Development and Application of the Frequency-Scanning-Method for Filtered Rayleigh Scattering (FSM-FRS)

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Outline

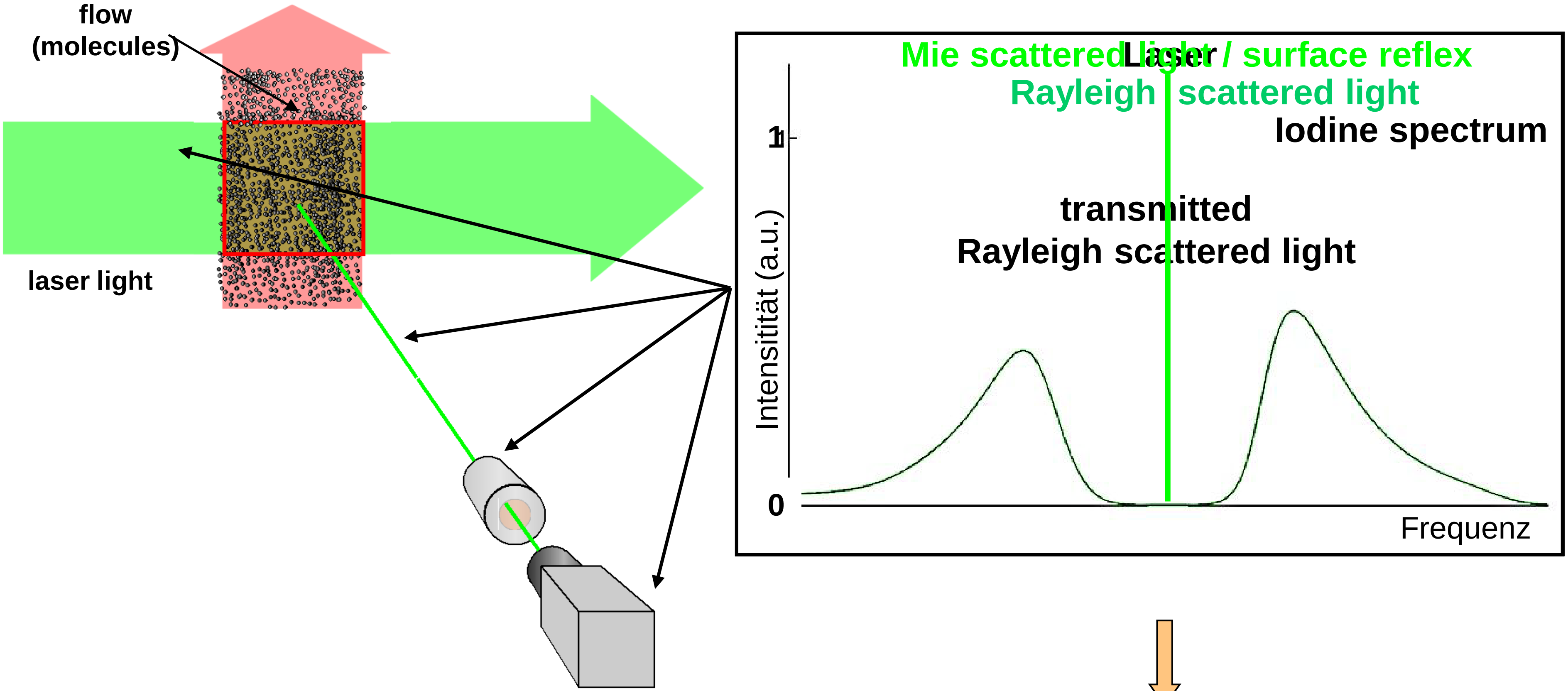
1. Filtered Rayleigh Scattering (FRS)

2. Frequency-Scanning-Method of FRS (FSM-FRS)

3. Applications of FSM-FRS

4. Summary and conclusions for FSM-FRS

1. Filtered Rayleigh Scattering (FRS) the principle

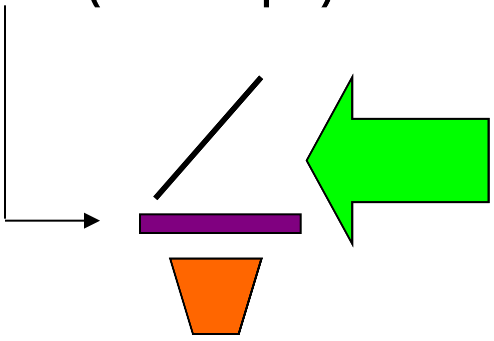


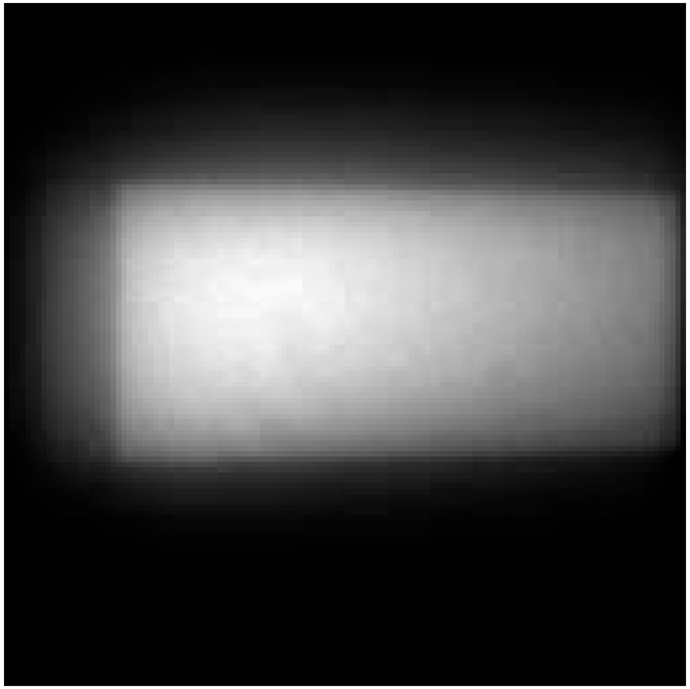
on-chip integration produces one intensity value
loss of information problem…!

temperature, pressure, density, Doppler frequency / velocity

1. Filtered Rayleigh Scattering (FRS) surpressing laser reflex light

molecular absorption filter
(iodine vapor)

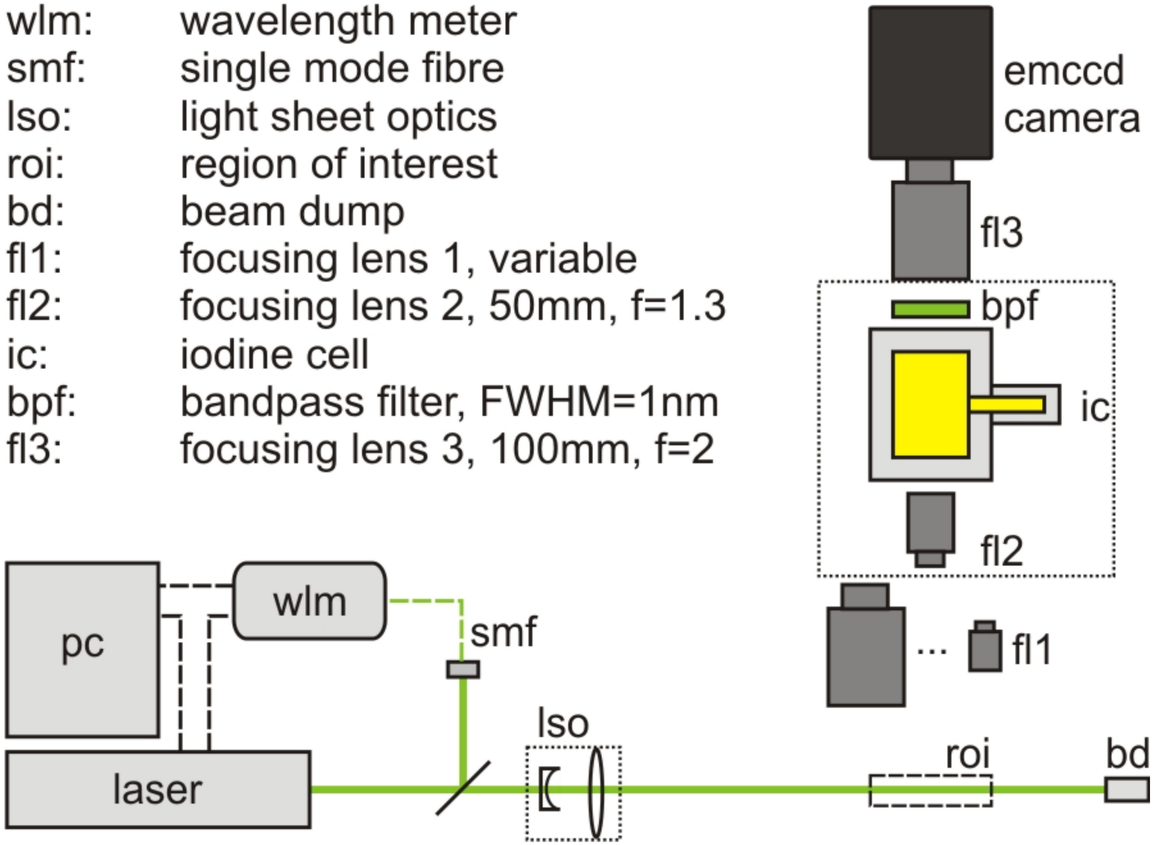




Enables measurement near walls or other objects!

1. Typical FRS setup

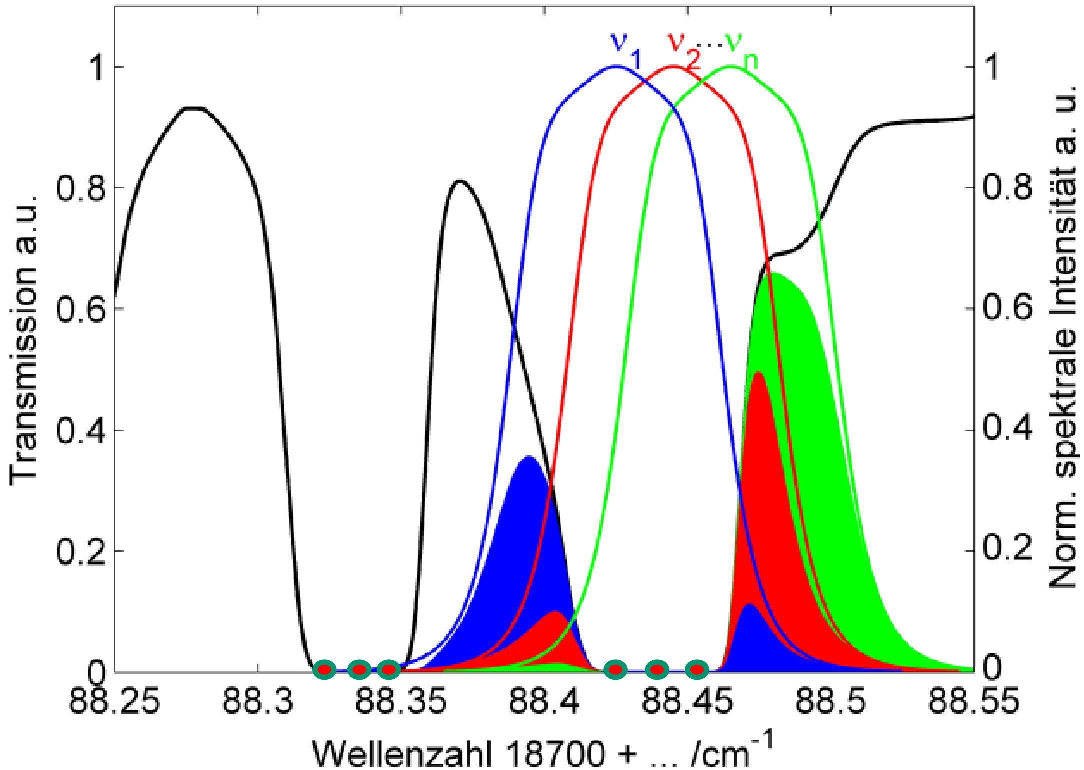
wlm:	wavelength meter
smf:	single mode fibre
lso:	light sheet optics
roi:	region of interest
bd:	beam dump
fl1:	focusing lens 1, variable
fl2:	focusing lens 2, 50mm, f=1.3
ic:	iodine cell
bpf:	bandpass filter, FWHM=1nm
fl3:	focusing lens 3, 100mm, f=2



Continuous wave laser system @ 532nm

Narrow linewidth (FWHM < 5MHz), tuning range 60GHz

2. Frequency scanning method of FRS



Trade-off:

Multi-Parameter + accuracy

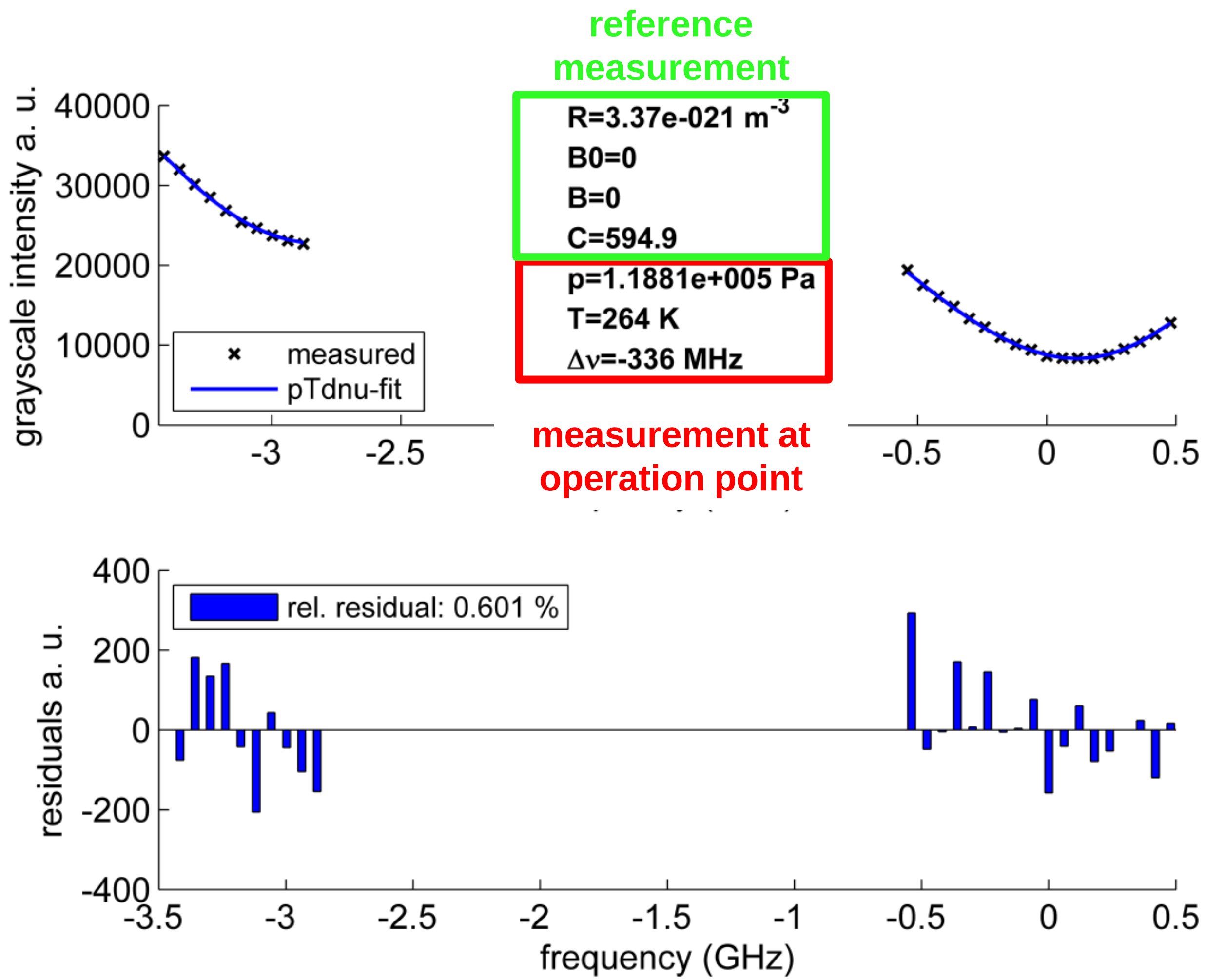
vs.

Measurement time (mean values)

dependency of the FSM-FRS signal intensity (convolution of Rayleigh and iodine spectra) :

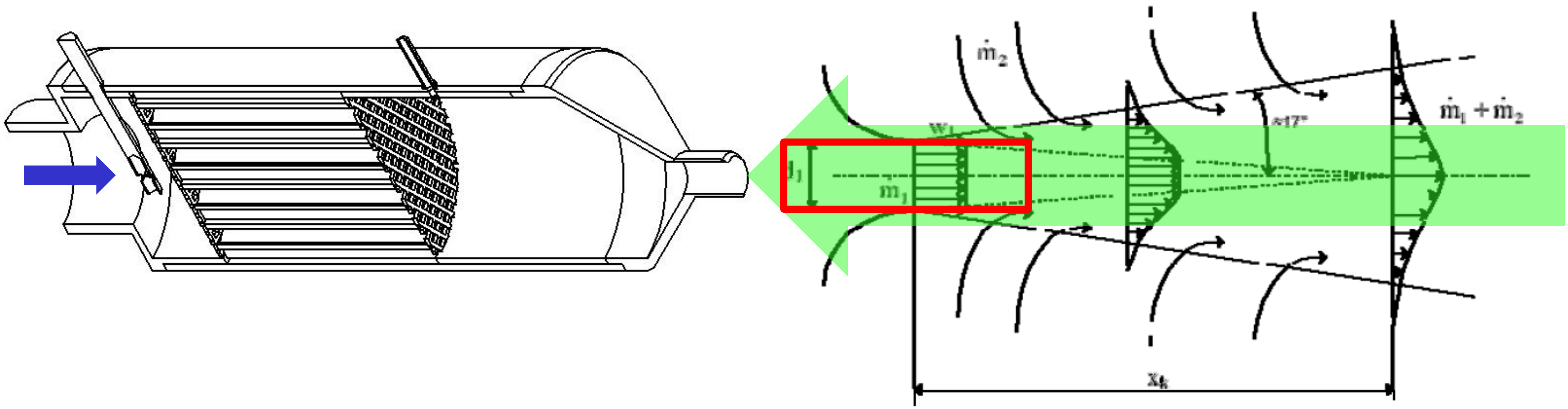
- **frequency shift (velocity component via Doppler effect)**
- **profile shape (width correlates with temperature, shape transforms with pressure)**
- **amplitude (number of scatter particles, density)**

2. Frequency scanning method of FRS

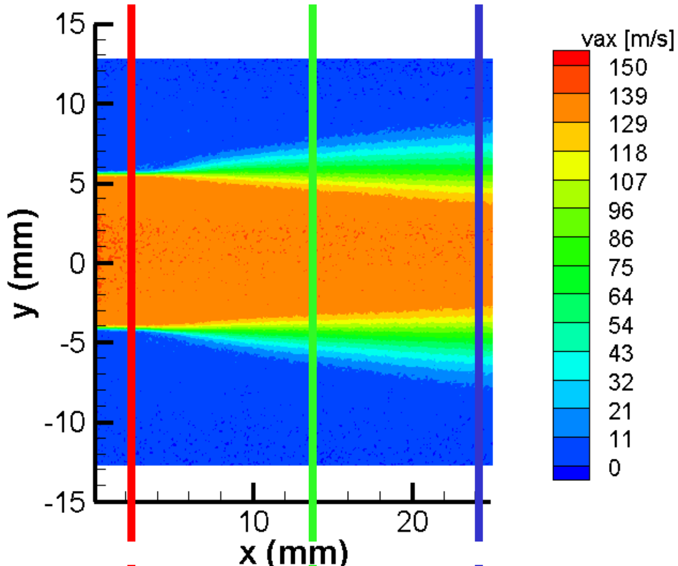


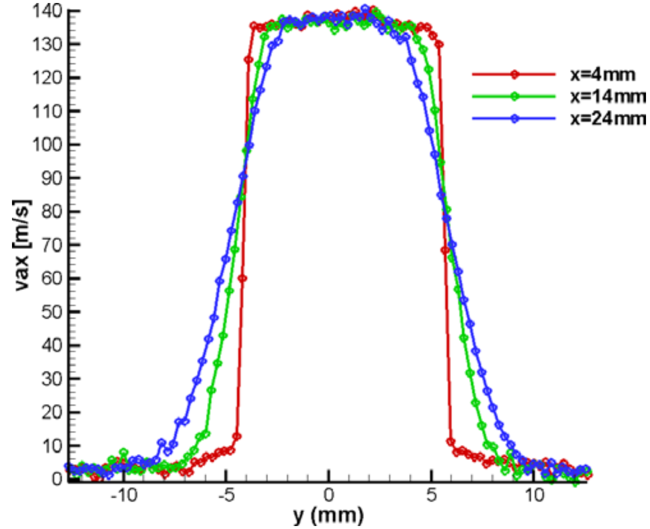
measurement of FRS spectrum for every camera pixel (ca. 128x128 up to 512x512)

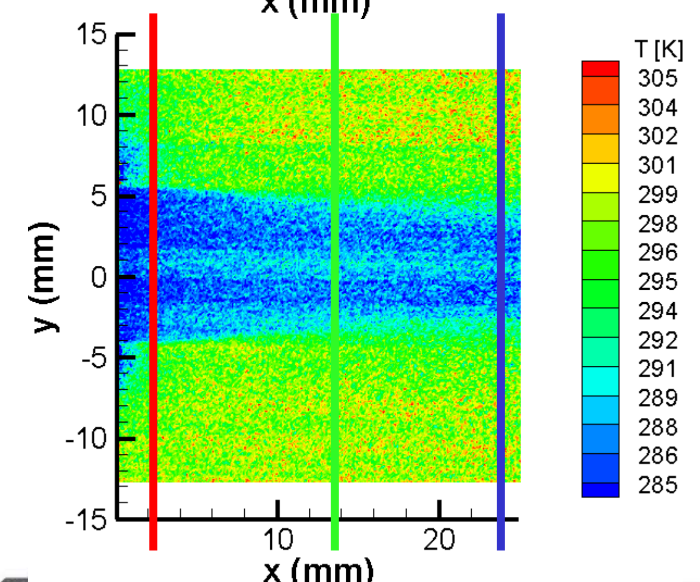
3. Applications of FSM-FRS: A) Free jet experiment

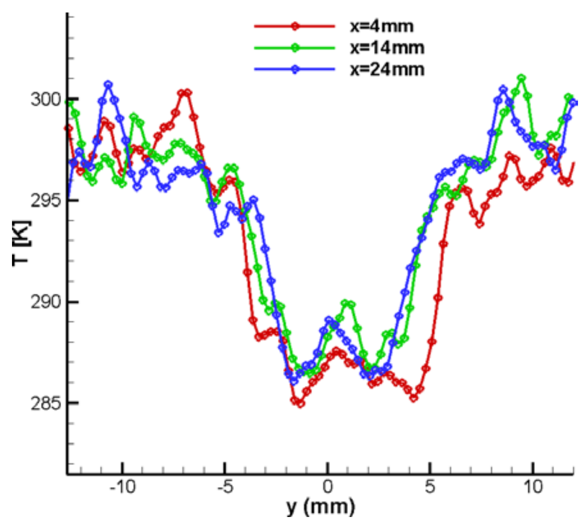


A) Free jet experiment

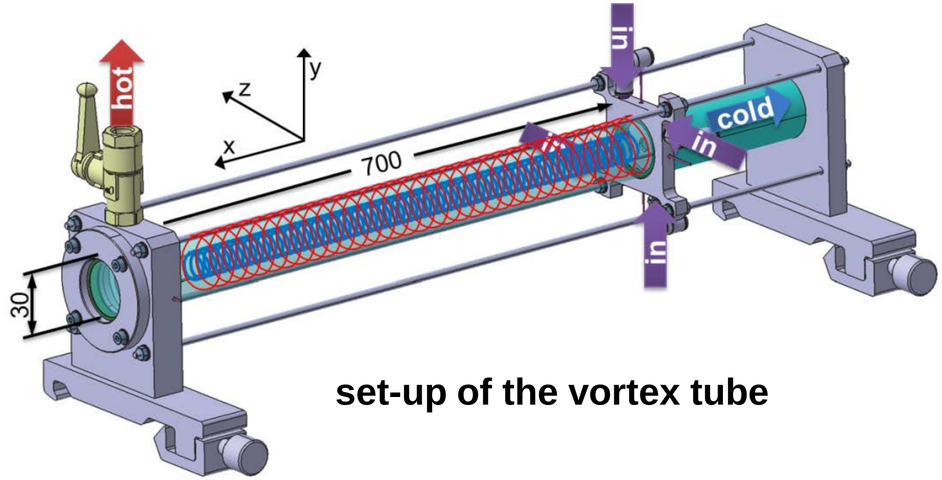




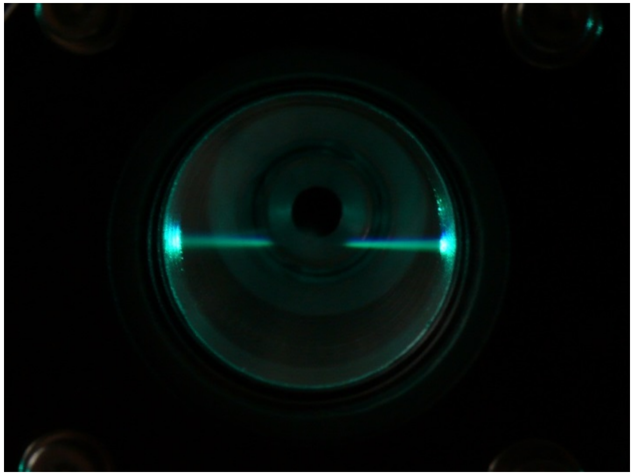




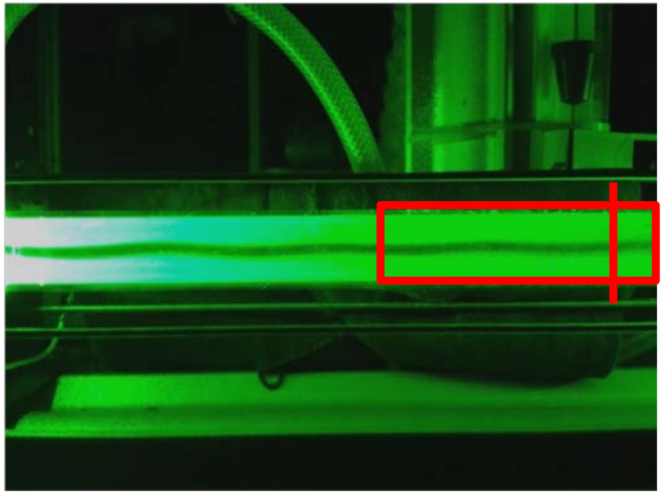
B) Ranque-Hilsch vortex tube



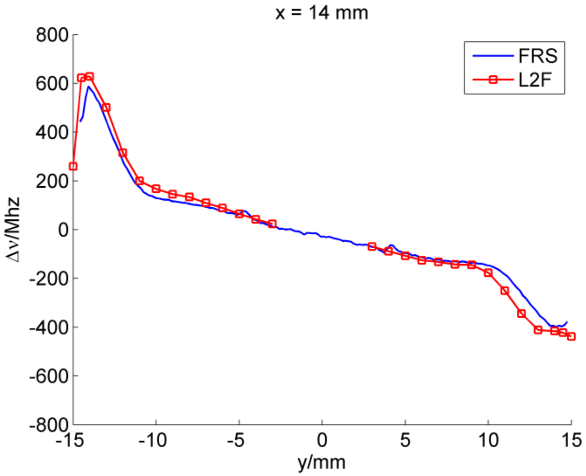
set-up of the vortex tube



seeded flow and radial laser beam viewed from hot

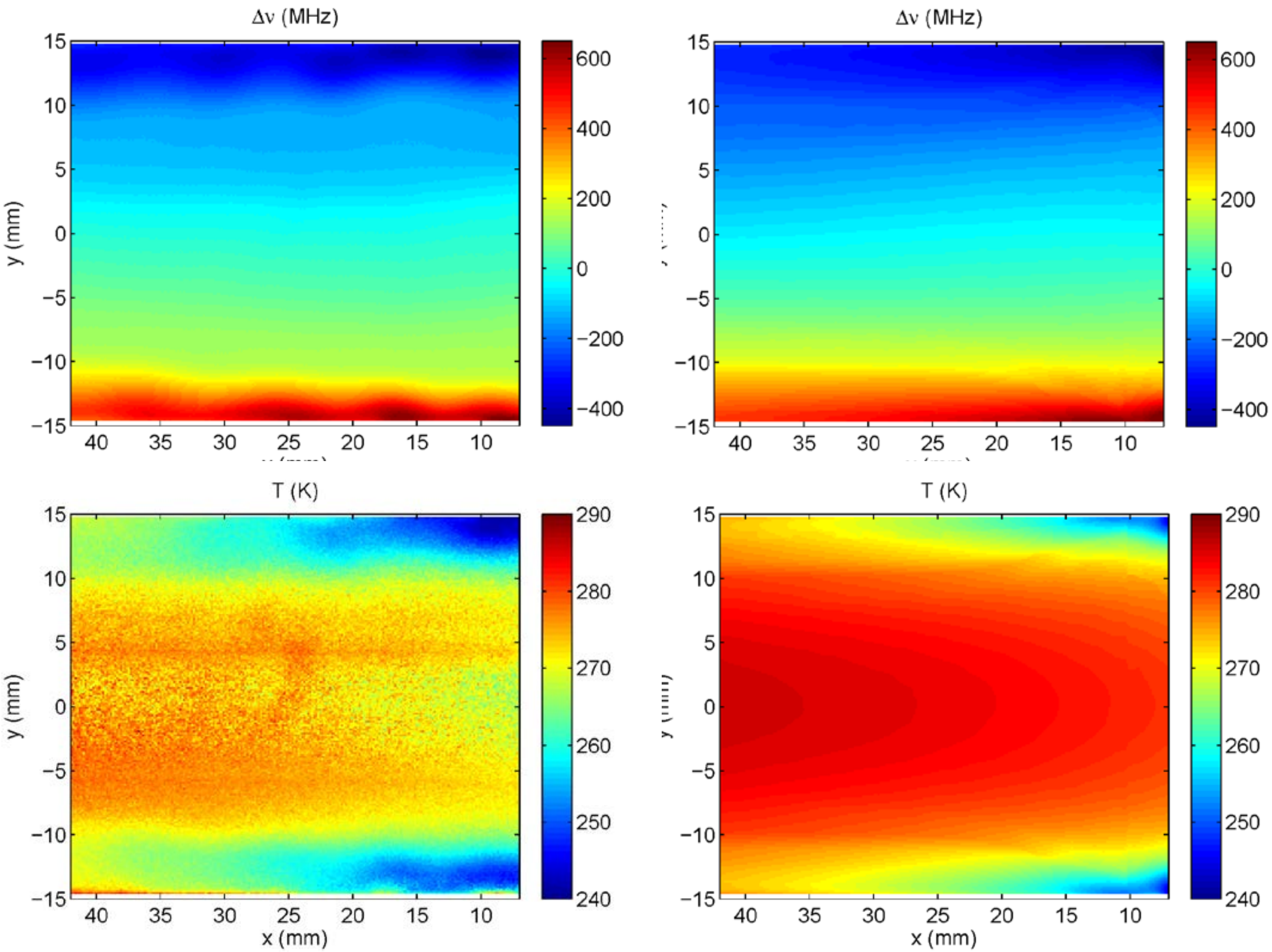


seeded flow and axial laser sheet viewed side-on



comparison of FRS and L2F results

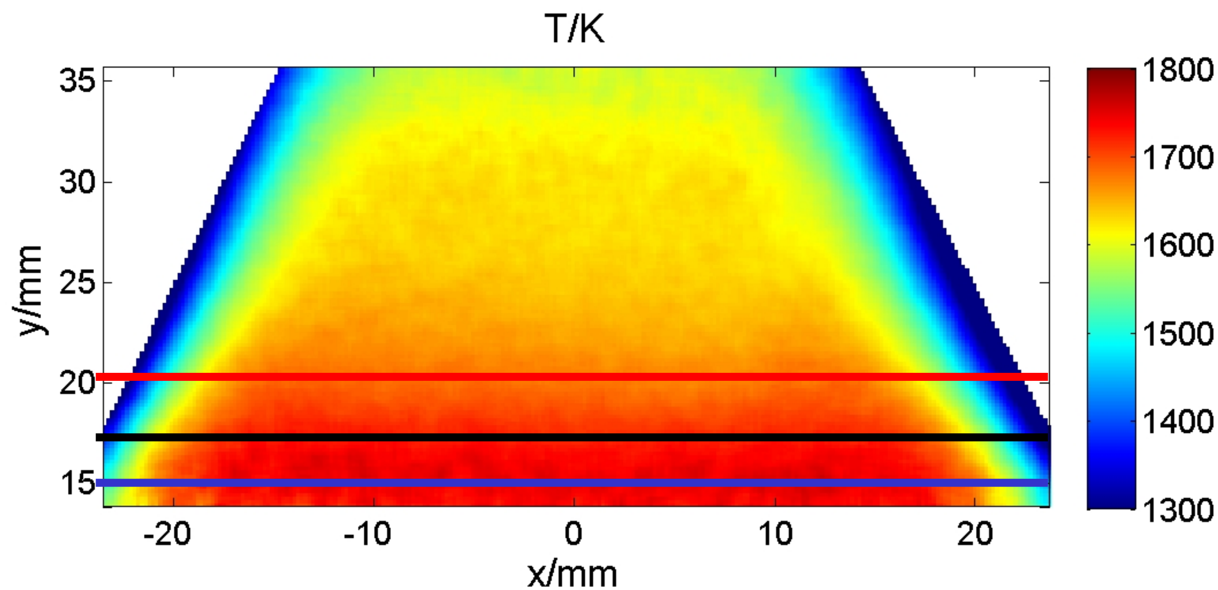
B) Ranque-Hilsch vortex tube

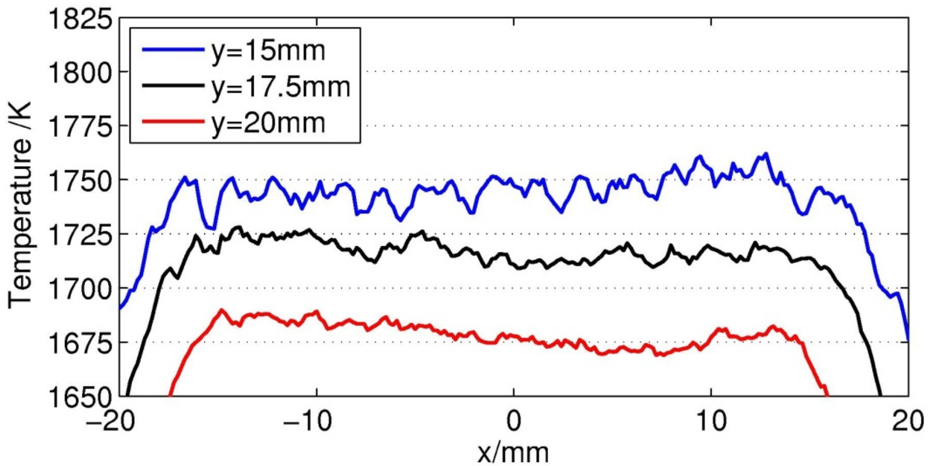


FRS results **CFD results**

C) Atmospheric combustion

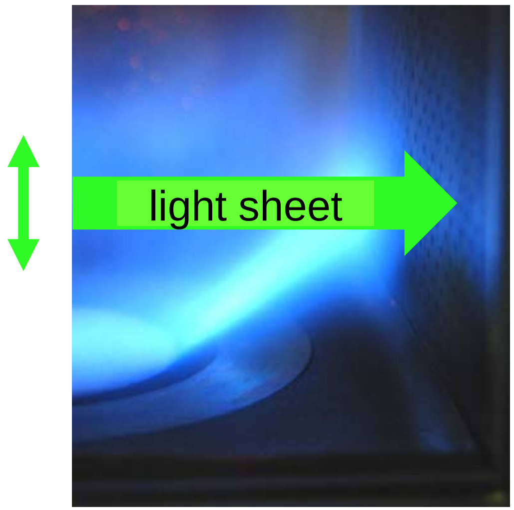
laboratory methane-air flame



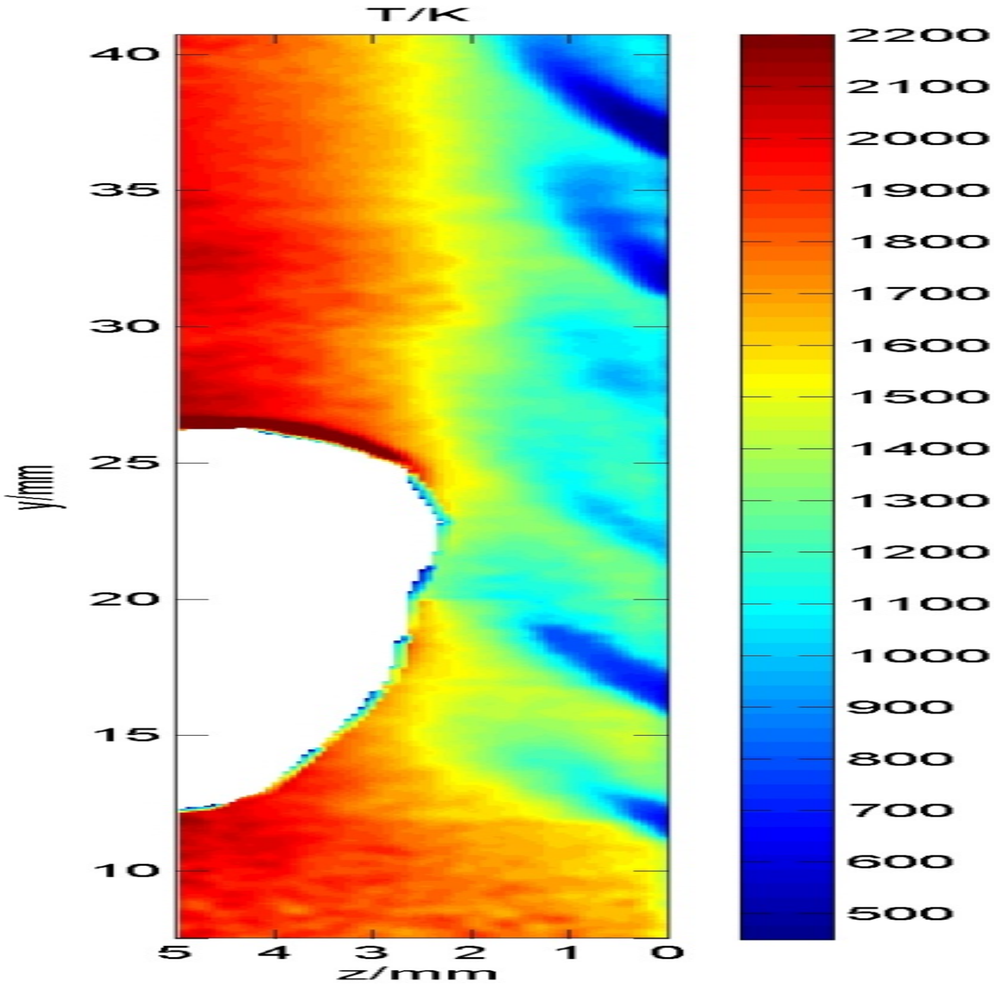


$T_{FRS}=1733\ K \leftrightarrow T_{CARS}=1765\ K$

D) Quantification of cooling films

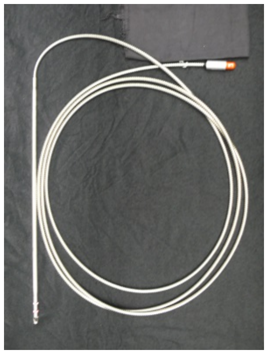


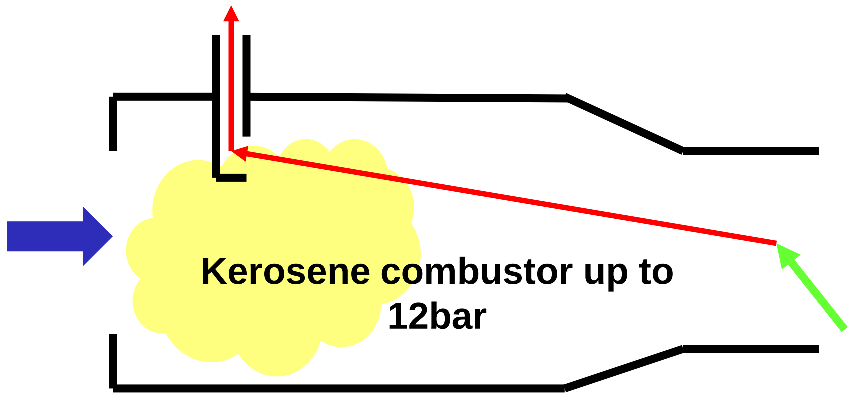
effusion cooled wall inside a single sector combustor (5 bar, preheated air @ 450K)



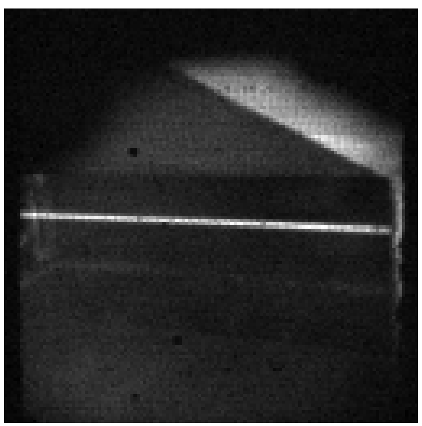
E) Determination of turbine entrance profiles

Image transfer with 4.5m flexible endoscope





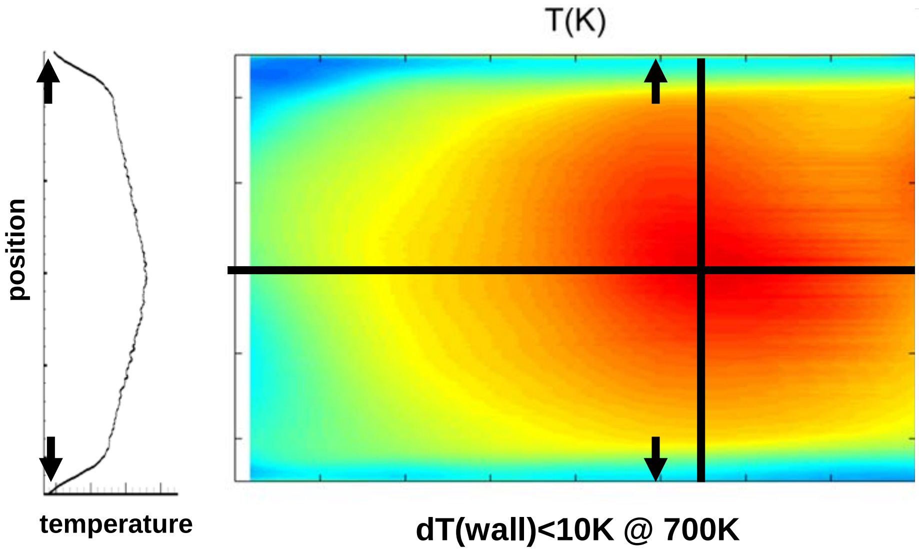
Laser light transfer with 11m photonic crystal fiber

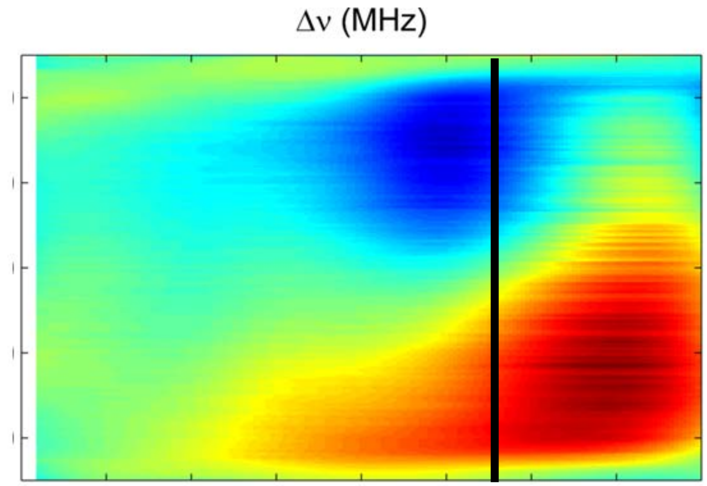


Traversing the laser beam allows reconstruction of complete measurement plane (interpolated)

FRS signal observed from endoscope

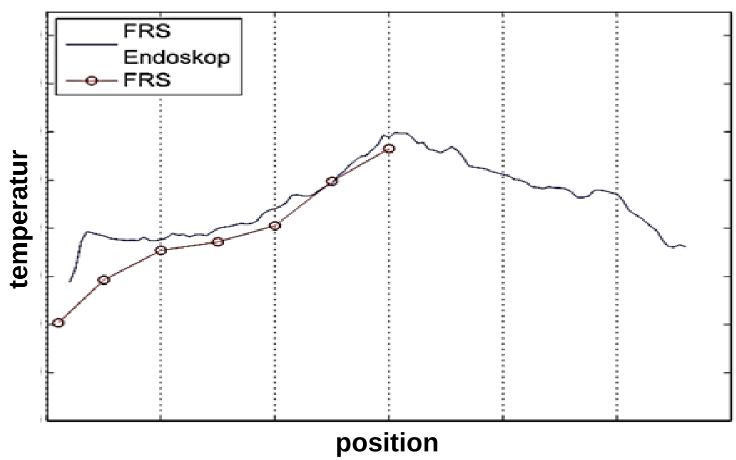
E) Determination of turbine entrance profiles

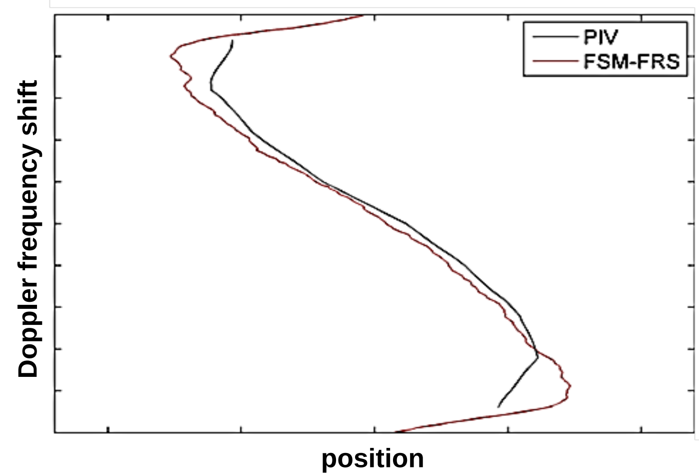




dT(wall)<10K @ 700K

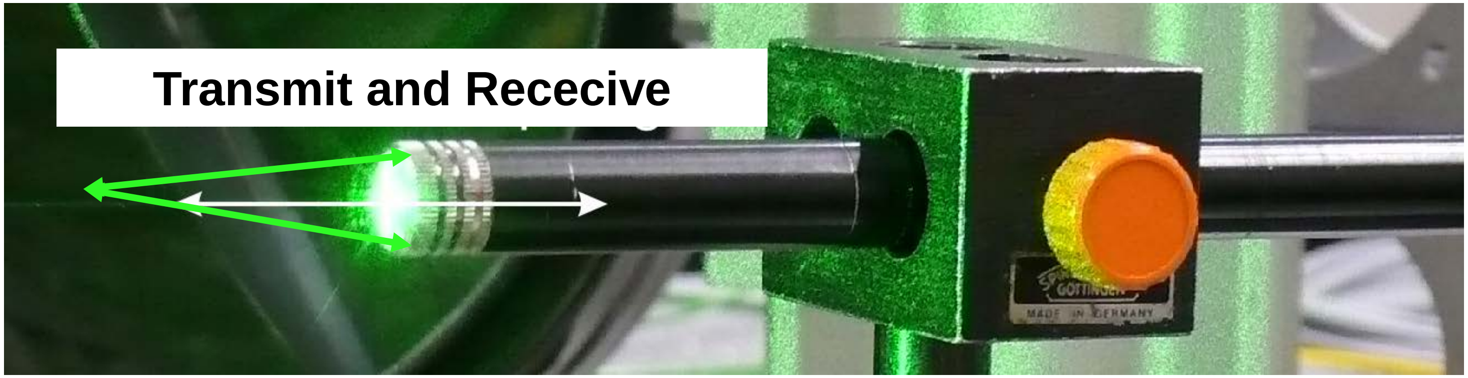
df <5MHz without influence of walls

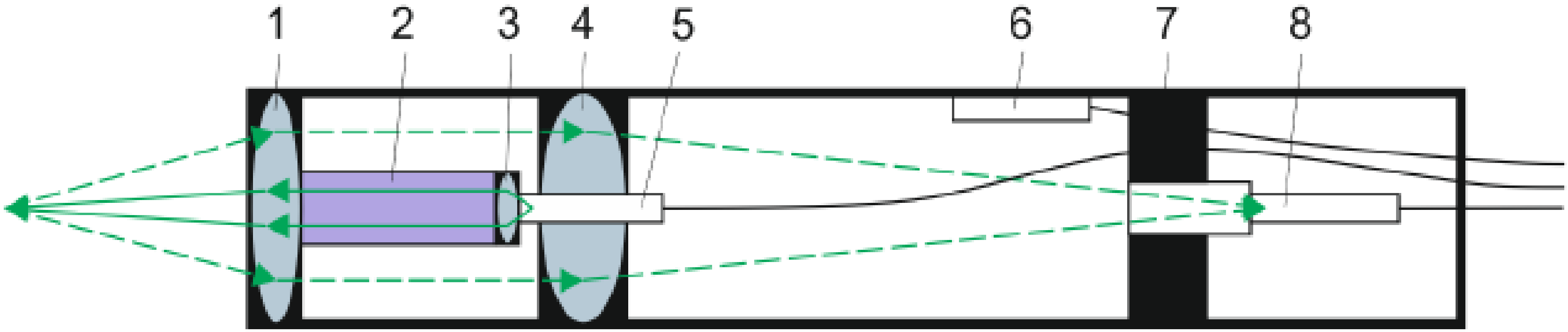




Successful test of endoscopic hardware and validation with PIV and wall temperature probes!

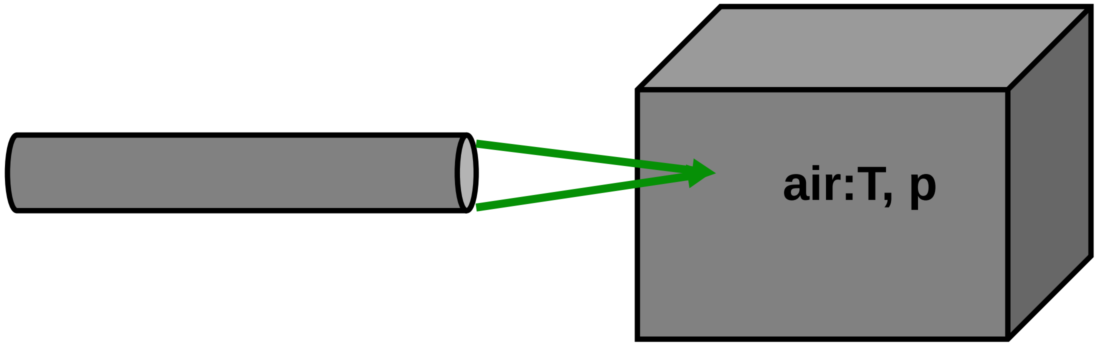
F) Development of a FRS point sensor

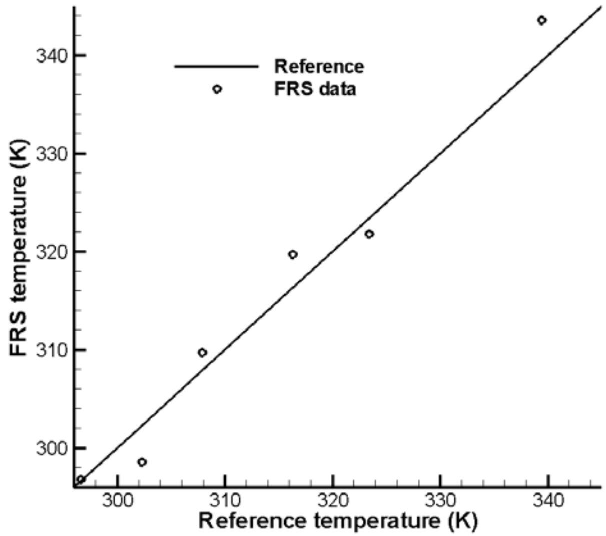


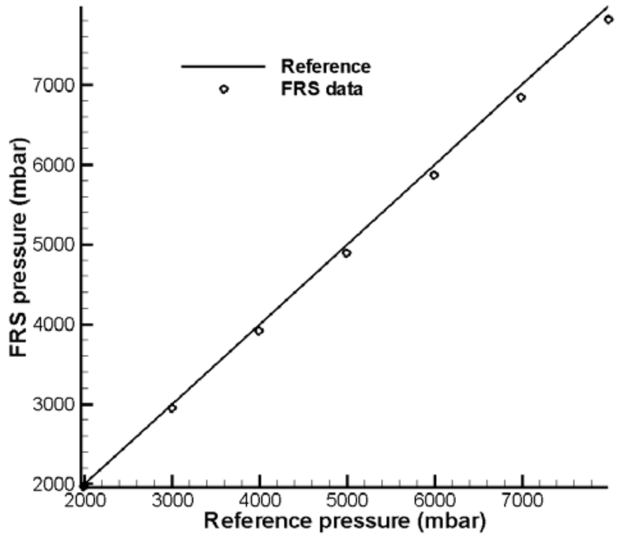


sensor dimensions: outer diameter=12mm, length=200mm
moving the sensor head allows to obtain multiple point measurements along the line of sight.

F) Development of a FRS point sensor







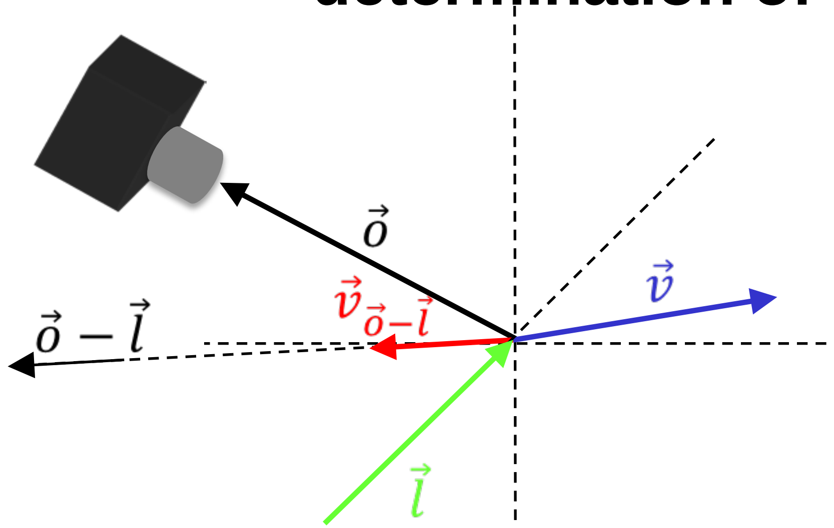
Performance: temperature +/- 1%, pressure 1-2% systematic deviation because of increasing defocussing with increasing pressure

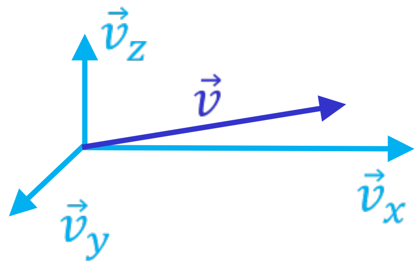
4. Summary and conclusions for FSM-FRS

- further developed optical measurement technique for the determination of temperature, pressure and Doppler frequency shifts (stationary but planar)
- principle: spectral **f**iltering of **R**ayleigh-**s**cattered light through a molecular absorption filter (iodine vapour)
- the **f**requency **s**canning **m**ethod yields the convolution of the Rayleigh spectrum with an iodine absorption line
- suitable for measurements near walls or objects because laser reflexes are completely surpressed
- technique is compatible with endoscopic hardware for access in capsulated environments (usage of flexible fiber bundles for laser light & image transport)
- vortex core measurements are possible since no seeding particles are required (light scattered of flow molecules)
- difficulties: gas composition has to be known, pressure measurements are challenging

Thank you for your attention!

2. Filtered Rayleigh Scattering (FRS) determination of velocity





$$\Delta\nu = \nu - \nu_0 = \frac{\nu_0}{c}\left(\vec{o}-\vec{l}\right)\cdot\vec{v}$$

Bsp.: $\vec{v}_z = 0,\ \vec{v}_y = 0$

$$\Delta\nu = -105\ MHz \rightarrow \vec{v}_x \cong 65\ m/s$$

variations of observing direction o and/or laser direction l enables measurement of all 3 velocity components