Design Overview of the Strong Hadron Cooler ERL at the Electron-Ion Collider

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Outline

- Introduction
- Layout
- Optics
- Laser Heater
- Injection Cooler ERL Option
- Summary

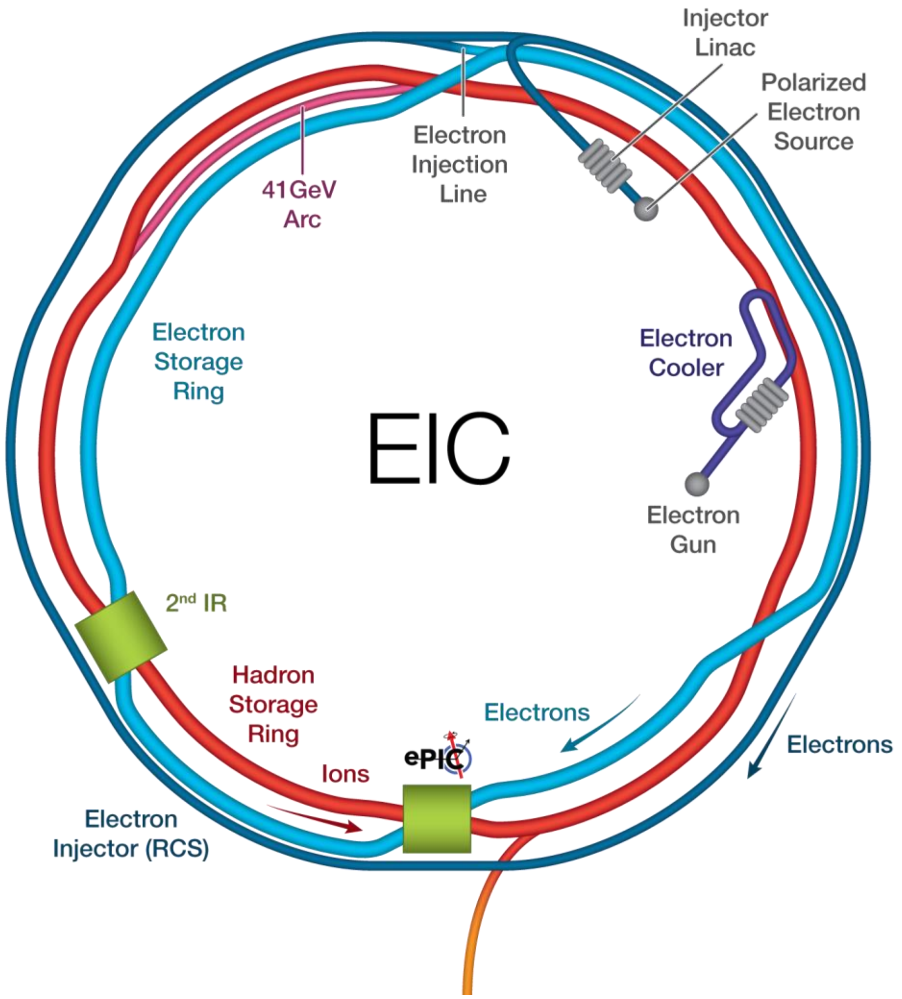
Introduction: Electron-Ion Collider

- The Electron-Ion Collider (EIC) is a future accelerator currently being developed that will be built at Brookhaven National Lab (BNL) which collides electrons and hadrons

- Protons are injected, cooled (injection cooling), ramped to collision energy, and cooled (strong cooling) while collisions occur

- Cooling is necessary during collision for the target luminosity

- The Strong Hadron Cooler (SHC) ERL is meant to deliver an electron beam which provides Coherent electron Cooling (CeC) for the two collision energies of 275 and 100 GeV – corresponding to 150 and 55 MeV electrons



Introduction: Microbunched Electron Cooling

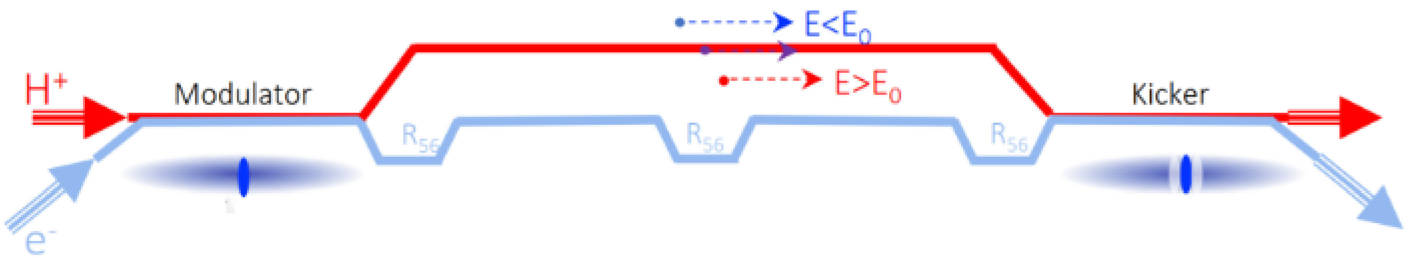
- Coherent electron cooling (CeC) uses an electron bunch to “measure” the position of the protons, then use the same electron bunch to apply energy kicks to reduce the emittance of the proton bunch in the longitudinal and transverse directions

- Anticipated timescale for the proton store is on the order of 10 hours, but intrabeam scattering (IBS) and beam-beam effects will cause emittance growth on the timescale of 2 hours, reducing luminosity over the duration of the store

- To preserve the proton beam emittance and increase the luminosity, cooling during collisions is required to counteract the emittance growth

Introduction: Microbunched Electron Cooling

- Microbunched electron cooling (MBEC) is a specific type of CeC and is the mechanism proposed for the SHC-ERL to provide cooling for the EIC protons during collision



- An electron bunch with the same relativistic gamma as the protons co-propagates with the proton beam in the modulator, where the protons imprint on the electrons

- Once separated, the electrons are sent through a series of chicanes and drifts to amplify the energy modulations induced by the protons, and convert them into density modulation

- The electrons and protons co-propagate in the kicker, where the density modulation of the electrons provide a corrective kick to the protons in order to cool them

Introduction: Beam Parameters

	100 GeV	275 GeV
Gamma	107.6	294
Energy (MeV)	55	150
Bunch charge (nC)	1	
Repetition rate (MHz)	98.5	
Average current (mA)	98.5	
Bunch length, rms (mm)*	9	7
Peak current (A)	10	13
Slice energy spread (dp/p)	0.6–1.5e-4	4–8e-5
Normalized emittance (mm-mrad)	2.8	

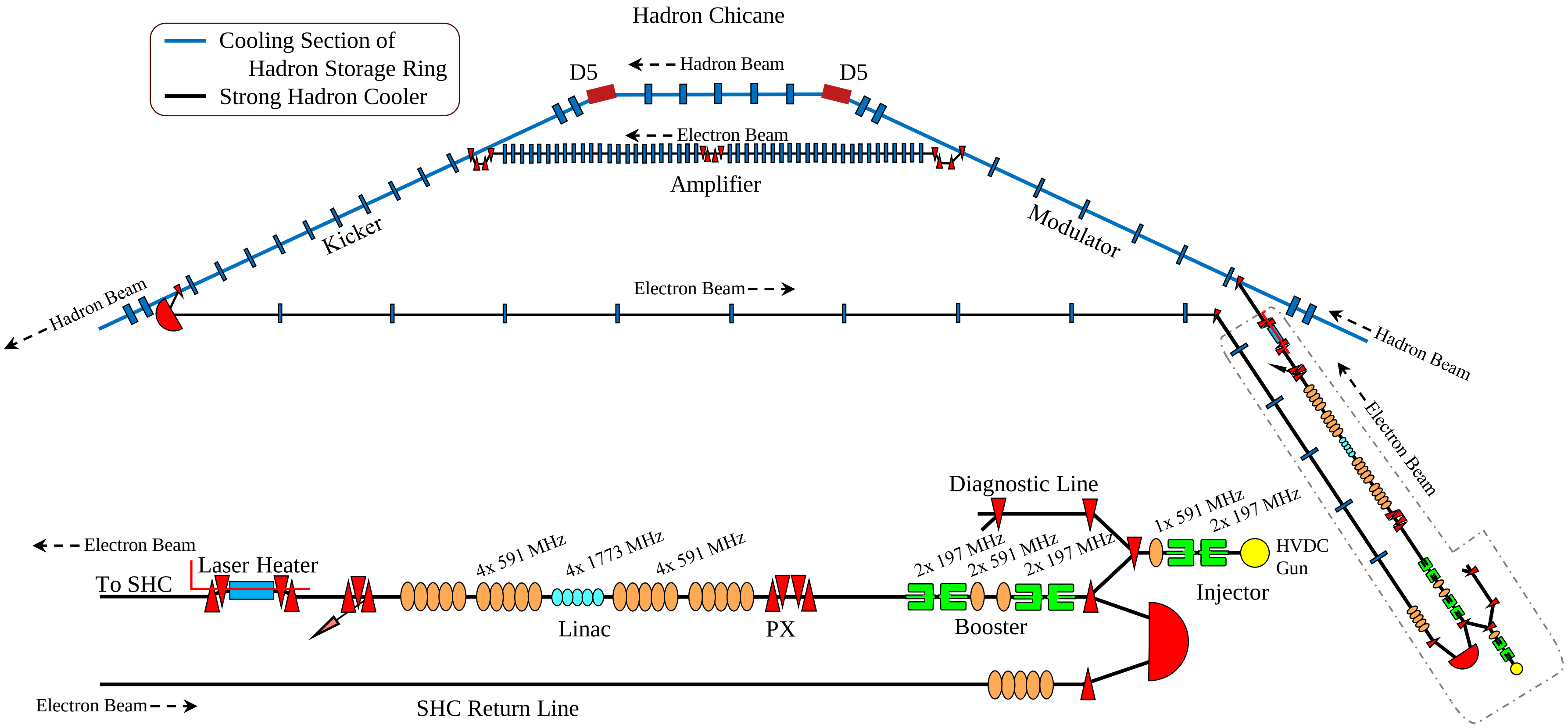
* Assumes supergaussian of order ~4

Introduction: Cooling Channel Parameters

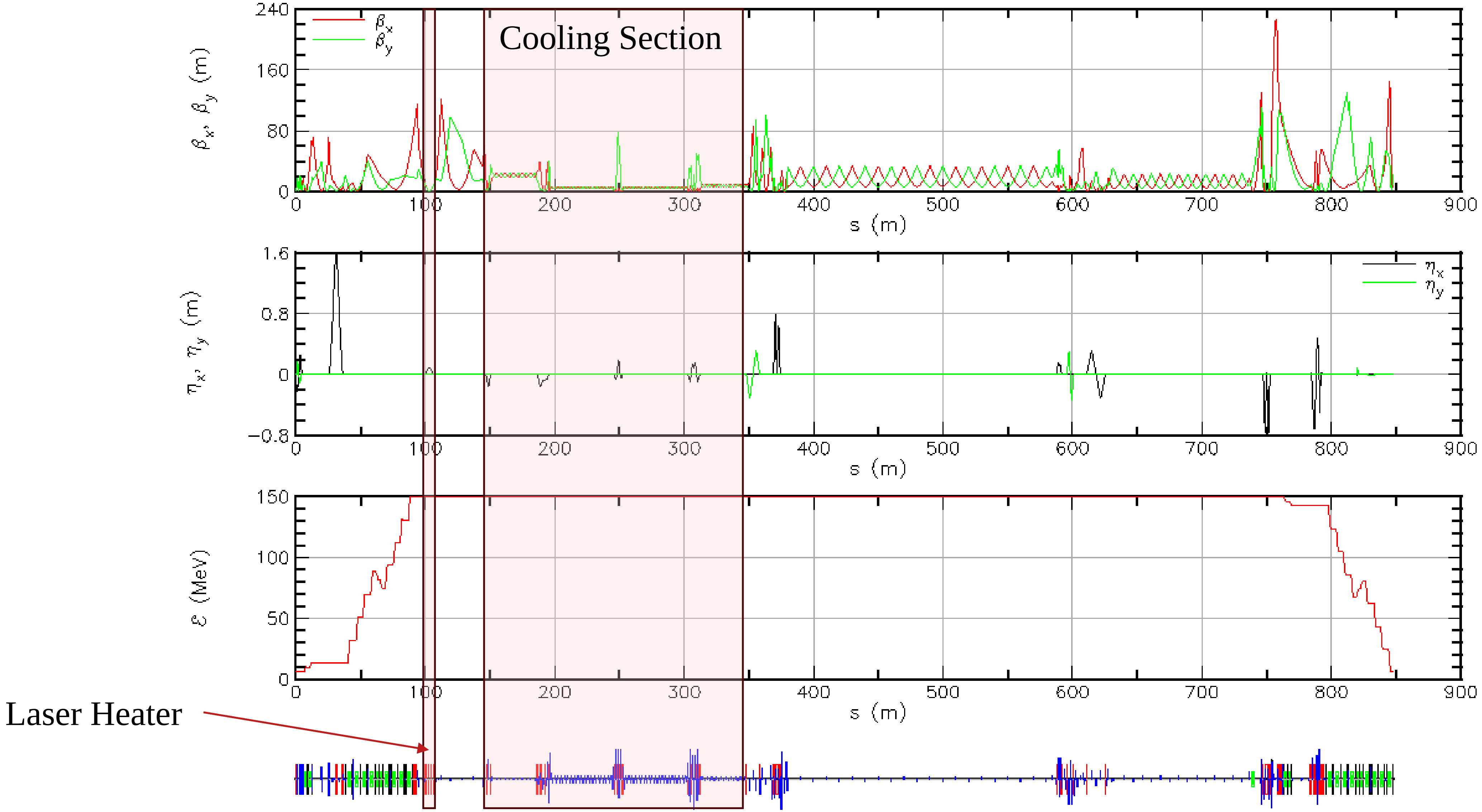
	100 GeV	275 GeV
Gamma	107.6	294
Energy (MeV)	55	150
Modulator / Kicker Length (m)	33	
Number of Amplifier Drifts (m)	2	
Amplifier Drift Length (m)	49	
β_y/β_x in Modulator (m)	20.0 / 20.0	21.4 / 21.4
β_y/β_x in Kicker (m)	29.7 / 4.09	7.89 / 7.89
β_y/β_x in Amplifier (m)	12.0 / 12.0	4.89 / 4.89
R_{56} in First / Second / Third Chicane (mm)	23.3 / -16.7 / -18.2	12.0 / -6.66 / -6.85

- Beam parameters in the cooling channel provided by Will Bergan (BNL)
  Details at DOI:10.18429/jacow-ipac2024-thyd1

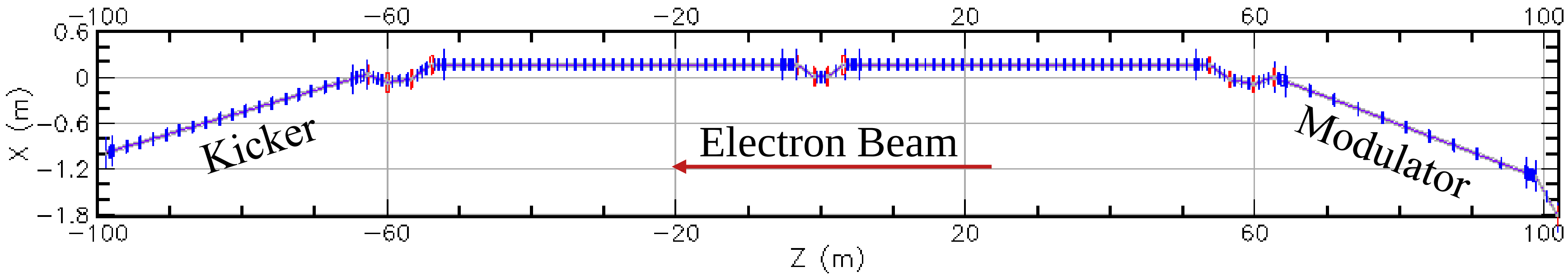
Layout: Representative

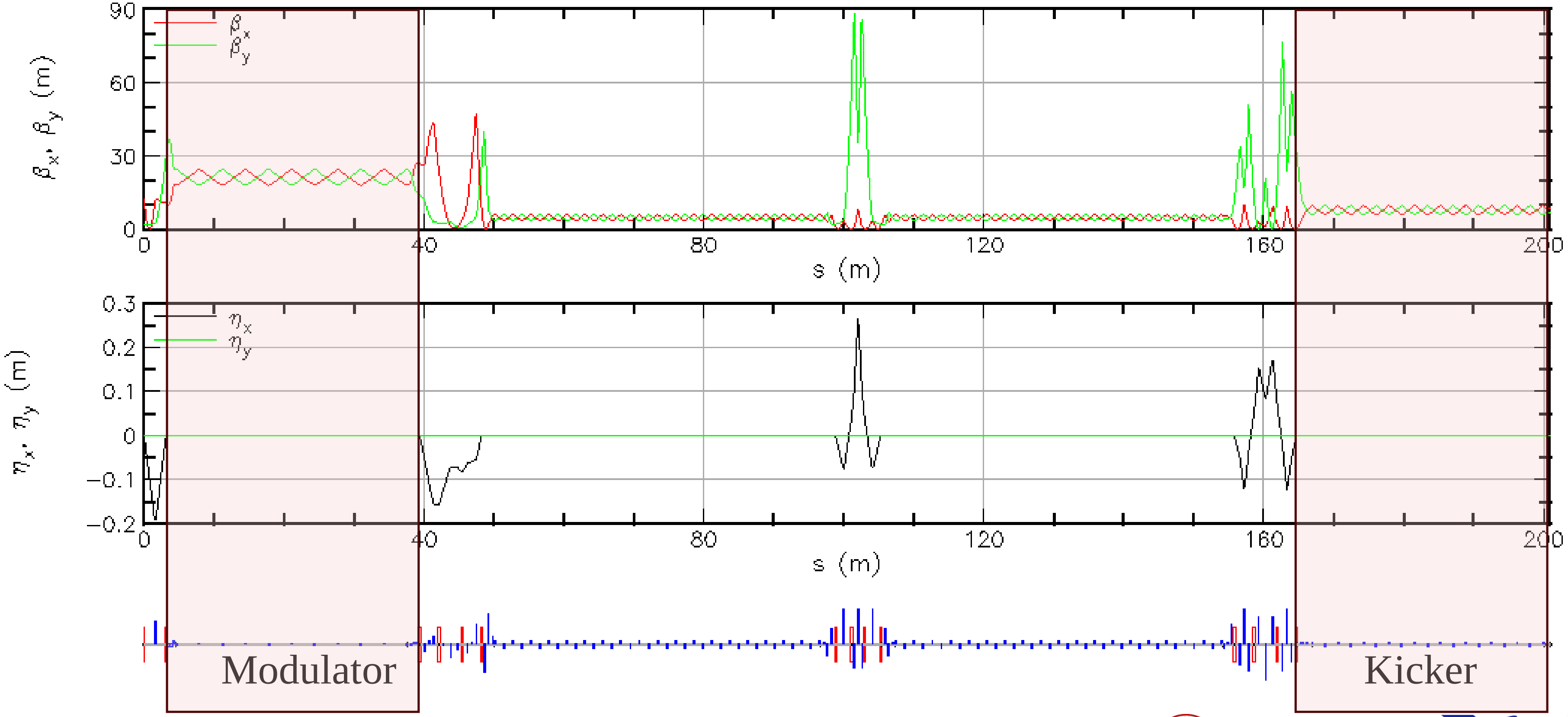


Optics at 150 MeV: Complete Machine



Optics at 150 MeV: Cooler

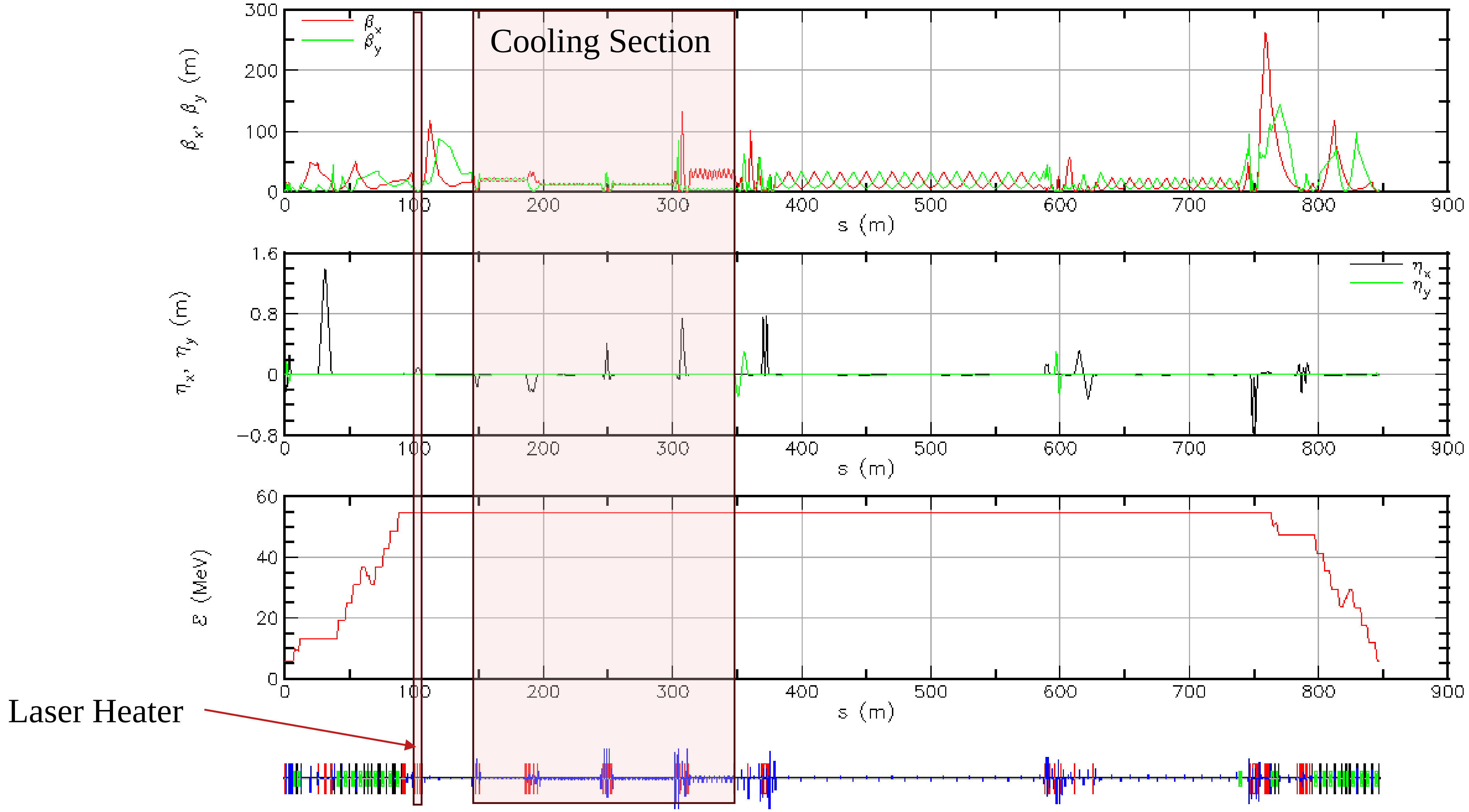




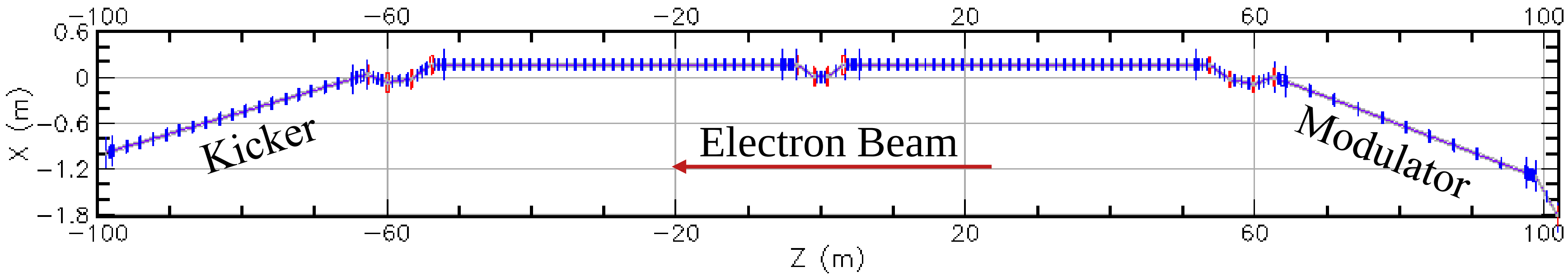
Above: Layout of cooler

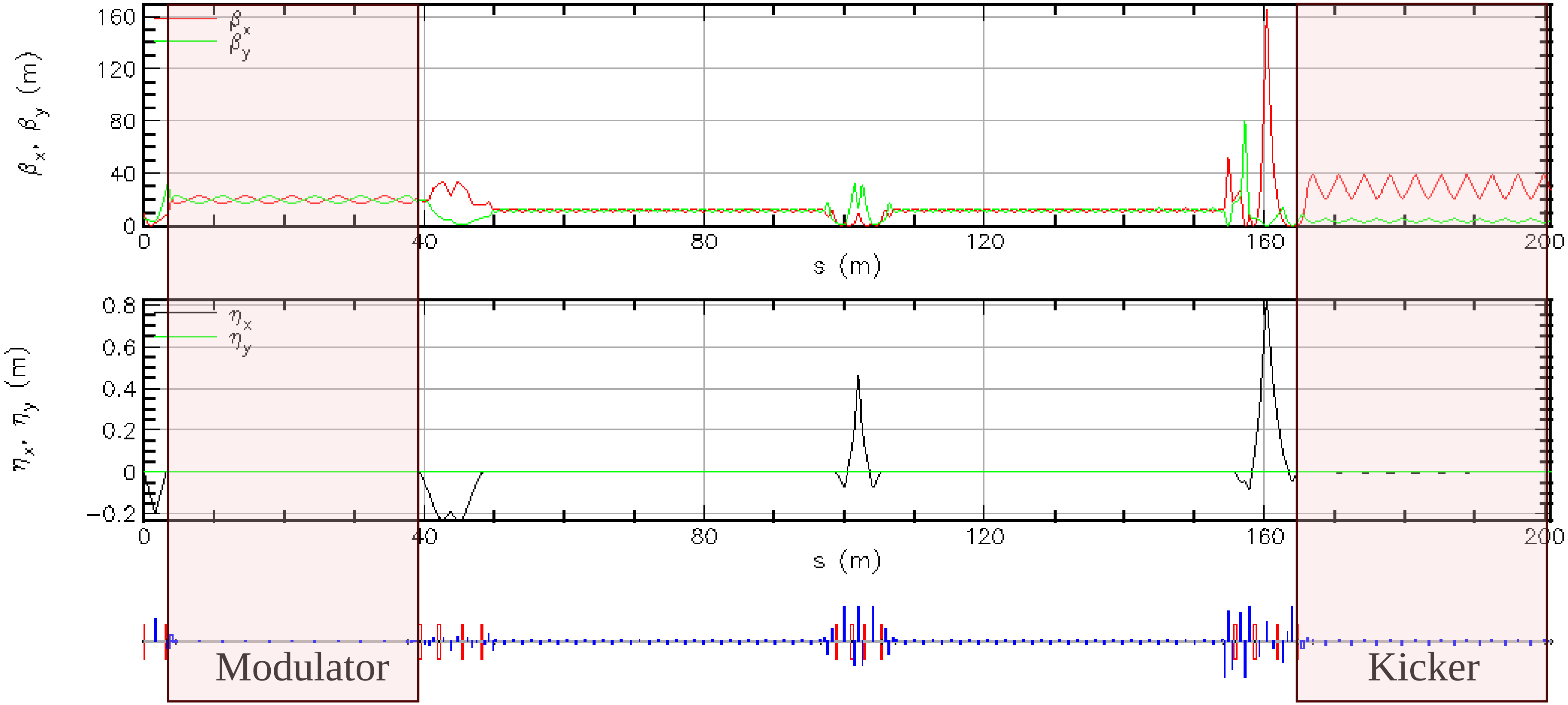
Left: Transverse optics and lattice layout

Optics at 55 MeV: Complete Machine



Optics at 55 MeV: Cooler

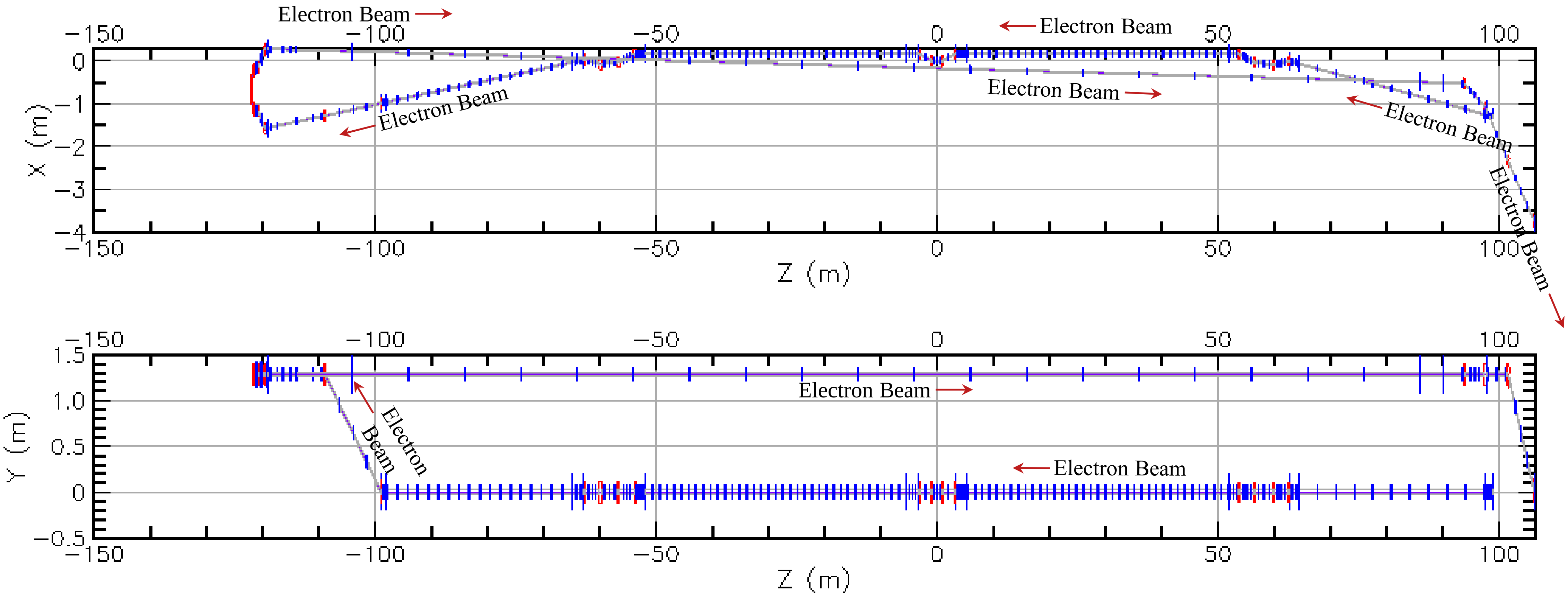




Above: Layout of cooler

Left: Transverse optics and lattice layout

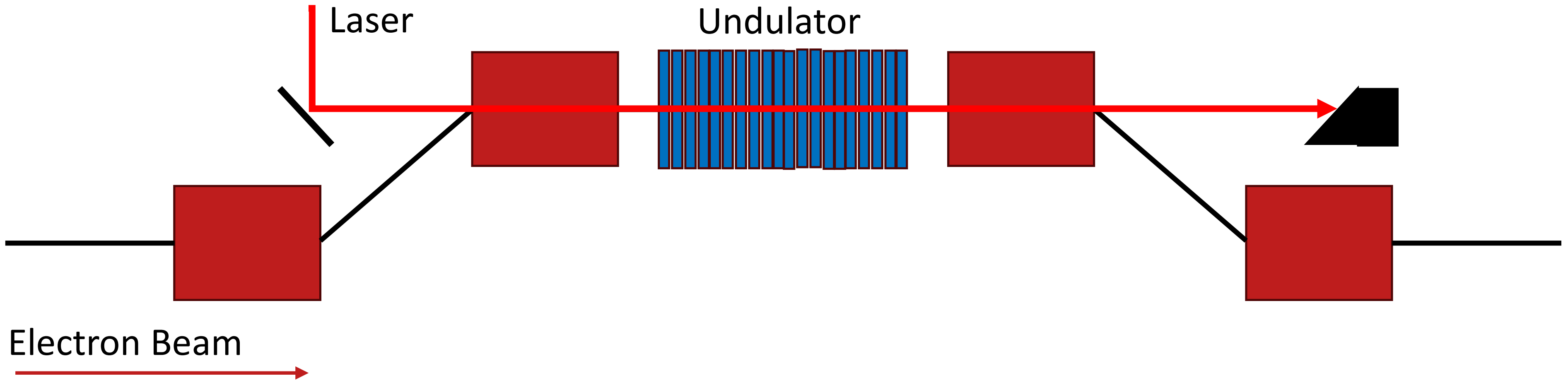
Layout: Actual



- Top: XZ view of floor plan for cooler and first part of return line
- Bottom: YZ view of floor plan for cooler and first part of return line

Laser Heater

- Coherent electron cooling is highly sensitive to the slice energy spread of the electron beam – for the EIC, it must fall in a range, not just below a maximum
- To increase the slice energy spread, and provide an adjustable knob for this parameter outside of the injector, a laser heater is located between the linac and the cooler
- The layout of the laser heater involves co-propagating a laser with the electron beam inside an undulator in the center of a chicane; a simple layout is below



Laser Heater

- The momentum modulation on the electron beam resulting from the laser interaction within the undulator is smeared out in the second half of the laser heater chicane

- Given the anticipated parameters, emittance growth is negligible

- However, due to the cooling mechanism, it is critical microbunching gain does not occur before the cooler – preliminary evaluations indicate that the laser heater chicane does not result in microbunching gain, but this will have to be evaluated with full CSR simulations at a later stage

Injection Cooler ERL: Introduction

- For the EIC, protons must be cooled twice: after injection (before ramping to collision energy) and during collision

- Currently, the scheme is to provide injection cooling using bunched beamed cooling, as used in the Low Energy RHIC electron Cooler (LEReC)

- While there is the option to provide electrons for injection cooling with a standalone linac, one available concept is to add a transport line and use portions of the SHC-ERL to have an Injection Cooler ERL

- Additionally, this allows for the option of adding additional cryomodules to the booster, to accelerate the beam up to 22 MeV for bunched beam cooling of the 41 GeV protons during collision

Injection Cooler ERL: Beam Parameters

	23 GeV
Gamma	25.4
Energy (MeV)	13
Modulator+Kicker length (m)	120
Bunch charge (nC)	3x1.33
Bunch length, rms (mm)*	40
Slice energy spread (dp/p)	5e-4
Normalized emittance (mm-mrad)	2

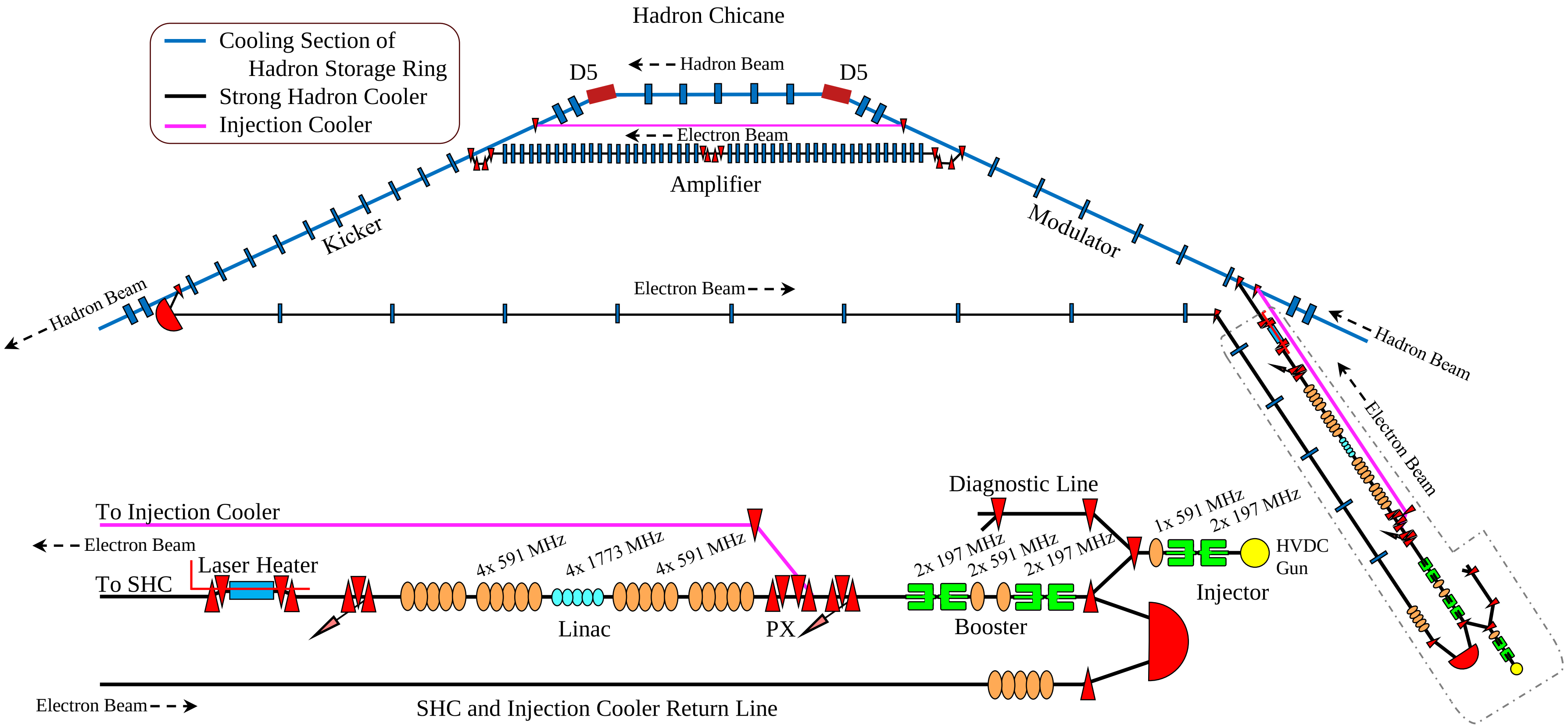
Longer cooling section than SHC

3 electron bunches overlap each proton bunch

* Assumes supergaussian of order ~ 2 – 4

- Does require air-core Panofsky quads in common transport in the cooler to minimize remnant magnetic field during injection cooling

Injection Cooler ERL: Layout



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Summary

- A preliminary design exists for both design energies of the Strong Hadron Cooler ERL meant to provide cooling during collisions at the Electron Ion Collider
- This approach also allows the option of incorporating bunched beam cooling at the proton injection energy and bunched beam cooling during collision of the 41 GeV proton beam
- While a complex design, no show-stoppers have been found
- As collective effects and design alternatives are evaluated, we anticipate completing a mature, robust design for an ERL-driven strong cooler

Thanks for your attention!