



Characterizing the growth of current filamentation instability using laser wakefield accelerated beams

Jason Cardarelli
APS Division of Plasma Physics 2021

Y. Ma, P.T. Campbell, A.F. Antoine, M. Berboucha, R. Fitzgarrald, R. Hollinger, B. Kettle, K. Krushelnick, S.P.D. Mangles, J. Morrison, R. Nedbailo, Q. Qian, J.J. Rocca, G. Sarri, D. Seipt, H. Song, M.J.V. Streeter, S. Wang, L. Willingale, A.G.R. Thomas

Acknowledgement to the NSF (grant # 1804463) and DOE Fusion Energy Sciences Lasernet US (grant # DE-SC0021246)



MICHIGAN ENGINEERING

THE GÉRARD MOUROU CENTER FOR ULTRAFAST OPTICAL SCIENCE



Open-access model

- 40+ research groups worldwide are using OSIRIS
- 300+ publications in leading scientific journals
- Large developer and user community
- Detailed documentation and sample inputs files available

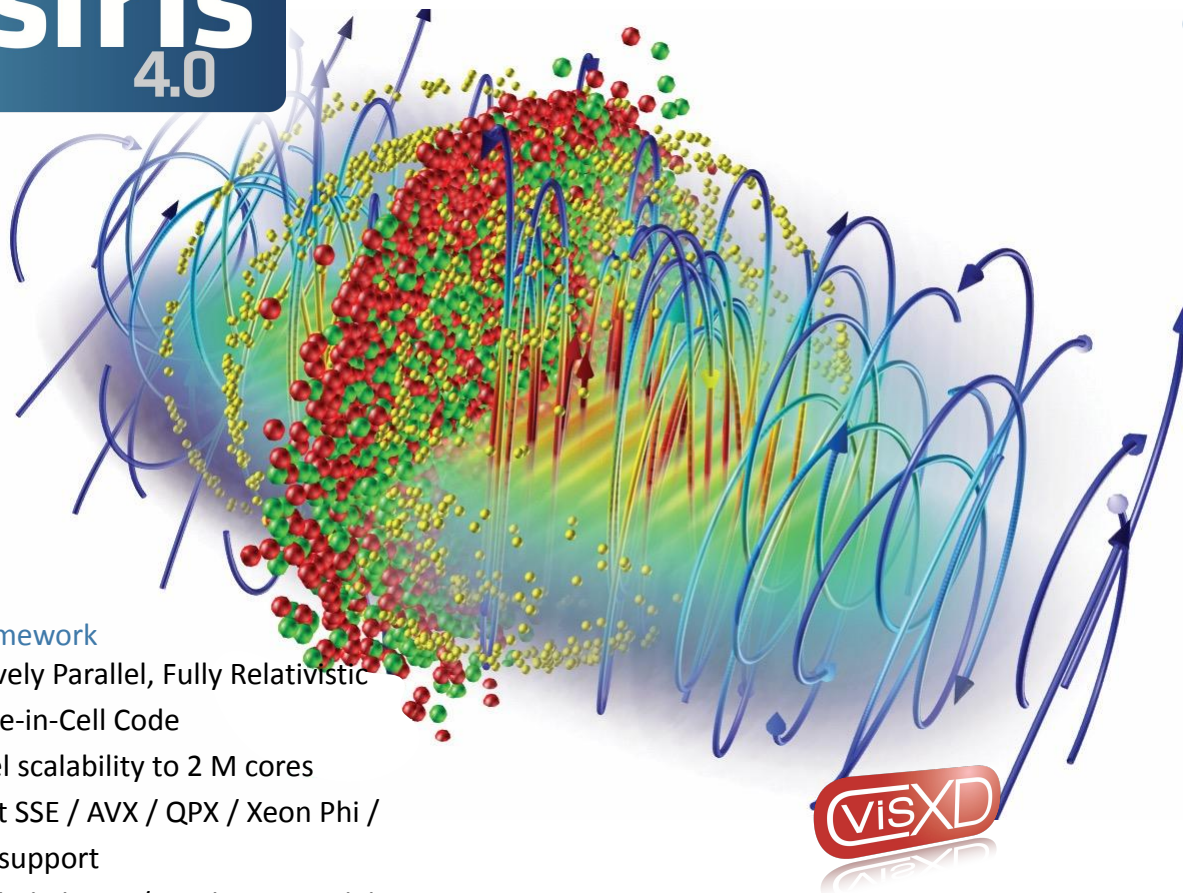
Using OSIRIS 4.0

- The code can be used freely by research institutions after signing an MoU
- Find out more at:

<http://epp.tecnico.ulisboa.pt/osiris>

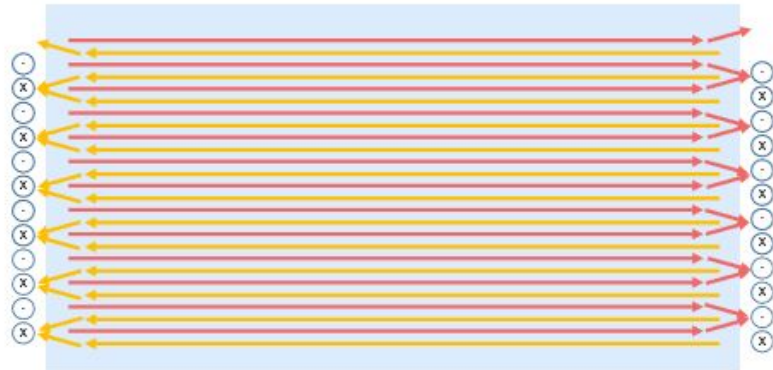
OSIRIS framework

- Massively Parallel, Fully Relativistic Particle-in-Cell Code
- Parallel scalability to 2 M cores
- Explicit SSE / AVX / QPX / Xeon Phi / CUDA support
- Extended physics/simulation models



Relativistic Current Filamentation Instability

Stationary Ion Background



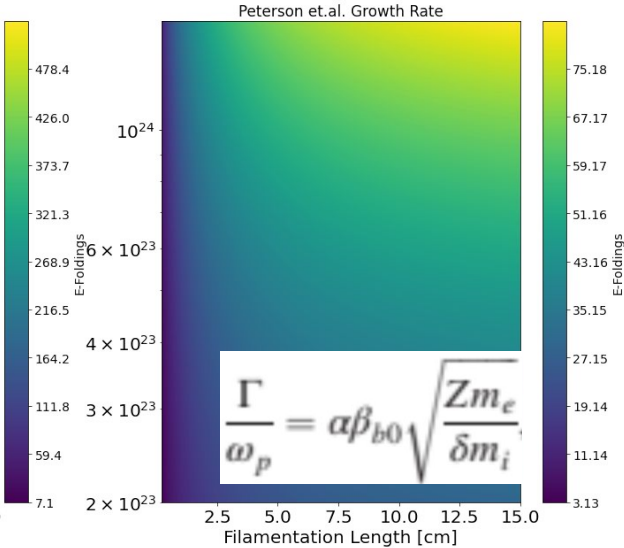
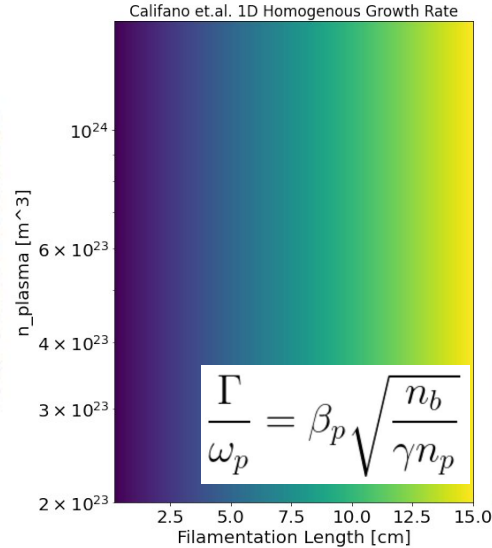
Plasma Electrons

Beam Electrons

$$\vec{v}_p = -v_0 \hat{z}$$

$$\vec{v}_b = +v_0 \hat{z}$$

$$\vec{B} = B_1 e^{i(kx - \omega t)} \hat{y}$$

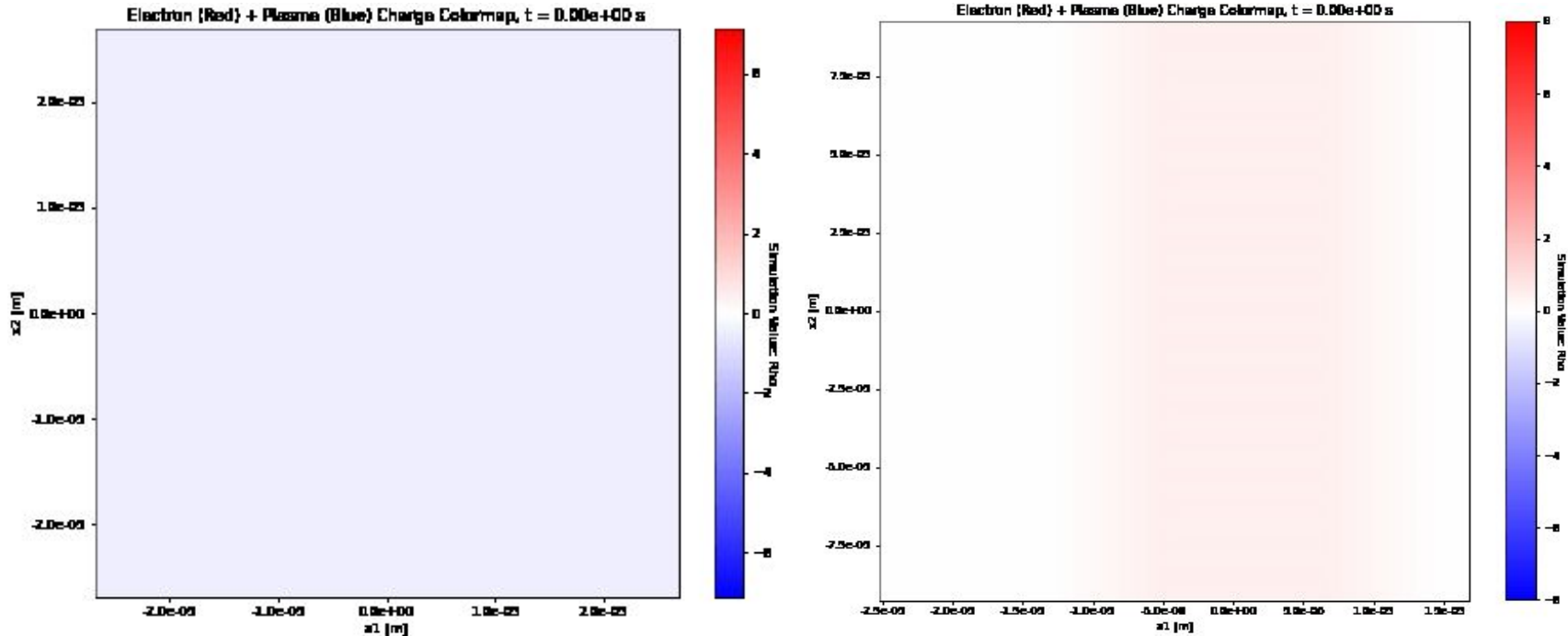


Peterson, J. et al. "Magnetic field amplification by a nonlinear electron streaming instability." Physical Review Letters (2021)

Califano, et al. "Nonlinear filamentation instability driven by an inhomogeneous current in a collisionless plasma." Physical Review E (1998)

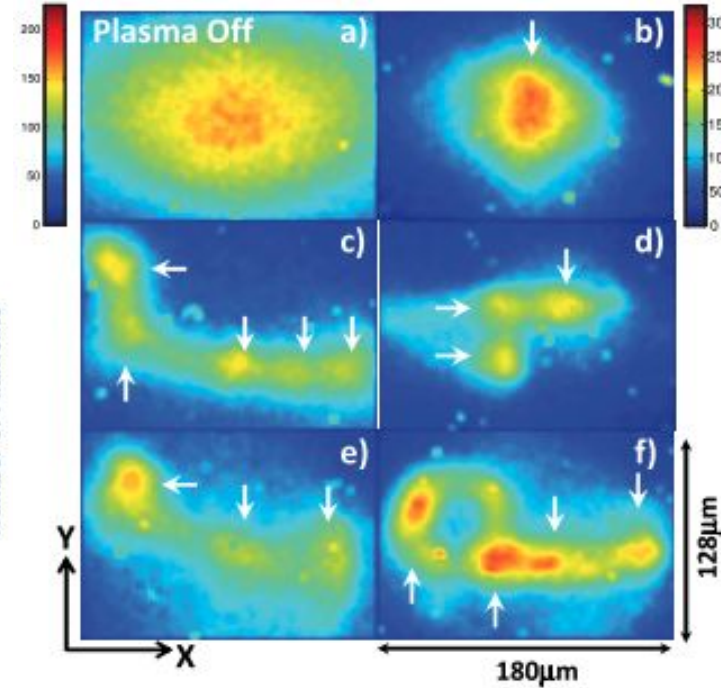
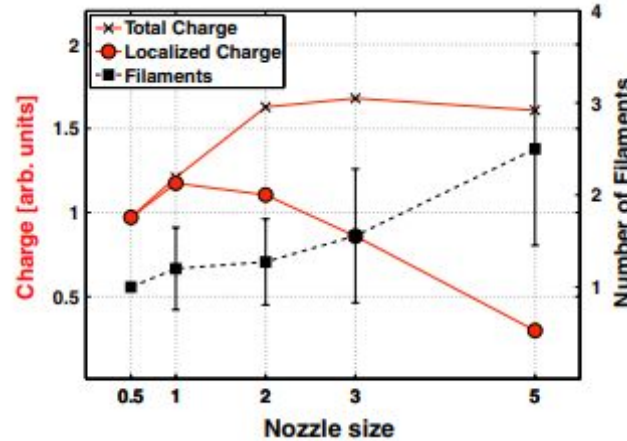
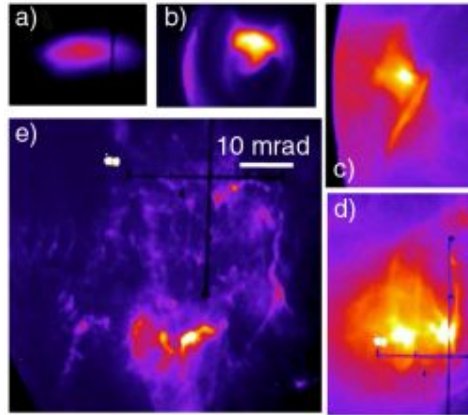


PIC Modelling of Current Filamentation Instability



Current Filamentation Instability - Previous Works

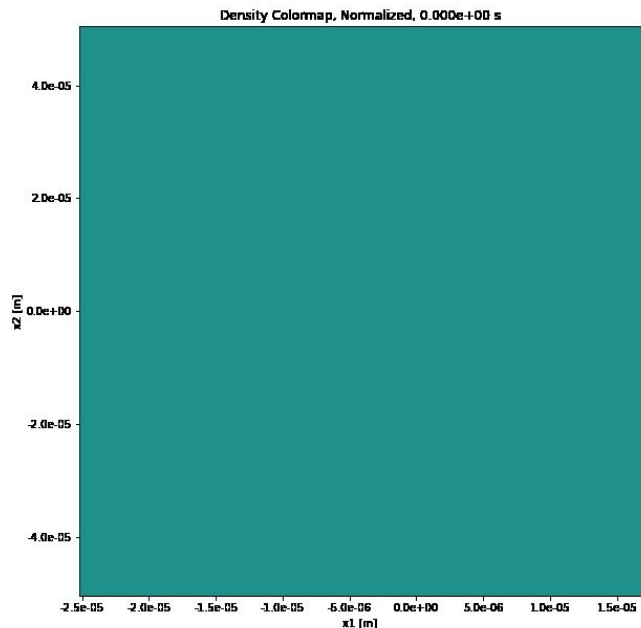
- Proof-of-concept LWFA experiment has been done by our group in the past (Huntington et al.)
- Previous experiments demonstrate early growth of instability, but do not explore a large parameter space.



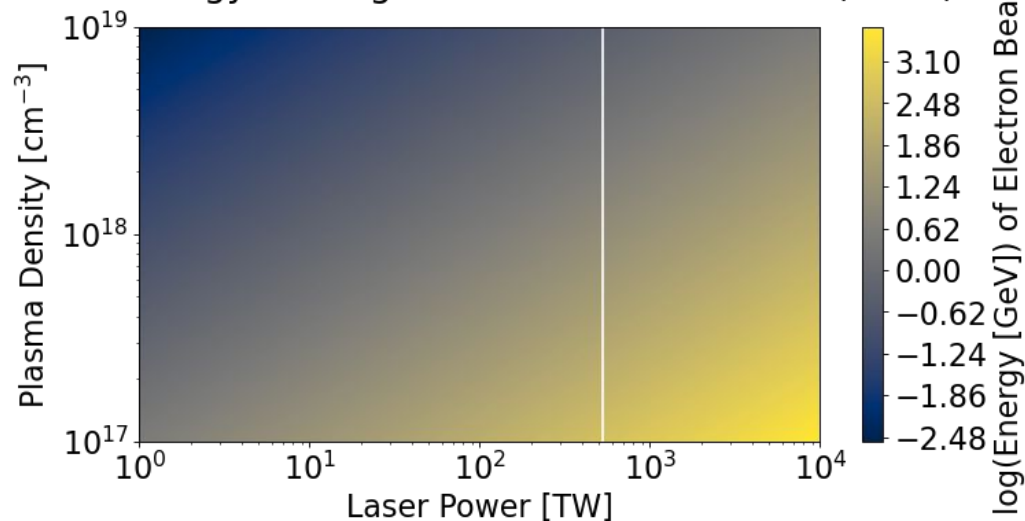
Huntington, et al. "Current filamentation instability in laser wakefield accelerators." Physical review letters (2011)

Allen, Brian, et al. "Experimental study of current filamentation instability." Physical Review Letters (2012)

Laser Wakefield Acceleration (LWFA) of Electron Beams

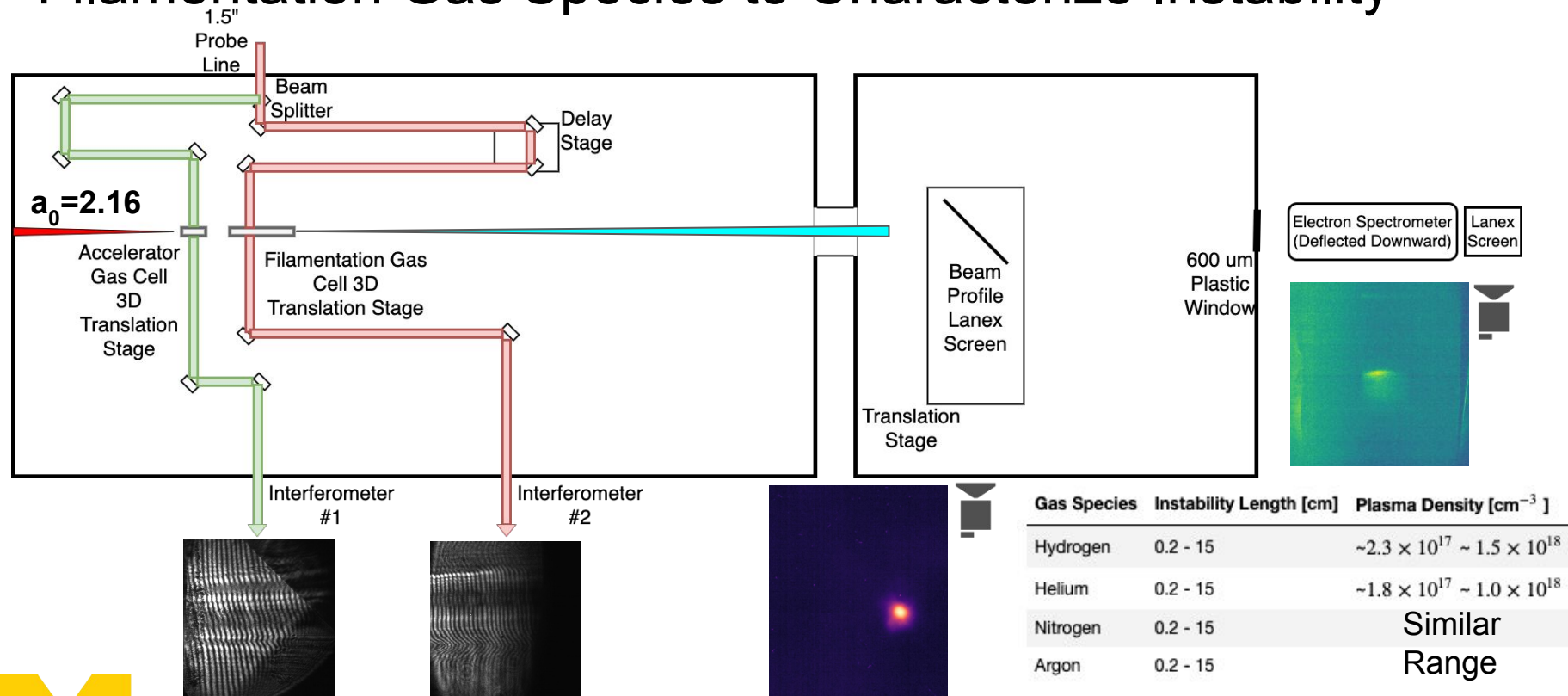


Beam Energy Scaling from Lu, W. et al. PRAB (2007)

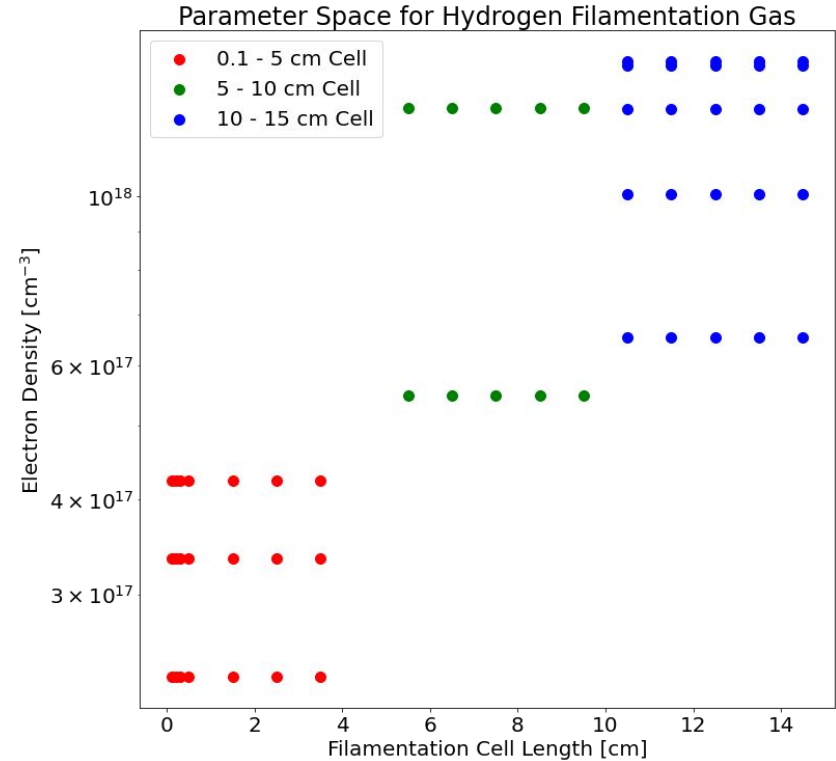
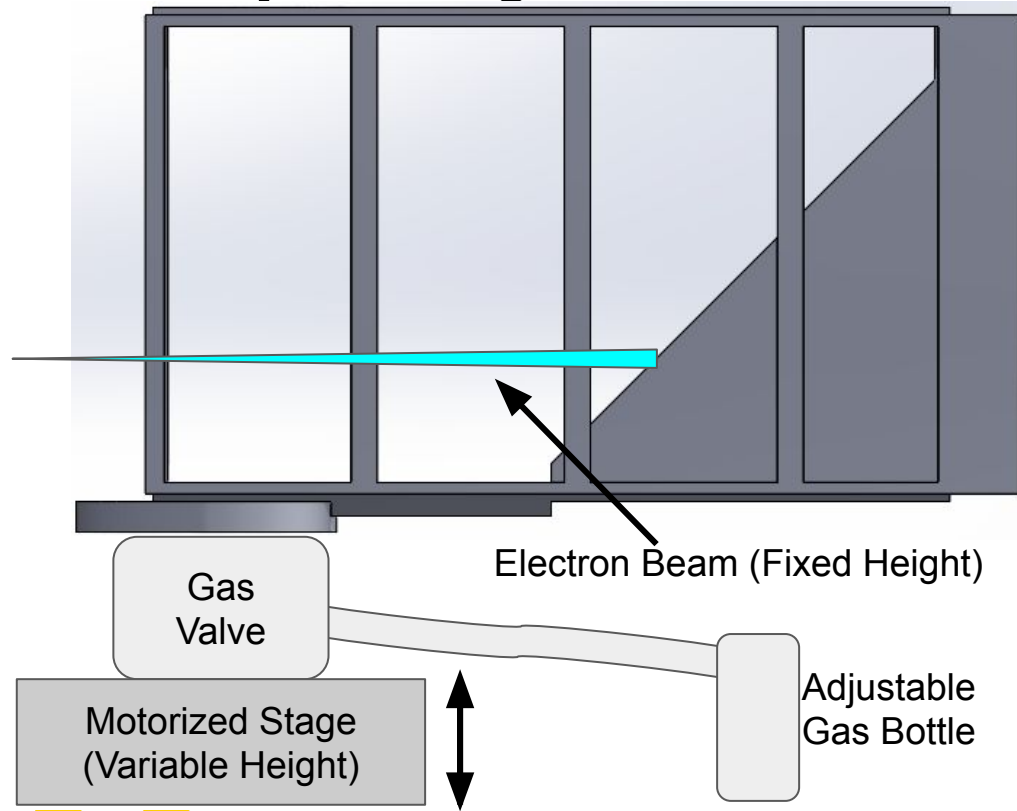


- LWFA produces ultrashort (fs time scale), **high current density**, low-divergence, relativistic electron beams.
- Beam parameters (high current density, GeV-class energy, tunability) make LWFA an attractive source of particle beams to study current filamentation instability in spatial scales suitable to a lab setting.

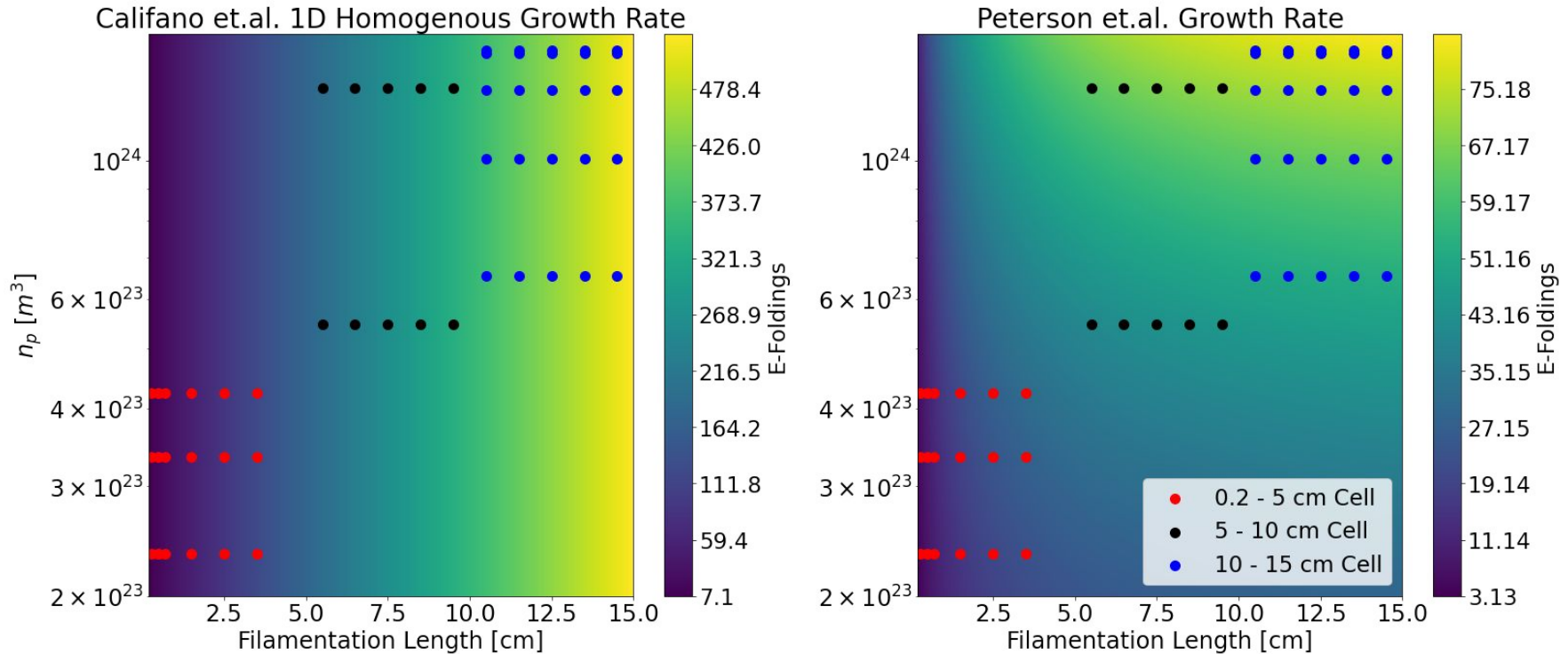
Experiment at CSU: Scan Length, Plasma Density, and Filamentation Gas Species to Characterize Instability



Surveyed Length & Plasma Density in Filamentation Cell

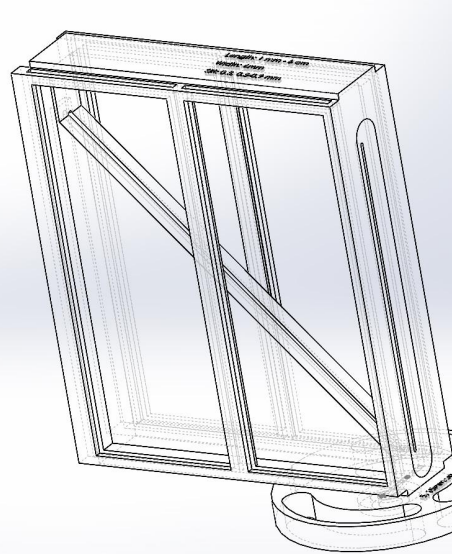


Example of Parameter Space Measured

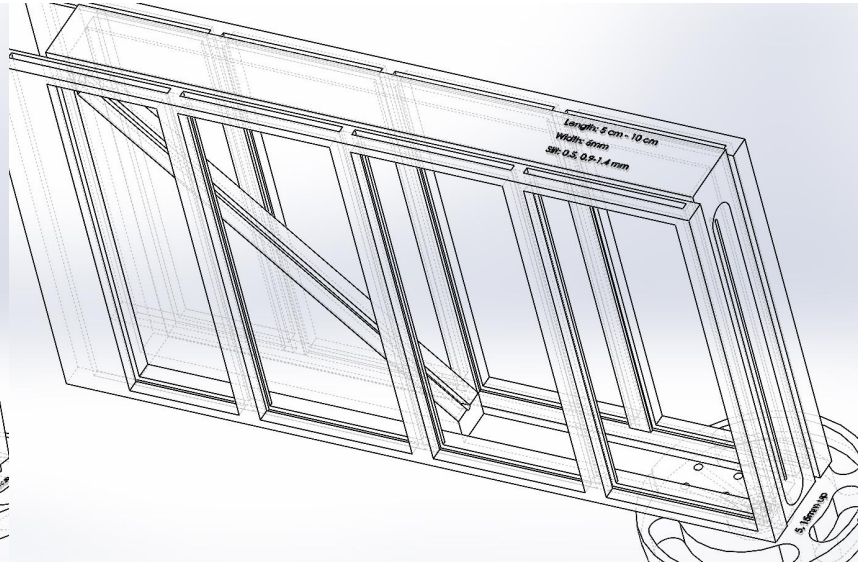


Filamentation Stage: Variable-Length Cell Designs

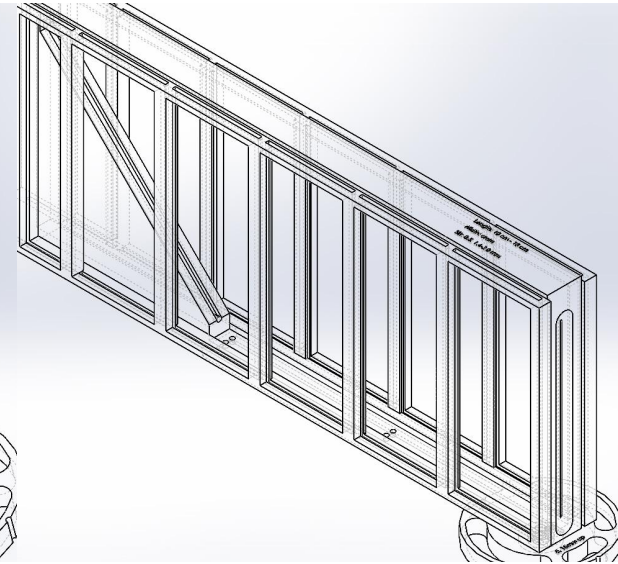
0.2 - 5 cm



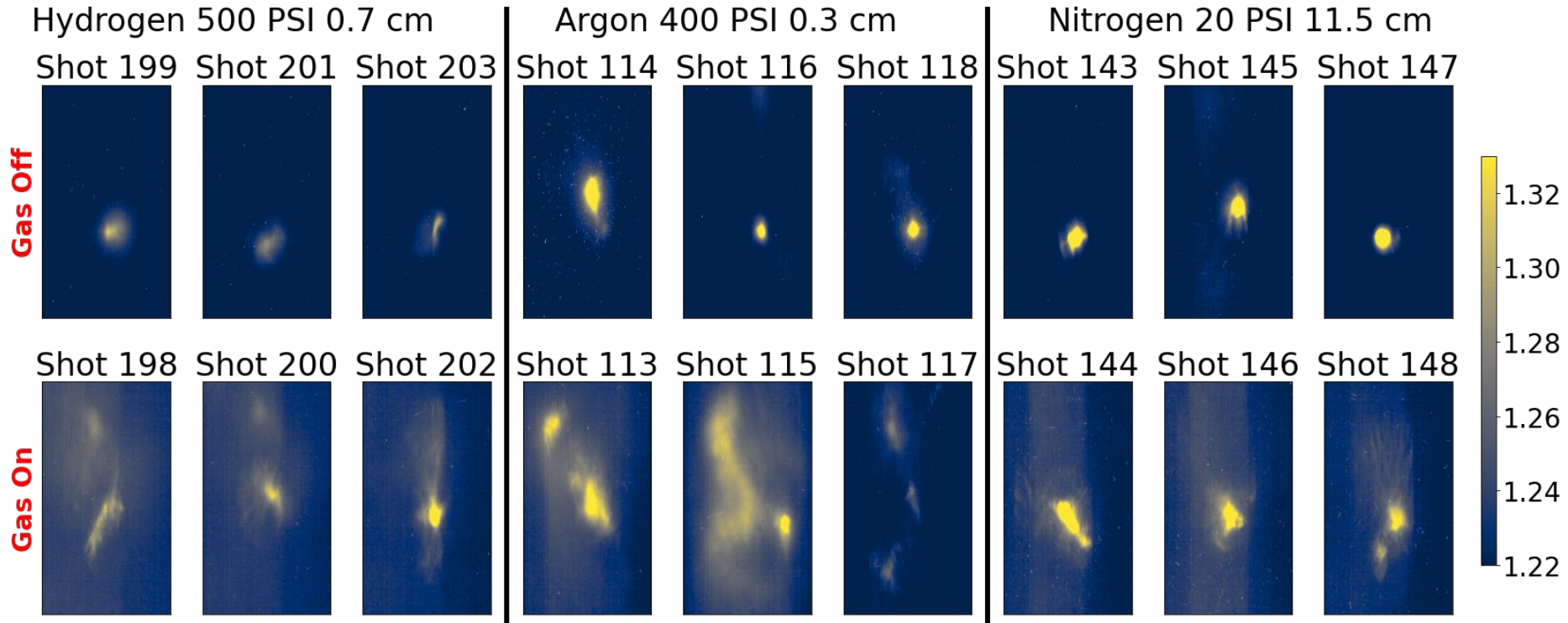
5 - 10 cm



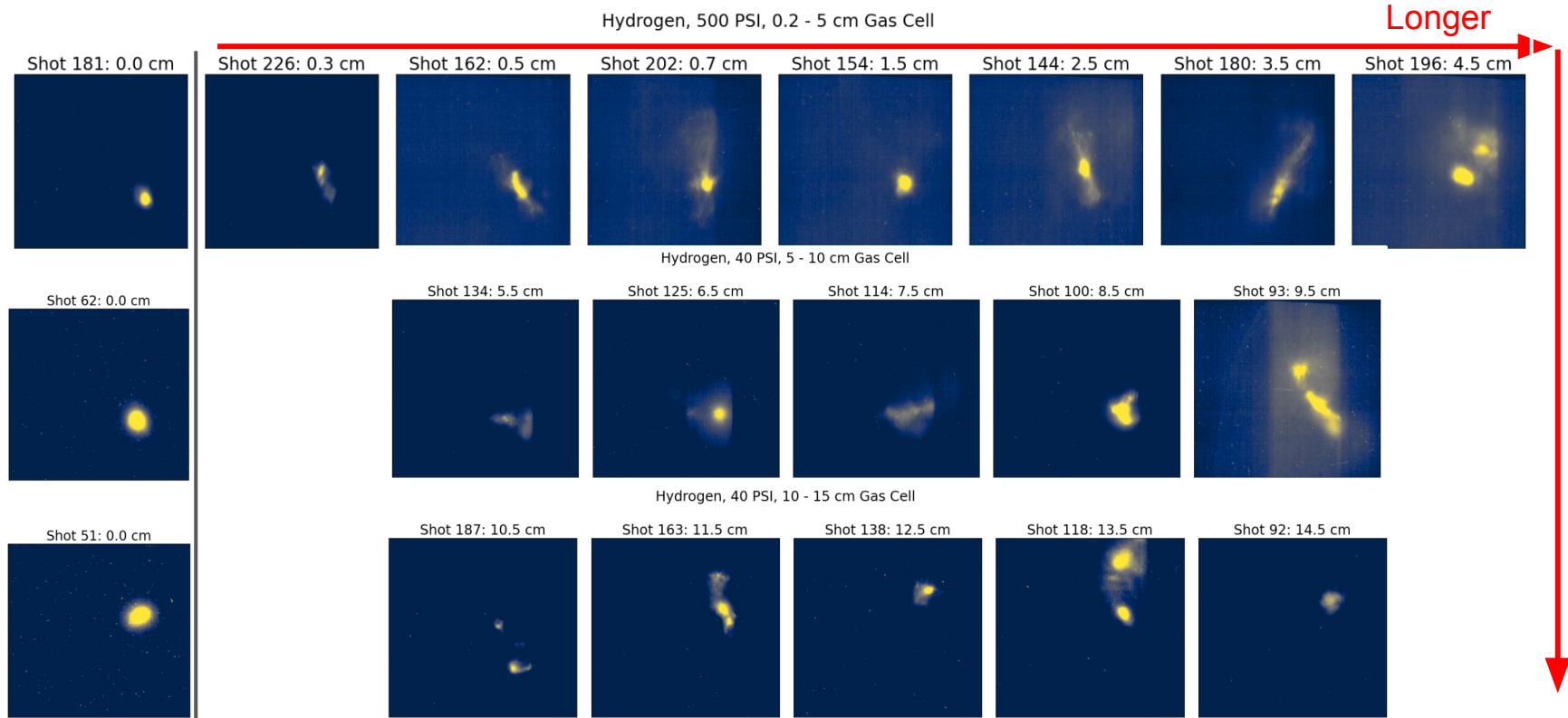
10 - 15 cm



Sequential Off / On Test of Filamentation Gas Cell

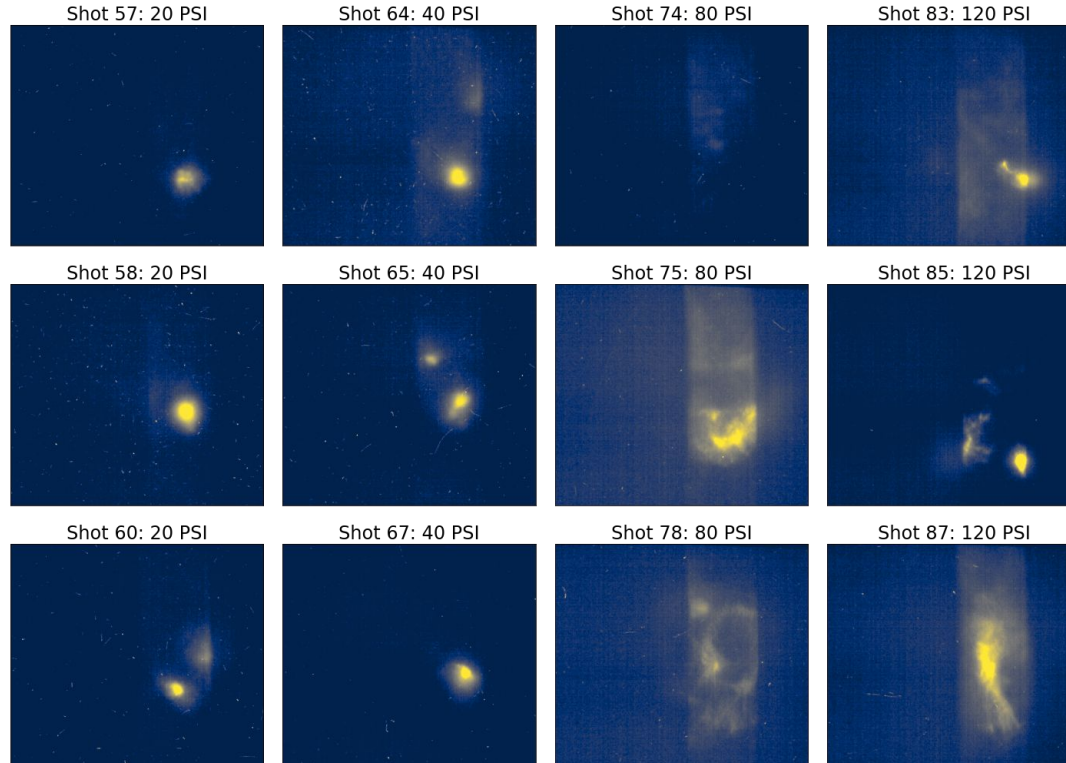


Scanning Length of Instability for Similar Gas Densities



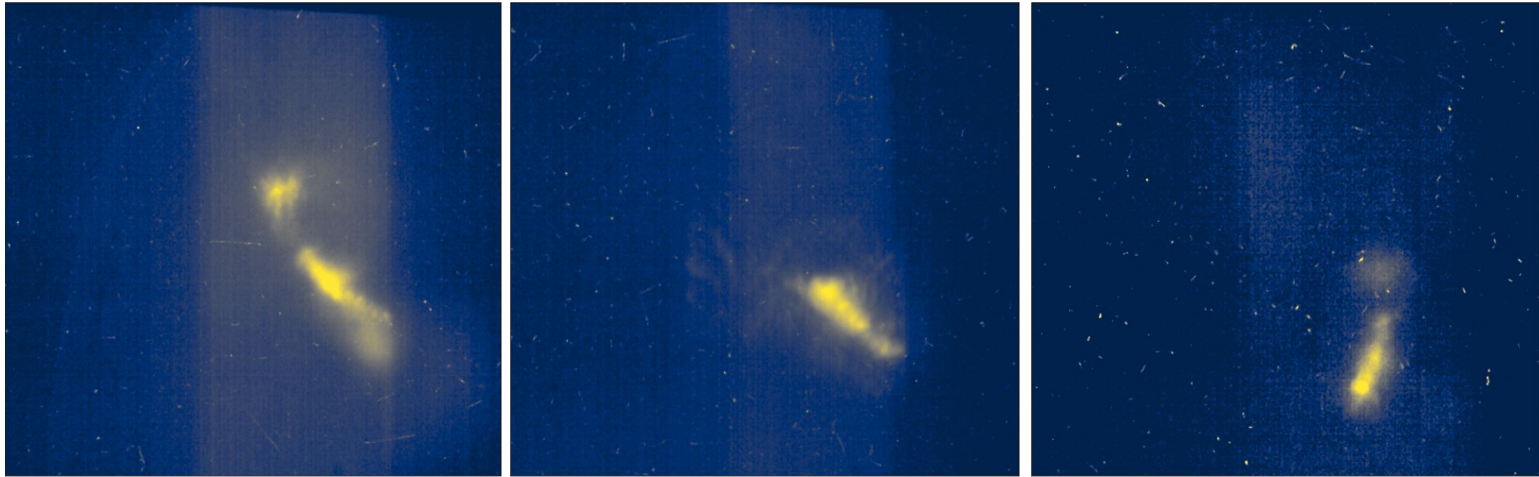
Scanning Plasma Density: Clear Dependence

Hydrogen, 14.5 cm Instability Length



Conclusion / Ongoing Analysis

- Filamentation was observed over a wide range of instability parameters.
- Work is ongoing to quantify the growth rate as a function of the experiment's parameter space.

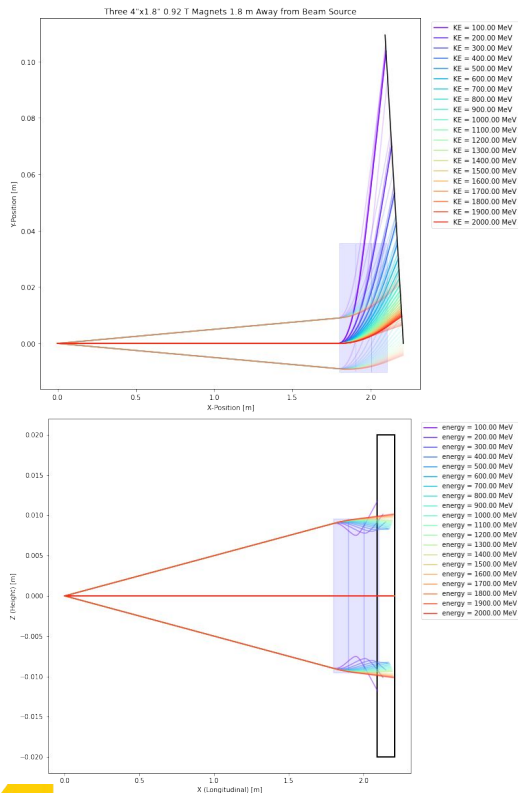


Thank you! Questions?

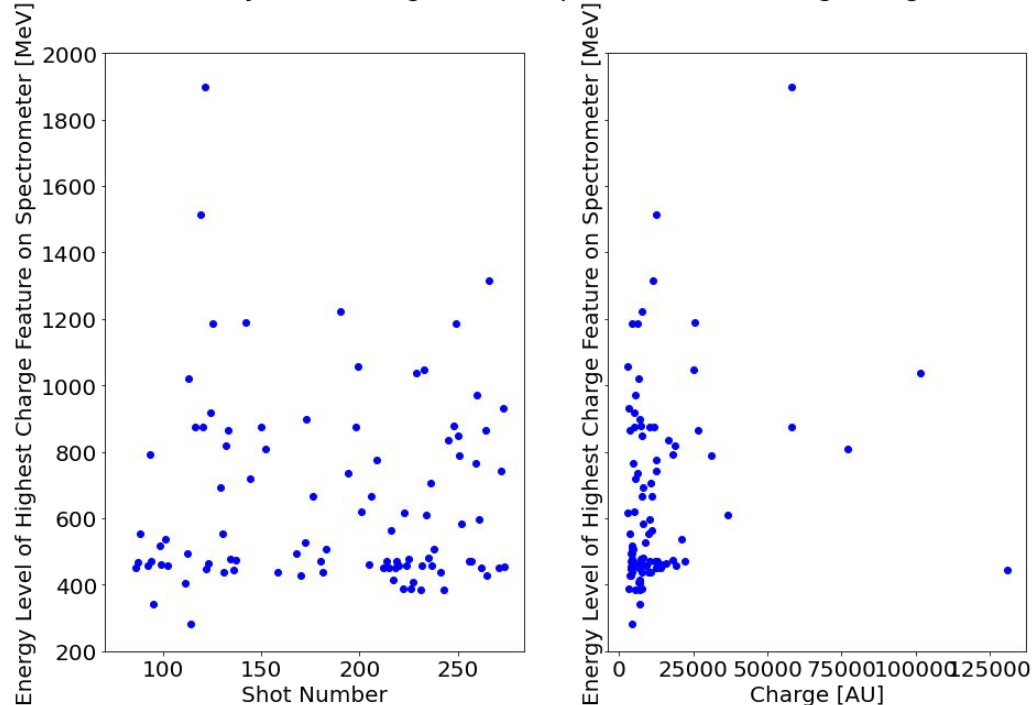
Email: jcardar@umich.edu



Extra: Spectrometer Measurements From CSU Setup

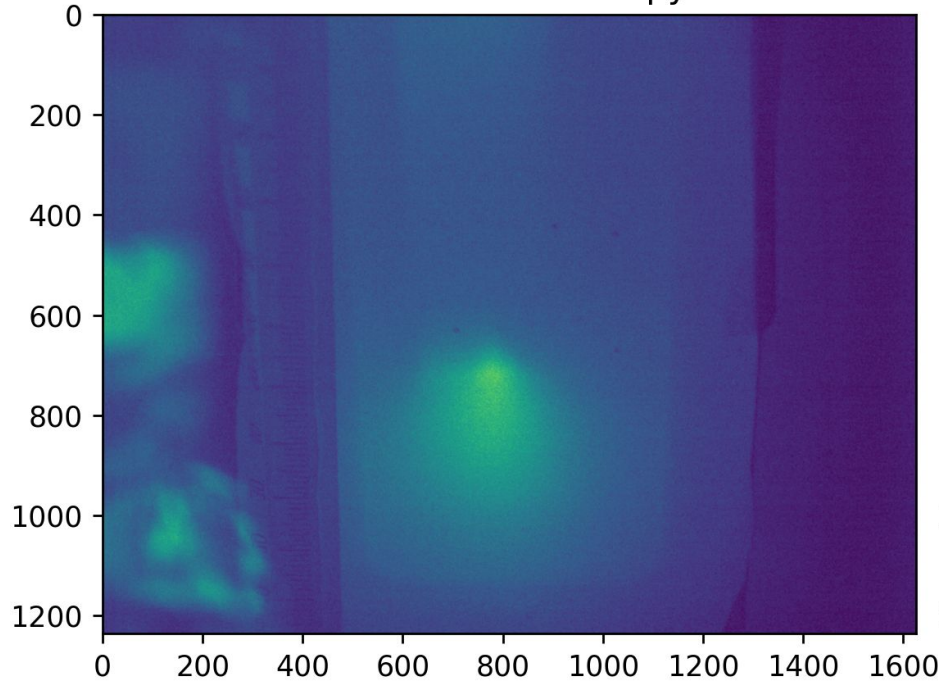


Accelerator-Only ESPEC Diagnostic: Dispersion Fit Assuming Straight Pointing

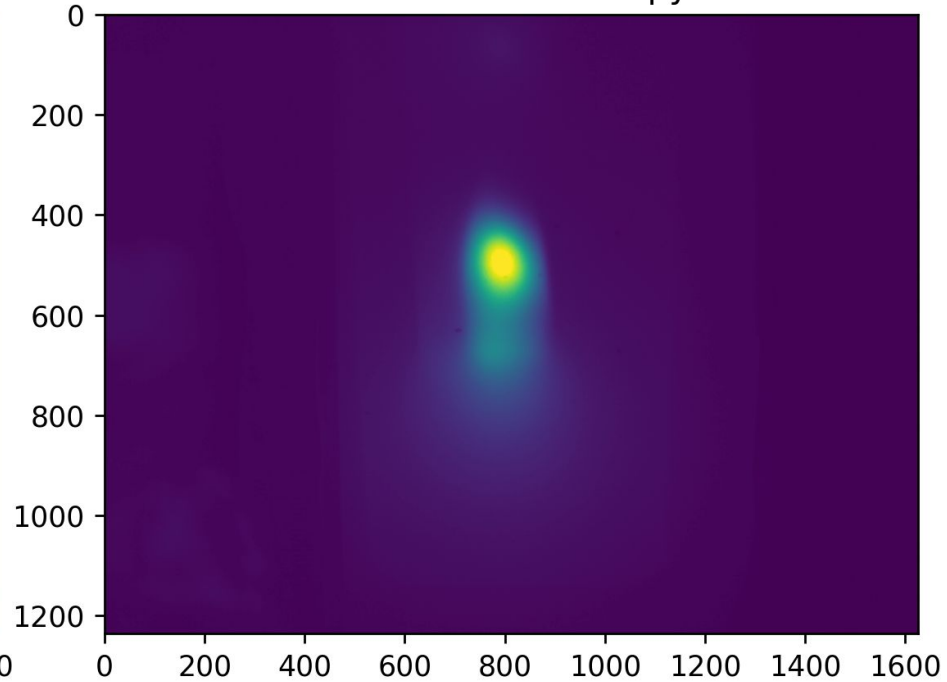


Extra: ESPEC On/Off test ~3 mm long, 500 PSI

20210910 Run1 shot222.npy EProfile

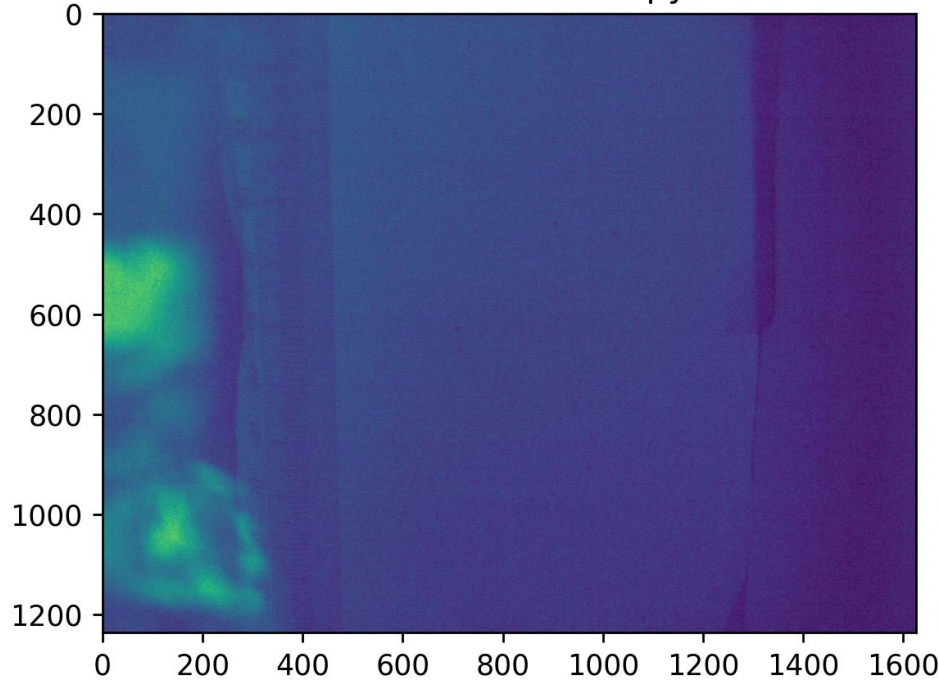


20210910 Run1 shot223.npy EProfile

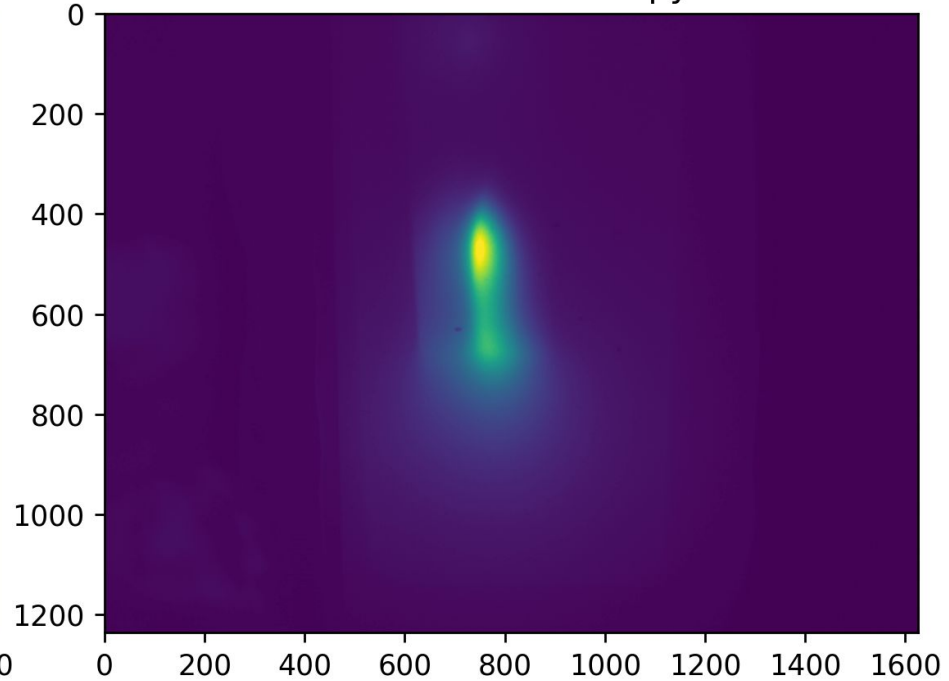


Continued...

20210910 Run1 shot224.npy EProfile

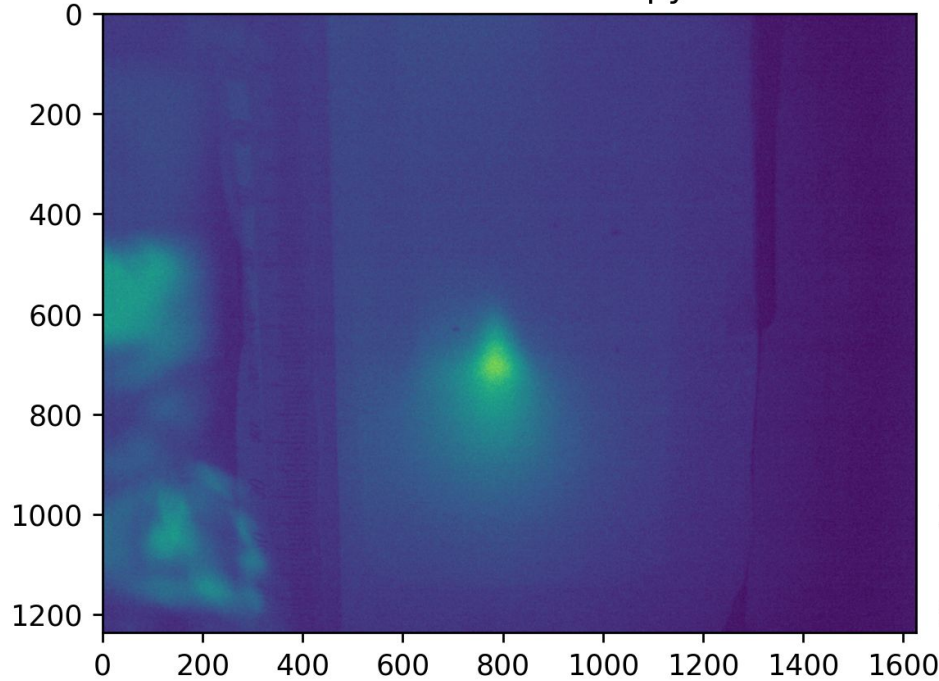


20210910 Run1 shot225.npy EProfile



Continued...

20210910 Run1 shot226.npy EProfile



20210910 Run1 shot227.npy EProfile

