DEVELOPMENT OF GAS TARGETS FOR VARIOUS LASER-PLASMA EXPERIMENTS

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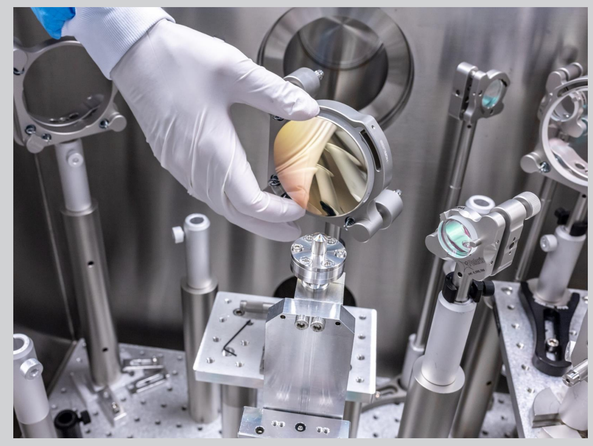
Various laser-plasma experiments from **laboratory astrophysics**, **particle acceleration**, **plasma physics**, and **X-ray sources** require the implementation of gas target technology (a system delivering specific gas with a pre-defined density profile inside a high-vacuum environment). The generated particle beams and radiation in these experiments strongly depend on the choice of optimal density profile formed in a gas target.

Here, we present the development of standardized gas targets suitable for various laser-plasma experiments driven by high-intensity ultra-short laser pulses at high repetition rates. Hydrodynamic simulations of the neutral gas flow are implemented to design the targets. Then, the target characterization is performed by interferometric measurement and tomographic reconstruction of the density profile. The data obtained from in-situ testing of the targets in the laser-plasma experiments are then benchmarked with P-I-C plasma simulations. To improve the stability of the interactions, some targets are optimized to work in a continuous flow operation regime.



GAS TARGET DEVELOPMENT

Demands for the density profile

From theoretical models and PIC simulation predictions

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3D geometry design

Computational fluid dynamics simulations

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Prototyping

Precise manufacturing technology (EDM)

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Benchmarking and verification

Interferometric measurement | Tomographic reconstruction

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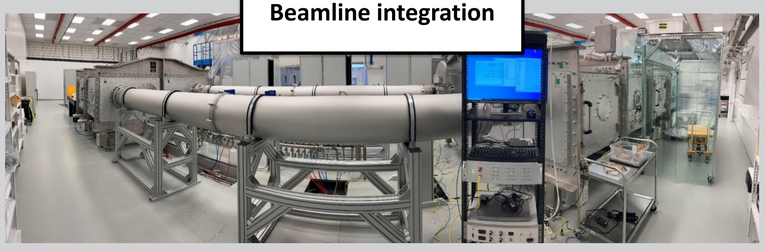
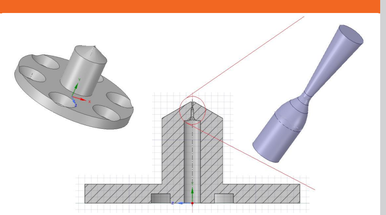
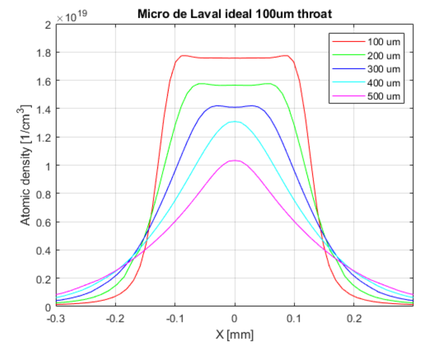
Beamline integration



CONICAL MICRO-NOZZLES

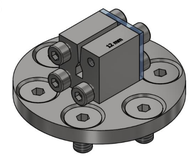
- Flat-top density profile, steep gradients on sides
- Exit diameter 0.2 – 3.0 mm
- < 5 um manufacturing accuracy in the divergent part of the nozzle
- High-density version producing up to ~ 10^{20} atoms/cm^3
- Dedicated to continuous flow operation – successfully tested with differential pumping system
- Demonstration of up to 50 MeV electron beams at kHz repetition rate in ALFA beamline [5]

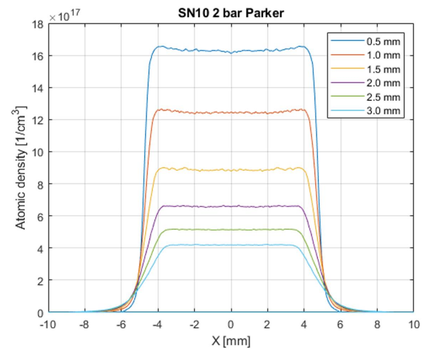




SLIT SUPERSONIC NOZZLES

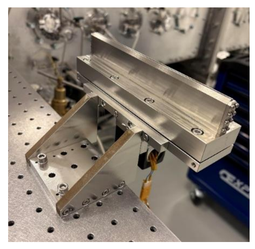
- Designed for PW LWFA experiments
- Lengths of the slit 4-50 mm, flat-top density profile
- Replaceable components (consumables) to protect the target from the laser damage
- Non-conductive insulation against EMP effects

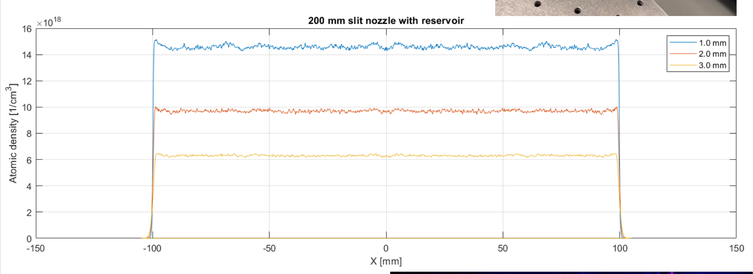




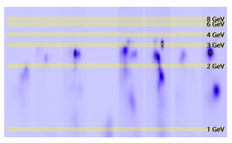
Very-long nozzle jets (~100 mm)

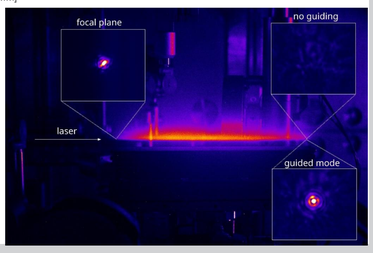
- Gas target for Bessel beam LPA experiments towards muon beam production
- Density variation within 4 % along the profile





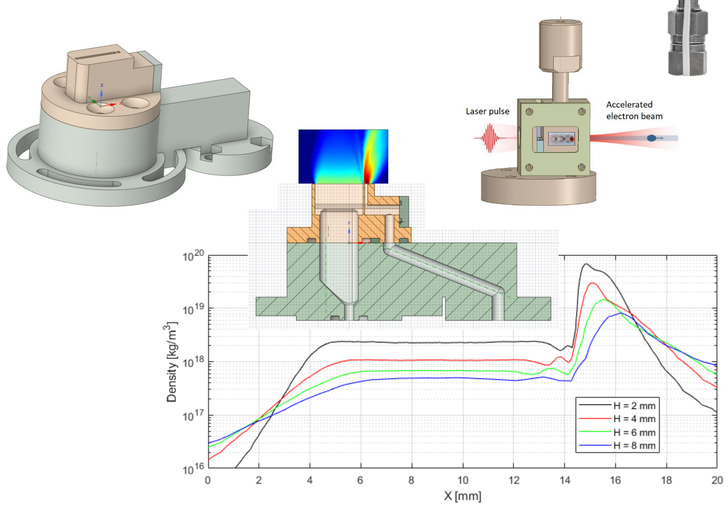
- Stable multi-GeV electron beams generated in ELBA beamline ->





DUAL-STAGE GAS TARGETS

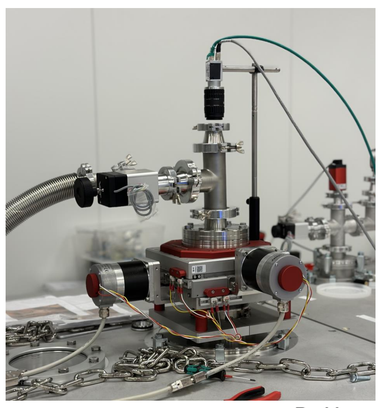
- 2 independently controlled gas inlets with different gasses
- Peak-to-plateau ratio can be adjusted remotely by independent pressure settings
- Open volume/close volume solution
- High versatility:
  - Density drop and ionization injection schemes
  - X-ray generation schemes
  - Laboratory astrophysics experiments

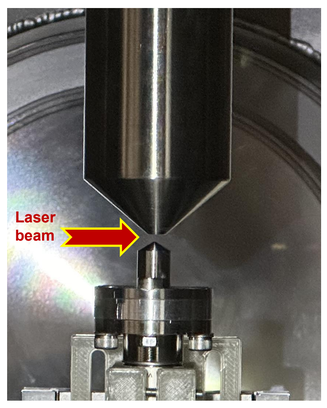


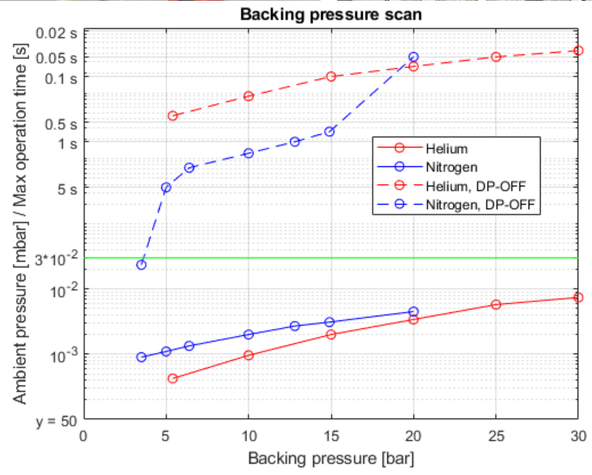
DIFFERENTIAL PUMPING

- Crucial for high stability and high repetition rate experiments
- **ALFA beamline continuous kHz electron acceleration**:

	GAS	PARAMETER	OFF	ON
High power mode ->	N	Gas load reduction	/	800x
	N	Max opening time @ 13 bar	1 sec	continuous
	N	Saturation pressure	/	1x10^{-2} mbar
High energy mode ->	He + 5% N	Gas load reduction	/	4000x
	He + 5% N	Max opening time @ 30 bar	50 msec	continuous
	He + 5% N	Saturation pressure	/	4x10^{-3} mbar



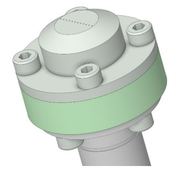


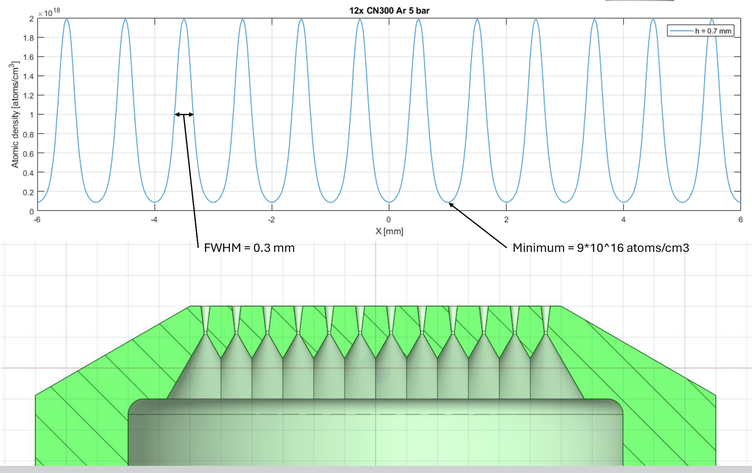


Parameter scan of the skimmer design dimensions S. Lorenz et. al., (2025, in prep.)

PERIODIC NOZZLE JETS

- Periodic row of supersonic micro-nozzles
- Designed for HHG experiments
- Allows for enhanced diagnostics





[1] C. M. Lazzarini et. al., Int. J. Mod. Phys. A 34, 1943010 (2019)

[2] S. Lorenz et. al., Matter Radiat. Extremes 4, 015401 (2019)

[3] S. Karatodorov et. al., Sci. Rep. 11, 15072 (2021)

[4] S. Lorenz et al., Meas. Sci. Technol. 31, 085205 (2020)

[5] C. M. Lazzarini et. al., Phys. Plasmas 31(3), 030703 (2024)

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European Structural and Investing Funds
Operational Programme Research,
Development and Education