An optically multiplexed single-shot time resolved probe of laser-plasma dynamics

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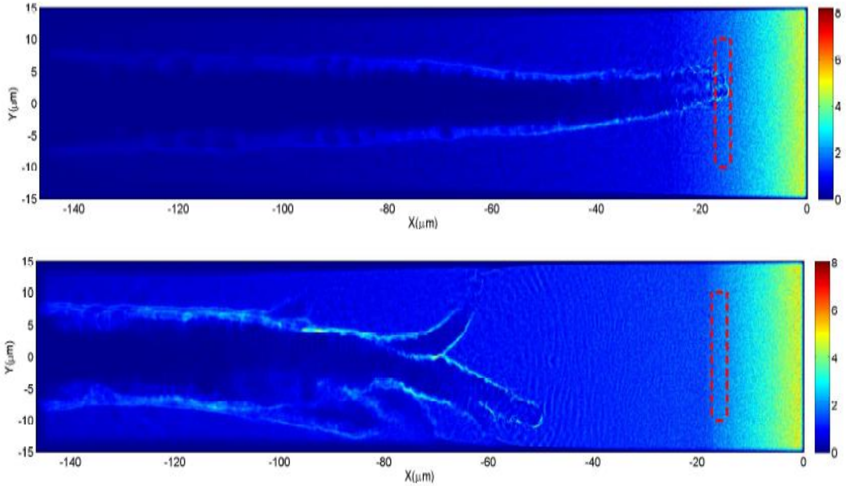
BLIN4

Plasma density scalelength is a key parameter effecting laser driven ion acceleration & beyond…

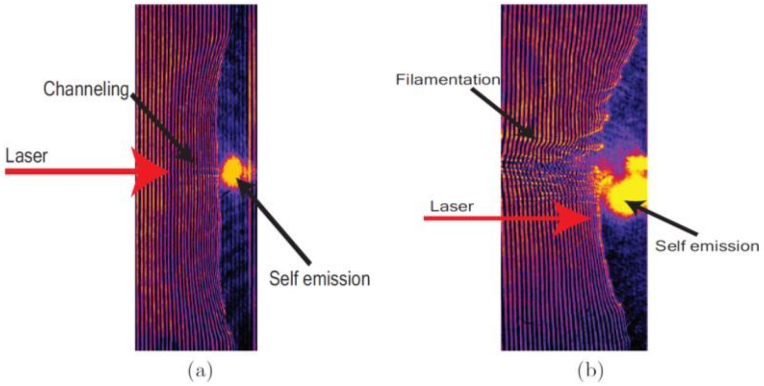
R.J Gray *et al.* New J. Phys. 16, 113074 (2014)



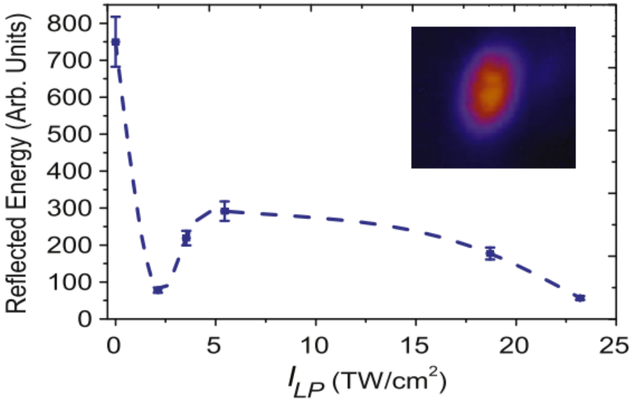
…self-focusing and filamentation modify laser-coupling and ultimately proton max energy and conversion efficiency…

…for beam stability and control, pulse evolution has to be carefully monitored

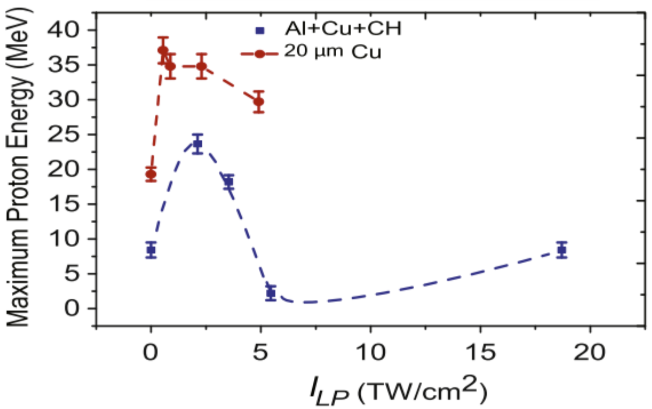
Optical Probe Interferometry



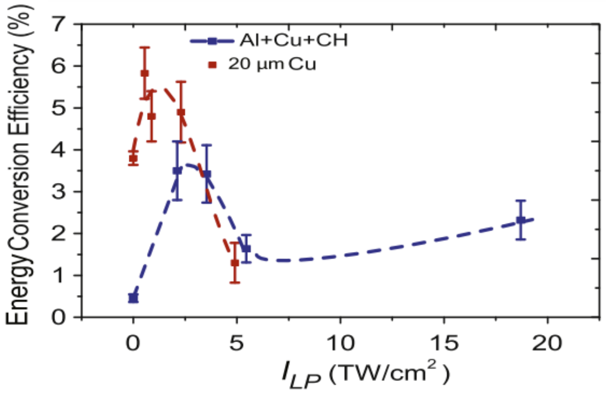
Reflected Light



Proton Max Energy



Proton conversion efficiency



Motivating question…

Can we measure the plasma evolution and pulse propagation during a single shot?

Existing pump-probe methodologies…

Optical Probing

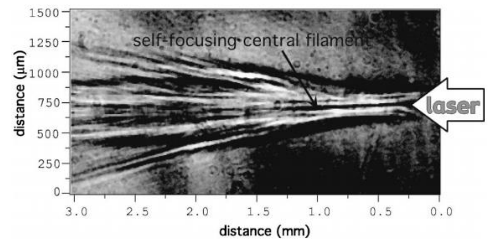
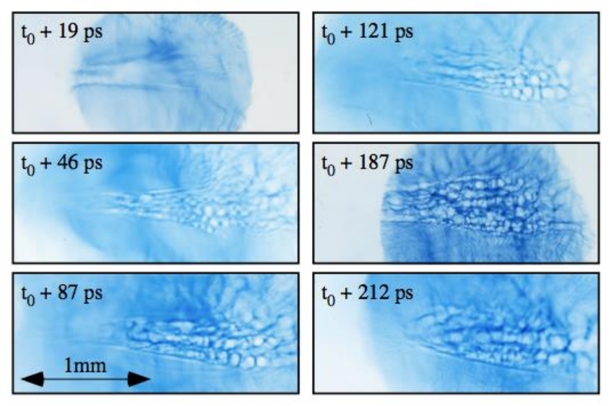


FIG. 1. Shadowgraph taken with $n_e = 2.9\times10^{19}$ cm^{-3}, $\tau_L \approx 0.9$ ps, P/P_{cr} ≈ 19 (image taken approximately 30 ps after main interaction).

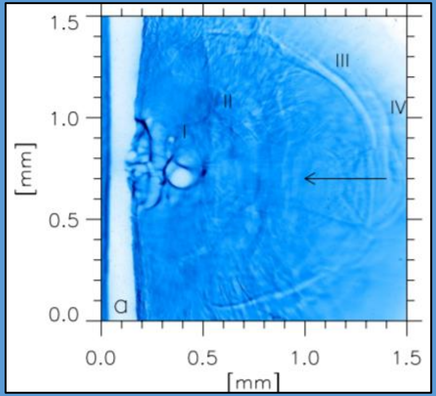
P.M. Nilson *et al.*, New Journal of Physics 12, 045014 (2010)

Z. Najmudin *et al.*, Phys. Plasmas, 10 (2) (2003)

Proton Radiography



L. Willingale *et al.*, Phys. Rev. Lett. 106, 105002 (2011)



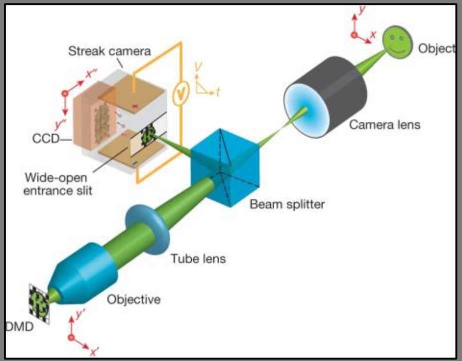
L. Romagnani, Phys. Rev. Lett. 105, 175002 (2010)

G. Sarri *et al.*, Physics of Plasmas 17, 113303 (2010)

S Kar *et al.*, 2007 New J. Phys. 9 402 (2007)

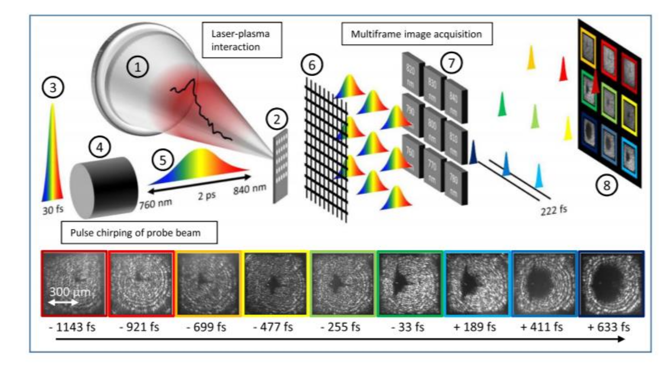
M. Borghesi, Phys. Rev. Lett. 78, 879 (2010)

Optical Streaking, Compressed ultrafast photography, etc…

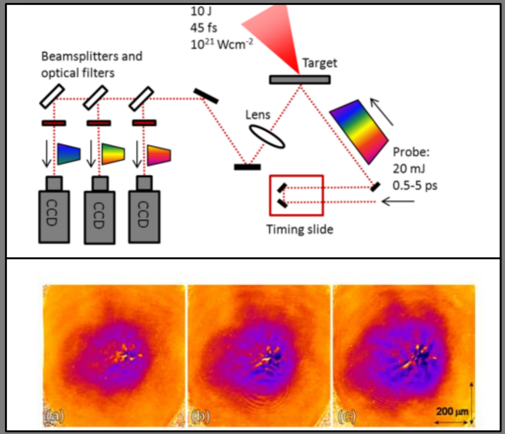


L. Gao *et al.*, Nature volume 516, 74–77(2014)

Chirped Optical Probing



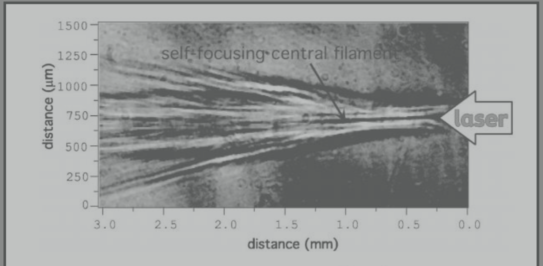
D. Haffa *et al.* Sci Rep., 9, 7697 (2019)



J.S Green *et al.*, J. Inst, 9 (03), P03003 (2014)

Existing pump-probe methodologies…

Optical Probing



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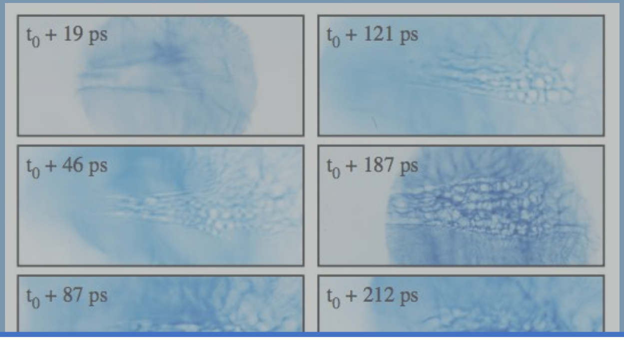
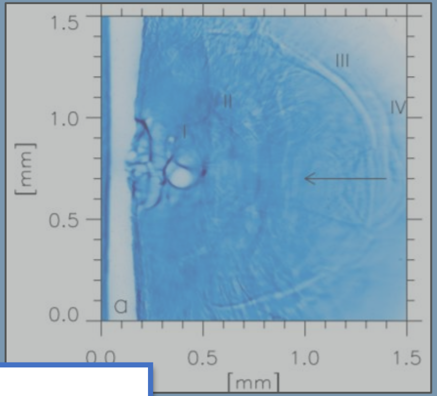
Z. Najmudin *et al.*, Phys. Plasmas, 10 (2) (2003)

Proton Radiography





Phys. Rev. Lett. 105, 175002 (2010)

Physics of Plasmas 17, 113303 (2010)

007 New J. Phys. 9 402 (2007)

hys. Rev. Lett. 78, 879 (2010)

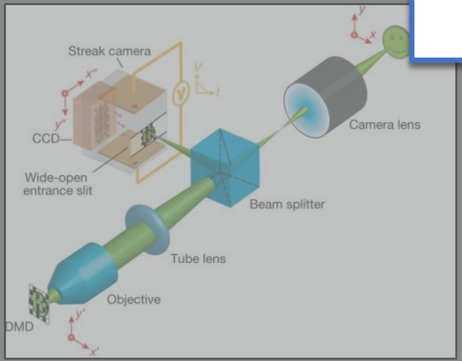
(1) Single shot measurements with temporal resolution

(2) Arbitrary control over the probe time (independent probes)

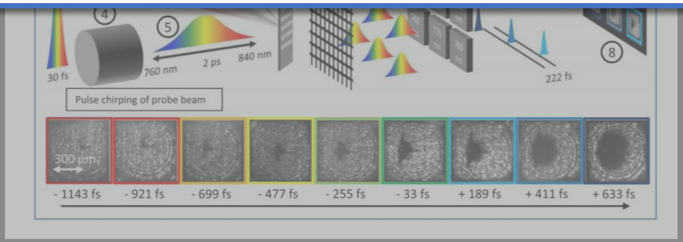
(3) 2D Spatial resolution (no streaking)

(4) Any laser system (no bandwidth effects)

Optical Streaking, Compressed u photography, etc…



L. Gao *et al.*, Nature volume 516, 74–77(2014)



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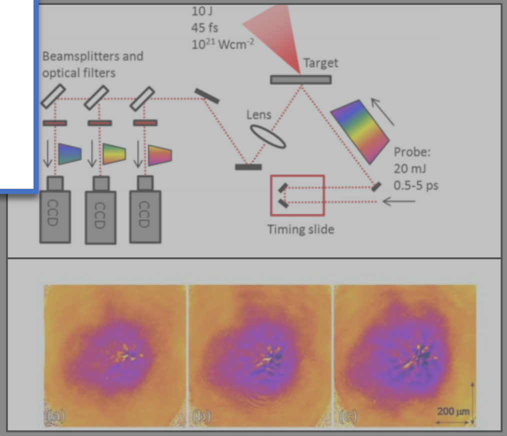
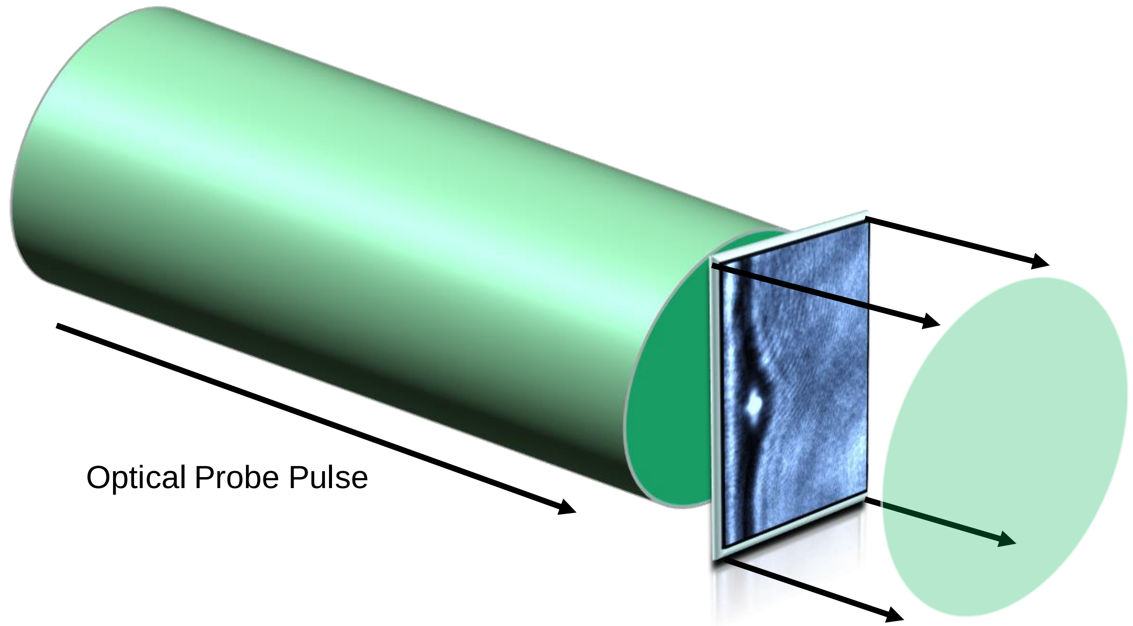
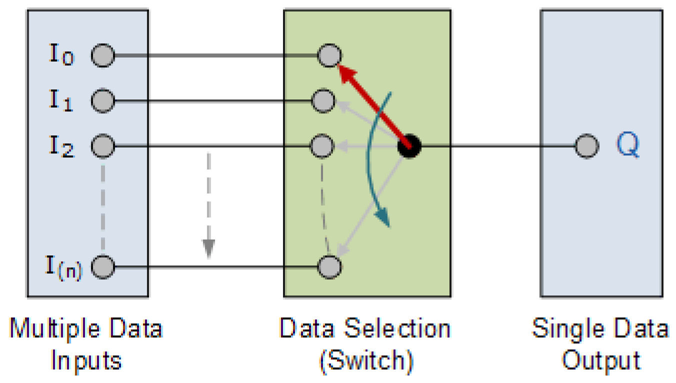


J.S Green *et al.*, J. Inst, 9 (03), P03003 (2014)

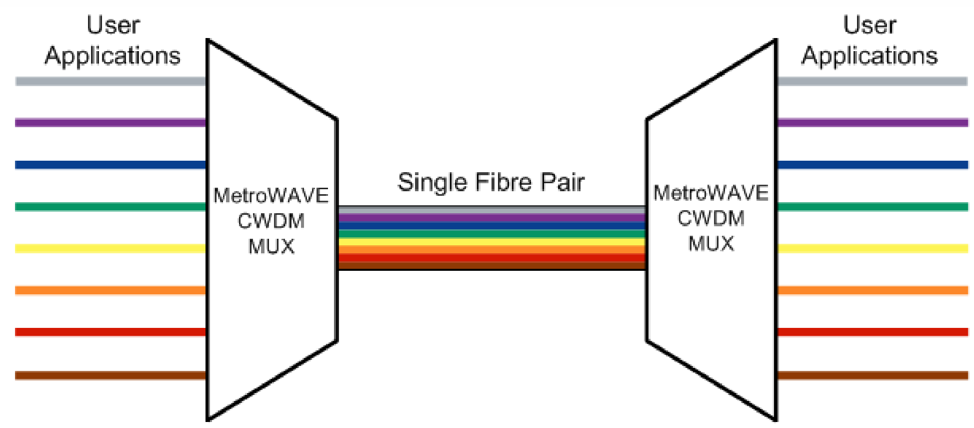
Using multiplexing to increase frame rate for optical probing…



In other words…how do we transfer more information over a single output line…

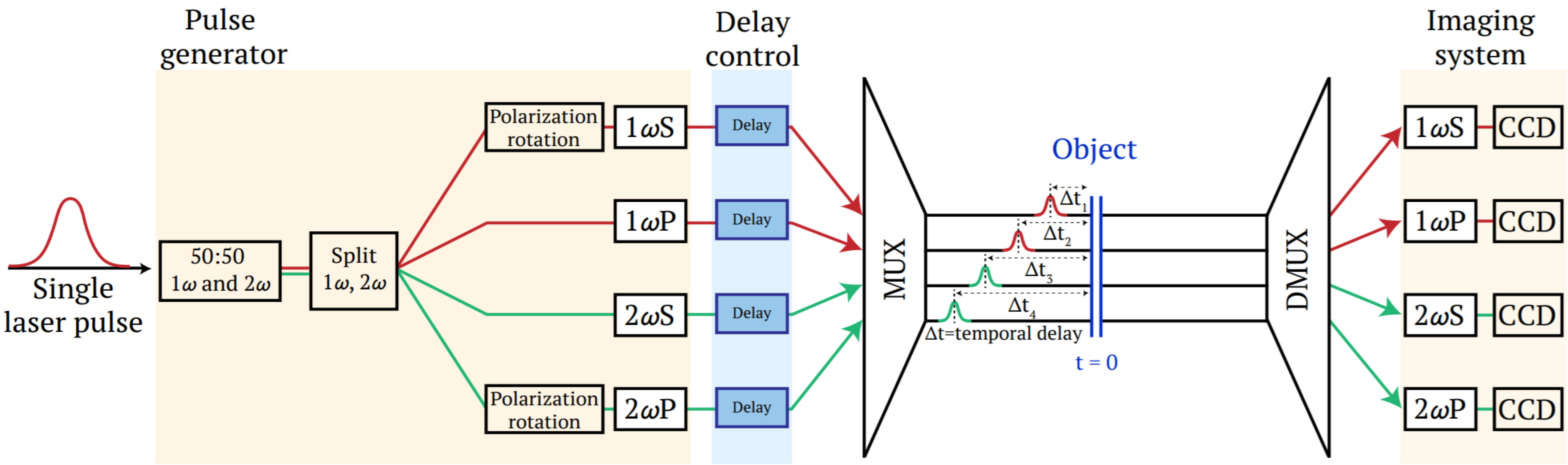


Basic Multiplexer Switch



Wavelength Division Multiplexing

A multiplexed optical probe…concept



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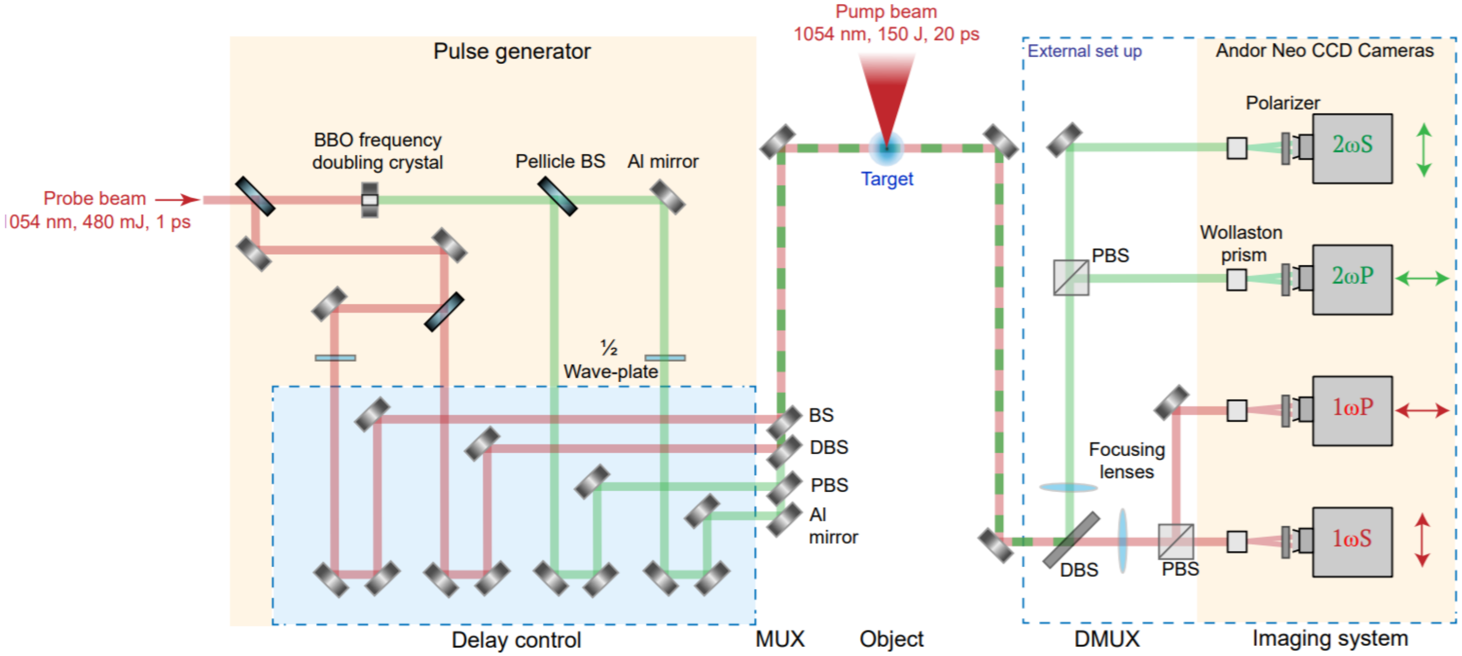
An optically multiplexed single-shot time-resolved probe of laser–plasma dynamics

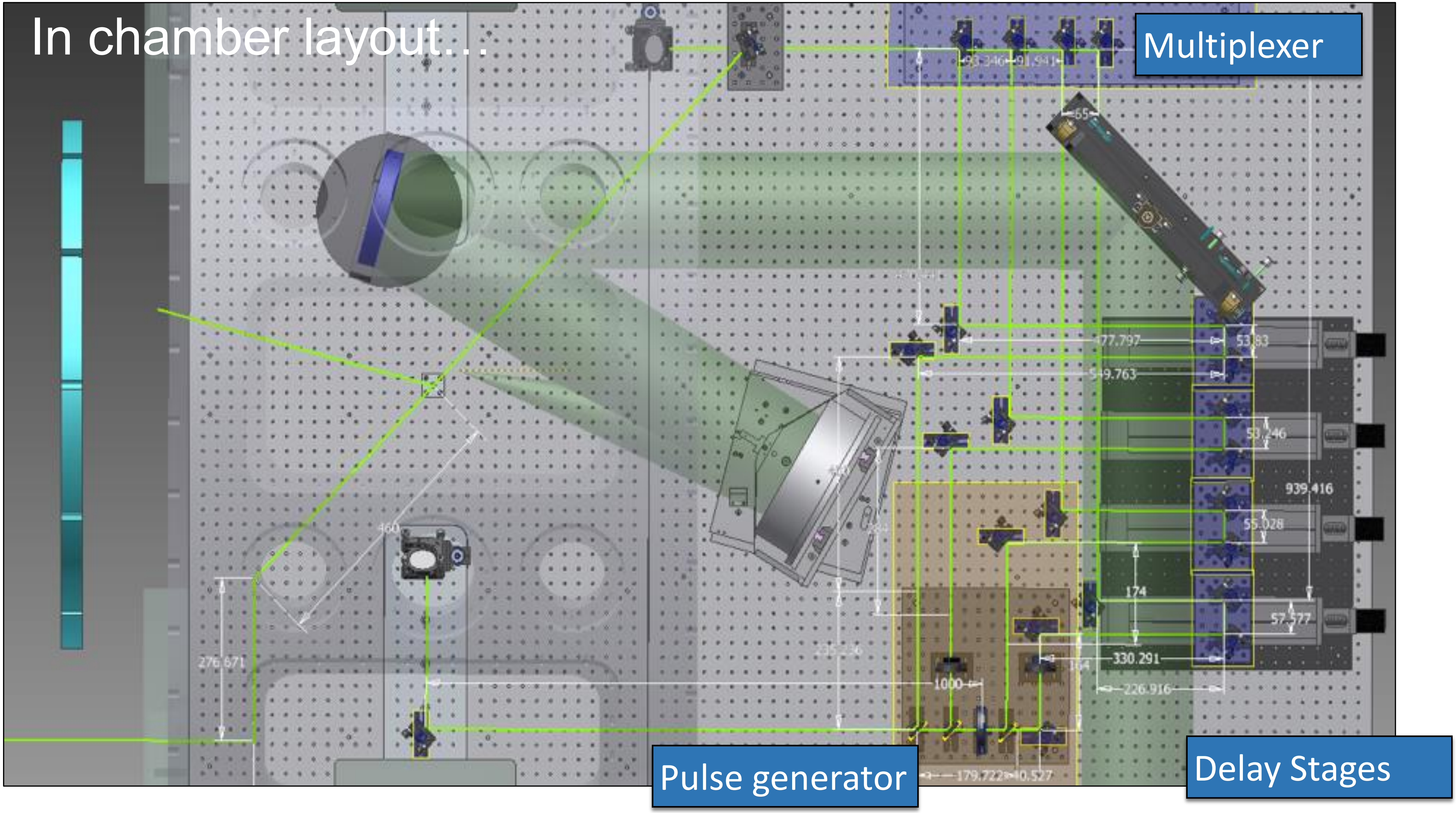
Z. E. Davidson,[1] B. Gonzalez-Izquierdo,[1] A. Higginson,[1] K. L. Lancaster,[2] S. D. R. Williamson,[1] M. King,[1] D. Farley,[2] D. Neely,[1,3] P. McKenna,[1] and R. J. Gray[1,*]

A multiplexed optical probe…optical design

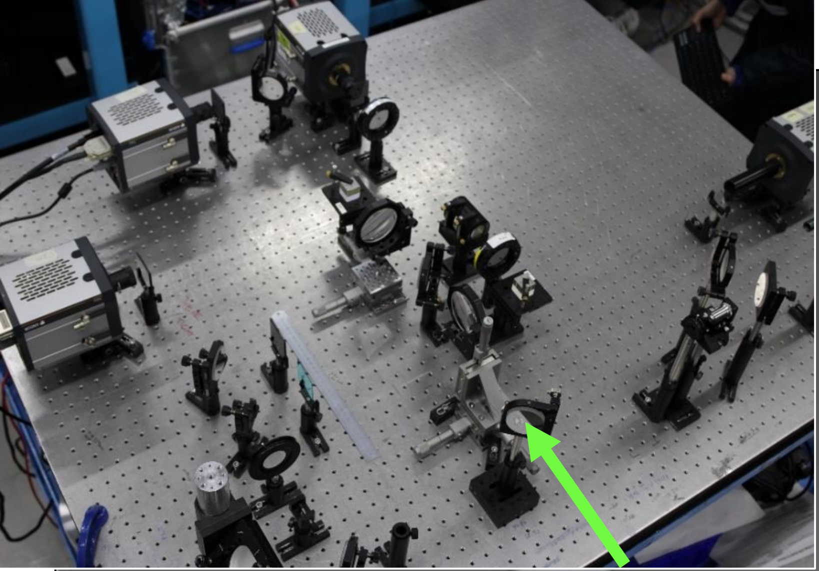


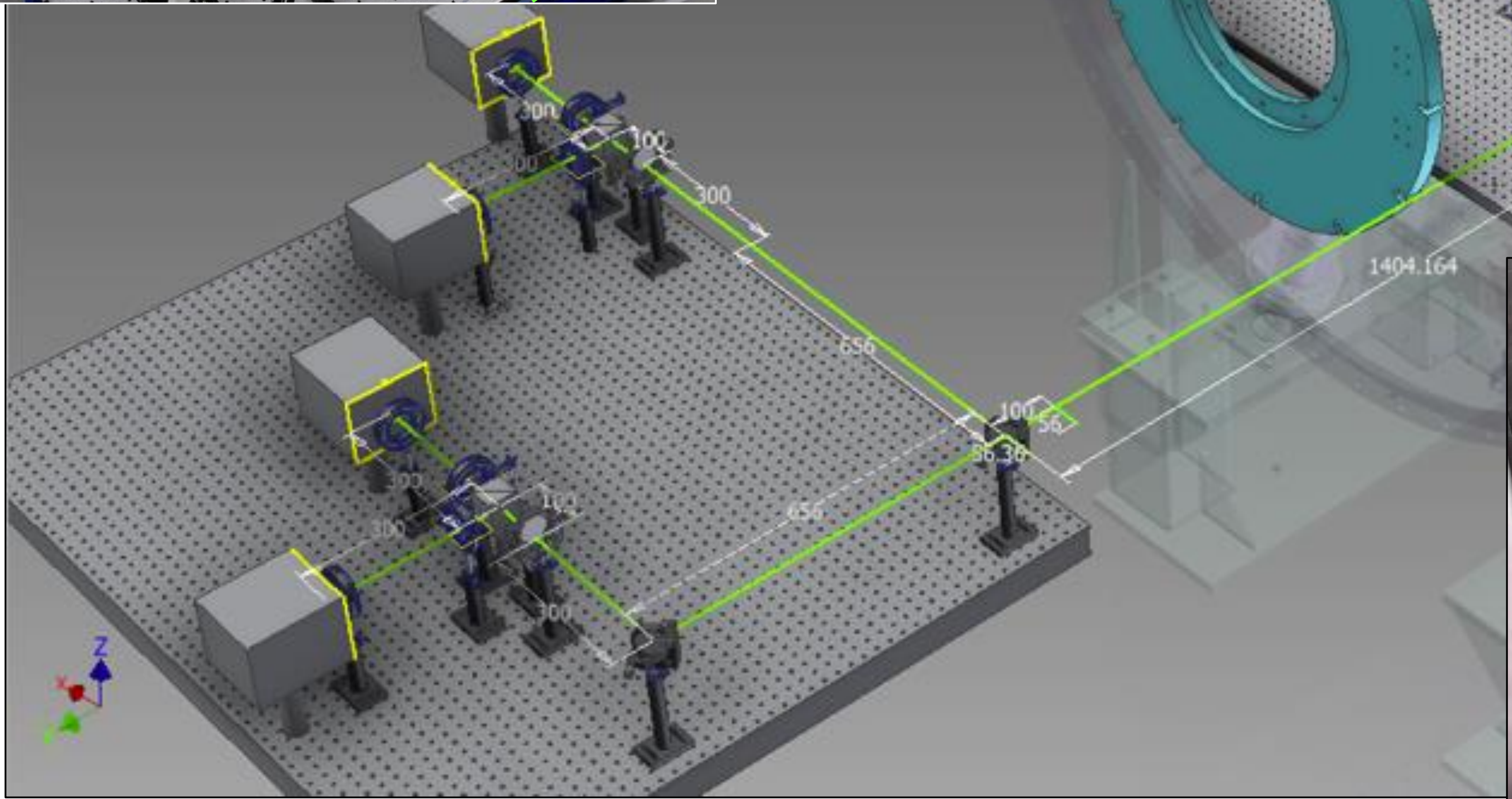
- 1w pulse is split and doubled to create 1w and 2w pulses
- These are split again and half of them are then rotated in polarisation by 90^0
- This produced 4x pulses: 1w(P), 1w(S), 2w(P), 2w(S)
- These are then delayed relative to each other (and the drive pulse)
- 4x pulse are then sent through plasma and split, image upon exit

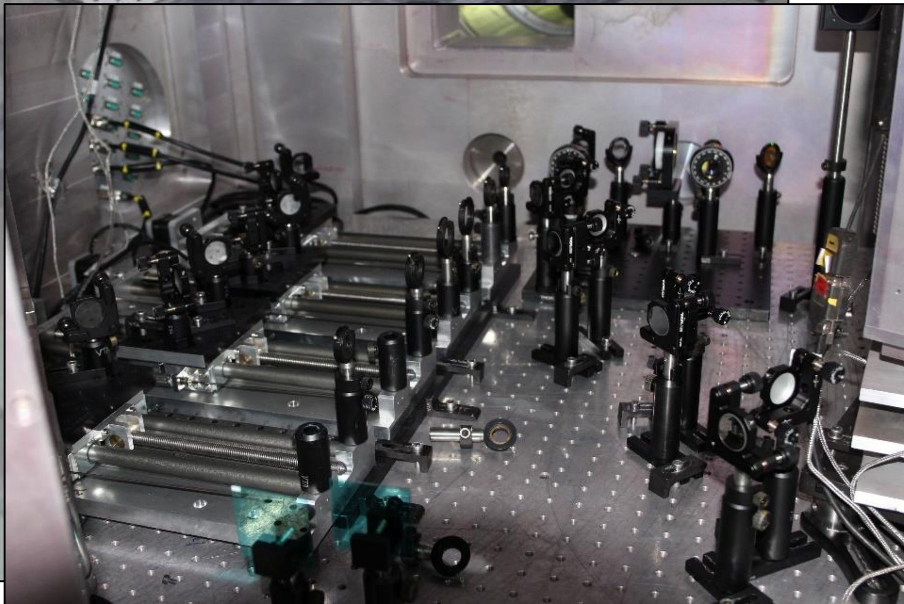
In chamber layout…



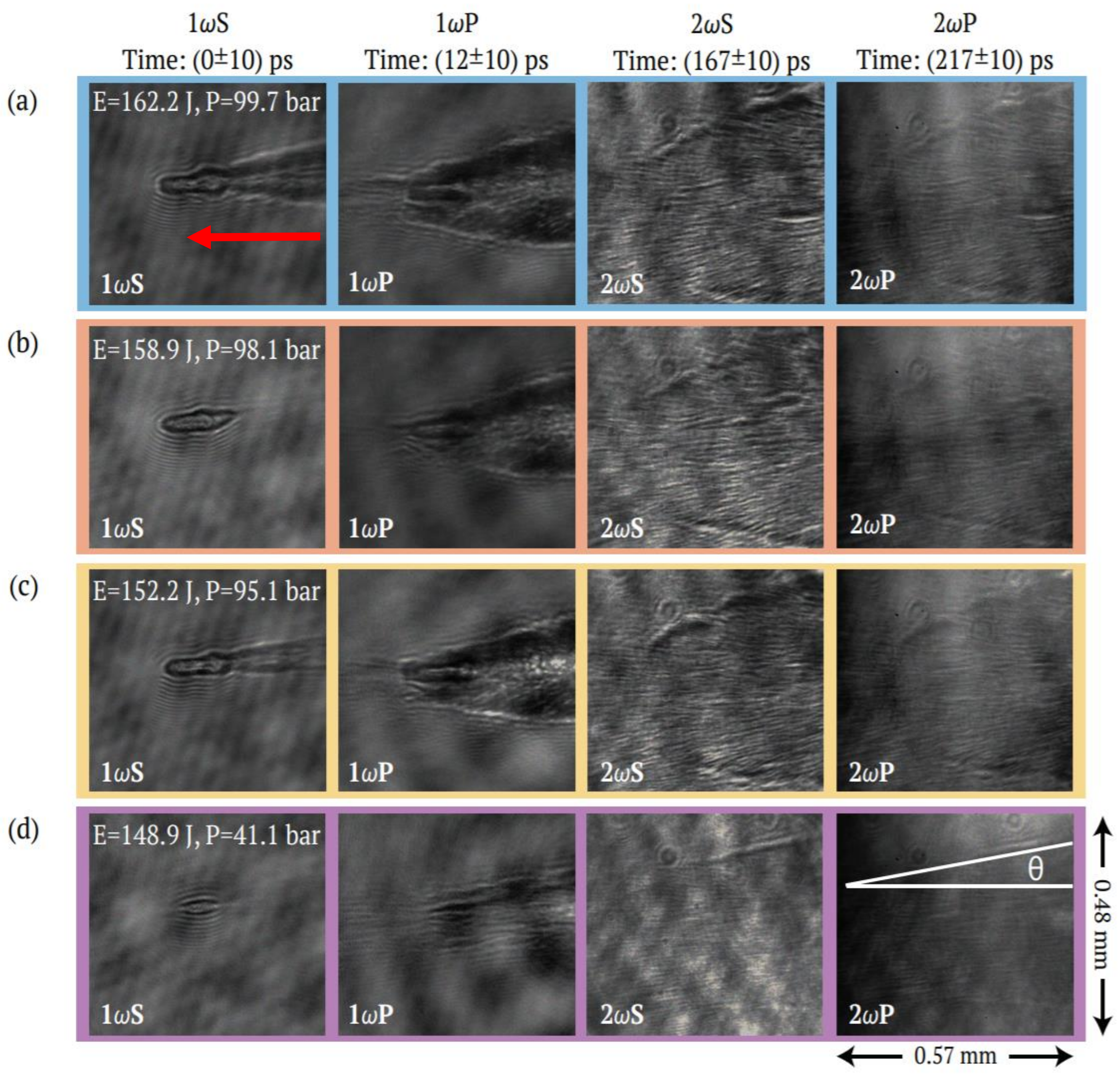
Full probe setup…







Initial tests using gas targets…



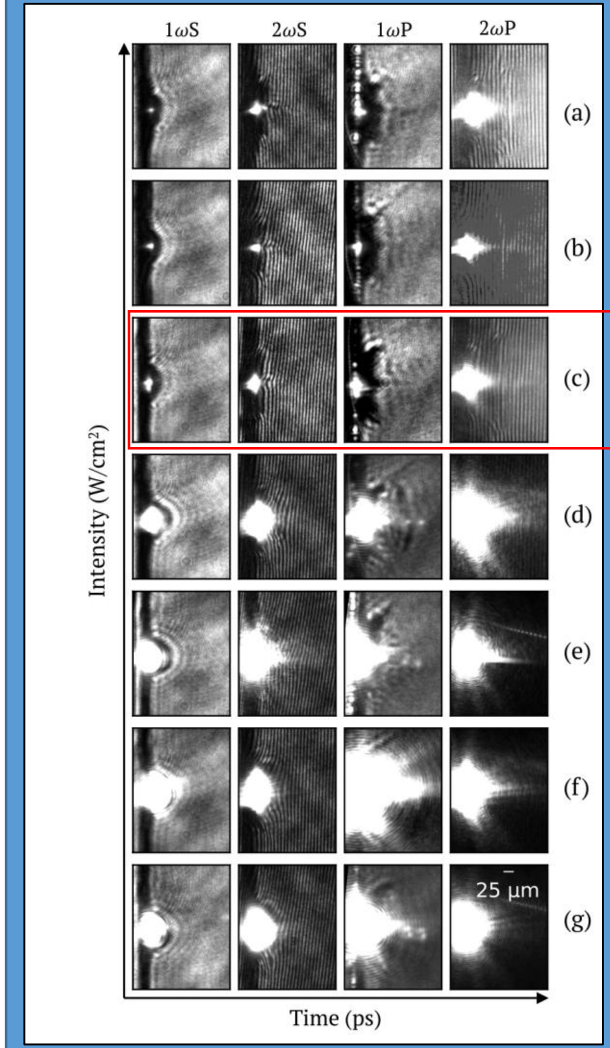
Gas jet results on Vulcan TAW:

- Vulcan @ 1054 nm, up to 200J in 20 ps
- 1 ps probe pulse duration (x4 pulses)

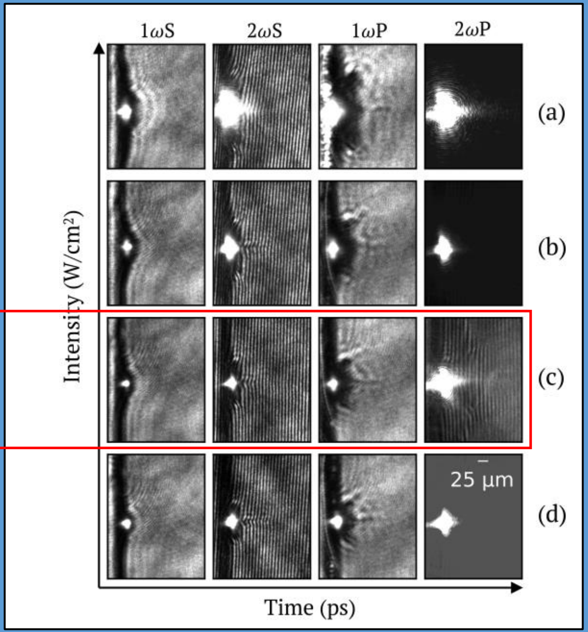
- In gas targets across shots with otherwise very similar conditions we measure significant changes in propagation, filamentation growth…
- Via conventional, multi-shot optical probing these variations are easily resolvable

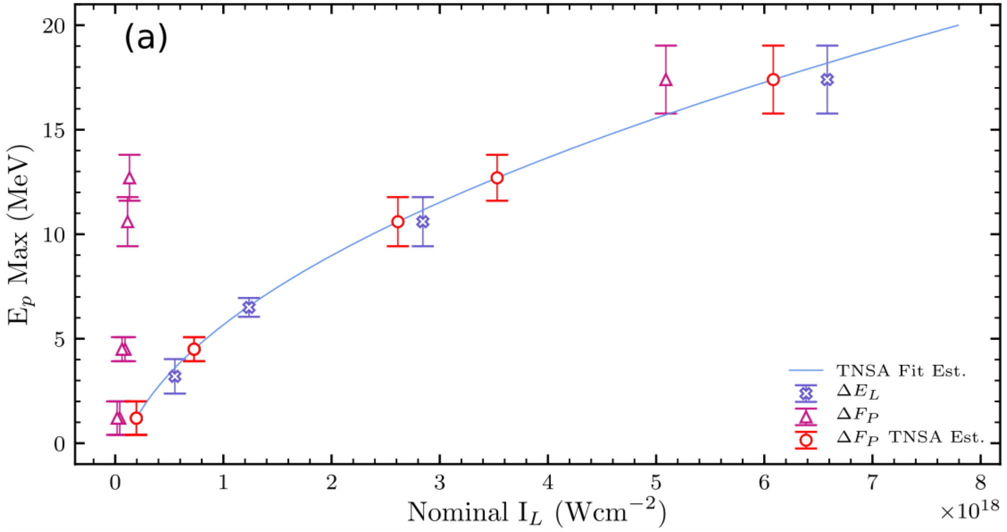
Initial tests using solid targets…

Intensity changed by spot size



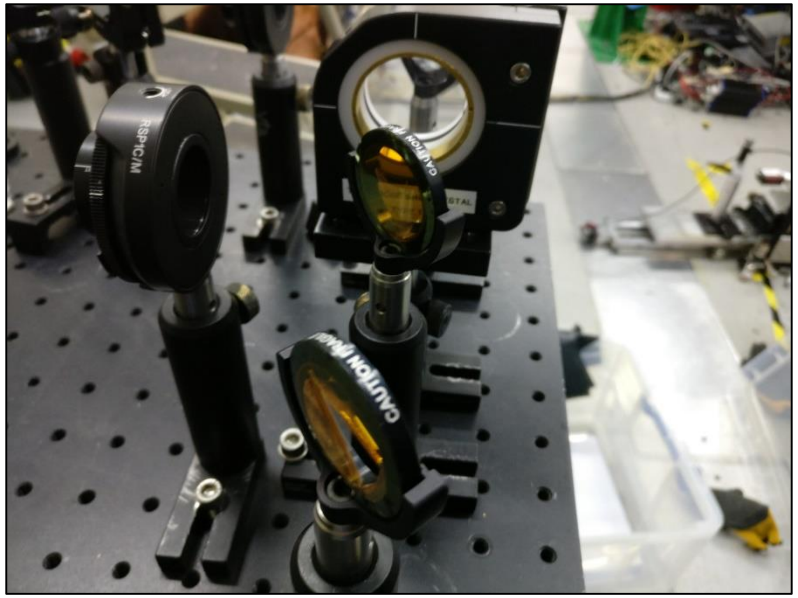
Intensity changed by energy…



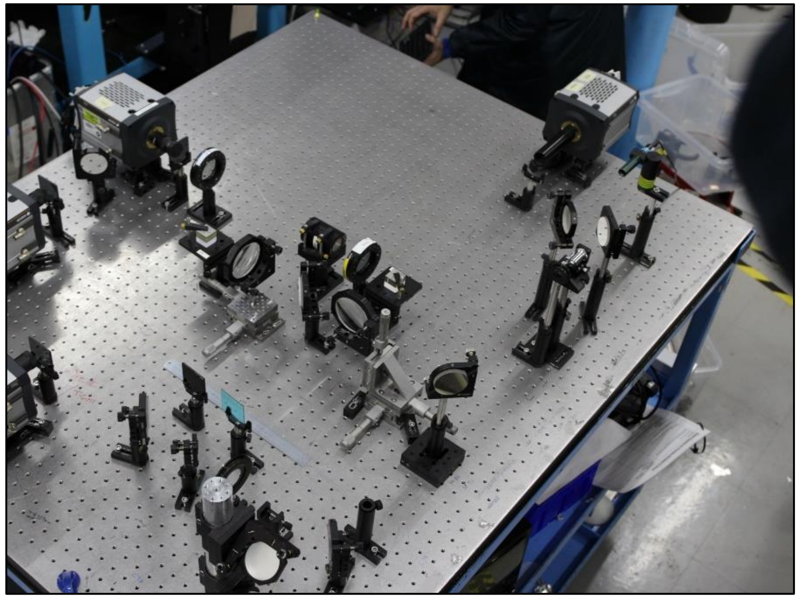


- We find the front surface expansion dynamics are different in laser intensity is varied by laser energy compared to laser spot size
- This is helping us to understand differences in the proton energy scaling with energy and spot size

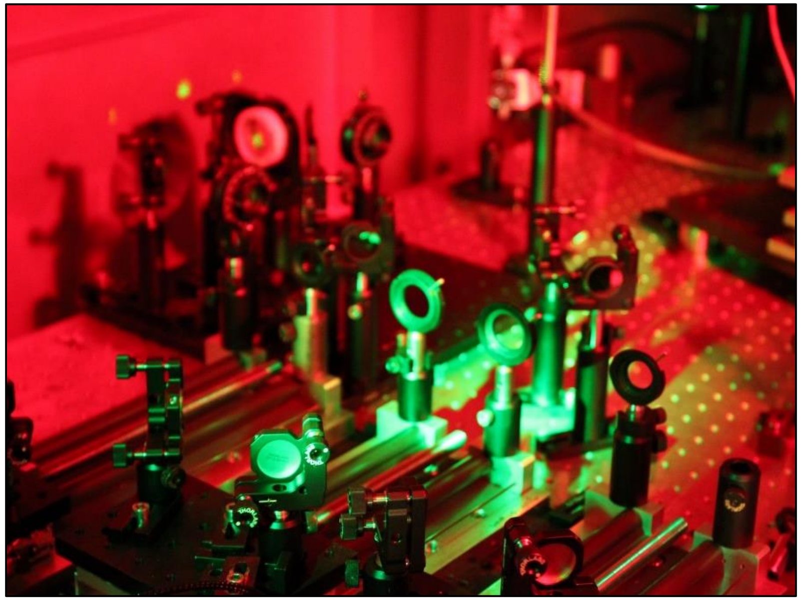
Key Issues/challenges with first design…



Losses in the system require high power levels…leading to damage on the first optics

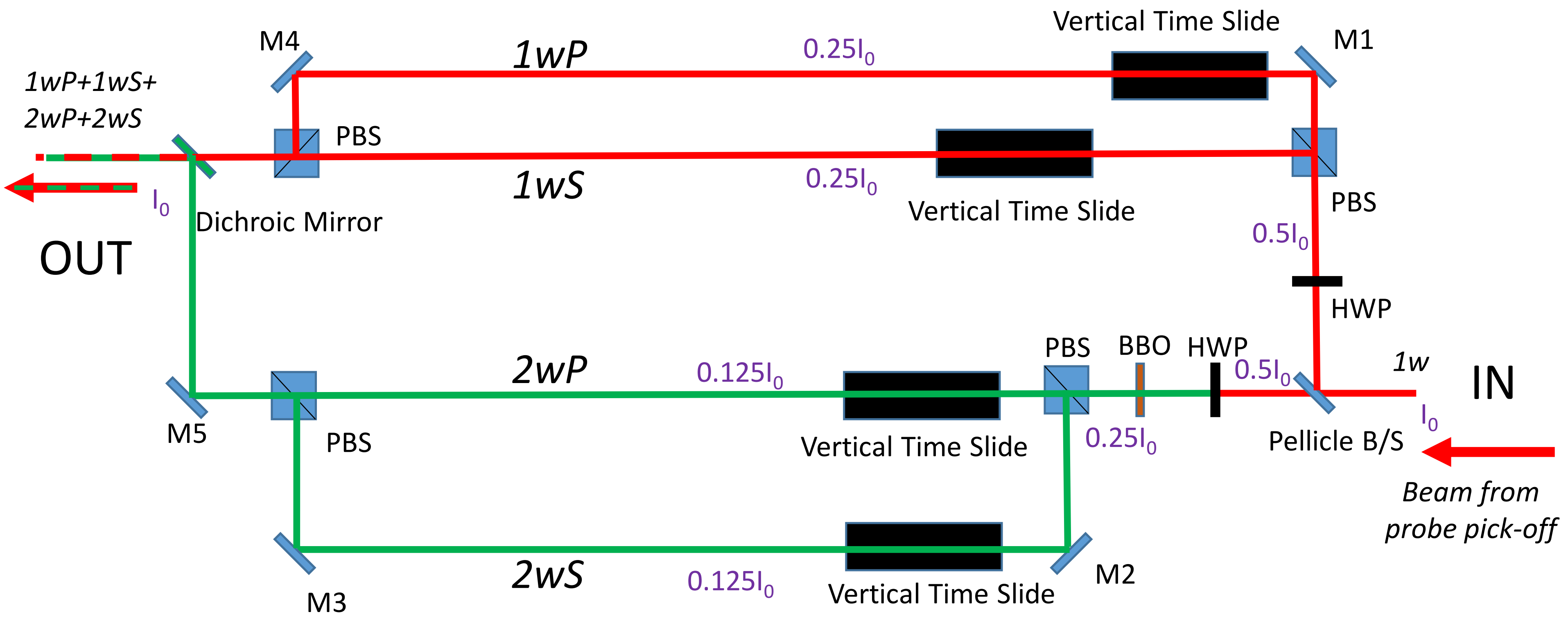


Good image quality at both wavelengths simultaneously is difficult with refractive optics



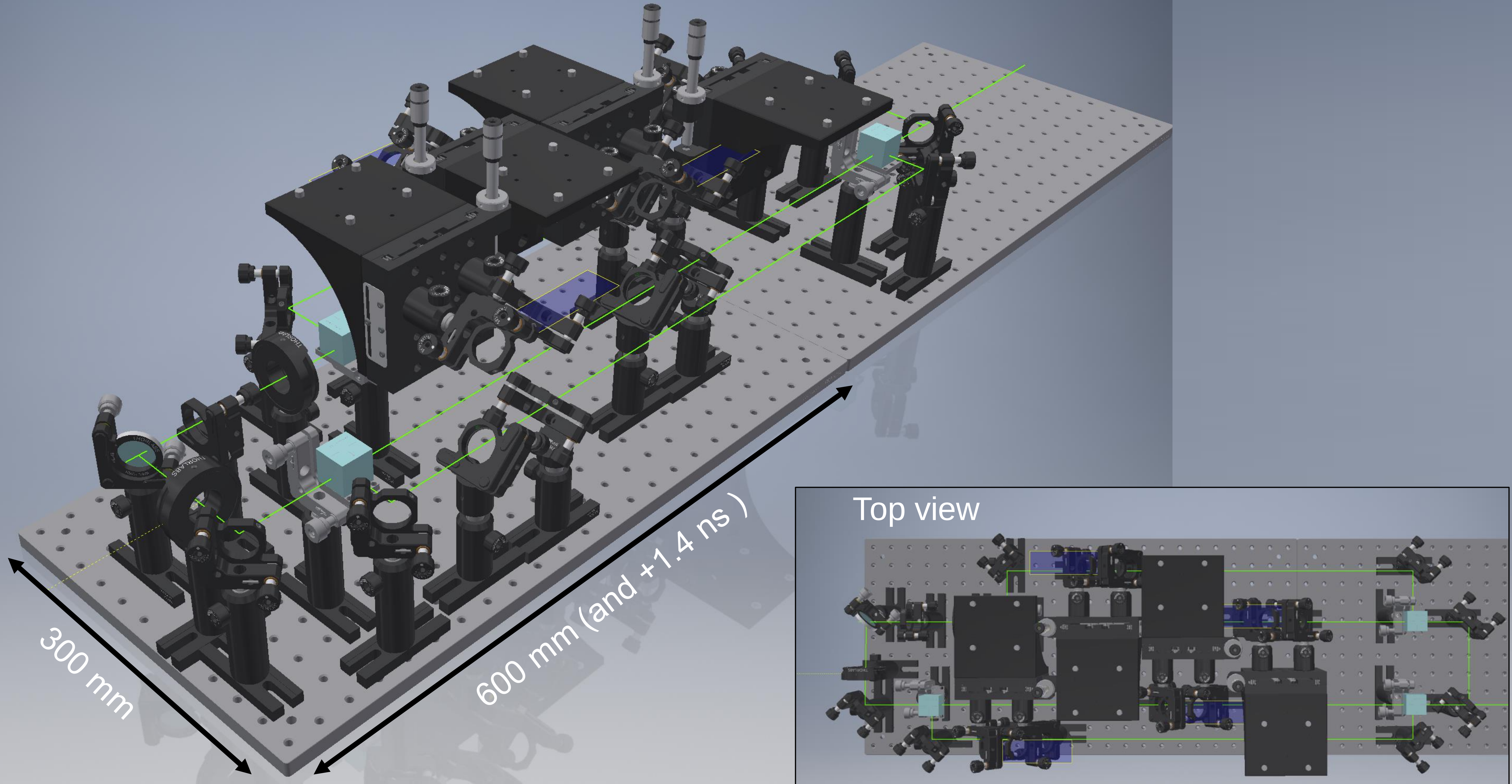
Relative complexity and large footprint of the system gives large delay offset

Ongoing development…



- Second design is considerably more energy efficient therefore lower probe energies can be used (damage issue)
- Also, much more compact (~600 x 300) and therefore less path length (less additional time added compared to the driver)

Ongoing development…



Summary…

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- We have developed a polarisation and wavelength multiplexing optical probe
- This has been demonstrated to enable 4-frames with picosecond-scale temporal resolution and ~<10 um 2D spatial resolution
- First tests using gas targets show the high degree of shot-to-shot variability in laser propagation and therefore the need for this type of system
- In solid targets we can also now able to see the difference in front surface plasma expansion dynamics
- A more compact, efficient design has been completed (due to run in April 2020 but delayed due to COVID-19)
- This design will be much more suited to smaller footprint and femtosecond scale sytems

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- Z.E Davidson, B. Gonzalez-Izquierdo, A. Higginson, M. King, S.D.R. Williamson, and P. McKenna – University of Strathclyde

- D. Neely – Central Laser facility

- K.L Lancaster and D. Farley – University of York

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Thank you for your attention!

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Z.E Davidson *et al.*, Optics Express, 27, 4 (2019)

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Other Recent Group Publications:

1. S.D.R Williamson *et al.,* New J. Phys. 22, 053044 (2020)
2. M.J Duff *et al.,* Scientific Reports 10, 1 (2020)
3. A. Higginson *et al.*, Nature Communications, 9, 724 (2018)
4. R.J Gray *et al.* , New J. Phys., 20, 033021 (2018)
5. B. Gonzalez-Izquierdo *et al.*, Nature Physics, 12, 505 (2016)