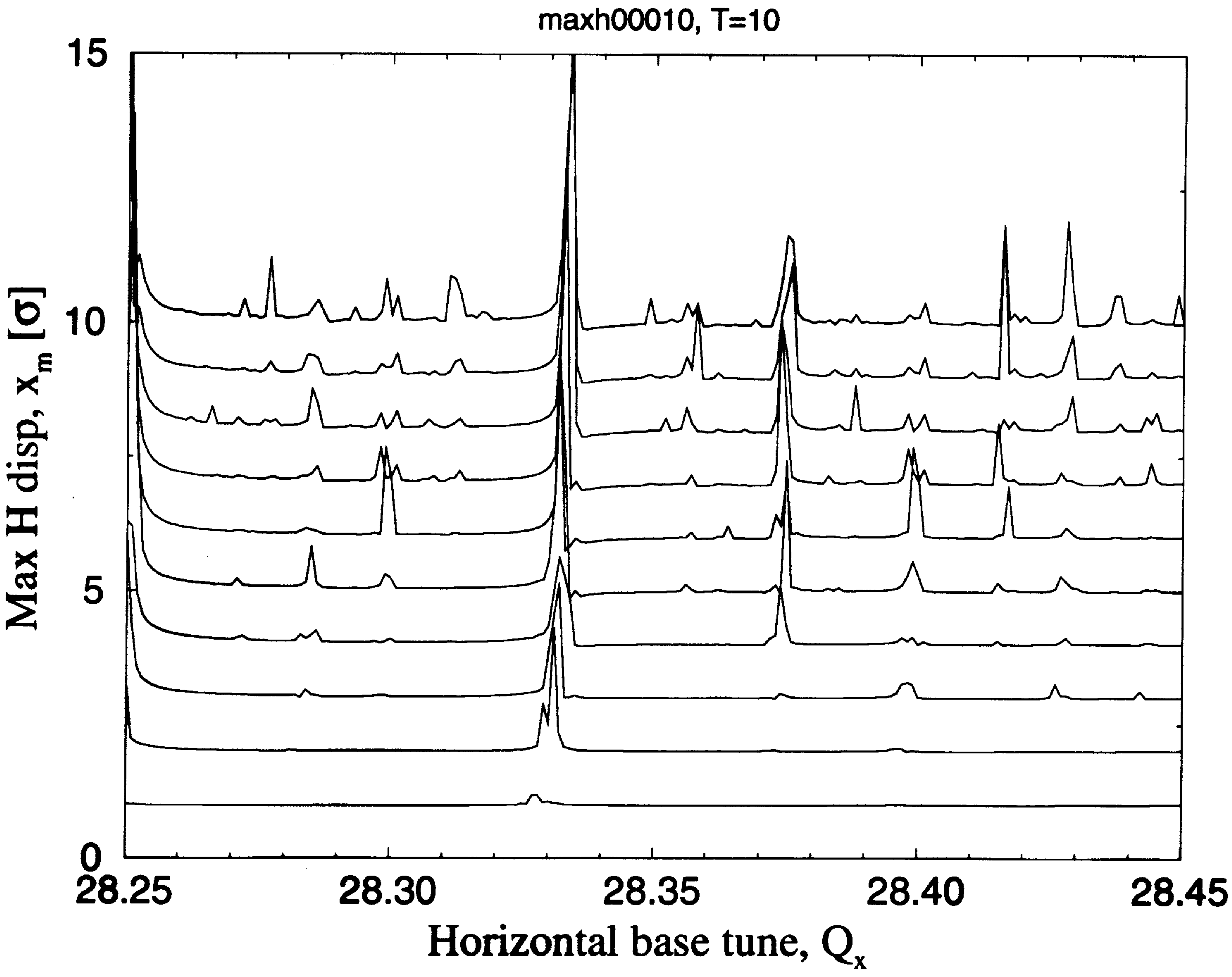
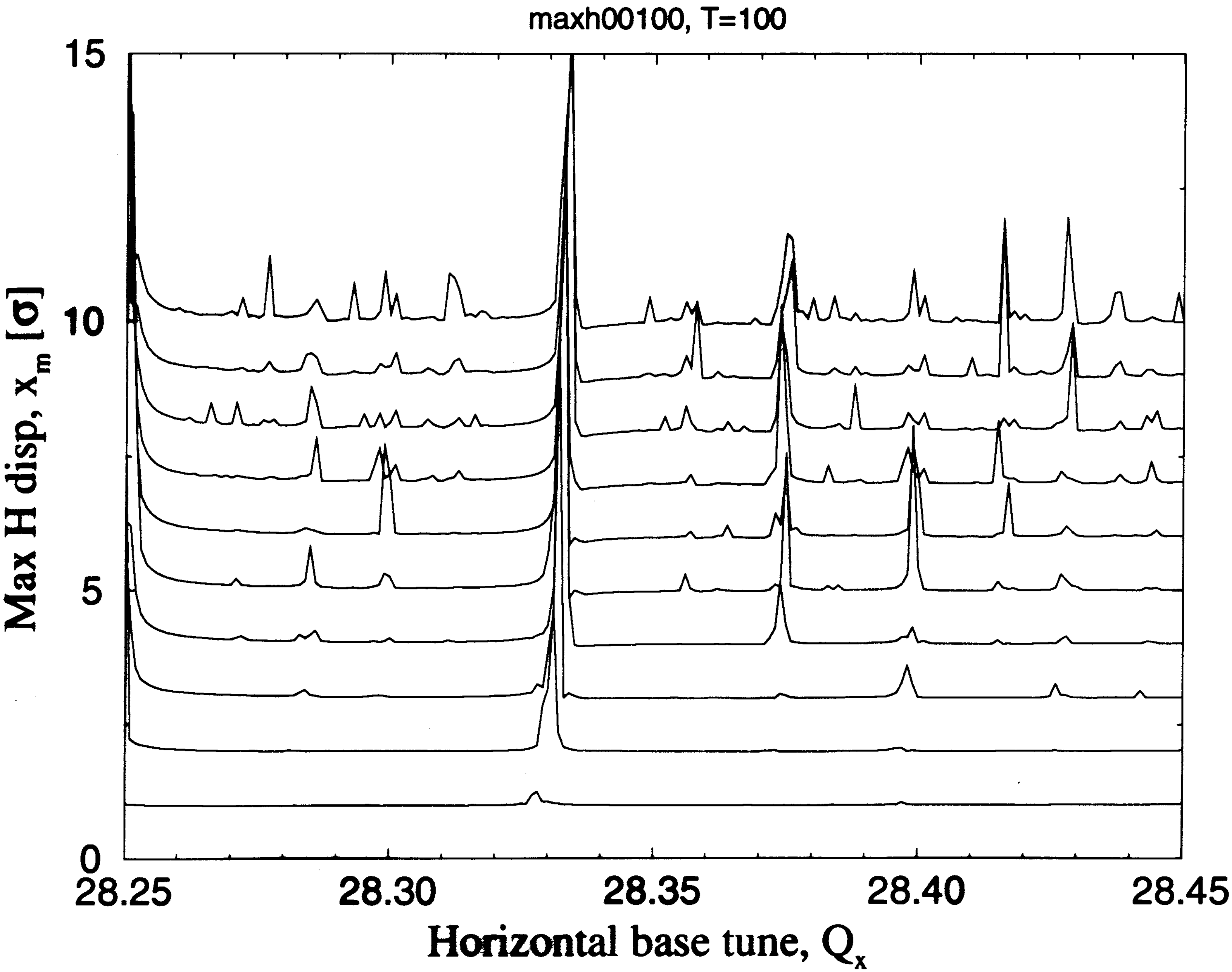

maxh00010, T=10
15
10
5
0
Max H disp, x_m [σ]
28.25
28.30
28.35
28.40
28.45
Horizontal base tune, Q_x


maxh00100, T=100
Max H disp, x_m [σ]
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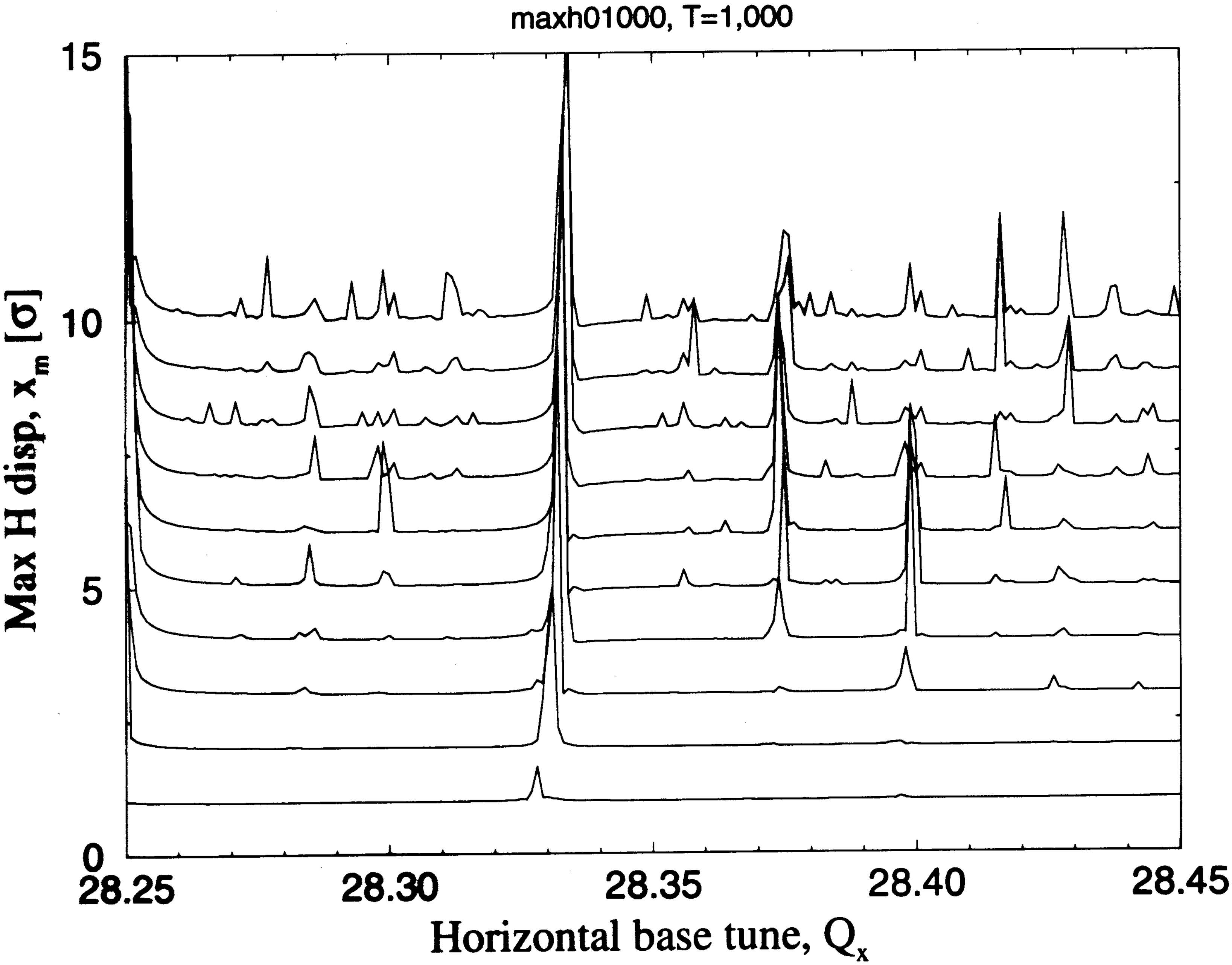
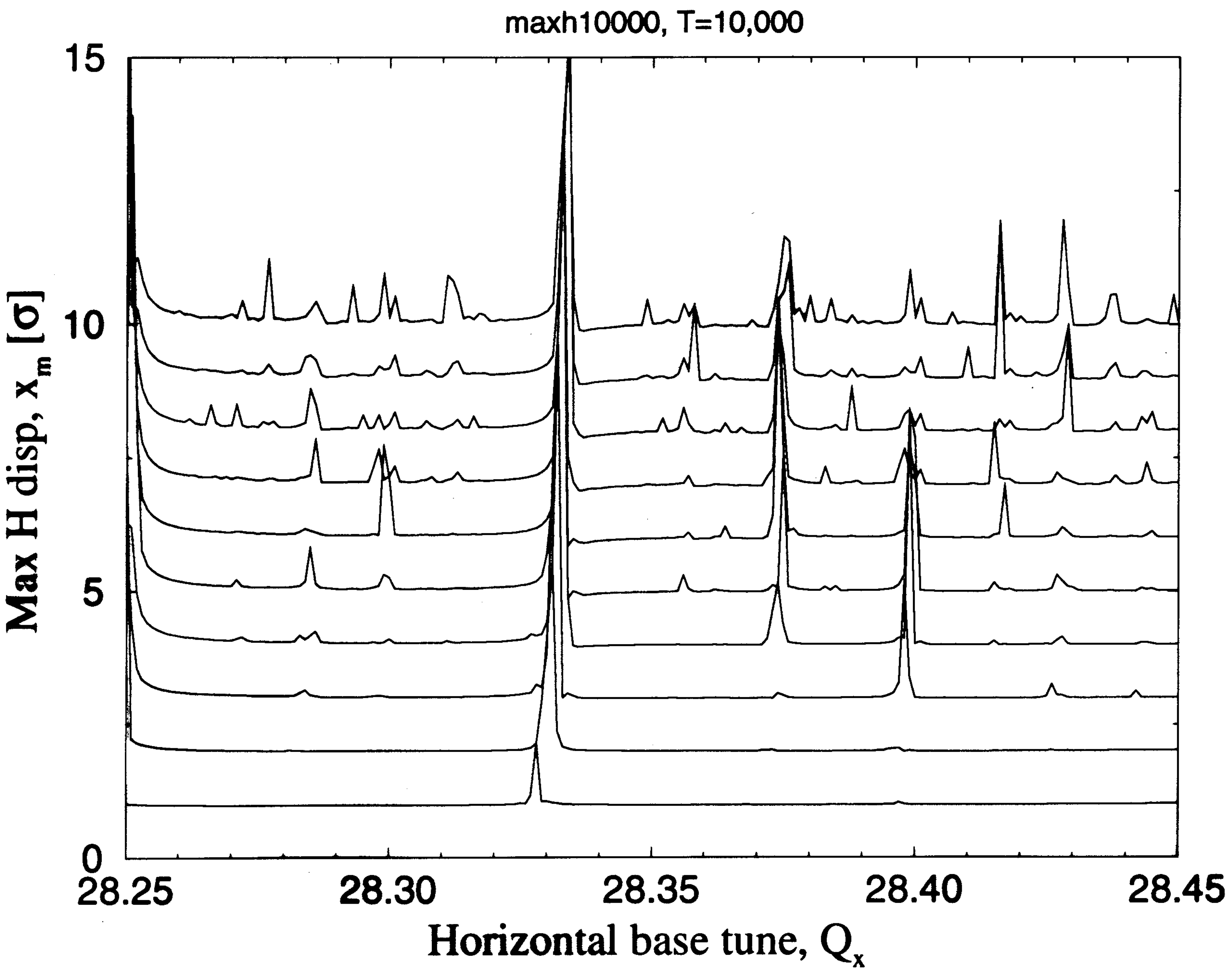
10
5
0
28.25
28.30
28.35
28.40
28.45
Horizontal base tune, Q_x


maxh01000, T=1,000
Max H disp, x_m [σ]
15
10
5
0
28.25
28.30
28.35
28.40
28.45
Horizontal base tune, Q_x


maxh10000, T=10,000
15
10
5
0
Max H disp, x_m [σ]
28.25
28.30
28.35
28.40
28.45
Horizontal base tune, Q_x

- * KAM surfaces usually limit emittance growth in 1-D (+ tune modulation)

- * ARE EMITTANCE GROWTH MODELS ACCURATE IN 2-D?

  ① DO SIMULATIONS AGREE WITH THEORY? (EG "MODULATIONAL DIFFUSION" cf. LICHTENBURG + LIEBERMAN

  ② DOES SIMULATION/THEORY AGREE WITH REALITY? (EXPERIMENTS?)

From Todd Satogata's PhD Thesis ...

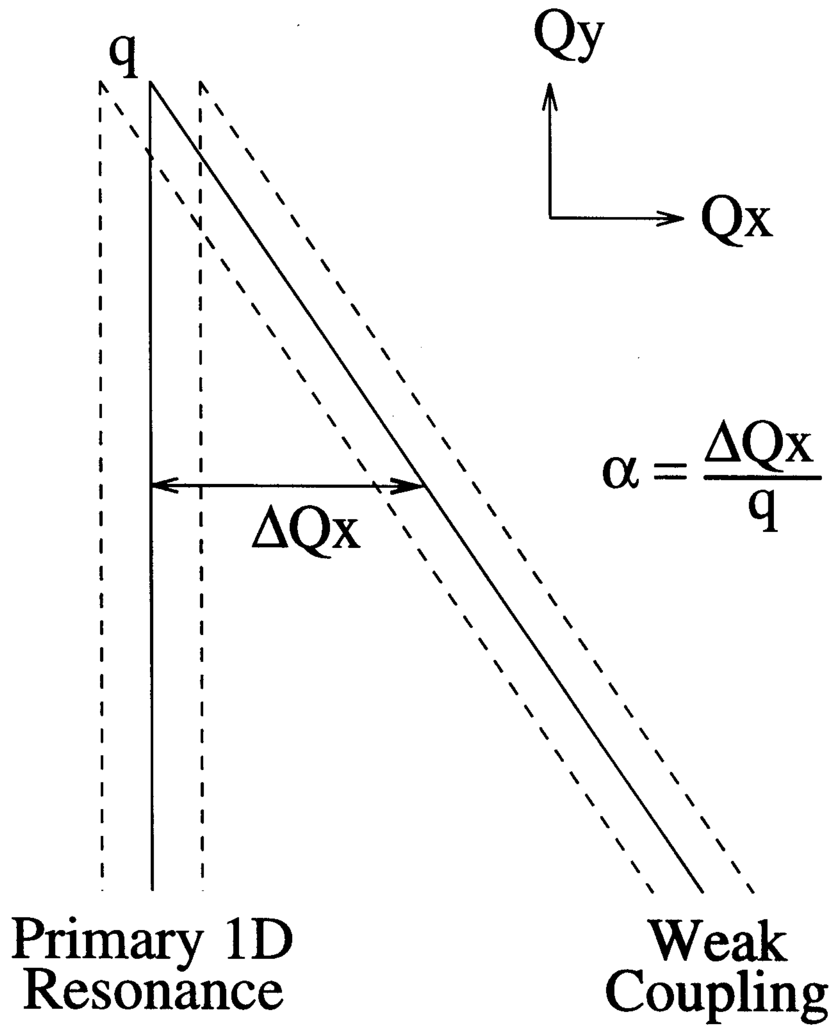
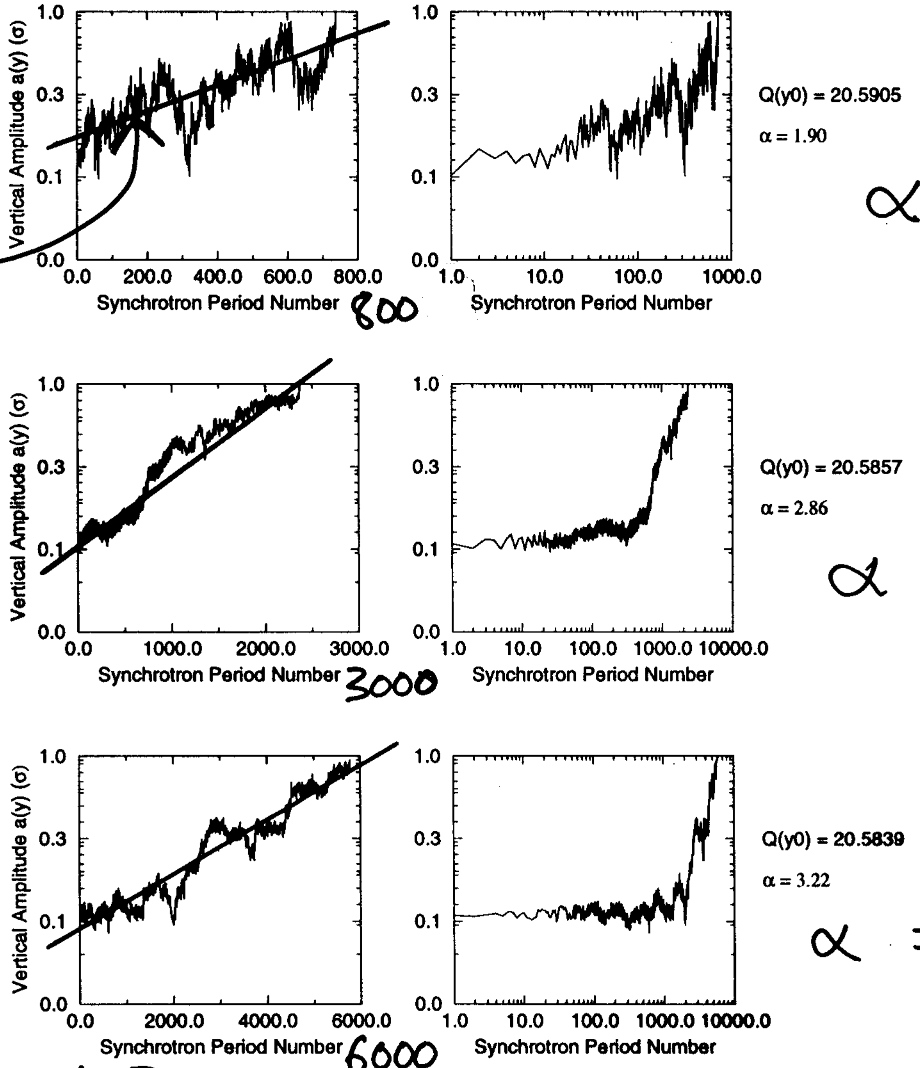


Fig 7.2: Modulational diffusion resonance structure. "α" is the tune distance between the primary driving resonance and the secondary weak coupling resonance, scaled by the modulation depth q.

T. Satogata

$a_{VERT} \sim D t^{\frac{1}{2}}$??

$t_V \sim e^{\boxed{\gamma} \frac{t}{T_M}}$



800

3000

6000

t [SYNCH. PERIODS]

α = 1.90

α = 2.86

α = 3.22

Fig 7.6: Vertical amplitude growth for particles launched with initial vertical amplitudes .1σ, and three different values of α. The modulational diffusion growth rate varies by an order of magnitude.

T. Satogata

$v \sim e^{\gamma t / T_M}$

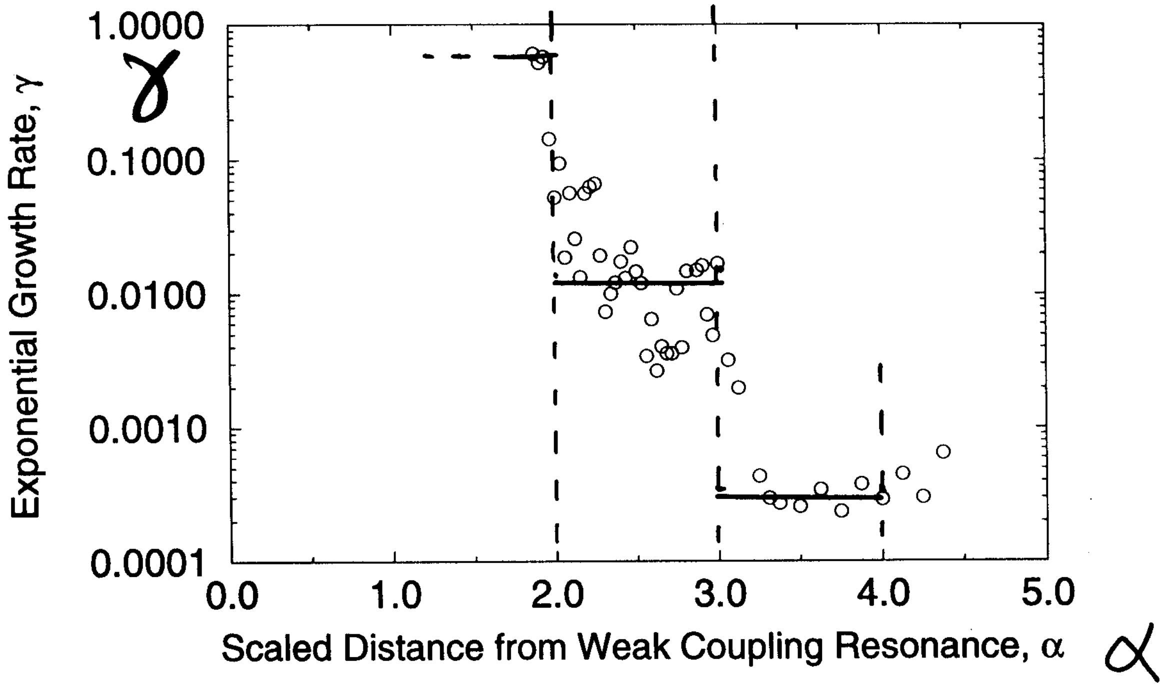
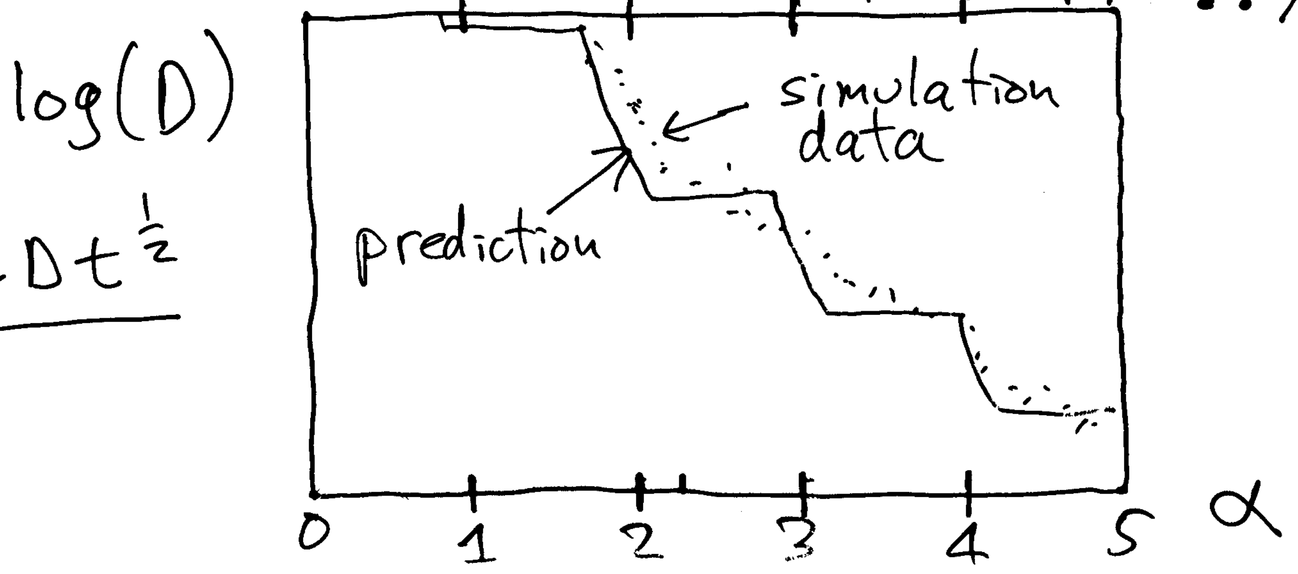
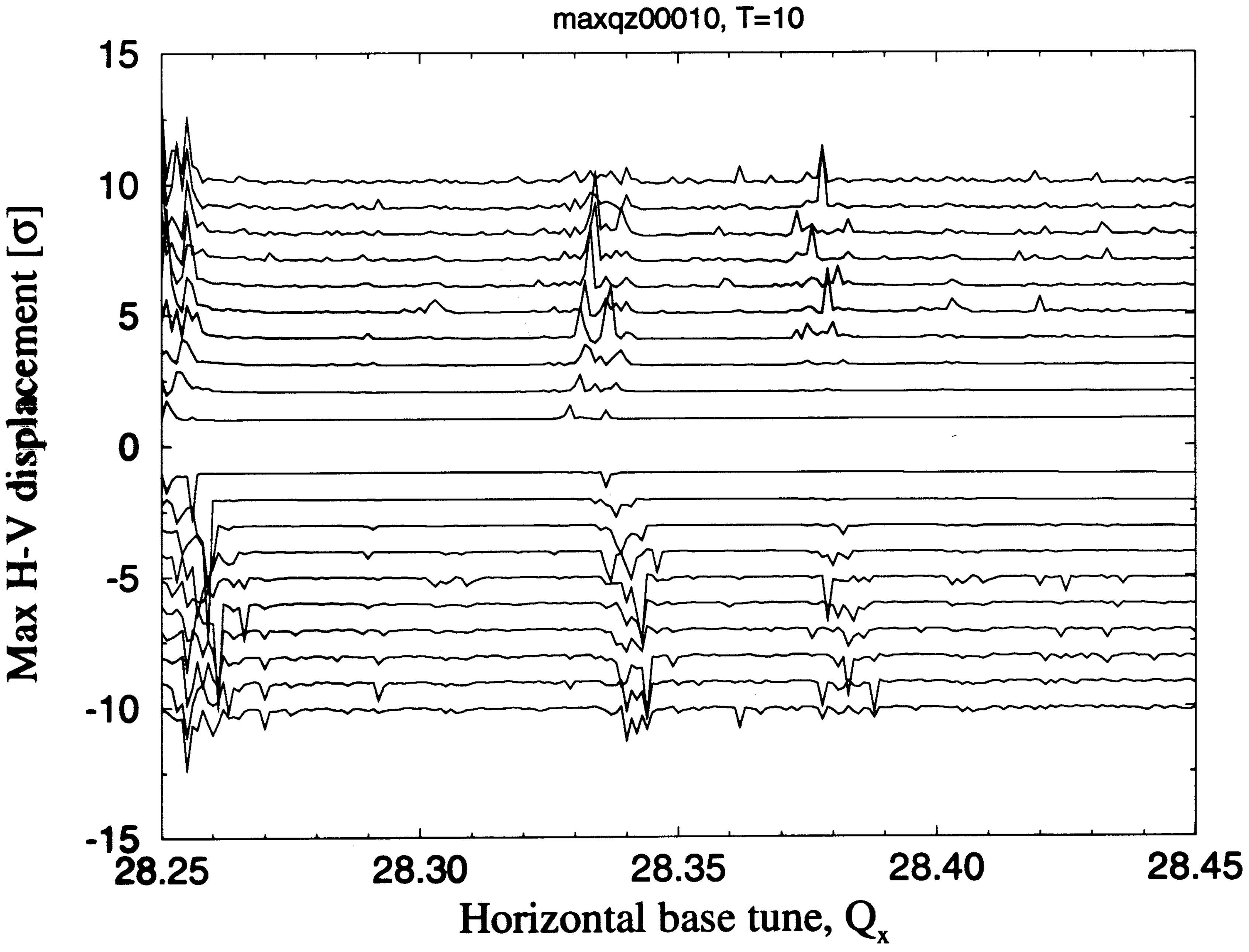


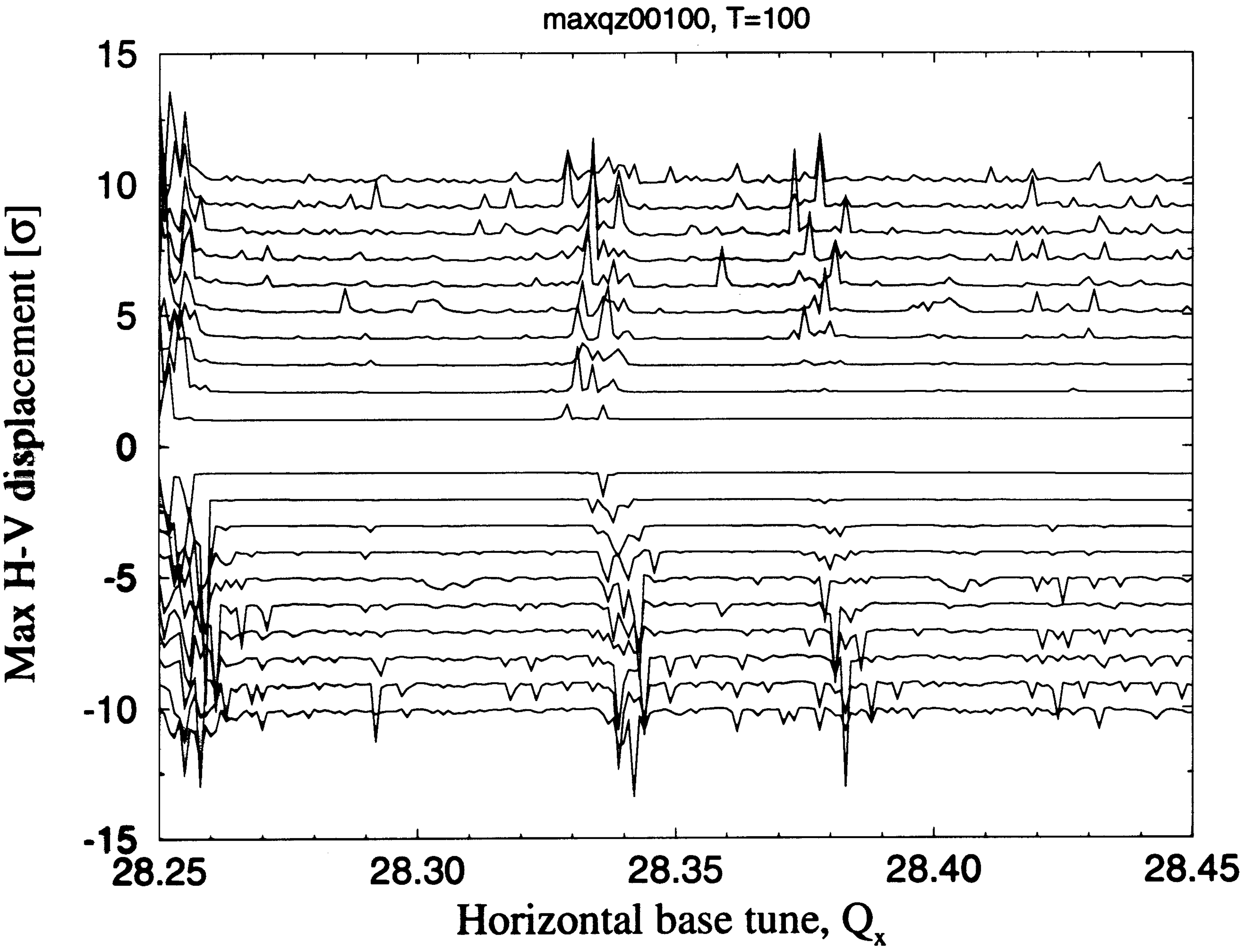
Fig 7.7: Exponential modulational diffusion growth rate γ plotted versus the scaled distance α from the $4Q_x + Q_y$ resonance. (Cf. Fig 6.14 in Lichtenberg & Lieberman, 2nd Ed.)

(DRAWN FROM MEMORY !?)



$a_v \sim D t^{\frac{1}{2}}$


maxqz00010, T=10
Max H-V displacement [σ]
15
10
5
0
-5
-10
-15
28.25
28.30
28.35
28.40
28.45
Horizontal base tune, Q_x


maxqz00100, T=100
15
10
5
0
-5
-10
-15
Max H-V displacement [σ]
28.25
28.30
28.35
28.40
28.45
Horizontal base tune, Q_x

1. Brief review of RHIC parameters

RHIC tune shift parameters

- Nominally there are $N = 10^{11}$ **protons** per bunch, with a 95% normalized transverse emittance of $\epsilon_N = 20\pi$ microns.

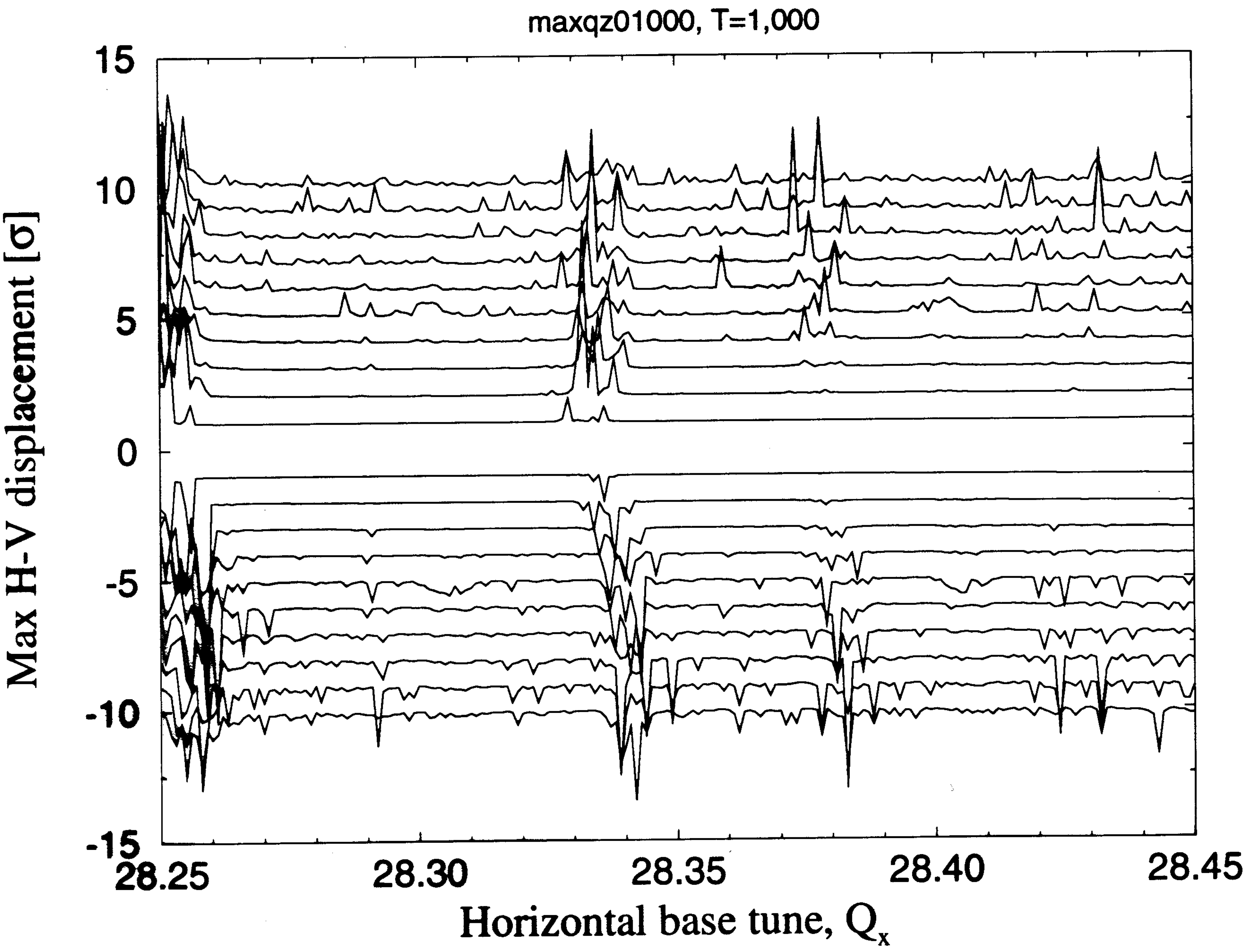
- With **gold**, there are $N = 10^9$ ions per bunch.

- **IBS** increases the **gold** emittance from 10π microns at injection to 40π microns at the end of a 10 hour store.

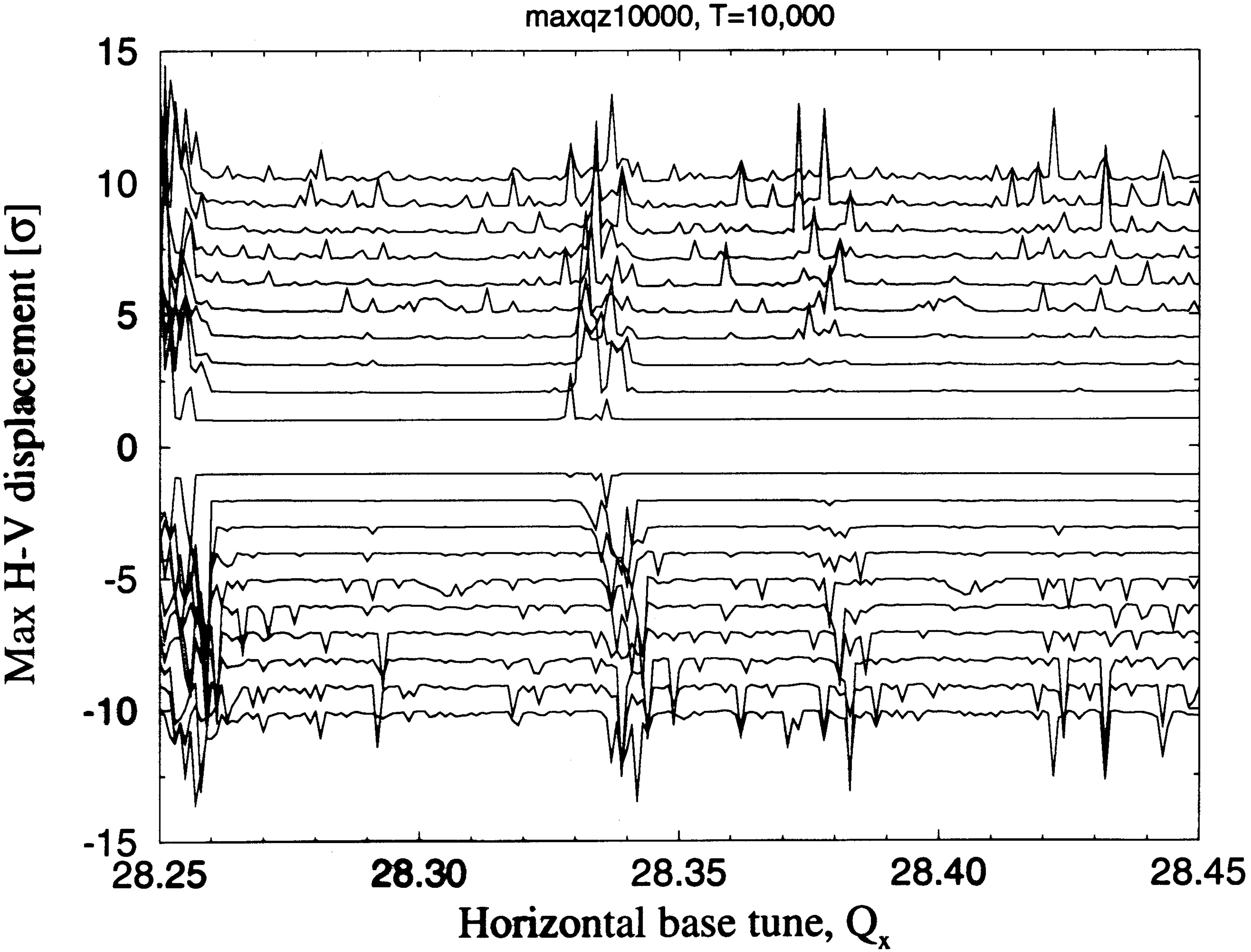
- Therefore, at each of the 6 IPs,

$$\begin{aligned}
\xi_p &= 0.00366 \, \frac{N}{10^{11}} \, \frac{20\pi\mu\text{m}}{\epsilon_N} \\
\xi_{Au} &= 0.00117 \, \frac{N}{10^{9}} \, \frac{20\pi\mu\text{m}}{\epsilon_N}
\end{aligned}$$

6 collision points


maxqz01000, T=1,000
Max H-V displacement [σ]
15
10
5
0
-5
-10
-15
28.25
28.30
28.35
28.40
28.45
Horizontal base tune, Q_x

$q_x = q_z = \cdot 001$, $\xi = \cdot 006$, $\Delta x_{co} = \Delta z_{co} = 0 \cdot 1\ \sigma$



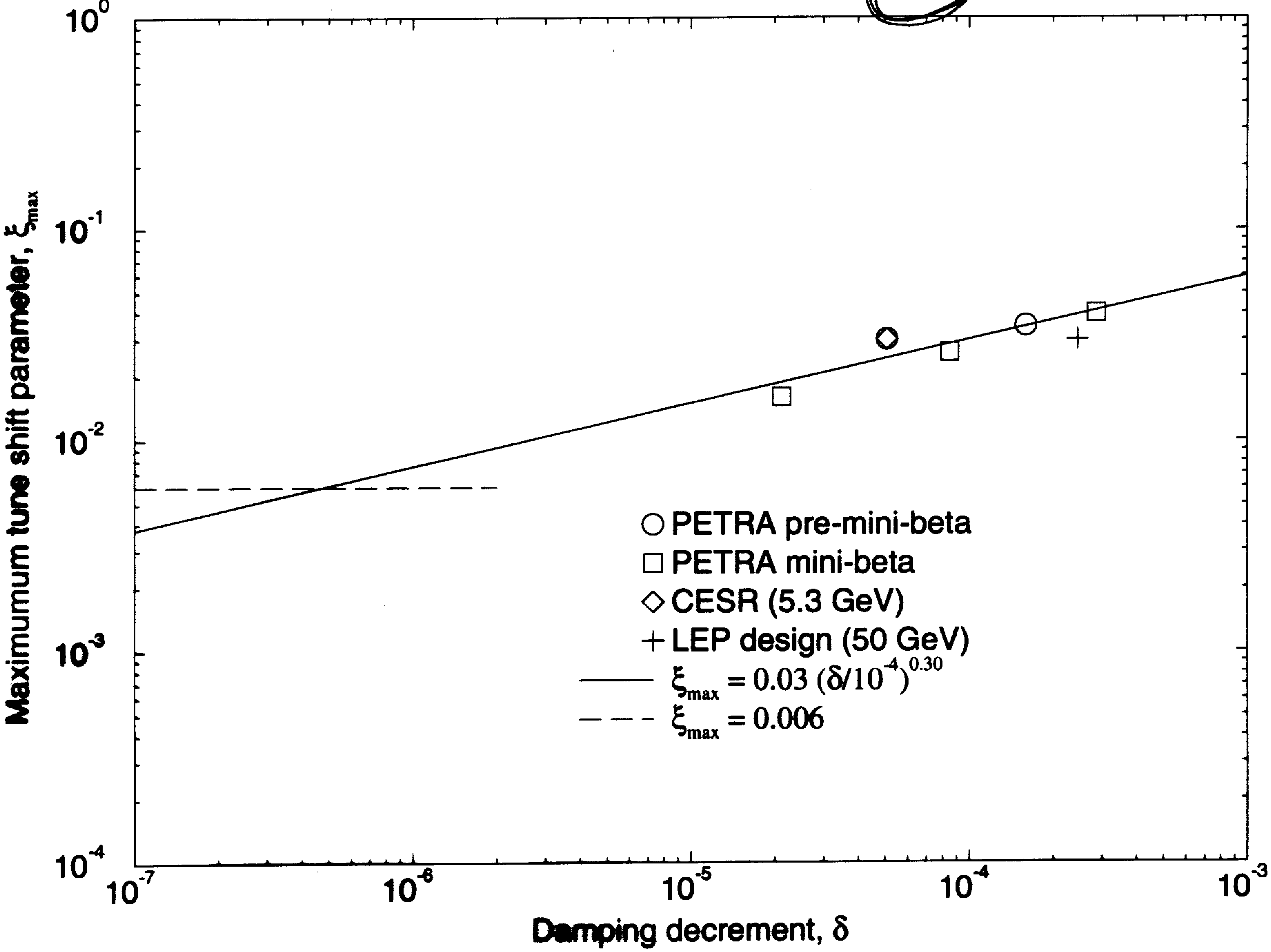
III). HIGH FIELD VLHC

EMPIRICALLY: Damping times $\tau \gtrsim 1$ hr must help observed slow emittance growth rates $\frac{d\epsilon_N}{dt} \sim 1\,\pi/\text{hr}$

BEAM-BEAM? IBS?

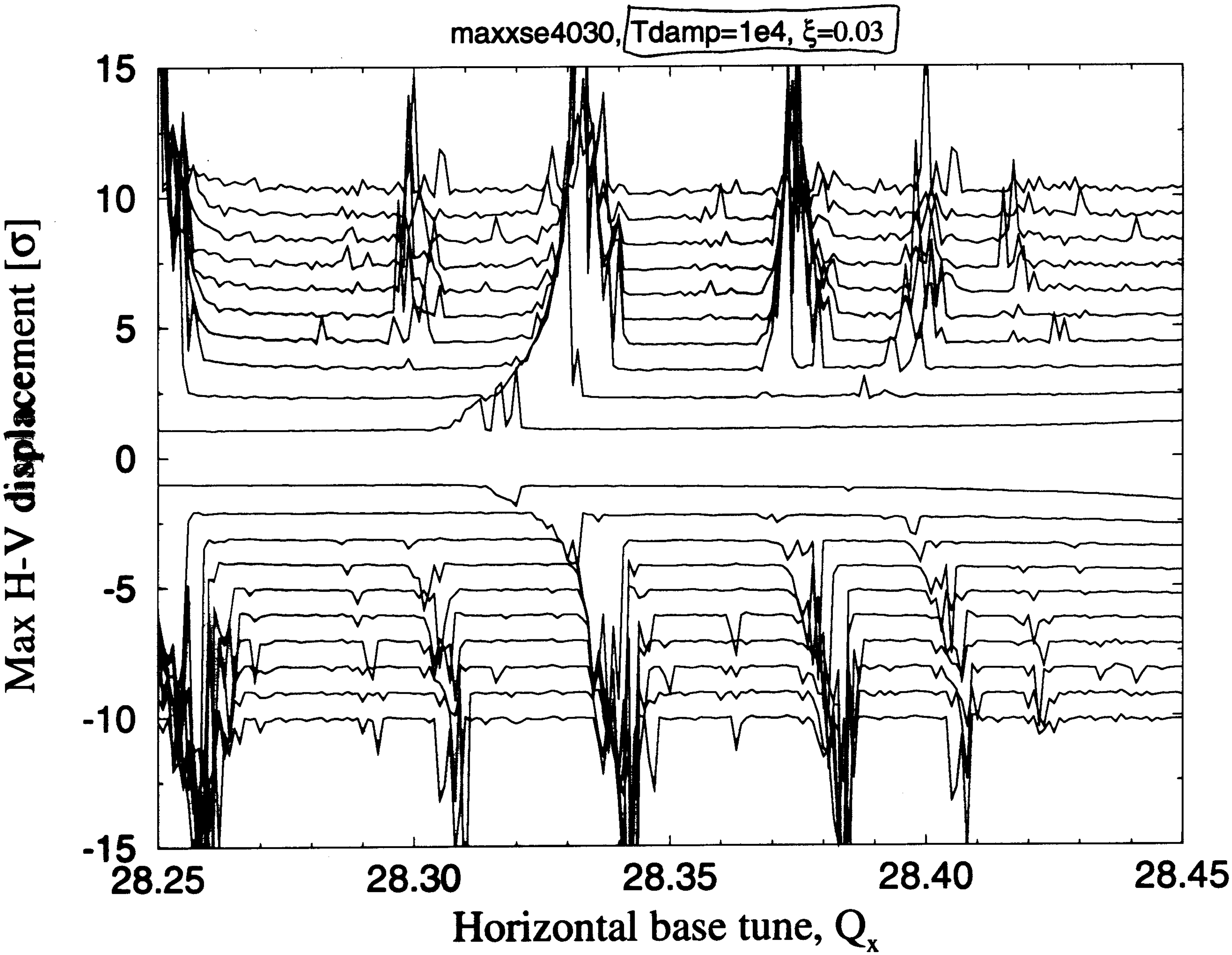
QUESTION: Do simulations show an increase in ξ_{MAX} when the DAMPING DECREMENT $\delta \simeq 10^{-7}$?

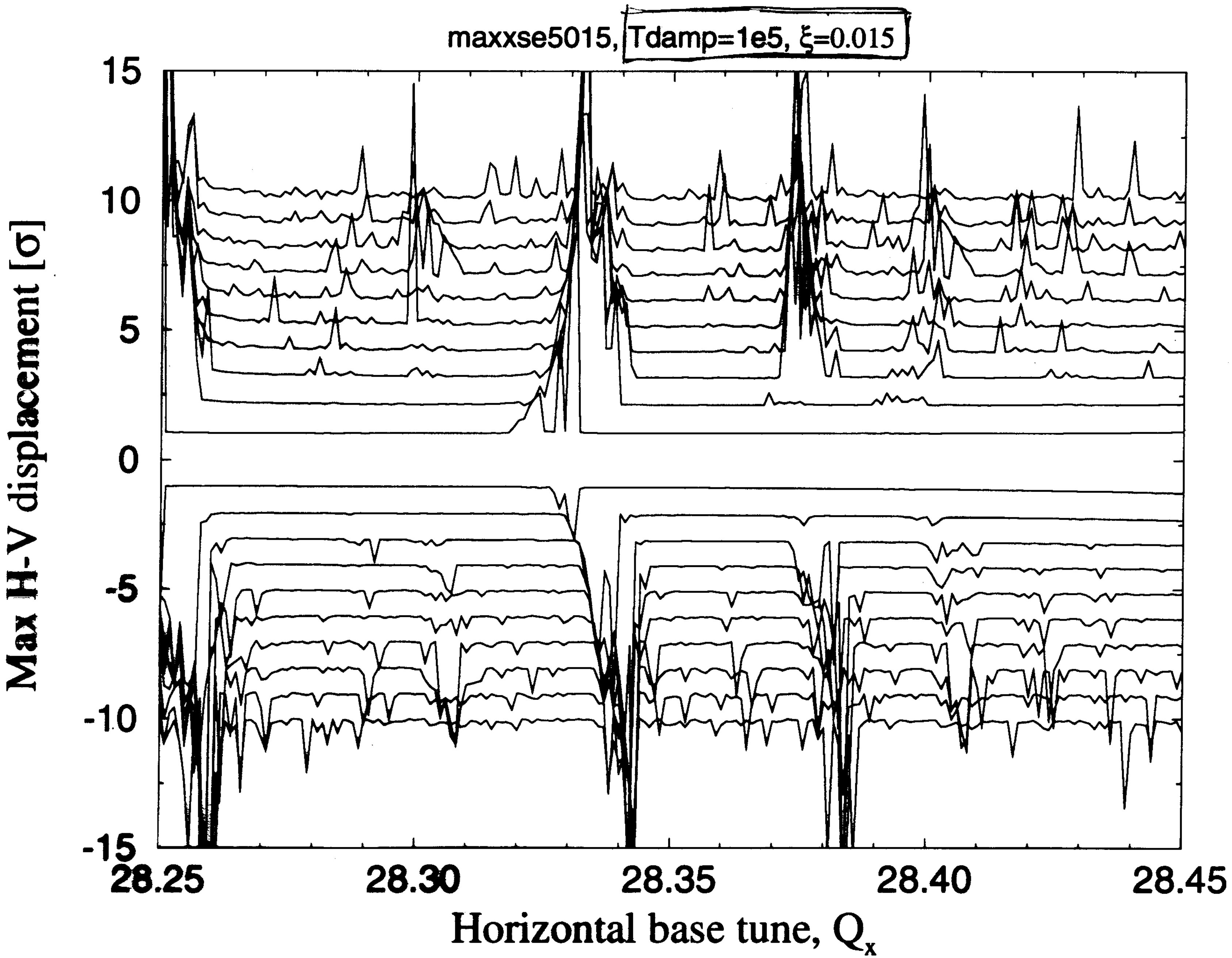
["DAMPING DECREMENT" $\equiv$ FRACTION OF A DAMPING TIME BETWEEN COLLISIONS]

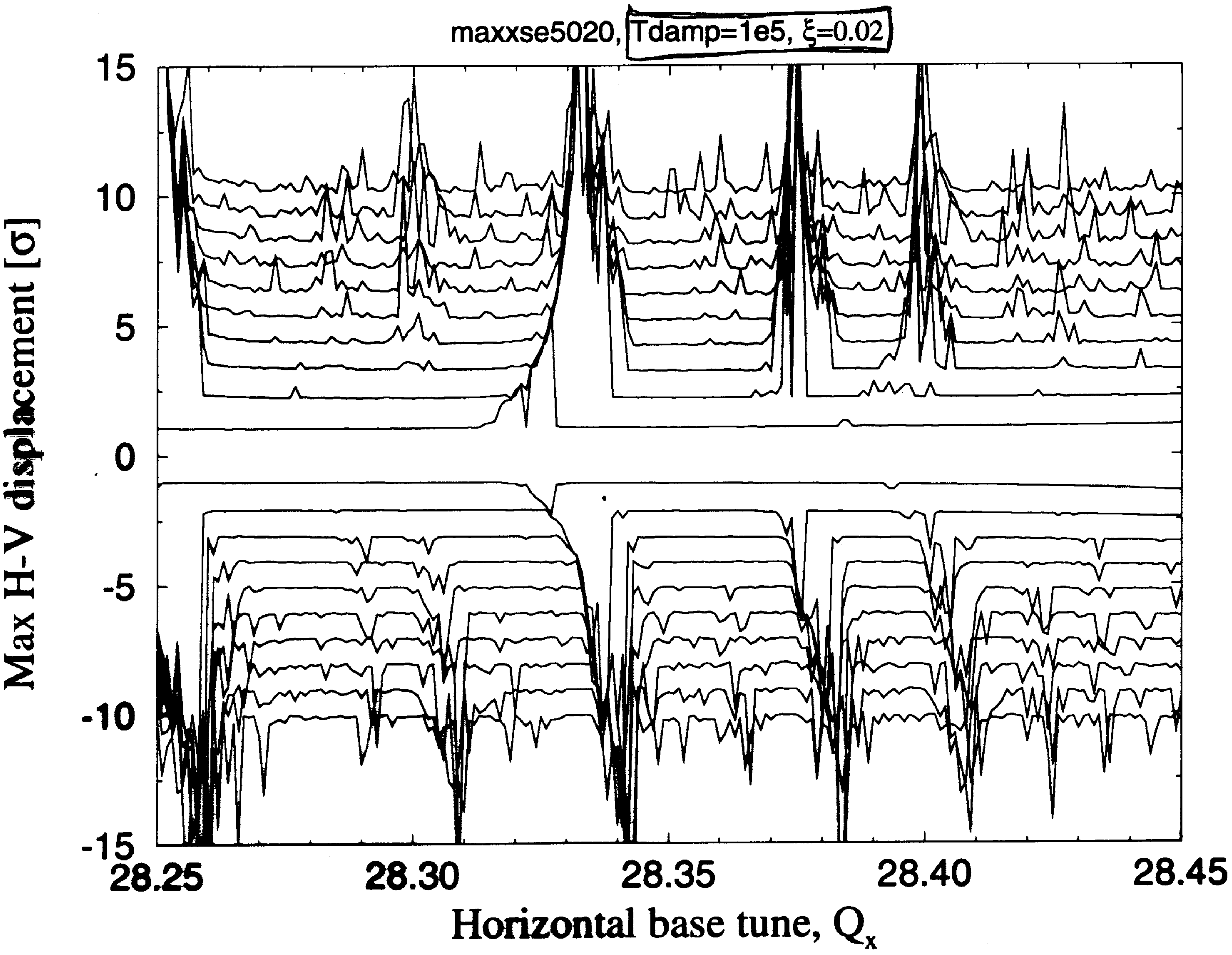


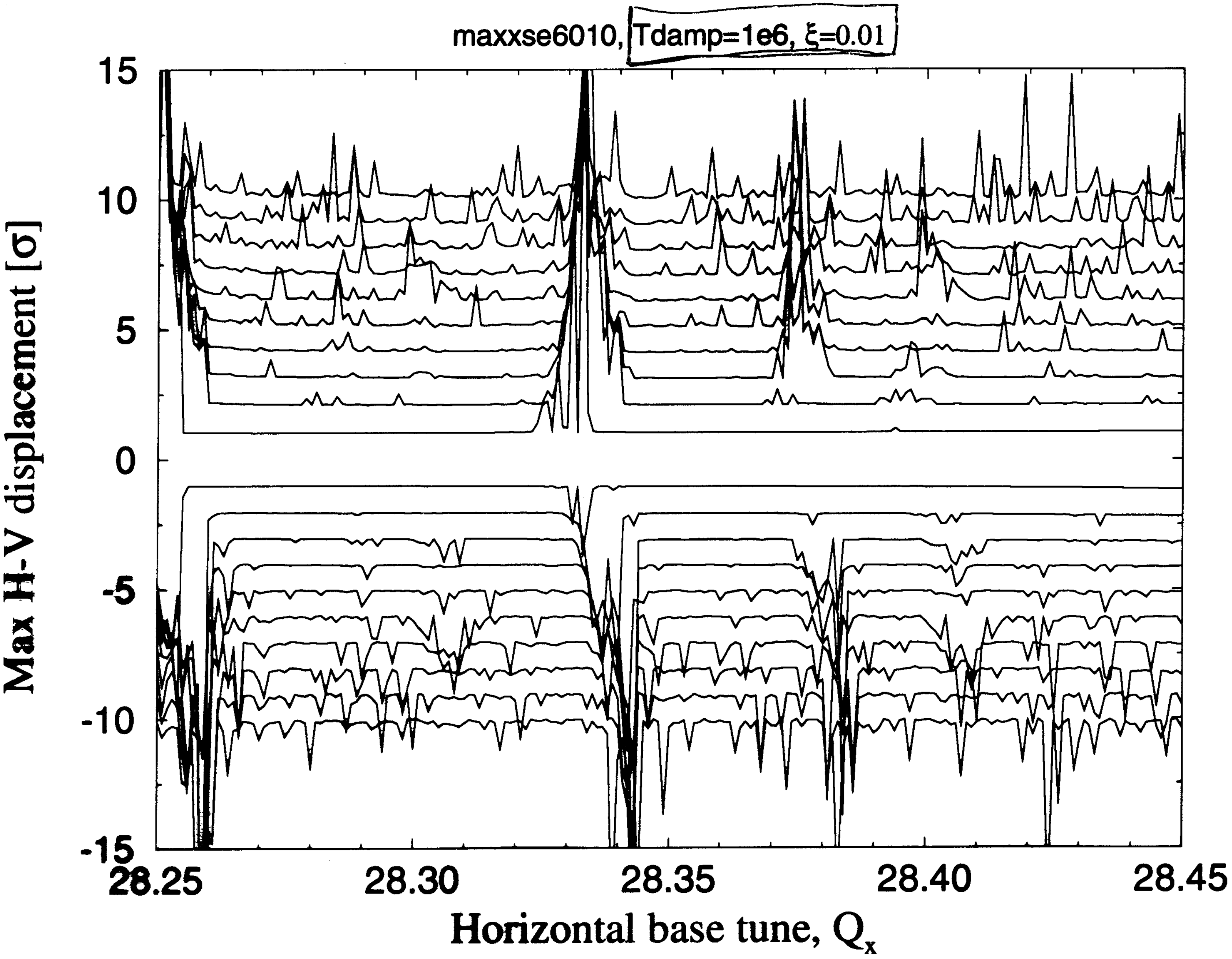
Keil-Talman plot (Particle Accelerators 1983 Vol.14)

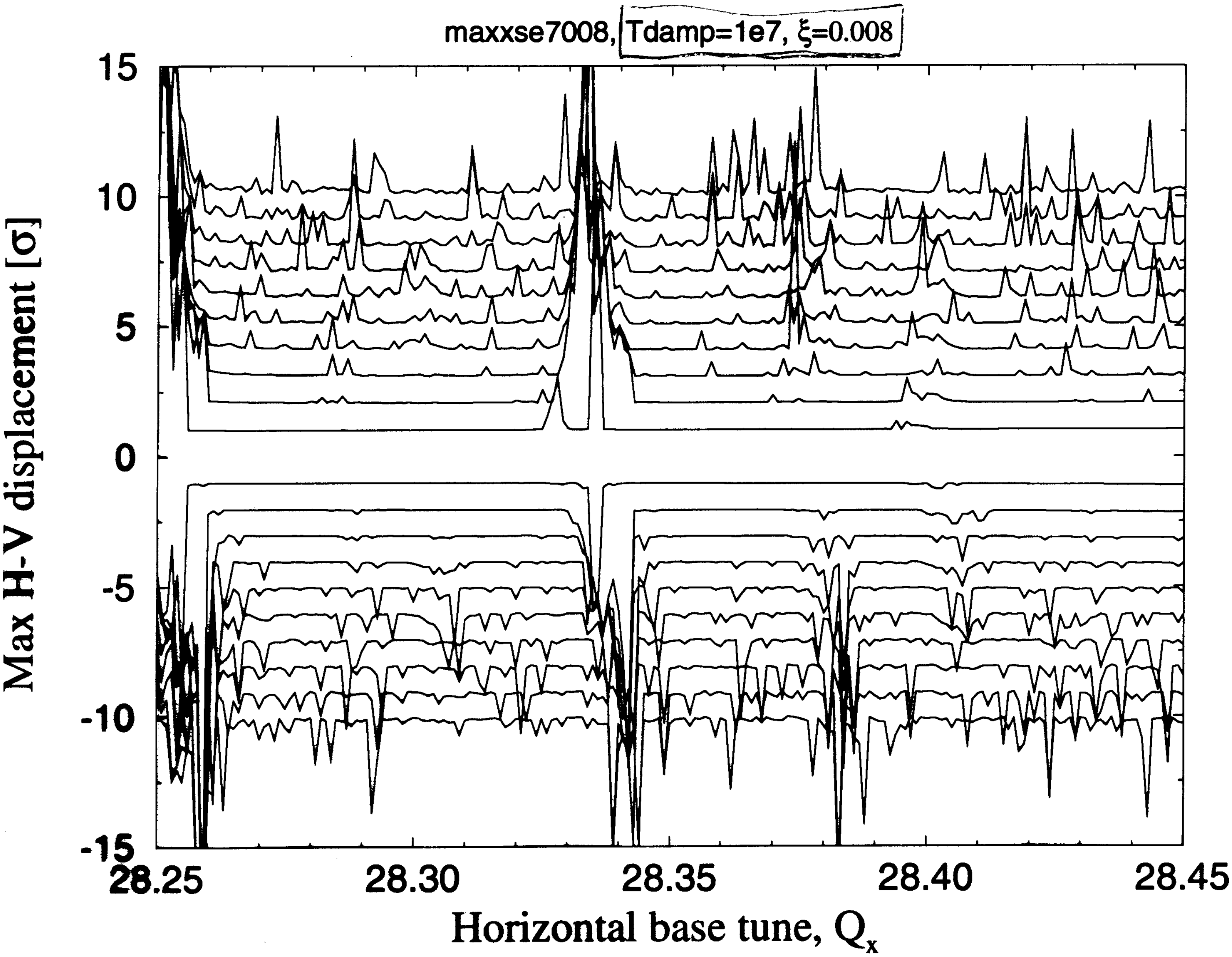
CALIBRATION

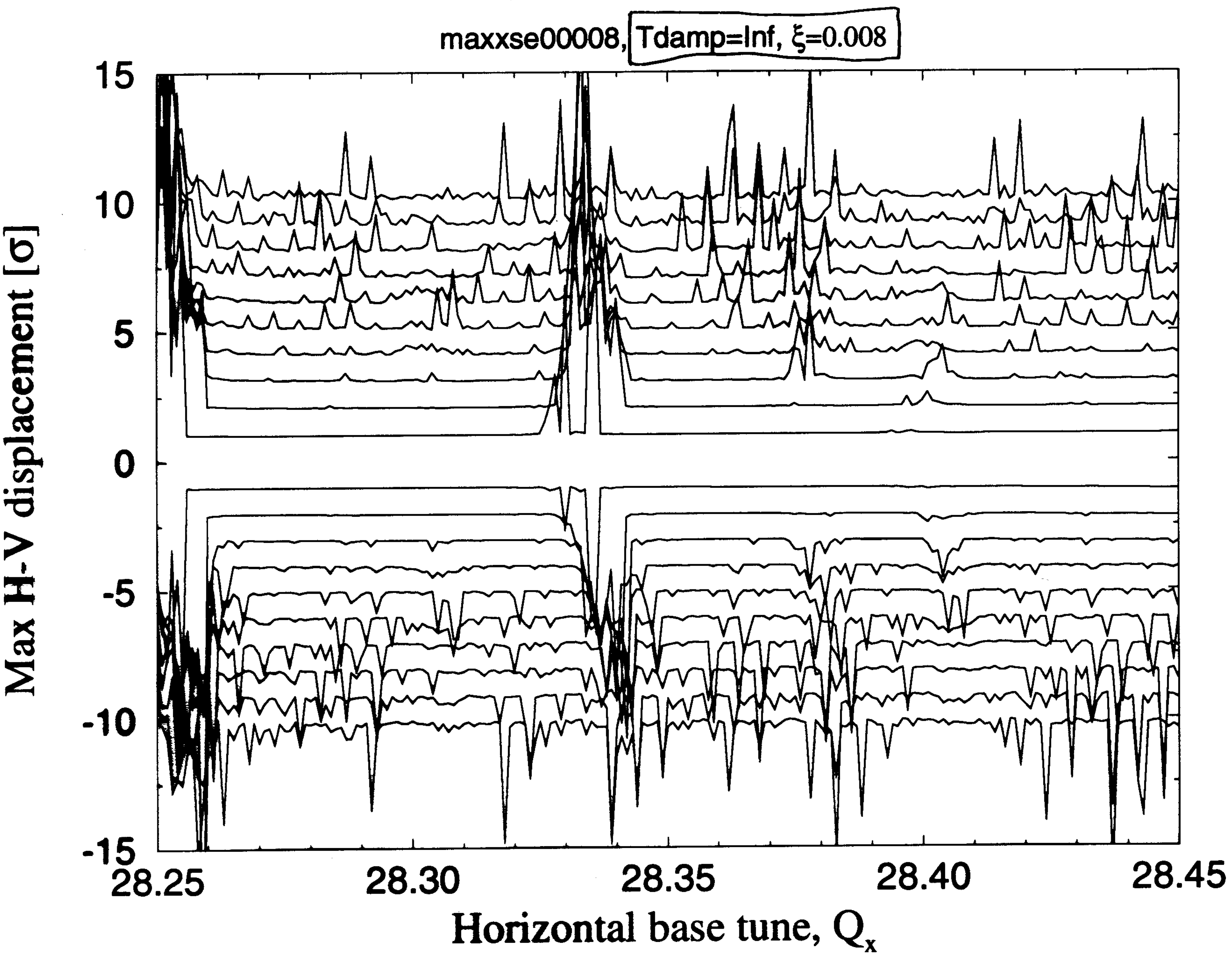



maxxse5015, Tdamp=1e5, ξ=0.015
Max H-V displacement [σ]
15
10
5
0
-5
-10
-15
28.25
28.30
28.35
28.40
28.45
Horizontal base tune, Q_x


maxxse5020, Tdamp=1e5, ξ=0.02
15
10
5
0
-5
-10
-15
Max H-V displacement [σ]
28.25
28.30
28.35
28.40
28.45
Horizontal base tune, Q_x


maxxse6010, Tdamp=1e6, ξ=0.01
Max H-V displacement [σ]
15
10
5
0
-5
-10
-15
28.25
28.30
28.35
28.40
28.45
Horizontal base tune, Q_x


maxxse7008, Tdamp=1e7, ξ=0.008
15
10
5
0
-5
-10
-15
28.25
28.30
28.35
28.40
28.45
Max H-V displacement [σ]
Horizontal base tune, Q_x


maxxse00008, Tdamp=Inf, ξ=0.008
Max H-V displacement [σ]
15
10
5
0
-5
-10
-15
28.25
28.30
28.35
28.40
28.45
Horizontal base tune, Q_x

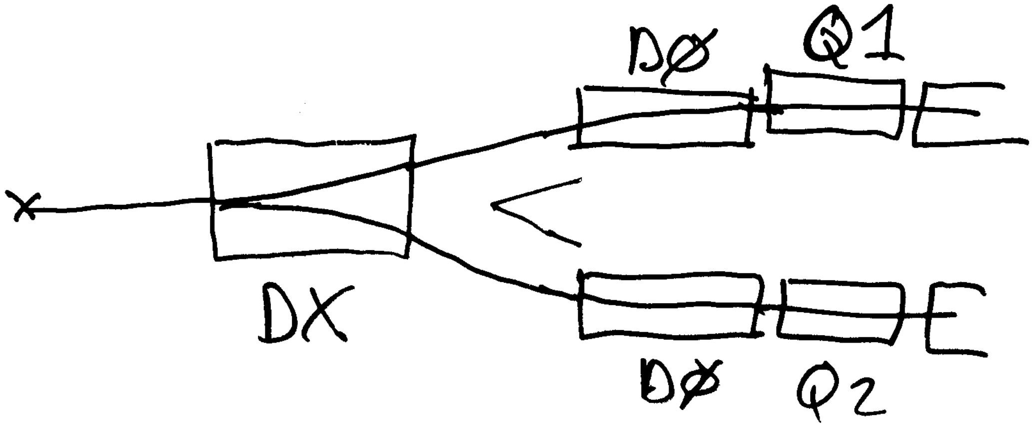
Beam separation geometry

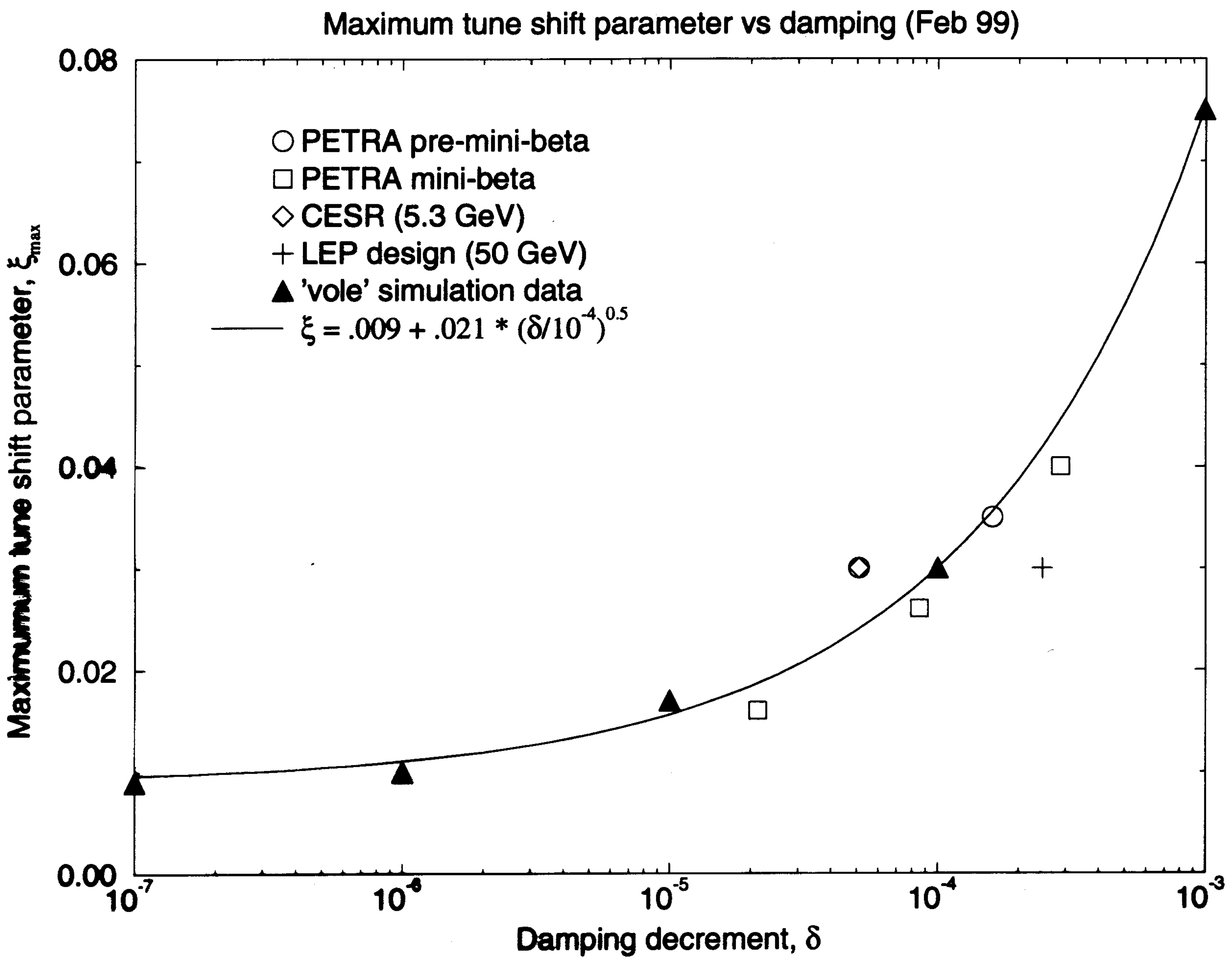
- Beam separation occurs **before** the first triplet quadrupole.

- The large bore magnet DX, nearest to the IP, is common to both beams.

- Side-by-side D0 magnets remove most (not all) of the angular divergence.

Quantity	Units	Value
DX magnetic length	[m]	3.70
DX bending radius	[m]	196.17
DX bend angle	[mrad]	18.86
DX bend center (from IP)	[m]	11.65
D0 magnetic length	[m]	3.60
D0 bending radius	[m]	237.06
D0 bend angle	[mrad]	−15.19
D0 bend center (from IP)	[m]	22.30




Maximum tune shift parameter vs damping (Feb 99)
○ PETRA pre-mini-beta
□ PETRA mini-beta
◇ CESR (5.3 GeV)
+ LEP design (50 GeV)
▲ 'vole' simulation data
$\xi = .009 + .021 * (\delta/10^{-4})^{0.5}$
Maximum tune shift parameter, ξ_{max}
0.08
0.06
0.04
0.02
0.00
10^{-7}
10^{-6}
10^{-5}
10^{-4}
10^{-3}
Damping decrement, δ

THUS

① No sign that $\delta \sim 10^{-7}$ increases maximum beam-beam tune shift

BUT

② Radiation damping MUST help slow emittance growth rates

IV) Hadron Collider beam dynamic experiments

goal: perform formal experiments at RHIC and/or the Tevatron "in the LHC-era"

1) LHC and VLHC activities in the US have a considerable overlap (in personnel and issues)

2) There is a groundswell of US support (eg in DoE) for US-LHC AP activities to be integrated with "future hadron collider" studies

To successfully present a formal proposal to a Program Advisory Committee at BNL or FNAL, must establish:

- the collaboration (from US & European labs & universities)
- fundamental physics goals
- support from the US community (DoE & labs)

Potential fundamental physics topics include:

- dynamic aperture evaluation
- beam-beam performance (is this true?)
- time dependent effects

Workshops

- LHC beam-beam workshop (April, CERN)
- HC beam experiments (fall 99, BNL)
- VLHC AP workshop (~February 00, ??)

CONCLUSIONS

1) RHIC has few parasitic collisions (early beam separation)

2) RHIC is convenient for beam-beam studies
   - two rings
   - independent control @ 6 IPs
   - worlds most intense injector (AGS)

3) 2-D weak-strong hadron beam-beam diffusion inconsistencies still exist between theory/simulation/observation

4) Crudely, radiation damping in a high field VLHC does not help maximum tune shift parameter, but MUST (?) help slow diffusion

5) IS THERE A FUNDAMENTAL BEAM-BEAM EXPERIMENT TO PROPOSE TO A PROGRAM ADVISORY COMMITTEE

Parasitic collisions

- Nominally there are 120 bunches (minus 5 or 6 for the abort gap).

- It may be possible to collide 180 or 360 bunches (kicker rise-time?)

- There are 0/1/2 parasitic collisions on each side of the IP with 120/180/360 bunches.

Quantity	Units	"0"	"1"	"2"
Location s	[m]	0.00	5.33	10.65
Total separation d	[m]	.0000	.0000	.0037
Injection β	[m]	10.0	12.84	21.34
Storage β	[m]	1.00	29.41	114.4
Proton inject d/σ_{20}		0.00	0.00	2.45
Proton store d/σ_{20}		0.00	0.00	3.11
Gold inject d/σ_{20}		0.00	0.00	1.55
Gold store d/σ_{20}		0.00	0.00	1.97

Crossing angles

- Protons **must** have a crossing angle when 180 or 360 bunches collide.
- Gold ions **possibly/probably** need a crossing angle when 180/360 bunches collide.
- The largest total crossing angle, $\alpha \simeq 1.26$ milliradians for gold, is easily achieved.

Quantity	Proton inject	Proton store	Gold inject	Gold store
ANGLES				
Beam $\sigma_{20}^{\prime *}$ [mrad]	0.10	0.11	0.16	0.18
Crossing α [mrad]	0.70	0.77	1.14	1.26
DX θ_X [mrad]	18.13	17.81	17.67	17.54
D0 $-\theta_0$ [mrad]	14.45	14.38	13.99	13.87
Length σ_z [m]	0.353	0.072	0.467	0.206

- p - Au

(Hadrons, Weak-Strong)

$\boxed{1\text{-D}}$: "resonance overlap" also known as "phase transitions in tune modulation space"

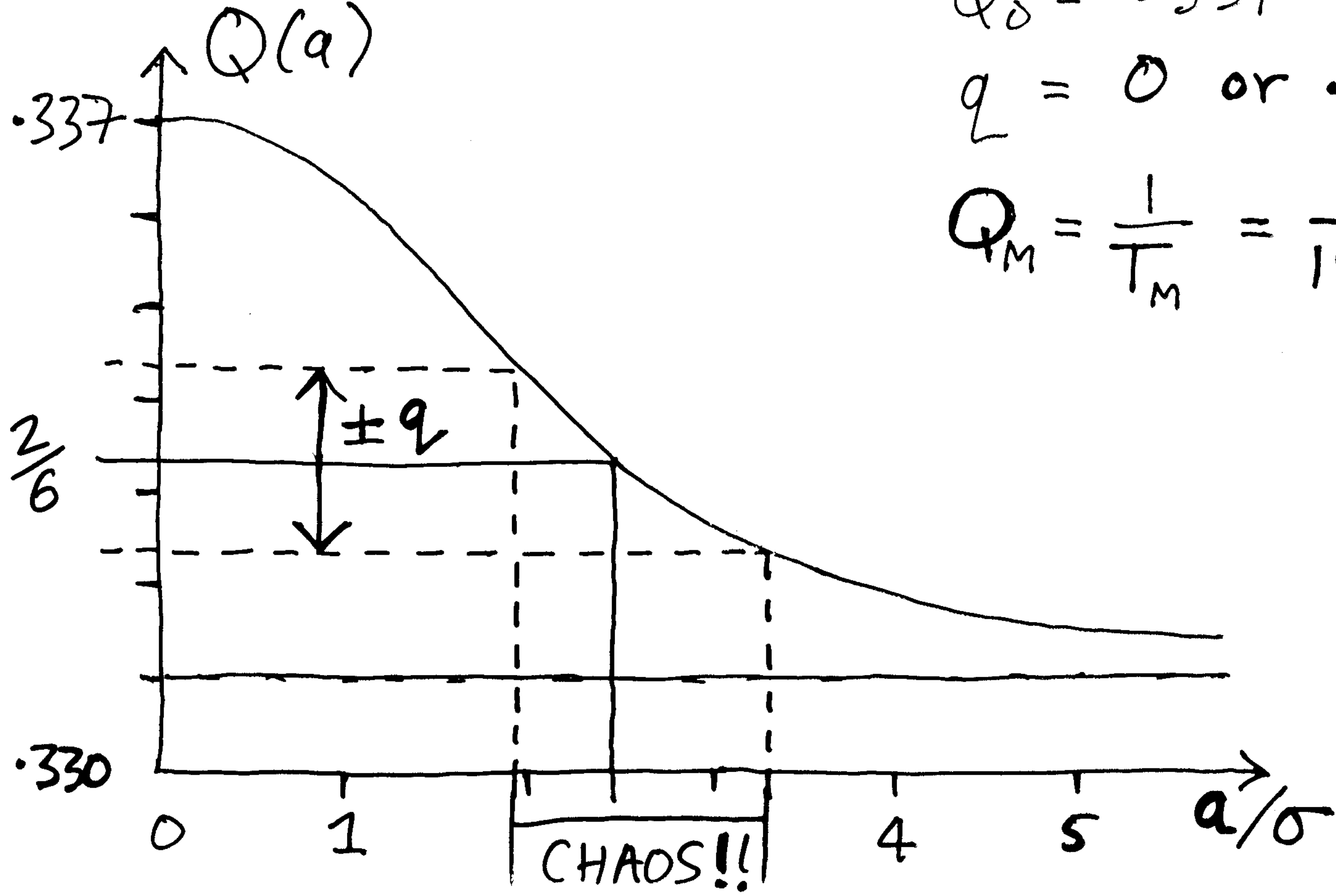
EXAMPLE:

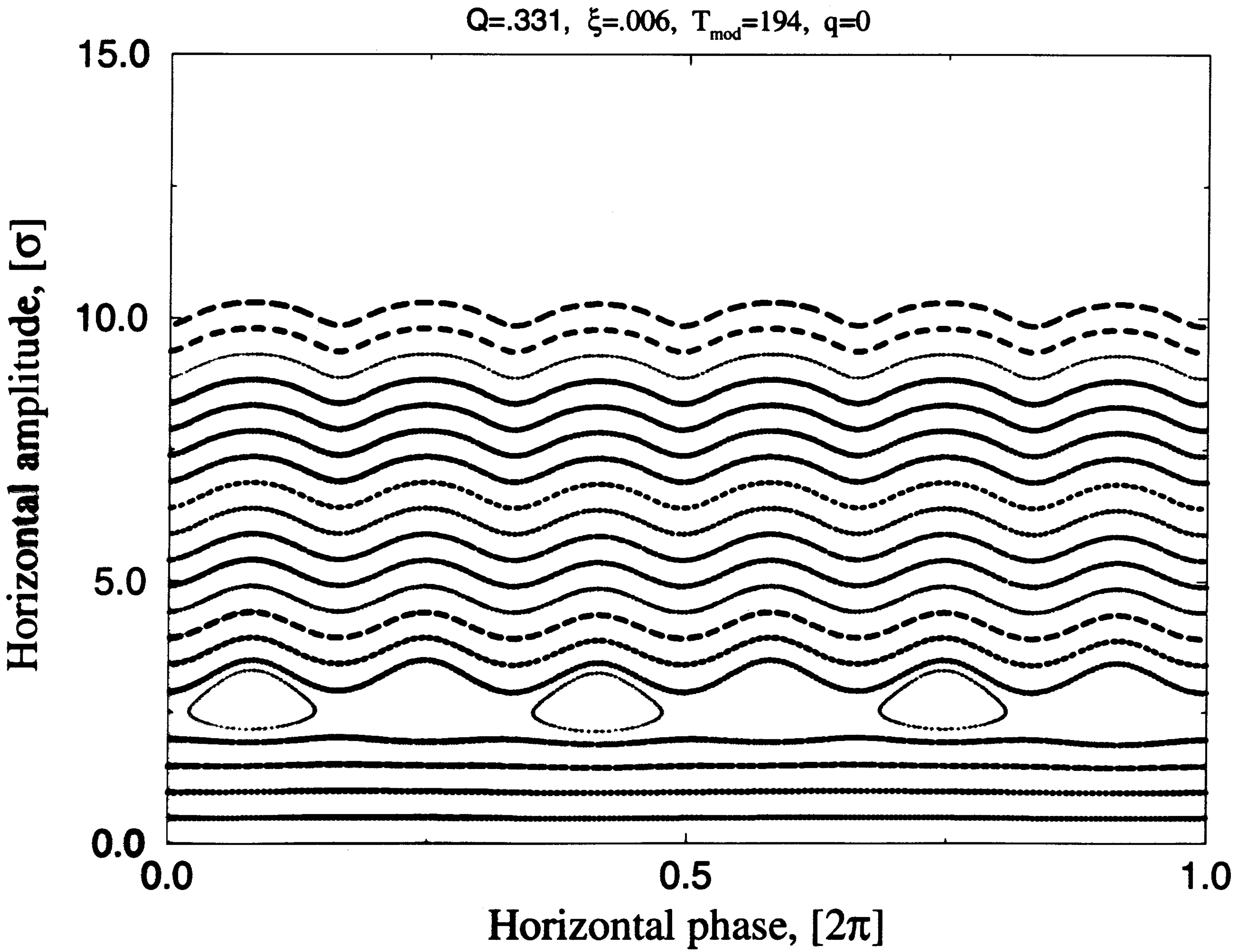
- 1 head on collision: $\xi = .006$
- Tune modulation: $Q = Q_0 + q \cos(2\pi Q_M t$

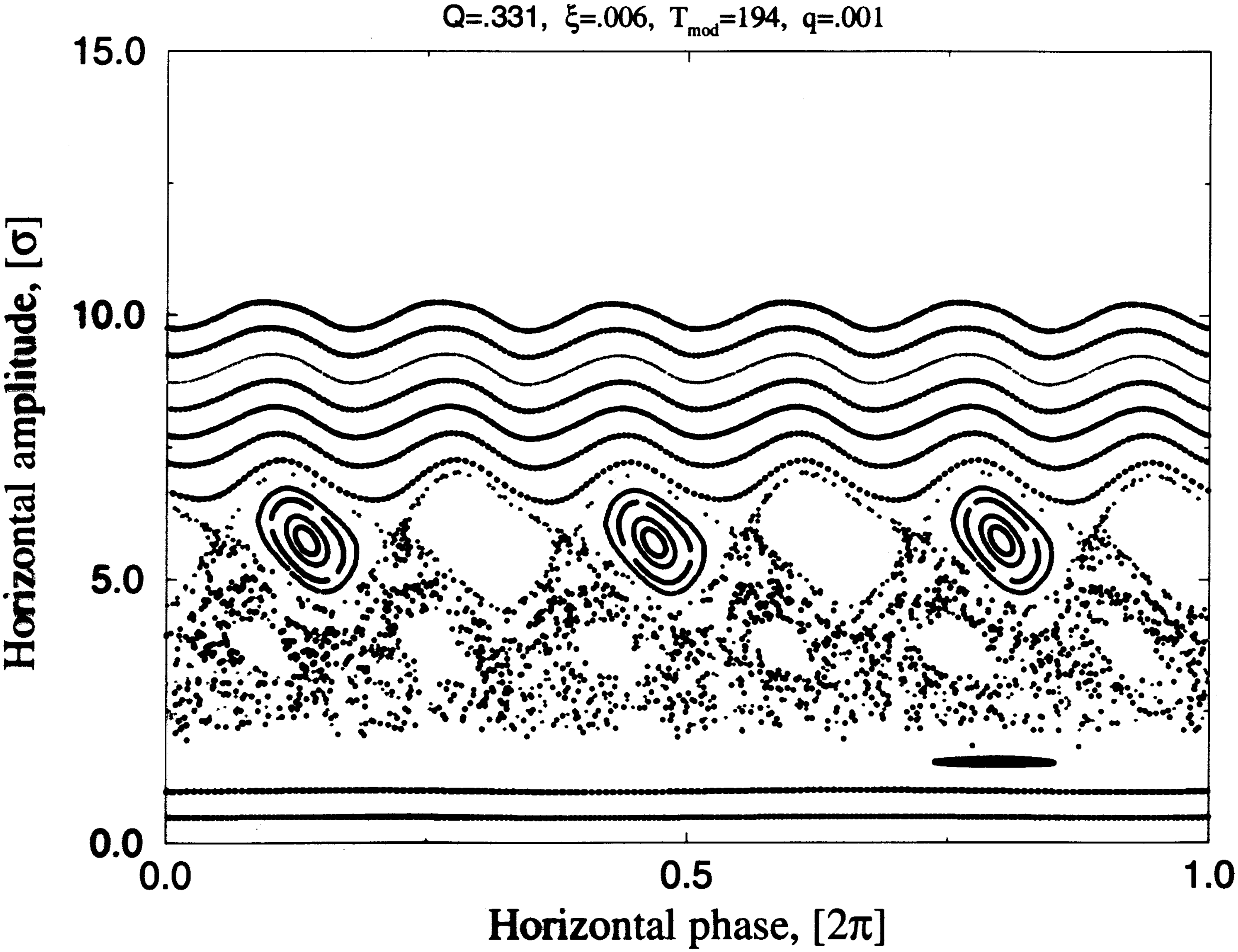
$Q_0 = .331$

$q = 0$ or $.001$

$Q_M = \frac{1}{T_M} = \frac{1}{194}$



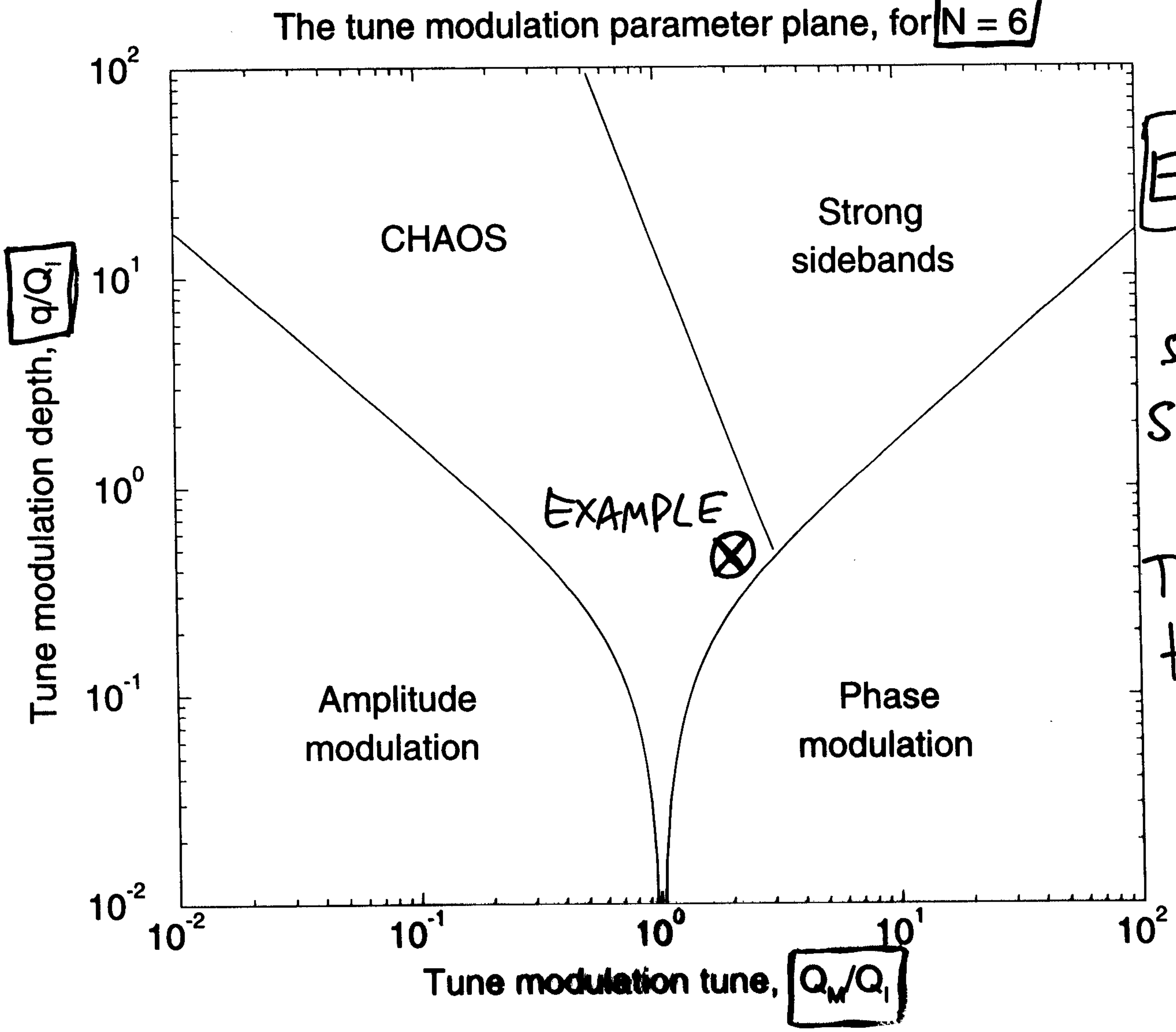

$Q=.331,\ \xi=.006,\ T_{mod}=194,\ q=0$
15.0
10.0
5.0
0.0
Horizontal amplitude, [σ]
0.0
0.5
1.0
Horizontal phase, [2π]


Q=.331, ξ=.006, T_{mod}=194, q=.001
15.0
10.0
5.0
0.0
Horizontal amplitude, [σ]
0.0
0.5
1.0
Horizontal phase, [2π]

Q: WHICH (Q_M, q) PARAMETERS LEAD TO CHAOS ?

A: IT DEPENDS UNIVERSALLY ON ISLAND TUNE Q_I AND RESONANCE ORDER N

PHASE TRANSITIONS APPROXIMATELY AS BELOW:



E778

see, eg, SSC-175

OR

T. Satogat

thesis