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Comparison of ERL Options and Greenfield ERL

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U.S. DEPARTMENT OF ENERGY

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Outline

- All optics design and evaluation done with **elegant**[1].
- Realization of an infield option
  - Geometry and optics
  - Emittance preservation for high-coherence mode
- Example of a racetrack Greenfield ERL
  - Geometry and optics
  - Emittance preservation
- Realization of an outfield option
  - Geometry, optics, emittance preservation
  - Energy aperture optimization
- Brightness comparisons.

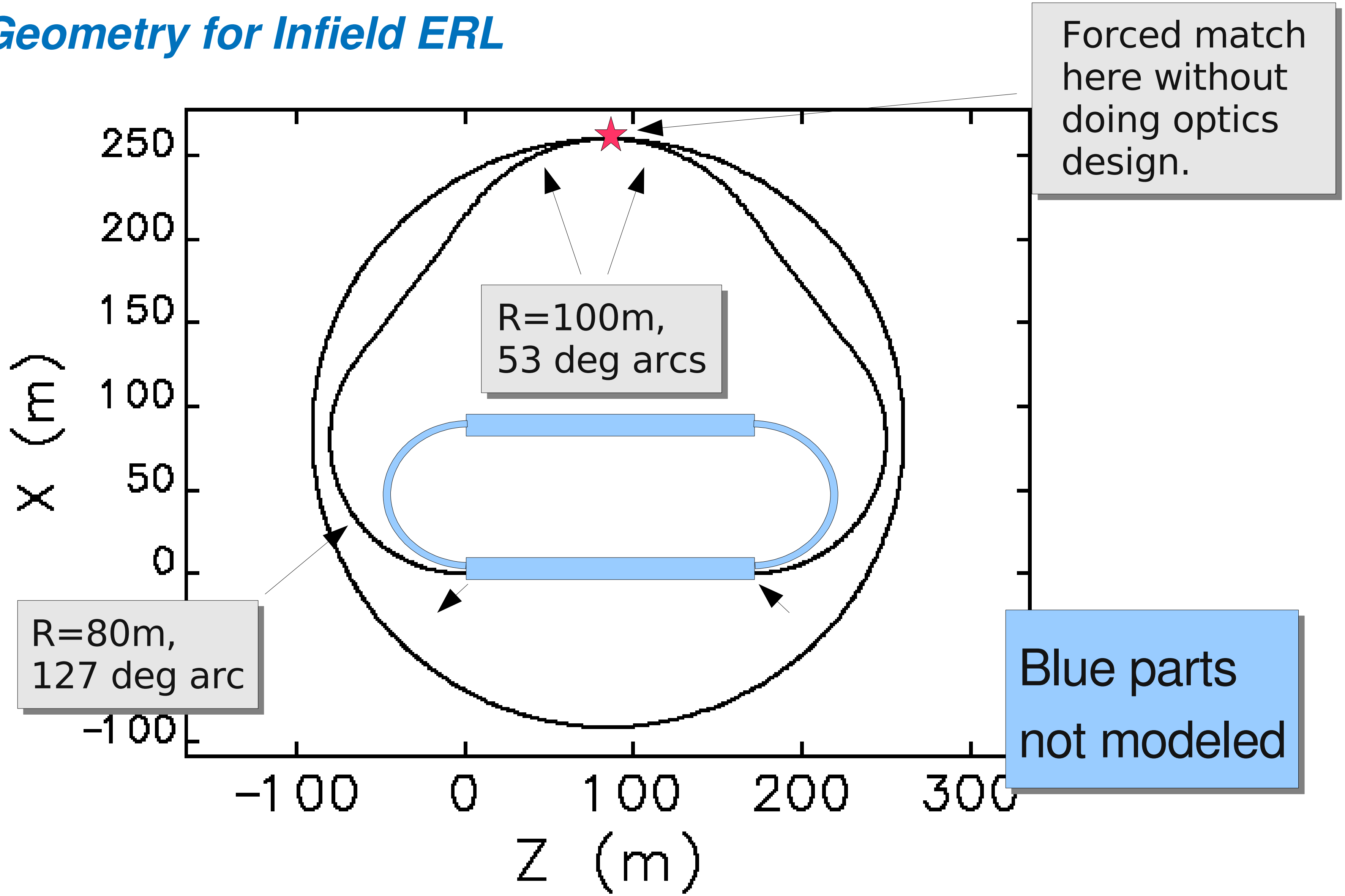
[1]M. Borland, APS LS287, September 2000.

Realization of Infield ERL Option

- Configuration suggested by R. Gerig, layout by N. Sereno and H. Friedsam[1]
  - Looked at Option 1 from N. Sereno's talk
- Limitations of work so far
  - Looked only at 7 GeV transport
  - Did not look at linac optics
  - Did not match linac to the transport arcs
  - No sextupoles or chromatic correction
  - Detailed join to APS not done
    - *Beamline simply comes tangent to the APS*
    - *Simply force the beam to have the right lattice functions when going into the APS.*

See also V. Sajaev, ASD/APG/2006-20, 8/30/06.
[1]N. Sereno, H. Friedsam, OAG-TN-2006-053, 11/8/06.

Geometry for Infield ERL

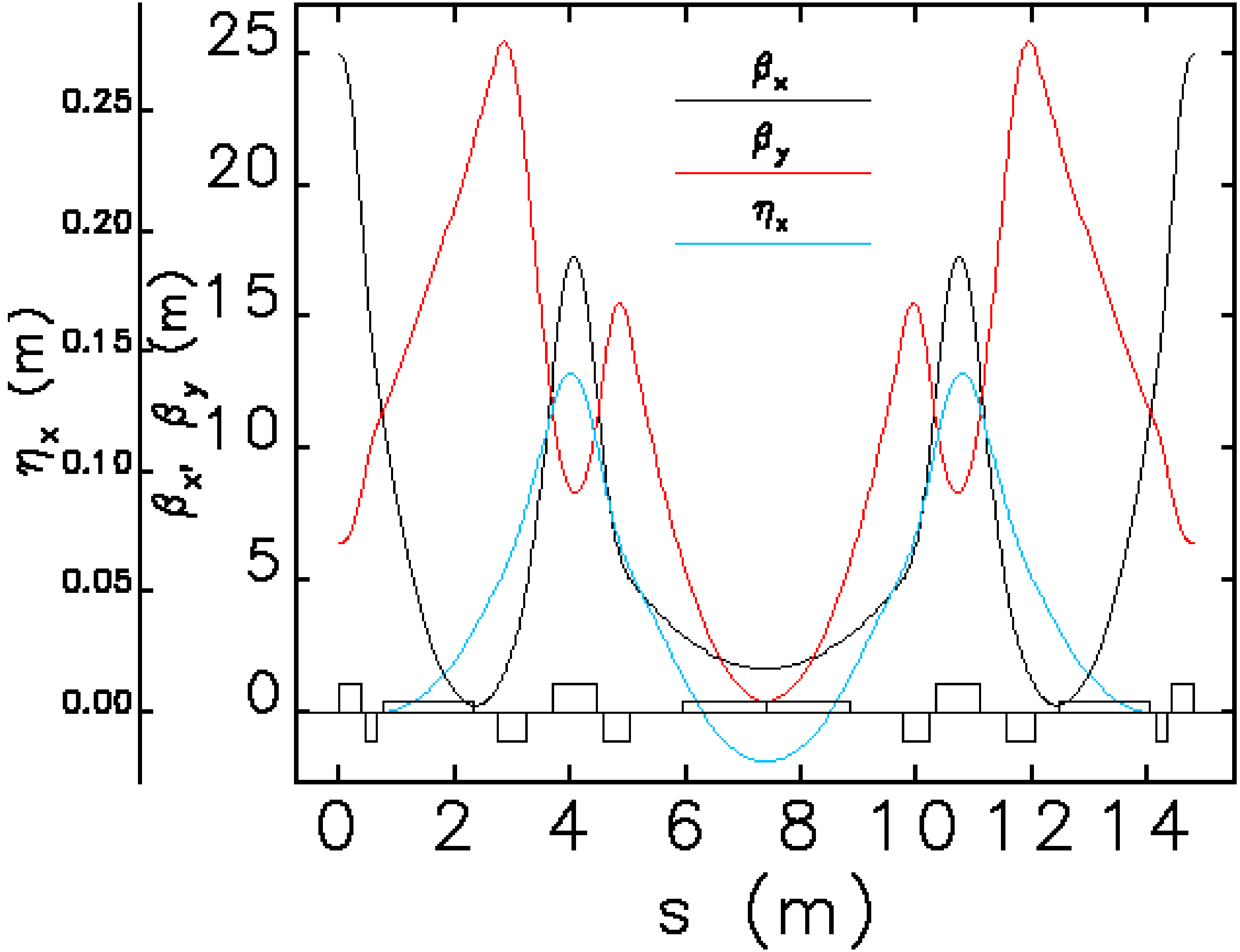


See also V. Sajaev, ASD/APG/2006-20, 8/30/06.

Infield R=80m, 127 degree Arc

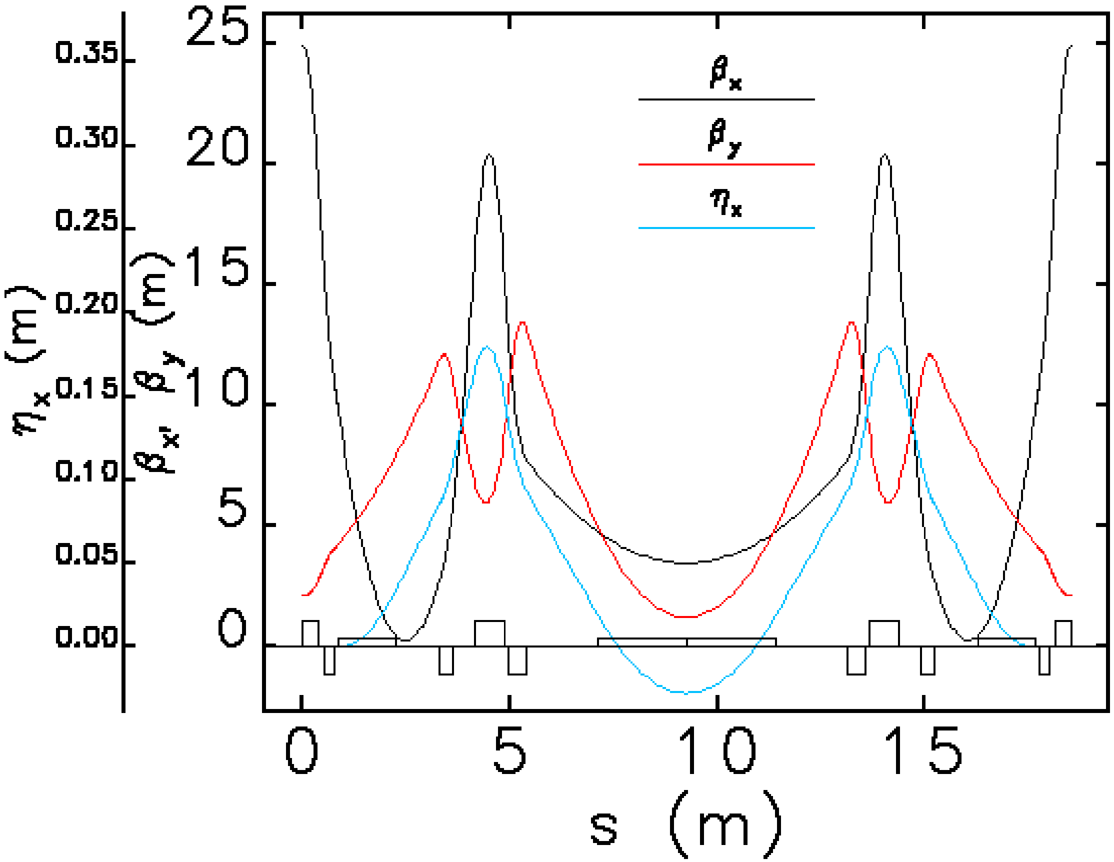
- Tight radius motivates short cells to reduce emittance growth
- 12 isochronous TBA cells, ~10 degrees per cell
- Horizontal phase advance per cell is 1.25
  - Natural value for an isochronous TBA
  - CSR cancellation every four cells
- Matching constraints included minimization of I_5 to control ISR emittance growth
  - Done for all the designs shown below as well
  - Got total $I_5 = 5.2 \times 10^{-6}$ 1/m
  - For 10 cells, I_5 was about double.

Lattice Functions for R=80m Arc (127/12 deg per cell)

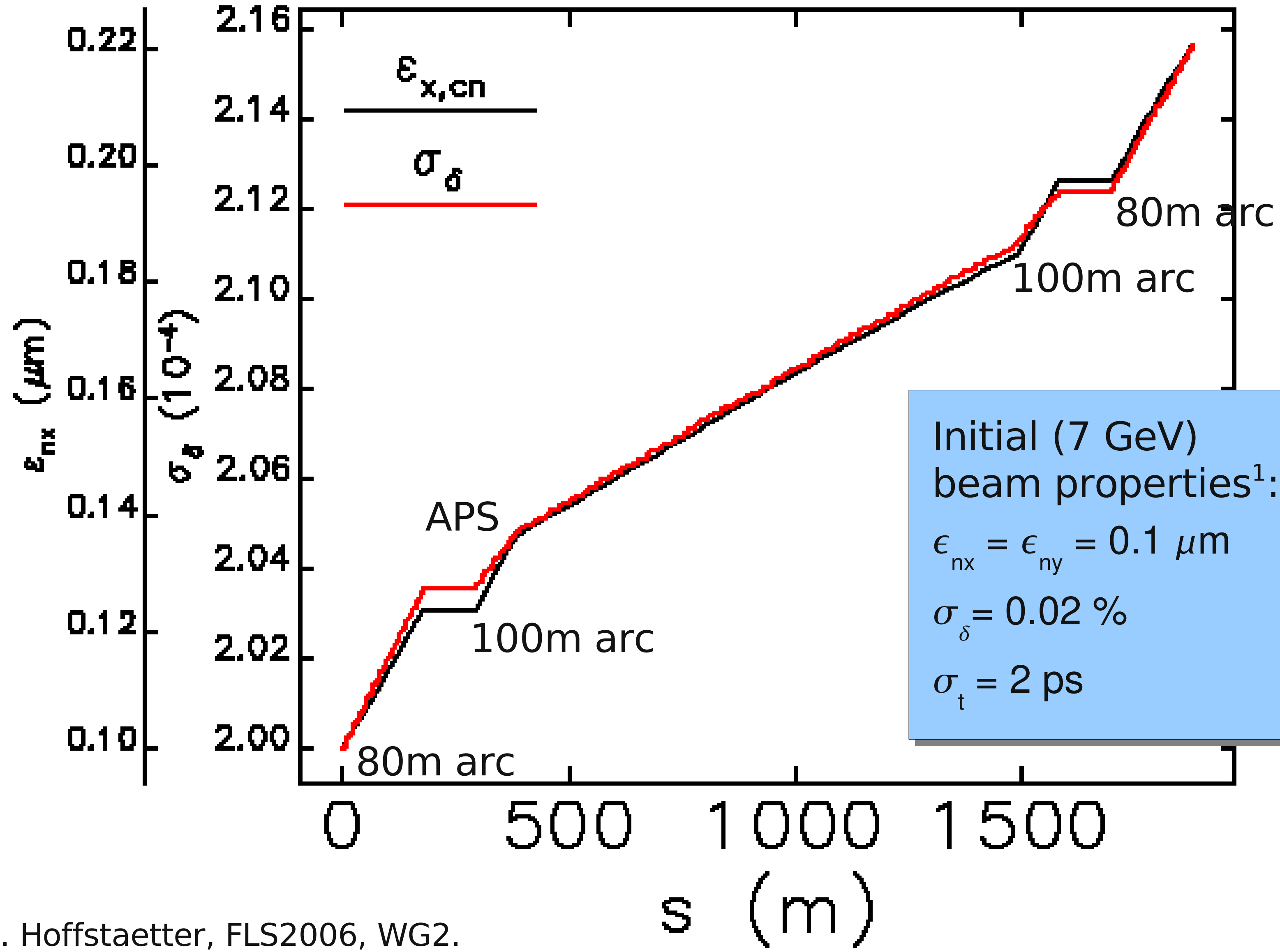


Infield R=100m, 53 degree Injection Arc

- 5 isochronous TBA cells, ~10 degrees per cell
- Horizontal phase advance per cell is 1.2
  - CSR cancellation at end of arc
- For each 5-cell arc, get $I_5 = 2.8 \times 10^{-6}$ 1/m



Infield ERL Beam Properties in Absence of CSR



Initial (7 GeV) beam properties[1]:

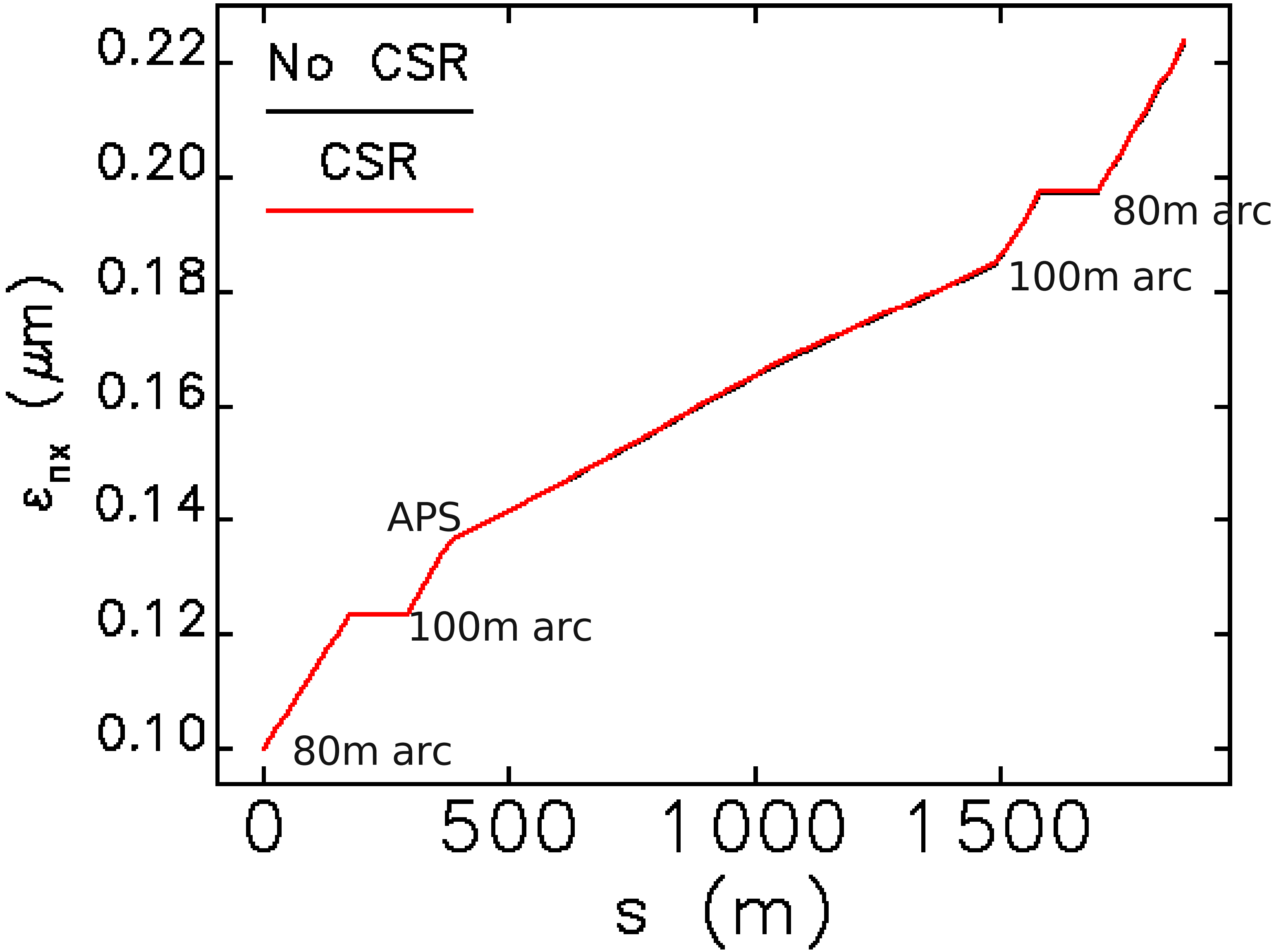
$\epsilon_{nx} = \epsilon_{ny} = 0.1\ \mu m$

$\sigma_\delta = 0.02\ \%$

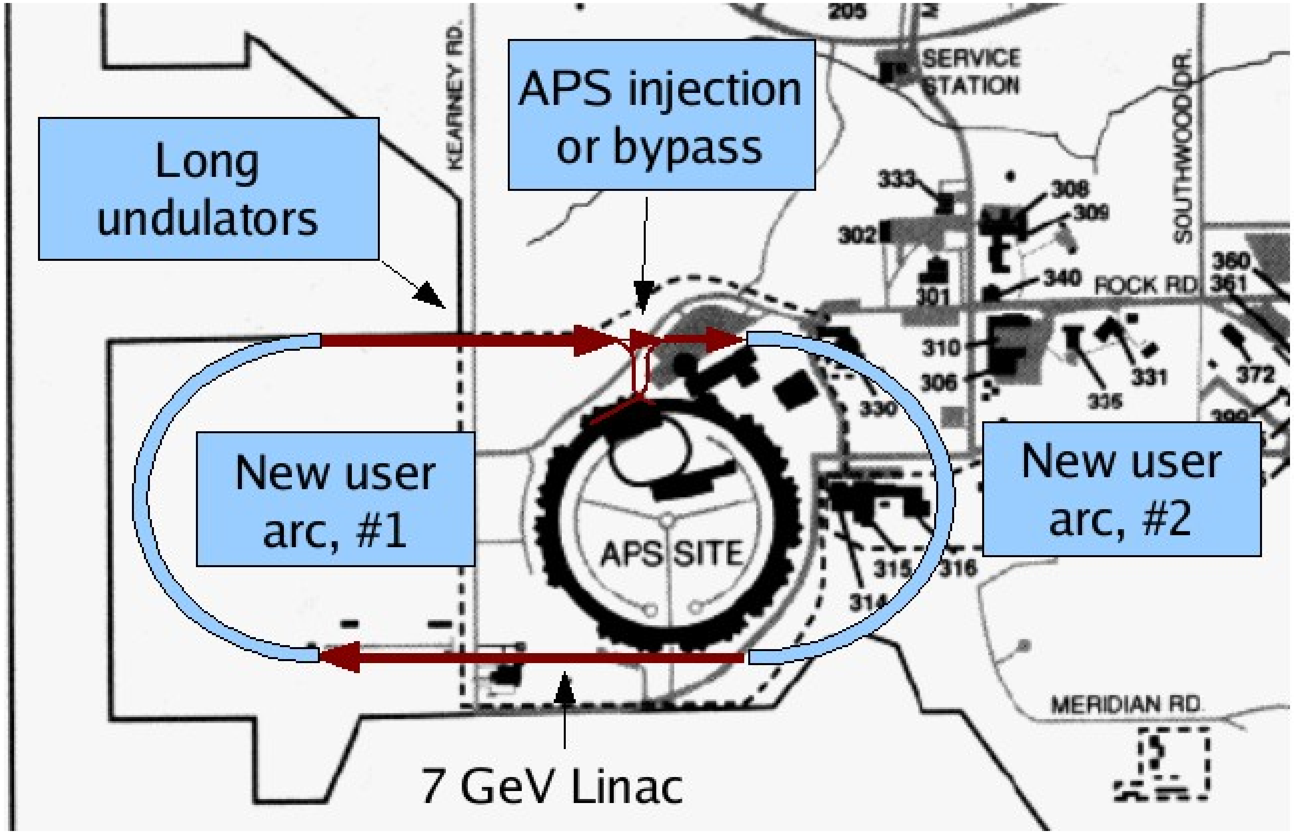
$\sigma_t = 2\ ps$

[1]G. Hoffstaetter, FLS2006, WG2.

Infield ERL Emittance Impact from CSR (77 pC/bunch)



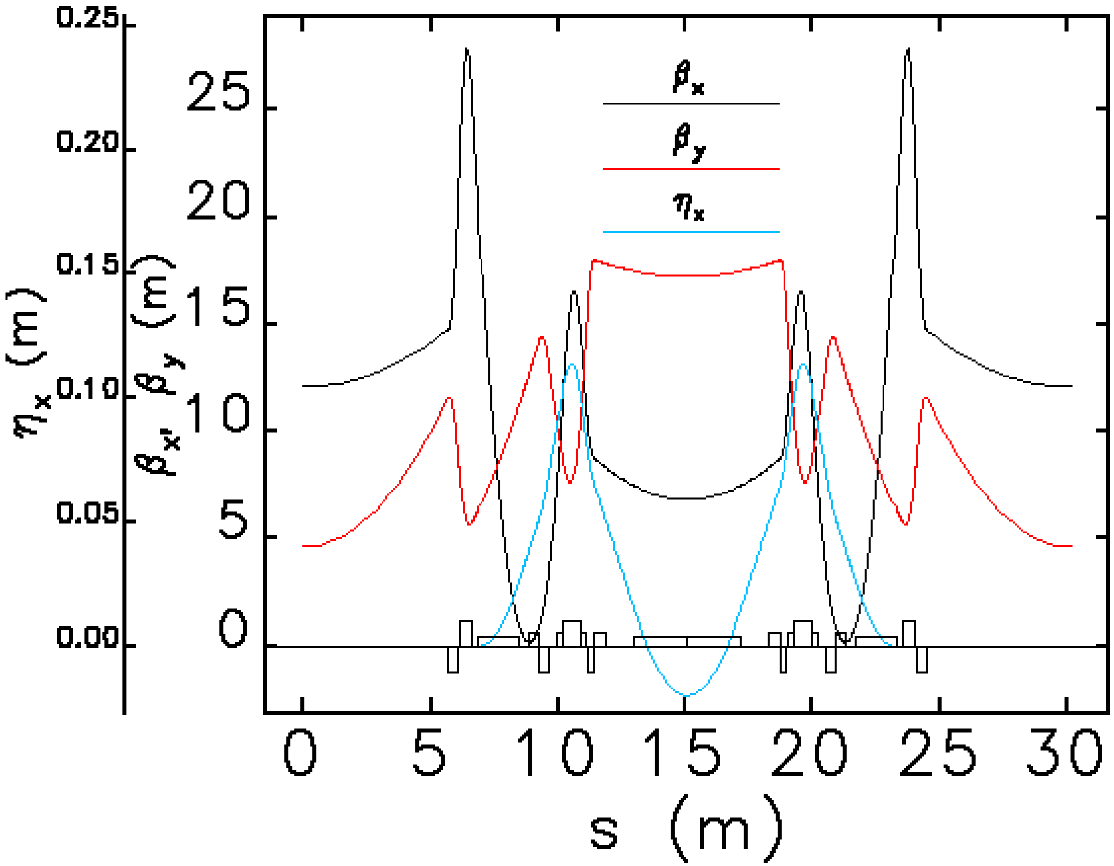
Example of a Racetrack Greenfield ERL[1,2]



- Size chosen to fit around APS as shown
- ERL could stand alone or part of APS
- Limitations of work so far
  - Did not simulate gun, merger or dump
  - Did not optimize energy aperture (sextupoles are present)

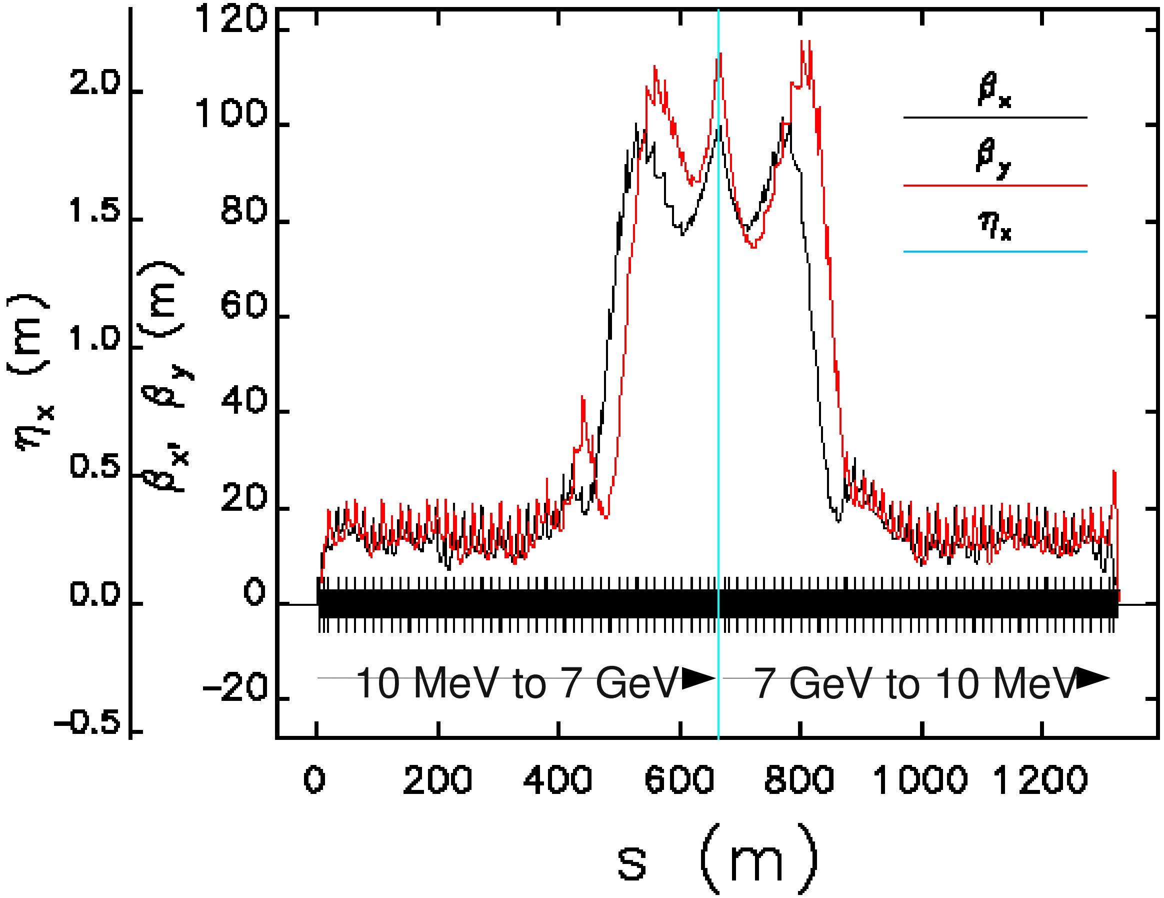
[1]M. Borland, OAG-TN-2006-031, 8/16/06.
[2]M. Borland, OAG-TN-2006-042, 9/17/06.

Arc Design for GF ERL with R=230m



- 10 m straights (like APS ring upgrades)
- Isochronous
- x tune is 1.25 per cell
- 48 cells
- Total I_5=6.6 x 10^{-6} 1/m
  - Less than Infield ERL transport lines
- Four sextupole families
- 5 quadrupoles for optics control
  - R_{56} tuning?
  - Beta function customization?

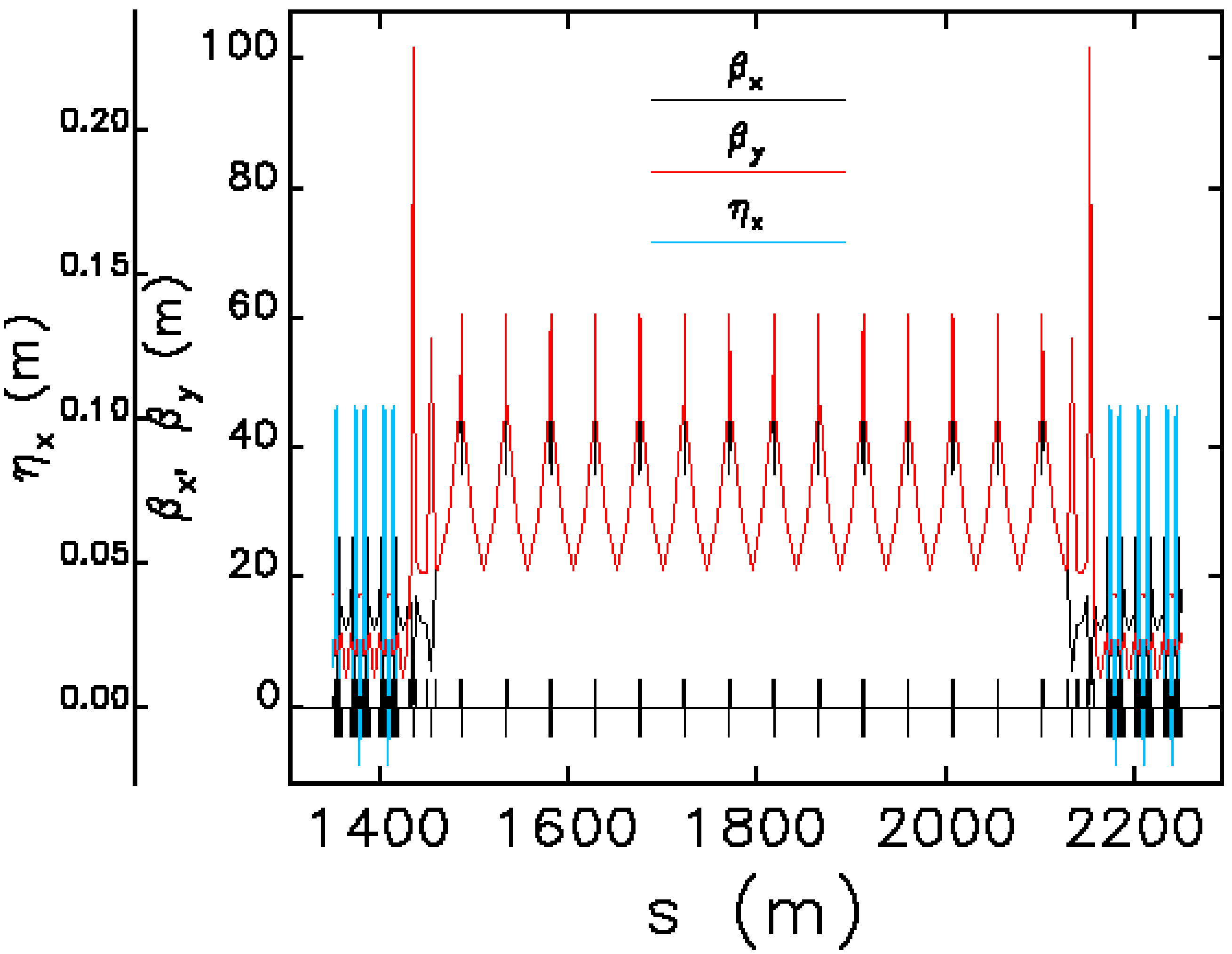
Linac Design for 7 GeV GF ERL



- Inject at 10 MeV
- Optimized graded gradient[1] doublet optics[2]
- Use TESLA 9-cell cavity parameters in Nassiri's configuration
  - 352 cavities
  - 20 MV/m
- Cavity filling factor 0.52
- 92 quadrupoles

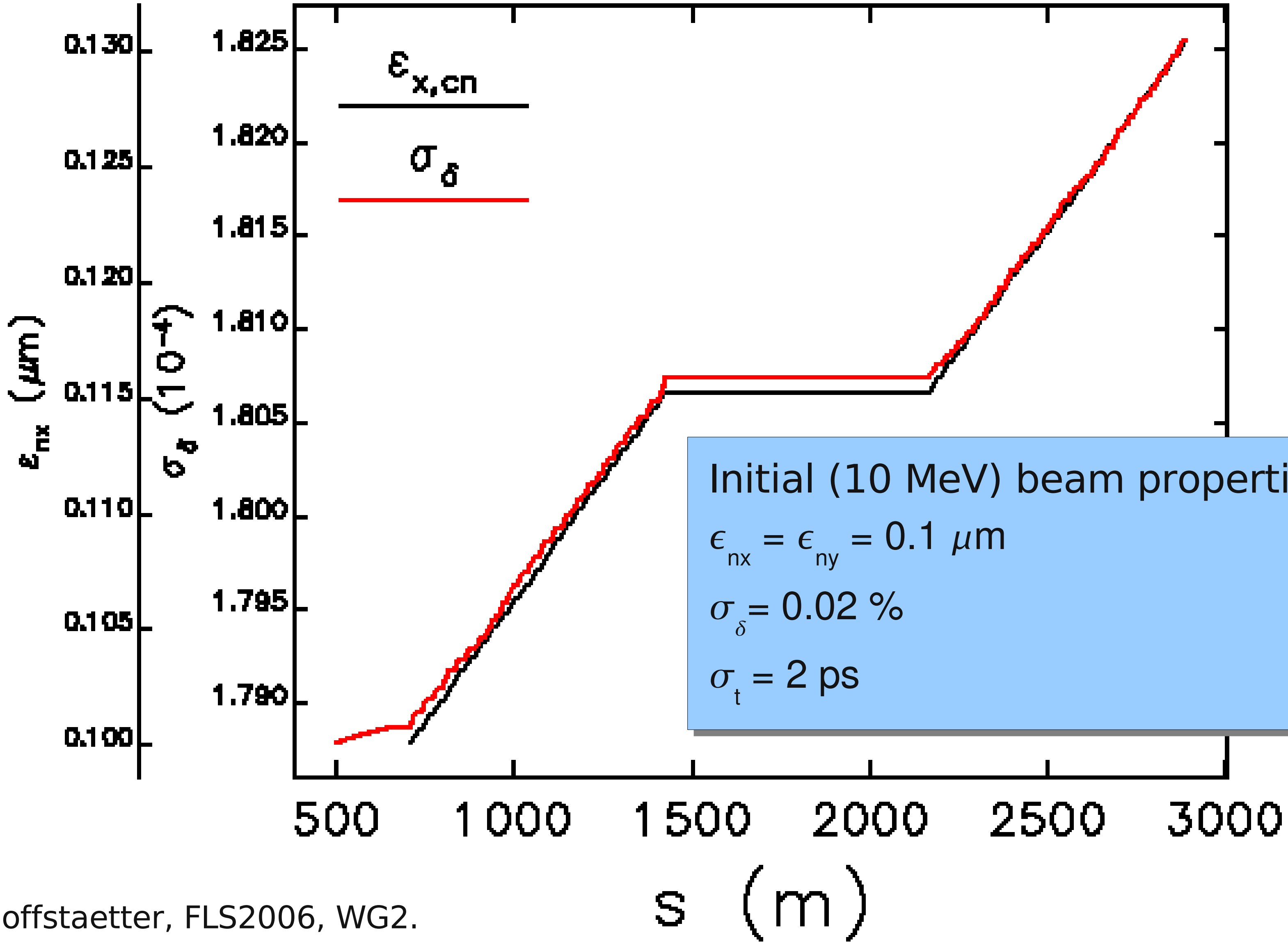
[1]D. Douglas, JLAB-TN-00-027, 11/13/00.
[2]M. Borland, OAG-TN-2006-041, 9/17/06.

Straight Section Design for GF ERL



- Use a series of triplets for the long straight
- Matching with arcs done with a pair of triplets

GF ERL Tracking Results without CSR



Initial (10 MeV) beam properties:

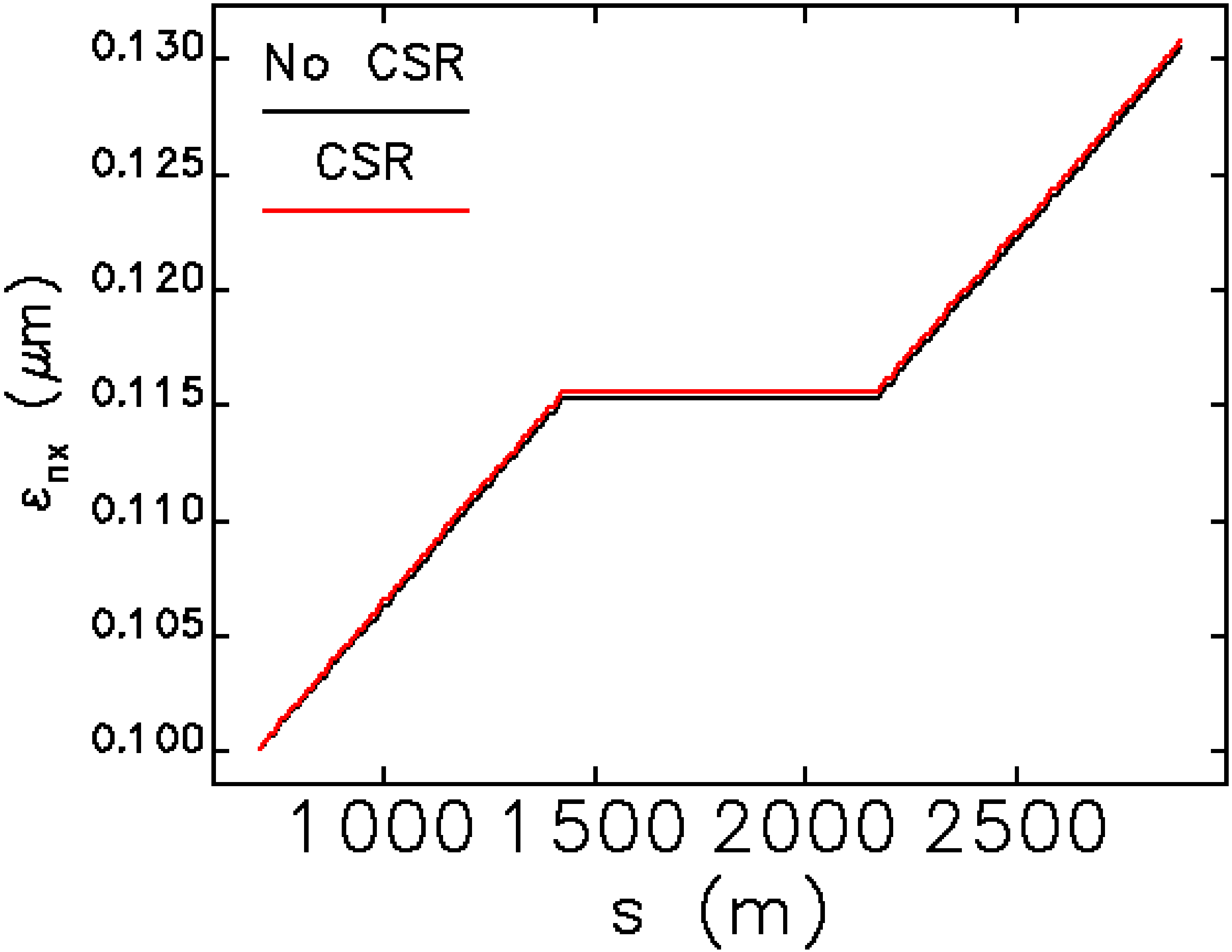
$\epsilon_{nx} = \epsilon_{ny} = 0.1\ \mu$m

$\sigma_\delta = 0.02$ %

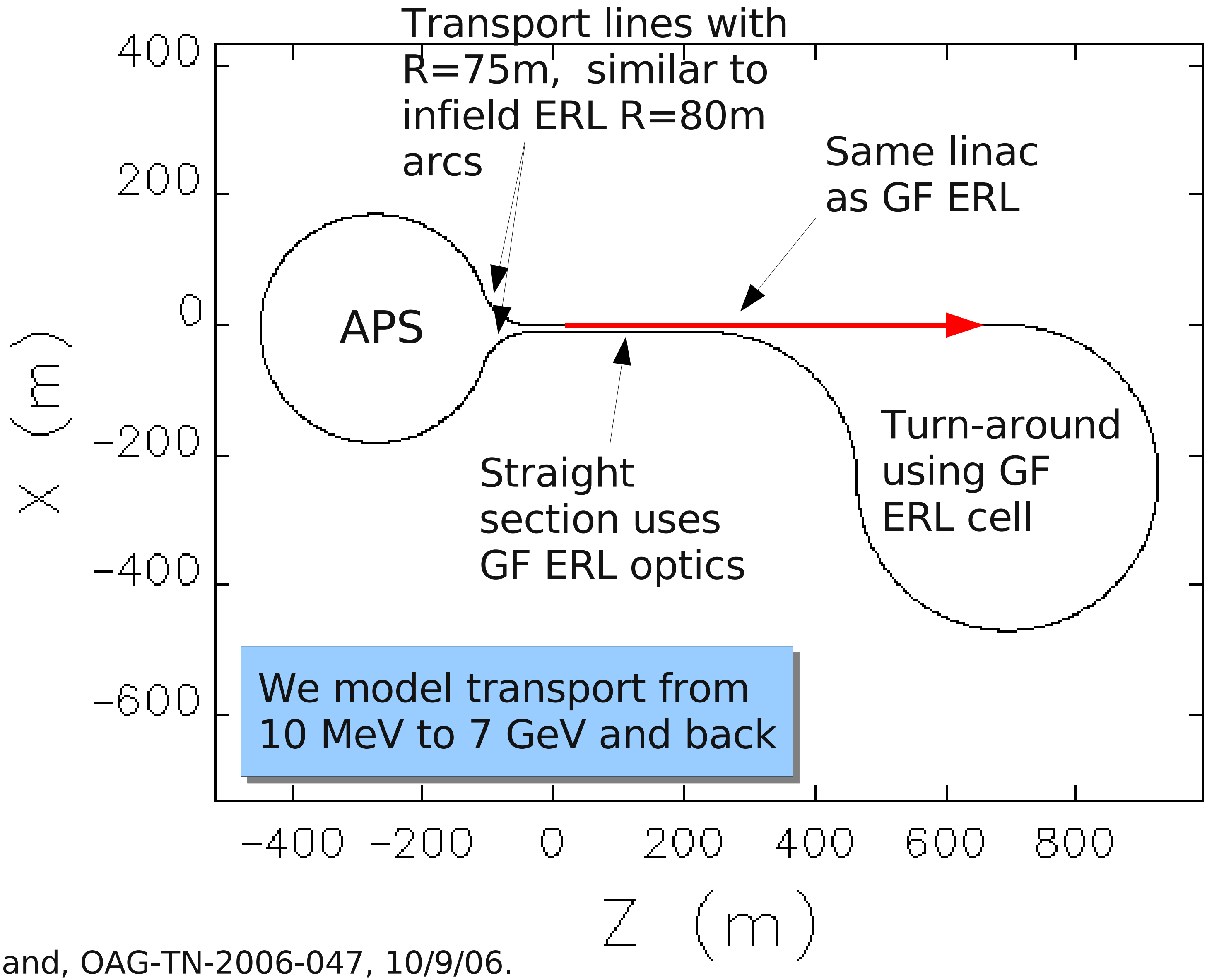
$\sigma_t = 2$ ps

[1]G. Hoffstaetter, FLS2006, WG2.

GF ERL Tracking Results with CSR (77 pC/bunch)

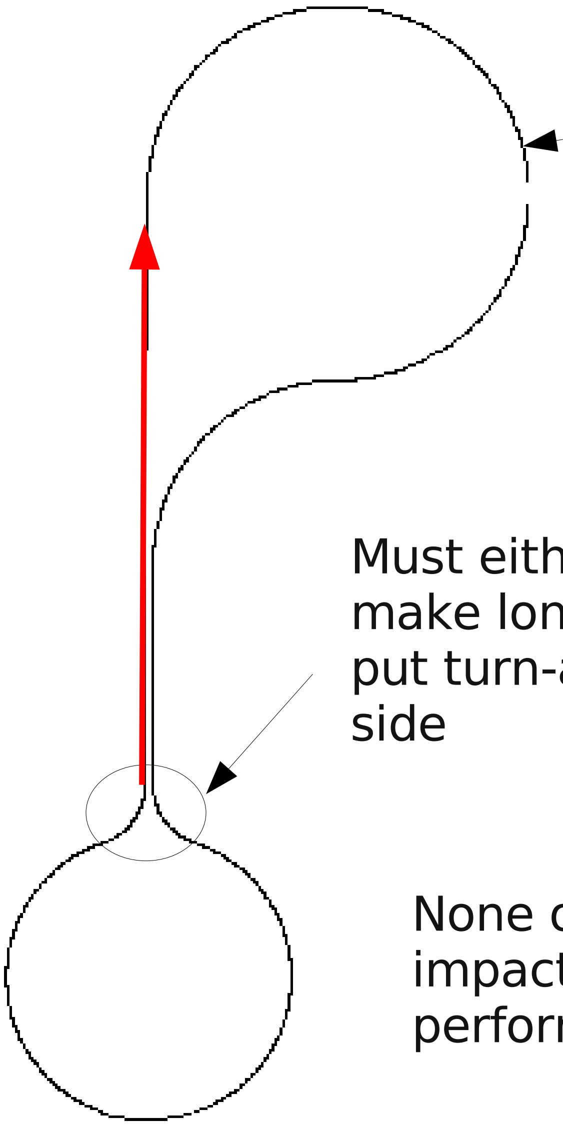


Realization of Decker's Outfield ERL Concept[1]



[1]M. Borland, OAG-TN-2006-047, 10/9/06.

(Non-essential) Issues with this Geometry



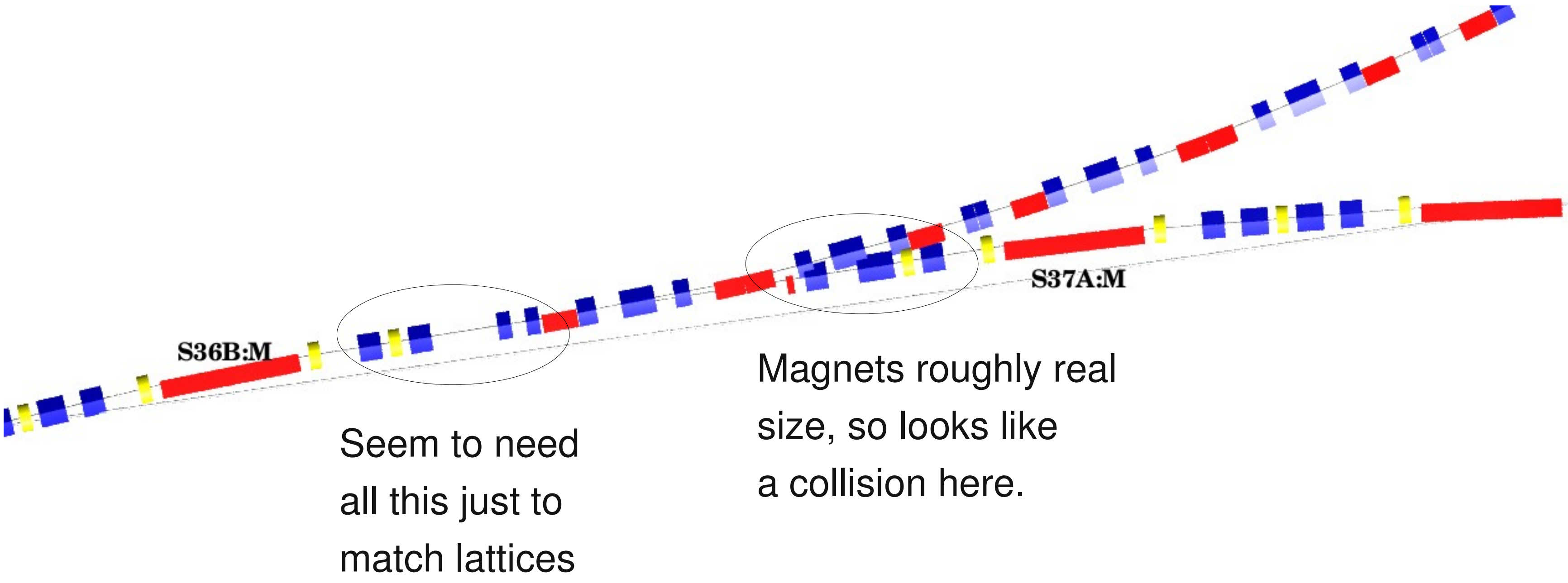
Turn-around is on wrong side: may hit buildings and wetlands

Must either cross here or make longer corridor to put turn-around on other side

None of these issues impacts evaluation of performance.

Courtesy G. Decker.

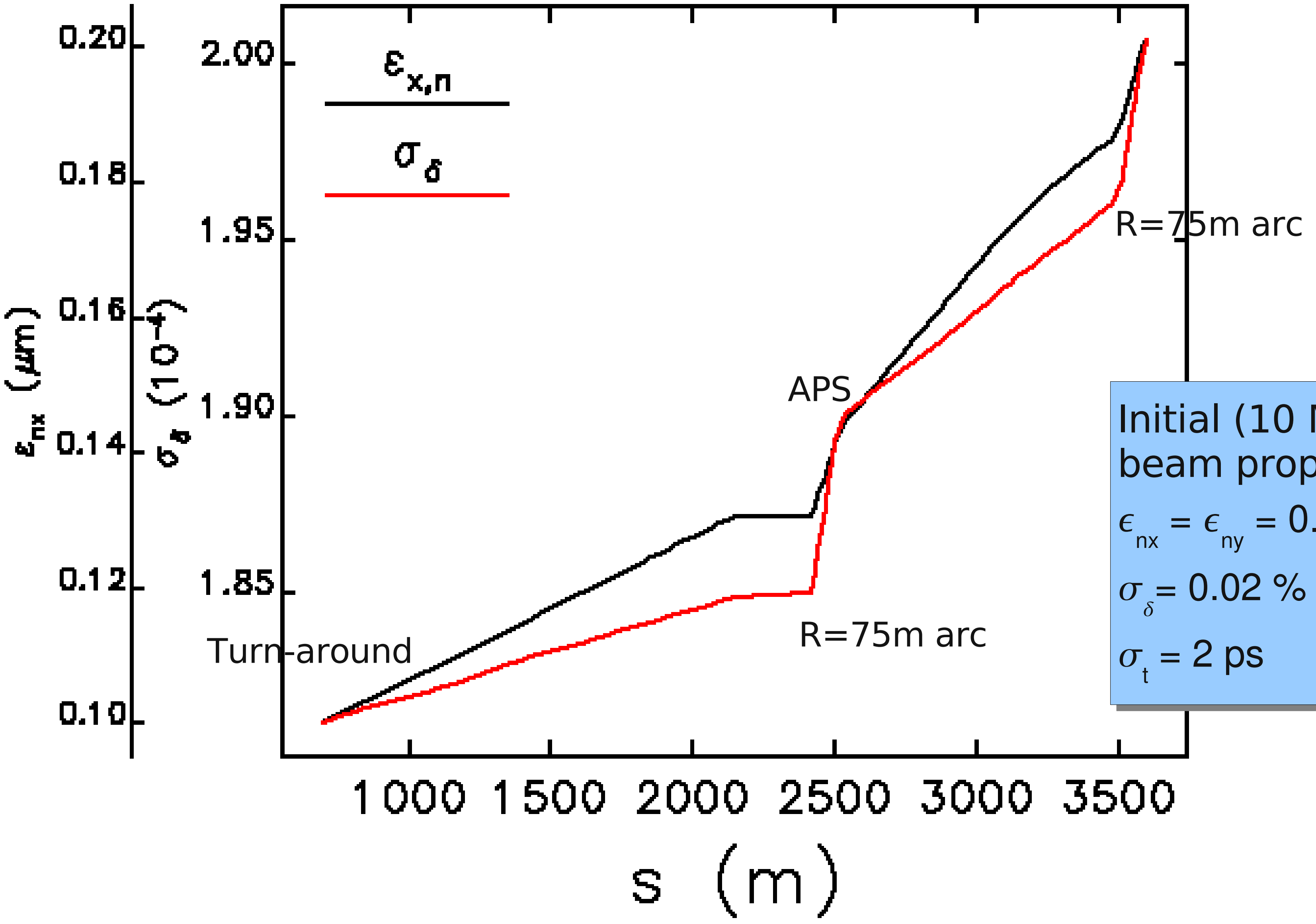
Magnet Layout for Outbound Beam (Rough)



- Possible solutions:
  - Make the bends in the first cell stronger.
    - *Will mess up the CSR emittance compensation, so may have to do four cells*
  - Turn off S36B:M and bring beam out sooner.

Thanks to L. Emery for help with figure.

Outfield ERL Tracking Results without CSR



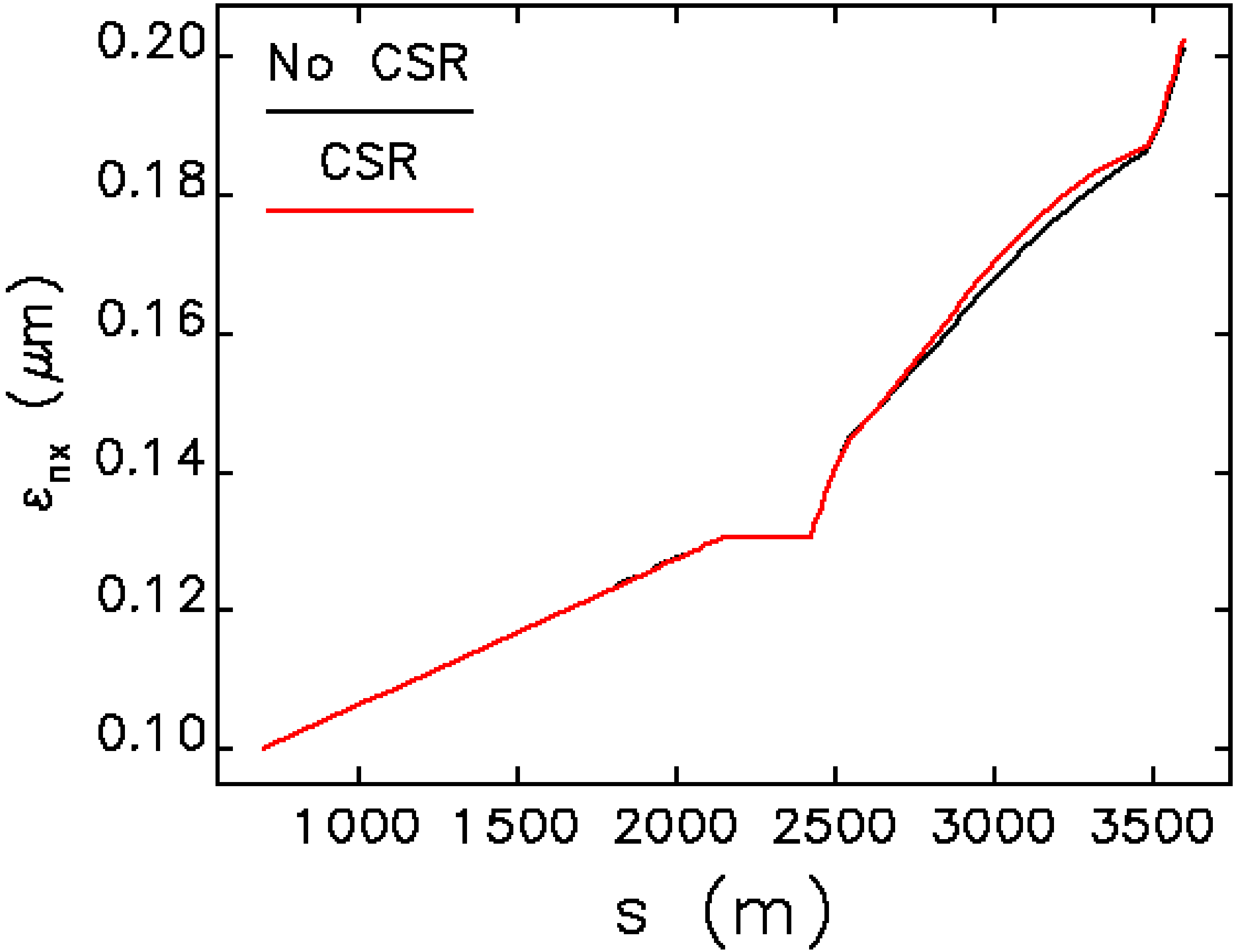
Initial (10 MeV) beam properties:

$\epsilon_{nx} = \epsilon_{ny} = 0.1\ \mu$m

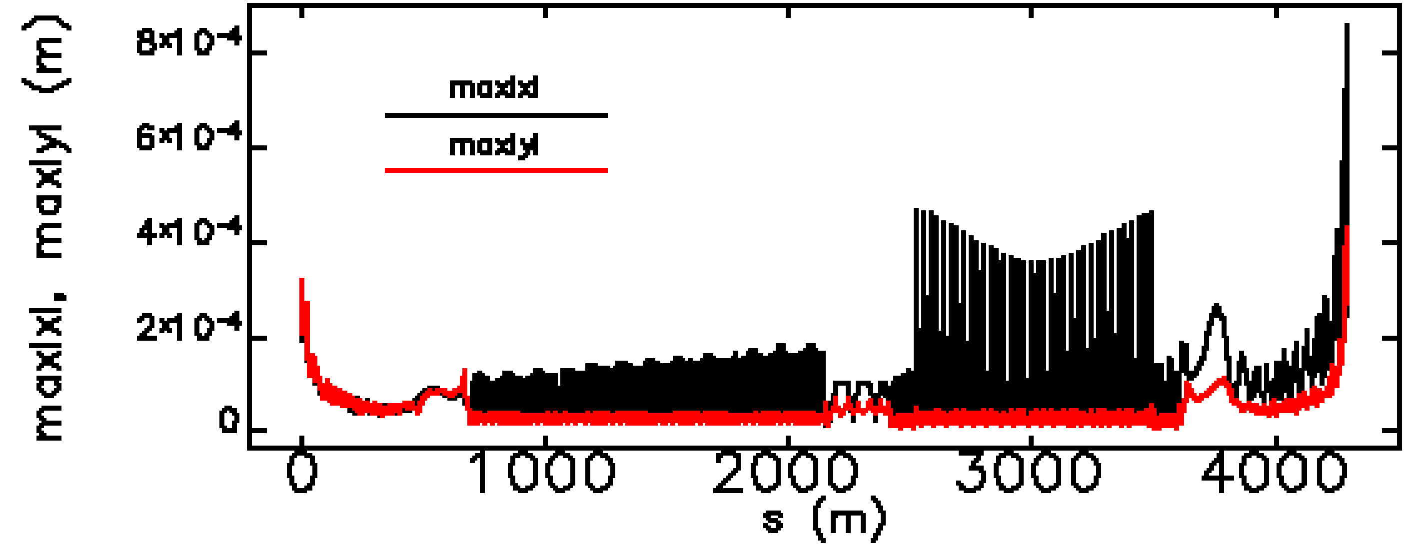
σ_δ = 0.02 %

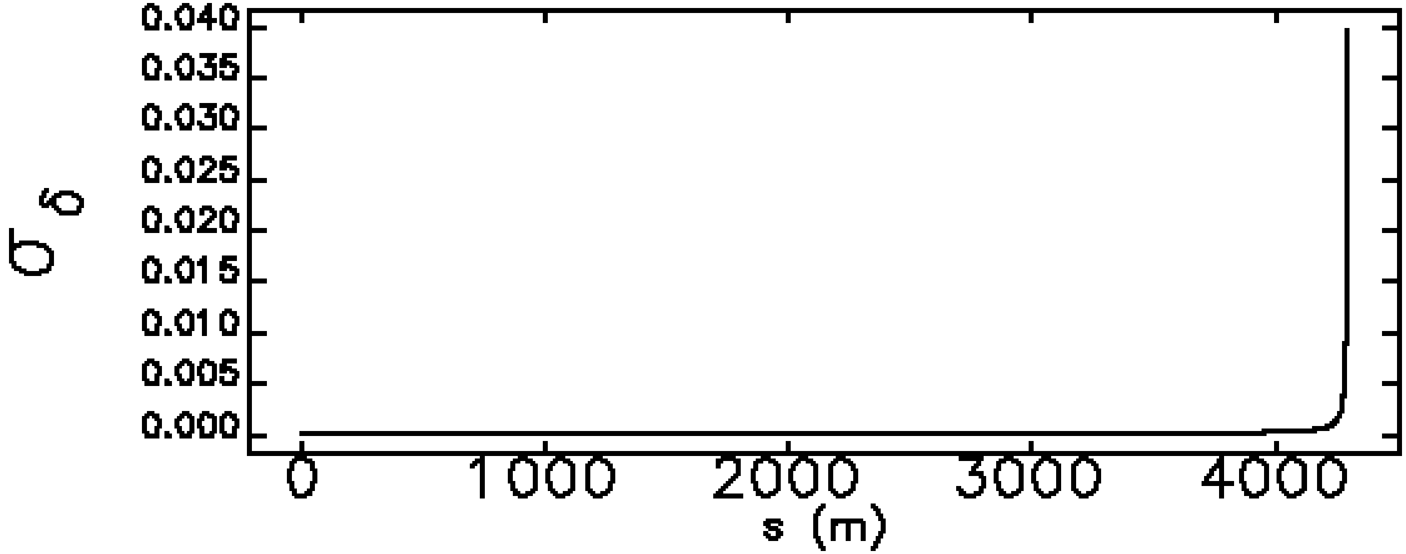
σ_t = 2 ps

Outfield ERL Tracking Results with CSR (77 pC/bunch)



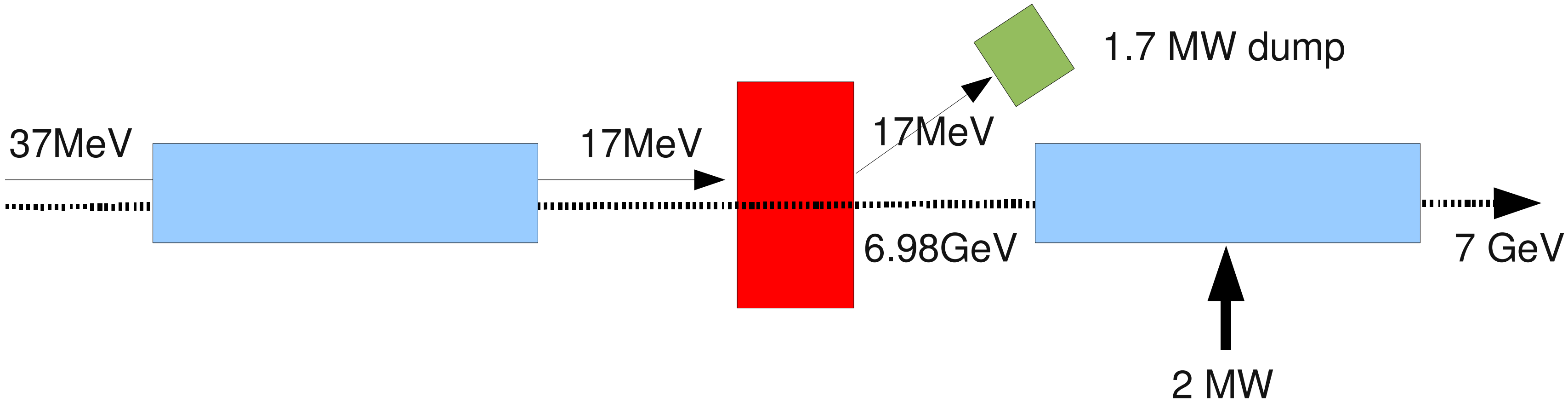
Good Beam Control to End of Linac



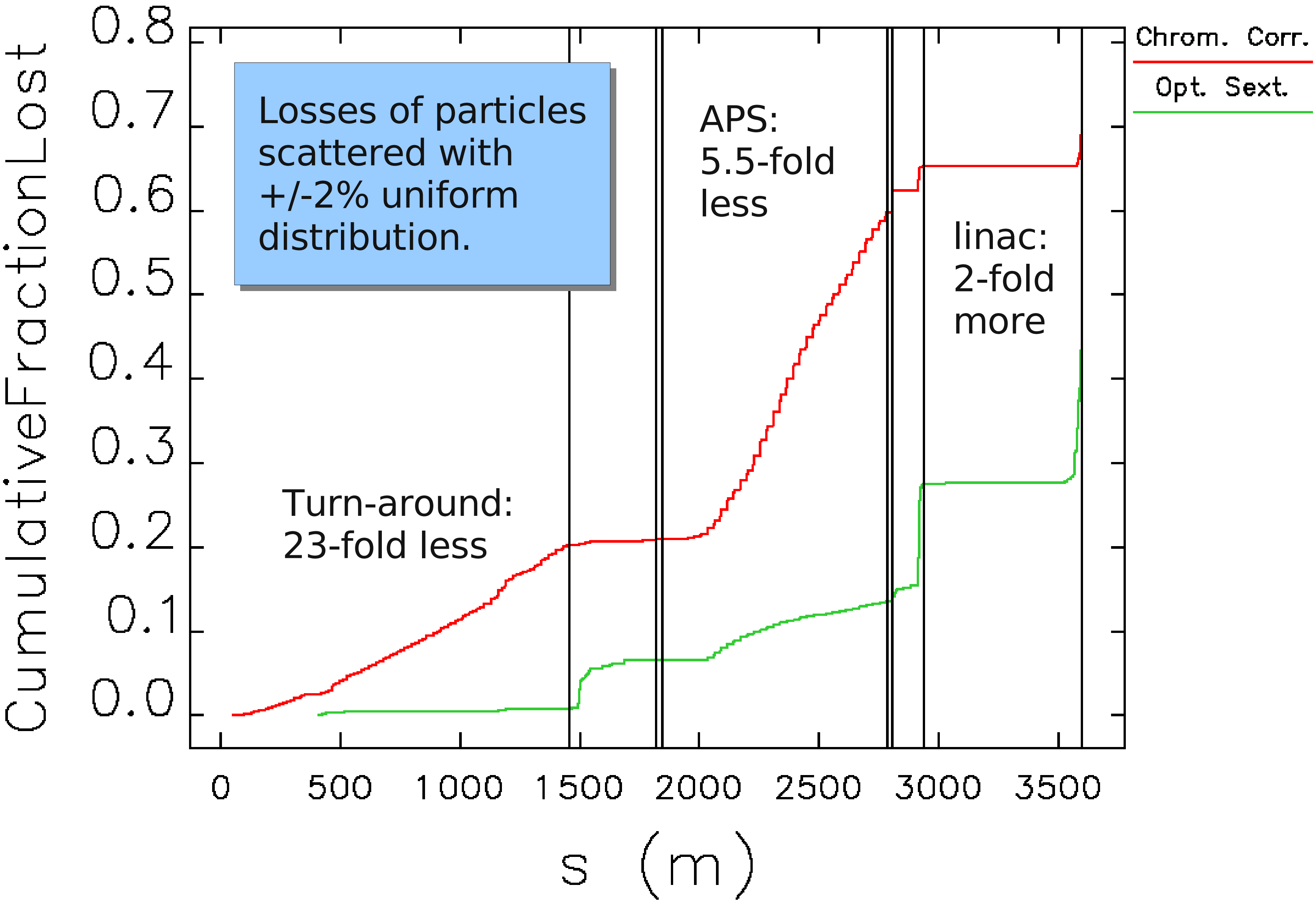


Energy Loss Issue

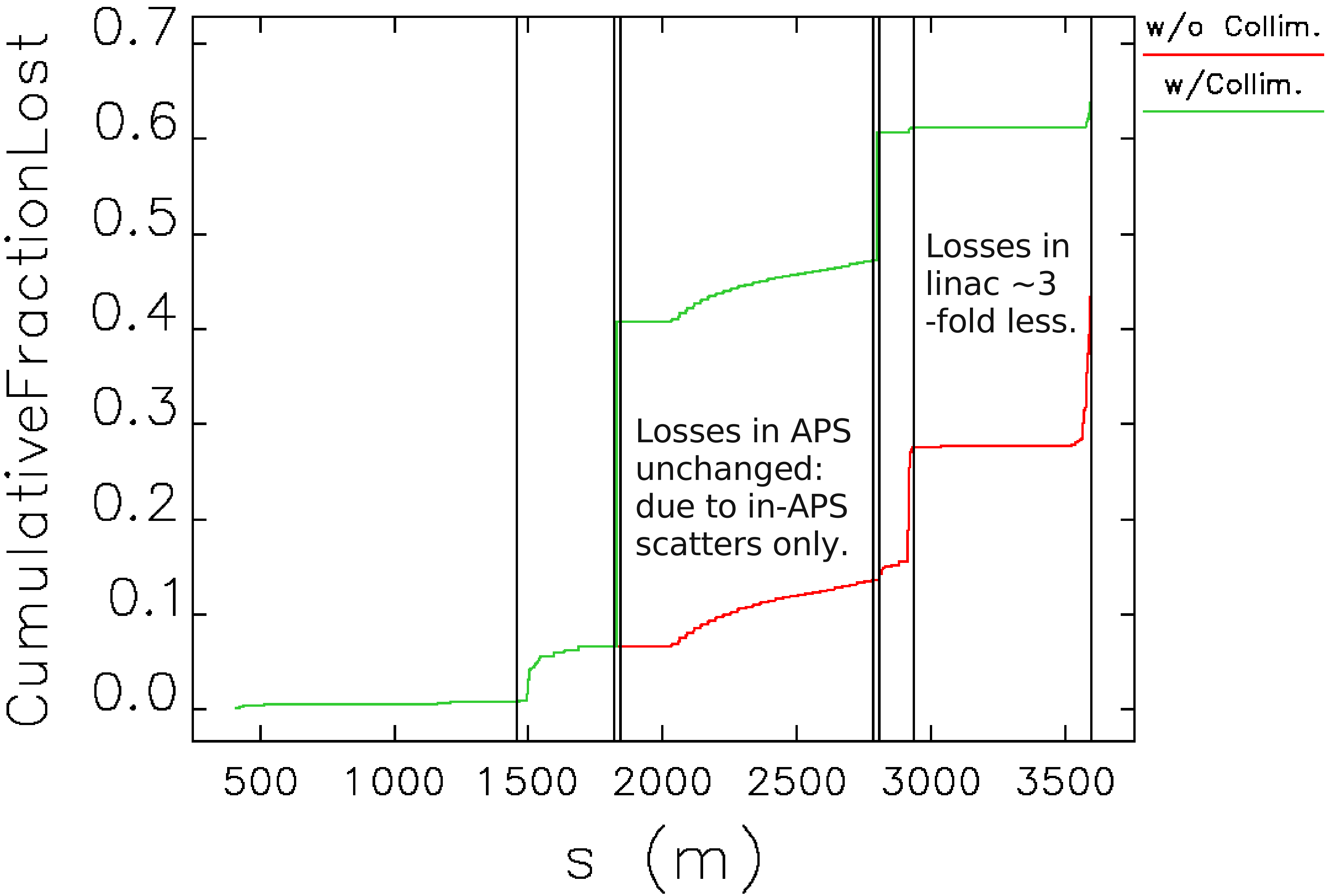
- Lose 12.5 MeV in one turn around this system
- By energy conservation, must at minimum supply another 1.3 MW of power
  - If we divert beam before the last cavity, must supply 2 MW (not 1.3)
  - Already supplying 1 MW for the preacceleration to 10 MeV.
- Dump power is up by 70% to 1.7 MW
  - Could put a ~10 MeV decelerator in the dump line to convert most of the beam energy to rf power (and then into heat).



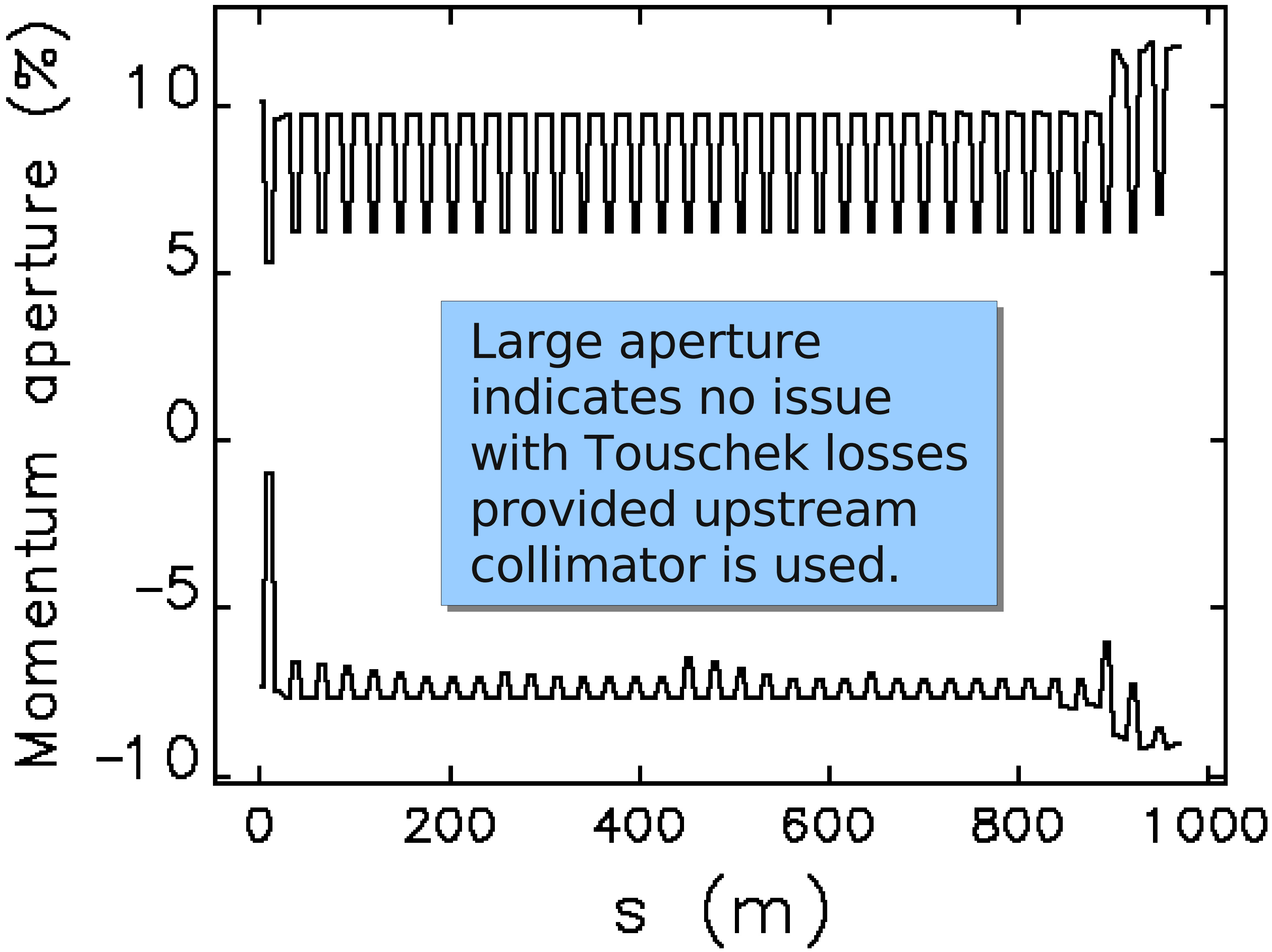
Simulation of Losses with Standard Apertures



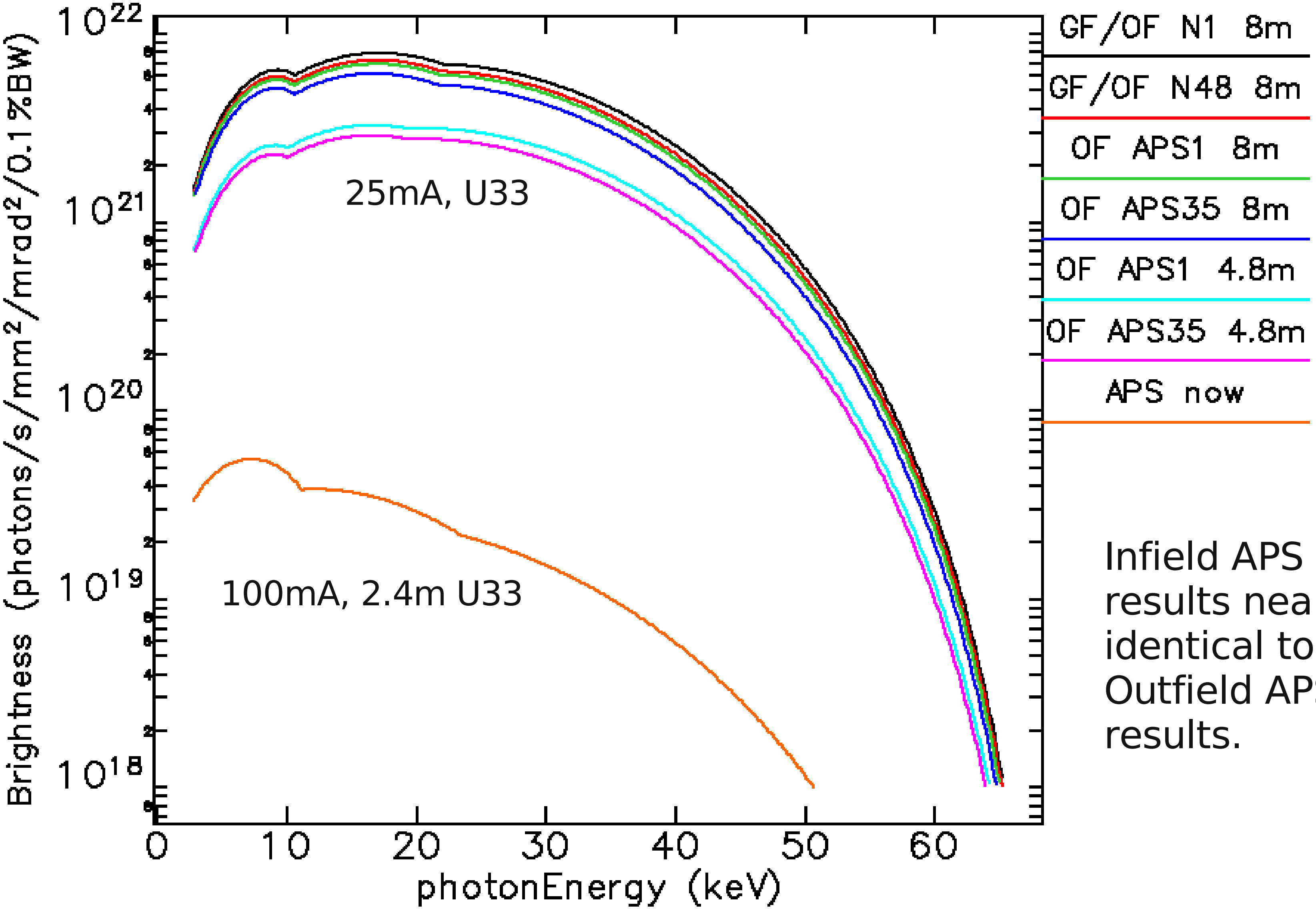
Simulation of Losses with Collimators in First/Last APS Sectors



Single-pass Momentum Aperture of APS Ring Portion



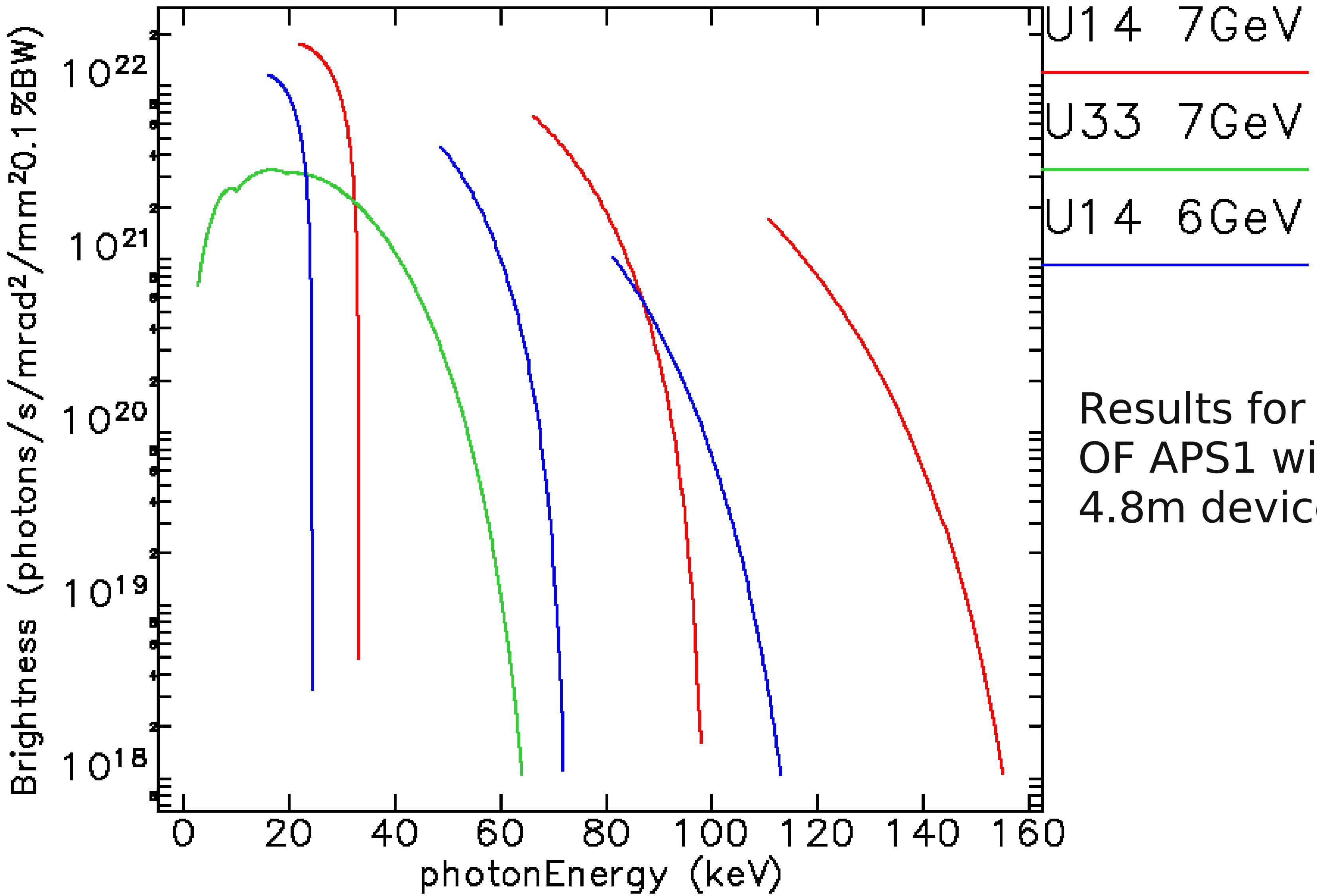
Brightness Comparison for High Coherence Mode



Infield APS results nearly identical to Outfield APS results.

Computed with sddsbrightness (H. Shang, R. Dejus).

Is 6 GeV an Option?



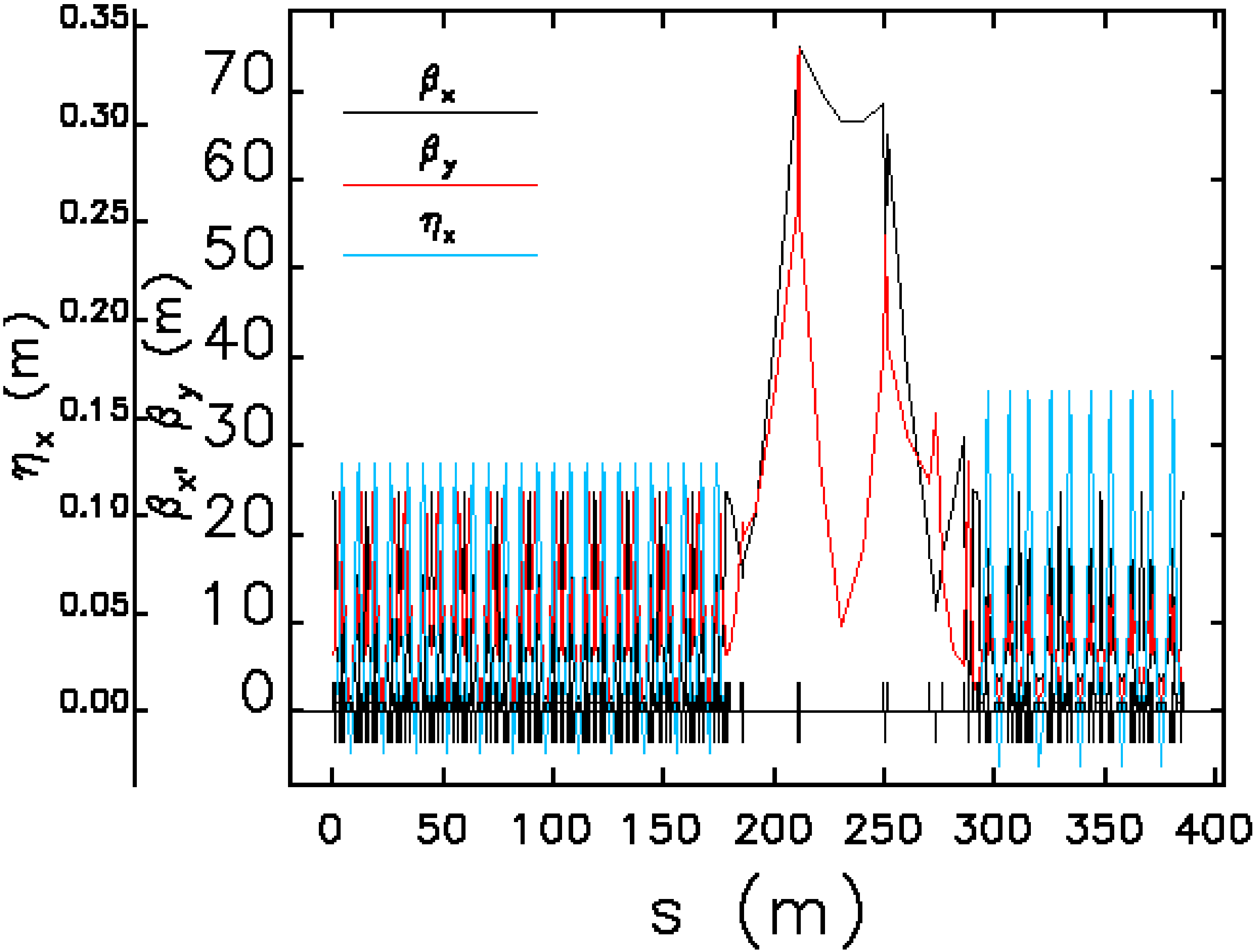
Results for OF APS1 with 4.8m devices

Conclusion

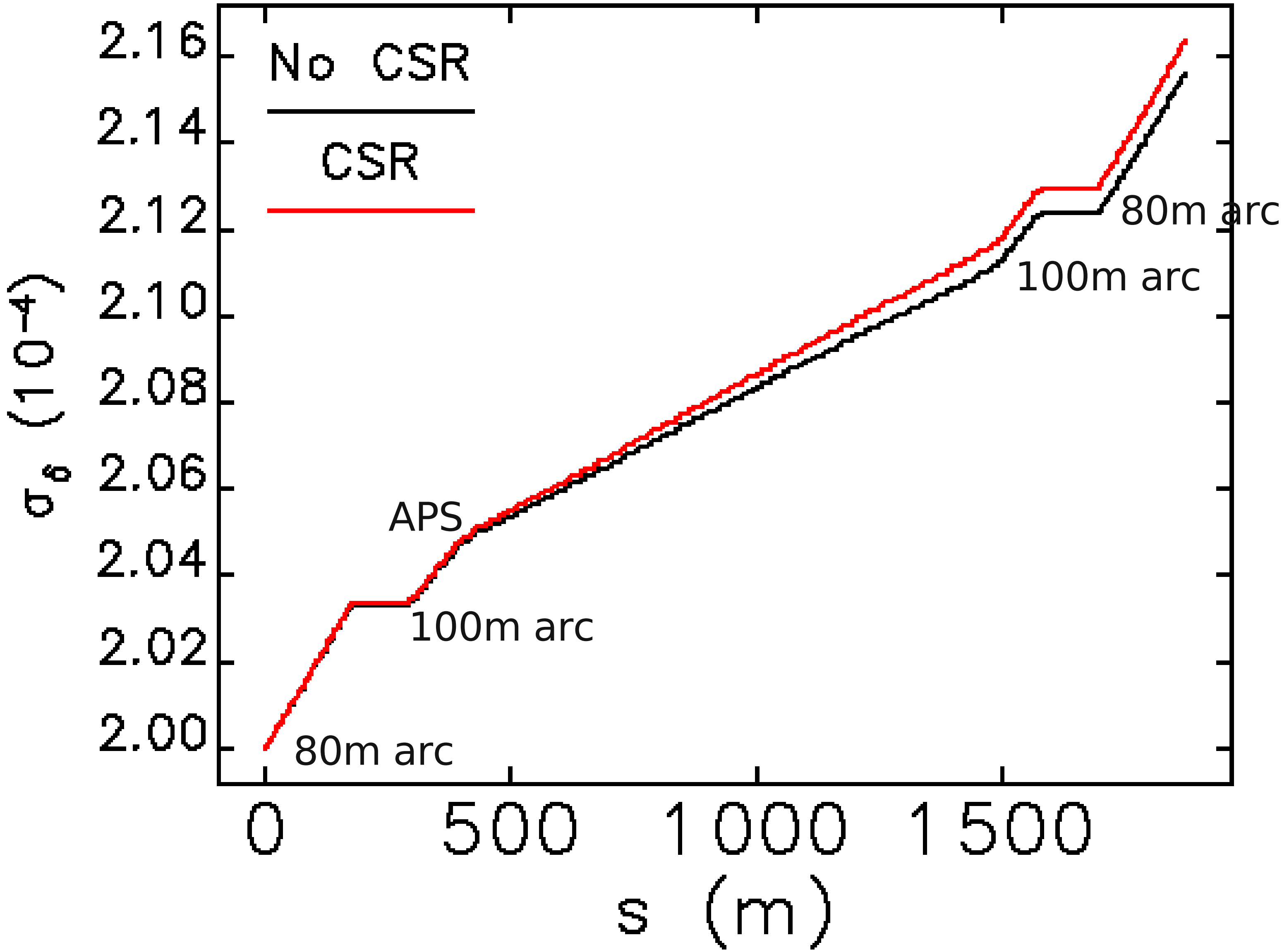
- We modeled various options with particular attention to beam quality preservation
  - No serious issues for any of the options
  - CSR probably fine even above 77 pC
- Progress made understanding Touschek scattering and energy aperture issues to limit beam losses in user arcs
- Performance of both APS options is revolutionary
  - 2 or more orders of magnitude brightness increase
  - Outfield ERL supports 48 additional beamlines with ~3 times higher brightness
    - *APS beamlines are about equal if long straights are implemented*
- A Greenfield ERL is not significantly better than an ERL@APS
- 6 GeV is worth study but 7 GeV will always deliver more for high-energy photon users.

Supplemental Material Follows

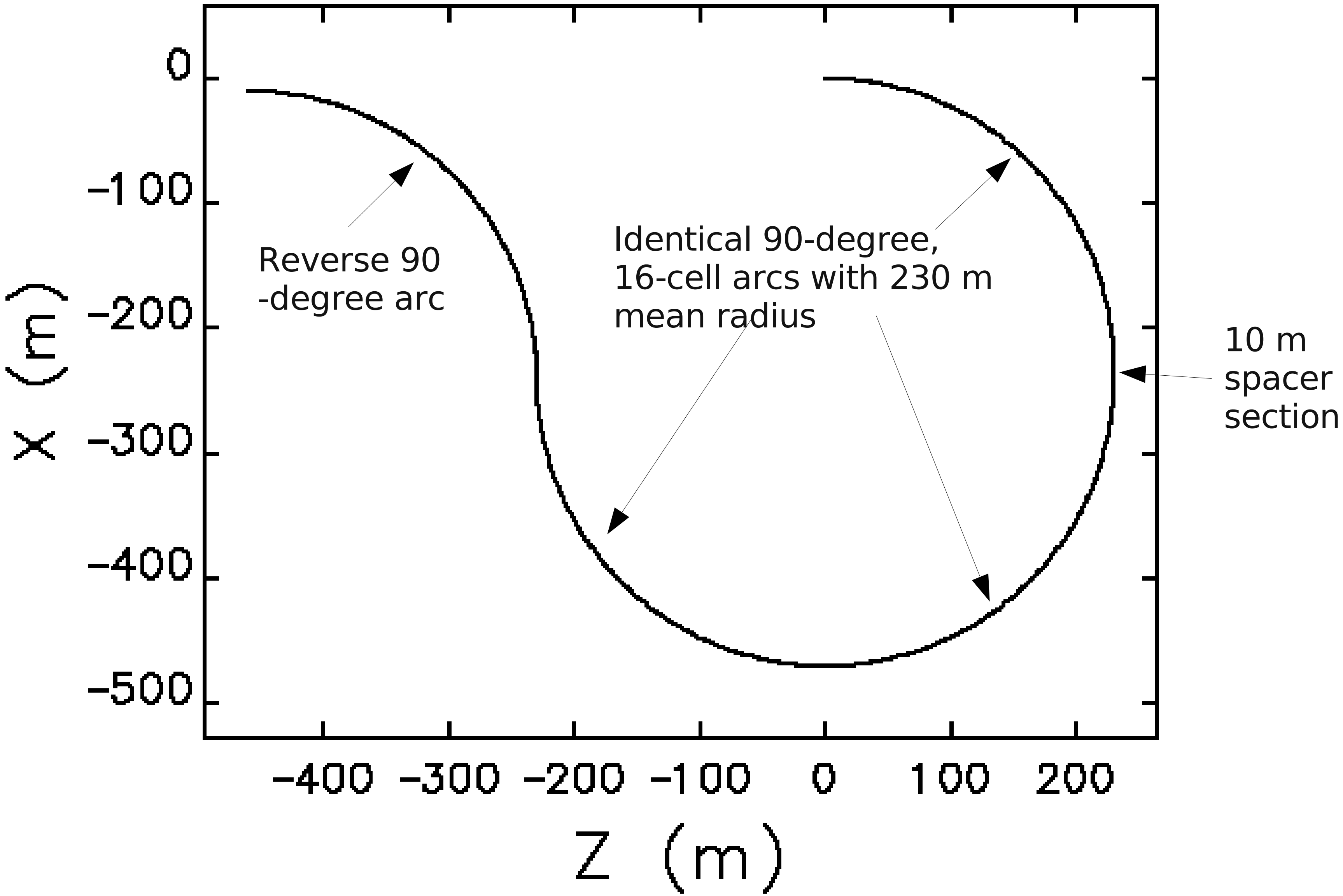
Infield Linac to APS Solution



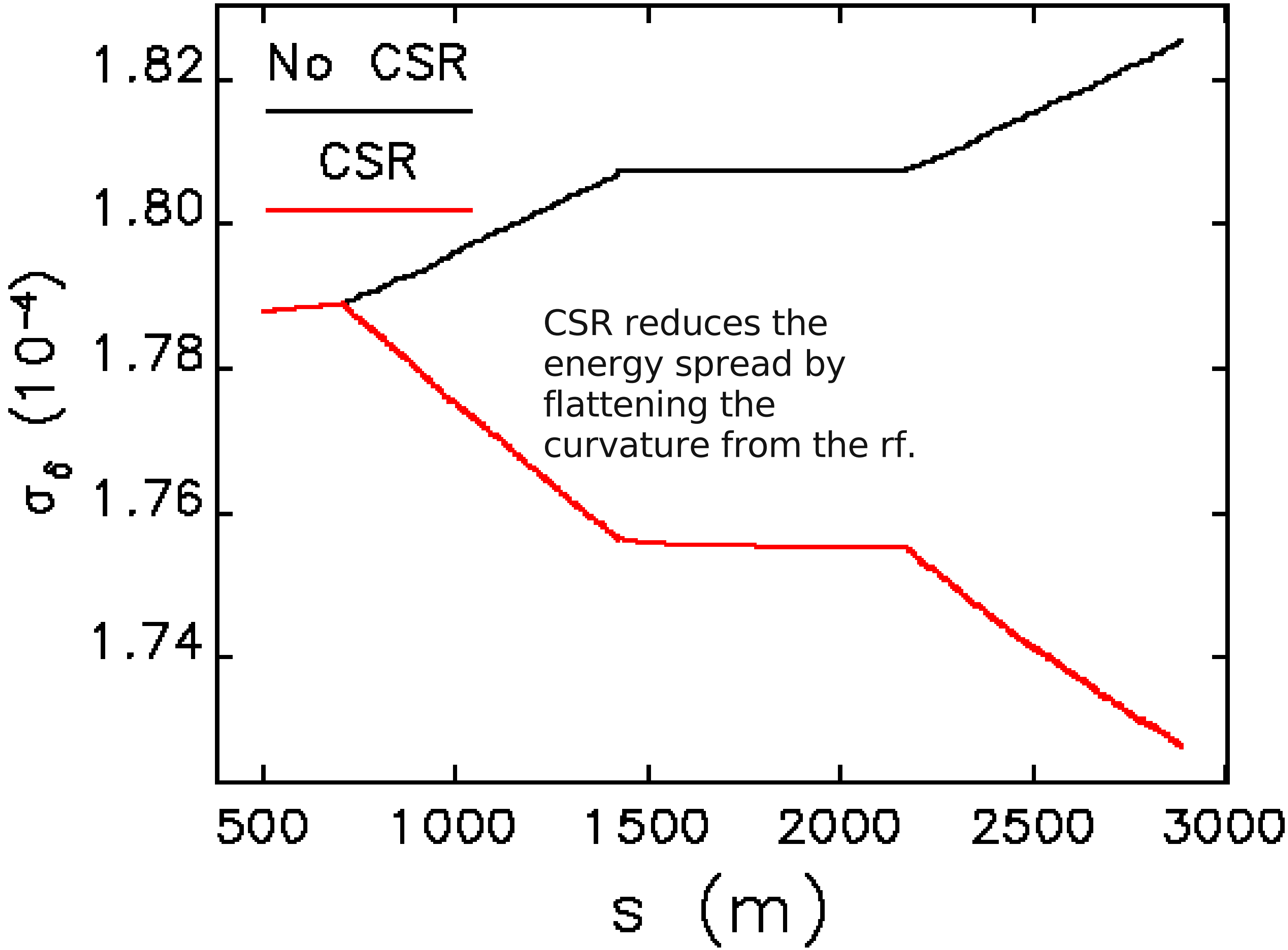
Infield ERL Energy Spread Impact of CSR (77 pC/bunch)



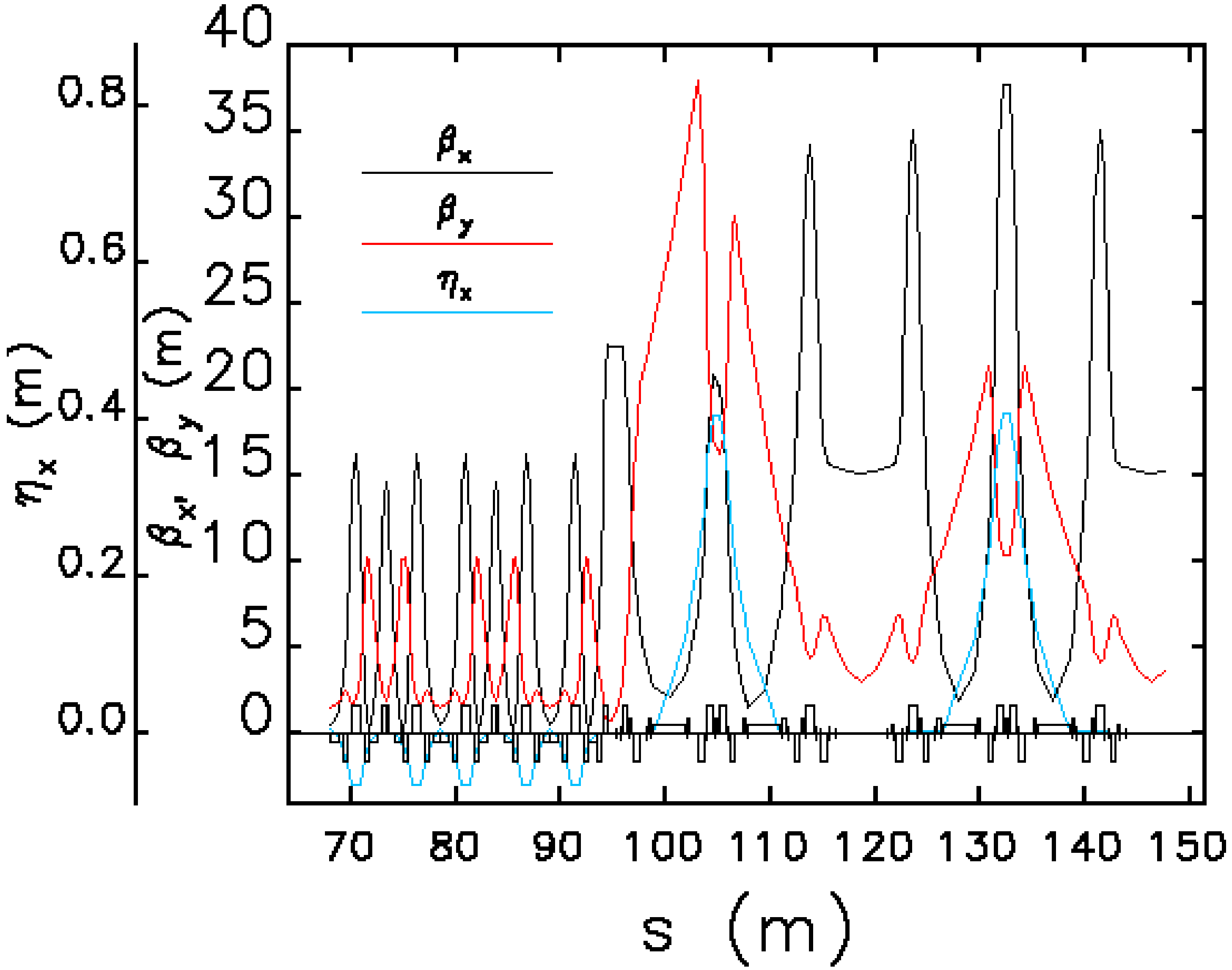
Turn-Around Arc for Outfield ERL



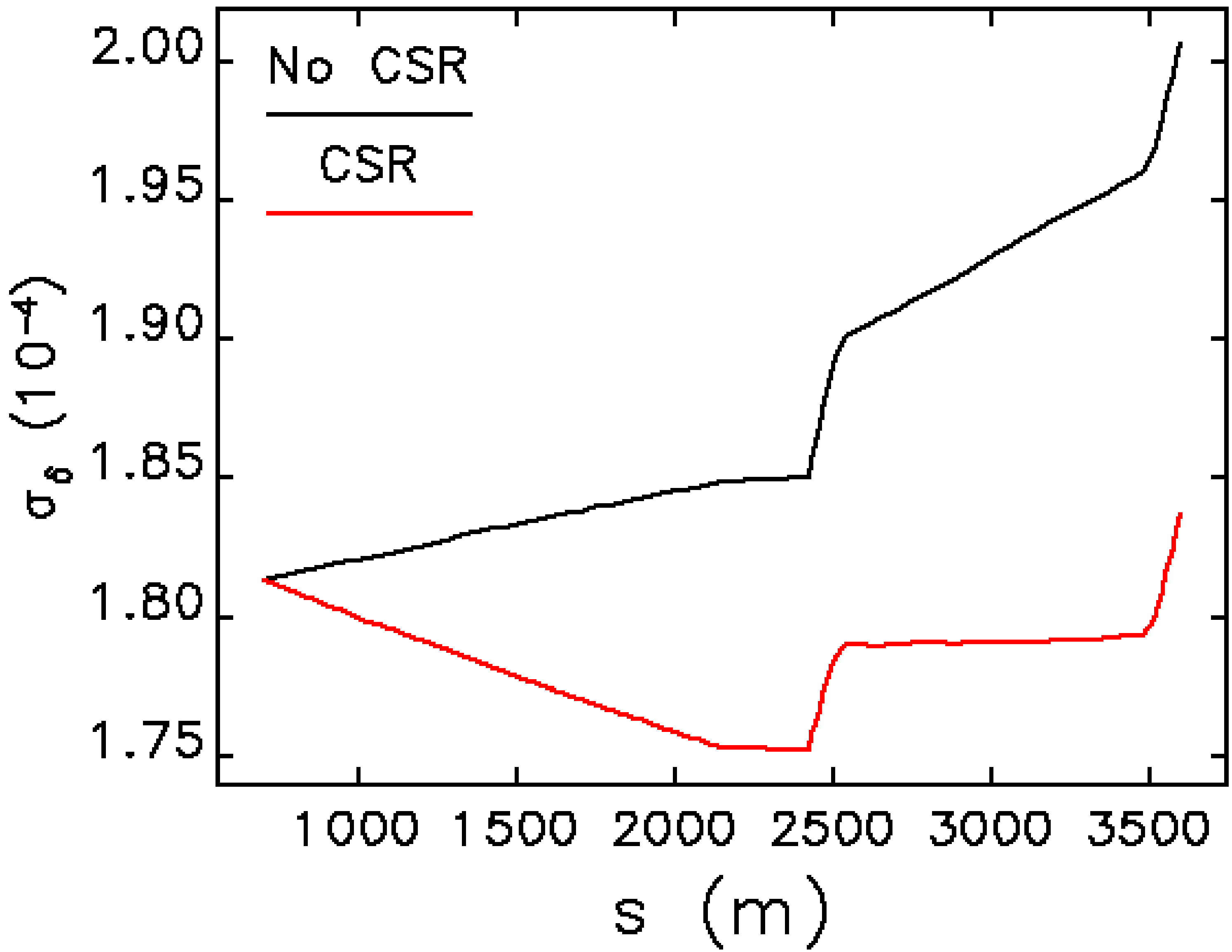
GF ERL Tracking Results with CSR (77 pC/bunch)



Optics from Transport Arc into APS



Outfield ERL Tracking Results with CSR (77 pC/bunch)



Energy Loss Issue

- Synchrotron radiation losses are 12.5 MeV
  - Turn-around: 3.8 MeV
  - Transport arcs: 1.9 MeV each
  - APS: 4.9 MeV
  - Didn’t include insertion devices
- In the absence of SR, last cavity decelerates beam to 10 MeV
  - Linac cavities accelerate/decelerate by 20 MeV each
  - However, the beam is missing 13 MeV
  - Must divert the beam before this cavity to avoid back-acceleration
- In our simulations, we actually stopped at about 17 MeV (one TESLA cavity short).

Infield ERL Magnet Parameters

- Quadrupoles
  - 346 magnets
  - 20 families
  - Maximum strength K_1=2.34 1/m^2
  - Lengths between 0.15m and 0.77m
- Dipoles
  - 102 magnets
  - 4 families
  - Lengths between 1.4 and 4.3 m
  - Angles between 0.043 and 0.049 rad
  - Fields under 0.83 T
- Sextupoles
  - None at present.

GF ERL Magnet Parameters

- Quadrupoles
  - 544 magnets
  - 111 families (92 in linac, 19 elsewhere)
  - Maximum strength K_1=2.35 1/m^2
  - Lengths between 0.25m and 0.68m
- Dipoles
  - 144 magnets
  - 2 families
  - Lengths are 1.6 and 4.2 m
  - Angles are 0.033 rad
  - Fields under 0.5 T
- Sextupoles
  - 384 magnets
  - 4 families
  - Strengths not yet determined
  - Lengths between 0.17 and 0.45 m

Outfield ERL Magnet Parameters (Excluding APS Magnets)

- Quadrupoles
  - 648 magnets
  - 123 families (92 in linac, 31 elsewhere)
  - Maximum strength K_1=2.35 1/m^2
  - Lengths between 0.25m and 0.75m
- Dipoles
  - 192 magnets
  - 4 families
  - Lengths between 0.85 and 4.2 m
  - Angles are 0.033 and 0.039 rad
  - Fields under 1.1 T
- Sextupoles
  - 384 magnets
  - 4 families
  - Maximum strength K_2=154 1/m^3
  - Lengths between 0.17 and 0.45 m