E308 FY22 Progress and Plans for FY23

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FACET-II PAC 2022 – SLAC Nat’l Lab
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

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)

<table>
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<th>Type</th>
<th>$K \text{ [m}^{-2}\text{]}$</th>
<th>$L \text{ [mm]}$</th>
<th>$f \text{ [cm]}$</th>
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<td>Plasma</td>
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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
- 2024: High-performance two-bunch plasma lens studies
- 2025: Oide studies; utilize plasma lens for other experiments
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
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

$55.1 \mu m$, $10^{16}$ cm$^{-3}$

$70.41 \text{ cm}$

$108.2 \text{ cm}$
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
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

APS DPP Meeting - Oct. 19, 2022
Ongoing Analysis of Commissioning Data:

- Scanned plasma density (gas jet pressure)
- Scanned imaging spectrometer object plane
- Goal: measure beam waist ($\beta^*$) 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
**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
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., “Underdense Plasma Lens with a Transverse Density Gradient”, in preparation, will be submitted and on arxiv very soon