E-310 + E-31x Progress in FY24 and Plans for FY25

Bernhard Hidding, Edgar Hartmann, Andrew Sutherland, Fahim Habib *et al.*

FACET-II 2024-11-19

SLAC National Accelerator Laboratory

Outline

- Intro (Bernhard)
- 1^{st} Beamtime report (Edgar Hartmann)
- Next steps and plans (Bernhard)

Invited experiments FY 24/25

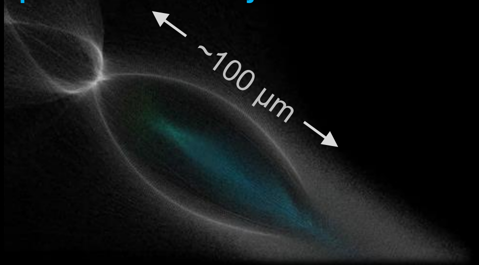
Heinrich Heine Universität Düsseldorf

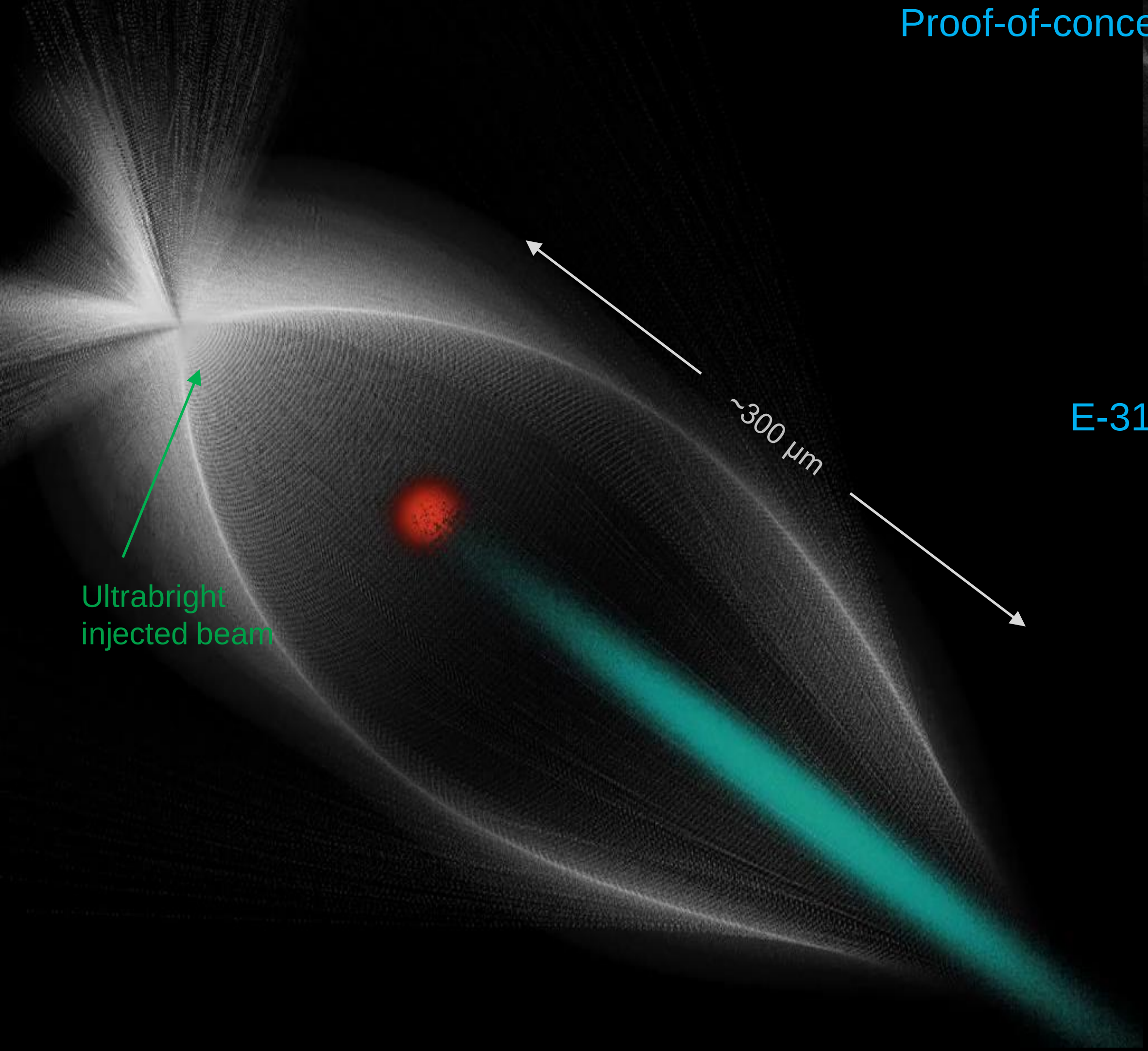
- E-310 “Trojan Horse-II” (PIs Hidding, Rosenzweig)
- E-311 “Plasma Torch Optical Density Downramp Injection” (PIs Hidding, Rosenzweig, Heinemann)
- E-315 “Plasma Afterglow Attosecond Metrology” (PIs Hidding, Sutherland)

Further accepted proposals

- E-313 “Multibunch dechirper for ultrahigh 6D brightness beams” (PIs Hidding, Habib)
- E-316 “Icarus: Transient tunneling ionization of crossing laser and electron beams” (PIs Hidding, Heinemann)
- E-312 “High Brightness Electron Beams from Dragon Tail Injection (PIs Rosenzweig, Hidding)
- E-314 “Experimental Investigations of Ion Collapse in the PWFA” (PIs Rosenzweig, Hidding)

Proof-of-concept E-210: Trojan Horse at FACET: µm-rad





E-310: Trojan Horse-II at FACET-II: 10 nm-rad

Collinear geometry
incoming beam precision
larger blowout

Key components for E-310, E-311, E-315

1. Stable electron beam > 5 kA. Need strong wake to trap cold electrons from rest.

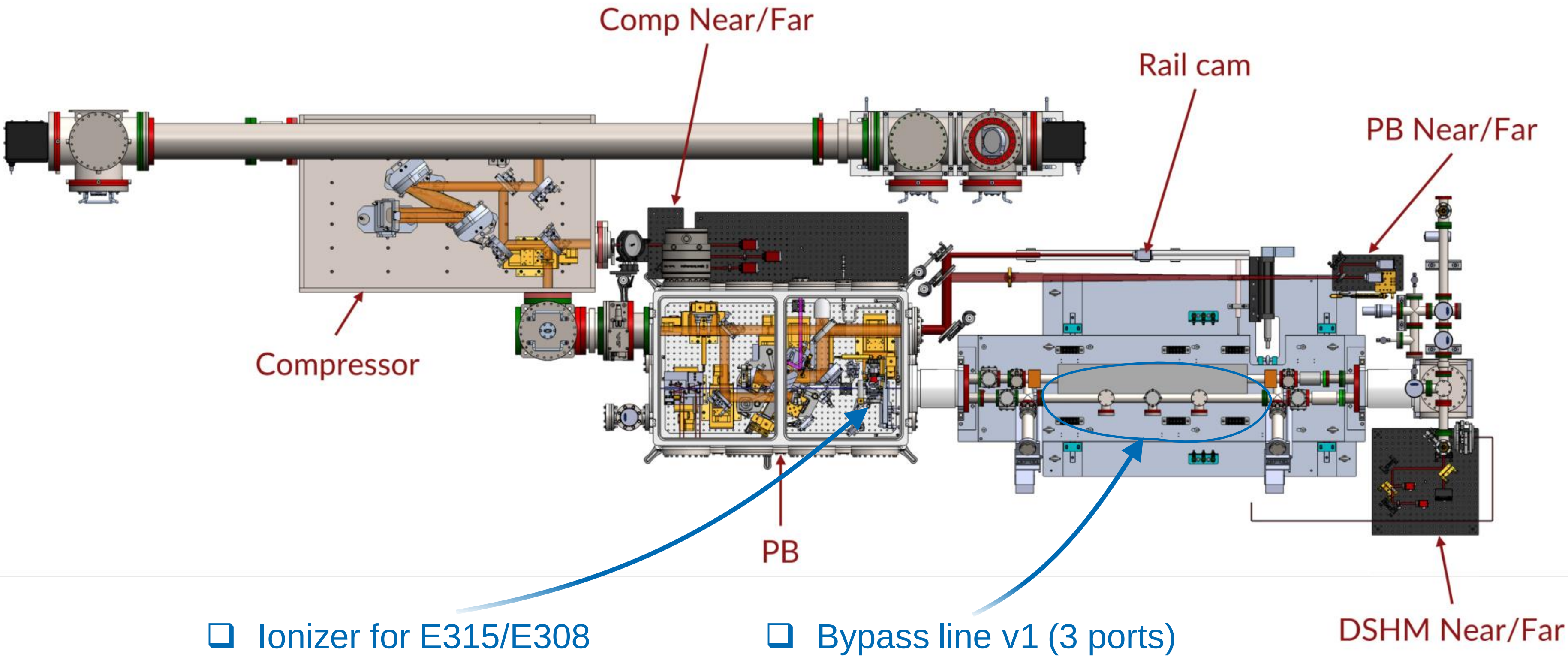
2. Two-component gas with low (LIT) and high ionization threshold (HIT) component. LIT supports wake, HIT used for plasma photocathode laser etc. LIT/HIT combination H_2/He (as at FACET) or He/He^+ or Ar/Ar^+…

3. Preionizer laser to generate wide plasma channel with selective ionization capability (e.g. only LIT, not HIT)

4. Spatiotemporally synchronized (injector) laser pulse for Trojan Horse and Plasma Torch in 90° or collinear geometry

5. Ionizer at PB (E-315/E-308), and downstream of PB (E-310, E-311 etc.)

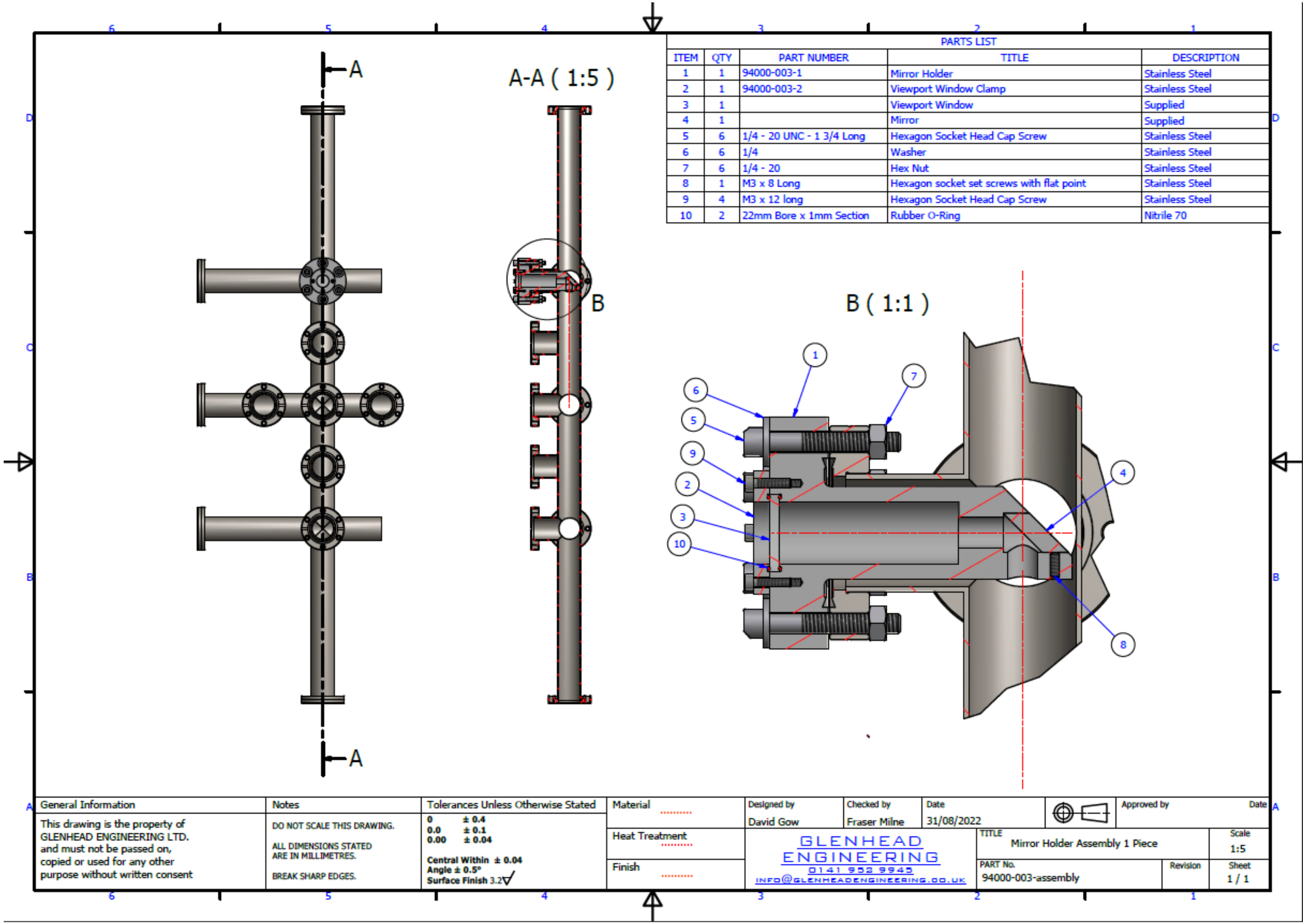
Old bypass line



- Ionizer for E315/E308
- Bypass line v1 (3 ports)

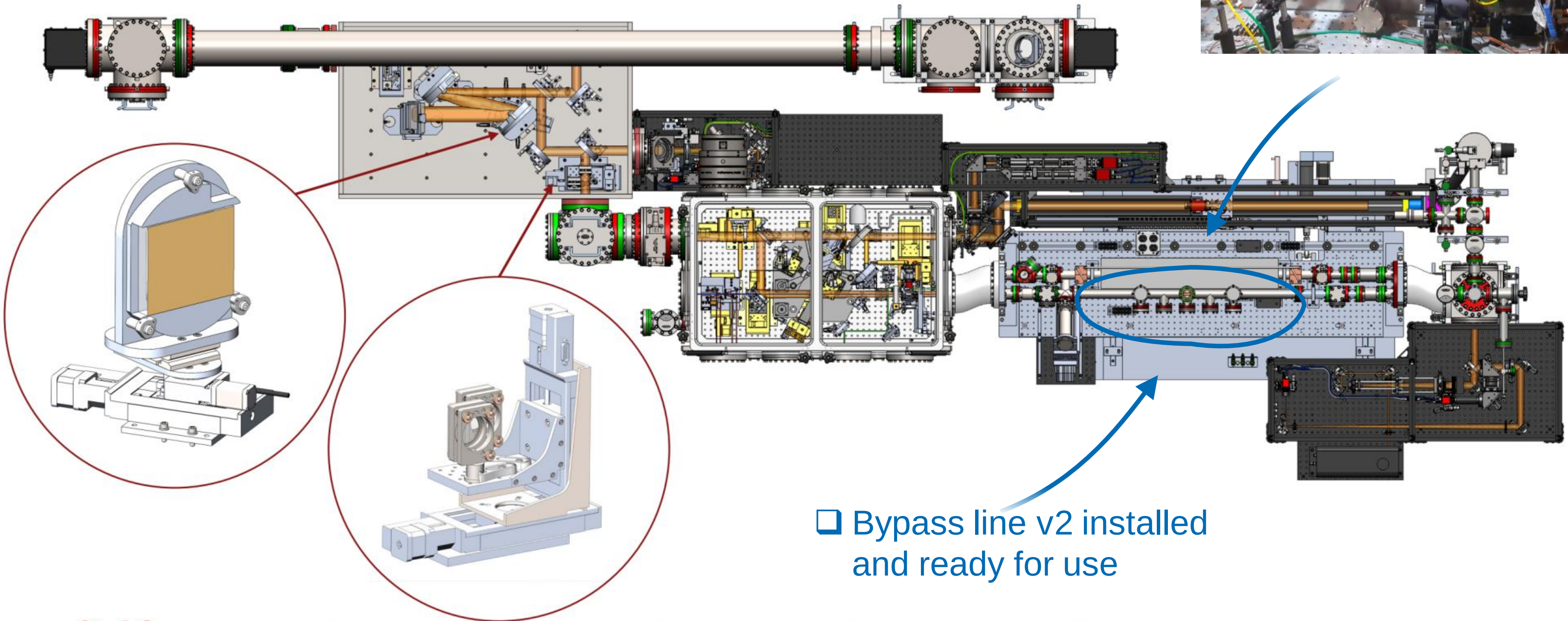
Bypass line 2.0

- 2 twins produced in Scotland (Sutherland)
- One shipped to SLAC, the other kept in UK & Germany for further prototyping
- Designed to facilitate
  a) more viewports (e.g. for plasma source imaging such as E-301 and E-31x) and
  b) to allow Trojan and plasma torch injection in 90° and collinear



ITEM	QTY	PART NUMBER	TITLE	DESCRIPTION
1	1	94000-003-1	Mirror Holder	Stainless Steel
2	1	94000-003-2	Viewport Window Clamp	Stainless Steel
3	1		Viewport Window	Supplied
4	1		Mirror	Supplied
5	6	1/4 - 20 UNC - 1 3/4 Long	Hexagon Socket Head Cap Screw	Stainless Steel
6	6	1/4	Washer	Stainless Steel
7	6	1/4 - 20	Hex Nut	Stainless Steel
8	1	M3 x 8 Long	Hexagon socket set screws with flat point	Stainless Steel
9	4	M3 x 12 long	Hexagon Socket Head Cap Screw	Stainless Steel
10	2	22mm Bore x 1mm Section	Rubber O-Ring	Nitrile 70

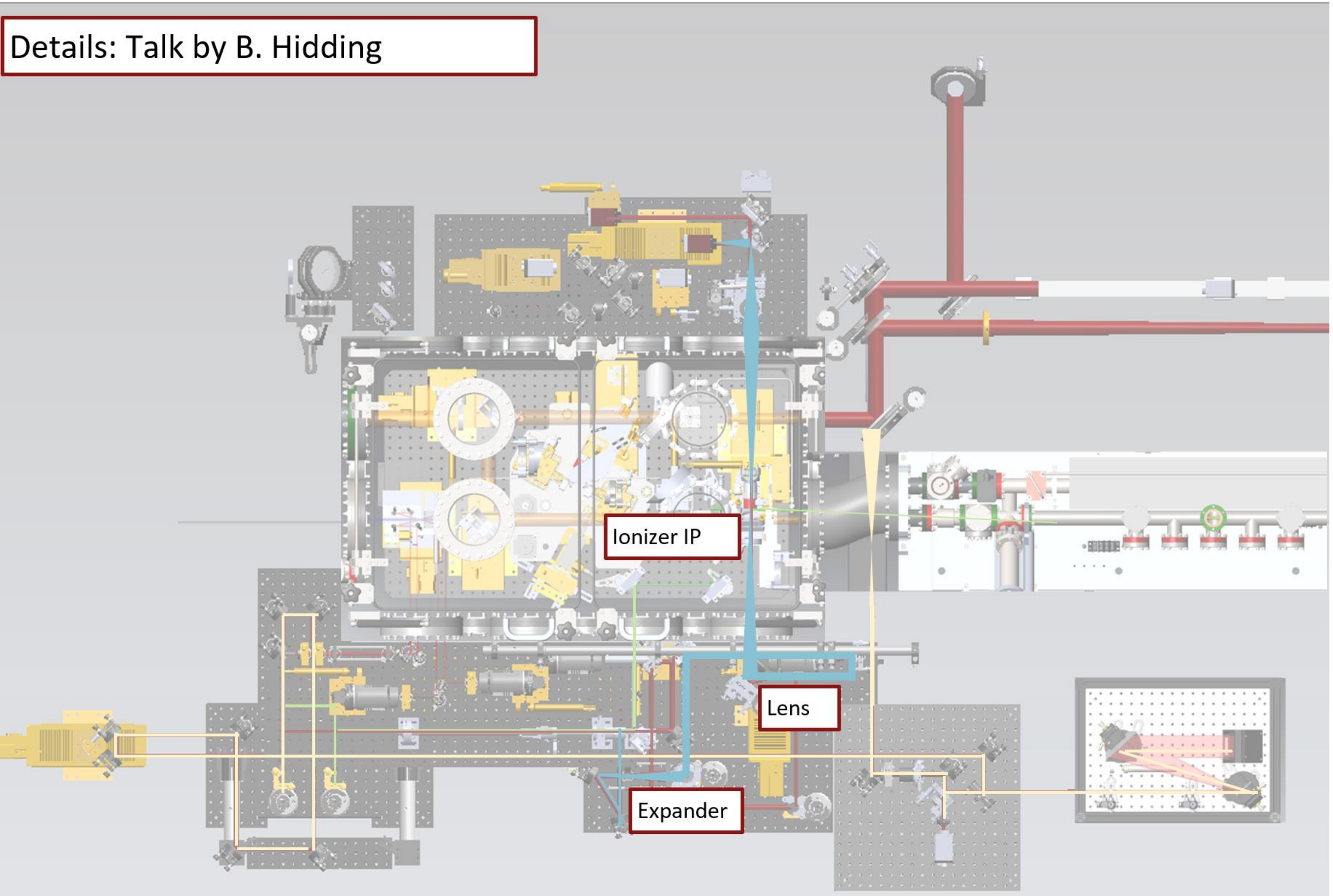
Bypass line 2.0 installed



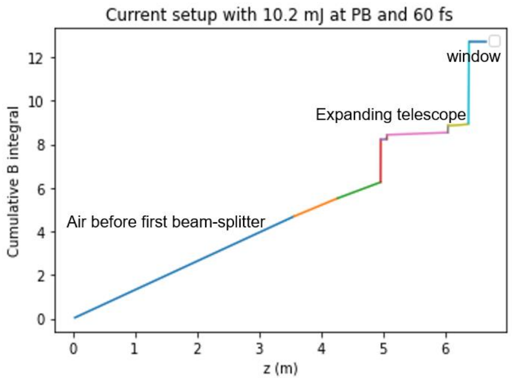
❑ Bypass line v2 installed and ready for use

Sector 20 probe beam: ionizer

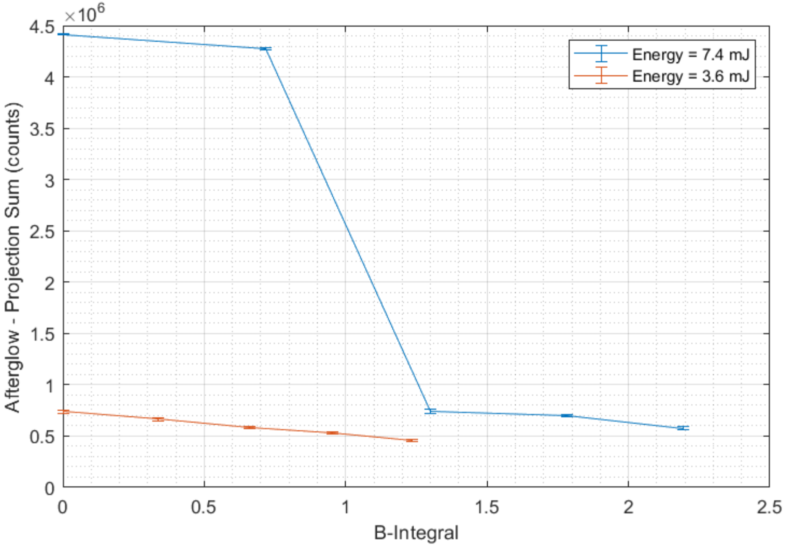
Details: Talk by B. Hidding

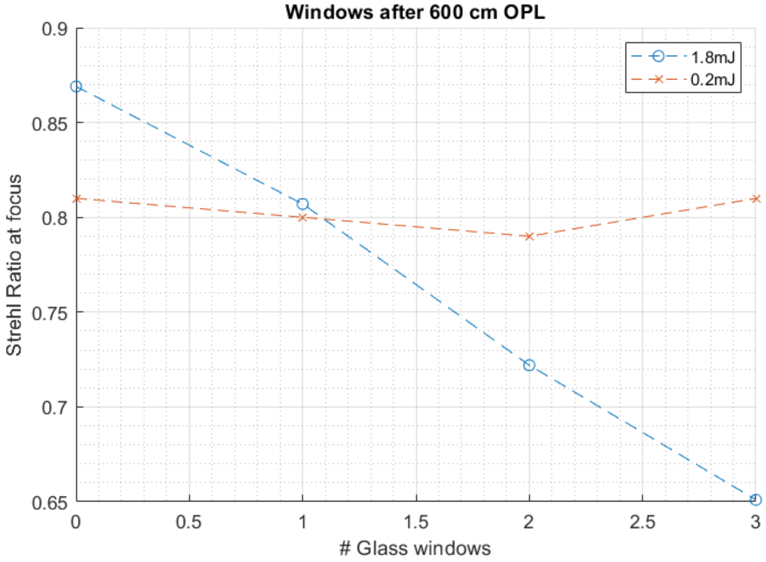


- OAP replaced with f=600 mm lens
- No ionization, yet
- B-integral studies performed by L. Berman and A. Sutherland



B-Integral study





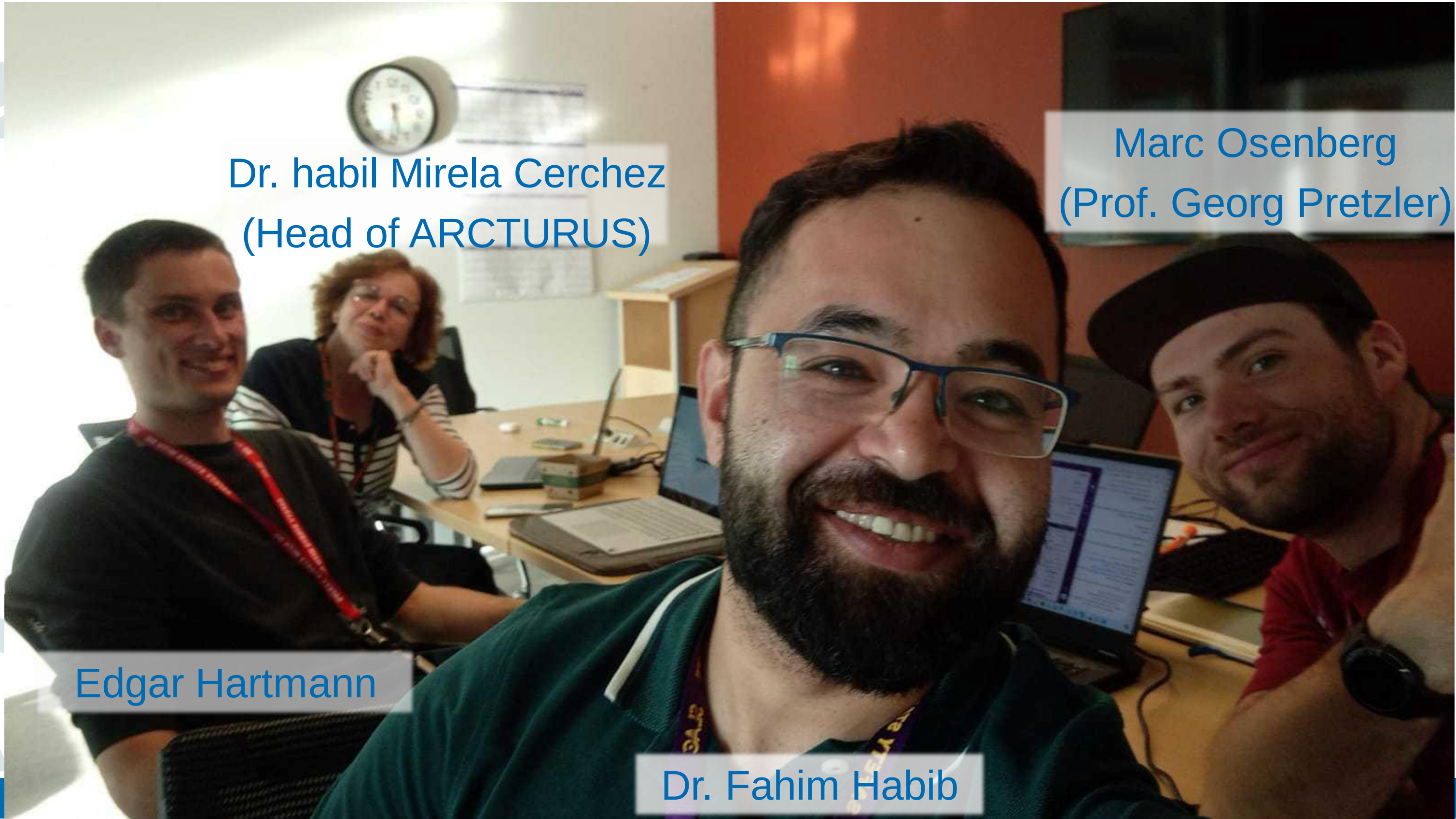
Ionization tests at Strathclyde

- Ionization cuts-off when $\int B > 1$
- Becomes a worse problem when compensating poor focus quality with increased energy

Focus Quality tests at FACET-II

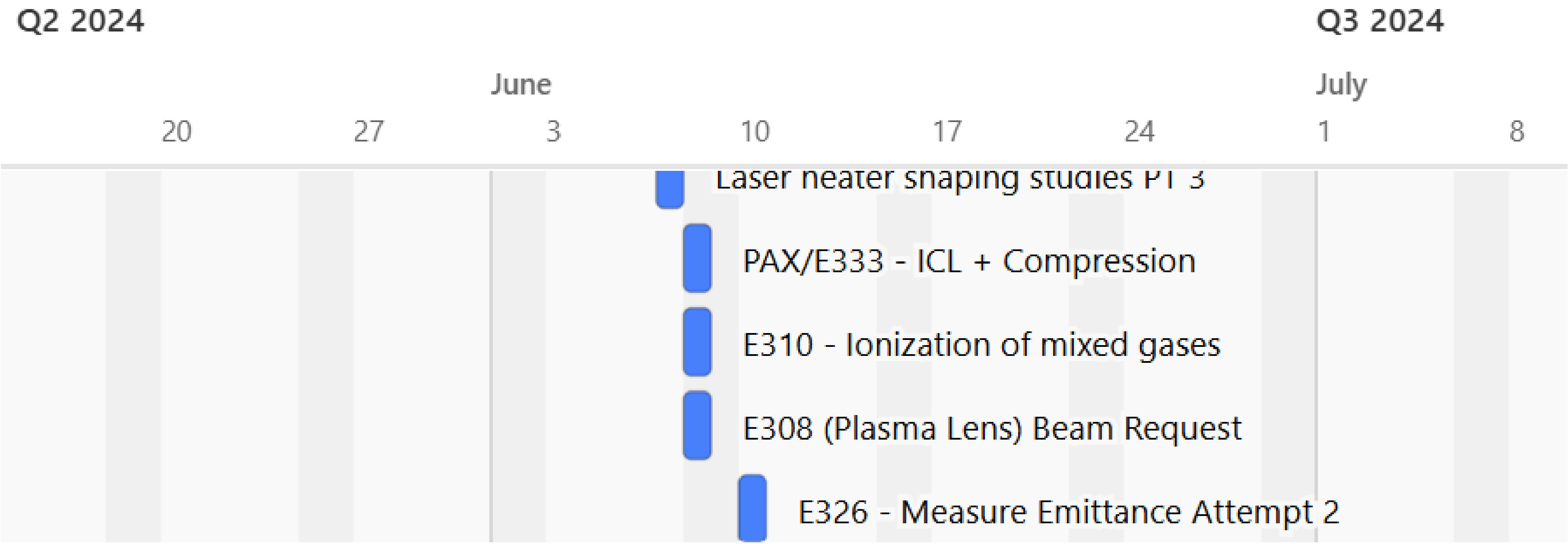
- Air path length not significantly affecting quality
- SiO2 Glass window makes a measurable difference

New SLAC Users from Düsseldorf 2024



Beamtime June 2024!

Heinrich Heine
Universität Düsseldorf



E-310 Trojan Horse-II
Ionization of mixed gases
Beamtime Report June 2024

FACET-II PAC Meeting 2024

Edgar Hartmann, HHU PhD student

Outline

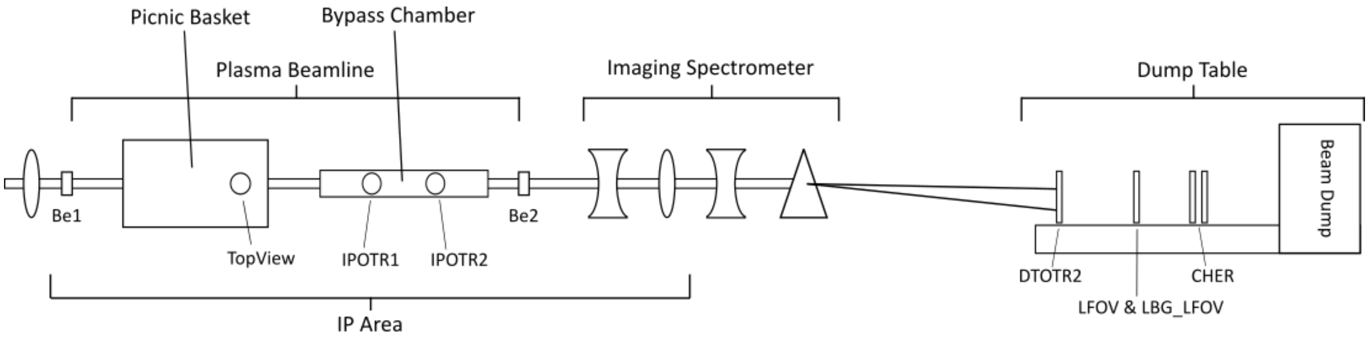
Heinrich Heine
Universität Düsseldorf

Introduction

- First E-310 shift, single 8h shift
- Shift personnel: Alex Knetsch, Brendan O’Shea, Nathan Majernik, Fahim Habib, Andrew Sutherland, Mirela Cerchez, Marc Osenberg, Edgar Hartmann
  - Contributions: Robert Ariniello, Ivan Rajkovic
- Selective ionization crucial for Trojan Horse injection
  - Mixed gases required, only single gas experiments at FACET-II so far

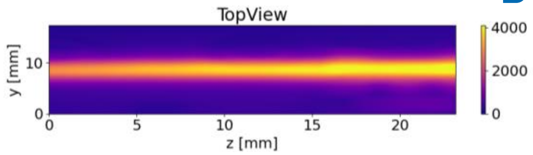
Set-Up

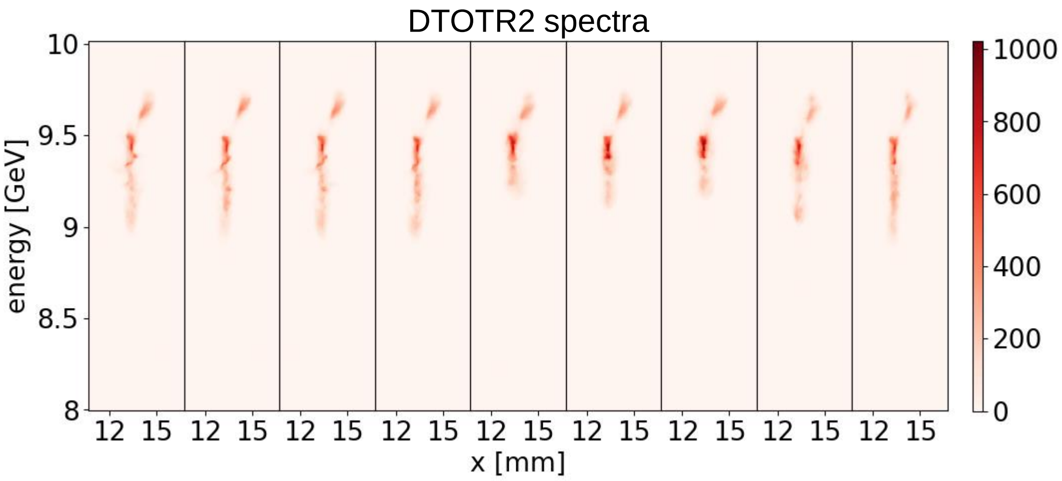
- Picnic Basket and bypass chamber in static fill
  - Either 50/50 H2/He mixture (mol%) or pure He
- Observation of the plasma afterglow with the TopView, IPOTR1 and IPOTR2 cameras
  - All cameras are equipped with 590 nm bandpass filter (strong He line) on flippers
  - IPOTR1&2 additionally with 660 nm bandpass filter (strong H line) on flippers
- Detection of electron spectra on DTOTR2, LFOV or CHER
- Laser focused by axilens into the Picnic Basket
- Electron beam energy E=9.4 GeV with a charge of Q=1.6 nC



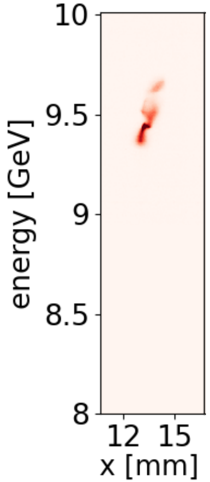
Self-ionization

- Observation of H2 and He self-ionization in the mixture
- No observed afterglow in pure He → He is only ionized in the mixture
- Several 100 MeV decelerated charge observed in the mixture → decelerating wakefield in self-ionized plasma





Reference shot without gas:



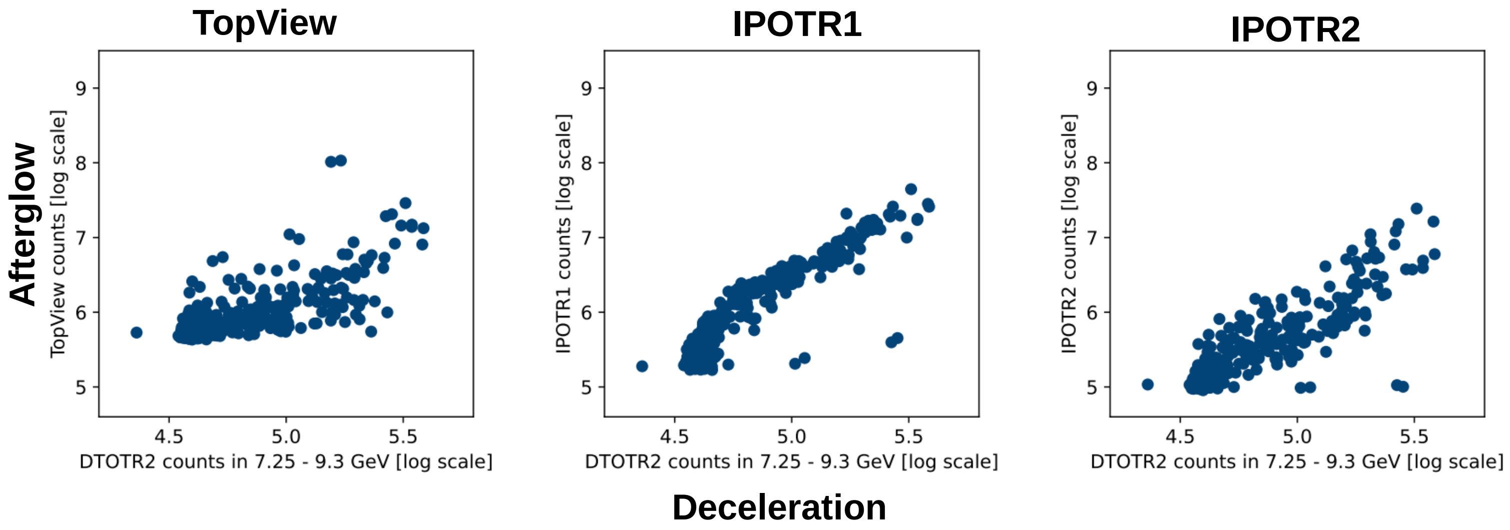
→ Decelerating field in the gas mixture

Afterglow-Deceleration correlations

E-315

Heinrich Heine Universität Düsseldorf

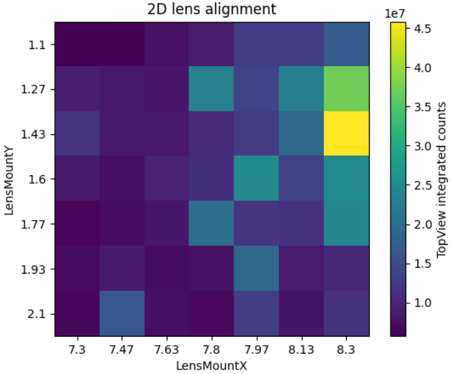
- Afterglow counts vs. sum of all counts on DTOTR2 below 9.3 GeV (down to 7.25 GeV, screen limit)
- eBeam focused to IPWS1 into the mixture, 590nm/He – bandpass filters in place

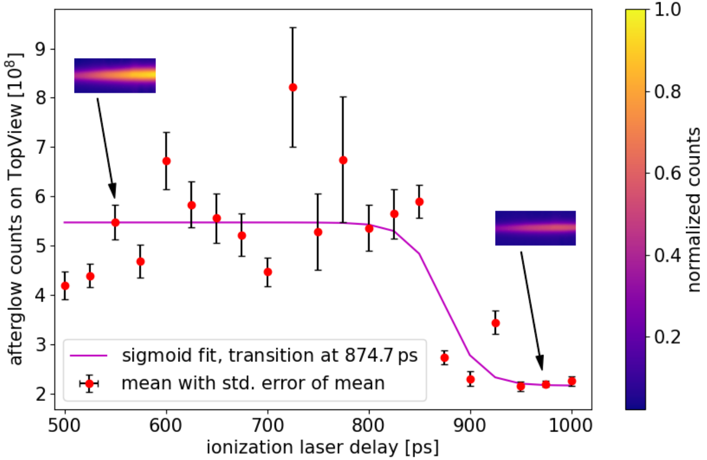


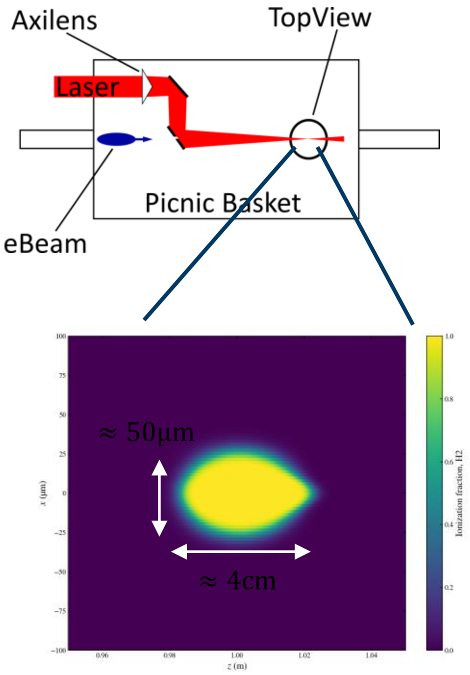
→ Linear correlation as a measure for energy deposition into plasma

Pre-ionization

- Ionization laser focused by axilens with an energy of 6.5 mJ
  - Creating a few centimeter long plasma
- eBeam focused to Picnic Basket center
- 2D axilens and eBeam alignment via the afterglow observed in TopView
- Delay scan to find temporal overlap of eBeam and laser-ionized plasma







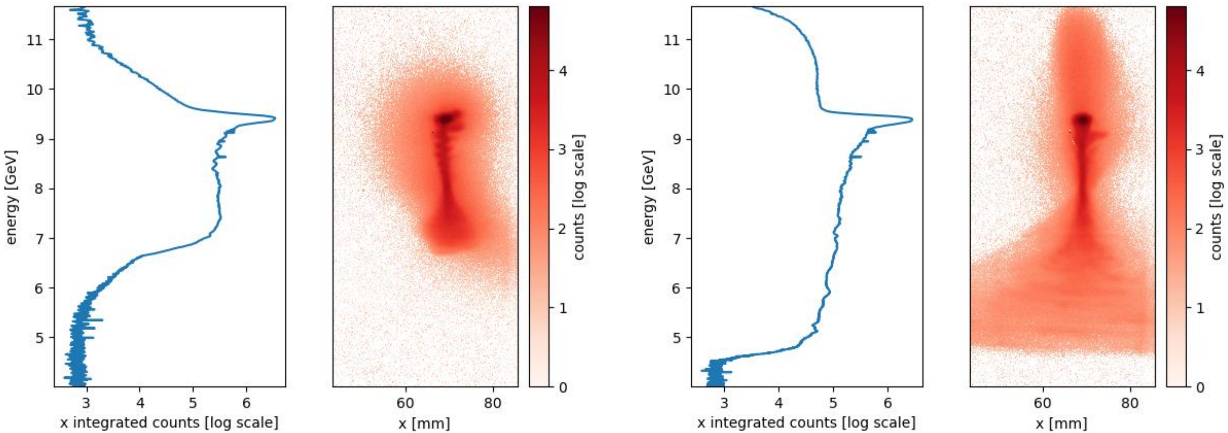
Simulation done by Robert Ariniello

→ Alignment of laser and eBeam via afterglow

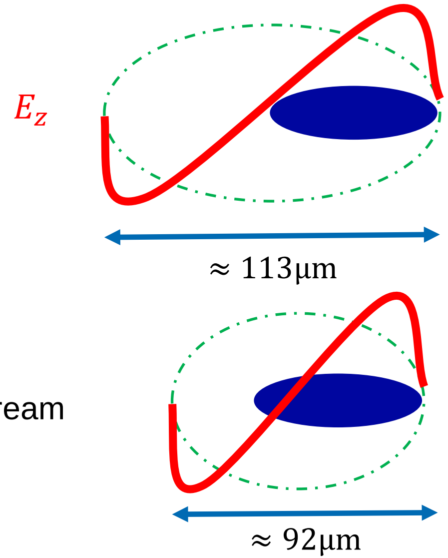
Pre-ionization

- Often decelerated charge is observed (left)
- Some shots show accelerated charge, likely when the pre-ionized plasma is hit properly (right)

CHER spectra



Reduction of blowout size due to higher plasma density, driver bunch tail injection $\sigma_z \approx 30\mu m$:

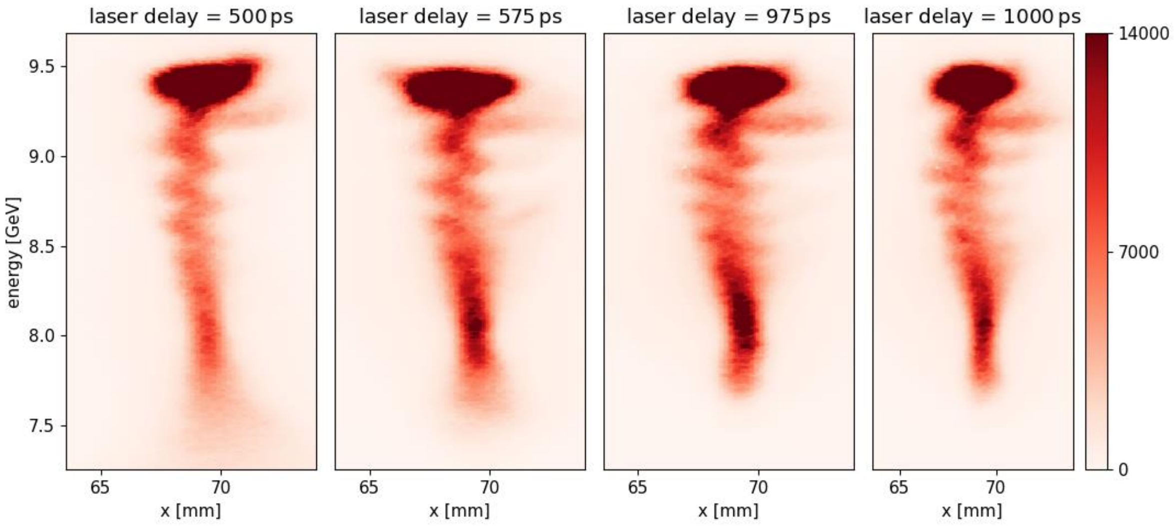


- Deceleration and acceleration not only in pre-ionized plasma, self-ionized plasma downstream of Picnic Basket is likely contributing

→ Wakefields in pre-ionized plasma

Additional observation

- Spectra of the laser delay scan show betatron oscillations
- Previous work where similar observations have been used to estimate accelerating field
- Further analysis in progress



Summary

- eBeam self-ionization in the H2/He mixture → towards selective ionization for Trojan Horse injection
- Deceleration in the self-ionized plasma
- Afterglow-Deceleration correlations as measure for energy deposition into the plasma → E-315
- Laser ionized plasma and eBeam alignment procedure via afterglow
- Wakes driven with pre-ionized plasma → Trojan Horse and longitudinal Torch injection
- Further analysis of betatron oscillations in the spectra is in progress

Some relevant publications

Heinrich Heine Universität Düsseldorf

- E. Oz et al., *Optical Diagnostics for Plasma Wakefield Accelerators*, AIP Conference Proceedings, 2004
- A. Knetsch et al., *Stable witness-beam formation in a beam-driven plasma cathode,* Physical Review Accelerators and Beams, 2021
- P. Scherkl et al., *Plasma photonic spatiotemporal synchronization of relativistic electron and laser beams*, Physical Review Accelerators and Beams 25.5, 2022
- L. Boulton et al., *Longitudinally resolved measurement of energy-transfer efficiency in a plasma-wakefield accelerator*, arXiv, 2022
- Y. Glinec et al., *Direct observation of betatron oscillations in a laser-plasma electron accelerator*, EPL 81.6, 2008

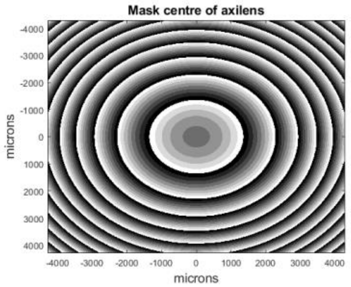
Plans FY25 and beyond

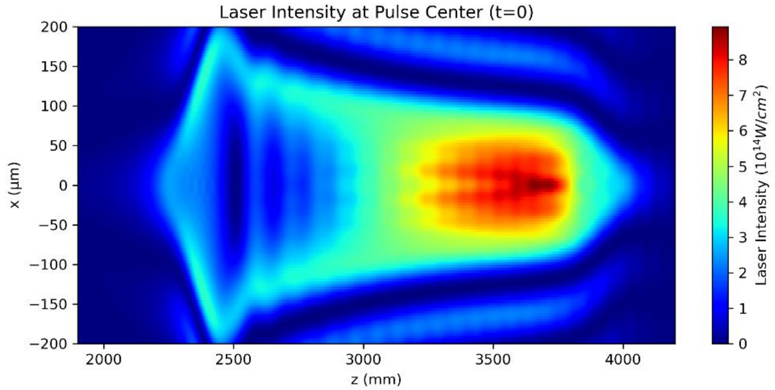
Heinrich Heine Universität Düsseldorf

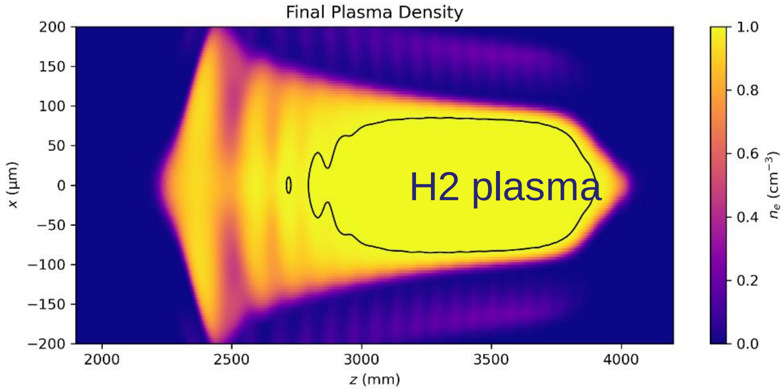
- Electron beam ok for E-310-312, should ideally be more stable for E315/316
- Afterglow proven extremely useful as expected
- Preionization optics to be tested
- Ionizer needs work/time (upstream and downstream)…
- E-310/11 optics in bypass line 2.0 to be commissioned
- Big downstream chamber “PB2”?

Plasma source for E31x

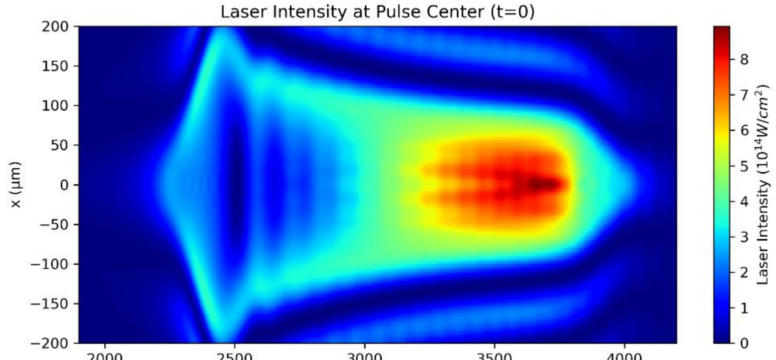
- Optics designed with U Colorado code (M. Litos et al., link to E-301) to design optimum optics for plasma channel generation (Adam Hewitt)
- Produced by NILT
- E.g. w/ 212 mJ, 55 fs FWHM, 20 mm top-hat intensity profile in H2/He:

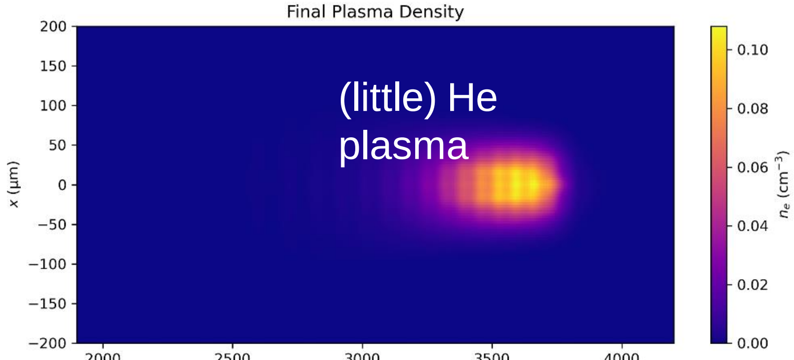






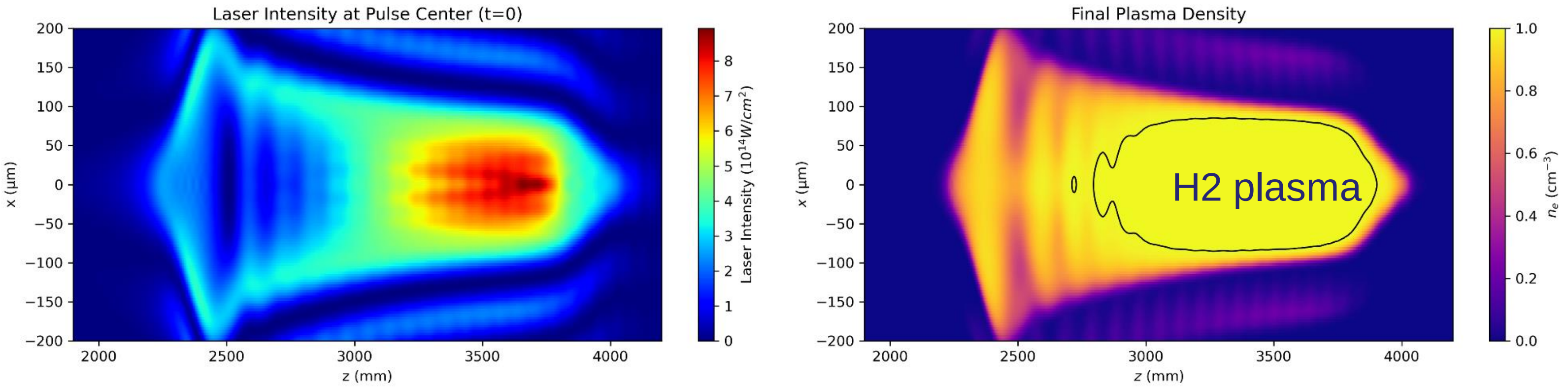
Big fat H2 plasma in 3.6e16 cm^{-3}, λ_p~175 µm



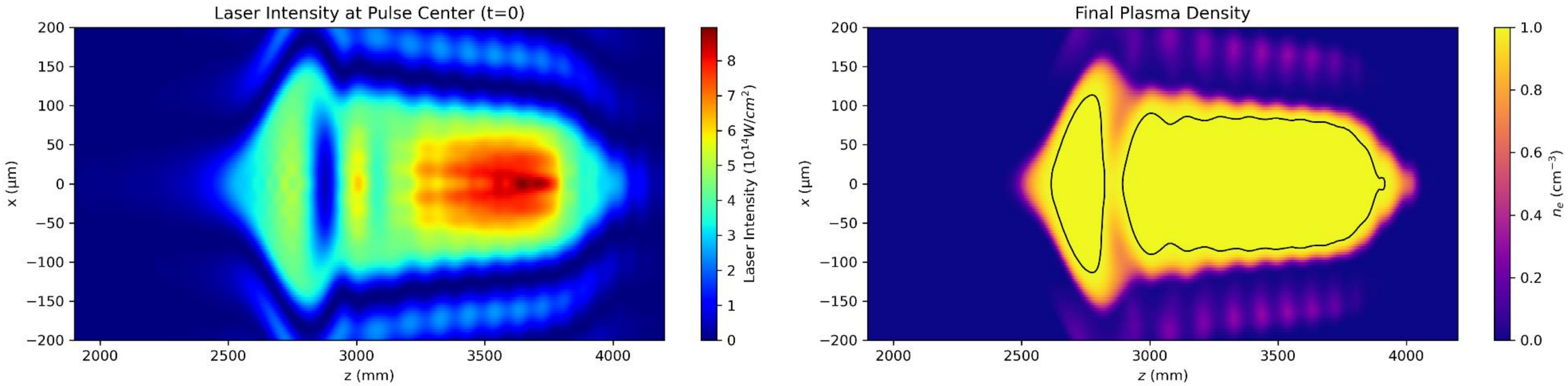


Plasma source for E31x

- First plasma blob not fully ionized, not useful.

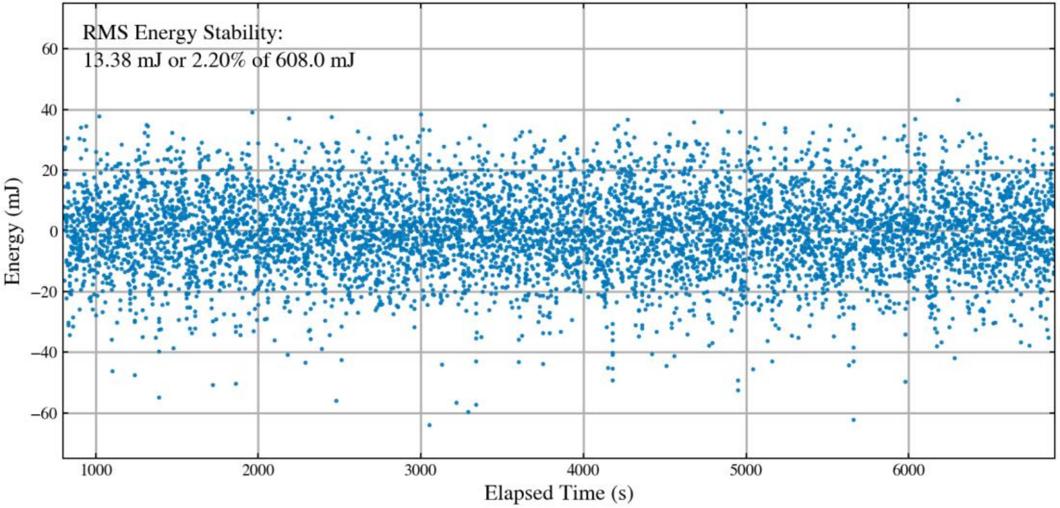


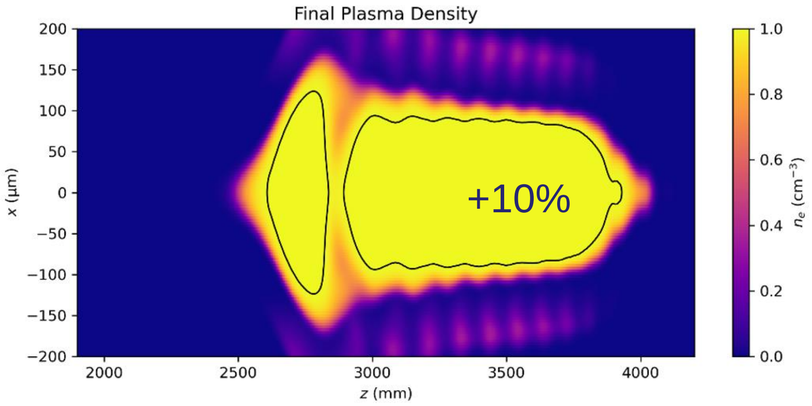
- Can get rid of this part by using central masks:

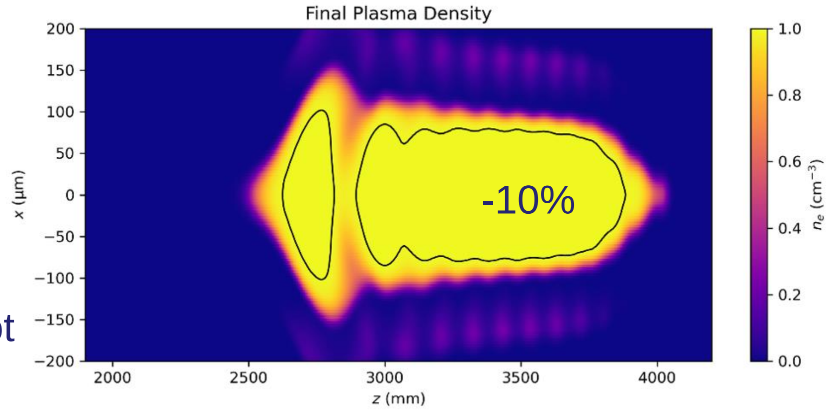


Plasma source for E31x

- Is preionization laser energy jitter critical?



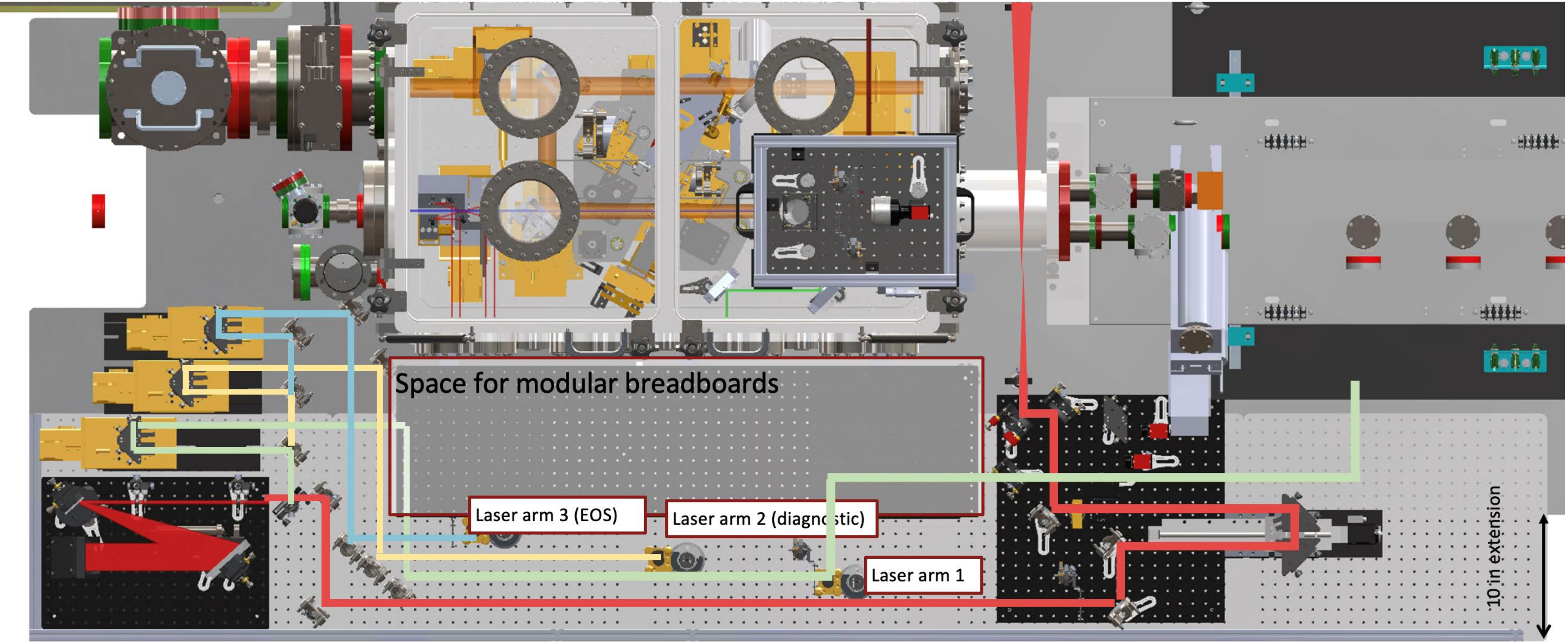




Maximum variance 60 mJ, so ~10% at 600 mJ

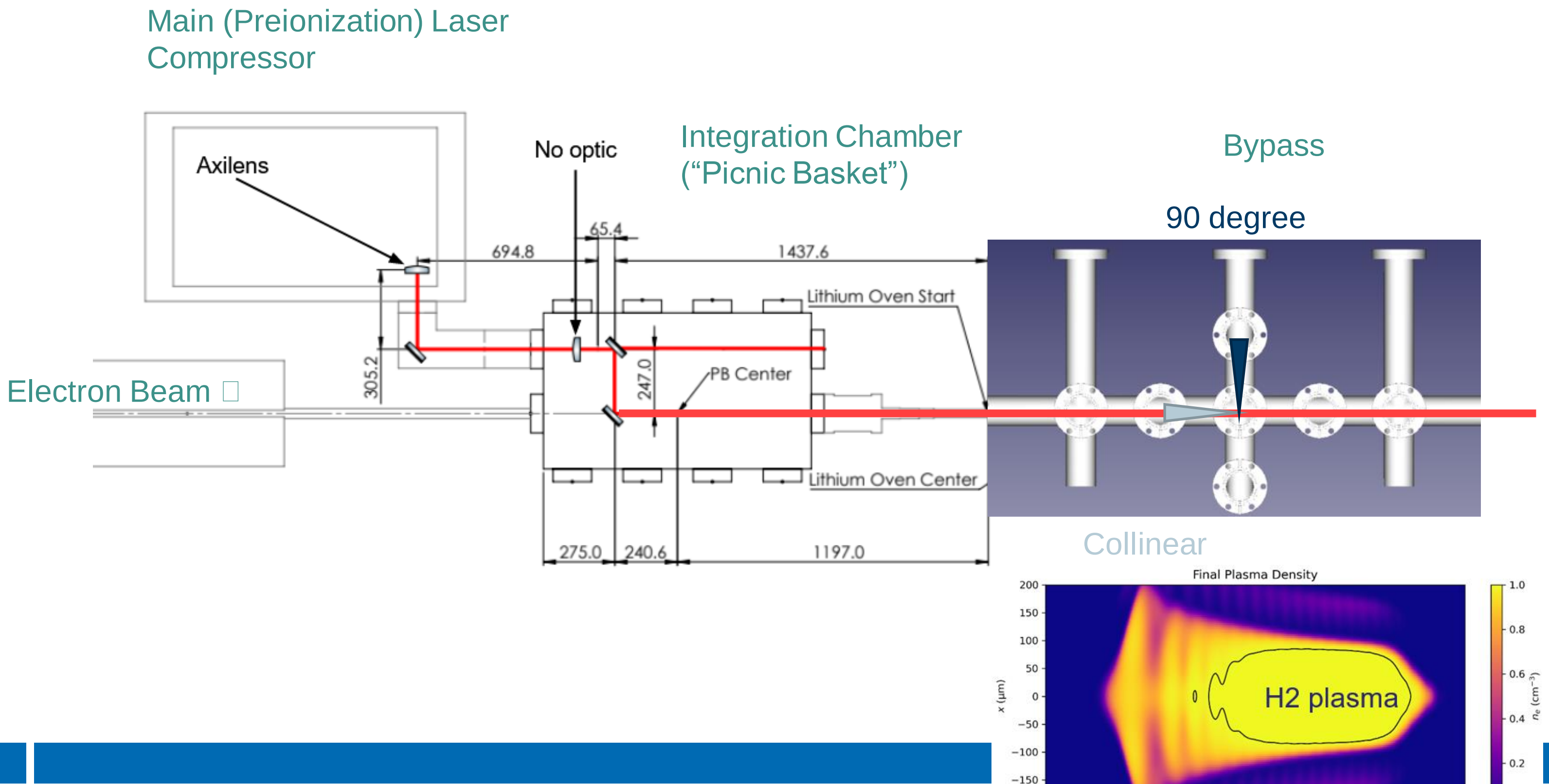
- No, plasma robust. There is a bit more He in the hot spot region, but no significant problem for acc. or injection
- Testing required, using FACET-II railcam and afterglow

Green: DS injector path



Courtesy Alex Knetsch

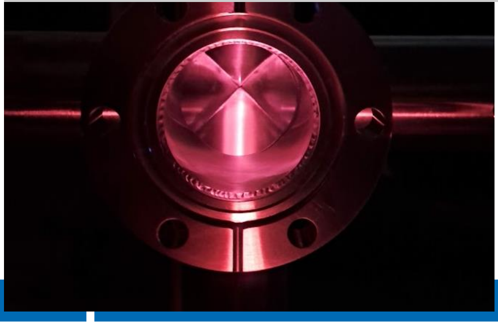
Bypass line 2.0 can facilitate collinear and 90° injection

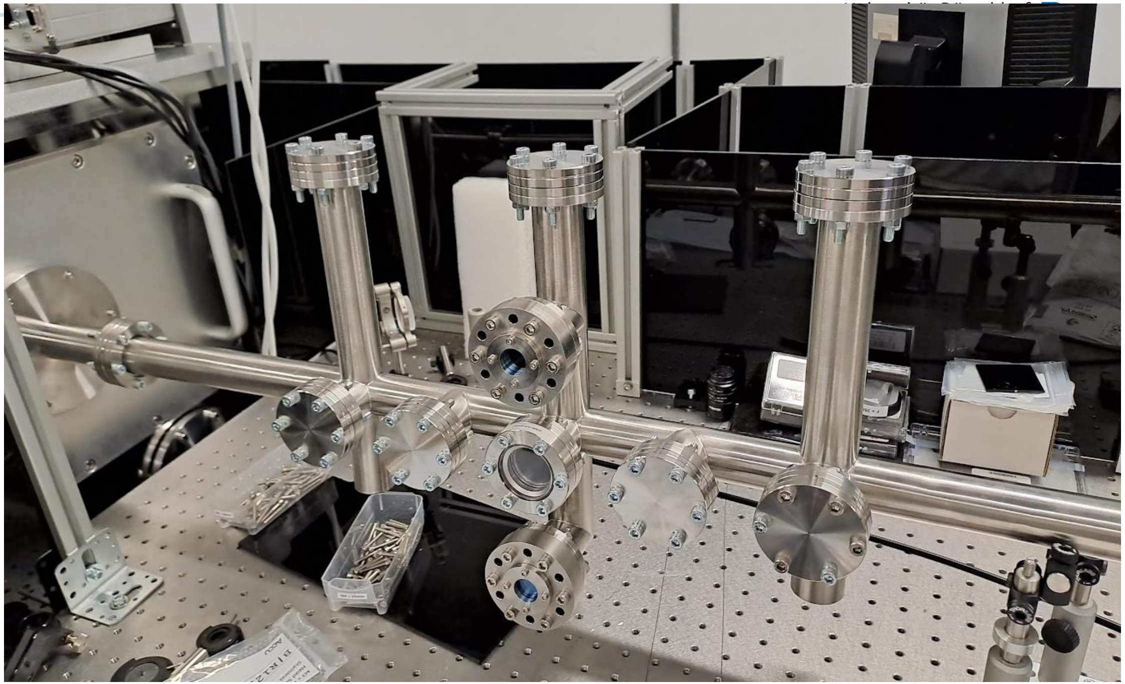


E-310 injection prototyping

- ❑ 90° Internal Mirror Holders

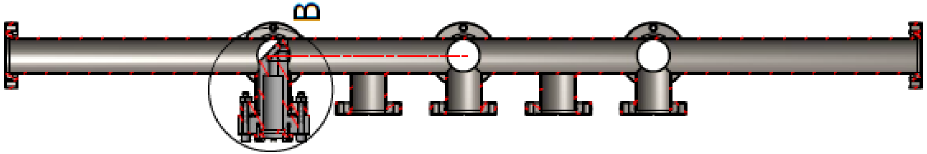
- ❑ Air alignment and ionization





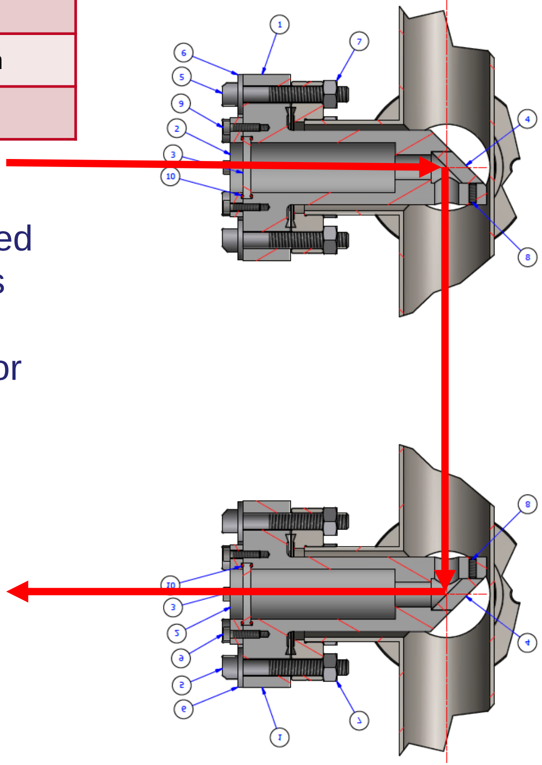
- ❑ Replica bypass and optical path successfully tested over here
- ❑ Commissioning at FACET-II required

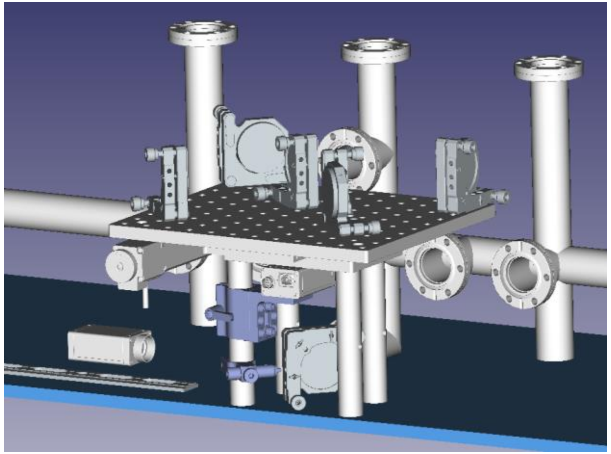
E-310 injection prototyping



Energy	0.5	mJ
Duration	60	fs
waist	9	um
a0	0.0489	

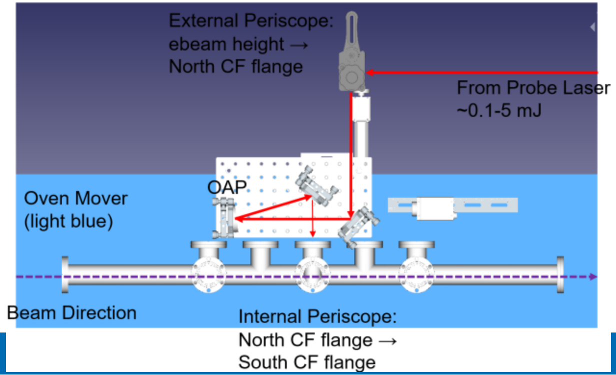
❑ 90° Internal Mirror Holders





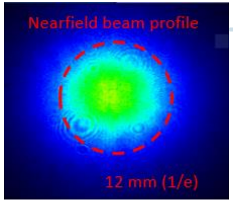
❑ Equipment for Trojan Horse designed to accommodate injection in bypass

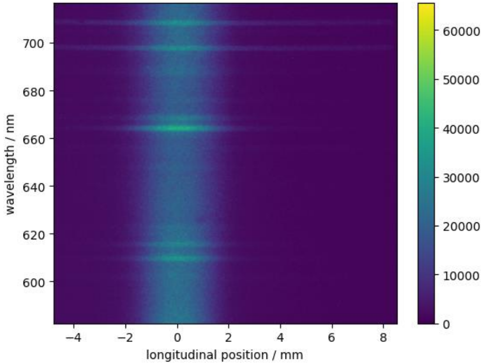
❑ Opto-mechanical layout designed for integration onto oven mover table

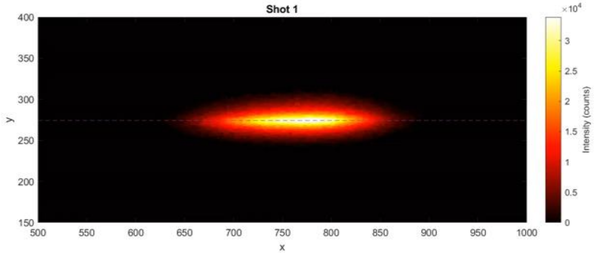


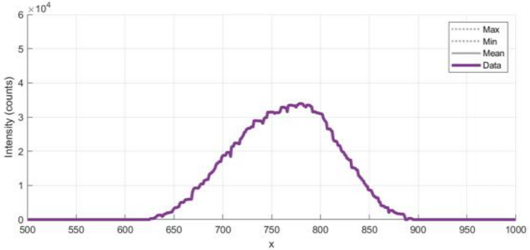
Andrew Sutherland

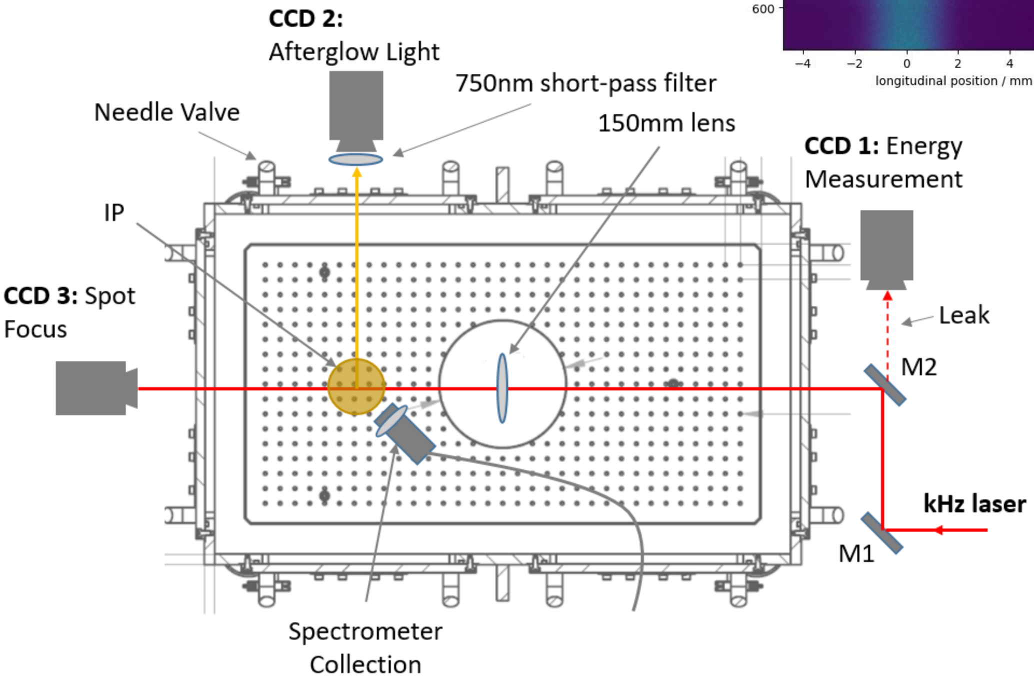
Plasma photocathode afterglow studies



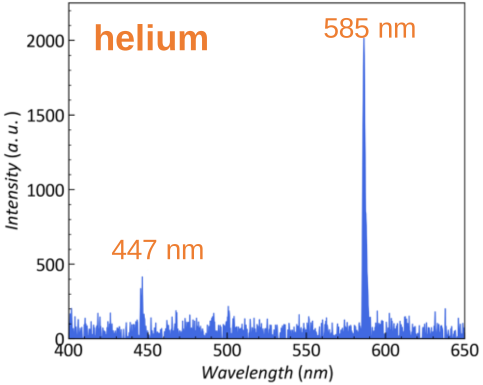








- ❑ Spectrally resolved afterglow diagnostics desirable



Summary & next milestones

- Very successful if short shift in FY24: afterglow (E315), e-beam-laser timing, self-ionized PWFA (deceleration & acceleration), preionizer-enhanced PWFA, selective ionization in gas mixes (E310/E311)
- Fully preionized PWFA next
- Reorganized & improved ionizer + downstream beamline
- E-310/11 in bypass line
- E-310/11 in big chamber…