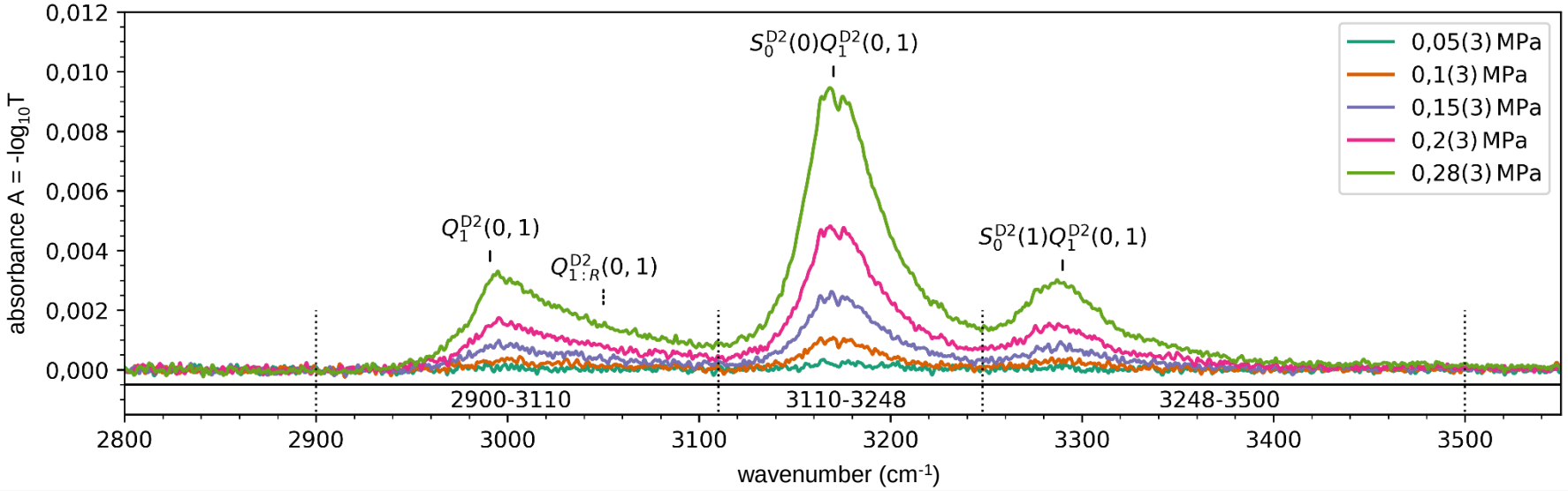
Karlsruher Institut für Technologie

Tritium Laboratory Karlsruhe

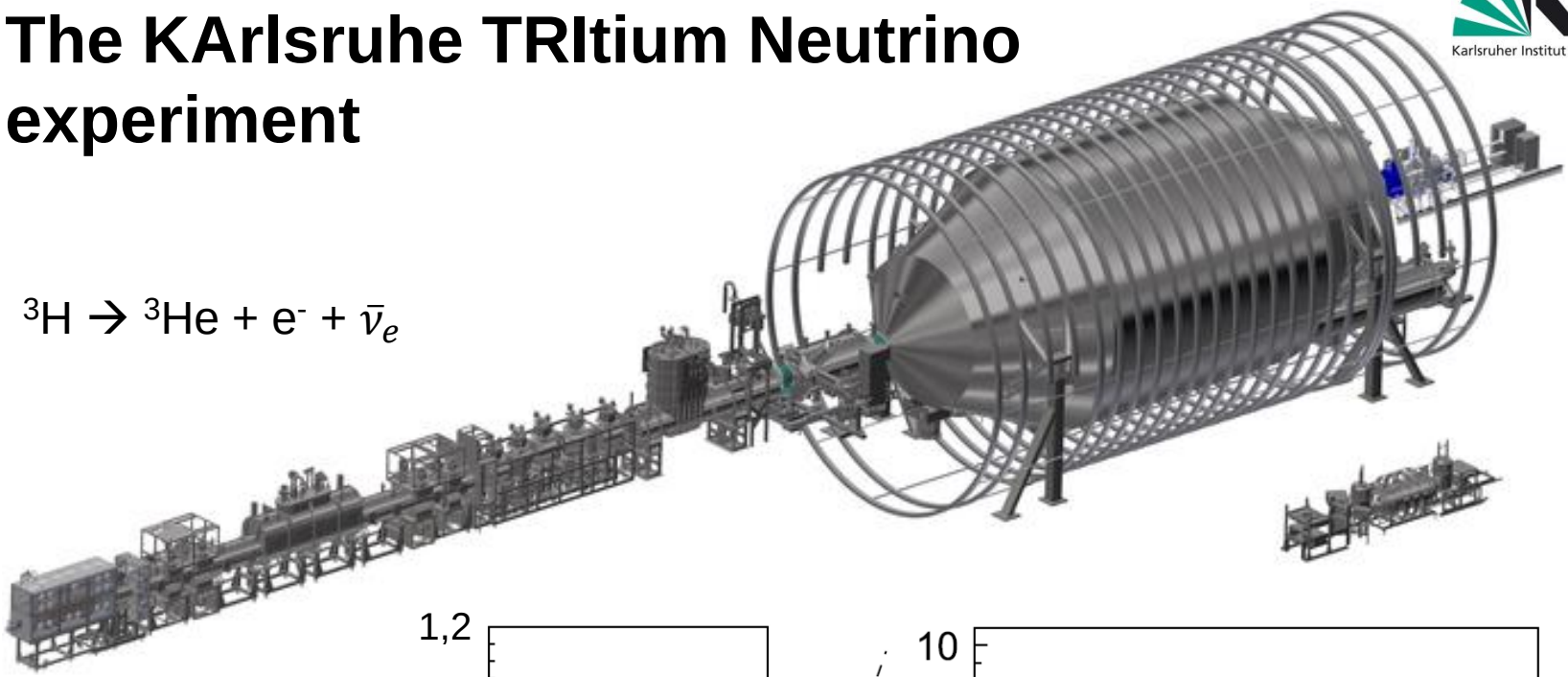
Van-der-Waals cluster formation as a systematic uncertainty for the KATRIN neutrino mass measurement

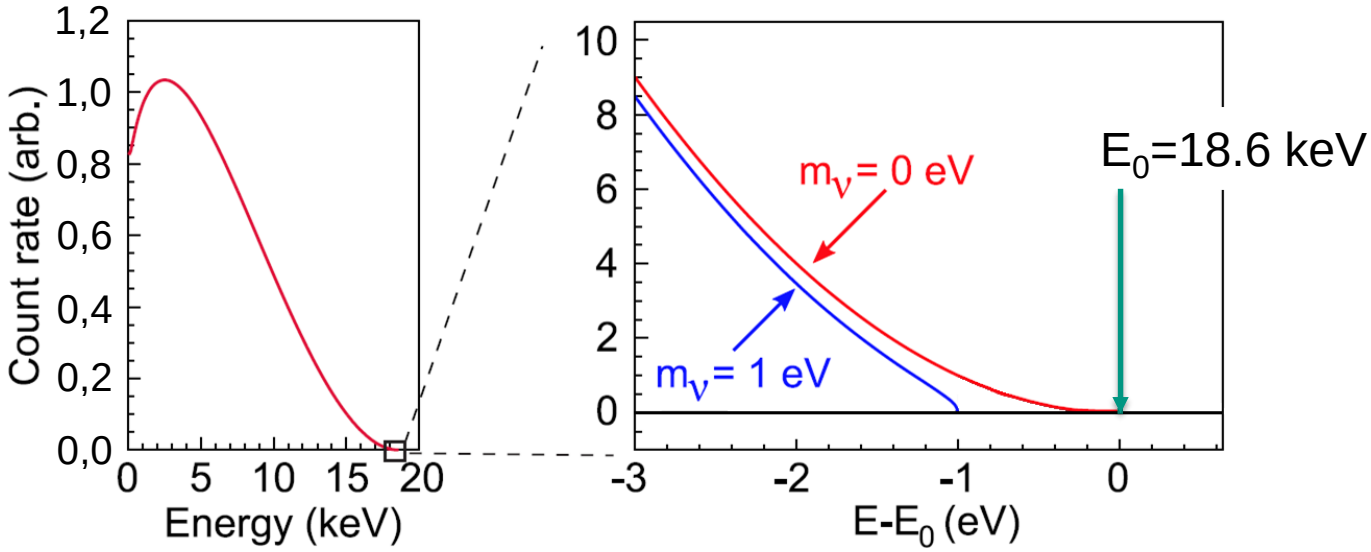
Sebastian Mirz – Tritium Laboratory Karlsruhe, Institute for Nuclear Physics, Karlsruhe Institute of Technology



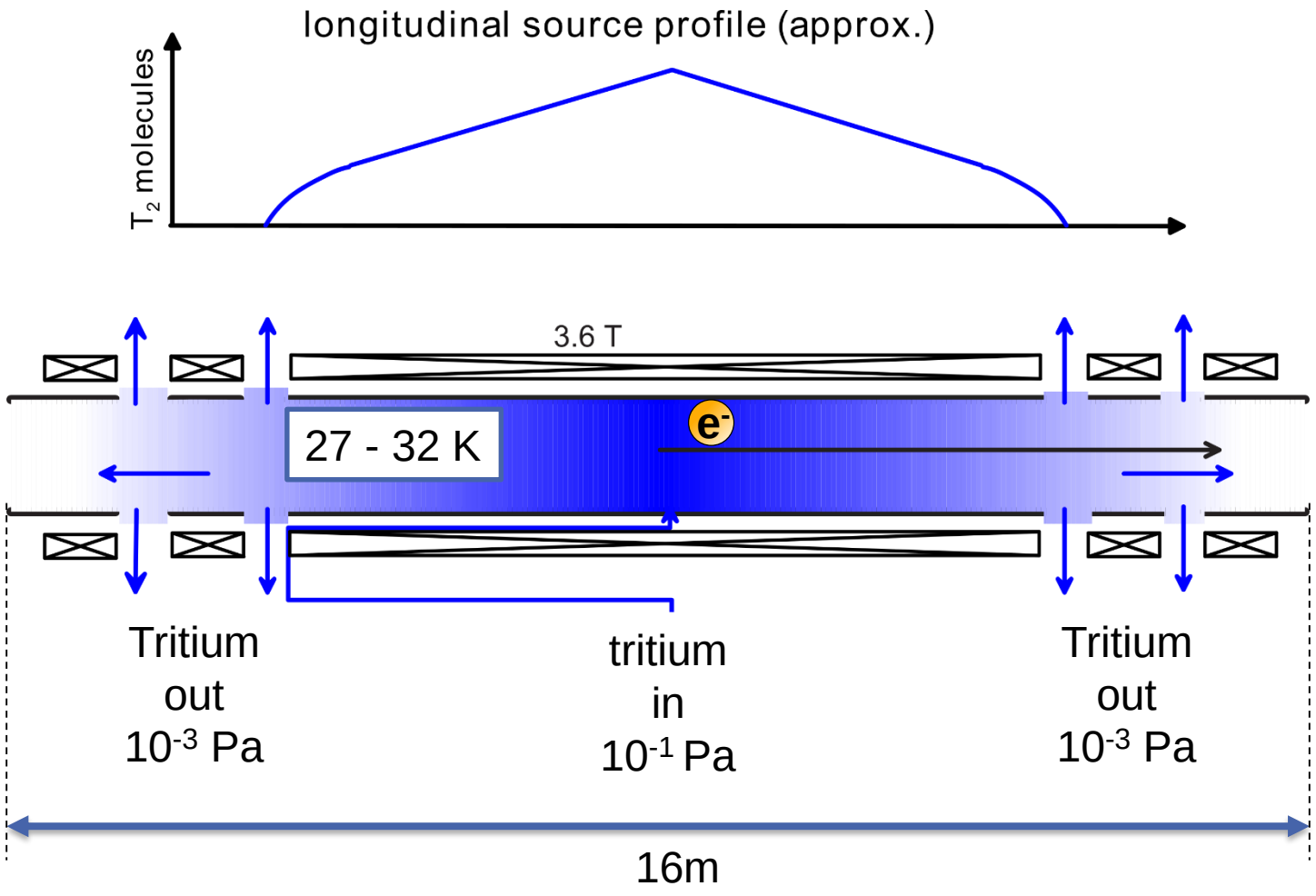
The KArlsruhe TRItium Neutrino experiment

$^3H \rightarrow {}^3He + e^- + \bar{\nu}_e$

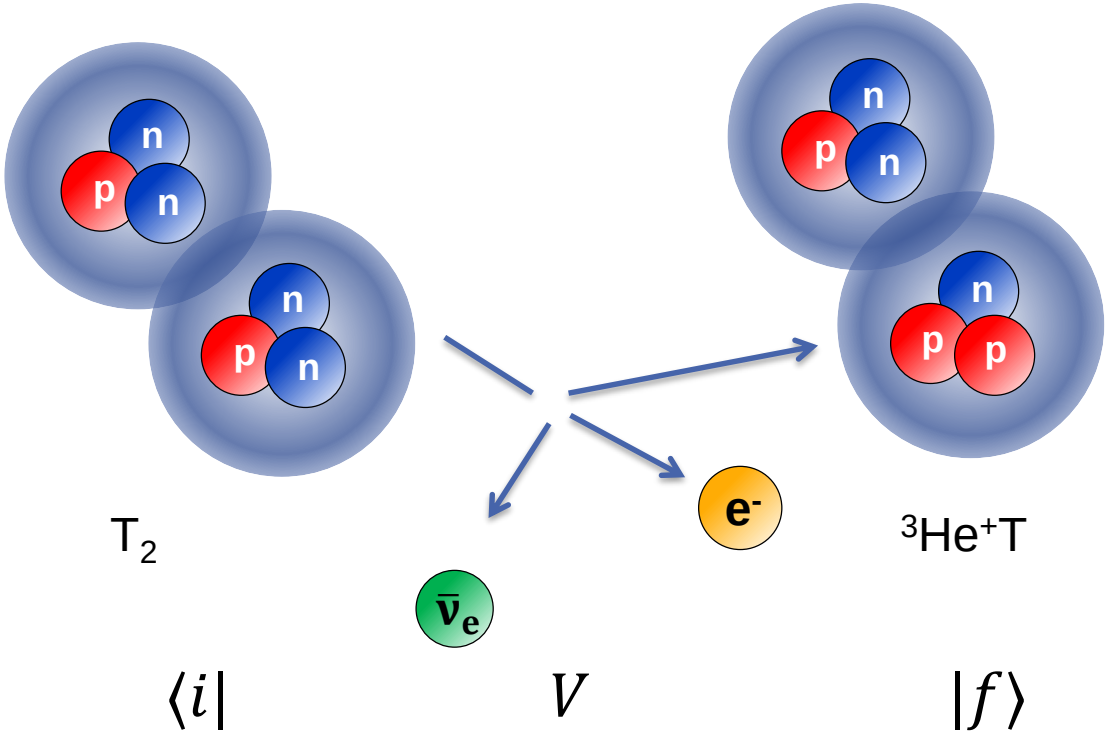




Windowless Gaseous Tritium Source (WGTS)



Molecular β-decay

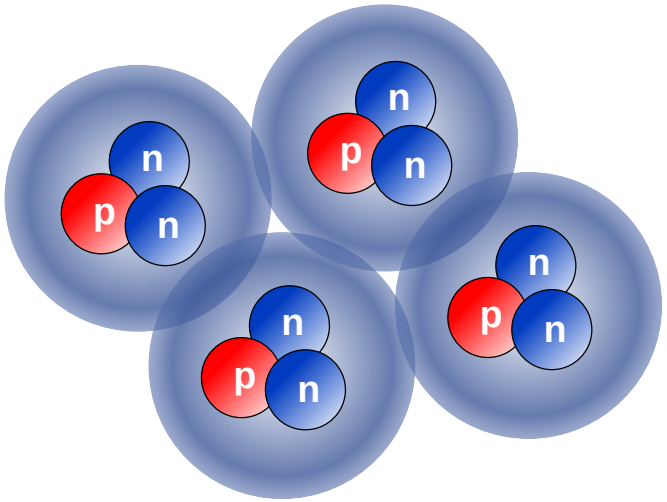


β-spectrum depends on initial and final state distribution

relevant for β-spectrum:

- excitation energy for an initial final state combination E_i
- probability $P(E_i)$

Influence of Van-der-Waals clusters



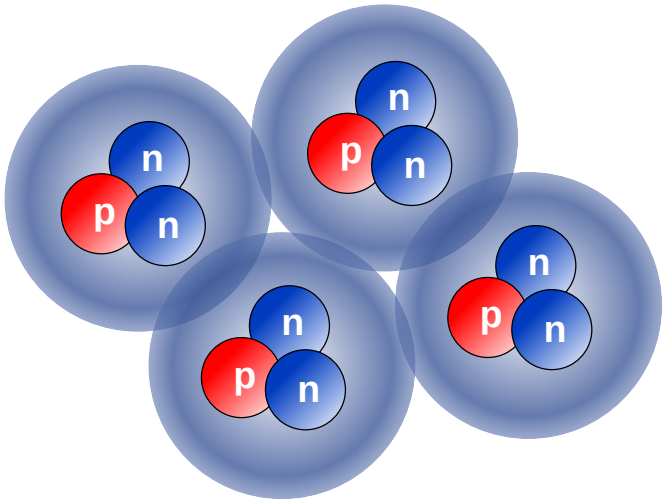
$(T_2)_2$ Van-der-Waals dimer

London dispersion force:

$$w(r) \propto \frac{\alpha_1 \alpha_2}{r^6}$$

α: polarizability

Influence of Van-der-Waals clusters



$(T_2)_2$ Van-der-Waals dimer

Influence by different…

… initial state distribution

… binding energy (e.g. 0.36 meV für $(H_2)_2$)

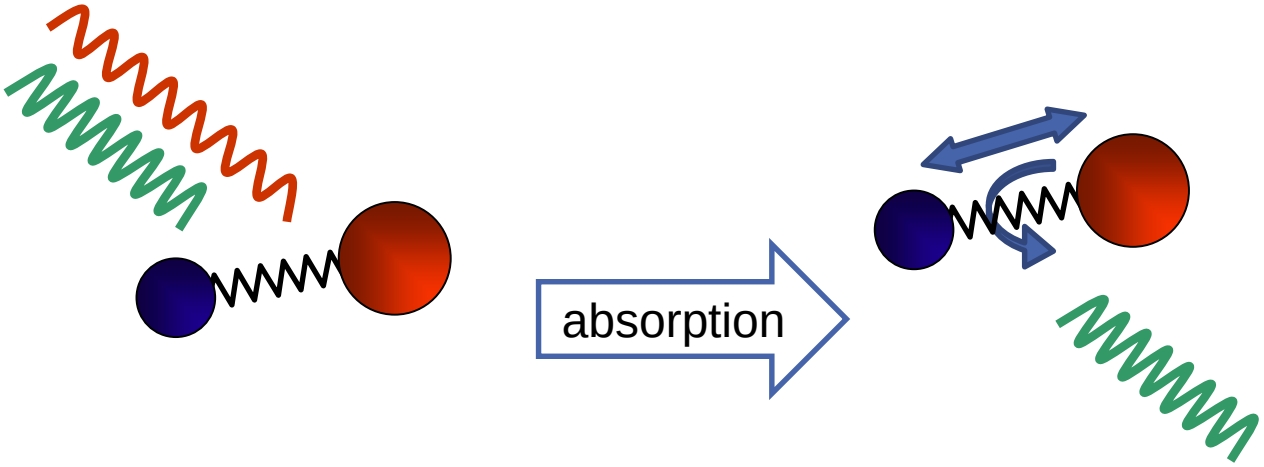
… recoil energy (1.7 eV for single T_2)

… final state distribution

Cluster formation to be included in uncertainty budget for FSD: 0.02 eV^2

KATRIN needs the concentration and excitation energies of the clusters
Problem: No theoretically or experimentally determined values available for HT, DT and T_2

Experimental investigation: IR absorption spectroscopy

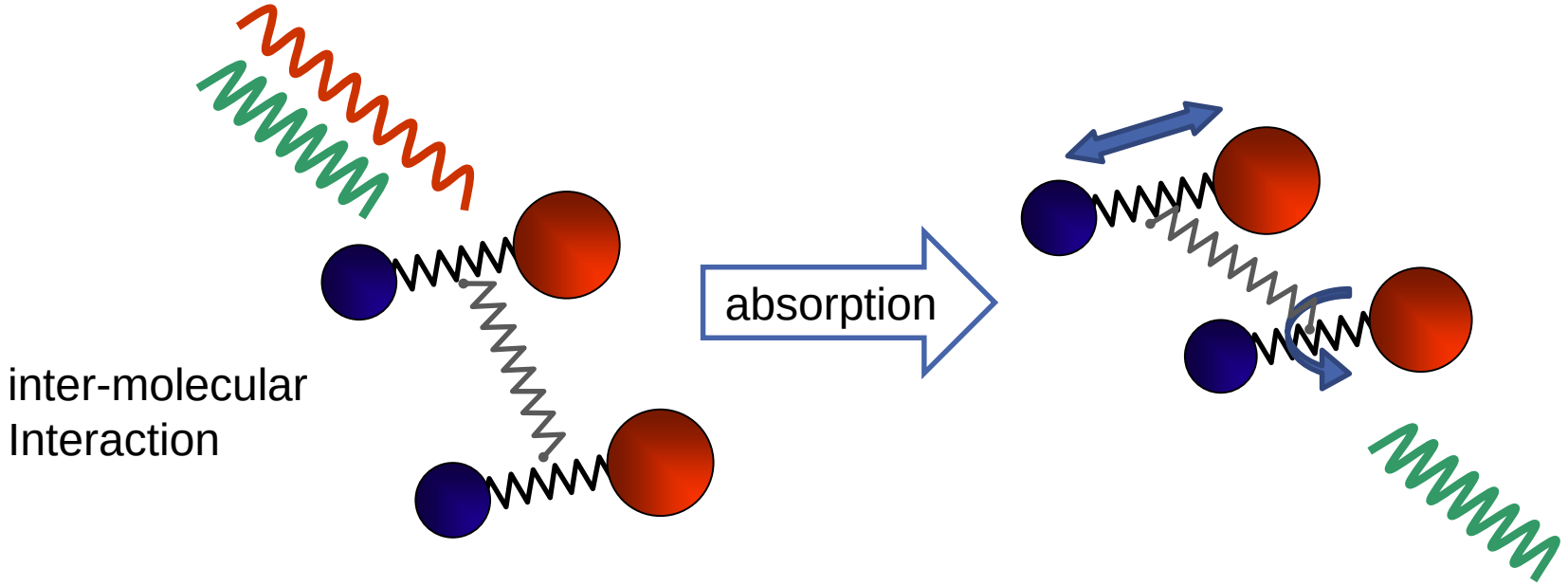


(Dipole-) absorption requires:

- Permanent electrical dipole moment
- or an electrical dipole moment, that changes during vibration

- H_2, D_2, T_2: no electrical dipole moment
- HD, HT, DT: electr. dipole moment negligible ($3{,}3 \cdot 10^{-34}$ Cm for HD)

Experimental investigation: IR absorption spectroscopy



Inter-molecular interaction: Collision, Van-der-Waals binding
→ induced dipole moment → induced absorption

IR absorption spectroscopy is sensitive to Van-der-Waals clusters

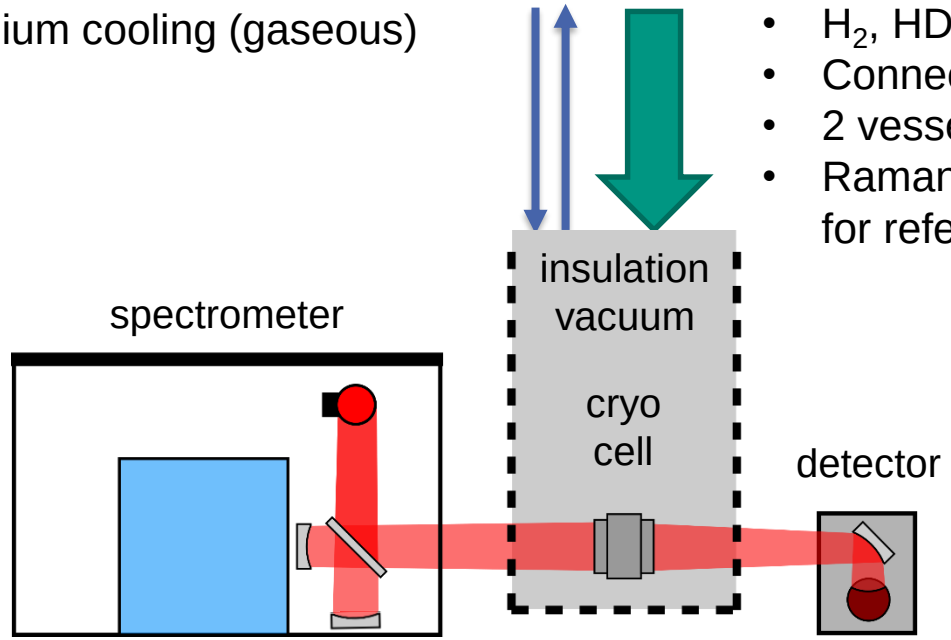
Experiment: TApIR at the Tritium Laboratory Karlsruhe

Cooling:

- helium cooling (gaseous)

Gas supply:

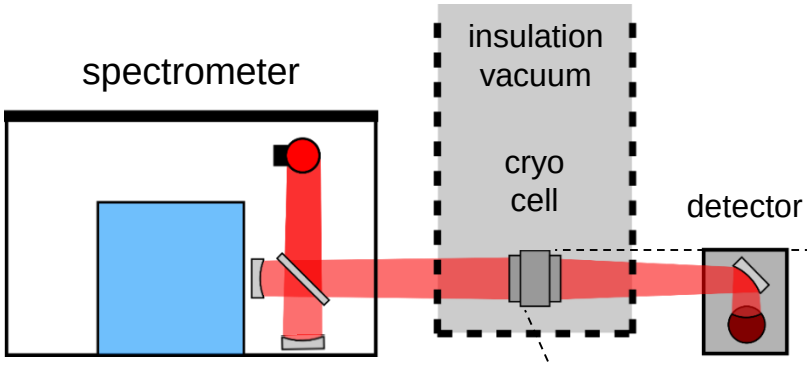
- H_2, HD, D_2
- Connection to cryo distillation
- 2 vessels: 100l + 1l
- Raman system
  for reference calibration



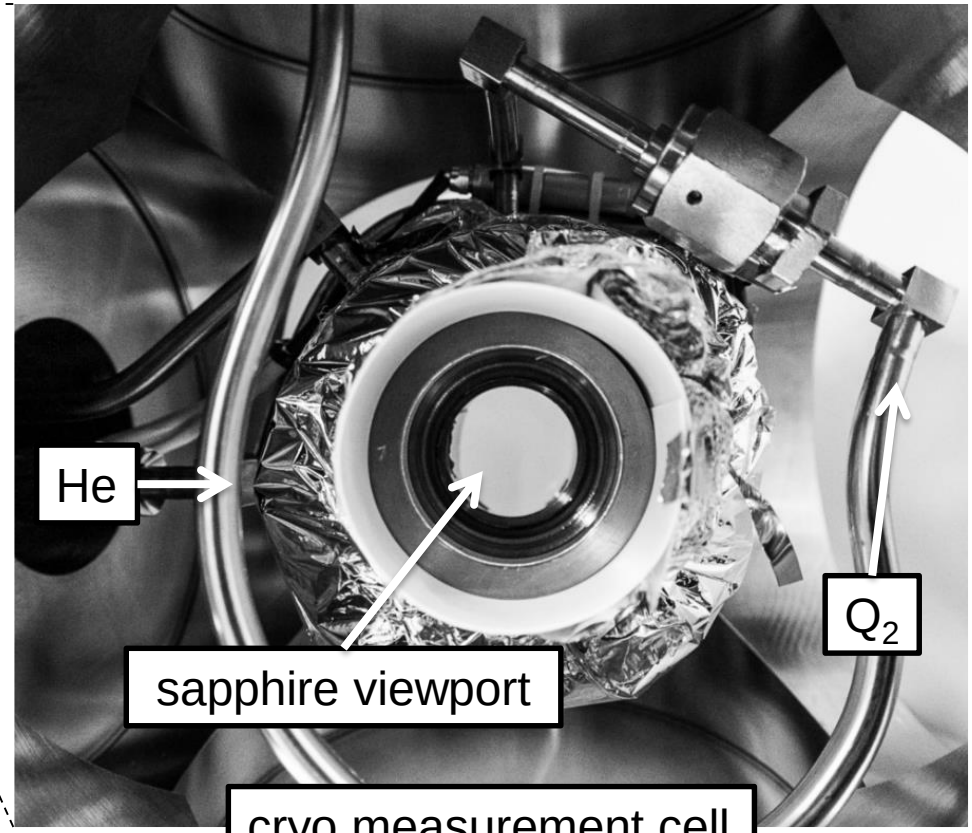
Spectrometer:

- Bruker TENSOR 27: Resolution < 0.9 cm^{-1} (0.2 nm @1500 nm)
- Bruker VERTEX 70: Resolution < 0.4 cm^{-1} (0.09 nm @1500 nm)

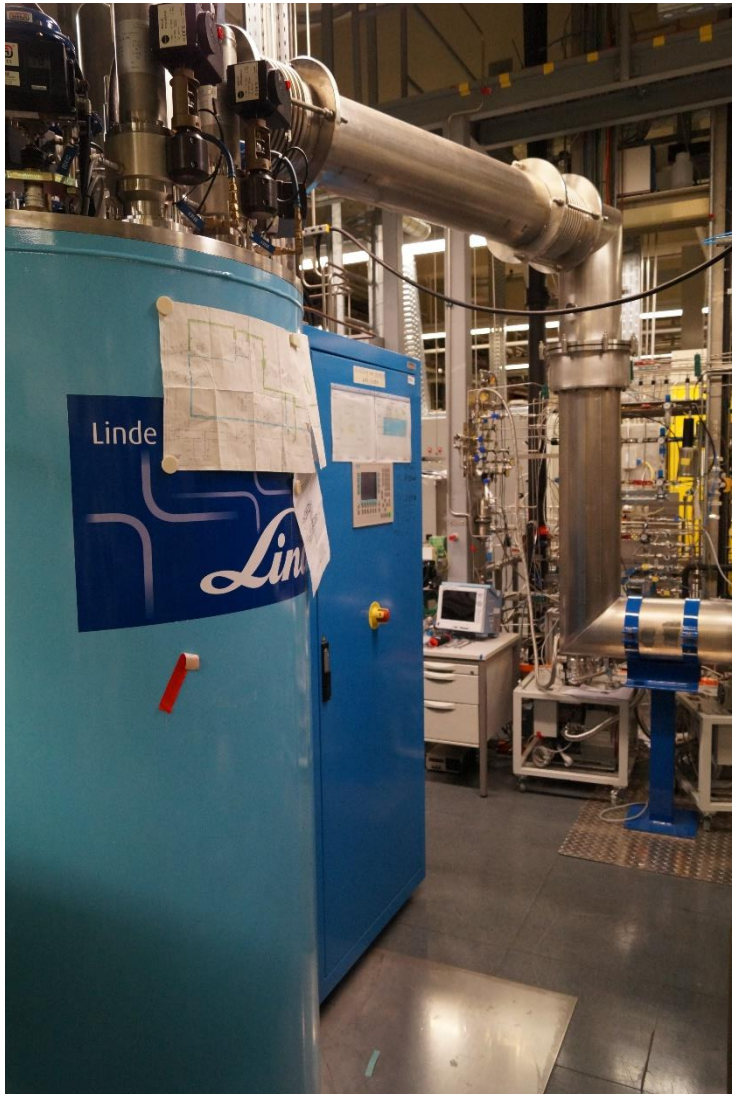
Measurement cell



- absorption lenght: 5 cm
- temperature: 18 K to 35 K
- pressure: 0.05 MPa to 0.28 MPa

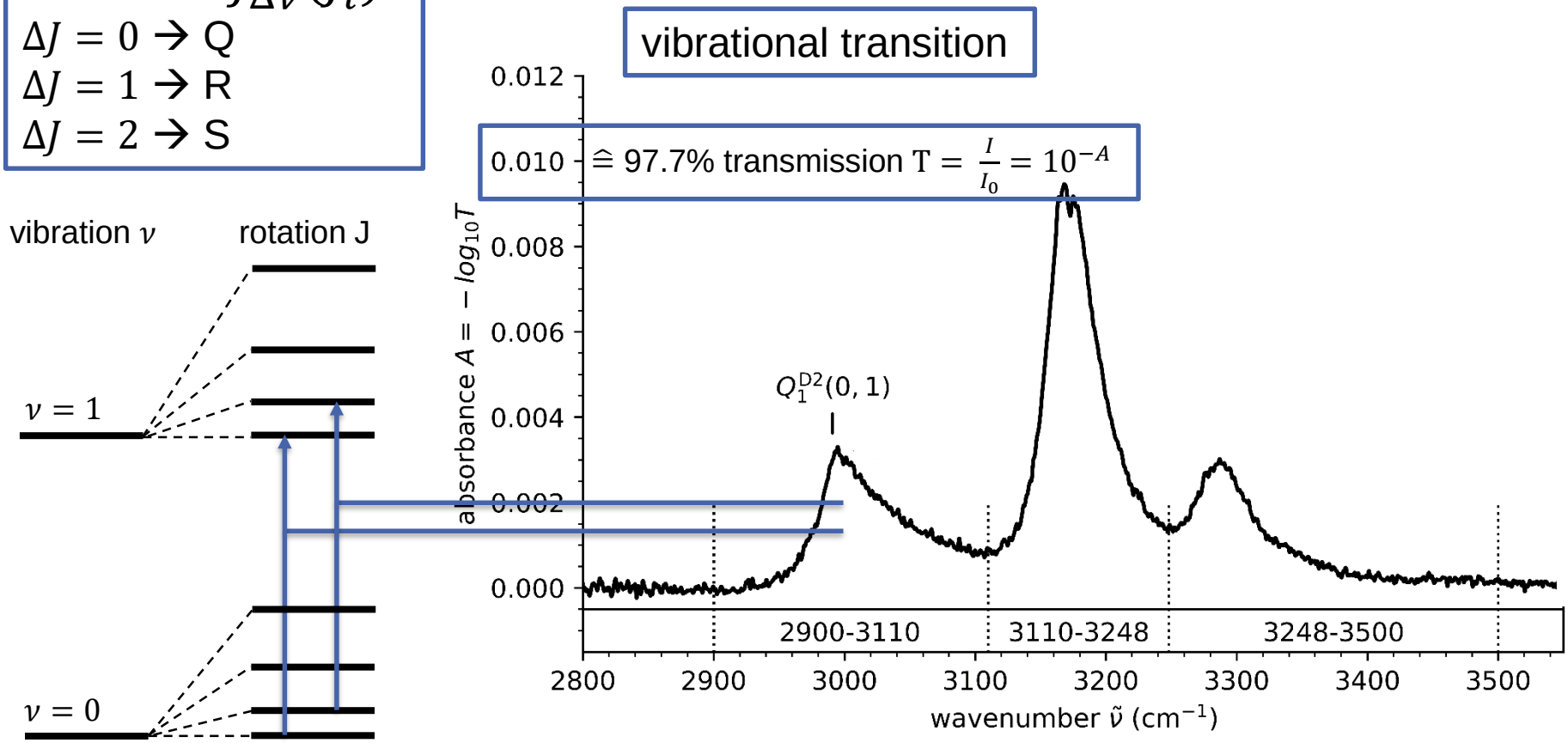


TApIR experiment



Structure of the IR spectra

Notation: $\Delta J_{\Delta\nu}(J_i)$
$\Delta J = 0 \rightarrow$ Q
$\Delta J = 1 \rightarrow$ R
$\Delta J = 2 \rightarrow$ S



Structure of the IR spectra

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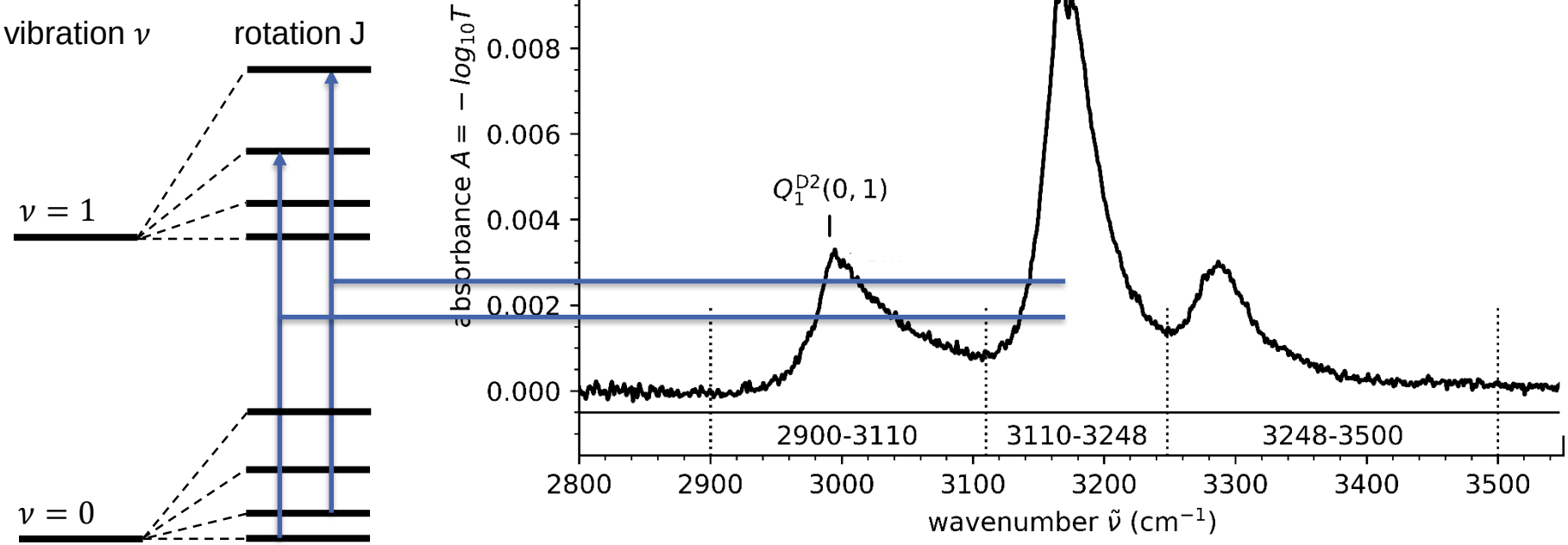
rotational-vibrational transition



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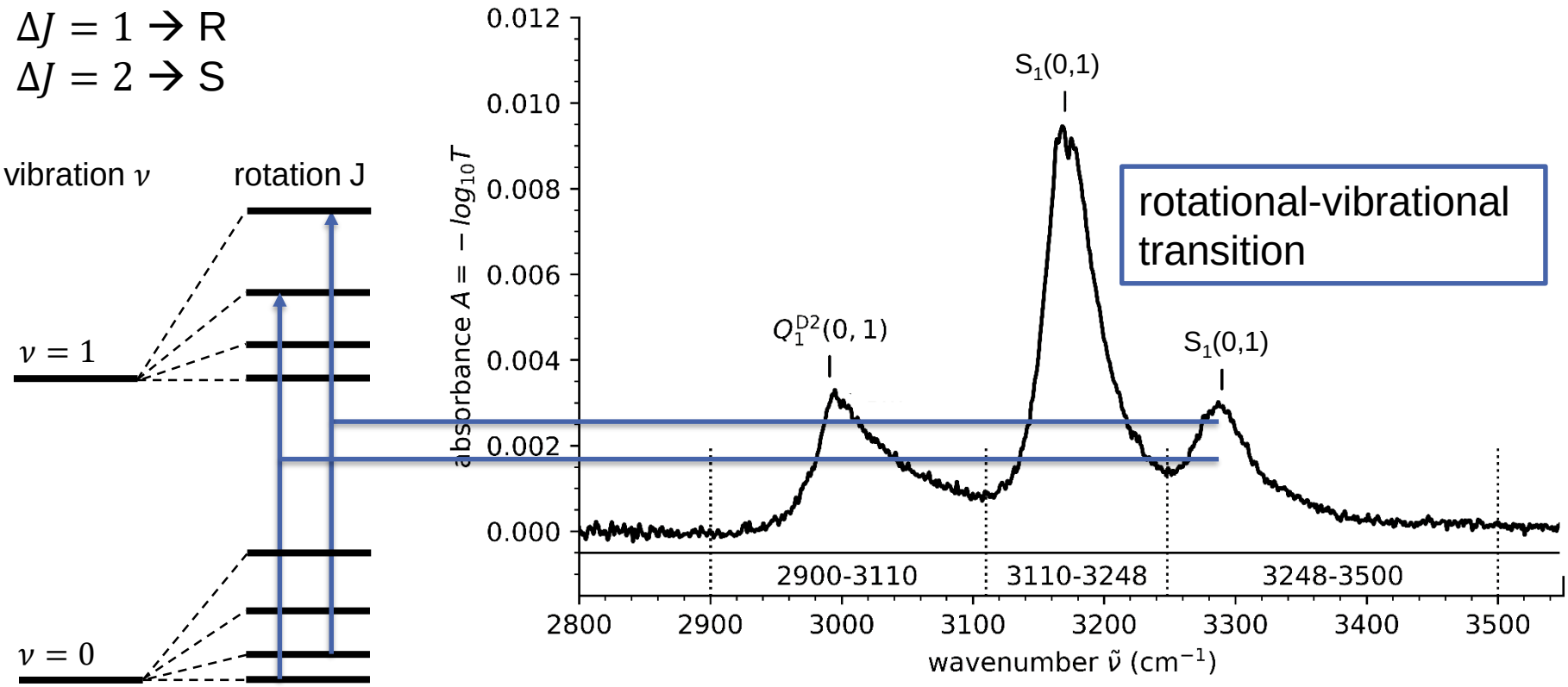

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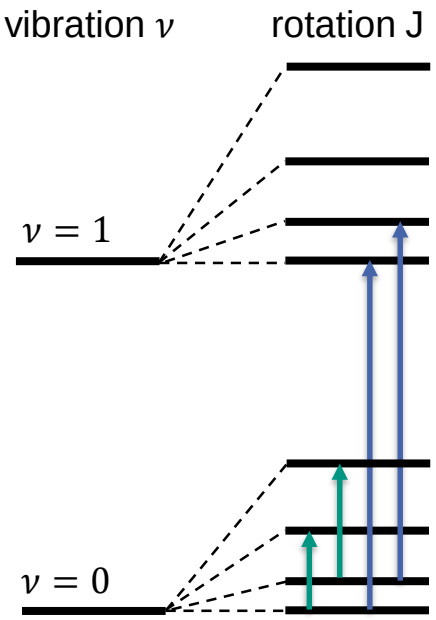
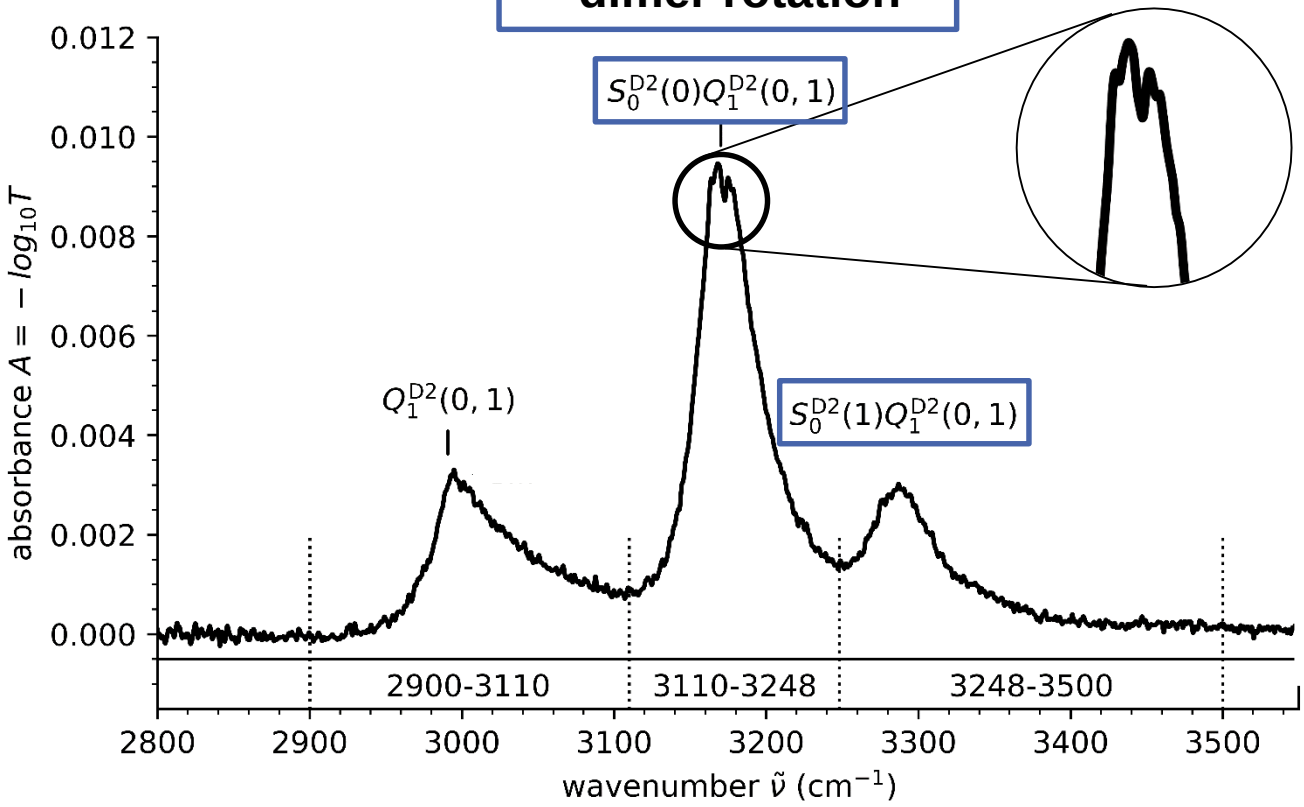
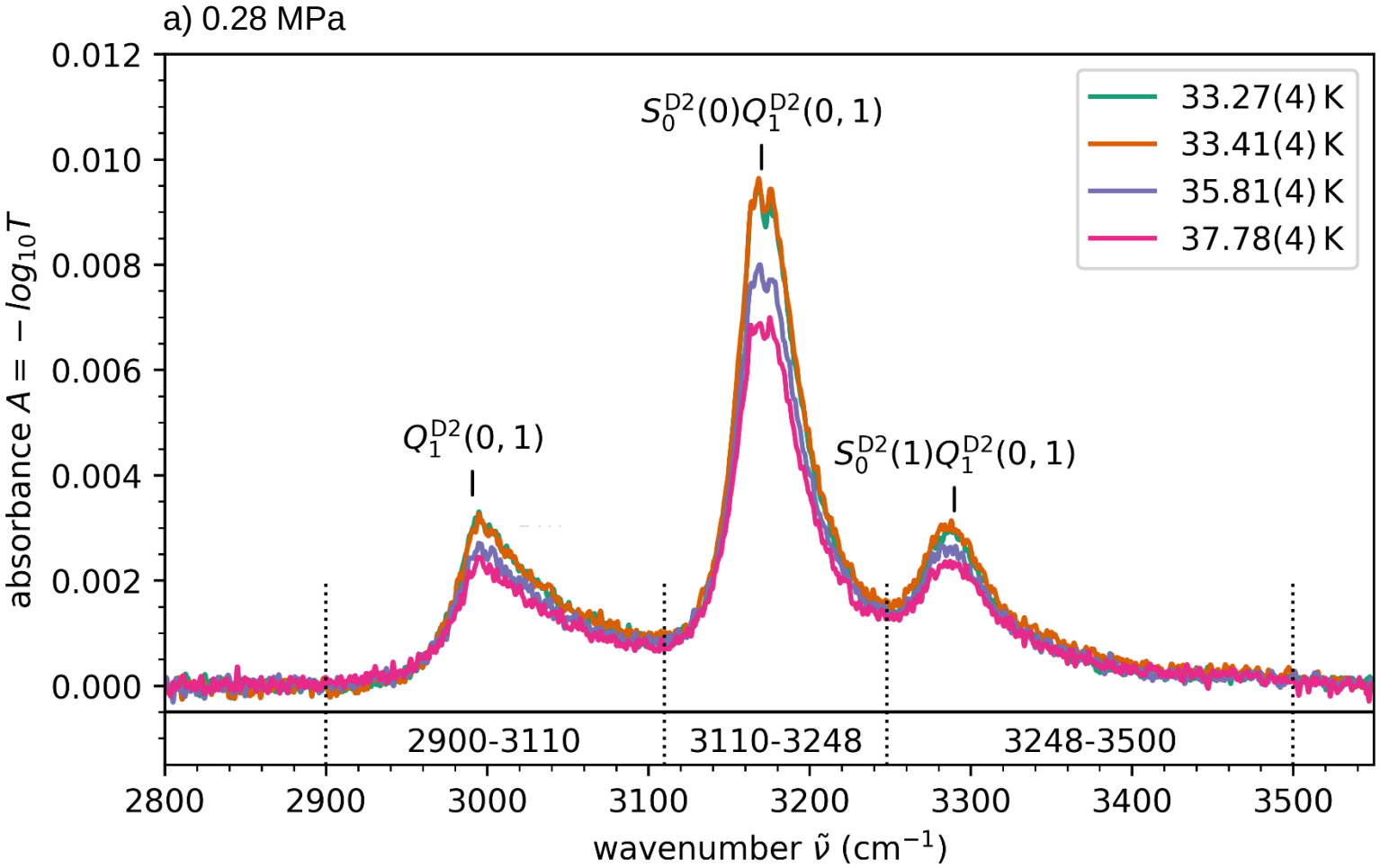


splitting:
- double transition
- **dimer rotation**



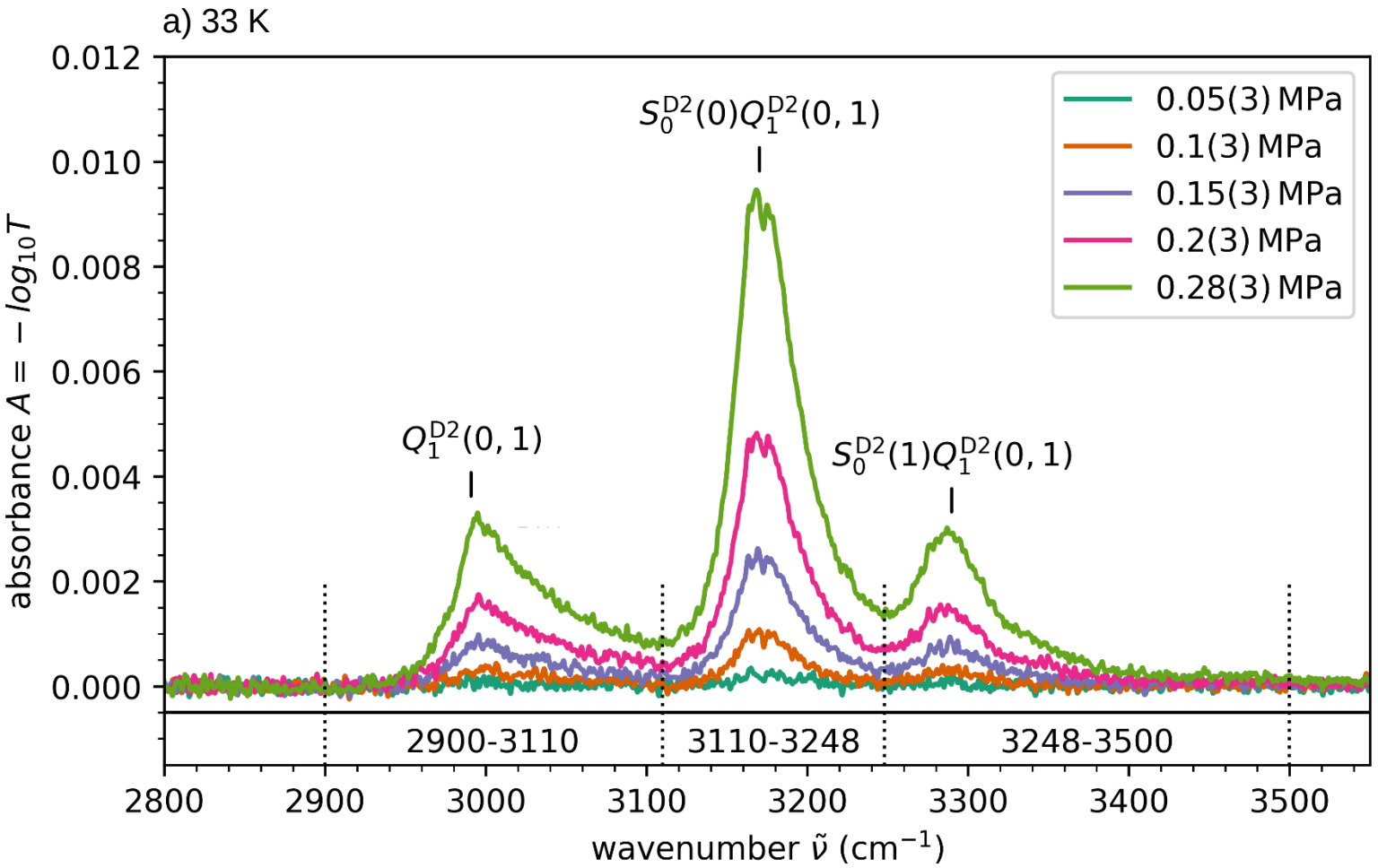
broad background by collisions + sharp dimer excitations

Line selection: Gaseous D_2



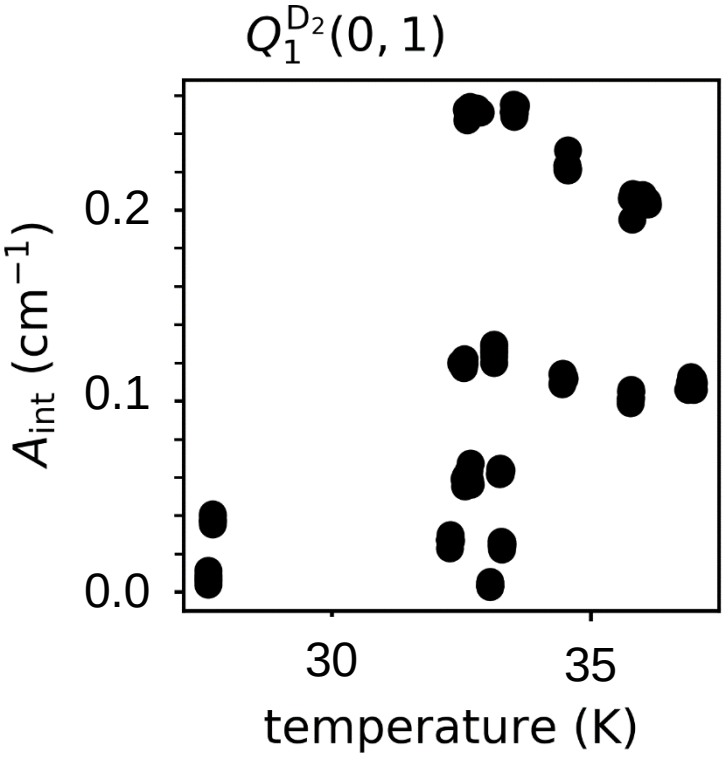
higher temperature → less absorbance

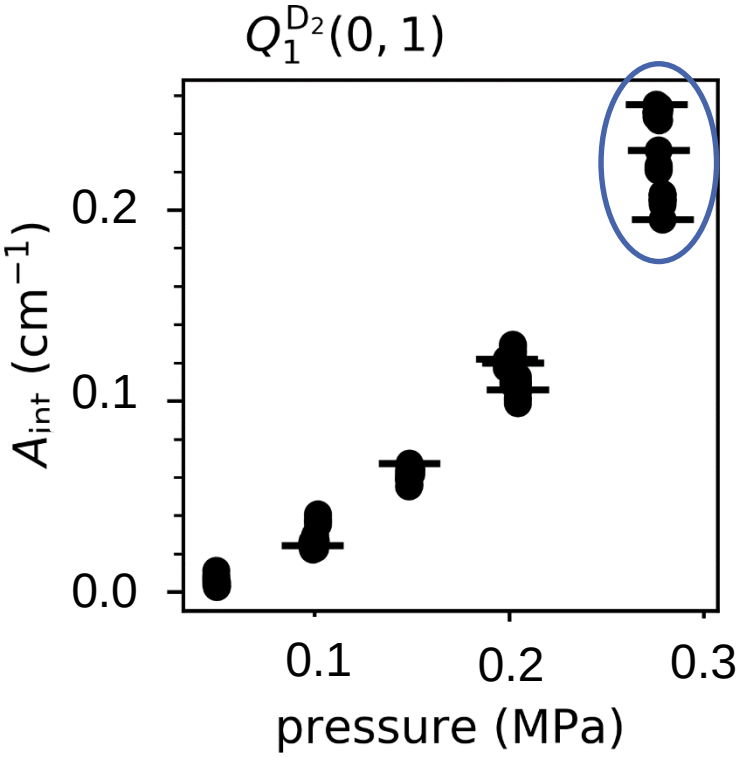
Line selection: Gaseous D_2



higher pressure → more absorbance

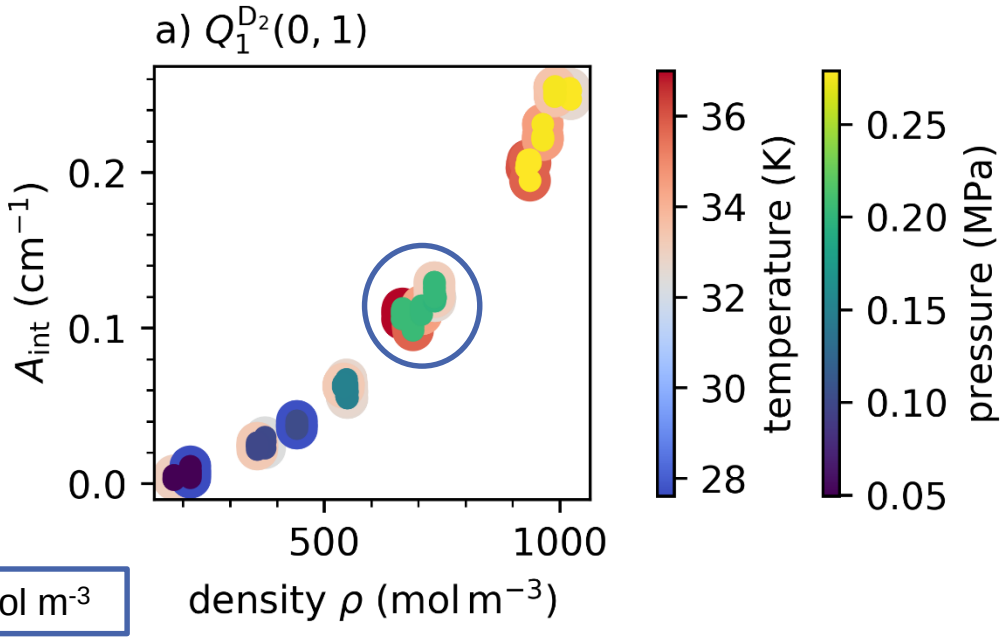
Pressure and temperature dependency





no clear correlations visible

Solution: Density dependency

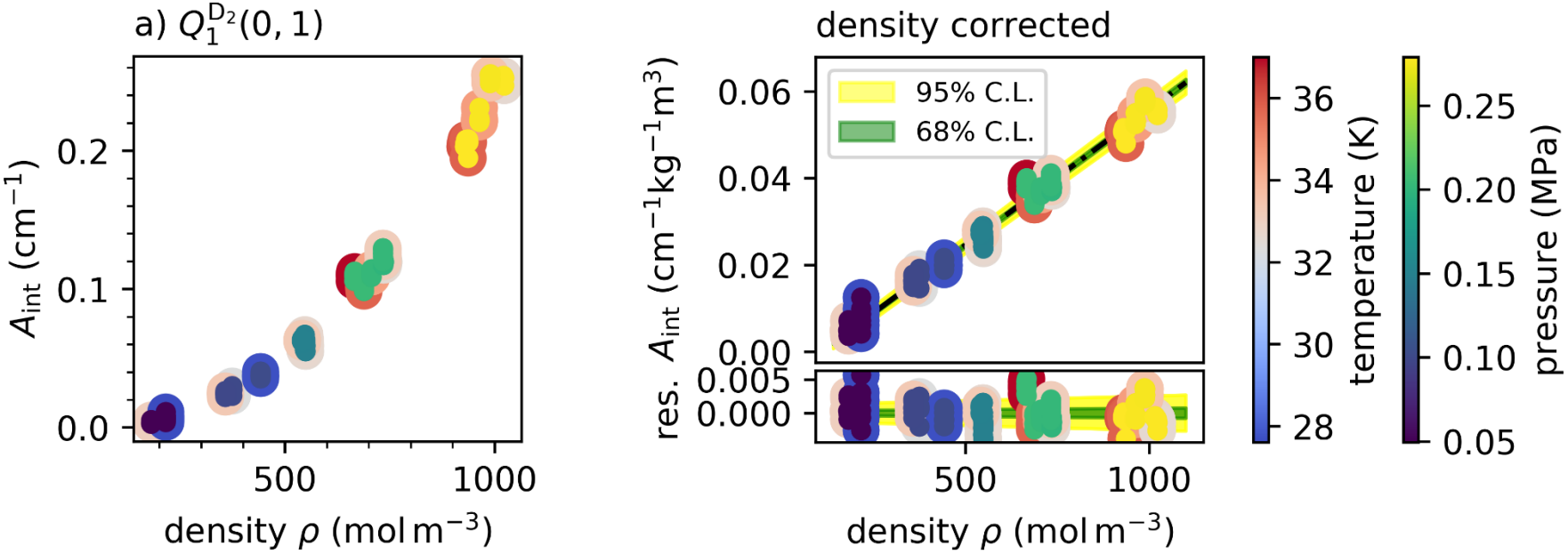


WGTS inlet: $4 \cdot 10^{-5}$ mol m^{-3}

temperature and absorbance not clearly correlated

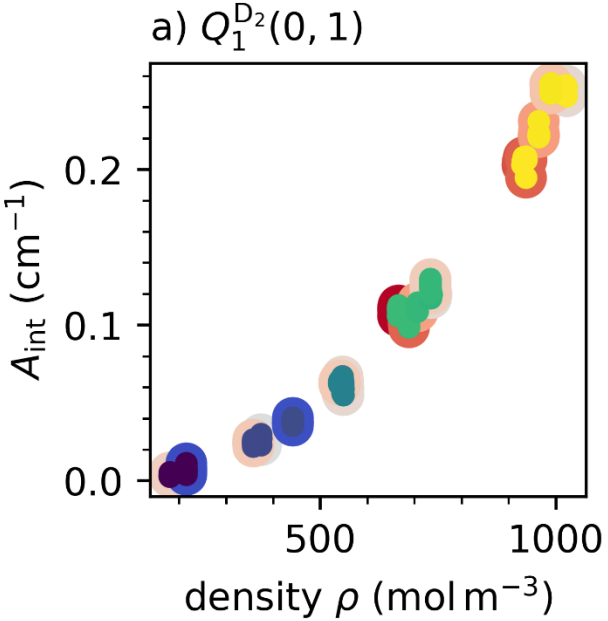
temperature dependency is actually a density dependency

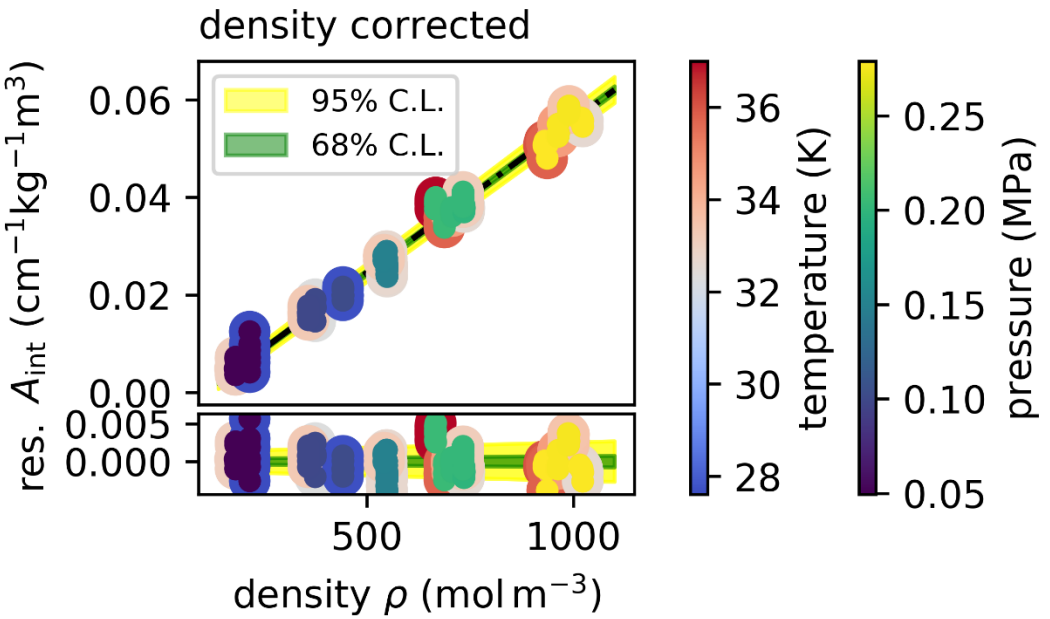
Density dependency



quadratic density dependency: $A_{int} \propto \rho^2$

Density dependency





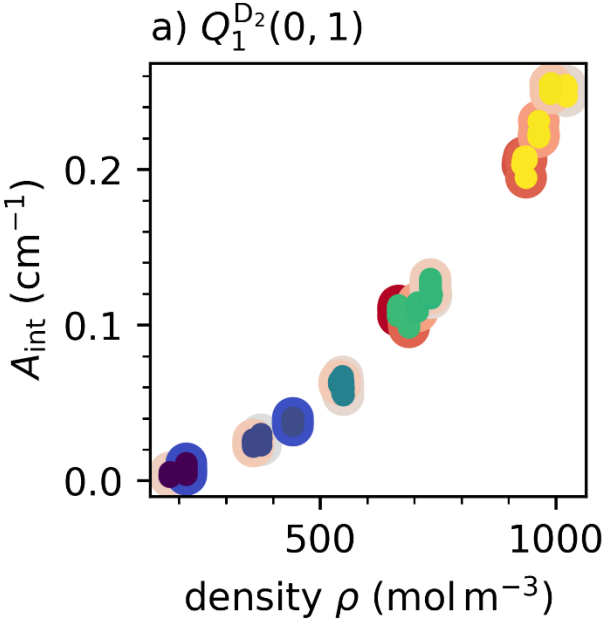
integrated absorbance: $A \propto A_1\rho + A_2\rho^2 + A_3\rho^3$

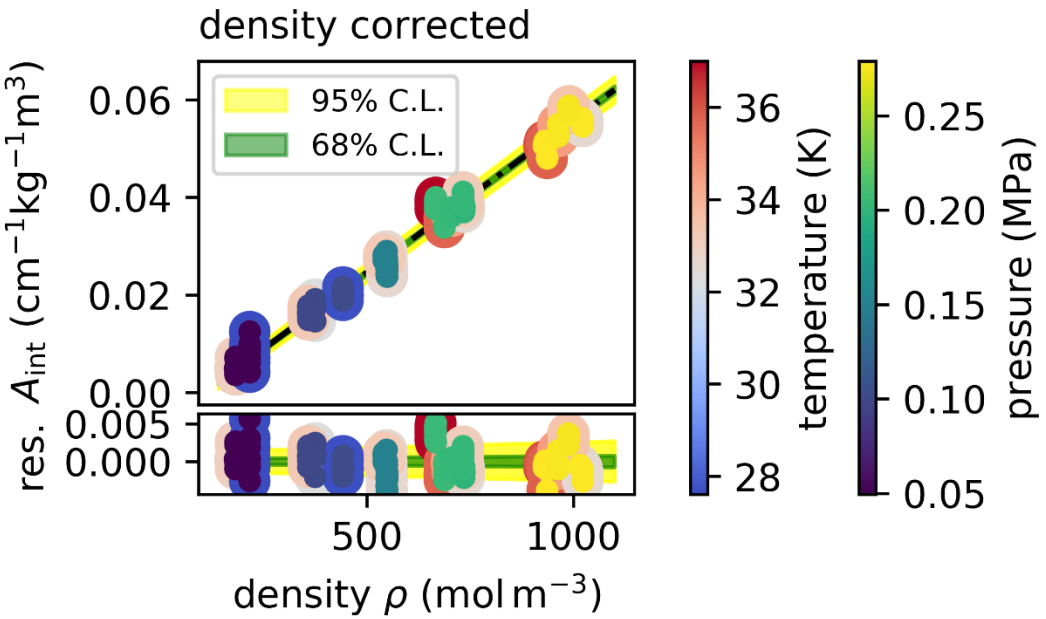
intrinsic

2 molecule interaction

3 molecule interaction

Density dependency





integrated absorbance: $A \propto A_1\rho + A_2\rho^2 + A_3\rho^3$

intrinsic

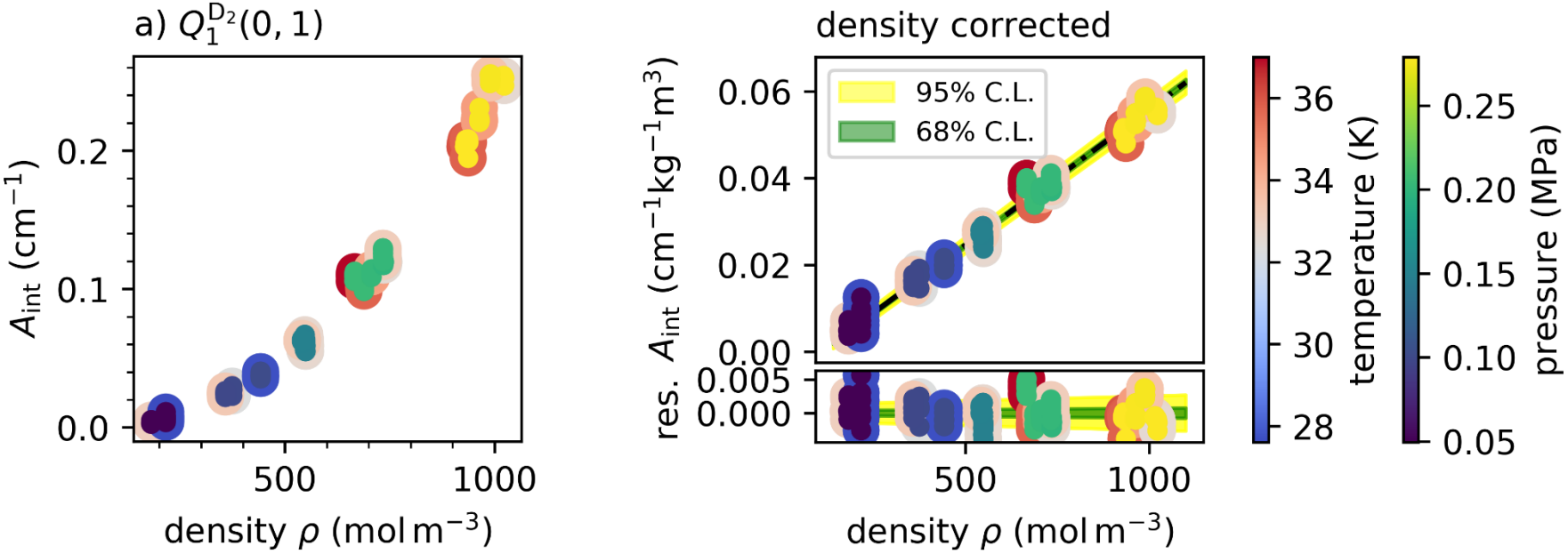
2 molecule interaction

3 molecule interaction

- free-free-scattering at the Van-der-Waals potential
- dimer formation ~ ρ^2

quadratic density dependency

Density dependency : Dimers?



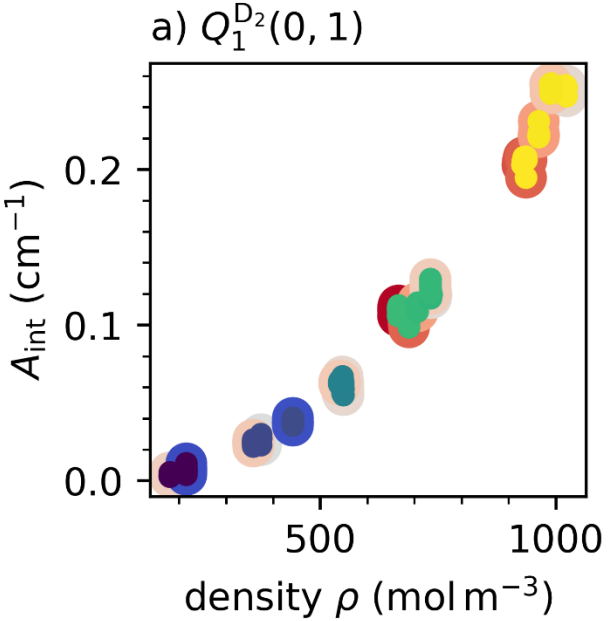
integrated absorbance: $A \propto A_1\rho + A_2\rho^2 + A_3\rho^3$

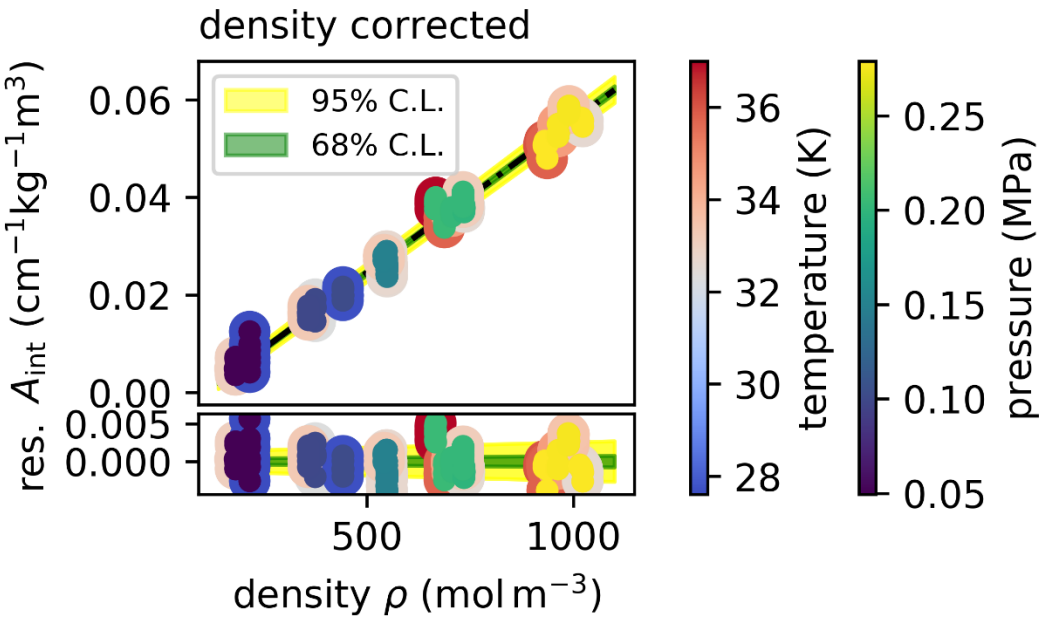
dimer intrinsic

2 dimer interaction

3 dimer interaction

Density dependency : Dimers?





integrated absorbance: $A \propto A_1\rho + A_2\rho^2 + A_3\rho^3$

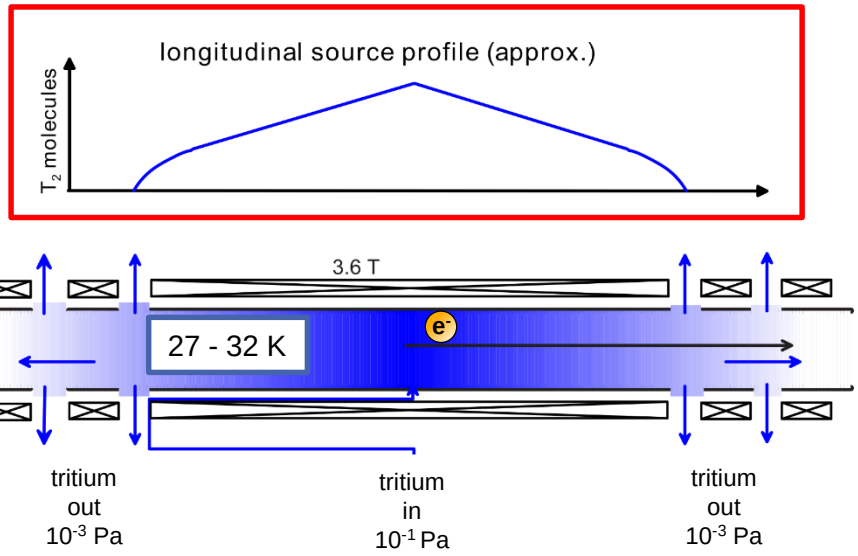
dimer intrinsic

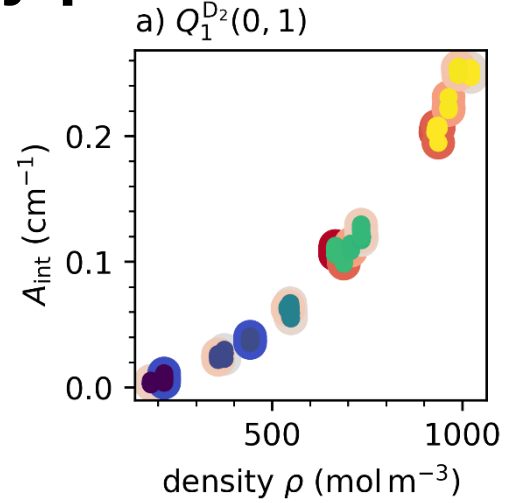
2 dimer interaction

3 dimer interaction

dimer-dimer-interaction
→ larger clusters?

Impact on KATRIN: WGTS density profile





absorption ∝ density^2

Extrapolation:

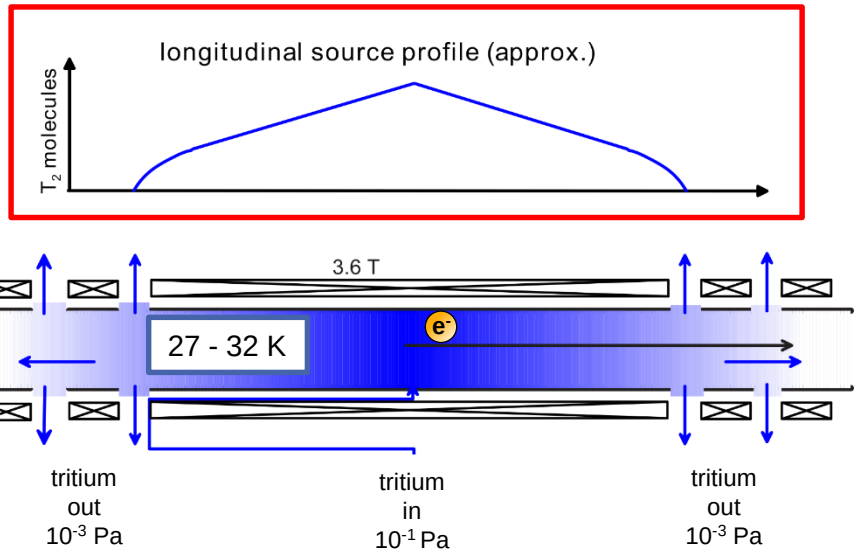
Assumption: 100% dimers at 0.05 MPa

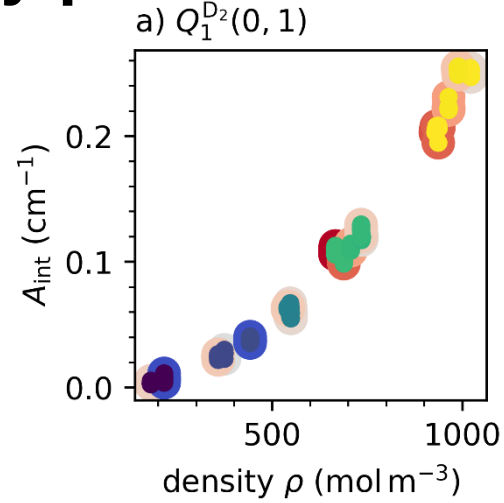
→ 10^{-6} % dimers at the WGTS inlet

Comparison with literature values:

- 10^{-4} % $(H_2)_2$ dimers under WGTS conditions
  (own calculations according to Frommhold 1993)
- 0.1 % $(H_2)_2$ dimers at 20 K, no pressure given (Watanabe et al. 1964)
- a few % $(H_2)_2$ dimers at 20 K, no pressure given (Watanabe et al. 1965)

Impact on KATRIN: WGTS density profile



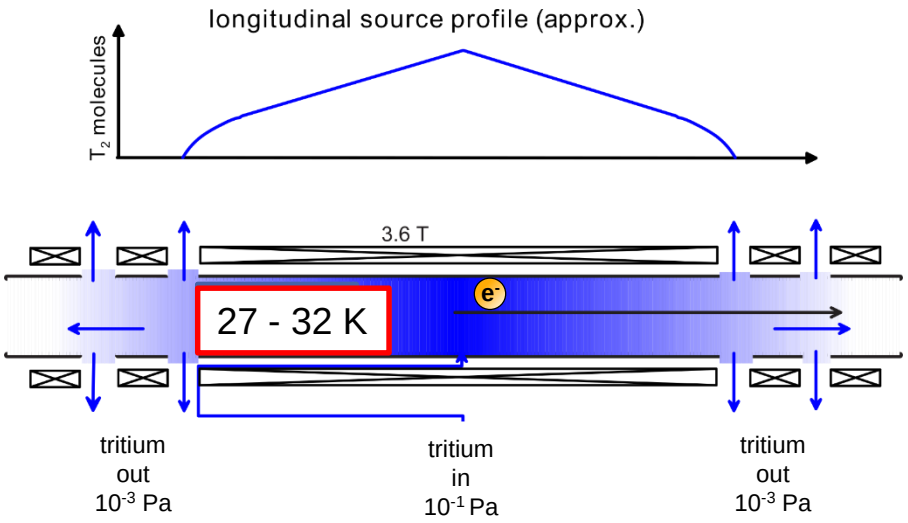


absorption ∝ density^2

Possible variation of the Van-der-Waals cluster density along the WGTS density profile

Future measurements with lower densities necessary to clarify this influence
→ T_2ApIR experiment: Commissioning + first data in 2020

Impact on KATRIN: WGTS temperature



~~"To use much lower temperatures than 30K is not possible, because tritium clusters may be created out of the T_2 molecules."~~

KATRIN Design Report 2004

An increase of the WGTS temperature cannot significantly reduce the cluster concentration

→ tritium data needed to quantify or neglect the influence

→ T_2ApIR experiment

THANK YOU FOR YOUR ATTENTION!