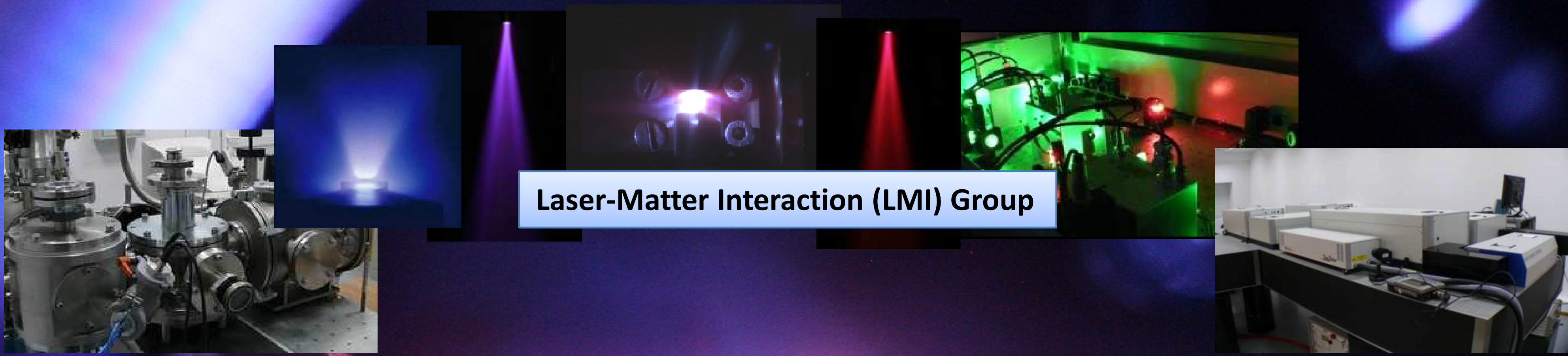
Laser PlasmaTargetry Workshop

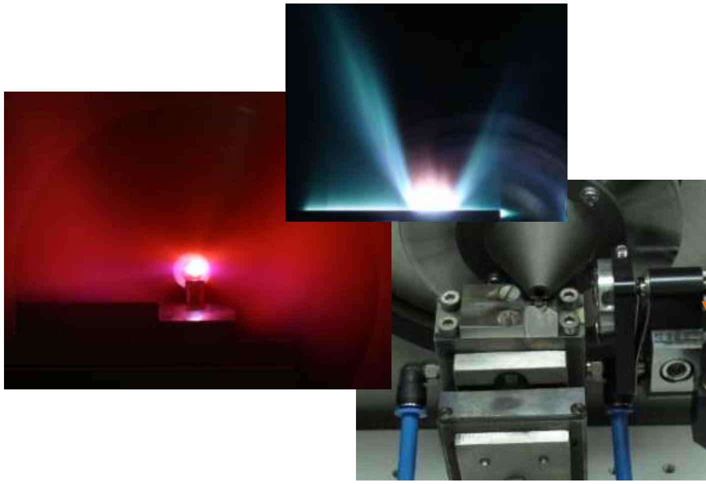
PARIS 20-22 April 2015



"Characterization of gas puff targets for laser matter interaction experiments, using extreme ultraviolet and soft X-ray radiography and tomography techniques"

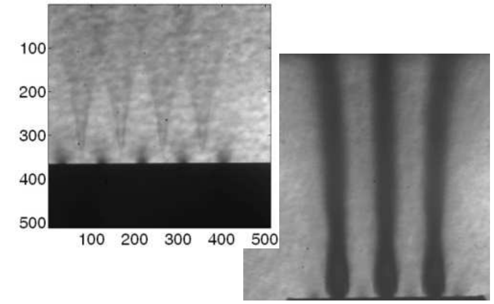
P. W. Wachulak*, A. Bartnik, L. Wegrzynski,
T. Fok, R. Jarocki, J. Kostecki, M. Szczurek, and H. Fiedorowicz
Institute of Optoelectronics,
Military University of Technology, Poland
*wachulak@gmail.com

Outline



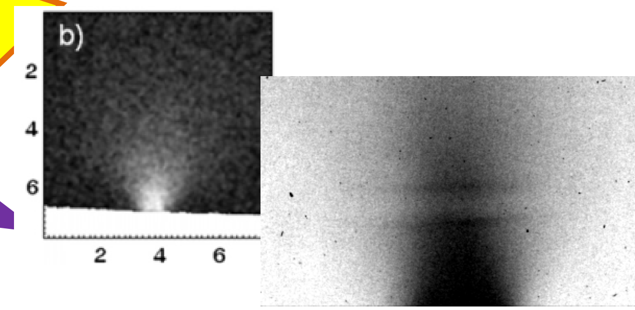
EUV radiography

- Single stream modulated gas targets
- Multi-jet double stream gas puff targets

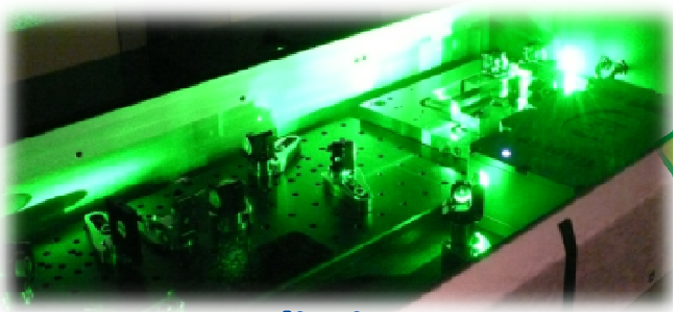


SXR radiography

- Elongated gas targets
- Elongated plasma channels



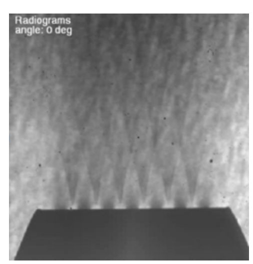
Efficient generation of the SXR/EUV high intensity radiation, laser-plasma sources



Laser radiation

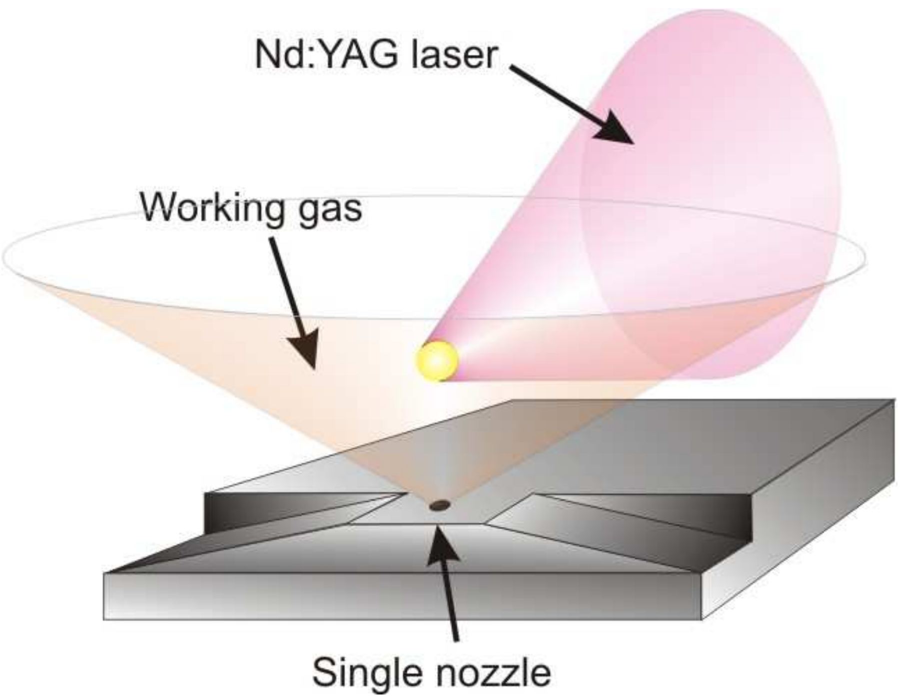
EUV tomography

- Single stream modulated gas targets



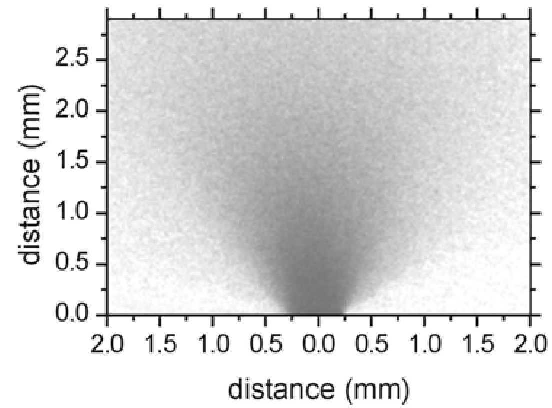
Double stream gas puff target

Single stream gas puff target

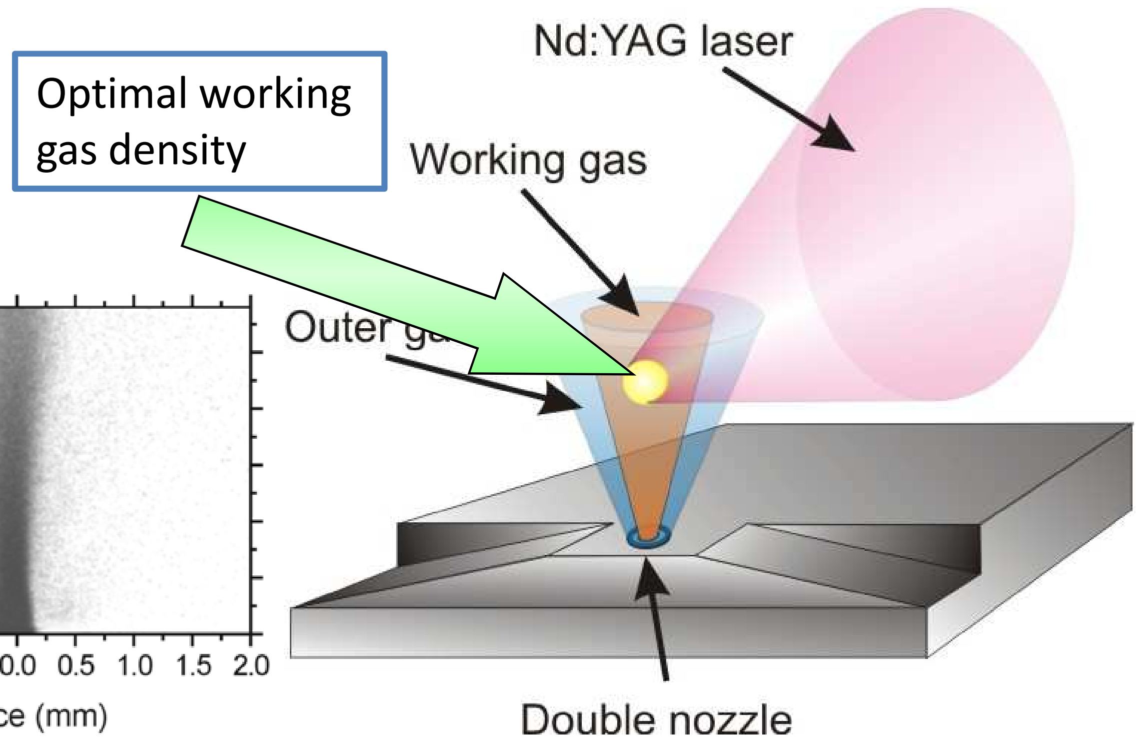


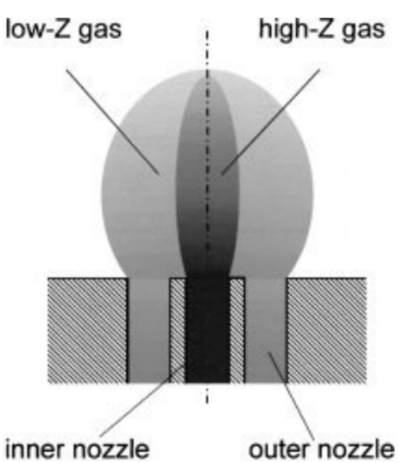
Problems:

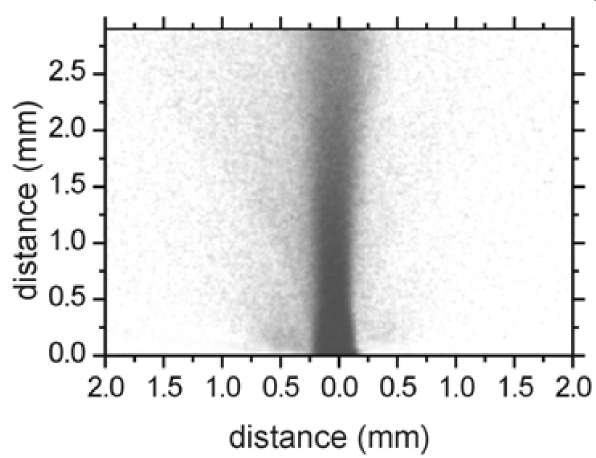
- ✓ high working gas jet divergence
- ✓ difficult to achieve a proper gas density far away from the nozzle
- ✓ nozzle ablation and debris production



Double stream gas puff target



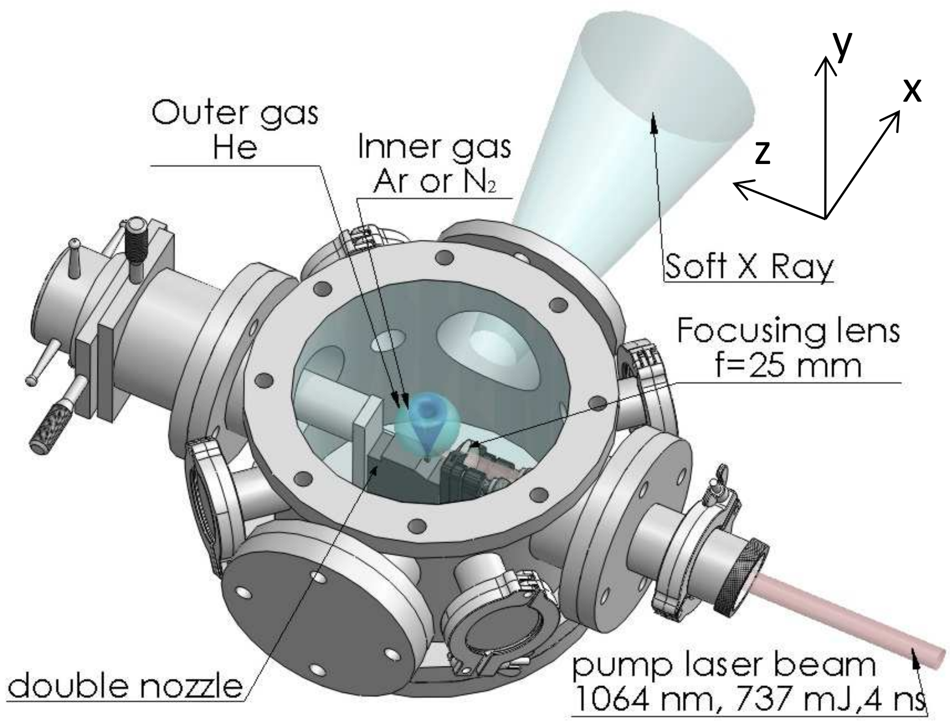




H. Fiedorowicz et al., ***Appl. Phys. B 70, 305–308 (2000)***

Double stream gas puff target laser-plasma EUV/SXR source

LMI



Scheme of the EUV/SXR gas-puff target source

Photograph of the system for EUV/SXR radiography

Pumping laser	Nd:YAG laser (EKSPLA), 4 ns/500mJ pulses, repetition rate **10Hz**
Nozzle	Inner: circular 0.4mm in diameter Outer: ring 0.7mm/1.5mm diameters
Gasses	Working gasses: **Kr (SXR), Xe (EUV/SXR)** outer gas : **He**

Advantages:

✓ **no debris from gaseous targets**

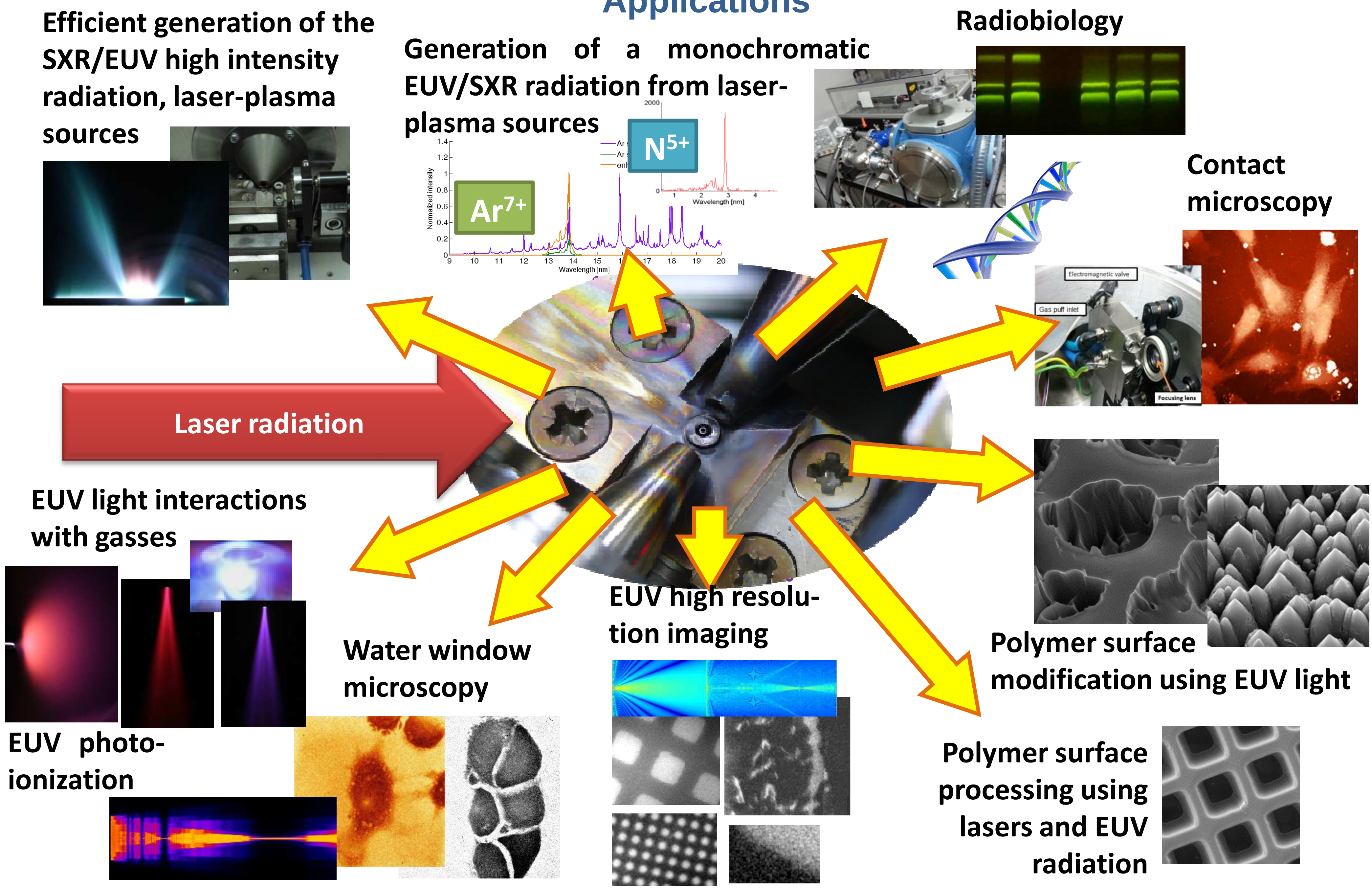
✓ compact construction, high repeatability

✓ high conversion efficiency, very robust – thousands of shots/day

P.W. Wachulak, A. Bartnik, H. Fiedorowicz, P. Rudawski, R. Jarocki, J. Kostecki, M. Szczurek, Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms 268, 10, 1692-1700 (2010)

Double stream „circular" gas puff target laser-plasma EUV/SXR source

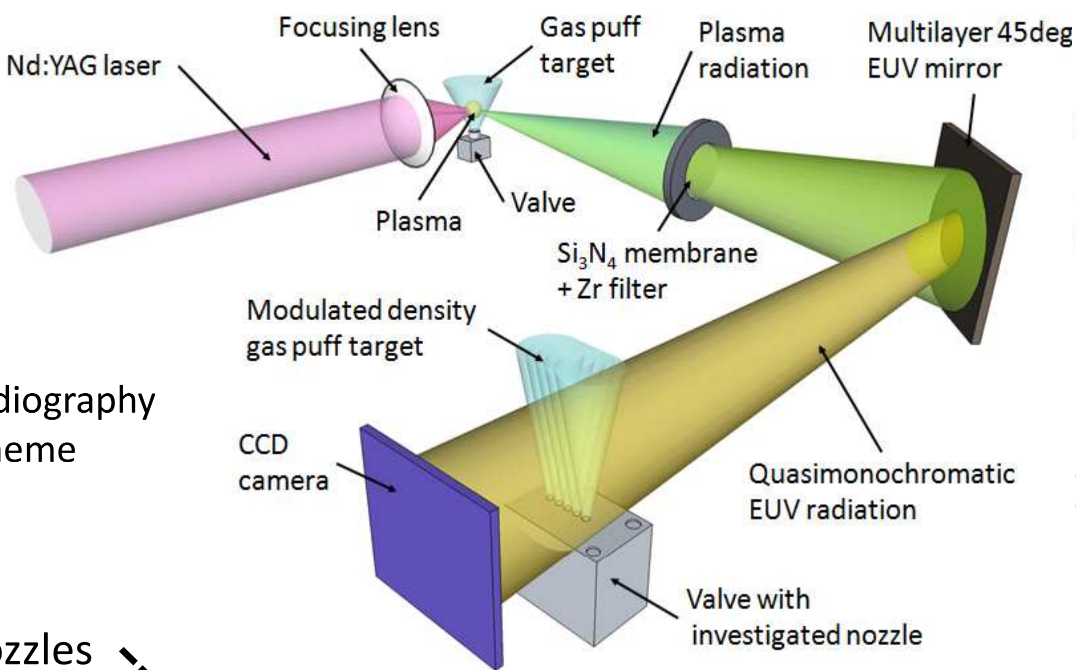
Applications

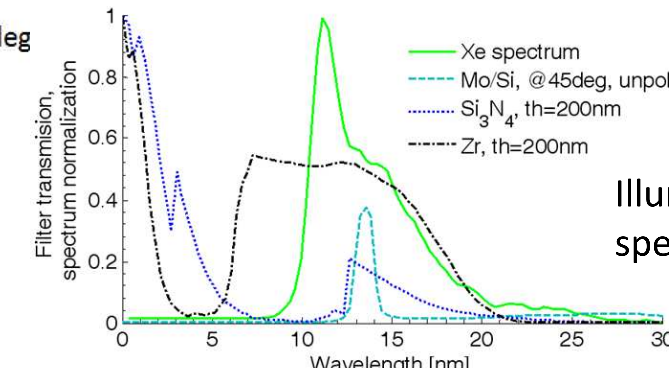


EUV radiography – projection imaging

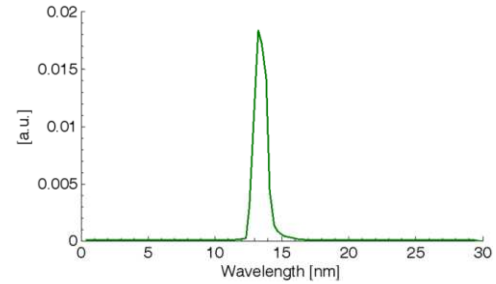
Single stream modulated gas targets

Radiography scheme



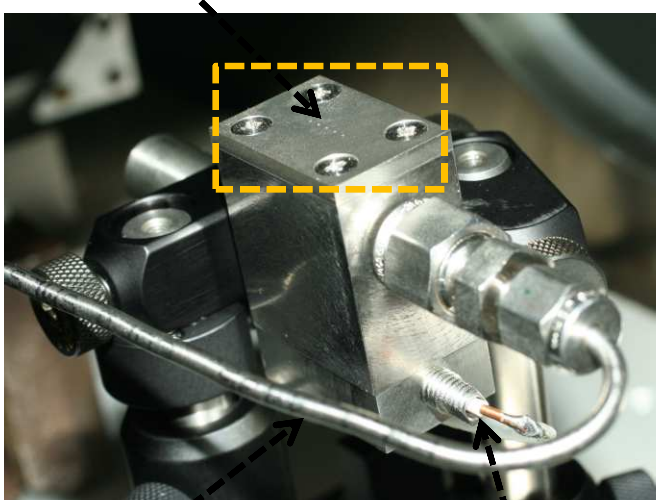


Illumination spectrum



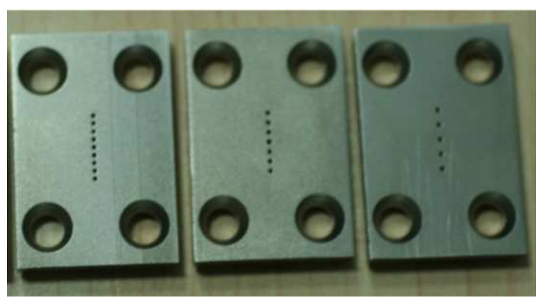
Radiation from **Xe** plasma was spectrally narrowed with multilayer mirror

Nozzles



Gas supply Electrical connector

Single stream multi-jet nozzles



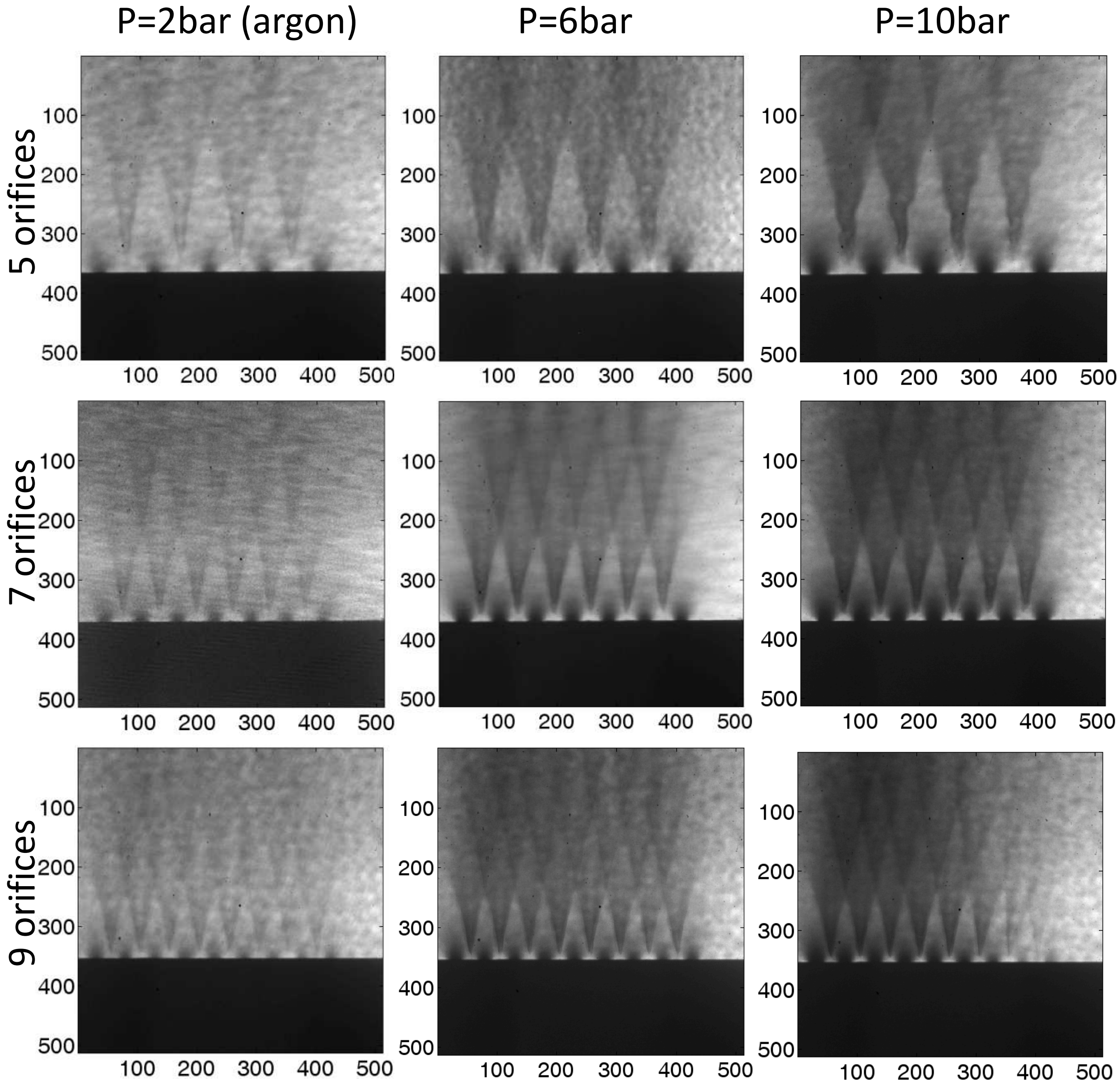
Experimental details:

Xe/He gas puff target source,
SiN 200nm thick membrane + 200nm thick Zirconium filter,
CCD camera: X-Vision M-25, Reflex, 512x 512 pix, 0.5x0.5in^2 in size, each pixel 25.4x25.4 µm^2
Multilayer mirror: Mo/Si, peak R=38% @ λ=13.5nm
Magnification: ~1.16x
Acquisition time: single EUV impulse (~3ns)

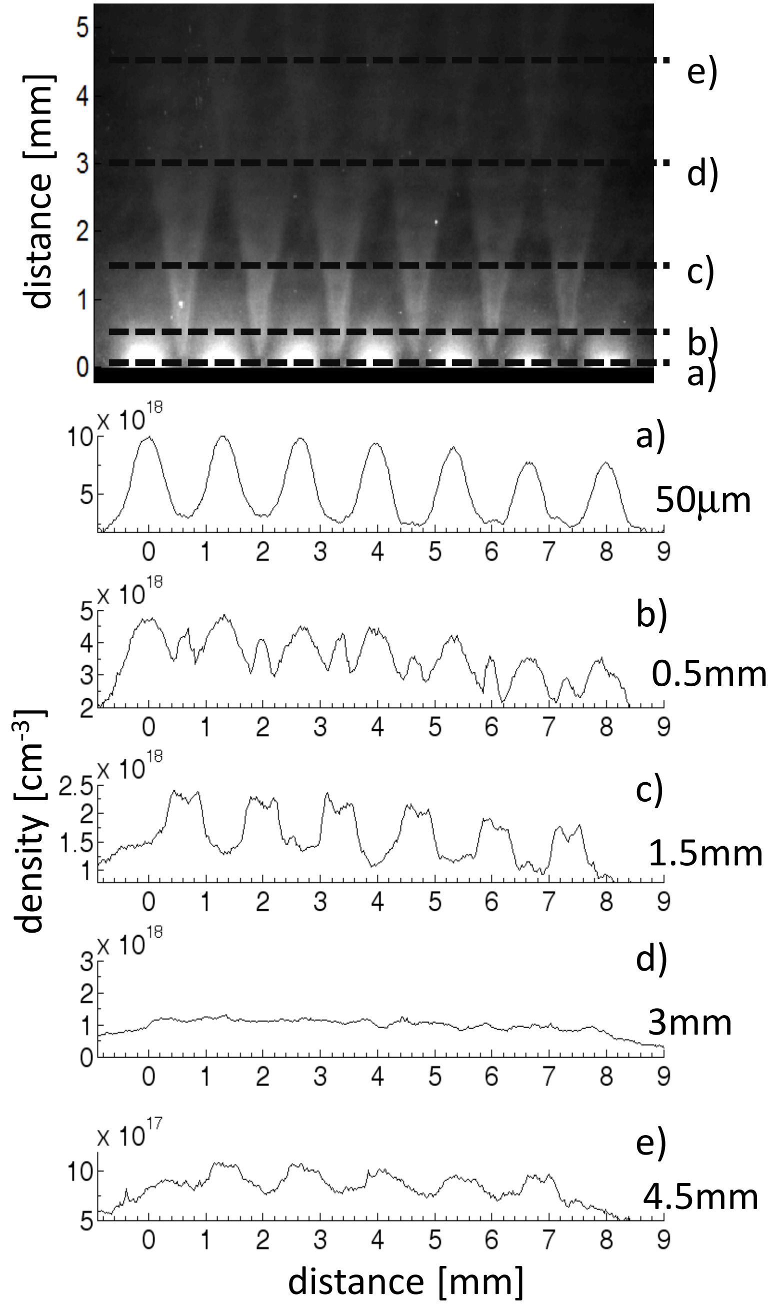
EUV radiography results

Single stream modulated targets

Target transmission images

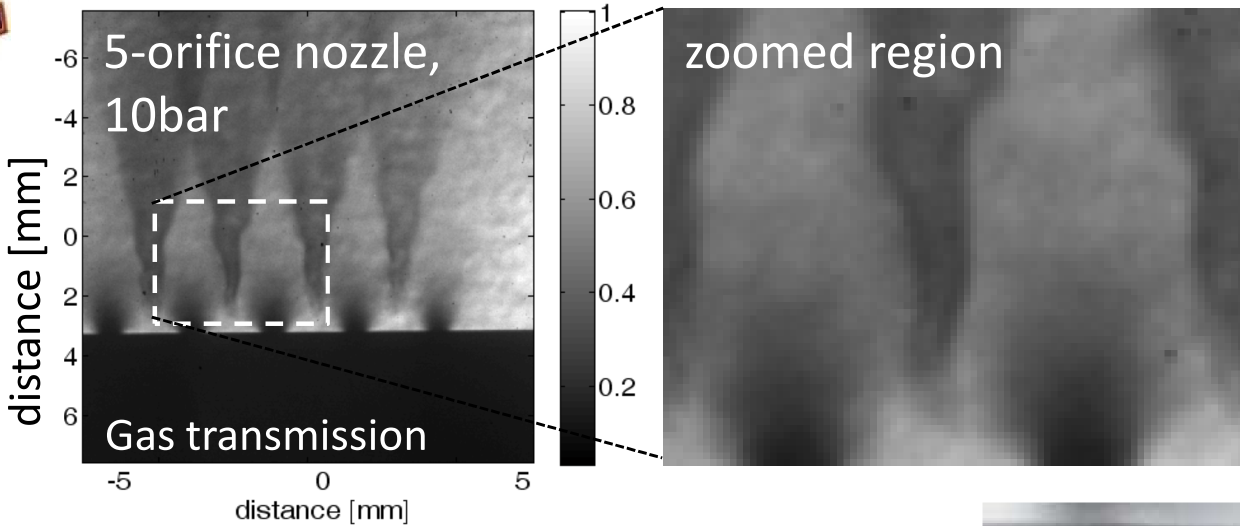


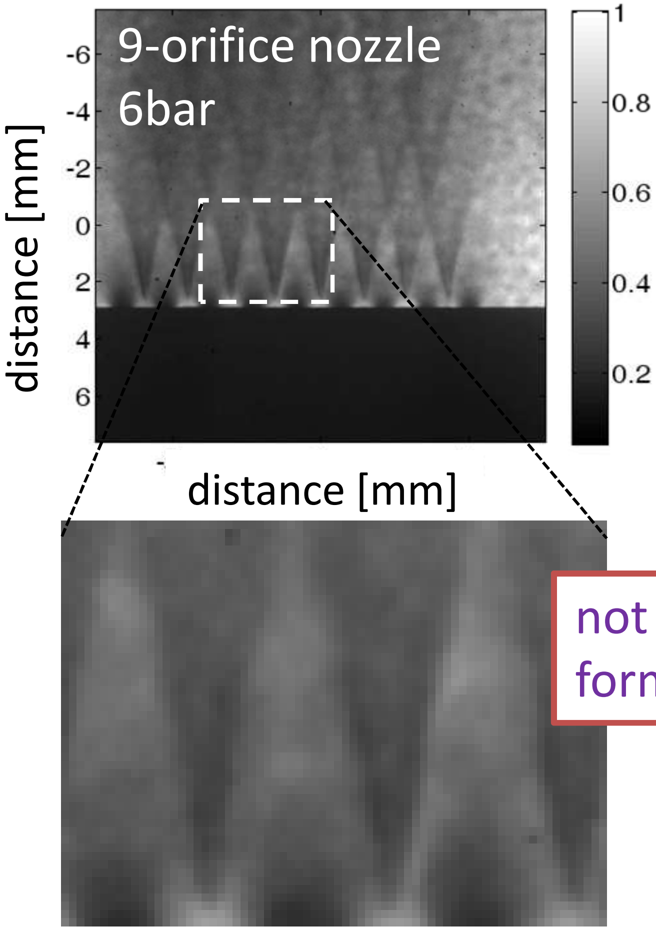
Target density profiles



"Characterization of multi-jet gas puff targets for high-order harmonic generation using EUV shadowgraphy", P.W. Wachulak, A. Bartnik, R. Jarocki, H. Fiedorowicz, **Nuclear Instruments and Methods in Physics Research Section B, 285, 15, 102–106 (2012)**

EUV radiography ns-time resolution (3ns)

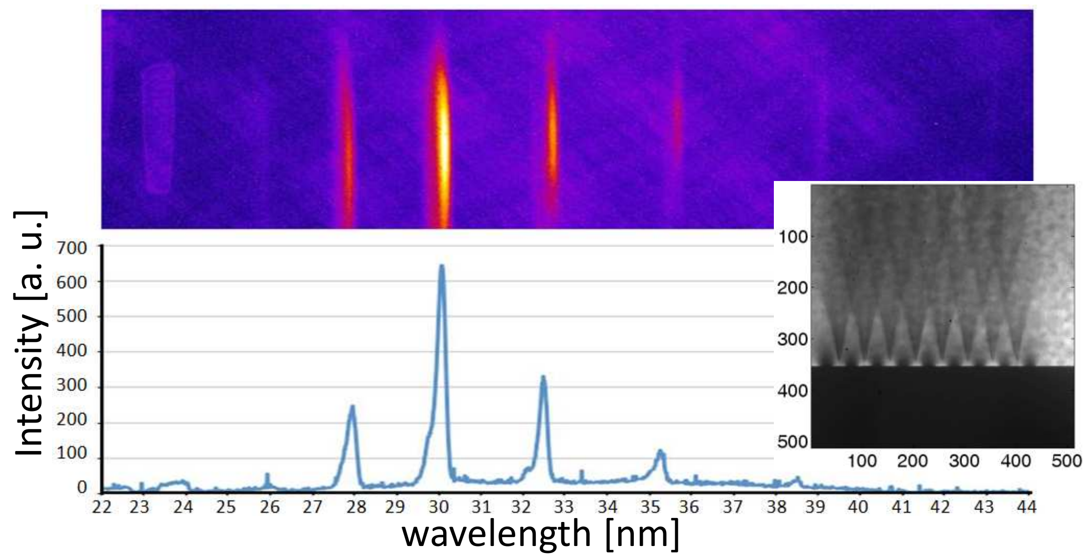




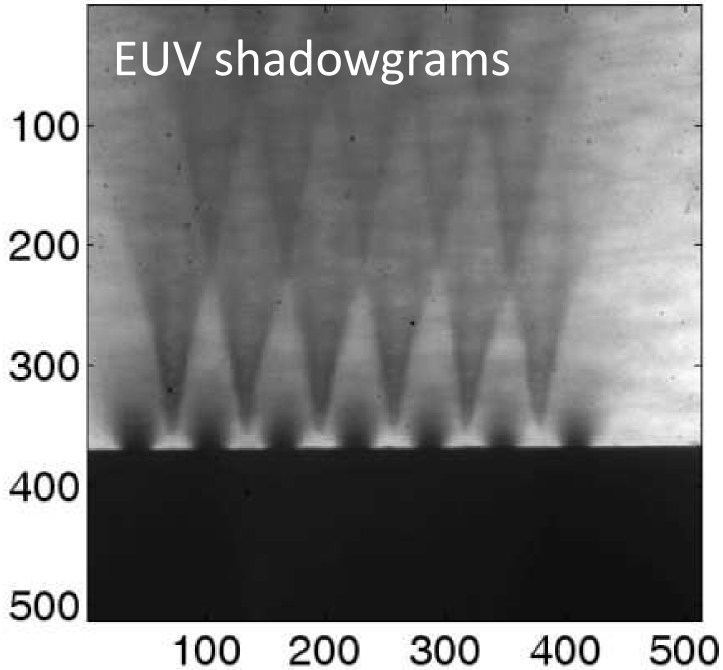
not vortex formation

HHG preliminary results

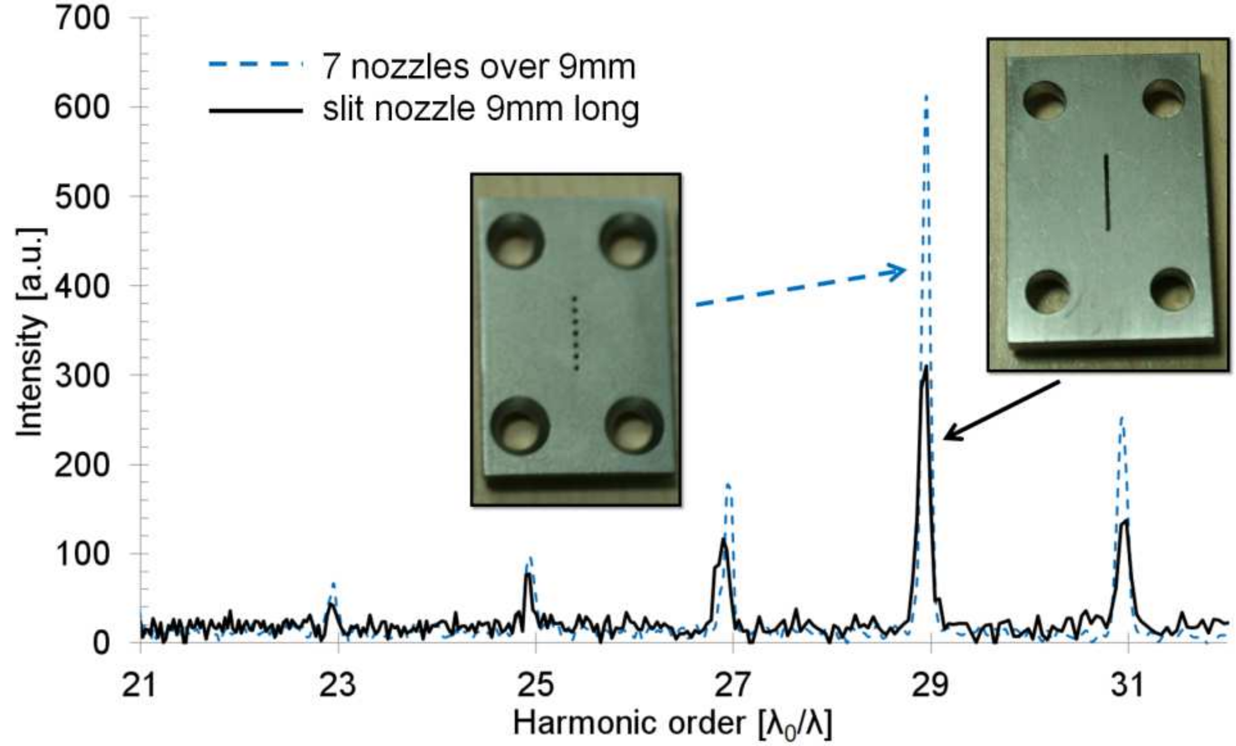
Collaboration with Mischa Kozlova & Jaroslav Nejdl, exp. performed at PALS, Czech Republic

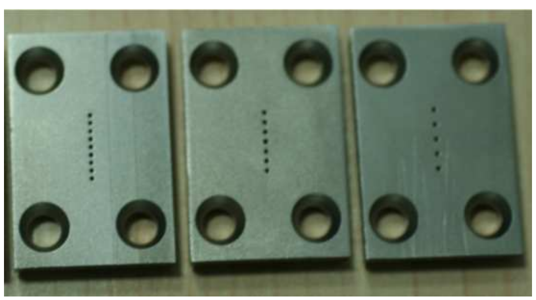


EUV tomography for diagnostics of modulated density targets used in QPM HHG



HHG spectral measurements (preliminary data)





Modulated density single gas targets

Experimental details:

Ar, P=1bar,
λ=810nm, t=40fs, E~1mJ pulses,
lens f = 750mm
1.5mm above the nozzle exit
FWHM focus diameter 90µm,
laser intensity in the focus 10^{14} W/cm^2

100% increase in intensity for certain harmonics

P.W. Wachulak, et al., ***LPB 31, 2, 219-227 (2013)***
P.W. Wachulak, et al., ***NIM B, 285, 15, 102–106 (2012)***

Work done in cllaboration with M. Kozlova and J. Nejdl from PALS, Czech Republic

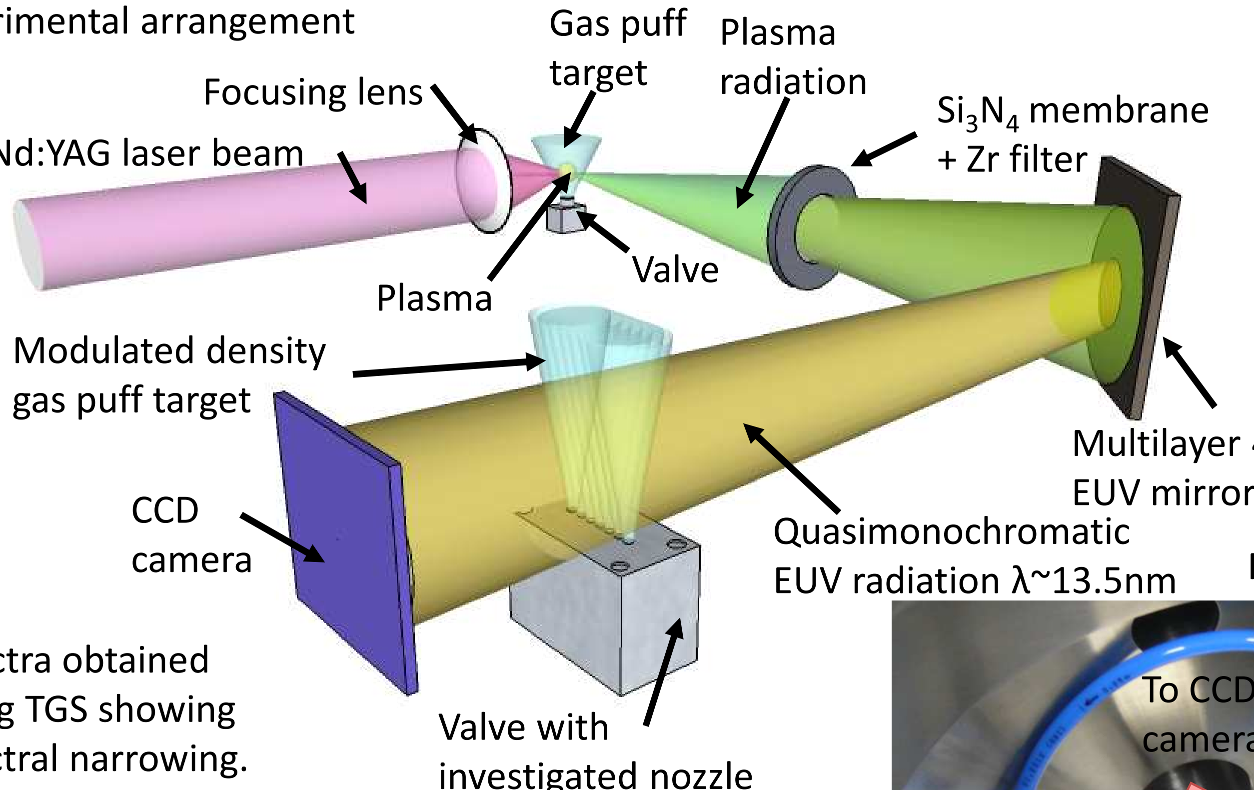
T. Fok, et al., ***PLP 6, 1, 14-16 (2014)***

PALS
PRAGUE ASTERIX LASER SYSTEM

EUV radiography

Double stream multi-jet gas targets

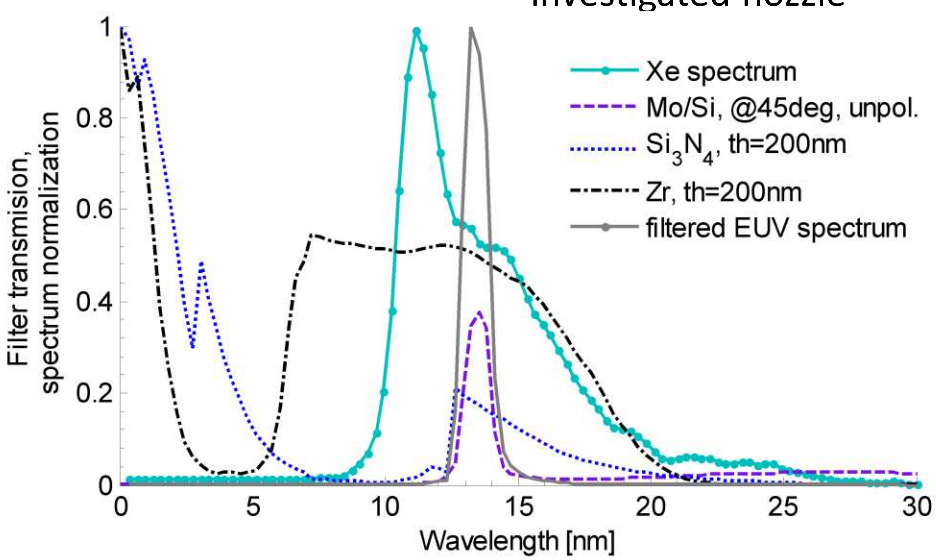
Experimental arrangement



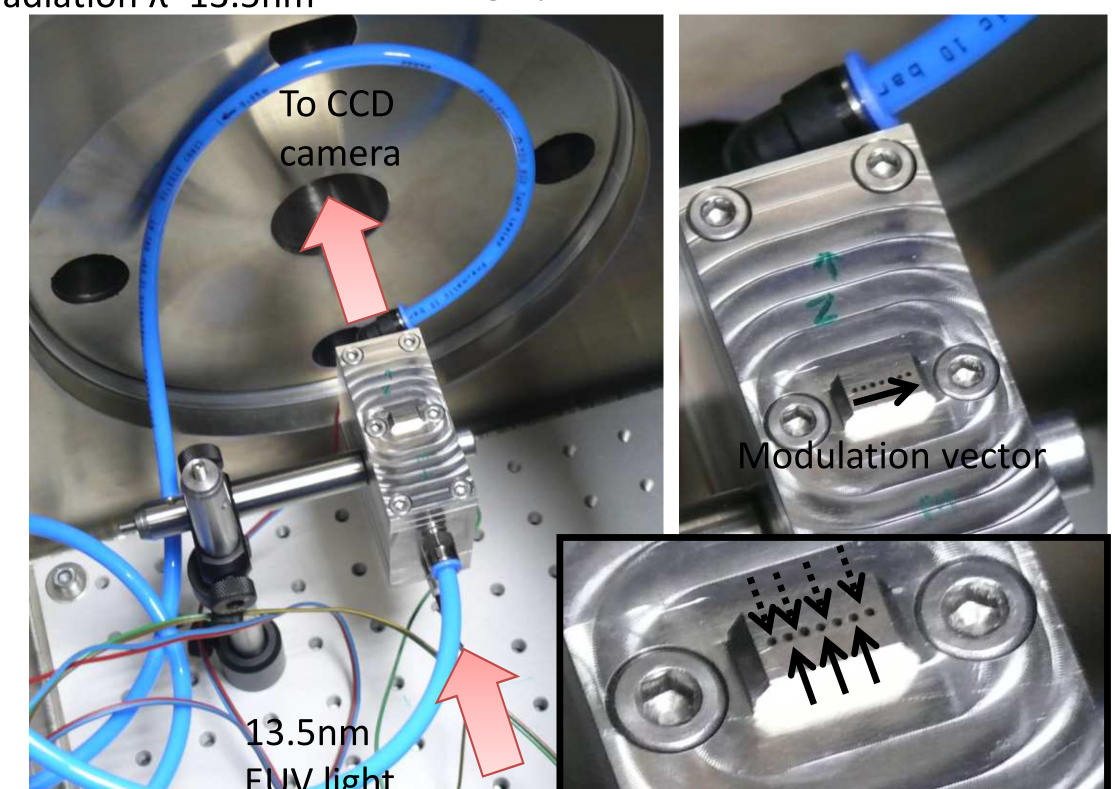
Experimental details:

Xe/He gas puff target source,
SiN 200nm + Zr 200nm
CCD camera: X-Vision M-25, Reflex, 512x 512 pix, 0.5x0.5in^2 in size,
EUV mirror: Mo/Si, R=38% @ λ=13.5nm
Magnification: ~1.14x
Acquisition time: single EUV pulse (~3ns)

Spectra obtained using TGS showing spectral narrowing.

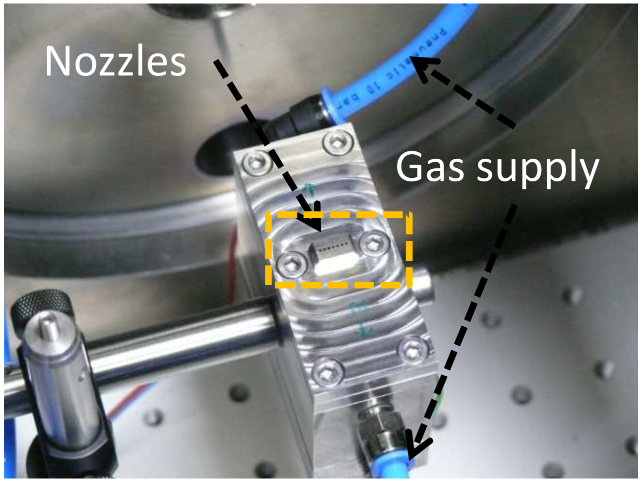


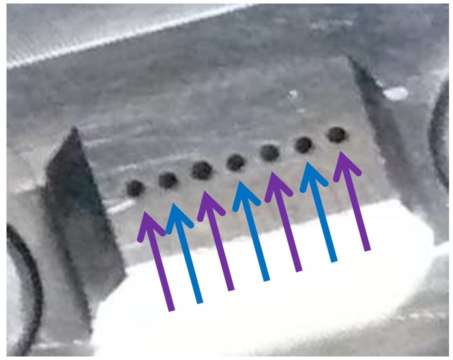
Photographs of the valve and the nozzles



EUV radiography (Xe gas)

Double stream multi-jet gas targets





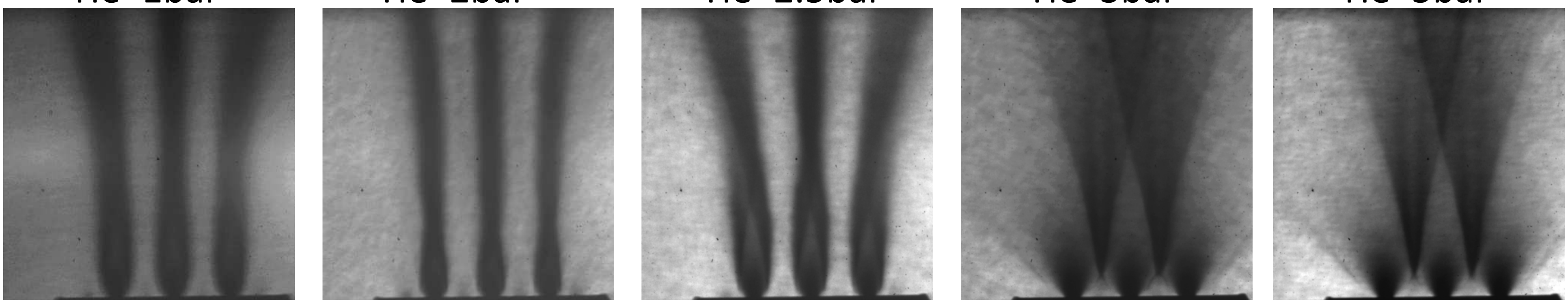
Double stream multi-jet nozzles

Xe-1bar, He-variable
Nozzle opening time 1ms

Images 12x12 mm^2

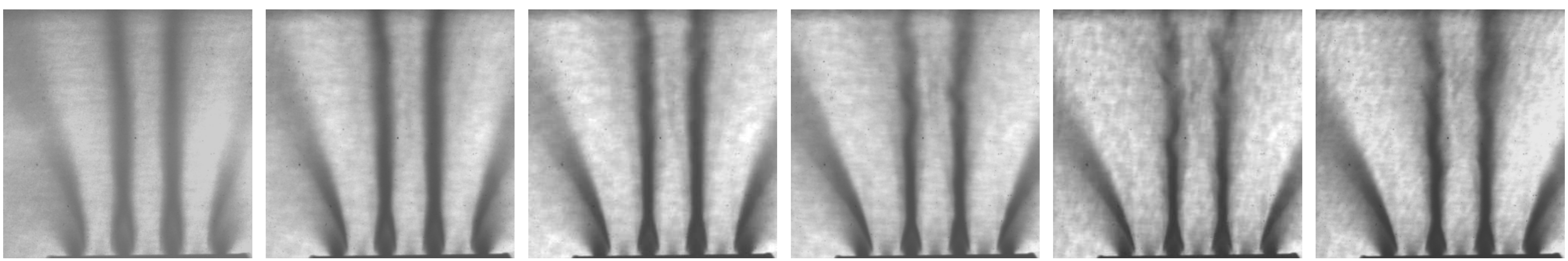
Xe in ineer 3 nozzles

He=1bar | He=2bar | He=2.5bar | He=3bar | He=5bar



Xe in 4 outer nozzles

He=1bar | He=2bar | He=3bar | He=4bar | He=5bar | He=6bar

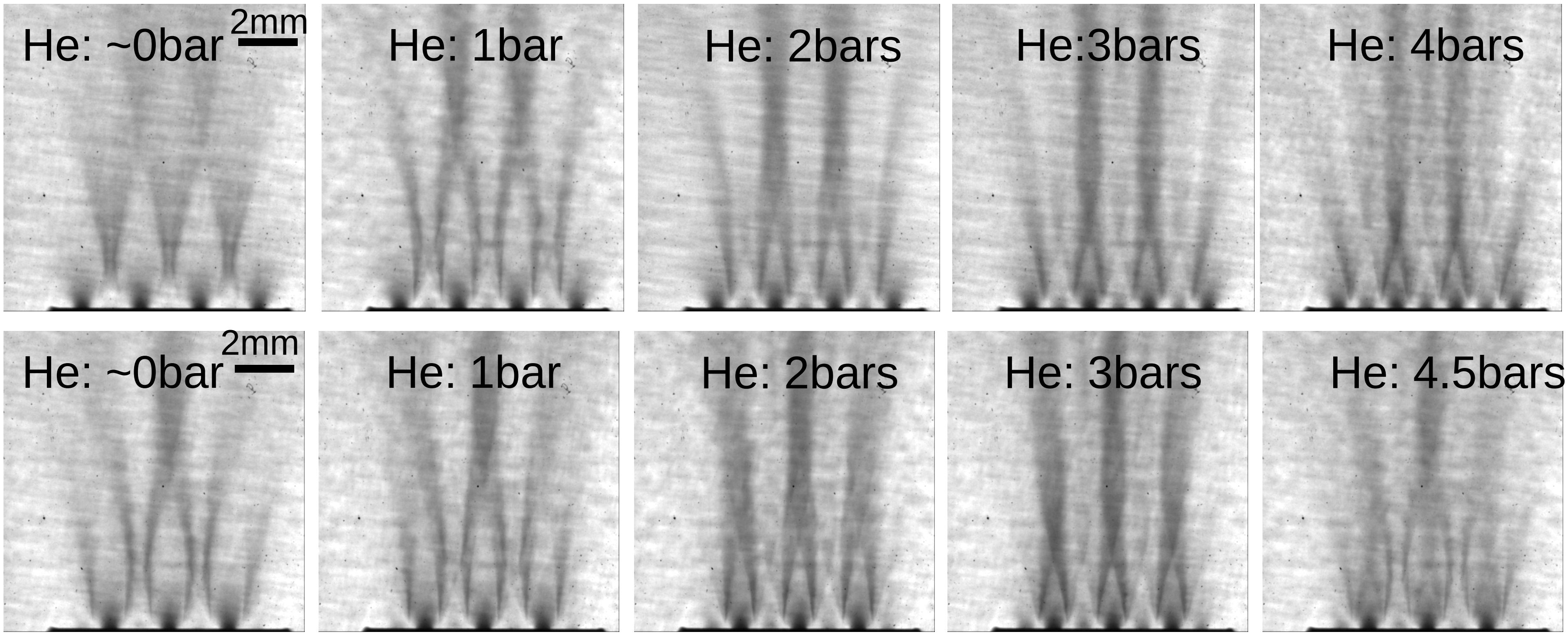


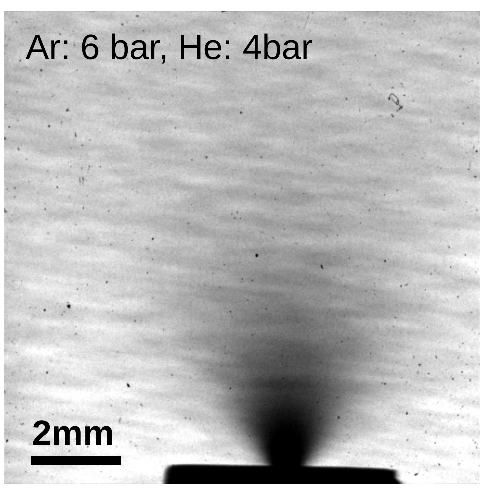
EUV radiography (Ar gas)

Double stream multi-jet gas targets

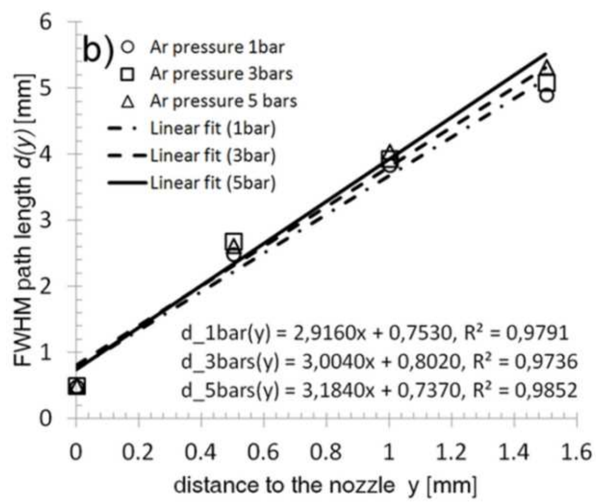
Argon (outer nozzles) = 3 bars

Argon (inner nozzles) = 3 bars





Typical shadowgram, obtained for modulation vector parallel to the direction of EUV beam



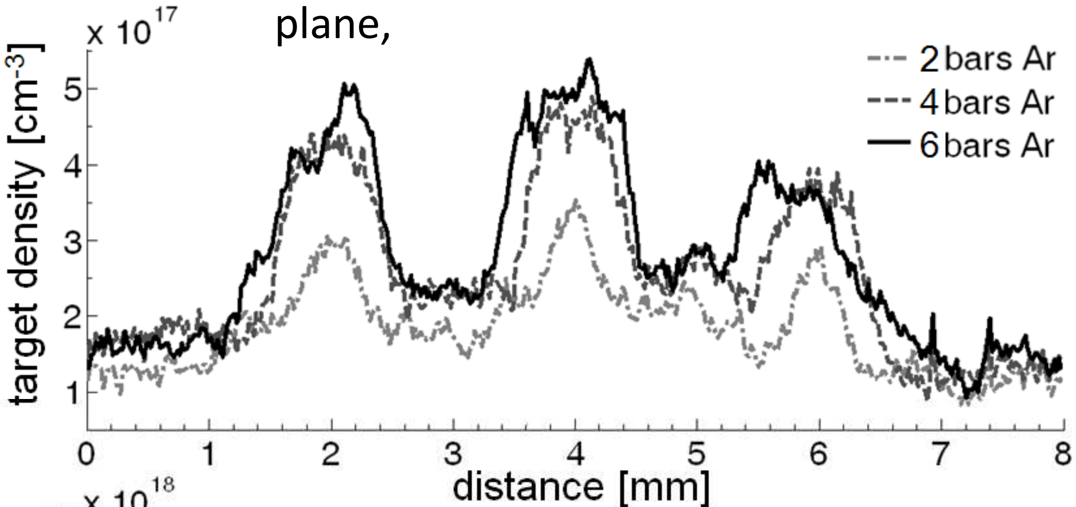
Results of *d(y)* interpolation for various Ar pressures

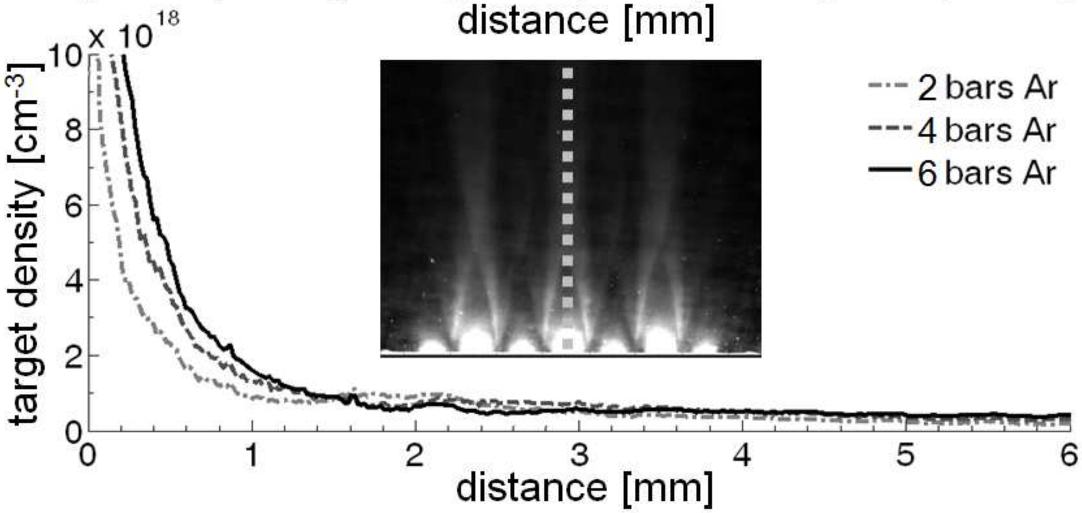
"Characterization of a dual-gas multi-jet gas puff target for high-order harmonic generation using EUV shadowgraphy", P.W. Wachulak, L. Wegrzynski, A. Bartnik, T. Fok, R. Jarocki, J. Kostecki, M. Szczurek and H. Fiedorowicz, **Laser and Particle Beams (2013) -accepted**

EUV radiography (Ar gas)

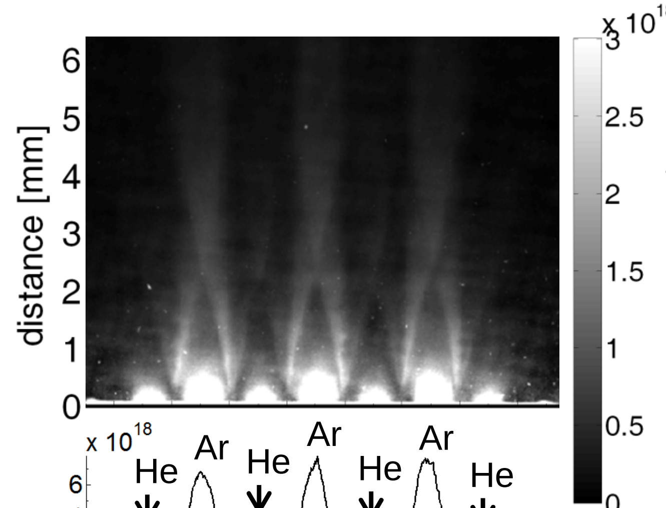
Density measurements

Cross-sections of density maps obtained at 1mm from nozzle exit plane,



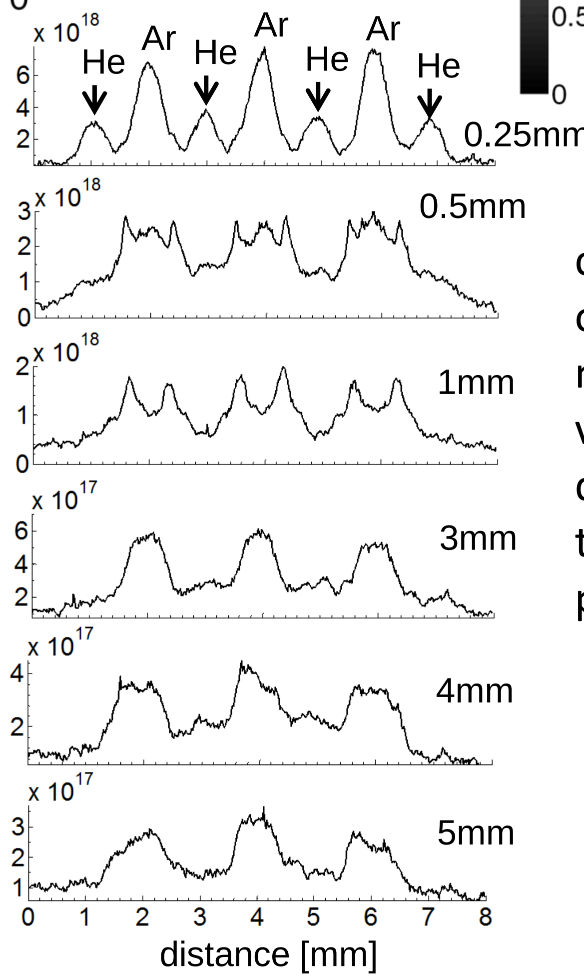


Peak Ar density in the jets as a function of the distance from the orifices, for three different Ar gas backing pressures



cm^{-3}

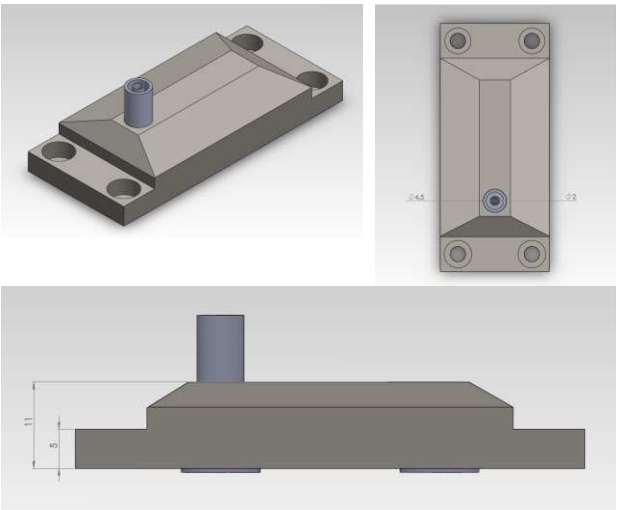
2-D density map for [Ar,He] = [3, 3] bars



cross-sections of the density map, at various distances from the nozzle exit plane

EUV radiography (Ar gas)

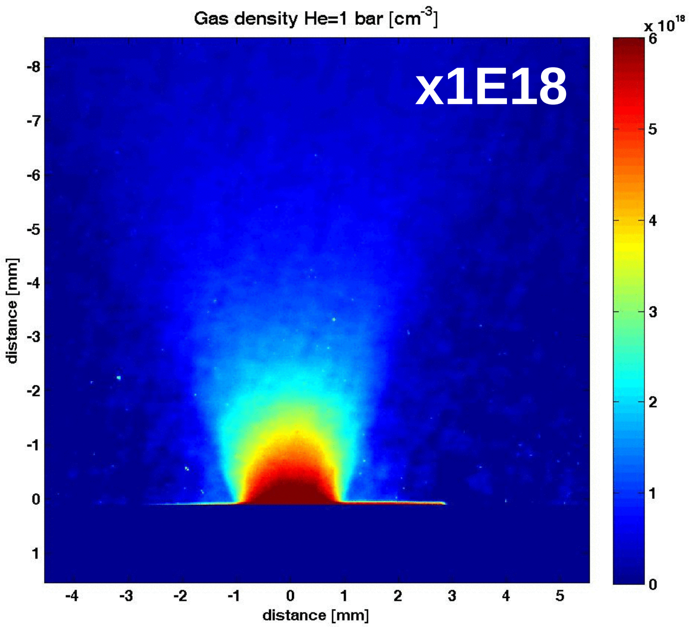
Cooled down targets for cluster experiments (University of Illinois, Chicago)



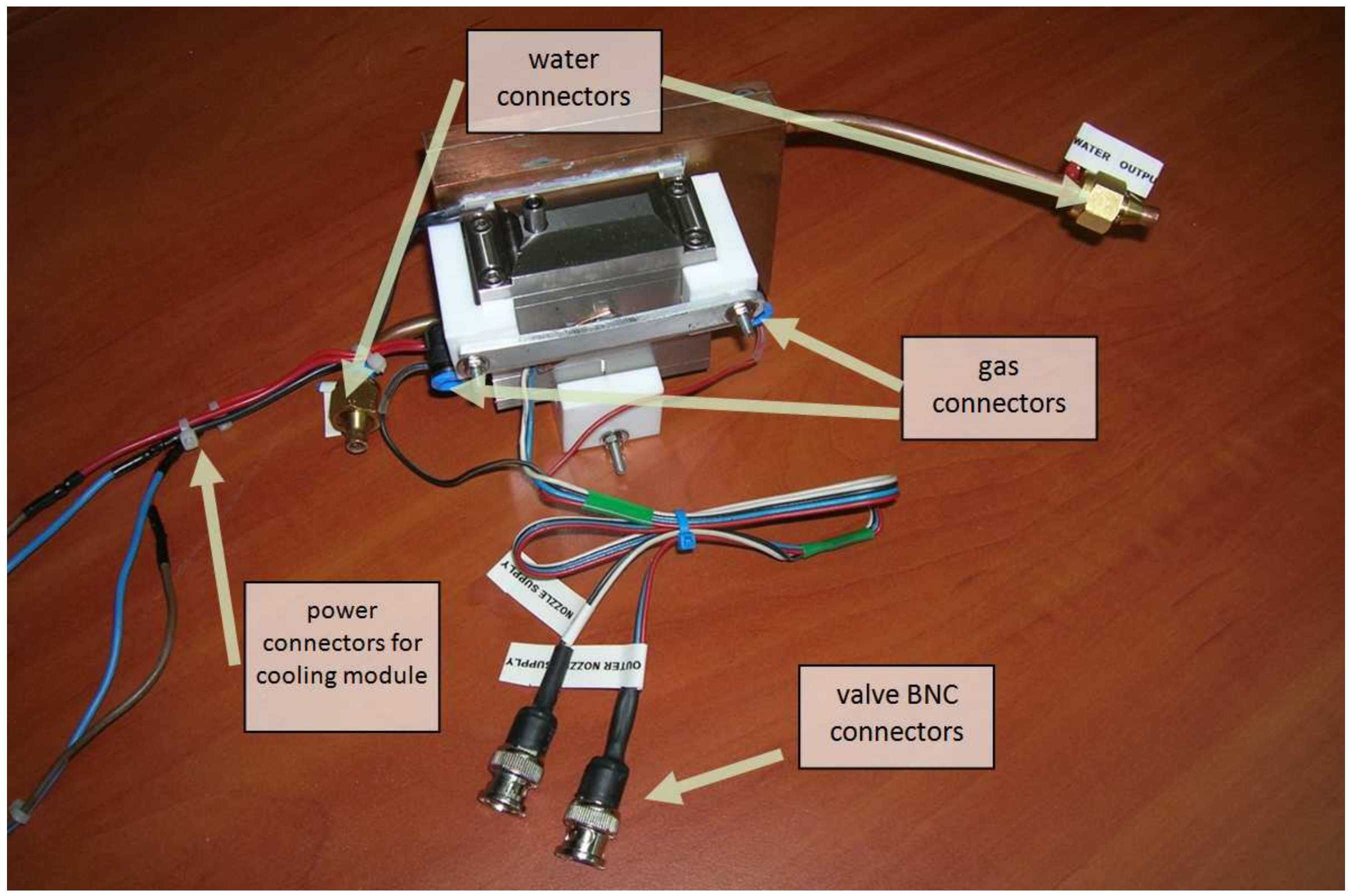
Requirements:

- High pressure electromagnetic valve
- Inner nozzle diameter >**2mm**
- Target density **~10^{18} at/cm^3**
- Termoelectric cooling **-25°C**

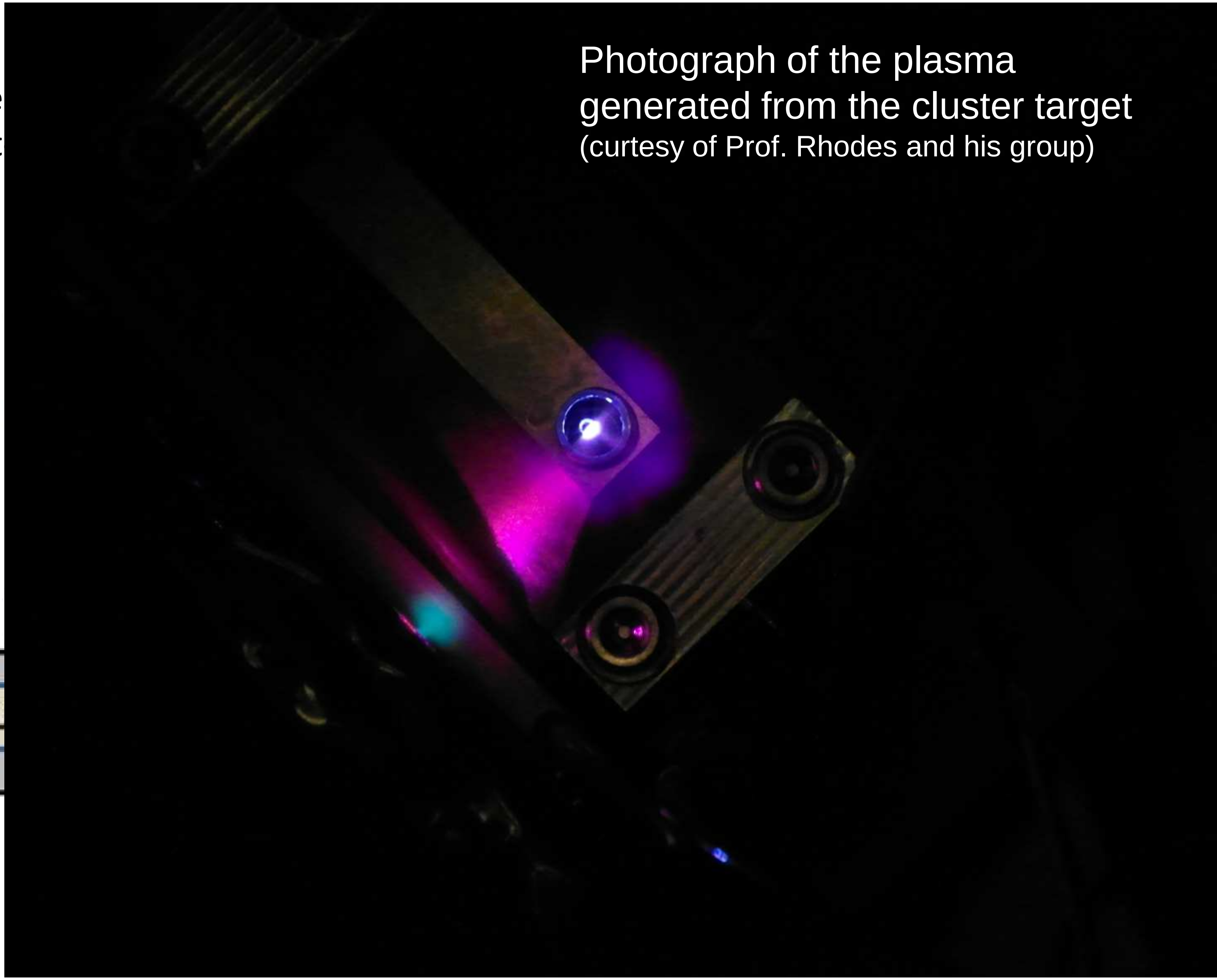
X-Ray Microimaging and Bioinformatics Laboratory (Prof. Rhodes)



P_{Ar} = 4 bar, P_{He} = 1-6 bar, 10 EUV pulses, T= -28°C, t_{open} = 2ms



Sche
clust



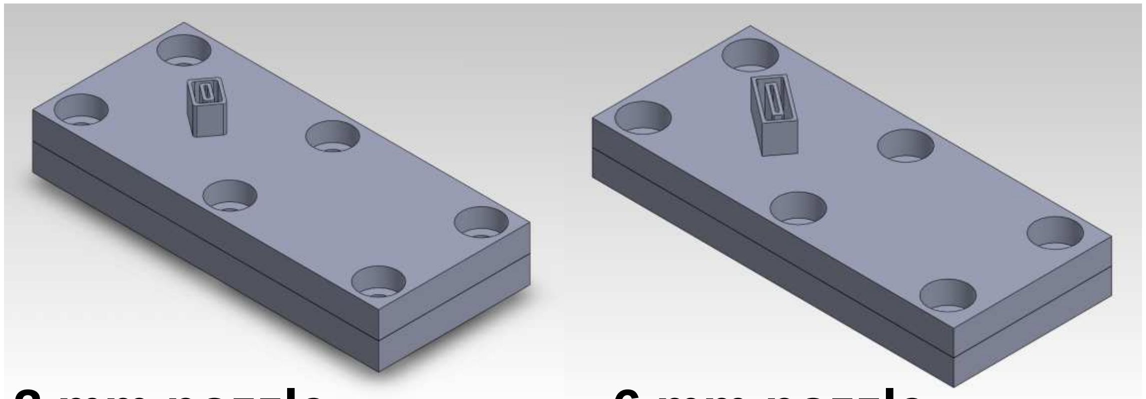
Photograph of the plasma generated from the cluster target
(curtesy of Prof. Rhodes and his group)

outlet

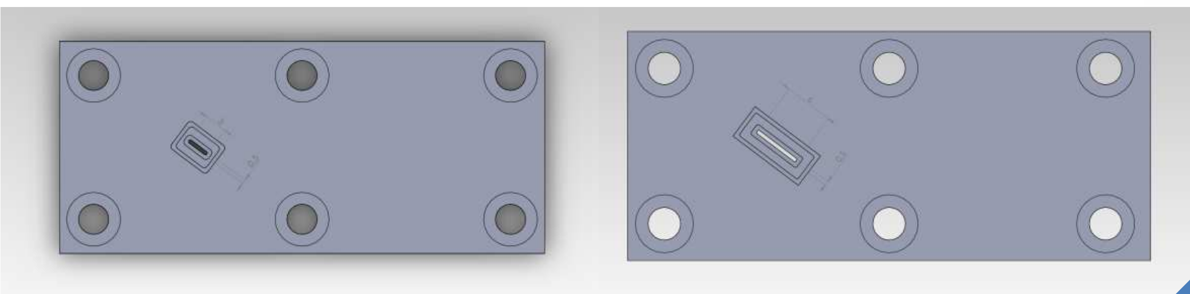
EUV radiography (Ar gas)

Cooled down targets for cluster experiments

(University of Illinois, Chicago)



3 mm nozzle   6 mm nozzle

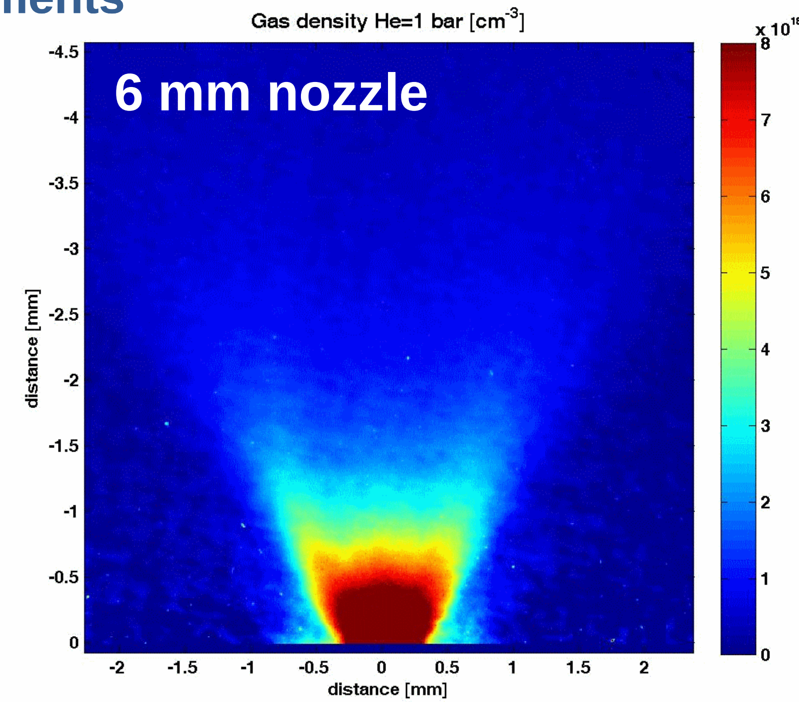


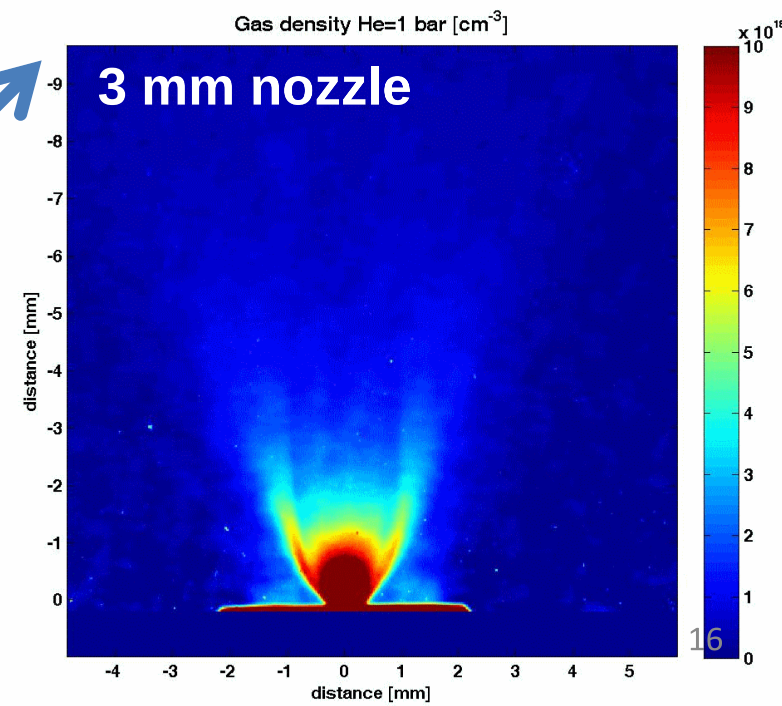
Requirements:

- Inner slit width **500µm**,
- Slit length : **3 mm and 6 mm**
- Nozzle @ **37deg** angle
- Pressures up to 5 bar
- Gas dentity up to **10^{19} at/cm^3**
- Operation with repetition

Density measurements

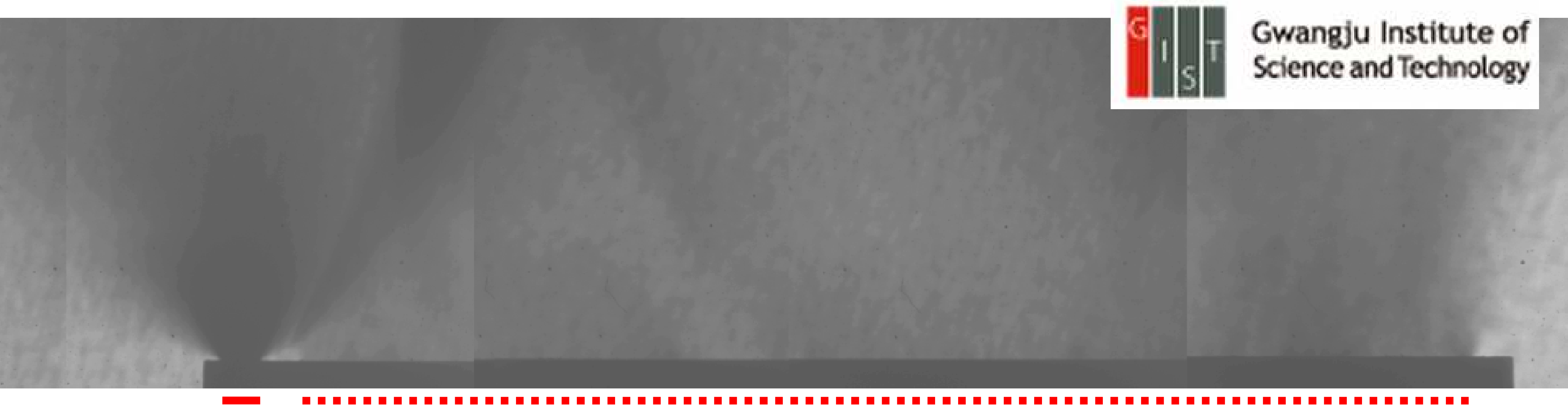
P_{Ar}=3 bar,
10 EUV pulses
P_{He}=1-5bar
t_{open} = 2ms
T= -28°C





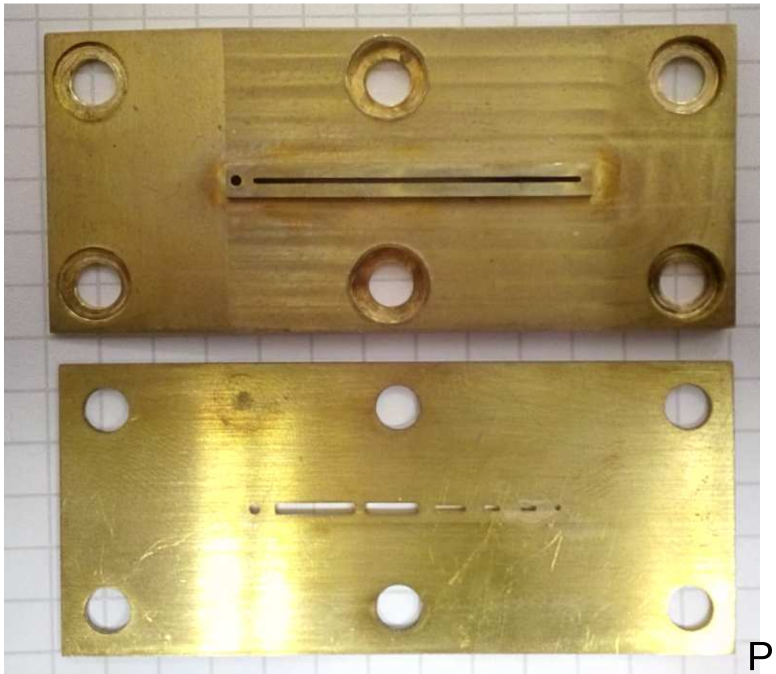
EUV radiography (Xe gas)

Structured target for high energy acceleration experiments (GIST, Korea)

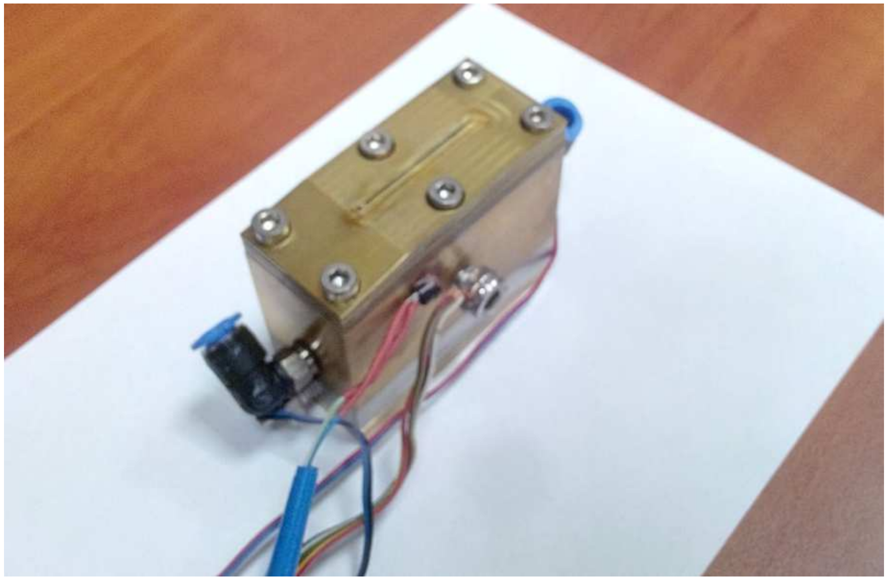


Source of electrons

Acceleration area – different density of gas



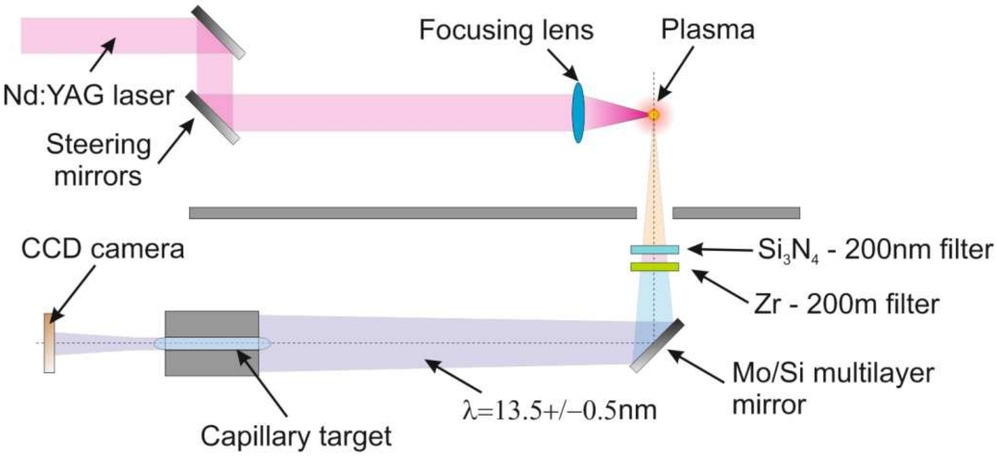
P_{Xe}=2 bar,
5 EUV pulses,
t_{open} =2 ms
(opimal time)
Dimensions
Source ϕ=1mm
Accelerator:
30mm x 0.5mm

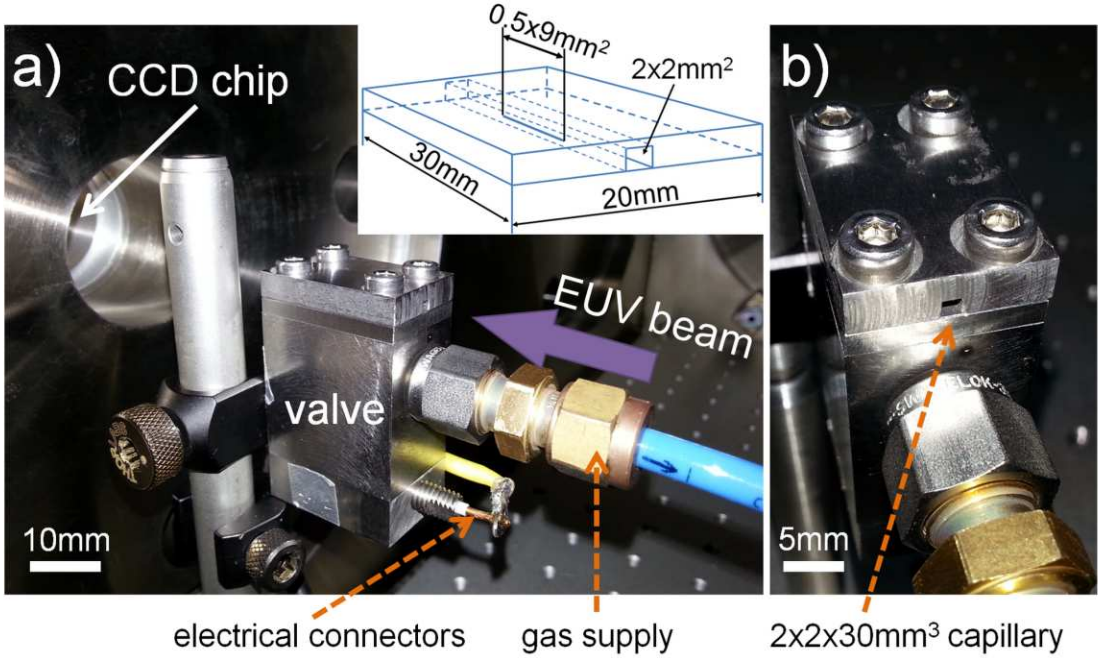


Proof of principle: Hyung Taek Kim, Phys. Rev. Lett. **111**, 165002 (2013)

Pulsed capillary channel gas puff target

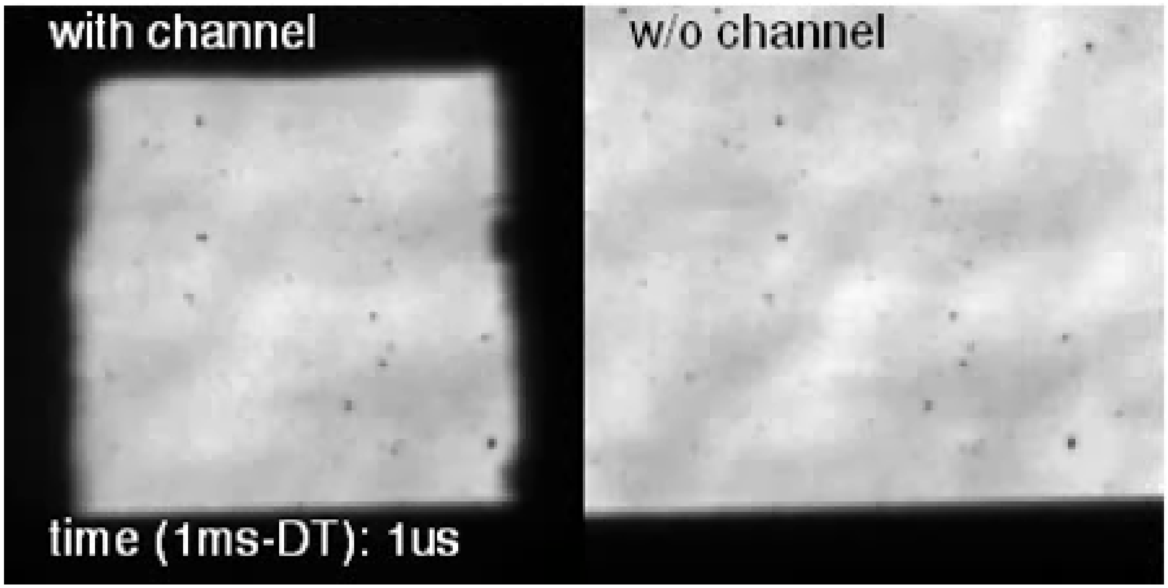
Shadowgraphy experimental setup





Merging two ideas: classical pulsed gas puff target and the capillary geometry

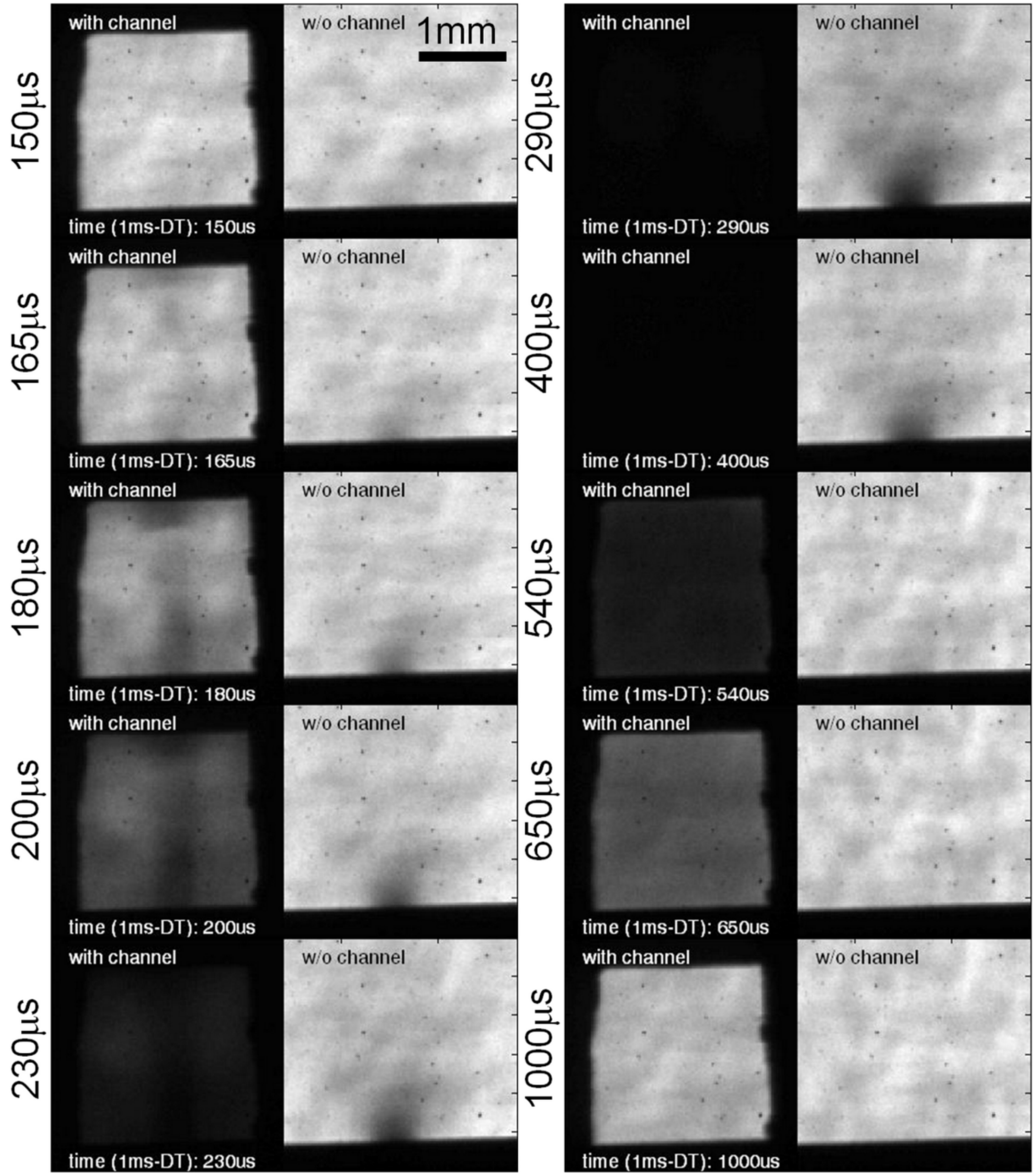
- ❑ capillary-like guiding and density profiles
- ❑ much higher densities possible
- ❑ pulsed operation – less stress on the pumps, allows additional optimization
- ❑ very easy to align in your system
- ❑ allows for synchronization with the laser (driver)

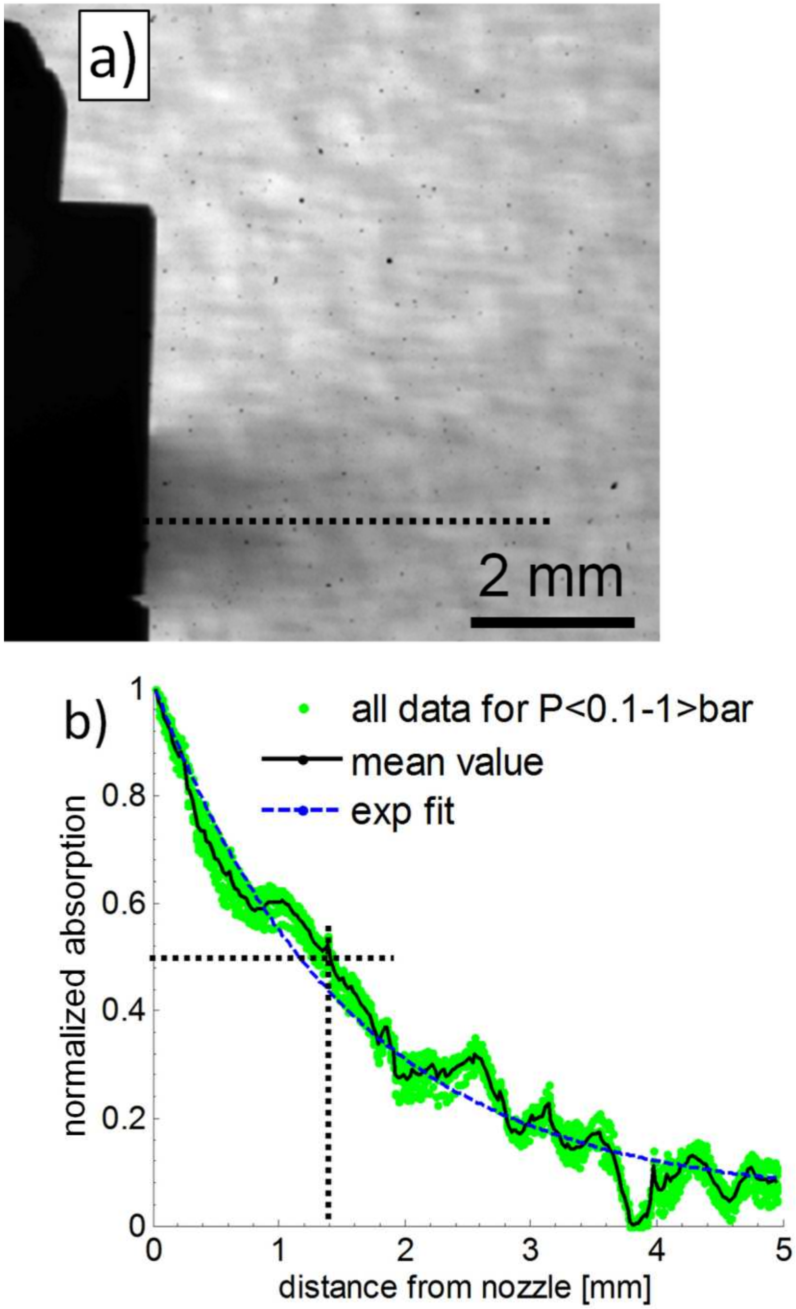


Wachulak et al. NIM B 342, 15-21 (2015)

Pulsed capillary channel gas puff target

Time resolved shadowgraphy results

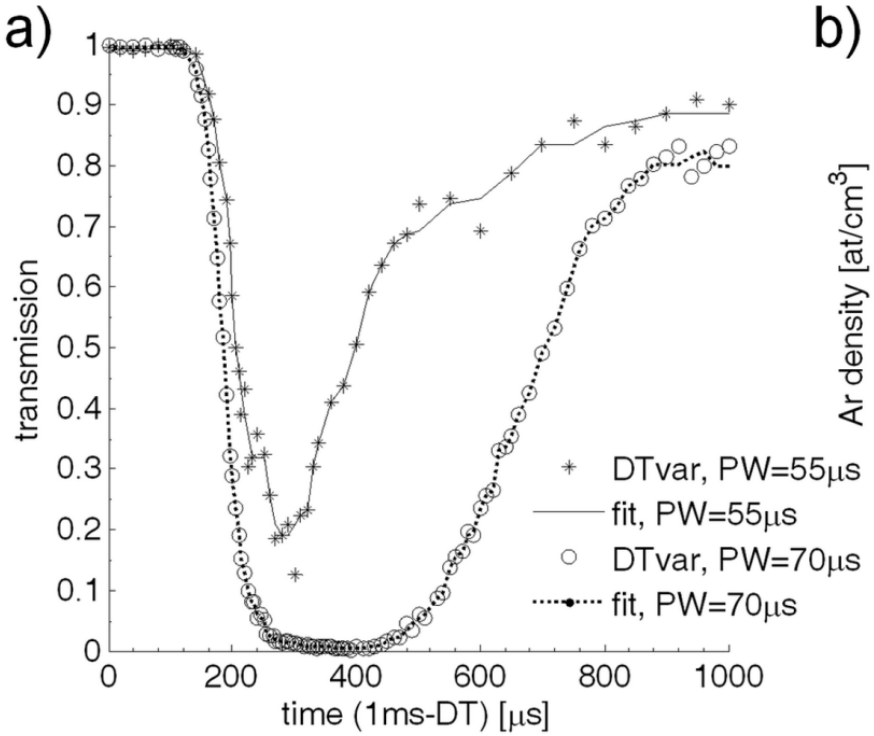


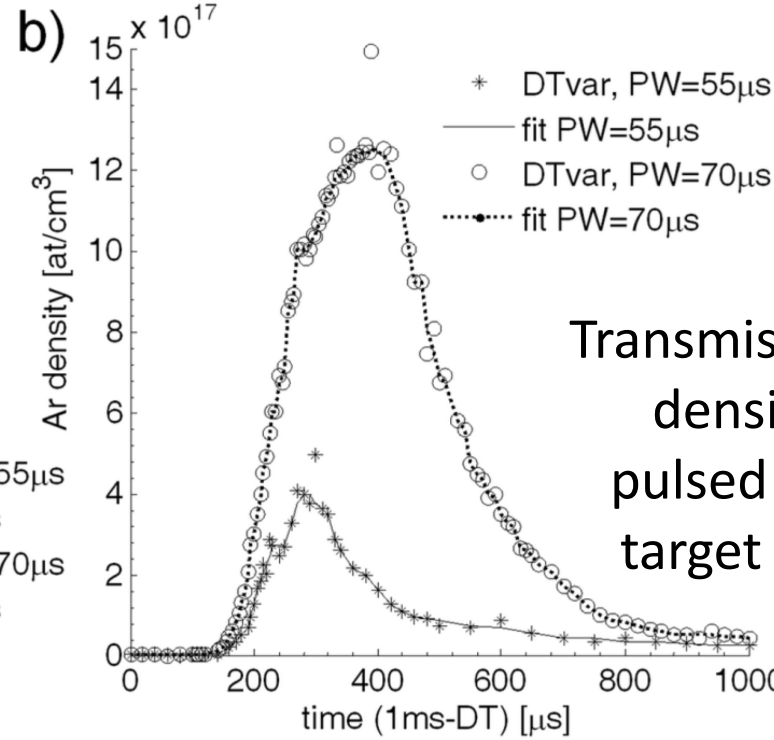


Wachulak et al. NIM B 342, 15-21 (2015)

Pulsed capillary channel gas puff target

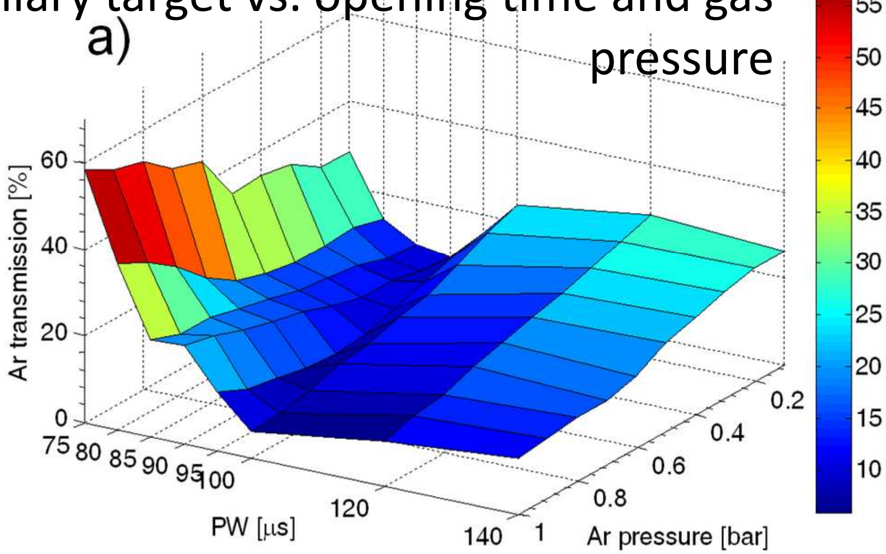
Density measurements

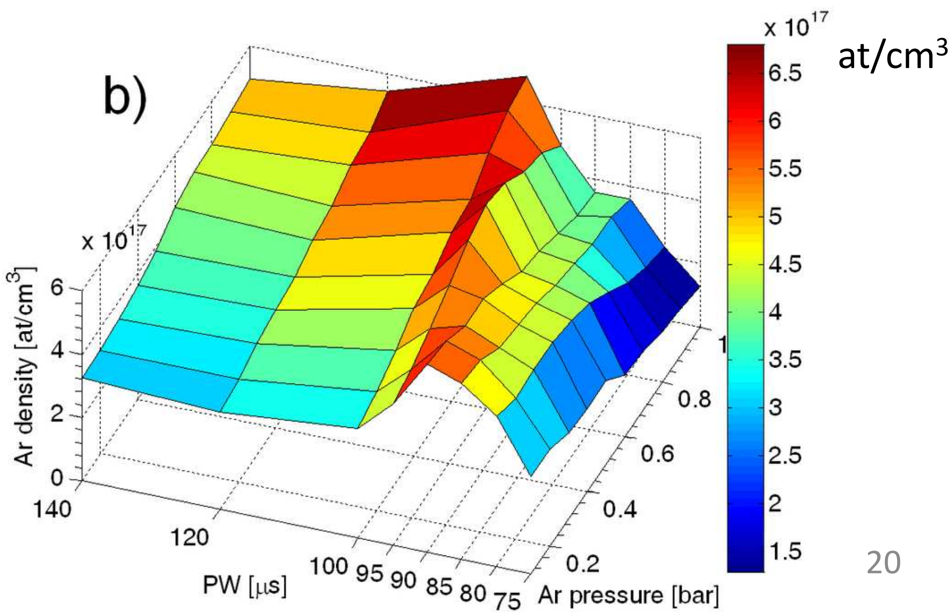




Transmission and density of the pulsed capillary target vs. delay time

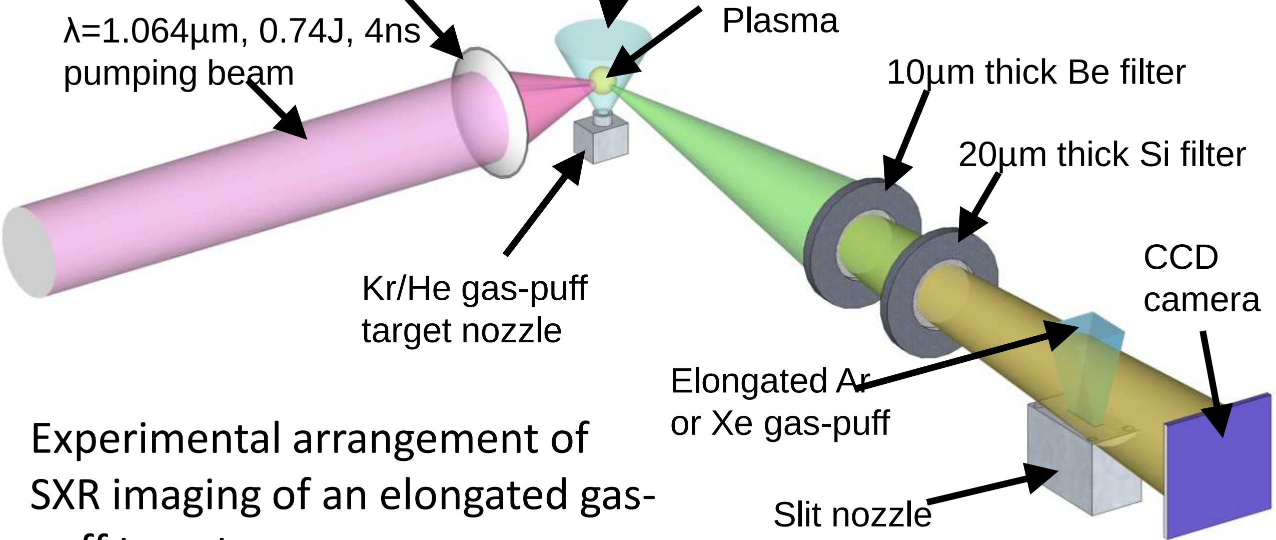
Transmission and density of the pulsed capillary target vs. opening time and gas pressure





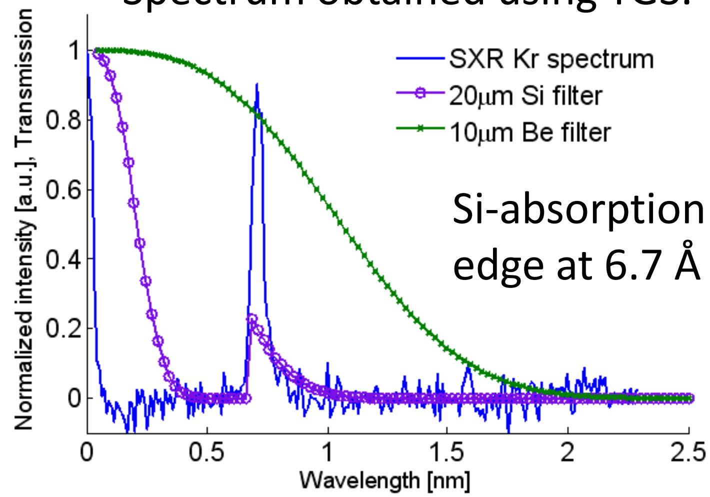
SXR radiography

Elongated gas targets

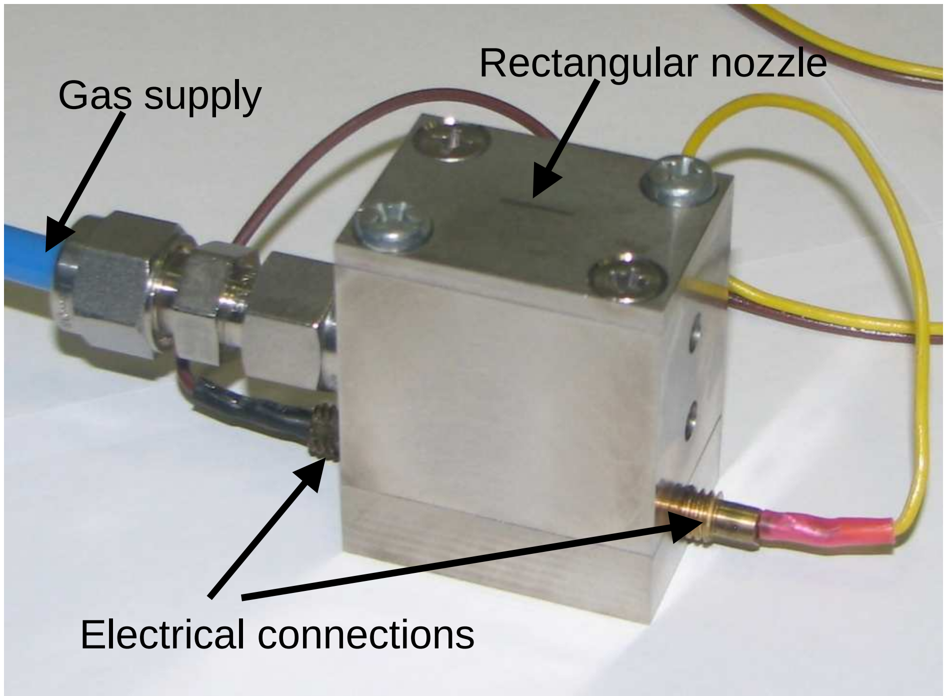


Experimental arrangement of SXR imaging of an elongated gas-puff target

Spectrum obtained using TGS.



Be filter - to block the radiation at longer wavelengths. Transmission curves for both filters are based on data available from CXRO



Photograph of the elongated, slit-shaped nozzle valve

Experimental details:

Xe/He gas puff target source,

Be 10µm + Si 20µm,

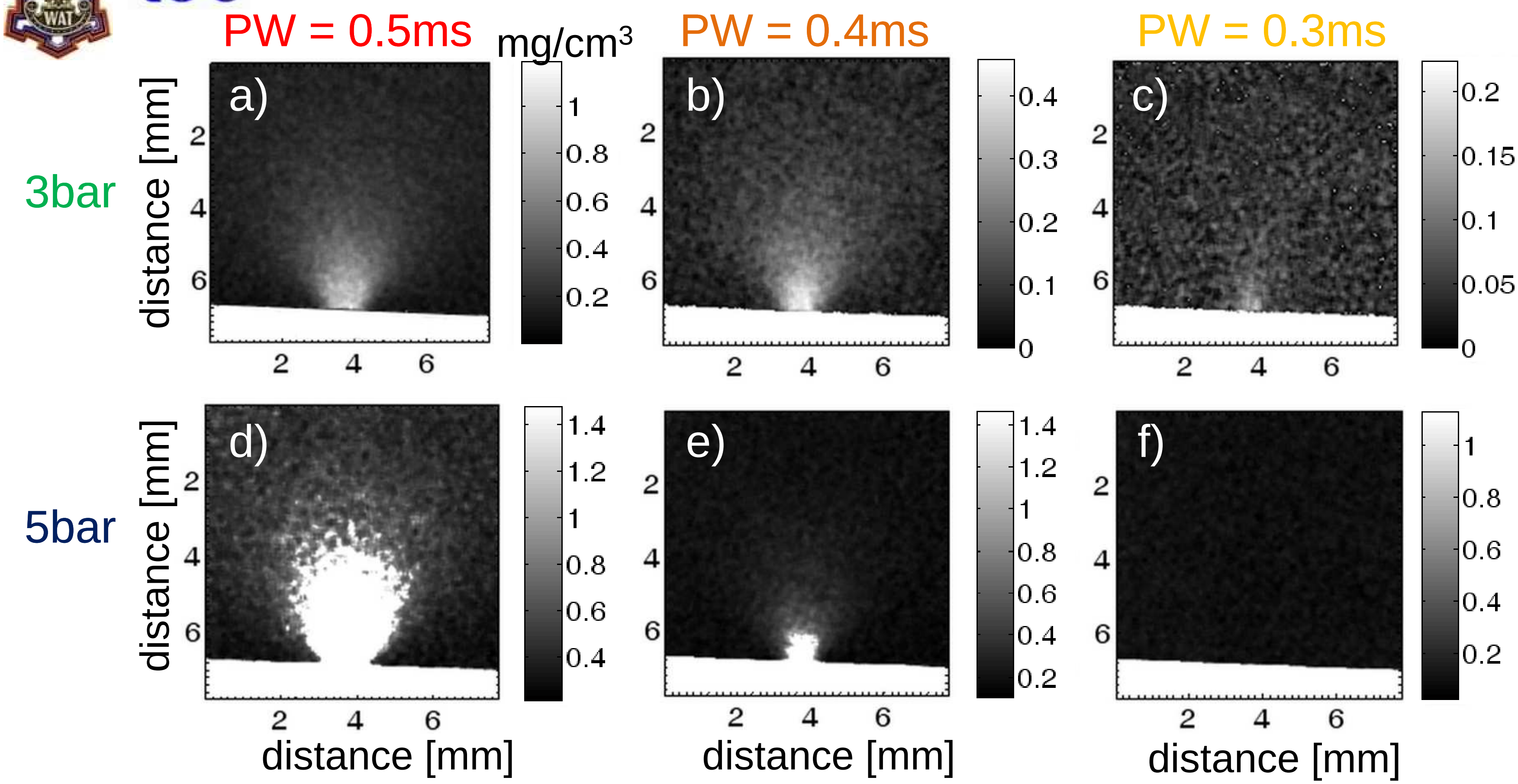
CCD camera: X-Vision M-25, Reflex, 512x 512 pix, 0.5x0.5in^2 in size,

Magnification: ~1.15x

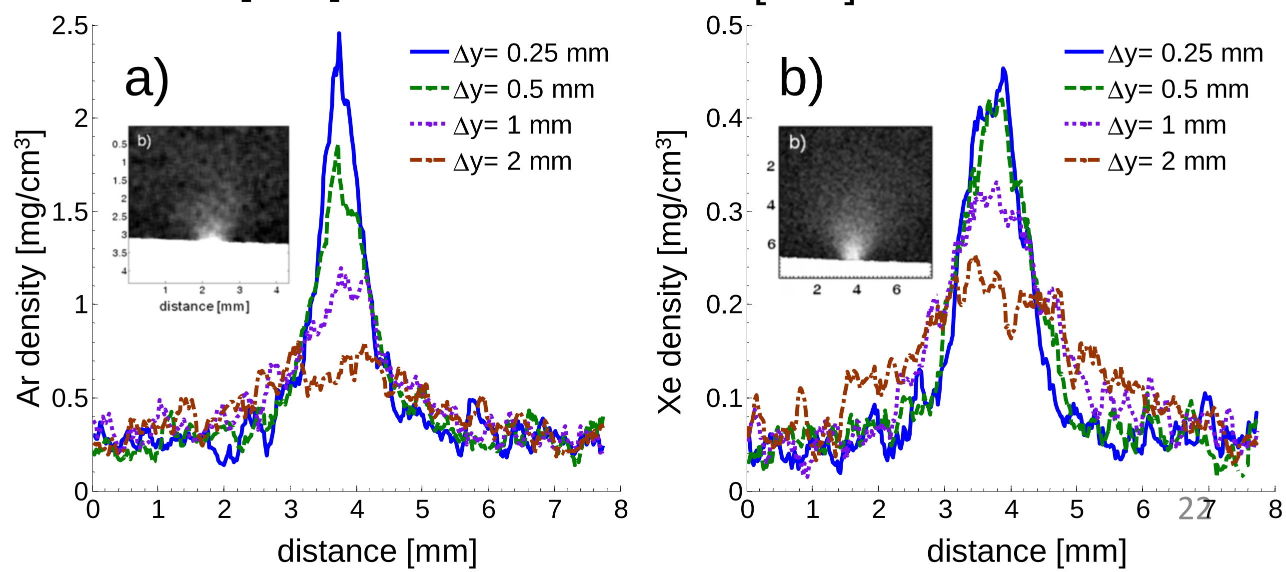
Acquisition time: 100 SXR pulses

P.W. Wachulak, A. Bartnik, H. Fiedorowicz, R. Jarocki, J. Kostecki, M. Szczurek, **Nuclear Inst. and Methods in Physics Research, B 276, 1, 38-43, (2012)** DOI information: 10.1016/j.nimb.2012.01.029

SXR radiography (results)



2-D target density maps – backlighting images for **Xe target** at different conditions

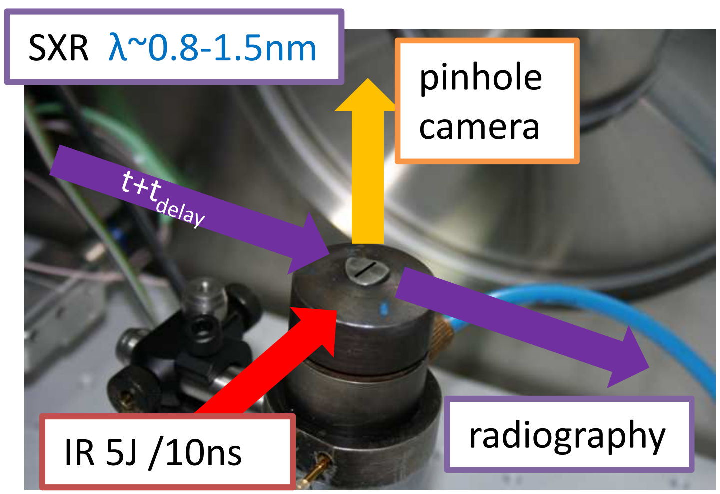


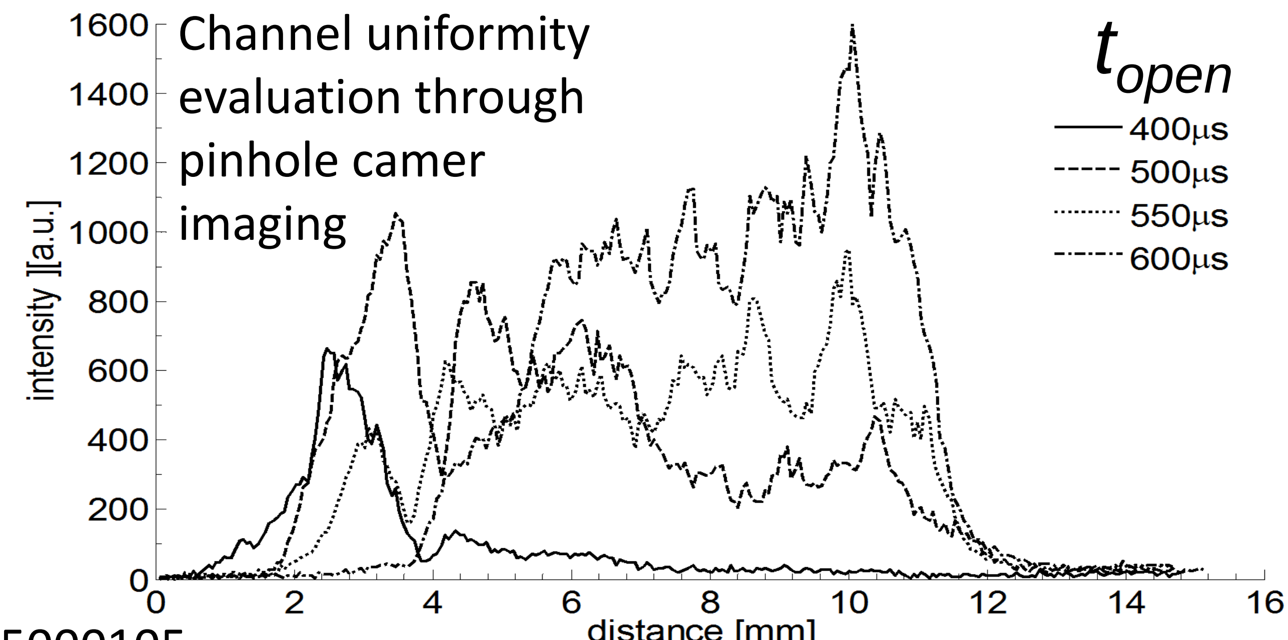
Density profiles through the 2-D density maps for (a) – **Ar**, (b) – **Xe**, Δy – distance fron the nozzle.

SXR radiography (exp. results)

Comparison images

Comparison of plasma channel images:
-VIS light photo
-EUV (pinhole)
-SXR radiogram





P. Wachulak et al., LPB (2015) - online, doi:10.1017/S0263034615000105

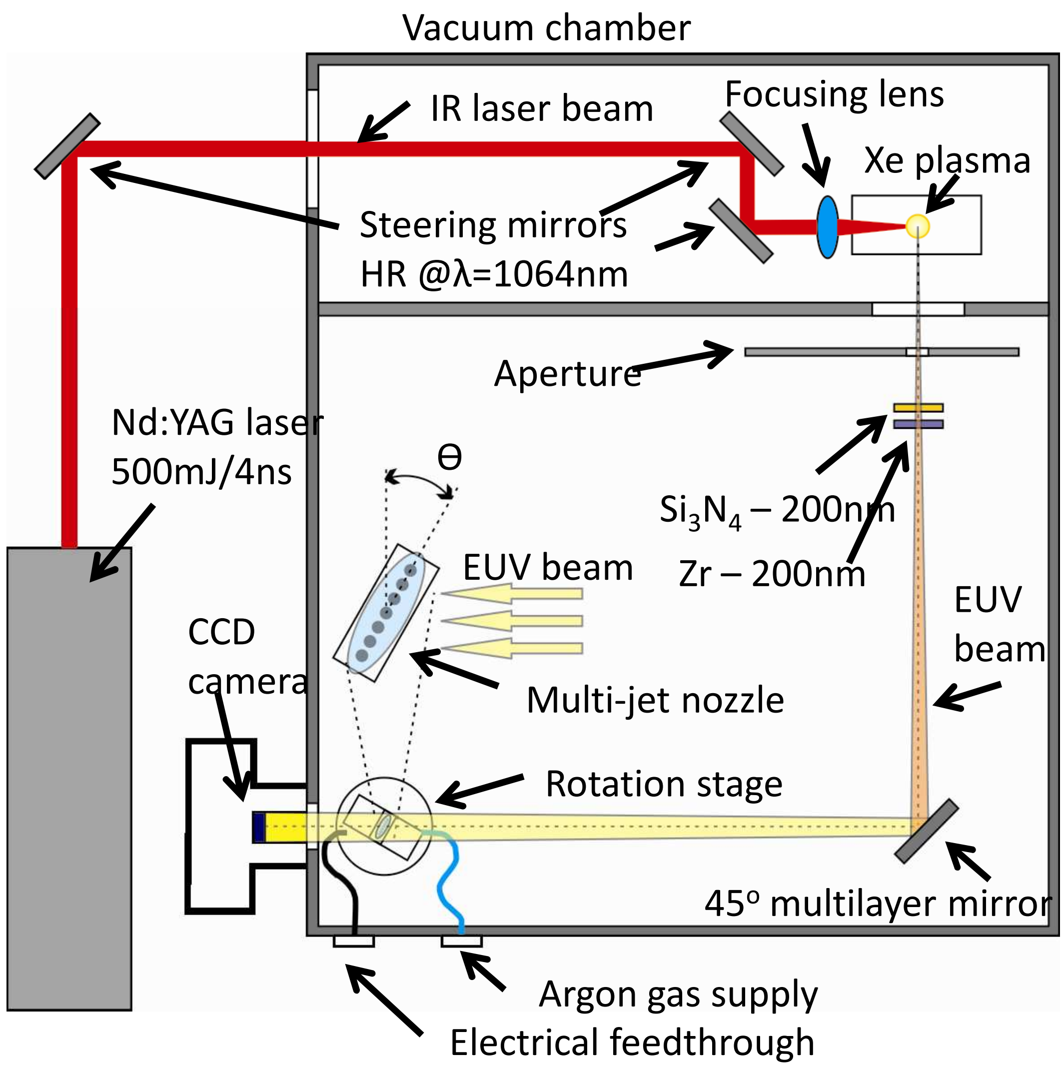
Gas puff target EUV laser-plasma short wavelength source employed for tomography

LMI

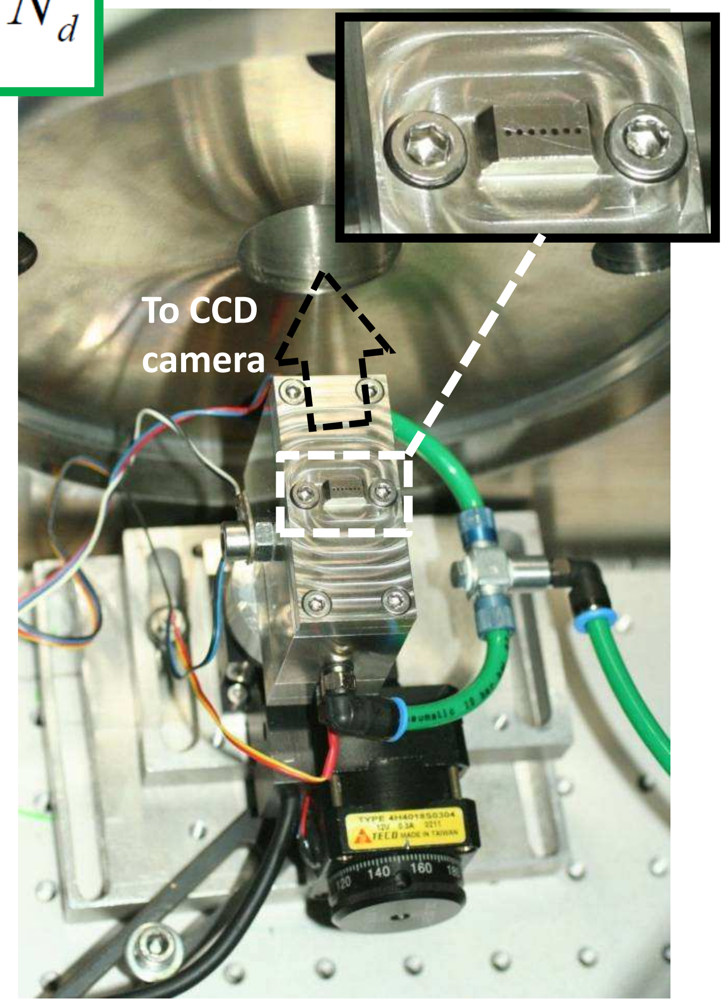
Experimental details:

Xe/He gas puff target source, Si_3N_4 200nm thick membrane + 200nm thick Zirconium filter,
CCD camera: X-Vision M-25, Reflex, Nd=512x 512 pix, 0.5x0.5in^2 in size, each pixel 25.4x25.4 μm^2
Multilayer mirror: Mo/Si, peak R=38% @ λ=13.5nm, Magnification: ~1.16x
Acquisition time: 5 EUV pulses per projection, Np=900 projections every 0.4°

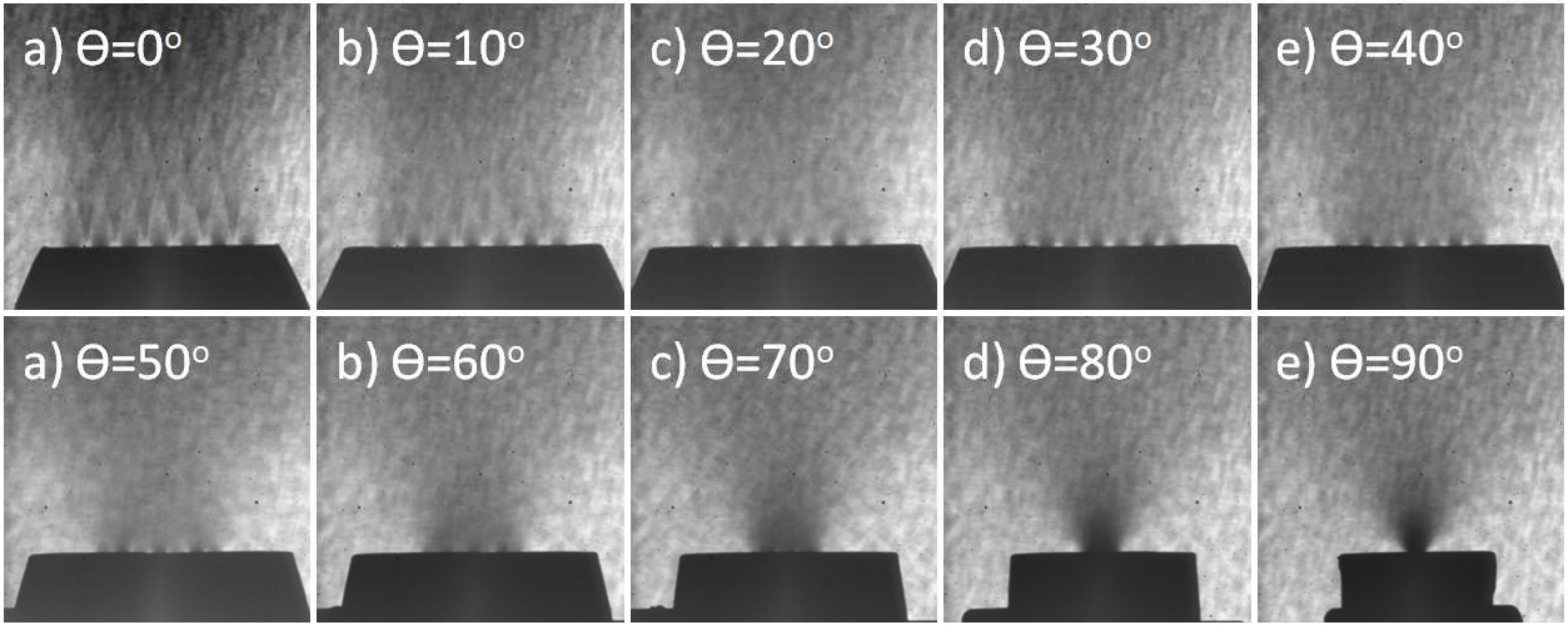
$$N_p \geq \frac{\pi}{2} \cdot N_d$$



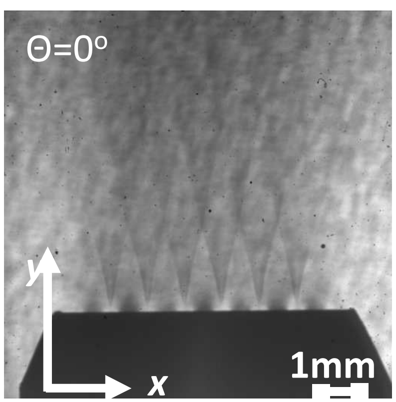
Scheme of the EUV tomography using laser-plasma EUV source

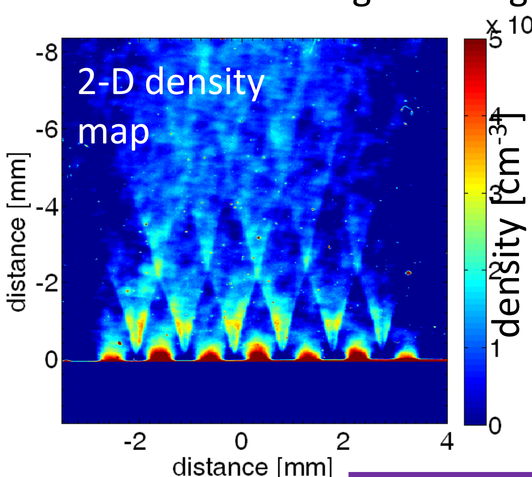


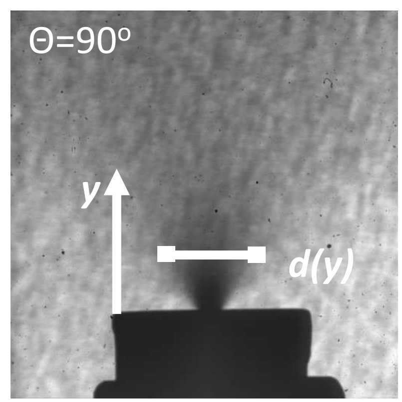
Acquiring projections/radiograms and density calculations



Sequence of a few EUV shadowgram images of the target over π/2 rotation angle







$\mu_a = 2r_0 \cdot \lambda \cdot f_2$ - atomic photoabsorption cross-section

$r_0 = 2.82 \cdot 10^{-15} m$
- classical electron radius

λ= 13.5nm – wavelength

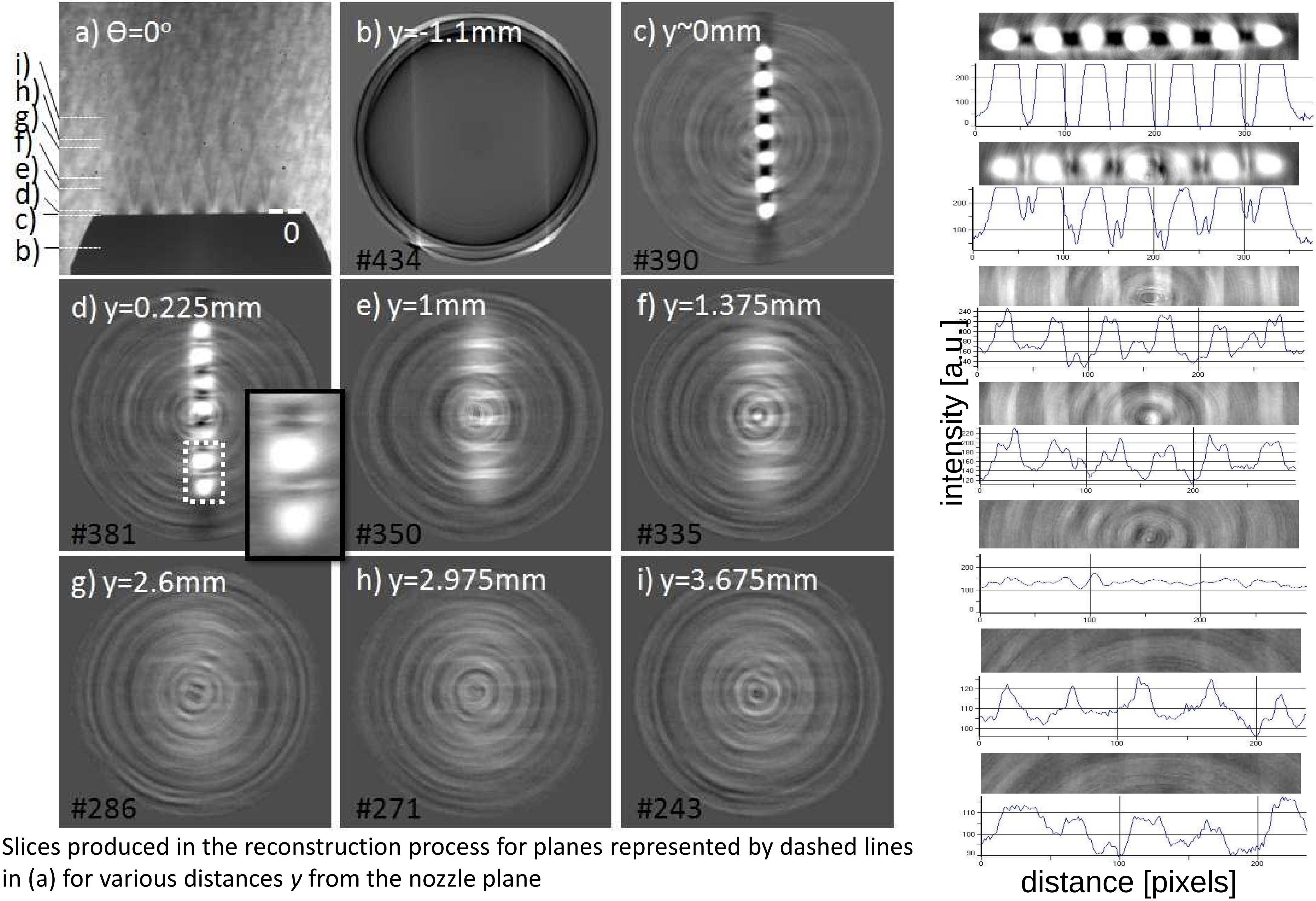
f_2 - is the imaginary part of the atomic scattering factor

d(y) - is the path-length on which the EUV beam is absorbed in the gas

$$\rho(x,y) = \frac{-\ln\left[Tr(x,y)\right]}{\mu_a \cdot d(y)} \cdot m_{at}$$

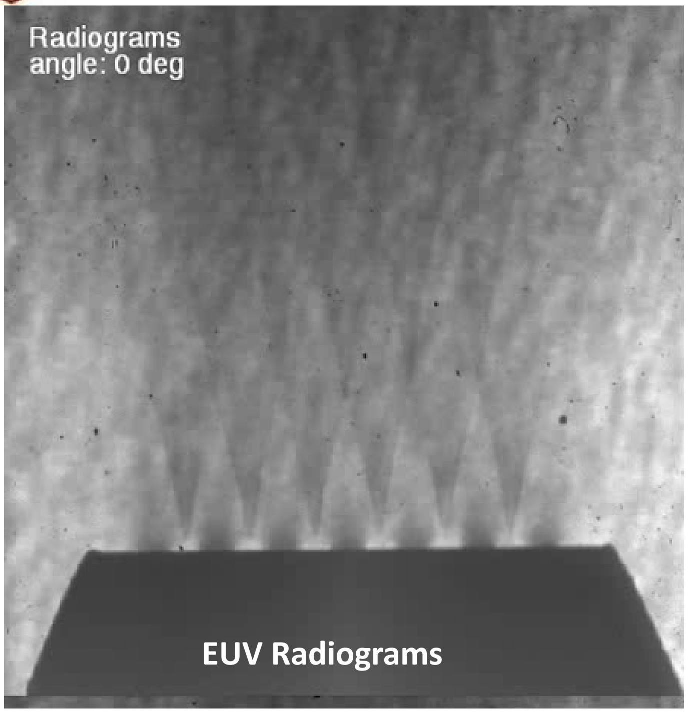
Wachulak et al., ***Optics Letters 39, 3, 532-535 (2014)***
Wachulak et al., ***Applied Physics B, online: DOI 10.1007/s00340-014-5829-7 (2014)***

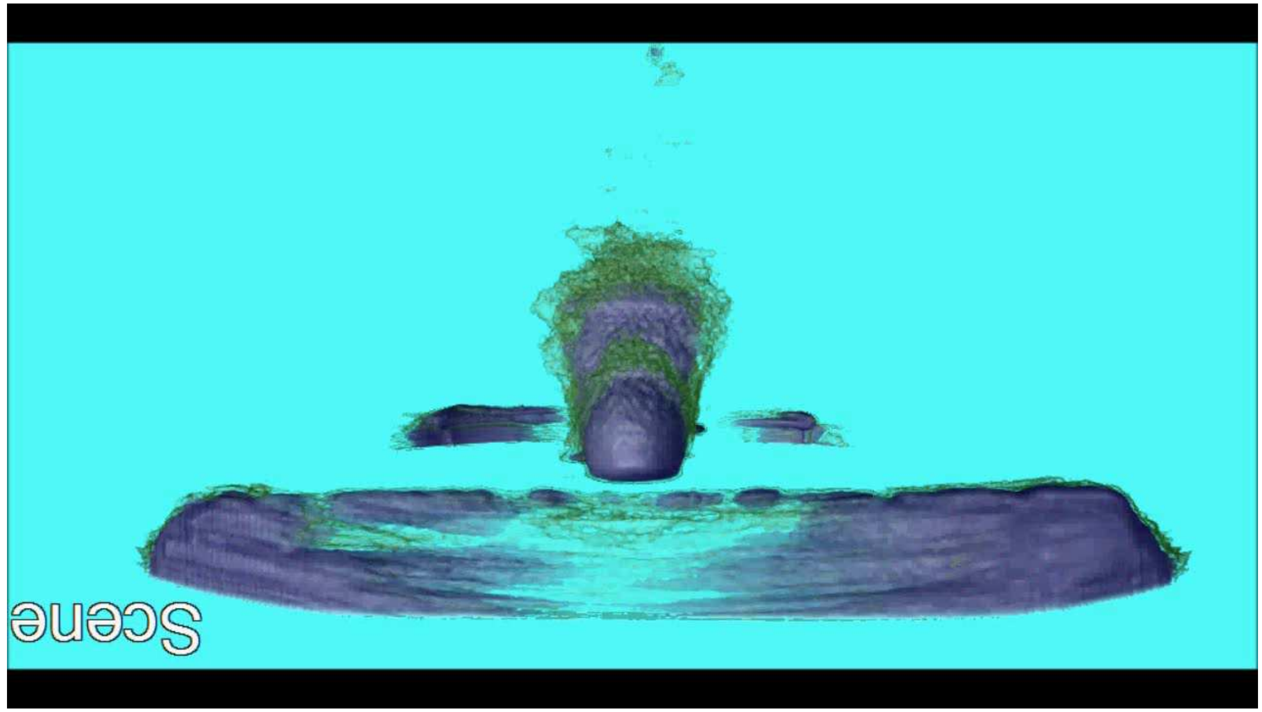
EUV tomography of a gaseous target - results



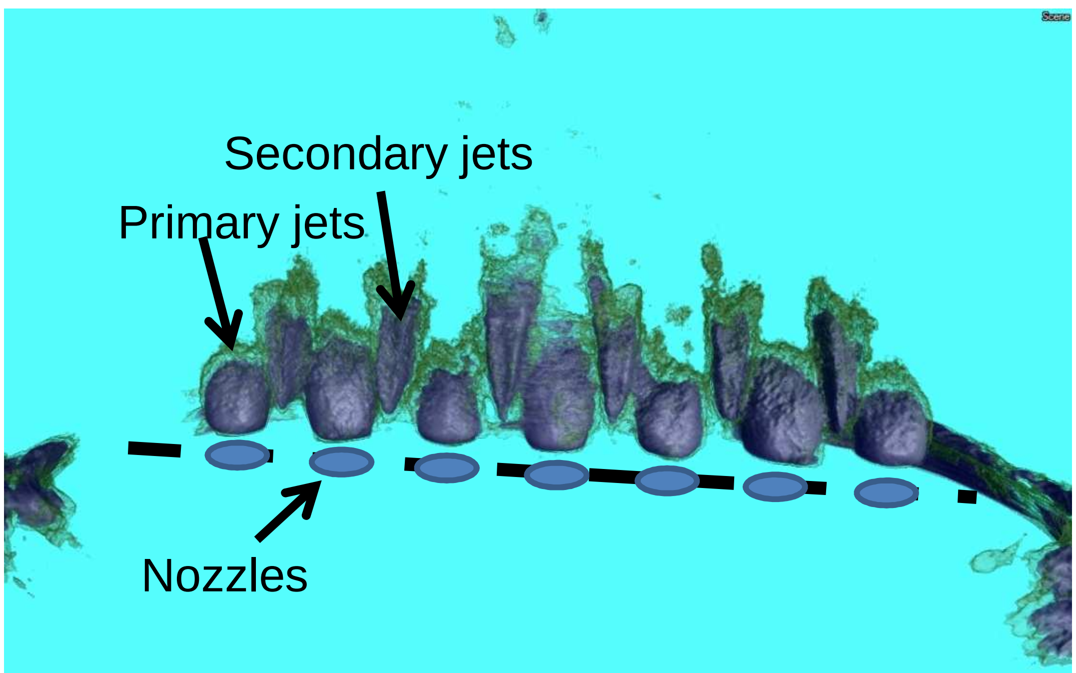
Slices produced in the reconstruction process for planes represented by dashed lines in (a) for various distances *y* from the nozzle plane

3-D EUV reconstructions + rendering





Three-dimensional visualization of the reconstructed gas puff target showing primary and secondary gas jets.



Octopus - processing of 2D radiography projections into CT slices.
VGStudio 2.1.5 (http://www.volumegraphics.com) - stacking of CT slices and for the 3D rendering and visualization

P. Wachulak, et al., ***Optics Letters 39, 532 (2014)***
P. Wachulak et al., ***Applied Physics B 117, 1, 253-263 (2014), DOI 10.1007/s00340-014-5829-7***

Summary and Conclusions

LMI

✓ well-known imaging techniques radiography and tomography were presented and applied in EUV and SXR spectral region to various geometry gaseous targets

✓ various geometries, timing, pressure conditions , etc. of the gas puff targets were investigated,

✓ varius applications of such targets were shown

✓ we are hoping thos … tions related to gas puff target applications, … s and development of plasma medium for X-ra…

Thank you for your attention

…ts

LMI

Laser Matter Interaction Laboratory
http://www.ztl.wat.edu.pl/zoplzm/

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