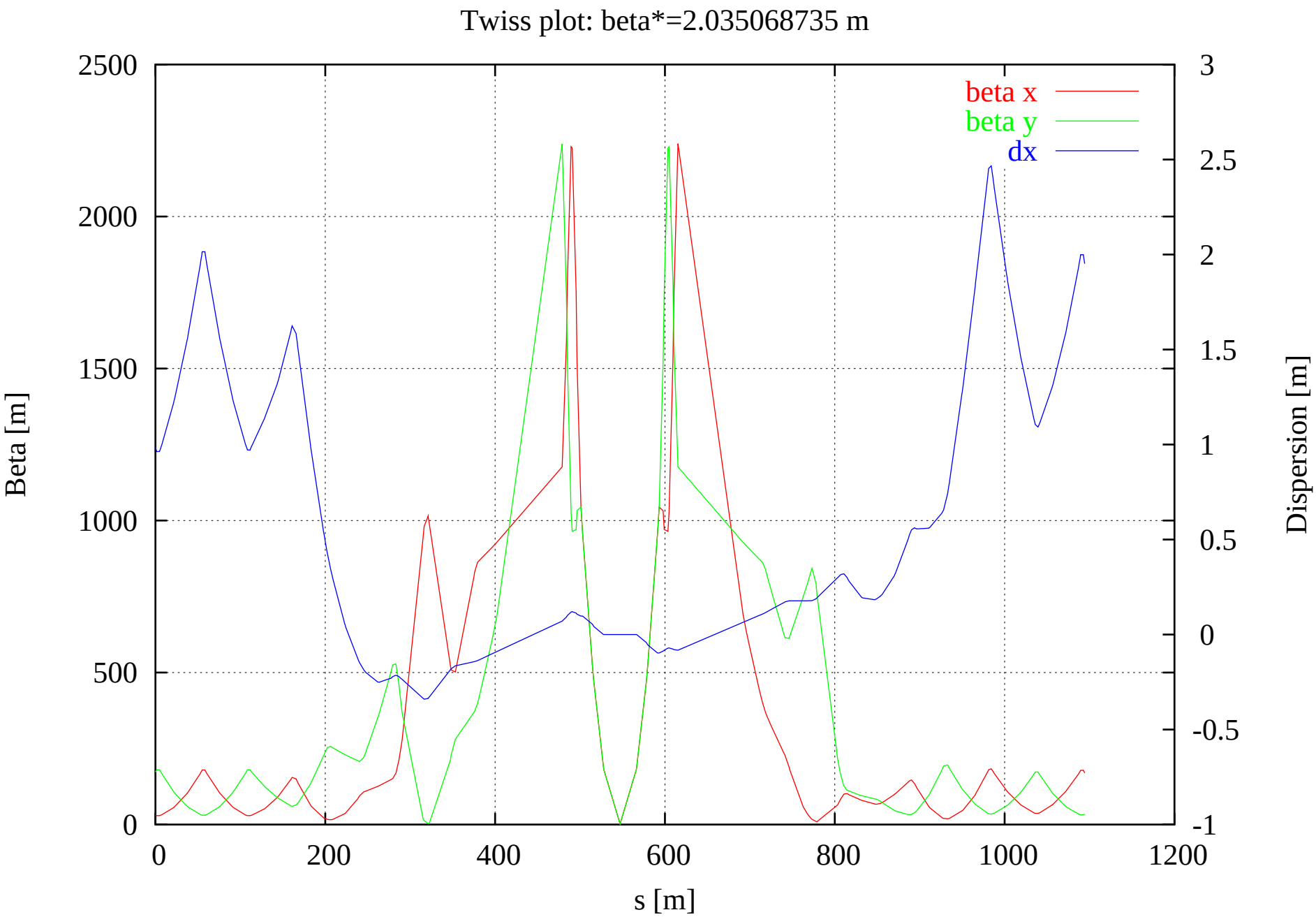

Twiss plot: beta*=1.263617571 m
beta x
beta y
dx
Beta [m]
Dispersion [m]
s [m]
4000
3500
3000
2500
2000
1500
1000
500
0
3
2.5
2
1.5
1
0.5
0
-0.5
-1
0
200
400
600
800
1000
1200

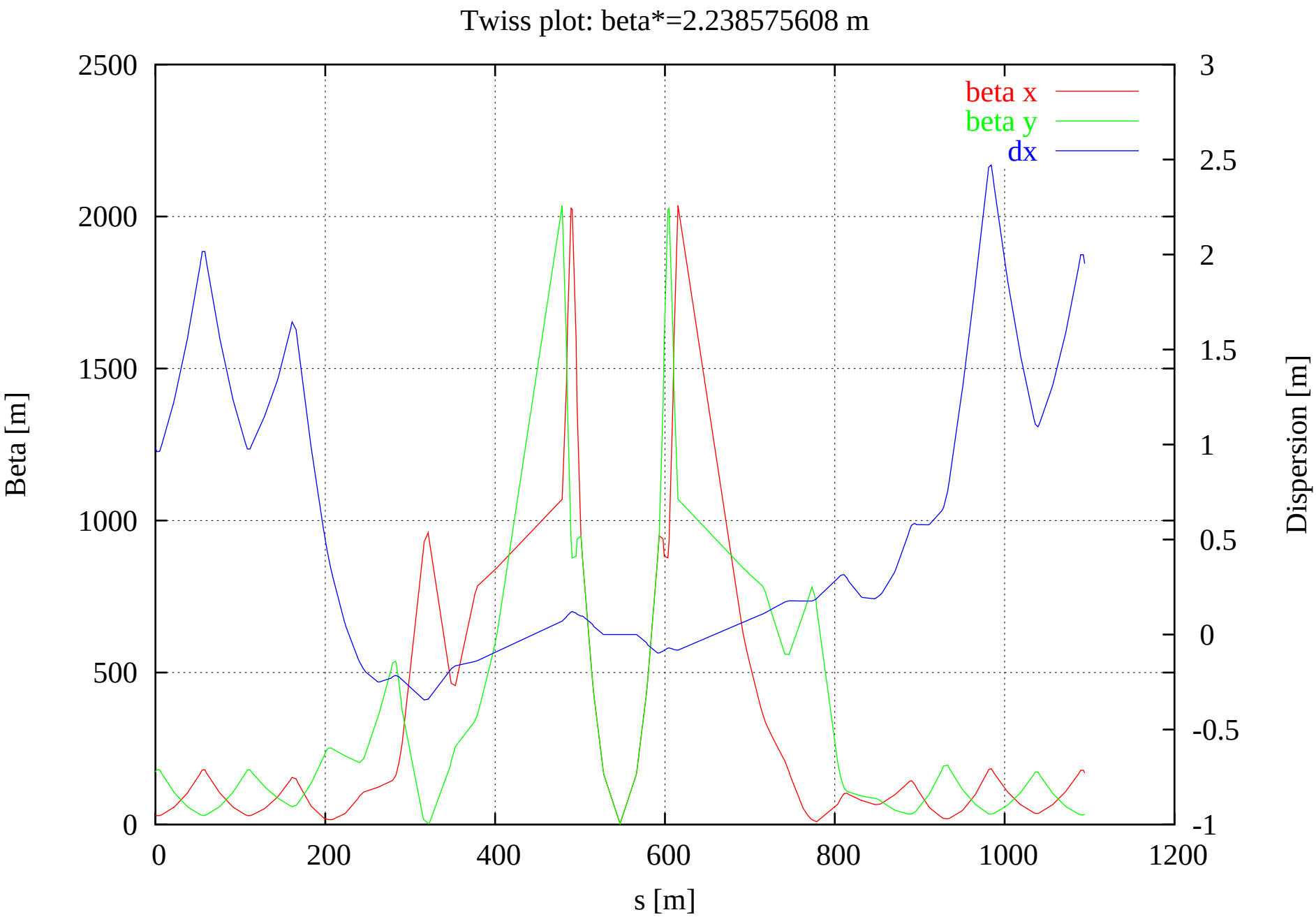

Twiss plot: beta*=1.389979328 m
beta x
beta y
dx
Beta [m]
Dispersion [m]
s [m]
3500
3000
2500
2000
1500
1000
500
0
3
2.5
2
1.5
1
0.5
0
-0.5
-1
0
200
400
600
800
1000
1200

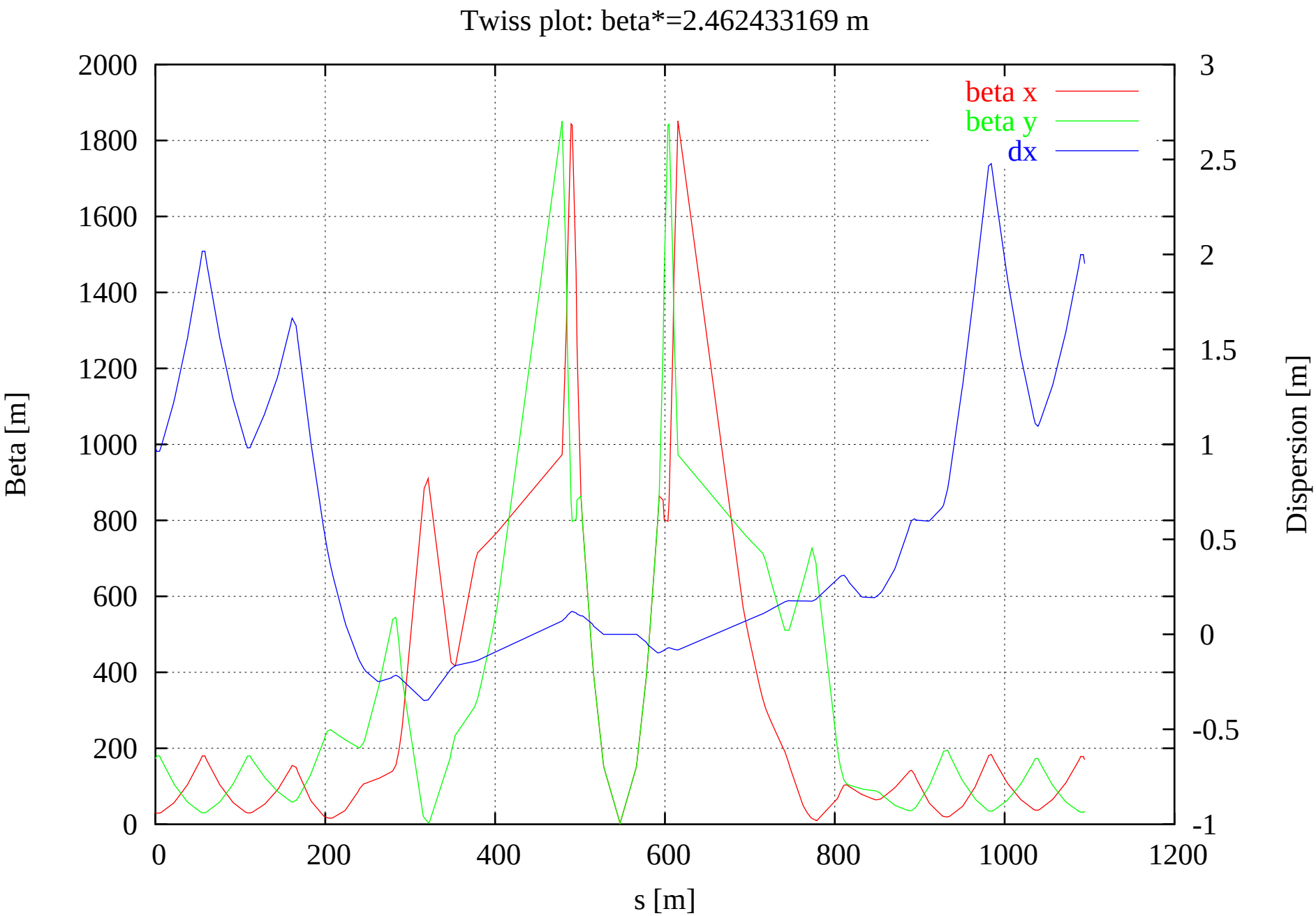

Twiss plot: beta*=1.528977261 m
beta x
beta y
dx
Beta [m]
Dispersion [m]
s [m]
3000
2500
2000
1500
1000
500
0
3
2.5
2
1.5
1
0.5
0
-0.5
-1
0
200
400
600
800
1000
1200

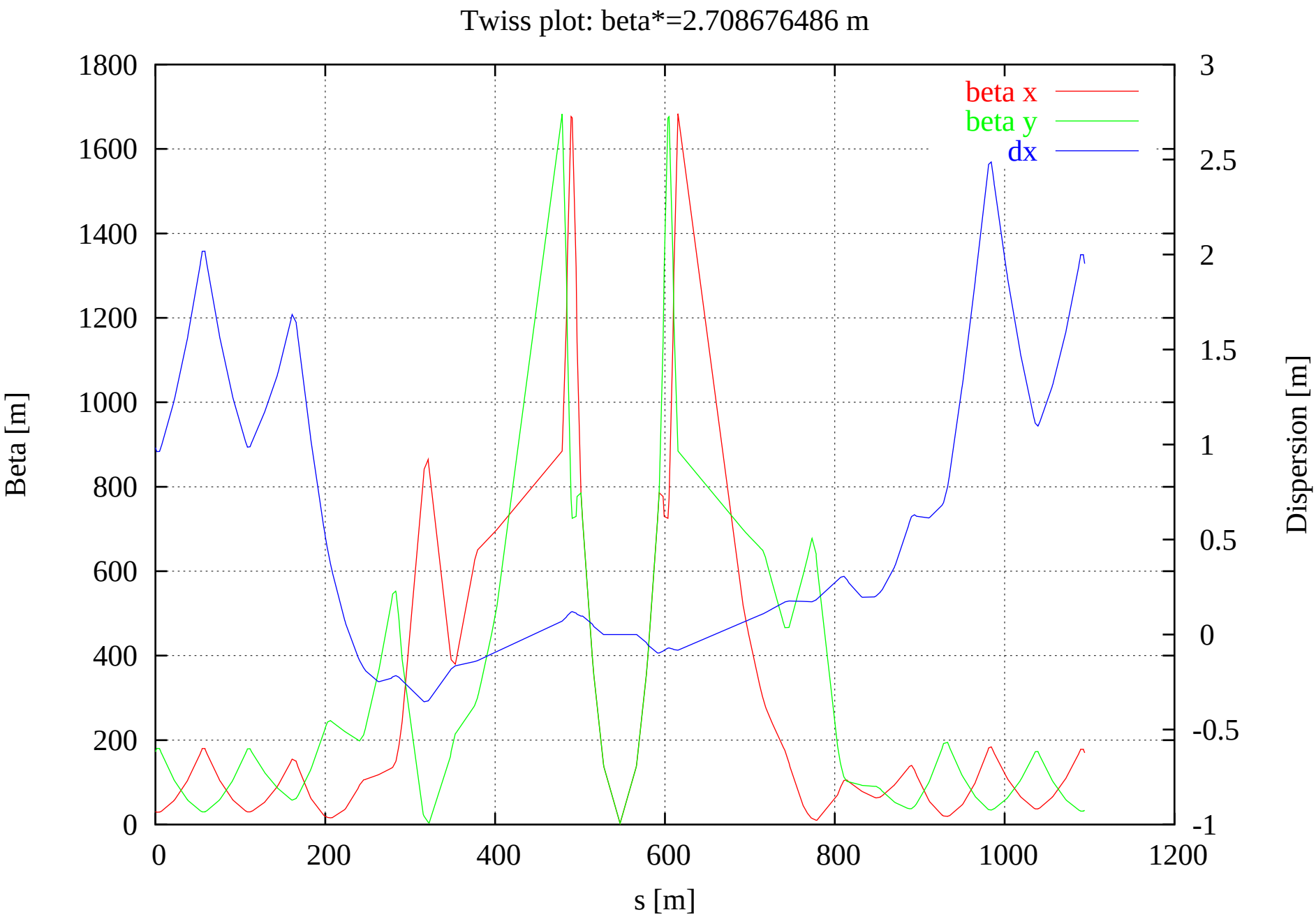

Twiss plot: beta*=1.681874987 m
beta x
beta y
dx
Beta [m]
Dispersion [m]
s [m]
3000
2500
2000
1500
1000
500
0
3
2.5
2
1.5
1
0.5
0
-0.5
-1
0
200
400
600
800
1000
1200

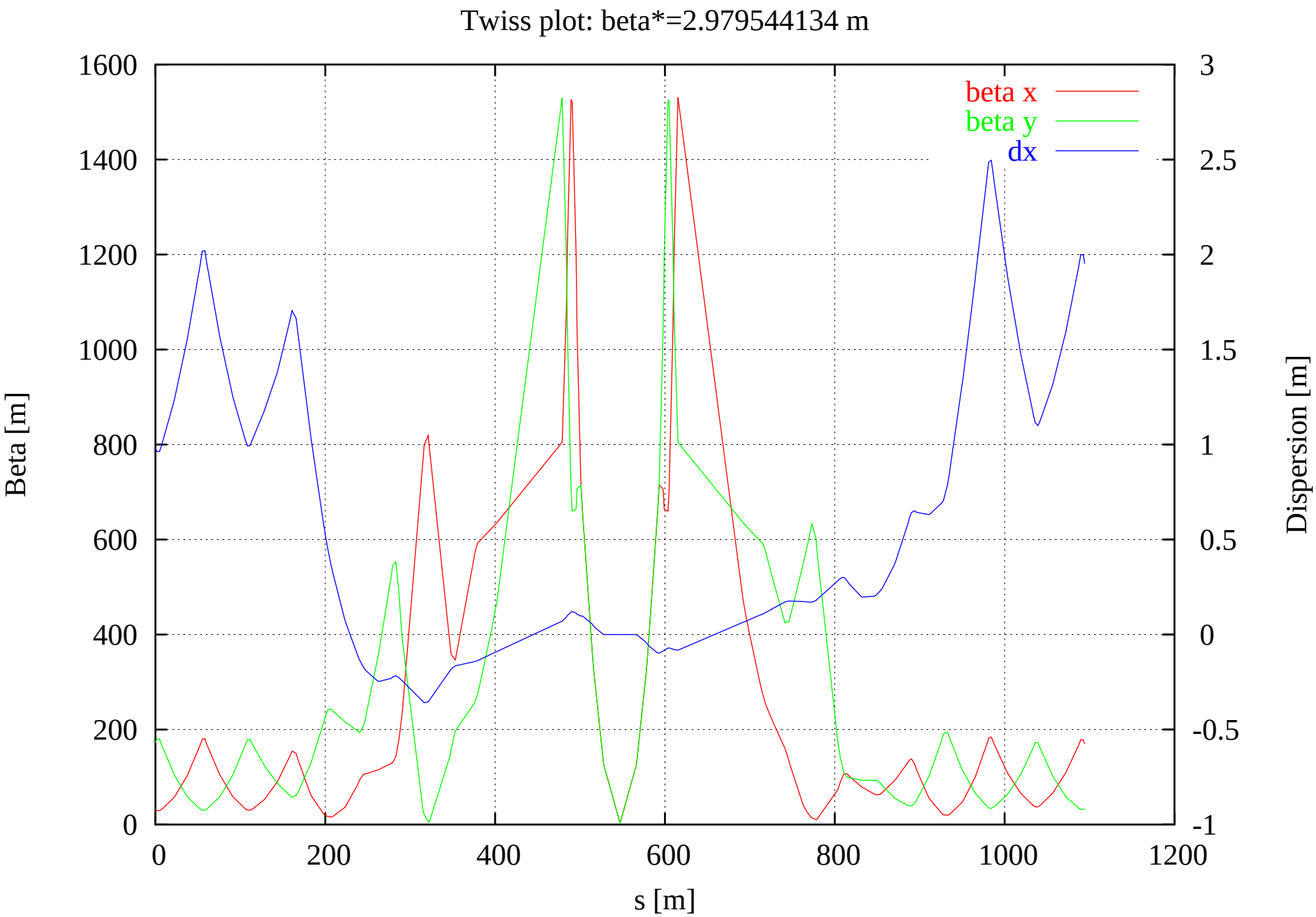

Twiss plot: beta*=1.850062486 m
beta x
beta y
dx
Beta [m]
Dispersion [m]
s [m]
2500
2000
1500
1000
500
0
3
2.5
2
1.5
1
0.5
0
-0.5
-1
0
200
400
600
800
1000
1200

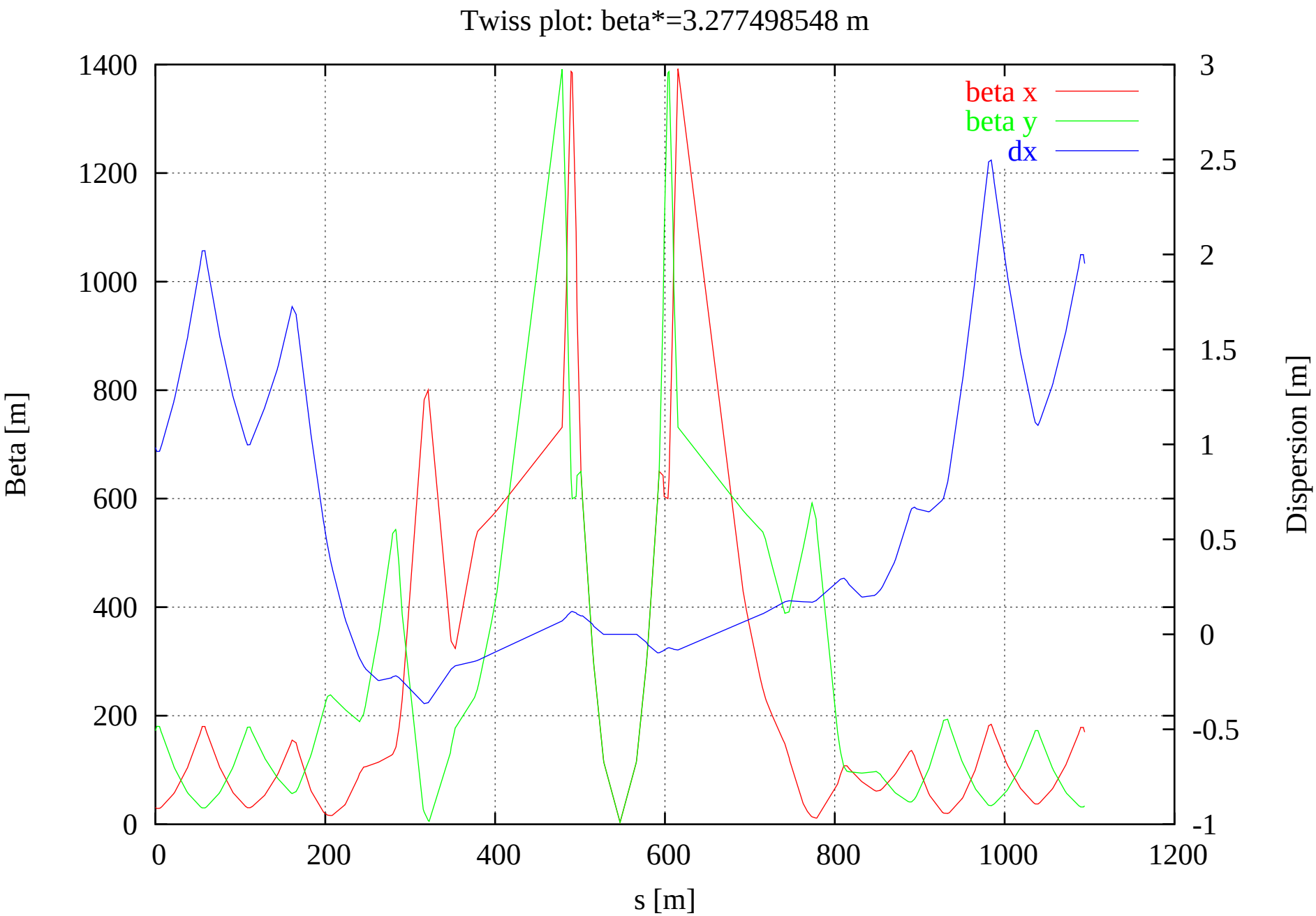

Twiss plot: beta*=2.035068735 m
beta x
beta y
dx
Beta [m]
Dispersion [m]
s [m]
2500
2000
1500
1000
500
0
3
2.5
2
1.5
1
0.5
0
-0.5
-1
0
200
400
600
800
1000
1200

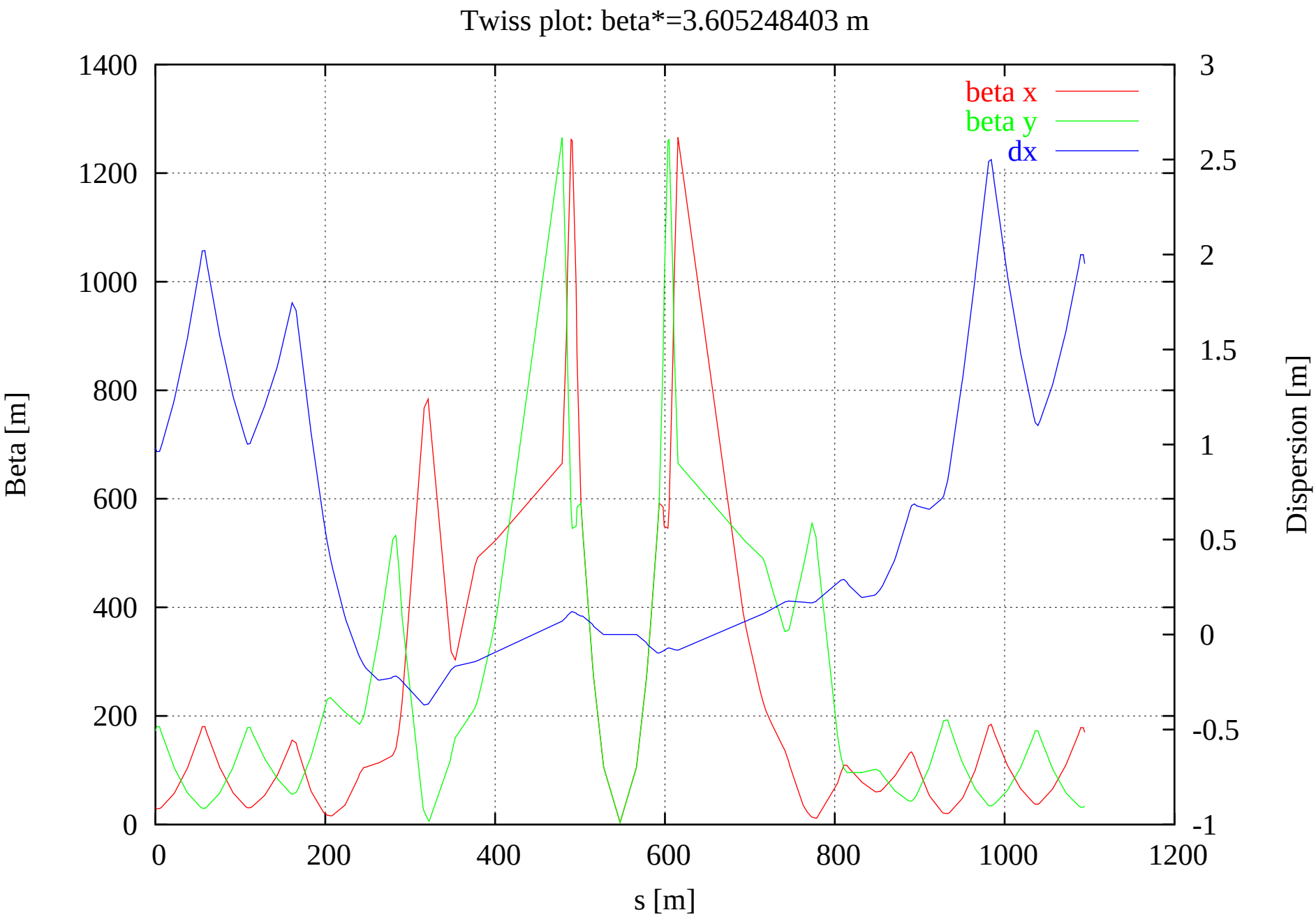

Twiss plot: beta*=2.238575608 m
beta x
beta y
dx
Beta [m]
Dispersion [m]
s [m]
2500
2000
1500
1000
500
0
3
2.5
2
1.5
1
0.5
0
-0.5
-1
0
200
400
600
800
1000
1200

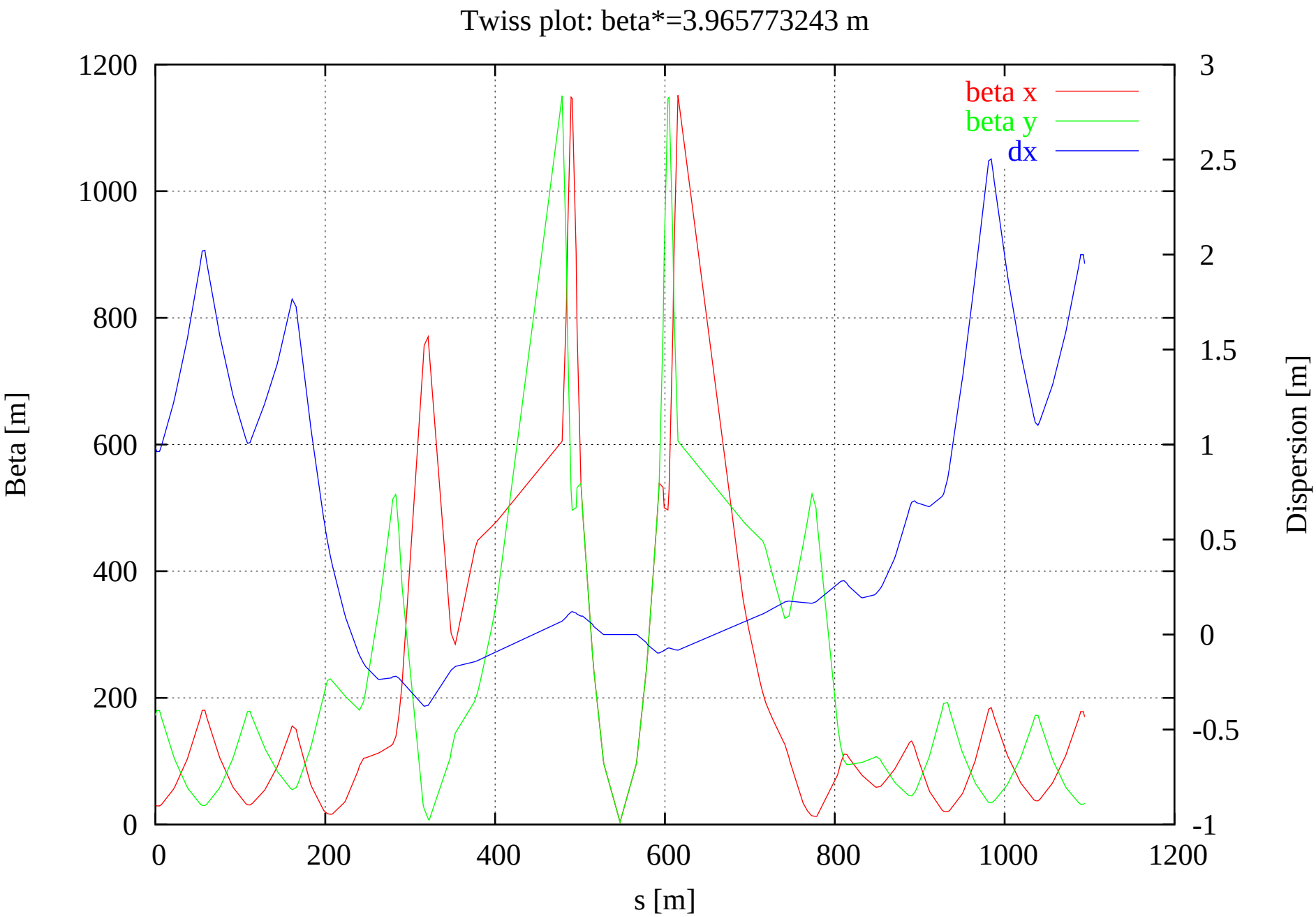

Twiss plot: beta*=2.462433169 m
beta x
beta y
dx
Beta [m]
Dispersion [m]
s [m]
2000
1800
1600
1400
1200
1000
800
600
400
200
0
3
2.5
2
1.5
1
0.5
0
-0.5
-1
0
200
400
600
800
1000
1200

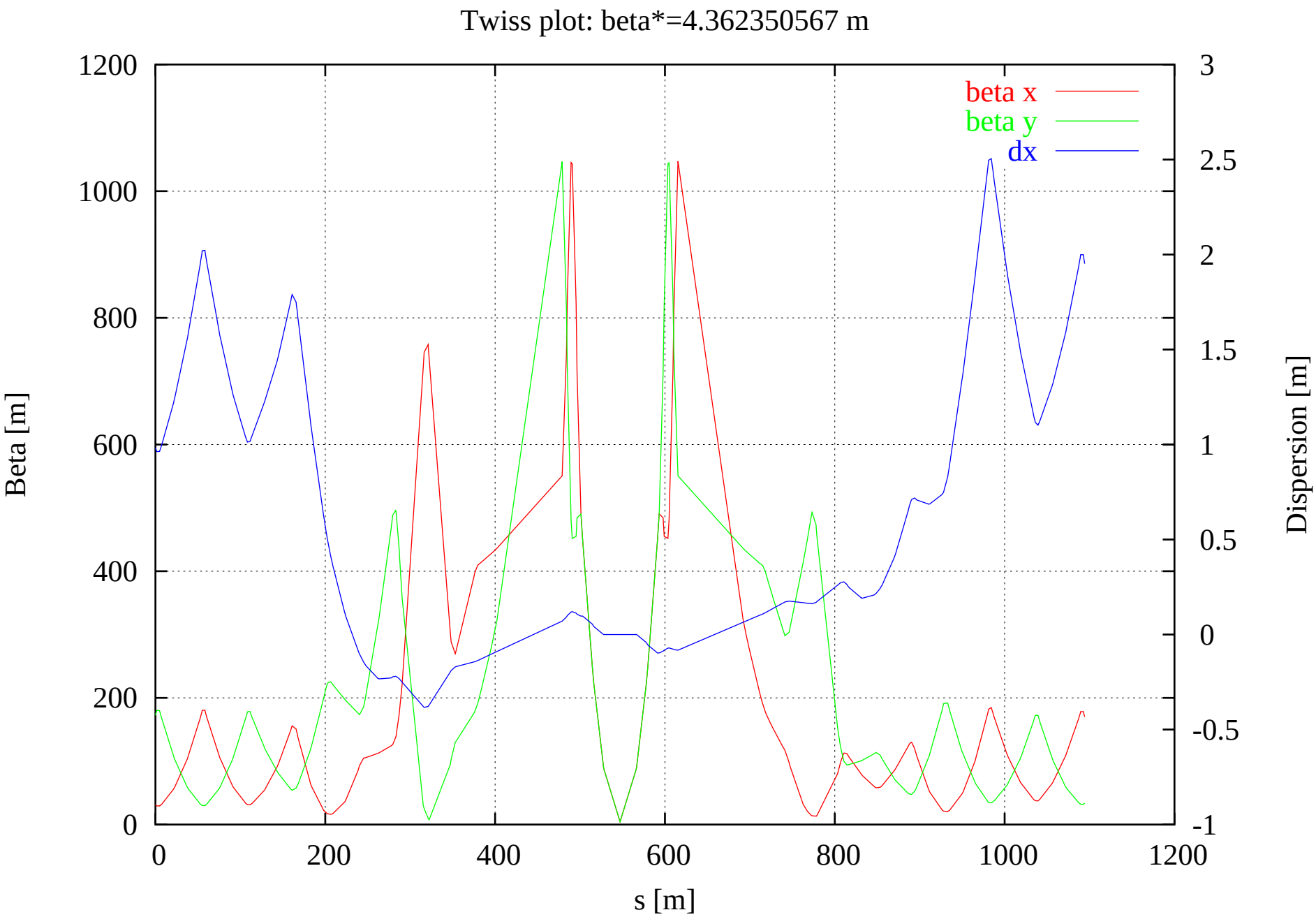

Twiss plot: beta*=2.708676486 m
beta x
beta y
dx
Beta [m]
Dispersion [m]
s [m]
0
200
400
600
800
1000
1200
1400
1600
1800
-1
-0.5
0
0.5
1
1.5
2
2.5
3

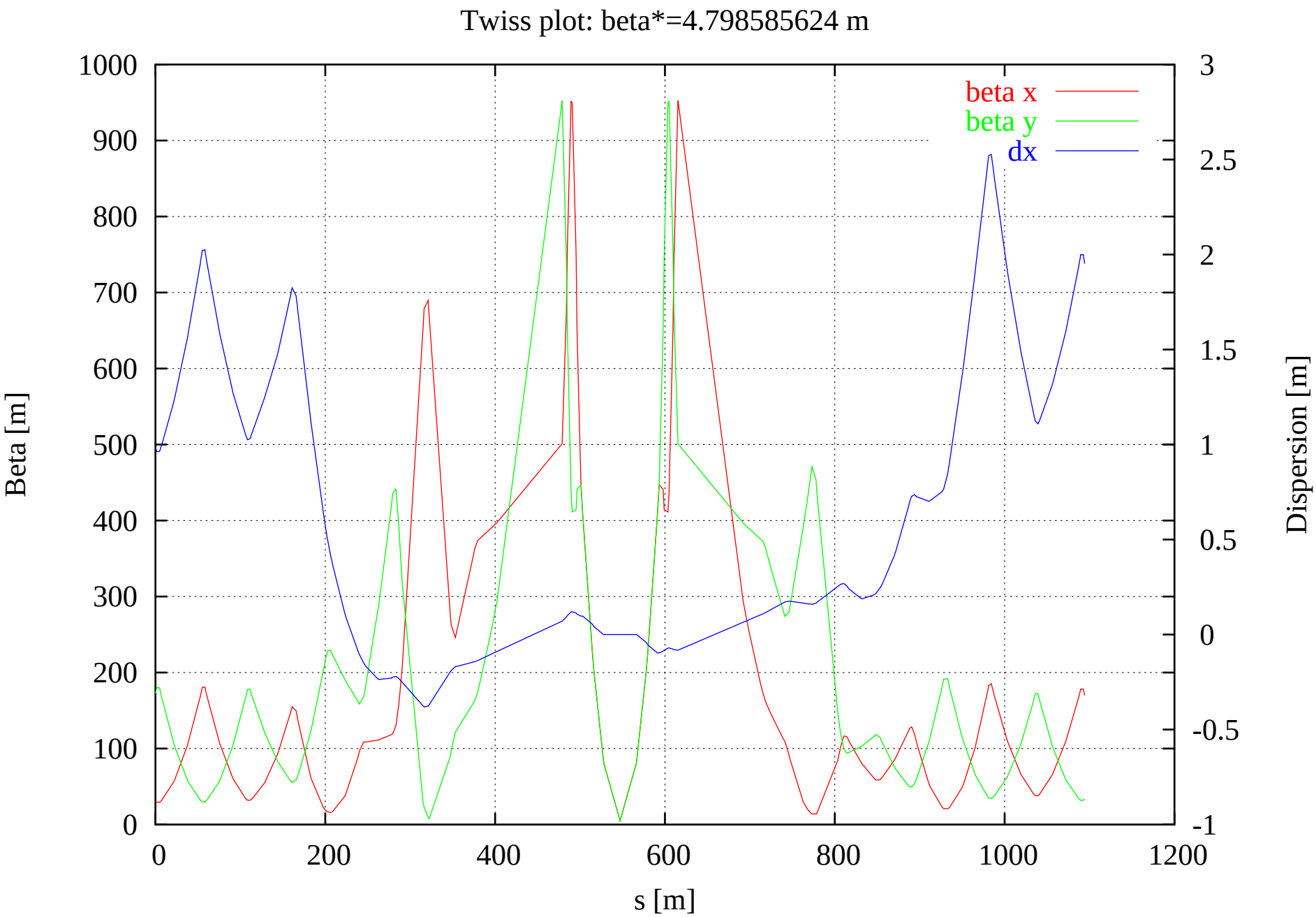

Twiss plot: beta*=2.979544134 m
beta x
beta y
dx
Beta [m]
Dispersion [m]
s [m]
0
200
400
600
800
1000
1200
1400
1600
-1
-0.5
0
0.5
1
1.5
2
2.5
3

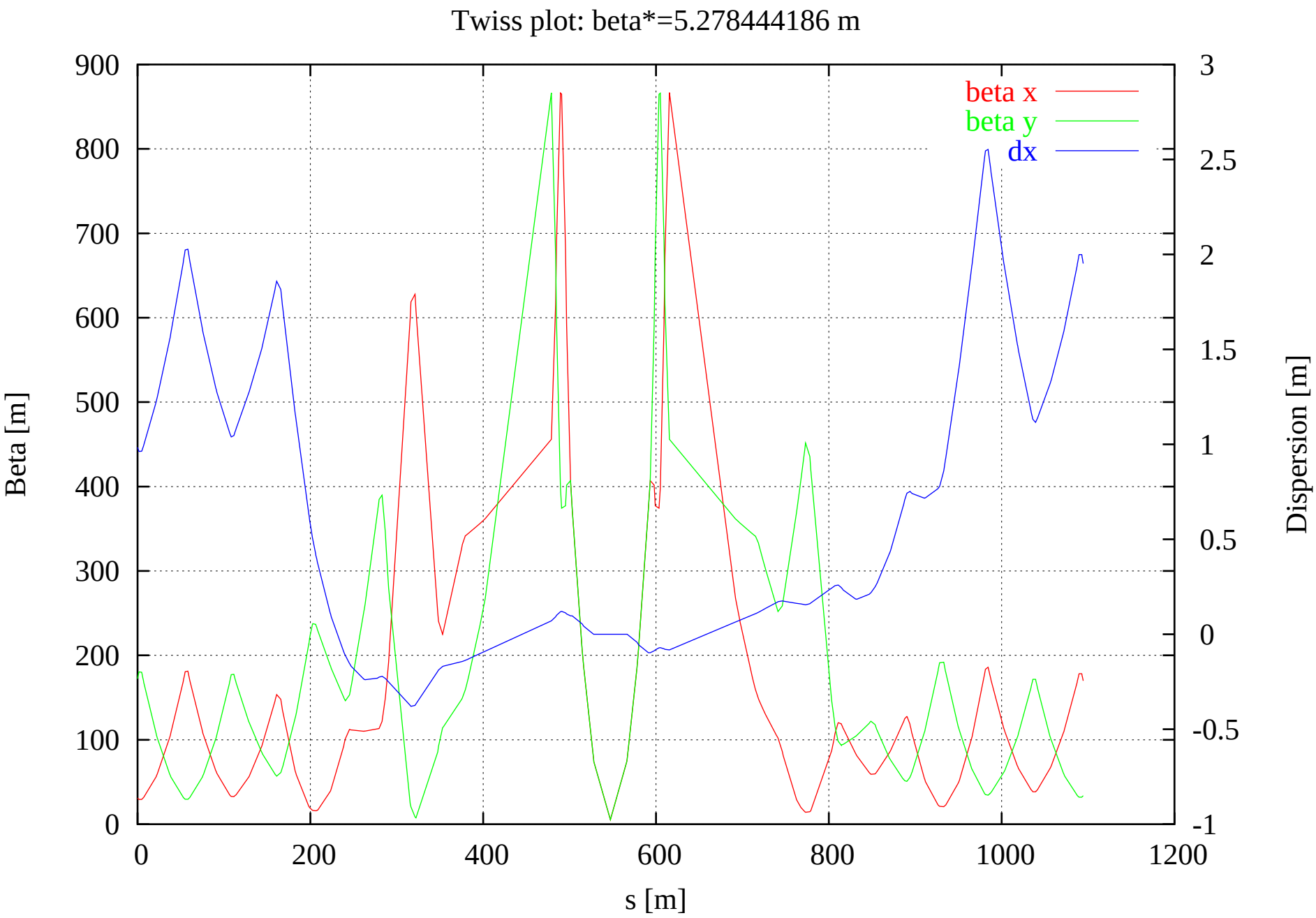

Twiss plot: beta*=3.277498548 m
beta x
beta y
dx
Beta [m]
Dispersion [m]
s [m]
0
200
400
600
800
1000
1200
1400
-1
-0.5
0
0.5
1
1.5
2
2.5
3

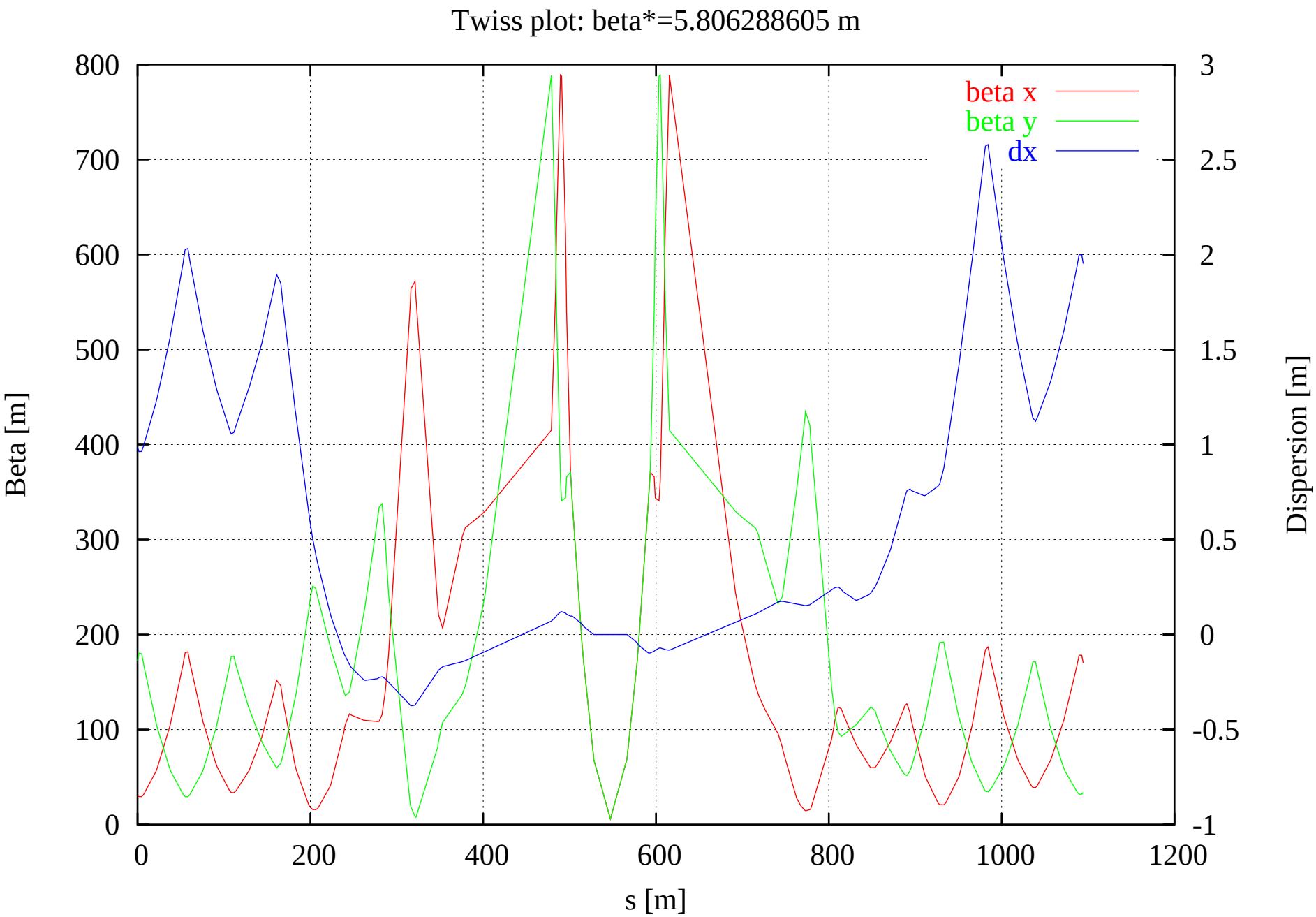

Twiss plot: beta*=3.605248403 m
beta x
beta y
dx
Beta [m]
Dispersion [m]
s [m]
0
200
400
600
800
1000
1200
1400
-1
-0.5
0
0.5
1
1.5
2
2.5
3

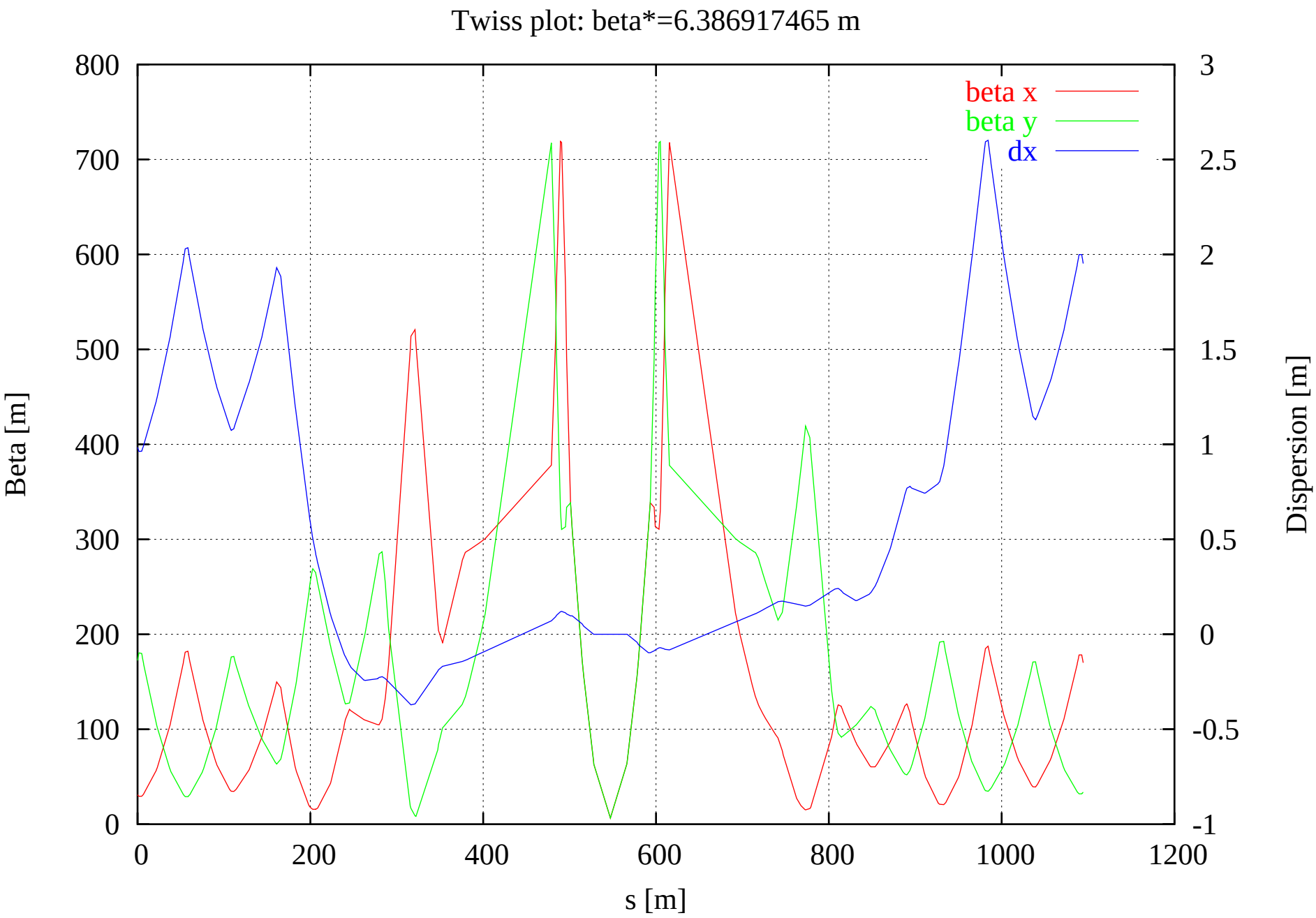

Twiss plot: beta*=3.965773243 m
beta x
beta y
dx
Beta [m]
Dispersion [m]
s [m]
0
200
400
600
800
1000
1200
-1
-0.5
0
0.5
1
1.5
2
2.5
3

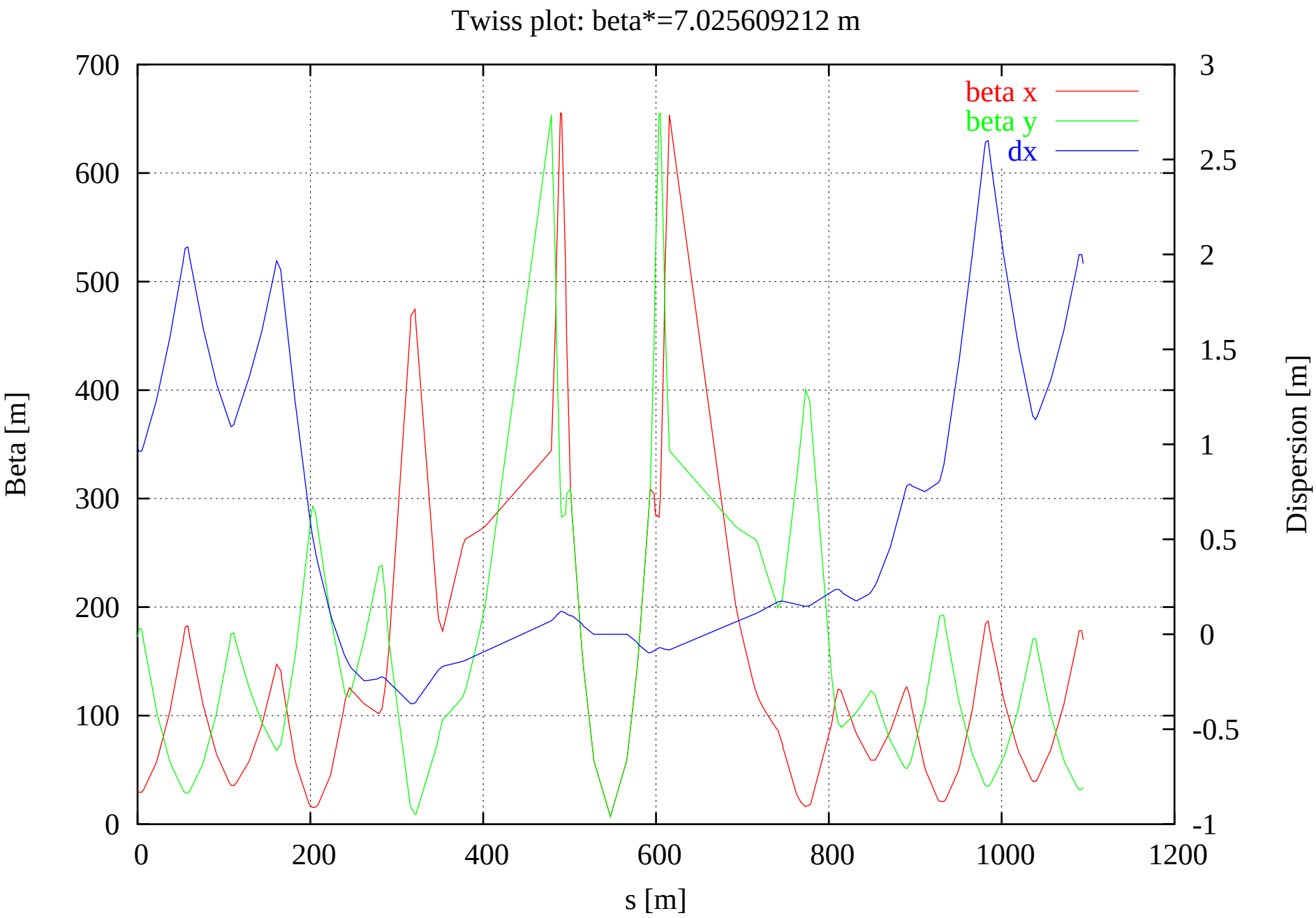

Twiss plot: beta*=4.362350567 m
beta x
beta y
dx
Beta [m]
Dispersion [m]
s [m]
0
200
400
600
800
1000
1200
-1
-0.5
0
0.5
1
1.5
2
2.5
3

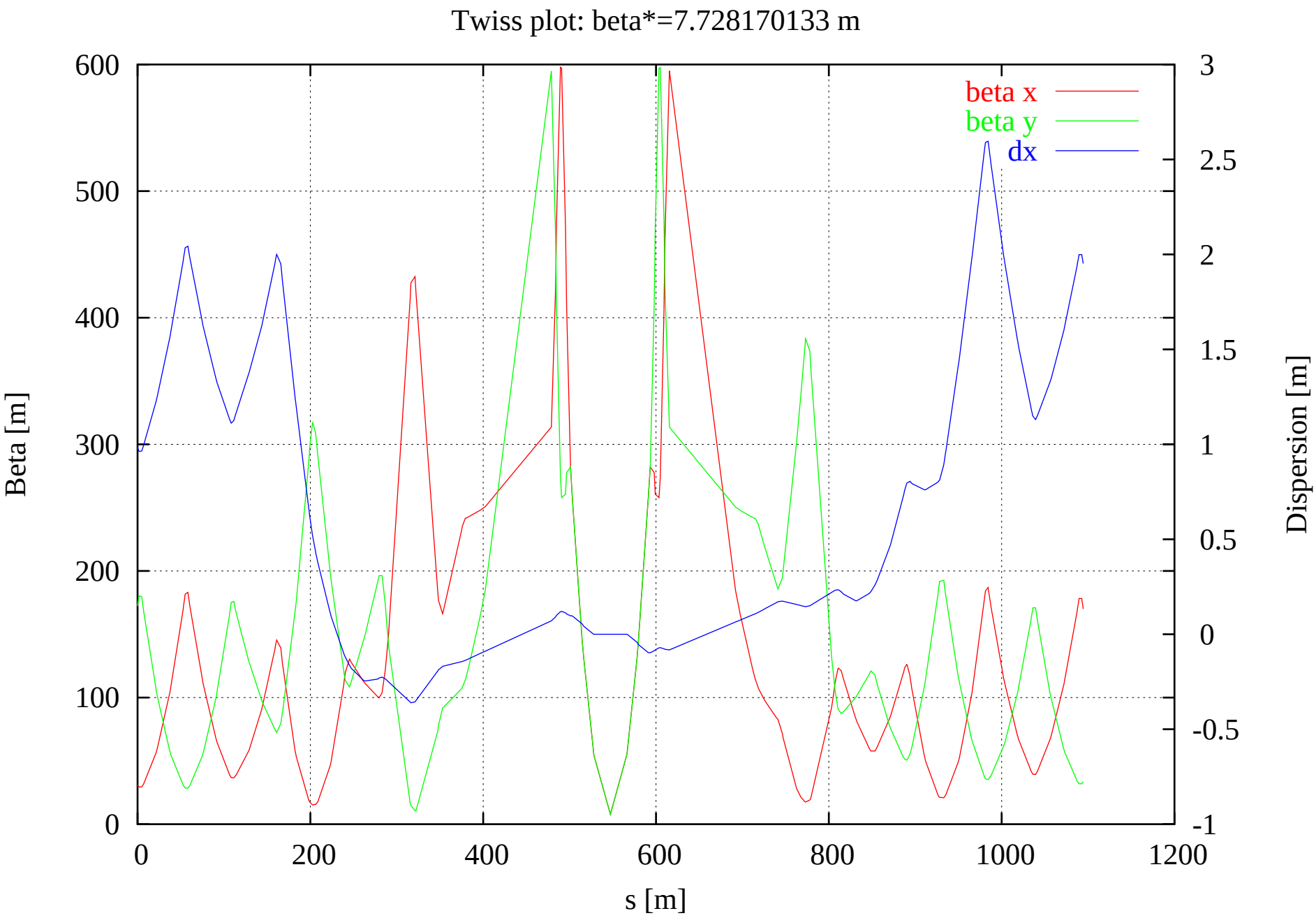

Twiss plot: beta*=4.798585624 m
beta x
beta y
dx
Beta [m]
Dispersion [m]
s [m]
0
100
200
300
400
500
600
700
800
900
1000
-1
-0.5
0
0.5
1
1.5
2
2.5
3
0
200
400
600
800
1000
1200

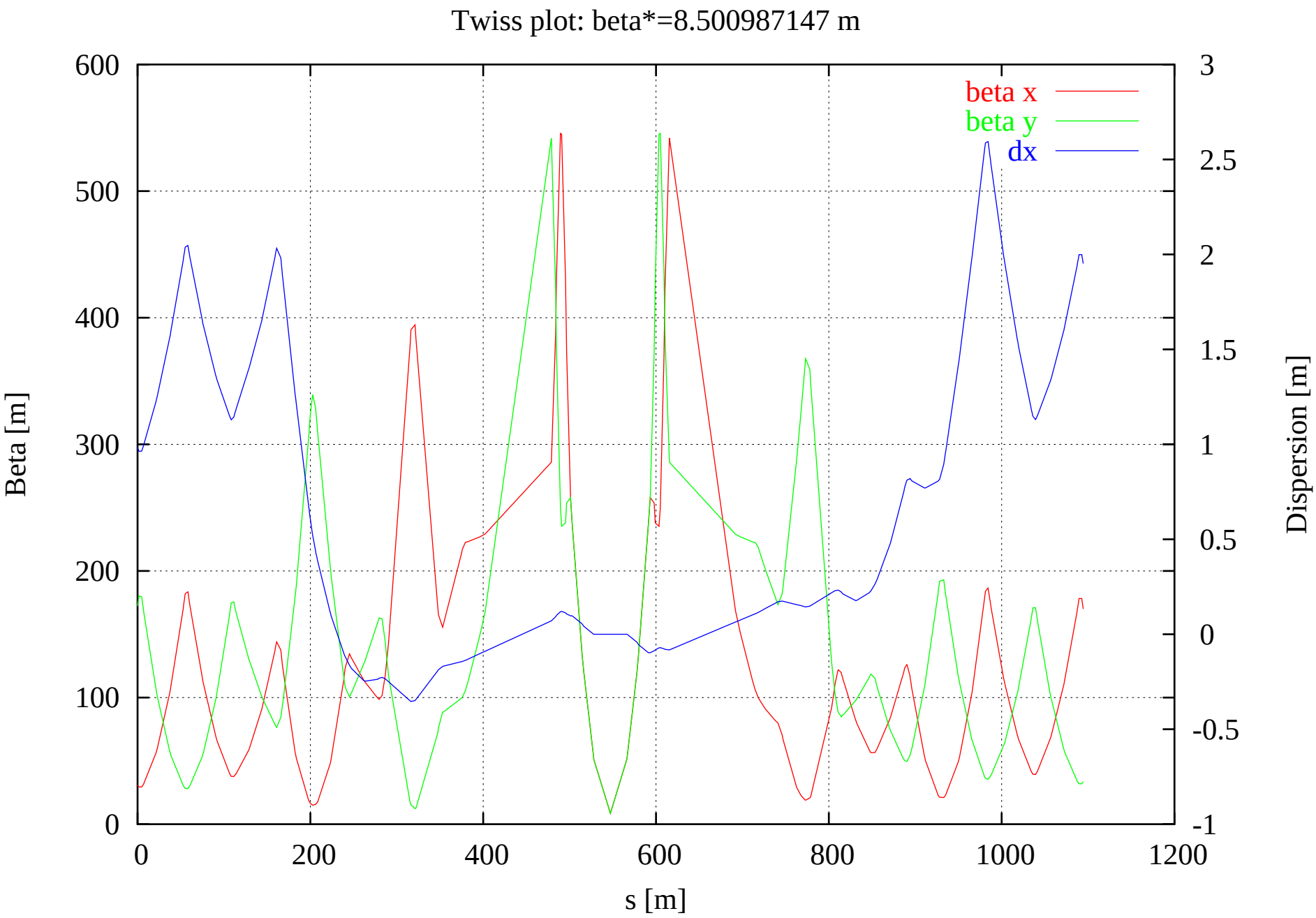

Twiss plot: beta*=5.278444186 m
beta x
beta y
dx
Beta [m]
Dispersion [m]
s [m]
0
100
200
300
400
500
600
700
800
900
-1
-0.5
0
0.5
1
1.5
2
2.5
3
0
200
400
600
800
1000
1200

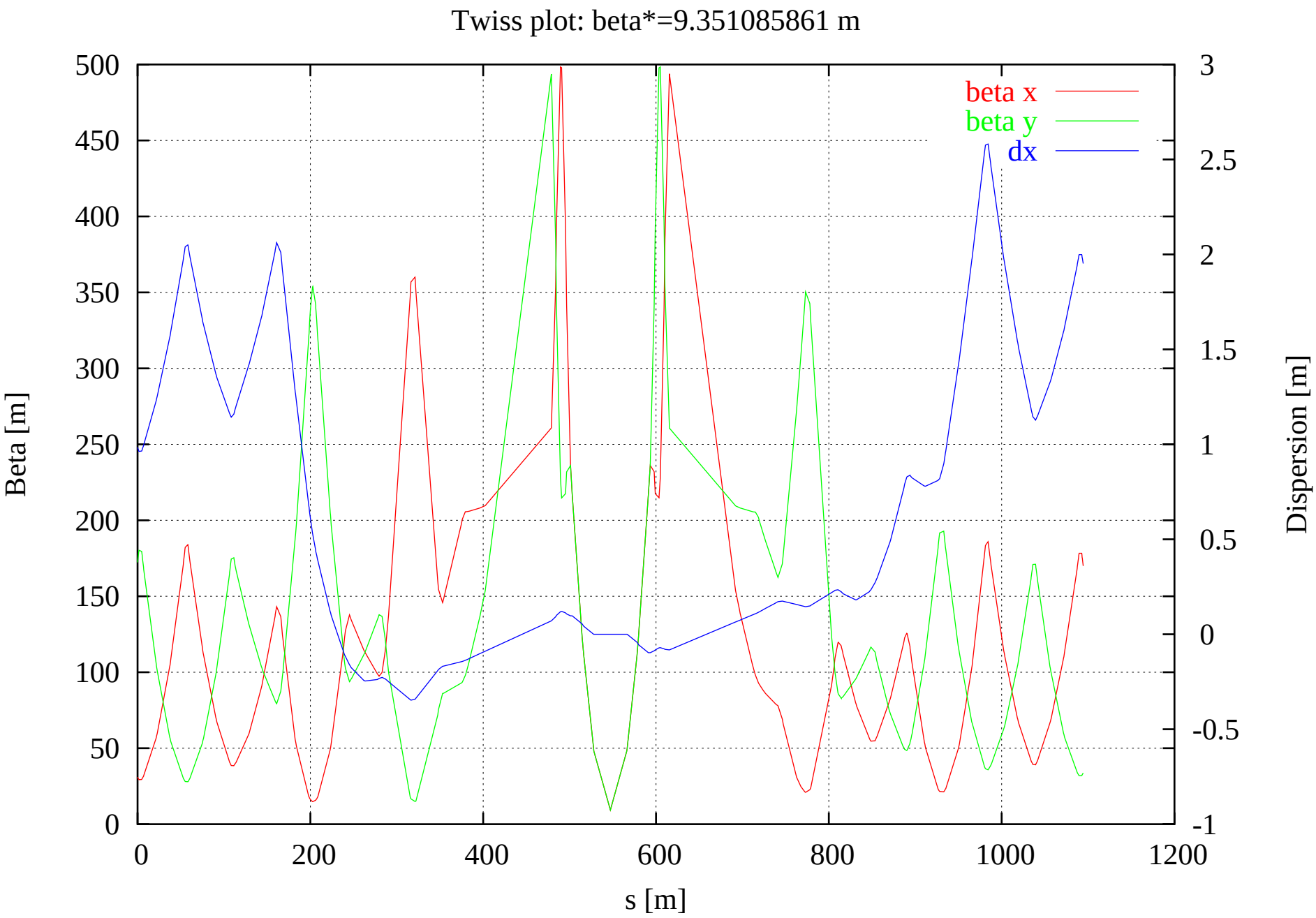

Twiss plot: beta*=5.806288605 m
beta x
beta y
dx
Beta [m]
Dispersion [m]
s [m]
0
100
200
300
400
500
600
700
800
-1
-0.5
0
0.5
1
1.5
2
2.5
3
0
200
400
600
800
1000
1200

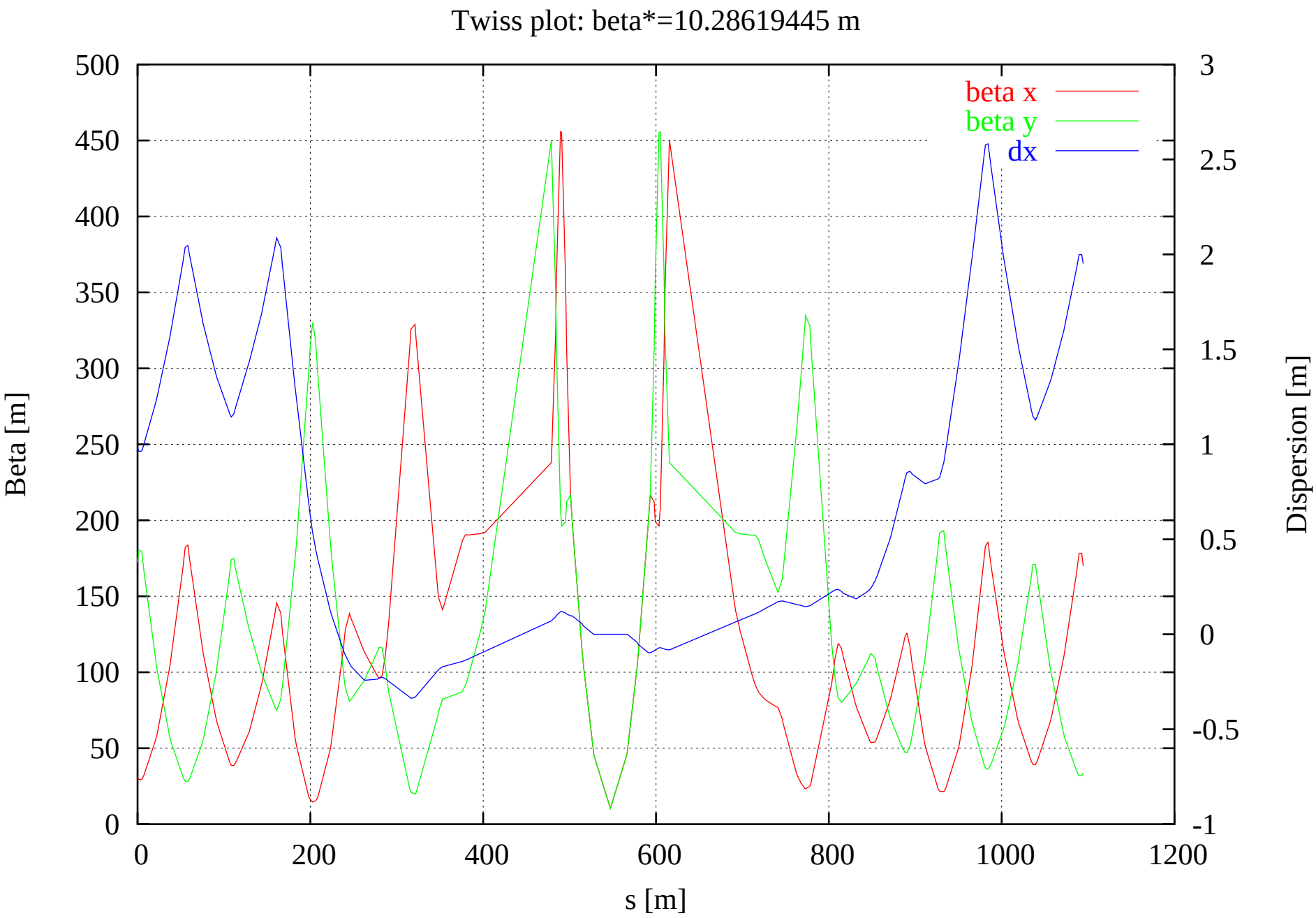

Twiss plot: beta*=6.386917465 m
beta x
beta y
dx
Beta [m]
Dispersion [m]
s [m]
0
100
200
300
400
500
600
700
800
-1
-0.5
0
0.5
1
1.5
2
2.5
3
0
200
400
600
800
1000
1200

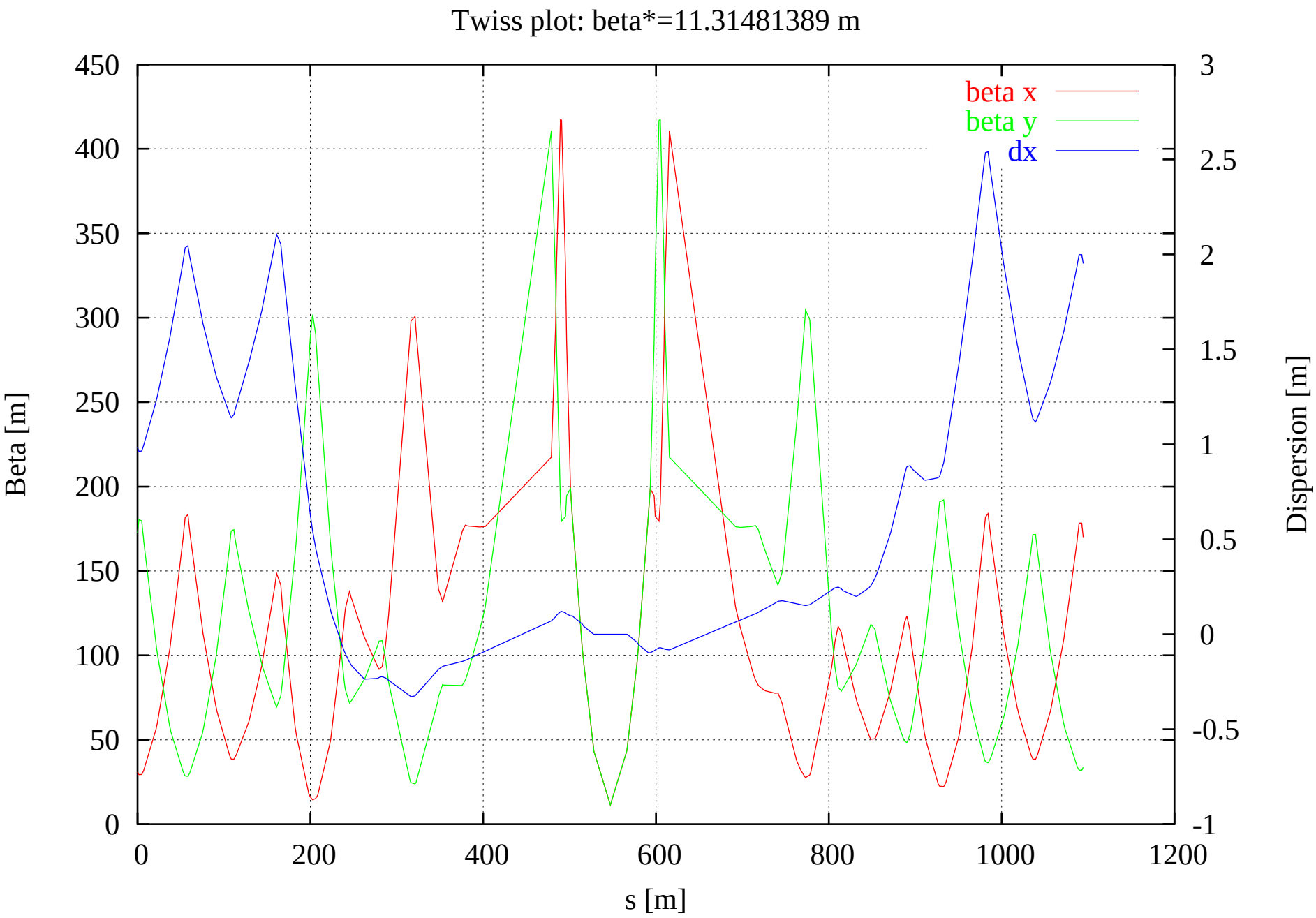

Twiss plot: beta*=7.025609212 m
beta x
beta y
dx
Beta [m]
Dispersion [m]
s [m]
0
100
200
300
400
500
600
700
-1
-0.5
0
0.5
1
1.5
2
2.5
3
0
200
400
600
800
1000
1200

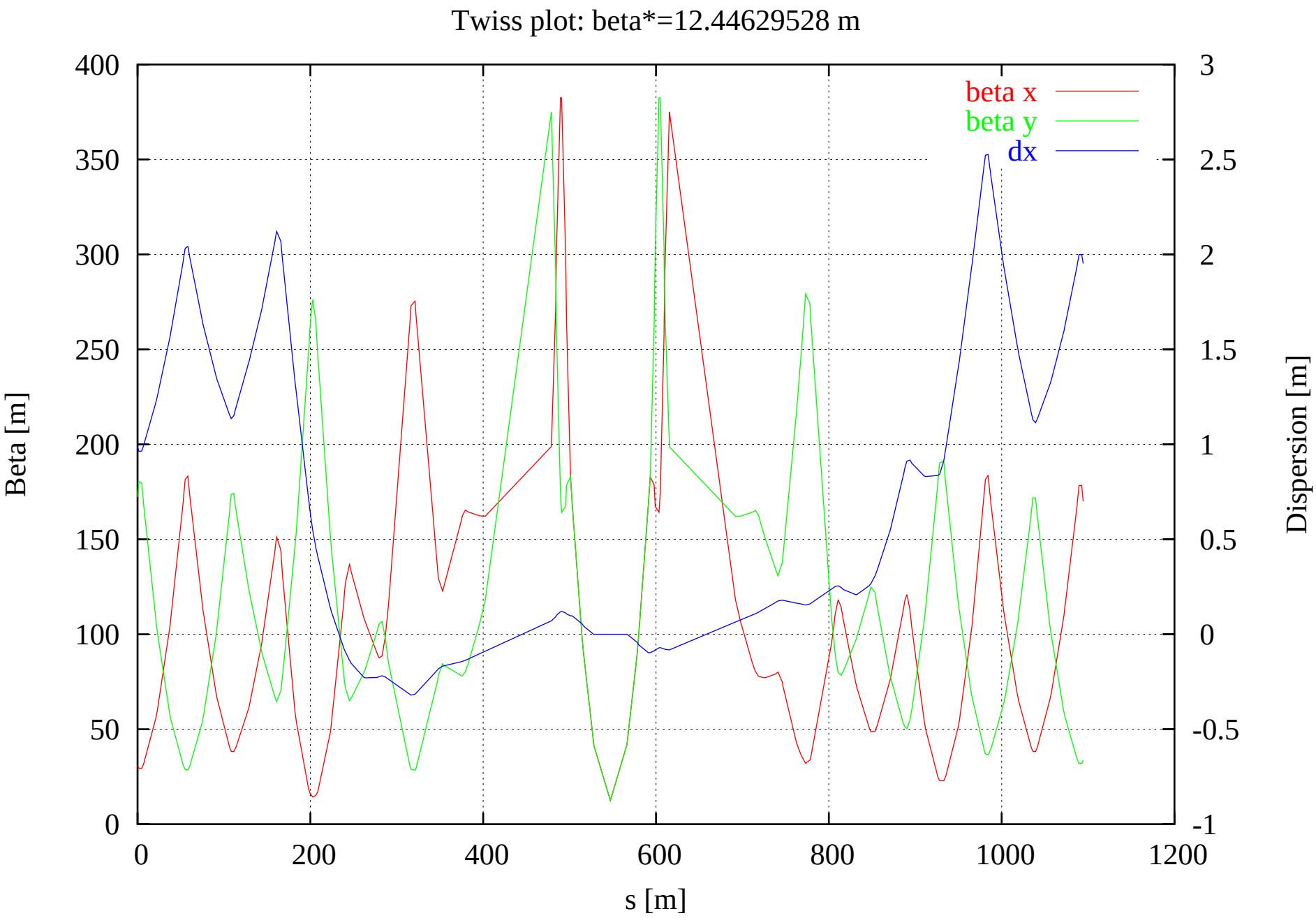

Twiss plot: beta*=7.728170133 m
beta x
beta y
dx
Beta [m]
Dispersion [m]
s [m]
0
100
200
300
400
500
600
-1
-0.5
0
0.5
1
1.5
2
2.5
3
0
200
400
600
800
1000
1200

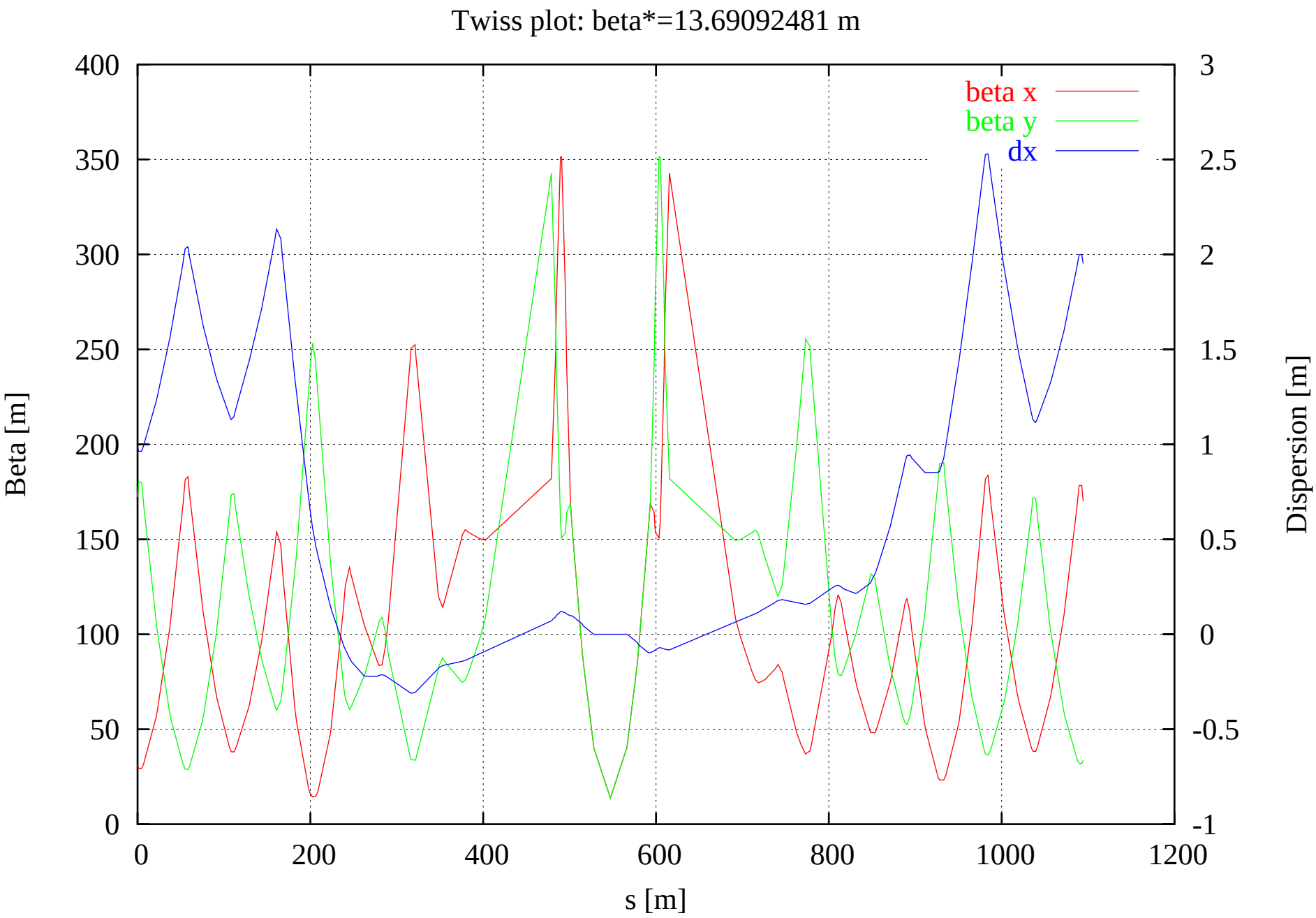

Twiss plot: beta*=8.500987147 m
beta x
beta y
dx
Beta [m]
Dispersion [m]
s [m]
600
500
400
300
200
100
0
3
2.5
2
1.5
1
0.5
0
-0.5
-1
0
200
400
600
800
1000
1200

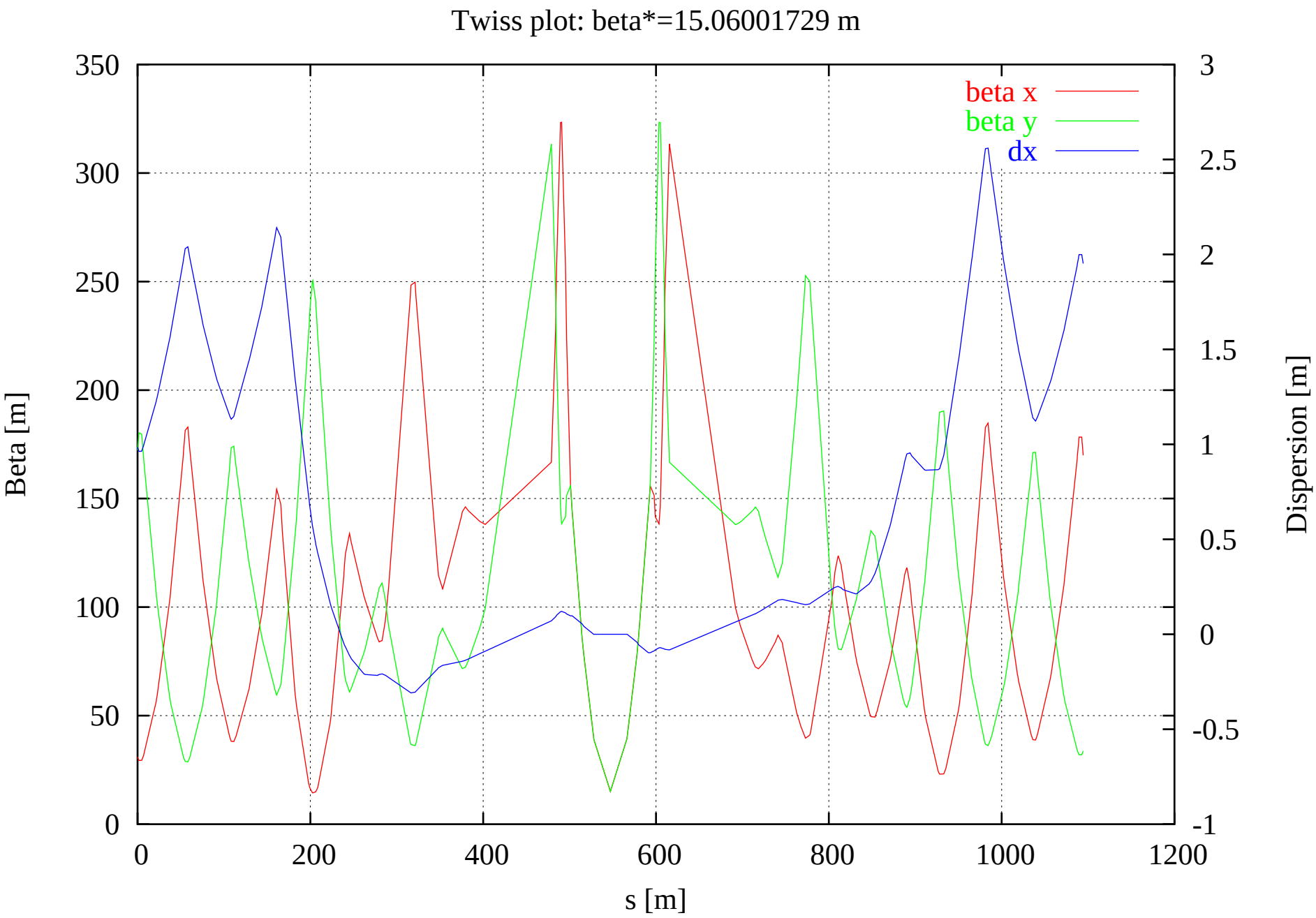

Twiss plot: beta*=9.351085861 m
beta x
beta y
dx
Beta [m]
Dispersion [m]
s [m]
0
50
100
150
200
250
300
350
400
450
500
-1
-0.5
0
0.5
1
1.5
2
2.5
3
0
200
400
600
800
1000
1200

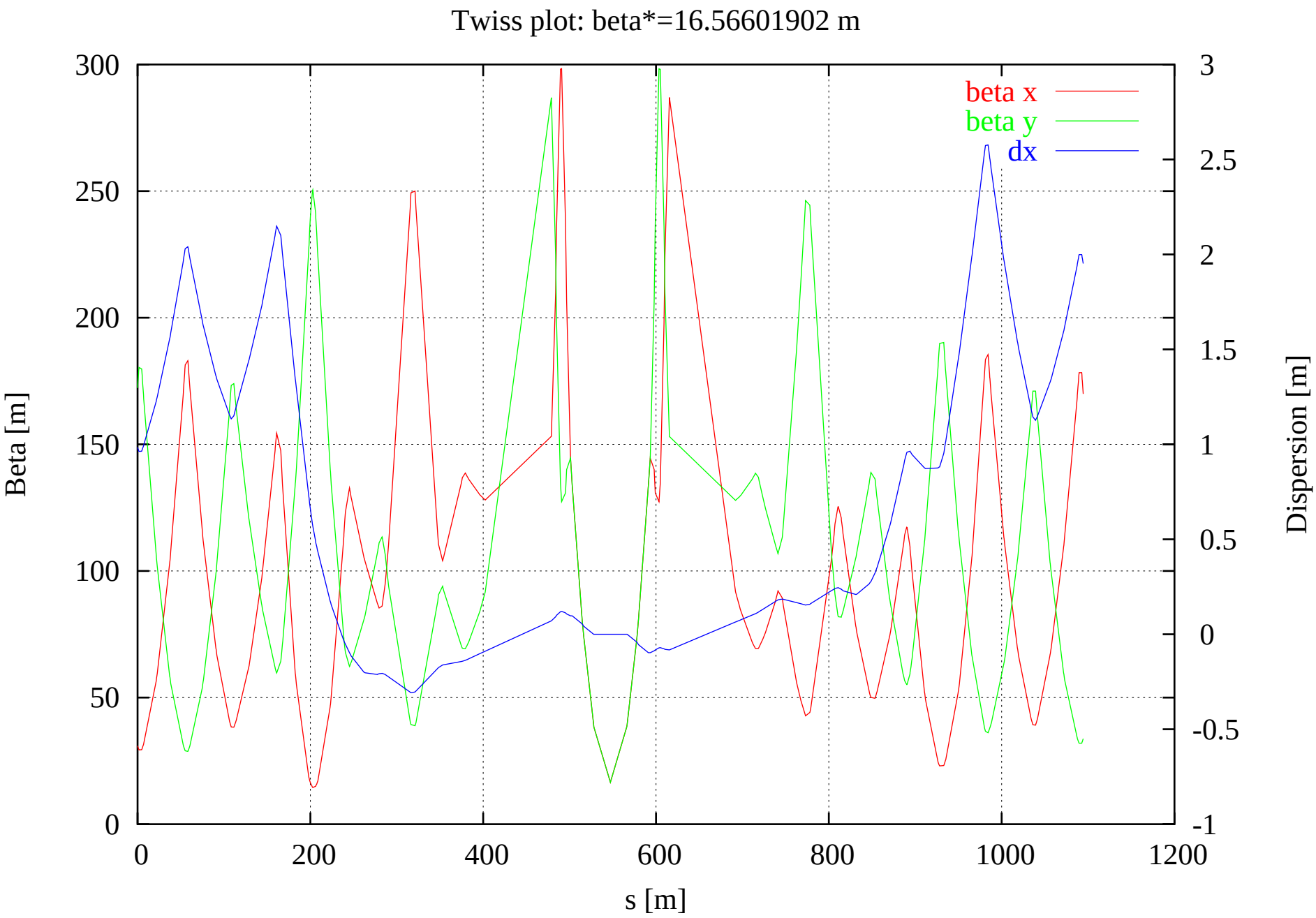

Twiss plot: beta*=10.28619445 m
beta x
beta y
dx
Beta [m]
Dispersion [m]
s [m]
0
50
100
150
200
250
300
350
400
450
500
-1
-0.5
0
0.5
1
1.5
2
2.5
3
0
200
400
600
800
1000
1200

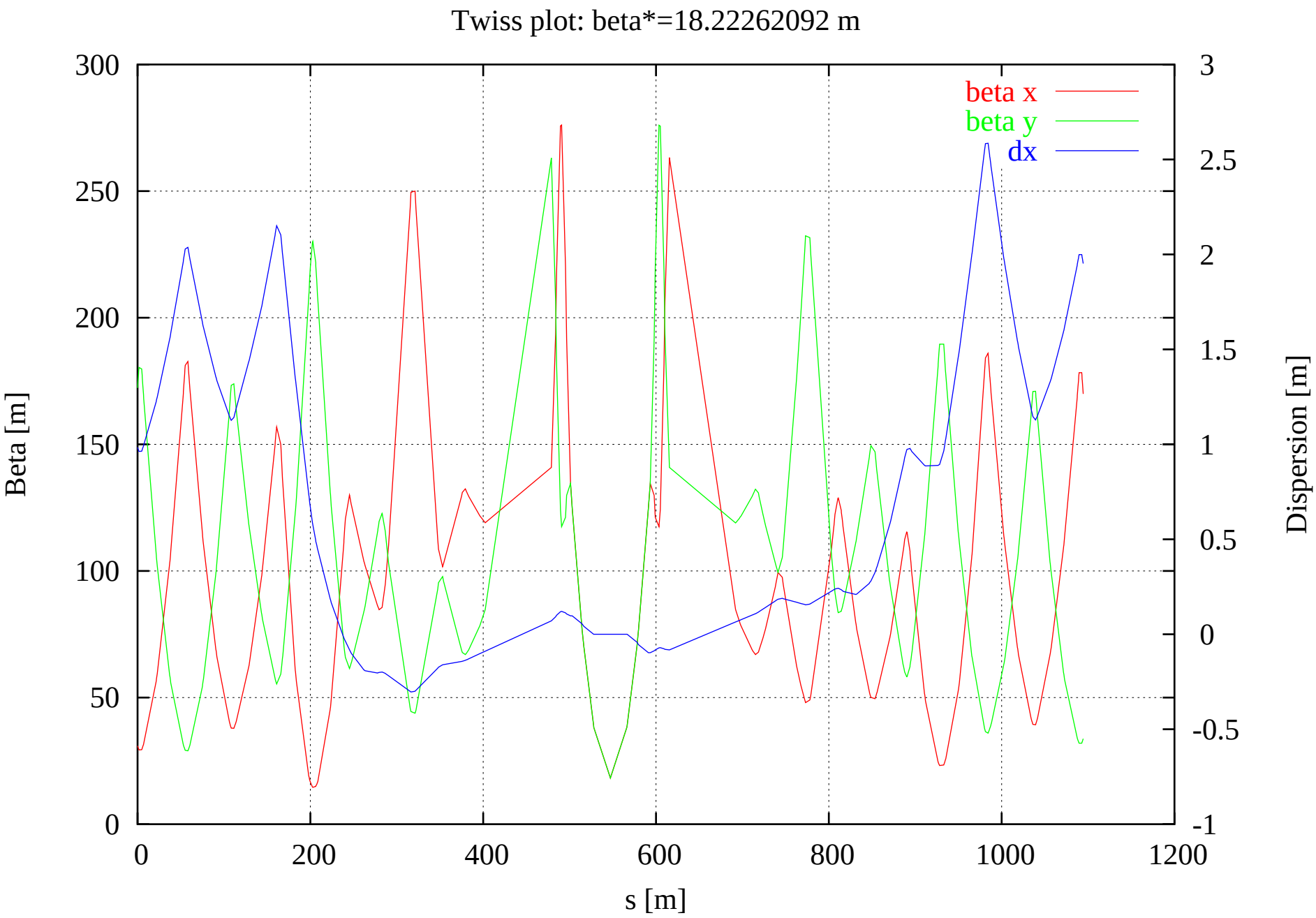

Twiss plot: beta*=11.31481389 m
beta x
beta y
dx
Beta [m]
Dispersion [m]
s [m]
0
50
100
150
200
250
300
350
400
450
-1
-0.5
0
0.5
1
1.5
2
2.5
3
0
200
400
600
800
1000
1200

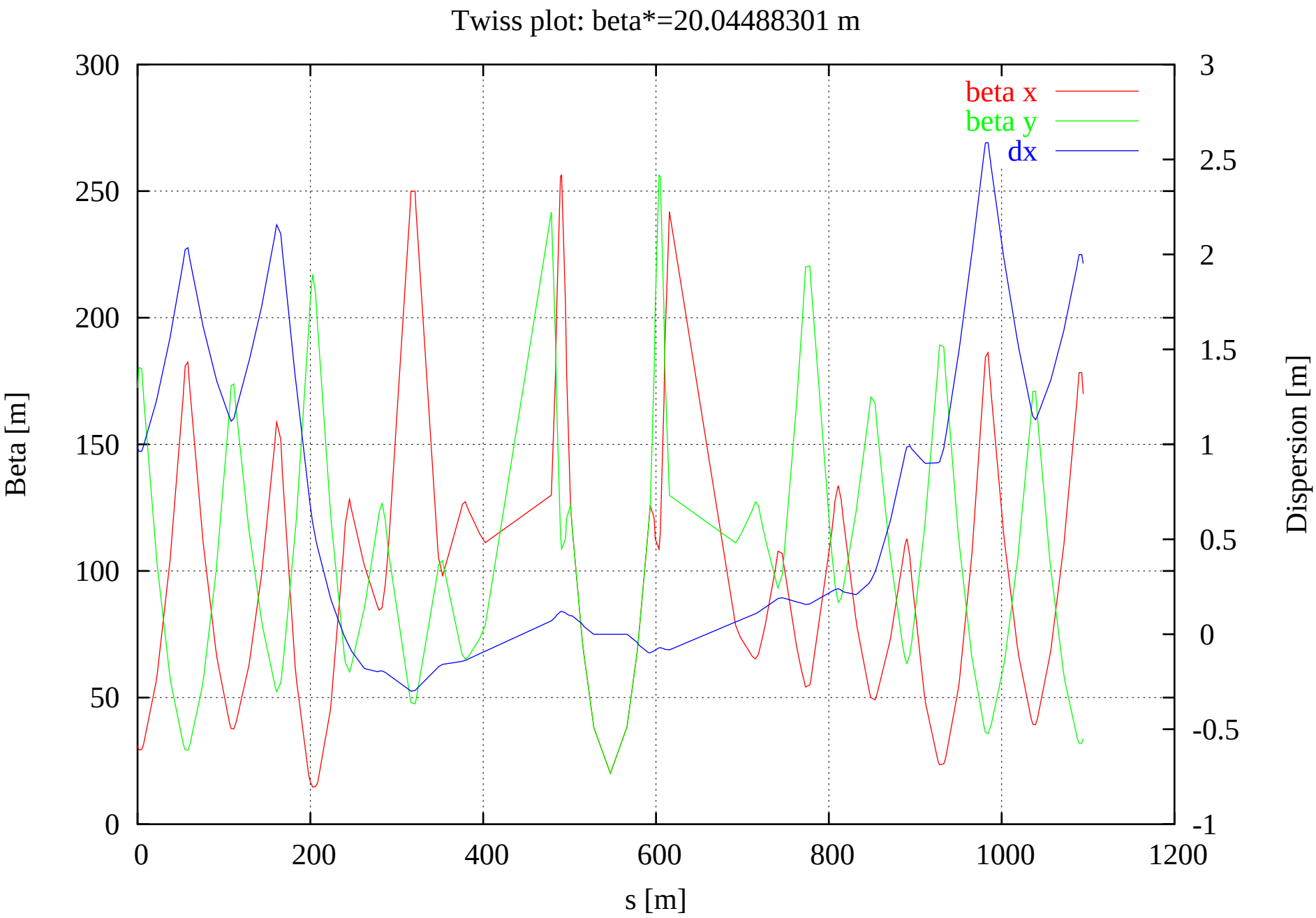

Twiss plot: beta*=12.44629528 m
beta x
beta y
dx
Beta [m]
Dispersion [m]
s [m]
0
50
100
150
200
250
300
350
400
-1
-0.5
0
0.5
1
1.5
2
2.5
3
0
200
400
600
800
1000
1200

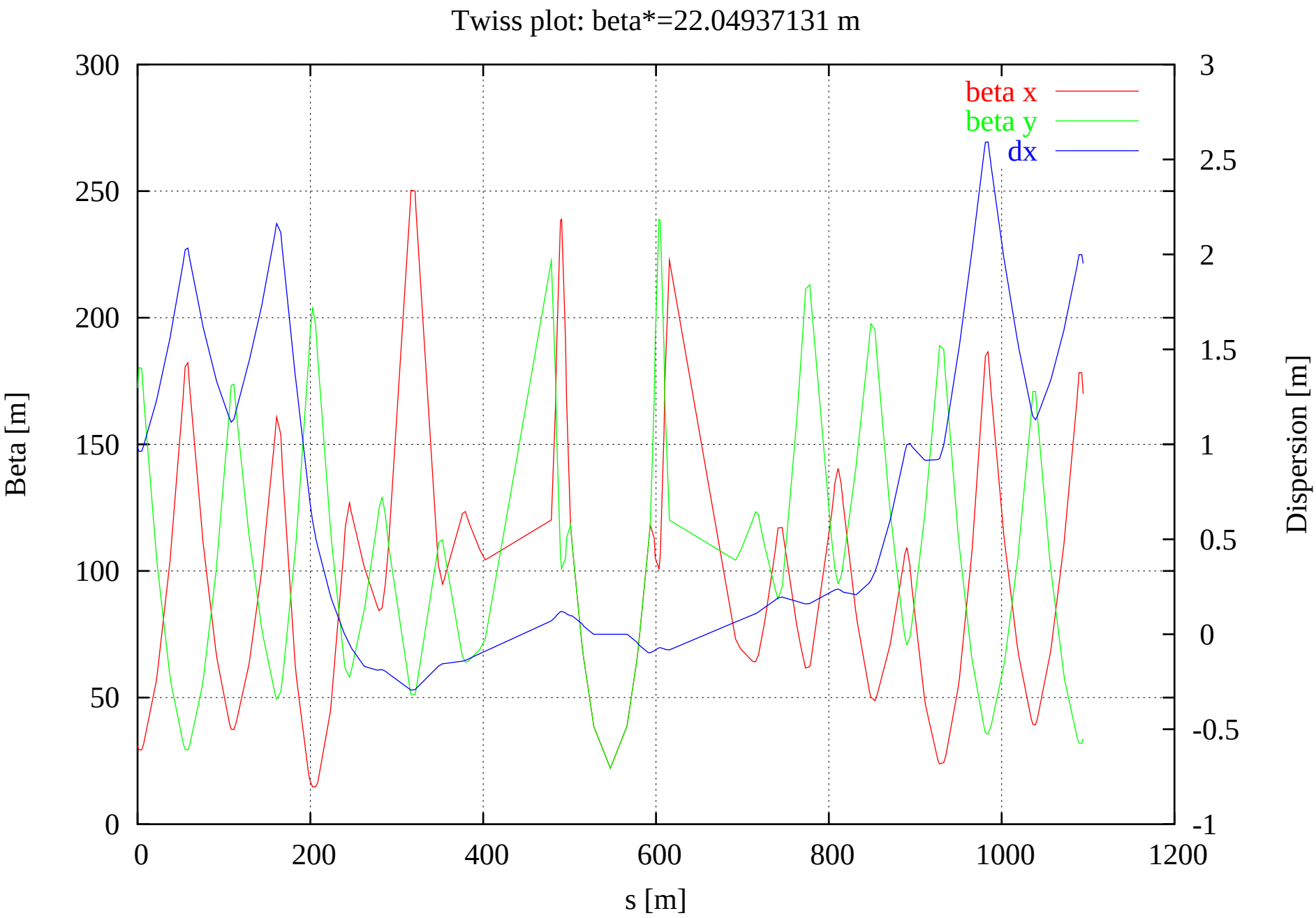

Twiss plot: beta*=13.69092481 m
beta x
beta y
dx
Beta [m]
Dispersion [m]
s [m]
0
50
100
150
200
250
300
350
400
-1
-0.5
0
0.5
1
1.5
2
2.5
3
0
200
400
600
800
1000
1200

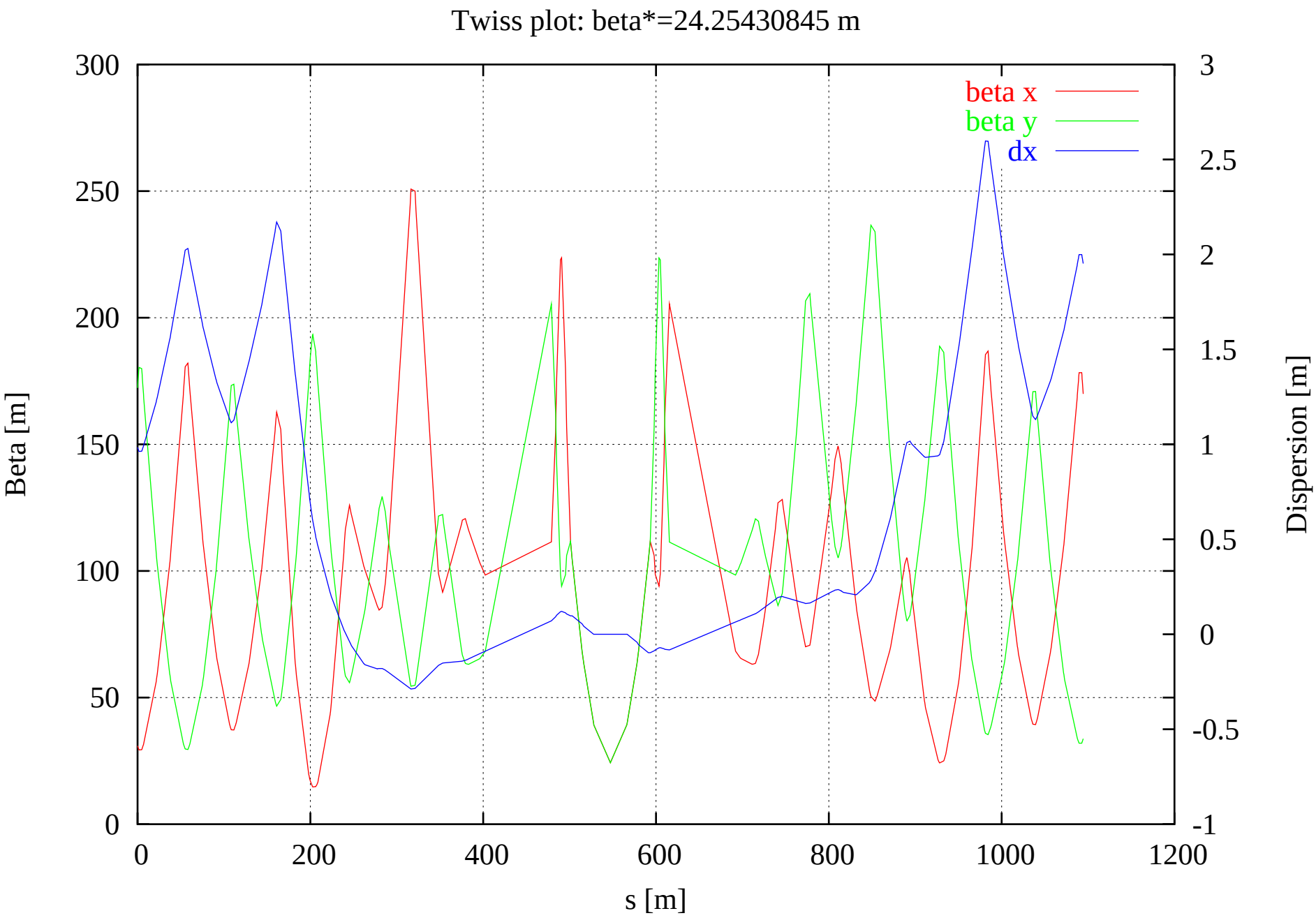

Twiss plot: beta*=15.06001729 m
beta x
beta y
dx
Beta [m]
Dispersion [m]
s [m]
0
50
100
150
200
250
300
350
-1
-0.5
0
0.5
1
1.5
2
2.5
3
0
200
400
600
800
1000
1200

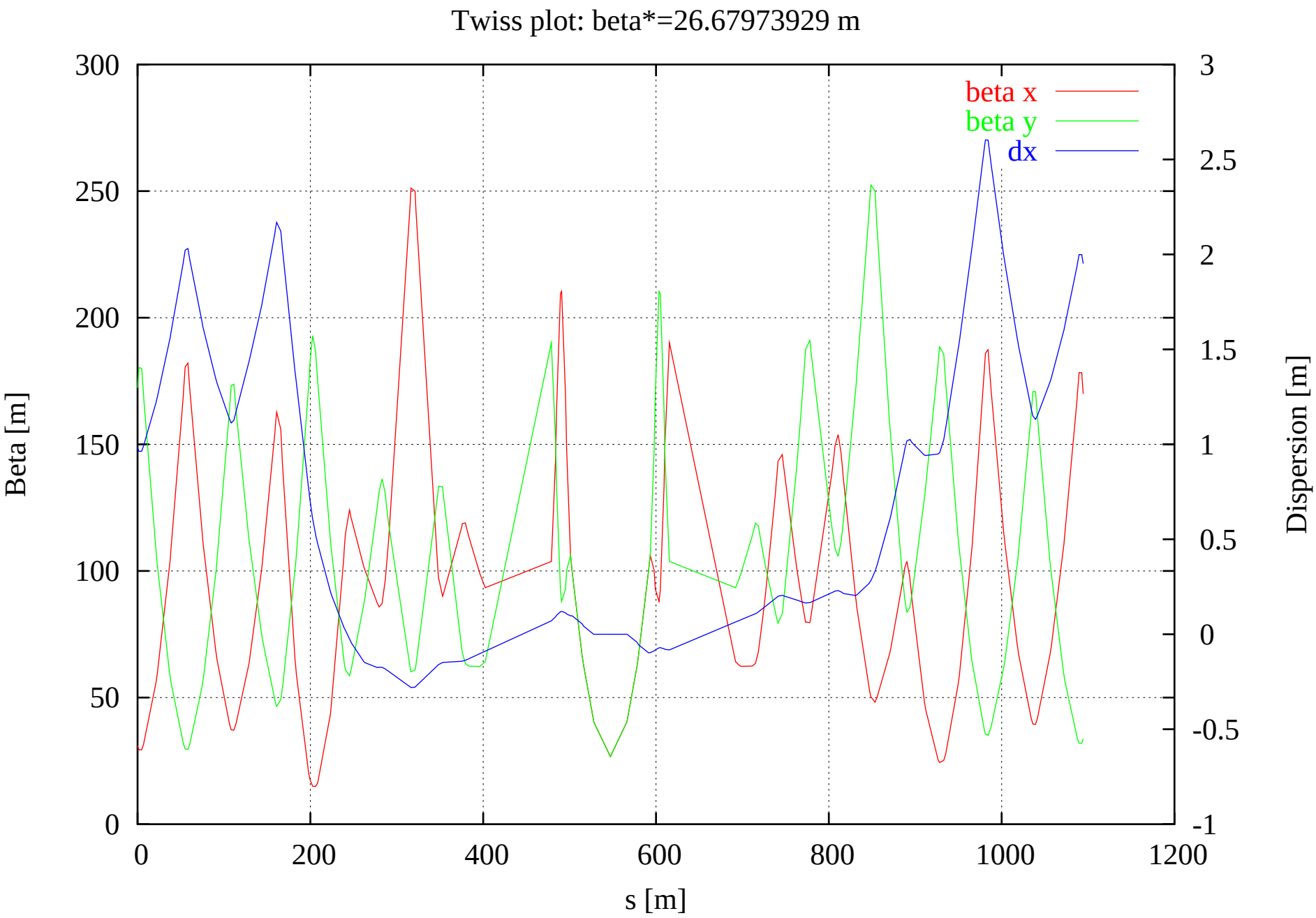

Twiss plot: beta*=16.56601902 m
beta x
beta y
dx
Beta [m]
Dispersion [m]
s [m]
300
250
200
150
100
50
0
3
2.5
2
1.5
1
0.5
0
-0.5
-1
0
200
400
600
800
1000
1200

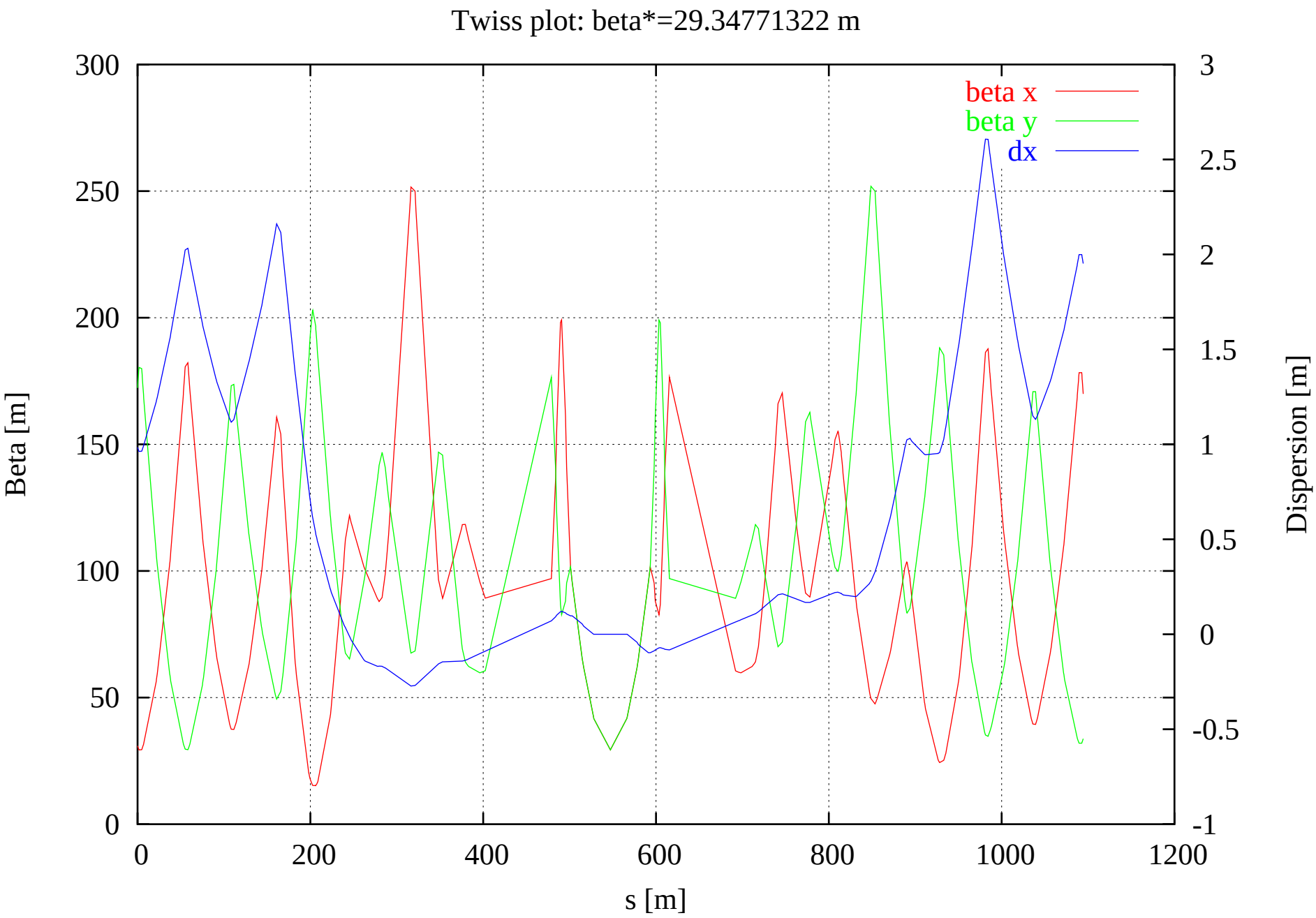

Twiss plot: beta*=18.22262092 m
beta x
beta y
dx
Beta [m]
Dispersion [m]
s [m]
300
250
200
150
100
50
0
3
2.5
2
1.5
1
0.5
0
-0.5
-1
0
200
400
600
800
1000
1200

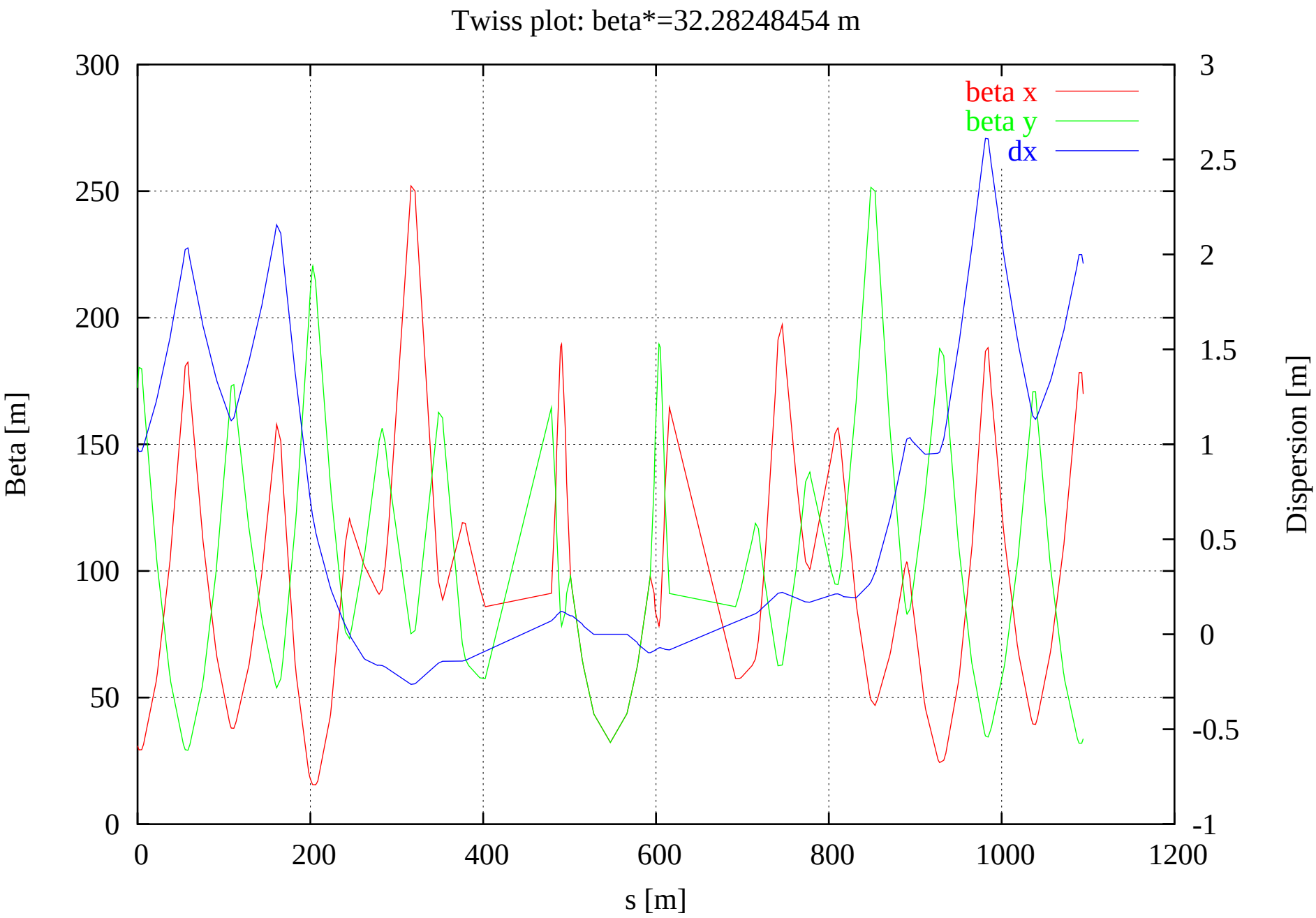

Twiss plot: beta*=20.04488301 m
beta x
beta y
dx
Beta [m]
Dispersion [m]
s [m]
300
250
200
150
100
50
0
3
2.5
2
1.5
1
0.5
0
-0.5
-1
0
200
400
600
800
1000
1200

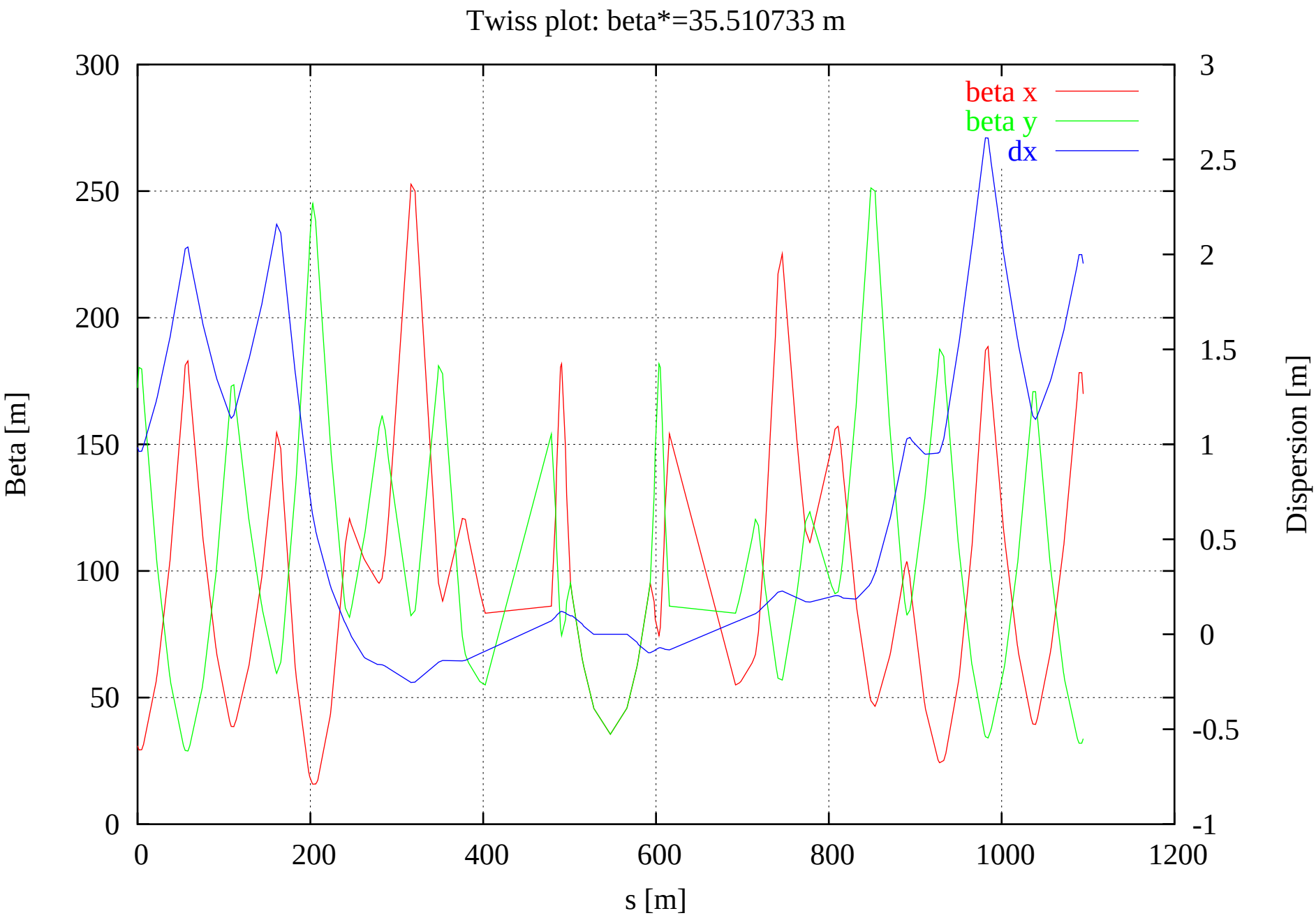

Twiss plot: beta*=22.04937131 m
beta x
beta y
dx
Beta [m]
Dispersion [m]
s [m]
300
250
200
150
100
50
0
3
2.5
2
1.5
1
0.5
0
-0.5
-1
0
200
400
600
800
1000
1200

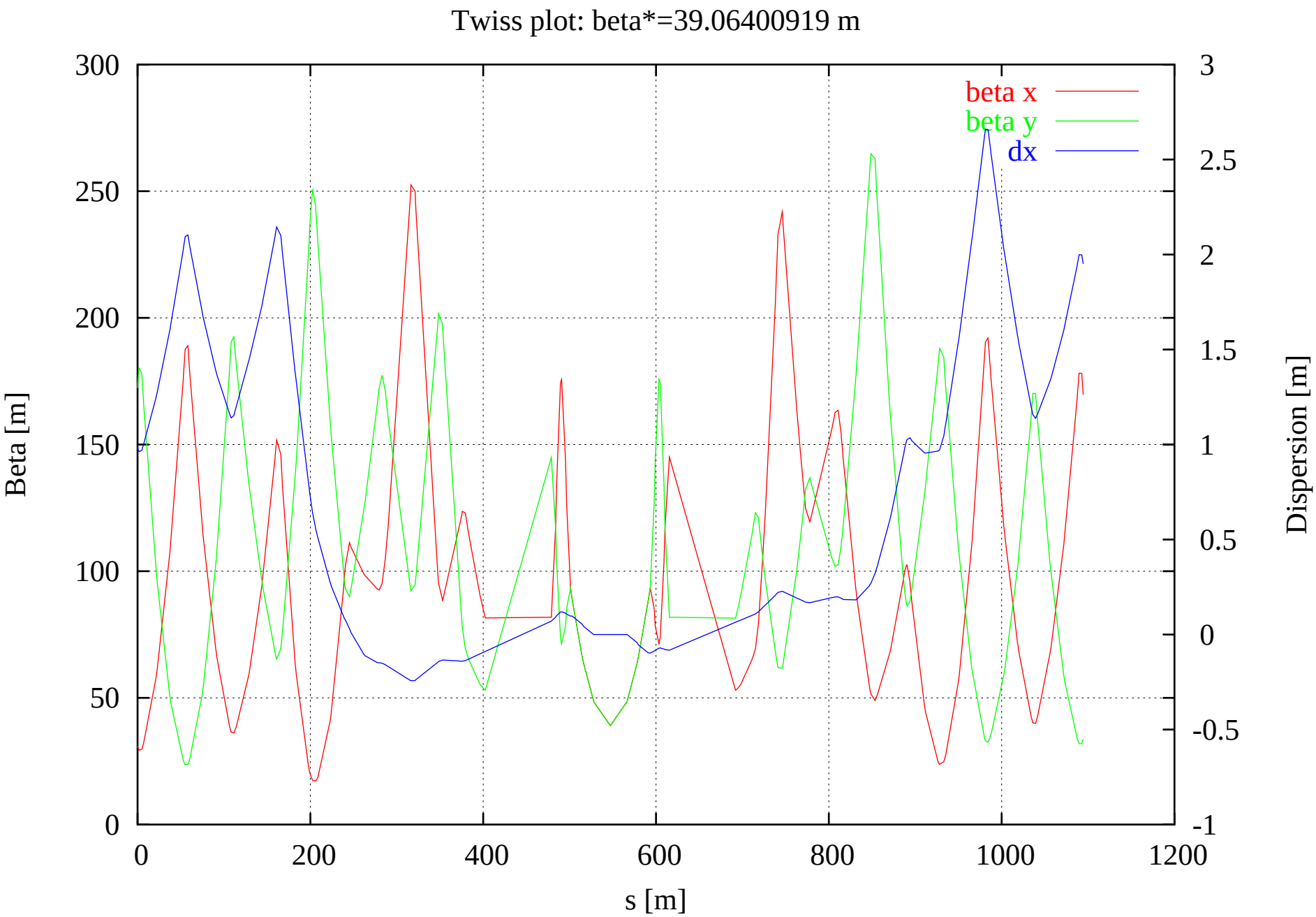

Twiss plot: beta*=24.25430845 m
beta x
beta y
dx
Beta [m]
Dispersion [m]
s [m]
300
250
200
150
100
50
0
3
2.5
2
1.5
1
0.5
0
-0.5
-1
0
200
400
600
800
1000
1200


Twiss plot: beta*=26.67973929 m
beta x
beta y
dx
Beta [m]
Dispersion [m]
s [m]
300
250
200
150
100
50
0
3
2.5
2
1.5
1
0.5
0
-0.5
-1
0
200
400
600
800
1000
1200


Twiss plot: beta*=29.34771322 m
beta x
beta y
dx
Beta [m]
Dispersion [m]
s [m]
300
250
200
150
100
50
0
3
2.5
2
1.5
1
0.5
0
-0.5
-1
0
200
400
600
800
1000
1200


Twiss plot: beta*=32.28248454 m
beta x
beta y
dx
Beta [m]
Dispersion [m]
s [m]
300
250
200
150
100
50
0
3
2.5
2
1.5
1
0.5
0
-0.5
-1
0
200
400
600
800
1000
1200


Twiss plot: beta*=35.510733 m
beta x
beta y
dx
Beta [m]
Dispersion [m]
s [m]
300
250
200
150
100
50
0
3
2.5
2
1.5
1
0.5
0
-0.5
-1
0
200
400
600
800
1000
1200


Twiss plot: beta*=39.06400919 m
beta x
beta y
dx
Beta [m]
Dispersion [m]
s [m]
300
250
200
150
100
50
0
3
2.5
2
1.5
1
0.5
0
-0.5
-1
0
200
400
600
800
1000
1200