ENSTA IP PARIS

cnrs UMR 7639

ÉCOLE POLYTECHNIQUE IP PARIS

loa

FACET-II E-305: Beam filamentation and bright gamma-ray bursts

Alexander Knetsch on behalf of the E-305 collaboration

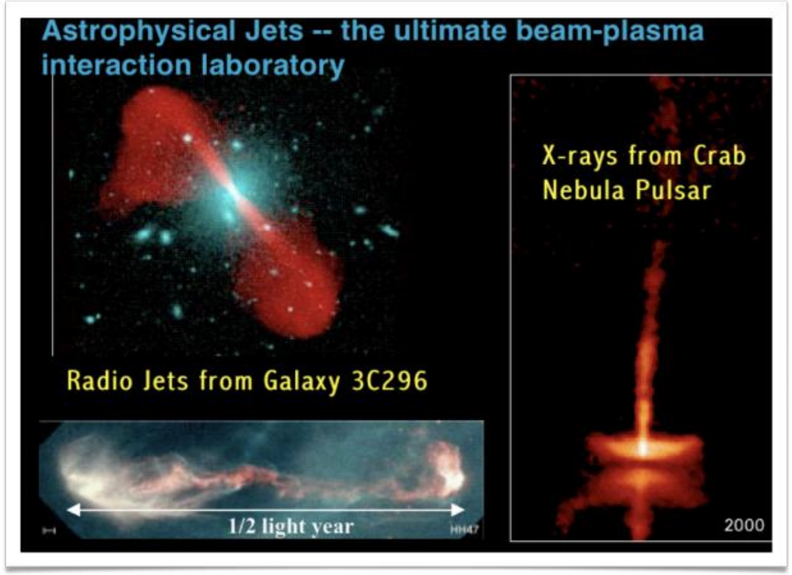
INSTITUT POLYTECHNIQUE DE PARIS

UCLA

SLAC NATIONAL ACCELERATOR LABORATORY

Motivation

Relativistic streaming instabilities in astrophysics



T. Katsouleas, role of Weibel instability in astrophysics and cosmic jets.

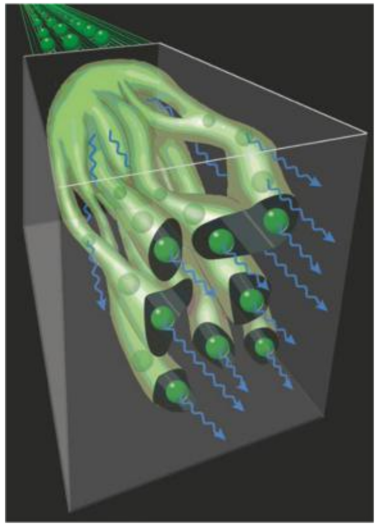
- They are thought to play a key role in **blazars**, cosmic magnetisation at interstellar and intergalactic scales and high-energy explosive transients (e.g. **GRB**).
- Are of fundamental importance as provide a mechanism for energy conversion from particles to EM fields and to **gamma rays.**

Motivation

Relativistic streaming instabilities in applications

- They set important limitations on the feasibility of experimental concepts such as **ICF** or a **plasma-based acceleration**.

- They can channel beam kinetic energy into ɣ-rays (*Benedetti, A., Tamburini, M. & Keitel, C.H. Giant collimated gamma-ray flashes. [Nature Photon 12, 319–323 (2018)]*)

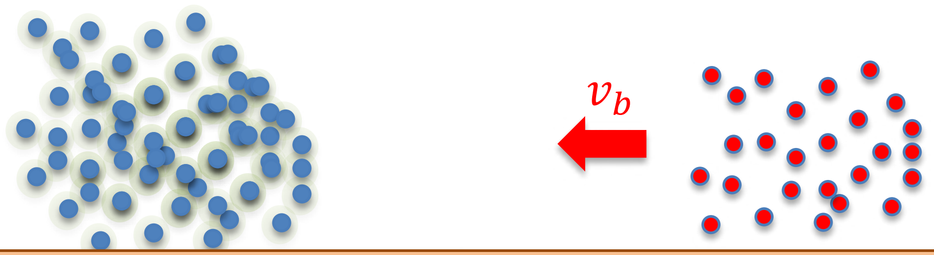


Relativistic beam-plasma instabilities

See talk by P. San Miguel Claveria
Thursday WG3 8:45

Plasma electrons & Plasma ions

Particle Beam



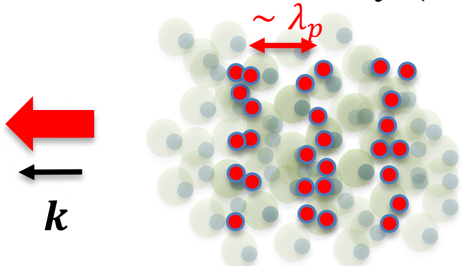
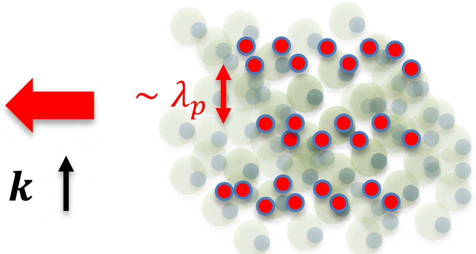
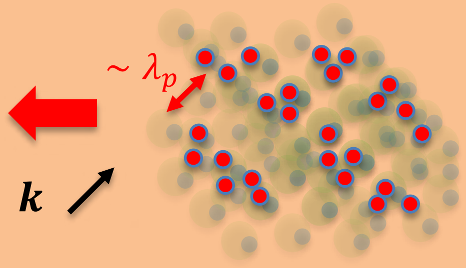
Unstable electromagnetic modes exponentially growing from noise

$\alpha = {}^{n_b}/_{n_p}$ $\quad \gamma_b$ = beam Lorentz factor

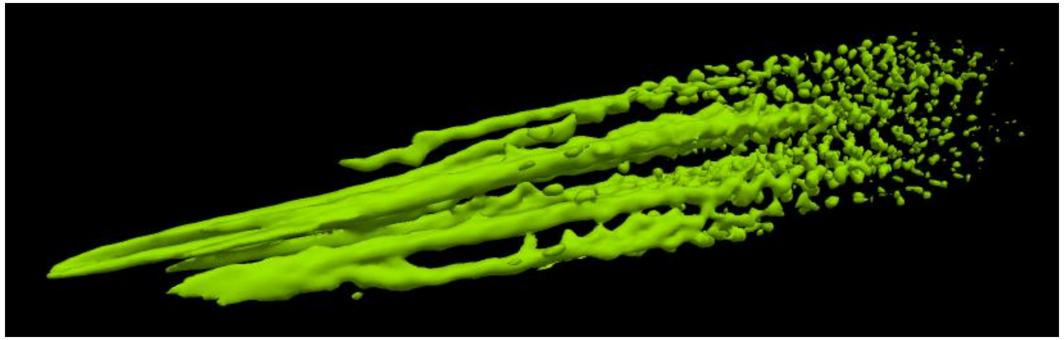
In the ultra-relativistic regime ($\gamma_b \gg 1$), oblique modes dominate the interaction

Depending on the orientation ($\boldsymbol{k}$) of the mode w.r.t. the beam propagation, there exist three types of beam-plasma instabilities

A. Bret, L. Gremillet, and M. E. Dieckmann, Phys. Pla. 17, 120501 (2010).

	Two-Stream Instability (TSI)	Current Filamentation Instability (CFI)	Oblique Instability (OTSI)
	 Electrostatic longitudinal mode	 Electromagnetic transverse mode	 Electrostatic oblique mode
Maximum Growthrate (Kinetic theory for cold colissionless **unbounded** systems)	$\Gamma_{\mathrm{TSI}} = \frac{\sqrt{3}}{2^{4/3}} \frac{\alpha^{1/3}}{\gamma_b} \omega_p$	$\Gamma_{\mathrm{CFI}} = \beta \sqrt{\frac{\alpha}{\gamma_b}} \omega_p$	$\Gamma_{\mathrm{Obl}} = \frac{\sqrt{3}}{2^{4/3}} \left(\frac{\alpha}{\gamma_b}\right)^{1/3} \omega_p$

Towards controlled experiments at SLAC - the E305 experiment



Simulated beam density at saturation of FACET-II beam propagating in an Al target (credits to G. Raj).

E-305 experiment at FACET-II facility at SLAC with the goals of:

- Study relativistic beam-plasma instabilities with plasma densities in the range 10^{18-24} cm^{-3} , by sending FACET-II 10 GeV electron beams into gaseous or solids targets.
- Charaterize resulting ɣ-ray radiation
- Study the interplay of different modes in the nonlinear stage
- Investigate additional physics such as collisional effects in exotic nonequilibrium warm dense matter states (solid), **finite bunch length and finite beam size effects**, **and competition with plasma wakefields** (gas)

E305 Collaboration

LOA (IP Paris): S. Corde, M. Gilljohann, A. Knetsch, O. Kononenko, Y. Mankovska, A. Matheron, G. Raj, P. San Miguel Claveria, V. Zakharova

UCLA: C. Joshi, K. A. Marsh, N. Zan, C. Zhang

SLAC: R. Ariniello, H. Ekerfelt, F. Fiuza, S. Gessner, M. Hogan, B. O'Shea, J. Peterson, D. Storey

CU Boulder: J. Cary, C. Doss, K. Hunt-Stone, V. Lee, M. Litos

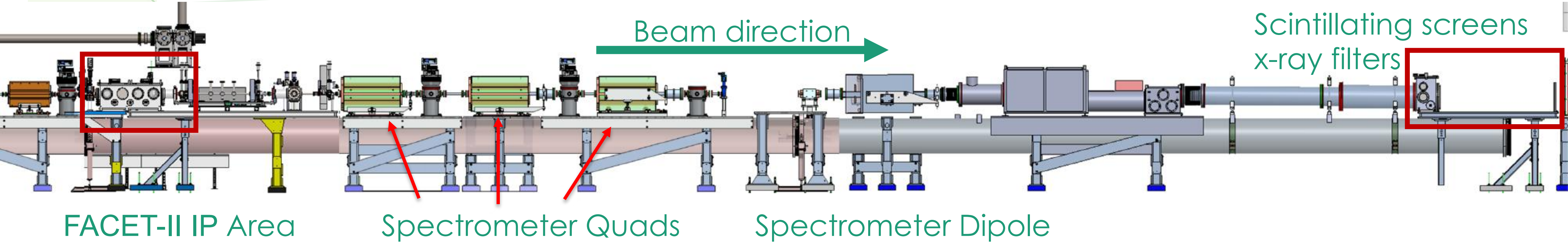
Stony Brook U.: N. Vafaei-Najafabadi

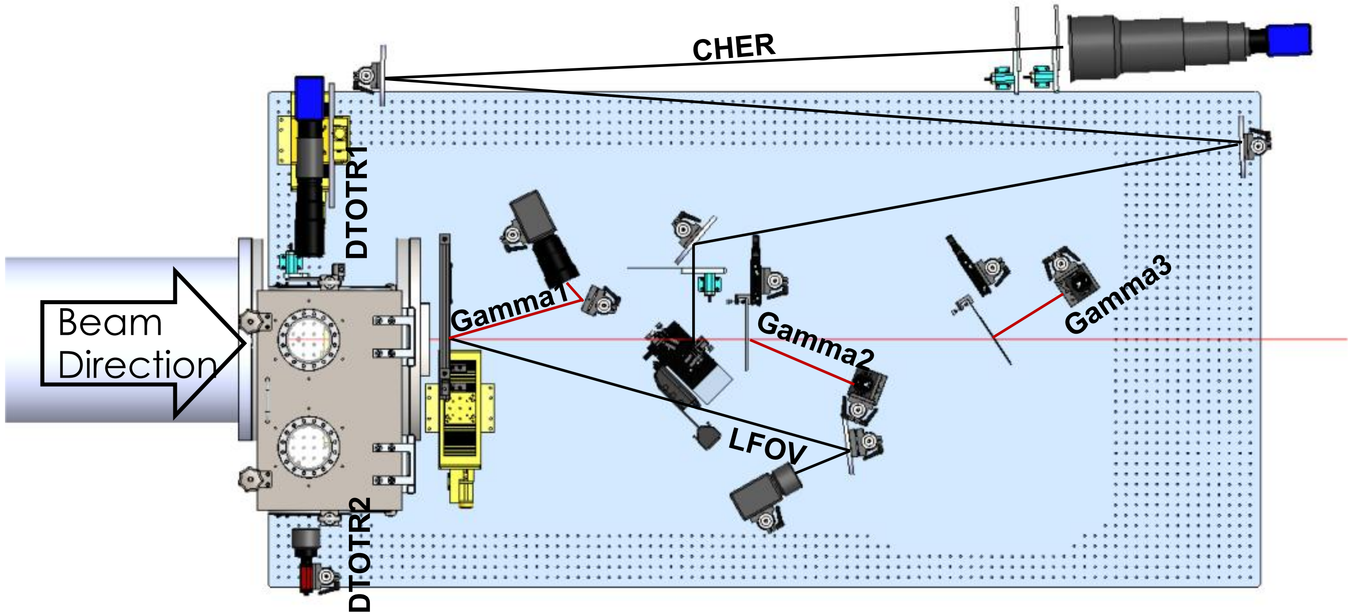
U. Oslo: G. Cao, E. Adli

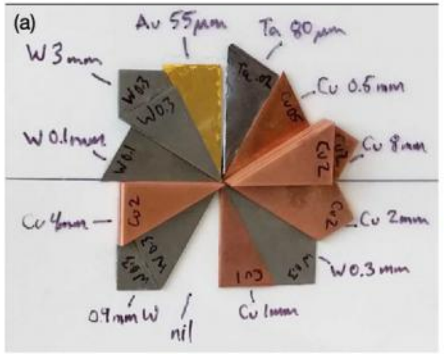
MPIK: C. Keitel, M. Tamburini, A. Sampath,

CEA: X. Davoine, J. Faure, L. Gremillet

Setup and relevant diagnostics



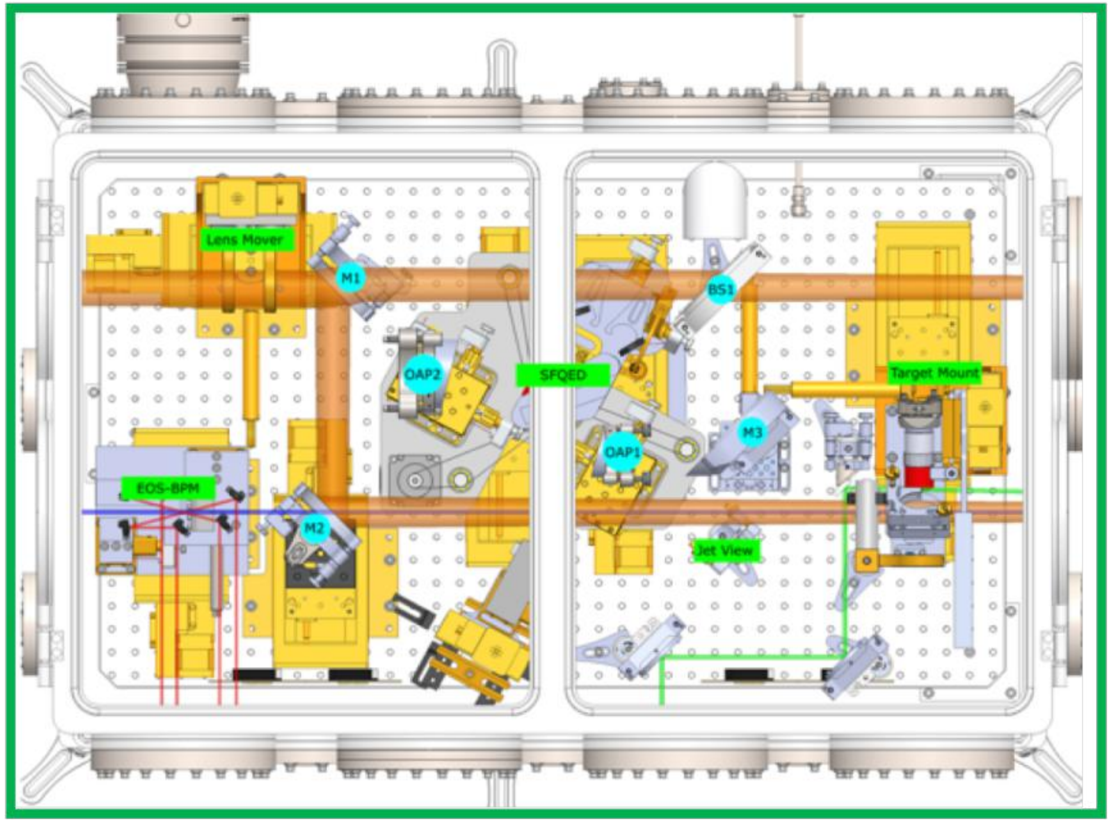


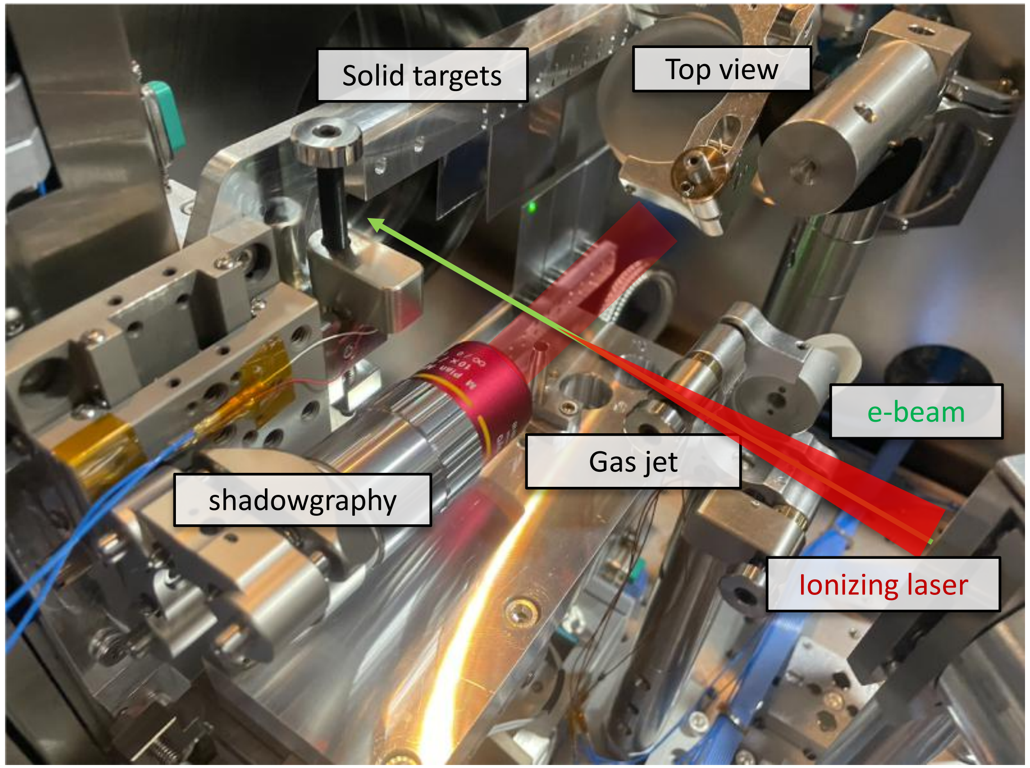


See talk by P. San Miguel Claveria
Wednesday WG4+7 13:50 (next talk)

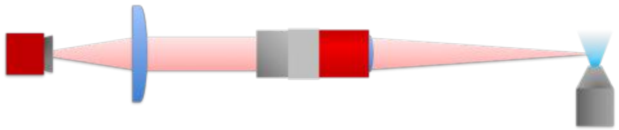
- Imaging electron spectrometer
- High-resolution screens (DTOTR1/2)
- Gamma ray diagnostics

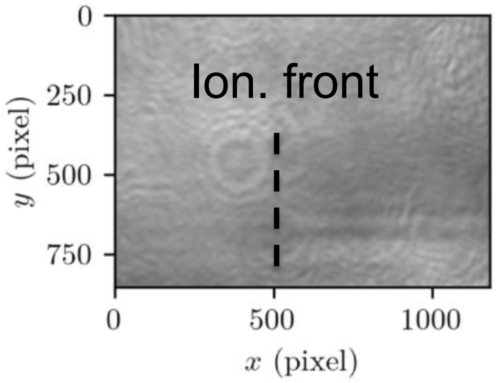
The IP: An overview

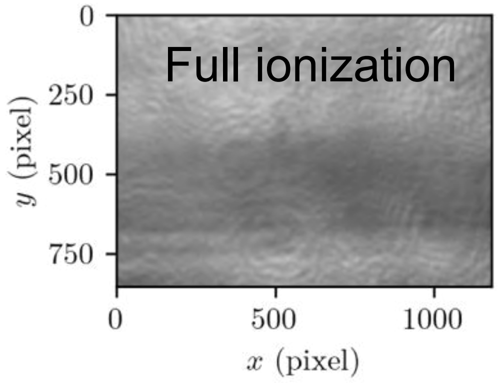


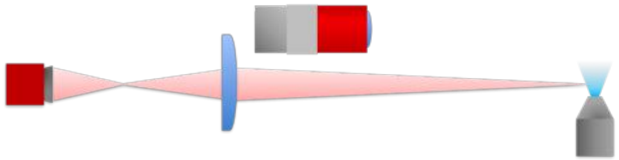


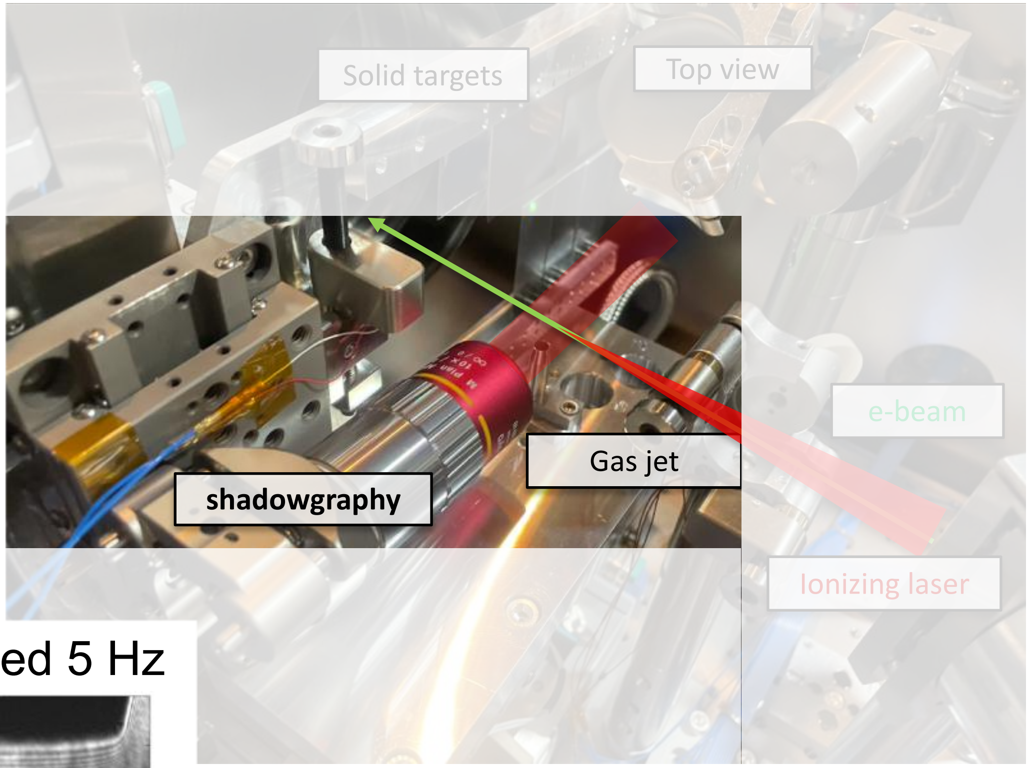
The IP: Shadowgraphy



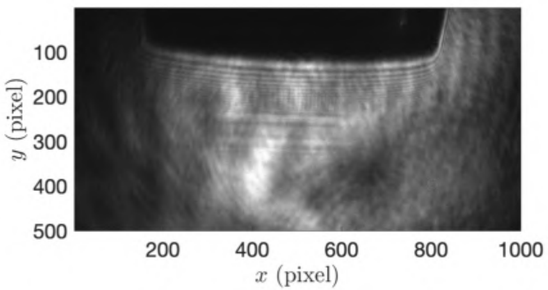




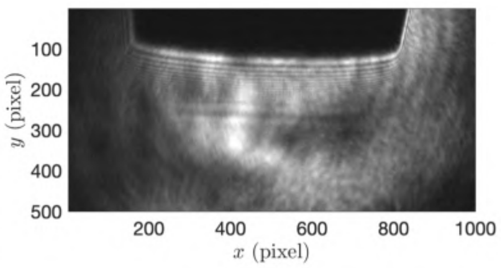




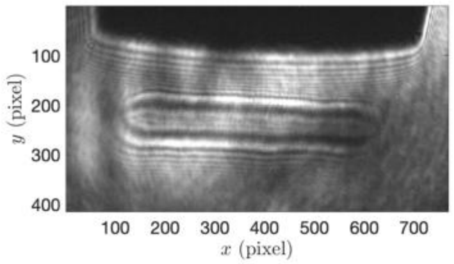
Laser ionized



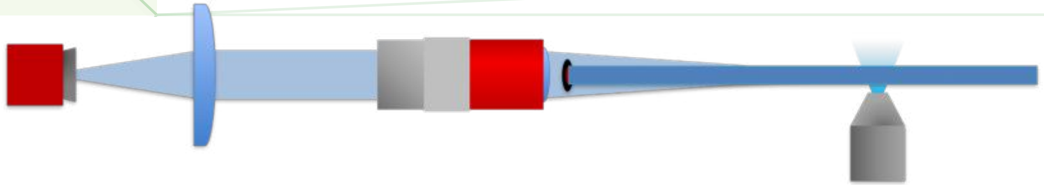
Beam ionized 1 Hz



Beam ionized 5 Hz

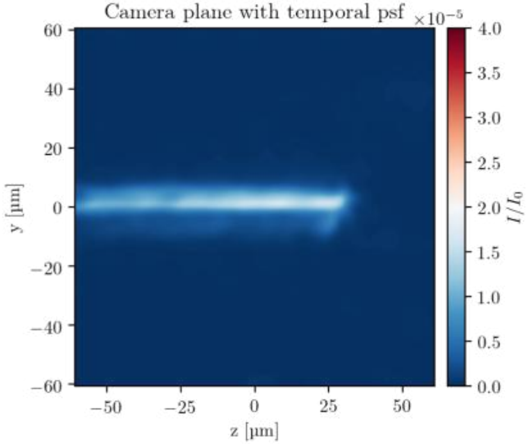


The IP: Shadowgraphy – future upgrades

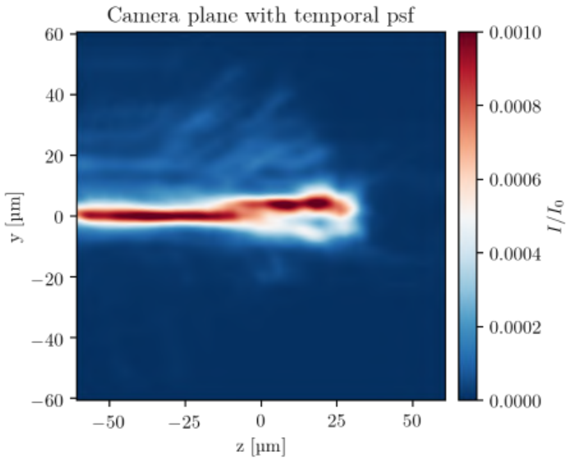


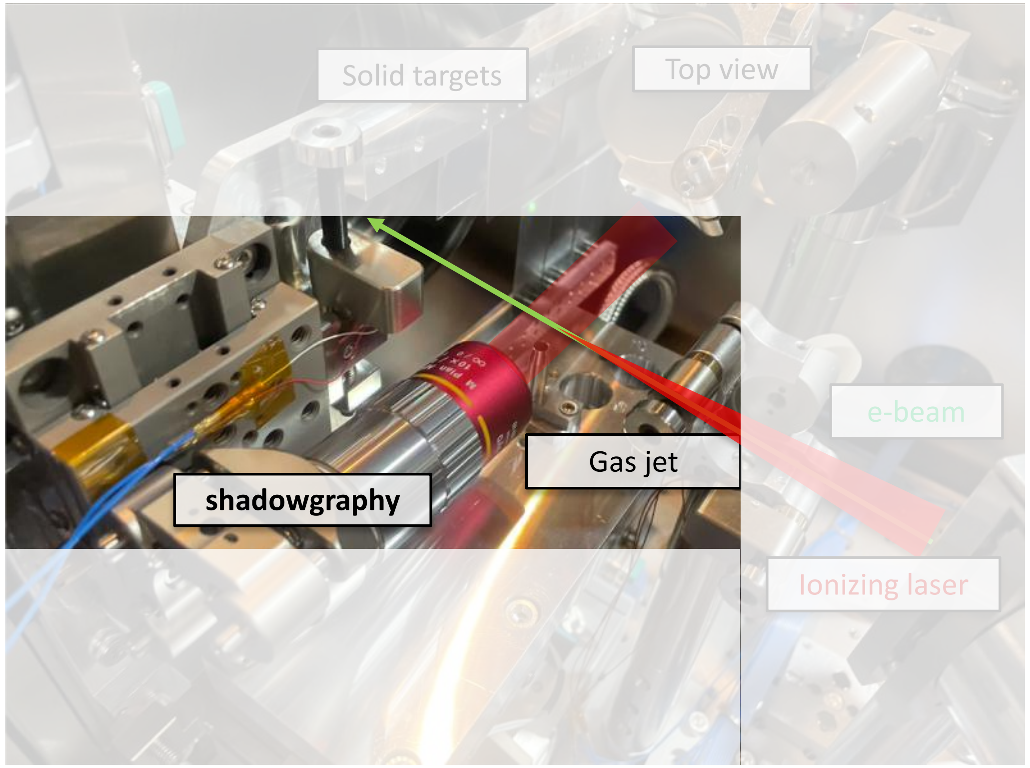
- Spatial filter for Darkfield shadowgraphy
- Frequency-doubling to 400 nm to increase SNR

Filamentation

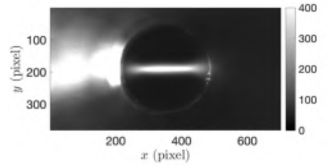


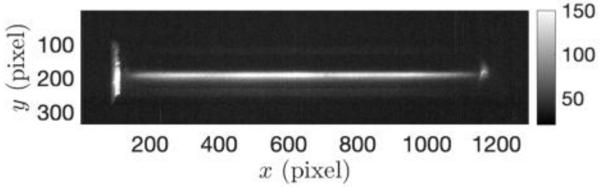
Blowout

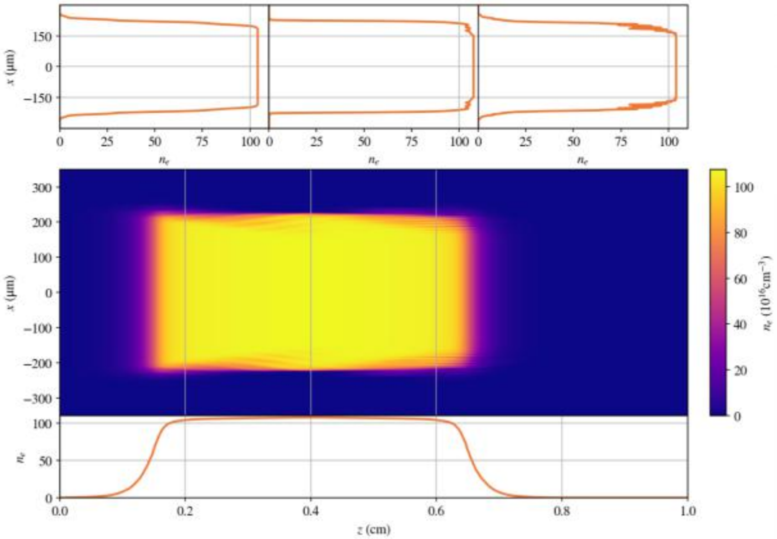




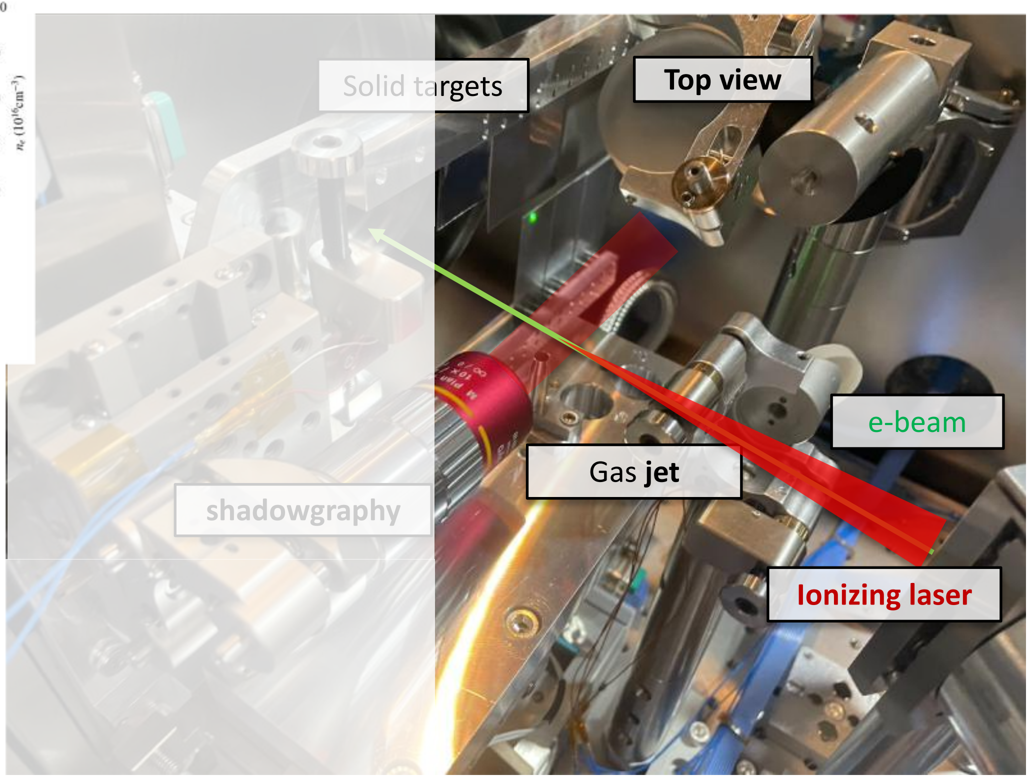
The IP: Gas jet plasma target

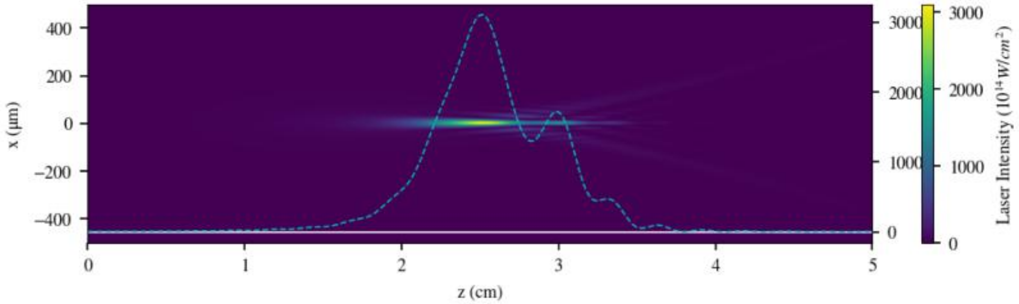






Simulation and design by R. Ariniello

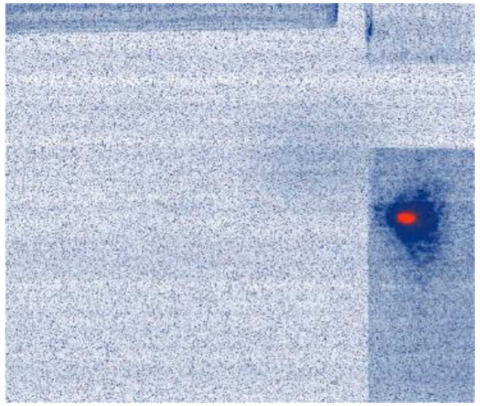




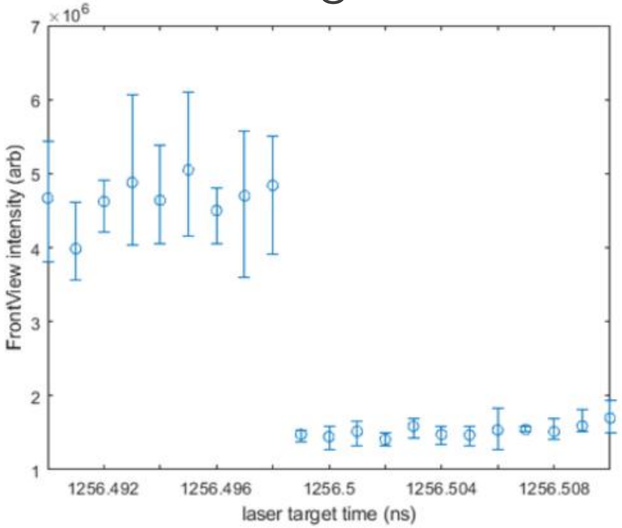
- Transition from 5 mm round to 15 mm slit nozzle
- Axilens as focusing element
- Succsessfull gas load tests for backing pressure range: 5 Hz up to 200 psi and 1 Hz up to 1250 psi

The IP: Alignment and Synchronization

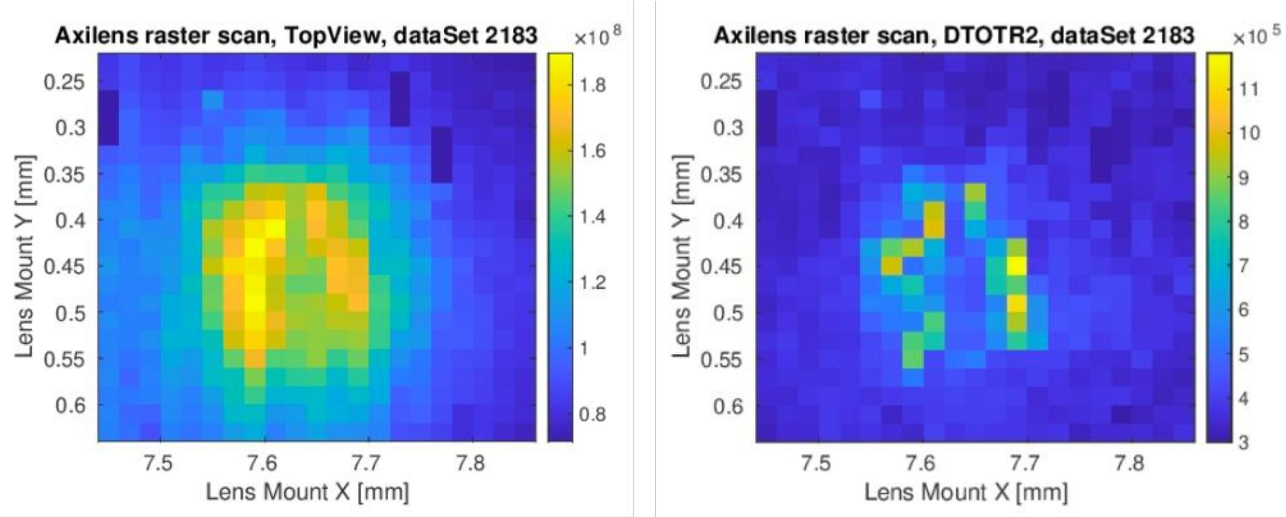
Solid targets as OTR screens

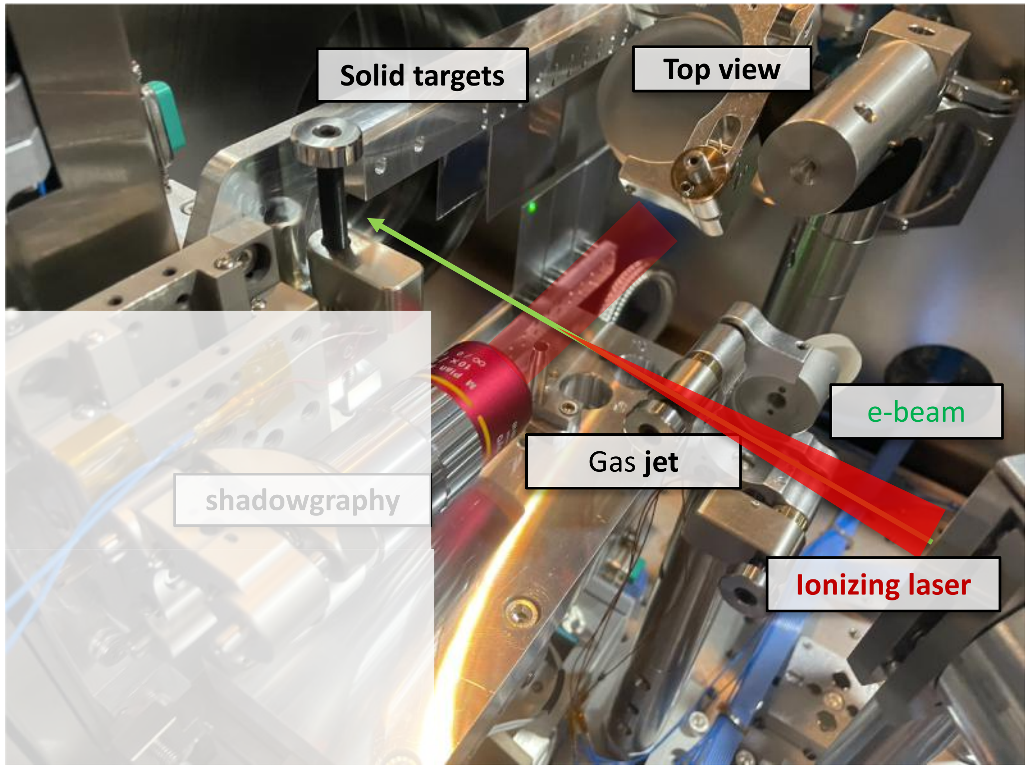


Plasma afterglow



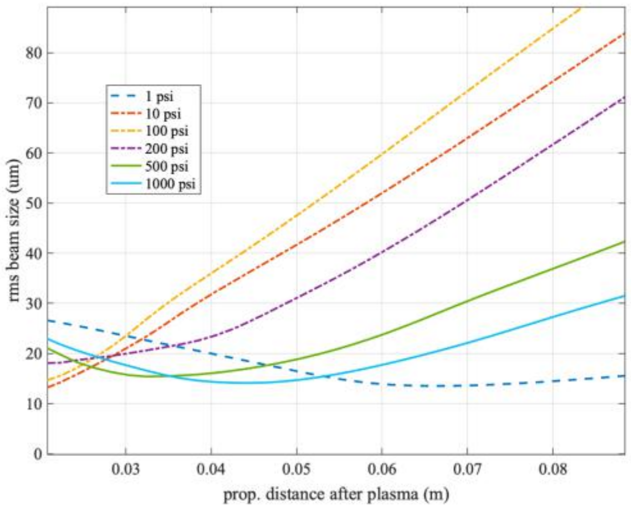
2D raster scans



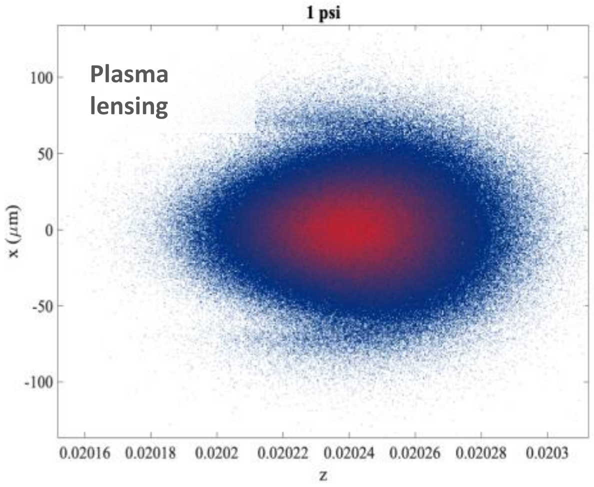


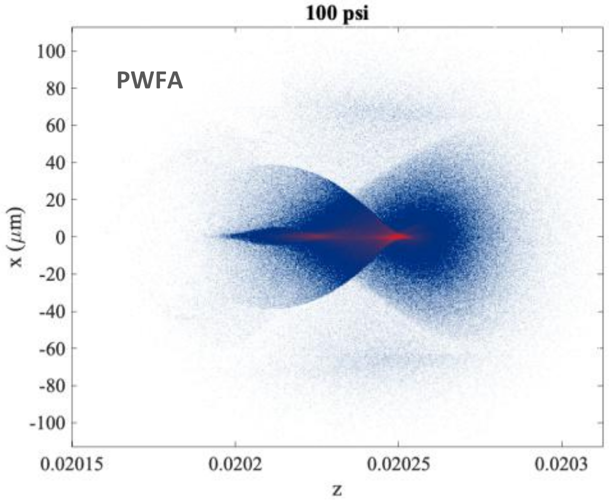
First attempt on a full measurement: pressure scan 1 psi – 1250 psi

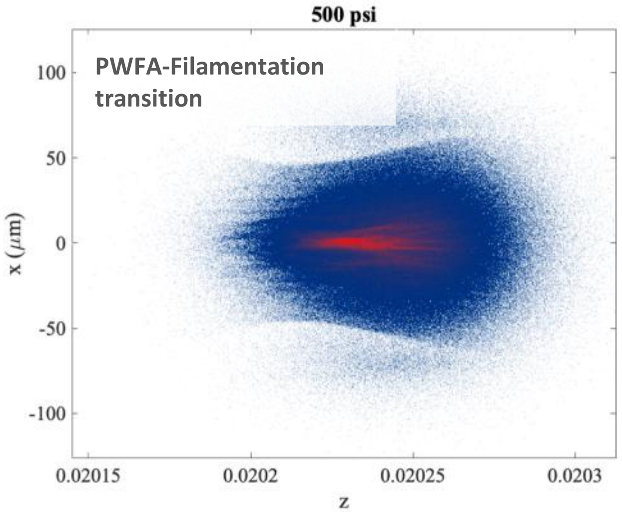
See talk by P. San Miguel Claveria
Thursday WG3 8:45



Beam parameters	
Rms beam size on target x,y	136.1 um x 36.7 um
Charge	1.6 nC

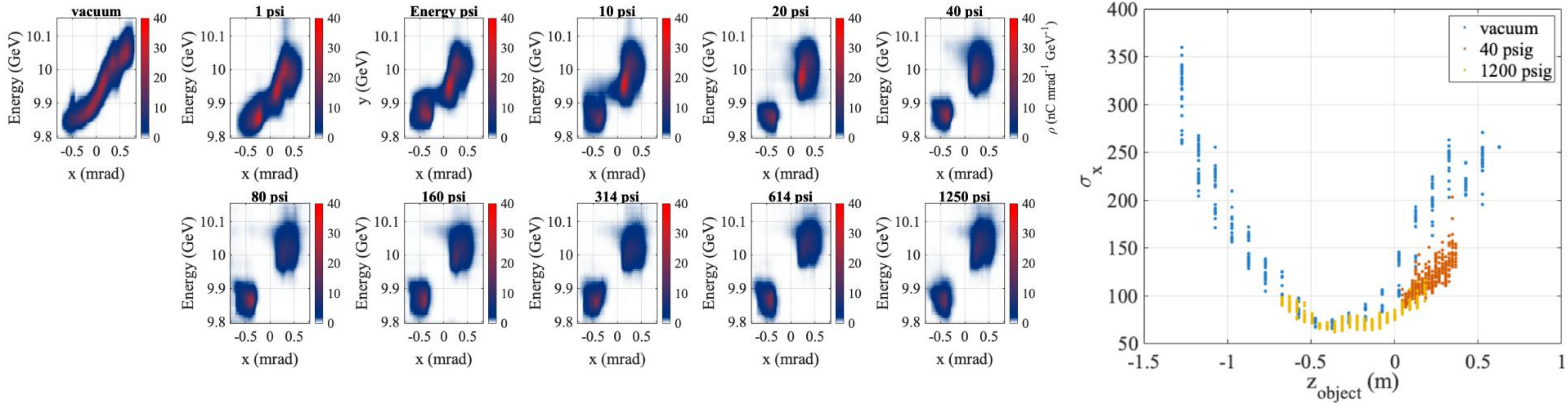






Electron Spectrometer

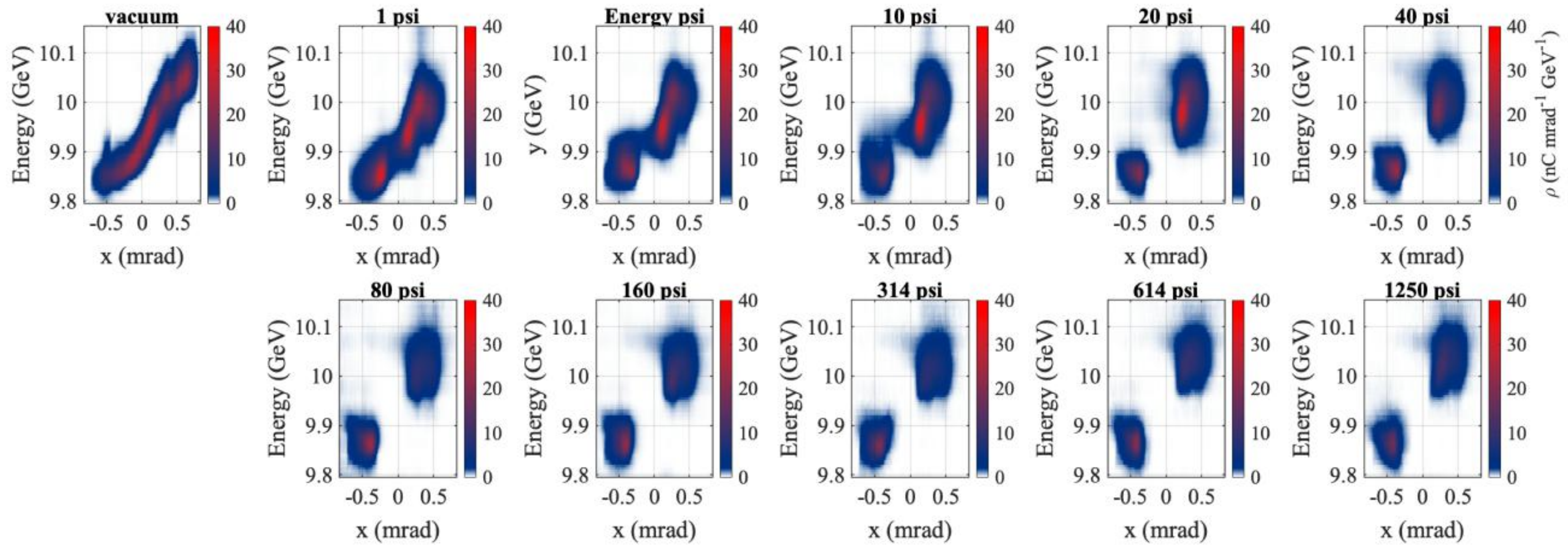
Divergence-sensitive measurement M12=10 m



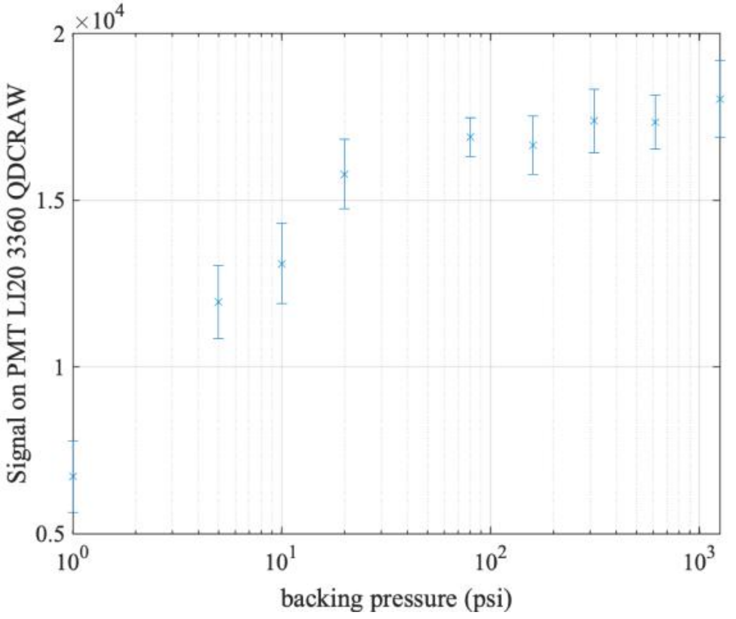
- Increased divergence of central beam part
- Object-plane scan reveals: outer beam parts were unperturbed

Electron Spectrometer

Divergence-sensitive measurement M12=10 m

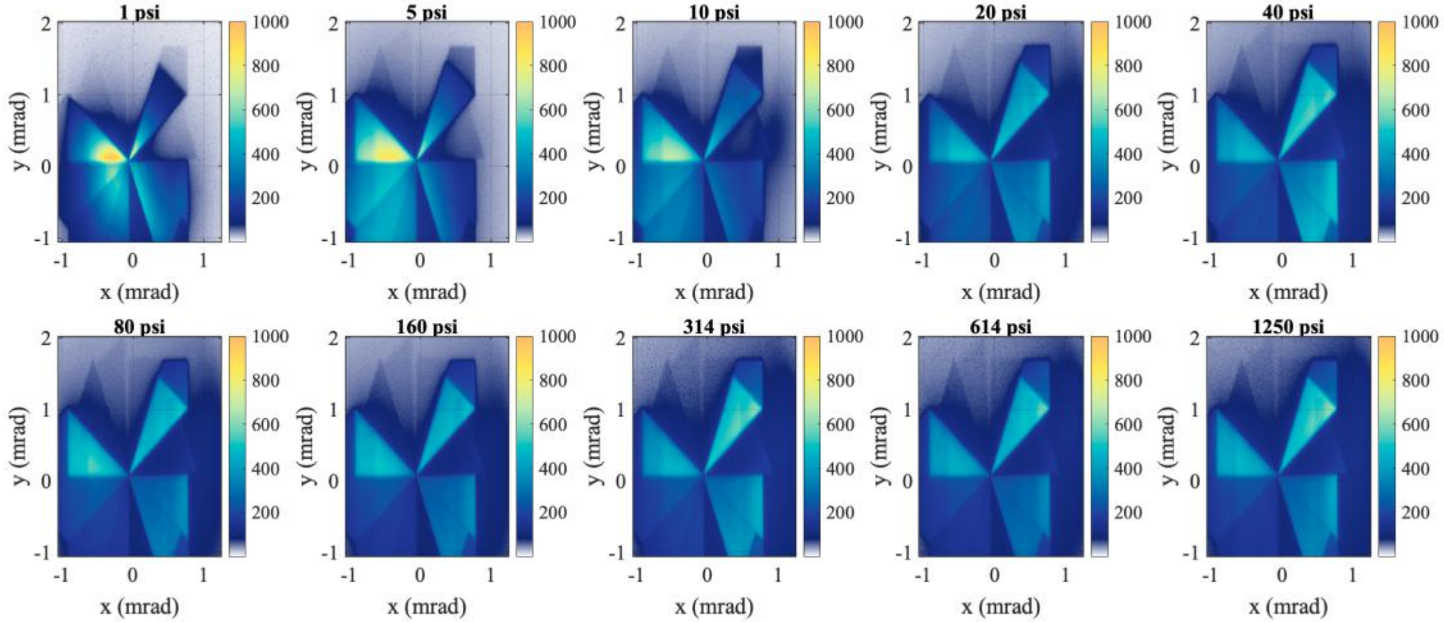


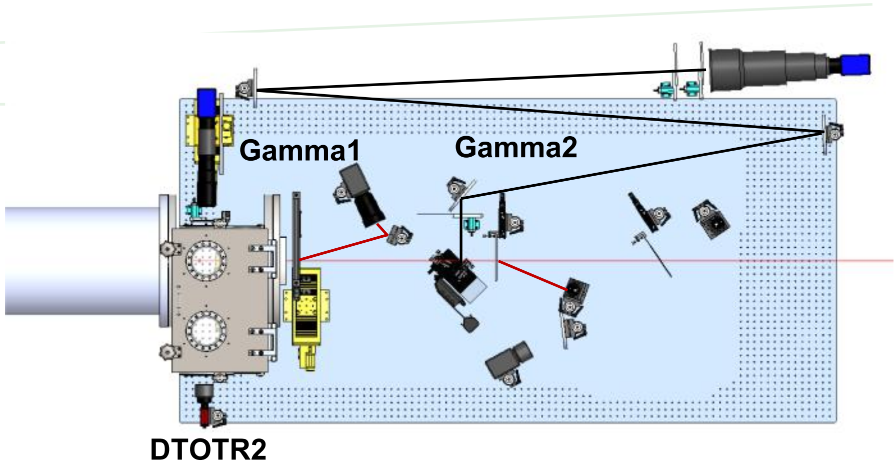
Beam losses



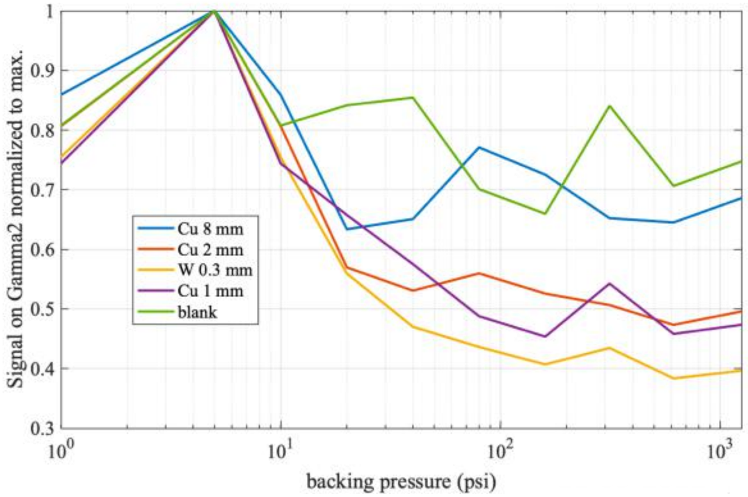
- Increased divergence of central beam part
- Object-plane scan reveals: outer beam parts were unperturbed
- Higher losses with increased backing pressure indicates perturbed charge is not imaged

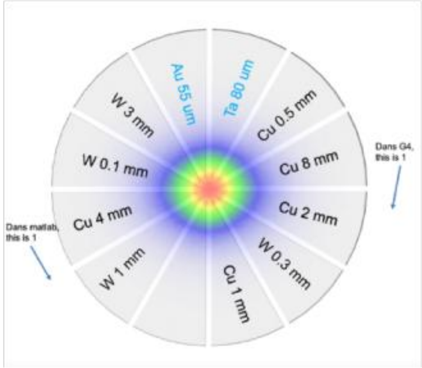
Gamma 2 diagnostic:



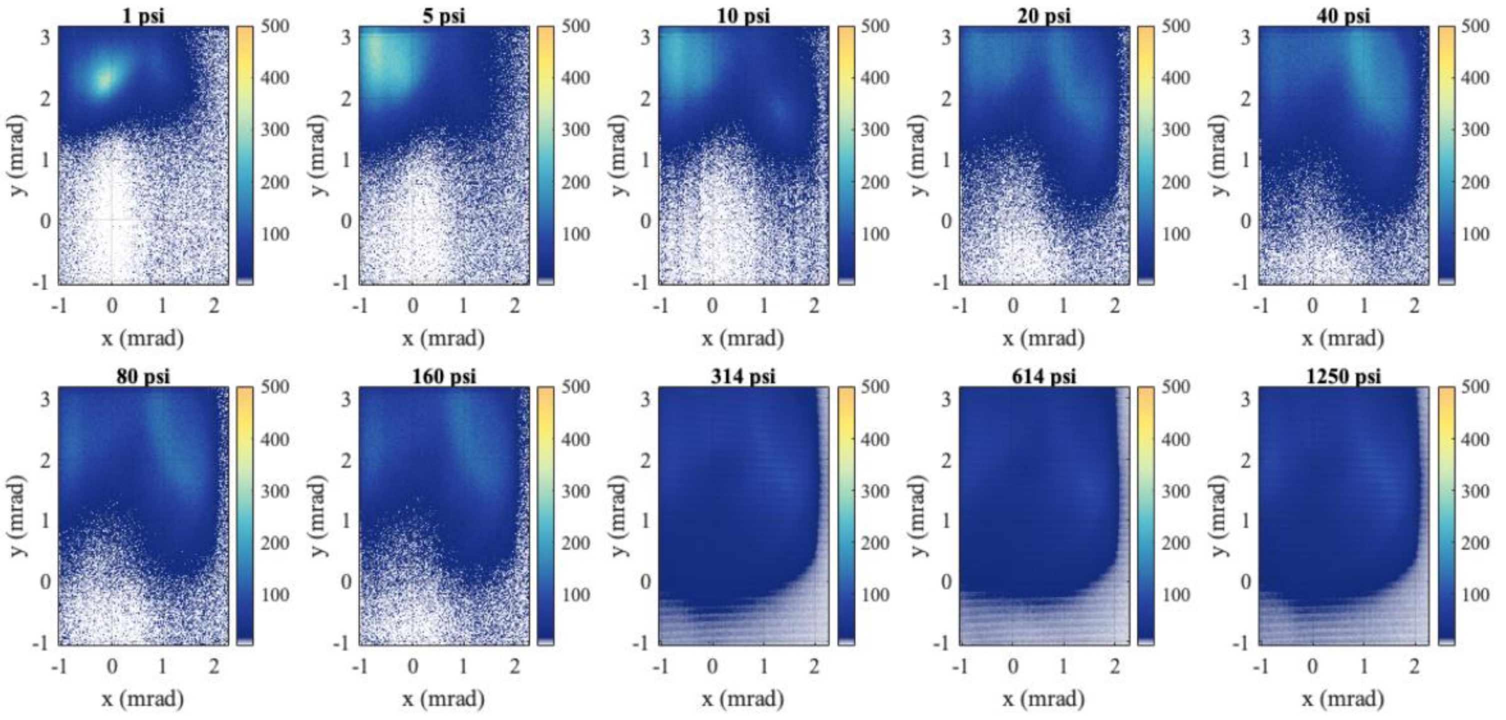


- Strong dependence of pointing on plasma density

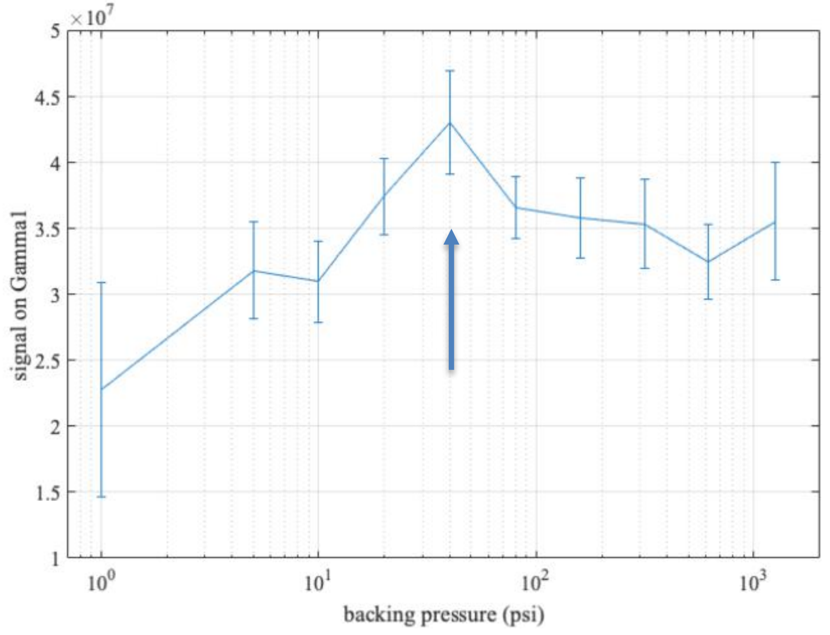




Signal on Gamma 1 diagnostic (no filter)



For p>300 psi CsI was used, result corrected by sensitivity

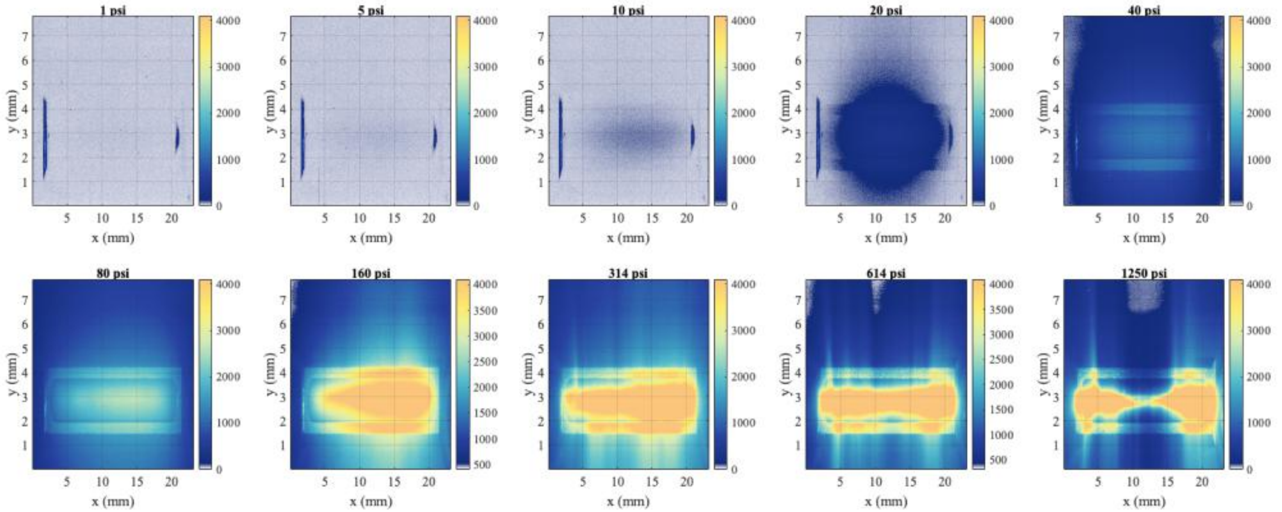


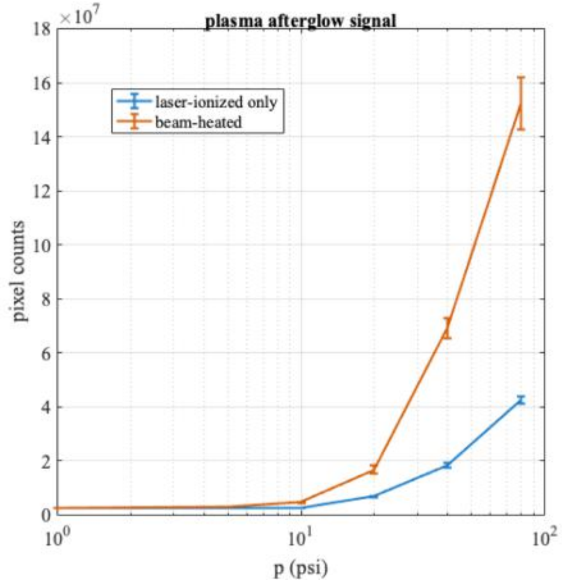
- Pressure-dependent features observable
- Maximum at 40 psi
- beyond 40 psi reduced signal

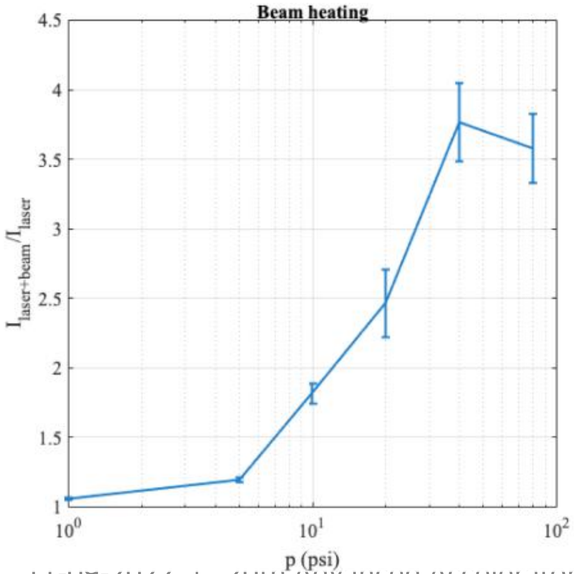
Plasma afterglow

See talk by A. Sutherland
Thursday 13:30 WG 5

See also poster by P. Muggli







- Beam-heated plasma afterglow signal is sensitive to energy deposition into plasma
- In the transition from PWFA to filamentation a drop in energy deposition is expected.
- Drop in additional signal strength at 40 psi hints at decreased energy deposition
- Higher dynamic range of plasma afterglow light collection necessary

Summary

- Good progress in setup commissioning
  - Gas jet operation
  - Low-resolution/high-resolution shadowgraphy
  - Imaging spectrometer
  - Alignment and synchronization
- First complete dataset collected

- More improvements upcoming
  - Darkfield shadowgraphy
  - High-resolution imaging with OTR screen
  - Plasma afterglow with higher dynamic range

- Repetition with improved beam parameters, improved ionization

- Experiments with chirped beams to study spatio-temporal behavior of filamentation

Thank you for your attention