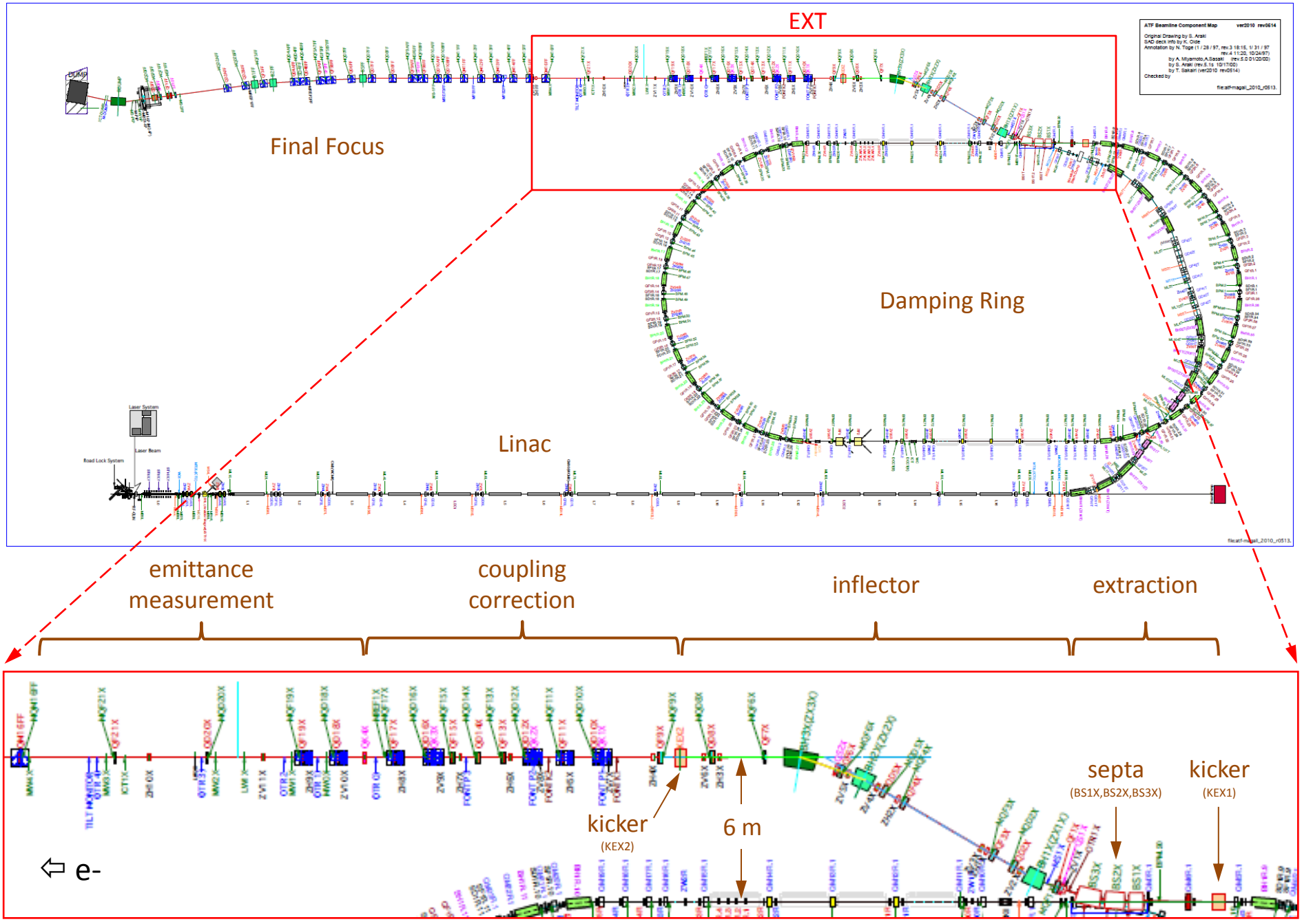
Kicker Optics
– or –
Selected ATF-II EXT Line Performance Issues


EXT
Final Focus
Damping Ring
Linac
emittance measurement
coupling correction
inflector
extraction
kicker (KEX2)
6 m
septa (BS1X,BS2X,BS3X)
kicker (KEX1)
e-

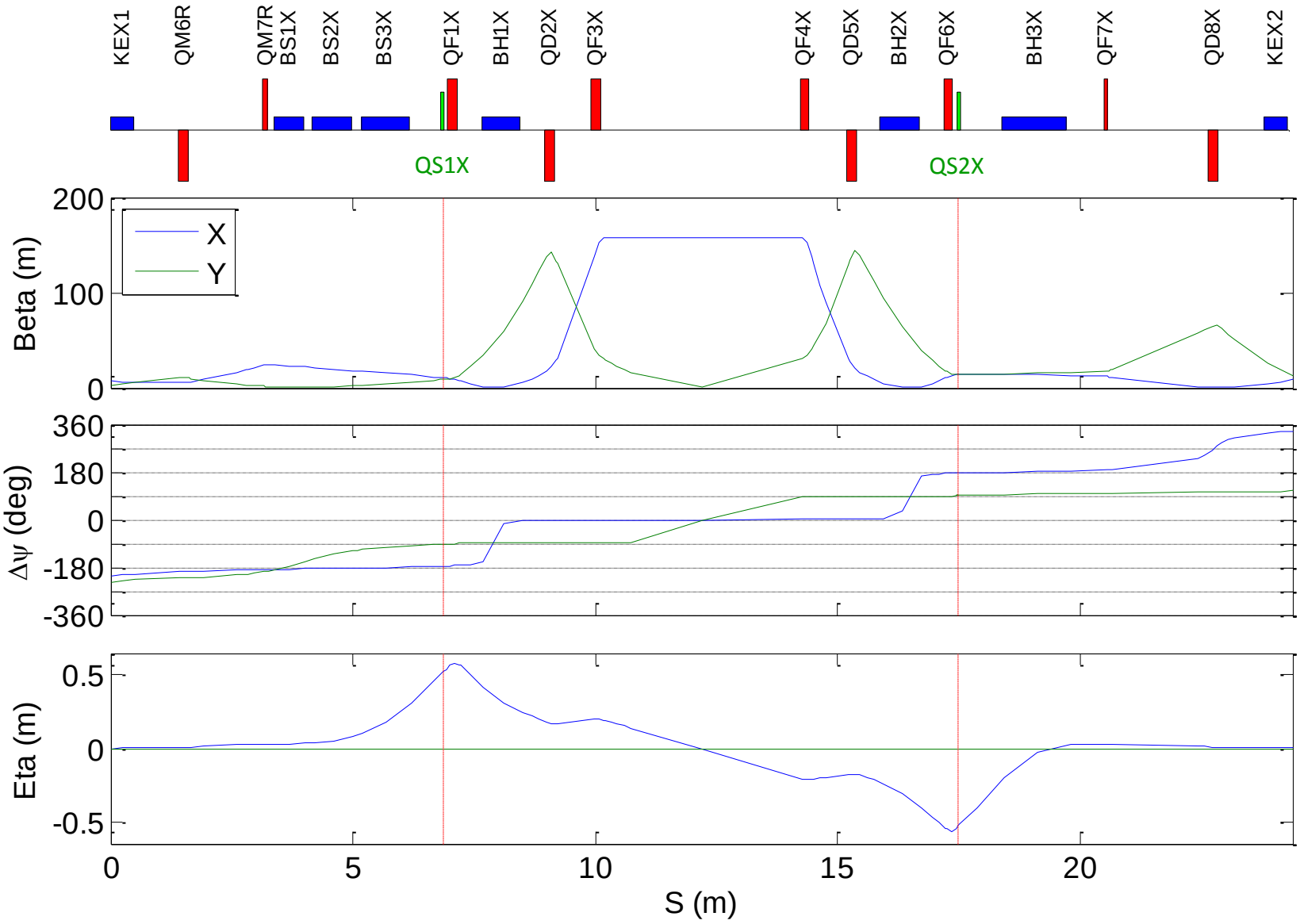
Outline

- EXT optics
- vertical dispersion correction
- emittance measurement in EXT
  - stability
  - emittance growth (DR to EXT)
  - bunch charge dependence
- coupling correction
- beta matching
- extraction kicker
  - multipole components (simulation and beam-based measurements)
- QM7R replacement
- BS3X rotation
- extraction kicker (2)
  - strength calibration
  - rotation
- BS3X skew field
- Summary

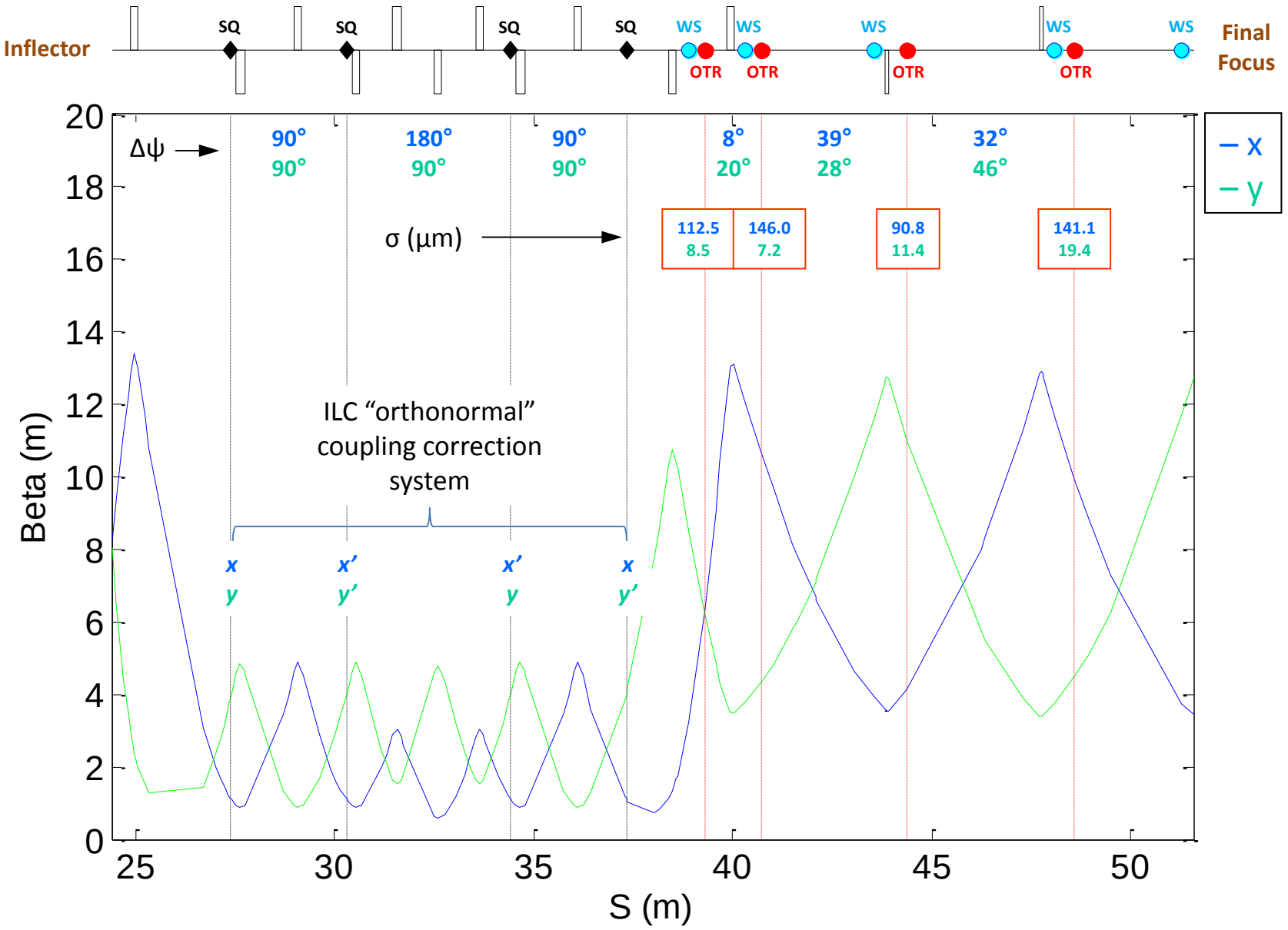
Optics

- most inflector magnets at the same phase … corrections within the inflector correct errors that originate in the inflector (single-phase corrections)
- two skew quadrupoles are included in the inflector for vertical dispersion correction
  - "sum" mode (Σ-knob) generates vertical dispersion (no coupling)
  - "difference" mode (Δ-knob) generates coupling (no vertical dispersion)
- coupling correction section is standard ILC orthonormal system (four skew quadrupoles)
- emittance diagnostic section is a compromise due to space limitations … 2D reconstruction with beam tilts from 4 OTRs

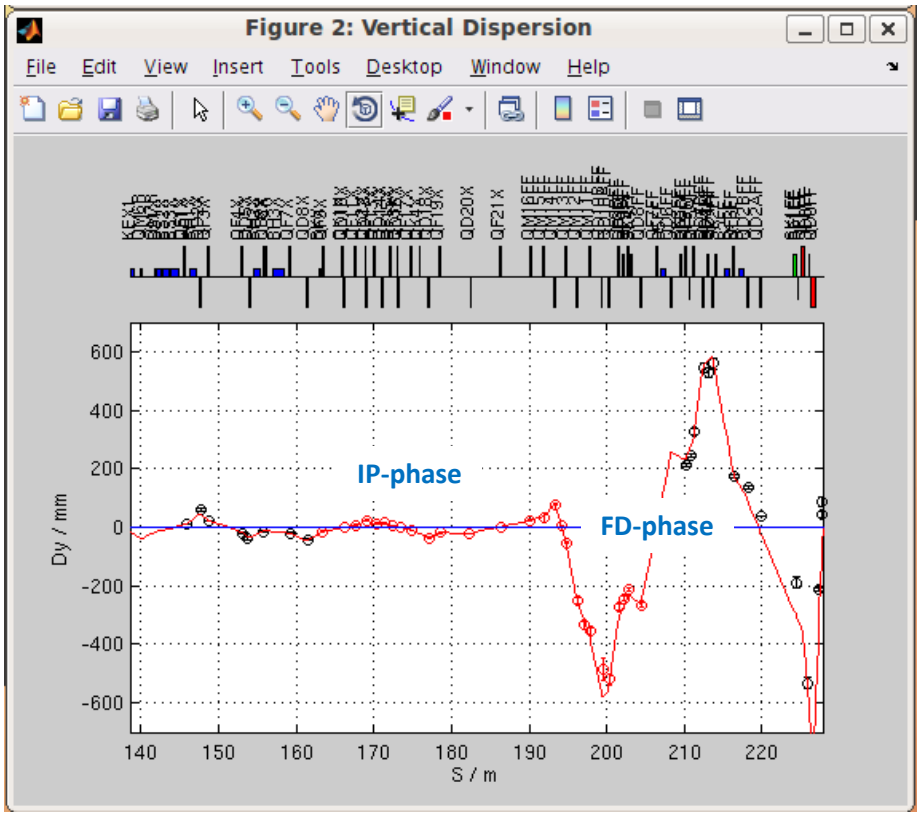
Extraction + Inflector



EXT Coupling Correction / Emittance Diagnostic Section

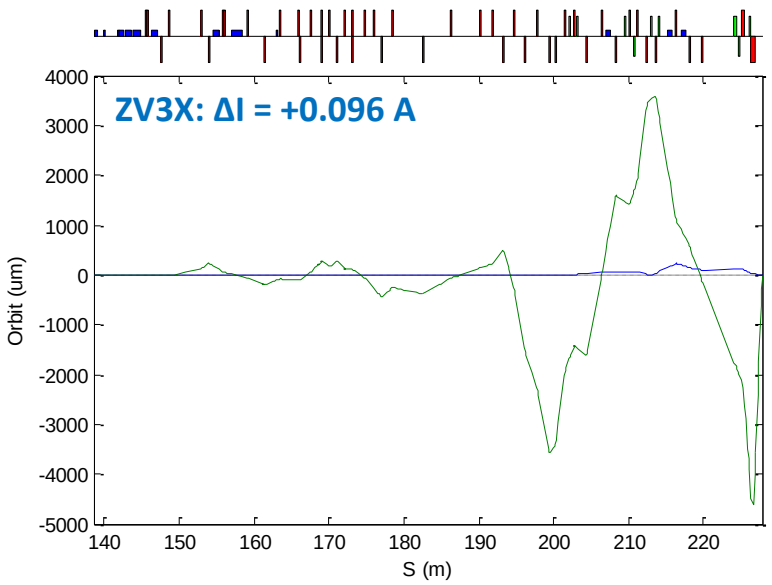


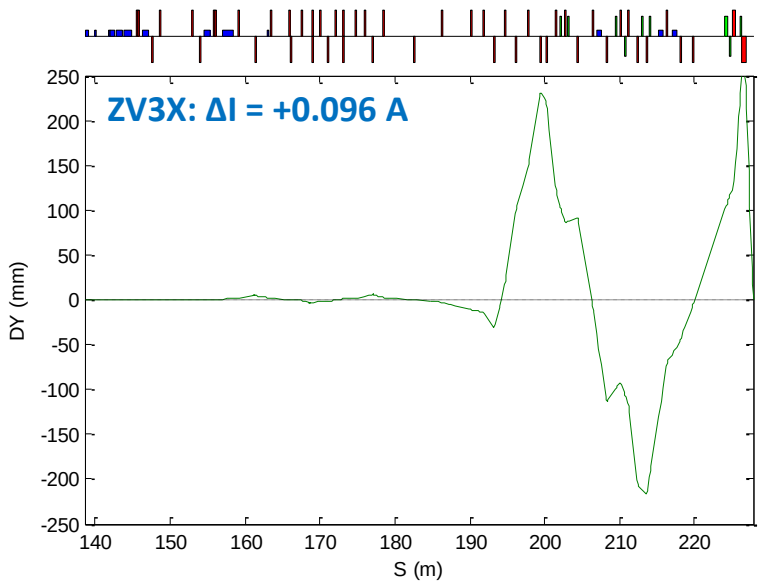
Vertical Dispersion Correction

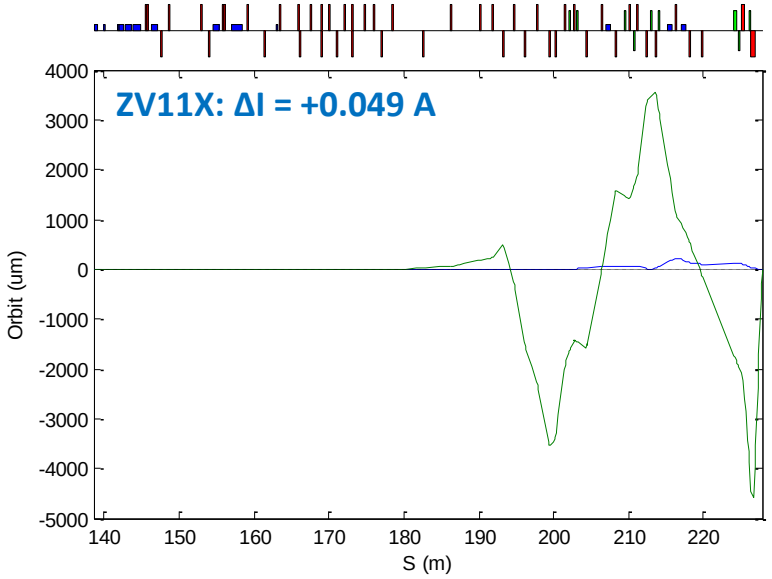


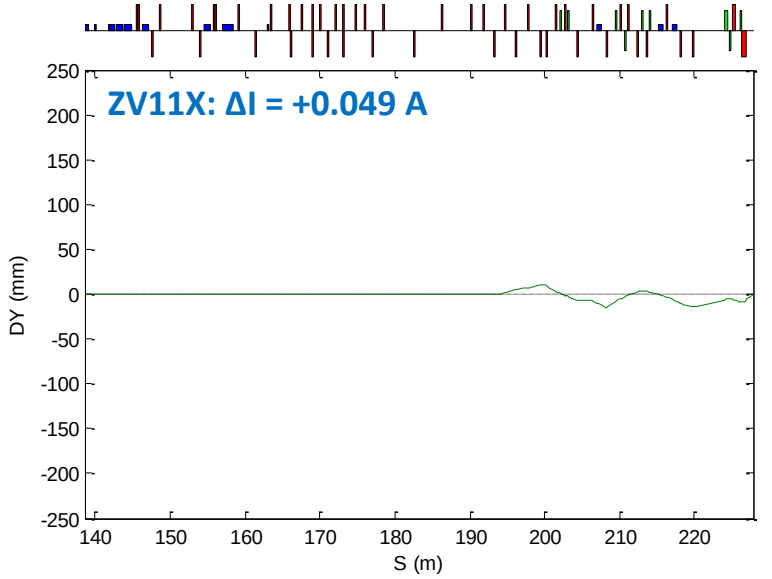
- best emittance measurements when η_y at OTRs is small (millimeter-ish)
- can't correct η_y at EXT OTRs (IP-phase) and in FF (FD-phase) simultaneously using the QS Σ-knob
- presence of KEX2 prevented use of vertical dipole correctors for η_y correction
  - emittance growth due to sextupole component when off axis vertically
  - KEX2 is now gone (using BKX dipole instead) … more later
- now use both QS Σ-knob and vertical dipole correctors for vertical dispersion correction
- see Okugi-san's talk this afternoon for updates …

Simulation


ZV3X: ΔI = +0.096 A
Orbit (um)
S (m)

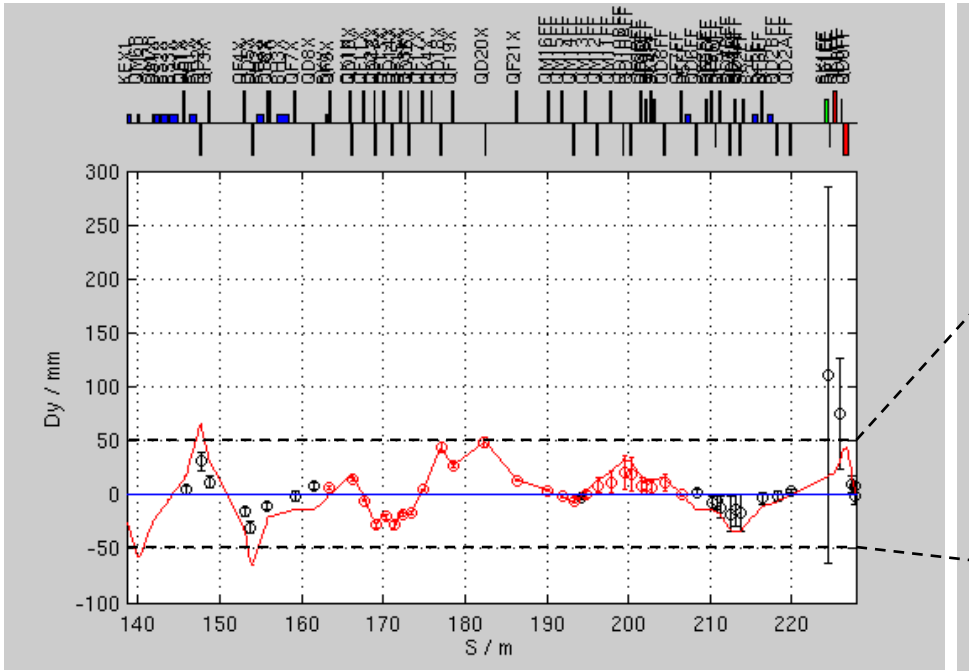

ZV3X: ΔI = +0.096 A
DY (mm)
S (m)


ZV11X: ΔI = +0.049 A
Orbit (um)
S (m)

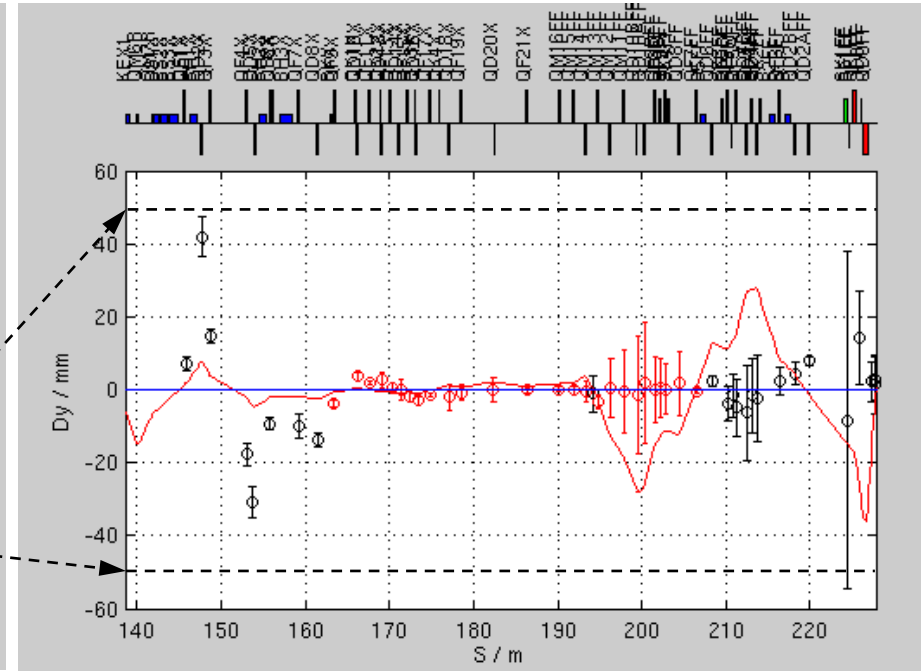

ZV11X: ΔI = +0.049 A
DY (mm)
S (m)

Monday Day Shift, December 17, 2012

after QS Σ-knob only FD-phase correction



after QS Σ-knob + ZV correction



QS*X : -1.050 A ⇨ -0.113 A (ΔI = +0.937 A) … correct IP-phase η_y

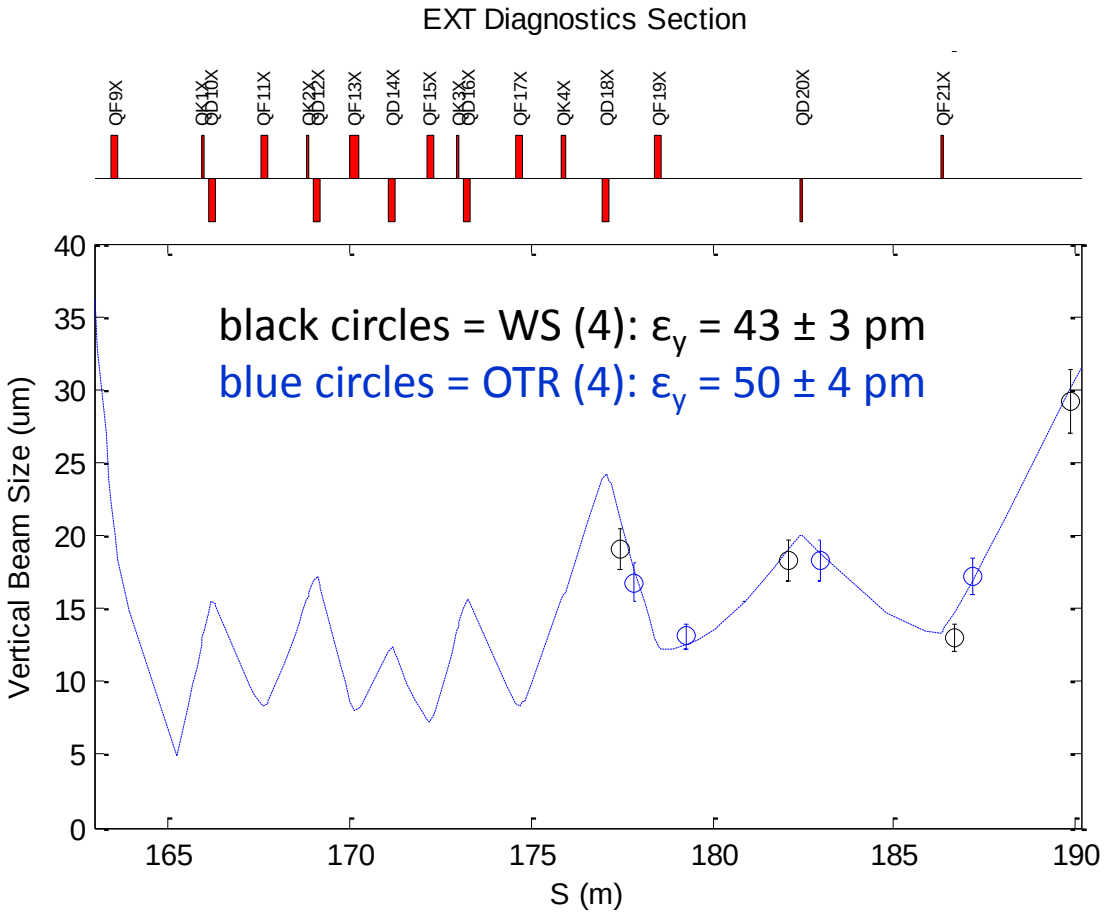
ZV3X : +0.172 A ⇨ +0.047 A (ΔI = -0.125 A) … correct FD-phase η_y

ZV11X : +0.201 A ⇨ +0.229 A (ΔI = +0.028 A) … correct FF orbit

EXT Emittance Measurements

- do we believe the OTR measurements?
- how stable/reproducible are the measurements?
- observations (DR XSR and EXT multi-OTR)
  - charge dependence

Wire Scanner / OTR Comparison



OTR Vertical Emittance Measurement

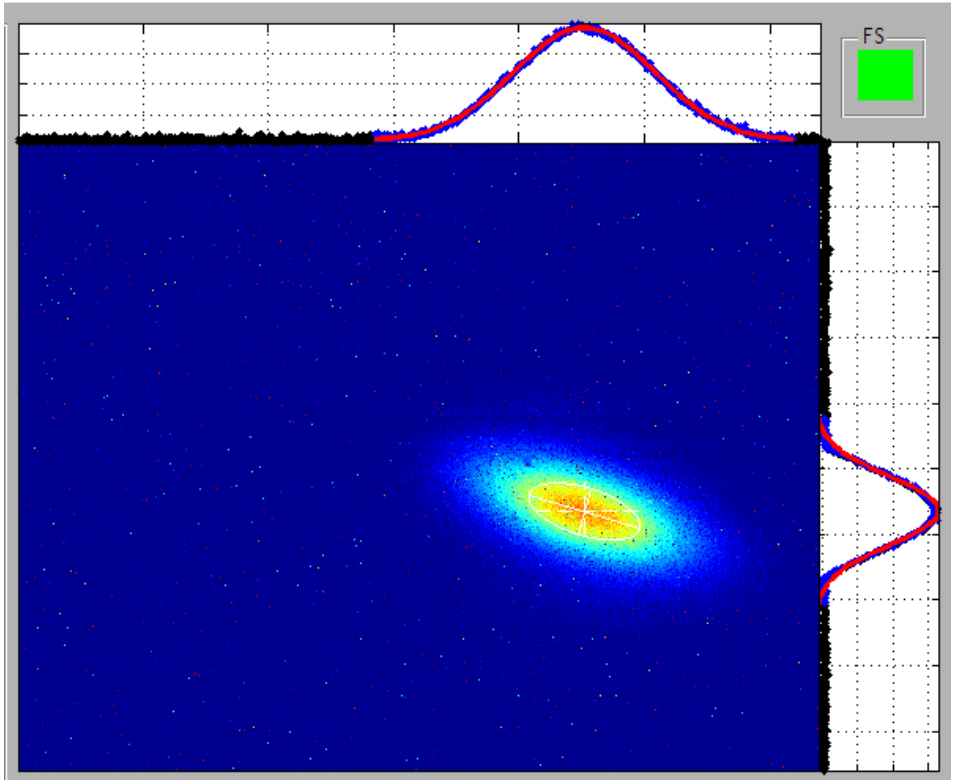
December 14, 2011 07:44

Wire Scanner Measured Vertical Beam Sizes

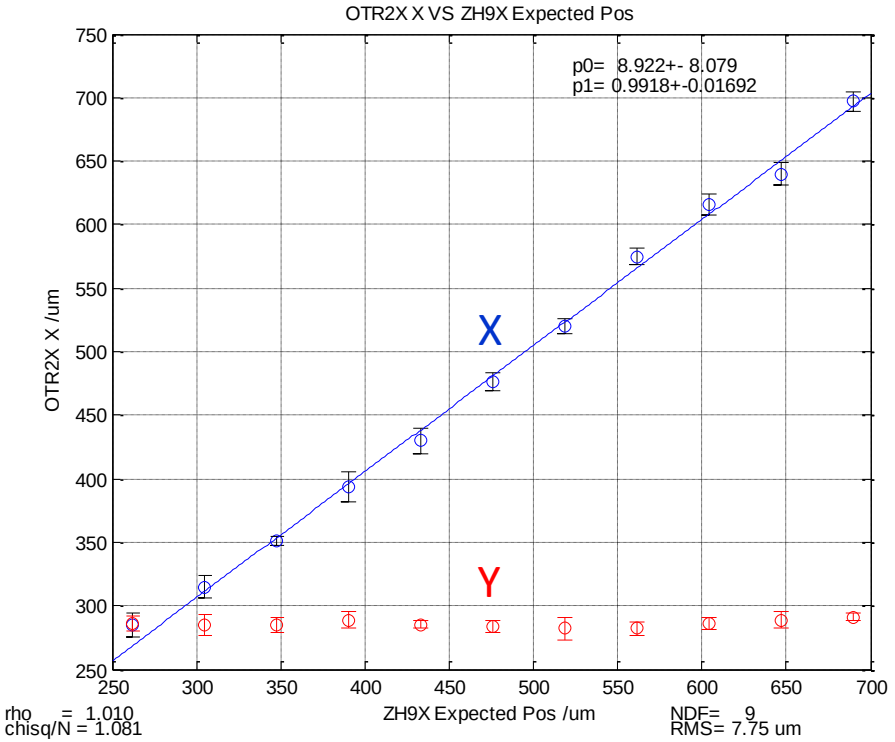
December 14, 2011 09:30

(MW1X σ_y value ignored)

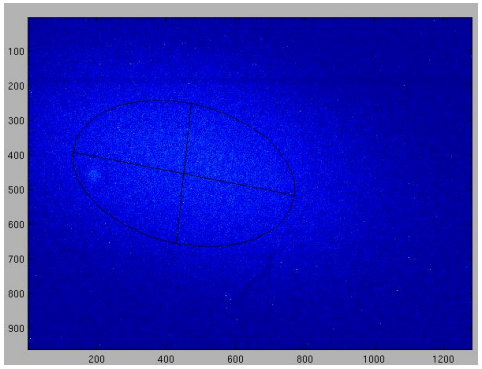
OTR2X beam tilt … is the beam rotated?



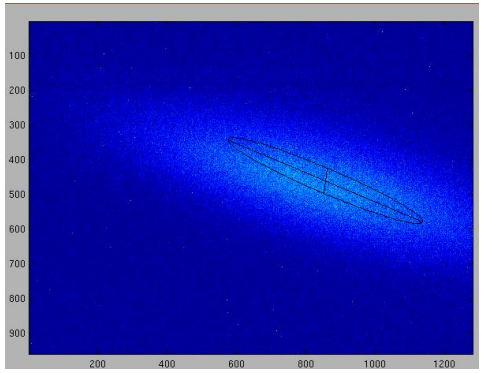
Check measured response to ZH9X



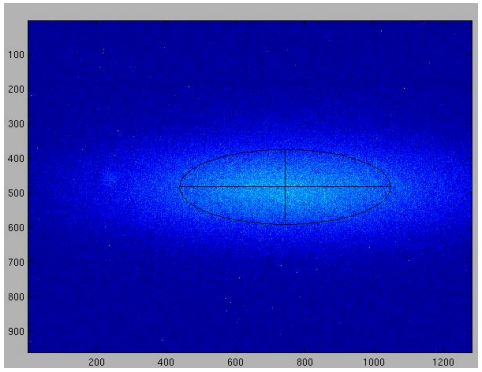
OTR0X before corrections



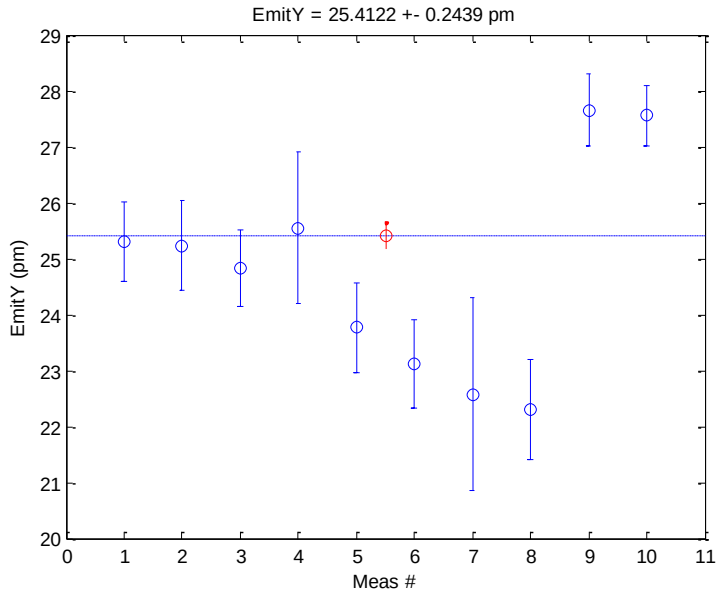
OTR0X after dispersion correction

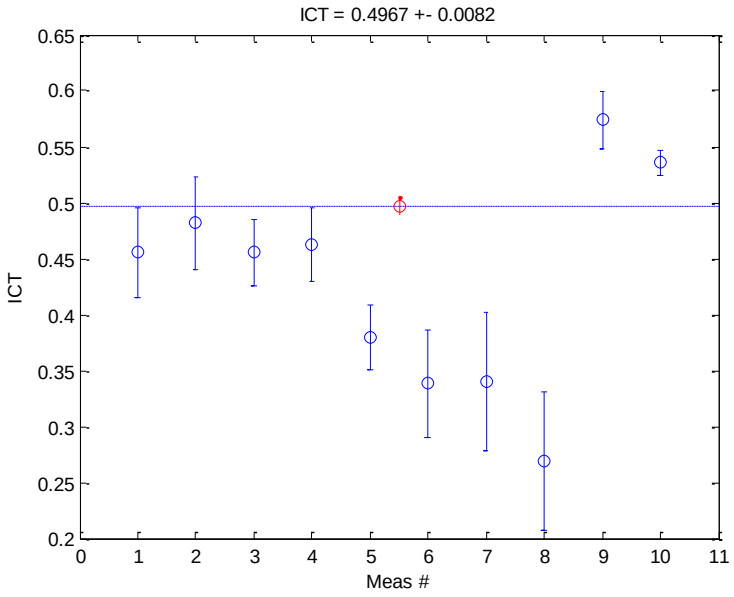


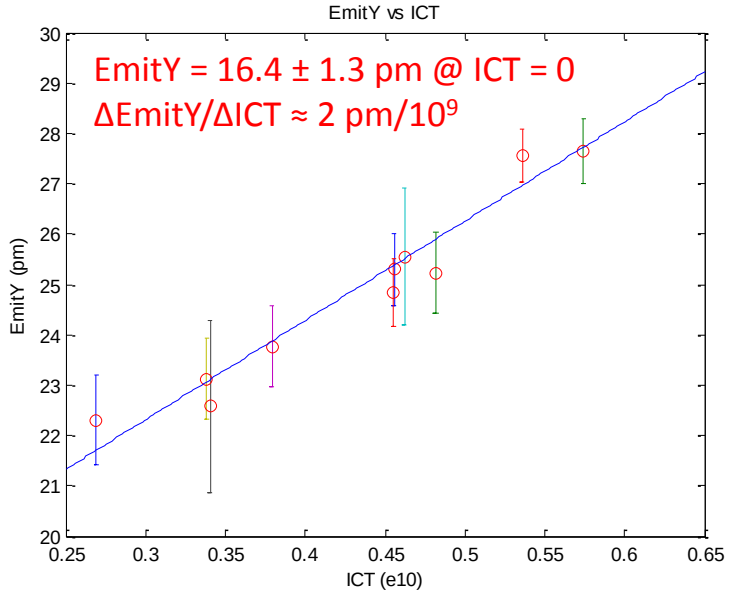
OTR0X after coupling correction

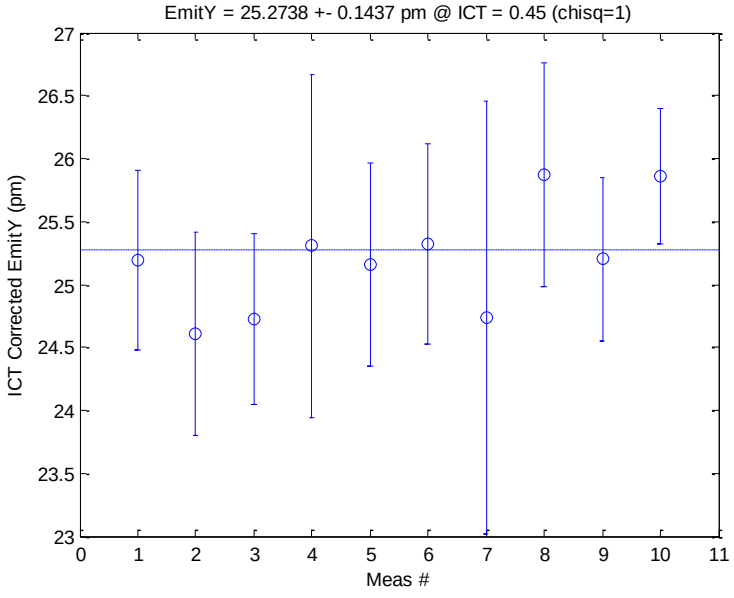


Stability: 10 Consecutive EXT Emittance Measurements (November 29, 2012 … ~30 minutes)



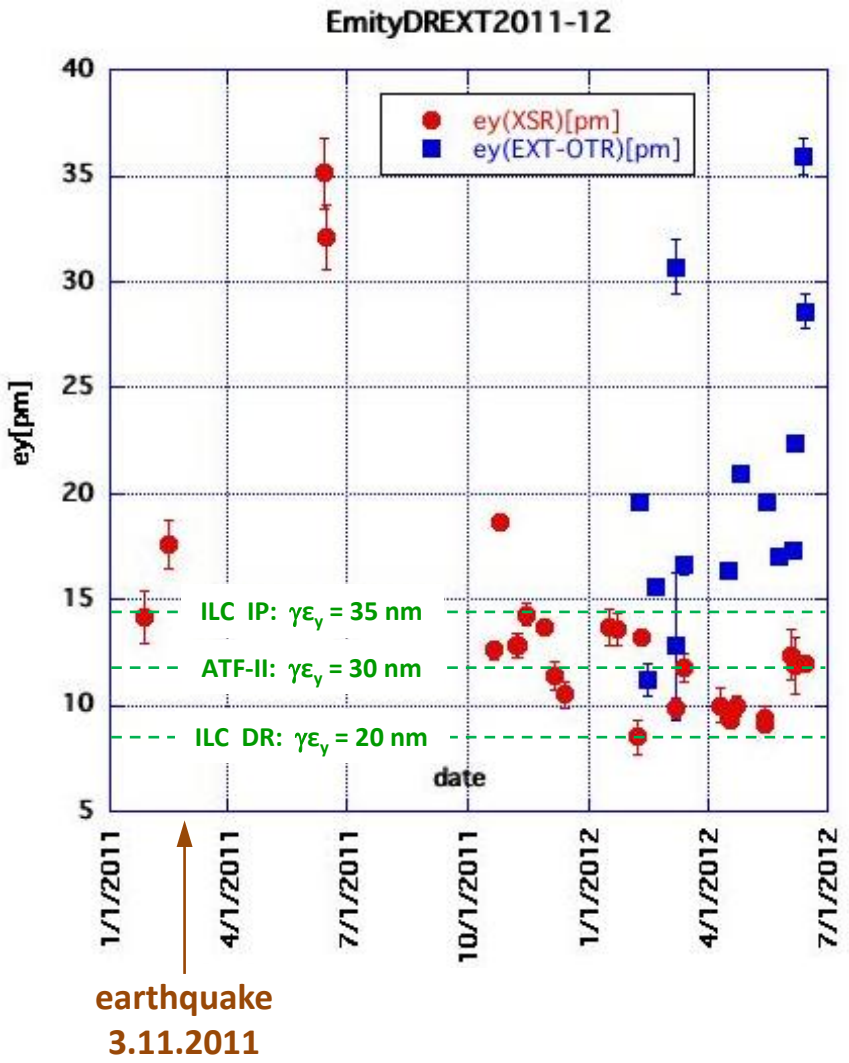






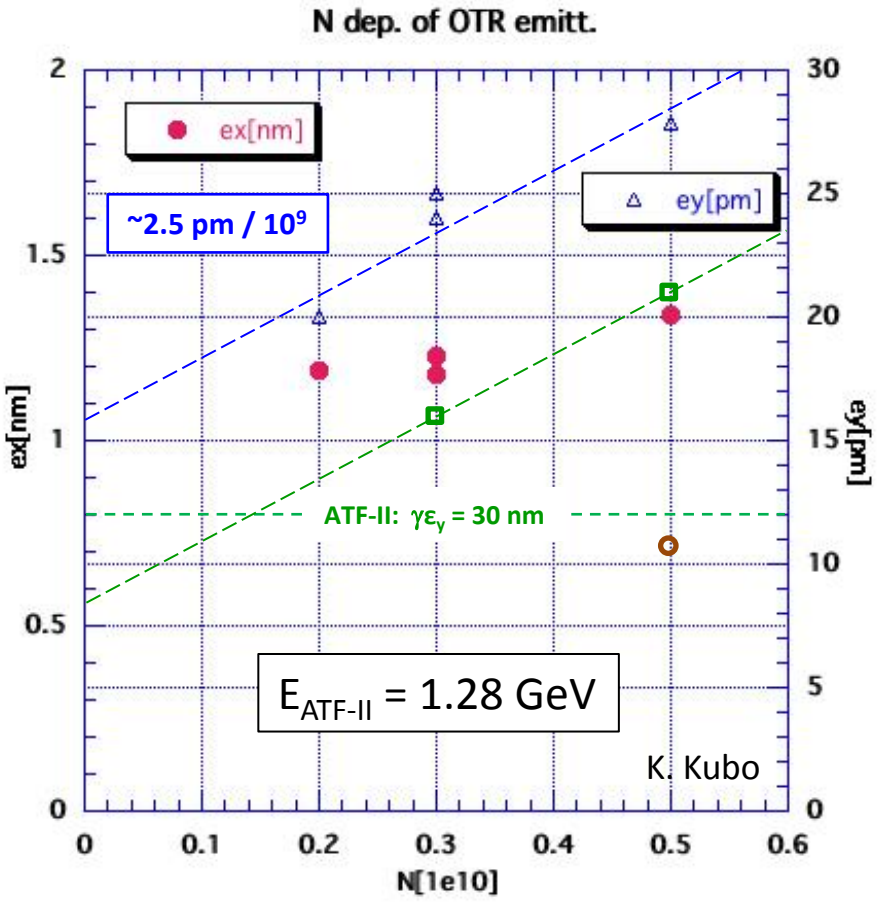
Emittance: 2011 – 2012

(S. Kuroda)



Emittance: March 2013

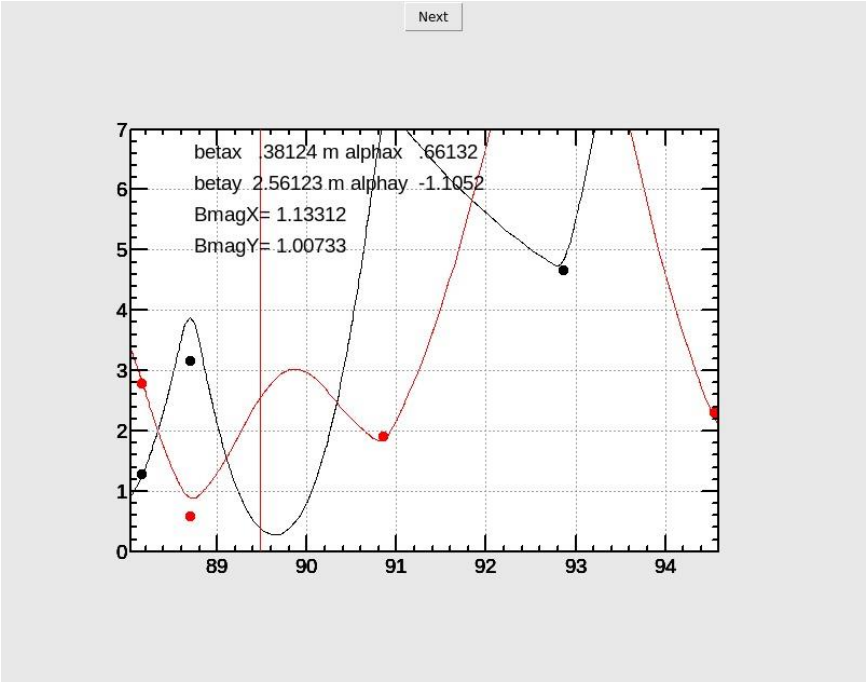
(K. Kubo, T. Okugi)



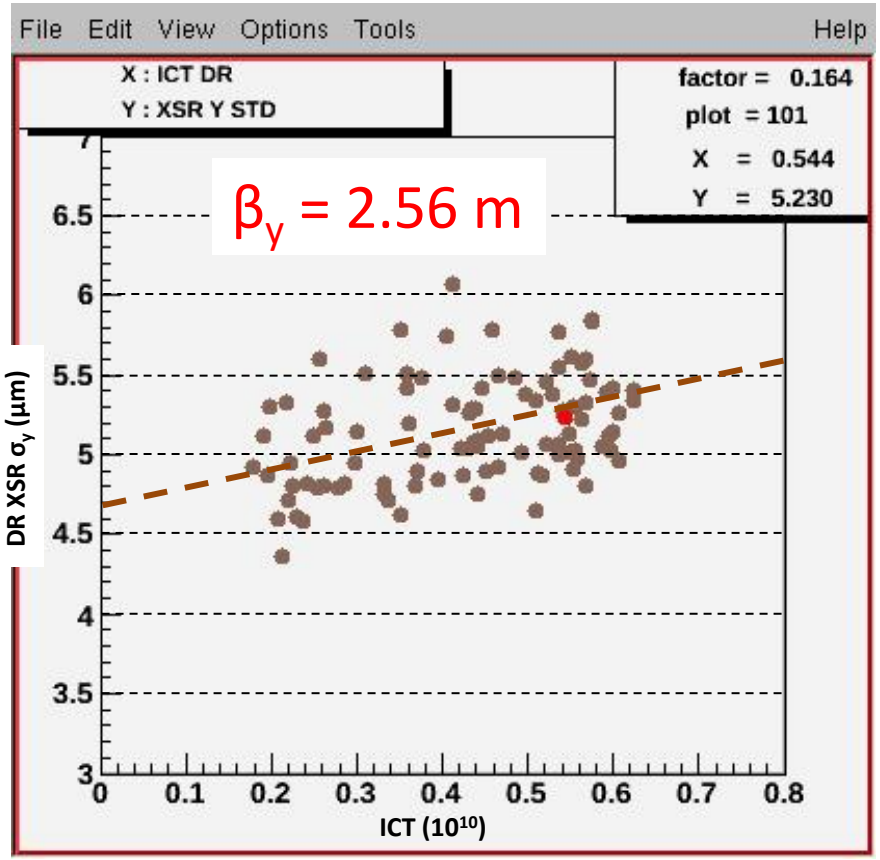
- March 12, 2013 (XSR)
- March 12, 2013 (OTR; QS Δ-knob; QKs off)
- March 15, 2013 (OTR; QS Δ-knob; QKs off)

November 6, 2012 Owl Shift

XSR source-point β_y measurement



DR XSR σ_y vs ICT



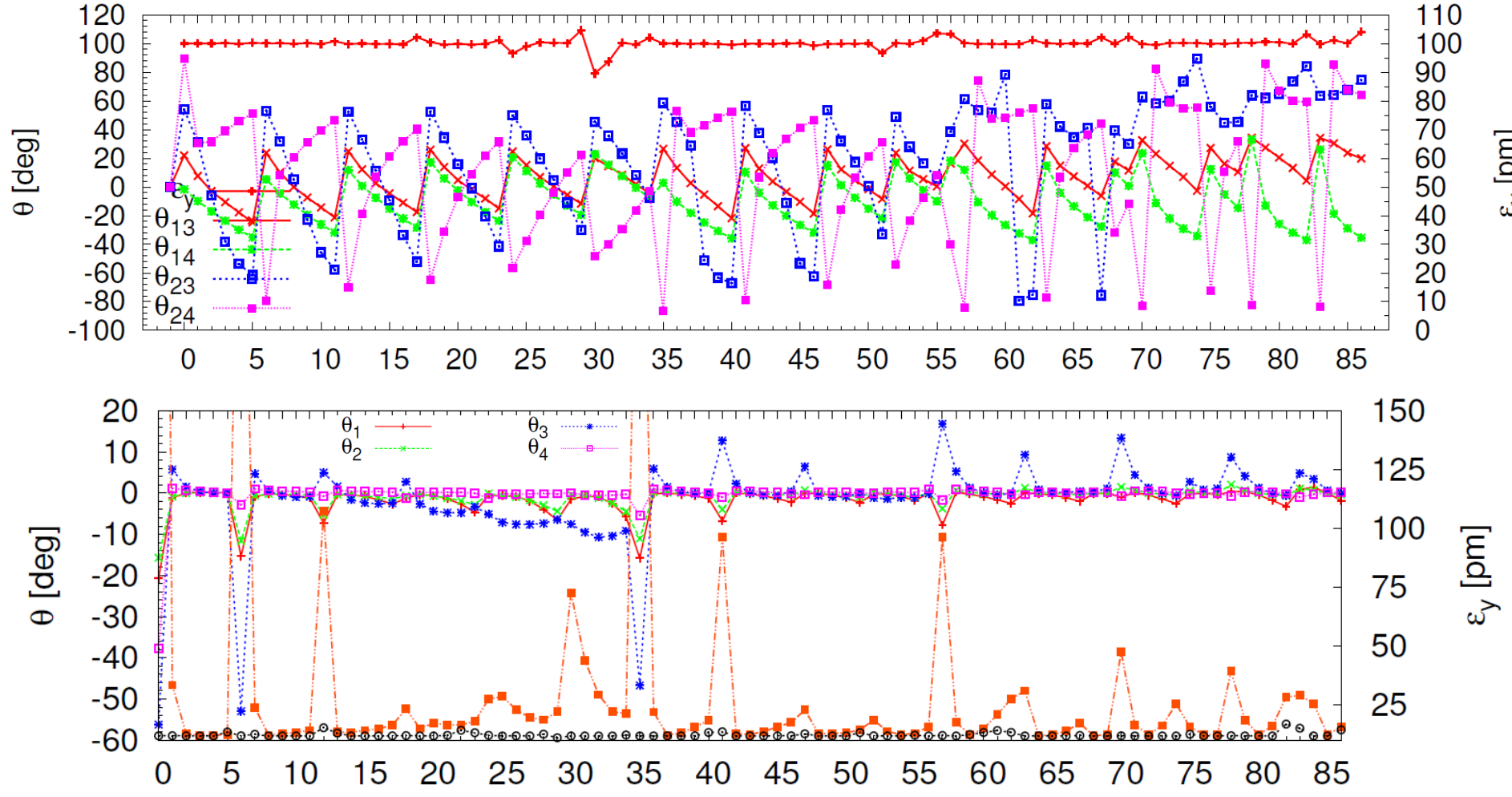
$\Delta\varepsilon_y/\Delta ICT \approx 0.6$ pm / 1e9

Coupling Correction

- given installed emittance diagnostic section, is measurement and correction of arbitrary phases of input coupling possible?
- recently (February 2013) Okugi-san had success correcting coupling at OTRs using QS1X/QS2X difference knob … see his talk this afternoon

- assume matched DR beam with ε_y = 12 pm
- add coupling at many random phases … projected ε_y = 100 pm
- correct projected ε_y two ways
  - use 4 skew quadrupoles (QKs) to correct measured beam tilt at each OTR using a modeled response matrix
  - (effectively) scan 4 QKs to minimize projected ε_y (proposed ILC method)

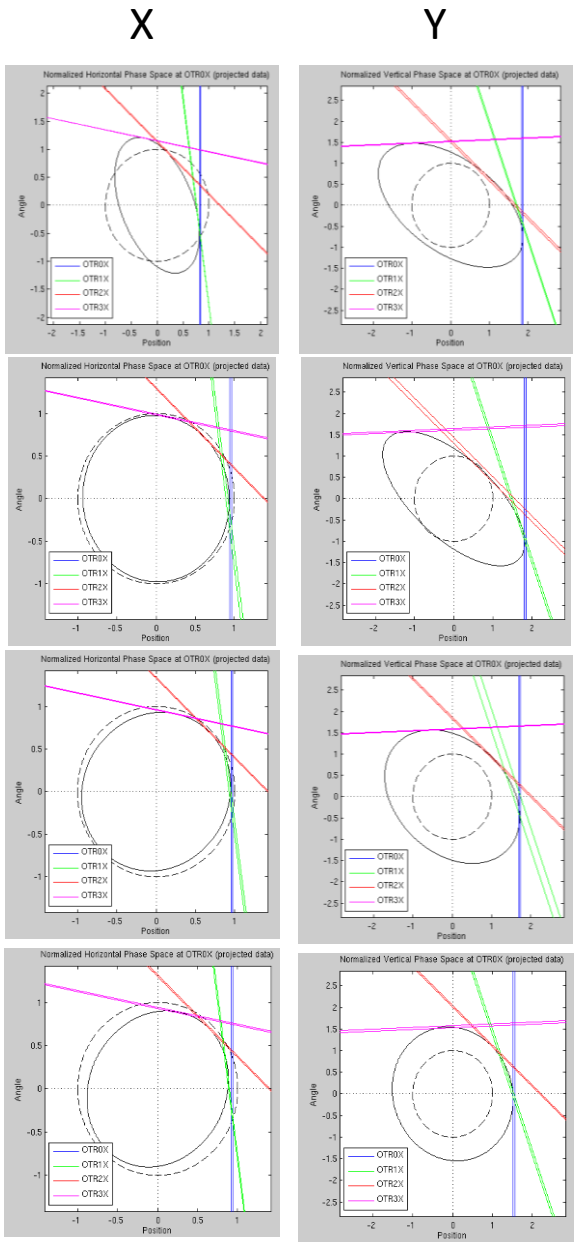
E. Marin



Beta Matching

- 6 dedicated β-matching quadrupoles are provided at the start of the Final Focus, but they are downstream of the EXT OTRs
  – used for changing β*
- β-matching now being done with EXT quadrupoles, upstream of the OTRs … beta match can easily be verified

Beta Matching (December 12 2012 owl)

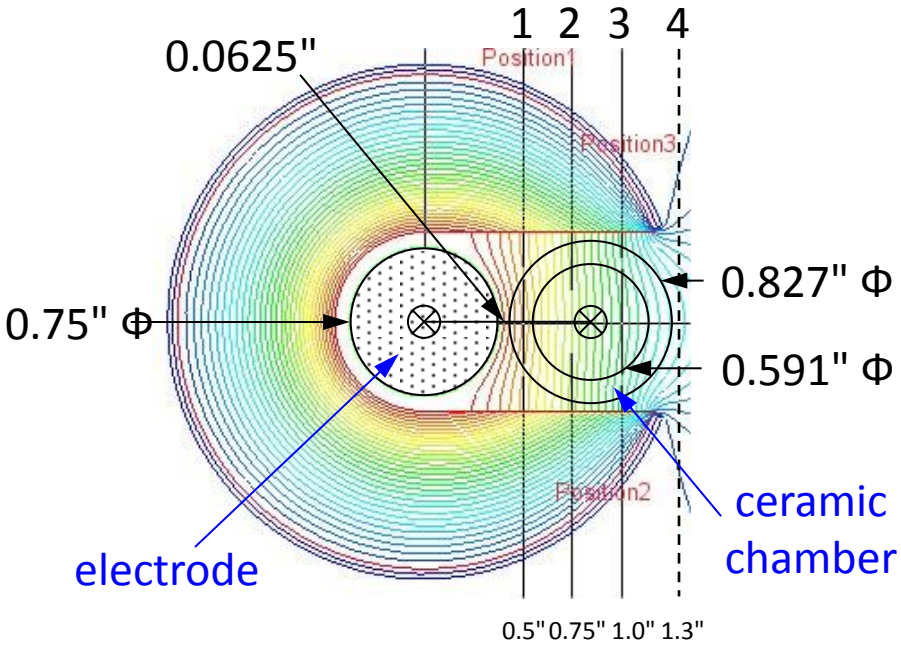


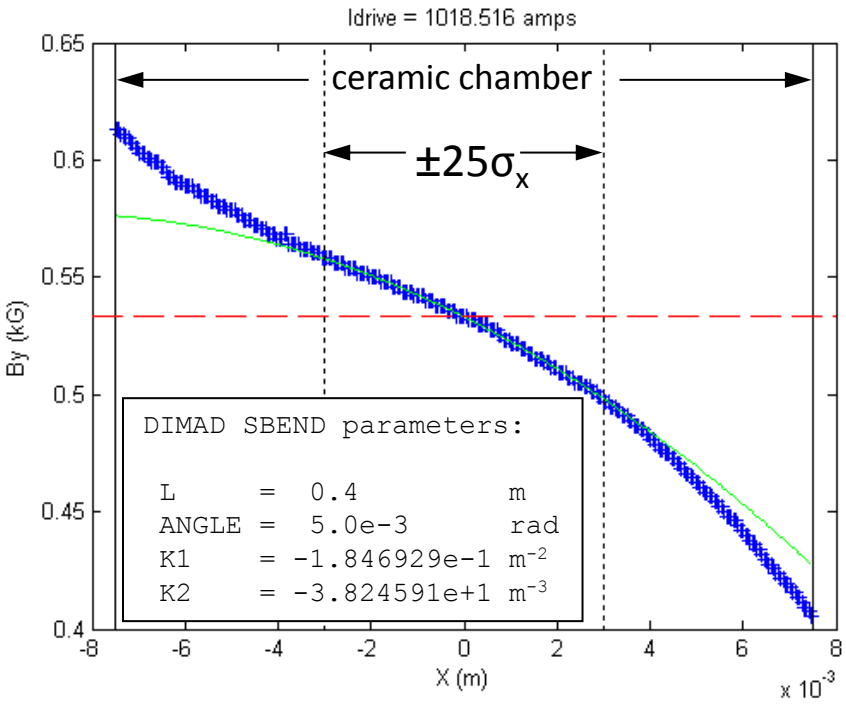
name	match0	match1	match2	match3	design
file	054152	061717	080625	084346	
EmitX	1.7894	1.8228	1.7587	1.5860	
BmagX	1.1946	1.0013	1.0026	1.0076	1.0000
EmBmX	2.1376	1.8251	1.7633	1.5981	
BetaX	4.7239	6.0386	6.4327	6.2257	6.3052
AlphaX	-2.8890	-4.2795	-4.6550	-4.5596	-4.4943
EmitY	28.4846	25.7572	30.8175	28.2300	
BmagY	1.2000	1.3489	1.0554	1.0034	1.0000
EmBmY	34.1808	34.7439	32.5253	28.3262	
BetaY	9.1308	9.4923	7.1151	6.0766	6.1903
AlphaY	4.4037	4.8369	3.2854	2.6087	2.5763
QF1X	50.682	50.947	50.812	50.812	49.024
QD2X	42.865	43.035	43.312	43.312	42.865
QF3X	30.497	30.724	30.800	30.800	30.498
QF4X	30.863	30.710	30.636	30.636	30.864
QD5X	41.940	42.083	41.995	41.995	41.940
QF6X	52.983	52.753	52.692	52.692	51.556
QF7X	54.600	54.524	57.931	57.931	54.601
QD8X	26.862	26.850	27.005	27.005	26.863
QF9X	34.701	36.133	36.027	36.027	34.702
QD10X	52.965	51.764	56.860	56.860	52.964

Extraction Kicker

- multipole fields (quadrupole/sextupole): are they real?
- 2nd kicker (KEX2) removed from beamline and replaced with a strong dipole corrector in January 2012

POISSON Field Simulation (C. Pappas, SLAC)

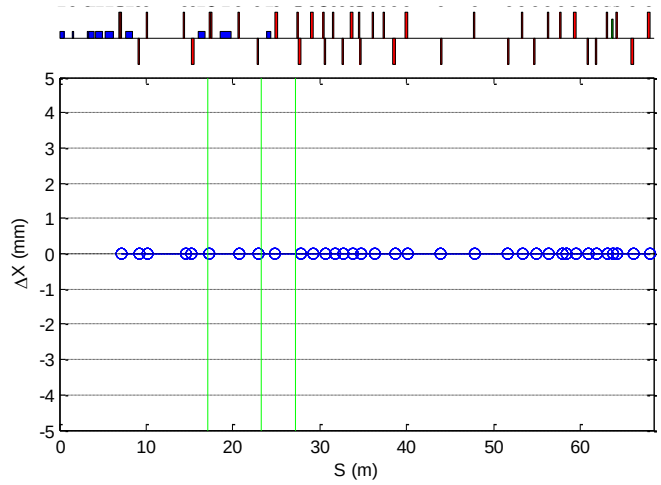


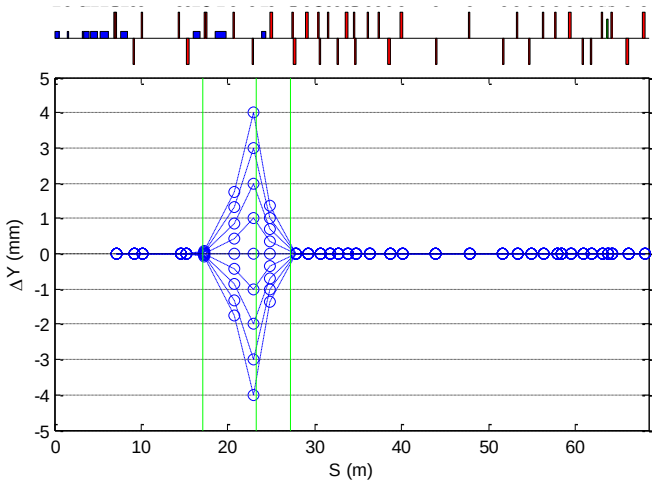


scale: 1.14" (figure) ≈ 0.75" (actual)

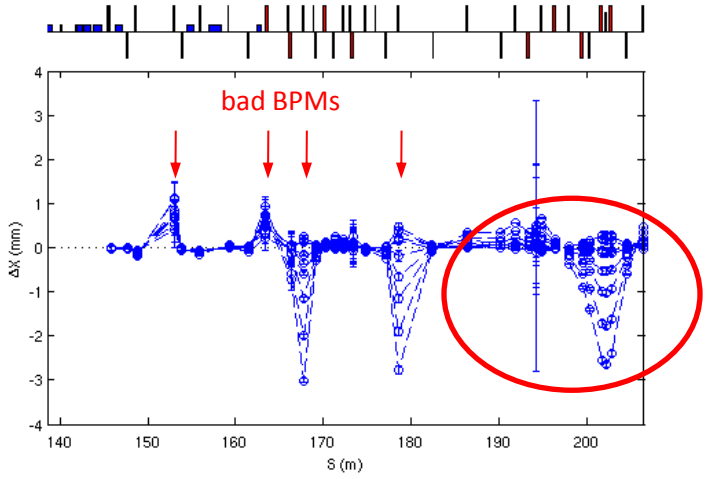
Orbit Bump Study (February 2010): bump vertically through KEX2

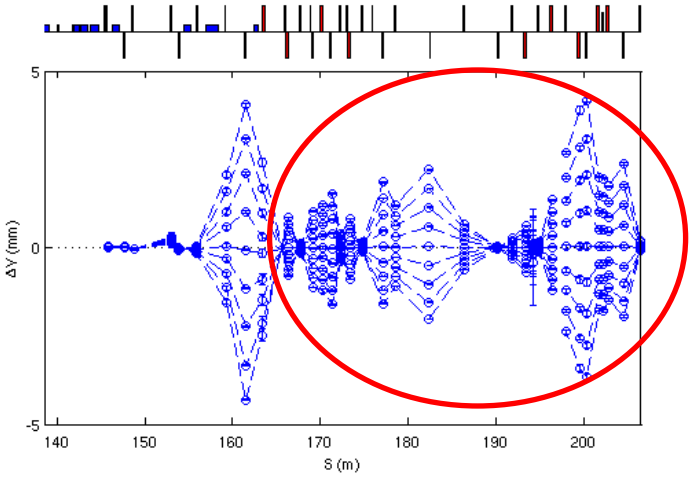
what we expected to see (no kicker multipoles) …





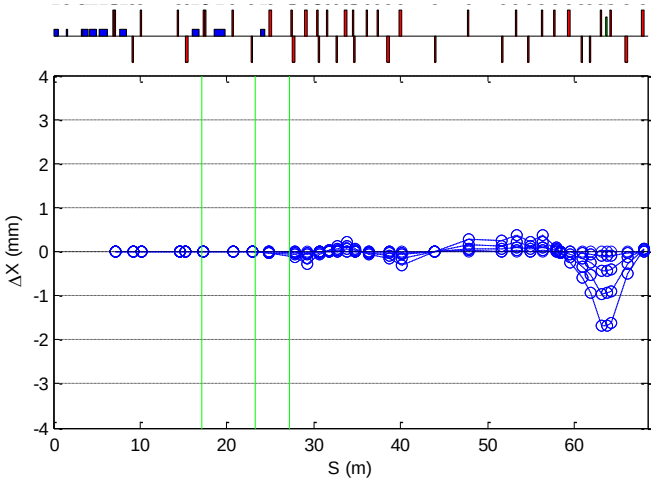
… what we observed

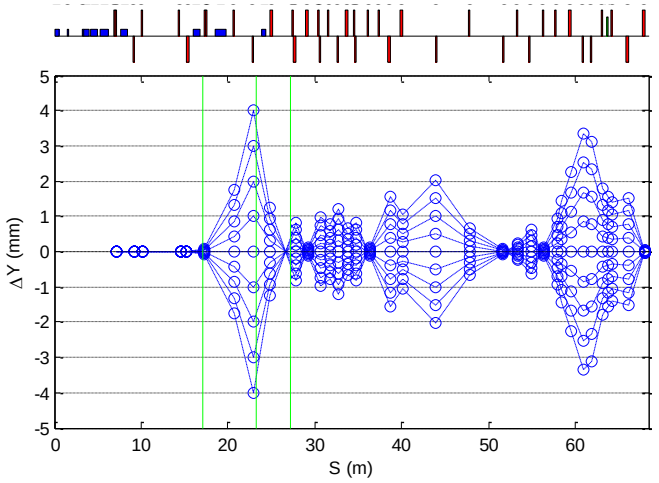




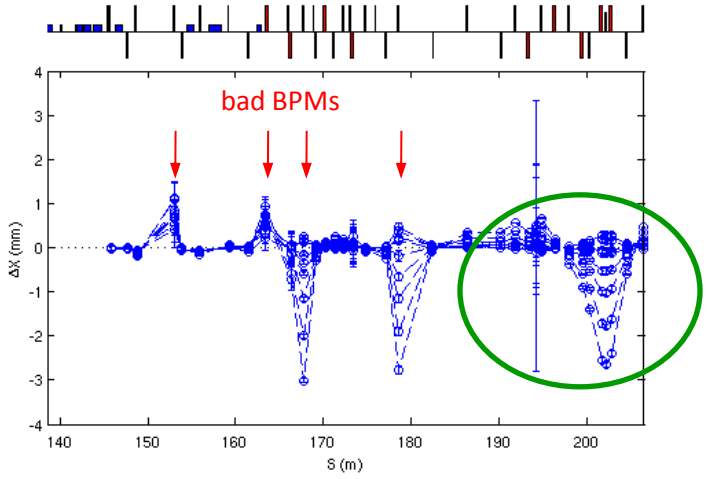
Orbit Bump Study (February 2010): bump vertically through KEX2

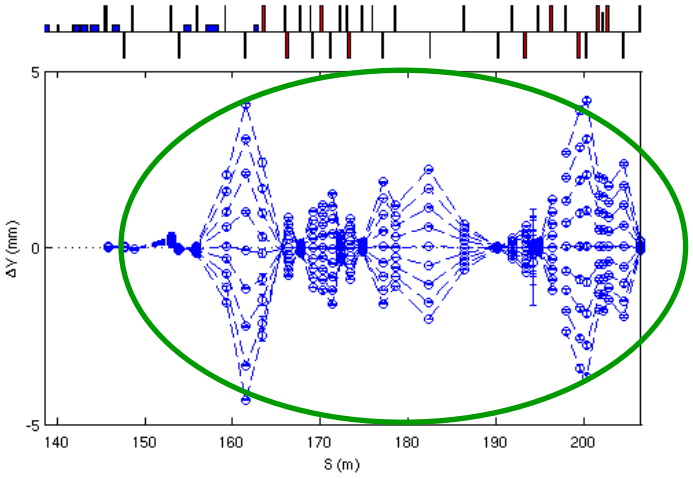
what we expected to see (with predicted kicker multipoles) …

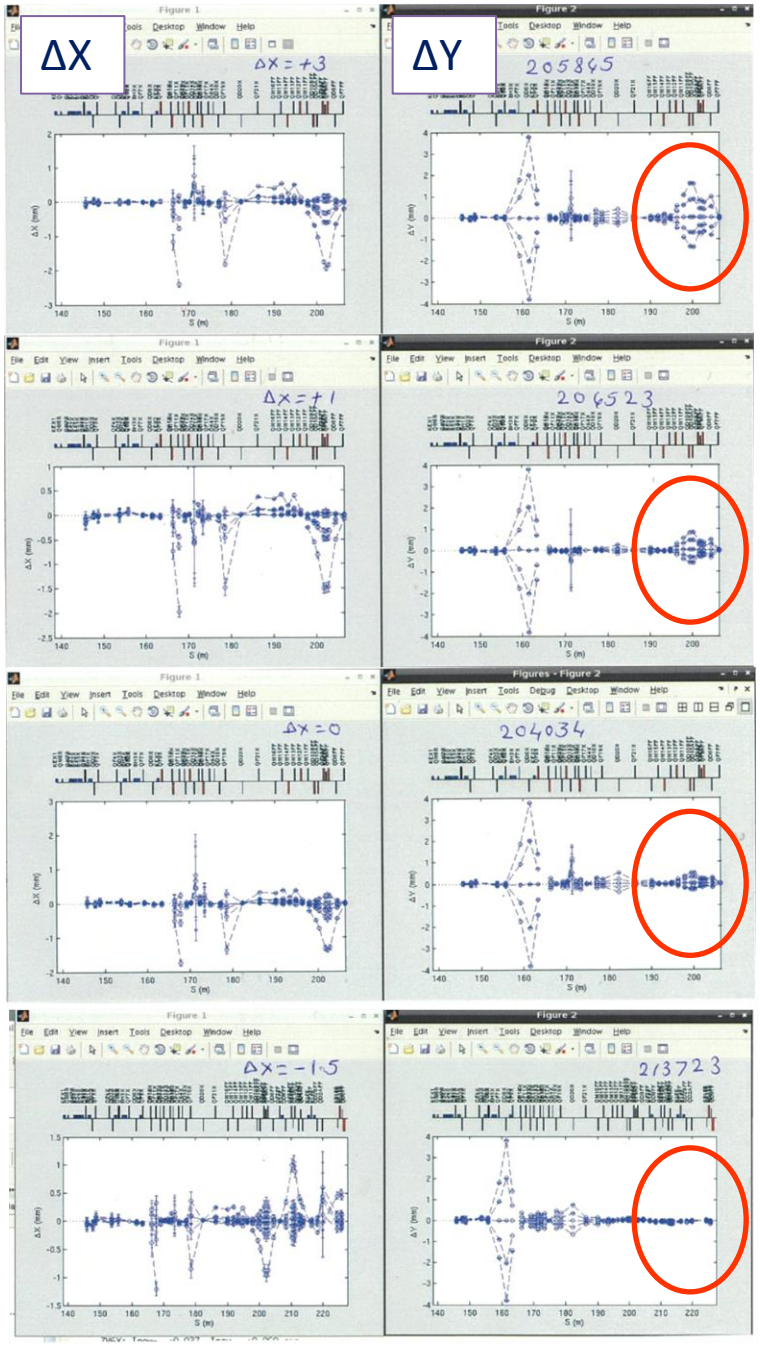




… what we observed







ΔX = +3 mm

ΔX = +1 mm

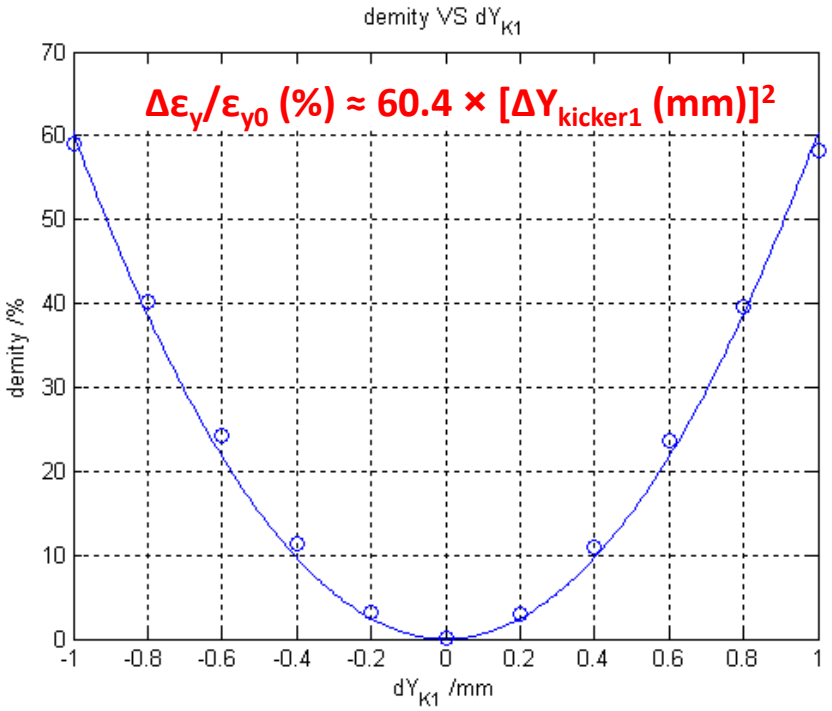
ΔX = 0

ΔX = -1.5 mm

set ZH3X/ZH4X/ZH5X X-bump; scan ZV5X/ZV6X/ZV7X Y-bump; find X-bump setting where Y-bump closes

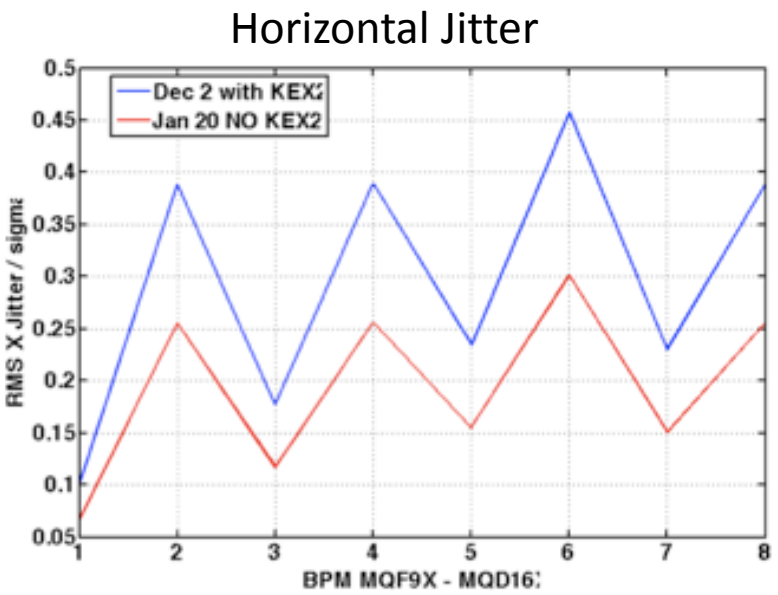
at this point the quadrupole field seen by the beam in KEX2 has the value predicted by POISSON for the vacuum chamber center

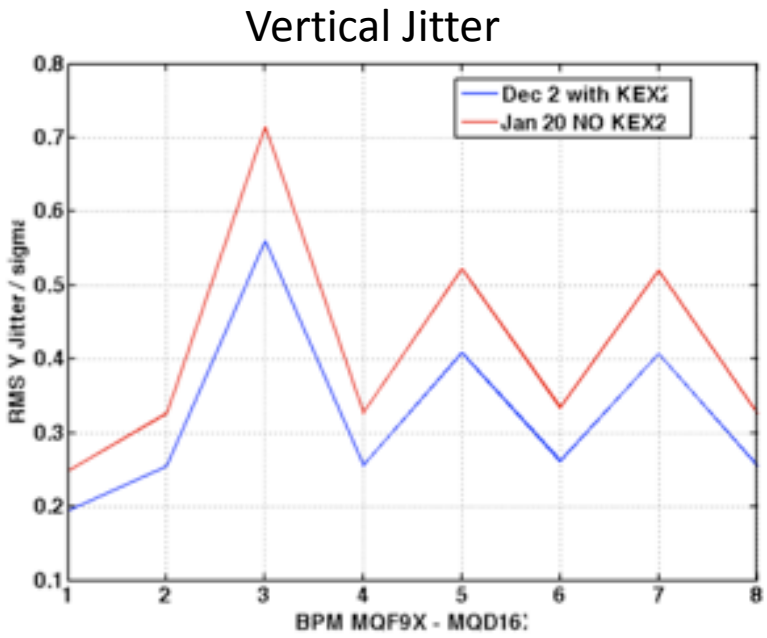
Predicted Vertical Emittance Growth (η_y corrected)



15 pm -> 24 pm @ +- 1 mm

KEX2 removed January 2012

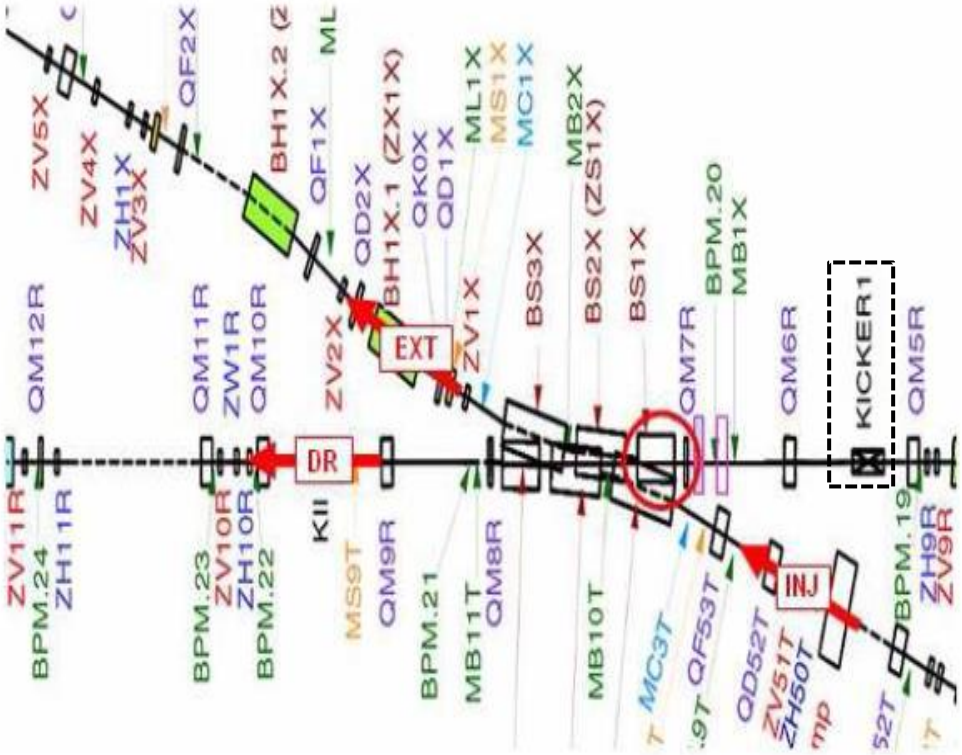


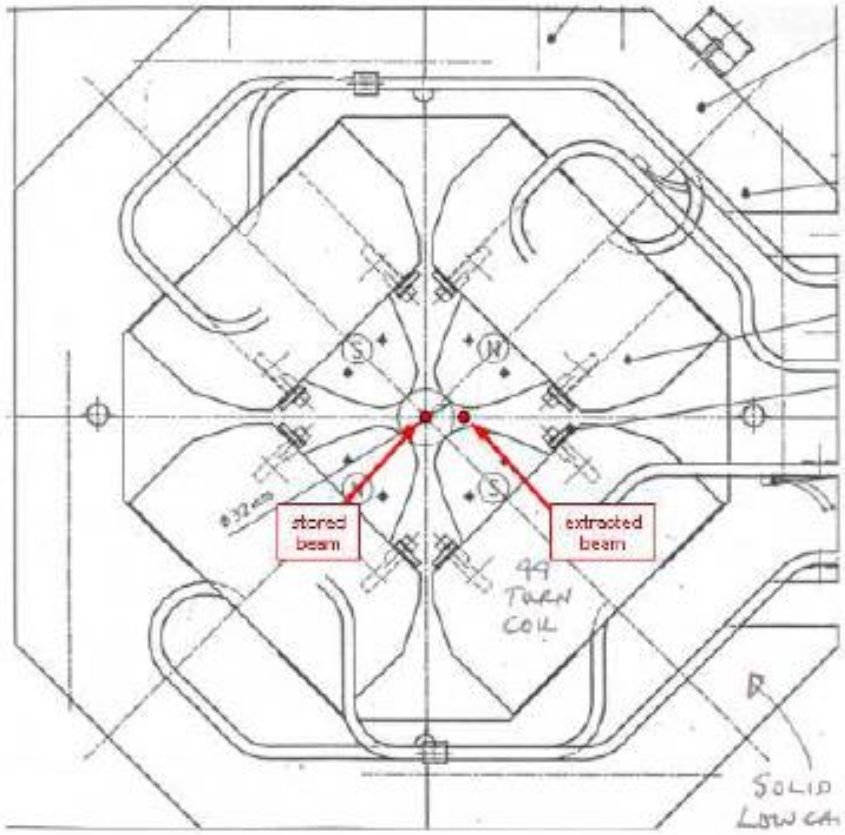


QM7R Replacement

- original quadrupole (Tokin 3393) had 16 mm pole-tip radius
- extracting beam passed through at 22.5 mm … in the coil pocket
- PRIAM simulations (P. Bambade) predicted large sextupole component at extracting trajectory
- QM7R replaced (January 2009) … new quadrupole (Tokin 3581) has 21 mm pole-tip radius
  - sextupole strength (K2L) reduced from 47 m^{-2} to 1 m^{-2}

QM7R: pole-tip radius = 16 mm … extracted beam offset = 22.5 mm





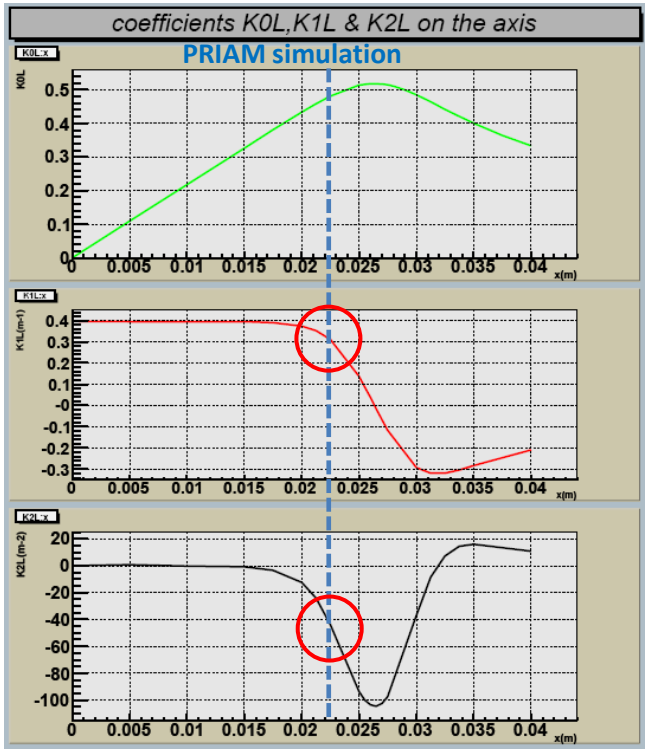
Tokin 3393 (Φ = 32 mm)

QM7R replaced with larger bore (Φ = 42 mm) quadrupole in January 2009

K1L = 0.3 m^{-1} = 0.76 × nominal
➔ optics mismatch

K2L = 46.6 m^{-2}
➔ x-y coupling for vertically off-axis beam:
factor ~ 2-3 × ε_y for Δy = 1 mm (ε_x:ε_y = 100:1)

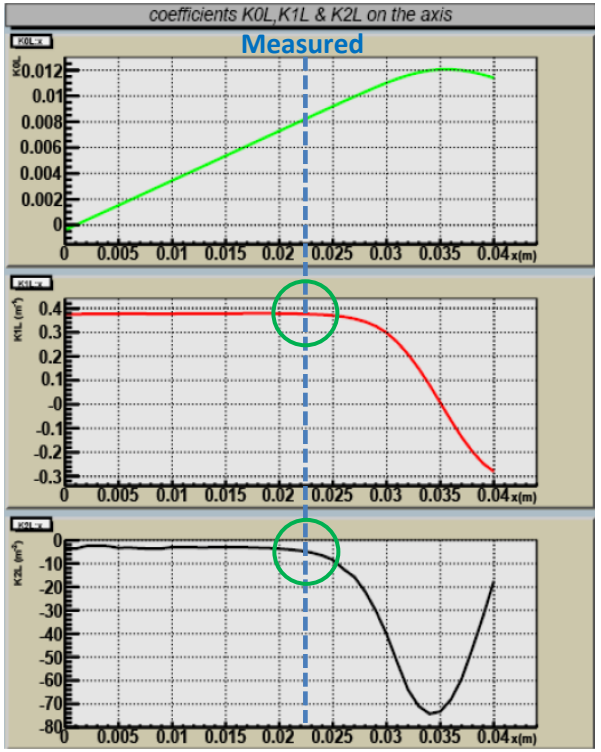
➔ K1L = 0.392 m^{-1} = 0.99 × nominal
➔ K2L = 1 m^{-2}



K0L

K1L

K2L



Tokin 3393 (Φ = 32 mm)

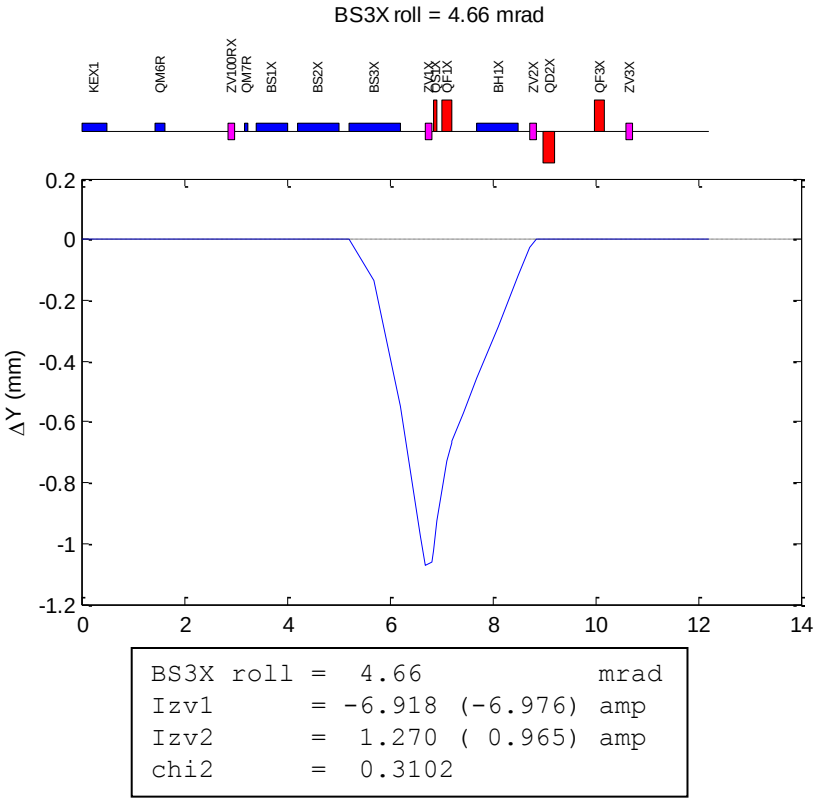
Tokin 3581 (Φ = 42 mm)

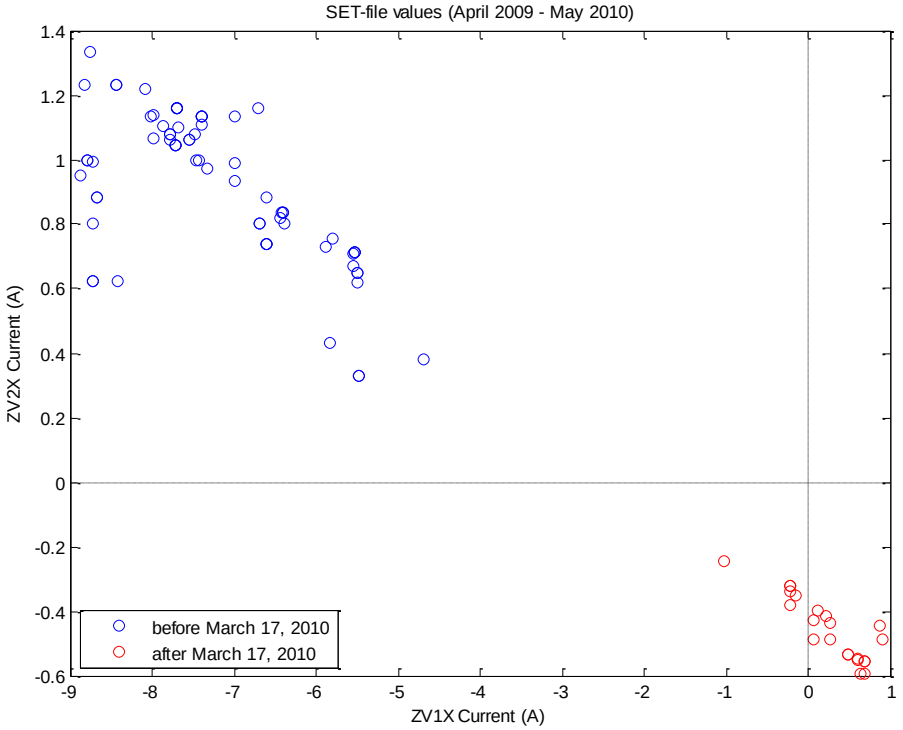
BS3X Rotation

- origin of strong vertical corrector ZV1X at beginning of EXT line and observed anomalous vertical dispersion in EXT/FF?
  - measured vertical dispersion in DR at extraction point is normally small
- 3rd septum magnet BS3X thougth to be kicking vertically
- BS3X was physically rolled ~ -4 mrad on March 17, 2010
- vertical orbit and measured ε_y improved

Observed that first 2 EXT vertical correctors (ZV1X and ZV2X) needed to be strong to properly launch into EXT (since before EXT rebuild for ATF2 …)

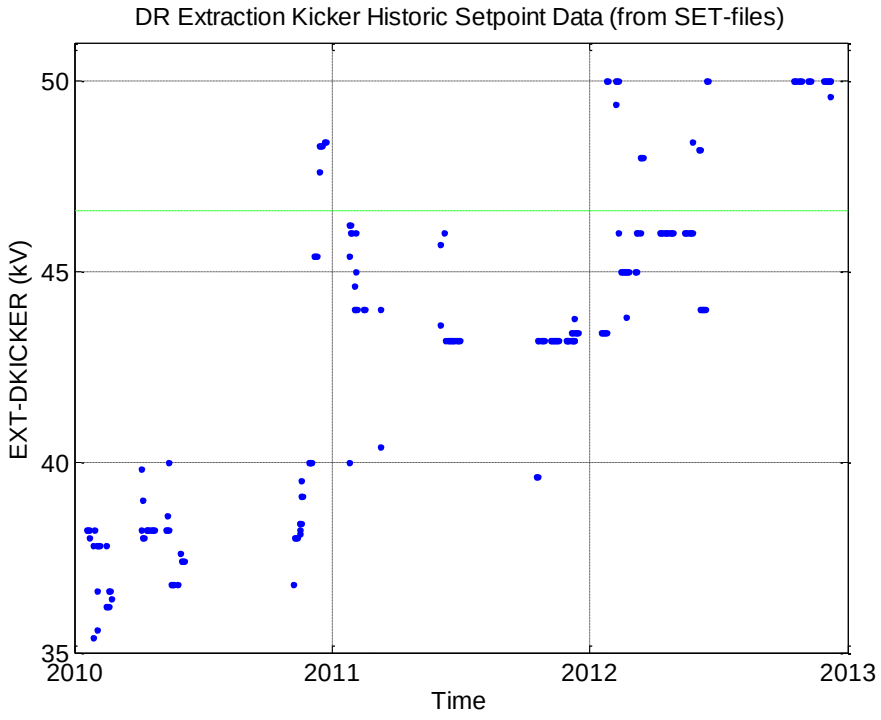
- hypothesize that correctors are compensating for a kick error in extraction channel
- simulate error kick by rolling individual elements; use ZV1X and ZV2X to correct orbit
- find error that gives best fit to actual ZV1X/ZV2X values → BS3X septum magnet roll
- BS3X was physically rolled ~ -4 mrad (March 17, 2010) to relieve ZV1X and ZV2X
- projected vertical emittance in EXT before coupling correction was improved (~20-40 pm before → ~10-20 pm after)

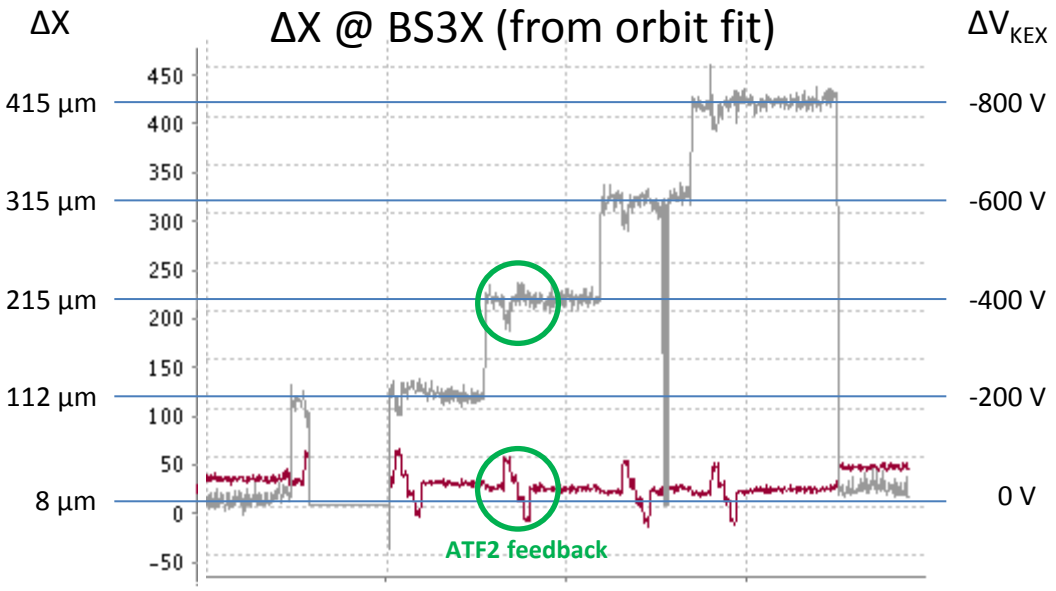




Extraction Kicker (2)

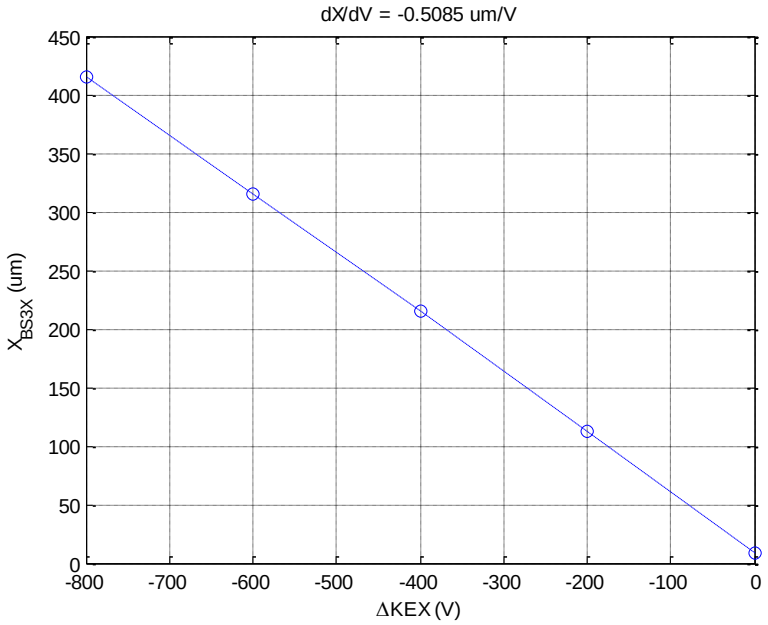
- kicker strength setpoint (voltage) has been creeping up
- beam-based calibration measurement
- vertical steering … rotation





measurement: 2012/12/07 Owl Shift

Horizontal orbit position at BS3X center estimated by back-propagation from EXT BPM measurements (QF1X-QF4X)
… courtesy of Yves Renier



$$\Delta x = R_{12}\Delta\theta\ ,\ \Delta\theta = c\Delta V\ ,\ c = \frac{1}{R_{12}}\left(\frac{\Delta x}{\Delta V}\right)$$

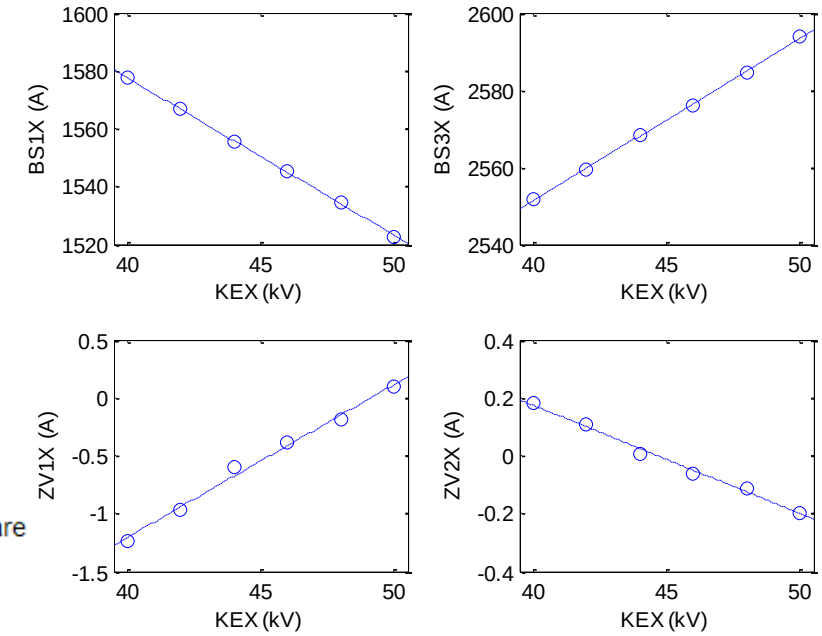
R12 = 4.7329 mm/mrad
dX/dV = -0.5085 mm/kV
dθ/dV = -0.1074 mrad/kV
θ_0 = -5 mrad ⇨ V_0 = 46.5 kV
(SLAC NDR KEX: 0.1158 mrad/kV)

EXT Orbit (Corrected) vs KEX Voltage
December 13, 2012 Day Shift
(Okugi)

Kicker & Septum Orbit Data

In order to make same EXT orbit, we must set to the following Septum and vertical steering settings

KEX	BS1X	BS3X	ZV1X	ZV2X
46000	1545.49A	2576.02A	-0.391A	-0.062A
48000	1534.29A	2584.62A	-0.181A	-0.112A
50000	1522.69A	2593.62A	+0.099A	-0.197A
44000	1555.29A	2568.42A	-0.601A	+0.003A
42000	1566.69A	2559.42A	-0.961A	+0.108A
40000	1577.49A	2551.52A	-1.241A	+0.183A



The vertical orbit data analysis

The slope of ZV1X/ZV2X as a function of kicker amplitude are

- ZV1X ; +0.1321 A/kV
- ZV2X ; - 0.0375 A/kV
- ratio ZV1X/ZV2X ; -3.524

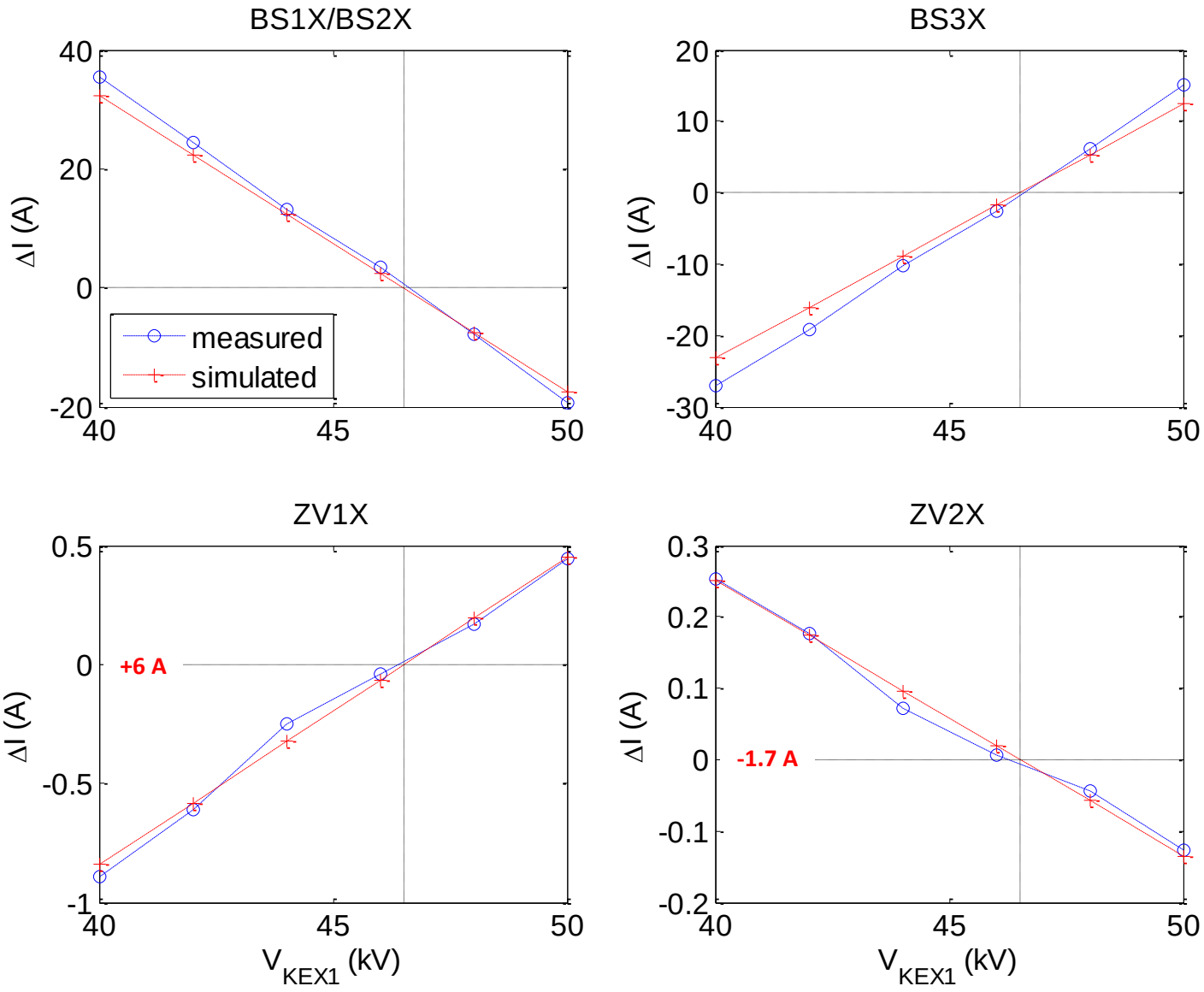
When KEX, BS1X, BS2X, BS3X are kicked by 1mrad, the currents for ZV1X, ZV2X are

	KEX1	BS1X	BS2X	BS3X
ZV1X [mrad]	-4.864	-4.342	-3.353	-2.145
ZV2X [mrad]	+1.386	+1.106	+0.779	+0.379
ZV1X/ZV2X	-3.509	-3.926	-4.304	-5.660

If we assumed the vertical kick was come from the kicker, the data was consistent.

But, If we assumed the kicker amplitude was 5mrad at 58kV,
the vertical kick at kicker was 0.52mrad (about 100mrad rotation).

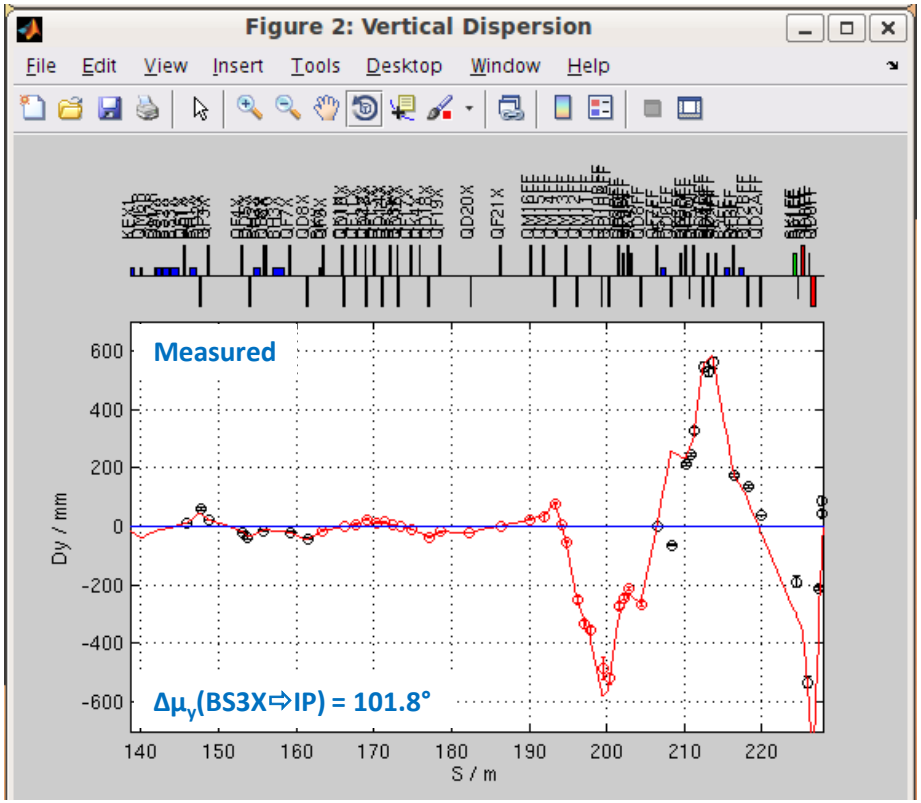
KEX1 Roll ≈ -85 mrad (-5° !)

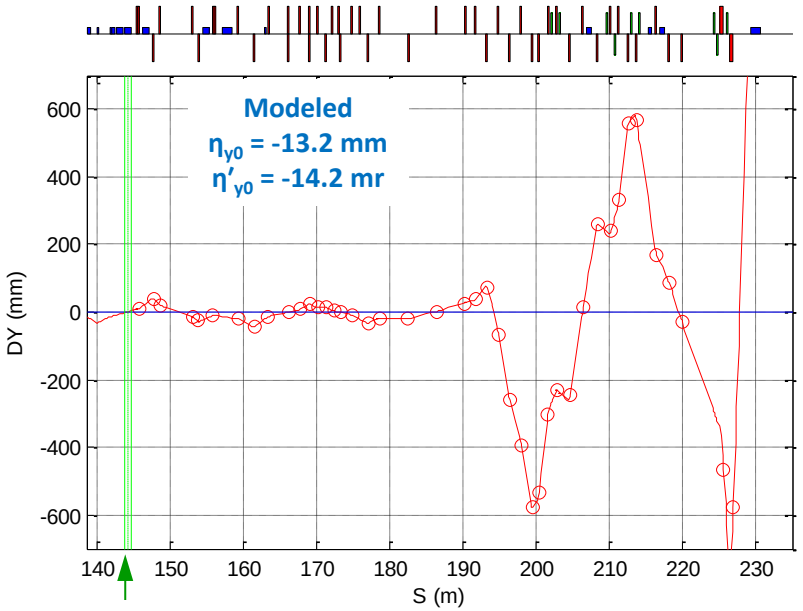


BS3X Skew Field

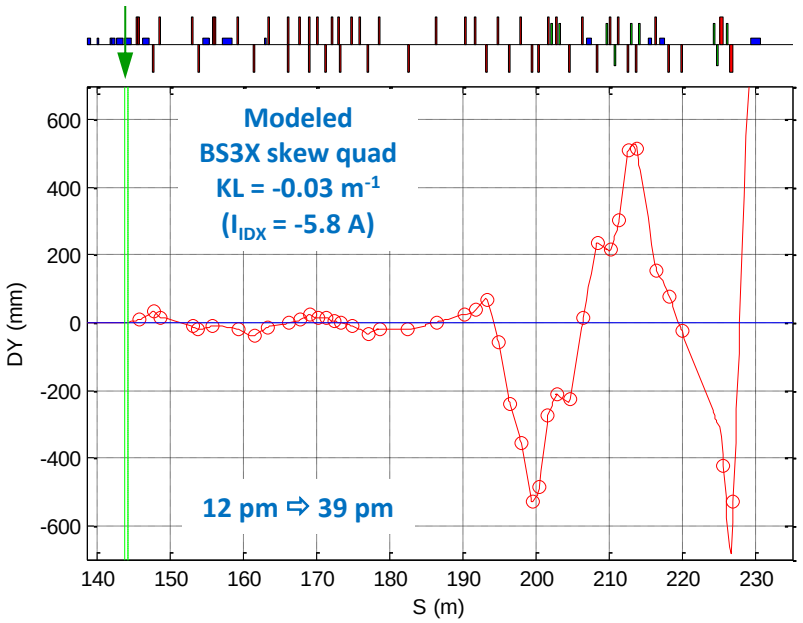
- observed anomalous vertical dispersion in EXT/FF
  - measured vertical dispersion in DR at extraction point is small
  - well modeled with a skew quadrupole field at BS3X septum
- we have had problems with BS3X in the past
  - BS3X had to be physically rolled ~ -4 mrad (March 17, 2010)
- measured dependence of inferred skew quadrupole strength versus horizontal position in BS3X is consistent with a skew sextupole field with: $K_2L = 16\ m^{-2}$
  - our strongest FF sextupole (SD4FF) has $K_2L = 14.91\ m^{-2}$

NOTE: η_x = 179 mm @ BS3X

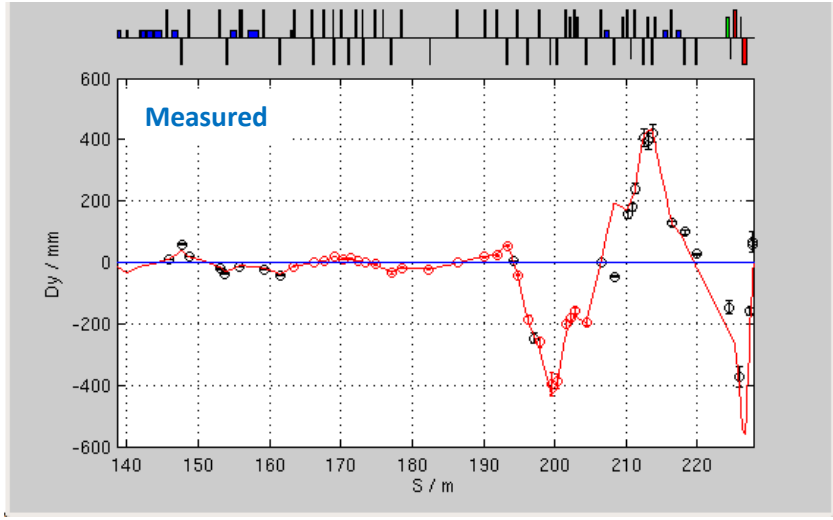




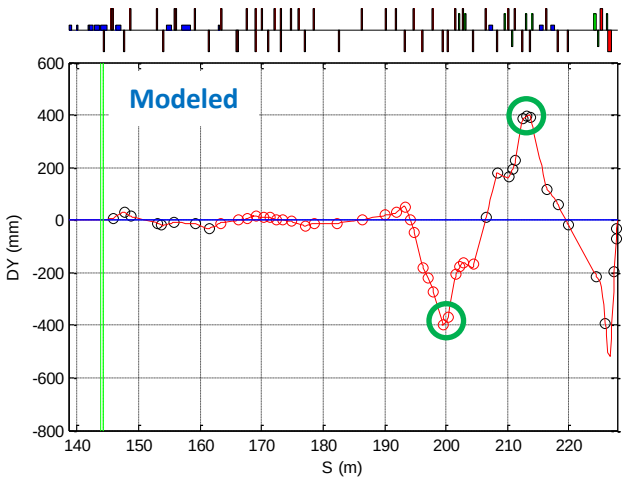
BS3X



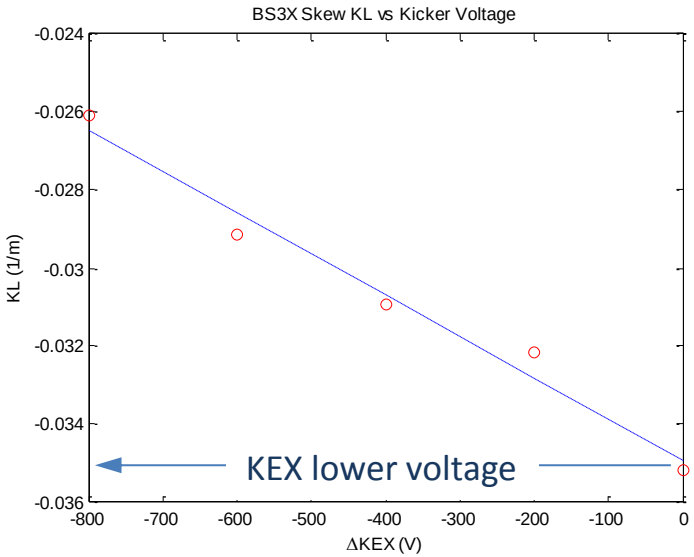
ΔKEX = -800 V



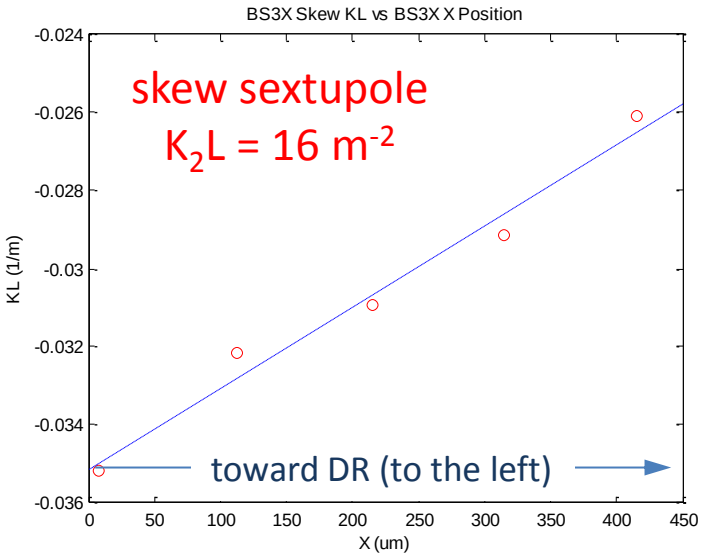
$KL_{BS3Xskew}$ = -0.02610 m^{-1}



BS3Xskew = 0 @ KEX = 46.7 kV

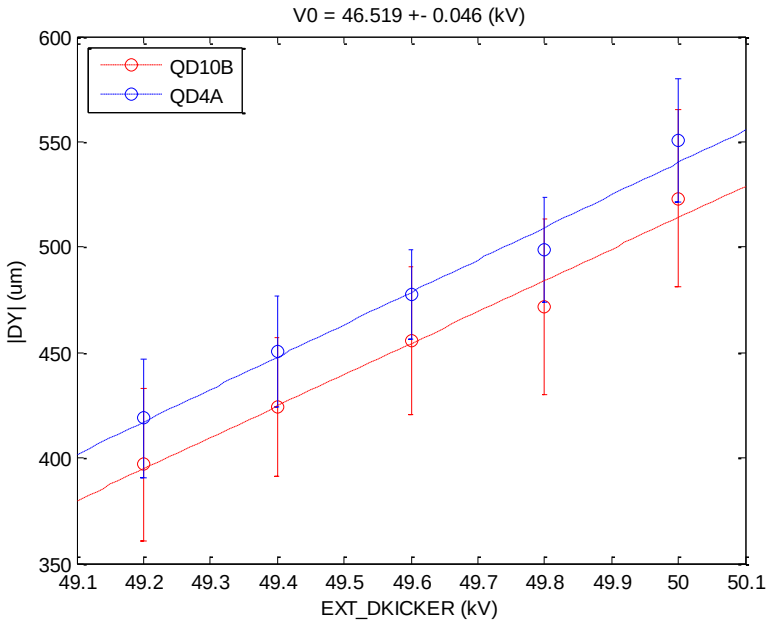


BS3Xskew = 0 @ BS3X X = +1.7 mm

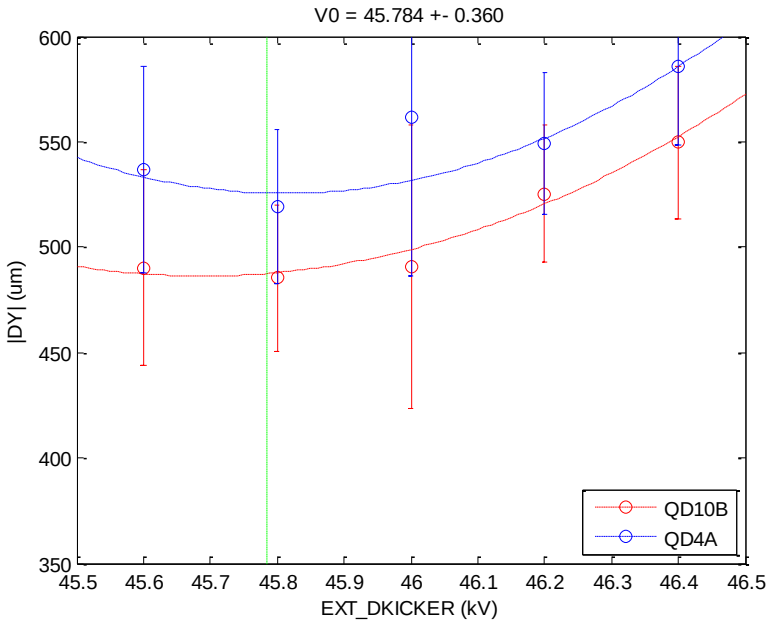


Set EXT Kicker Voltage to 46 kV

Dec 7 (KEX @ 50 kV)



Dec 12 (KEX @ 46 kV)



Study by Edu Marin (March 2013)

Conclusions

- In general, a rotation of the kicker explains almost all the orbit and dispersion measurements. The obtained values are -9, -16 and -20 mrad
- In addition, the BH3X and the septum are also good candidates to explain the considered observables
- The strength of the skew quadrupole obtained from the coupling correction by misaligning the kicker plus another magnet is as the one observed in the experimental runs.
- The QK correction pattern for $\Delta x, \Delta y$ for BHs BSs magnets is consistent with the measurements *(assuming KEXTT=-9mrad)*
- The QK correction is sensitive to BHs and BSs rotations *(assuming KEXTT=-9mrad)*

Recommendation:
According to the studies presented I would recommend to tilt the kicker in steps of +1 mrad and record the orbit, dispersion and emittance at each step in order to determine the kicker rotation that minimises the mentioned measurements

ATF Operation

http://atf.kek.jp/twiki/pub/ATFlogbook/Meeting201307/EXT_misalignments_Study.pdf

Summary

- EXT optics is well understood and capable of delivering matched and dispersion-corrected beams to the Final Focus
  - there are some remaining anomalies in the DR extraction channel
  - still looking for sources of emittance growth (and its current dependence)
- multi-OTR EXT emittance measurements are reliable and stable
  - measured beam tilt (coupling) values are believable and correspond to real X-Y coupling
  - direct beam tilt correction using a modeled response matrix looks like a superior coupling correction technique
- extracted vertical emittance is strongly dependent on bunch charge
  - 2-3 pm per 10^9 … much larger than observed in DR
  - weaker dependence observed recently? … see Okugi-san's talk this afternoon
- extraction magnets (kicker, QM7R, septa) have been problematic, but improvements are being made
- observed KEX1 quadrupole/sextupole field components agree with POISSON field simulation
  - tracking simulations indicate that vertical beam offset in KEX1 is not a source of significant emittance growth
  - removing 2nd kicker gave us more tuning flexibility, without significantly increasing beam jitter
- roll alignment of bending magnets has been problematic, but improvements are being made
- some mysteries remain
  - is KEX1 rolled? by how much? can it be fixed?
  - are there anomalous magnetic fields in BS3X, or are other errors fooling us?
  - if there are anomalous magnetic fields in BS3X, can the magnet be fixed?
- can Okugi-san's QS Δ-knob coupling correction technique tell us more about any coupling sources?