Booster & AGS β & γ-function manipulation studies for Run8 Polarized Protons

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11/2/07

Reducing Emittance Growth During Booster Injection

Emittance Growth

Emittance growth due to multiple scattering

$$\Delta\varepsilon \equiv n\beta\theta^2$$

N=number of traversal: Pulse Length & Rev. Freq.

β= Beta function at foil: ring lattice, (matching etc.)

θ= Scattering angle: Material of foil, Thickness (*x*)

For a thin foil the amount of angular spread introduced into the distribution is

$$\theta_0 = 14.2z\frac{\sqrt{x/X_0}}{\beta cp}\left[1 + 0.038\ln(xz^2/X_0\beta^2)\right]$$

$$\theta_0 = \theta_{plane}^{rms} = \frac{1}{\sqrt{2}}\theta_{space}^{rms}$$

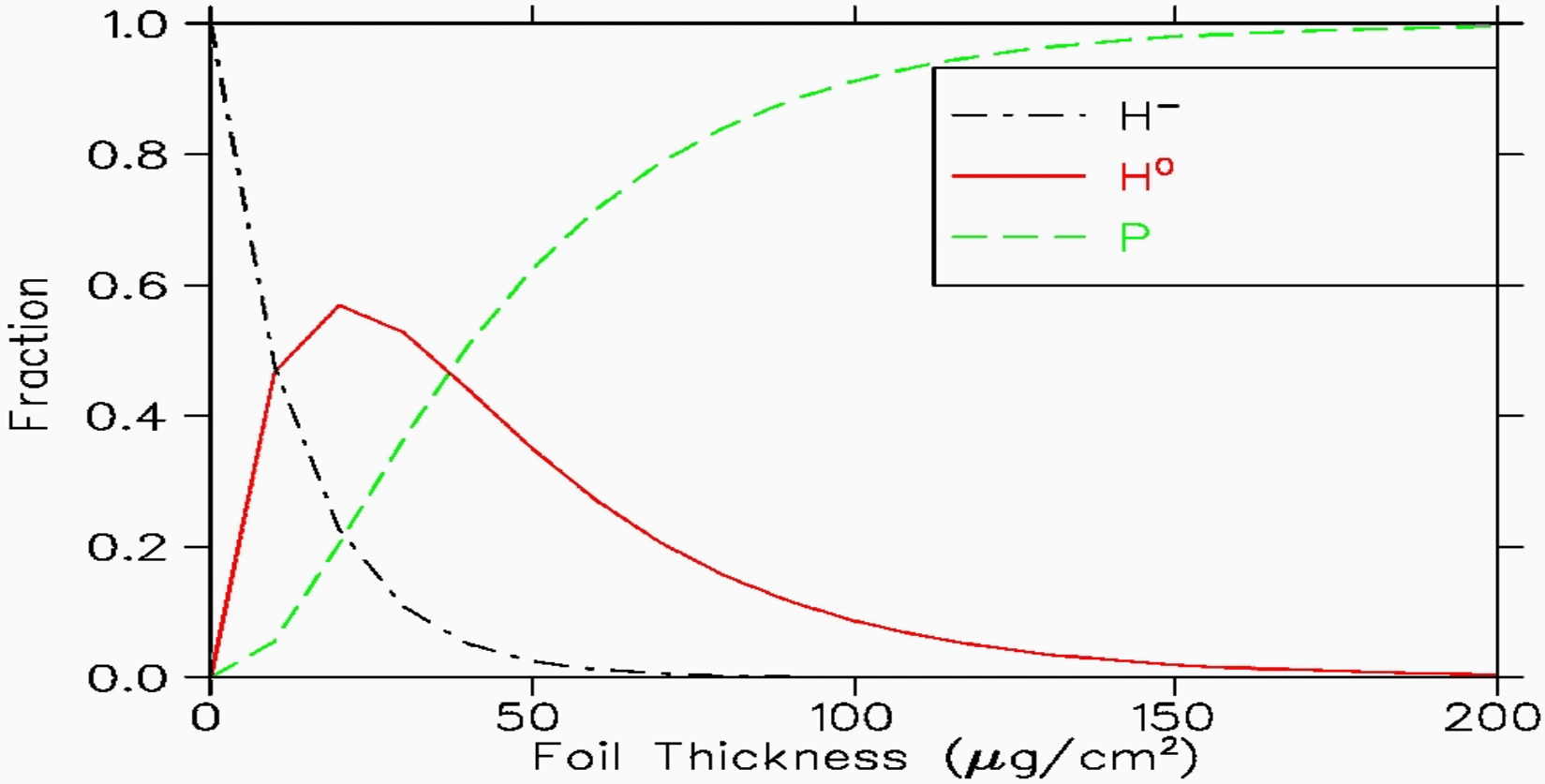
Stripping Efficiencies

Thick foil

$$\theta_0 = \frac{13.6MeV}{\beta cp} z\sqrt{x/X_0}\left[1+0.038\ln(x/X_0)\right]$$

Thin Foil

$$\theta_0 = 14.2z\frac{\sqrt{x/X_0}}{\beta cp}\left[1+0.038\ln(xz^2/X_0\beta^2)\right]$$



½ integer stop-band strings

4 Power Supplies; 20 Amp max each (30 V) = 3 A/msec max

Polarities ensure no 10θ, 5θ, 4θ, or 0θ harmonics are produced. Produce 9θ

QVSTR1: +QVA1 +QVA7-QVBl -QVB7+QVCl +QVC7-QVDl -QVD7 +QVE1 +QVE7 -QVF1 -QVF7.

QHSTR1: +QHA2 +QHA8 -QHB2 -QHB8 +QHC2 +QHC8 -QHD2 -QHD8 +QHE2 +QHE8 -QHF2 -QHF8.

QVSTR2: +QVA3 -QVA5 -QVB3 +QVB5 +QVC3 -QVC5 -QVD3 +QVD5 +QVE3 -QVE5 -QVF3 +QVF5.

QHSTR2: +QHA4 -QHA6 -QHB4 +QHB6 +QHC4 -QHC6 -QHD4 +QHD6 +QHE4 -QHE6 -QHF4 +QHF6.

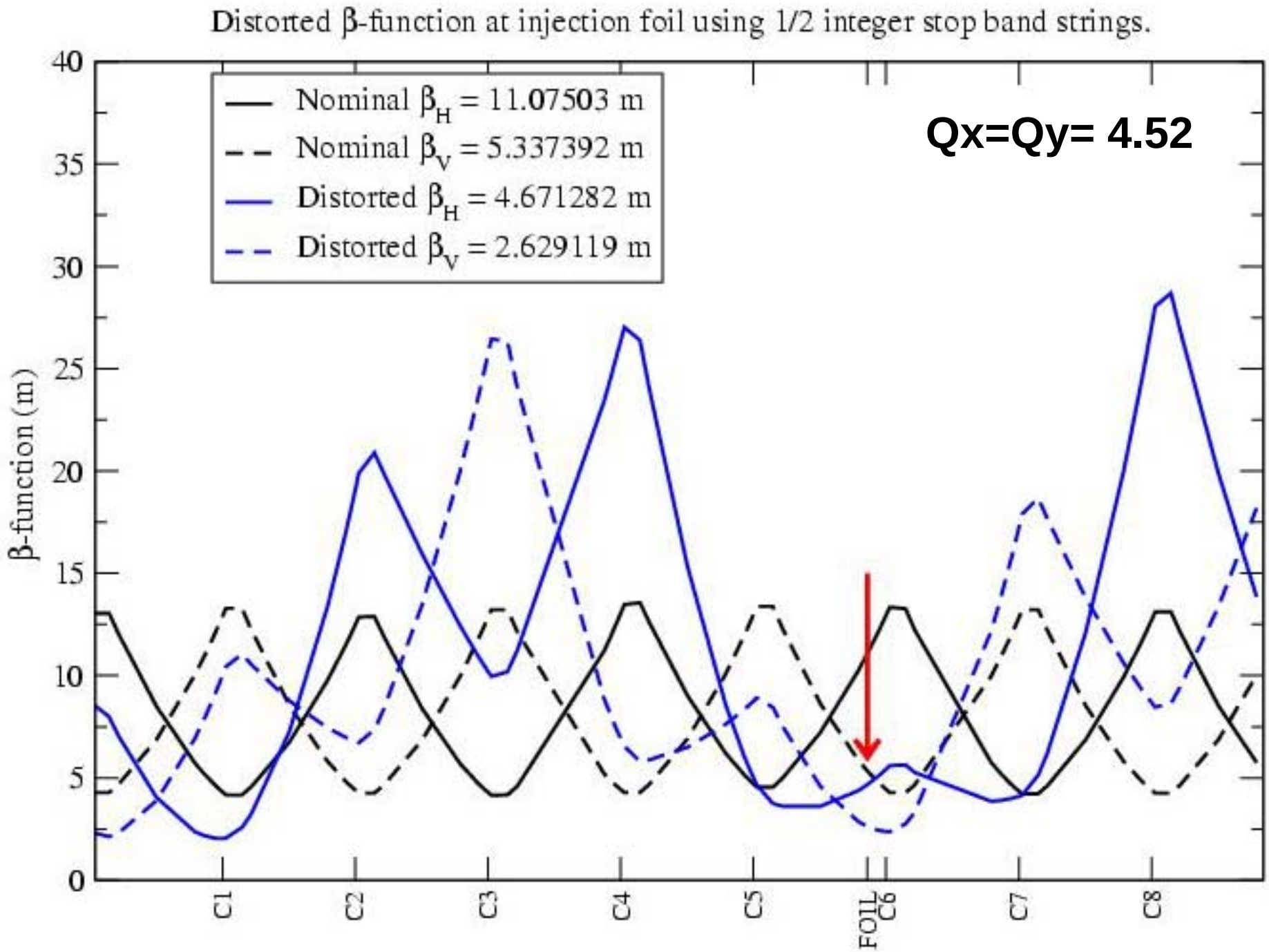
See AGS Div. Tech Note 465, Kip Gardner, 1997

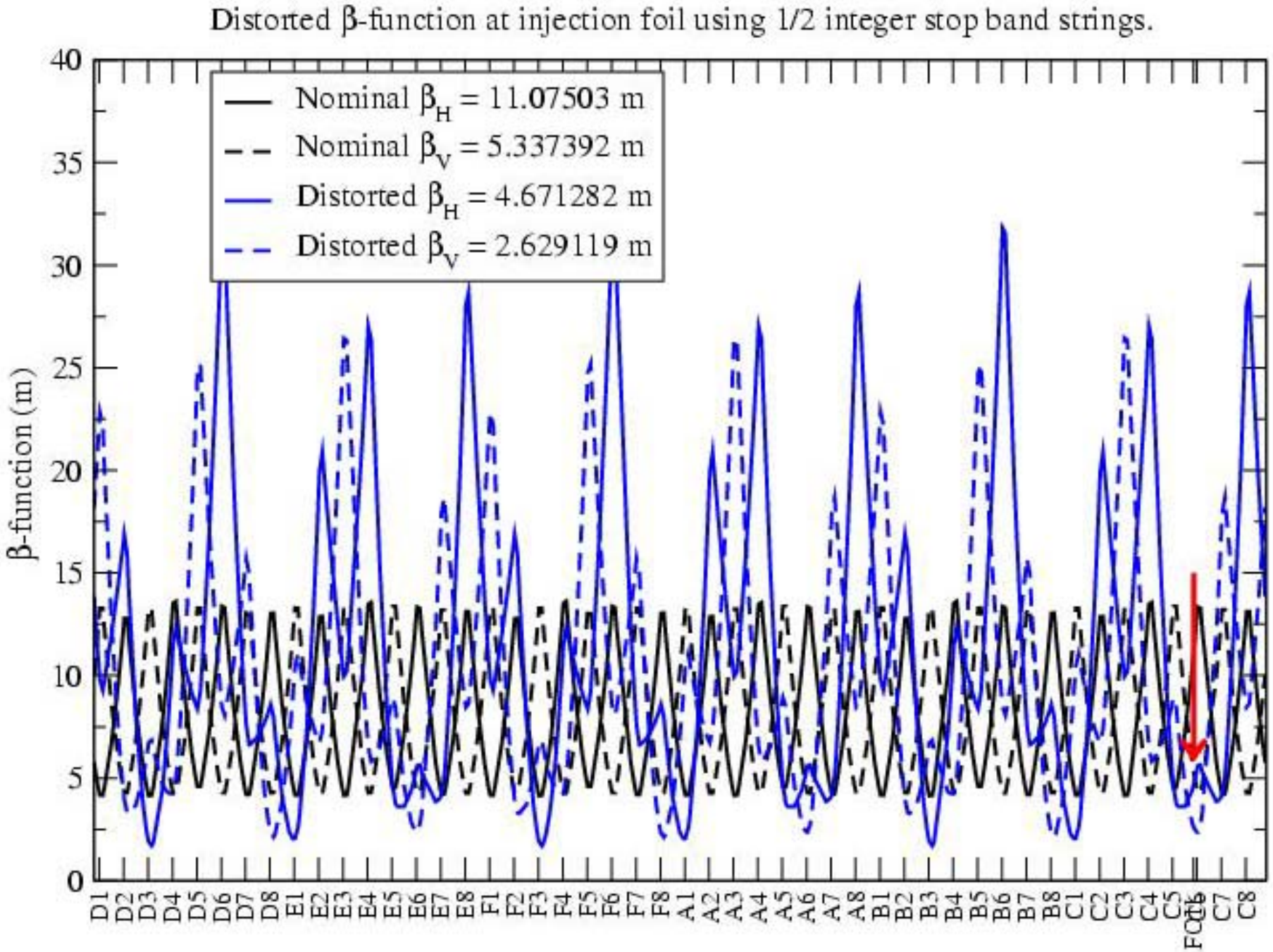
Nomenclature

- The four ½ integer stop-band corrector strings are excited with currents J_1, J_2, J_3, & J_4. In this case:

$$\begin{pmatrix} \cos 9x \\ \sin 9x \\ \cos 9y \\ \sin 9y \end{pmatrix} = N\left(\frac{C}{P}\right)\boldsymbol{MQ}\begin{pmatrix} J_1 \\ J_2 \\ J_3 \\ J_4 \end{pmatrix}$$

- Where, N is a normalization constant and (C/P) is the beam rigidity (in T-m). $\boldsymbol{M}$ and $\boldsymbol{Q}$ are transfer matrices.


Distorted β-function at injection foil using 1/2 integer stop band strings.
Nominal β_H = 11.07503 m
Nominal β_V = 5.337392 m
Distorted β_H = 4.671282 m
Distorted β_V = 2.629119 m
Qx=Qy= 4.52
β-function (m)
0
5
10
15
20
25
30
35
40
C1
C2
C3
C4
C5
FOIL
C6
C7
C8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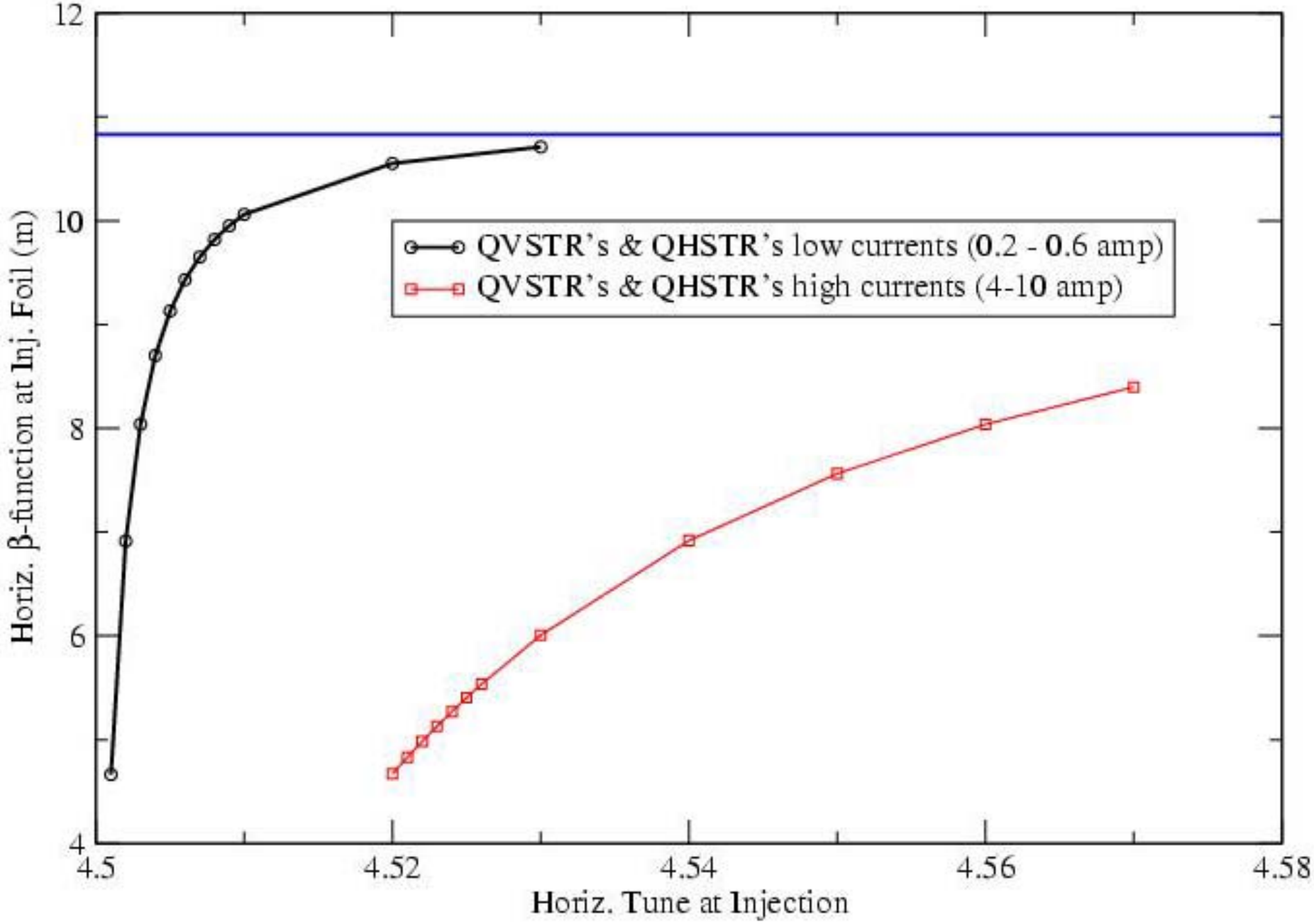
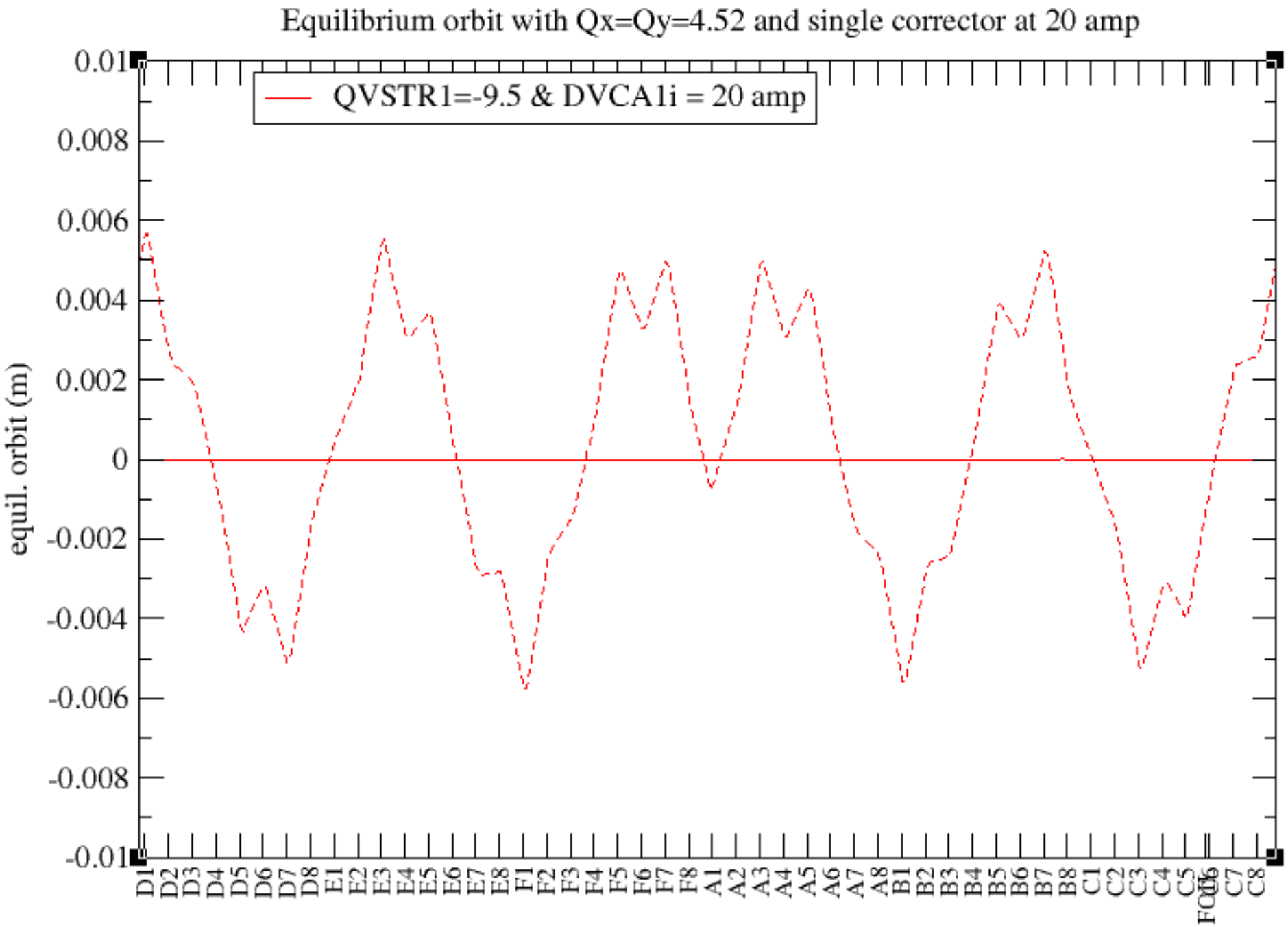
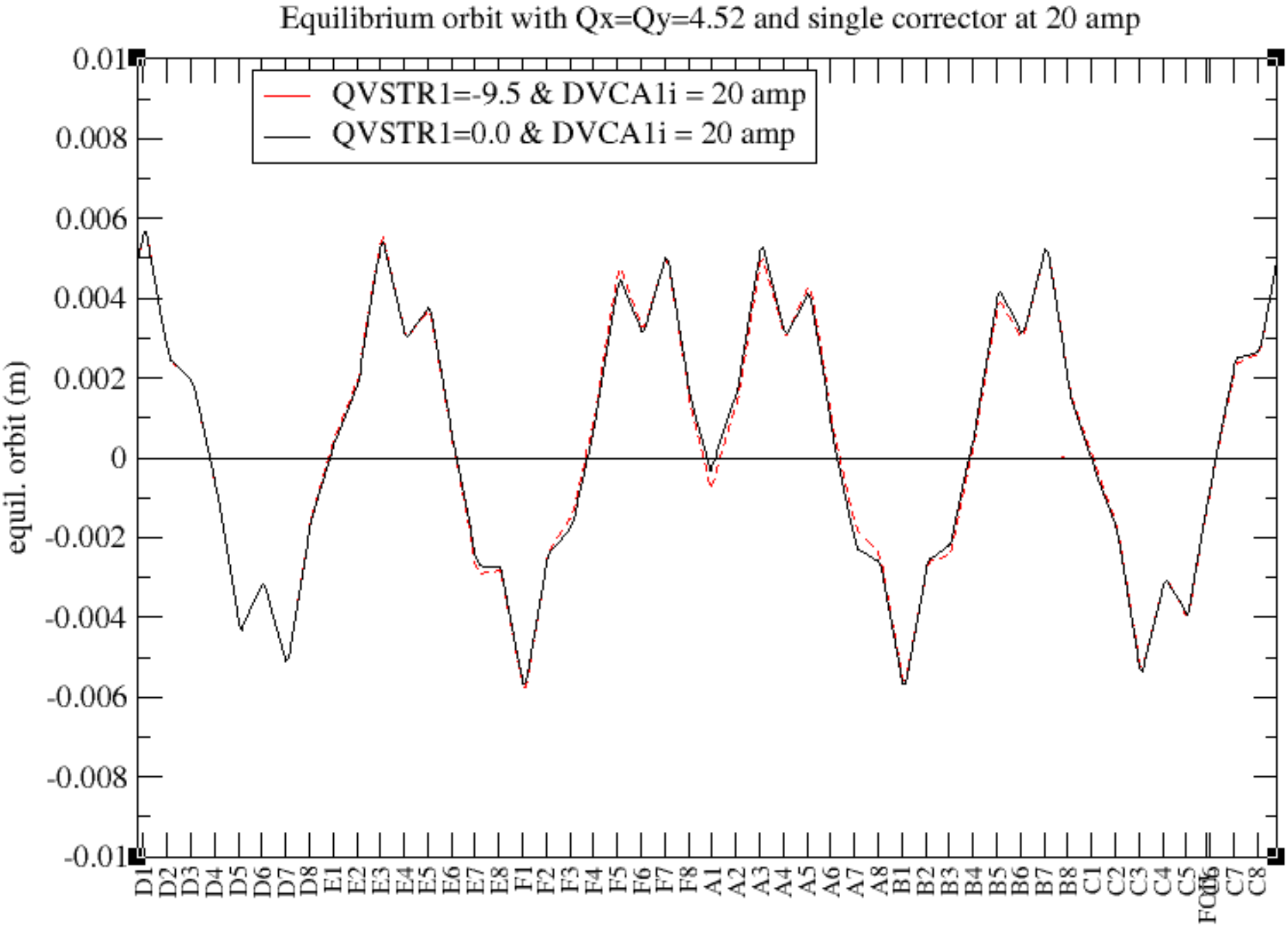
Nominal β_H = 11.07503 m
Nominal β_V = 5.337392 m
Distorted β_H = 4.671282 m
Distorted β_V = 2.629119 m
β-function (m)
0
5
10
15
20
25
30
35
40
D1 D2 D3 D4 D5 D6 D7 D8 E1 E2 E3 E4 E5 E6 E7 E8 F1 F2 F3 F4 F5 F6 F7 F8 A1 A2 A3 A4 A5 A6 A7 A8 B1 B2 B3 B4 B5 B6 B7 B8 C1 C2 C3 C4 C5 C6 C7 C8
FOIL

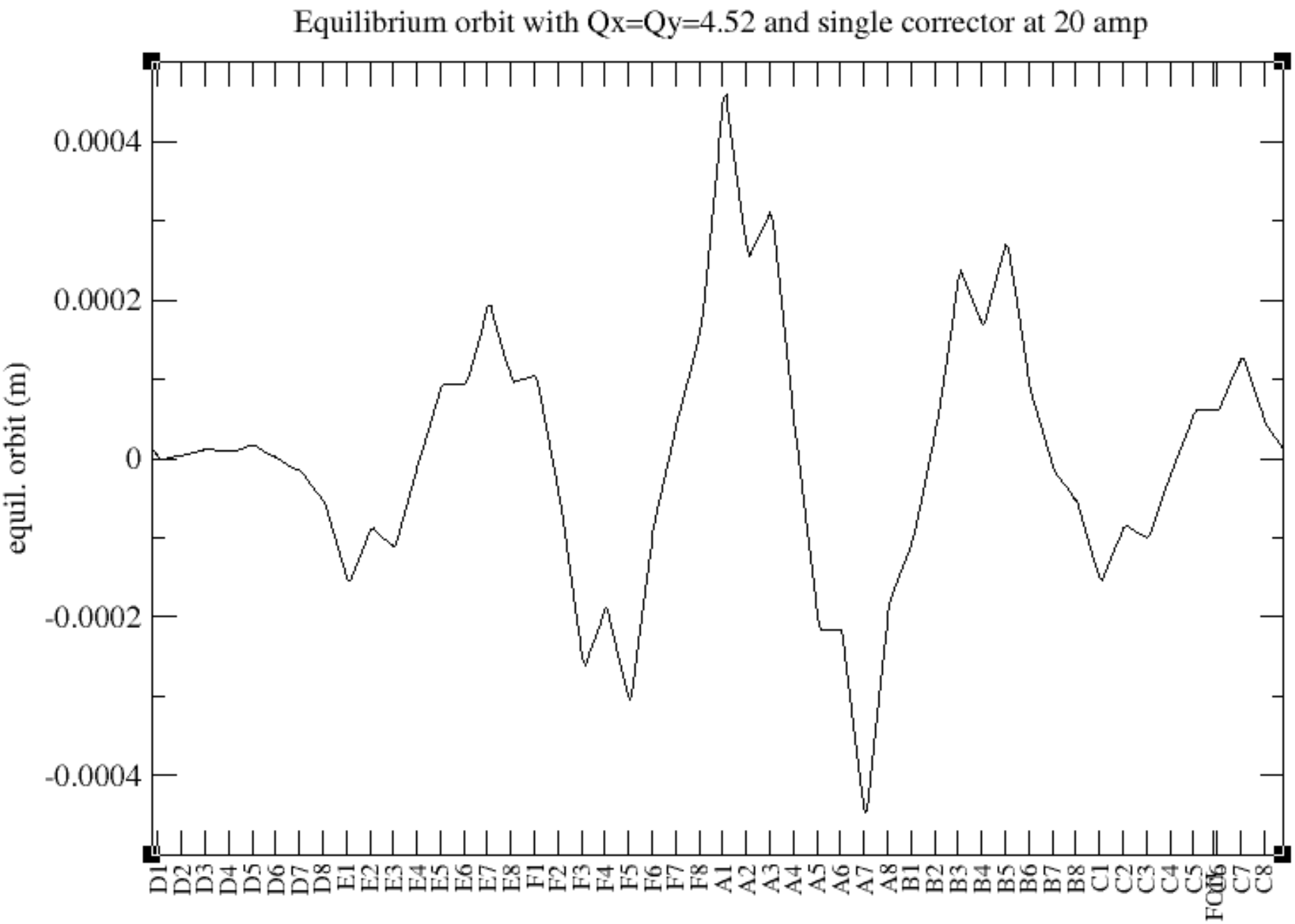

QVSTR's & QHSTR's low currents (0.2 - 0.6 amp)
QVSTR's & QHSTR's high currents (4-10 amp)
Horiz. β-function at Inj. Foil (m)
Horiz. Tune at Injection
12
10
8
6
4
4.5
4.52
4.54
4.56
4.58

Beam Studies for model tests

- Push the tunes to *4.52*.
- Measure the change in the equilibrium orbit (e.o.) when *each of the four stopband strings is powered to +/- 9.5A* as well as with the design settings. The reference e.o. is taken with *one corrector (e.g. A1 vertical correction dipole) powered as hard as allowed* without losing beam
- Measure coherence amplitude at different turn-by-turn bpm's when beam is kicked by E3 (Horz. and Vert. kickers) and by F3 (Horz. Only). Compare these to the model predictions.


Equilibrium orbit with Qx=Qy=4.52 and single corrector at 20 amp
QVSTR1=-9.5 & DVCA1i = 20 amp
equil. orbit (m)
0.01
0.008
0.006
0.004
0.002
0
-0.002
-0.004
-0.006
-0.008
-0.01
D1 D2 D3 D4 D5 D6 D7 D8 E1 E2 E3 E4 E5 E6 E7 E8 F1 F2 F3 F4 F5 F6 F7 F8 A1 A2 A3 A4 A5 A6 A7 A8 B1 B2 B3 B4 B5 B6 B7 B8 C1 C2 C3 C4 C5 C6 C7 C8


Equilibrium orbit with Qx=Qy=4.52 and single corrector at 20 amp
QVSTR1=-9.5 & DVCA1i = 20 amp
QVSTR1=0.0 & DVCA1i = 20 amp
equil. orbit (m)
0.01
0.008
0.006
0.004
0.002
0
-0.002
-0.004
-0.006
-0.008
-0.01
D1 D2 D3 D4 D5 D6 D7 D8 E1 E2 E3 E4 E5 E6 E7 E8 F1 F2 F3 F4 F5 F6 F7 F8 A1 A2 A3 A4 A5 A6 A7 A8 B1 B2 B3 B4 B5 B6 B7 B8 C1 C2 C3 C4 C5 C6 C7 C8


Equilibrium orbit with Qx=Qy=4.52 and single corrector at 20 amp
equil. orbit (m)
0.0004
0.0002
0
-0.0002
-0.0004
D1
D2
D3
D4
D5
D6
D7
D8
E1
E2
E3
E4
E5
E6
E7
E8
F1
F2
F3
F4
F5
F6
F7
F8
A1
A2
A3
A4
A5
A6
A7
A8
B1
B2
B3
B4
B5
B6
B7
B8
C1
C2
C3
C4
C5
C6
C7
C8

Booster Tune Meter

File Edit Operate Tools Browse Window Help

Date/Time
10/26/07
11:38 AM

Server IP address
130.199.111.200

Server Port
9723

Enter Ion Species: (20 char. max)

LOAD DATA

STOP PROGRAM

pet Controls:

user #
1

Booster Cycle #
BC1

Main Trigger
200 time (ms)

Scope-Kicker Delay
20 time (us)

***Note that Main Trigger is entered in ms and Scope-Kicker Delay is entered in us

Bunch Width
100 ns

ACQUIRE & PROCESS DATA

# of Acquisition Iterations
1

PROCESS FFT ALGORITHM

PROCESS FIT TUNES

HORIZONTAL:

ON

Hor kick (kV)
6.0

horiz kick length
long

Trigger Time
200

VERTICAL:

ON

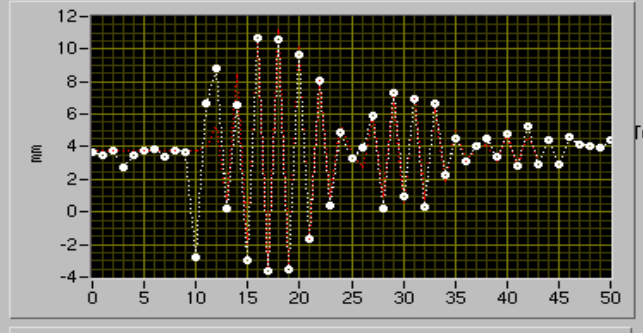
Vert kick (kV)
6.0

vert kick length
long

H Fit

Amplitude	8.2522
Tune Spread	0.0213
Tune	4.5320
Tune Shift/Turn	0.0005
Phase	1.5633

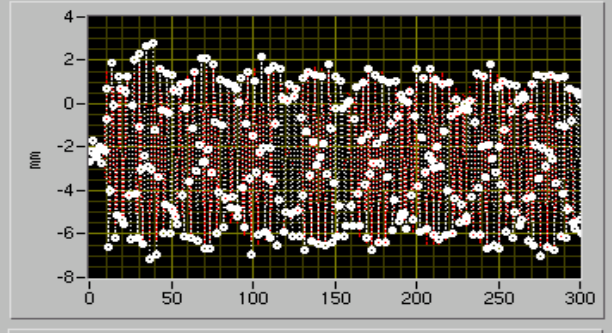
H Goodness of Fit
0.320854



V Fit

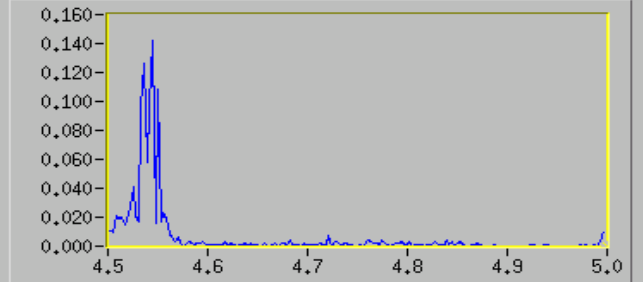
Amplitude	4.1173
Tune Spread	-0.0003
Tune	4.7573
Tune Shift/Turn	-0.0000
Phase	1.8998

V Goodness of Fit
1.12392



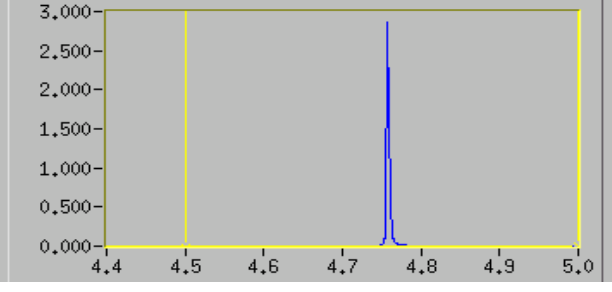
H-peak
4.5433

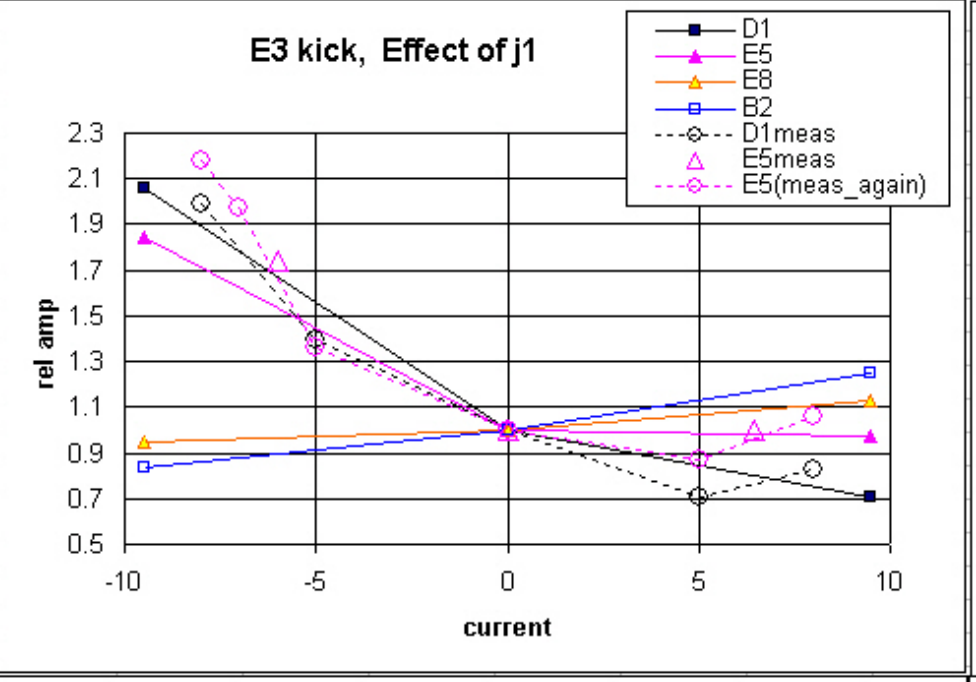
H-width
0.0137

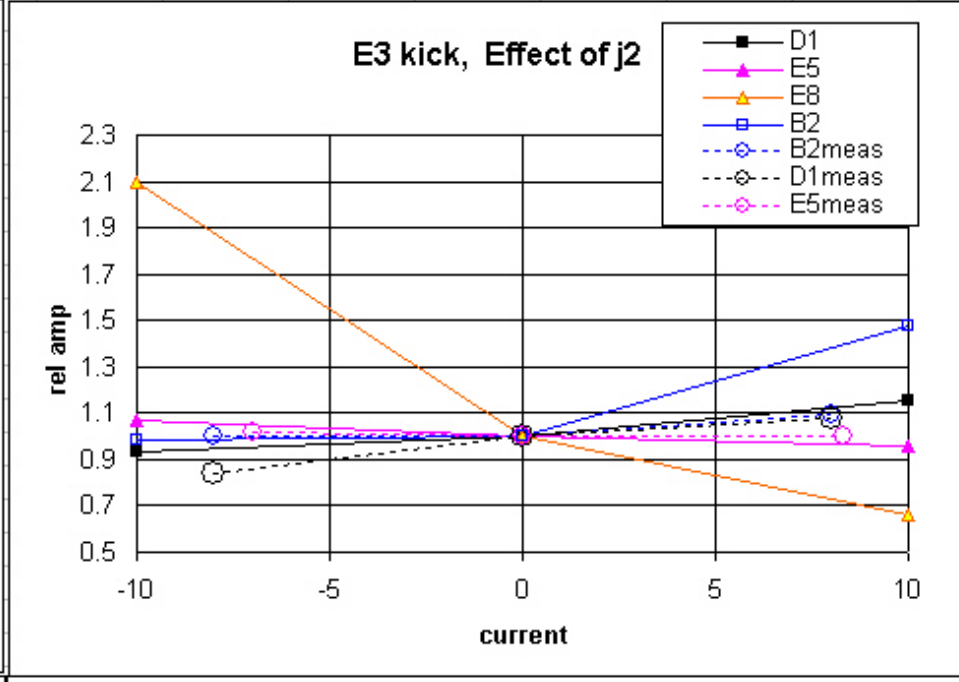


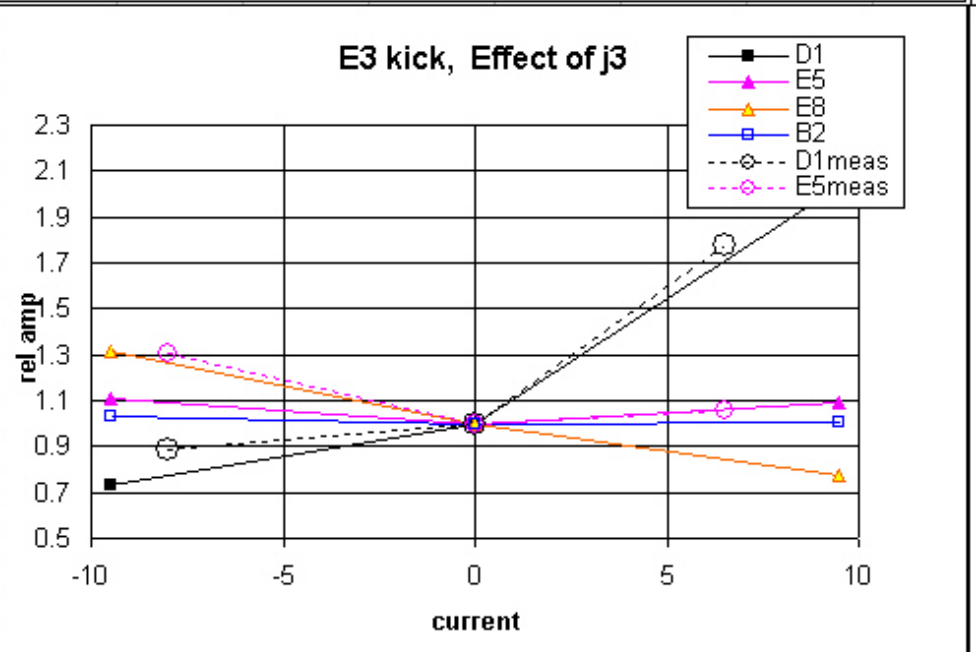
V-peak
4.7582

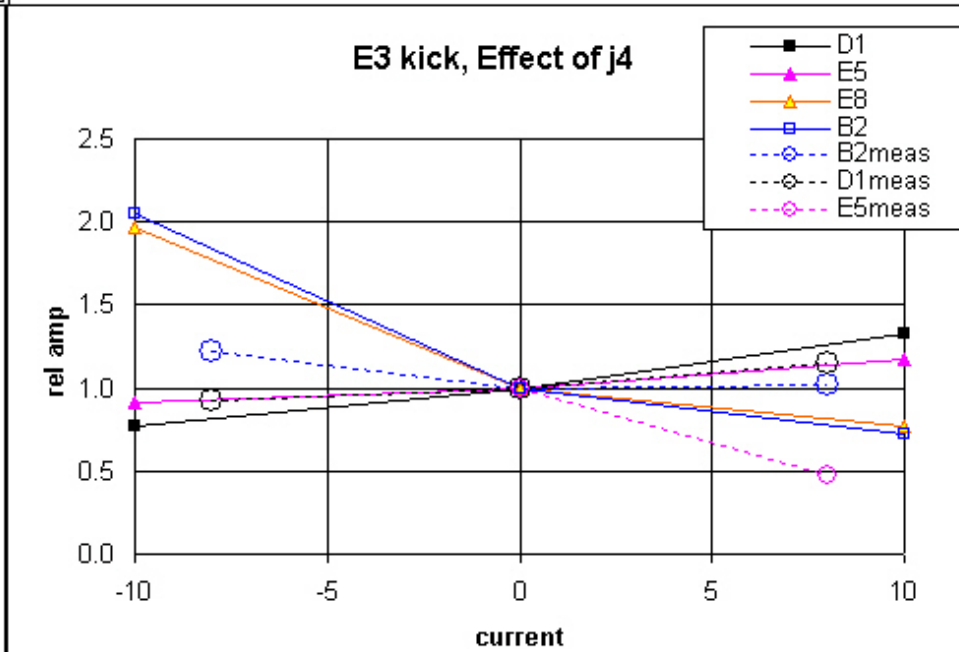
V-width
0.0032

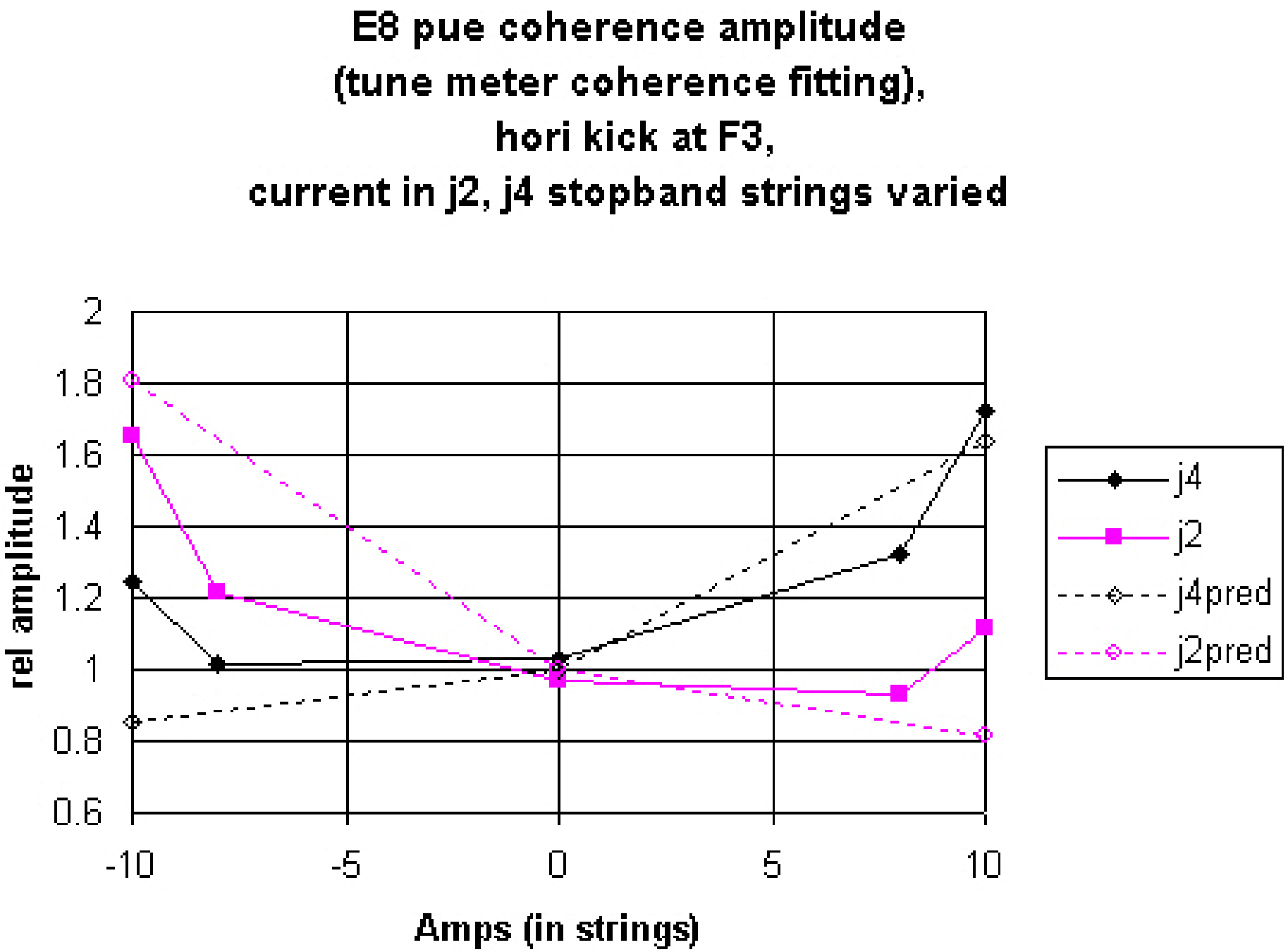



E3 kick, Effect of j1
D1
E5
E8
B2
D1meas
E5meas
E5(meas_again)
rel amp
current
2.3
2.1
1.9
1.7
1.5
1.3
1.1
0.9
0.7
0.5
-10
-5
0
5
10


E3 kick, Effect of j2
D1
E5
E8
B2
B2meas
D1meas
E5meas
rel amp
current
2.3
2.1
1.9
1.7
1.5
1.3
1.1
0.9
0.7
0.5
-10
-5
0
5
10


E3 kick, Effect of j3
D1
E5
E8
B2
D1meas
E5meas
rel amp
current
2.3
2.1
1.9
1.7
1.5
1.3
1.1
0.9
0.7
0.5
-10
-5
0
5
10


E3 kick, Effect of j4
D1
E5
E8
B2
B2meas
D1meas
E5meas
rel amp
current
2.5
2.0
1.5
1.0
0.5
0.0
-10
-5
0
5
10


E8 pue coherence amplitude
(tune meter coherence fitting),
hori kick at F3,
current in j2, j4 stopband strings varied
rel amplitude
2
1.8
1.6
1.4
1.2
1
0.8
0.6
-10
-5
0
5
10
Amps (in strings)
j4
j2
j4pred
j2pred

What's next?

- Study injection into Booster with both tunes near 4.5
- Develop methods for determining LTB optics match to Booster lattice.
- Measure change in emittance using distorted β function optics (need LTB match to these optics).

What's needed?

- Power supplies
  - Stop band correctors do not come on easily, need attention.
  - LTB modifications? First pass, no.
- Instrumentation
  - Flag/camera systems at F6 (this year, being worked on)
  - Booster Tune Meter → sophisticated and powerful, but not easy to use. Could use simplifying, requires better infrastructure (bpm electronics, rev-tick).
  - New multi-wire at D3 → need a design (ME) and schedule for installation for next summer shutdown (cost est.?, approvals, etc. = need fast!)

Reducing Horizontal (snake generated) intrinsic resonance strengths: reducing the γ–function at the two snakes.

Horizontal Intrinsic Resonance in AGS

- The Polarization for a Gaussian beam after passing n isolated resonances:

$$\left\langle \frac{P_f}{P_i} \right\rangle = \prod_{n(\gamma)} \frac{1 - \dfrac{\pi \, |\varepsilon(\gamma)|^2}{\alpha}}{1 + \dfrac{\pi \, |\varepsilon(\gamma)|^2}{\alpha}}$$

α : the acceleration rate

- The horizontal intrinsic resonance is given approximately :

$$\varepsilon(\gamma) = \sqrt{\gamma} \, \frac{G}{2\pi} P_h(\gamma) \sqrt{\frac{(1+\alpha_x^2) \cdot E}{\beta_x}} \cdot \sin(\pi \nu_x)$$

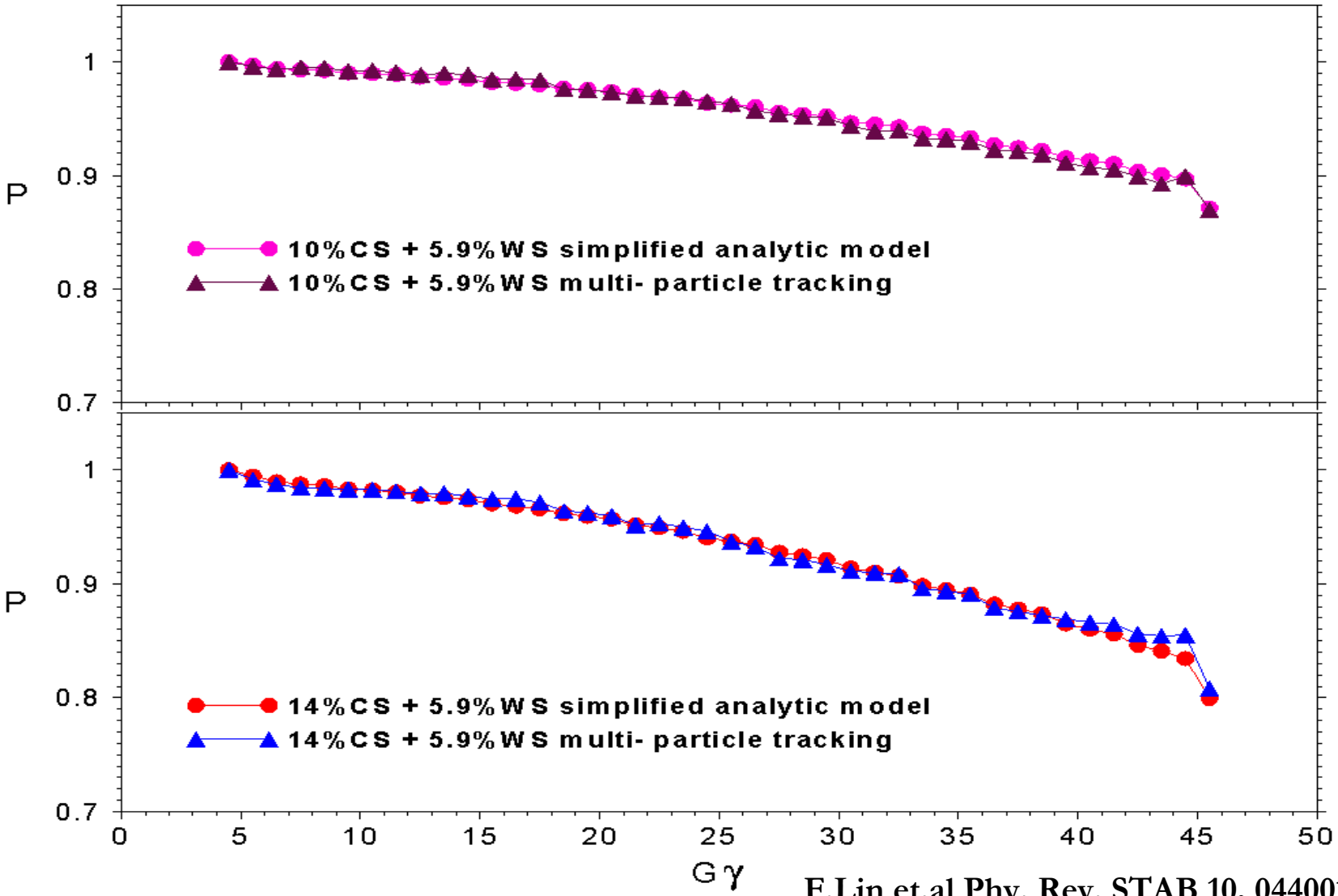
Horizontal component of the stable spin direction

rms emittance of the beam

- A reduction of $\gamma_x = (1+\alpha_x^2)/\beta_x$ by 2 can reduce the polarization loss by the same factor (note: γ_x is ~ constant in the snakes at high energy).

Horizontal Intrinsic Resonance in AGS (2)

The agreement between the simulation and theoretical calculation allows us to give the estimated horizontal resonance strength using the formula.



F.Lin et.al Phy. Rev. STAB 10, 044001 (2007)

½ Integer Stop Band Quadrupoles in AGS

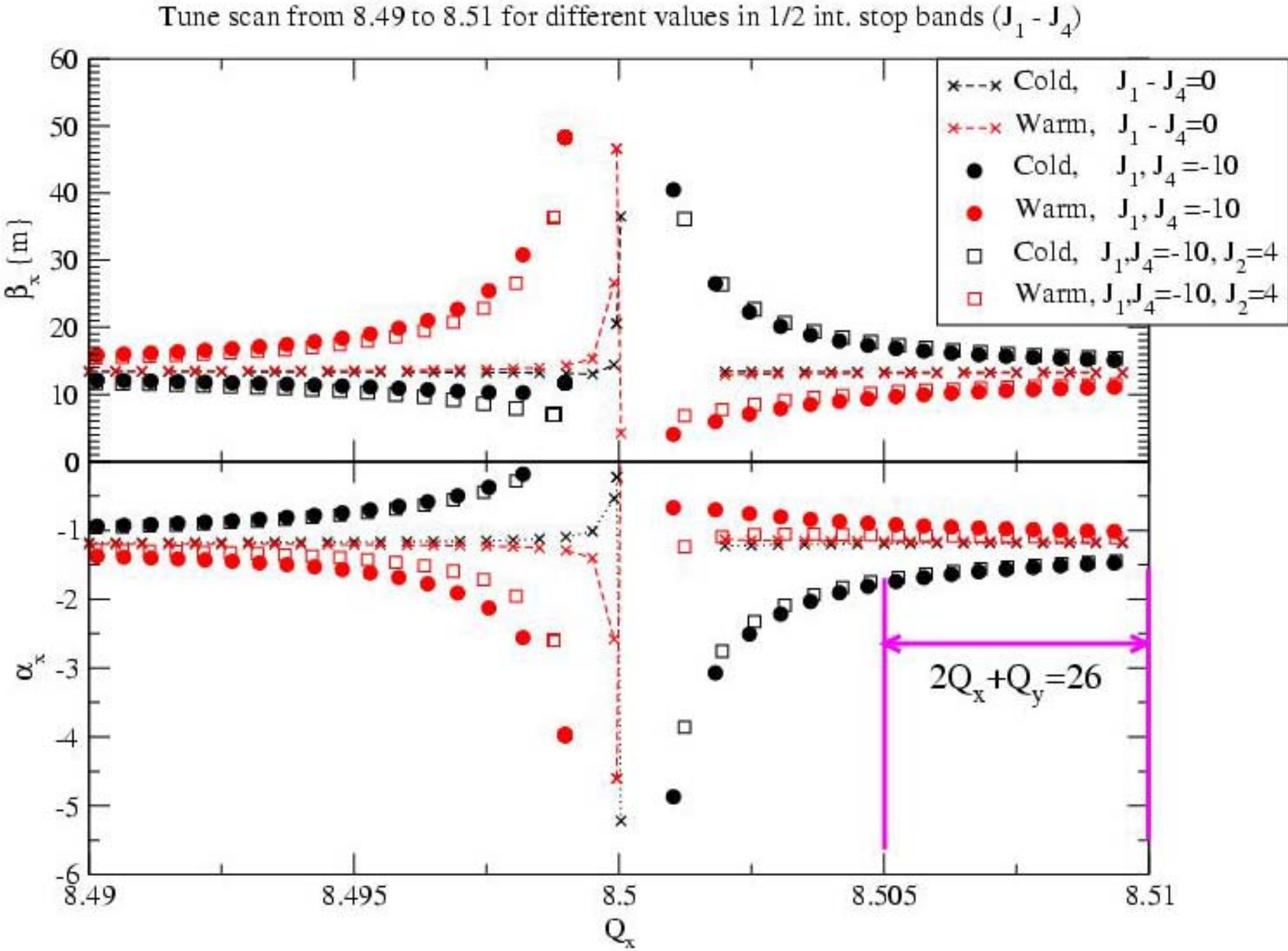
Power supplies (device names) QH_CEIK17, QH_FHLB17
QV_CEIK03, QV_FHLB03

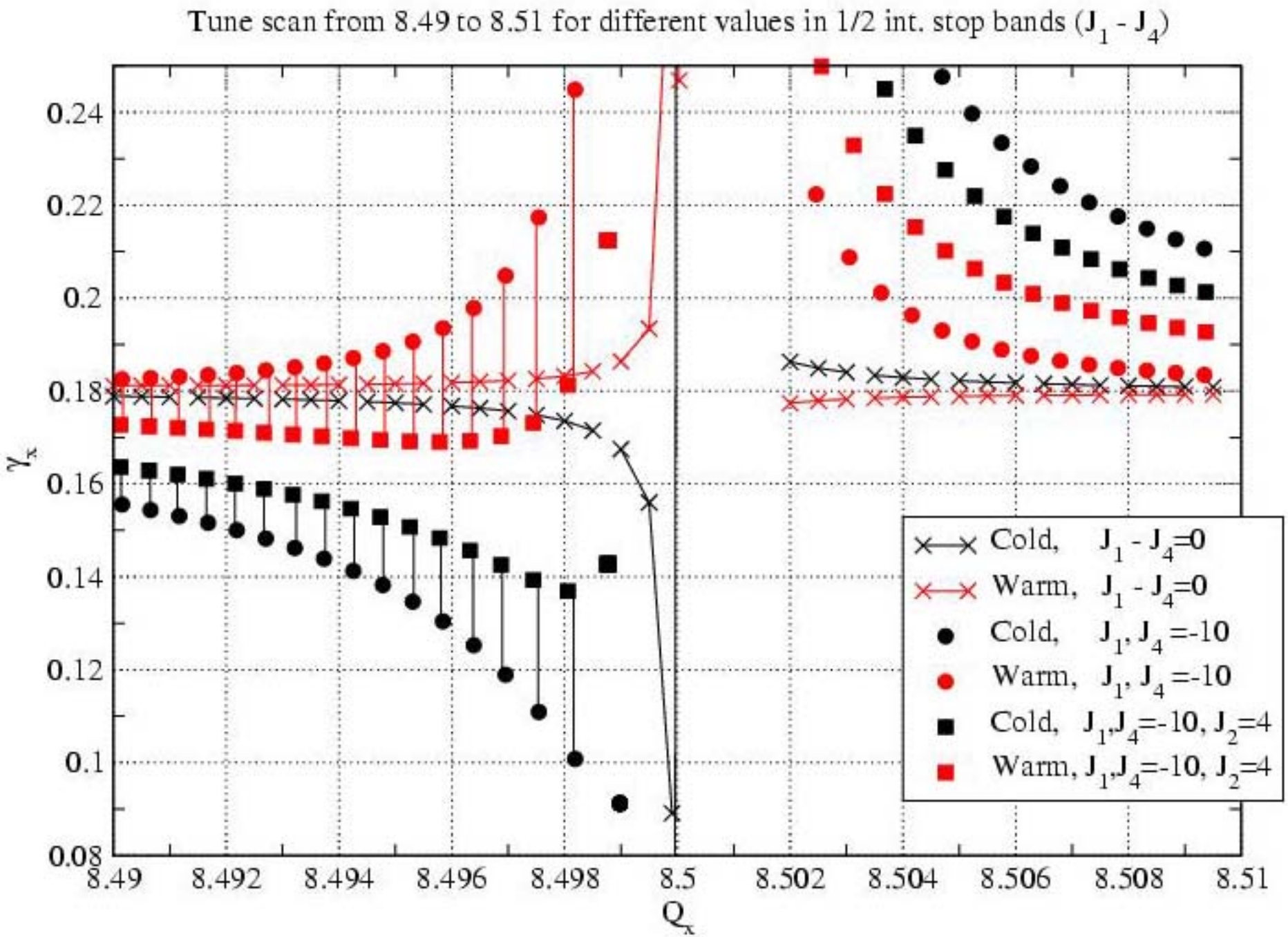
12 turns/pole (windings on main tune quads)
208 mohm/magnet, 1.5 mH/magnet
#10 copper wire
Imax = 10 amp (ps limit)

Wire-ups:
Horizontal Quadupole strings
CEIK17: C17, E17, -I17, -K17
FHLB17: F17, H17, -L17, -B17

Vertical Quadupole strings
CEIK03: C03, E03, -I03, -K03
FHLB03: F03, H03, -L03, -B03

See AGS Div. Tech Note 455, Ed Bleser, 1997


Tune scan from 8.49 to 8.51 for different values in 1/2 int. stop bands (J_1 - J_4)
Cold, J_1 - J_4=0
Warm, J_1 - J_4=0
Cold, J_1, J_4 =-10
Warm, J_1, J_4 =-10
Cold, J_1,J_4=-10, J_2=4
Warm, J_1,J_4=-10, J_2=4
β_x [m]
α_x
Q_x
$2Q_x+Q_y=26$
60
50
40
30
20
10
0
-1
-2
-3
-4
-5
-6
8.49
8.495
8.5
8.505
8.51


Tune scan from 8.49 to 8.51 for different values in 1/2 int. stop bands (J_1 - J_4)
0.24
0.22
0.2
0.18
0.16
0.14
0.12
0.1
0.08
γ_x
8.49
8.492
8.494
8.496
8.498
8.5
8.502
8.504
8.506
8.508
8.51
Q_x
Cold, J_1 - J_4=0
Warm, J_1 - J_4=0
Cold, J_1, J_4 =-10
Warm, J_1, J_4 =-10
Cold, J_1,J_4=-10, J_2=4
Warm, J_1,J_4=-10, J_2=4

Studies?

- 1st need to convince ourselves the polarities of the ½ int. stop bands in the model agree with those in the real machine
- Determine whether we can move to a working point in which γ_x is a minimum in the snakes.
- Polarization scans and polarization profile comparisons (function of Q_h, stop band currents, ?)