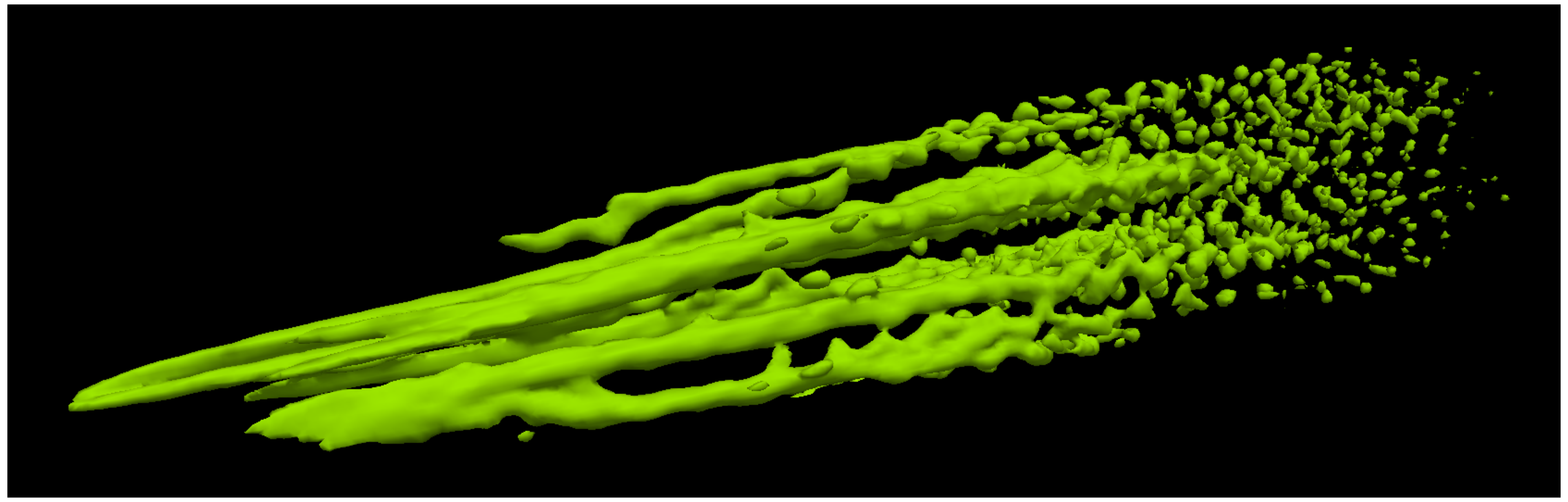
# E-305 FY22 Progress and Plans for FY23



Principal Investigators:

Sébastien Corde

Ken Marsh

Frederico Fiuza

École Polytechnique, Institut Polytechnique de Paris

UCLA

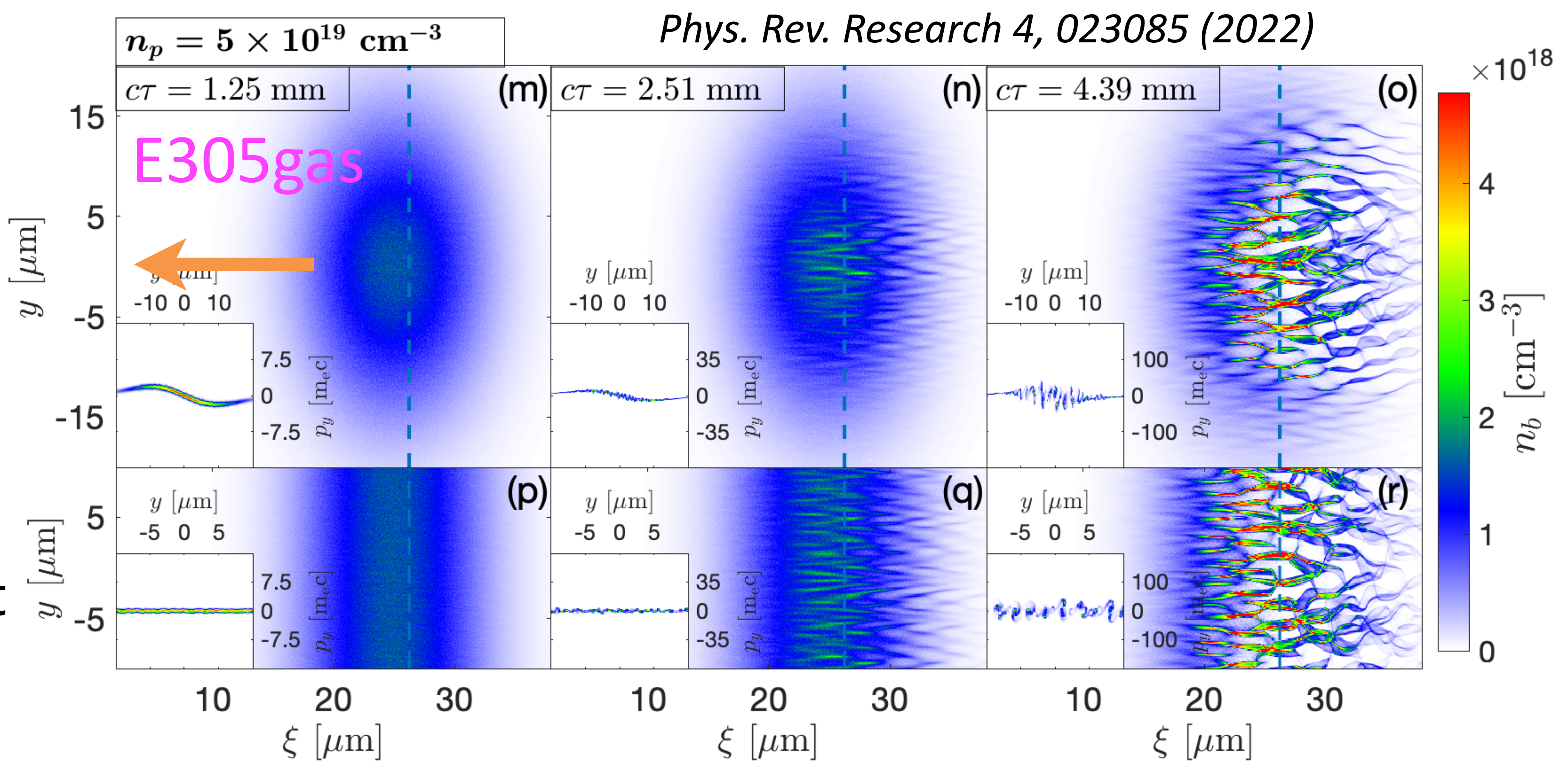
SLAC National Accelerator Laboratory

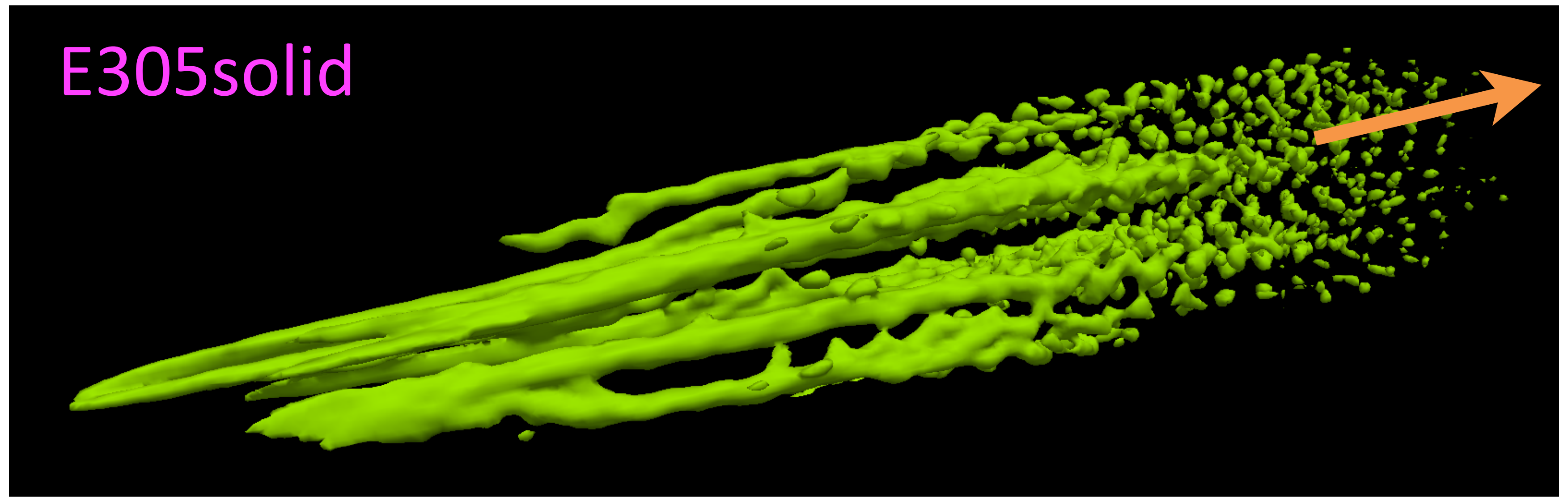
Collaborators: E-300 collaboration, CEA (France), MPIK (Germany)

# E305 - Science goals and definition of success

Two main configurations are considered for E305:

- High-density gas jets (plasma at $10^{18\text{-}20}$ cm$^{-3}$) - E305gas
- Solid targets (plasma at $10^{23\text{-}24}$ cm$^{-3}$) - E305solid




- Science goal 1 - push our understanding of relativistic kinetic plasma instabilities, including spatiotemporal dynamics, interplay of different modes, nonlinear stage, and ultrafast condensed matter physics in exotic states
  - Evidence of filamentation in E305gas (1.5 years)
  - Evidence of filamentation in E305solid (3 years - dependent on delivered beam parameters)
  - Characterisation of spatiotemporal growth and saturation/nonlinear stage as a function of beam and plasma parameters (3 years)
  - Benchmark against simulations, especially regarding collisional models for E305solid (3 years)
  - Distinguishing different modes of instability, showing how the interplay between oblique and CFI evolves with propagation, from front to rear of the bunch, and with bunch density (4 years)
  - Study instabilities with relativistic plasma response and/or with electron-positron fireball beams (5 years)

- Science goal 2 - generate bright gamma rays
  - First measurement of gamma-ray signal at a level distinguishable from the Bremsstrahlung background for E305solid (3 years)
  - Characterisation of the gamma-ray source as a function of beam and target parameters, comparison with blow-out in gas jet (3 years)
  - Demonstration of gamma-ray conversion efficiency exceeding the percent level (4 years), and possibly using a plasma lens to exceed 10%

# E305 - Experimental timeline

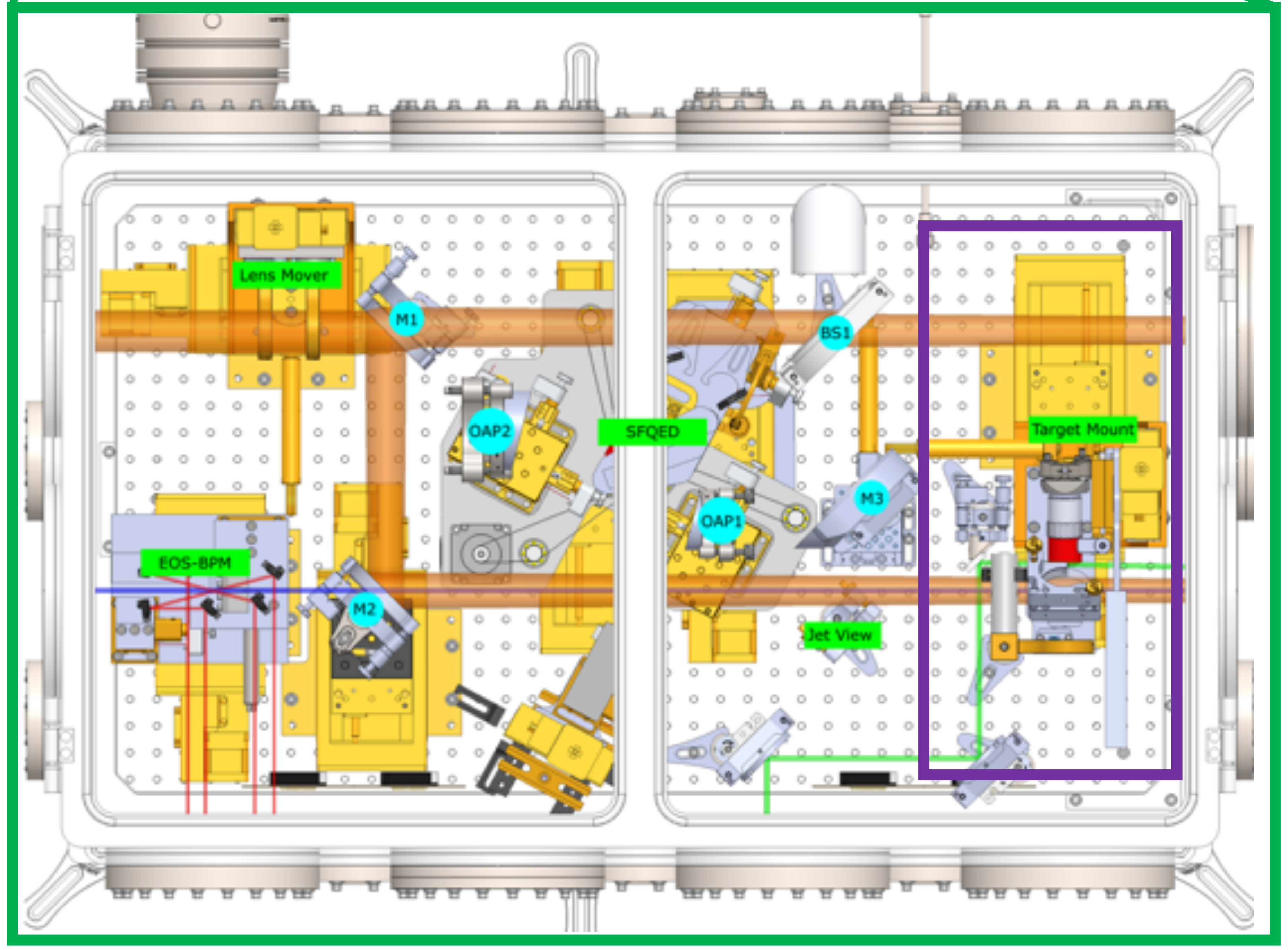
- Commissioned during 2022 summer run:
  - Targets (gas jet and solids)
  - Electron and gamma diagnostics
  - Laser ionisation of gas jet with E305 focusing optics
  - Low-resolution shadowgraphy in gas jet, first tests for high-resolution
  - Beam-laser overlap methods
  - Beam-based characterisation of laser-generated plasma

- Desired beam configurations: max compression (10-50 kA peak current, <30x30 micron beam size, <30x30 micron emittance) or chirped beam (work in progress)

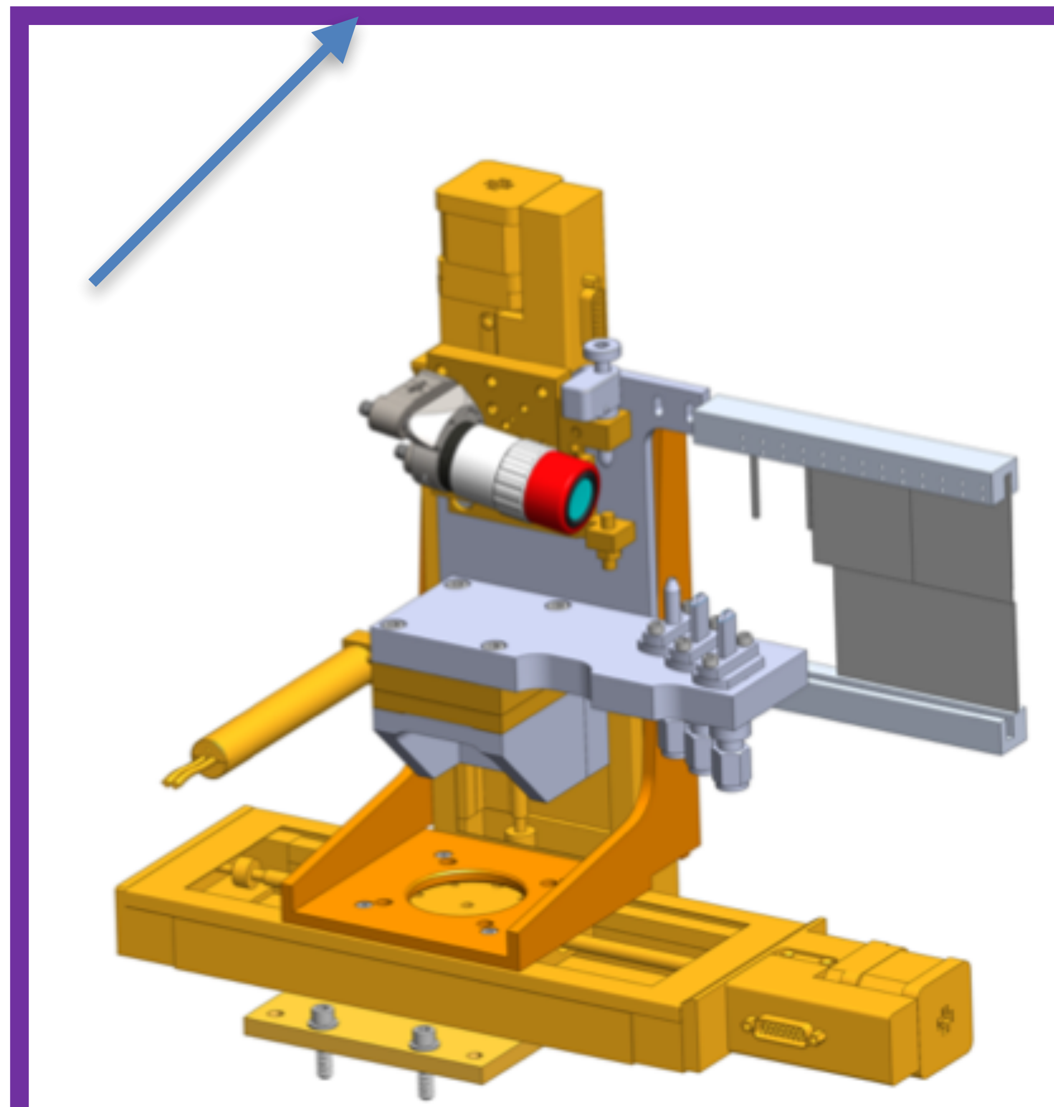
- Science program:
  - Phase 1 - FY23-24: filamentation experimental tests in gas. Expect observation of filamentation and blowout in gas. Diagnostics: high-resolution electron spectrometer, gamma-ray diagnostics, electron angular profile, high-k shadowgraphy.
  - Phase 2 - FY24-25: first filamentation experimental tests in solids with improved beam parameters, and full physics study in gas with upgraded/additional advanced diagnostics (e.g. CTR).
  - Phase 3 - FY25-26: full physics study in solids and generation of bright gamma rays. Include advanced diagnostic (CTR) to uncover mode interplay in solids, characterisation of positron generation influenced by instability, and integration of plasma lens with E308 to reach higher bunch densities.
  - Phase 4: electron-positron fireball beams to reach high density ratio in gas jets (astrophysically relevant, and avoid detrimental effect of gas ramps)

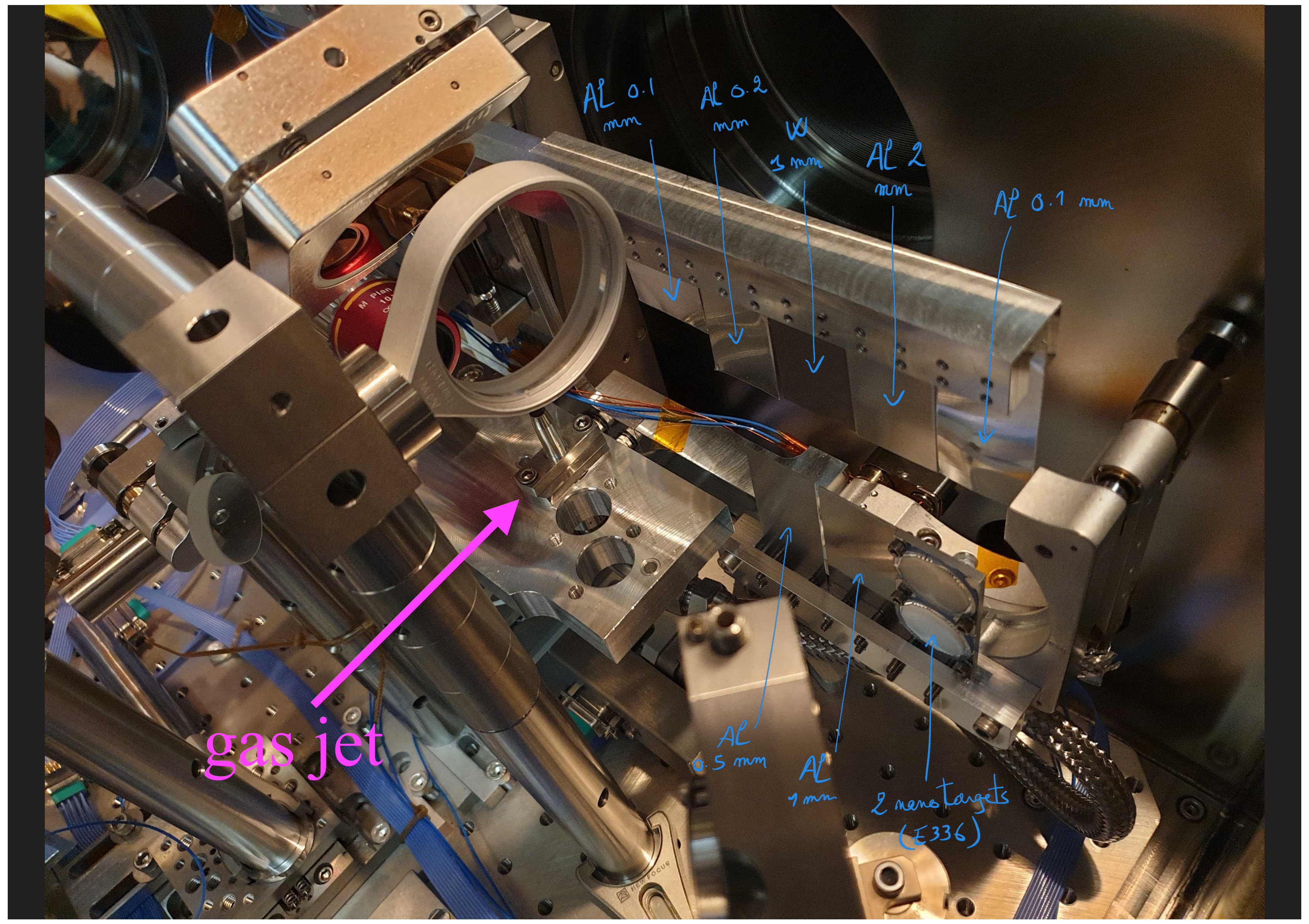
# Experimental layout


Experimental vacuum chamber (Picnic Basket)




Gas jet and solid targets are mounted on the E305 target mount:

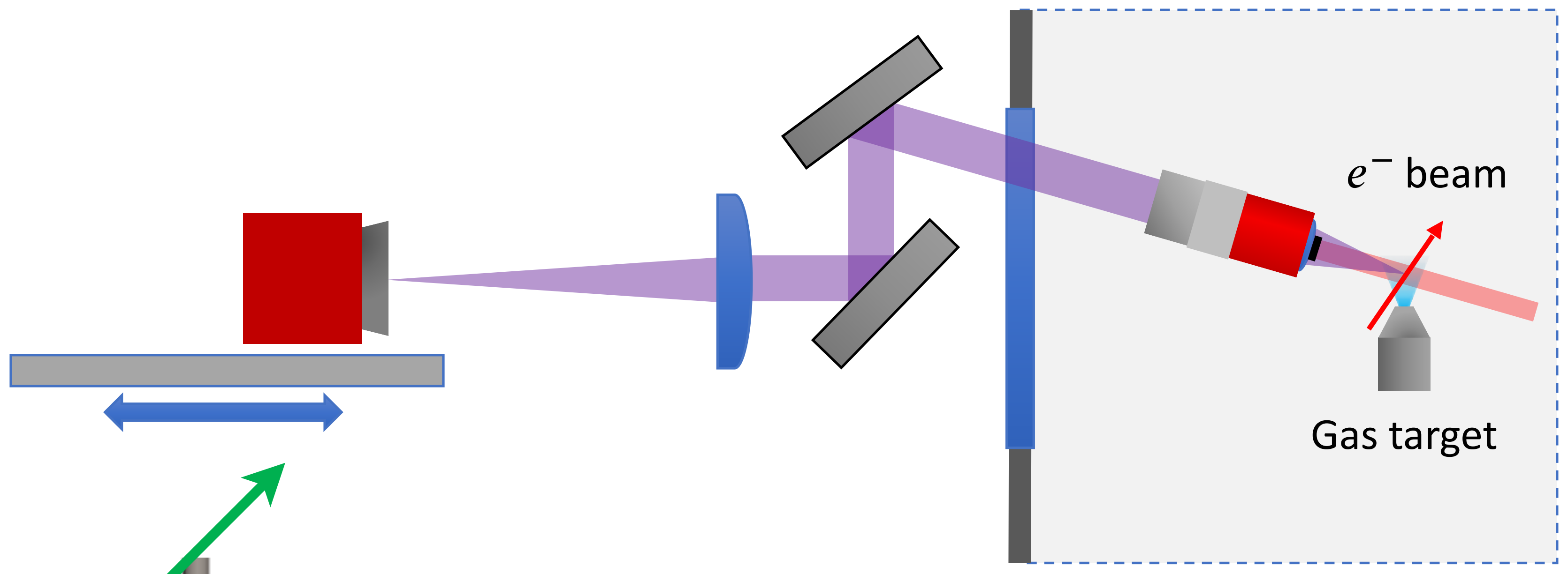





X-Y stages for rastering and gas jet positioning and Out position, Z stage longitudinal gas jet positioning. In-out motor for objective.

# Diagnostics and observables

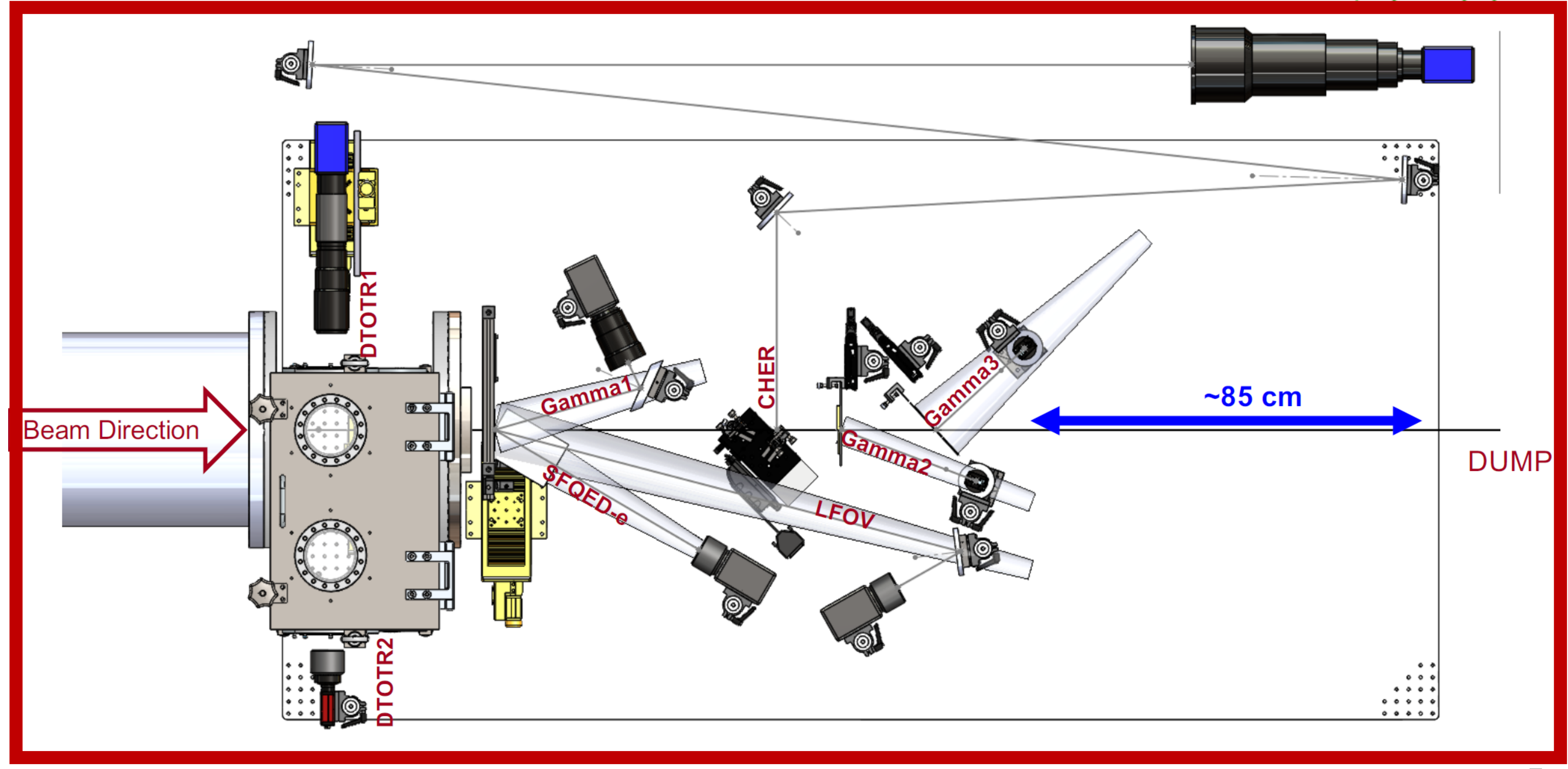
High-k shadowgraphy




Main observables:

- Electrons
- Gamma rays
- Afterglow on topview
- High-k scattering in gas jet

Beam direction




Electrons:

- Coherent OTR prevents the use of profile monitors downstream of IP
- High-resolution in-vacuum OTR at the dump table (DTOTR)

Gammas:

- $\gamma$ screens at the dump table (incl. CsI to detect small gamma signals)

# E305 - FY22 Progress

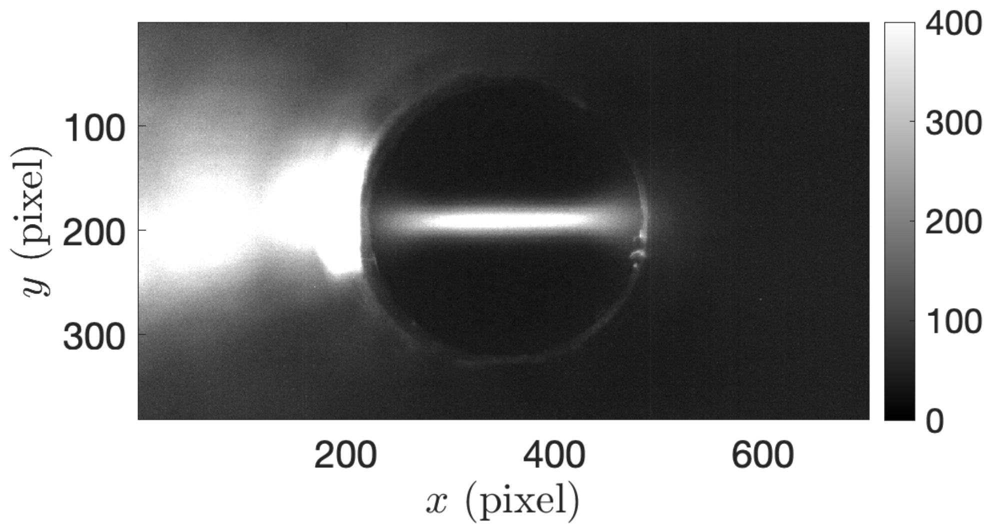
- Commissioning of gas jet operation with He and $H_2$ and of PB pumping:
  - Numerous tests performed to evaluate the residual background pressure for different gas jet opening time, repetition rate, backing pressure and type of gas
  - Successfully operated gas jet at 5 Hz for backing pressure up to 200 psi
  - At high backing pressure of up to 1200 psi, gas jet operation limited to 1 Hz (with beam at 10 Hz); required DAQ development and tests
  - 5-mm round nozzle and 2-cm slit nozzle tested successfully

**He Pressures in Torr in Picnic basket, US4 and DS2**

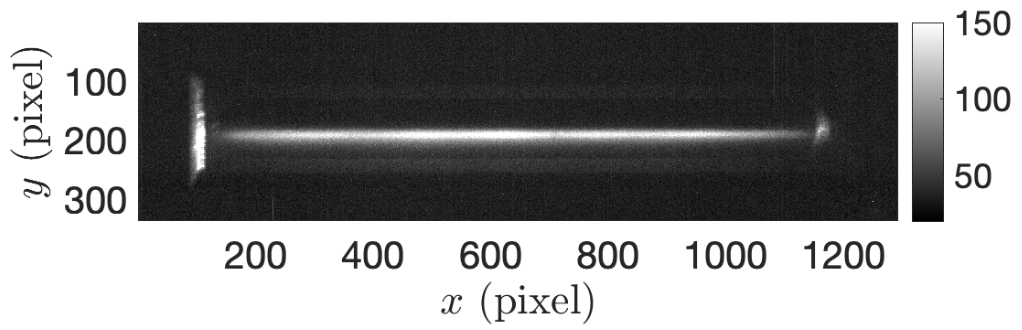
- 1ms width

| Gas pressure | | 0.2 Hz | 0.5 Hz | 1 Hz | 5 Hz | 10 Hz |
|---|---|---|---|---|---|---|
| 30 psi | TM | | | | | 4.2e-5 |
| | PB | | | | | under |
| | US4 | | | | | 2.1e-10 |
| | DS2 | | | | | 3.7e-9 |
| 60 psi | TM | | | | | 8e-5 |
| | PB | | | | | 2.3e-4 |
| | US4 | | | | | 2.1e-10 |
| | DS2 | | | | | 4.2e-9 |
| 100 psi | TM | 4e-6 | 9e-6 | 2e-5 | 8e-5 | 1.7e-4 |
| | PB | under | under | under | 3e-4 | 2e-3 |
| | US4 | 2.1e-10 | 2.1e-10 | 2.1e-10 | 2.1e-10 | 2.1e-10 |
| | DS2 | 3.7e-9 | 3.6e-9 | 3.9e-9 | 4.4e-9 | 9.3e-9 |
| 200 psi | TM | 6e-6 | 1.5e-5 | 2.8e-5 | 1.3e-4 | 3.e-4 |
| | PB | under | under | under | 1e-3 | 8.6e-3 |
| | US4 | 2.1e-10 | 2.1e-10 | 2.1e-10 | 2.1e-10 | 2.2e-10 |
| | DS2 | 4e-9 | 4e-9 | 4.3e-9 | 8.3e-8 | 1.7e-8 |
| 400 psi | TM | 1.3e-5 | 3e-5 | 4.7e-5 | 2.9e-4 | 6.8e-3 |
| | PB | under | under | under | 6.5e-3 | 3.8e2 |
| | US4 | 2.1e-10 | 2.1e-10 | 2.1e-10 | 2.2e-10 | 2.3e-10 |
| | DS2 | 4e-9 | 4e-9 | 4e-9 | 1.4e-8 | 3e-8 |
| 800 psi | TM | 2e-5 | 4e-5 | 8.3e-5 | 2e-3 | 1e-2 |
| | PB | under | under | 5e-4 | 2.2e-2 | 6e-2 |
| | US4 | 2.1e-10 | 2.1e-10 | 2.1e-10 | 2.2e-10 | 2.3e-10 |
| | DS2 | 4.5e-9 | 4.7e-9 | 5e-9 | 2e-8 | 4e-8 |
| 1200 psi | TM | 3e-5 | 6.5e-5 | 1.3e-4 | 9e-3 | 6e-2 |
| | PB | 2e-3? | ? | 2e-3 | 6e-2 | over |
| | US4 | 2.1e-10 | 2.1e-10 | 2.1e-10 | 2.3e-10 | 2.6e-10 |
| | DS2 | 4e-9 | 4e-9 | 8e-9 | 4e-8 | 9e-7 |

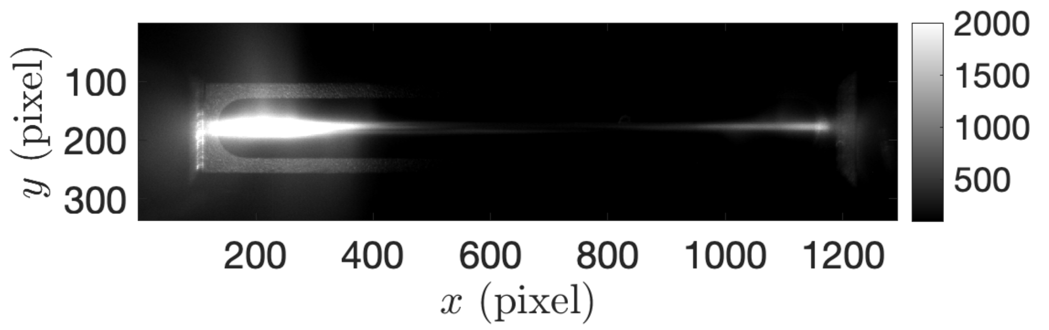
- Laser ionization:
  - Specific focusing optics for E305: diffractive axilens with 1-cm line focus for monochromatic light, stretched to 3-4 cm line focus by chromatic focusing with the real FACET-II laser
  - Successfully generated plasma in 5-mm nozzle, and in 2-cm slit nozzle up to 200 psi
  - Need to understand what's limiting the plasma length at higher backing pressure



5-mm nozzle, $H_2$ at 110 psi



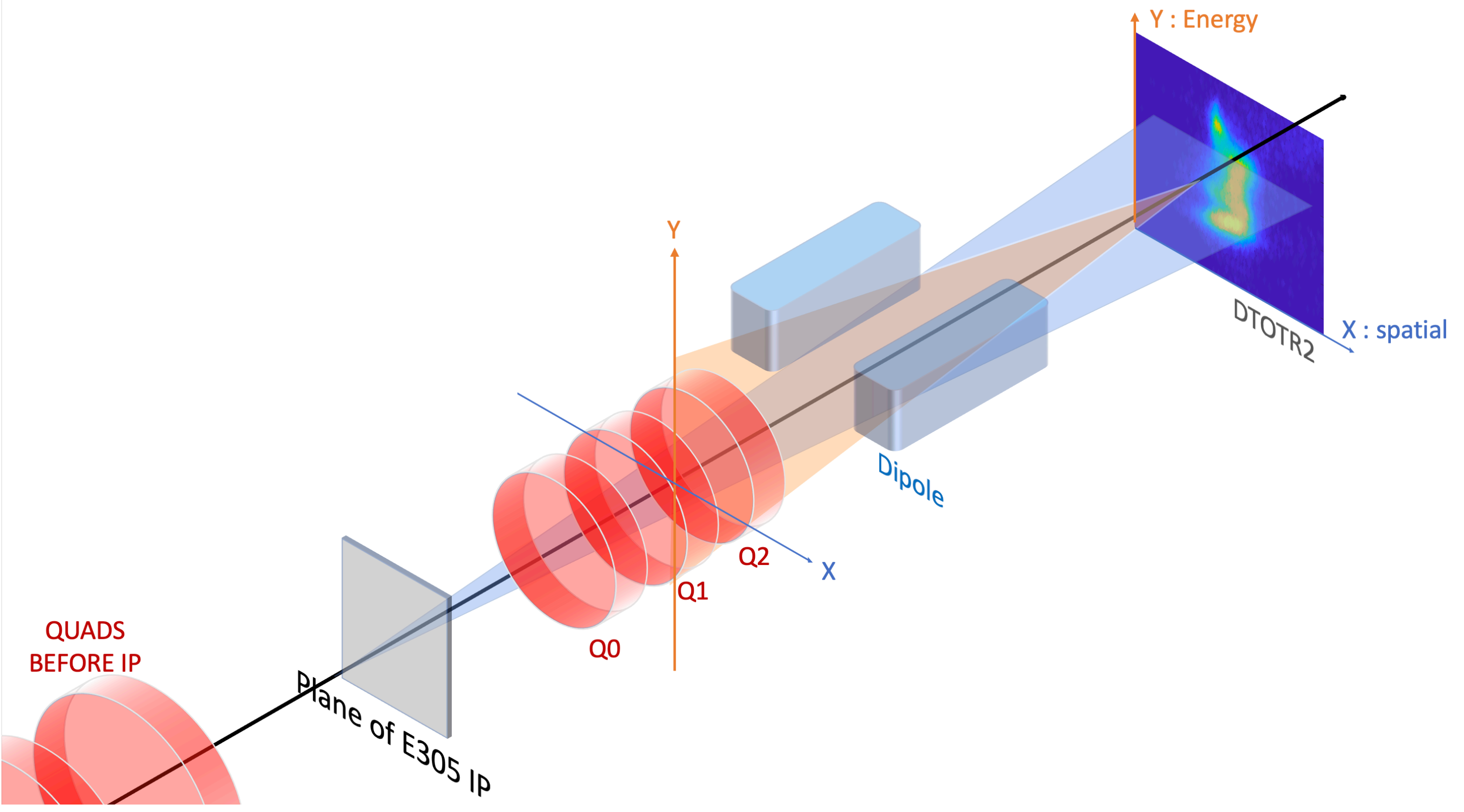
2-cm nozzle, $H_2$ at 150 psi



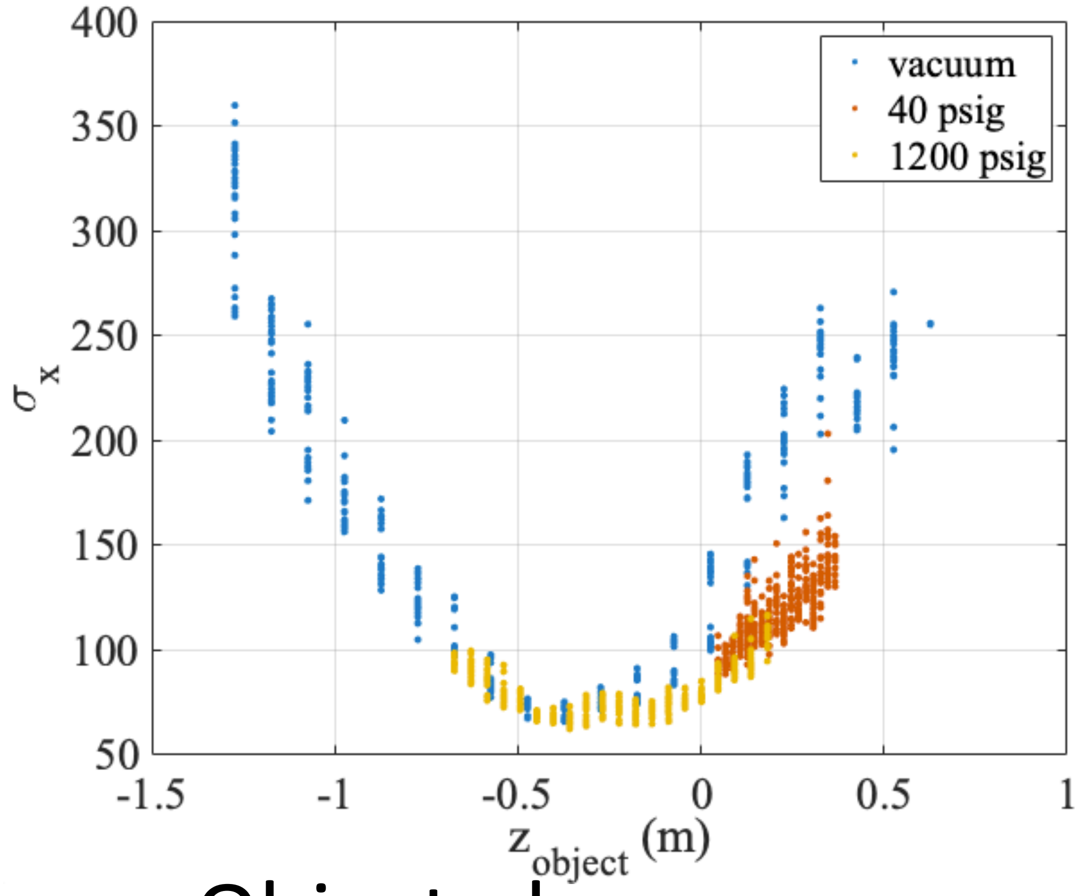
2-cm nozzle, $H_2$ at 614 psi

# E305 - FY22 Progress

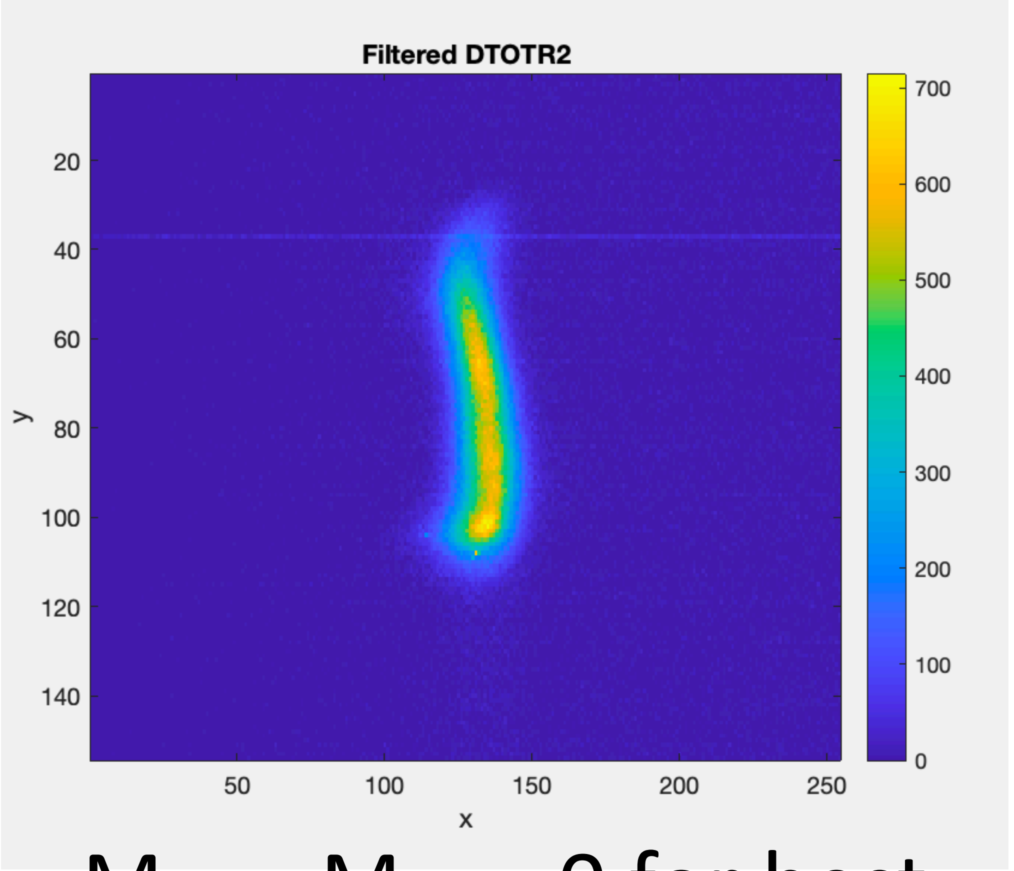
- Electron and gamma diagnostics:
  - Instead of using a profile monitor downstream of IP for a measurement of the beam angular profile (compromised by coherent OTR light), we rely on DTOTR electron spectrometer at the dump table:



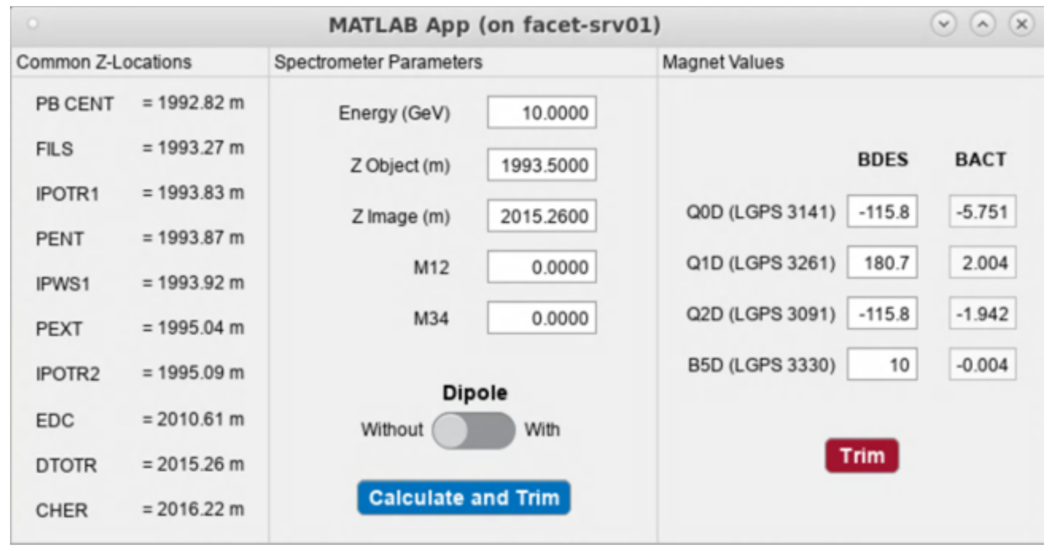

Large $M_{12}$ and $M_{34}$ = 0 to measure horizontal momentum $p_x$




Object plane scan

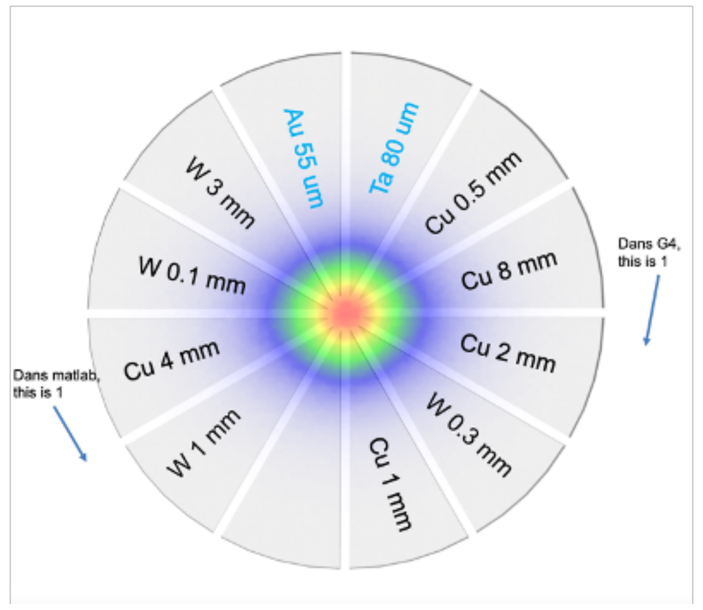


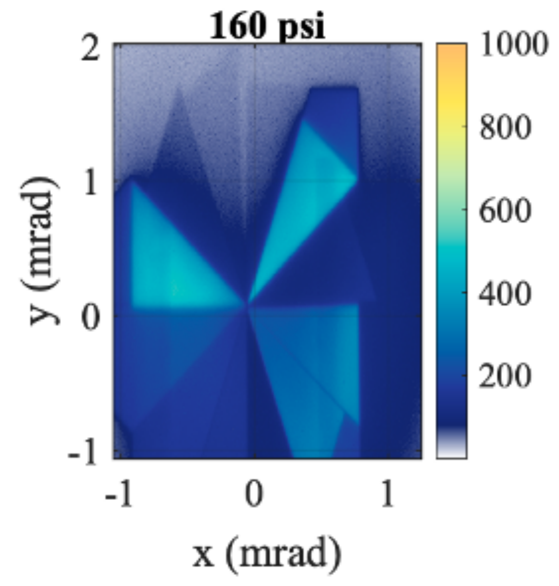

$M_{12}$ = $M_{34}$ = 0 for best energy measurement

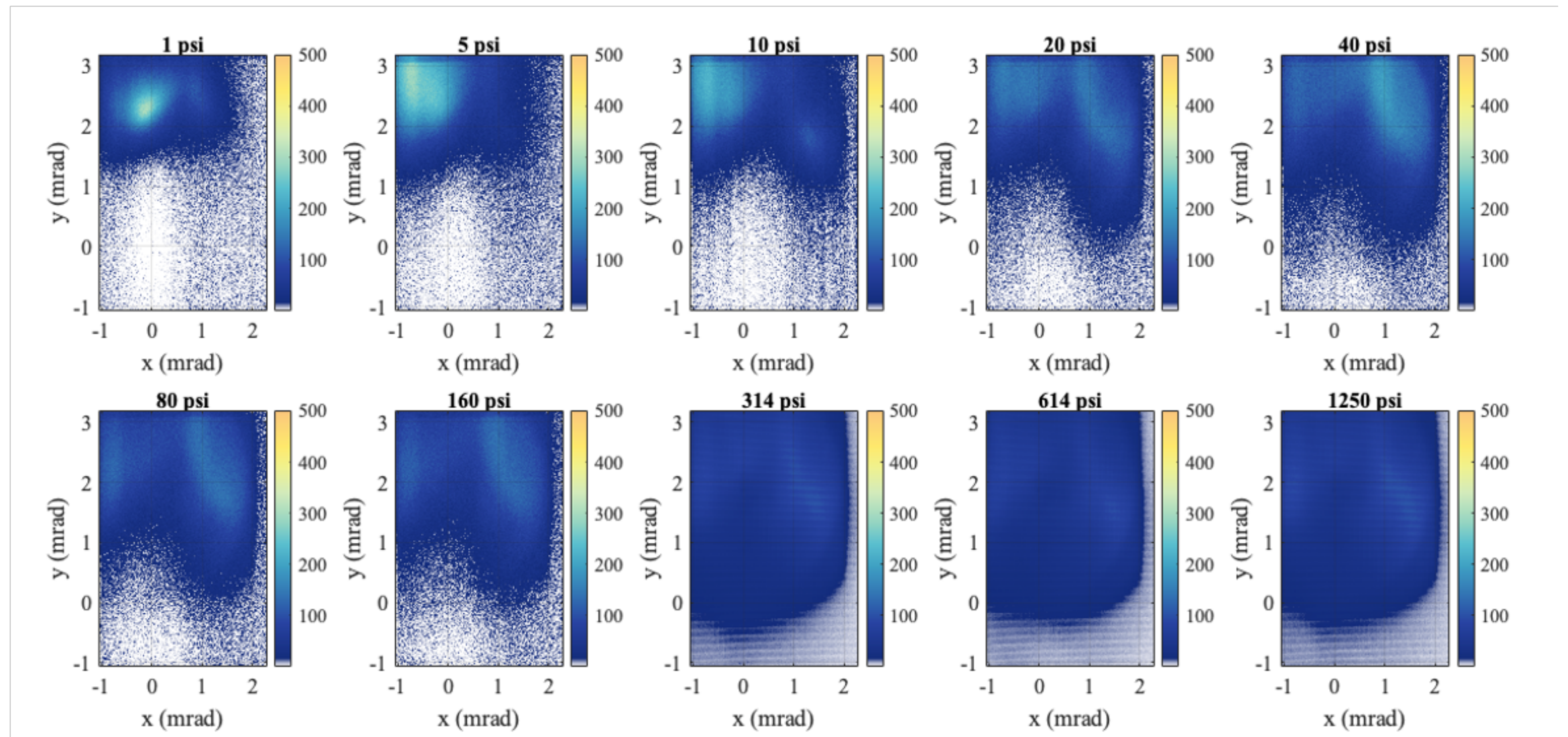


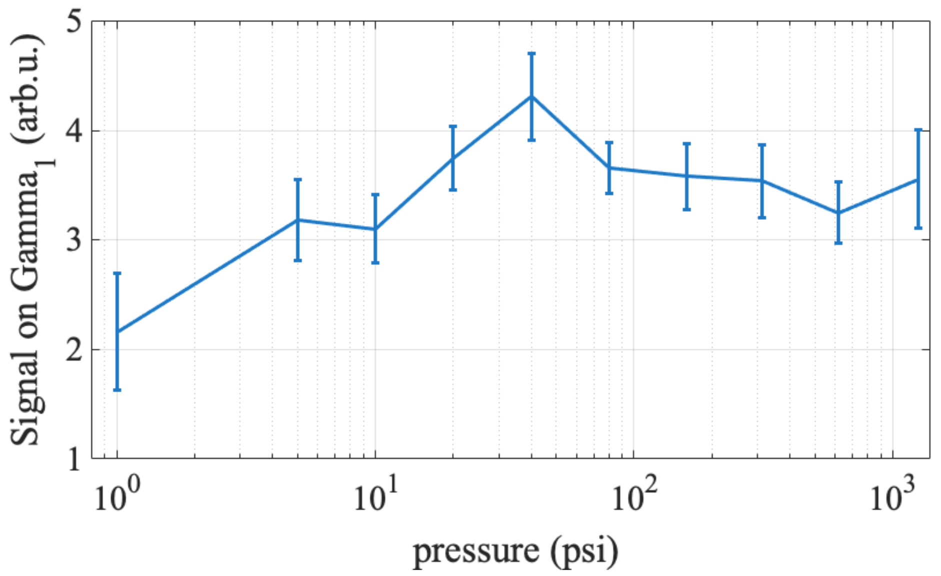

GUI +
DAQ functions

- Gamma screens commissioned for E305



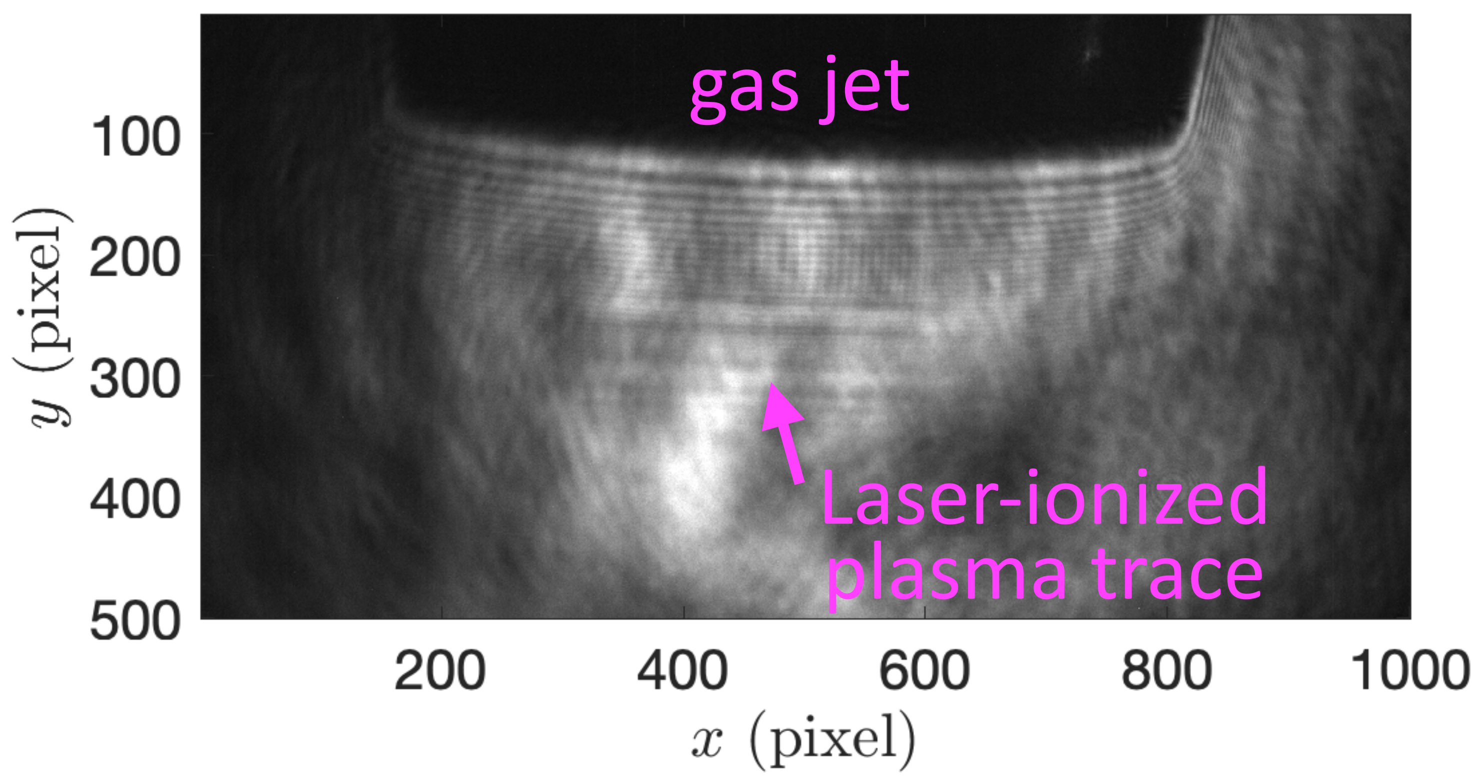



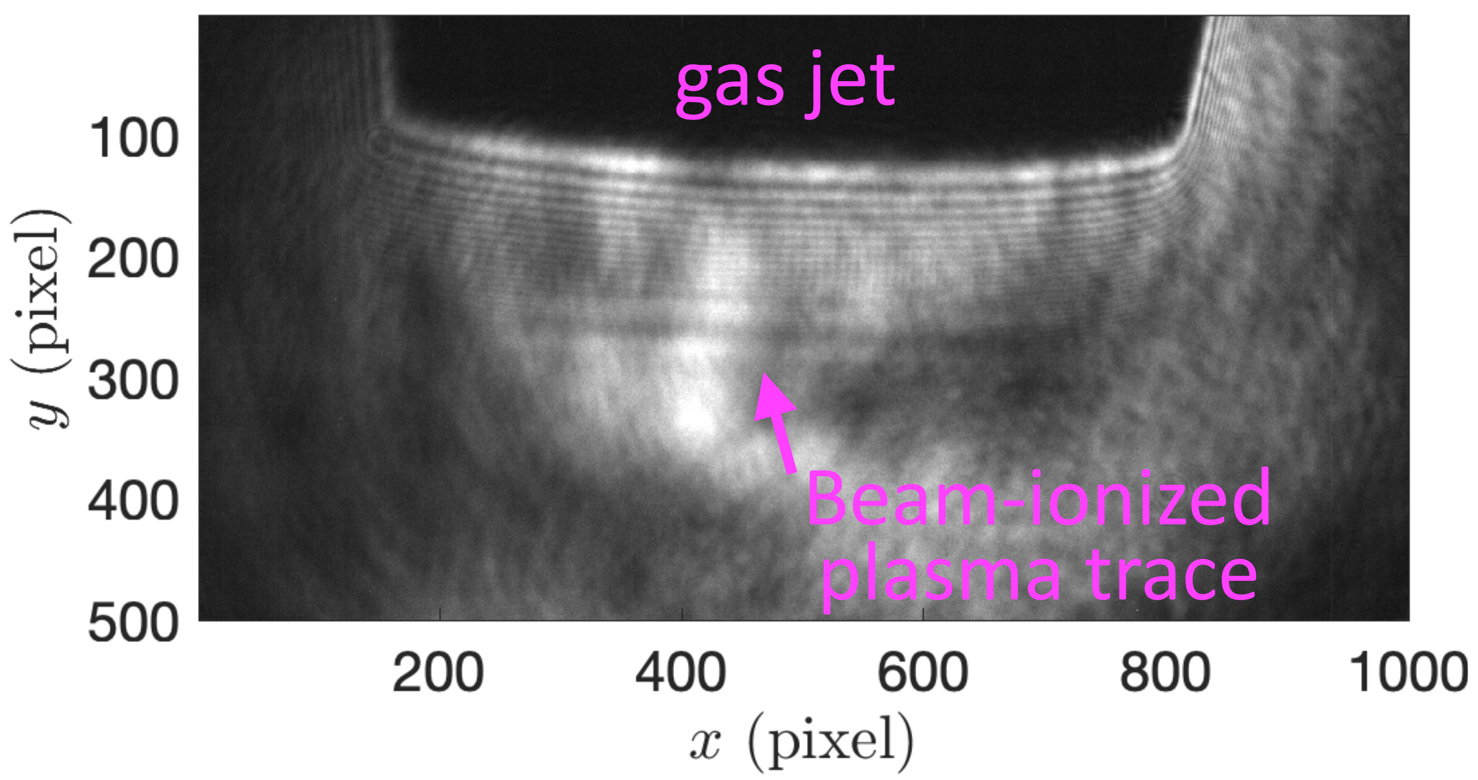
# E305 - FY22 Progress

- Shadowgraphy:
  - Low resolution fully commissioned:

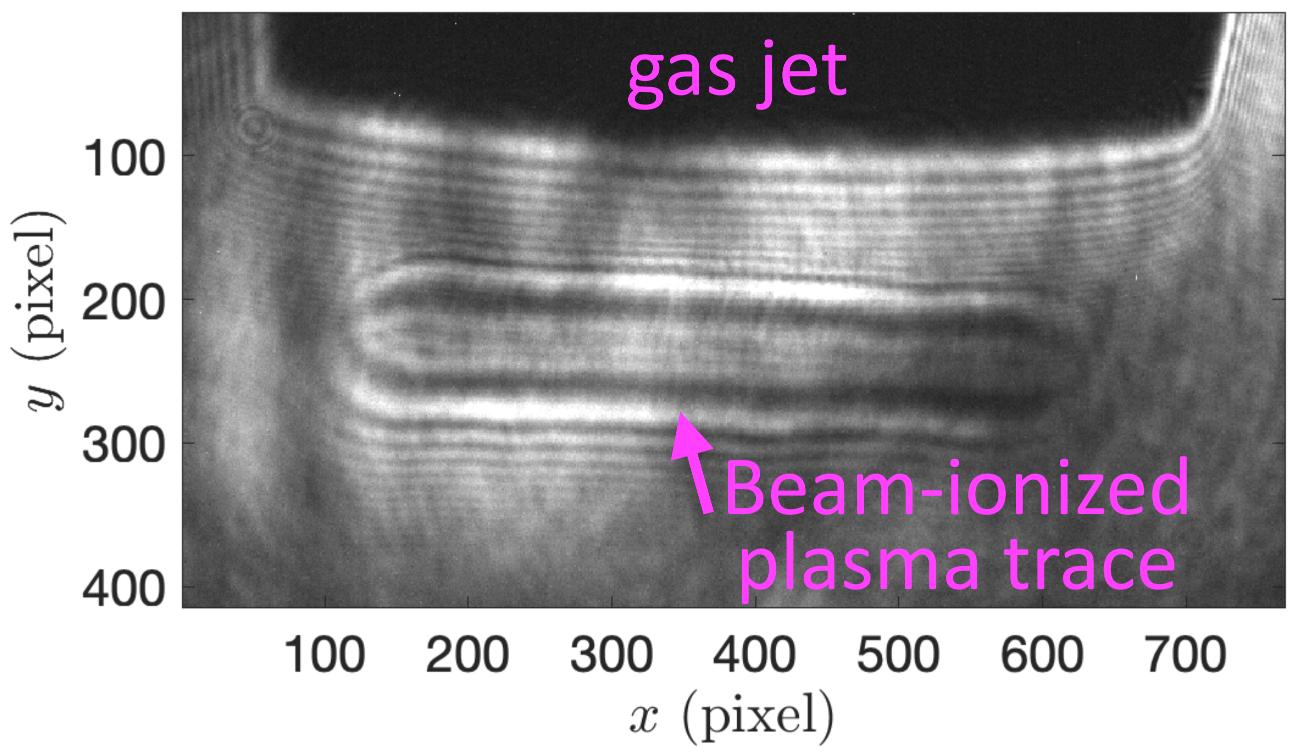
Conditions:
$H_2$, 110 psi




Conditions:
$H_2$, 1010 psi and 1 Hz



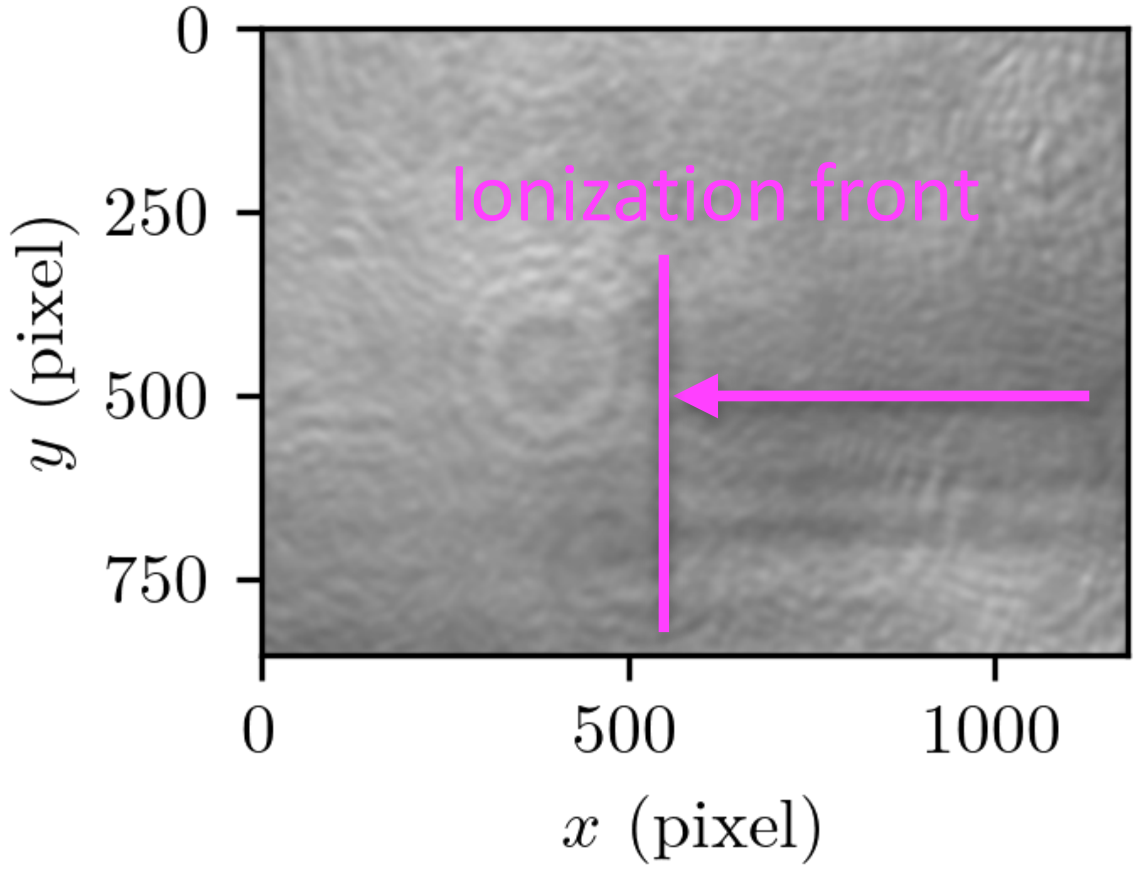

Conditions:
$H_2$, 1010 psi and 5 Hz

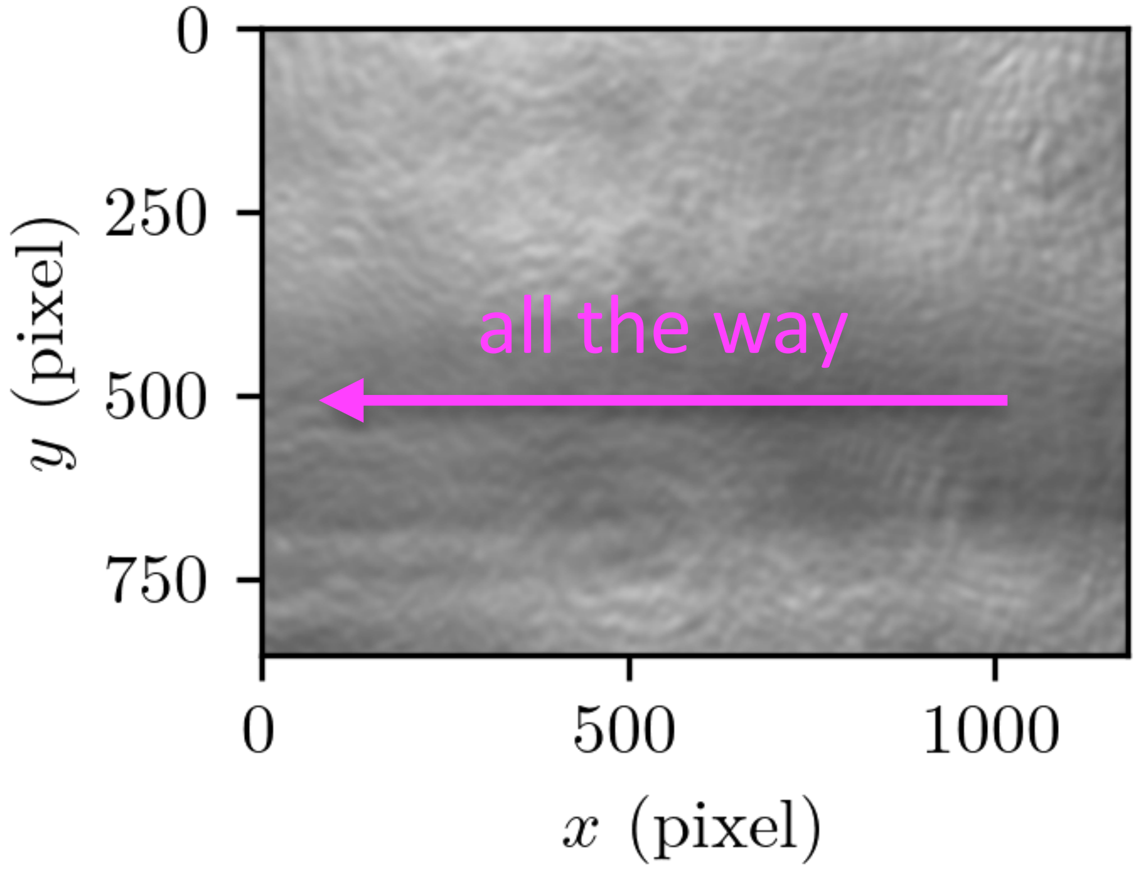



—> residual background pressure in PB (~0.1 Torr)

—> self-focused electron beam entering the gas jet

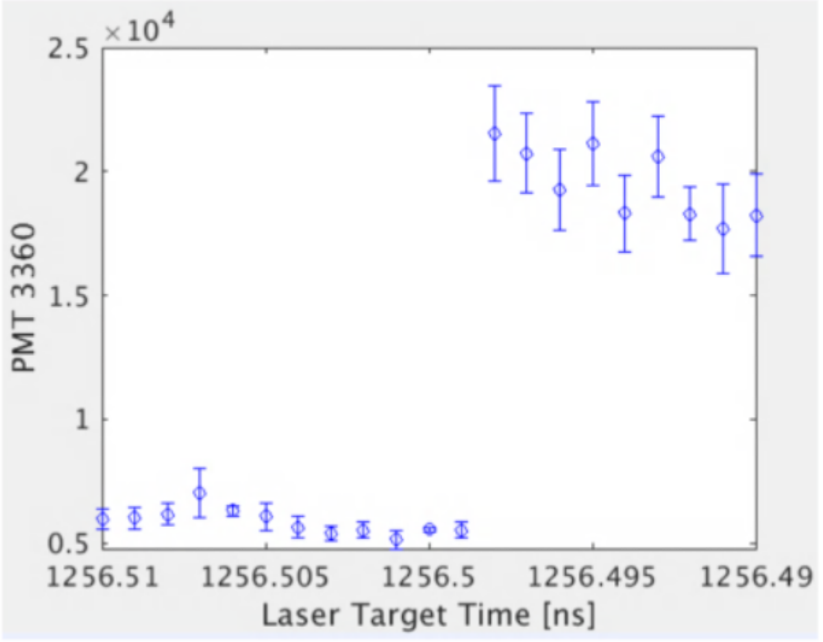
- First tests of high resolution, with microscope objective inserted and with laser ionization front identified:



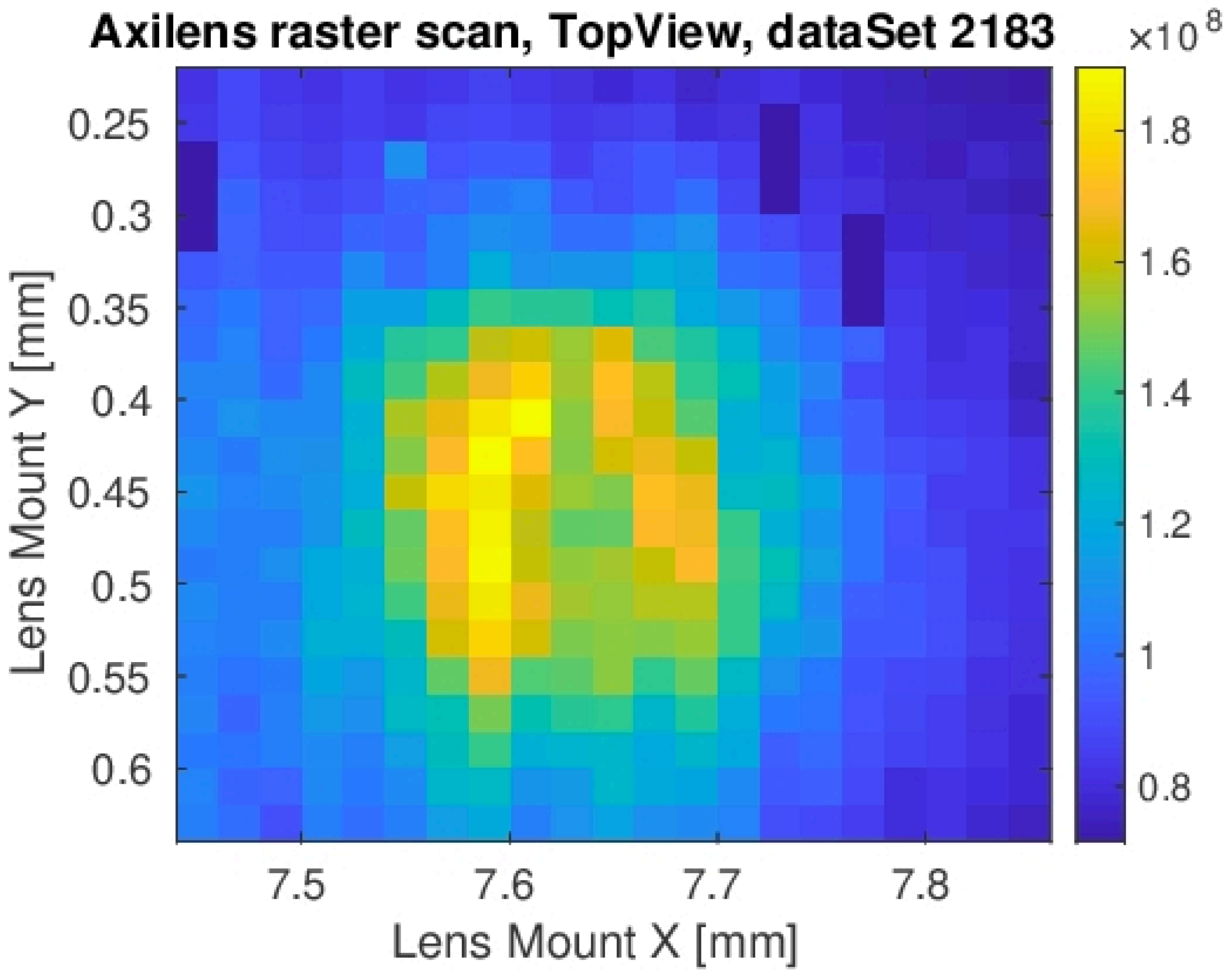




Conditions:
$H_2$, 500 psi

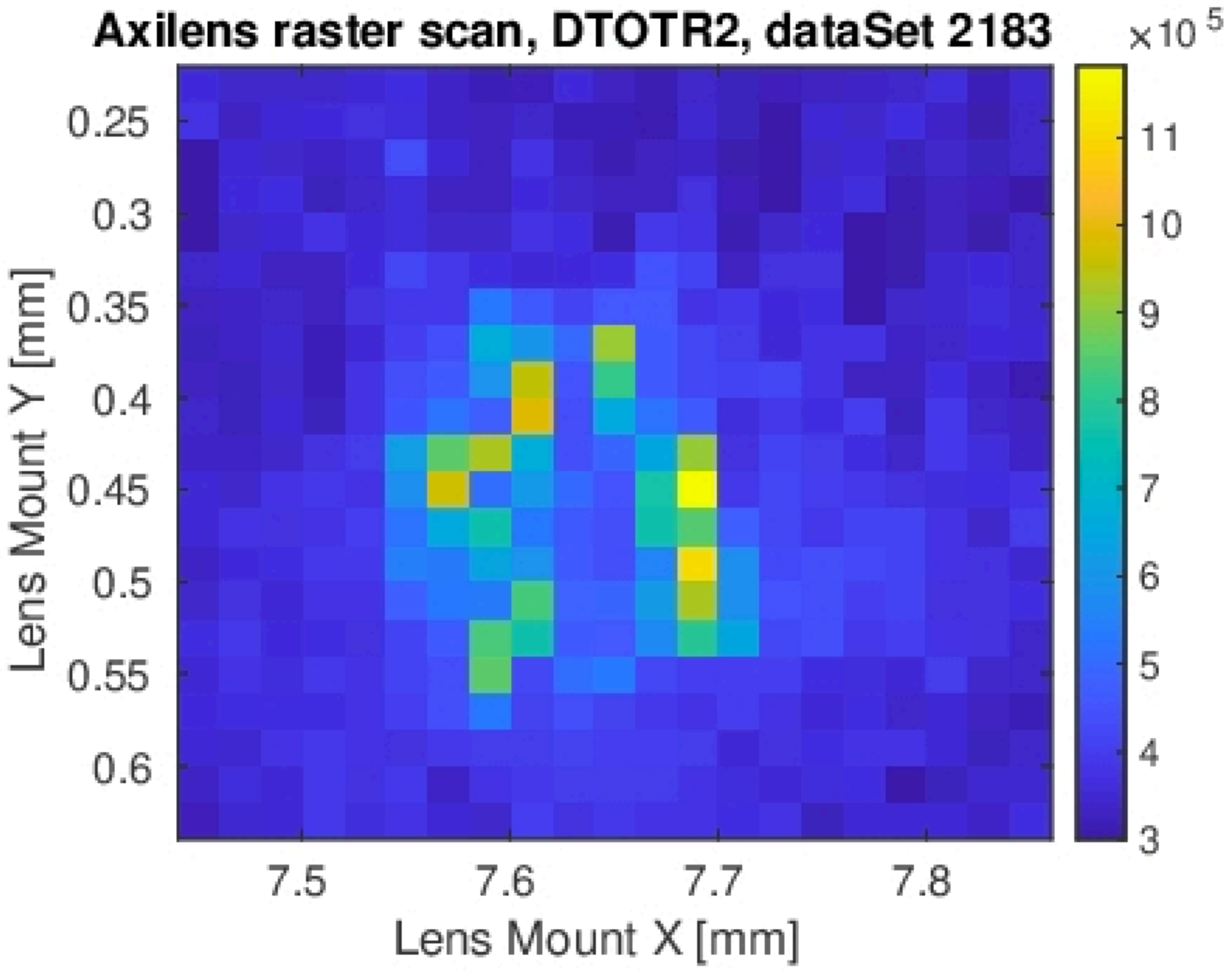
# E305 - FY22 Progress




- Laser-ebeam overlap and beam-based characterisation of laser-produced plasma:
  - Timing: clear transition identified on most diags (shadowgraphy can be used for very high accuracy)
  - Approximate spatial overlap done on front view
  - More precise spatial overlap can be achieved from plasma traces on topview and shadow
  - Afterglow signal was found to be very powerful to quickly fine tune the laser-ebeam overlap
  - Laser raster scans give us a beam-based characterisation of laser-produced plasma:




Sum of count on topview Afterglow signal

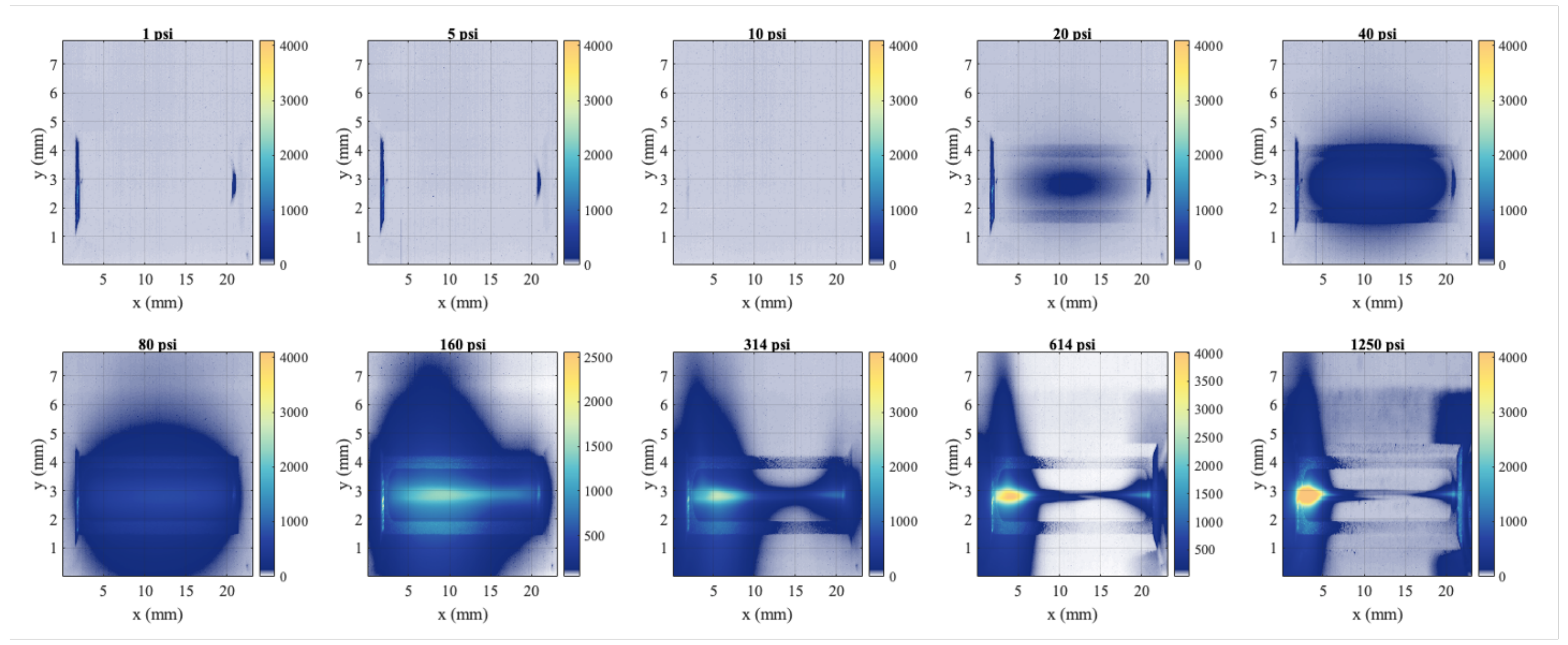



Sum of count outside initial beam location on DTOTR2

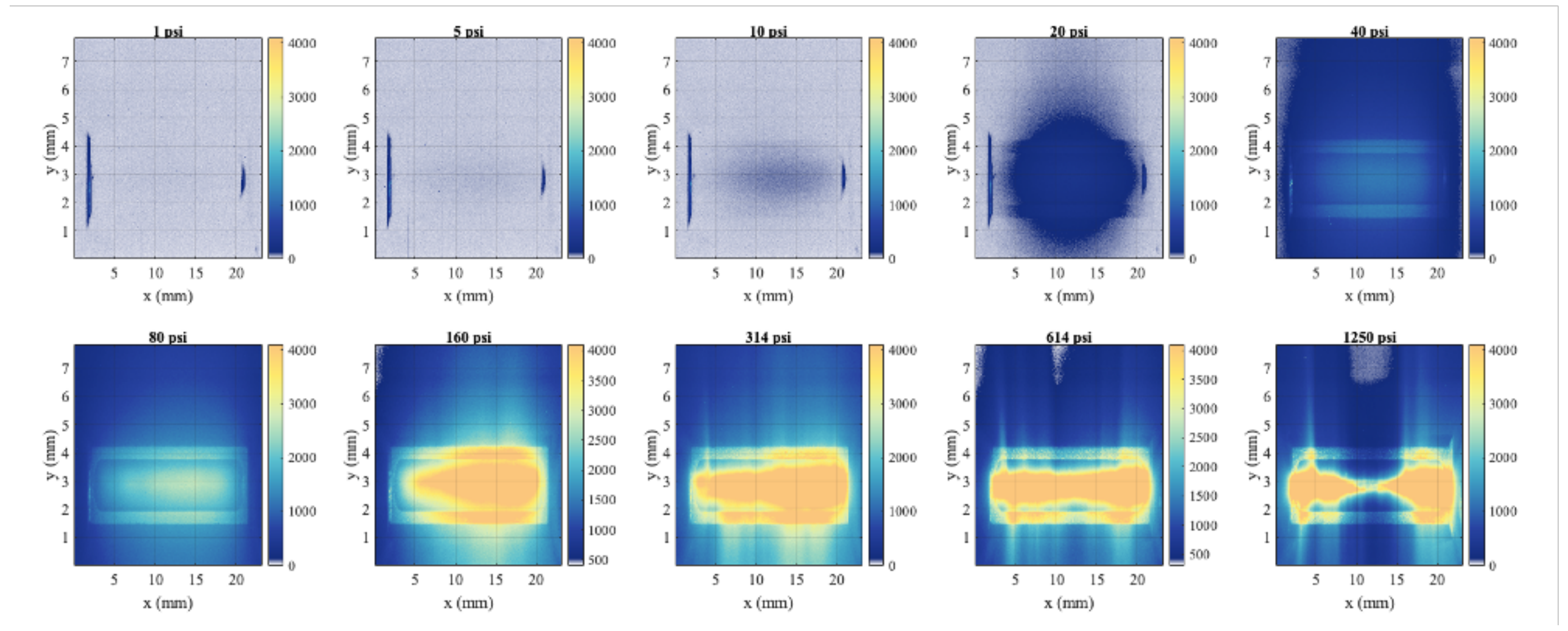
# E305 - FY22 Progress

- First beam-plasma interactions in gas jet:
  - Expected from simulations: spanning regimes going from plasma lensing, PWFA, to beam filamentation when the pressure is increased from 1 to 1000 psi.
  - Experimental observations: complex outcome that can be understood by a beam larger than the plasma along the horizontal axis, affecting only the central part of the beam.

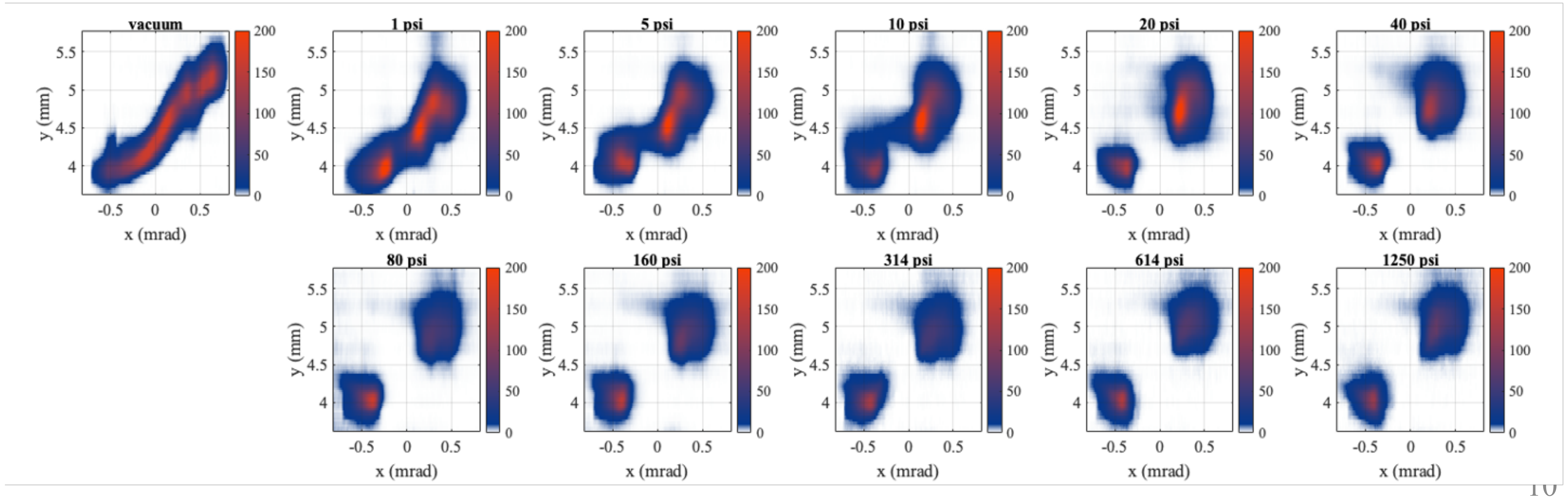
Laser only



Laser + ebeam



DTOTR2



# E305 - Plans for FY23

- Plans for E305 experimental set-up:
  - Understand and solve the problem of plasma generation at high pressure for length greater than 5 mm
  - Produce clean and transversely-uniform plasma, larger than the beam
  - Afterglow: increase dynamic range (lens to increase light collection and filters on a flipper)
  - Shadowgraphy:
    - change pico by stepper motor
    - commission dark-field mode with mask for Fourier filtering (high-k shadowgraphy)
    - prepare plan and design for frequency-doubled shadowgraphy

- Plans for E305 shifts:
  - Repeat beam-plasma interaction with improved beam and plasma
  - Carry out the experiment with a chirped beam

# Potential evolution of the experiment and facility upgrades

Possible evolution of the experiment:

- Chirped beams for spatiotemporal instability measurements in gas.
- Afterglow to measure energy deposited in plasma.
- Dark-field shadowgraphy with frequency-doubled probe.
- CTR diagnostic to distinguish different modes of instability.

Desired facility upgrades:

E305 benefits from the highest bunch densities.

- In gas, the beam size cannot be too small (otherwise we enter blow-out regime), thus one needs high peak current, and an upgrade from 50-100 kA to 300 kA would be strongly beneficial.
- In solid, bunch densities in excess of $10^{20}$ $cm^{-3}$ are desired to uncover the full physics potential of E305solid. This requires focusability to beam size of $\lesssim 2-3\ \mu$m and compression to bunch length of $\lesssim 2-3\ \mu$m.

# Collaboration and institutions

I. Andriyash, S. Corde, M. Gilljohann, A. Knetsch, O. Kononenko, Y. Mankovska, A. Matheron, P. San Miguel Claveria, V. Zakharova

C. Keitel, S. Montefiori, A. Sampath, M. Tamburini

X. Davoine, J. Faure, L. Gremillet, S. Passalidis

H. Ekerfelt, C. Emma, F. Fiuza, E. Gerstmayr, S. Gessner, M. Hogan, A. Marinelli, J. Peterson, B. O'Shea, D. Storey, X. Xu, V. Yakimenko

C. Joshi, K. Marsh, W. Mori, N. Nambu, Z. Nie, Y. Wu, C. Zhang

R. Ariniello, J. Cary, C. Doss, K. Hunt-Stone, V. Lee, M. Litos

E. Adli

J. Yan, N. Vafaei-Najafabadi

Thank you for your attention