Karlsruhe Institute of Technology

Systematic effects in Laser Raman measurements for KATRIN

Forschungszentrum Karlsruhe
in der Helmholtz-Gemeinschaft

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Teilprojekt A1

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- **Systematic effect**
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  - **Background features**
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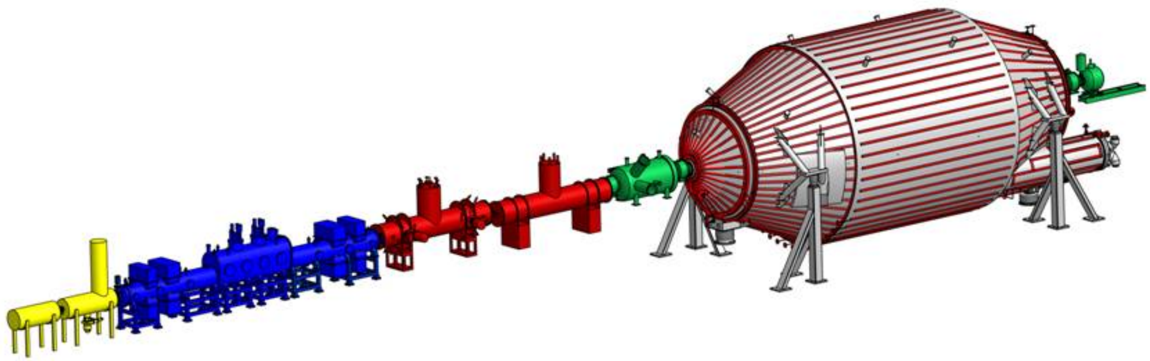
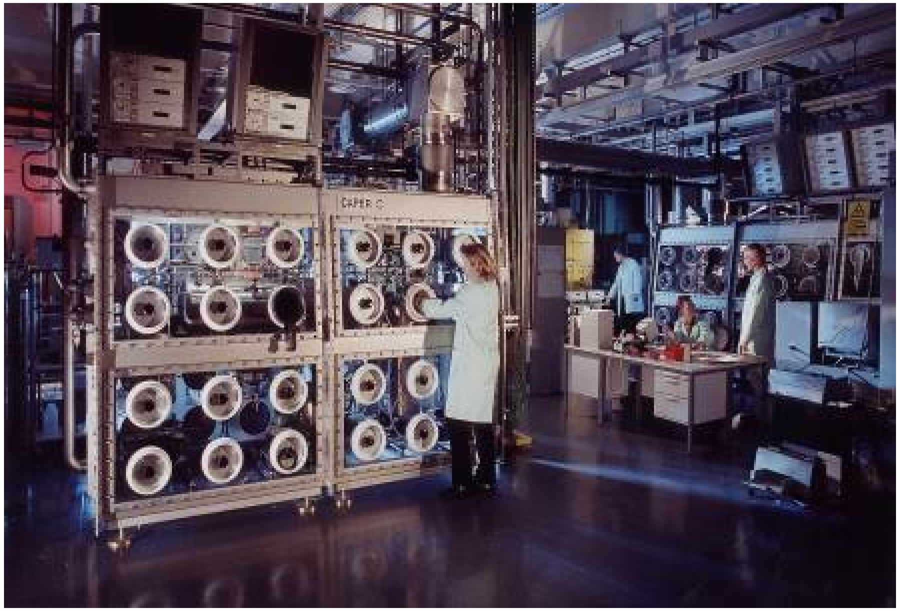
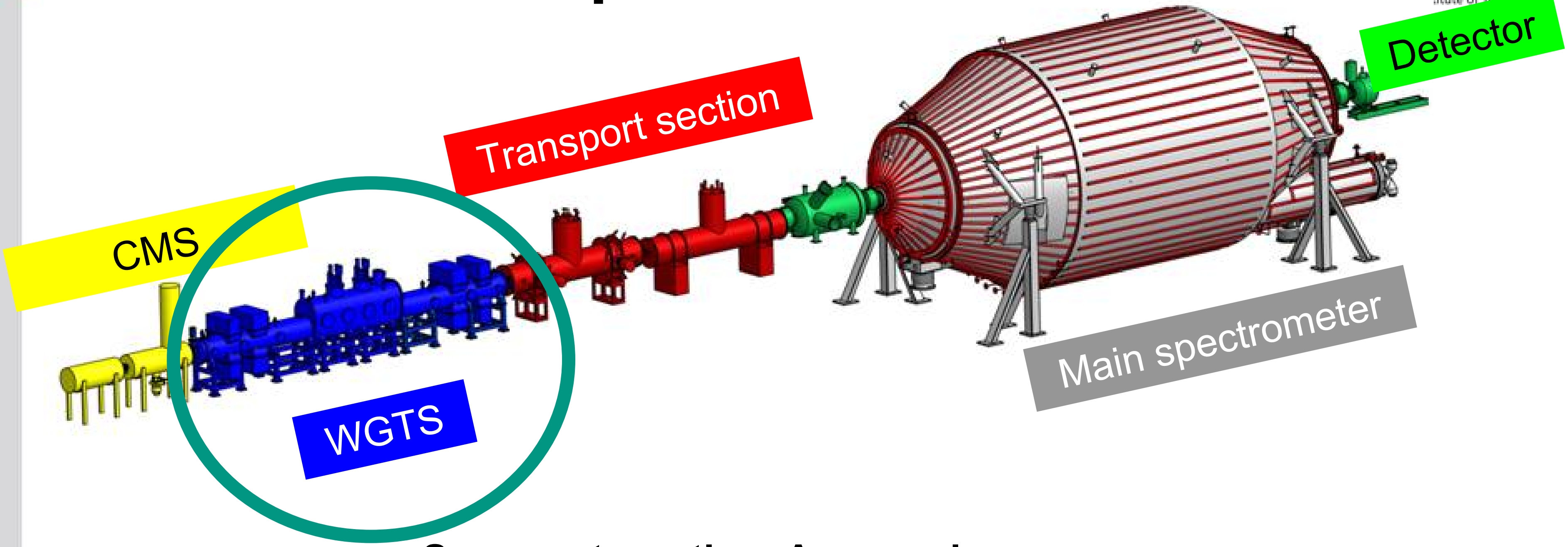




Tritium Laboratory Karlsruhe

The KATRIN-Experiment



Source strength = $A_Q \cdot \rho d \cdot \varepsilon_T$

- **column density** — $\rho d = 5 \cdot 10^{17} cm^{-2}$
- **tritium injection rate** — $q_{in} = 1.8$ mbar l s^{-1}
- **beam tube temperature** — $T = 30$ K
- **tritium purity** — $\varepsilon_T \geq 95\%$

stability in the range of 10^{-3}

monitoring → **Laser-Raman Spectroscopy**

Magnus Schlösser | SFB - Transregio 27 Heidelberg | 10.July 2009
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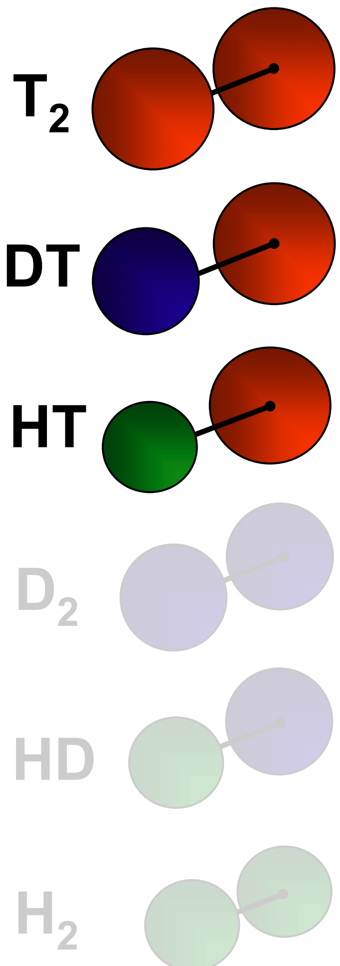
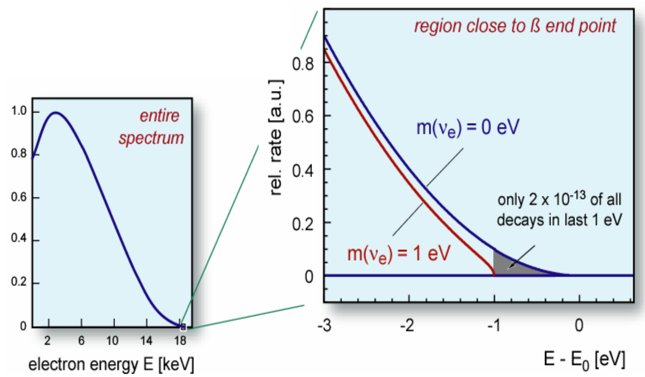
Isotopic purity (ε_T)

Isotopologues of hydrogen



Direct contribution to count rate at endpoint



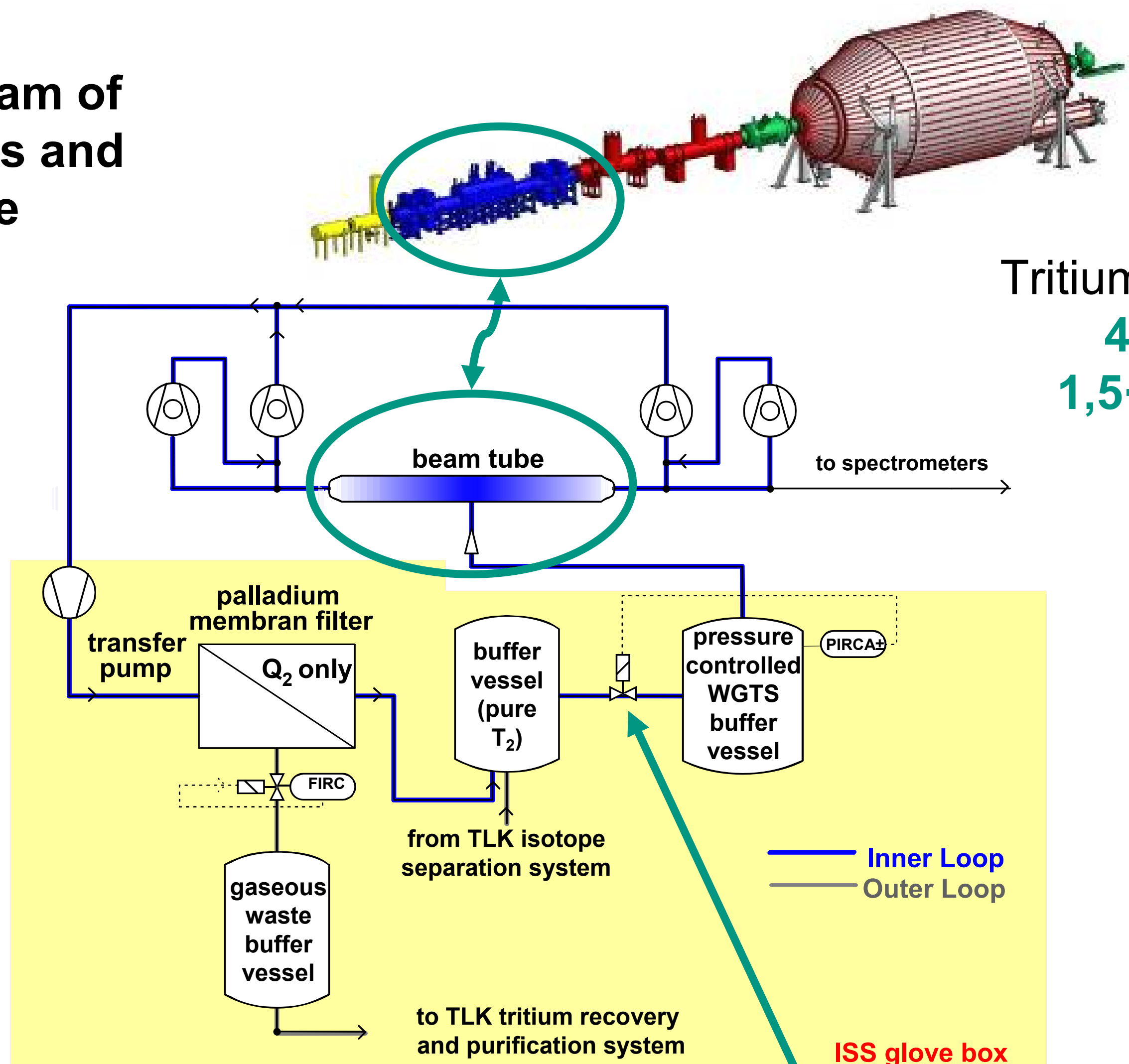
Different final states

Requirements for LARA

- Measurement of tritium purity before injection into WGTS with a precision of **0,1 %**
- Determination of isotopologue composition
- Acquisition time as short as possible (minutes)
- Entire T2 pumped through LARA-cell (no Bypass)

LARA for KATRIN

Flow diagram of Inner Loops and Source



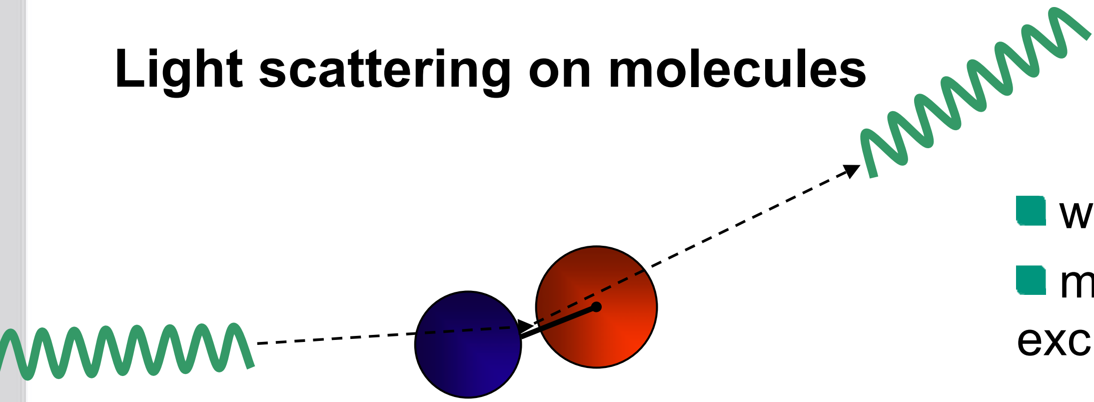
Tritium throughput
40 g/d = $1{,}5 \cdot 10^{16}$ Bq/d

LARA-Measurements @ p ≈ 100 mbar

Q = H, D, T

Fundamentals

Light scattering on molecules

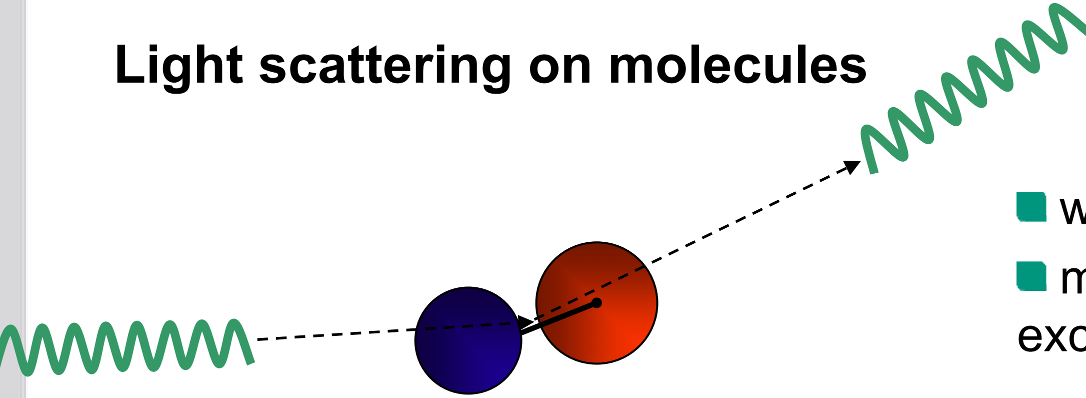


elastic collisions
Rayleigh-scattering

- wavelength of photons invariant
- molecule remains in state of excitement

Fundamentals

Light scattering on molecules



elastic collisions
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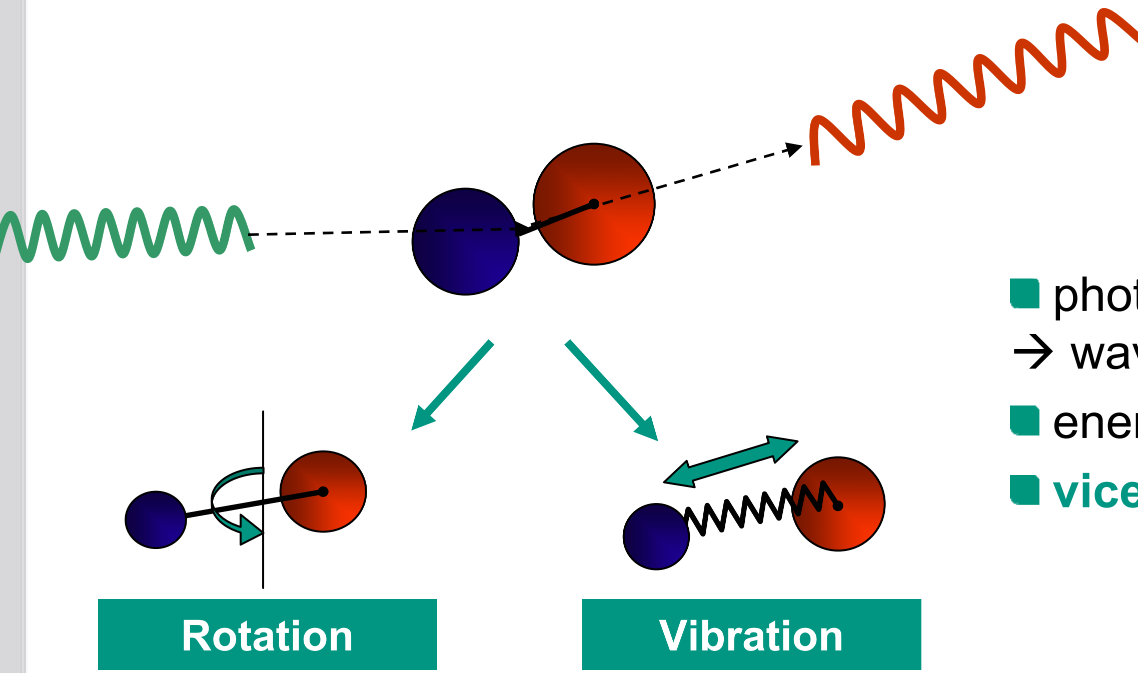
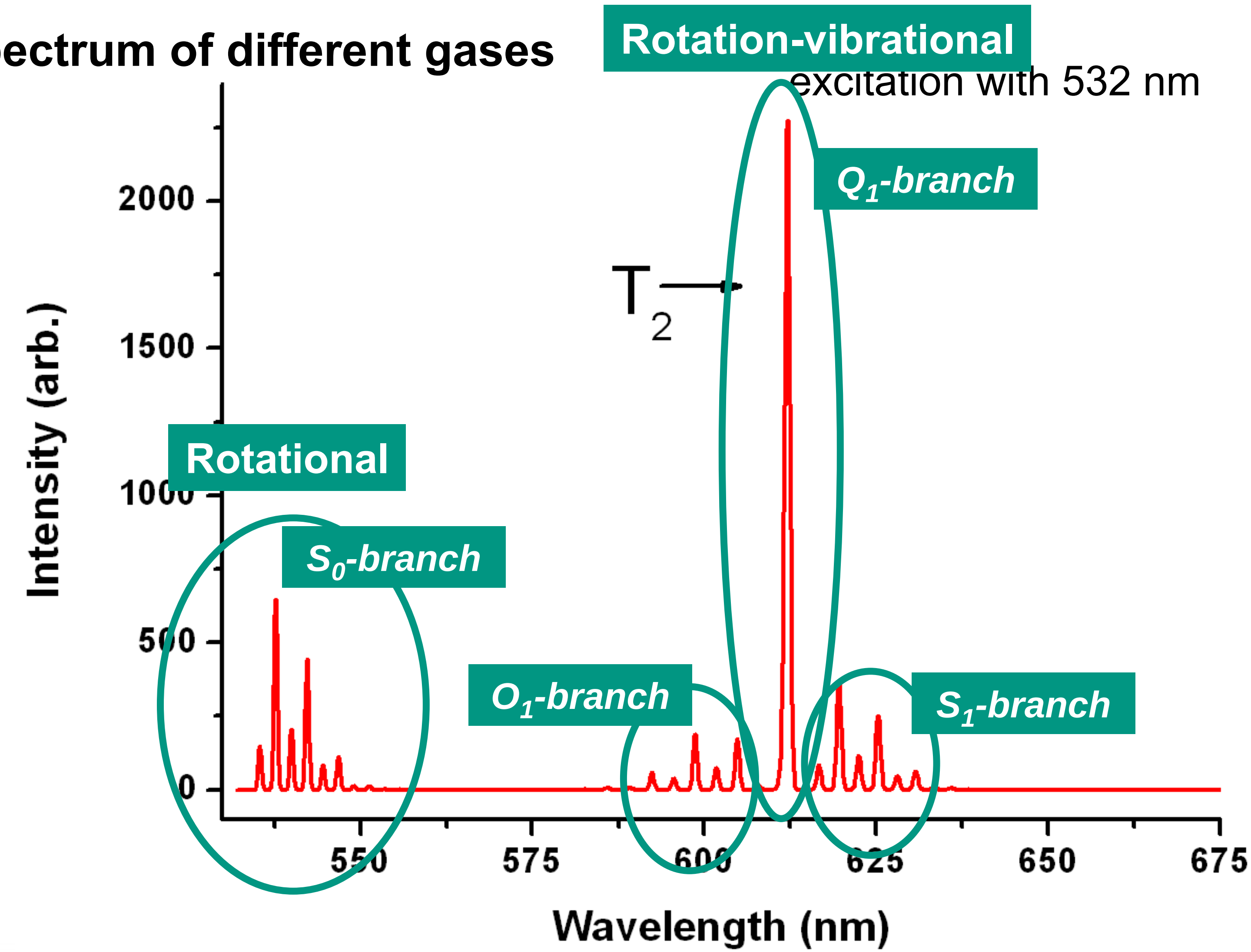


inelastic collisions
Raman-scattering

- photon loses a fraction of its energy
→ wavelength increases
- energy is transferred to molecule
- **vice versa process also possible!**

Fundamentals

Spectrum of different gases



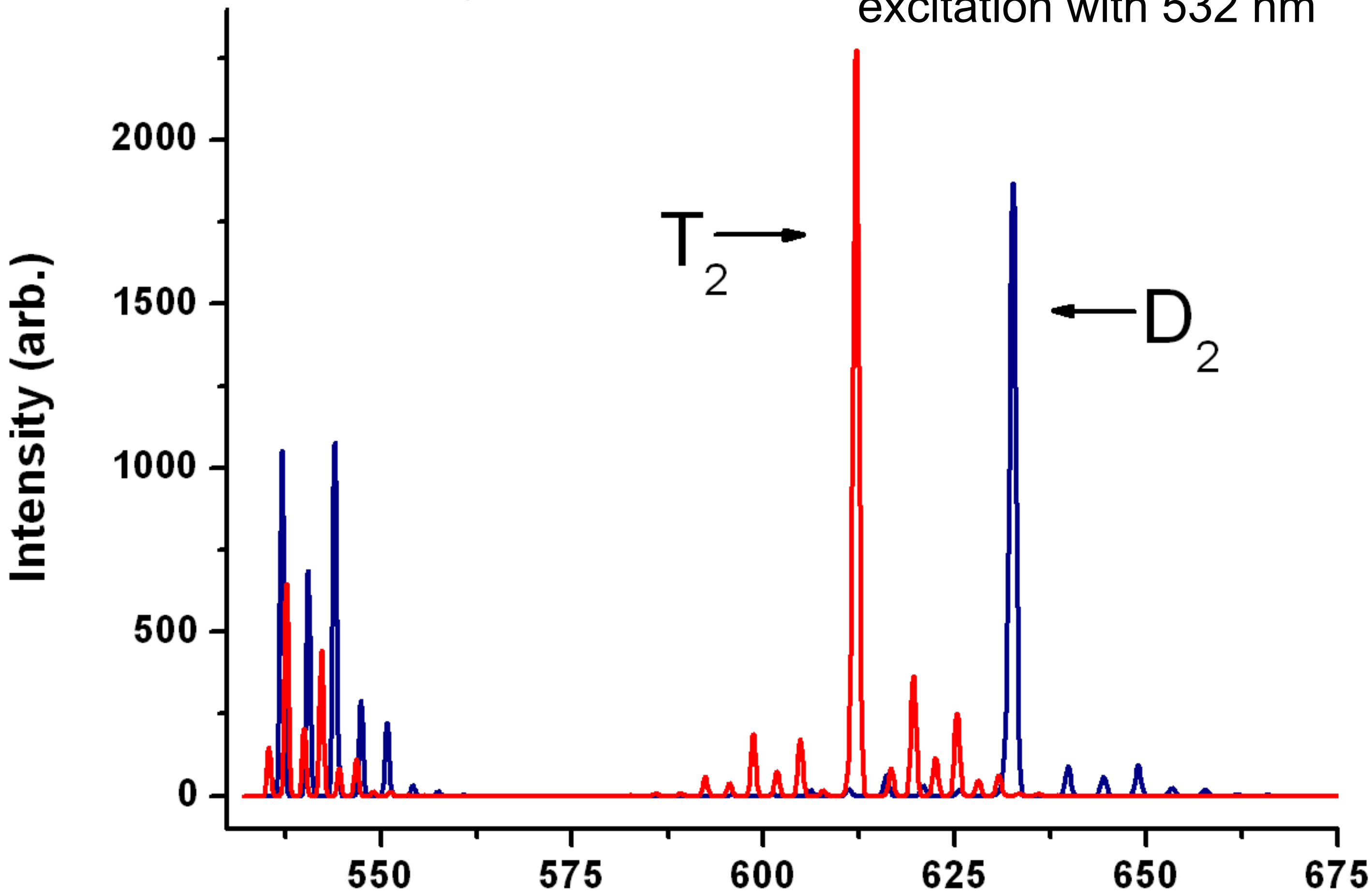
simulated spectrum

(SpecGen)

Fundamentals

Spectrum of different gases

excitation with 532 nm

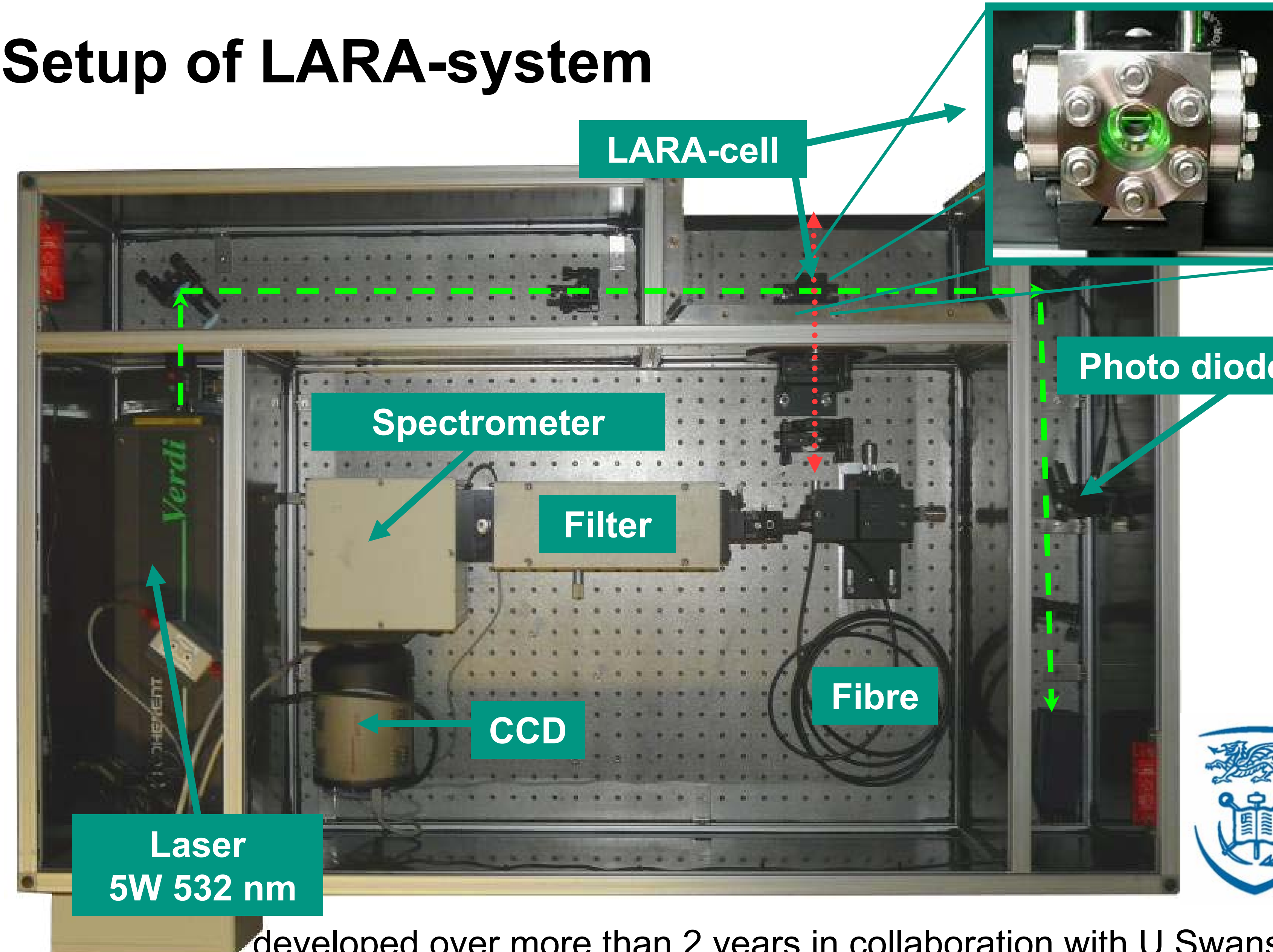


simulated spectrum

(SpecGen)

quantitative analysis of mixture possible

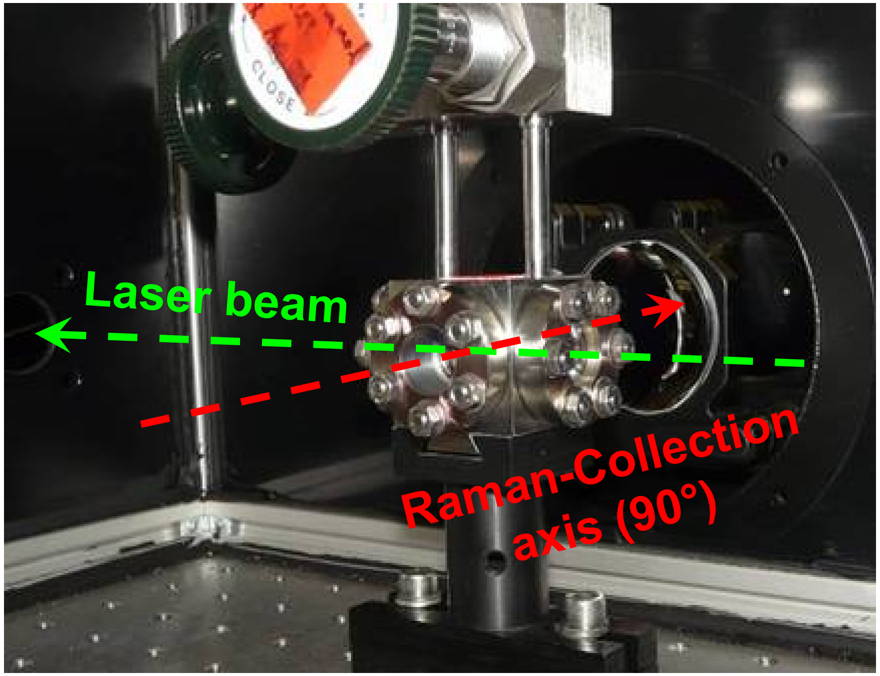
Setup of LARA-system

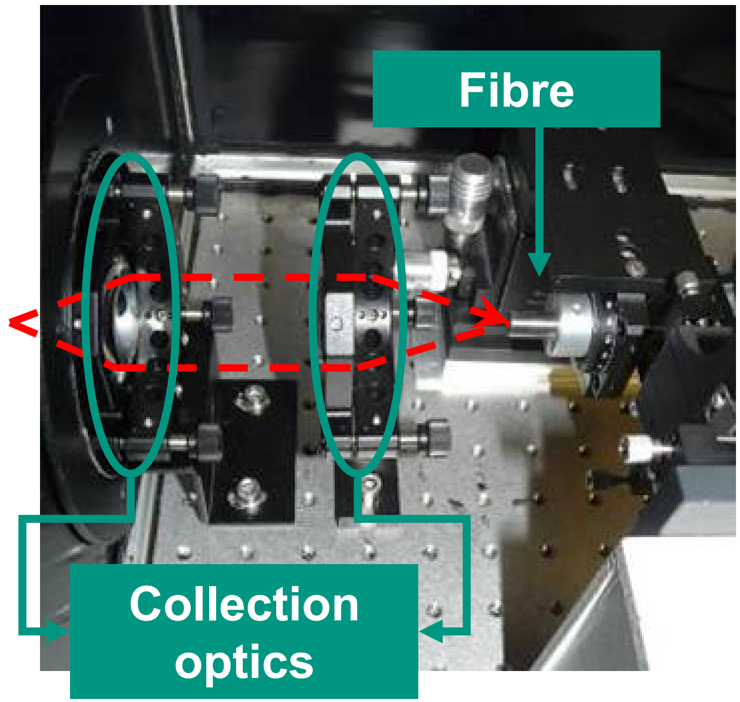


developed over more than 2 years in collaboration with U Swansea

Setup of LARA-system

1:1 image of scattered light on a fibre bundle





Laser-Raman-Cell

- Volume: 7,1 cm^3
- Operation: „static“ or „in flow“

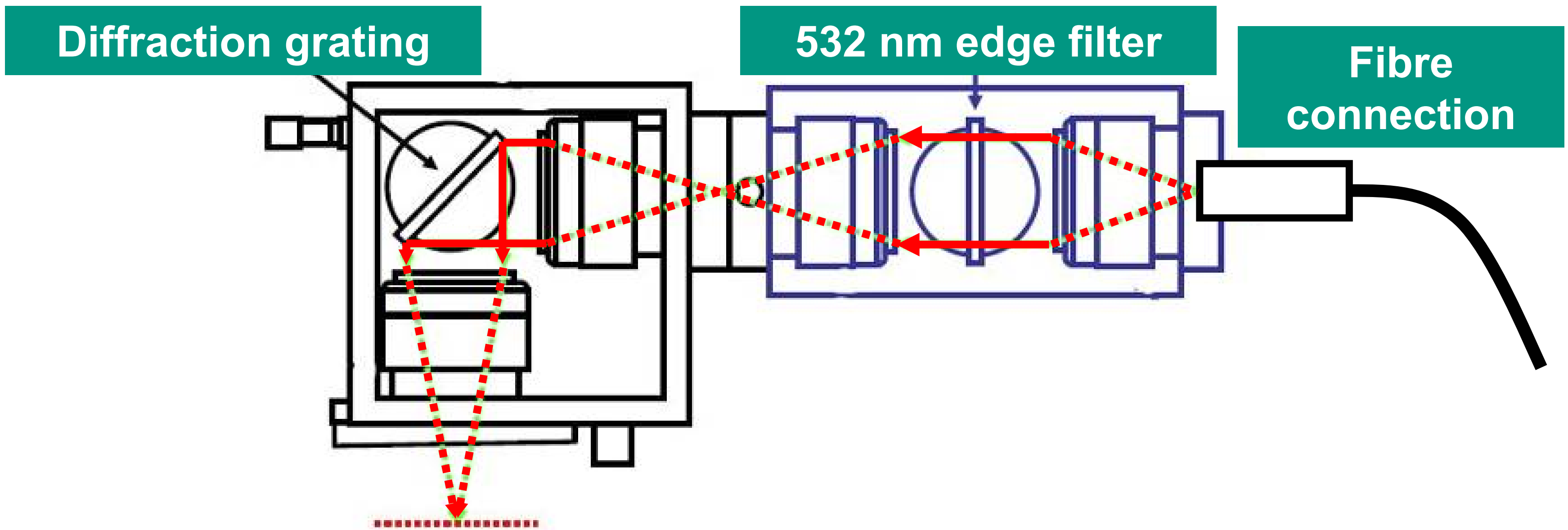
Fibre

- 48 single fibres adjoining
- simple adjustment
- robust construction

Setup of LARA-system

Transmission Spectrometer

- high light throughput → high intensity
- moderate resolution 600mm^{-1} → covers region of interest



CCD

- 2048 x 512 Pixel
- cooled down to -75° C

designed for detection of minimal intensities

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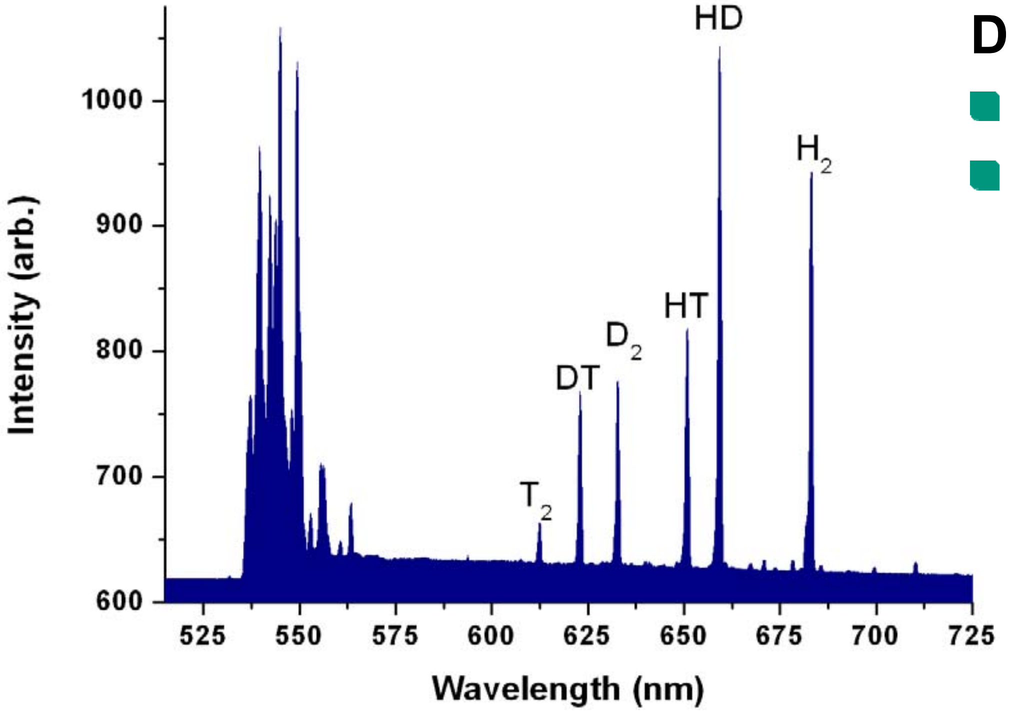
Detection limit



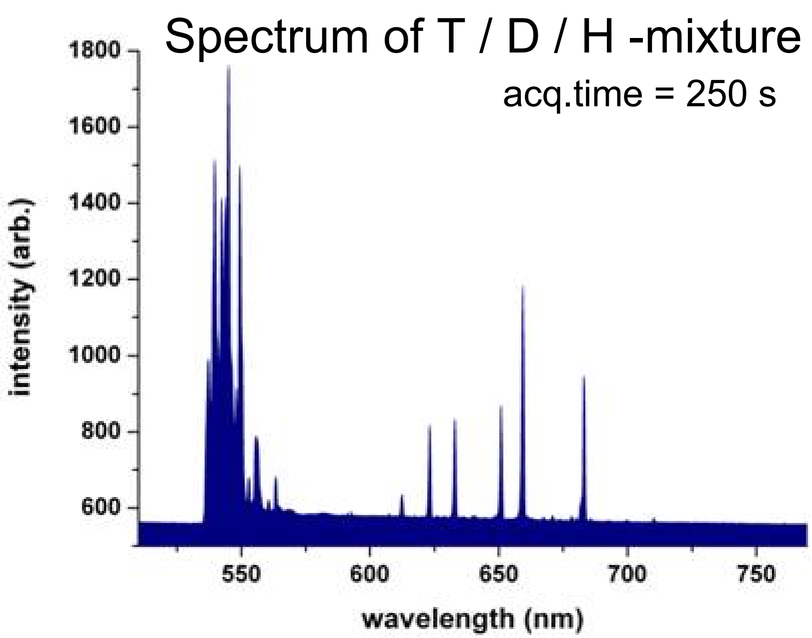
Detection limit

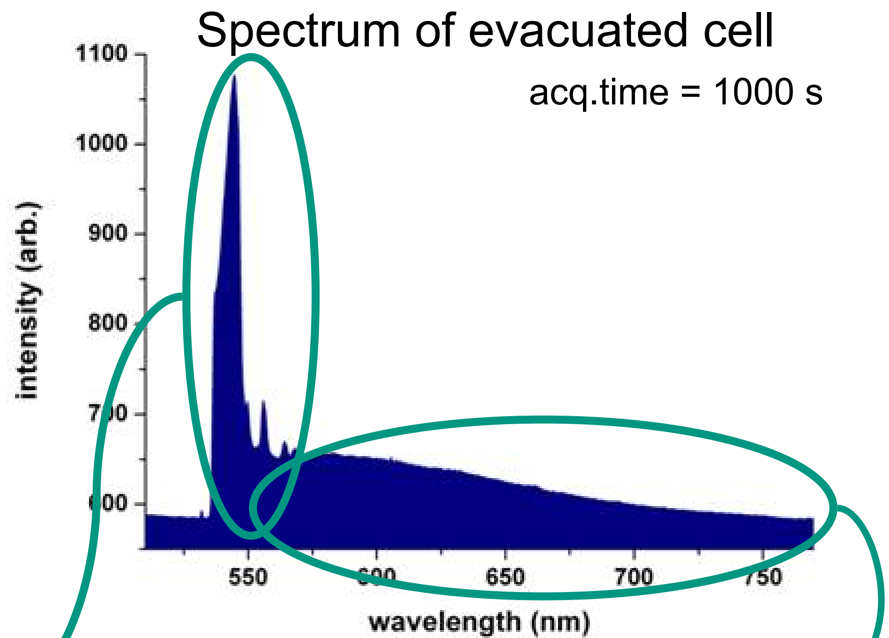
- Peak height ≈ 2 · noise-level
- This sample:
  - Total pressure:
    $p_{tot} \approx 110$ mbar
  - noise-level = 0.32
  - Sum of all 6 peak intensities:
    Σ_{tot}signal = 1274
  - minimal detectable partial pressure:

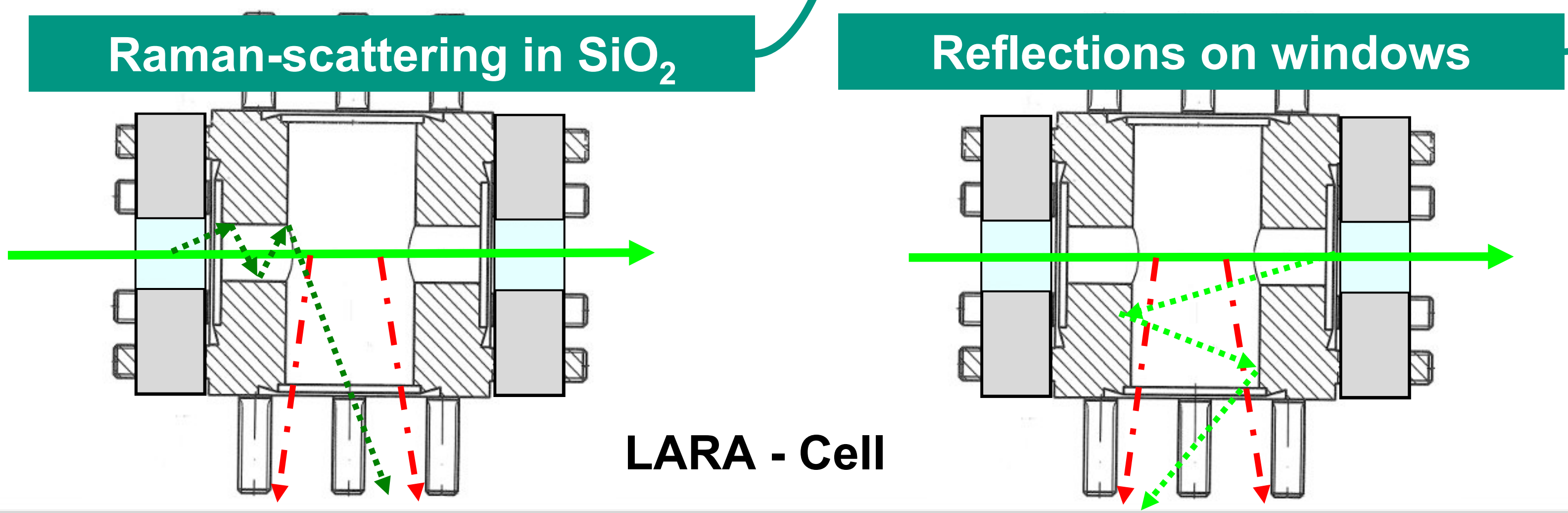
$$p_{min} = \frac{2 \cdot noise\text{-}level}{\sum_{tot} signal} \cdot p_{tot}$$

Detection limit for hydrogen isotopologues < 0,06 mbar partial pressure
(250s, 5W)

Background features







Precision

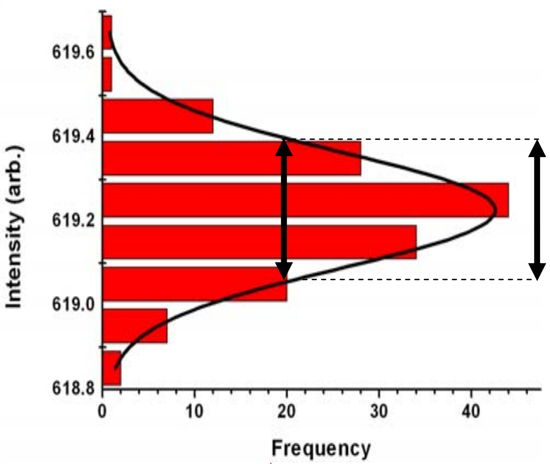
Noise

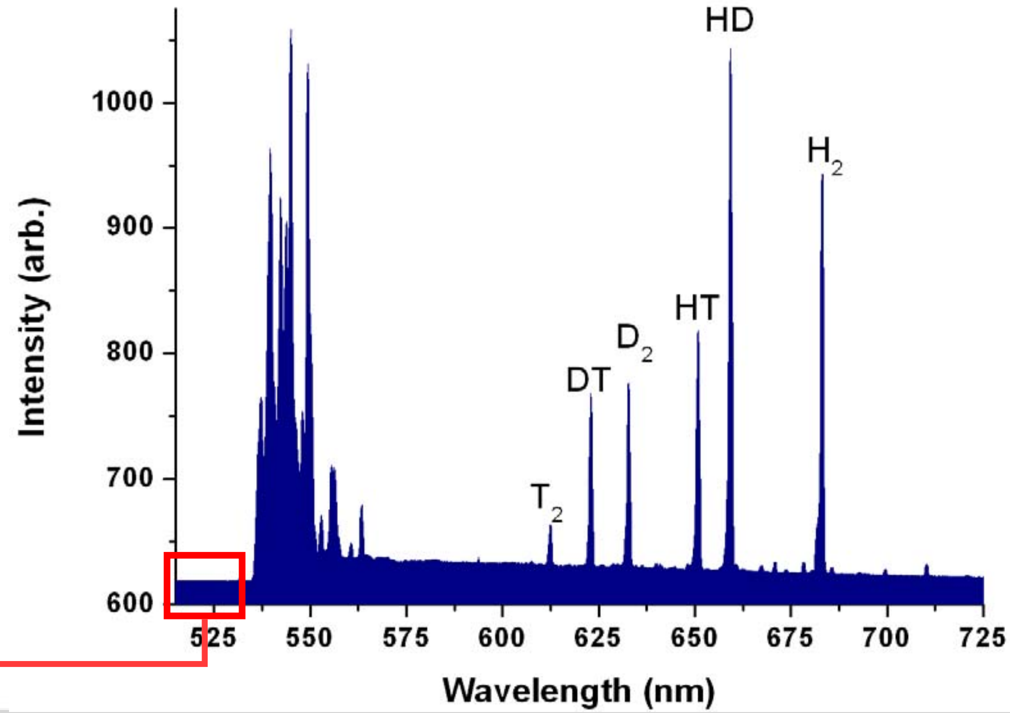
Definition: Noise-amplitude N = 2 σ

Precision

$$\Delta I = \frac{\text{Noise}}{\text{Signal}}$$

Isotop.	Intensity	S/N	Precision = N/S
T_2	33	108	0.92 %
DT	139	462	0.22 %
HT	190	636	0.15 %
D_2	148	494	0.20 %
HD	417	1392	0.07 %
H_2	318	1060	0.09 %

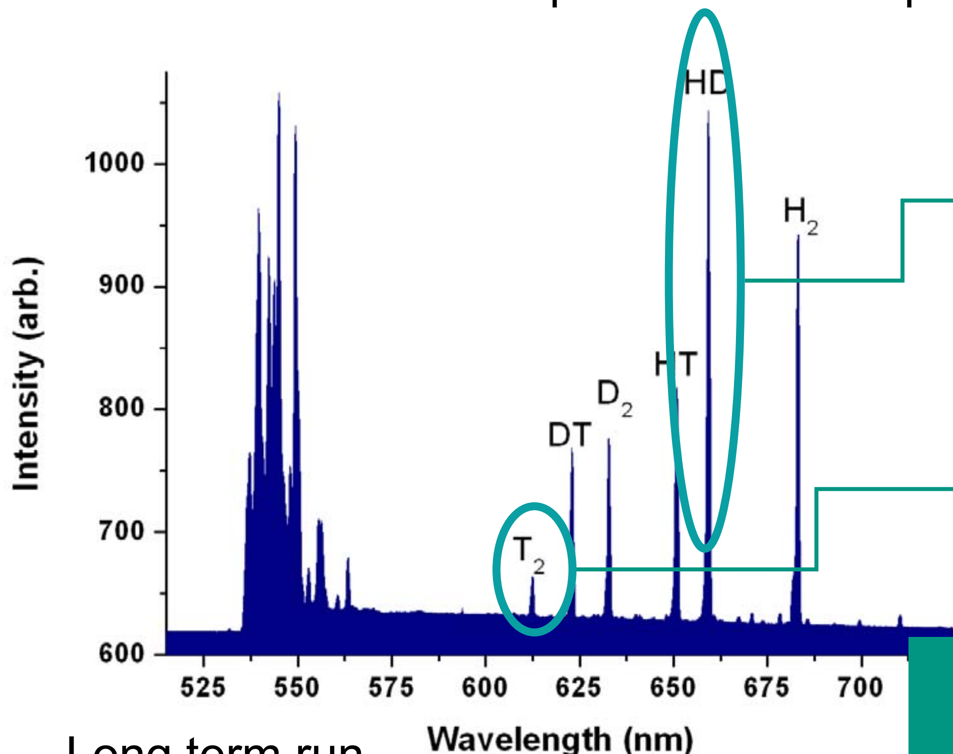




Stability of long term runs

Test of stability

- Repeated measurements of static mixture
- All fluctuations are related to acquisition and analysis
- Calculate σ for each peak from all acquisitions



HD	Intensity	precision
Abs.	431	0.82%
Rel.	33.84 %	0.31%

T_2	Intensity	precision
Abs.	29	2.21%
Rel.	2.28 %	1.98%

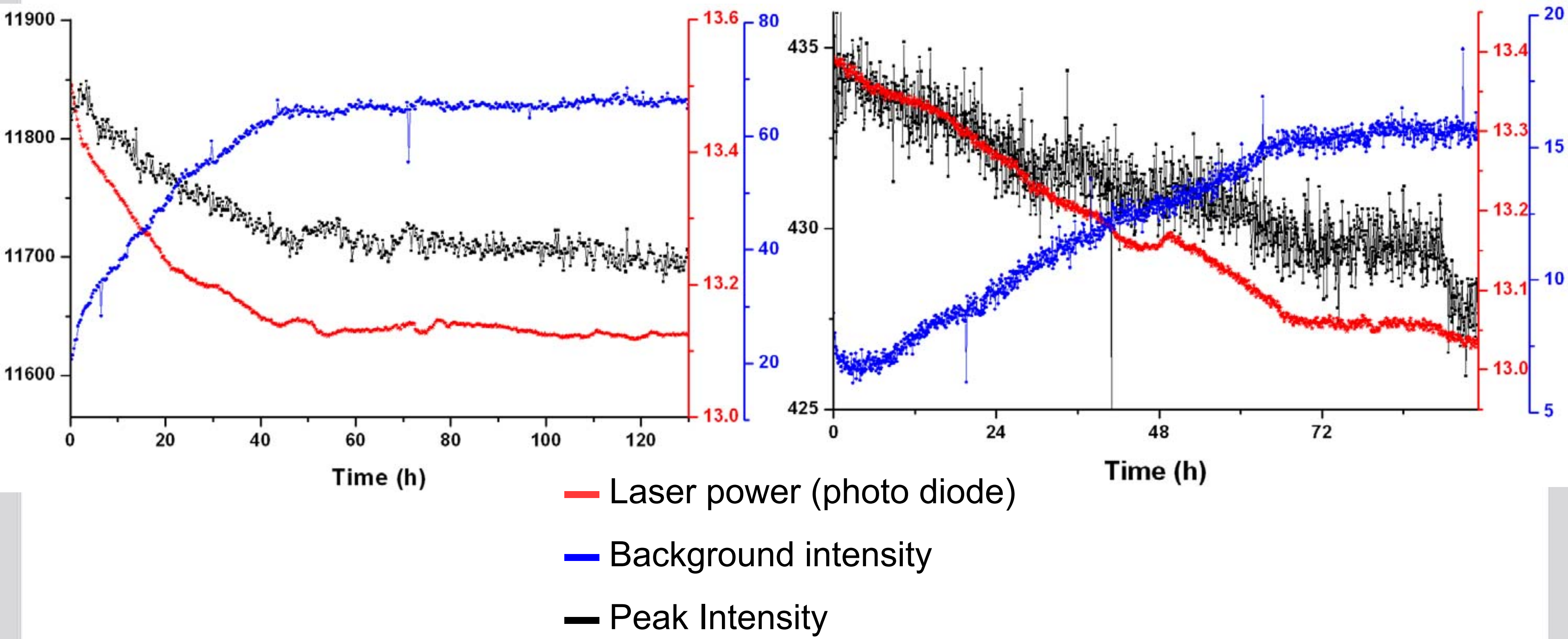
Long term run
(p≈100mbar) 1329 x 250 s = 95 h

Highest fraction in KATRIN will be T_2 (95%) ≈ 3 x HD(this Run)

➔ 0.1% seems to be feasible in 250 s

Stability of long term runs

Long term measurement - Laser power



Diametric trend of laser power / background visible!

Wear out of coating? Thermal misalignment? Pointing stability?

Stability of long term runs

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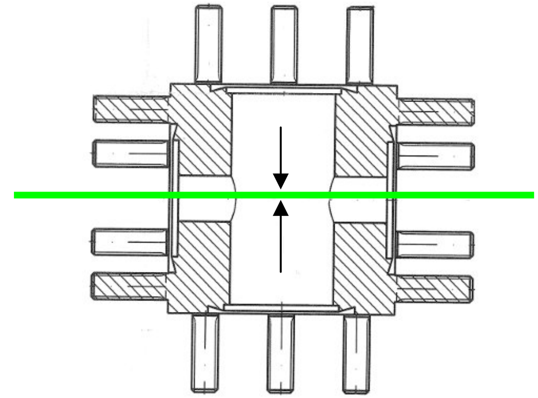
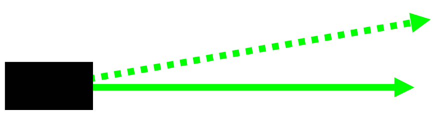
Influence on laser power and background



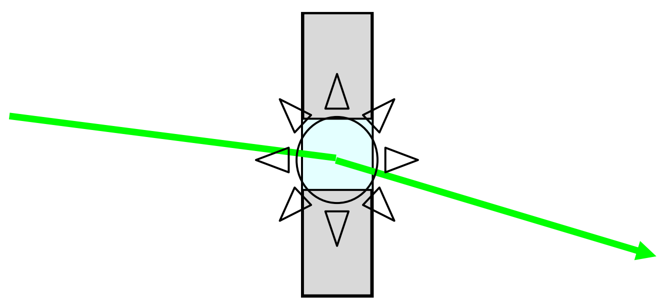
scattering region

beam width≈20µm

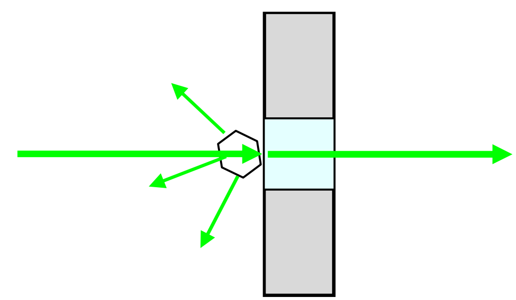
Pointing stability



Thermal lensing



Dust on optics or laser beam



- **Trace laser beam with modified webcam**
- **Laser service**

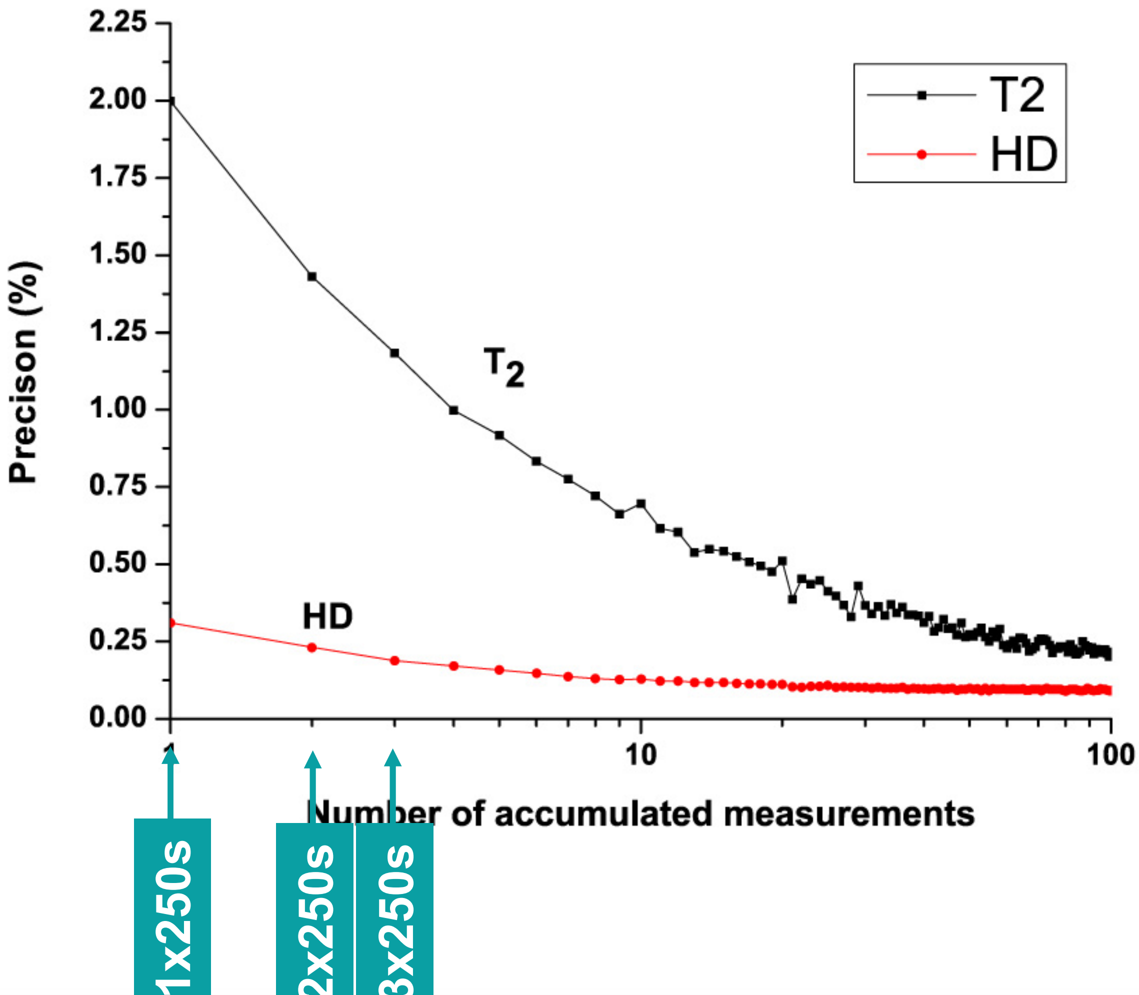
- **Sequential shutter up/down measurements**

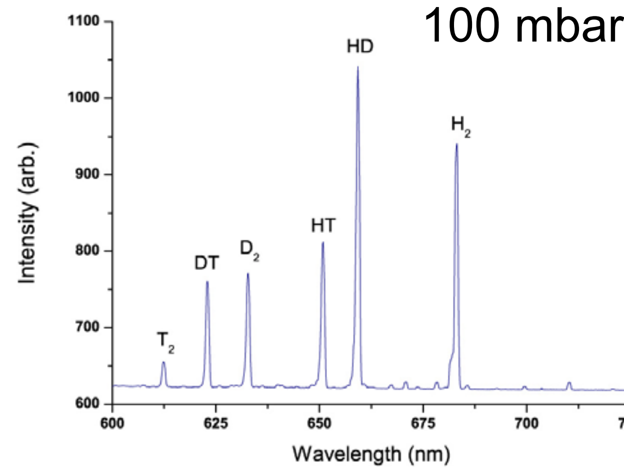
- **Keep dust out (Tubes)**

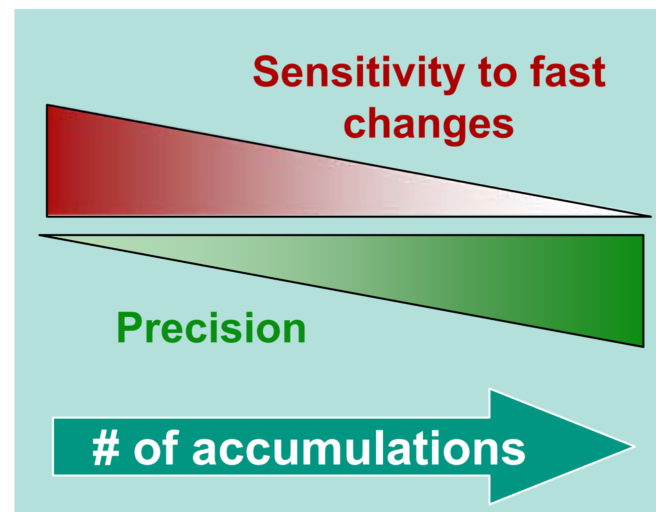
Stability of the Laser Raman System

Long term measurement

- **Peak stability for accumulated intensity values**







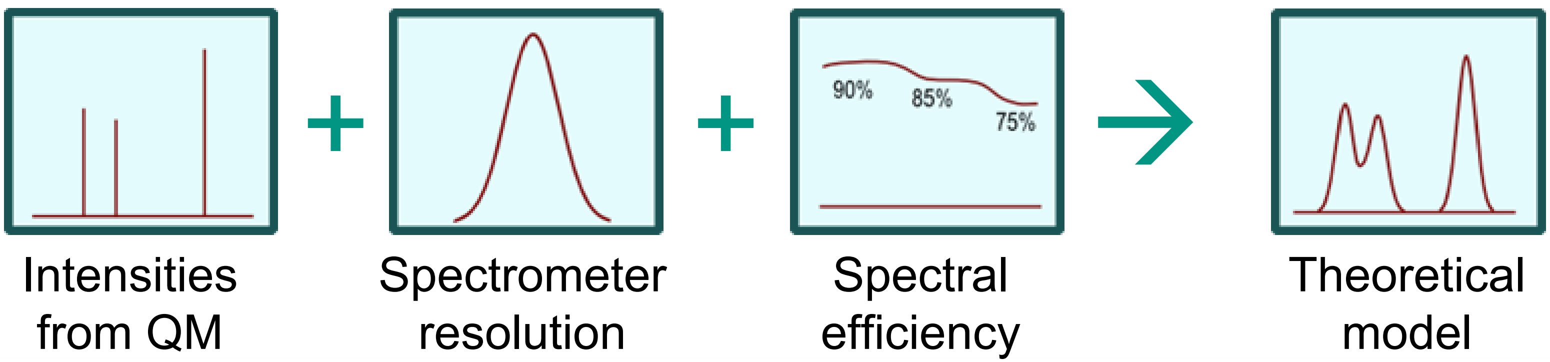
Quantitative analysis

Until now:

- Investigation of systematic effect via **peak area** measurements
- relative spectral intensities not proportional to relative composition

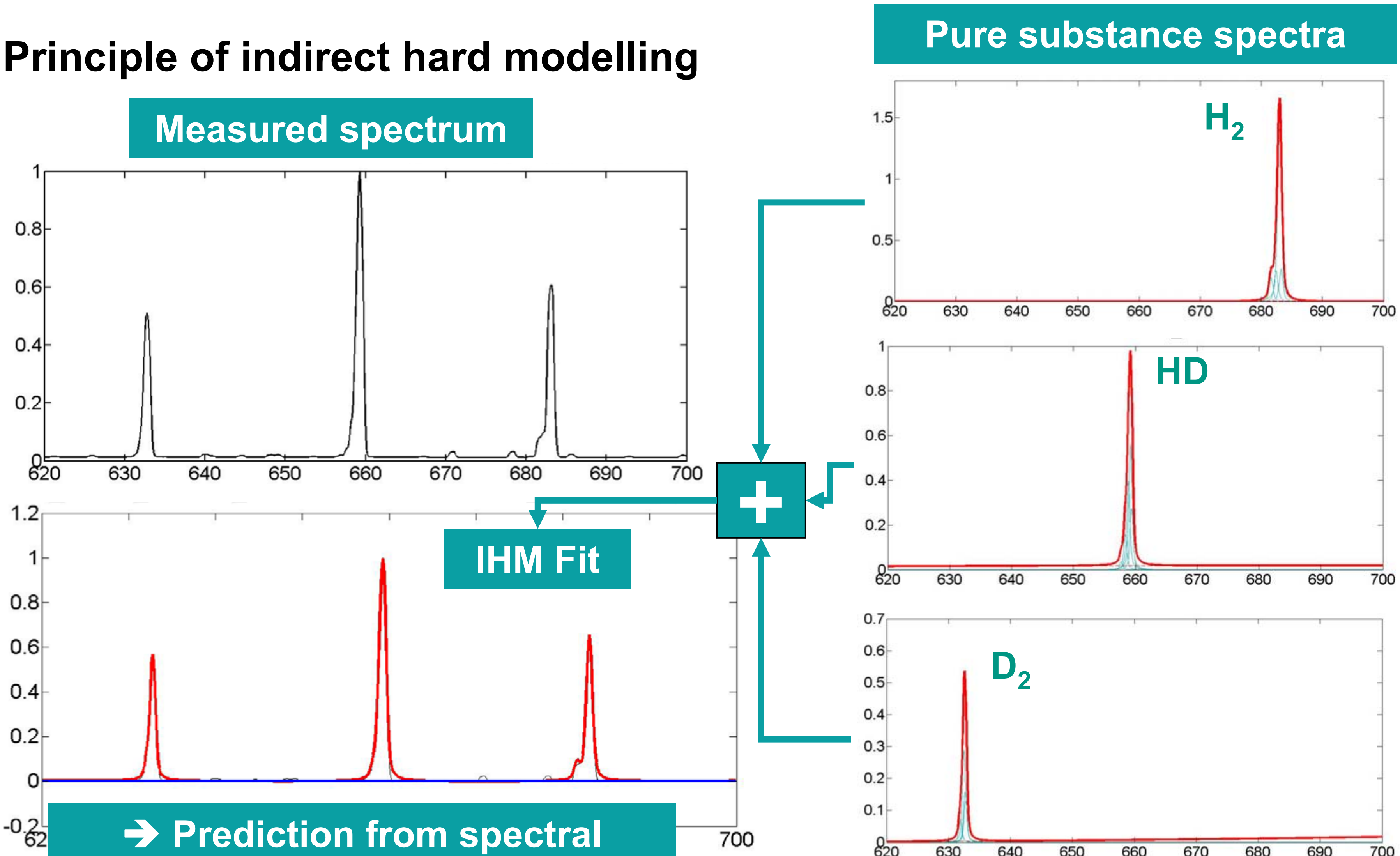
Indirect Hard Modelling

- Uses quantum mechanical models for **quantitative** analysis
- Further advantage: Use of theoretical known peak shapes **reduces systematic uncertainties** (e.g. base line detection)



Indirect Hard Modelling

Principle of indirect hard modelling



➔ Prediction from spectral weights and calibration data

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Indirect Hard Modelling

Comparison of precision (First results)

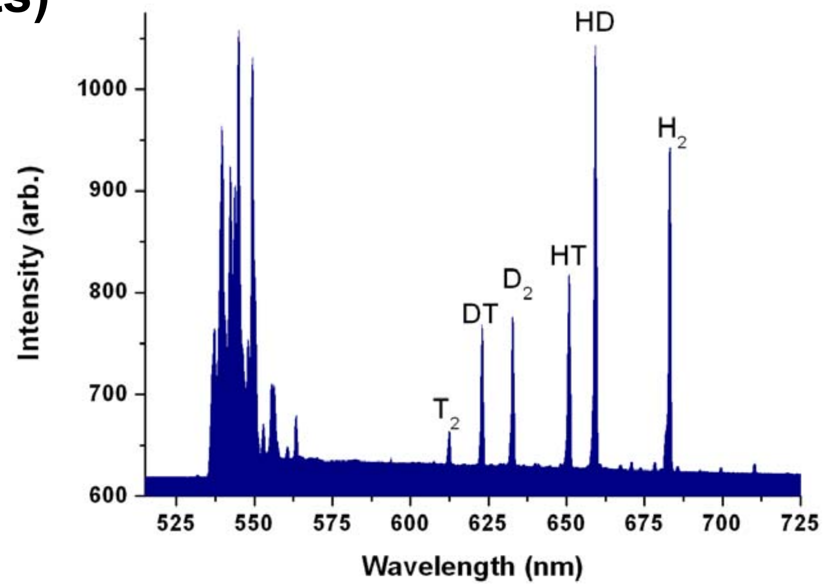
- **First tests (demonstration)**
  - **semi-quantum mechanical model used**
  - **spectral corrections missing**
  - **no calibration**

- **Stability of relative measurements**

Precision	T_2	HD
"Peak areas"	**1.50%**	**0.28%**
IHM	**1.02%**	**0.20%**

each time analysis of 322 spectra

IHM increases precision by about 30%



Most KATRIN-a-like measurement (p≈100mbar, 250s)

Summary and Outlook

- Laser Raman monitors the isotopic purity for KATRIN
- System has been invested for more than 8 month on systematic effects (e.g. background, long term stability,…)

Status

- KATRIN requirements (0.1% precision) reachable
- At the moment: Laser stability is not satisfying
- IHM method can improve analysis precision and allows quantitative analysis
- Actual detection limit < 0.06 mbar in 250 s

Next steps

- Investigations and improvements of laser stability
- Theoretical modelling and spectra corrections for IHM
- Determination of spectroscopic data for tritium

Michael Sturm, Sebastian Fischer, Helmut Telle, Richard Lewis, Magnus Schlösser, Beate Bornschein

Data-Processing