Target development for LWFA experiments at HZDR: Supersonic gas jets and plasma waveguides

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20th April 2015

Outline

Where is the HZDR located?

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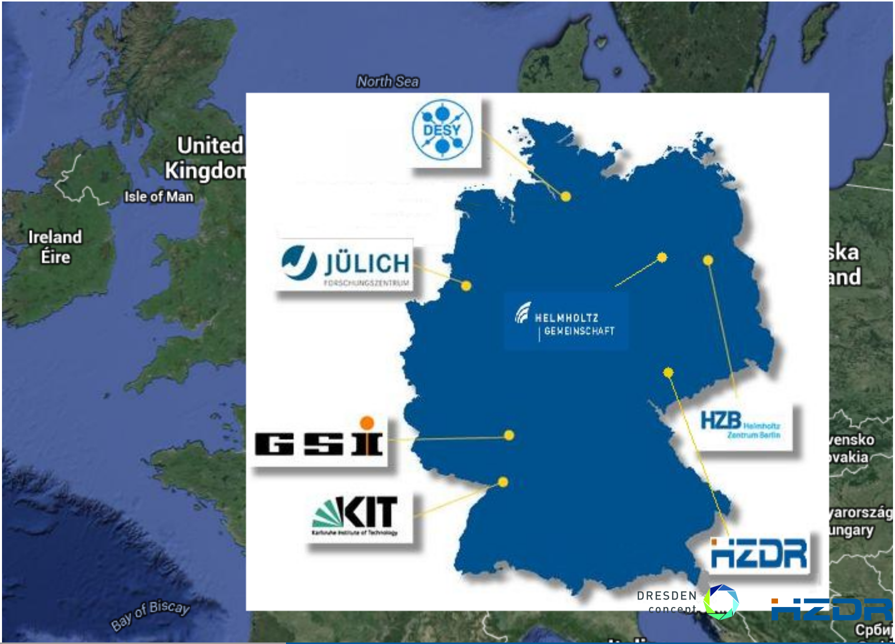
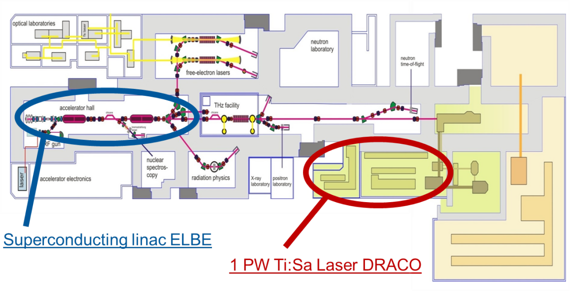


DRESDEN concept

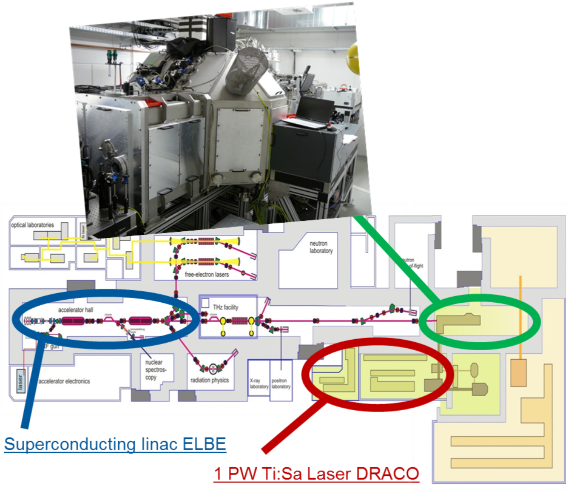
Electron and X-ray facility at HZDR



Unique facility with:

- Short-pulse high energy laser system DRACO
- Conventional electron accelerator ELBE
- Both synchronised with 100 fs precision

Electron and X-ray facility at HZDR



Unique facility with:

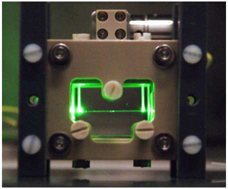
- Short-pulse high energy laser system DRACO
- Conventional electron accelerator ELBE
- Both synchronised with 100 fs precision

Targetry

Gas jet targets

- High density
- Short interaction length
- Plasma created by laser ionisation
- Relativistic self-guiding limits interaction length

Capillary targets

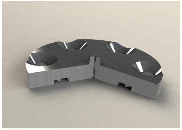


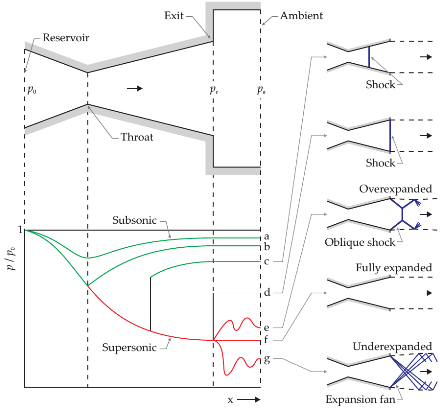
- Low density
- Long interaction length
- Plasma created by electrical discharge
- Guiding via preformed refracting index profile
- More complex setup for discharge

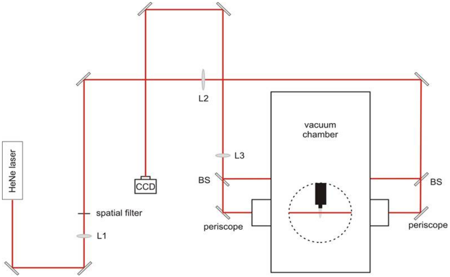
Supersonic gas jet targets

Laval nozzle

- Supersonic outflow with high Mach number







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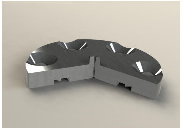
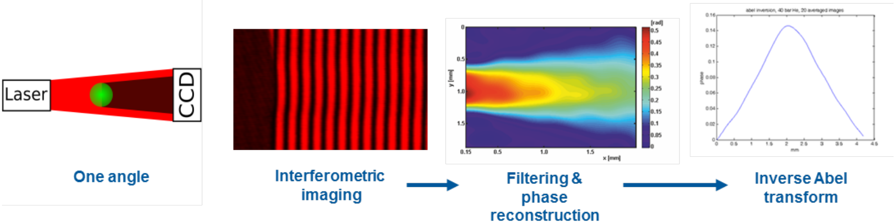
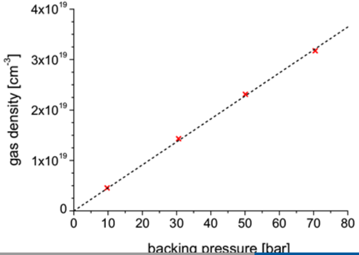
Axissymmetrical gas jets and Abel inversion

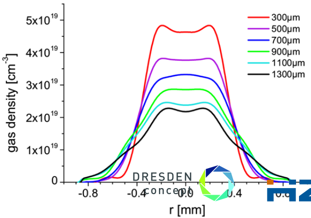
Inverse Abel transform

- Main assumption: cylindrical symmetry of gas jet
- Averages non-symmetrical details





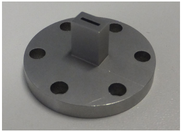


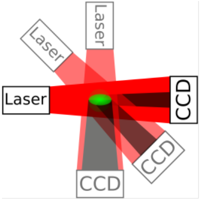


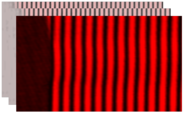
Slit nozzles and Tomography

Tomography allows analysis of:

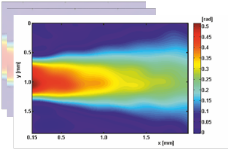
- non-axialsymmetrical features
- slit nozzles



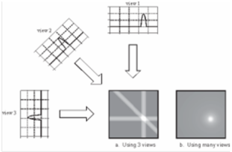




Interferometric imaging



Filtering & phase reconstruction



Tomographic backprojection

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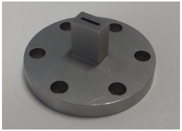
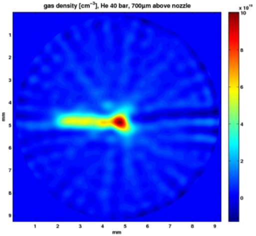
Slit nozzle tests

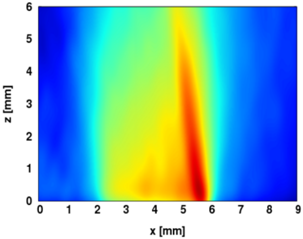


Resolution test:

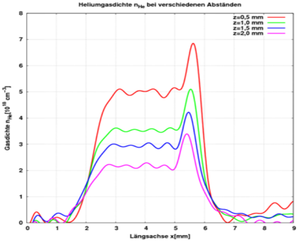
- Knife edge at nozzle exit
- Shockwave created



Top view



Projected side view



Plot along laser axis

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Summary of gas jet targets

Abel inversion

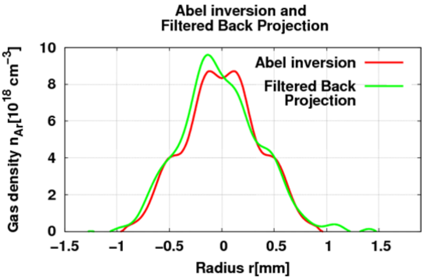
- Requires only one interferogram
- Left-right-asymmetries averaged out

Tomography

- Multiple interferograms at different angles
- Possible to detect asymmetries

Conclusion

Tomography provides better characterisation of density profile



Capillary target

Motivation

Laser-plasma interaction length in centimeter scale

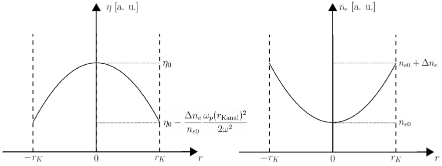
Principle

- Discharge creates plasma in gas filled capillary
- Discharge current heats plasma in the middle
- Plasma cooled at wall
- Equilibrium creates parabolic refracting index profile

Sapphire capillary

- Submillimeter cross section
- High mechanical strength
- High thermal conductivity
- Structure fabricated by Laser ablation

Refraction index vs. e^--density



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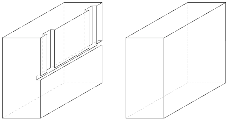
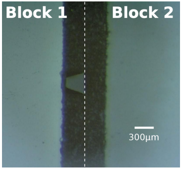
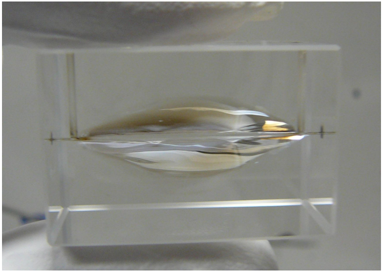


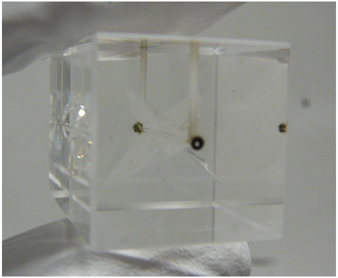


Target life time

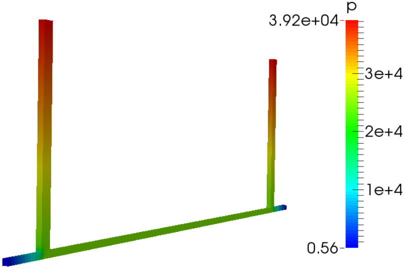
Life time reducing factors:

- Heat deposition on channel walls during discharge
- High thermal stress on edges
- Ablation of electrodes and channel
- Deposition of sputtered material inside channel

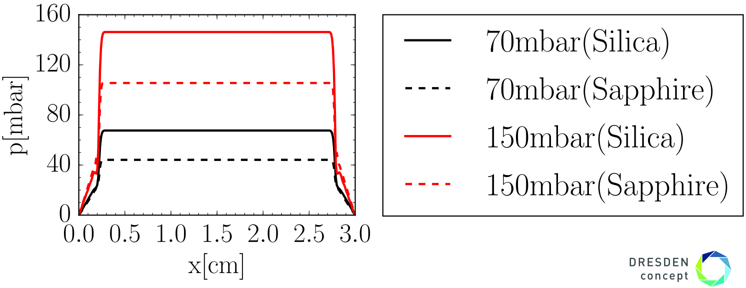




Simulated gas density inside capillary



- Simulated gas density in OpenFOAM
- Constant profile between inlets
- Different density because of different cross section of both capillaries



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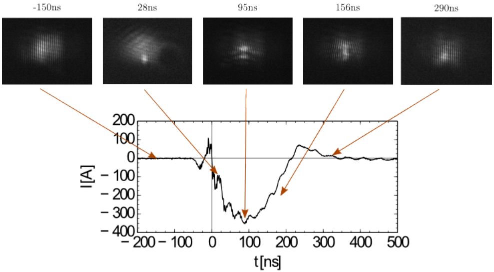
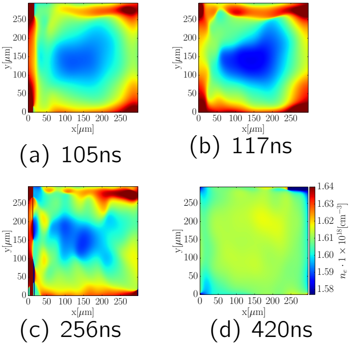
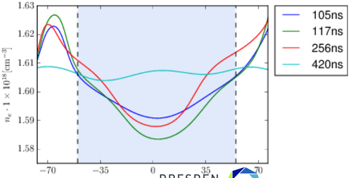
Time evolution of electron density n_e



- Discharge duration 250 ns, 20 kV
- Image captured by ICCD at 5 ns
- Channel formation visible
- Channel stable around discharge current peak
- Refraction index $\propto n_e^{-1}$





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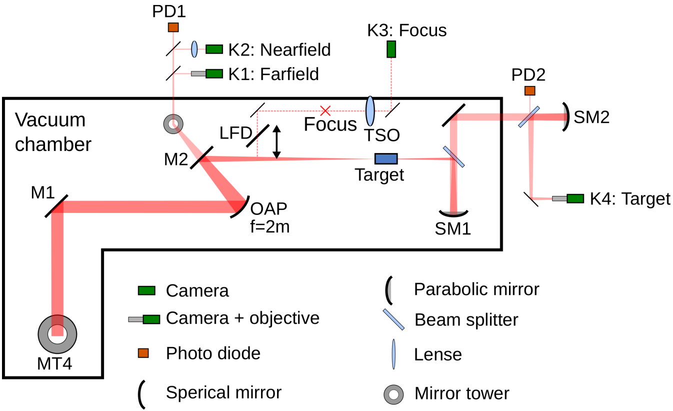
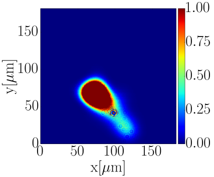
Test guiding measurements with DRACO



DRACO (Dresden laser acceleration source):

- 800 nm
- Pulse width: 40 fs
- Energy: 20 mJ
- Waist: 30 μm
- Rayleigh-length: 4,8 mm

Focus profile:



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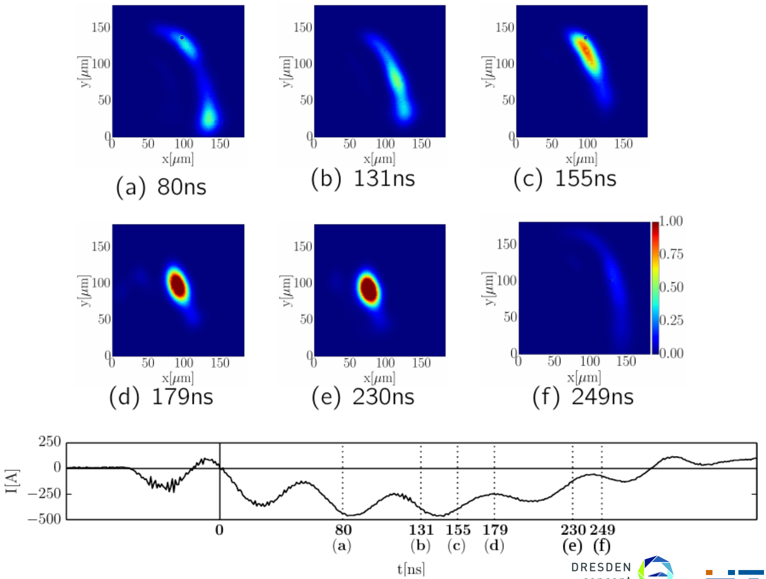
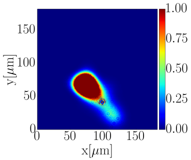
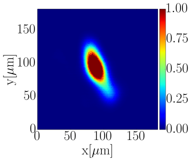
Time dependence of guided laser pulse



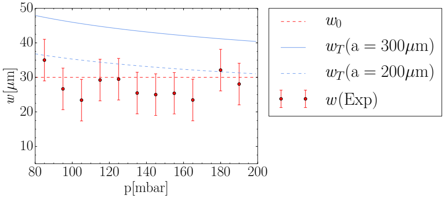
Calculated vs. measured matched spot size



Entrance



Exit



(A. Gonsalves: "Transverse Interferometry of a Hydrogen-Filled Capillary Discharge Waveguide" PRL 98 (2007)):

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

Conclusion

Good match for a=200 μm

Outlook

Next experiments with better focus profile and higher energy

Thank you for your attention!

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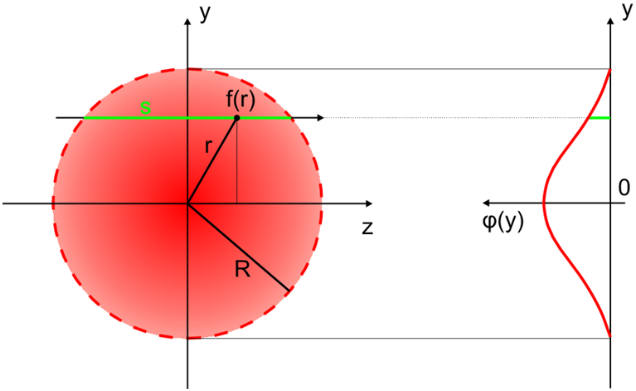
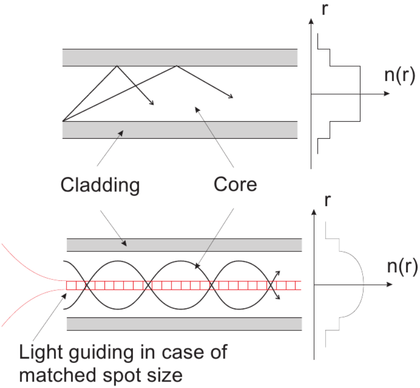
Abel inversion



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

Fundamentals of waveguides



Stoop, C.H.: *Tailoring plasma waveguides for high intensity laser guiding*, 2006

- Step index fibre: reflexion on core $\rightarrow$ cladding
- Graded index fibre: parabolic gradient of refraction index
- Matched Spot Size:

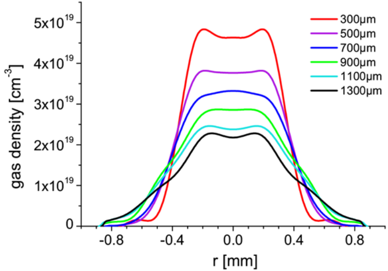
$$w_m = \sqrt[4]{\frac{r_{\mathrm{Chan}}^2}{\pi \Delta n_e r_e}}$$

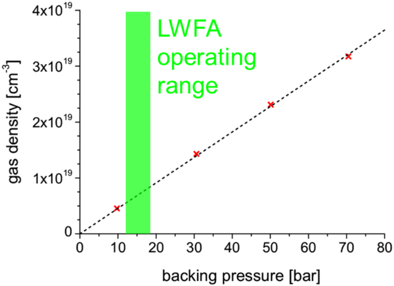
$\rightarrow$ Light rays remains focused $(v_\varphi(n))$, constant beam radius

Axissymmetrical gas jets and Abel inversion

Inverse Abel transform

- Main assumption:
  zylindrical symmetry
- Averages
  non-symmetrical details





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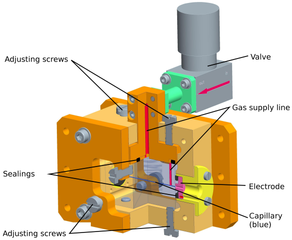
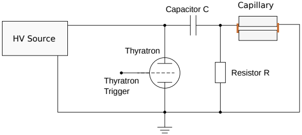
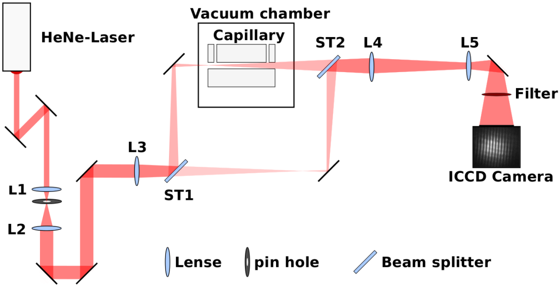
Measurement of longitudinal electron density n_e







- 20 kV discharge circuit with thyratron
- Mach-Zehnder-Interferometer
- HeNe-Laser 633 nm (cw)
- Camera shutter open for 5 ns

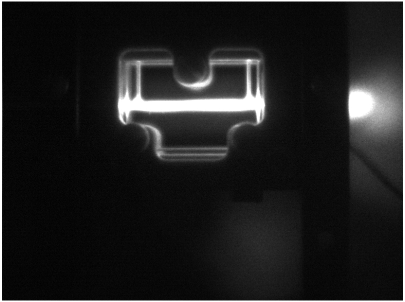
Comparision of guiding parameter

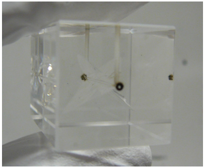
	Sillica	Sapphire	Sapphire
Gas	He	He	H_2
$w_M[\mu m]$	25 ± 5	25 ± 5	35
Pressure[mbar]	110 ± 10	175	135 ± 15
Time[ns]	$90 \ldots 105$	125 ± 10	205 ± 25

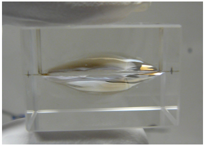
Gonsalves

$$w_M = 6,6 \cdot 10^4 \mu\mathrm{m} \cdot \left(\frac{a_{\mathrm{Kap}}}{2\,\mu\mathrm{m}}\right)^{0{,}651} \cdot \left(\frac{n_{\mathrm{H}_2,\,0}}{\mathrm{m}^{-3}}\right)^{-0{,}1875} \tag{1}$$

Elektrische Entladungen







- Entladungsweg hängt von Füllungsgrad der Kapillare ab
- Stabile Entladungen bei vollständig gefüllter Kapillare
- Kammerdruck wichtig
- EMP
- Entladungsdauer beeinträchtigt Lebensdauer der Kapillare