Towards high-repetition-rate plasma accelerators with HOFI channels

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[4]Central Laser Facility, Rutherford Appleton Laboratory

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** Now at: *York Plasma Institute, University of York*

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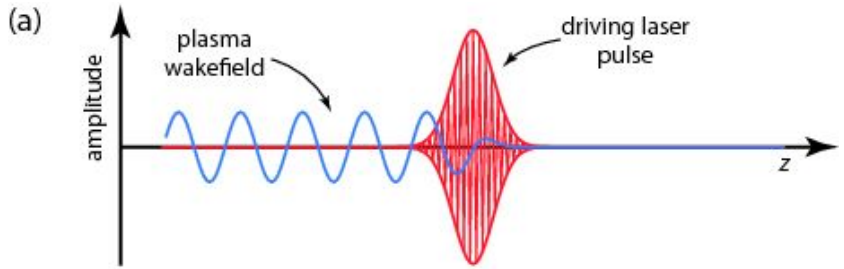
Overview of laser plasma accelerators



Energy gain of electrons in LPA

Plasma density

$$\Delta E \propto n_0^{-3/2}$$

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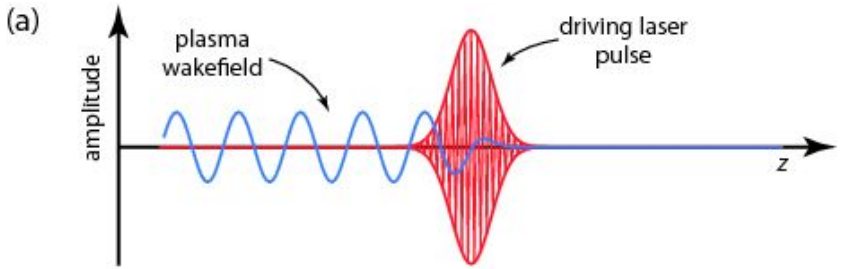
Overview of laser plasma accelerators



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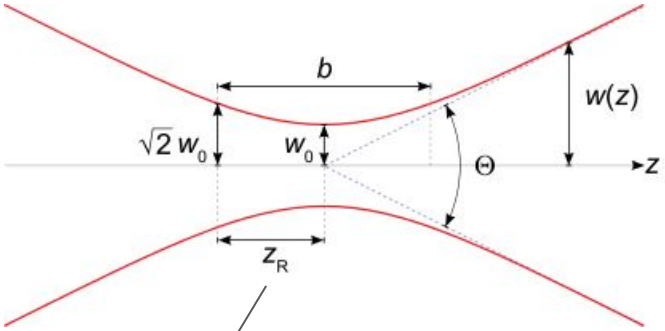

Rayleigh length

Dephasing length and laser rayleigh length of limit the energy gain of LPA's

- At low densities, the dephasing length is several tens of mm's
- Rayleigh length is only few mm's - need waveguides!

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Next generation facilities

BELLA 10 GeV Stage[1]

L_{acc} ~ 60 cm

n_e ~ 0.96 x 10^{17} cm^{-3}

EuPRAXIA 5 GeV Stage[2]

L_{acc} ~ 11.8 cm

n_e ~ 1.8 x 10^{17} cm^{-3}

[1] W. P. Leemans et al., Proc. PAC 2011, **1416** 5 (2011)
[2] T. Audet et al., EuPraxia Milestone Report M3.1 (2017)
[3] D. J. Spence et al., J. Opt. Soc. Am. B **20**, 138-151 (2003)

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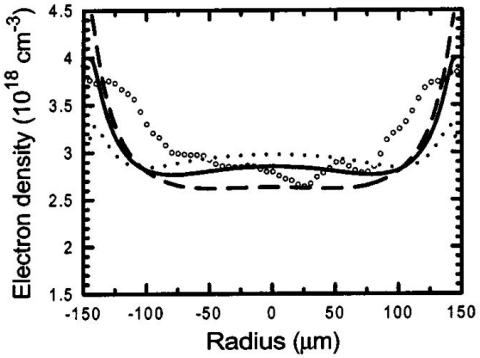
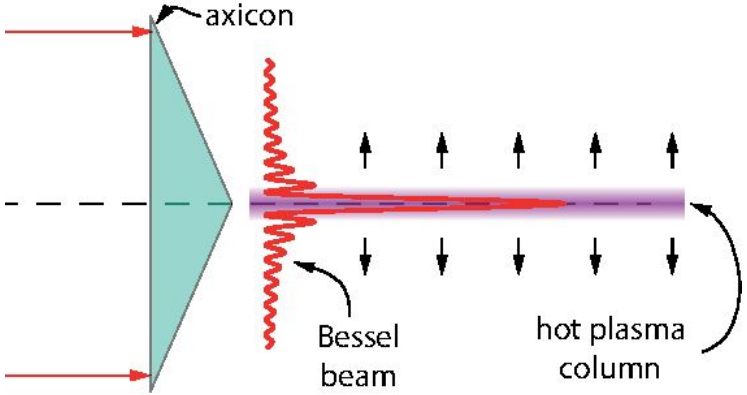


Next generation LPA facilities require next generation waveguides

- Capillary discharge waveguides[3] have been used to accelerate electrons up to several GeV…
- But they can be damaged by the laser at high rep. rates!

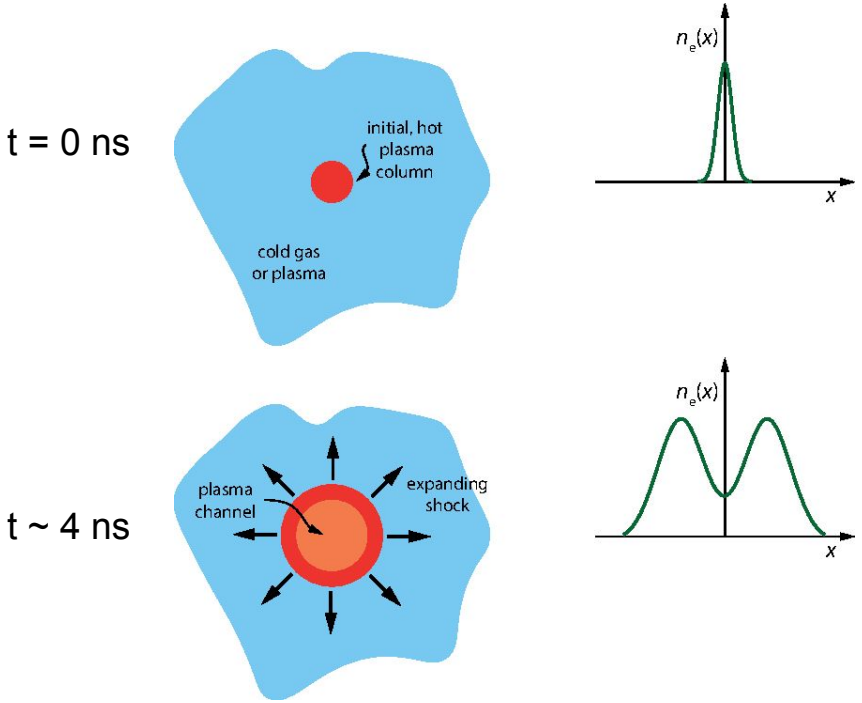
[1] W. P. Leemans et al., Proc. PAC 2011, **1416** 5 (2011)
[2] T. Audet et al., EuPraxia Milestone Report M3.1 (2017)
[3] D. J. Spence et al., J. Opt. Soc. Am. B **20**, 138-151 (2003)

Plasma channels as waveguides



Axicon-formed plasma channels were produced 25 years ago but:

- Using collisional heating
- Not reproducible at low densities



[1] C. G. Durfee & H. M. Milchberg Phys. Rev. Lett., **71** 2409 (1993)

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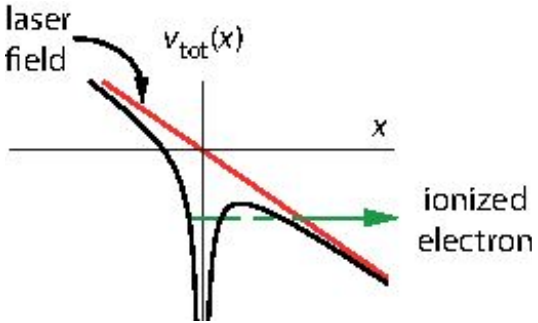
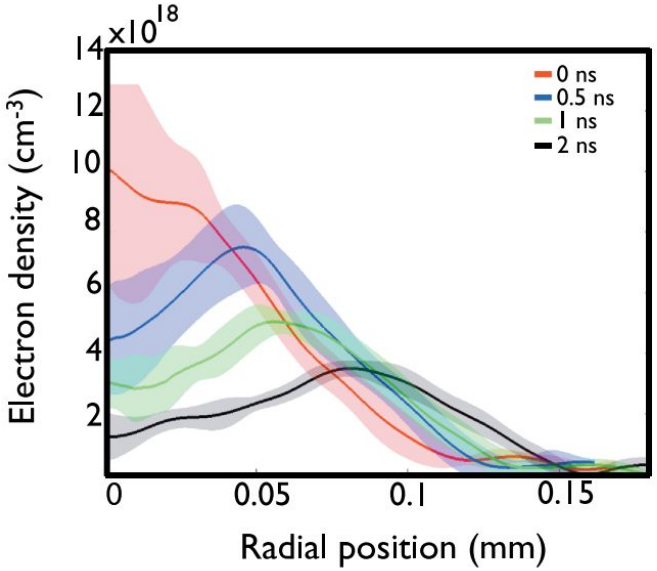
HOFI channels

HOFI - Hydrodynamic, optically-field-ionized





HOFI channels were demonstrated experimentally[1-3] but:

- Not at low densities
- Only using a lens to form the channel

[1] N. Lemos et. al. , Physics of Plasmas, **20** 063102 (2013)
[2] N. Lemos et. al. , Physics of Plasmas, **20** 103109 (2013)
[3] N. Lemos et. al. , Nat. Sci. Rep, **8** 3165 (2018)

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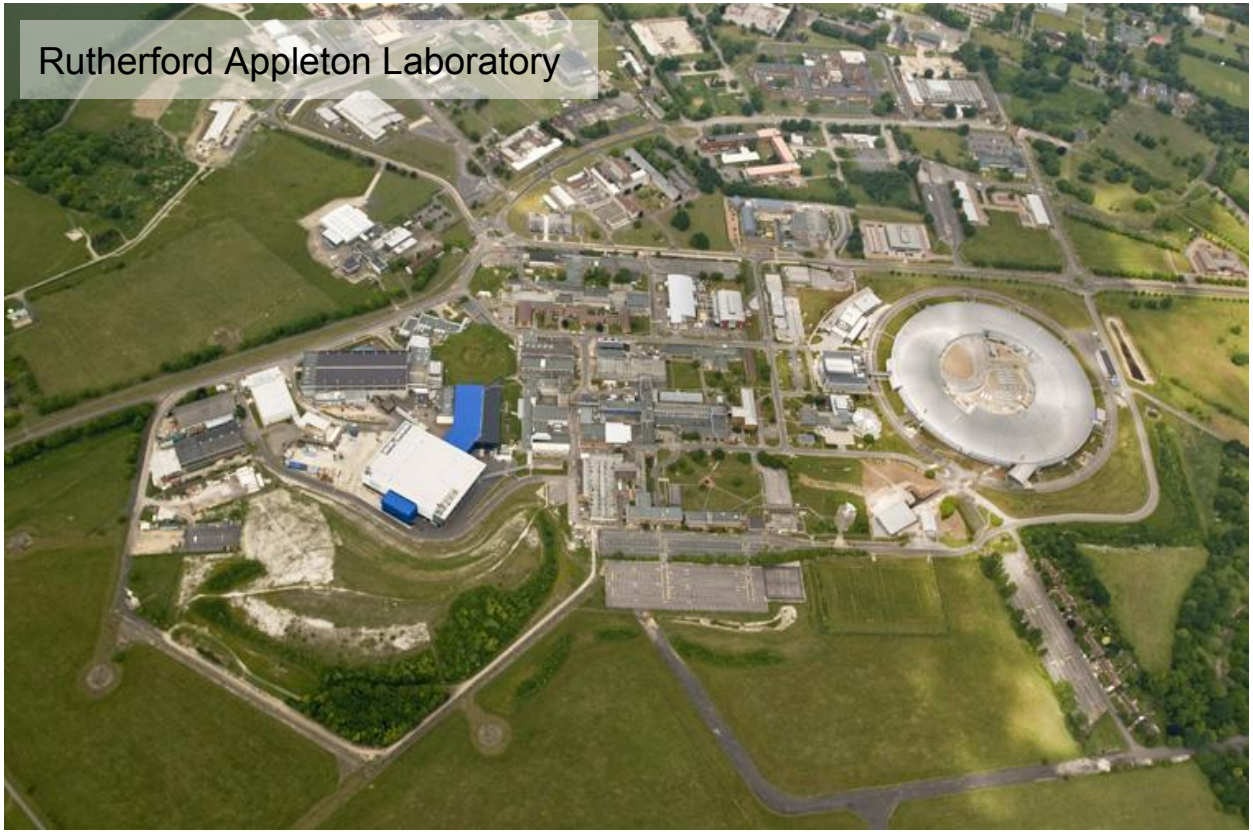
Experiment at the Central Laser Facility



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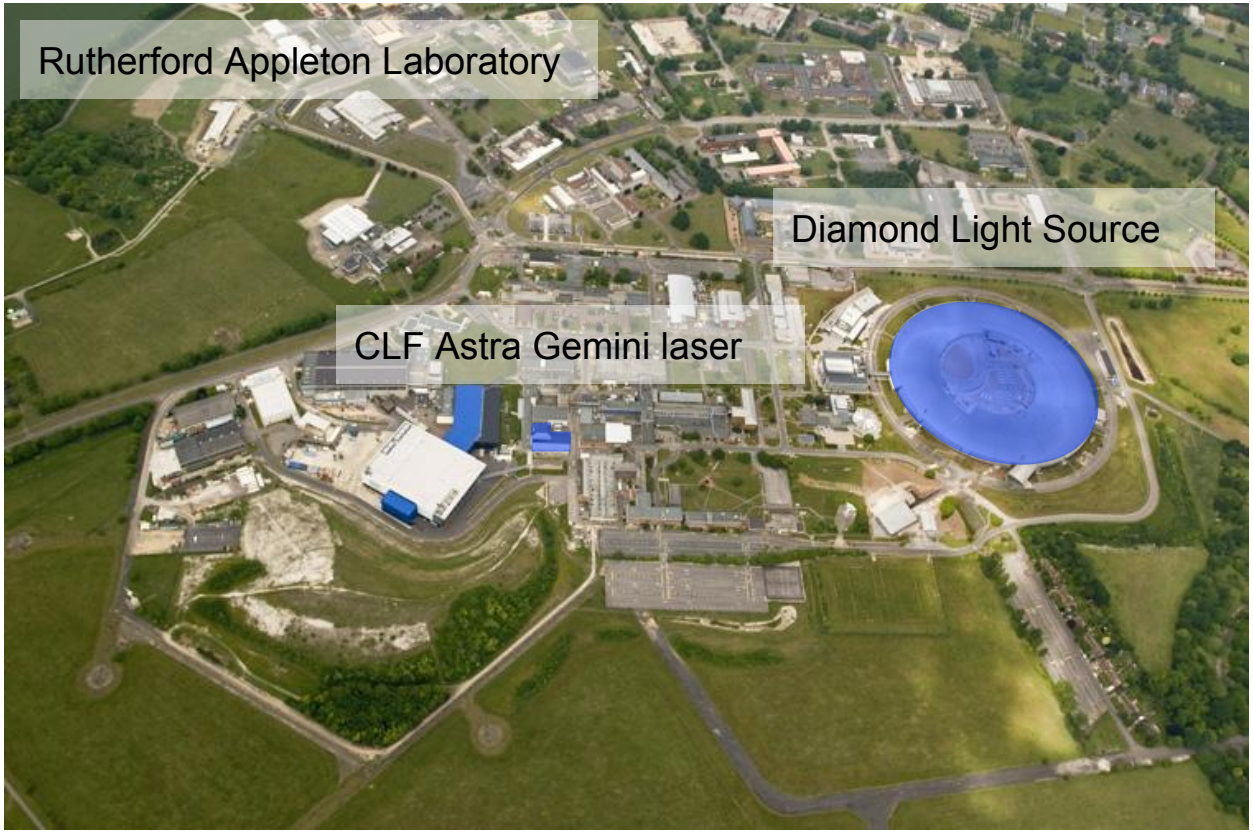

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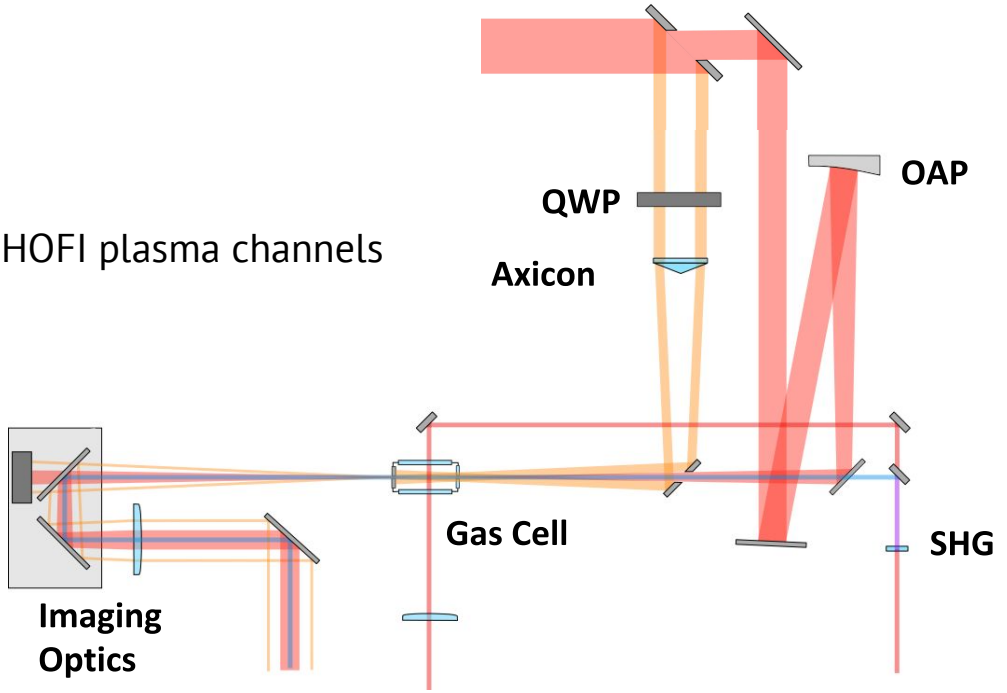
Astra 2018: HOFI experiment layout

Objectives

- Demonstration of low-density axicon formed HOFI plasma channels
- Demonstration of high-intensity guiding
- Demonstration of 5Hz guiding



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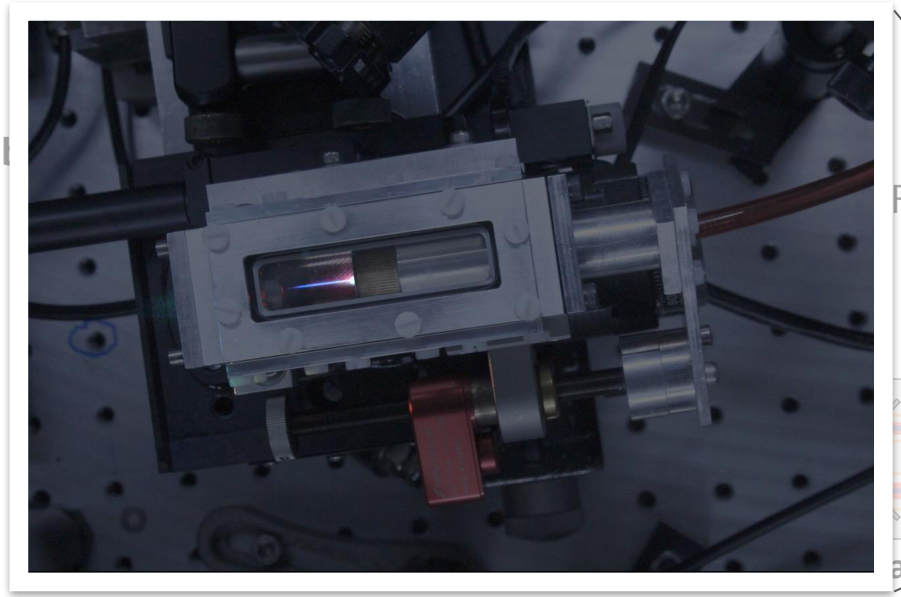
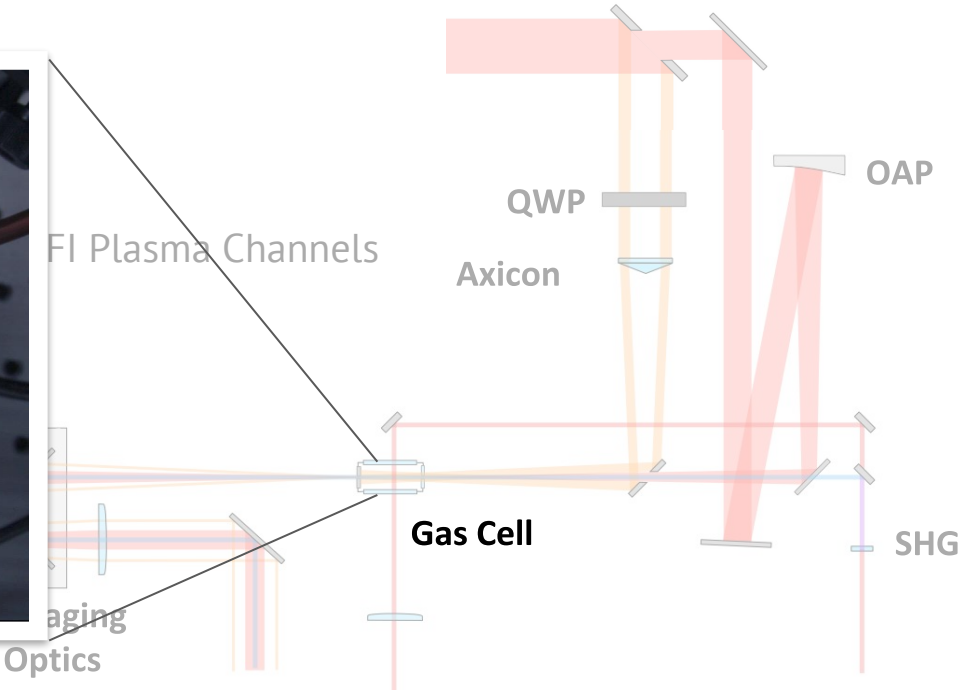
Astra 2018: HOFI experiment layout



FI Plasma Channels

aging
Optics



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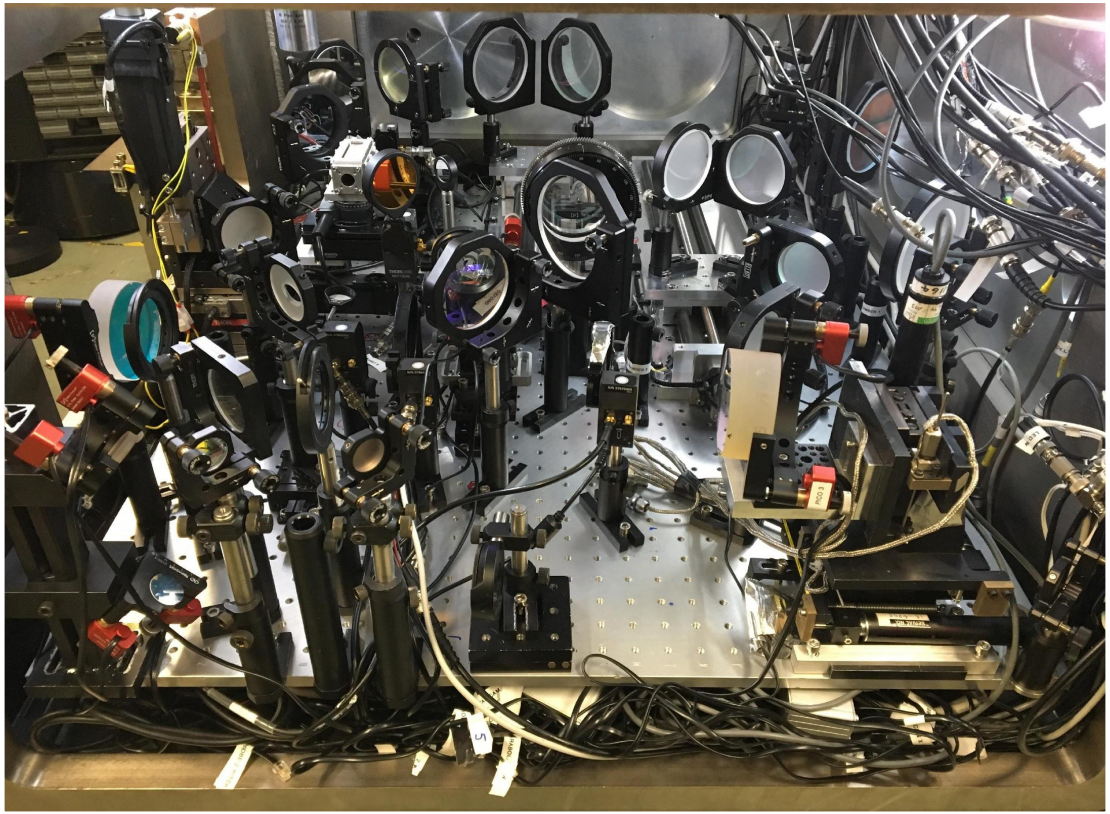

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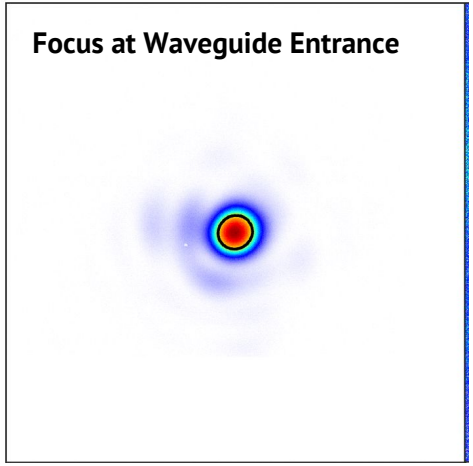
Guiding results



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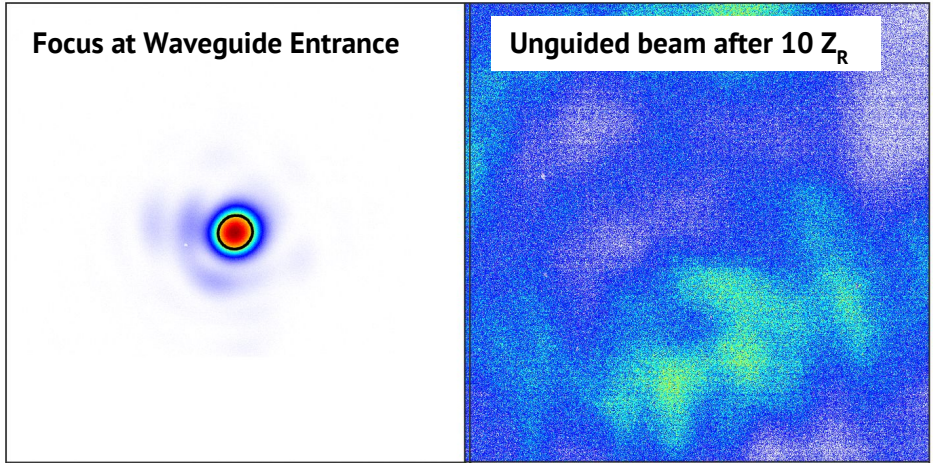

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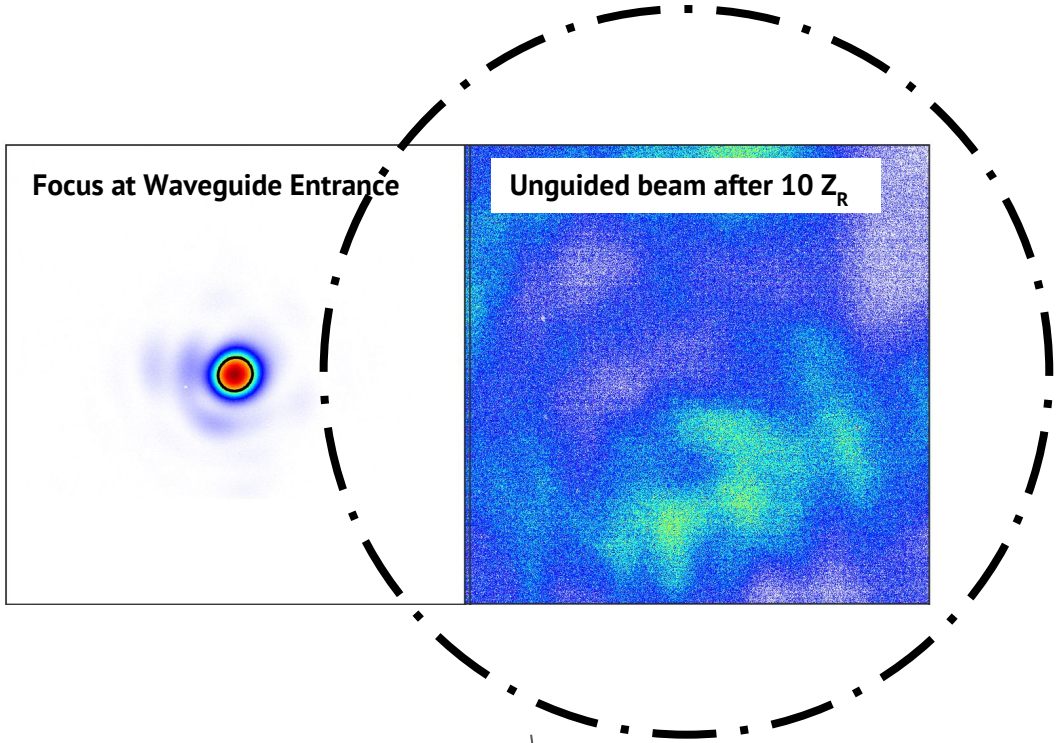

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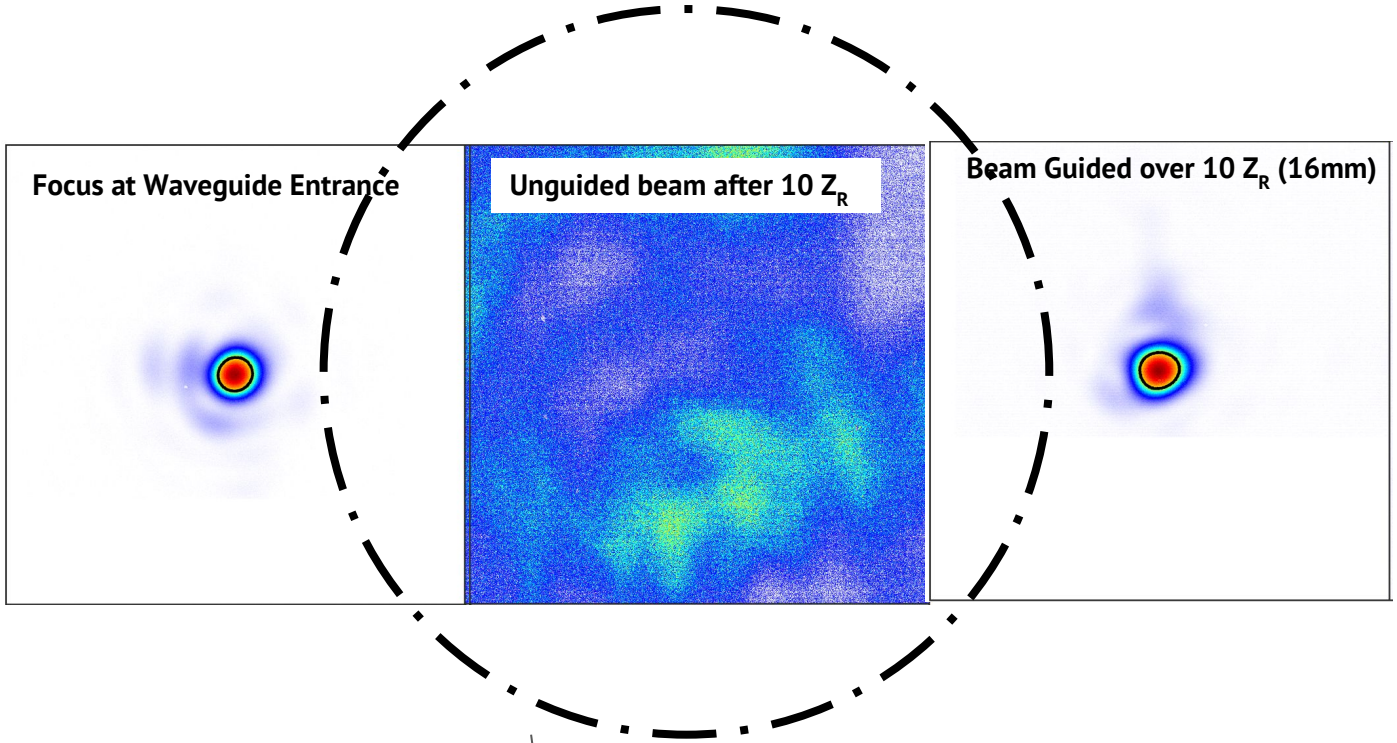

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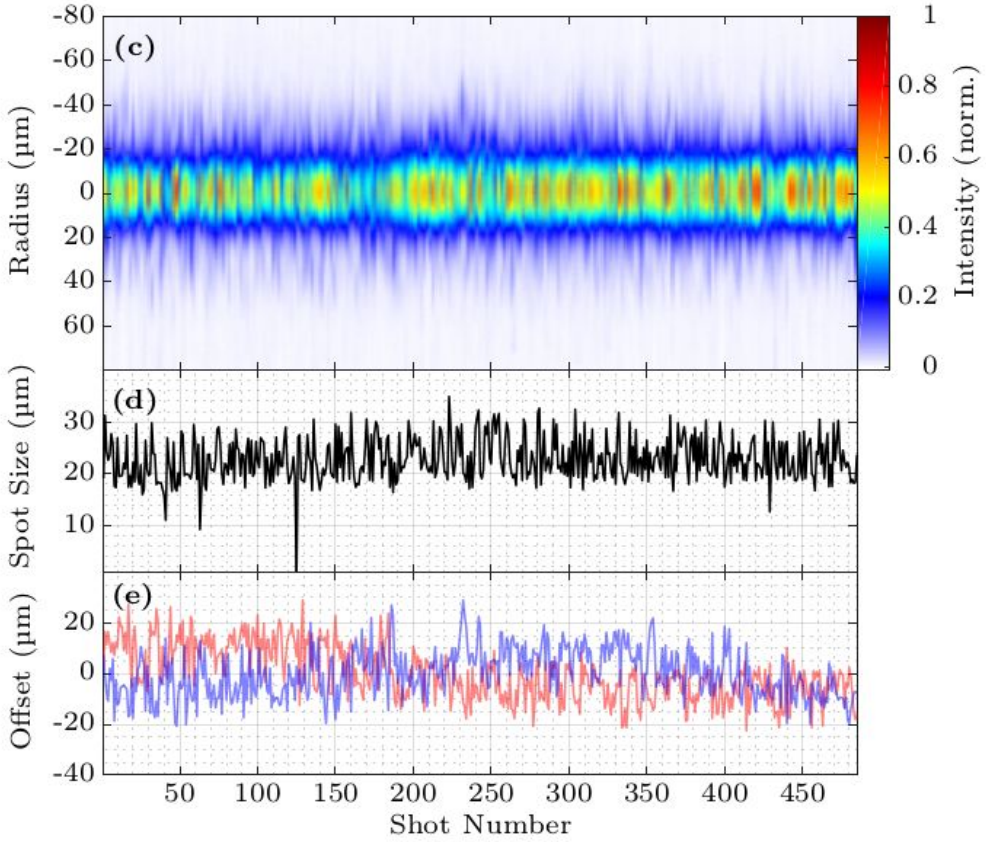
Stability of channels



Guiding results show

- Guided beam spot size and offset stable at 5 Hz
- Channel generation limited by laser repetition rate

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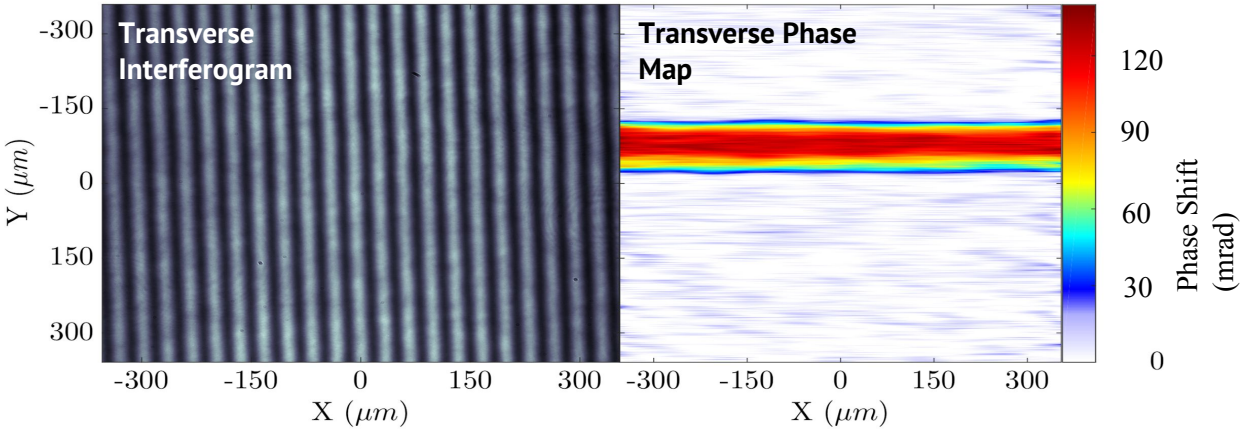
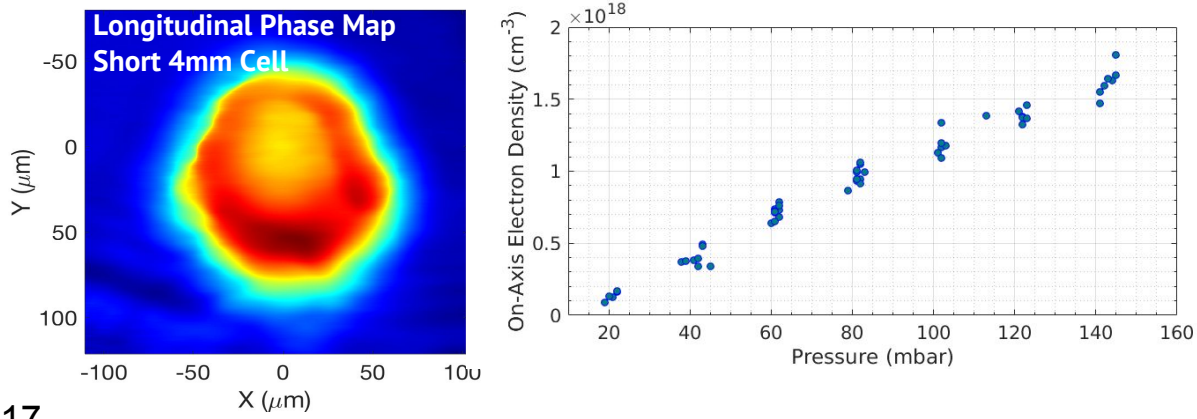
Interferometry analysis

In progress…



Transverse interferometry

- Shows 2D projection of 3D channel: Abel inversion required
- Need to account for channel asymmetry



Longitudinal Interferometry

- Performed in 2-4 mm cells
- End-cap effects unknown

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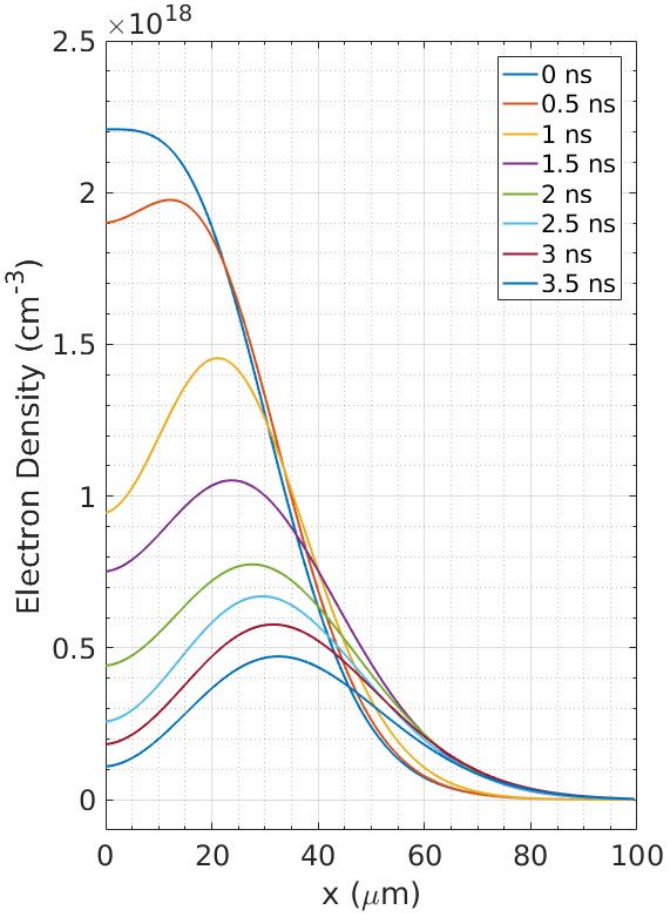
Interferometry results

In progress…



Transverse interferometry

- Clearly shows channel expanding on ns timescale
- Shows evidence of low density channels: on-axis density ~ 1 x 10^{17} cm^{-3} after 3.5 ns

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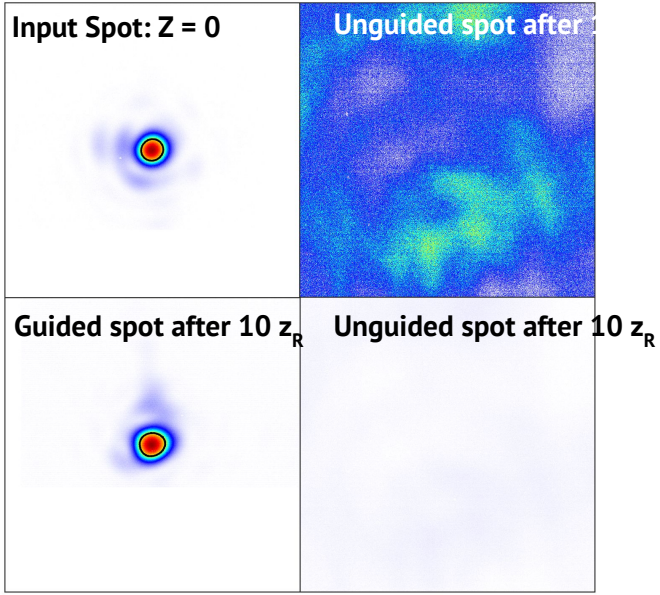
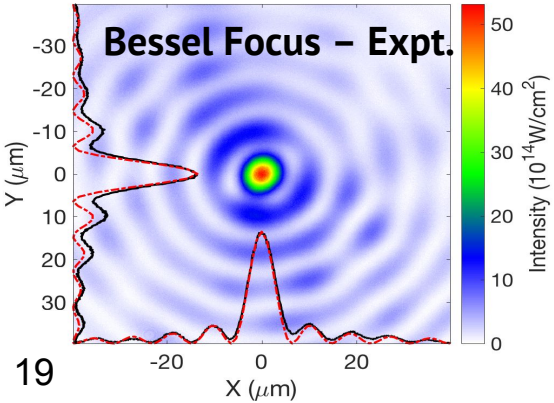
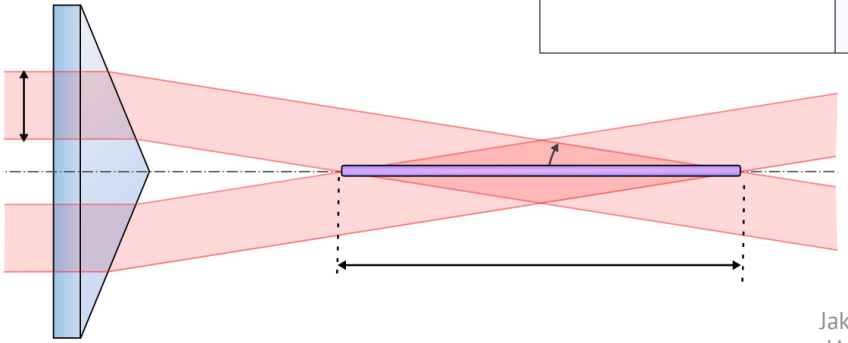
Summary

- **HOFI Plasma channels** formed with an **Axicon**
- Guiding Observed over **10 Rayleigh Ranges**
- **Guiding of high-intensity** (5 x 10^{17} W cm^{-2}) **@ 5Hz**
- **5.0 - 8.4 mJ/cm of channel** of laser energy required
- **Throughput ~ 40-60 %** at high intensity
- The channels are **stable** and **scalable**
- Next step: **accelerate electrons** in HOFI channels







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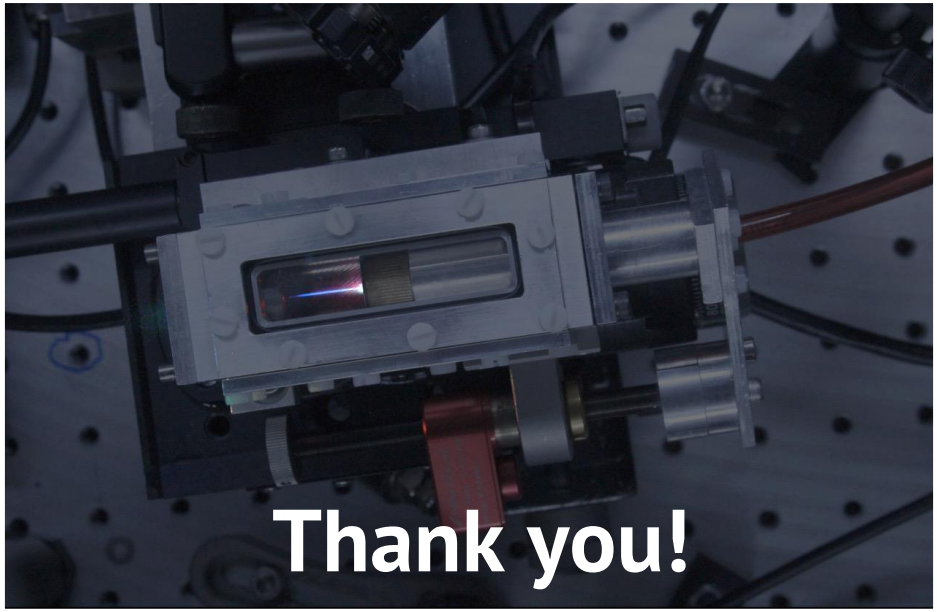

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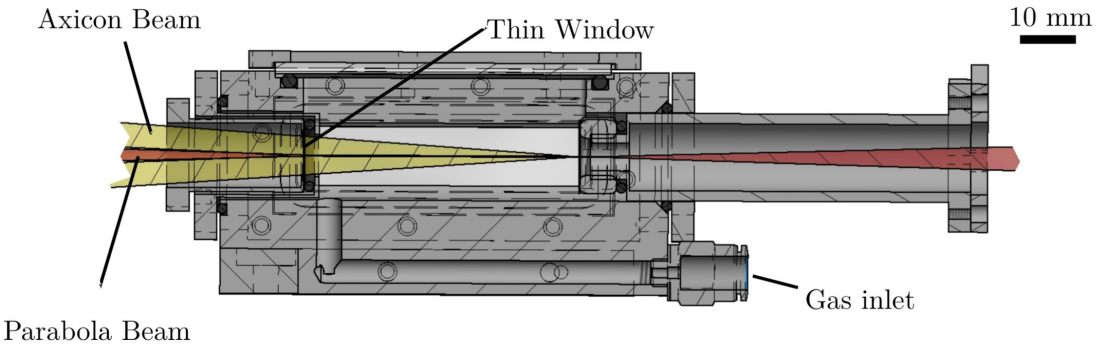
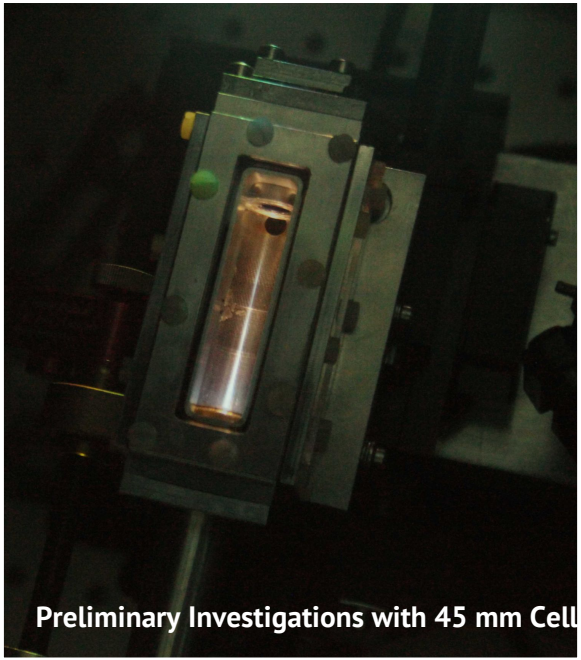
Next Steps – Gas Cell Scalability

Work in Progress…

- Current Guiding Length limited by cell design
- Working toward developing new gas cells capable of long cell channel formation
- Need to reduce residual neutral gas at high rep-rate
- Robustness of cell must also be investigated for high rep rate operation




Preliminary Investigations with 45 mm Cell