

Targetry for Laser Wakefield Acceleration

Laser Applications at Accelerators Conference
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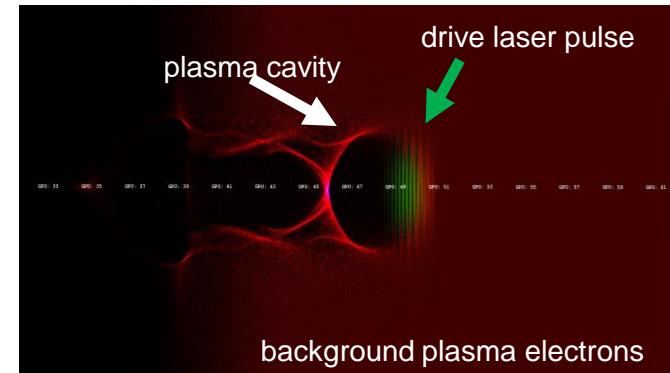


LA³NET has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement no 289191



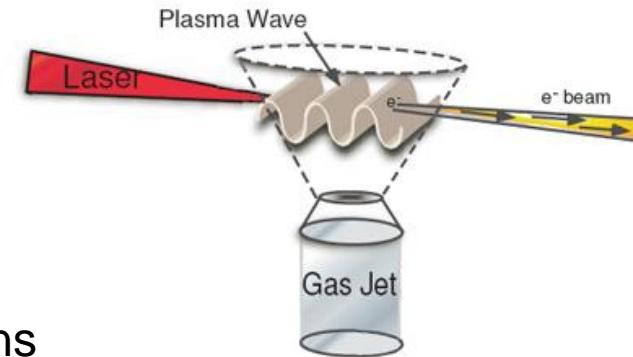
Laser wakefield acceleration (LWFA)

- Electron acceleration in the wake of a high-intensity laser pulse in plasma
- fs-scale electron bunches source



Targets for LWFA

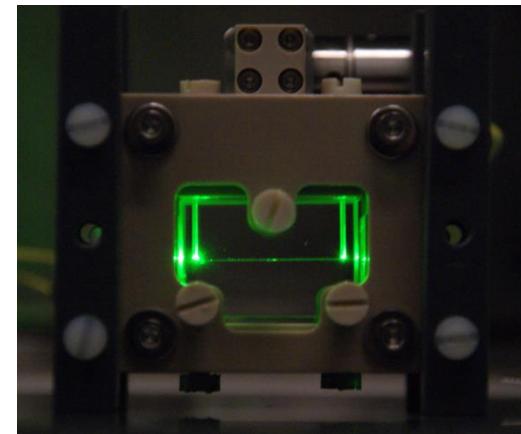
- System to deliver medium for LWFA
 - Inside a vacuum
 - Target development
 - Characterisation and tunability
- Theory & Particle in Cell (PIC) simulations
→ Stable and reproducible electron beams



Gas jet targets



Capillary targets



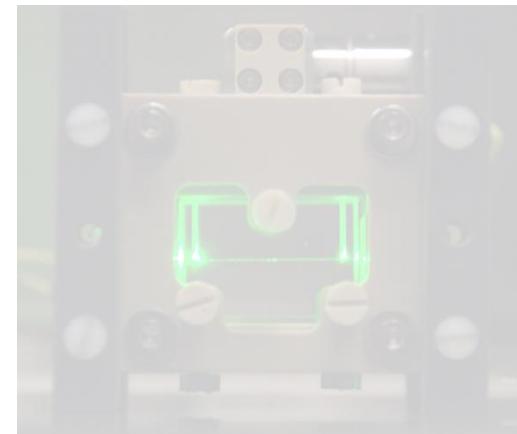
- Short interaction length
- High density
- Self-focusing
- “Easy”

- Long interaction length
- Low density
- Guiding structure by electric discharge
- Complex

Gas jet targets

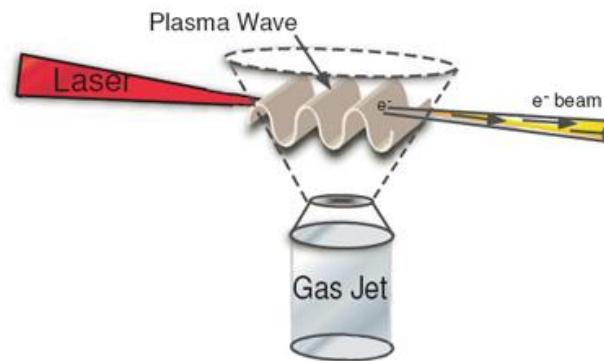


Capillary targets

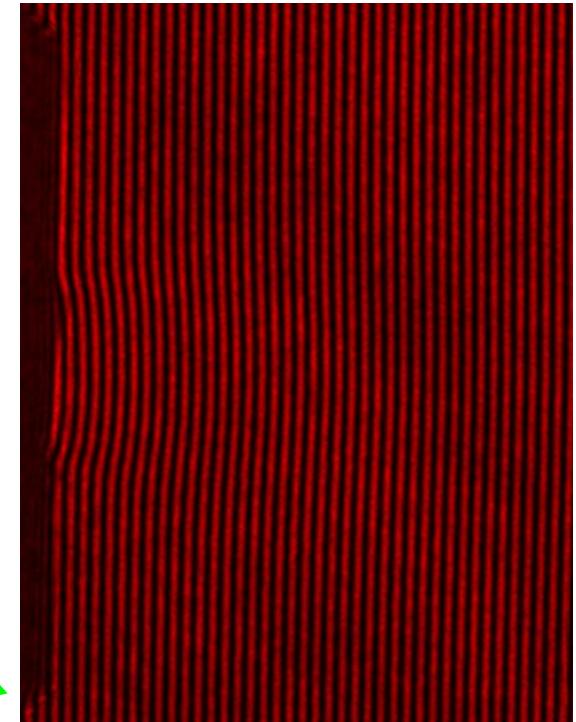
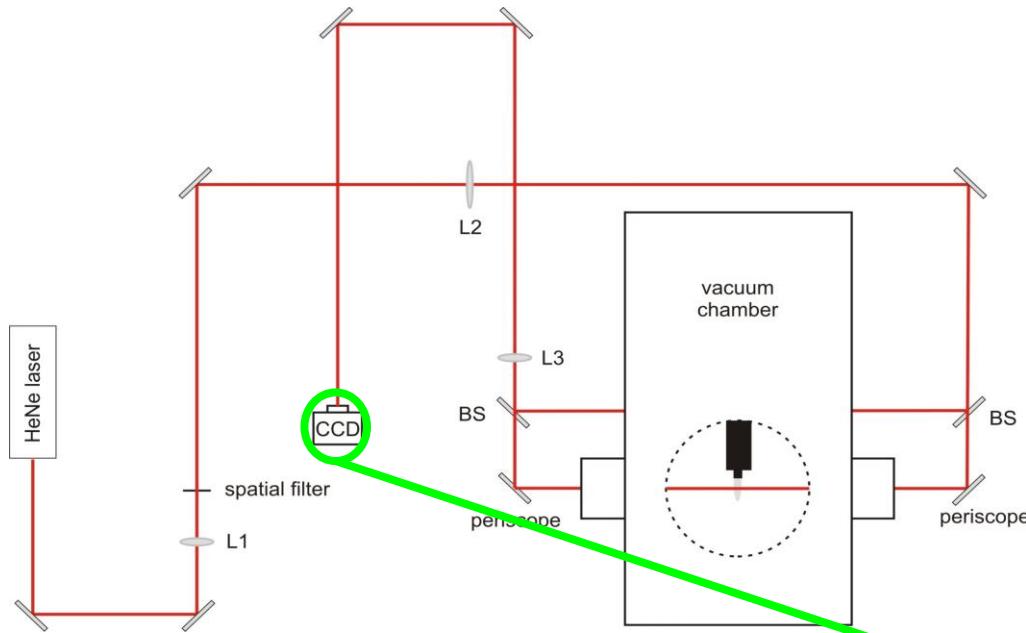


- Short interaction length
- High density
- Self-focusing
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- Long interaction length
- Low density
- ... structure by electric



Gas jet target interferometry



The gas jet induces an optical path length difference

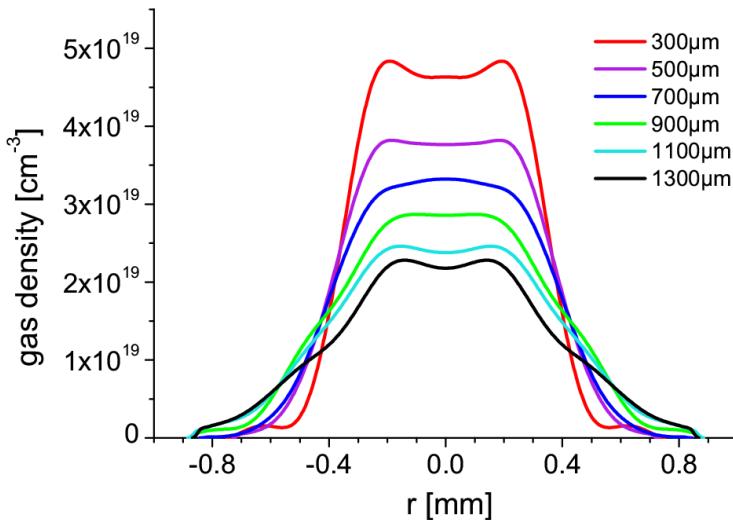
$$\Delta OPL = \int_s \Delta n(s) ds$$

which information is contained in the intensity image on the camera

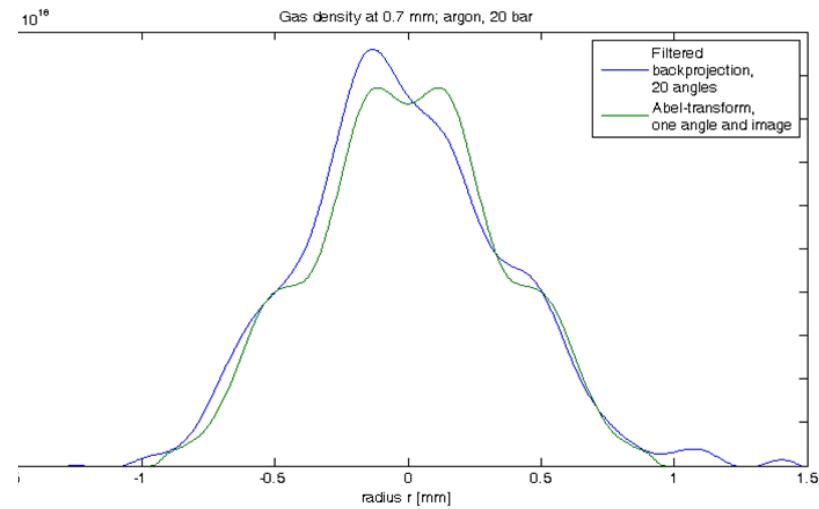
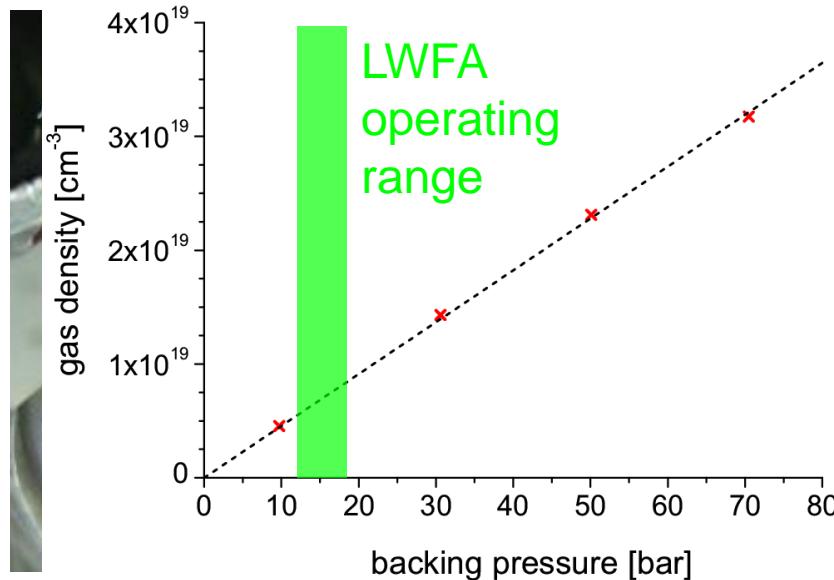
$$I = 2I_0 [1 + \cos(\varphi)] \quad \text{with,} \quad \varphi = kx \sin(\alpha) + \frac{2\pi \Delta OPL}{\lambda}$$

- Able to analyze 0.75 mm gas-jets at helium densities down to $\sim 4 \times 10^{18} \text{ cm}^{-3}$

Gas jet target interferometry

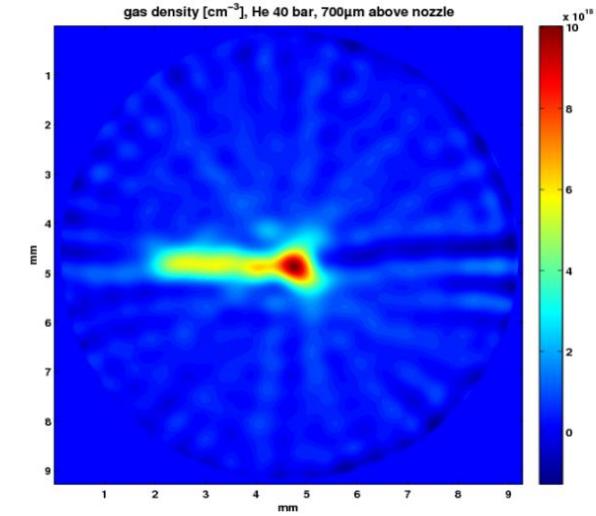
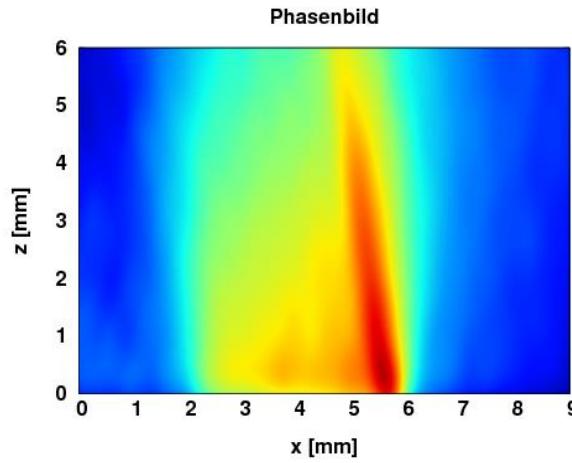
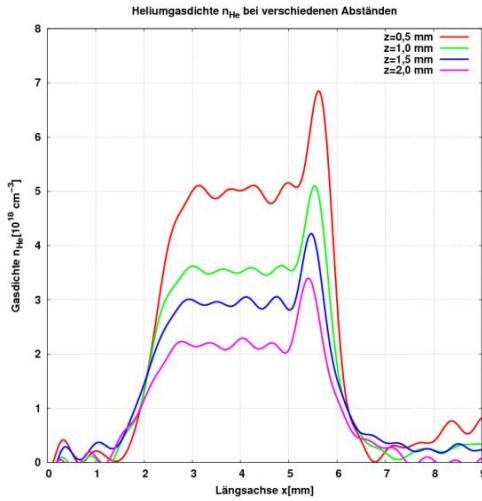
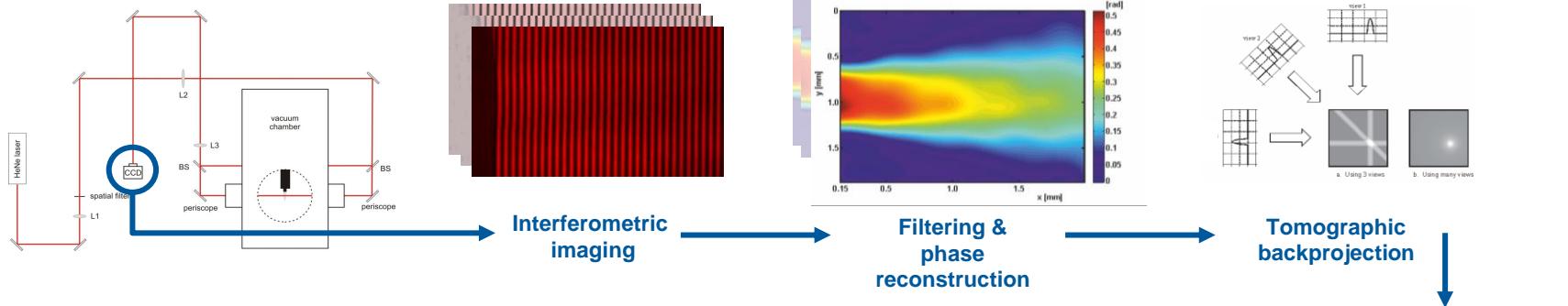
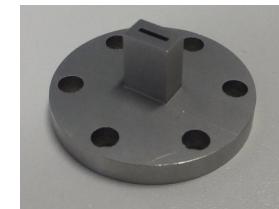


- Gas (electron) density distribution knowledge vital for prediction and control of laser electron accelerator

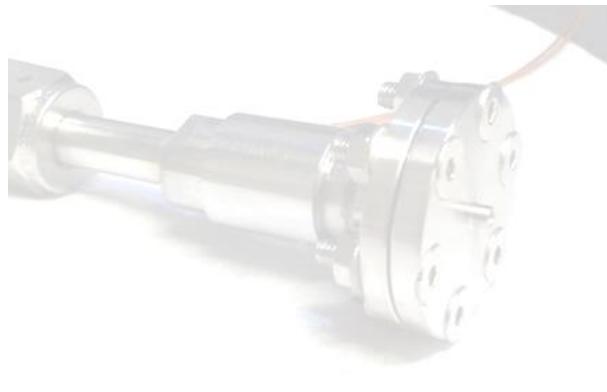


Gas jet target interferometry

- Tomography allows analysis of non-axisymmetrical features and slit nozzles.

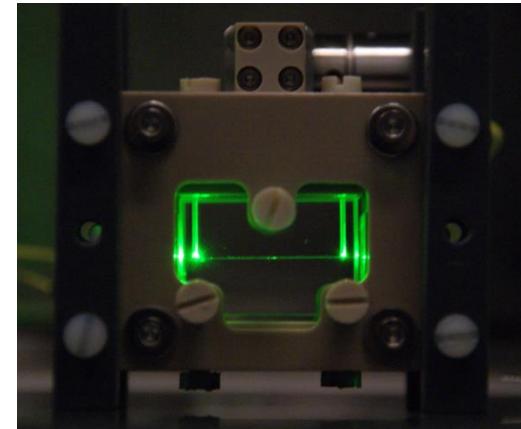


Gas jet targets



- Short interaction length
- High density
- Self-focusing
- “Easy”

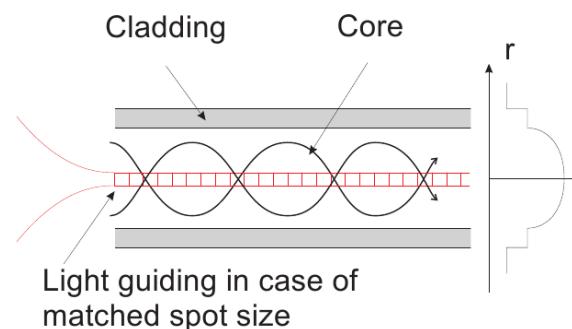
Capillary targets



- Long interaction length
- Low density
- Guiding by external discharge
- Complex

Capillary target

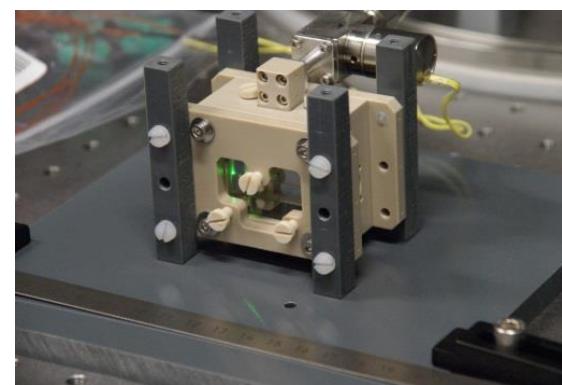
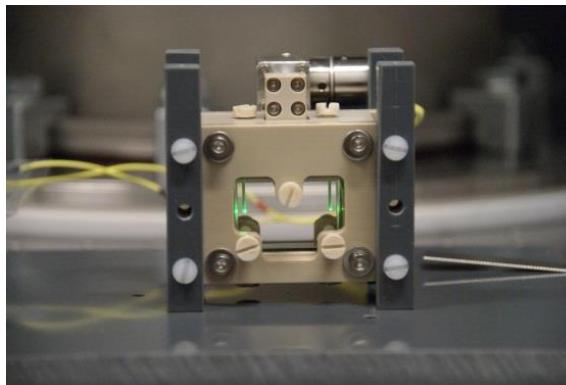
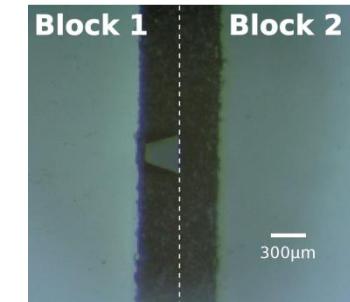
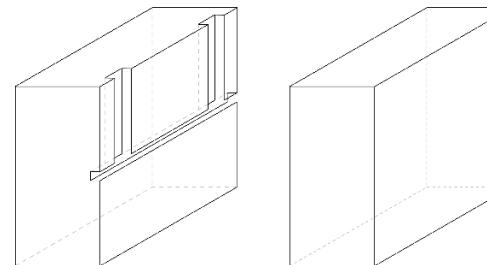
- Long interaction length
- Low density
- Guiding by external discharge induced density gradient
 - Heating by discharge
 - Cooling on capillary walls



$$w_m = \sqrt[4]{\frac{r_{\text{Chan}}^2}{\pi \Delta n_e r_e}}$$

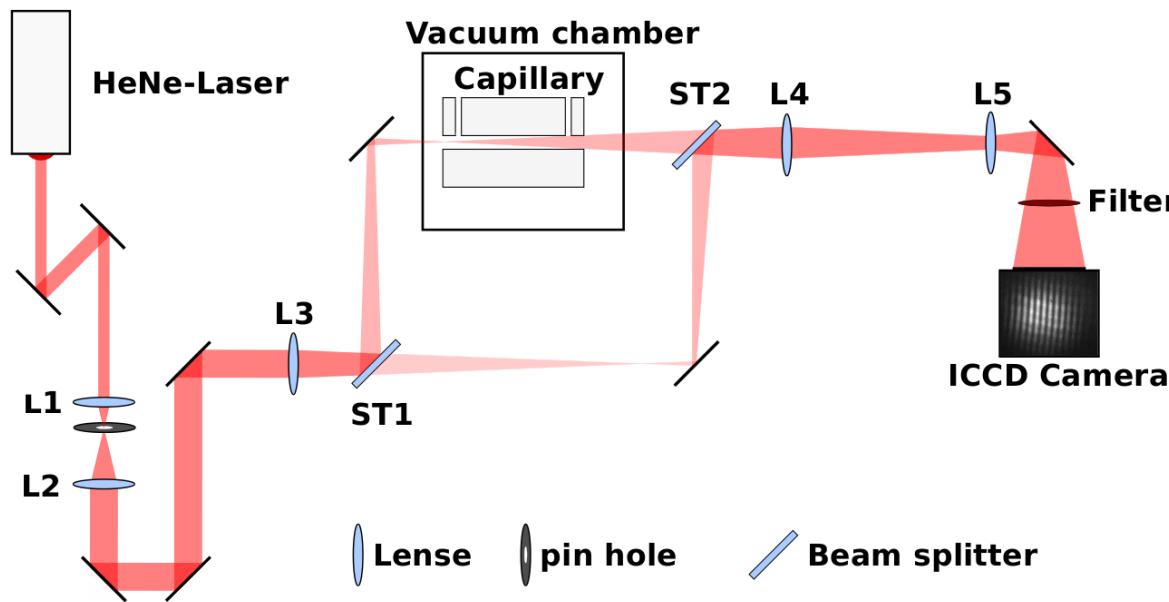
Sapphire target

- High mechanical strength
- High thermal conductivity
- 300 µm cross-section
- Fabricated by laser ablation
- 20 kV thyratron discharge (250 ns)



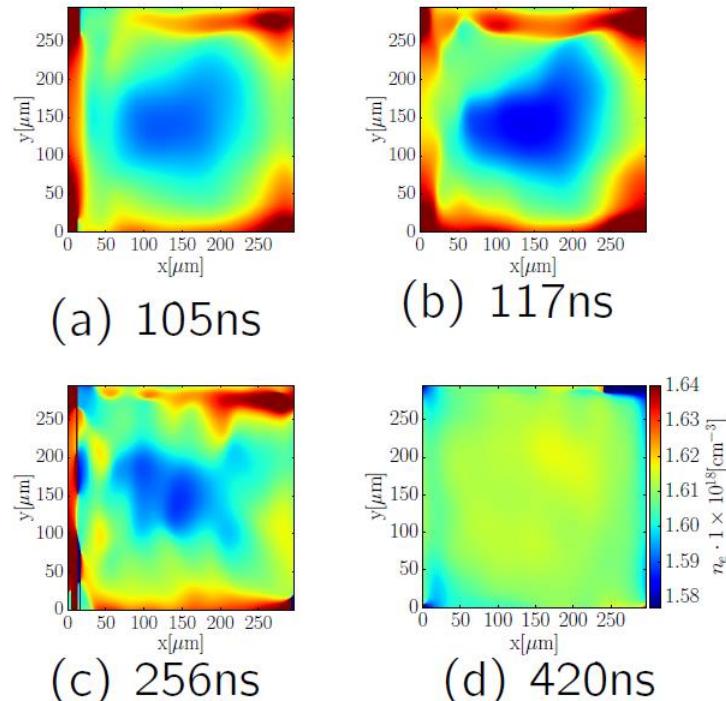
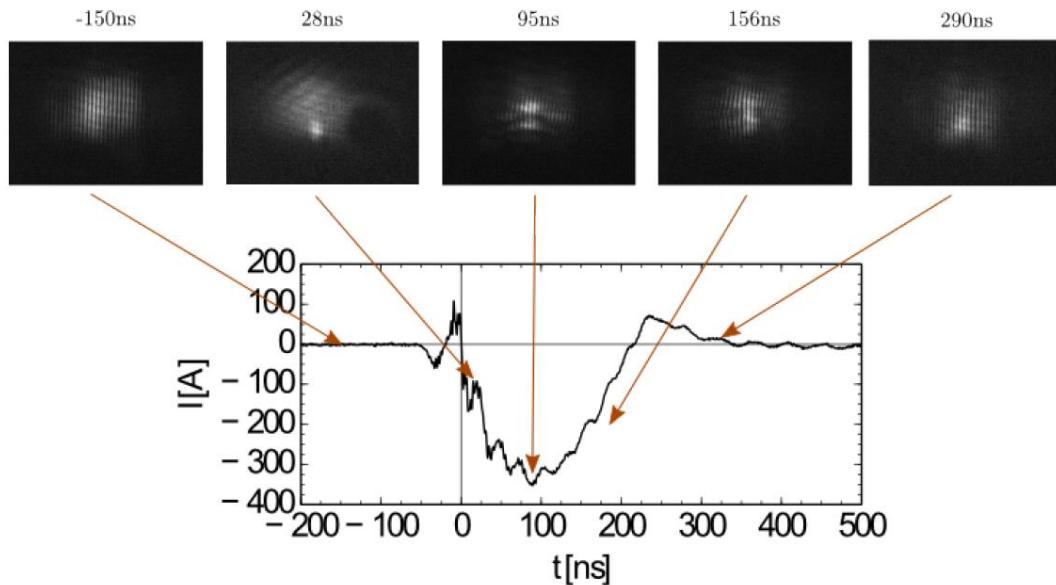
Capillary target

- Guiding is:
 - Pressure-dependent
 - Time-dependent



Channel formation

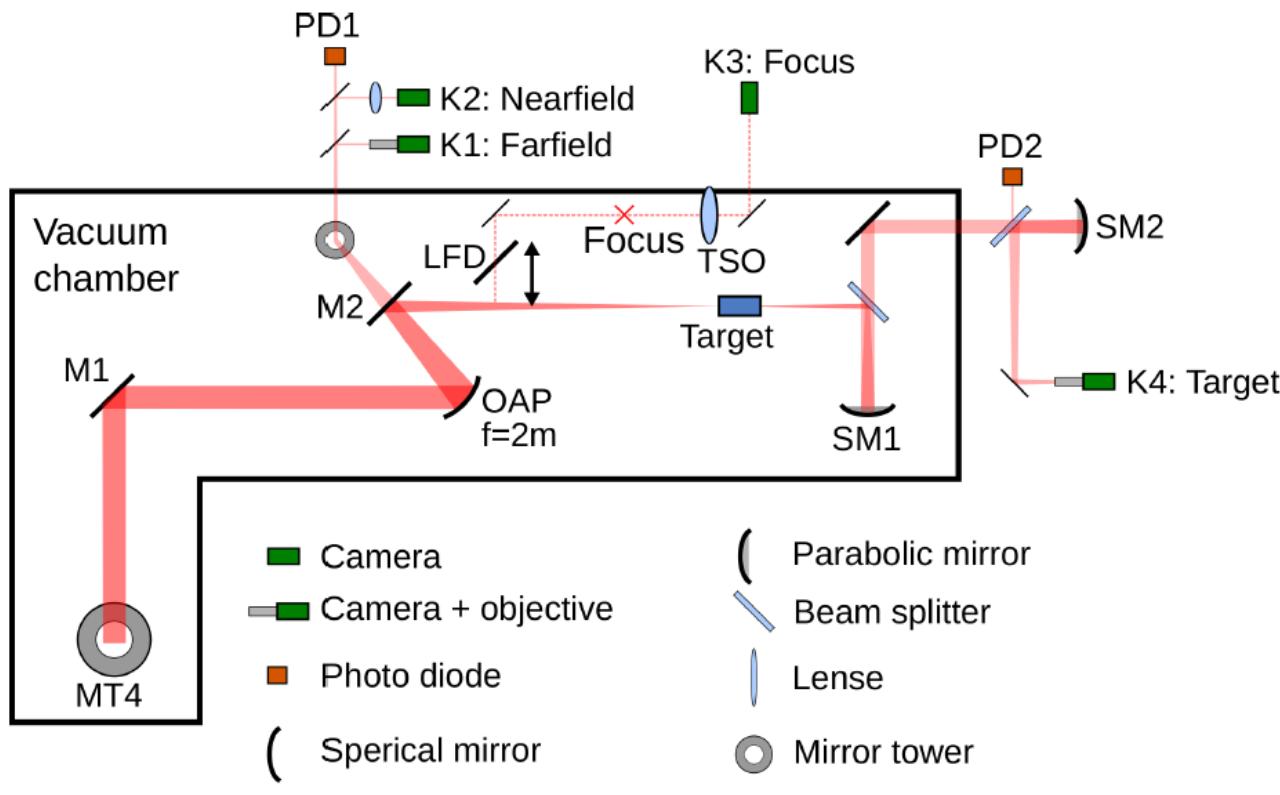
- 20 kV, 250 ns discharge
- Image capture by 5 ns ICCD
- Refractive index $\propto n_e^{-1}$



- Channel formation visible
- Stable channel around discharge current peak

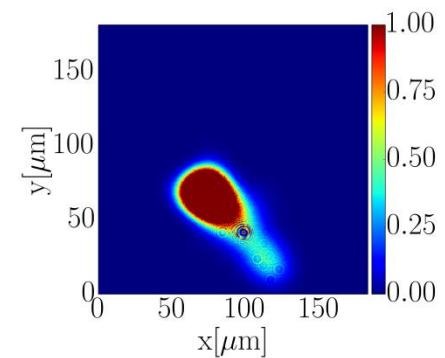
Guiding optimisation

- Pressure dependence
- Timing dependence

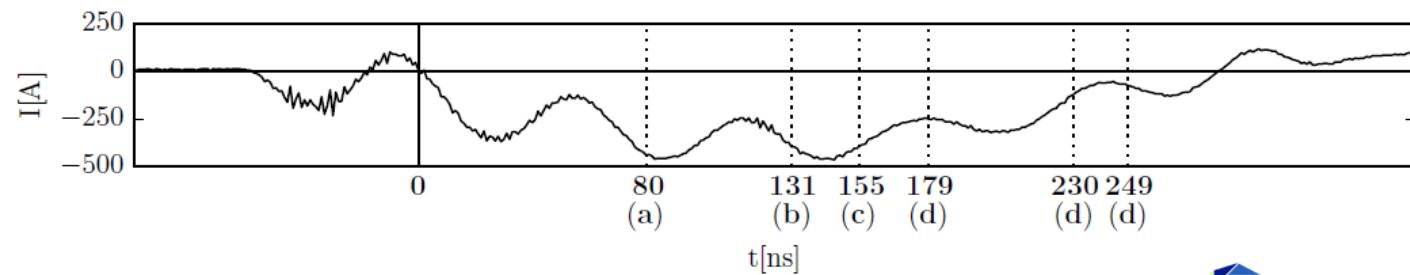
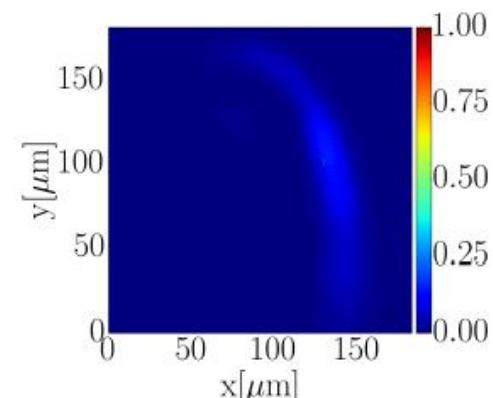
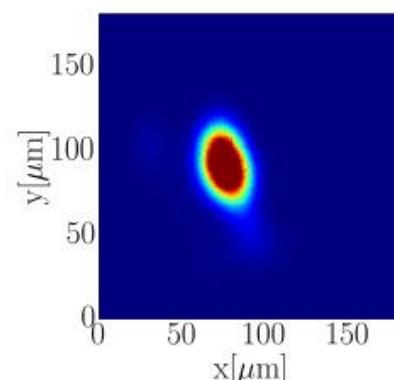
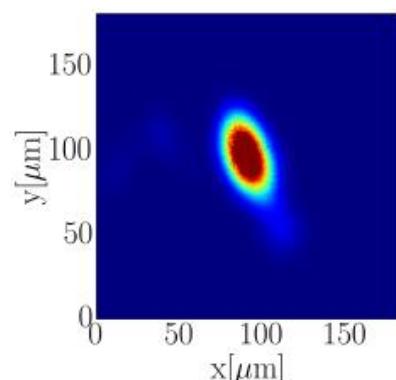
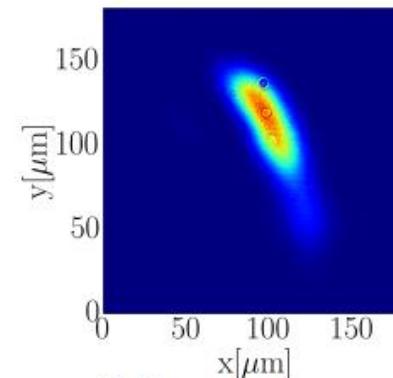
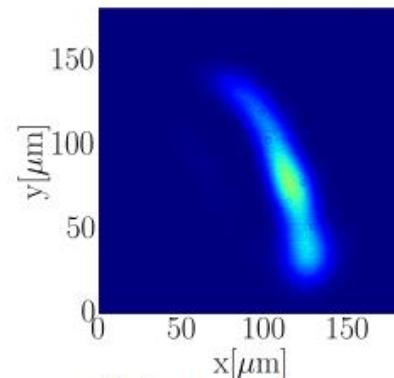
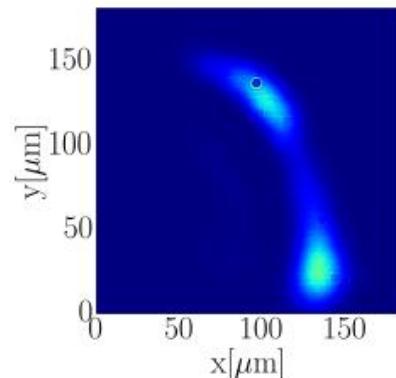


DRACO

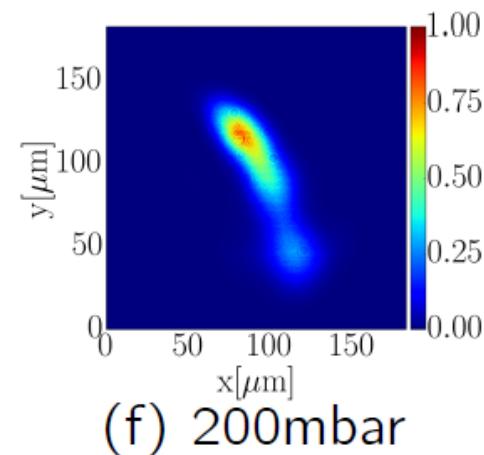
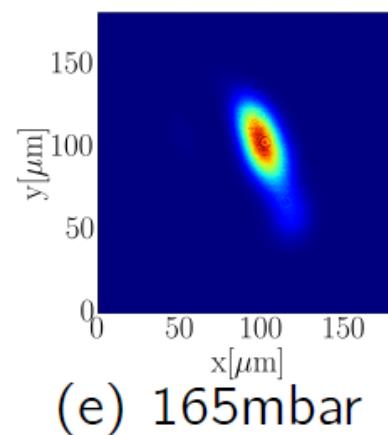
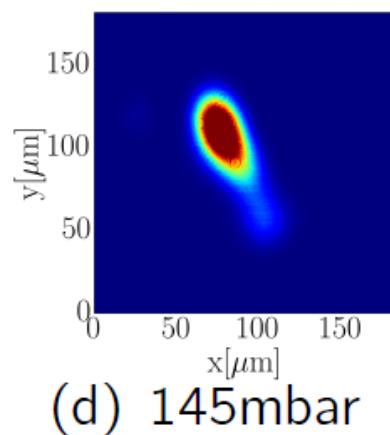
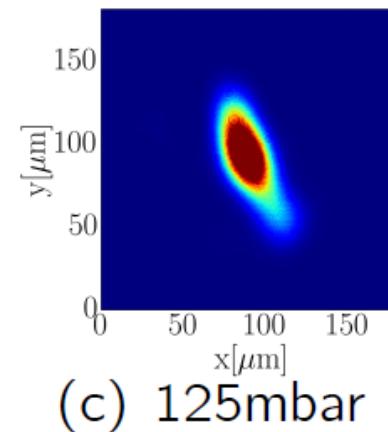
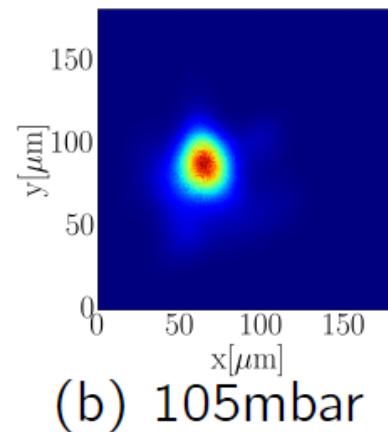
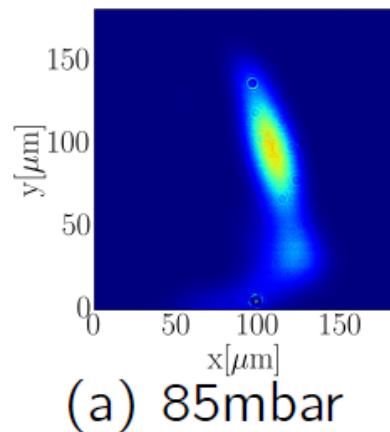
- 800 nm
- Pulse length: 40 fs
- Energy: 20 mJ
- Waist: 35 μm
- Rayleigh length: 4.8 mm



Timing dependence



Pressure dependence

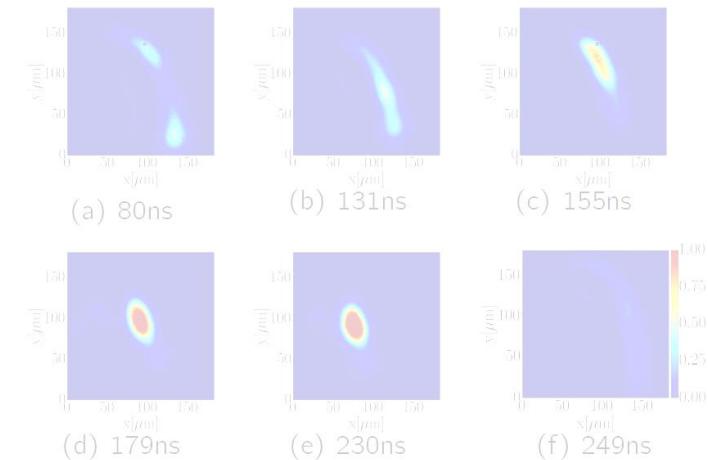
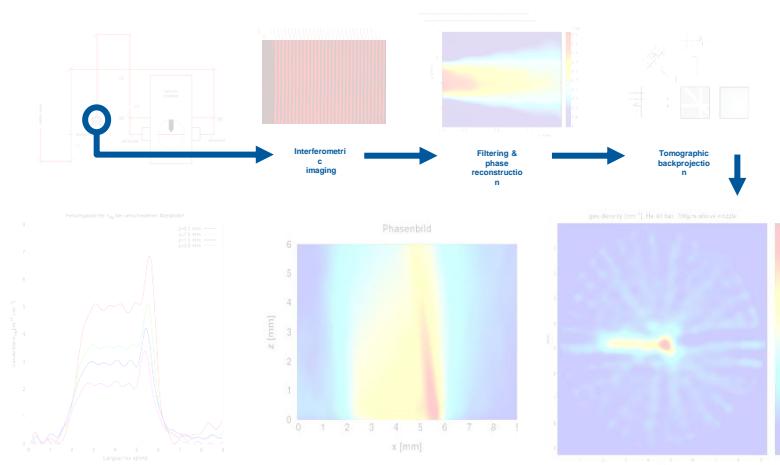
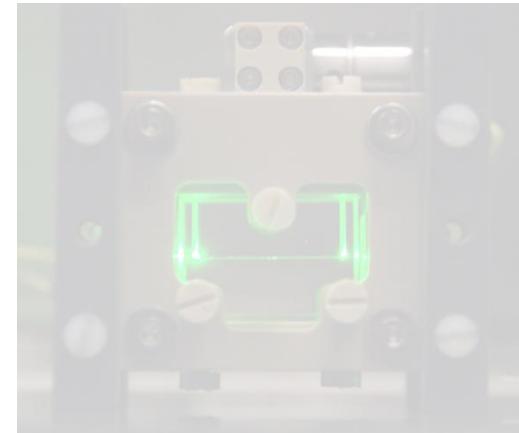


- Best guiding window between 120 to 150 mbar

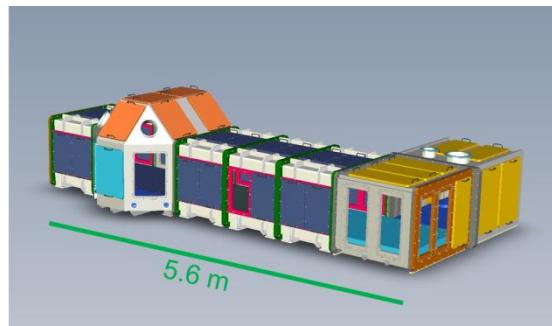
Gas jet targets



Capillary targets

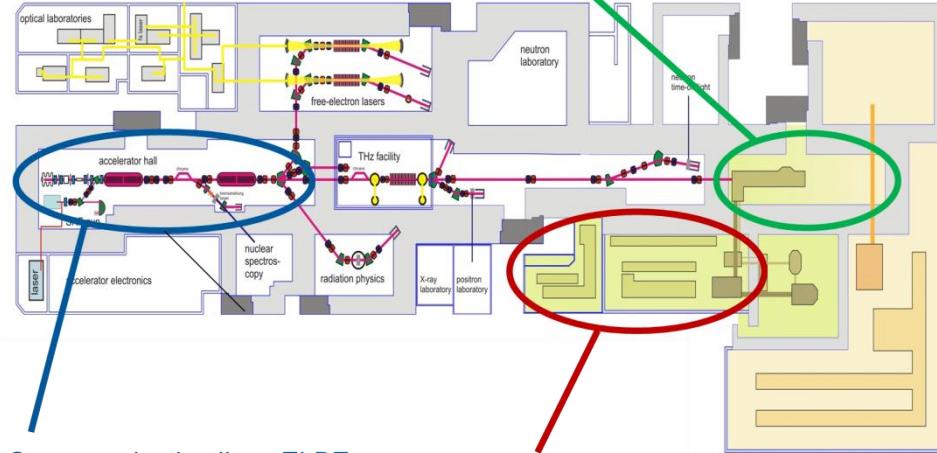


Electron (& X-ray) facility at HZDR



Access to:

- Short-pulse high energy DRACO laser system
- ELBE conventional electron accelerator enabling both:
 - **Laser wakefield acceleration (LWFA) experiments**

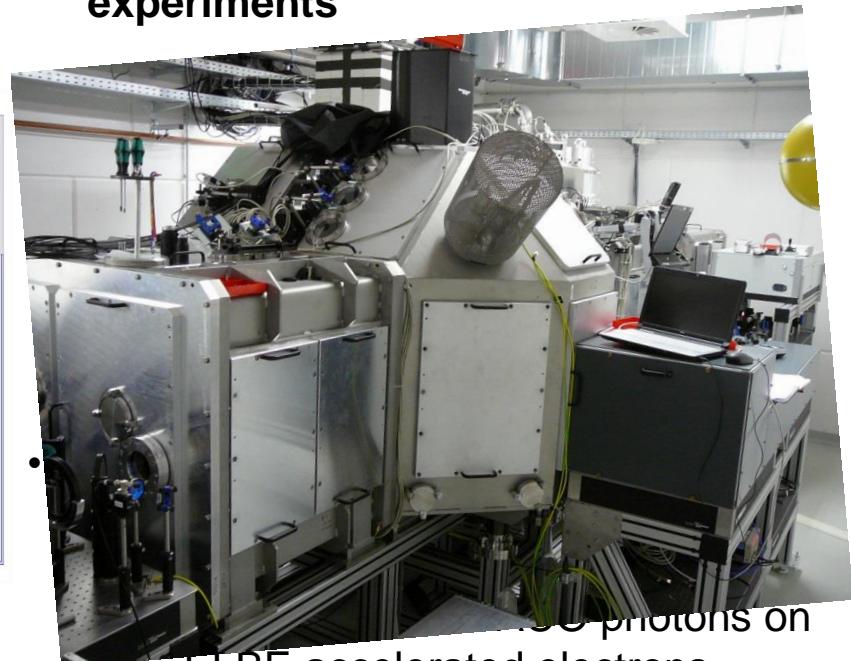


[Superconducting linac ELBE](#)

	Thermionic	SRF
pulse frequency	10 Hz	1 Hz
beam energy	24 - 30 MeV	
bunch length	4 ps (FWHM)	
bunch charge	1...77 pC	1...77 pC
trans. emittance	15 π mm mrad	5 π mm mrad

[1 PW Ti:Sa Laser DRACO](#)

- $\lambda_0 = 800 \text{ nm}$
- 10 Hz repetition rate
- 2 beam output
- Up to 25J + 4J on target
- 30...500 fs pulse width (FWHM)



150 photons on

ELBE accelerated electrons

- Stepping stone experiments towards fully laser driven Thomson backscattering X-ray source

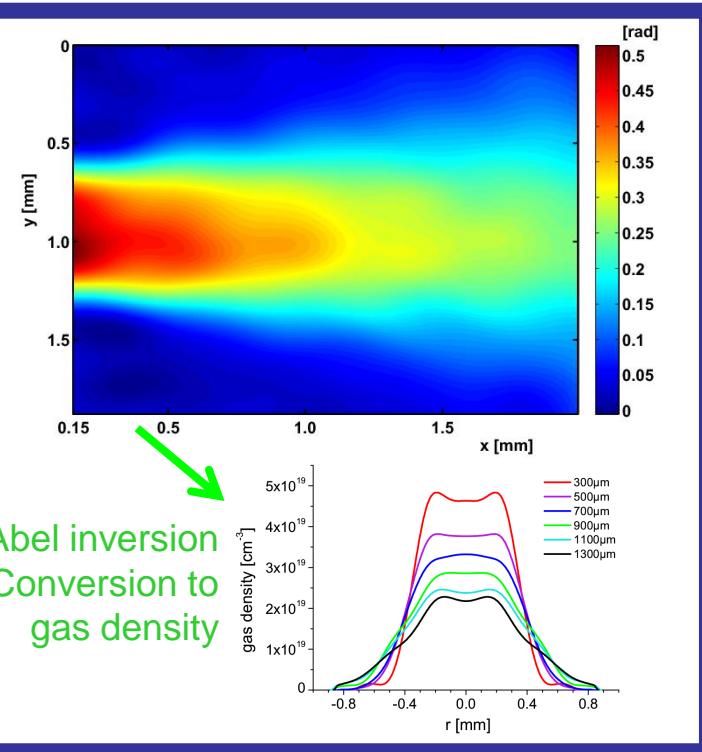
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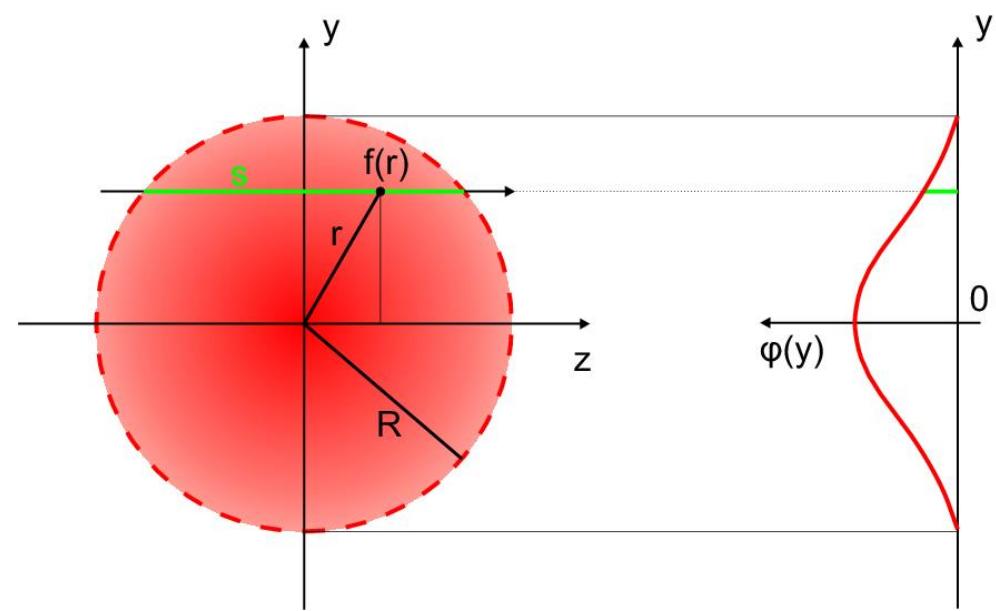


Mitglied der Helmholtz-Gemeinschaft



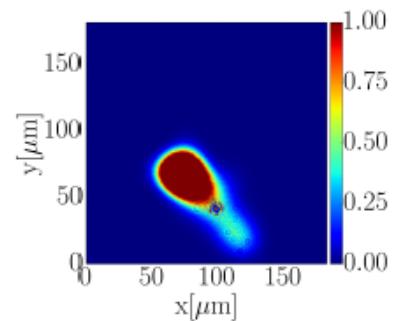
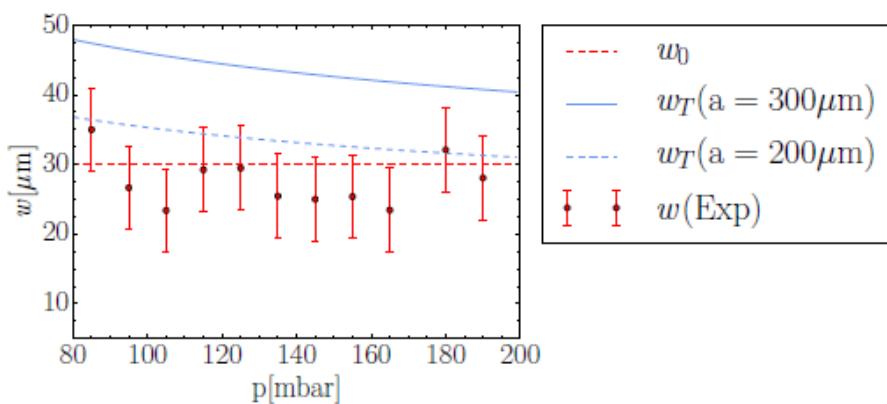
- The phase image is a 2-D projection of the 3-D gas-jet.
- Assuming an axisymmetrical gas-jet; by Abel inversion the projected function is converted to a radial gas-density function

-

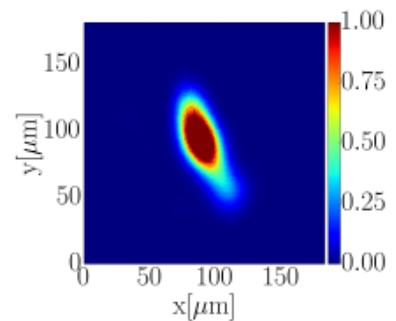


IDEA - interferometric data evaluation algorithms, software for fringe analysis
and phase data reduction. <http://www.optics.tugraz.at/idea/idea.html>

$$f(r) = -\frac{1}{\pi} \int_y^R \frac{d\varphi(y)}{dy} \frac{dy}{\sqrt{r^2 - y^2}} dr$$



Entrance



Exit

Theory (Gonsalves)

$$w_T = 6,6 \cdot 10^4 \mu\text{m} \cdot \left(\frac{a_{\text{Cap}}}{2\mu\text{m}} \right)^{0,651} \cdot \left(\frac{n_{\text{H}_2,0}}{\text{m}^{-3}} \right)^{-0,1875}$$

Conclusion

Good match for $a=200\mu\text{m}$ due to asymmetrical capillary