Design and Performance of the Future Cluster-Jet Target for $\overline{\text{P}}$ANDA at FAIR

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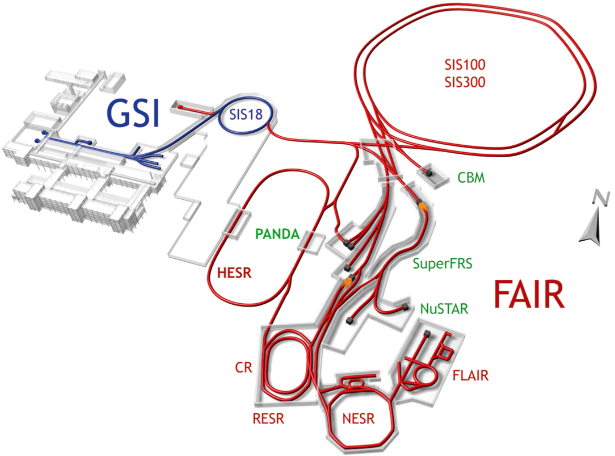
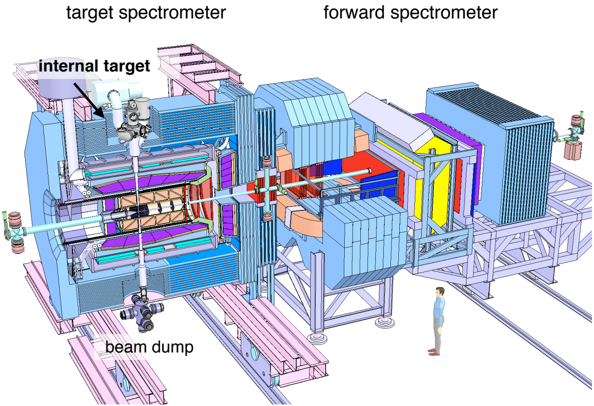
Bundesministerium für Bildung und Forschung

- **FAIR**: Facility for Antiproton and Ion Research
- **HESR**: High Energy Storage Ring
- **$\overline{\text{P}}$ANDA**: AntiProton ANnihilation at DArmstadt



The $\overline{\text{P}}$ANDA experiment at FAIR
$\overline{\text{P}}$ANDA detector

$\bar{p} + p \longrightarrow$ mesons, exotic hadrons $\Rightarrow$ insights into strong interaction



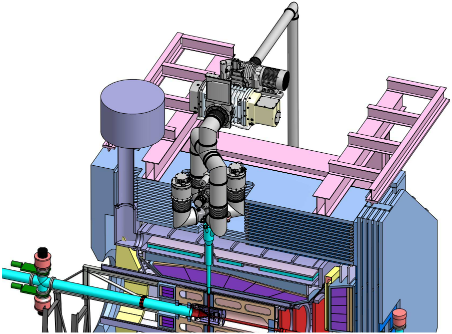
For 4π solid angle acceptance $\longrightarrow$ installation of the internal target in a distance of 2.1 m from interaction point

Planned internal targets for $\overline{\text{P}}$ANDA: cluster-jet target & pellet target

Requirements for an internal target for $\overline{\text{P}}$ANDA

- High purity of used target material
  $\longrightarrow$ **Decrease of background reactions**
- Target density
  - ρ_T in order of $10^{15}\ \frac{\text{atoms}}{\text{cm}^2}$ at $2.1\,\text{m}$
    $\longrightarrow$ **Full exploit of antiproton production rate**
  - Constant in time & adjustable (offline)
    $\longrightarrow$ **For data aquisition**
- Variable target beam size & shape (offline)
  $\longrightarrow$ **Depends on experimental programm**
- Effective target beam size as small as possible
  $\longrightarrow$ **Low influence on vacuum conditions in the HESR**

cluster-jet target

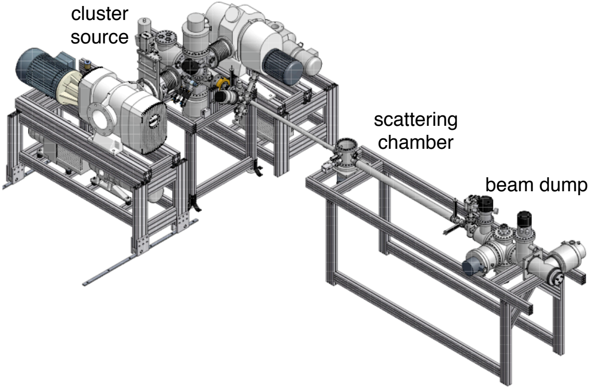


target spectrometer

Prototype of a high density cluster-jet target for $\overline{\text{P}}$ANDA

Overview

- Prototype already built up and set successfully into operation
- **Complete system installed in $\overline{\text{P}}$ANDA geometry**
  (scattering chamber corresponds to $\overline{\text{P}}$ANDA interaction point)



- Cluster beam characteristics can be transferred directly to the situation at $\overline{\text{P}}$ANDA
- Target beam diagnostics in scattering chamber

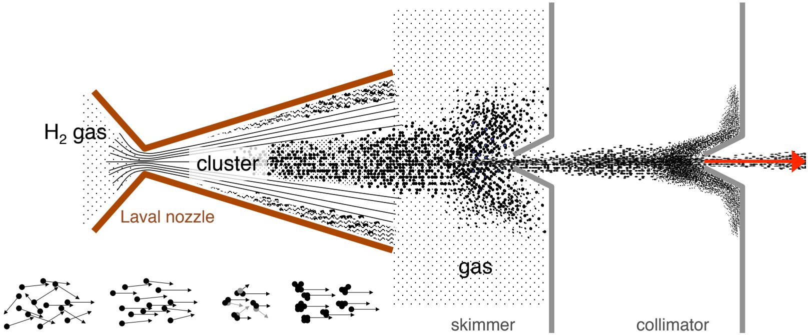
  $\Longrightarrow$ Determination of cluster beam position, size & density

Prototype of a high density cluster-jet target for $\overline{\text{P}}$ANDA

Cluster production with a Laval nozzle (in case of hydrogen gas)

- **Cluster**: Particle with *n* atoms/molecules, in this case van der Waals interactions responsible for bonding

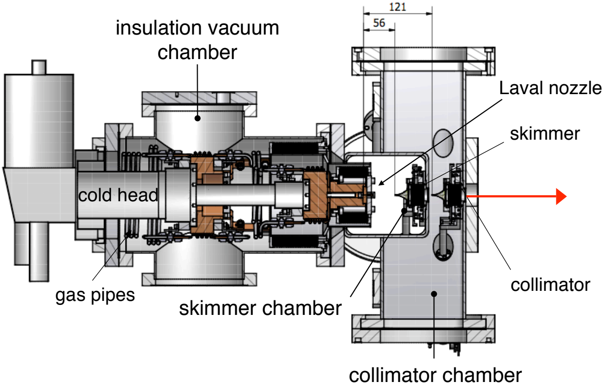
$10^{-1}\,\mathrm{mbar}$ $10^{-5}\,\mathrm{mbar}$
(differential pump system)



- Temperature range: $T = 20 - 50\,\mathrm{K}$
- Pressure range: $p = 7 - 20\,\mathrm{bar}$
- Laval nozzle: $\varnothing = 28\,\mu\mathrm{m}$ (narrowest point)
- Skimmer: $\varnothing = 0.5\,\mathrm{mm}$ (movable)
- Collimator: $\varnothing = 0.7\,\mathrm{mm}$ (movable)

Prototype of a high density cluster-jet target for $\overline{\text{P}}$ANDA

Cluster source



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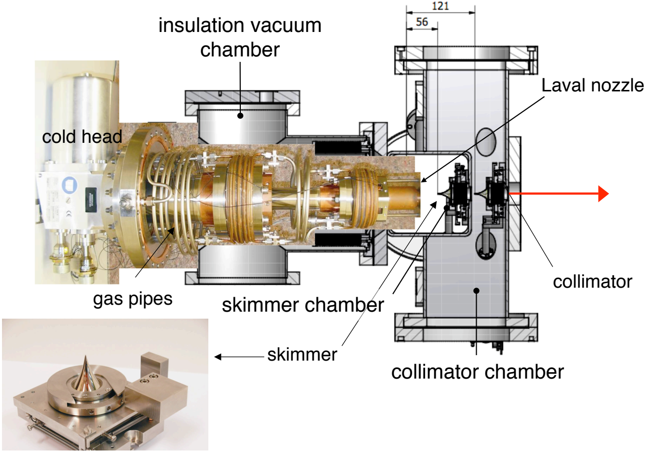

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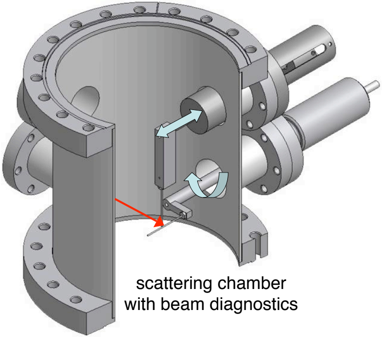
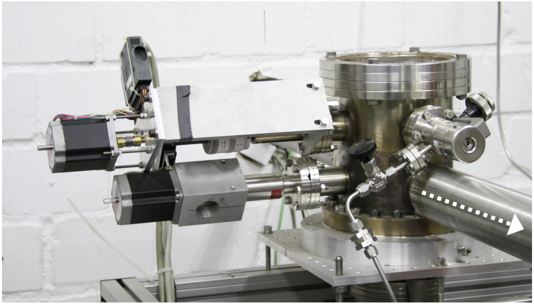
Prototype of a high density cluster-jet target for $\overline{\text{P}}$ANDA

Scattering chamber



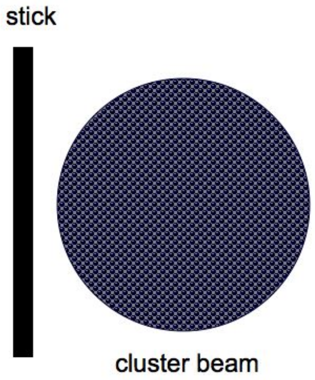


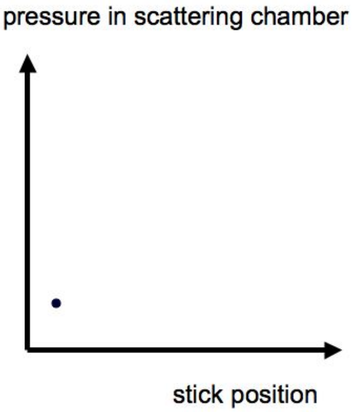
Scattering chamber equipped with a beam diagnostic system $\Longrightarrow$ **Determination of:**

- **target position**
- **size**
- **density**

Scattering chamber

Determination of target position, size and density





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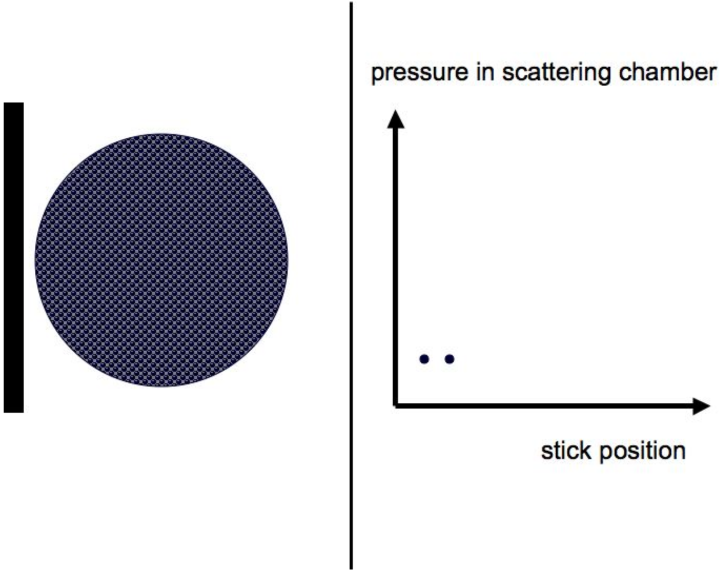

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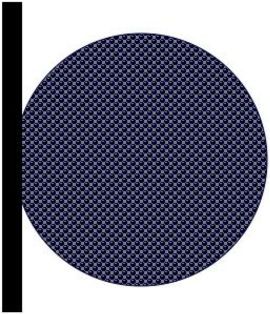

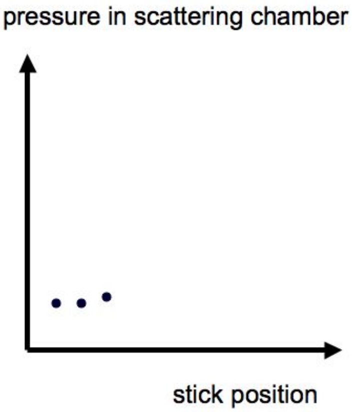

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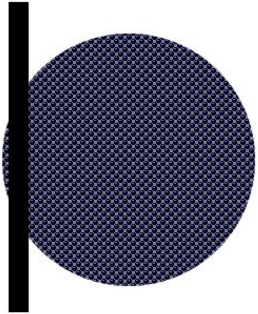

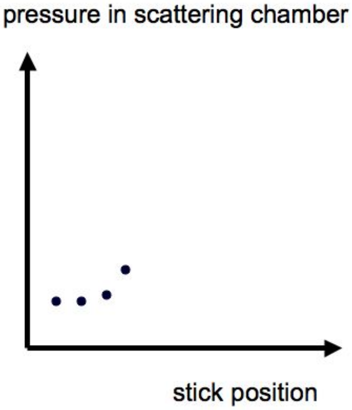

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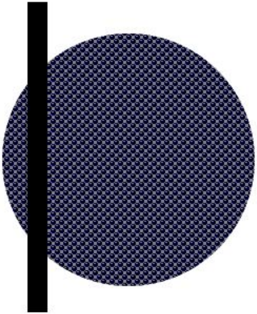

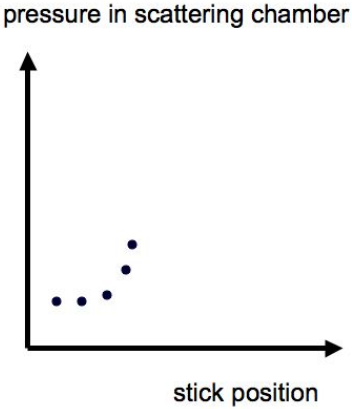

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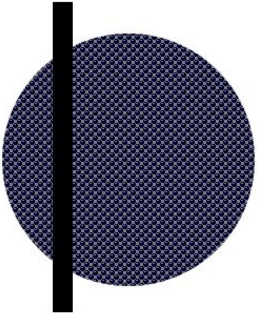

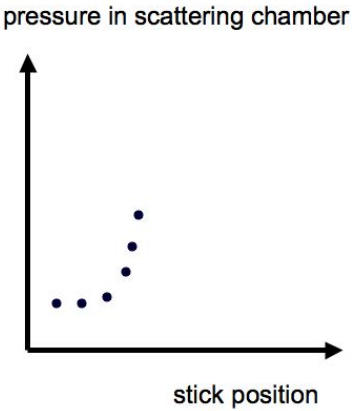

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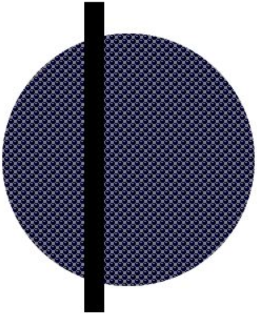

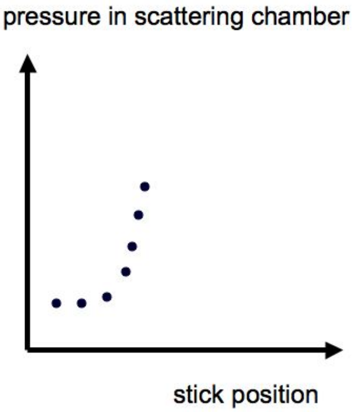

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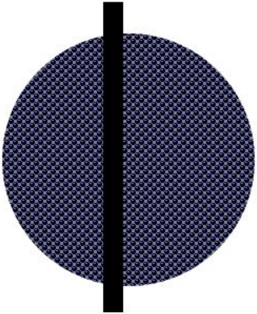

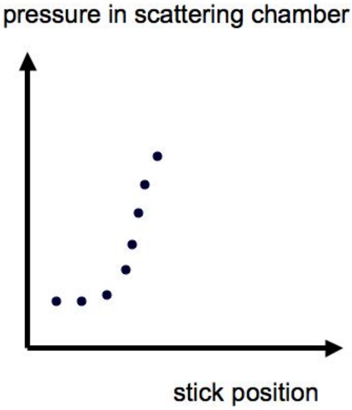

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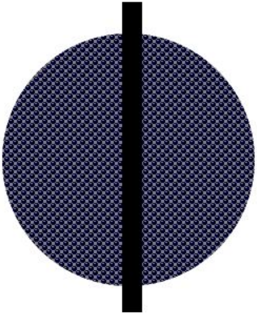

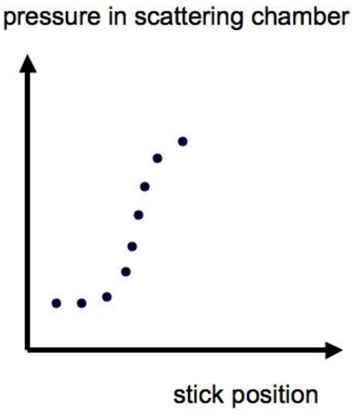

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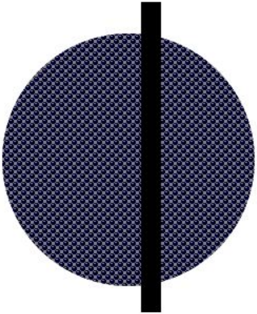

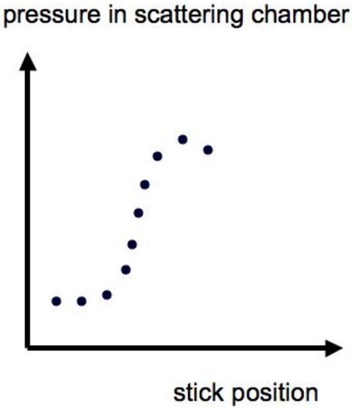

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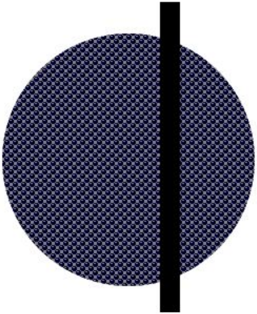

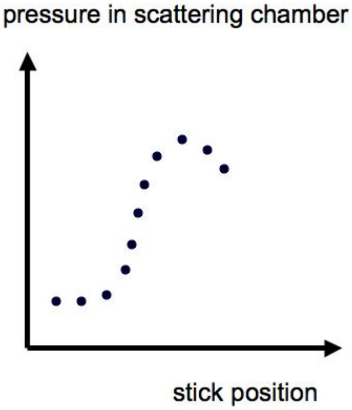

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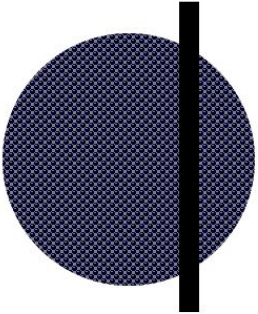

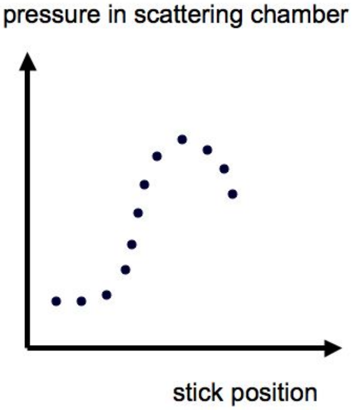

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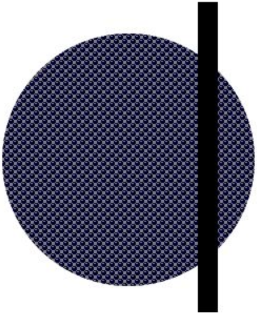

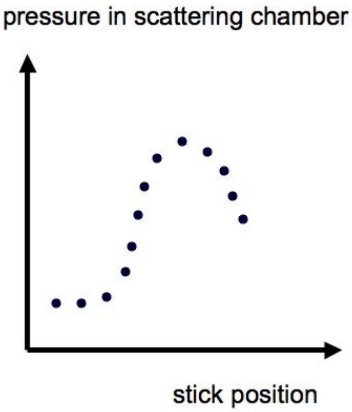

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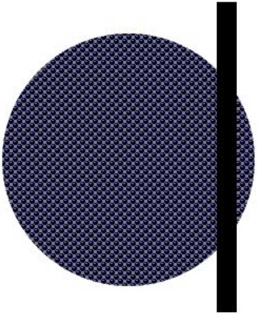

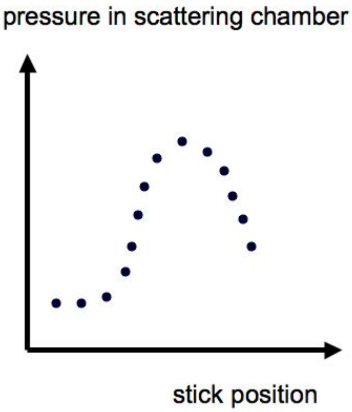

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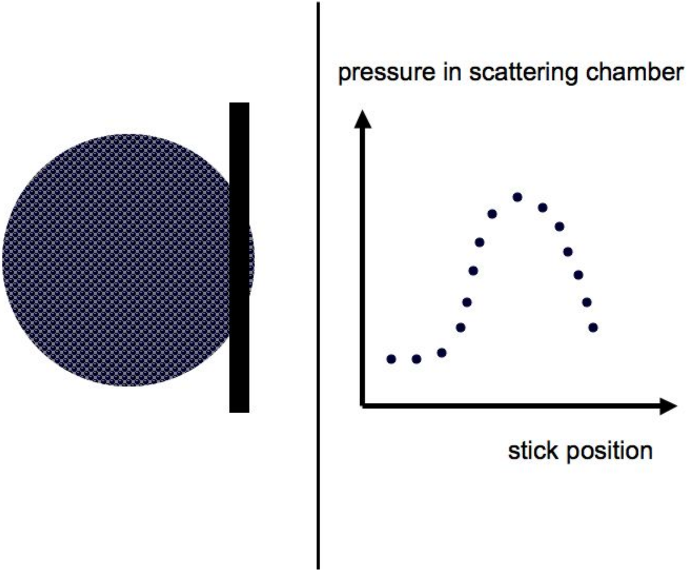

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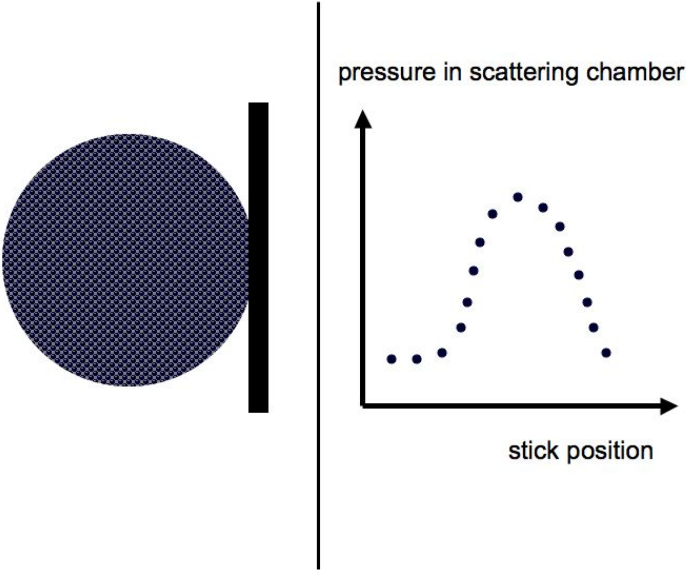

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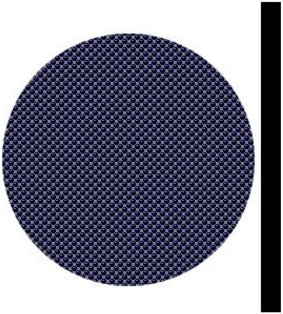

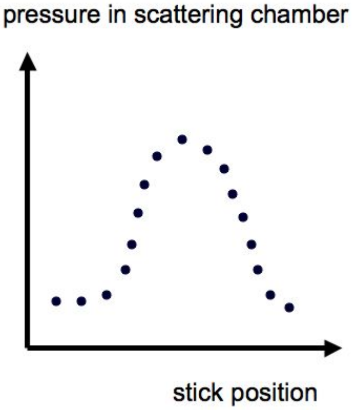

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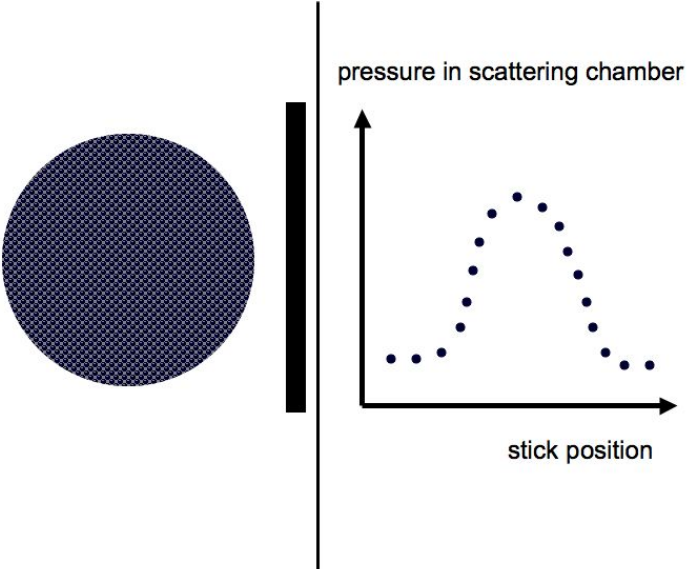

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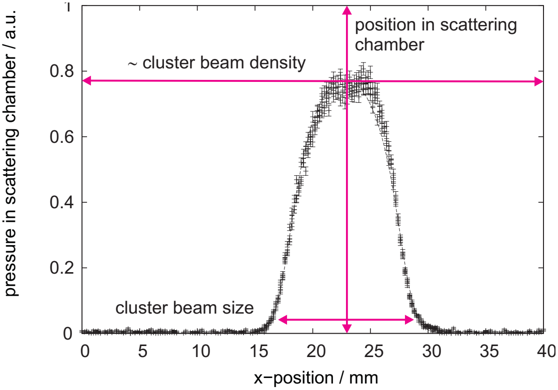


$$\rho_T \sim \frac{p_{sc}}{v_c}$$

ρ_T: Target density

p_{sc}: Pressure increase in scattering chamber

v_c: Cluster velocity $(200 - 1000\,\mathrm{m/s})$

$\longrightarrow$ see talk of A. Täschner at 12.20

Target density

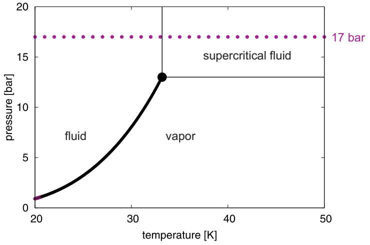
Important parameters of different cluster-jet targets

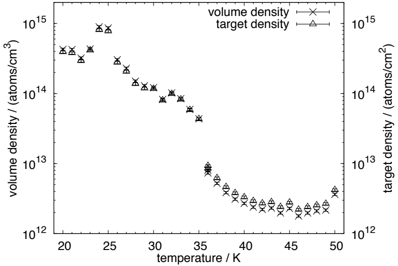
	PROMISE/WASA (CELSIUS)	E835 (FERMILAB)	ANKE, COSY11 (COSY)	PANDA Prototype (IKP Münster)
nozzle diameter	$< 100\,\mu m$	$37\,\mu m$	$11 - 16\,\mu m$	$28\,\mu m$
gas temperature	$20 - 35\,K$	$15 - 40\,K$	$22 - 35\,K$	$20 - 35\,K$
gas pressure	$1.4\,bar$	$< 8\,bar$	$18\,bar$	$> 18\,bar$
distance from nozzle r	$0.325\,m$	$0.26\,m$	$0.65\,m$	$2.1\,m$
max. areal density	$1.3 \times 10^{14}\,cm^{-2}$	$2 \times 10^{14}\,cm^{-2}$	$\gg 10^{14}\,cm^{-2}$	$8 \times 10^{14}\,cm^{-2}$ (with presented setup)

Target density decreases with $1/r^2$

Target density

...at 17 bar, above critical point (33.18 K, 13 bar)

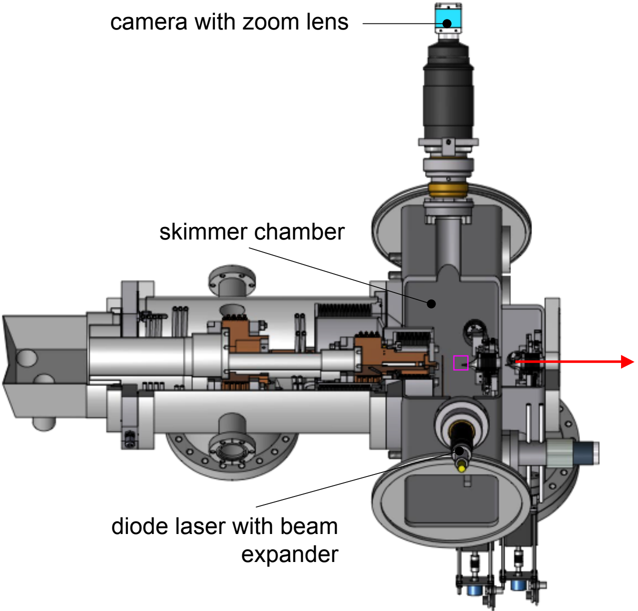




- Target density **easy to vary** over several orders of magnitude (T, p)
- **Increase** of target density with decreasing temperature up to 24 K (with small variations)
- **Drop** because of different state of matter at formation of clusters (supercritical fluid $\longrightarrow$ fluid)
- **Decreasing** target density below 24 K **???**

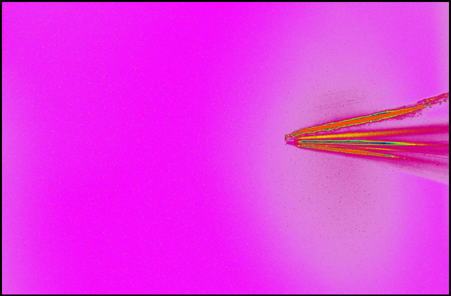
Cluster beam in skimmer chamber

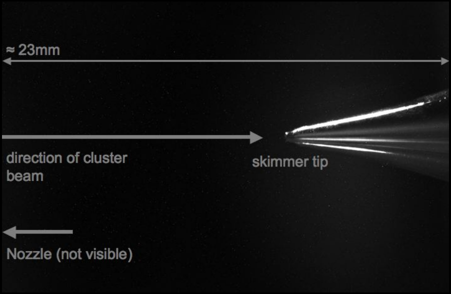
Overview



Cluster beam in skimmer chamber

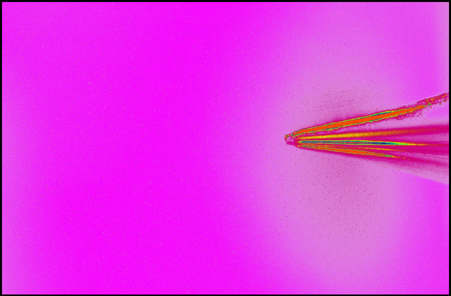
50 K, 18.5 bar

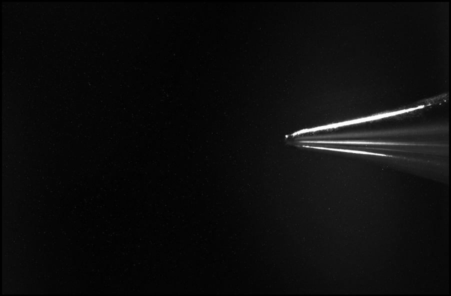




Cluster beam in skimmer chamber

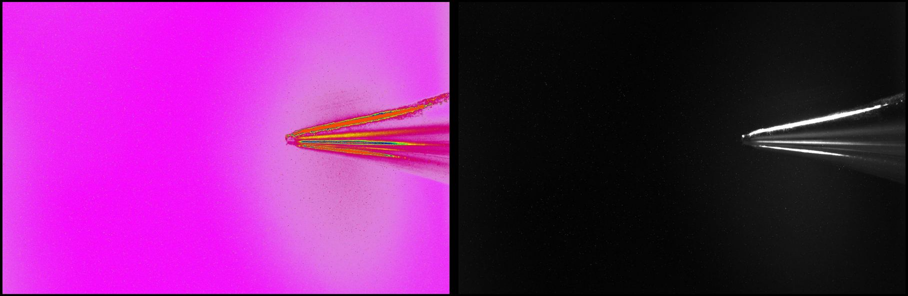
49 K, 18.5 bar





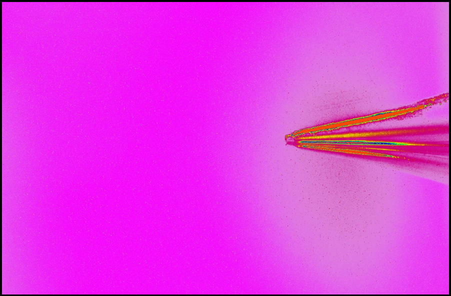
Cluster beam in skimmer chamber

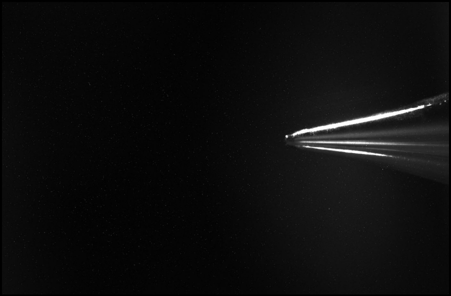
48 K, 18.5 bar



Cluster beam in skimmer chamber

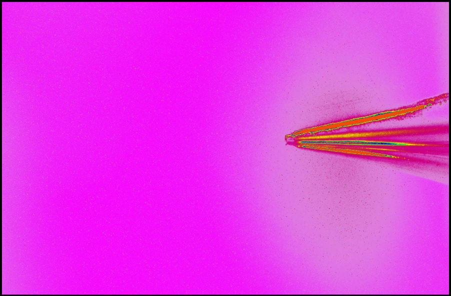
47 K, 18.5 bar

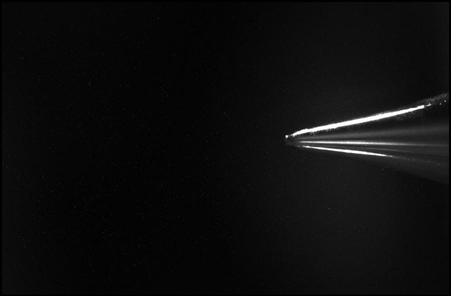




Cluster beam in skimmer chamber

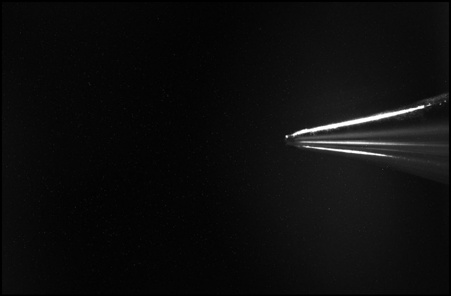
46 K, 18.5 bar





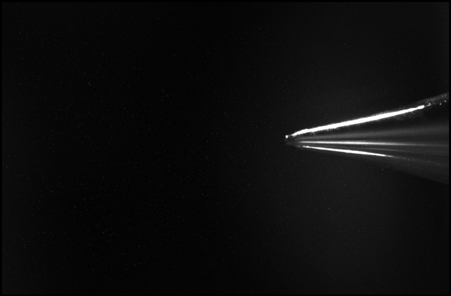
Cluster beam in skimmer chamber

45 K, 18.5 bar



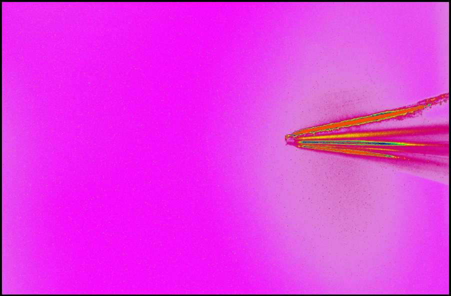
Cluster beam in skimmer chamber

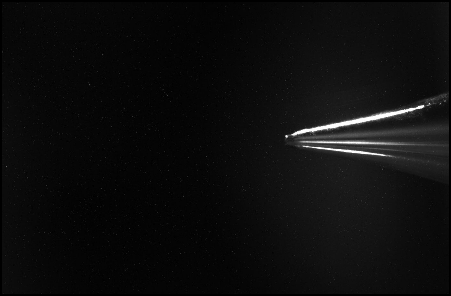
44 K, 18.5 bar



Cluster beam in skimmer chamber

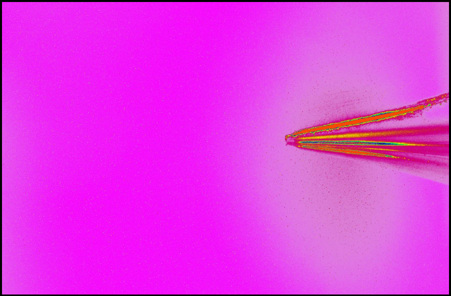
43 K, 18.5 bar

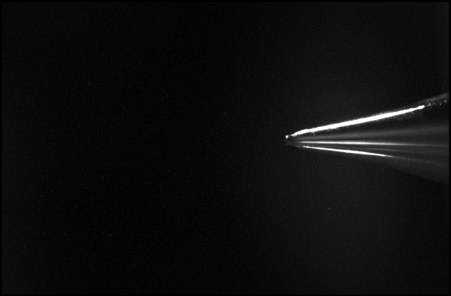




Cluster beam in skimmer chamber

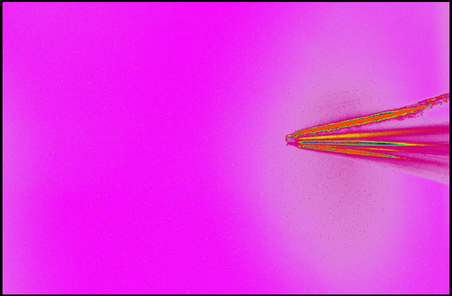
42 K, 18.5 bar

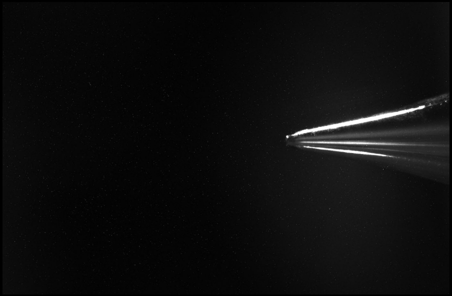




Cluster beam in skimmer chamber

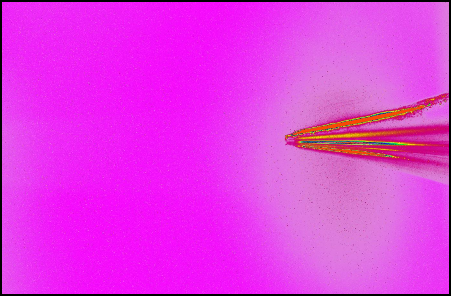
41 K, 18.5 bar

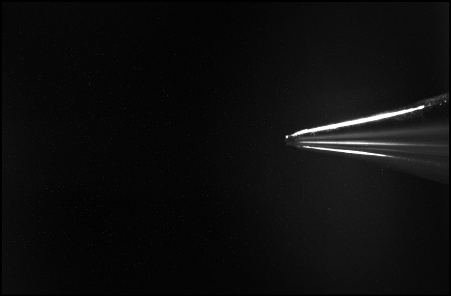




Cluster beam in skimmer chamber

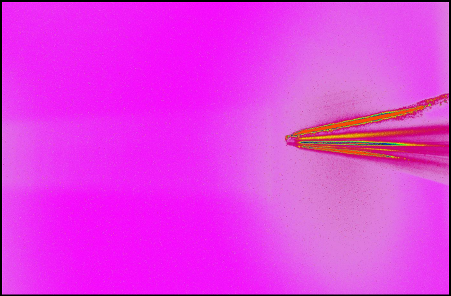
40 K, 18.5 bar

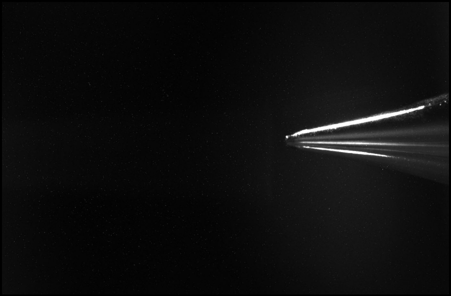




Cluster beam in skimmer chamber

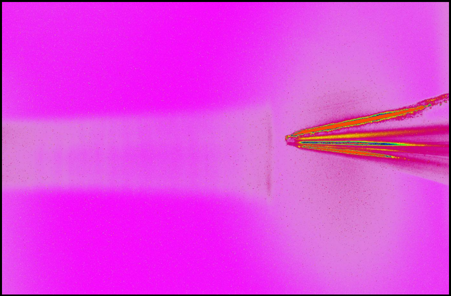
39 K, 18.5 bar

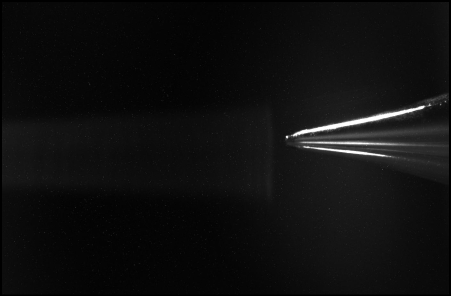




Cluster beam in skimmer chamber

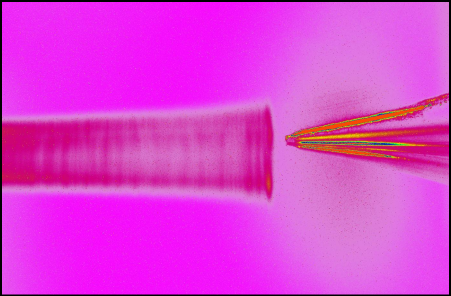
38 K, 18.5 bar

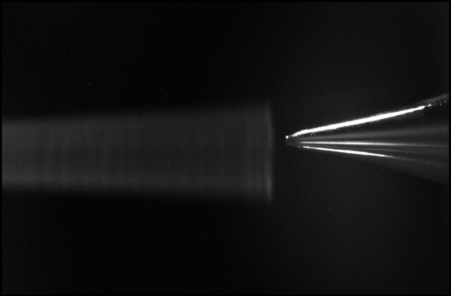




Cluster beam in skimmer chamber

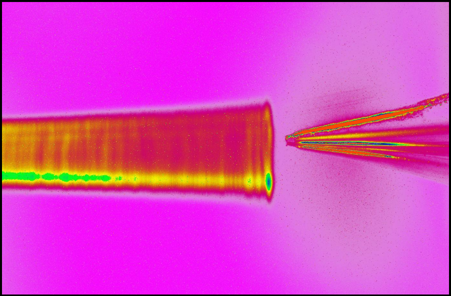
37 K, 18.5 bar

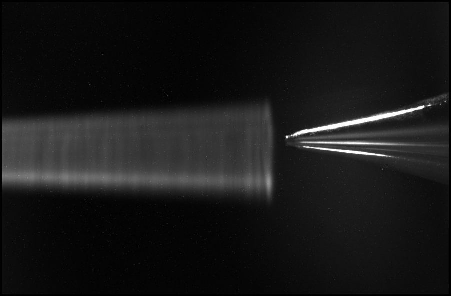




Cluster beam in skimmer chamber

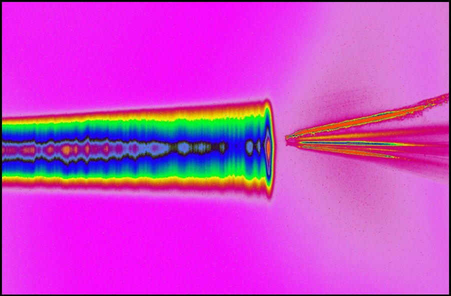
36 K, 18.5 bar

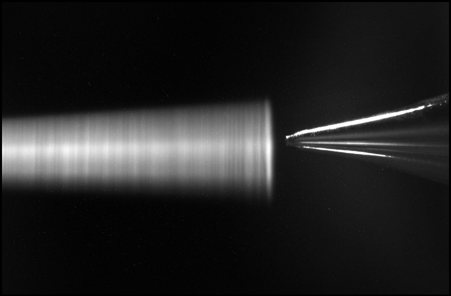




Cluster beam in skimmer chamber

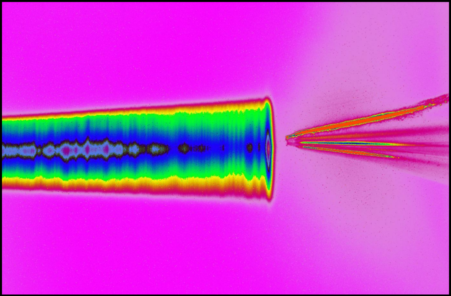
35 K, 18.5 bar

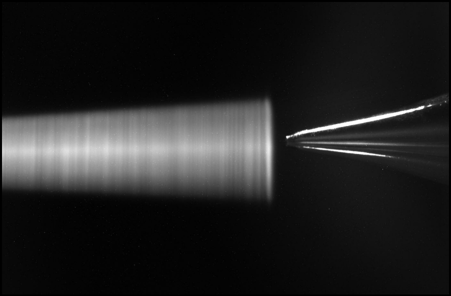




Cluster beam in skimmer chamber

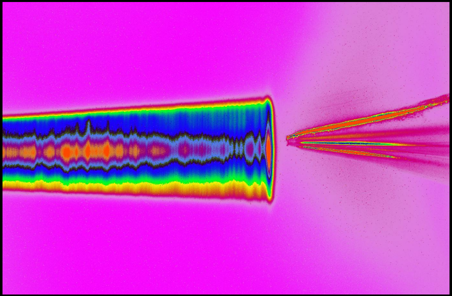
34 K, 18.5 bar

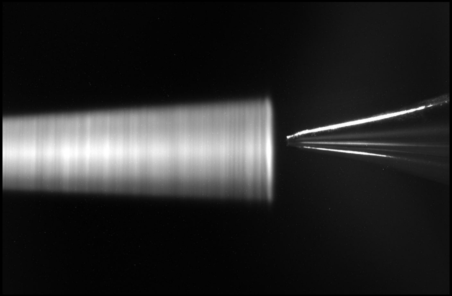




Cluster beam in skimmer chamber

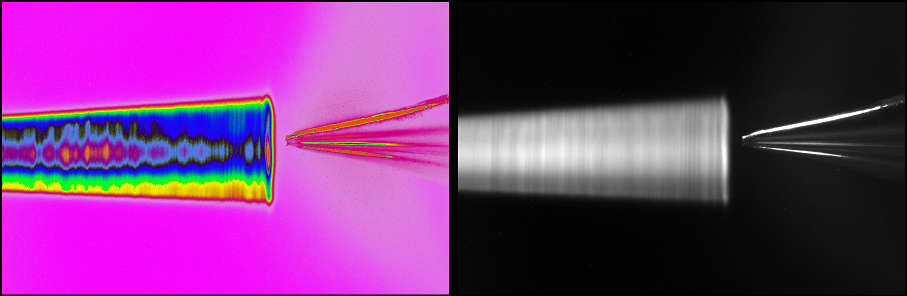
33 K, 18.5 bar





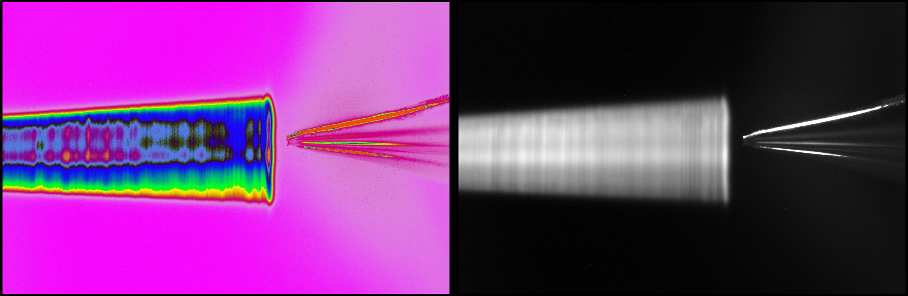
Cluster beam in skimmer chamber

32 K, 18.5 bar



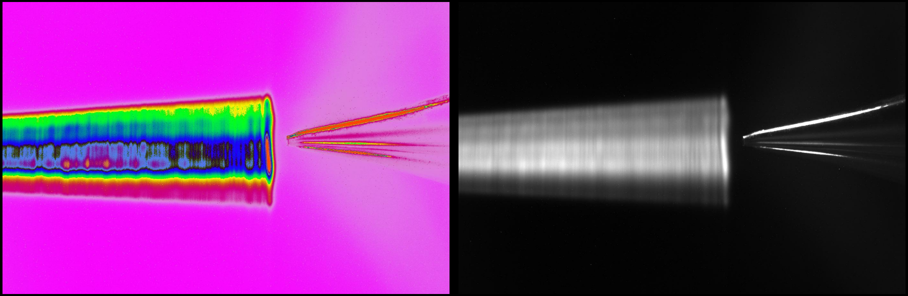
Cluster beam in skimmer chamber

31 K, 18.5 bar



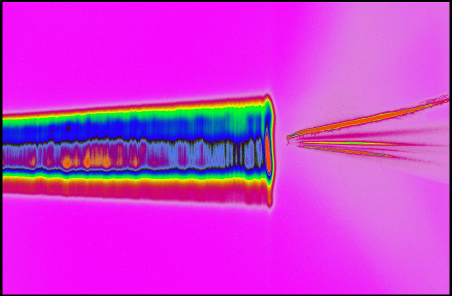
Cluster beam in skimmer chamber

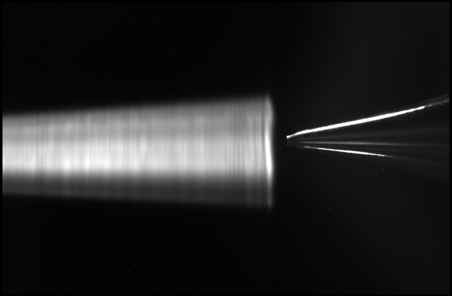
30 K, 18.5 bar



Cluster beam in skimmer chamber

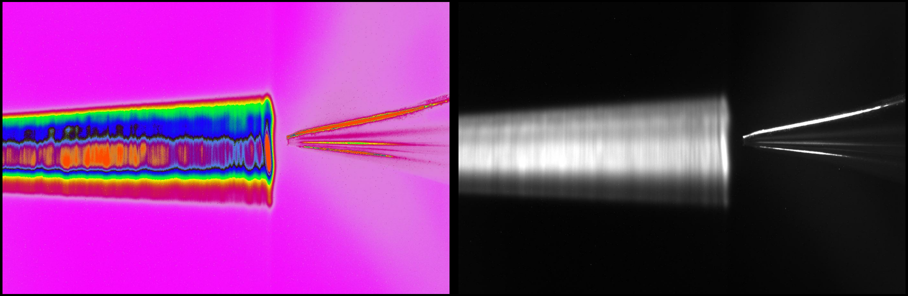
29 K, 18.5 bar





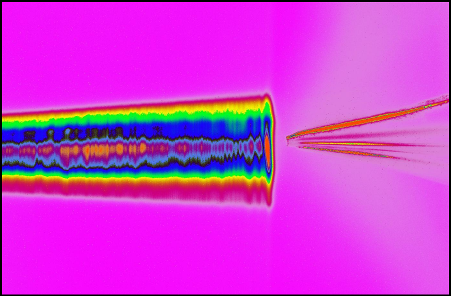
Cluster beam in skimmer chamber

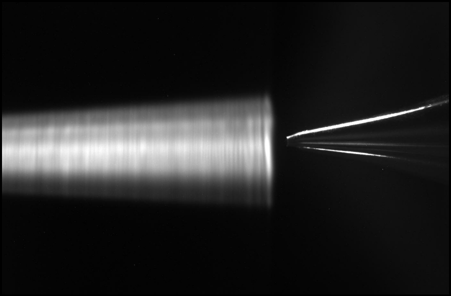
28 K, 18.5 bar



Cluster beam in skimmer chamber

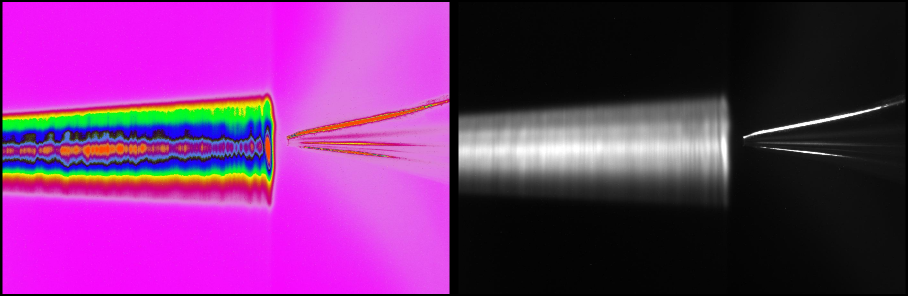
27 K, 18.5 bar





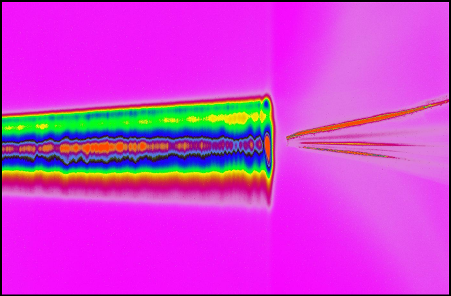
Cluster beam in skimmer chamber

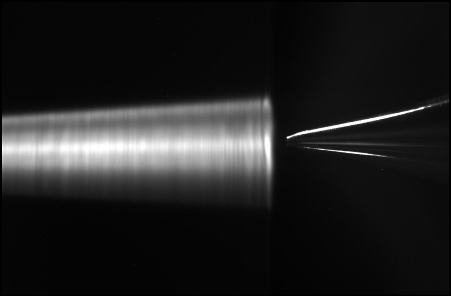
26 K, 18.5 bar



Cluster beam in skimmer chamber

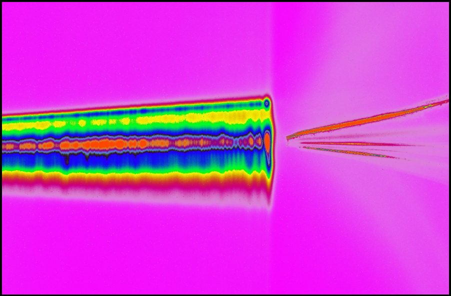
25 K, 18.5 bar

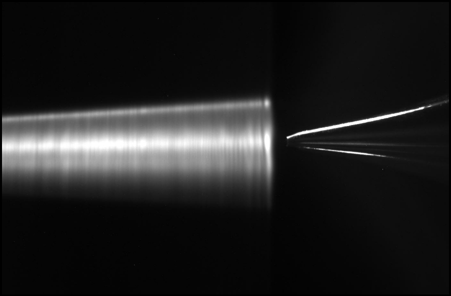




Cluster beam in skimmer chamber

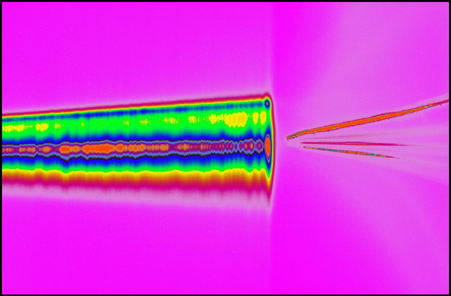
24 K, 18.5 bar

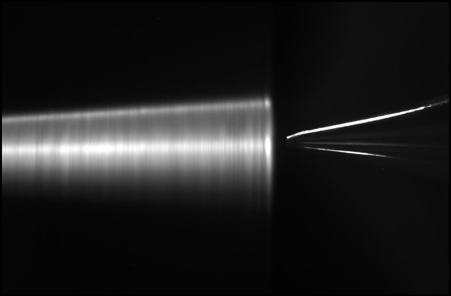




Cluster beam in skimmer chamber

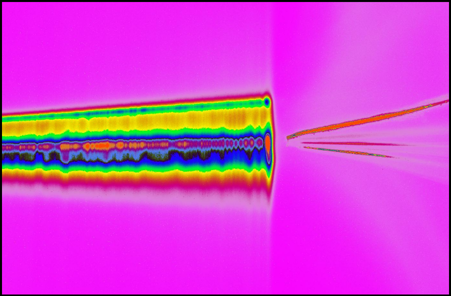
23 K, 18.5 bar

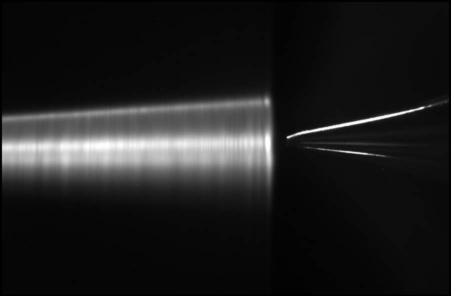




Cluster beam in skimmer chamber

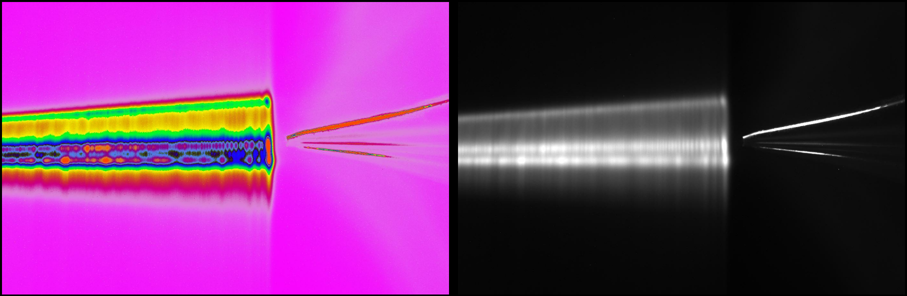
22 K, 18.5 bar





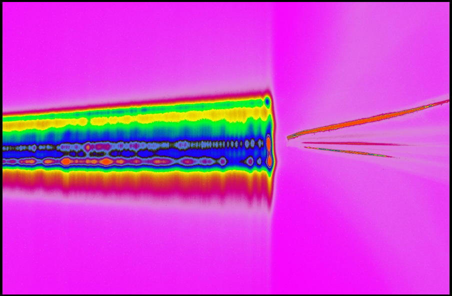
Cluster beam in skimmer chamber

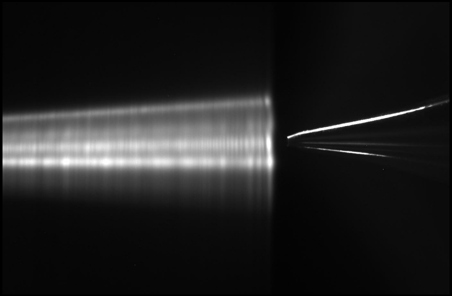
21 K, 18.5 bar



Cluster beam in skimmer chamber

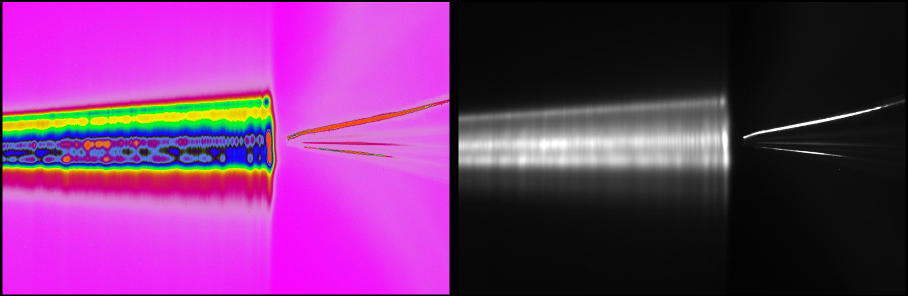
20 K, 18.5 bar





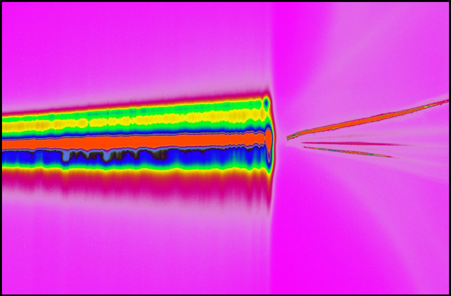
Cluster beam in skimmer chamber

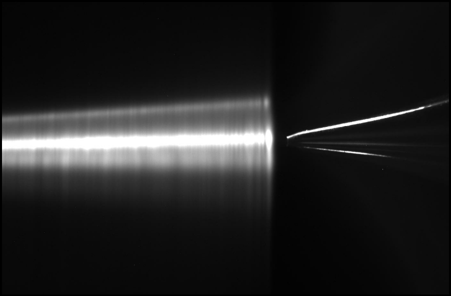
19 K, 18.5 bar



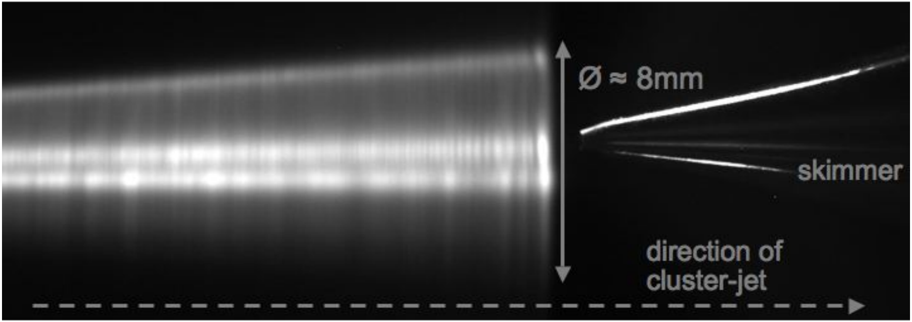
Cluster beam in skimmer chamber

18.3 K, 18.5 bar





Cluster beam in skimmer chamber

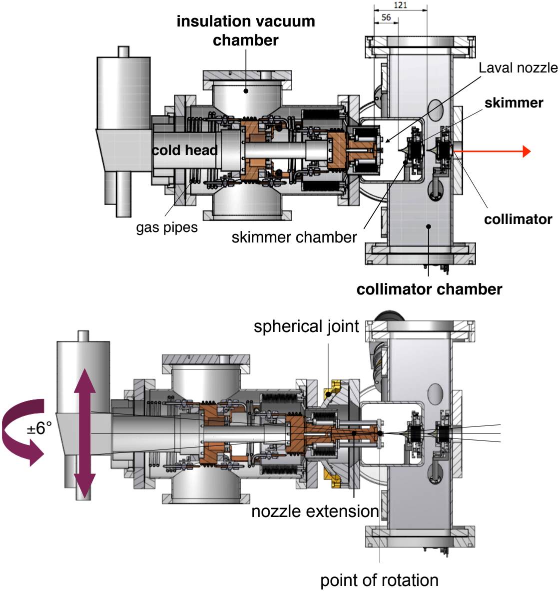


- Inhomogeneous cluster beam in skimmer chamber
- Density still constant in scattering chamber
  ($\overline{\text{P}}$ANDA interaction point) $\longrightarrow$ extracted beam is homogeneous
- **Do we have a higher density at the brighter area?**

$\Longrightarrow$ **Movable nozzle required**

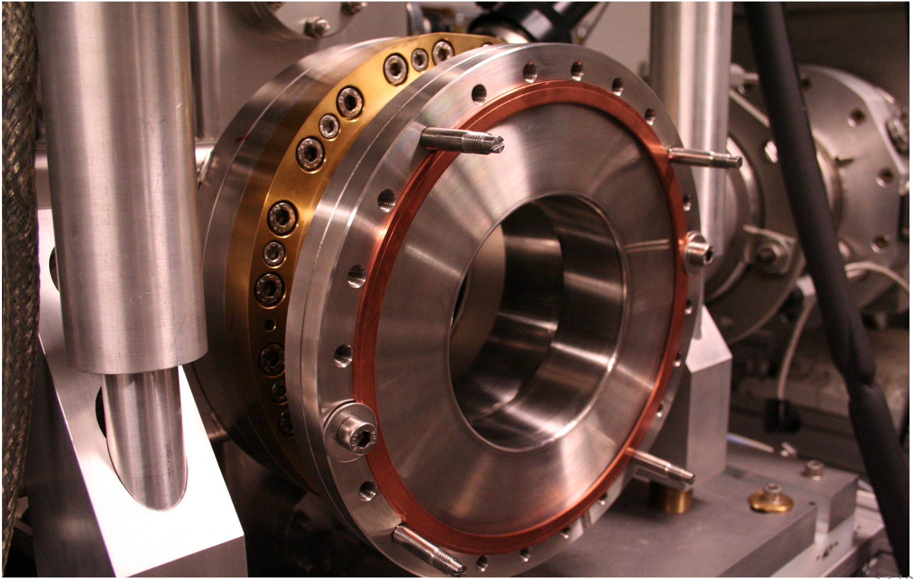
Improvement of target density

Movable nozzle



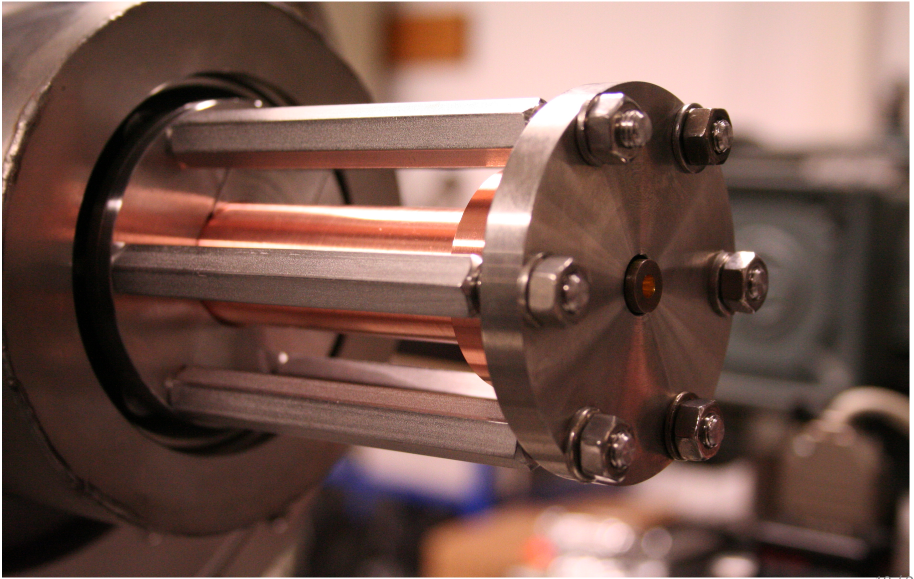
Improvement of target density

Spherical joint



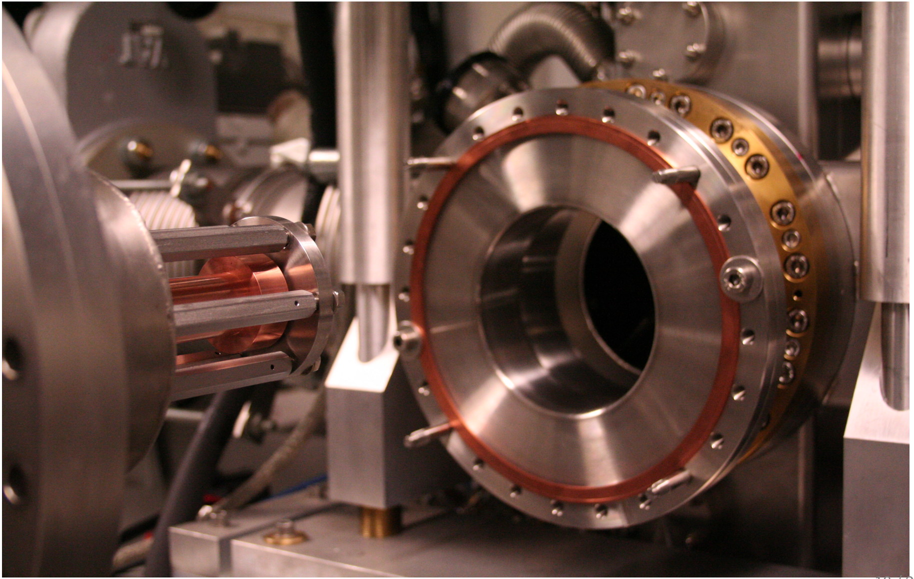
Improvement of target density

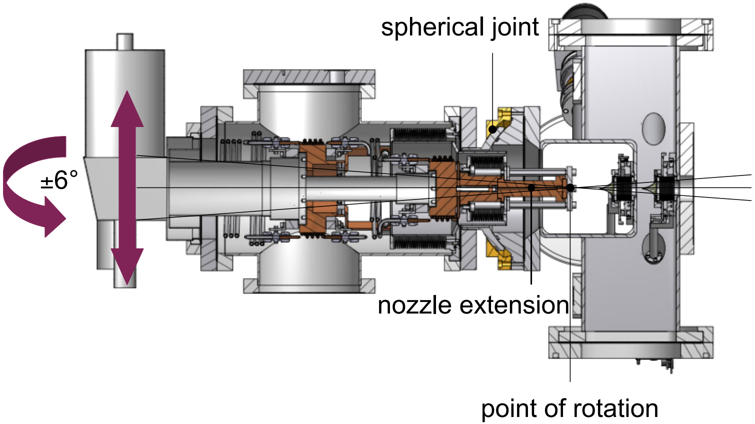
Nozzle extension



Improvement of target density

Movable nozzle

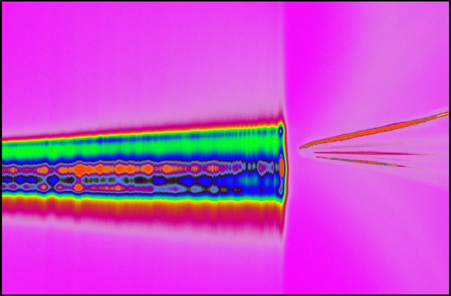


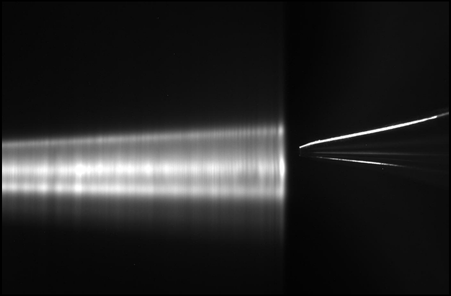


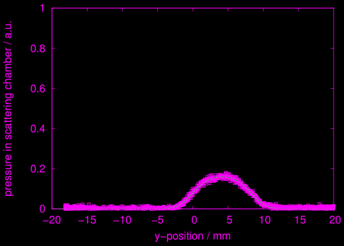
spherical joint
±6°
nozzle extension
point of rotation

Improvement of target density

19 K, 18.5 bar

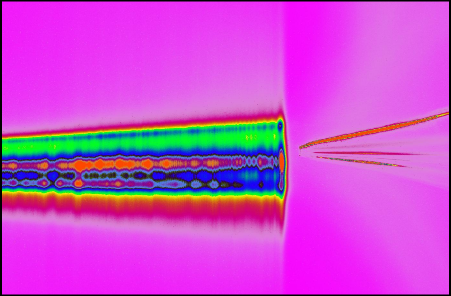


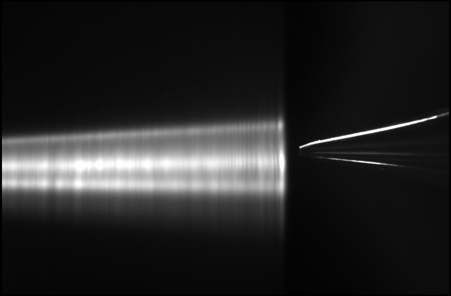


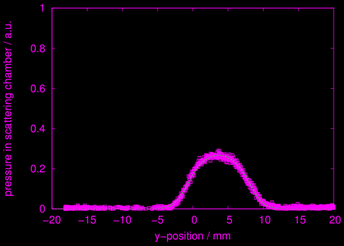


Improvement of target density

19 K, 18.5 bar

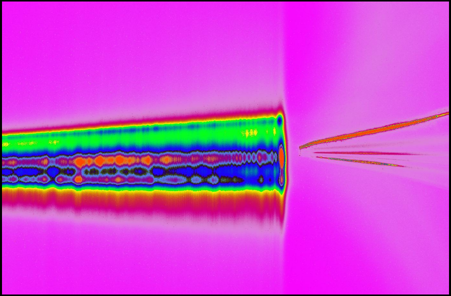


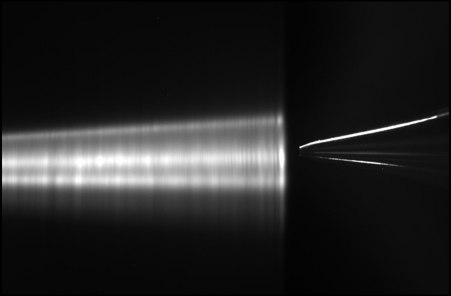


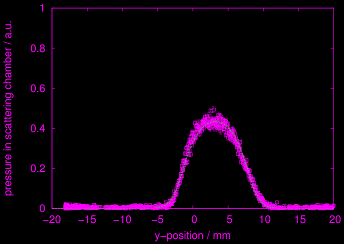


Improvement of target density

19 K, 18.5 bar

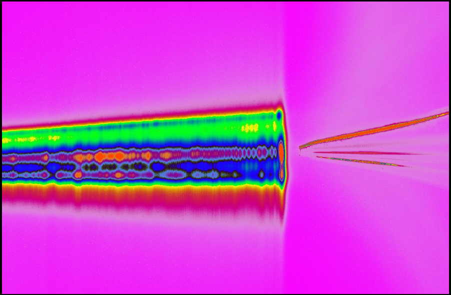


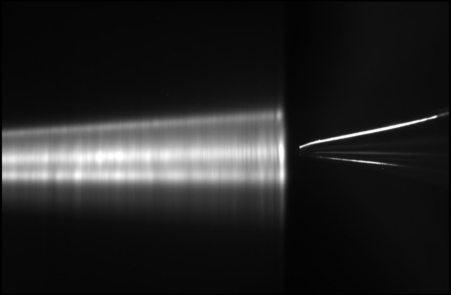


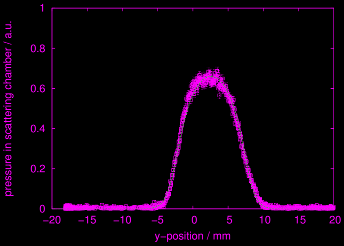


Improvement of target density

19 K, 18.5 bar

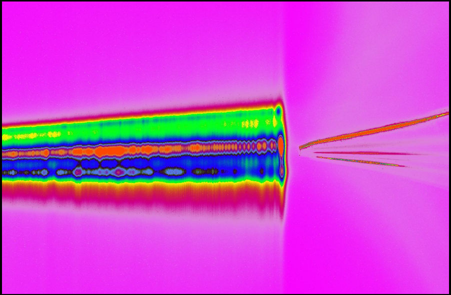


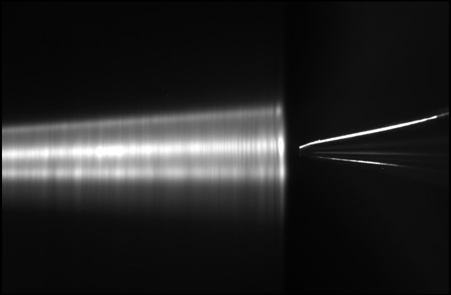


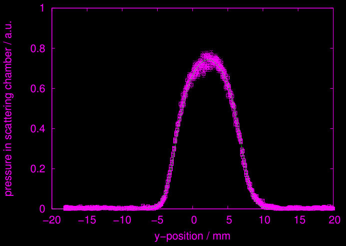


Improvement of target density

19 K, 18.5 bar

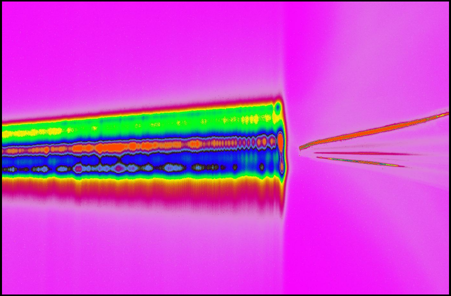


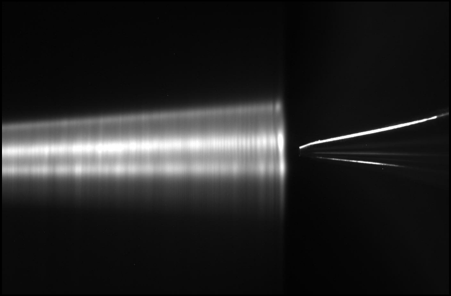


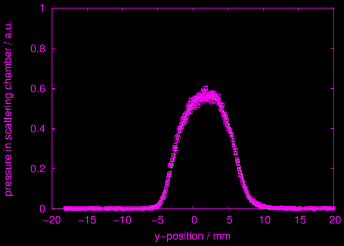


Improvement of target density

19 K, 18.5 bar

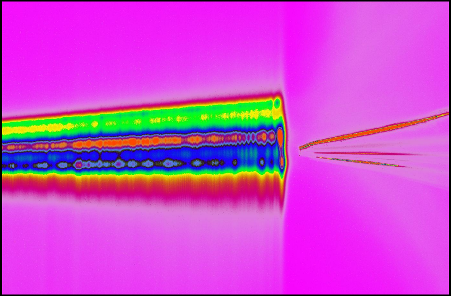


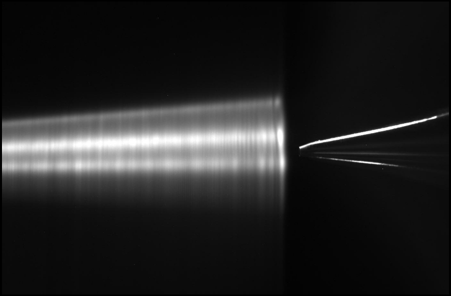


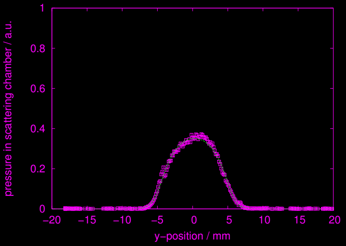


Improvement of target density

19 K, 18.5 bar

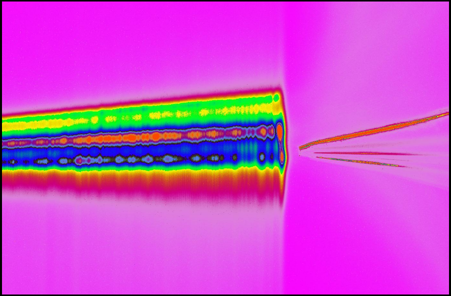


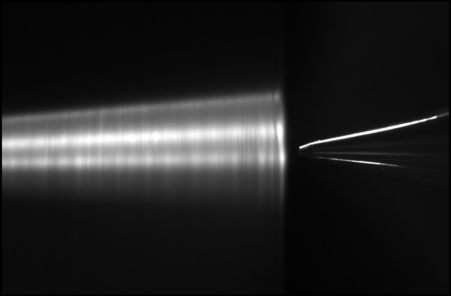


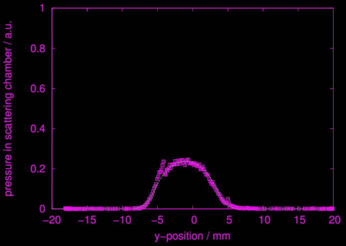


Improvement of target density

19 K, 18.5 bar

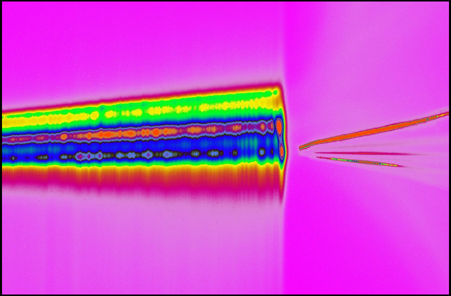


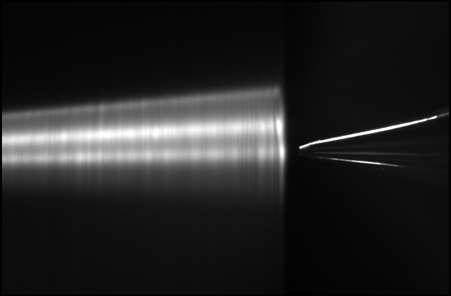


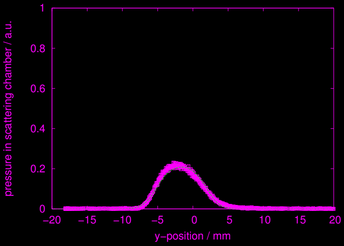


Improvement of target density

19 K, 18.5 bar

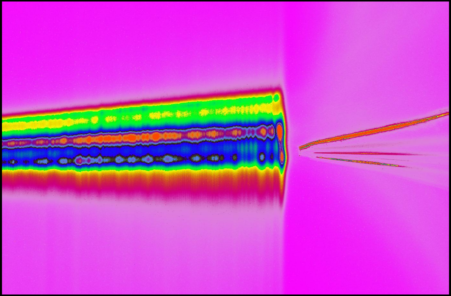


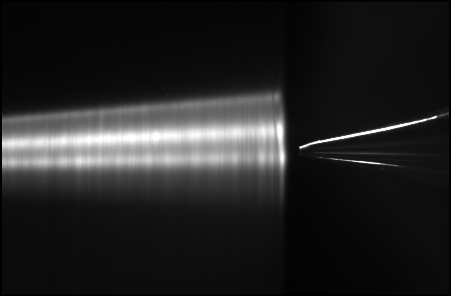


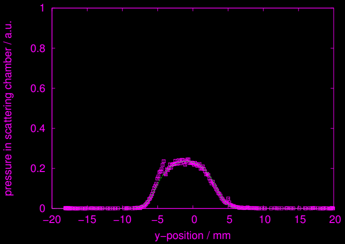


Improvement of target density

19 K, 18.5 bar

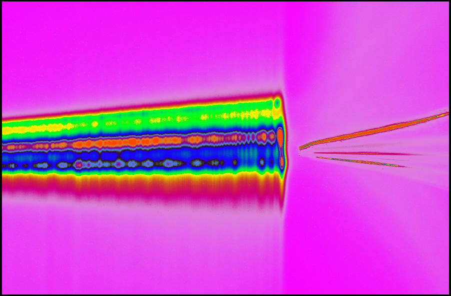


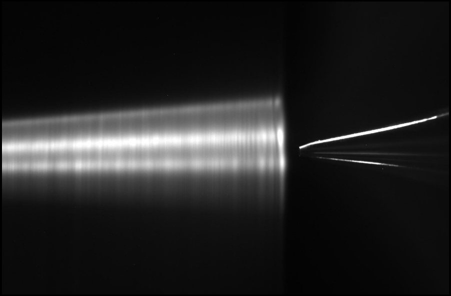


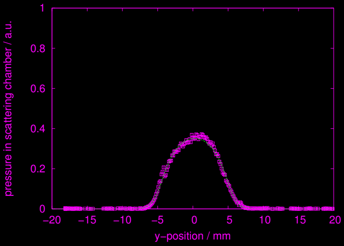


Improvement of target density

19 K, 18.5 bar

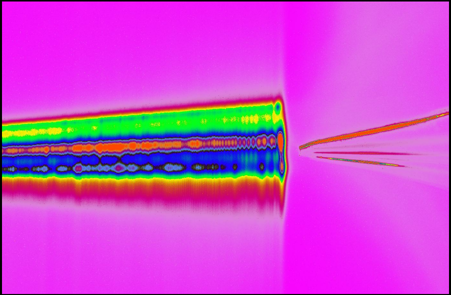


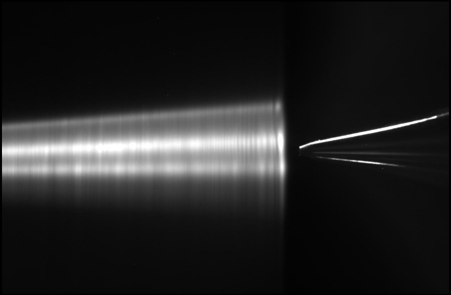


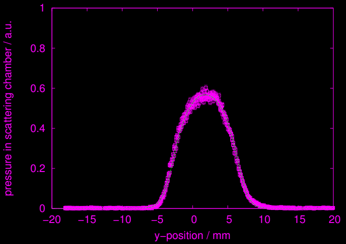


Improvement of target density

19 K, 18.5 bar

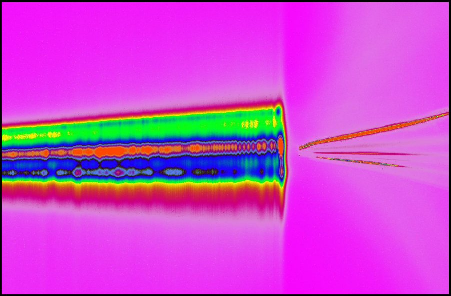


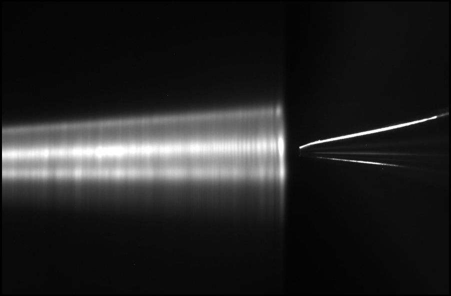


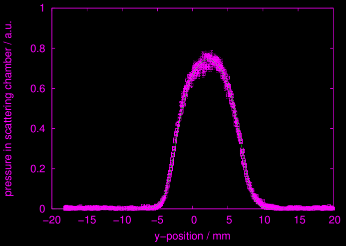


Improvement of target density

19 K, 18.5 bar

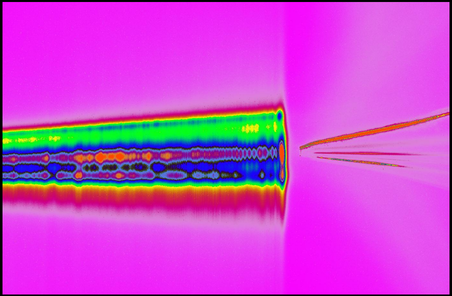


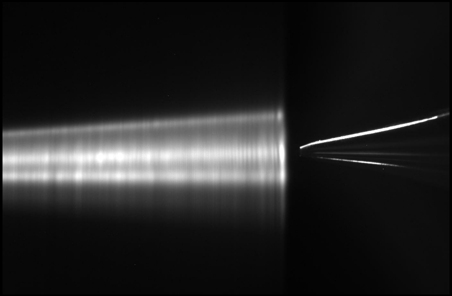


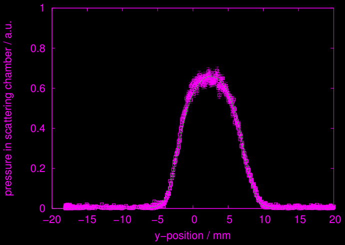


Improvement of target density

19 K, 18.5 bar

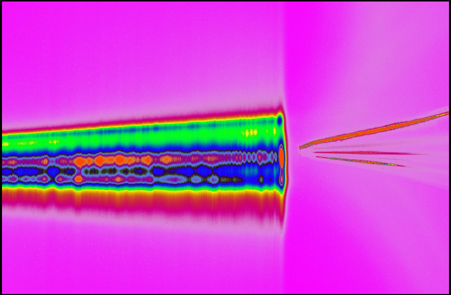


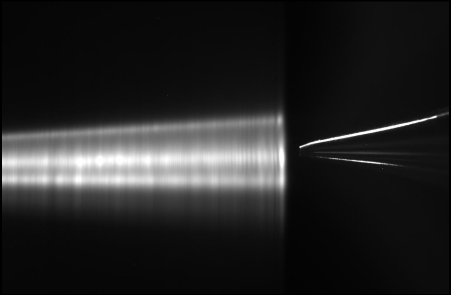


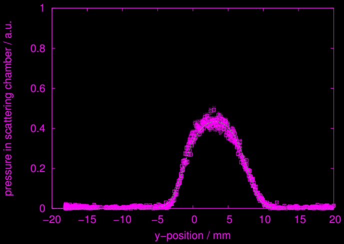


Improvement of target density

19 K, 18.5 bar

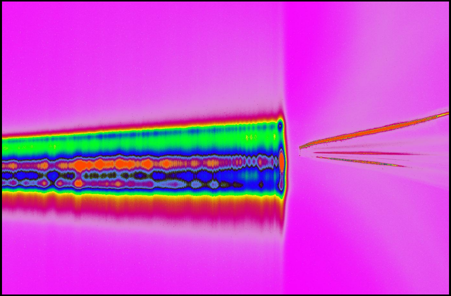


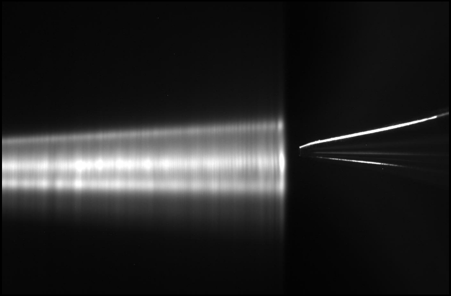


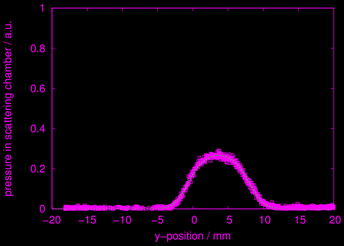


Improvement of target density

19 K, 18.5 bar

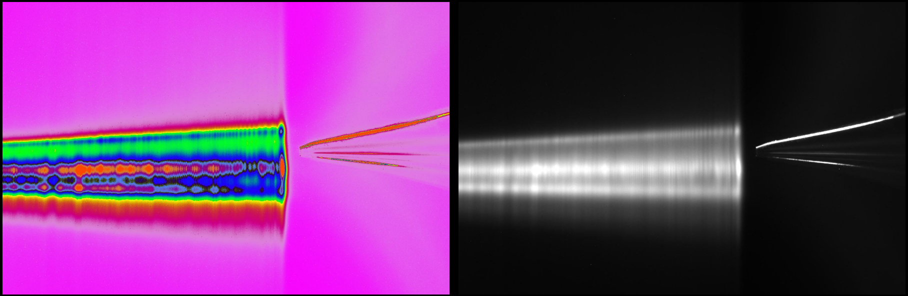


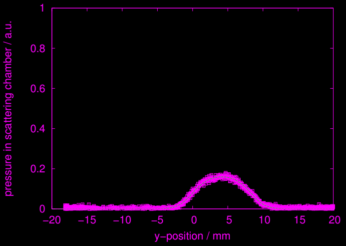




Improvement of target density

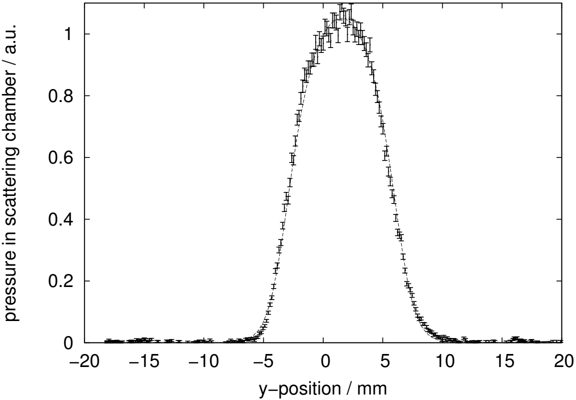
19 K, 18.5 bar





Improvement of target density

- temperature:
  19 K
- pressure:
  18.5 bar
- diameter:
  10.3 mm
- velocity:
  253 m/s

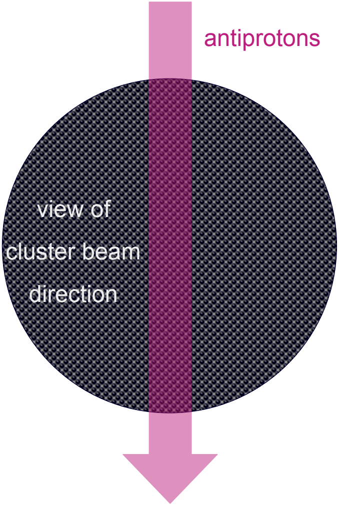


- Volume density:

$$\mathbf{1.9 \times 10^{15}}\ \mathrm{atoms/cm^3}$$

Improvement of vacuum in scattering chamber

Special shaped collimator

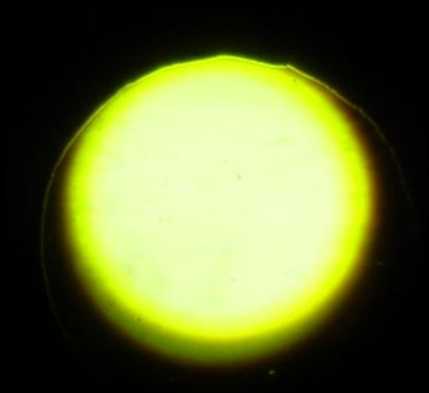


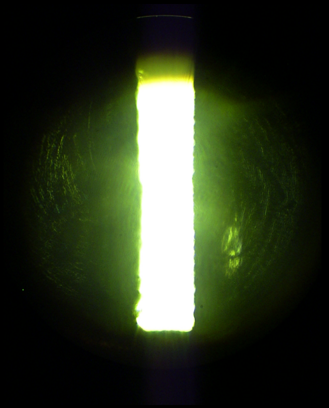
- Using a collimator with a slit instead of a round opening

  $\Longrightarrow$ Reduces the influence on the vacuum in scattering chamber or rather in the HESR

Improvement of vacuum in scattering chamber

LM-Micrograph of a collimator with round opening and slit

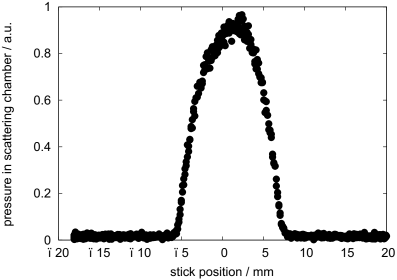


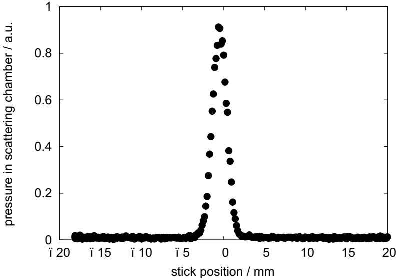


$\varnothing = 0.7\,\mathrm{mm}$ $\quad$ $150 \times 860\,\mu\mathrm{m}$

Improvement of vacuum in scattering chamber

Round shaped cluster beam vs. line formed cluster beam





Cluster beam is easy to shape with an orifice

$\Longrightarrow$ Effective target beam size as small as possible

Requirements for an internal target for $\overline{\text{P}}$ANDA

- High purity of used target material **H_2** ✓
  (good experience with the use of D_2 at previous cluster-jet targets)
- Target density
  - ρ_T in order of $10^{15}\,\frac{\text{atoms}}{\text{cm}^2}$ at $2.1\,\text{m}$ with **movable nozzle** ✓
  - constant in time & adjustable **(depends on temperature & pressure settings)** ✓
- Variable target beam size & shape **(collimator)** ✓
- Effective target beam size as small as possible
  $\longrightarrow$ Low influence on vacuum conditions in the HESR
  (special shaped collimator) ✓

All requirements are fulfilled by using a cluster-jet target

Summary and Outlook

Summary

- Cluster-jet target prototype built up in $\overline{\text{P}}$ANDA geometry
- Prototype set successfully into operation
  (see A. Täschner, et al., Nucl. Instr. and Meth. A (2011)
  & talk of A. Khoukaz, Friday 14.10.2011 at 12.30)
- Inhomogeneous clusterbeam & use of spherical joint lead to higher densities $\Longrightarrow$ Target density: $1.9 \times 10^{15}\ \frac{\text{atoms}}{\text{cm}^3}$ at $2.1\,\text{m}$ ...so far $\ddot\smile$
- The prototype fulfills all requirements for $\overline{\text{P}}$ANDA

Outlook

- Search for settings with the highest density
- Search for smallest size for a special shaped collimator to improve vacuum conditions
- Research on cluster size and mass
- Construction of the final target for $\overline{\text{P}}$ANDA in progress

Thank you for your attention!

Westfälische Wilhelms-Universität Münster

Bundesministerium für Bildung und Forschung