E338 (PAX) Progress in FY25

FACET-II PWFA Collaboration meeting

SLAC National Accelerator Laboratory

July 24th, 2025

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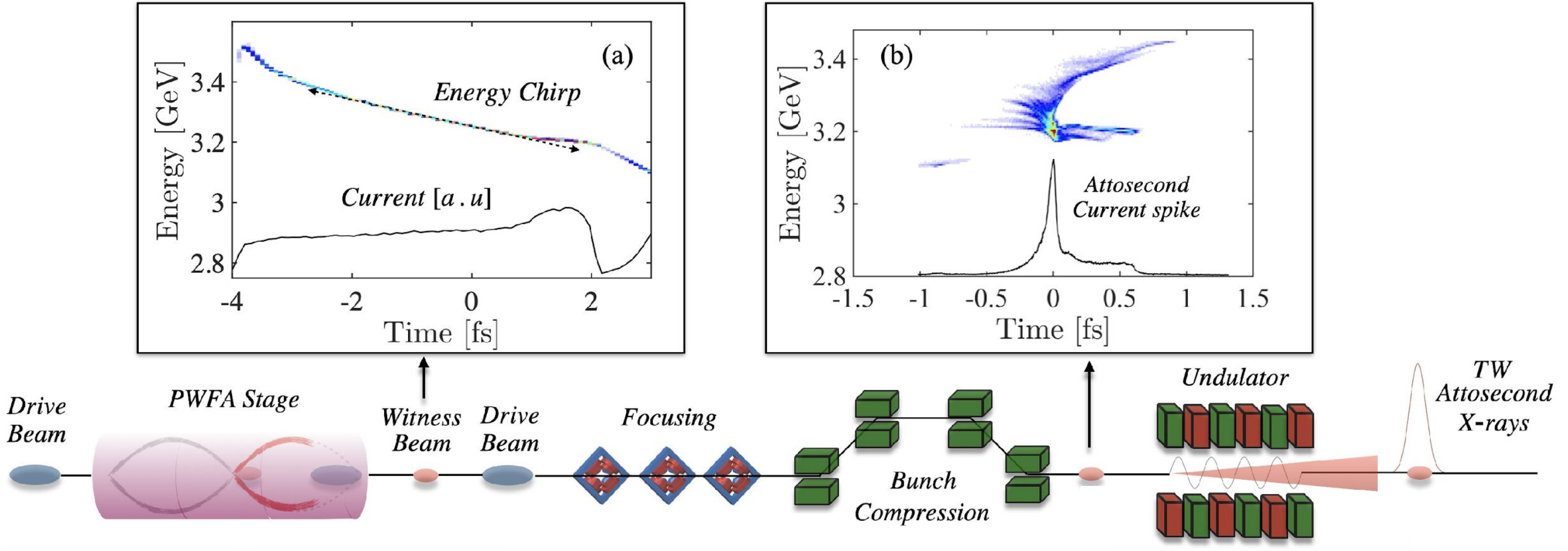
FACET-II

SLAC NATIONAL ACCELERATOR LABORATORY

Stanford University | U.S. DEPARTMENT OF ENERGY

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



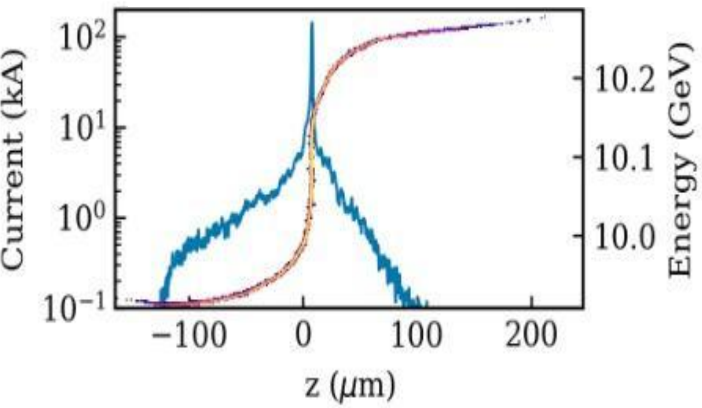
C. Emma et al., APL Photonics, **6**, 076107 (2021)

Large chirp, small slice energy spread make PWFA beams ideal for post-compression & coherent emission

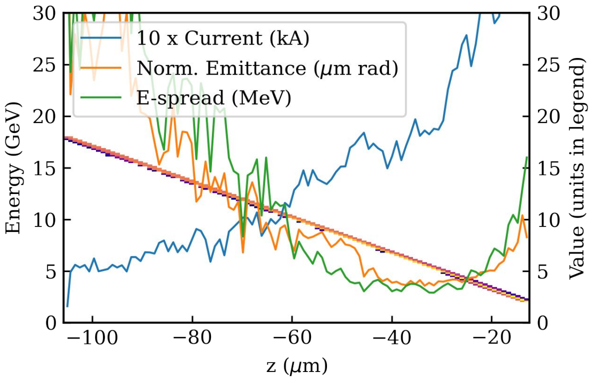
E338 Experimental goals at FACET-II

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 down to 50 nm

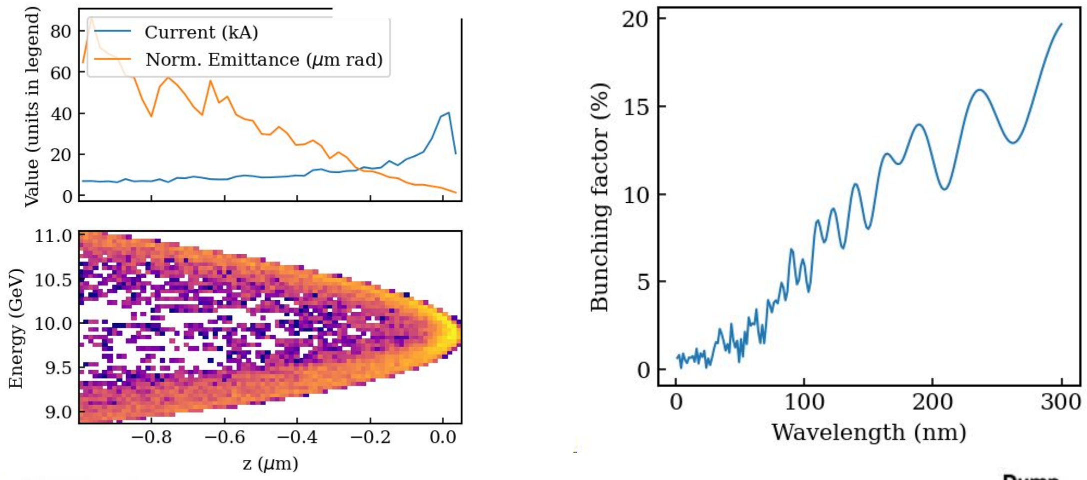
Before Plasma

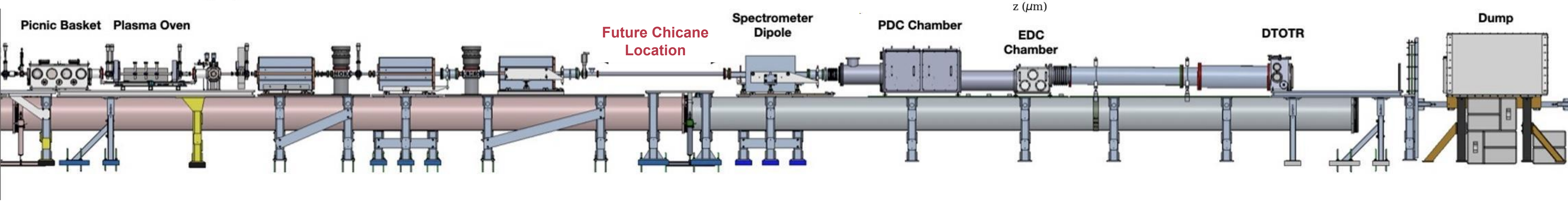


After Plasma



After Chicane





E338 Overview of experimental setup and diagnostics

Plasma Sources

- Gas Jet

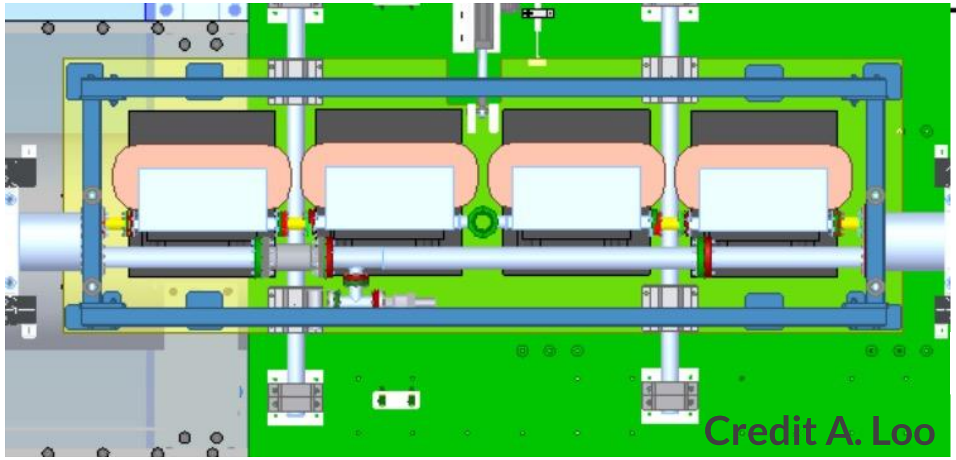
$n_e = 10^{18} - 10^{20}$ cm^{-3}

- Li Oven

ne = $10^{16} - 10^{17}$ cm^{-3}

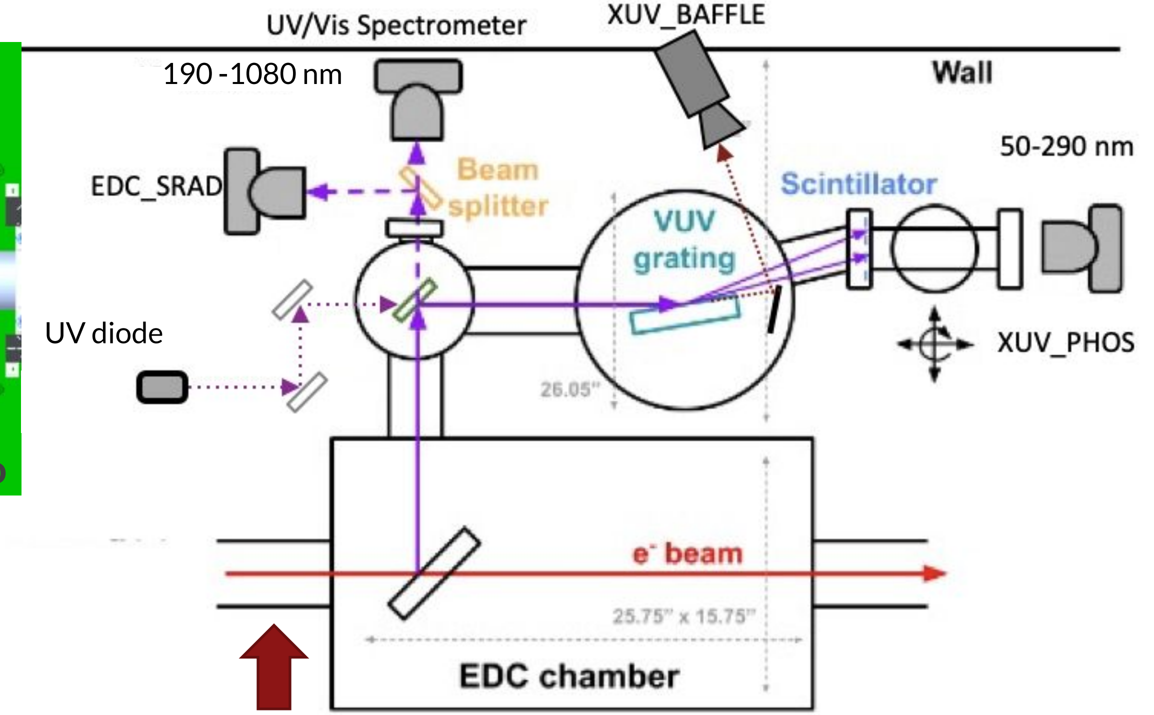
- Static fill

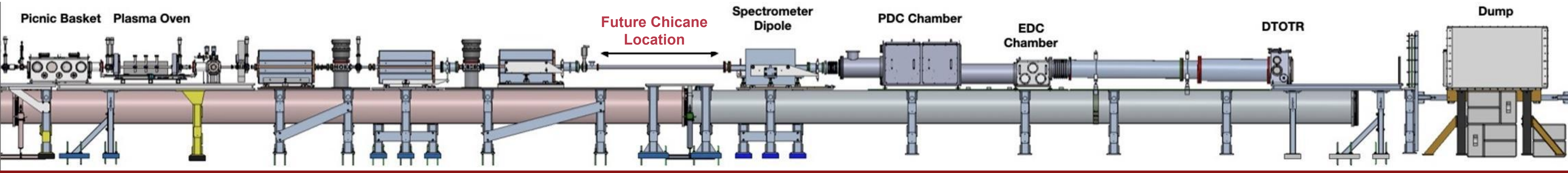
Chicane + bypass line



Spectral Measurement Setup

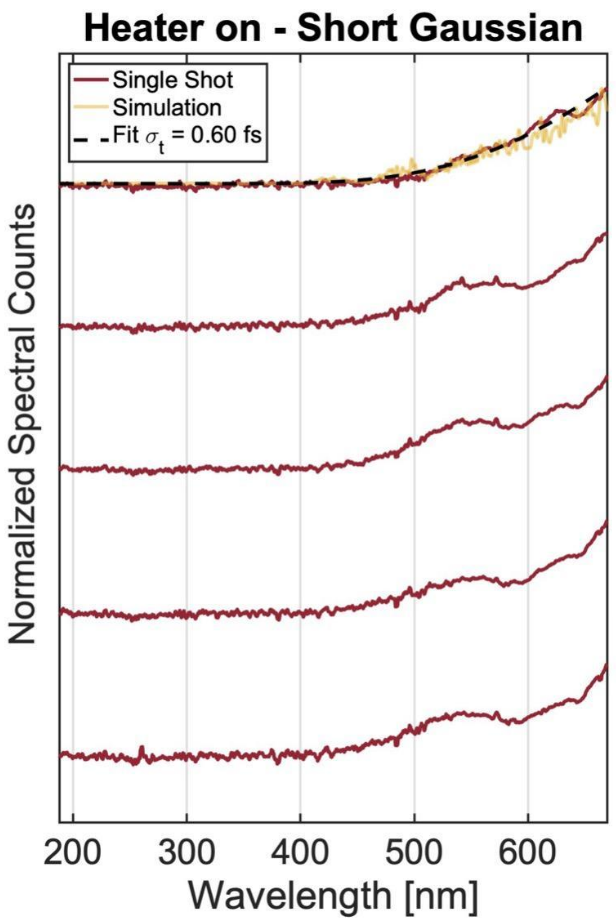
Confluence

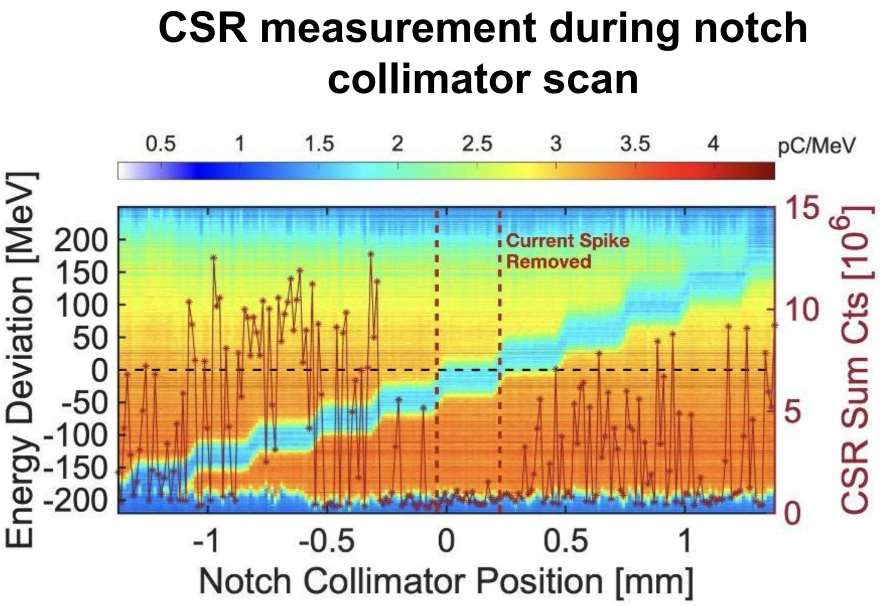


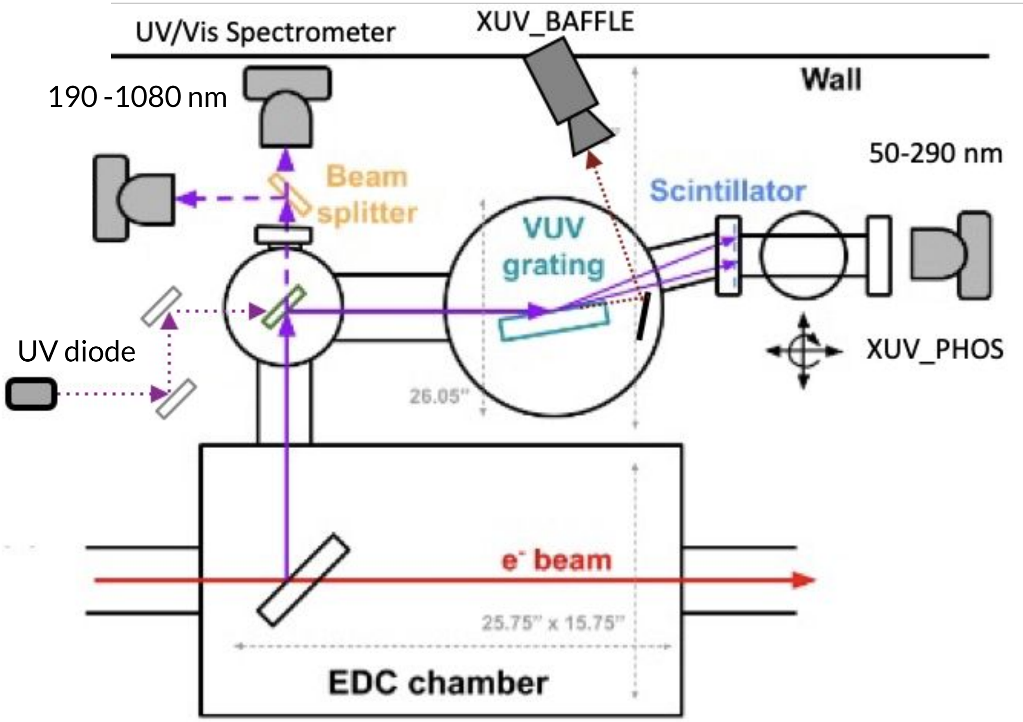


Radiation setup detects broadband spectral content to map bunching factor of fully-compressed e-beam

E338 FY25 Diagnostics commissioning progress







- Spectral 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

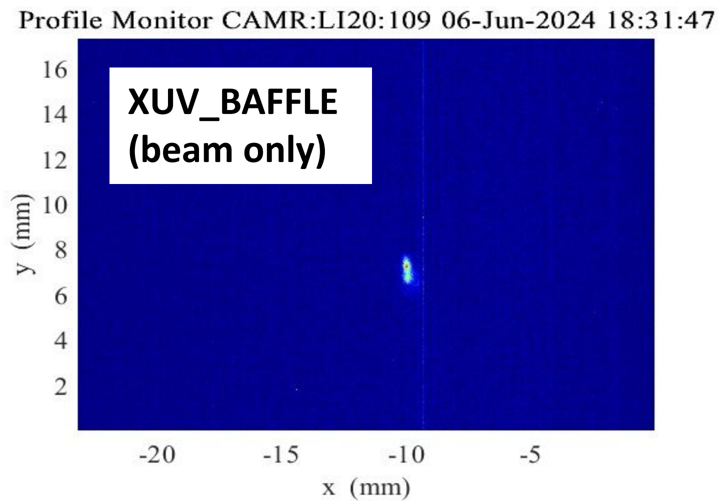
E338 Diagnostics: XUV signal

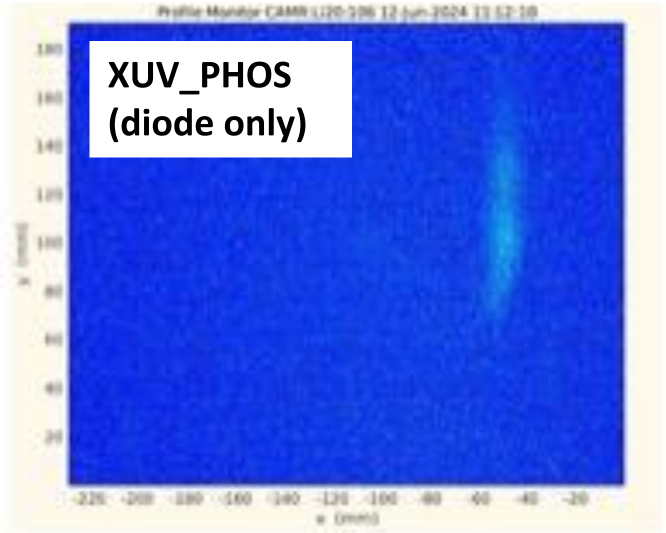
(1) XUV spectrometer calibrated, aligned and tested with UV diode

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

(3) Risk mitigation strategy: increase collection efficiency

- From phosphor screen to camera (fiber optic windows, move camera directly in front of phosphor screen)
    - Expect ~600x increase over current setup
- Direct XUV detection (Andor XUV/x-ray camera)
    - Expect ~1200x increase over current setup

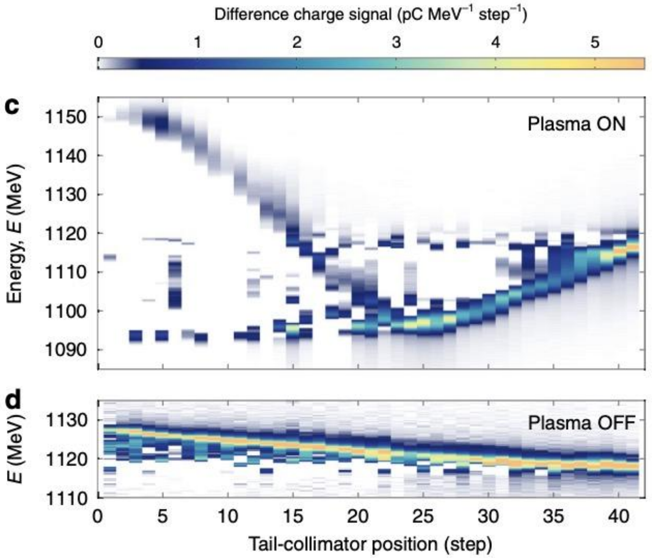




Radiation setup being improved to measure shortest (sub 100 nm) bunches

Experimental shifts in FY25 - Longitudinal Wakefield mapping

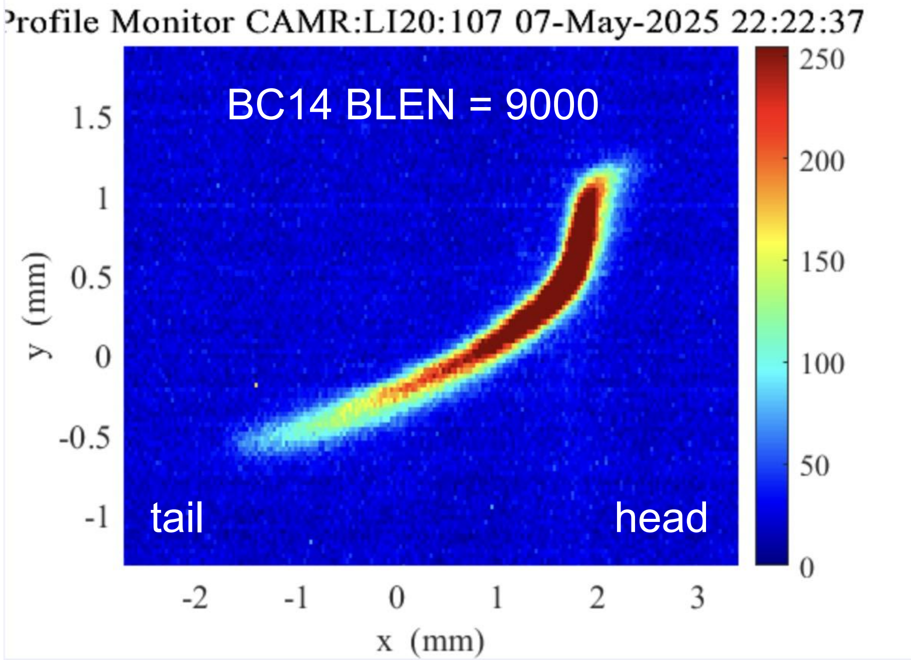
FlashForward



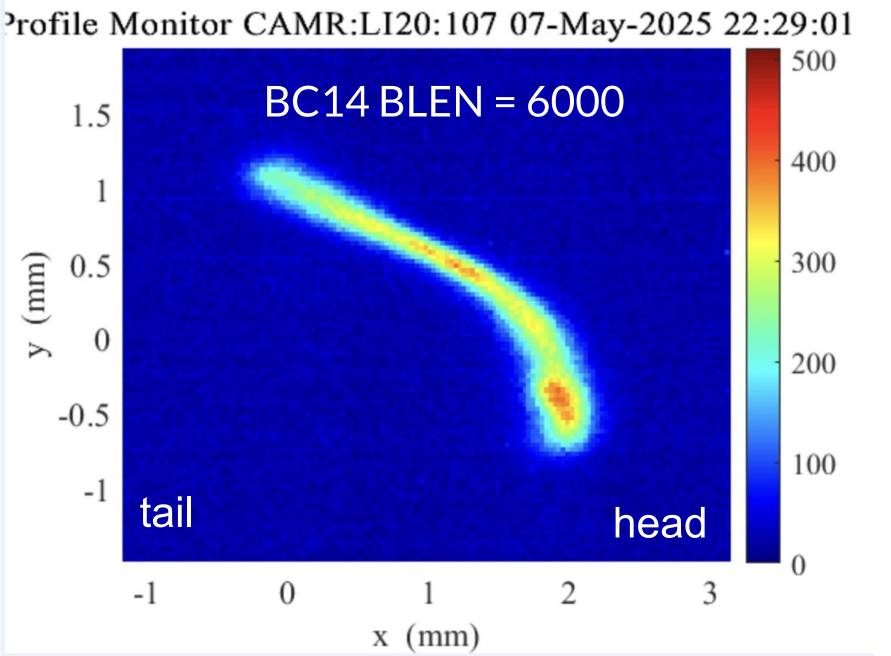
S. Schroder, et al *Nature Comm.* (2020) 5984 (2020)

FACET-II

Under-compressed



Overcompressed



Chose under-compressed working point for wakefield mapping: longer tail, larger drive-witness current ratio, more stable machine.

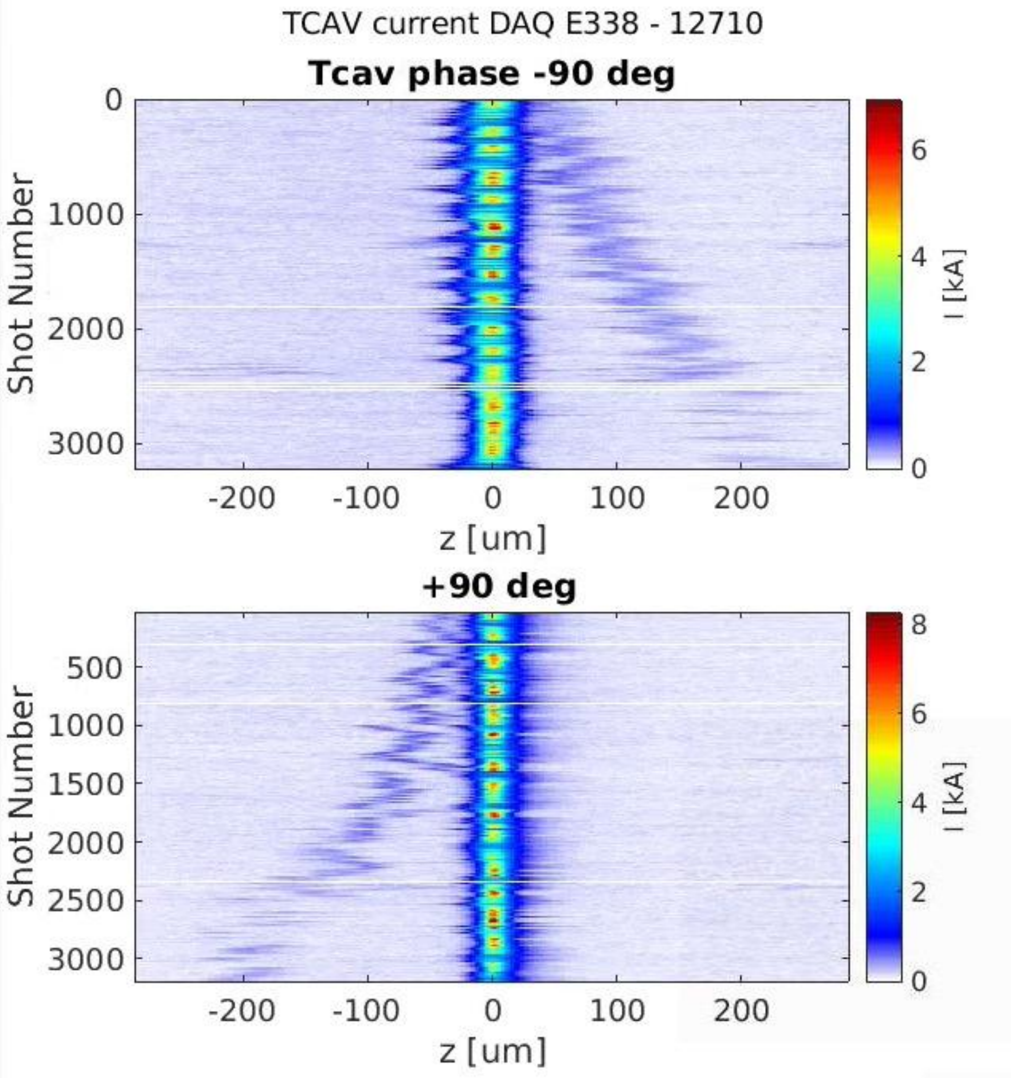
Notched two-bunch configuration optimized for longitudinal wakefield mapping

Notched two-bunch beam characterization with XTCAV

Parameter	Value
Charge (drive, wit)	0.6 nC , 0.1 nC
RMS bunch length (drive,wit)	10-20 um , 10-30 um
Peak current ratio	5-10
Separation *	50 - 200 um

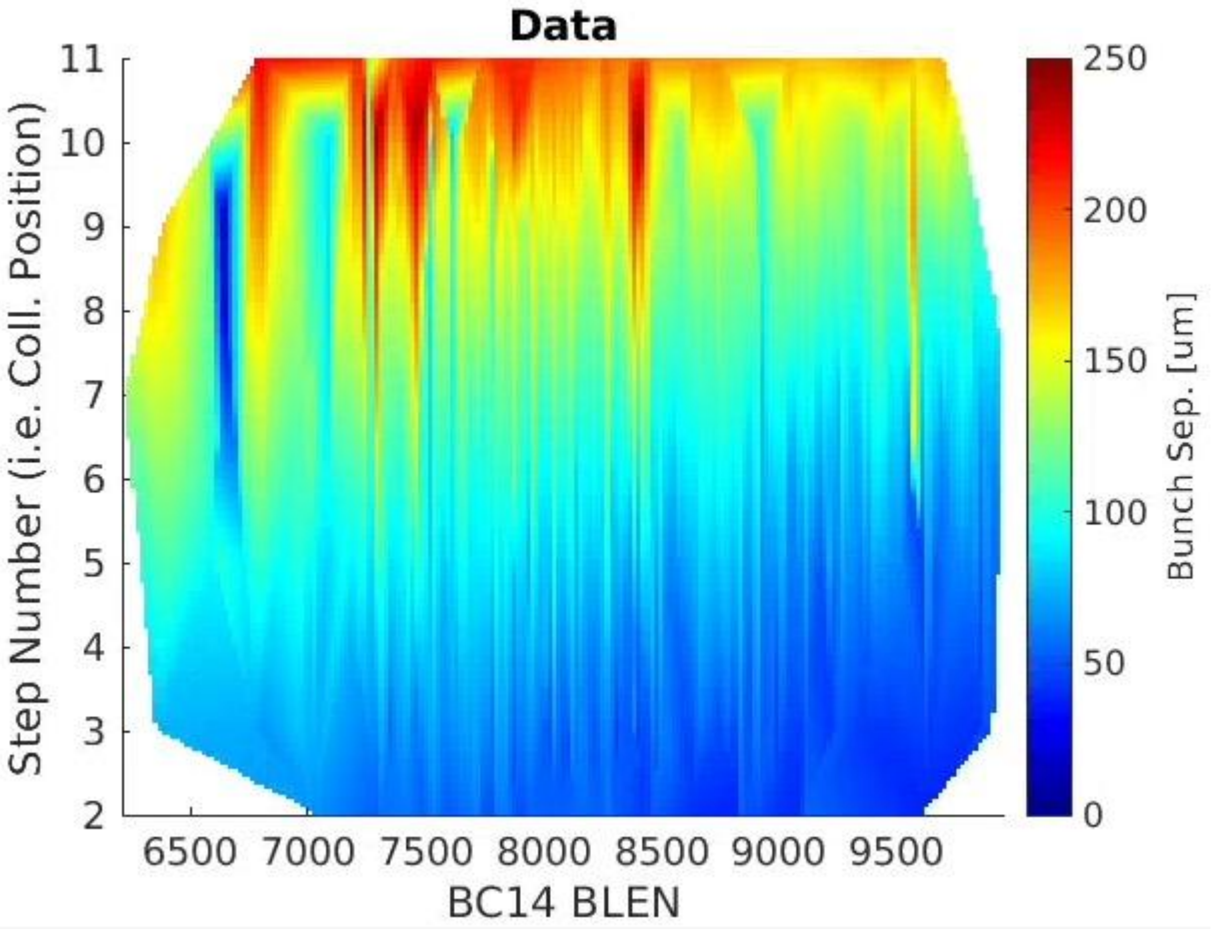
* Assumes 1167 um/deg TCAV calibration

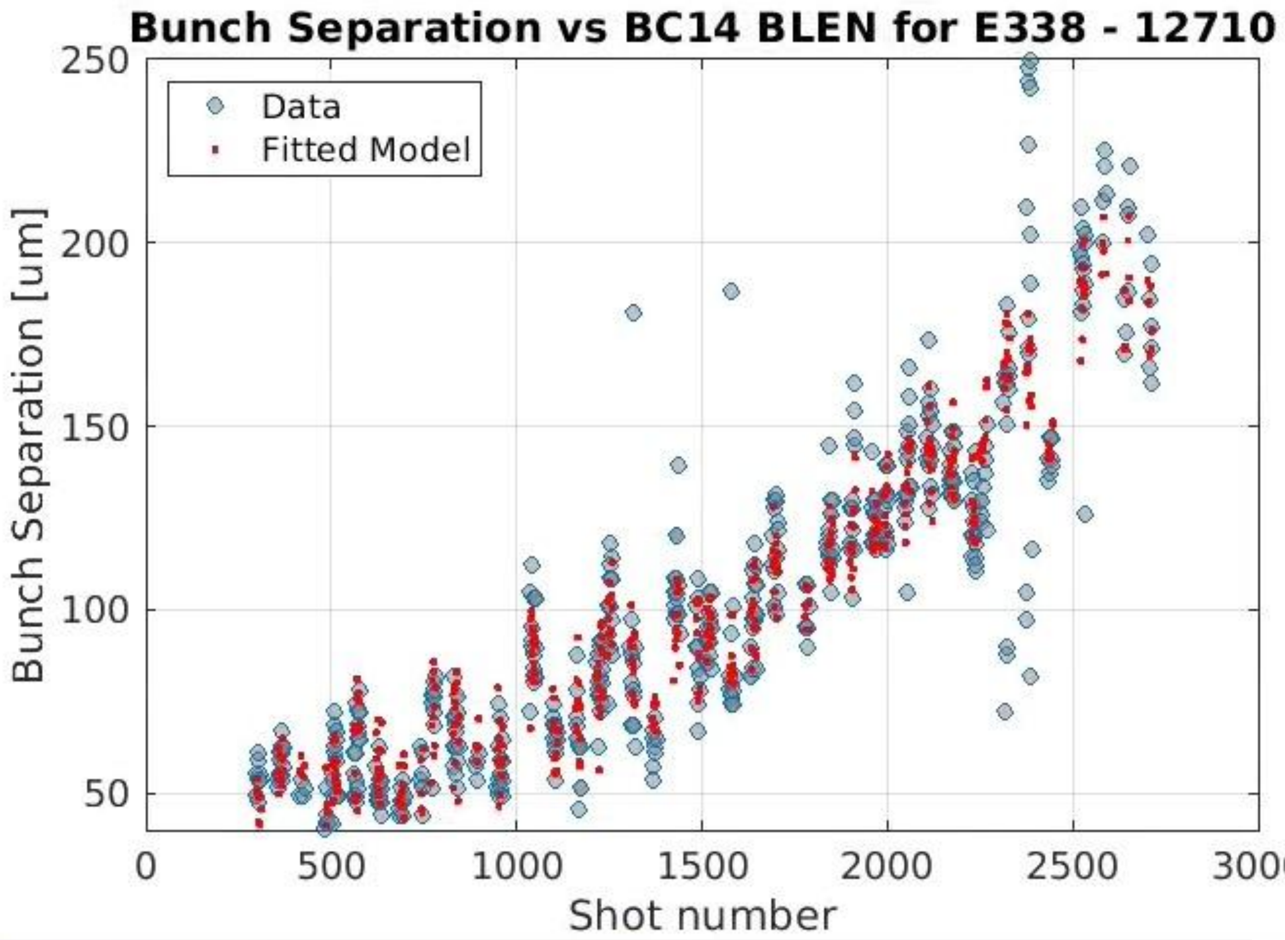
- LPS in under-compressed configuration
- XTCAV data taken during notch width + jaw position scan **with** BLEN sinusoidalizer
- XTCAV calibration very noisy, varied +/- 50% on the day in successive calibration scans



Notched two-bunch configuration measurements show favorable beam parameters for mapping

Fitting bunch separation to collimator setpoint and BC14 BLEN

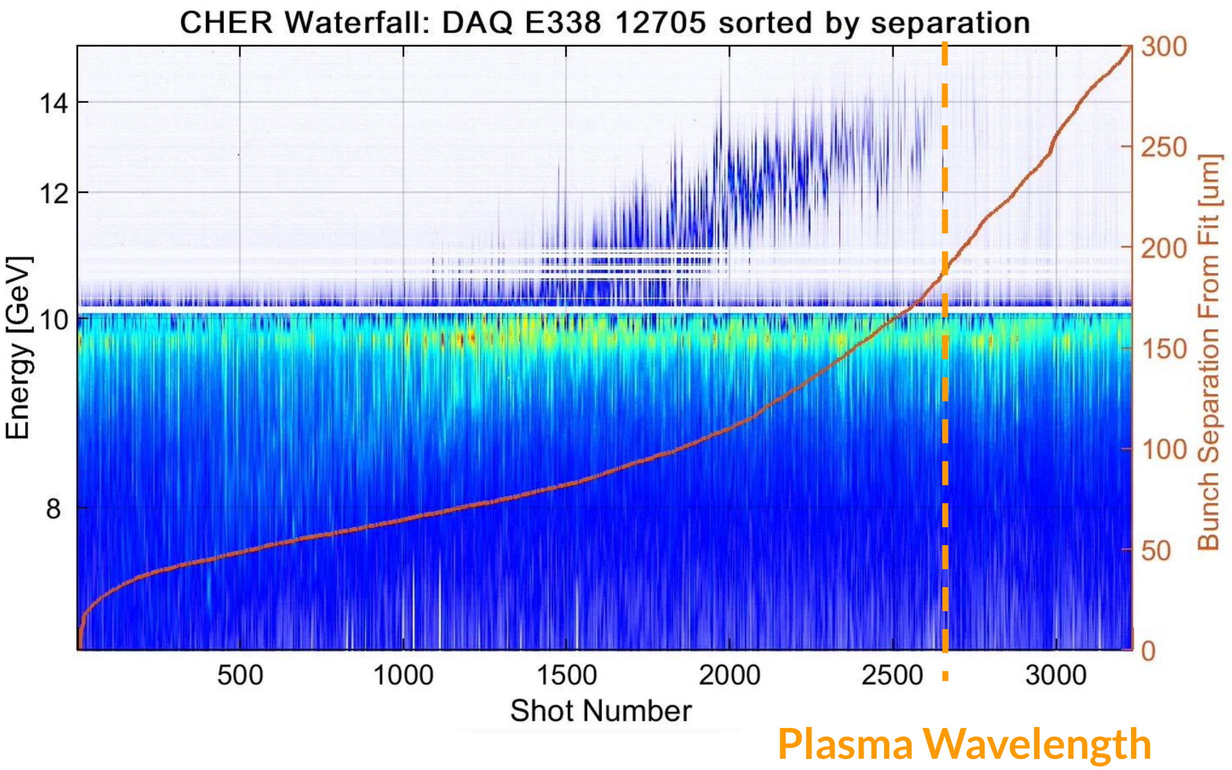




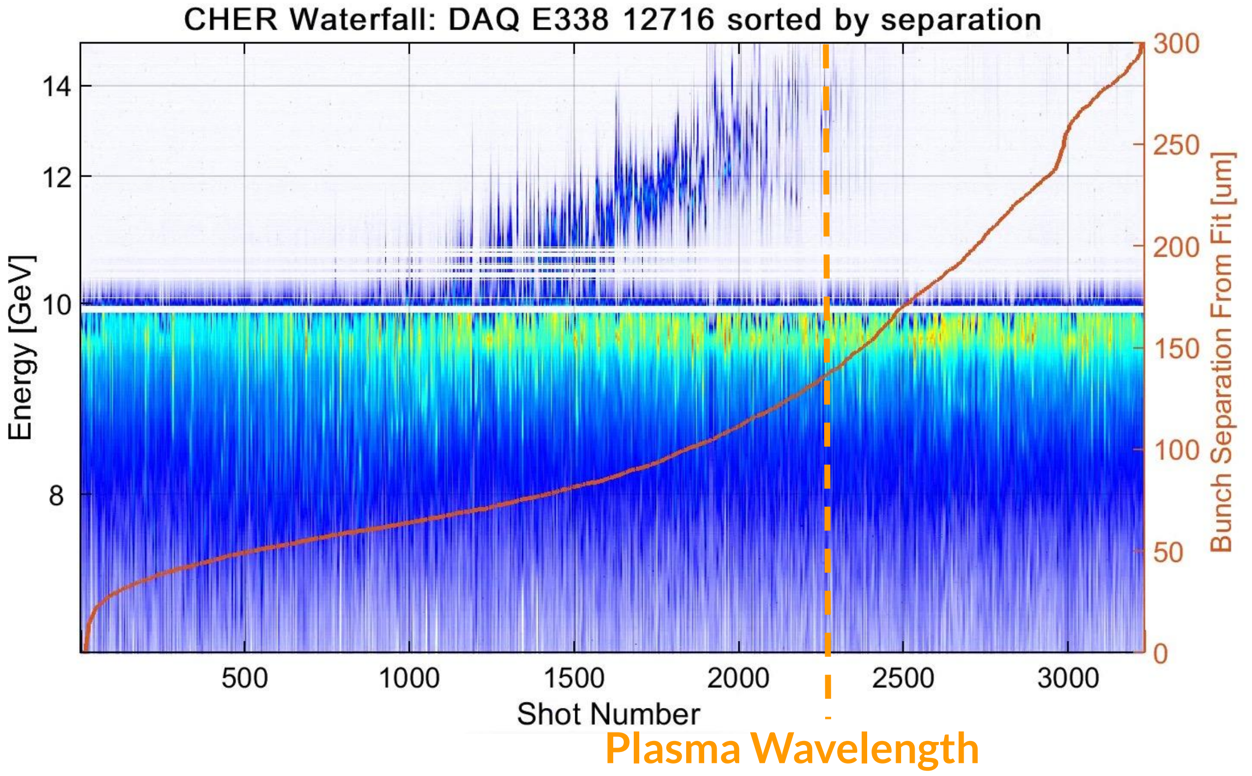
No shot-to-shot measurement of drive-witness separation with plasma. Fit required to calculate chirp

Waterfall plots with Li oven

Oven at 4 Torr, n_p = 3.5e16



Oven at 8 Torr, n_p = 6.7e16

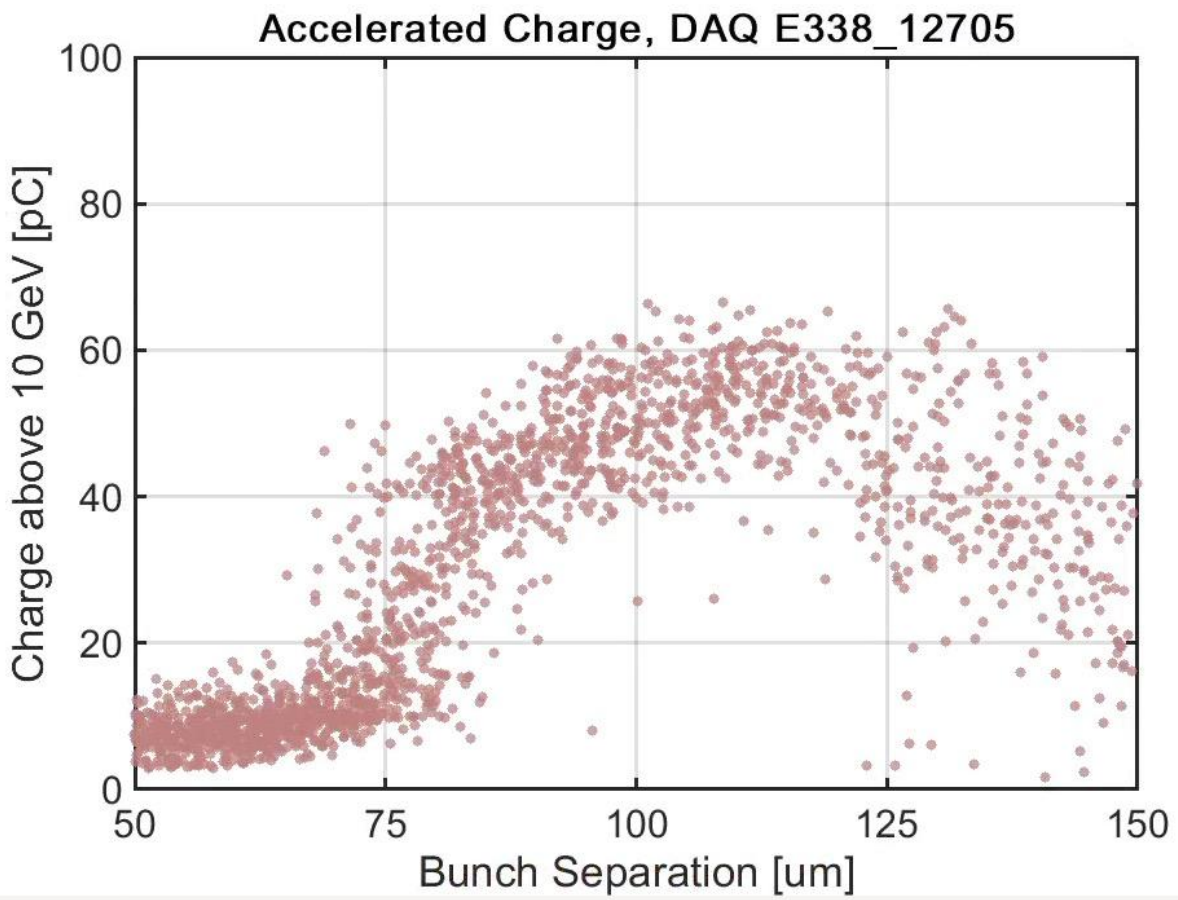


Both datasets taken with laser pre-ionization.

Higher plasma density gives same energy gain over smaller drive-witness separation

Accelerated Charge

Oven at 4 Torr, n_p = 3.5e16



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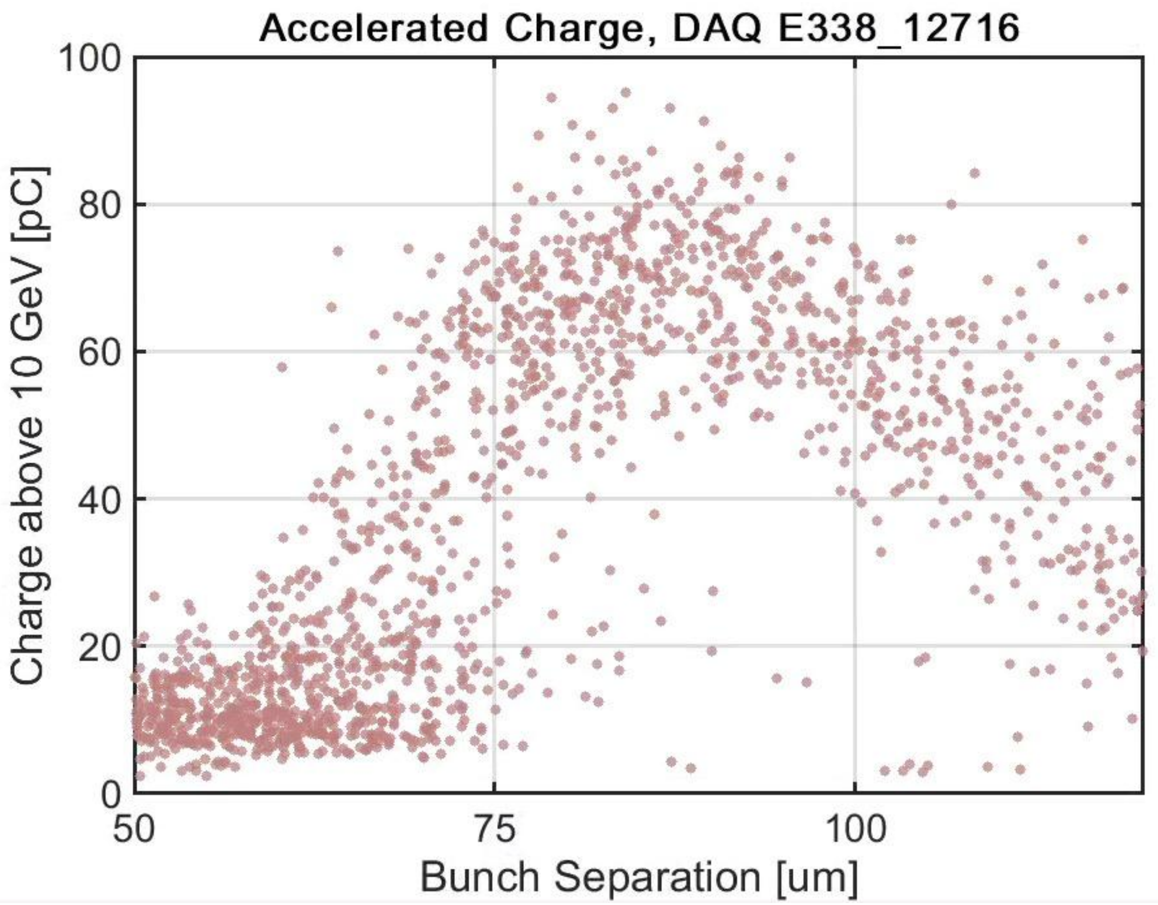
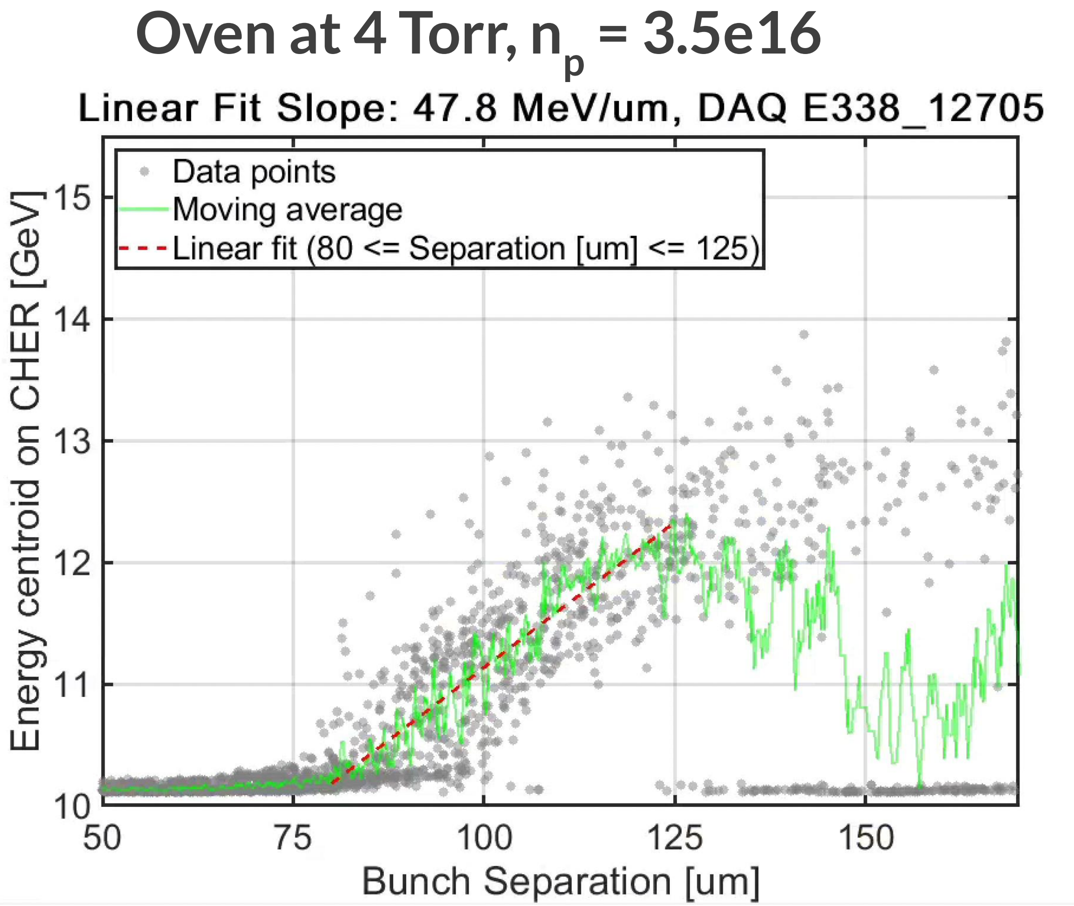
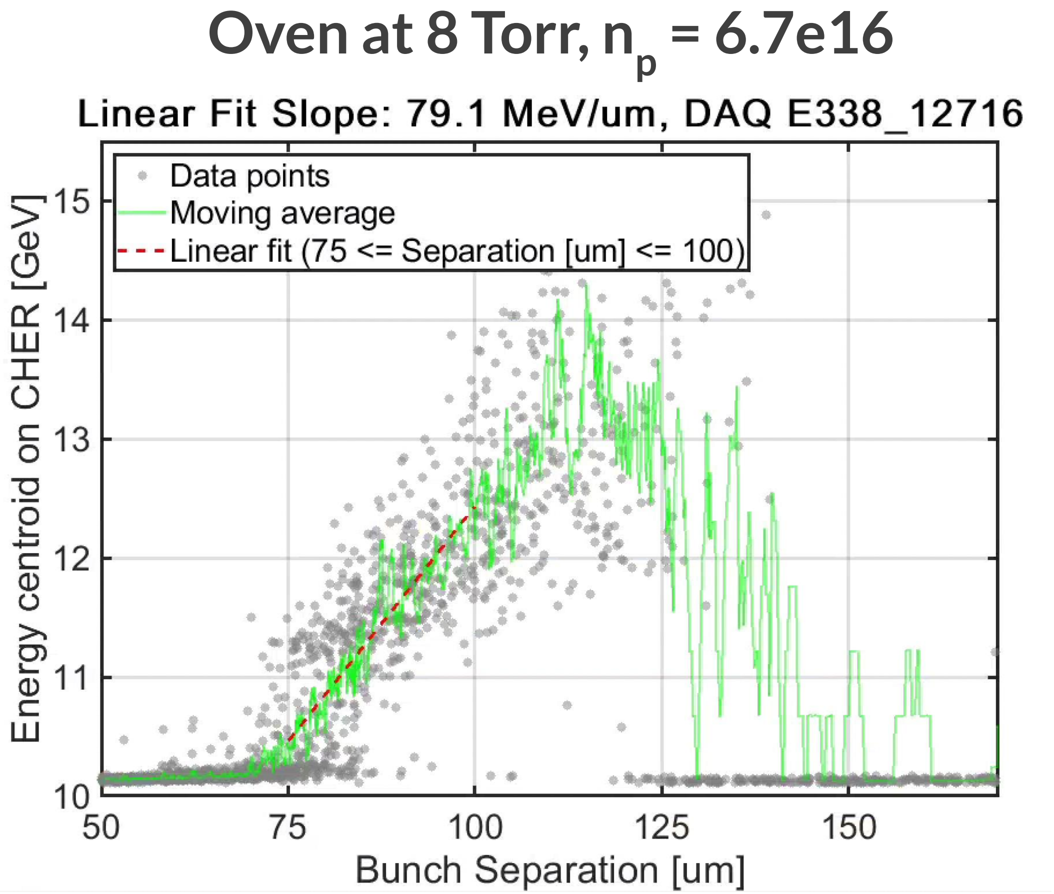


Reasonably good charge capture (>60%) obtained for bunch separations at 1-2 GeV energy gain

Chirp calculation





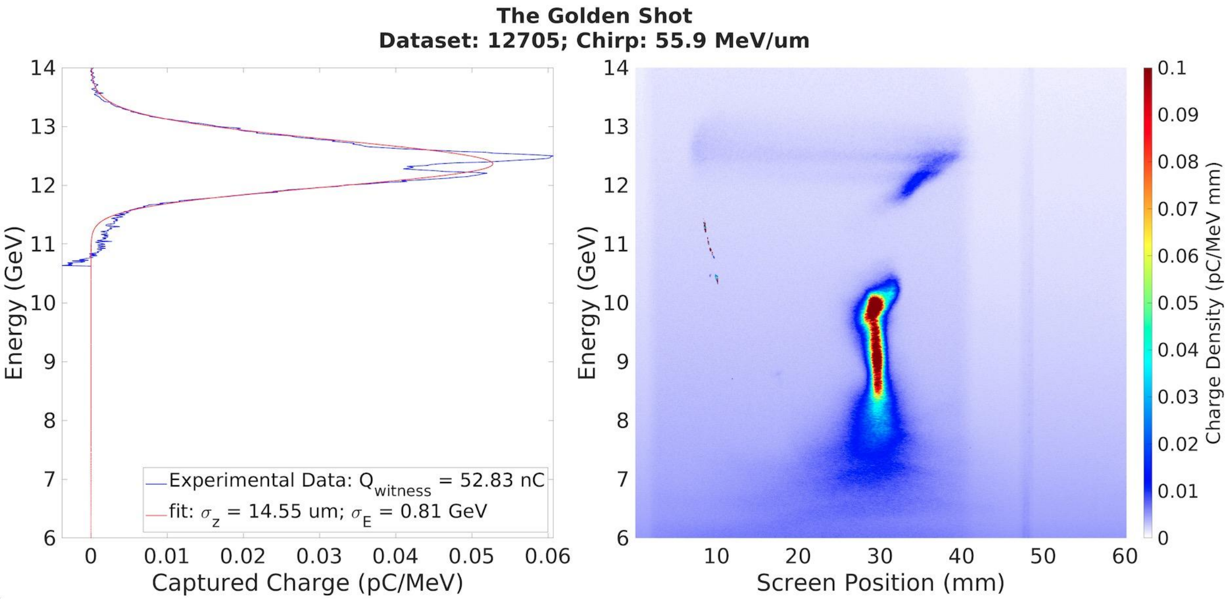
Energy centroid obtained from Gaussian fit of electron energies > 10.1 GeV.
Different bunch separation ranges for the linear fit correspond to ~10-12.5 GeV energy where we want to operate E338.

Measured chirps of ~50-80 MeV/um. Uncertainty comes from fit to bunch separation and energy centroid

Rafi Hessami

Direct chirp calculation from selected shots

Oven at 4 Torr, n_p = 3.5e16



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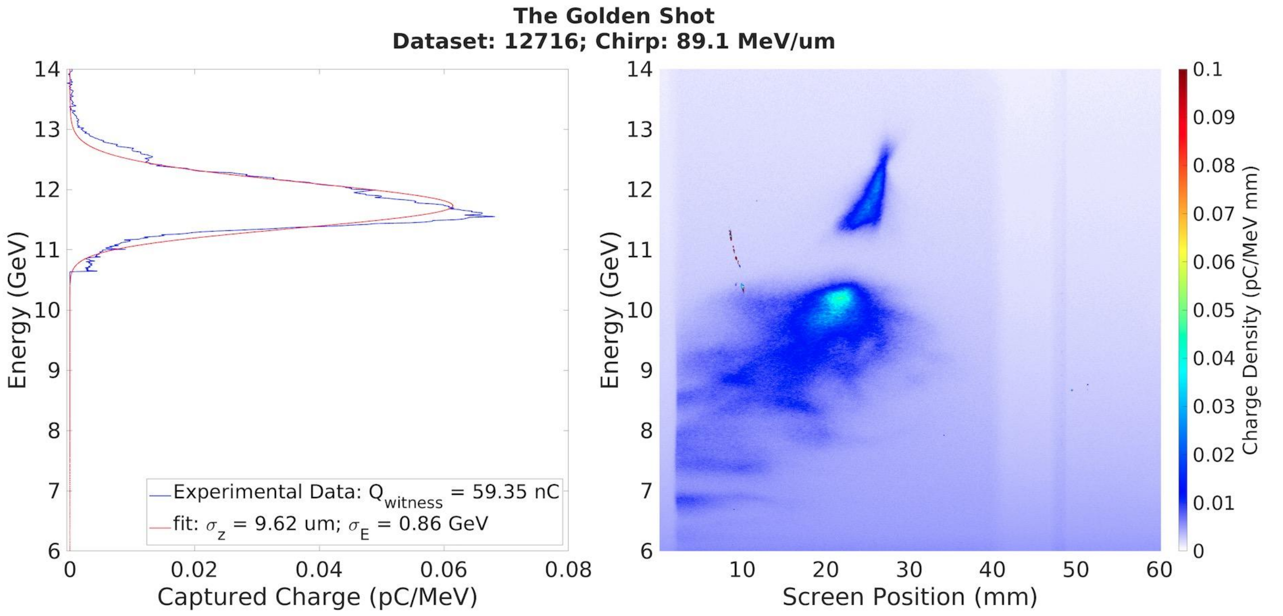


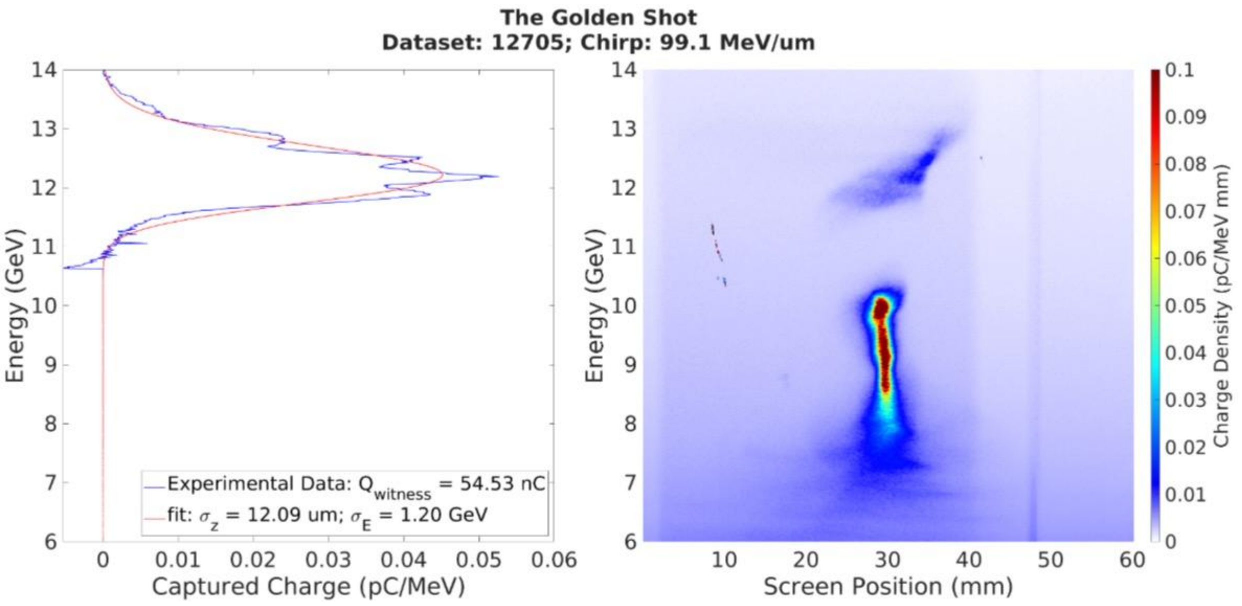
Energy centroid obtained from Gaussian fit of CHER profile. RMS bunch length obtained from fit to XTCAV-on dataset.

Direct calculation of chirp from selected shots consistent with average chirp numbers

Rafi Hessami

Direct chirp calculation from selected shots

Oven at 4 Torr, n_p = 3.5e16



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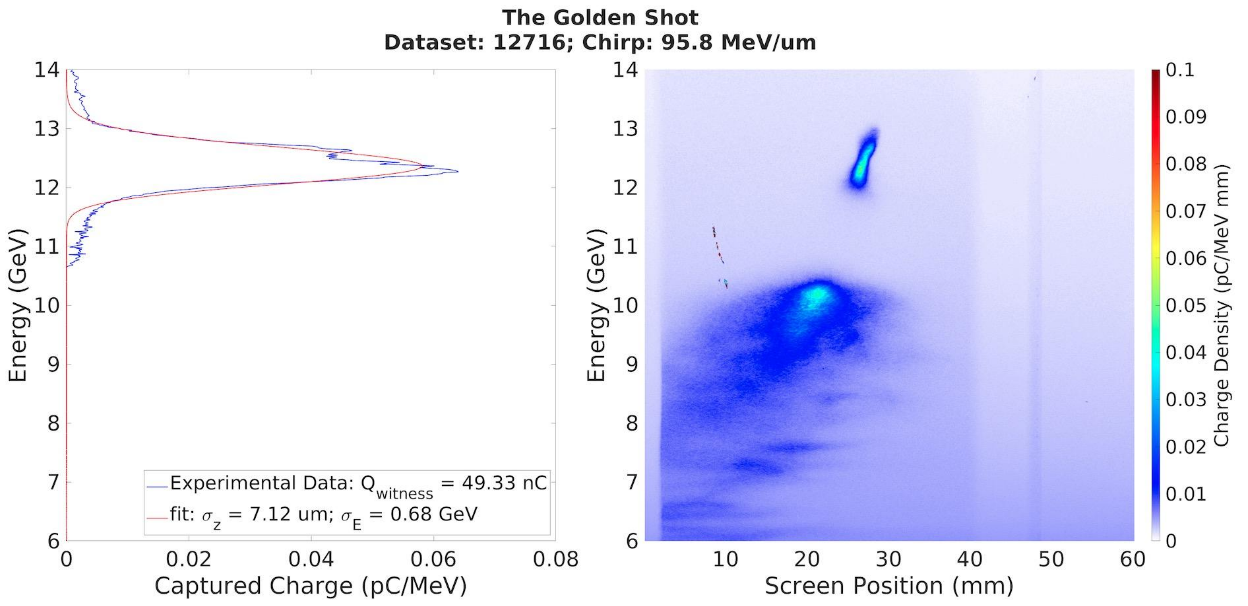

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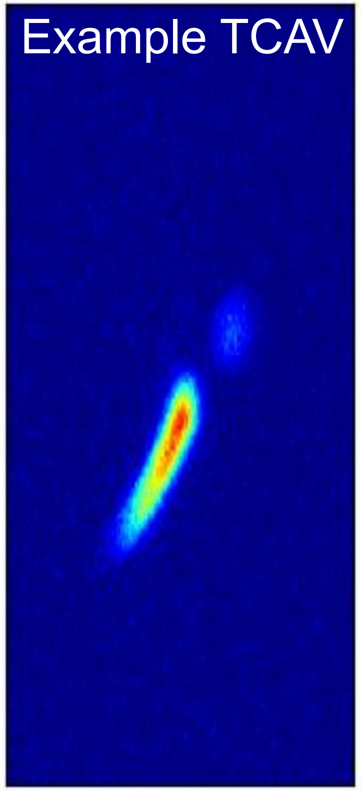
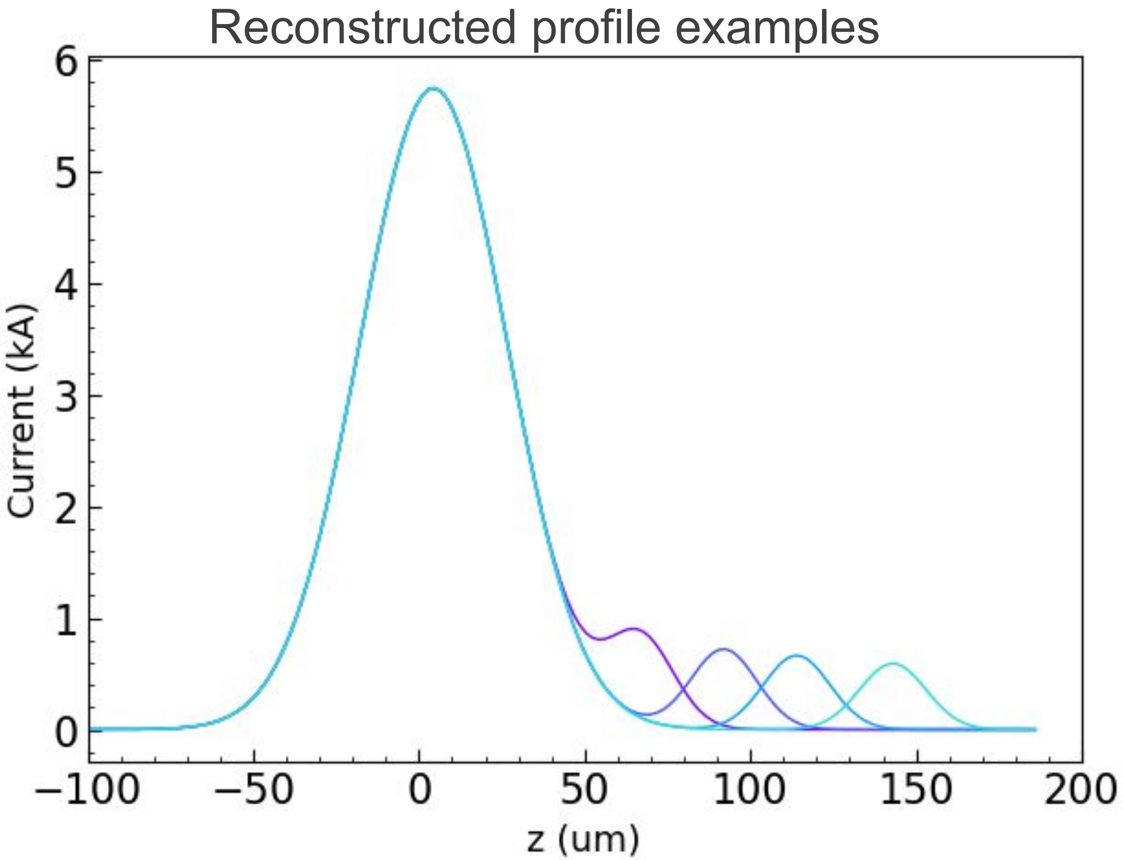
Direct calculation of chirp from selected shots consistent with average chirp numbers

Comparison with QPAD simulations





- Current profiles reconstructed from XTCAV and matched to plasma shots using the fitted bunch separation.

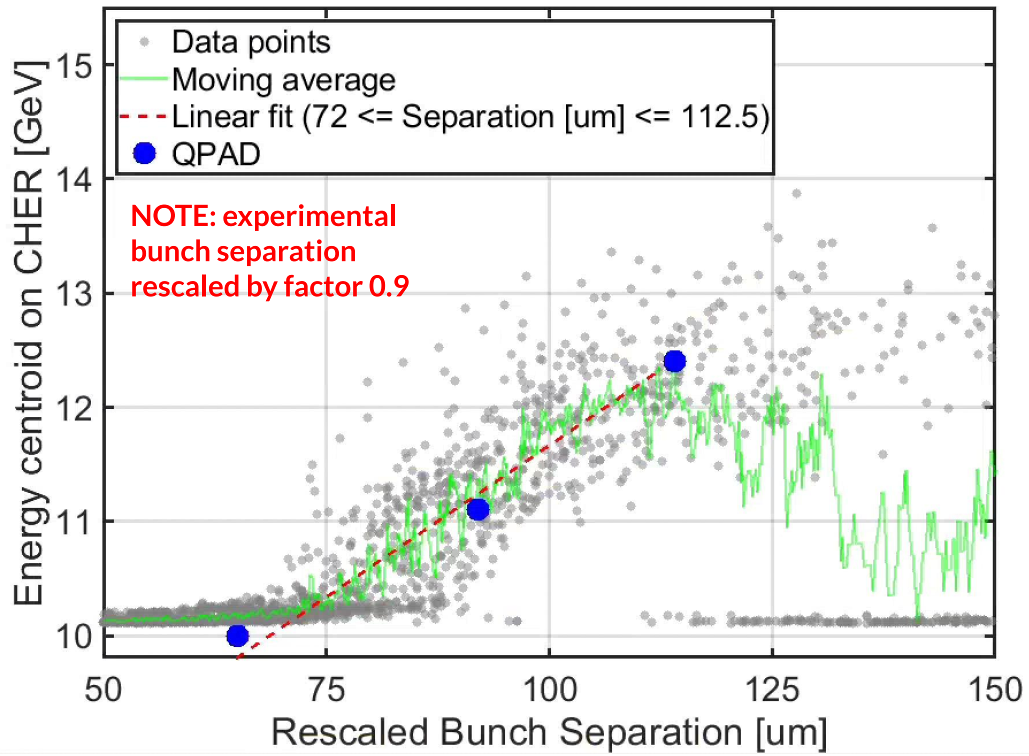
XTCAV profiles used to provide realistic input to PIC simulations

Kelly Swanson

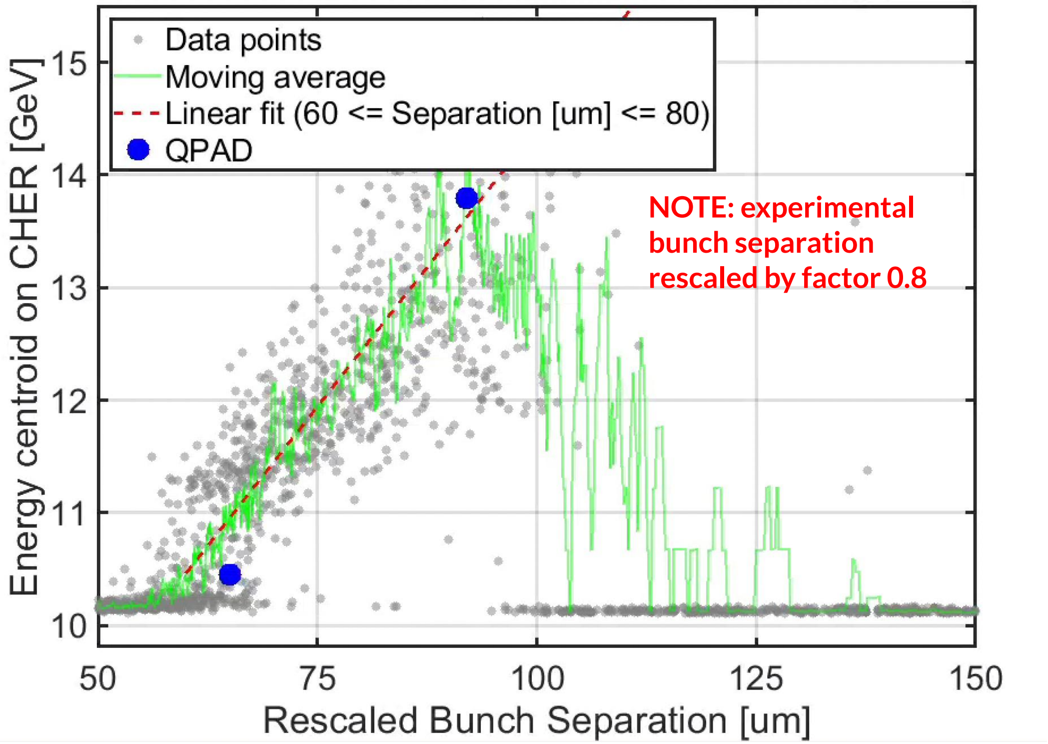
Comparison with QPAD simulations

Plasma density (10^{16} cm^{-3})	Experimental chirp (MeV/um)	Simulation chirp (MeV/um)
3.5	47.8	43.8
6.7	79.1	87.0

Oven at 4 Torr, n_p = 3.5e16



Oven at 8 Torr, n_p = 6.7e16



- QPAD simulations show reasonable agreement with data in both chirp and witness energy gain (improvements ongoing)

Higher chirps can be achieved with higher plasma density

Summary

- Successfully commissioned E338 spectral/CSR diagnostics to measure bunch length of fs current spikes using laser heater shaping.

- Tested first beam configuration: notched single bunch under-compressed in Li oven.

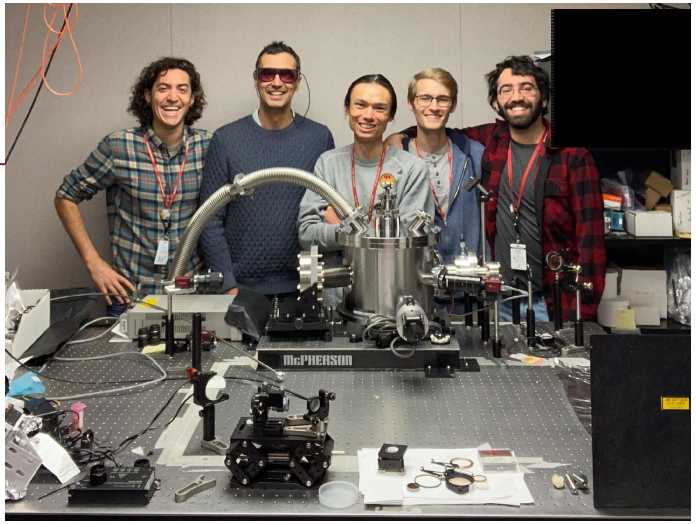
- Measured witness beam chirps of ~50-80 MeV/um. On paper this chirp is sufficient to achieve full compression at witness energies of 9-11 GeV or lower with our chicane parameters.
  - Pending further data analysis/simulation this may be worthy of publication in collab. w E300

- Shot-to-shot bunch separation diagnostic (EOS) highly desirable for future experiments.

- To do in upcoming runs (more details Friday):
  - Test alternative beam configurations with similar wakefield mapping measurements (two bunch and/or notched single bunch in Li oven and/or static fill).
  - Install chicane (soon…)
  - Run first compression experiments

E338 well positioned to meet its goals with successful commissioning of diagnostics and beam setup

Acknowledgments



Collaborators

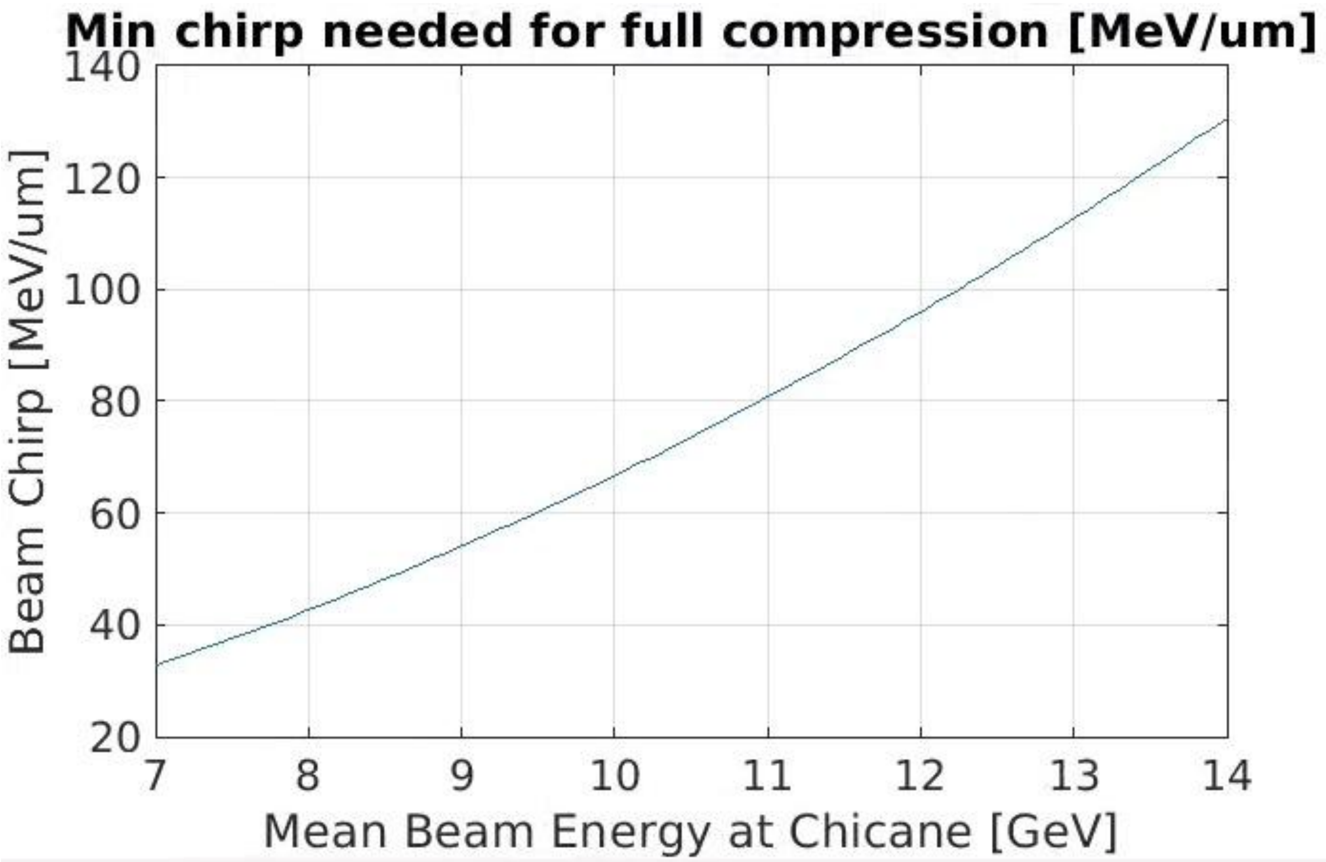
- **SLAC**: R. Hessami, K. Larsen, R. Robles, K. Swanson, C. Emma, A. Marinelli, FACET-II AARD & Beam Physics groups
- **UCLA**: A. Fisher, P. Musumeci, C. Zhang, C. Joshi, K. Marsh
- **Experimental Collaborations with:** E-300, E-304, E310, …

- ***Special thanks to***: Doug for operating oven, Sebastien for operating laser and Sebastien + Sheldon for writing notch + jaw scan function, Nathan for sinusoidalizer/sextupole optimization tools we used during wakefield mapping shift

Thank you for your attention

Backup Slides

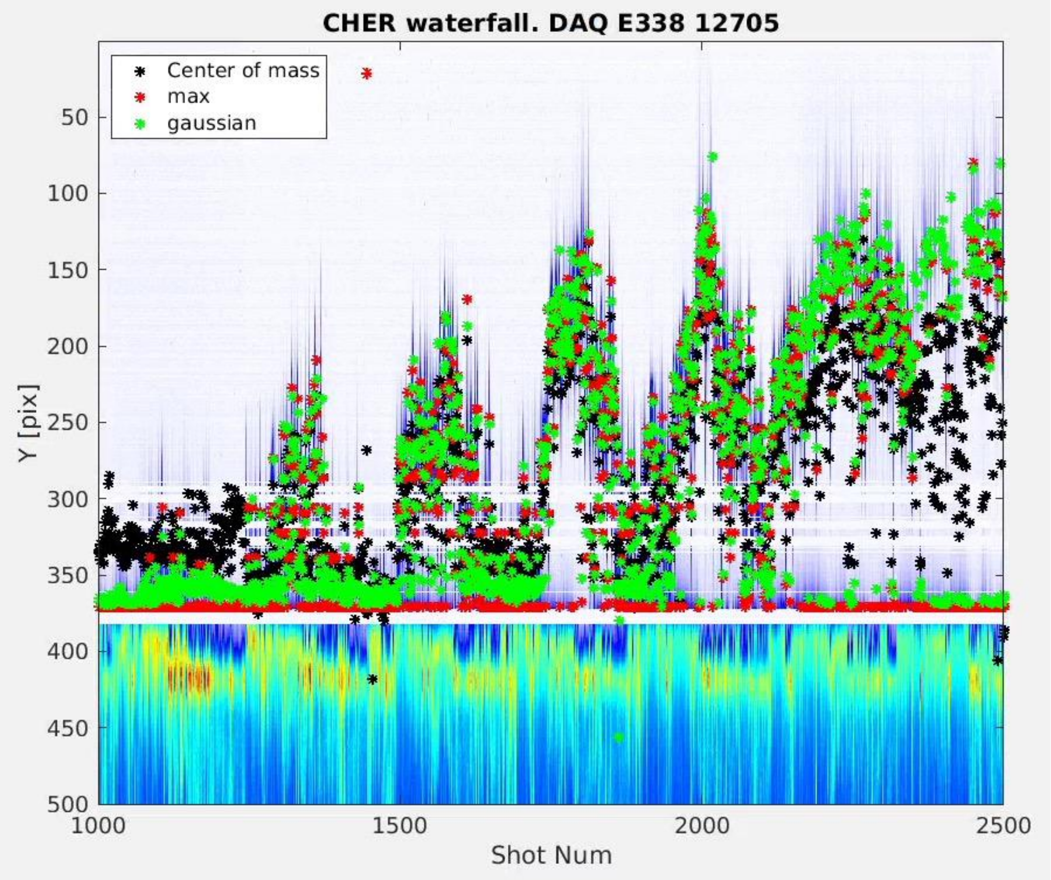
Chirp required for full compression



Assumes our chicane runs at max R56 of 150 um at 10 GeV and that full compression is achieved when |chirp| = 1/R56

Comparing fit methods for centroid calculations

Oven at 4 Torr, n_p = 3.5e16



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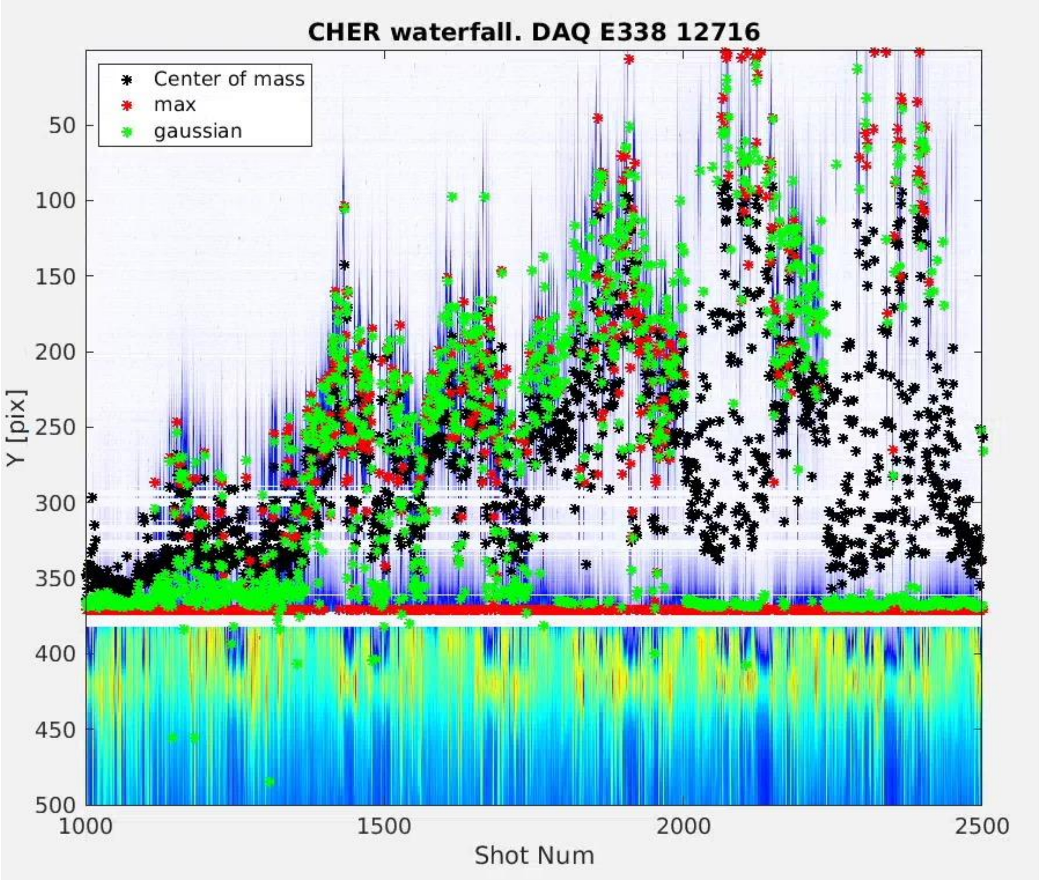
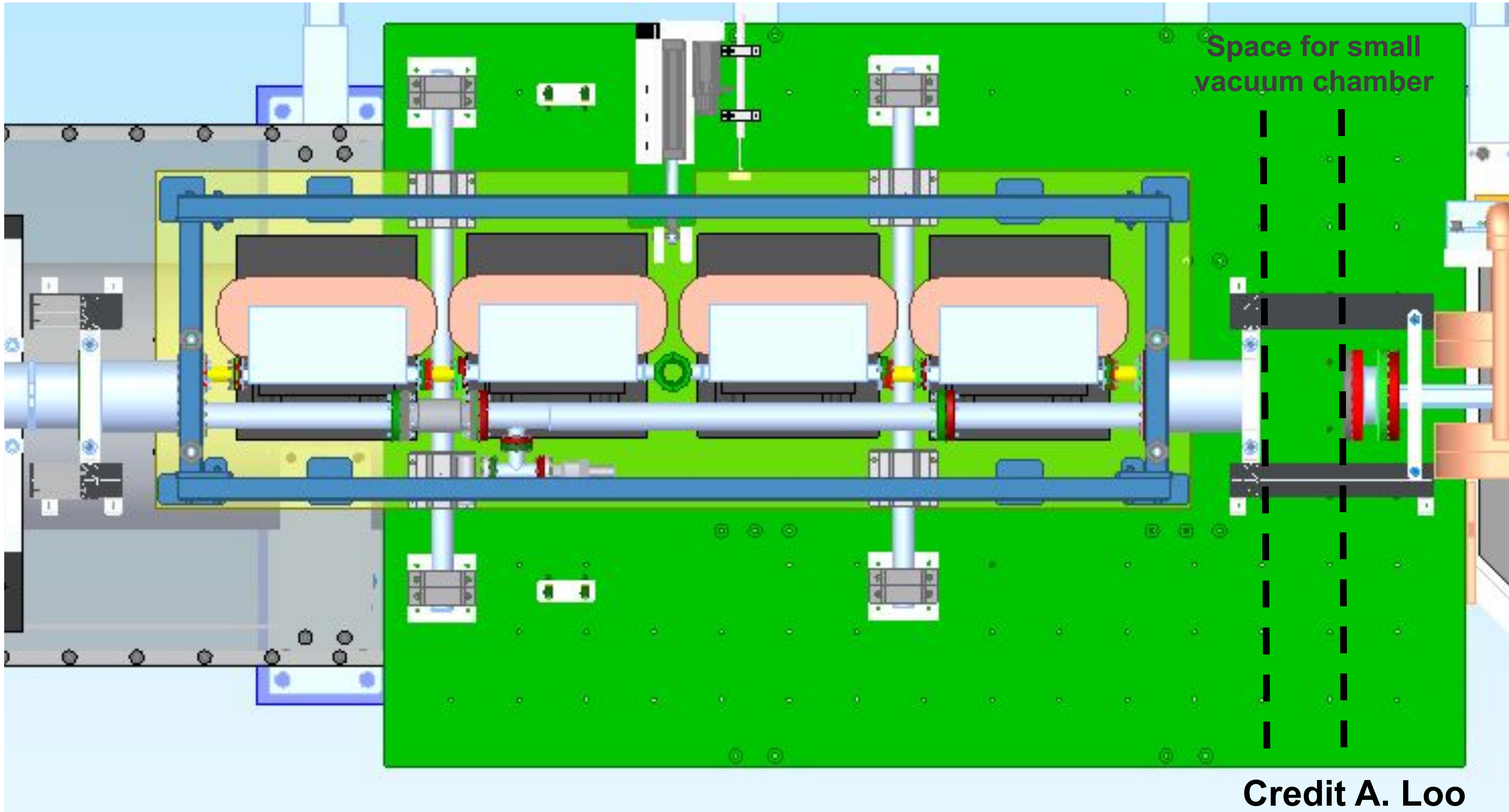


Center-of-mass systematically underestimates witness energy. Max and Gaussian are better fits.

E338 Chicane + bypass line design

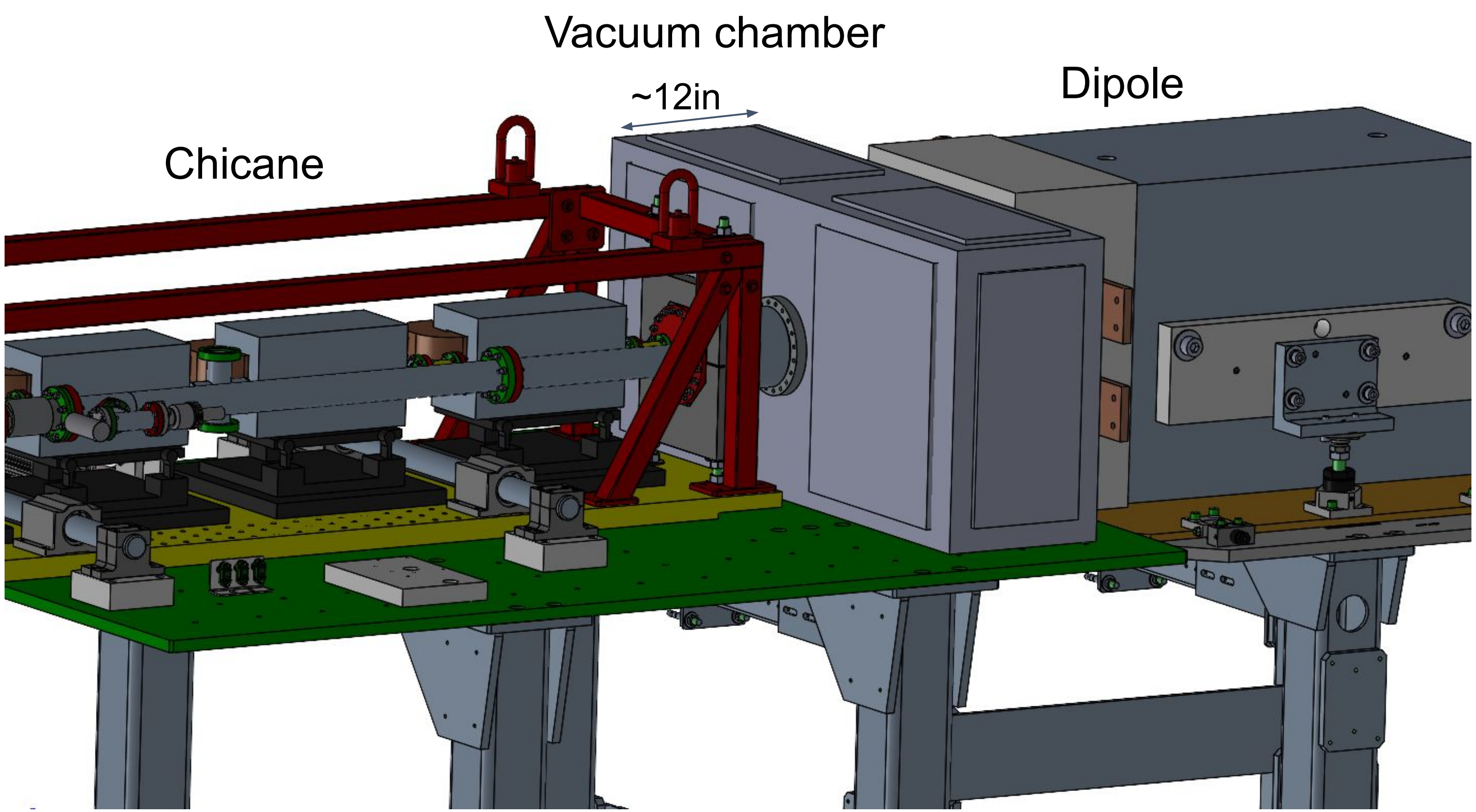
- Chicane + bypass line engineering design completed
- Chicane sits on a mover table remotely insertable in beamline
- R_{56} < 150 um at 10 GeV
- Space for small interaction chamber downstream before dump dipole.
- Magnets + bypass line ordered, expected 08/2025, installation summer 2025



Chicane will be available for experiments starting Fall 2025

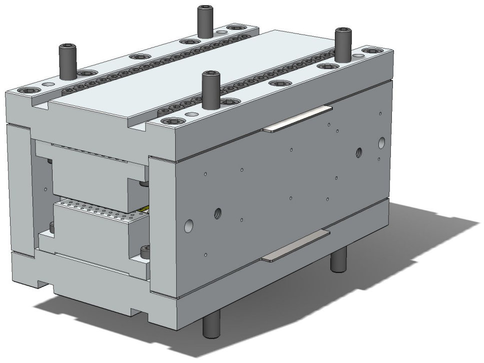
K. Swanson

Post-chicane chamber



Chamber can support:

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

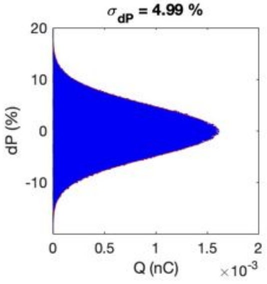


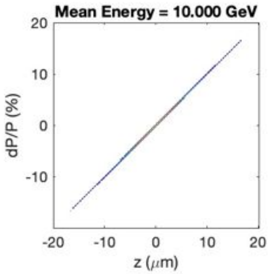
Stakeholders consulted during design process

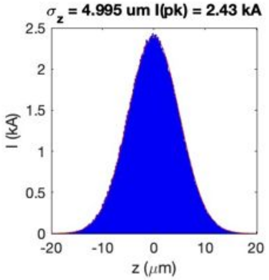
Post-chicane chamber will be available for experiments with or without compressed beams

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

LPS at exit of plasma







rms dP/P = 4.995 %

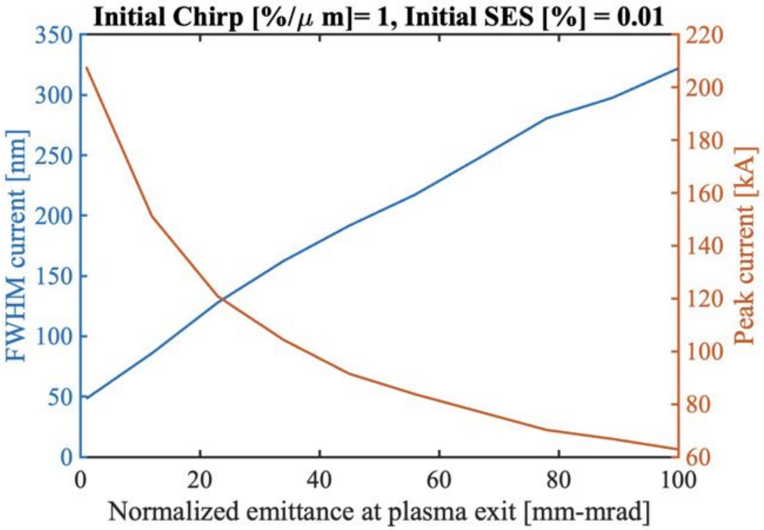
rms Z = 4.99513 um

Initial Chirp = 1 %/um

Initial SES = 0.01 - 0.1 %

Initial Q = 100 pC

Output beam parameters after chicane



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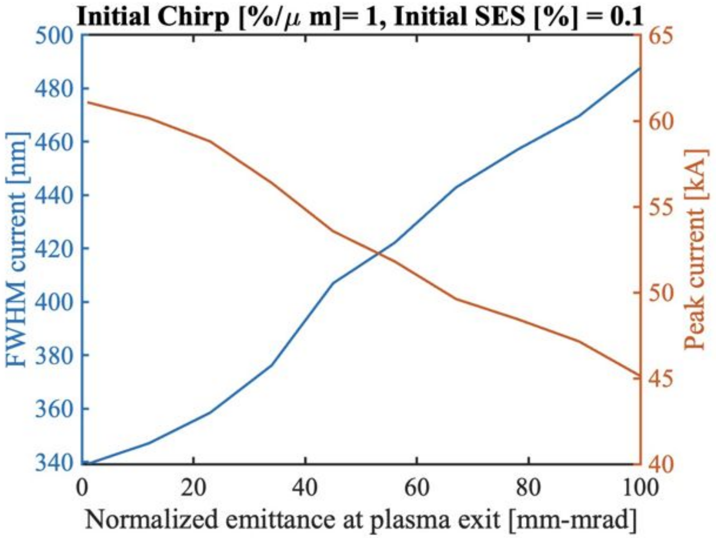
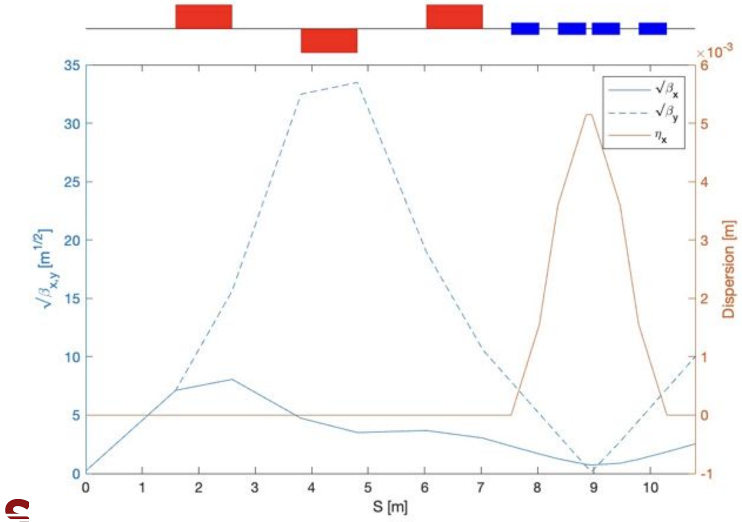
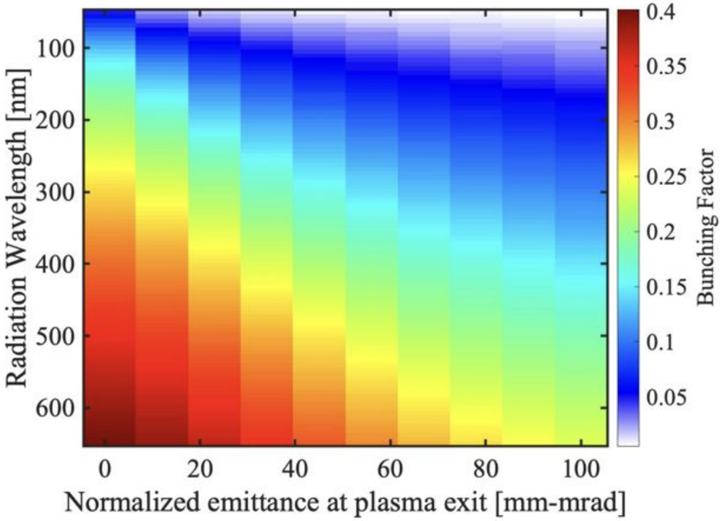
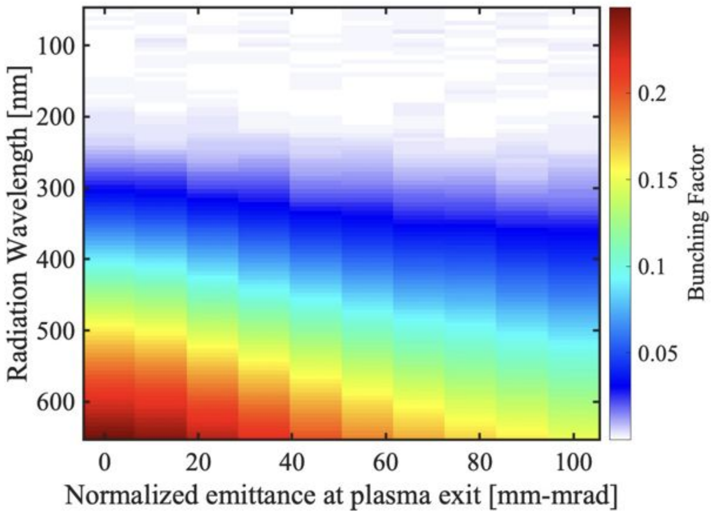


Focusing triplet and post-plasma chicane

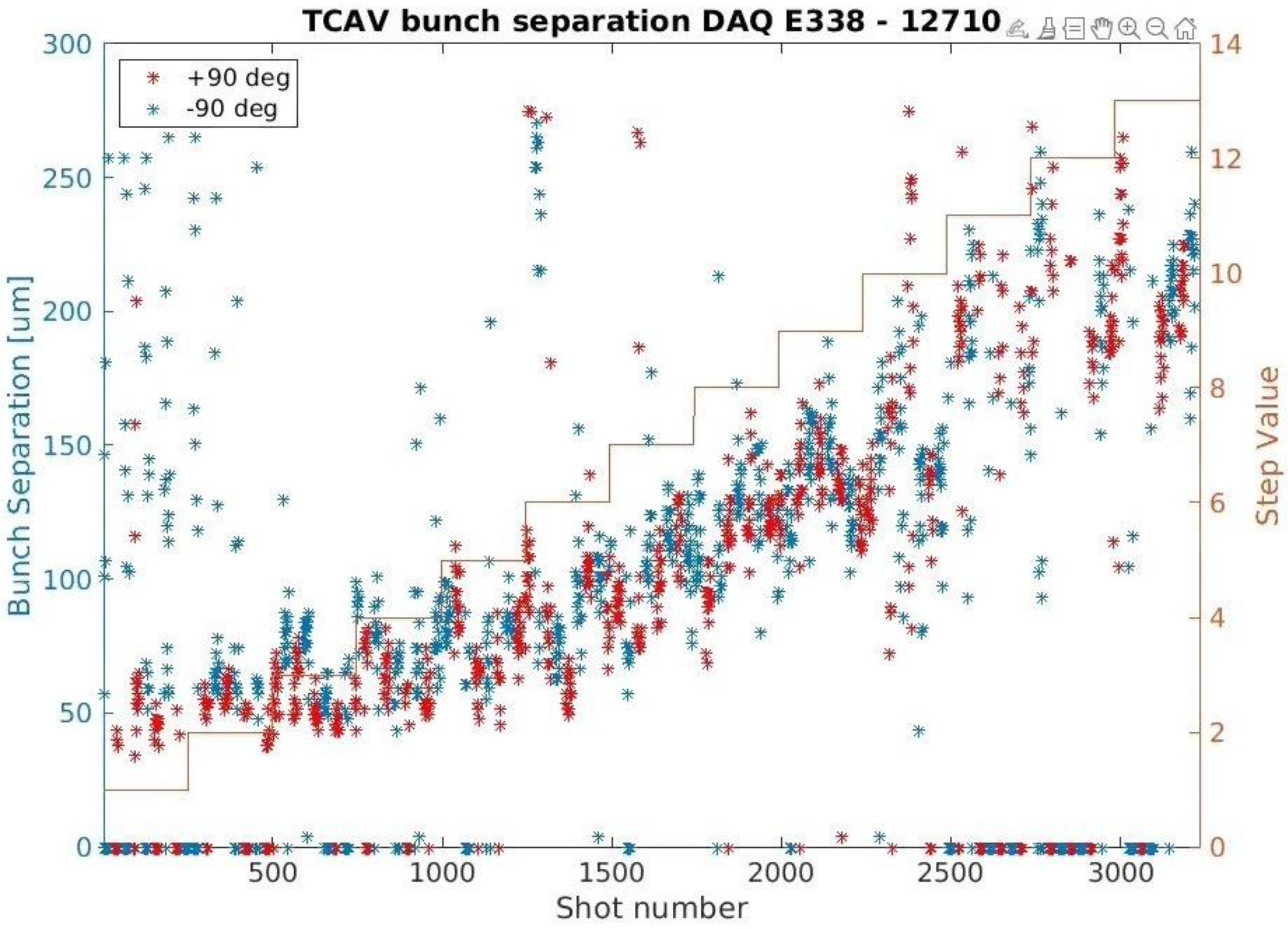






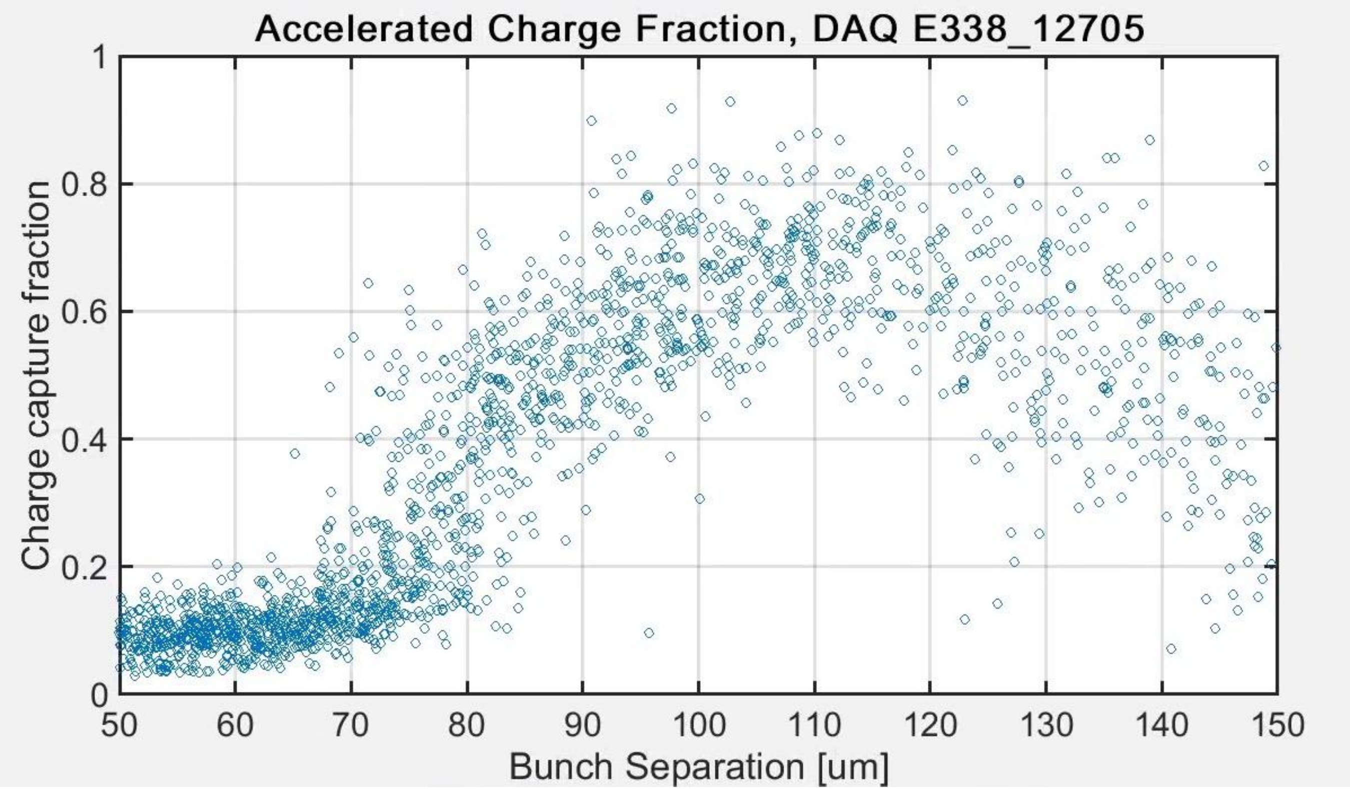
XTCAV reconstruction notes

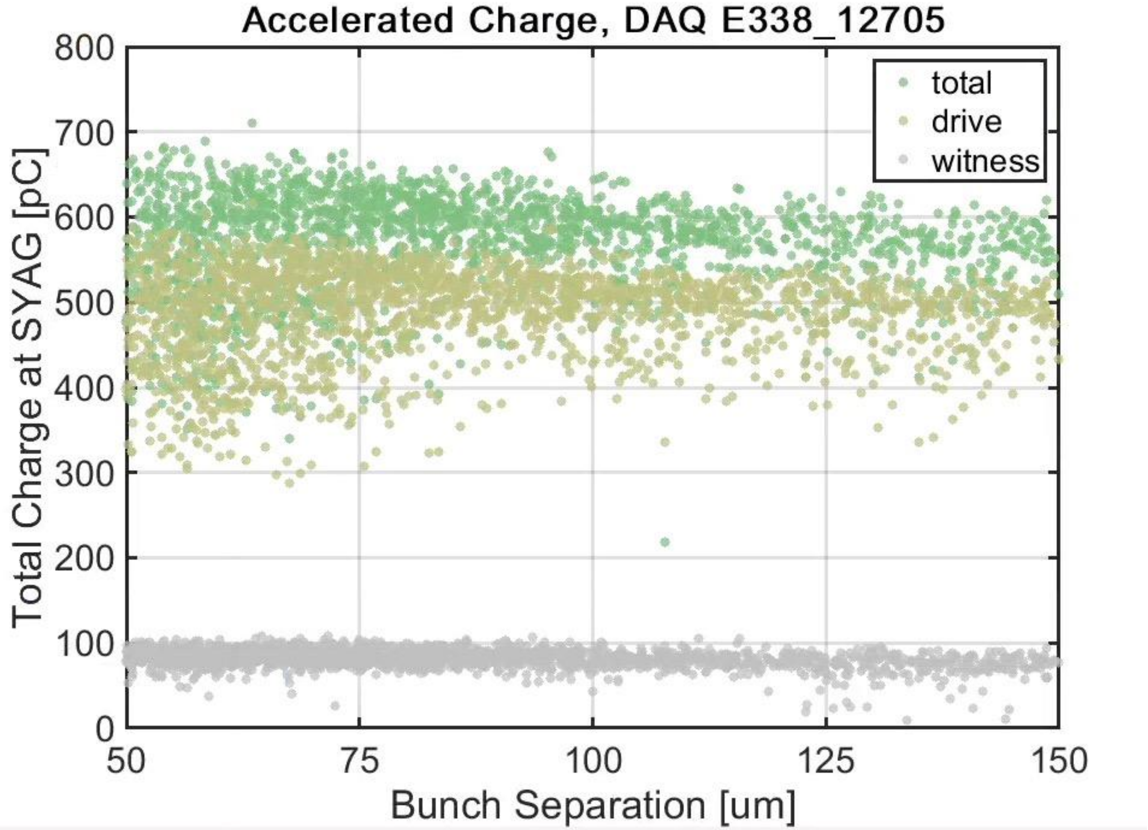
Bunch separation from each zero crossing fairly consistent during 2D notch + jaw and BLEN scan



Accelerated Charge

Oven at 4 Torr, n_p = 3.5e16





Good charge capture (>60%) obtained for bunch separations at 1-2 GeV energy gain