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Status on the Production of Laval Nozzles and Determination of the Cluster Size Distribution

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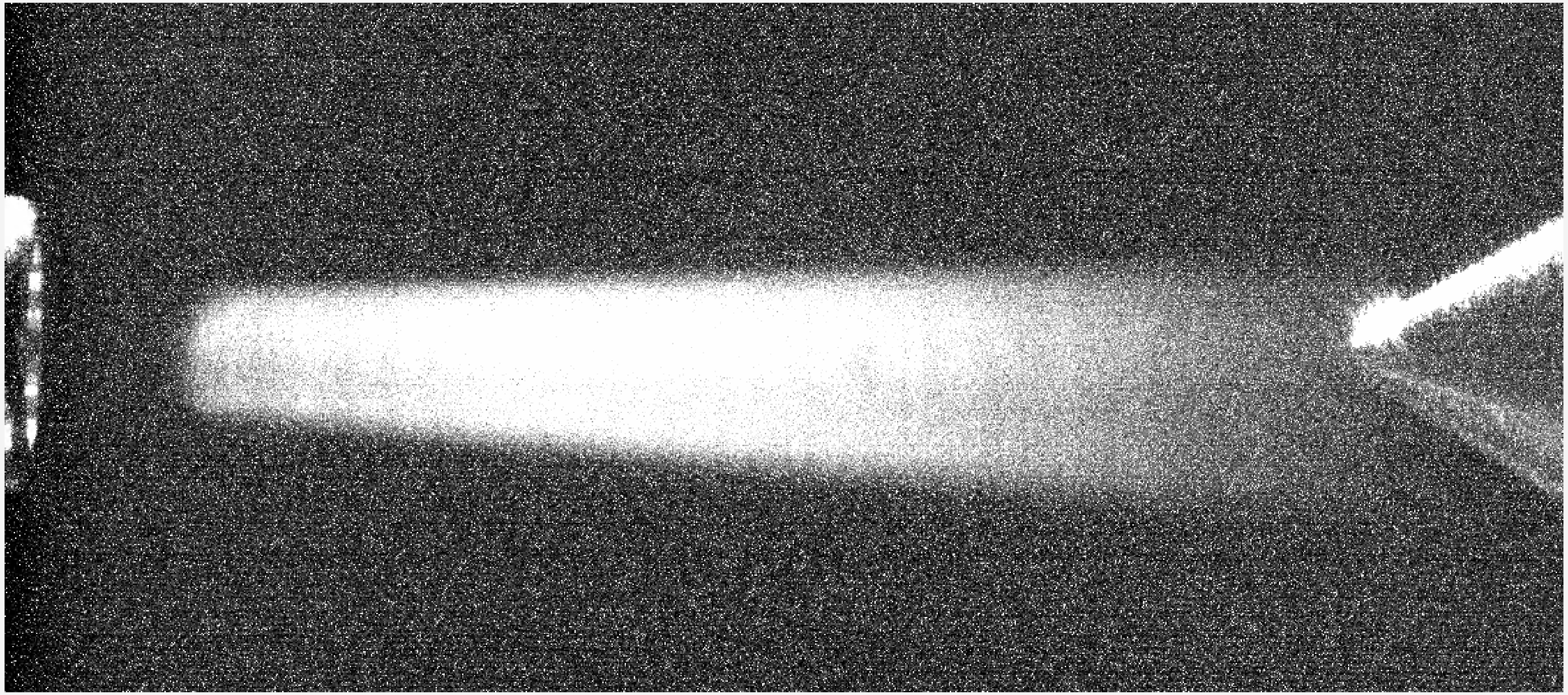
Institute for nuclear physics, WWU Münster, October 12, 2022

PANDA Meeting
October 10 – October 14, 2022

Münster Laval Nozzle production

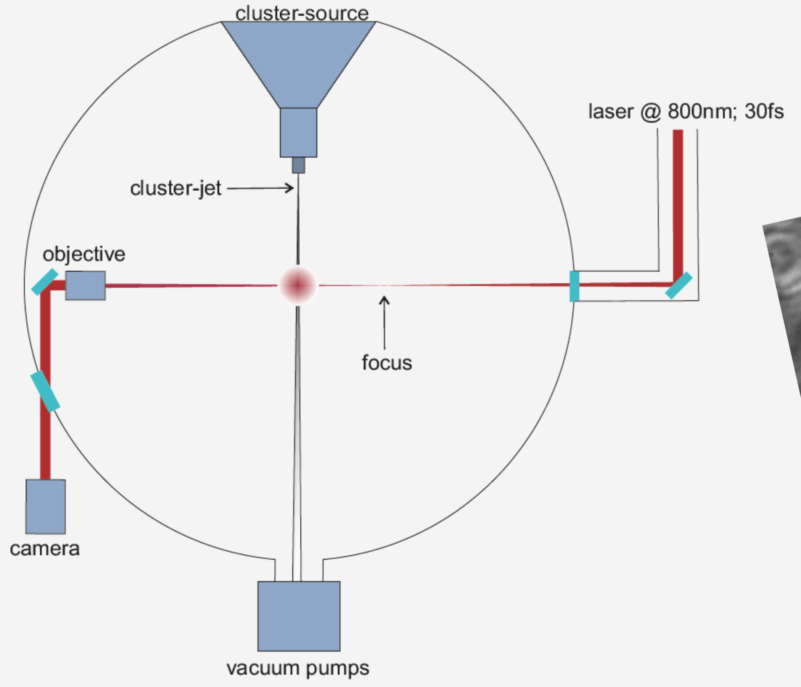
- Convergent-divergent shape with narrowest diameter of only $\approx 30\mu\text{m}$ and a total length of 1.8cm (i.e., $l = 600 \cdot d$)
- Specially shaped Laval nozzle with challenging, multi-step production process (completely in-house):
  - Galvanize nozzle outlet negative
  - Lathe outer geometry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

Resulting Cluster-Jet

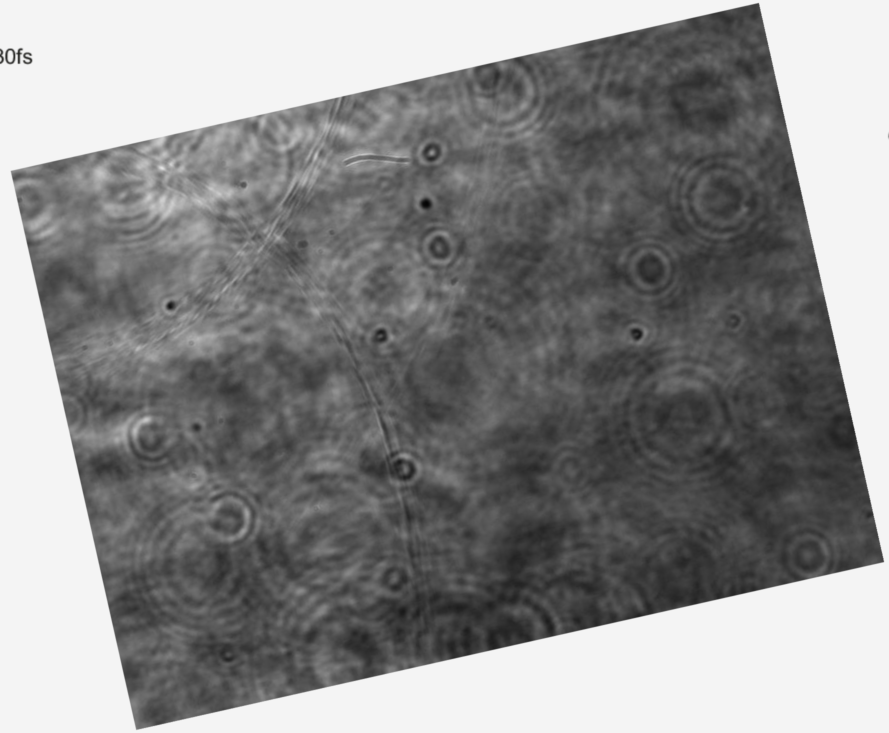


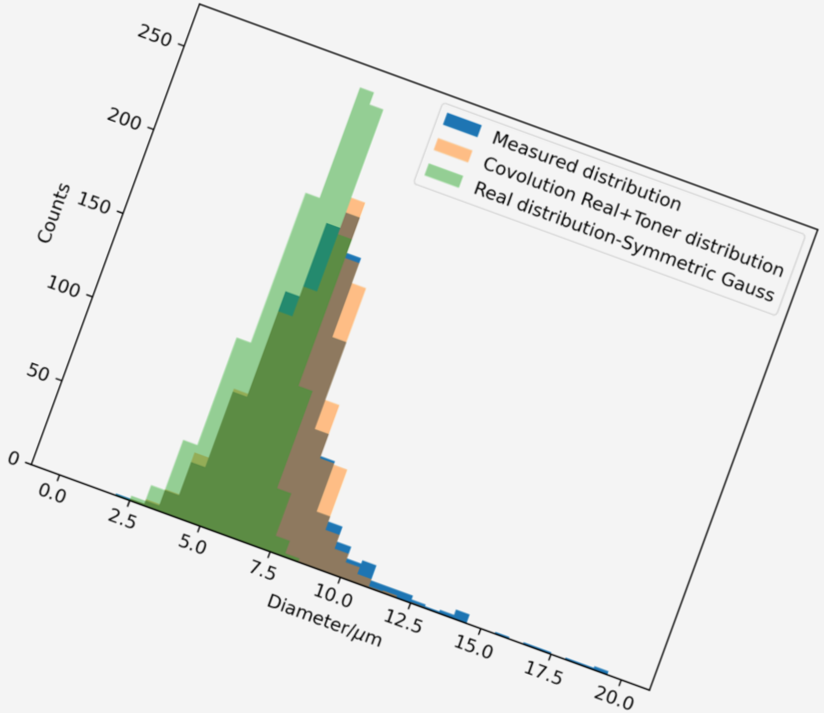
- Thickness:
  $2.7 \cdot 10^{14}$ atoms/cm^2
- Stable over several hours

Reminder: Shadowgraphy Measurements



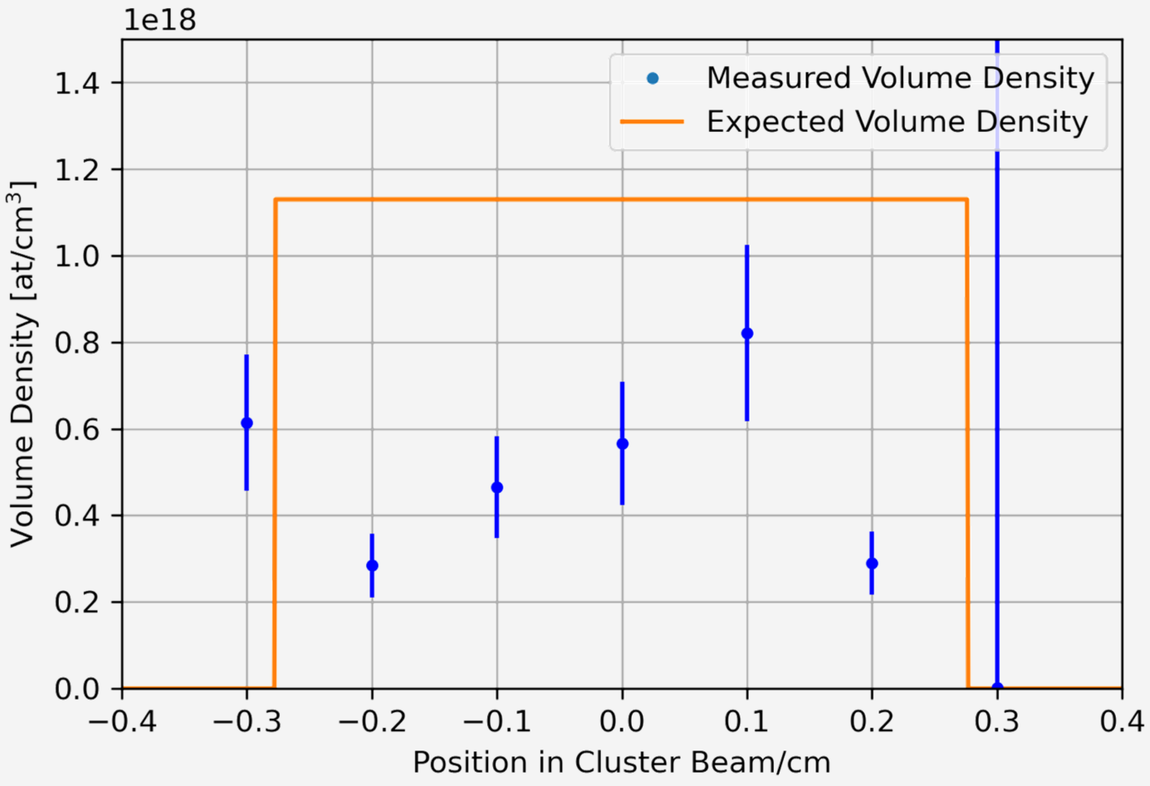
Created by Christian Mannweiler





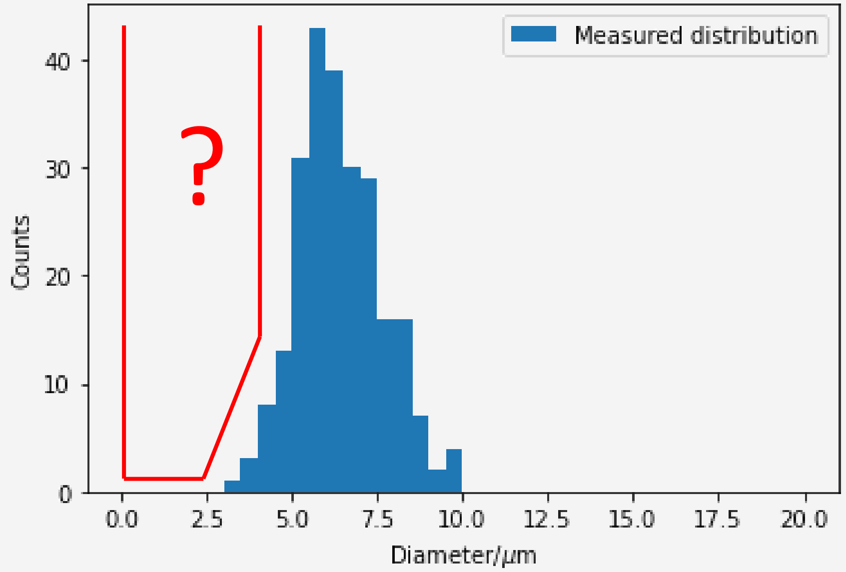
Volume Density Distribution

- Calculated volume density for every position in the cluster beam (blue)
- Not all the density comes from the big clusters → also smaller clusters have impact
- Structure can be seen in profile of cluster beam (→ core beams)
- Volume Density will change slightly since velocities are taken from simulations but are measured currently



Distribution of Smaller Clusters

- It is very likely that there are also smaller clusters, but they cannot be found with shadowgraphy method (at the mentioned conditions)
- Methods to find the distribution of smaller clusters will be tested in the future (3-WEM measurements)

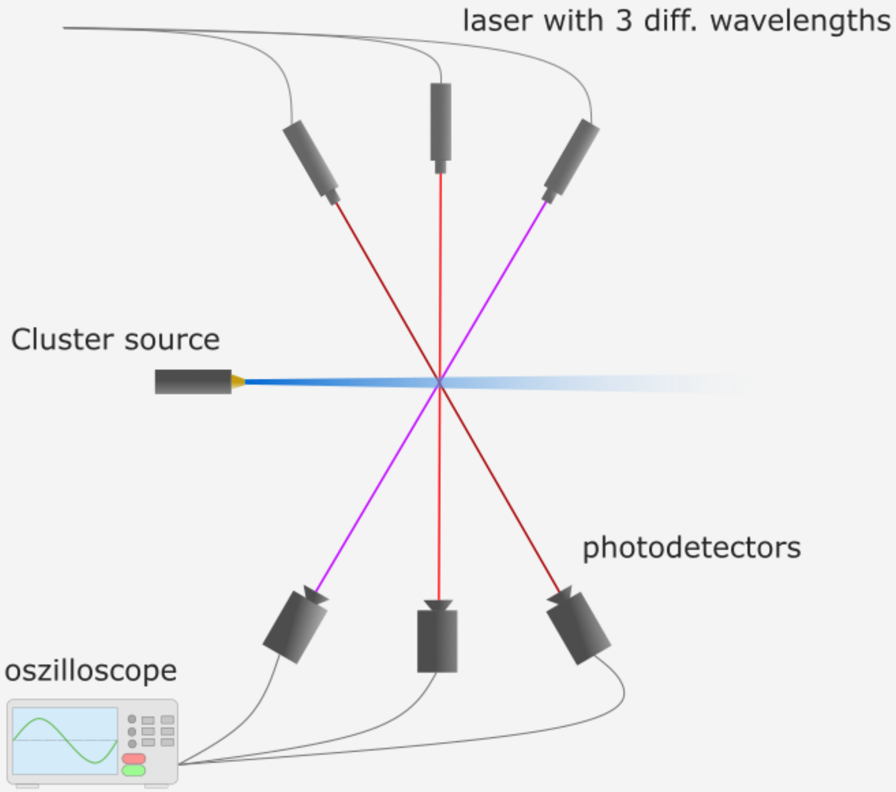


New Method to Determine Cluster sizes: 3-WEM

- 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 — incident intensity — particle distribution — extinction coefficient

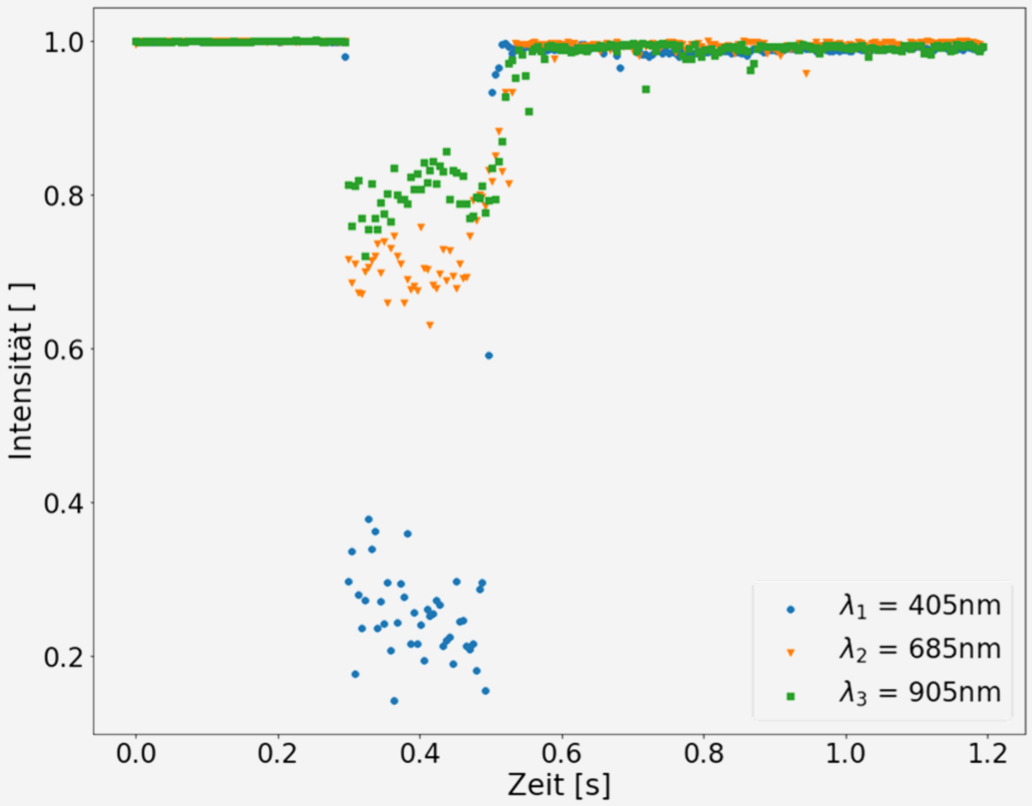


3-WEM

$$\frac{ln\left(\frac{I}{I_0}\right)_{\lambda_1}}{ln\left(\frac{I}{I_0}\right)_{\lambda_2}} = \frac{\int_0^\infty \pi\left(\frac{D}{2}\right)^2 p(D) Q_{ext}(D,\lambda_1,m)}{\int_0^\infty \pi\left(\frac{D}{2}\right)^2 p(D) Q_{ext}(D,\lambda_2,m)}$$

$$\frac{ln\left(\frac{I}{I_0}\right)_{\lambda_2}}{ln\left(\frac{I}{I_0}\right)_{\lambda_3}} = \frac{\int_0^\infty \pi\left(\frac{D}{2}\right)^2 p(D) Q_{ext}(D,\lambda_2,m)}{\int_0^\infty \pi\left(\frac{D}{2}\right)^2 p(D) Q_{ext}(D,\lambda_3,m)}$$

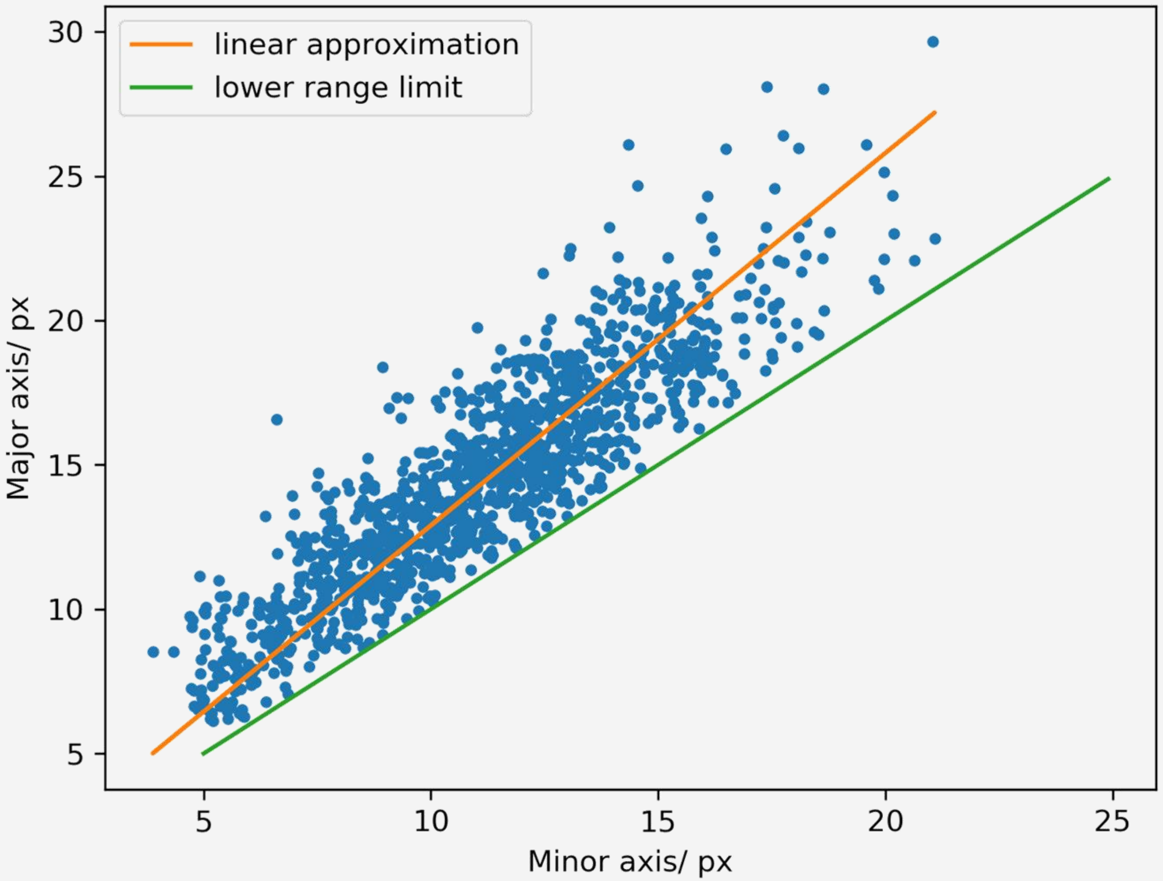
- First test measurements with water spray bottle
- Determine wavelength-dependent extinction ratio between incident intensity I_0 and attenuated intensity I
- Ratio between different wavelengths reveals information about mean and standard deviation of cluster size distribution



→ Measurements with cluster-jet pending

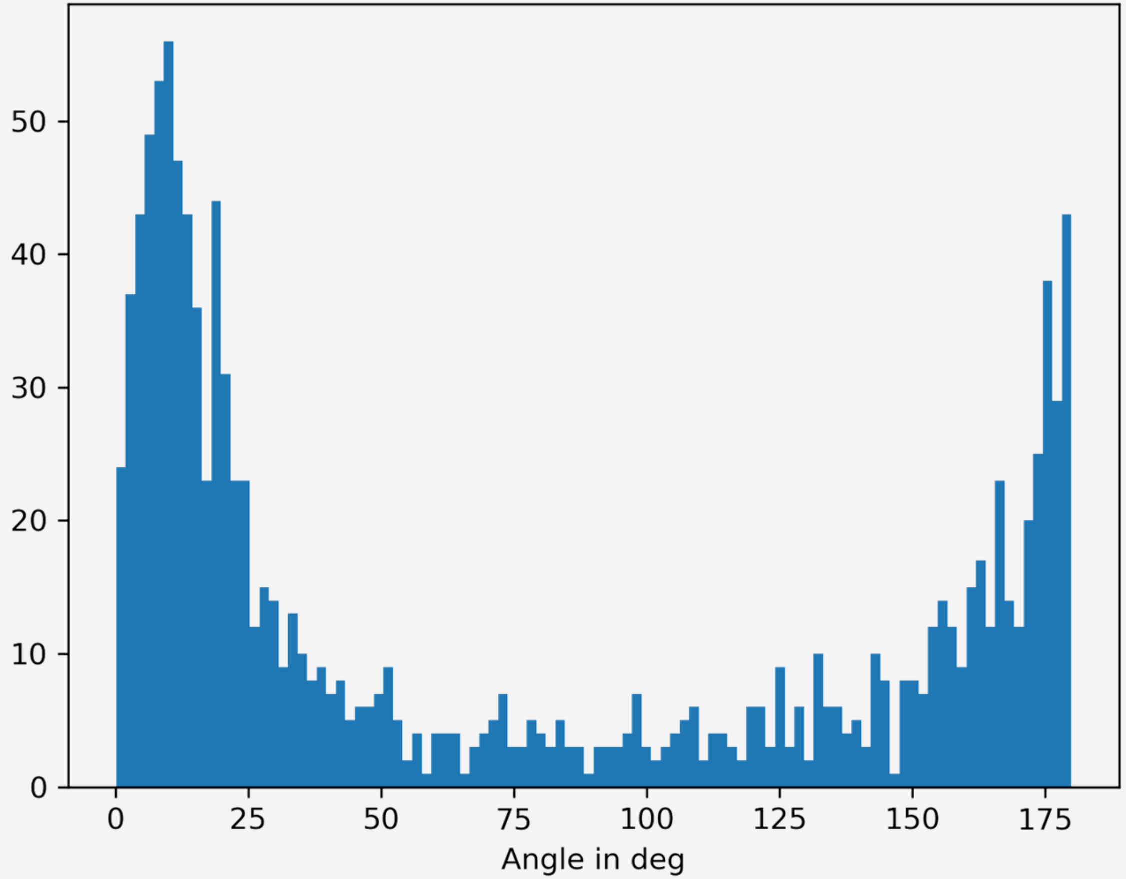
Shape and Orientation of the Clusters

- Image processing program *ImageJ* approximates found clusters with an ellipse and calculates the length of the minor and major axis
- If clusters would be perfectly round, maximum of distribution would be close to green line
- Orange line shows linear approximation of data points → different slope than lower range limit



Shape and Orientation of the Clusters

- Image processing program *ImageJ* approximates found clusters with an ellipse and calculates also the angle of the ellipse relative to the horizontal of the picture (flight direction of the cluster beam)
- Most of the clusters close to the nozzle are elongated into the flight direction



Summary

- First Laval nozzle with diameter of approx. 30µm is produced completely in-house
- Based on results of shadowgraphy measurements new method tested to find distribution of smaller clusters
- Clusters close to the nozzle are not perfectly spherical and most are elongated into flight direction