FIZINIŲ IR TECHNOLOGIJOS MOKSLŲ CENTRAS

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The control of laser wakefield accelerated electron beams and betatron X-ray radiation using multiple gas jet arrays

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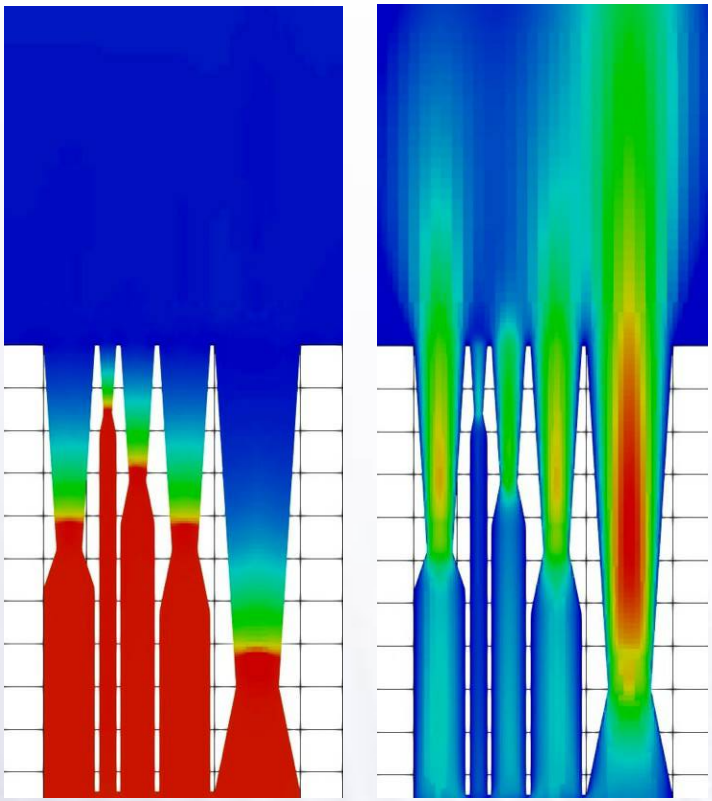
[2]Vytautas Magnus University, Kaunas, Lithuania
[3]Department of Physics, Lund University, Lund, Sweden

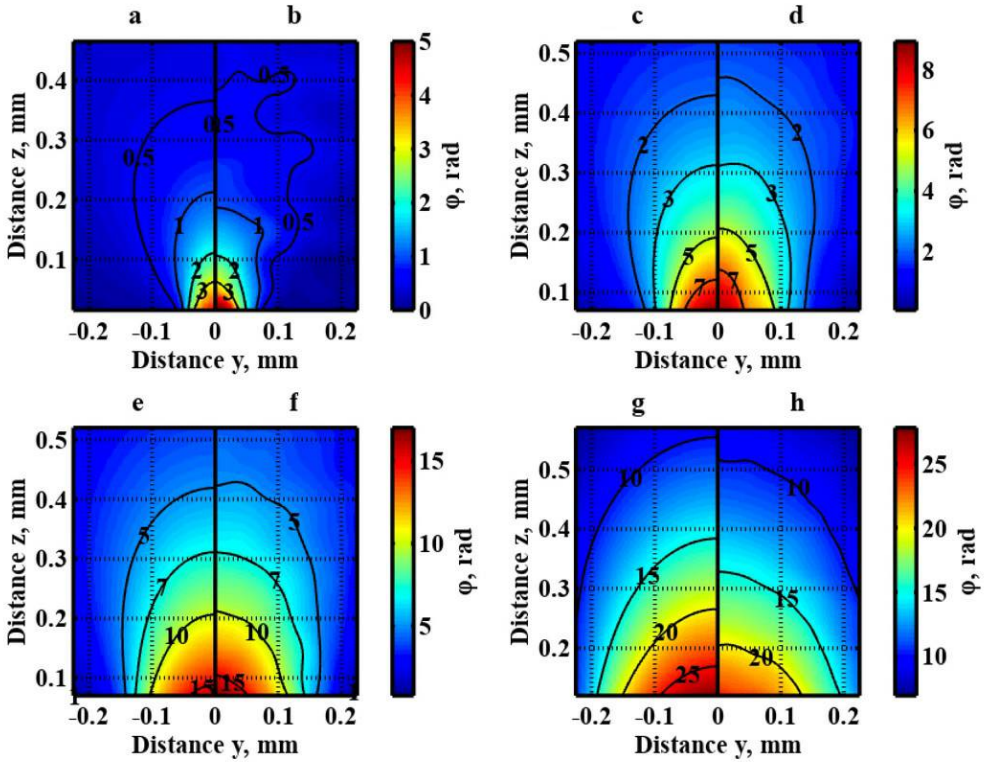
Split | May 7, 2019

Scope of the Project

- The development of tabletop X-ray sources used at the modest scale of research facilities requires the improvement in efficiency of Laser Plasma Wakefield Accelerators (LWFA) and the design of betatron sources with higher critical energy
- In this report, we present the results of LWFA and X-ray generation using monolithic gas jet microarrays manufactured from fused silica at the 40 TW 30 fs Lund Laser Centre
- Density-triggered injection of electrons by single-nozzle and multiple-nozzle array with following acceleration was investigated
- Two-stage nozzle arrays were used for laser electron acceleration in plasma region with lower plasma concentration and following higher plasma density region, acting as an efficient betatron radiator

Open Foam CFD Simulation





#8 nozzle ◎ Laval 2.25 mm
#15 nozzle ❒ Laval slit 1.5 mm

#11 nozzle ◎ 2.25 mm Laval - 1 x 800 µm
#58 nozzle ❒ 1.5 mm Laval - 1 x 300 µm
#44 nozzle ❒ 1.5 mm - 4 x 200 µm
#45 nozzle ◎ 2.25 mm - 4 x 200 µm

OpenCFD Ltd., https://www.openfoam.com/

Characterisation of the Nozzles

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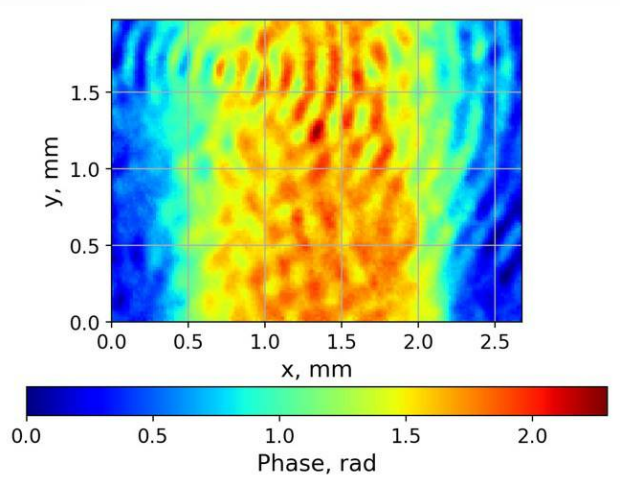
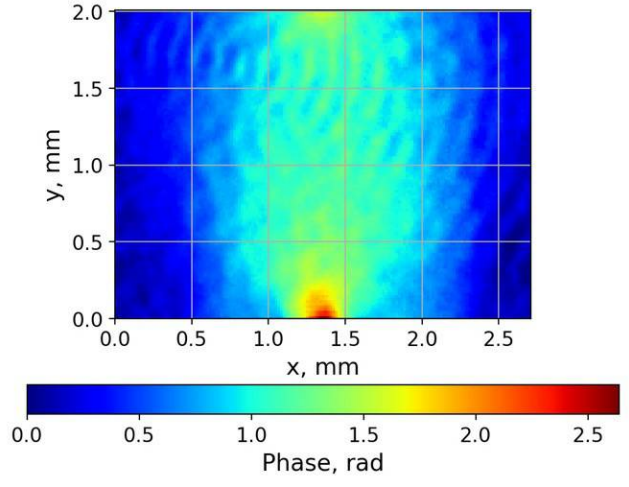
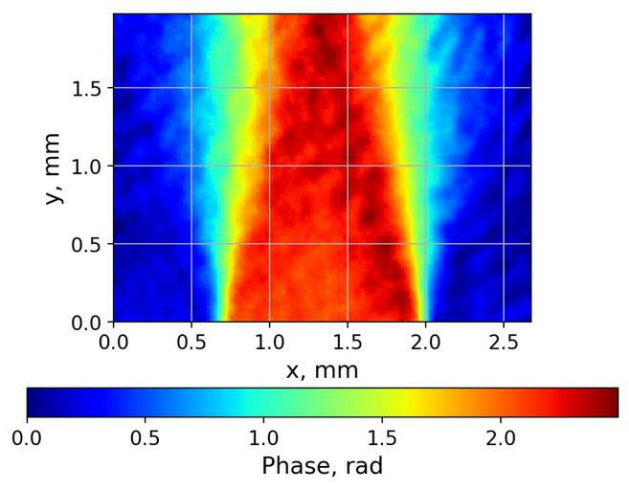
#8 nozzle
◎ 2.25 mm
p = 30 bar

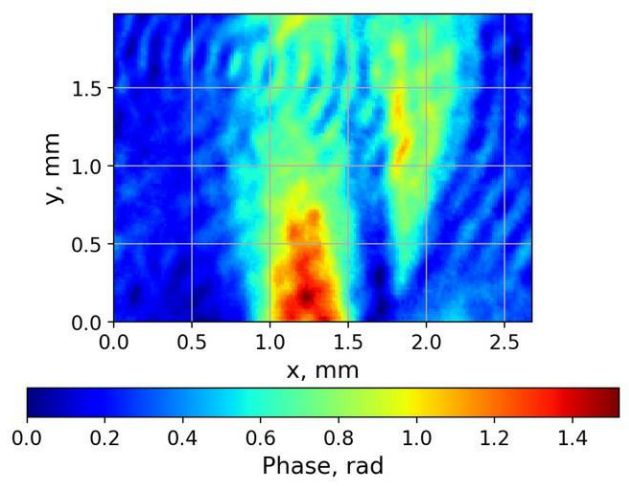




#11 nozzle
◎ 2.25 mm
1 x 800 µm
p = 25 bar

#15 nozzle
❒ 1.5 mm
p = 30 bar





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FBPIC Simulation of LWFA

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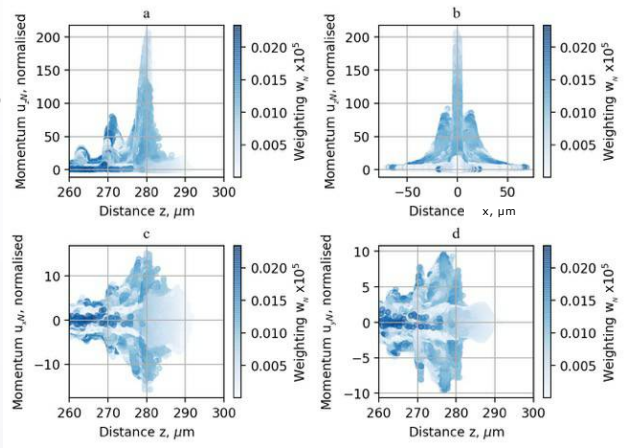
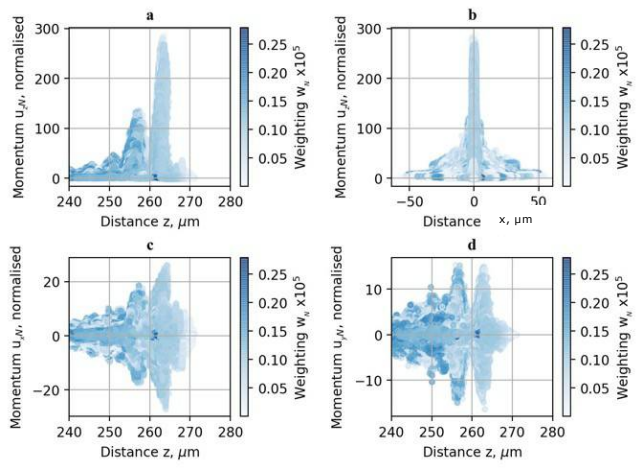
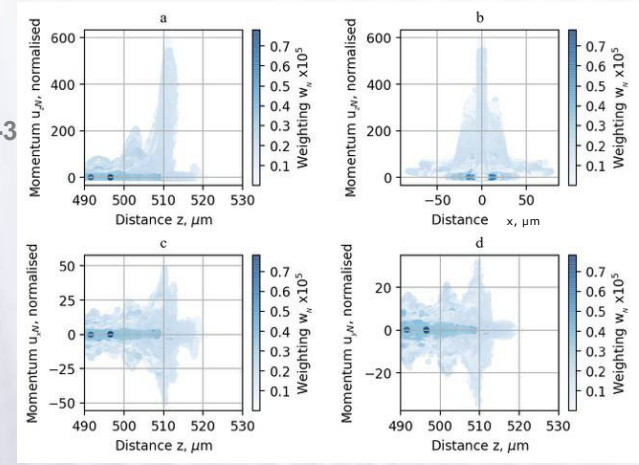
5400 step
270 μm a_0=2
0.5% 3e18 cm^{-3}
30 fs – 8.0 μm



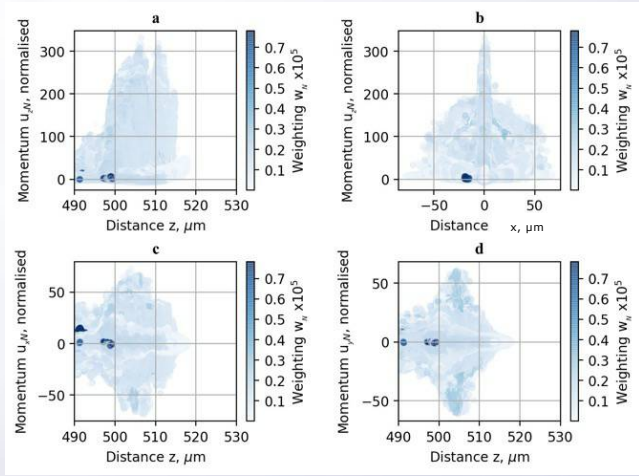
5400 step
270 μm a_0=2
1% 2e19 cm^{-3}
30 fs – 8.0 μm



10000 step
500 μm a_0=3
0.5% 3e18 cm^{-3}
30 fs – 8.0 μm



10000 step
500 μm a_0=3
1% 2e19 cm^{-3}
30 fs – 8.0 μm



R. Lehe et al. , Comp. Phys. Comm., 203, 66-82 (2016)

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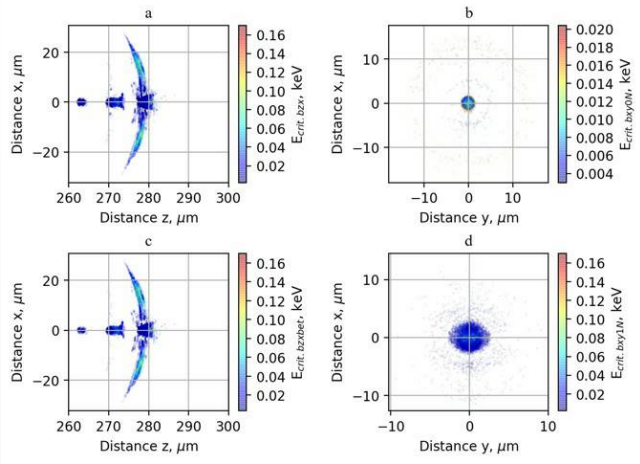
Postprocessing of FBPIC simulation

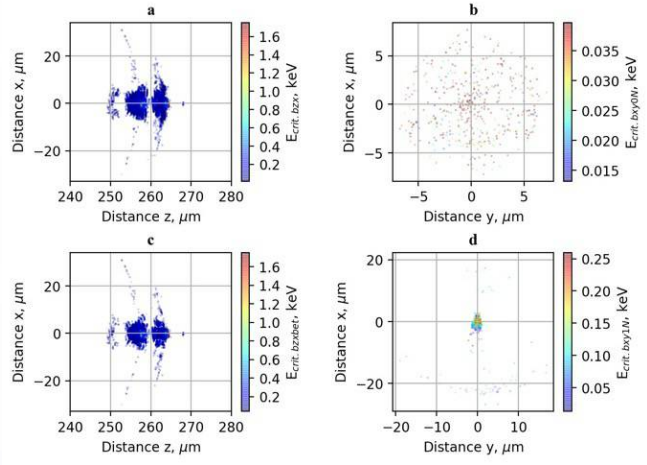
FIZINIŲ IR TECHNOLOGIJOS MOKSLŲ CENTRAS

5400 step
270 μm a_0=2
0.5% 3e18 cm^{-3}
30 fs – 8.0 μm



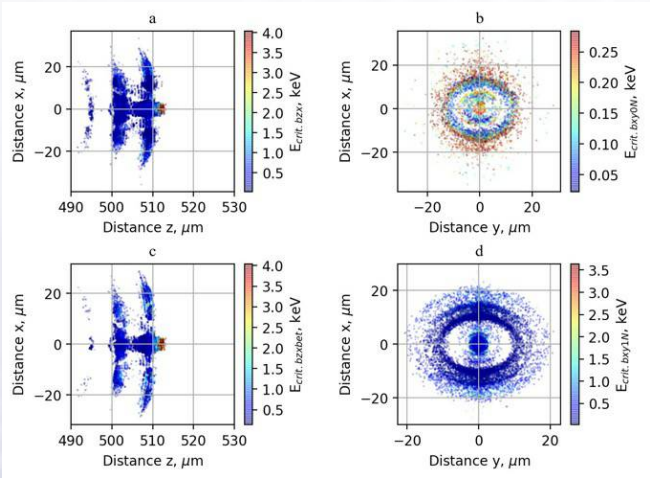
5400 step
270 μm a_0=2
1% 2e19 cm^{-3}
30 fs – 8.0 μm

$$\nu = \frac{r_0^2}{2\gamma_z}$$



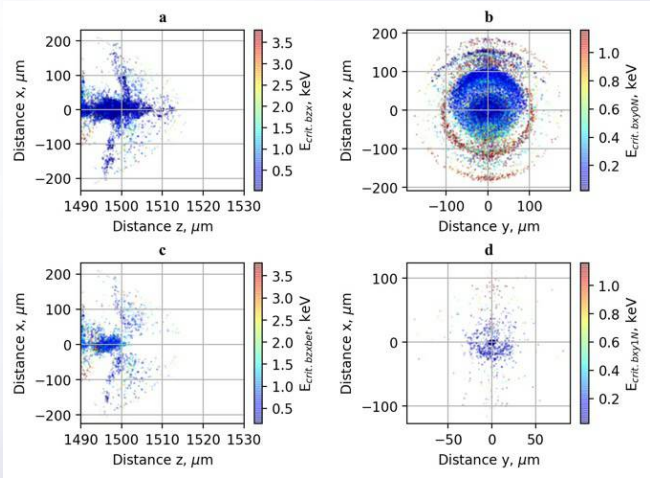
10000 step
500 μm a_0=3
0.5% 3e18 cm^{-3}
30 fs – 8.0 μm

$$r_0^2 = \frac{2p_\perp^2}{\gamma_z}$$



10000 step
500 μm a_0=3
1% 2e19 cm^{-3}
30 fs – 8.0 μm

$$\nu = \frac{p_x^2}{\gamma_z^2} = \frac{p_\perp^2}{\gamma_z^2}$$



I. Kostyukov et al., https://arxiv.org/abs/physics/0302026v1

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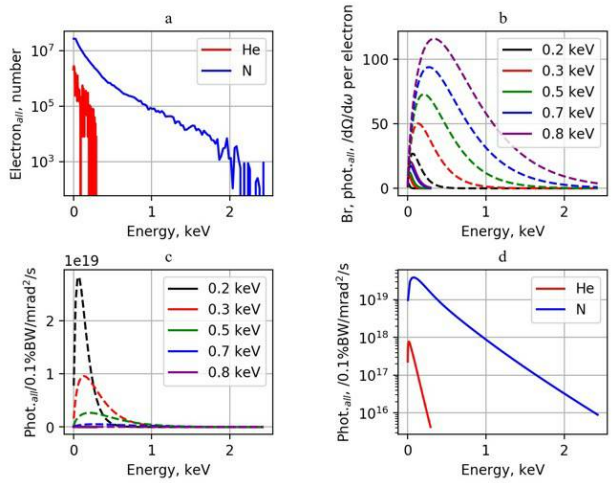
Postprocessing of FBPIC simulation

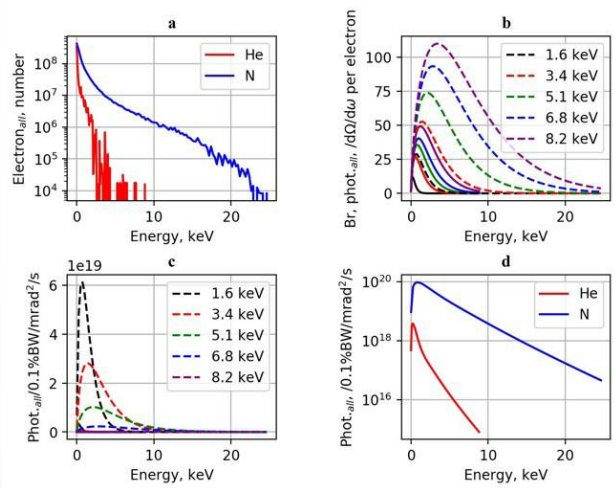
FIZINIŲ IR TECHNOLOGIJOS MOKSLŲ CENTRAS

5400 step
270 μm a_0=2
0.5% 3e18 cm^{-3}
30 fs – 8.0 μm

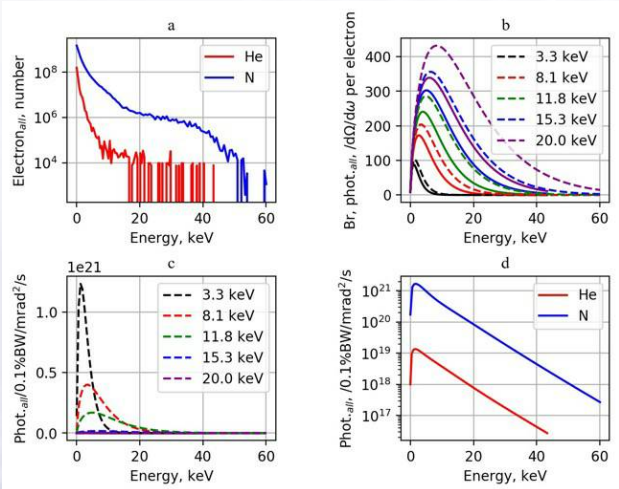


5400 step
270 μm a_0=2
1% 2e19 cm^{-3}
30 fs – 8.0 μm

$$\nu = \frac{r_0^2}{2\gamma_z}$$



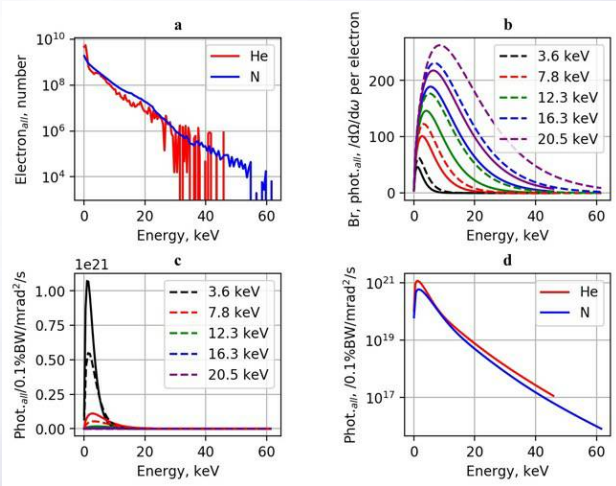
10000 step
500 μm a_0=3
0.5% 3e18 cm^{-3}
30 fs – 8.0 μm



$$r_0^2 = \frac{2p_\perp^2}{\gamma_z}$$

10000 step
500 μm a_0=3
1% 2e19 cm^{-3}
30 fs – 8.0 μm

$$\nu = \frac{p_x^2}{\gamma_z^2} = \frac{p_\perp^2}{\gamma_z^2}$$



$$\hbar\omega_c[keV] \simeq 1.1\times10^{-23}\gamma^2 n[cm^{-3}]r_\beta[\mu m]$$

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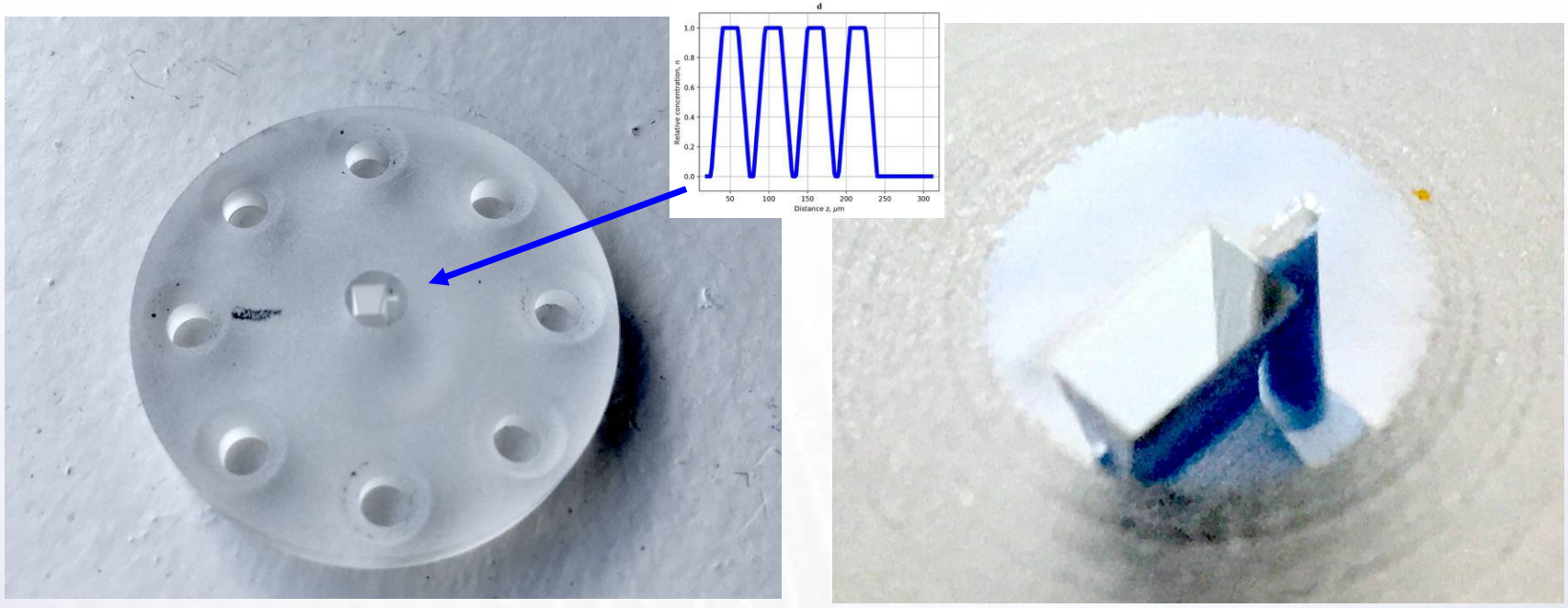
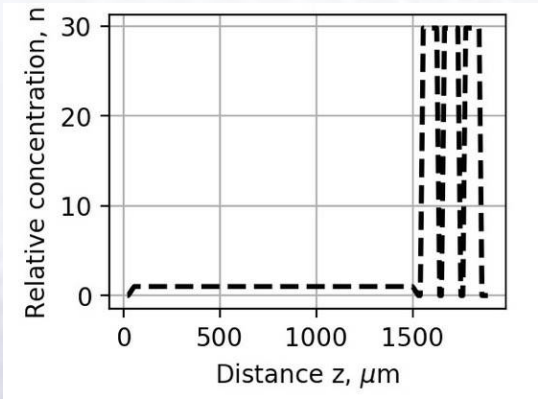
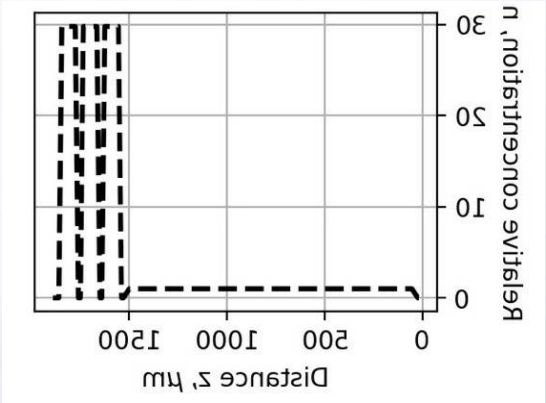
Nozzle Configurations



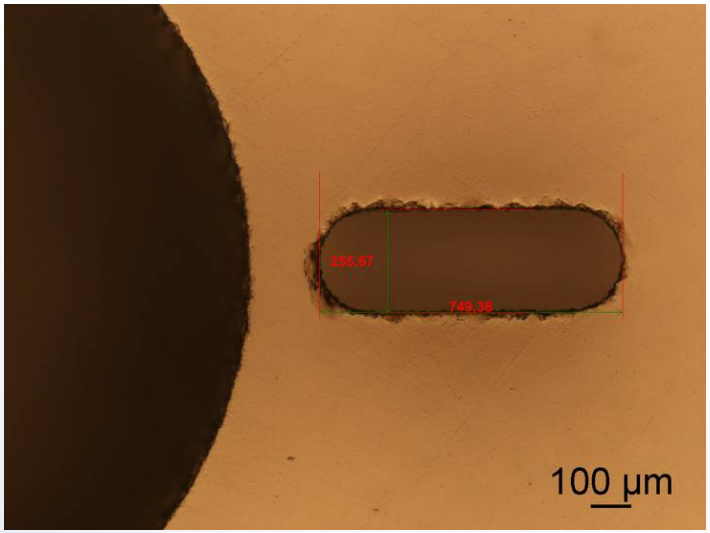


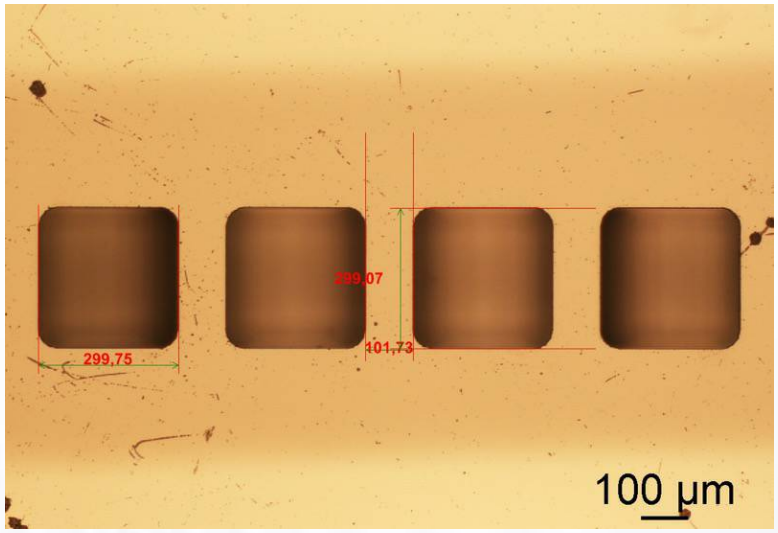


◎ 2.25 mm
❒ 1.5 mm
1 x 800 µm
4 x 200 µm

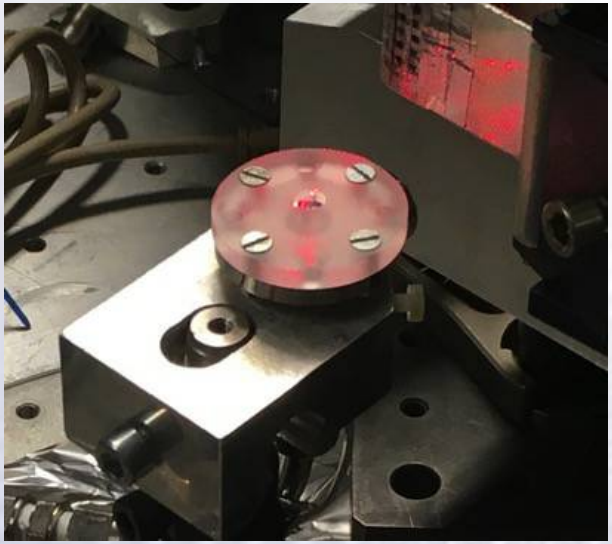
1 x 300 µm
4 x 200 µm
◎ 2.25 mm
❒ 1.5 mm

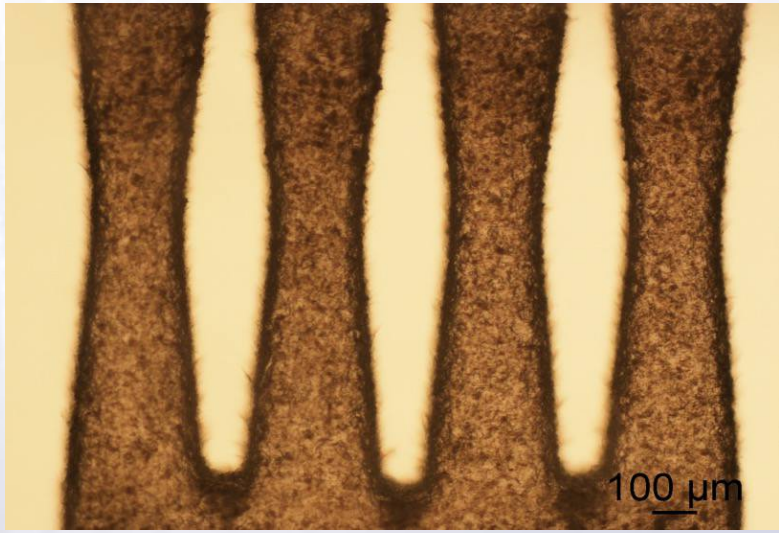
Nozzle Configurations





◎ 2.25 mm
1 x 800 µm
4 x 200 µm





1 x 300 µm
❒ 1.5 mm
4 x 200 µm

Experimental Setup

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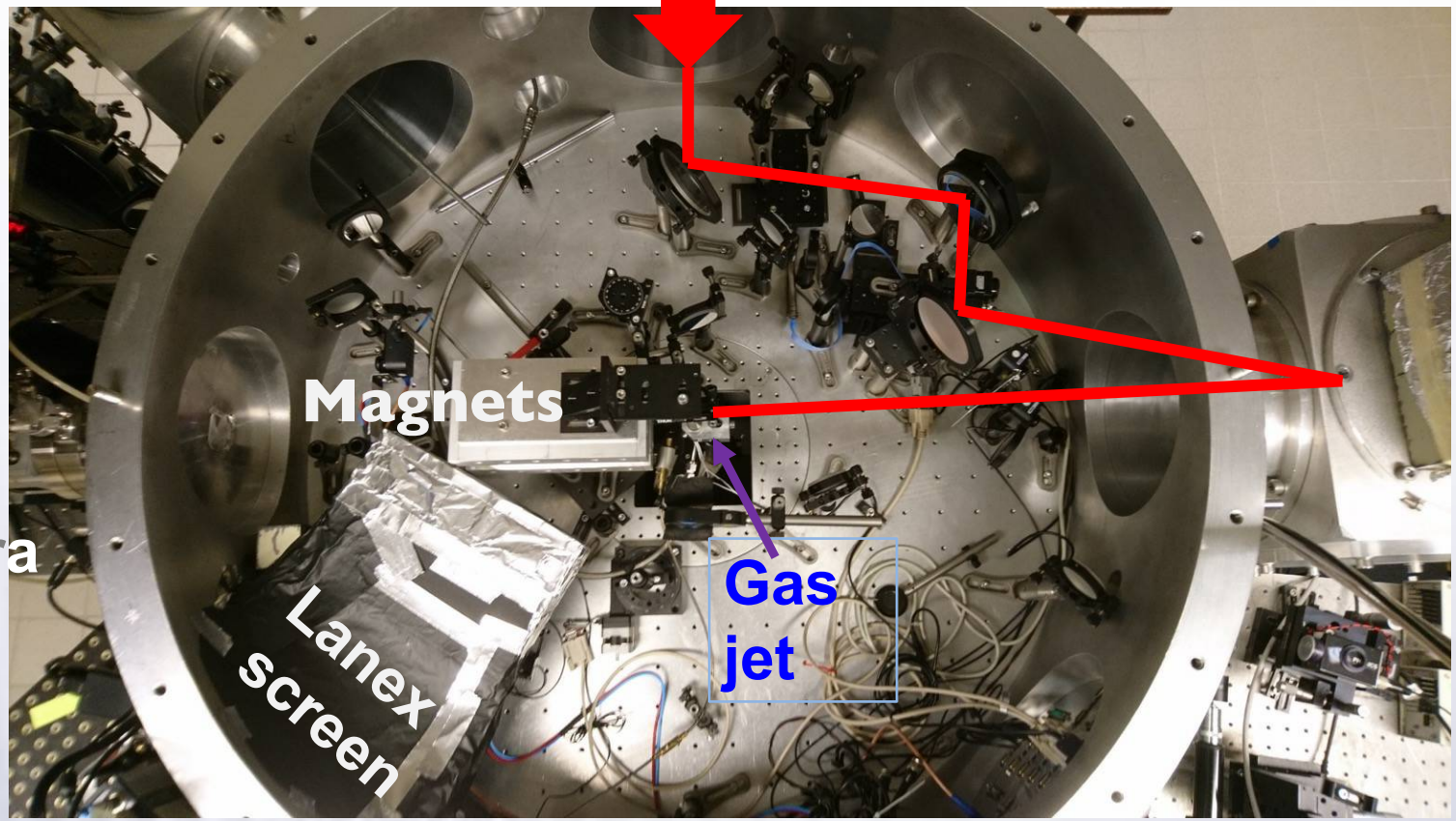
Incoming Laser beam

Andor Ikon L X-ray Camera



Off-axis parabola (775 mm) (465 mm)

800 nm, 900 mJ, 30 fs, FWHM = 13 μm / 8 μm

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Electron Acceleration and Injection

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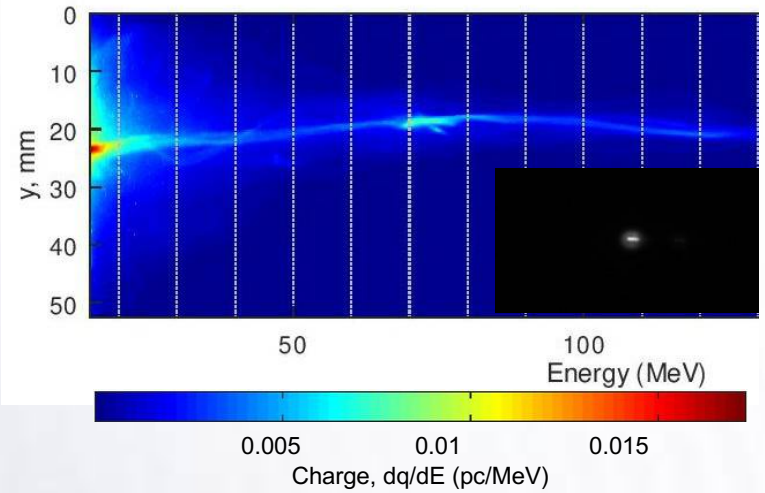
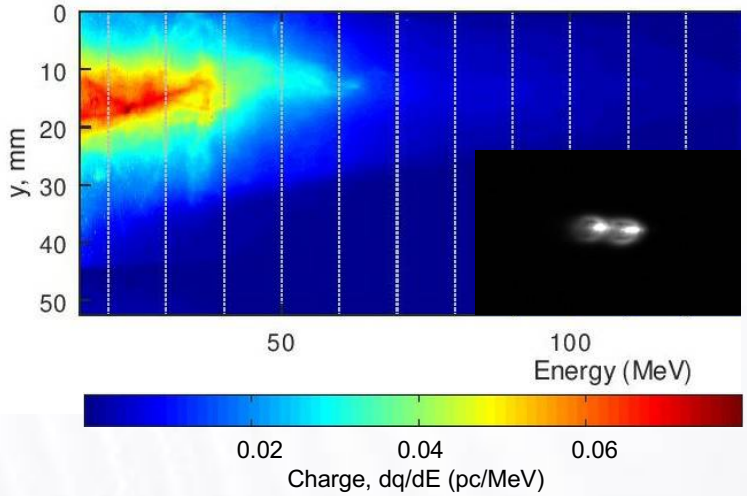
#8 n., #11 shot

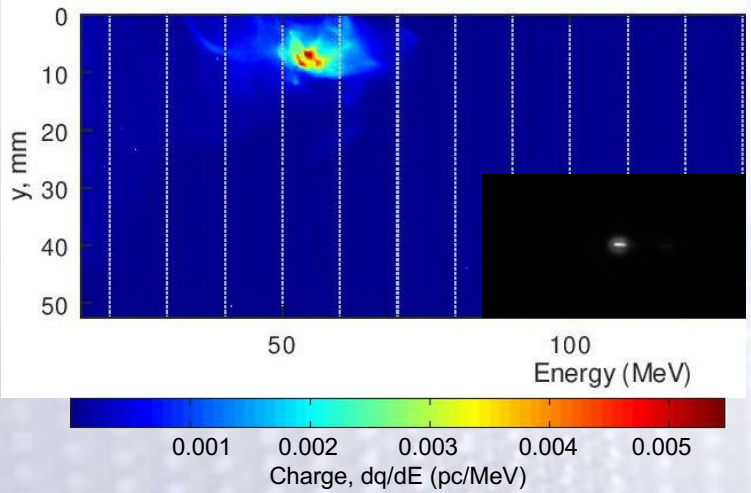


#45 n., #277 shot

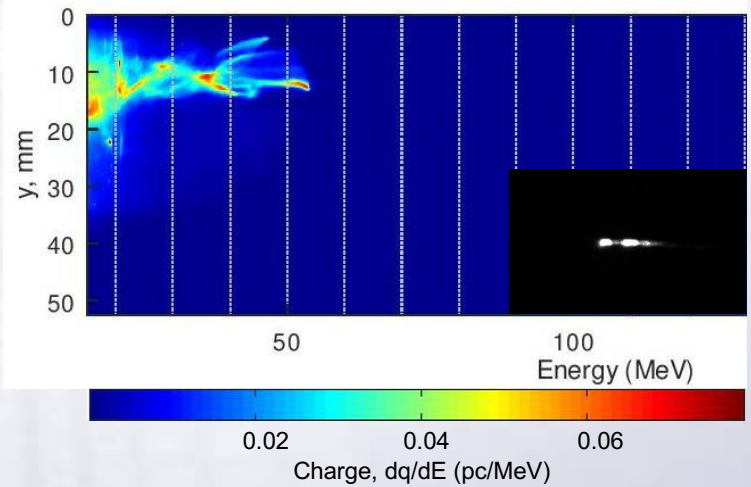


◎ 2.25 mm
4 x 200 μm
p = 15 bar
p = 25 bar

#58 Inv. n. , #79 shot



#45 Inv. n., #173 shot



1 x 300 μm
❒ 1.5 mm
p = 7 bar
4 x 200 μm
◎ 2.25 mm
p = 17 bar

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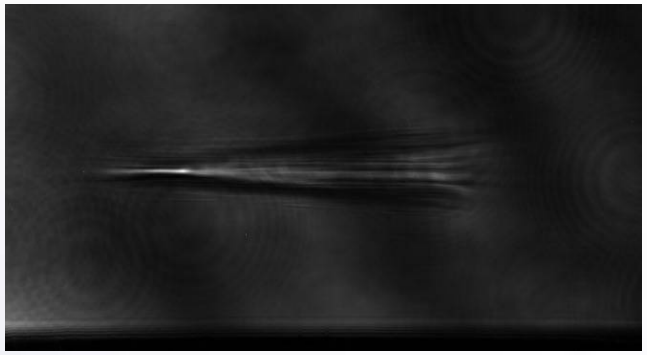
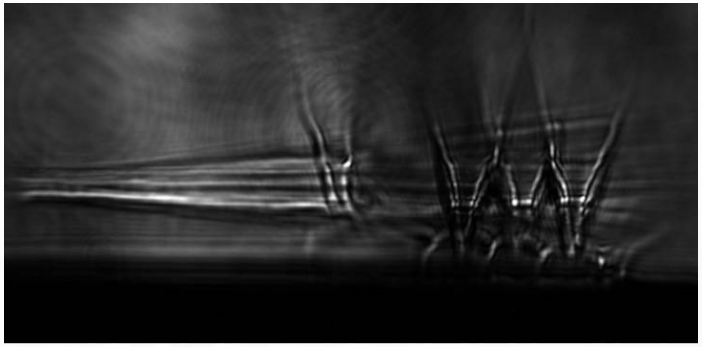
Electron Acceleration and Injection

FIZINIŲ IR TECHNOLOGIJOS MOKSLŲ CENTRAS

#8 n., #11 shot

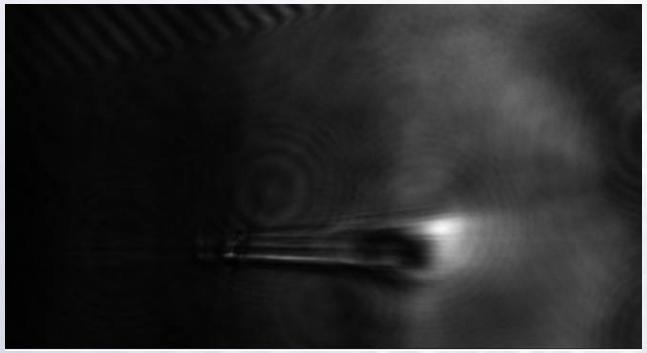


#45 n., #277 shot

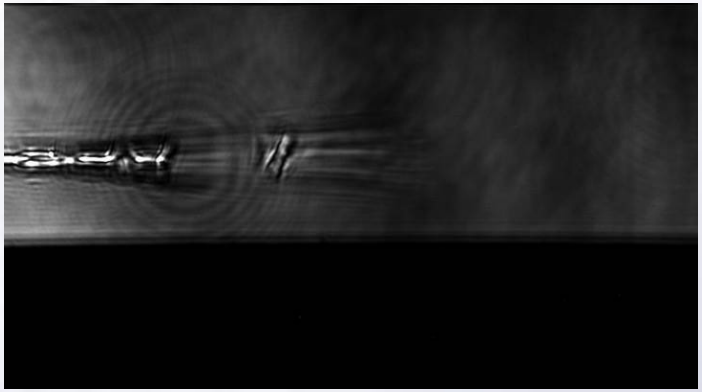


◎ 2.25 mm
4 x 200 µm
p = 15 bar
p = 25 bar

#58 Inv. n. , #79 shot



#45 Inv. n., #173 shot



1 x 300 µm
❒ 1.5 mm
p = 7 bar
4 x 200 µm
◎ 2.25 mm
p = 17 bar

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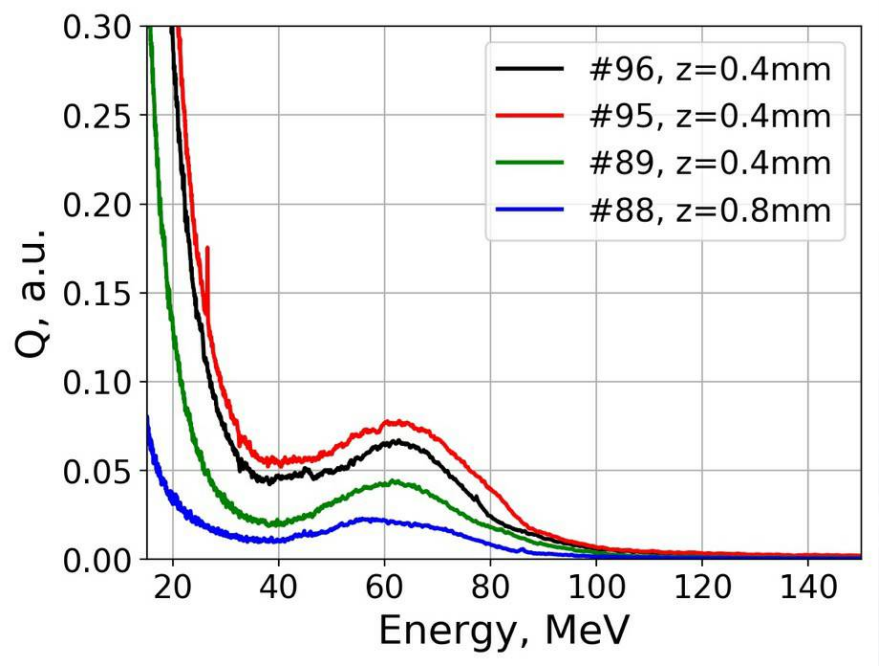
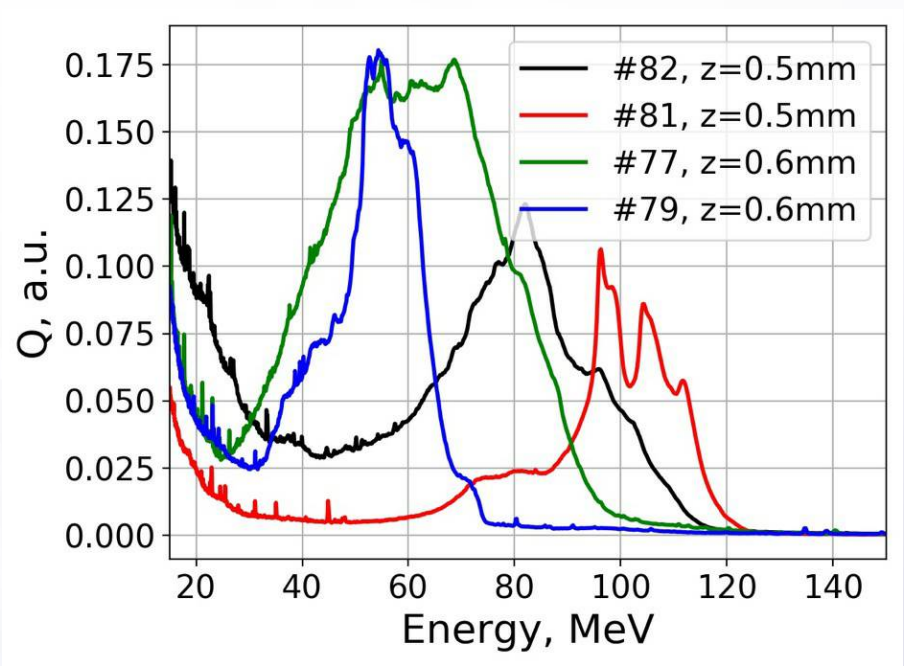
Density Triggered Injection

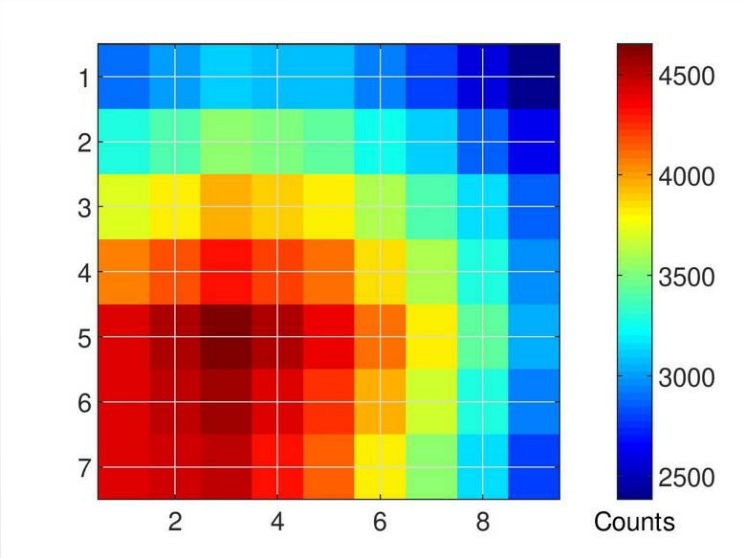


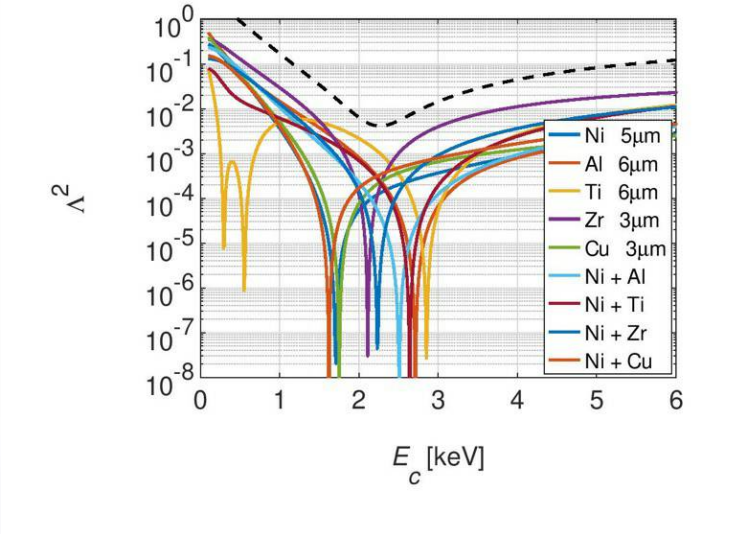


#11 Inv. n.
1 x 800 µm ◎ 2.25 mm
p = 14 bar

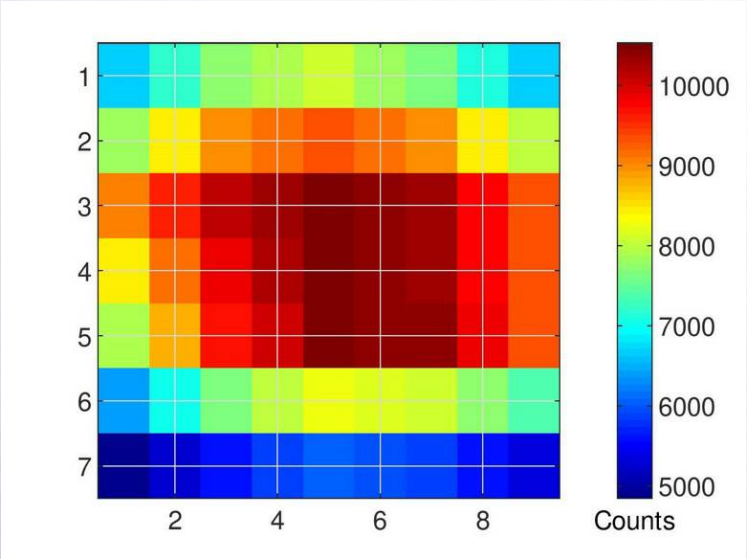
#58 Inv. n.
1 x 300 µm ❒ 1.5 mm
p = 7 bar

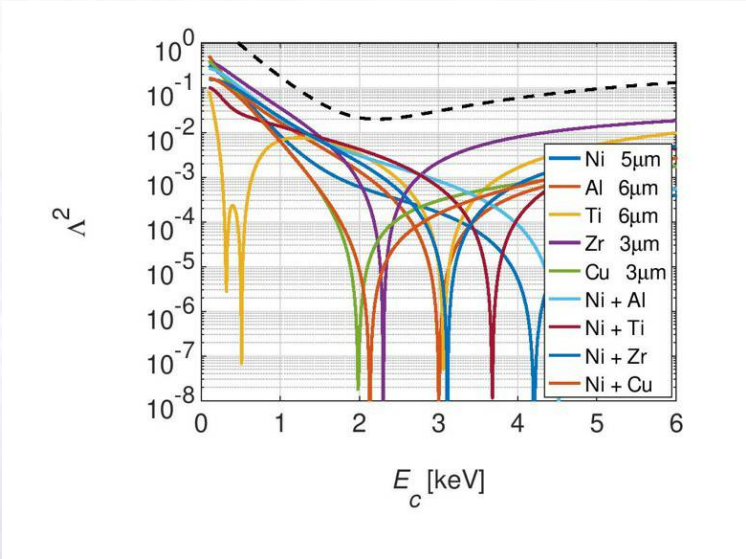
Betatron X-ray radiation





#8 nozzle
◎ 2.25 mm
#45 shot
p = 21 bar





#45 nozzle
◎ 2.25 mm 4 x 200 μm
#274 shot
p = 25 bar

Cross wire shadow

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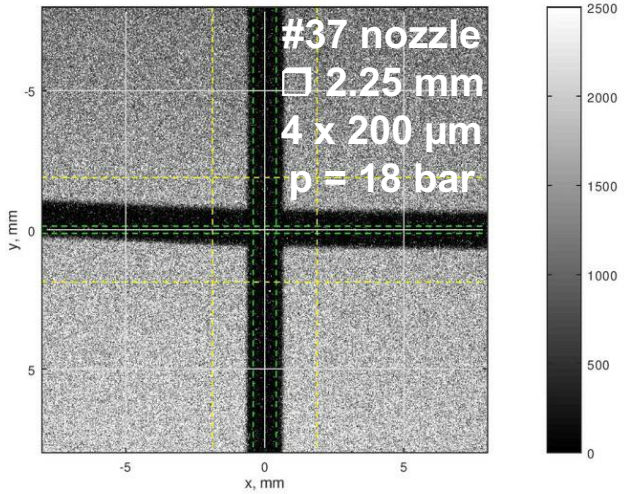
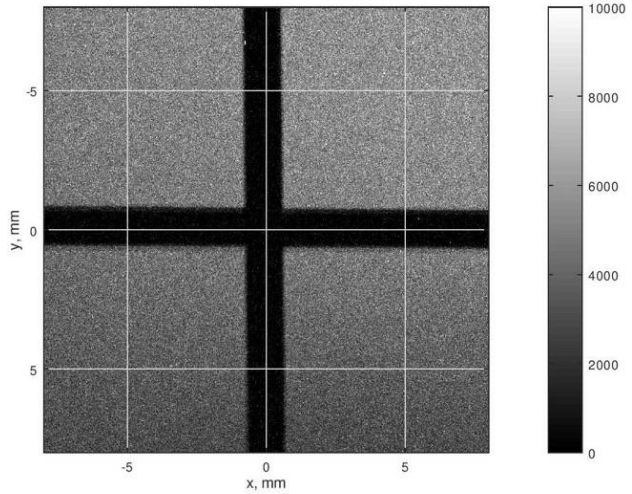
FWHM 11 µm

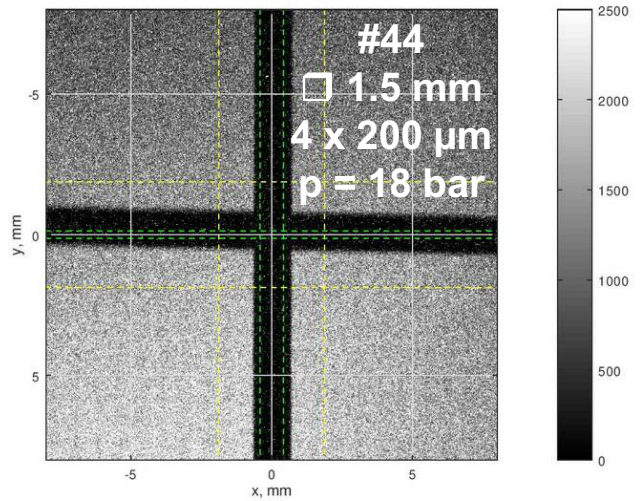


FWHM 11 µm

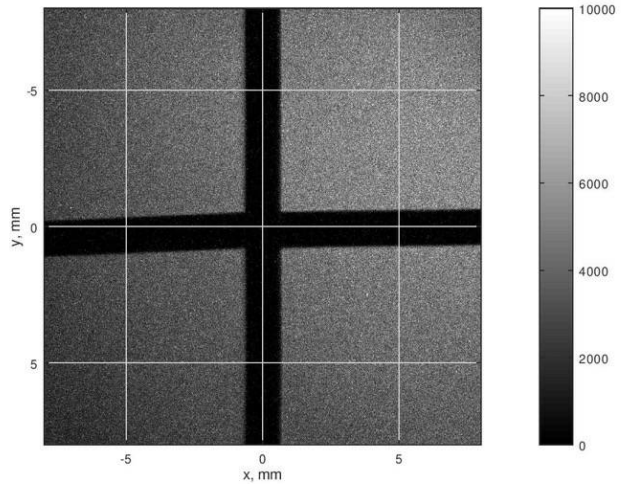


#15 nozzle
❒ 1.5 mm
p = 18 bar

FWHM 11 µm



FWHM 8 µm



#45 nozzle
◎ 2.25 mm
4 x 200 µm
p = 25 bar

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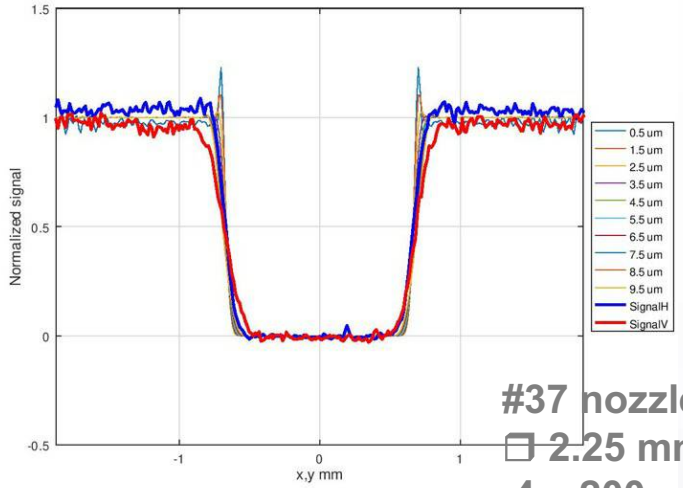
Cross wire shadow

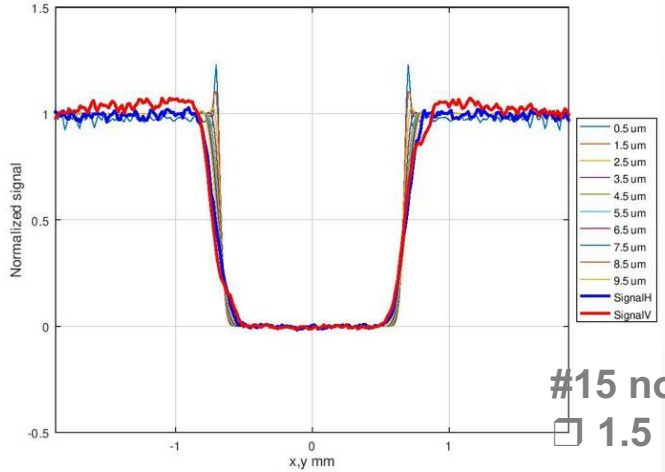
FIZINIŲ IR TECHNOLOGIJOS MOKSLŲ CENTRAS

FWHM 11 µm



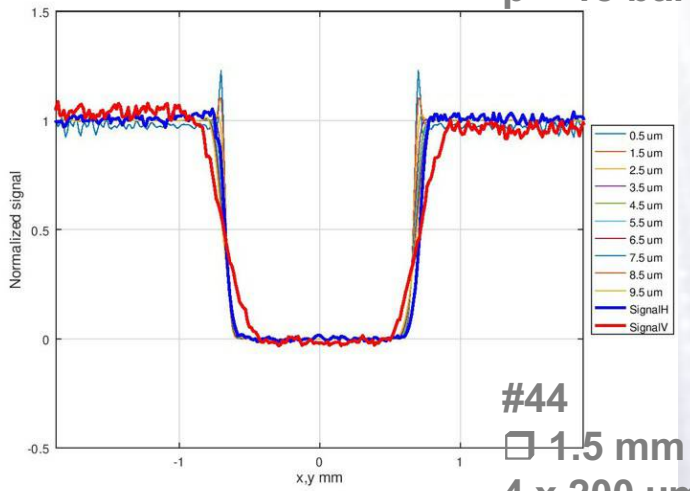
#37 nozzle
❒ 2.25 mm
4 x 200 µm
p = 18 bar

FWHM 11 µm



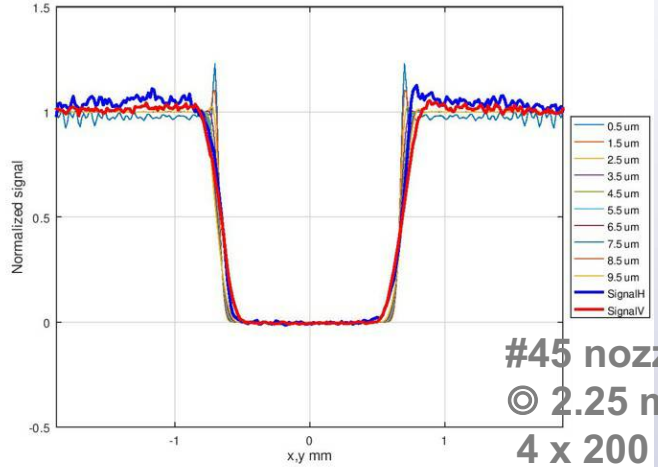
#15 nozzle
❒ 1.5 mm
p = 18 bar

FWHM 11 µm



#44
❒ 1.5 mm
4 x 200 µm
p = 18 bar

FWHM 8 µm



#45 nozzle
◎ 2.25 mm
4 x 200 µm
p = 25 bar

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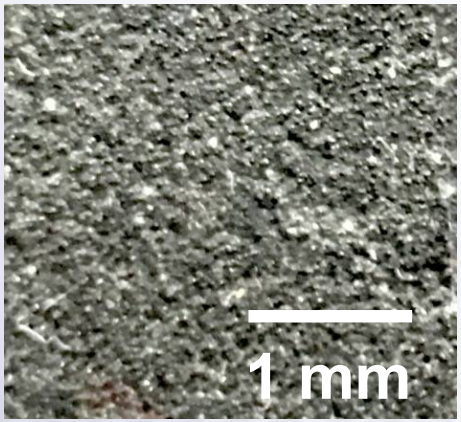
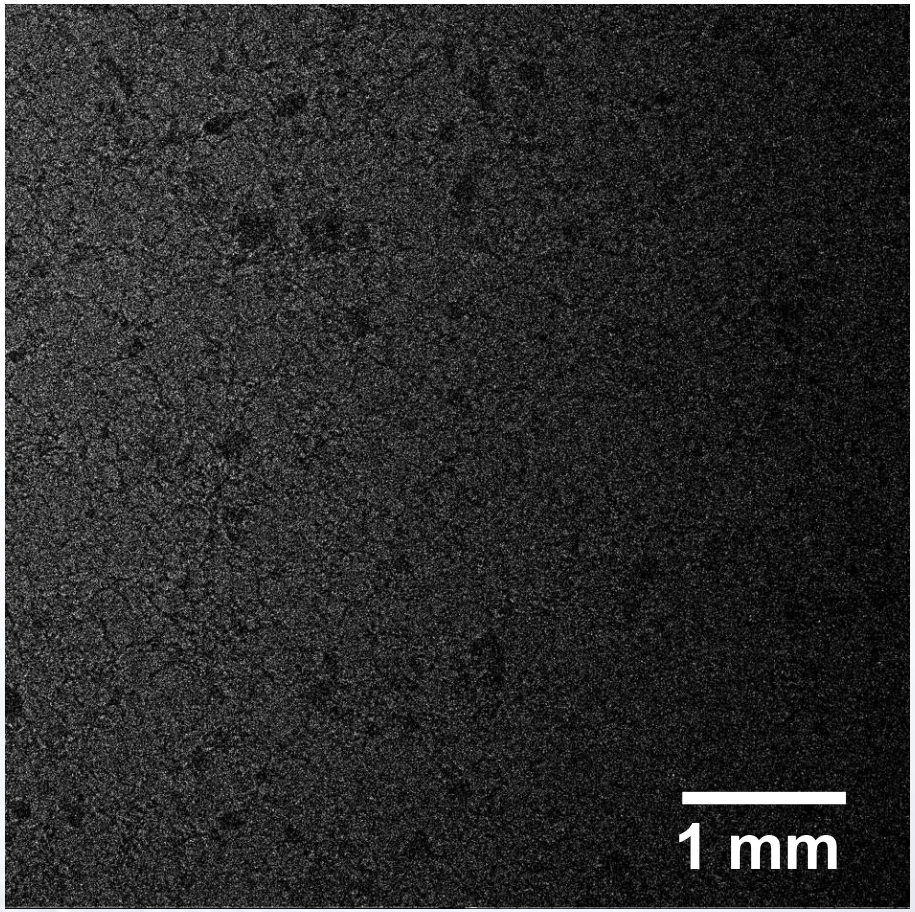
Betatron X-ray radiation

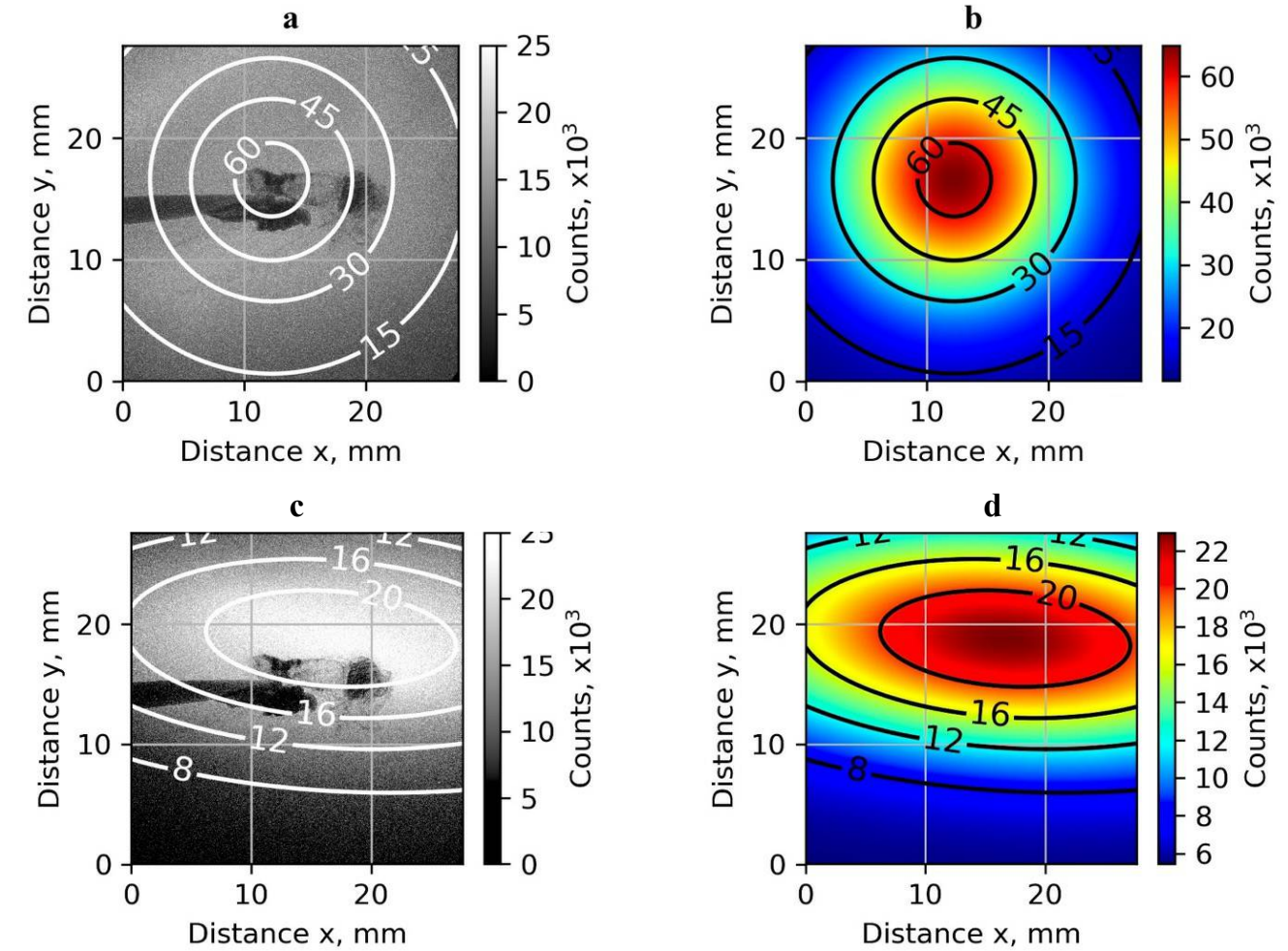




#45 nozzle
◎ 2.25 mm
4 x 200 µm
p = 25 bar

Andor IkonL SO X-ray camera, ~ 20 000 counts

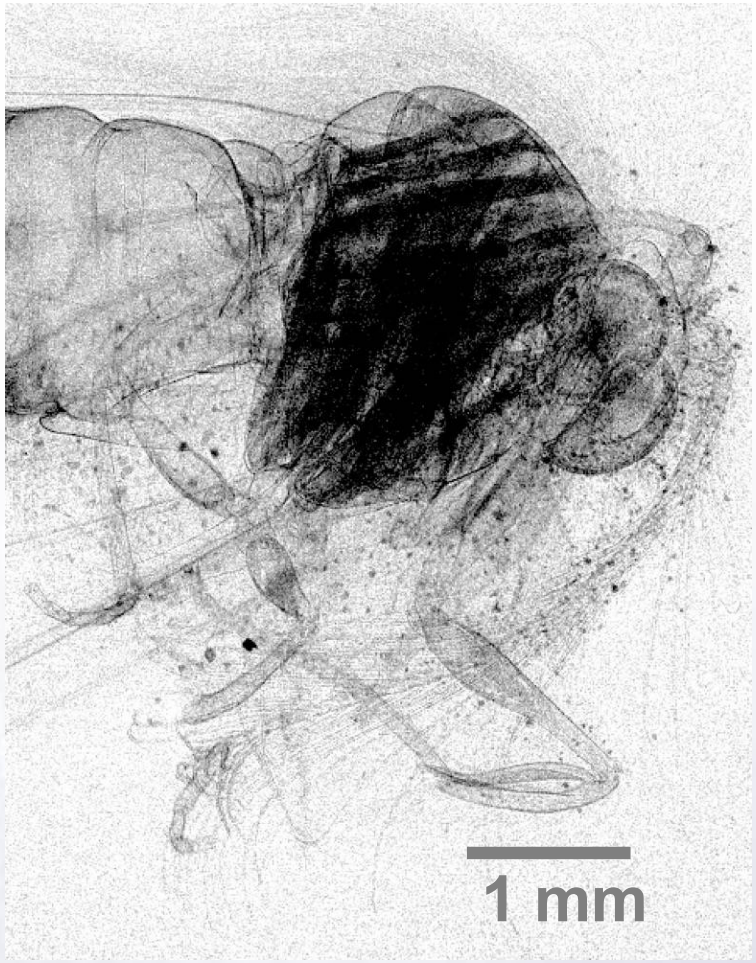
Betatron X-ray radiation



#45 nozzle
◎ 2.25 mm
4 x 200 µm
p = 25 bar

Andor IkonL SO X-ray camera, ~ 20 000 counts

Betatron X-ray radiation



#45 nozzle
⌀ 2.25 mm
4 x 200 µm
p = 25 bar

Andor IkonL SO X-ray camera, ~ 20 000 counts
Averaged over 10 shots, 10^8 photons per shot

Summary of the results

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- The density profiles of gas jets were simulated using OpenFOAM compressible solver. The propagation of laser beam and acceleration of electrons were modeled using spectral FBPIC (Fourier–Bessel PIC) algorithm
- Low density gas targets of De Laval cylindrical and slit nozzles (0.5 – 2.25 mm) were used for electron acceleration. High density gas targets of single and four-array cylindrical nozzles (Φ200 - 800 μm), were implemented for the density triggered injection and X-ray plasma radiator
- The electron beams of the energy of 30 -180 MeV and charge of 20 – 600 pC using pure He and mixture of 1% N and He were demonstrated. The energy of betatron X-ray radiation was 1.5 – 4.5 keV with $2\cdot10^7$ - $1\cdot10^8$ photons per shot. Four-jet gas array of 200 μm diameter resulted in the increase of betatron photon energy by a factor of 1.5 – 2 compared to the single-nozzle target

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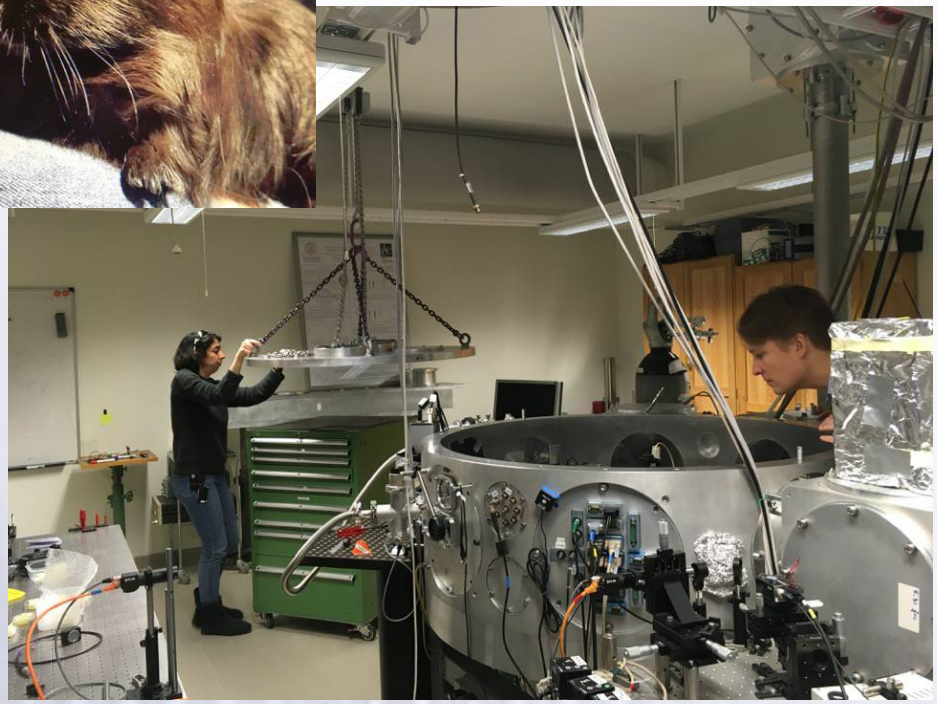
THANK YOU FOR ATTENTION!



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