Calculation and measurement of cluster velocities
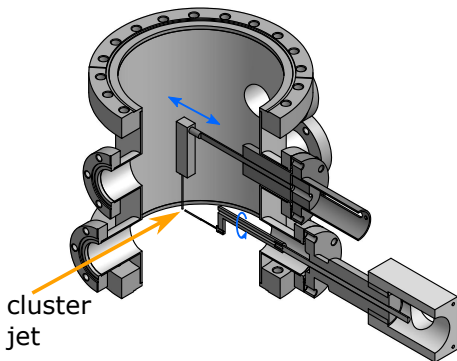
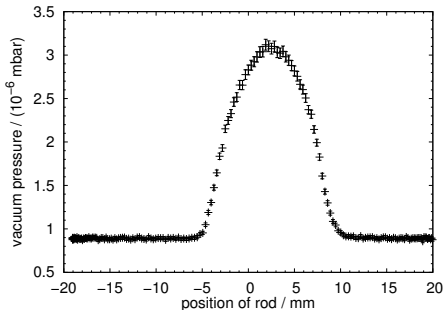## FutureJet Meeting Wien 2013

Alexander Täschner
(taschna@uni-muenster.de)

Measurement of the target thickness

cluster jet

target thickness n_T:

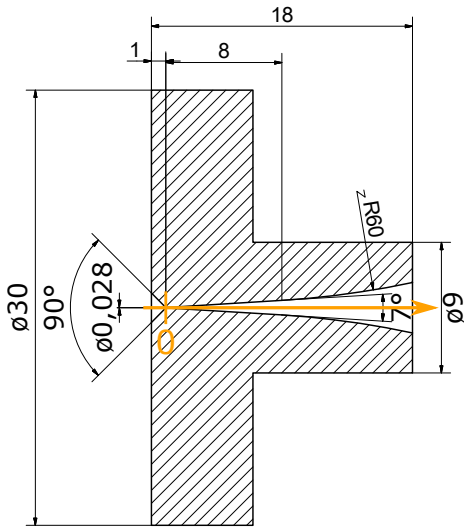$$n_T = \frac{\Phi_{jet}}{A \cdot v_{jet}}$$

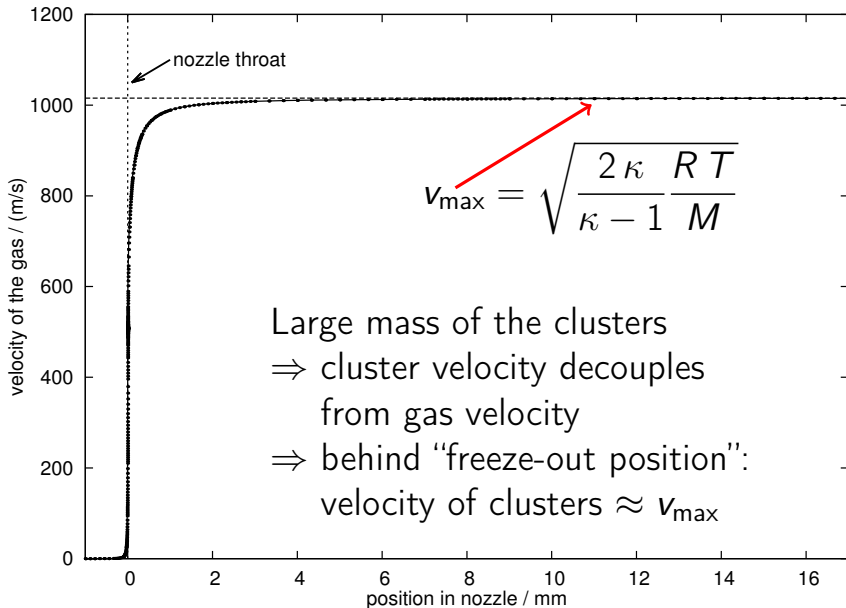Φ_{jet} = cluster jet flow

A = cross section of jet

v_{jet} = cluster jet velocity
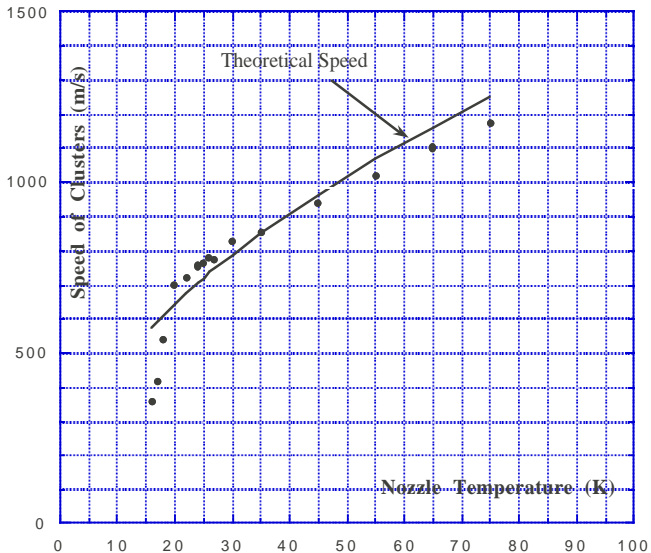
Simulation of the nozzle flow

- inviscid flow is assumed
  (high Reynolds number)
  $\Rightarrow$ entropy is conserved

- stationary
  quasi-one-dimensional
  model:
  nozzle geometry described
  by area $A(z)$

- different equations of state
  can be used, e.g.
  - perfect gas
  - Van der Waals gas

Velocity of perfect gas

nozzle throat

$$v_{\max} = \sqrt{\frac{2\,\kappa}{\kappa - 1}\frac{R\,T}{M}}$$

Large mass of the clusters
$\Rightarrow$ cluster velocity decouples
  from gas velocity
$\Rightarrow$ behind "freeze-out position":
  velocity of clusters $\approx v_{\max}$
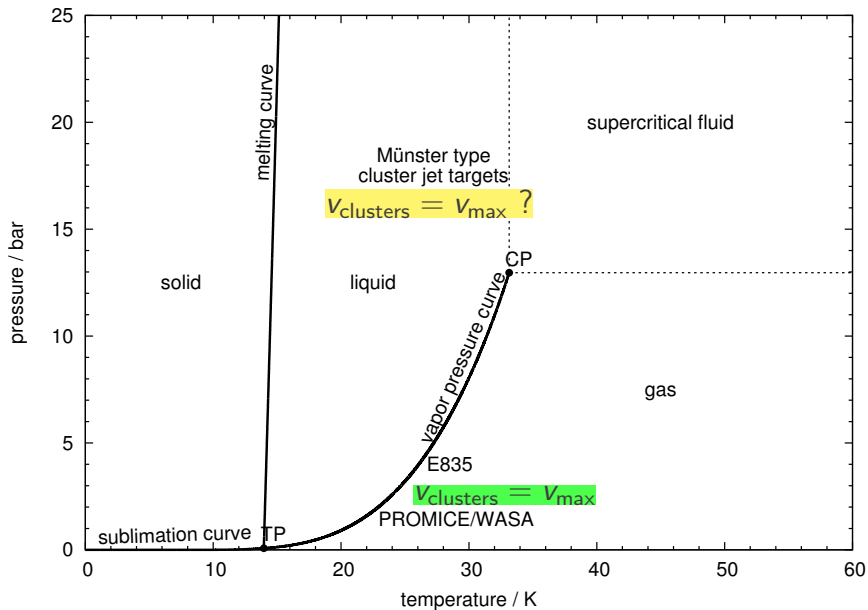
velocity of the gas / (m/s)

position in nozzle / mm

Measurements at FERMILAB E835

good agreement between the theoretical speed of the perfect gas and the speed of the clusters
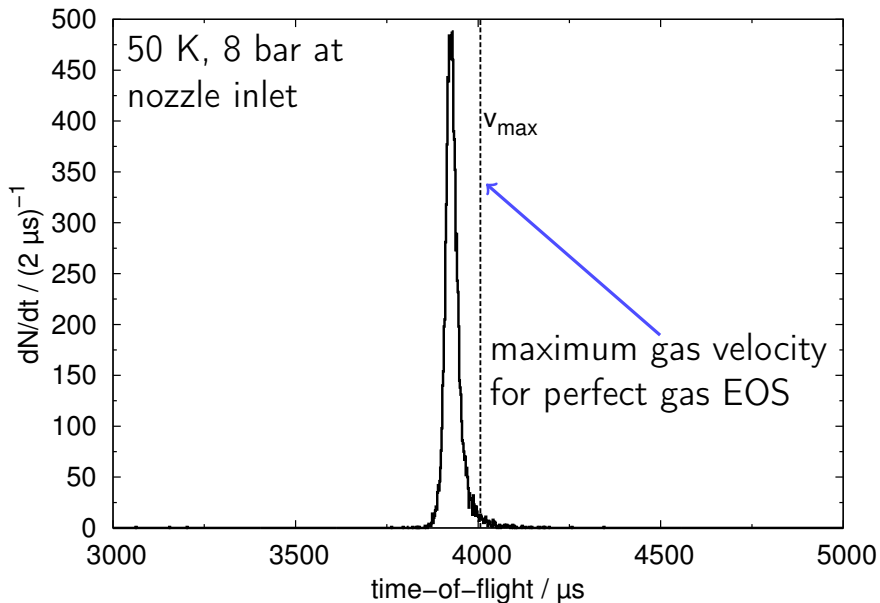
[graduation thesis G. Garzoglio]

Region of operation for cluster jet targets

A phase diagram with pressure / bar (0 to 25) on the y-axis and temperature / K (0 to 60) on the x-axis. Labeled regions: solid, liquid, gas, supercritical fluid. Curves labeled: melting curve, vapor pressure curve, sublimation curve, with points TP (triple point) and CP (critical point). Annotations: Münster type cluster jet targets $v_{clusters} = v_{max}$?; E835, PROMICE/WASA with $v_{clusters} = v_{max}$.

Velocity determination via time-of-flight

pulsed electron gun
$\Rightarrow$ ionizes a cluster
$\Rightarrow$ start signal for TOF

distance $\approx 3.5\,$m

channeltron detects
the ionized cluster
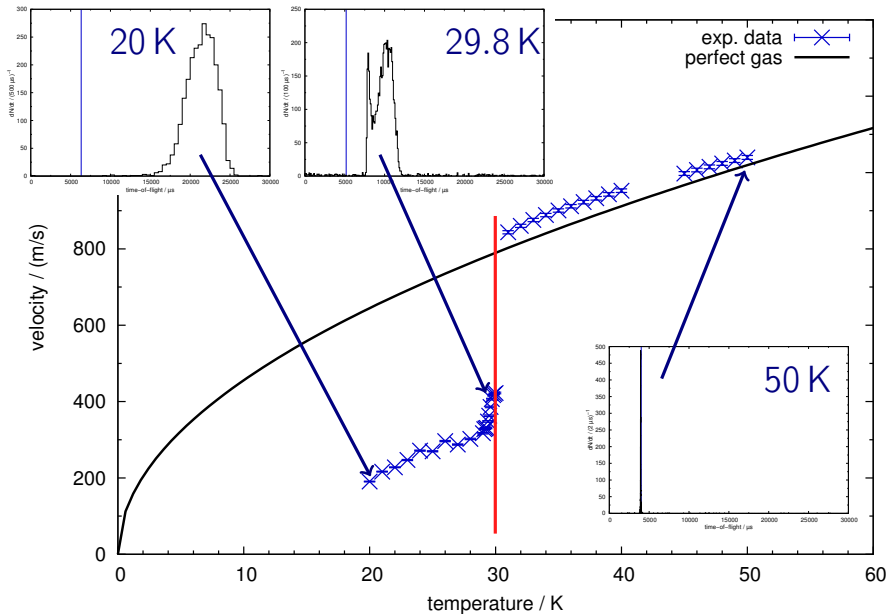$\Rightarrow$ stop signal for TOF
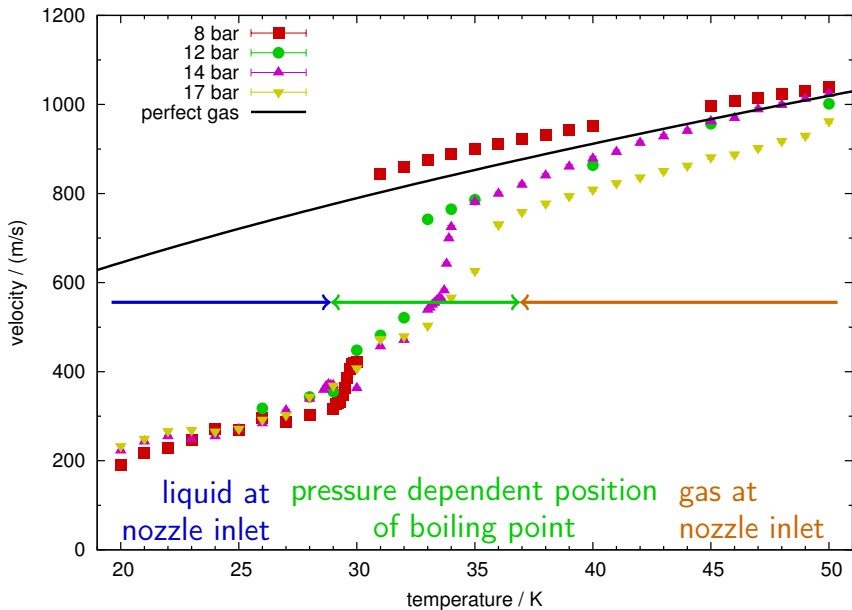
2 m
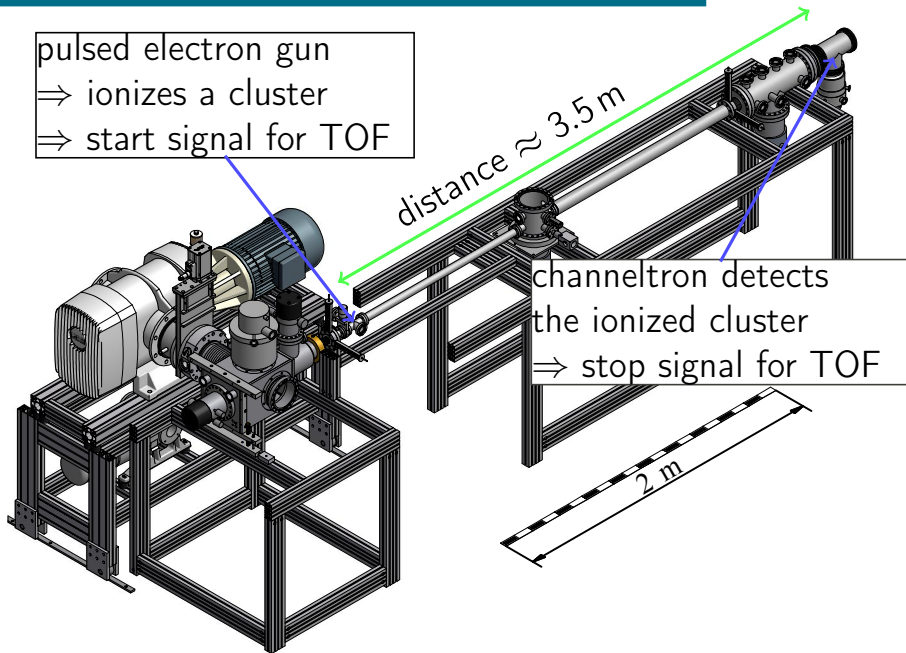
TOF spectrum of clusters
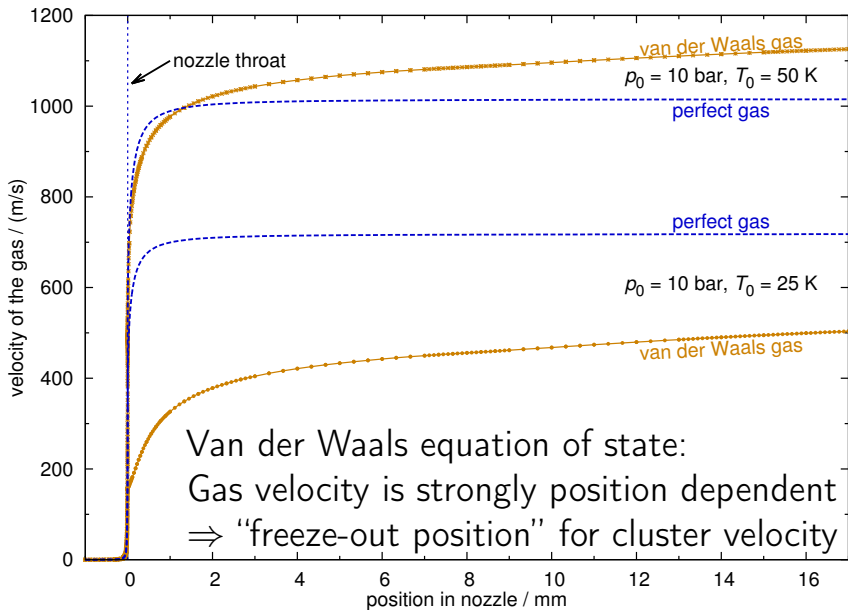
Cluster velocity at 8 bar isobar
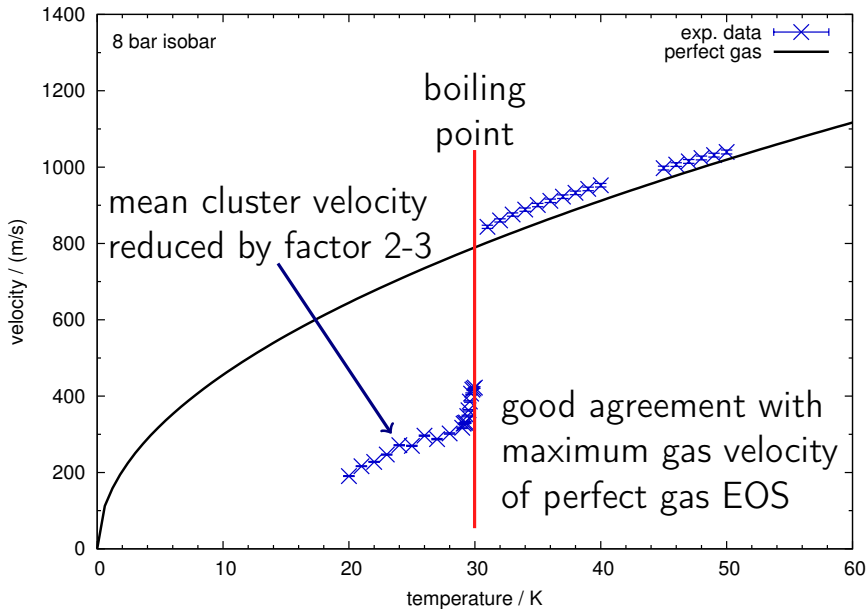
Velocity distributions at 8 bar isobar

Cluster velocity at various isobars

Velocity of the Van der Waals gas

Van der Waals equation of state:
Gas velocity is strongly position dependent
⇒ "freeze-out position" for cluster velocity
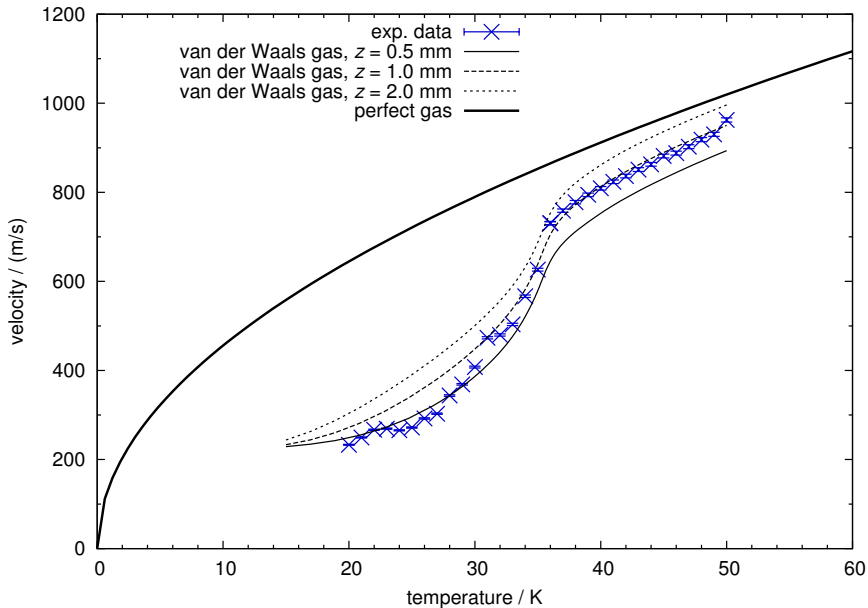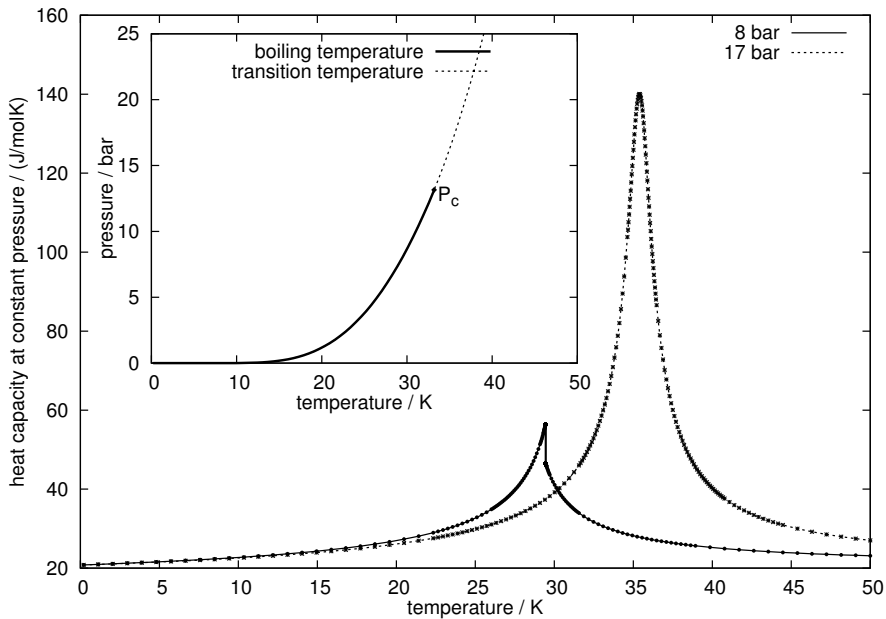
Van der Waals model for 8 bar isobar
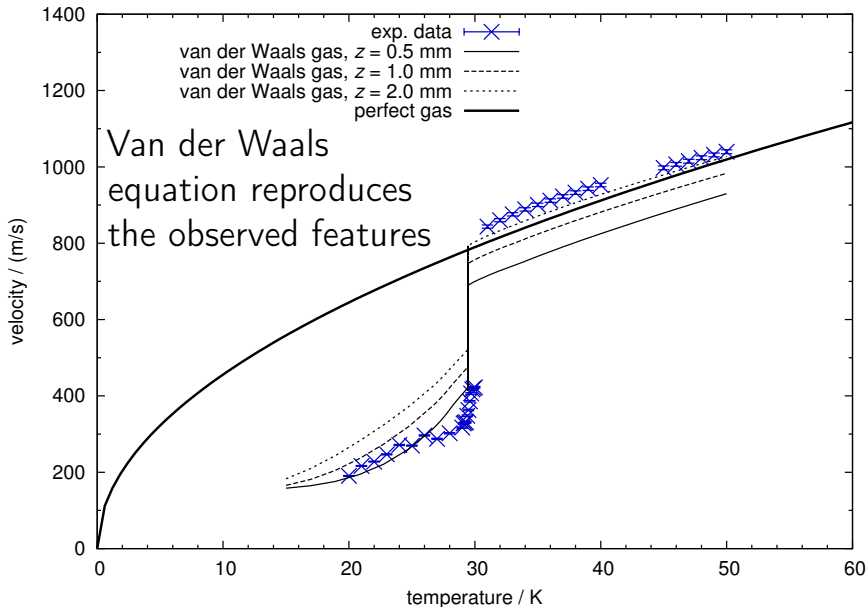
Van der Waals model for 17 bar isobar

Transition temperature

Description of the measured cluster velocities

- Van der Waals model provides an accurate description of the measured data with two free parameters z_l and z_g:

$$u_C(p_0, T_0) = \begin{cases} u_{\text{VdW}}(p_0, T_0, z_l) & \text{for} \quad T_0 < T_{\text{tr}}(p_0) \\ u_{\text{VdW}}(p_0, T_0, z_g) & \text{for} \quad T_0 \geq T_{\text{tr}}(p_0) \end{cases}$$

  T_{tr}: pressure dependent transition temperature

- Fit to the measured data:

	MCT1	MCT2	all data
z_l / mm	0.736(37)	0.445(14)	0.500(15)
z_g / mm	1.52(20)	1.67(20)	1.61(16)
AAD / %	4.4	5.1	5.4

average absolute deviation (AAD) $\approx$ 5 %

Description of the measured isotherms
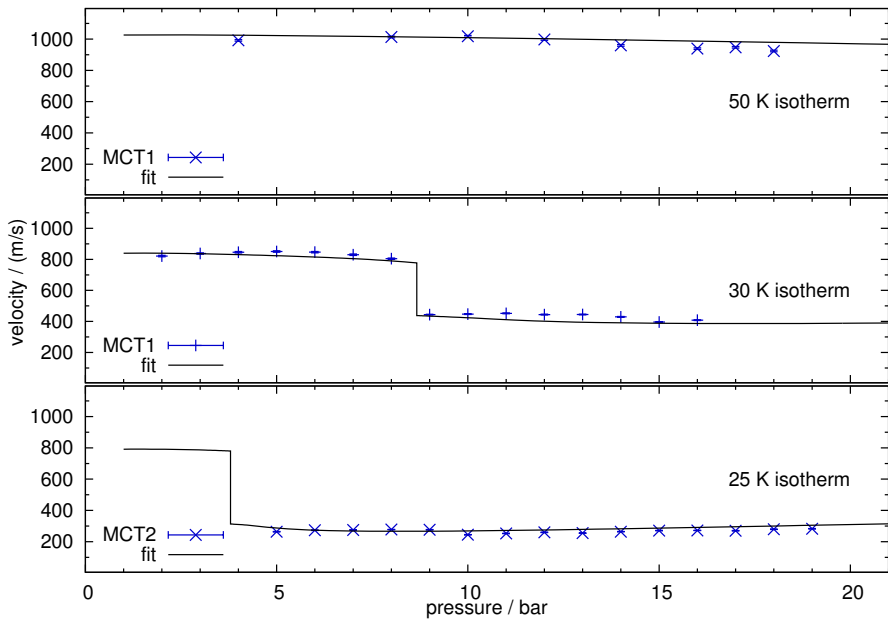
Cluster formation process

- Liquid hydrogen passes the nozzle throat
- Cluster formation from evaporation $\Rightarrow$ "spray"

Cluster formation by gas condensation

(plot labels) pressure / bar; temperature / K; melting curve; vapor pressure curve; sublimation curve; solid; liquid; gas; supercritical fluid; CP; TP; E835; PROMICE/WASA
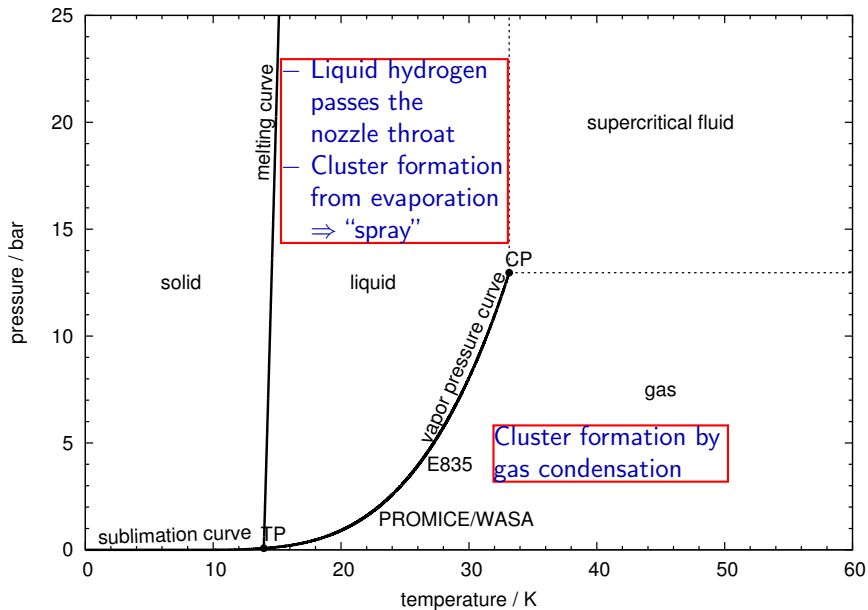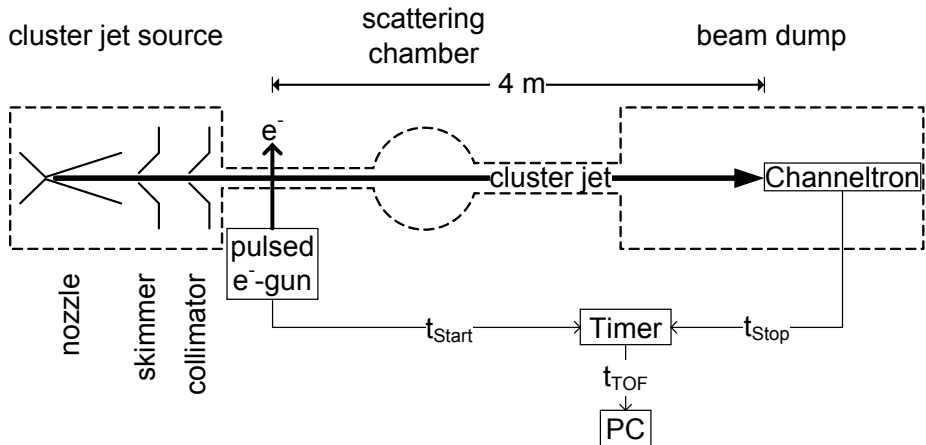
Summary and outlook

- Precise technique for velocity measurements of clusters
- Comparison between measurements and simulation:
  $\Rightarrow$ better comprehension of the cluster production process
  $\Rightarrow$ important for improved nozzle design / cluster density
- Found **two cluster regimes**:

  <u>conventional targets</u>   <u>Münster type</u> (at highest density)

  - Clusters formed from **condensated gas**
  - Cluster velocity = perfect gas velocity
  - **Lower density**

  - Clusters formed from **evaporation of liquid**
  - Cluster velocity = velocity of real gas
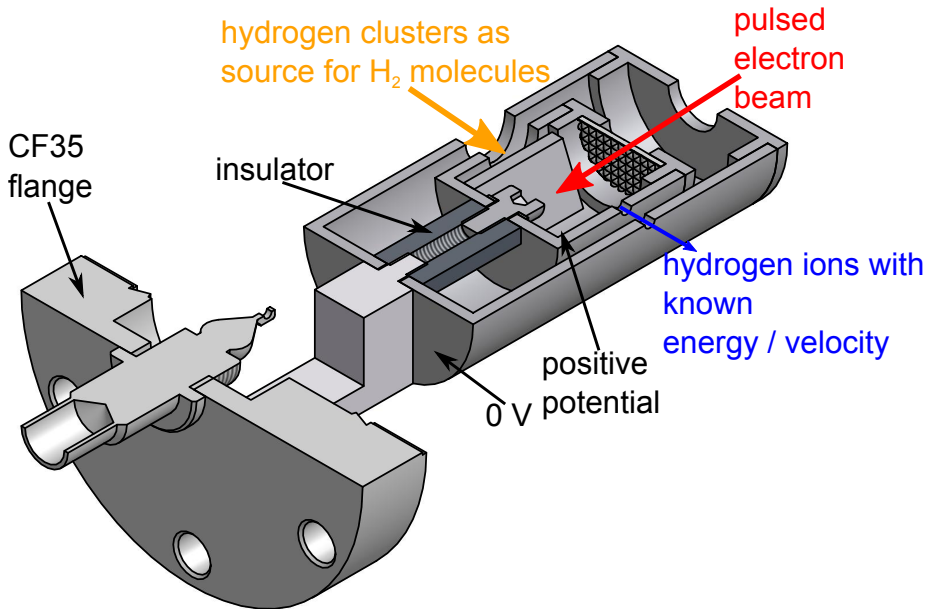 - **Higher density**

- **In the future:**
  Investigation of the mass distribution of the clusters
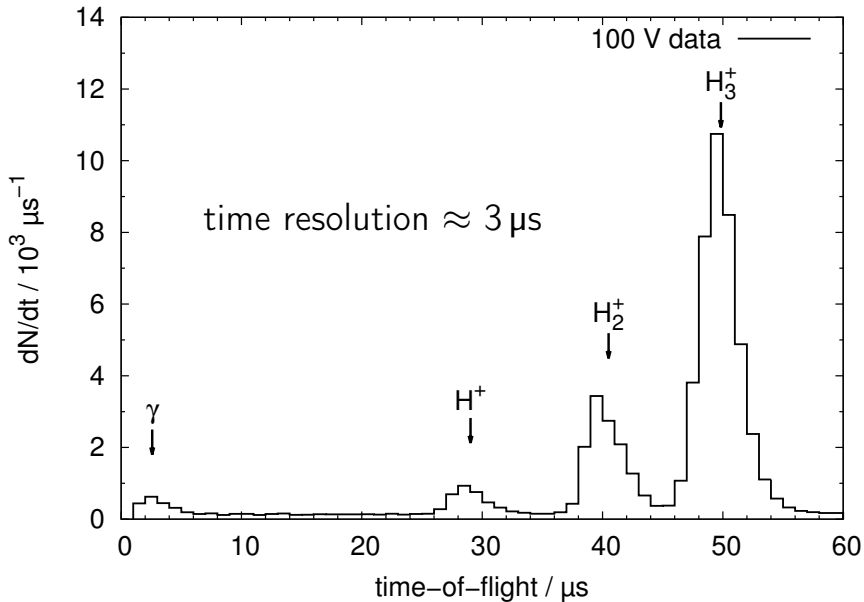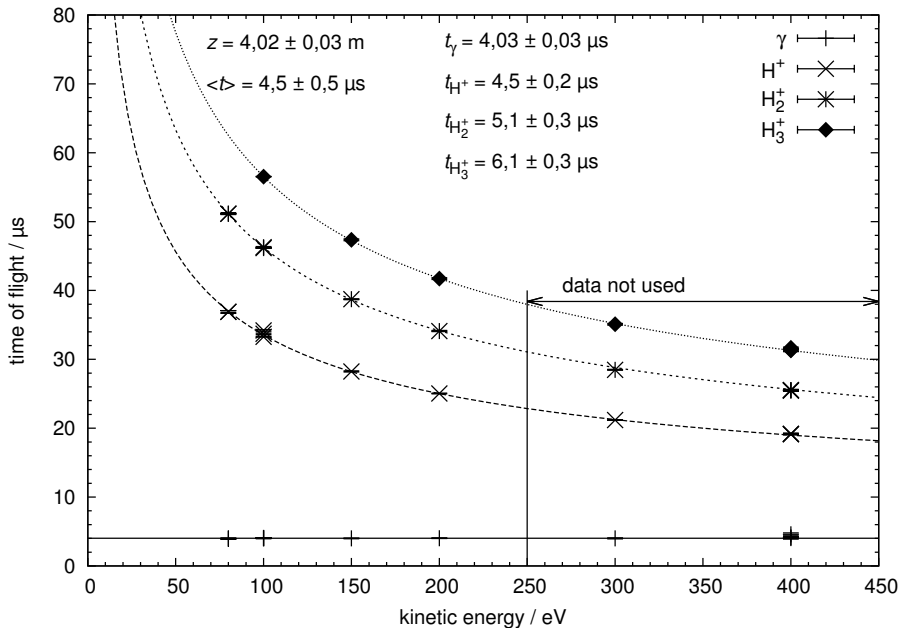
Additional slides

Time-of-flight method

cluster jet source

scattering chamber

beam dump

4 m

nozzle

skimmer

collimator

e^-

cluster jet

Channeltron

pulsed e^--gun

t_{Start}

Timer

t_{Stop}

t_{TOF}

PC

Calibration of the time-of-flight

hydrogen clusters as source for H_2 molecules

pulsed electron beam

CF35 flange

insulator

hydrogen ions with known energy / velocity

positive potential

0 V

TOF spectrum of the calibration source

Calibration of TOF measurements

Description of the measured isobars