FIZINIŲ IR
TECHNOLOGIJOS MOKSLŲ
CENTRAS

Manufacturing of Gas Targets from Transparent Materials using 3D Laser Machining

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ChETEC-INFRA 3rd General Assembly and Transnational Access User Meeting

Debrecen | June 6-7, 2023

1) Introduction

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2) Hybrid 3D Laser machining technique

3) Tailored Injection, Charge, Energy and Betatron Radiation Using Shaped Gas Targets

4) Proton, Deuteron Acceleration

5) Gas targets for the Nuclear Astrophysics Research

6) Summary

1) Tailored plasma targets

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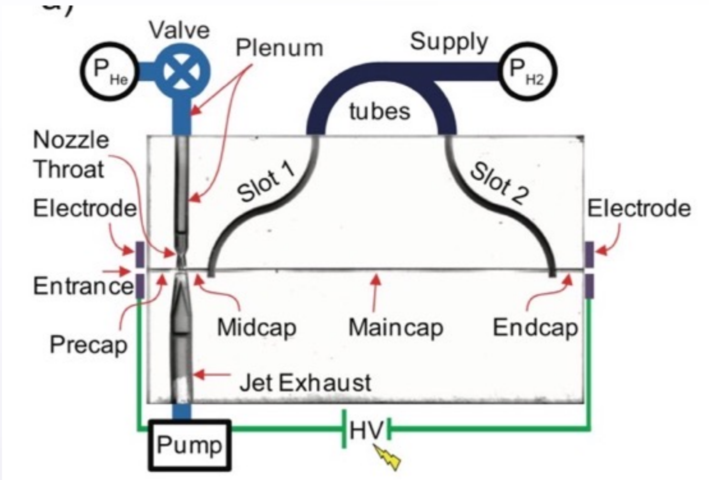

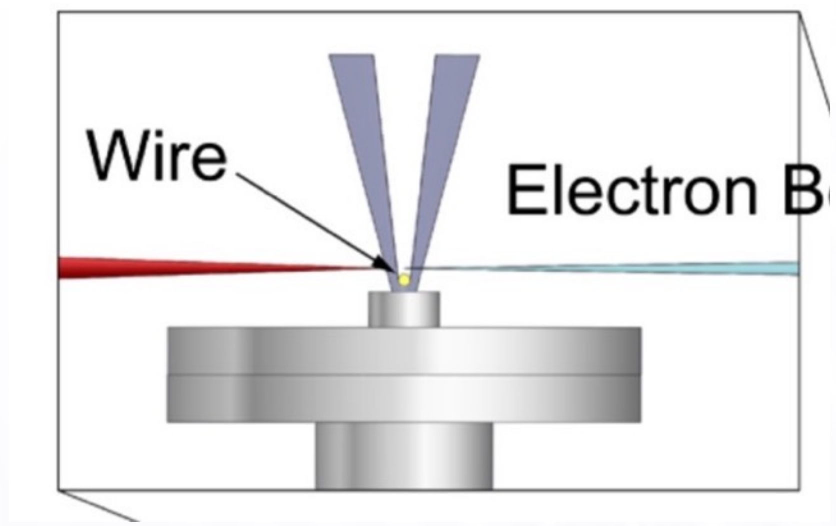

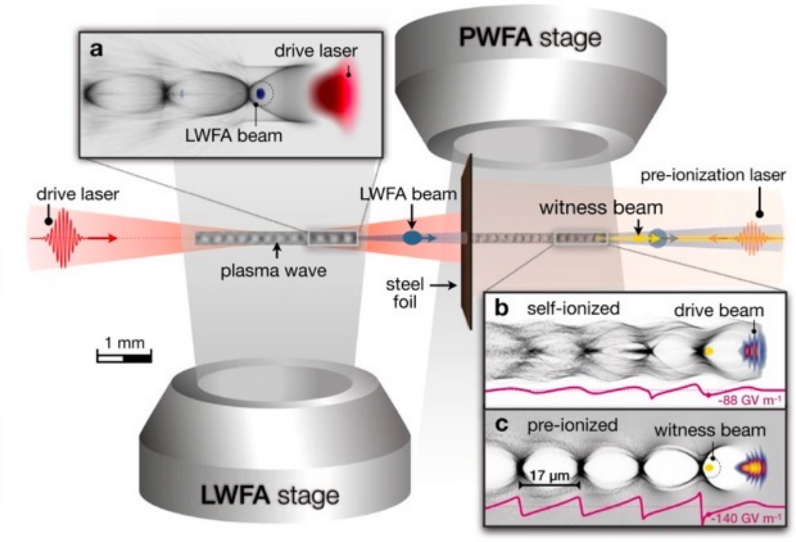

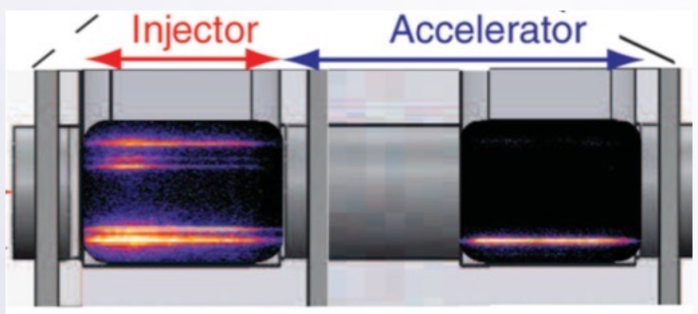

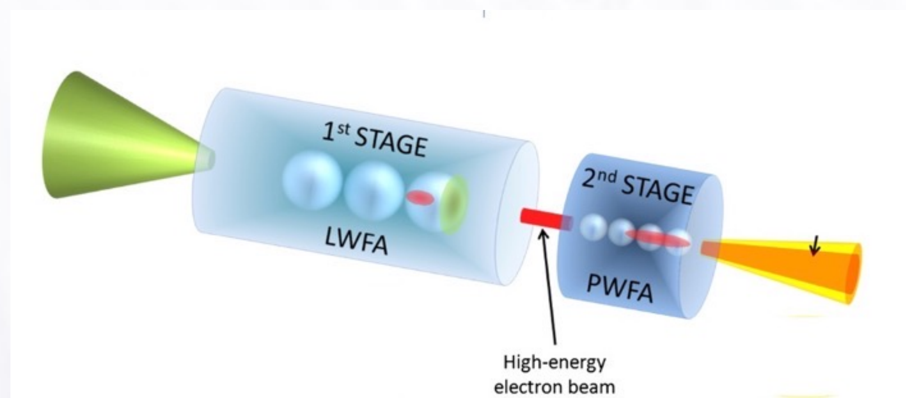

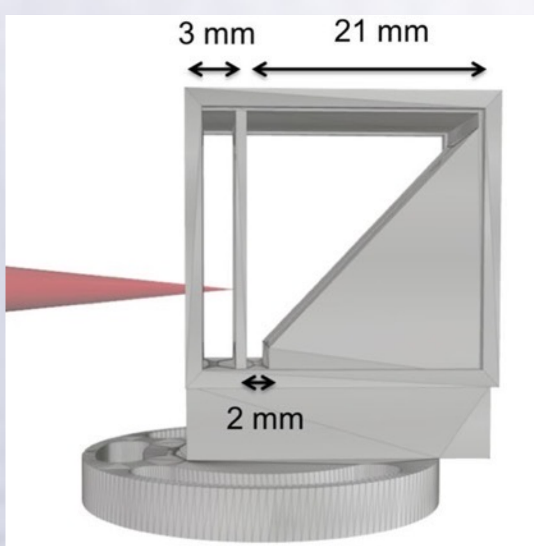

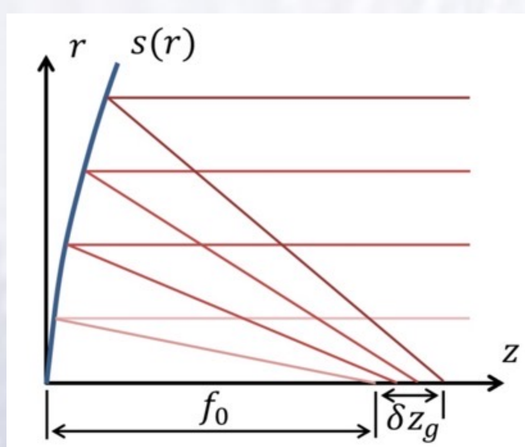

N. H. Matlis et al., (2016), M. Hansson et al., (2015), M. Burza et al., (2013), M. Zeng et al., (2014), J. Ferri et al., (2018), S. Cipiccia et al,(2011) P. Tomassini et al., (2018) , T. Kurz et al., (2021), C. Thaury et al., (2014), S. Smartsev et al., (2021)

- Gas capillaries and cells
- Density triggered injection of electrons and plasma radiator
- Injection of gas with lower ionisation energy, self-truncated injection
- Oscillation in plasma wake, Multipulse ionisation
- ”Non-diffracting” beams, compensation of group velocity phase delay

2) Hybrid 3D Laser Machining Technique

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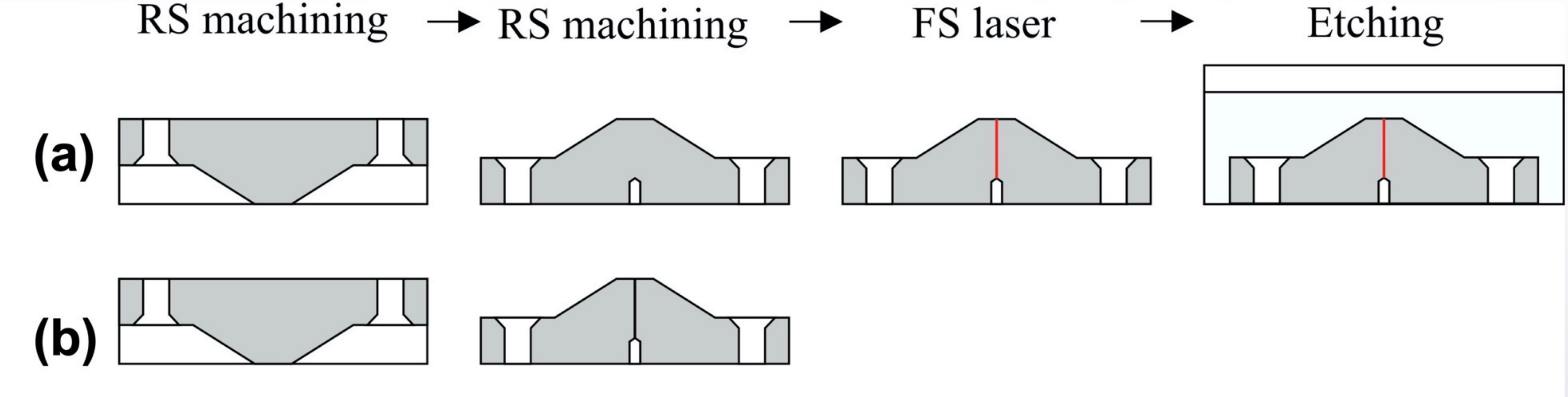
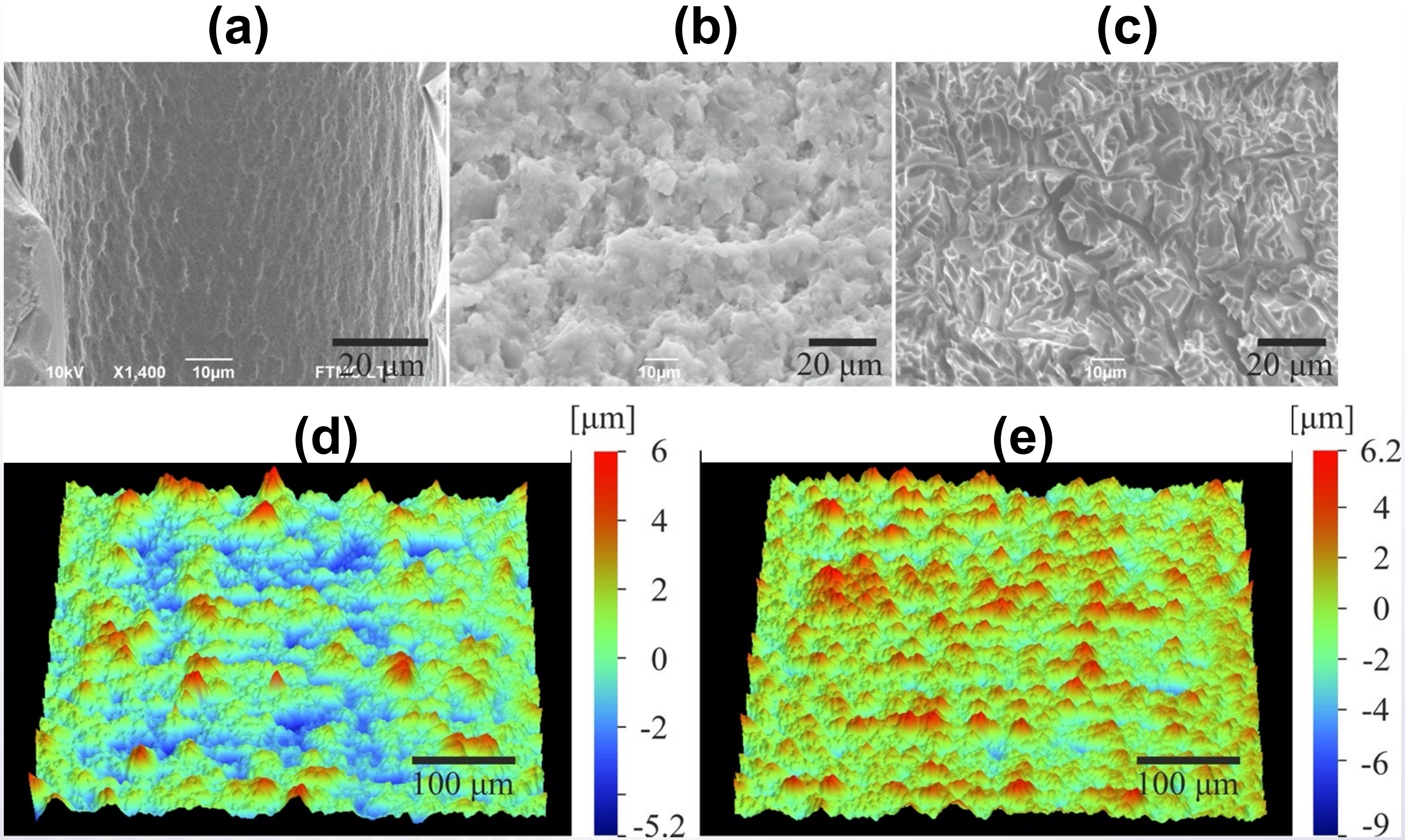


- The formation precision of nanosecond rear-side processing -± 20 μm, surface roughness ± 5-8 μm, high material removal rate ~ 2 mm^3/s.
- The formation precision of Femtosecond Laser-assisted Selective Chemical Etching (FLSE) ± 2 μm, surface roughness < 0.7 μm, modification of ∅ 100 μm x 2 mm structure takes 21 min. plus etching in KOH - 22 h

V. Tomkus et al., Opt. Express. 26, 27965, (2018)
V. Tomkus et al., Appl. Surf. Sc., 483, 205-211, (2019)

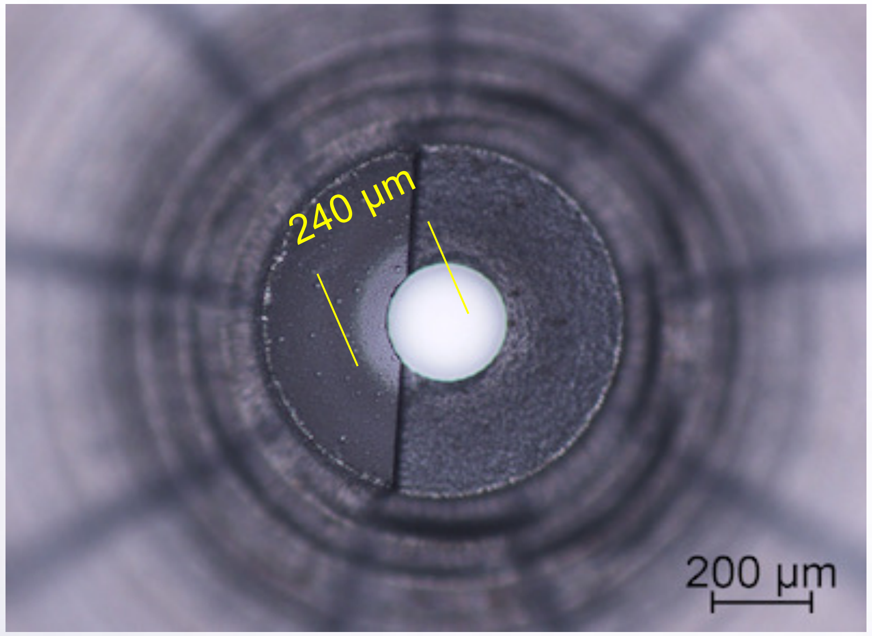
2) Micro-nozzle surface roughness

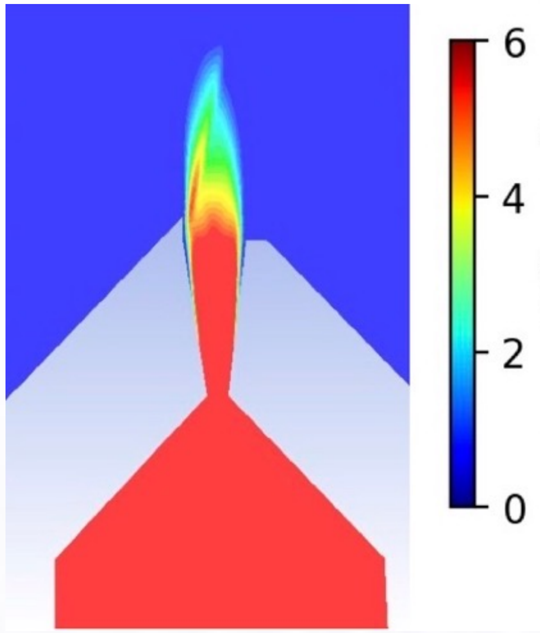


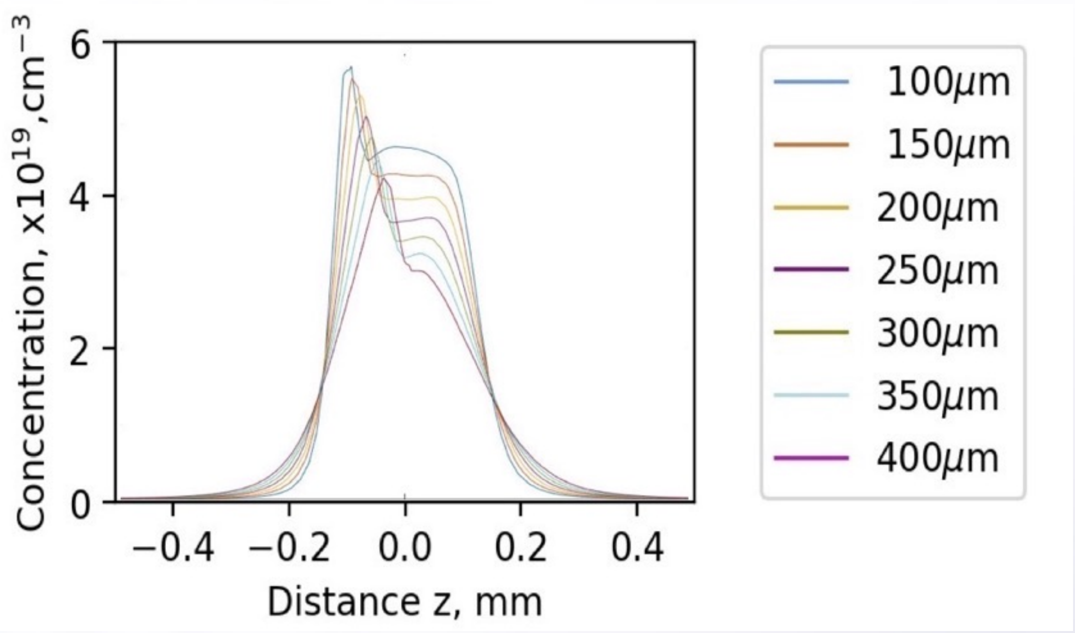
SEM images - FLSE **(a)**, nanosecond rear-side processing **(b)** with subsequent etching in KOH **(c)**. Surface topographies - nanosecond rear-side processing **(d)** with subsequent etching in KOH **(e)**

V. Tomkus et al., Appl. Surf. Sc., 483, 205-211, (2019)

3) One-side shock micro-nozzles used in near-one cycle LWFA of electrons







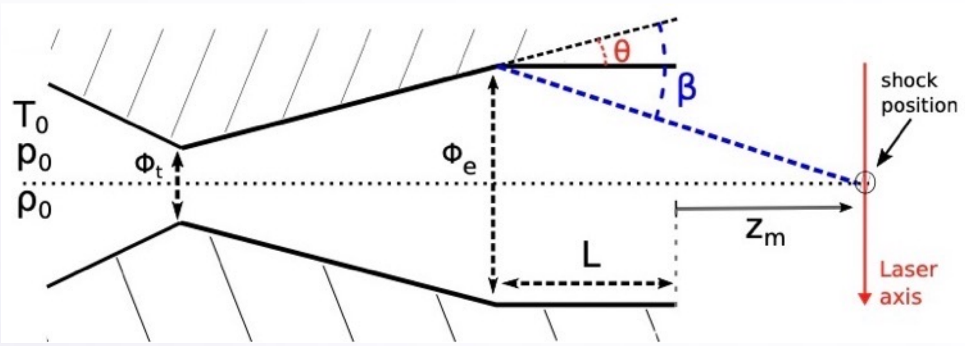
∅ 240 µm „one-sided shock“ nozzle manufactured by combined technique

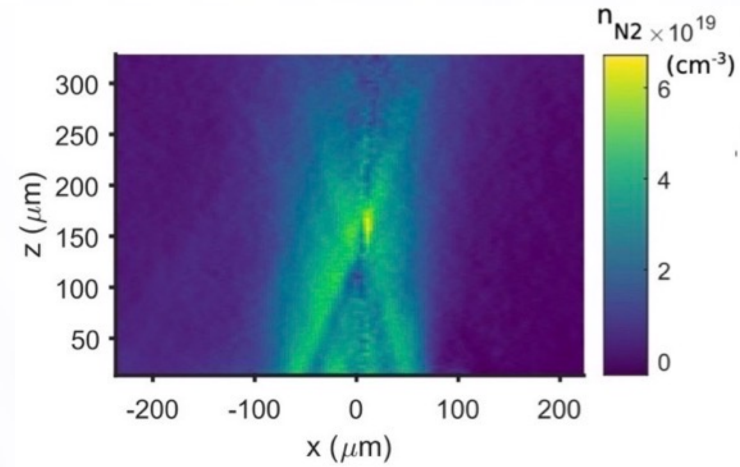
- **Injector structure** formed by One-Sided Shock jet of 300 µm De Laval nozzle with a straight section at the outlet (LOA)
- Concentration down-ramp gradient simulated by Fluent 3D software
- Demonstration of stable long-term operation of a kilohertz laser-plasma accelerator

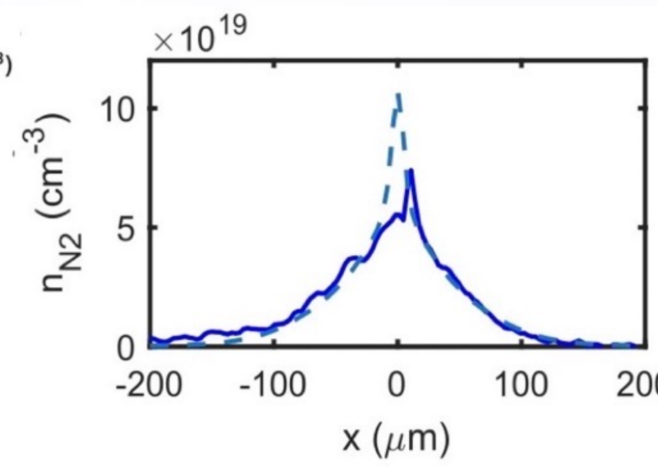
V. Tomkus et al. Optics Express 26, 27965 (2018)
L. Rovige et al., Phys. Rev. Accelerators an Beams, 23, 093401(9), (2020)

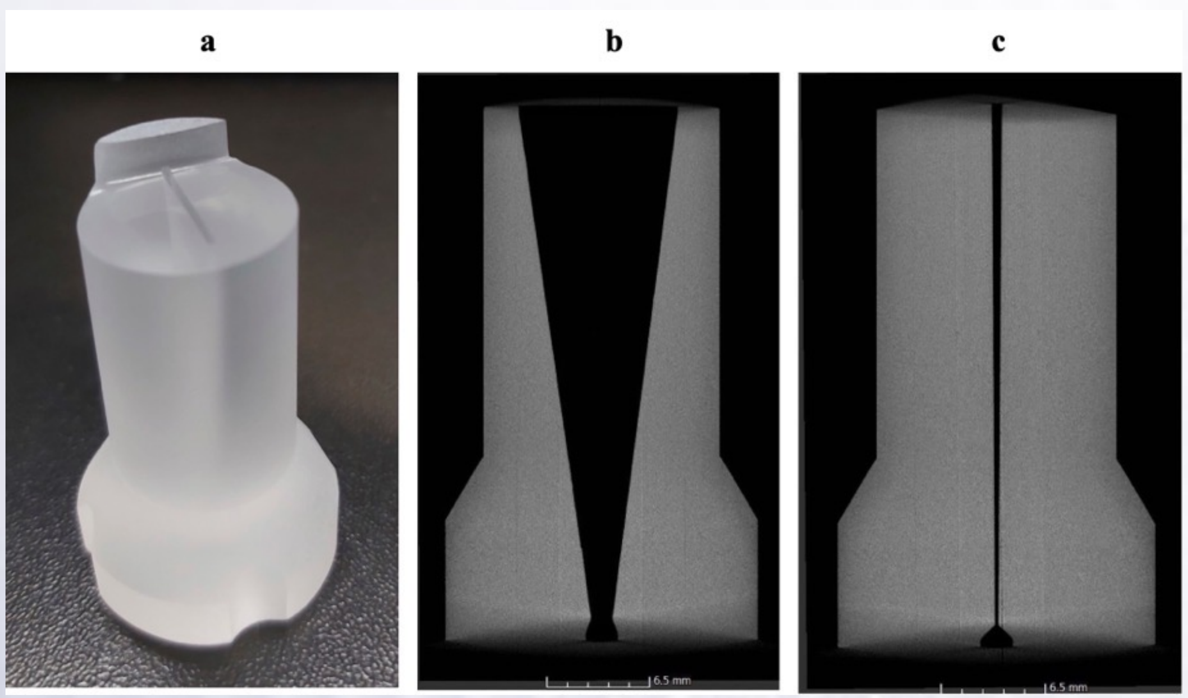
3) IFAST

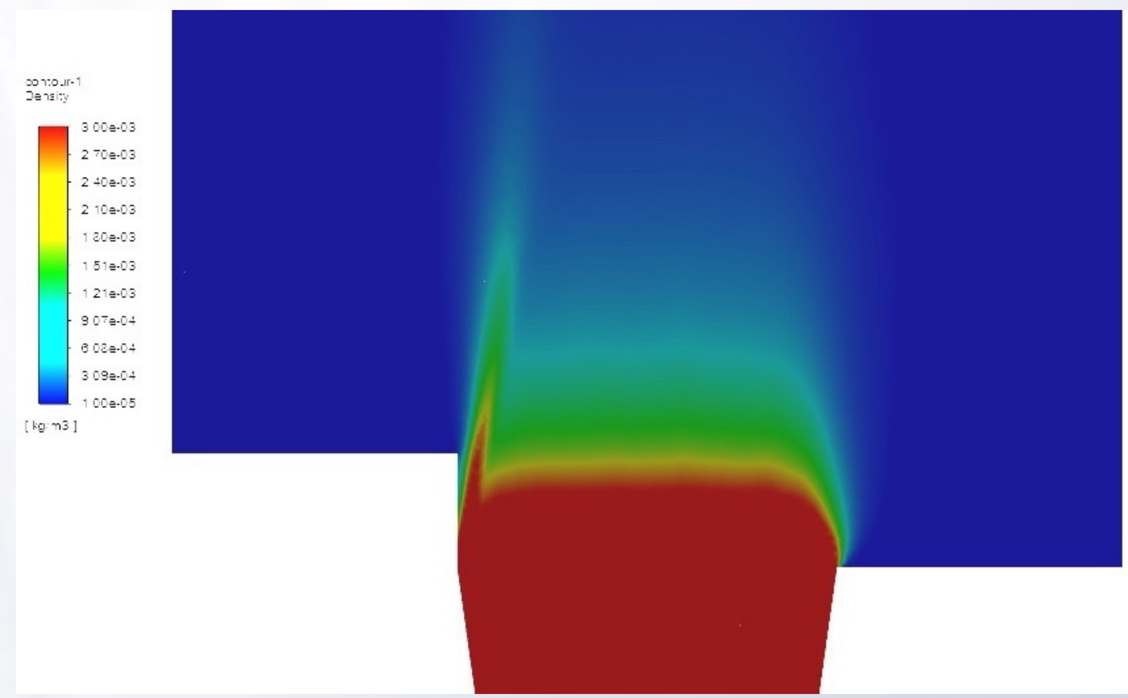
IFAST - Innovation Fostering in Accelerator Science and Technology







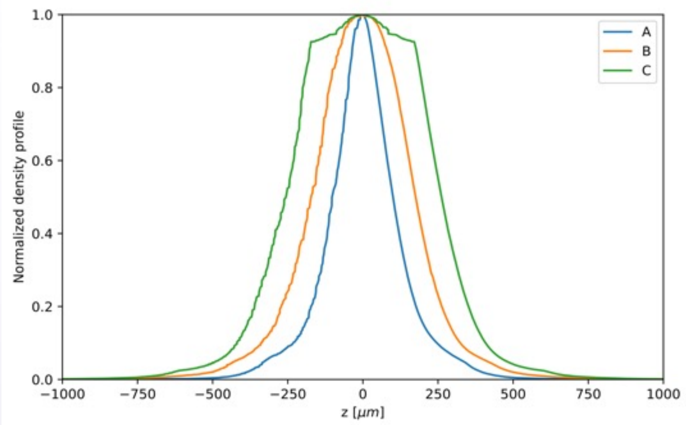




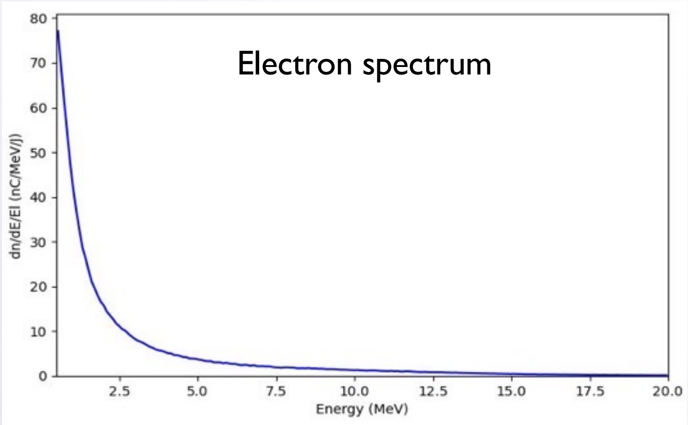
Simulations, J. Faure, C. Thaury et al., LOA,
Tomography – Thales,
Manufacturing FTMC

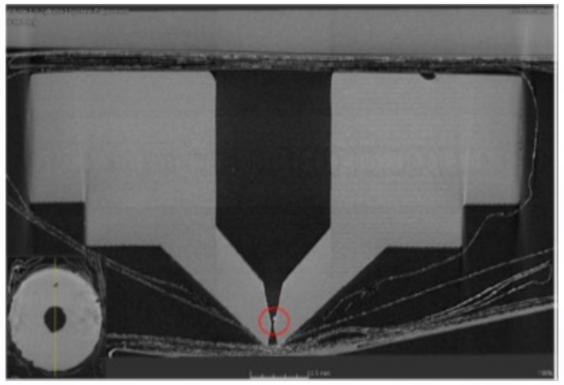
3) Multiscan 3 D project

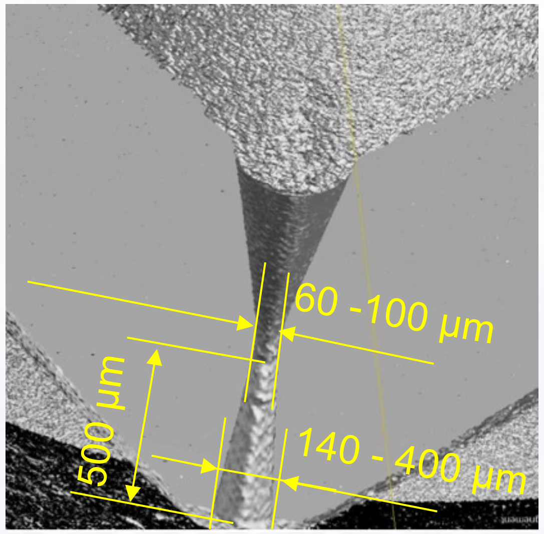
Simulations of 3 ultrashort nozzles

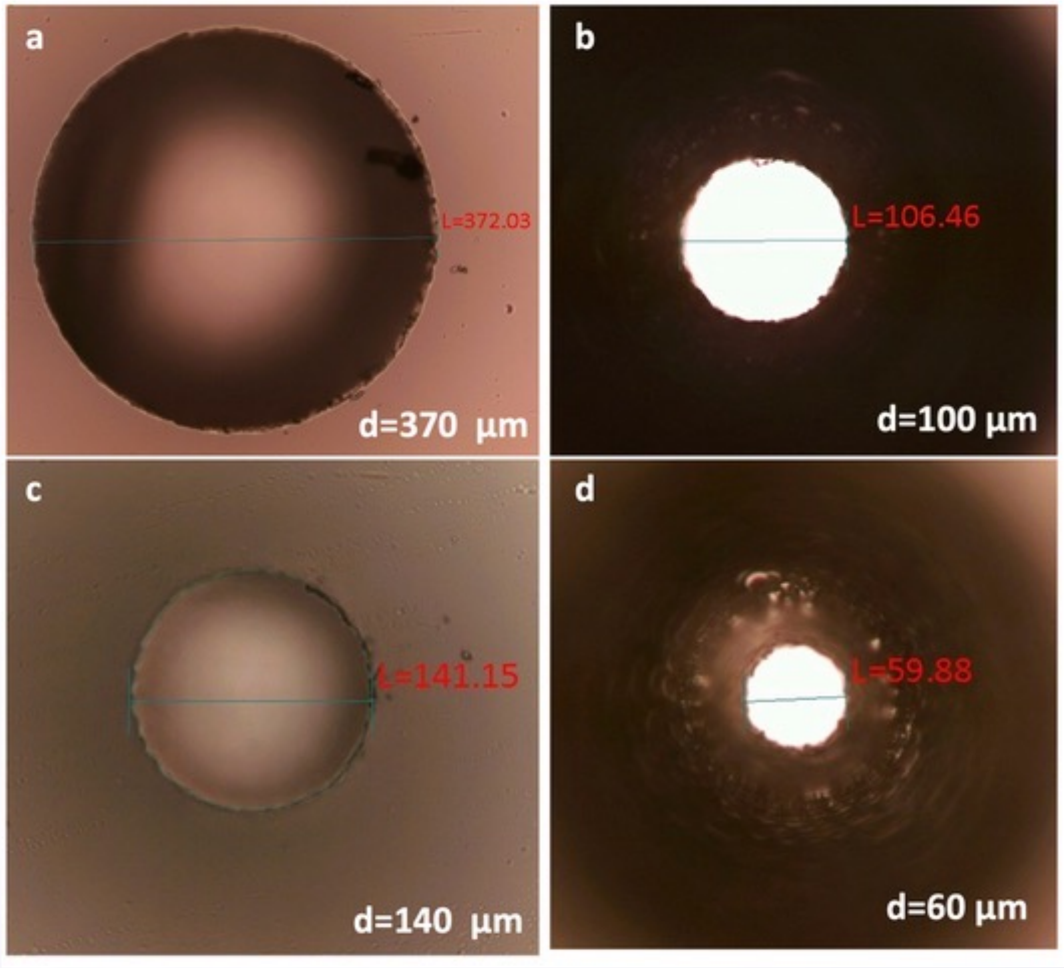


Distance above the nozzle outlet
A= 800 µm, B = 400 µm , C= 200 µm









For operation with High-Z γ-Converter

0.7 J / 30 fs laser pulse

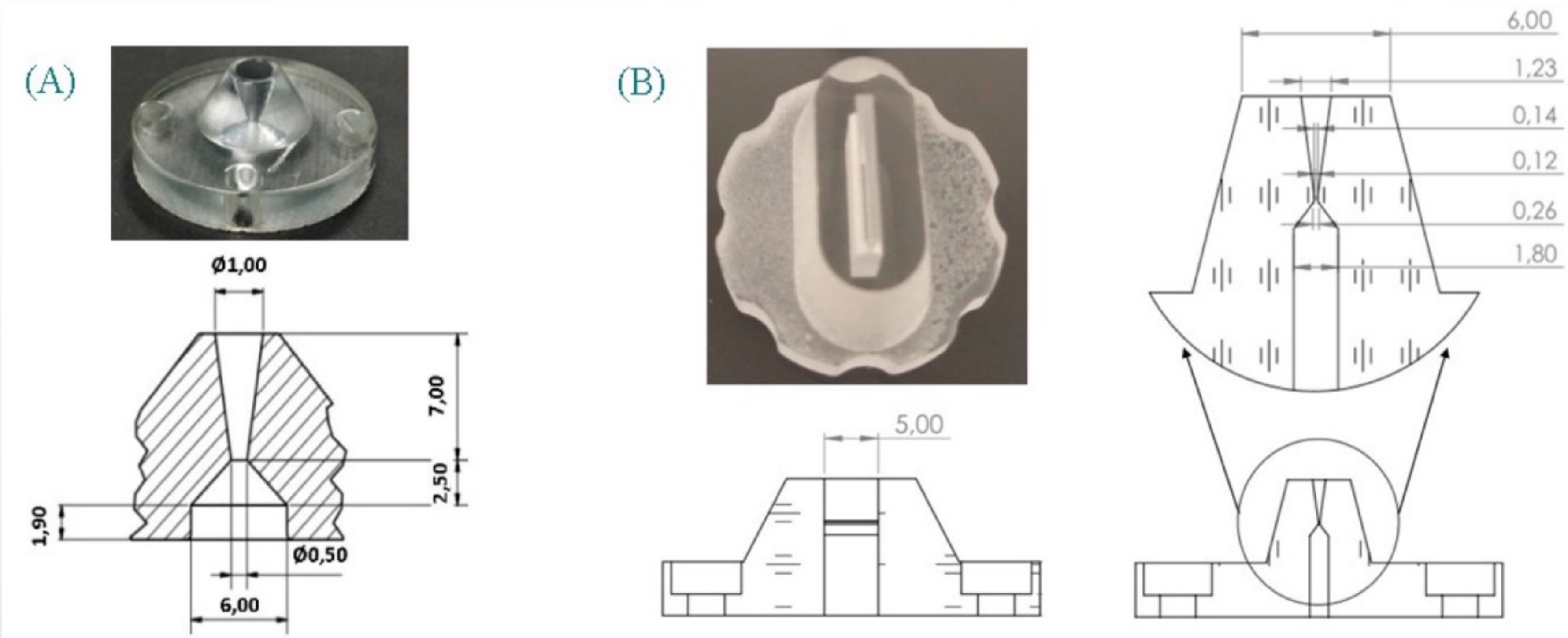
2.6 MeV electron beam mean energy

63 nC charge in the range [0.5, 10] MeV

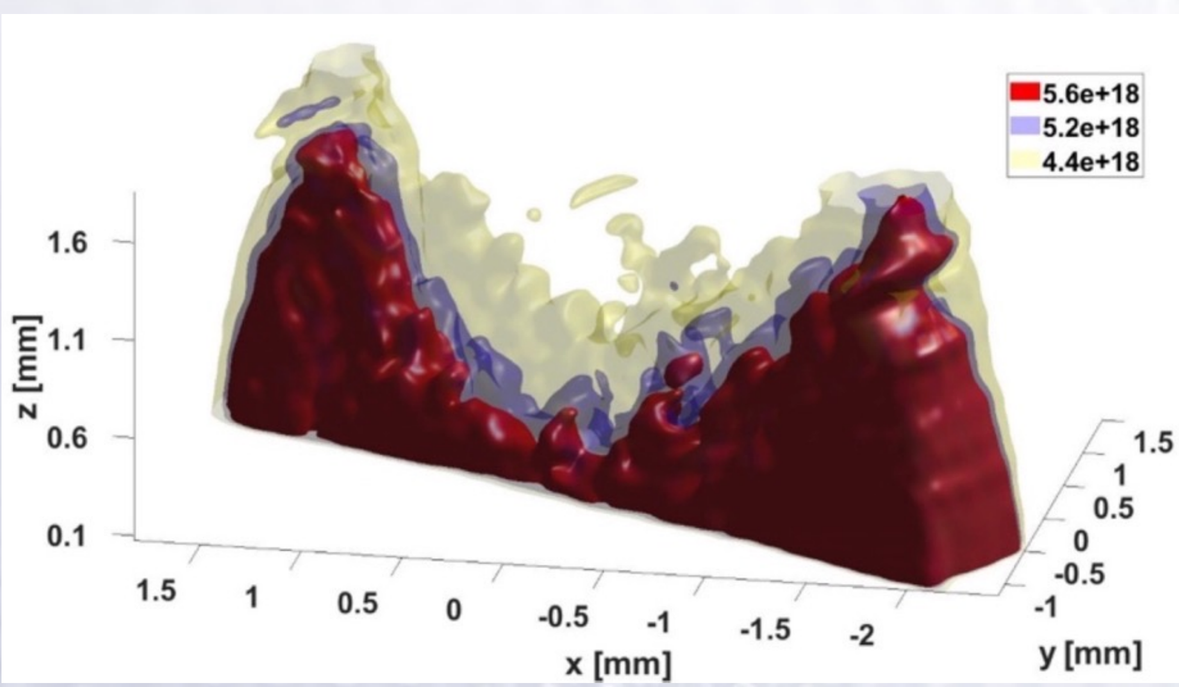
860 mrad emission cone

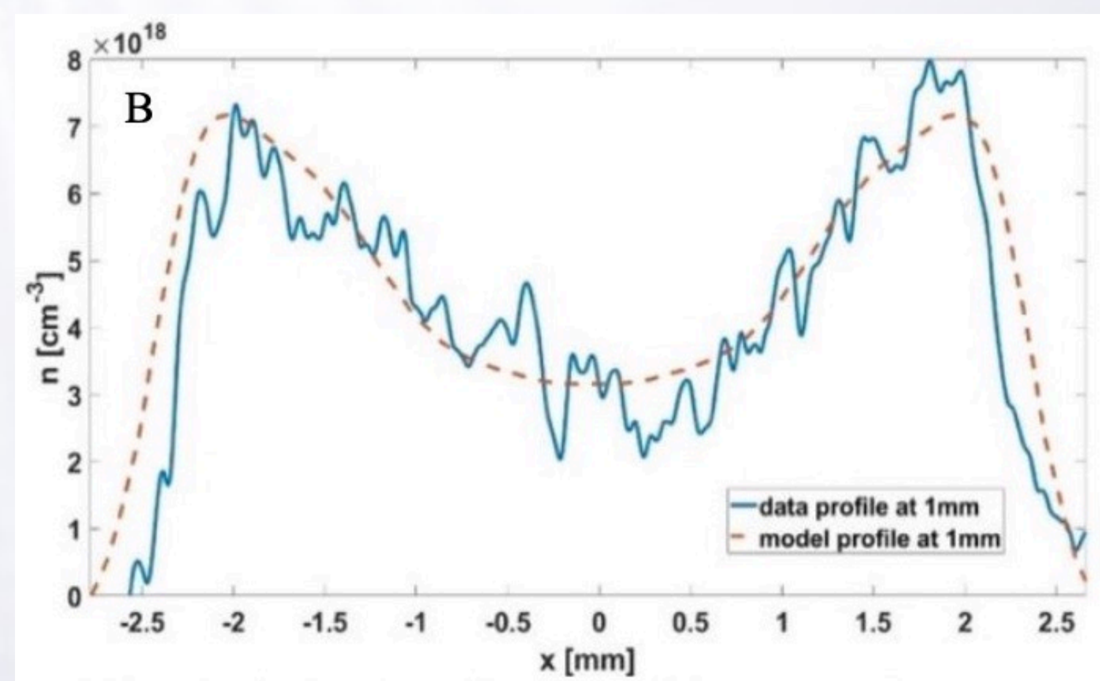
Simulations, C. Thaury et al., LOA,
Tomography – Thales,
Manufacturing FTMC

3) Gas Targets for Betatron Source



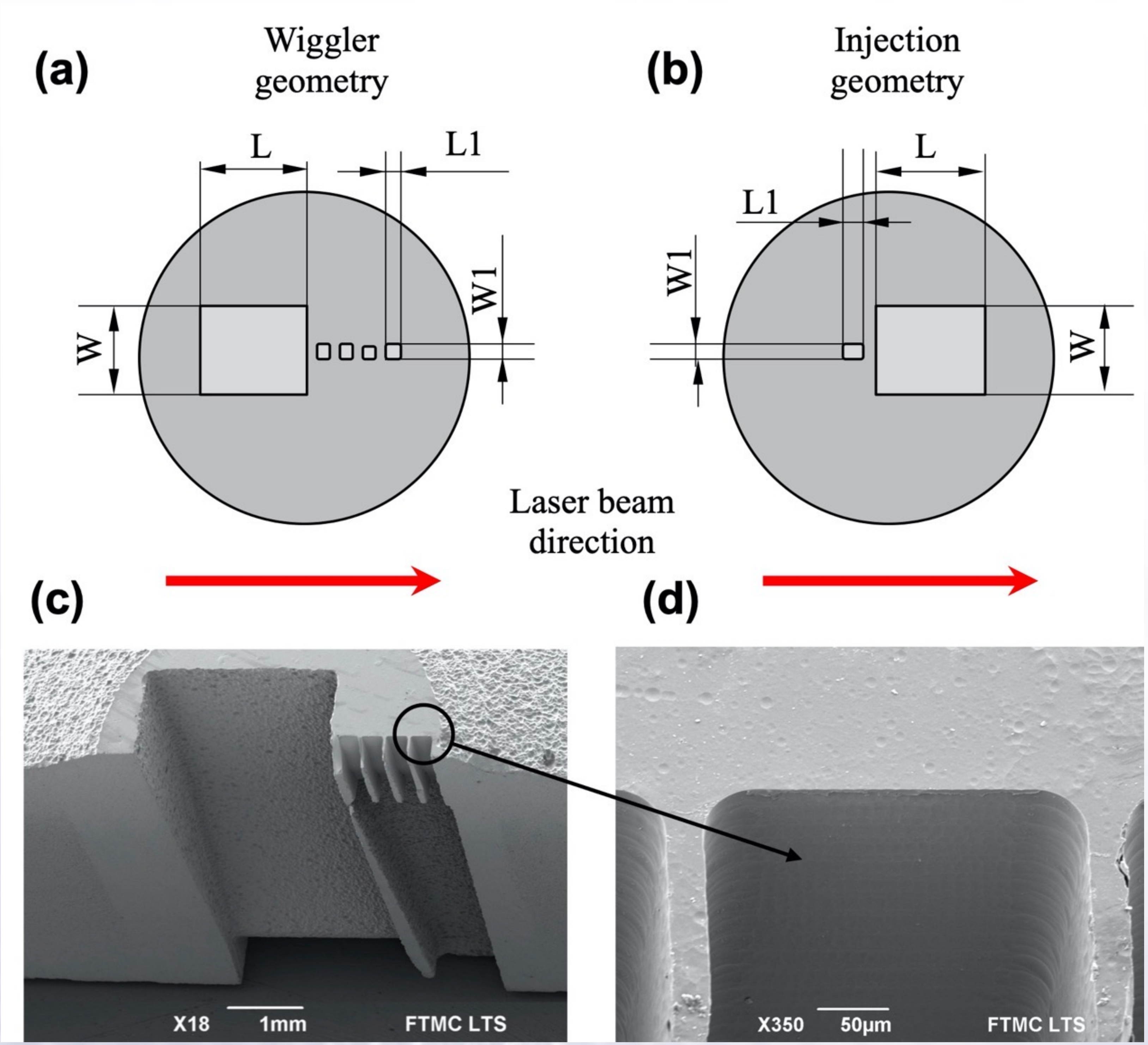
Gas targets for the Betatron X-ray Source at ChETEC-INFRA-Beamlines





Simulations and Design U. Chaulagain et al., ChETEC-INFRA Beamlines, Manufacturing FTMC

3) Micro-nozzles array



Wiggler structure

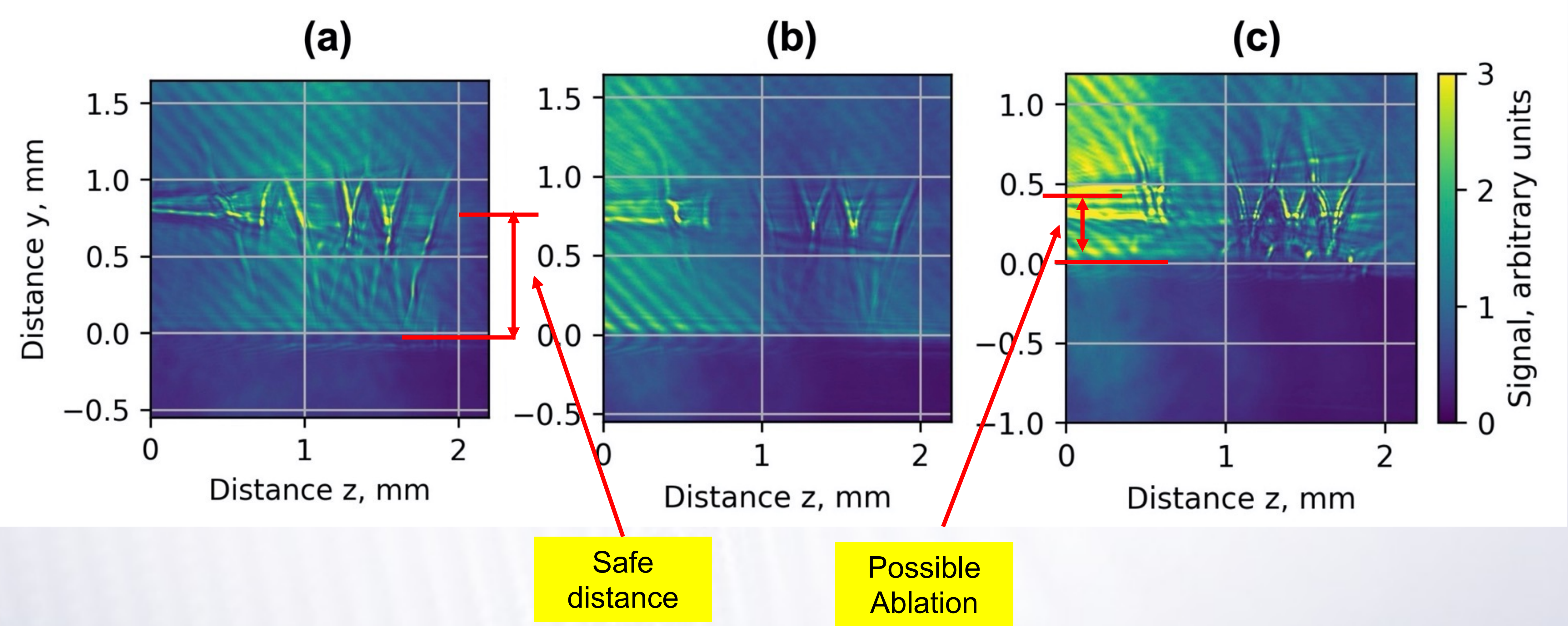
- 1.5 mm converging-diverging slot nozzle **S1** with 4 x 200 µm nozzles - array **Arr2**
- ∅ 2.25 mm De Laval nozzle with 4 x 200 µm nozzles - array **Arr3**

Injector structure

- 300 µm slot nozzle with 1.5 mm converging-diverging slot nozzle - array **Arr4**

 V. Tomkus et al., Sci. Rep. 10, 16807, (2020)

3) Laser Beam Shadowgrams of Wiggler structures



Shadowgrams of **Wiggler structures** formed by the intersecting shock waves in gas of arrays **Arr2** (a) and **Arr3** (b,c) for the laser beam propagating at the distance of 800 μm (b) and 400 μm (c) above the nozzle outlet

V. Tomkus et al., Sci. Rep. 10, 16807, (2020)

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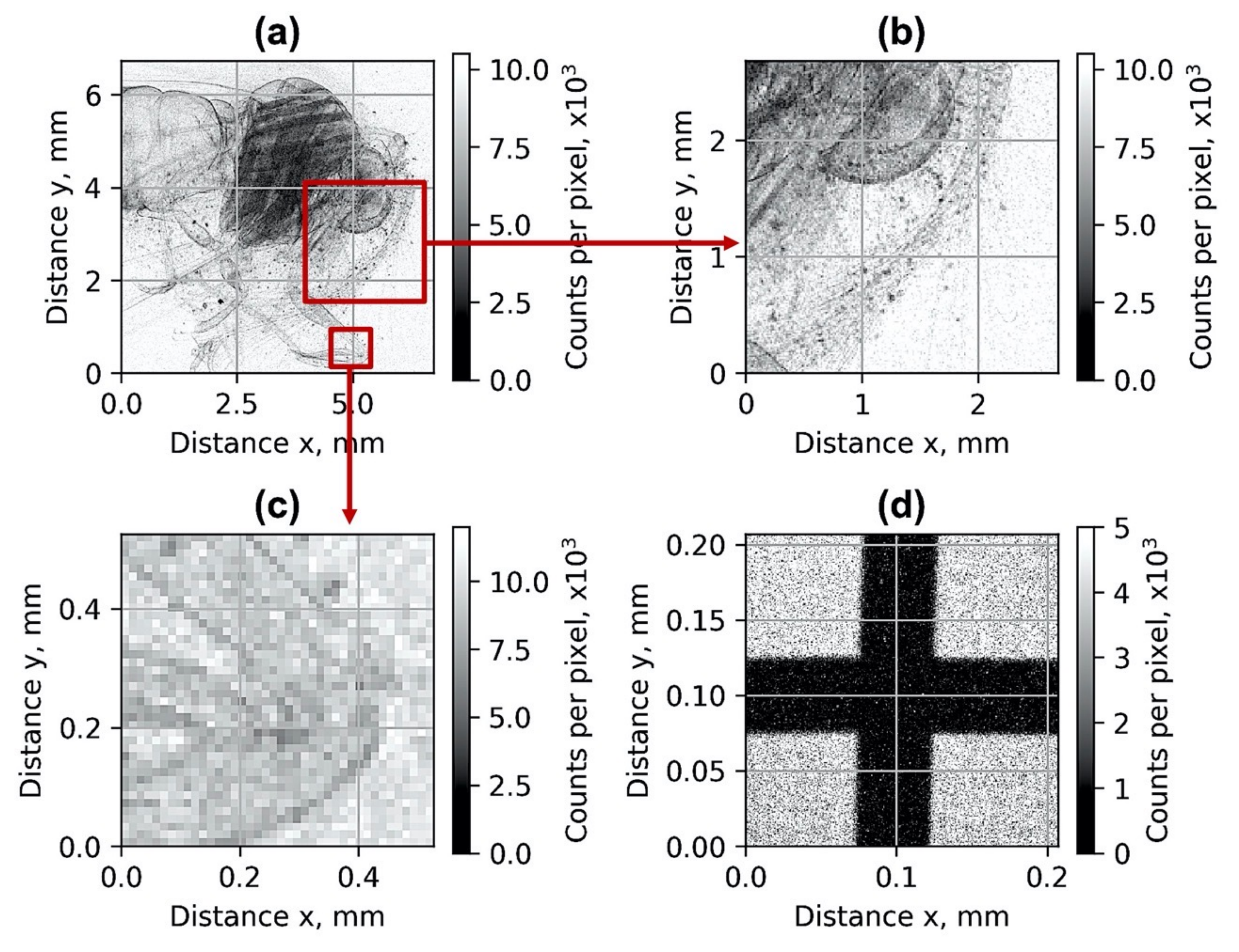
3) Resolution of X-ray Imaging

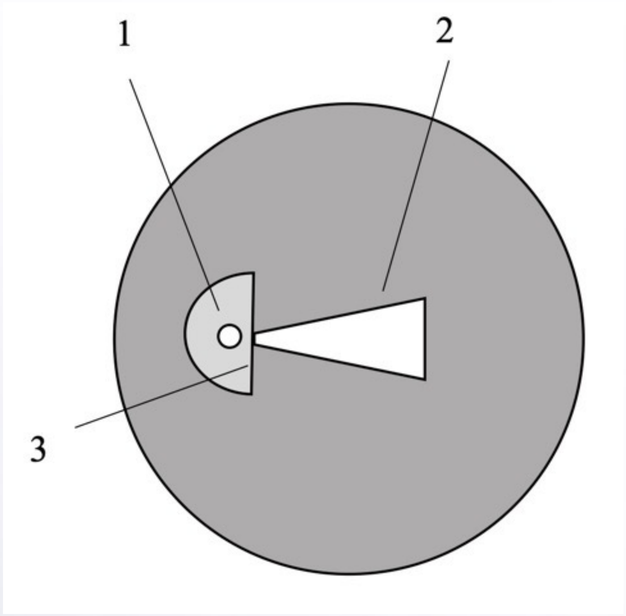


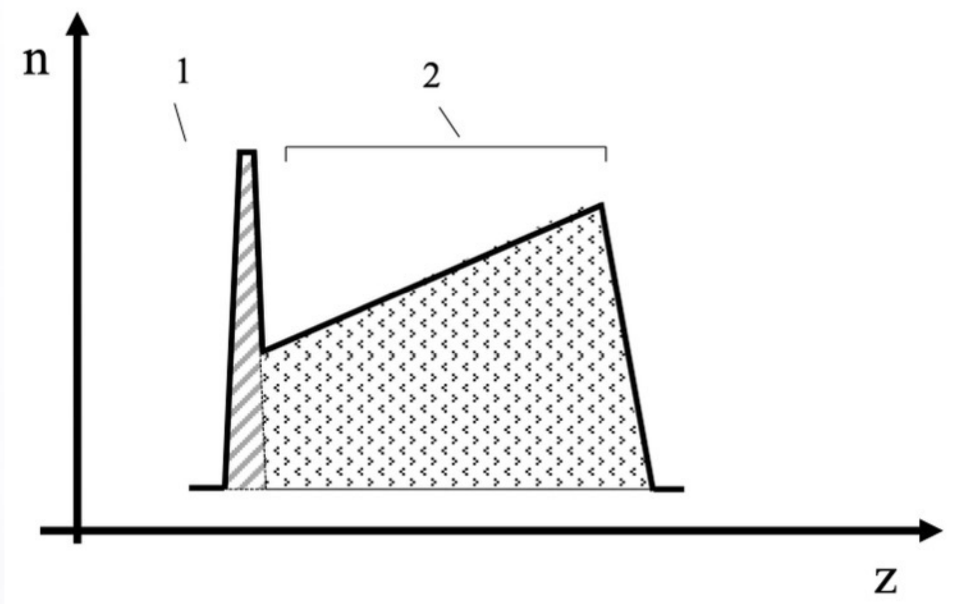
- X-ray image using ∅ 2.25 mm **Arr3** **Wiggler structure** (400 μm) (a, b)
- Resolution of X-ray imaging was limited by the pixel size of 13.5 μm (c)
- Resolution of X-ray imaging limited by source size< 9 μm (d)

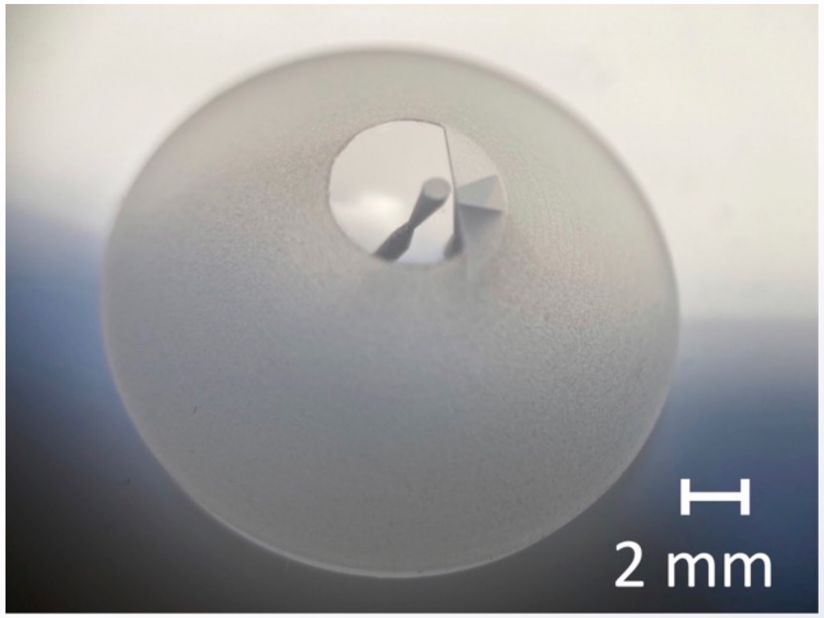
Arr2 Wiggler structure increased the number of X-ray photons per shot ($1.1 - 2.9 \times 10^8$) and brightness ($0.3 - 0.7 \times 10^{20}$ ph/s/mrad^2/mm^2/0.1%BW) by a factor of 2-3.

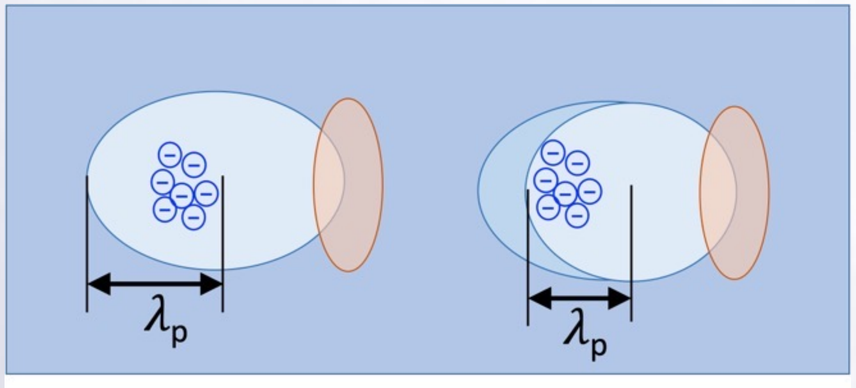
V. Tomkus et al., Sci. Rep. 10, 16807, (2020)

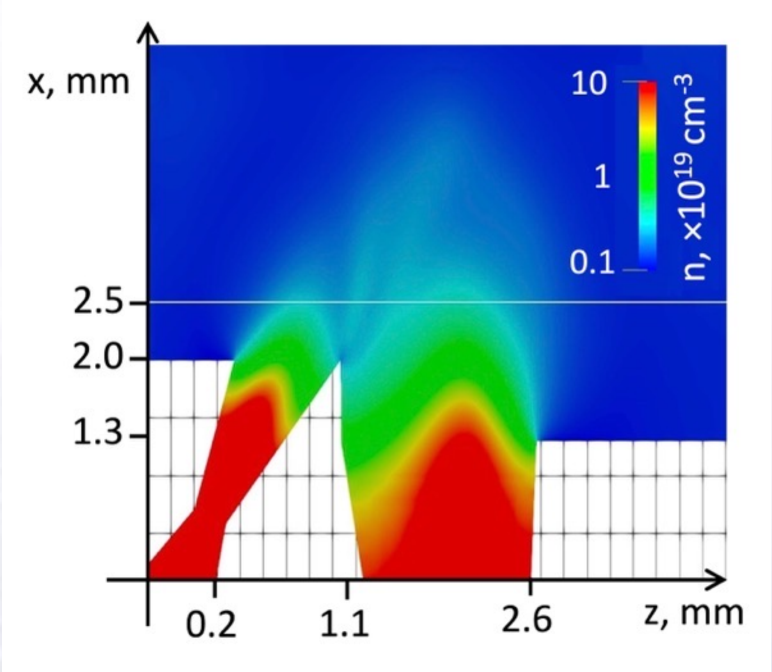
3) Double gas nozzle

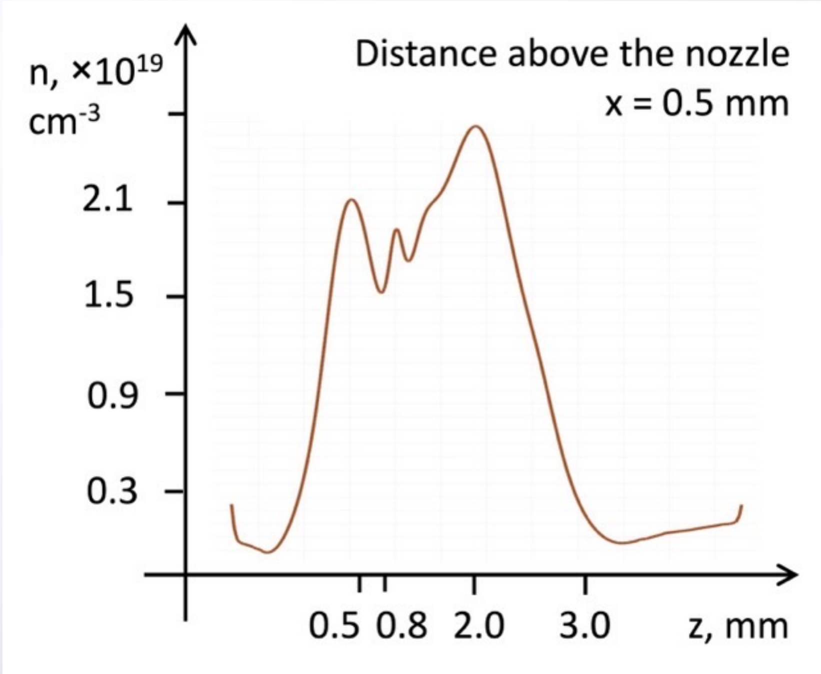










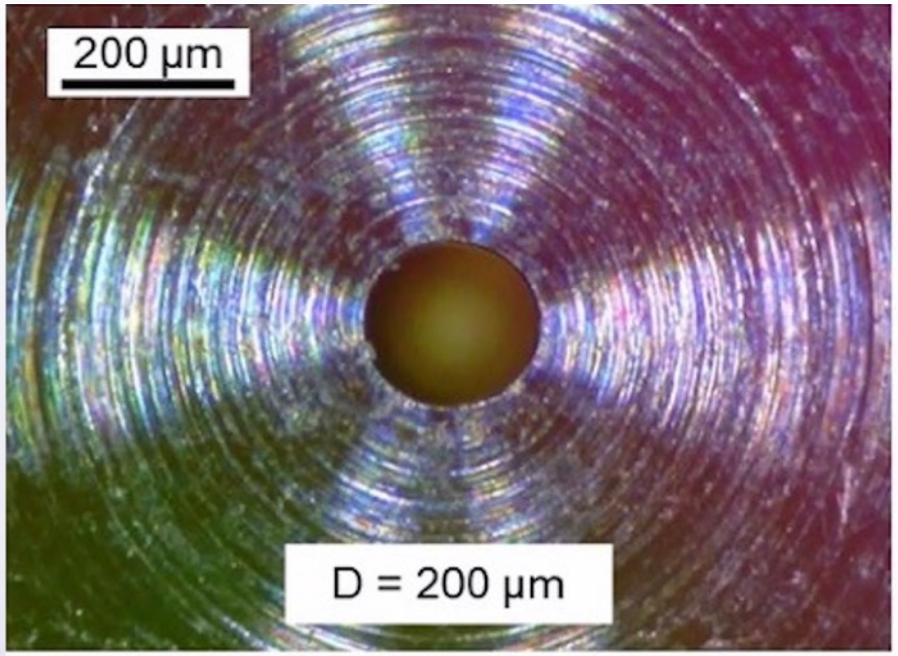


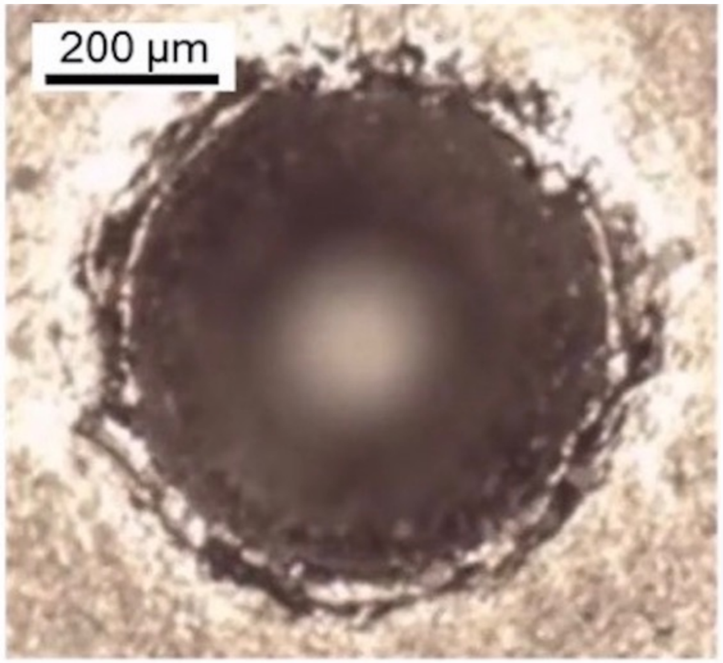
Grant Agreement of
Research Council of
Lithuania No. S-MIP-21-3

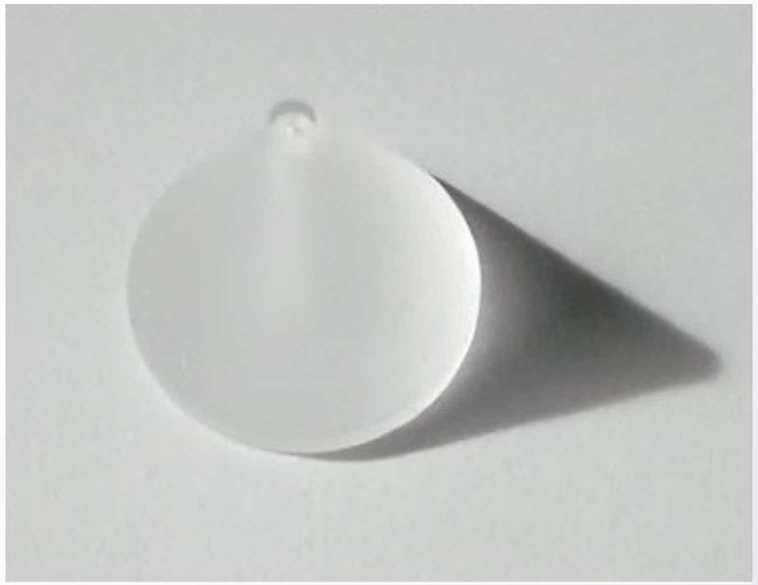
4) Proton Acceleration

Before laser shot
D= 200 µm

After laser shot
D*= 760 µm







PICO2000 (LULI)
(E=50J, t-1 ps, λ=1 µm
Shot at 400 µm above the outlet

Fused silica, the system withstood 1000 bar, measured 13/03/2020

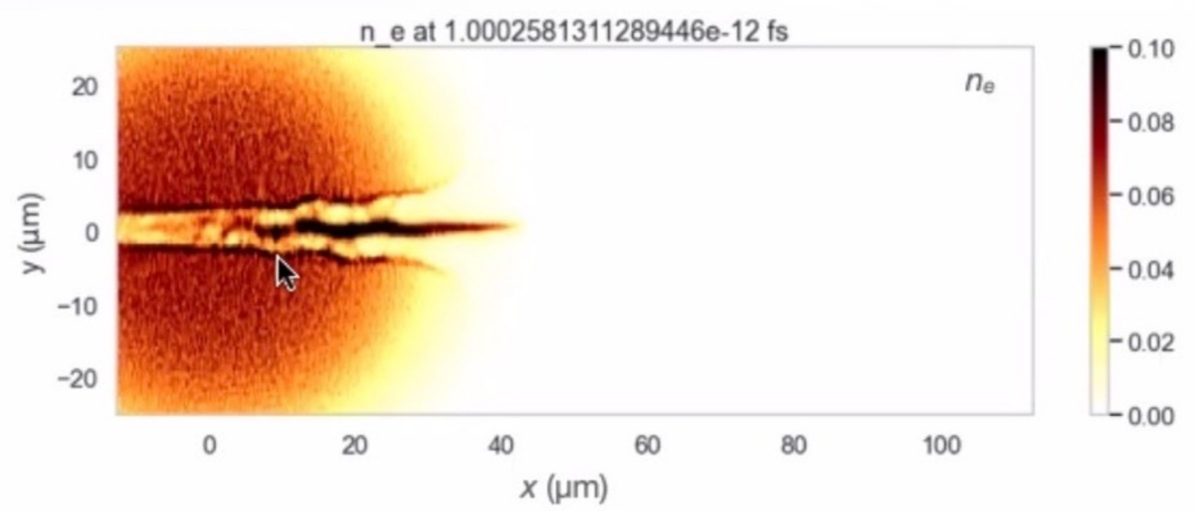
CENBG

CLPU CENTRO DE LÁSERES PULSADOS

Destruction problems

Simulations, J. Henares et al., CENBG/CLPU
Manufacturing FTMC

4) Deuteron acceleration



Formation of sub-critical gas targets:
Non-shock nozzle – Extension 1:2
Shock nozzle – Extension 1:6
Super-gaussian profile
σ = 30 - 70 μm

Laser - 3 μm spot size FHWM
12 fs pulse length
I = 3×10^{19} W/cm^2

John Adams Institute for Accelerator Science

National Laser-Initiated Transmutation Laboratory University of Szeged

Simulations, nozzle design - N. Zulfikar et al., JAI, Laser facility - ChETEC-INFRA ALPS,
K. Osvay et al, National Laser-initiated Transmutation Laboratory

5) Nuclear Astrophysics Research

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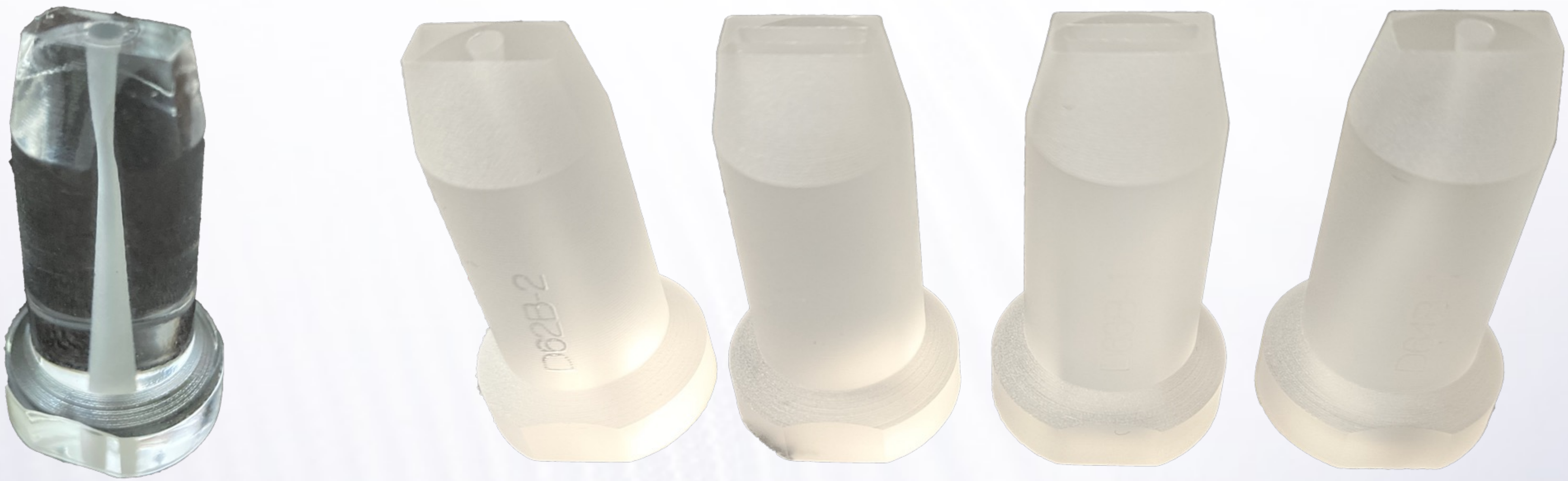

Formation of gas targets:
De Laval nozzle d 2.75 mm/1mm
Slit nozzle – 9.75 mm x 1.85 mm,
throat 8 mm x 0.1 mm

HZDR
HELMHOLTZ ZENTRUM DRESDEN ROSSENDORF

Simulations, nozzle design - Konrad Schmidt, Manfred Sobiella, HZDR

5) Nuclear Astrophysics Research

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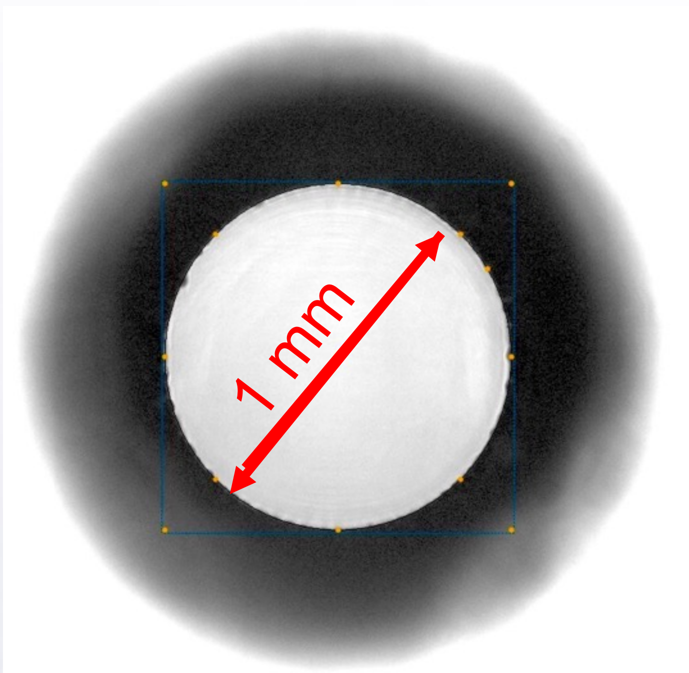

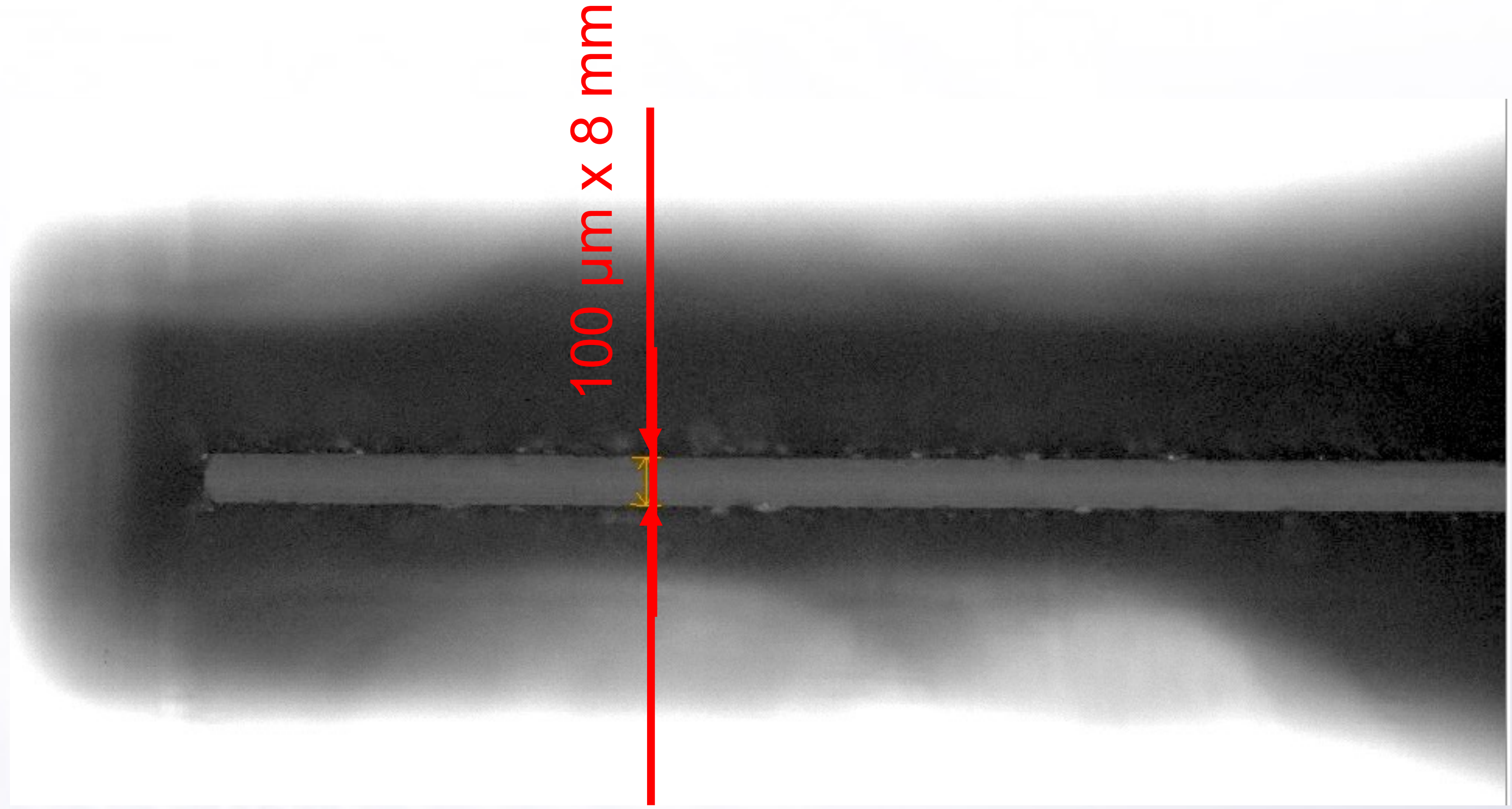

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HZDR
HELMHOLTZ ZENTRUM
DRESDEN ROSSENDORF

Simulations, nozzle design - Konrad Schmidt, Manfred Sobiella, HZDR

Summary

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- The plasma target should be matched to the pulse energy and spatial-temporal parameters of the driving laser
- Tailored injection mechanism ensure stable long-term operation of a kHz laser-plasma accelerator. Double nozzle allows independent adjustment of injection position and injected electron charge.
- Micronozzle arrays of micrometric dimensions resistant to optical damage can be manufactured from transparent materials, such as fused silica, combining fast high-volume removal laser nanosecond rear side processing and high-precision Femtosecond laser-assisted selective etching (FLSE) technique.
- Gas targets can be implemented for electron, proton and deuteron acceleration using kHz class lasers as well as nuclear astrophysics research.

THANK YOU FOR ATTENTION!

FP7: 2013-2017

H2020: 2020-2024

Innovation Fostering in Accelerator Science and Technology

MULTISCAN 3D
H2020: 2021-2025

Laser-plasma based source 3D Tomography for cargo inspection

AXENON
Lithuanian Research Council: 2021-2023

Electron Acceleration using Partially Non-diffracting Laser Beams with Spatio-temporal Coupling