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The Münster Cluster-Jet Target for the Future PANDA Experiment

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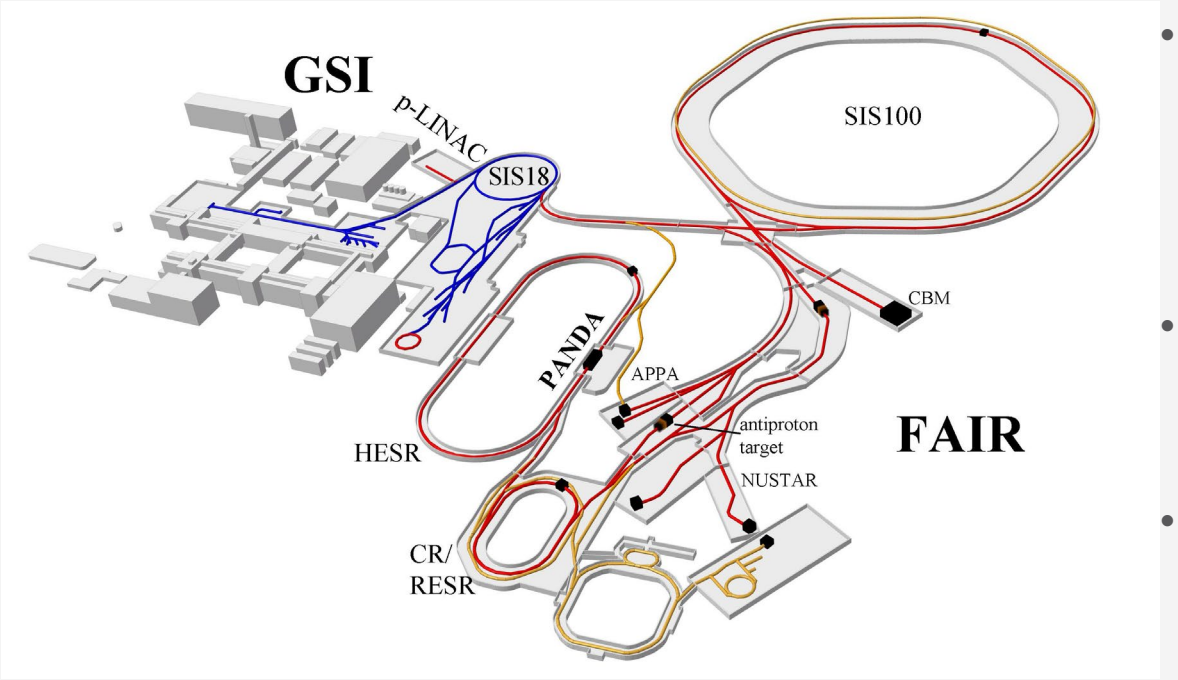
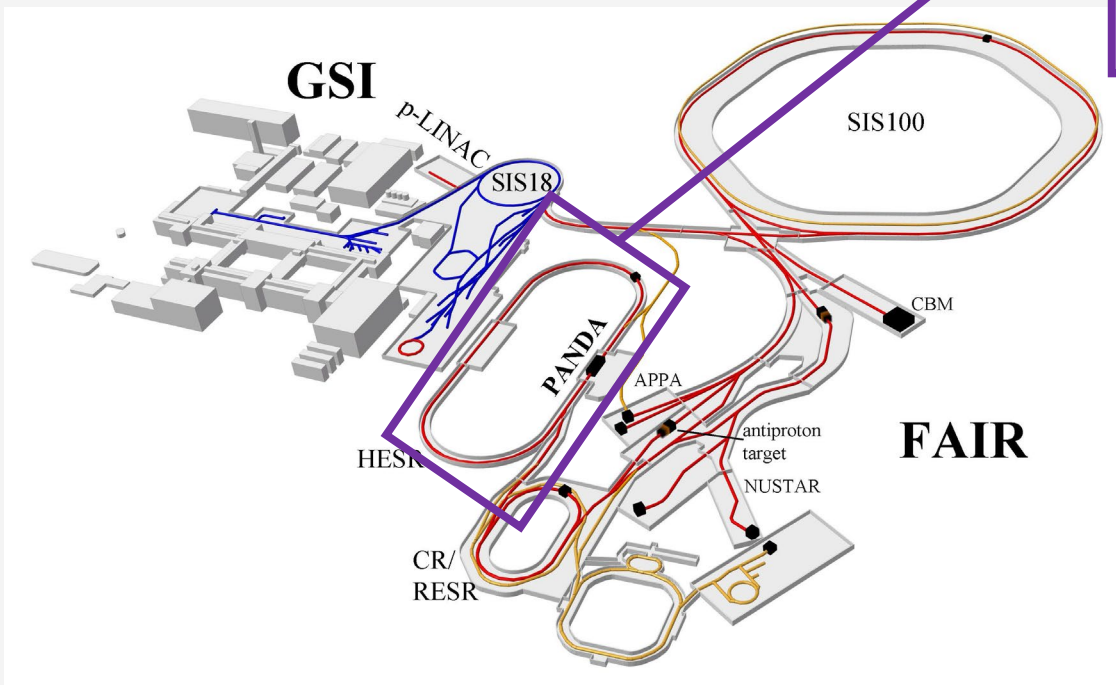
Outline

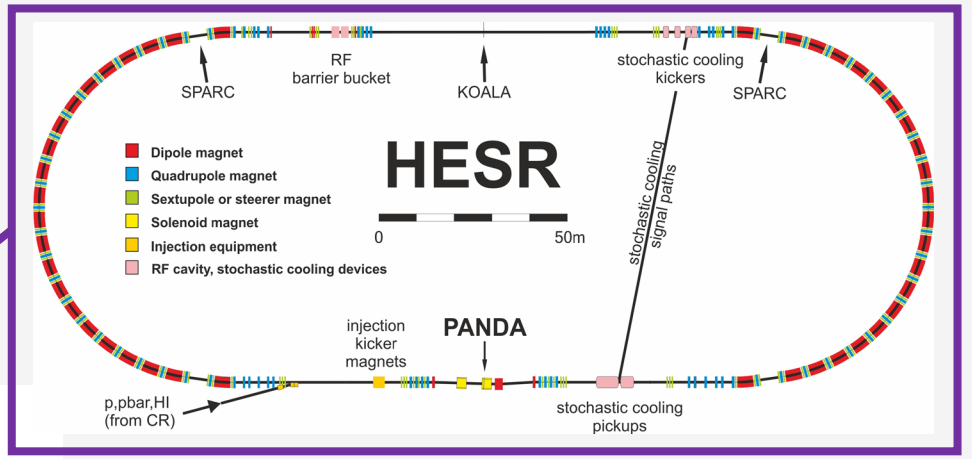
- What is the PANDA Experiment at FAIR?
- Which special requirements must the PANDA target fulfill?
- The Münster Cluster-Jet Target as internal target at PANDA
- Current development plans

PANDA @ FAIR



- Fundamental questions of the QCD will be investigated [1,2], e.g.:
  - Theory of strong interaction
  - Hadron physics
- Facility for Antiproton and Ion Research (FAIR, under construction) will produce and accumulate antiprotons
- Antiprotons are injected into the High Energy Storage Ring (HESR)





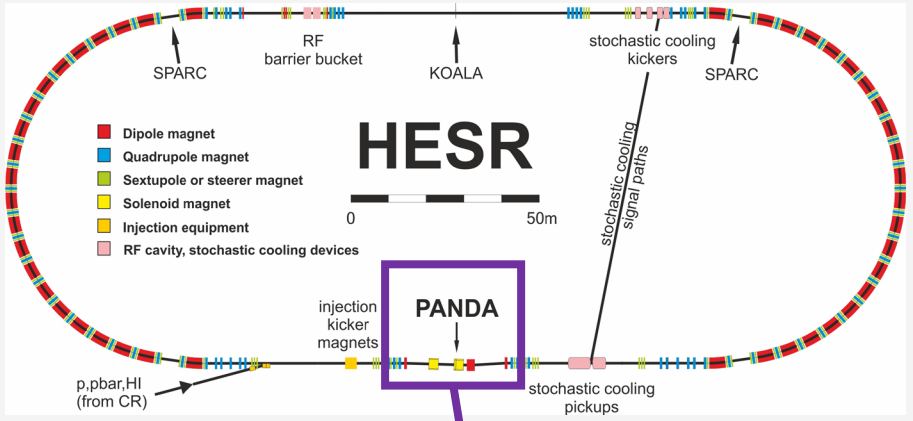
- Beam momentum of up to $15\ \mathrm{GeV/c}$
- Interaction with internal proton target (other target fluids at later expansion stages)
- Cycle length of approx. $30\ \mathrm{min}$
- Luminosities between $2 \cdot 10^{31}$ and $2 \cdot 10^{32}\ \mathrm{cm^{-2}s^{-1}}$
- Relative momentum spread ranging from

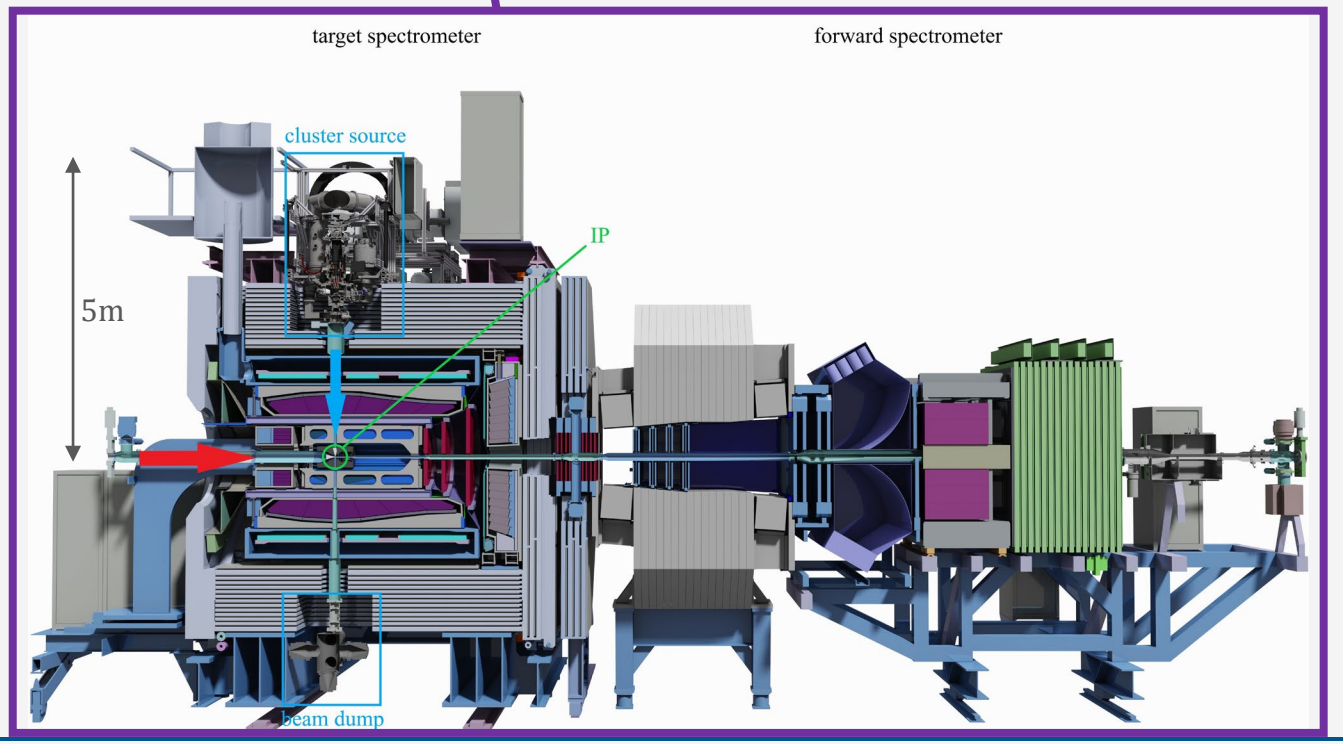
  $\frac{\Delta p}{p} = 4 \cdot 10^{-5}$ to $4 \cdot 10^{-4}$

panda @ FAIR

- 4π detector
- Onion shell structure

→ Luminosity, momentum resolution and detector setup lead to several challenging requirements on the internal target





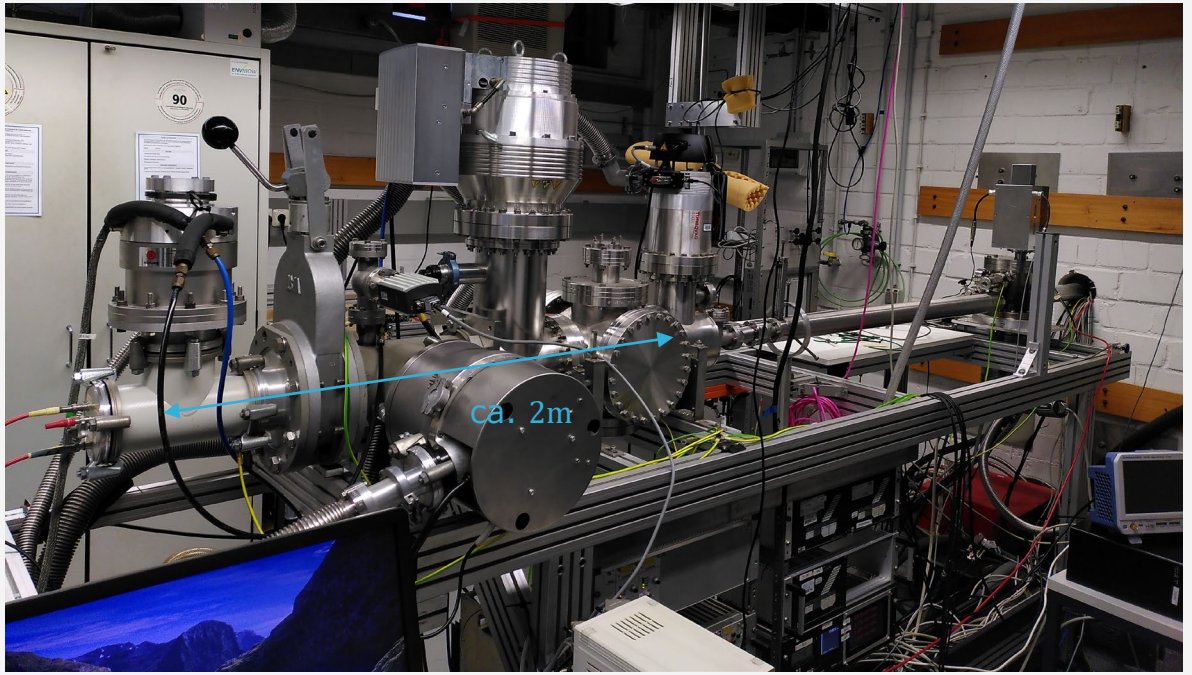
Some of the requirements for the PANDA internal target

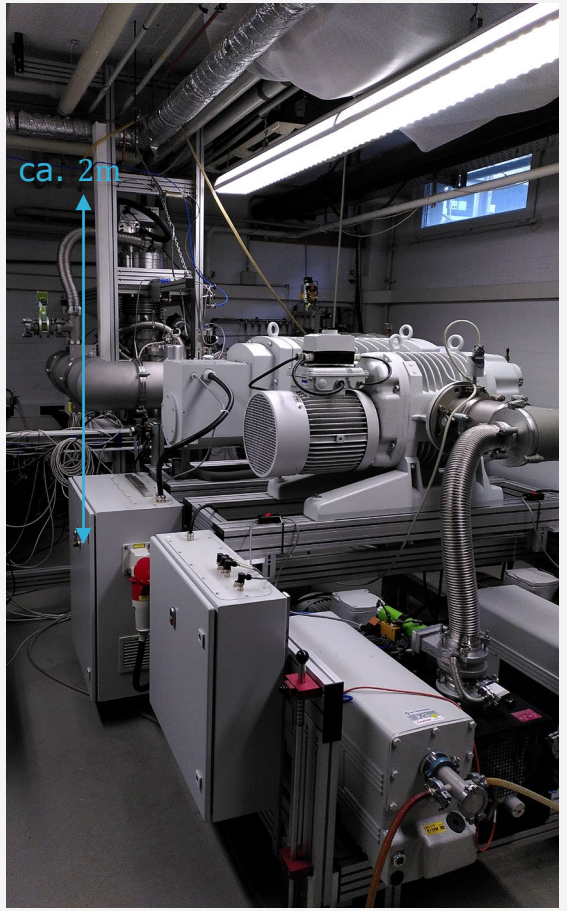
- Target thickness in the order of $10^{15}\,\mathrm{atoms/cm^2}$ [4] in an adjustable manner
- Target source and its beam dump for excess target material each with minimal distance to IP of $\approx 2.5\,\mathrm{m}$, only connected by a narrow target pipe down to $2\mathrm{cm}$ in diameter
- Dilute and localized accumulation of matter needs to be placed in ultra-high vacuum of a storage ring
- Clean environment (i.e. no windows or multicomponent systems)
- Low background reaction rates lead to necessity of differential pumping system
- No time structures in the event rate
- Small interaction zone

→ Cluster-Jet Target and Pellet Target are foreseen, depending on experimental program

First test with a prototype target in Münster

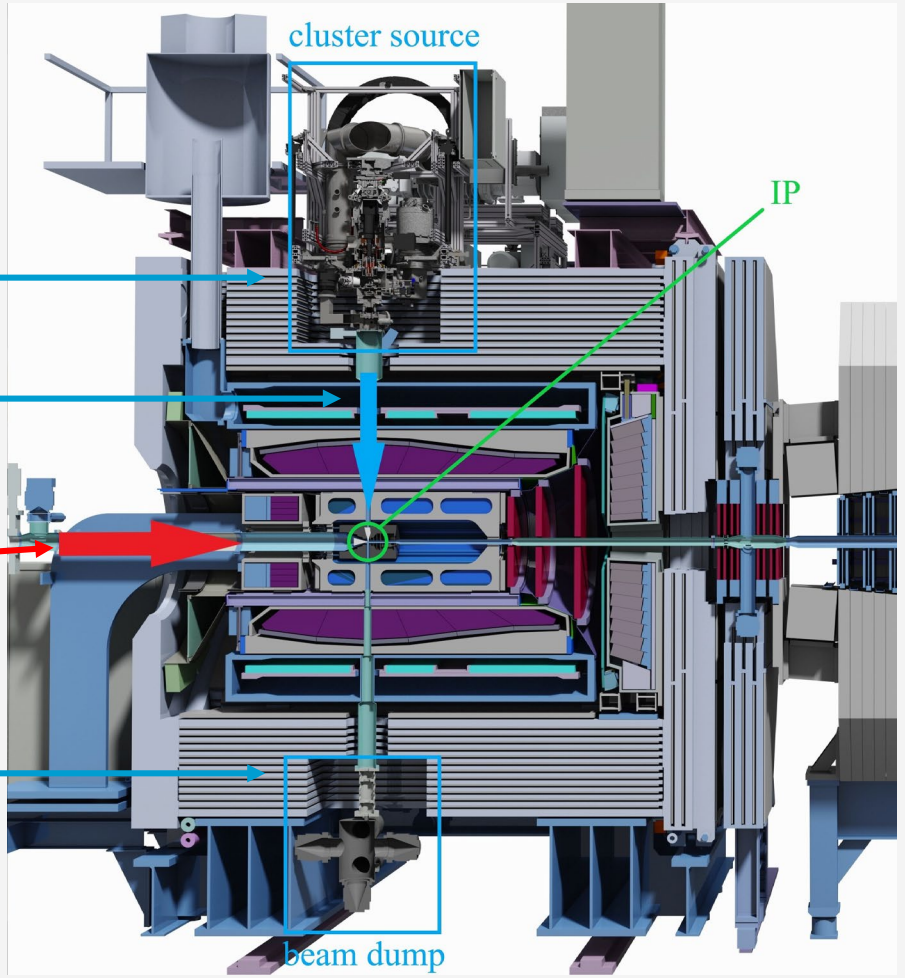
- Proof of principle
- Exceeded the desired target thickness with $4.5 \cdot 10^{15}\ \mathrm{atoms/cm^2}$ in a distance of $> 2\ \mathrm{m}$ from the source [3]
- Further optimizations can be tested easily



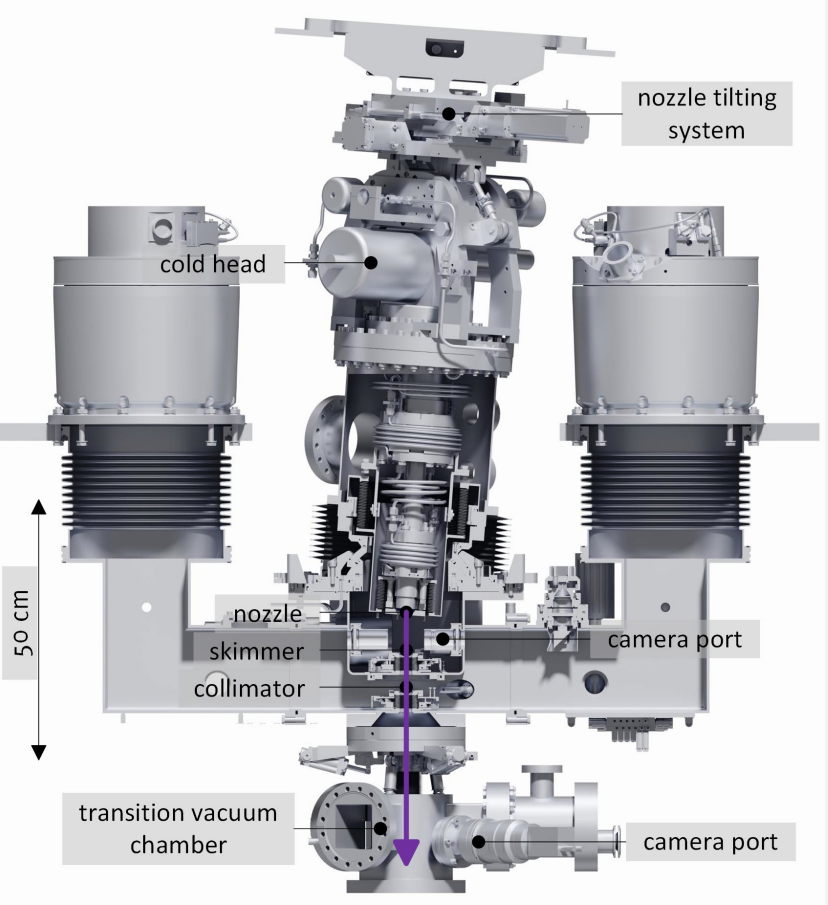


Münster Cluster-Jet Target for PANDA

- A source generates small droplets of hydrogen or "clusters"
- Due to 4π detector, clusters need to travel $\approx 2.25\ \mathrm{m}$ from nozzle to interaction point
- At IP clusters interact with antiproton beam
- Clusters which did not interact, need to be dumped in differentially pumped beam dump

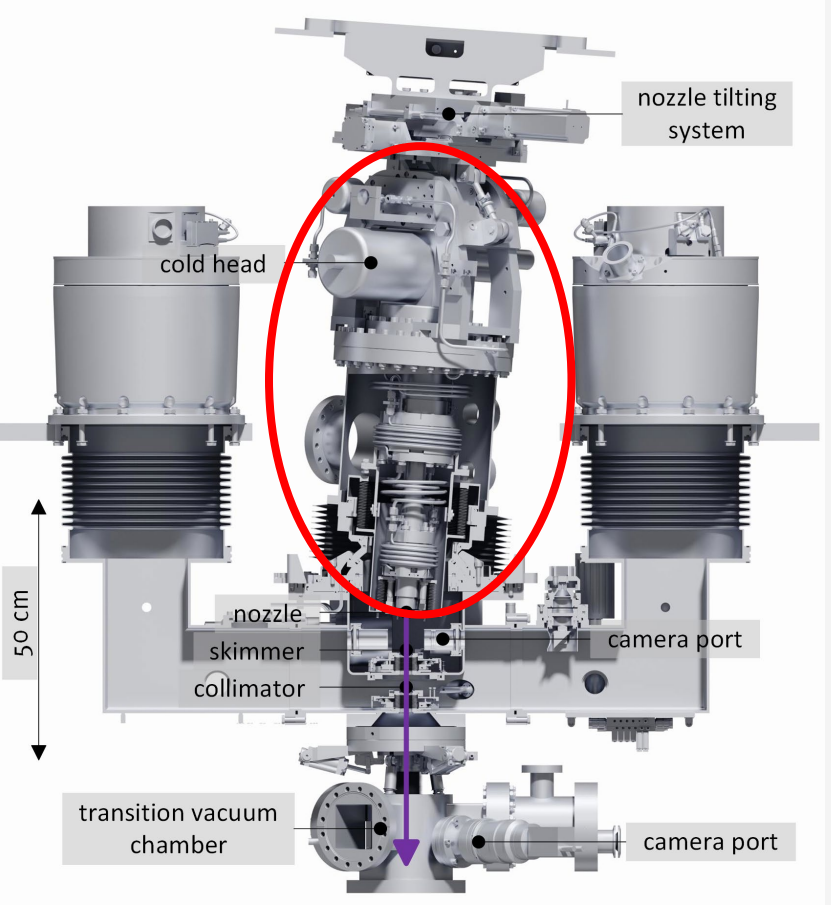


Münster Cluster-Jet Source



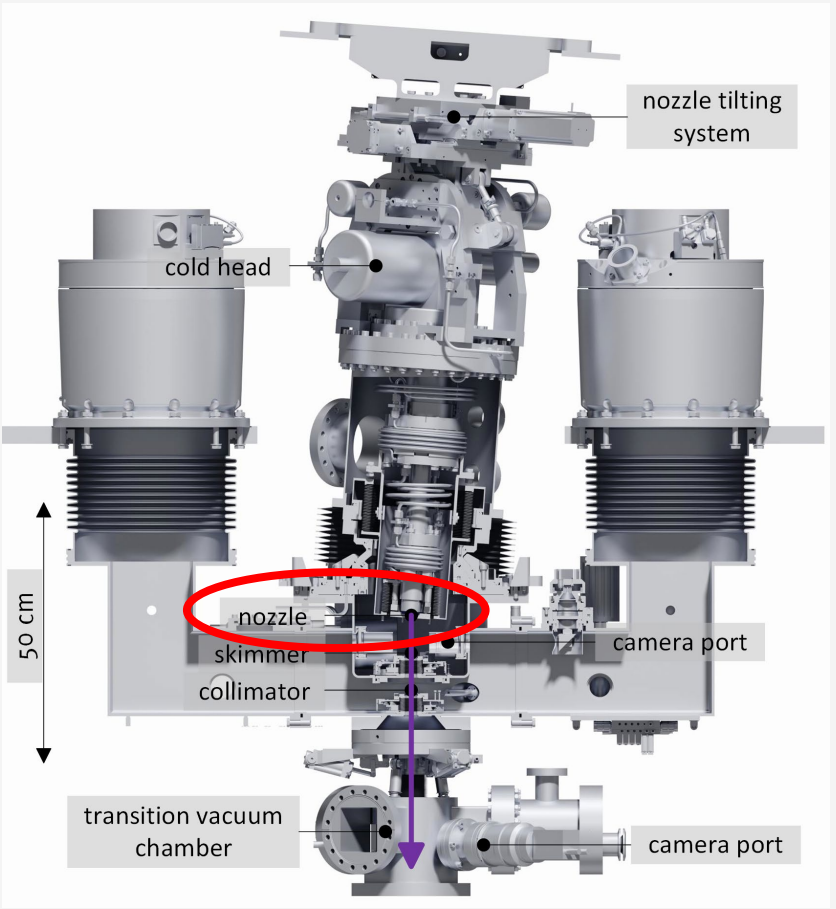
Münster Cluster-Jet Source

- Hydrogen gas is cooled by a two stage cold head
  - Temperature: 20 - $40\,\mathrm{K}$
  - Pressure: 5 - $20\,\mathrm{bar}$
- Then fed through a nozzle



Münster Cluster-Jet Source

- Convergent-divergent shape with narrowest diameter of only $\approx 30\mu m$ 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)



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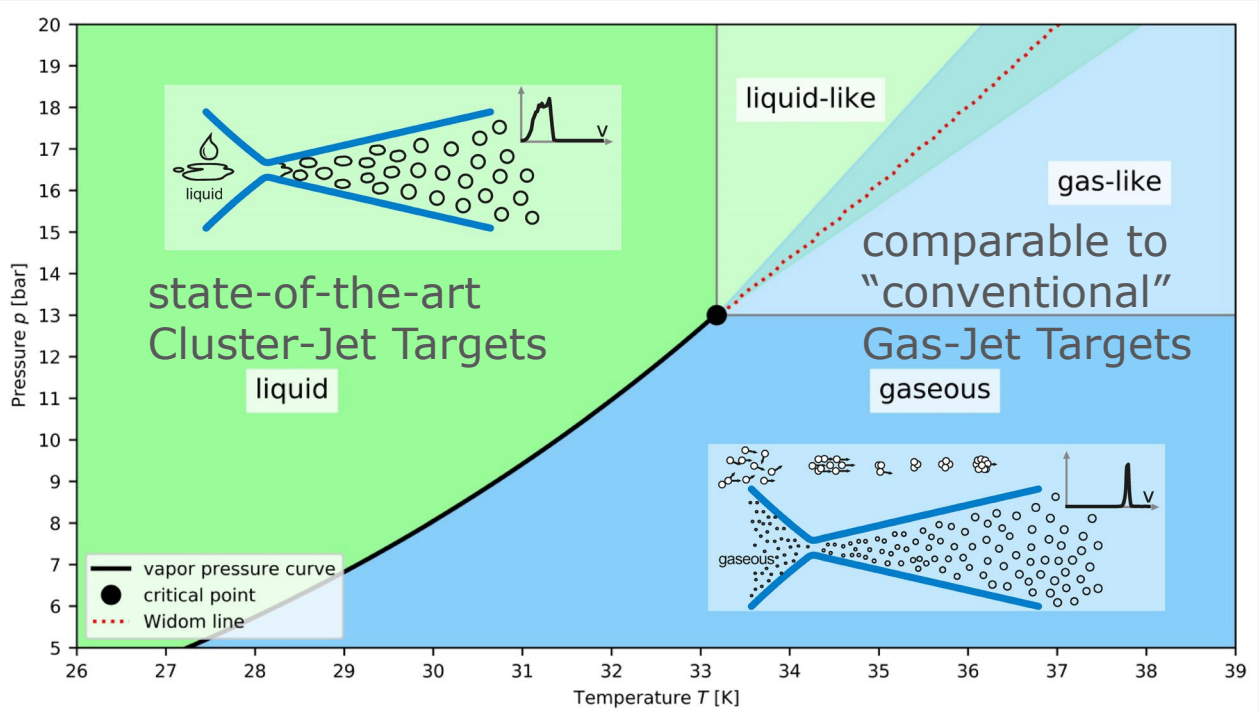


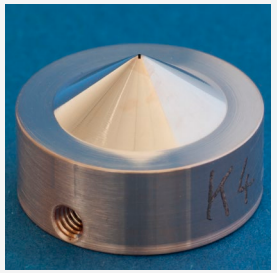
Figure from: Vestrick et al., "Crossing the Widom line: Cluster formation as sensitive probe of supercritical Fluids", doi.org/10.1016/j.supflu.2022.105686

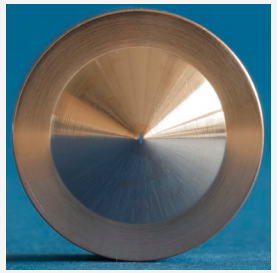
- Two operation modes (liquid, gaseous) resulting in two cluster production processes
- Accumulation of millions of hydrogen atoms in clusters
- Resulting in a stable cluster-jet, with additional residual gas background

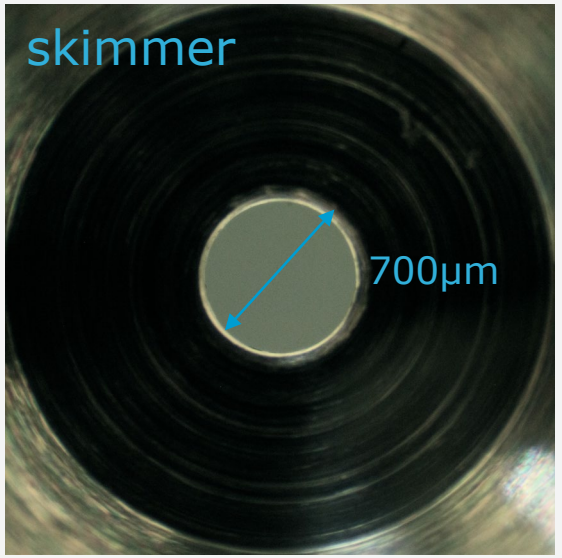
→ Operating Münster Cluster-Jet Targets with liquid hydrogen can lead to world-record target thicknesses

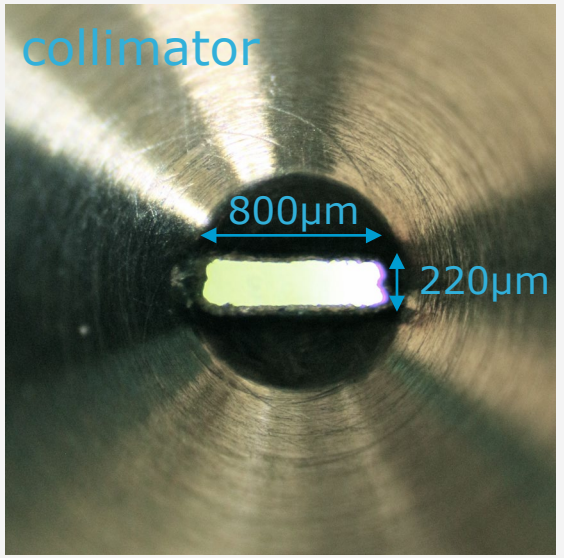
Münster Cluster-Jet Source

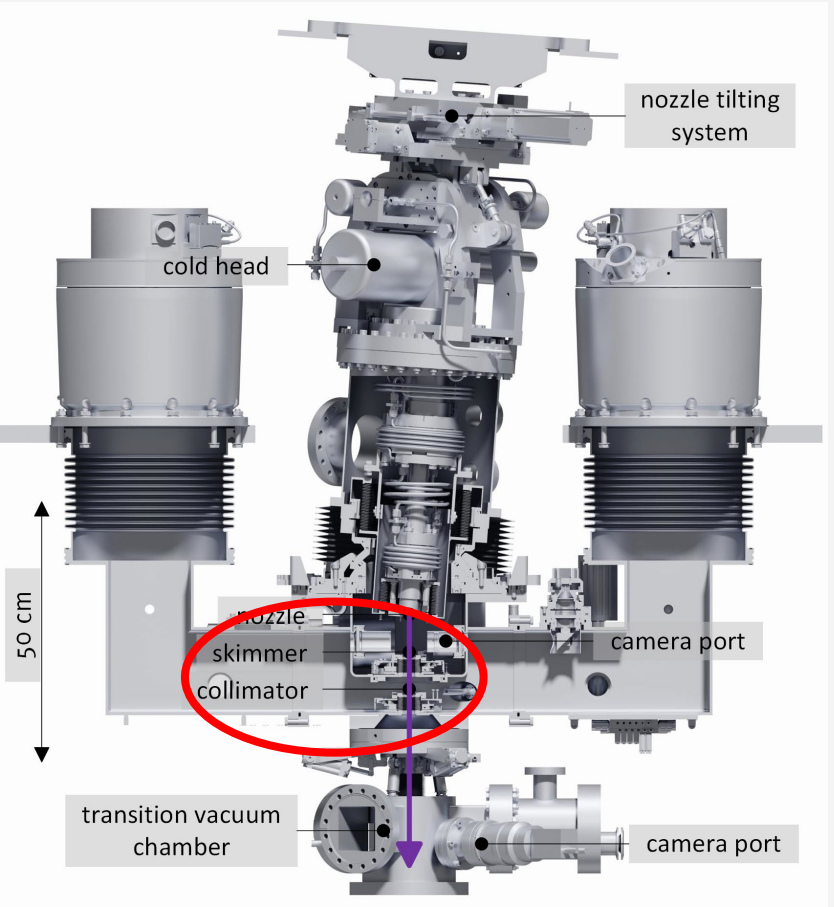
- Cluster-jet is separated from residual gas background by skimmer
- Second conical orifice (collimator) tailors the cluster-jet
- Collimator also defines final shape and size of cluster-jet at IP





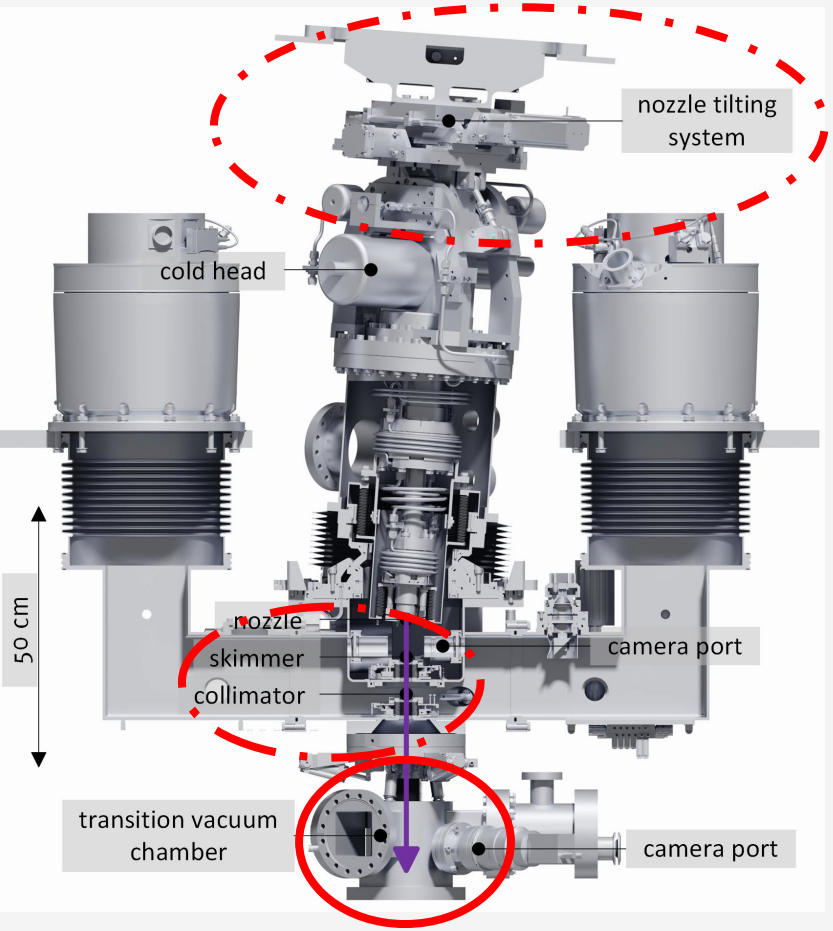






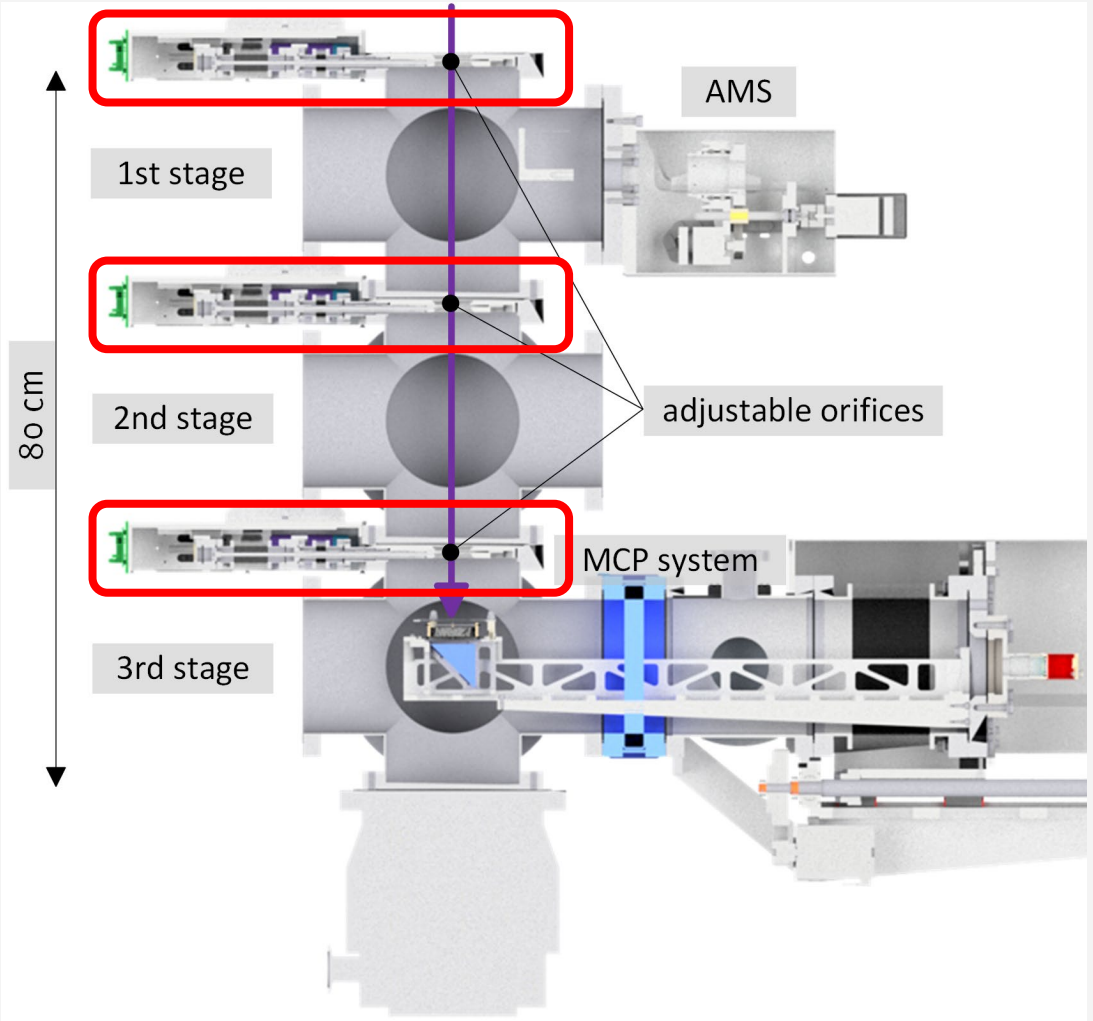
Münster Cluster-Jet Source

- Transition vacuum chamber further reduces residual gas background before entering accelerator vacuum
- Nozzle tilting system and movable skimmer and collimator allow for extraction of high intense cluster-jet region



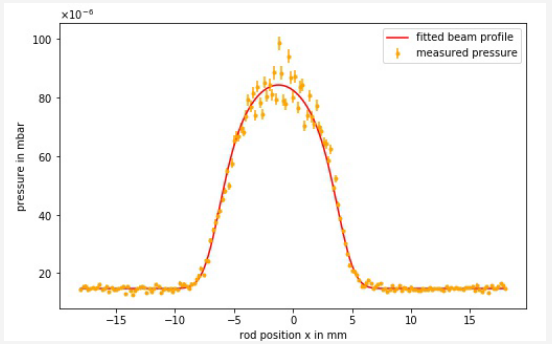
Münster Cluster-Jet Beam Dump

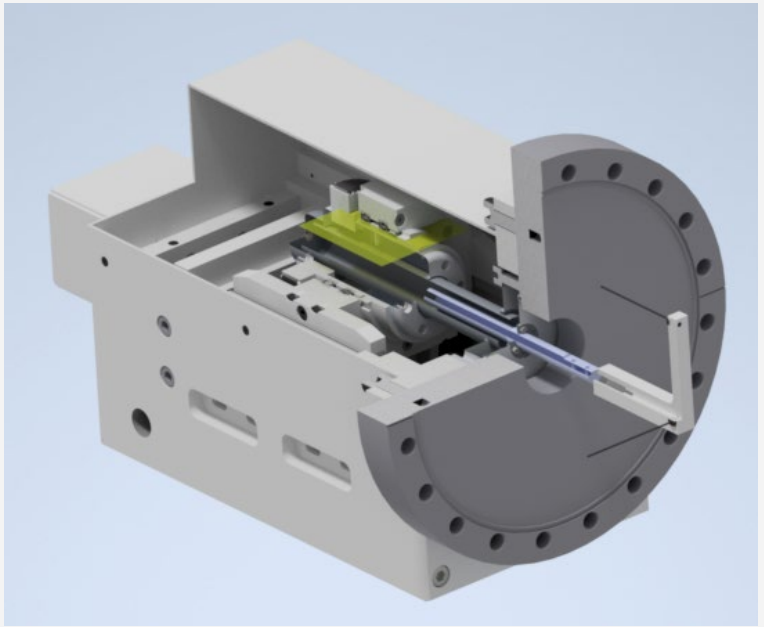
- Not all clusters will interact with accelerator beam
- Differentially pumped beam dump after total flight path of nearly $5\,\mathrm{m}$
- Adjustable orifices ensure minimal gas backflow
- Several cluster-jet diagnostic tools

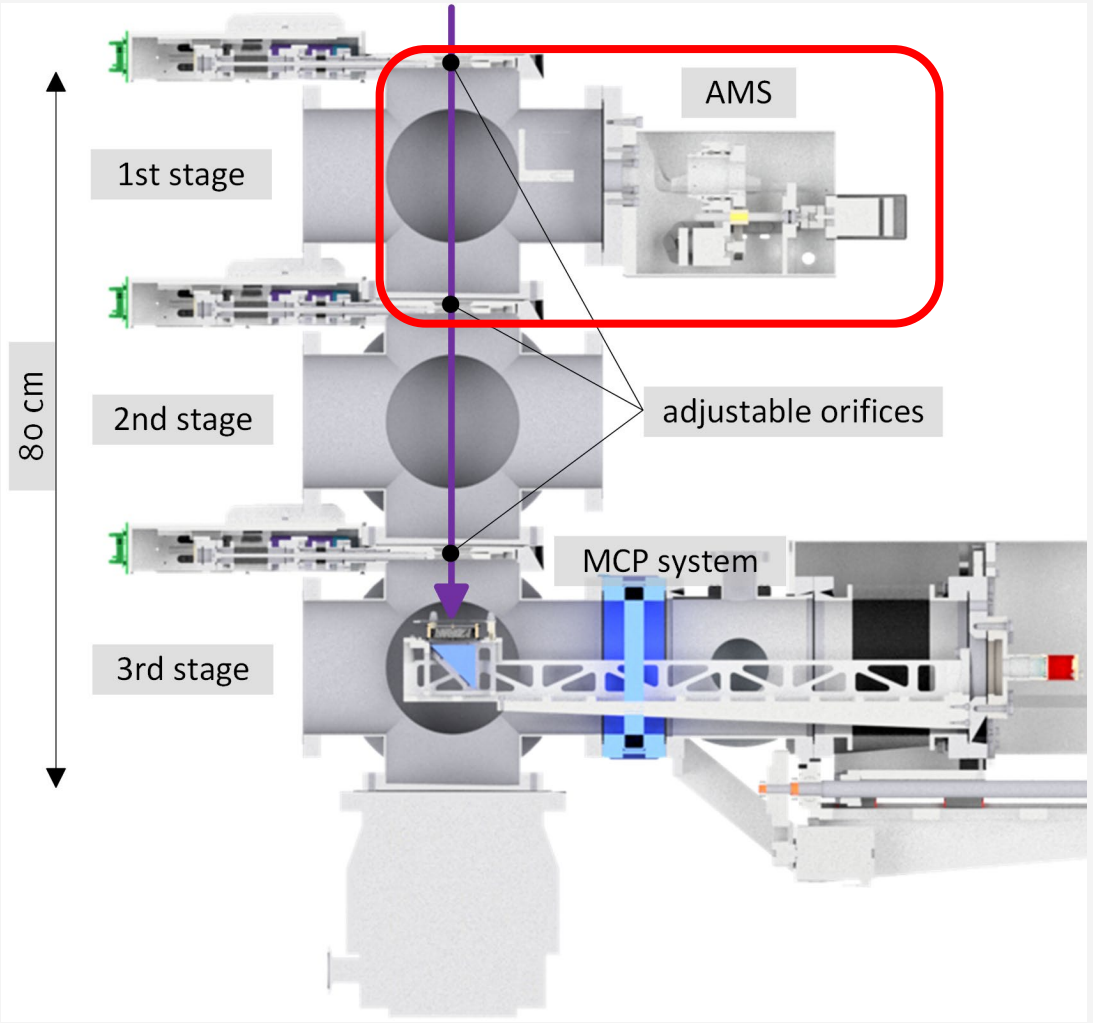


Münster Cluster-Jet Beam Dump

- 1st stage equipped with Absolute Thickness Monitor System (AMS)
- Movable rods lead to pressure increase proportional to the target thickness

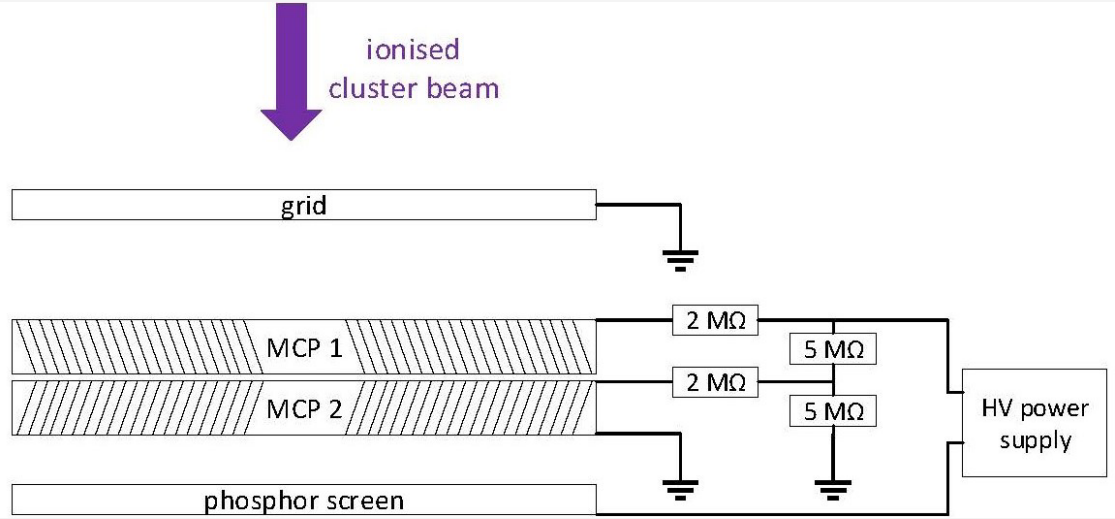


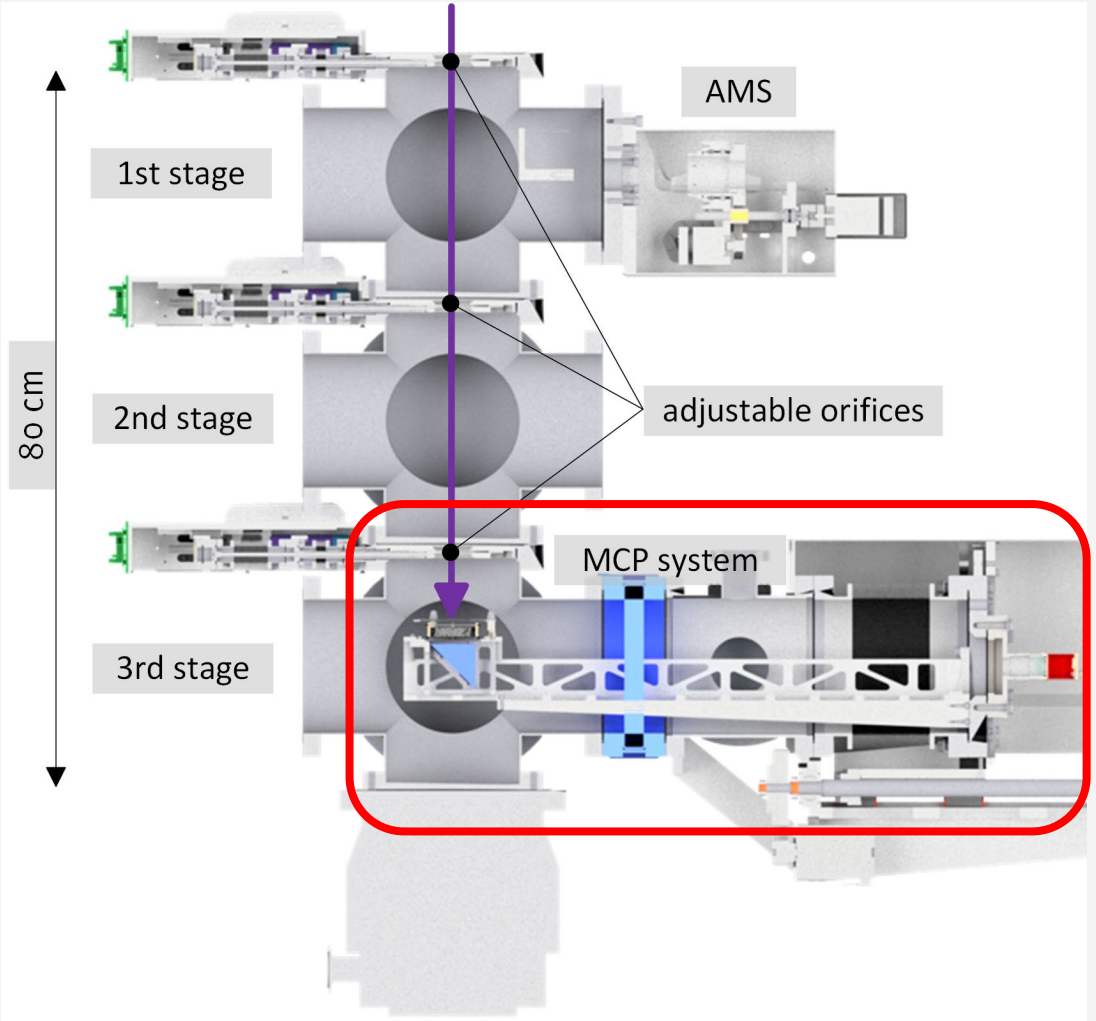




Münster Cluster-Jet Beam Dump

- 3rd stage equipped with Multi-Channel Plate (MCP)
- Movable: in cluster-jet for analysis, out for optimal vacuum condition whilst PANDA measurements





Münster Cluster-Jet Beam Dump

- Several measurements possible:
  - Visualization of vertex zone

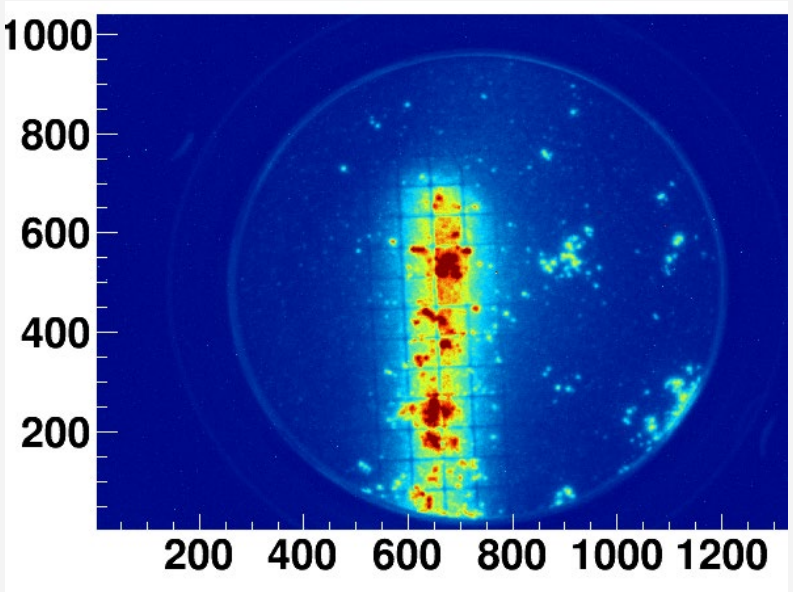
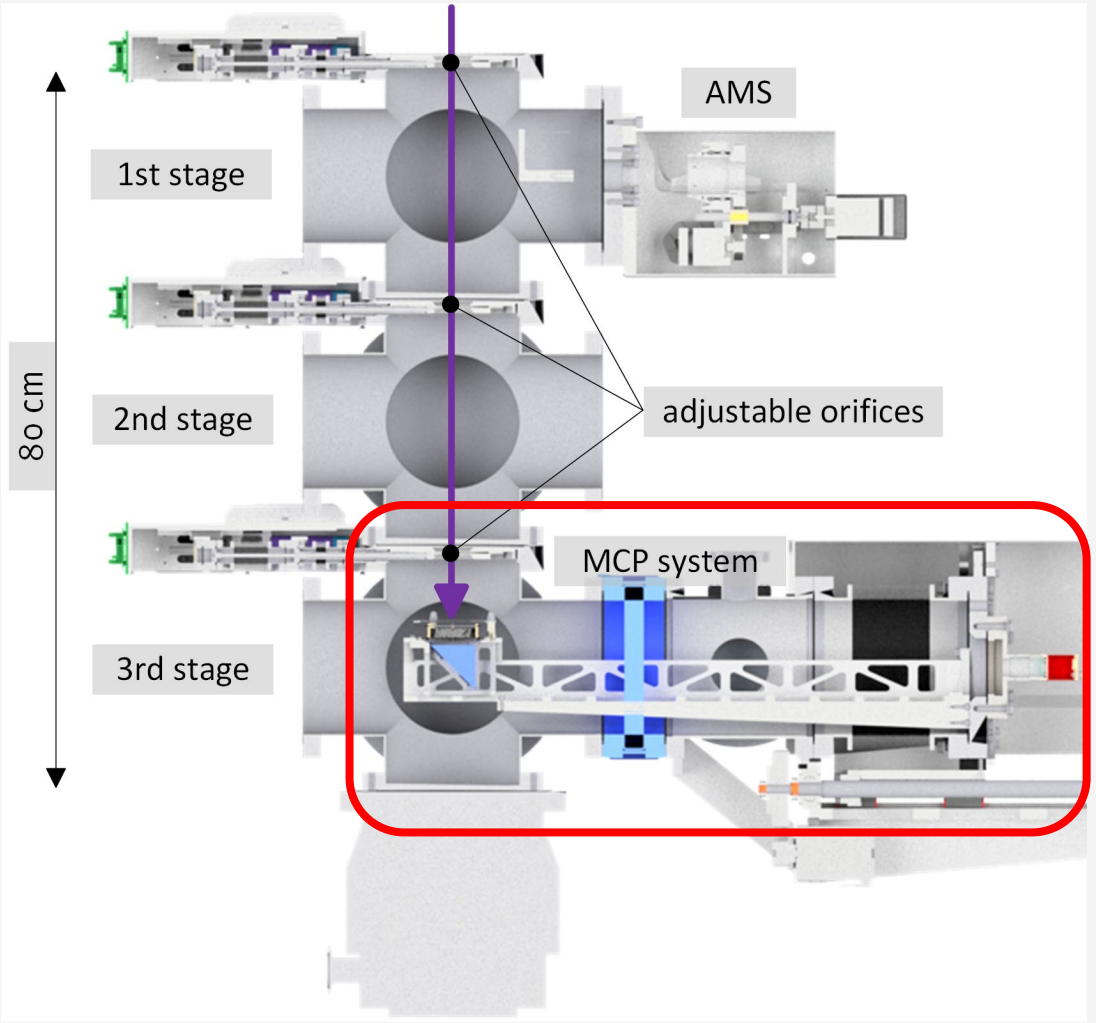
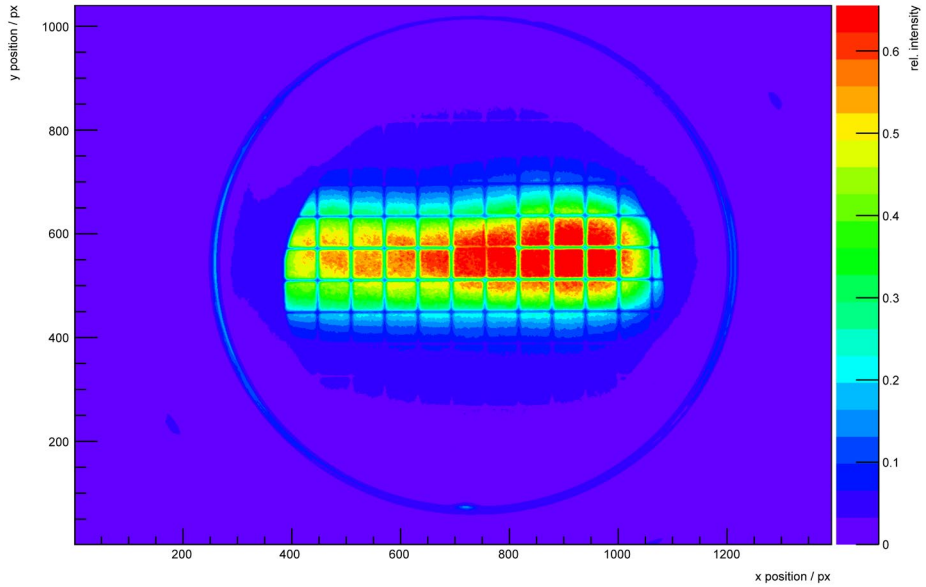


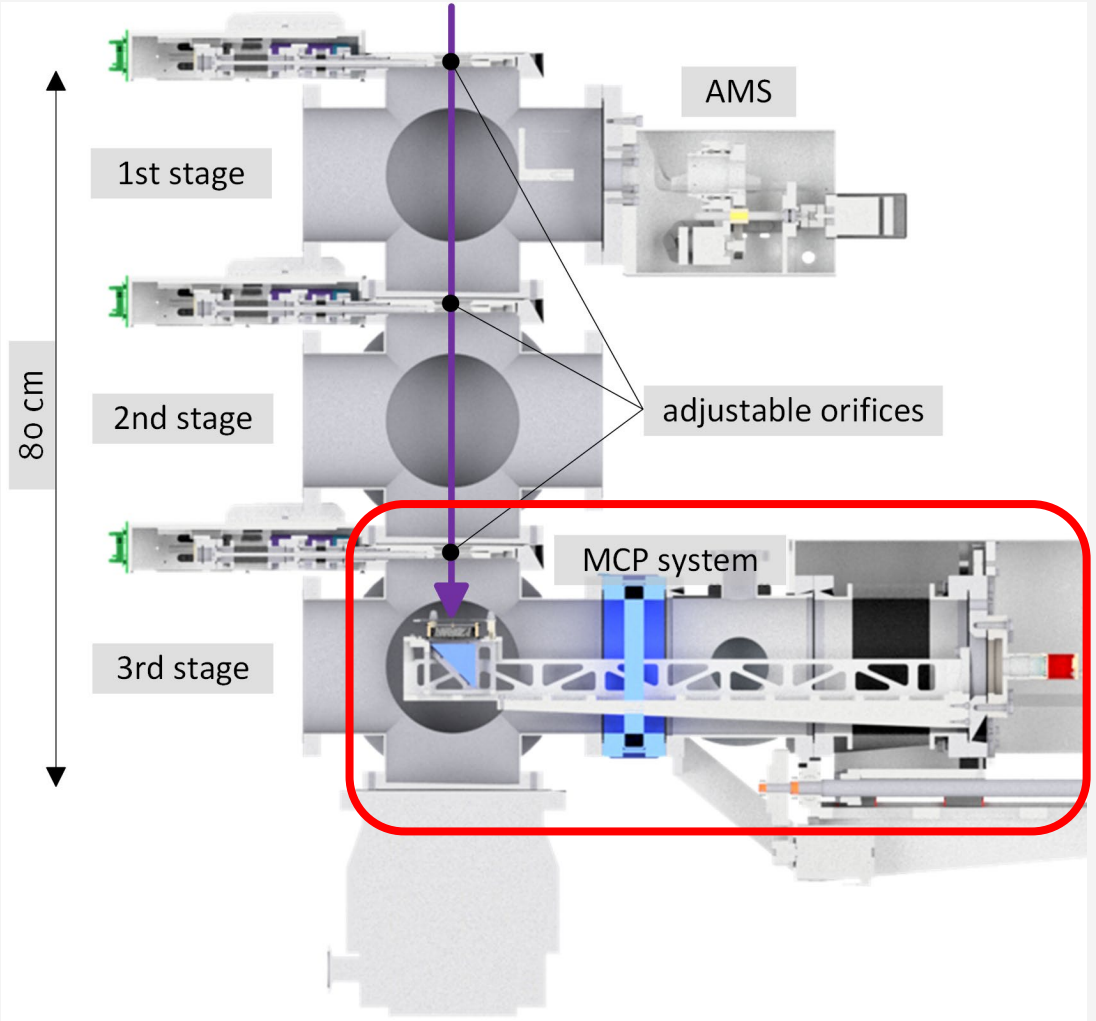
Figure from: Khoukaz et al., "Two-dimensional visualization of cluster beams by microchannel plates", doi.org/10.1016/j.nima.2013.08.085



Münster Cluster-Jet Beam Dump

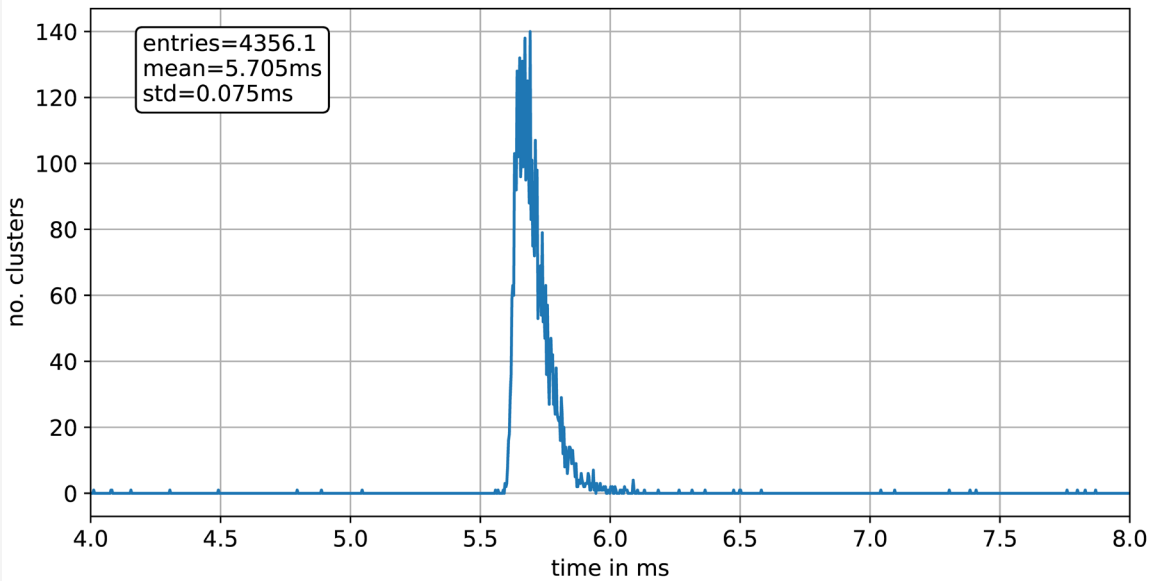
- Several measurements possible:
  - Visualization of total cluster-jet (with e-gun)

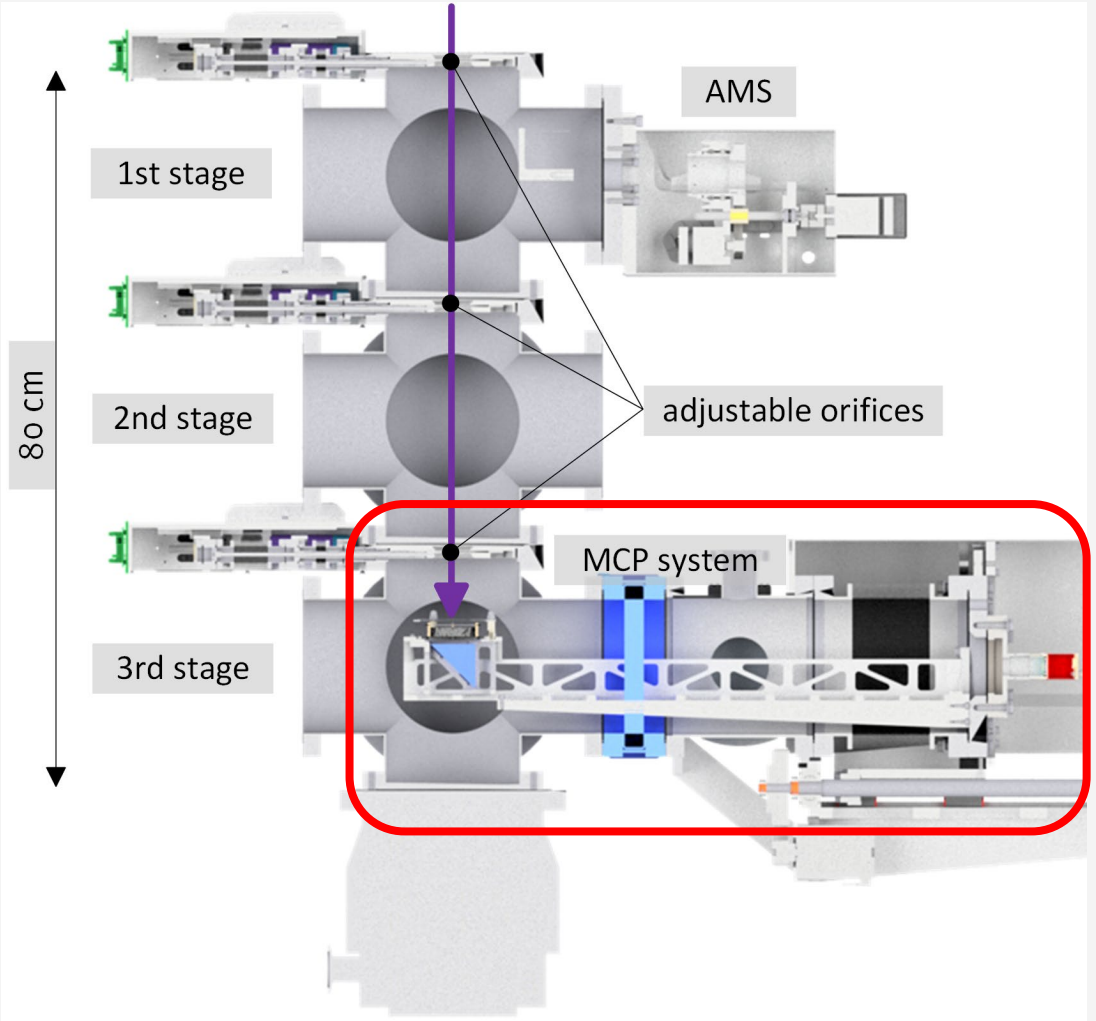




Münster Cluster-Jet Beam Dump

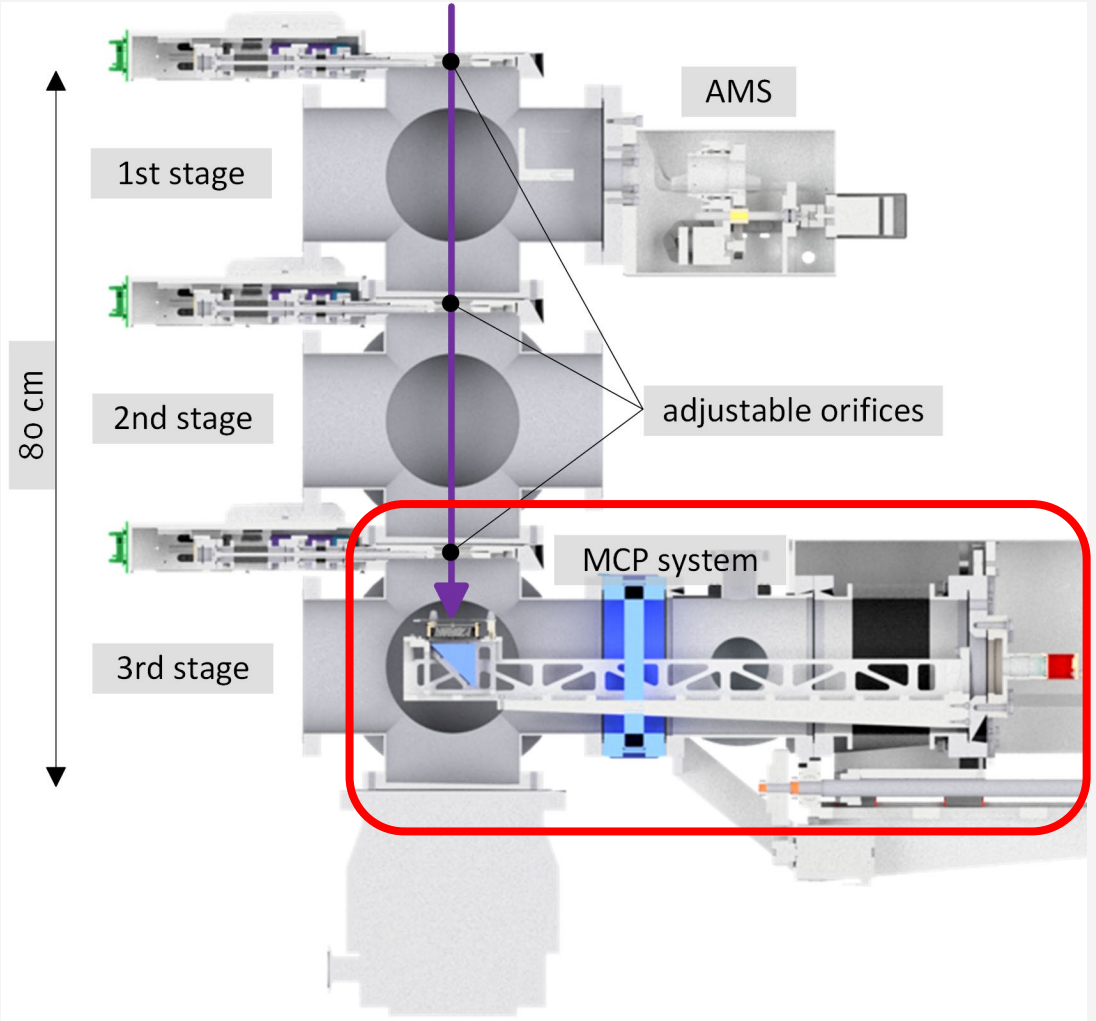
- Several measurements possible:
  - Time-of-Flight setup (with pulsed e-gun)





Münster Cluster-Jet Beam Dump

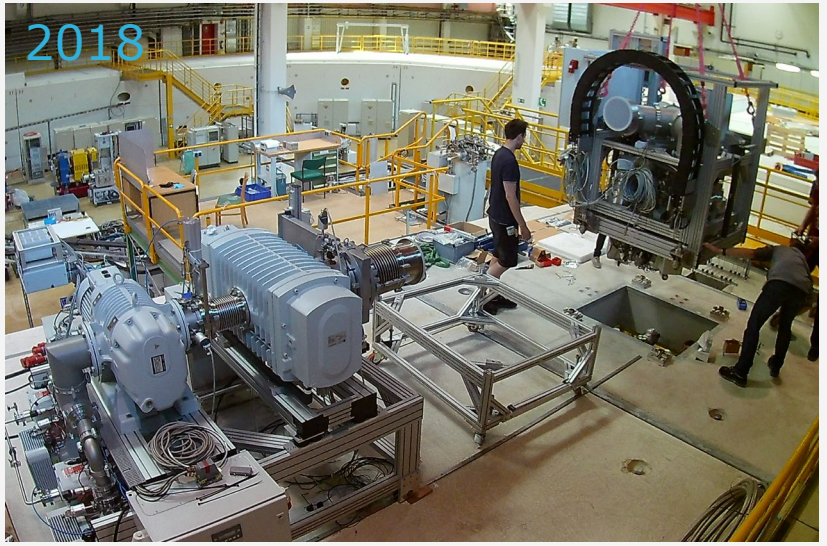
- Resulting information:
  - From TOF: Cluster velocity distribution
  - From cluster-jet visualization, after calibration and with velocity: cluster-jet thickness
  - From vertex zone visualization, after calibration: Luminosity monitor



Münster Cluster-Jet Target in short

- Liquified, pressurized hydrogen is fed through specially designed and manufactured Laval nozzle
- Resulting high-intense cluster-jet is extracted and shaped by movable skimmer and collimator
- Cluster-Jet is guided over $\mathbf{5m}$ through a down to $\mathbf{2cm}$ narrow target beam pipe until it is dumped
- At IP ($\mathbf{2.25m}$ **distance** to nozzle) a target with thickness of O($\mathbf{10^{15} atoms/cm^2}$) is placed in a vacuum of O($\mathbf{10^{-8} mbar}$), with adjustable thickness over **several orders of magnitude**
- Several self-developed tools allow for determination of: cluster-jet position, cluster velocity, target thickness, target density, beam-target-interaction region, luminosity, …
- **Windowless** target **without time structures**
- Modifiable target material

Current developments



- MCT currently installed at Cooler Synchrotron COSY
  (proton storage ring) for test measurements
  - Investigation of target-beam interaction (with proton beam)
  - Physical data on pion-production
  - Accelerator beam lifetime studies in presence of a cluster-jet target
  - Vacuum studies with an accelerator beam present
- Monitor systems and parts (e-gun, MCP, …) under investigation at Münster laboratories
- Fully in-house nozzle production in optimization process
- Other non nuclear physics related measurements (e.g., fluid dynamics as in [5] on the Widom line)

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Thank you for your attention

The Münster Cluster-Jet Target for the Future PANDA Experiment - INTDS 2022

Name: Sophia Vestrick

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Literature

[1] PANDA Collaboration et al, Strong Interaction Studies with Antiprotons, arXiv: 0903.3905 (2009).

[2] G. Barucca et al., "PANDA Phase One", European Physics Journal A57, 44, arXiv: 2101.11877 (2021).

[3] S. Grieser, Doctoral thesis, WWU Münster (2018).

[4] PANDA Collaboration, Technical Design Report for the PANDA Internal Targets: The Cluster-Jet Target and Developments for the Pellet Target. Technical report. FAIR. (2012).

[5] Vestrick et al., "Crossing the Widom line: Cluster formation as sensitive probe of supercritical Fluids", DOI: 2022.105686 (2022).

[6] Khoukaz et al., "Two-dimensional visualization of cluster beams by microchannel plates", DOI: 2013.08.085 (2013).

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