Experimental design for generating low-density plasma channels by optical field ionization

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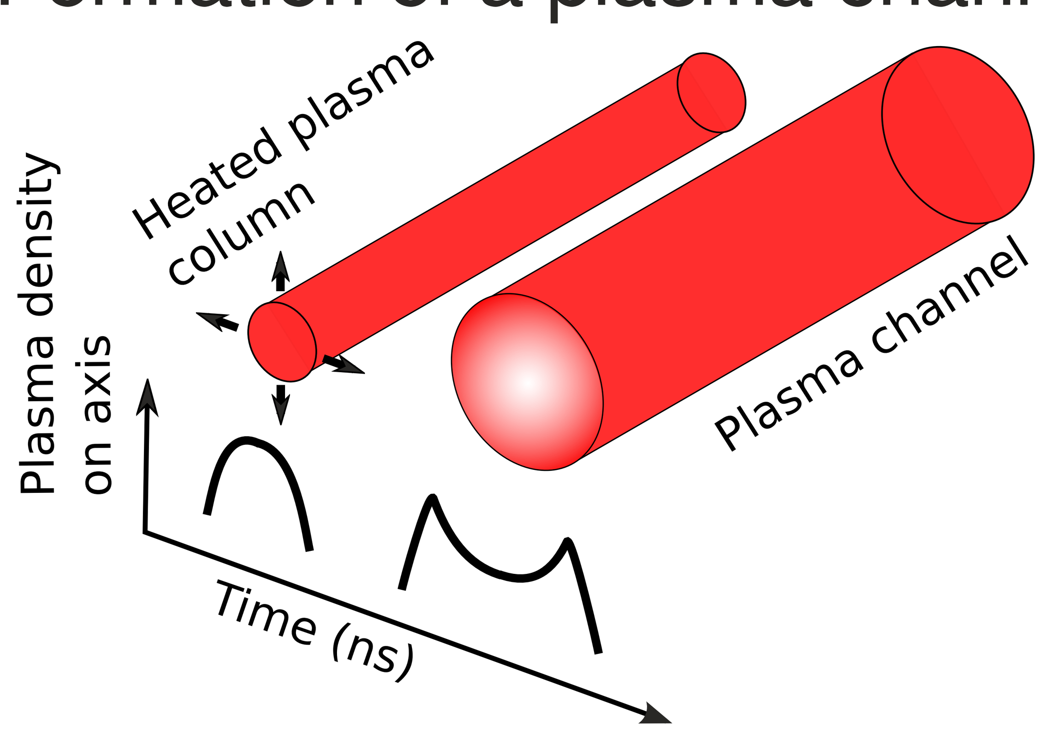
Introduction

- The development of damage-resistent, high repetition rate plasma channels at densities of 1-2 x 10^{17} cm^{-3} is of interest to plasma accelerators driven by either particle bunches or laser pulses to reach high energies and repetition rates [1]
- We have proposed forming low-density plasma channels by hydrodynamic expansion of plasma columns formed by optical field ionization (OFI) [2], where the plasma is initially heated by the high intensity optical field
- We will present the design considerations for an experiment to generate OFI plasma channels in hydrogen with an axicon lens using femtosecond duration laser pulses

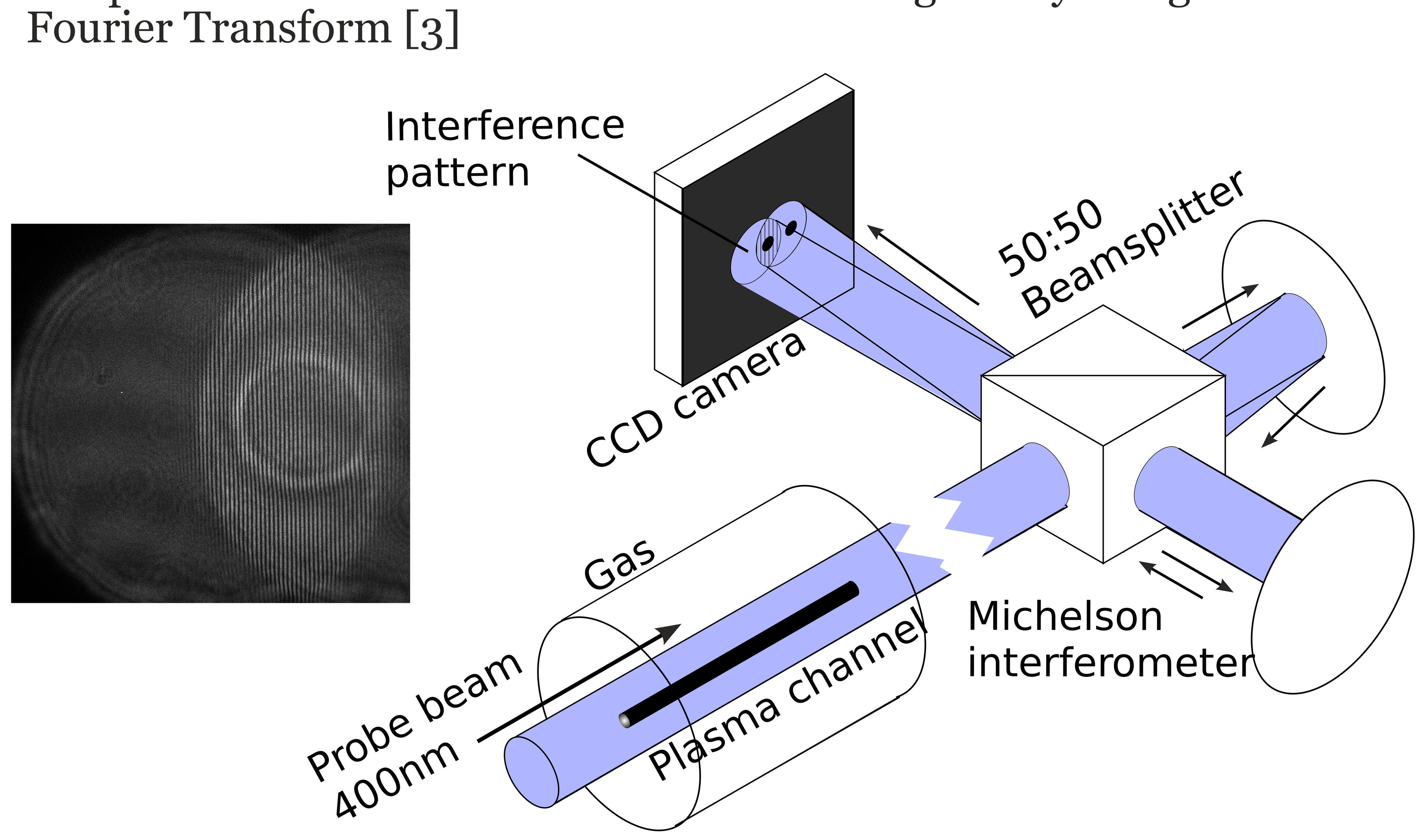
Formation of a plasma channel



- A heated plasma column with a diameter of 10's of µm is produced at the line focus of an axicon
- A few nanoseconds after ionisation, the shock-driven plasma expansion will form a density depression on axis

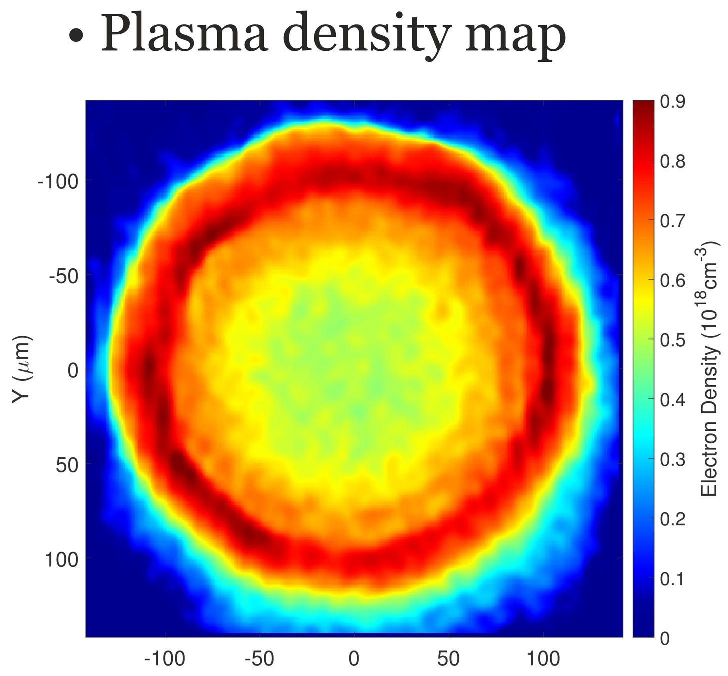
Probing plasma channels

- A collimated pulsed probe laser propagates through the plasma channel which imprints a phase shift on the beam. The phase shift, proportional to the plasma density, can be captured through folded wave interferometry
- The phase can be extracted from the interferogram by using 2D Fast Fourier Transform [3]

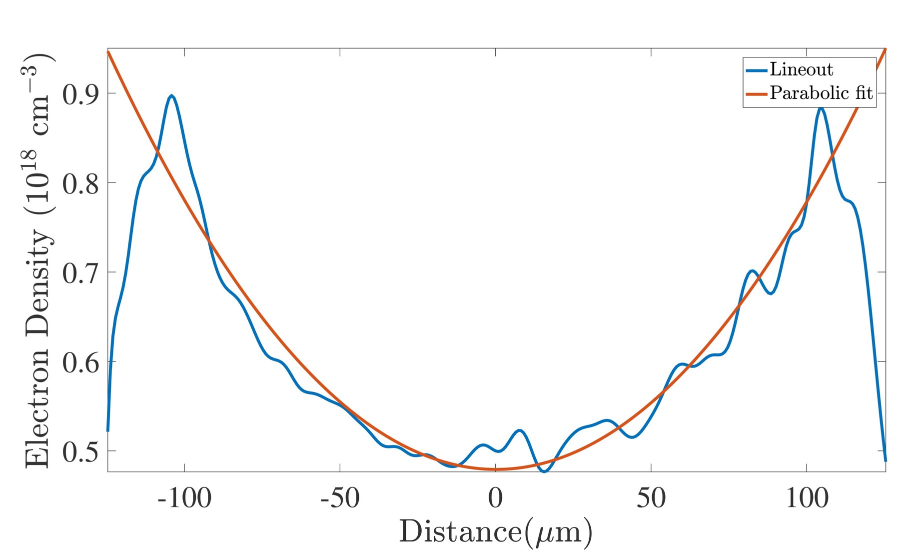


Results obtained using a lens as focusing optic:

- Plasma density map

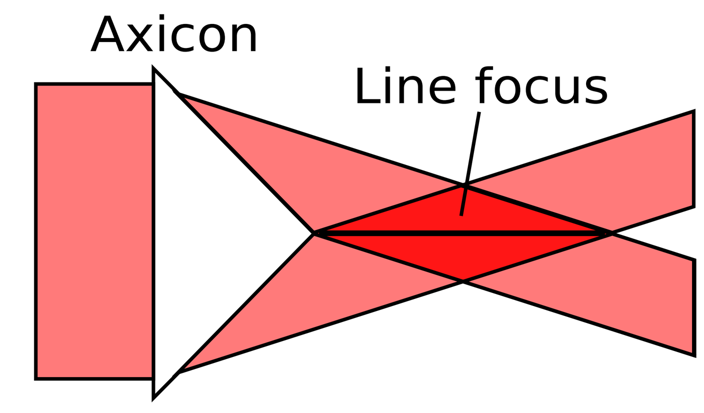


- Parabolic fit to density lineout

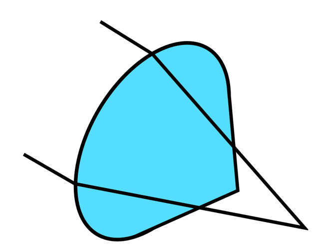


Axicon design

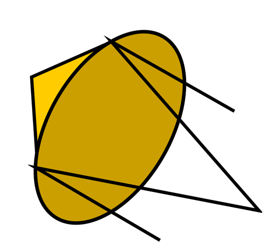
- Axicons are used to generate a line focus several centimetres in length to produce long plasma channels [4]



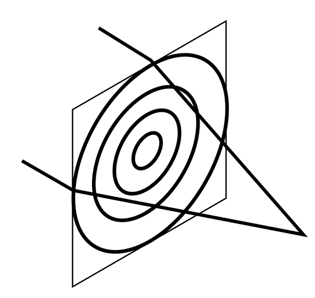
- Challenges of using axicons with high-intensity ultrafast lasers are:
  - B-integral: the material in transmissive axicons can cause self-phase modulation, reducing the intensity
  - Chromatic aberrations: different wavelengths focus at different positions, decreasing the peak intensity
  - Dispersion in optical materials can lead to pulse stretching in time
- We are considering three different axicon designs to generate plasma channels:



- Refractive axicon
  Pros: Simplest to implement, standard optical component
  Cons: B-integral, chromatic aberrations, dispersion



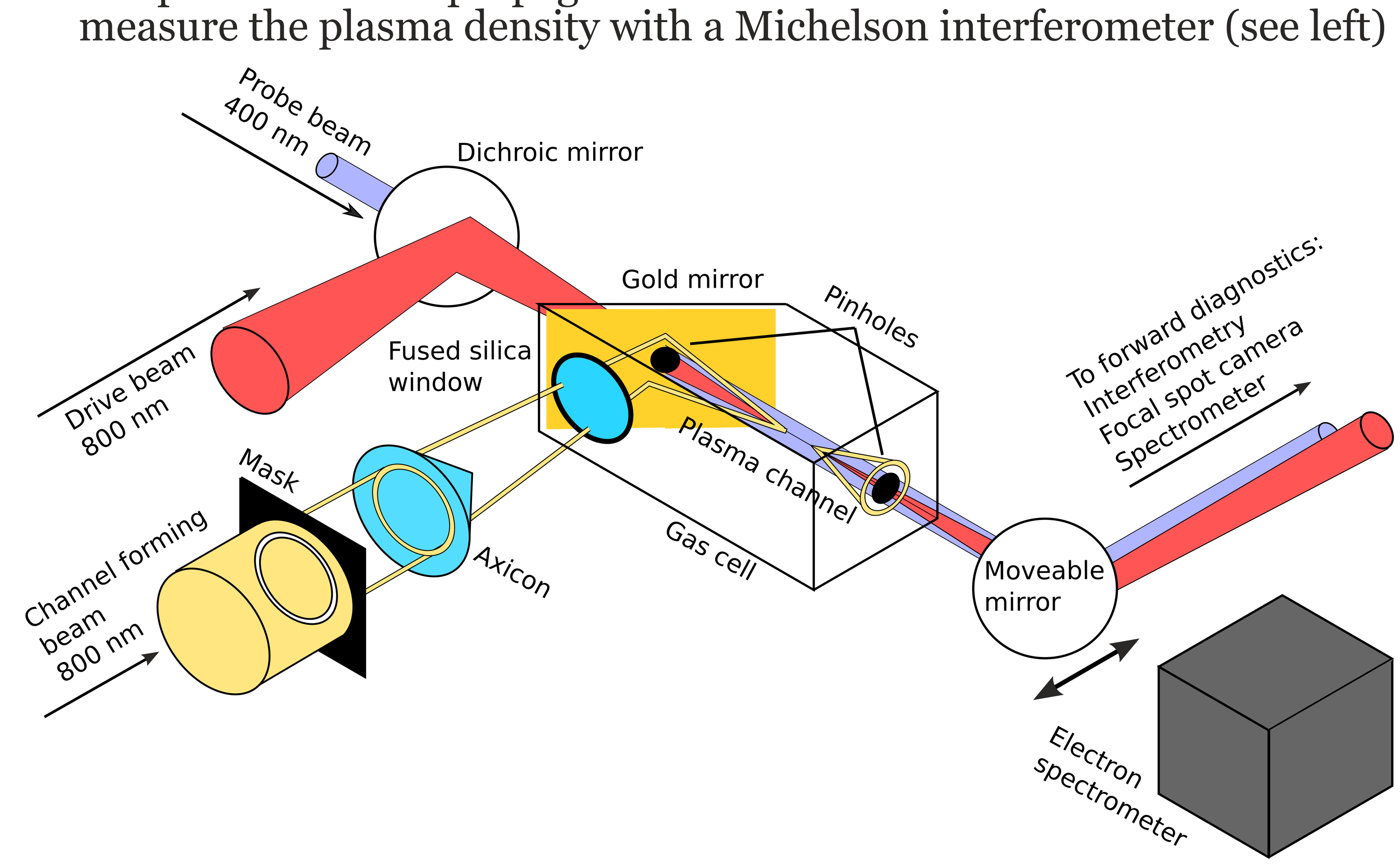
- Reflective axicon
  Pros: No B-integral or chromatic aberrations, less dispersion
  Cons: non-standard component, more complex layout



- Diffractive axicon (phase plate)
  Pros: Less B-integral and dispersion than refractive axicon
  Cons: non-standard component, chromatic aberrations

Experimental layout

- We mask out an annular section of the channel forming beam to limit the focal region length and focus it through an axicon to form a several mm long plasma channel in the gas cell
- The drive beam is focused onto and guided through the plasma channel. A focal spot camera measures the guiding of the high intensity beam through the channel
- The probe beam co-propagates with the channel and is used to measure the plasma density with a Michelson interferometer (see left)



Further information

- Experimental demonstration of a low-density plasma channel capable of high repetition rate operation - R. J. Shalloo (WG5)
- Simulations of low-density plasma channels capable of high repetition rate operation - C. Arran (WG5)

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References:

[1] Schroeder, C. B. *et al.*, *Phys. Rev. Spec. Top. Accel. Beams* 13, 101301 (2010)
[2] Lemos, N. *et al.*, *Phys. Plasmas* 20, 063102 (2013)
[3] Takeda, M. *et al.*, *J. Opt. Soc. Am.* Vol. 72, No. 1 (1982)
[4] Durfee, C.G and Milchberg, H.M., *Phys. Rev. Lett.* Vol. 71 No. 15 (1993)