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Experiments at the Cockcroft Institute 2023

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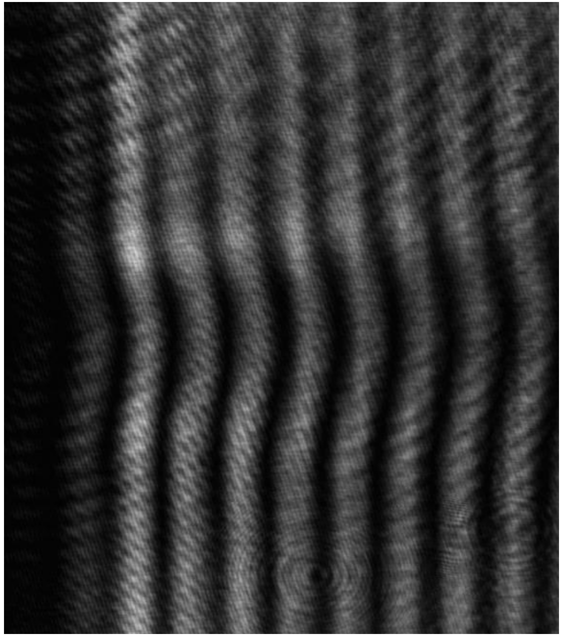
QUASAR Group

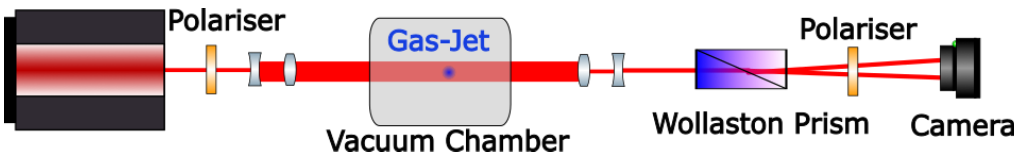
The Cockcroft Institute of Accelerator Science and Technology

Interferometry Measurements of Gas Jets

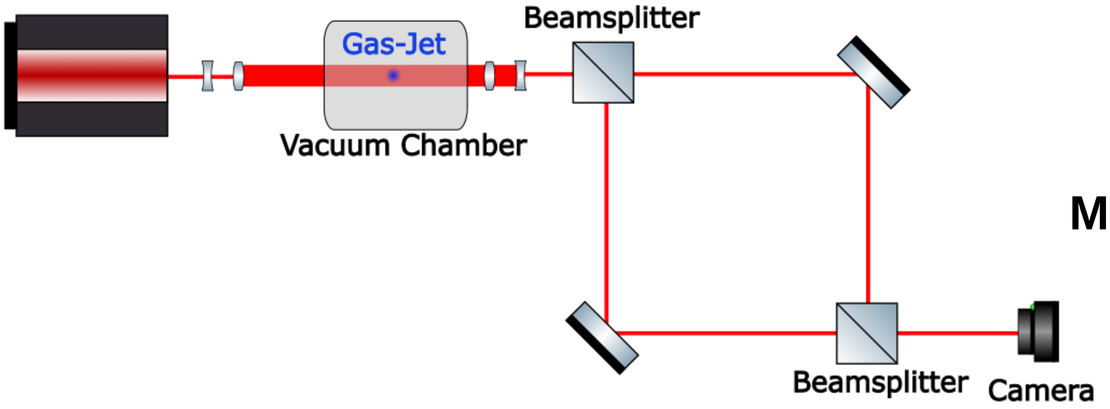
- Interferometry is a method of determining gas-jet density
- Uses difference in refractive index between jet and vacuum to produce a phase shift
- Density resolution limited to $\sim 10^{18}$ molecules per cm^3, thus only applied to pulsed jet currently.
- Multi-Pass interferometry could increase density range (aiming at smaller nozzle with continuous flow)
- A 4x pass system is implementable with no vacuum geometry change



Mach-Zehnder and Nomarski Set-Up



Nomarski



Mach-Zehnder

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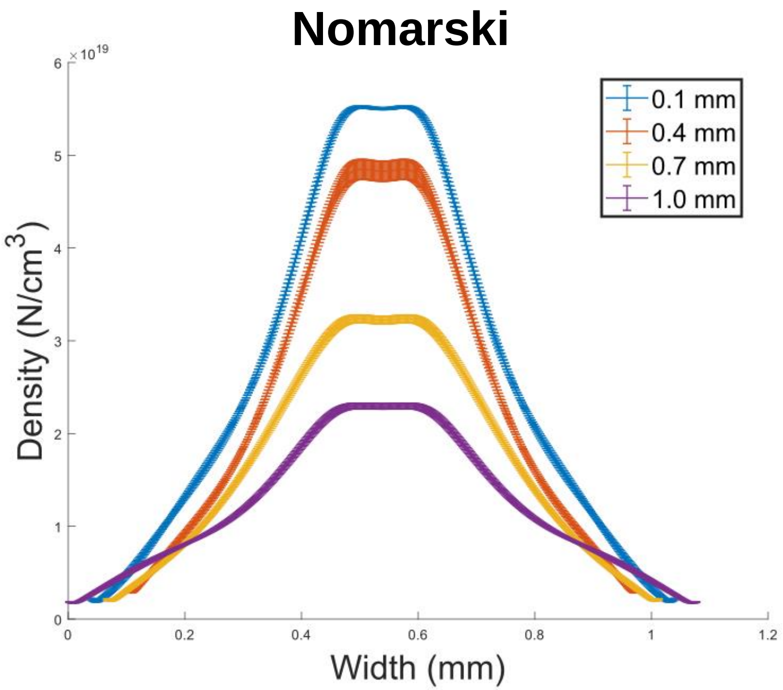
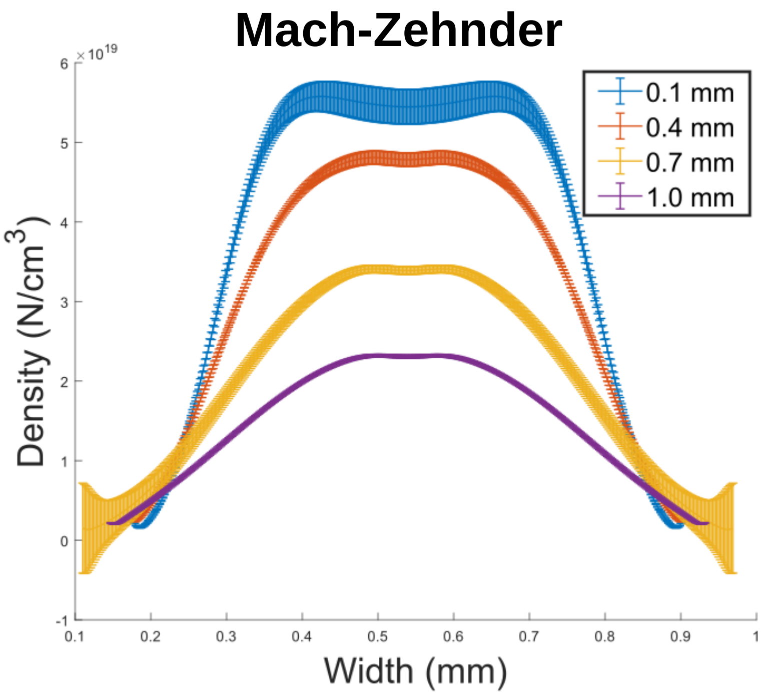
Interferometry Results (Recap)





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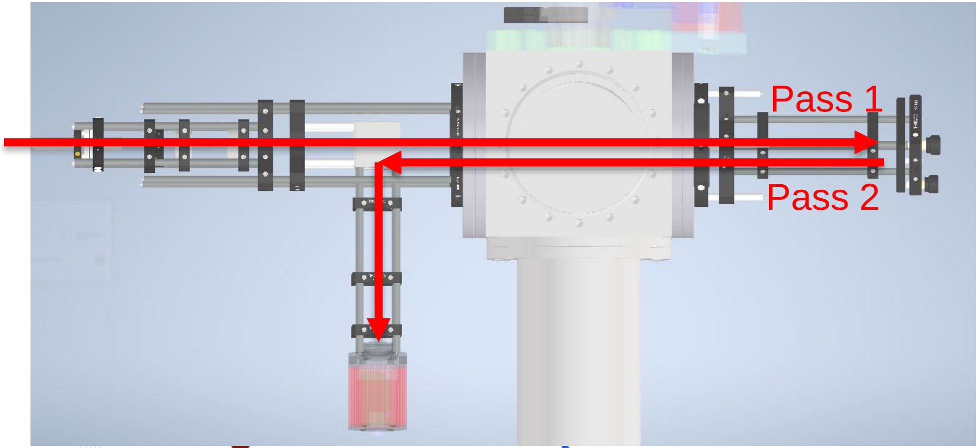
Analysed with IDEA [8]

Multi-Pass Interferometry

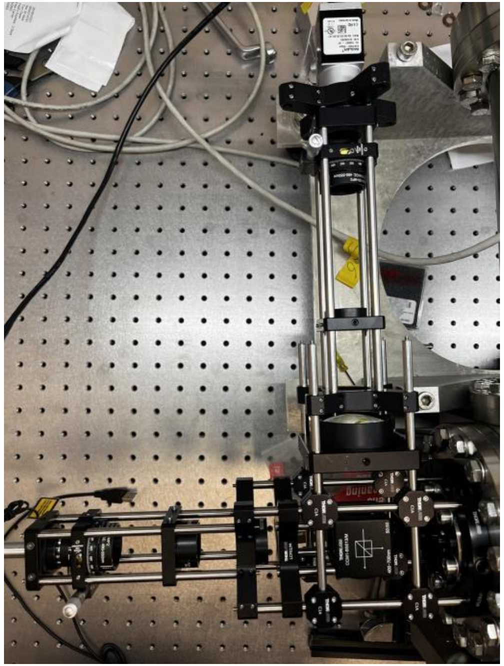
- Techniques are only able to measure high densities
- Increasing signal strength essential for lower density measurements – smaller nozzles and lower backing pressures
- Laser can be retroreflected through the jet region multiple times
- Double and even quadruple pass systems can be set up without changing the vacuum system

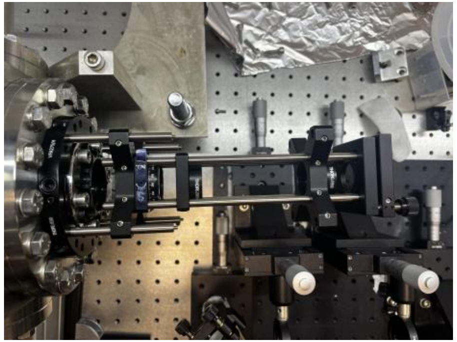
Double-Pass at the CI

- Double-pass system has been built at the CI
- Currently undergoing alignment
- Publication potential in Nuclear Instruments – comparison with direct interceptive techniques



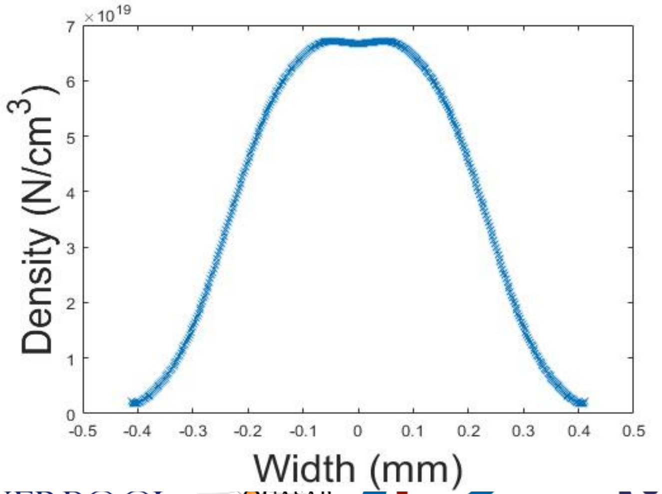
Pictures of the optics

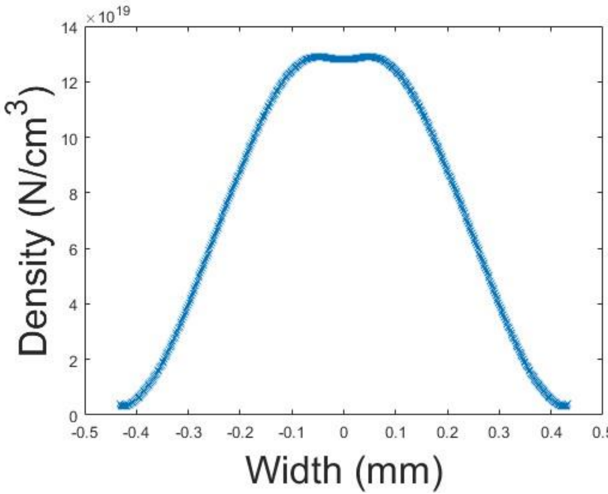




Double-Pass Results

- Have preliminary results from the double-pass set-up
- Below are a comparison of the single and double pass system
- Double pass artificially shows twice the density – signal strength is twice as large as expected

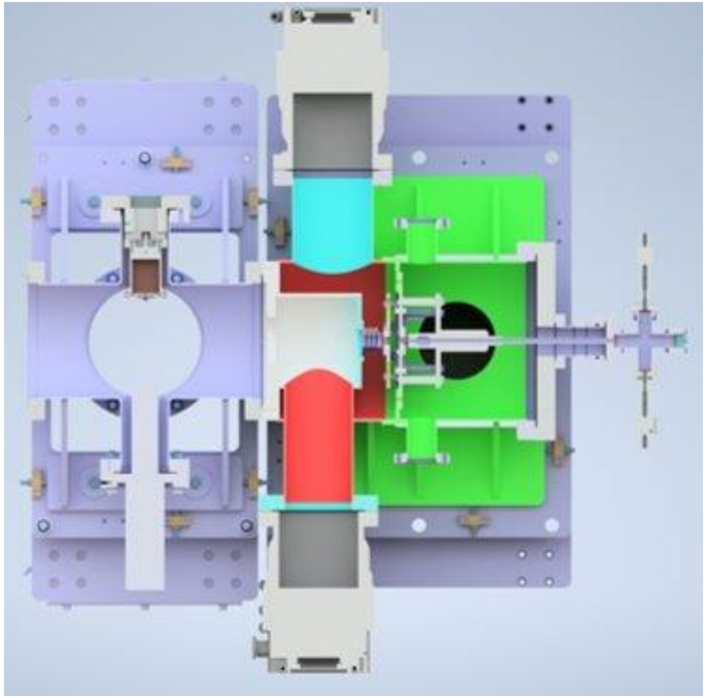


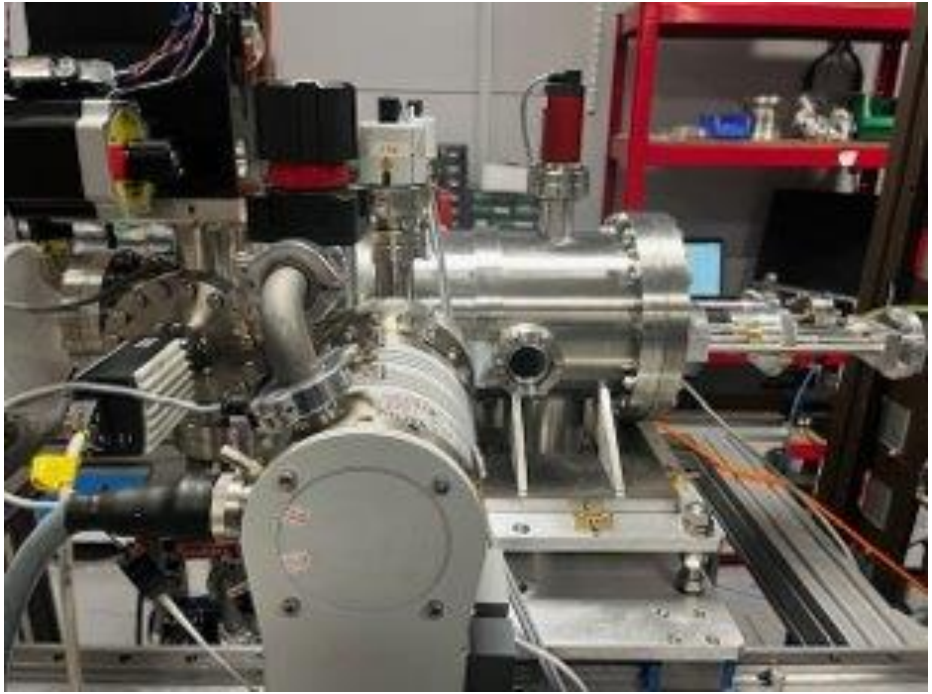


Interferometry – Next Steps

- Finish alignment for the 4x pass set-up
- Show increase in signal strength
- Move to lower densities on current 0.79mm nozzle – reduce backing pressure
- Move to smaller nozzle sizes – next target could be 100um nozzle.

New Test Stand (Jeremy)





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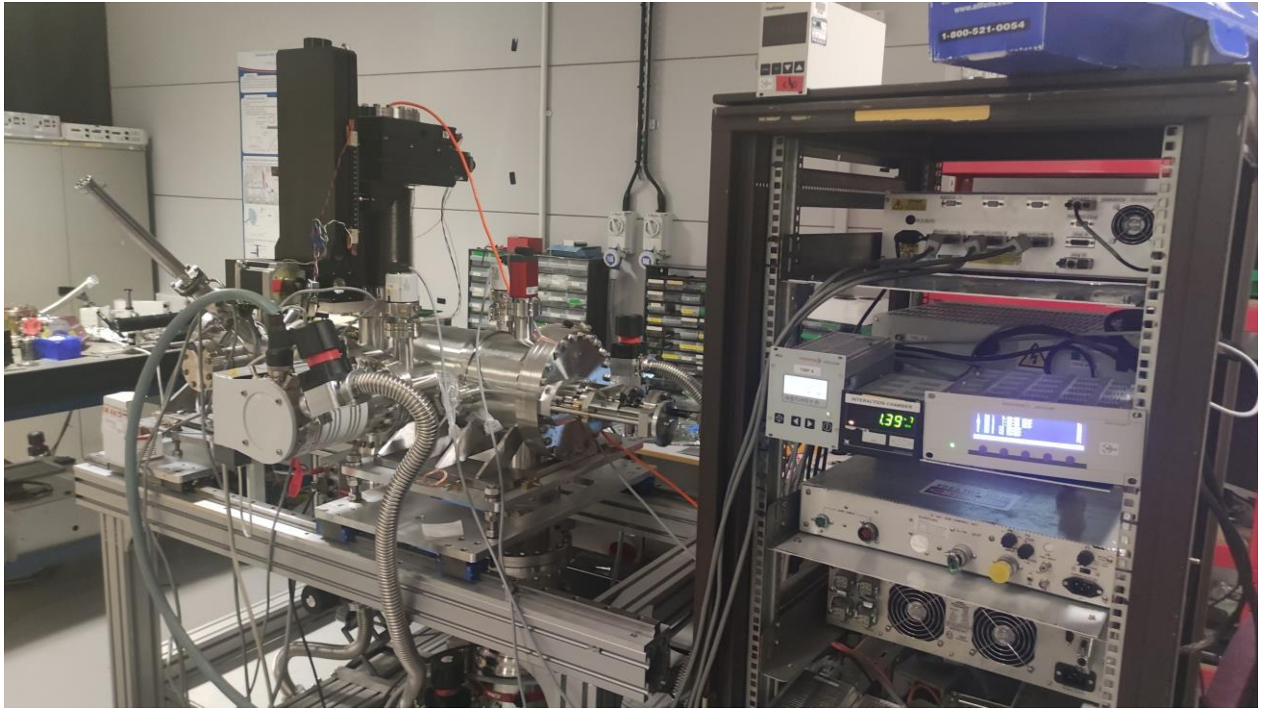
More pictures



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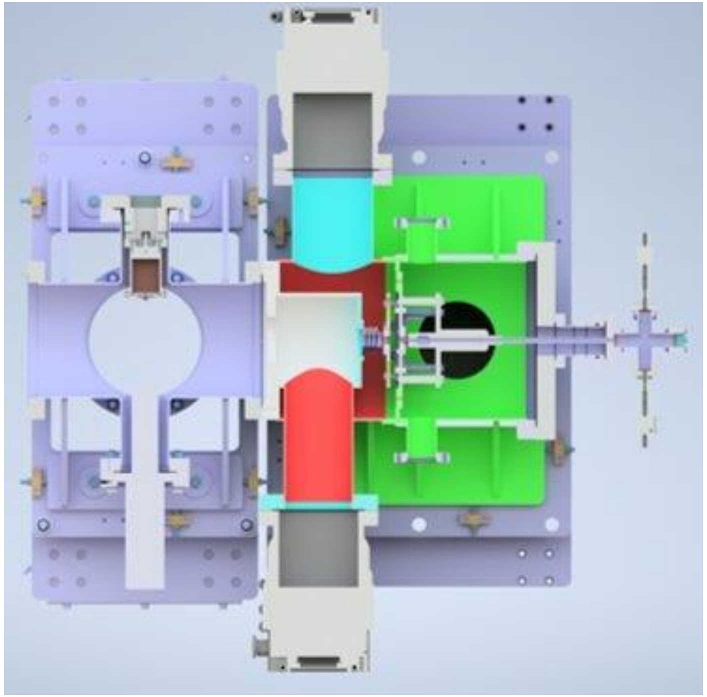
New Test Stand Features

- New test stand has been developed for gas jet research

New Features:

- Linear actuator for gas injection
- Interferometry port for gas jet characterisation
- Moveable bellows skimmer mount
- Smaller profile that previous test stand



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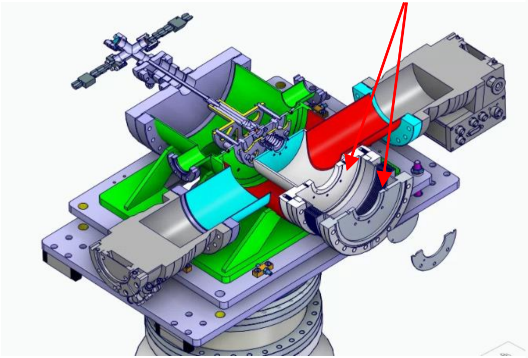
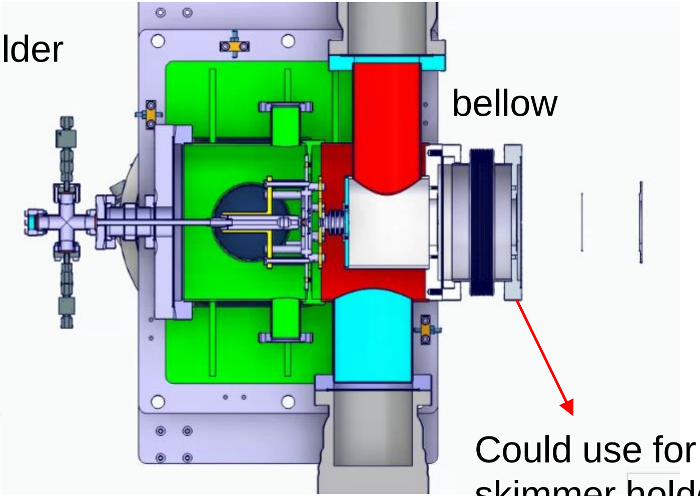
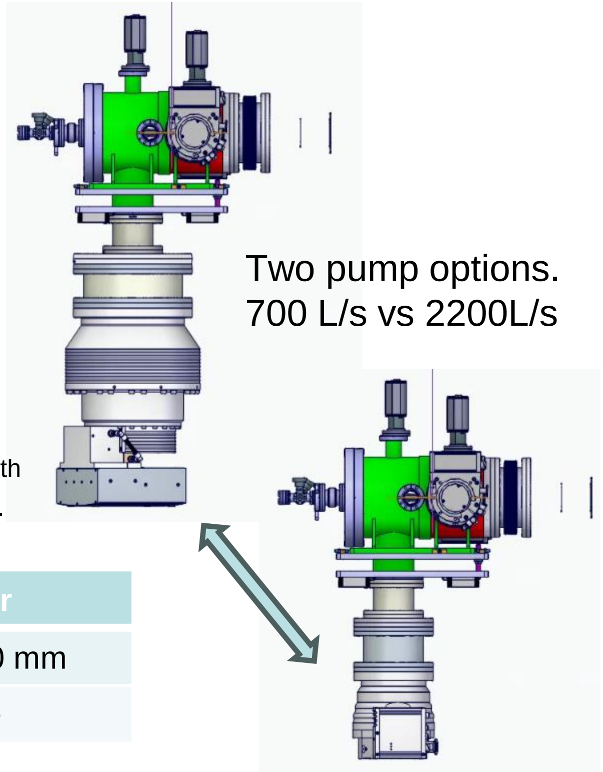
New gas jet test stand





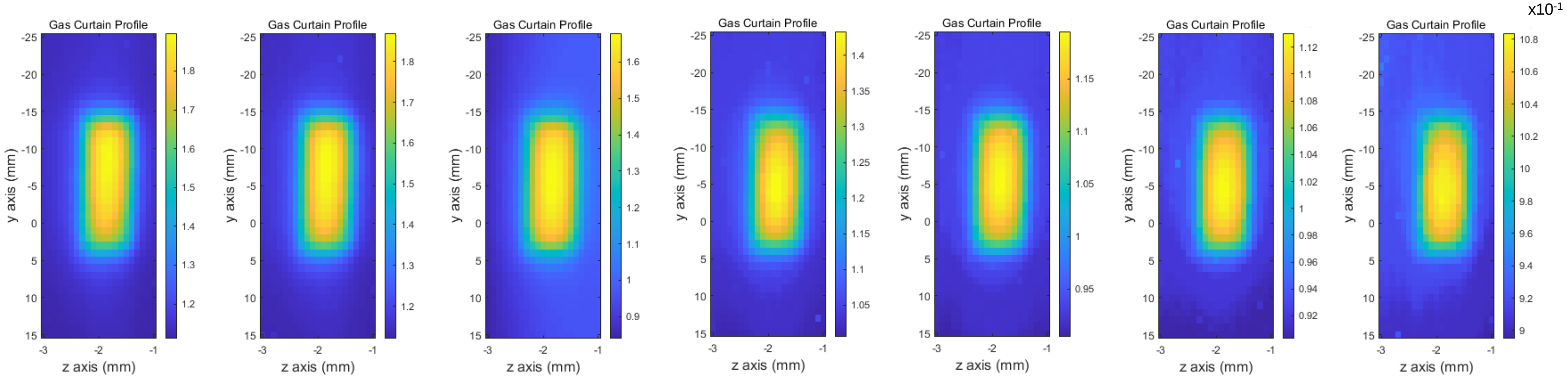


Current test geometry:

	nozzle	1st skimmer	2nd skimmer	3rd skimmer
Size	20 um	400 um	2 mm	0.1 mm * 40 mm
Location	0	2 mm +	30 mm +	180.7 mm +

Varying Nozzle – Skimmer 1 Distance

- X-Y Profile scans taken for different nozzle-skimmer 1 distances
- **No Background Subtraction**

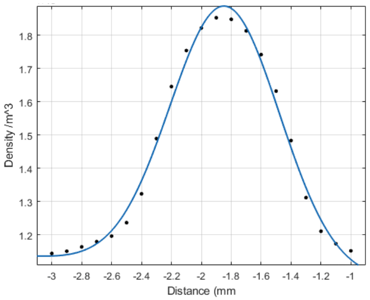


2.5mm 3.5mm 5.5mm 6.5mm 7.5mm 8.5mm 9.5mm

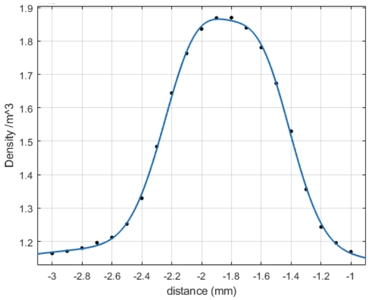
Nozzle-Skimmer I Distance (nitrogen with 5 bar inlet pressure)

Z-Axis Scan

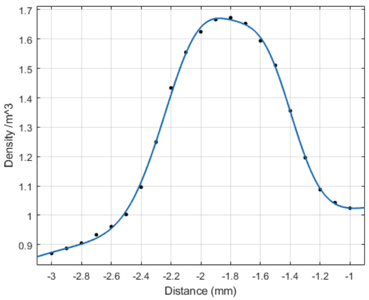
- Fitted using multi-term Gaussian (vertical: arbitrary unit)



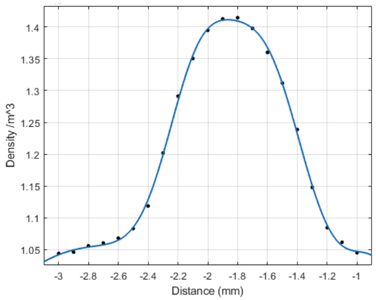
2.5mm



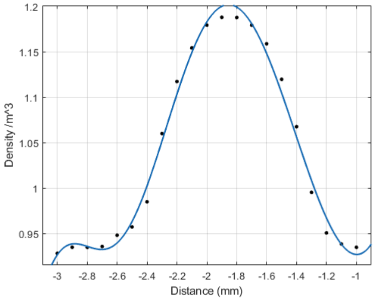
3.5mm



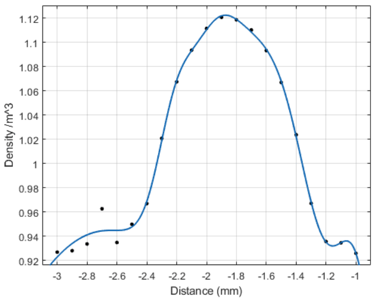
5.5mm



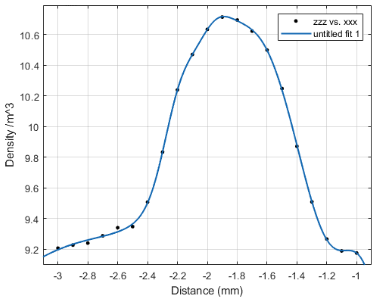
6.5mm



7.5mm



8.5mm



9.5mm

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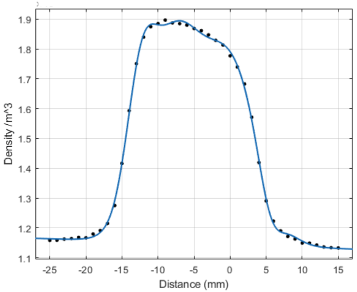
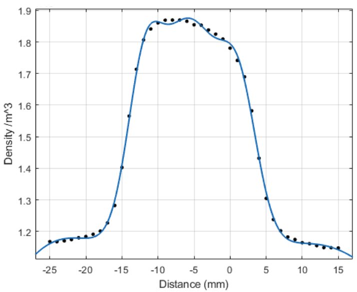
Y-Axis Scan

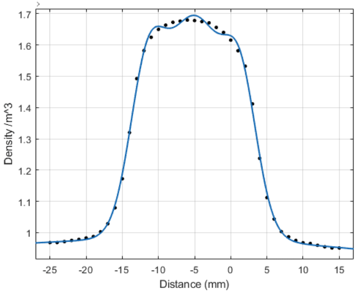
- Fitted using multi-term Gaussian (not really Gaussian)



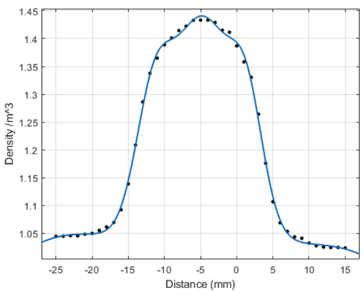
2.5mm



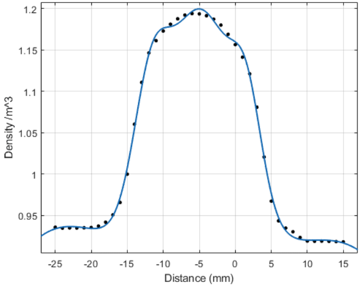
3.5mm



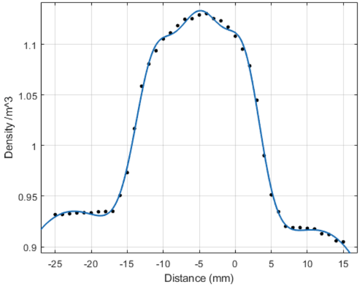
5.5mm



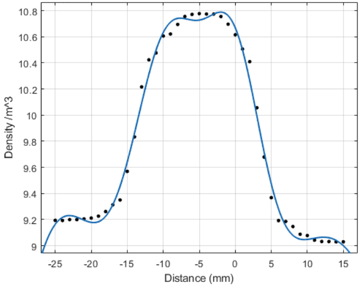
6.5mm



7.5mm



8.5mm



9.5mm

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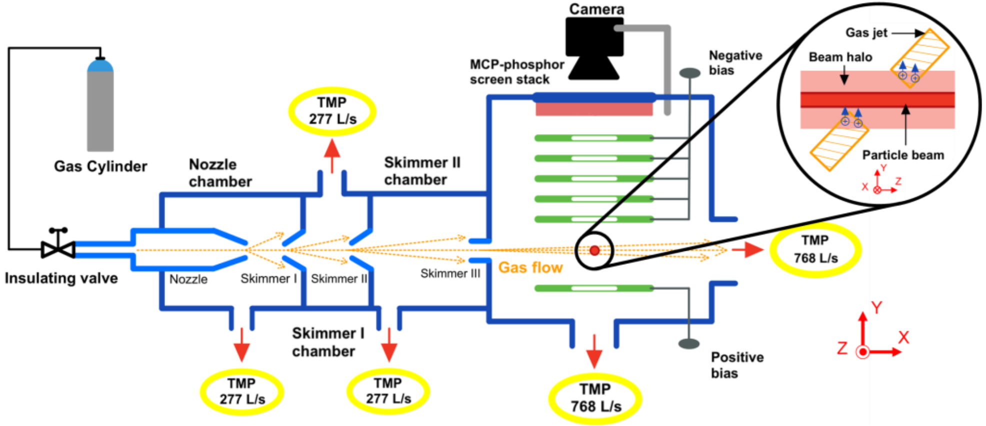
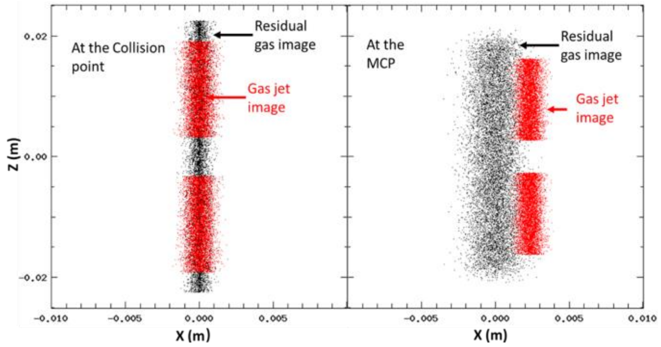
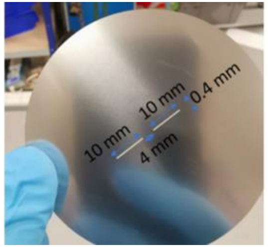
Summary

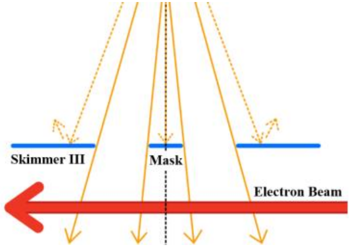
- Interferometry double pass system built and tested
- Moving towards a 4x pass system for increased sensitivity to lower density jets
- New gas jet test stand (JEREMY) is ready.
- Test measurements taken on new gas jet test stand at various nozzle – skimmer distances
- System can now be used for more in-depth studies

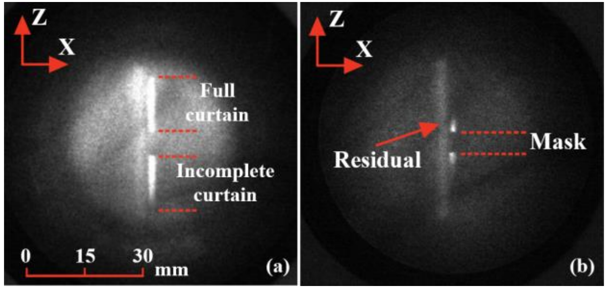
Other activities: Halo jet











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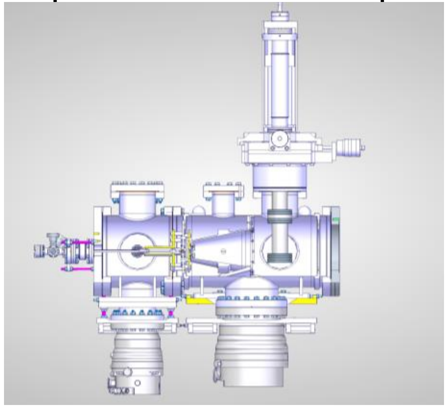
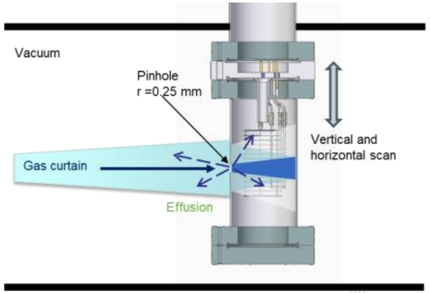
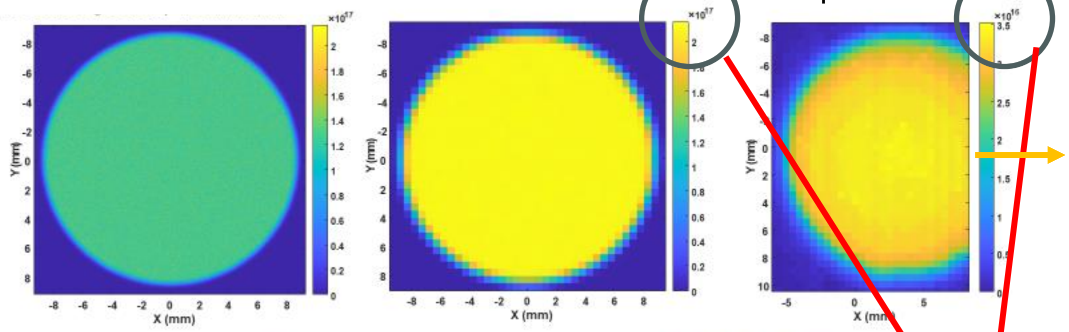
Simulation and experimental study of gas curtain formation

Experiment on v2 setup

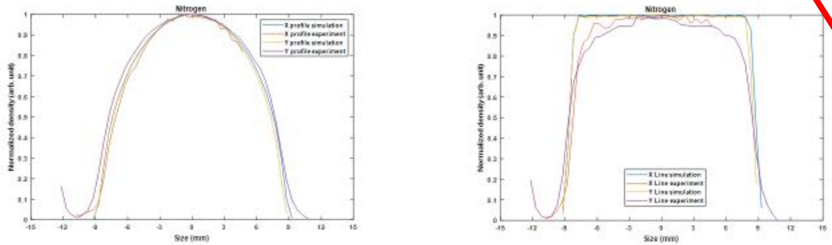




Simulation Convolution Experiment



Missing data due to misalignment of the nozzle-skimmer assembly to the chamber centre,



Size and shapes matched very well

Understand the discrepancy of the density between experiment (3.5e16) and simulation (2e17)

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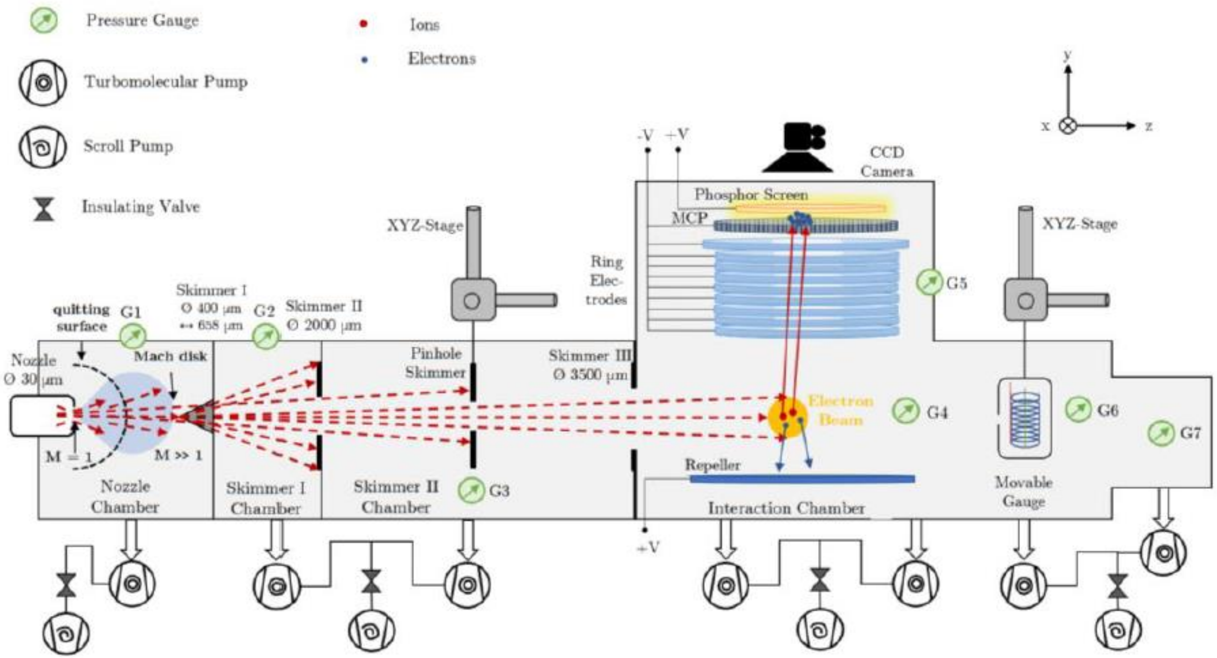
Quantum Jet Scanner – Pinhole system

- Schematic of gas jet used for pinhole measurements
- Electron beam can be scanned across the gas jet
- Movable gage can be used to characterise the density of the quantum jet



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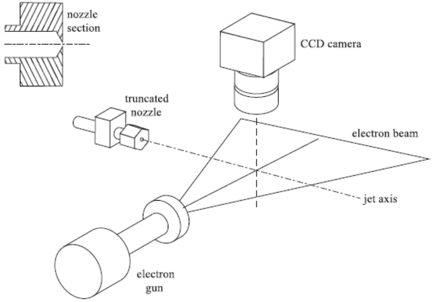
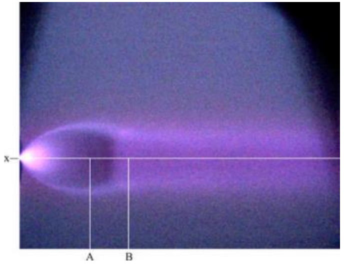
Future steps

- EBTS geometry test aiming at 60 mm jet on new gas jet test stand.

	nozzle	1st skimmer	2nd skimmer	3rd skimmer
Available Sizes	30 um	600,700, 800 um	4 mm ~ 8 mm (using m4-m8 washer)	0.1 mm * 20 mm 0.1 mm * 30 mm 0.1 mm * 40 mm
Location	0	2 ~ 10 mm	25~35 mm	180.7 mm
Simulation		700 um	4.49 mm	0.11*26.4 mm
		4 mm	27.49 mm	168.5 mm



- Study on new gas jet test stand.
  - Jet density: Pitot tube VS Multi-pass interferometer VS Electron beam fluorescence.
  - Pulse nozzle study (parker nozzle, 0.1mm or 0.79 mm) with nozzle shape.
  - Plasma targets.
- Other applications (QuantumJet, QHAM, HaloJet)
- BGC for EBTS procurement



Credit: Exp Fluids (2008) 45:501–511

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Any Questions?

Extra Slides

Theory of Interferometric Imaging

Density of a gas related to refractive index by Lorentz-Lorenz equation:

$$\frac{(\eta^2 - 1)}{(\eta^2 + 2)} = \frac{4\pi}{3}\alpha N$$

n is refractive index, N is number of molecules per unit volume, α_m is mean polarisability of gas. As beam passes through jet, phase accumulates in the direction of propagation of laser, given by the Abel transform [7]

$$\Delta\Phi(y) = \frac{4\pi}{\lambda}\int_y^{r_0} \frac{(n(r) - 1)r}{\sqrt{r^2 - y^2}} dr$$

where r_0 is radius far outside influence of jet and y is coordinate perpendicular to direction of beam. Assuming axisymmetric geometry of jet, density can be calculated using Abel inversion:

$$\frac{2\pi}{\lambda}(n(r) - 1) = \frac{1}{\pi}\int_r^{r_0} \frac{d}{dy}\frac{\Delta\Phi(y)}{\sqrt{y^2 - r^2}} dy$$

This forms the basis of how the density of the gas jets can be calculated using the measured phase shift from the interferograms.

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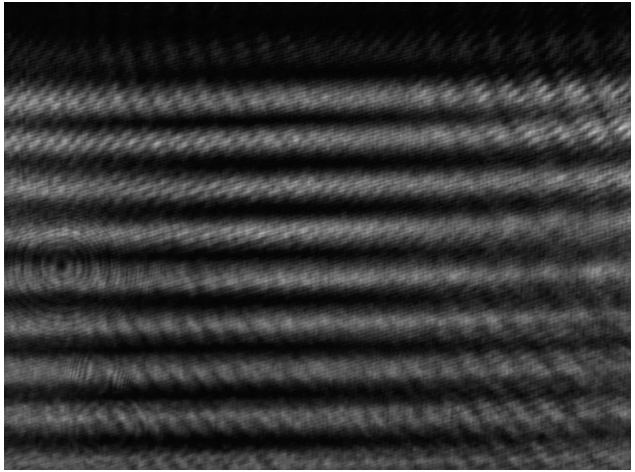
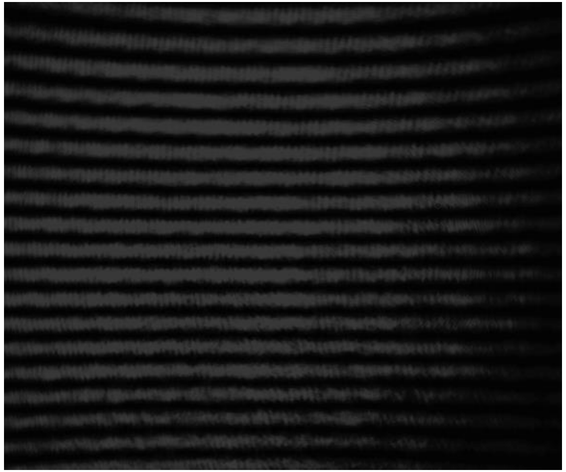
Nomarski Stability

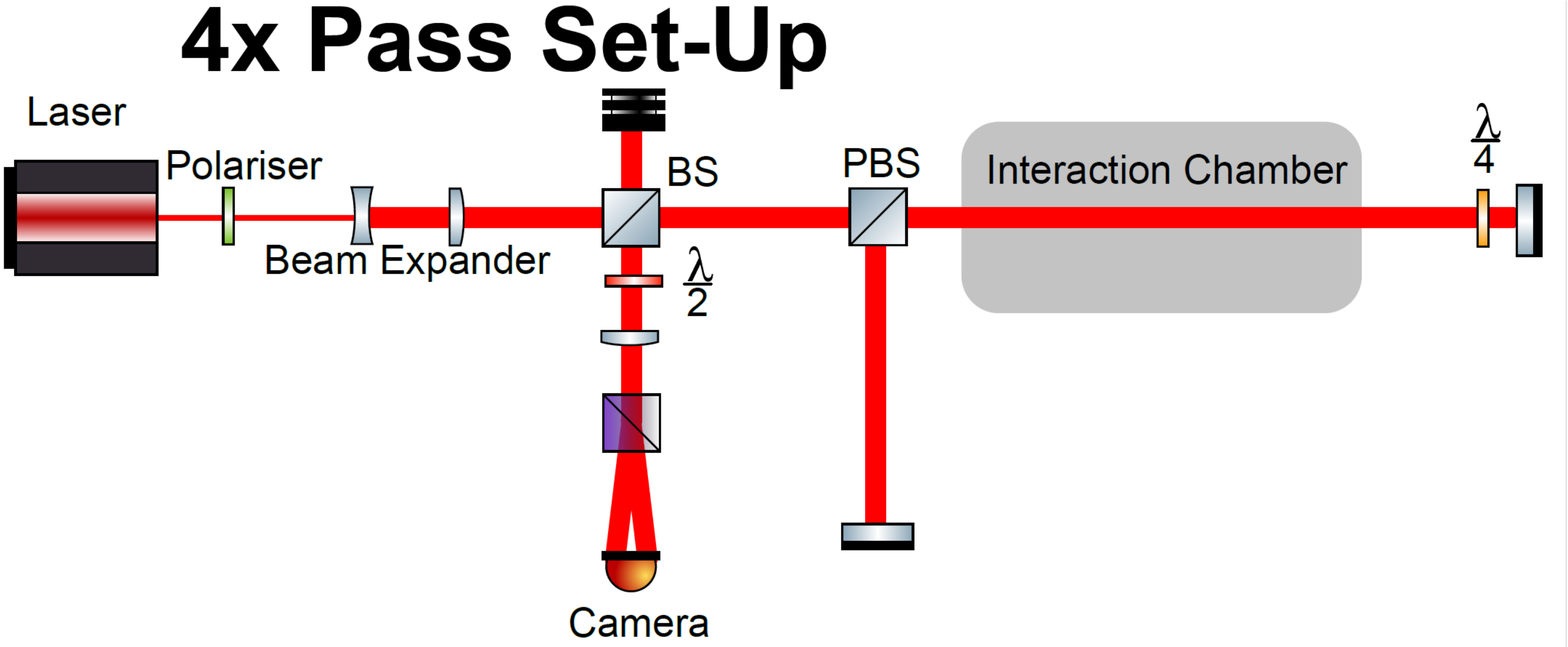
Previous on-table set-up

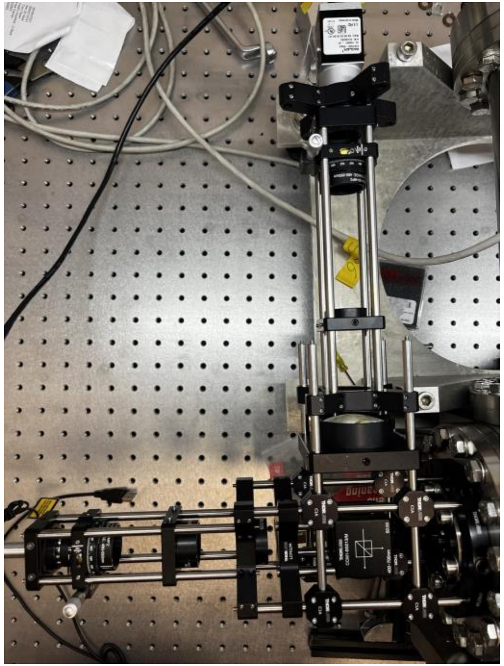


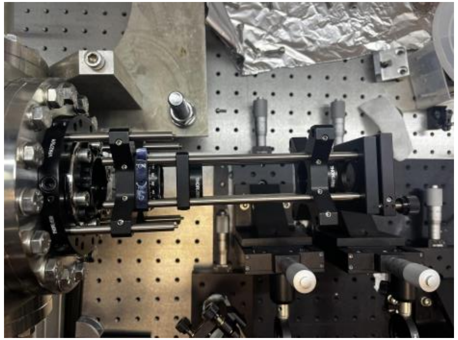
Current on-chamber set-up



4x Pass


4x Pass Set-Up
Laser
Polariser
Beam Expander
BS
λ/2
PBS
Interaction Chamber
λ/4
Camera





References

[1] P. A. P. Nghiem*, N. Chauvin, W. Simeoni Jr. , D. Uriot, “BEAM HALO DEFINITIONS AND ITS CONSEQUENCES” in Proc. HB'12, Beijing, China, Sep. 2012, paper THO3A04, pp. 511-513

[2] T. P. Wangler and K. R. Crandall. Beam halo in proton linac beams. eConf, C000821:TU202, 2000

[3] Oscar Frasciello. Wake Fields and Impedance Calculations of LHC Collimators’ Real Structures. 07 2016.

[4] A. Friedman, et al. "Computational Methods in the Warp Code Framework for Kinetic Simulations of Particle Beams and Plasmas,” IEEE Trans. Plasma Sci. vol. 42, no. 5, p. 1321, May 2014.

[5] O. Stringer, N. Kumar, C. P. Welsch, and H. D. Zhang, “A Gas Jet Beam Halo Monitor for LINACs”, in Proc. 31st Linear Accelerator Conf. (LINAC'22), Liverpool, UK, Aug.-Sep. 2022, pp. 227-230.

[6] Narender Kumar *et. Al* “DEVELOPMENT AND TESTING OF QUANTUM GAS JET BEAM PRO-FILE SCANNER” presented at the 14th International Particle Accelerator Conf. (IPAC’23), Venice, Italy, May 2023 paper THPL067, this conference.

[7] John David Jackson. Classical electrodynamics. Wiley, New York, NY, 3rd ed. edition, 1999.

[8] Y. Ping, I. Geltner, A. Morozov, and S. Suckewer. Interferometric measurements of plasma density in microcapillaries and laser sparks. Physics of Plasmas, 9(11):4756–4766, 10 2002.