Towards fast prototyping and industrial mass production of targets for high repetition rate free-electron lasers

Industrial opportunities at XFEL

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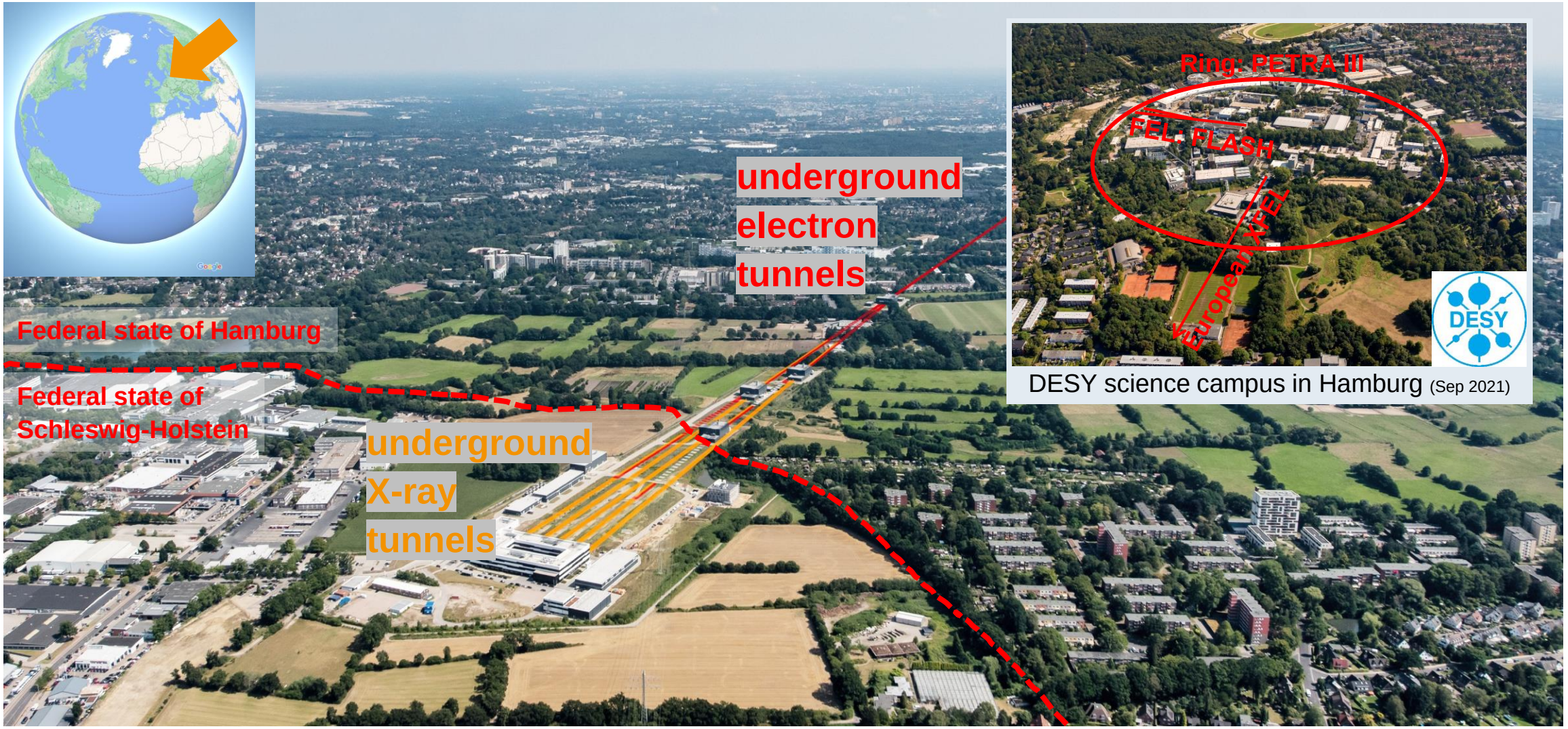
Granada, 5th October 2022



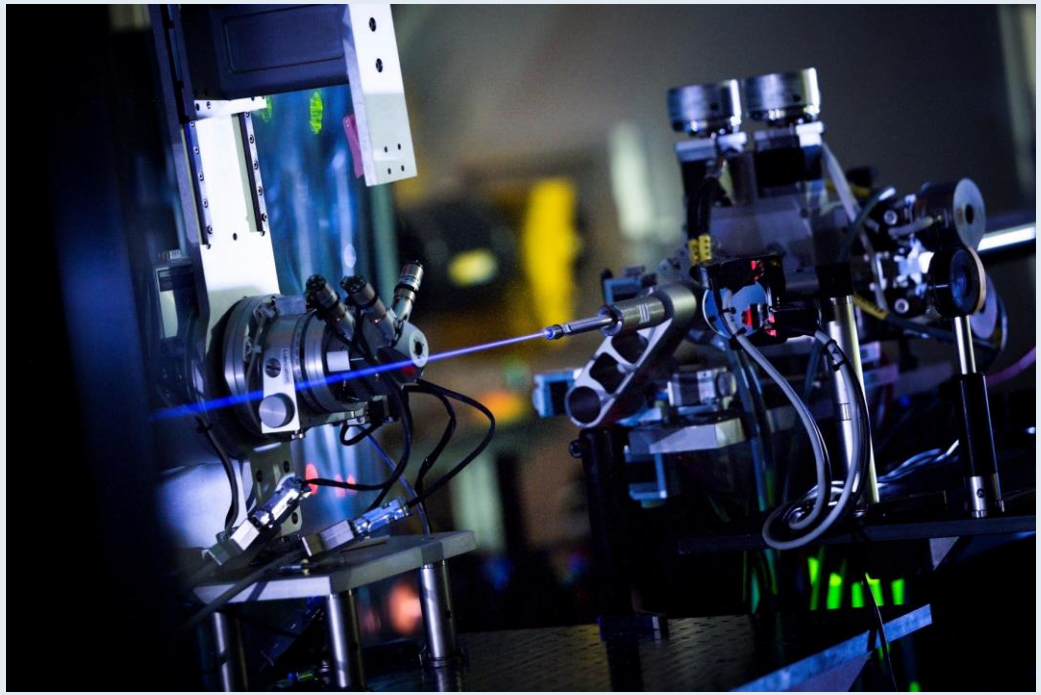
DESY science campus in Hamburg (Sep 2021)

Underground tunnels drawn on an aerial picture (August 2020)

A Microscope for Molecular Movies

European XFEL: An ultra fast, super intense X-ray source

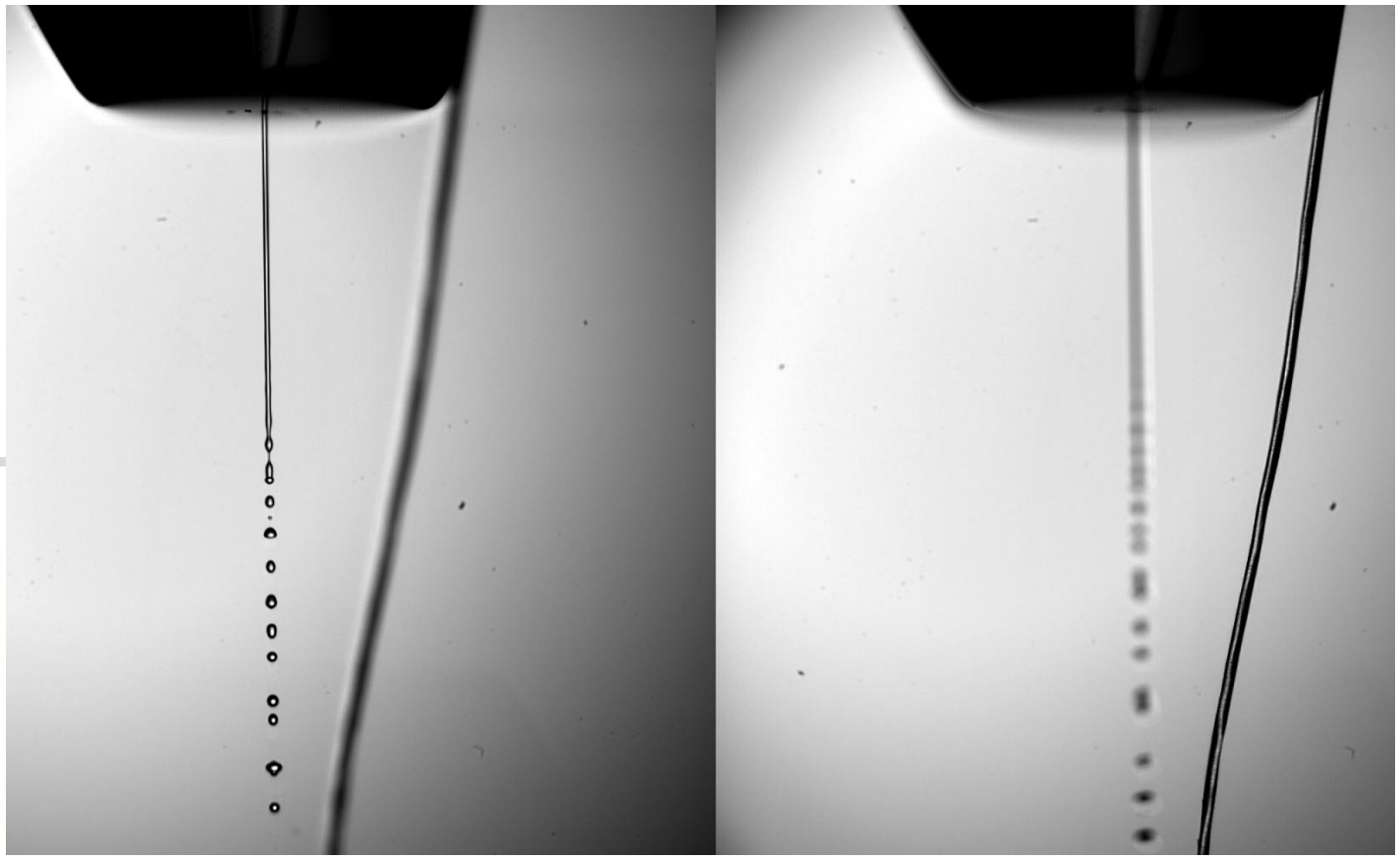
- Ultra fast
  - High repetition rate:
    - ► Up 27.000 pules per second
    - ► 600 µs long pulse trains in 10Hz
  - Sample change rate
    - ► 10 Hz for single bunch or bunch train
    - ► Up to 4.5 MHz for
- Super intense
  - Samples are often destroyed in a single shot
- X-rays
  - Everything needs to be controlled remotely

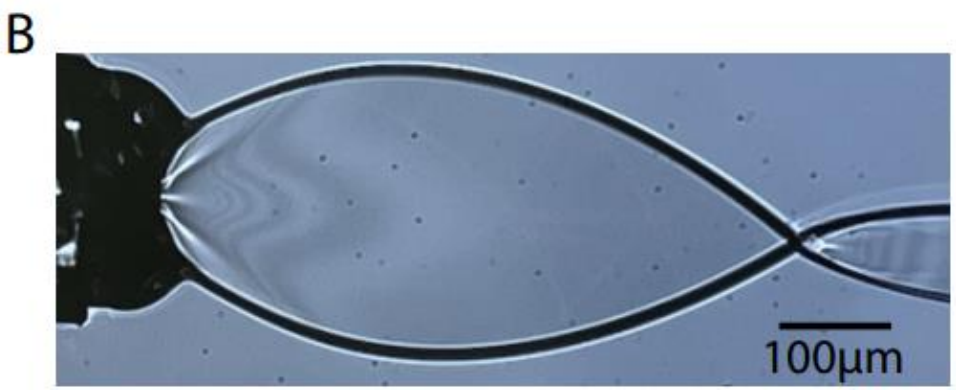


The X-ray beam at our scientific instrument FXE

Liquid jet sample delivery

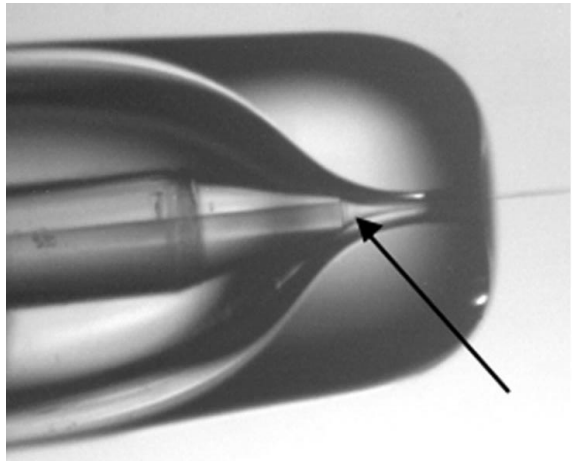
- Megahertz sample delivery with liquids
  - Gas dynamic virtual nozzle



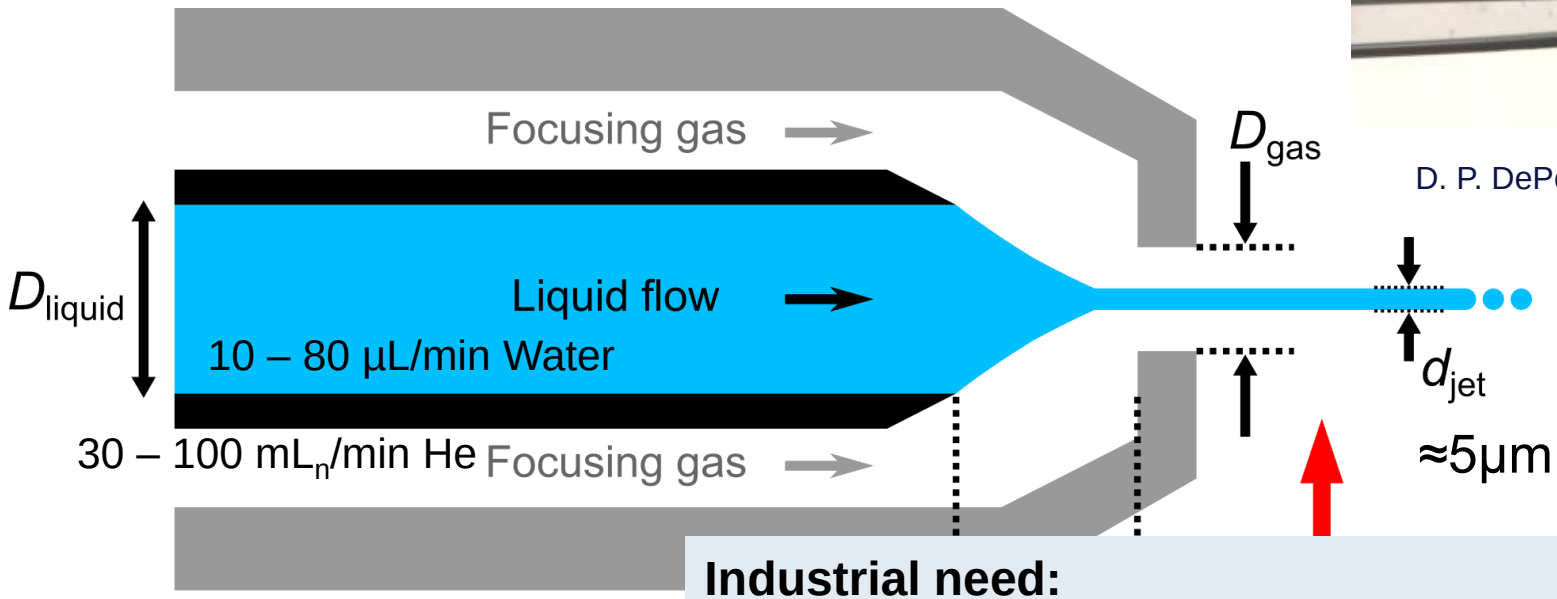


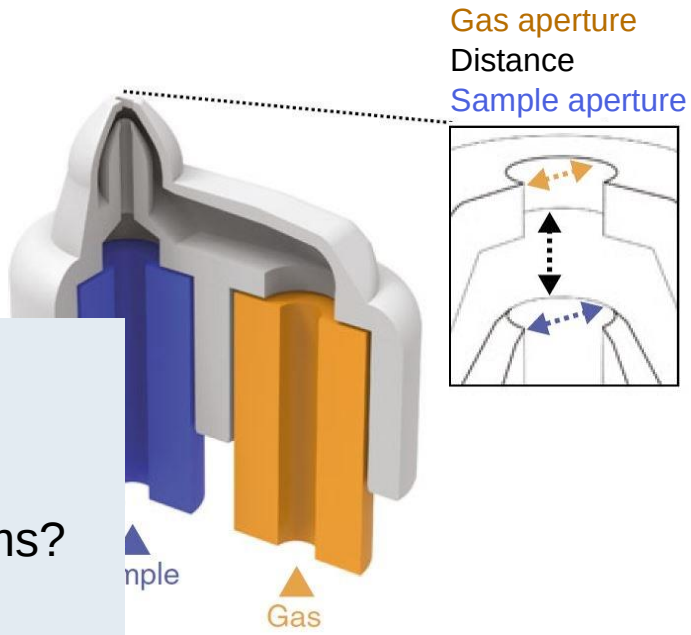
Flat sheet jet (3D printed nozzle) at vacuum conditions with a water flow of 300 ul/min

Gas dynamic virtual nozzles (GDVN)



D. P. DePonte, R. B. Doak *et al.*, *J. Phys. D. Appl. Phys.* (2008), 41, 195505.





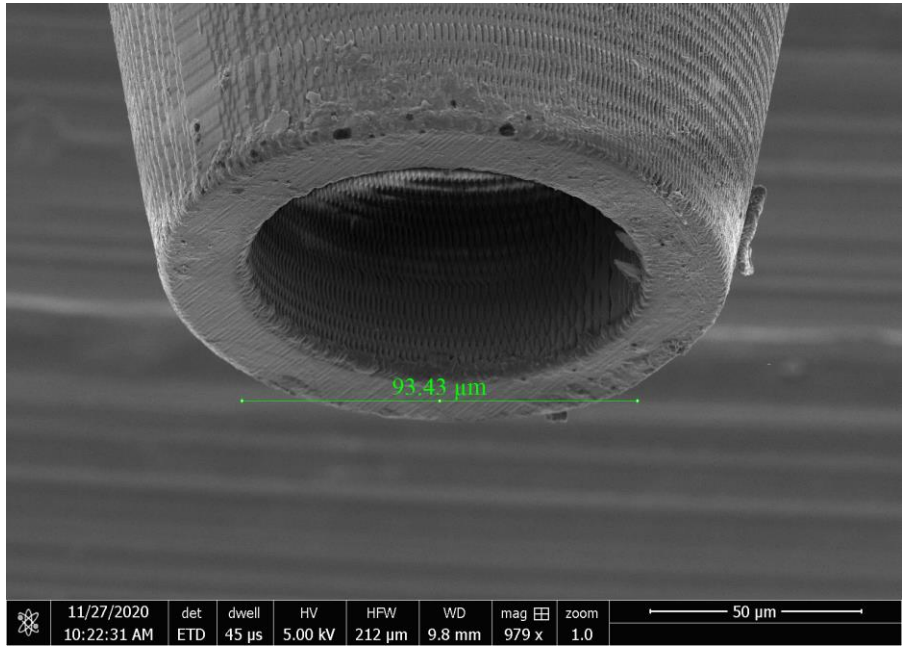
J. Knoška, M. Heymann *et al.*, *Nat. Comm.* (2020), 11, 657.

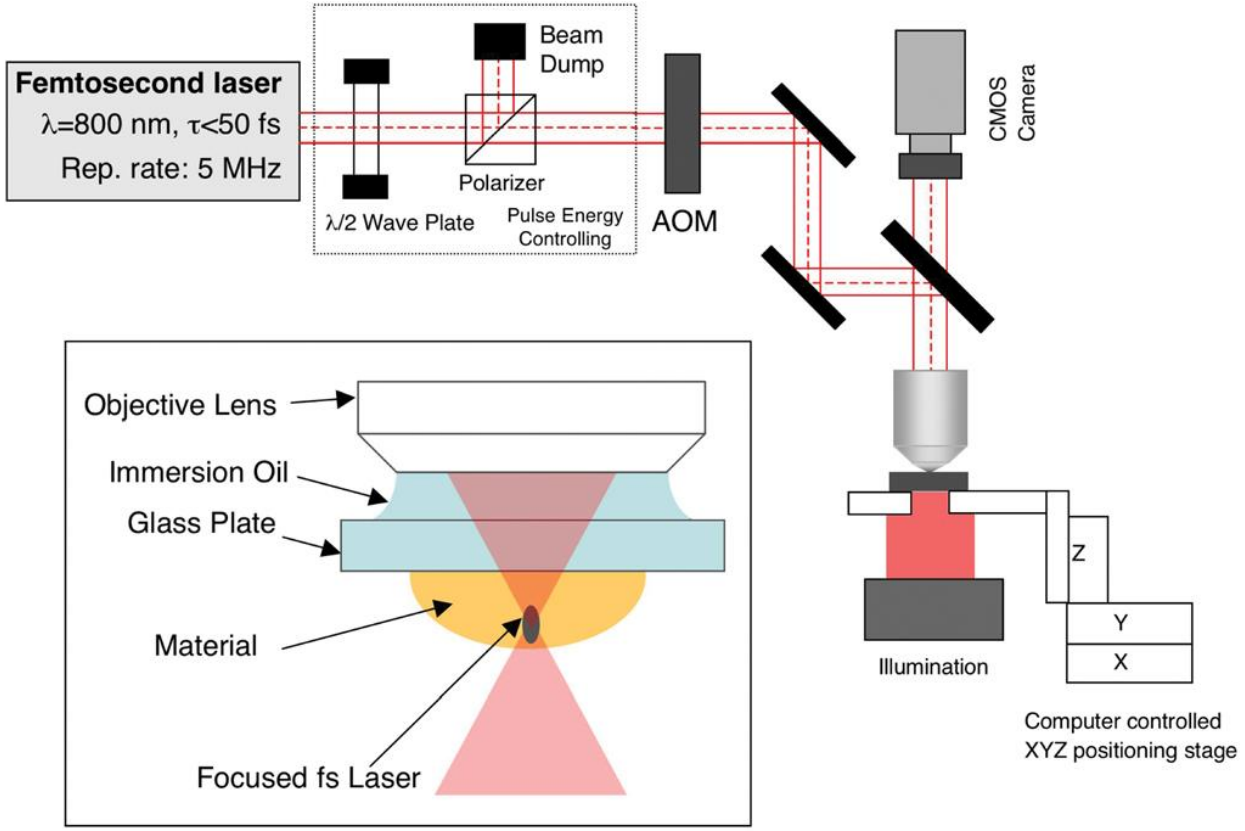
Industrial need:

- Is there a better way to
  - **Develop** more complex jetting systems?
  - **Mass produce** standard systems?

2-photon polymerization for rapid prototyping and small-series production

- Direct writing in UV hardening photo-resin



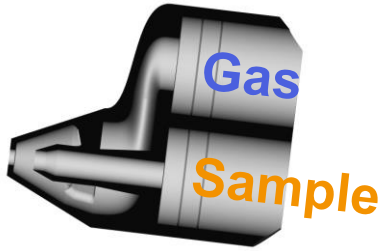


V. Paz, M. Emons, K. Obata, A. Ovsianikov, S. Peterhänsel, K. Frenner, C. Reinhardt, B. Chichkov, U. Morgner, W. Osten (2012) J. Laser Applications. 24. 10.2351/1.4712151.

Two-photon polymerization 3D-printed devices

- A variety of injection devices available
  - Gas Dynamic Virtual Nozzles (GDVN)
  - Double Flow Focusing (DFFN)
  - Mixing devices and nozzles
  - Reproducible nozzle tips
- Available for users
  - Printed and assembled by SEC group
  - Tests with sample
    - ► At users' laboratories
    - ► In-house with or without users
  - Designs published: M Vakili et al.
    J. Synchrotron Radiat. 29 (2), 1–16 (2022)
    - ► Users can copy or further develop

Gas Dynamic Virtual Nozzles (GDVNs)

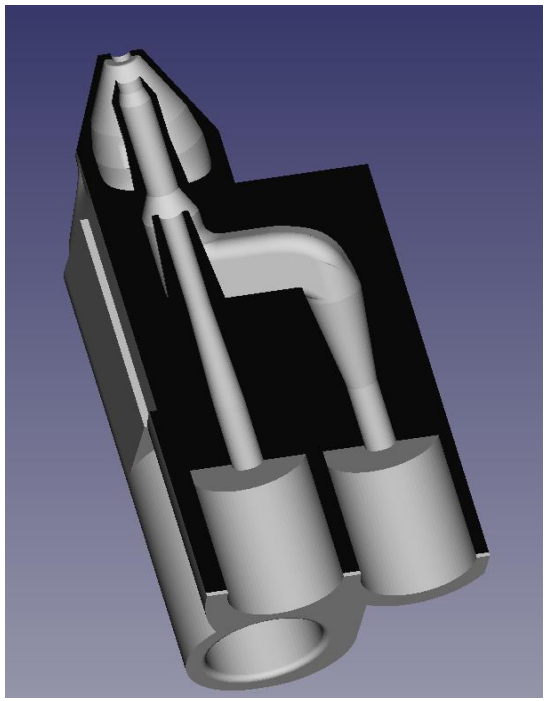


J. Knoška, M. Heymann *et al.*, *Nat. Comm.* (2020), 11, 657.

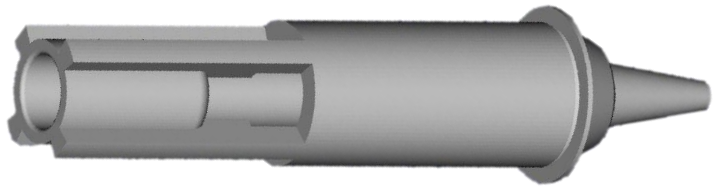
Double Flow Focusing Nozzles (DFFNs)

Juraj Knoska et al.
Nature Comm. 11:657 (2020)

Mixing GDVNs

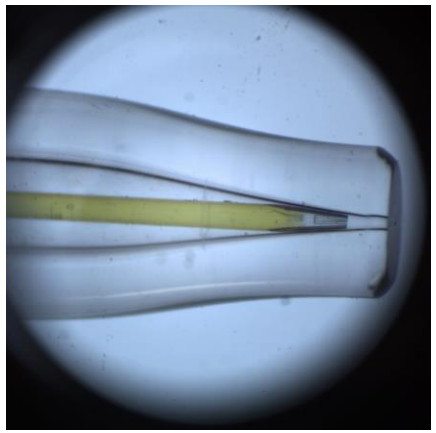


High Viscosity Extrusion Nozzle



Nozzle production

- Nozzle production is time consuming
  - For a long time GDVNs where produced by hand
    - ► Grinding nozzles demands skill and patience
    - ► The reproducibility is limited, every nozzle is different
  - Since 2018, we use a Nanoscribe 3D printer
    - ► This makes the tips reproducible
    - ► Assembly still requires a steady hand
  - Microfluidic chips have the potential for mass production
    - ► Laser etching in glass
      - Dan DePonte from SLAC works on a standard
    - ► Soft lithography using PDMS
  - Ceramic injection moulding
    - ► First successful tests have been done



Hand grounded
Glass nozzle

3D printed design from
Juraj Knoska,
Michael Heymann

Glass is a preferred material!
Fast prototyping in glass?

Is **injection moulding** able to provide our users with standard samples?

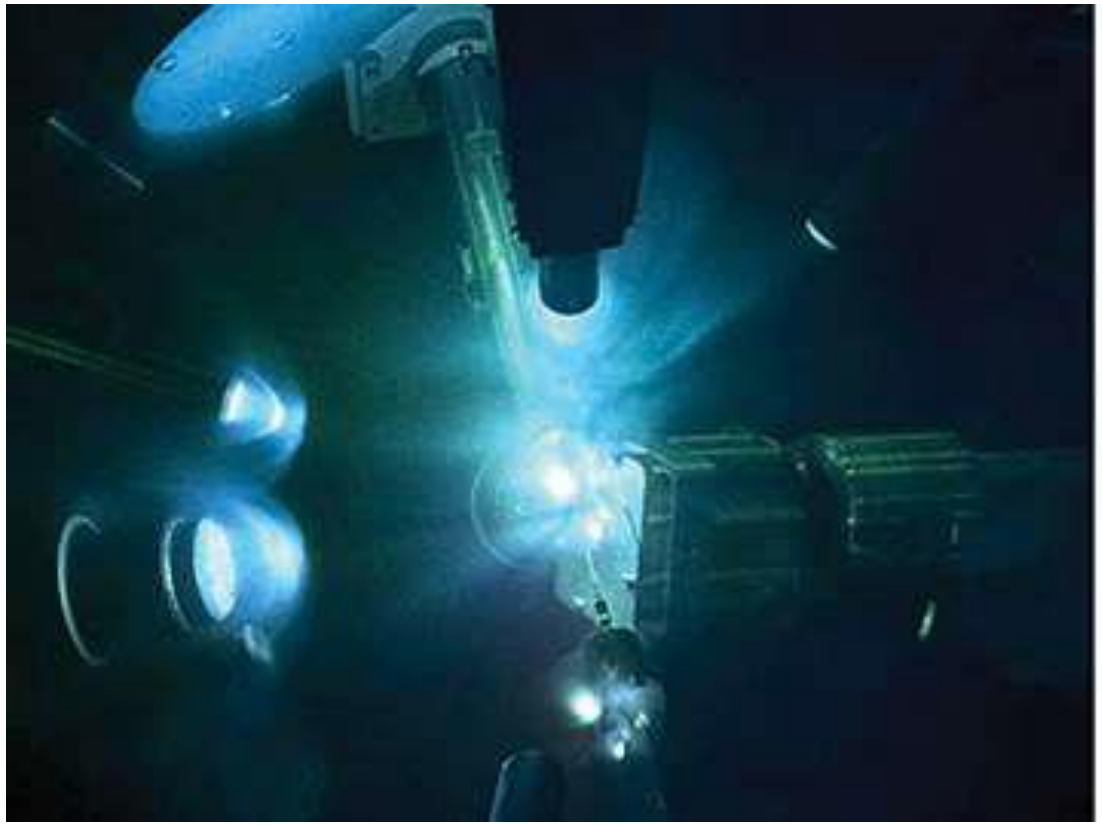
PDMA device from Martin Trebbin

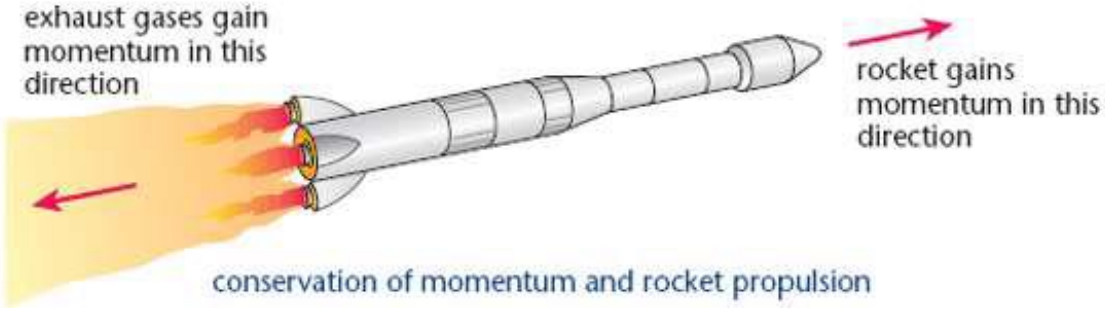
Glass device from Femtoprint
developed by Rita Graceffa

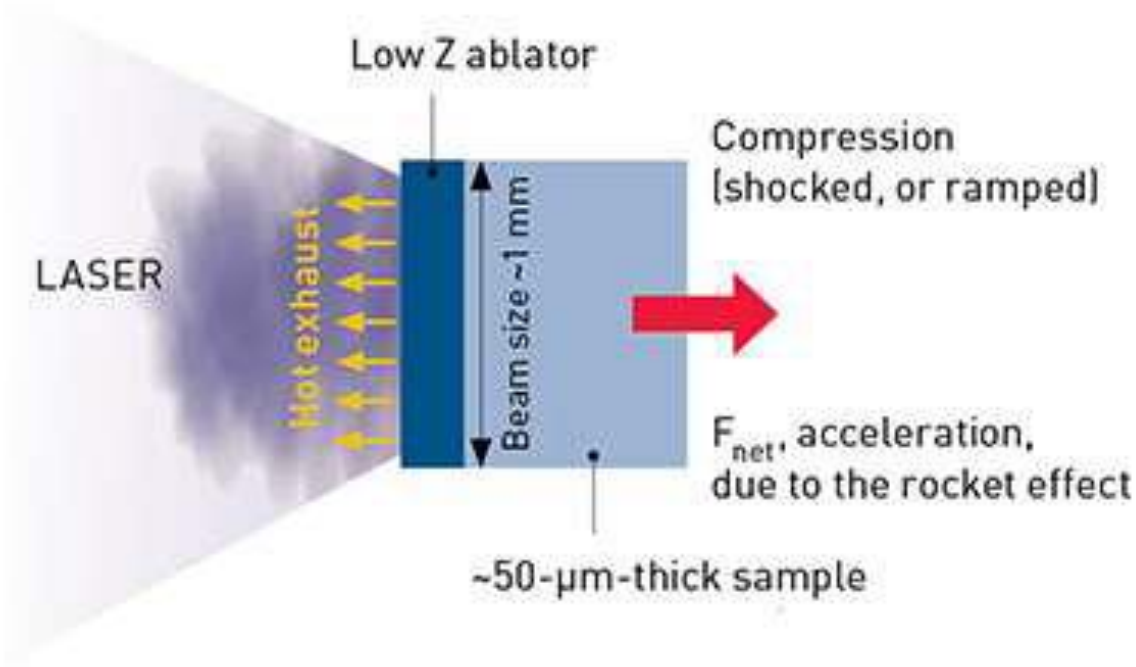
High Energy Density Experiments

- Our HED instrument offers combined use of high power and high intensity lasers with X-ray pulses
  - 10 Hz operation
  - Sample holder with 100x100 mm active area
    - ► 1 sample per mm²
    - ► 100x100 mm -> 10.000 samples
    - ► Sample for 1000 seconds at 10 Hz
      - A bit more than ¼ hour
  - Our users **need large amounts** of sample

Ablation pressure launches a shock wave





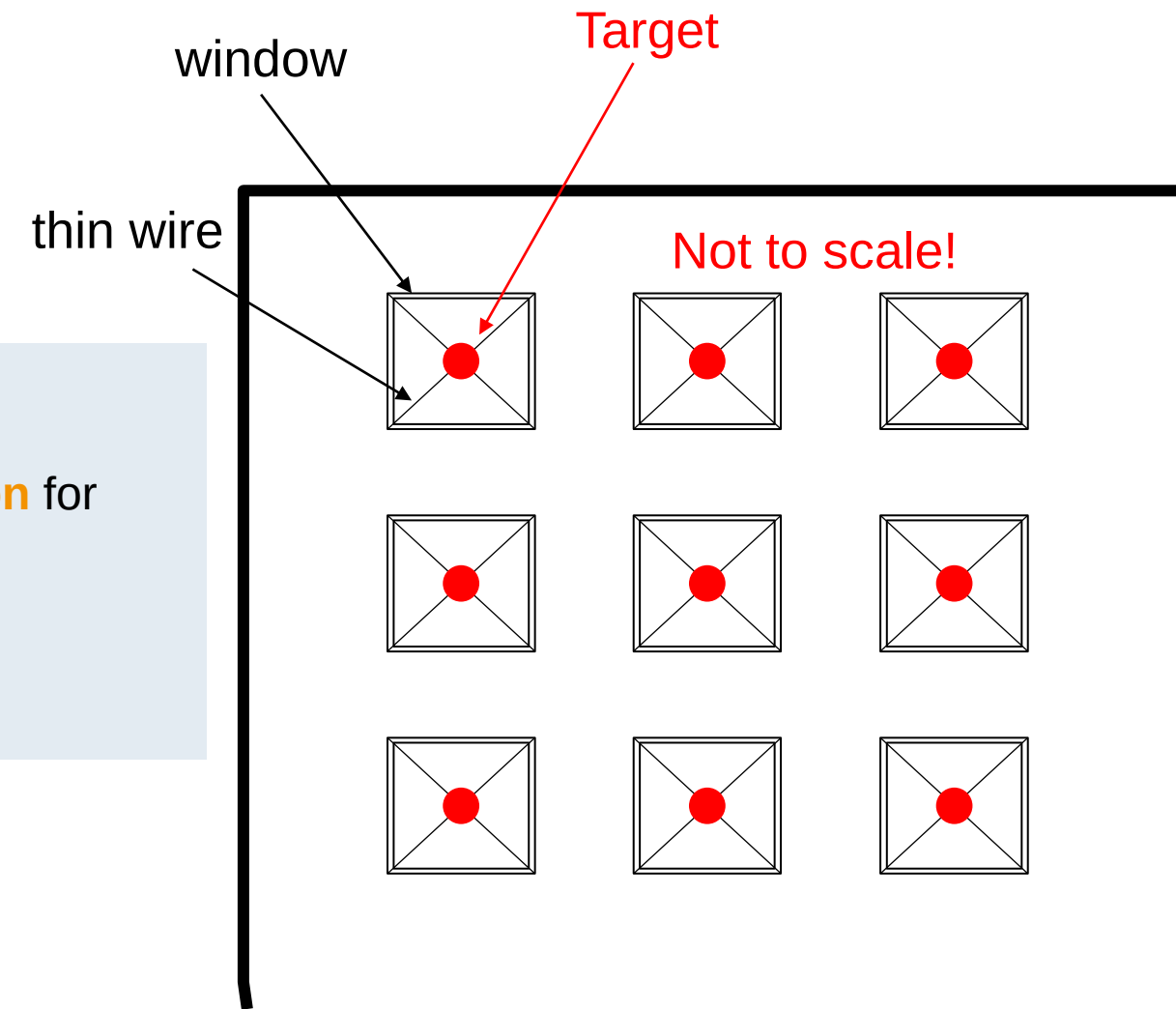


Plasma targets

- Lasers produce plasma with single shot
  - X-rays to probe plasma properties
- Needs for sample delivery:
  - “Drops” of matter free in vacuum
  - Hydrogen liquid droplets
  - or micro structured targets
    - ► Carbon based (plastic)
    - ► Or metals
- Example
  - Wafer with windows ~mm
  - Free target ~µm
  - Hold be a wire as thin as possible

Need for:

- **Target production** for user experiments
  - Reproducible
  - Accurate



Our dream:
Off the shelf sample environments for users

- Nozzles for liquid jets
  - Designs:
    - ► A hand full of different designs and sizes
    - ► Not necessarily adaptable
    - ► Ready to use or easy assembly
  - Material requirements
    - ► Hydroscopic for better flow
    - ► Chemical resistance
    - ► Biology compatibility
    - ► Non-fluorescent
    - ► Not too brittle

Glass is the optimal material!

- Targets for shock wave experiments
  - Wafers with well characterized homogeneous layers
    - ► Absorption layer on top of sample layer
- Targets for plasma creation
  - Free-standing “drops” of matter with little contact to the environment
  - Mass produced and easy to manipulate
    - ► E.g. on a wafer
- Costs
  - Per-unite prices should be affordable to user groups
  - European XFEL and partners willing to invest in development