E338 (PAX) Progress in FY24 and plans for FY25

FACET-II PAC Meeting

SLAC National Accelerator Laboratory

November 19th, 2024

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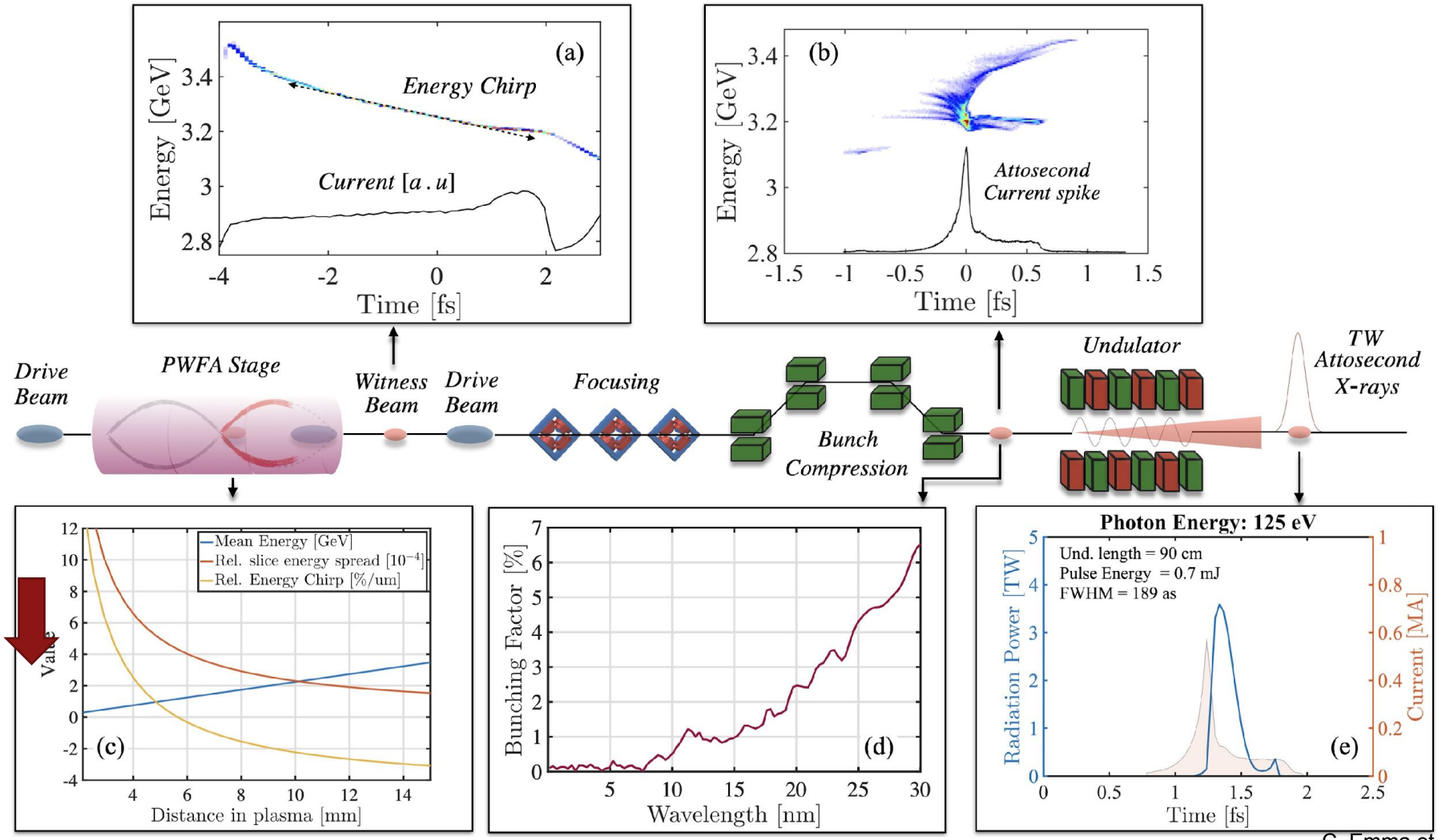
FACET-II

SLAC NATIONAL ACCELERATOR LABORATORY

Stanford University | U.S. DEPARTMENT OF ENERGY

PAX concept: a Plasma-driven Attosecond X-ray Source

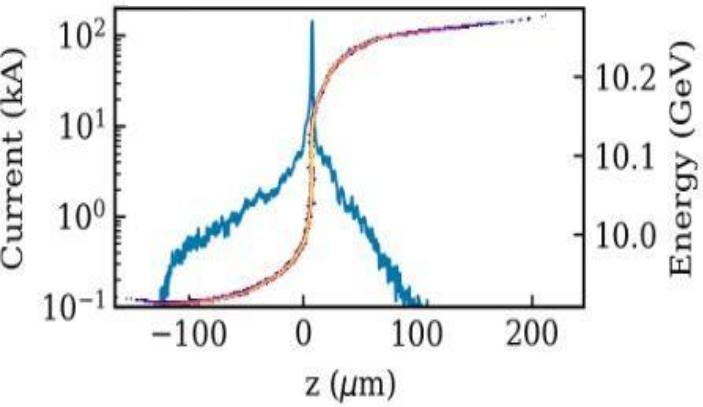


C. Emma et al., APL Photonics, **6**, 076107 (2021)

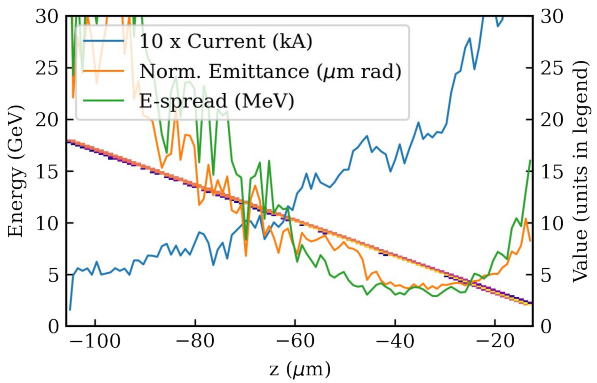
E338 Experimental goals at FACET-II

Science Goals
1. Demonstrate post-plasma sub-fs compression of e- beam
2. Measure + characterize XUV CSR for compressed e- beam down to 100 nm
3. Using plasma-injector, compress + measure coherent XUV at 50 nm

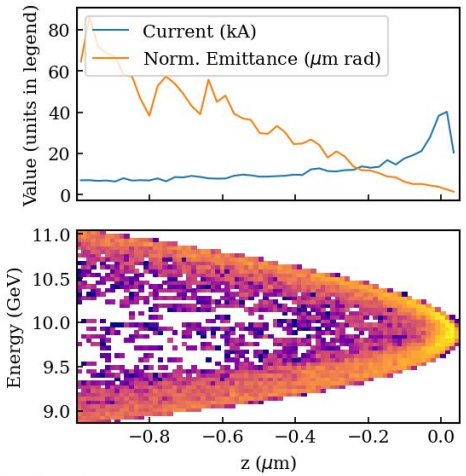
Before Plasma

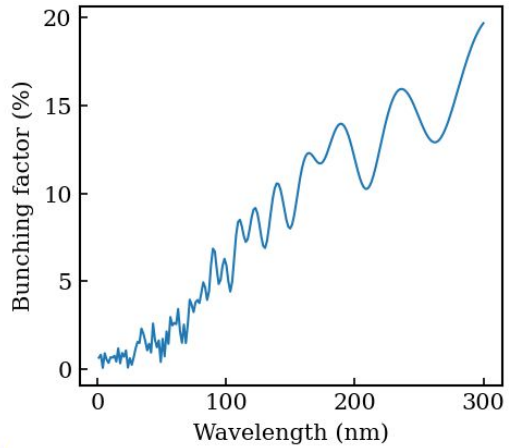


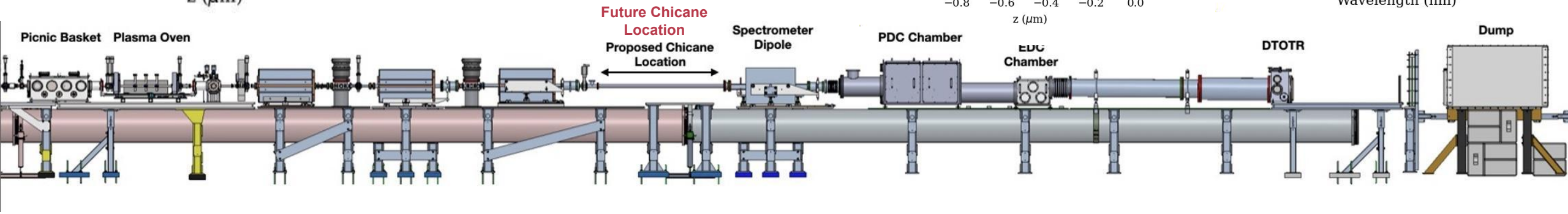
After Plasma



After Chicane



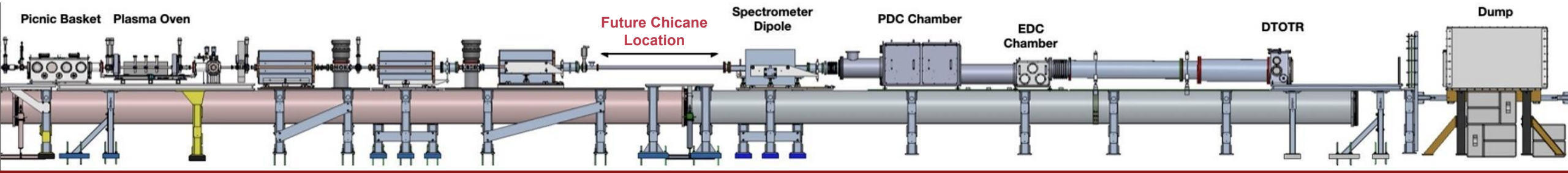




E338 Overview of experimental installation/diagnostics

Plasma Sources

- Gas Jet
  ne = 1e18 – 1e20
  cm^-3
- Li Oven
  ne = 1e16 cm^-3
- Static fill



Radiation setup detects broadband spectral content to map bunching factor of fully-compressed e-beam

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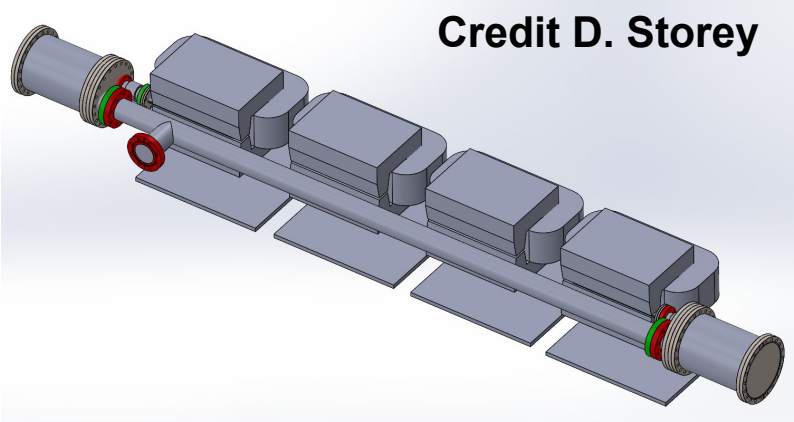
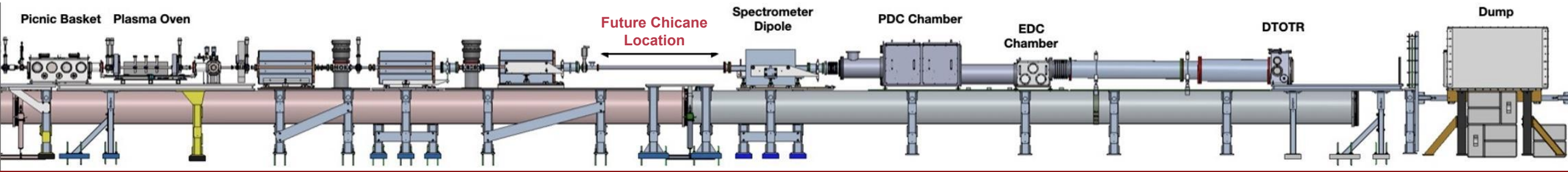
Chicane + bypass line design





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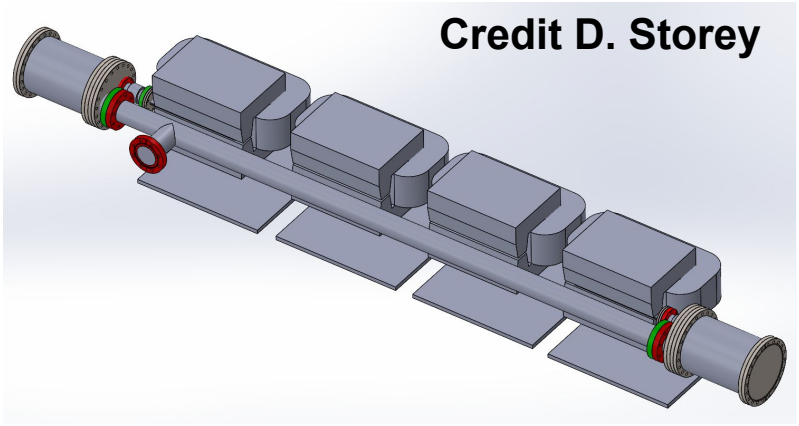
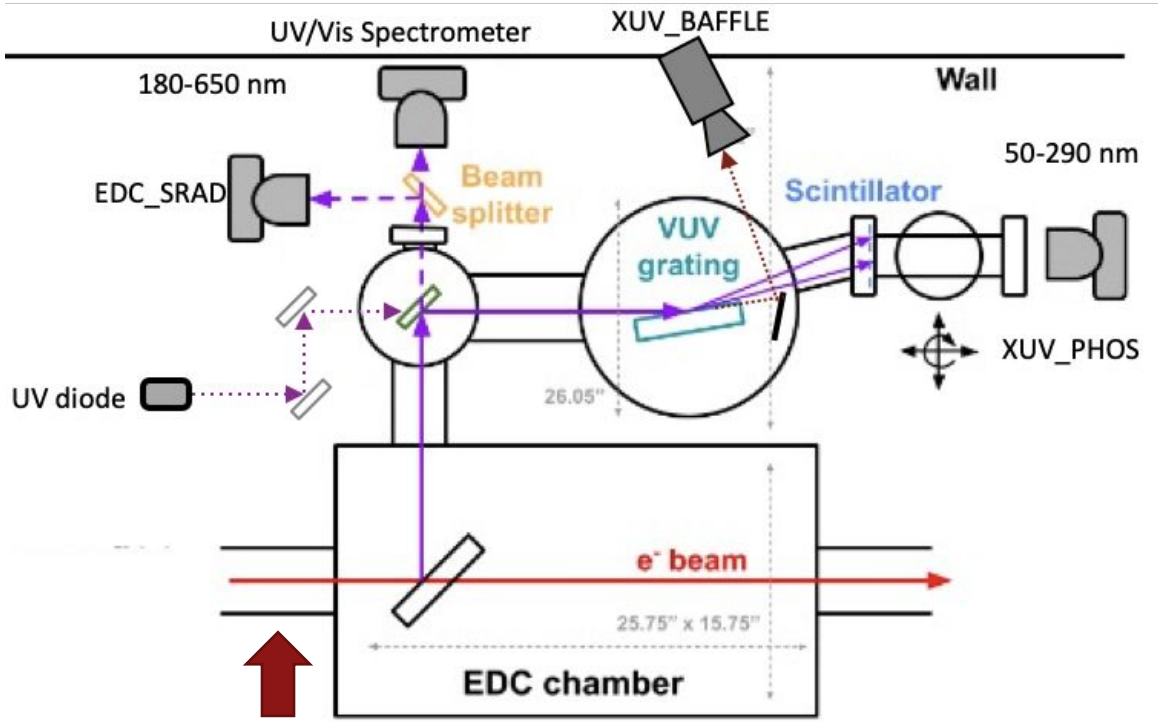
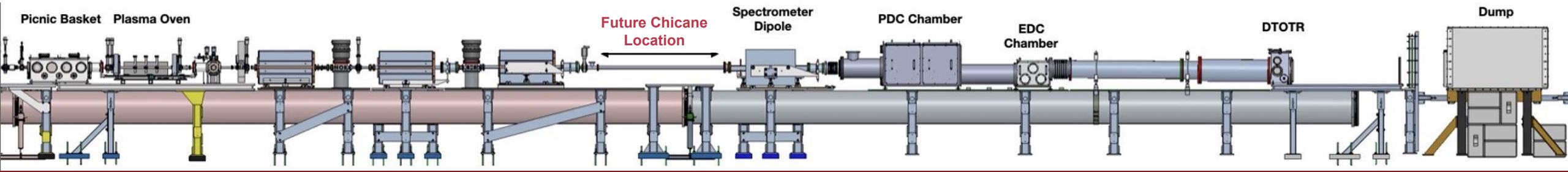


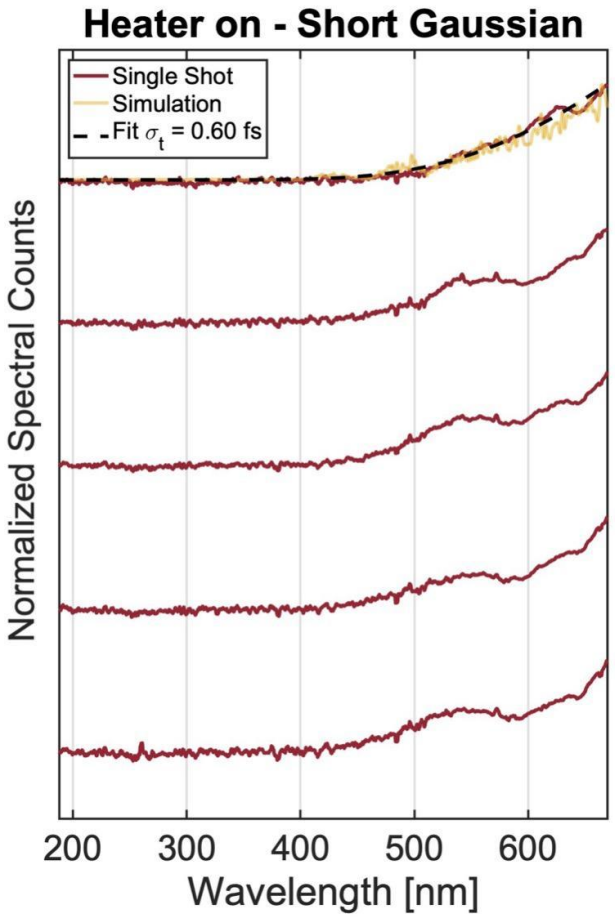
Spectral Measurement Setup

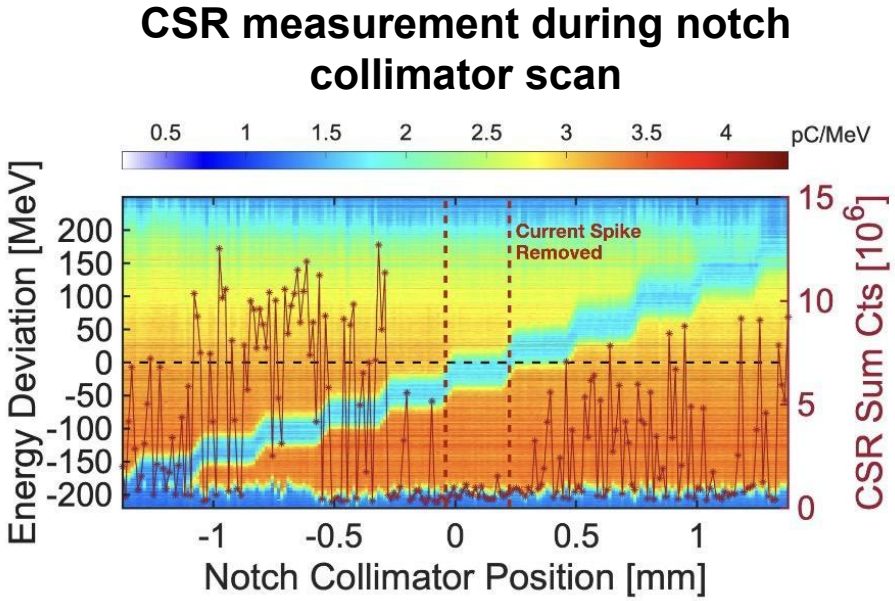


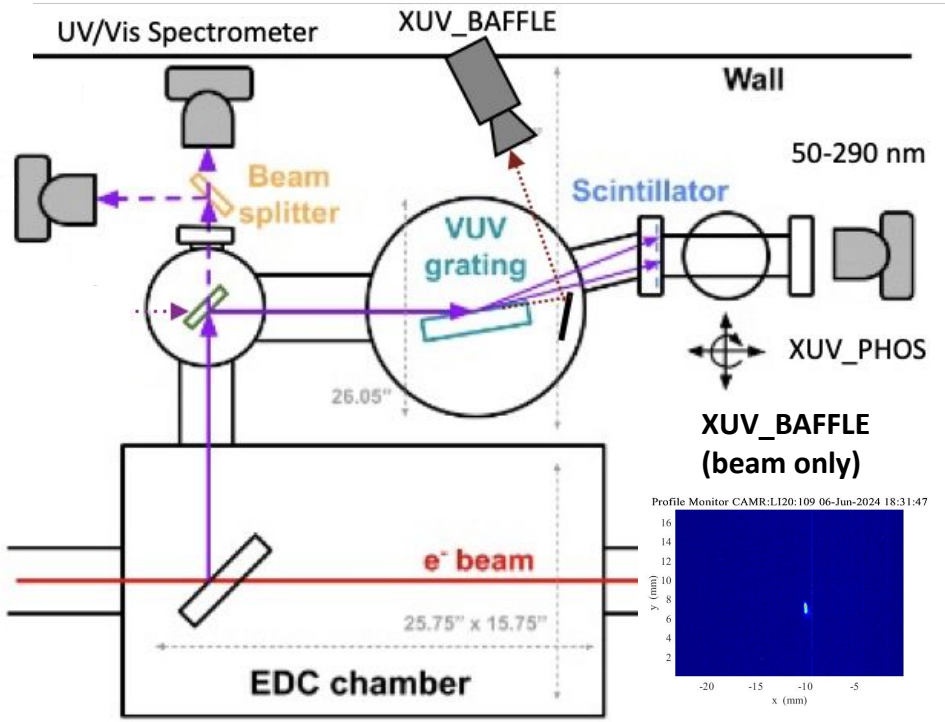


Radiation setup detects broadband spectral content to map bunching factor of fully-compressed e-beam

E338 Diagnostics commissioning progress







- Spectral and CSR diagnostics used to characterize laser heater shaped high current beams.
- UV-Vis spectra measured in good agreement with simulated beam profiles.

Radiation setup used to measure fs current spikes from laser heater shaping

E338 Diagnostics: XUV signal

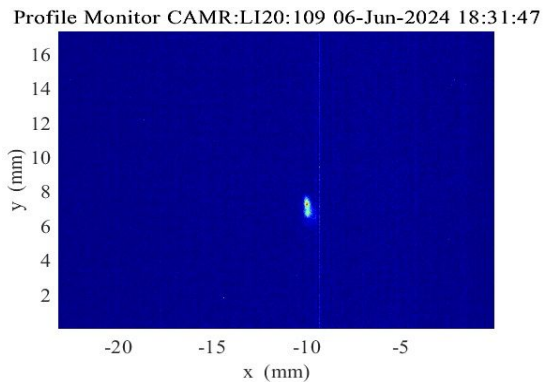
(1) XUV spectrometer calibrated, aligned and tested with UV diode

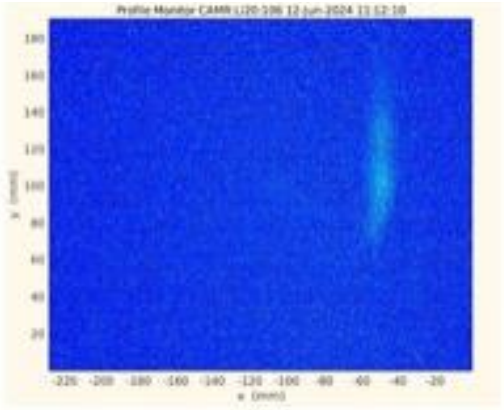
(2) No signal from e-beam observed on XUV spectrometer yet, likely due to lack of e-beam bunching

(3) Risk mitigation strategies

- Increase collection efficiency from YAG screen to camera (fiber optic tapers, move camera directly in front of YAG screen)
- Direct XUV detection (Andor XUV/x-ray camera)

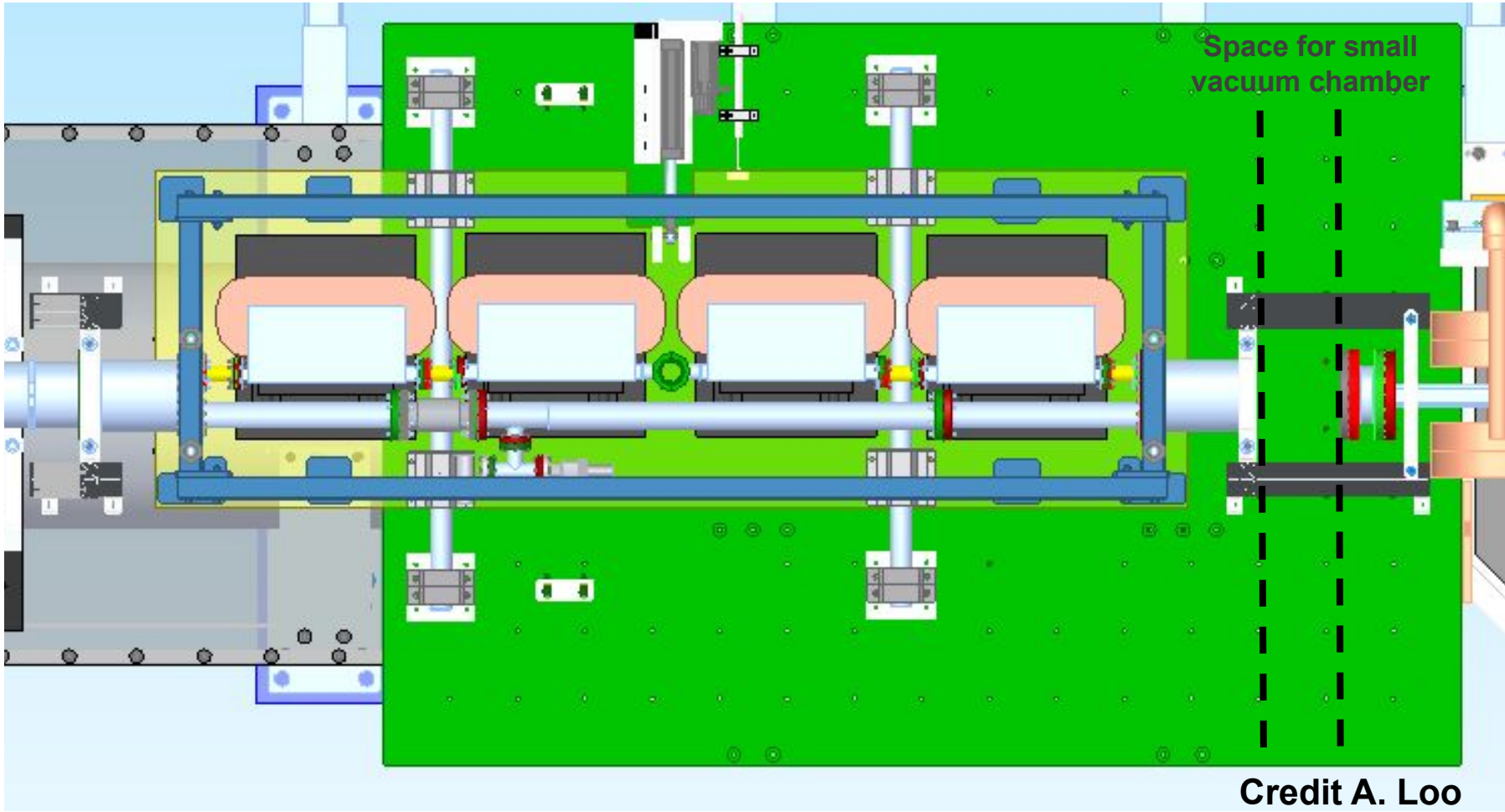
XUV_BAFFLE
(beam only)





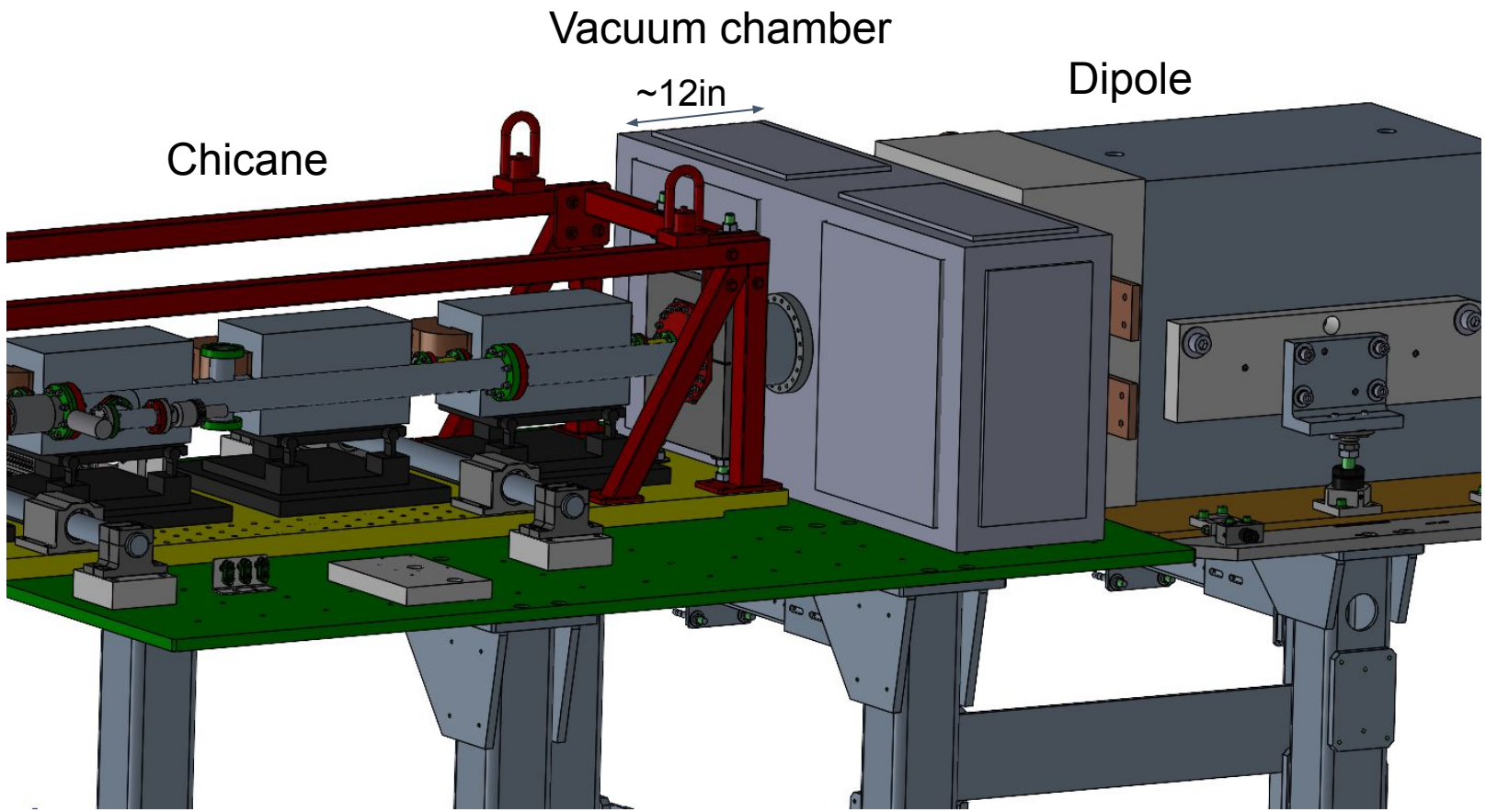
E338 Chicane + bypass line design

- Chicane + bypass line engineering design completed
- Chicane sits on a mover table remotely insertable in beamline
- R_{56} < 150 umat 10 GeV
- Space for small interaction chamber downstream before dump dipole.
- Magnets + bypass line ordered, expected 03/2025, installation summer 2025



Chicane will be available for experiments starting Fall 2025

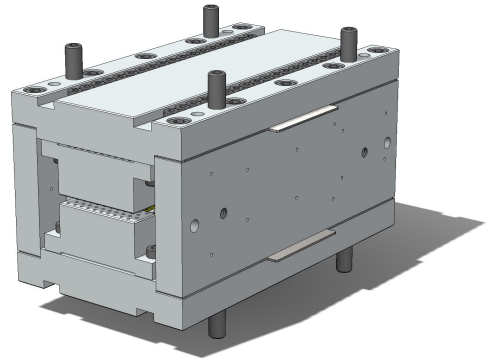
Post-chicane chamber



Chamber can support:

- Gas jets
- Solid targets
- OTR screens
- Undulators
- Others?

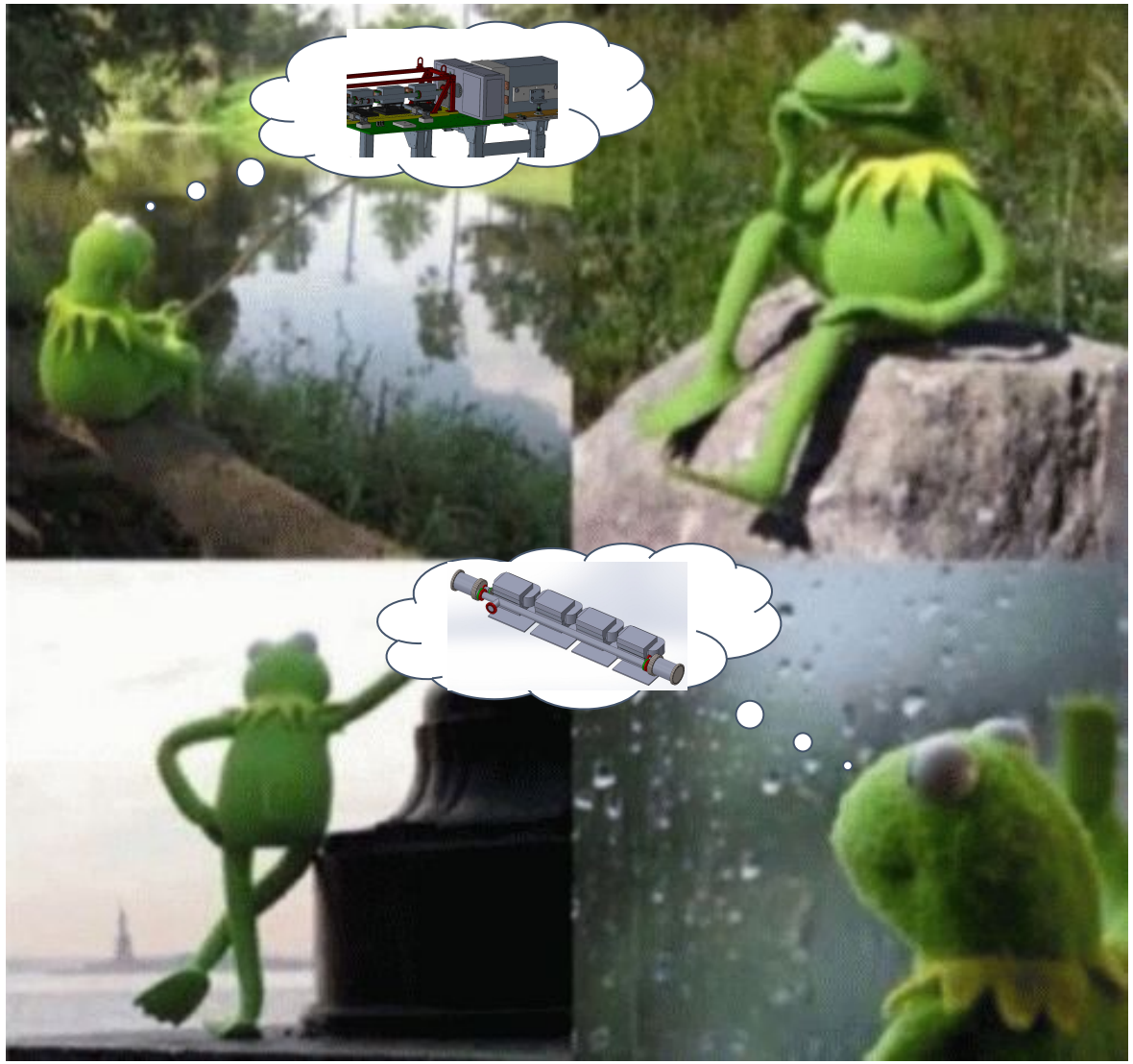
Compact undulator



Stakeholders consulted during design process

Post-chicane chamber will be available for experiments with or without compressed beams

Experimental plans FY25



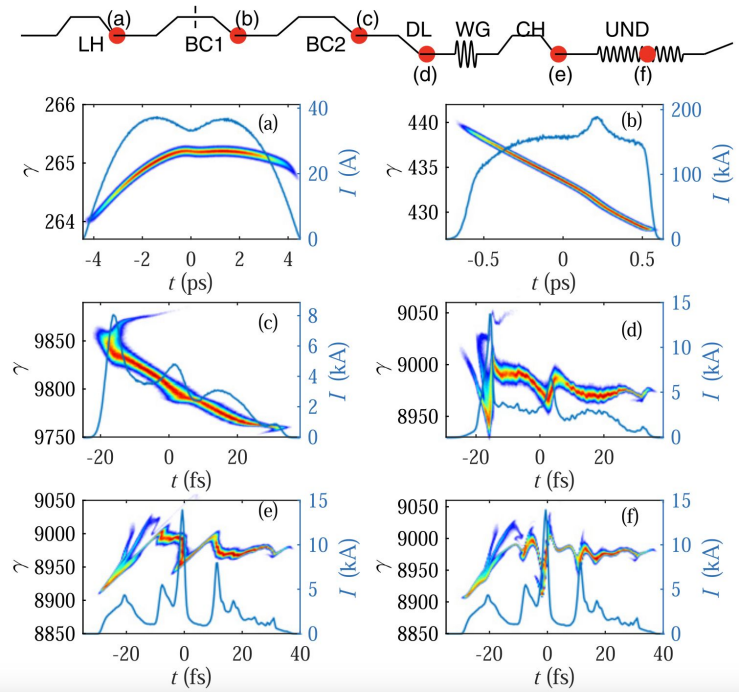
Experimental plans FY25

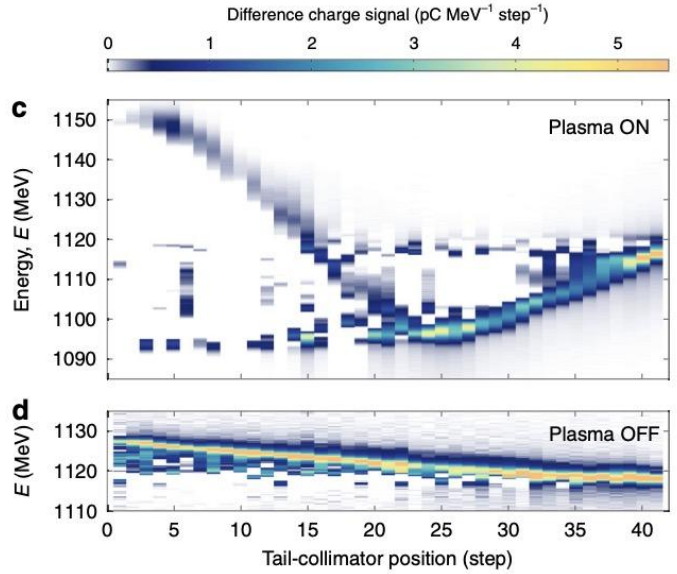
Beam time requests before chicane:

- Tomographic measurement of energy chirp (collaboration with E-300)
  see e.g. https://d-nb.info/1224296974/34

- Cathode shaping to make sub-fs spikes

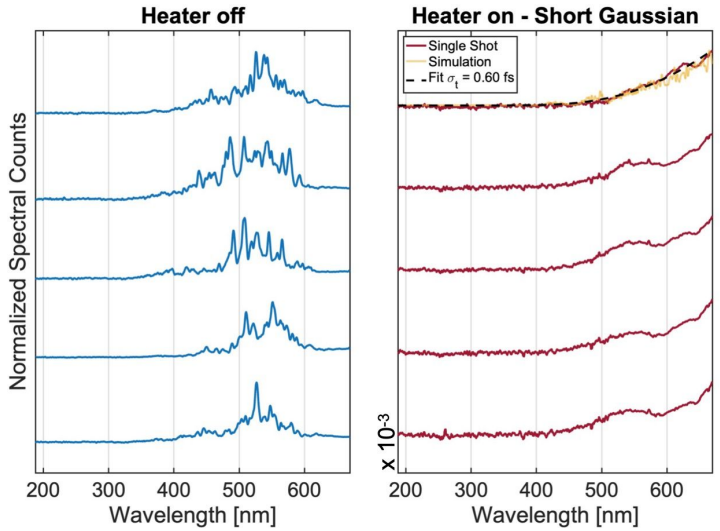
Zhang, Zhen, et al *New journal of physics* 22.8 (2020): 083030.





S. Schroder, et al *Nature Comm.* (2020) 5984 (2020)

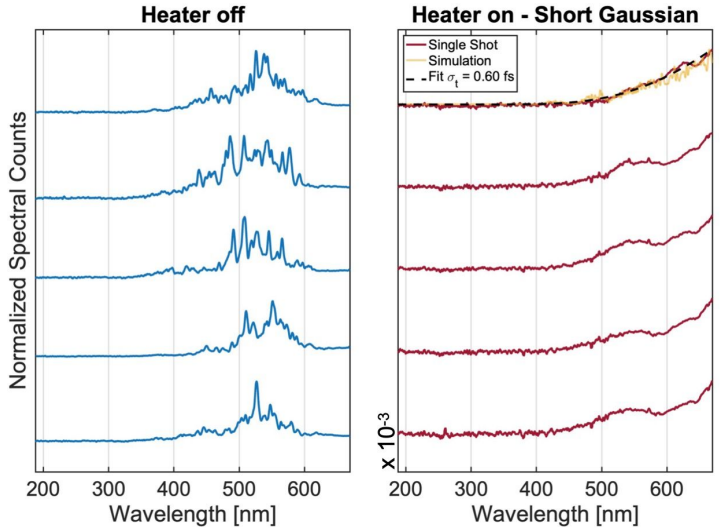
Towards time-domain experiments

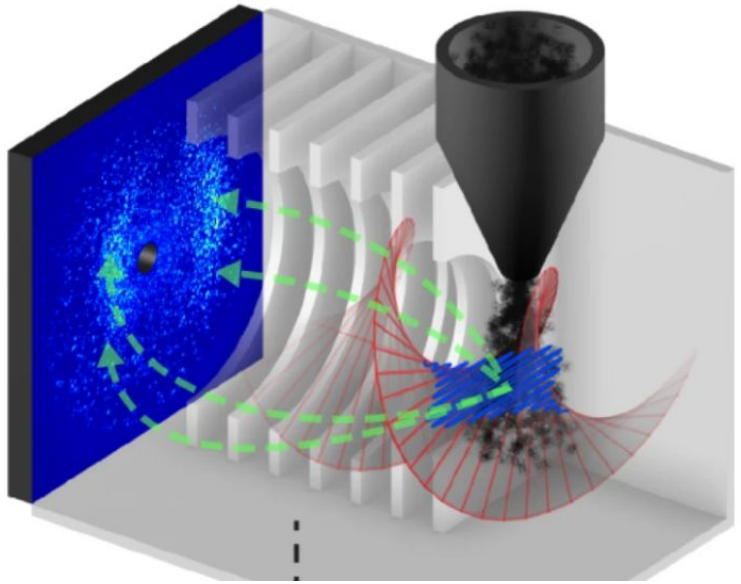


Spectral measurement:

- qualitative information (single spike vs amplification of shot-noise)
- time-domain information is model-dependent

Towards time-domain experiments





Spectral measurement:

- qualitative information (single spike vs amplification of shot-noise)
- time-domain information is model-dependent

Time-domain measurements using photoelectron streaking:

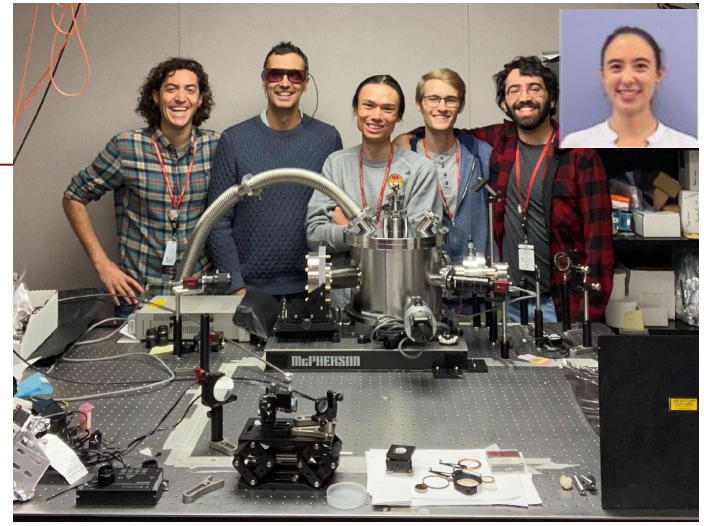
- direct time-domain information (correlate time/angle or time/energy)
- angular streaking using external laser
- synchronized experiments using beam-generated radiation (can be linear streaking)

Summary

- Path towards single/few cycle soft x-ray pulses.
- Staged demonstration experiment is underway at FACET-II.
  - plasma compression of FACET e-beam ~ 100 nm bunching (CSR)
  - compression of plasma-generated e-beam < 50 nm (CSR)
- Radiation diagnostics installed in tunnel and commissioned.
- Long term vision is to outline a path forward dedicated to plasma-driven attosecond science experiments.

PAX is moving steadily from concept to experimental realization

Acknowledgments



Collaborators

- **SLAC**: R. Hessami, K. Larsen, R. Robles, K. Swanson, C. Emma, A. Marinelli, FACET-II AARD & Beam Physics groups
- **UCLA**: A. Fisher, P. Musumeci, C. Zhang, C. Joshi, K. Marsh
- **Experimental Collaboration with:** E-300, E-304, E310

Funding Sources

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Thank you for your attention

Backup Slides

(E338) Shifts since last PAC

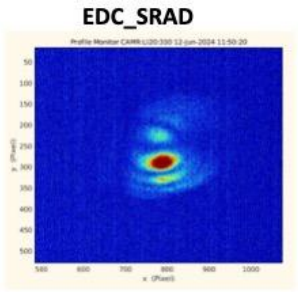
Beam time: 2 shifts + parasitic time

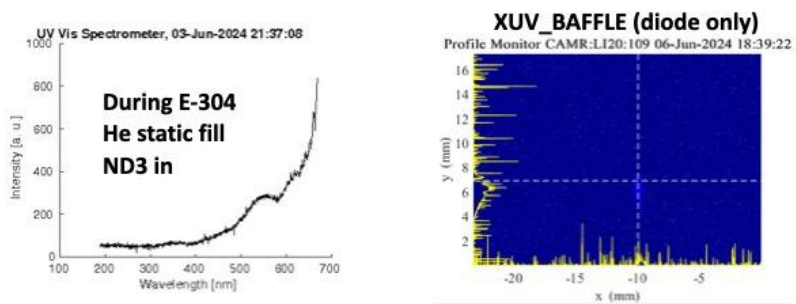
What worked

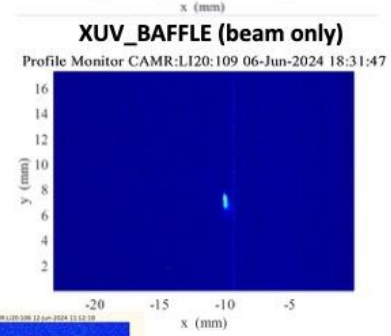
- Installed all radiation diagnostics in the tunnel. Commissioned UV-Vis spectrometer + remote alignment of XUV spec.
- UV-vis spec has been useful for e.g. E300 He wakes, E304, LH shaping
- Chicane PO awarded, timeline for delivery ~9 months expected installation summer 2025

What we can improve

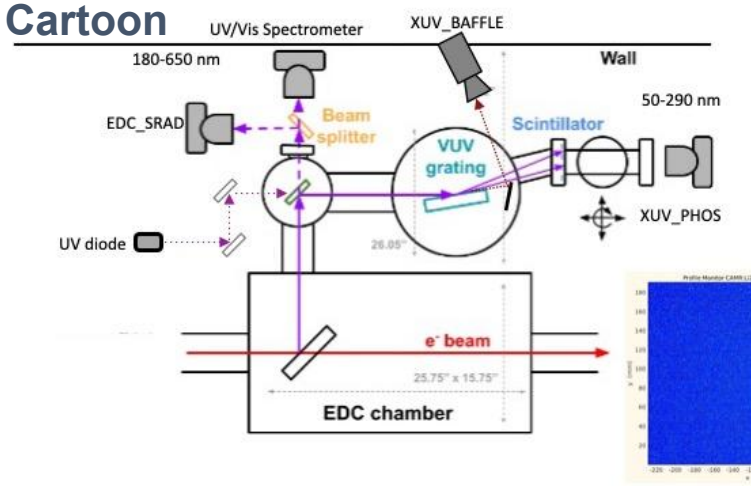
- UV-vis spectrometer timestamping with DAQ
- Increase spectral range of UV-Vis spectrometer (190-1090nm spectrometer purchased)
- No 50-290 nm radiation seen (yet) on XUV spectrometer

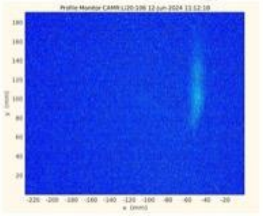






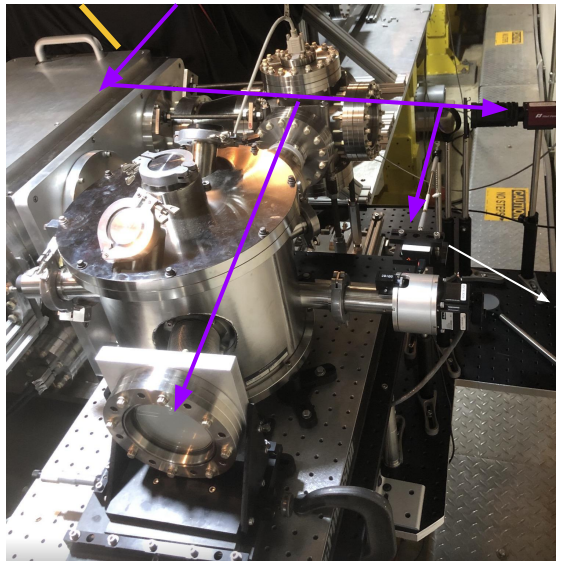
Cartoon



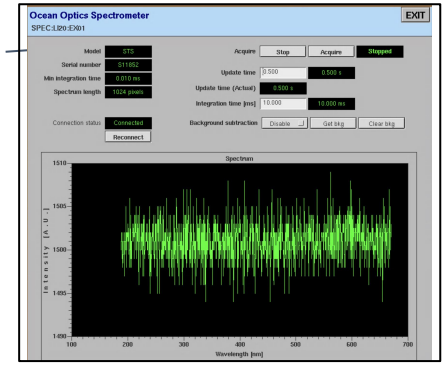


XUV_PHOS (diode only)

As built

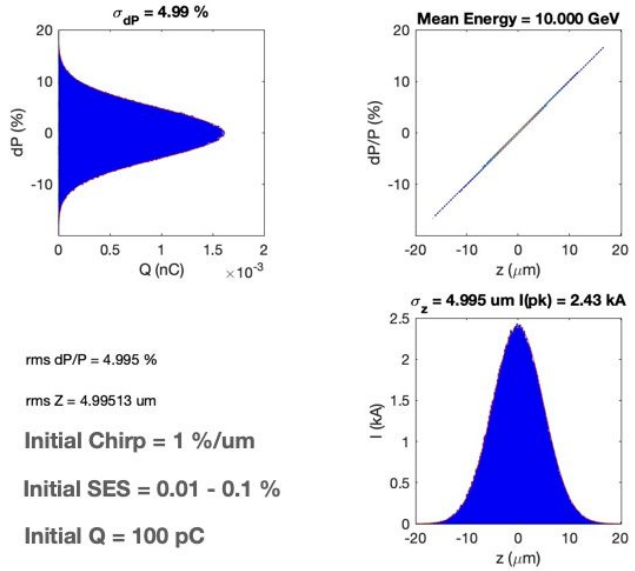


UV-Vis spectrometer GUI



PAX first E300-like experiments: tolerances to beam emittance and SES

LPS at exit of plasma



rms dP/P = 4.995 %

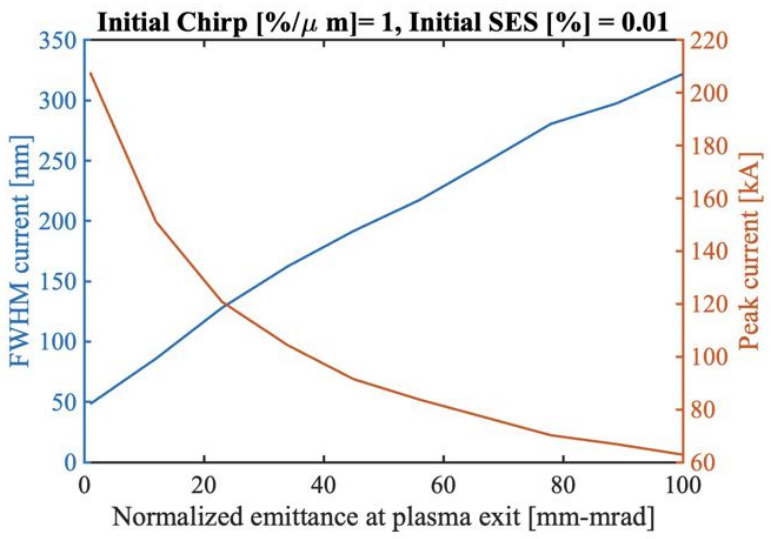
rms Z = 4.99513 um

Initial Chirp = 1 %/um

Initial SES = 0.01 - 0.1 %

Initial Q = 100 pC

Output beam parameters after chicane



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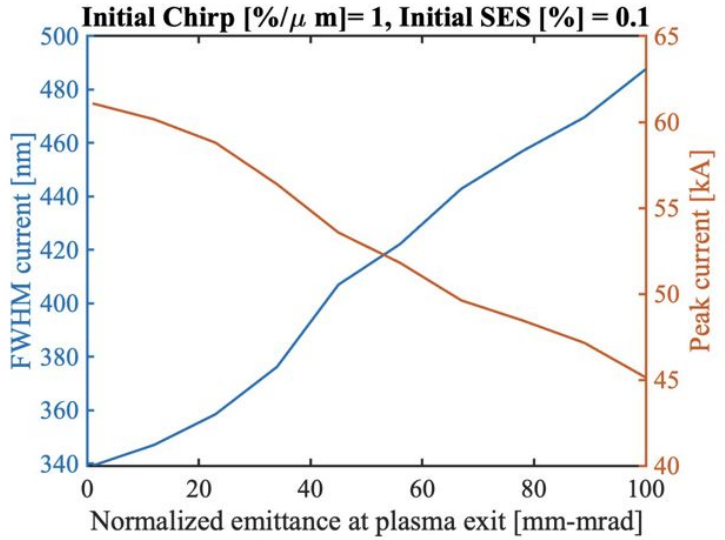
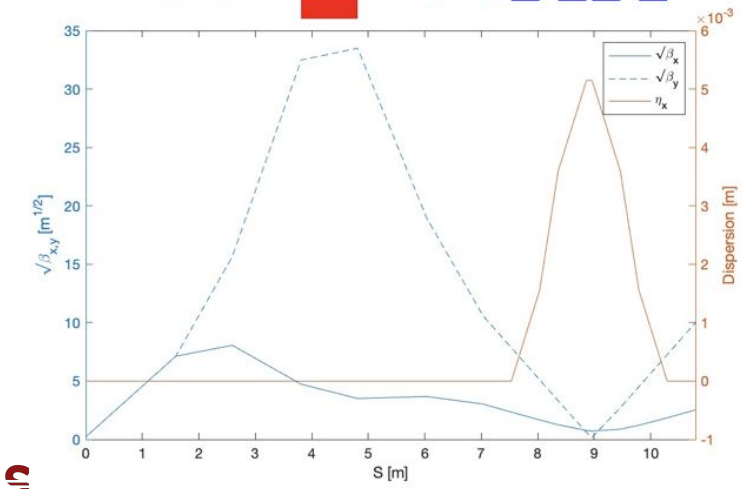
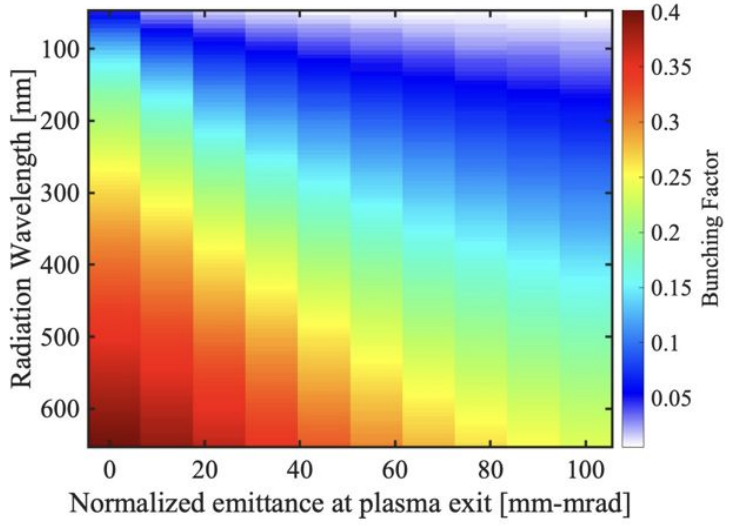
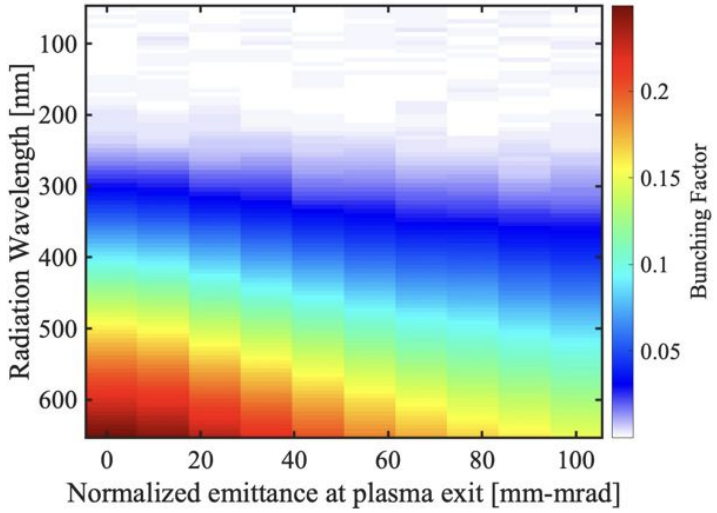


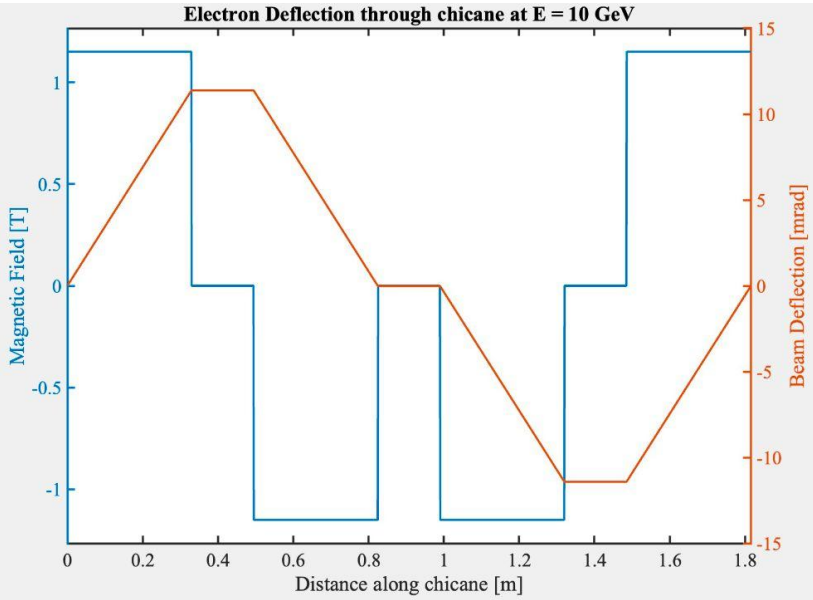
Focusing triplet and post-plasma chicane

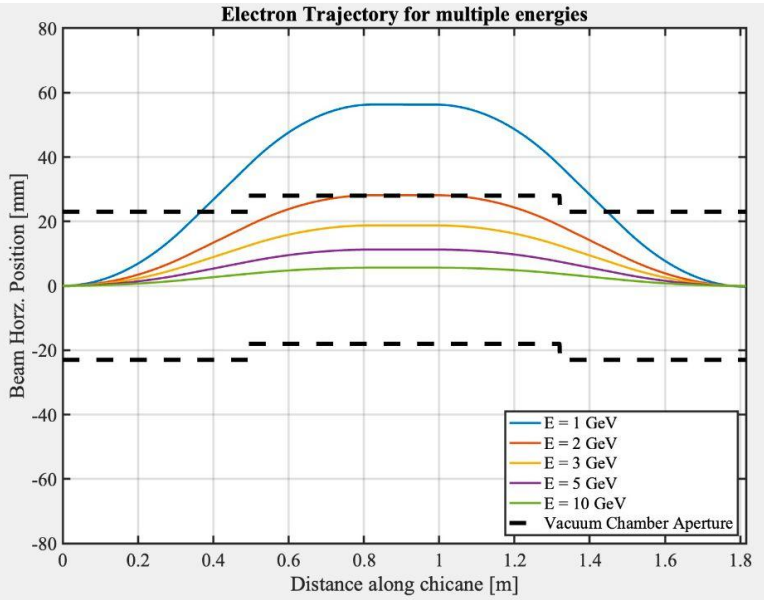




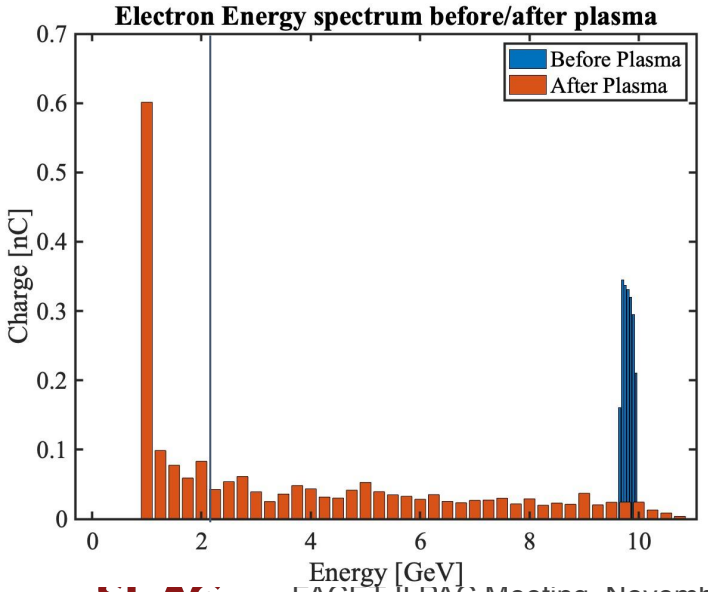


Chicane electron deflection and trajectories at design R56 = 100 um





Parameter	Design Value	Unit
Electron Beam Energy	10	GeV
Momentum Compaction R_{56}	100	um
Bend Length	33	cm
Drift Length between bends	16.5	cm
Total length (bellows-to-bellows)	2.15	m
Max Bend Angle	11.27	mrad
Max single bend integrated field strength	0.38	T.m
Peak Magnetic Field Strength	1.15	T
Max beam deflection	6.10	mm



- Low energy electrons (<2 GeV) lost in chicane vacuum chamber.
- Discussions with Radiation Physics group at SLAC underway to determine shielding requirements.
- Shielding will be installed to mitigate adverse effects to downstream systems.