Physics Improvement at SLAC/FRIB and Potential Challenge

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Physics Improvement Summary

- SLAC version:
  - Use MAD/DiMAD algorithms and in good agreement
  - All transverse (4x4) benchmarked and validated
  - Dipole bend edge effect handled
  - Dispersion, phase advance, chromaticity coded and checked
  - Suitable for light source
  - Should be one algorithm within XAL
- FRIB version
  - New FRIB specific device types added
  - 6x6 matrix benchmarked
- For Chicane Dipoles, SLAC uses a special algorithm to figure out the right fields for each dipole – this is outside simple caget()
  - Dipole edge effect is not handled in an elegant way, i.e. hard coded in SLG package

Potential Challenge [1]

- Multi-charge state modeling
  - Preliminary ideas (Carla)
  - Deal with many particle species
    - » Initial conditions saved in RDB and accessed via Model Service
- Solenoids mix x- and y-planes
- (Mis)Alignment support in XAL
- Multi-particle tracking
  - Model data access API via XAL/Model Server (Paul)
- Better solver
  - Generic algorithm solver – collaborating with GO AI Services
- RFQ model

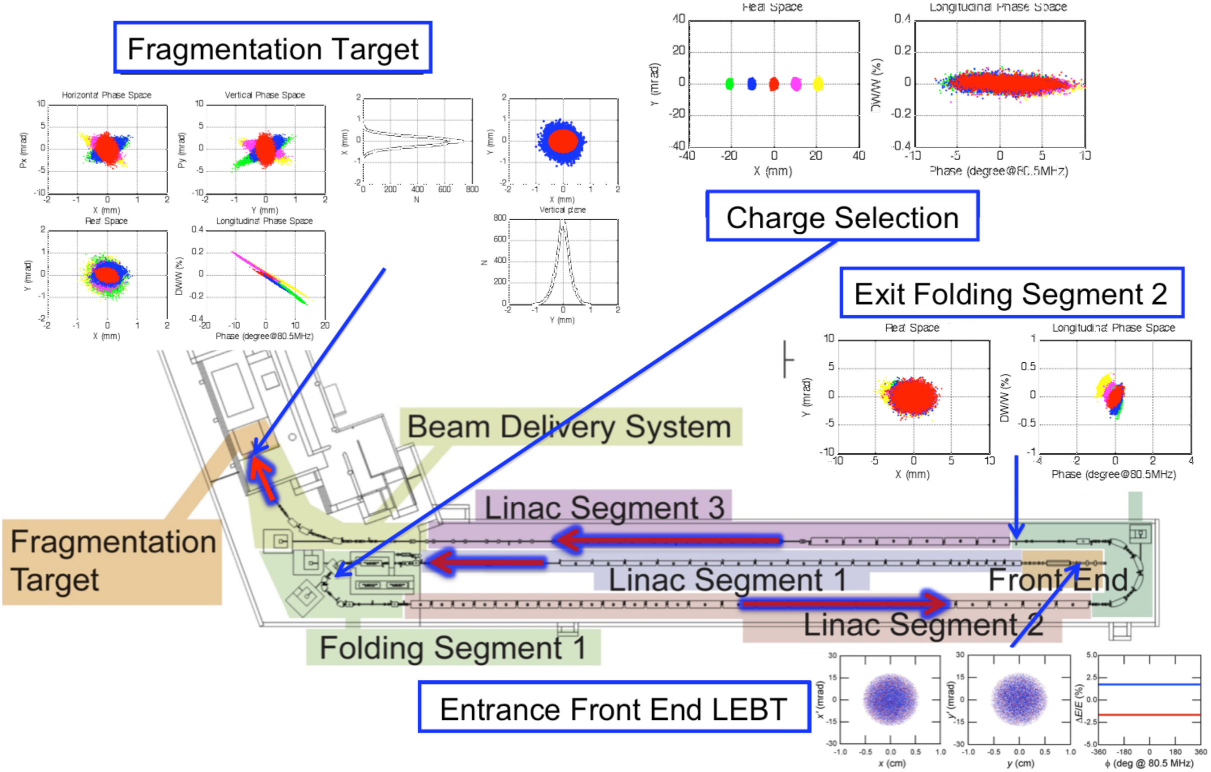
Potential Challenge [2]

- Longitudinal coordinates/conversion among different conventions
- Longitudinal part still need further benchmark
- Better mapping among Java, XML and database
  - New “global” database collaboration try to improve the database for XAL
  - Can/should we initialize XAL directly from RDB?
- Physics applications
  - Cavity tuning
  - Linac energy manager
  - …
- Turn applications into services and follow Service-Oriented Architecture for better reusability and better software architecture
- Performance
  - Data extraction from accelerator objects

Physics Improvement to XAL

- Multi-charge state capability
- Foil Stripper model
- RFQ element add to XAL

Goal: End-to-end simulation for multiple charge states



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Adding Multicharge State Capability to XAL

- XAL is set up to run one charge state at a time
- Need Δϕ for each different charge state at each cavity—calculate ToF, Energy Gain, Δϕ
  - $t_1=(d/c)\cdot(1/\mathrm{sqrt}(1-1/\mathrm{gamma}_1^2))$
  - $\Delta\phi=\omega\,\Delta t$
  - $\Delta E=(Q/A)\cdot ETL\cdot\cos(\phi) \rightarrow \Delta E=(Q_{cs}/A)\cdot ETL\cdot\cos(\phi+\Delta\phi)$
- Need to calculate separation of charge states through bend elements
  - Use <x> tracking capability of XAL (7x7 matrix)
  - Edit probe sigma matrix element <z'> (σ67) at each dipole
- Need to combine multiple envelopes into one
  - Add Gaussian distributions with different normalizations, means, and rms sizes

Bend Element Charge State Separation

$$\sigma_1 = R\sigma_0 R^T$$

Calculate

Dipole

Nonzero elements

$$\sigma = \begin{pmatrix} \langle x^2\rangle & \langle xx'\rangle & \langle xy\rangle & \langle xy'\rangle & \langle xz\rangle & \langle xz'\rangle & \langle x\rangle \\ \langle xx'\rangle & \langle x'^2\rangle & \langle x'y\rangle & \langle x'y'\rangle & \langle x'z\rangle & \langle x'z'\rangle & \langle x'\rangle \\ \langle xy\rangle & \langle x'y\rangle & \langle y^2\rangle & \langle yy'\rangle & \langle yz\rangle & \langle yz'\rangle & \langle y\rangle \\ \langle xy'\rangle & \langle x'y'\rangle & \langle yy'\rangle & \langle y'^2\rangle & \langle y'z\rangle & \langle y'z'\rangle & \langle y'\rangle \\ \langle xz\rangle & \langle x'z\rangle & \langle yz\rangle & \langle y'z\rangle & \langle z^2\rangle & \langle zz'\rangle & \langle z\rangle \\ \langle xz'\rangle & \langle x'z'\rangle & \langle yz'\rangle & \langle y'z'\rangle & \langle zz'\rangle & \langle z'^2\rangle & \langle z'\rangle \\ \langle x\rangle & \langle x'\rangle & \langle y\rangle & \langle y'\rangle & \langle z\rangle & \langle z'\rangle & \langle 1\rangle \end{pmatrix}$$

$$R = \begin{pmatrix} (x|x) & (x|x') & (x|y) & (x|y') & (x|z) & (x|z') & (x|\langle x\rangle) \\ (x'|x) & (x'|x') & (x'|y) & (x'|y') & (x'|z) & (x'|z') & (x'|\langle x'\rangle) \\ (y|x) & (y|x') & (y|y) & (y|y') & (y|z) & (y|z') & (y|\langle y\rangle) \\ (y'|x) & (y'|x') & (y'|y) & (y'|y') & (y'|z) & (y'|z') & (y'|\langle y'\rangle) \\ (z|x) & (z|x') & (z|y) & (z|y') & (z|z) & (z|z') & (z|\langle z\rangle) \\ (z'|x) & (z'|x') & (z'|y) & (z'|y') & (z'|z) & (z'|z') & (z'|\langle z'\rangle) \\ (\langle x\rangle|x) & (\langle x'\rangle|x') & (\langle y\rangle|y) & (\langle y'\rangle|y') & (\langle z\rangle|z) & (\langle z'\rangle|z') & 1 \end{pmatrix}$$

$$\Rightarrow \langle x\rangle_1 = 1\cdot\Big((x|x)\cancelto{0}{\langle x\rangle_0} + (x|x')\cancelto{0}{\langle x'\rangle_0} + \cancelto{0}{(x|y)}\langle y\rangle_0 + \cancelto{0}{(x|y')}\langle y'\rangle_0 + \cancelto{0}{(x|z)}\langle z\rangle_0 + (x|z')\langle z'\rangle_0 + \cancelto{0}{(x|\langle x\rangle)_0}\Big)$$

$$(x|z') = \rho(1-\cos\theta) = \frac{3.3564\,p_0}{Q_0\cdot B}(1-\cos\theta)$$

⟵ XAL Rmatrix calculates

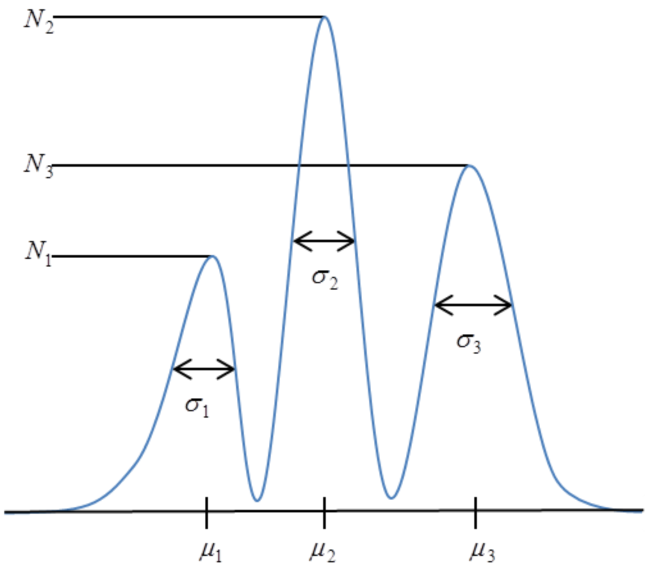
$$\langle z'\rangle_0 = \frac{1}{\gamma_0^2}\frac{\Delta B\rho}{B\rho_{ref}} = \frac{1}{\gamma_0^2}\frac{Q_{ref}}{\sqrt{\gamma_{ref}^2-1}}\left(\frac{\sqrt{\gamma_0^2-1}}{Q_0} - \frac{\sqrt{\gamma_{ref}^2-1}}{Q_{ref}}\right)$$

⟵ Make new XAL probe correlation

Adding Gaussian Distributions

$$f(x)=\frac{1}{\sigma\sqrt{2\pi}}e^{-\frac{1}{2}\left(\frac{x-\mu}{\sigma}\right)^2}$$

$$f_{tot}(x)=\sum_i \frac{N_i}{\sigma_i\sqrt{2\pi}}e^{-\frac{1}{2}\left(\frac{x-\mu_i}{\sigma_i}\right)^2}$$

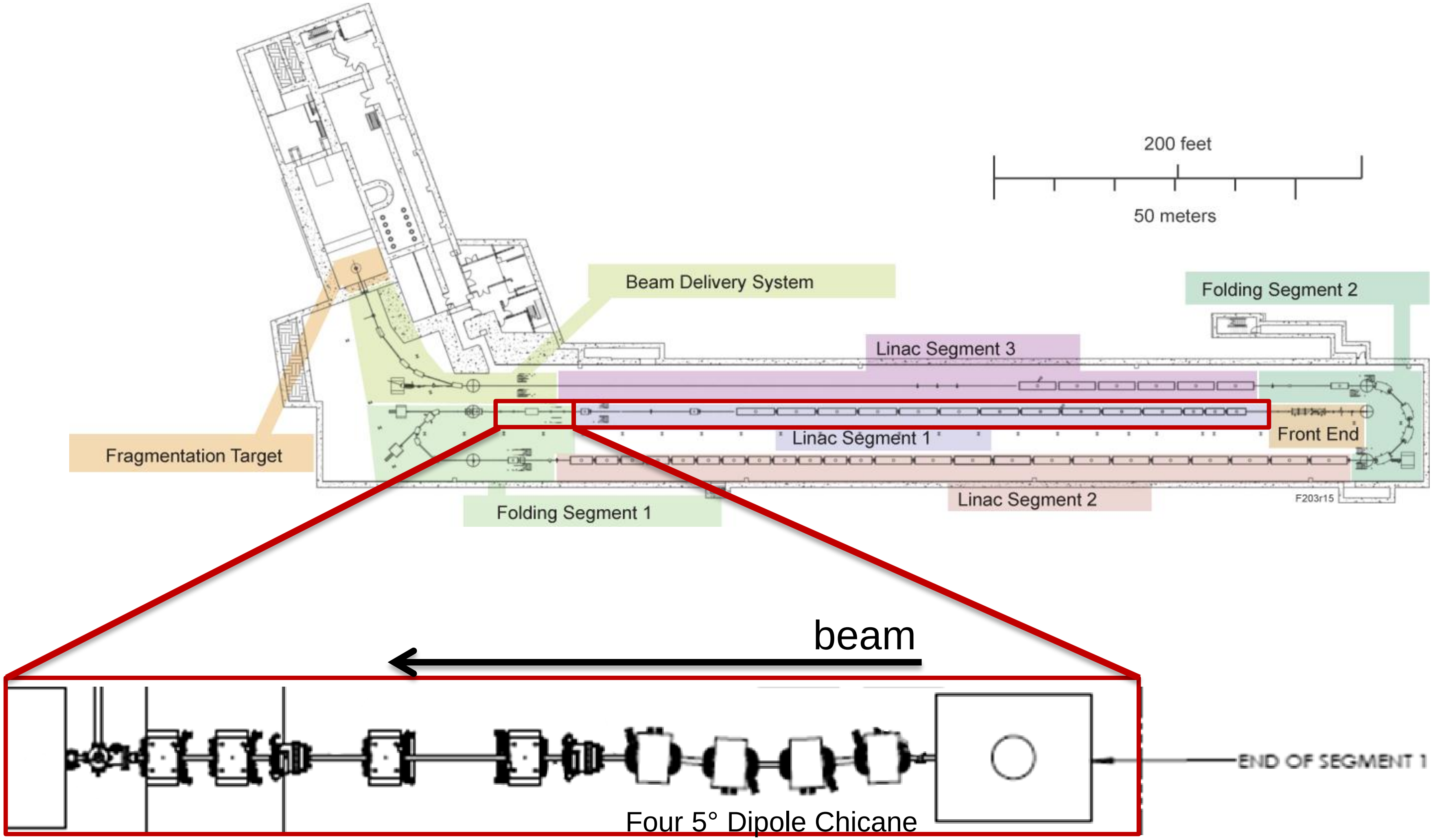


$$\sigma_{tot}^2=\left\langle x^2\right\rangle_{tot}=\frac{\int_{-\infty}^{\infty}(x-\mu_{tot})^2\sum_i \frac{N_i}{\sigma_i\sqrt{2\pi}}e^{-\frac{1}{2}\left(\frac{x-\mu_i}{\sigma_i}\right)^2}dx}{\int_{-\infty}^{\infty}\sum_i \frac{N_i}{\sigma_i\sqrt{2\pi}}e^{-\frac{1}{2}\left(\frac{x-\mu_i}{\sigma_i}\right)^2}dx}$$

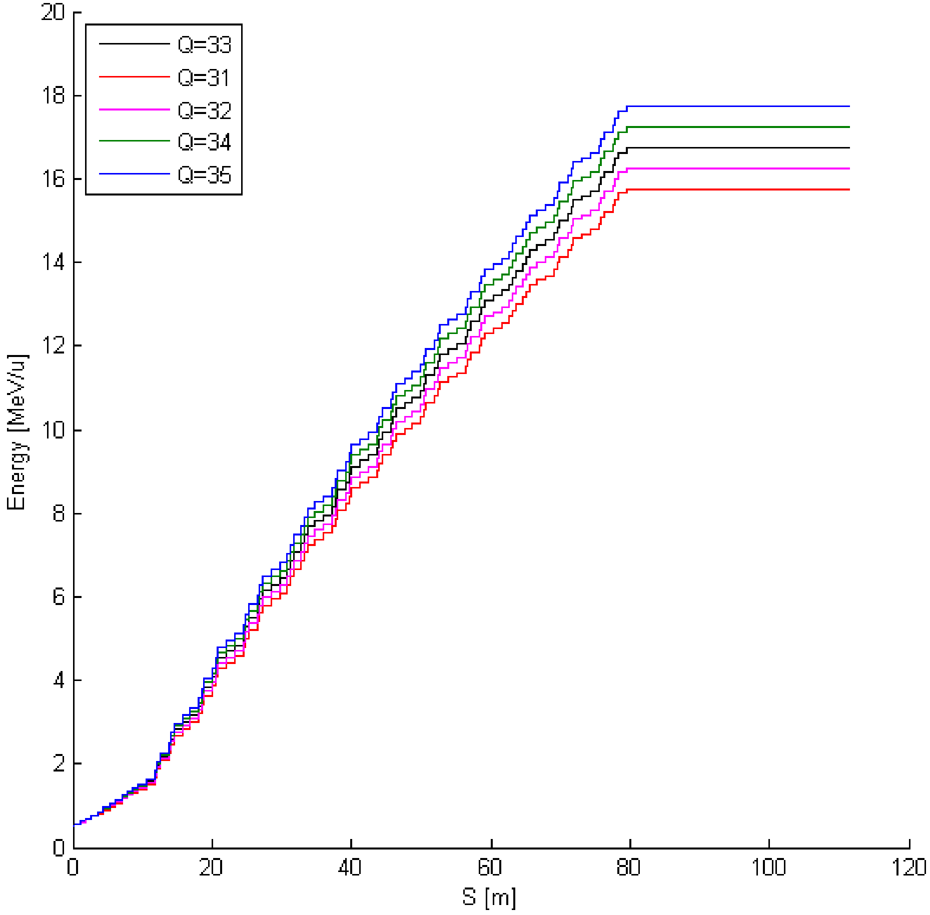
$$\mu_{tot}=\left\langle x\right\rangle_{tot}=\frac{\sum_i N_i\mu_i}{\sum_i N_i}$$

$$\sigma_{tot}=\sqrt{\frac{\sum_i N_i\left(\sigma_i+\left(\mu_i-\mu_{tot}\right)\right)^2}{\sum_i N_i}}$$

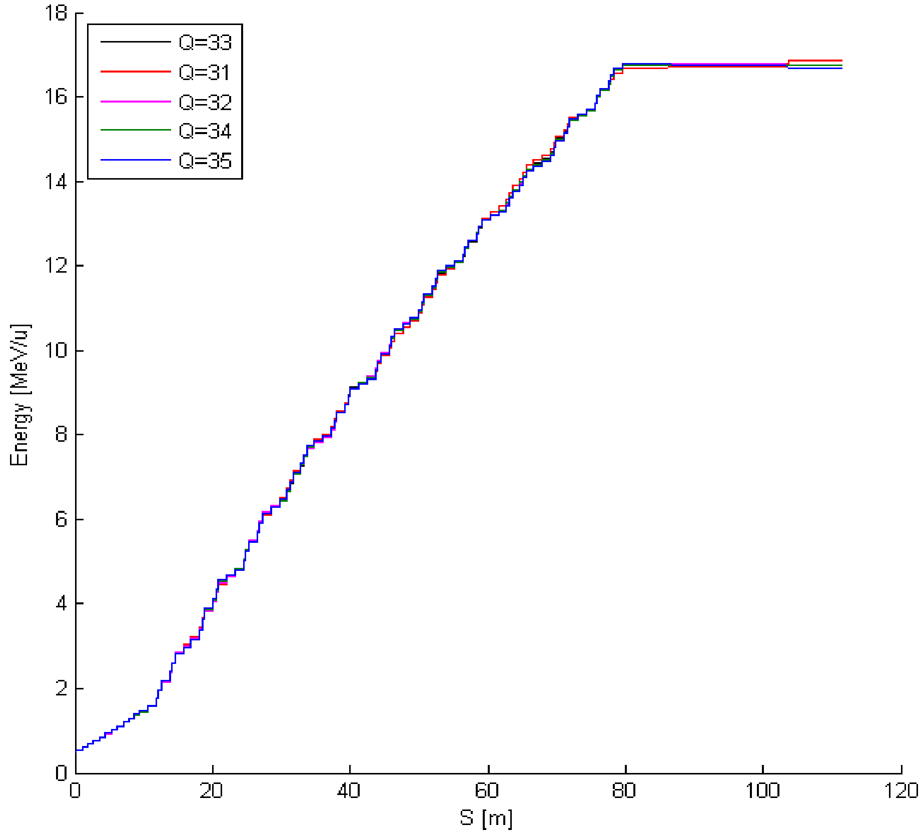
FRIB Seg1 to Stripper



Energy Gain dPhi added

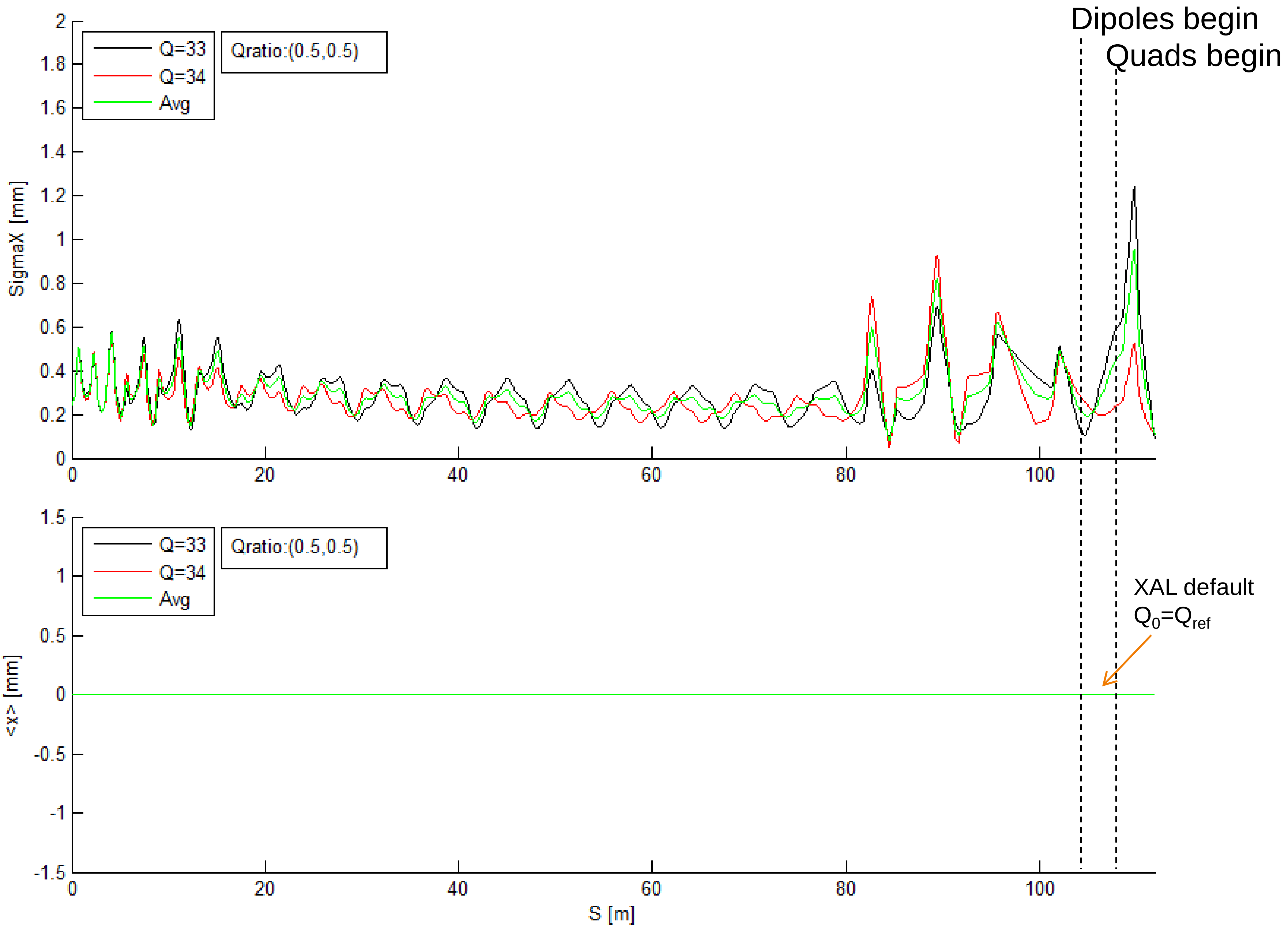


No Phi Change

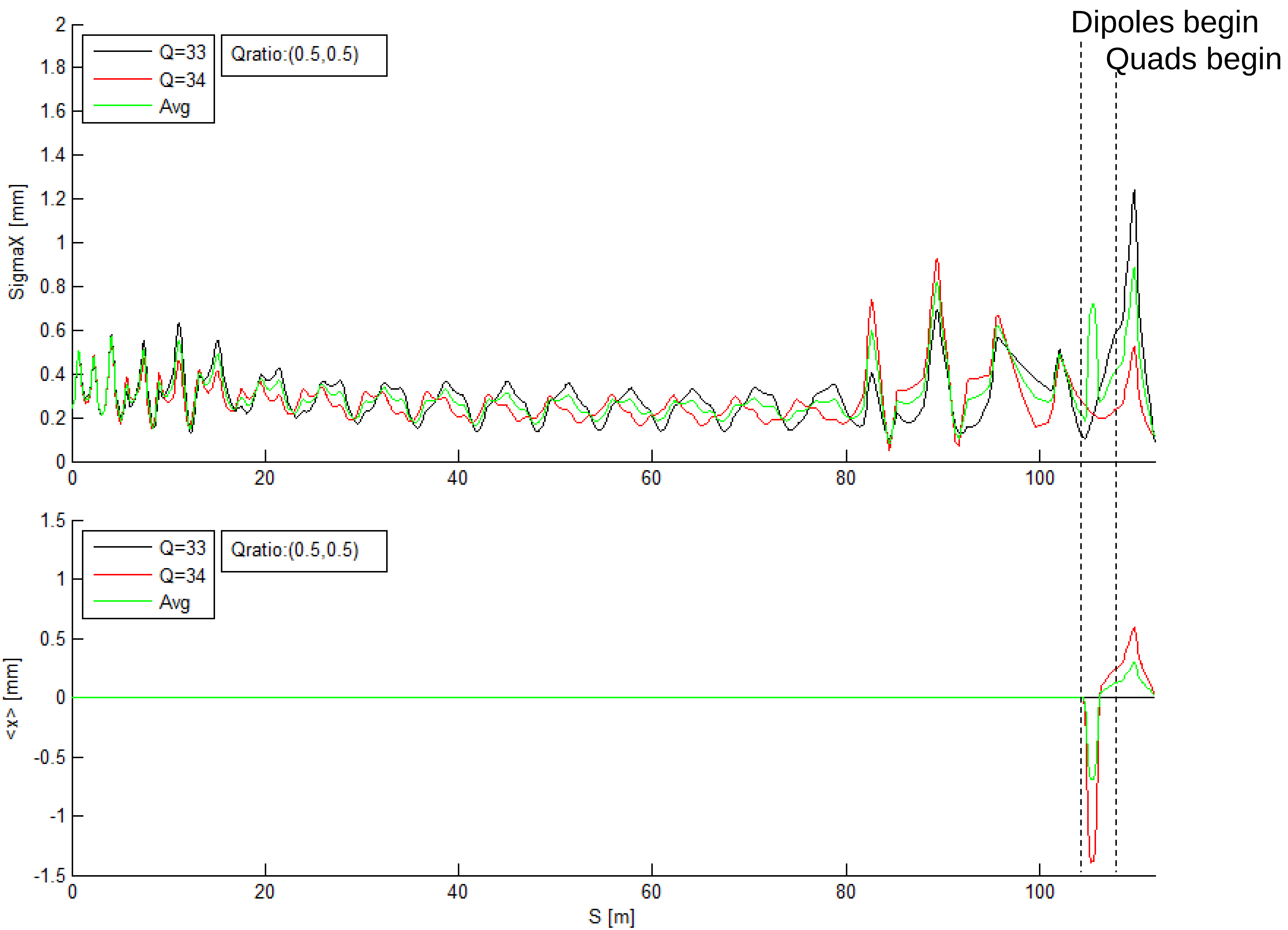


dPhi Added

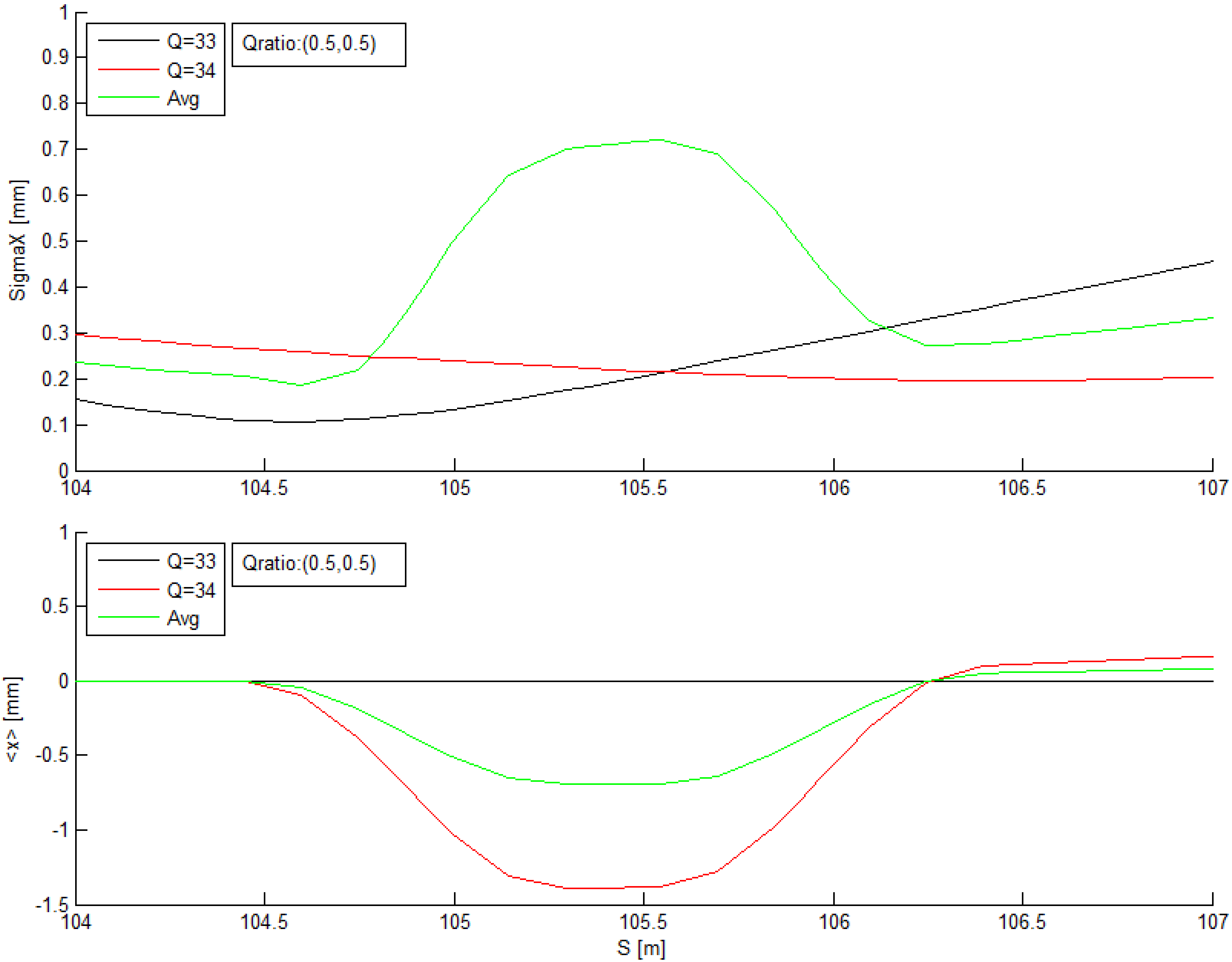
No Offset <z'> Added



With Offset <z'> Added



4 Dipoles (5deg each)--Chicane



End-to-End Beam Simulations

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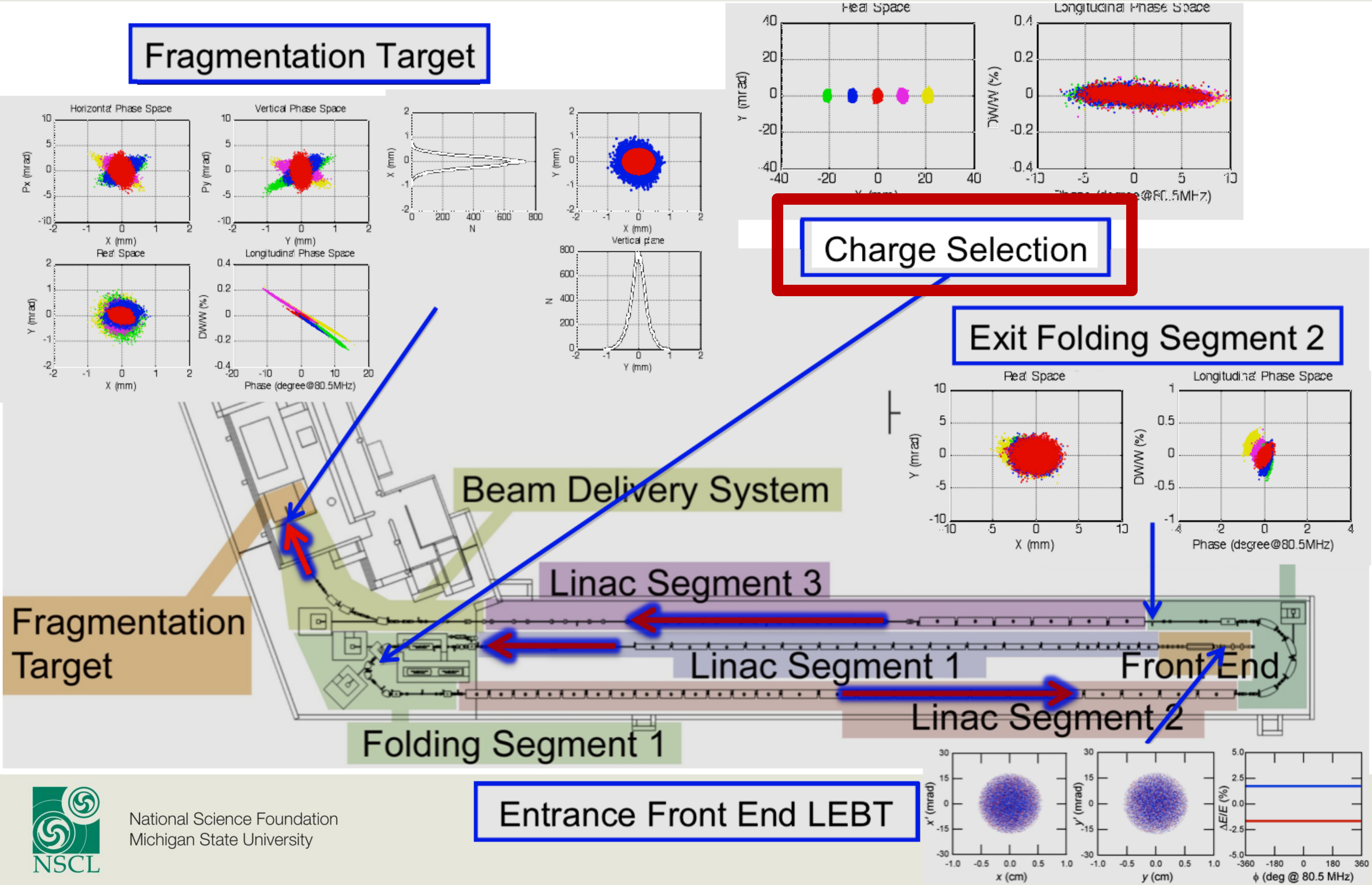


Charge Stripping Model in XAL?

$$\alpha_1 = \frac{\alpha_0 \varepsilon_0}{\varepsilon_1}$$

$$\beta_1 = \frac{\beta_0 \varepsilon_0}{\varepsilon_1}$$

$$\varepsilon_1 = \varepsilon_0 \sqrt{1 + \frac{\langle \theta_x \rangle^2}{(\gamma_0 \varepsilon_0)^2}}$$

For xx' phase space, assume broadening in x' space only

Equivalent to applying delta kick in angle, no position change at stripper foil

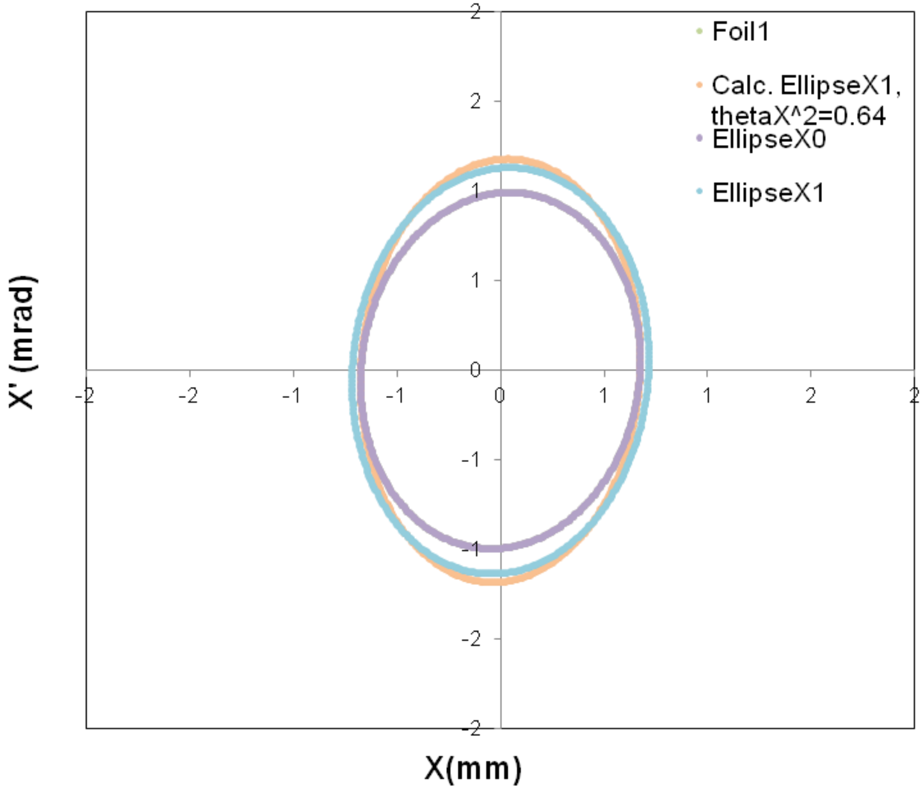
Compare to:

Ion Charge Stripping Foil Model for Beam Dynamics Simulation (D. Gorelov and F. Marti)

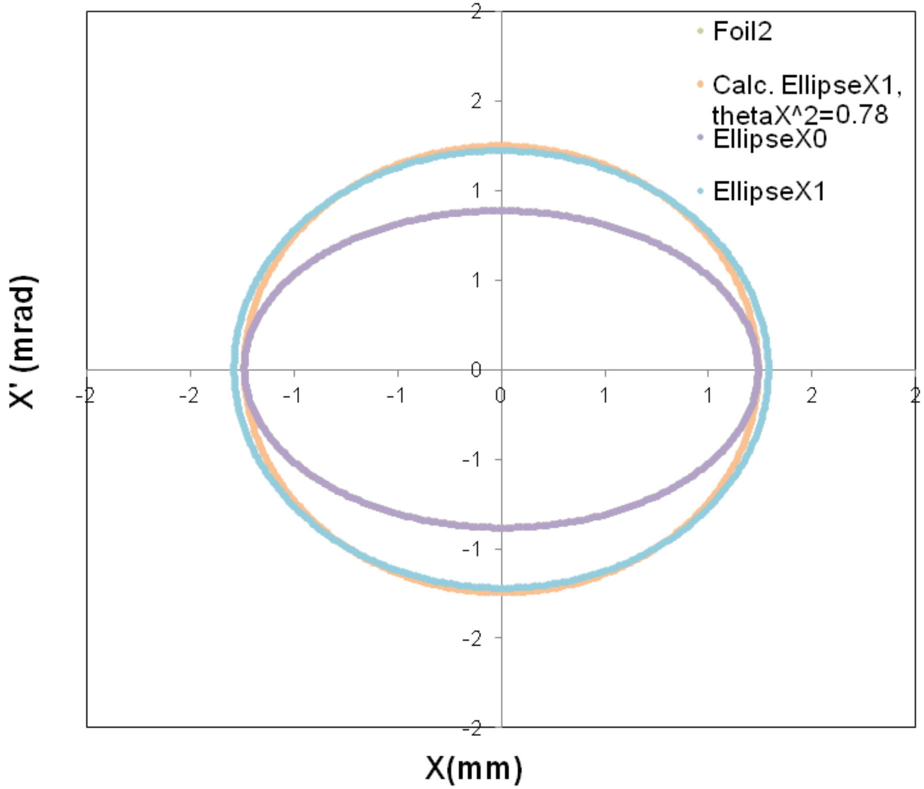
- Uses SRIM calculation for Energy Loss/Straggling
- IMPACT multiparticle tracking for twiss parameters before/after stripper foil

Phase Space X

Foil1: 12MeV/u

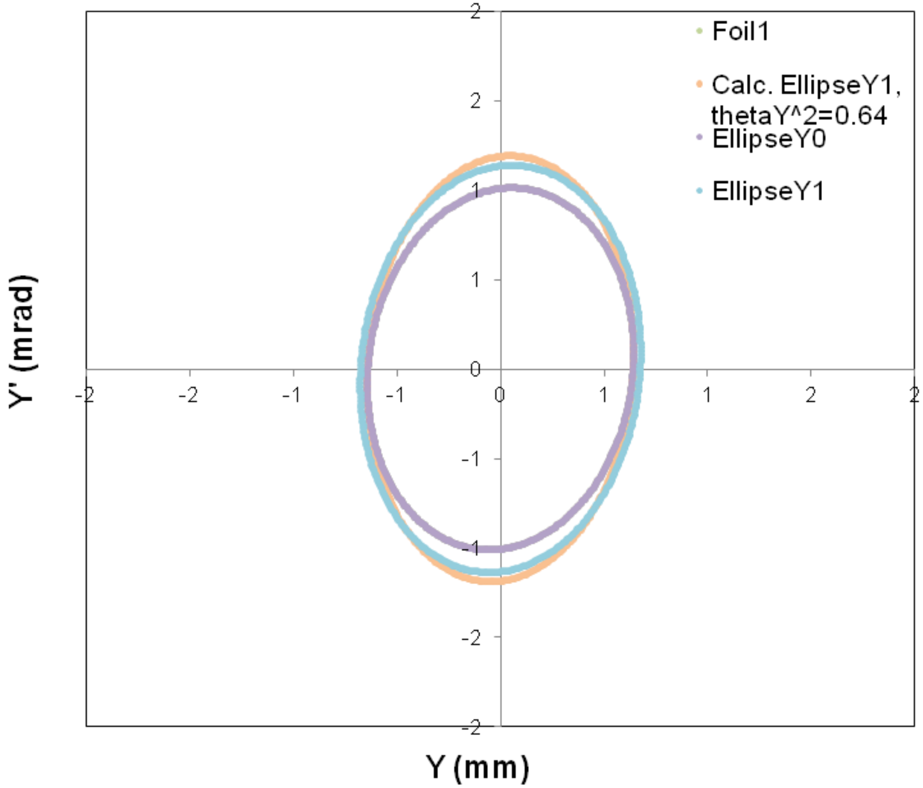


Foil2: 90MeV/u

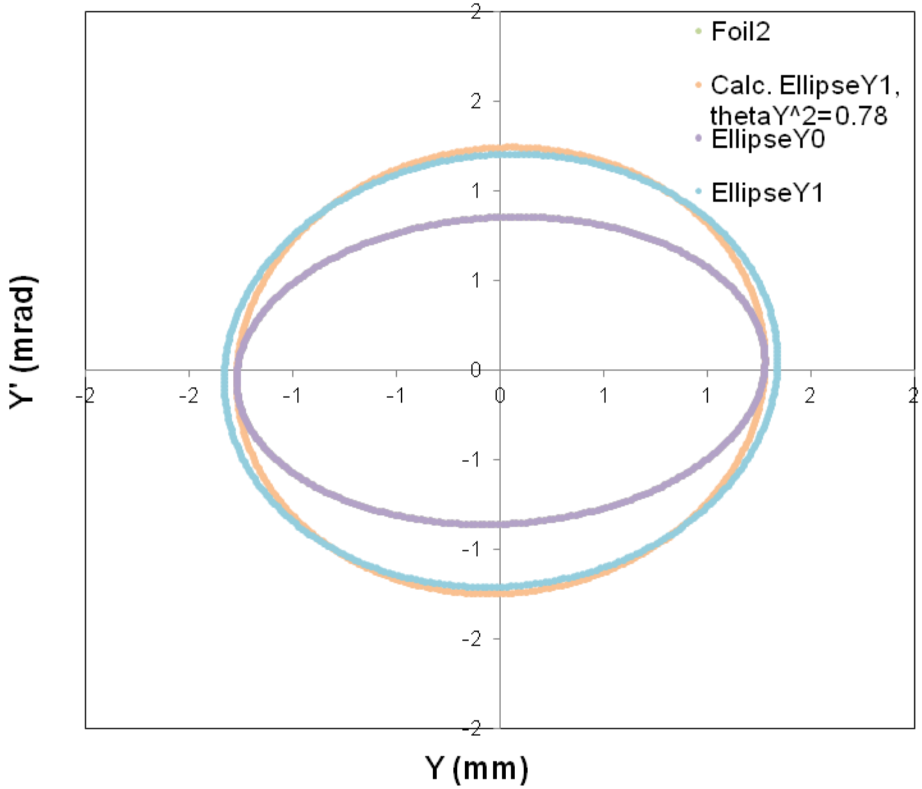


Phase Space Y

Foil1: 12MeV/u

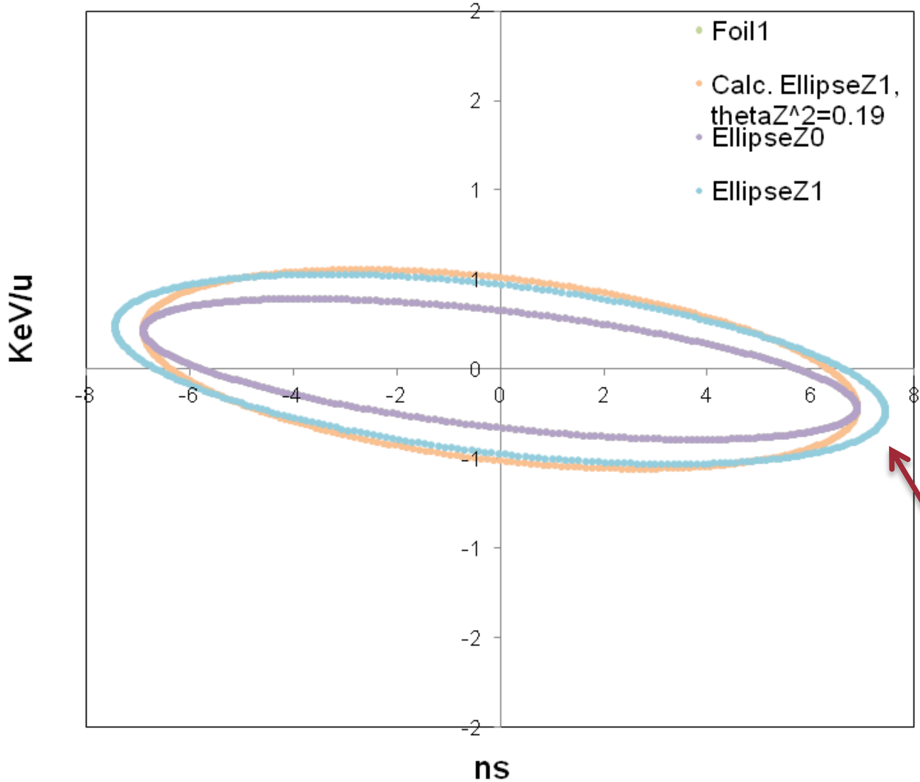


Foil2: 90MeV/u

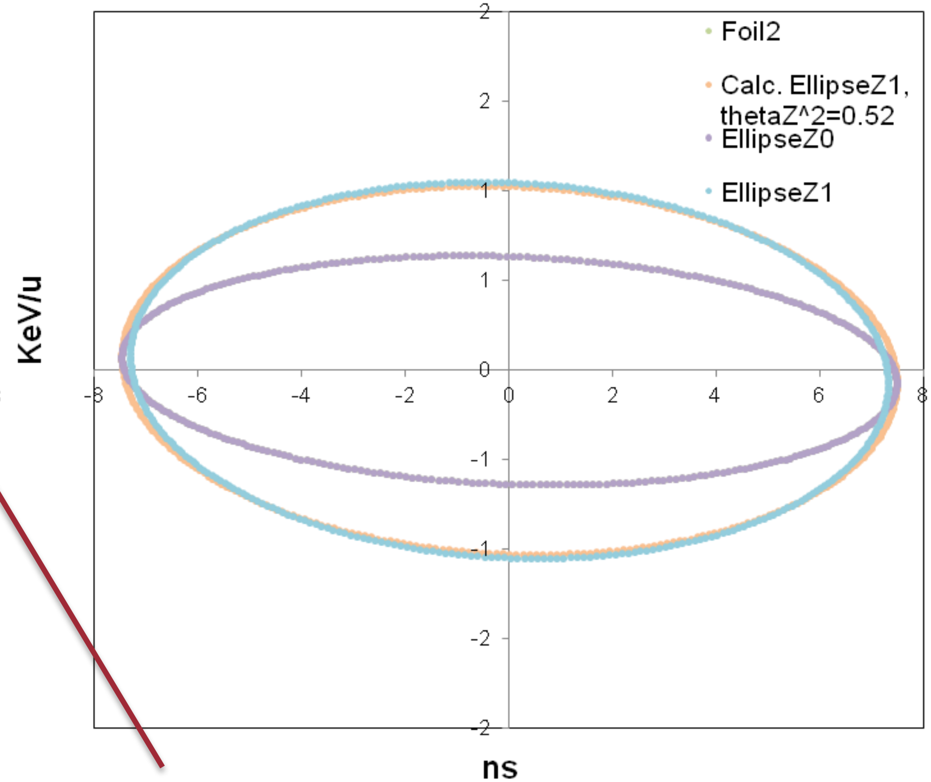


Phase Space Z

Foil1: 12MeV/u



Foil2: 90MeV/u



Here "delta kick" in z' may not work
There's a broadening in z direction

Summary

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- Foil Stripper model
- RFQ element add to XAL

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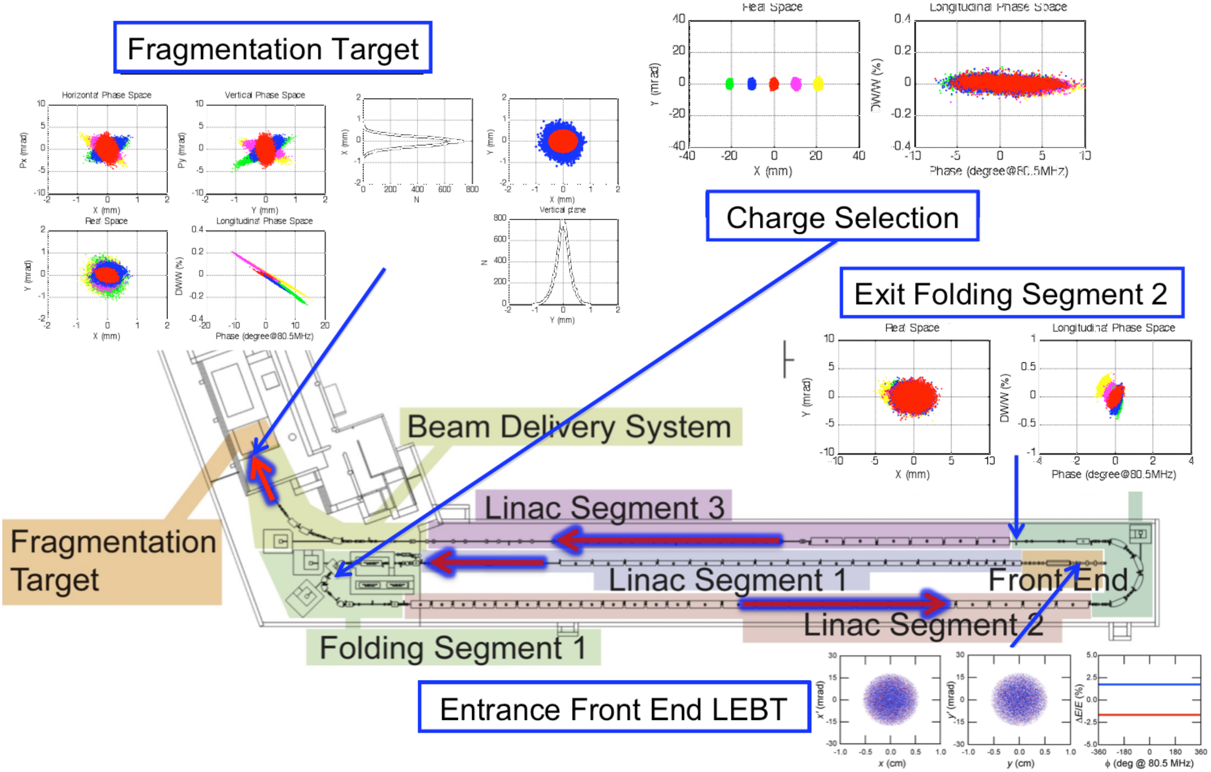

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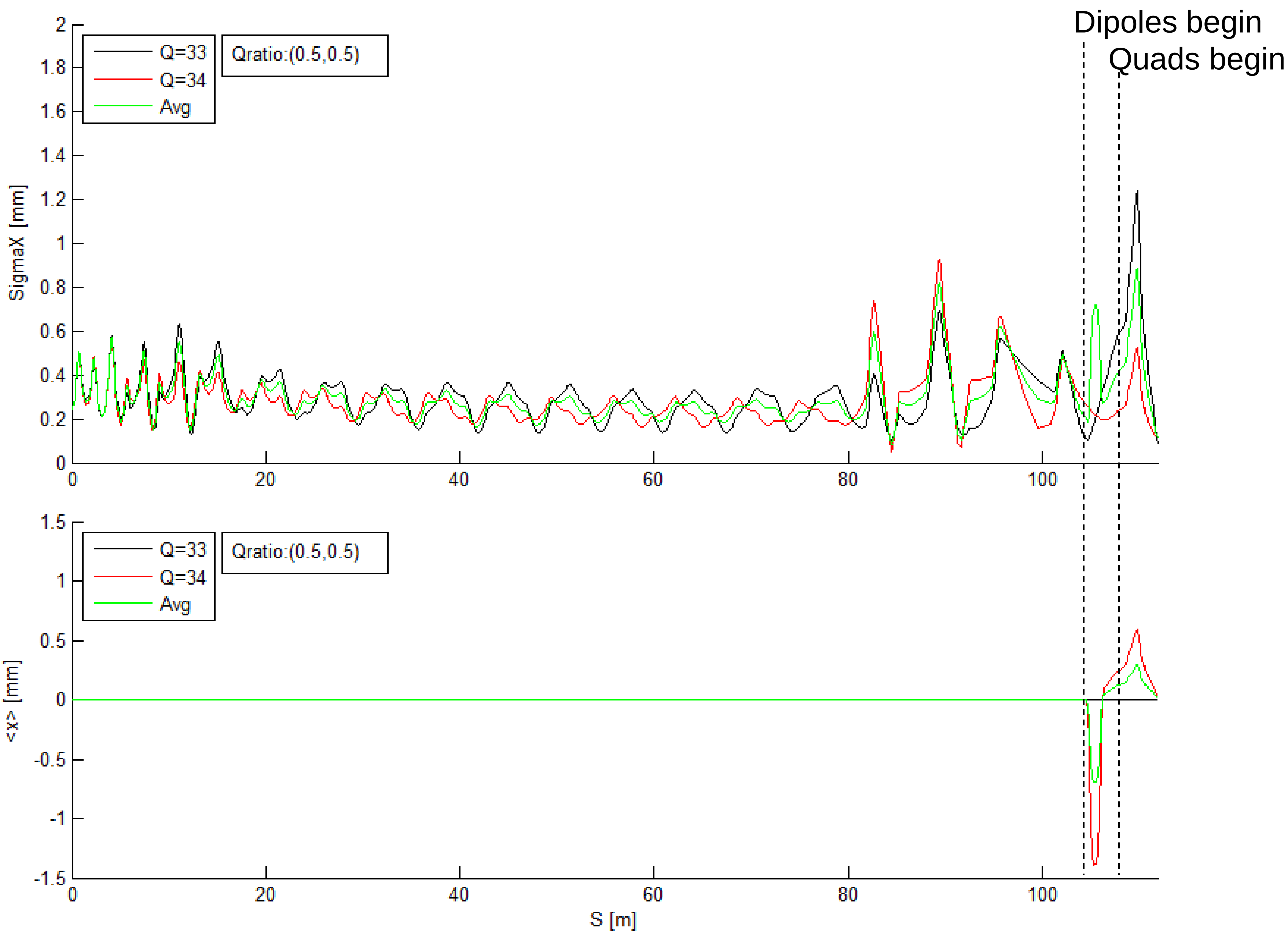
Extra Slides

With Offset <z'> Added



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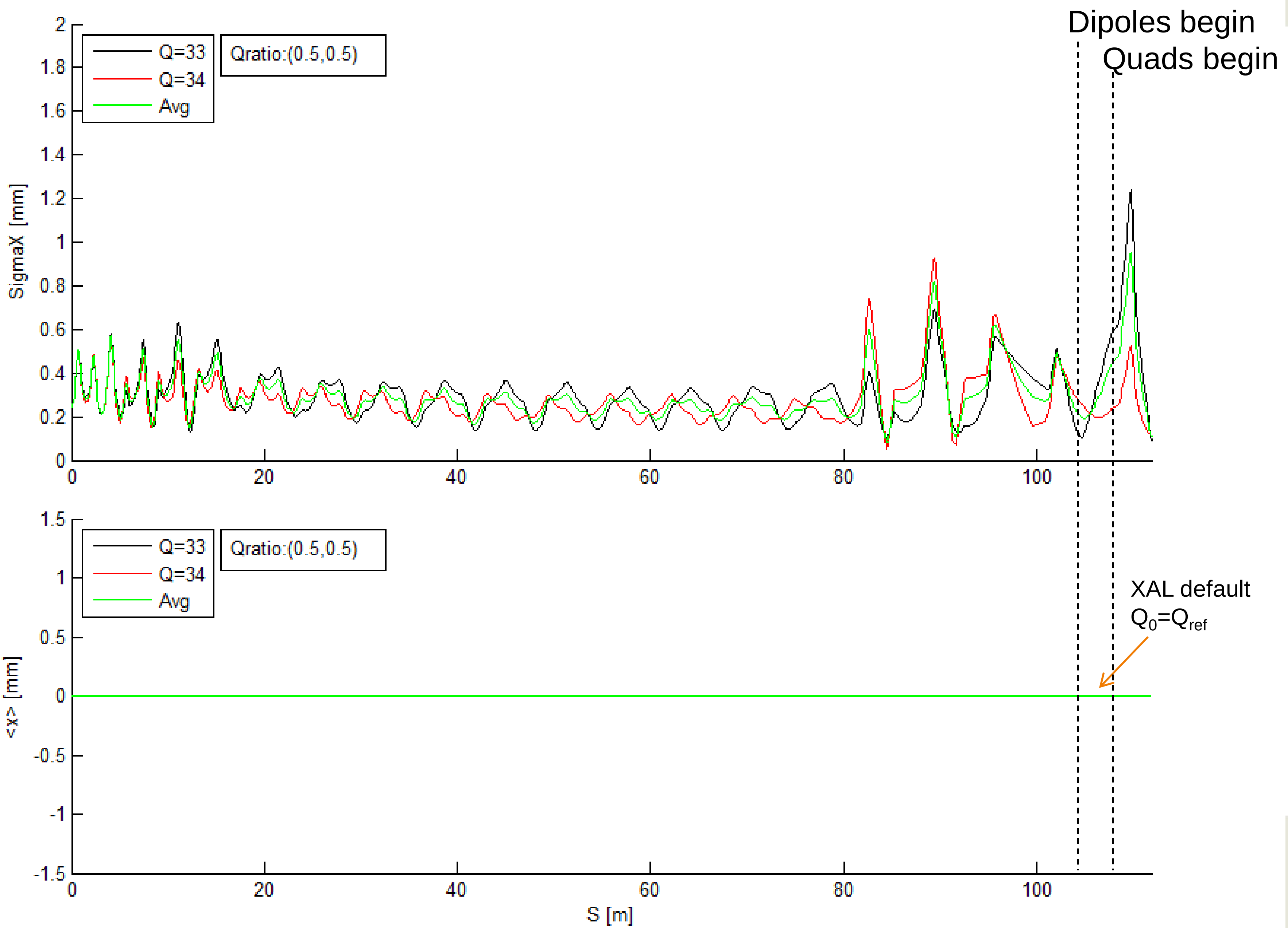

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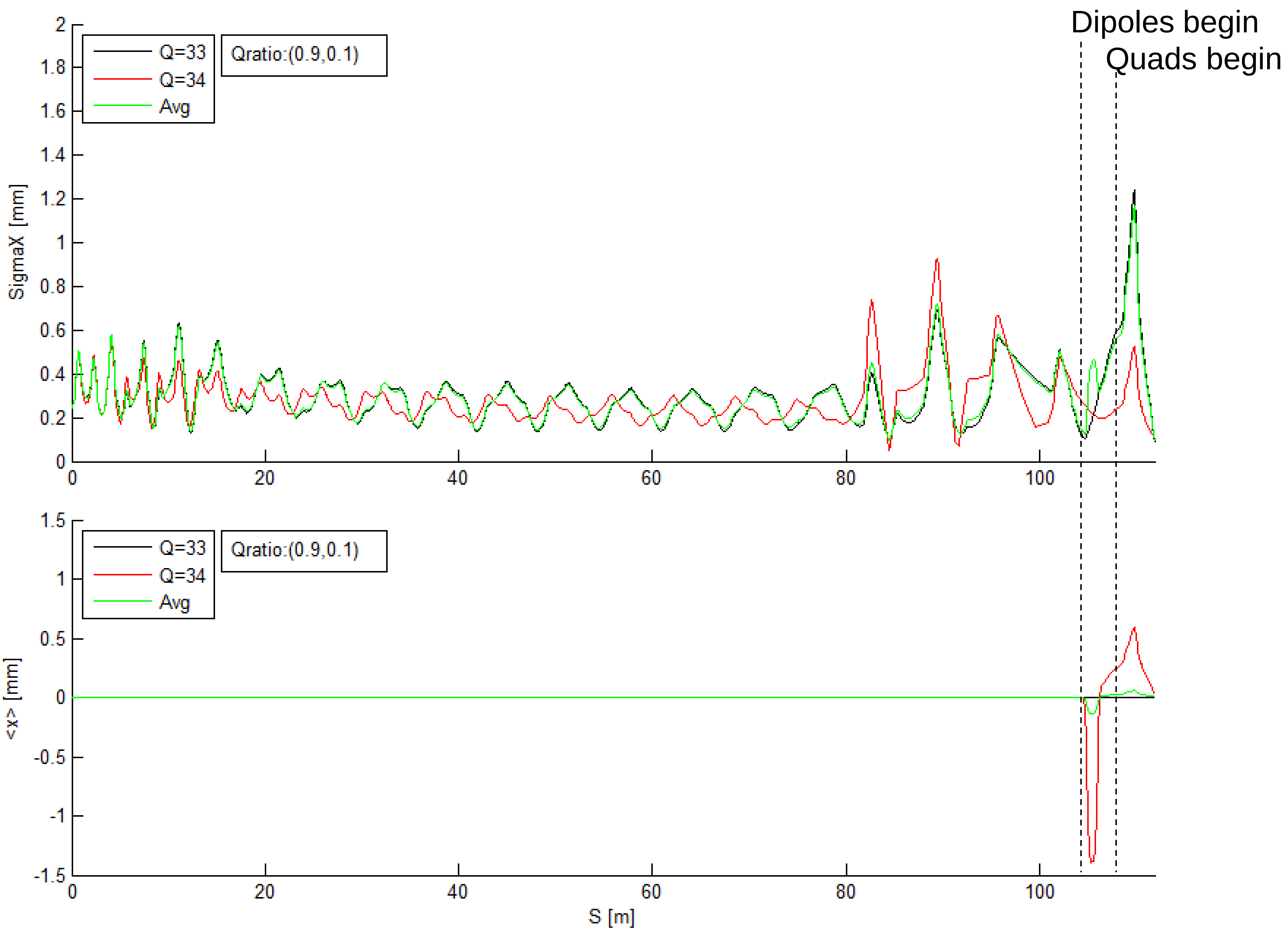

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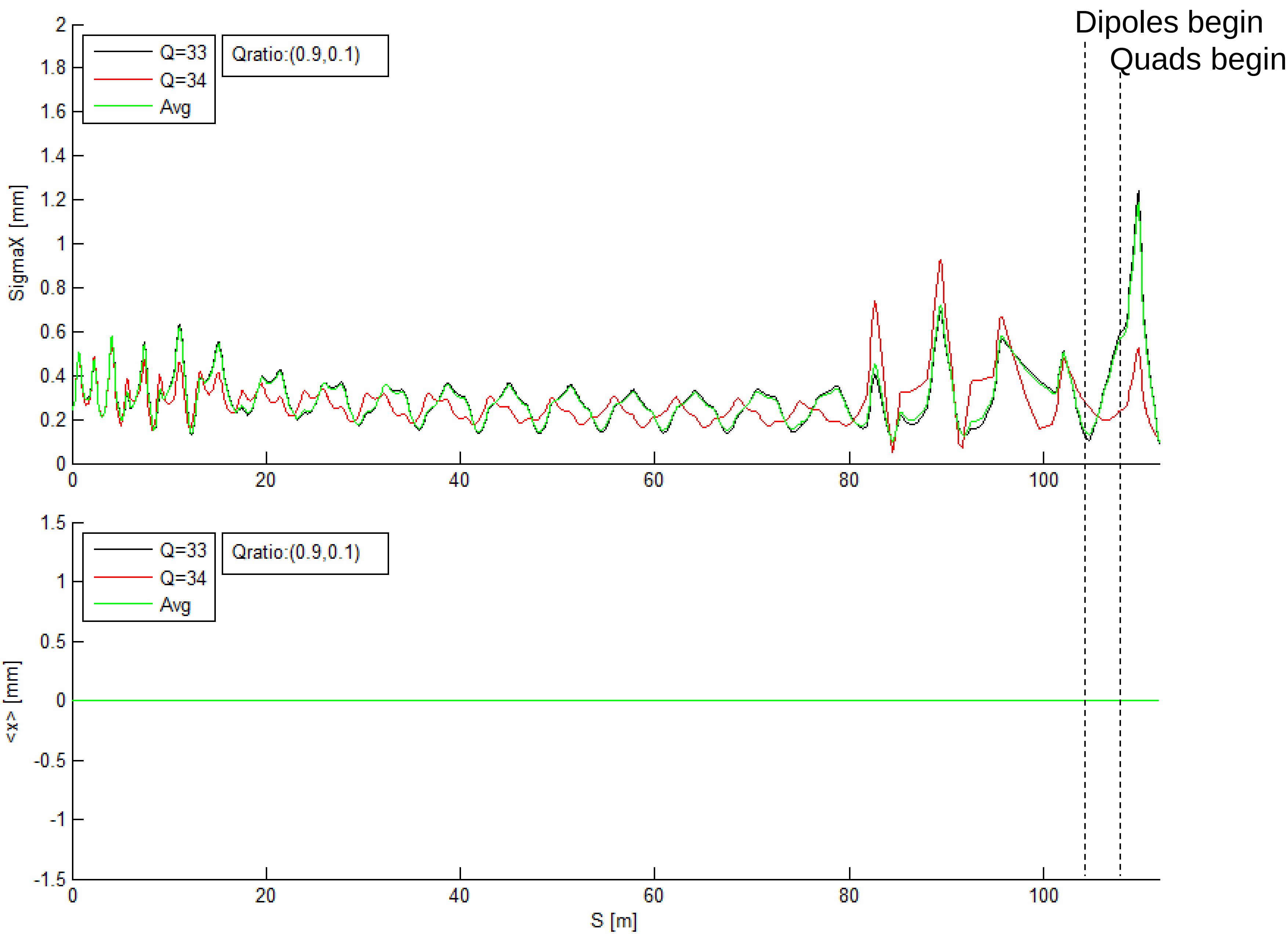

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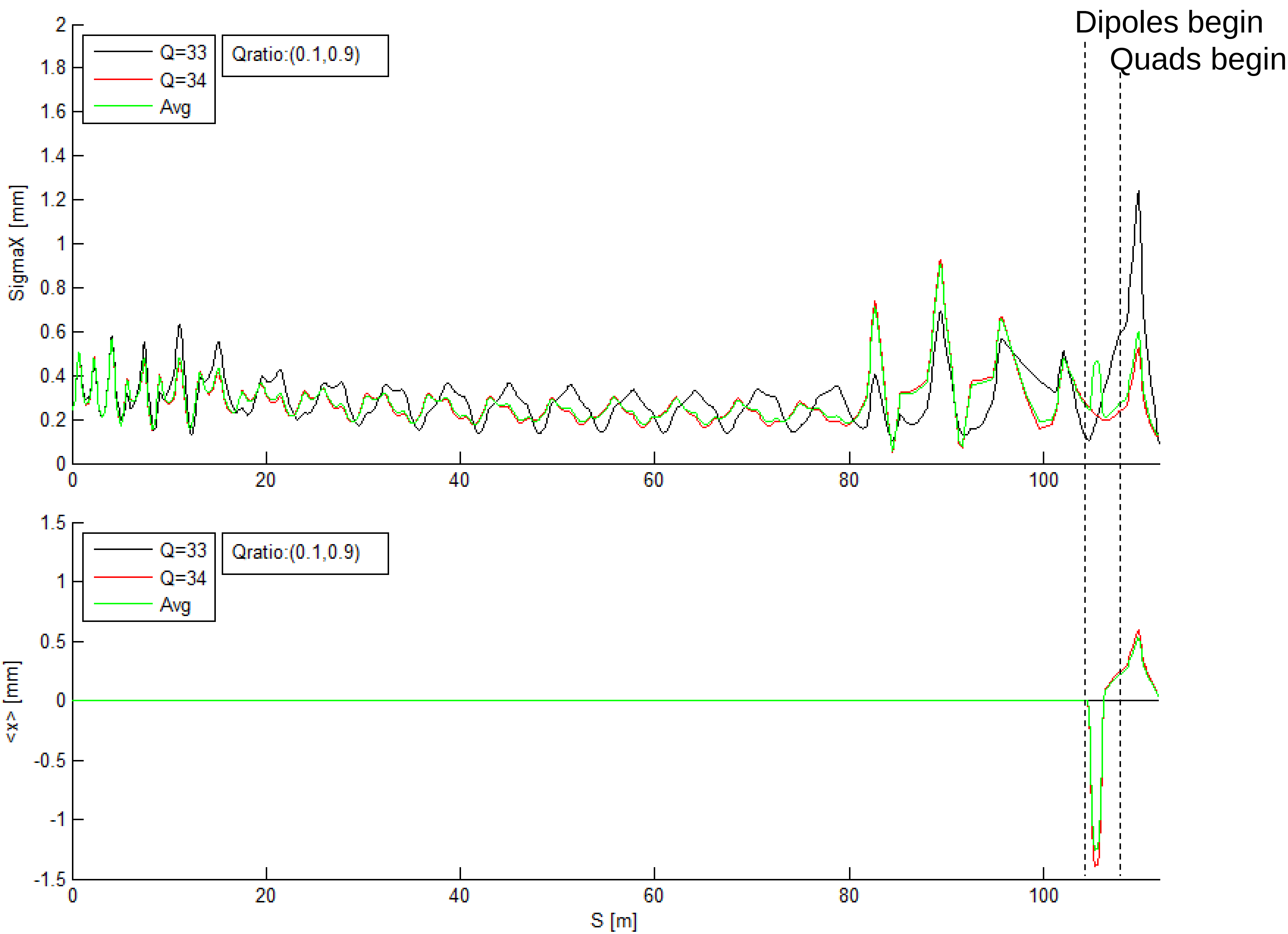

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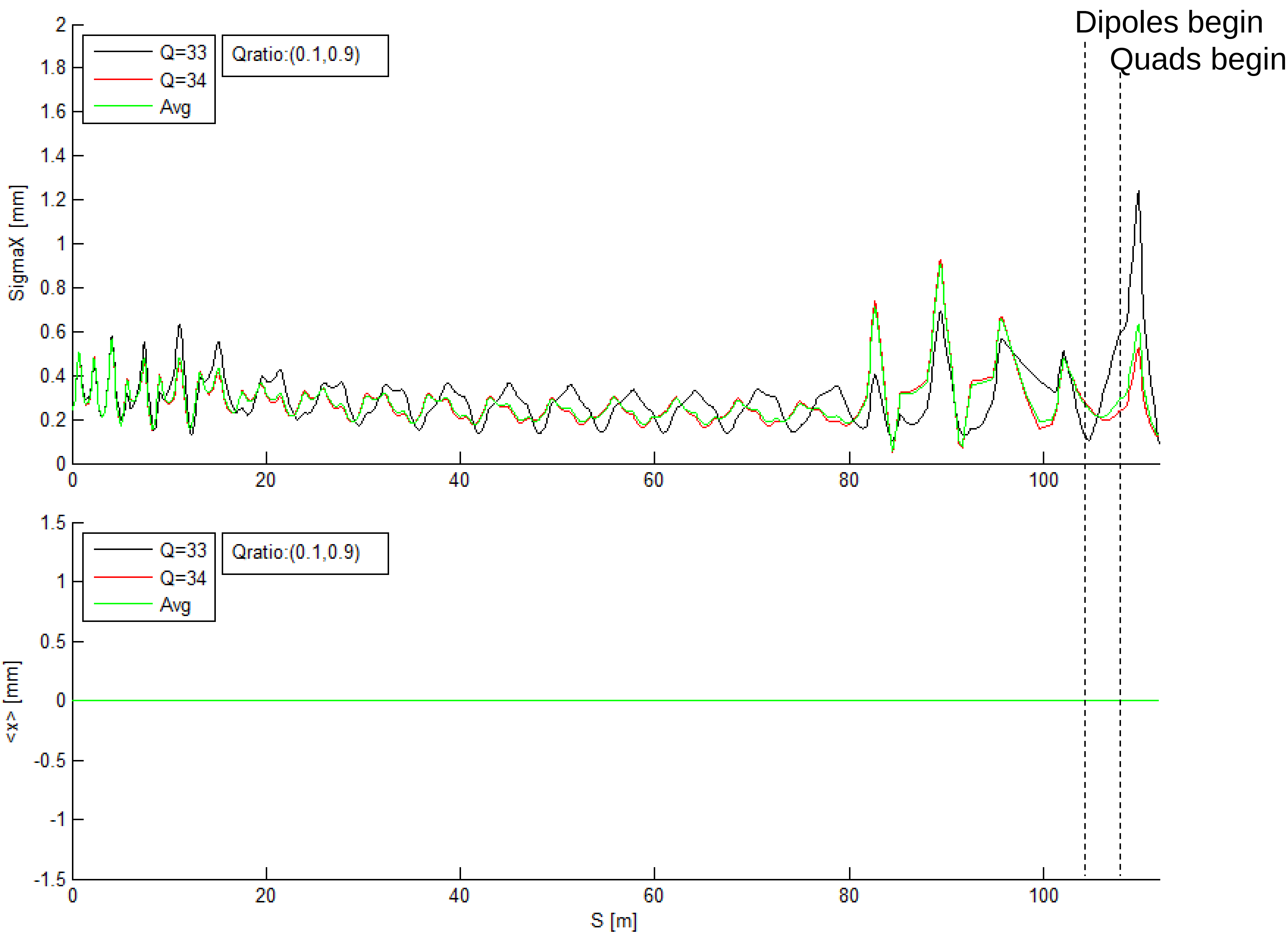

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