Recirculation Optics for XFEL-O

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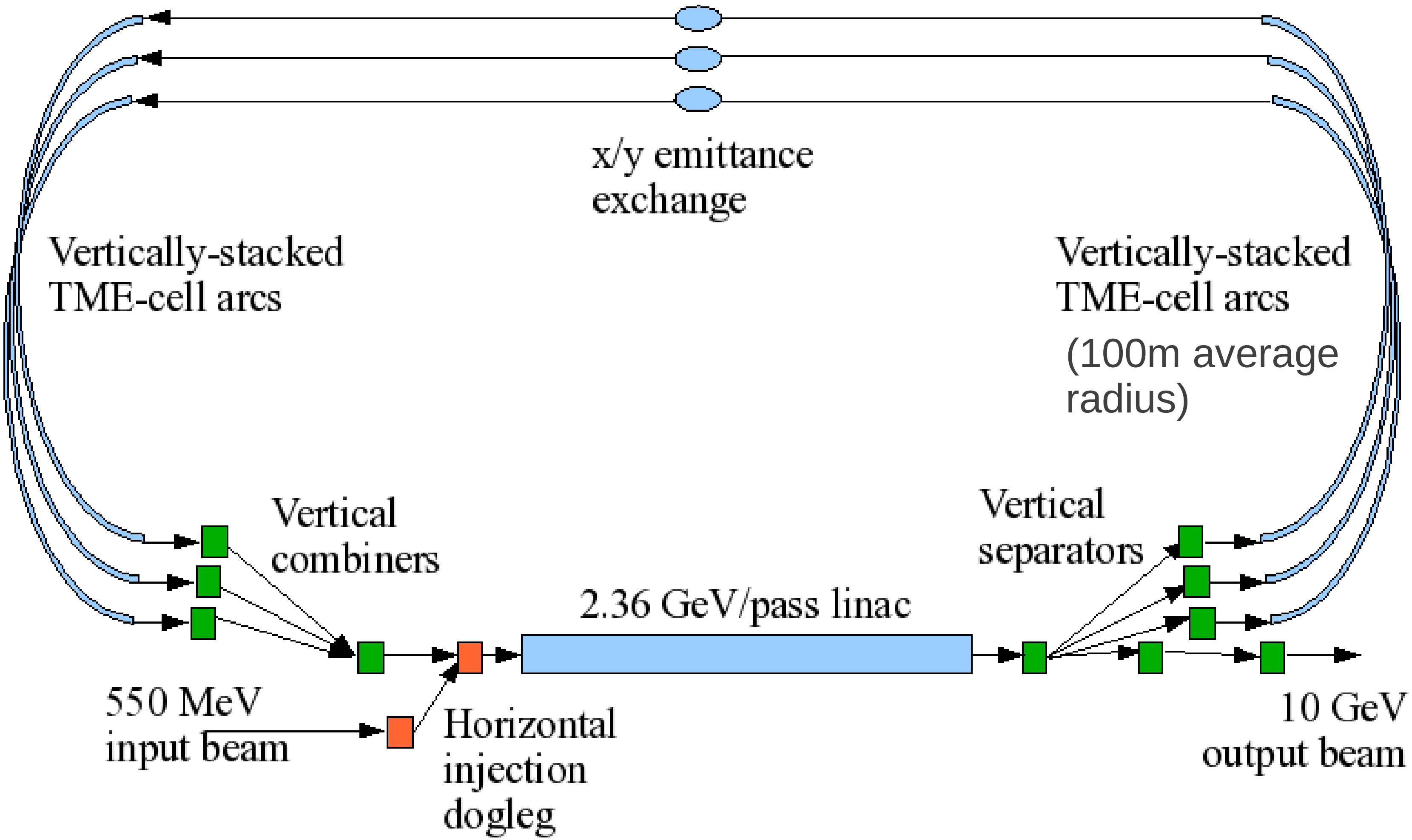
Introduction

- XFEL-O is an idea[1] for a high-brightness x-ray source
  - Oscillator x-ray FEL using crystals as x-ray mirrors
- Requires high-quality beam
  - 7 GeV or higher
  - 0.1 micron normalized emittance
  - 0.02% rms momentum spread
  - 20~40 pC in a 2 ps rms bunch
  - Few MHz bunch spacing
- A multi-pass linac may have cost advantages
  - Beam quality preservation is the main challenge
  - Complexity also a concern
- Design may be informative for multi-pass ERLs
- Designed and evaluated system using **elegant**[2]

[1]K. J. Kim *et al*., Phys. Rev. Lett. 100, 244802 (2008).
[2]M. Borland, APS LS-287, 2001; Y. Wang *et al*., PAC07, 3444-3446.

System Schematic and Overview[1]



[1]M. Borland, Proc. PAC09, TU5RFP048, to be published.

Design Sequence

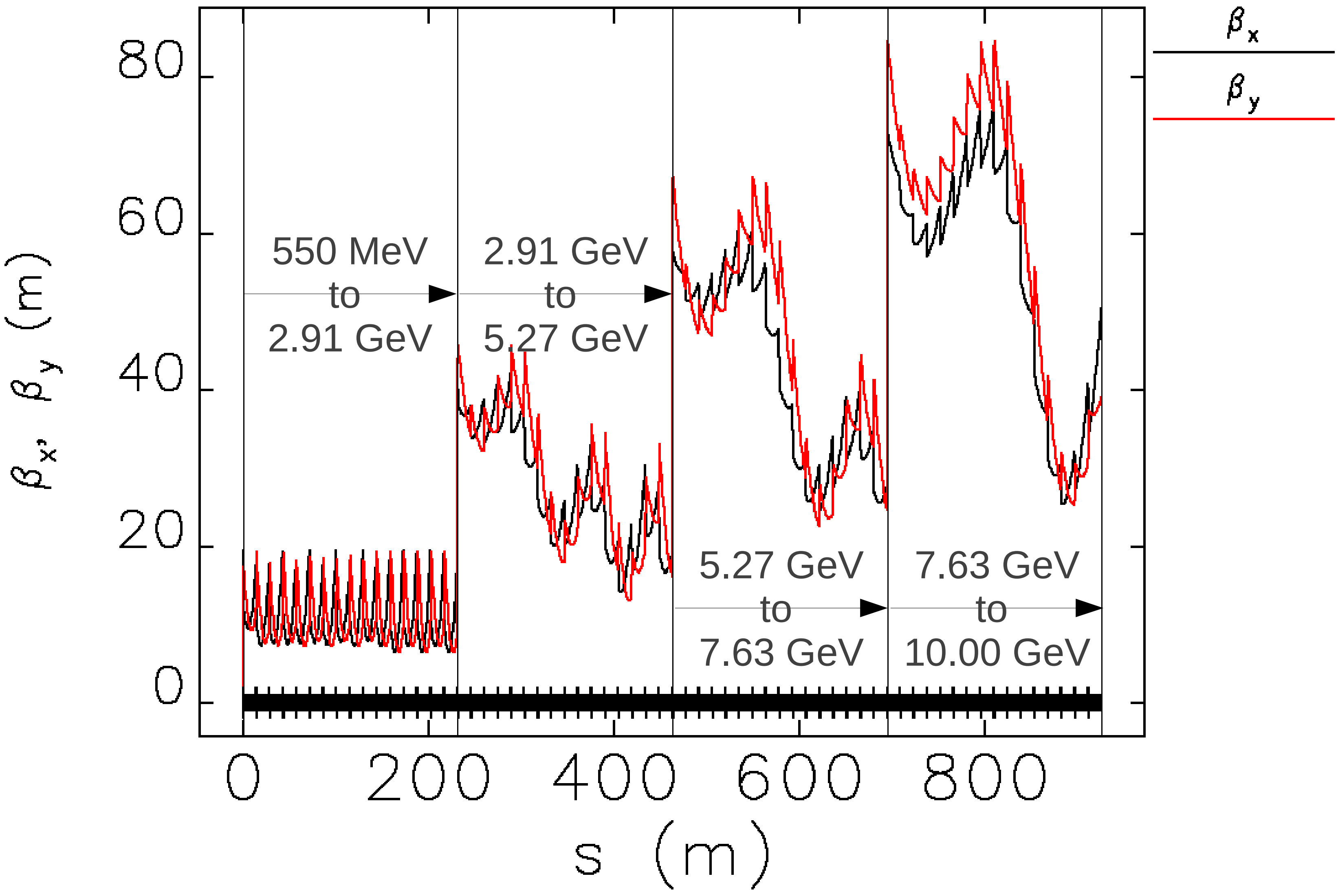
- Match multi-pass linac optics for four beams
- Design emittance preserving arcs with same average radius for three beam energies
- Design x-y rotator and relay optics
- Match injection system to linac 1st pass
- Match from linac to 1st arc
- Match from 1st arc to relay optics
- Reverse solutions to get to exit of 2nd arc
- Match from arc to linac 2nd pass
- Repeat for subsequent passes
- Match from final linac pass through extraction system
- In total, about 140 **elegant** runs needed
  - Passing information between runs with SDDS files helps prevent errors and insanity

Linac Configuration

- Very similar to ERL@APS linac designs[1]
  - 20 MV/m in 1-m-long, 1.3 GHz cavities
  - Doublet focusing
- Started with graded-gradient solution[2]:
  Set quadrupoles to give constant focal length for lowest energy beam
- Optimized all four passes simultaneously in two steps
  - Optimize common focal length, spacing to minimize the maximum beta functions
  - Refine, allowing all gradients and spacing to vary independently
  - Major goal is to reduce maximum beta functions
  - Initial lattice functions allowed to vary at each energy
    - Makes matching to upstream systems harder later on…

[1]M. Borland *et al.*, Proc AccApp'07, 196-203 (2007).
[2]D. Douglas, JLAB-TN-98-040, TJNAF, Oct. 1998.

Linac Optics Solution



Arc Designs

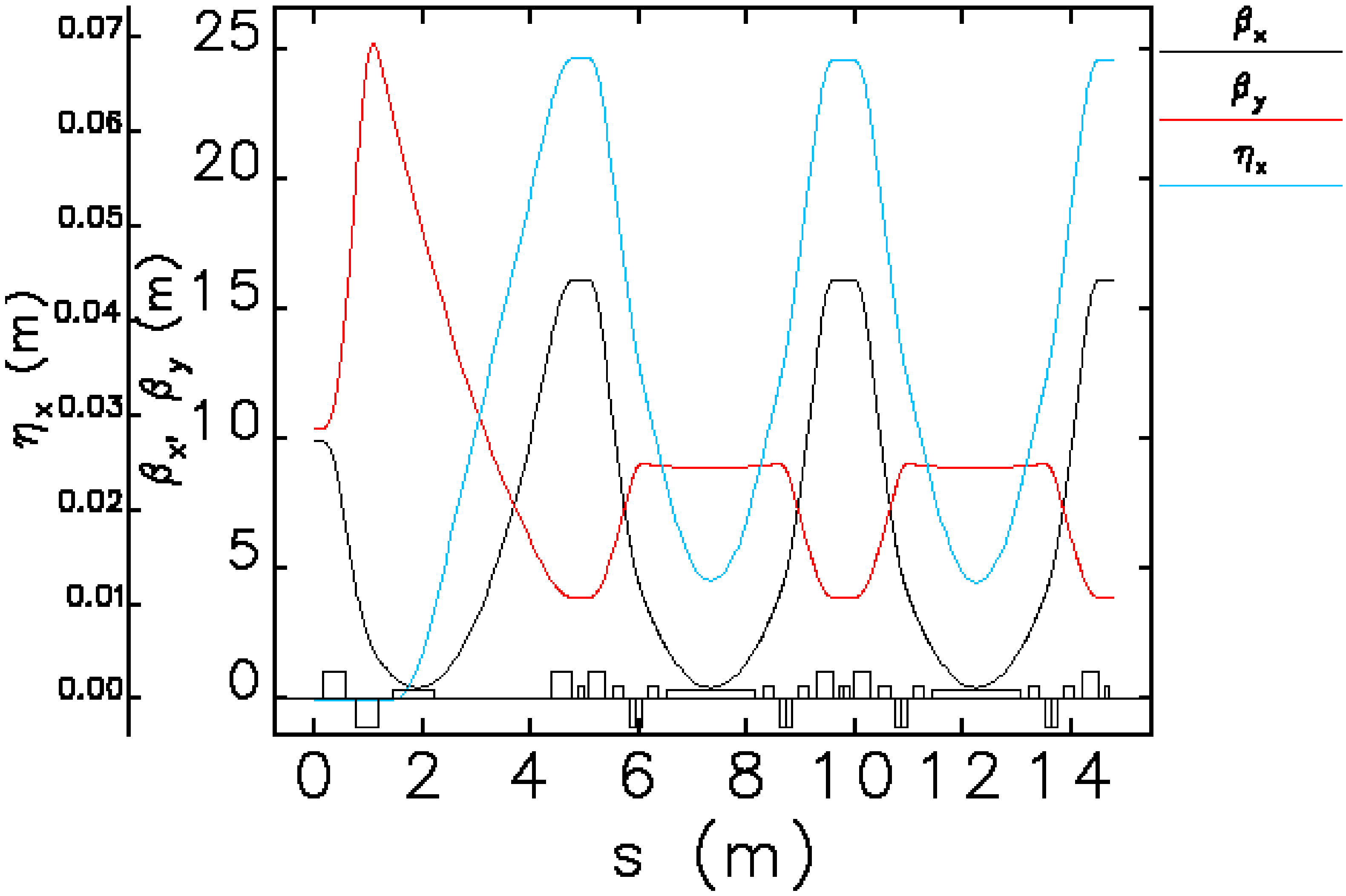
- Emittance growth per pass scales like

$$\frac{\gamma^5}{f^2 N_d^3 R}$$

where f is the dipole filling fraction, N_d is the number of cells, and R is the mean radius.

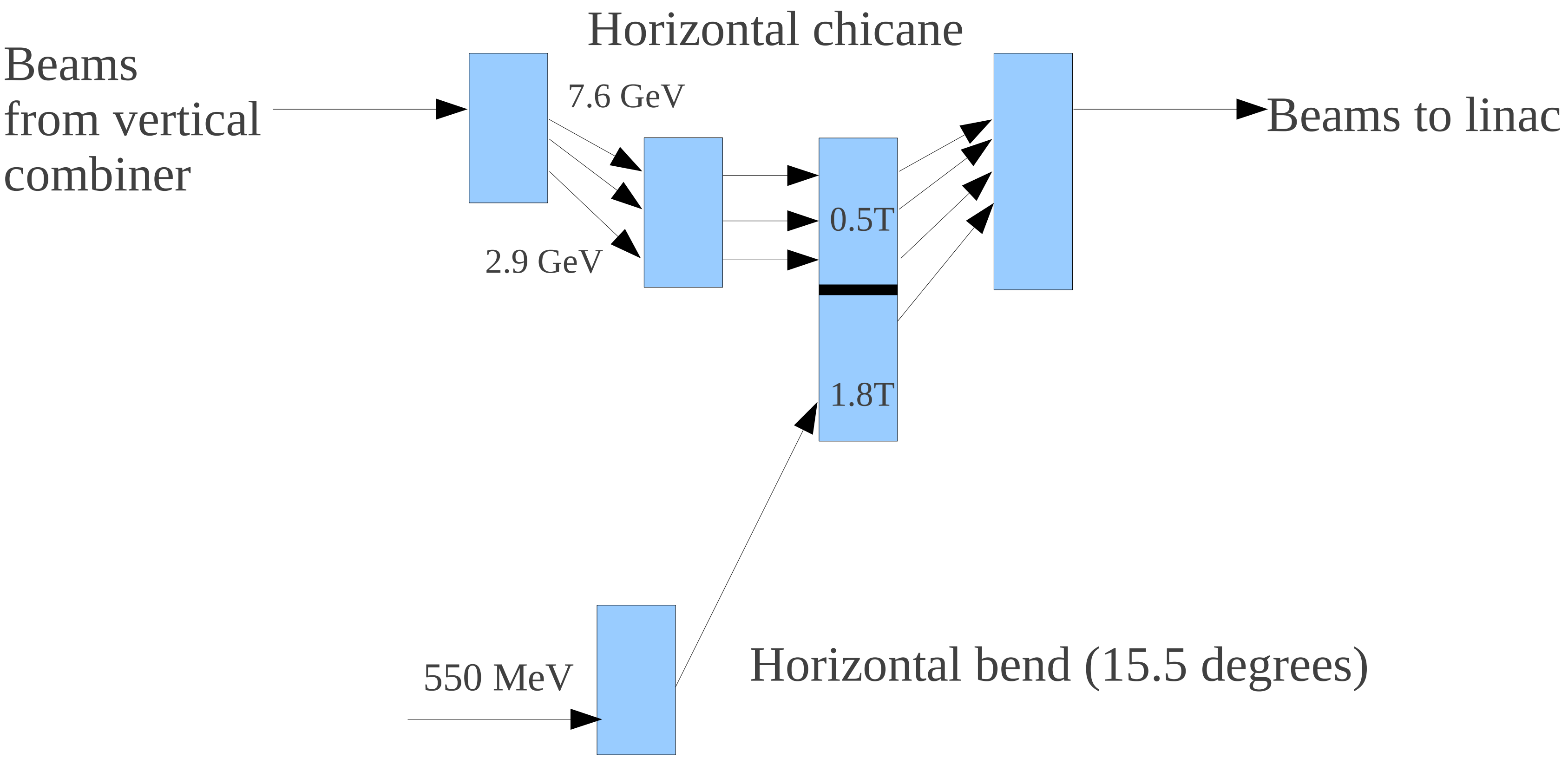
- To keep R small, need lots of cells for higher-energy arcs
  - Chose a mean radius of 100m
- Used TME cells for arcs
  - 2.9 GeV: 15 cells per 180 arc plus dispersion suppressors
  - 5.3 GeV: 31 cells per arc, plus suppressors
  - 7.6 GeV: 63 cells per arc, plus suppressors
- Dispersion suppressors use half-length, half-angle dipoles
- Sextupoles are included, but set at zero for now

Example of Arc Optics

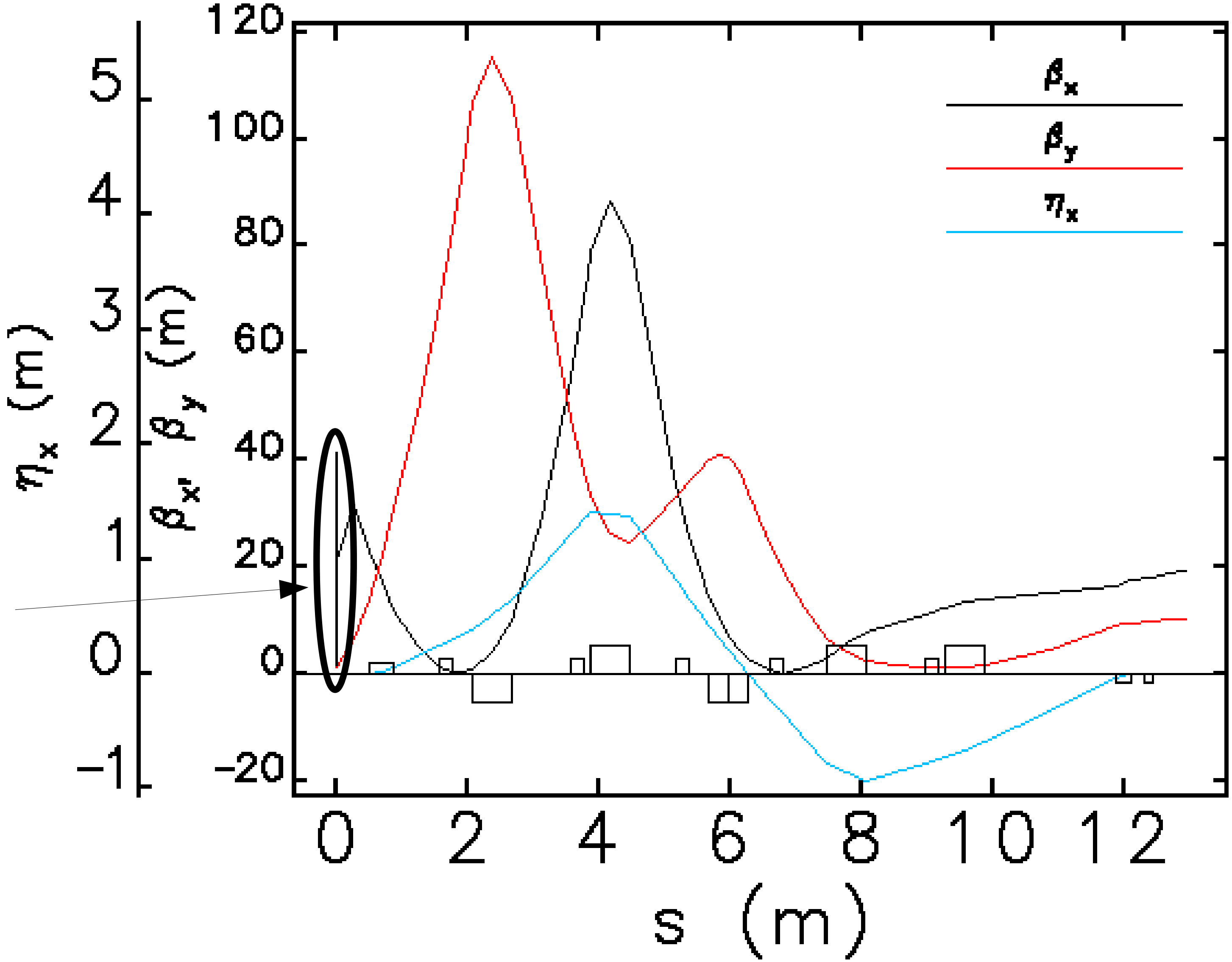


Injection

- Need to inject 550 MeV beam without perturbing recirculating beams
- Decided to use a horizontal chicane and septum
- Avoids having the 550 MeV beam go through strong vertical combiner dipole
- Keeps injector linac and main linac at same height



Injection Optics

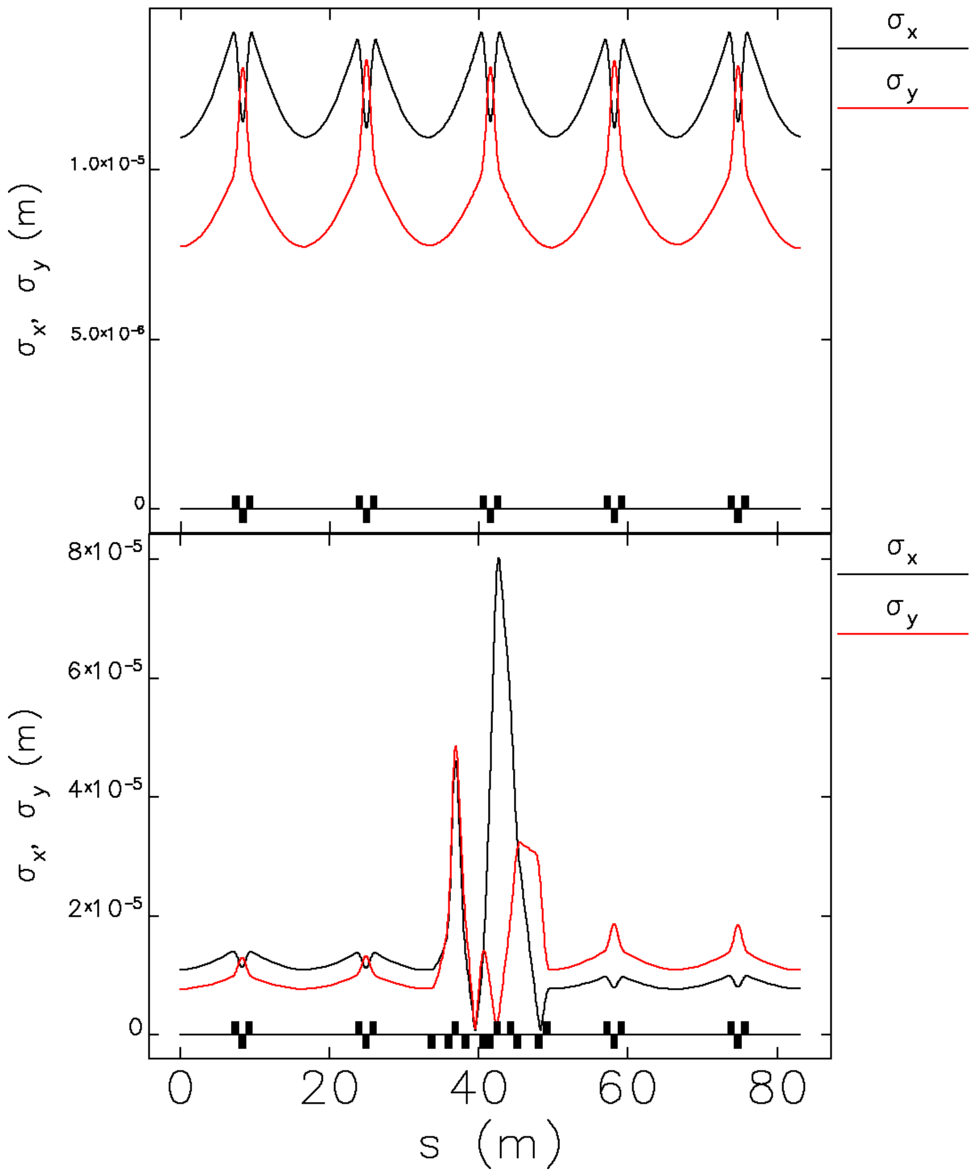


Initial lattice functions free to vary

Relay Optics and Emittance Exchange

- Beam is transported between arcs using triplet cells ("relay" optics)
- Optional x-y rotation allows exchanging emittances
  - Share emittance growth between x and y planes
  - Rotation module starts and ends at position of waists in the relay system
  - Require 4 skew quadrupoles to exchange emittances
  - 7 additional normal quads used for matching
  - Can be turned off easily due to incorporation of a relay triplet into the sequence of normal quads

Rotation Module Example ($\varepsilon_x = 2\varepsilon_y$)

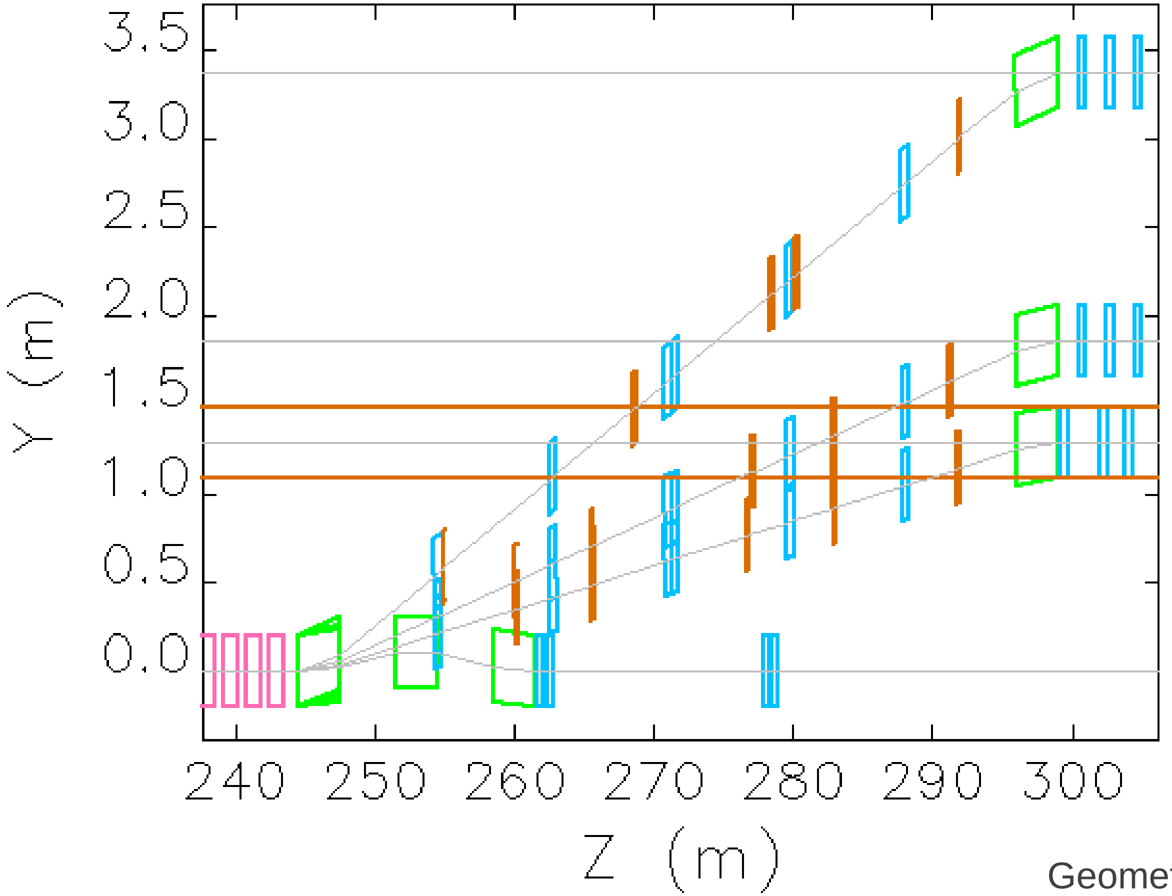


Without rotation

With rotation

Vertical Separators (Combiners are Similar)

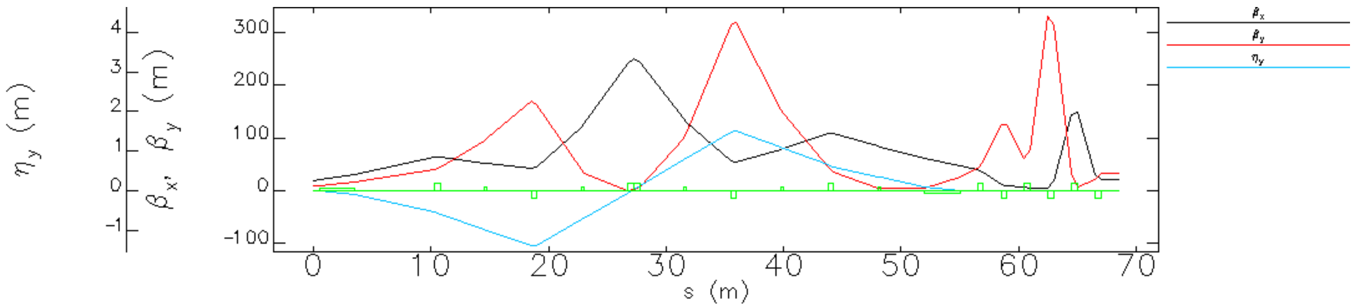
- Beam from linac must be fanned out into the arcs
- Used vertical doglegs with a common first dipole
- 10 GeV beam will also see this dipole

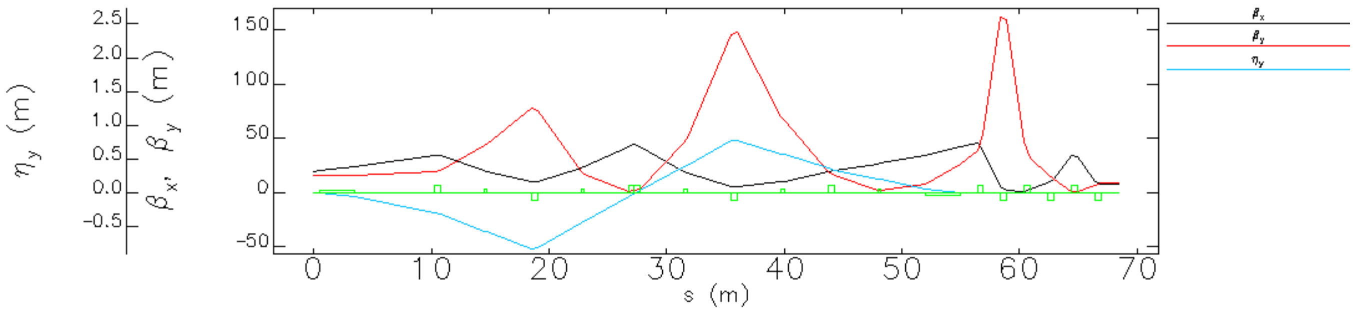


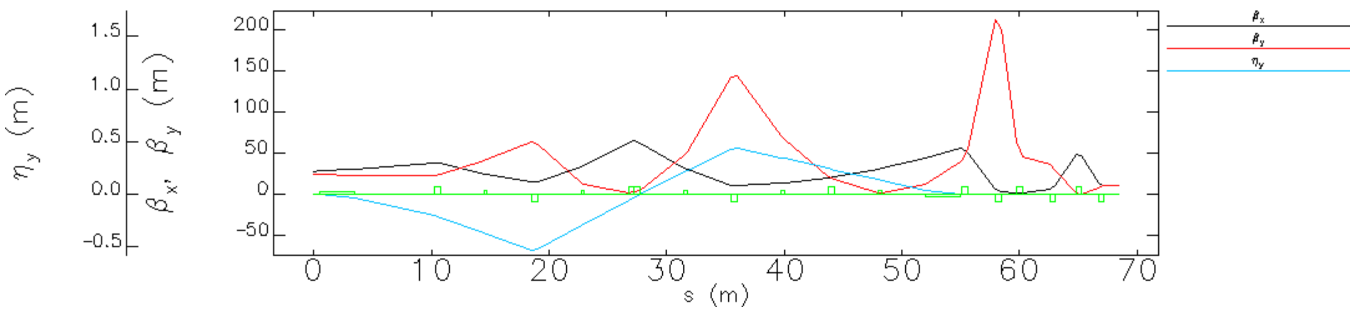
- Some magnet collisions evident
- Can stagger quads and sexts
- Consider multi-axis or off-axis yoke designs
- Use shielded tubes if needed
- Use septum for middle magnet of 10 GeV chicane

Geometry plot made with modified version of a script by A. Petrenko (FNAL).

Separator Optics (Combiners are Similar)

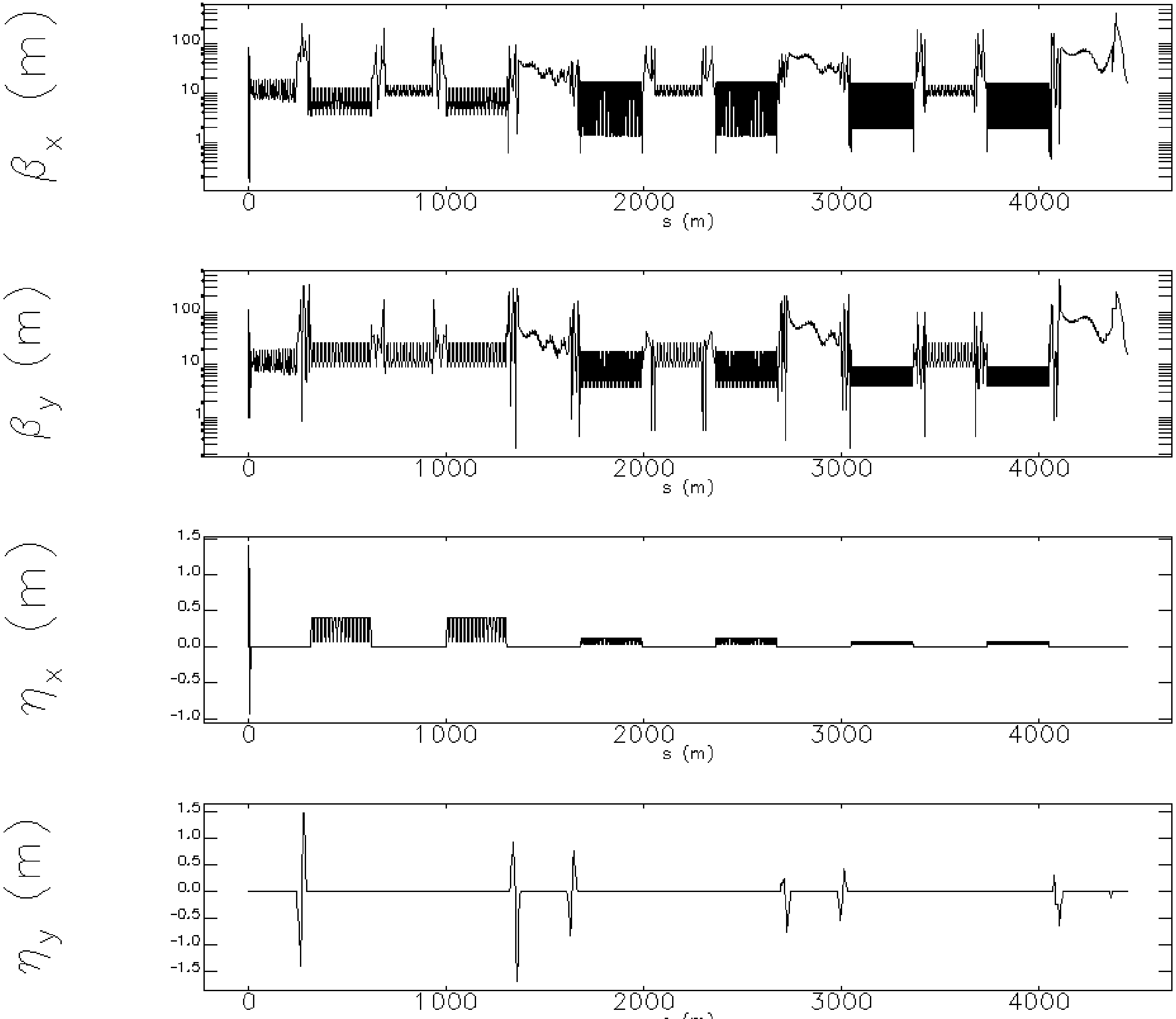




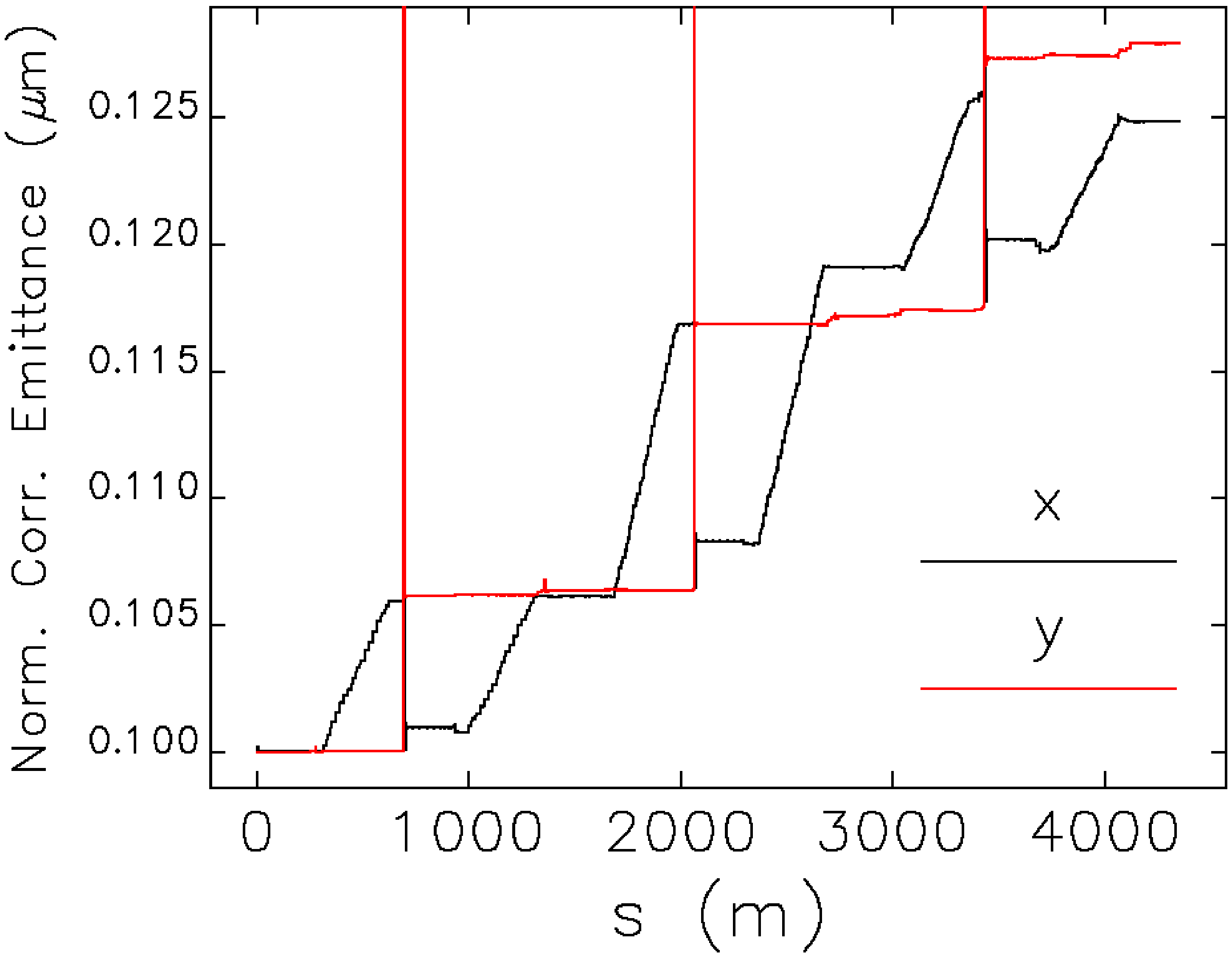


- Sextupoles needed to prevent emittance growth from chromatic aberrations
- Sextupole strengths, positions optimized by tracking

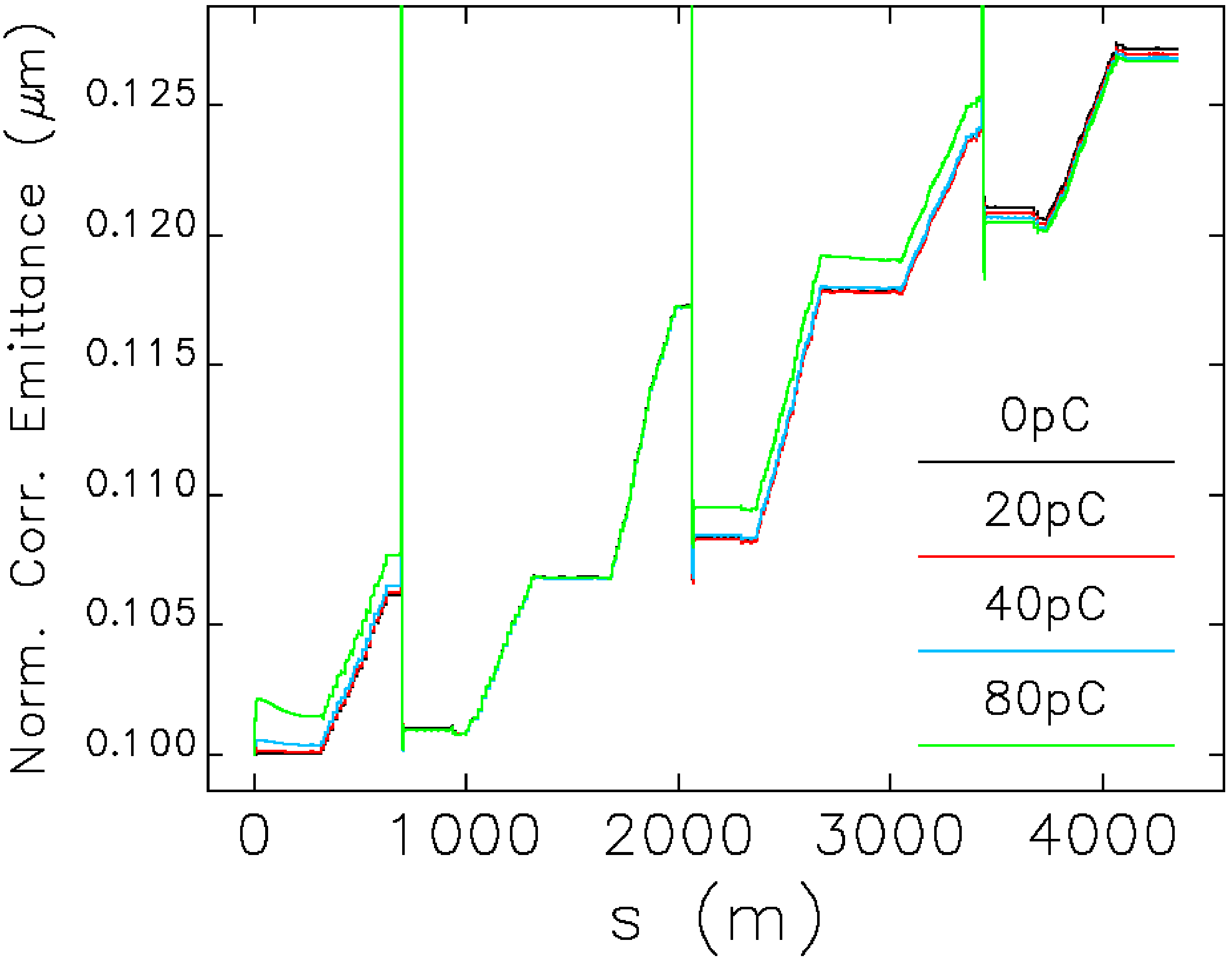
Full System Optics (Rotators Off)



Tracking Results (SR, Q=0, Rotation On)



Tracking Results (SR, Rotation On)



Conclusions

- Developed optics solution for a four-pass linac and recirculation system
- Realistic optics design with all components included
- Some element collisions, but looks solvable
- Less than 30% emittance growth in both planes
- No issues with CSR
- x-y rotators share emittance growth between planes
  - Requires low energy spread to avoid emittance growth
  - How will it work with errors, non-ideal beams?
- Is this cheaper than a straight linac?
  - ~250 bends, ~1200 quads, ~1100 sextupoles
- Perhaps a two-pass system is a good compromise
  - I.e., a single 5 GeV recirculation arc