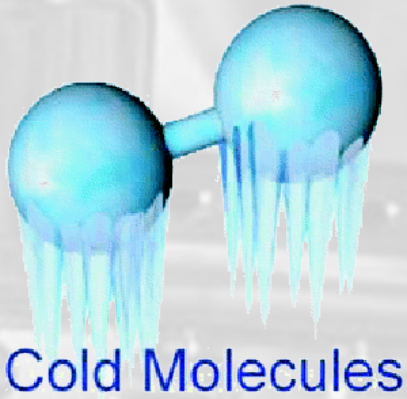
Manipulating the Motion of Large Molecules

Alternate Gradient Focusing and Deceleration of Benzonitrile

Jochen Küpper

Fritz-Haber-Institut der MPG
Berlin



21. June 2006

Applications of cold molecules

Experiments with molecules in high-field seeking states

- Getting complete control over both the internal and external degrees of freedom of molecules:
  - Beams of molecules in a single or small subset of quantum states
  - Spatially oriented molecules
  - Beams of molecules with computer-controlled velocities
  - Packets of trapped molecules
- Slow molecular beams for metrology, sensitive symmetry tests:
  - **Weak interactions in chiral molecules**
  - Time-reversal violating electric dipole moment of the electron (EDM)
  - Time-variation of fundamental constants (i.e. $\dot{\alpha}/\alpha$)
- Novel molecular beam collision, reaction and interferometry experiments:
  - **Conformational interchange and dynamics (*folding*)**
  - Collisions at variable, well-defined energies
  - Scattering resonances
  - **Quantum-controlled chemistry**
- Ultra-low temperature phenomena:
  - Anisotropic dipole-dipole interaction:
    repulsive: $\uparrow\uparrow$
    attractive: $\rightarrow\rightarrow$
  - Molecular BEC

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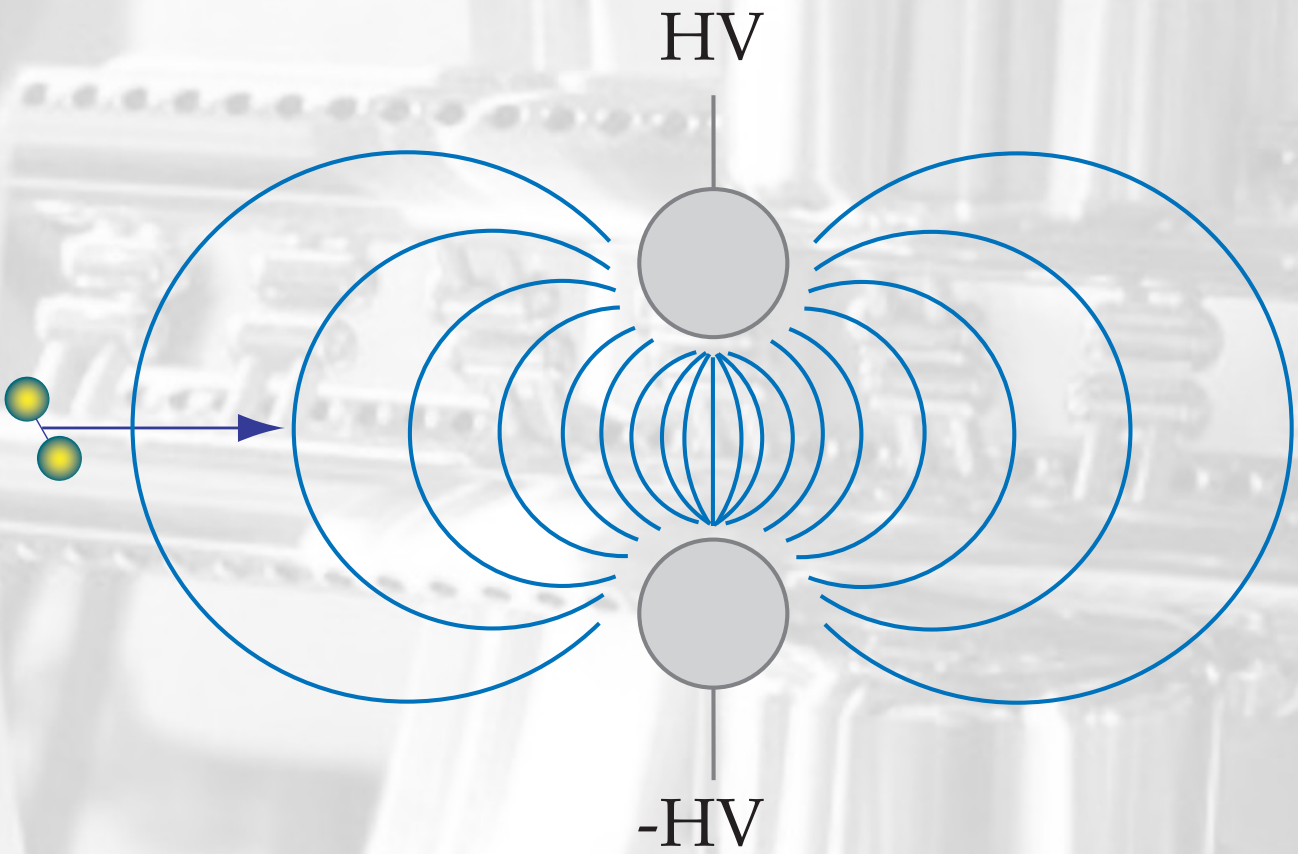
Stark effect

Interaction of molecular charge distribution with external electric field:



$$U_{pot} = W_{Stark}$$

$$W_{Stark} = -\vec{\mu} \cdot \vec{E}$$

$$F_{Stark} = -\frac{\partial W_{Stark}}{\partial z}$$

Stark effect

Stark energy of $^{15}ND_3$

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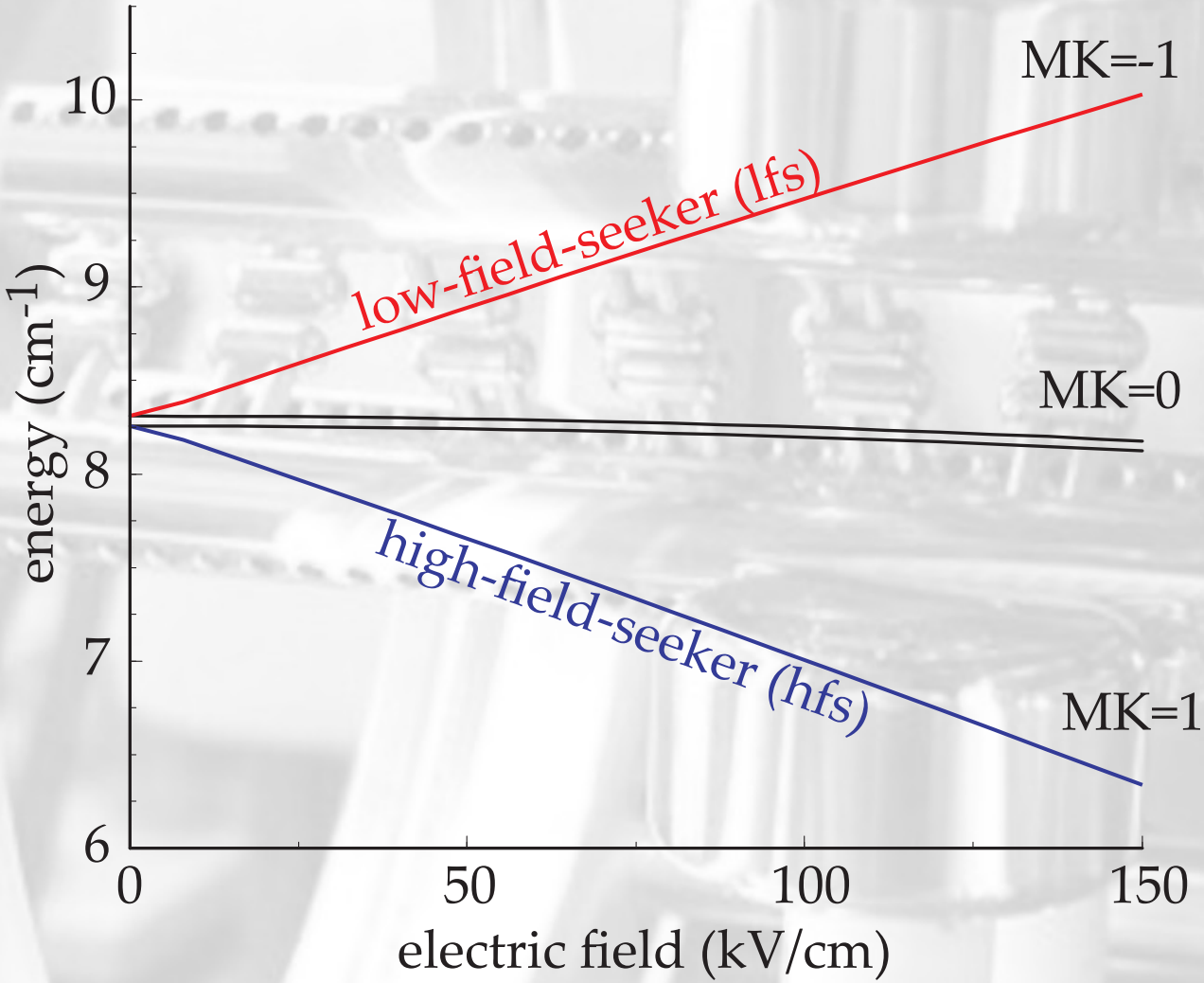

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Stark effect of large molecules

Stark energy of benzonitrile (C_7H_5N)

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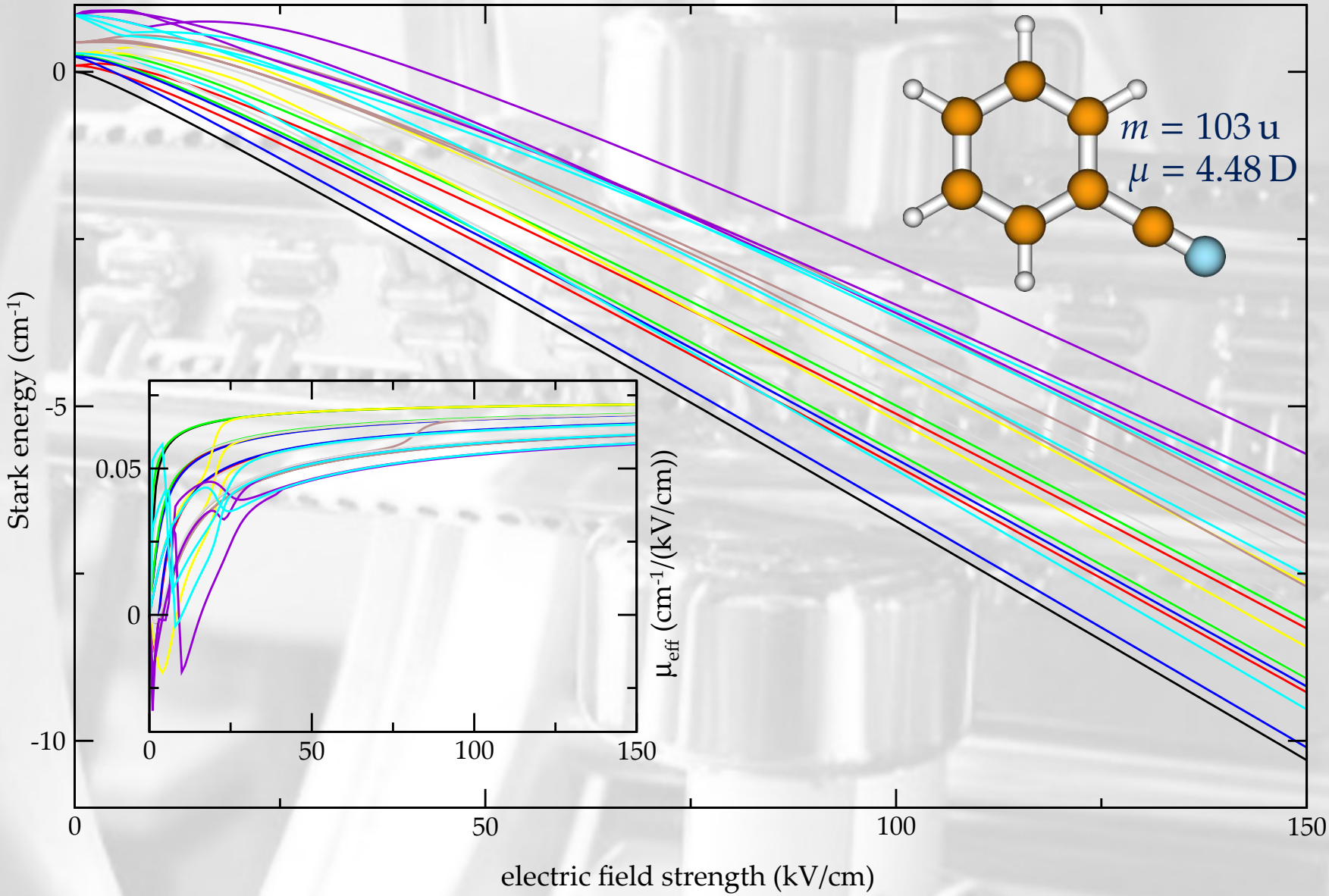
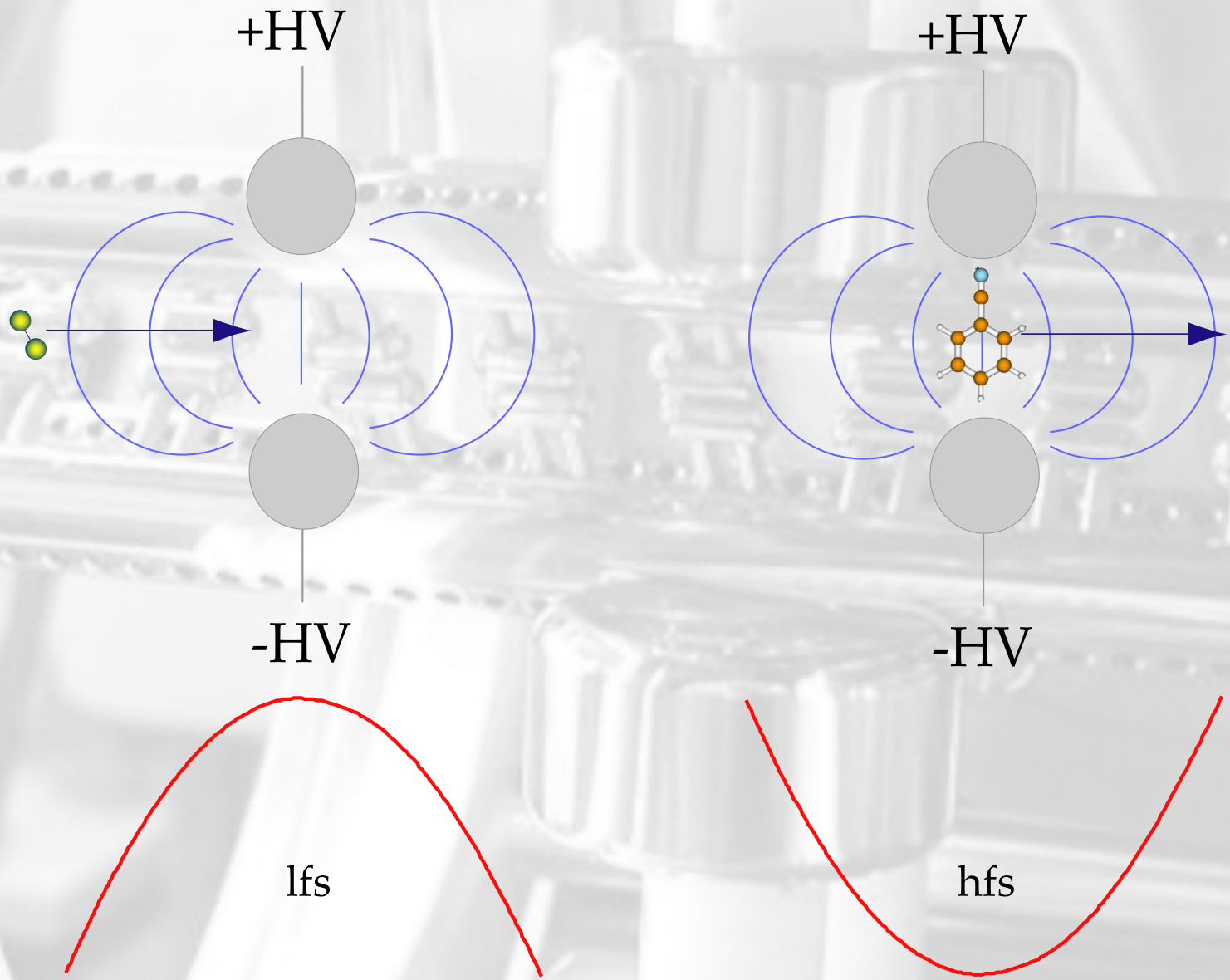
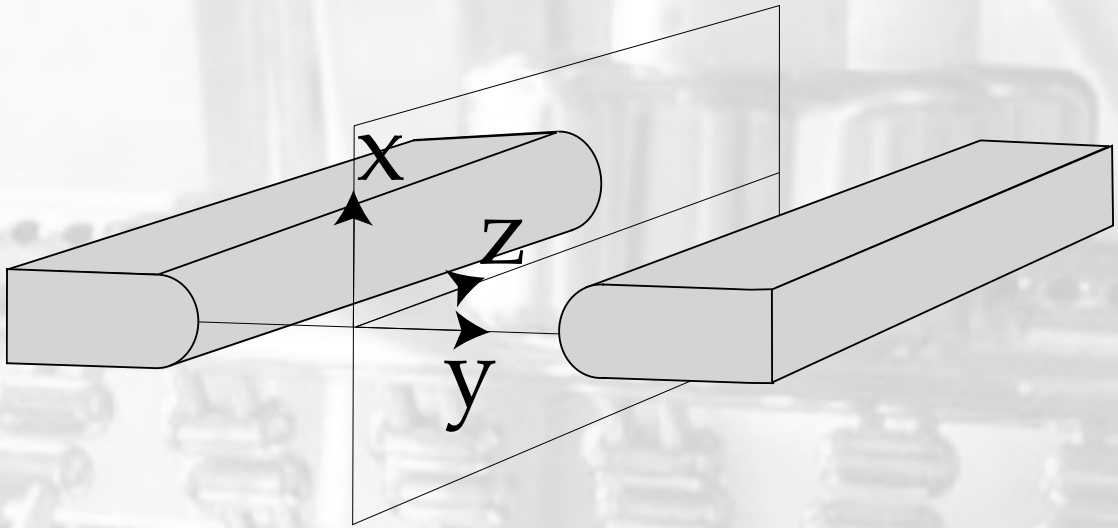


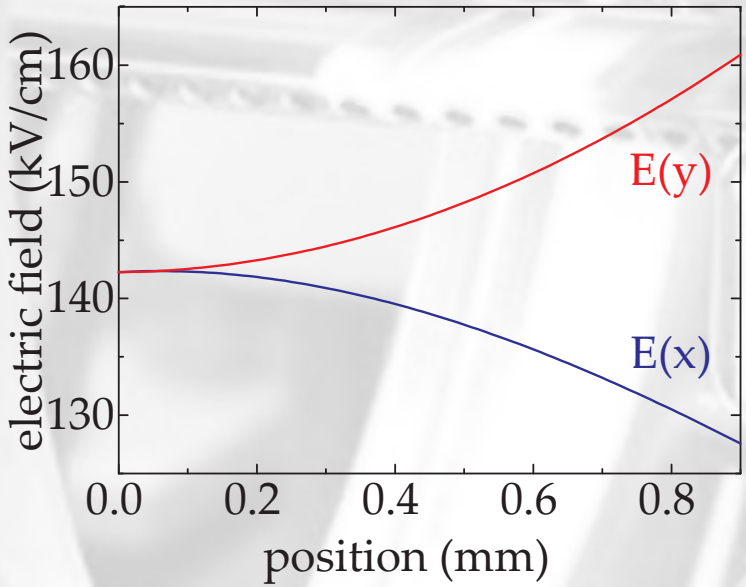
Stark deceleration
Longitudinal motion

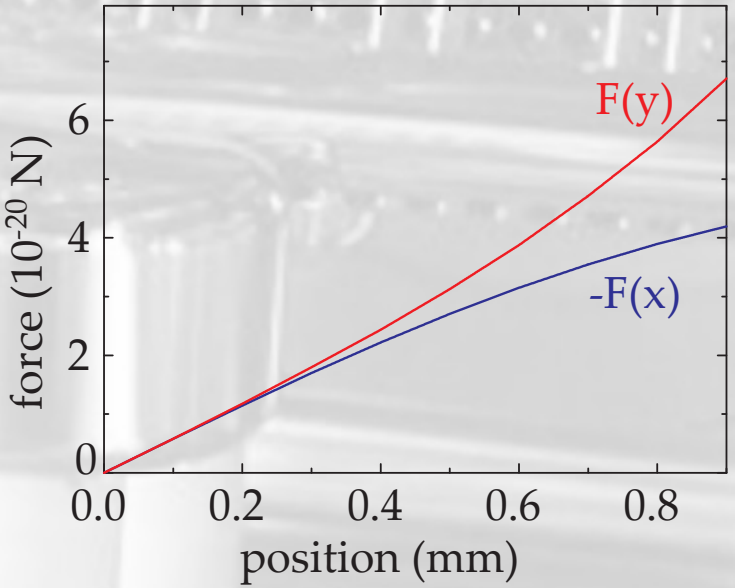


Deceleration of molecules in hfs states

Transverse motion (focusing)







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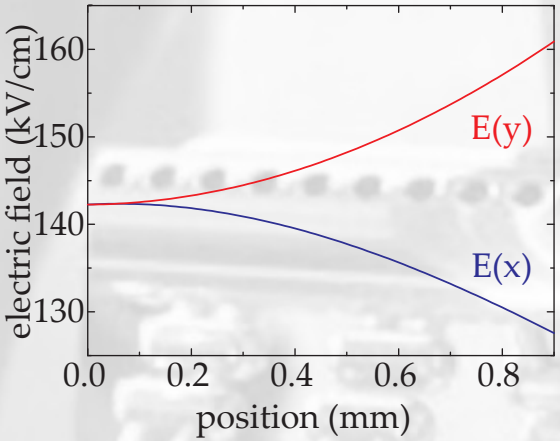
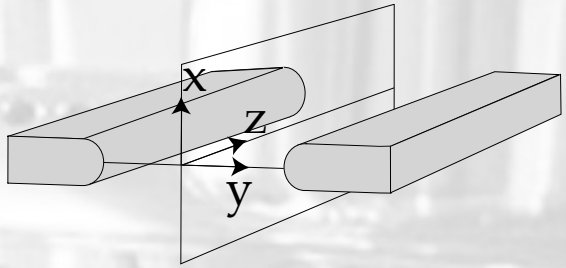
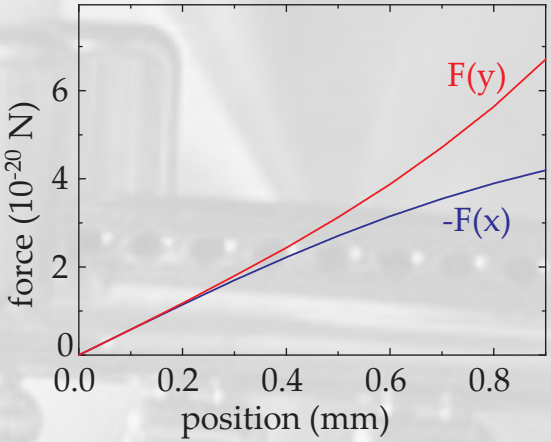
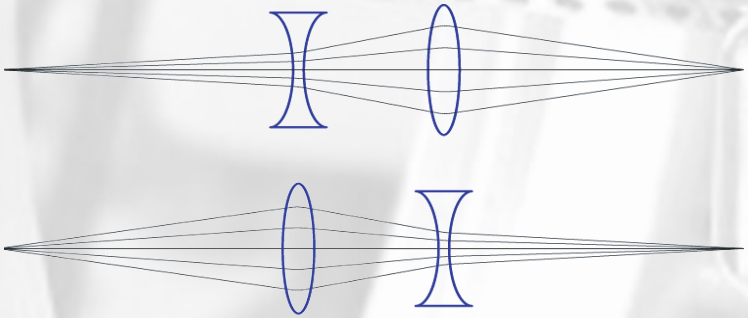
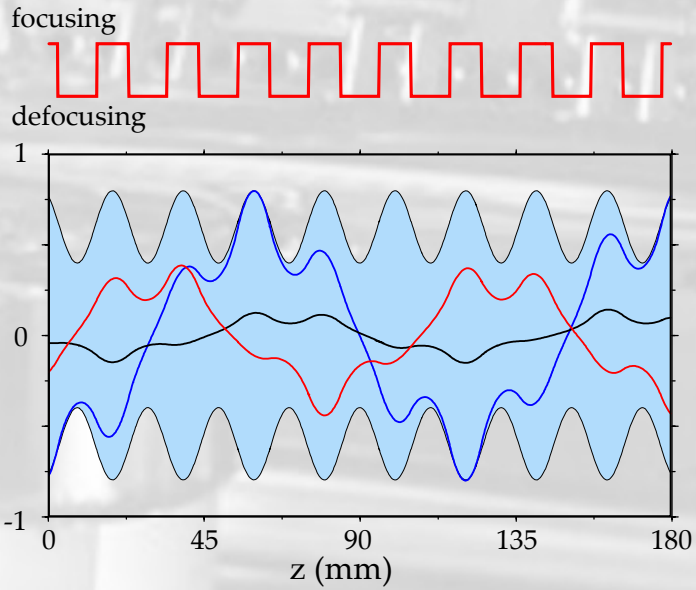






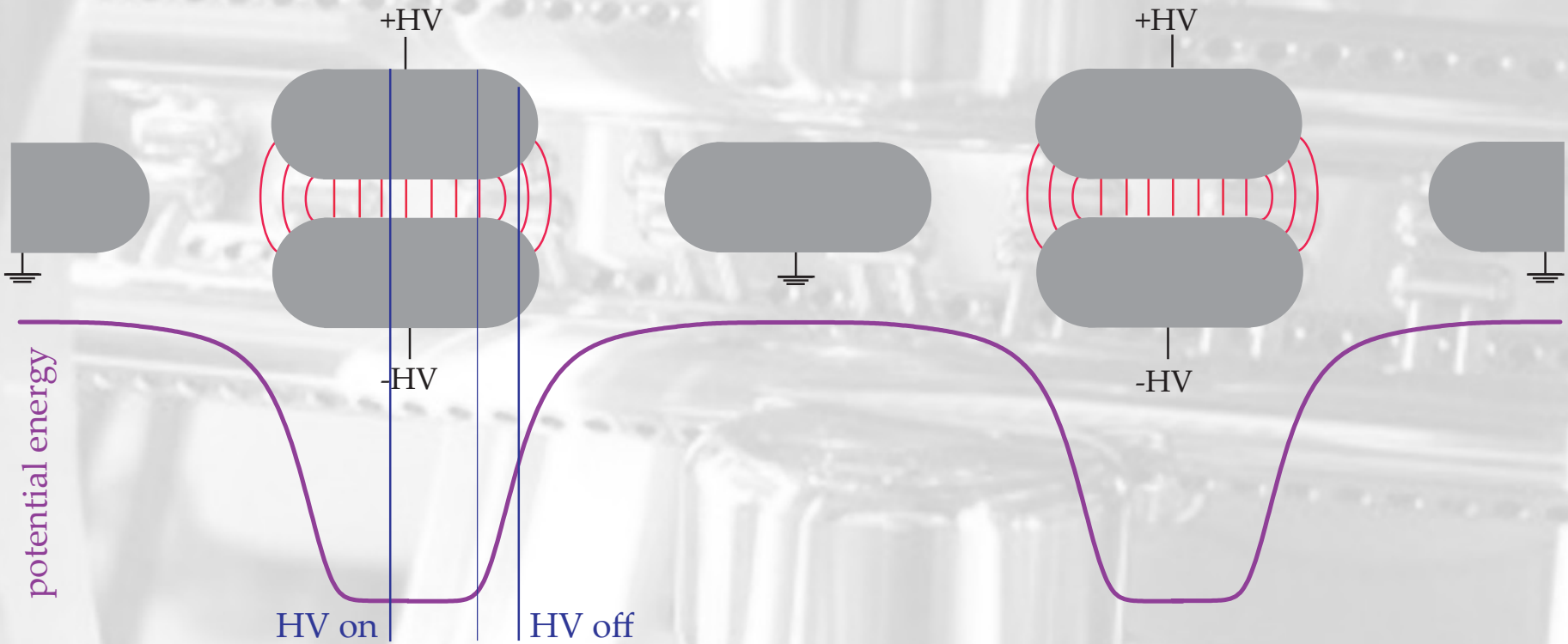




Deceleration of molecules in hfs states

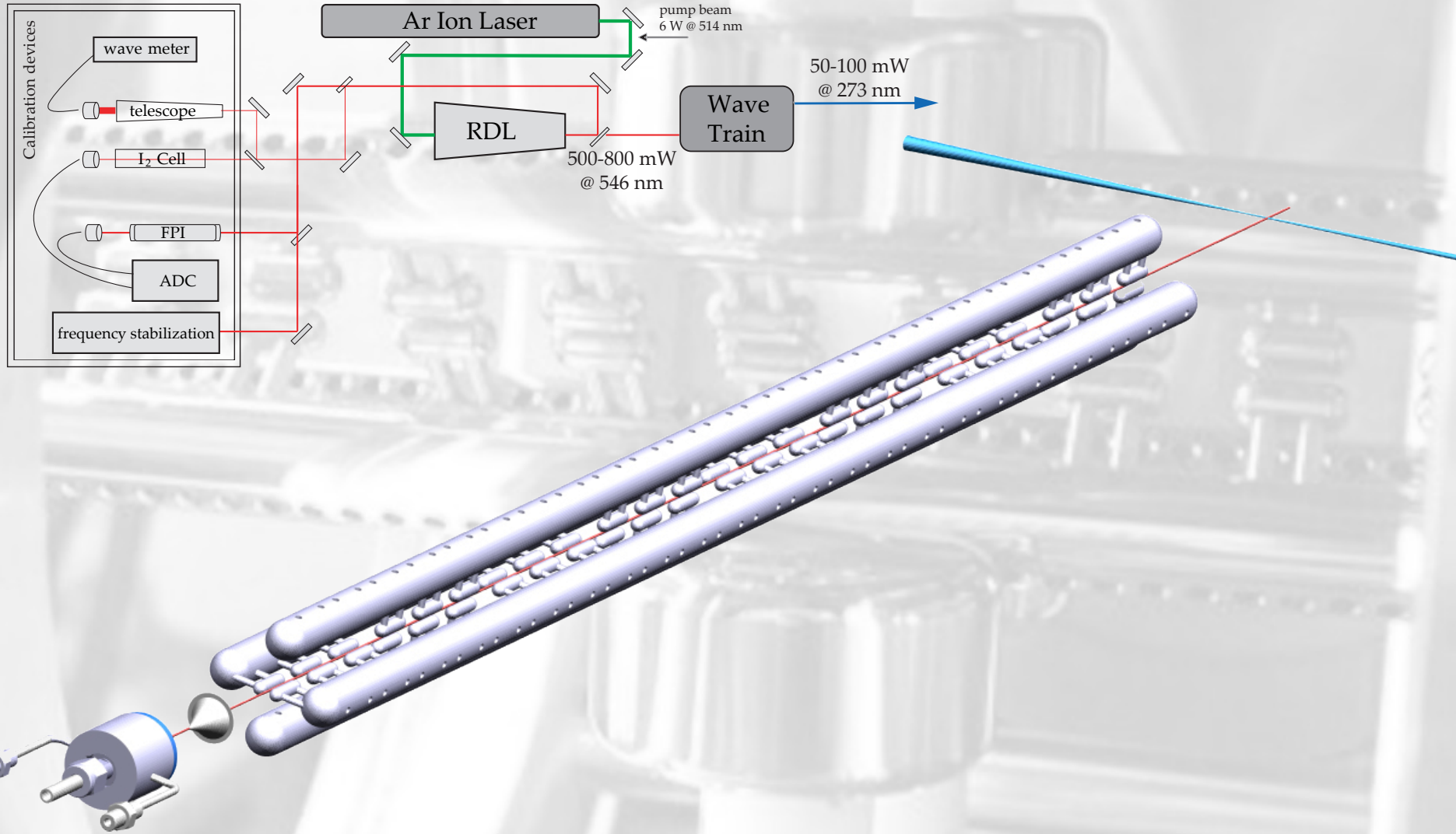
Longitudinal and transverse motion (deceleration and focusing)

independent control of transverse and longitudinal motion



Experimental setup

A modular Alternate Gradient decelerator



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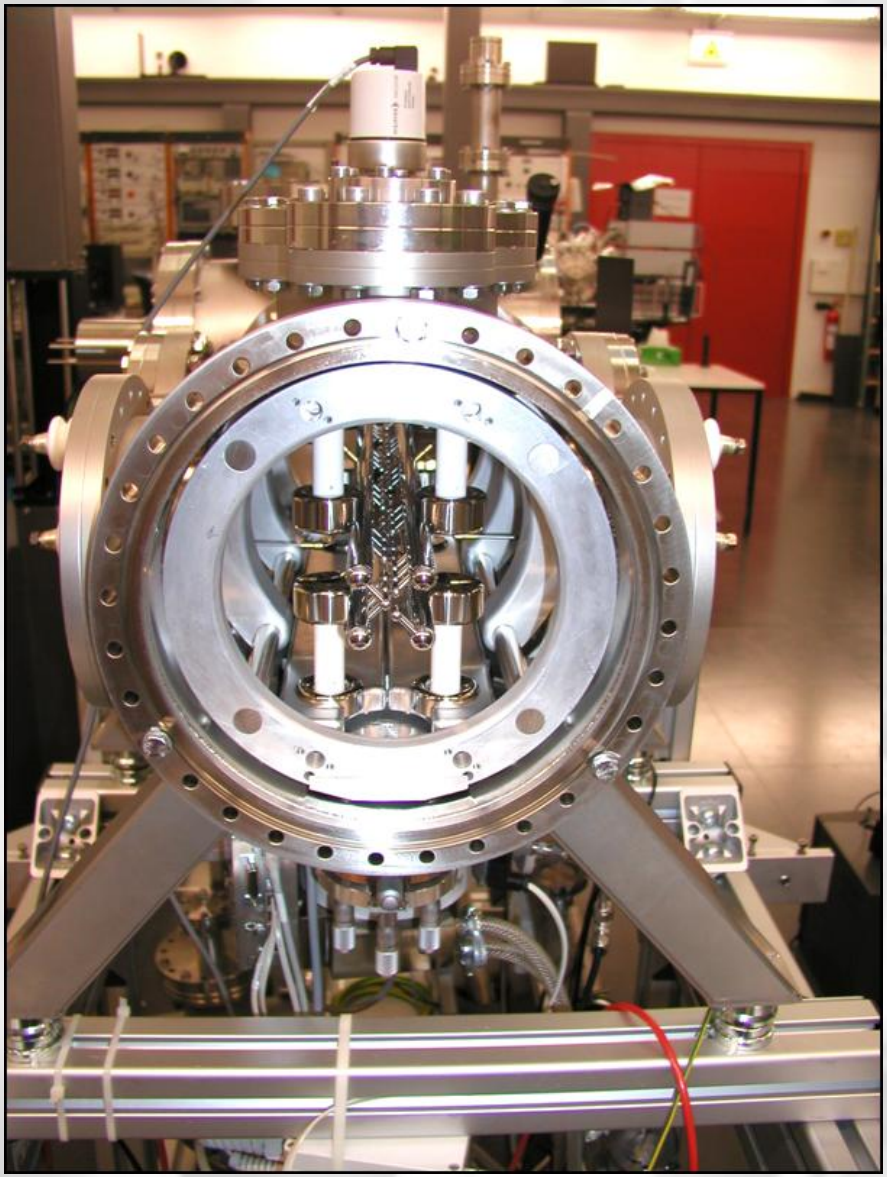
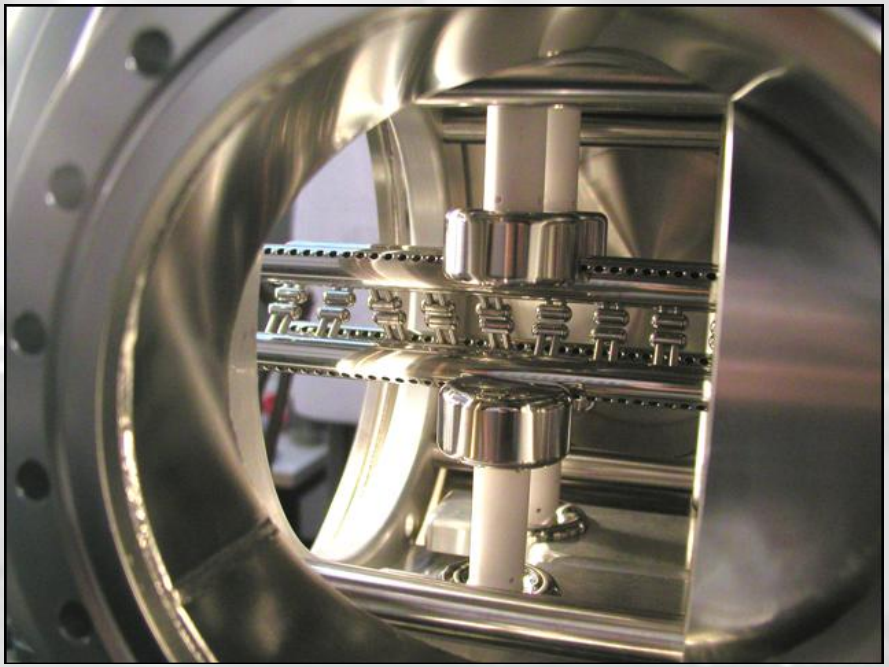
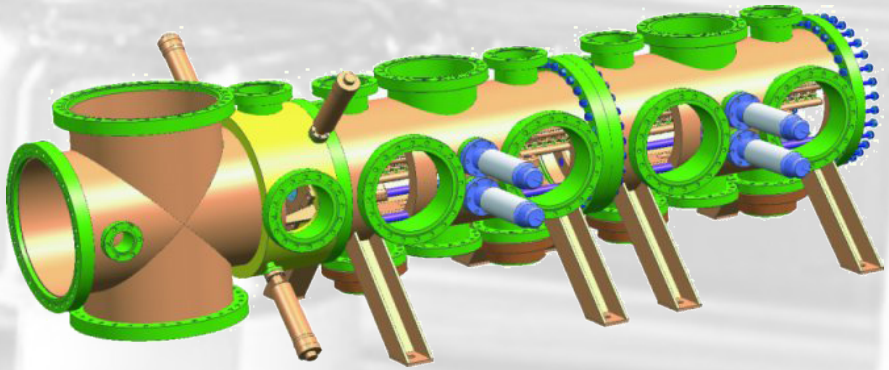
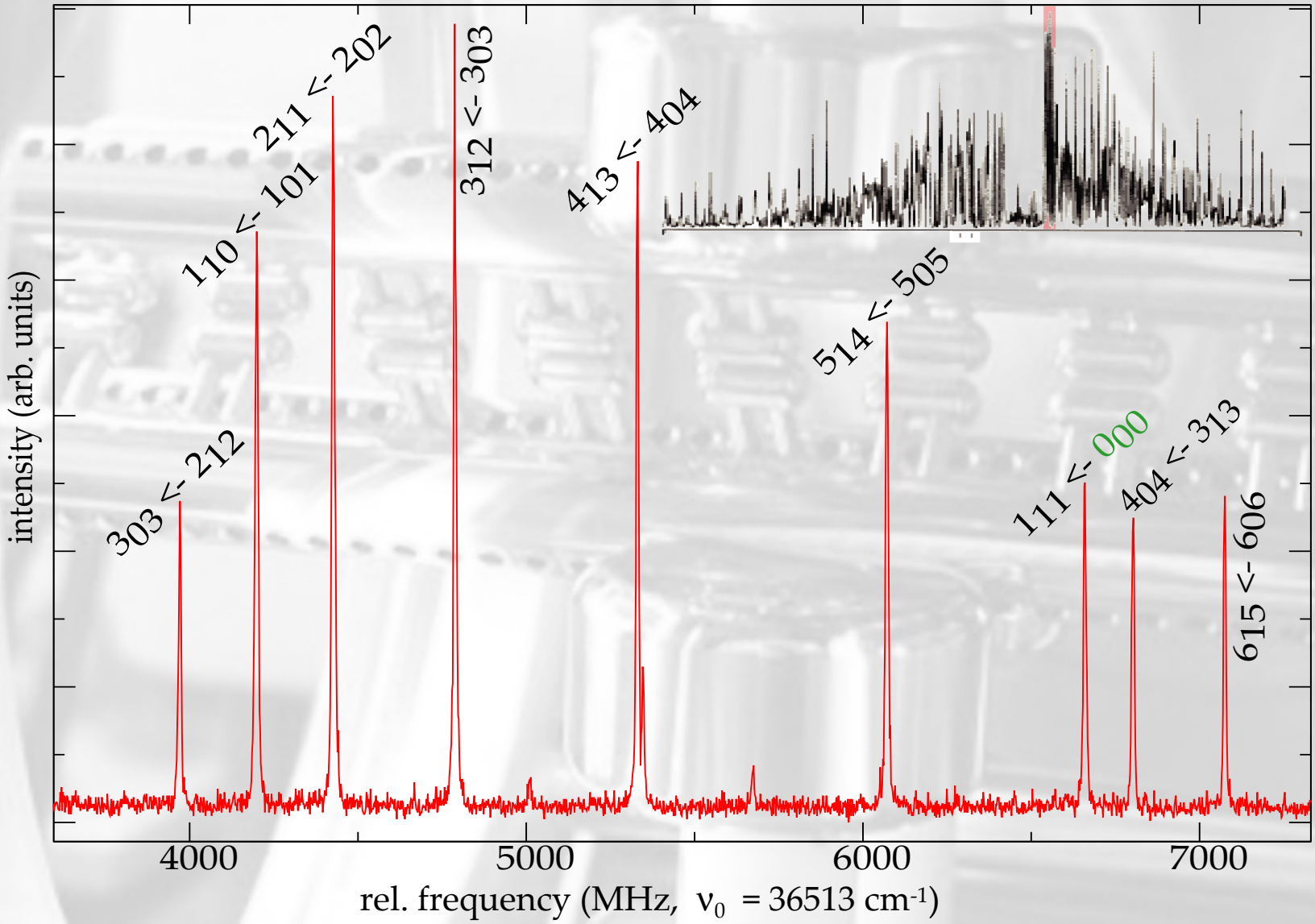






Quantum state selective detection

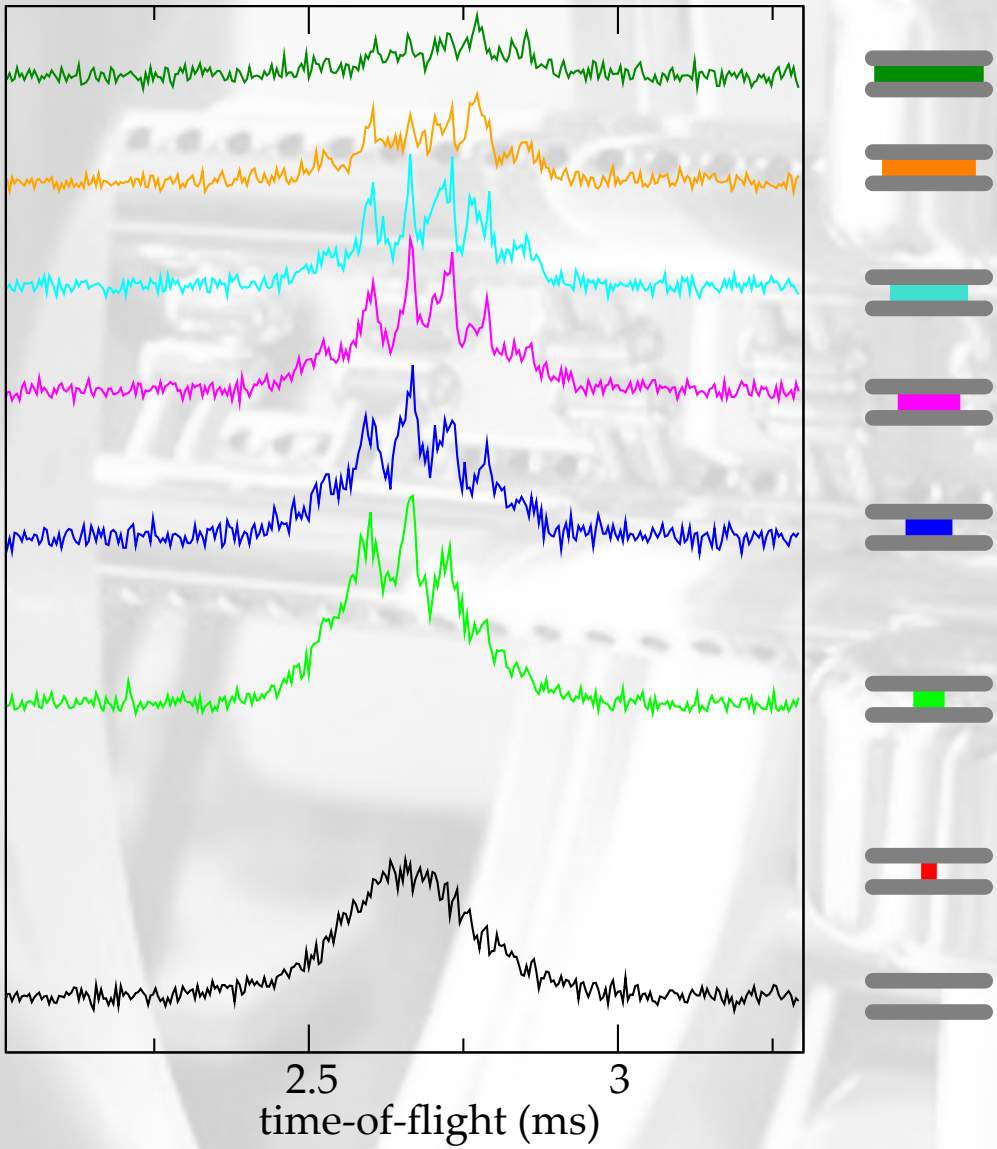
Rotationally resolved *laser induced fluorescence* spectroscopy of benzonitrile ($S_1 \leftarrow S_0\ 0_0^0$)



inset: D.R. Borst, T.M. Korter, D.W. Pratt, *Chem. Phys. Lett.* **350**, 485 (2001)

Alternate Gradient focusing and guiding

Benzonitrile $S_0, v = 0, |J_{K_a K_c}\rangle = 0_{00}$



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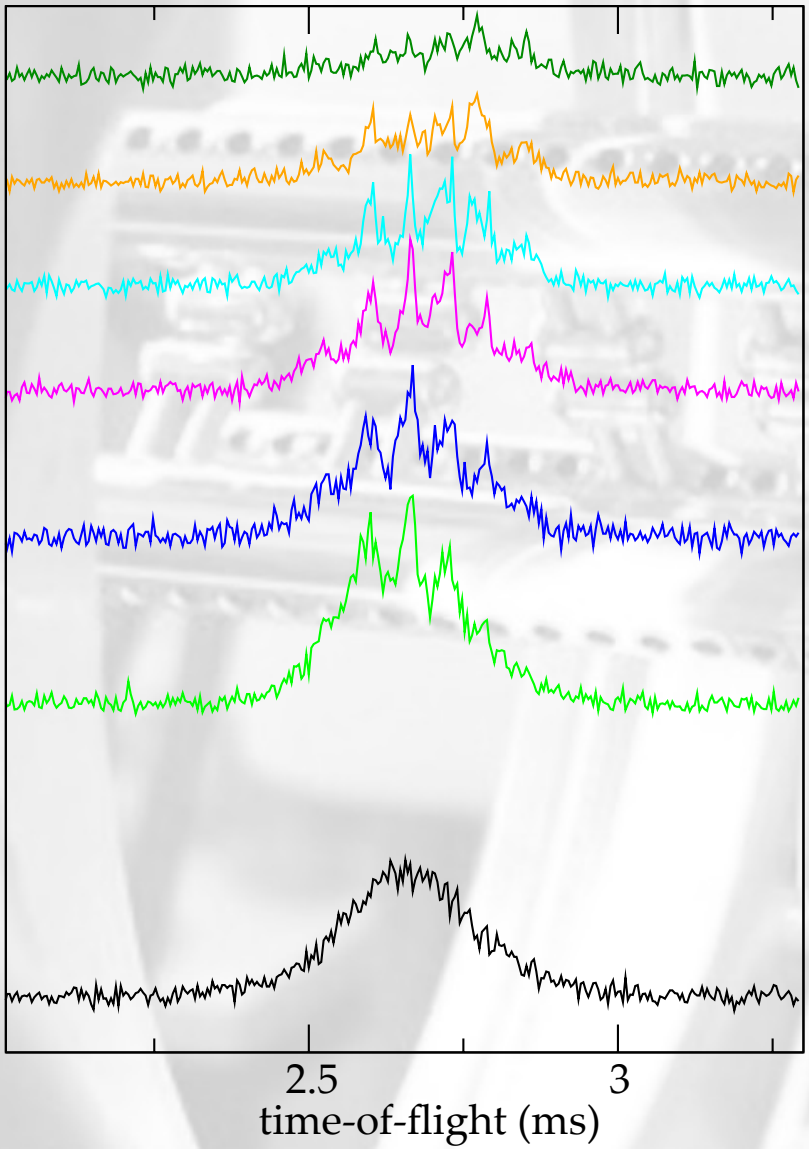

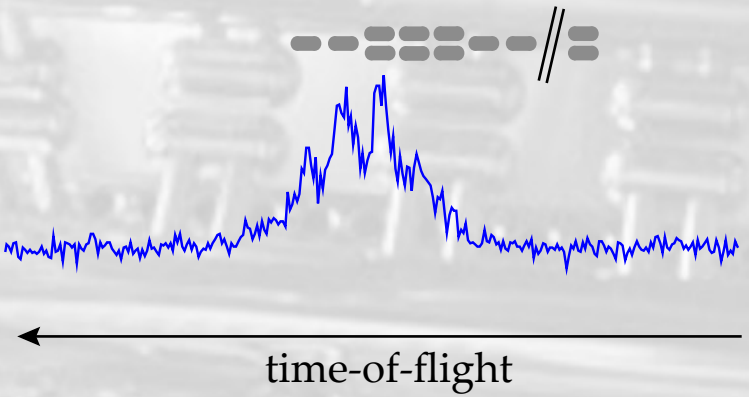

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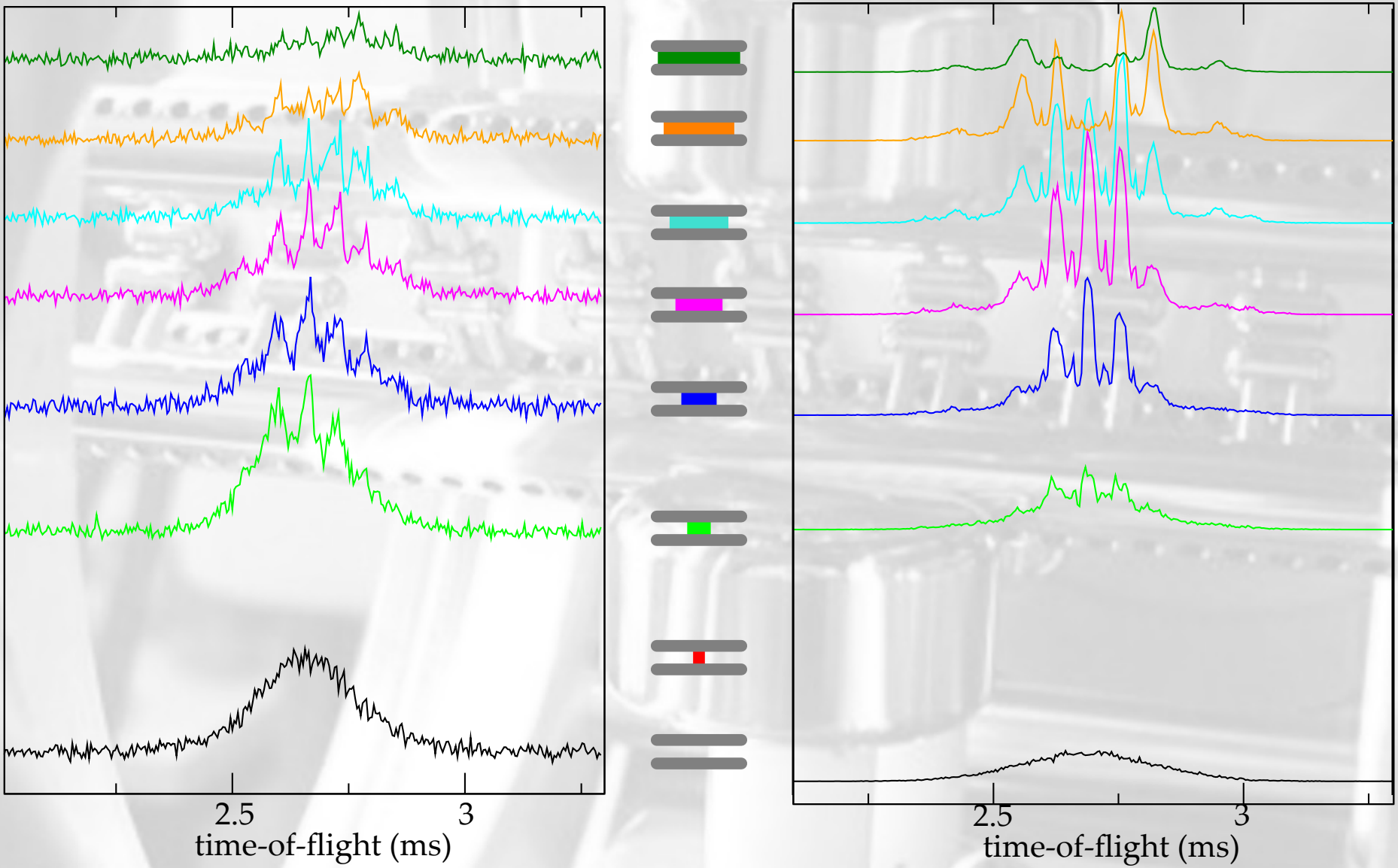
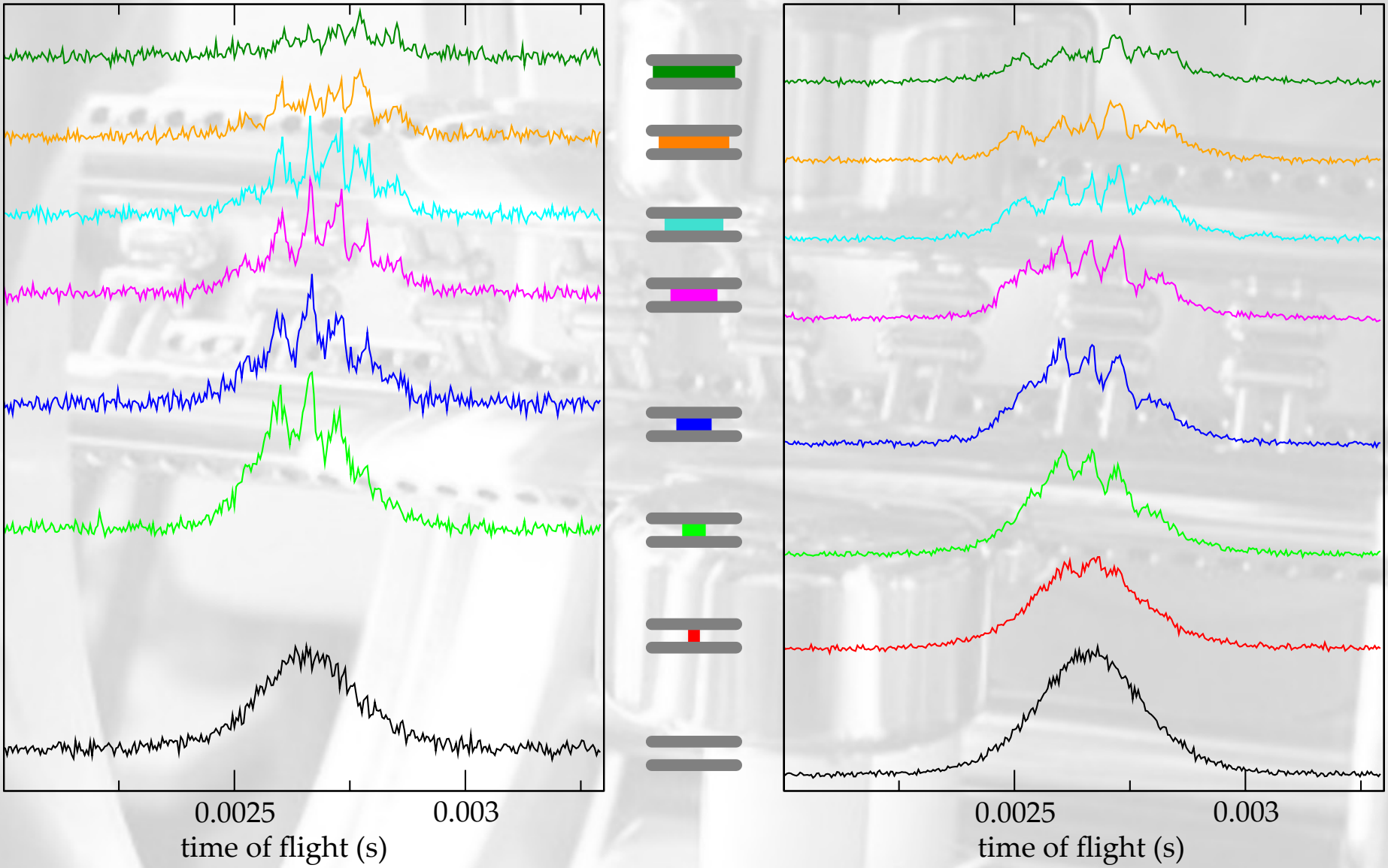


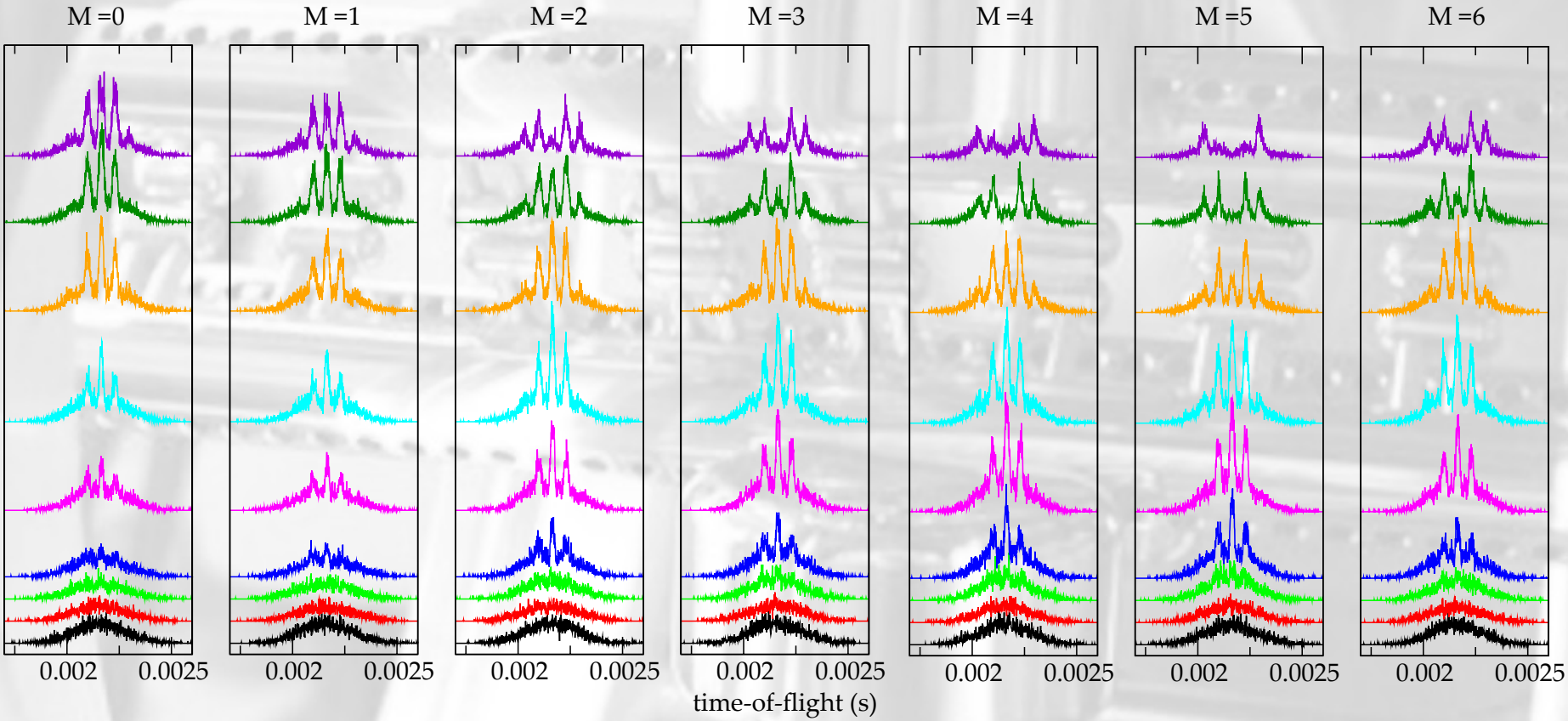
State selection

Guiding different eigenstates: $S_0, v = 0, |J_{K_a K_c}\rangle = 0_{00}$ vs 6_{06}



State selection

Guiding different eigenstates: Individual M-components of $S_0, v = 0, |J_{K_a K_c}\rangle = 6_{06}$



Decelerating ground-state benzonitrile

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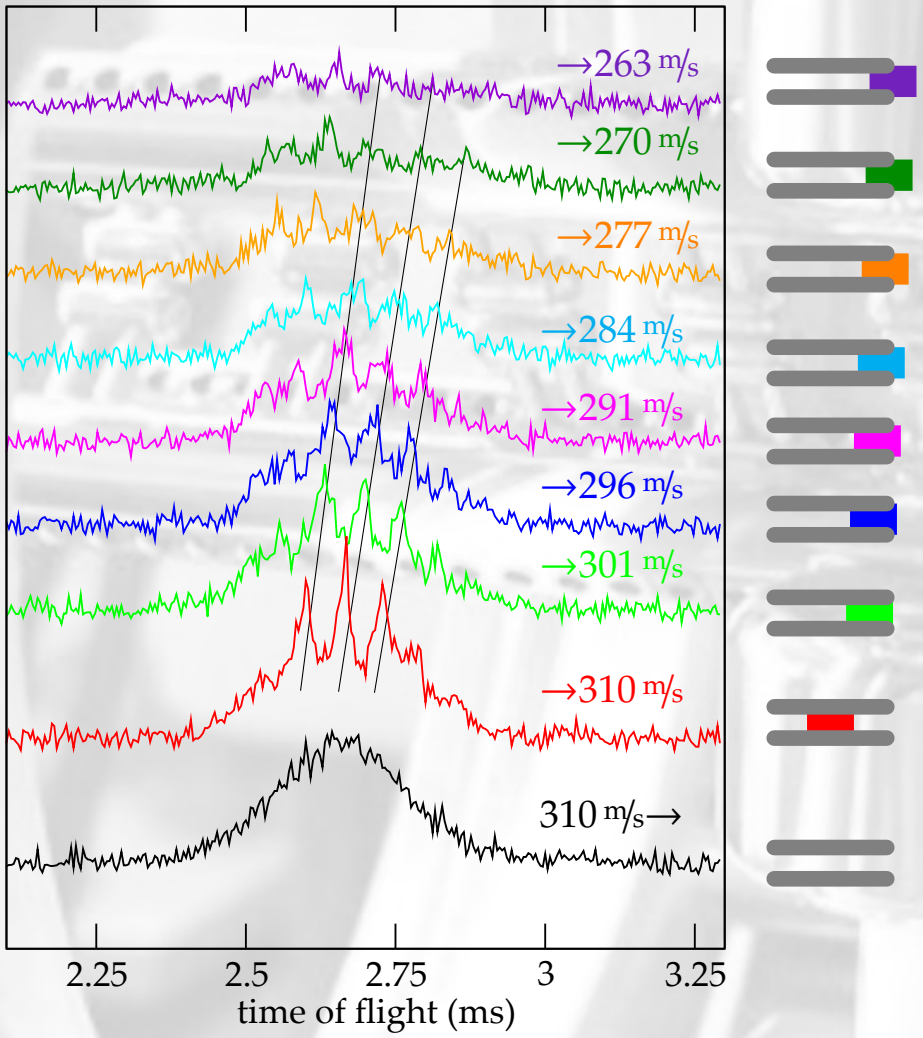

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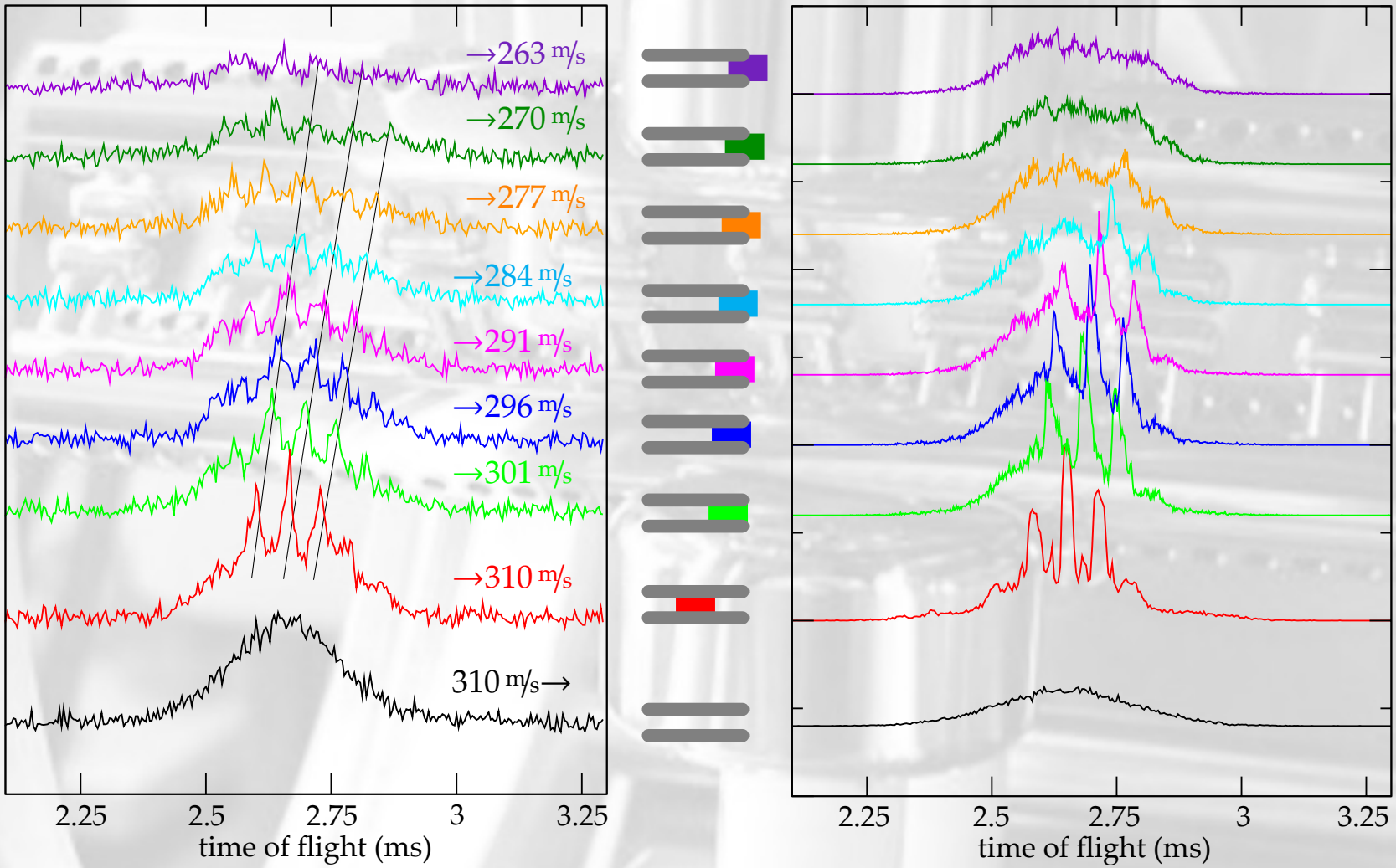
310 m/s → 263 m/s: 28 % of kinetic energy removed



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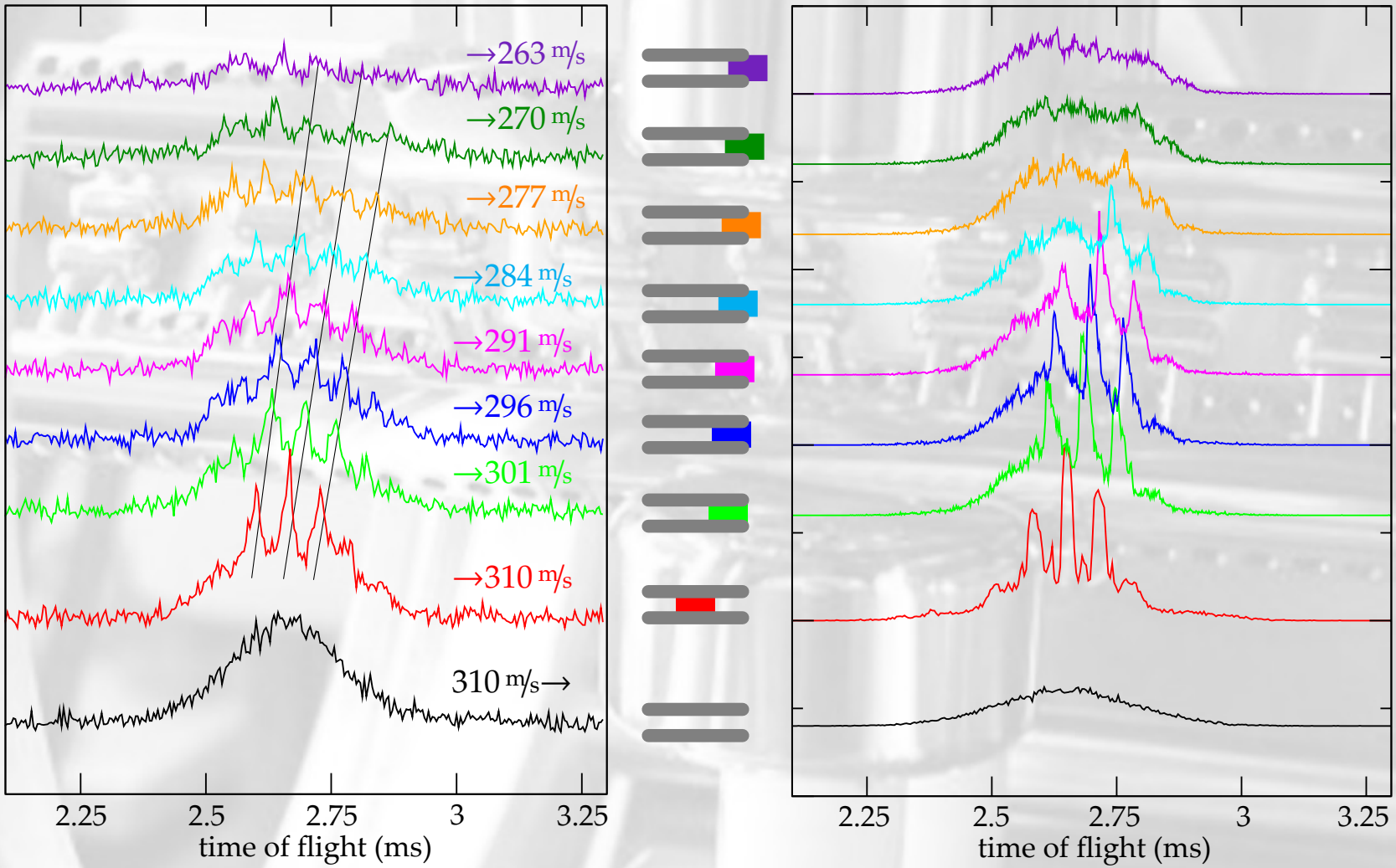
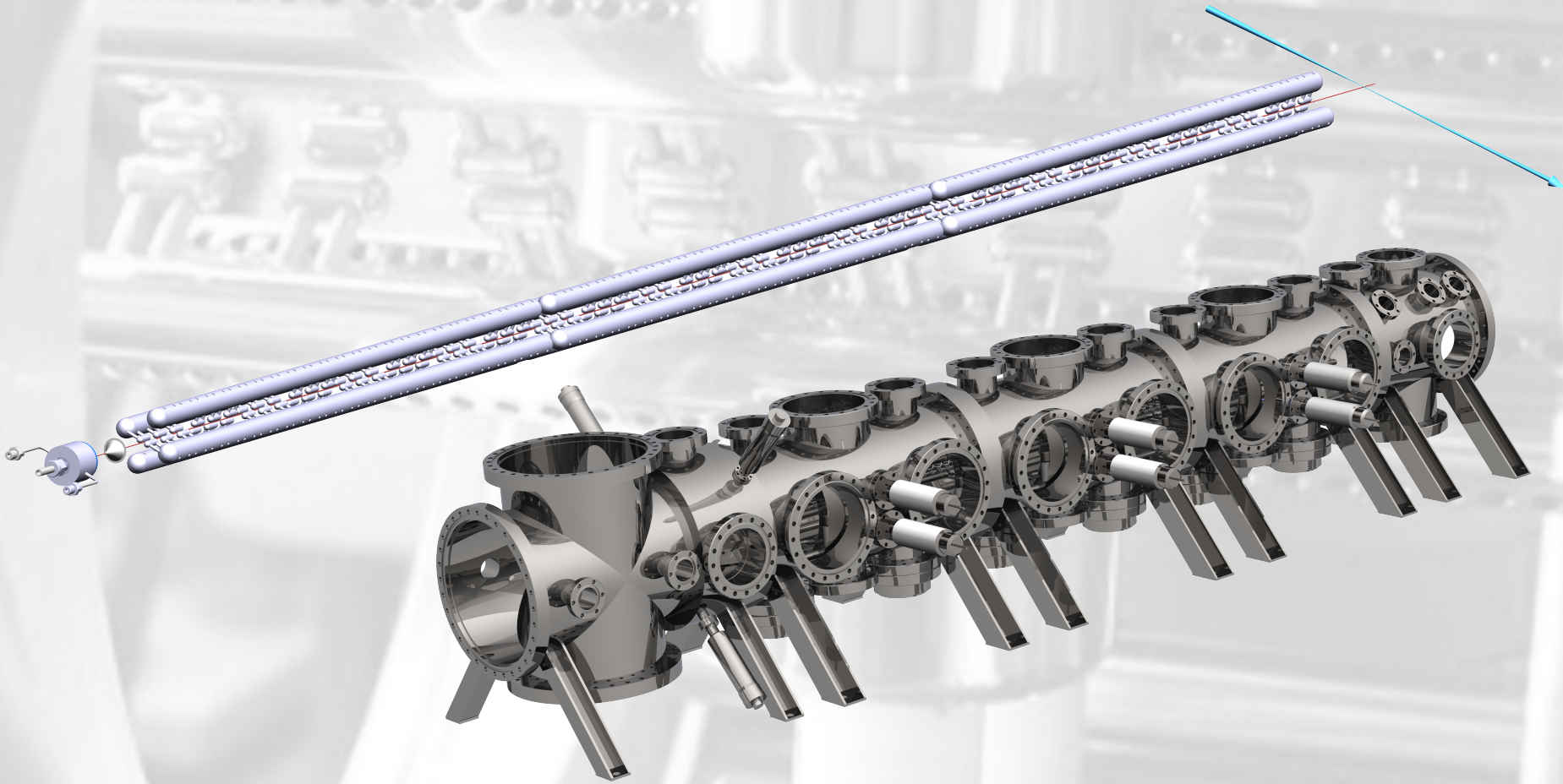


Extended experimental setup – a modular decelerator

Decelerating large molecules to a *quasi*-standstill



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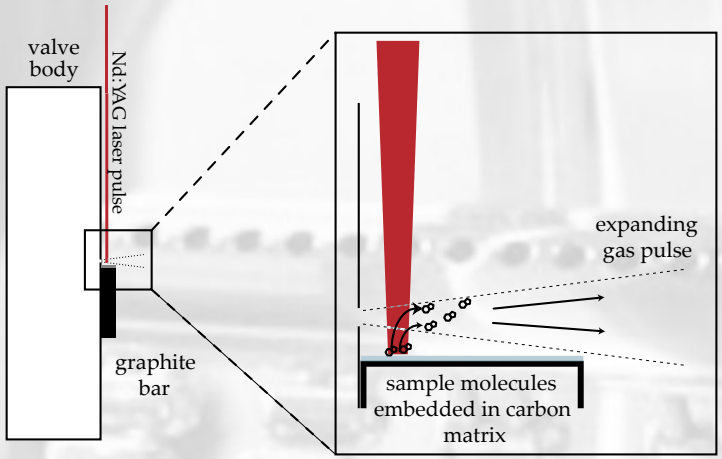
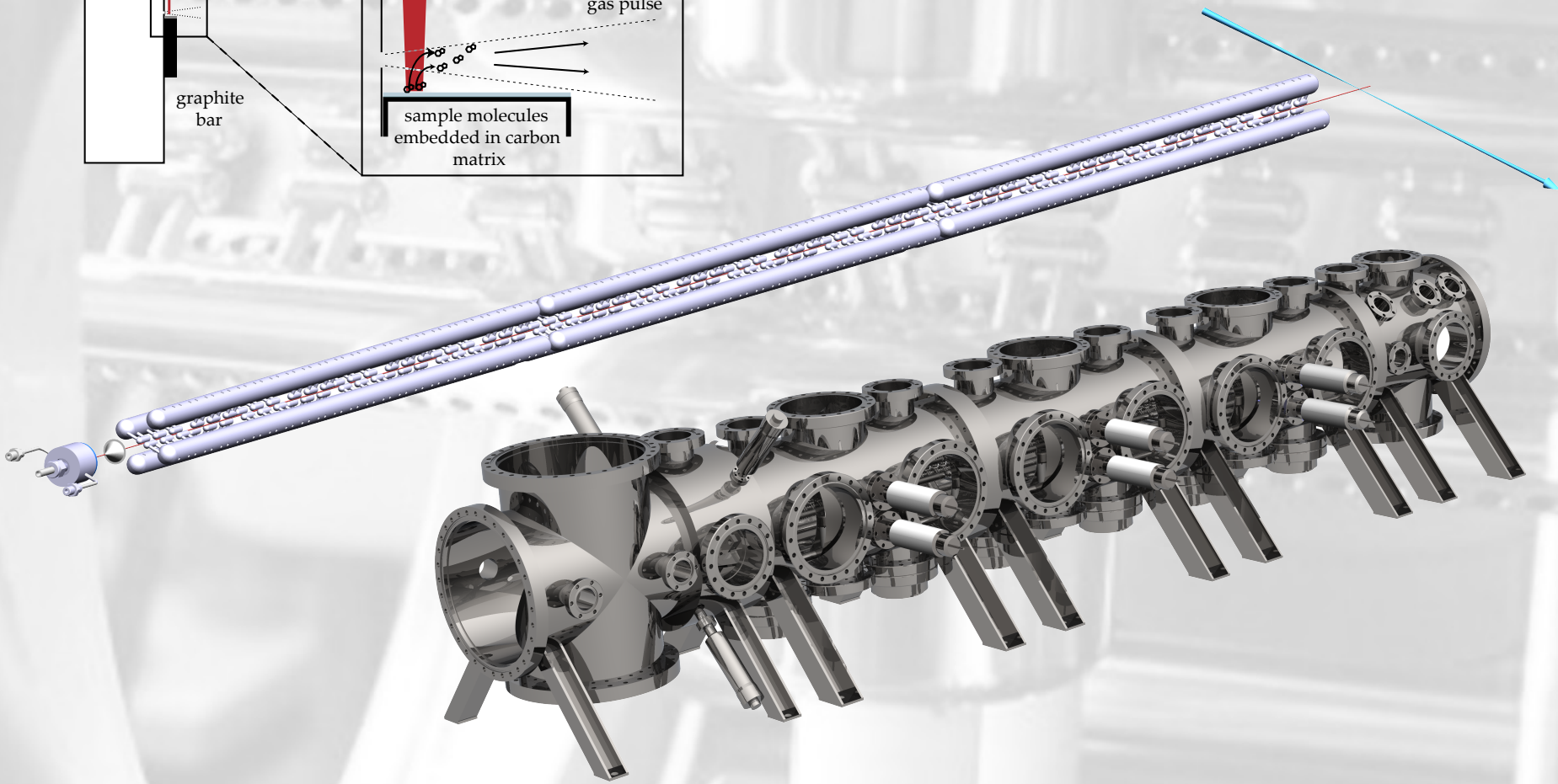
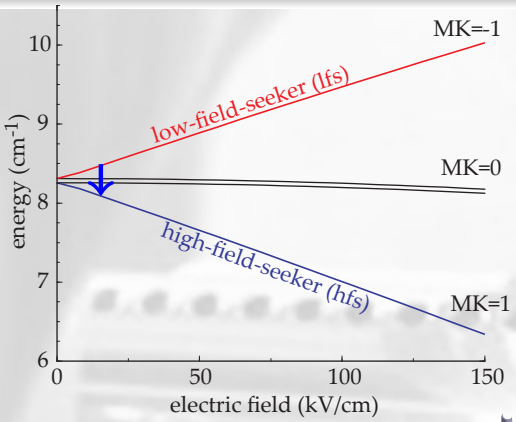
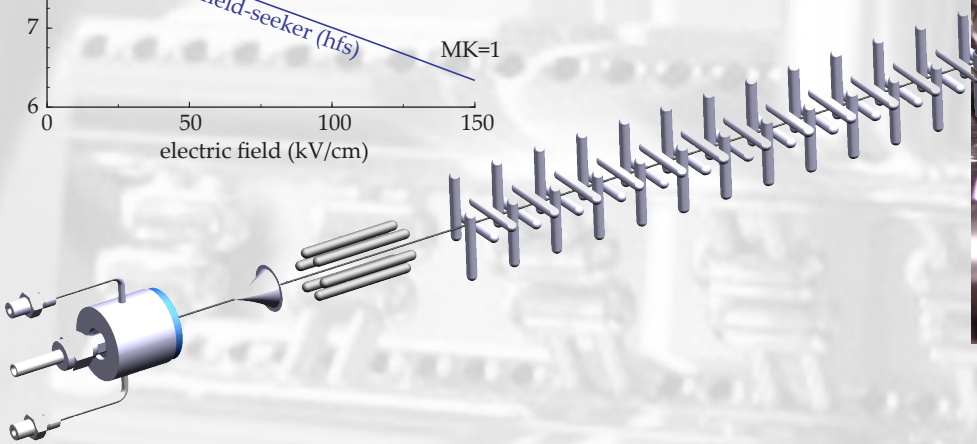
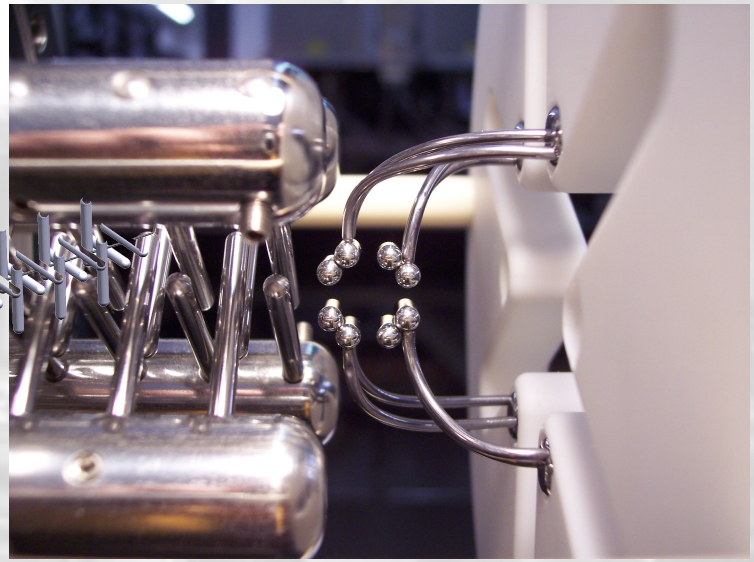




AC traps for molecules in high-field seeking states







van Veldhoven et al, *Phys. Rev. Lett.* **94**, 083001 (2005); Schnell et al, *in preparation*

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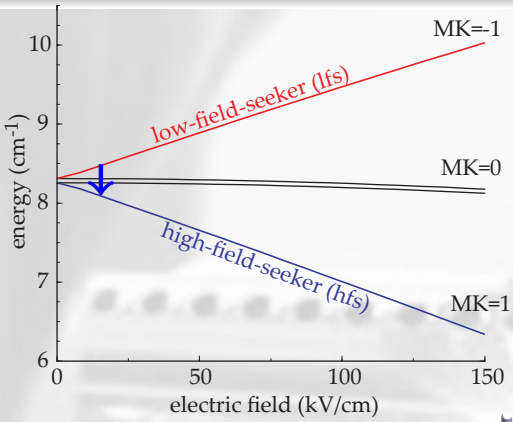

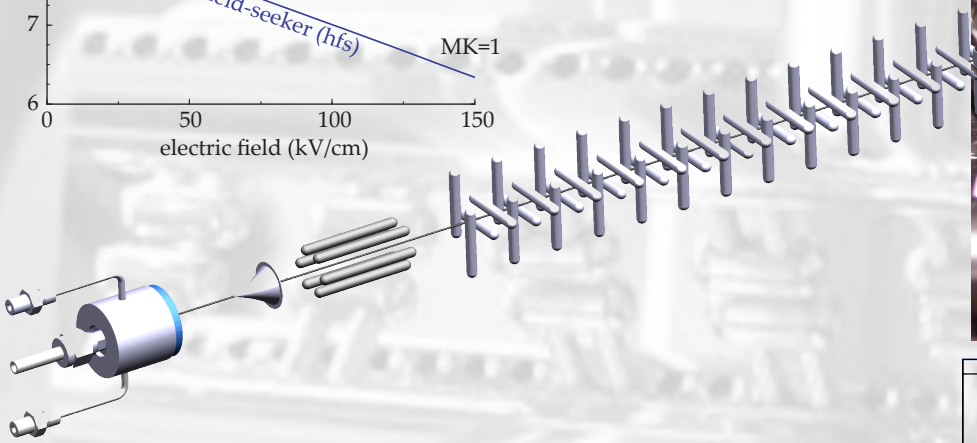

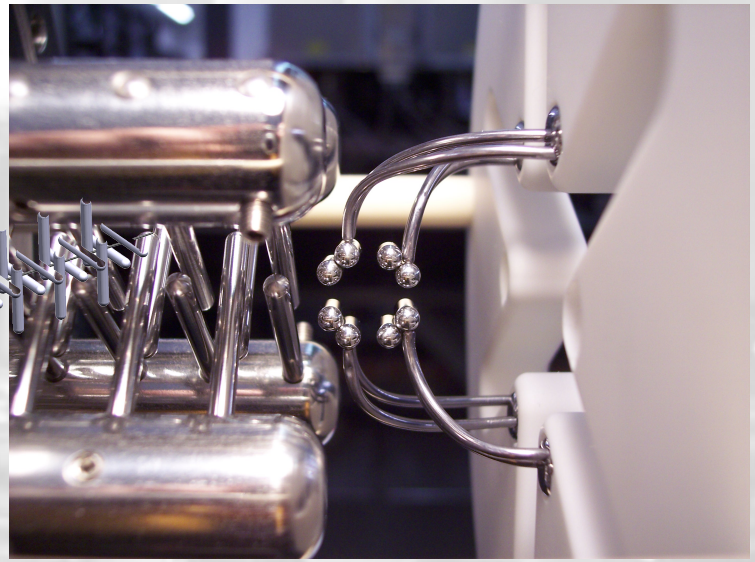

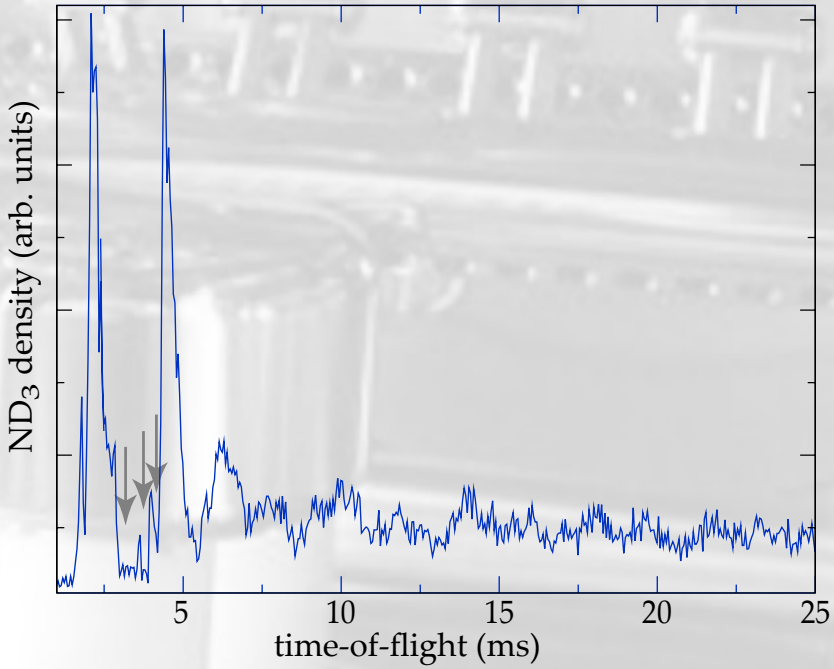

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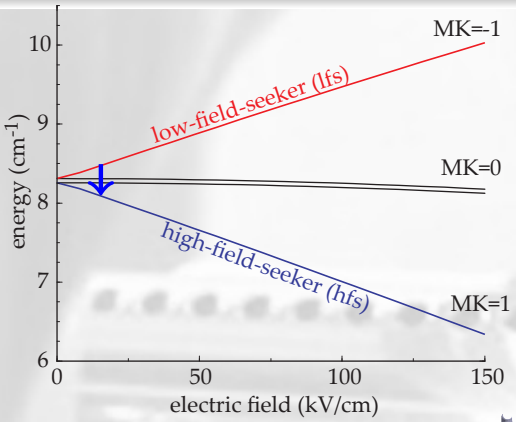

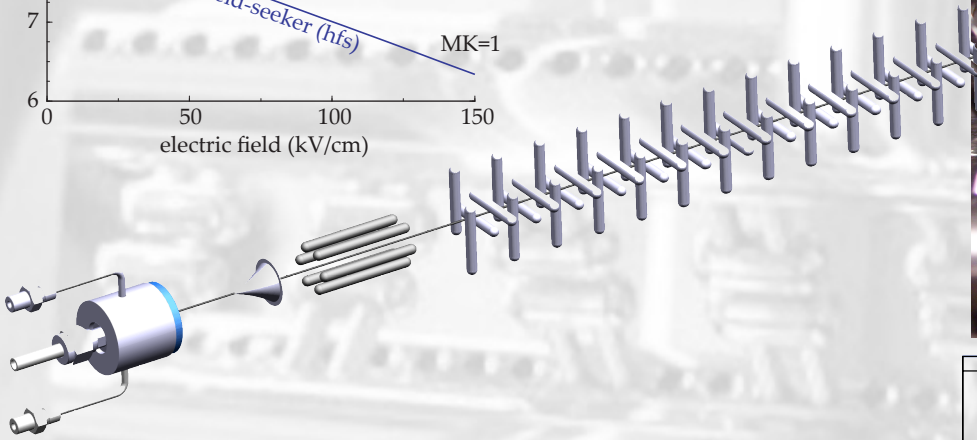

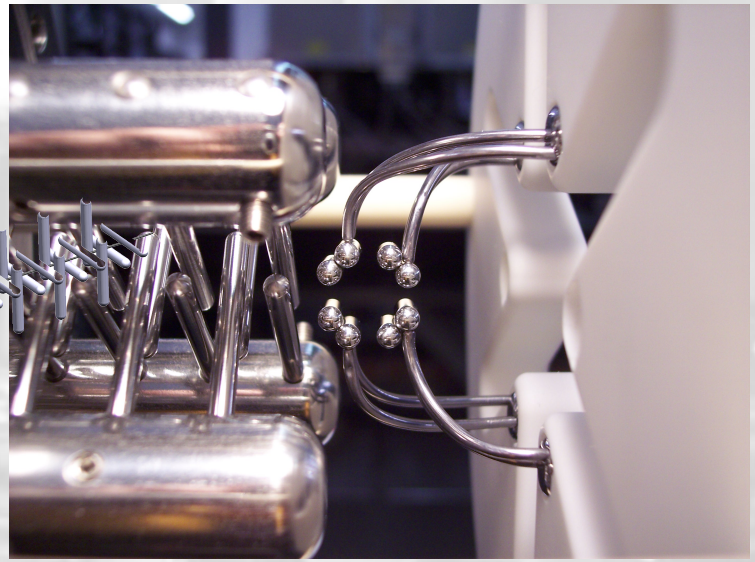

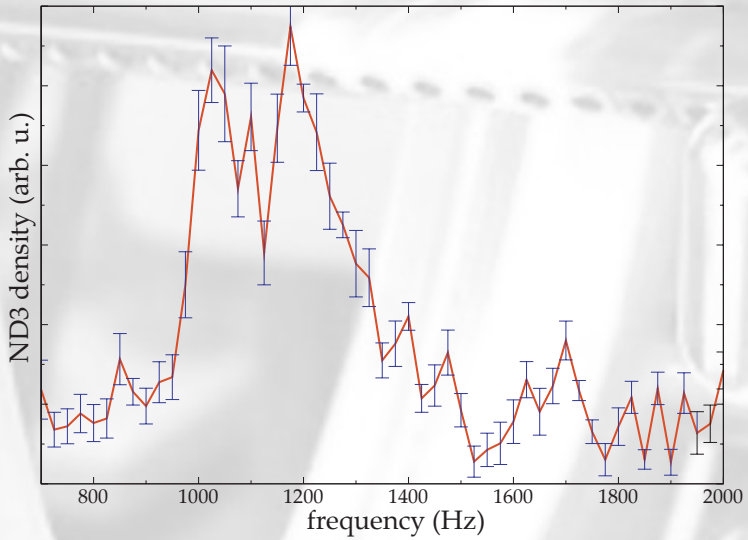

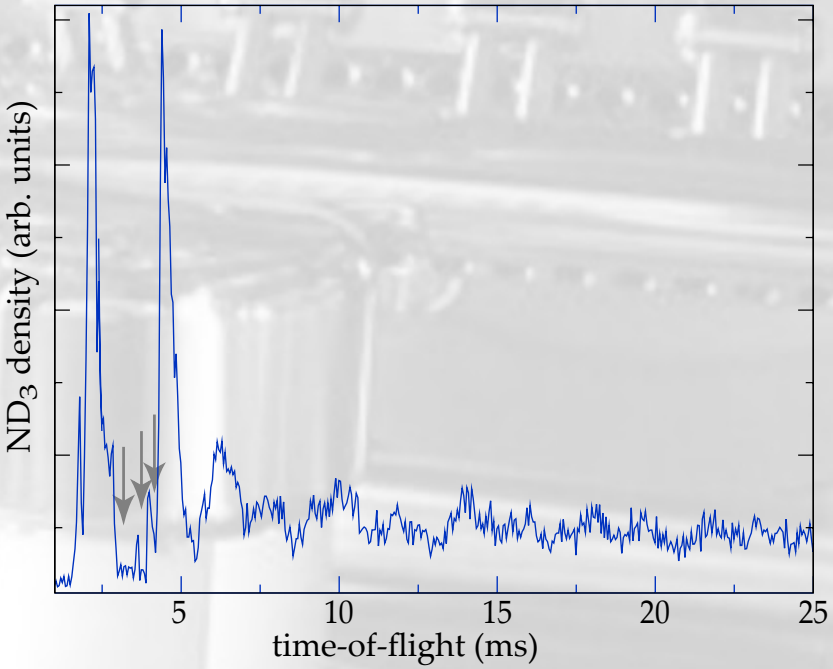

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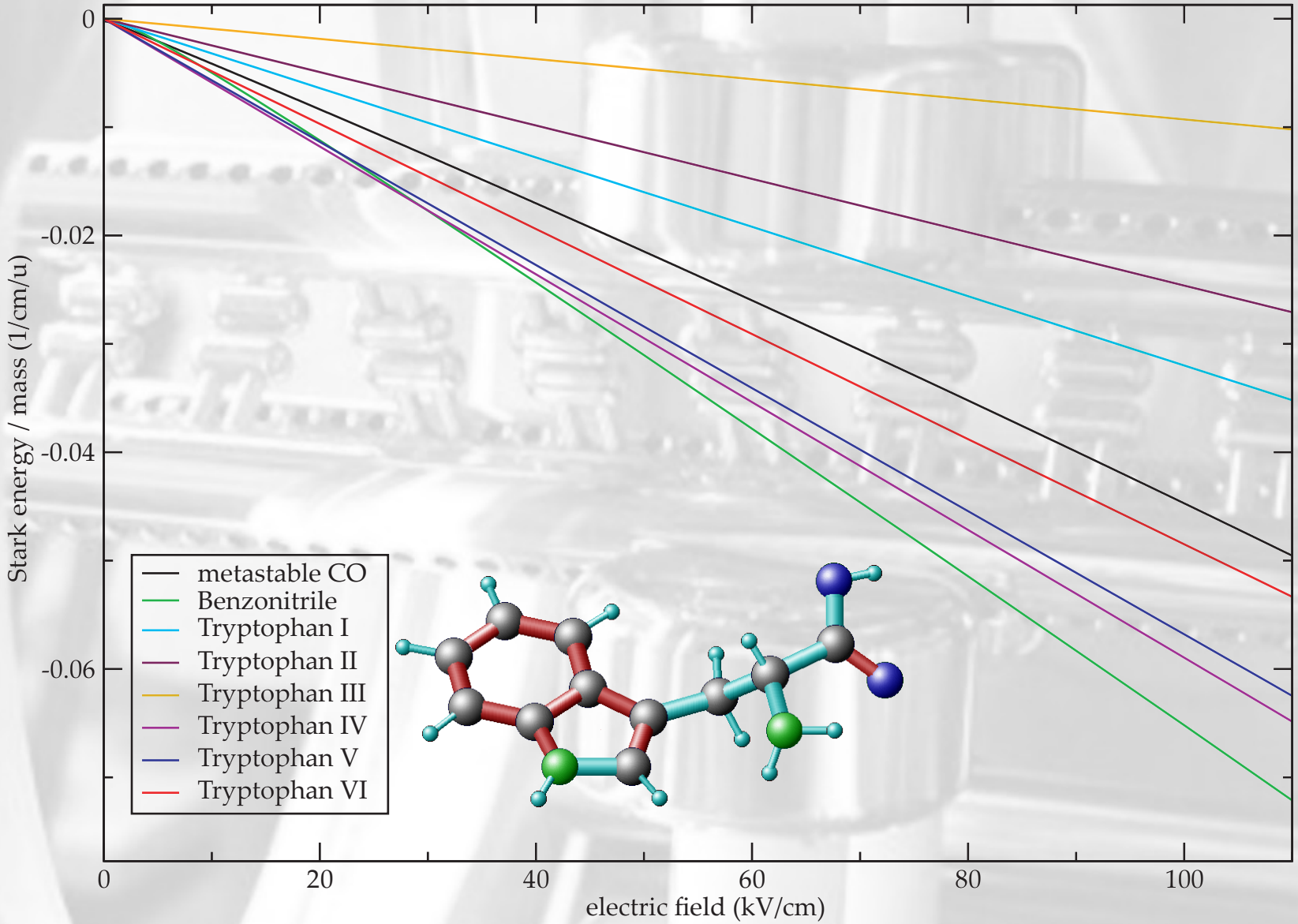
Decelerating larger molecules

Selecting tryptophan conformers



Conclusions

- Alternate Gradient focusing can be used to decelerate, bunch, focus, and trap polar neutral large and heavy molecules
  - Metastable CO in its hfs state has been decelerated from 250 m/s to 198 m/s
  - Benzonitrile (C_7H_5N) has been decelerated from 310 m/s to 263 m/s (removing 1/3 of its kinetic energy)
  - ND_3 has been trapped in a hfs state
  - Alternate Gradient deceleration provides novel control of large and/or ground state molecules:
    - External motion can be precisely controlled
    - Internal state(s) can be selected from original sample
- Using the full experimental setup it will be possible to decelerate large molecules to a quasi-standstill in the laboratory-frame and successively trap them
- Preparing intense beams of large, molecular (bio-) molecules, i. e. using laser desorption, will allow novel (precision) studies of conformer-selected samples of such systems

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Acknowledgment

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