E308 FY22 Progress and Plans for FY23

Mike Litos

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FACET-II PAC 2022 – SLAC Nat'l Lab

University of Colorado **Boulder**

E-308 Science Goals

E-308: underdense, passive, thin plasma lens

Unique features:

- Extremely strong, axisymmetric focusing – strongest possible focusing
- Blowout regime – linear focusing; high peak current okay (unlike active lens)
- Ultra-compact – laser-ionized gas jet or unconfined gas
- Easily tunable – gas pressure; laser focusing

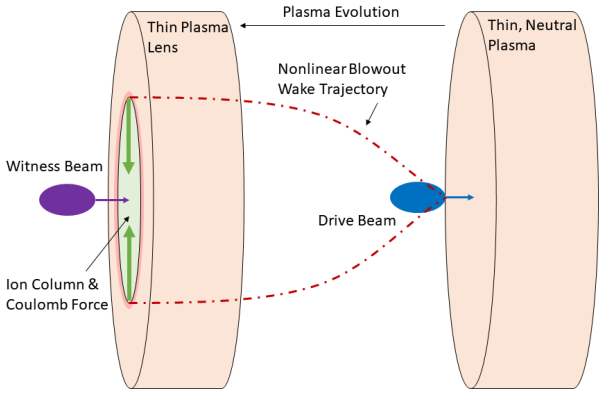
Type	K [m^{-2}]	L [mm]	f [cm]
EM Quad	0.3	180	1000
PMQ	150	8.2	81
Plasma	88400	0.34	3.3

Science Goals:

- Strong, axisymmetric focusing (**1-2 years**)
  - Show stronger focusing than FF magnets
  - Single bunch and two-bunch operation
- Study Oide effect (**2-3 years**)
  - First experimental study of Oide effect
  - Scaled-down collider FF studies
- Platform for other experiments (**2-5 years**)
  - Beam matching for PWFA (E301)
  - Filamentation in high density targets (E305)
  - SFQED (E320)
  - Divergence control for injected beams (E304, E307, E31X)

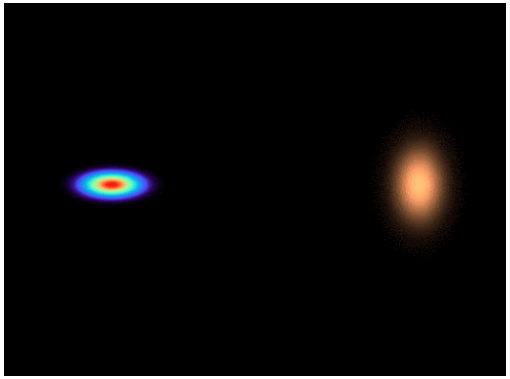
E-308 Experimental Timeline

2018-2021:
- Advancement of theory - multiple papers
- Simulation campaign – gas jet and plasma lens
- Experimental planning and design
- Hardware installation and commissioning at FACET-II



2022:
- Continued commissioning at FACET-II
- Summer: Attempt to ionize H2 gas jet with probe (probe laser not ready)
- Summer: Axilens ionized 20 mm H2 gas jet with main laser (not ideal)
- Summer: Commissioning data taken with 20 mm plasma lens
- Fall: Preliminary analysis of commissioning data

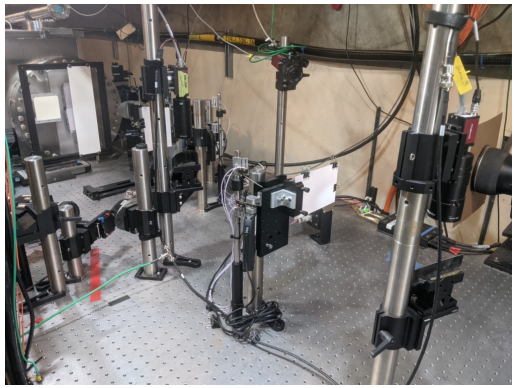
Future:
- Ongoing: Reassess and optimize FACET-II probe laser
- Dec. 2022: Test new spatial filter design at CU
- Jan. – June 2023: Reoptimize probe laser; reattempt 1-bunch plasma lens
- July – Dec. 2023: Two-bunch plasma lens studies
- 2024: High-performance two-bunch plasma lens studies
- 2025: Oide studies; utilize plasma lens for other experiments

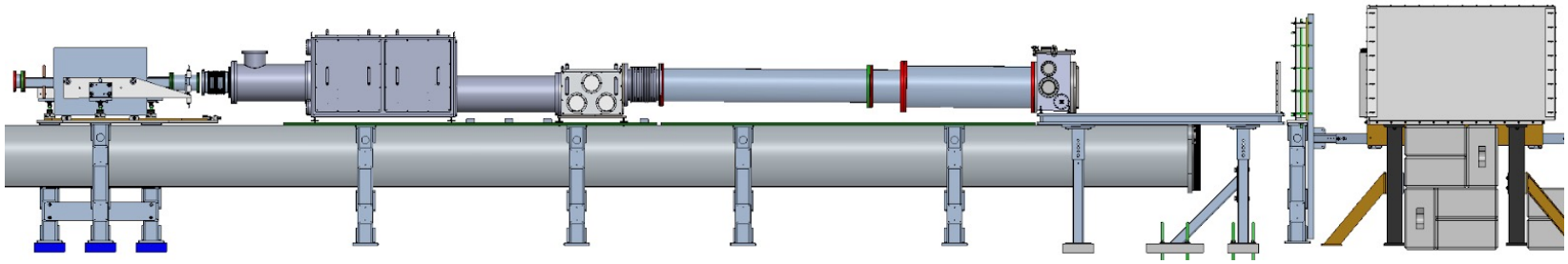


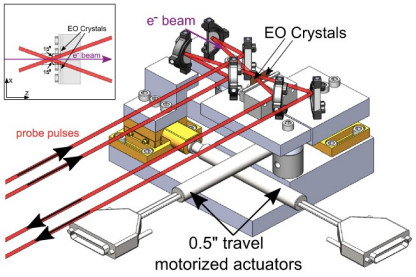
E-308 Diagnostics and Observables

Primary Diagnostic Systems

- Standard upstream diagnostics (charge, spectrum, etc.)
- Imaging spectrometer
- Betatron radiation screens
- EOS-BPM
- ML phase space reconstruction (E327)
- Gas jet plasma diagnostics (E305/E332/E31X)







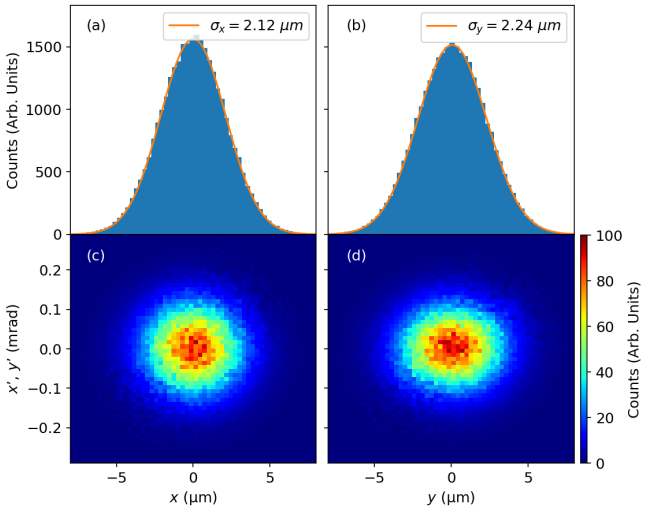
Experimental Observables

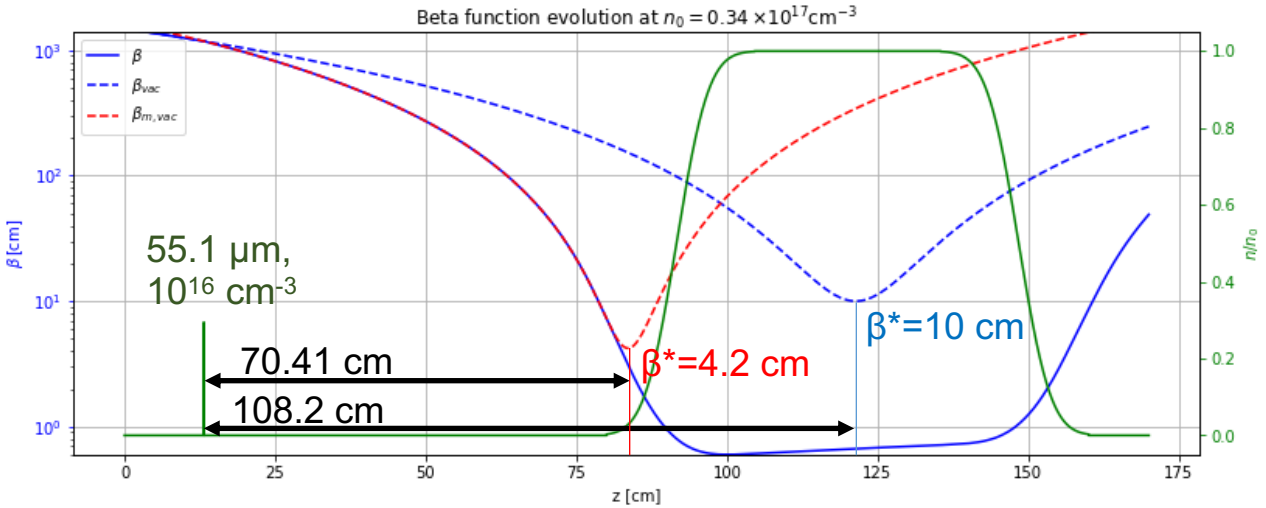
- Dispersed and re-imaged e-beam
- Betatron radiation angular spectrum
- Initial plasma density, length, and width
- Reconstructed initial beam parameters

E-308 Progress to Date (1)

2018-2022 University of Colorado:

- Plasma lens theory development: 2 papers
- PIC simulations of experimental parameters
- Open-Foam simulations of gas jet profile
- Plasma source density profile design
- Laser ionization code development
- Laser focusing scheme development
- Beam diagnostic techniques and hardware
  - with SLAC and Ecole Polytechnique
- Numerical PWFA matching studies

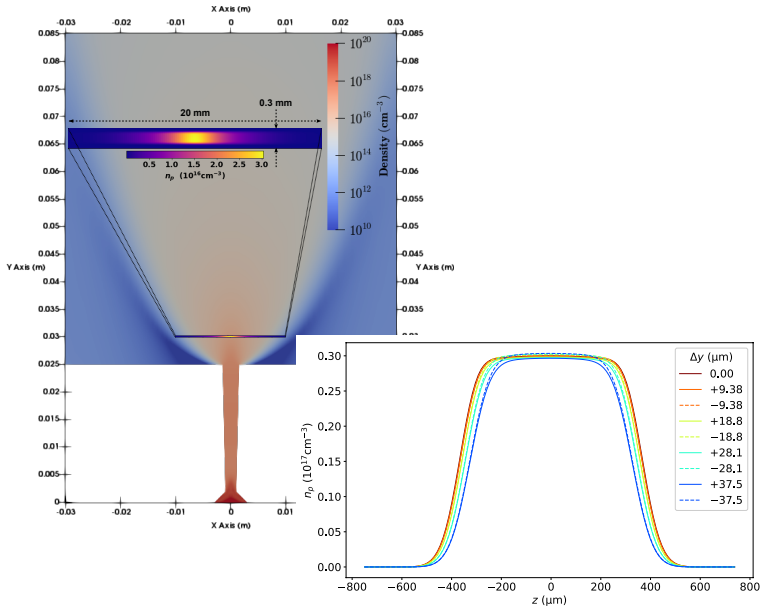


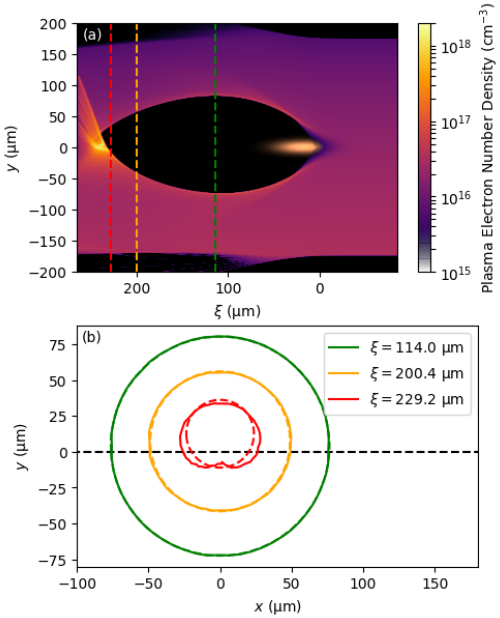


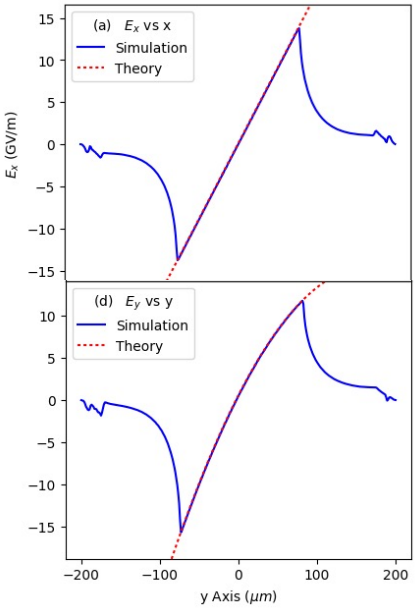
E-308 Progress to Date (2)

Detailed simulations and theoretical exploration of plasma lens...

- OpenFoam simulations of gas jet profile
- Split-step Fourier simulations of laser ionization
- Found percent-level variation along gas jet flow direction
- Motivated theoretical study of transverse density gradient...
  - Not a problem for typical plasma lens
  - Could be leveraged for advanced use cases
  - First step toward more general theory for PWFA



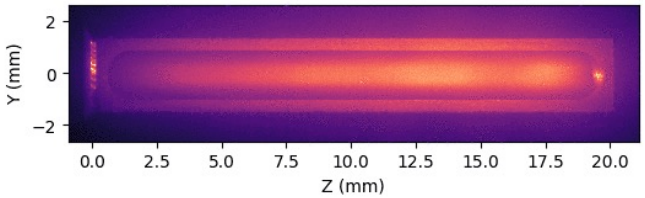


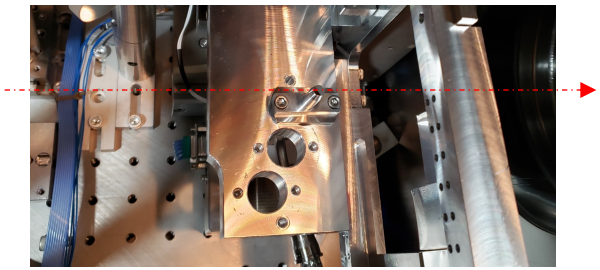


E-308 Progress to Date (3)

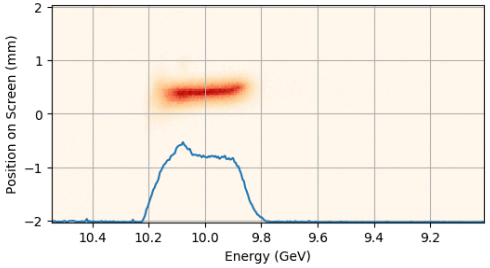
2018-2022 FACET-II:

- Design of IP area to accommodate plasma lens experimental hardware
- Installation of IP area hardware
- Commissioning of FACET-II laser system
- Design and installation of gas jet system
- Installation and alignment of plasma lens optics
- First attempt to produce plasma in H2 with probe – probe laser not ready
- Plasma produced with main laser axilens ionization of H2 in 2mm gas jet
- Commissioning data collected with 20 mm gas jet plasma lens
- Ongoing: analysis of commissioning data; optimization of laser system

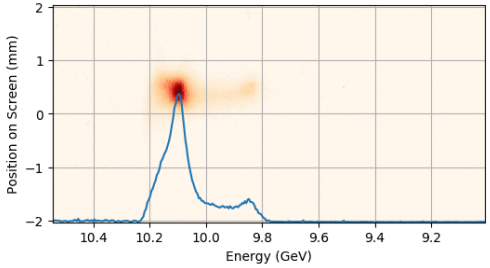




Plasma Off



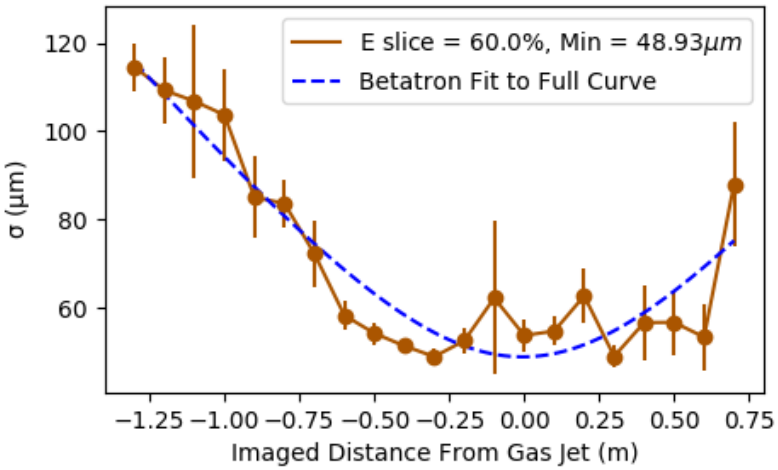
Plasma On

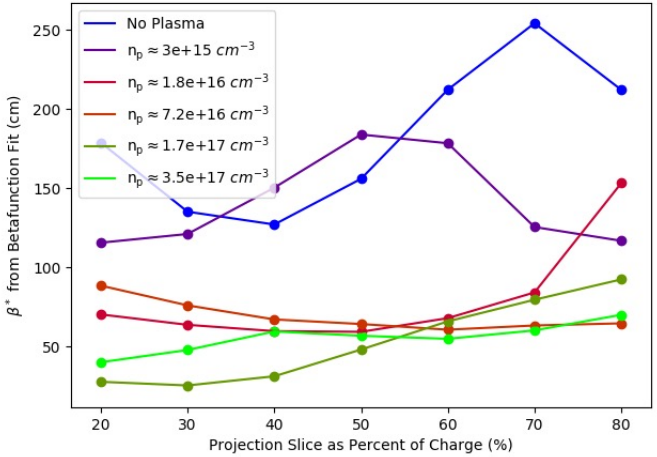


E-308 Progress to Date (4)

Ongoing Analysis of Commissioning Data:

- Scanned plasma density (gas jet pressure)
- Scanned imaging spectrometer object plane
- Goal: measure beam waist (β^*) as function of plasma density
- Findings (so far):
  - Incoming beam not characterized well enough
  - Jitter makes analysis and in-situ tuning difficult
  - Further characterization of imaging spectrometer needed
  - Possibly operating in linear regime for most data collected
- **Further commissioning needed, but summer was a big step forward**

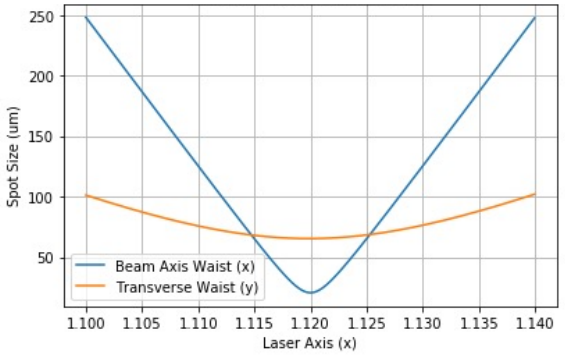




E-308 Future Evolution

Advanced Optical Setup

- Control plasma with more sophisticated optics
  - Crossed cylindrical lenses
  - Diffractive lens



Collider Final Focus Studies

- Study potential use of plasma lens for collider FF system (Snowmass)
  - Oide effect
  - Background production

Transverse Density Gradient

- Strong transverse density gradient could lead to interesting new use cases
  - “Plasma Dipole” – strong dipole-like kick
  - “Plasma Dogleg / Chicane” – series of plasma dipoles
  - “Plasma Sextupole” – sextupole-like nonlinear force in one dimension; low sensitivity to offset in opposite dimension (unlike magnetic sextupole)

E-308 Desired Facility Upgrades

Sector 20 Probe Laser System Overhaul

- High energy transmission to target
- Optimized pulse compression
- Flat wavefront into final optics
- Uniform intensity profile
- Same requirements for diagnostic probe beam
- CU working with SLAC on new spatial filter

Electron Beam Quality and Stability

- Shot-to-shot and long-term stability
- Clean two-bunch beam with performance params

Further Beam Diagnostic Development

- Accurate measurements of full 6-D phase space
- Ability to measure <1 mm-mrad emittance beams (E330)
- Ability to measure <1 μm spot sizes (E330)

E-308 Collaboration

E31X and E305 members are considered E308 collaborators

Strathclyde: B. Hidding's group

UCLA: C. Joshi's group

SLAC: FACET-II group

Stony Brook: N. Vafaei-Najafabadi's group

Ecole Polytechnique: S. Corde's group

University of Oslo: E. Adli's group

University of Colorado Boulder: M. Litos's group

E-308 Publications and Students

University of Colorado Boulder Students

- **Chris Doss – Ph.D. expected in 2023**
- Robert Ariniello – now at SLAC
- Keenan Hunt-Stone – now in law school
- Valentina Lee
- Claire Hansel
- Numerous undergraduates

Relevant Publications

- C. E. Doss, et al., “Laser-ionized, beam-driven, underdense, passive thin plasma lens”, Phys. Rev. Accel. Beams 22, 111001 (2019)
- C. E. Doss, et al., “Underdense Plasma Lens with a Transverse Density Gradient”, in preparation, will be submitted and on arxiv very soon