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# Energy Recovery Linac Designs and Studies for Electron Cooling of Hadron Beams (DoE Phase II SBIR)

August 16th, 2023

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# Outline

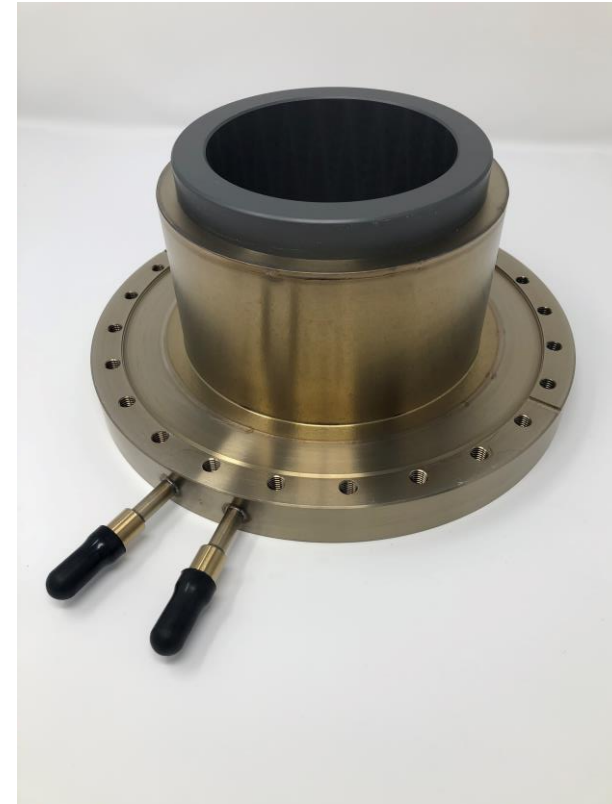
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- Xelera Background
  - EIC Cooler ERL Specs and Layout
  - Design Details
  - Conclusions
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# Xelera Research LLC: Company Overview

- Formed in 2013 by 5 partners – 150+ years of accelerator design expertise
- Most of Xelera came from the Cornell ERL development team, who designed and built the world's highest current, high brightness photoinjector, which evolved into significant component of 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)





# Project Technical Objectives

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- **The EIC at BNL is the next major accelerator project for DOE – using an electron beam as a probe of nuclear structure at the existing RHIC collider**
    - Cooling the hadron beam via Coherent electron Cooling leads to higher luminosity and thus higher rates of data collection
  - **ERL Beam Dynamics Designs Satisfying Specifications for CeC of the EIC**
    - Optimized lattice from cathode to beam stop
    - Include relevant effects: space charge, CSR
  - **Tolerance Studies:**
    - Investigate error effects (misalignments, mis-powering, and field inhomogeneities)
    - Practical correction strategies
    - Cost/benefit analysis of higher quality hardware versus cost.
  - **Beam Breakup (BBU) Studies:** demonstrate the threshold current is above the operating current.
  - **Start-to-End Simulation Studies:** High fidelity simulations to confirm cooling specs satisfied and beam can be energy recovered
  - **Beam Halo Studies:** Catalogue likely sources, investigate mitigation strategies
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# A Different Kind of SBIR

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## **Business Concept:**

*A company working at / beyond the state of the art can provide physics and engineering value to our national accelerator labs*

AND

Apply this experience to the commercial realm

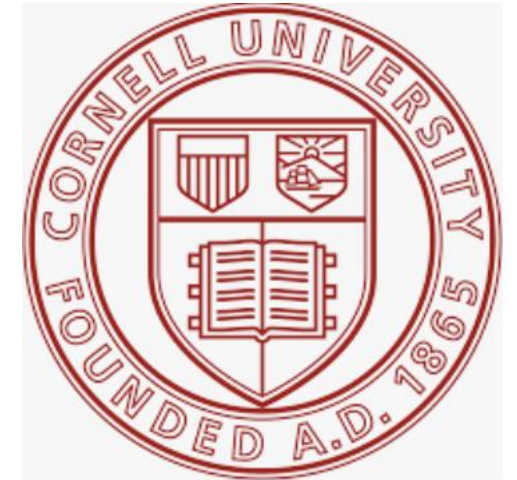
- The SBIR program provided us with a “First Example” project allow us to prove to the accelerator design community our capabilities
  - No one would believe us without an example of our work!
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# Collaboration

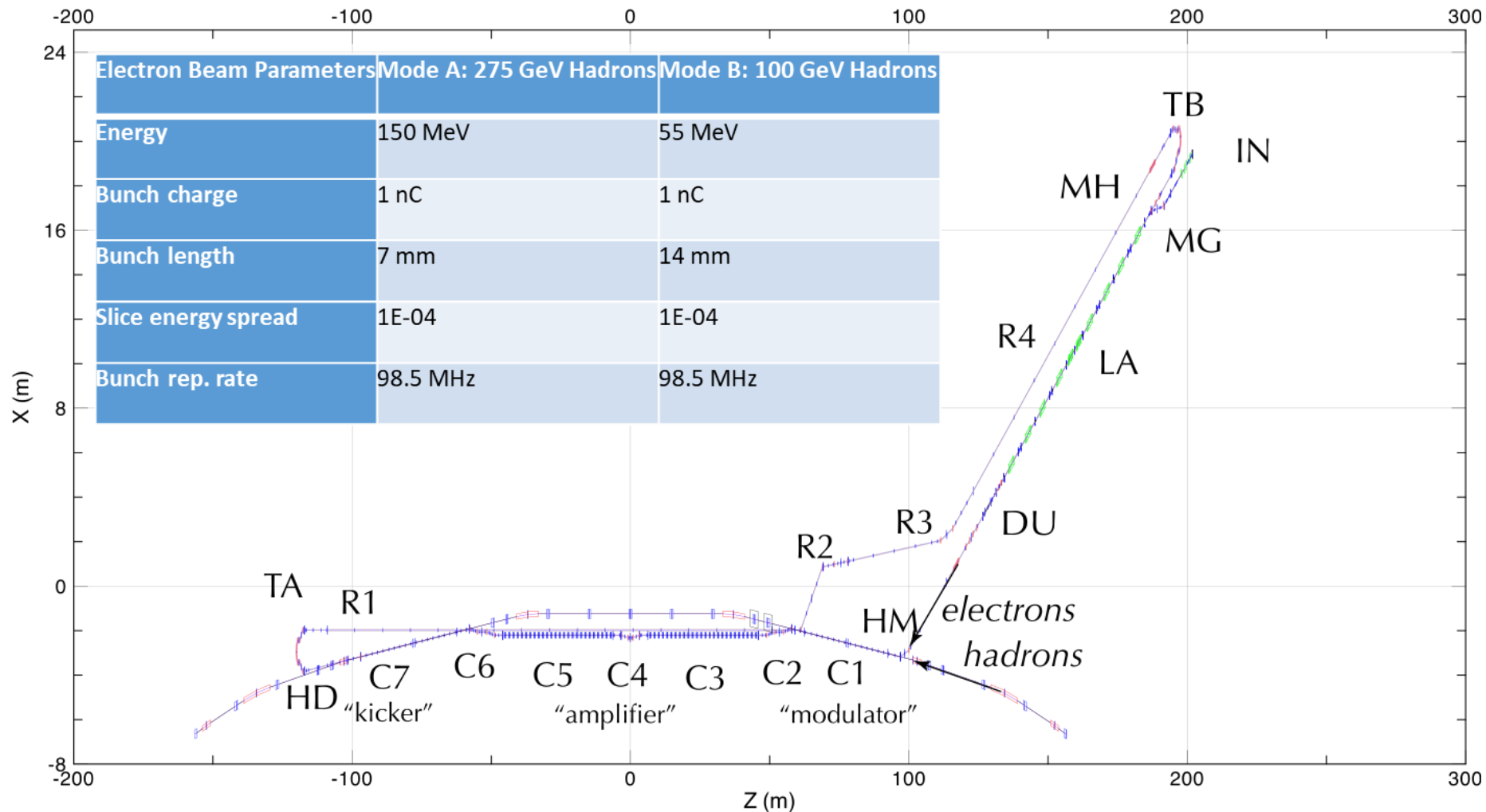
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- Erdong Wang, Steve Peggs, Will Bergan, Derong Xu (BNL)
- Steve Benson, Kirsten Deitrick (JLab)
- Georg Hoffstaetter, Ningdong Wang (Cornell)





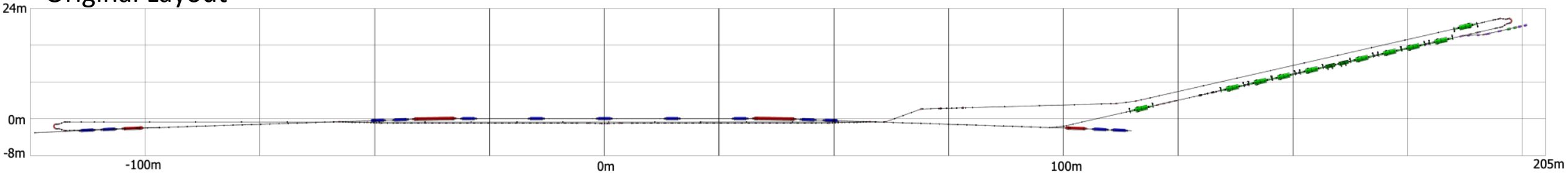
# ERL Designs: Specs and Original Layout



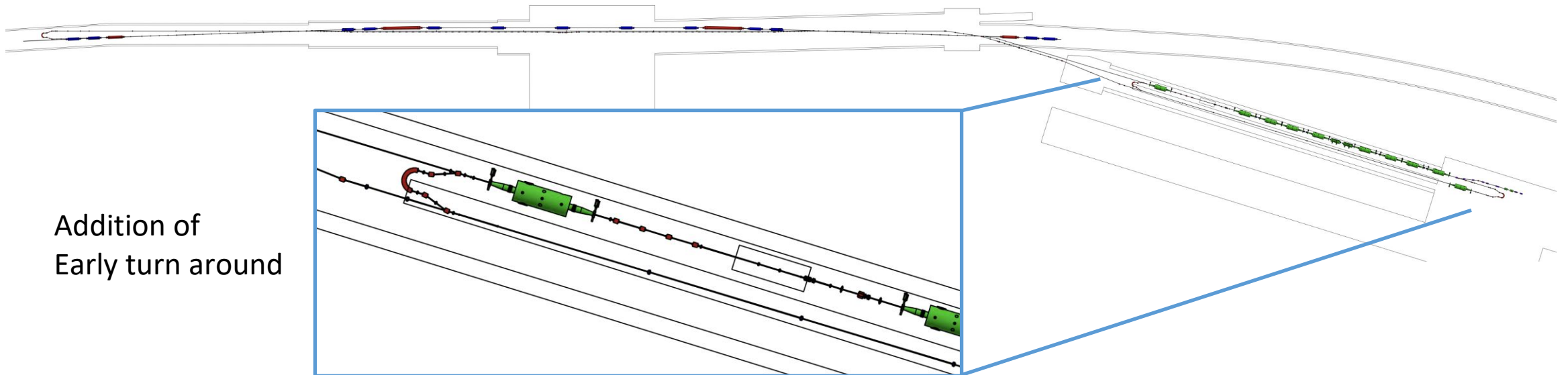


# Layout: Plan View (Original Layout)

Original Layout



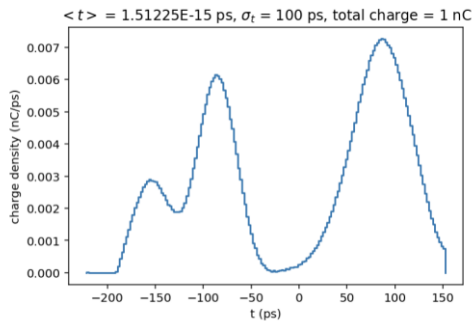
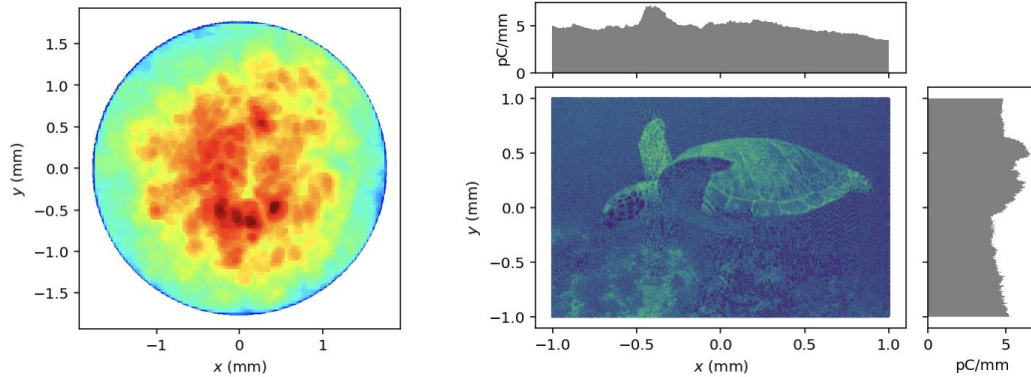
Inside Layout



Addition of  
Early turn around



Distgen: Python code for generating initial particles

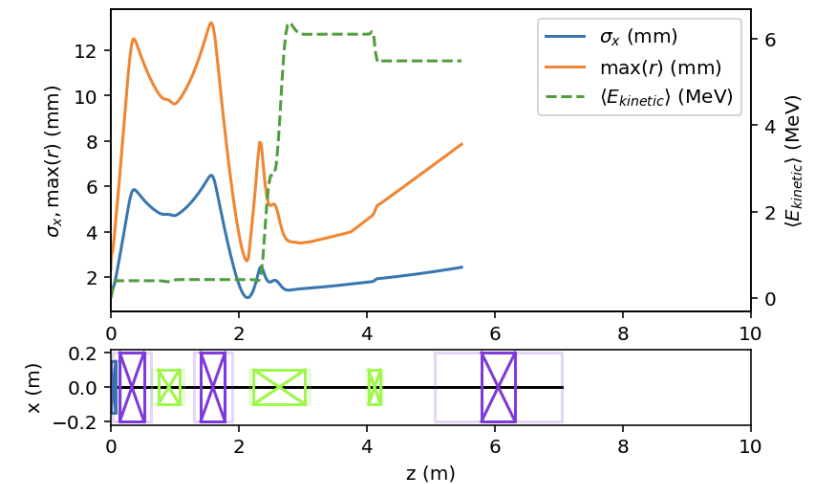


- Standard distribution types
- Low-discrepancy (Hammersley, etc)
- Pseudo random generation (“rand”)
- Output to GPT, ASTRA, h5 (Bmad), etc

<https://github.com/ColwynGulliford/distgen>

LUME-GPT: Python wrapper for running and displaying GPT simulations

- Generate GPT lattice files
- Plot lattice layouts

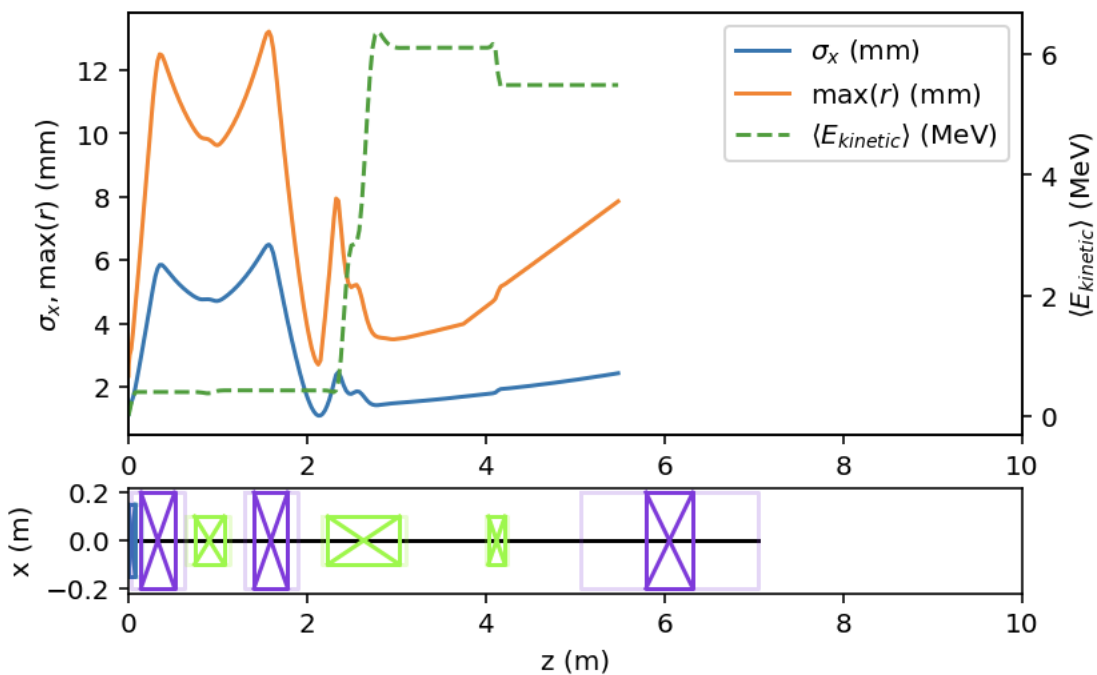


<https://github.com/ColwynGulliford/lume-gpt>

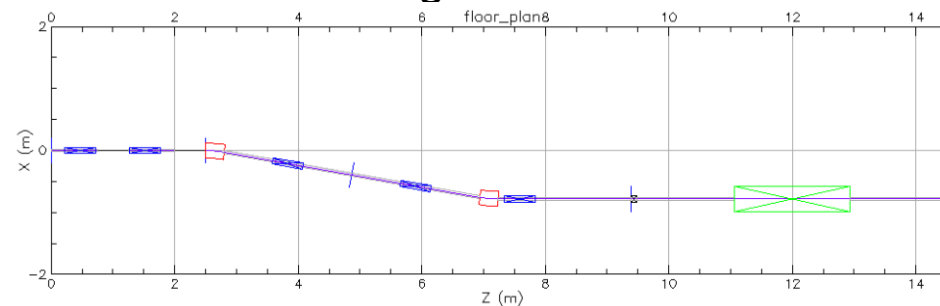
Part of larger ecosystem:  
<https://www.lume.science>

# GPT:Bmad Hybrid Injector + Merger Model

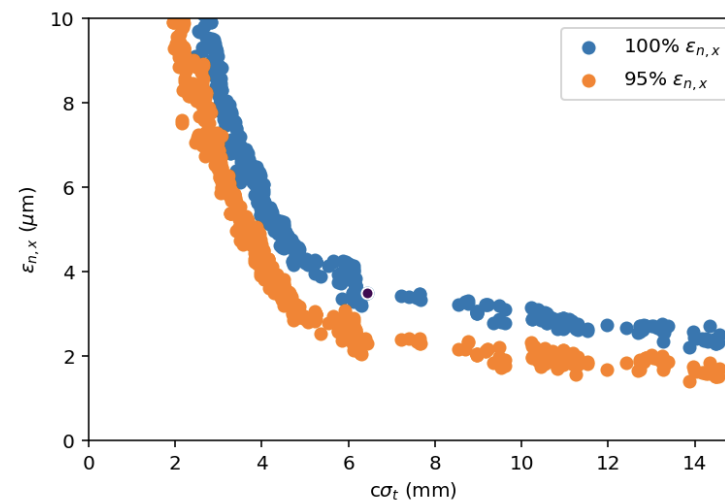
## GPT Injector Model



## Bmad Merger + Linac Model

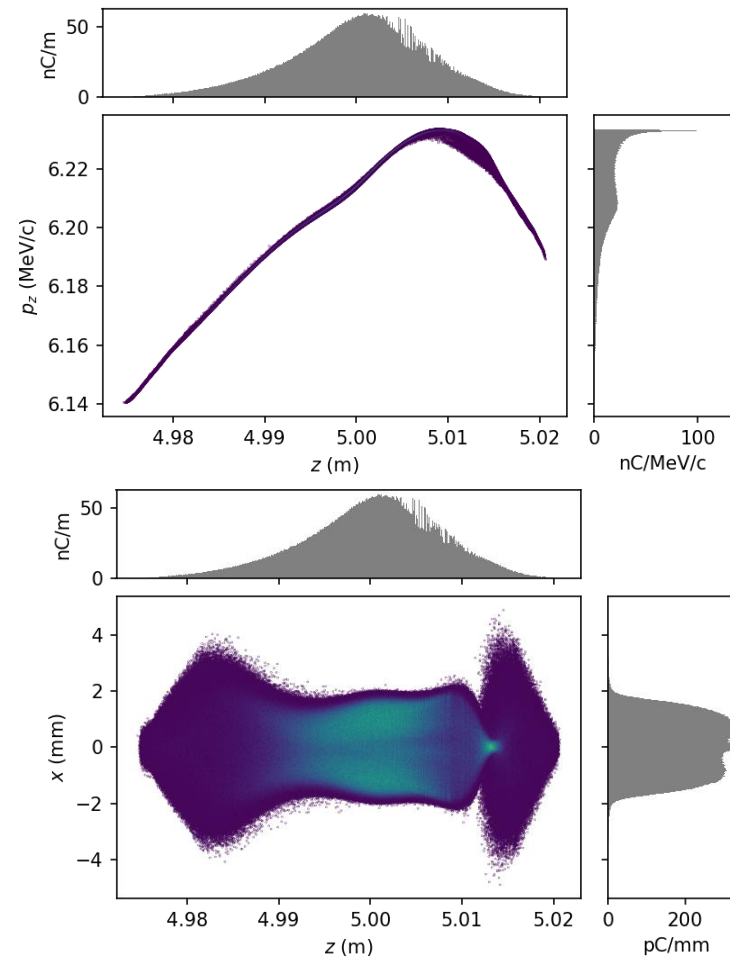
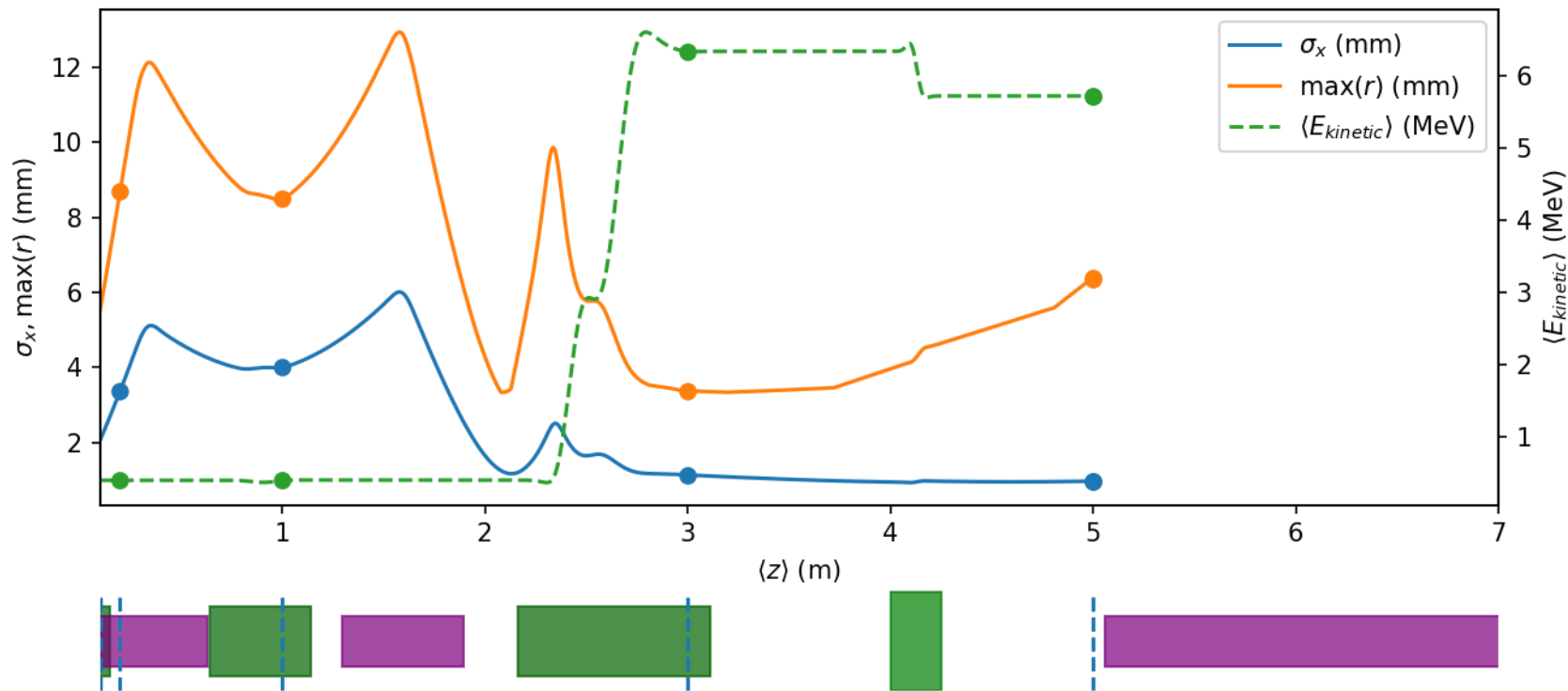


Optimize emittance vs. bunch length after 1st linac cryomodule



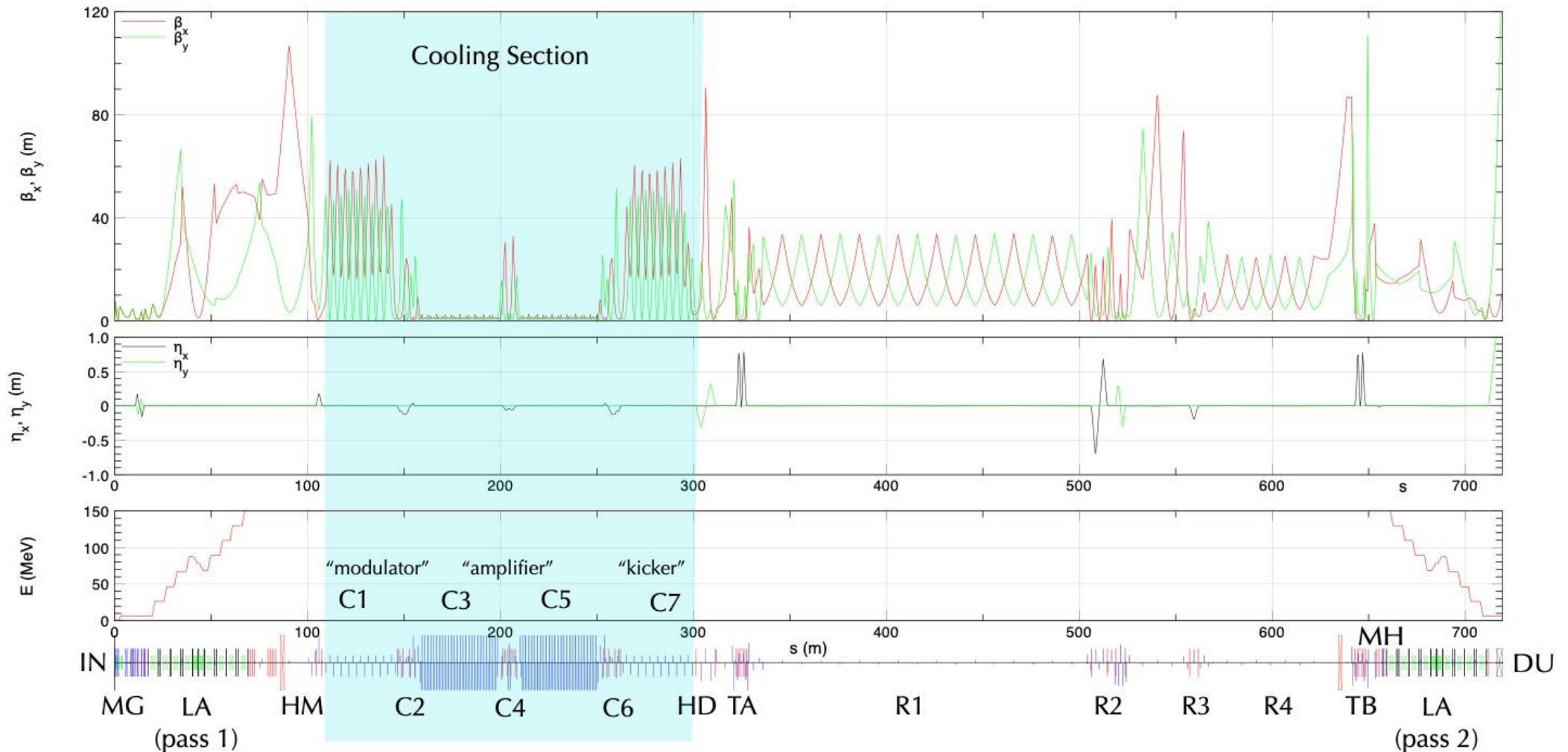


# Impact-T Injector: 10 Million particle tracking



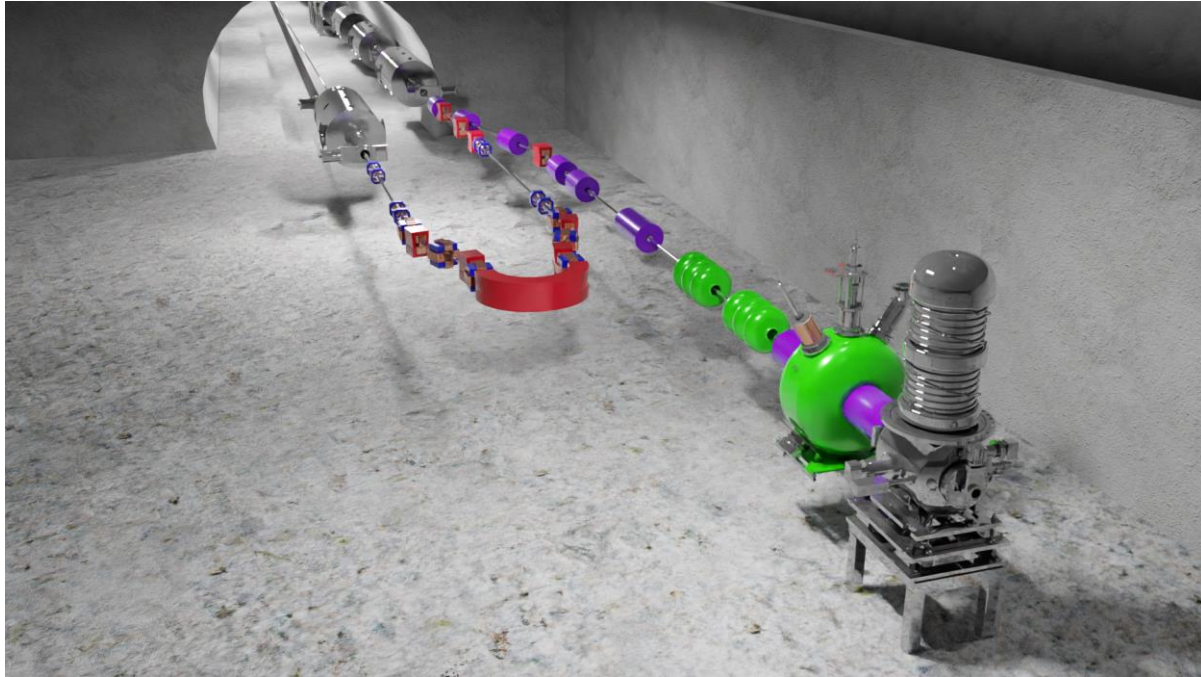
Leveraging massive computing power of NERSC and AWS (amazon)

# ERL Beam Dynamics Designs: Optics

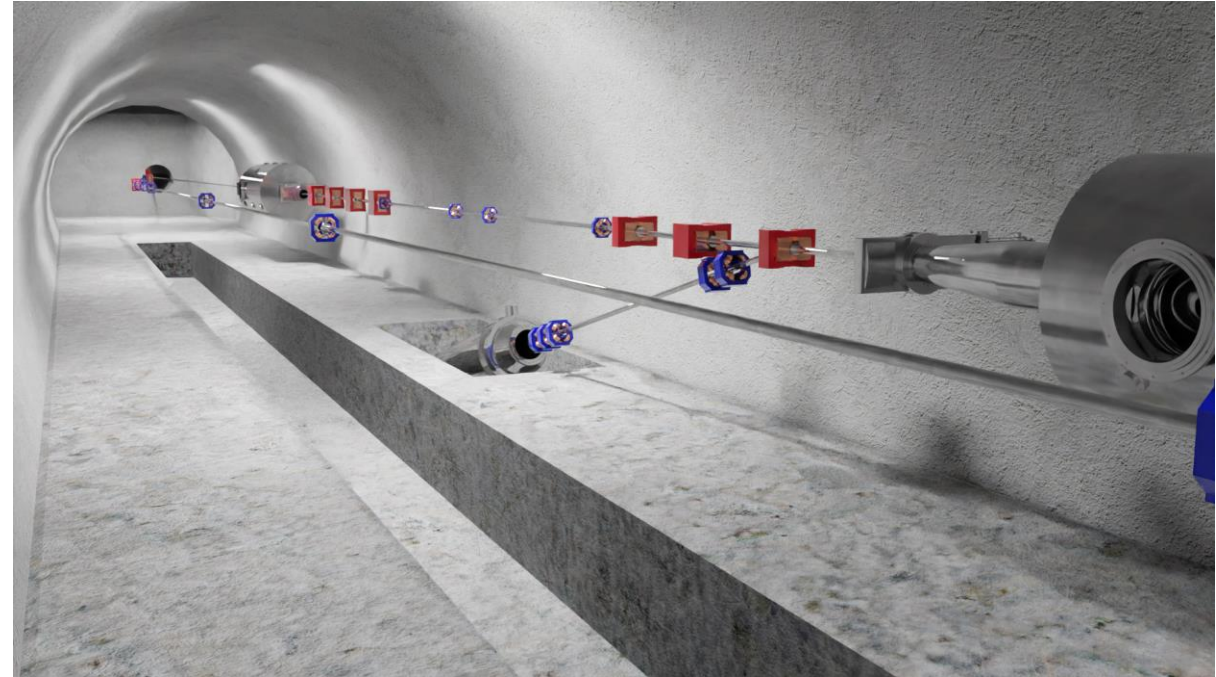


A Complete Design?

# 3D Models and Renders (Blender)

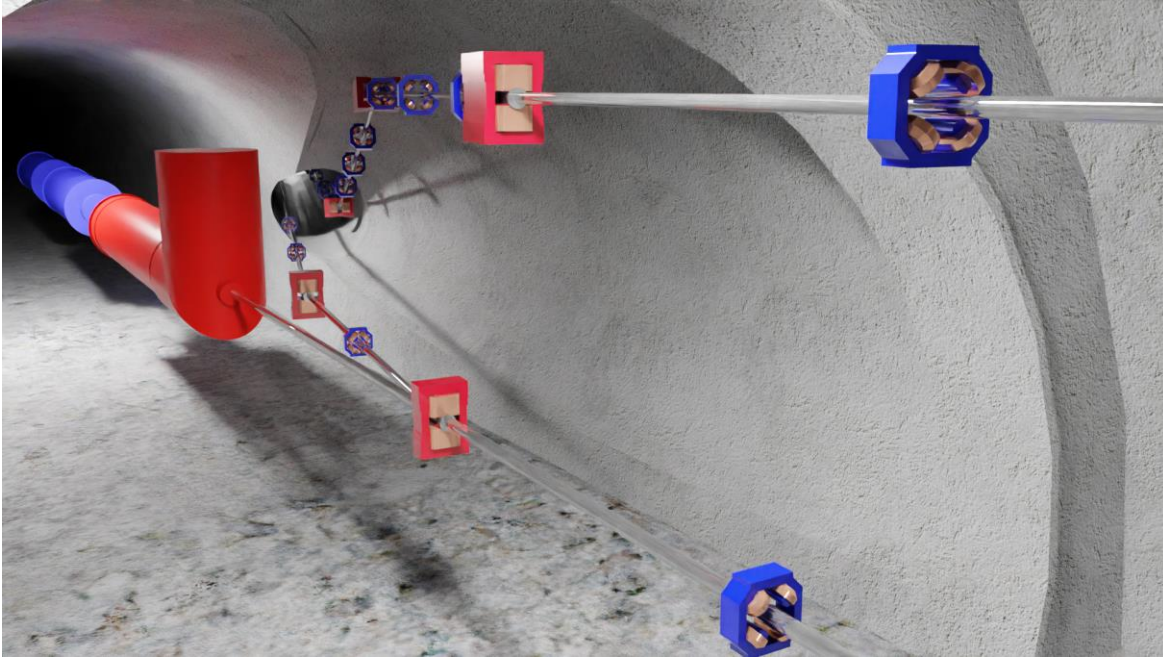


Injector, Merger, Return

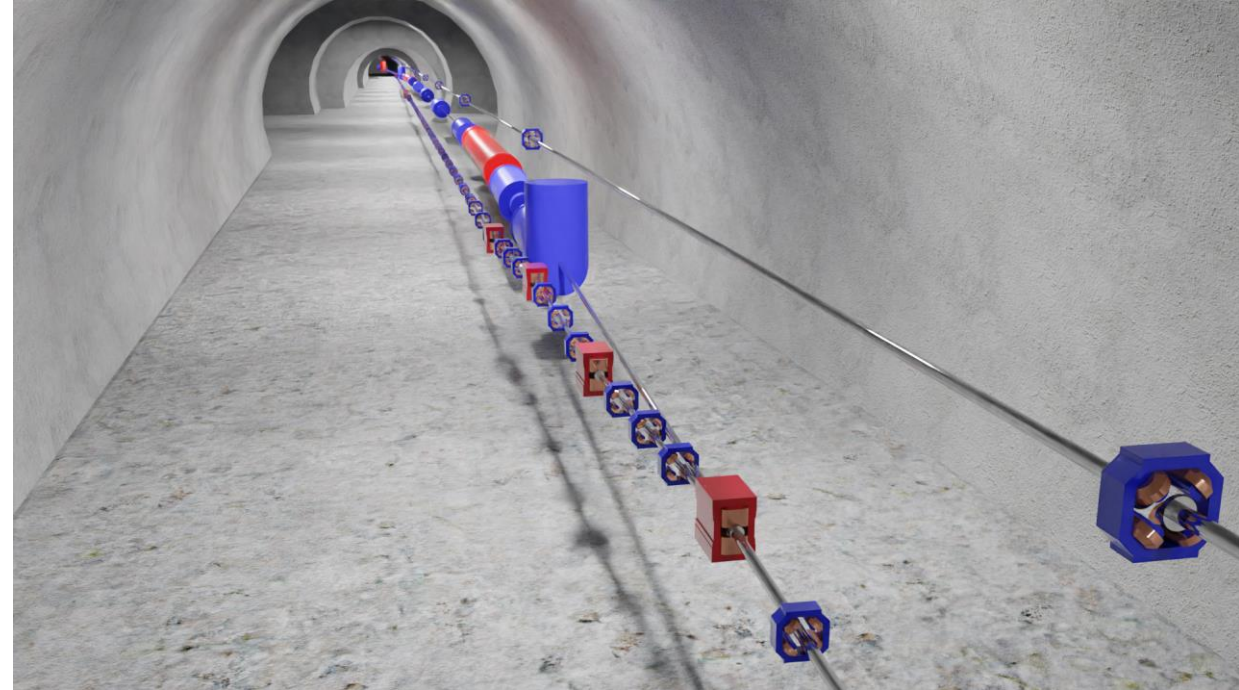


End of Linac, Dump, to Hadrons, Return

# 3D Models and Renders (Blender)



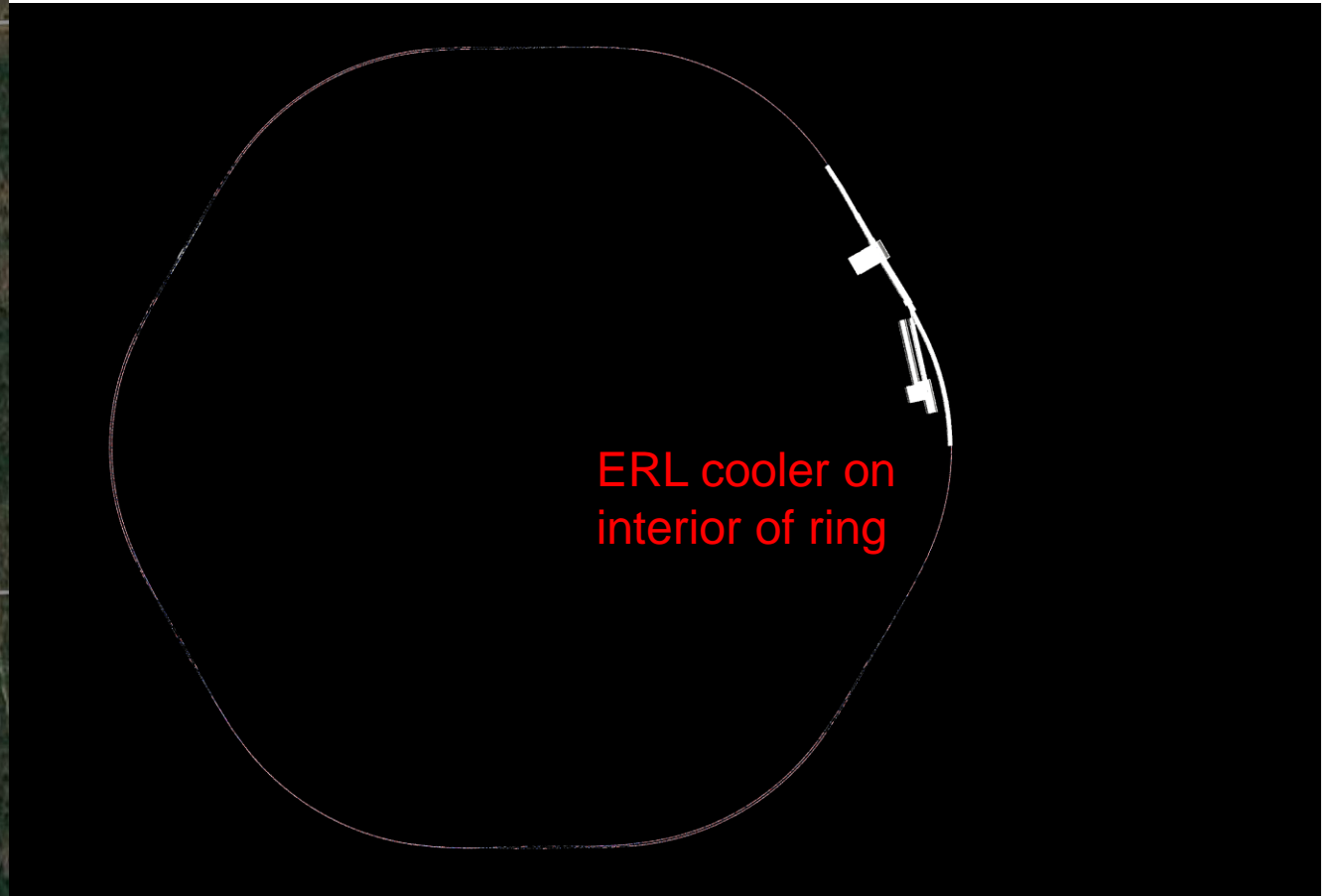
Merge electrons with hadrons into common “Modulator” cooling section.



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



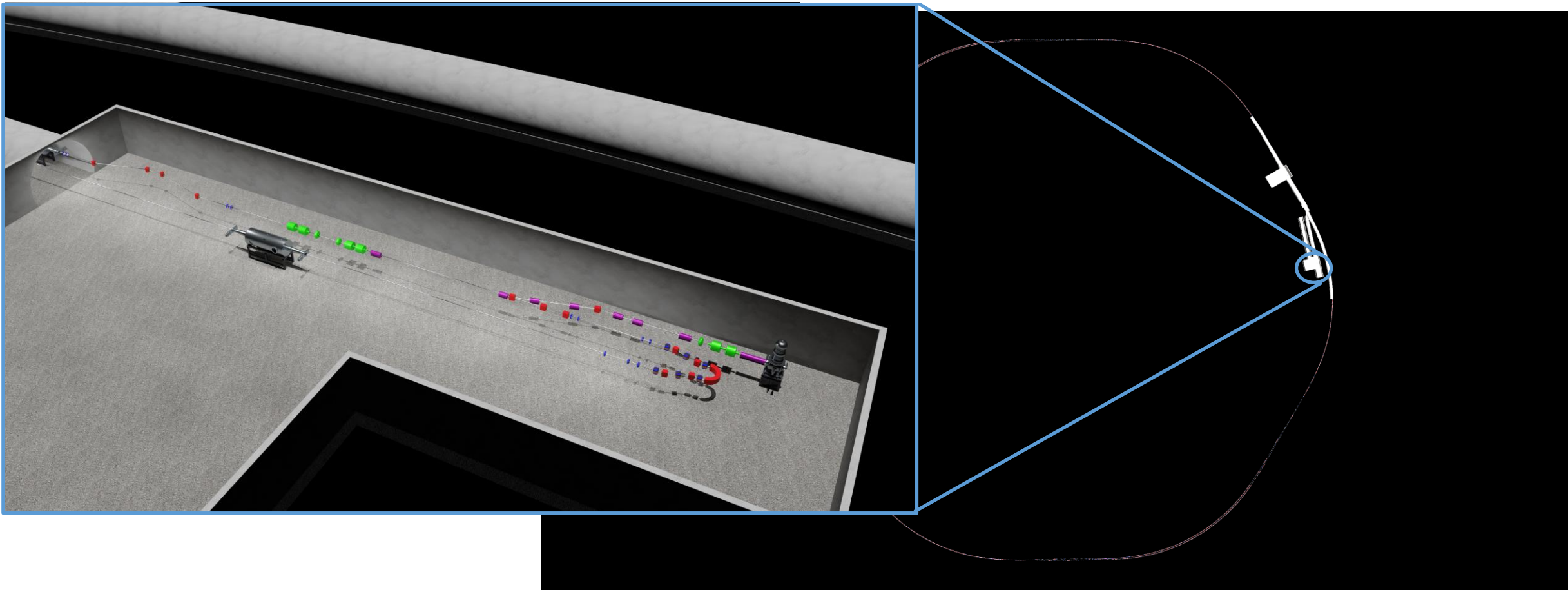
# Updated Layout



Balancing Civil Engineering / Mechanical Design / Accelerator Physics as the project progressed



# Updated Layout







# Visualizations

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

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# Marketing!

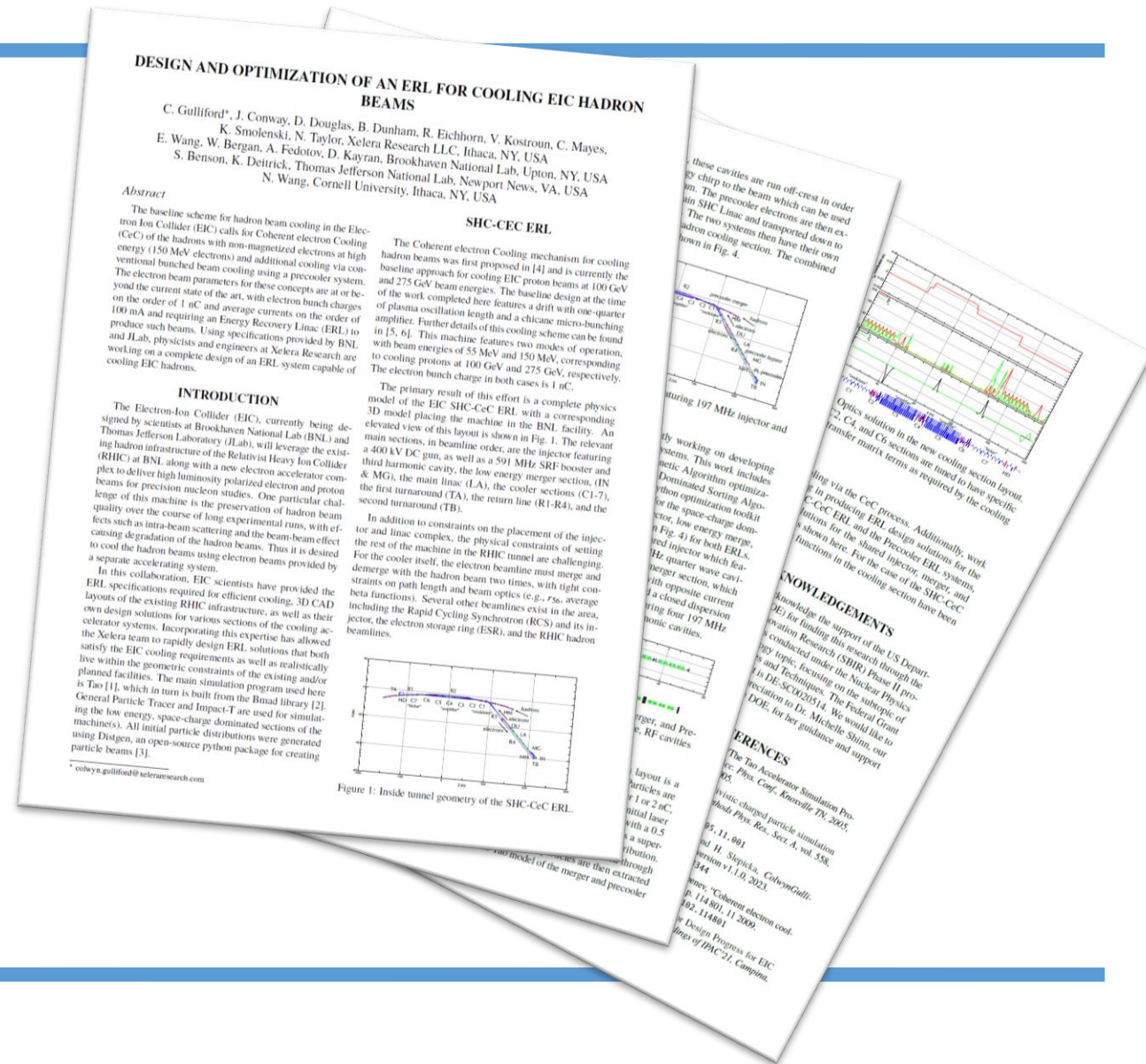
## How do we advertise?

Support of workshops: ICFA ABDW ERL '22

Presentations at ERL '22 and IPA '23

Published a summary paper on the design

Supporting and mentoring graduate students (ODU, Cornell, Cooper Union, etc.)





# Project Success

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## **Following the completion of the SBIR Phase II:**

- Currently on-contract with JLab for remainder of FY 2023, and expectations for another contract for FY 2024 to continue design and development work on EIC Cooler
  - Also on-contract with a leading Silicon Valley startup working on accelerators for semiconductor lithography. Multiple startups are currently working next generation lithography facilities, and we are poised to provide as-needed accelerator expertise (they understand lithography / we understand accelerators)
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# Thank you for your support

- Produced an initial closed lattice for EIC ERL cooler.
  - Used this as the basis for further studies (e.g. tolerances, start-to-end, BBU).
  - Incorporating major changes into the design (precooler and new cooling section design).
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- **Thank you** to Michelle Shinn and the DOE-NP SBIR program
  - Brookhaven, Jefferson Lab, and Cornell collaborators

