STRONG-2020 ANNUAL MEETING (2022)

JRA11 – CRYOJET: CRYOGENICALLY COOLED PARTICLE STREAMS FROM NANO- TO MICROMETER SIZE FOR INTERNAL TARGETS AT ACCELERATORS

Alfons Khoukaz (WWU)

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 824093

JRA11/WP29 OBJECTIVES

Significantly advance the science and technology of cryogenic target beams for various fields

- Internal targets for accelerator experiments (FAIR, MESA, LEAF, ...)
- Particle-laser interaction (ARCTURUS@HHUD, POLARIS@Jena, ...)

Development of advanced diagnostic tools

Special focus:

- Cluster-Jet, Microjet, Pellet Beams
- Low-Z elements (H_2, D_2) + heavier gases (N_2, O_2, Ar, Xe)
- Boundary-free targets for hadron physics experiments

Aim: Higher efficiency and performance of targets for future physics facilities

TASKS OF JRA11/WP29

Cluster-jet beam studies

- New nozzle production techniques
- Studies on jet beams: highest performance and cluster formation
- Laser-induced particle acceleration (H_2 clusters and heavier gases)

Cryogenic droplet beam target

- Studies on droplet nozzles designs and efficiency
- Measurements on long term stability
- Investigations on high performance

Pellet source studies

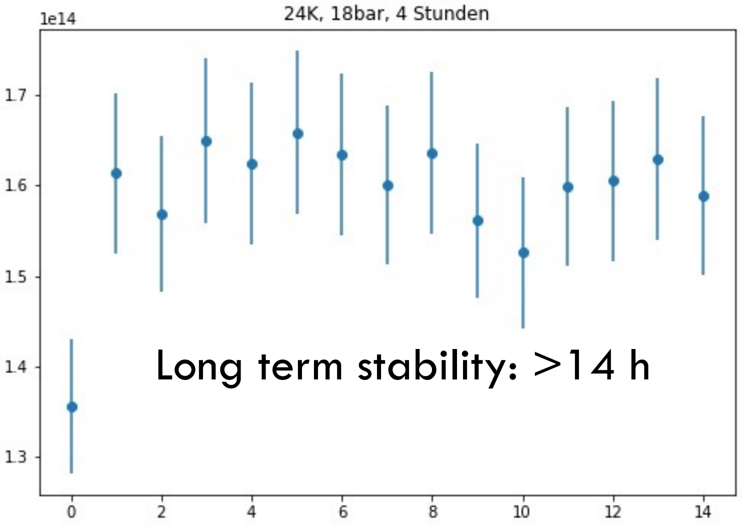
- Development and studies with new pellet diagnostic systems
- New nozzle and pellet production techniques

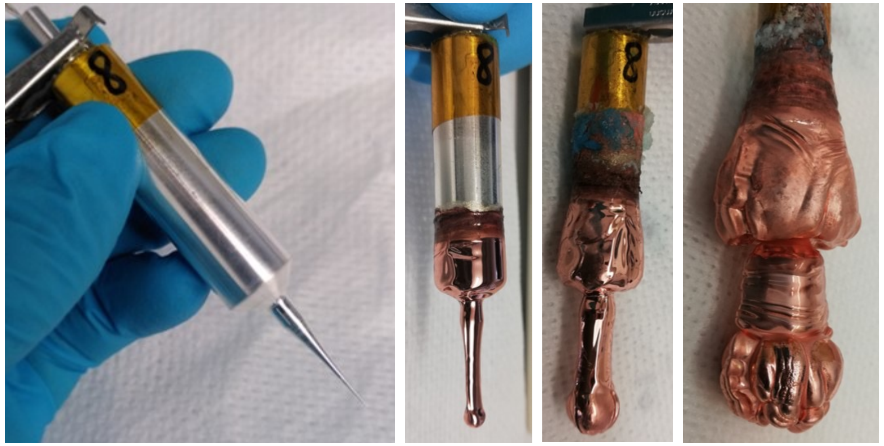
1.) SCIENTIFIC RESULTS OBTAINED SINCE THE LAST YEAR

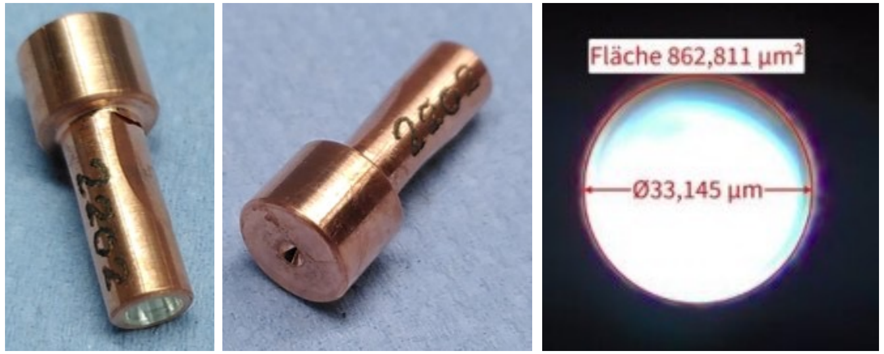
CLUSTER-JET BEAM STUDIES

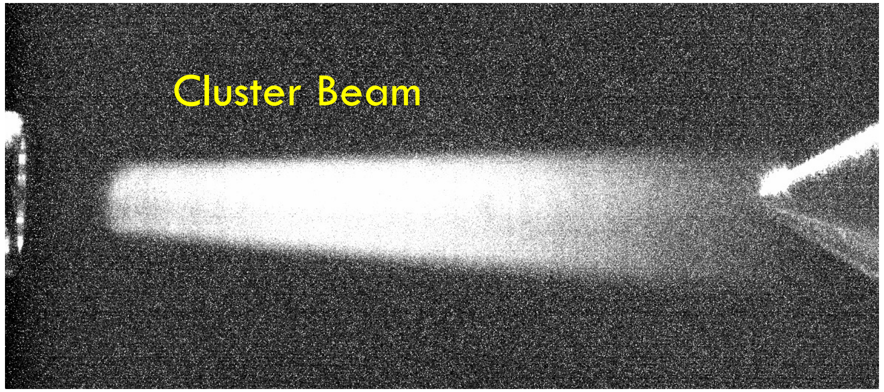
Laval Nozzle Production at WWU

- Convergent-divergent shape with narrowest inner diameter of only $\approx 30\mu\text{m}$ and a total length of 1.8cm (*i.e.*, $l = 600 \cdot d$)
- Specially shaped Laval nozzle with challenging, multi-step production process (completely in-house):
  - Galvanize nozzle outlet negative
  - Lathe outer geometry
  - Drill convergent inlet
  - Drill narrowest diameter in multiple steps
  - Remove outlet negative chemically





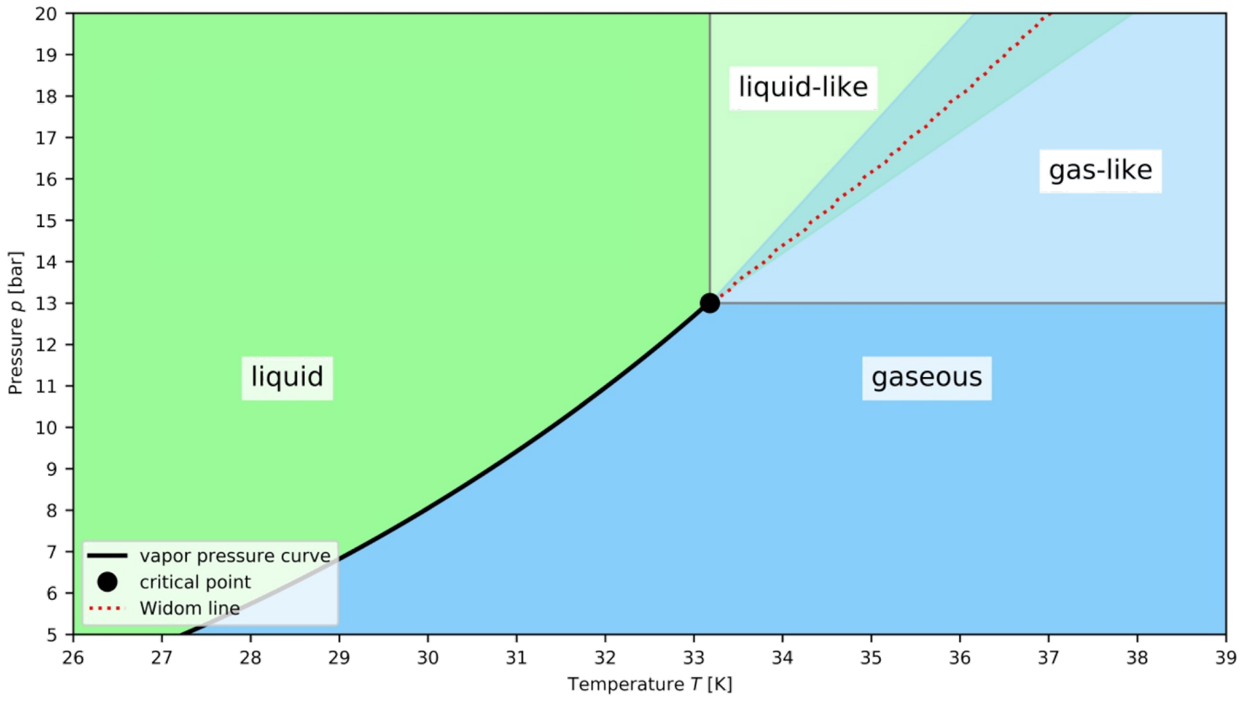




CLUSTER-JET BEAM STUDIES

Development of a new technique to determine the Widom line

- Widom line:
  - Higher order phase transition, separating the super-critical phase into liquid-like and gas-like regions
  - Experimental determination typically challenging
- Idea:
  - Produce hydrogen cluster beams at different stagnation conditions
    - Liquid phase, gaseous phase, supercritical phase



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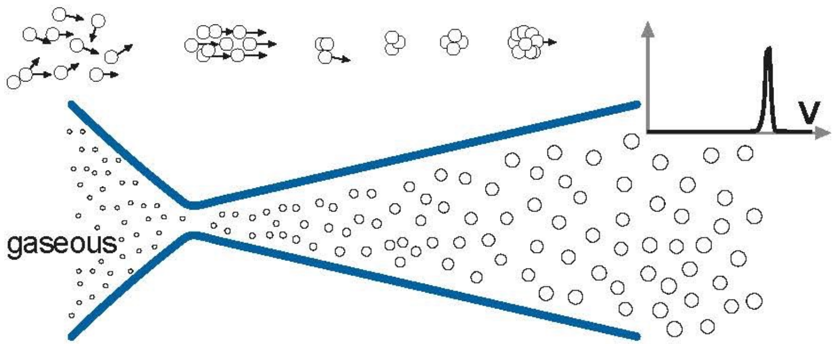

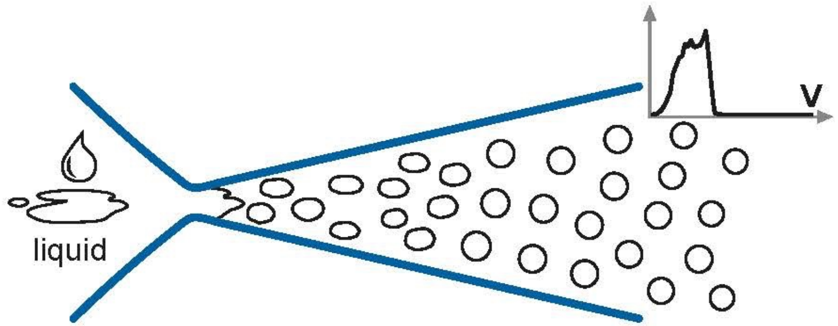

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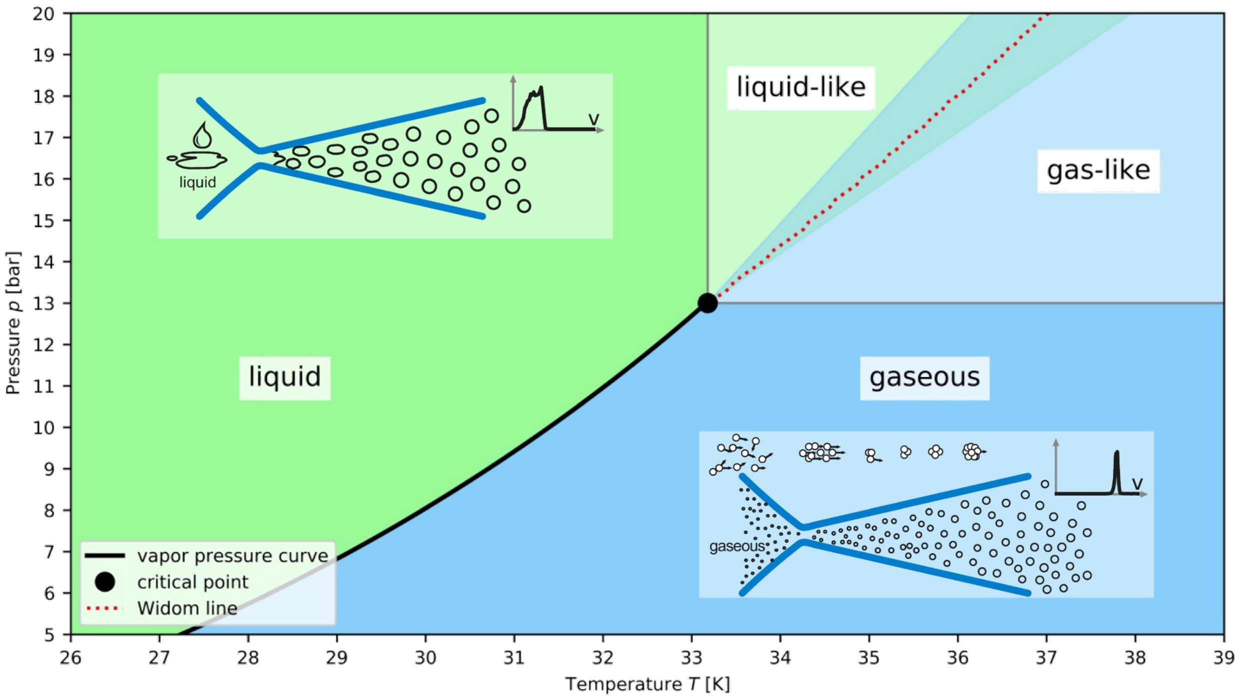

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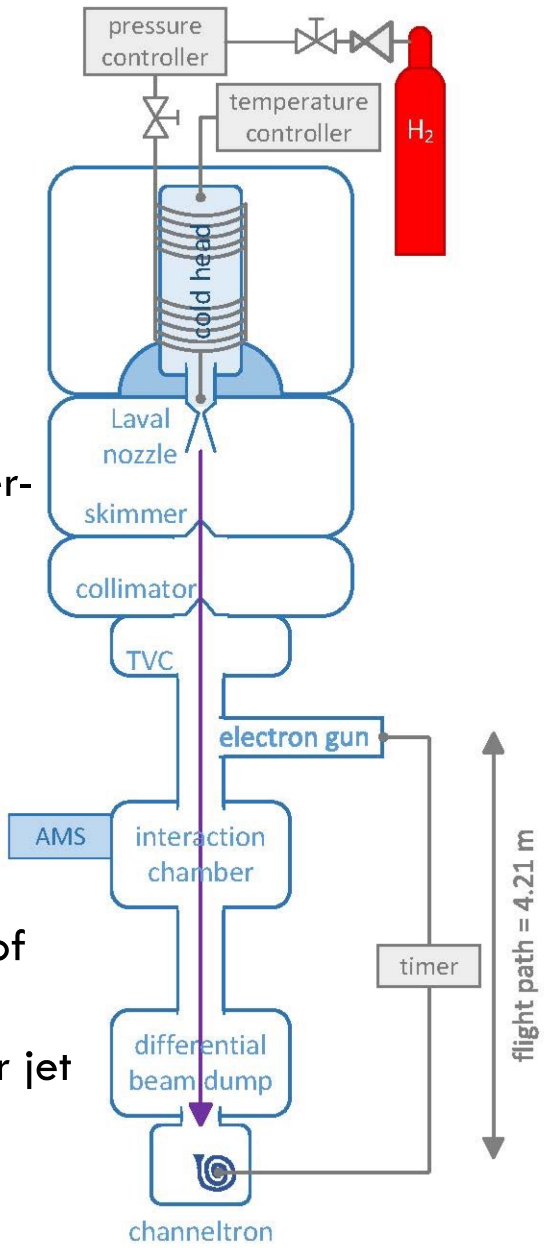

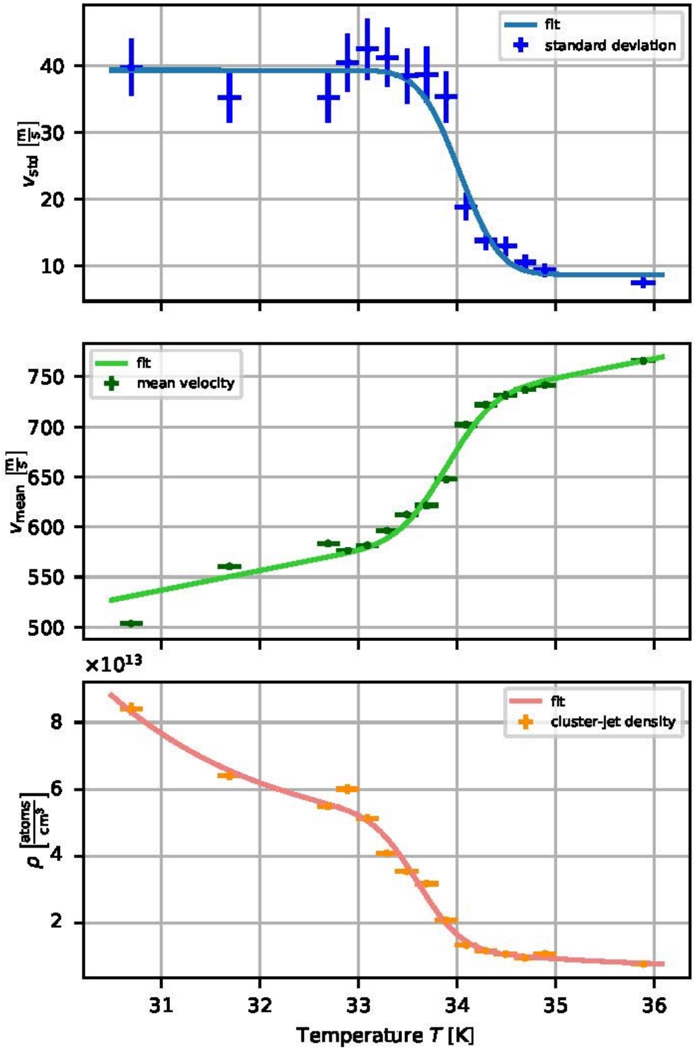

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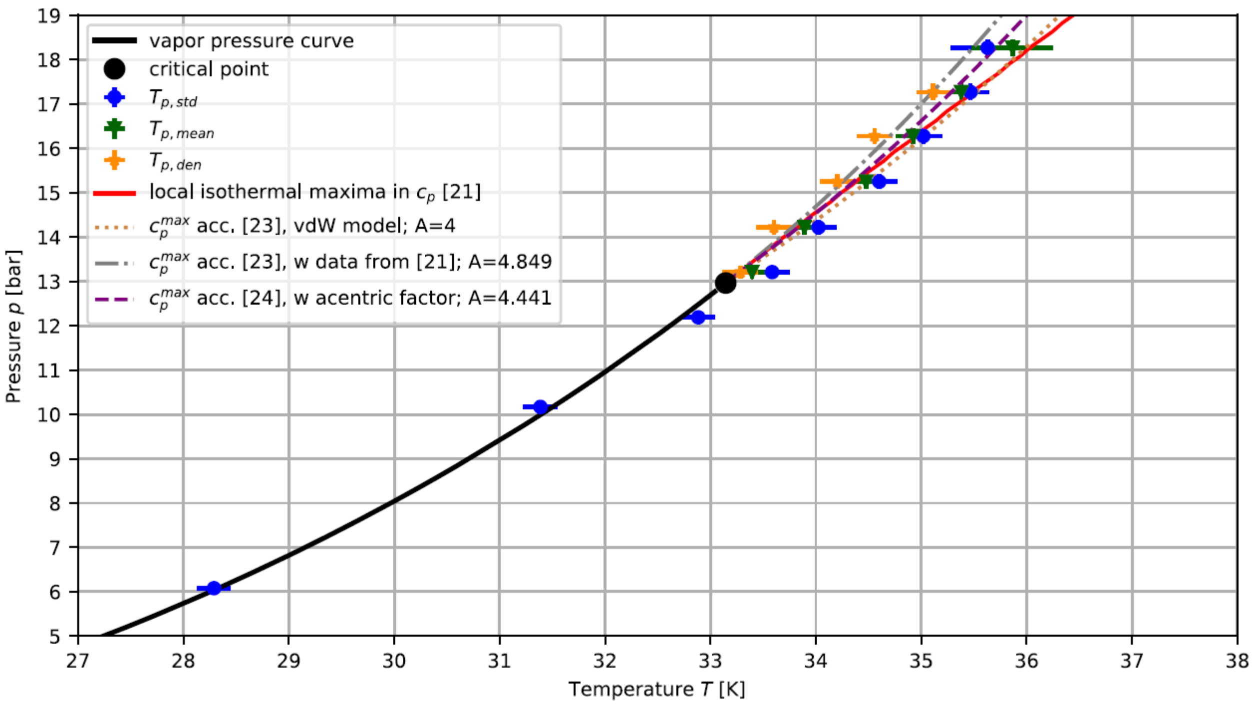
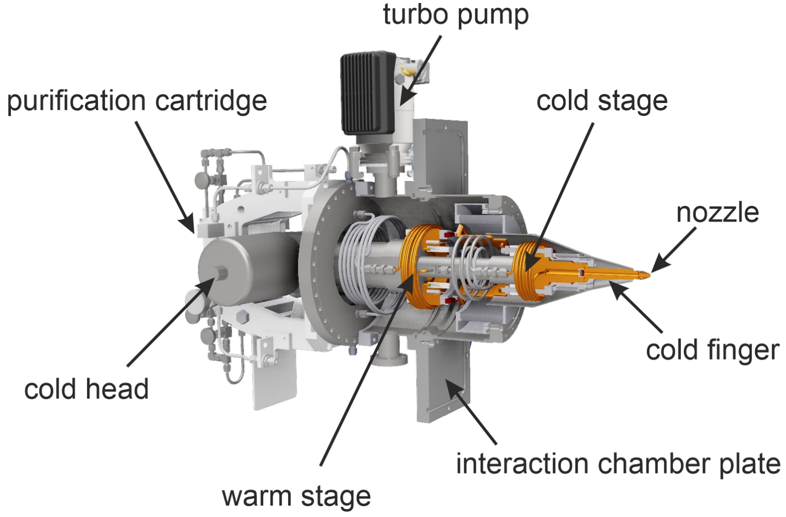


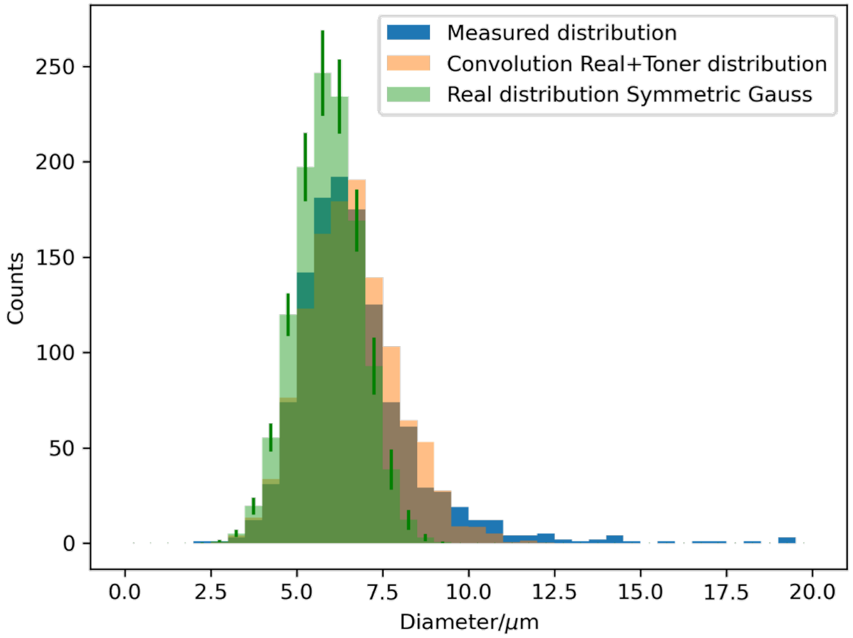
S. Vestrick, C. Fischer, AK, J. Supercritical Fluids 188 (2022) 105686

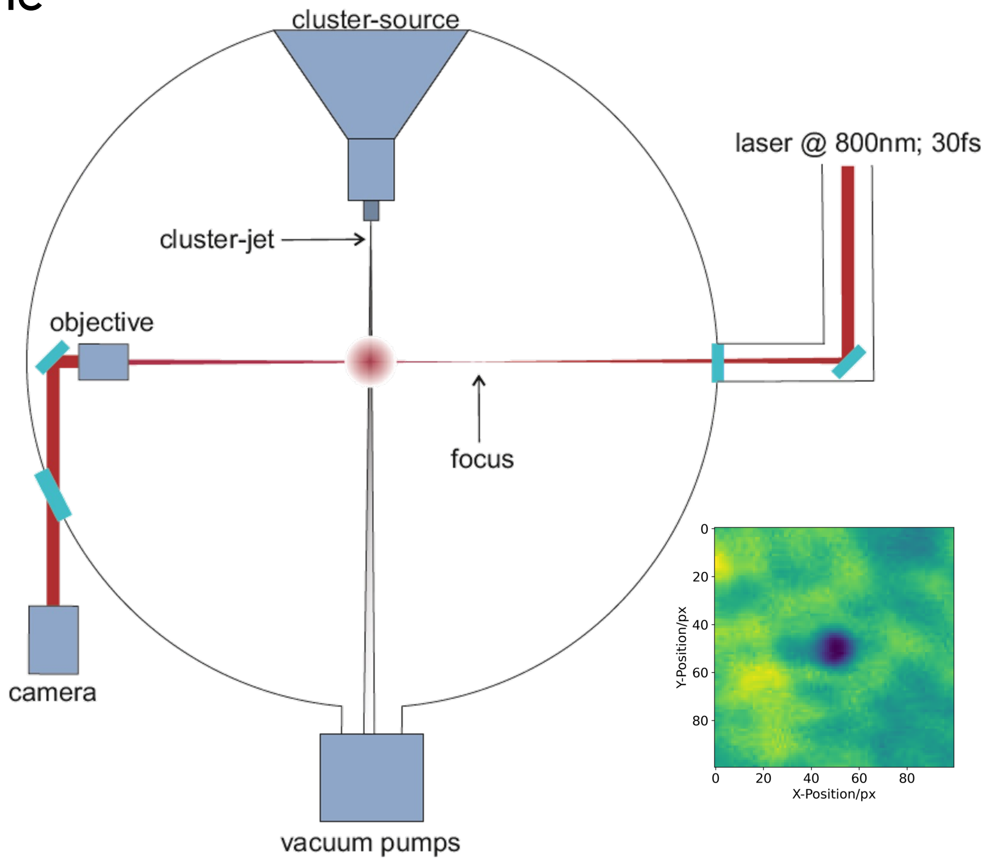
CLUSTER-JET BEAM STUDIES



Cluster studies using shadowgraphy

- Cluster-jet target at 200 TW ARCTURUS laser (Düsseldorf)
- Investigation of H_2 cluster formation in the liquid regime
- Determination of mean cluster size and distance

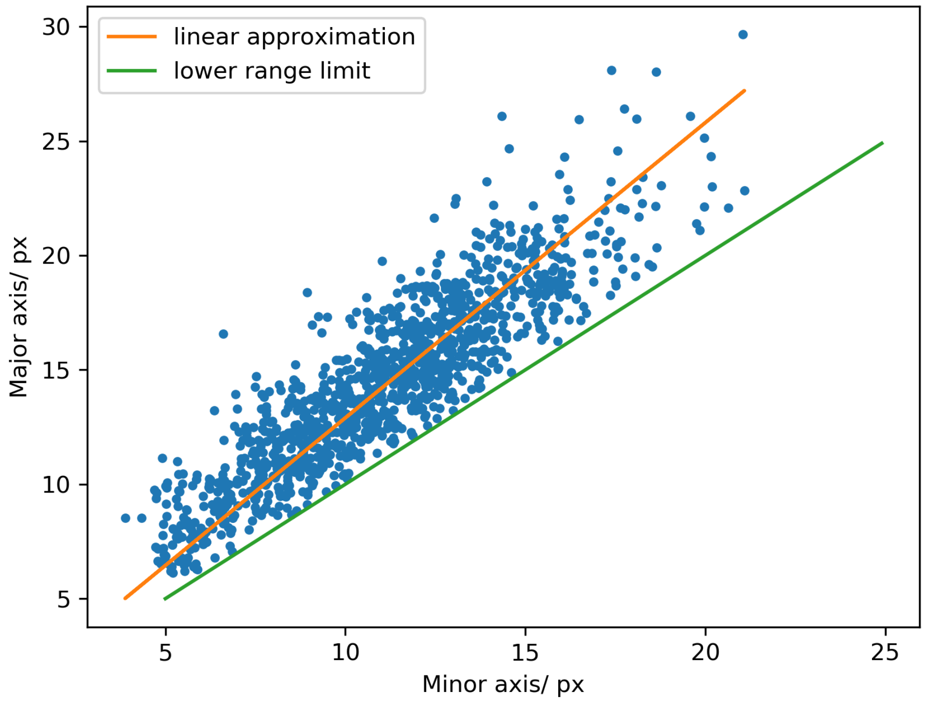


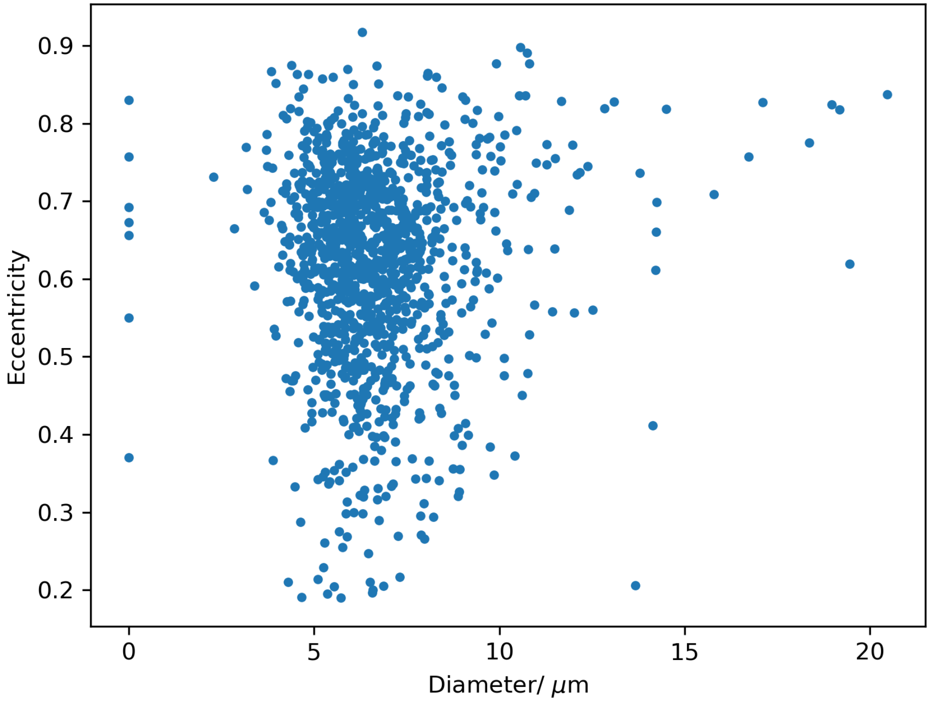


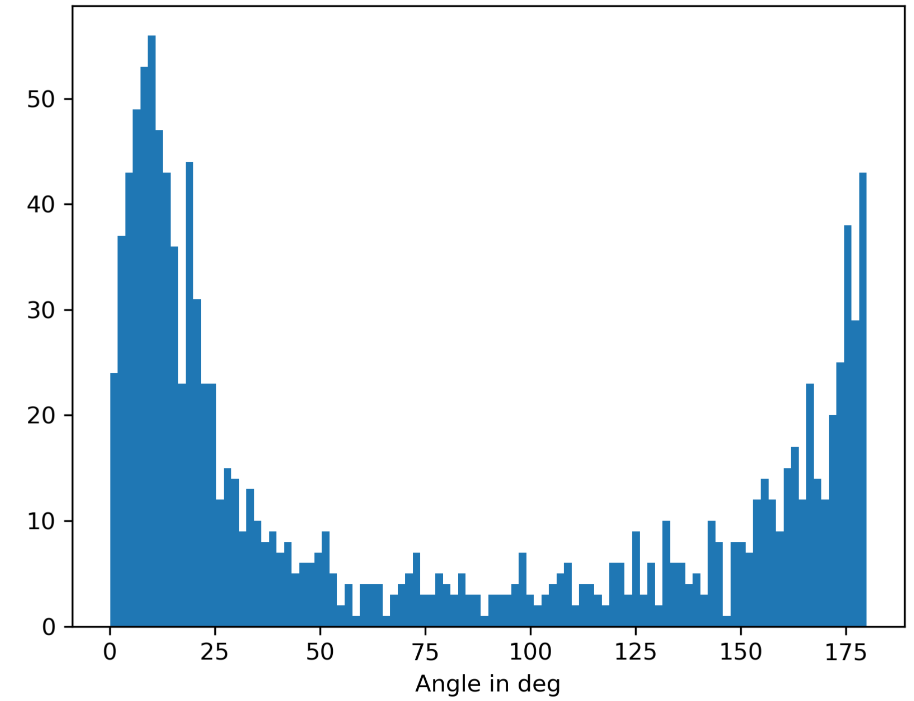
CLUSTER-JET BEAM STUDIES

Cluster studies using shadowgraphy

- Deformation of cluster/droplets directly behind nozzle
- Deformation (major axis) in flight direction
- Studies on eccentricity



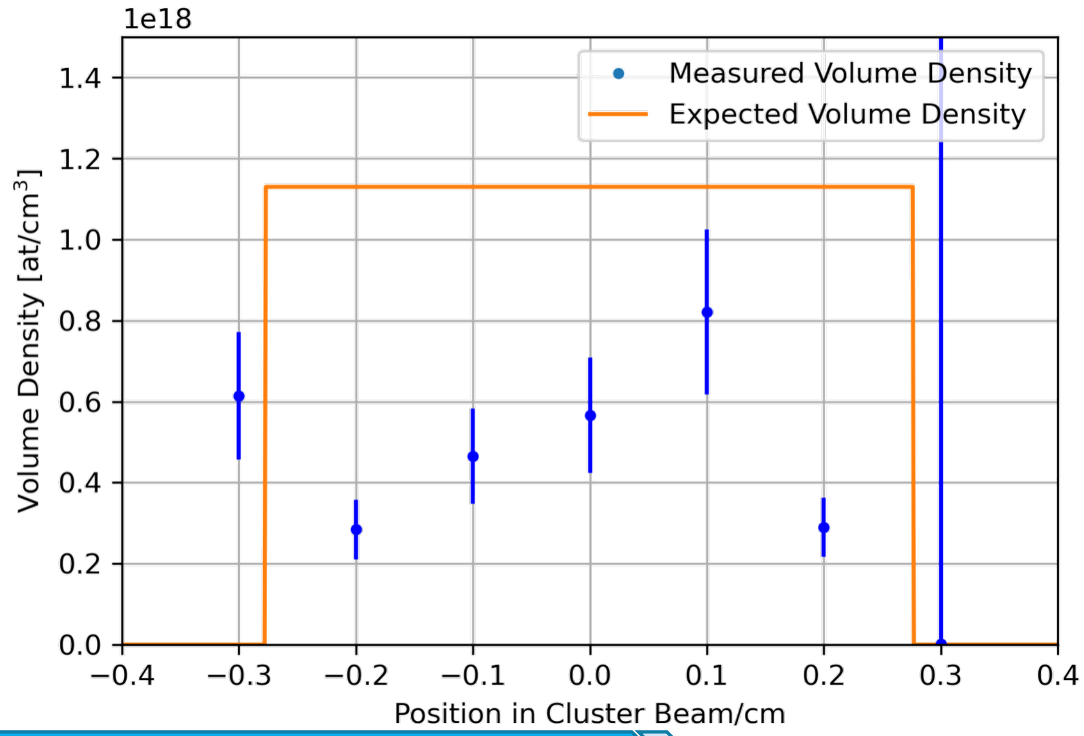


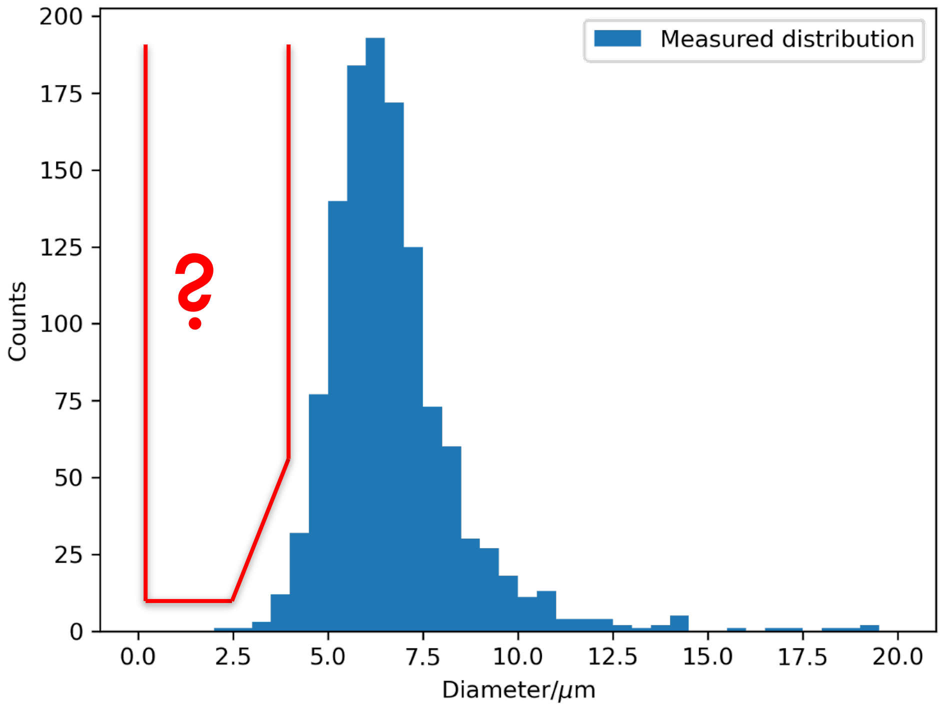


CLUSTER-JET BEAM STUDIES

Cluster studies using shadowgraphy

- Clusters observed by shadowgraphy correspond to only 50% of total volume density
- Further studies on "invisible clusters" of interest, i.e. < 3 µm





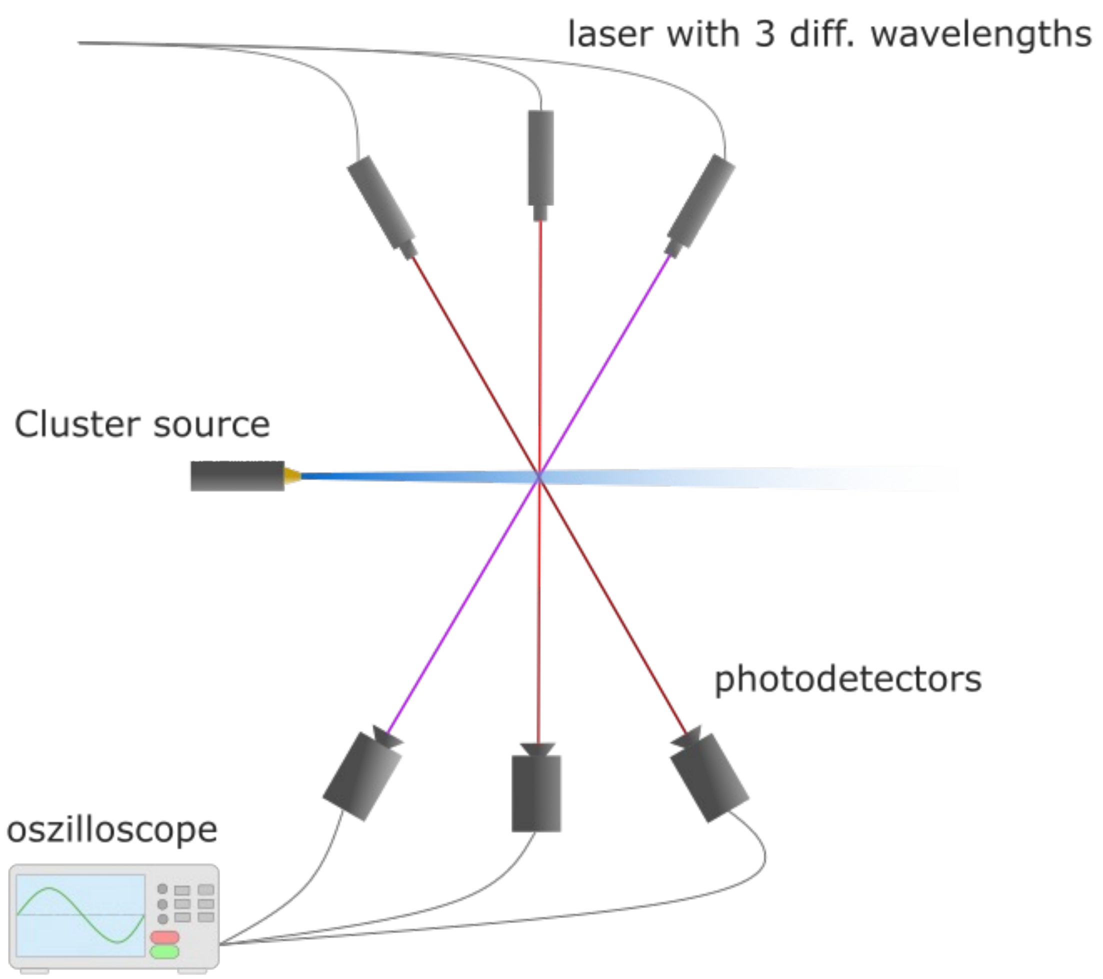
CLUSTER-JET BEAM STUDIES

3-WEM setup in preparation at WWU to measure even smaller clusters

- Three Wavelength Extinction Method (3-WEM)
- Laser is attenuated while crossing cluster-jet
- Attenuation dependent on wavelength, particle size distribution, material, …

$$I = I_0 \cdot exp\left\{ -NL \int_0^\infty \pi \left(\frac{D}{2}\right)^2 p(D) Q_{ext}(D, \lambda, m) \right\}$$

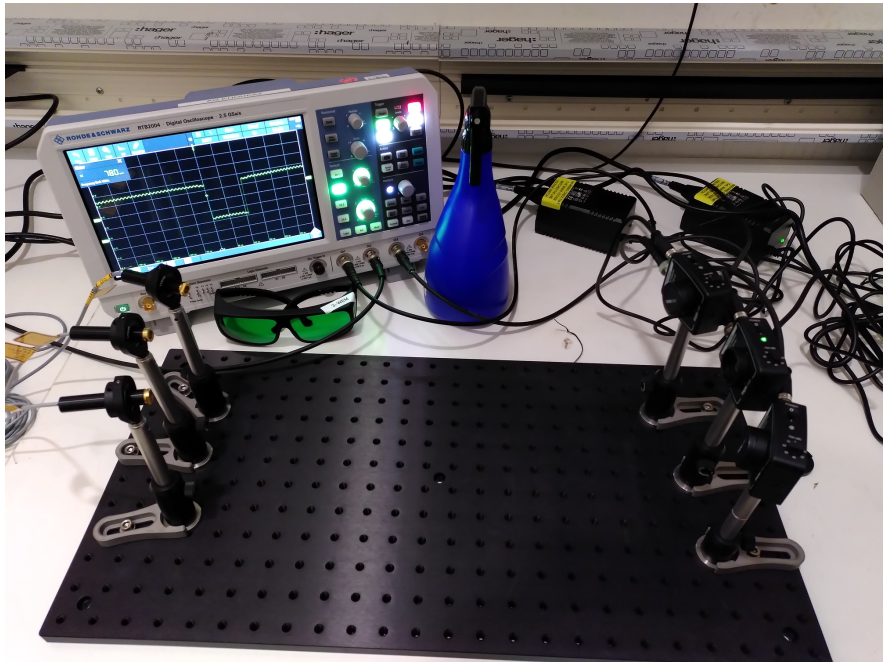
detected intensity (I); incident intensity (I_0); particle distribution ($p(D)$); extinction coefficient ($Q_{ext}(D, \lambda, m)$)

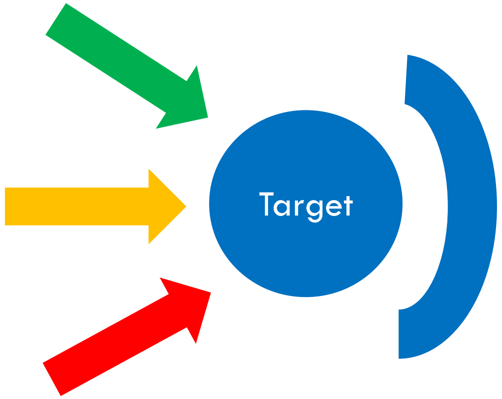


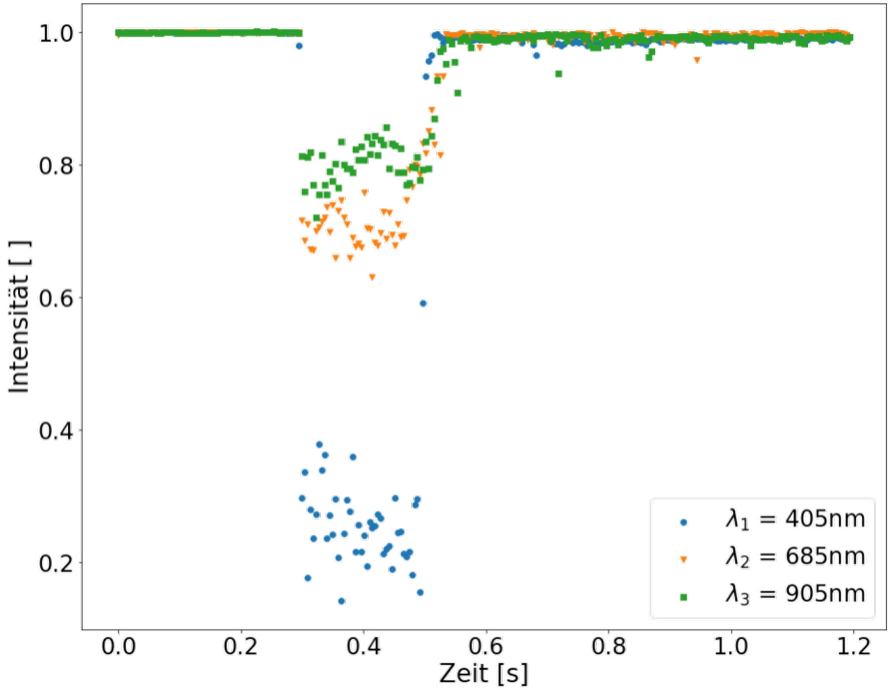
CLUSTER-JET BEAM STUDIES

3-WEM setup in preparation at WWU to measure even smaller clusters

- Test measurements using water sprays in progress (droplet size ~10µm) at WWU
  - Test of signals and electronics
- Experiments at cluster-jet in preparation



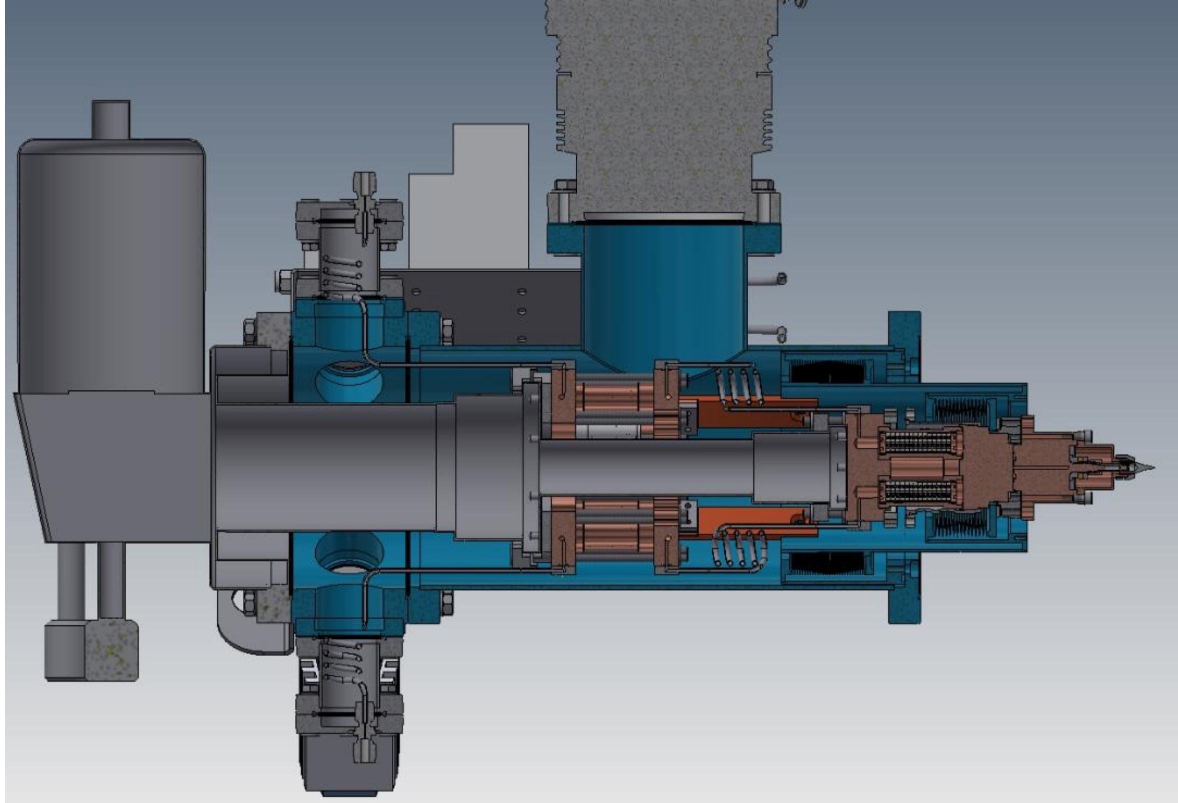


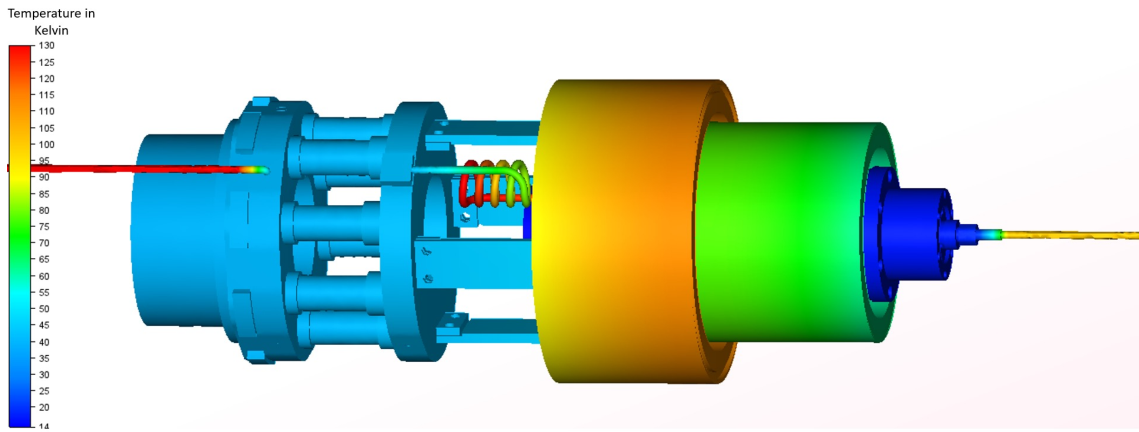


CRYOGENIC DROPLET BEAM TARGET

Preparation and test of new droplet generator

- First vacuum tests successfully performed
- Required cryogenic temperatures reached
- Argon droplet studies finished
- Hydrogen droplet experiments in progress
- In parallel: Numerical simulation studies on cryogenic heat exchanger and droplet gas temperature
  - Test the relevance of (additional) heat shieldings
  - Study temperature distributions, especially at the nozzle
- First hydrogen droplets expected soon

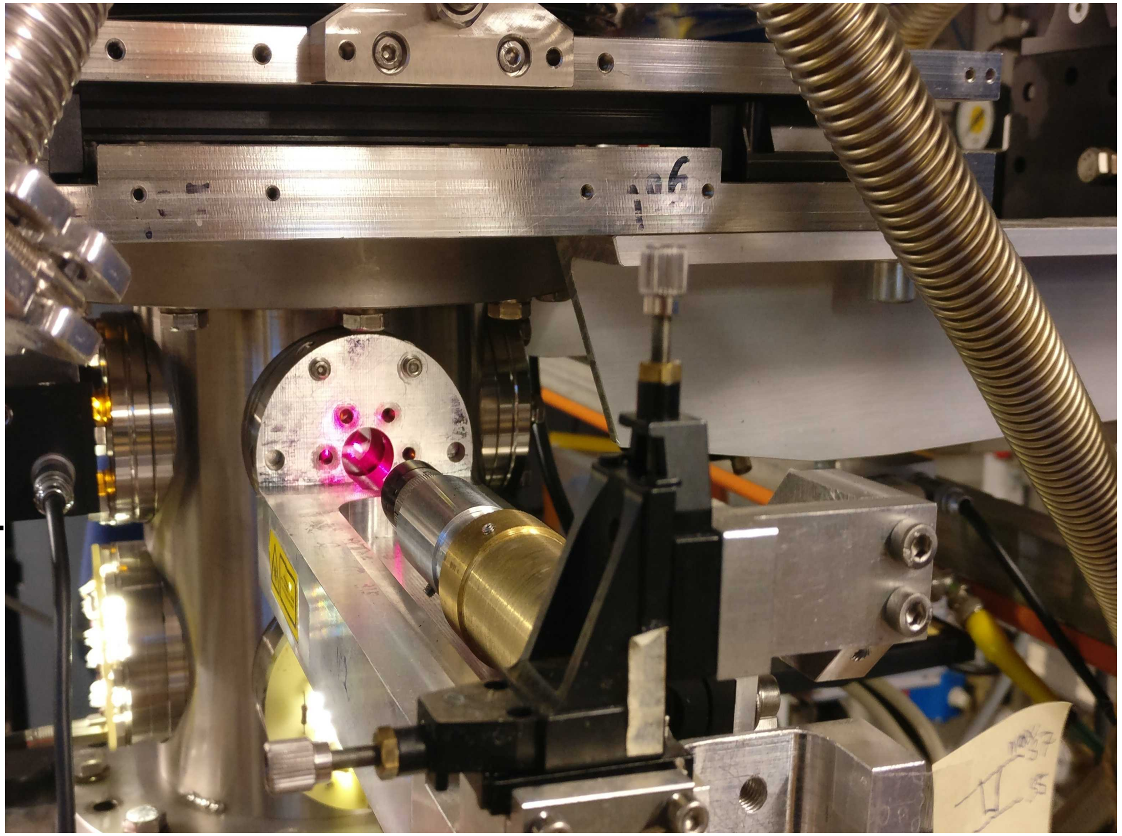




PELLET SOURCE STUDIES

Production of regular droplet/pellet streams

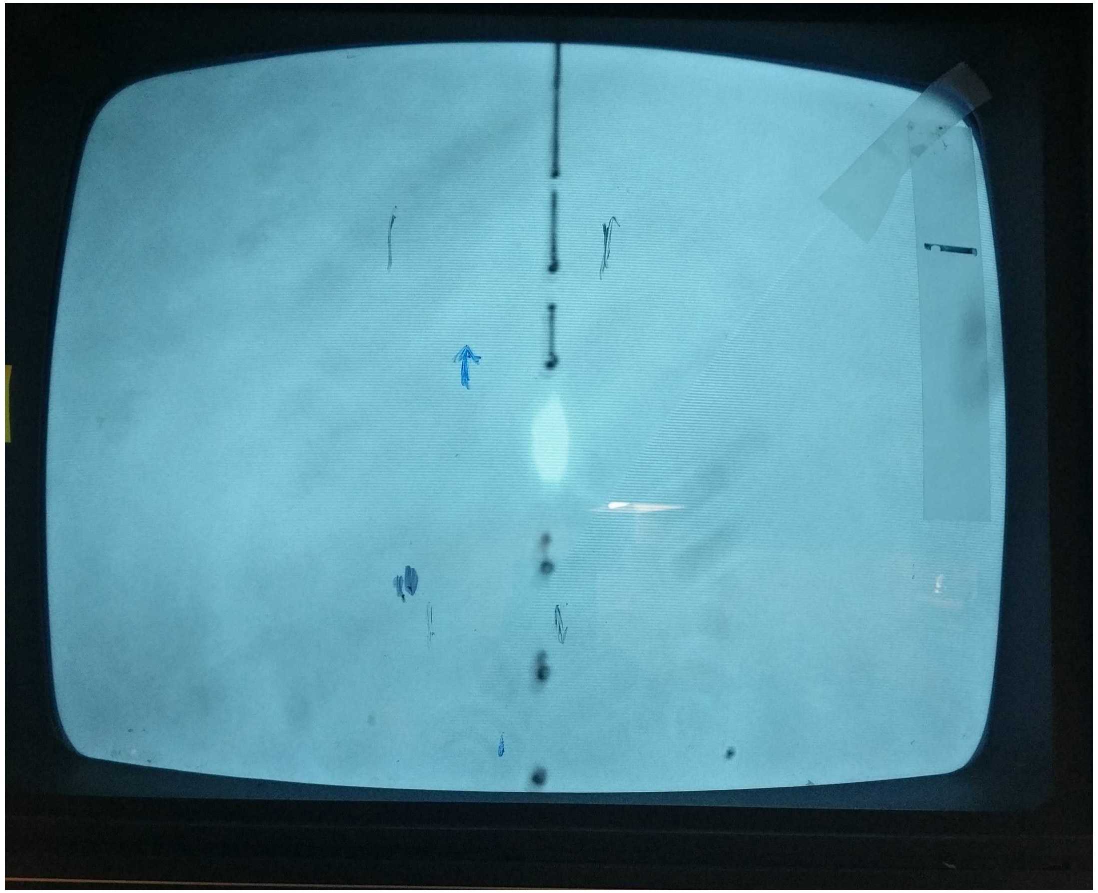
- Droplet/pellet formation occurs commonly via
  - Spontaneous Rayleigh breakup
  - Vibration induced breakup using piezo excitation
- Novel idea: stimultated breakup by pulsed laser beams
- Or : Can a focused laser beam affect the droplet production and influence the pellet beam quality?
- Tests in May and September 2022 with a 100mW laser installed at the UPTS



PELLET SOURCE STUDIES

Production of regular droplet/pellet streams

- Parameters for UPTS test measurements:
  - Laser point diameter approx. 80 µm
  - Pellet-laser overlap time 4.2 µs
  - Pellet beam data recorded by line-scan cameras 30cm below vacuum injection
- Pellet beam properties as function of
  - Laser-droplet hit position
  - Laser pulse length: 1…6 µs
  - Laser pulse dealy: ±10 µs
- Can the laser remove drops or impurities between drops?
  - Data are being analyzed



2.) MODIFICATIONS OF THE SCIENTIFIC WORK PLAN

Pellet beam studies

- Covid-19 related access limitations lifted at UU only Feb 15, 2022
  - Limited access to Uppsala Pellet Test Station has caused delays of the project (despite continuous adaptation of workplan)
  - Investigation of other shapes of solid target beams at UU cannot be guaranteed
- Cooperation with Russian pellet group suspended
  - No further Russian contribution on pellet nozzle production and droplet beam generation
  - But: Part of this activities can be performed at WWU in the context of droplet beam generation

    → possibly need of additional time for this task (see next slide)

3.) POSSIBILITIES/NEEDS OF ANOTHER REQUEST FOR THE EXTENSION OF THE PROJECT (BEYOND 30 NOVEMBER 2023)

- Foreseen loss of critical pellet target infrastructure at UU in the second half of 2023
  - Project work at UU would not benefit from another request for extension of the project

- Extension of the project beyond 30 November 2023 would offer possibilities at WWU
  - Part of the Russian contribution on pellet nozzle production and droplet beam generation could be done at the WWU droplet setup $\rightarrow$ need of additional time to cover this topic
  - Generation of stable cryogenic droplet beams is very challenging and might need additional time
  - An extension of the project would be welcome to safely reach all the envisaged cluster-jet goals, e.g., also exhaustive studies on clusters of heavier gases
  - Implementation of a new 3-WEM setup to measure cluster sizes of $< 3\ \mu m$ will require also additional time for installation and experiments

SUMMARY

- Despite of the limitations caused by Covid-19 and the Ukraine war, the Cryojet project is going very well
- Experiments are successfully performed at
  - the local laboratories of WWU Münster, UU Uppsala and GSI Darmstadt
  - the TW ARCTURUS Laser of the University Düsseldorf
  - the electron accelerator MAMI at Mainz
  - the proton synchrotron COSY at FZ Jülich
- Experiments resulted in new technologies, relevant for other fields
  - Example: Studies on supercritical fluids (Widom line determination)

PLAN OF PRESENTATION

1) Scientific results obtained since the last year
2) Modifications of the scientific Work Plan (as compared to the initial plan in the Grant Agreement)
3) Possibilities/needs of another request for the extension of the project (beyond 30 November 2023)

(We kindly ask to focus on the scientific aspects of the work carried out without administrative issues or timeline questions for deliverables and milestones)

JRA11

Work package number	29
Work package acronym	CryoJet
Work package title	JRA11-Cryogenically cooled particle streams from nano-to micrometer size for internal targets at accelerators

TASKS/Subtasks	**Year 1**				**Year 2**				**Year 3**				**Year 4**			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
1. Cluster-Jet Beam Studies																
1.1 New nozzle production techniques								1								
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