Monolithic laval nozzles

Seminar
INFN Frascati
2.12.2013

Alexander Täschner
(taschna@uni-muenster.de)

Bundesministerium
für Bildung
und Forschung

Westfälische
Wilhelms-Universität
Münster

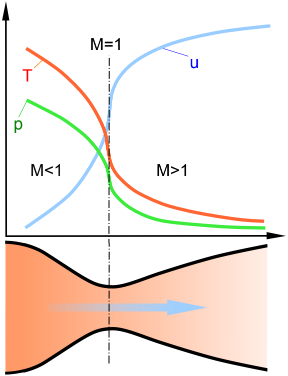
Laval nozzles

- convergent-divergent nozzle
- accelerates a gas to supersonic velocities via a pressure gradient

  Mach number:

  $$Ma = \frac{u}{a} \begin{array}{l} \leftarrow \text{ local velocity} \\ \leftarrow \text{ speed of sound} \end{array}$$

- wide field of applications: rocket/jet engines, steam turbines, fuel injection, . . ., cluster-jet targets



[Wikimedia Commons]

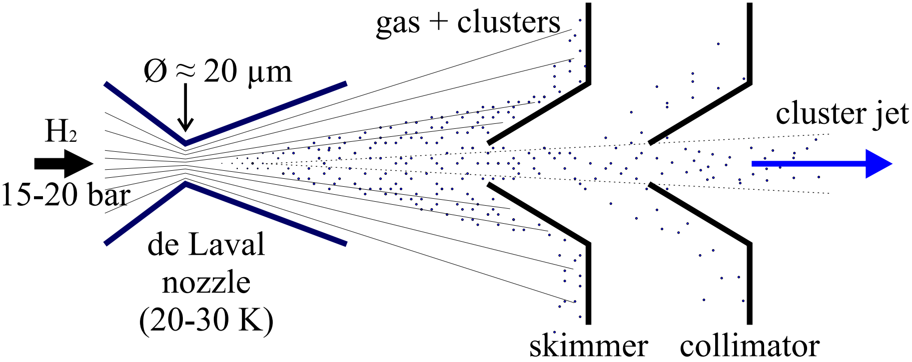
area-velocity relation:

$$\frac{\mathrm{d}A}{A} = \left(Ma^2 - 1\right)\frac{\mathrm{d}u}{u}$$

A : local area

Cluster-jet targets

Principle of operation:
purified H_2 or D_2 gas passes a de Laval nozzle
⇒ formation of clusters surrounded by gas



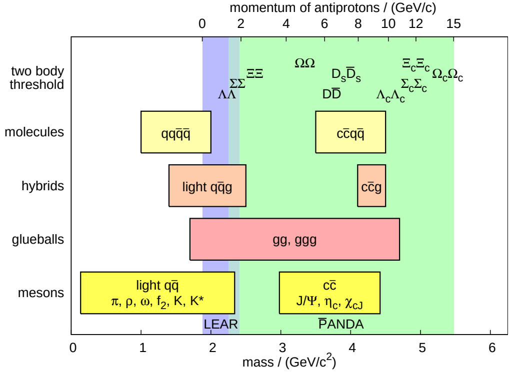
Münster-type cluster-jet targets: Highest density when operated with liquid H_2 at nozzle inlet

Properties of cluster-jet targets as internal targets

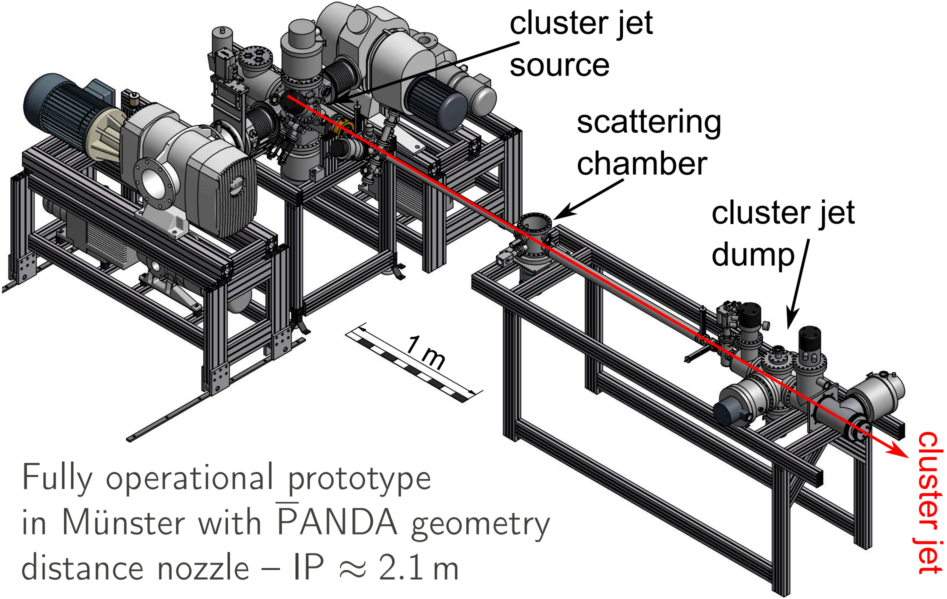
- pure target material (especially H_2 and D_2)
- small influence on the vacuum conditions in the storage ring
- maximum target thickness n_T of about 2×10^{15} atoms/cm^2 in a distance of 2 m between target source and interaction point
- target thickness adjustable between about 10^{12} atoms/cm^2 and 2×10^{15} atoms/cm^2
- target beam can be switched on or off at any time
- volume density is homogenous
- no distinct time structure in the target thickness
- effective target size and shape can be adapted by special collimators

The $\overline{\text{P}}$ANDA experiment

- Anti-**P**roton **AN**nihilation at **DA**rmstadt:
  Study of hadron interactions in proton-antiproton collisions
- one of the main experiments of FAIR
  (**F**acility for **A**ntiproton and **I**on **R**esearch)
- Momentum range:
  1.5 GeV/c to 15 GeV/c
- Number of antiprotons:
  10^{10} to 10^{11}
- Physics topics
  - Charmonium spectroscopy
  - Hybrids and glueballs
  - Open charm spectrum
  - Hadrons in nuclear matter
  - Hypernuclei
  - Electromagnetic processes

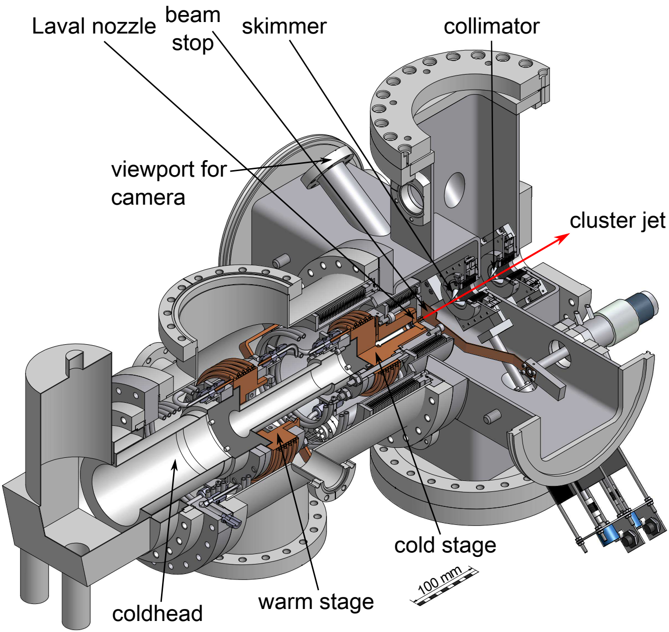


The $\overline{\text{P}}$ANDA cluster-jet target prototype



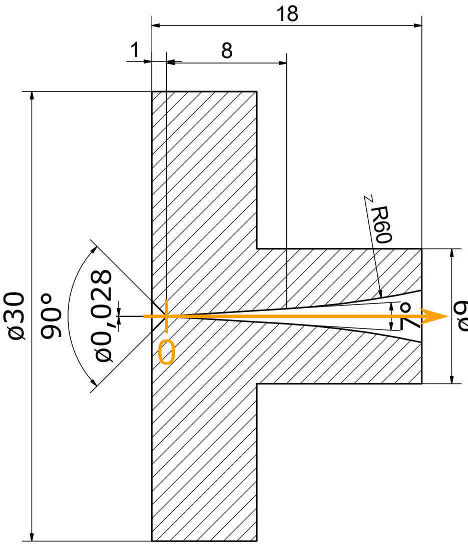
Fully operational prototype
in Münster with $\overline{\text{P}}$ANDA geometry
distance nozzle – IP $\approx 2.1\,\text{m}$

The $\overline{\text{P}}$ANDA cluster-jet target prototype – cluster source

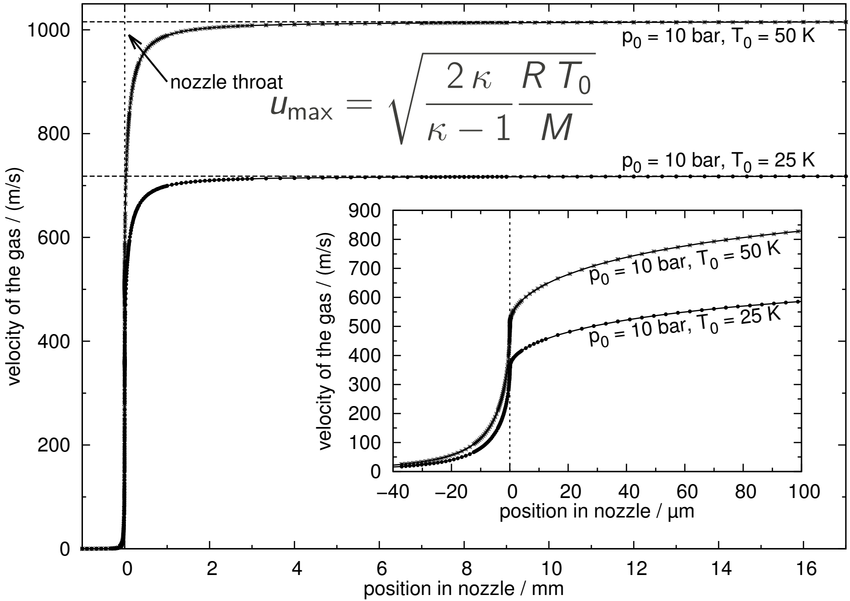


Laval nozzle used in Münster cluster-jet targets

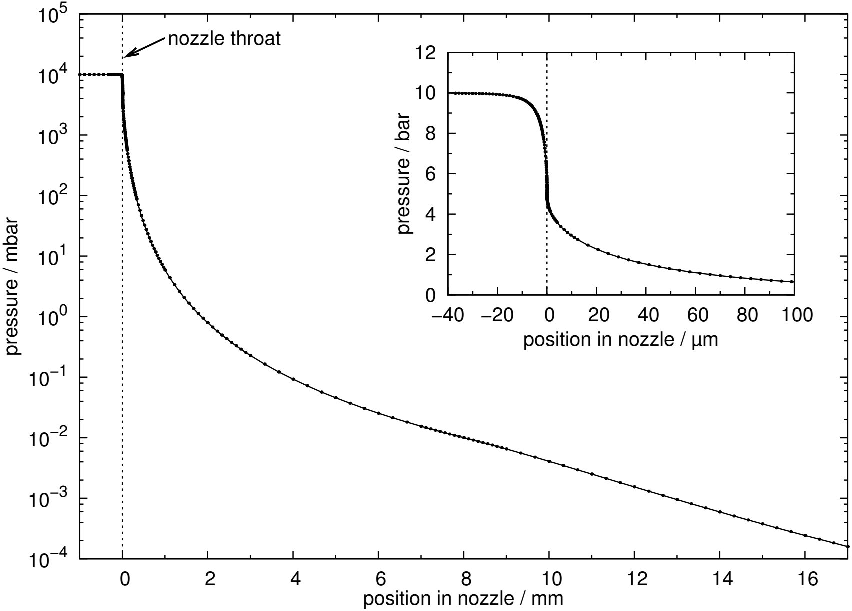
- made of copper
- produced at CERN workshop
- diameter of the throat: 28 µm



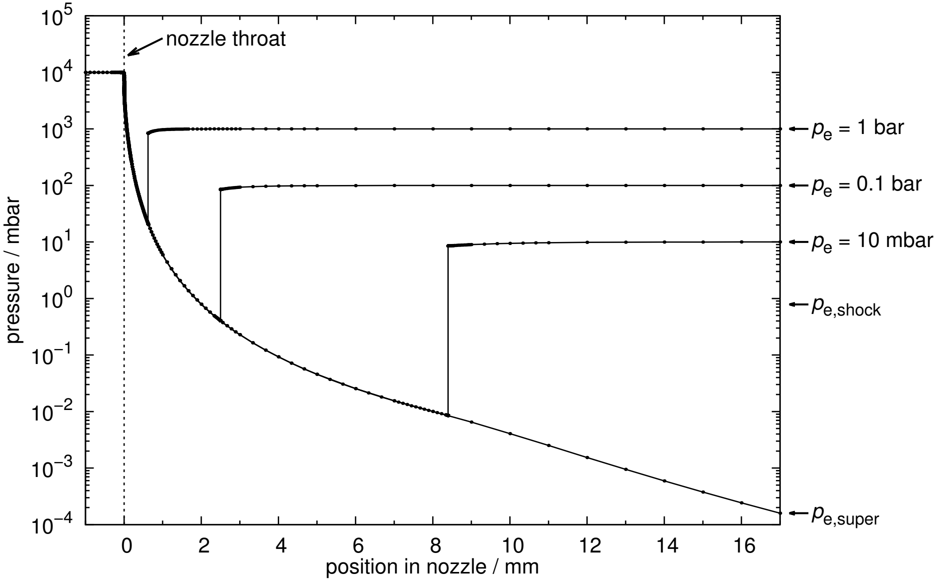
Velocity of perfect gas inside a Laval nozzle



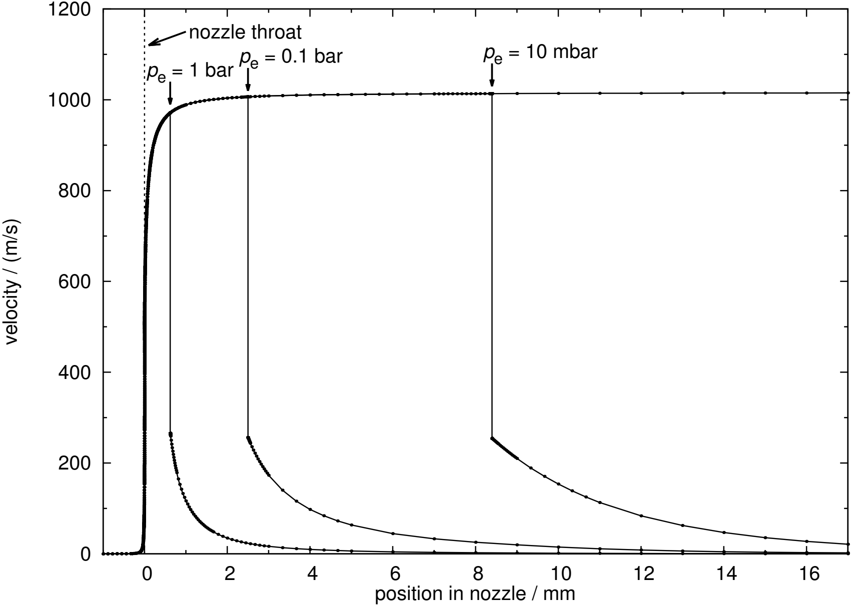
Pressure inside the Laval nozzle



Influence of the exit pressure on the pressure



Influence of exit pressure on the velocity (I)

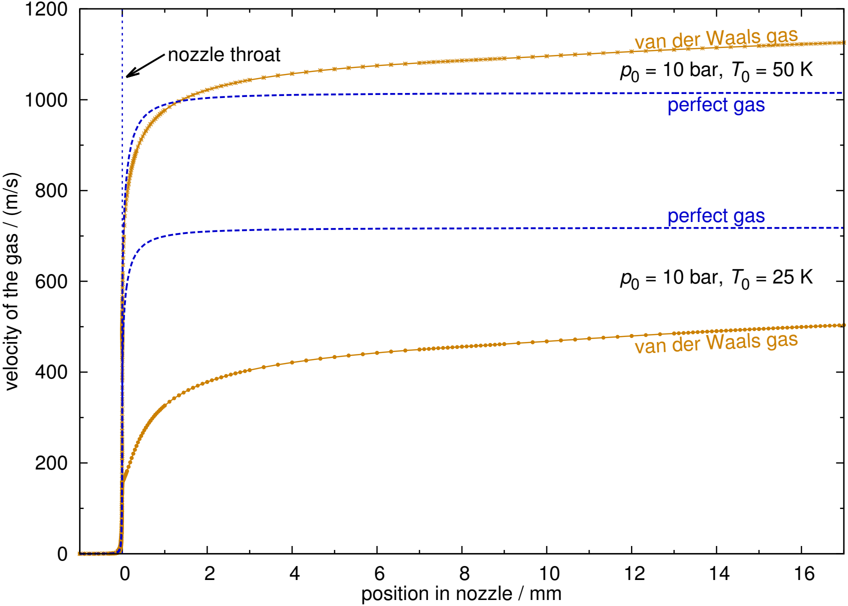


Influence of exit pressure on the velocity (II)

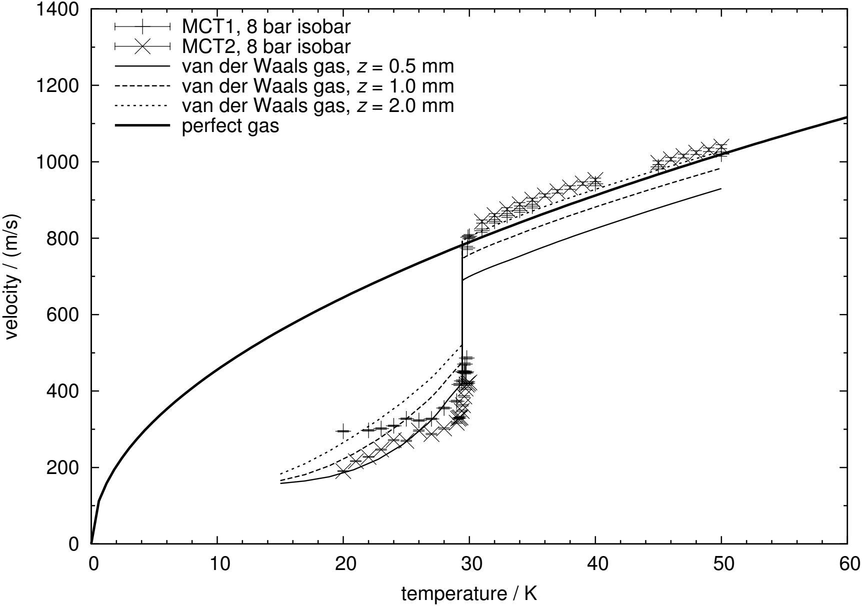
- Pressure at the nozzle outlet should be significantly lower than at the inlet to prevent shock inside the nozzle.
- In case of cluster-jet target:
  $p_{e,\text{shock}} > p_e > p_{e,\text{super}}$
  $\Rightarrow$ nozzle is overexpanded: the local pressure inside the nozzle is lower than the pressure at the outlet
  $\Rightarrow$ shocks outside the nozzle

[www.edwards.af.mil]

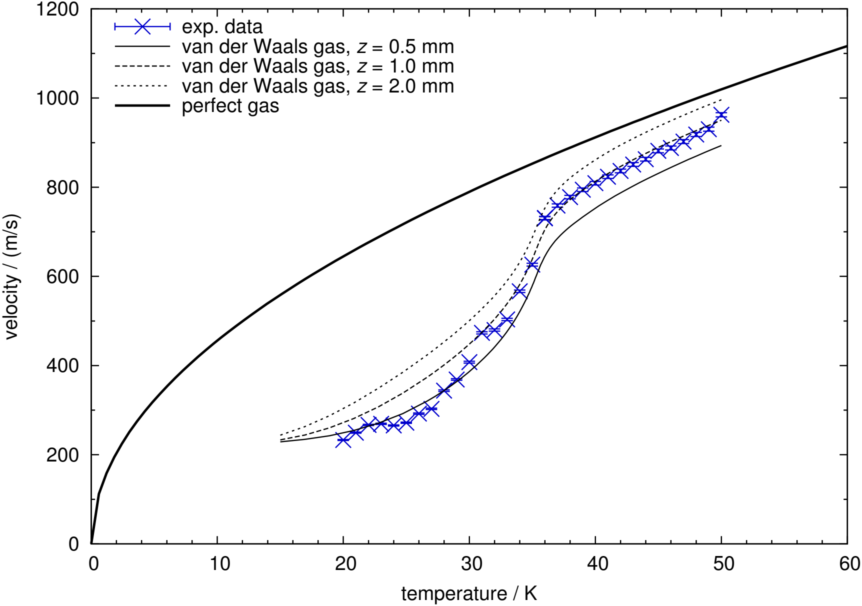
Real gas inside a Laval nozzle



Mean cluster velocity – 8 bar isobar

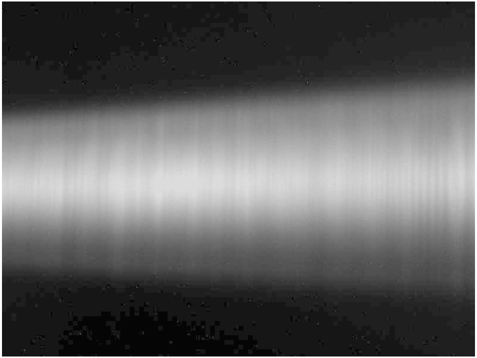


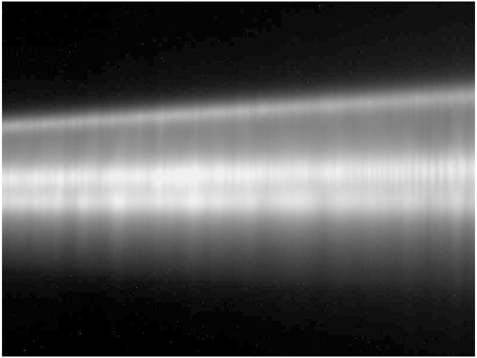
Mean cluster velocity – 17 bar isobar



Structure of the jet

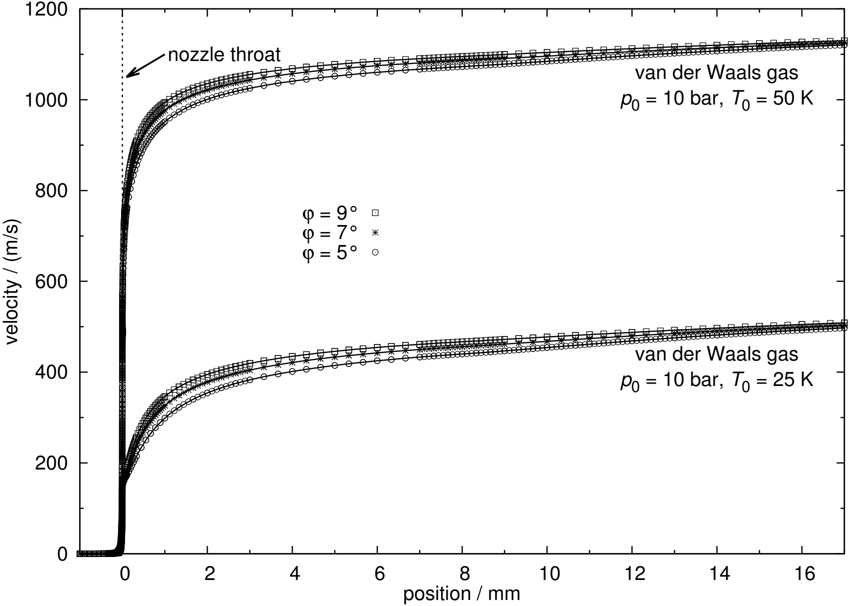
gas at inlet | liquid at inlet



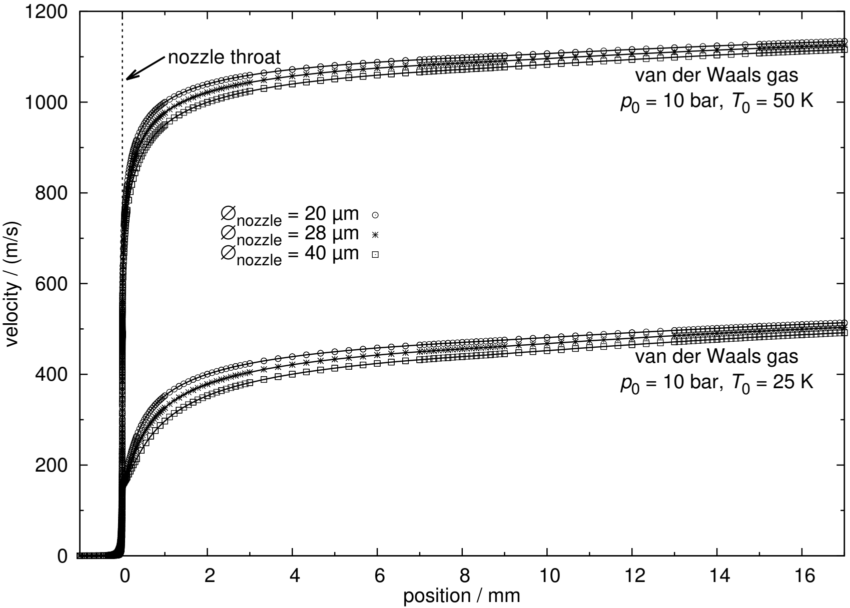


Strong influence of the flow behind the nozzle
on the equation of state / on the particle interactions.

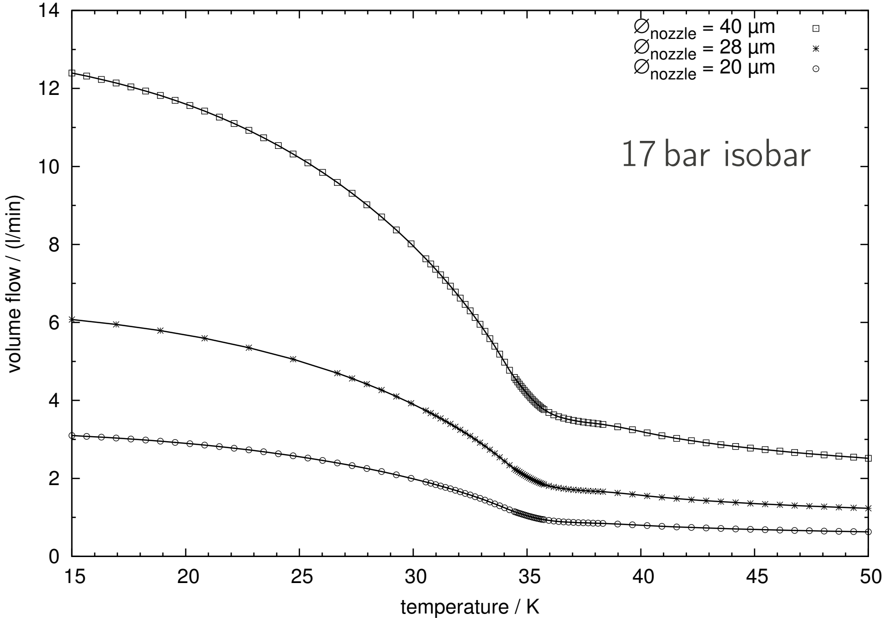
Dependance on the opening angle



Dependance on the throat diameter – velocity

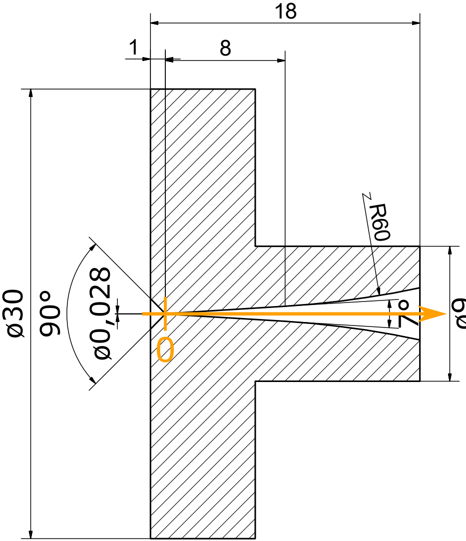


Dependance on the throat diameter – volume flow

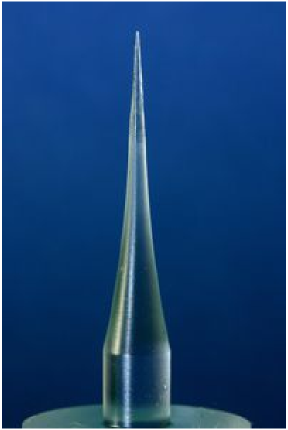


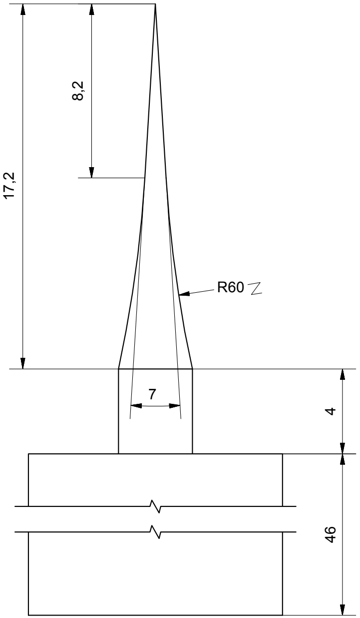
Laval nozzle used in Münster cluster-jet targets

- made of copper
- produced at CERN workshop
- diameter of the throat: 28 µm



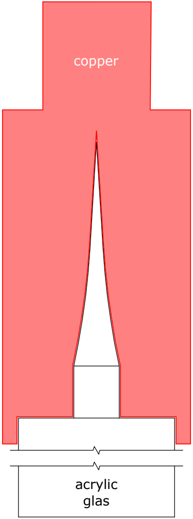
Production of a negative of the trumpet





- produced from acrylic glass (PMMA)
- tip diameter of 30 µm to 60 µm

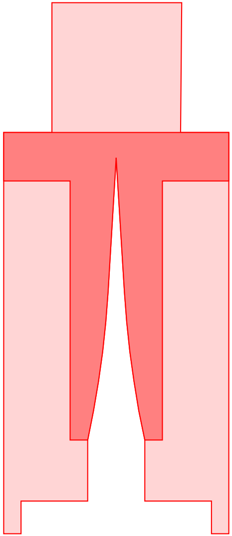
Production of the body of the Laval nozzle

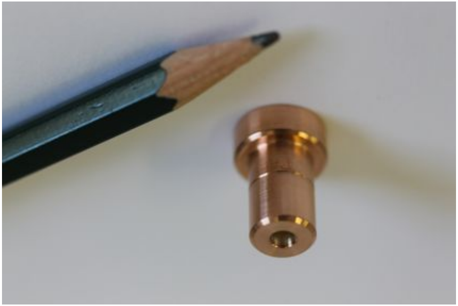


- galvanic deposition of copper
- mechanical extraction of the PMMA negative
- remaining PMMA particles can be removed by chloroform

$\Rightarrow$ residue-free removal of the PMMA negative

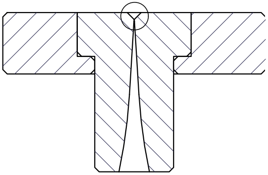
Final outer shape of the Laval nozzle

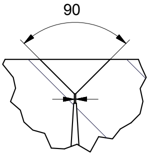




Additional copper is removed to achieve the final outer shape of the Laval nozzle.

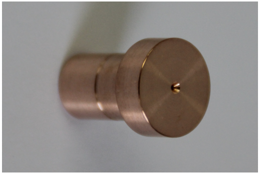
The inlet of the Laval nozzle





- 90° cone inserted by mechanical processing.
- Connection between inlet and outlet manufactured using a laser technique.

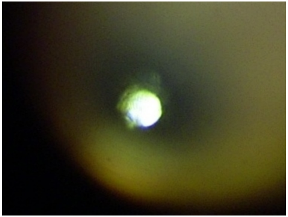
Adaptation to CERN nozzle geometry



$\Rightarrow$

First batch of produced nozzles

- Produced 11 complete nozzles with throat diameters between 42 µm and 105 µm.
- Six of these nozzle with desired length of the inlet cone and round throat. Mean diameter of these nozzles: (55 ± 8) µm
- One nozzle tested successfully at the prototype for the PANDA cluster-jet target.



Summary

- Laval nozzles:
  accelerates gas (liquids) to supersonic velocities
  via a given pressure gradient
- Wide field of applications – here:
  Application for cluster production in
  cluster-jet targets for storage beam experiments
- New production of Laval nozzles in
  CERN geometry started in Münster
- New production methods enables the
  production of nozzles with different geometries
- Successful production of first set of Laval nozzles