Energy Recovery Linac Designs and Studies for Electron Cooling of Hadron Beams

DoE Phase II SBIR
August 23, 2022

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Bruce Dunham, Ralf Eichhorn, Karl Smolenski, Joseph Conway

Xelera Research LLC: Company Overview

- Formed in 2013 by 5 partners – 150+ years of accelerator design expertise
- Most of Xelera were from the Cornell ERL development team, who designed and built the world's highest current, high brightness photoinjector, which evolved into the 4-pass ERL: CBETA
- Now at 10 total employees
- Focus Areas:
  - Accelerator design & simulations (EIC magnetized injector design, EIC Cooler)
  - Radiation physics consulting (ASU BioDesign C safety systems design)
  - Accelerator hardware:
    - Electron & X-ray beam stops (ASU Graves Lab)
    - Cathode transport systems (ASU Karkare Lab)
    - Vacuum system designs, coatings (JLab, Poelker)
    - Higher Order Mode loads (HZB, Germany)
    - Electron source design and fabrication (JLEIC Cooler Magnetized Gun)

Administrative Summary

- PI: Prof. Val Kostroun
- Authorized Representative: Dr. Christopher Mayes
- Additional subcontract: David Ross Douglas Consulting
- Period performance: May 2021 – May 2023 (2 years)
- Federal Grant Number: DE-SC0020514
- Program Manager: Dr. Michelle Shinn
- Phase I Report: DOE-XELERA-0020514

Technical Objectives (Deliverables)

- **ERL Beam Dynamics Designs** *Develop complete ERL electron beam dynamics designs from cathode to beam stop. These will be optimized for the critical effects of space charge and coherent synchrotron radiation and will provide the desired beam quality for Coherent Electron Cooling (CeC) of the hadron beam. The designs will include the effect on the electron beam due to the cooling process, as well as the second pass (energy recovery) of the beam through the main Linac.*
- **Tolerance Studies** *Produce analytical and simulation studies of the impact of various error effects (misalignments, mis-powering, and field inhomogeneities) on the ERL cooler performance. Additionally, provide practical correction strategies, and produce a cost/benefit analysis of higher quality hardware versus cost.*
- **Beam Breakup (BBU) Studies** *Perform BBU simulation studies on the ERL designs, including realistic Higher Order Modes (HOMs) in the accelerating cavities, that demonstrate that the threshold current will be well above the desired operating current.*
- **Start-to-End Simulation Studies** *Produce high-fidelity beam tracking studies that demonstrate that the beam will be able to provide sufficient cooling and also be able to be energy recovered.*
- **Beam Halo Studies** *Produce analytical and simulation studies that characterize and catalogue the likely sources of beam halo, and provide strategies to suppress halo formation or eliminate it through collimation.*

Communication and Computing

- Xelera leads EIC Lattice biweekly Zoom meetings with:
  - Erdong Wang, Steve Peggs, Will Bergan, Derong Xu (BNL)
  - Steve Benson, Kirsten Deitrick (JLab)
  - Georg Hoffstaetter, Ningdong Wang (Cornell)
- Slack channel/workspace for continuous communication.
- Shared Dropbox folder for files.
- Private GitHub repository: github.com/xelera/eic-lattice
- Technical website: xelera.github.io/eic-lattice/index.html
- NERSC allocation (m3645) with 4M hours (PI: Nicholas Taylor)
- Group email: cooler@xeleraresearch.com

Schedule

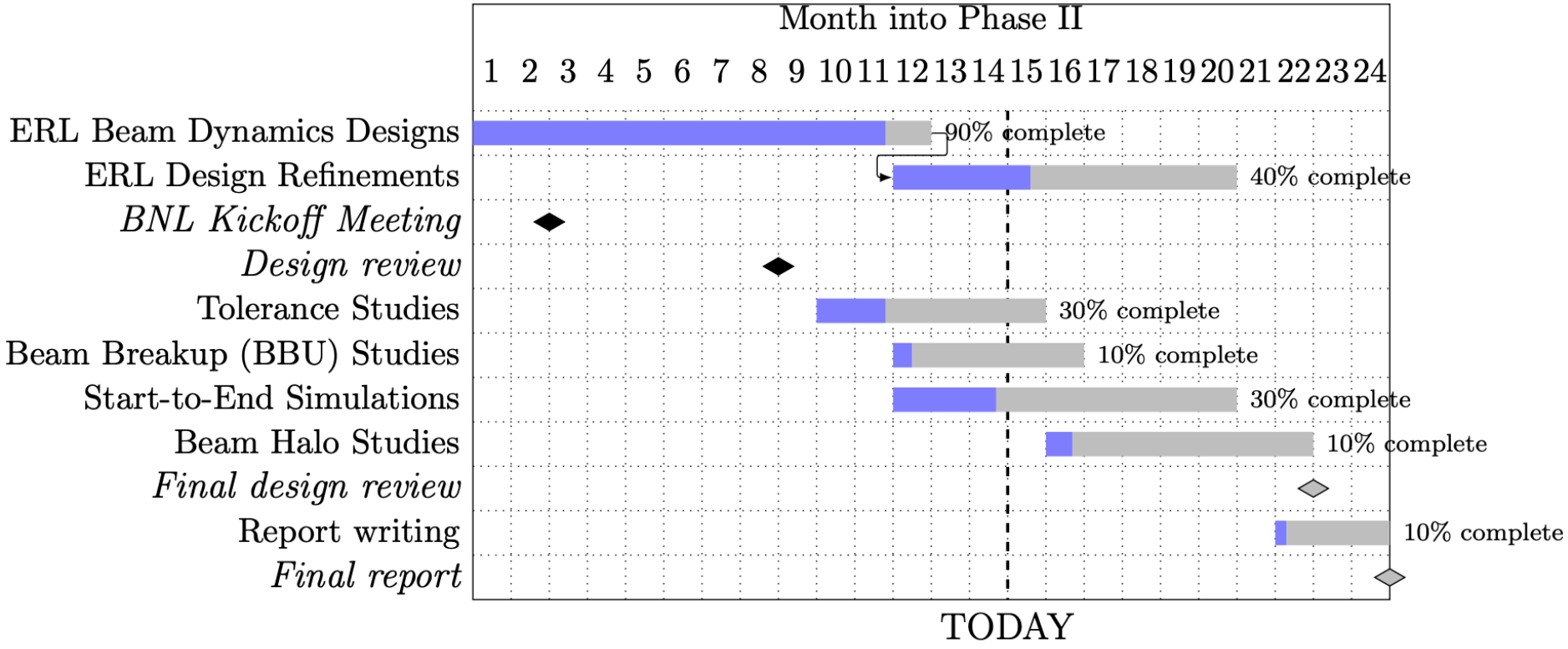
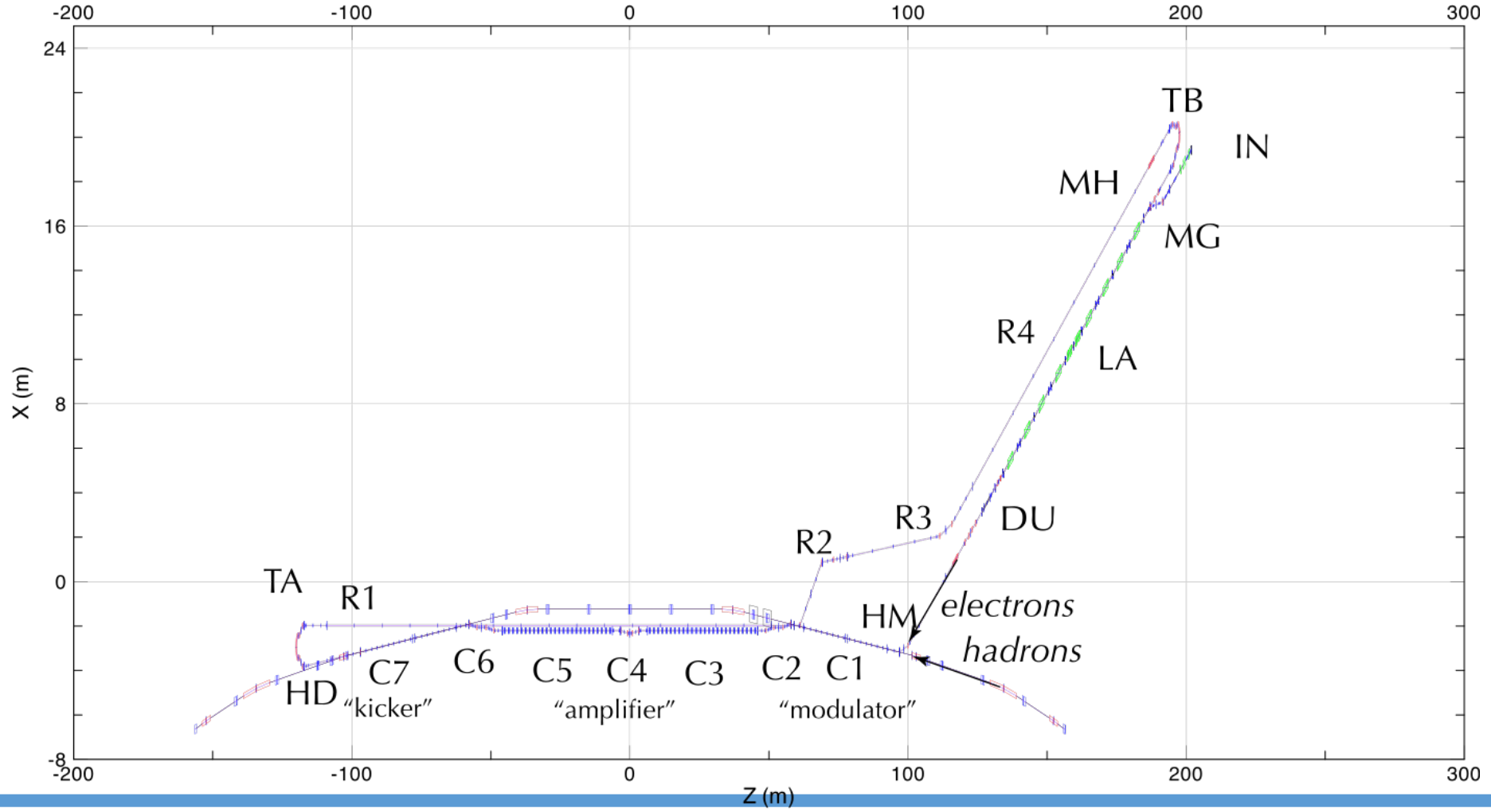
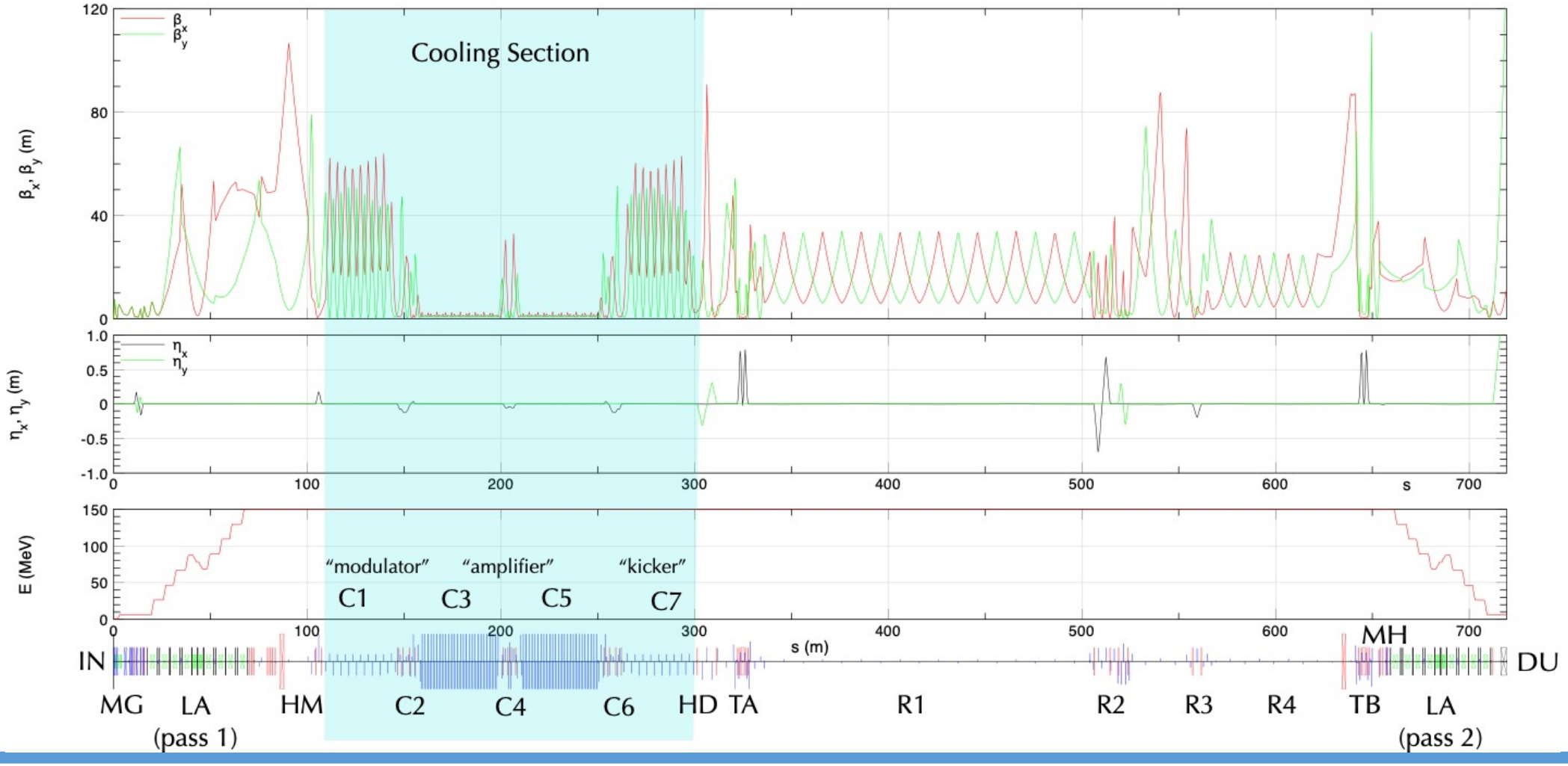


Figure II.1: Schedule from the original Phase II proposal, with estimated progress as a percentage.

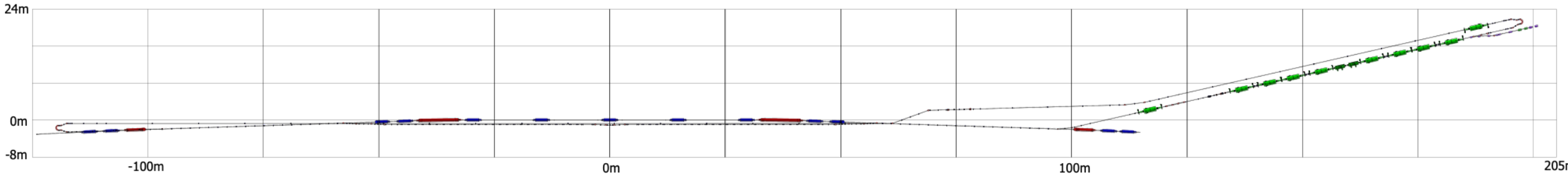
ERL Beam Dynamics Designs: Original Layout

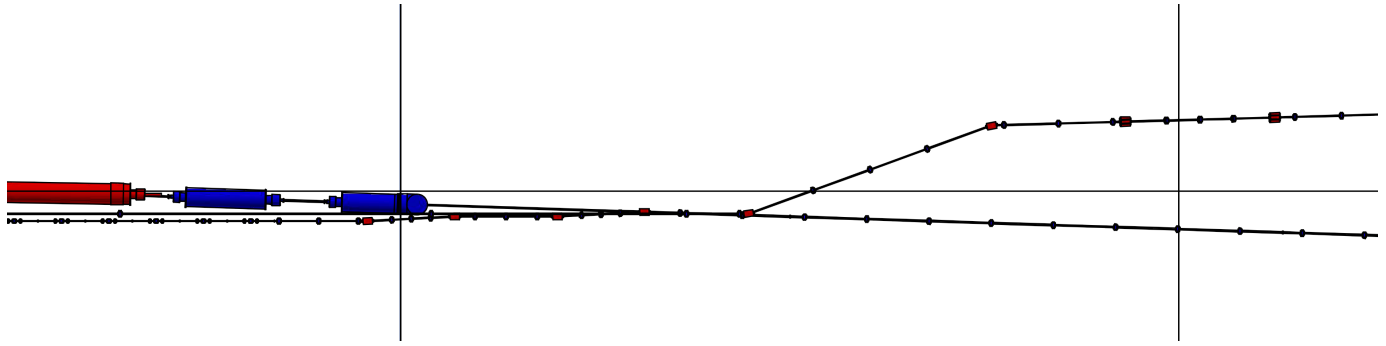


ERL Beam Dynamics Designs: Optics

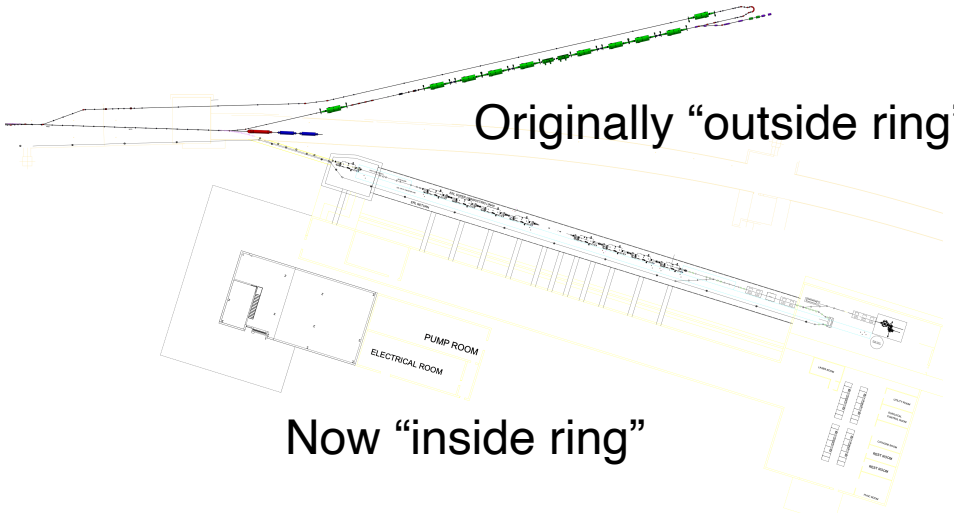


Original Layout: Plan View





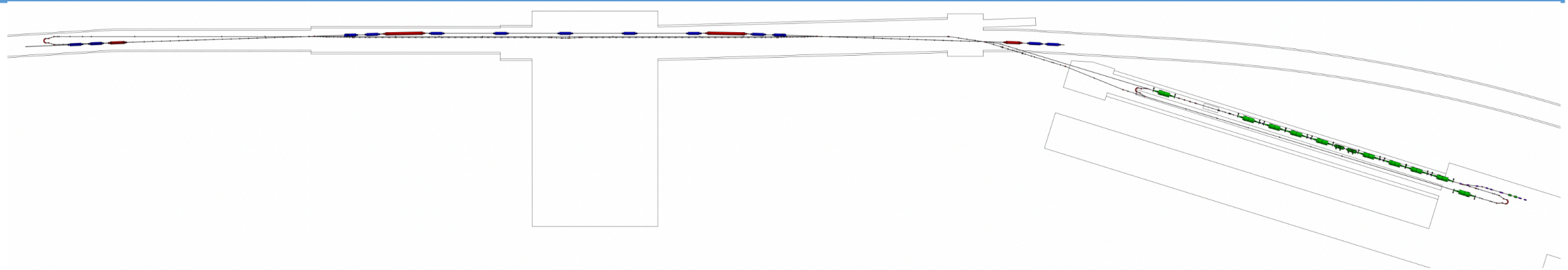
Detail

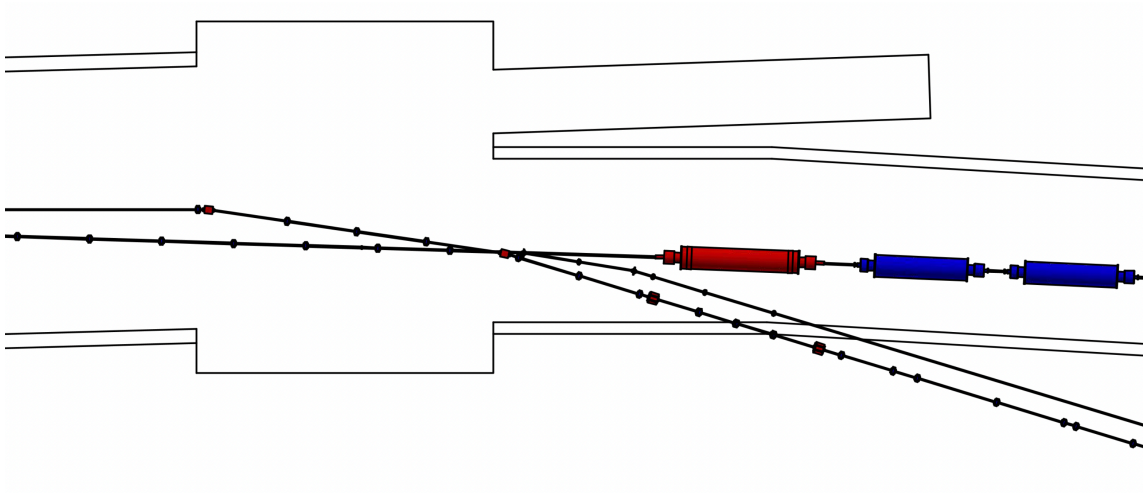


Originally “outside ring”

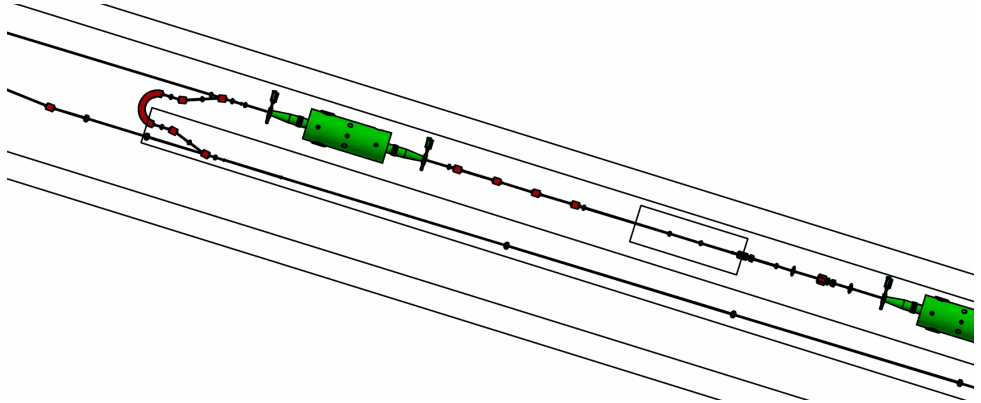
Now “inside ring”

New Layout: Plan View



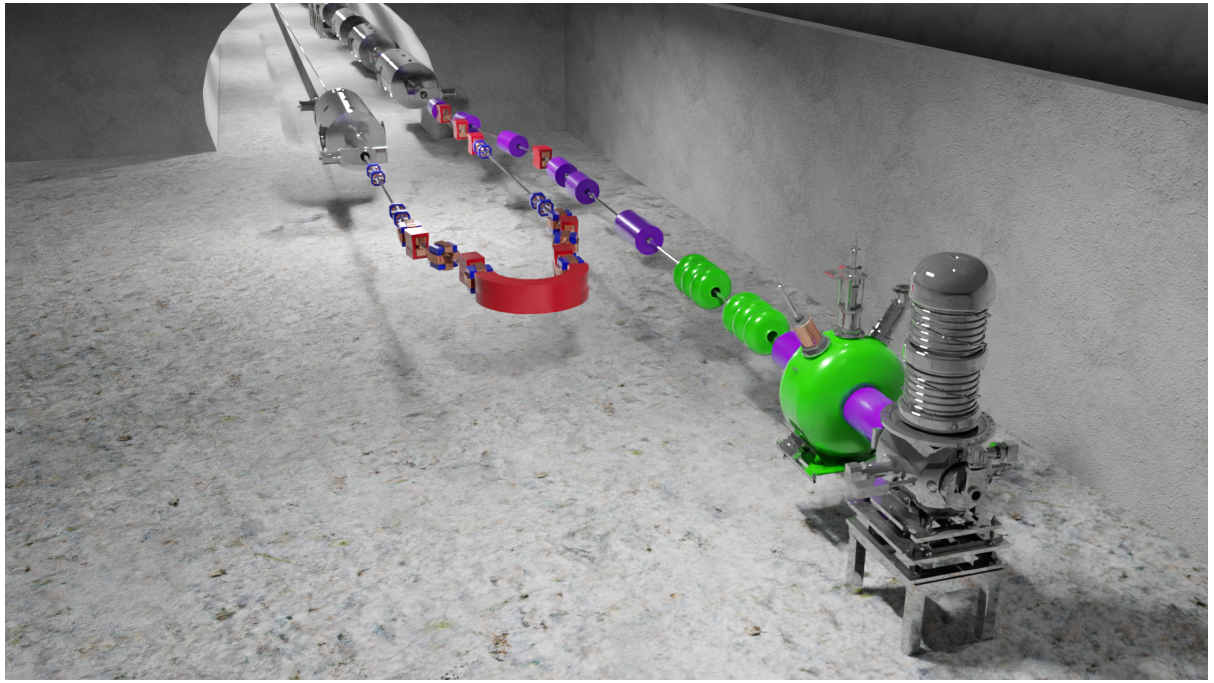


Electron-Hadron Merge

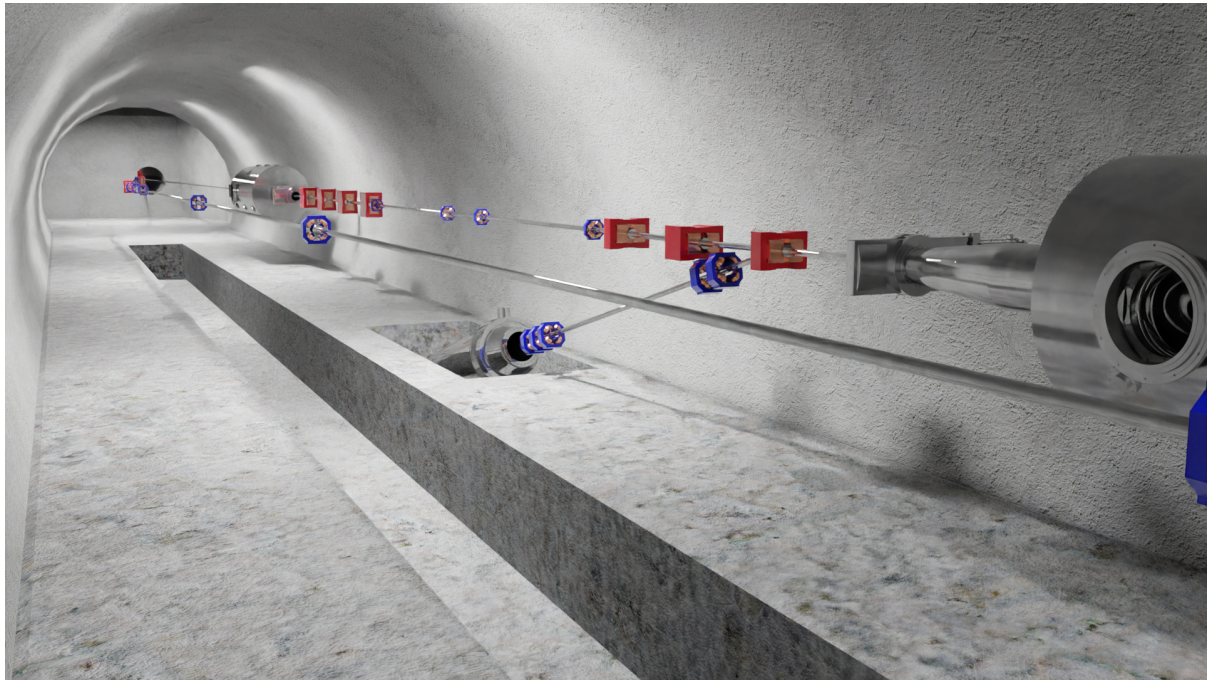


Experimental Line

3D Models and Renders (Blender)

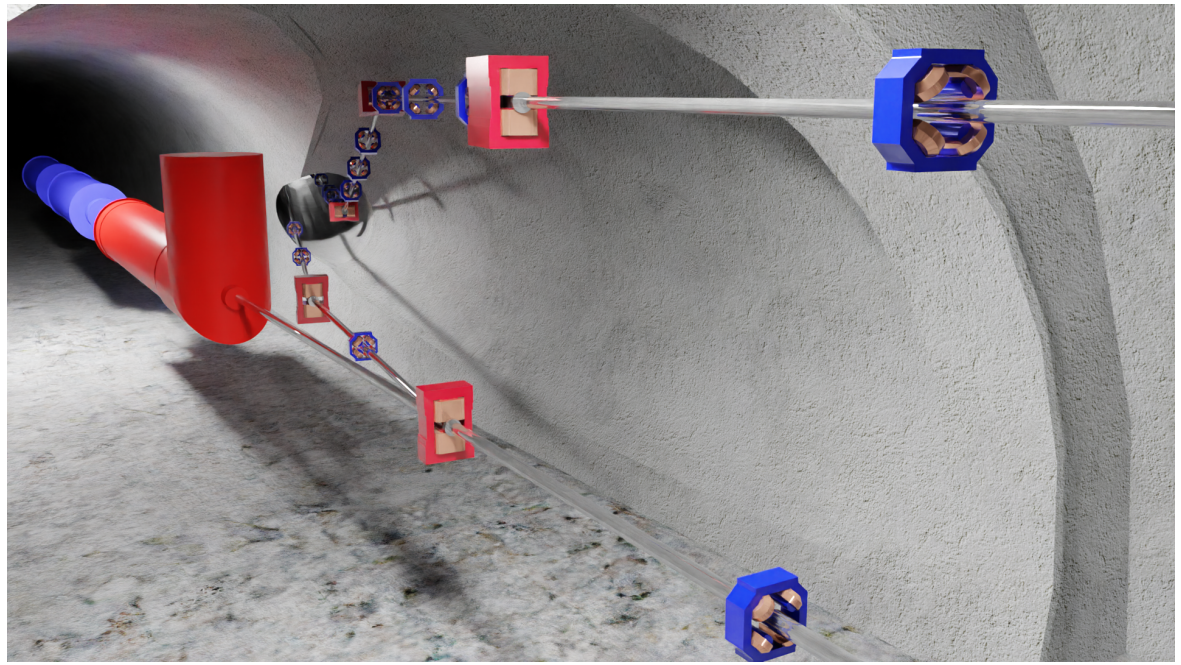


Injector, Merger, Return

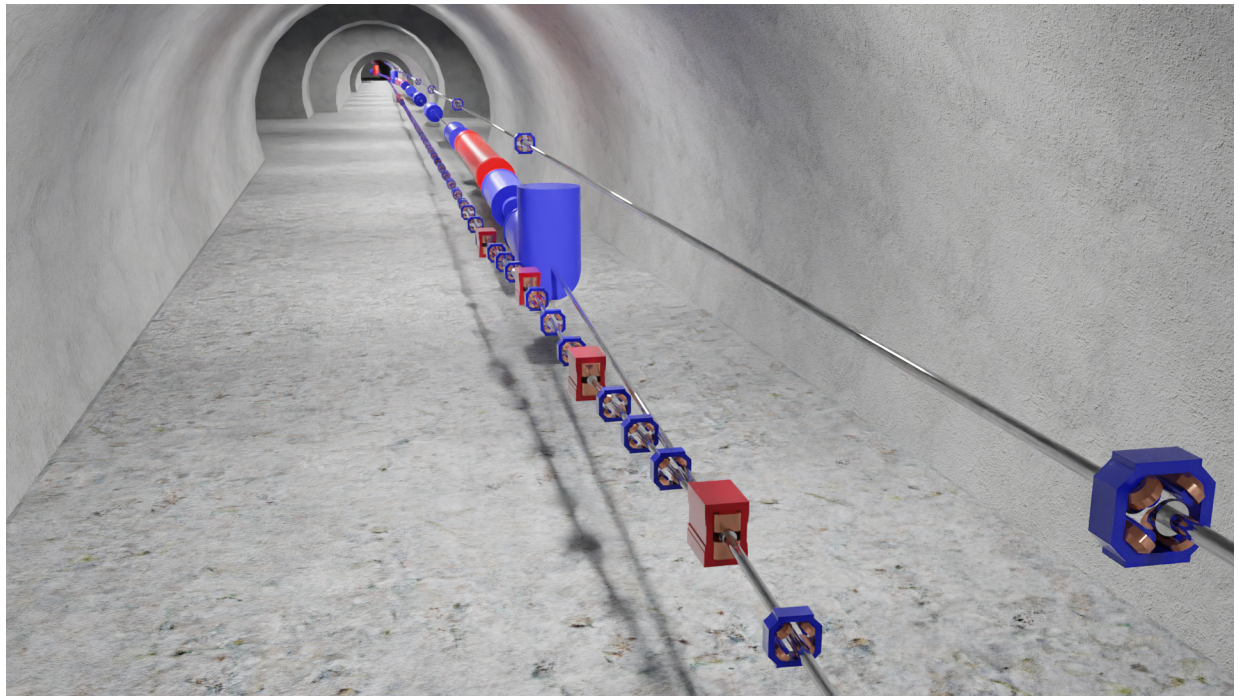


End of Linac, Dump, to Hadrons, Return

3D Models and Renders (Blender)

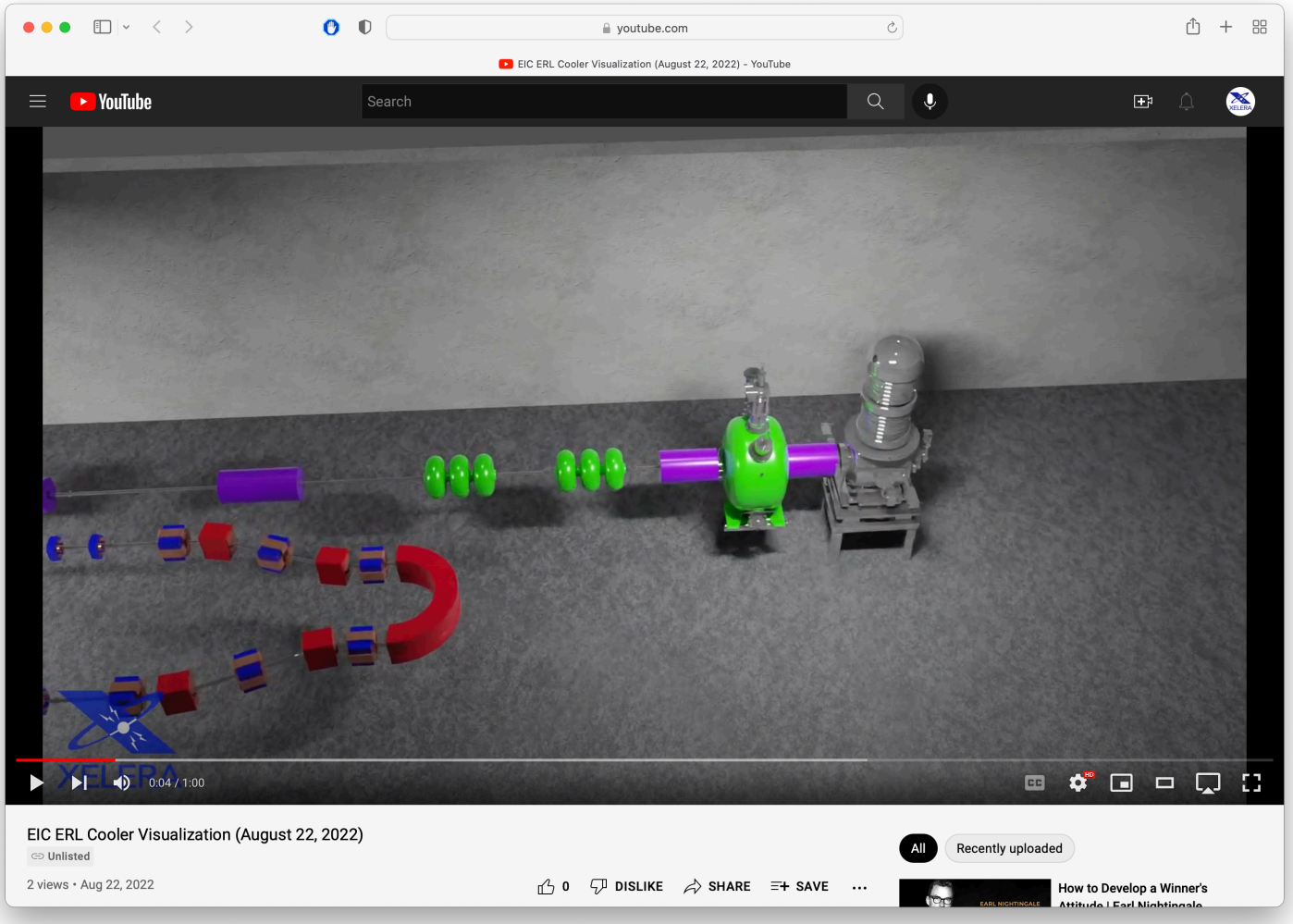


Merge electrons with hadrons into common “Modulator” cooling section.



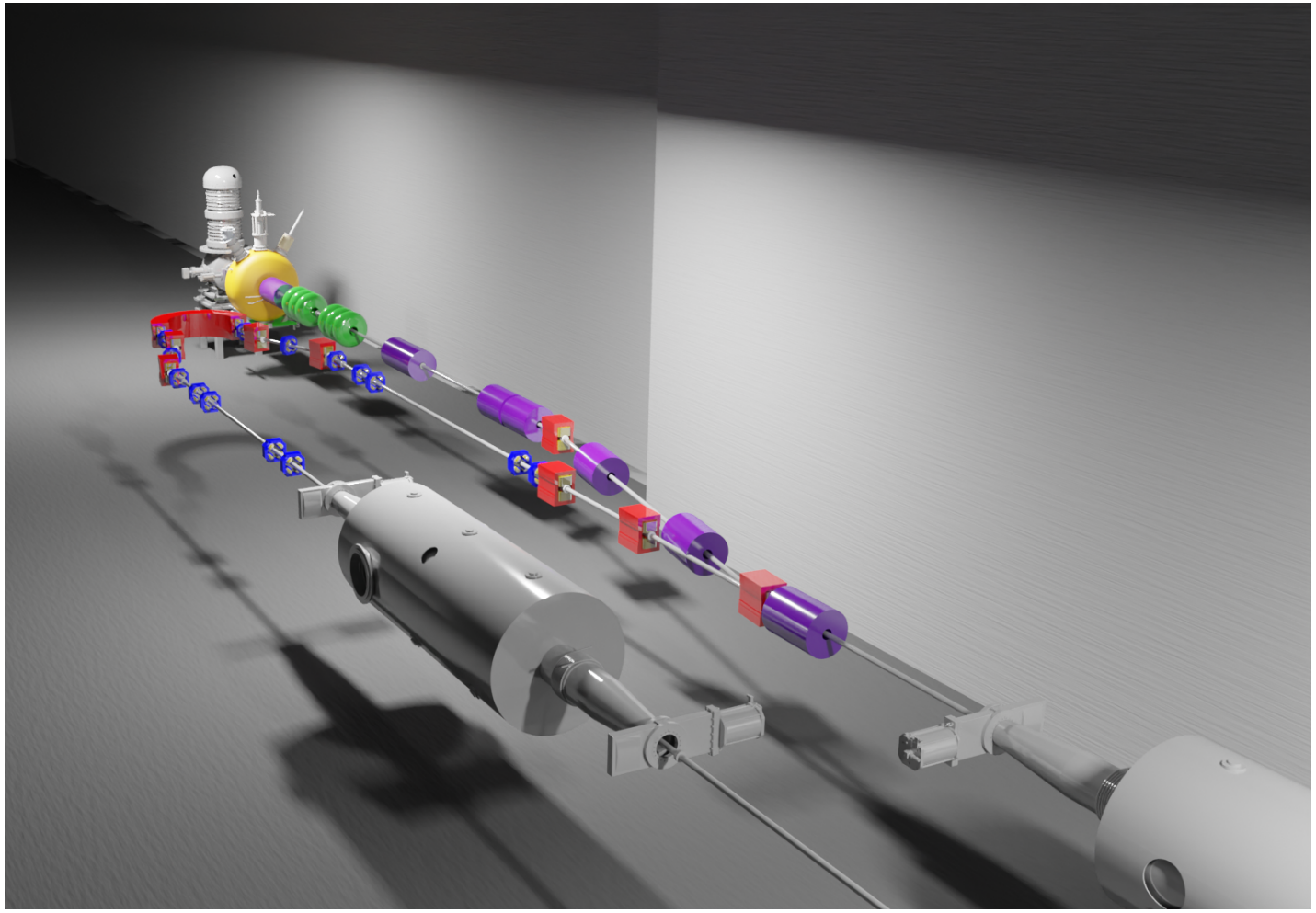
Demerge electrons from hadrons, into the “Amplifier” section.

EIC Cooler Flythrough



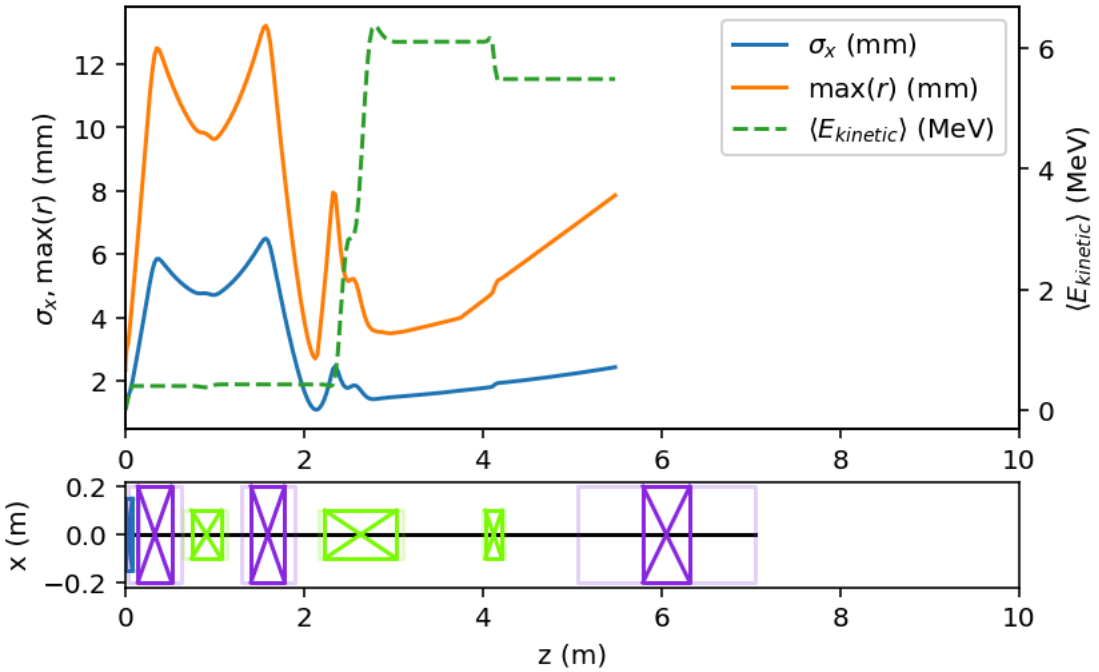
https://www.youtube.com/watch?v=qol34YQ9hmE

Technical Details

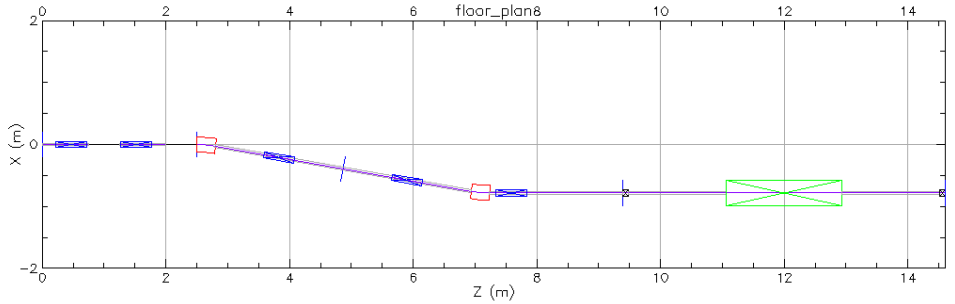


GPT:Bmad Hybrid Injector + Merger Model

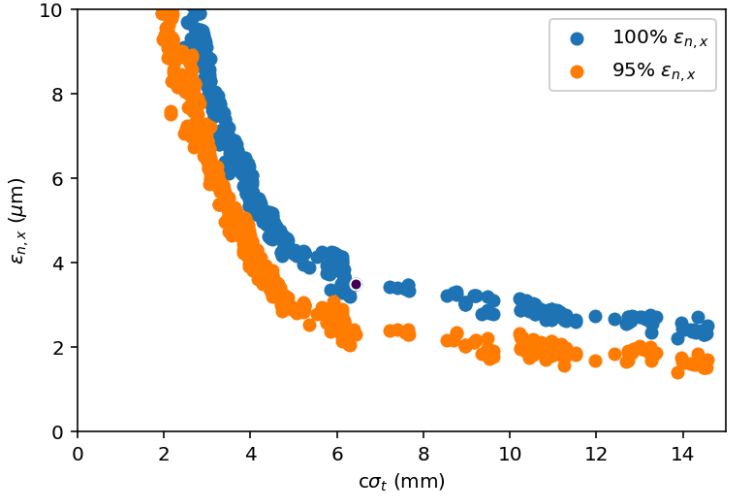
GPT Injector Model



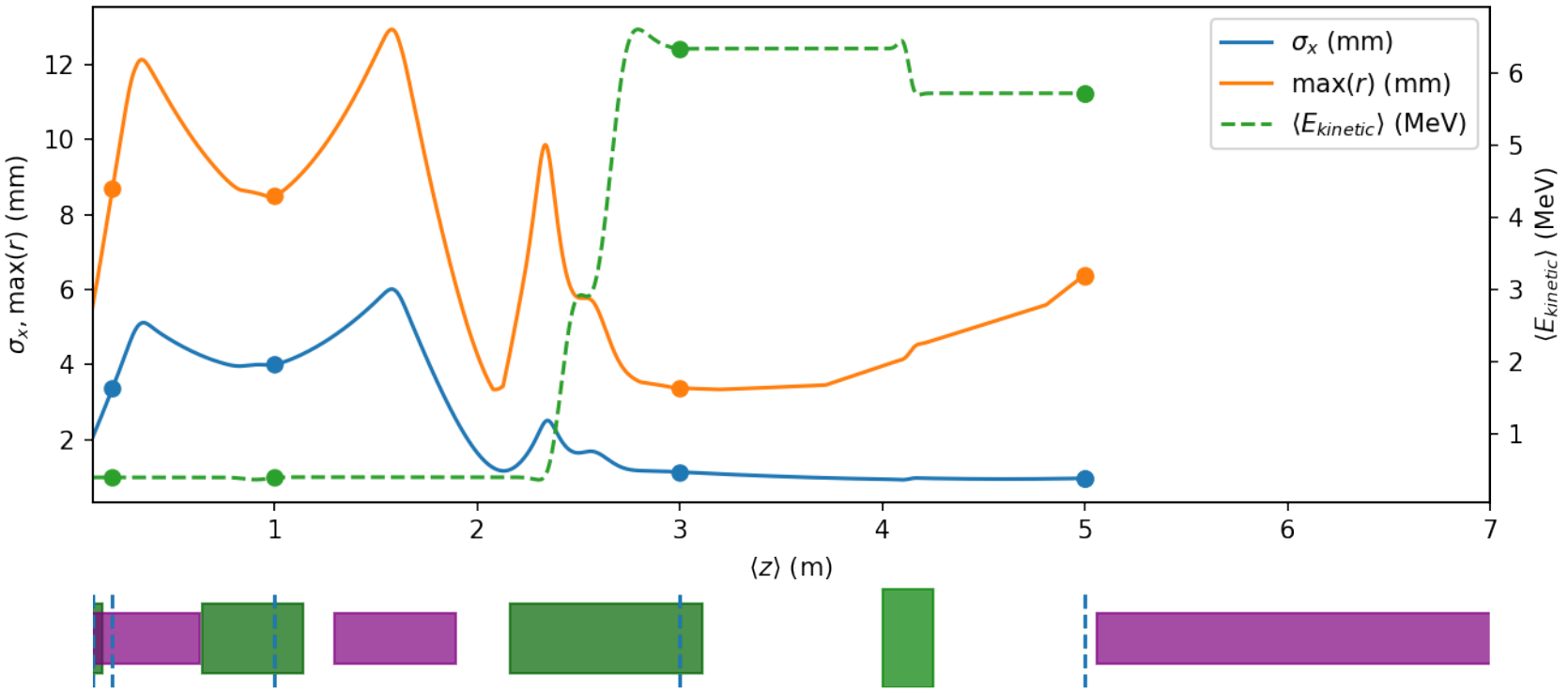
Bmad Merger + Linac Model

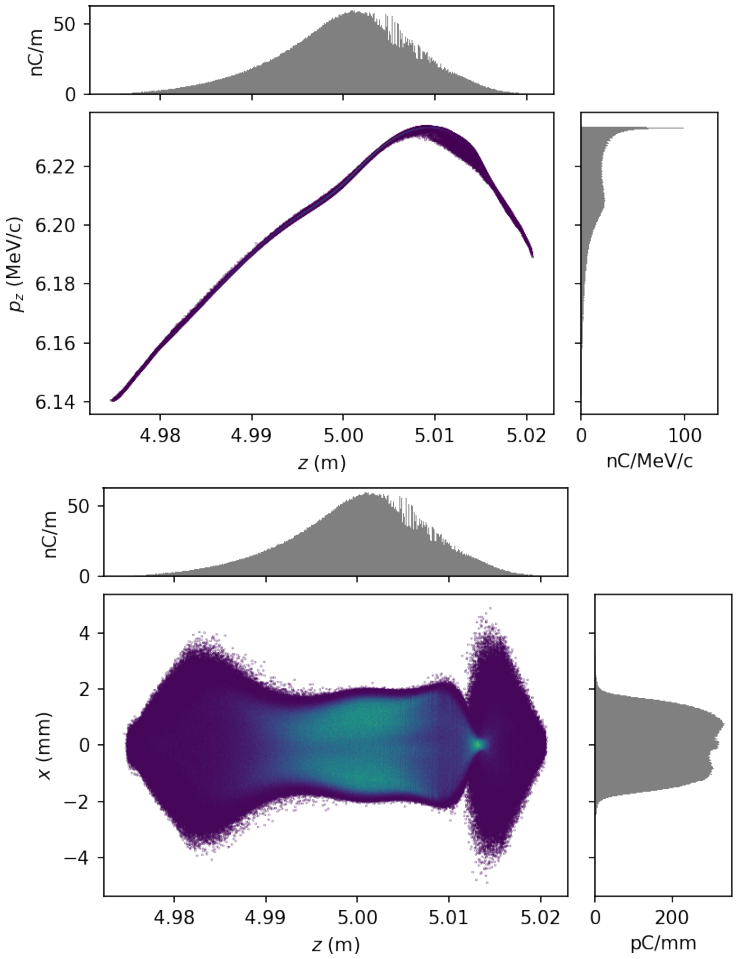


Optimize emittance vs. bunch length after 1st linac cryomodule

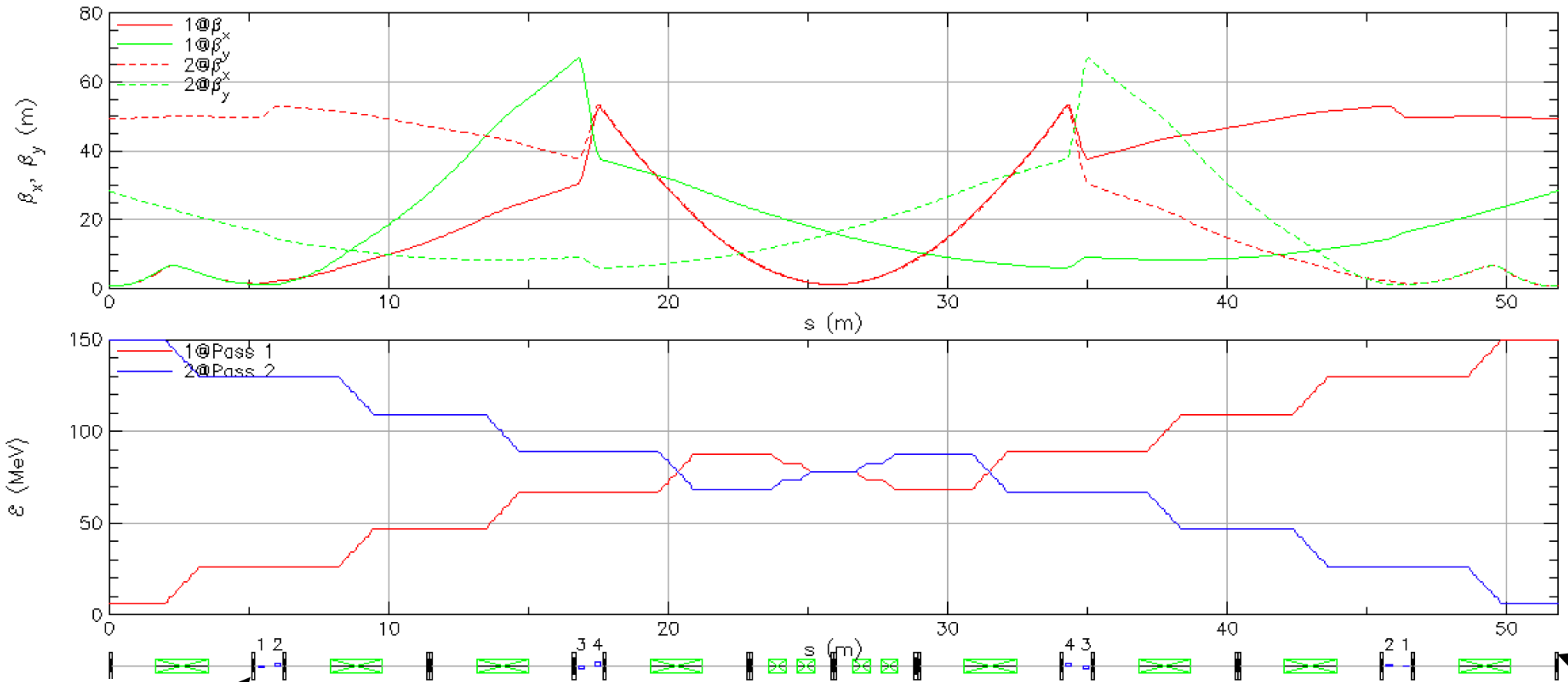


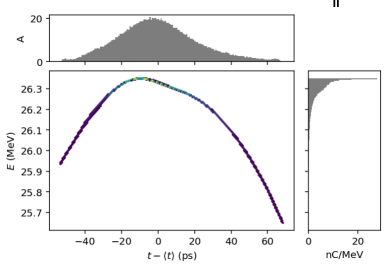
Impact-T Injector: 10 Million particle tracking

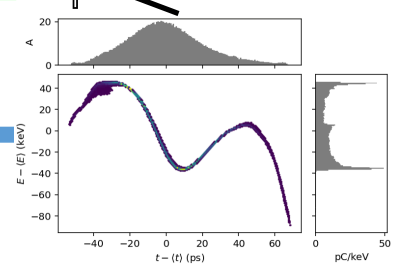




Multipass Linac Optics: Mode A (150 MeV)

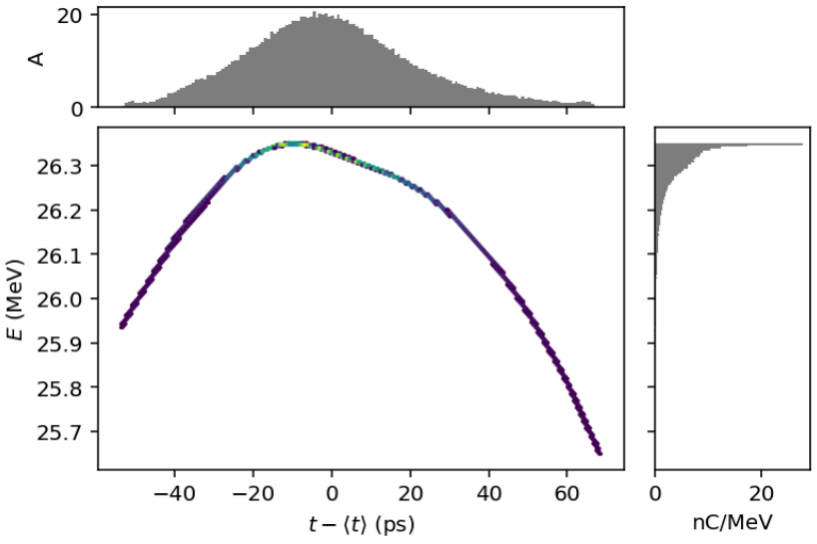




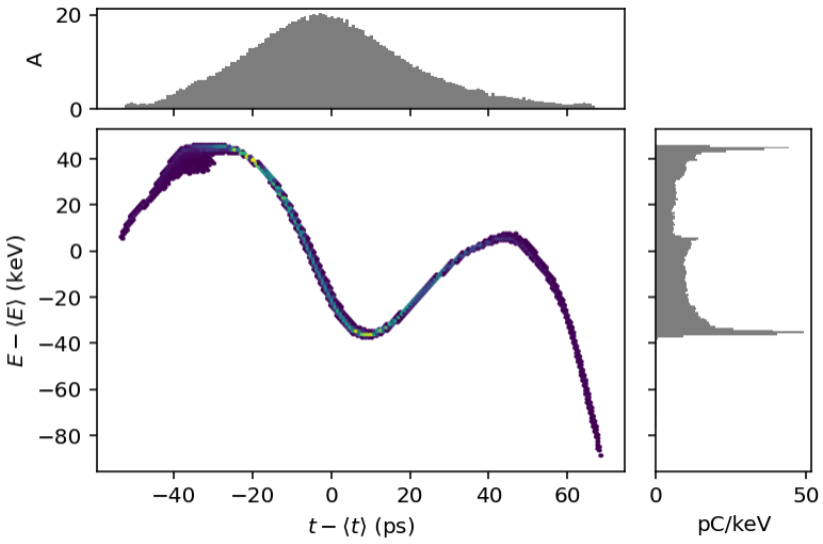


Beam Tracking, Mode A (100k particles)

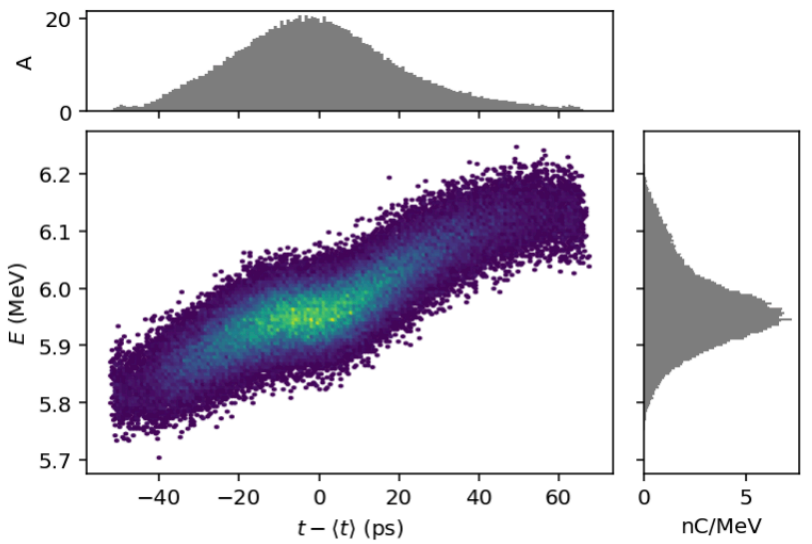
LA.CRMOD01.Mar.END\1



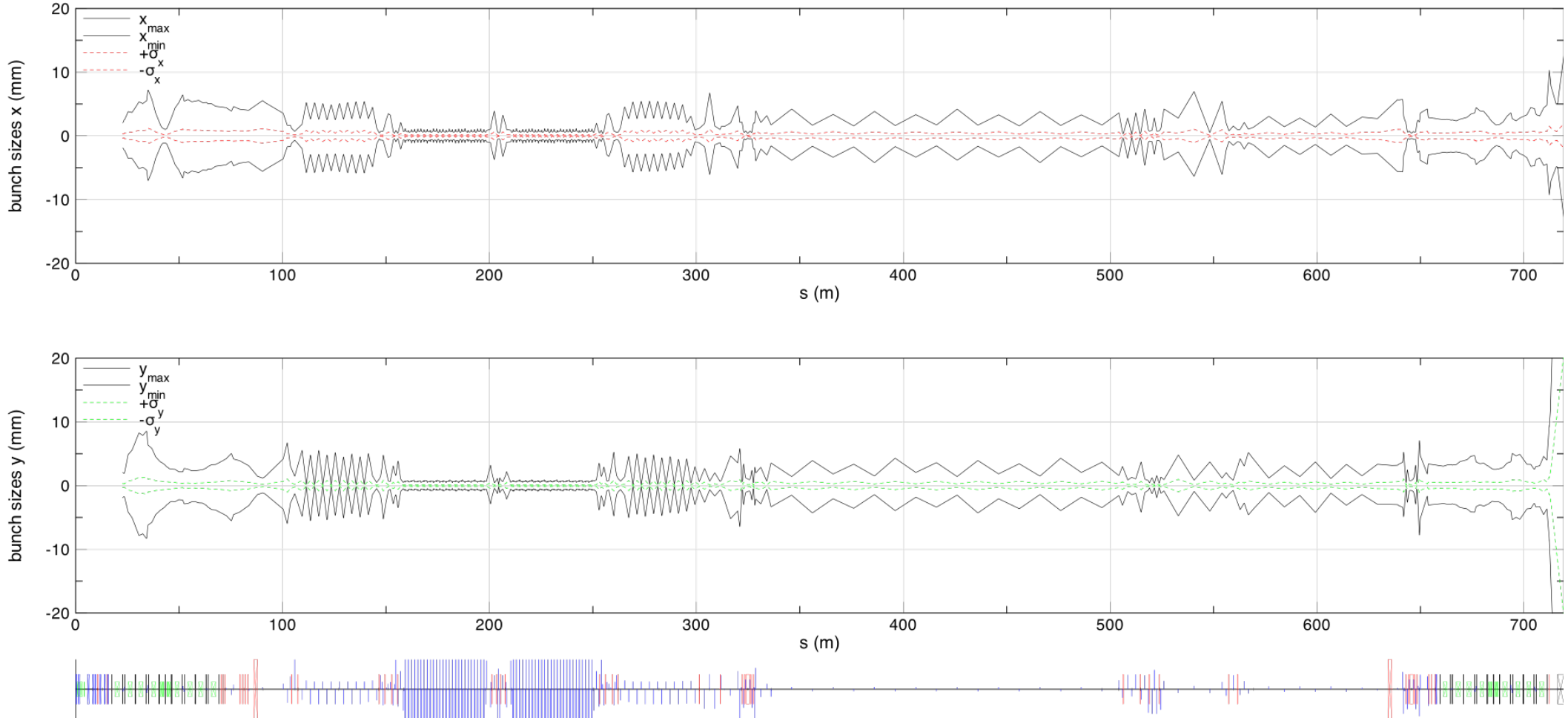
LA.Mar.END\1 (150 MeV)



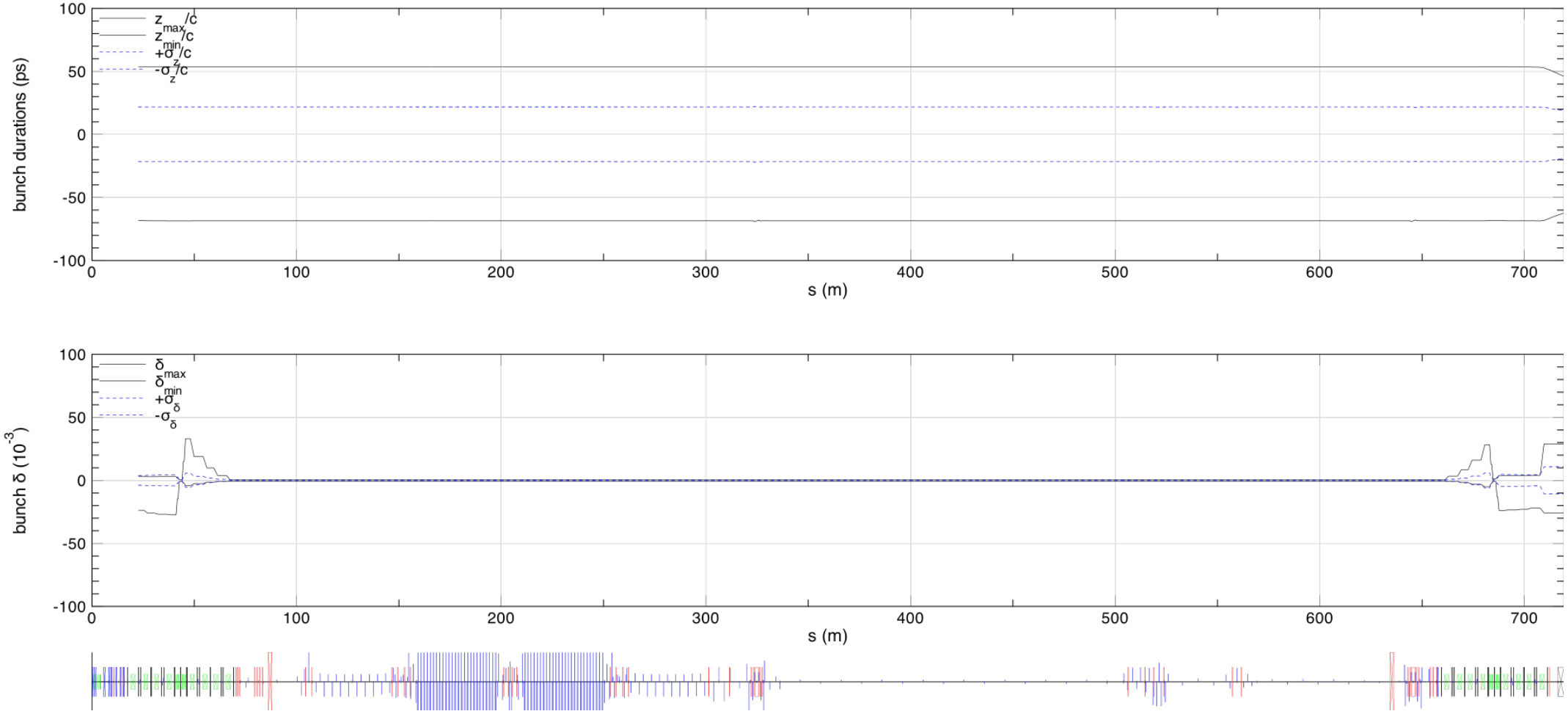
LA.Mar.END\2 (6 MeV)



Beam Tracking, Mode A (100k particles)

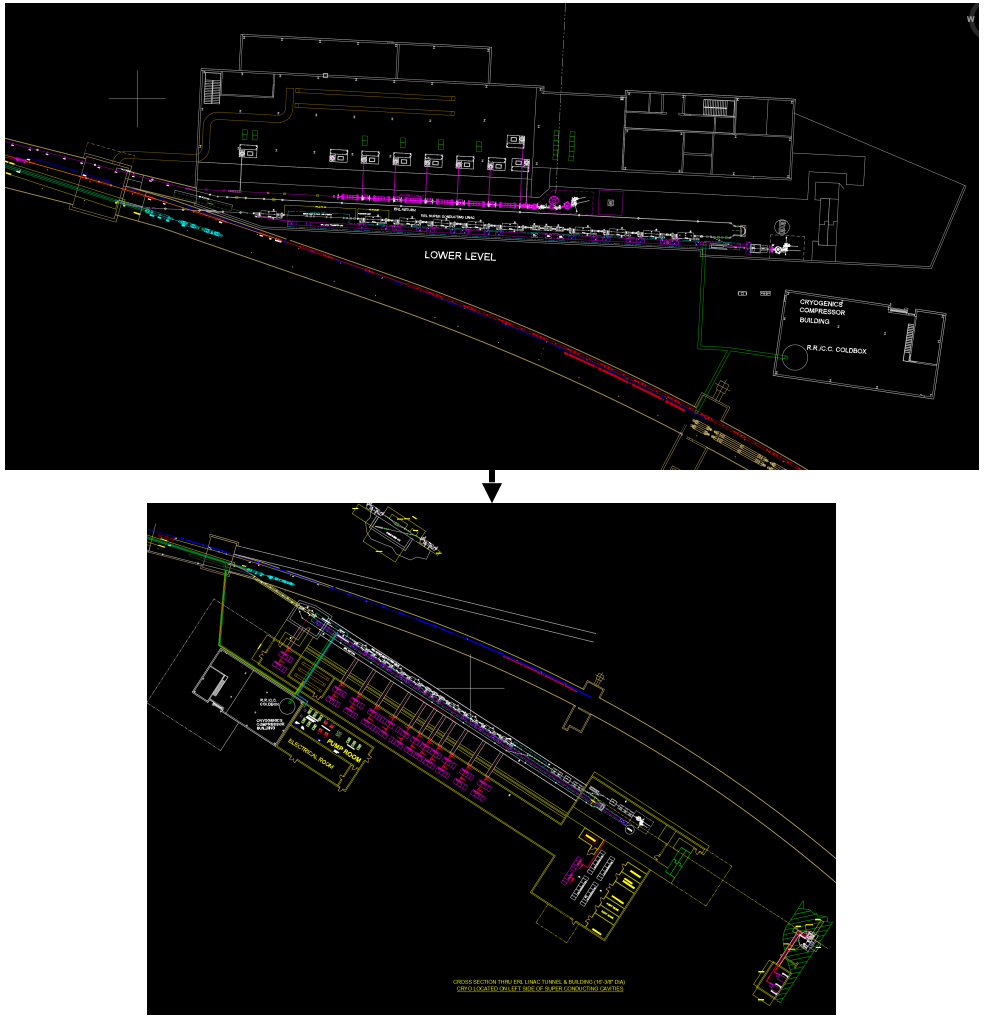


Beam Tracking, Mode A (100k particles)



Challenges Faced

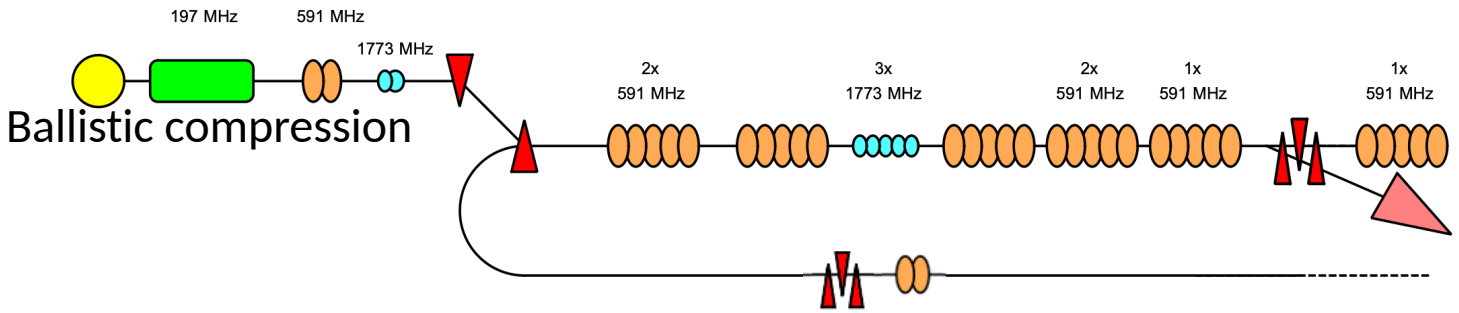
- Layout changes: Linac moved to the inside of the ring.
- Possible incorporation of pre-cooler system into strong hadron cooling (SHC) ERL (previously called the low-energy cooler).
- Cooling parameters changing, due to evolving simulations.



Incorporating Pre-cooler: Initial BNL Concept

SHC only: 591 MHz Injector

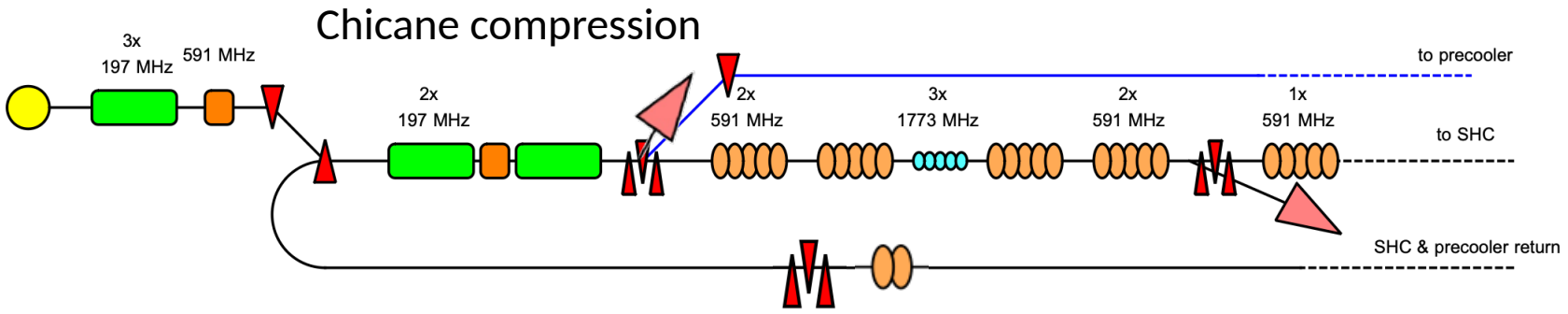
(591 MHz SRF injector)



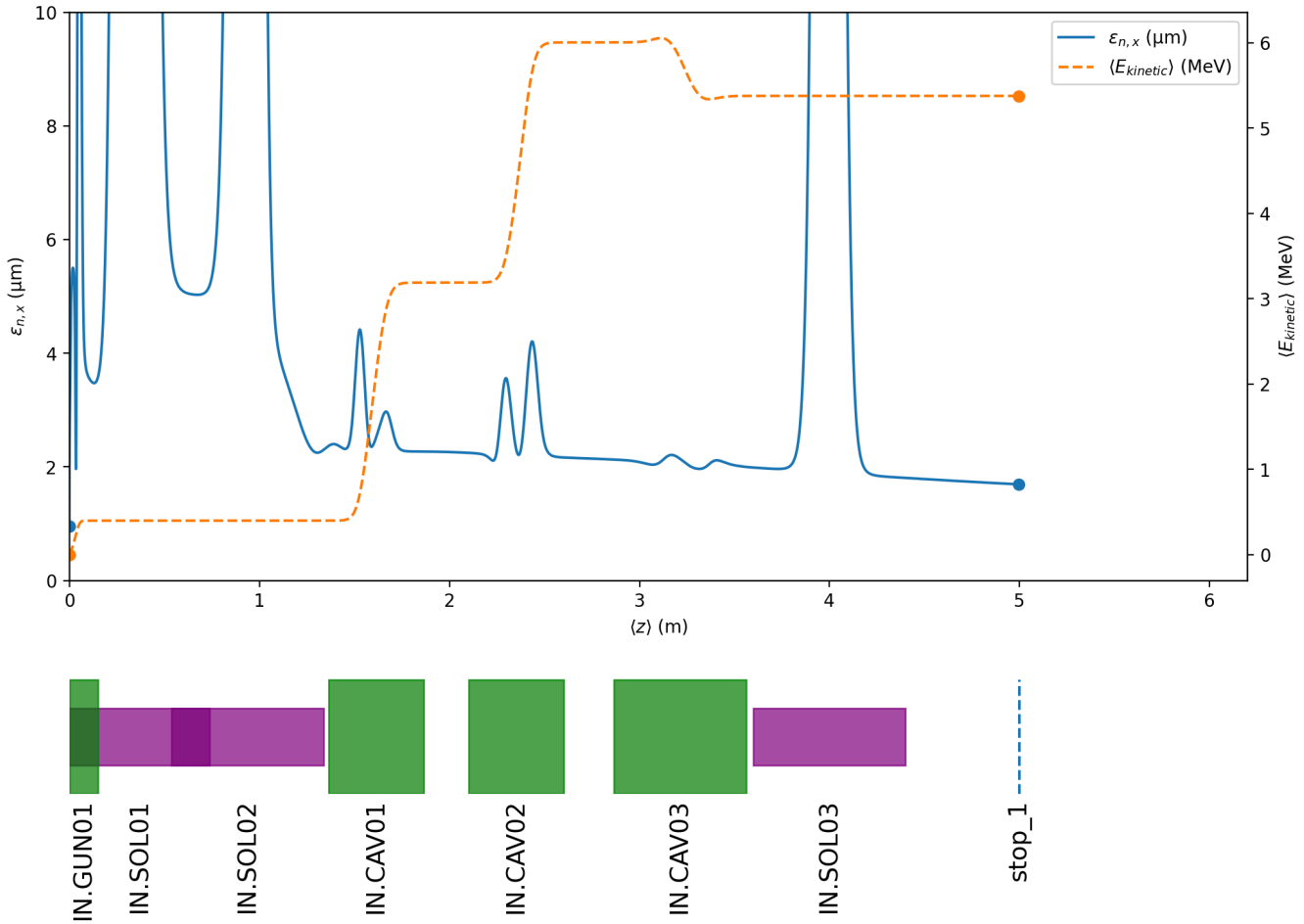
Also requires significant modifications to cooling section

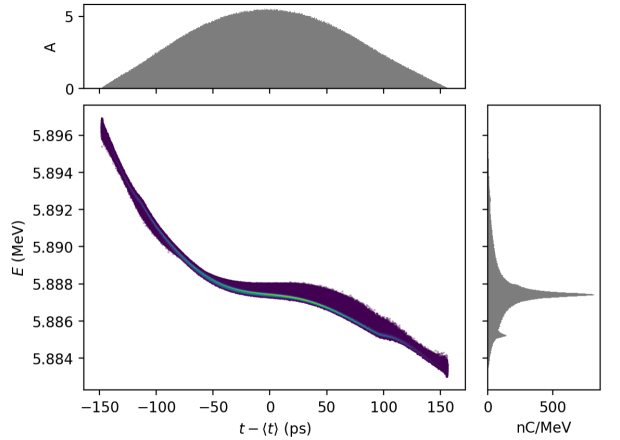
Combined SHC with Pre-cooler

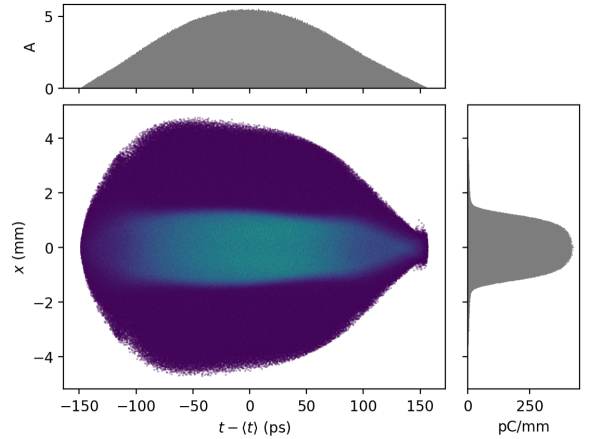
(197 MHz SRF injector)



Impact-T New Injector: 10 Million particle tracking







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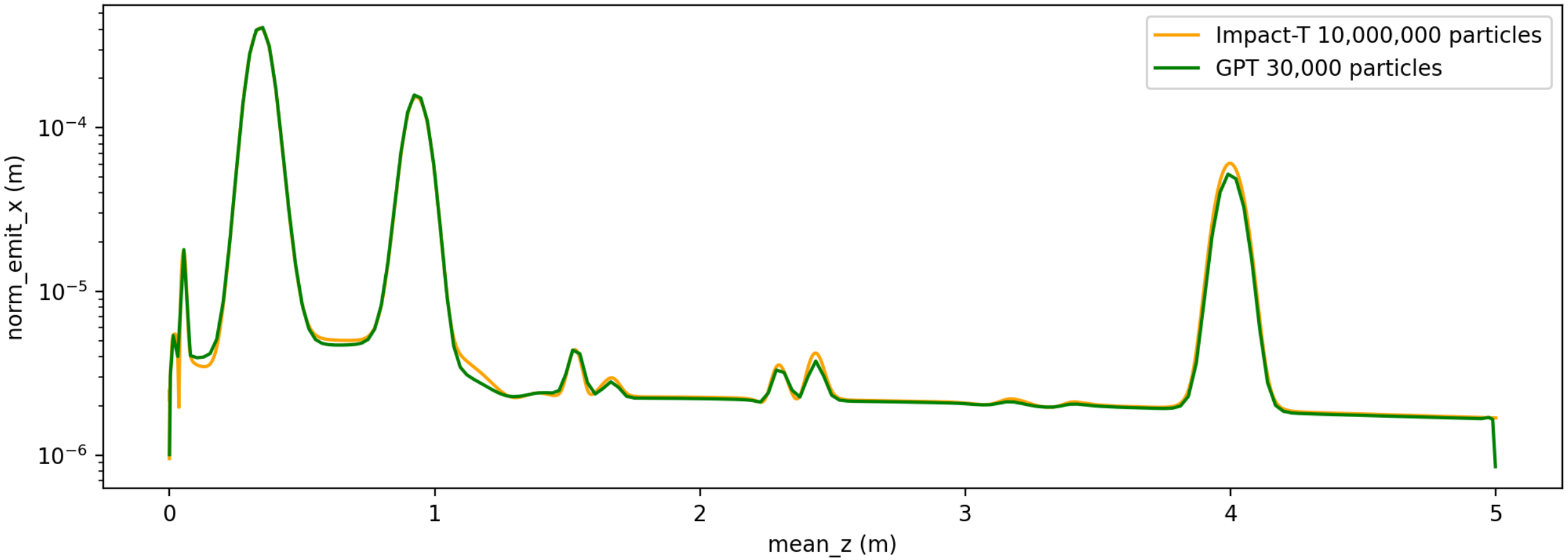

Conclusions

Through this SBIR Xelera has:

- Produced an initial closed lattice for EIC SHC ERL.
- Used this as the basis for further studies (e.g. tolerances, start-to-end, BBU).
- Worked closely with BNL, JLAB, and Cornell colleagues.

We are currently working to incorporate major changes into the design (pre-cooler, new cooling section design).

Thank you to the SBIR program and our colleagues for allowing us to contribute to the EIC design.