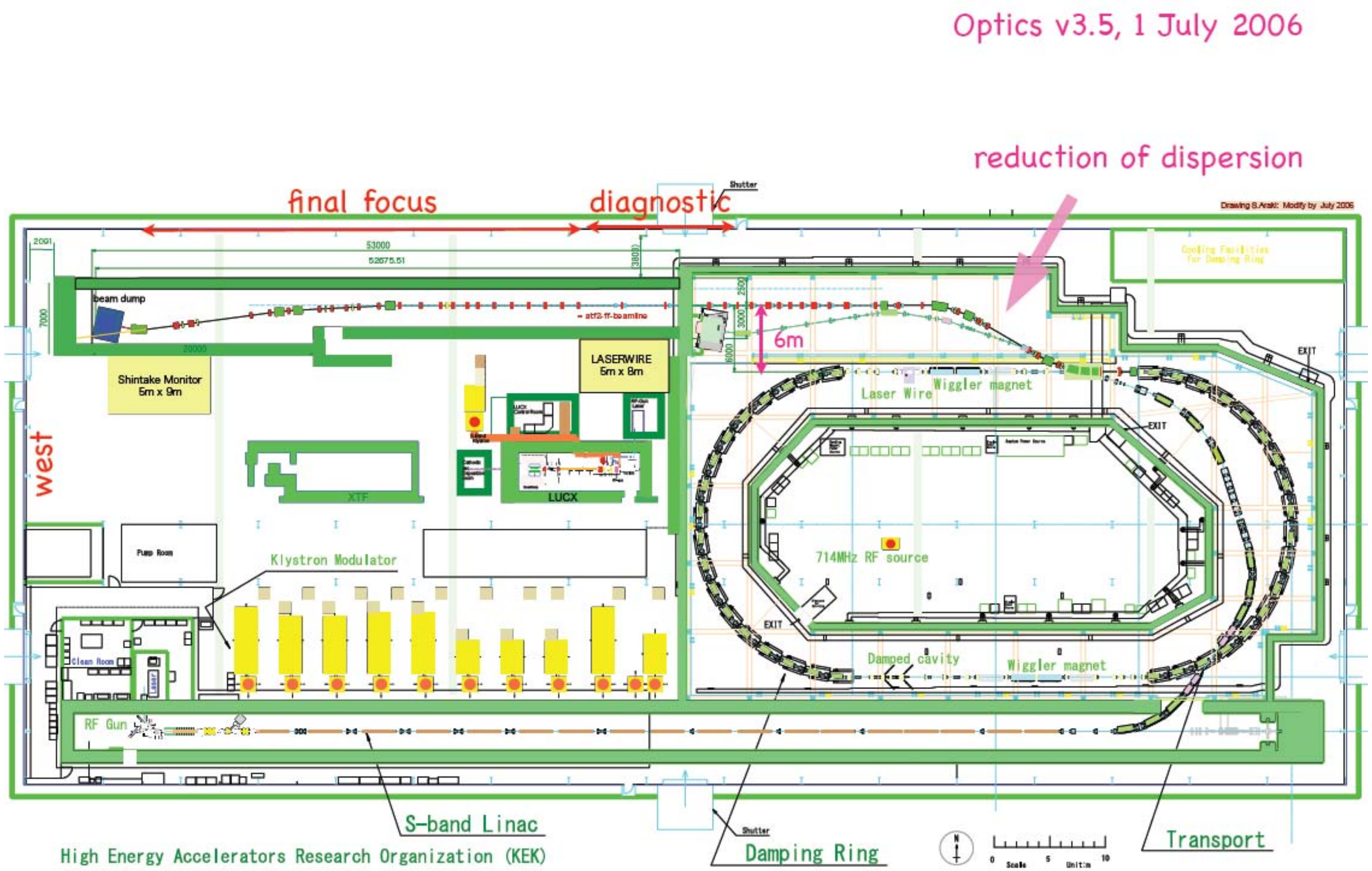
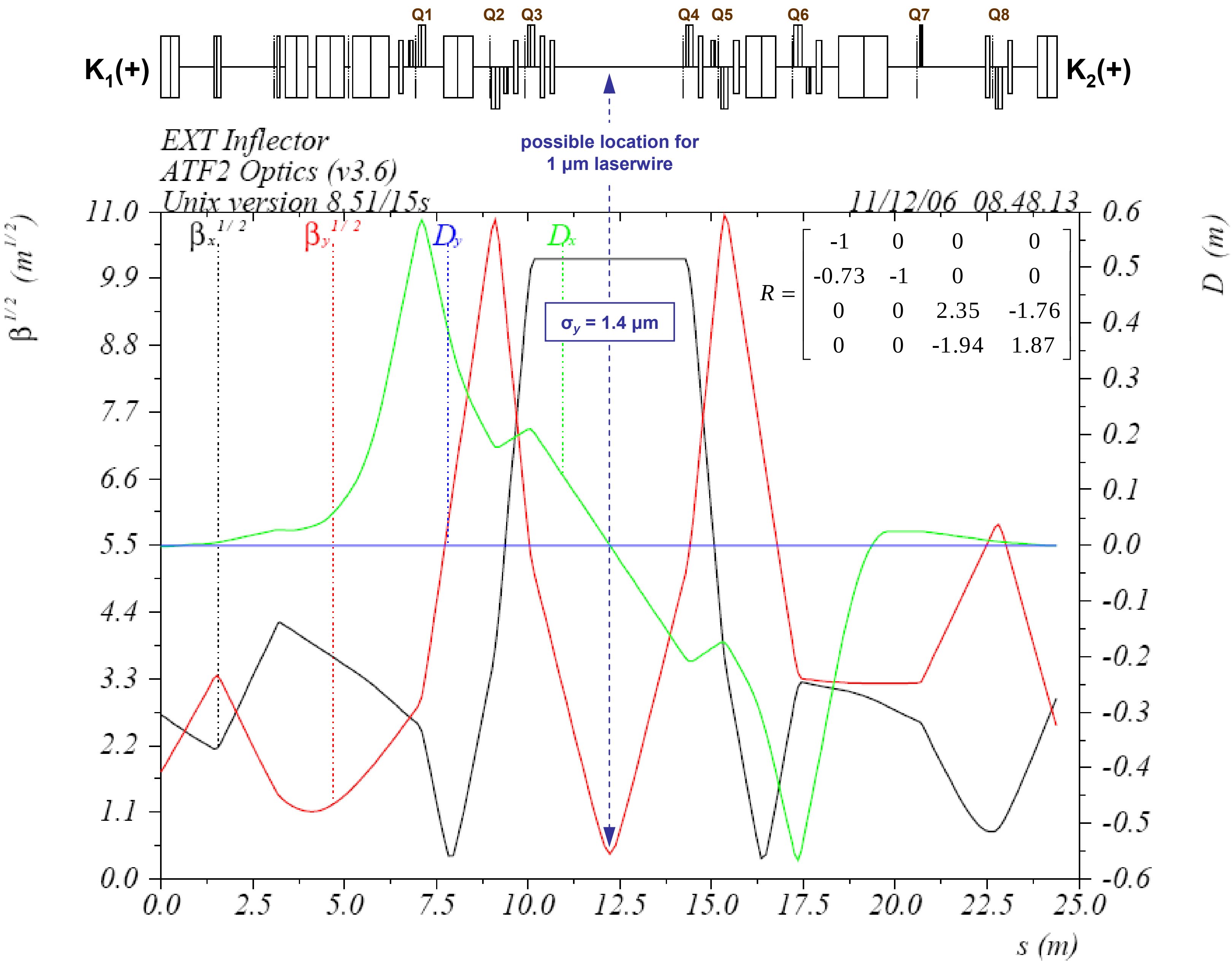
Correction of Anomalous Vertical Dispersion in the ATF2 EXT Line (v3.6)





For MAD files see http://www.slac.stanford.edu/~mdw/ATF2/v3.6

Simulation Parameters

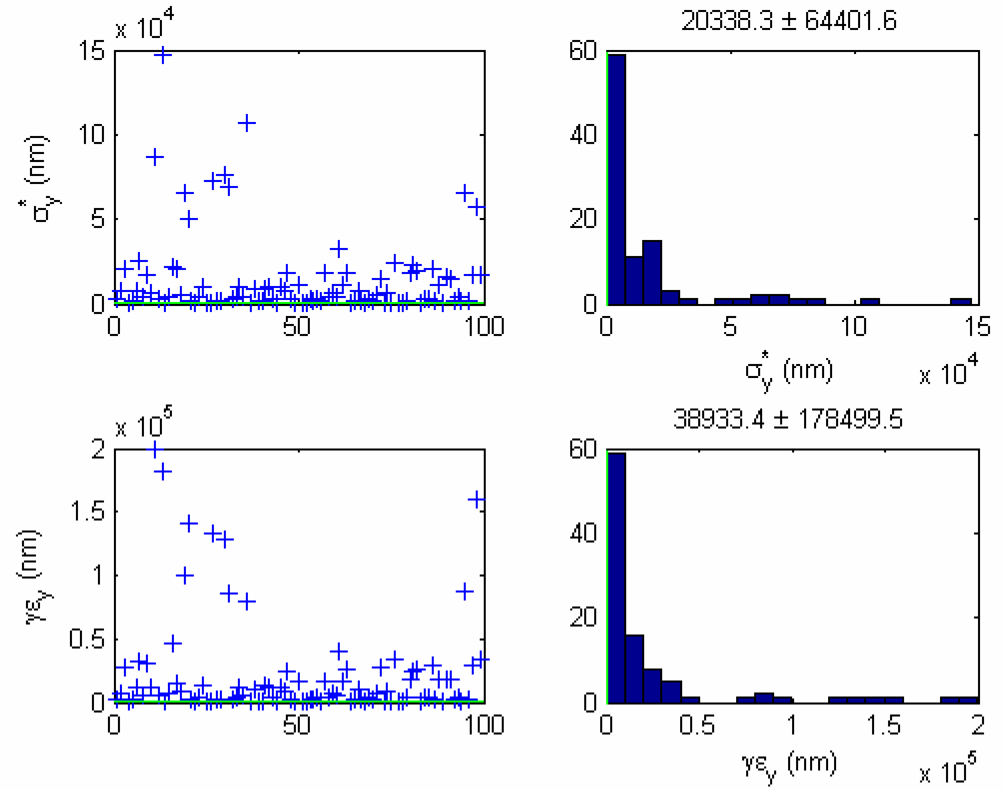
- use Peter Tenenbaum's Lucretia[1] simulation code
- included
  - perfect beam from Damping Ring (ε_x=2×10^{-9} m, $\gamma\varepsilon_y$=3×10^{-8} m) … errors begin after extraction septa, unless otherwise noted
  - perfect Final Focus
  - dipole errors[2]: ΔY = 100 μm (rms)
  - quadrupole errors: ΔX = 50 μm, ΔY = 30 μm, Δθ = 0.3 mrad (rms)
  - sextupole errors: ΔX = 50 μm, ΔY = 30 μm, Δθ = 0.3 mrad (rms)
  - BPM resolution: 5 μm (rms)
- *not* included
  - quadrupole strength errors (ΔK/K)
  - BPM offsets
  - BPM rolls
  - wire scanner rolls: $|\theta| \le 0.2°$ (uniform)
  - wire scanner beam size errors: $\sigma = \sigma_0(1+\Delta\sigma_{relative})+\Delta\sigma_{absolute}$
  - coupling errors in the DR extraction channel
  - tuning in FF

[1] http://www.slac.stanford.edu/accel/ilc/codes/Lucretia/
[2] EXT dipoles BH1 and BH2 are assumed to have nonzero sextupole components

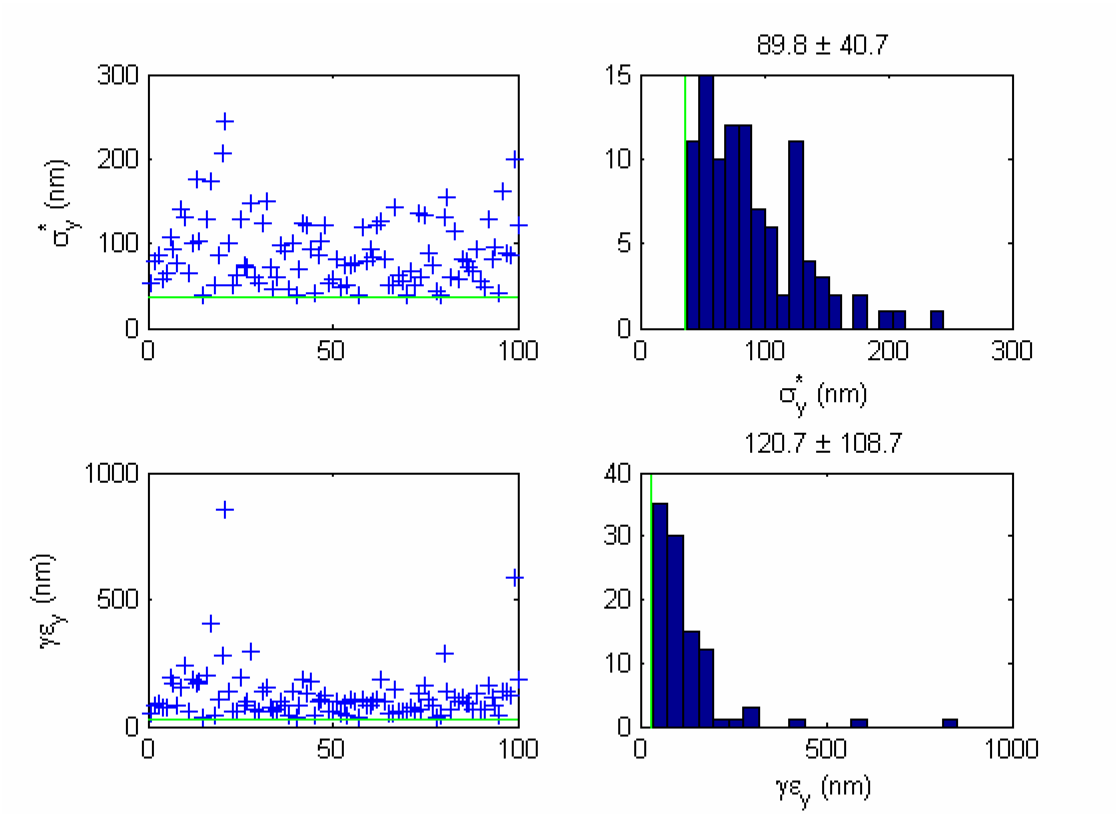
Simulation Procedure

1. apply errors
2. steer flat (EXT only)
3. launch into FF
   - use 2 virtual correctors
   - steer to 2 virtual BPMs (one at the IP and one 90° upstream)
   - virtual BPMs are perfect
4. measure dispersion in diagnostic section
   - scan input beam energy
   - measure orbits
   - fit position vs energy at each BPM … linear correlation is η
   - back-propagate measured η to start of diagnostic section to get η_0 and η'_0
5. correct dispersion in diagnostic section
   - use QF1X + QF6X multiknobs for η_x and η'_x
   - correct η_y using skew quads in inflector (thin lenses at quad centers)
6. correct coupling
   - scan 4 skew quadrupoles sequentially
   - deduce projected ε_y from wire scanner measurements
   - set each skew quad to minimize projected ε_y

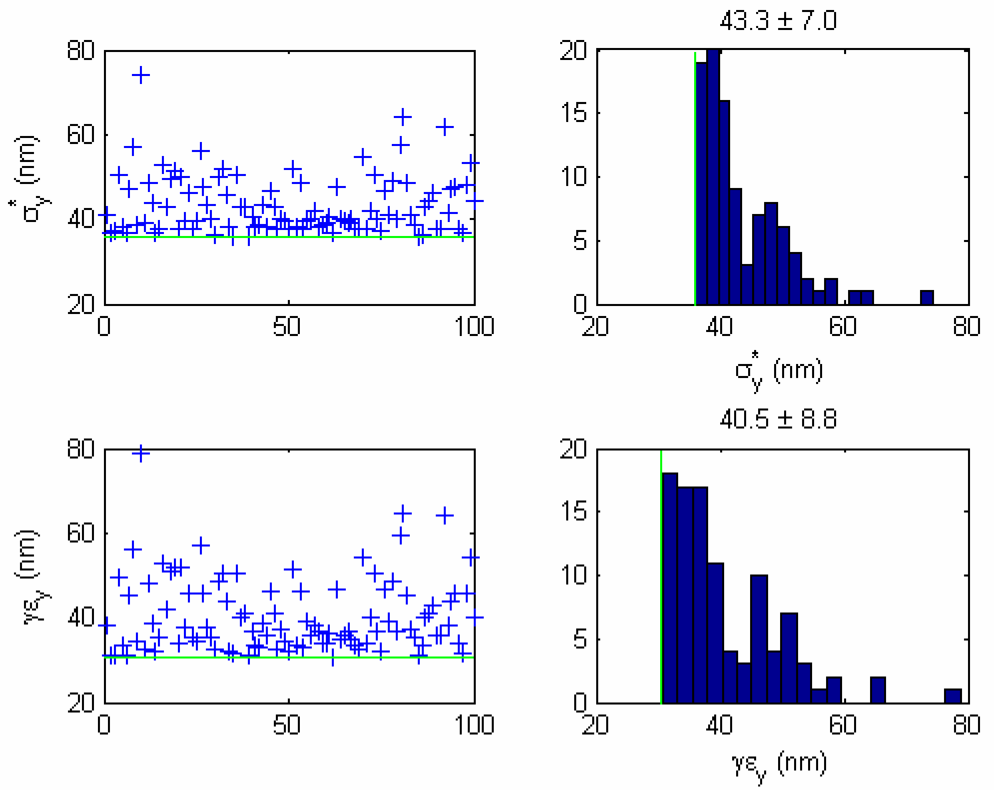
errors only (100 seeds)



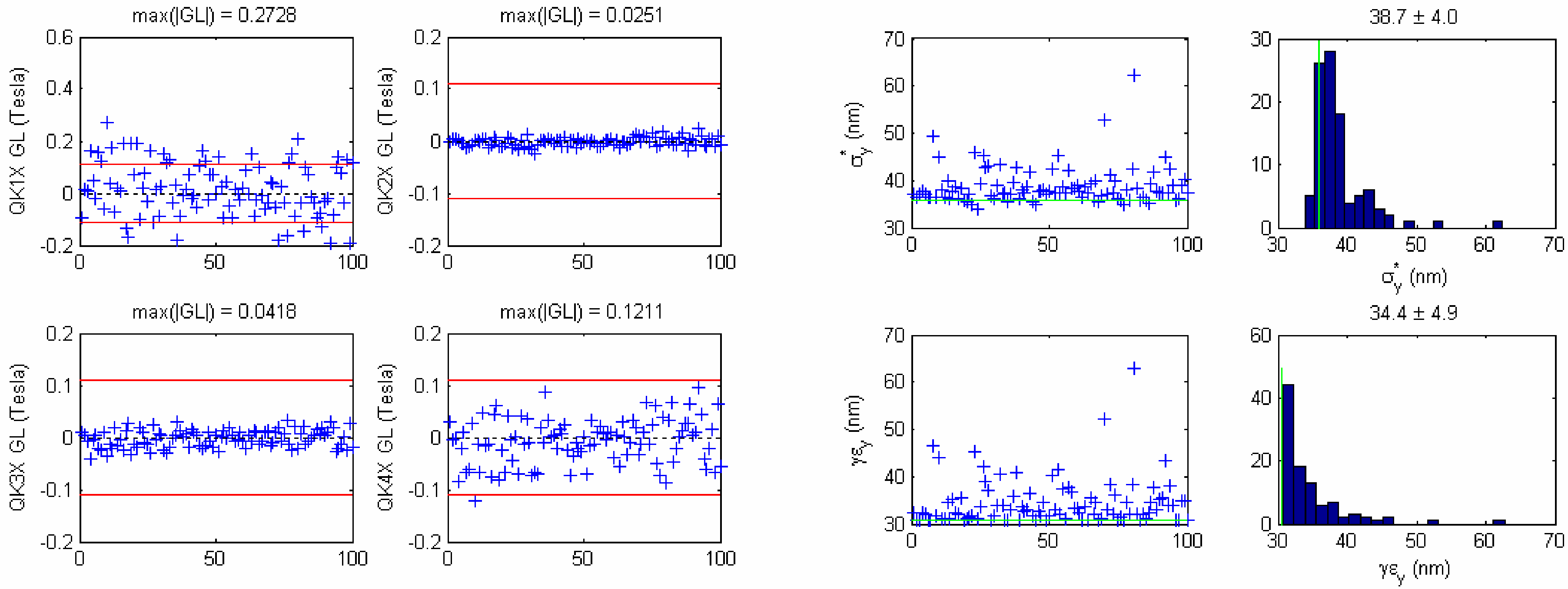
errors, FF launch



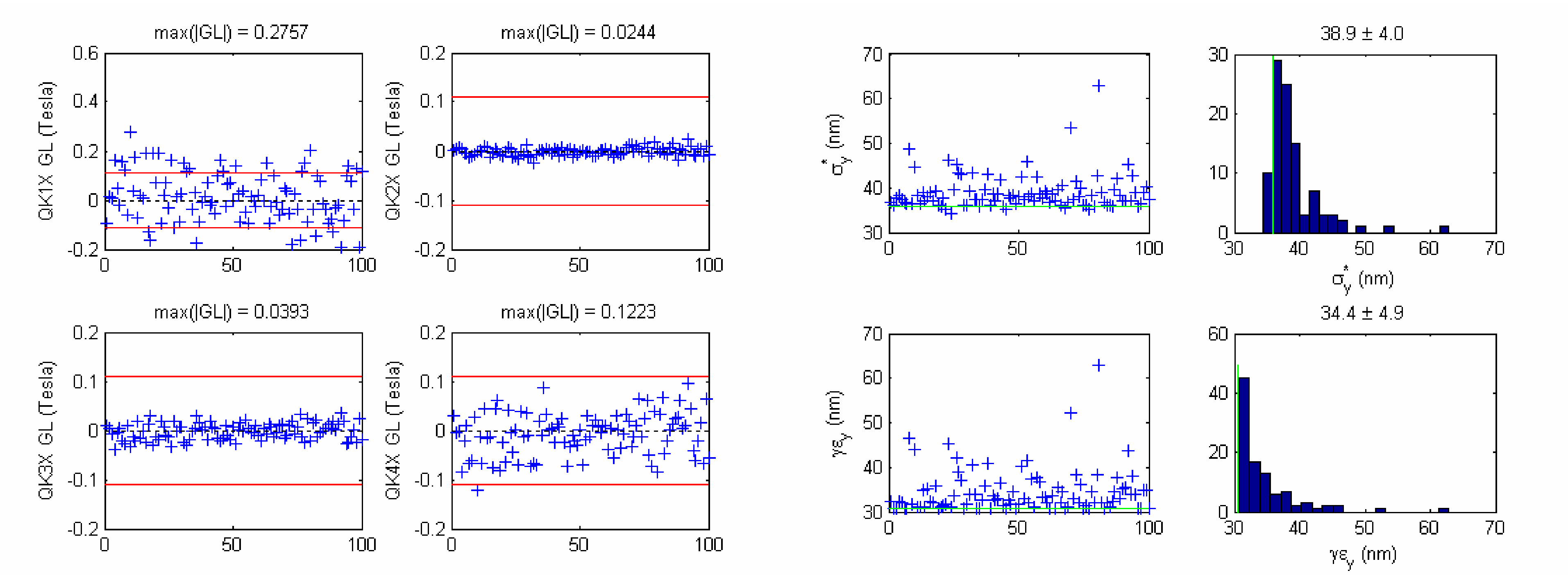
errors, steer flat, FF launch

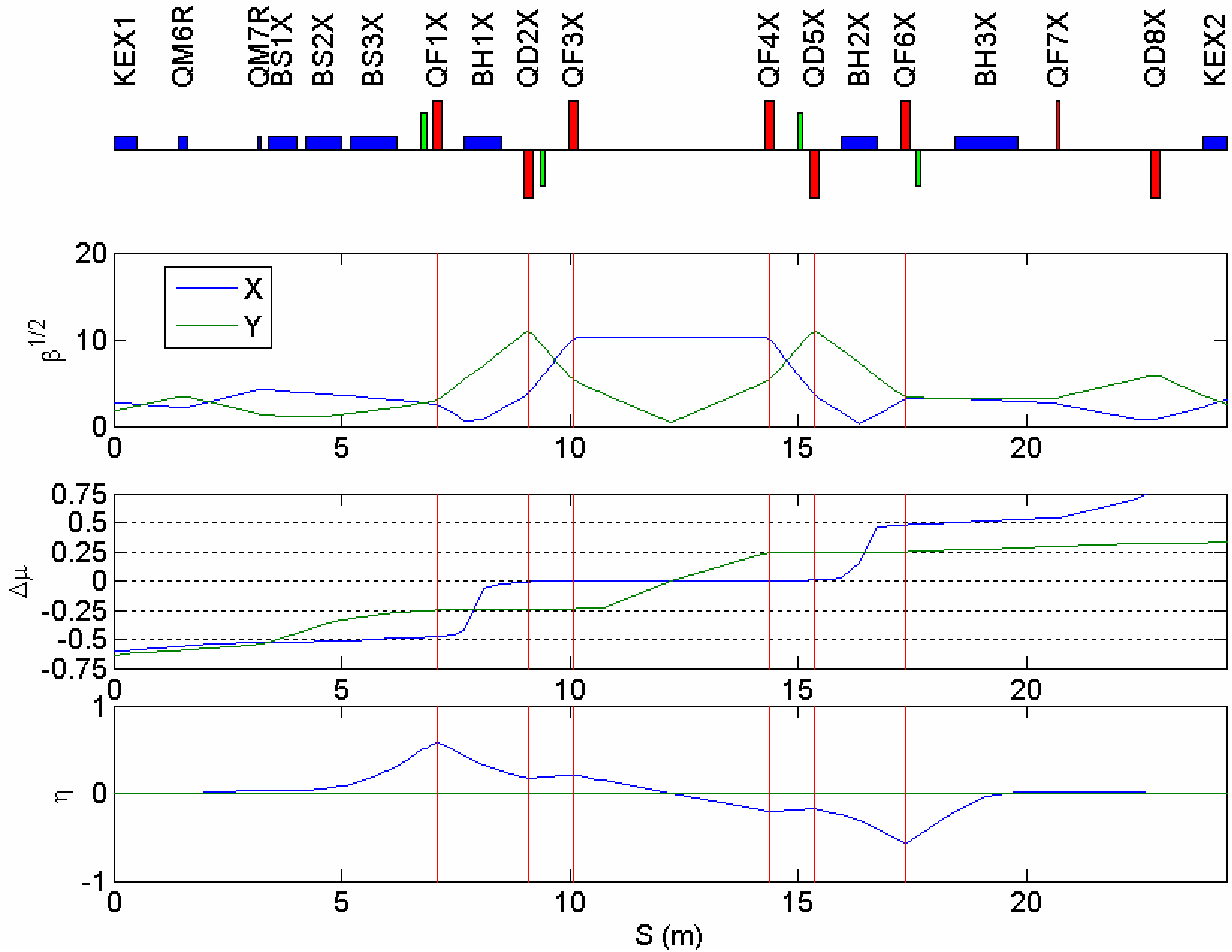


errors, steer flat, correct coupling, FF launch

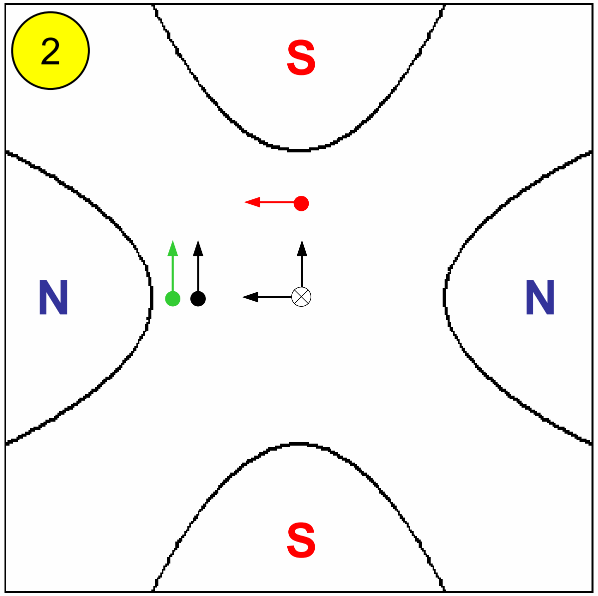


Note: red lines represent maximum integrated strength of IDX-type skew quadrupole (KLmax ≈ 0.1 T @ 5 amp) errors, steer flat, correct η_x, correct coupling, FF launch




KEX1
QM6R
QM7R
BS1X
BS2X
BS3X
QF1X
BH1X
QD2X
QF3X
QF4X
QD5X
BH2X
QF6X
BH3X
QF7X
QD8X
KEX2
X
Y
$\beta^{1/2}$
$\Delta\mu$
η
S (m)

after 1st skew quad

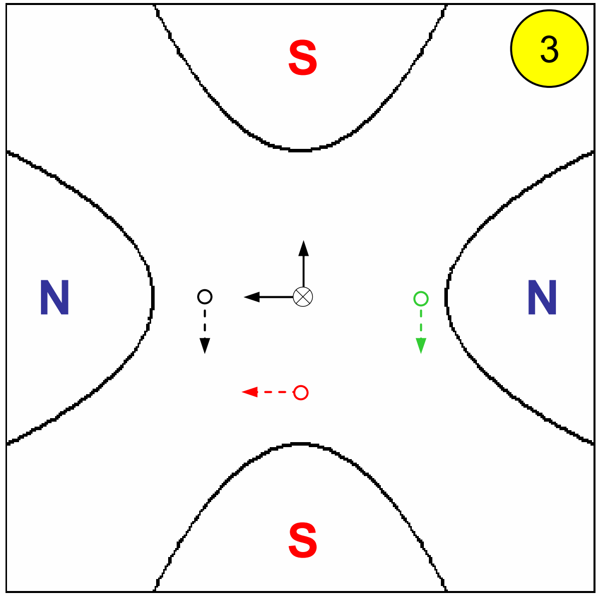


$\Delta\mu_x = 0{,}360°$

$\Delta\mu_y = 180°$

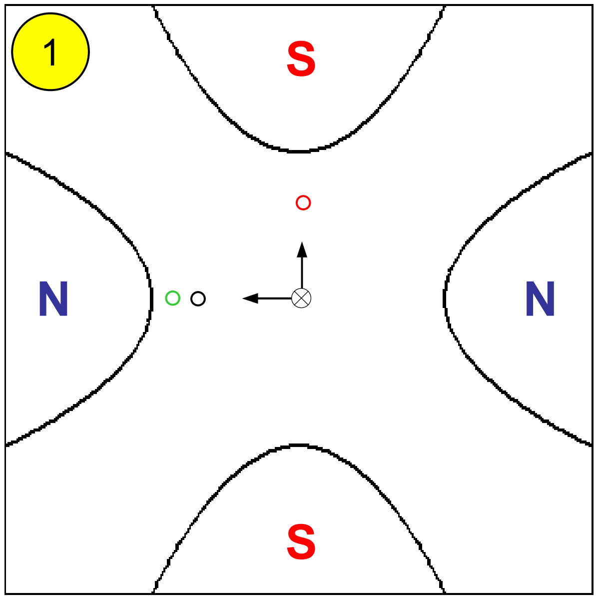
$+\eta_x \rightarrow -\eta_x$

before 2nd skew quad



how to generate η_y without introducing coupling

before 1st skew quad



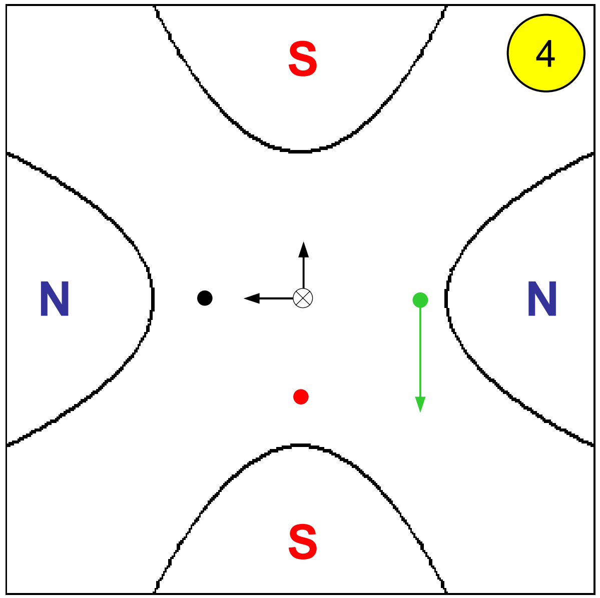
β_x (on-energy)

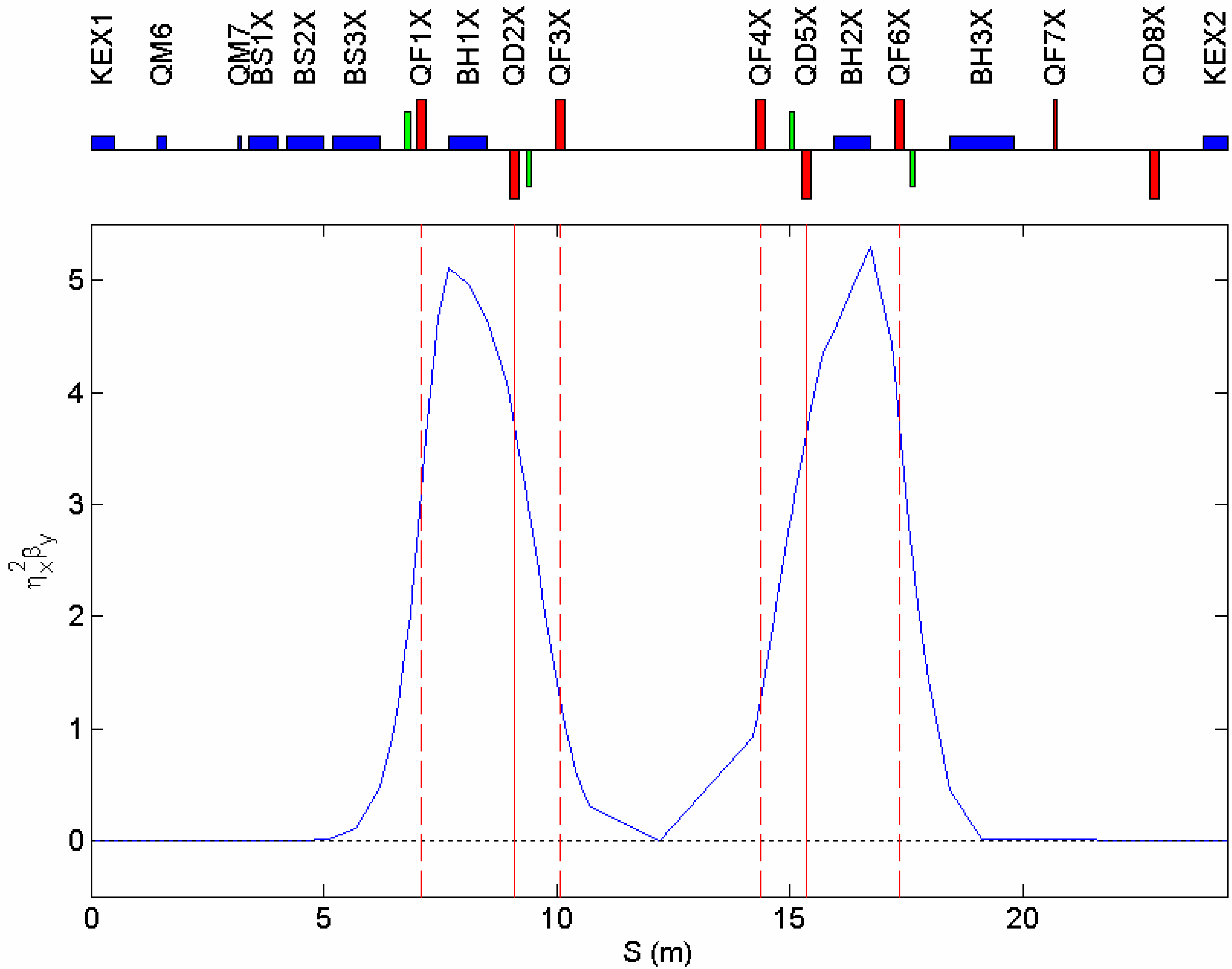
β_y (on-energy)

η_x (off-energy)

skew quads have equal strengths ("sum knob")

after 2nd skew quad




KEX1
QM6
QM7
BS1X
BS2X
BS3X
QF1X
BH1X
QD2X
QF3X
QF4X
QD5X
BH2X
QF6X
BH3X
QF7X
QD8X
KEX2
$\eta_x^2\beta_y$
S (m)
0
5
10
15
20
0
1
2
3
4
5

η_y correction: residual *x-y* coupling

$$R = \begin{bmatrix} R_{11} & R_{12} & R_{13} & R_{14} \\ R_{21} & R_{22} & R_{23} & R_{24} \\ R_{31} & R_{32} & R_{33} & R_{34} \\ R_{41} & R_{42} & R_{43} & R_{44} \end{bmatrix} \equiv \begin{bmatrix} \mathrm{A} & \mathrm{B} \\ \mathrm{C} & \mathrm{D} \end{bmatrix}$$

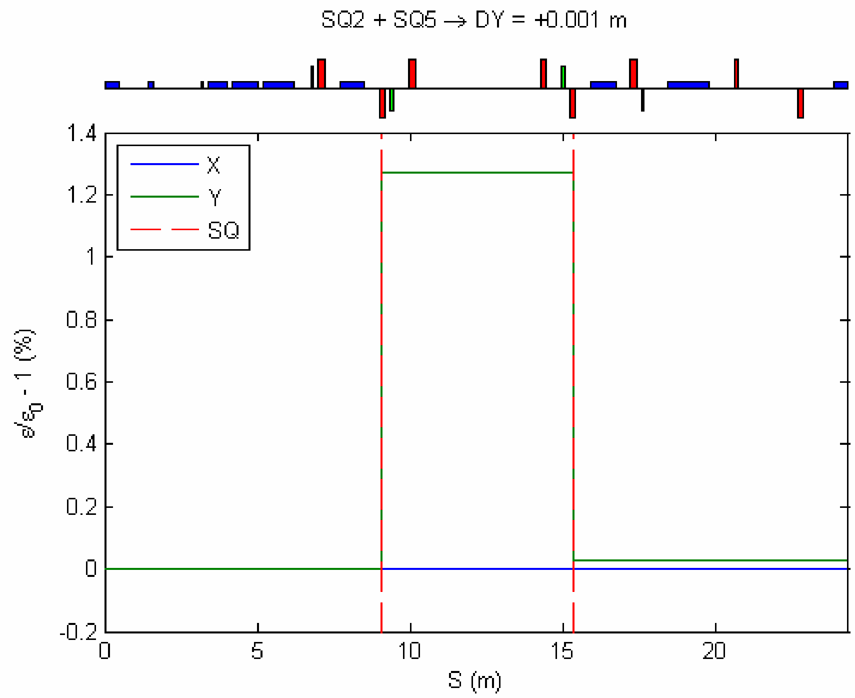
$$\mathrm{Q}_{x,y} \equiv \frac{1}{\sqrt{\beta_{x,y}}} \begin{bmatrix} \beta_{x,y} & 0 \\ -\alpha_{x,y} & 1 \end{bmatrix}$$

$$\mathrm{P} \equiv \mathrm{Q}_x^{-1} \mathrm{A}^{-1} \mathrm{B} \mathrm{Q}_y$$

$$\lambda = \mathrm{tr}\left(\mathrm{P}\mathrm{P}^{\mathrm{T}}\right)$$

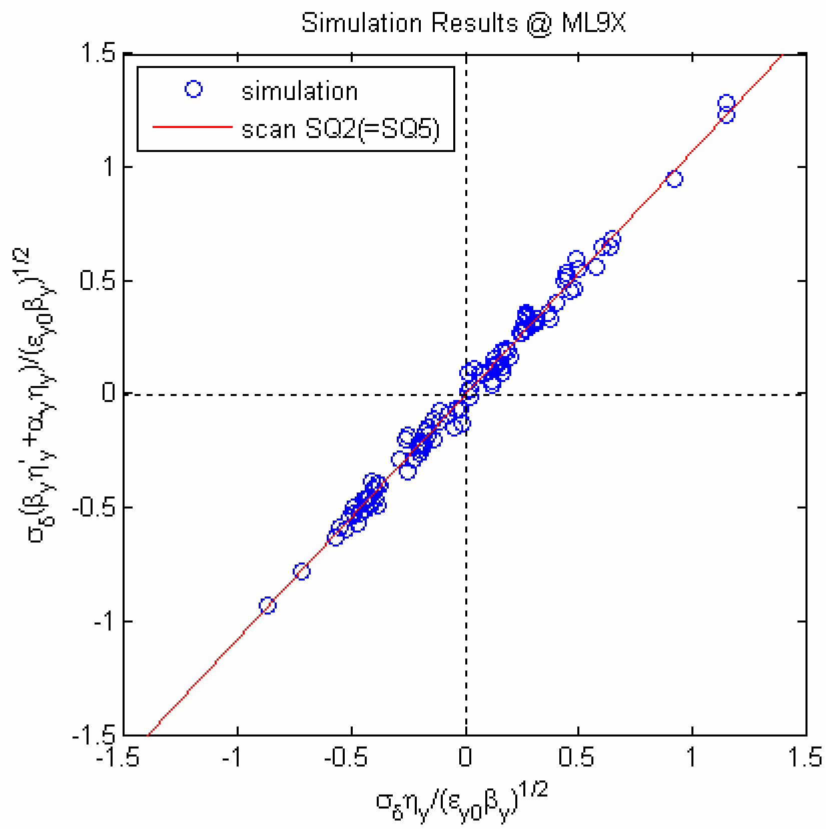
$$\varepsilon_x^2 = |\mathrm{A}|^2 \varepsilon_{x0}^2 + |\mathrm{C}|^2 \varepsilon_{y0}^2 + |\mathrm{A}|^2 \varepsilon_{x0}\varepsilon_{y0}\lambda$$

$$\varepsilon_y^2 = |\mathrm{C}|^2 \varepsilon_{x0}^2 + |\mathrm{A}|^2 \varepsilon_{y0}^2 + |\mathrm{A}|^2 \varepsilon_{x0}\varepsilon_{y0}\lambda$$



	SQ2	SQ5
βx =	14.557	13.494
αx =	-18.187	18.354
ηx =	0.177	-0.174
βy =	118.109	119.830
αy =	10.711	-12.069
Δμx =	-	5.337
Δμy =	-	172.957
kl/klmax =	0.012	0.012
residual =	0.0003	

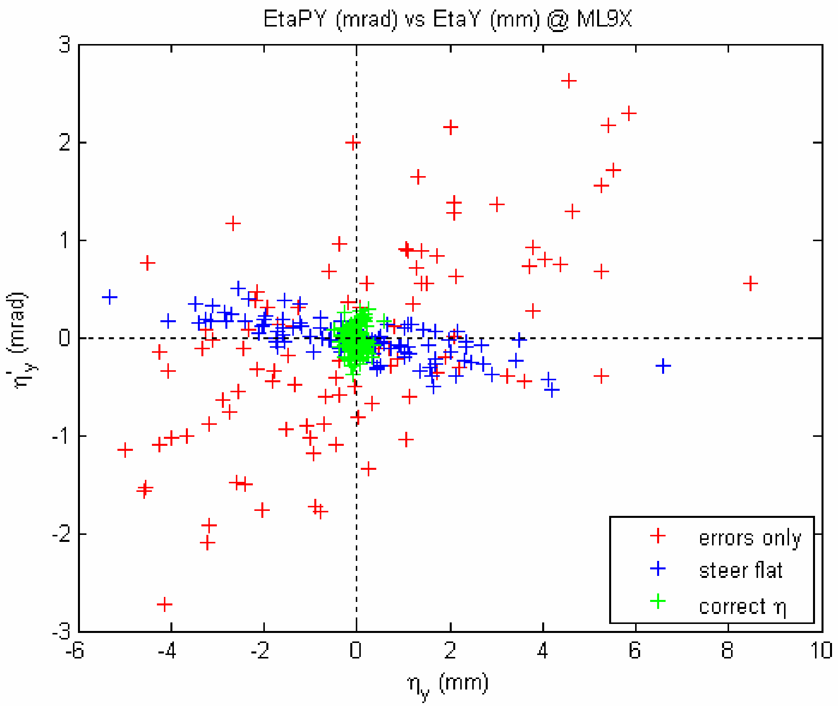
η_y and η'_y at ML9X (start of diagnostic section) after steering EXT flat (100 seeds)



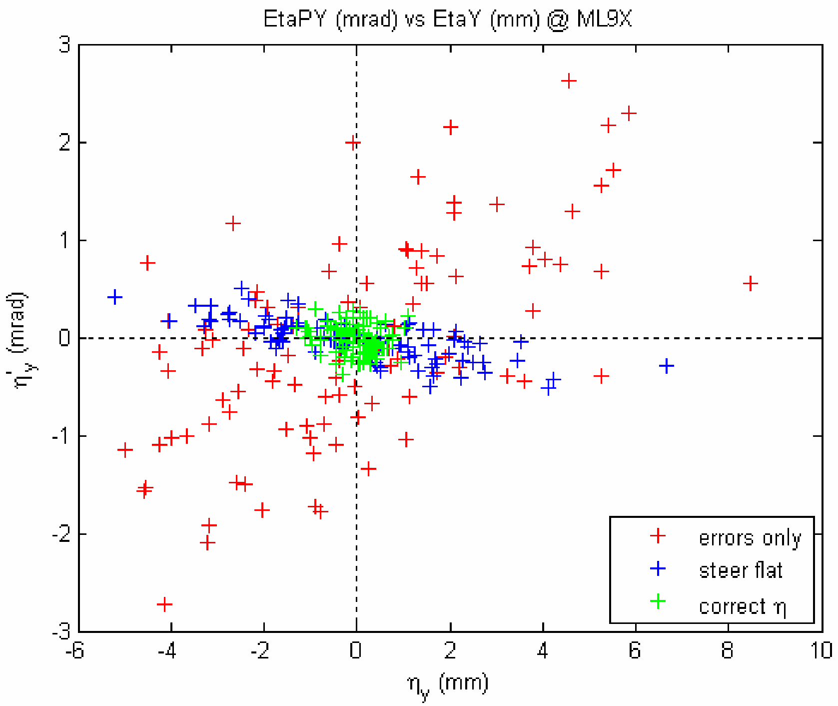
$$\frac{\varepsilon_y}{\varepsilon_{y0}} = \sqrt{1+\sigma_\delta^2\left\{\frac{\eta_y^2+\left(\beta_y\eta_y'+\alpha_y\eta_y\right)^2}{\varepsilon_{y0}\beta_y}\right\}}$$

@ ML9X: β_y = 1.675 m, α_y = 1.195

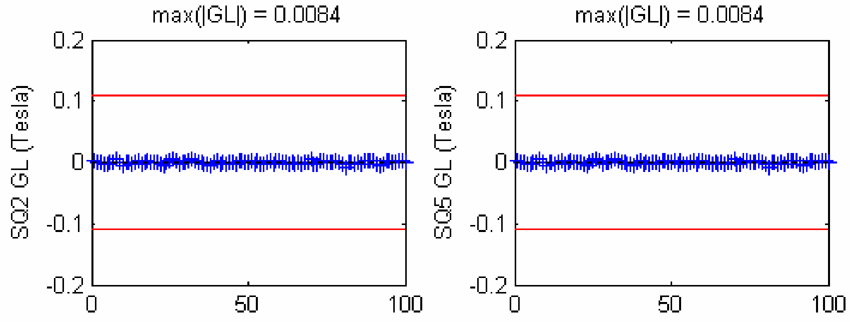
use SQ2 and SQ5 for η_y correction



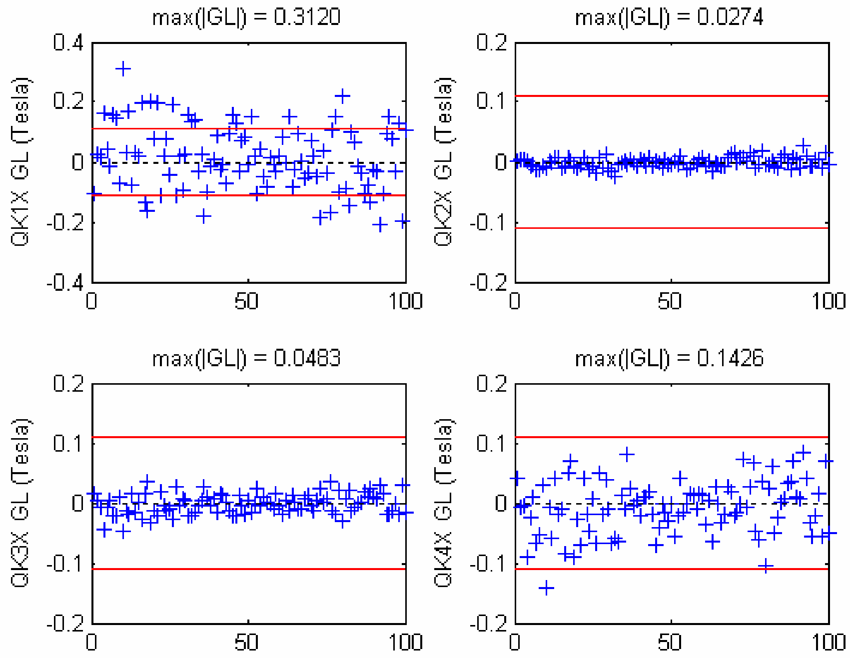
BPM resolution = 0

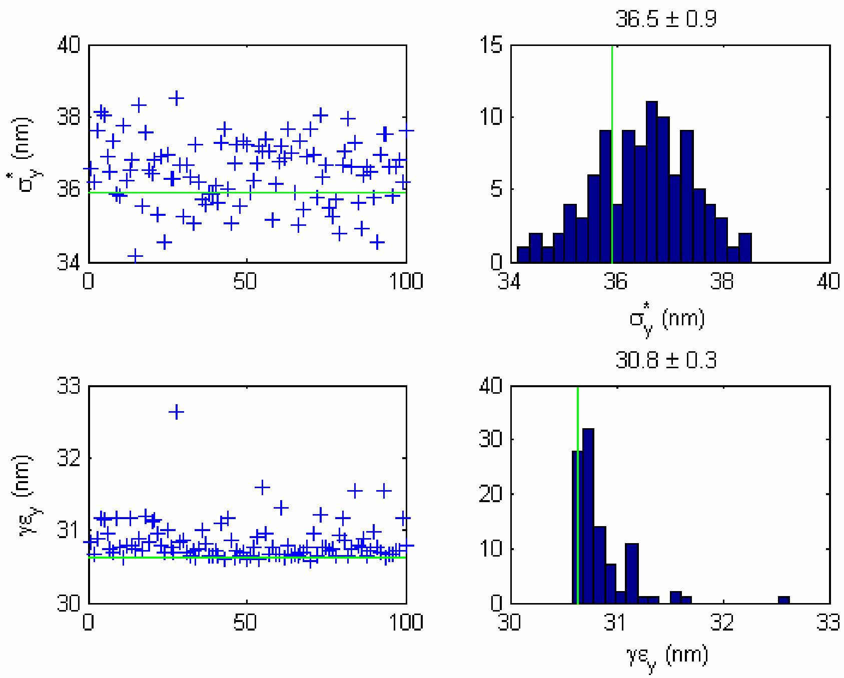


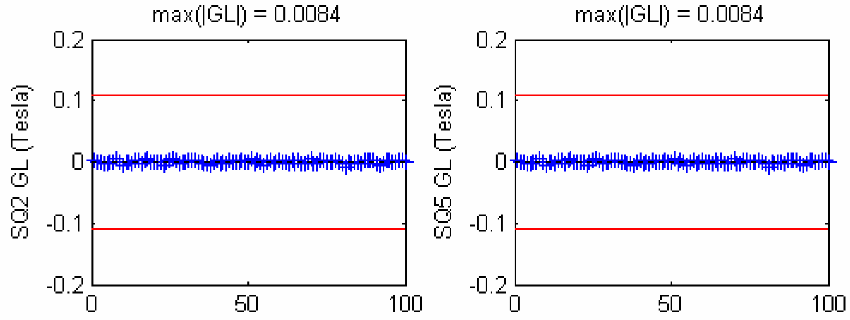
BPM resolution = 5 μm



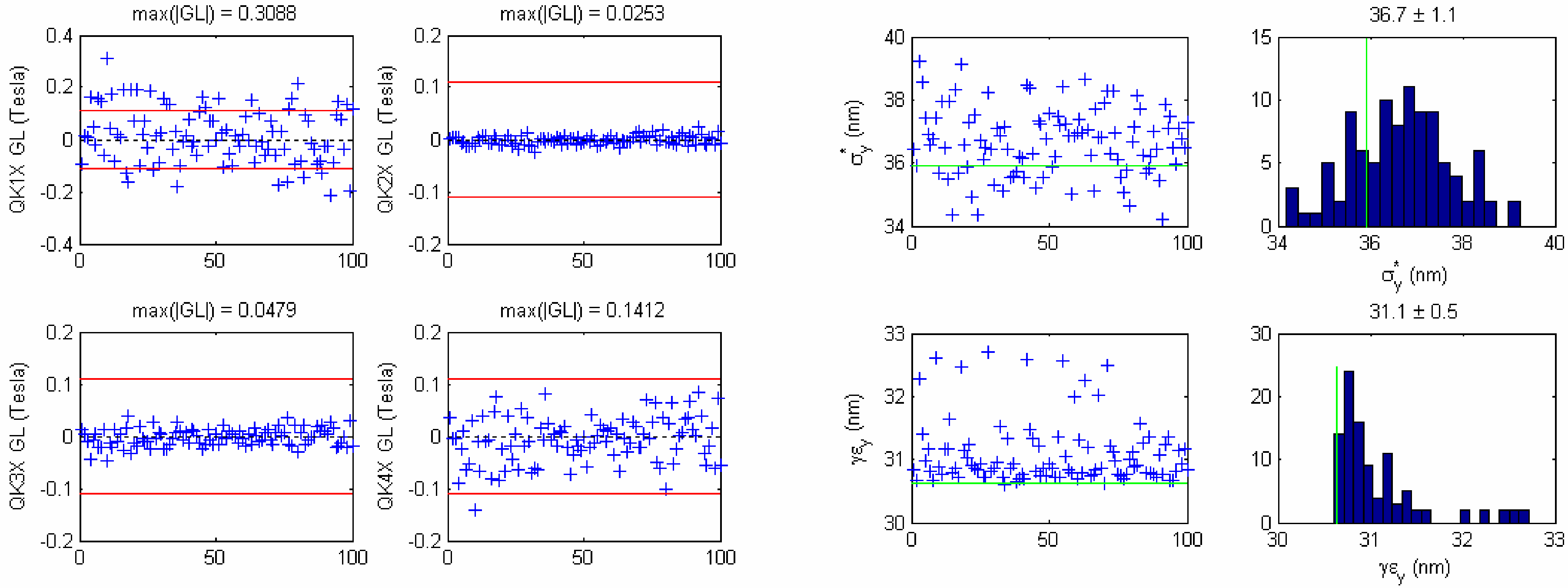
use SQ2 and SQ5 for η_y correction
(BPM resolution = 0)

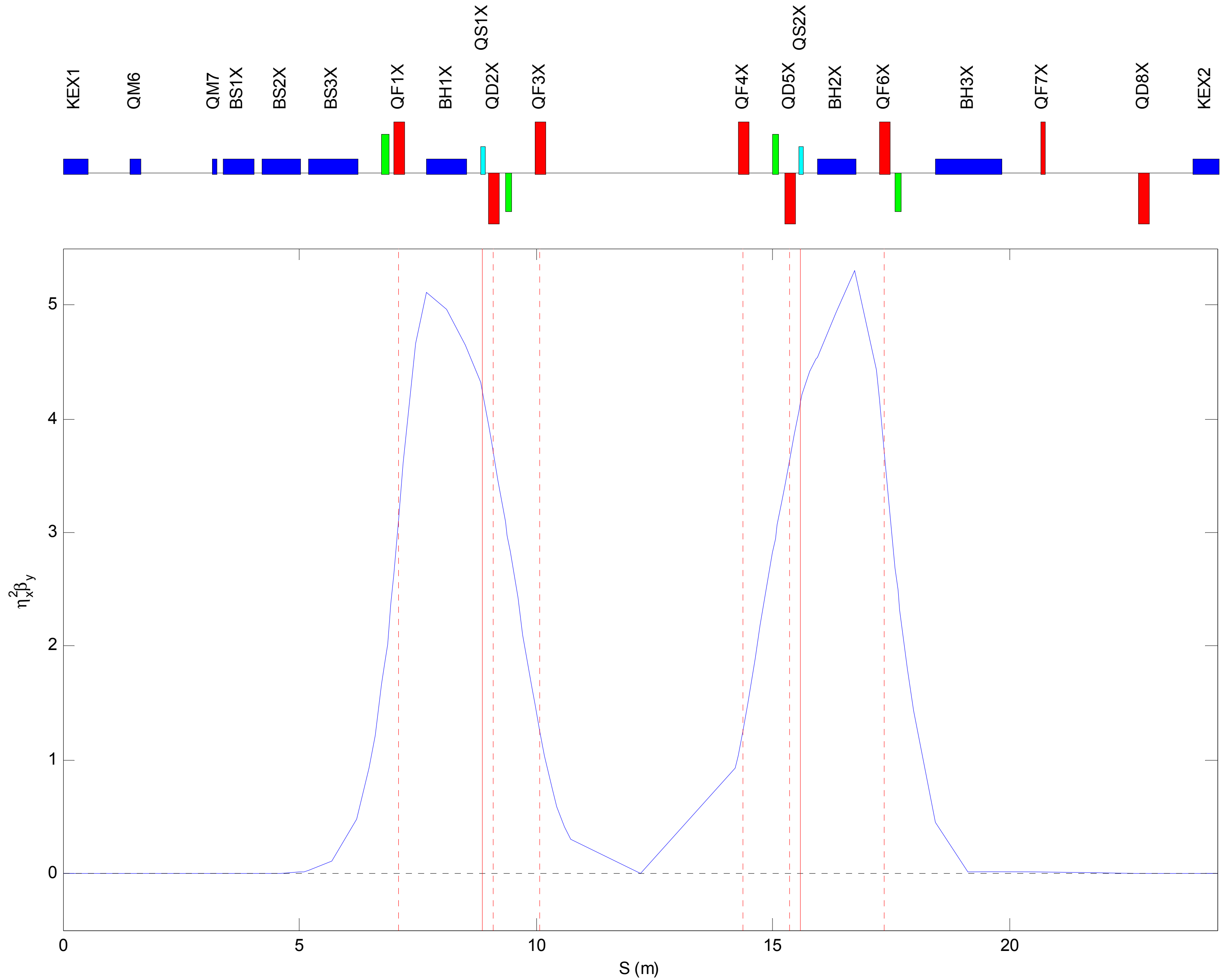




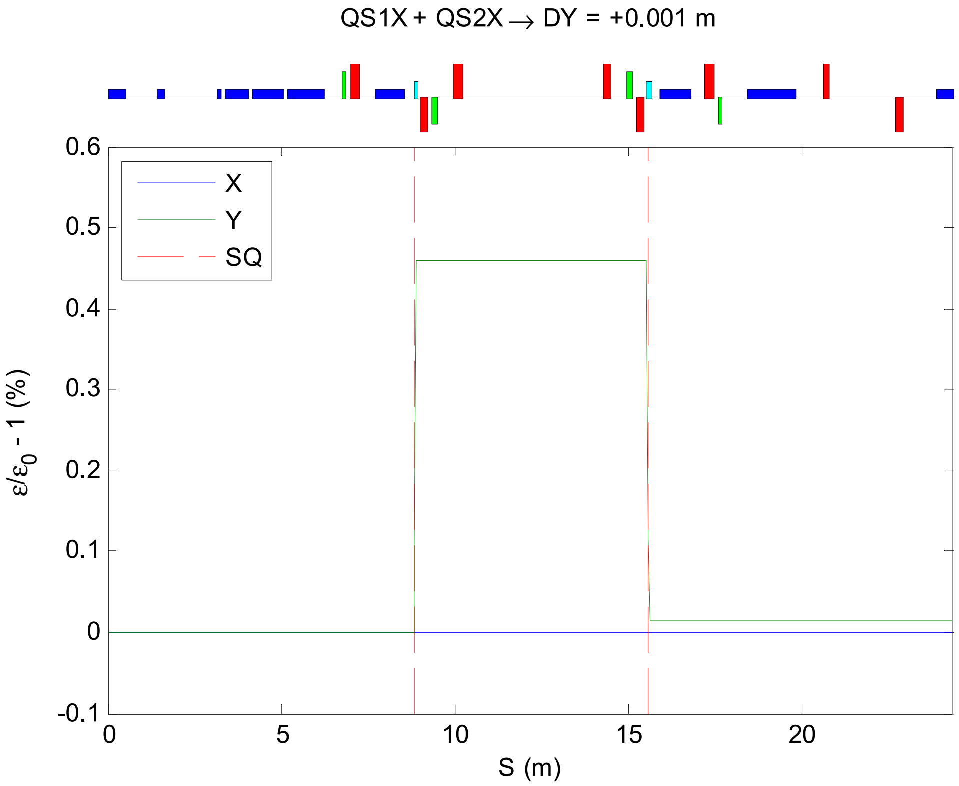


use SQ2 and SQ5 for η_y correction
(BPM resolution = 5 µm)



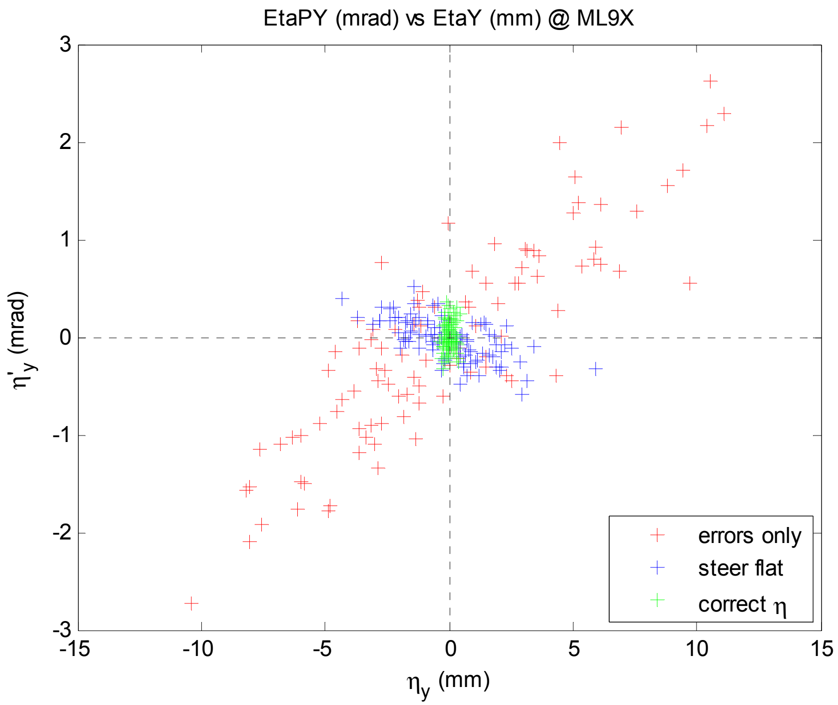


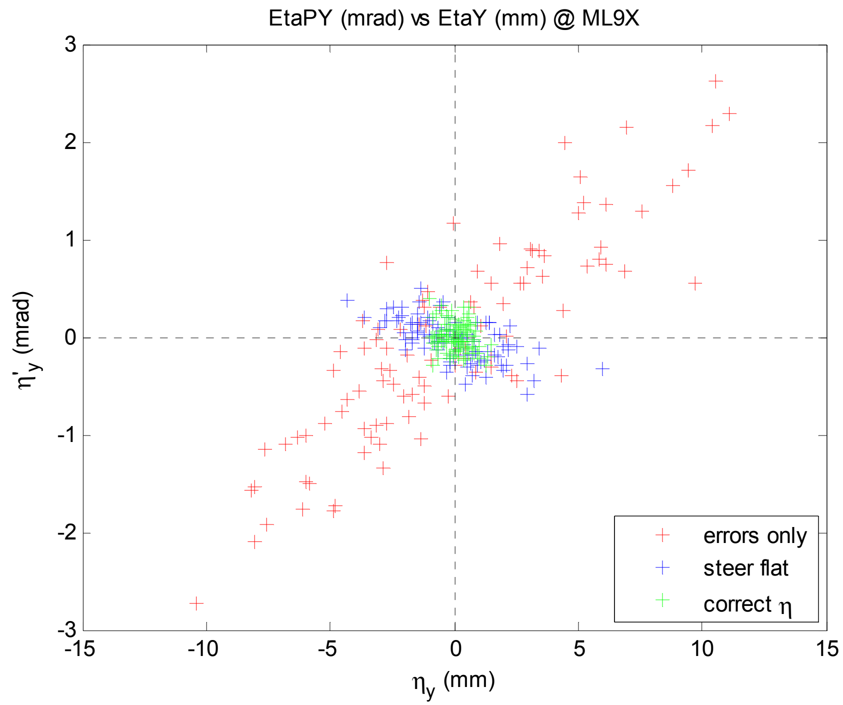
KEX1
QM6
QM7
BS1X
BS2X
BS3X
QF1X
BH1X
QS1X
QD2X
QF3X
QF4X
QS2X
QD5X
BH2X
QF6X
BH3X
QF7X
QD8X
KEX2
$\eta_x^2\beta_y$
S (m)
0
1
2
3
4
5
0
5
10
15
20



		QS1X	QS2X
βx	=	9.005	9.005
αx	=	-9.192	9.192
ηx	=	0.203	-0.203
βy	=	102.805	102.805
αy	=	-41.677	41.677
Δμx	=	-	7.710
Δμy	=	-	173.207
kl/klmax	=	0.121	0.121
residual	=	0.0001	

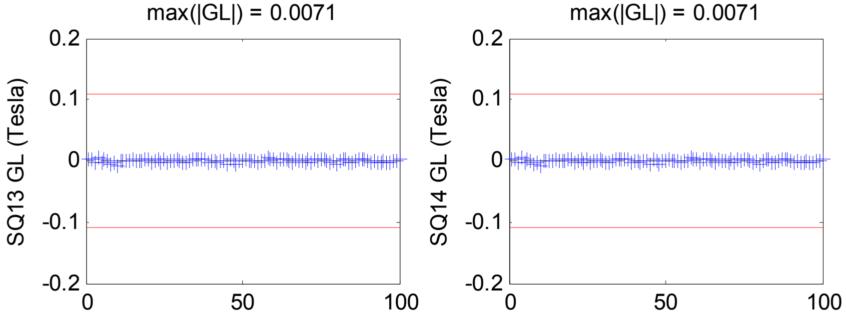
use QS1X and QS2X for η_y correction



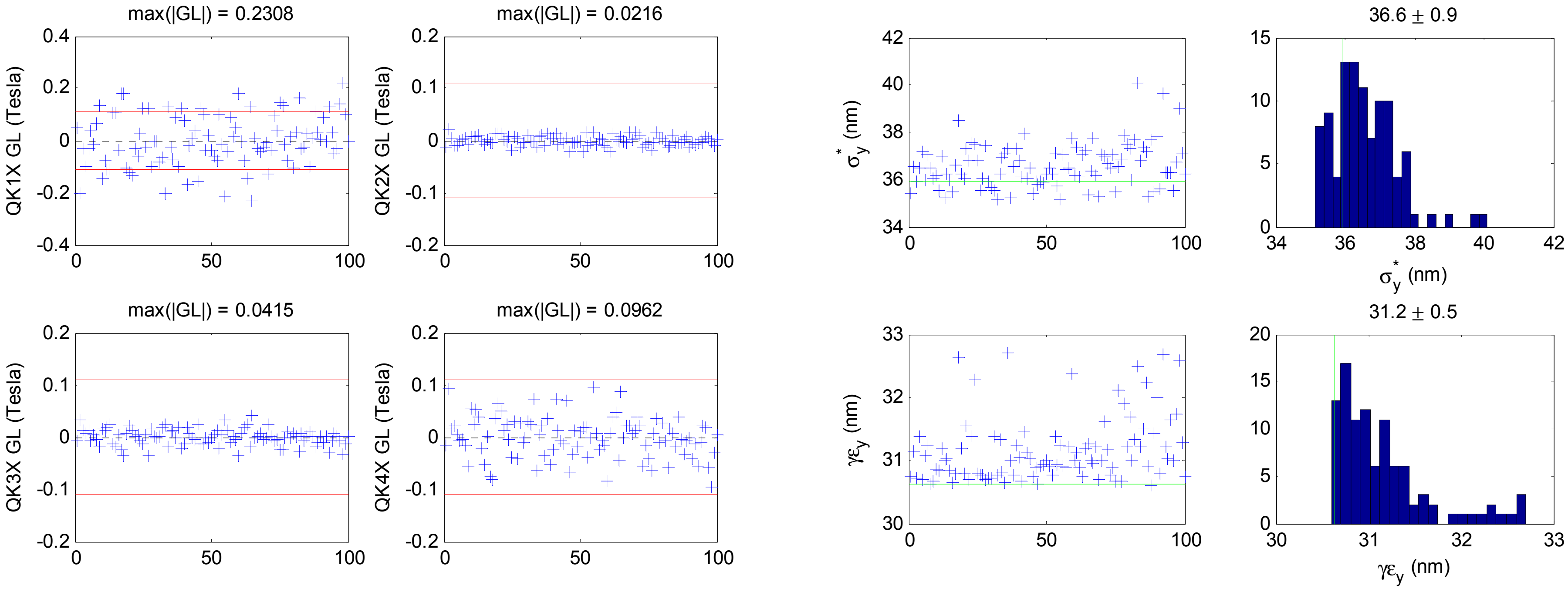


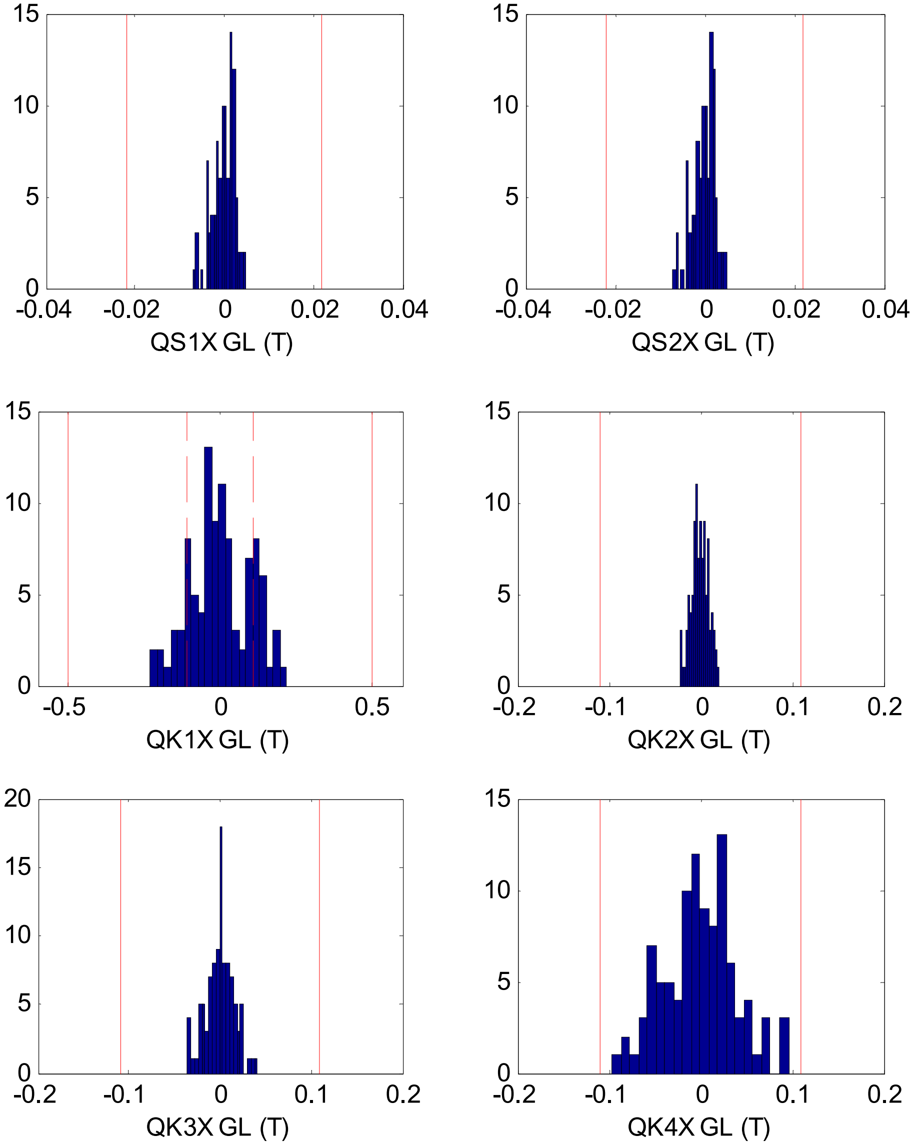
BPM resolution = 0

BPM resolution = 5 μm



use QS1X and QS2X for
η_y correction
(BPM resolution = 5 μm)





<u>QS1X, QS2X</u>

GLmax = 0.022 T

(20% IDX @ 5 amp)

<u>QK1X</u>

GLmax = 0.5 T

(Tokin 3393 @ 38 amp)

<u>QK2X, QK3X, QK4X</u>

GLmax = 0.11 T

(IDX @ 5 amp)

Conclusions

- simulated system performance, for the given errors and diagnostic resolution, is adequate for the achievement of ATF2 goal "A" (35 nm IP σ_y)
- including vertical dispersion correction provides 5% improvement in IP σ_y (10% in ε_y), and can be achieved with two skew quadrupoles (near QD2X and QD5X) with maximum integrated strengths of ≈ 0.02 T (corresponds to an IDX skew quad at 1 amp)
- coupling correction provides 10% improvement in IP σ_y (20% in ε_y)
- two of the coupling correction skew quadrupoles (QK2X and QK3X) can definitely be IDX skew quadrupoles; QK4X can probably be an IDX skew quadrupole (maybe with slightly higher maximum operating current?)
- QK1X, because it is in phase with all errors in the inflector that cause coupling, requires up to 3 times the strength of an IDX skew quadrupole at 5 amps, at least in these simulations … a Tokin 3393 quadrupole, converted to a skew quadrupole and operating at 40 amps maximum, would provide ≈ 50% overhead in strength

Continuing Work

- correction of vertical dispersion from the inflector is done by running QS1X and QS2X in “sum mode” (both with the same strength), which generates dispersion but no coupling … running these skew quadrupoles in “difference mode” (opposite strengths) should generate coupling but no dispersion; because these skew quadrupoles are in phase with the coupling errors in the inflector, perhaps this effect can be used to reduce the required strength of QK1X
- coupling errors in the DR extraction channel must be included in future simulations … if emittance growth is happening there now, it will still be happening after the EXT rebuild, and our diagnostic and correction tools must be able to deal with such errors
- the effects of finite wire scanner resolution on the tune-up scheme must be studied
- magnet strength errors, BPM offsets, and BPM rolls should be included
- it should be possible to correct the vertical dispersion by minimizing the projected vertical emittance, similar to scanning one of the coupling correction skew quadrupoles, rather than by changing the DR energy, measuring dispersion on BPMs, and back-propagating … these two methods should be compared