

High-resolution In-source Laser Spectroscopy with Highest Isobar Suppression:

HFS Studies on Radioactive Holmium Isotopes in Perpendicular Atom - Laser Beam Geometry

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➤ Scheme development for highest ionization efficiency

- Determination of the IP: Talk of D. Studer
- Medical isotopes for MEDICIS: Talk of V. Gadelshin



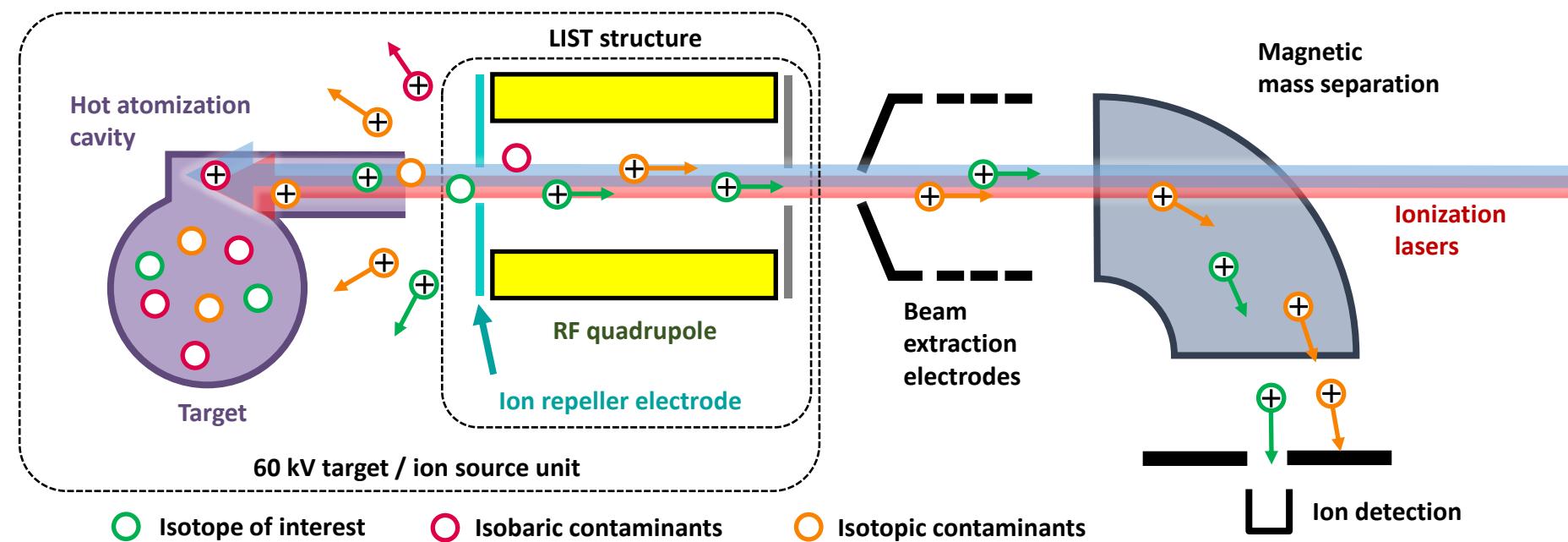
➤ ^{163}Ho ion implantation for the ECHo project

- Determination of the v_e mass
- Highest ionization and implantation efficiency
- Isotopic contamination suppression



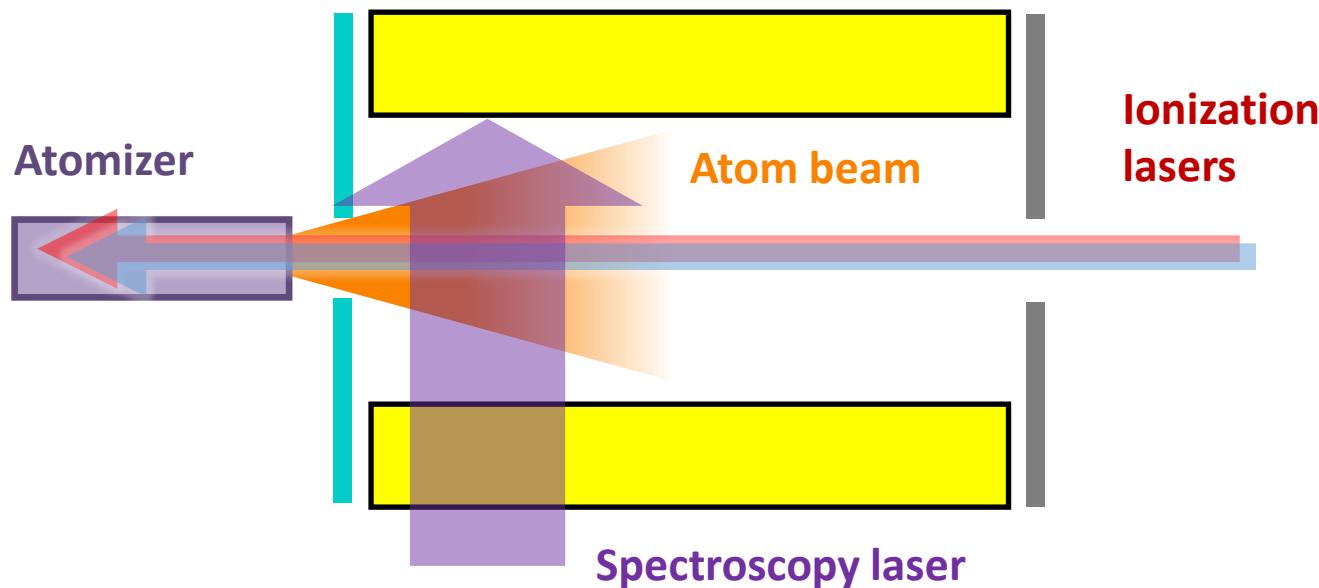
➤ High resolution HFS spectroscopy on radioisotopes

- Tc in the PI-LIST setup
- Ho in a PI-LIST on-line adaption



- Spatial separation of hot atomization cavity and volume of laser ionization
- Suppression of isobaric contaminants from unspecific surface ionization
- In-source laser spectroscopy of species formerly oppressed
- Ion Guide mode enables „standard“ RILIS operation

Spectral resolution dominated by Doppler broadening in hot atom vapor (typically 1 – 3 GHz)

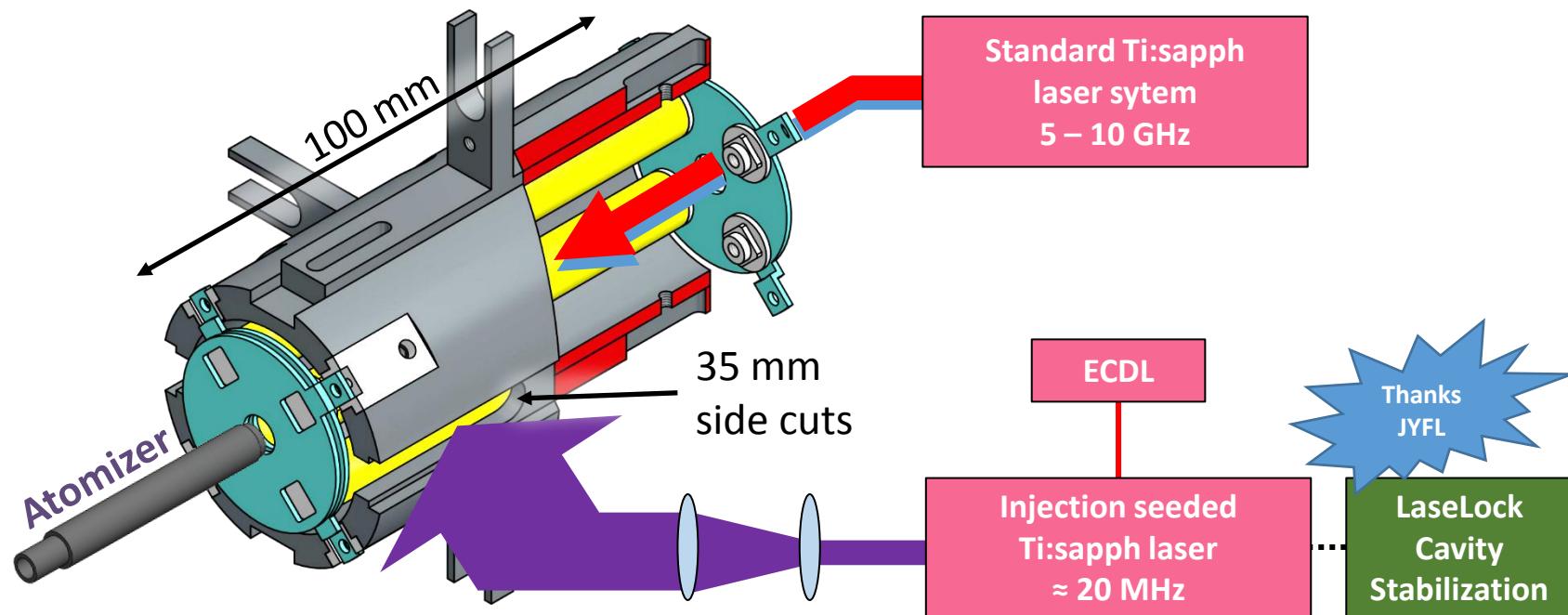


Background suppression + high resolution spectroscopy:

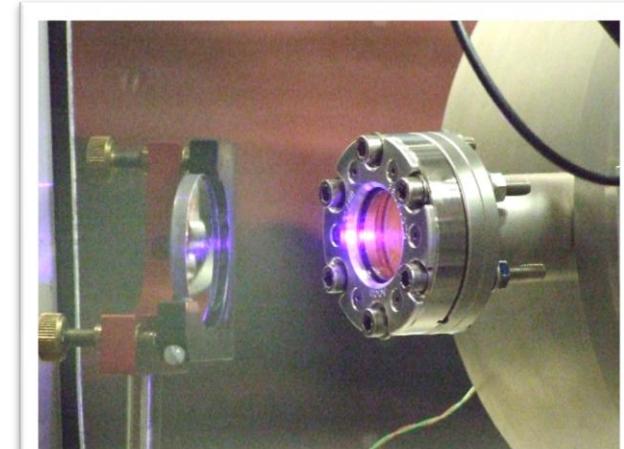
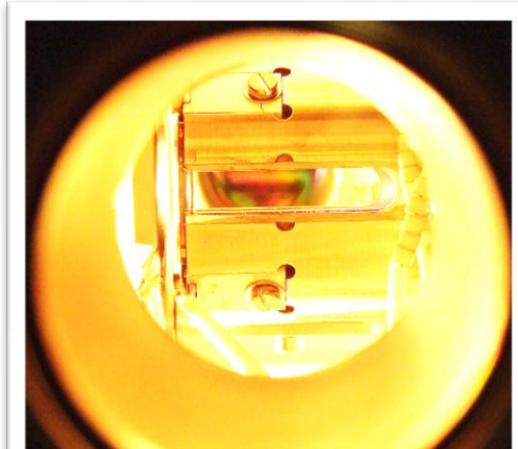
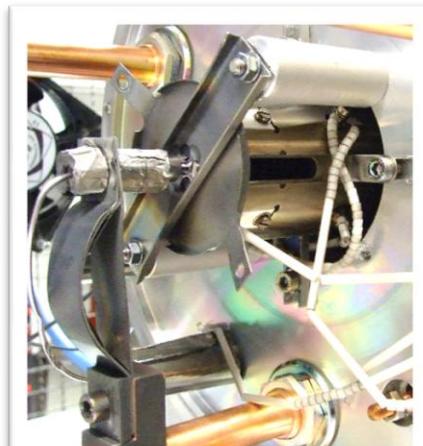
The Perpendicularly Illuminated Laser Ion Source and Trap *PI-LIST*

→ Residual Doppler broadening only by transversal velocity classes in laser overlap

- Installation at the ISOLDE-like RISIKO off-line separator at Mainz University



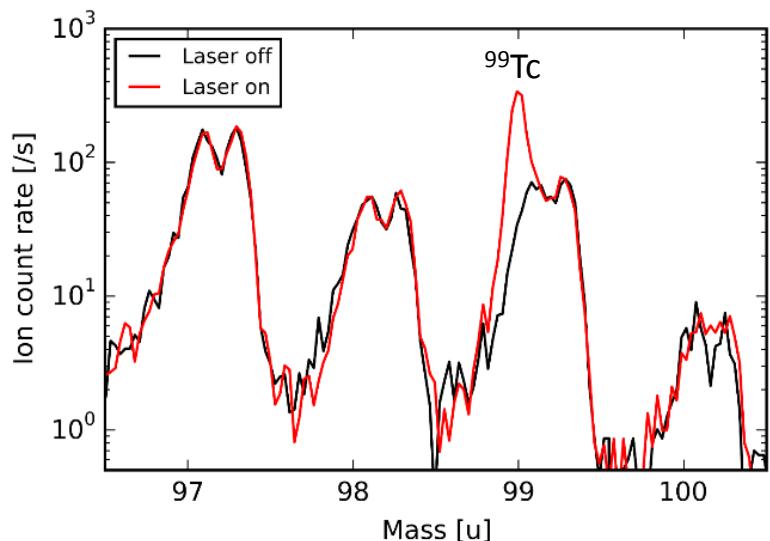
- Perpendicular incoupling through side window on source chamber



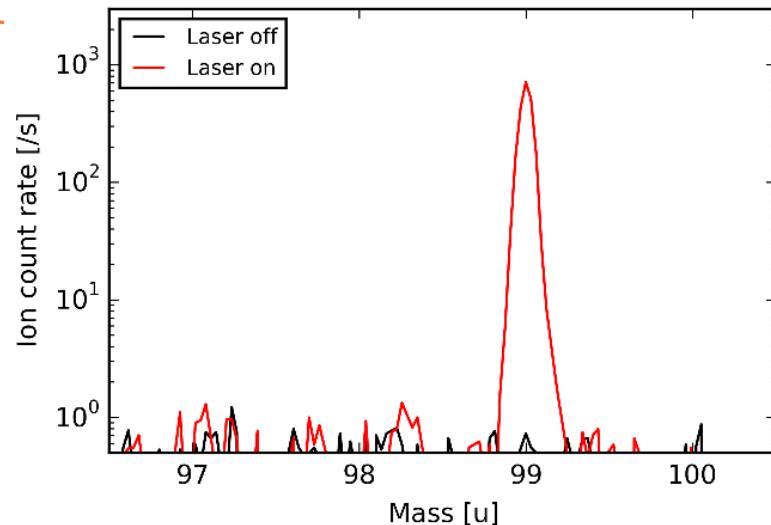
Background Suppression: Double Repeller

First test with graphite atomizer and single ion detection:

- Poor background suppression in LIST mode
- Caused by electron impact induced ionization



Double Repeller Design

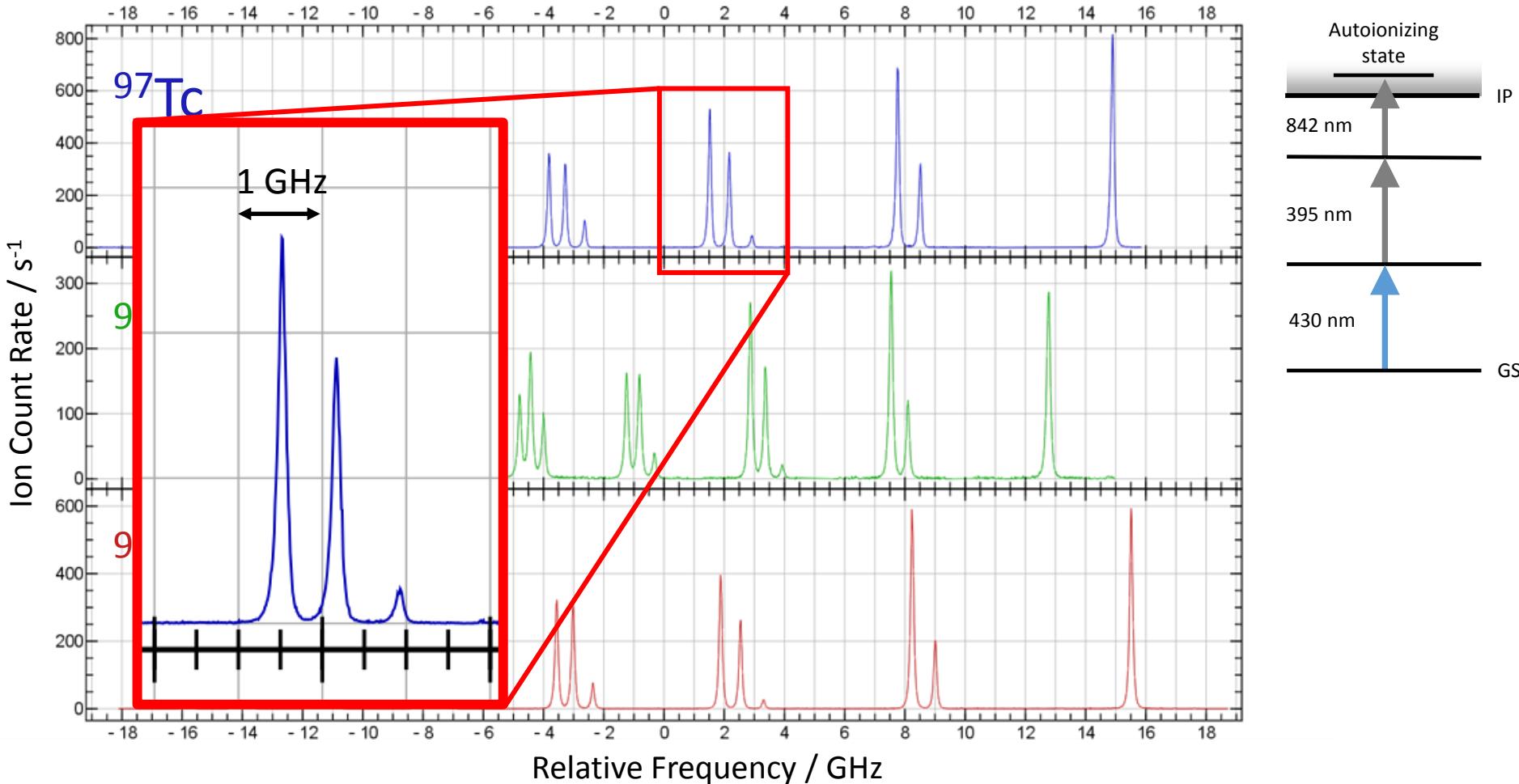


Introduction of a second repeller

- Suppression of ions and electrons
- Signal-to-noise: 10 ➔ > 3000
- Requirement for investigation on minuscule samples or low production rates

High Resolution HFS Spectroscopy of Technetium

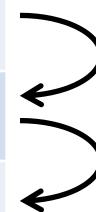
- $^{97,98,99}\text{Tc}$ samples produced at TRIGA Mainz,
provided by the institute of nuclear chemistry



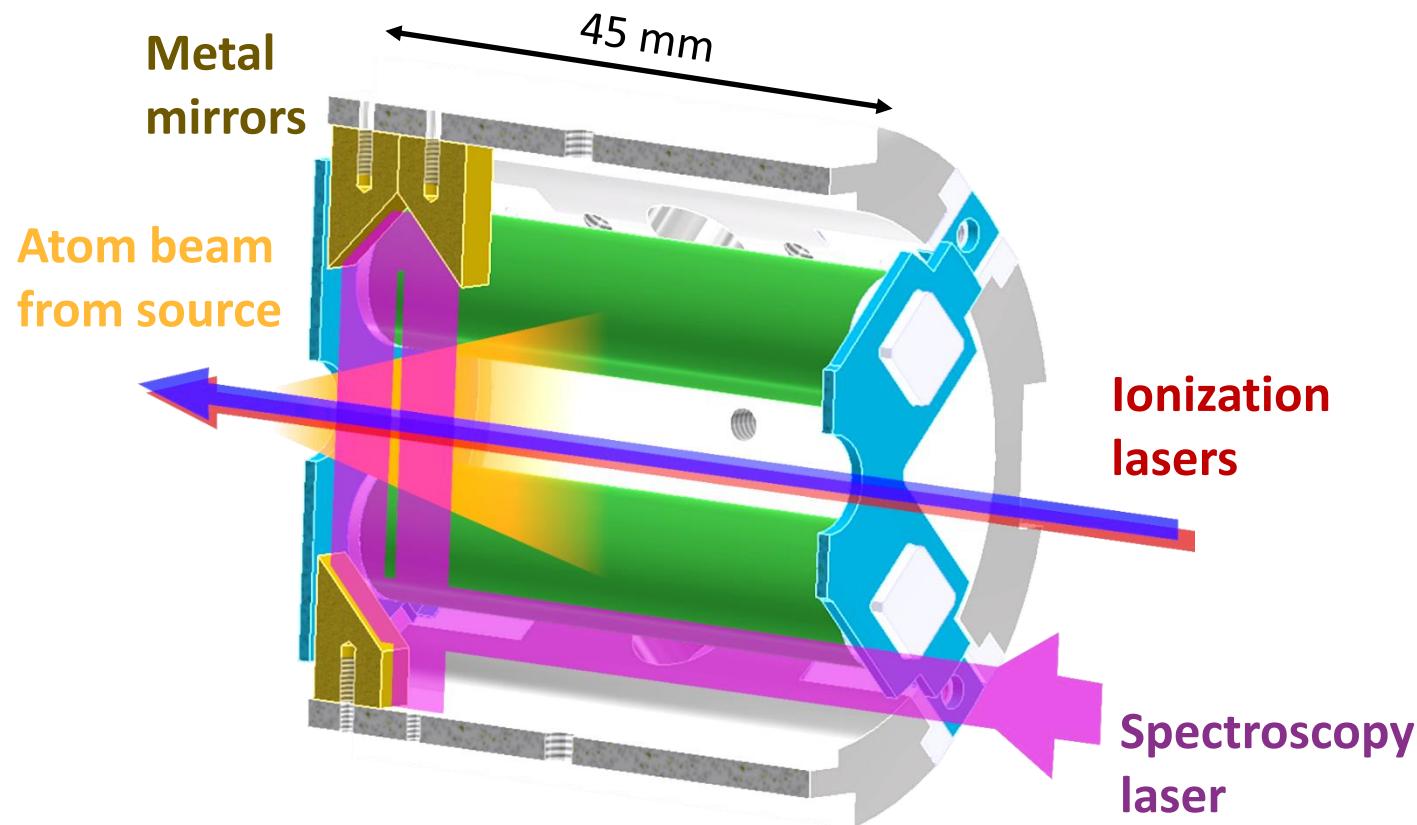
Results of First PI-LIST Campaign

- High resolution HFS Scans on 3 transitions for 3 isotopes $^{97-99}\text{Tc}$
- Experimental linewidth < 100 MHz
- New information on nuclear properties: Publication in preparation (T. Kron et al.)
- Efficiency considerations based on Tc:

Operation mode	Efficiency
Standard RILIS	4 %
LIST Ion Guide	2 %
LIST Suppression mode	0.02 %
PI-LIST	0.01 %

Signal loss factor
in broad band excitation

50 - 100
 ≈ 2

- ✓ HFS spectroscopy on 10^{11} atom samples of ^{227}Ac
- **PI-LIST** is a powerful tool for high resolution spectroscopy on minuscule samples
- Not directly transferable to on-line use

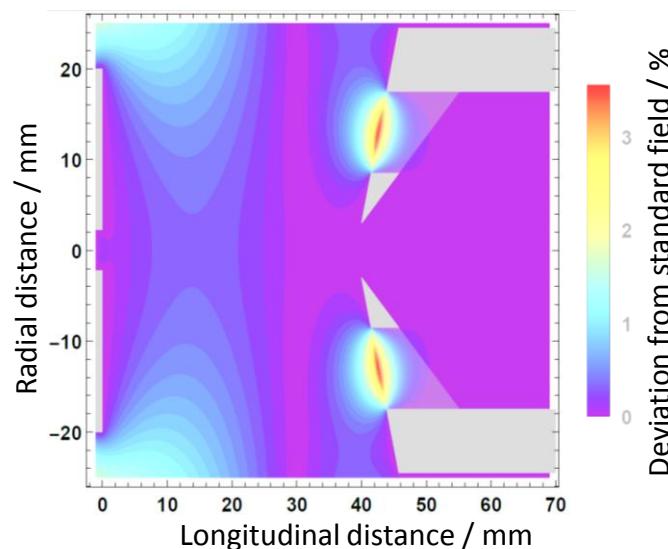
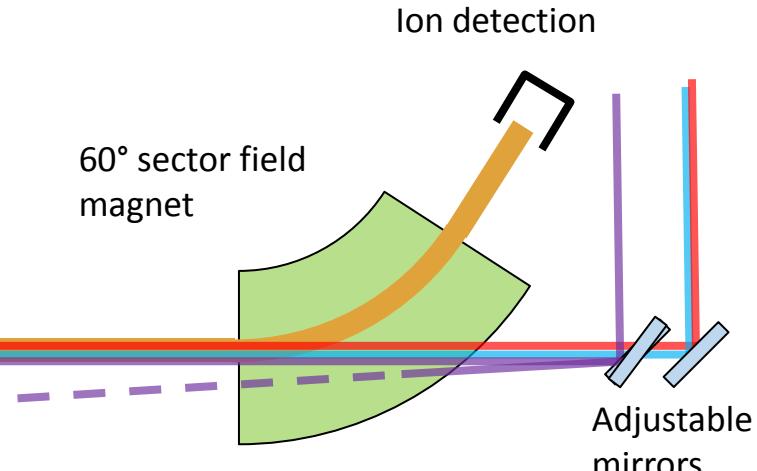
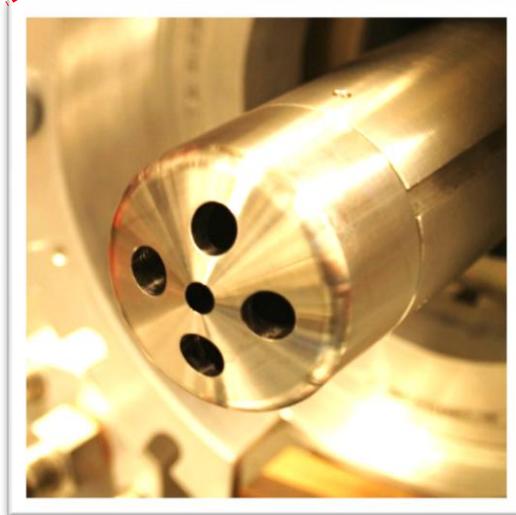
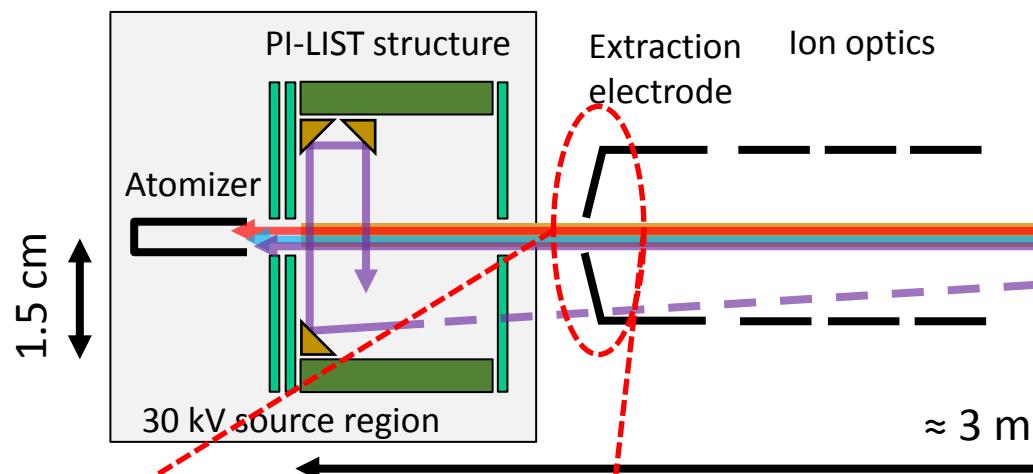


- Off-center transport of spectroscopy laser
- 90° reflection by robust metal mirrors right behind repeller
- Retro-reflecting for larger interaction volume

Technical Realisation at RISIKO

Easy switching by mirror adjustment

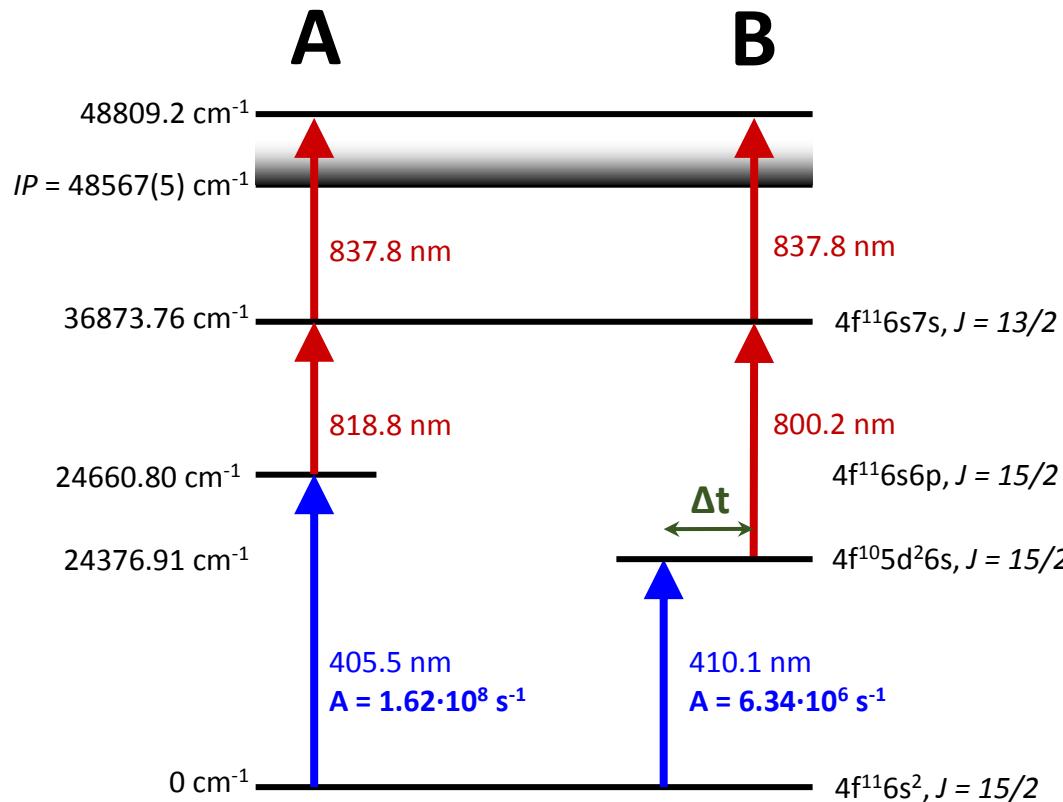
➤ Full conservation of „classical“ operation modes



Modified extraction electrode

< 1 % extraction field deviation

Holmium Ti:sapph excitation schemes for the ECHo project

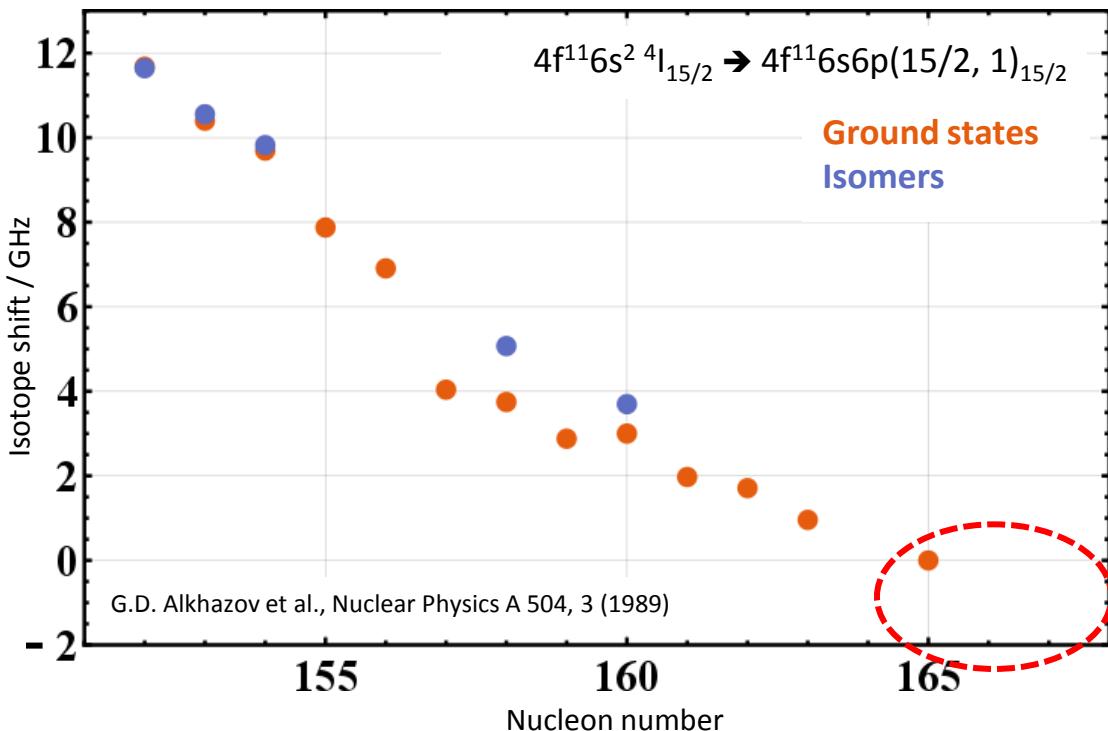


- Scheme A: High ionization efficiency > 40%
 - ✓ Used for ^{163}Ho implantation for the ECHo project
- Scheme B: Long FES lifetime → delay of 2nd and 3rd step
 - ✓ Used for high resolution spectroscopy

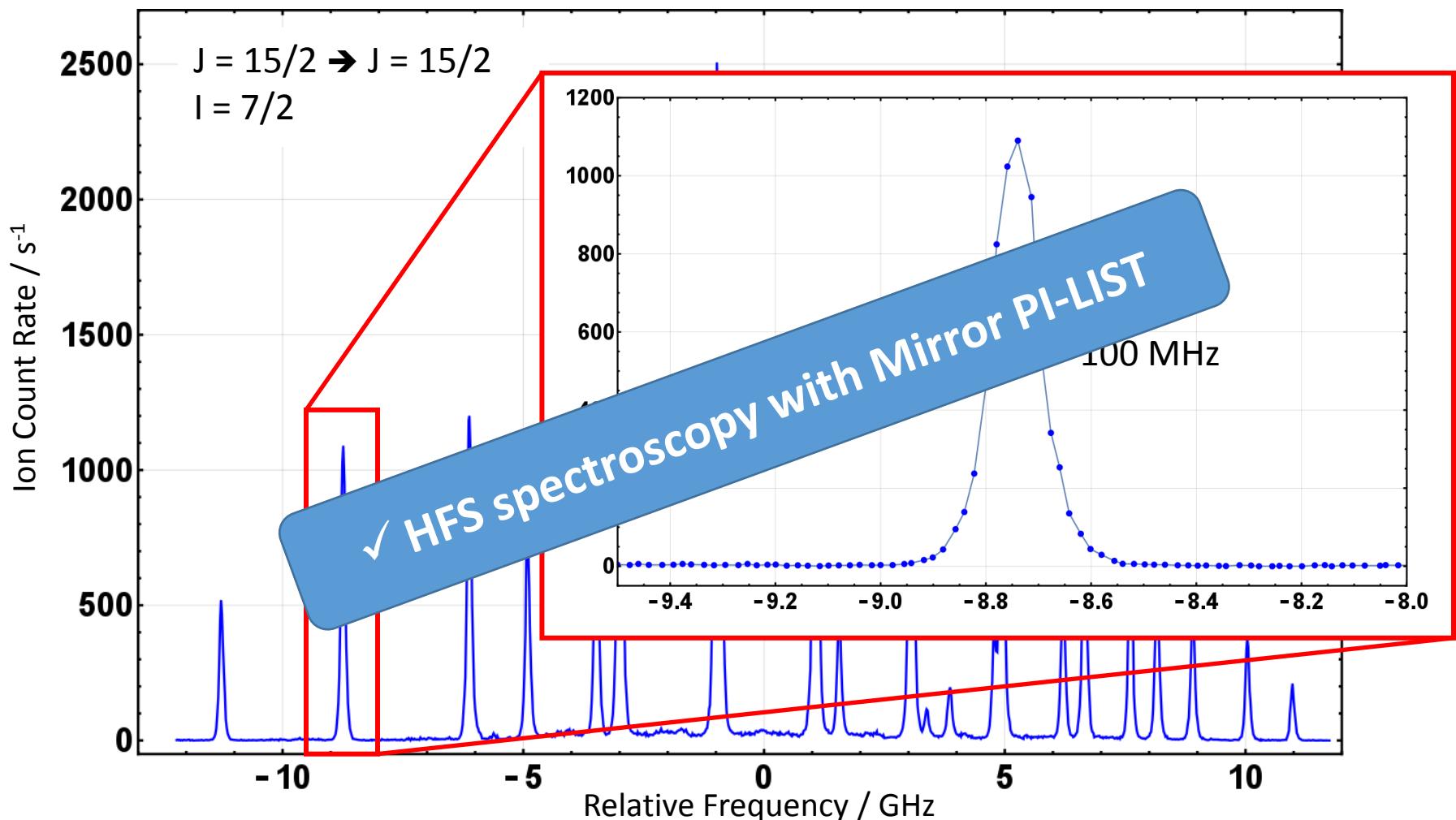
- Radioactive Ho isotopes produced at ILL Grenoble for the ECHo project
- Provided by the Institute of Nuclear Chemistry

- ^{165}Ho (stable): $I = 7/2$
- ^{163}Ho (4570 y): $I = 7/2$
- ^{166m}Ho (1200 y): $I = (7)$

- Evaluation of isotope shift
- HFS spectroscopy:
22 to 43 components

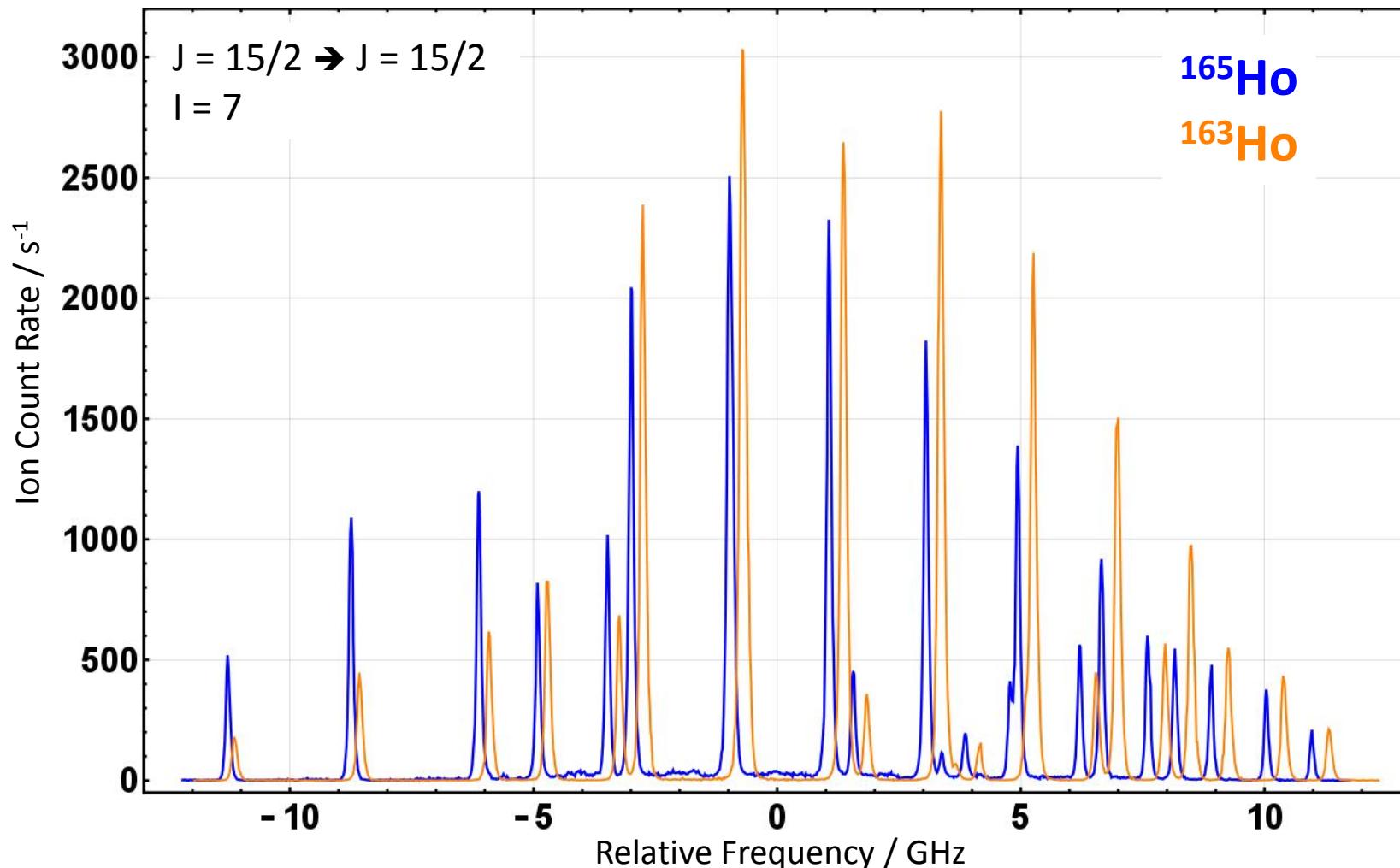


^{165}Ho full spectrum



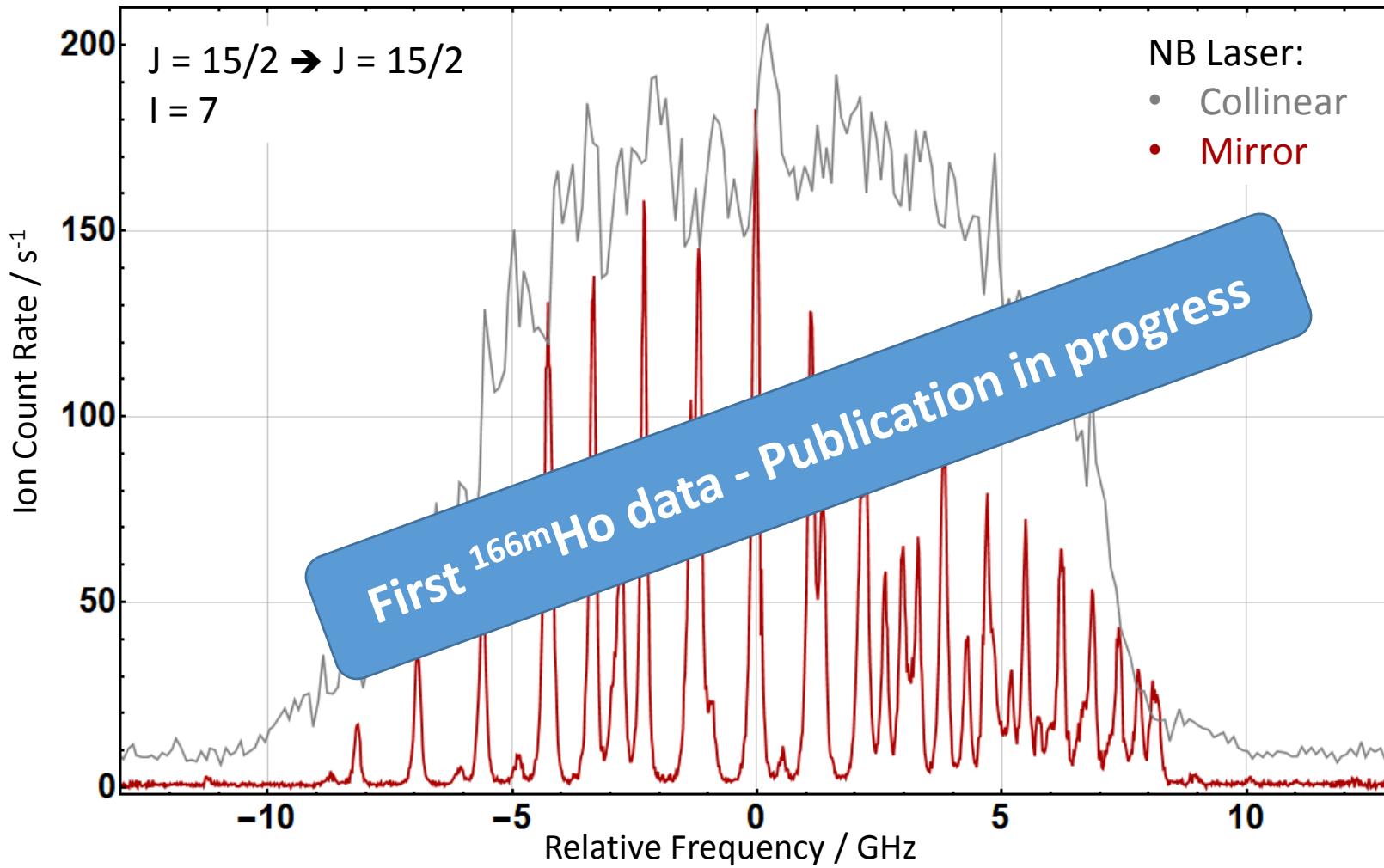
- FWHM linewidth 100 MHz \rightarrow 20 of 22 components well resolved
- Excellent signal-to-background ratio

Isotope Shift $^{165}\text{Ho} - ^{163}\text{Ho}$



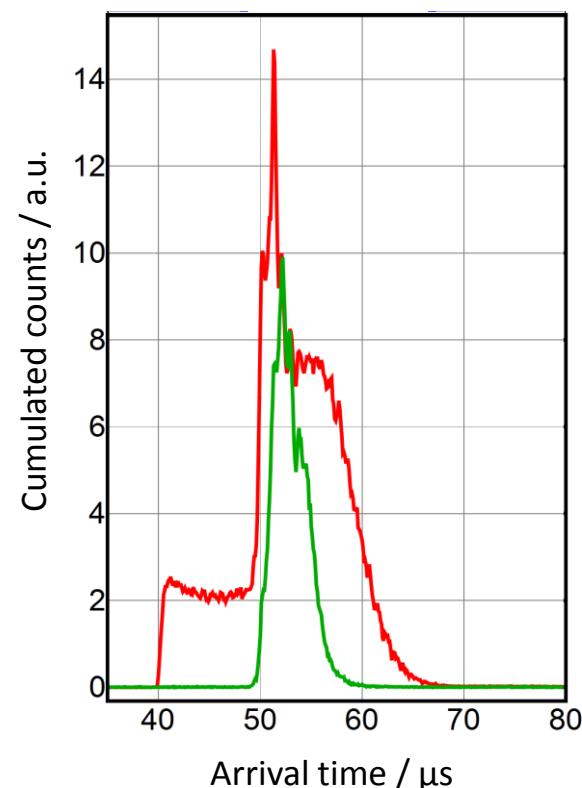
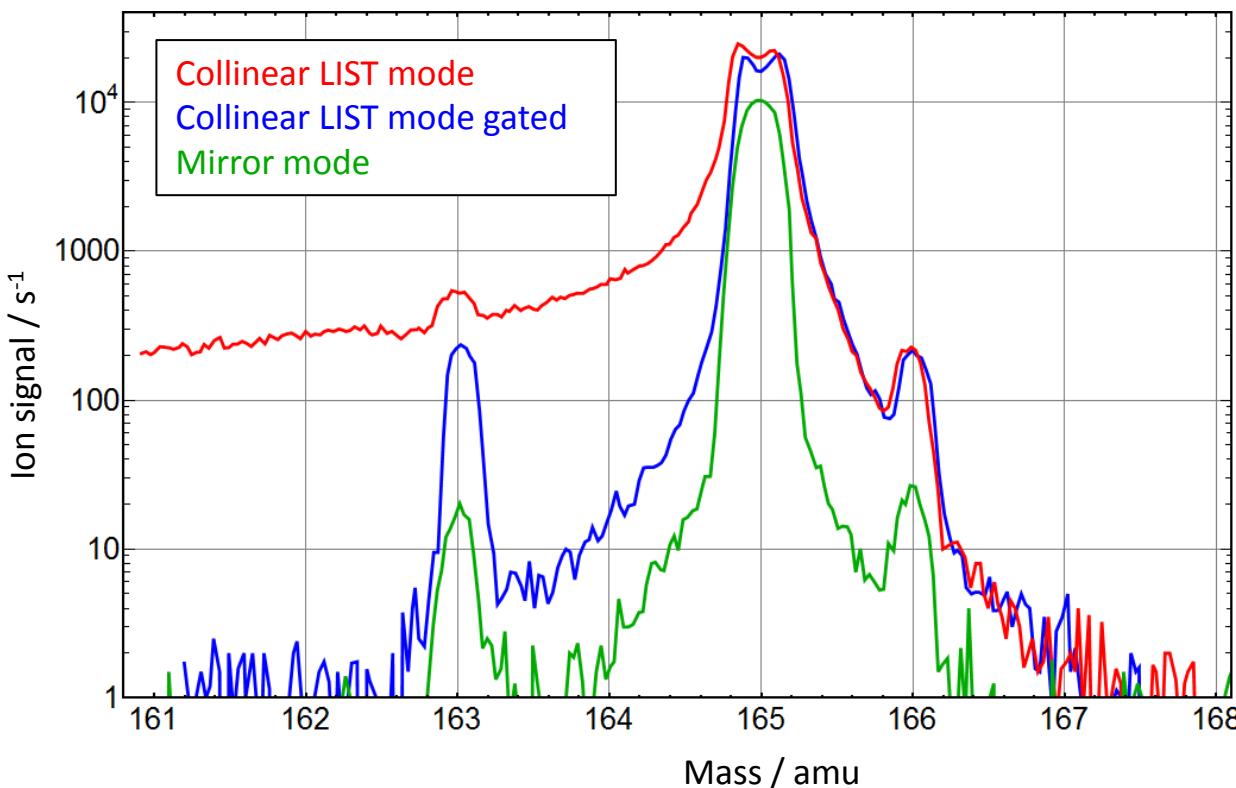
- Extraction of nuclear parameters ongoing
- Background determined by dark count rate of detector

First ^{166}Ho Data



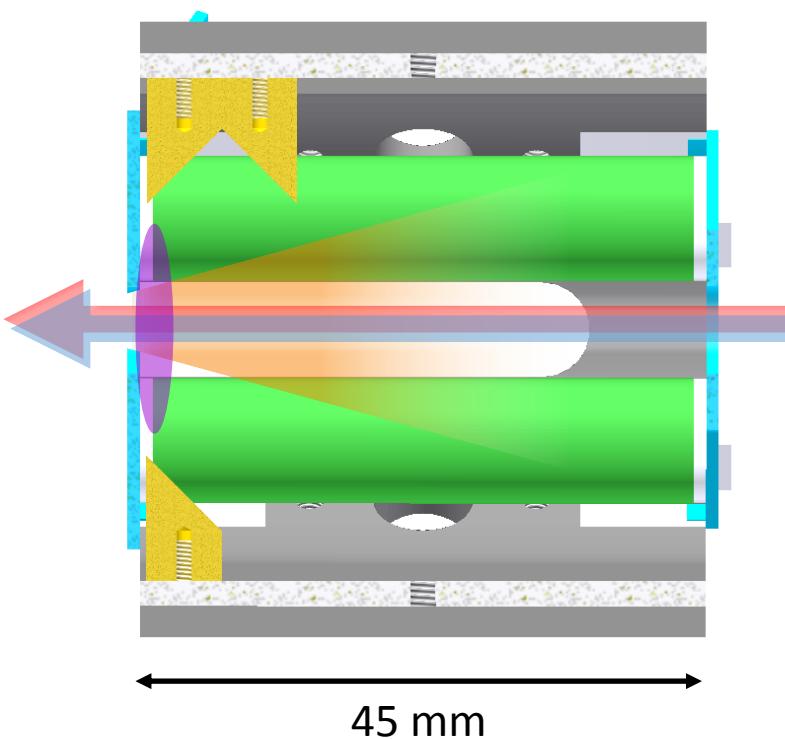
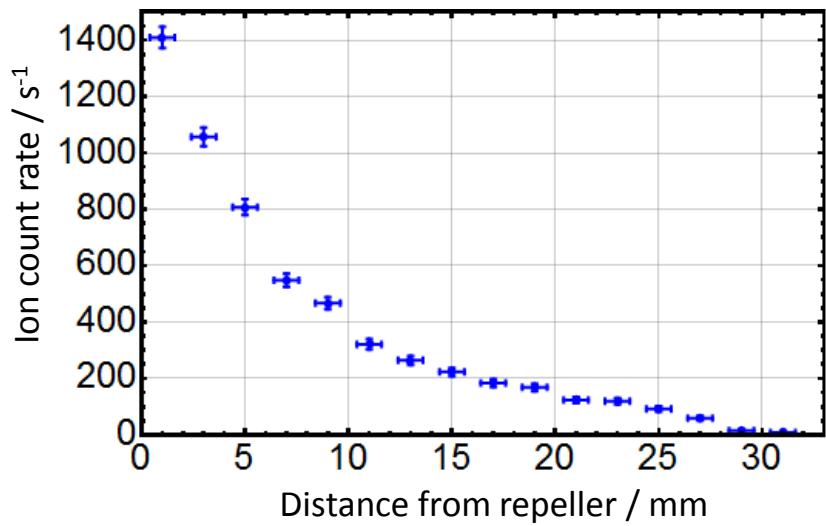
- 43 HFS components expected
- High resolution mandatory

Enhanced Neighbouring Mass Suppression



- Collinear LIST mode: Contamination by laser ionization in extraction field
- Suppression by μ beam gating
- Mirror mode: Distinct ionization region decreases energy spread
- Signal loss comparable to PI-LIST
- Additional gating on sharp time structure

- Atom density measurements on central axis
- Perpendicular laser beam scan in PI mode



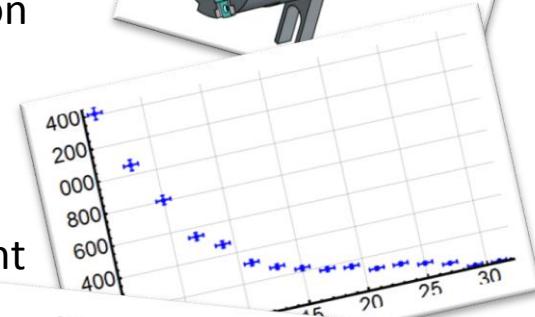
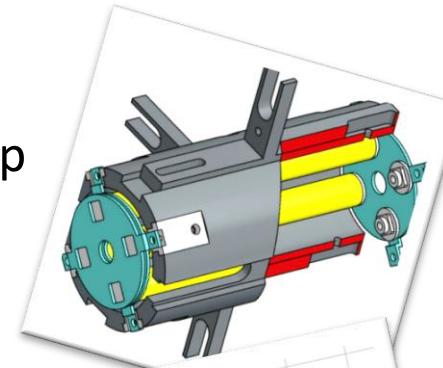
- Significant opening angle of atom beam
- Low efficiency loss in mirror mode
- Spacing and laser spot size crucial parameters
- Evaluation of atomizer design

→ PI-LIST as tool for ion source development

High Resolution In-source Spectroscopy

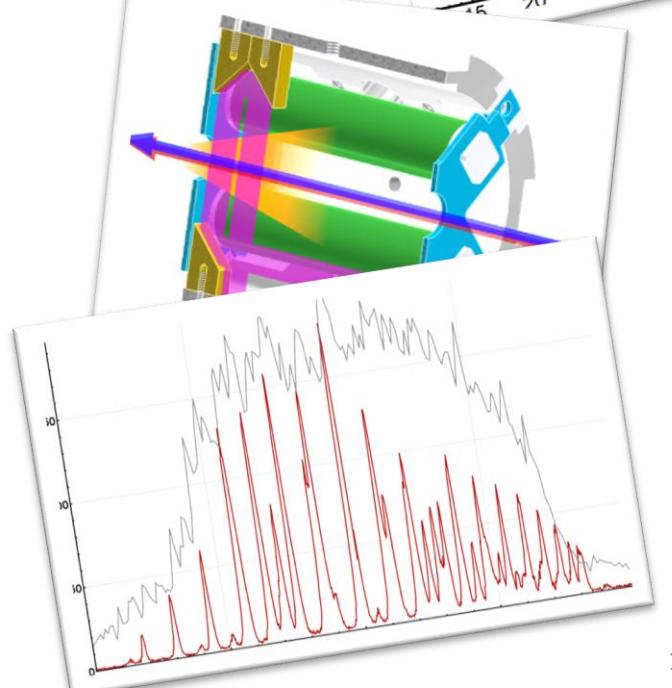
➤ **PI-LIST:** Perpendicularly Illuminated Laser Ion Source and Trap

- New atomic and nuclear data on $^{97-99}\text{Tc}$
- Powerful tool for off-line HFS investigation: 100 MHz resolution
- Measurements on minuscule radioactive samples
- „Background-free“ double repeller configuration
- Atom beam analysis for standard LIST / hot cavity development



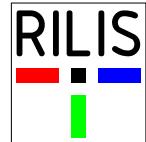
➤ On-line concept: **Mirror PI-LIST**

- In-beam line laser transport and deflection
- First time HFS spectroscopy on $^{166\text{m}}\text{Ho}$
- Exploitation of time structure and mass resolution
- 100 MHz: Application in isomer-selective production
- Acronym?



Thank you for LISTening ...

... and thanks to the group and all collaborators!



Mirror Performance

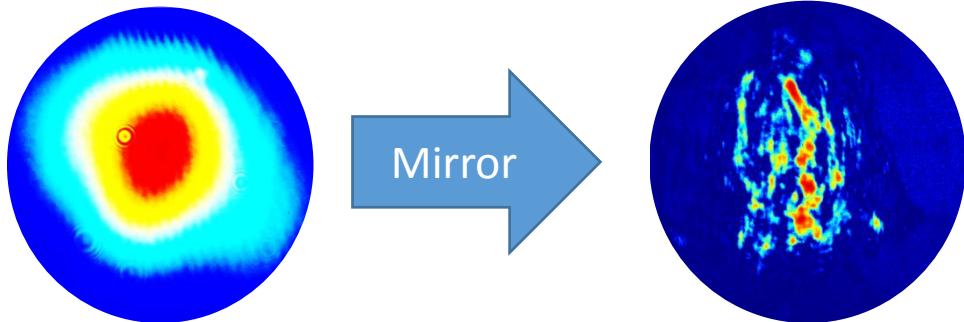
- 6 mm x 6 mm
polished steel, produced at institute workshop:

$R = 60 - 65 \%$ 3 weeks $R = 50 - 60 \%$
(20 % for last mirror)

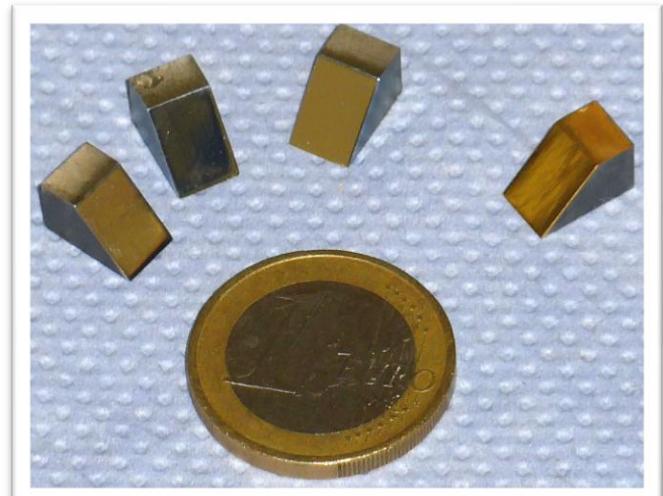
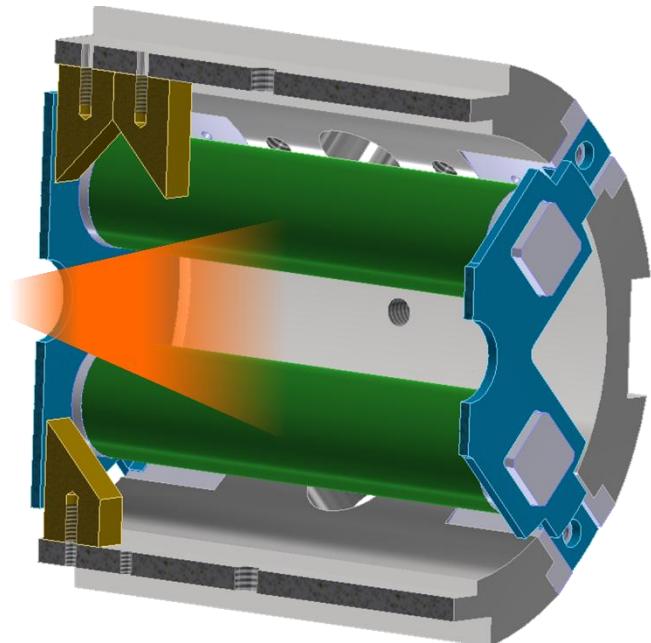
- Silver coating by pulsed laser deposition:

$R = 80 - 85 \%$ 6 weeks $R = \text{XXX} \%$

- Mirror influence on beam shape:

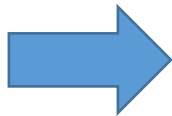
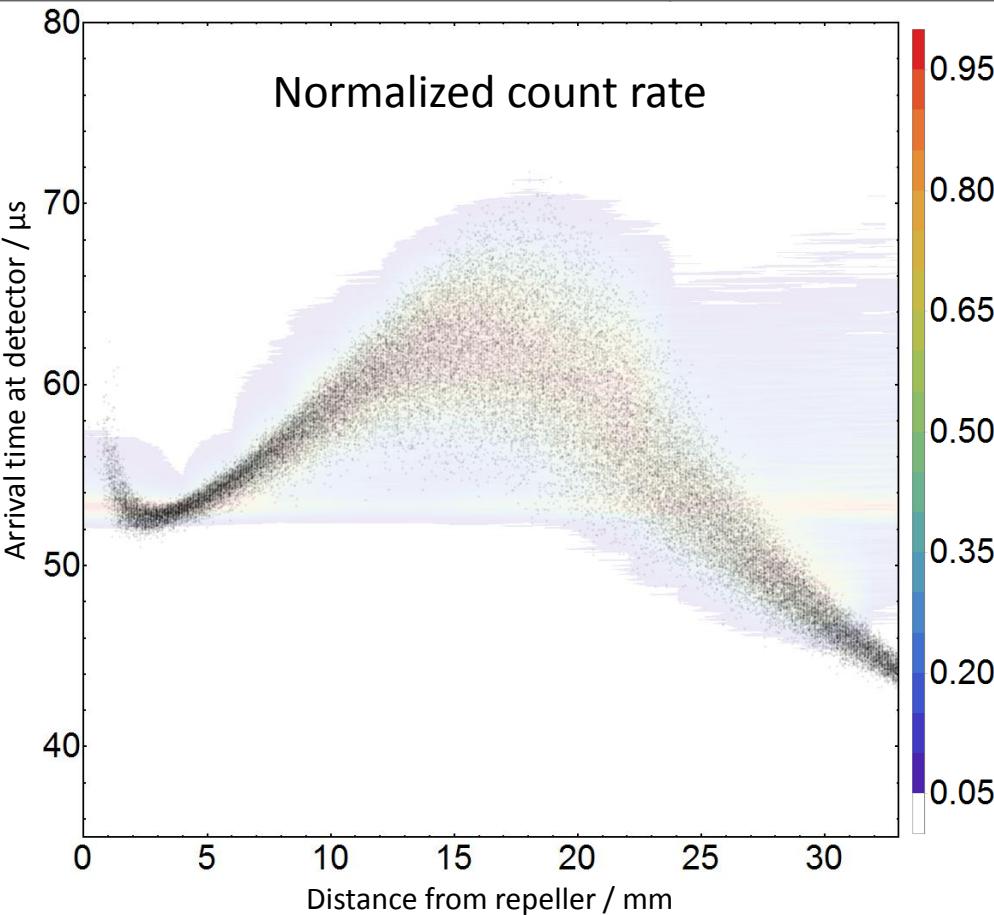


- Shape distortion, but no influence on opening angle

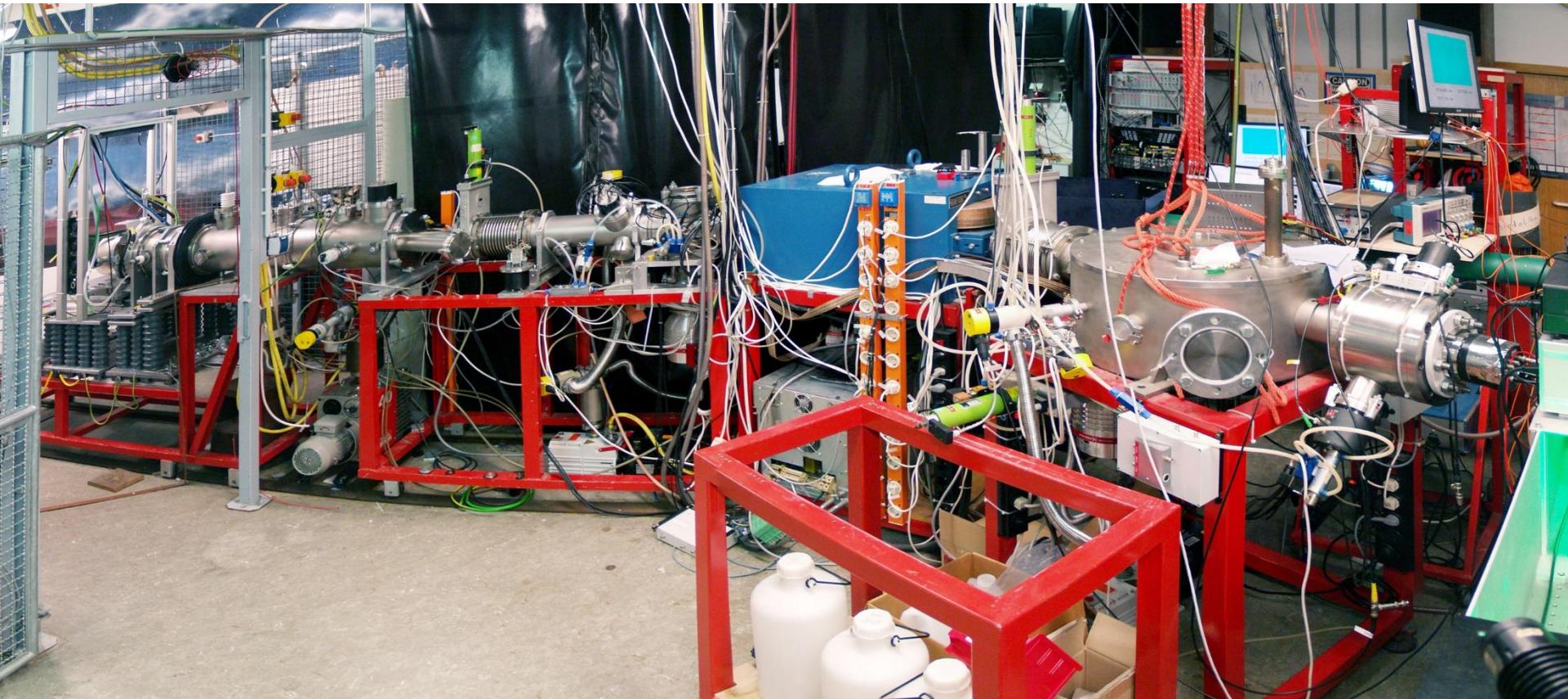


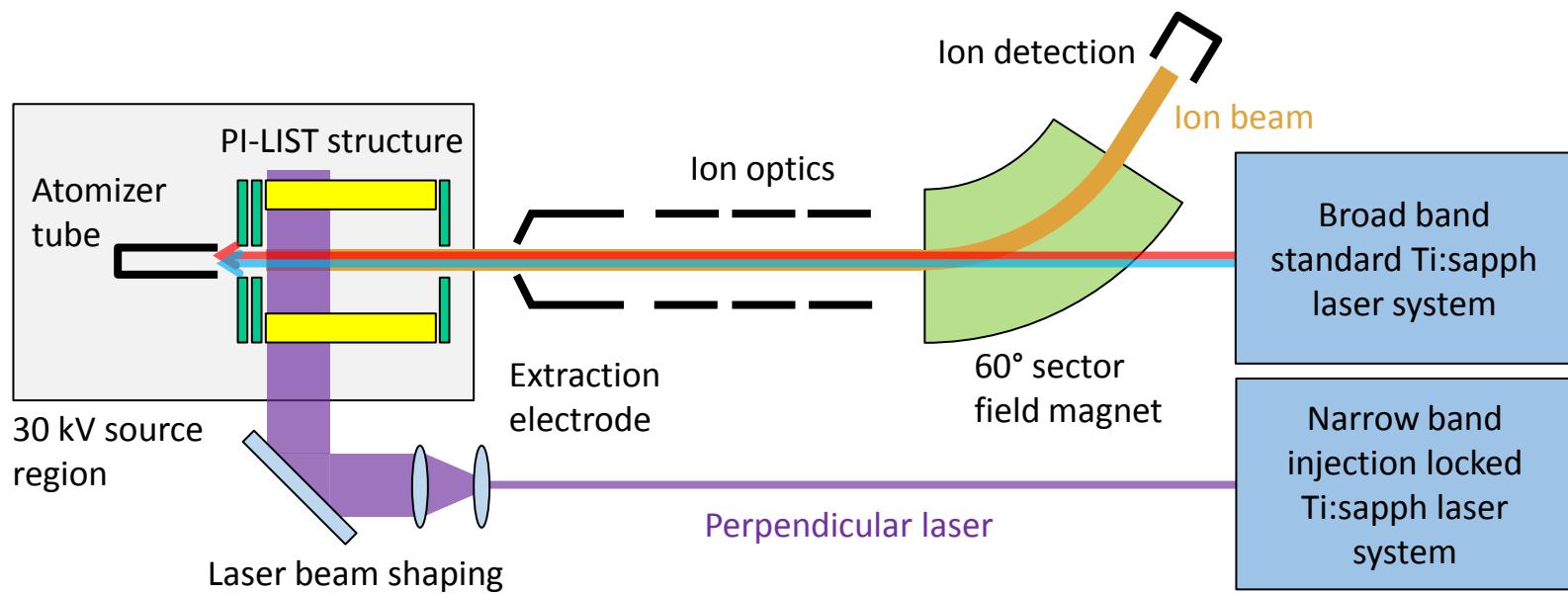
Time structure investigations

- Distribution of ion arrival times for different starting points
- Comparison with simulated data
 - Voltage settings and temperature
- Excellent agreement
- Distinct ionization regions:
 - Time-focused ions from repeller field
 - Temperature broadening in centrum
 - Time-focused ions from extraction field



PI-LIST is a powerful tool for off-line ion source development





Atom Beam Investigations

