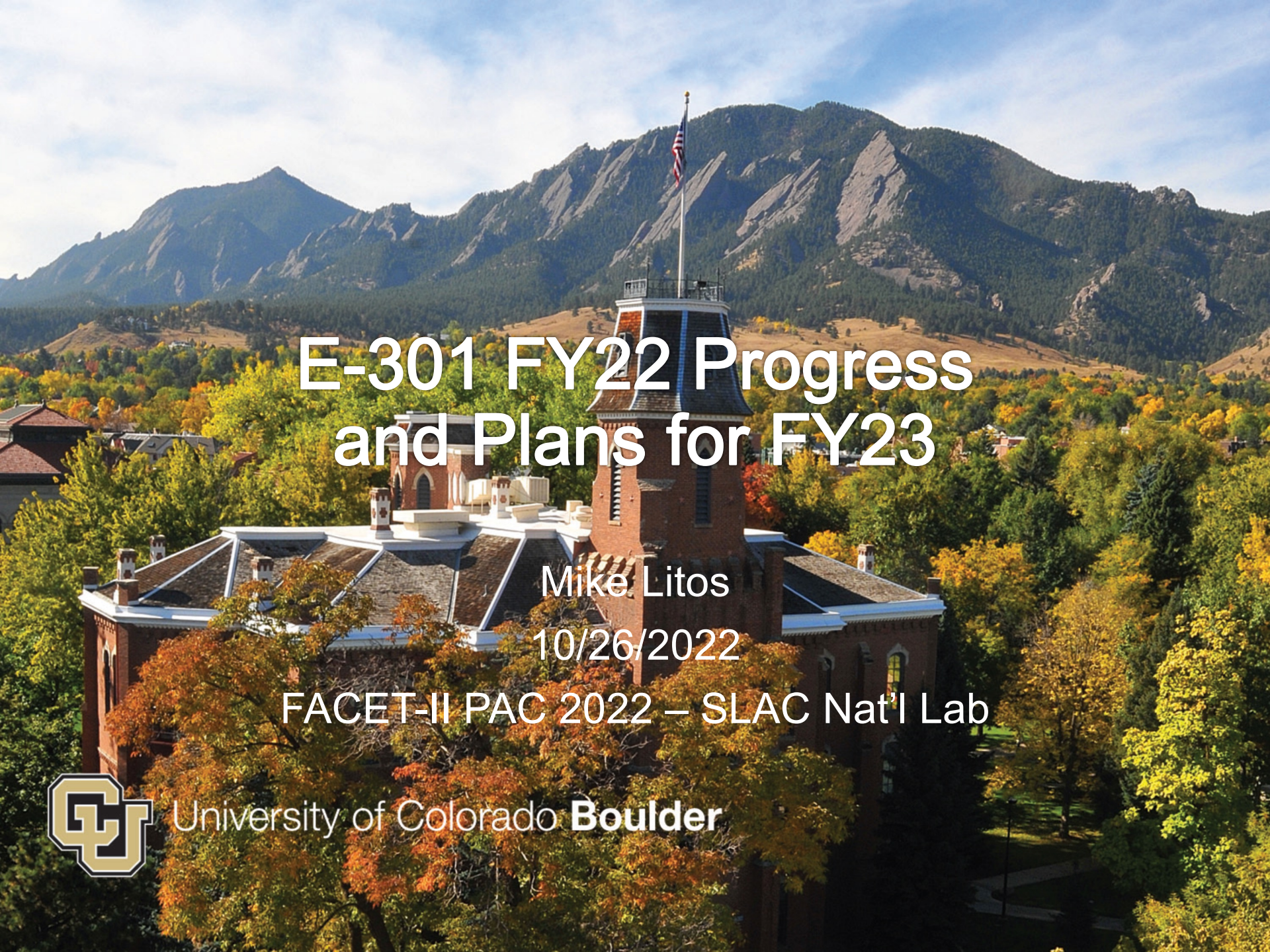


E-301 FY22 Progress and Plans for FY23

Mike Litos

10/26/2022

FACET-II PAC 2022 – SLAC Nat'l Lab

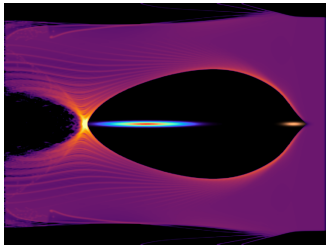
University of Colorado **Boulder**

E-301 Science Goals

E-301: PWFA in a laser-ionized, unconfined gas plasma source

Unique features:

- semi-arbitrary density profile controlled by laser focusing
- rapid tunability of plasma density and length
- permits localized gas jets of different species along main filament
- highly accessible to diagnostics

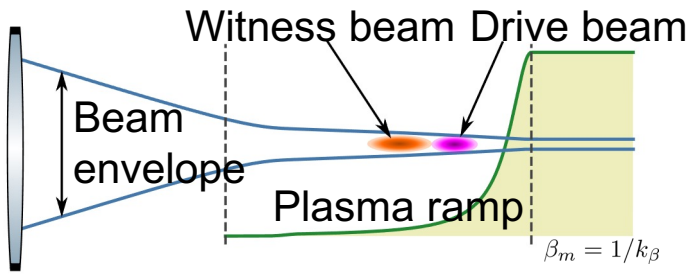


Science Goals:

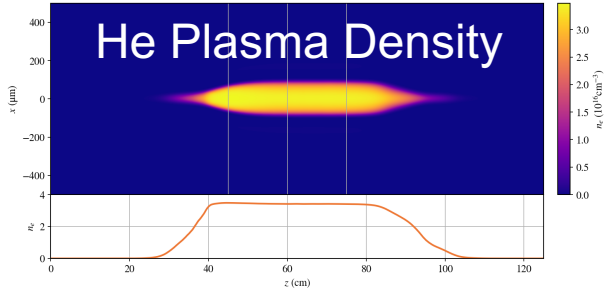
- Optimal performance PWFA stage at 10 GeV scale (**2-3 years**)
  - High energy gain, efficiency, and low energy spread
  - Full charge transmission and emittance preservation
- Detailed PWFA physics studies (**2-3 years**)
  - Longitudinal beam dynamics: loading, transformer ratio, efficiency
  - Transverse beam dynamics: chromatic phase mixing, hosing (E302)
- Platform for other experiments (**2-5 years**)
  - High brightness beam injection (E304, E307, E31X)
  - Narrow channel electron and positron PWFA (E333)
  - Ion channel laser (E306)
  - PWFA afterburner (Look out at the next PAC!)

E-301 Experimental Timeline

2018-2021:
- Advancement of theory - multiple papers
- Development of simulation tools
- Experimental planning and design
- Diagnostic development and testing
- Hardware installation and commissioning at FACET-II



2022:
- Continued commissioning at FACET-II
- Summer: Optical testing of PWFA diffractive lenses
- Summer: successful laser ionization of 20 mm gas jet with axilens
- Summer: e-beam sent through laser-ionized gas jet (see E-308 talk)
- Fall: Installation of Li PWFA diffractive lenses at FACET-II
- Fall: Attempt to ionize H2 with Li diffractive lenses (laser not quite ready)

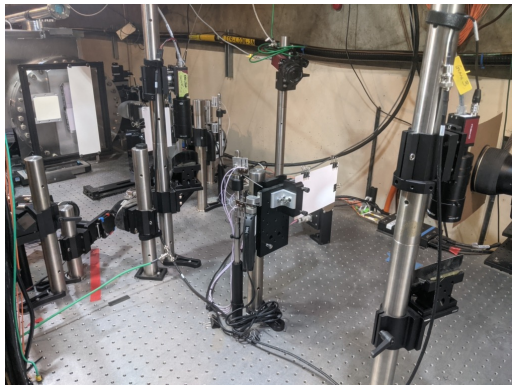


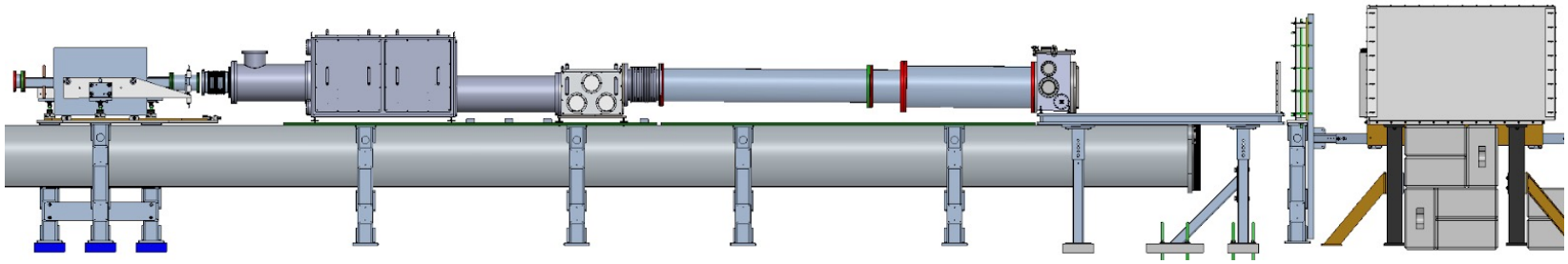
Future:
- Ongoing: Reassess and optimize FACET-II laser system
- Nov. 2022: successfully ionize plasma with diffractive lenses
- Dec. 2022: send single bunch through laser-ionized plasma
- Jan. – June 2023: single bunch PWFA studies – beam matching of tail
- July – Dec. 2023: initial two-bunch PWFA studies – clean accel. of witness
- 2024: high-performance two-bunch PWFA studies – emittance preservation
- 2025: laser-ionized, meter-scale gas jet PWFA

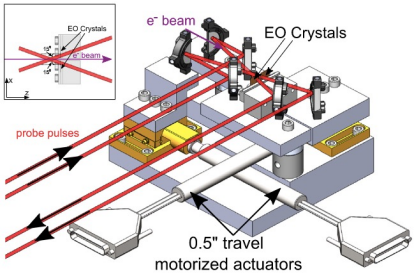
E-301 Diagnostics and Observables

Primary Diagnostic Systems

- Standard upstream diagnostics (charge, spectrum, etc.)
- Imaging spectrometer
- Betatron radiation screens
- EOS-BPM
- ML phase space reconstruction (E327)
- Plasma diagnostics (E324)







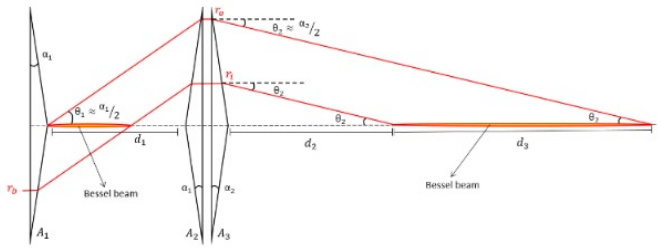
Experimental Observables

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

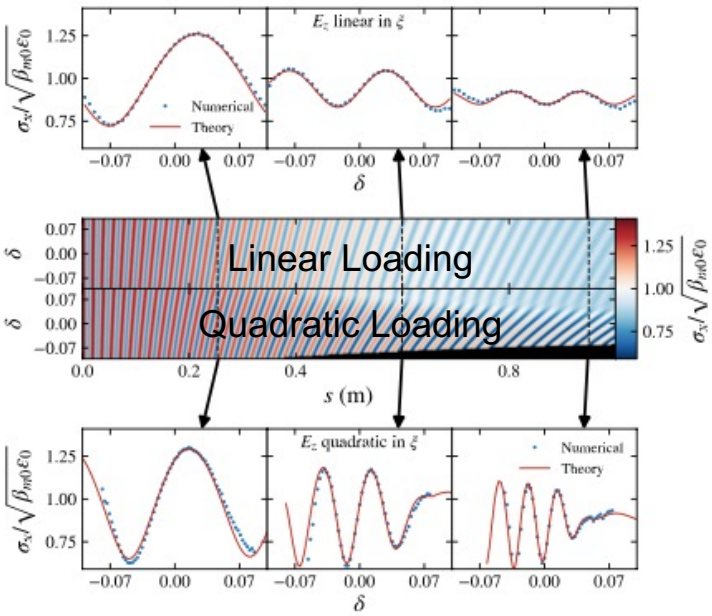
E-301 Progress to Date (1)

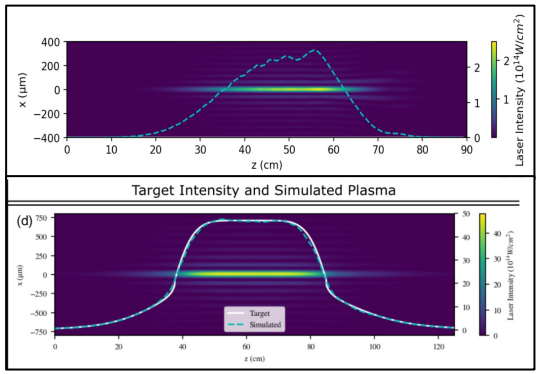
2018-2022 University of Colorado:

- PWFA beam theory development: 3 papers
- PWFA particle tracking code development
- Betatron radiation code development
- PIC simulations of experimental parameters
- Plasma source density profile design
- Custom vacuum pipe design and installation
- Laser ionization code development
- Laser focusing scheme development
- Diffractive lens design and fabrication
- Successful testing of diffractive lenses
- Plasma diagnostic development and testing
- Beam diagnostic techniques and hardware
  - with SLAC and Ecole Polytechnique
- Testing of alternative “triple axicon” scheme



Energy Slice Evolution



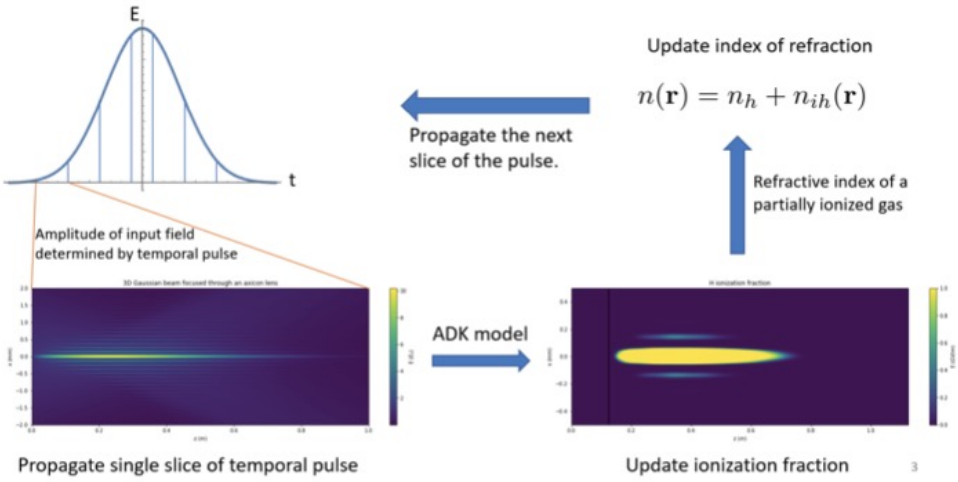


E-301 Progress to Date (2)

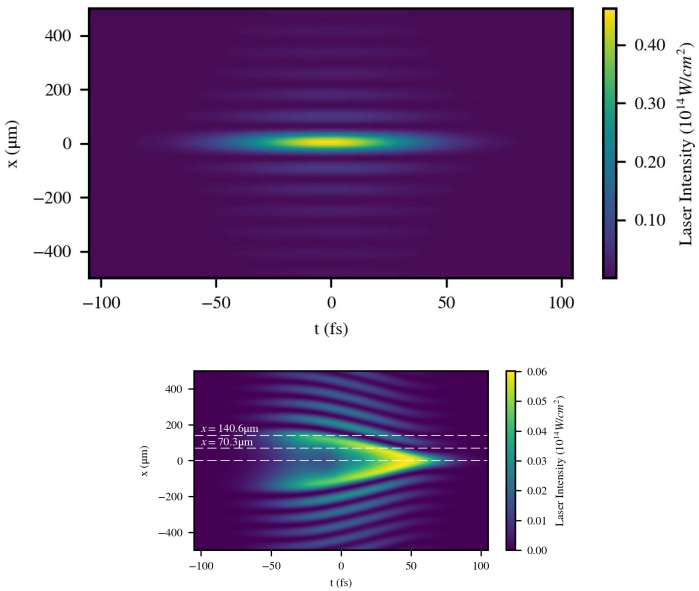
Developed custom split-step Fourier code to simulate...

- Propagation of laser after arbitrary phase manipulation (e.g. diffractive lenses)
- Time-slice resolved ionization of gas
  - performed deep dive into ionization models (ADK, PPT, TDSE models)
- Time-slice resolved refractive response to plasma formation
- Found that plasma refraction can be advantageous, widening plasma filament

Split-step Fourier algorithm



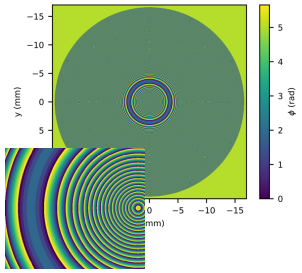
Wider plasma due to refraction

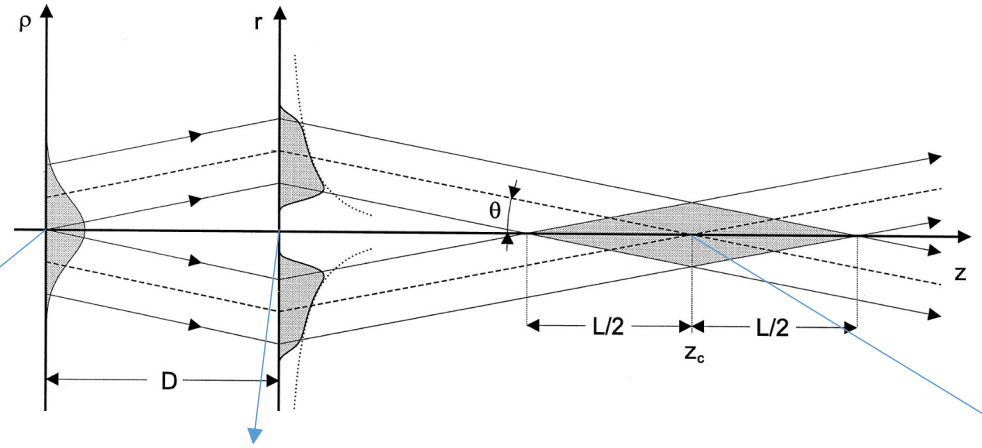


E-301 Progress to Date (3)

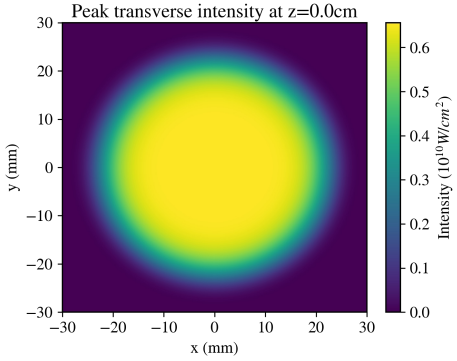
Fully developed scheme for producing laser-ionized plasma in unconfined gas utilizing a tandem pair of custom diffractive lenses

- Lens 1: shapes radial intensity profile (create donut beam)
- Lens 2: removes residual phase and add axicon-like phase

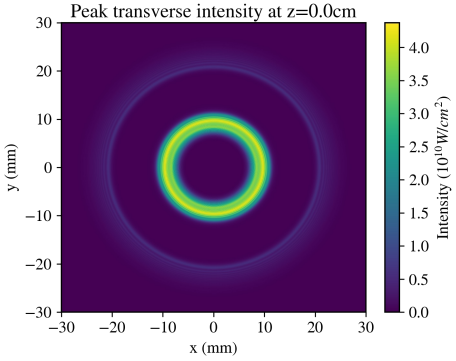




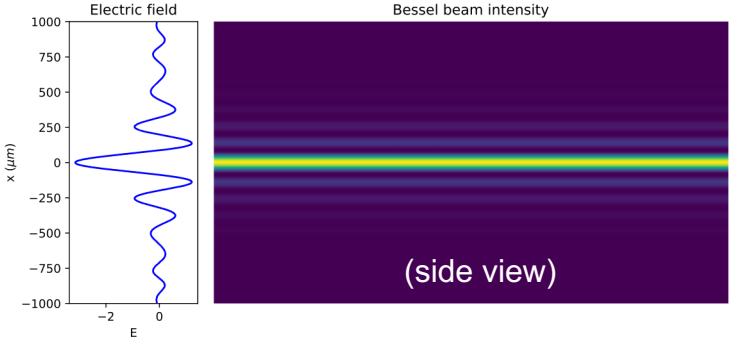
First Lens



Second Lens



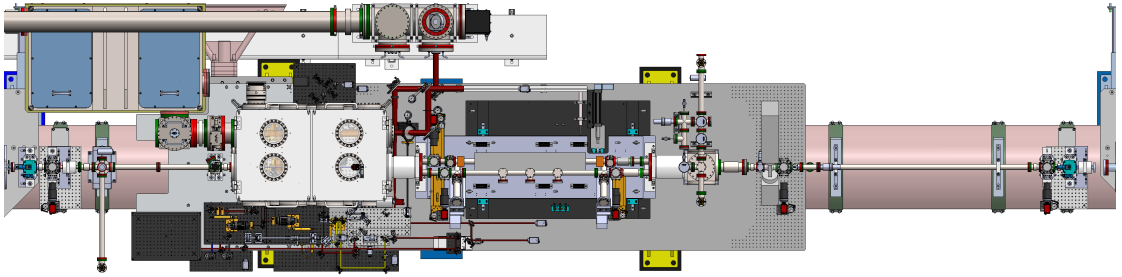
Focus Region

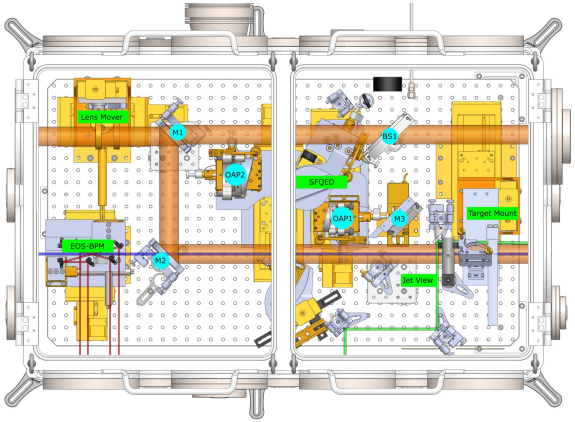


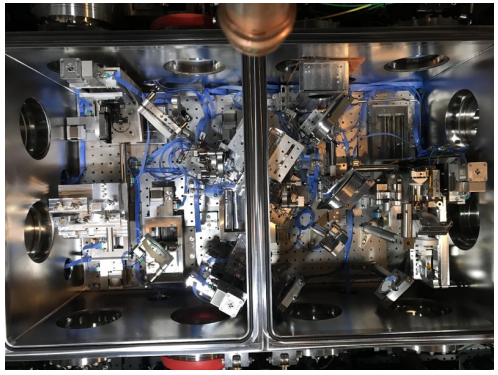
E-301 Progress to Date (4)

2018-2022 FACET-II:

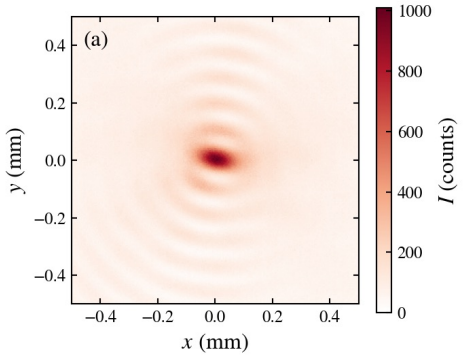
- Design of IP area to accommodate PWFA experimental hardware
- Installation of IP area hardware
- Commissioning of FACET-II laser system
- Design and installation of laser optics
- Installation and alignment of diffractive lenses (for Li)
- First attempt to produce plasma in H2 – laser not quite ready
- Ongoing: optimization of laser system







First Bessel beam from diffractive lenses at FACET-II



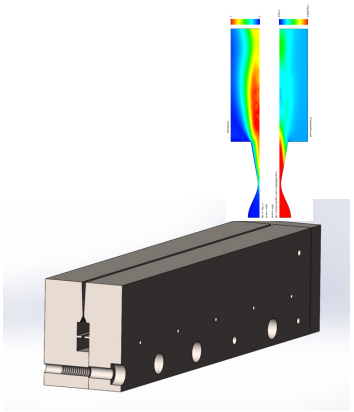
E-301 Future Evolution

Meter-Scale Gas Jet

- Extreme beams with ~1 mm-mrad emittance will beam ionize plasma ramps of unconfined laser-ionized gas plasma source
  - bad for percent-level emittance preservation
  - only solution: control gas profile

- High rep. rate requires rapid removal of heat from gas/plasma system
  - only solution(?): supersonic transverse flow of gas/plasma

- Future E-301 plasma source: Laser-ionized, meter-scale elongated gas jet
  - multi-centimeter gas jets proven in LWFA
  - need to control edge flow to shape ramps
  - need density uniformity along length
  - need rapid gas removal from vacuum chamber
  - need multiple degrees of freedom to align to e-beam
  - some design progress has already made



E-301 Desired Facility Upgrades

Continued Improvement of Sector 20 Laser System

- 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)

Additional Experimental Vacuum Chamber

- Second large experimental vacuum chamber in IP area

E-301 Collaboration

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-301 Publications and Students

University of Colorado Boulder Students

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

Relevant Publications

- R. Ariniello, et al., “Chromatic Dynamics of an Electron Beam in a Plasma Based Accelerator”, (submitted 2022) arXiv:2111.02332
- R. Ariniello, et al., “Transverse beam dynamics in a plasma density ramp”, Phys. Rev. Accel. Beams 22, 041304 (2019)
- M. Litos, et al, “Beam emittance preservation using Gaussian density ramps in a beam-driven plasma wakefield accelerator”, Phil. Trans. R. Soc. A 337, 20180181 (2019)
- K. Hunt-Stone, et al., “Electro-Optic Beam Sampling Beam Position Monitor”, Nucl. Istrum. Methods Phys. Res. A 999, 165210 (2021)