FOM-Institute for Plasma Physics Rijnhuizen

FELICE

Free Electron Laser for Intra-Cavity Experiments

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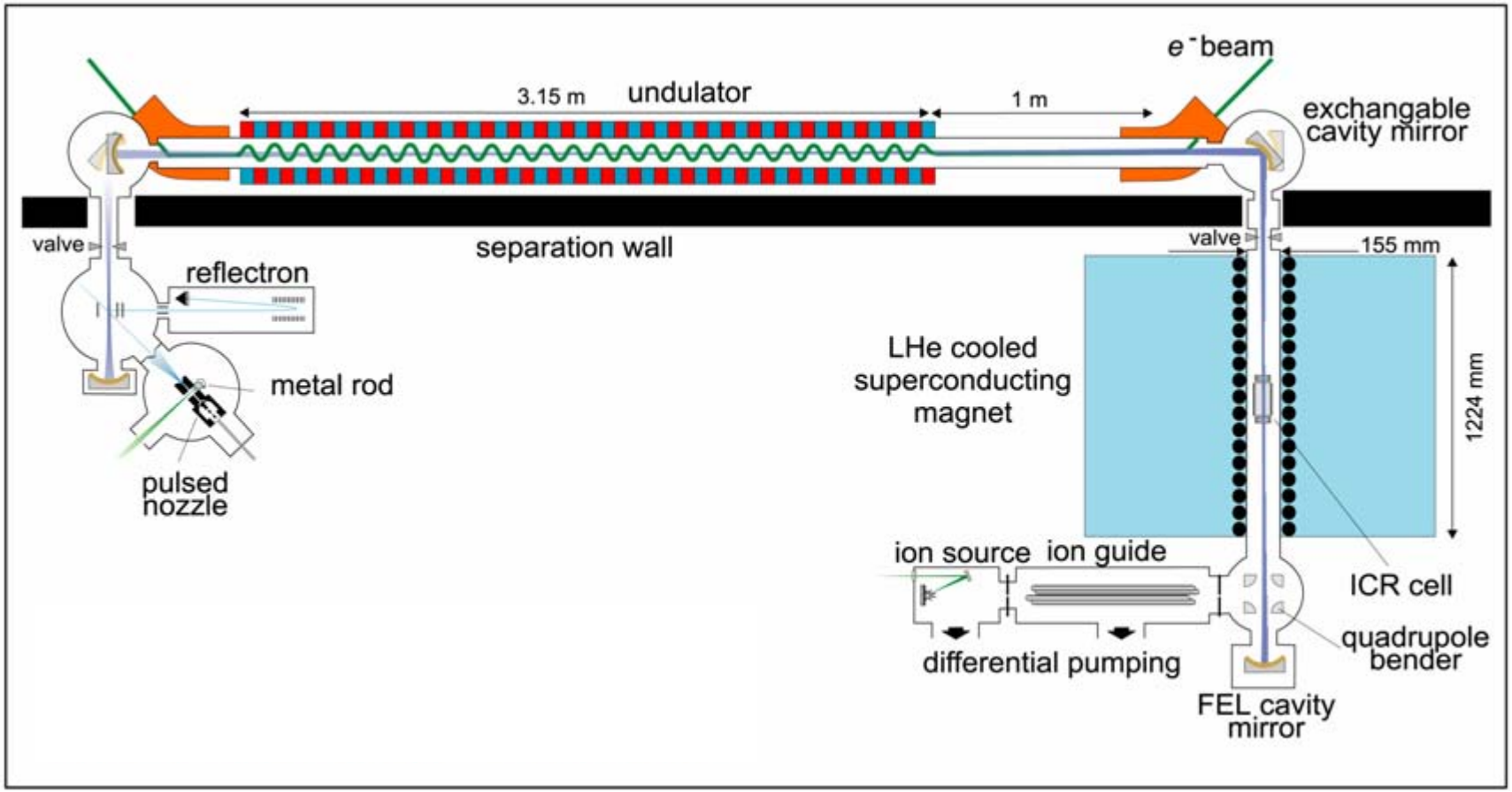
on behalf of the FELIX team

How FELICE started!



Why FELICE?

- enhance the capabilities of the facility for different types of action spectroscopy of (bio)molecules, ions, clusters and complexes in the gas-phase

- FELs such as FELIX are particularly suited for this type of research and the majority of the beam time at our facility is nowadays devoted to it

- despite the large number of successful experiments, for certain experiments even the output of FELIX is not sufficient, especially in the FIR

- as the absorption cross sections of the gas samples are inherently low, a very significant boost is possible by making use of the intra-cavity power

Action Spectroscopy

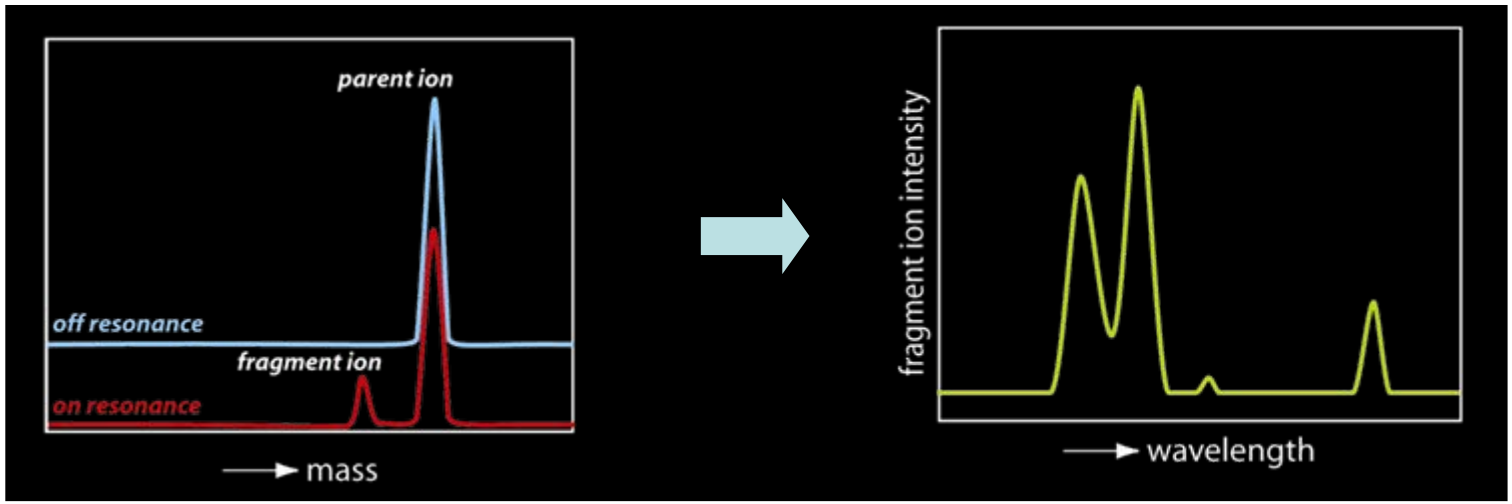
Direct absorption measurement

- not sensitive enough: low particle density
- not species specific: broad cluster / complex distributions

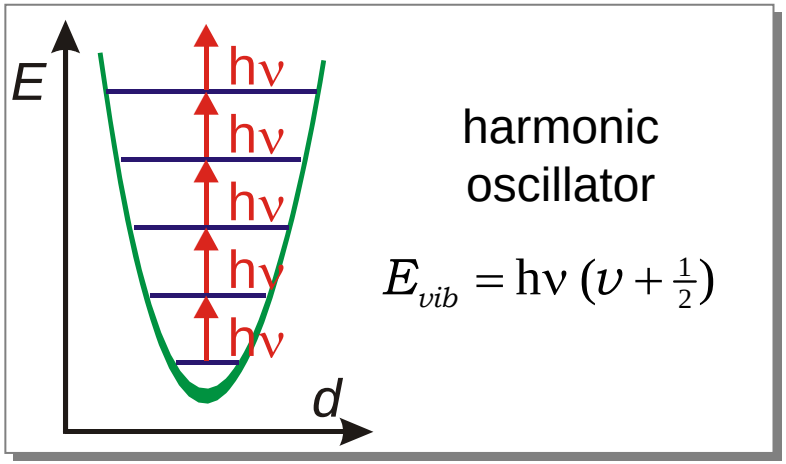
Action spectroscopy

IR absorption induced changes, e.g.

particle mass (dissociation, fragmentation, reaction)
charge state (ionization)
quantum state (saturation, ion dip)

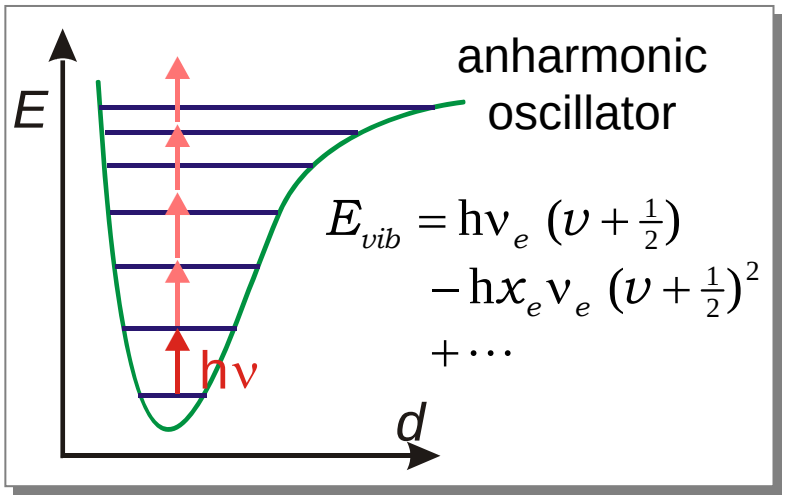


Mechanism of IR Multi-Photon Absorption



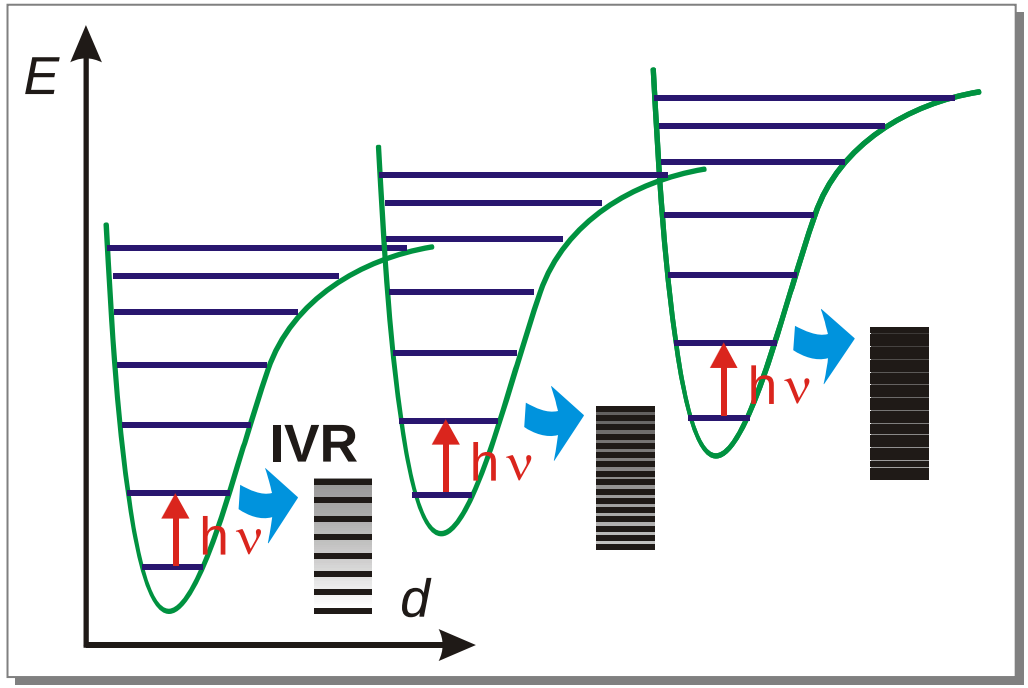
harmonic oscillator

$$E_{vib} = h\nu\,(\upsilon + \tfrac{1}{2})$$



anharmonic oscillator

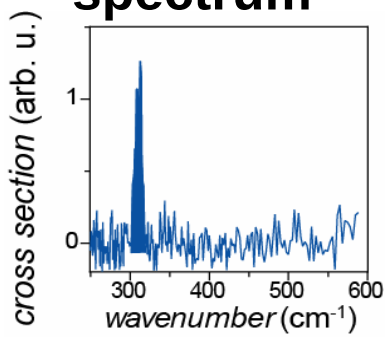
$$E_{vib} = h\nu_e\,(\upsilon + \tfrac{1}{2}) - hx_e\nu_e\,(\upsilon + \tfrac{1}{2})^2 + \cdots$$



- resonant absorption
- fast intramolecular vibrational redistribution (IVR), $t_{IVR} << 1$ ns
- absorption of the next photon
- etc.

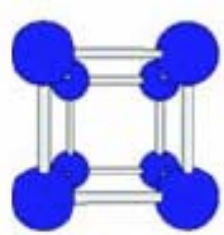
Obtaining structural information

experimental spectrum



calculated IR spectra for different structures

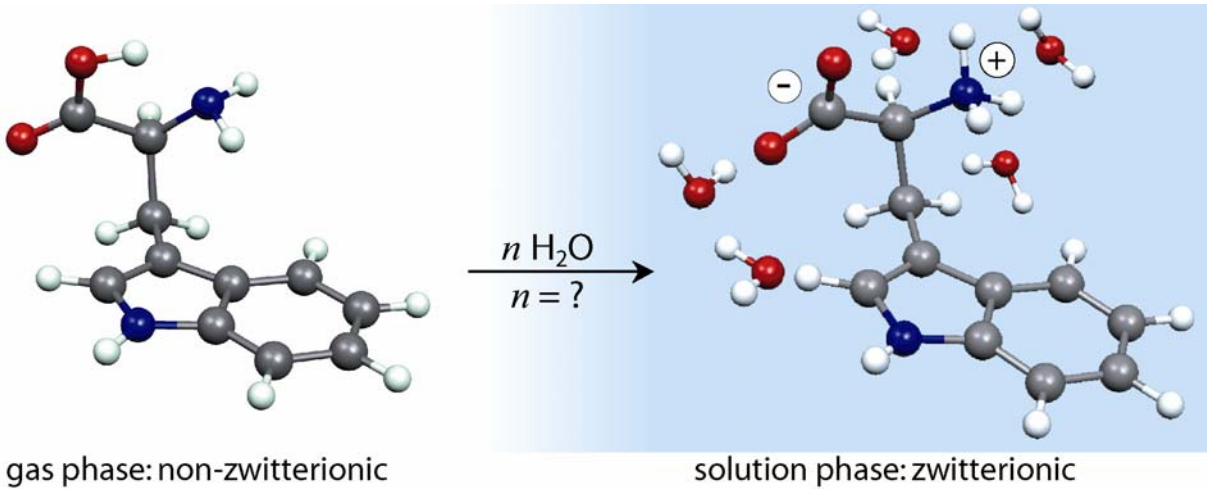
structure assignment



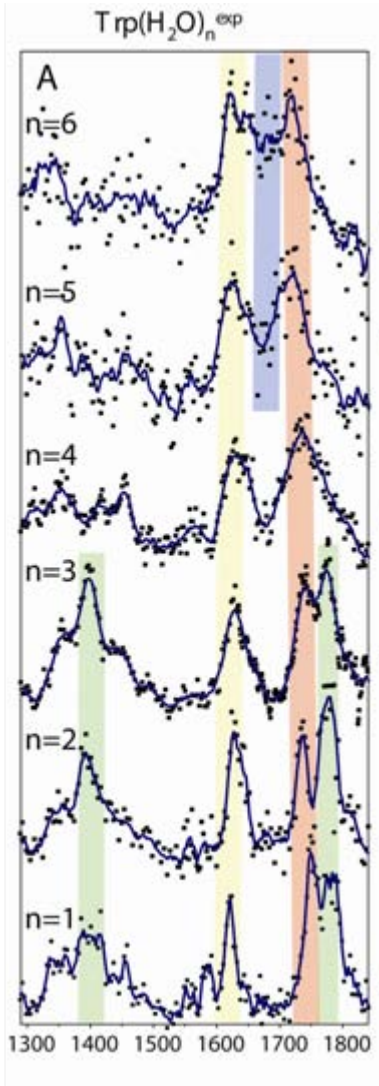
Examples of Action Spectroscopy

I. Conformer specific spectroscopy in a molecular beam

Biomolecules: gas phase vs solution



stepwise hydration of an amino acid:
appearance of the zwitterion

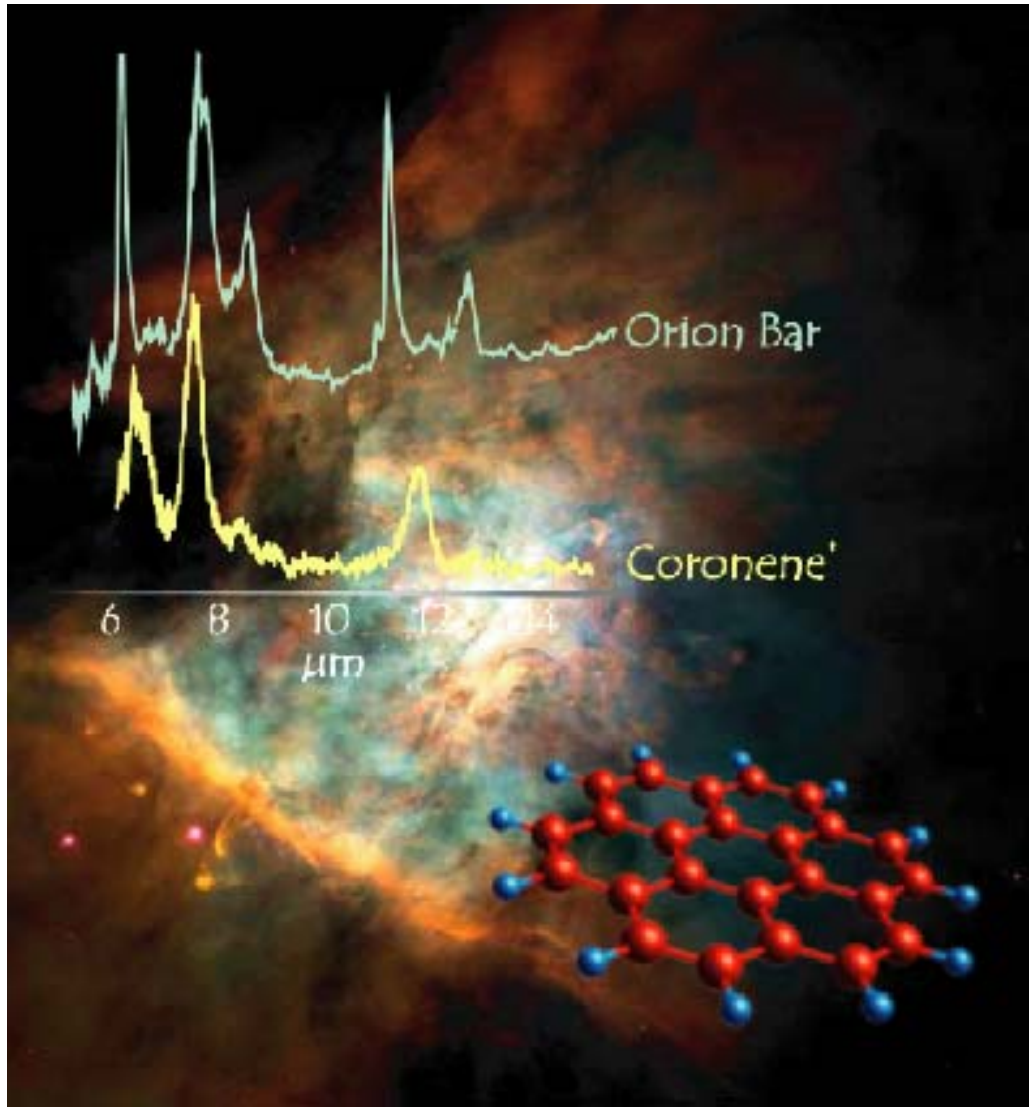


Blom et al. J. Phys. Chem. A 111 (2007) 7309-7316

Examples of Action Spectroscopy

II. IR Spectroscopy in Ion Traps

- Mass selective isolation
- Longer interaction times
- Ion-molecule reactions
- External ion sources
- Non-intrusive mass analysis
- Very high mass resolution

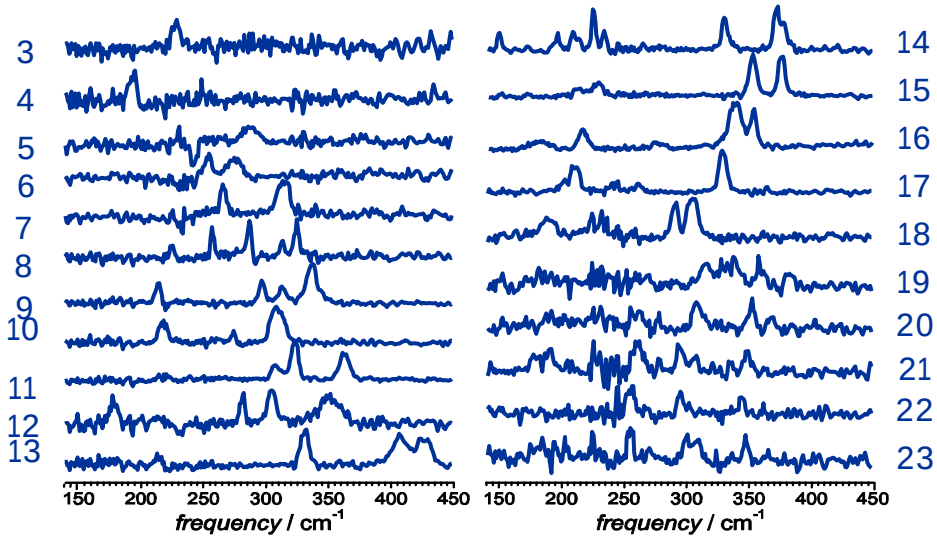


Oomens et al. ApJ 560 (2001) L99-103

Examples of Action Spectroscopy

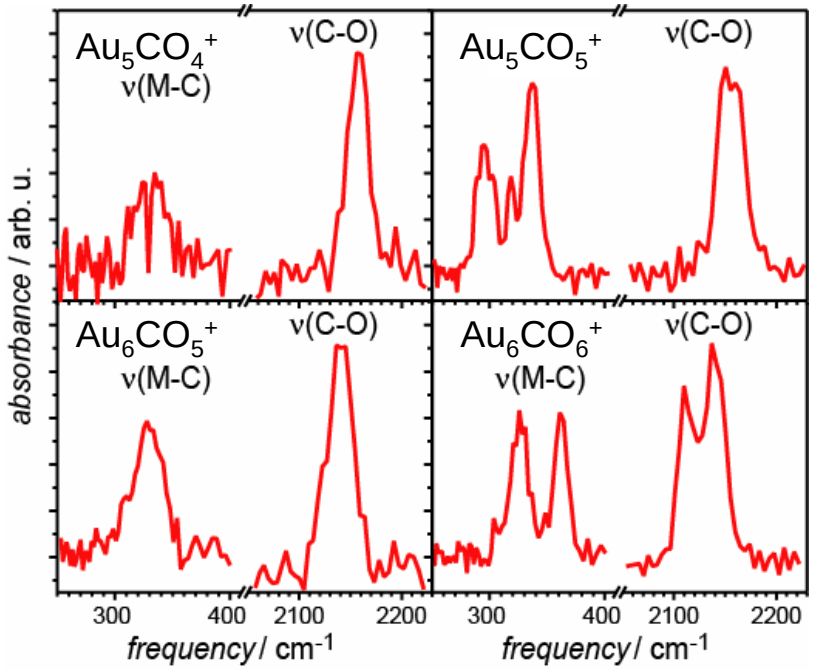
III. IR spectroscopy of metal clusters and metal cluster complexes

Argon complexes of vanadium cluster cations



Fielicke et al. Phys. Rev. Lett. 93 (2004) 023401

IR-MPD spectra of $Au_{5,6}CO_m^+$



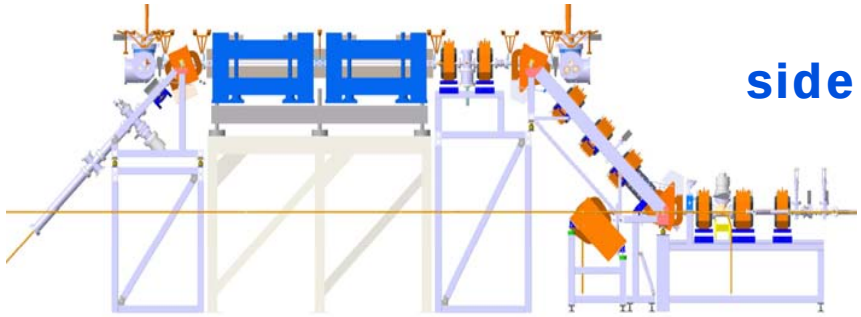
Fielicke et al. JACS 127 (2005) 8416

FELICE design specifications

FELICE is designed:

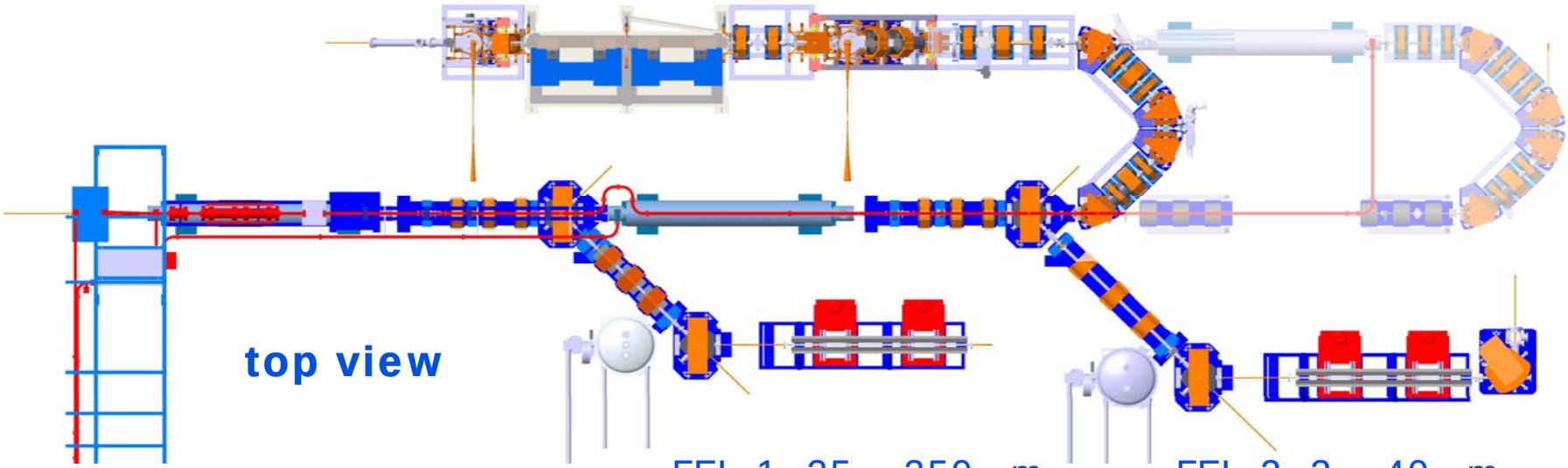
- to cover the wavelength range from 3 to 100 microns at a micropulse repetition rate of 1 GHz
- to run interleaved with the existing FELs at a macropulse repetition rate of up to 10 Hz
- to provide micropulse energies up to 1 mJ @ 0.4% rms BW
- to give a secondary focus at user experiments with small Rayleigh range (5 – 10 cm)
- to accommodate two experimental stations
- to allow (limited) access to the experimental setup during operation

FELICE design



side view of FELICE

FELICE, 3 – 100 μm



top view

FEL-1, 25 – 250 μm

FEL-2, 3 – 40 μm

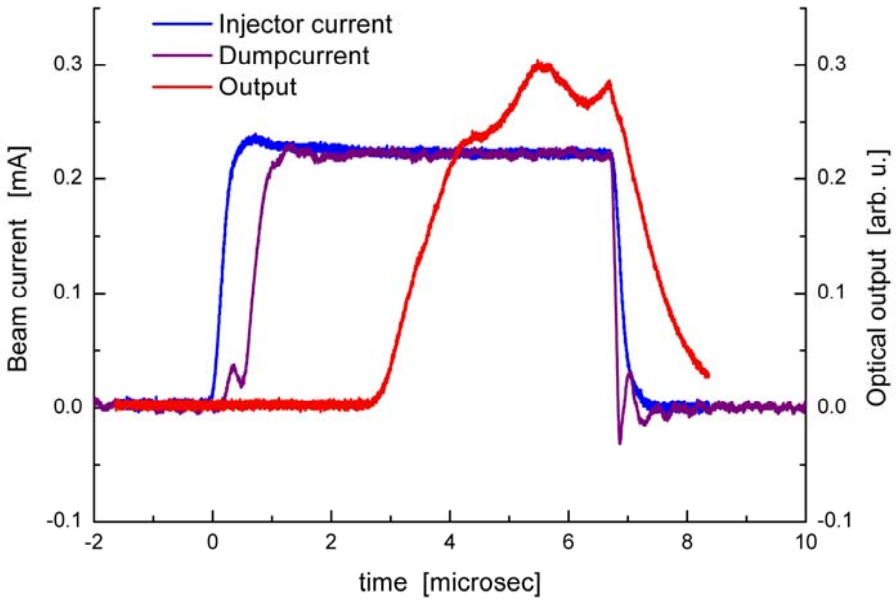
Present layout of the FELIX vault (shaded parts still need to be installed)

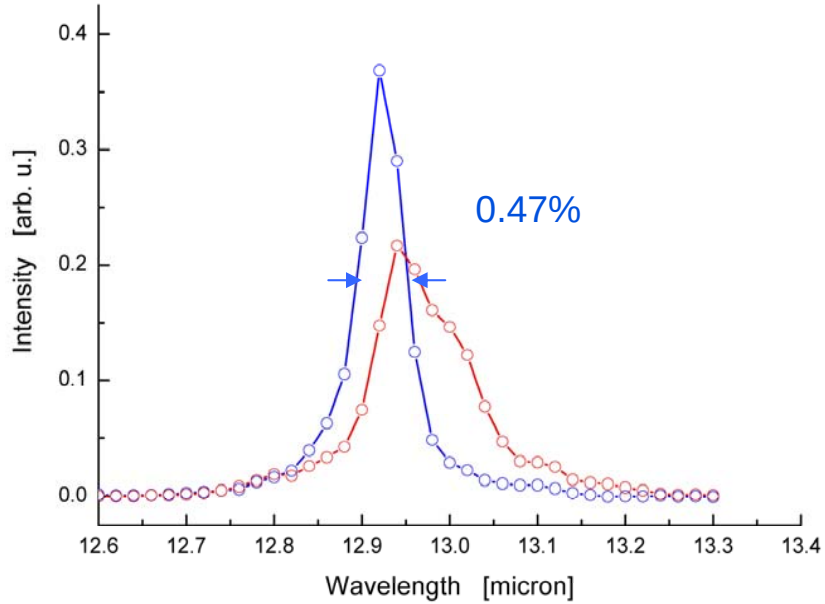
FELICE design choices

- FELIX linacs as front-end for FELICE (bunch charge 200 pC, repetition rate 1 GHz)
- extra linac for the energy range from 20 – 30 and 45 – 60 MeV
- switching of main dipoles of FELIX at 10 Hz
- one undulator with insertable partial waveguide
- two 4-mirror 9-m resonator configurations
- quasi-periodic undulator to suppress harmonic content
- rearrange high-power RF system to reduce interdependence of FELs

FELIX and FELICE

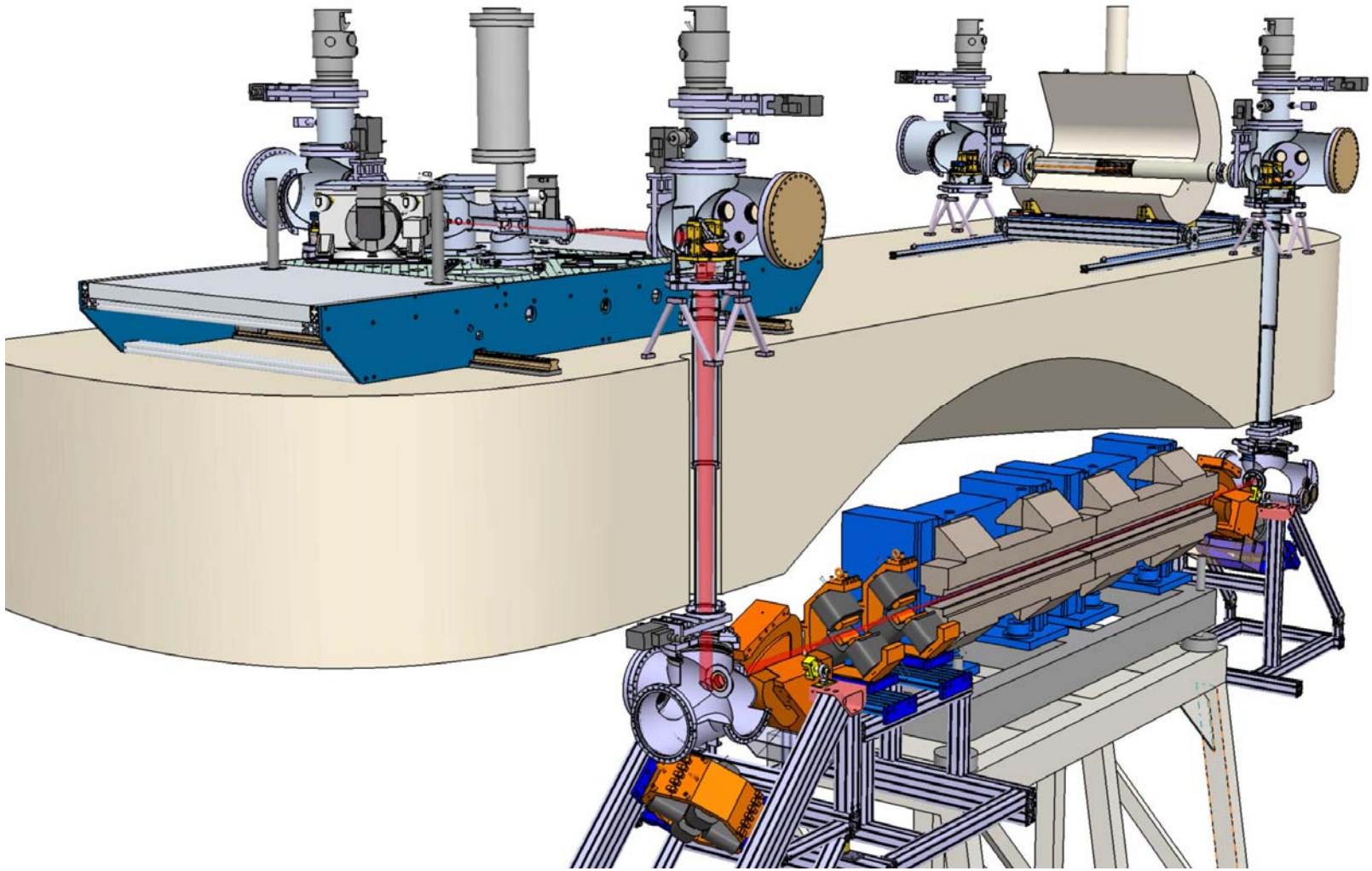
FELICE – first lasing





- Beam energy 45 MeV, wavelength 13 μm
- Micropulse energy: 10 μJ outcoupled ≈ 400 μJ intra-cavity
- Third-harmonic content: ≈ 2 x 10^{-4}
- Measured cavity loss: 12.5%, i.e. 4.5% higher than expected
- Interleaved operation with FEL-2 demonstrated

Artist's view of the intra-cavity setups



The intra-cavity setups

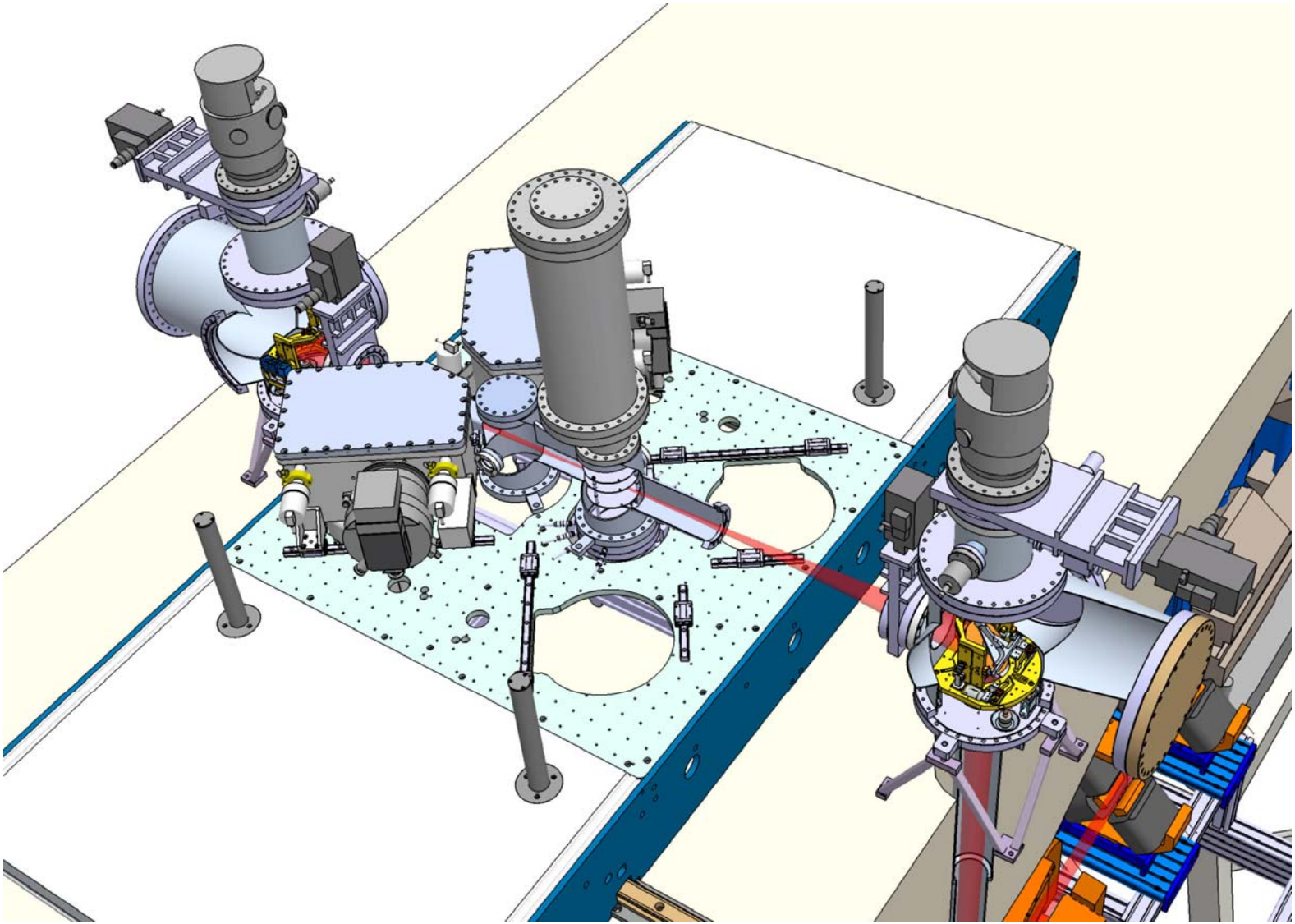
The molecular beam setup

- 4 experimental chambers connect to two interaction regions
- two setups equipped for molecular beam with time-of-flight detection
- hard focus: 5 cm Rayleigh range
- setup is movable along beam axis by 30 cm to change between the two interaction zones and to change the power density
- an optimization of the overlap of the molecular beam axis and the FEL axis is possible in z-direction

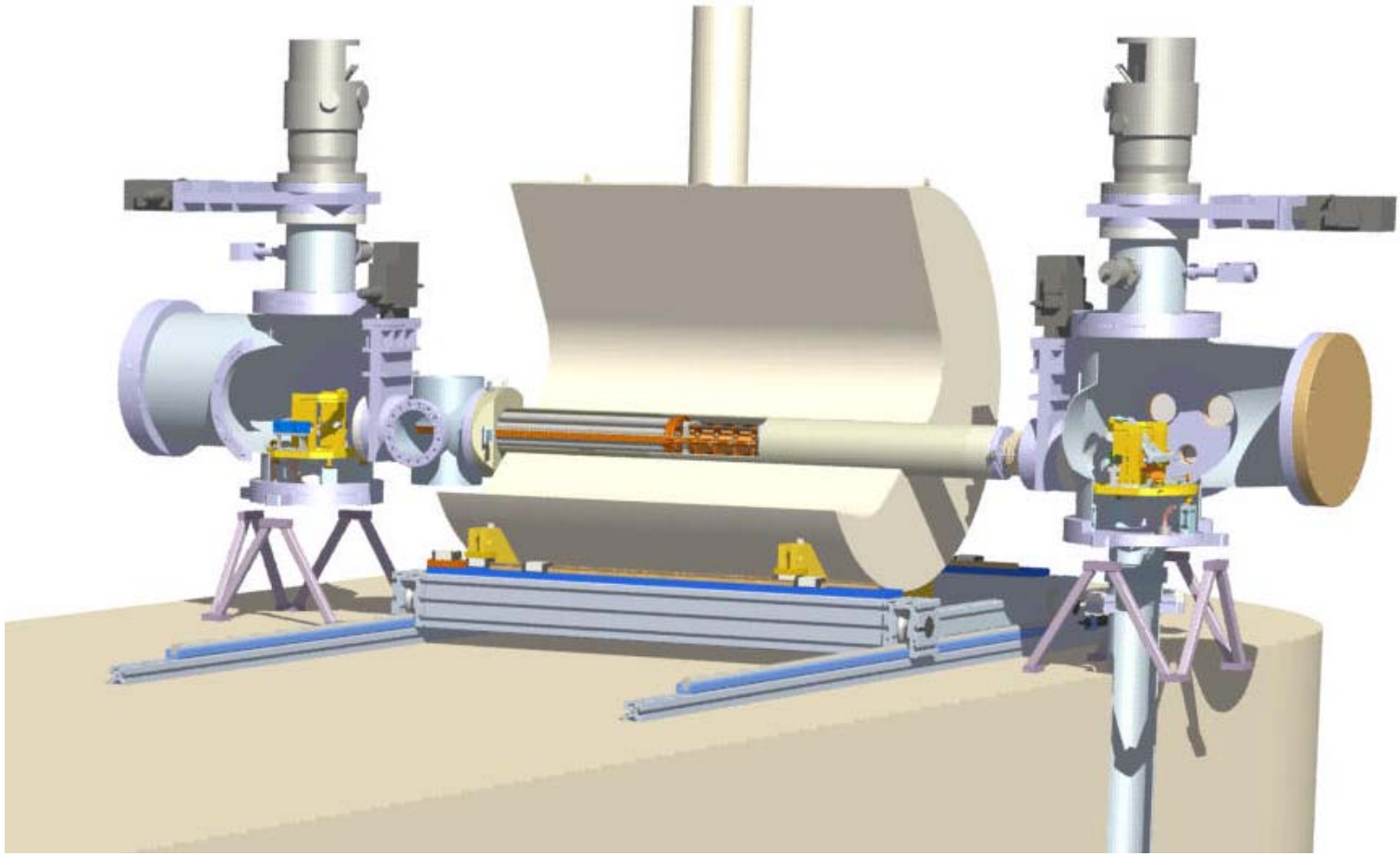
The ion trap setup

- 7T high-resolution FTICR mass spectrometer
- modest focus: 8 cm Rayleigh range
- movable in beam direction to optimize and change power density
- versatile ion sources attached like electron impact and electro-spray
- interaction region allows for collision induced reaction etc.

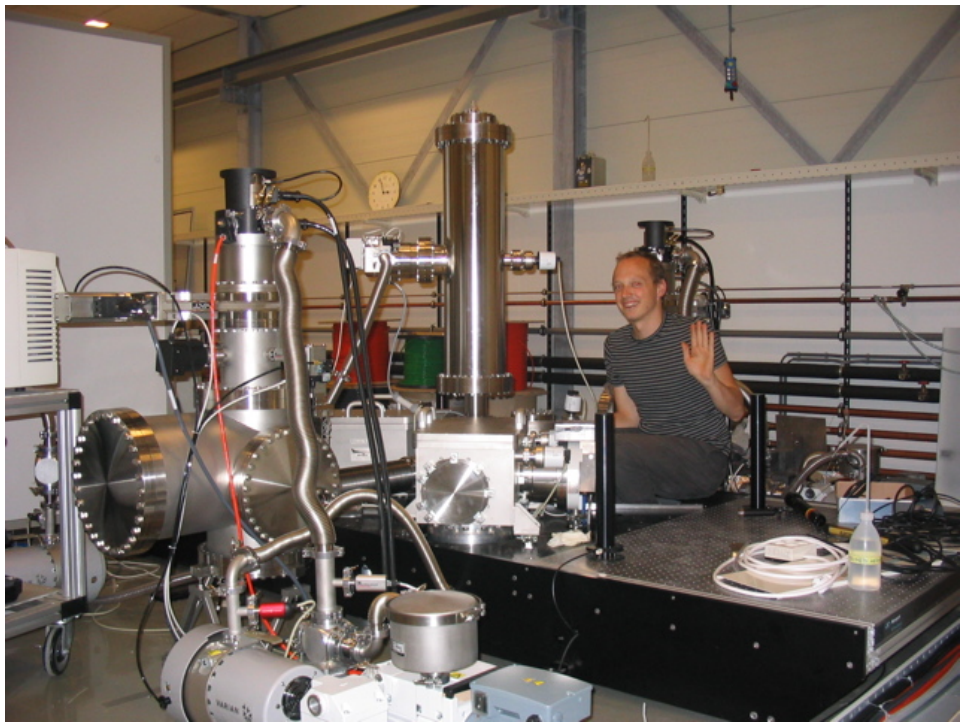
The molecular beam setup



The FTICR setup



FELICE – first experiments



experiments on gas-phase (bio)molecules, clusters and complexes:

- high flux
- high peak power
- time-resolved measurements
- …

they tried very hard but … ☹