Near-critical density interactions at the ATF

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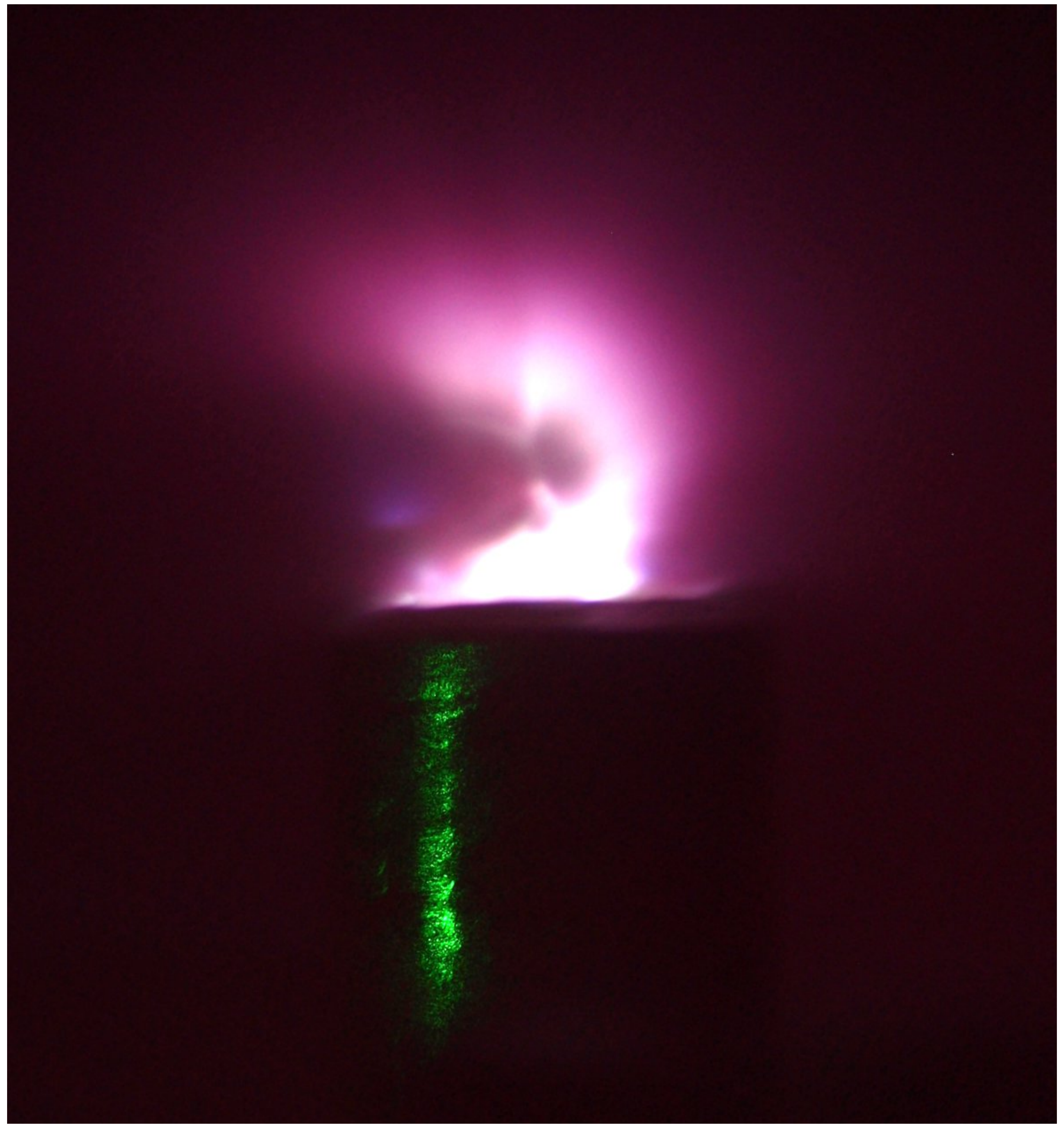

ATF Scientific Planning Workshop,
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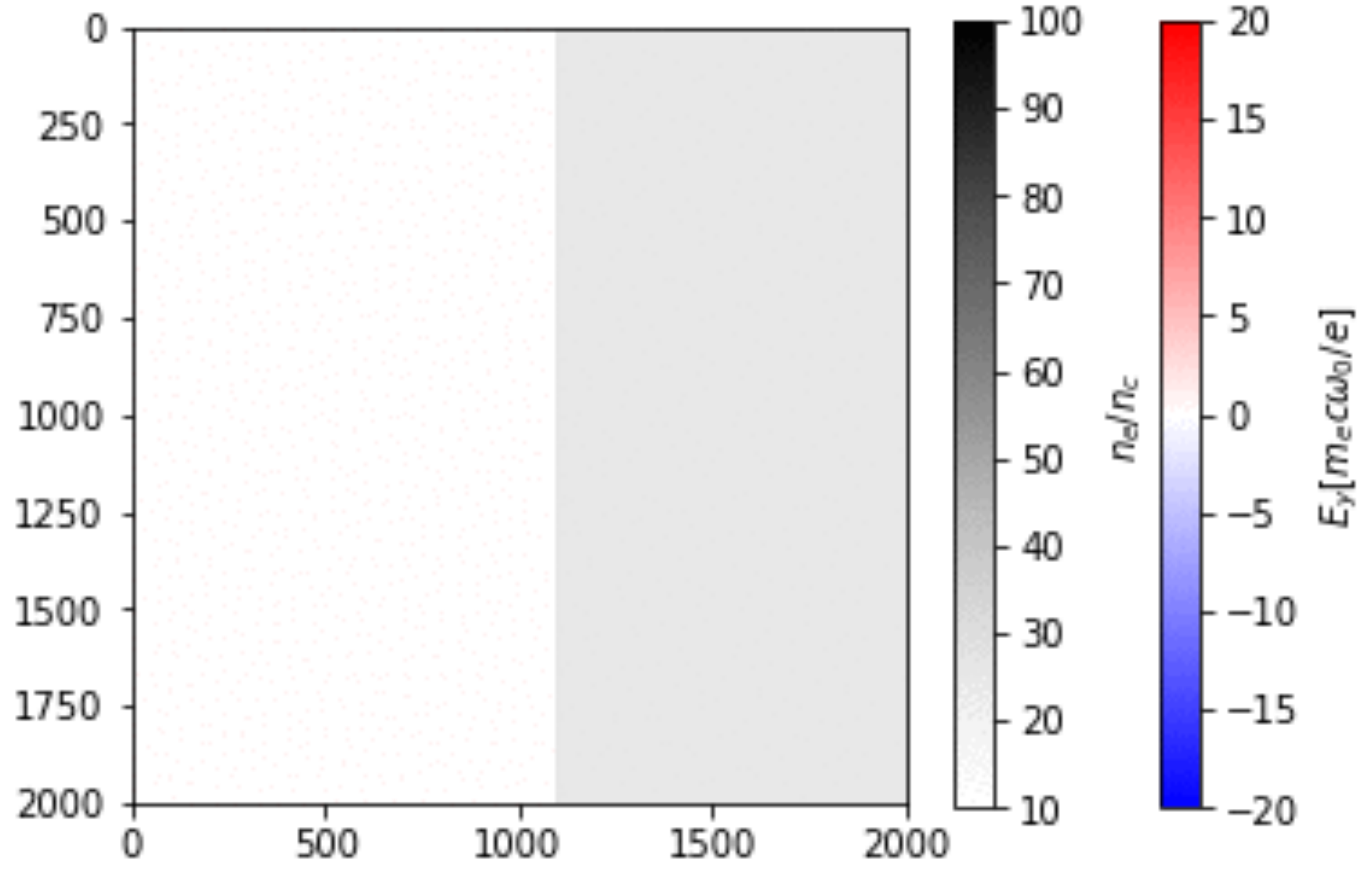
Diagnosing laser driven ion sources - why the ATF?

Nearly all laser driven ion source experiments performed in the near-IR

	Time	*Length*	*Density*
Typical dynamical scales	~10 fs	~1 µm	>~10^{21} cm^{-3}
Can we diagnose it?	Too quick ☹️	Too short ☹️	Too dense ☹️



Rely on simulations, many assumptions

- Reduced dimensionality
- Uncertainty over experimental parameters
- Can only verify by looking at certain outputs e.g. ion beam

Exploiting dimensional scaling of collisionless laser-plasmas

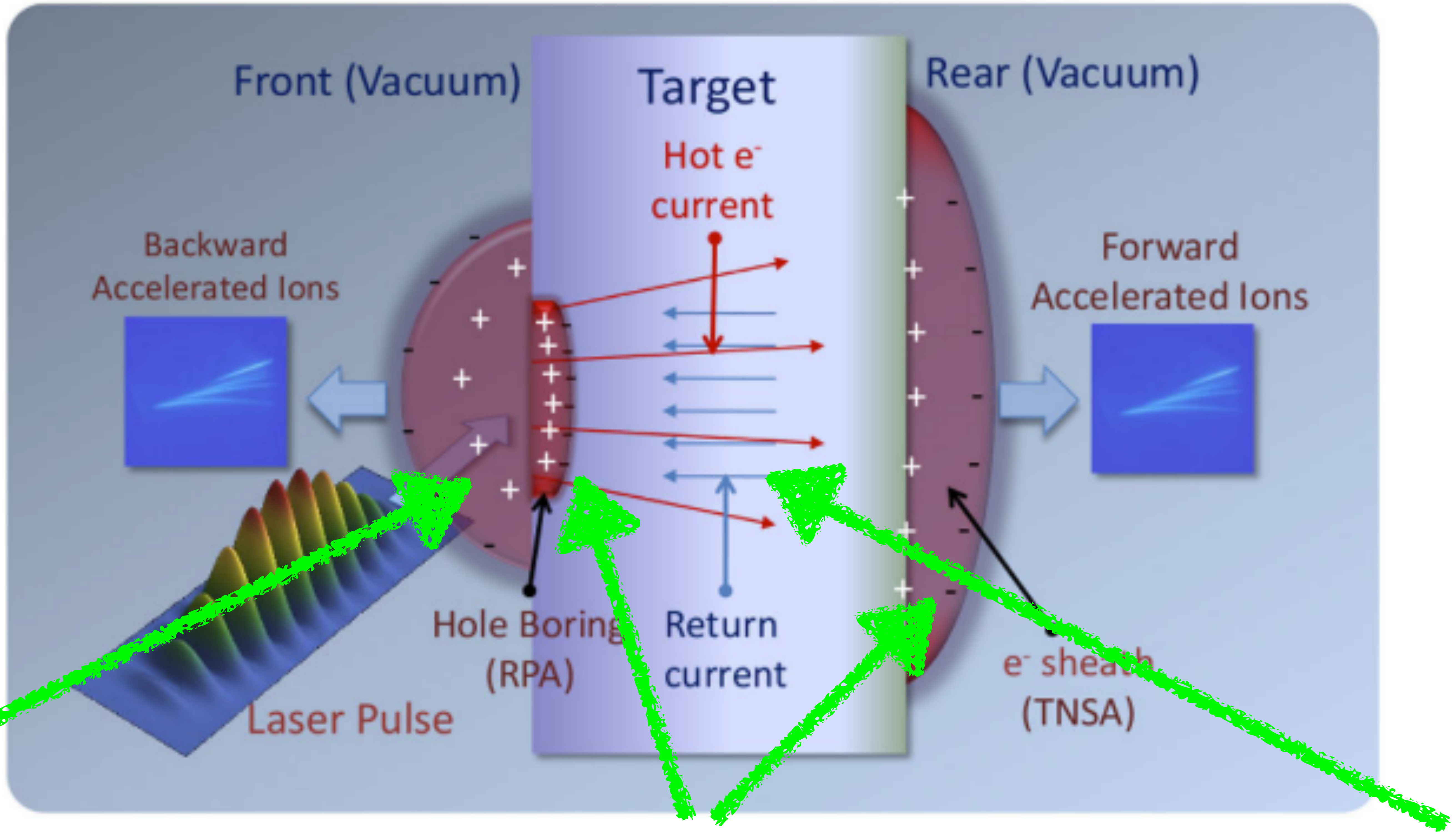
Collisionless laser plasmas can be defined using reference frequency*:

	Time	*Length*	*Density*	
	$\tilde{t} = \omega_L t$	$\tilde{x} = \frac{\omega_L}{c} x$	$\tilde{n} = \frac{1}{n_c} n \propto \frac{1}{\omega_L^2} n$	
near-IR	~10 fs	~1 μm	>~10^{21} cm^{-3}	☹
mid-IR	~100 fs	~10 μm	>~10^{19} cm^{-3}	😃
	Resolvable	Resolvable	Ideal for optical probing	

*if e.g. ionisation/QED not important

Physics of laser driven ion sources difficult to diagnose directly

From Macchi et al. Rev. Mod. Phys. **85** (2013)



Laser propagation in underdense plasma

Acceleration of ions at critical density surface and plasma boundary

Propagation of "fast" electrons in the target

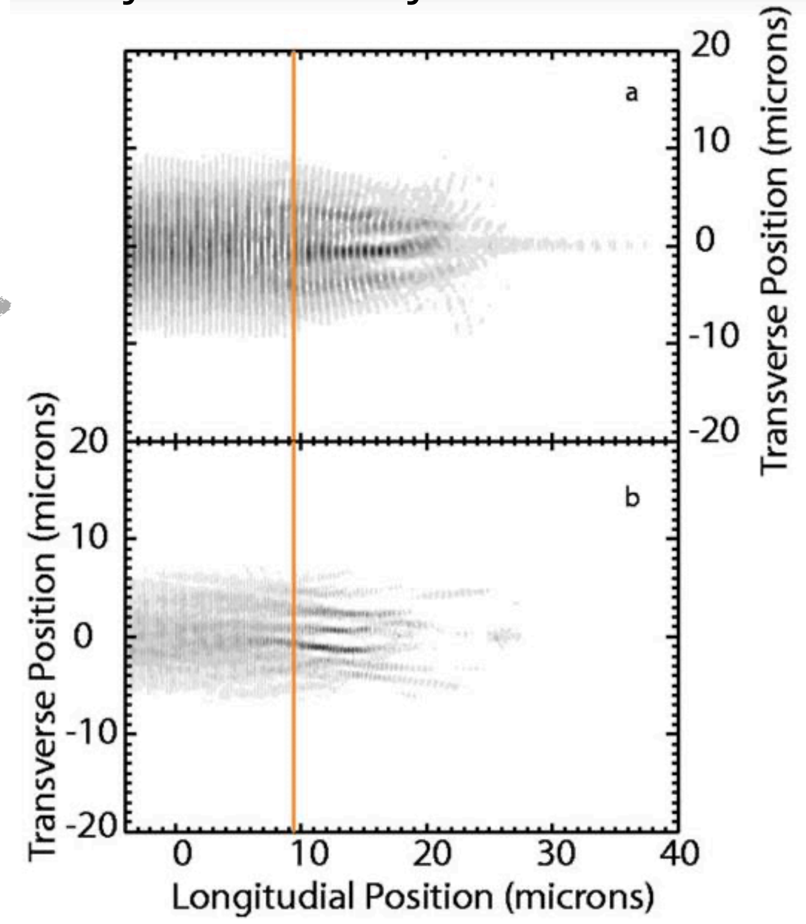
Ion sources undergo multiple nonlinear and dynamic processes, near-impossible to see experimentally

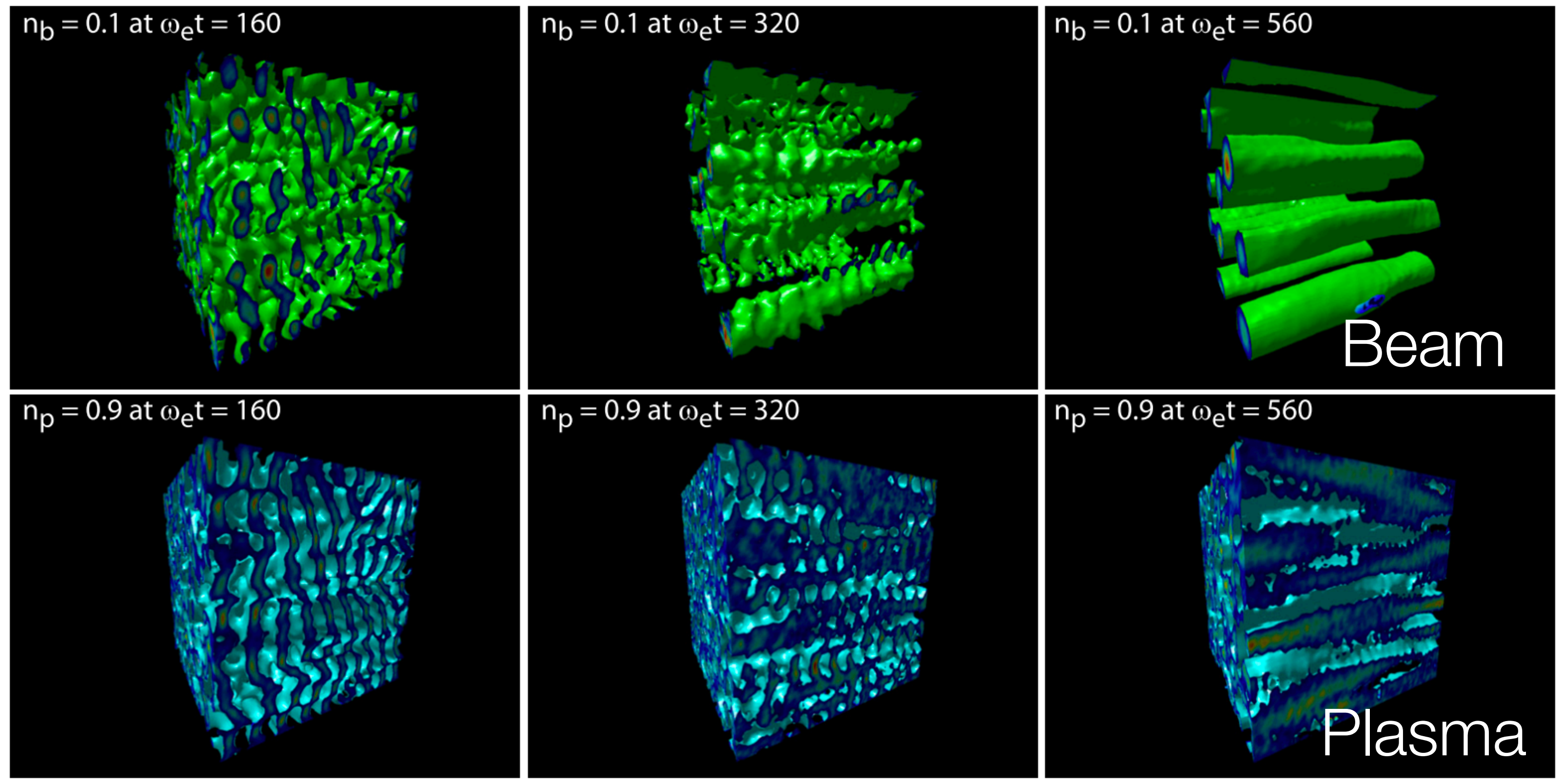
Interesting physics to study - the ATF is great!

Under the “umbrella” of ion acceleration, there are three main areas of interest which encapsulate a number of non-linear phenomena.

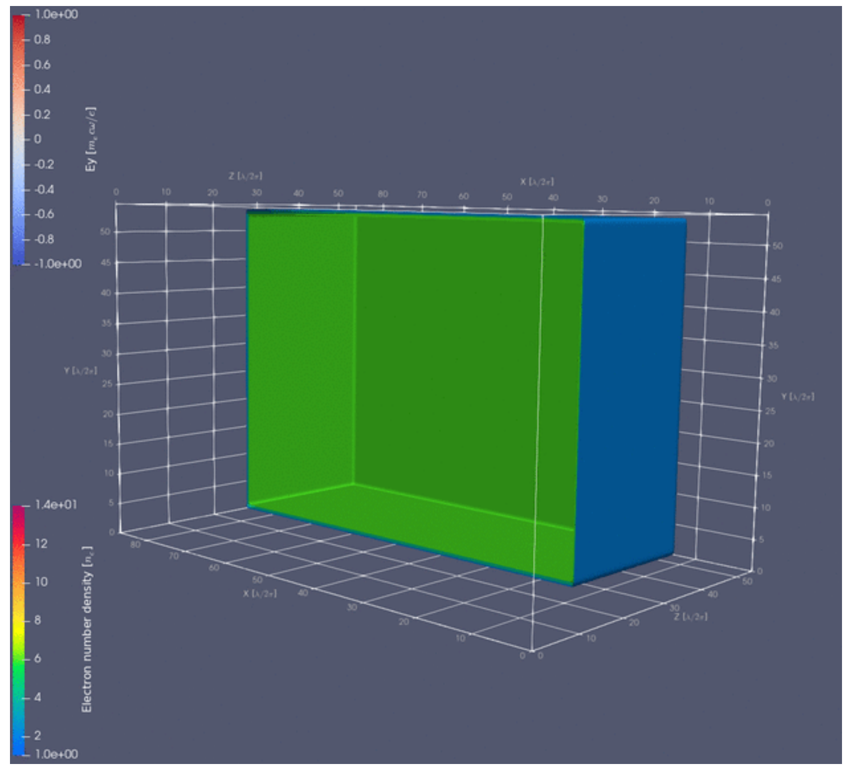
1. Laser propagation in underdense plasmas preceding the critical surface
2. The dynamics of ion acceleration by shock structures
3. Particle beam propagation through plasmas

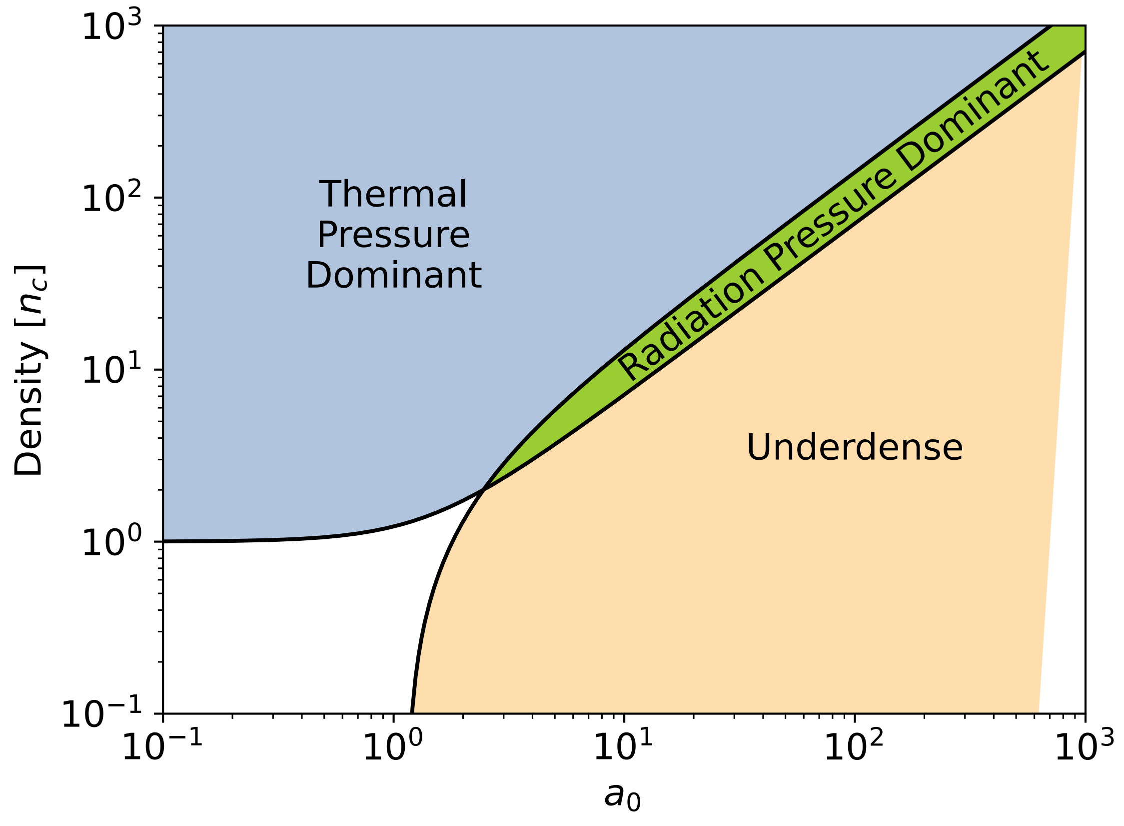
From Brady et al. Phys. Plasmas **19** (2012)





From Bret et al. Phys. Plasmas **17** (2010)

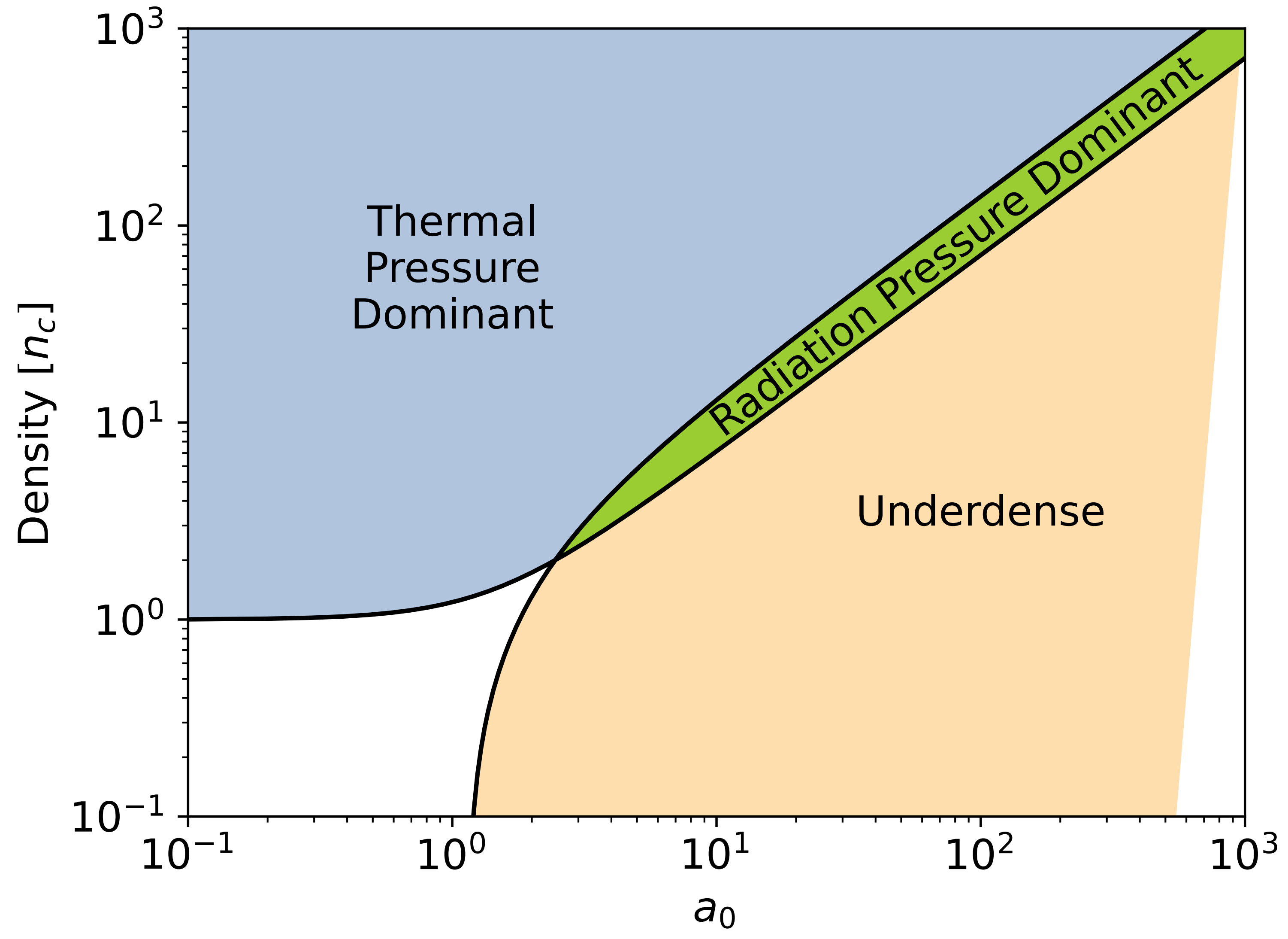




Future ATF development paths

What are the ATF future development paths that will best facilitate our research?

- Required CO2 beam parameters and upgrades



Ion acceleration:

- Hole-boring wants high intensity.
    - Shorter pulse lengths desirable (not too short), or higher energy can work.
- Collisionless shock acceleration wants high energy
    - Shorter pulses not desirable. More energy preferable.
    - Could we detune (or even bypass) the compressor?

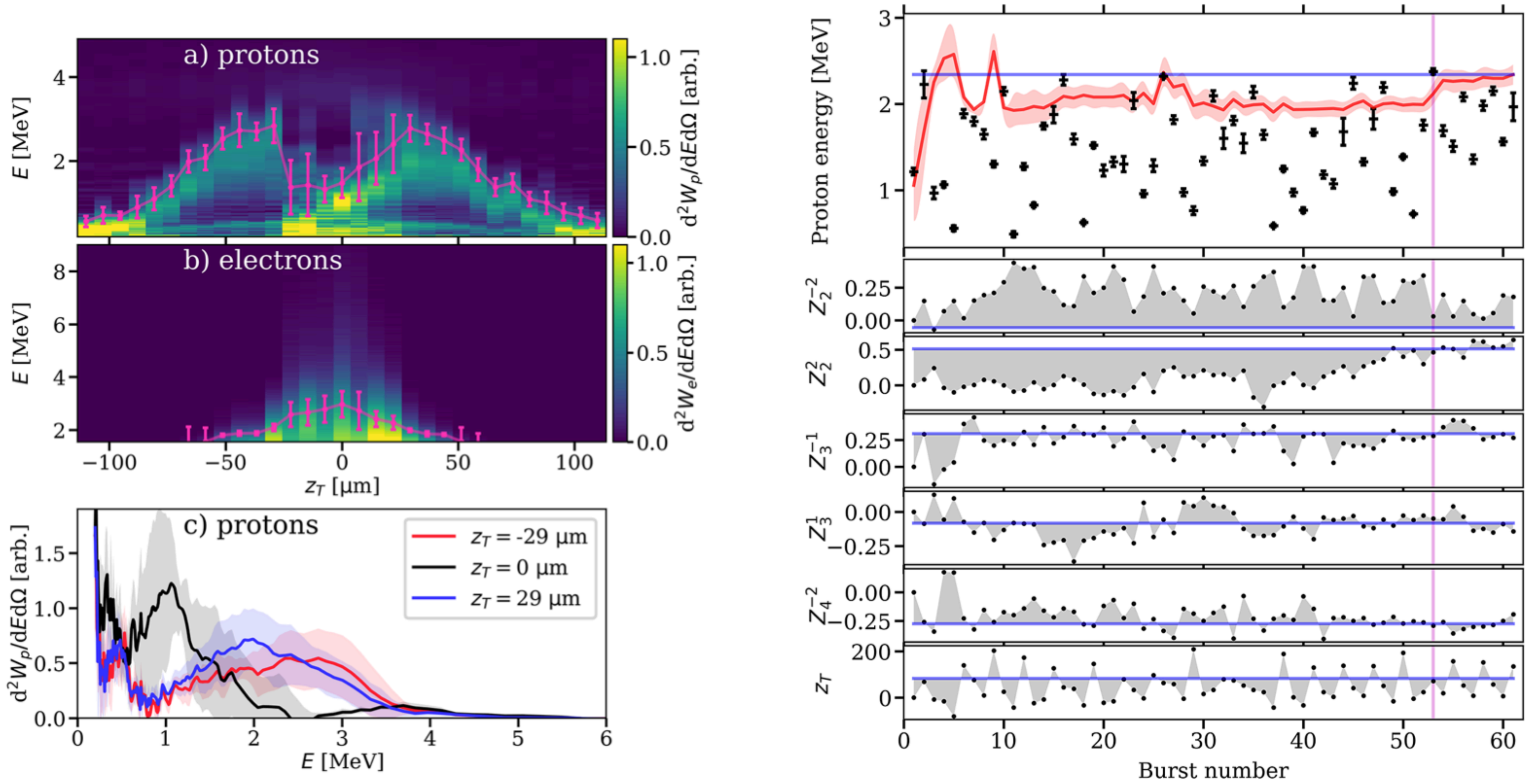
Future ATF development paths

What are the ATF future development paths that will best facilitate our research?

- Required CO_2 beam parameters and upgrades

Repetition rate:

- Higher rep. rates are desirable to apply machine learning techniques already successfully applied at other facilities to optimise ion acceleration process
- 10Hz is good, any higher and data acquisition quickly becomes more challenging/expensive
- Ability to effectively manage things like radiation/gas load in vacuum systems etc. needs to be considered

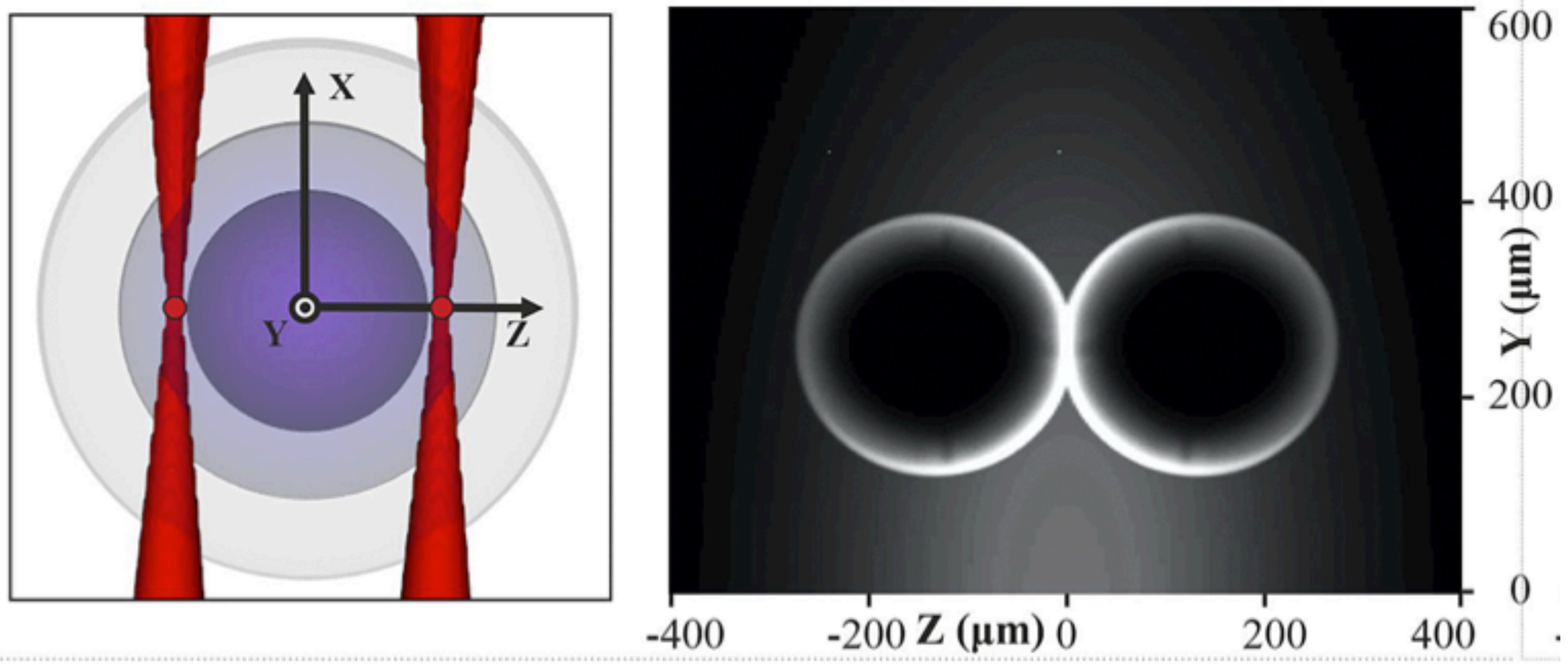


From Loughran et al. HPLSE **11** (2023)

Future ATF development paths

What are the ATF future development paths that will best facilitate our research?

- Auxiliary laser systems:



From Tazes et al. HPLSE **10** (2022)

- Plans to explore new gas shaping methods without the CO_2 pre-pulse

- Ability to have both the YAG and Ti:Sa lasers at the same time is desirable. YAG for gas shaping, Ti:Sa for interaction probing.
- Upgrade in energy to ~100mJ in the YAG needed for target shaping
- If CO_2 pulse gets much shorter, the Ti:Sa should get similarly shorter to make sure interactions don't get "washed out"

Future ATF development paths

What are the ATF future development paths that will best facilitate our research?

- Other requests:

Plasma shutter:

- Appreciate significant facility effort to install the plasma shutter, but now no longer needed. Ability to bypass would improve experiments
  - Remove 2 hard to optimise parabolas, and fix beam size issues on the final focussing optic (restricting final f/#)

New experimental chamber:

- Current chamber has limited diagnostic access (windows and around chamber)
- Need facility staff to open and close the lid

More centralised CO_2 diagnostics:

- CO_2 uncommon for most users, so centralised "typical" diagnostics might be helpful (and similar to offering at other user facilities) - things like spectrometers, cameras for beam imaging, ability to use the streak camera again etc.

Quad Chart

Scientific Outcomes

- Laser propagation in underdense plasmas
- Shock acceleration of ions
- Particle beam propagation through plasmas

Parameters Required

- Ti:S and YAG at 100mJ level
- Ability to bypass the CPA compressor
- More comprehensive CO_2 diagnostics - ps contrast, CO_2 spectrometer etc.

ATF Upgrade Roadmap

- Higher intensities via increased energy or reduced pulse length - benefits to both.
- Higher rep. rate for ML based optimisation.
- New chamber for better diagnostic access

Beyond Current Roadmap

- Dedicated CO_2 only target area, with new larger chamber and better diagnostic access, more radiation shielding etc.