# Nozzle Development and their Characterization by a Mach Zehnder Interferometer

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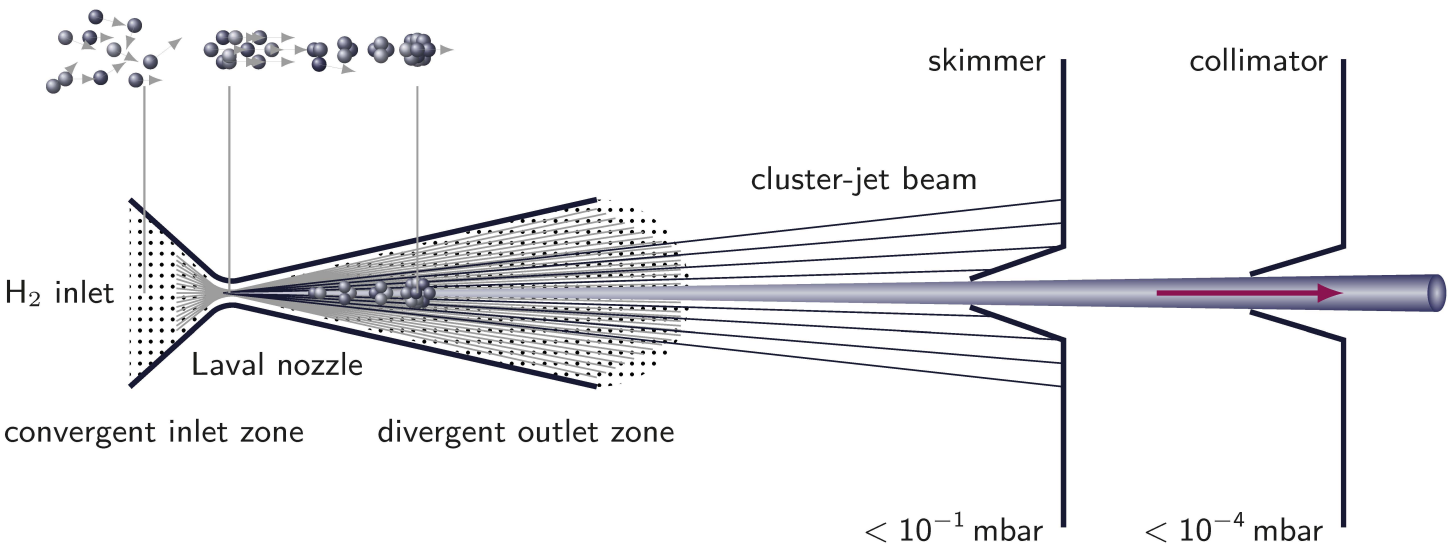
# Motivation

## Production of new Laval nozzles

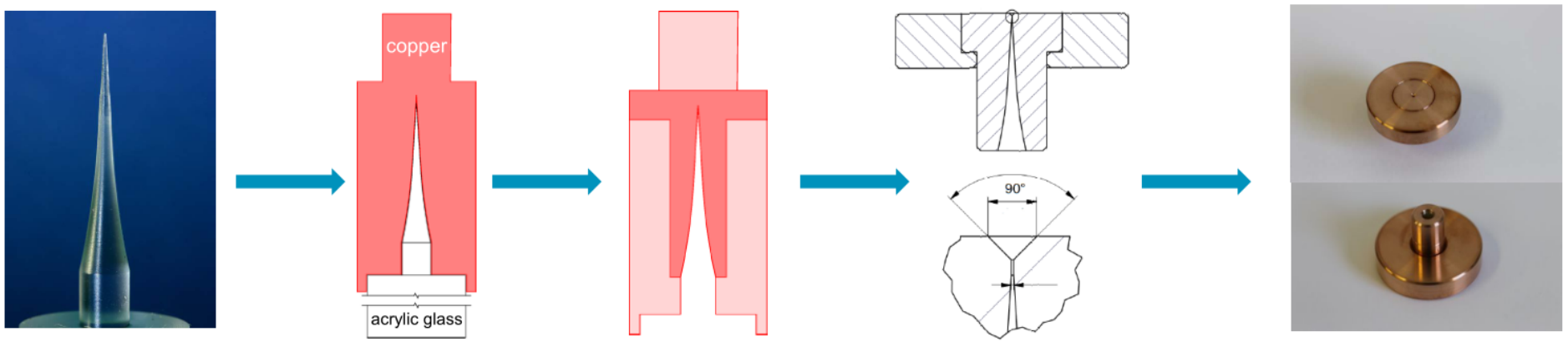
- Laval nozzle is the heart of a cluster source
- Specific convergent-divergent shape




- Production of a small inner diameter ($< 30$ µm) in combination with the complex geometry is a major technical challenge
- In the past these fine Laval nozzles were produced at CERN

# First produced Nozzles (galvanic deposition) at Münster

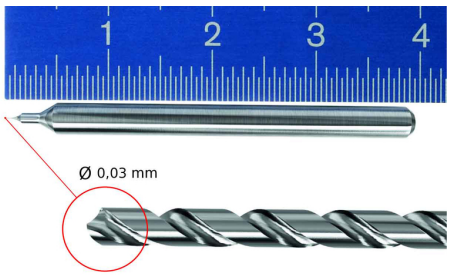
- To ensure the production an improved production process based on the CERN production was recently developed at the University of Münster

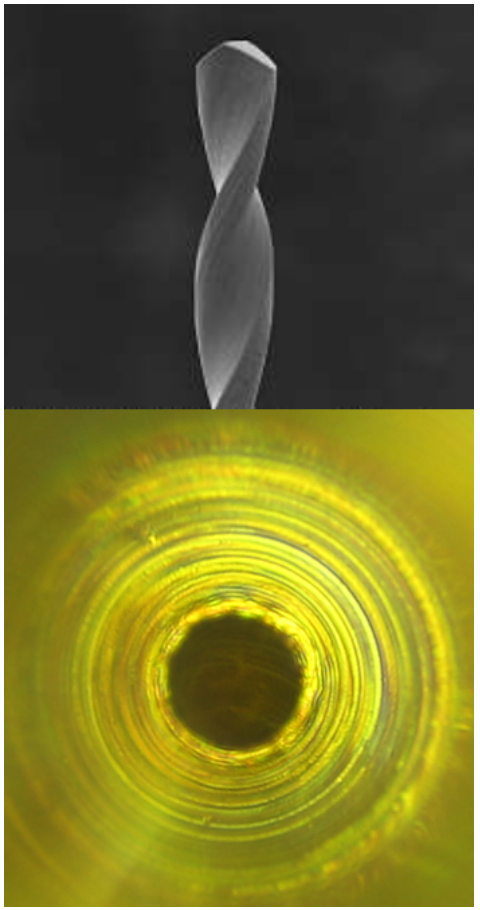


# First produced Nozzles (galvanic deposition) at Münster

## Precise drilling of the small inner diameter

- Drilling
  - Above: Micro drill (enlarged)
  - Below: Narrowest inner diameter of the nozzle (25 $\mu m$)



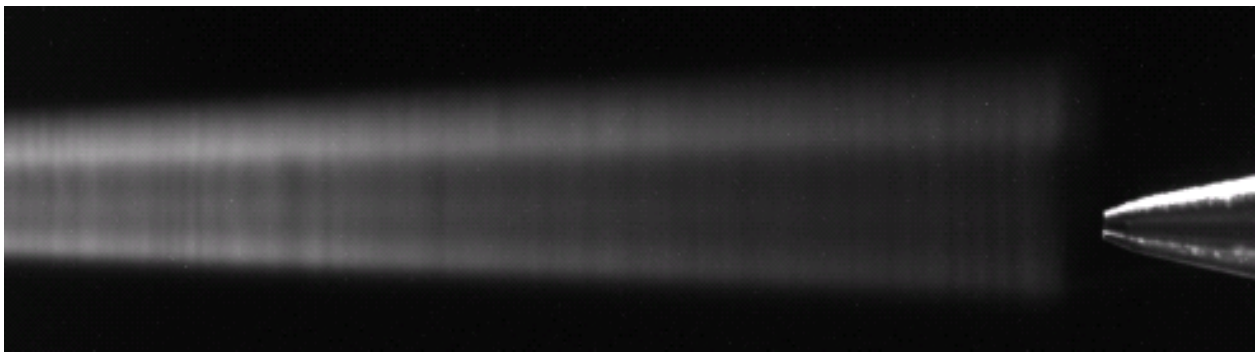



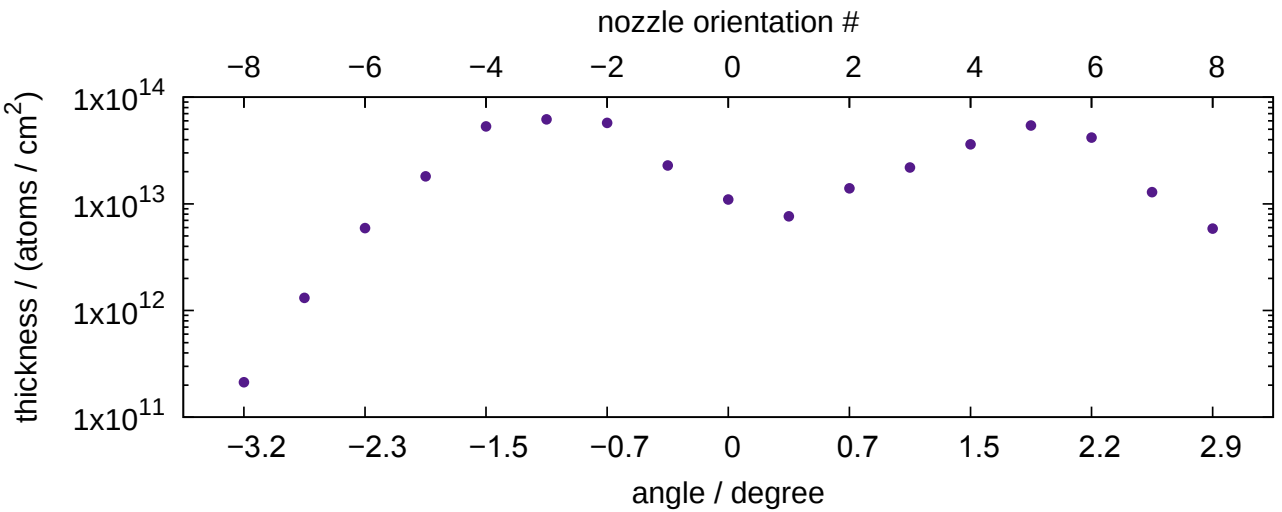
- Drill does not reach the opening cone
  - Possible reasons: By the galvanic deposition the tip of the negative became skew/ got blunted

$\Rightarrow$ More systematic work required

# Measurements with the first produced Nozzles at the $\overline{\text{P}}$ANDA Cluster-Jet Target Prototype

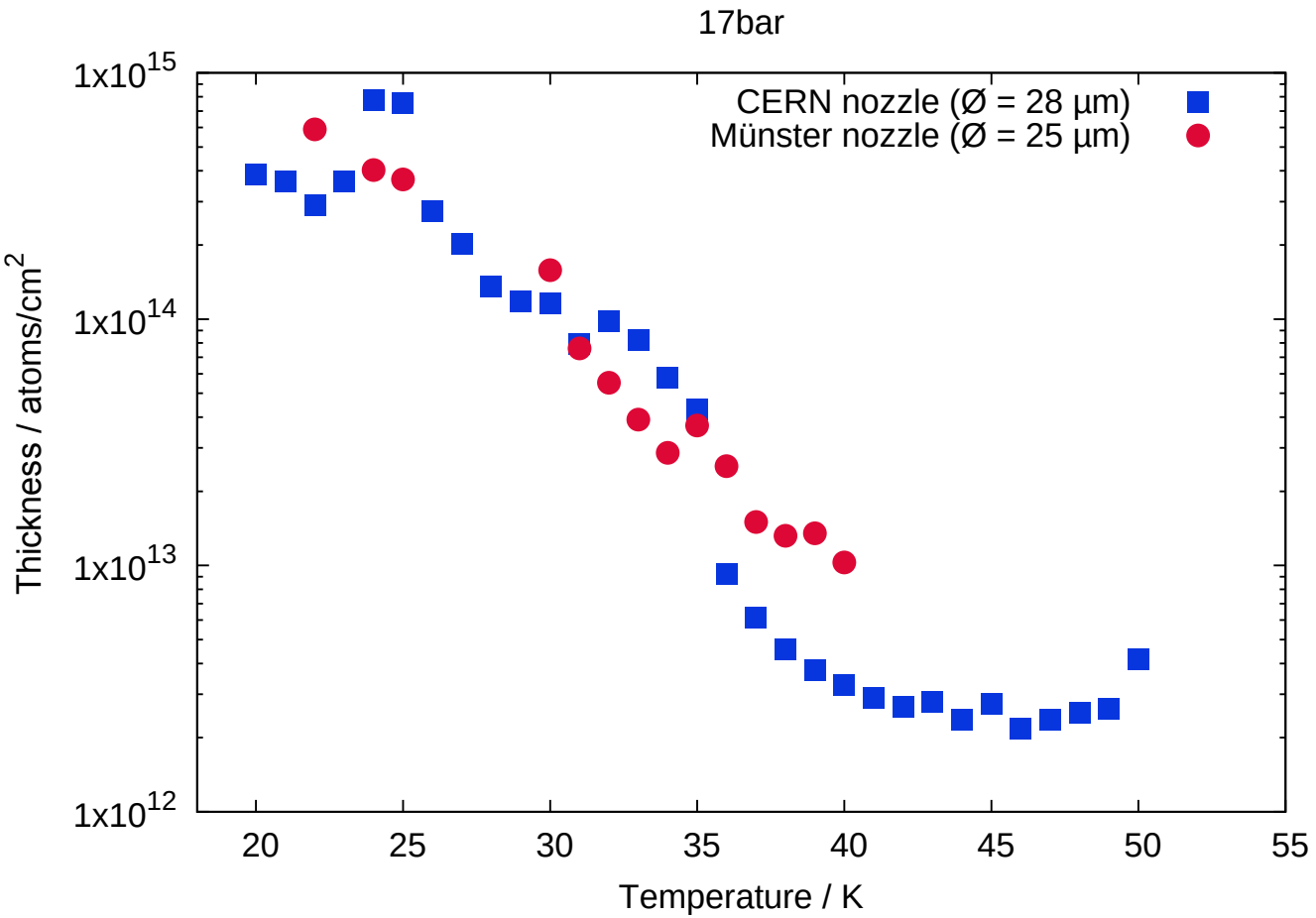
- Highly Intense Core Beams: 35 K, 17 bar (A.-K. Hergemöller, B. Hetz)





# Measurements with the first produced Nozzles at the $\overline{\text{P}}$ANDA Cluster-Jet Target Prototype

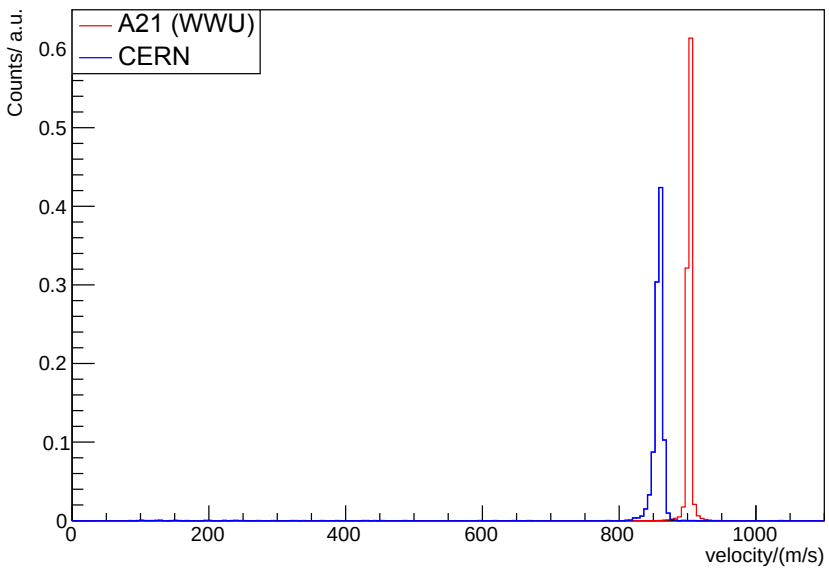
- Target thickness: 17 bar



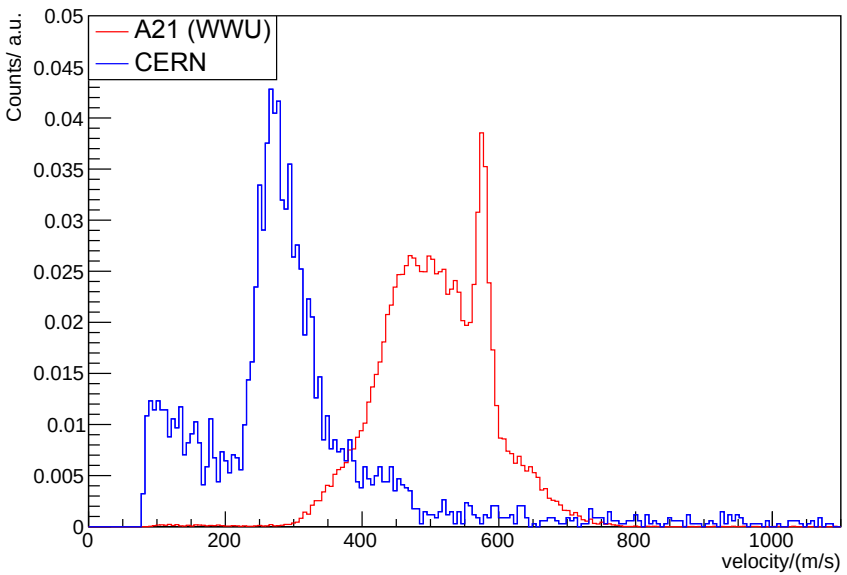
# Measurements with the first produced Nozzles at the $\overline{\text{P}}$ANDA Cluster-Jet Target Prototype

## Velocity

- 8 bar 32 K
- Gaseous $H_2$ in front of nozzle
- Typical slim distribution

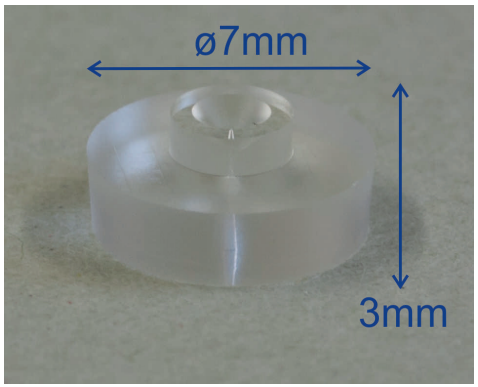


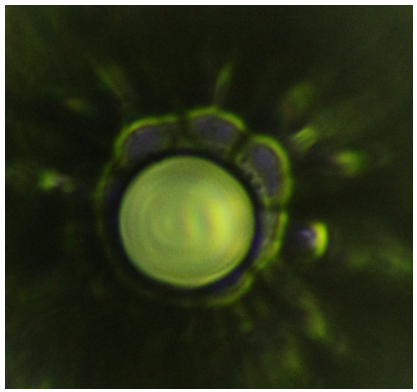

- 8 bar 28 K
- Liquid $H_2$ in front of nozzle
- Typical wide distribution



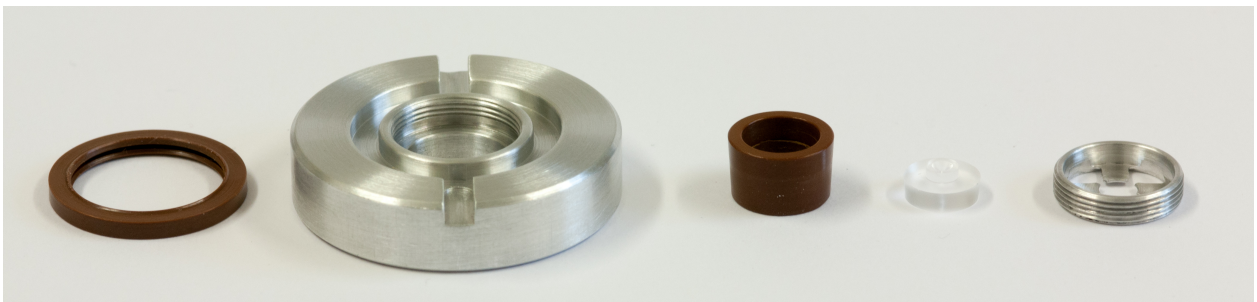

$\Rightarrow$ Currently under investigation

# Glass Nozzle



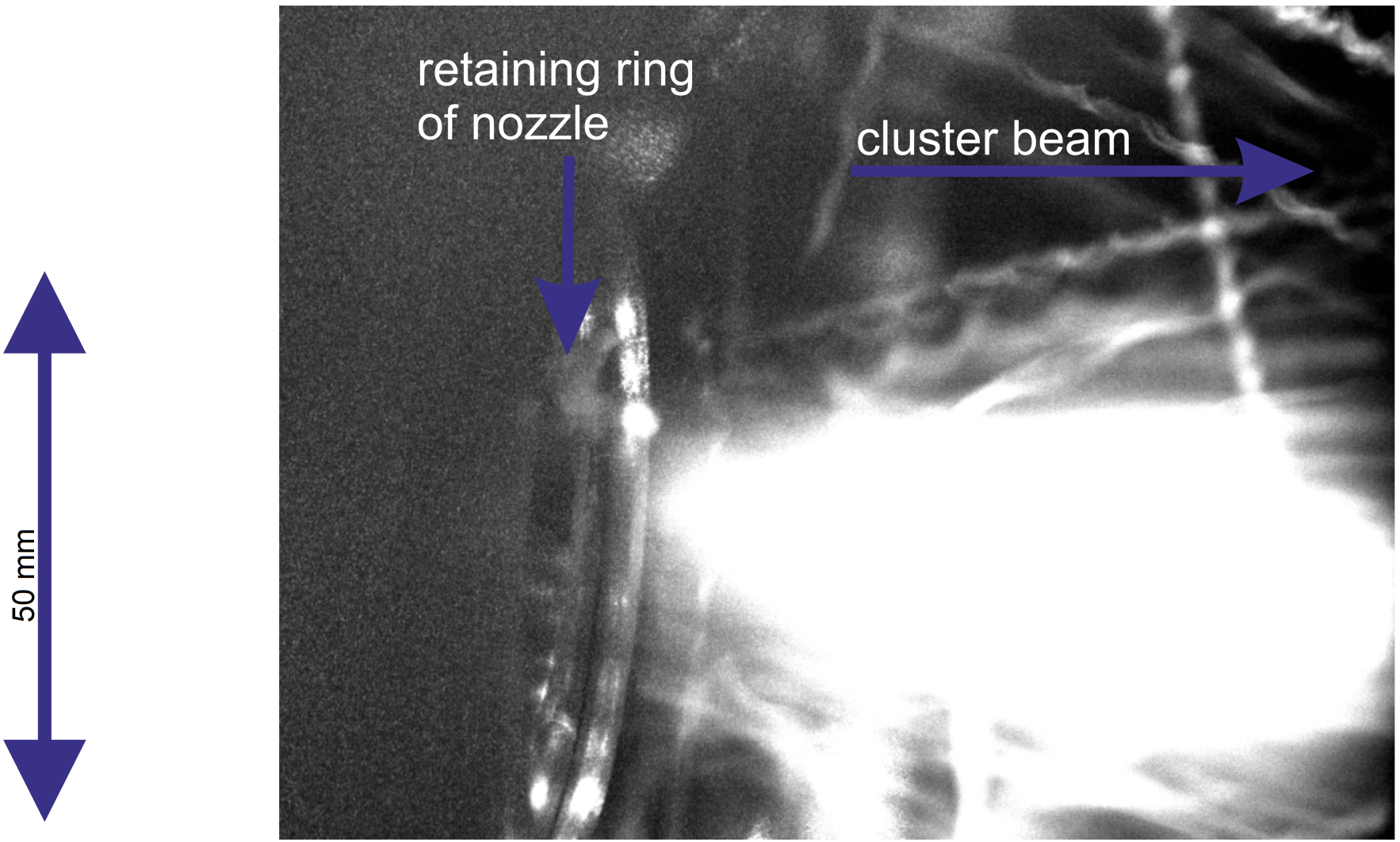



- Manufactured by selective laser etching of glass (30 $\mu$m)



- Sealing ensures: Accurate extraction, non-poisonous, reusable
  $\Rightarrow$ Excellent alternative for indium (even for the CERN nozzles)

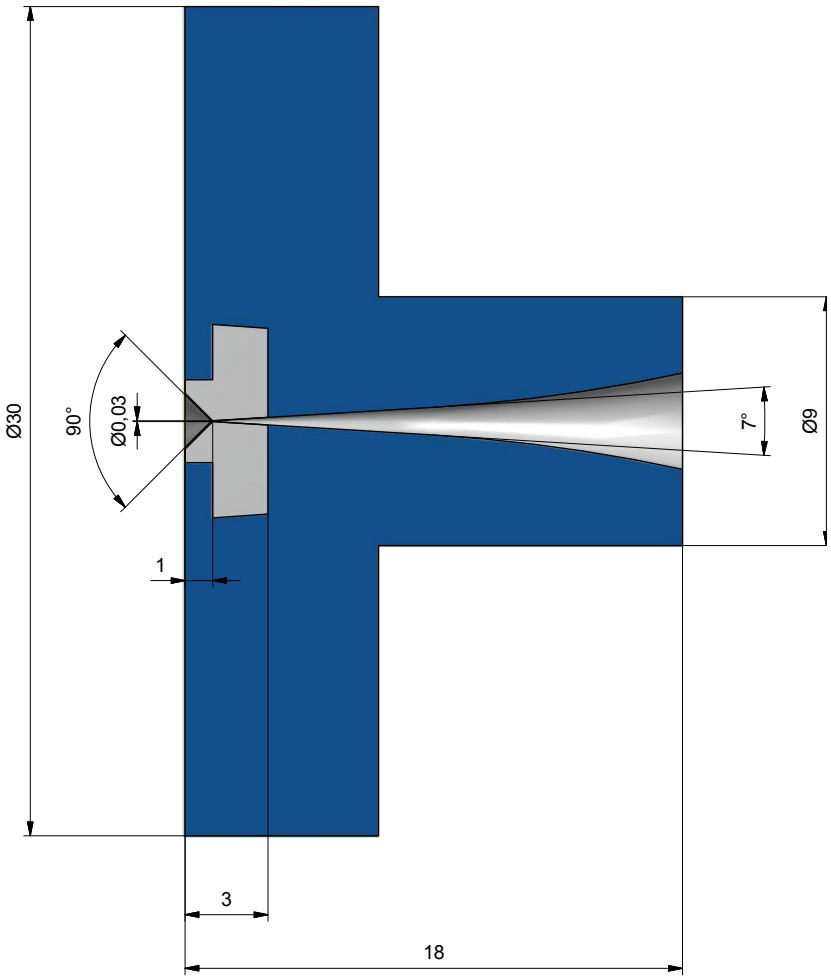
# Initial Measurements with new Nozzles at the $\overline{\text{P}}$ANDA Cluster-Jet Target Prototype: 25 K, 8 bar



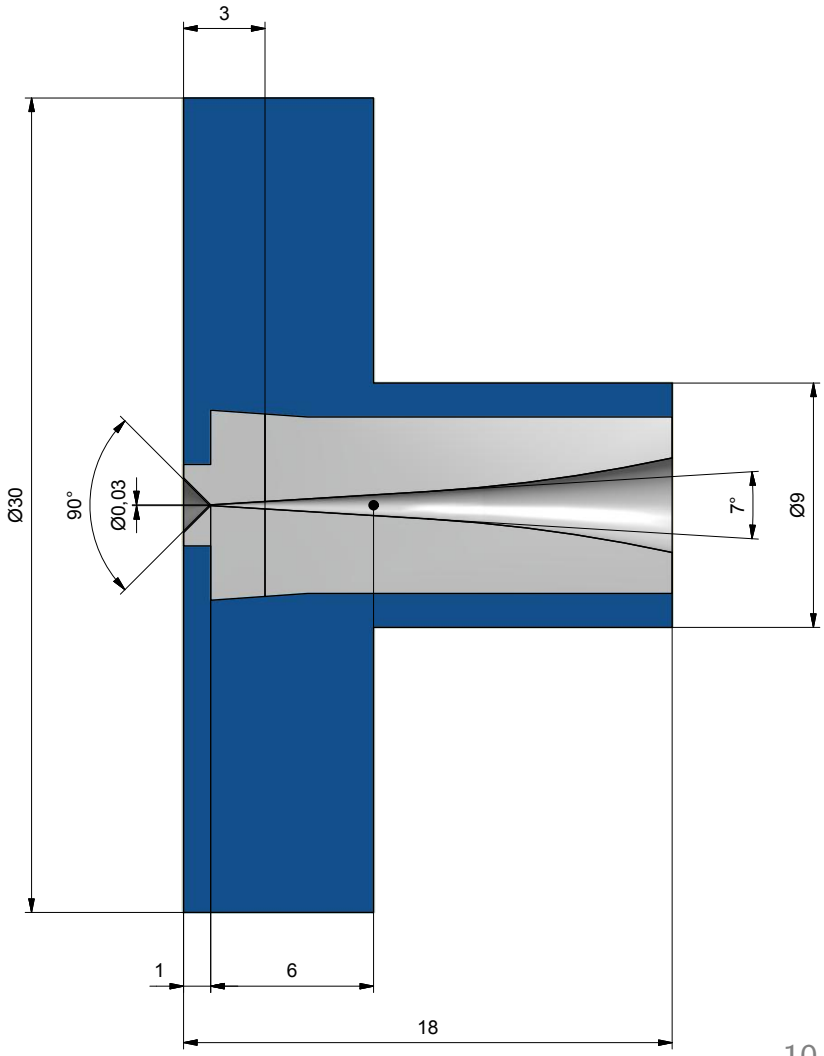
# Glass Nozzle

## Glass nozzle, CERN nozzle, Extension (⌀: 280 µm)

- Comparison between glass nozzle and CERN nozzles



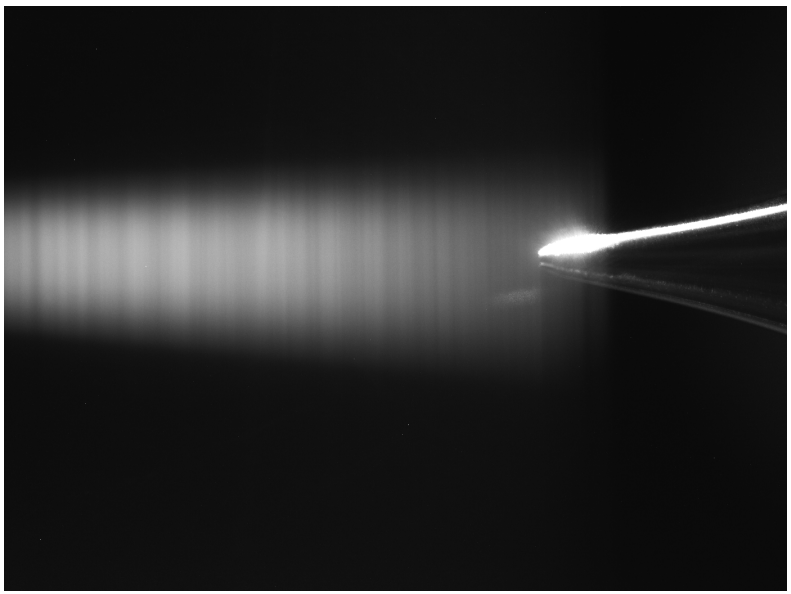

- Glass nozzle with extension



# Glass Nozzle

## Extension for Glass Nozzle

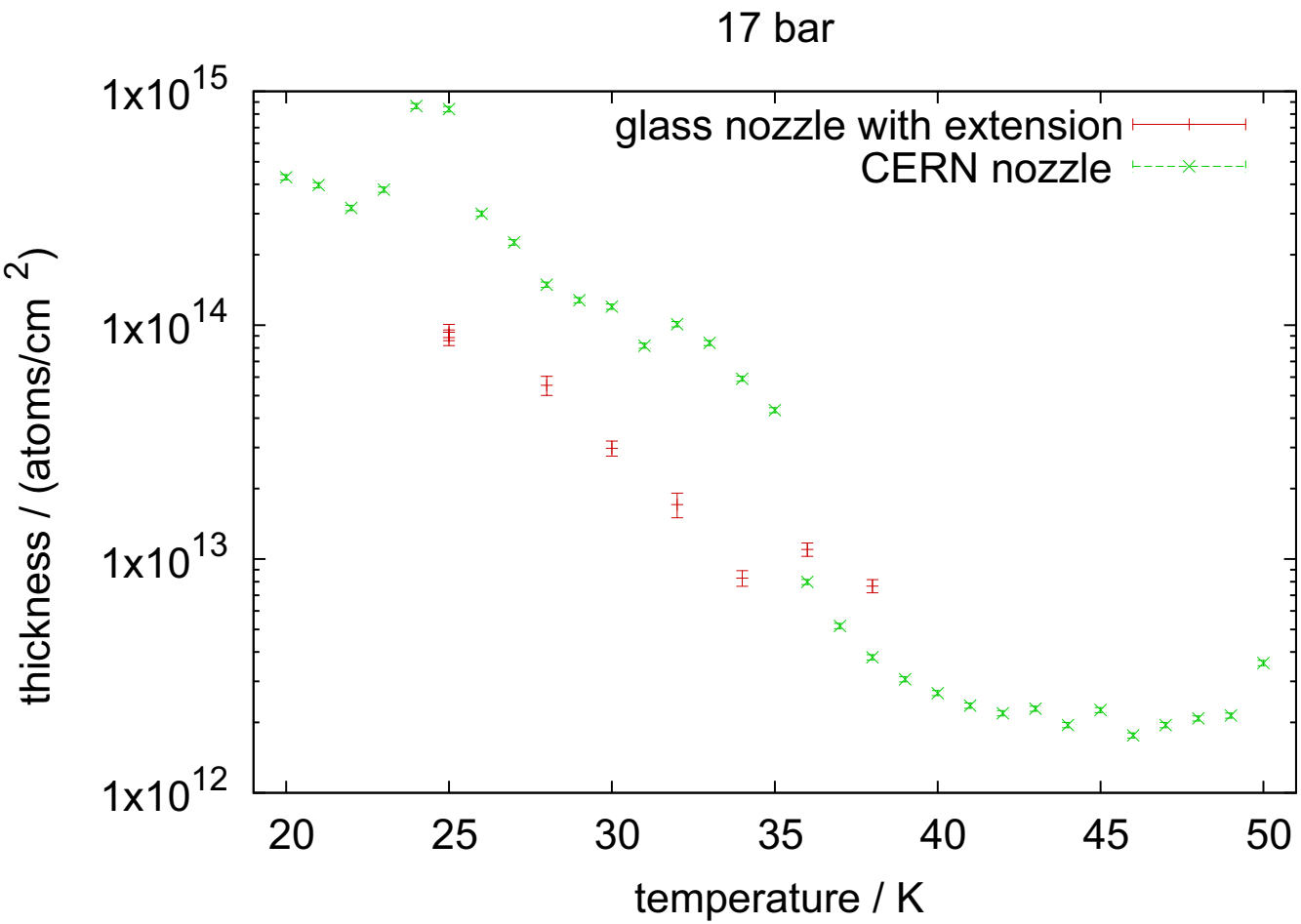
- Extension (narrowest inner diameter: 280 $\mu$m)



# Glass Nozzle

## Extension for Glass Nozzle

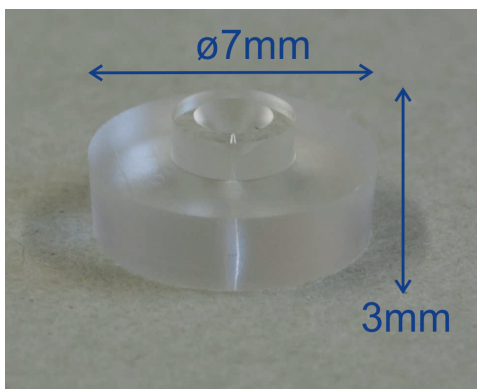
- Glass nozzle (30 $\mu$m) with extension (280 $\mu$m)
  $\Longrightarrow$ Without adjustments
- CERN nozzle (28 $\mu$m) (measured by Dr. E. Köhler)



# Interim Conclusion

## Nozzle Development at Münster

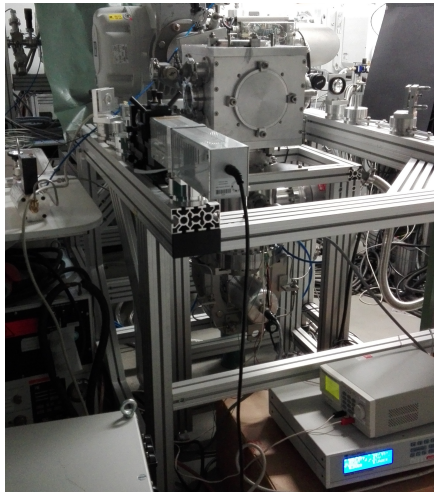
- Nozzle development on a good way
- Ideas for promising solution approach
- Further research and development optimizsation required
- Additional investigations needed
- More work required

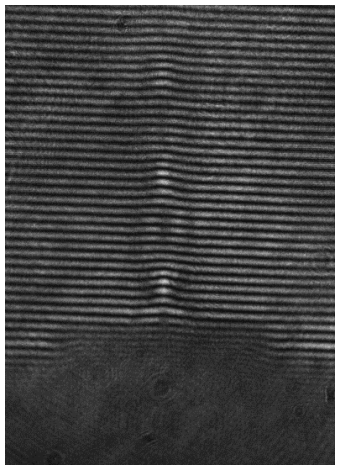


**Mach Zehnder Interferometer**

Investigations of

- Target thickness
- Shape of the target beam
- Range of the target beam
- Impacts of stagnation conditions at the nozzle
- Studies of nozzles with different geometries





**Mach Zehnder Interferometer**

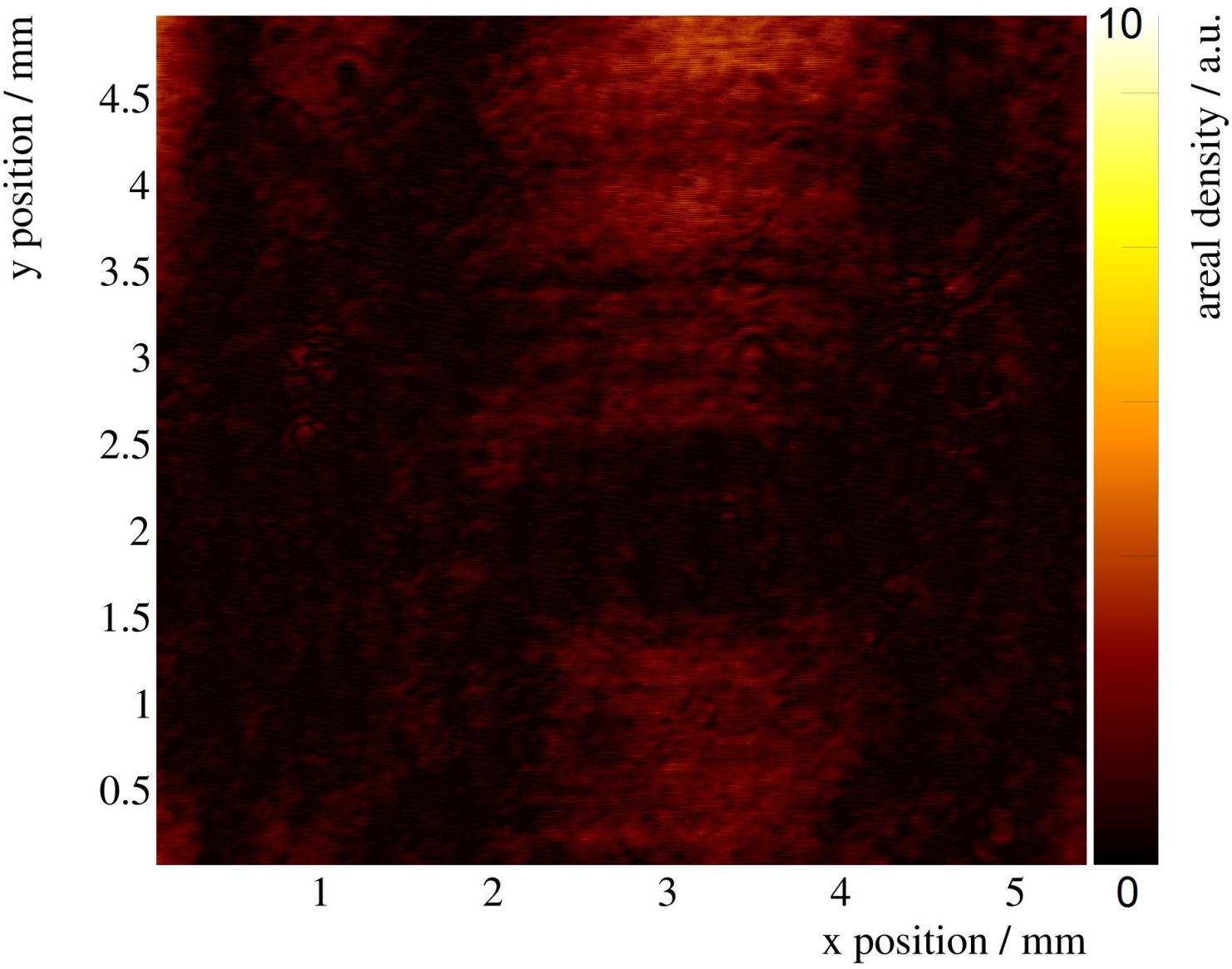
Experimental setup:

- Nitrogen
- Temperature: 288 K
- Pressure: 20 bar
- Round nozzle with $\varnothing$: 0.5 mm & outlet: 2 mm
- Exposure time: 10 µs

Analysis:

- Phase shift: $\rho_A(x, y) = \frac{\Delta\Phi(x,y)}{2\pi} \frac{\lambda}{k_{GD}}$
- Gladstone Dale constant: $k_{GD}$

# Investigations on Beam Properties: Expansion into Atmosphere



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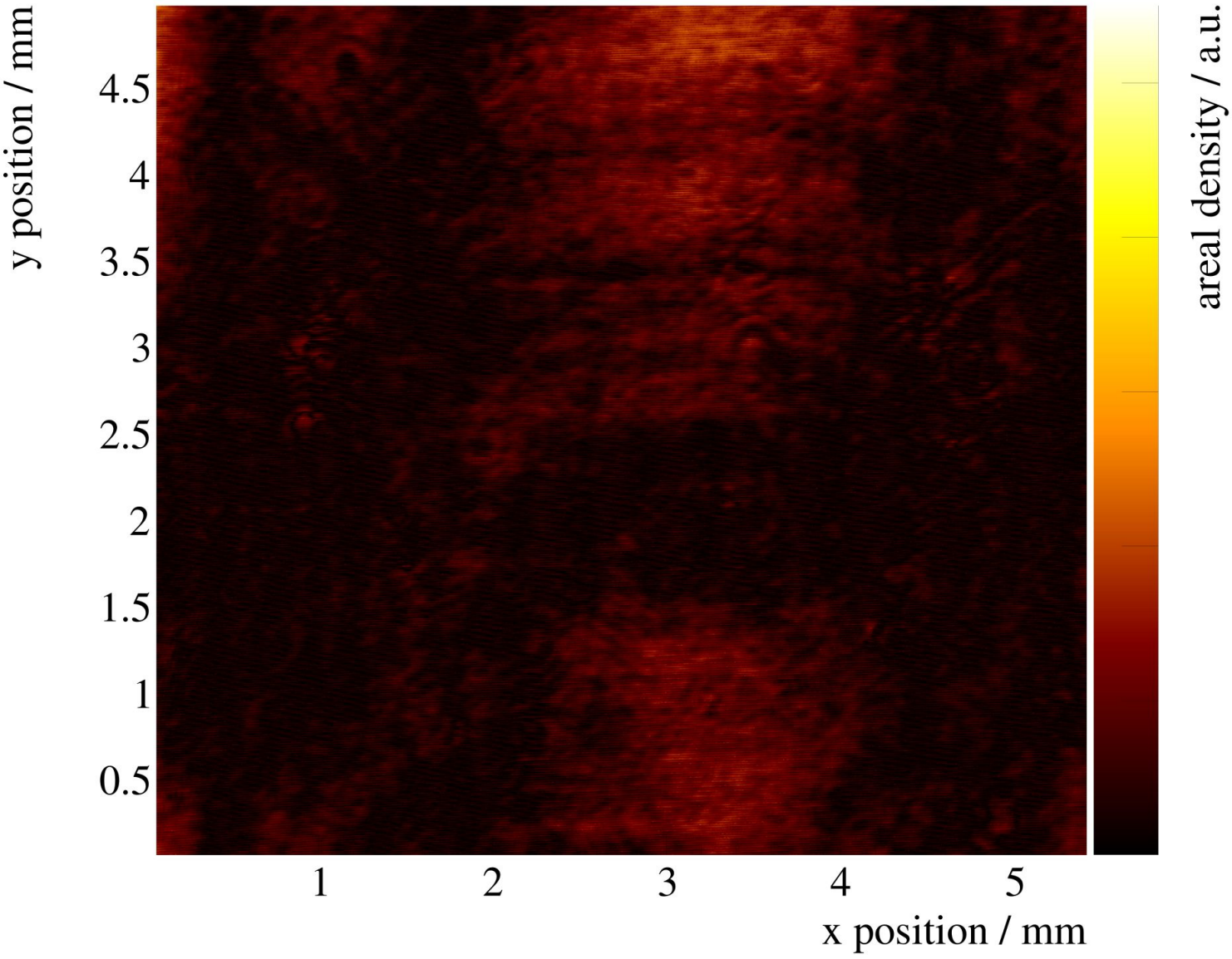

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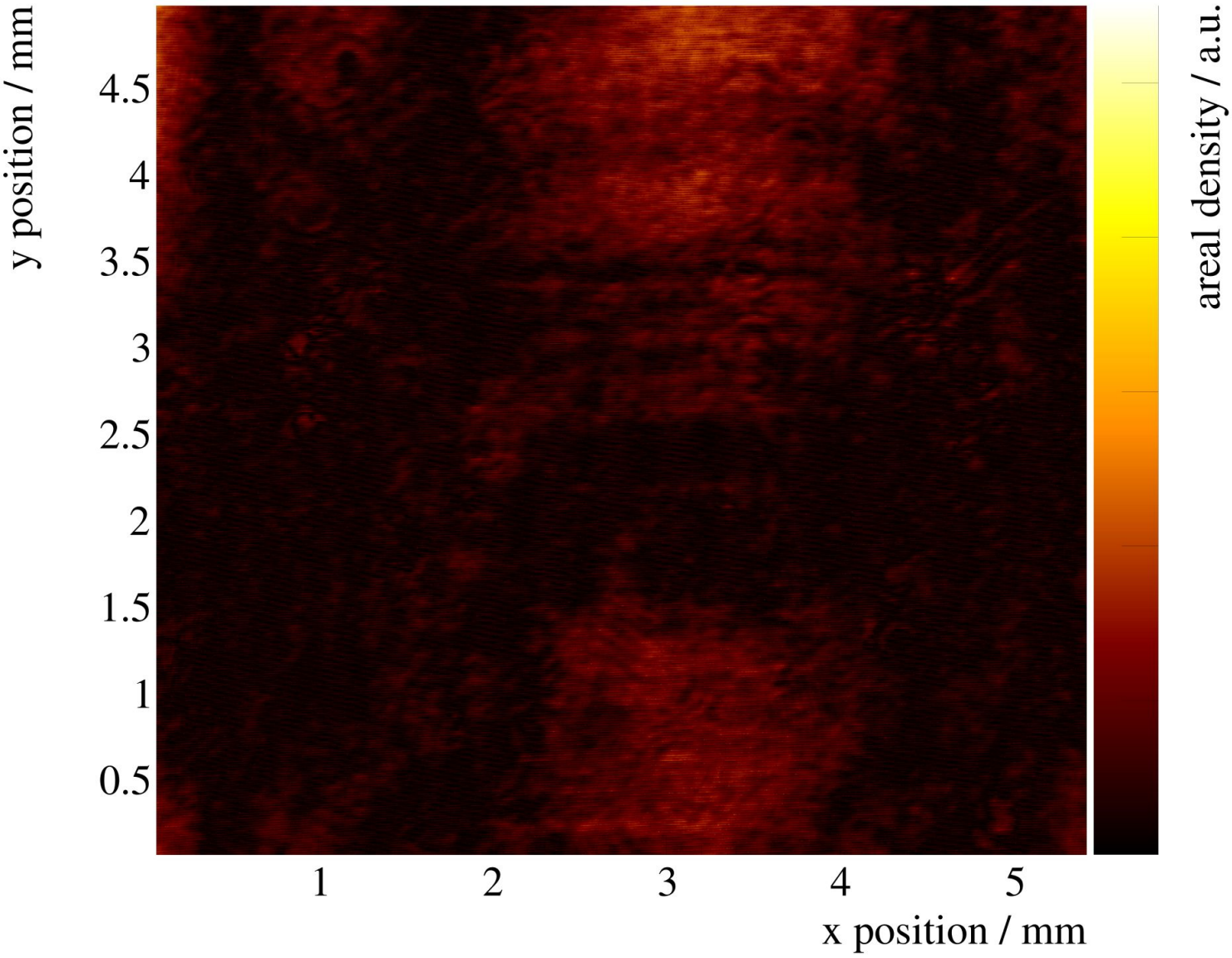

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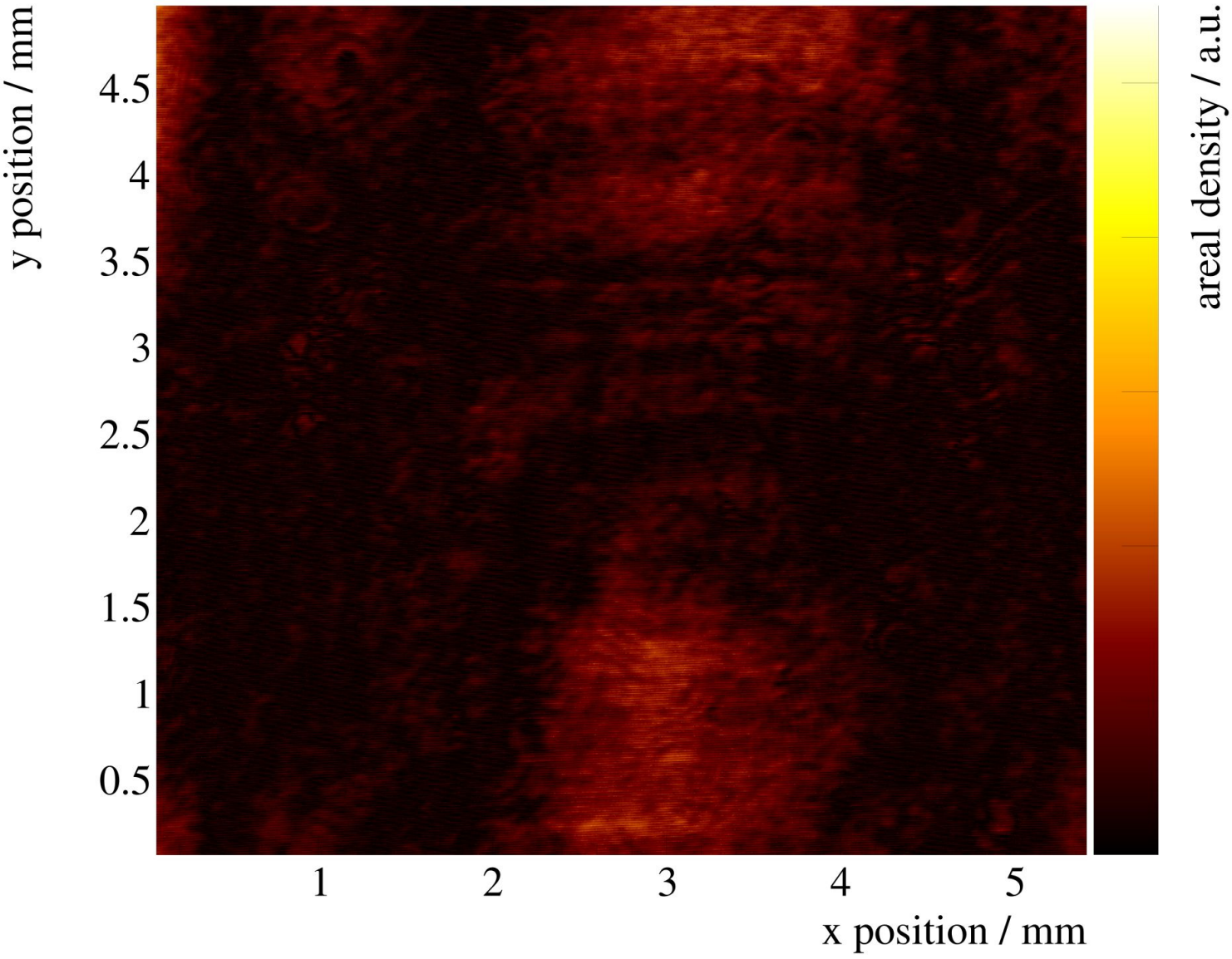

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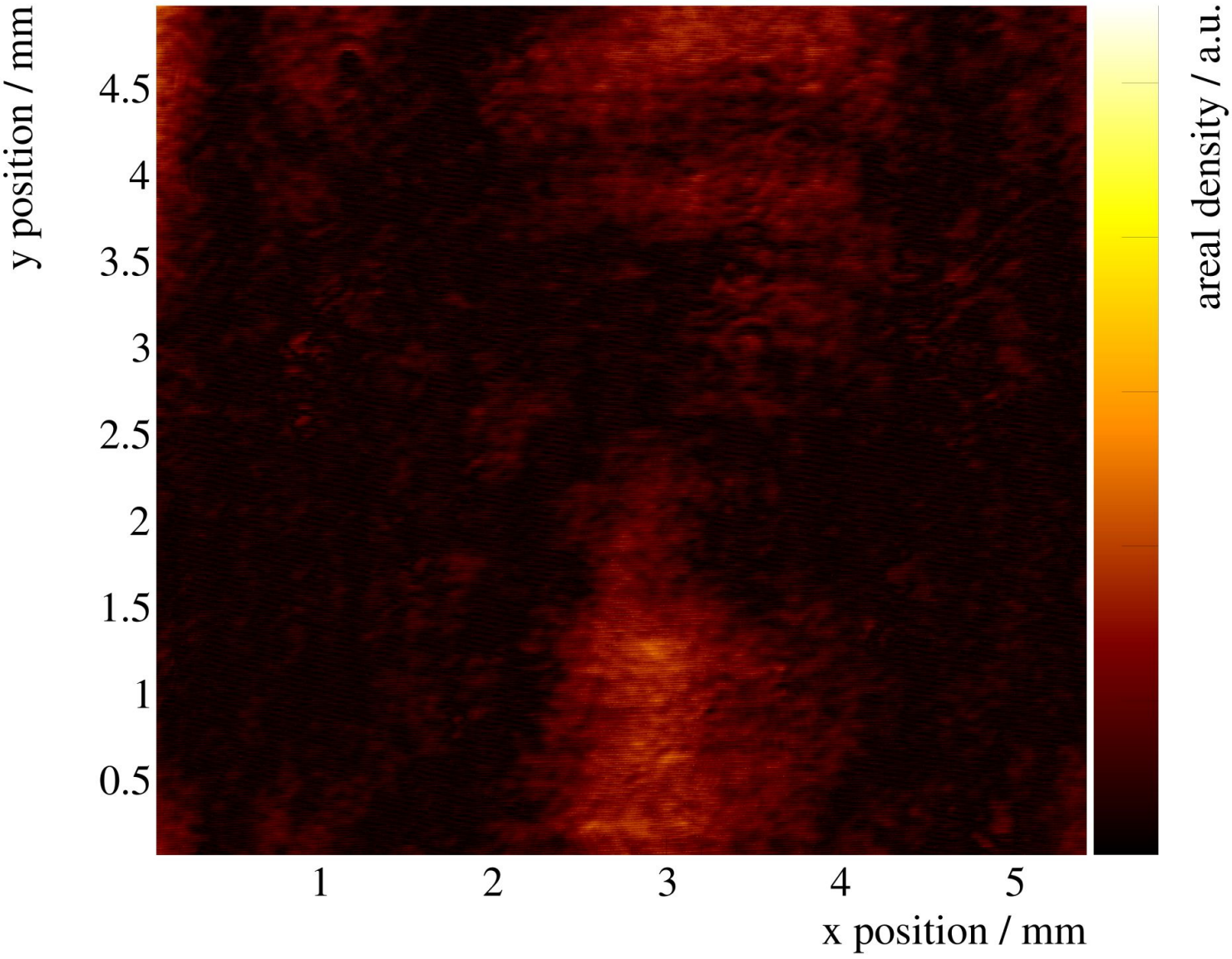

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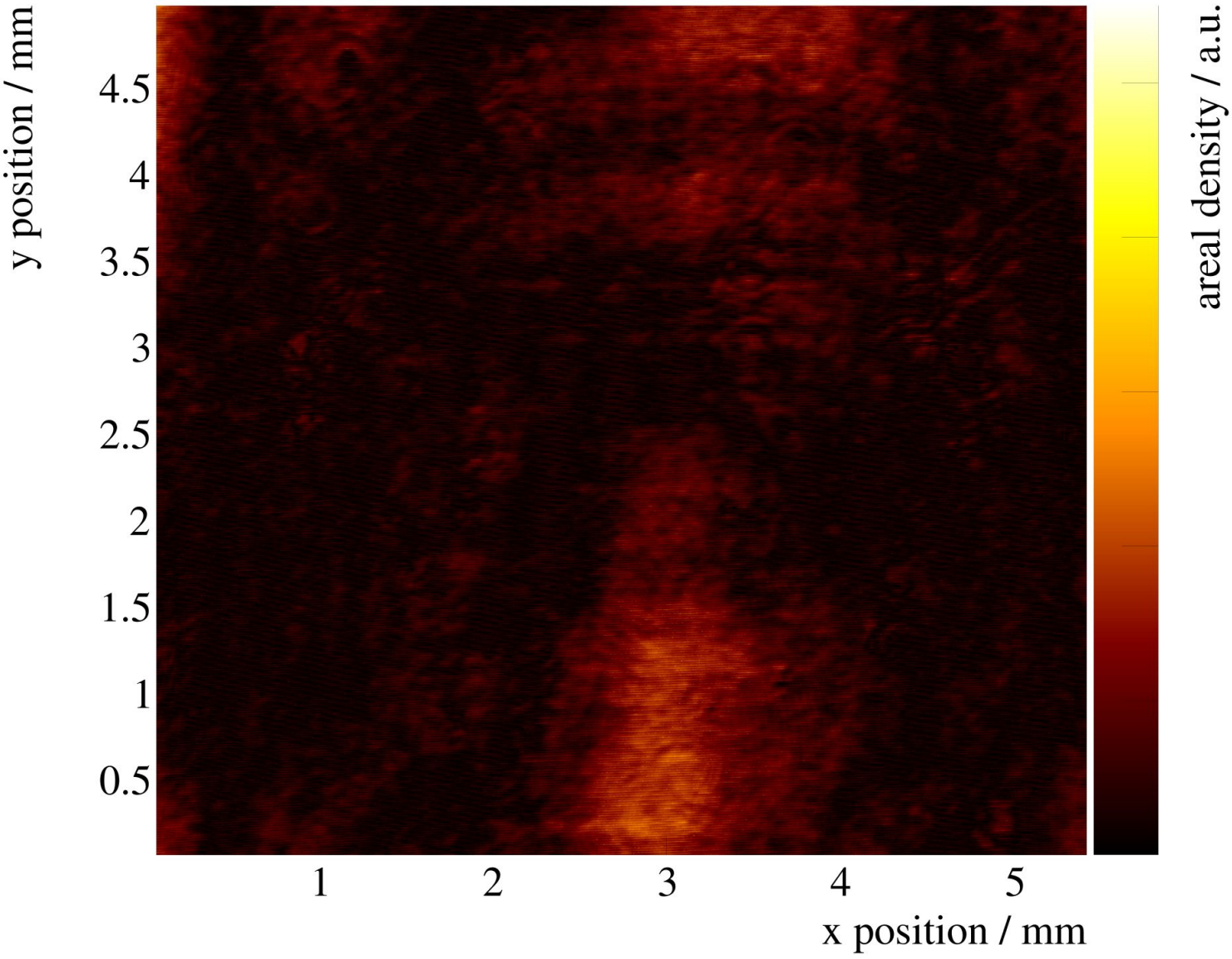

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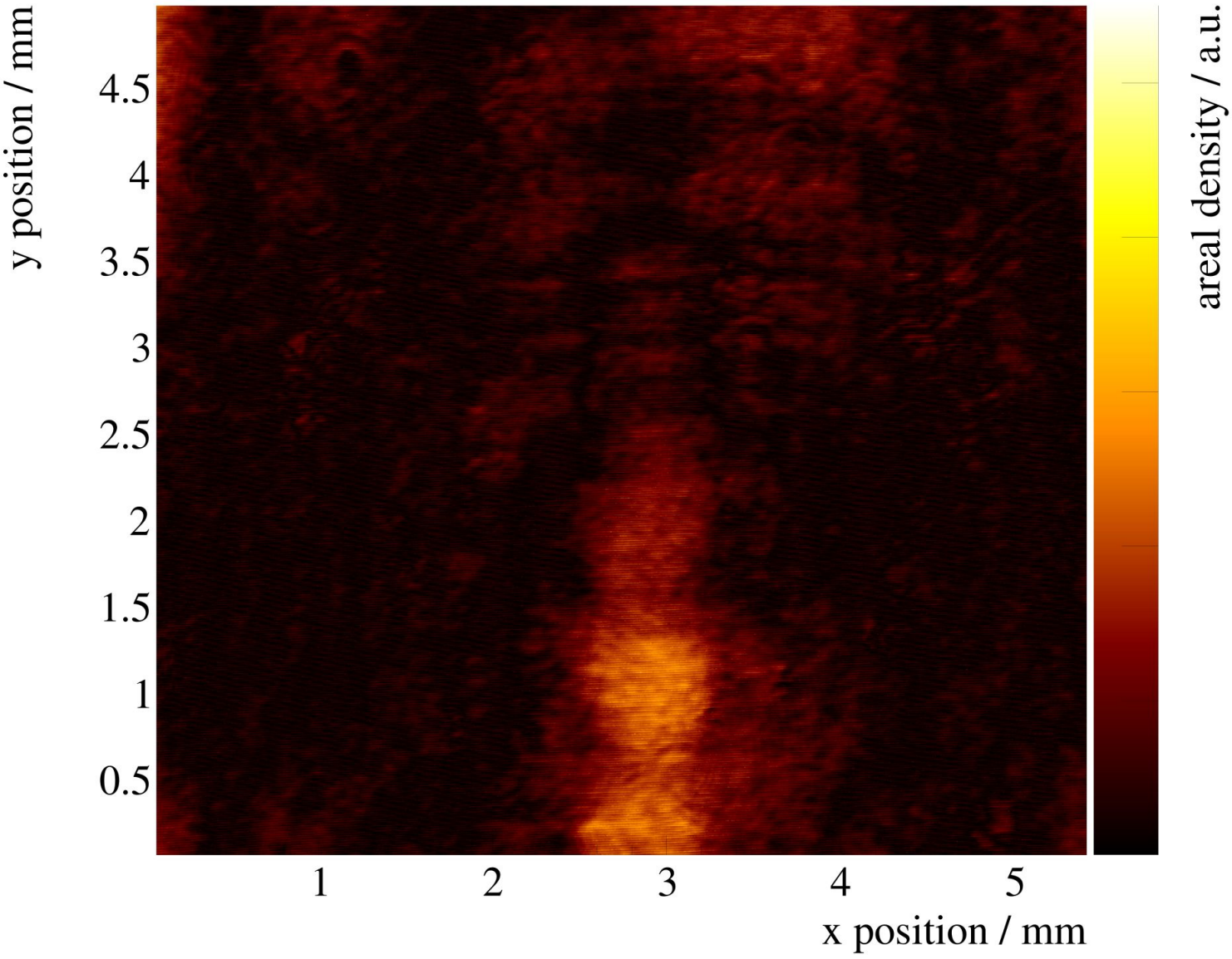

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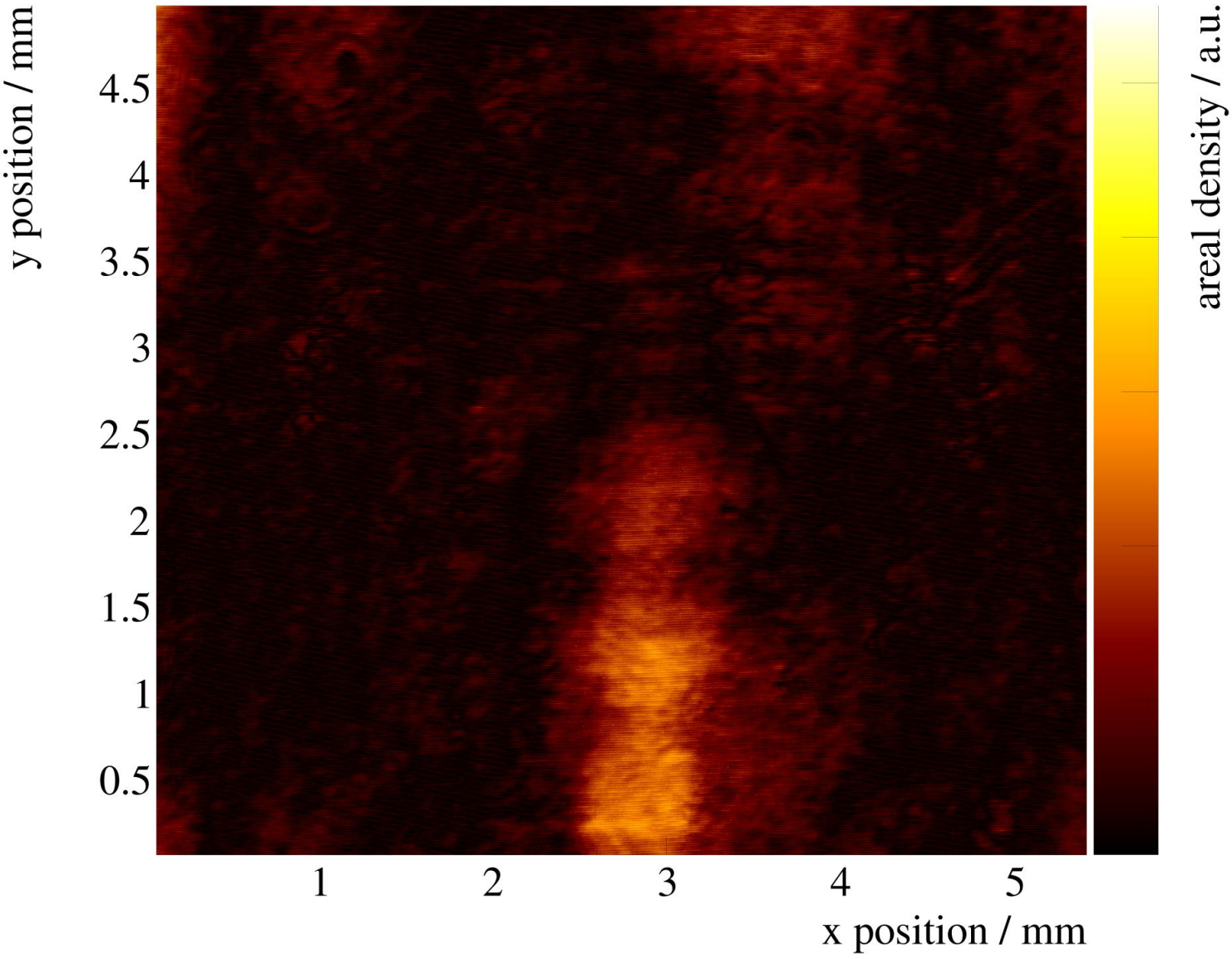

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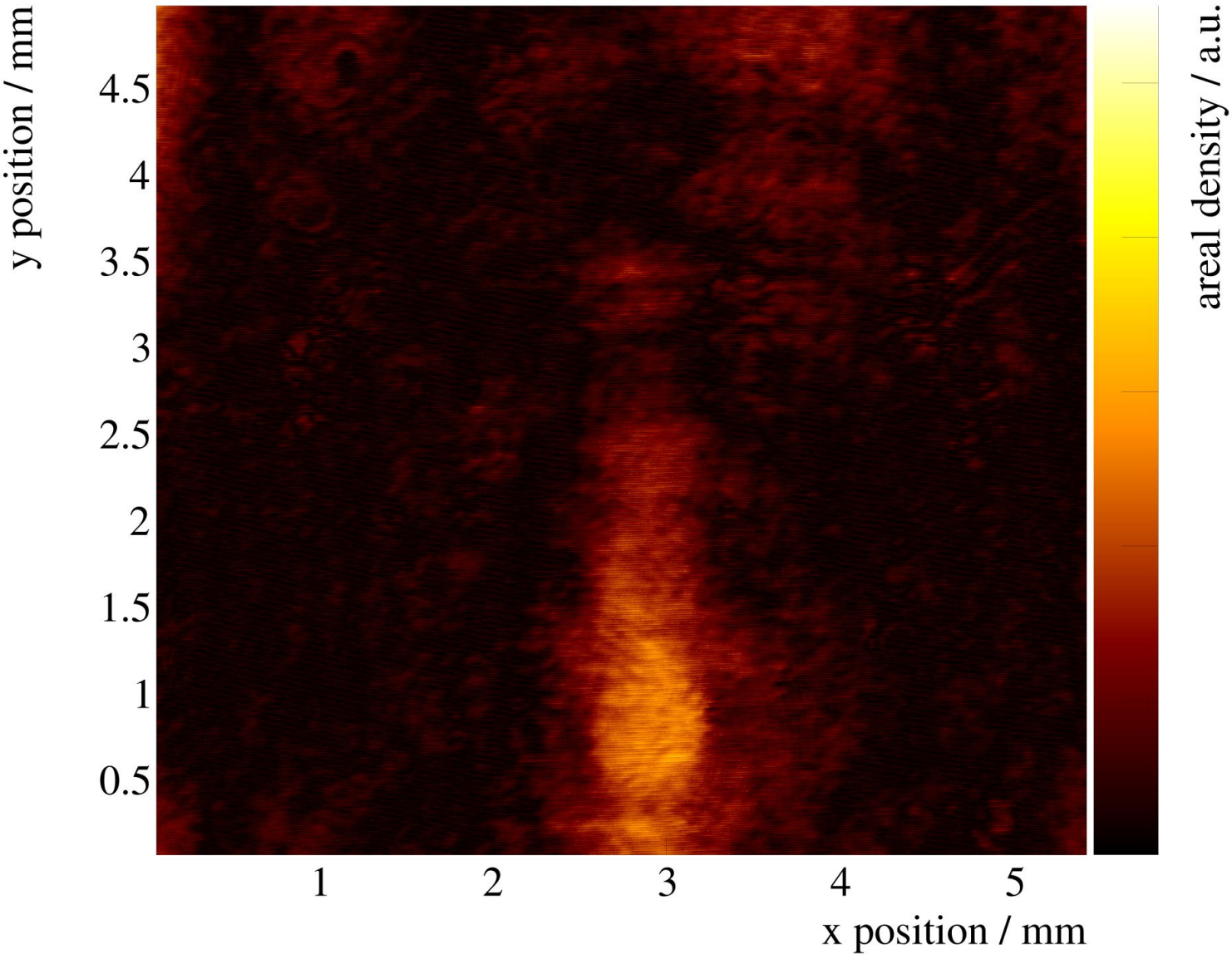

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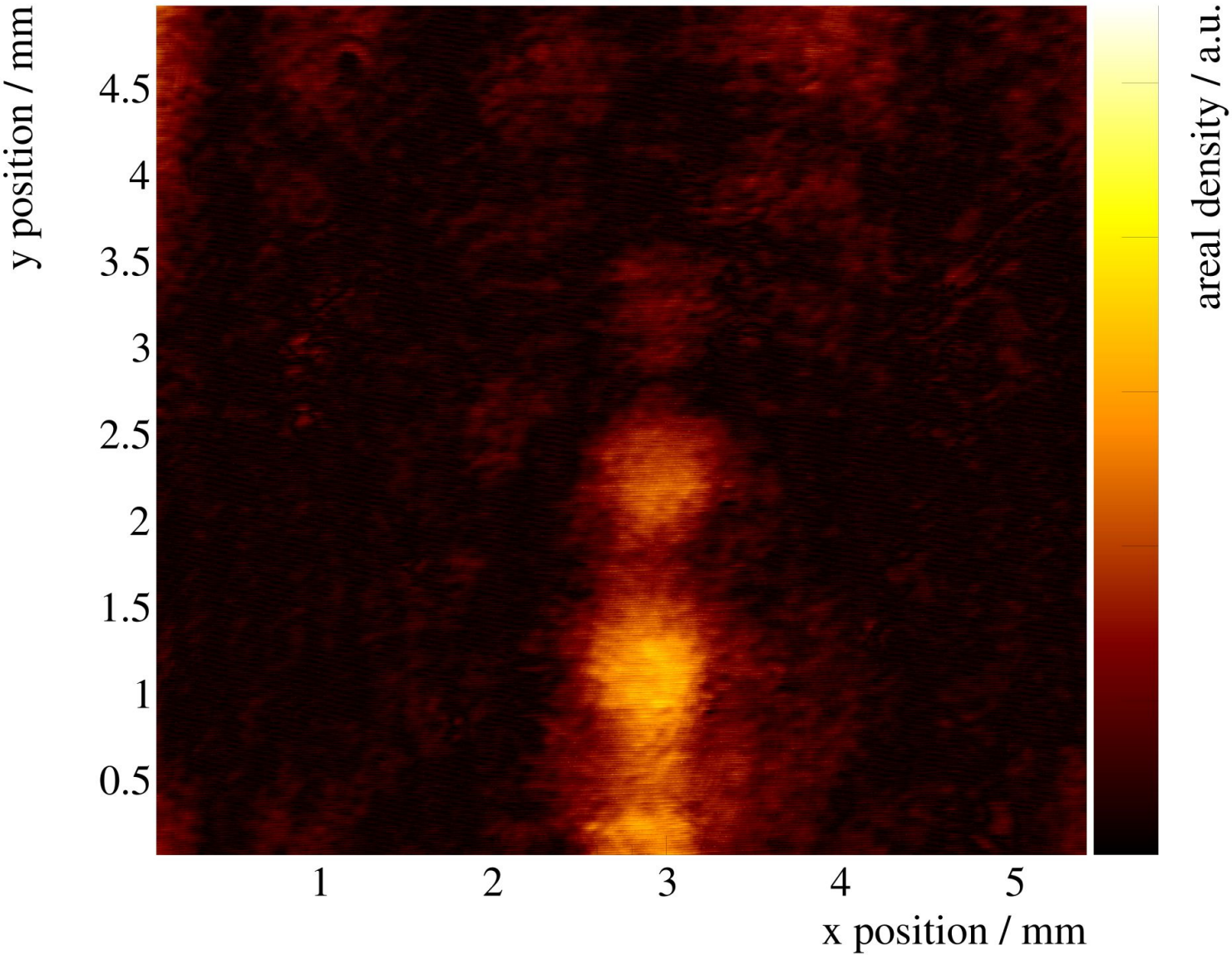

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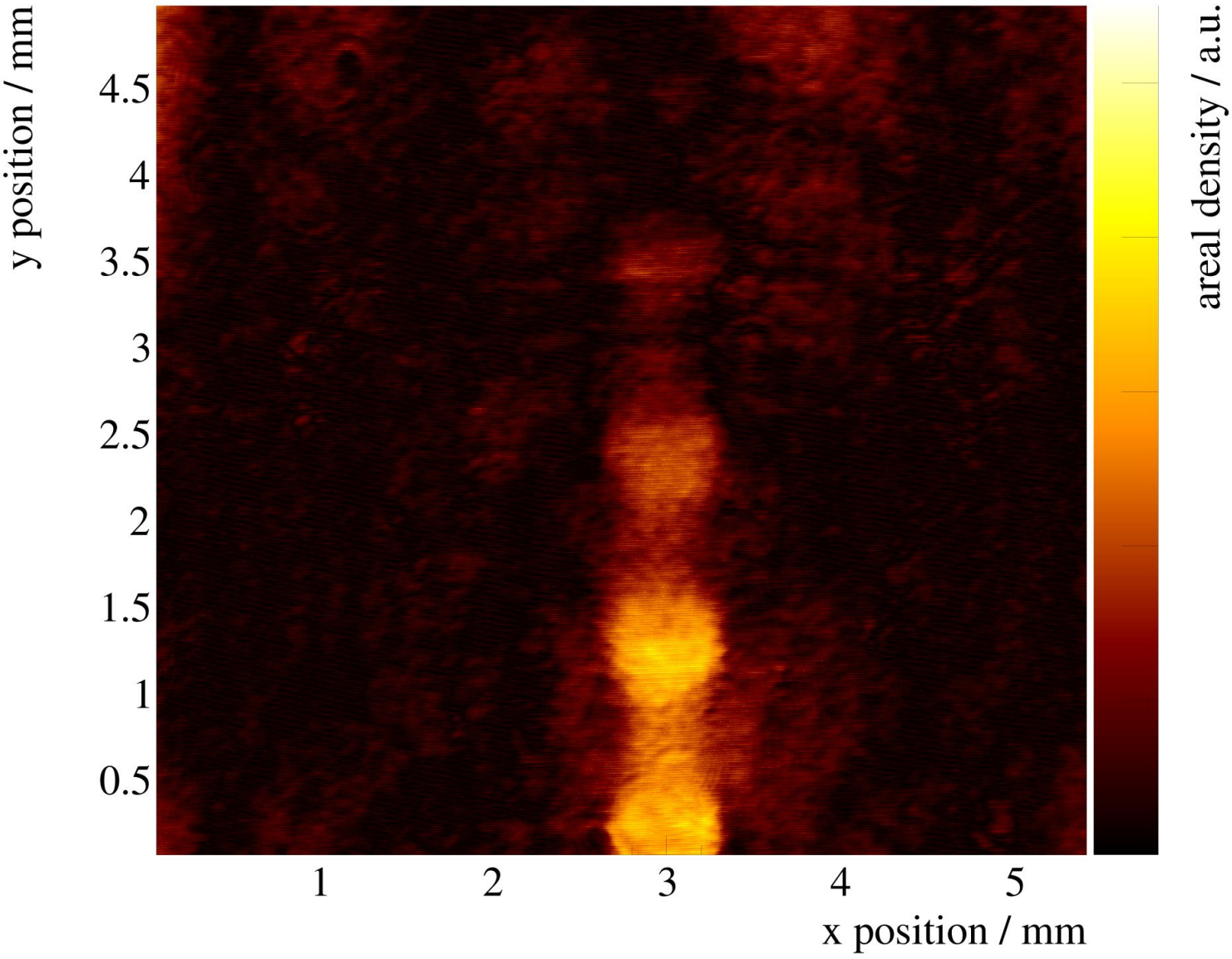

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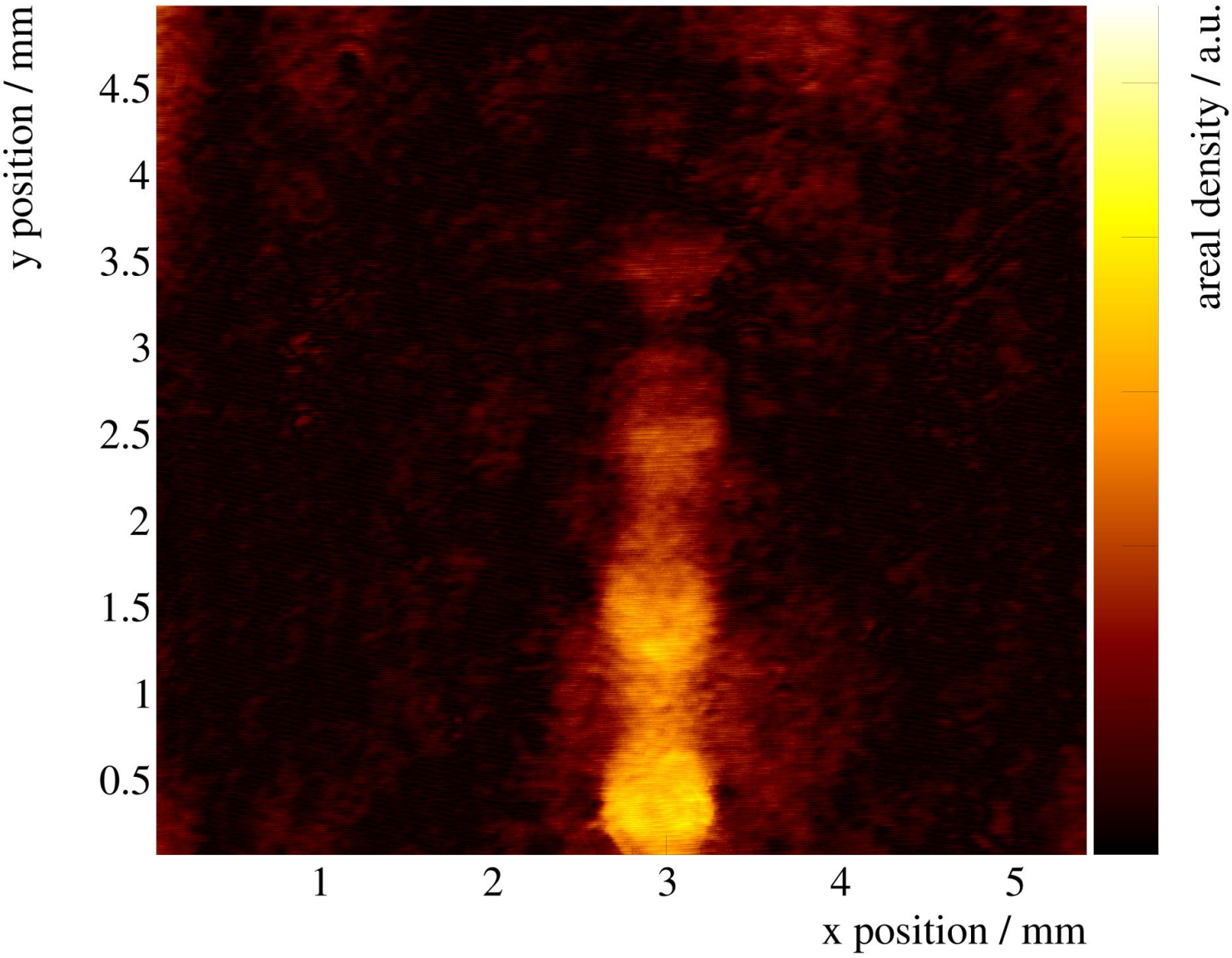

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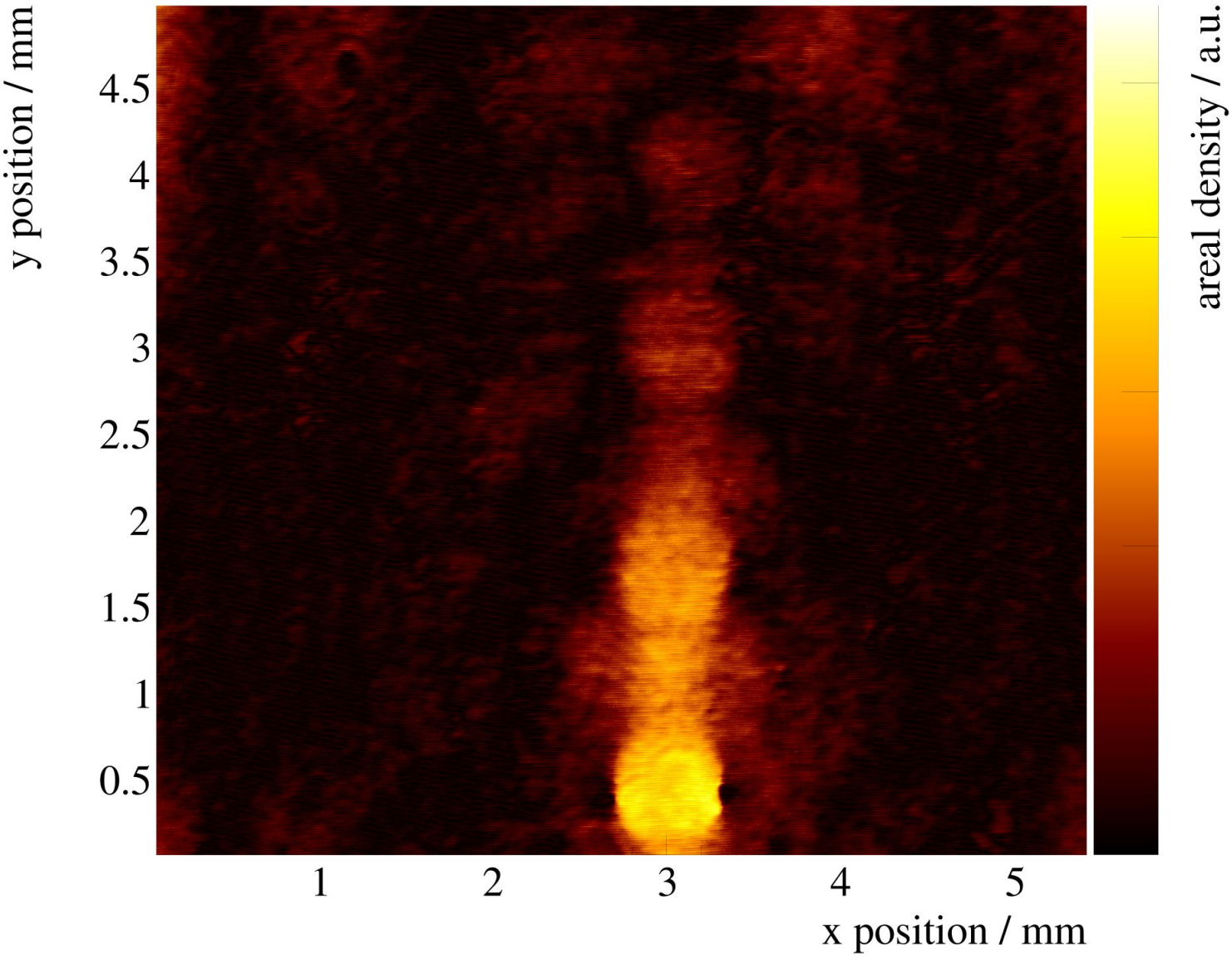

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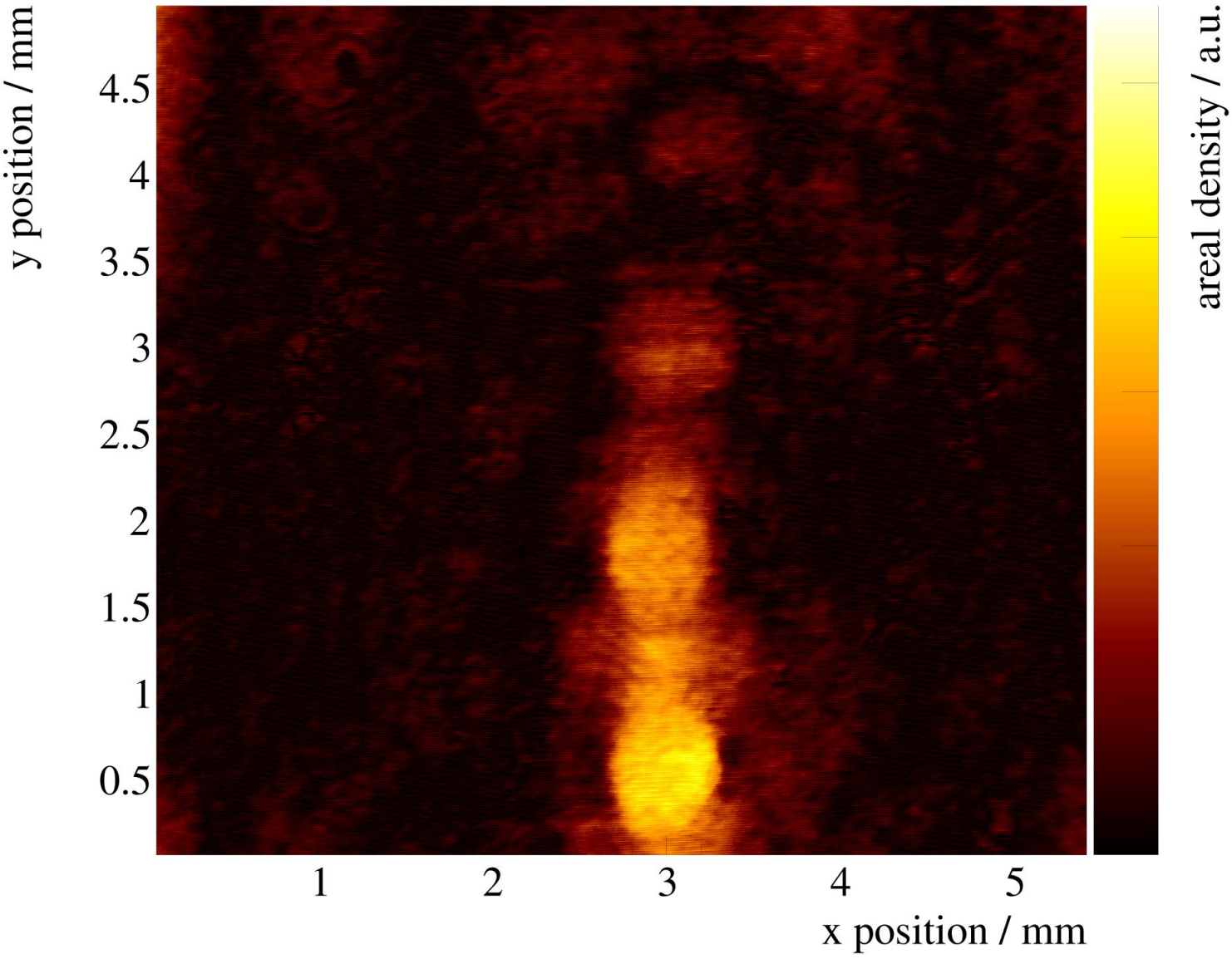

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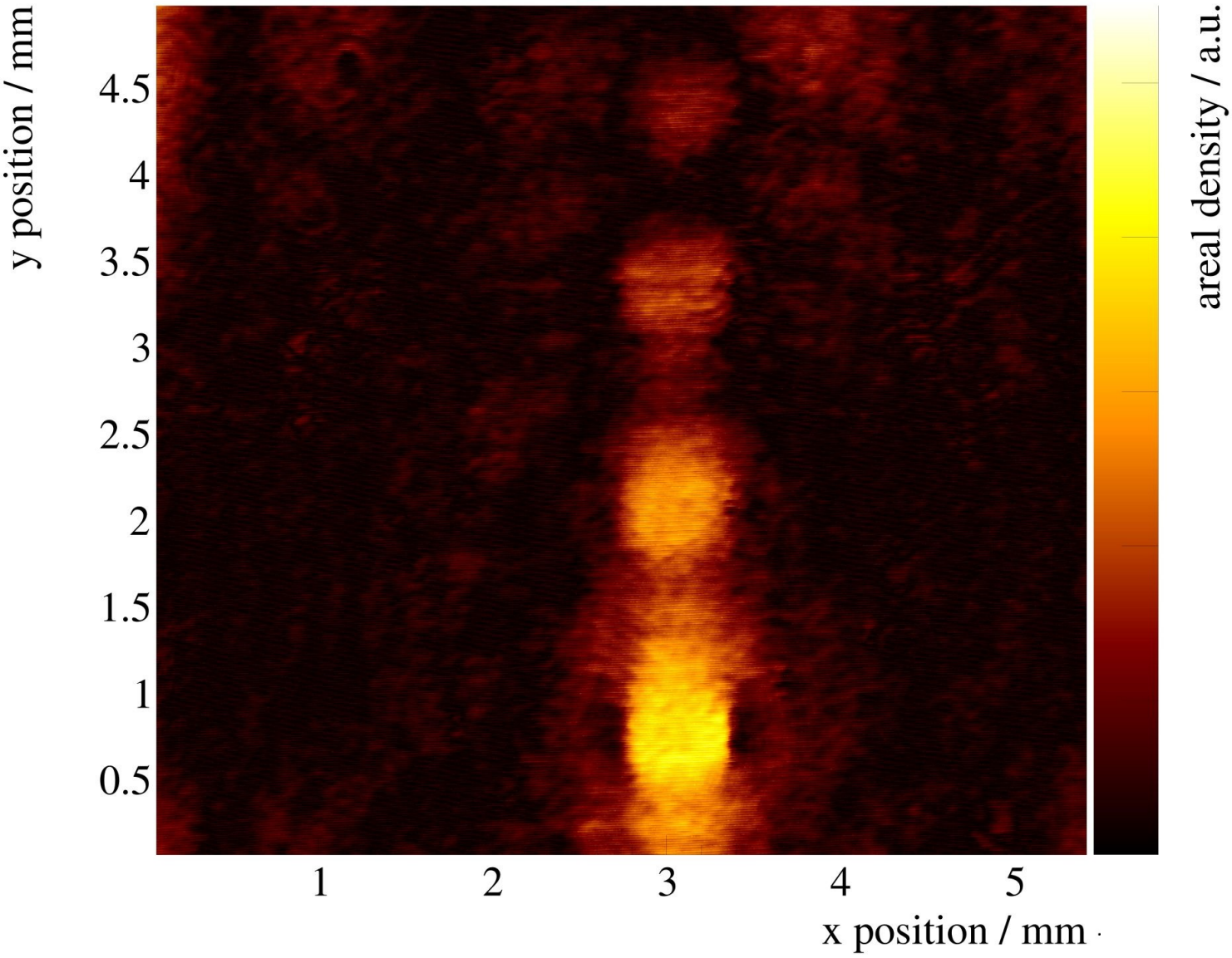

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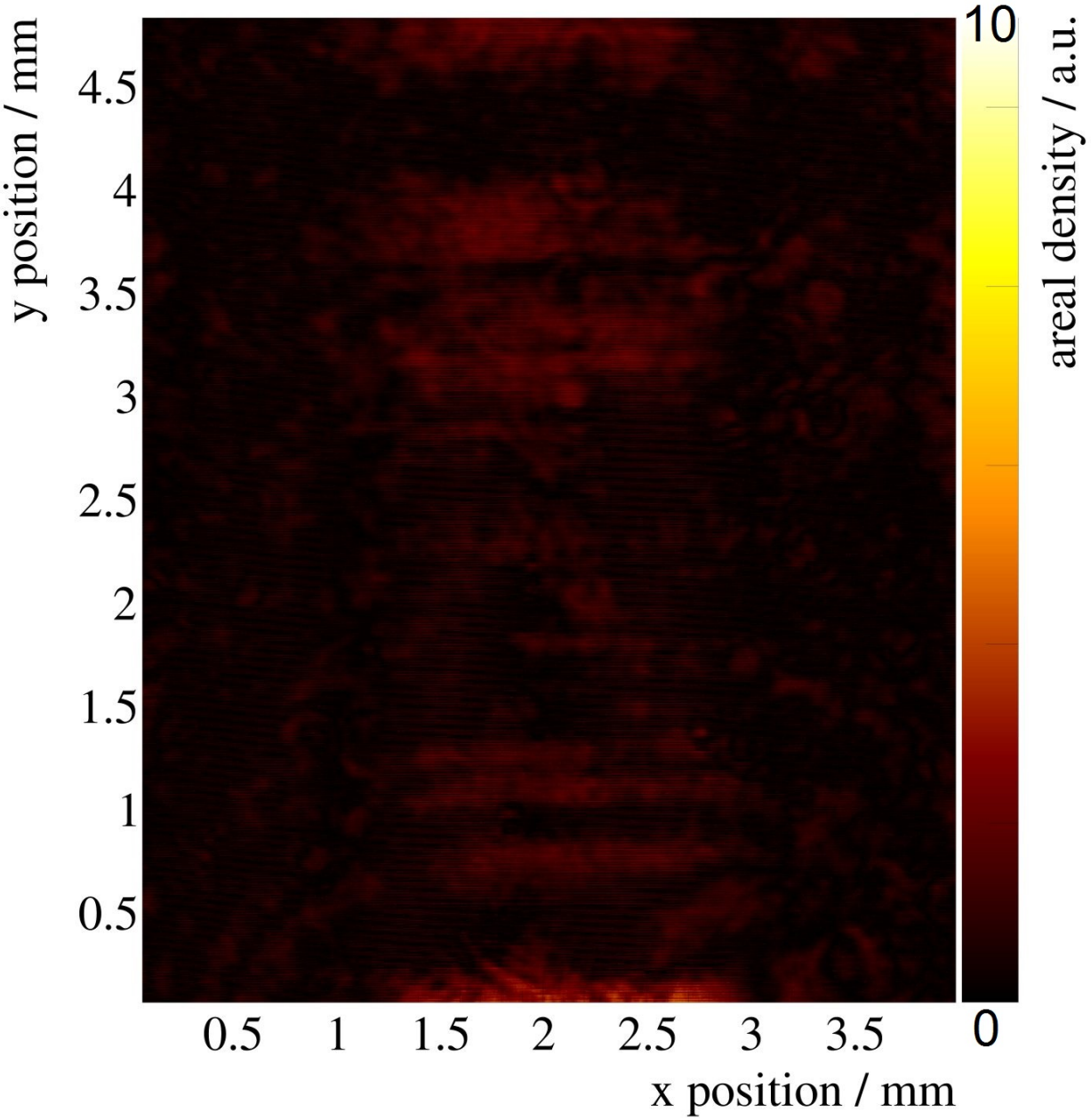

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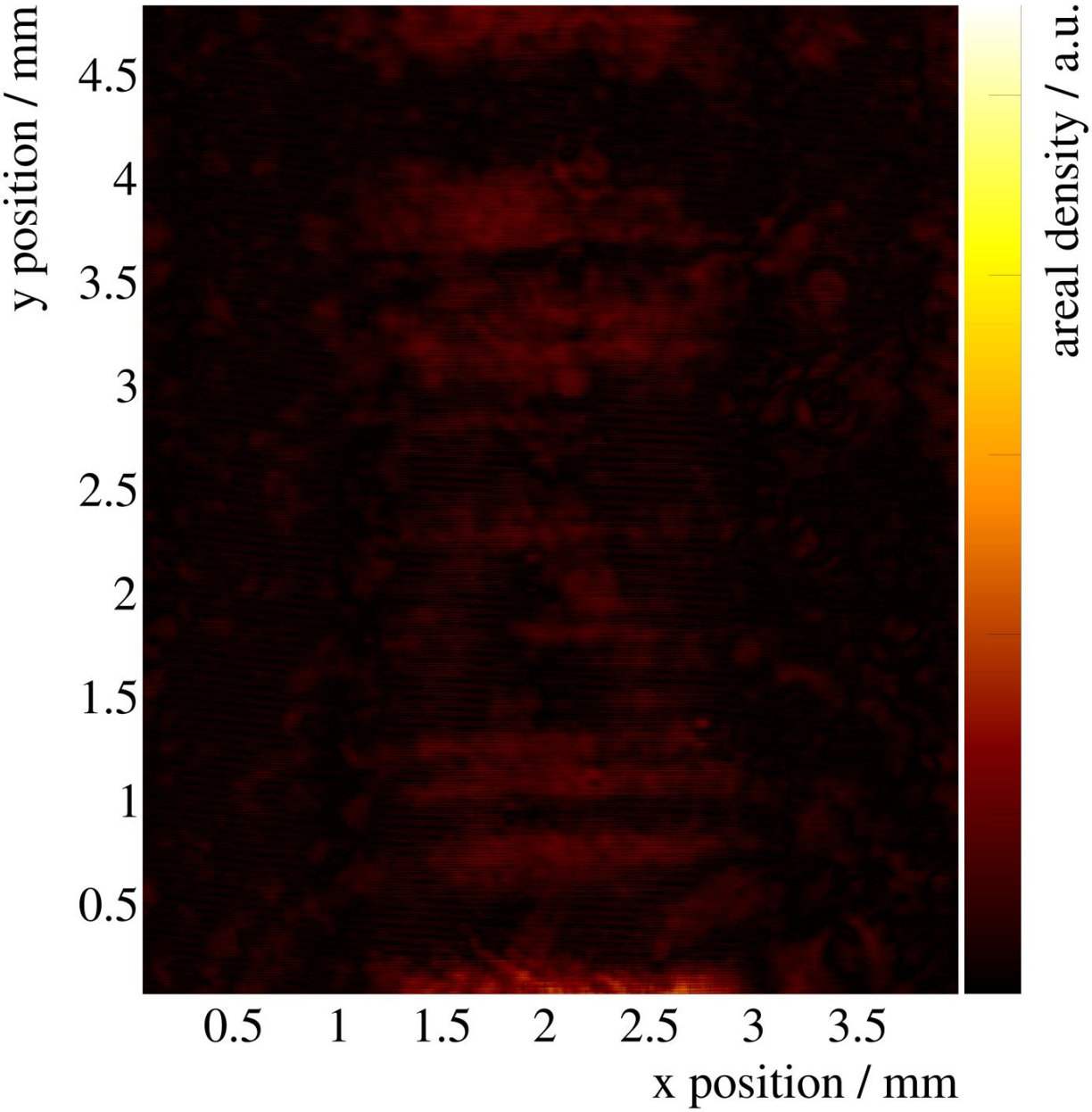

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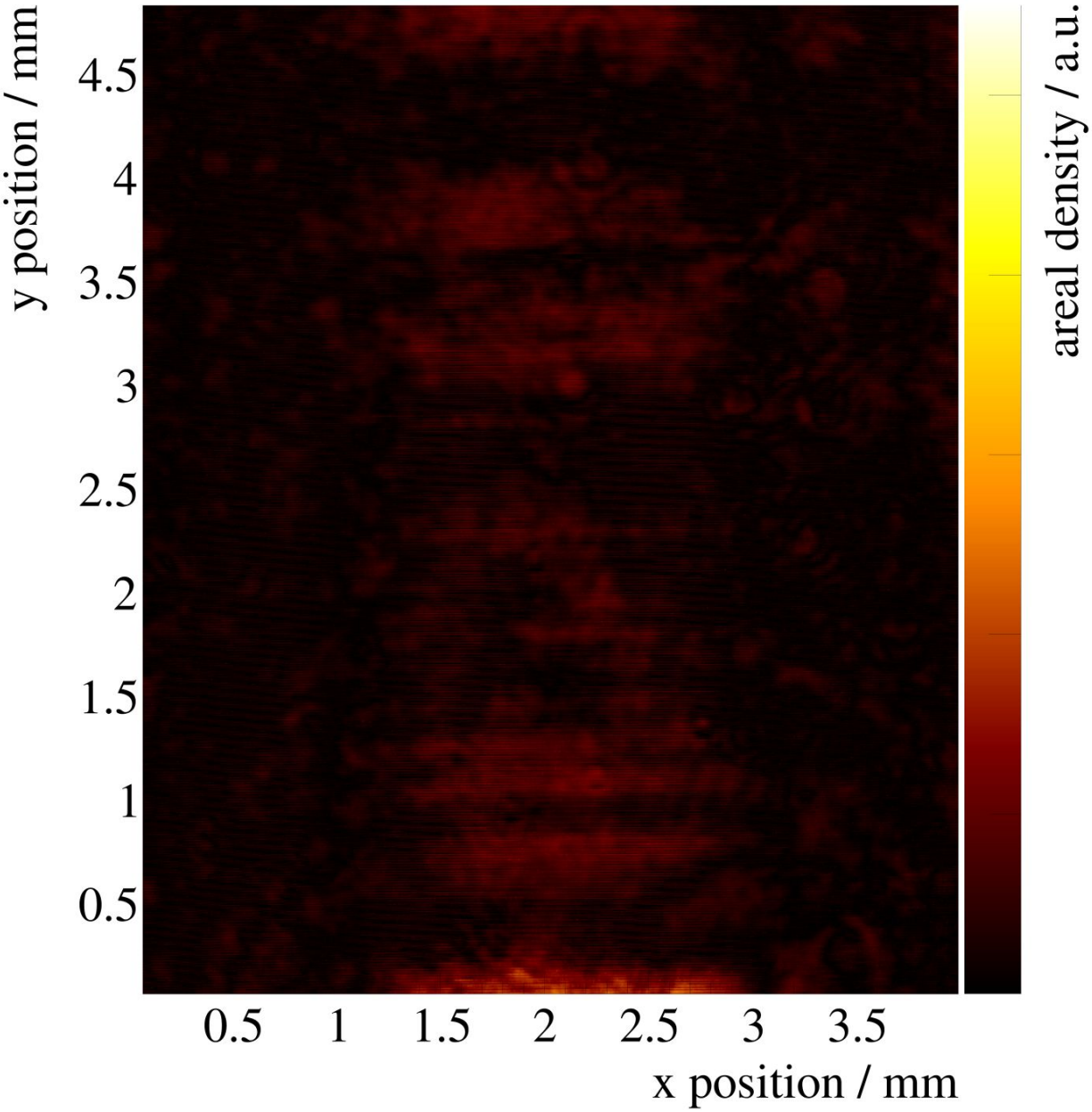

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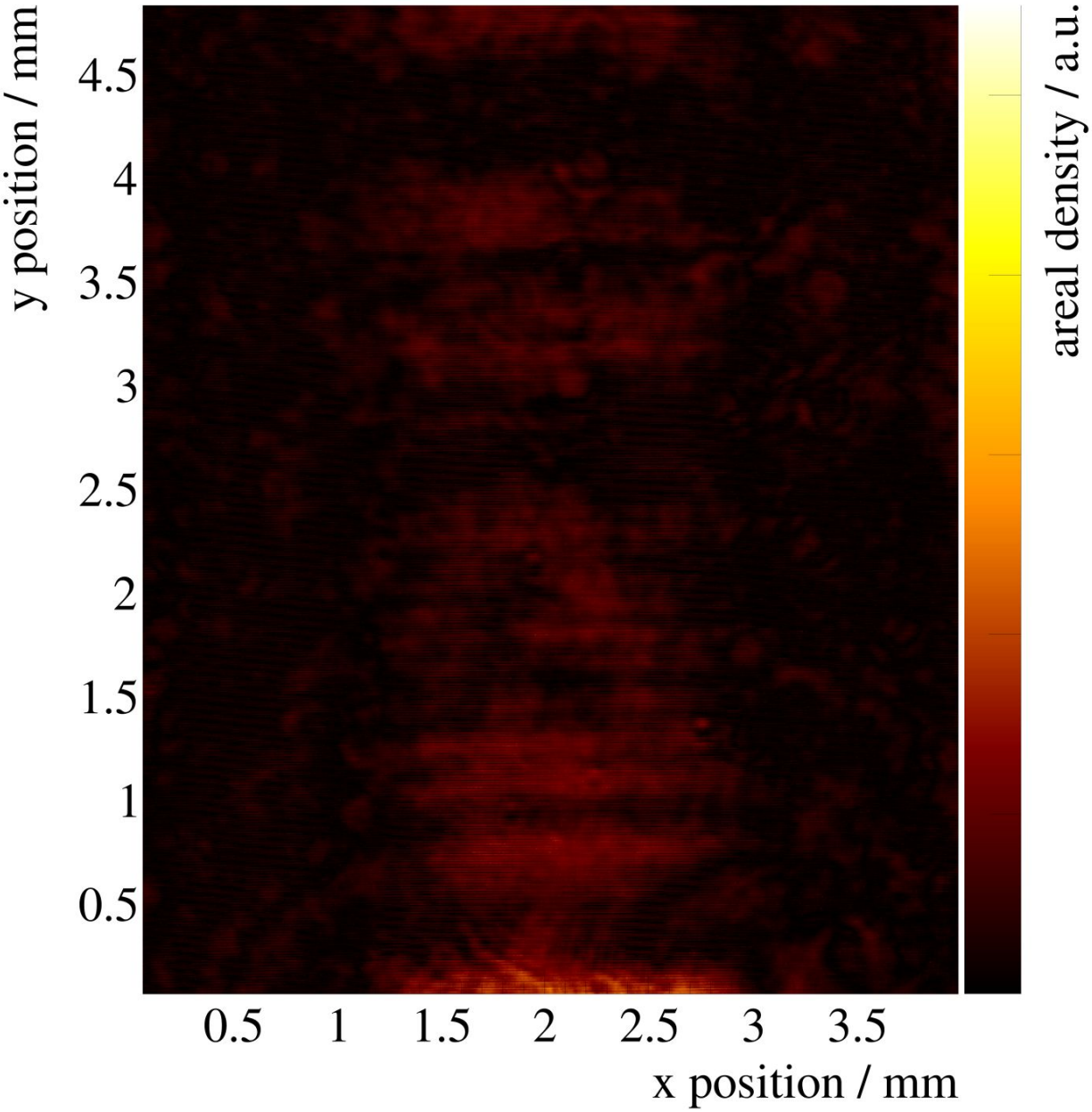

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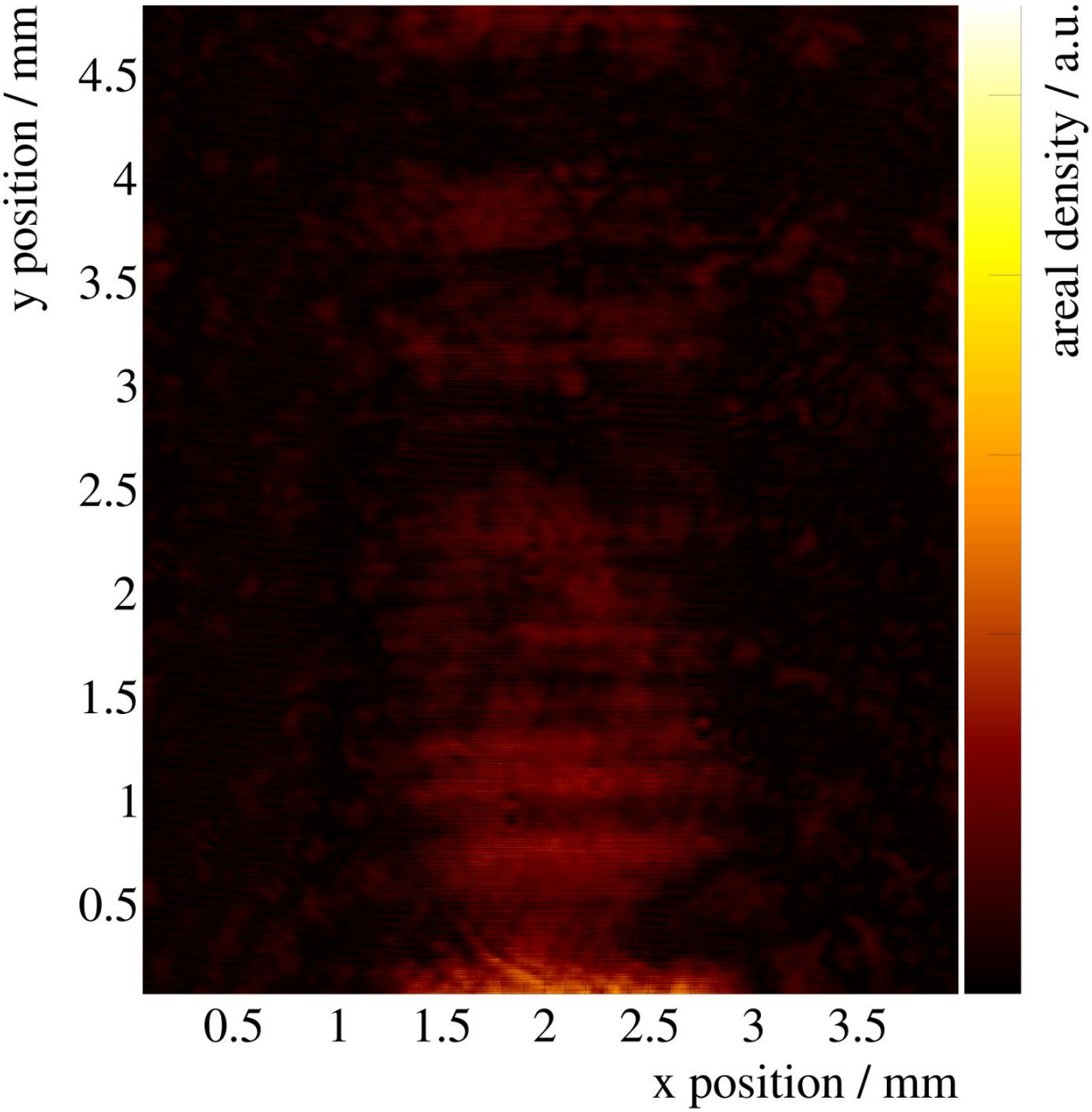

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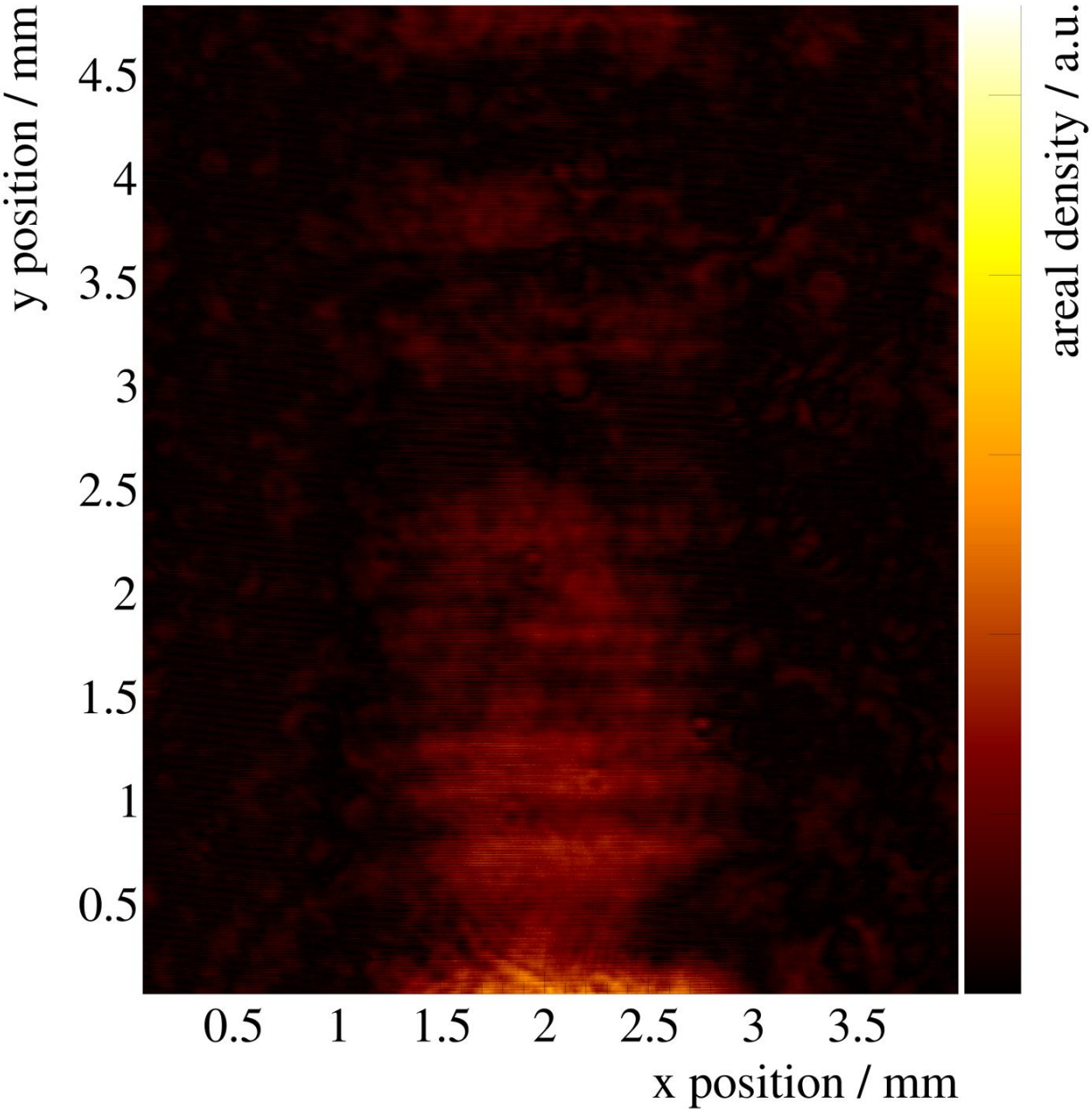

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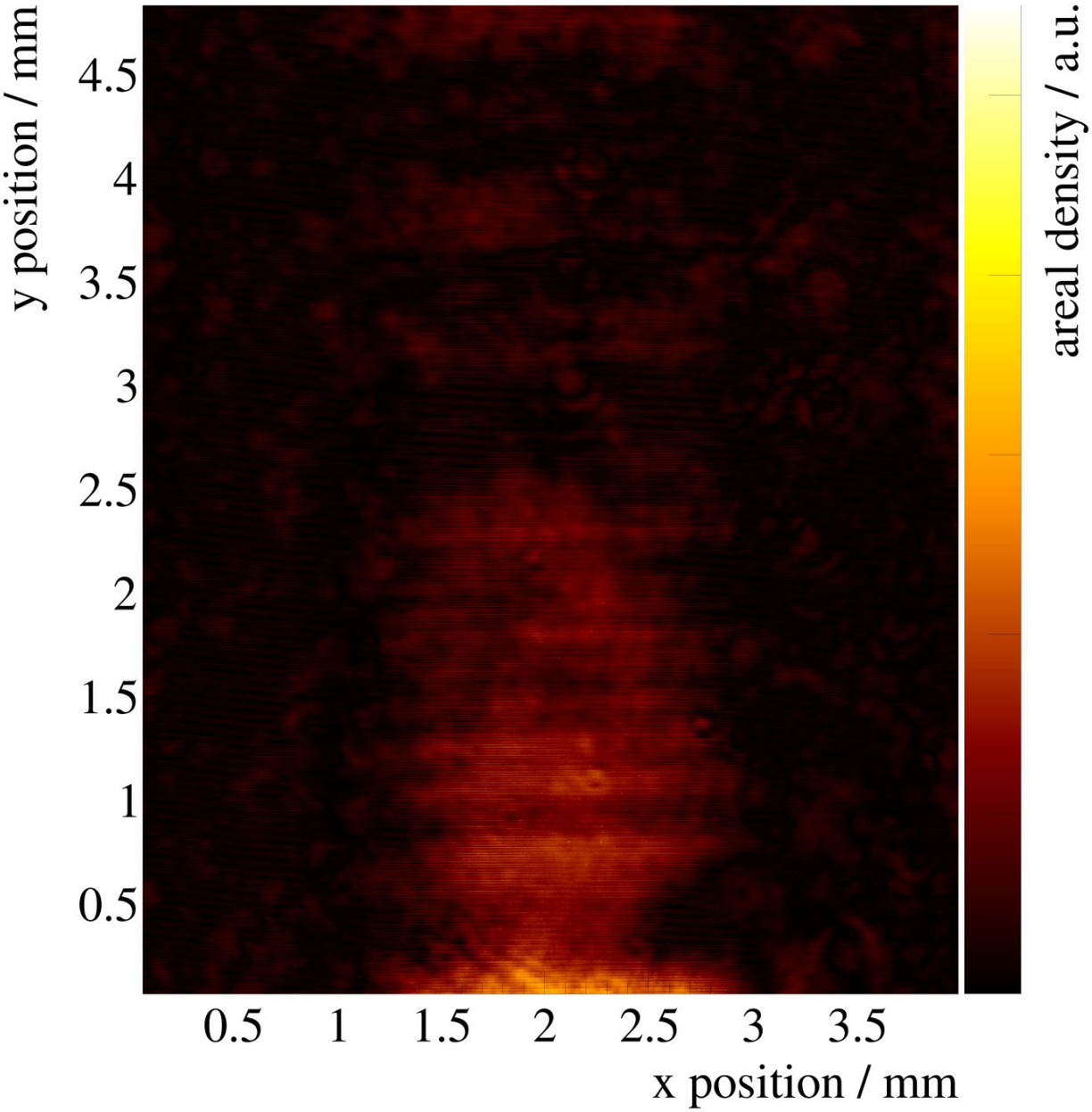

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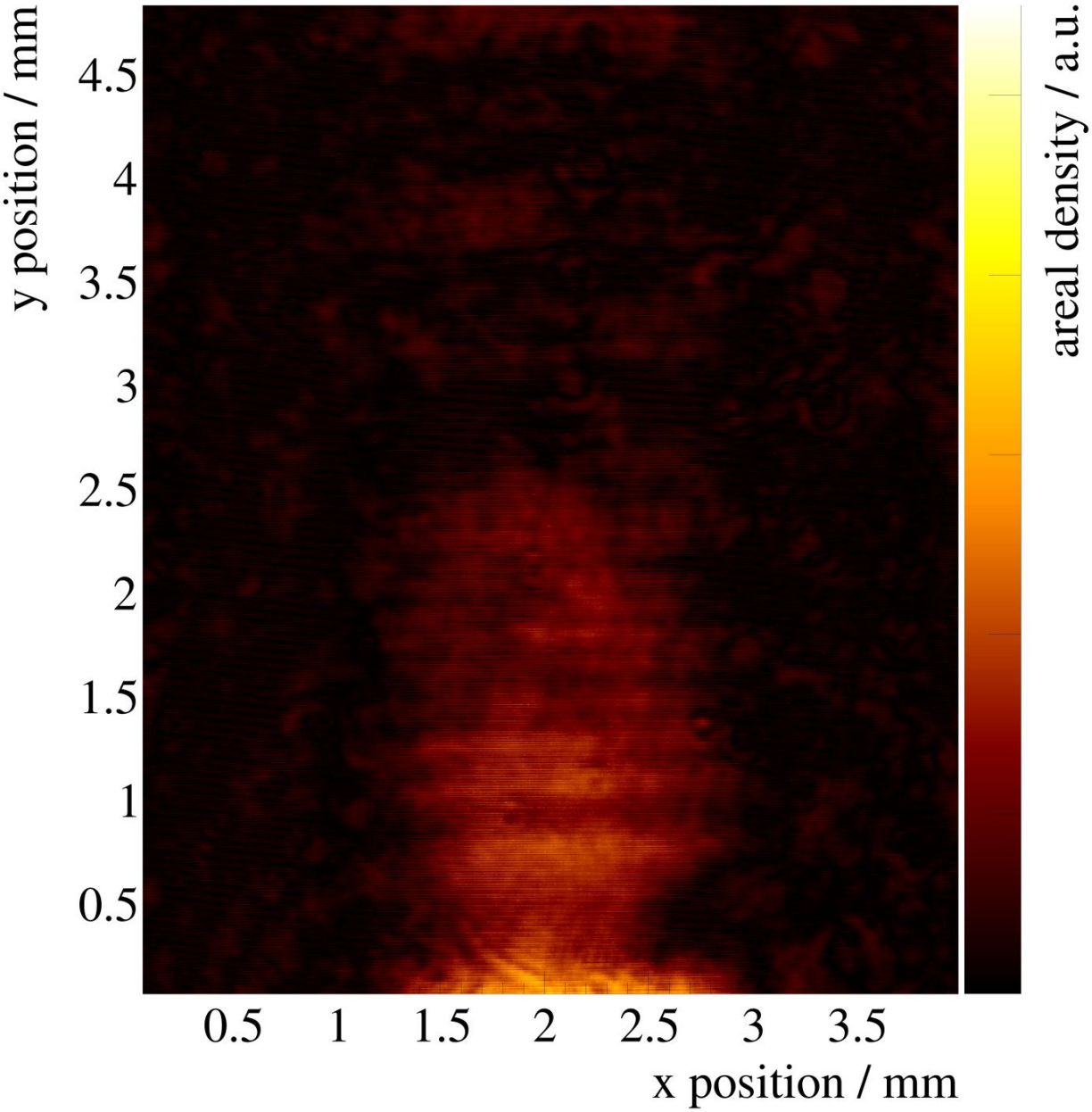

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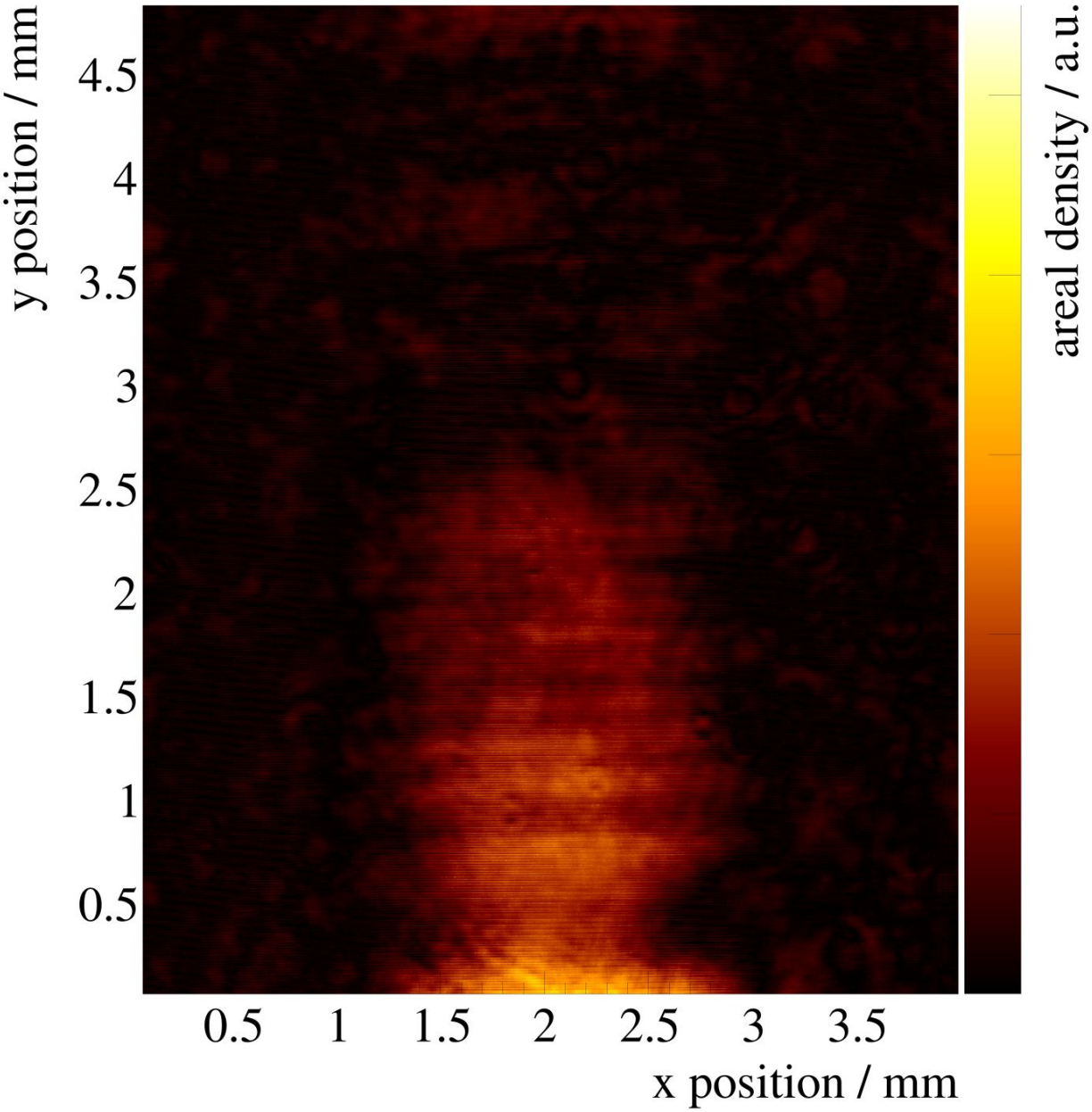

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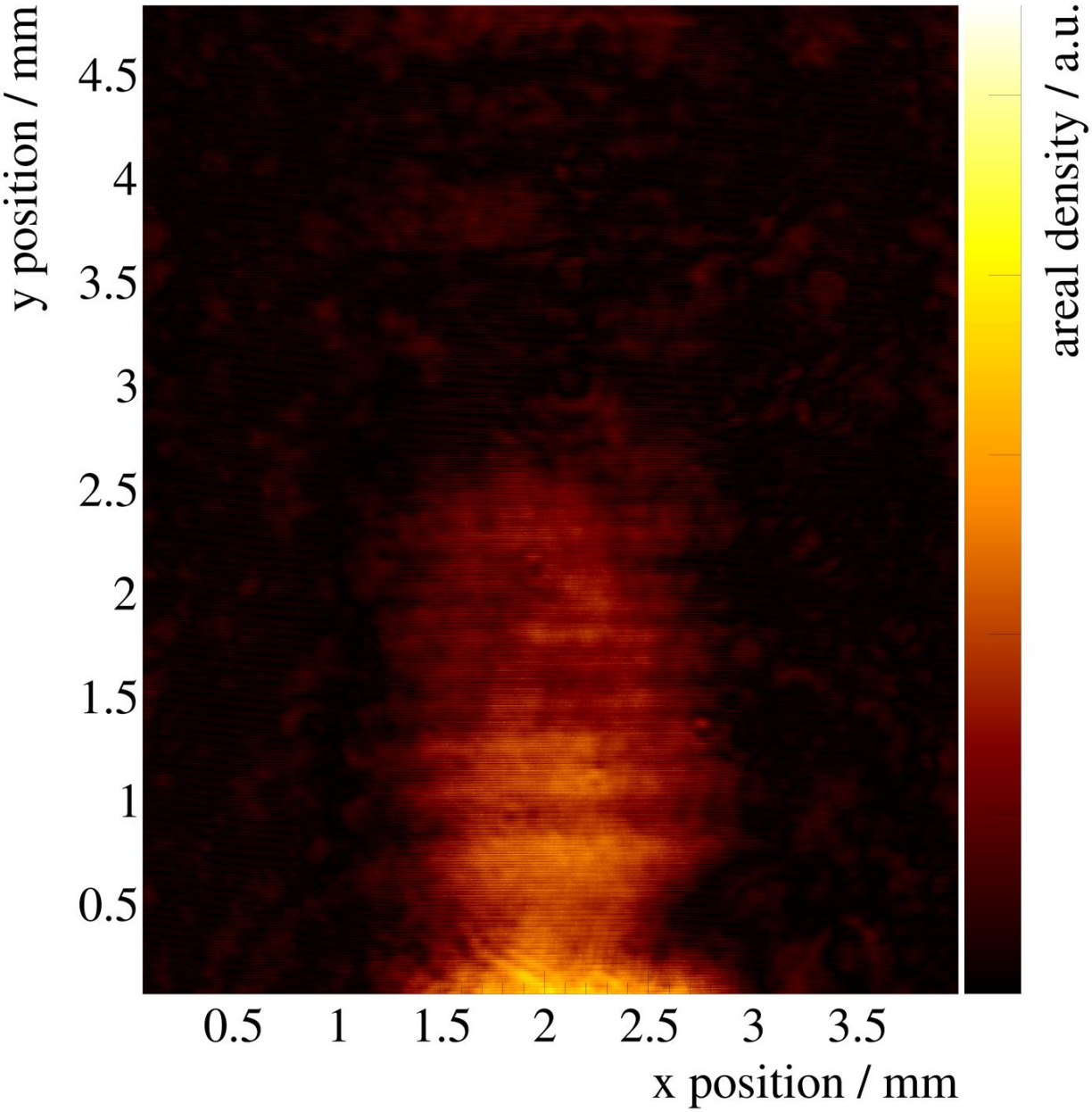

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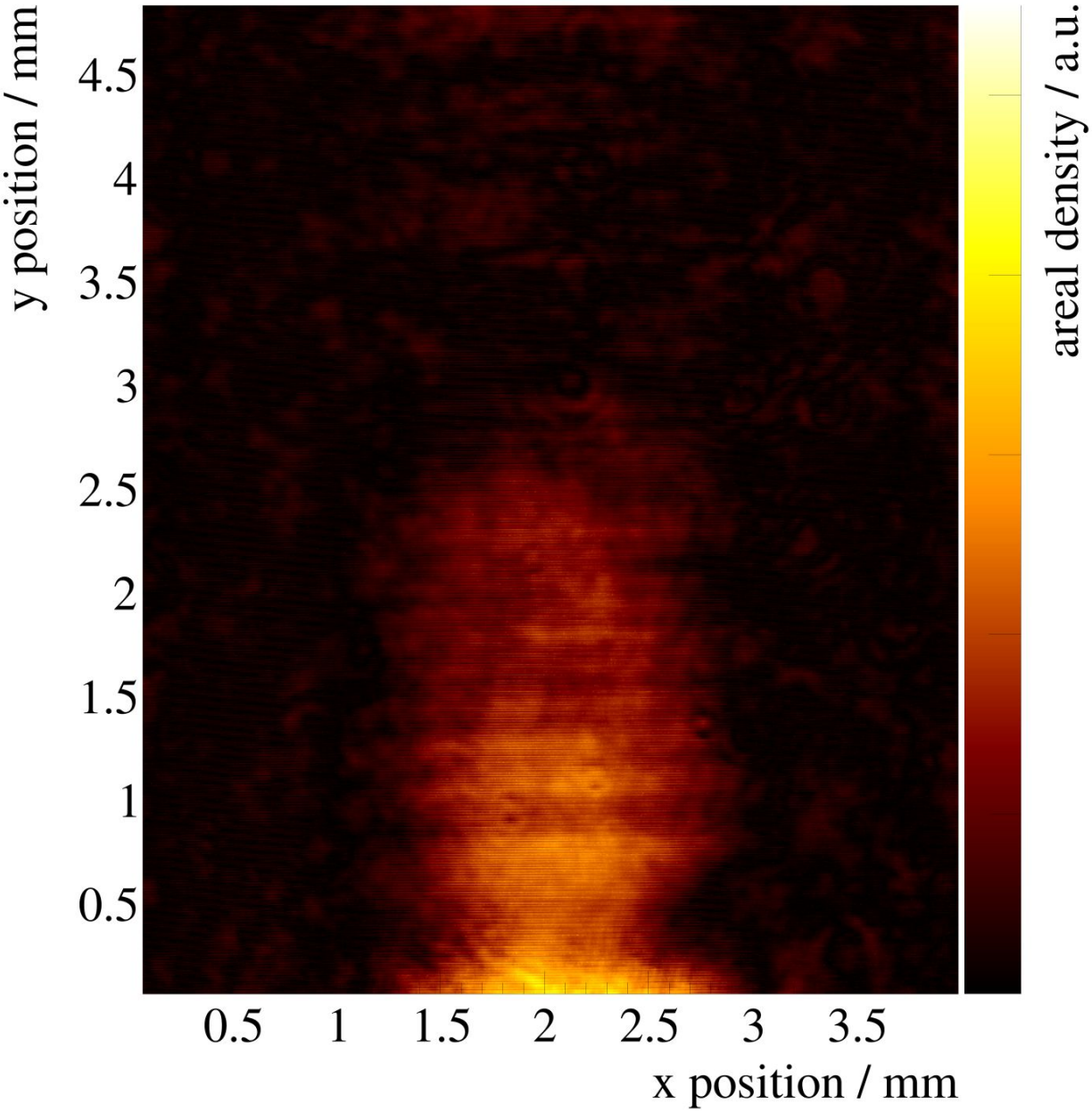

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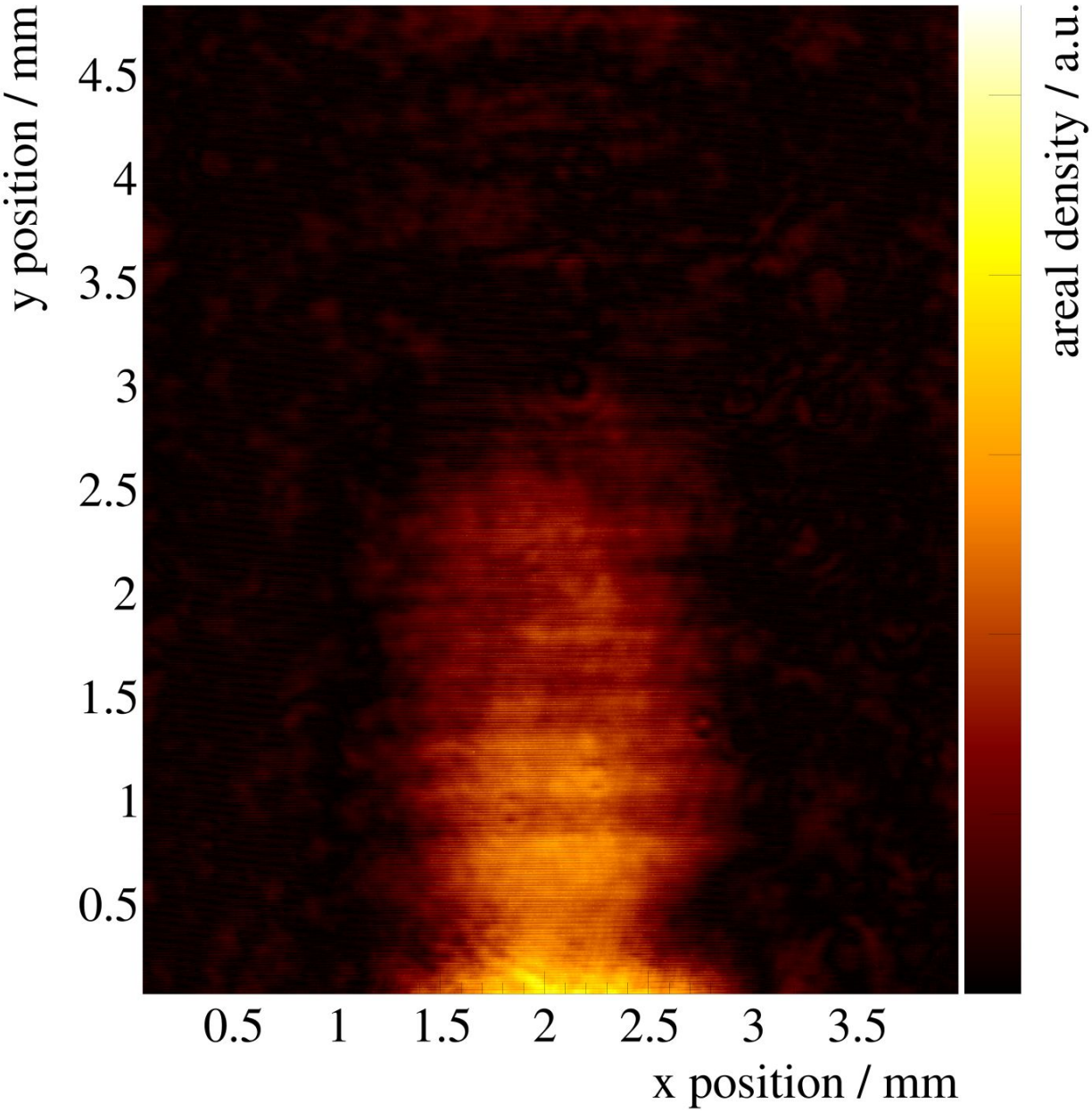

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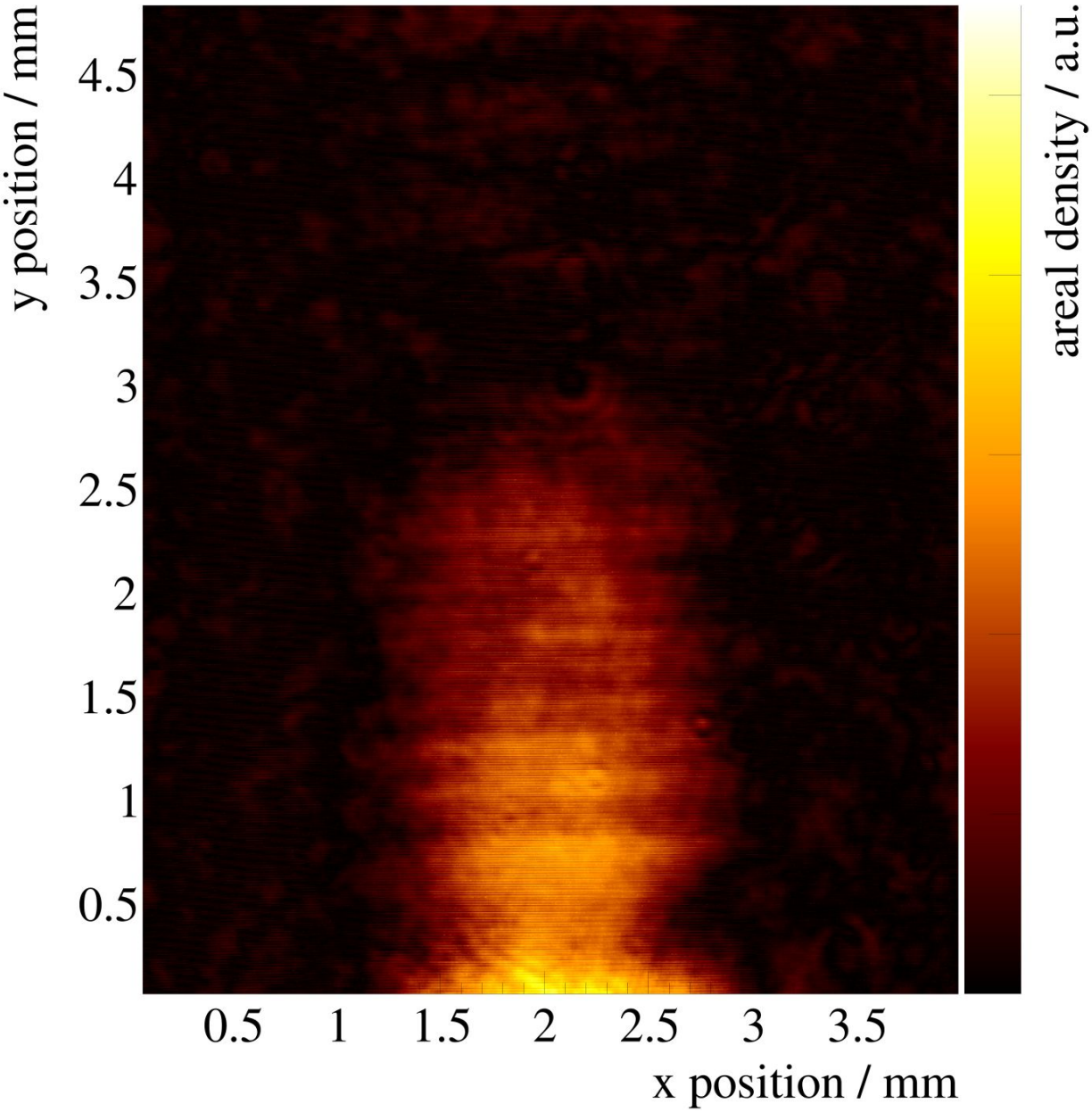

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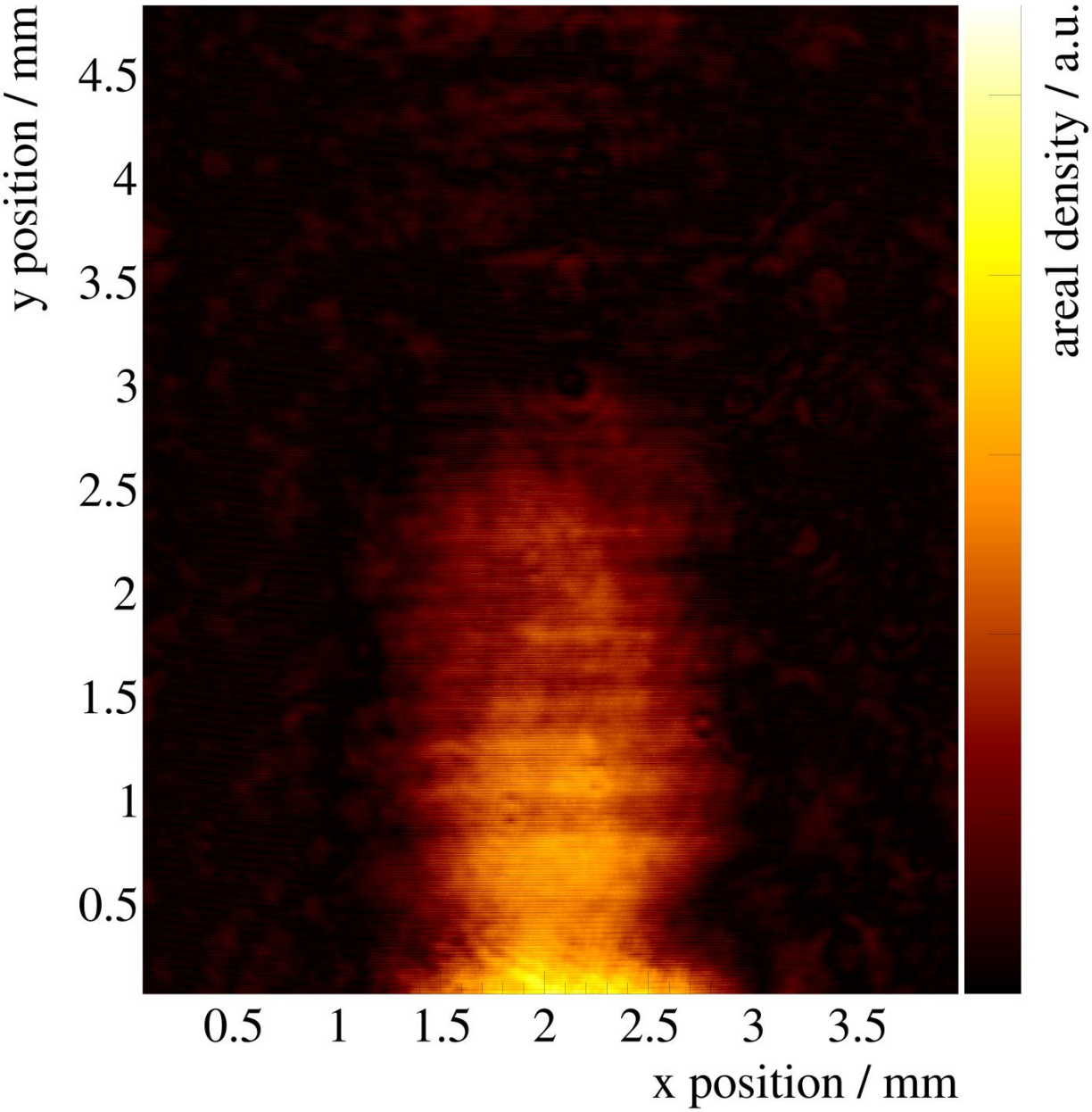

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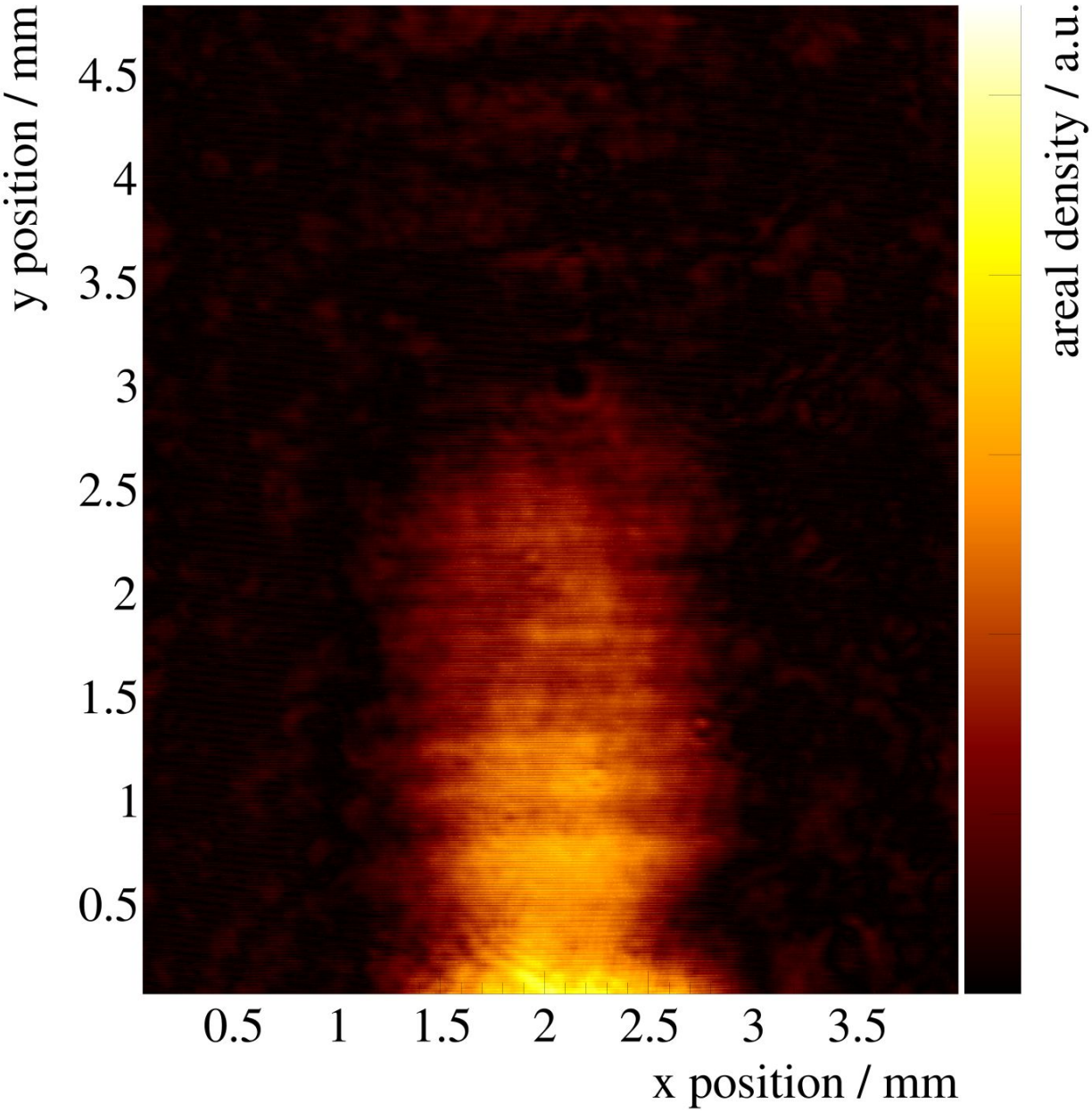

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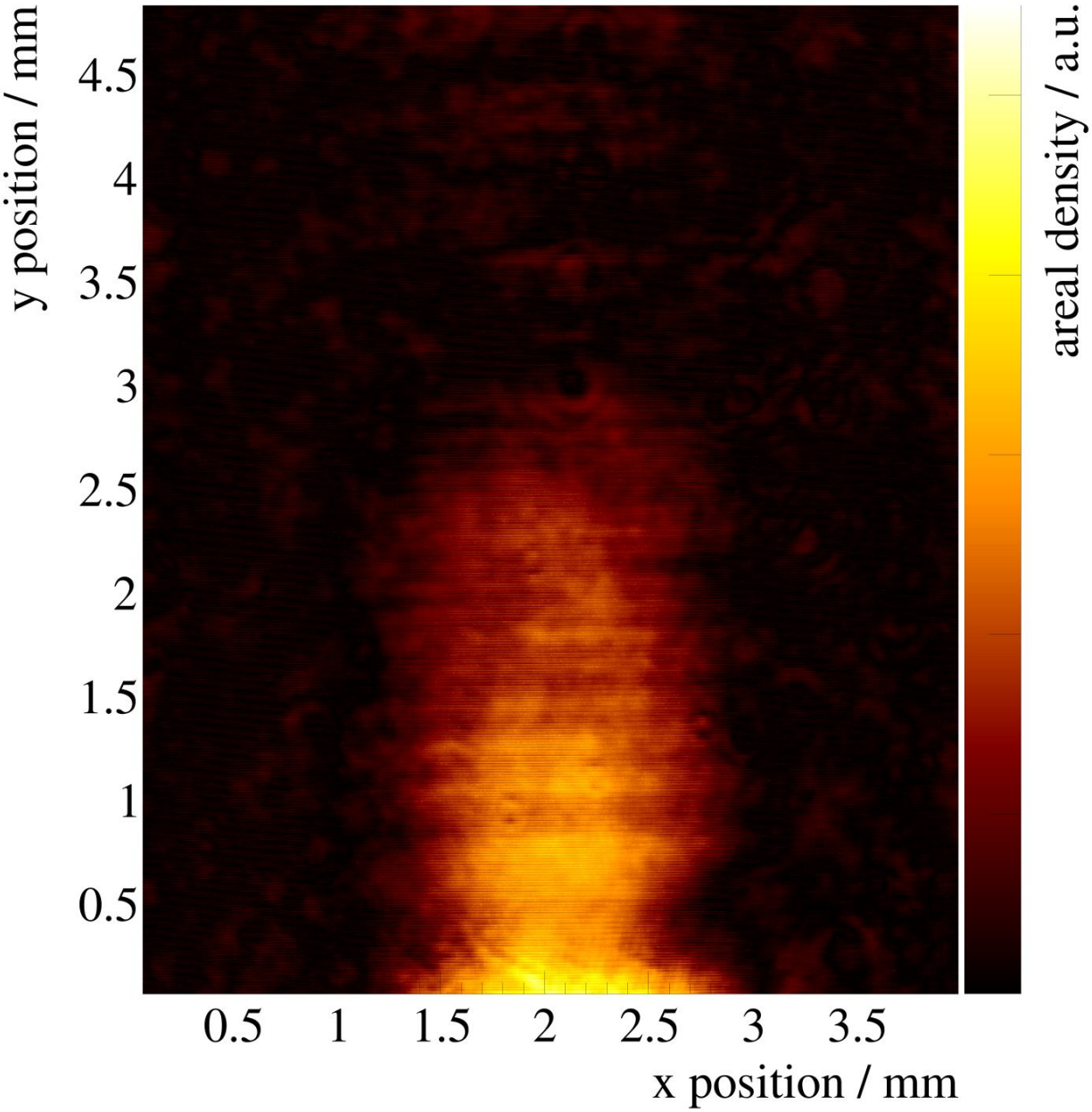

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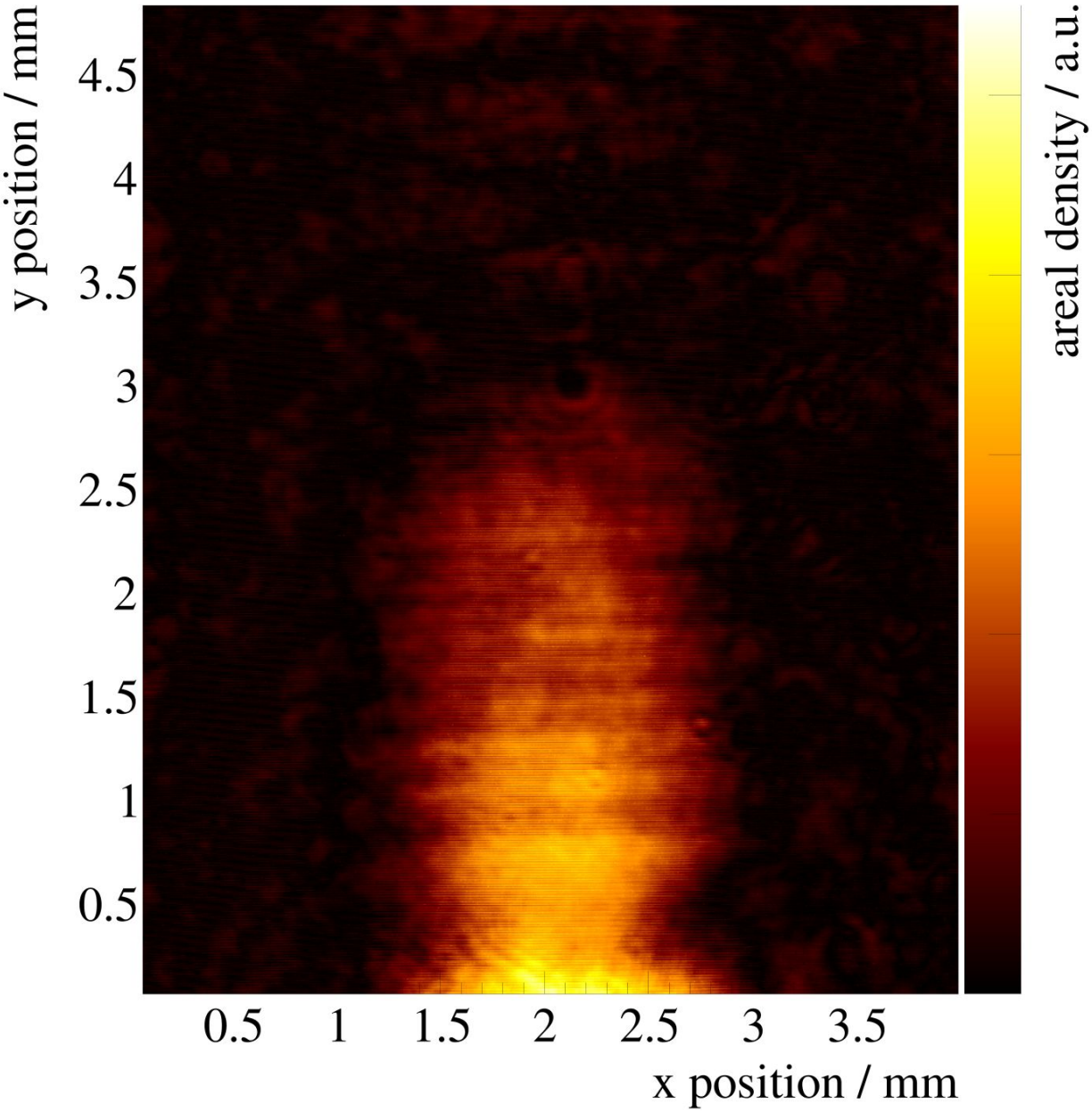

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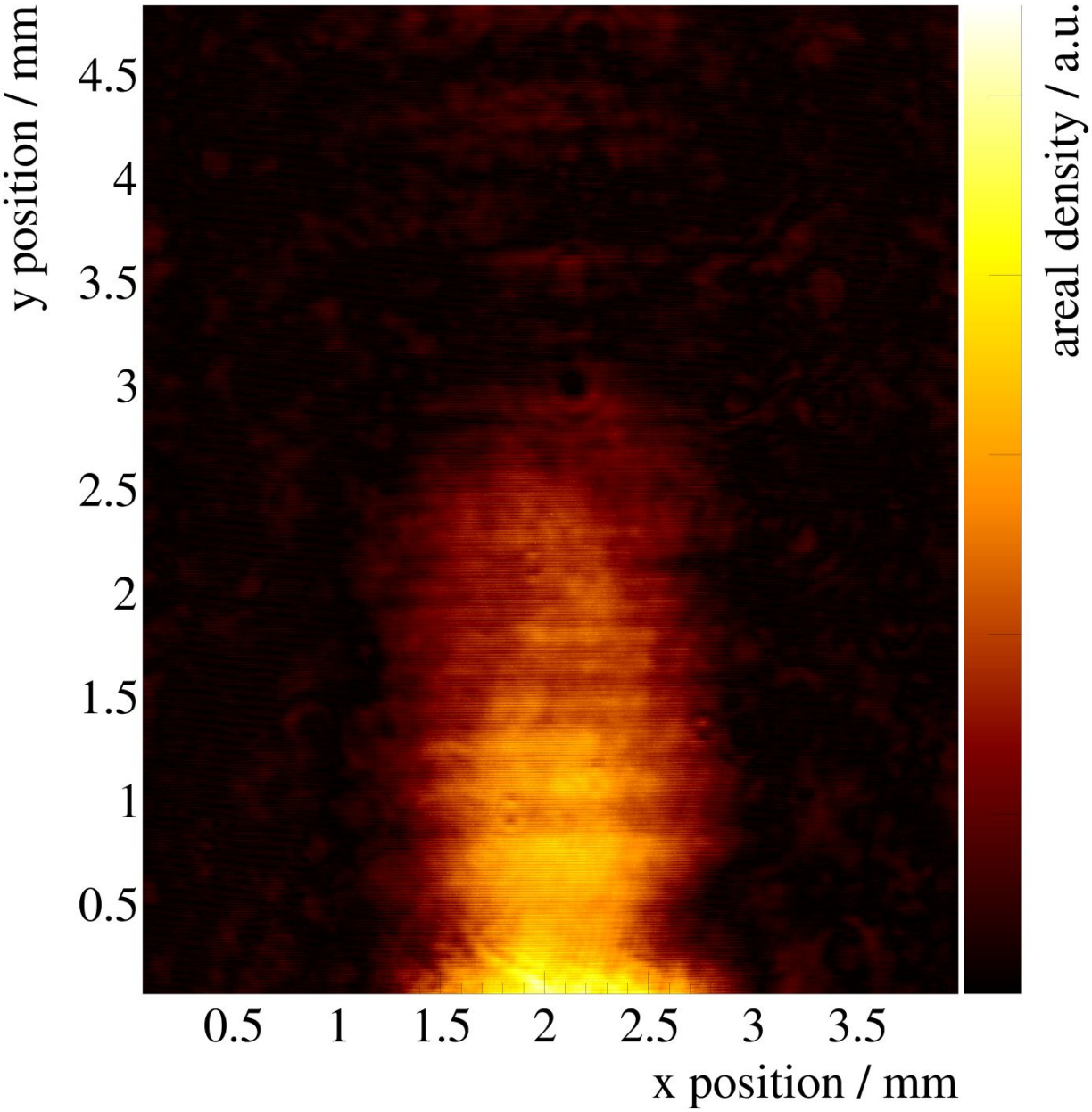

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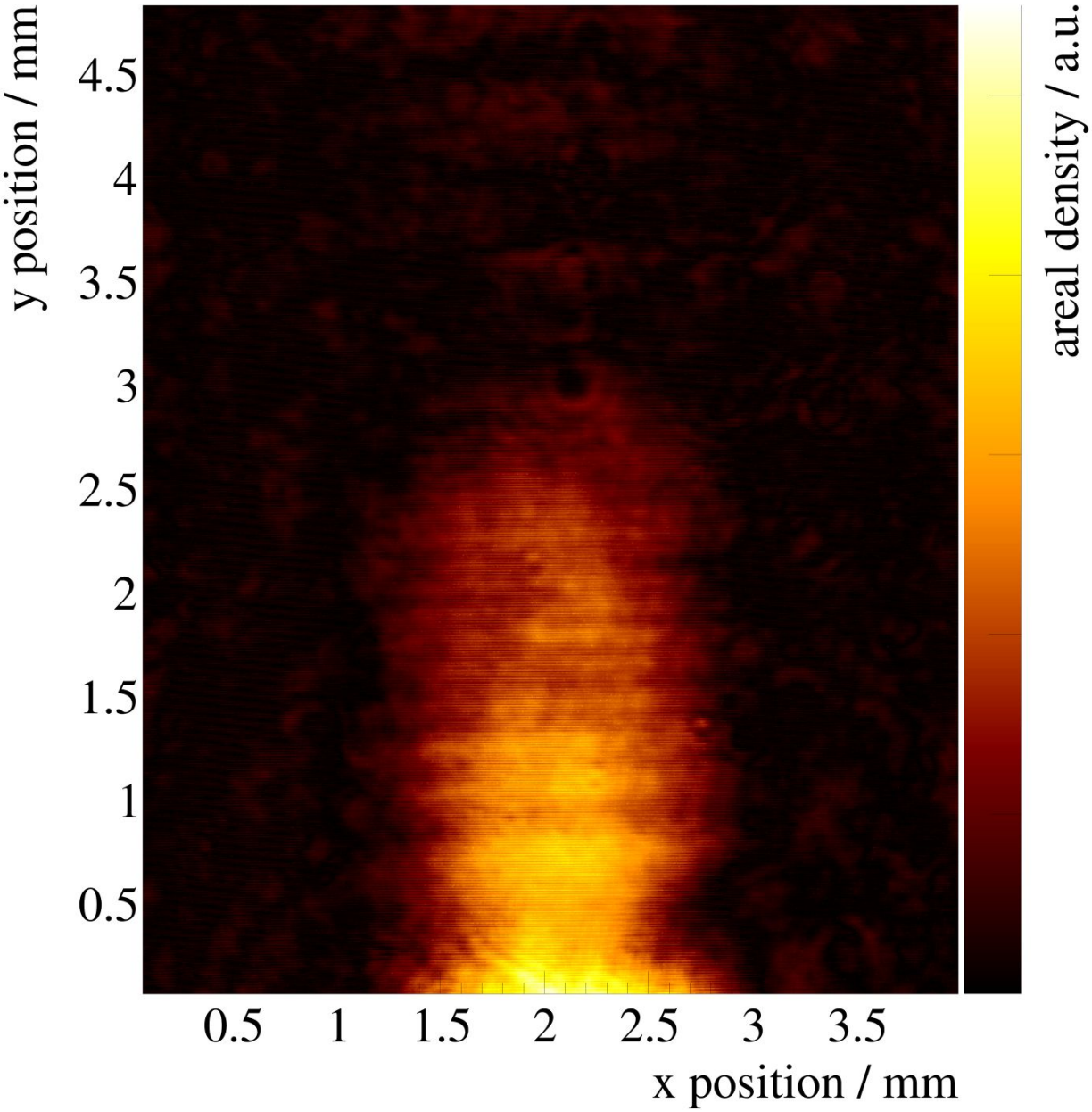

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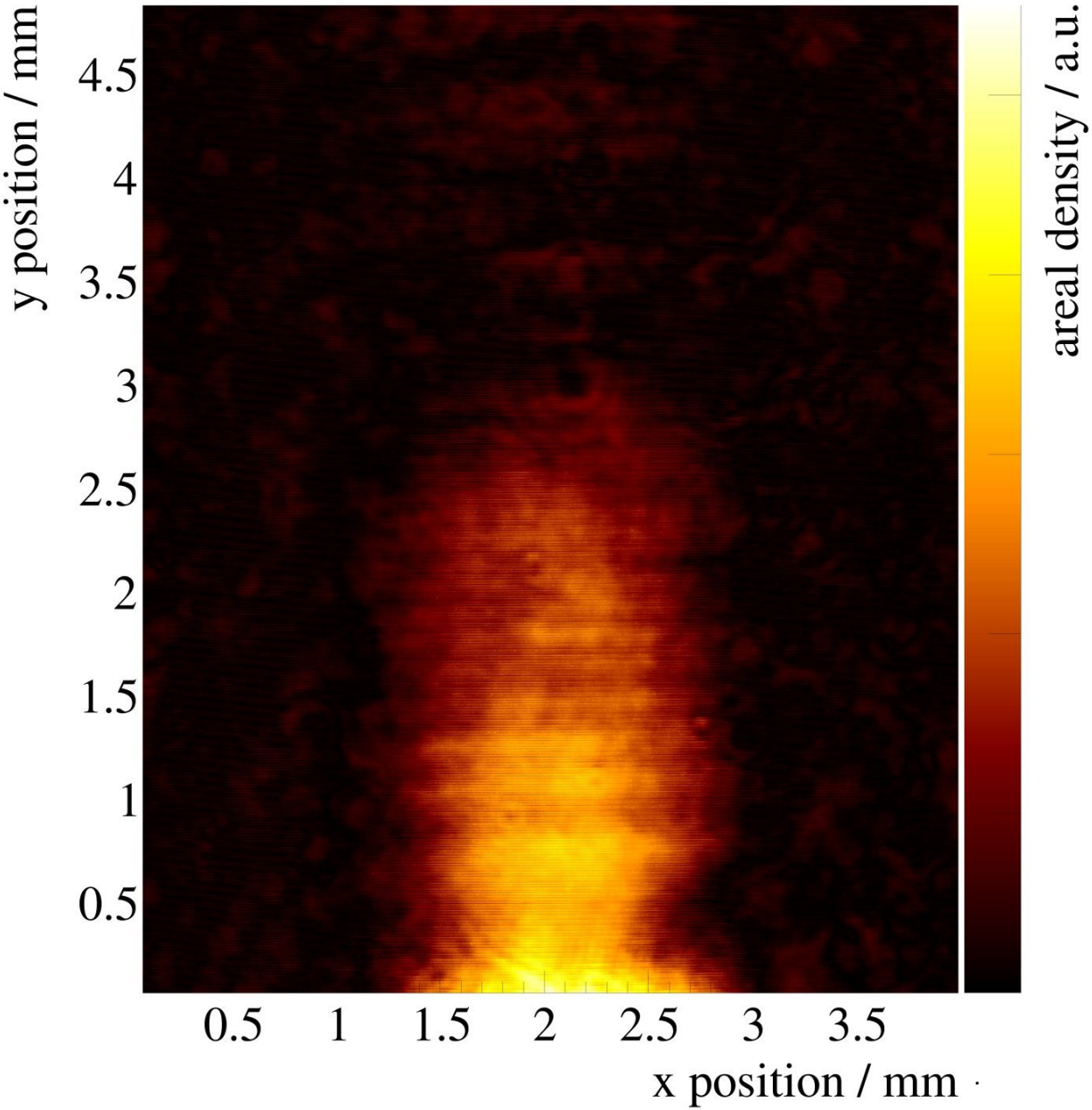
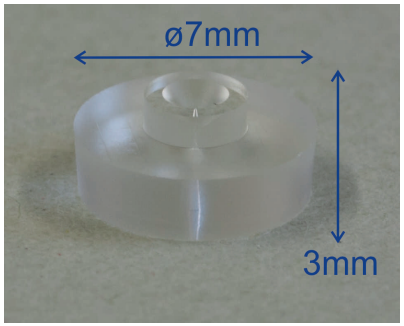


# Summary & Outlook

- First successfully produced nozzles (galvanic deposition)
  - ⇒ Typical highly intense core beams
  - ⇒ Target thickness in the same order compared to CERN nozzles
  - ⇒ Velocity distribution is currently under investigation
  - ⇒ More systematic work required

- Successfully produced glass nozzle
  - ⇒ Development of a new sealing
  - ⇒ Need of an extension
  - ⇒ Target thickness slightly lower compared to CERN nozzle (adjustments needed)
  - ⇒ More work necessary

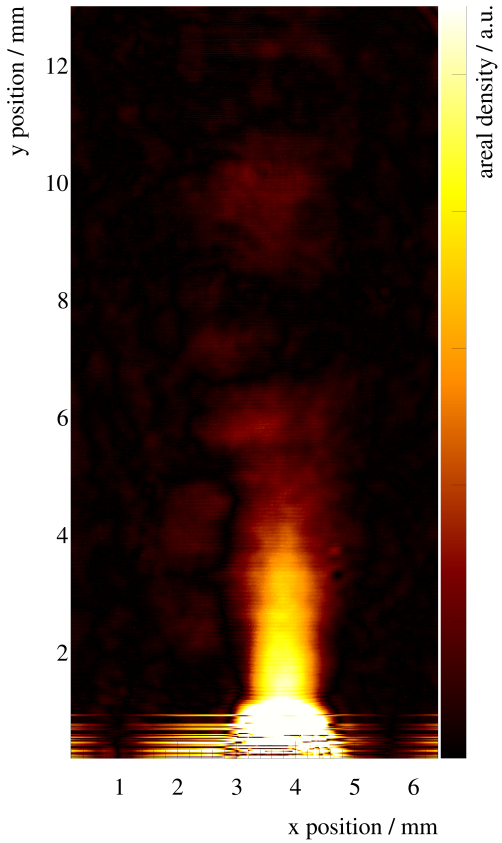


# Summary & Outlook

- Investigations on beam properties with a Mach Zehnder Interferometer

  ⇒ Target thickness
  ⇒ Shape of target beam
  ⇒ Range of target beam
  ⇒ Impacts of stagnation conditions at the nozzle
  ⇒ Studies of nozzles with different geometries

  ⇒ Possibility for measurements directly behind the nozzle
  ⇒ Investigations on cluster and gas properties (gaseous $H_2$ in front of nozzle)
  ⇒ Represents the real thickness (-distribution)
  ⇒ More measurements required



# Mach Zehnder Interferometer