

# JRA11 – CryoJet: Cryogenically cooled particle streams from nano- to micrometer size for internal targets at accelerators

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# JRA11/WP29 Objectives

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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 hadron physics facilities

# Tasks of JRA11/WP29

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## Cluster-jet beam studies

- New nozzle production techniques
- Studies on jet beams: highest performance and cluster formation
- Laser-induced particle acceleration (H<sub>2</sub> clusters and heavier gases)

## Cryogenic droplet beam target

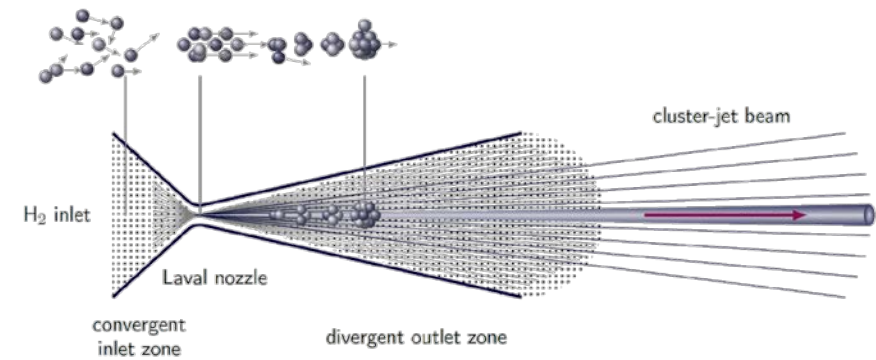
- Studies on droplet nozzles designs and efficiency
- Measurements on long term stability
- Investigations on high performance

## Pellet source studies

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

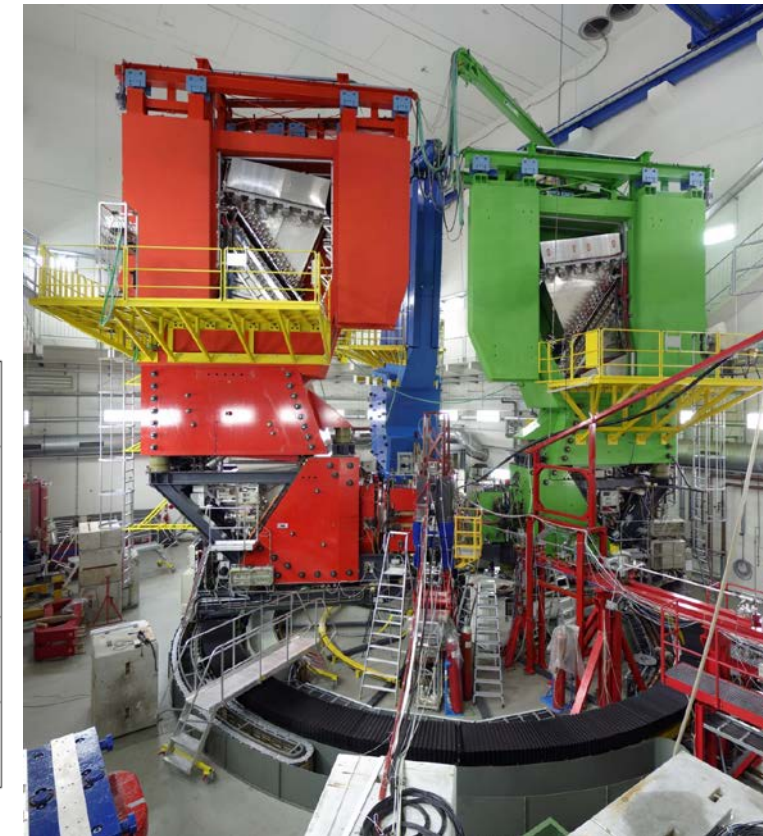
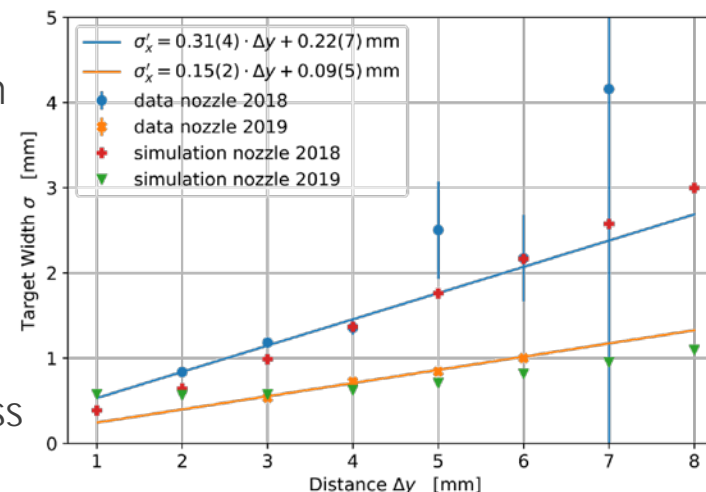


# Cluster-Jet Beam Studies

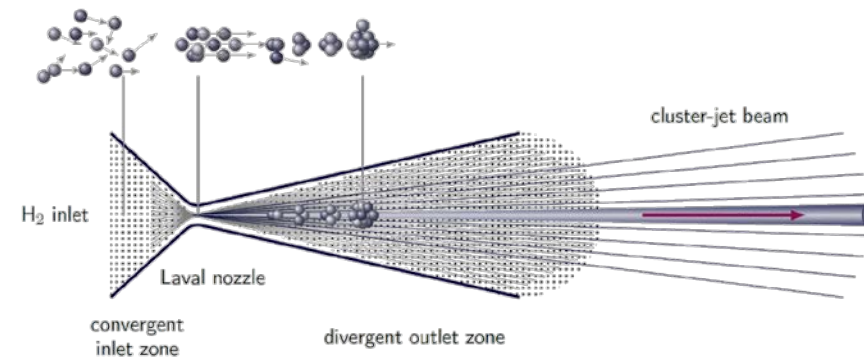


Numerical simulations on gas expansion in Laval nozzles for optimized jet target performance

- 3D simulations considering a real (Peng Robinson) gas
- Study of different nozzle geometries
  - Minimum inner diameter, outlet diameter, nozzle shape
  - Calculation of jet beam shape and thickness
- Comparison of simulation results with experimental data obtained at MAMI
  - Test of nozzles at the MAGIX target at A1
  - Jet beam scan using the MAMI electron beam
  - Excellent agreement of simulations with data
- Further simulations in preparation
  - Optimized nozzle design for
    - improved cluster beam formation/thickness
    - Improved gas jet beams of highest thickness

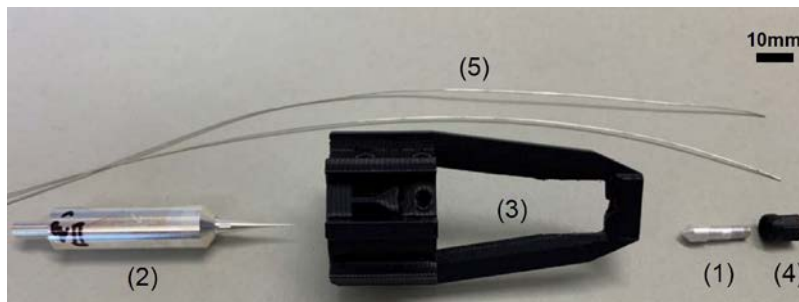


# Cluster-Jet Beam Studies

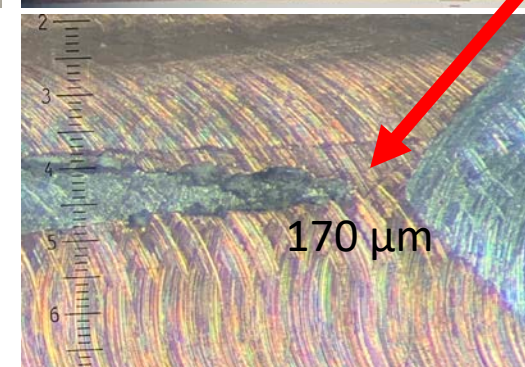
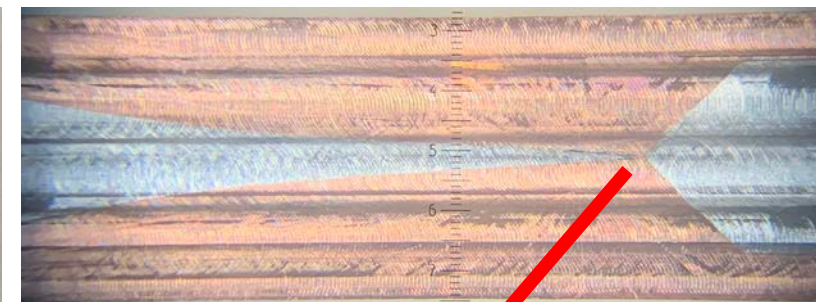


## Development of new Laval nozzles

- Galvanic production of monolithic copper nozzles
- Development of new production tools and techniques using, e.g., 3D printing



- Preparation of inlet/outlet connection hole ( $\varnothing = 30 \mu\text{m}$ ,  $dx = 170 \mu\text{m}$ ):
  - Laser drilling
  - Mechanical drilling
  - Electrical discharge machining

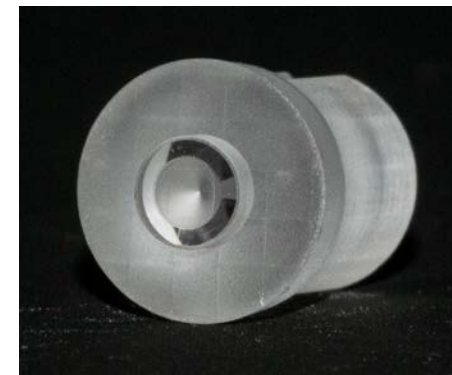
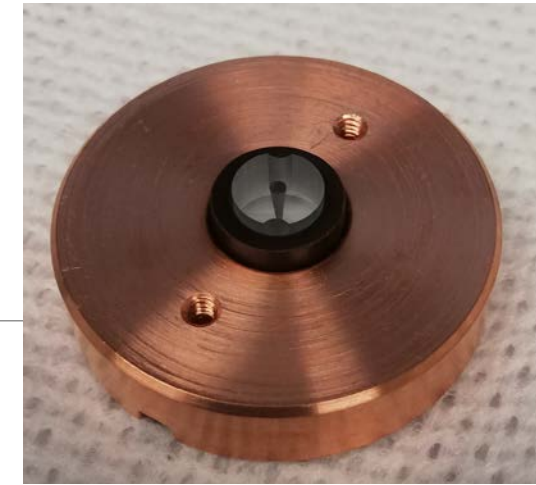




# Cluster-Jet Beam Studies

## Development of new Laval nozzles

- Production of glass nozzles via laser-induced etching process:
  - Close contact with the company LightFab GmbH (Germany)
  - Production of monolithic glass nozzles according to our specifications
  - Successful production of nozzles with at LightFab
    - 10 mm length,  $\varnothing = 30 \mu\text{m}$  inner diameter
    - First successful cluster-jet beam tests
    - Tests to produce new nozzles with length of 18 mm for optimized cluster-jet beams



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  - CryoJet glass nozzles shown in Company Flyer



### SLE with LightFab 3D Printer

SLE (selective laser-induced etching) is a new laser technology for rapid manufacturing of true 3D devices made out of transparent material consisting of cavities, tunnels and even mounted moving parts.

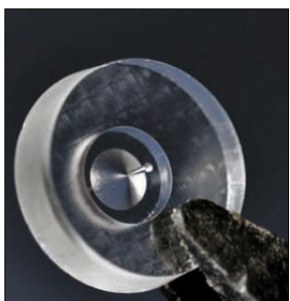
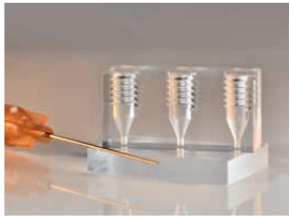
SLE is a two-step process: In a first step ultra-short pulsed laser radiation is focused to micrometer-sized focus to permanently modify the transparent material internally. This laser modification is done without cracks and with high precision – not to be confused with the 3D pictures in glass consisting of micro cracks. An arbitrary 3D connected volume is exposed inside the glass by 3D scanning of the focus. In a second step of developing only the modified material is removed by wet chemical etching starting at a surface of the workpiece.

For the precision of the SLE technique the selectivity is essential. The selectivity is the ratio of the etching rate of the modified material and the etching rate of the untreated material. For example the selectivity in fused silica glass is larger than 500:1 resulting in long fine channels with

small conicity. Therefore, by the SLE-technique complex 3D cavities can be produced, which are the basis of our products like micro fluidic structures and micro structured 3D parts.

Advantages of SLE are the large precision ( $\sim 1 \mu\text{m}$ ), no debris, true 3D capability and the high processing speed using our LightFab 3D Printer. Therefore, the SLE technology is perfect for digital 3D printing of components made out of transparent material.

Present state of the art for our realization of the SLE process chain includes the straightforward laser tool path generation from 2D & 3D-CAD models in a wide variety of common file formats. That way design changes can be easily implemented and tested e.g. for rapid prototyping. After identification of an adequate prototype for your special application even series production can be performed with the same system due to speed of the LightFab 3D Printer unrivaled at the market. For mass production of single designs the production can be transferred to our High Speed Microscanner which has to be customized for the special design.



#### LightFab GmbH

Steinbach Str. 15 · 52074 Aachen  
Germany  
www.lightfab.de

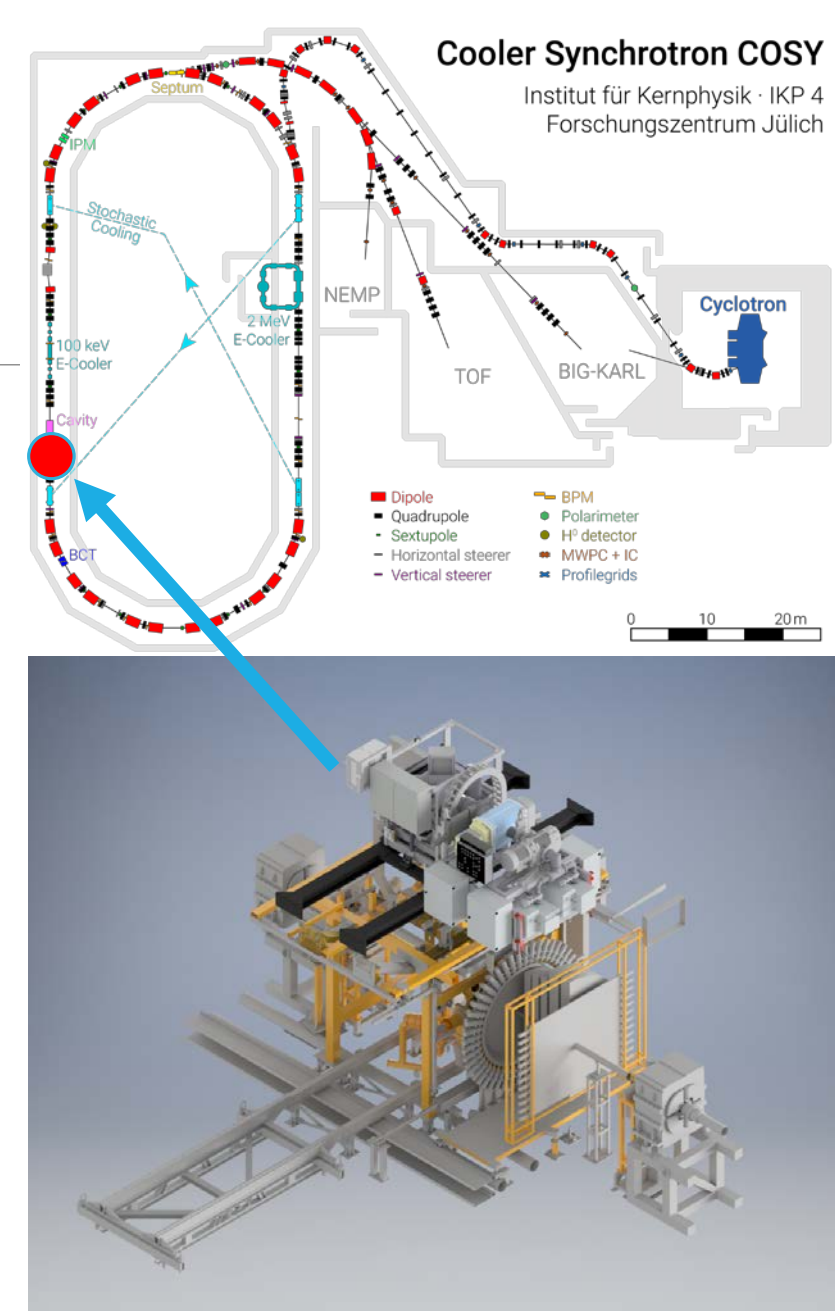
Fon +49 241 590 8272  
Fax +49 241 890 6121  
info@lightfab.de

USt-IdNr: DE291391467  
HRB 18166  
Registrierungsgericht Aachen

# Cluster-Jet Beam Studies

Accelerator beam quality studies in presence of a cluster-jet beam

- PANDA cluster-jet target at COSY
  - Stochastic beam cooling elements for HESR
  - Barrier Bucket
  - Schottky measurements
- Study of
  - Beam life time
  - Beam momentum width
  - Stability of mean beam momentum (energy scans!)
  - Ion beam induced cluster evaporation (vacuum!!!)
  - Test of new diagnosis systems
  - ...

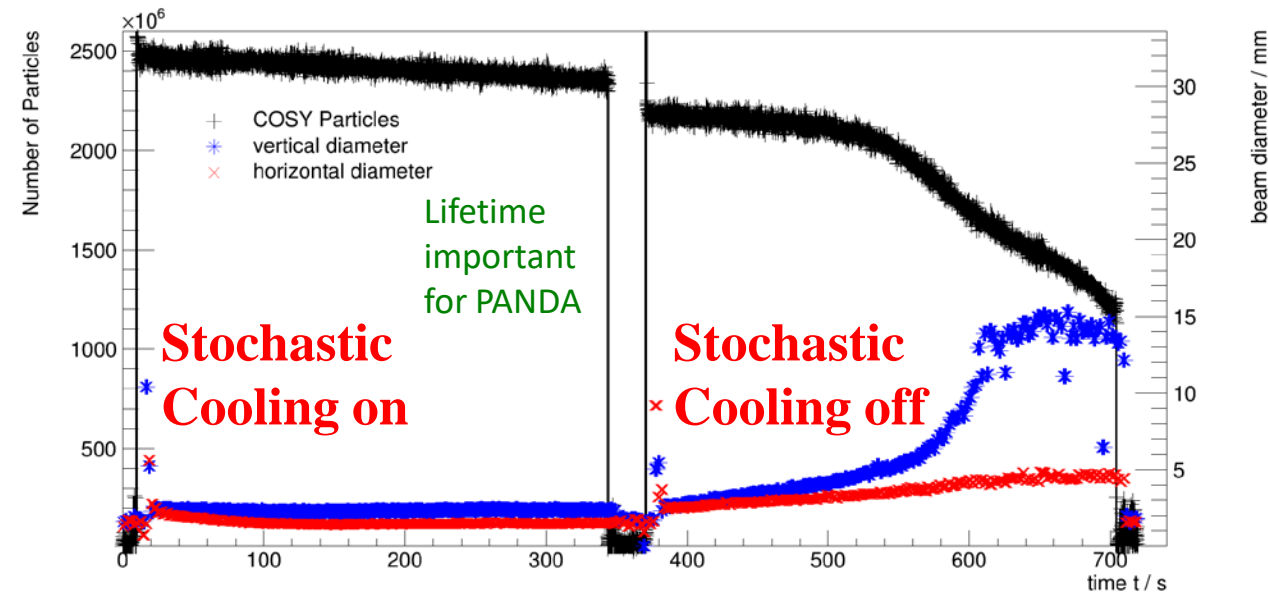
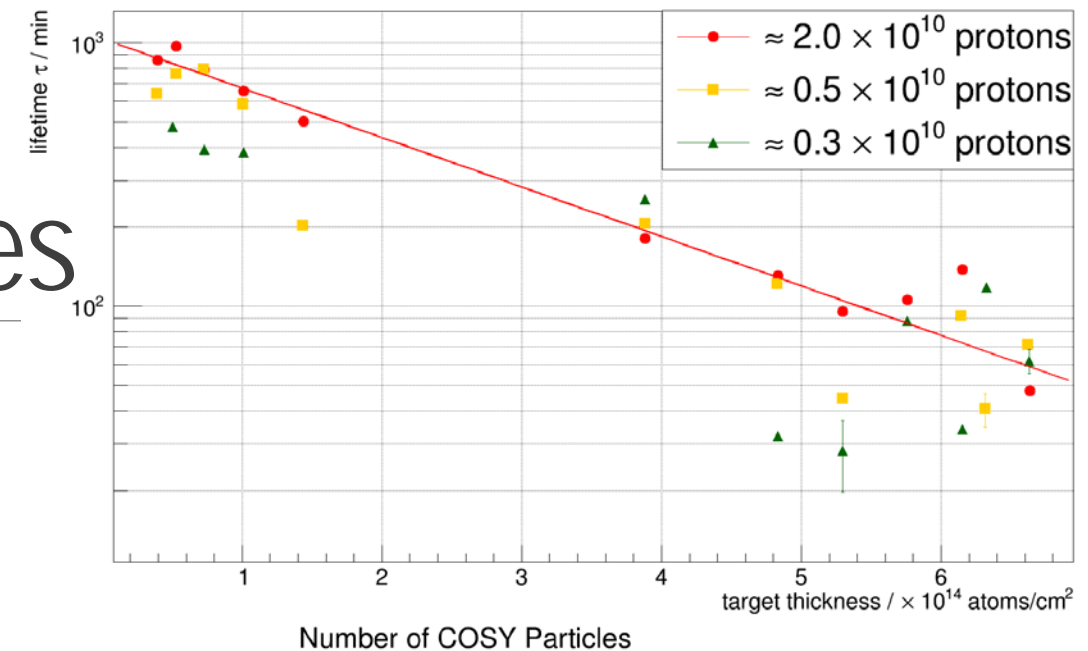




# Cluster-Jet Beam Studies

Accelerator beam quality studies in presence of a cluster-jet beam

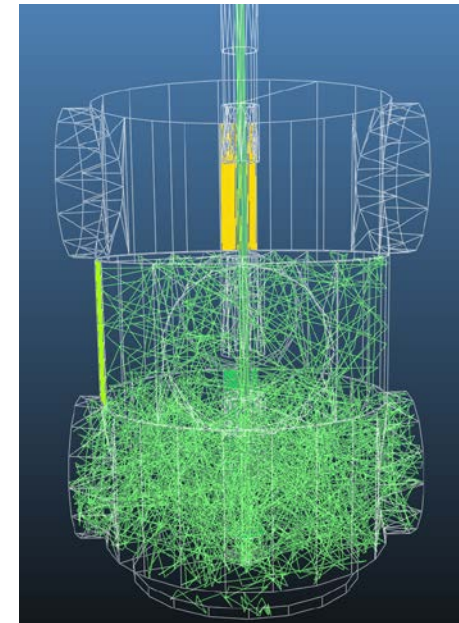
- First important results already available
  - Target thicknesses of  $\rho < 7 \times 10^{14}$  atoms/cm<sup>2</sup>
  - Beam revolution frequency stable within  $\delta f \approx 10^{-6}$
  - Beam momentum width  $\Delta p/p \approx 10^{-4}$
  - First estimates on ion beam induced cluster evaporation
- Beam time in 2020 canceled due to Covid-19 travel restrictions
  - New COSY beam time application for 2020/2021



# Cluster-Jet Beam Studies

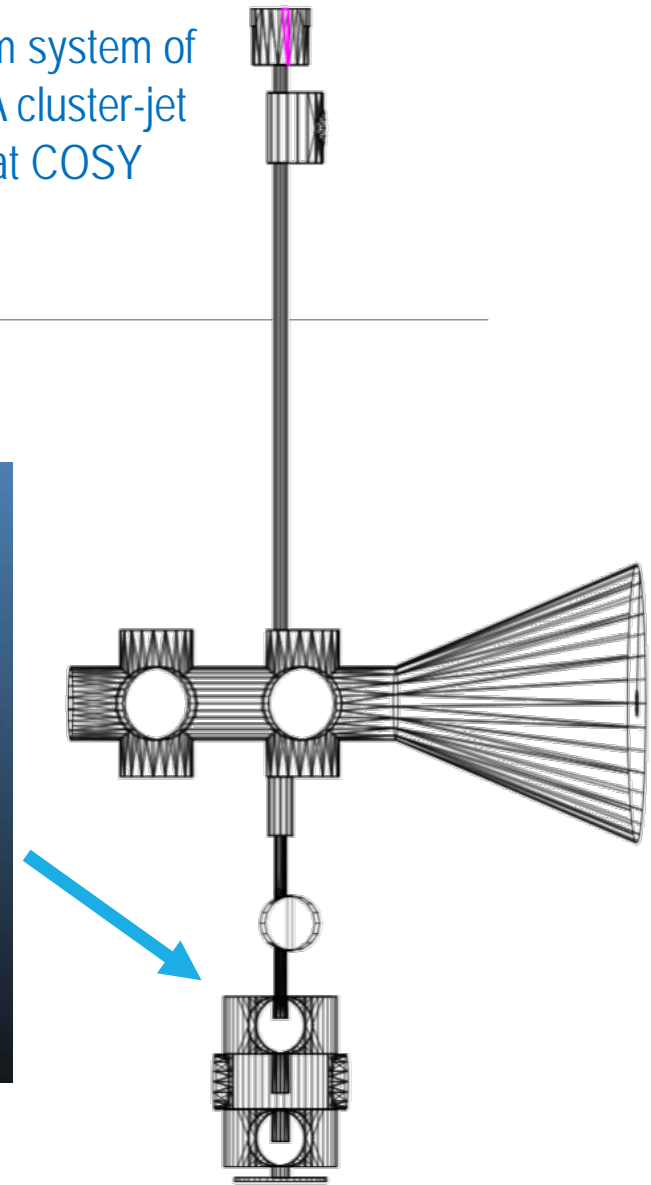
Studies on reduction of residual gas

- Careful understanding of residual gas origin important for improved target setups
- Experimental data from cluster targets
  - PANDA cluster-jet target at COSY
  - PANDA prototype cluster-jet target at WWU
- Numerical simulations for both targets
- Possible sources of residual gas at IP:
  - Molecular flow through orifices and vacuum pipes
  - Ion beam induced cluster evaporation
  - Evaporation from clusters due to heat radiation
  - Evaporation from clusters due to vapor pressure



Molflow+ simulation  
for the PANDA target  
at COSY

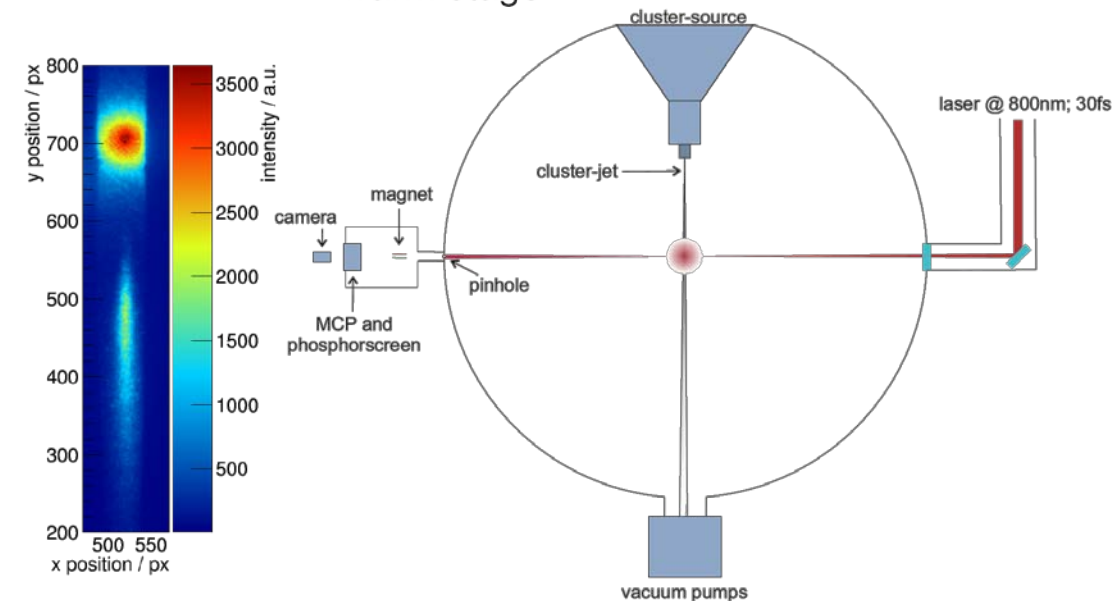
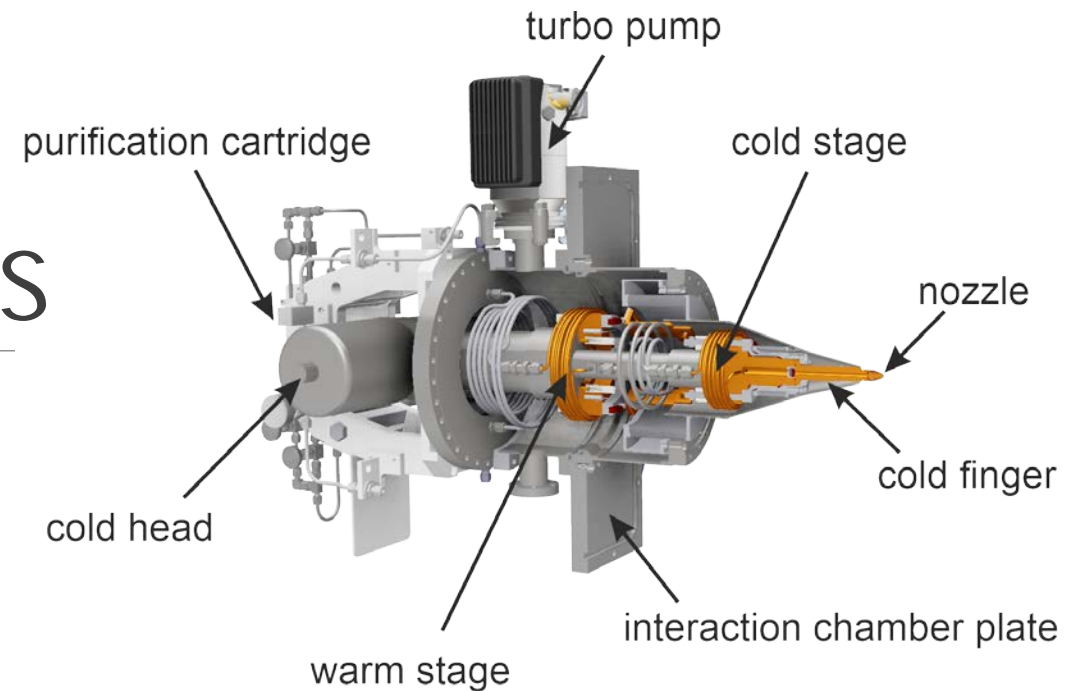
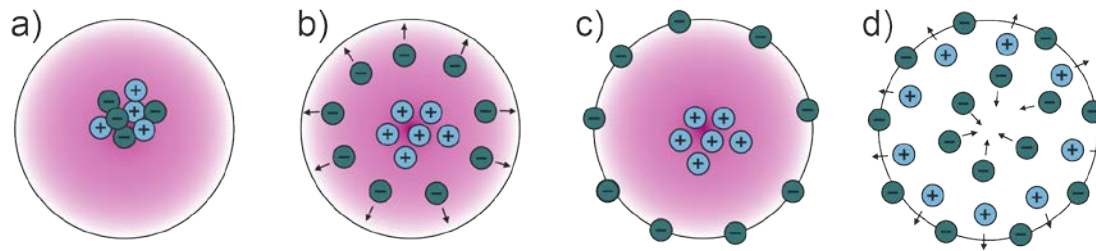
Vacuum system of  
PANDA cluster-jet  
target at COSY



# Cluster-Jet Beam Studies

Studies on laser-induced hadron acceleration

- Cluster-jet target at 200 TW ARCTURUS laser (Düsseldorf)
- Experiments using hydrogen and argon clusters
- Observation of a very high shot-to-shot stability of accelerated ions
- Proton acceleration driven by Coulomb explosion

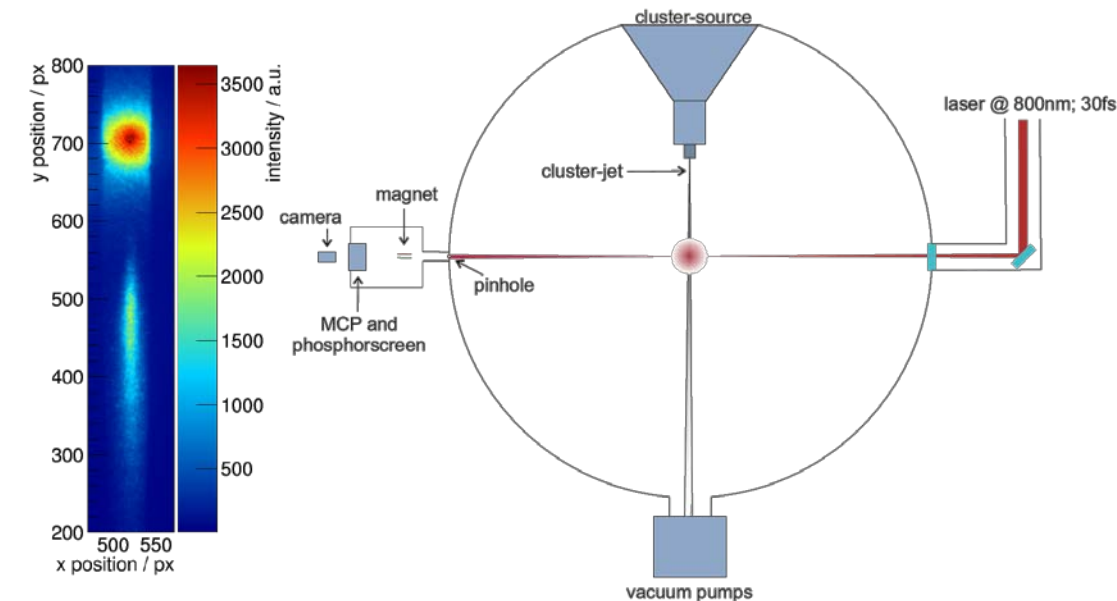
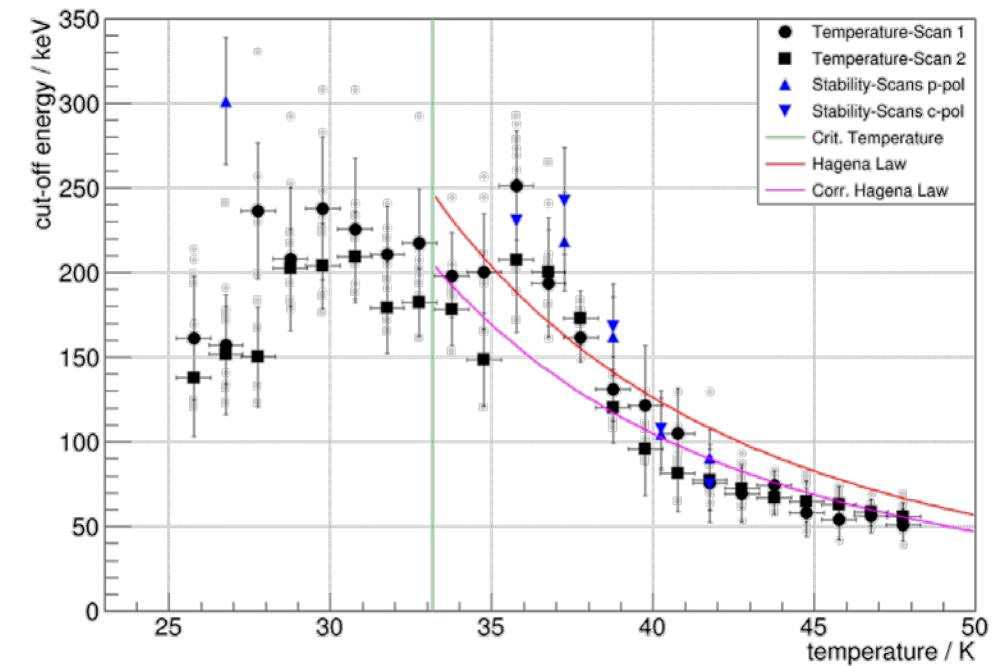




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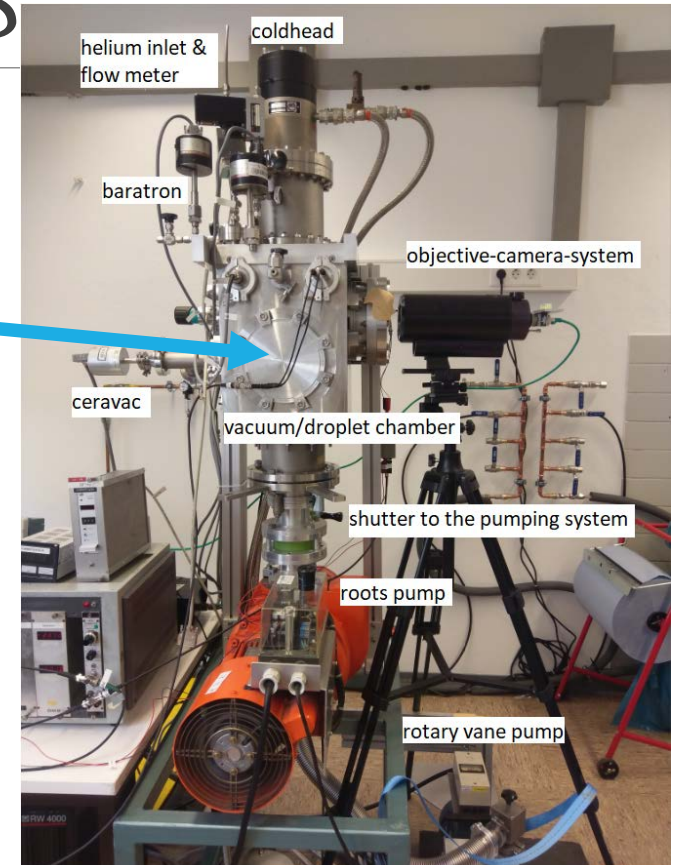
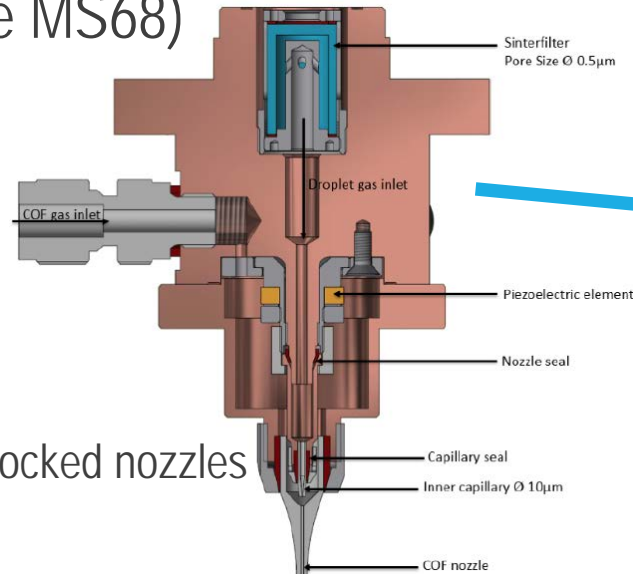
- Cluster-jet target at 200 TW ARCTURUS laser (Düsseldorf)
- Experiments using hydrogen and argon clusters
- Observation of a very high shot-to-shot stability of accelerated ions
- Proton acceleration driven by Coulomb explosion
- Observed cut-off energy given by
  - cluster size
  - laser amplitude at IP
- Maximum energy observed here given by size of the laser focus volume



# Cryogenic Droplet Beam Targets

Setup of a droplet test device (milestone MS68)

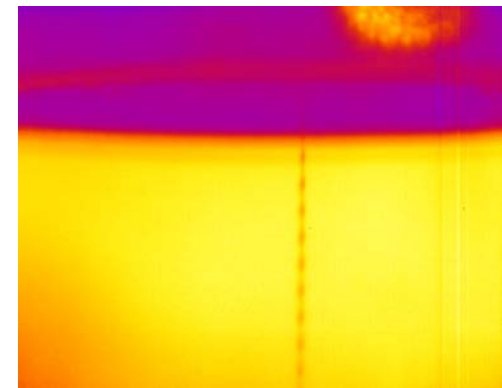
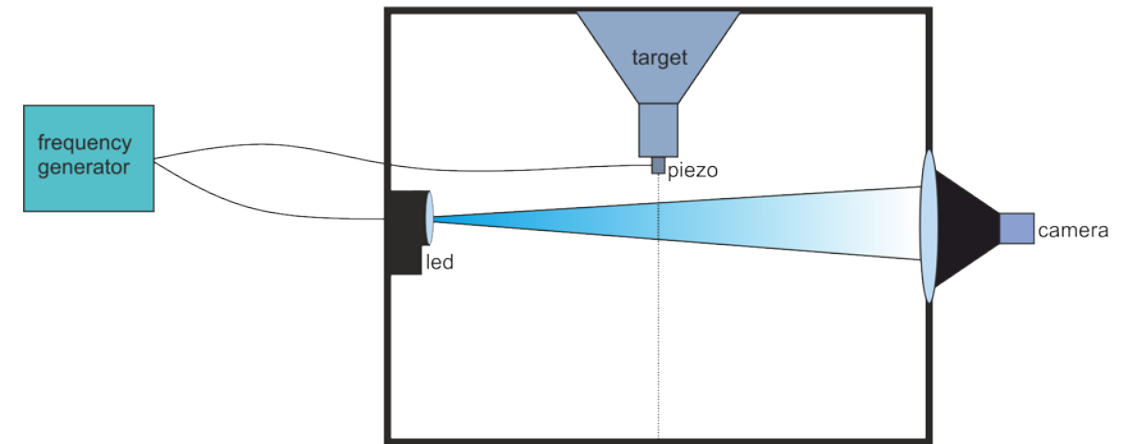
- Successful production of Argon droplets
- Test of different nozzle types
  - Glass nozzles w/wo co-flowing He gas
  - Metal plate nozzles
- Studies towards
  - Quick nozzle exchange and easy cleaning of blocked nozzles
  - Longer nozzle lifetimes
  - Prevention of nozzle blocking



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  - Longer nozzle lifetimes
  - Prevention of nozzle blocking
- Test of different optical diagnosis systems
  - Stroboscopic light
  - Single droplet pictures using ns lasers

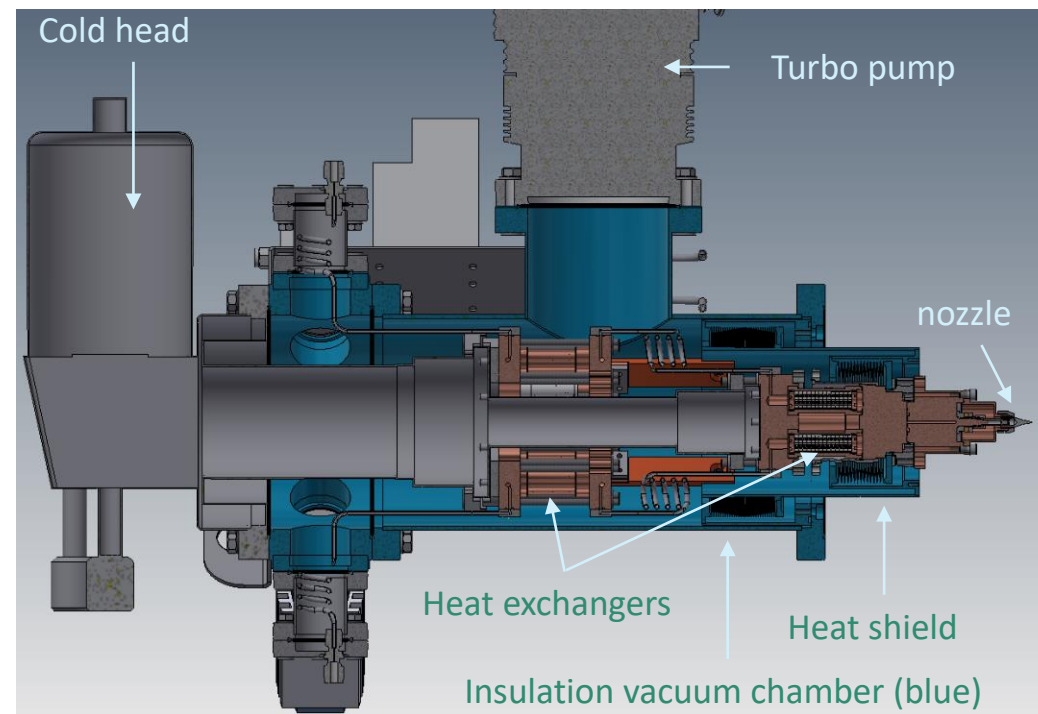
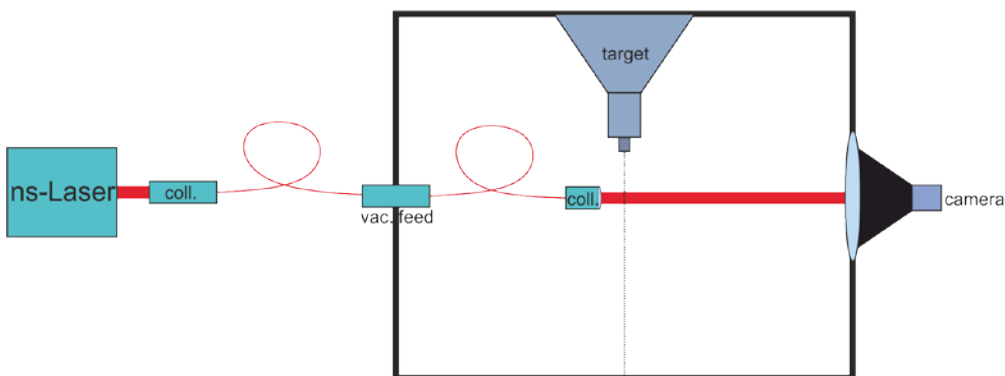




# Cryogenic Droplet Beam Targets

Development of an improved droplet device

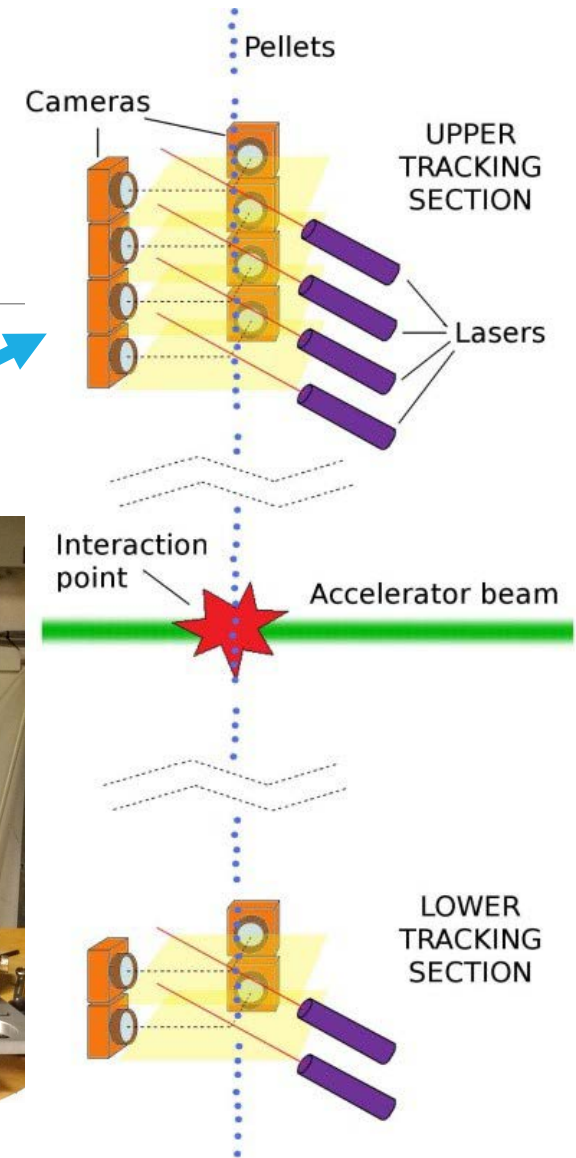
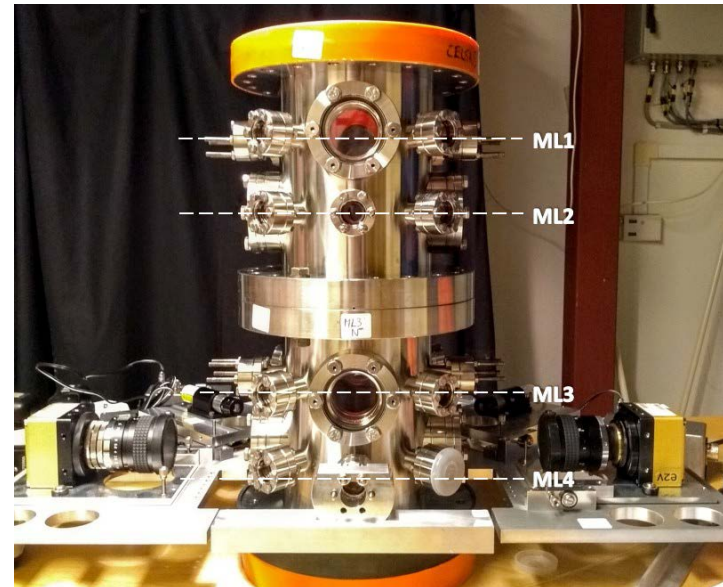
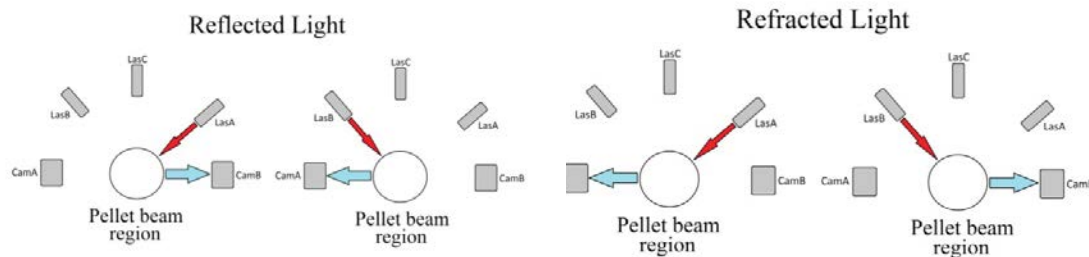
- New device currently in preparation
- Improved cooling power
- Less mechanical vibration
- Novel 3D printed heat exchangers
- New laser diagnosis system



# Pellet Source Studies

## Real-time pellet tracking system

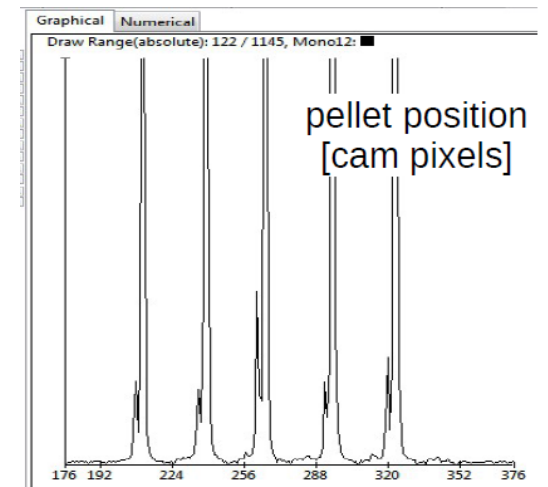
- Design of a pellet tracking system in progress
- Possible applications
  - Hadron physics accelerators
  - Laser-induced particle acceleration
- Aimed pellet reconstruction  $O(100 \mu\text{m})$
- Test setup with 4 measurement levels



# Pellet Source Studies

## Real-time pellet tracking system

- Test of performance of the prototype system
- Alignment found to be crucial
  - Mounting at the experimental setup
  - Mechanical vibrations
  - Temperature effects
- Reconstruction and stability investigated using 80  $\mu\text{m}$  fibers

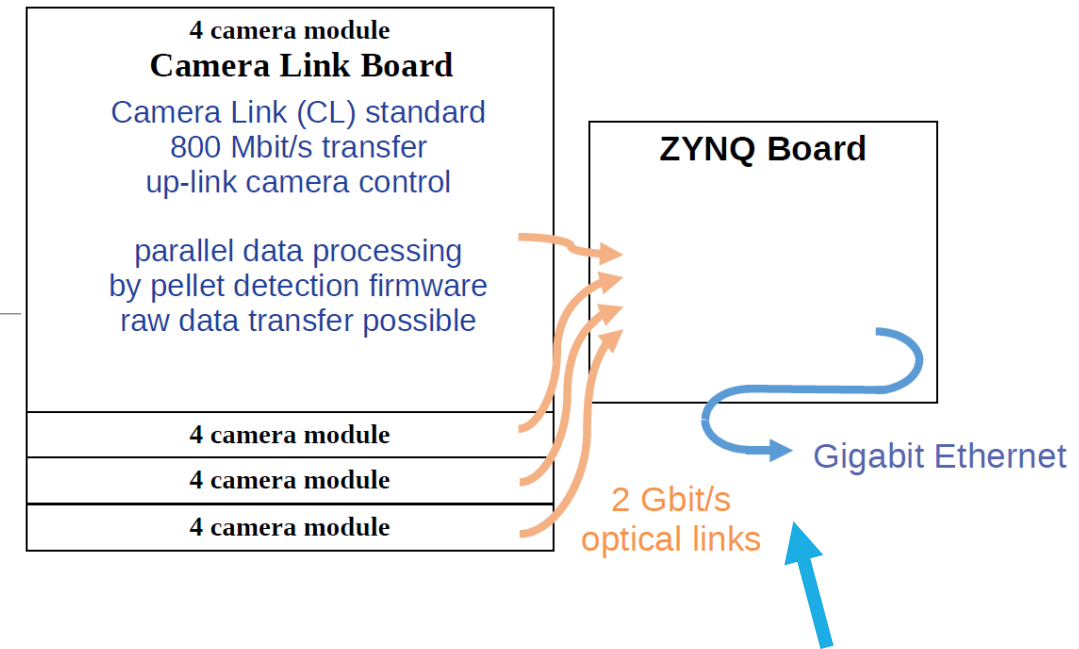




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- Test of performance of the prototype system
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  - Mounting at the experimental setup
  - Mechanical vibrations
  - Temperature effects
- Reconstruction and stability investigated using 80  $\mu\text{m}$  fibers
- Development of a readout and DAQ system
  - Synchronisation of line-scan cameras
  - Current setup: readout, data transfer from CamLink to ATLB and VME
  - Planned: readout, data transfer from CamLink to ZynqBoard



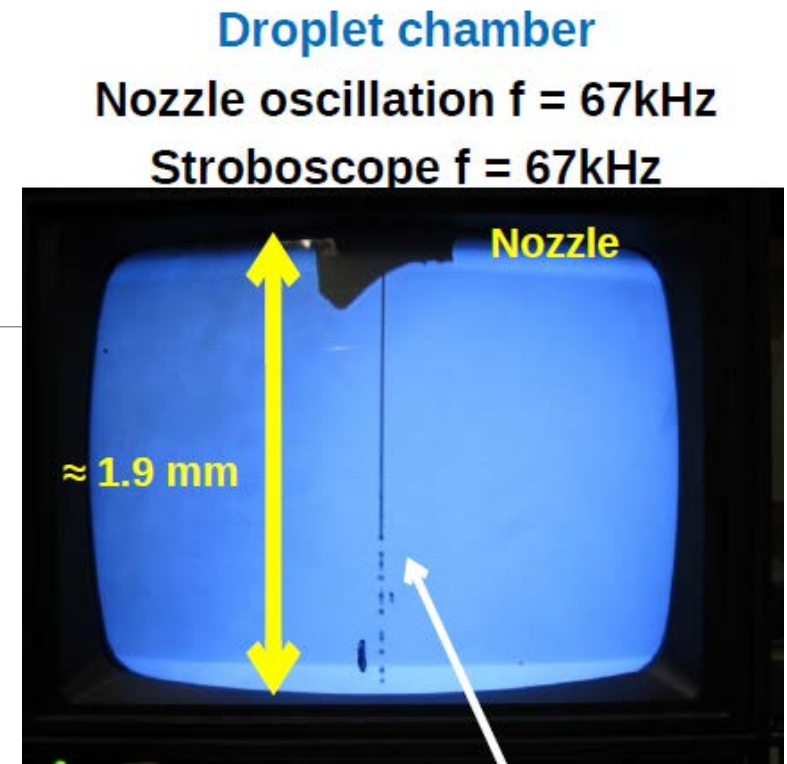
# Pellet Source Studies

## Pellet beams

- Droplet/pellet formation occurs commonly via
  - Spontaneous Rayleigh breakup
  - Vibration induced breakup using piezo excitation
- Novel idea: stimulated breakup by pulsed laser beams
  - Infrastructure in preparation for first tests
  - First measurements possible as soon as pellet test station (Uppsala) is in operation again

## Studies towards frozen fiber target beams

- Observation of frozen hydrogen fibers in vacuum
  - length ~1.5 m
  - Lateral stability within millimeters for hours



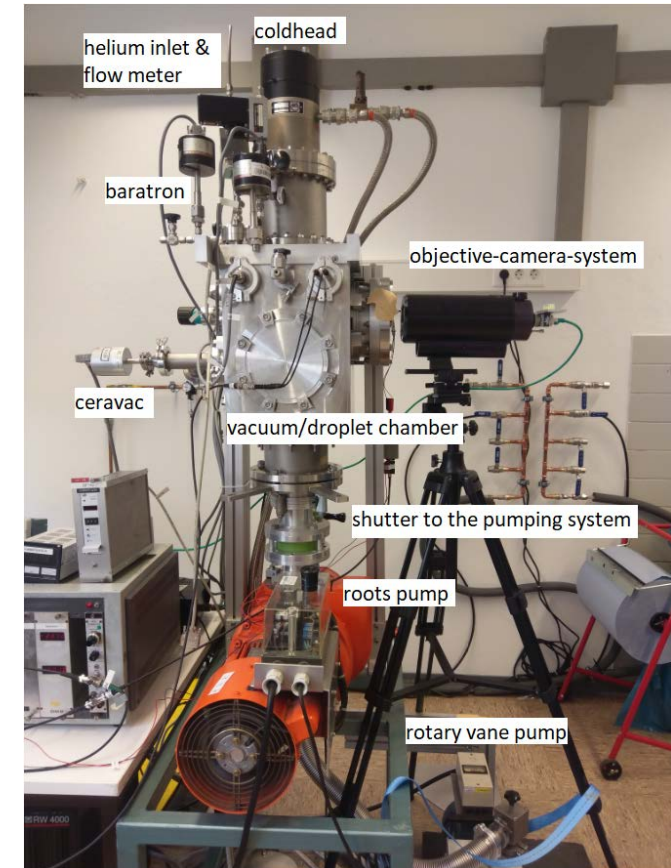
# Deliverables and Milestones

## Deliverables

- No deliverables are scheduled for the first reporting period

## Milestone MS68

- Setup of a droplet test device
- Lead beneficiary 16 – WWU
- Delivery month from Annex I: 12
- Actual delivery month: 4





# Expected Results and Potential Impact

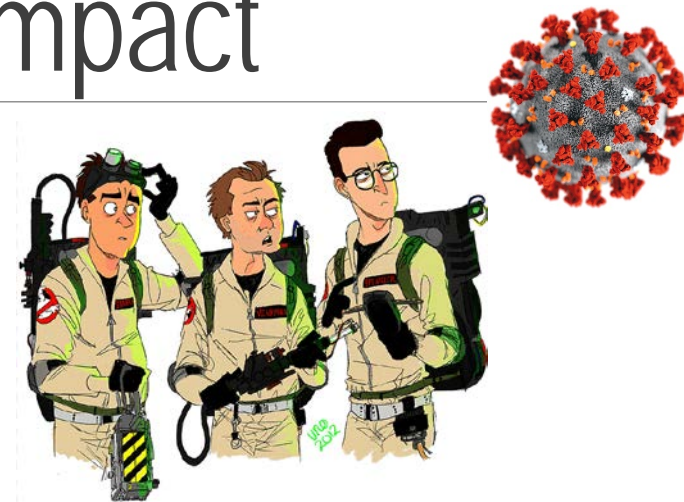
Great progress of JRA11/WP29, despite the Covid-19 restrictions

Newly developed production techniques and experimental methods

- New and reliable production lines for fine Laval nozzles
- Nozzles with long lifetimes
- Key for significantly improved cluster, droplet, and pellet targets
- Key for efficient experiments (duty factor)

Important impact for various fields

- Accelerator experiments using lepton and (anti)hadron beams
  - E.g., PANDA/FAIR, MAGIX@MESA, ...
- Targets for laser-induced hadron/lepton acceleration
- ...



Thank you for listening...



# Appendix

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# Tasks and Milestones

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															
<b>TASKS/Subtasks</b>	<b>Year 1</b>				<b>Year 2</b>				<b>Year 3</b>				<b>Year 4</b>			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
<b>1. Cluster-Jet Beam Studies</b>																
1.1 New nozzle production techniques								1								
1.2 Studies on jet beams: highest performance and cluster formation																
1.3 Laser-induced particle acceleration (H <sub>2</sub> clusters and heavier gases)																
<b>2. Cryogenic droplet beam target</b>																
2.1 Studies on droplet nozzles designs and efficiency				2												
2.2 Measurements on long term stability																
2.3 Investigations on high performance																
<b>3. Pellet Source Studies</b>																
3.1 Development and studies with new pellet diagnostic systems																
3.2 New nozzle and pellet production techniques								3								



# Use of Human Resources

Beneficiary number	Organization legal name (in italics the Research Units)	Short name	Human effort from Annex I (person-months for 18 months)	Actual human effort in the reporting period (person-months)
8	Gsi Helmholtzzentrum fuer Schwerionenforschung GMBH	GSI	3,40	0,00
16	Westfaelische Wilhelms-Universitaet Muenster	WWU	4,50	2,83
41	Uppsala Universitet	UU	3,00	0,9