Westfälische Wilhelms-Universität Münster

Unpolarized Cluster, Jet and Pellet Targets

Intense Electron Beams Workshop
Cornell University, June 17-19, 2015

Institut für Kernphysik

Alfons Khoukaz

wissen.leben
WWU Münster

Typical Requirements on Internal Targets

- Target material: H_2, D_2, N_2, Ne, Ar,..., Xe
  - Hydrogen as proton target for elementary reactions on the nucleon
  - Deuterium as deuteron or effective neutron target
  - Heavier gases (N_2, Ne, Ar, ..., Xe) for interactions with large nuclei (high A, Z)
- Pure target material without unwanted elements
  - Windowsless, no target holder, ...
- Pointlike interaction zone
- Homogeneous spatial target density
- Target thickness constant in time
  - No time structures
  - DAQ system ↔ dead time

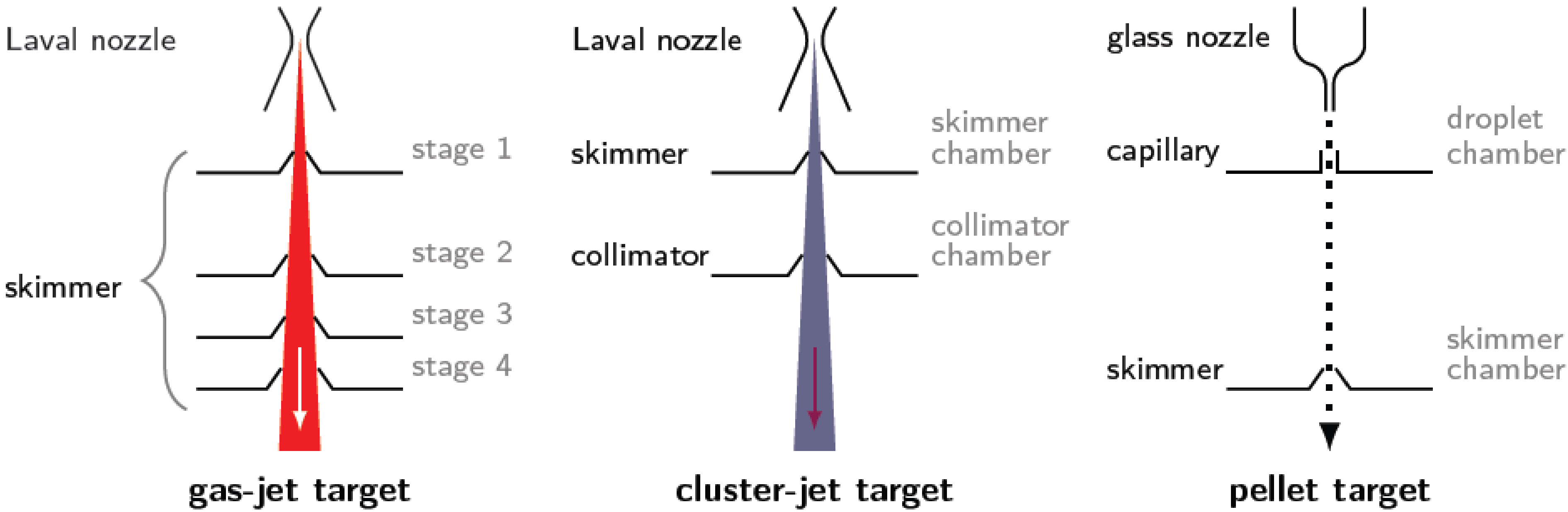
Typical Requirements on Internal Targets

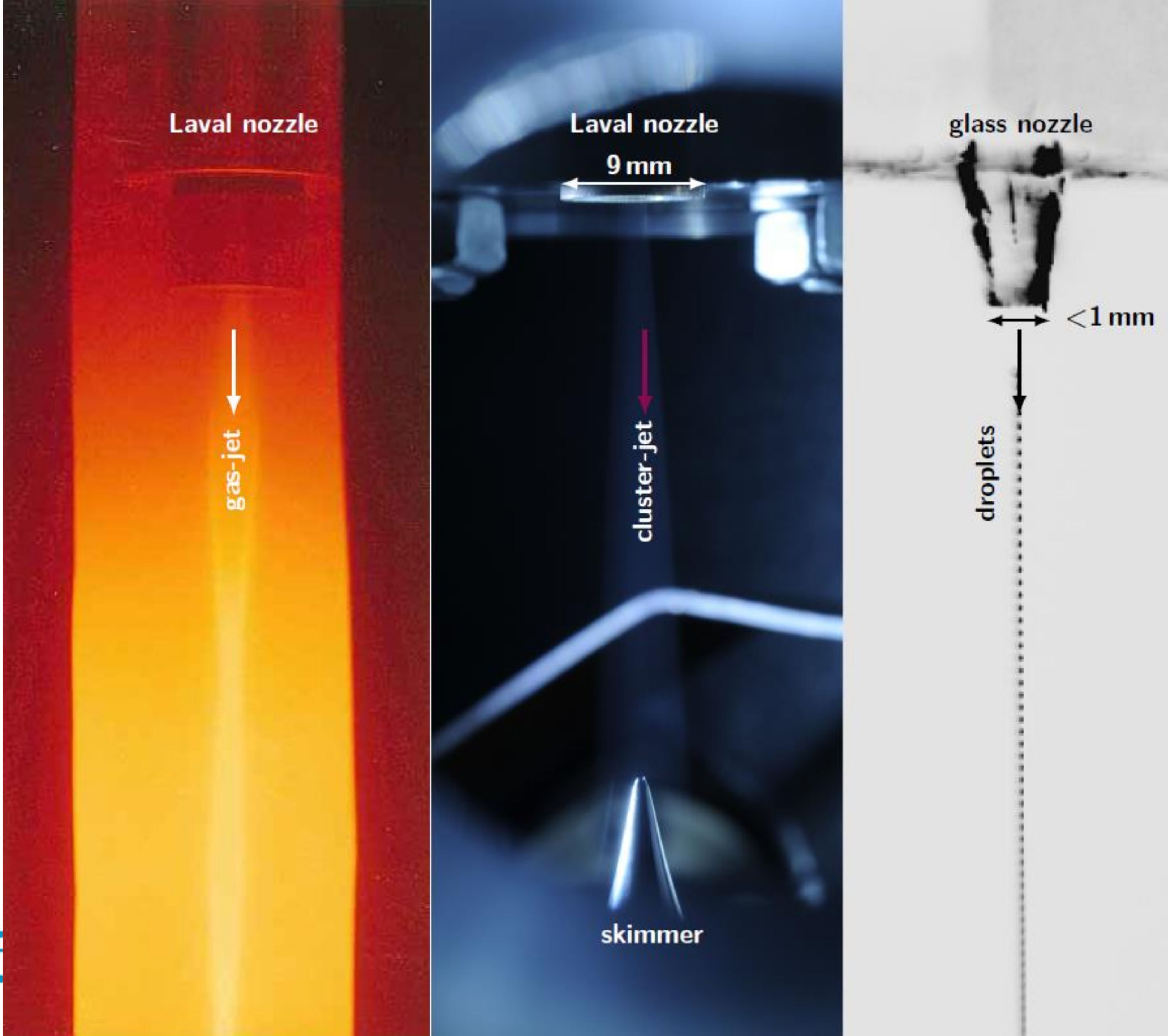
- Continously adjustable target thickness
  - Optimum event rates for individual experimental situation
  - Compensation of beam consumption → constant event rate
- Target should be compatible with a close to 4π detector
- The best target type depends on
  - the experimental setup (detector, accelerator, DAQ, ...)
  - the experimental program
  - the required event rate (luminosity, cross section, ...)
- Highly suited and well established:

Cluster targets, gas jet targets, pellet targets

Westfälische Wilhelms-Universität Münster

Production of Gas, Cluster and Pellet Beams




Laval nozzle
gas-jet
Laval nozzle
9 mm
cluster-jet
skimmer
glass nozzle
<1 mm
droplets

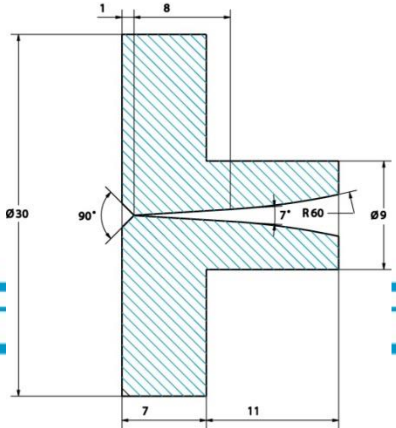
Westfälische Wilhelms-Universität Münster

Gas Jet Beams

wissen.leben WWU Münster

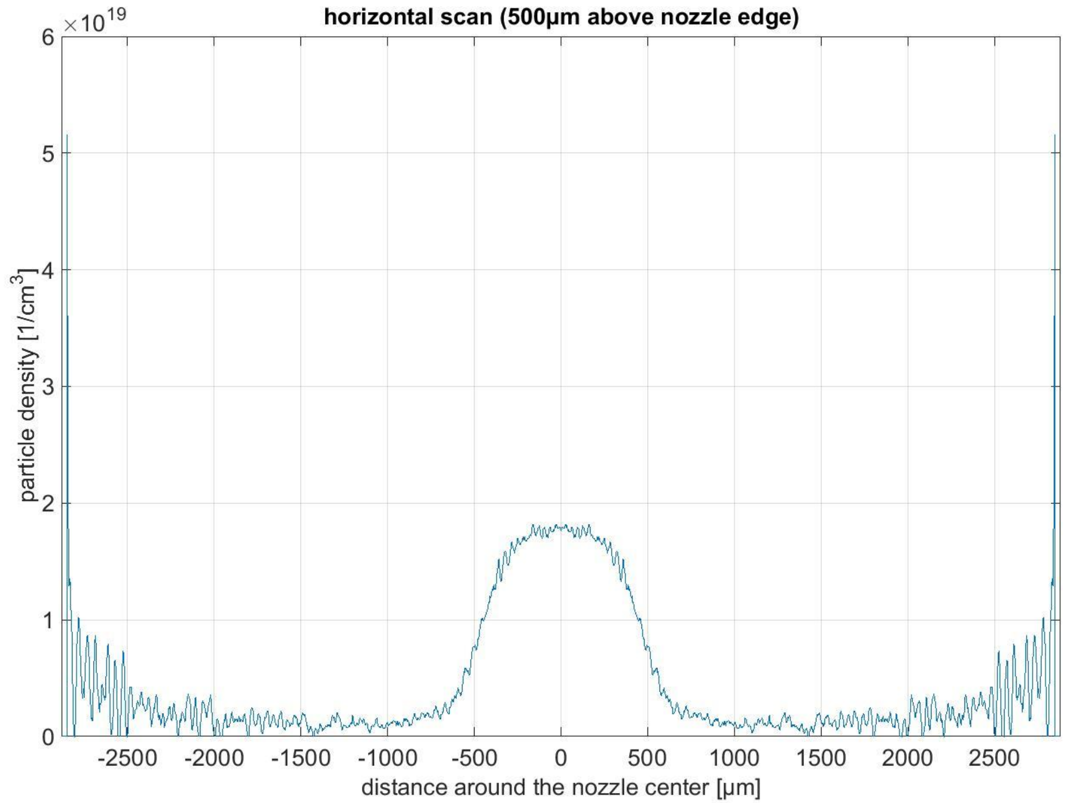
Production of Gas-Jet Beams

- Expansion of gas through Laval nozzles into vacuum
- Production of supersonic jets
- High target thickness directly behind nozzle
  - E.g. 10^{19} atoms/cm^3
  - Formation of typical node structure
- But:
  - Target thickness decreases rapidly with distance from nozzle
  - Gas beam strongly expands in lateral direction
  - High pumping speeds required



Gas Jet Beams

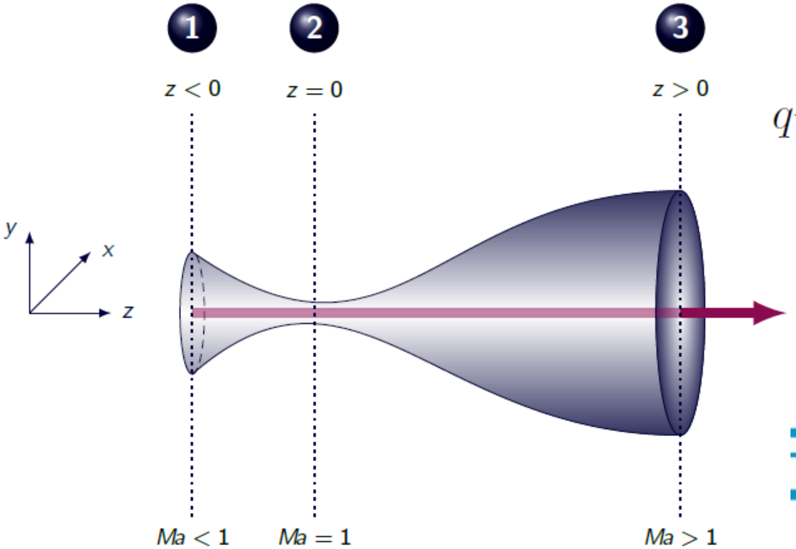
Argon (293 K, 17 bar)
Nozzle: A_{min} = 0.5 mm
A_{out} = 1.0 mm



Westfälische Wilhelms-Universität Münster

Gas Target Thickness Variation

- Gas input pressure p_0 variation
  - target thickness changes within e.g. one order of magnitude
  - thickness variation typically within seconds possible
- Gas starting temperature T_0 variation
  - thickness changes within several orders of magnitude
  - slow process (typically within minutes)



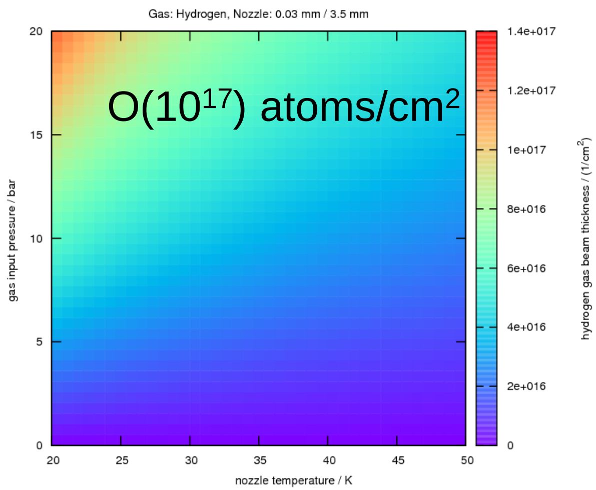
$$q_V = \dot{m}\,\frac{R\,T_N}{p_N\,M} = A^*\,\frac{p_0}{\sqrt{M\,T_0}}\,\frac{T_N}{p_N}\left(\frac{2}{\kappa+1}\right)^{\frac{\kappa+1}{2(\kappa-1)}}\sqrt{\kappa\,R}$$

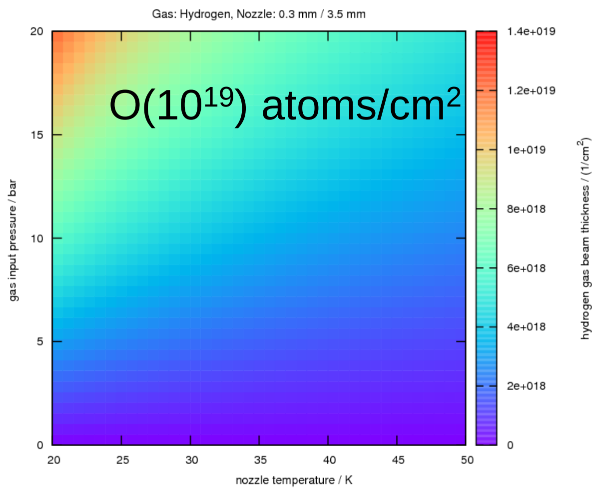
$$u_{\max} = \sqrt{\frac{2\,\kappa}{\kappa-1}\,\frac{R\,T_0}{M}}$$

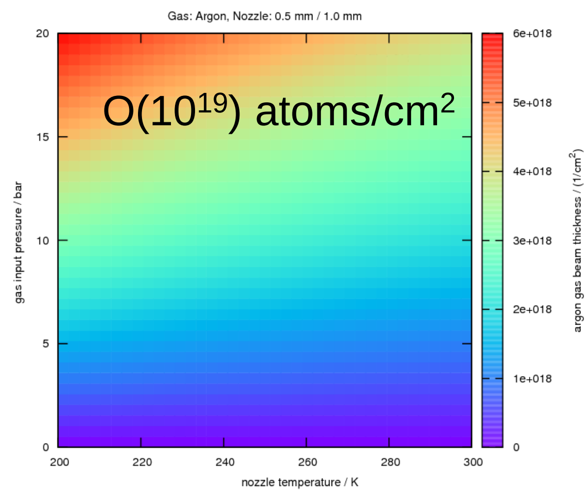
Gas Target Thickness Variation

Numerical calculations:

Target thickness directly above nozzle exit







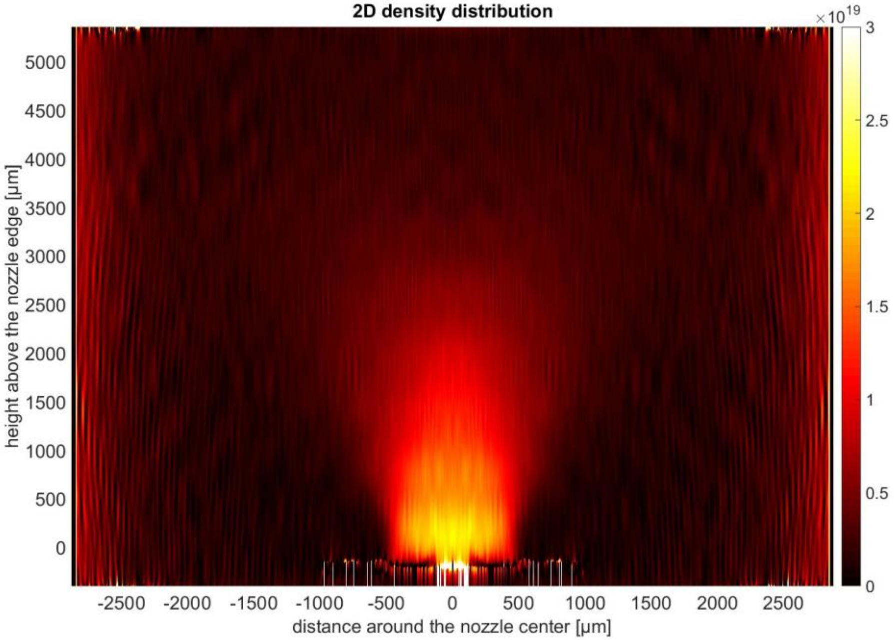
Hydrogen
Nozzle: a_{min} = 0.03 mm, a_{max} = 3.5 mm

Hydrogen
Nozzle: a_{min} = 0.3 mm, a_{max} = 3.5 mm

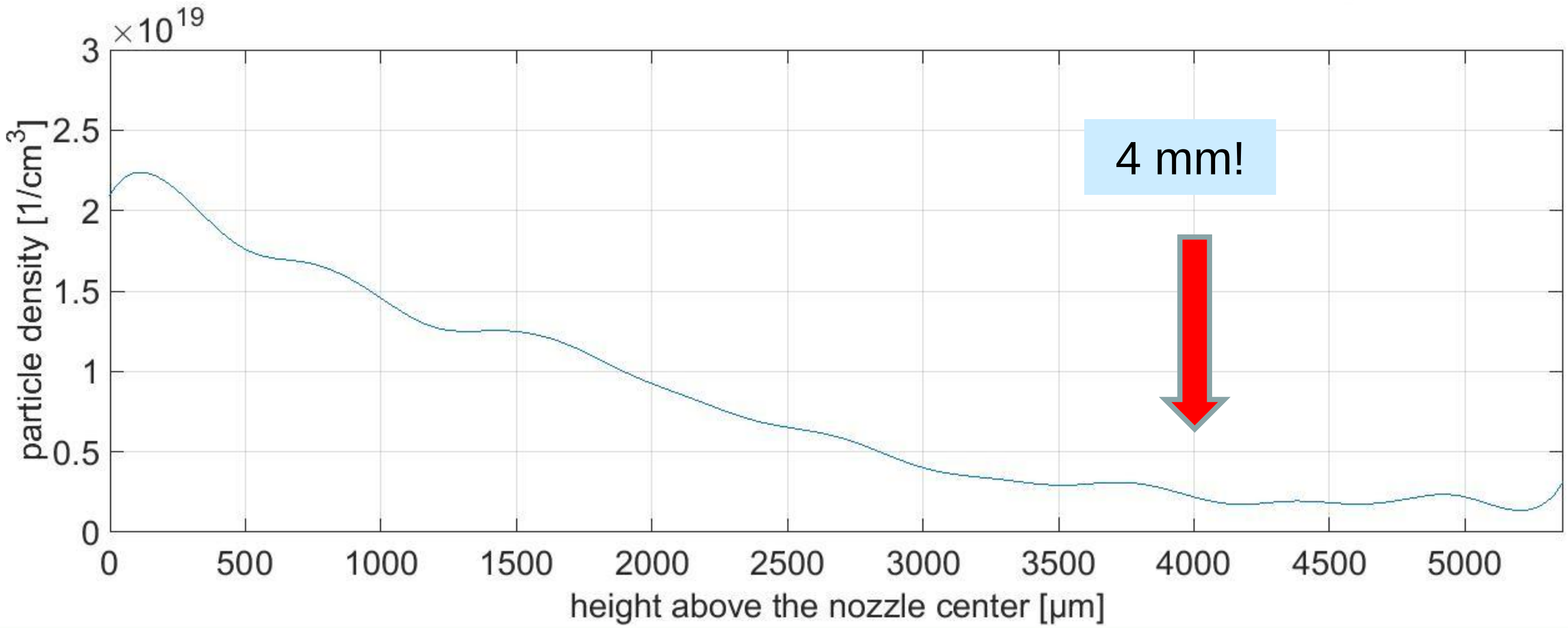
Argon
Nozzle: a_{min} = 0.5 mm, a_{max} = 1.0 mm

WESTFÄLISCHE WILHELMS-UNIVERSITÄT MÜNSTER

Gas Jet Beams



Argon (293 K, 17 bar)
Nozzle: A_{min} = 0.5 mm
A_{out} = 1.0 mm



Alfons Khoukaz

Westfälische
Wilhelms-Universität
Münster

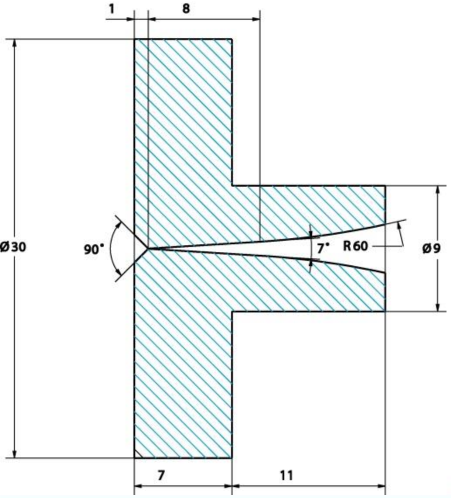
Cluster Jet Beams

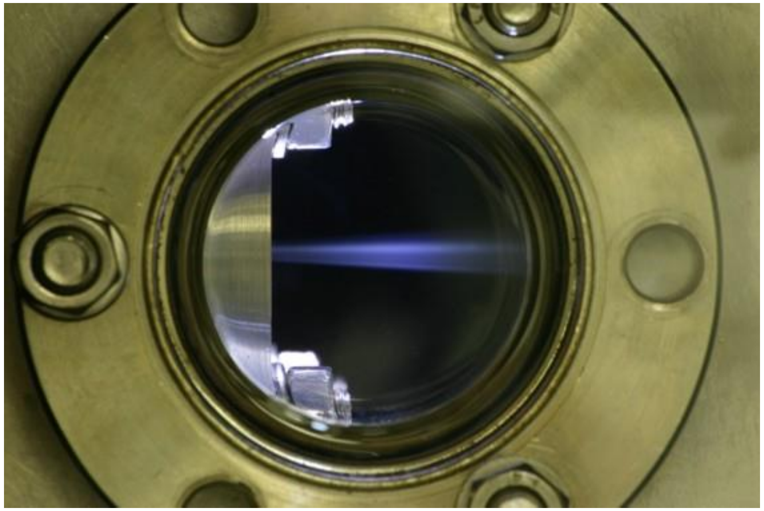
wissen.leben
WWU Münster

Alfons Khoukaz

Production of Cluster-Jet Beams

- Expansion of croygenic gas/liquid through fine (e.g. Ø 30 µm) Laval nozzles
- Condensation of gas or spraying of the liquid
  - formation of nano- to micro-meter sized particles
  - quasi-homogeneous beam

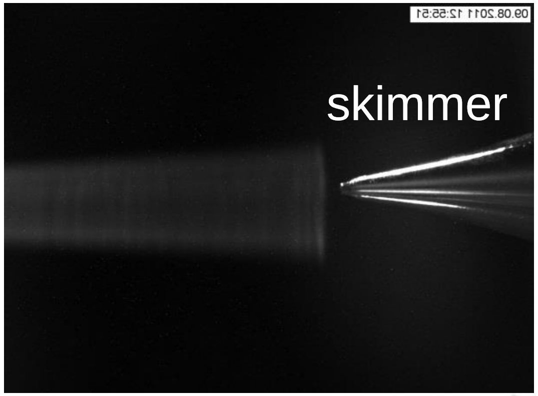


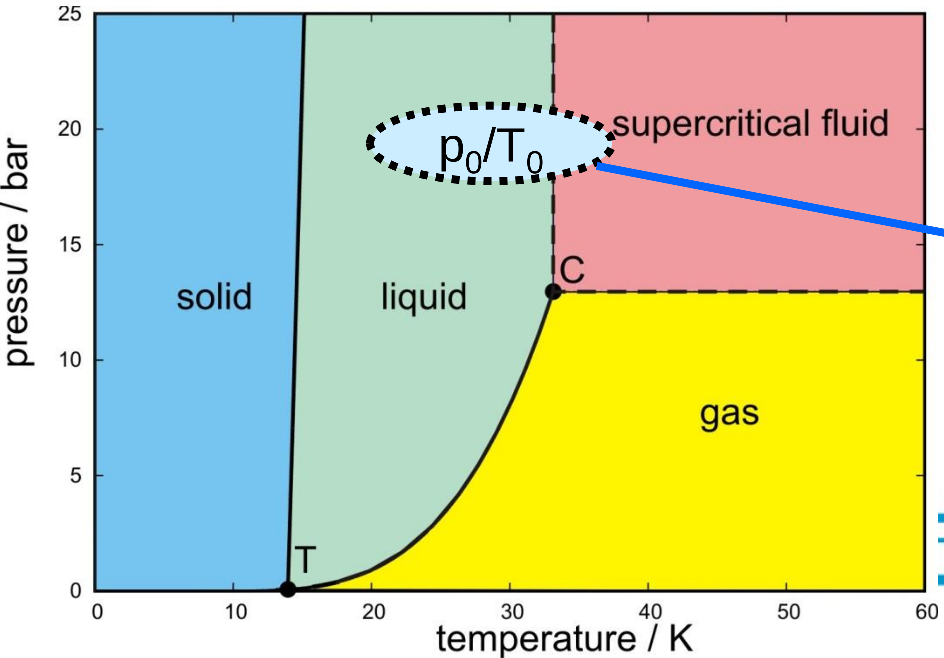


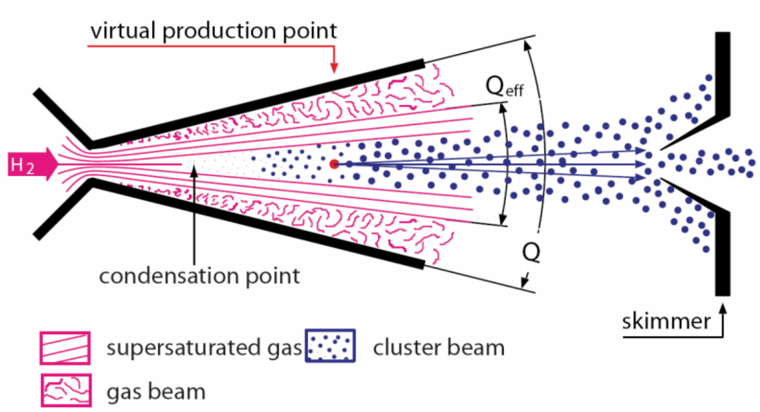
Westfälische Wilhelms-Universität Münster

Production of Cluster-Jet Beams

- Target beam thickness strongly depends on
  - nozzle properties (inner diameter e.g. 30 µm, shape, ...)
  - gas/liquid input pressure p_0
  - gas/liquid input temperature T_0

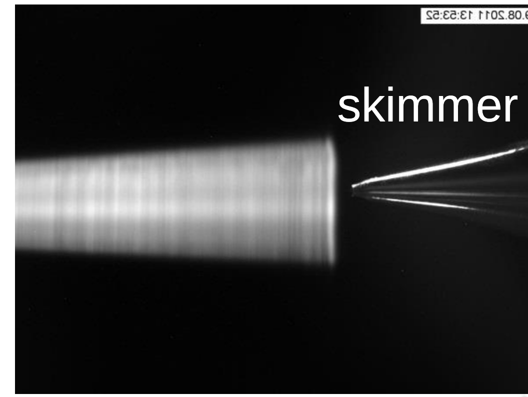




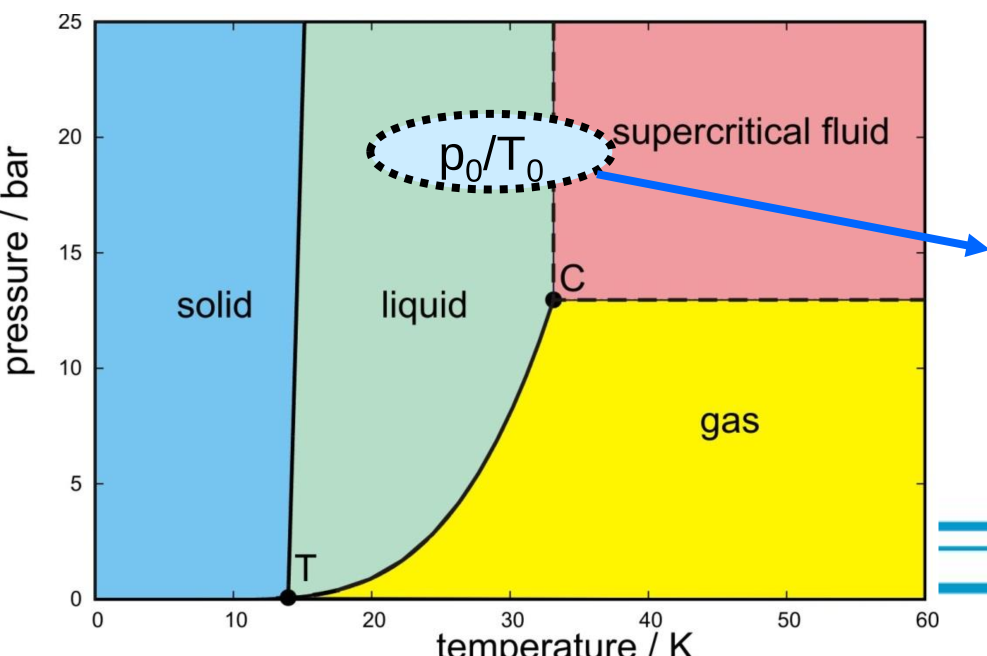


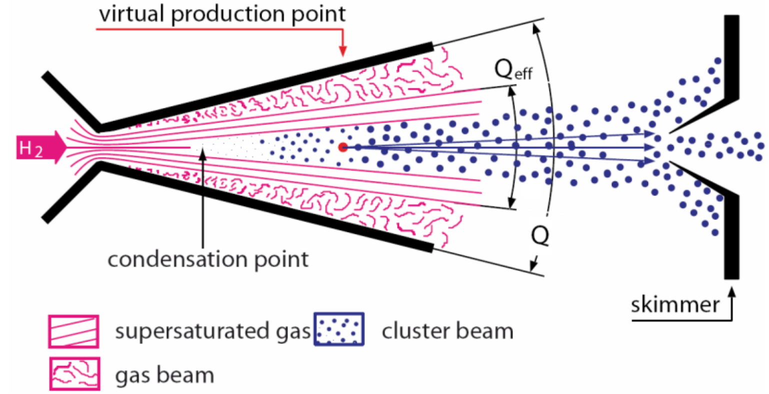
wissen.leben WWU Münster

Production of Cluster-Jet Beams

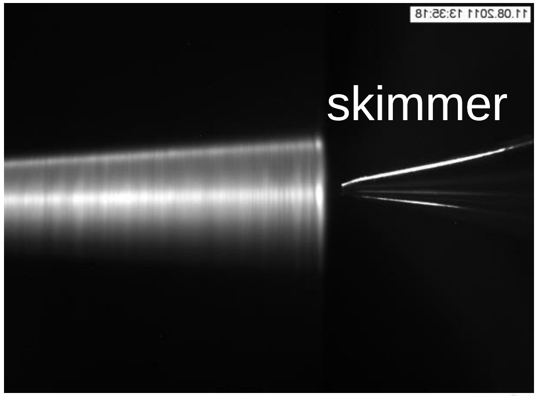


- Target beam thickness strongly depends on
  - nozzle properties (inner diameter e.g. 30 µm, shape, ...)
  - gas/liquid input pressure p_0
  - gas/liquid input temperature T_0

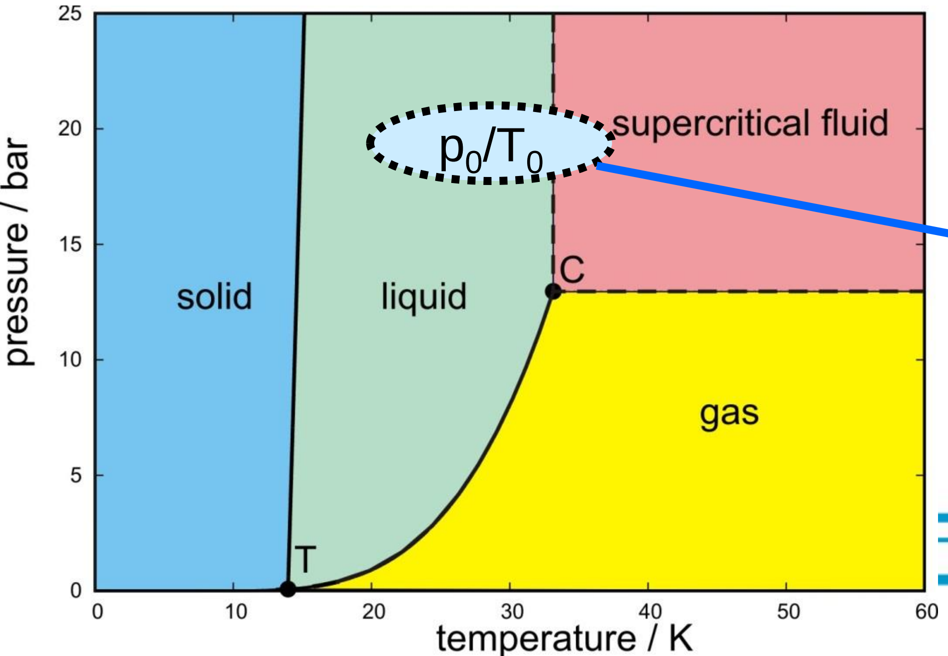


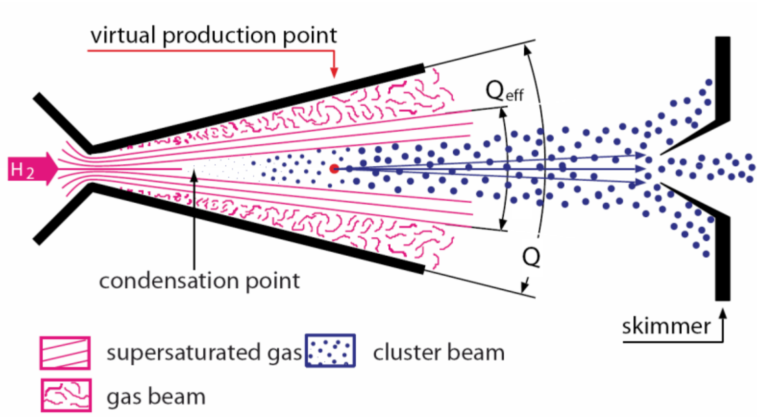


Production of Cluster-Jet Beams



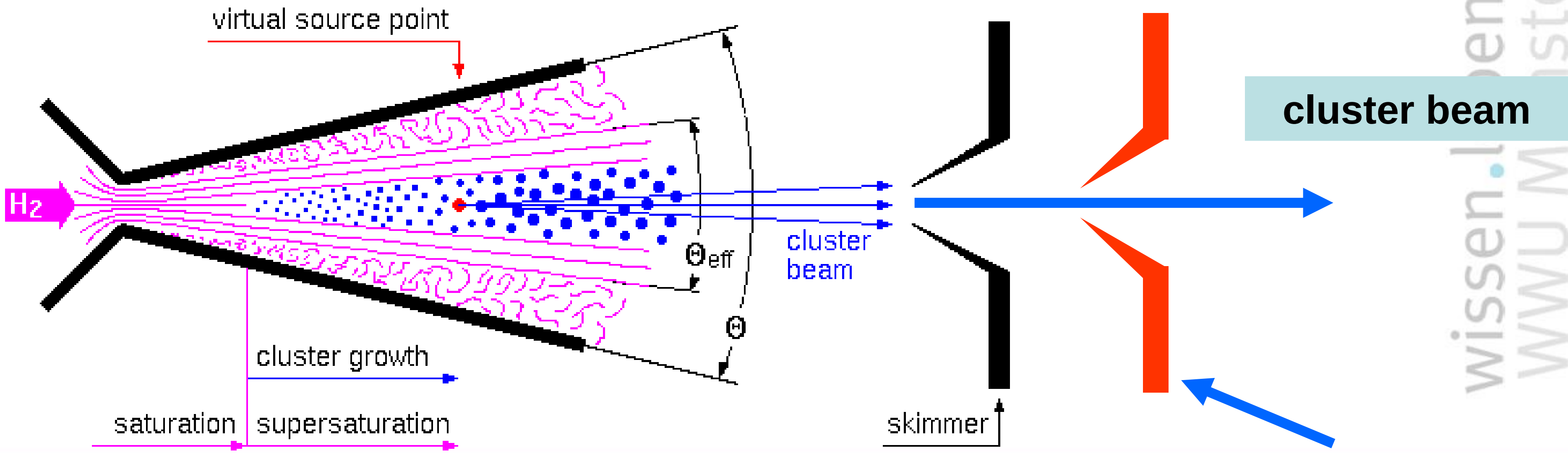
- Target beam thickness strongly depends on
  - nozzle properties (inner diameter e.g. 30 µm, shape, ...)
  - gas/liquid input pressure p_0
  - gas/liquid input temperature T_0





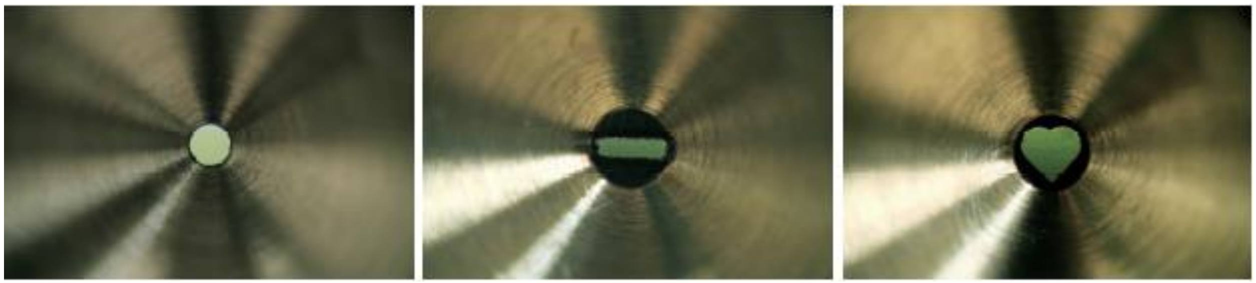
Production of Cluster-Jet Beams

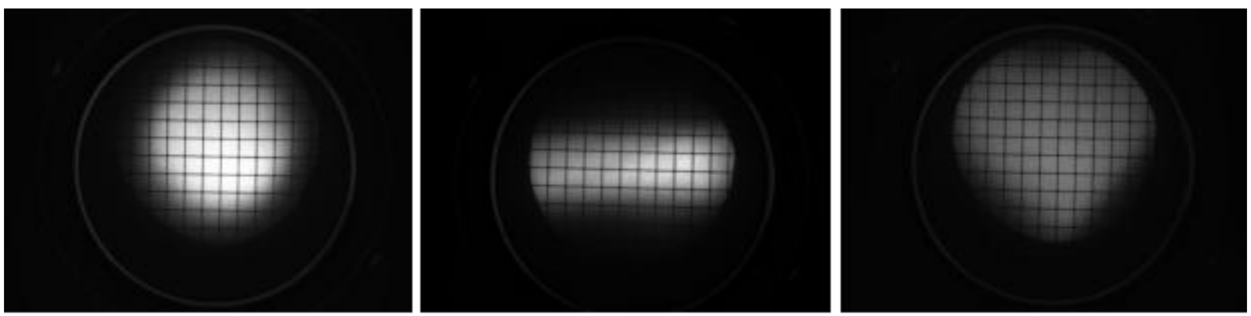
- Preparation of a cluster-jet beam by a set of two skimmers behind the nozzle
- Constant opening angle of the cluster-jet after the second skimmer



Cluster Beam Preparation by Skimmers

Skimmers (O(0.5 mm))



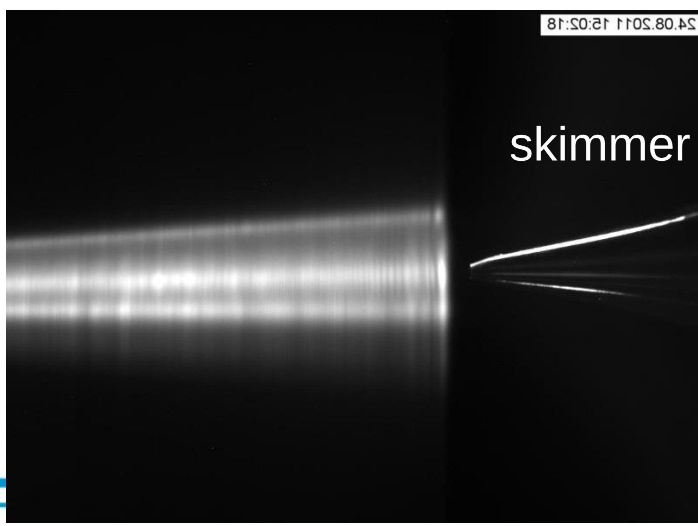


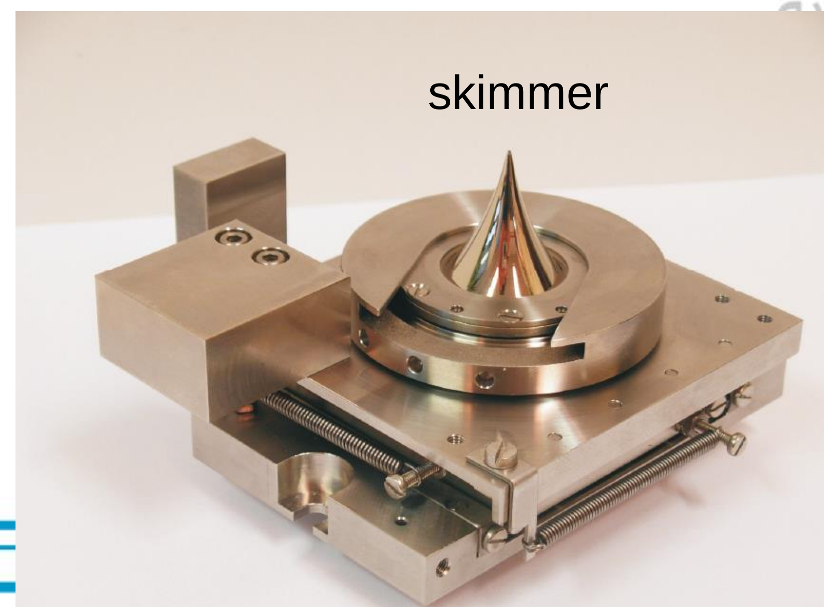
Cluster beam MCP images (after 5 m flight path)

Mechanical Adjustments

- Both skimmers can be moved during operation
  - Alignment of the target beam in the scattering chamber
- The complete nozzle setup can be tilted relative to the (fixed) skimmer
  - Selection of the high-density cluster core

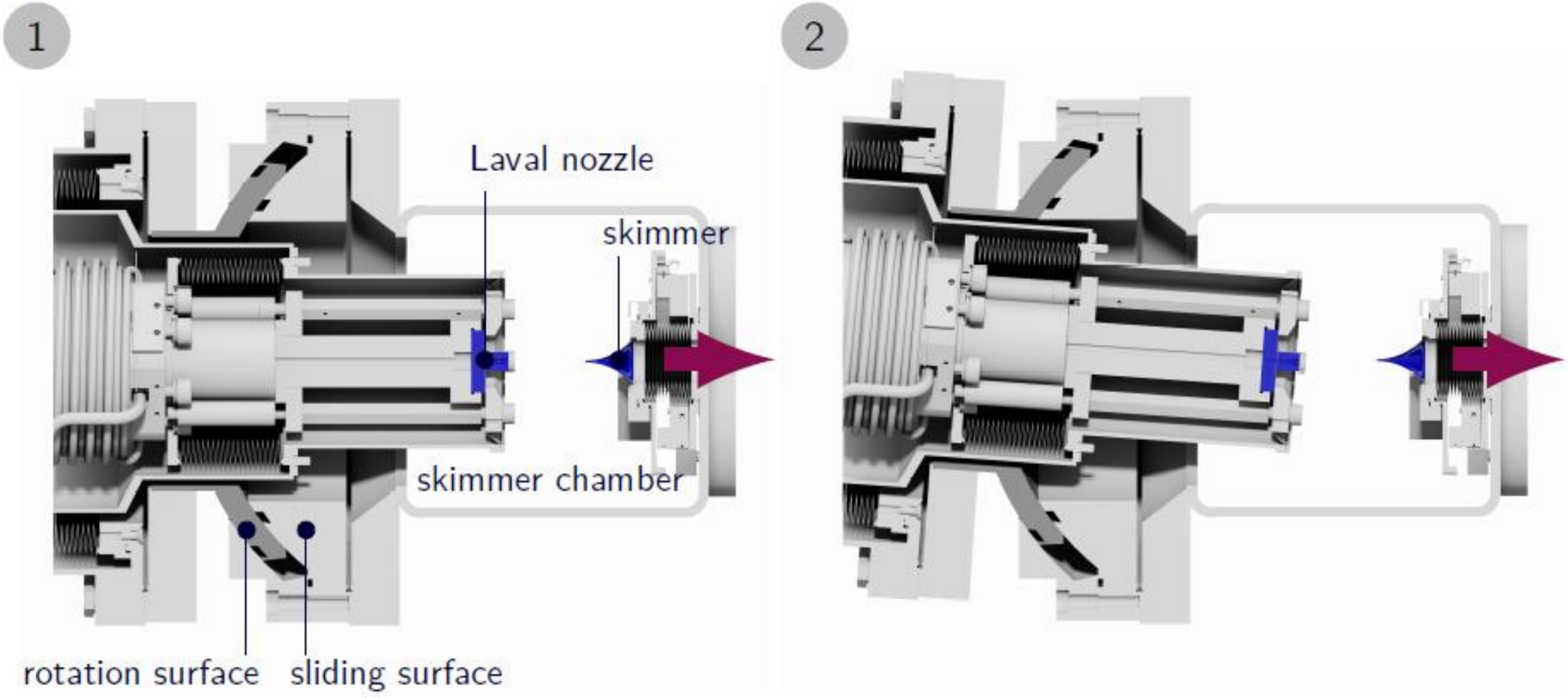
nozzle
(not visible)





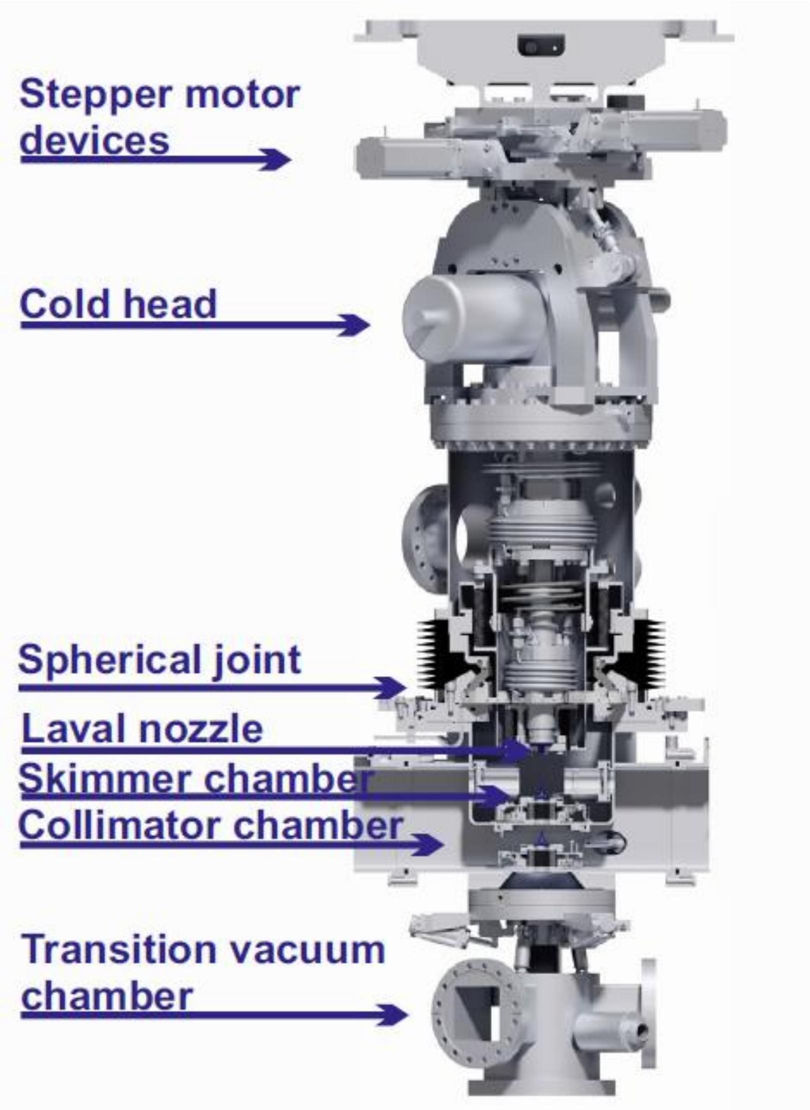
WESTFÄLISCHE
WILHELMS-UNIVERSITÄT
MÜNSTER

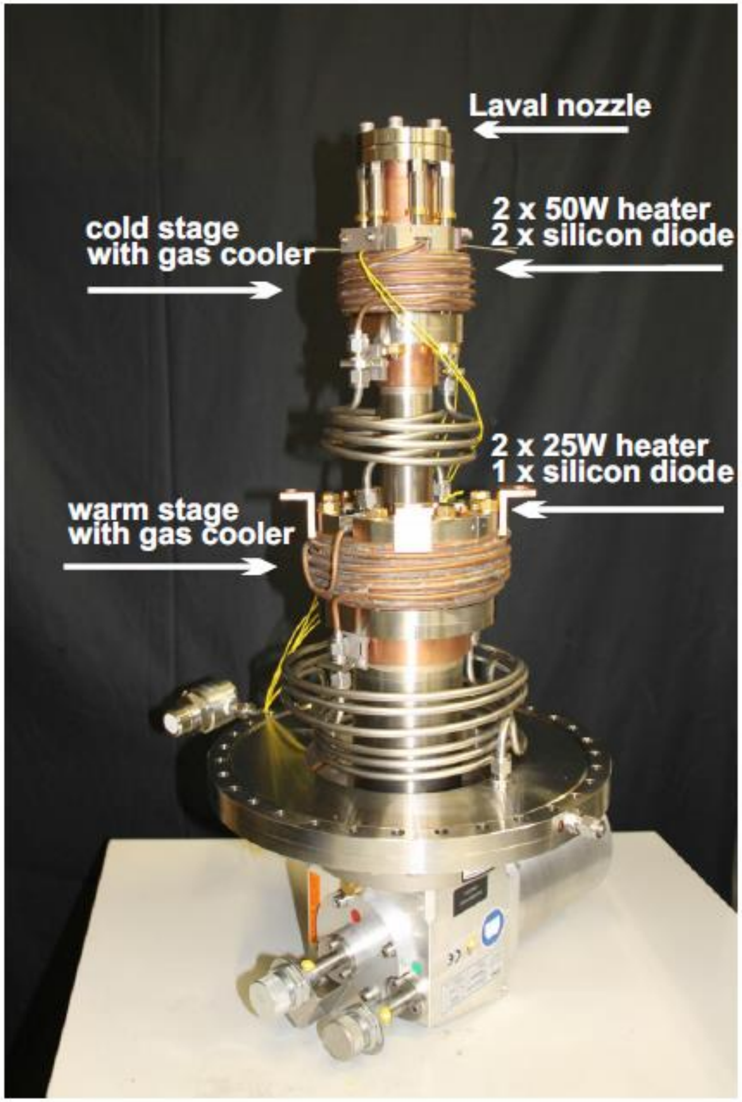
Mechanical Adjustments



Westfälische Wilhelms-Universität Münster

The PANDA Cluster-Source

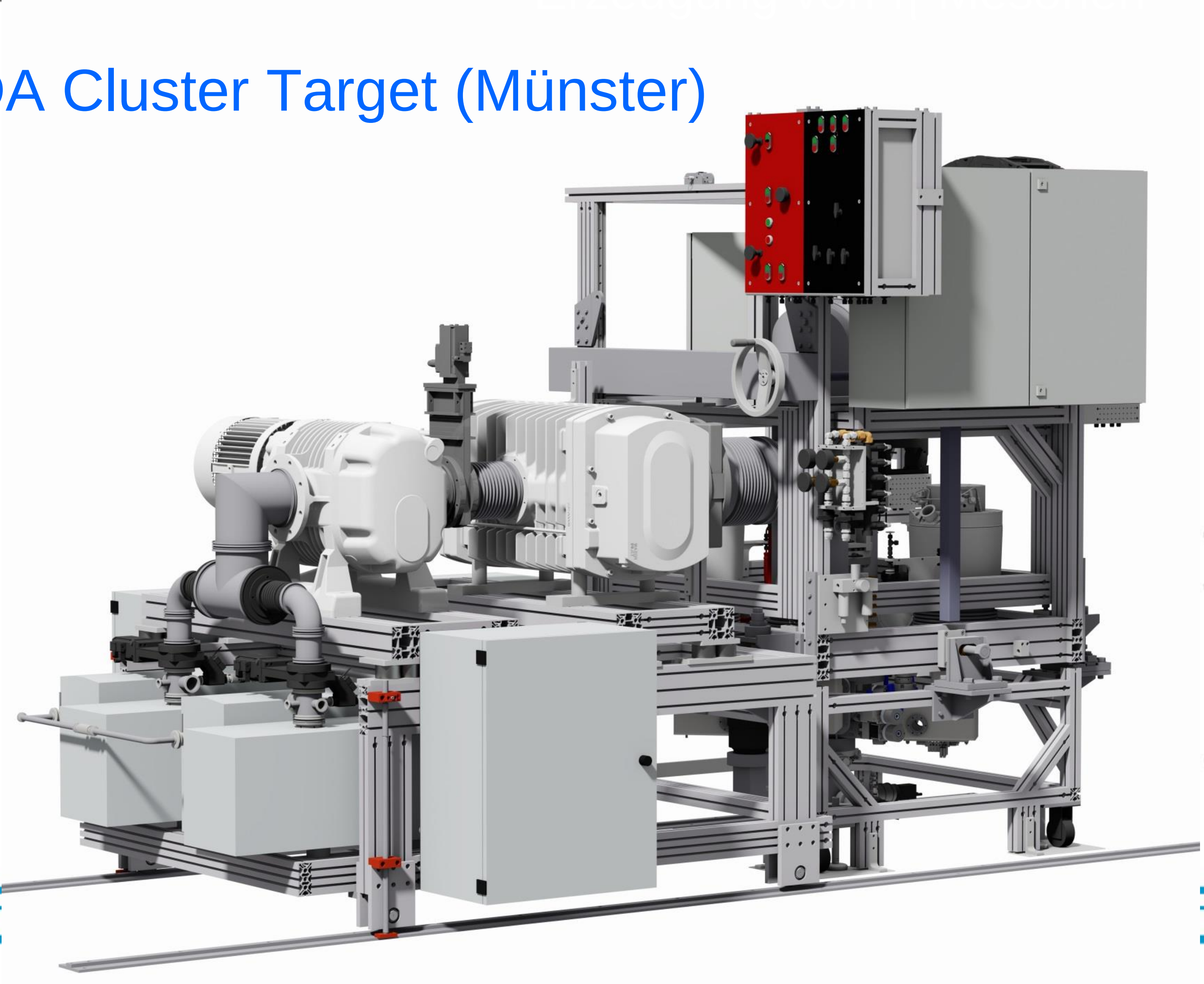




wissen.leben
WWU Münster

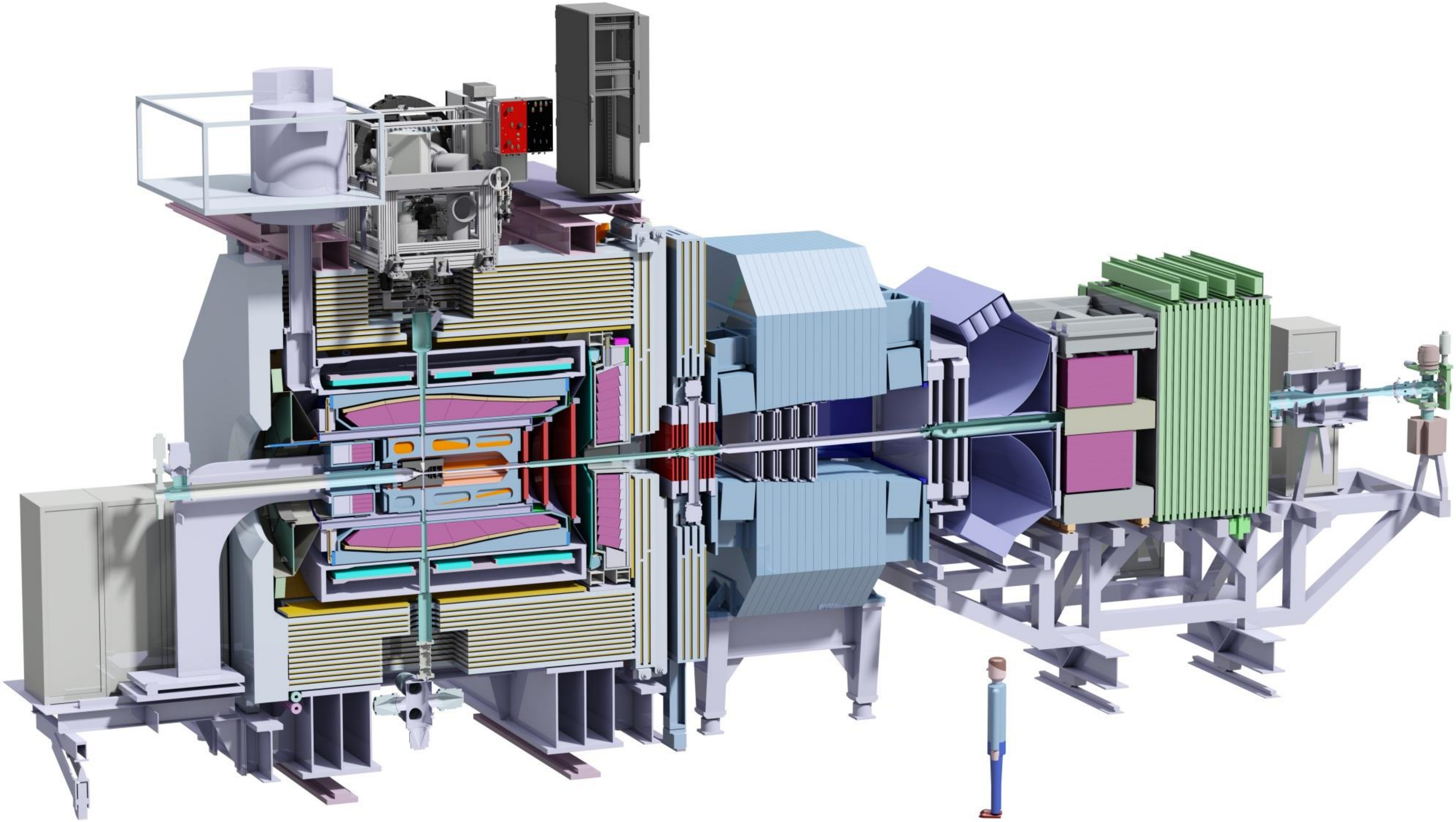
Westfälische Wilhelms-Universität Münster

PANDA Cluster Target (Münster)



wissen.leben WWU Münster

Planned PANDA Setup with Cluster Target



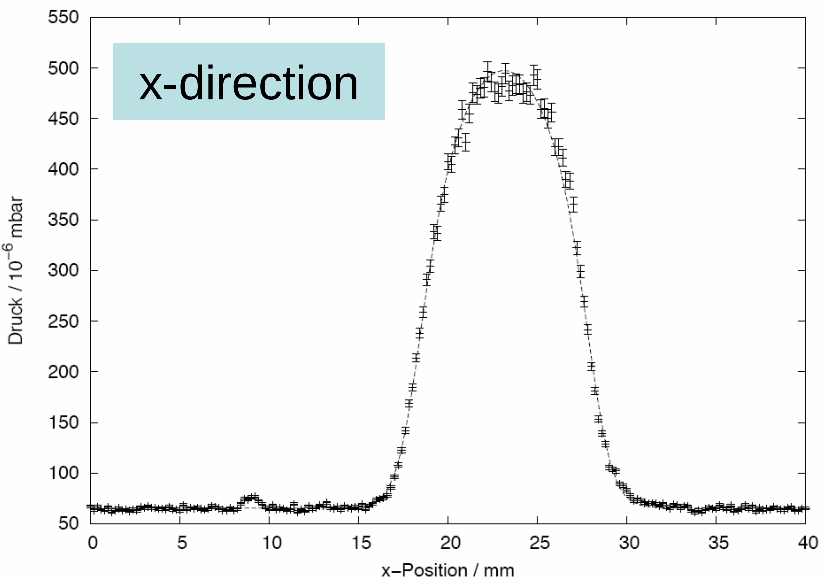
Westfälische Wilhelms-Universität Münster

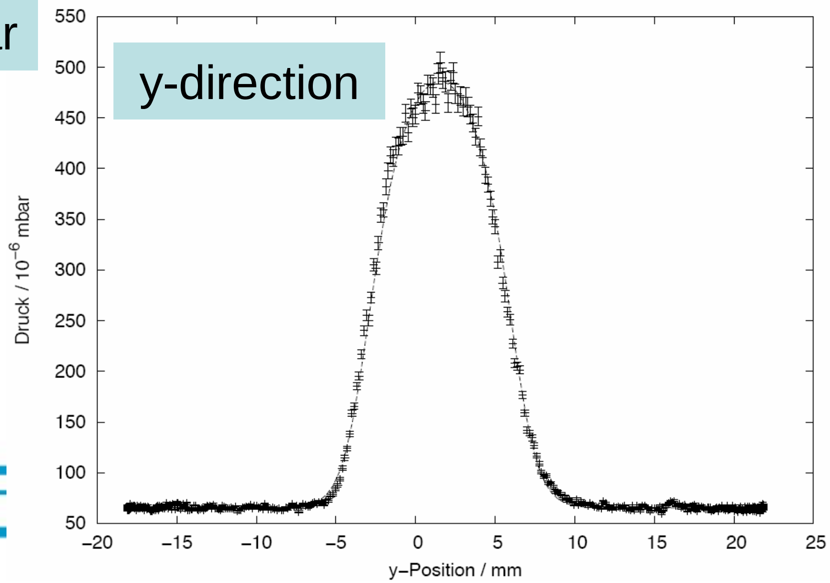
Cluster Beam Profiles at the PANDA Vertex Point

- Well defined target beam at a distance of d = 2 m behind the nozzle (corresponds to PANDA interaction point)
- Target thickness of $2x10^{15}$ H-atoms/cm^3 achieved

T_0=19 K

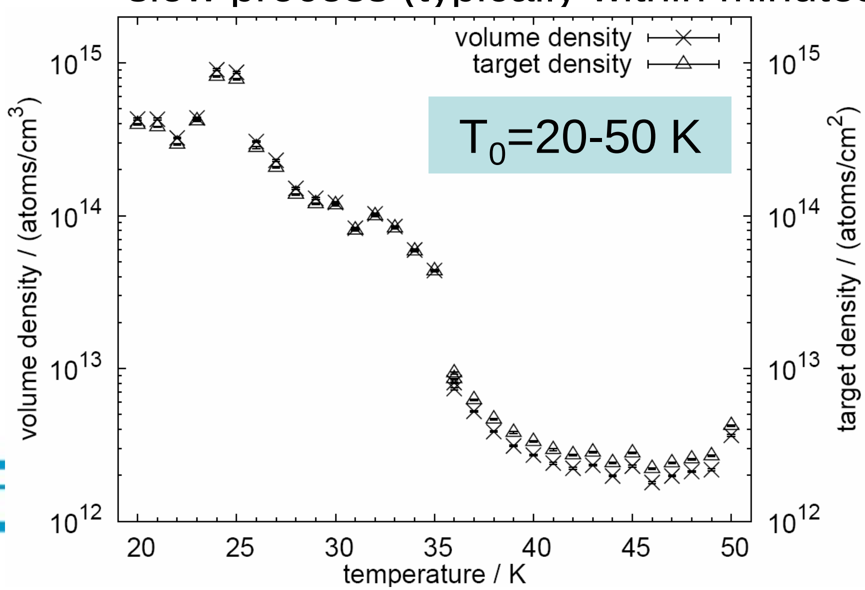
p_0=18.5 bar

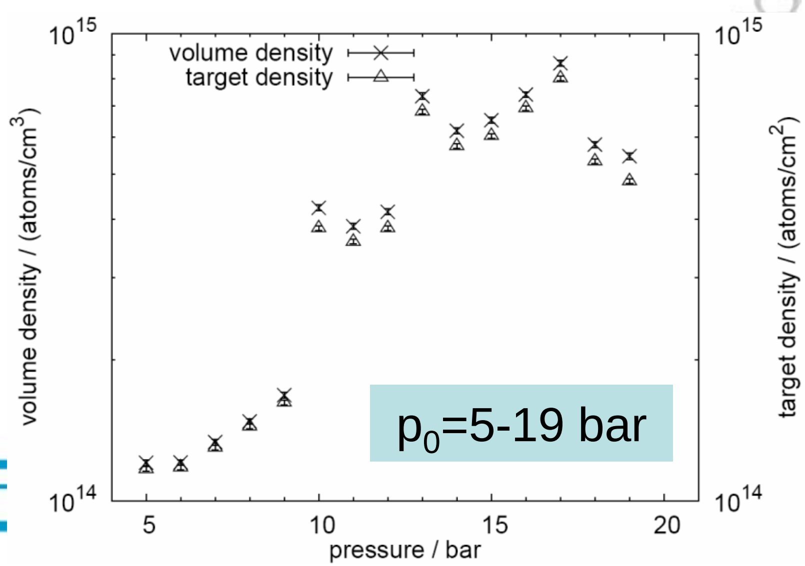




Target Thickness Variation

- Gas/liquid input pressure p_0 variation
  - target thickness changes within one order of magnitude
  - thickness variation typically within seconds possible
- Gas/liquid starting temperature T_0 variation
  - thickness changes within several orders of magnitude
  - slow process (typically within minutes)





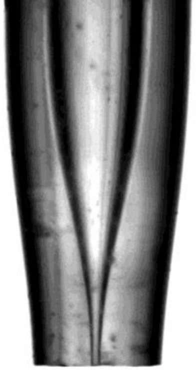
Westfälische Wilhelms-Universität Münster

Pellet Beams

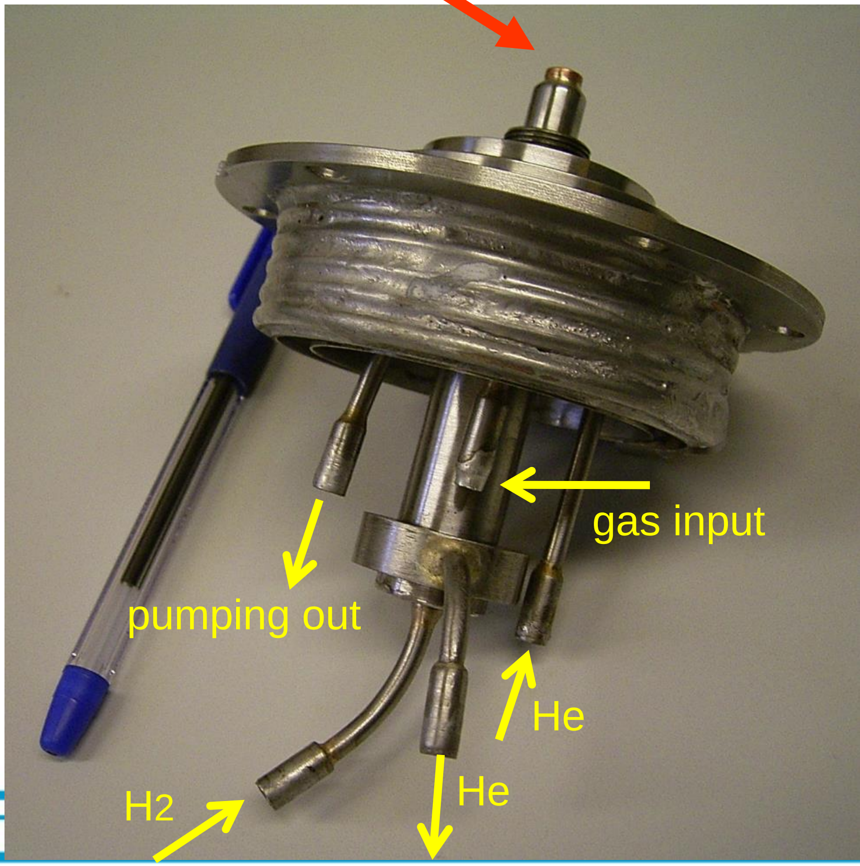
Production of Pellet beams

- Injection of a jet of a cryogenic liquid through a thin nozzle into a gas close to triple-point conditions
- Excitation of the nozzle by a piezoelectric transducer

  → periodic monosized droplets
- Droplet size depends on nozzle diameter and piezo frequency



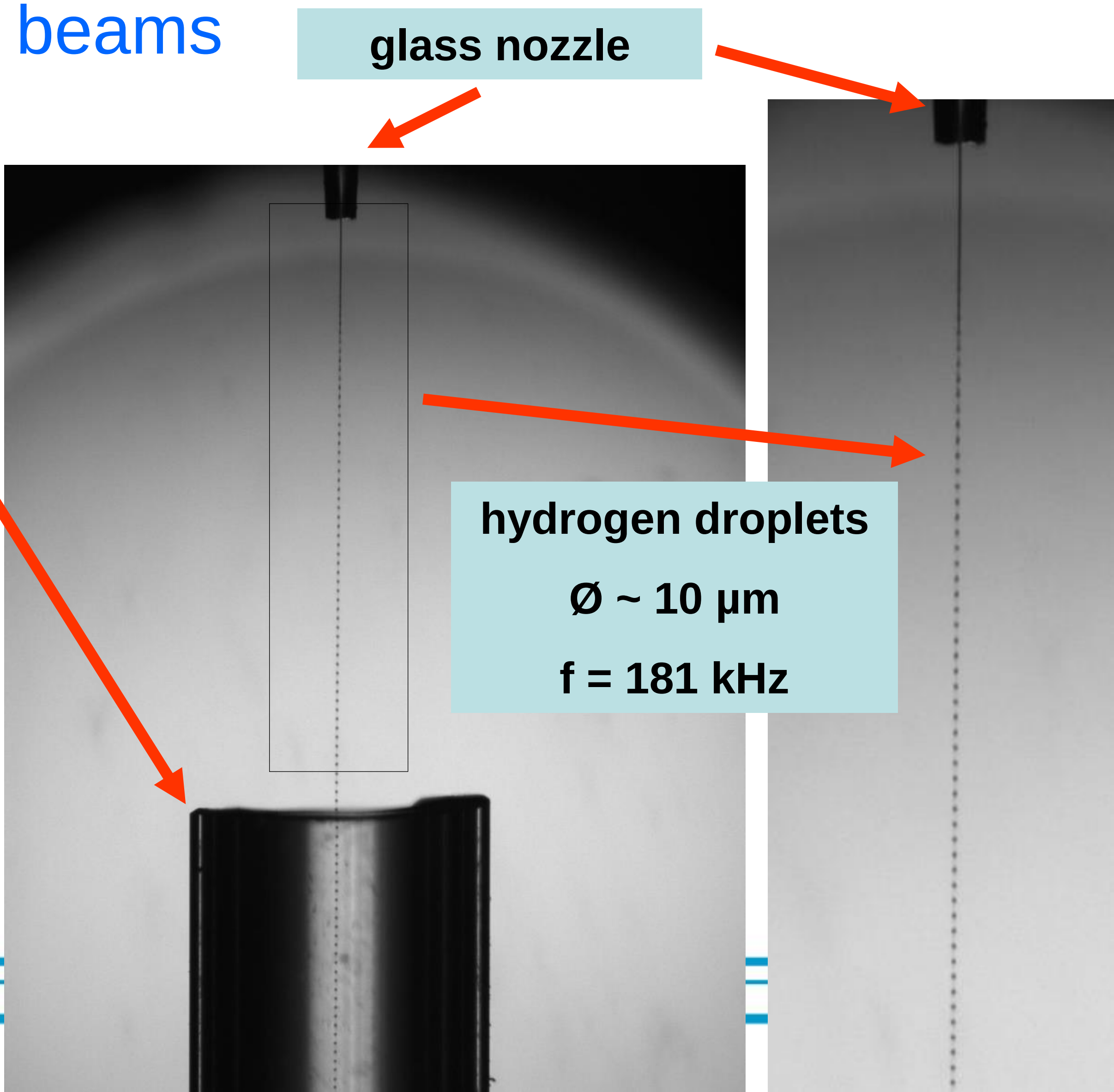
glass nozzle, Ø 10-20 µm



WESTFÄLISCHE
WILHELMS-UNIVERSITÄT
MÜNSTER

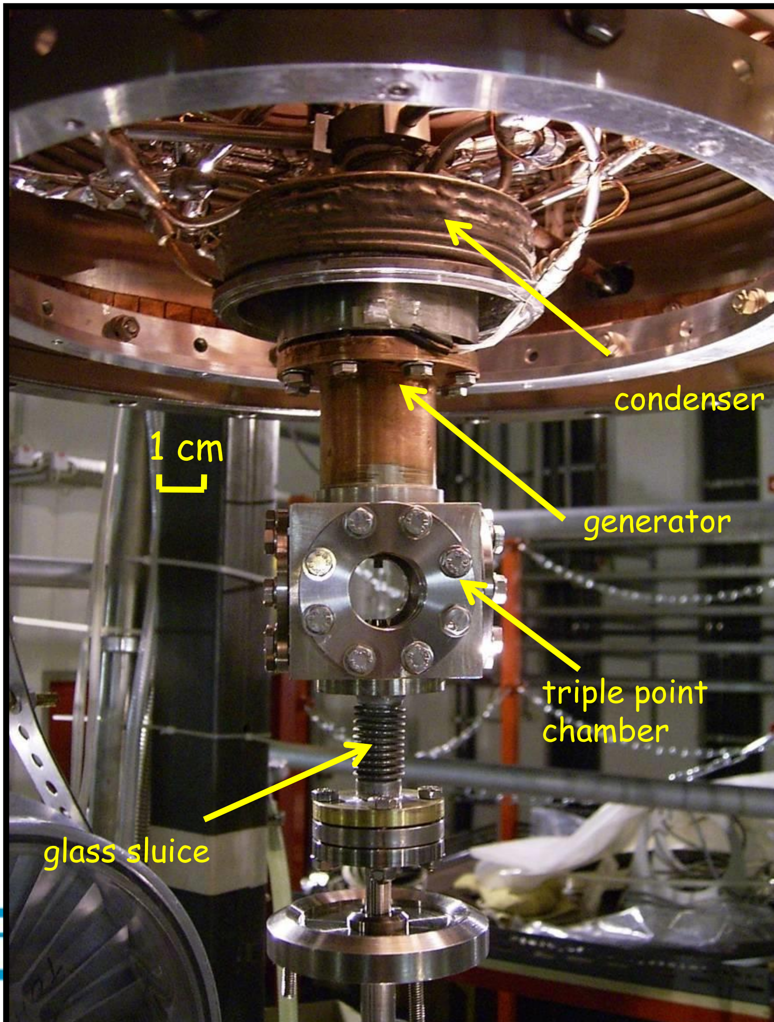
Production of Pellet beams

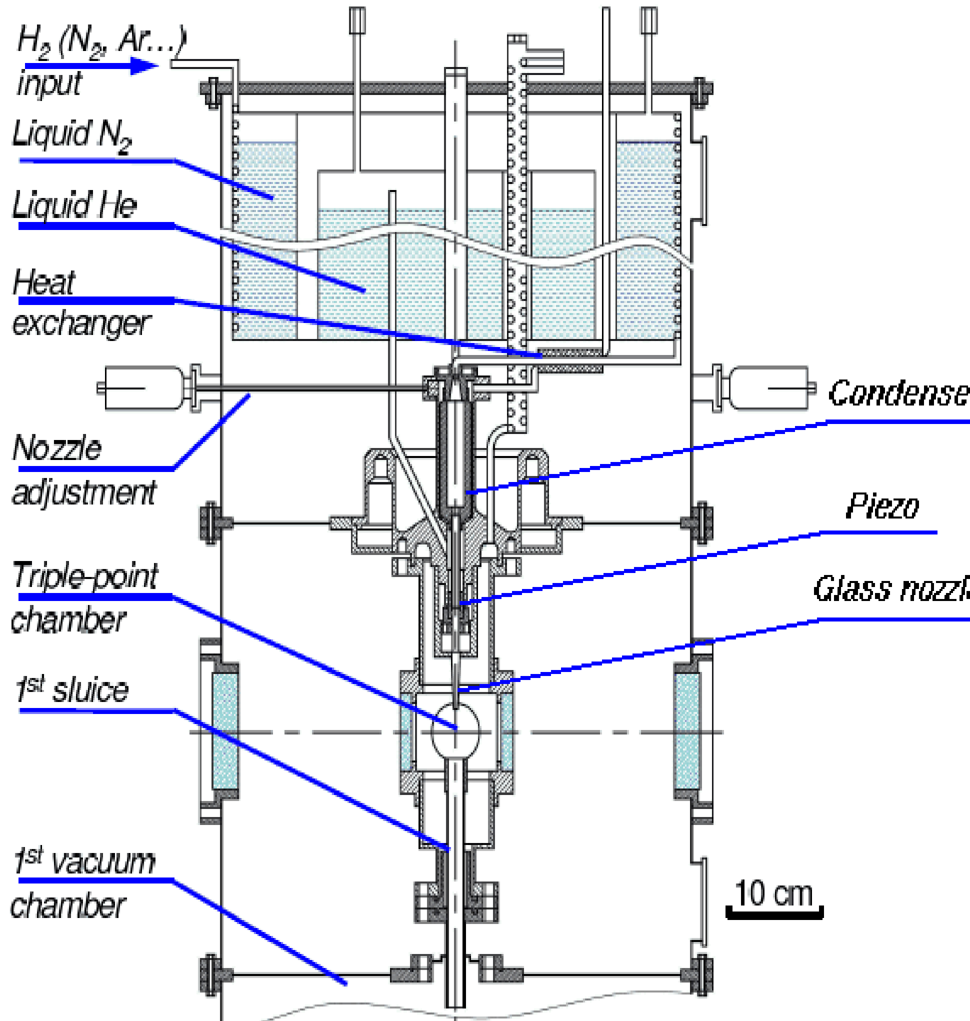
- Droplets pass through a thin tube into vacuum („vacuum injection“)
  → cooling due to surface evaporation
  → frozen pellets
- Pellets pass the scattering chamber



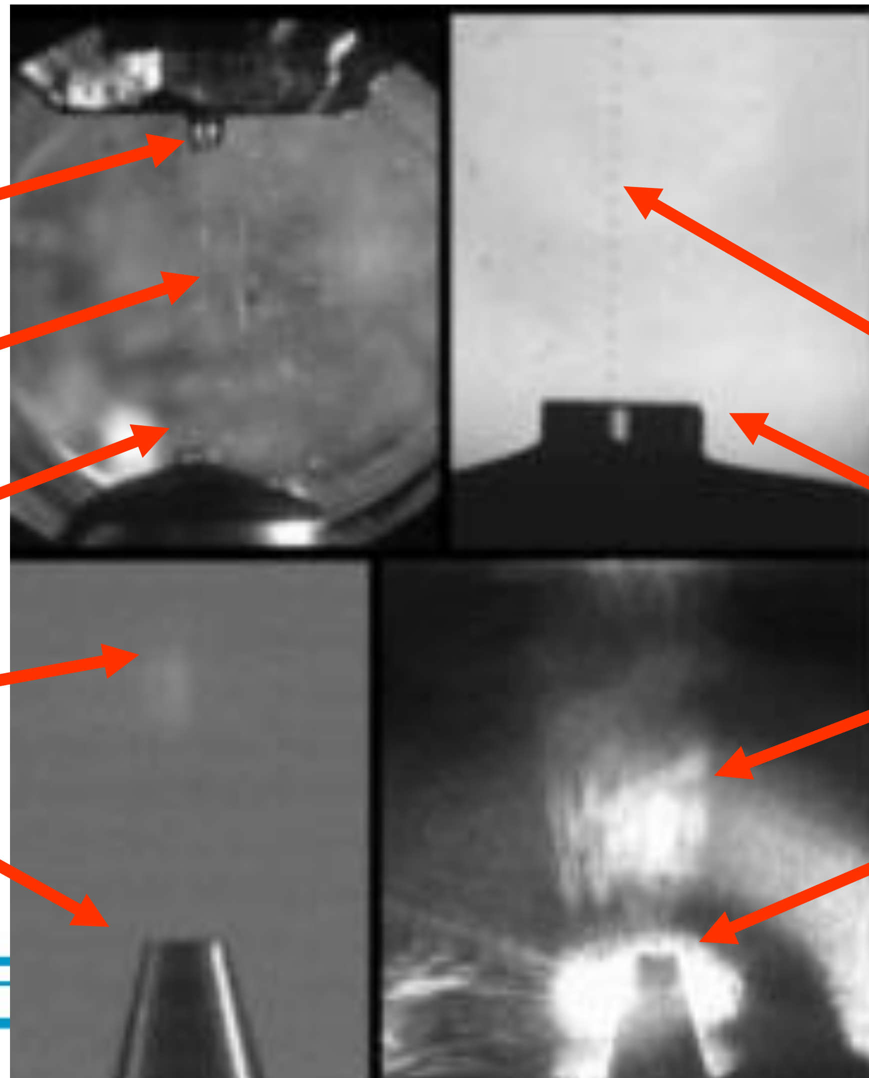
Westfälische Wilhelms-Universität Münster

Prototype for PANDA: The Jülich/Moscow Target

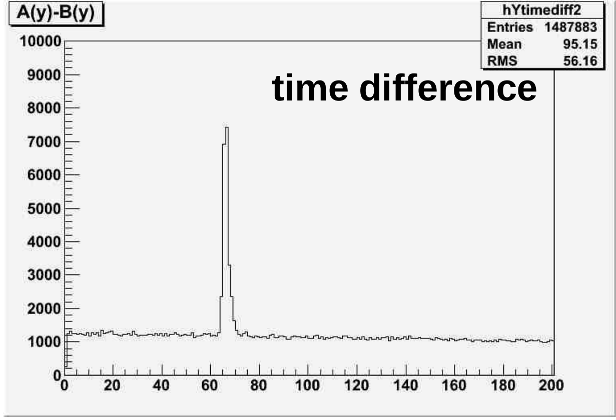




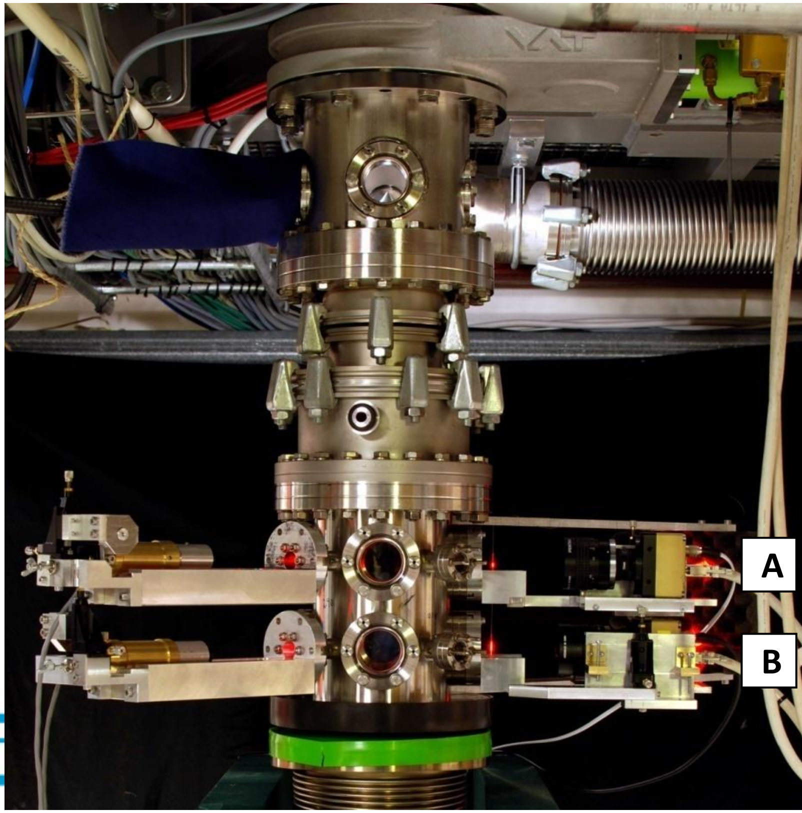
A Pellet Target in Operation: WASA-at-COSY



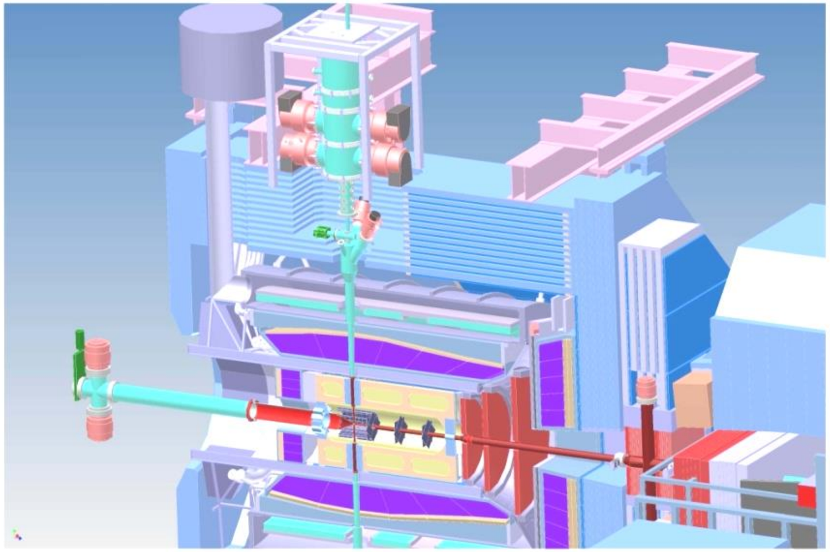
Pellet Tracking System



- Determination of the velocity and 3D-vertex information of individual pellets by a multi-camera tracking system
- Aimed resolution: < 1mm
- Upper tracking device with two levels (A+B) close to the pellet generator (8 linescan cameras)
- Lower tracking device with two levels at the beam dump (8 linescan cameras)



Westfälische
Wilhelms-Universität
Münster



From the Prototype to PANDA

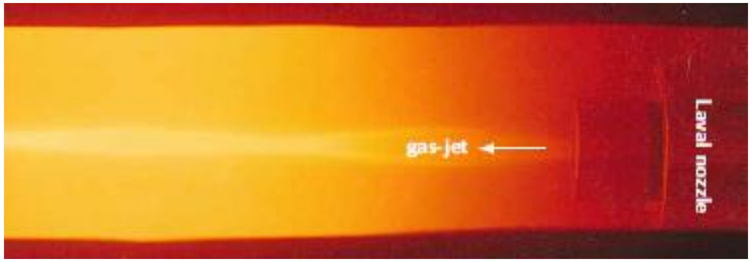
- Optimization and design studies on the pellet generator in progress (ITEP)
- Design of the pellet tracking is fixed and will be build up and optimized
  (Univ. Uppsala)

Expected Target Parameters at PANDA

	Cluster Target	Pellet Target	
		PTR mode (tracking)	PHL mode (high luminosity)
Effective target thickness	> 1×10^{15} at./cm^2	≤ 2×10^{15} at./cm^2	≥ 4×10^{15} at./cm^2
Cluster/Pellet size	nm - µm	Ø ≥ 20 µm	Ø ≤ 15 µm
Cluster/Pellet frequency	Continuous beam	≈ 15 k plt/s	≥ 150 k plt/s
Target stream diameter	4 mm x 12 mm	Ø ≈ 3 mm	Ø ≤ 3 mm
Average dist.between cluster/pellets	≤ 10 µm	≥ 4 mm	<< 4 mm
$\bar{p}$ beam size	Ø ≤ 1 mm	$Ø_{vertical}$ ≥ 3.5 mm	$Ø_{vertical}$ ≤ 3.5 mm
Average no. of cluster/pellets in $\bar{p}$ beam	≥ 10^7	≈ 1	≈ 10

Westfälische Wilhelms-Universität Münster

Summary

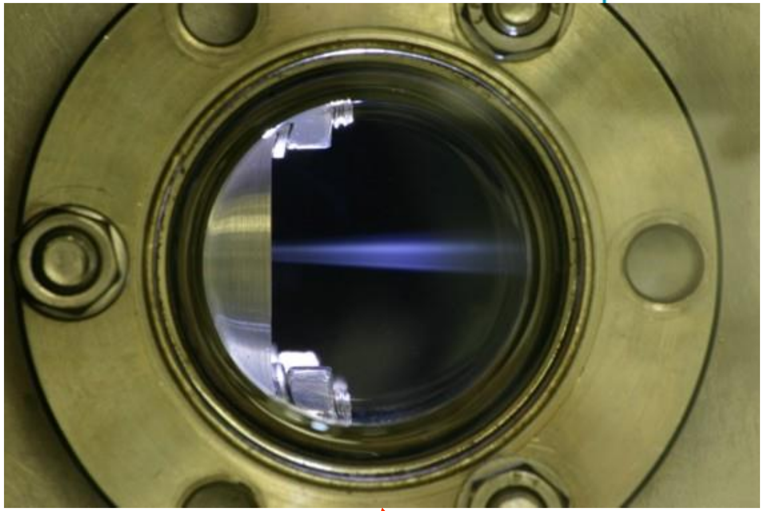


- Gas jet beams:
  - All types of gases can be used
  - High target beam thickness (O(10^{19}) atoms/cm^3) directly behind the nozzle
  - Interaction point very close to the nozzle
  - High gas load at the interaction point
  - Rapid expansion of the beam in all directions
  - Target beam without time structure
  - Simple target thickness variation
  - Compact target beam generator possible

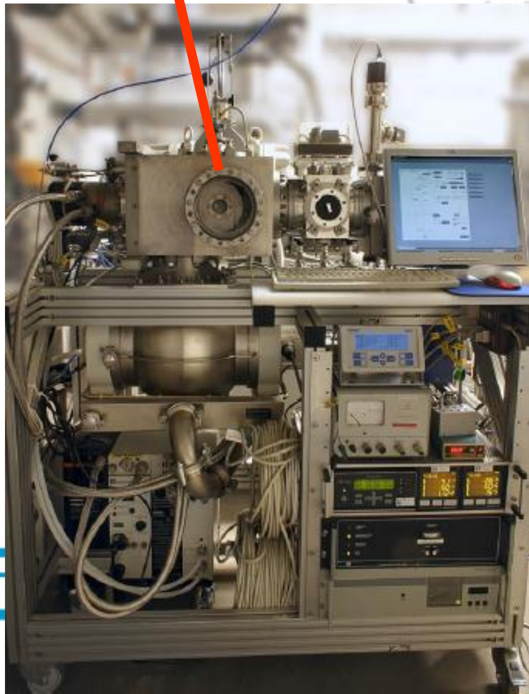
wissen.leben WWU Münster

Westfälische
Wilhelms-Universität
Münster

Summary

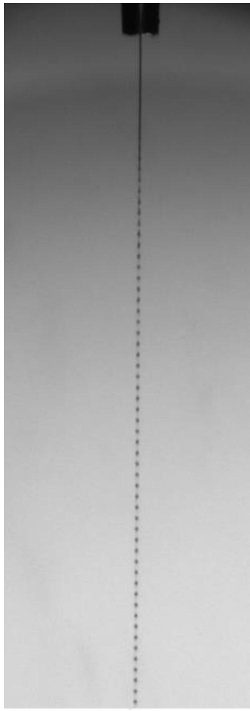


- Cluster jet beams:
  - All types of gases can be used
  - High target thickness (O(10^{19}) at./cm^3) directly behind nozzle
  - High target beam thickness (O(10^{15}) at./cm^3) also at large distances from the nozzle, i.e. 2 m
  - Target generator can work as gas and/or cluster source
  - Interaction point very close to nozzle or at larger distances
  - Easy target beam shaping and lower gas load at the interaction point by use of specially shaped collimators
  - Well defined beam shape even at large distances
  - Target beam with (nearly) no time structure
  - Simple target thickness variation
  - Compact target beam generator possible



Summary

- Pellet beams:
  - All types of gases can be used
  - Pellets with uniform size/diameter
  - Individual pellets have a mean thickness of O(10^{19}) atoms/cm^2
  - Effective target beam thickness of O(10^{15}) atoms/cm^2 at large distances from the nozzle, i.e. 2 m
  - Target beam shaping and lower gas load at the interaction point by use of collimators
  - Well defined beam shape even at large distances
  - Target beam with time structure
  - Target thickness variation possible (time structure)
  - More complex and larger target generator size




Thank you very much....