OPTICAL STOCHASTIC COOLING IN IOTA

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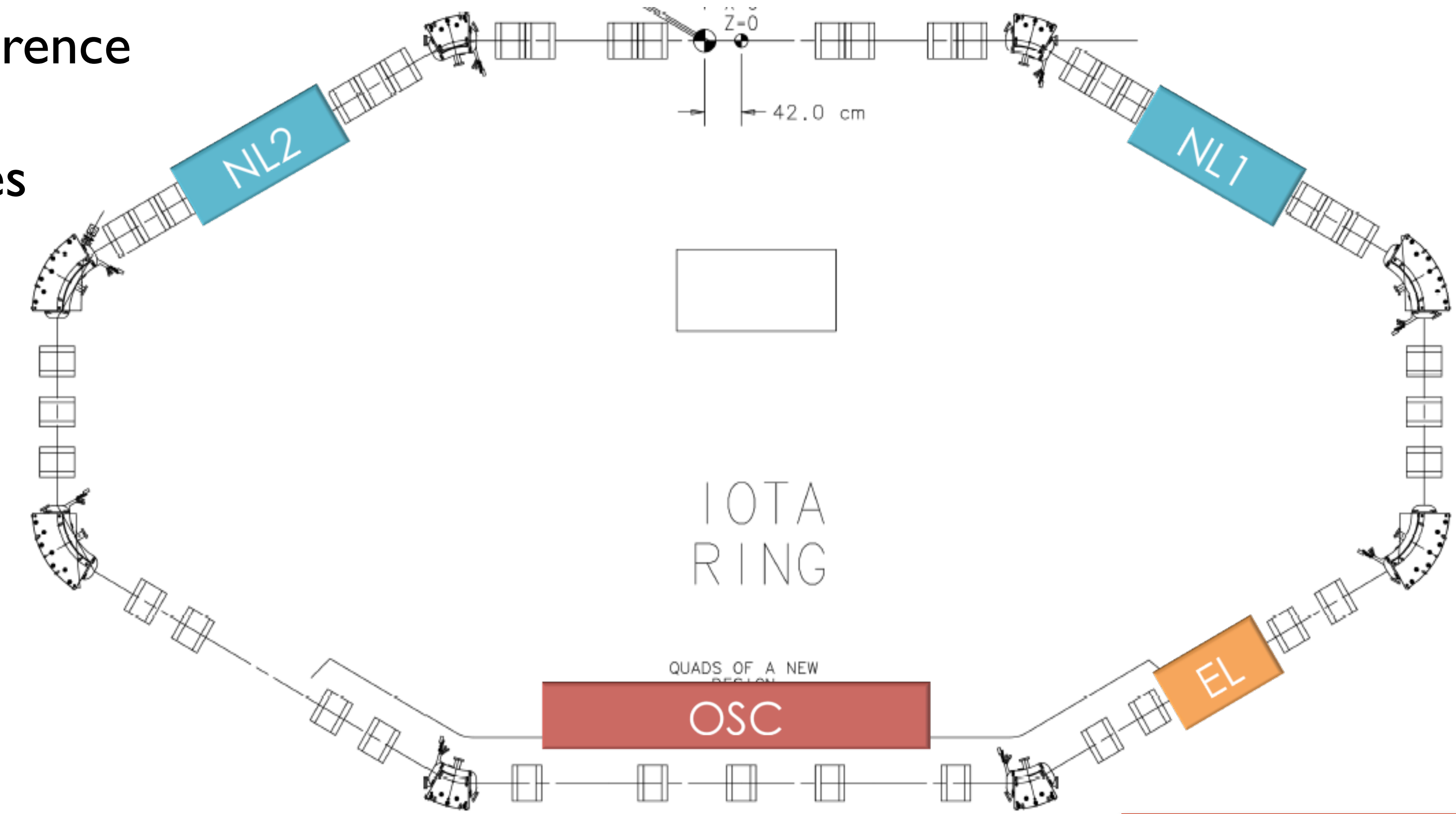
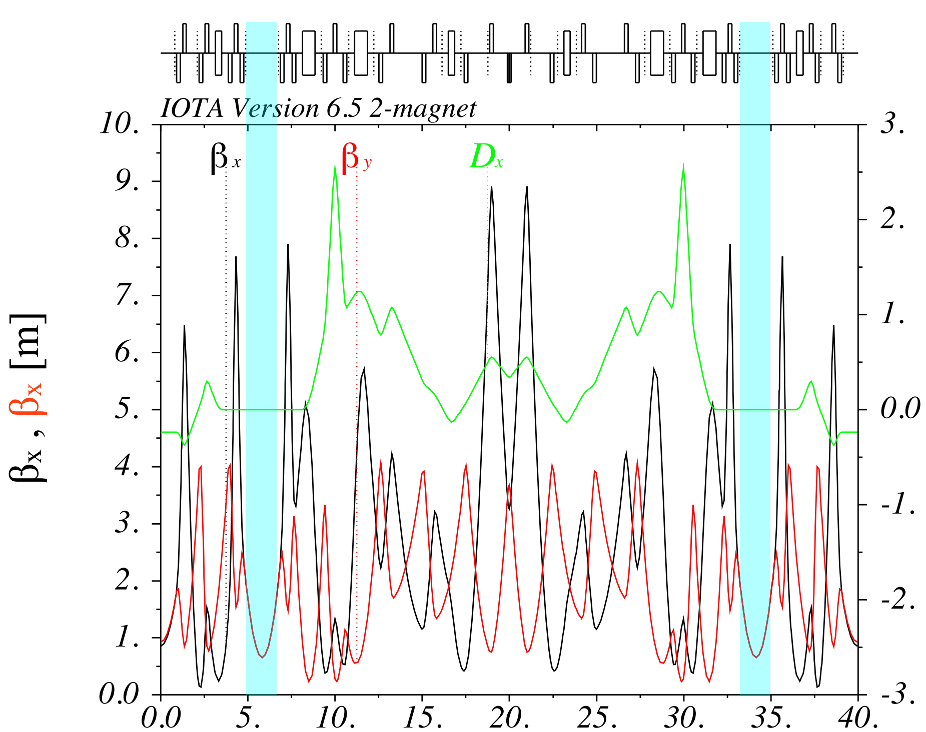
EXPERIMENTS IN IOTA

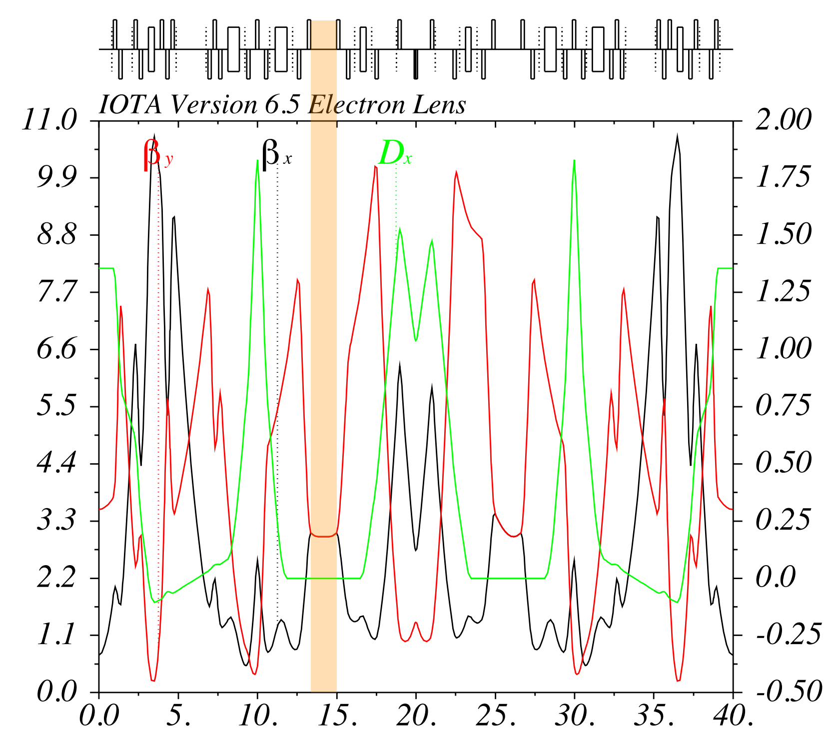
- 40 m circumference
- 8 dipoles
- 39 quadrupoles



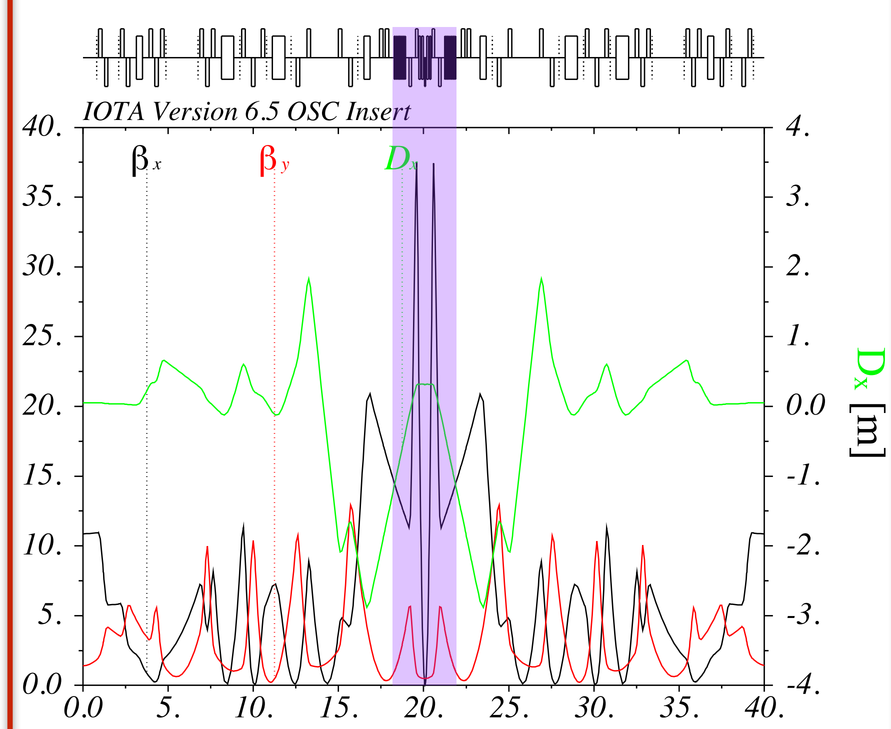
Nonlinear Integrable Optics



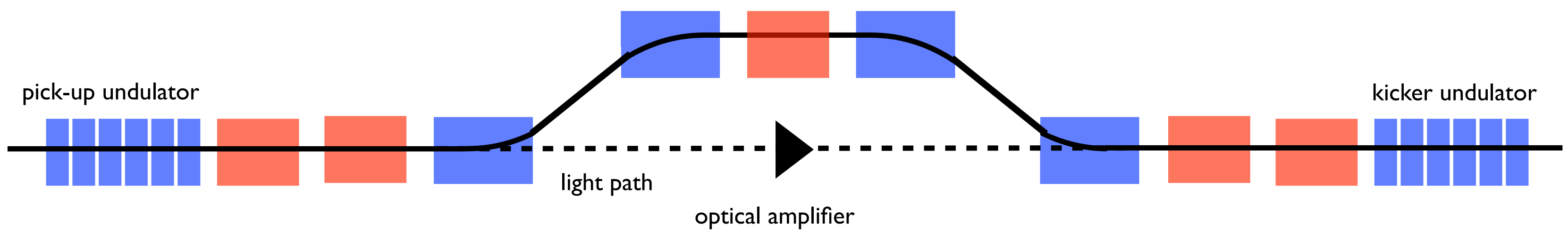
Electron Lens



Optical Stochastic Cooling



TEST OF OSC IN IOTA

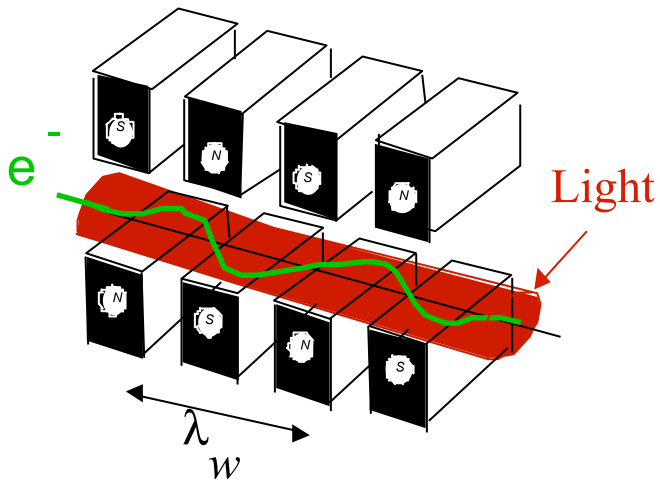


- OSC was first attempted in BATES in 2007
  - existing electron synchrotron
  - did not receive enough support

- Will be one of several tests in IOTA
  - test in small electron ring is cost effective

IOTA Parameters in OSC mode	Value
Circumference	40 m
Nominal Beam energy	100 MeV
Bending field	4.8 kG
Transverse RMS emittances,	11.5 nm
RMS momentum spread	1.23 x 10
SR damping times (ampl.),	1.4 / 0.67 s

OSC PRINCIPLES

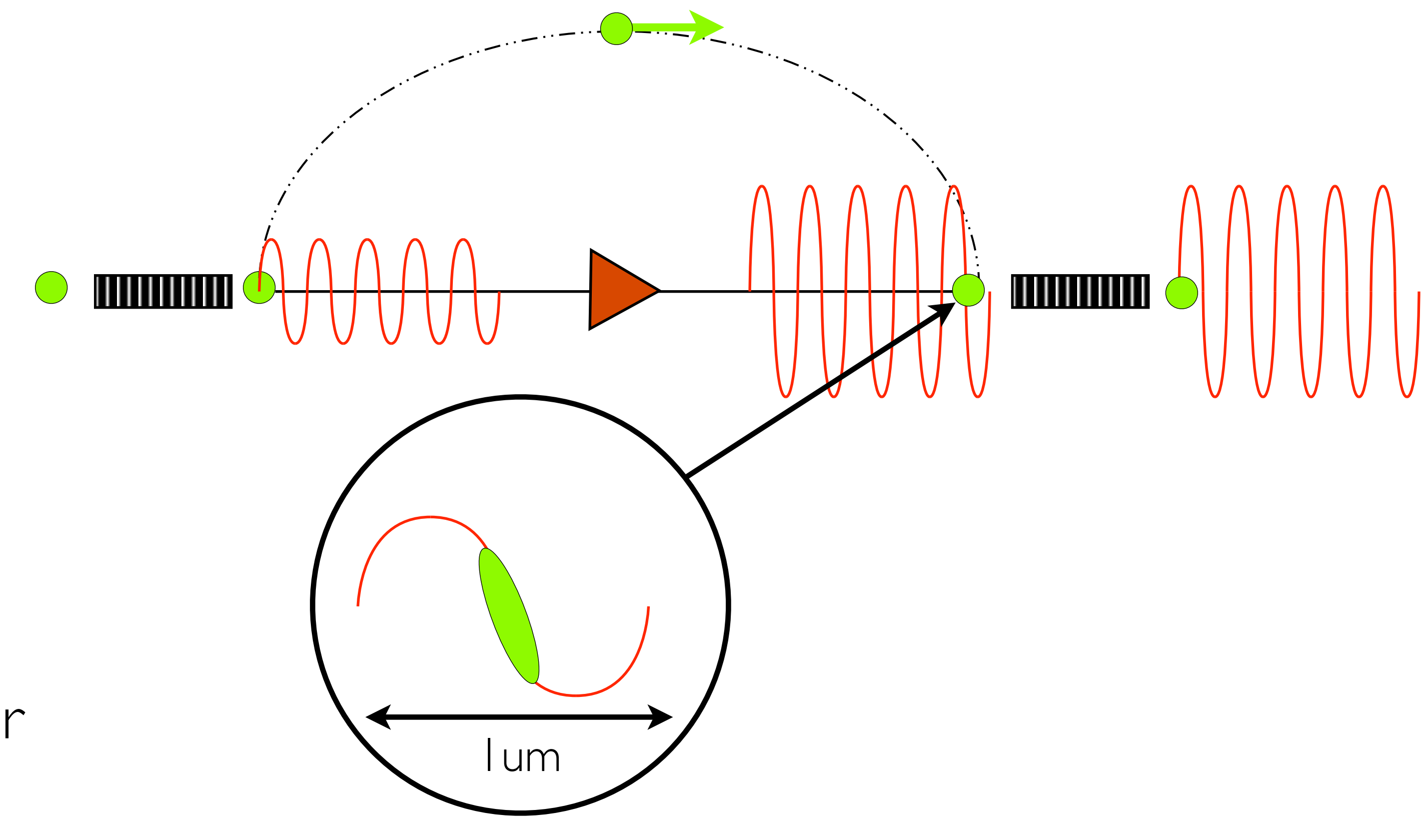


undulator period

laser wavelength

undulator parameter

$$\lambda_w = \frac{2\gamma^2 \lambda_L}{\left(1 + \frac{K^2}{2}\right)}$$



Only longitudinal kicks are effective for cooling:

cooling heating

$$\Delta\delta_i = \kappa \sin(k\Delta s_i) - \kappa \sum_{k \neq i}^{N} \sin(k\Delta s_i + \psi_{ik})$$

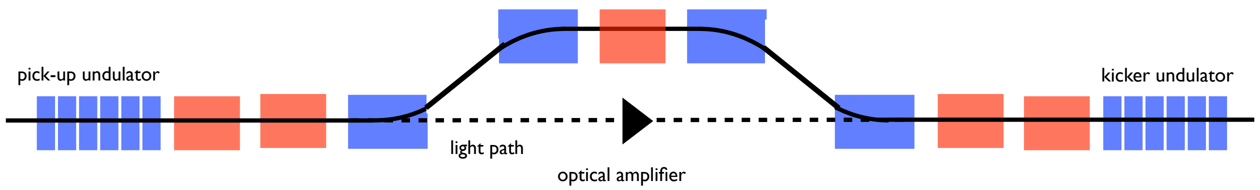
particle delay

- At optimum cooling rate is:
  - ~(bandwidth)/(number of slices in the sample)
- Correction signal is proportional to longitudinal position change
- Only longitudinal kicks are effective
  - longitudinal cooling requires s-x coupling
  - transverse cooling requires x-y coupling

OSC OPTICS

- Pickup-to-kicker Transfer Matrix (vertical plane is uncoupled and omitted)

$$\begin{bmatrix} x \\ \theta_x \\ s \\ \Delta p/p \end{bmatrix} = \begin{bmatrix} M_{11} & M_{12} & 0 & M_{16} \\ M_{21} & M_{22} & 0 & M_{26} \\ M_{51} & M_{52} & 1 & M_{56} \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x \\ \theta_x \\ s \\ \Delta p/p \end{bmatrix}$$



- Partial slip factor (pickup-to-kicker) describes a particle's longitudinal displacement

$$\tilde{M}_{56} = C\eta_{pk} = M_{51}D_p + M_{52}D'_p + M_{56}$$

- First order approximation of the LONGITUDINAL KICK in the pickup:

$$\Delta\delta = \kappa\Delta s = \kappa\left(M_{51}x + M_{52}\theta_x + M_{56}\frac{\Delta p}{p}\right)$$

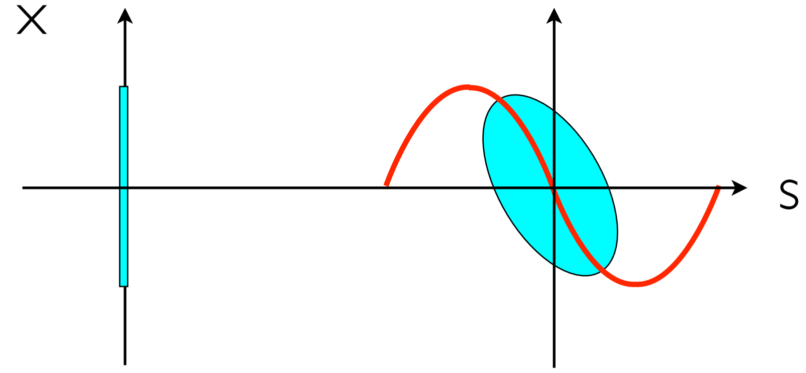
- Cooling rates per turn:

$$\begin{bmatrix} \lambda_x \\ \lambda_s \end{bmatrix} = \frac{\kappa}{2}\begin{bmatrix} M_{56} - \tilde{M}_{56} \\ C\eta_{pk} \end{bmatrix}$$

- x-y coupling outside the bypass allows for redistribution of horizontal damping rate into both transverse planes

OSC OPTICS

- A zero length sample will lengthen on its way from the pickup to the kicker; to first approximation, this is a linear kick.

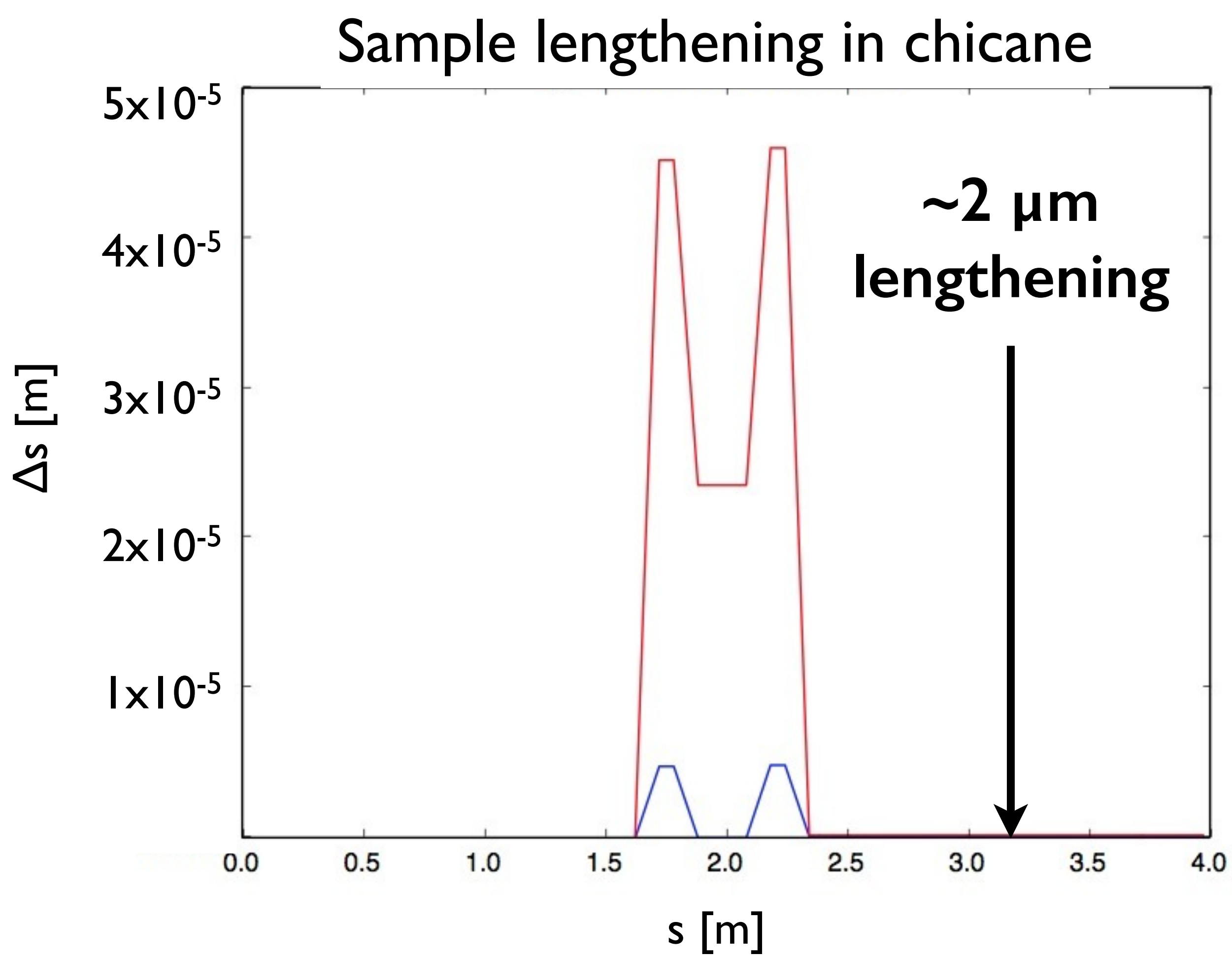


- Both $\Delta p/p$ and ε contribute to the sample lengthening $\sigma^2_{\Delta s} = \sigma^2_{\Delta s\varepsilon} + \sigma^2_{\Delta sp}$
  - For a Gaussian distribution:

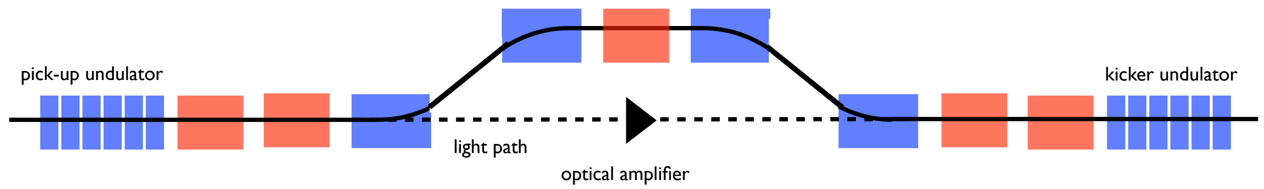
$$\sigma^2_{\Delta s\varepsilon} = \varepsilon\left(\beta_p M_{51}^2 - 2\alpha_p M_{51} M_{52} + \gamma_p M_{52}^2\right)$$

$$\sigma^2_{\Delta sp} = \sigma_p^2\left(M_{51} D_p - M_{52} D'_p + M_{56}\right)^2$$

- In the linear approximation, β_p and α_p do not affect damping rates, but affect sample lengthening and consequently the cooling range



OSC OPTICS



- The first approximation of cooling dynamics are determined by the:
  - orbit offset, h
  - path lengthening, δs
  - defocusing strength of the chicane quad, Φ
  - D^* and β^* in the center of the chicane
- δs is set by the delay in the amplifier
- $\Phi D^* h$ is set by the ratio of decrements
- The dispersion invariant, A, in the dipoles determines the equilibrium emittance.

$$M_{56} \approx 2\Delta s,$$

$$\tilde{M}_{56} \approx 2\Delta s - \Phi D^* h,$$

$$\lambda_x / \lambda_s \approx \Phi D^* h / \left(2\Delta s - \Phi D^* h\right),$$

transverse cooling range

$$n_{\sigma x} \approx \frac{\mu_0}{k\sigma_p}\left(2\Delta s - \Phi D^* h\right),$$

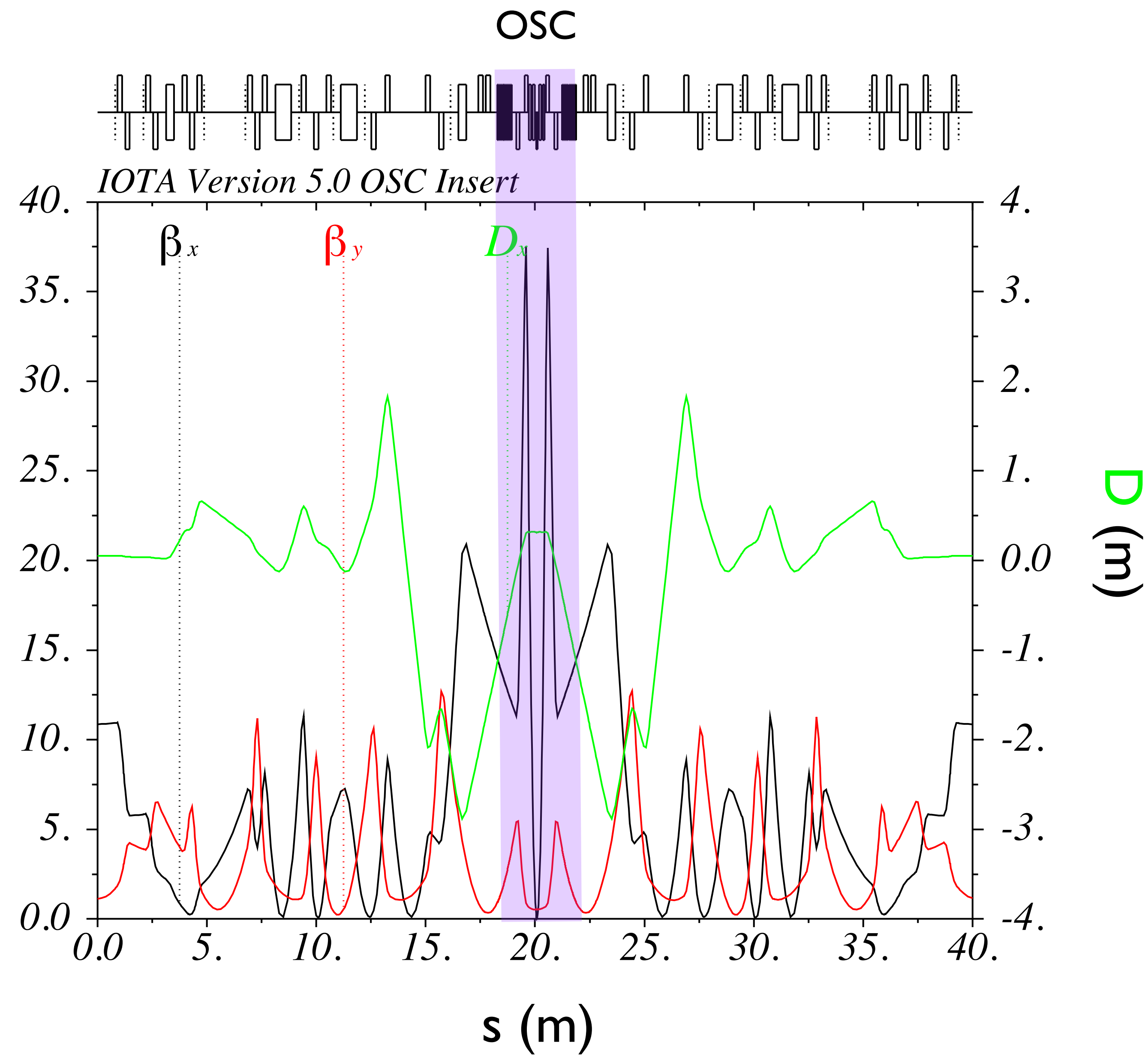
$$n_{\sigma x} \approx \frac{\mu_0}{2kh\Phi\sqrt{\varepsilon\beta^*}},$$

$$\Phi D^* h \approx \frac{\mu_0}{2kn_{\sigma x}}\sqrt{\frac{A^*}{\varepsilon}}$$

V. Lebedev

OSC OPTICS

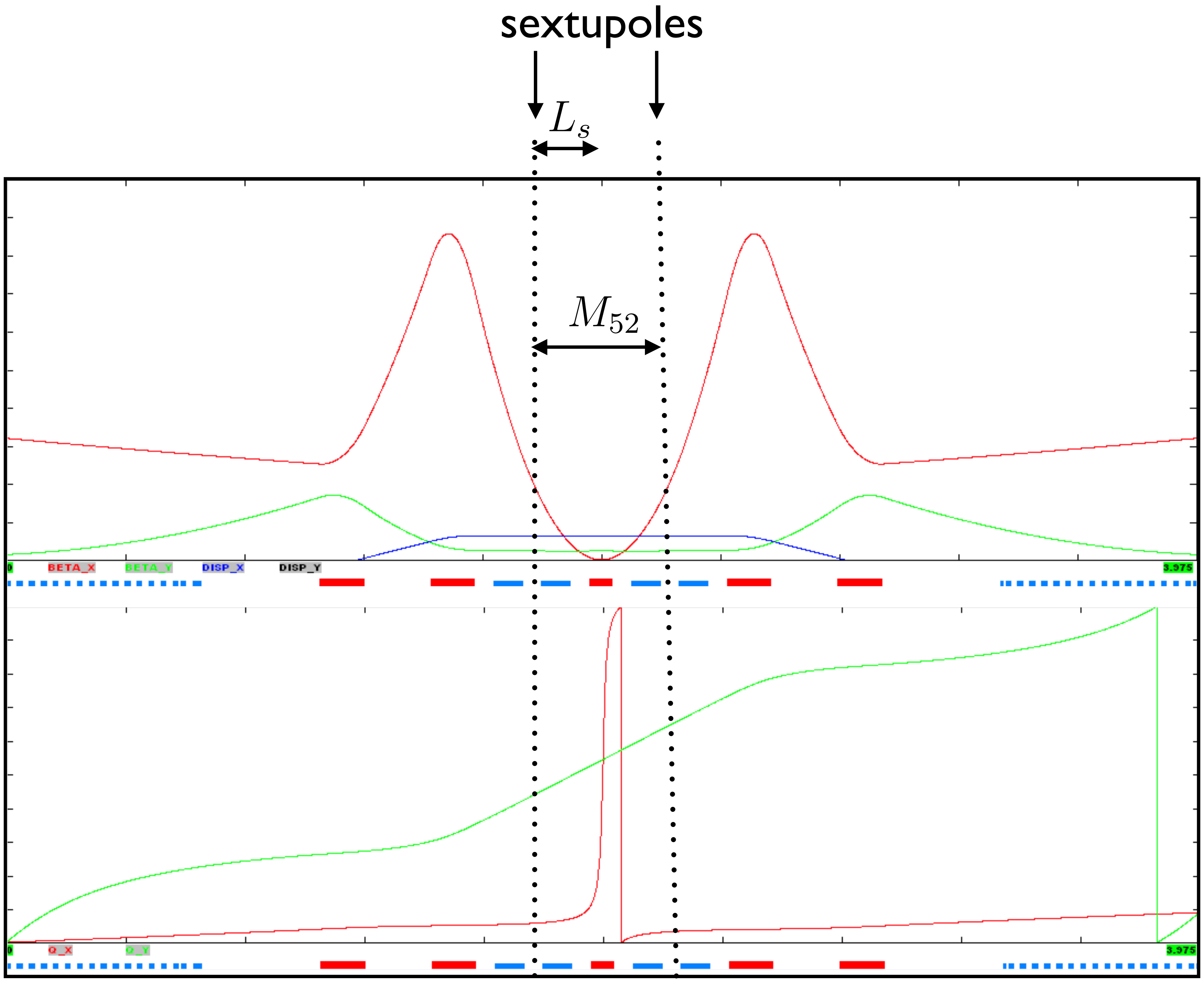
Cooling Chicane Parameters	Value
Delay in the chicane, Δs	2 mm
Horizontal beam offset, *h*	2.01 cm
M_{56}	3.95 mm
D^*	30 cm / 0.8 cm
Cooling rates ratio, $\lambda x=\lambda y/\lambda s$	1.18
Cooling ranges (before OSC)	2.1 / 3.2
Dipole: magnetic field * length	4.22 kG * 10 cm
Strength of central quad, GdL	1.58 kG
Damping rates (x=y/s)	200/170 Hz



- Energy reduced from 150 MeV to reduce ε, σ_p and undulator period and length
- Operating at the coupling resonance Qx/Qy=5.83/3.83 reduces horizontal emittance and introduces vertical damping
- Small β^* is required to minimize sample lengthening due to betatron motion

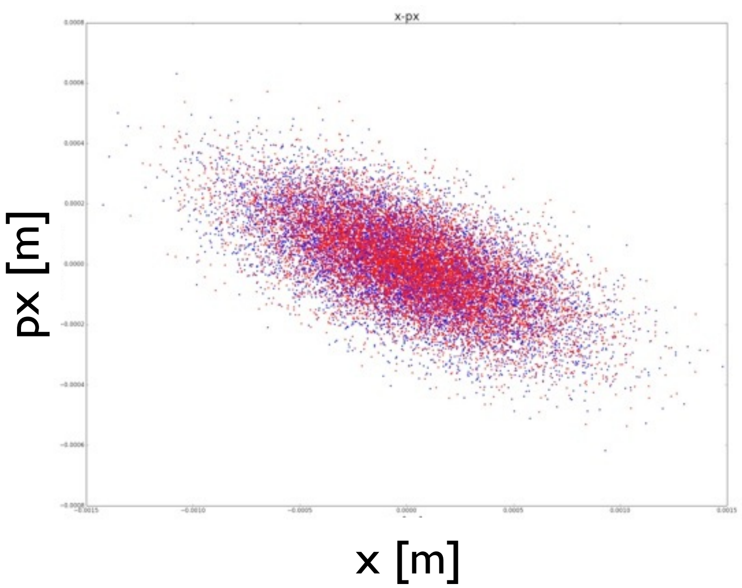
OSC OPTICS SECOND ORDER OPTICS

$$\delta\theta = \frac{\rho s L}{pc} x^2 = \frac{SL\left(L_s\theta\right)^2}{pc} \qquad \Delta L_s = M_{52}\delta\theta = M_{52}\frac{\rho S L L_s^2 \epsilon}{pc\beta^*}$$



OSC SECOND ORDER OPTICS

Using a realistic IOTA beam to develop second order optics



$$\Sigma_{beam} = V_{[6\times 6]}\varepsilon_{[6\times 6]}V^{T}_{[6\times 6]} =$$

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[[  1.417e-07  -3.479e-08   0.          0.          1.185e-07  -1.893e-08]
 [ -3.479e-08   2.131e-08   0.          0.         -1.169e-08   1.627e-08]
 [  0.          0.          5.509e-09   7.390e-09   0.          0.        ]
 [  0.          0.          7.390e-09   3.693e-08   0.          0.        ]
 [  1.185e-07  -1.169e-08   0.          0.          1.316e-04   9.088e-12]
 [ -1.893e-08   1.627e-08   0.          0.          9.088e-12   1.427e-08]]
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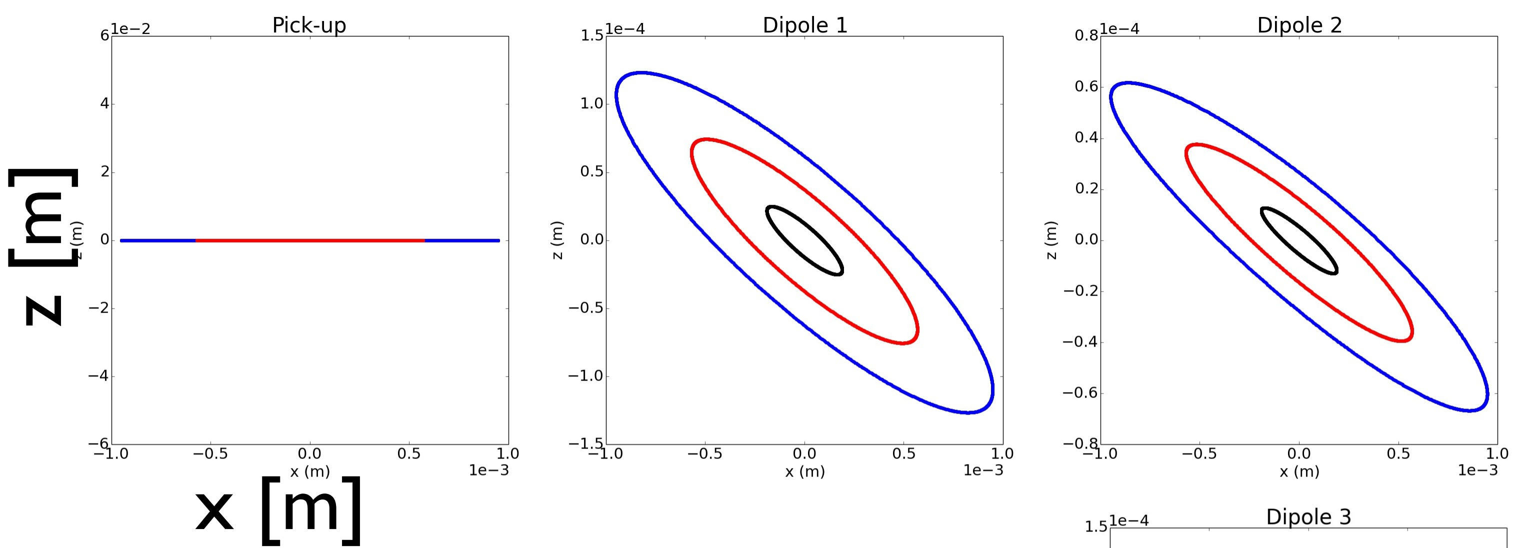
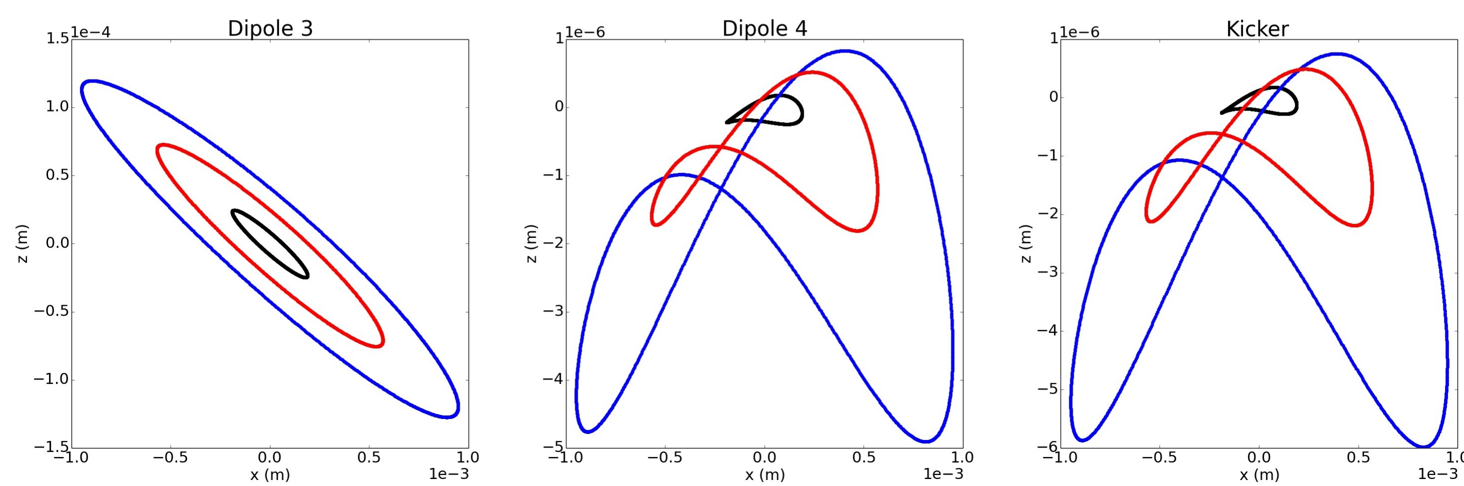
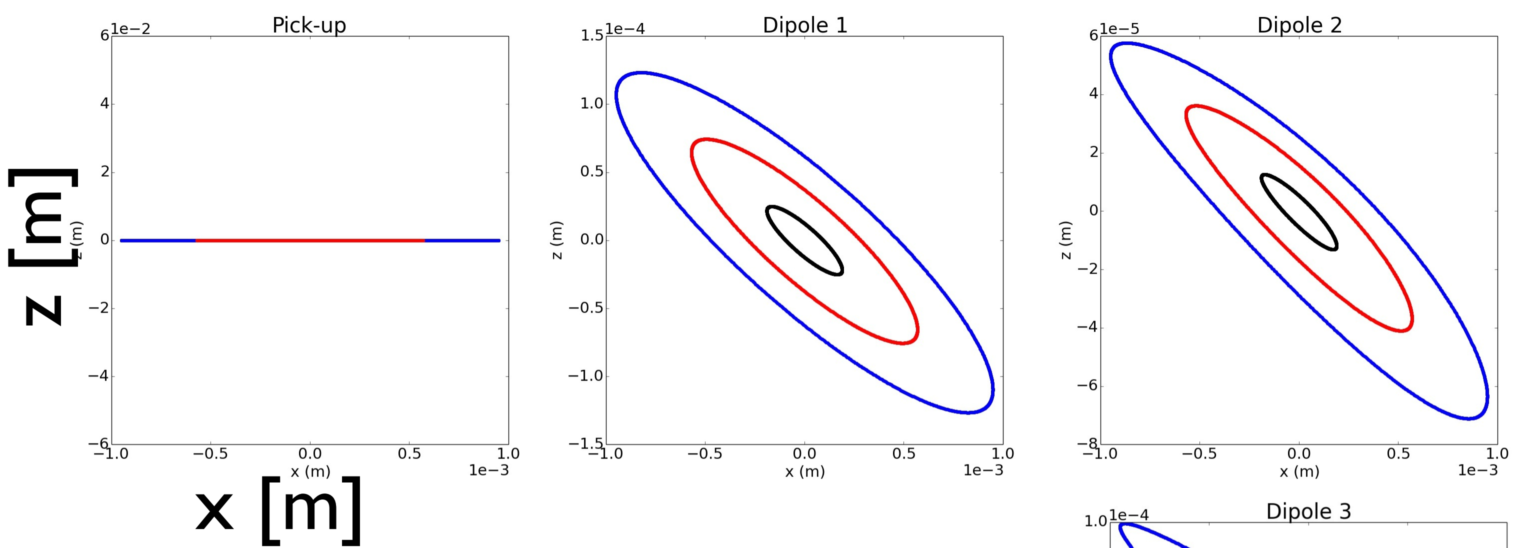


SAMPLE LENGTHENING DUE TO HORIZONTAL EMITTANCE

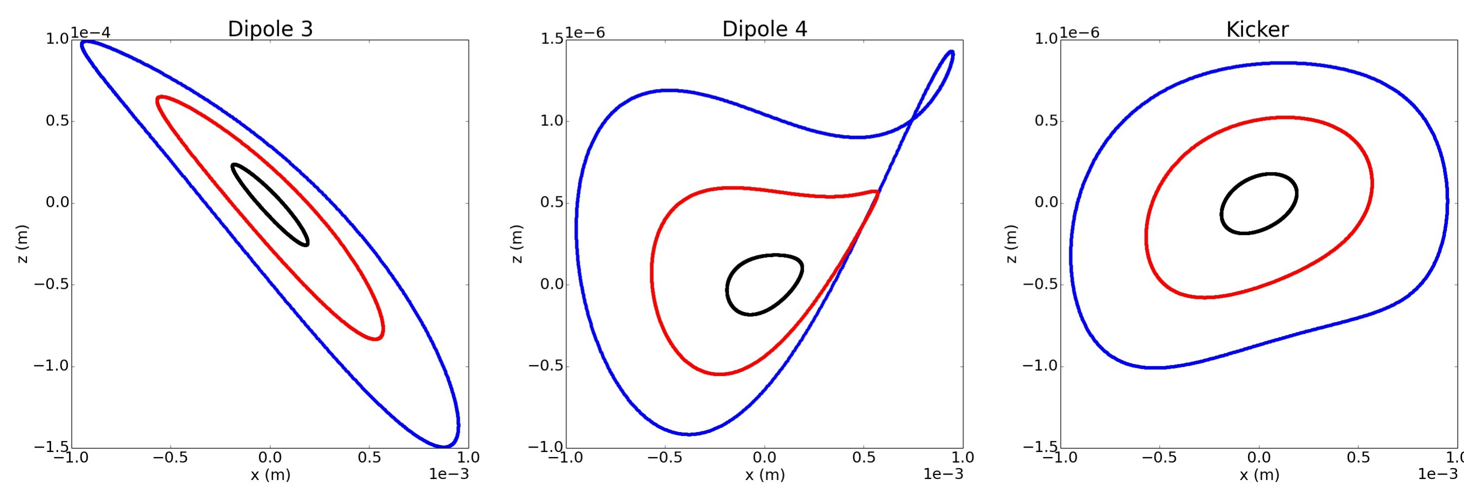


OSC SECOND ORDER OPTICS



SAMPLE LENGTHENING
DUE TO
HORIZONTAL EMITTANCE

WITH SEXTUPOLES



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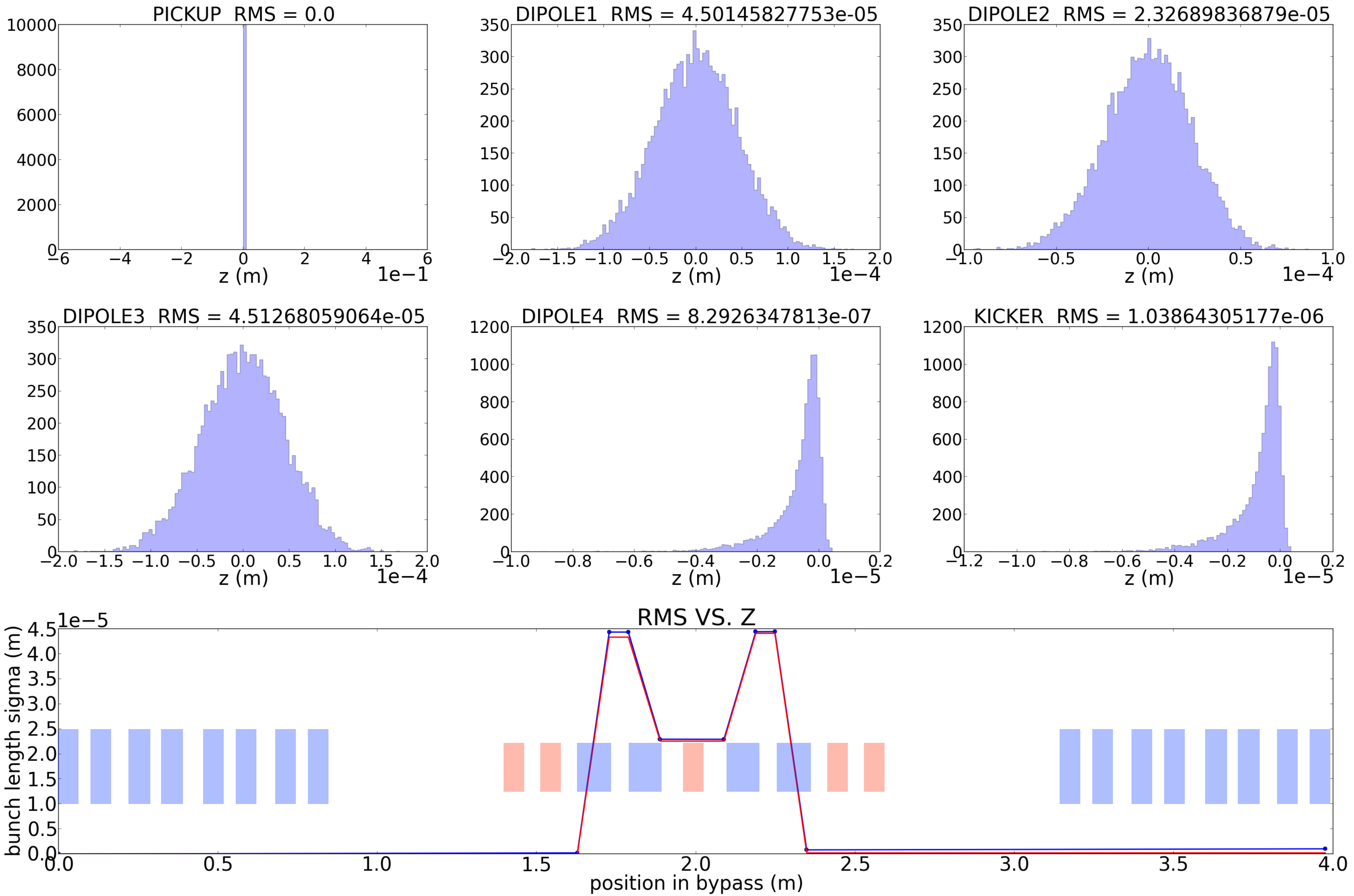
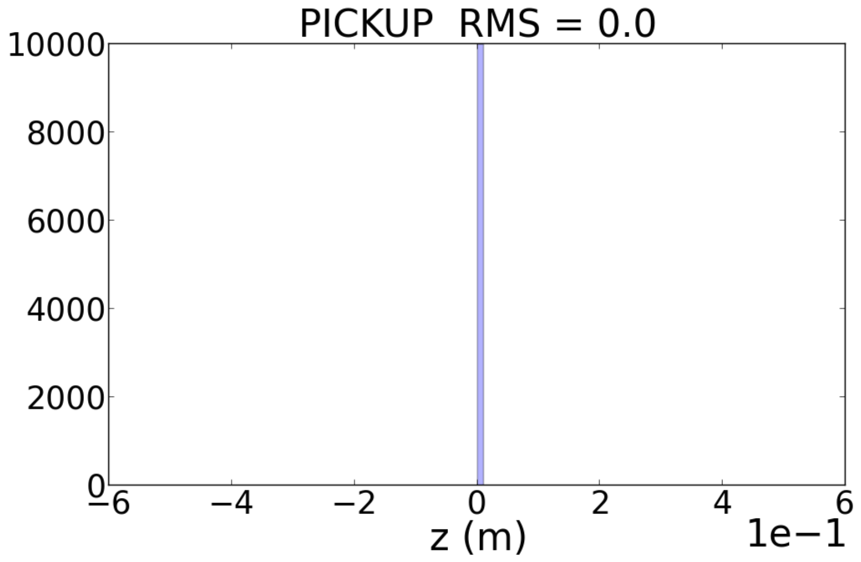
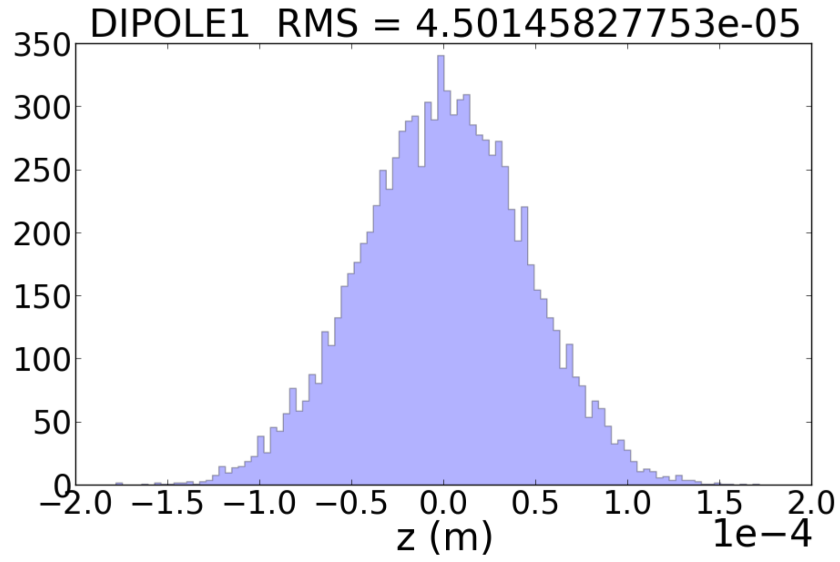
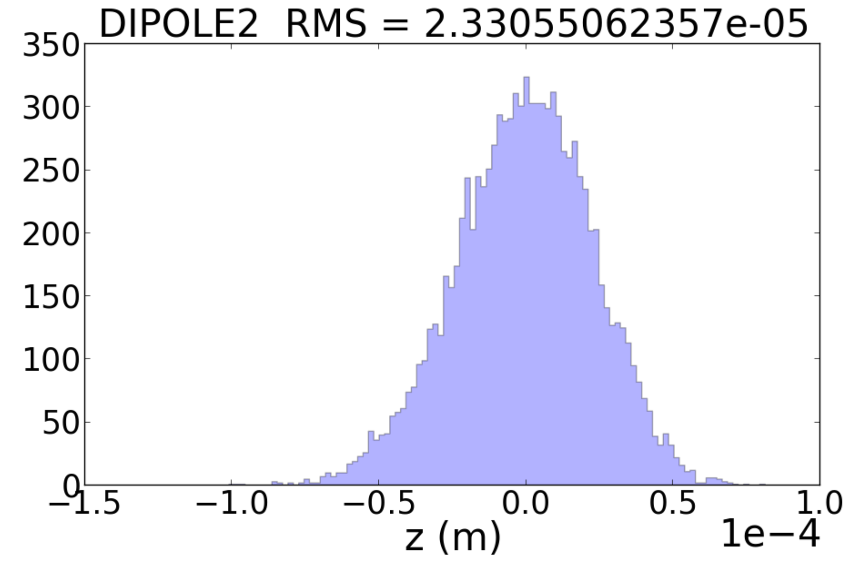
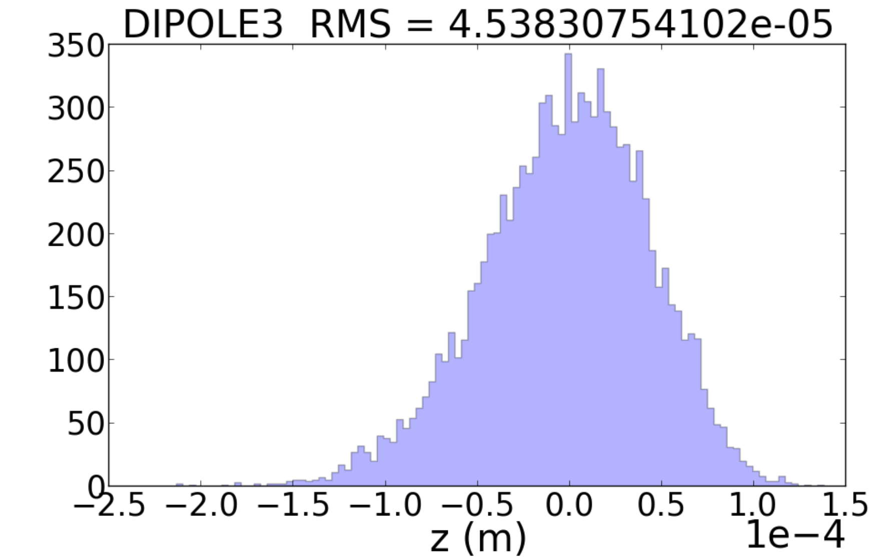


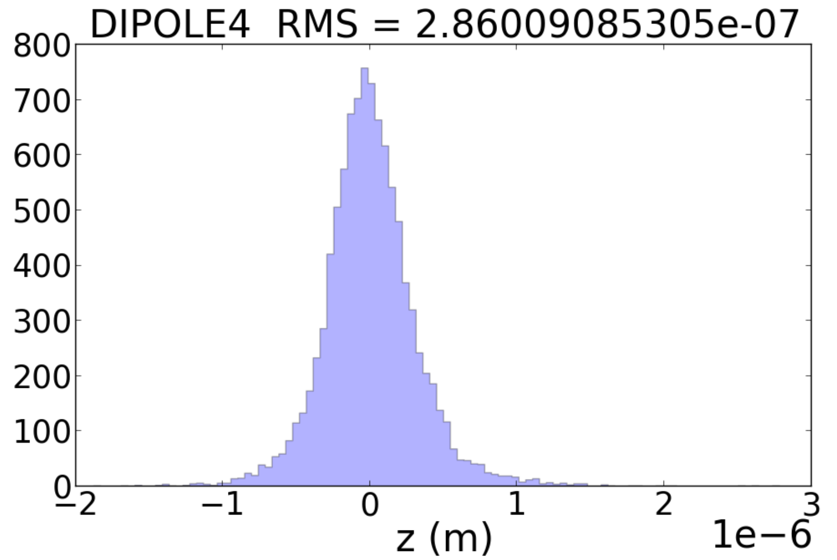
SAMPLE LENGTHENING

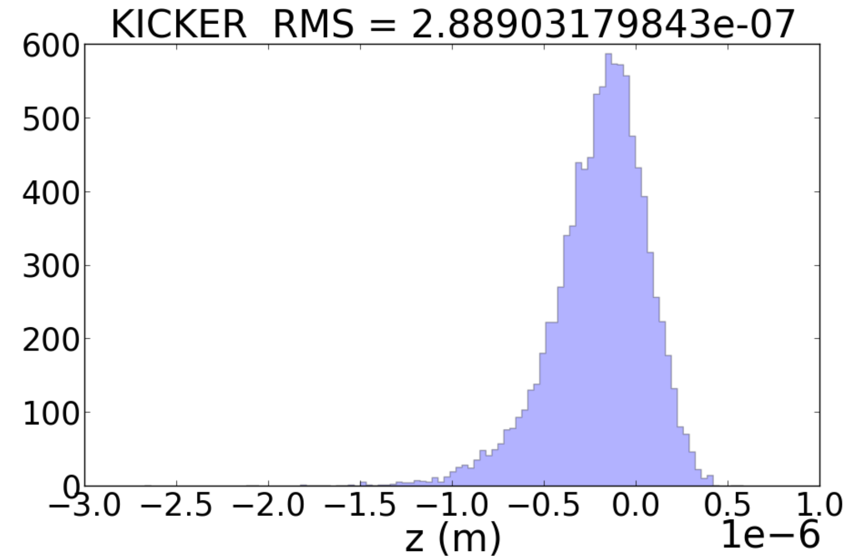


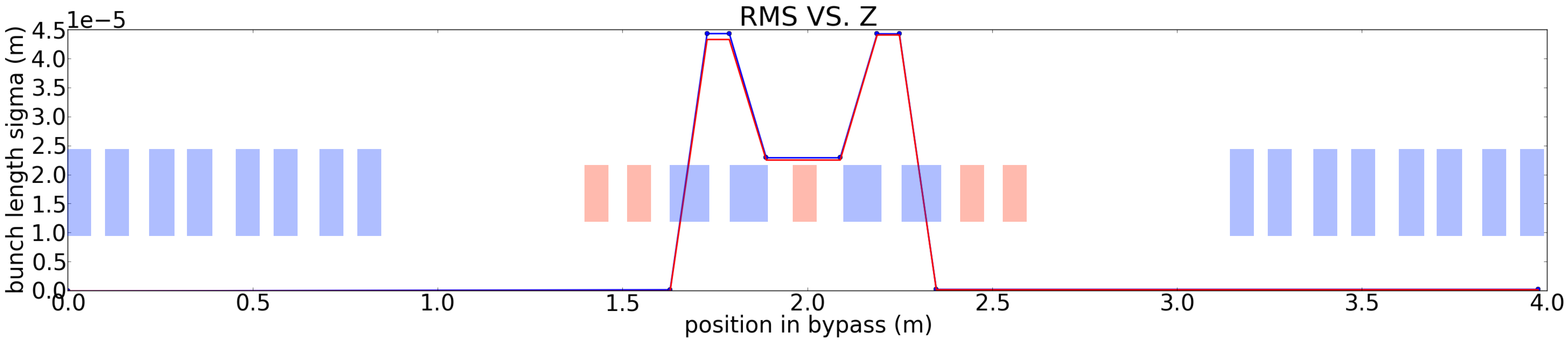












CONCLUSION

- Optics for OSC in ASTA has been developed, but the details are still being worked out; no show-stoppers have been identified.
- Strong sextupoles in the bypass drastically limit the dynamic aperture in the ring. This must be corrected.
  - will aim to demonstrate cooling with and without an amplifier; the latter having a damping time that exceeds SR damping by about an order of magnitude