Beam Based Alignment at DAΦNE

some preliminary results and observations

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- BBA experience at ATF DR (KEK)
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- determining quad-to-beam offsets
- analysis of 18 June 2002 data (e+)
- preliminary analysis of 20 June 2002 data (e-)
- a possible technique for determining absolute quad offsets
- a few words about: sextupole BBA, coupling due to the septum bump, uncoupled vs coupled models

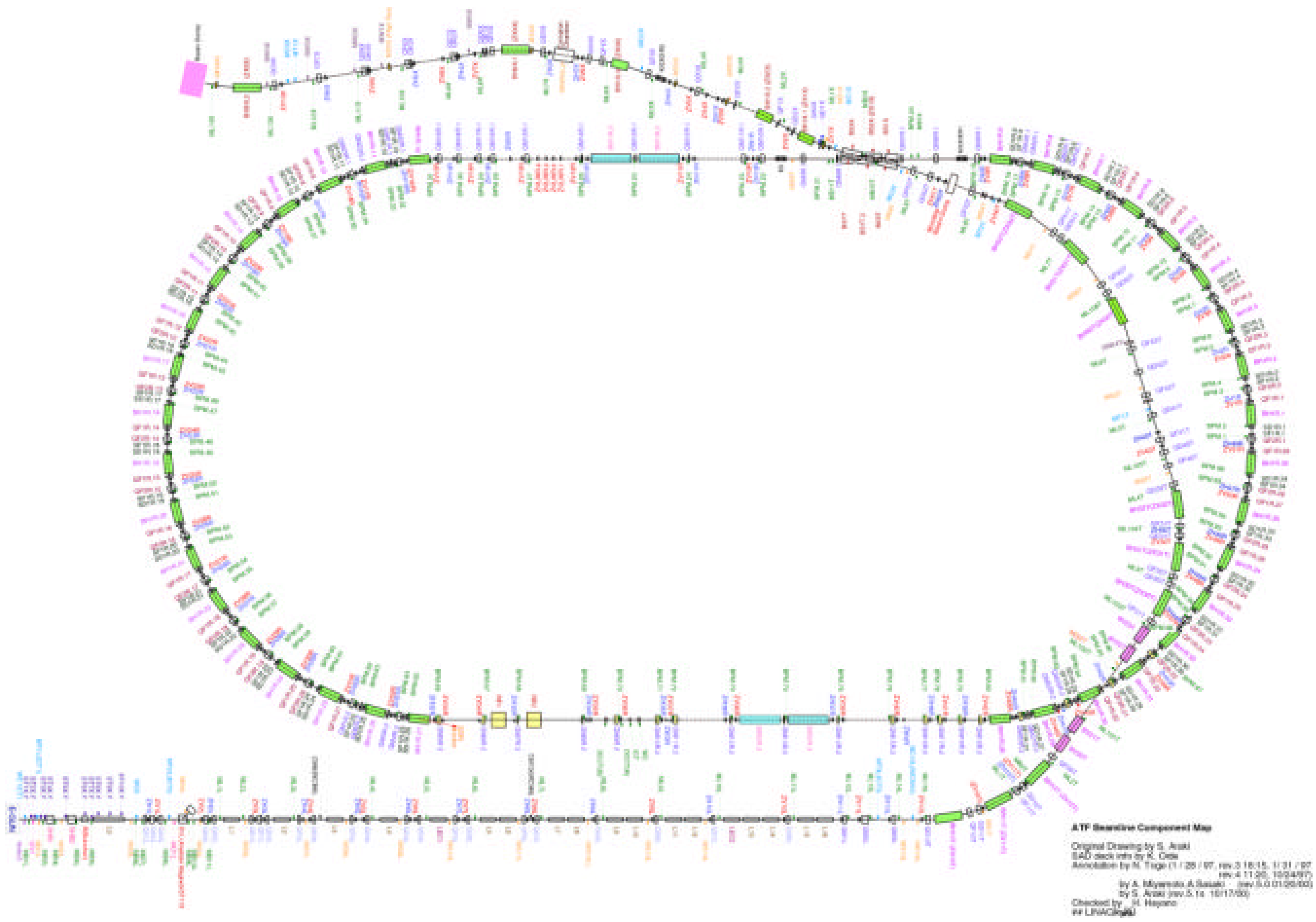
Beam-based Alignment at the ATF

Mark Woodley

ISG8, June 24-27, 2002, SLAC

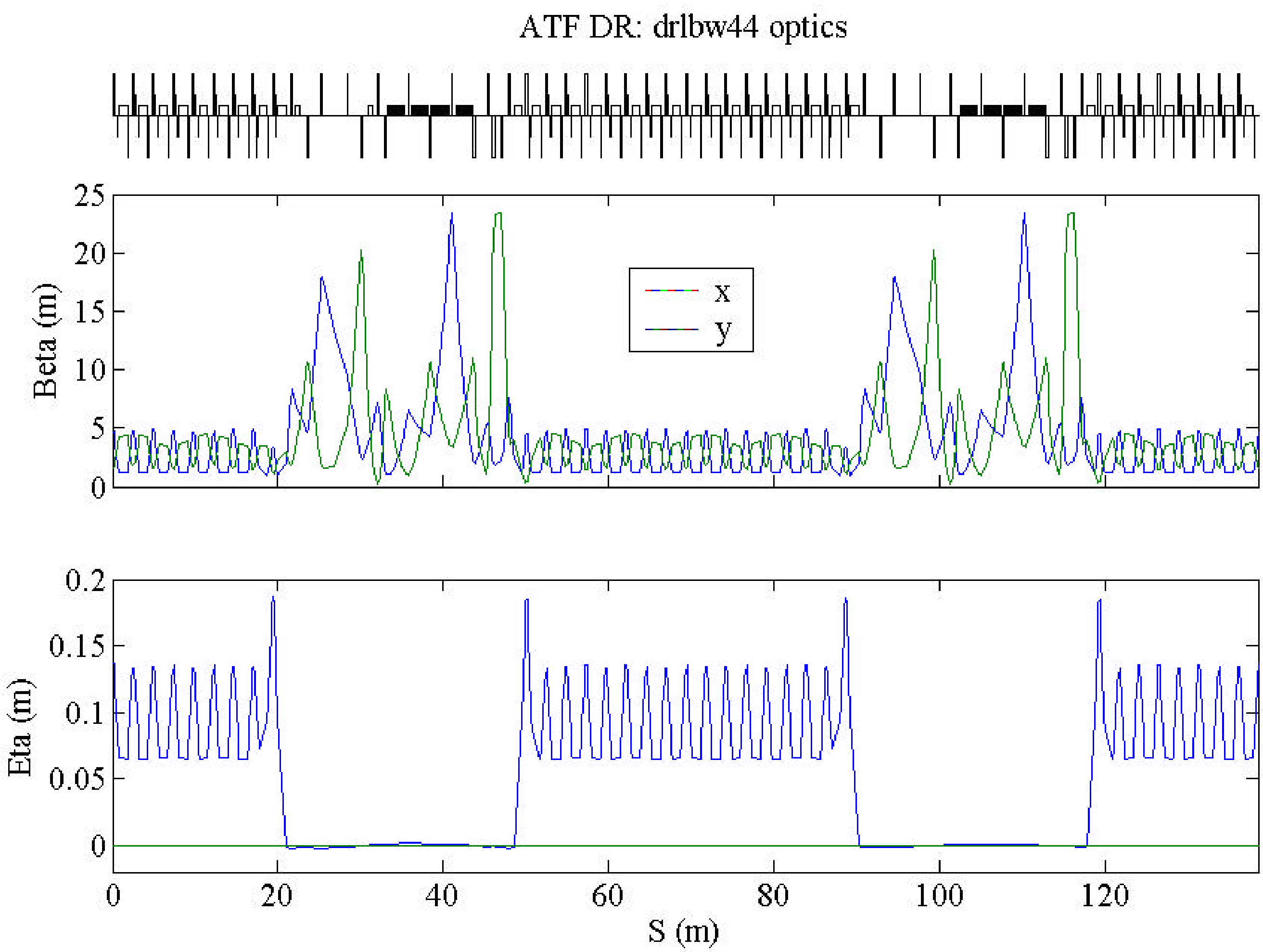
A brief review of measurements at the ATF,
presented on behalf of the participants:
the ATF staff,
M. Ross and J. Nelson (SLAC),
and A. Wolski (LBL).
This work is still in progress …

ATF Damping Ring Complex

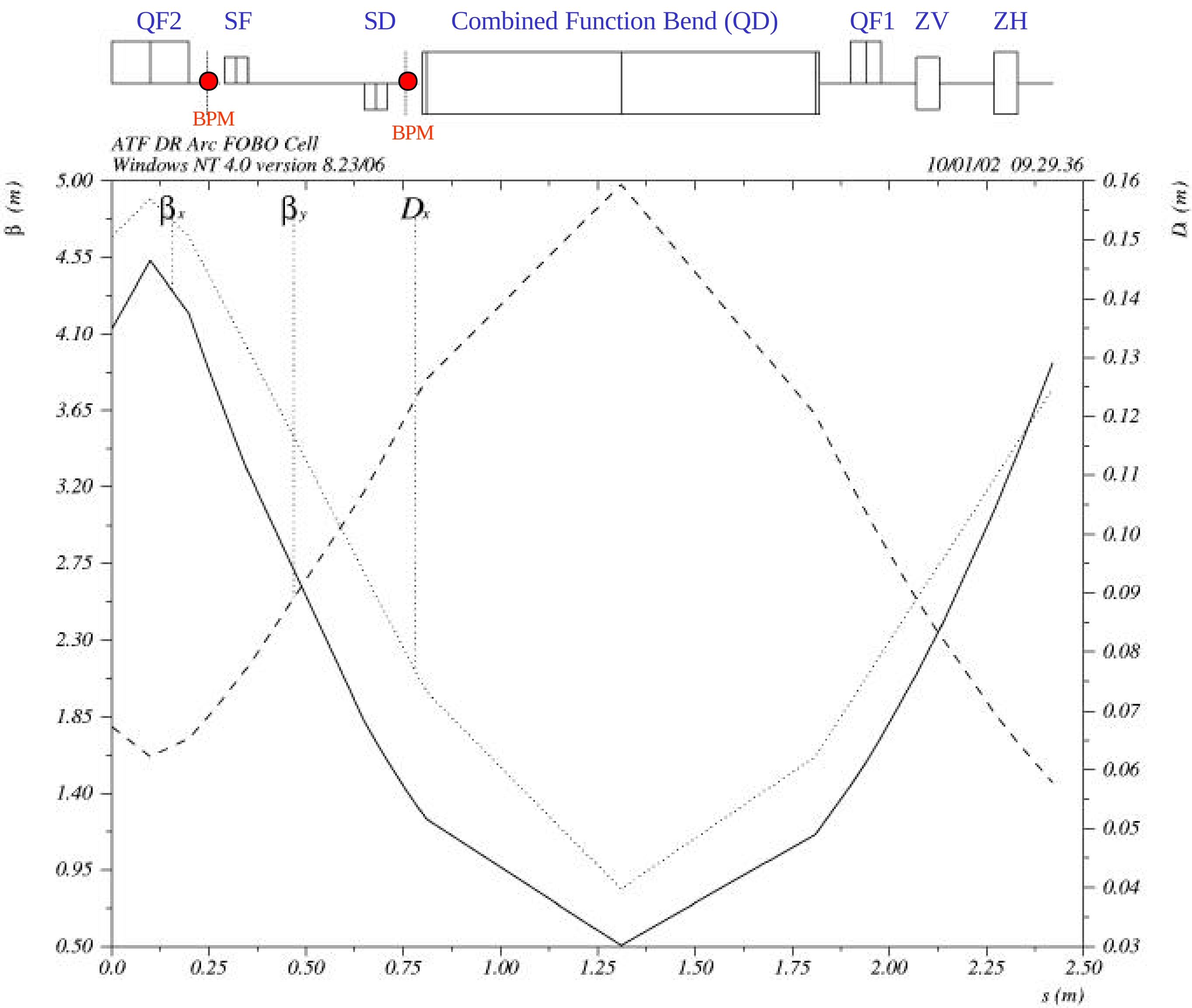


Circumference:	138.56 m
Arc Cell Type:	FOBO
Number of Arc Cells:	36
Energy:	1.279 GeV
Tunes:	15.192 / 8.542
Extracted Vertical Emittance:	ε_y = 11 pm-rad, $\gamma\varepsilon_y$ = 27 nm-rad

DRLBW44 Optics



Arc Cell



Phase Advance Per Cell:	120.3° / 48.5°
Phase Advance Between BPMs:	11.6° / 10.7°

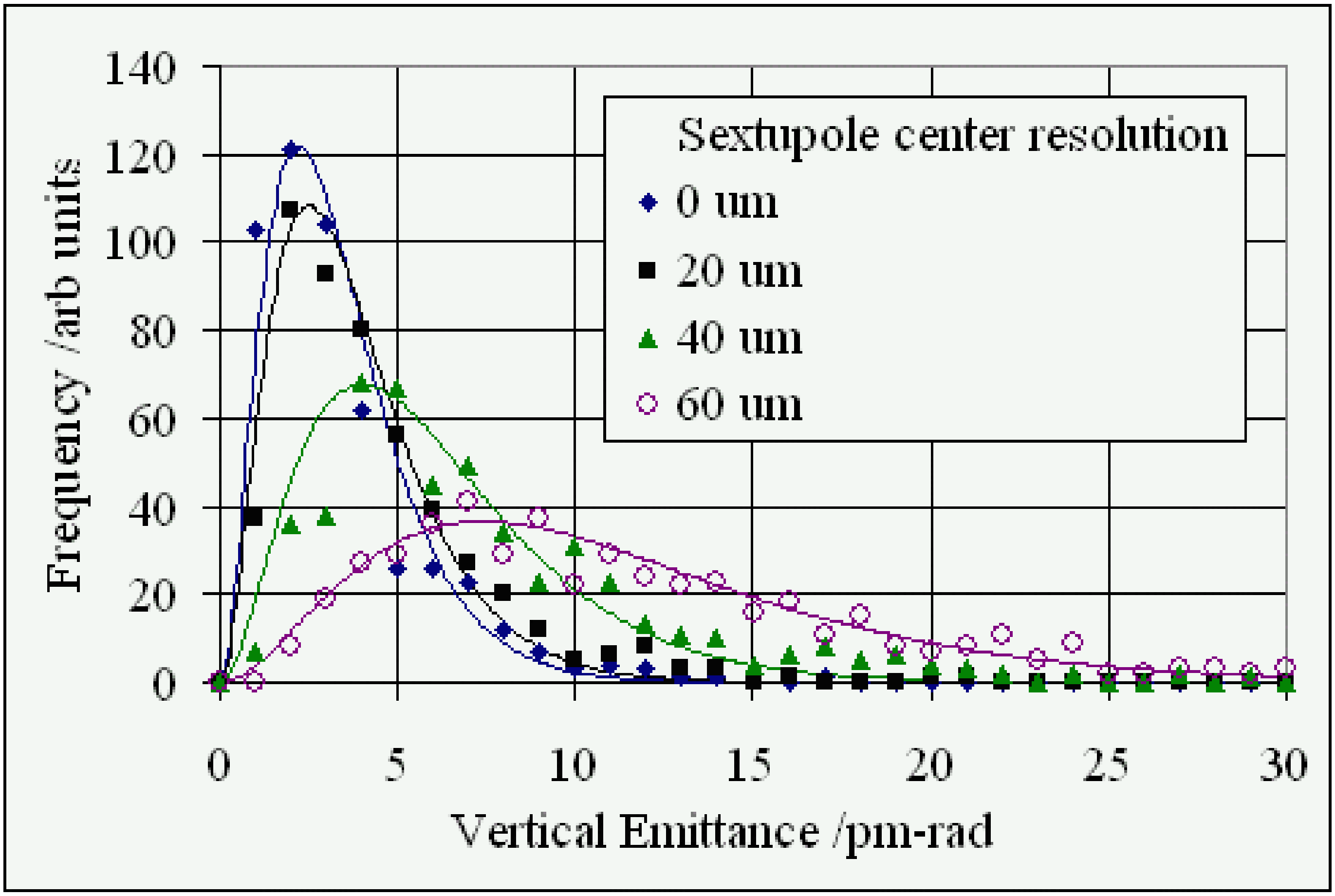
Each quadrupole has an independent trim
Each sextupole has an independent skew quadrupole trim

Reducing the Vertical Emittance

- present measured extracted vertical emittance is 11 pm-rad … measured down to e_y ~ 3 pm-rad @ low single-bunch charge
- vertical emittance is generated by spurious vertical dispersion and betatron coupling
- these effects can be minimized by aligning the quadrupoles and sextupoles and steering the beam through their magnetic centers
- desire alignment accuracy of 20 µm
- need to determine electronic offsets in the BPM readings

$\Rightarrow$ BBA!

Simulated emittance as a function of sextupole BBA resolution

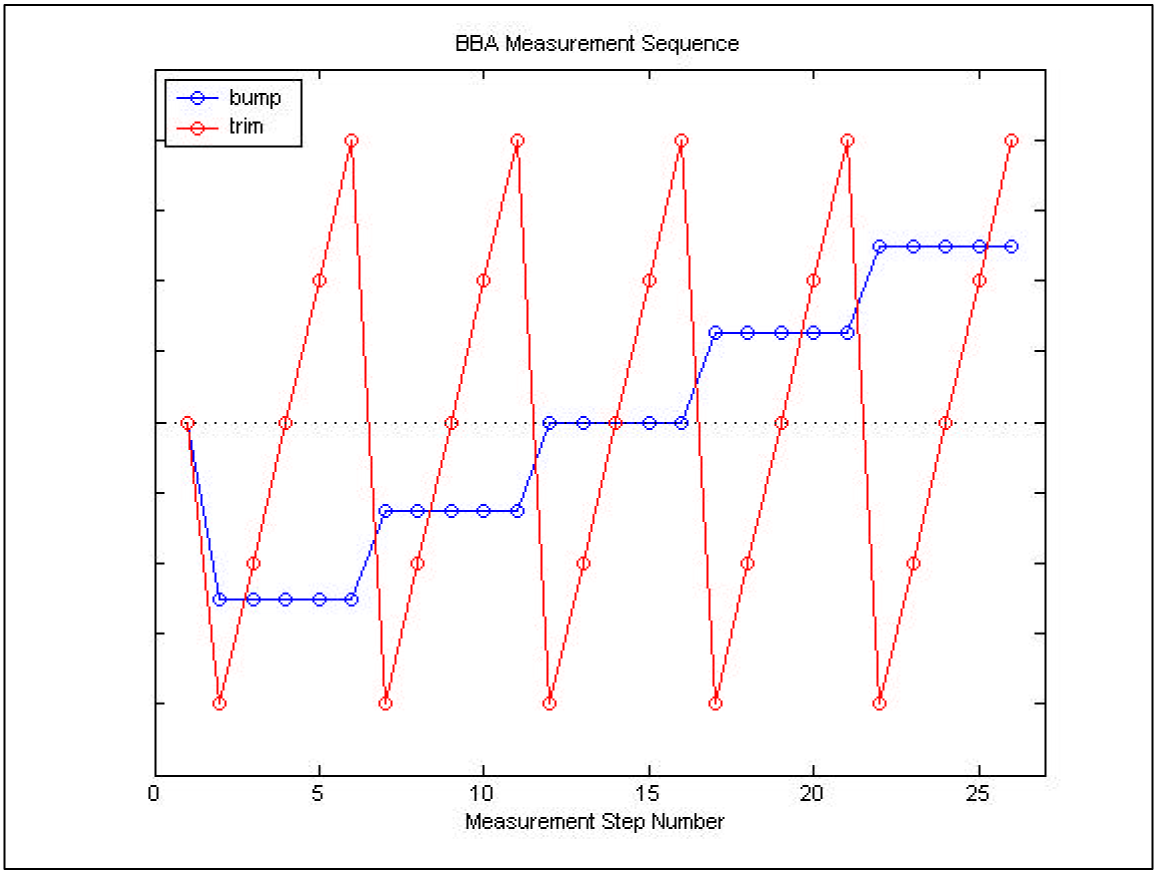


Correcting sextupole offsets without also correcting quad offsets can make ε much worse!

Measurement Challenges

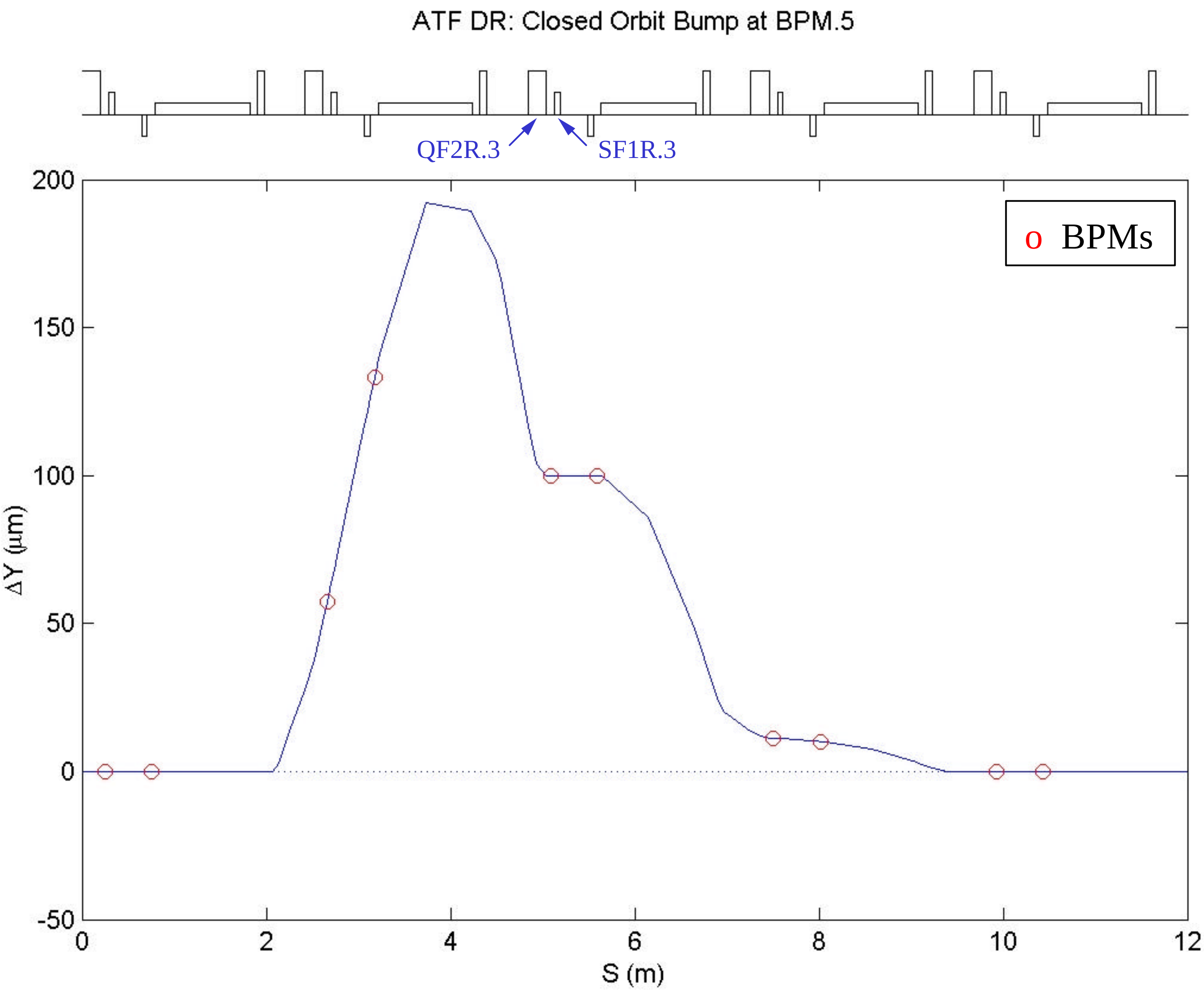
- intrinsic BPM resolution (intensity dependent; 20 μm @ 10^{10} e-/bunch, 40 μm @ 5×10^{9} e-/bunch)
  - ✓ orbit averaging
  - ✓ improved electronics
- intensity dependent position calibration
  - ✓ monitor intensity stability during acquisition
- energy drift
  - ✓ add energy error to horizontal orbit fits
- beam losses in ring cause fluctuating BPM readings
  - ✓ acquisition: bump/trim range selection (too big … losses; too small … resolution)
  - ✓ analysis: data winnowing
- sextupole skew-quad trims are weak ($\int$Gdl ~ ±0.3 kG)
  - ? measurement systematics (magnetic/hysteretic)
- alignment of combined function dipoles
  - ? ballistic techniques?
- time (single-turn orbit acquisition at 3 Hz machine rate; 20 orbit averaging; 5 bump steps; 5 trim settings; 100 BPMs; x and y)
  - ✓ automate data acquisition (≈8 minutes/magnet for a single plane)

BPM Offset Measurement Technique

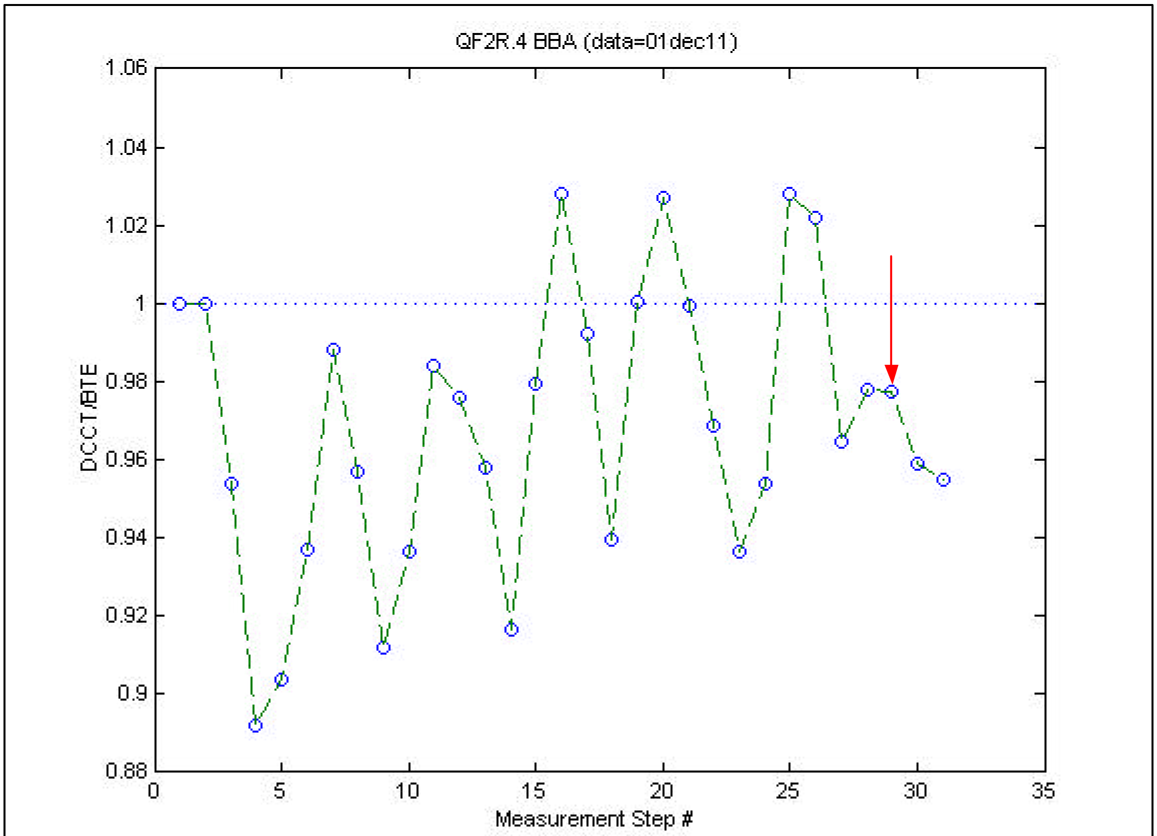


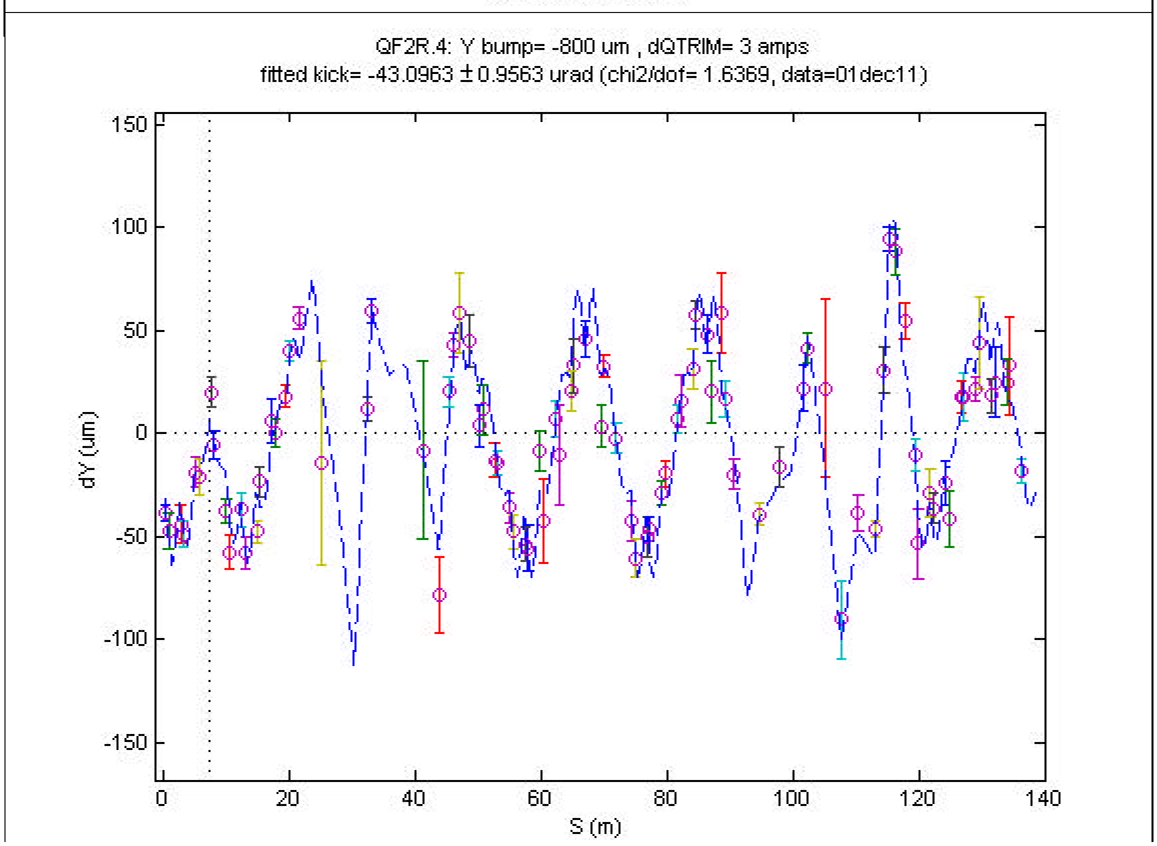
- make a closed local bump at target BPM
- use quadrupole or sextupole (skew quad) trims (?Q)
- make grid scan of bump amplitude and trim setting
- for each bump value make difference orbit w.r.t. to trim=0
- fit difference orbits for kick (k) at quadrupole or sextupole
- for each bump value fit kick vs trim: $k = f$ (?Q) = m ?Q+b
  - m is offset from magnetic center
  - for some trajectory through the magnet, m = 0
- plot fitted offset vs absolute reading of target BPM
  - horizontal intercept is BPM offset

4-corrector 100 μm Y-bump

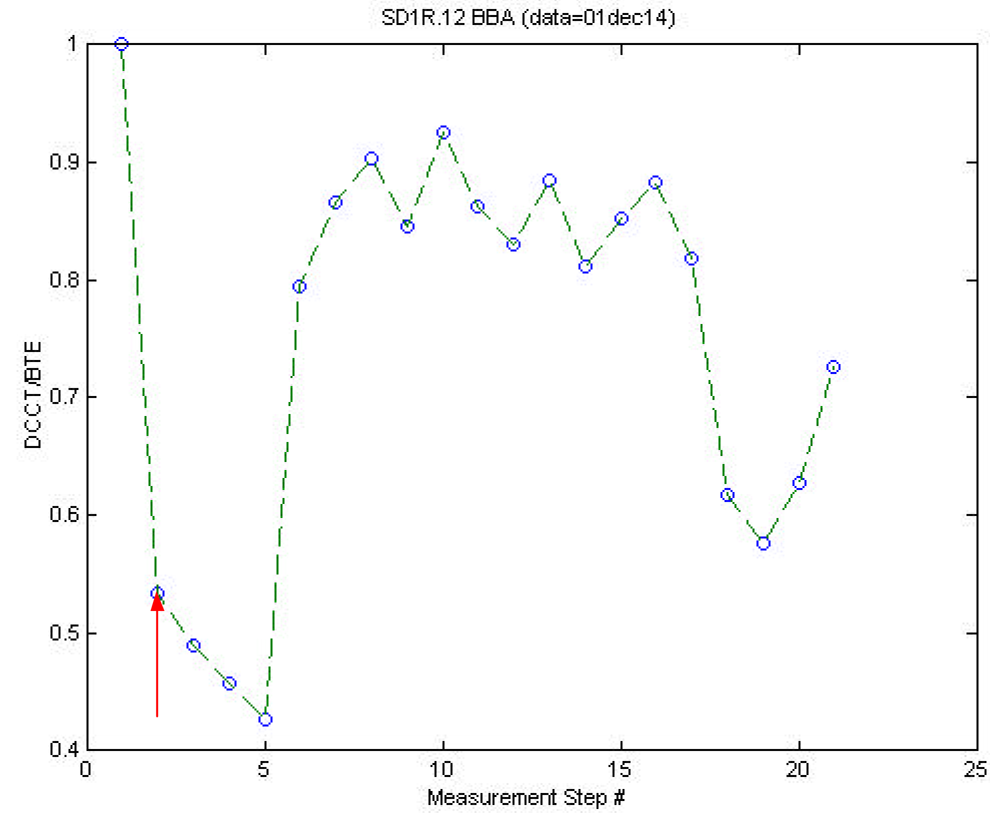


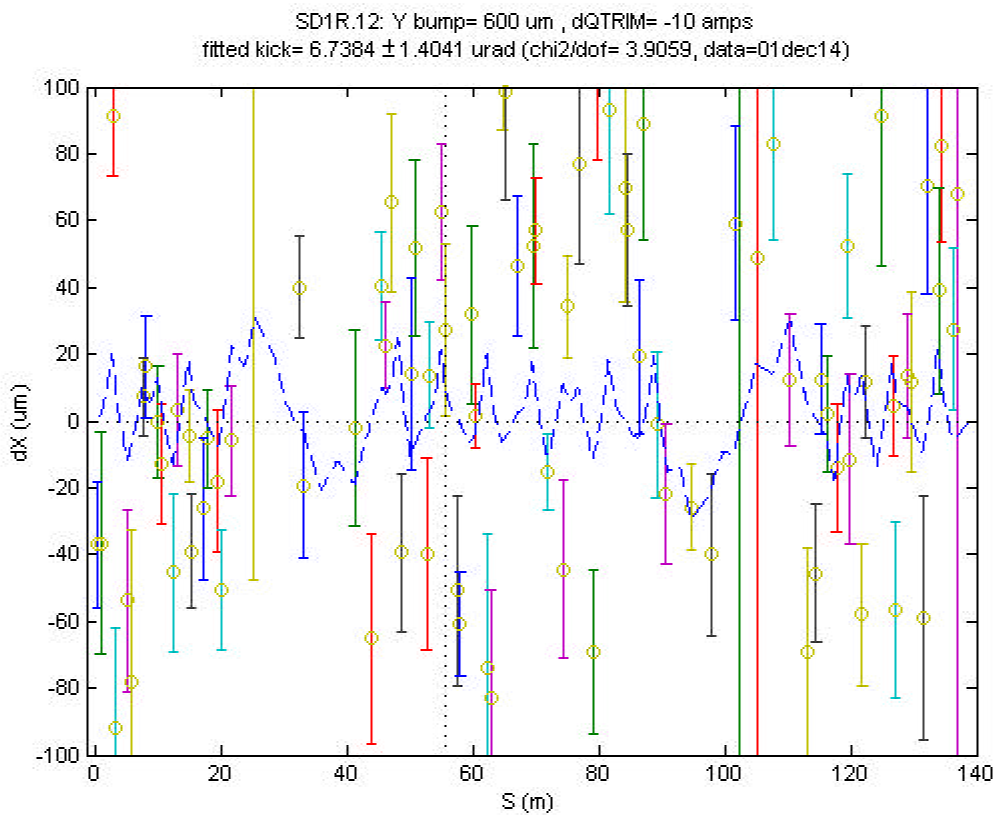
Good Orbit Fit



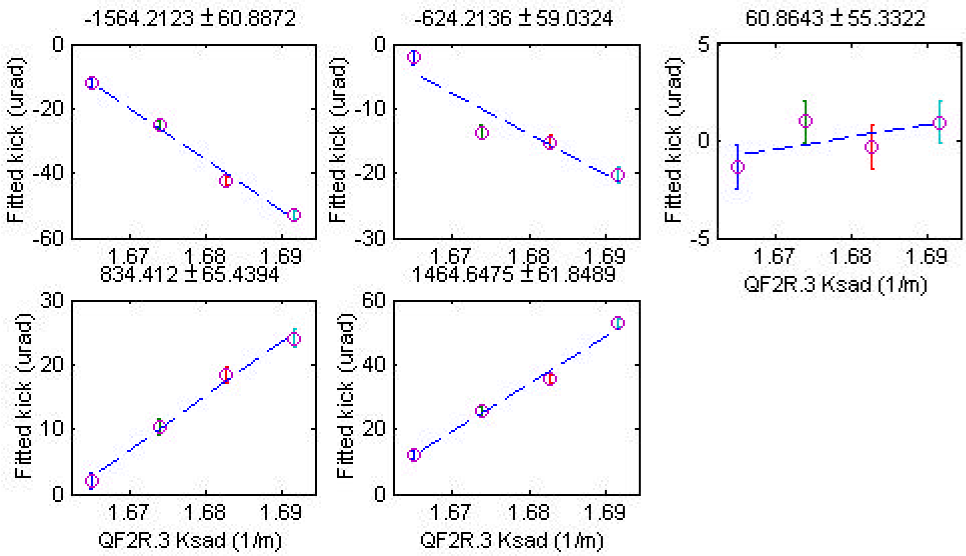


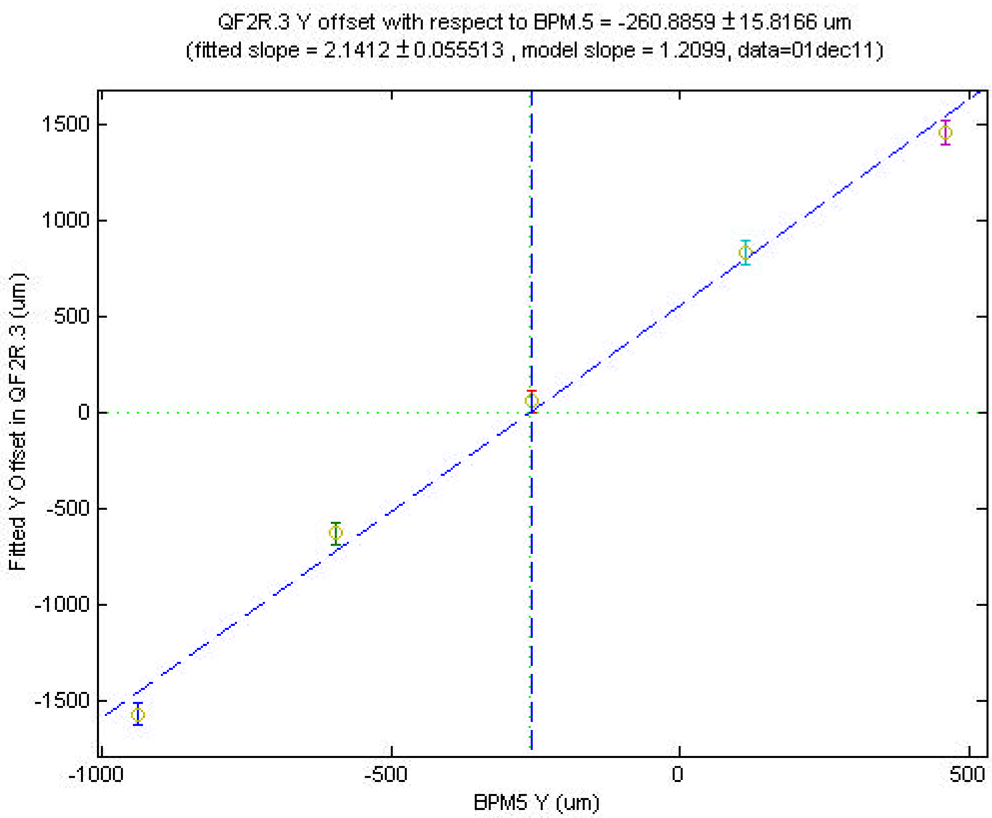
Bad Orbit Fit

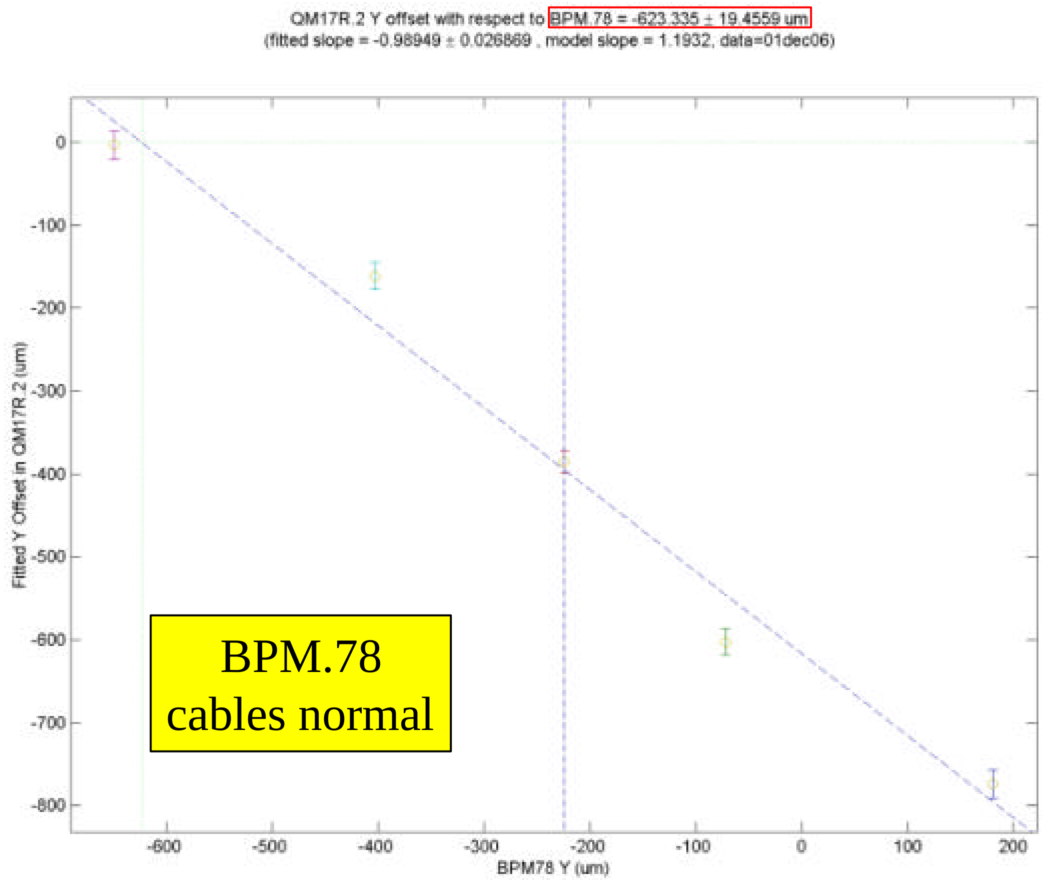


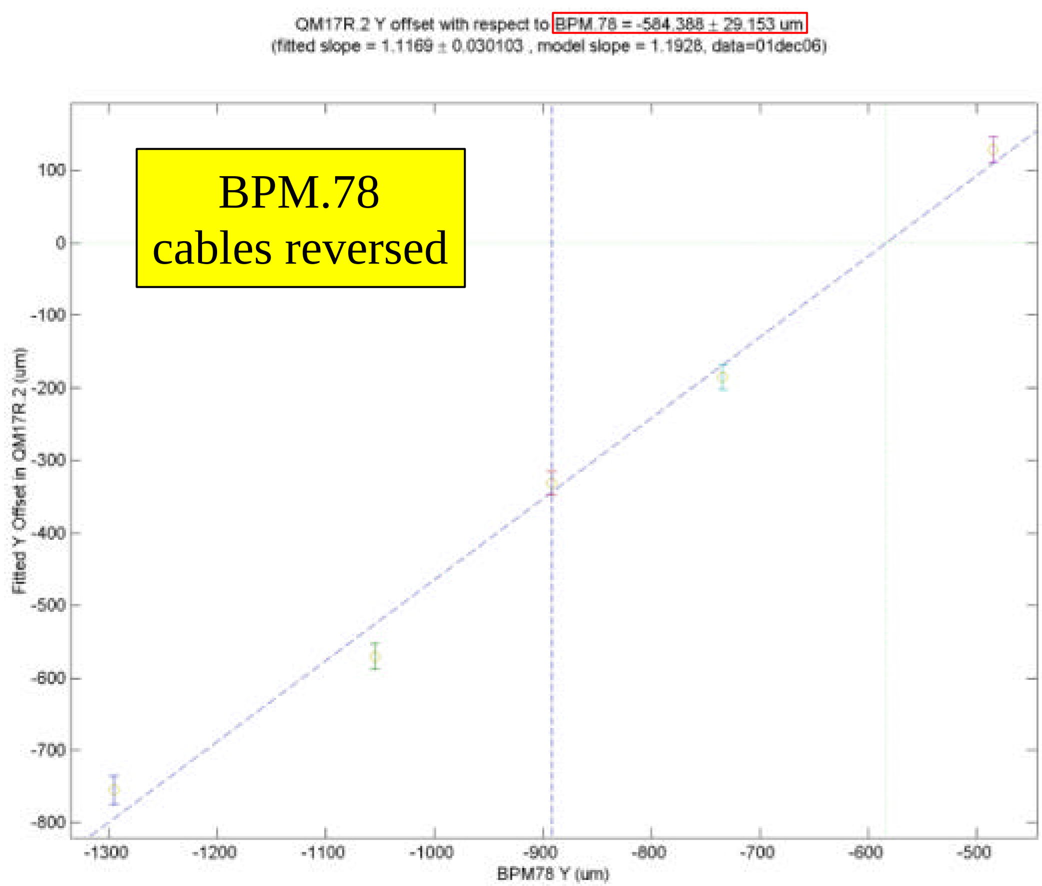


Analysis Results






QM17R.2 Y offset with respect to BPM.78 = -623.335 ± 19.4559 um
(fitted slope = -0.98949 ± 0.026869 , model slope = 1.1932, data=01dec06)
Fitted Y Offset in QM17R.2 (um)
BPM78 Y (um)
BPM.78
cables normal

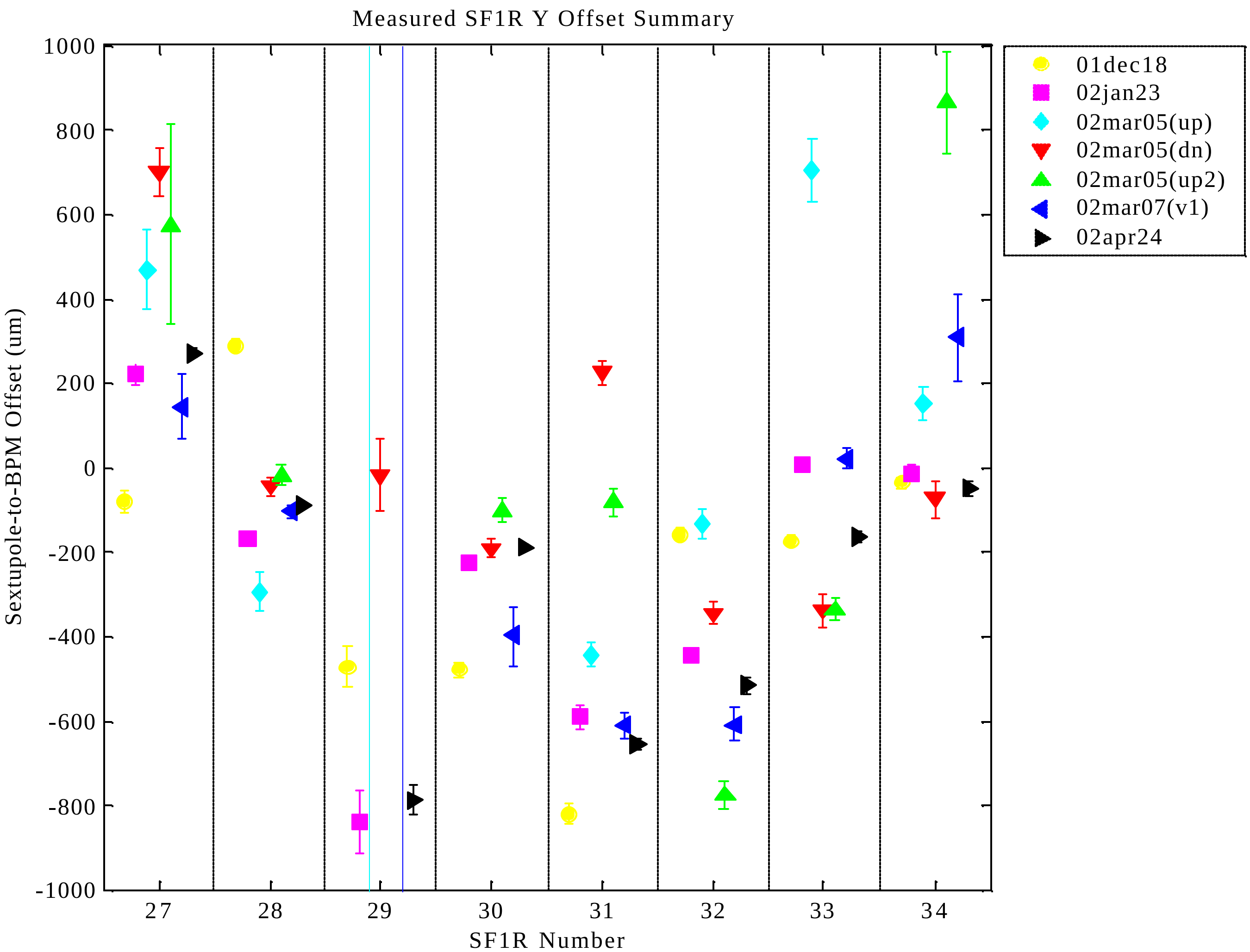

QM17R.2 Y offset with respect to BPM.78 = -584.388 ± 29.153 um
(fitted slope = 1.1169 ± 0.030103 , model slope = 1.1928, data=01dec06)
Fitted Y Offset in QM17R.2 (um)
BPM78 Y (um)
BPM.78
cables reversed

Reproducibility of quad centers

QF2R vertical BPM offset measurements

QF2 #	1/ 23	3/1 #1	3/1 #2	3/1 #3	rms
18	54.0	73.0	62.6		9.5
19	-421.2	-422.5	-426.5		2.8
20	-239.8	-200.9	-246.2	-243.1	21.2
21	-503.7	-551.7	-626.3	-586.2	52.1
22	47.1	-6.0	39.3	23.5	23.5
23	-211.0	-385.7	-295.4	-286.0	71.5
24	-255.6	-303.1	-294.8	-245.6	28.4
25	88.1	60.7	129.6	104.3	28.9

Reproducibility of sextupole centers



Possible Sextupole Systematic Error Sources

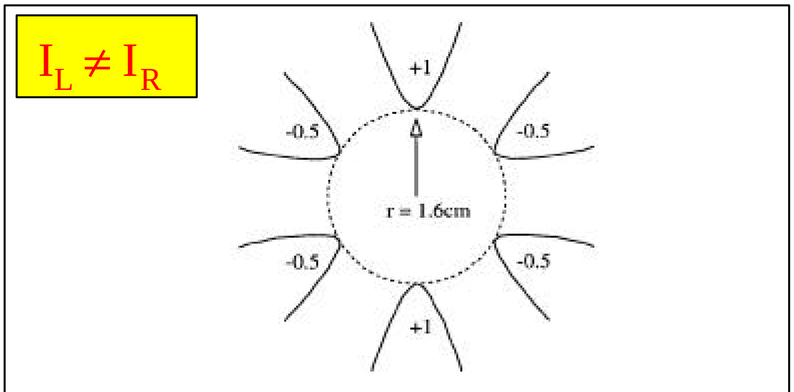


Figure 1: Sextupole pole configuration to generate skew quadrupole fields.

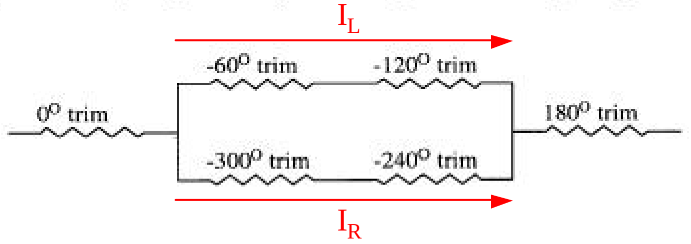
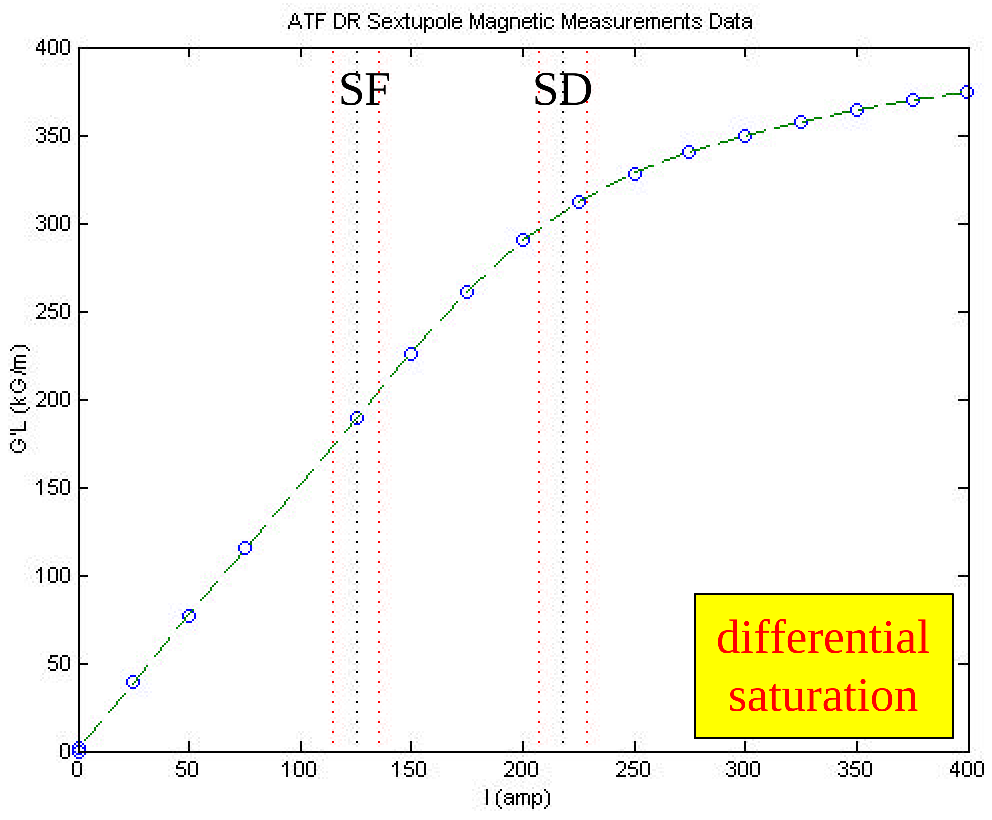


Figure 2: Wiring of sextupole trims to generate skew quadrupole fields.



What's Next

- measure BPM offsets for non-arc BPMs (more difficult due to vertical aperture restrictions in wigglers)
- use measured BPM offsets to create a "gold orbit" and steer to it, then do standard dispersion/coupling corrections and check vertical emittance

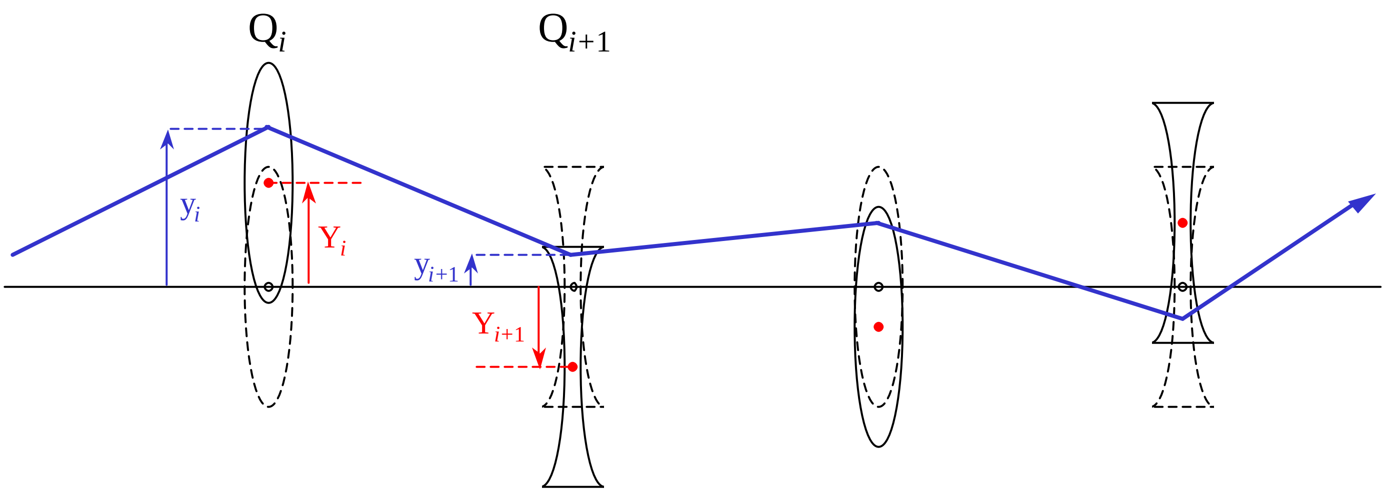
- understand systematics in sextupole skew-quad trim data … find source of non-reprodicibility
- improve analysis tools (actual sextupole settings, actual skew quad settings, …)
- continue checking stability of measured BPM offsets
- better understand why BPMs go "bad"

- try 3-corrector bumps instead of 4-corrector (maximum offset at target magnet)
- BBA for combined-function bends
- improved BPM electronics with 3 μm resolution (at 10^{10} e-/bunch) will be available early next year

Why BBA at DAΦNE?

- small emittance ratio and large dynamic aperture are desired
- vertical emittance is generated by spurious vertical dispersion and betatron coupling
- vertical dispersion is generated by vertical steering and vertical offsets in the sextupoles
- horizontal misaligments can affect the accuracy of the machine model
- these effects can be minimized by aligning the quadrupoles and sextupoles
- what is the desired alignment accuracy?
- need to determine electronic offsets in the BPM readings

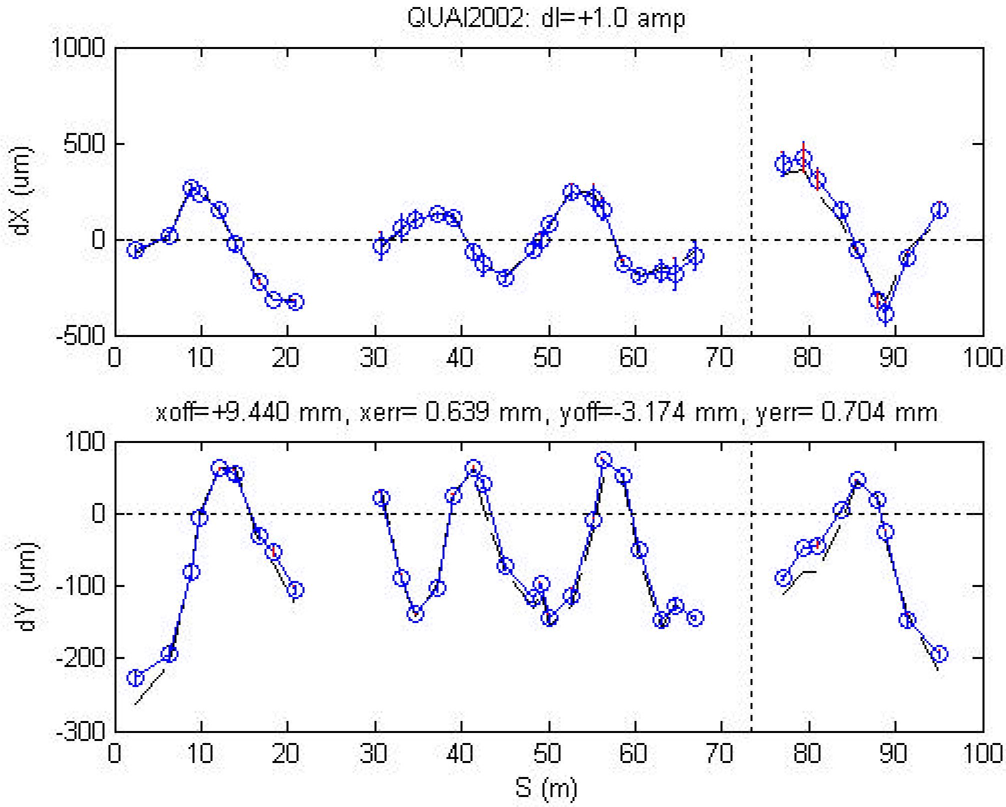
Determining Quad-to-Beam Offsets

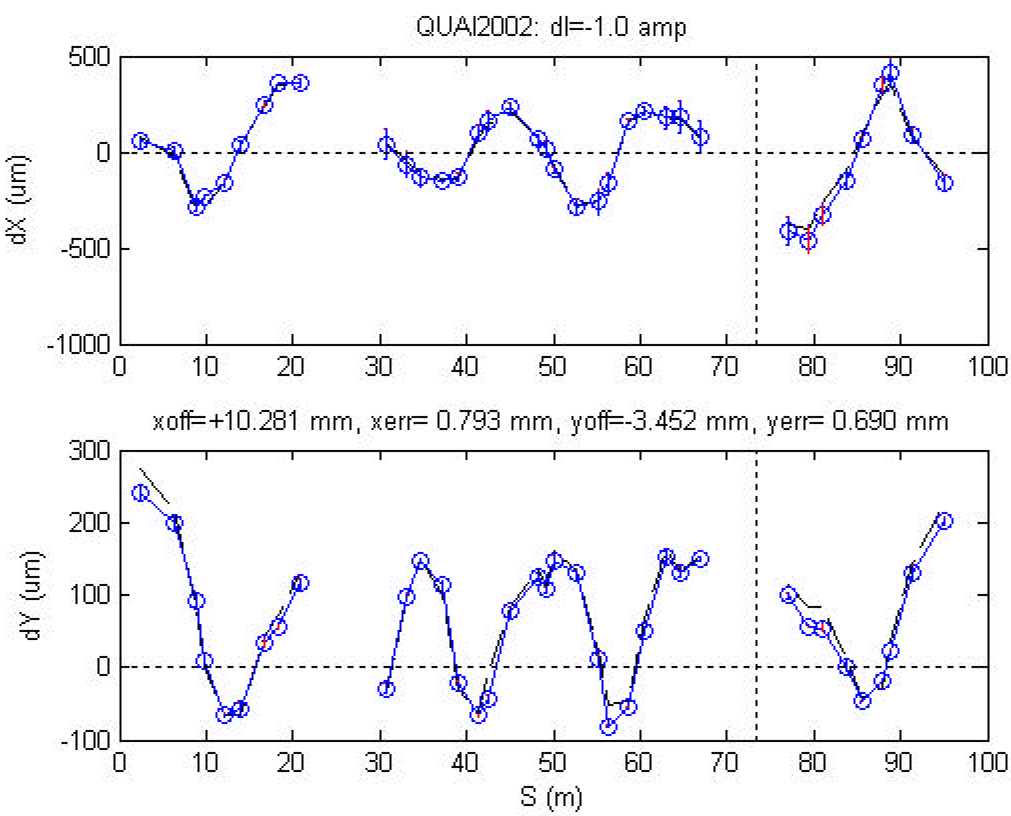


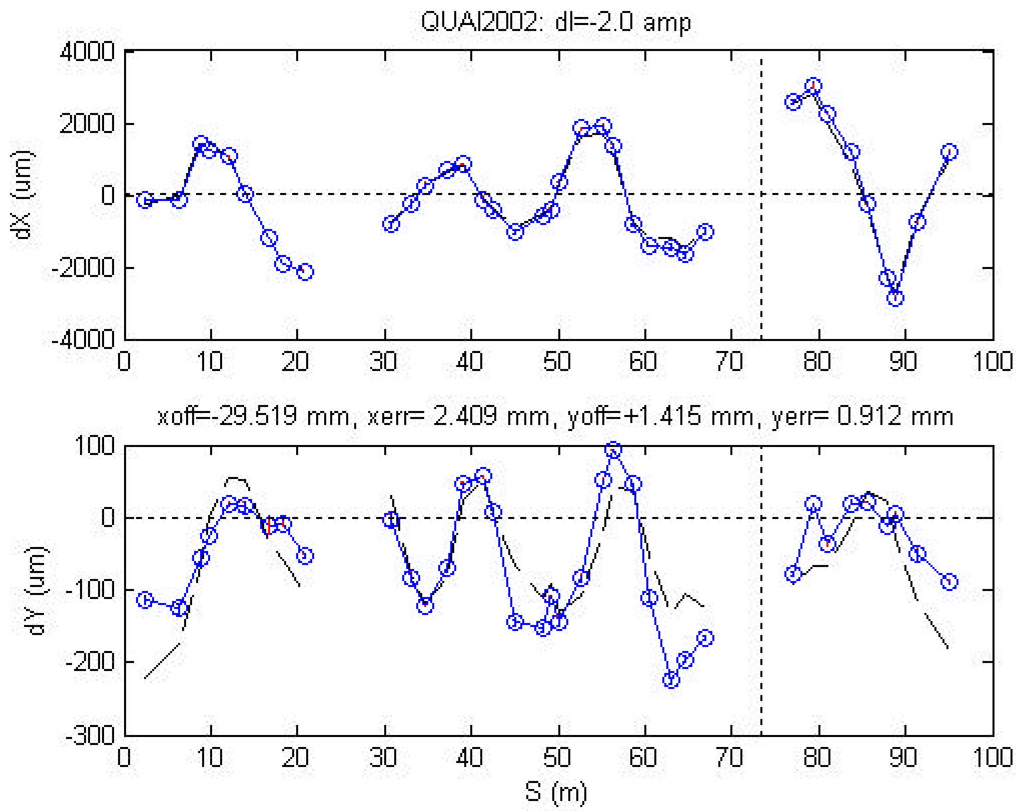
1. Save reference orbit: $I_Q = I_0$
2. Change quad current: $I_Q = I_0 + \Delta I$
3. Measure difference orbit: $\Delta y = y(I_0+\Delta I) - y(I_0)$
4. Form the same difference orbit in the model with an offset Y_M in the quad:
   $$\Delta y_M = y_M(I_0+\Delta I, Y_M) - y_M(I_0, Y_M)$$
5. Find the quad-to-beam offset (in a least-squares sense) by scaling the model difference orbit: $\Delta y = c\,\Delta y_M$, $y - Y = cY_M$

Notes:

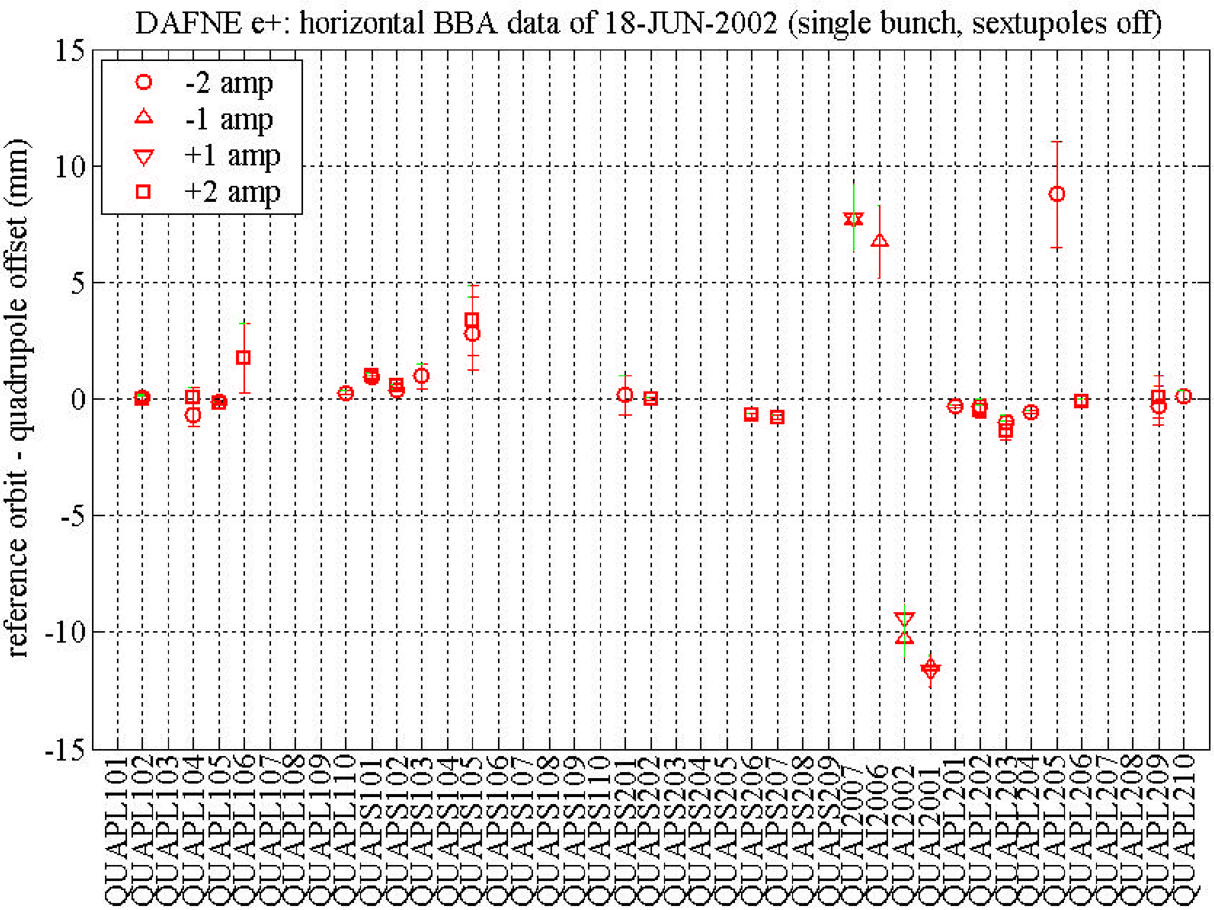
- adjust statistical errors on BBA difference orbit readings so that χ^2 of fit = 1 in order to estimate error on fitted quad-to-beam offset
- ignore KLOE and DEAR IR BPMs


QUAI2002: dI=+1.0 amp
dX (um)
1000
500
0
-500
0
10
20
30
40
50
60
70
80
90
100
xoff=+9.440 mm, xerr= 0.639 mm, yoff=-3.174 mm, yerr= 0.704 mm
dY (um)
100
0
-100
-200
-300
S (m)

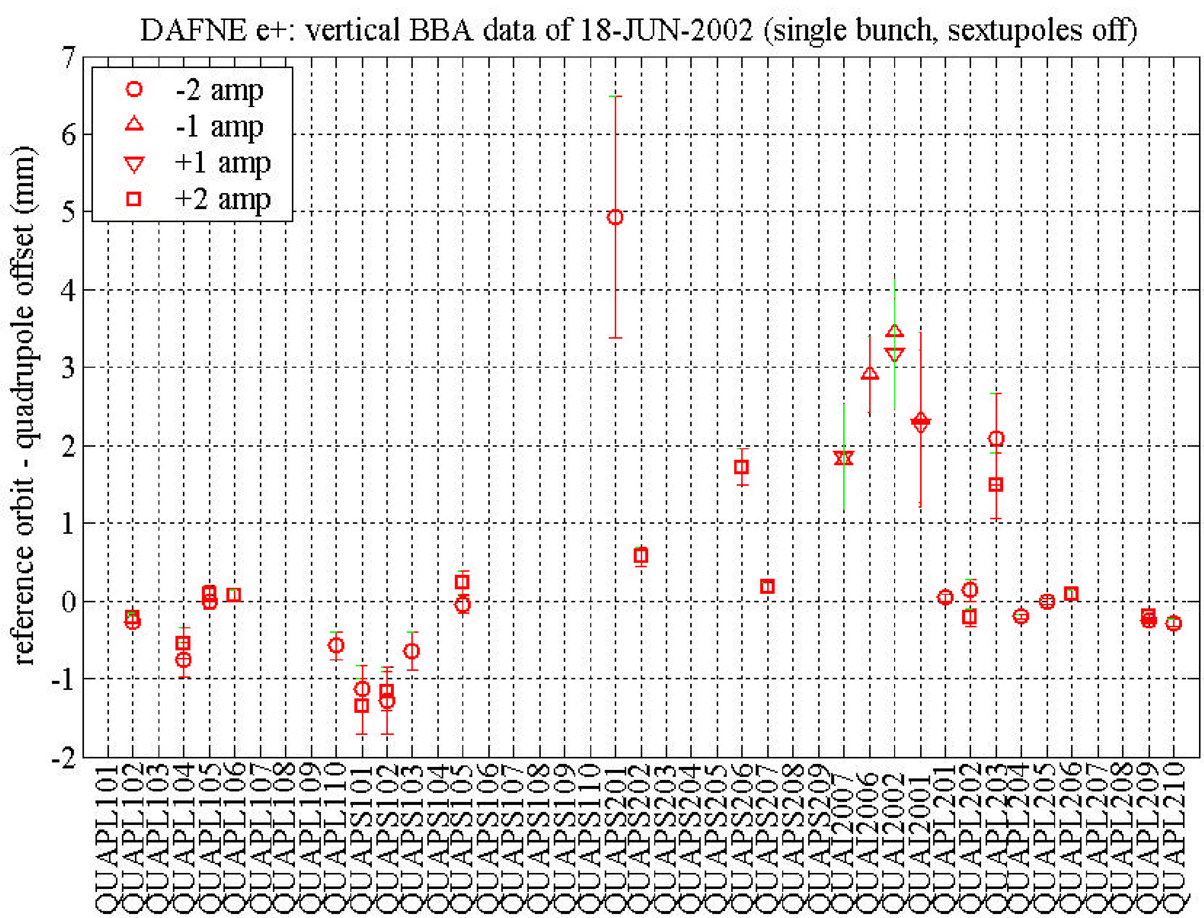

QUAI2002: dI=-1.0 amp
dX (um)
500
0
-500
-1000
0
10
20
30
40
50
60
70
80
90
100
xoff=+10.281 mm, xerr= 0.793 mm, yoff=-3.452 mm, yerr= 0.690 mm
dY (um)
300
200
100
0
-100
S (m)



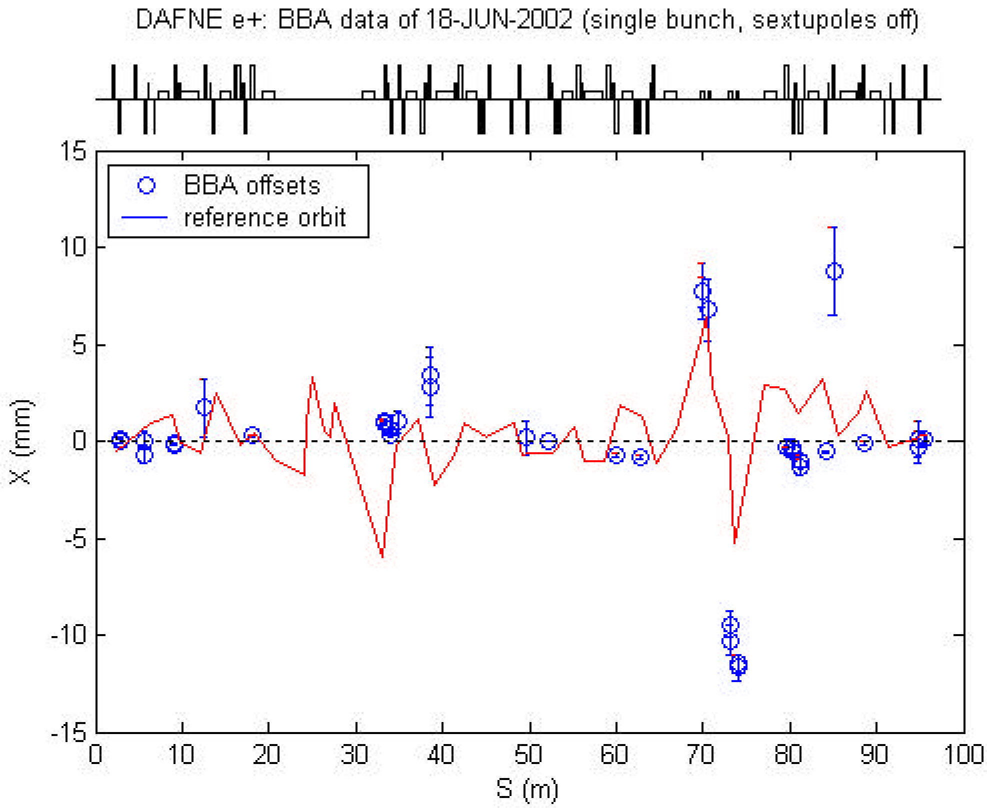
QUAI2002: dI=-2.0 amp
dX (um)
4000
2000
0
-2000
-4000
0
10
20
30
40
50
60
70
80
90
100
xoff=-29.519 mm, xerr= 2.409 mm, yoff=+1.415 mm, yerr= 0.912 mm
dY (um)
100
0
-100
-200
-300
S (m)

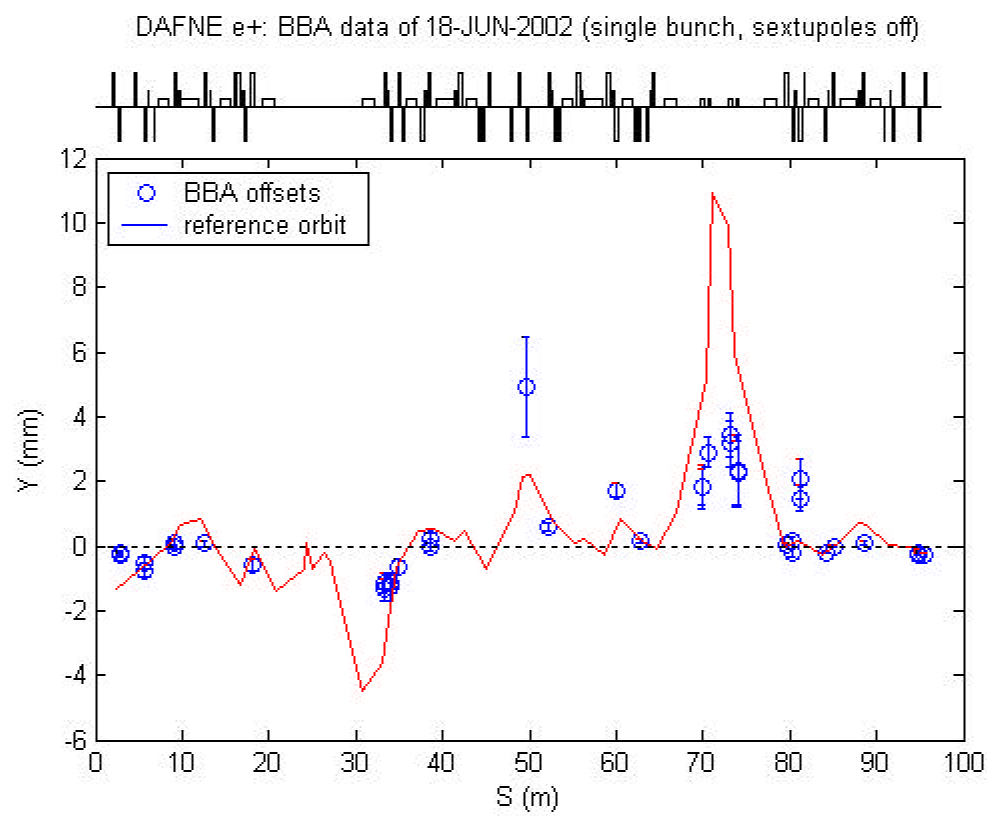


DAFNE e+: horizontal BBA data of 18-JUN-2002 (single bunch, sextupoles off)
-2 amp
-1 amp
+1 amp
+2 amp
reference orbit - quadrupole offset (mm)
15
10
5
0
-5
-10
-15
QUAPL101
QUAPL102
QUAPL103
QUAPL104
QUAPL105
QUAPL106
QUAPL107
QUAPL108
QUAPL109
QUAPL110
QUAPS101
QUAPS102
QUAPS103
QUAPS104
QUAPS105
QUAPS106
QUAPS107
QUAPS108
QUAPS109
QUAPS110
QUAPS201
QUAPS202
QUAPS203
QUAPS204
QUAPS205
QUAPS206
QUAPS207
QUAPS208
QUAPS209
QUAI2007
QUAI2006
QUAI2002
QUAI2001
QUAPL201
QUAPL202
QUAPL203
QUAPL204
QUAPL205
QUAPL206
QUAPL207
QUAPL208
QUAPL209
QUAPL210

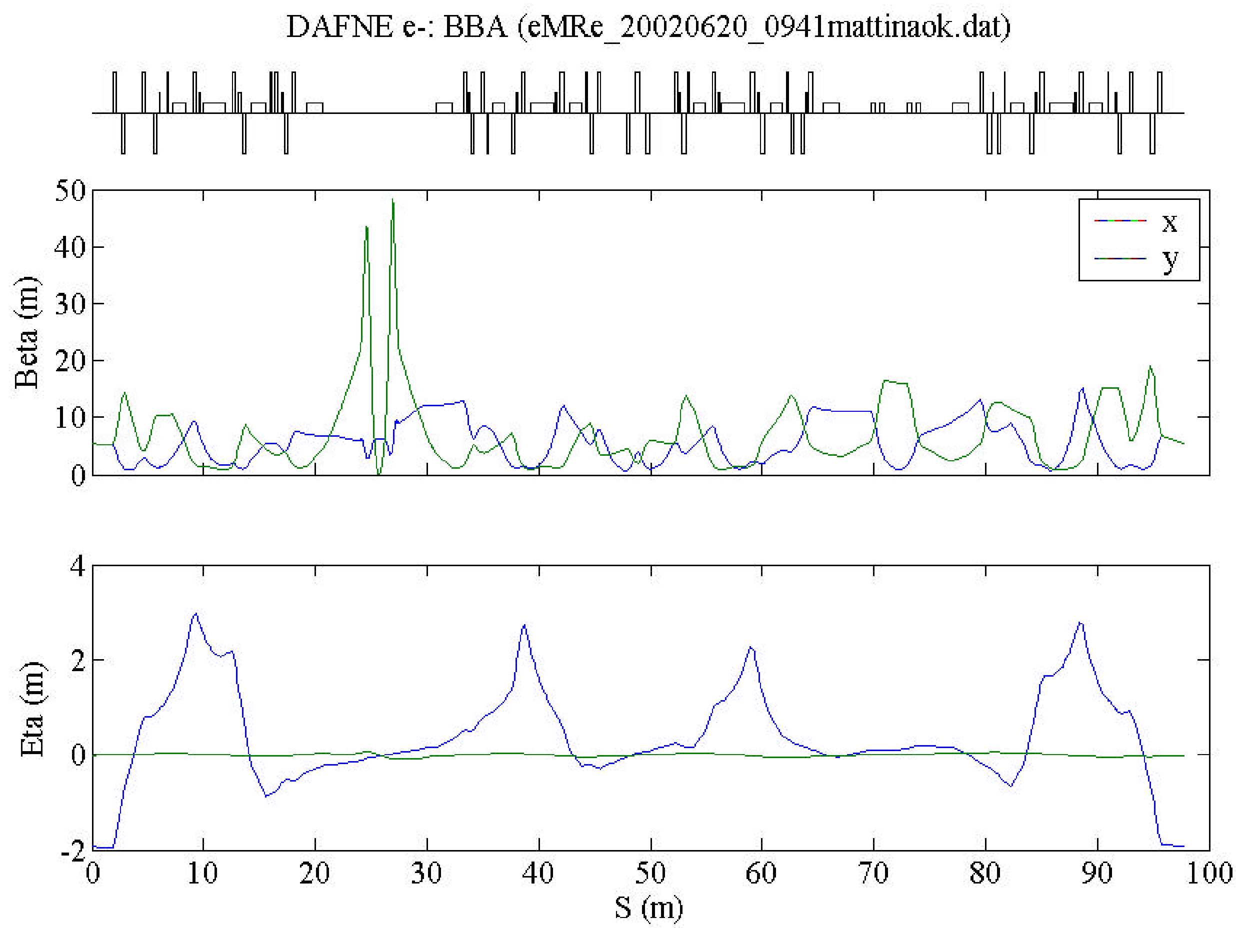


DAFNE e+: vertical BBA data of 18-JUN-2002 (single bunch, sextupoles off)
-2 amp
-1 amp
+1 amp
+2 amp
reference orbit - quadrupole offset (mm)
7
6
5
4
3
2
1
0
-1
-2
QUAPL101
QUAPL102
QUAPL103
QUAPL104
QUAPL105
QUAPL106
QUAPL107
QUAPL108
QUAPL109
QUAPL110
QUAPS101
QUAPS102
QUAPS103
QUAPS104
QUAPS105
QUAPS106
QUAPS107
QUAPS108
QUAPS109
QUAPS110
QUAPS201
QUAPS202
QUAPS203
QUAPS204
QUAPS205
QUAPS206
QUAPS207
QUAPS208
QUAPS209
QUAI2007
QUAI2006
QUAI2002
QUAI2001
QUAPL201
QUAPL202
QUAPL203
QUAPL204
QUAPL205
QUAPL206
QUAPL207
QUAPL208
QUAPL209
QUAPL210


DAFNE e+: BBA data of 18-JUN-2002 (single bunch, sextupoles off)
BBA offsets
reference orbit
X (mm)
S (m)
15
10
5
0
-5
-10
-15
0
10
20
30
40
50
60
70
80
90
100

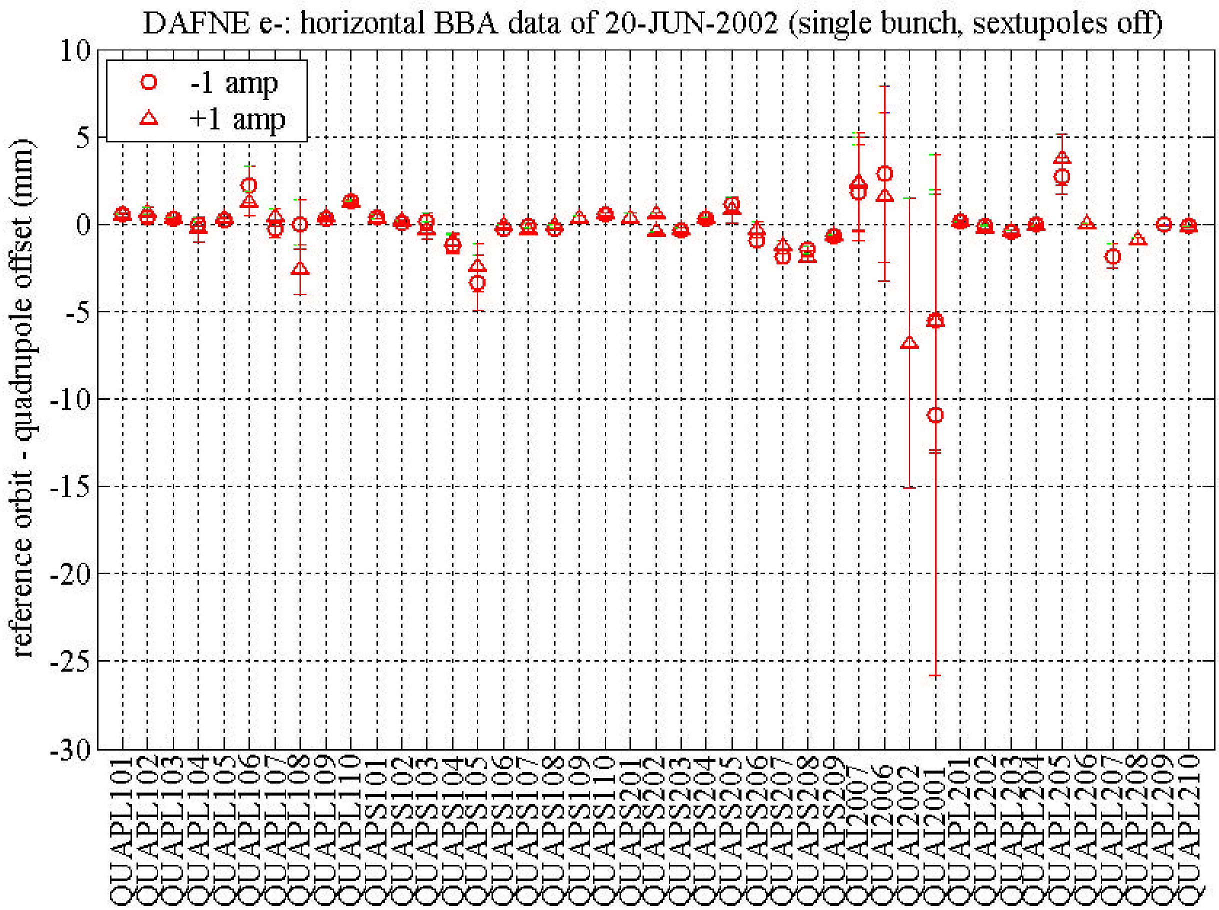

DAFNE e+: BBA data of 18-JUN-2002 (single bunch, sextupoles off)
BBA offsets
reference orbit
Y (mm)
S (m)
12
10
8
6
4
2
0
-2
-4
-6
0
10
20
30
40
50
60
70
80
90
100

e- BBA data analysis



Notes:

- e- ring, single bunch (?), single beam (?), 18-JUN-2002 data, ±1 amp (?)
- KLOE optics
- electromagnetic sextupoles OFF
- coupled model with wiggler sextupole & octupole


DAFNE e-: horizontal BBA data of 20-JUN-2002 (single bunch, sextupoles off)
-1 amp
+1 amp
reference orbit - quadrupole offset (mm)
10
5
0
-5
-10
-15
-20
-25
-30
QUAPL101
QUAPL102
QUAPL103
QUAPL104
QUAPL105
QUAPL106
QUAPL107
QUAPL108
QUAPL109
QUAPL110
QUAPS101
QUAPS102
QUAPS103
QUAPS104
QUAPS105
QUAPS106
QUAPS107
QUAPS108
QUAPS109
QUAPS110
QUAPS201
QUAPS202
QUAPS203
QUAPS204
QUAPS205
QUAPS206
QUAPS207
QUAPS208
QUAPS209
QUAI2007
QUAI2006
QUAI2002
QUAI2001
QUAPL201
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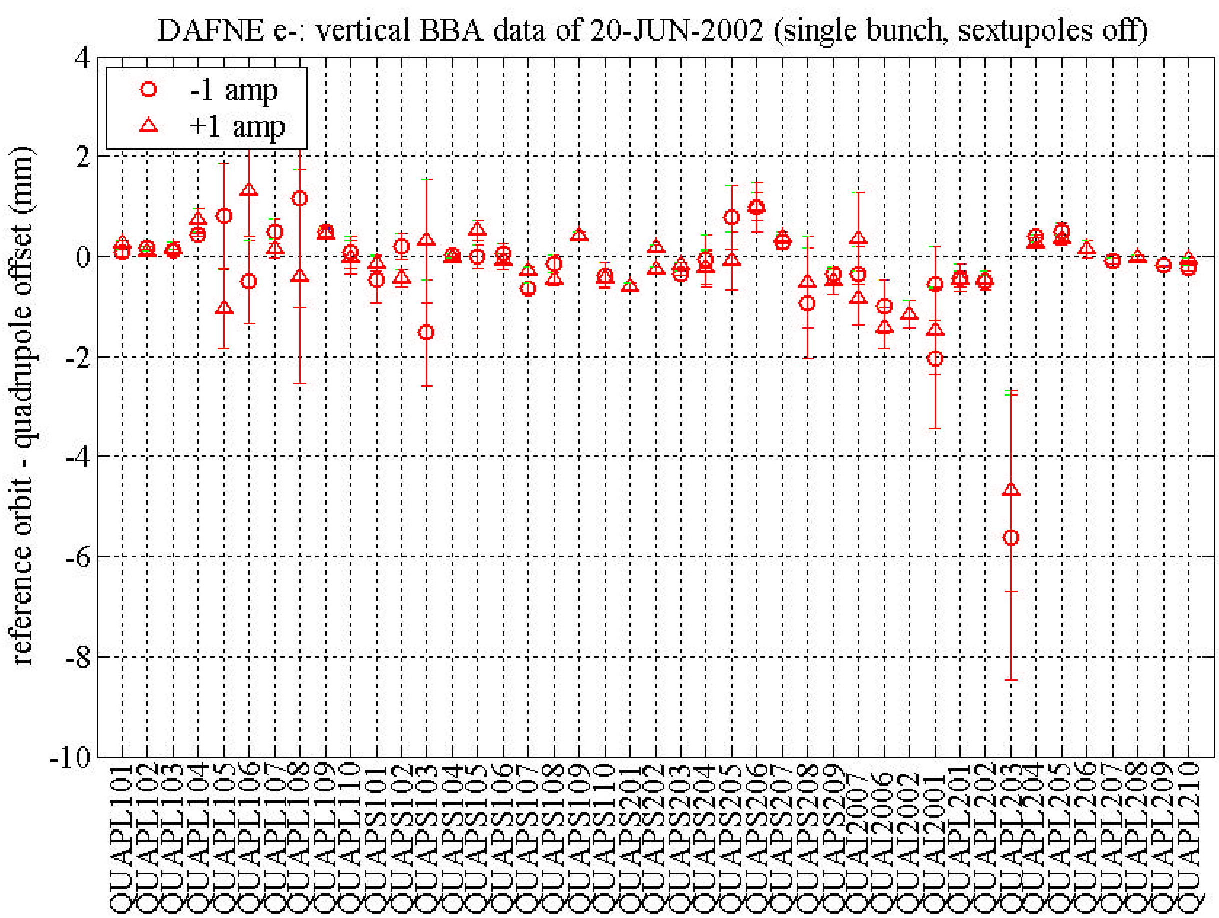
QUAPL209
QUAPL210


DAFNE e-: vertical BBA data of 20-JUN-2002 (single bunch, sextupoles off)
-1 amp
+1 amp
reference orbit - quadrupole offset (mm)
4
2
0
-2
-4
-6
-8
-10
QUAPL101
QUAPL102
QUAPL103
QUAPL104
QUAPL105
QUAPL106
QUAPL107
QUAPL108
QUAPL109
QUAPL110
QUAPS101
QUAPS102
QUAPS103
QUAPS104
QUAPS105
QUAPS106
QUAPS107
QUAPS108
QUAPS109
QUAPS110
QUAPS201
QUAPS202
QUAPS203
QUAPS204
QUAPS205
QUAPS206
QUAPS207
QUAPS208
QUAPS209
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QUAI2006
QUAI2002
QUAI2001
QUAPL201
QUAPL202
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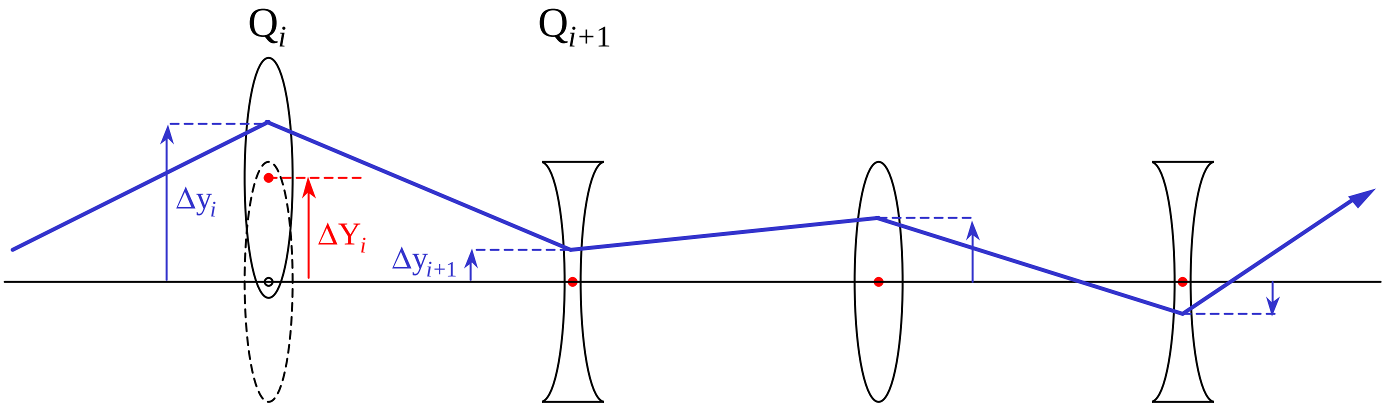
QUAPL209
QUAPL210

Determining Absolute Quad Offsets (?)



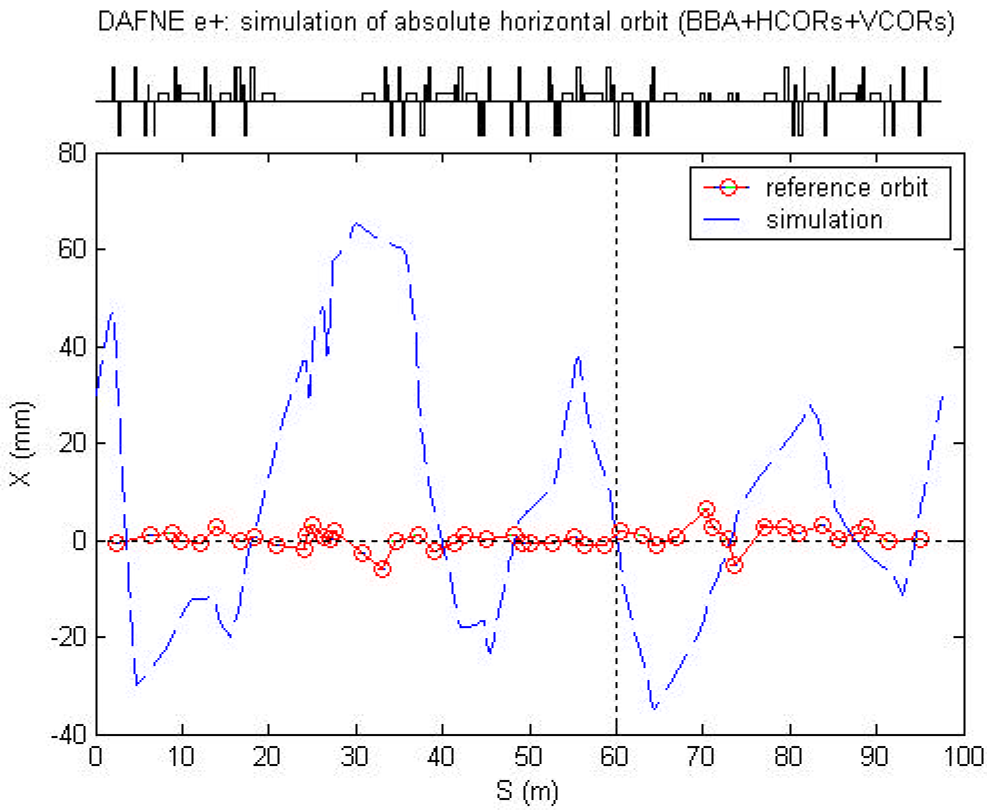
1. Start with a model that has no quad offsets and zero corrector strengths
2. Form the response matrix: $$\begin{pmatrix} \Delta y_1 - \Delta Y_1 \\ \Delta y_2 - \Delta Y_2 \\ \vdots \\ \Delta y_N - \Delta Y_N \end{pmatrix} = M_{i,j} \begin{pmatrix} \Delta Y_1 \\ \Delta Y_2 \\ \vdots \\ \Delta Y_N \end{pmatrix}$$
   M_{ij} gives the directed distance from the center of the i^{th} quad to the beam due to a unit offset of the j^{th} quad
3. Increase corrector strengths by 10% of their full values and get y_c at each quad
4. Subtract the BBA measured quad-to-beam offsets from y_c and apply the inverse of M to the difference in order to get additional incremental quad offsets:
$$M_{i,j}^{-1} \begin{pmatrix} y_{c_1} - \Delta Y_1 \\ y_{c_2} - \Delta Y_2 \\ \vdots \\ y_{c_N} - \Delta Y_N \end{pmatrix} = \begin{pmatrix} dY_1 \\ dY_2 \\ \vdots \\ dY_N \end{pmatrix} , \quad \begin{pmatrix} \Delta Y_1 \\ \Delta Y_2 \\ \vdots \\ \Delta Y_N \end{pmatrix} \Rightarrow \begin{pmatrix} \Delta Y + dY_1 \\ \Delta Y_2 + dY_2 \\ \vdots \\ \Delta Y_N + dY_N \end{pmatrix}$$
5. Increment 3 and 4 until correctors are at full strength and quad-to-beam offsets are as measured by BBA

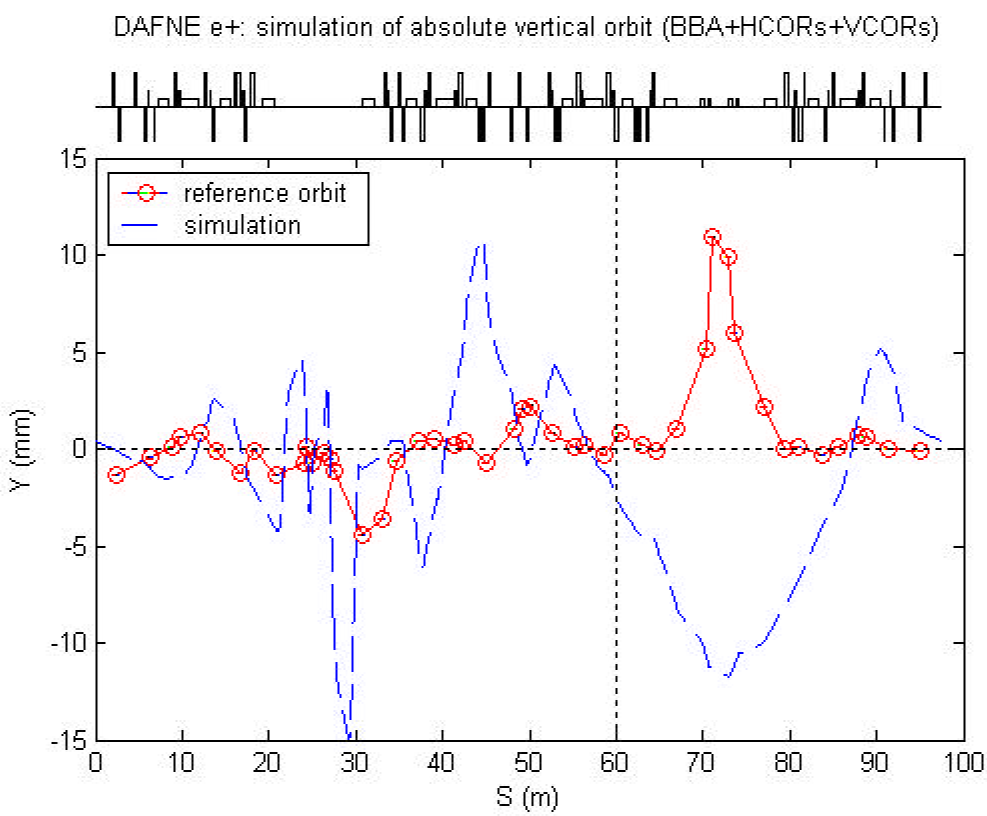
thanks to Andrzej Wolski …

Assumptions and Unknowns in Determining Absolute Quad Offsets

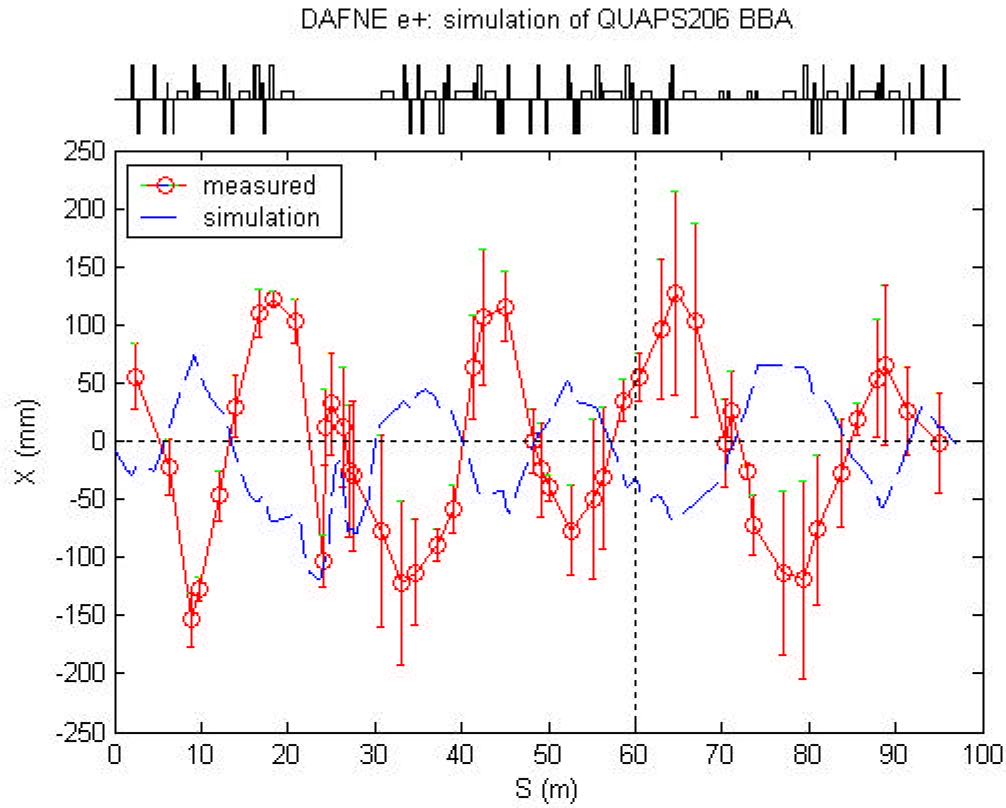
- need to model *all* kicks: correctors, BBA for all quads (we have data for 25 of 43 quads or ~60%)
- BBA data must be accurate (+ΔI and –ΔI for consistency check is good)
- corrector strengths must be accurate
- electrical/mechanical offsets in BPMs should be small
- non-linearities should be small

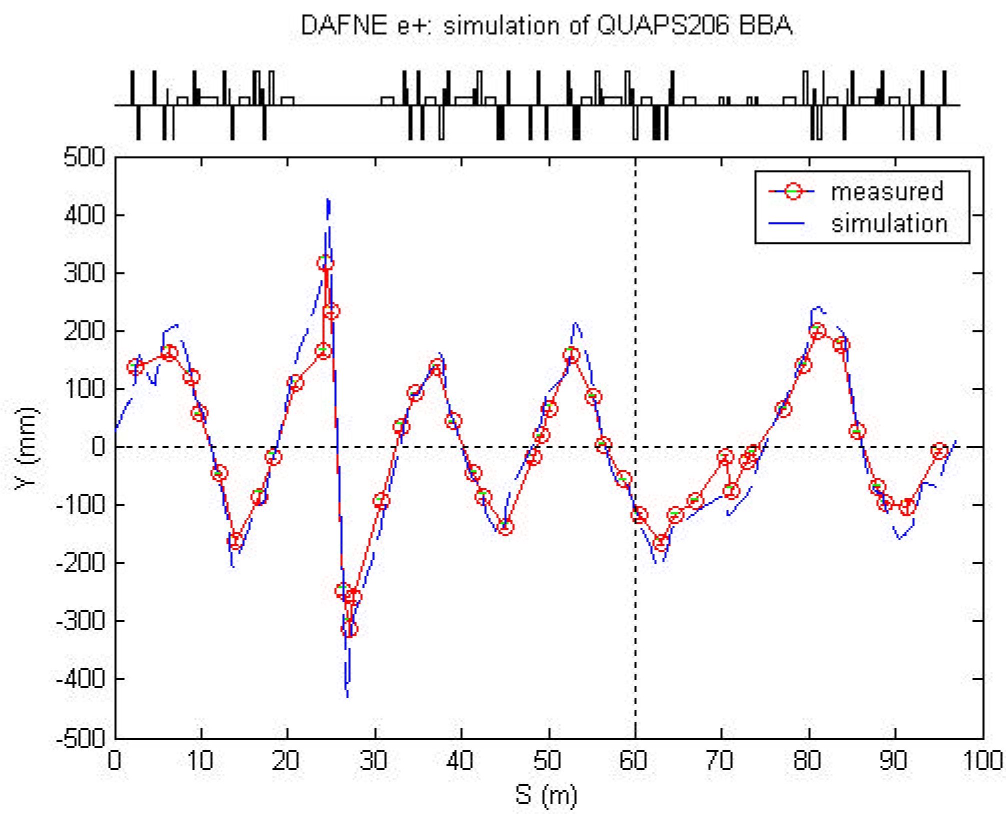
Absolute Orbits (coupled model)



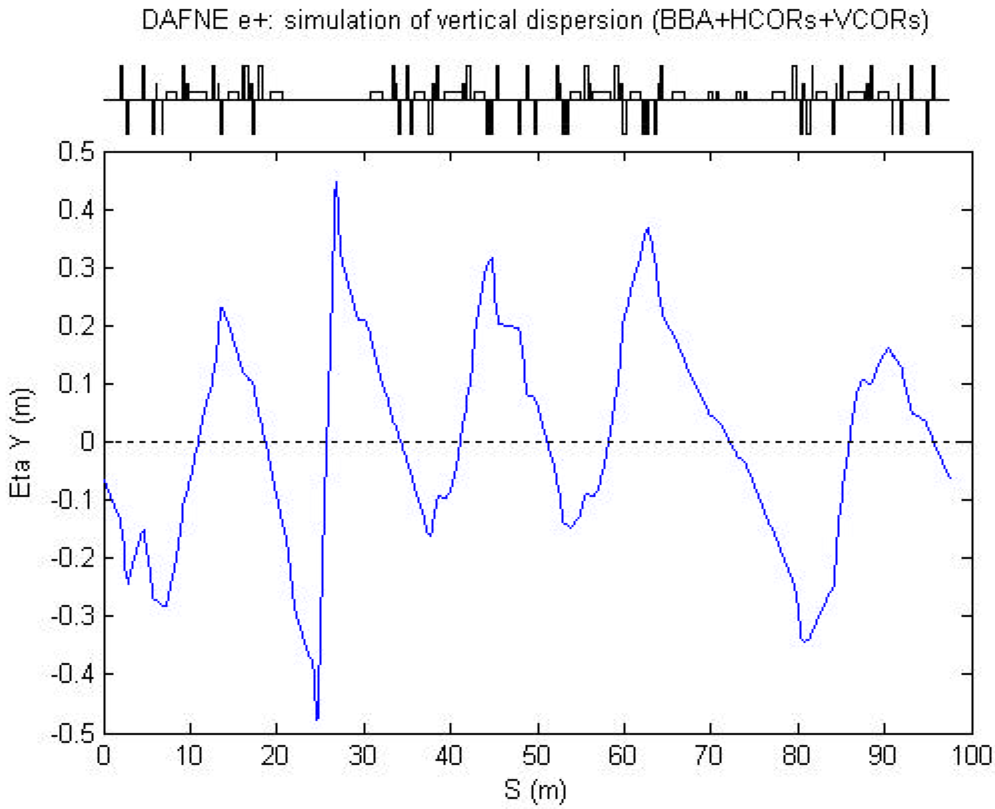


QUAPS206 BBA (coupled model)





Simulated Vertical Dispersion



Note:

- coupled model
- electromagnetic sextupoles and octupoles OFF
- no sextupole or octupole components in wigglers

A Few Words About …

- sextupole BBA … next time!
- septum bump coupling (~10% observed) … sorry, not analyzed yet!
- coupled vs uncoupled lattices … for KLOE optics not much difference seen in models

Final Thoughts …

- Special thanks to Pina … mille grazie!
- DAΦNE Accelerator Physicists and Operations staff sono amichevoli e molto professionisti!
- DAΦNE is molto divertimente!
- Frascati is molto bella!
- Rome is meravigliosa!
- Italy has been indimenticabile!

Mi sono divertito proprio …
grazie di tutto!