Commissioning of the 90 m Totem Optics

- **Introduction :   scenario;   β, phase advance, tune**

- **Compatibility of early physics and Totem 90 m optics**
  - **need for global tune compensation of “un-squeeze”**
  - **aperture, β-beating**
  - **smooth “un-squeeze” to 90 m**

- **Conclusion**

based on work and discussions within LCU, LHCCWG & LTC

Scenario : early physics and Totem 90 m optics

Earlier physics operation :

- **injection ; optics with β^* = 11 m in IR1/5, no crossing angle**
- **injection of limited number of bunches (43 to 156) and intensities ~ 5×10^{10} / bunch**
- **ramp with same β^* = 11 m in IR1/5**
- **prepare for physics**
  - **normally : increase Luminosity by local squeeze from 11 m down to 2 m in both IR1/5**
  - **here : local squeeze in IR1 to 2 m + "un-squeeze" in IR5 to 90 m β^***

    with phase advance of $\Delta\mu_y$ = 0.25 (90°), $\Delta\mu_x$ = 0.50 (180°) for outgoing beam between IR5 and roman pot at 220 m from IP (between Q5 and Q6).

What happens in the squeeze and un-squeeze and how does it compare ?

the main changes in tune (phase advance) and aperture can be derived from optics principles ---->

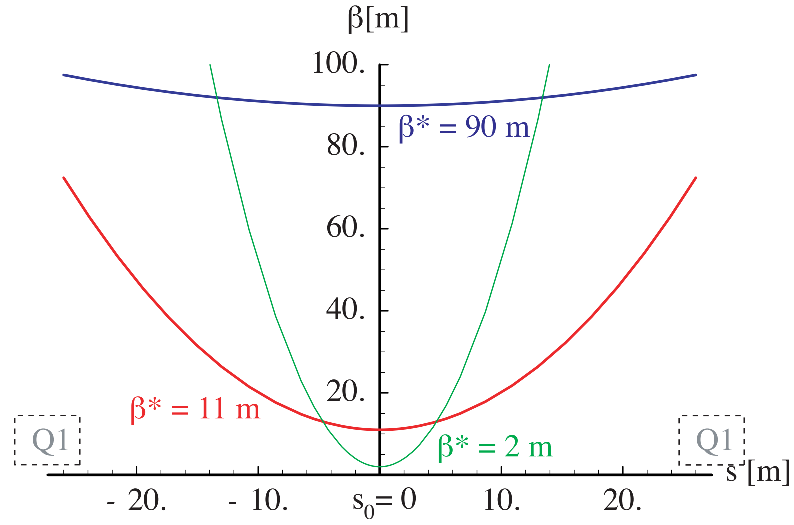
β-function, phase advance and tune

the β-function in a field free region has a form of a parabola with

$$\beta(s) = \beta^* + \frac{(s-s_0)^2}{\beta^*}$$

relation between phase advance ϕ(s), β(s) and tune Q(s) = ϕ(s) / 2π

$$\Phi(s) = \int \frac{1}{\beta(s)}\, ds$$

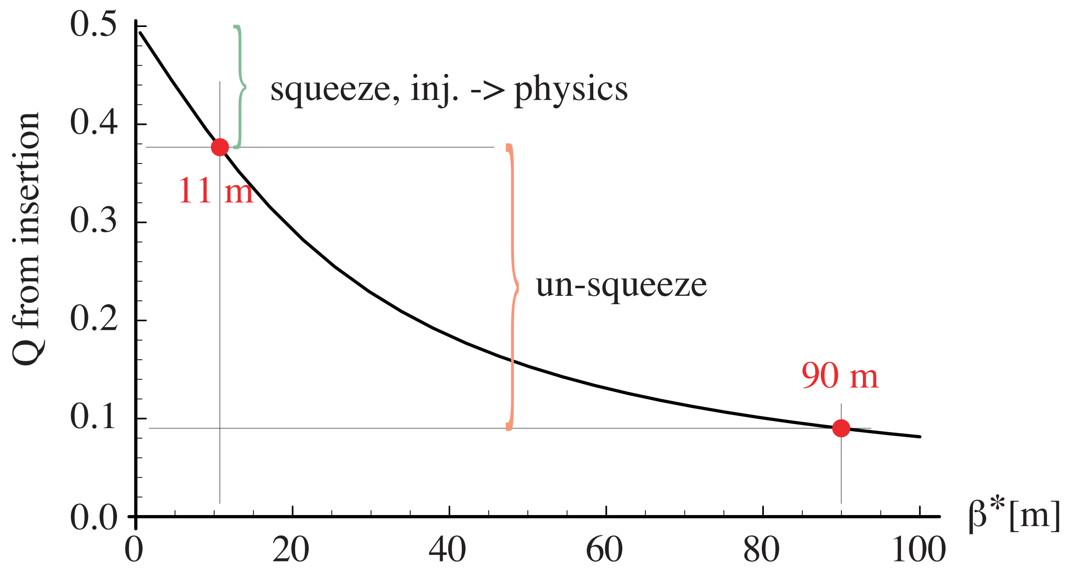


integrated symmetrically around the minimum

$$Q = \frac{1}{2\pi}\int_{s_0-l}^{s_0+l} \frac{1}{\beta(s)}\, ds = \frac{1}{\pi}\arctan\left(\frac{l}{\beta^*}\right)$$

contributes 0.5 in tune (π in phase) for low β* << l
going to 0 for high β* >> l

for the LHC with l = 26.15 m from IP to centre of Q1



LHC physics tune

Target physics tunes are Qx = 64.31 and Qy = 59.32 for both beams in the LHC

individual contributions from arcs and insertions :

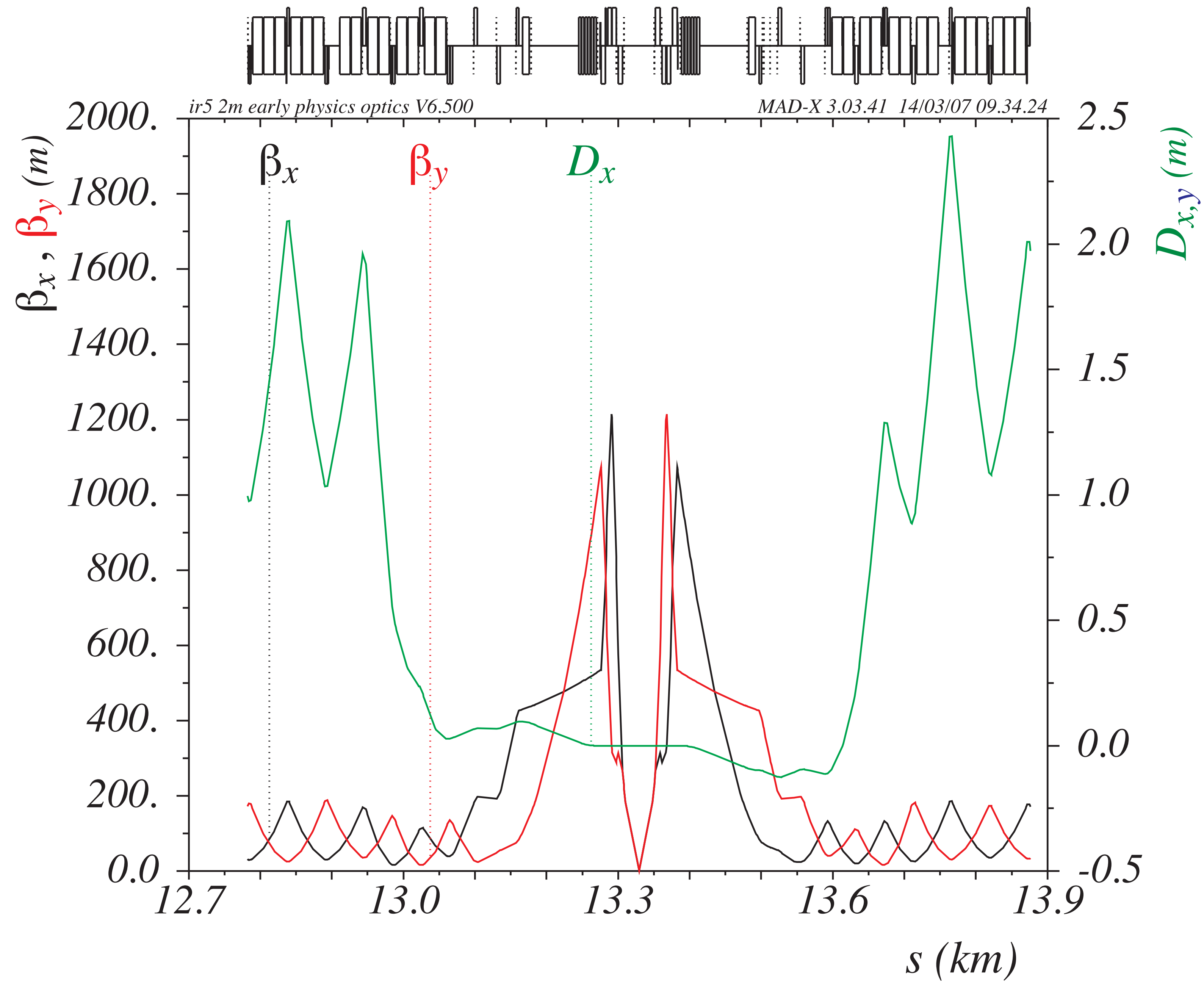
LHCVERSION V6.500

	beam1		beam2	
	MU_X	MU_Y	MU_X	MU_Y
arcs	44.1040	40.6890	44.1040	40.6890
IR1	2.6330	2.6490	2.6330	2.6490
IR2	2.9740	2.7980	2.9910	2.8440
IR3	2.2480	1.9430	2.2494	2.0066
IR4	2.1430	1.8700	2.1430	1.8700
IR5	2.6330	2.6490	2.6330	2.6490
IR6	2.0150	1.7800	2.0150	1.7800
IR7	2.3770	1.9680	2.4826	2.0504
IR8	3.1830	2.9740	3.0590	2.7820
tune	64.3100	59.3200	64.3100	59.3200

Remains constant from end of ramp through the squeeze

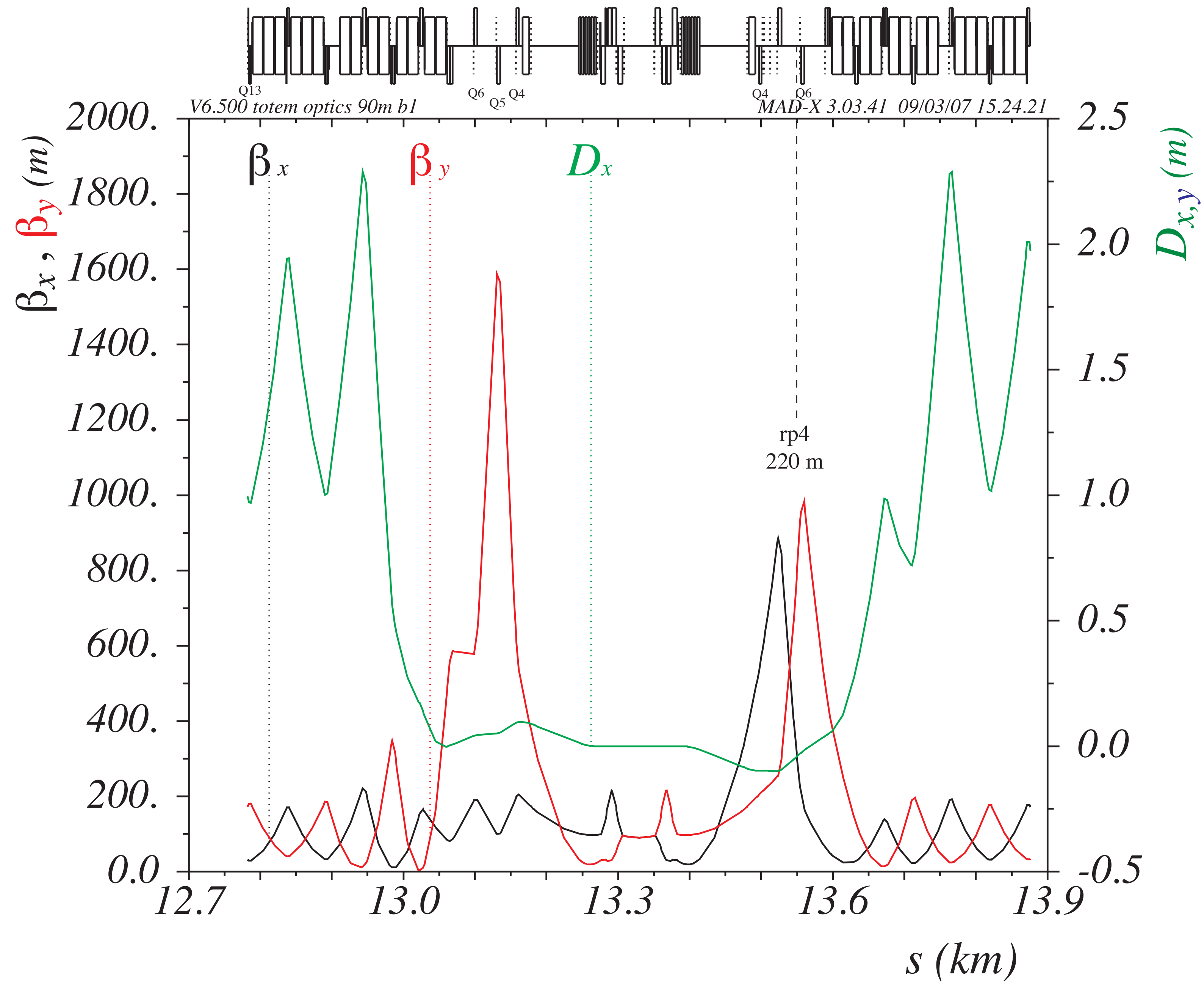
IR5 contributes 2.633 in Qx and 2.649 in Qy, both for beam 1 & 2

β* = 2 m physics optics in IR 5



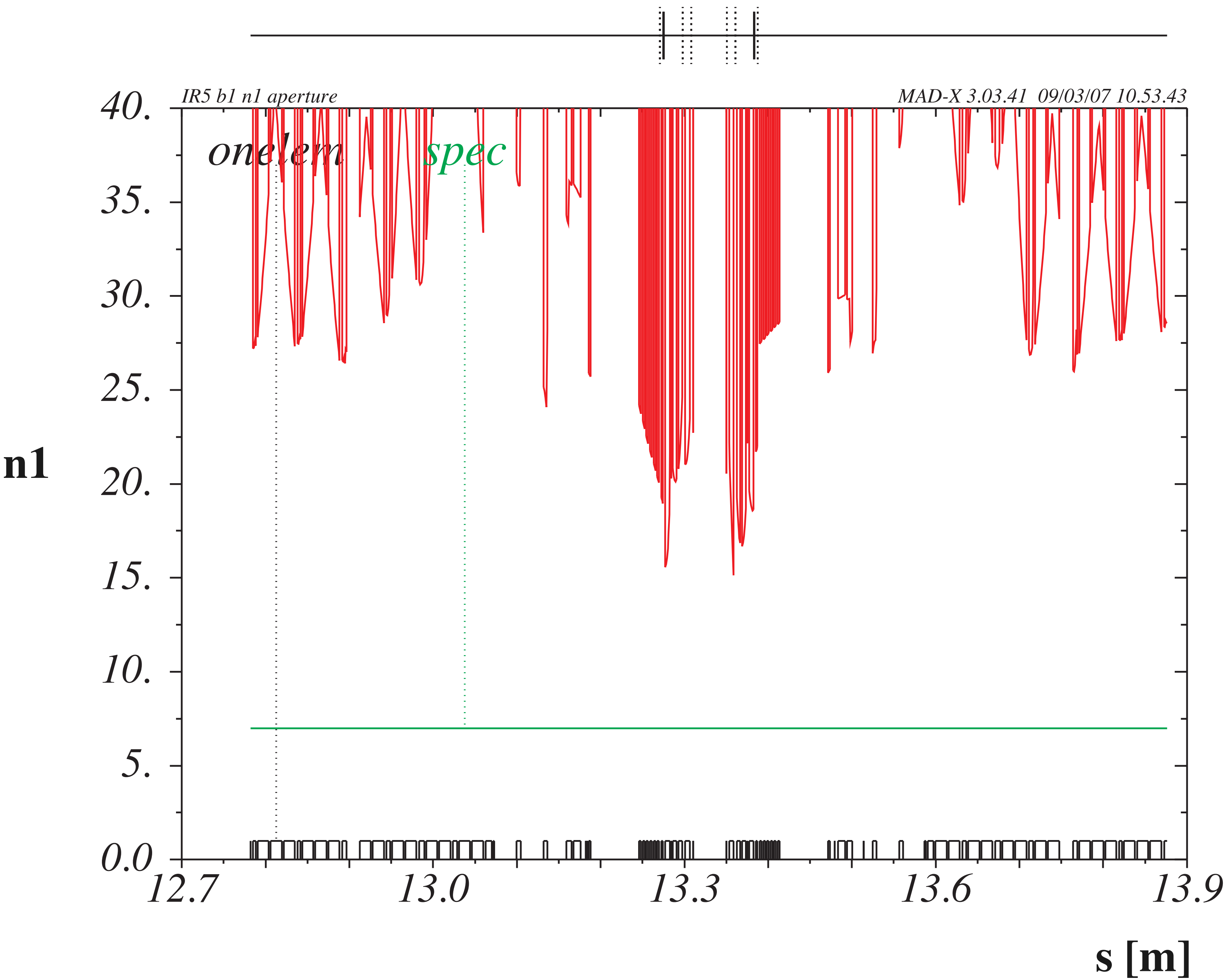
mux = 2.633 ; muy = 2.649

β* = 90 m Totem optics

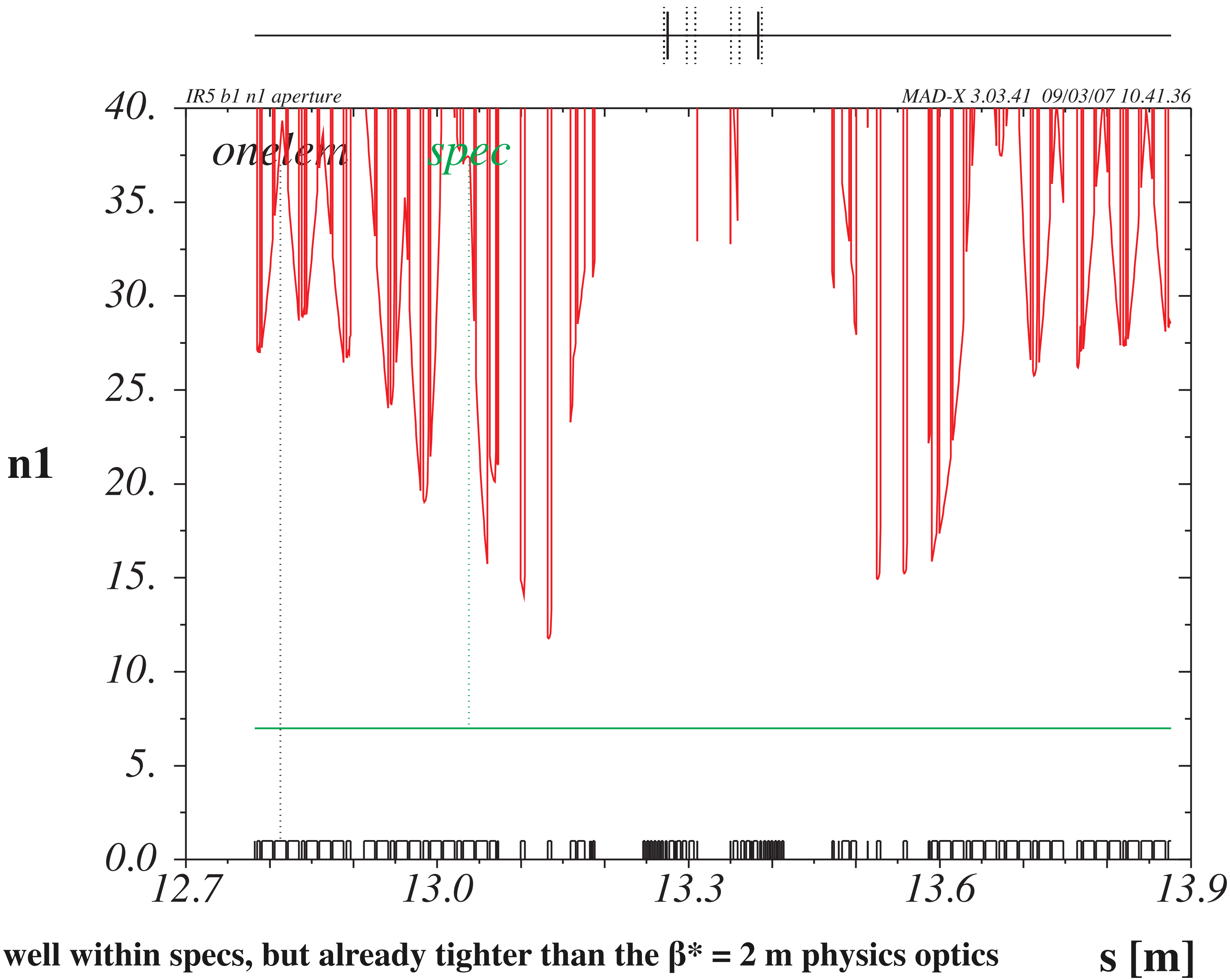


mux = 2.540 ; muy = 2.620 needs extra ΔQx = 0.093, ΔQy = 0.029 trim

Aperture of β* = 2 m physics optics in IR 5

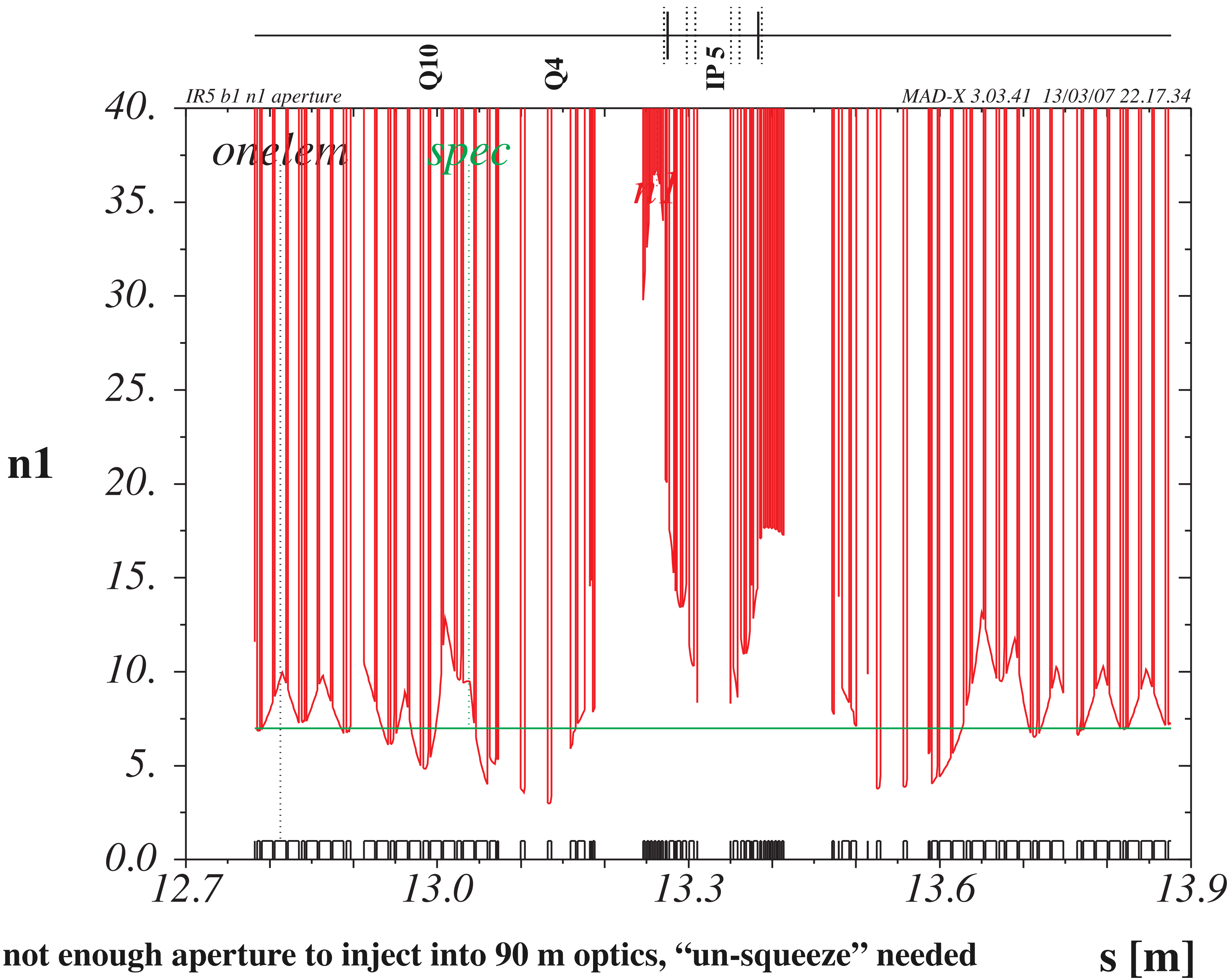


Aperture of β^* = 90 m Totem optics



well within specs, but already tighter than the β^* = 2 m physics optics

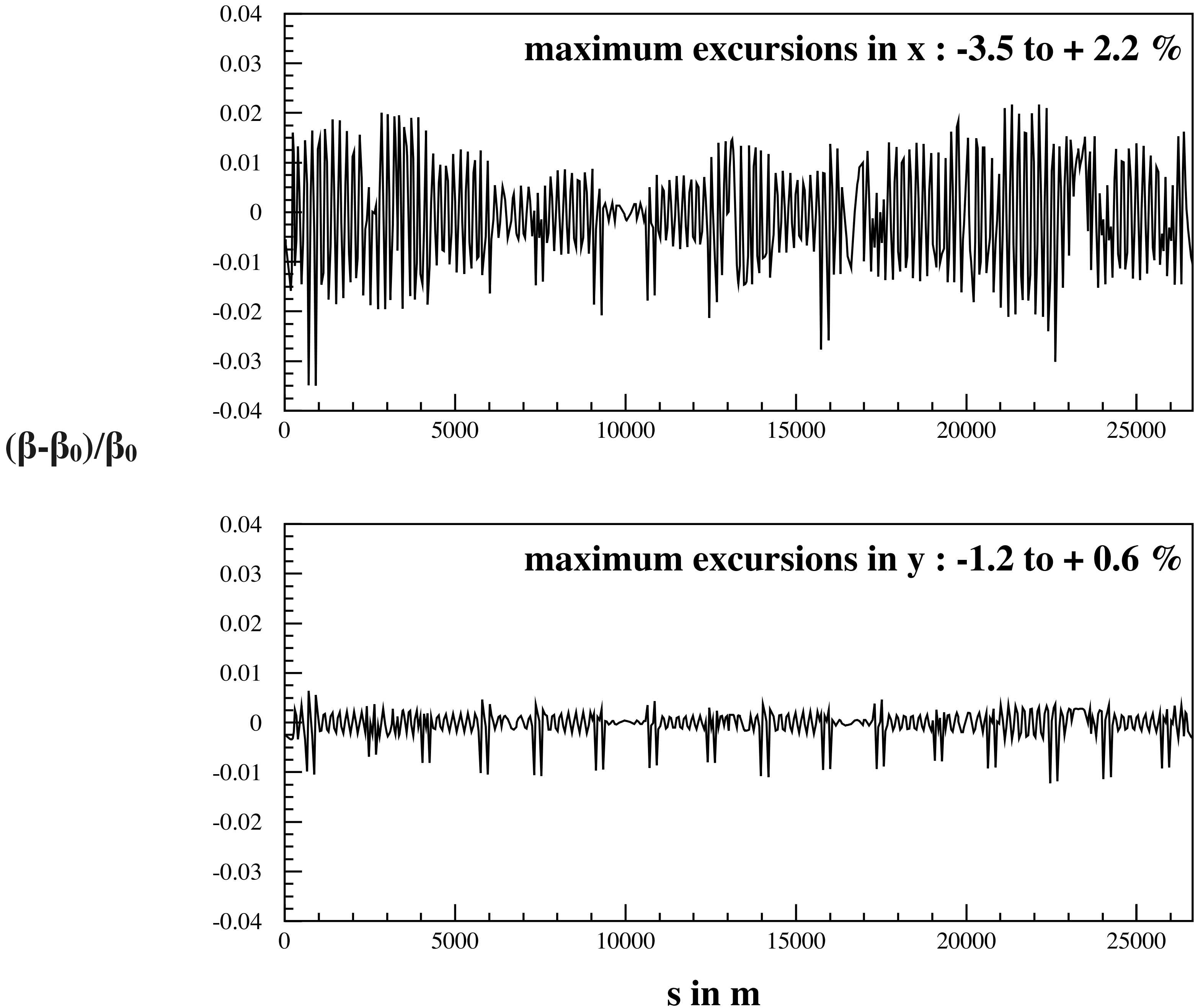
Aperture of 90 m Totem optics at injection



not enough aperture to inject into 90 m optics, "un-squeeze" needed

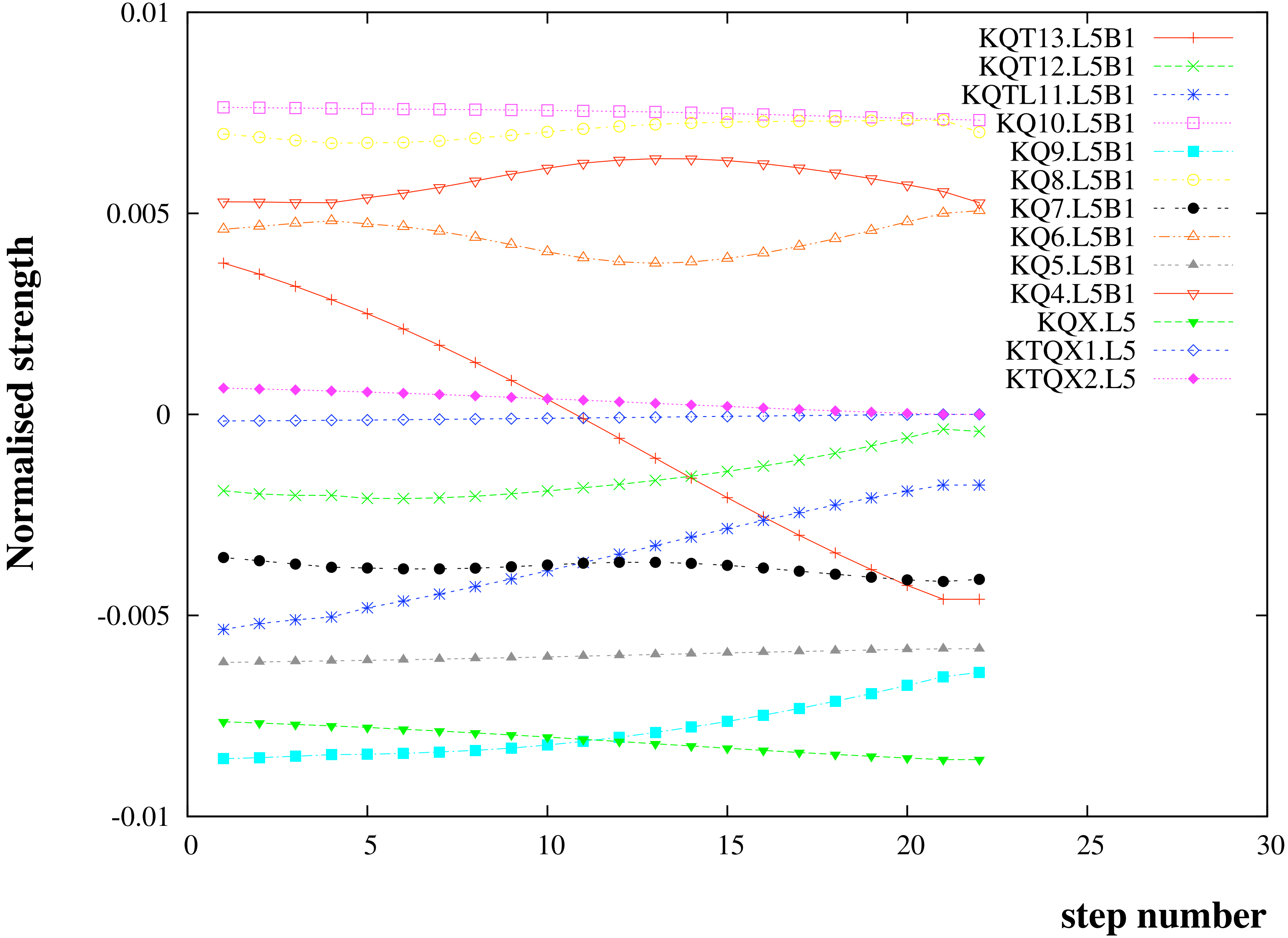
90 m Totem optics. $\Delta Qx = 0.093$, $\Delta Qy = 0.029$ using trim quads kqtd, kqtf

similar for both beams, shown here for beam 1



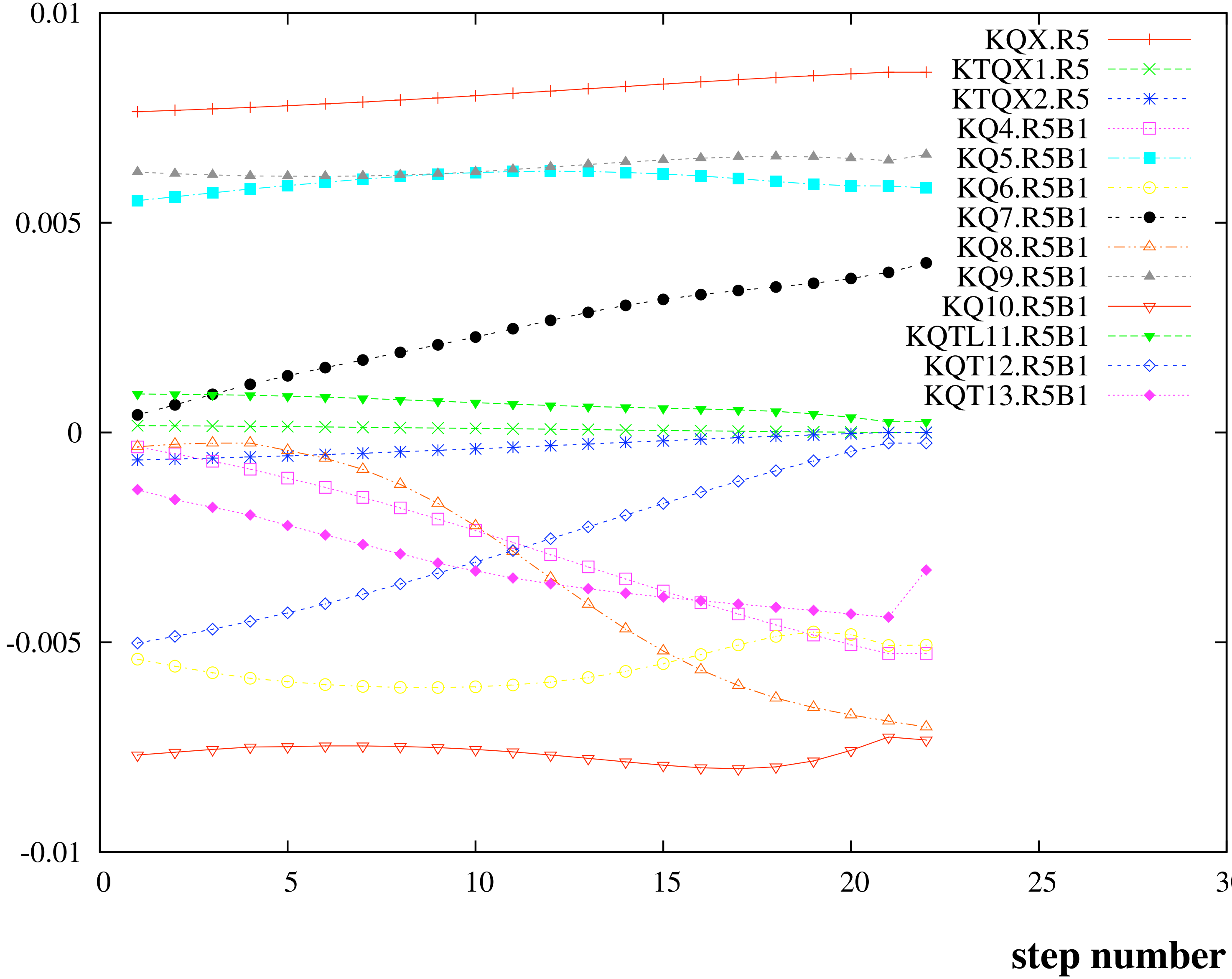
match “squeeze” from 90 m to 11 m in IR5, left side

In 21 steps, each step with a 10 % reduction in β* (90, 81, 73, ... 11 m). Last step shows our normal 11 m strength. Match with 23 variables (quad strength), 19 constraints β, D..



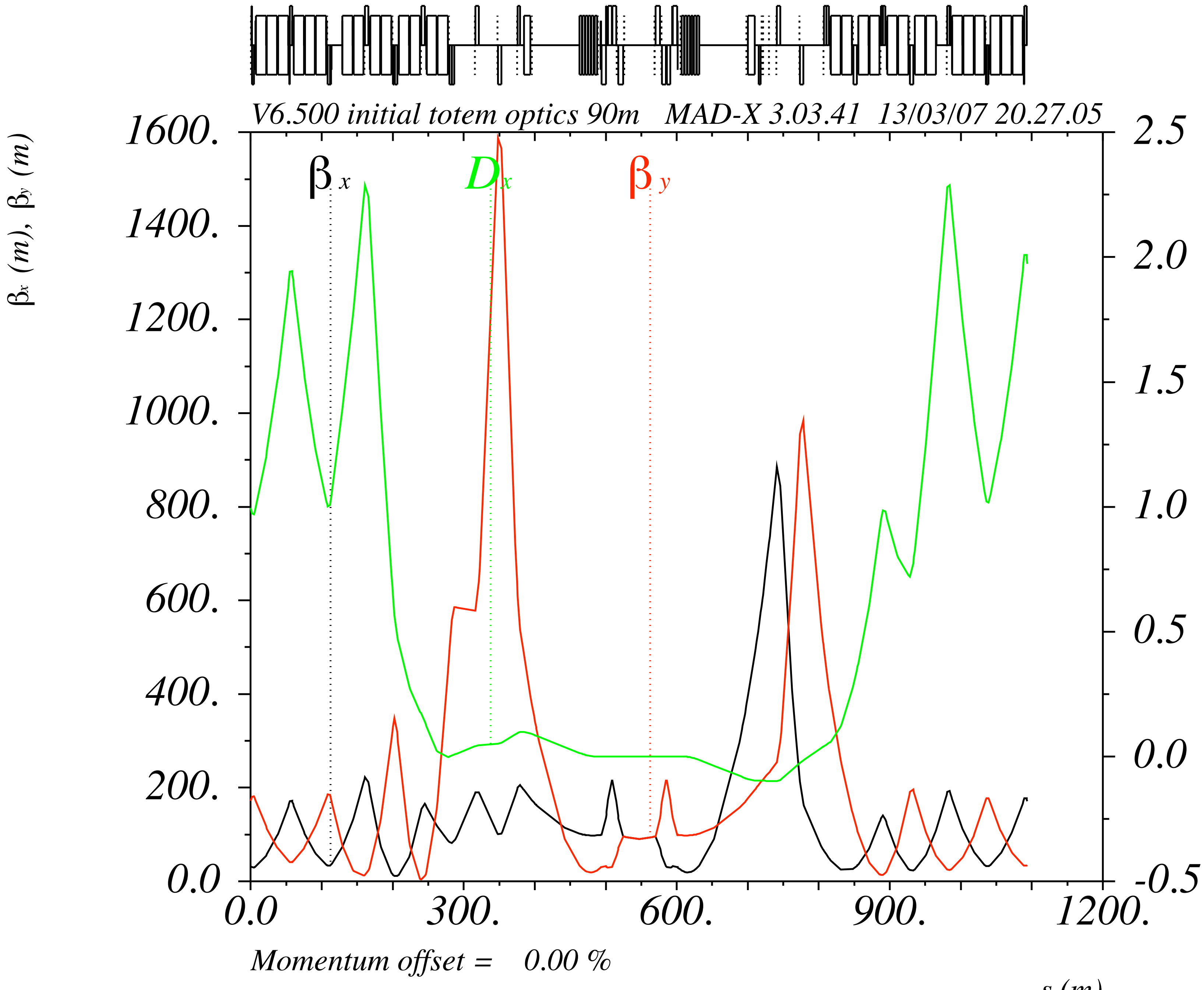
kqt13, kqtl11, kq5, kqx, ktqx1, ktqx2 interpolated between start / end

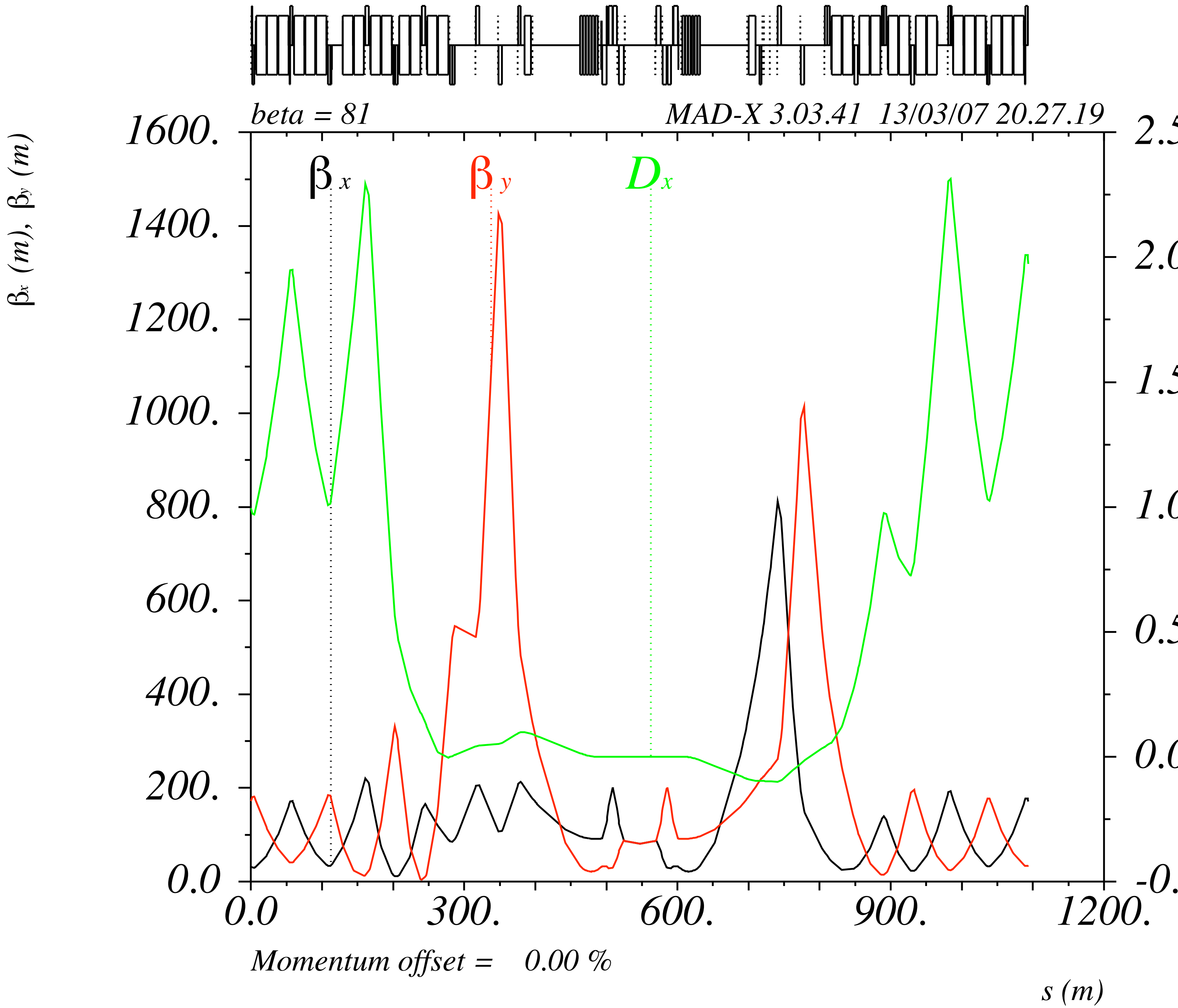
“squeeze” match from 90 m to 11 m in IR5, right side



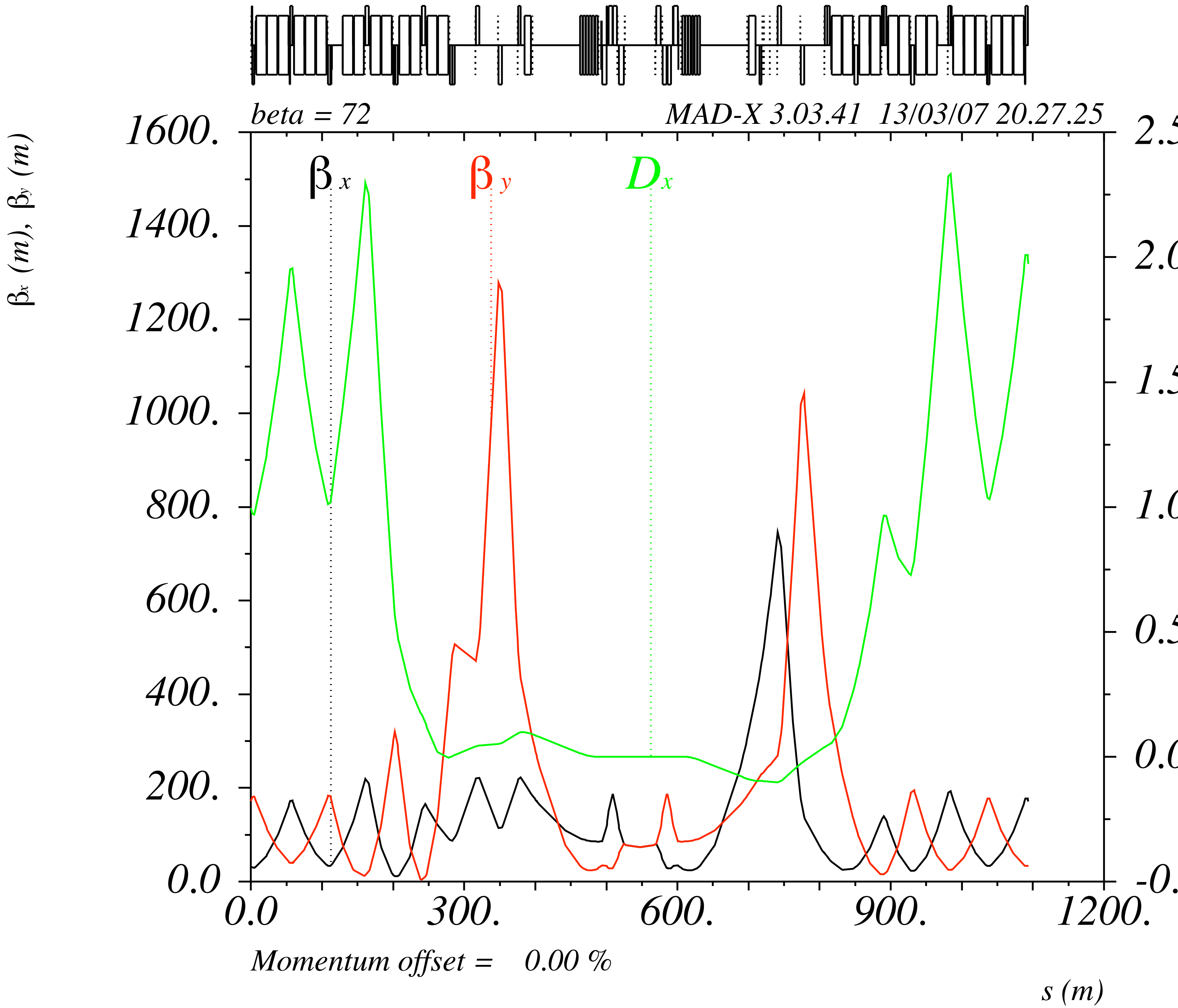
kqt13, kq4, kqx, ktqx1, ktqx2 interpolated between start / end

squeeze from 90 m to 11 m

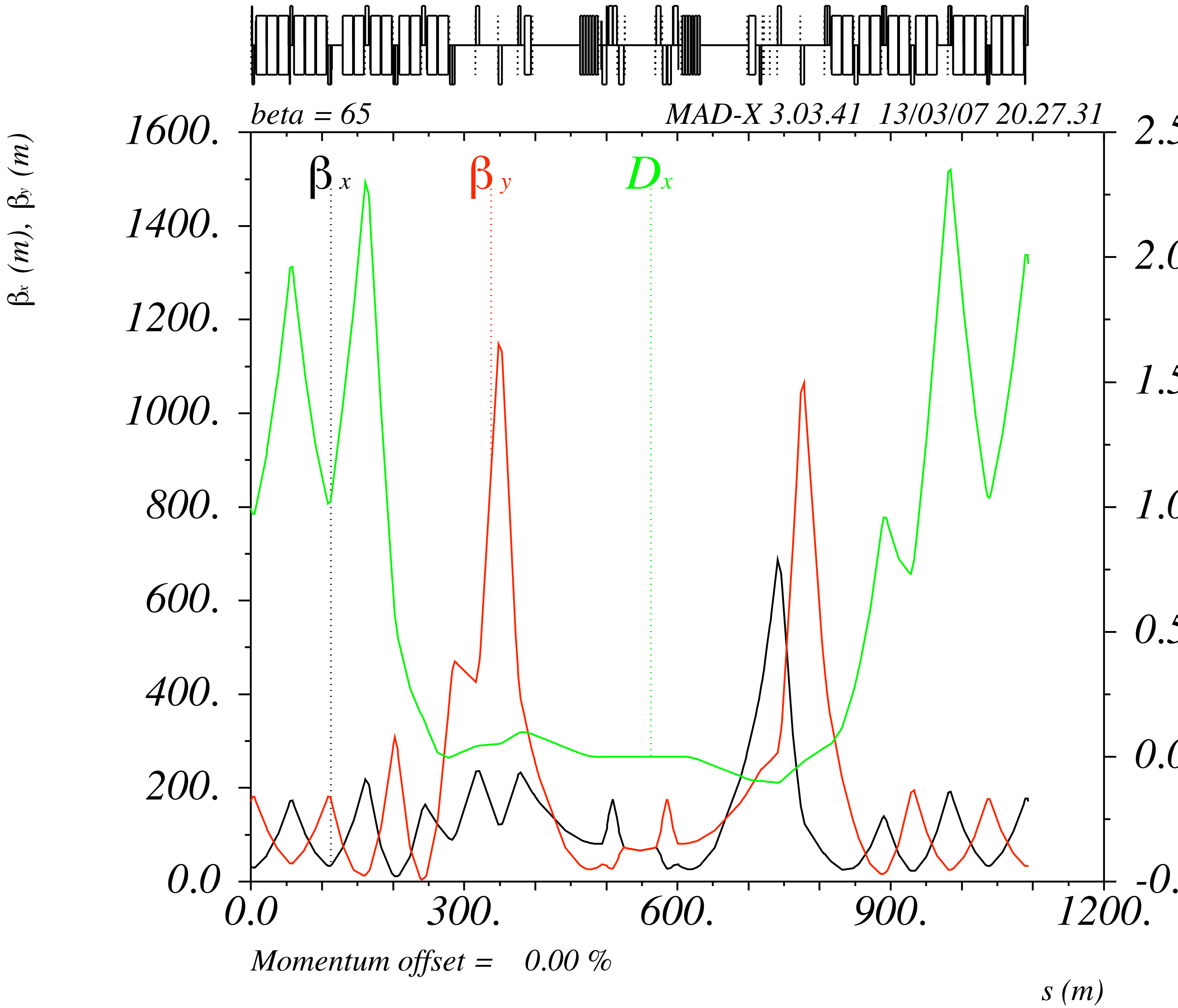


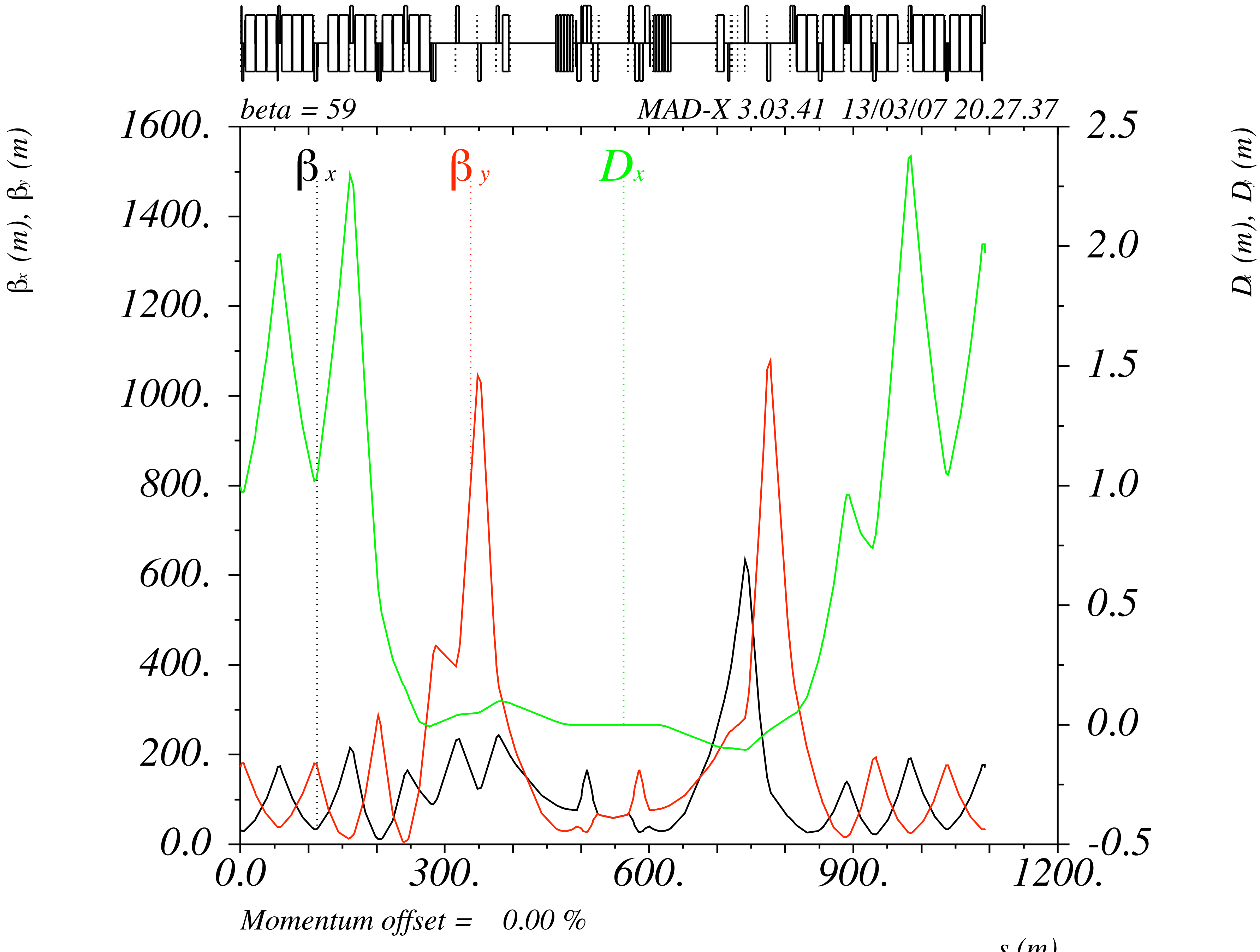


beta = 81
MAD-X 3.03.41 13/03/07 20.27.19
βx (m), βy (m)
Dx (m), Dy (m)
βx
βy
Dx
1600.
1400.
1200.
1000.
800.
600.
400.
200.
0.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
0.0
300.
600.
900.
1200.
Momentum offset = 0.00 %
s (m)

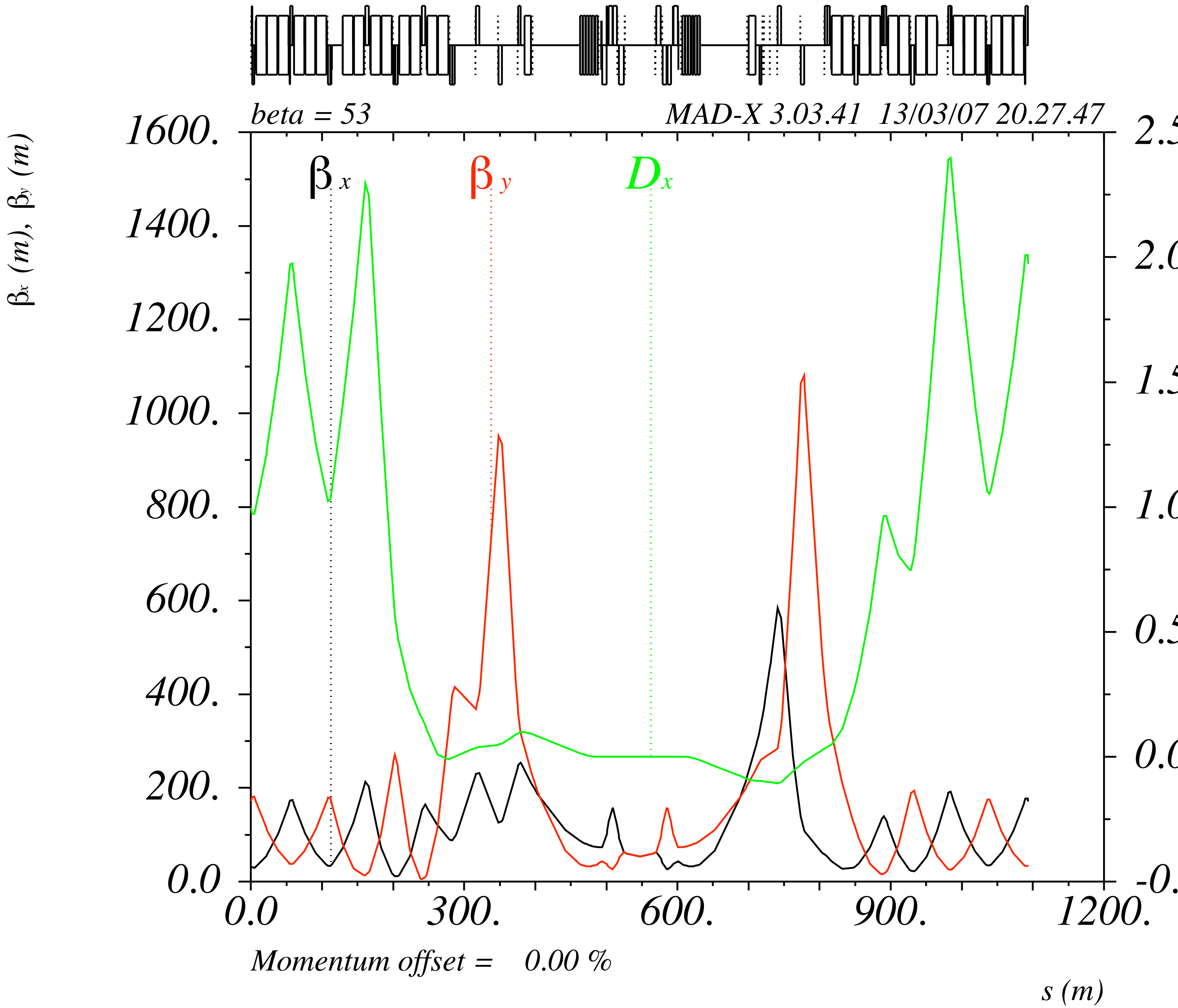


beta = 72
MAD-X 3.03.41 13/03/07 20.27.25
βx (m), βy (m)
Dx (m), Dy (m)
βx
βy
Dx
1600.
1400.
1200.
1000.
800.
600.
400.
200.
0.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
0.0
300.
600.
900.
1200.
Momentum offset = 0.00 %
s (m)

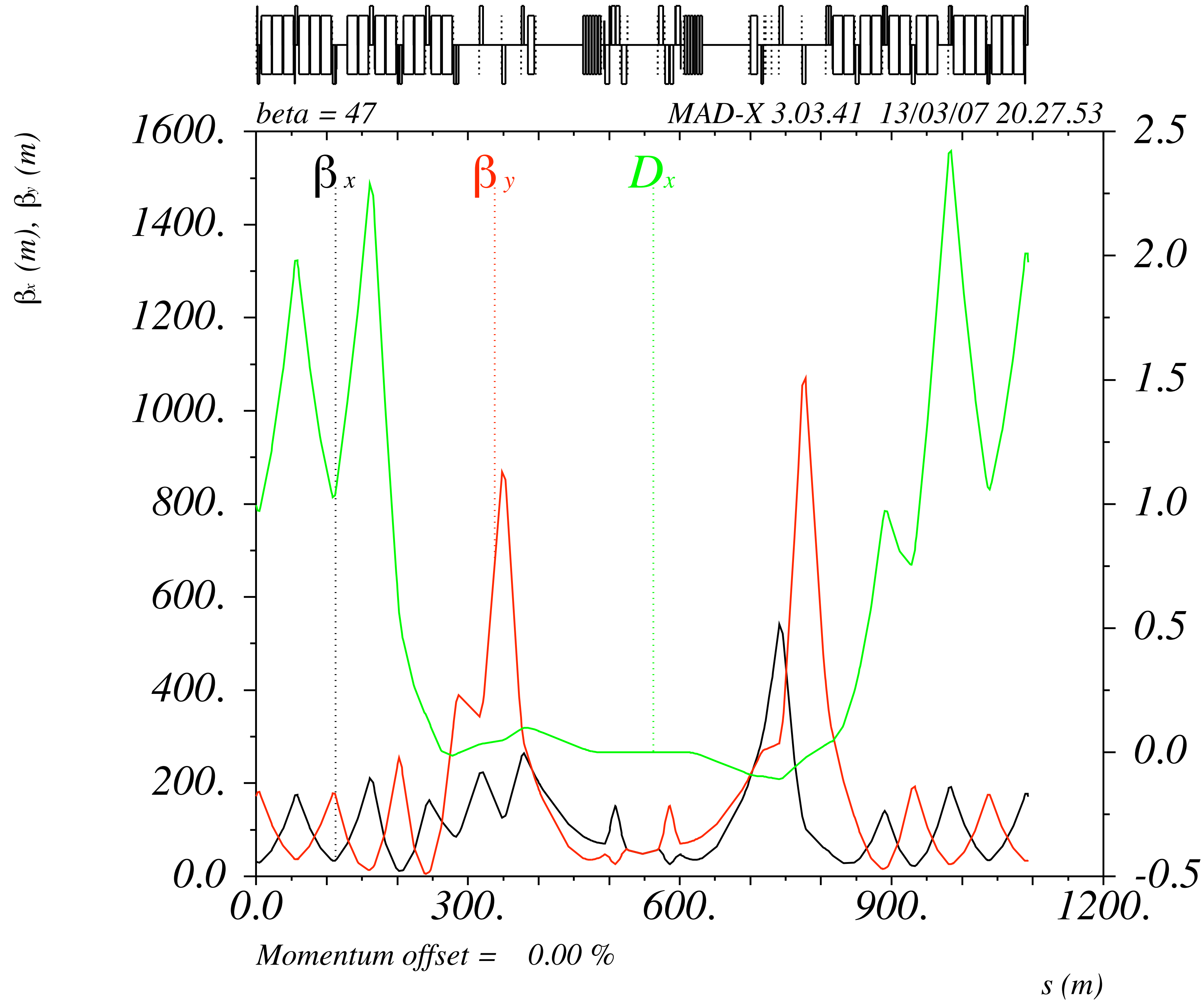

beta = 65
MAD-X 3.03.41 13/03/07 20.27.31
βx βy Dx
βx (m), βy (m)
Dx (m), Dy (m)
1600. 1400. 1200. 1000. 800. 600. 400. 200. 0.0
2.5 2.0 1.5 1.0 0.5 0.0 -0.5
0.0 300. 600. 900. 1200.
Momentum offset = 0.00 %
s (m)

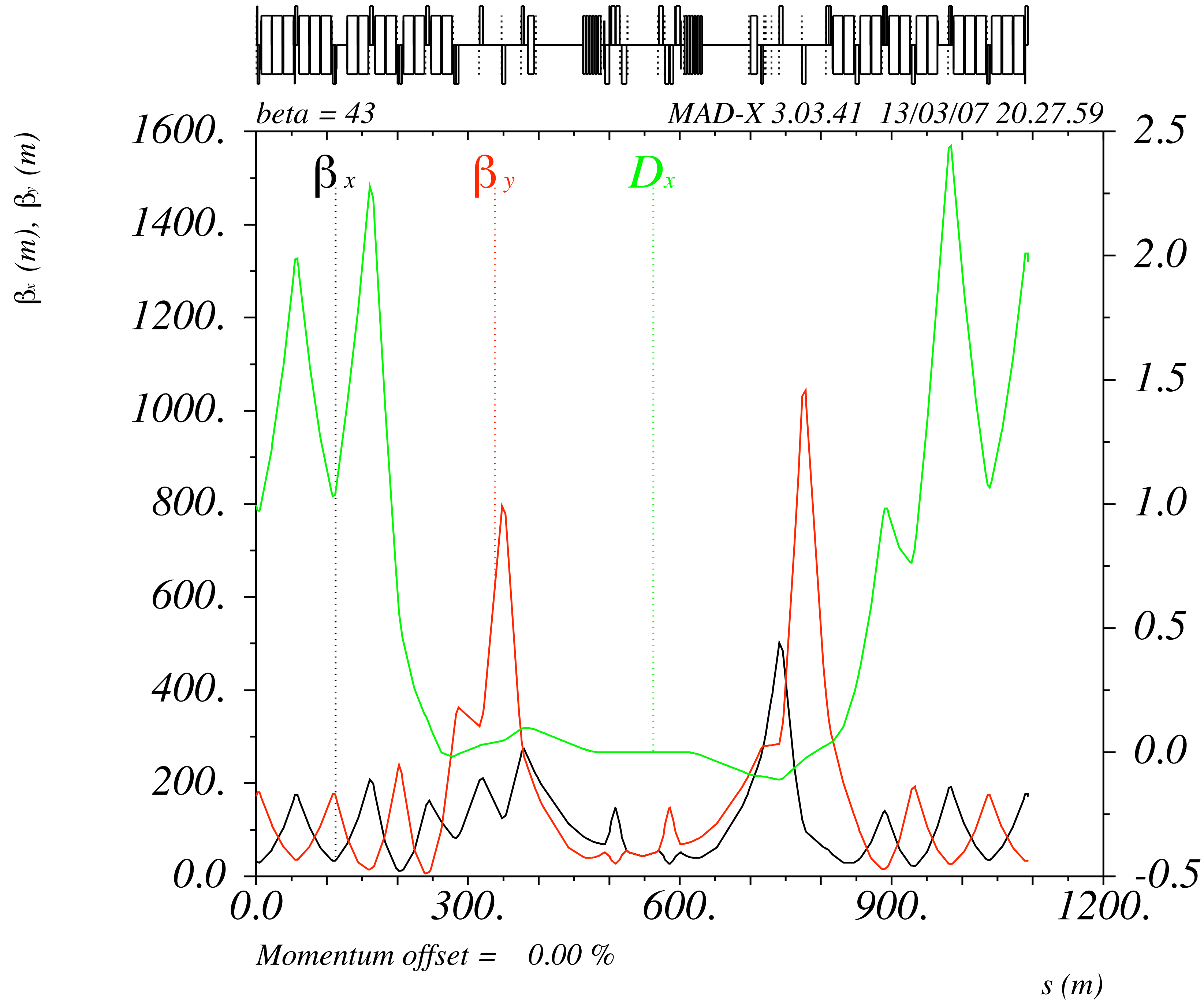


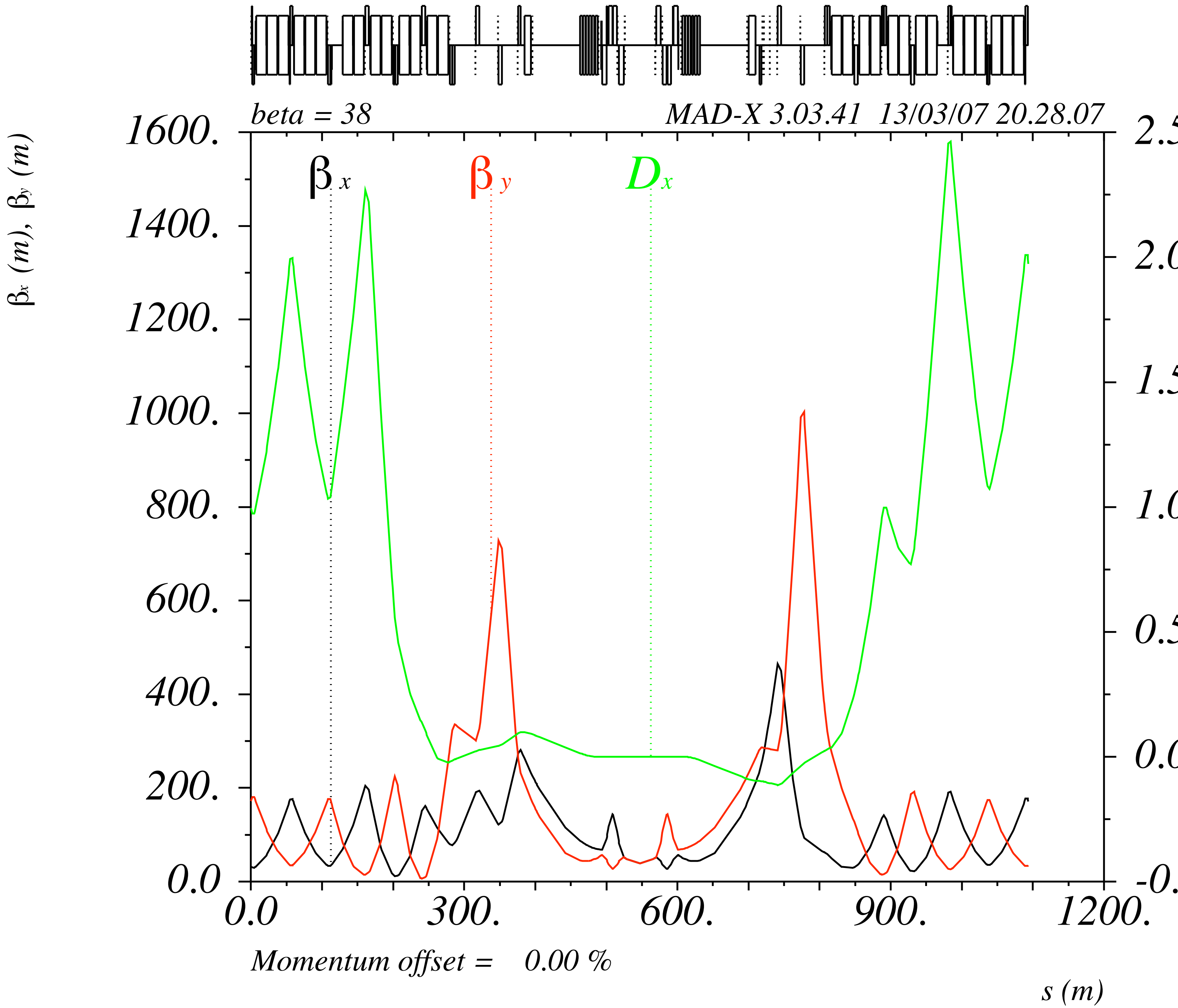
beta = 59
MAD-X 3.03.41 13/03/07 20.27.37
βx (m), βy (m)
Dx (m), Dy (m)
βx
βy
Dx
1600.
1400.
1200.
1000.
800.
600.
400.
200.
0.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
0.0
300.
600.
900.
1200.
Momentum offset = 0.00 %
s (m)

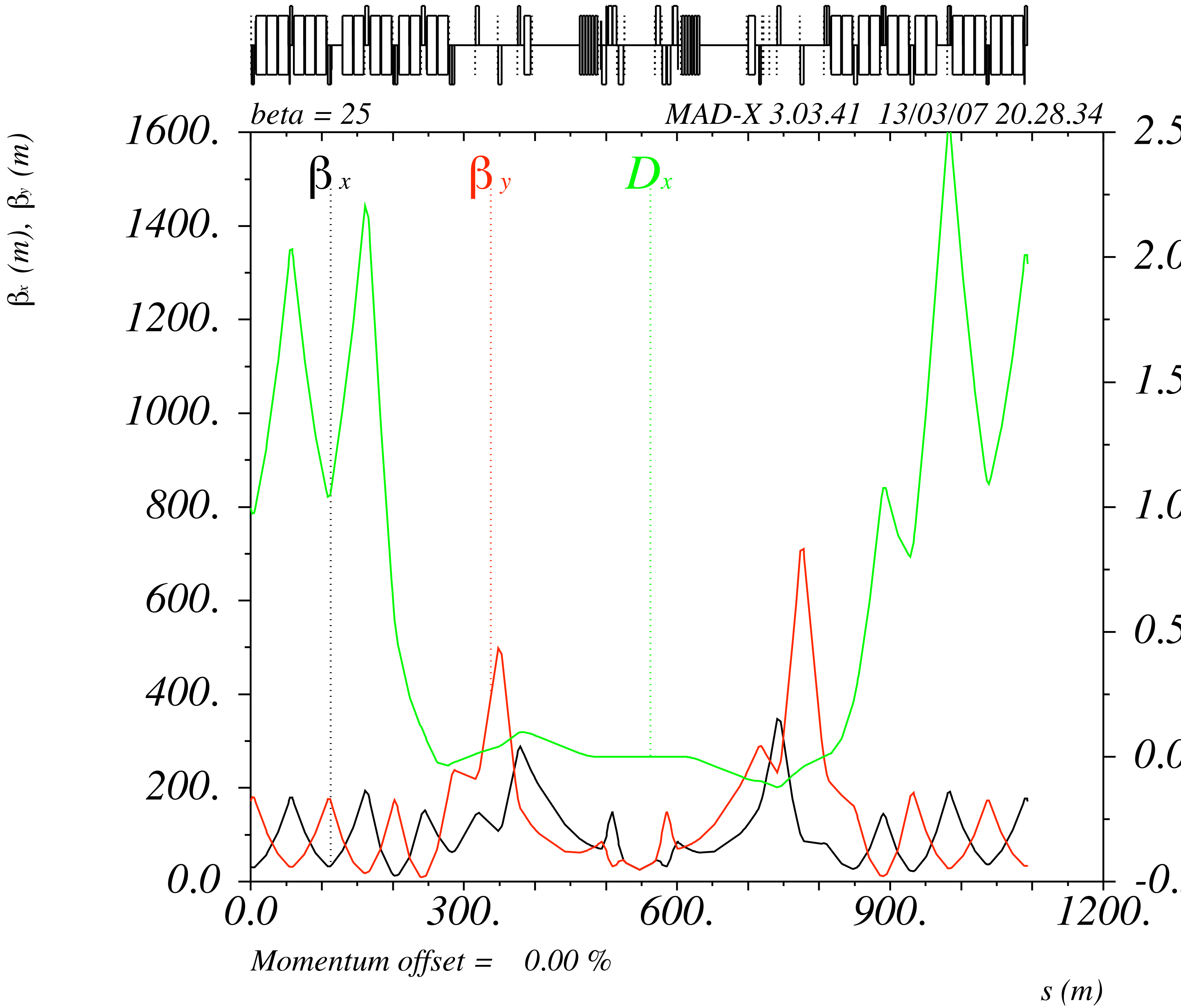


beta = 53
MAD-X 3.03.41 13/03/07 20.27.47
βx (m), βy (m)
Dx (m), Dy (m)
βx
βy
Dx
1600.
1400.
1200.
1000.
800.
600.
400.
200.
0.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
0.0
300.
600.
900.
1200.
Momentum offset = 0.00 %
s (m)

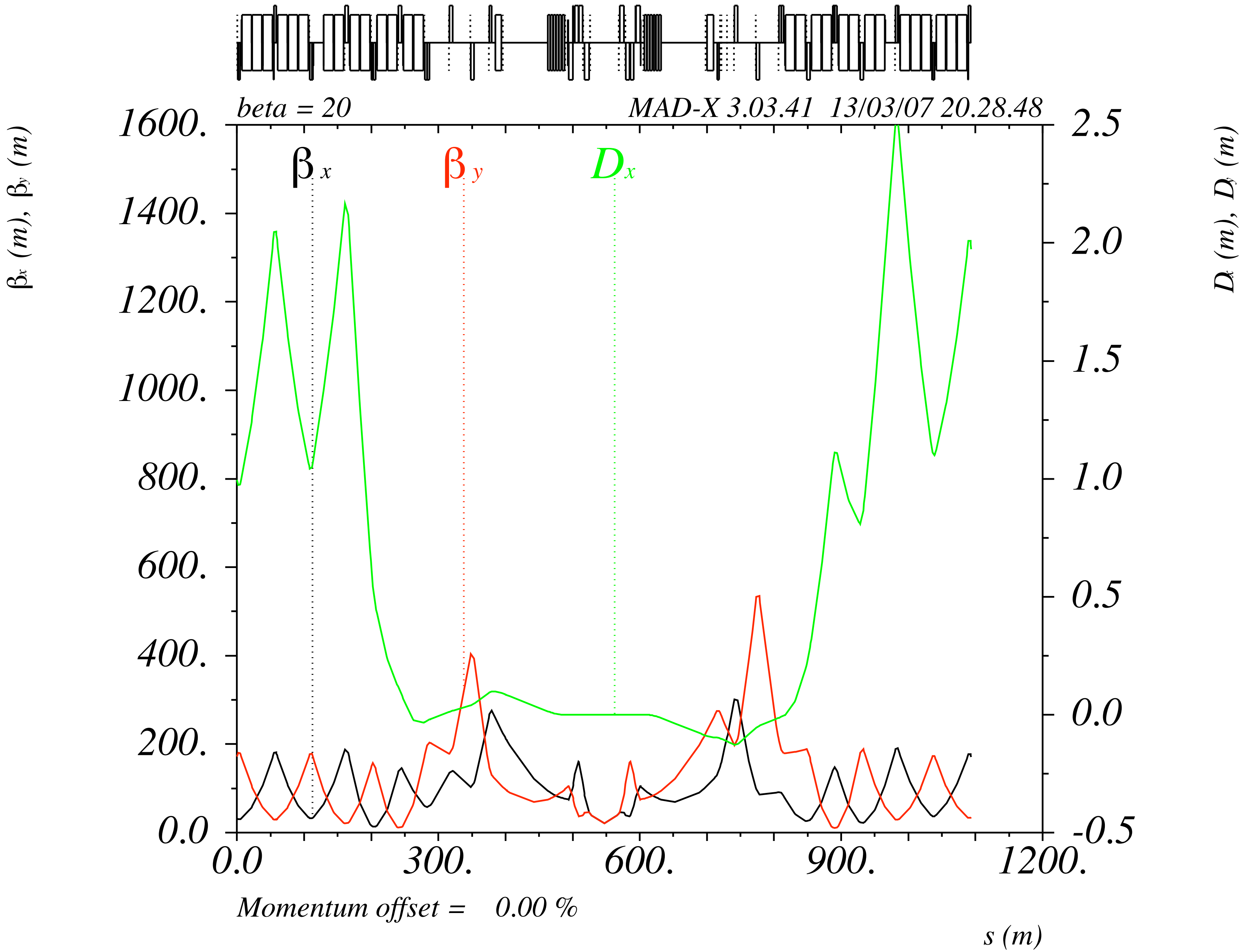

beta = 47
MAD-X 3.03.41 13/03/07 20.27.53
βx
βy
Dx
βx (m), βy (m)
Dx (m), Dy (m)
1600.
1400.
1200.
1000.
800.
600.
400.
200.
0.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
0.0
300.
600.
900.
1200.
Momentum offset = 0.00 %
s (m)

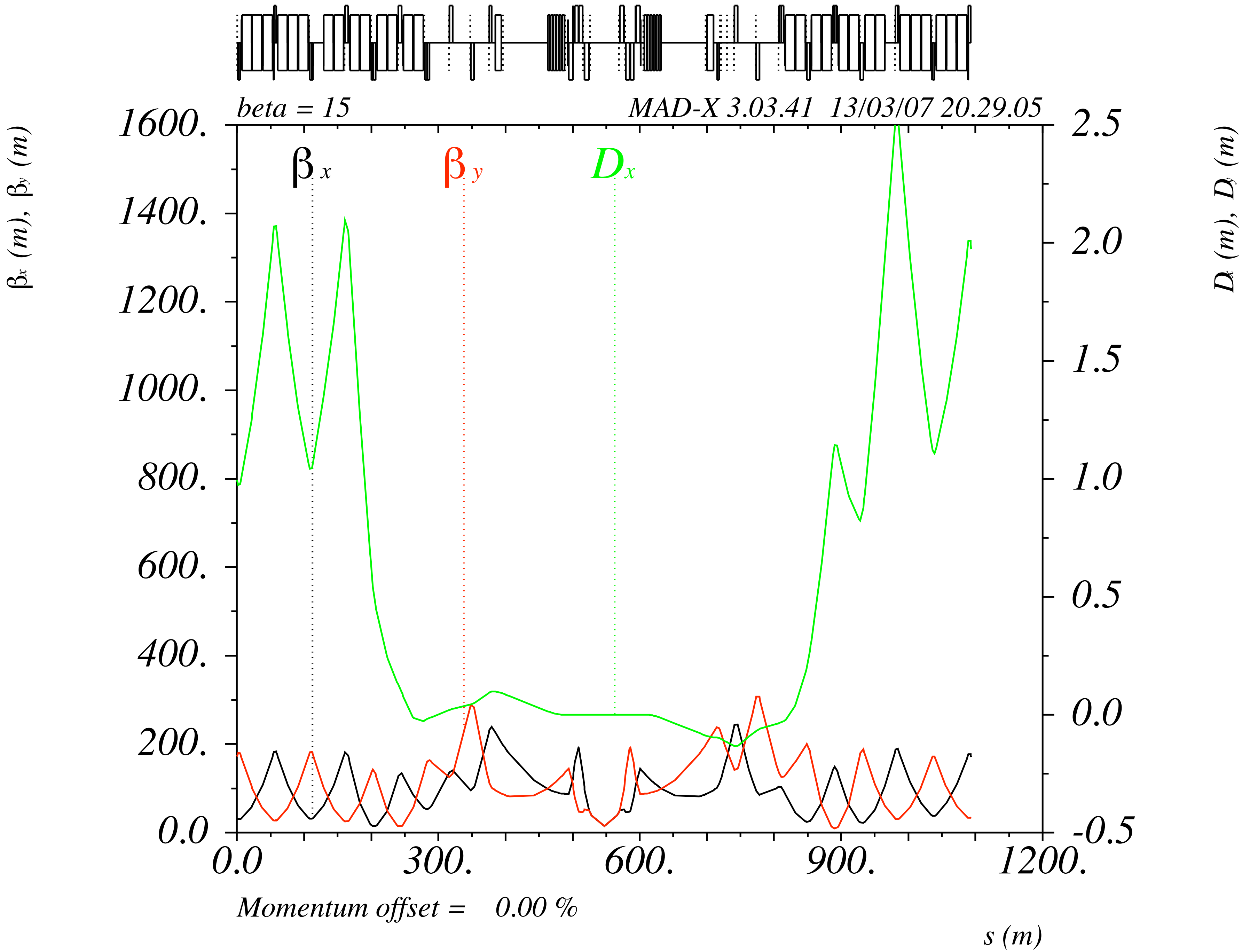

beta = 43
MAD-X 3.03.41 13/03/07 20.27.59
β_x β_y D_x
β_x (m), β_y (m)
D_x (m), D_y (m)
1600.
1400.
1200.
1000.
800.
600.
400.
200.
0.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
0.0
300.
600.
900.
1200.
Momentum offset = 0.00 %
s (m)


beta = 38
MAD-X 3.03.41 13/03/07 20.28.07
βx (m), βy (m)
Dx (m), Dy (m)
βx
βy
Dx
1600.
1400.
1200.
1000.
800.
600.
400.
200.
0.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
0.0
300.
600.
900.
1200.
Momentum offset = 0.00 %
s (m)

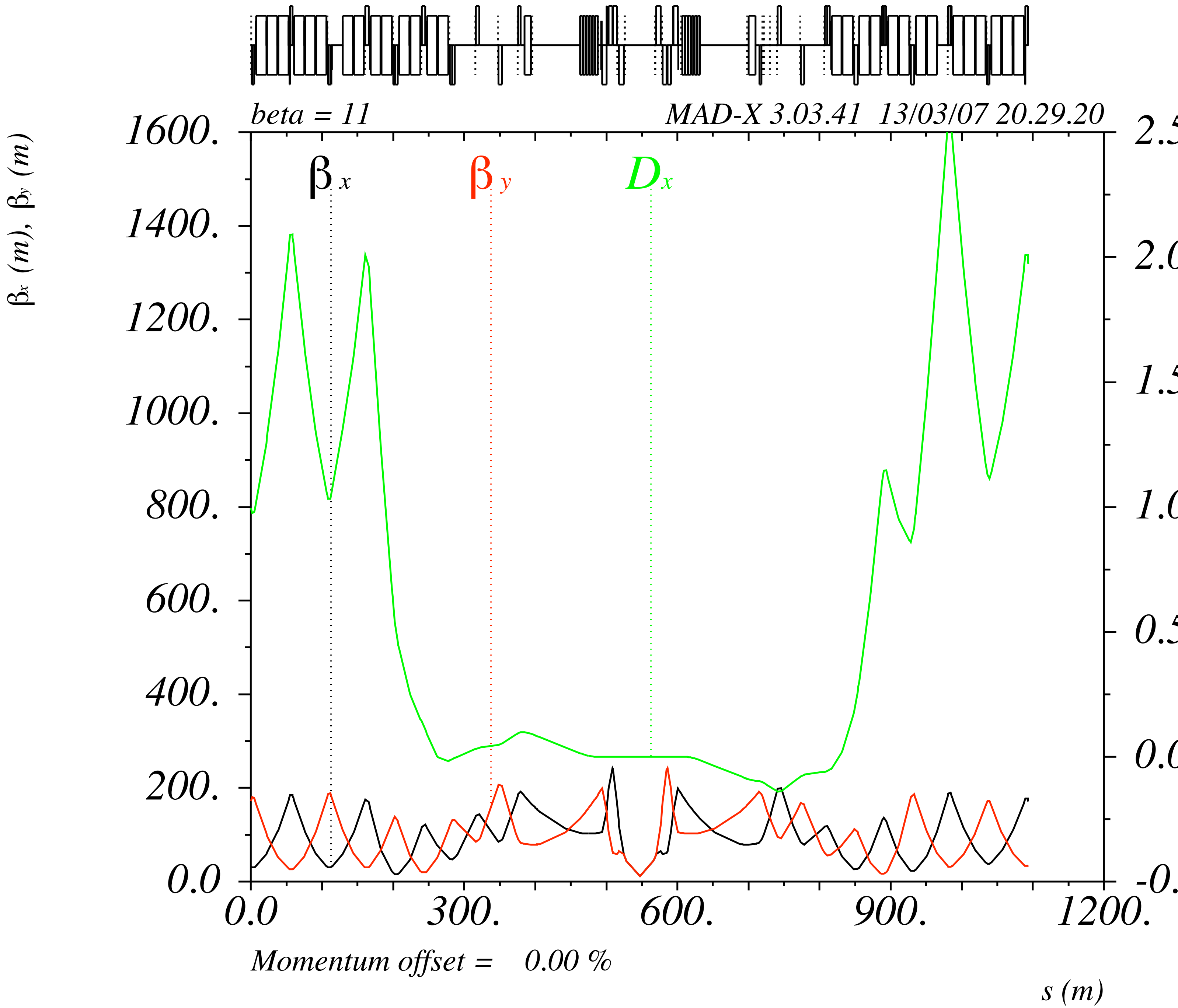


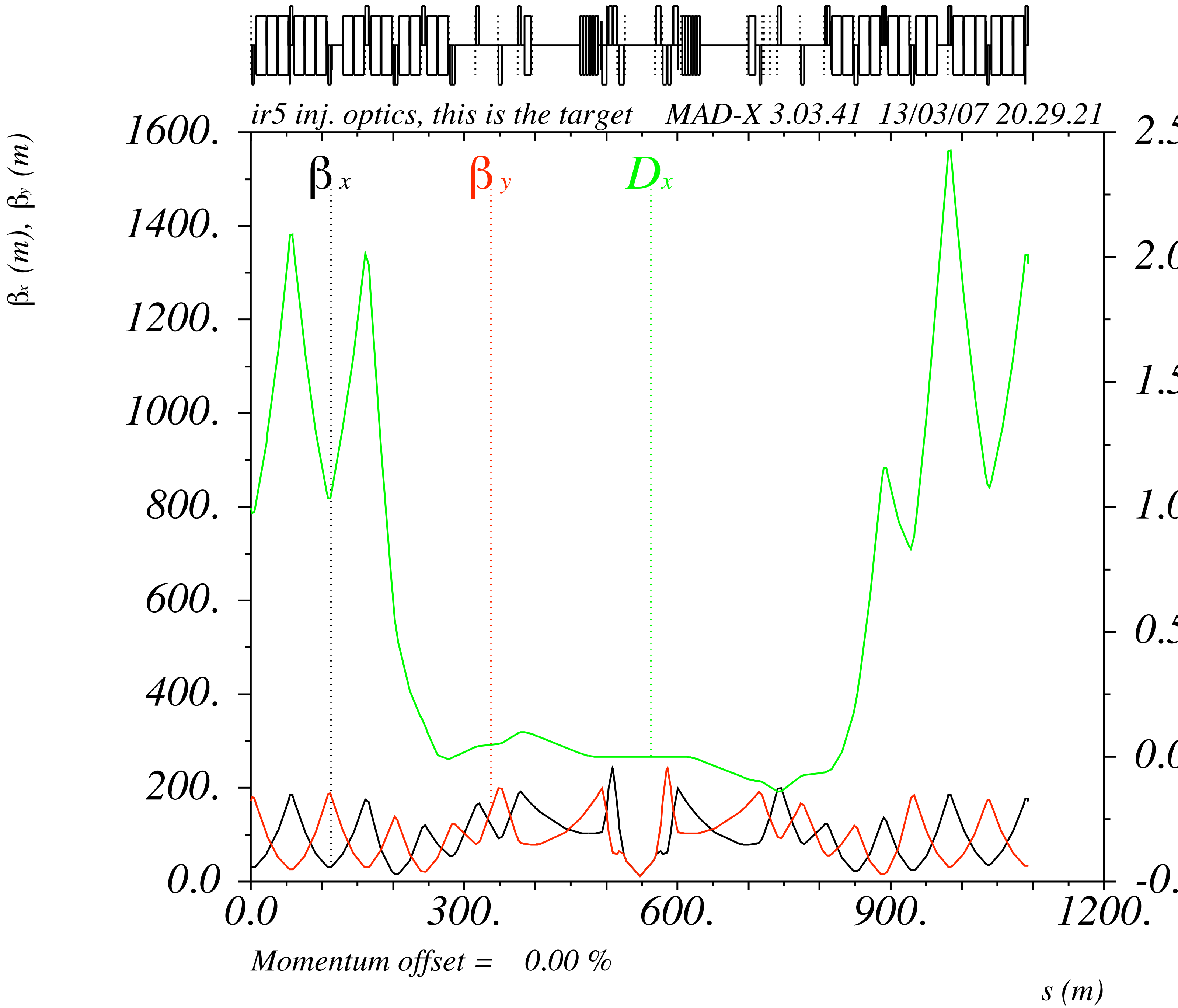
beta = 25
MAD-X 3.03.41 13/03/07 20.28.34
βx (m), βy (m)
Dx (m), Dy (m)
βx
βy
Dx
1600.
1400.
1200.
1000.
800.
600.
400.
200.
0.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
0.0
300.
600.
900.
1200.
Momentum offset = 0.00 %
s (m)


beta = 20
MAD-X 3.03.41 13/03/07 20.28.48
βx (m), βy (m)
Dx (m), Dy (m)
βx
βy
Dx
1600.
1400.
1200.
1000.
800.
600.
400.
200.
0.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
0.0
300.
600.
900.
1200.
Momentum offset = 0.00 %
s (m)



beta = 15
MAD-X 3.03.41 13/03/07 20.29.05
βx (m), βy (m)
Dx (m), Dy (m)
βx
βy
Dx
1600.
1400.
1200.
1000.
800.
600.
400.
200.
0.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
0.0
300.
600.
900.
1200.
Momentum offset = 0.00 %
s (m)


beta = 11
MAD-X 3.03.41 13/03/07 20.29.20
βx (m), βy (m)
Dx (m), Dy (m)
βx
βy
Dx
1600.
1400.
1200.
1000.
800.
600.
400.
200.
0.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
0.0
300.
600.
900.
1200.
Momentum offset = 0.00 %
s (m)



ir5 inj. optics, this is the target
MAD-X 3.03.41 13/03/07 20.29.21
βx
βy
Dx
βx (m), βy (m)
Dx (m), Dy (m)
1600.
1400.
1200.
1000.
800.
600.
400.
200.
0.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
0.0
300.
600.
900.
1200.
Momentum offset = 0.00 %
s (m)

Conclusion

Based on the optics / aperture arguments presented :
the “un-squeeze” from our standard 11 m injection&ramp optics to the 90 m Totem optics in IP 5 looks feasible.

One known issue :
The “un-squeeze” is not completely local : the global tune is reduced ; this is correctable by a global tune adjust within the nominal tuning range and not expected to be critical : to be verified in early operation or MD

Commissioning time

Hard to predict for a new machine of the size and complexity of the LHC
Probably similar to the time needed to commission the squeeze down to 2 m

Backup Slides

Outlook V6.501

Phase advances were kept fixed between optics versions V6.5 and V6.500

LHCVERSION V6.500

	beam1		beam2	
	MU_X	MU_Y	MU_X	MU_Y
arcs	44.1040	40.6890	44.1040	40.6890
IR1	2.6330	2.6490	2.6330	2.6490
IR2	2.9740	2.7980	2.9910	2.8440
IR3	2.2480	1.9430	2.2494	2.0066
IR4	2.1430	1.8700	2.1430	1.8700
IR5	2.6330	2.6490	2.6330	2.6490
IR6	2.0150	1.7800	2.0150	1.7800
IR7	2.3770	1.9680	2.4826	2.0504
IR8	3.1830	2.9740	3.0590	2.7820
tune	64.3100	59.3200	64.3100	59.3200

To allow for a more general optimisation, they were allowed to change for V6.501, mux increased in various places : IR2, IR7 can be expected to rather facilitate the integration of the early Totem 90 m optics.

LHCVERSION V6.501

	beam1		beam2	
	MU_X	MU_Y	MU_X	MU_Y
arcs	44.1040	40.6890	44.1040	40.6890
IR1	2.6330	2.6490	2.6330	2.6490
IR2	3.0098	2.8102	2.9908	2.8441
IR3	2.2050	1.9596	2.2088	1.9673
IR4	2.0815	1.9715	2.1737	1.8862
IR5	2.6330	2.6490	2.6330	2.6490
IR6	2.0150	1.7800	2.0150	1.7800
IR7	2.4500	1.9236	2.4894	2.0030
IR8	3.1786	2.8880	3.0622	2.8525
tune	64.3100	59.3200	64.3100	59.3200

$\Delta Qx = 0.093$, $\Delta Qy = 0.029$ adjust required for Totem 90 m same for b1, b2 : use main quads to adjust tune kqd, kqf