Laser **I**onization and **S**pectroscopy of **A**ctinides

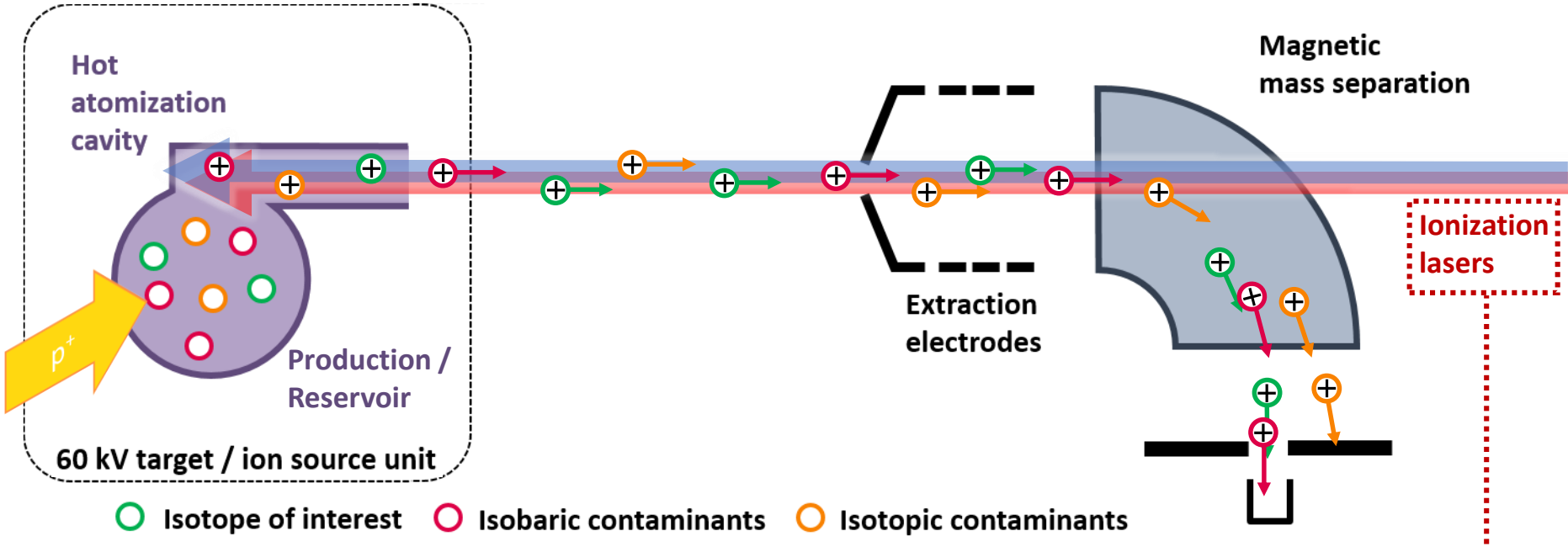
WP2: Novel techniques and technologies for actinide research

ESR2: Development of high-resolution in-source hot-cavity RILIS methods for actinides

LISA ITN Kick-off Meeting – CERN, 02.12.2019

Reinhard Heinke
on behalf of the LISA collaboration

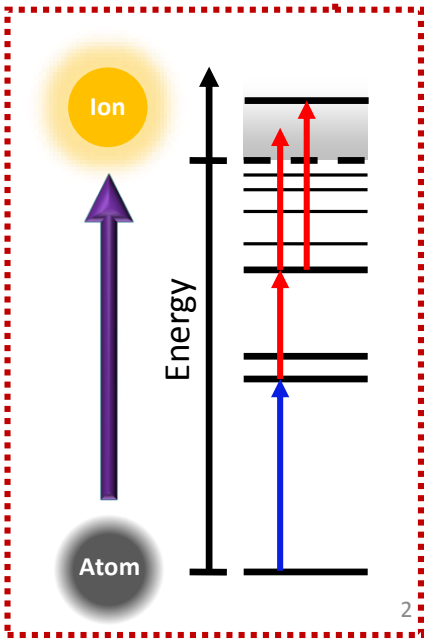
In-source hot-cavity RILIS



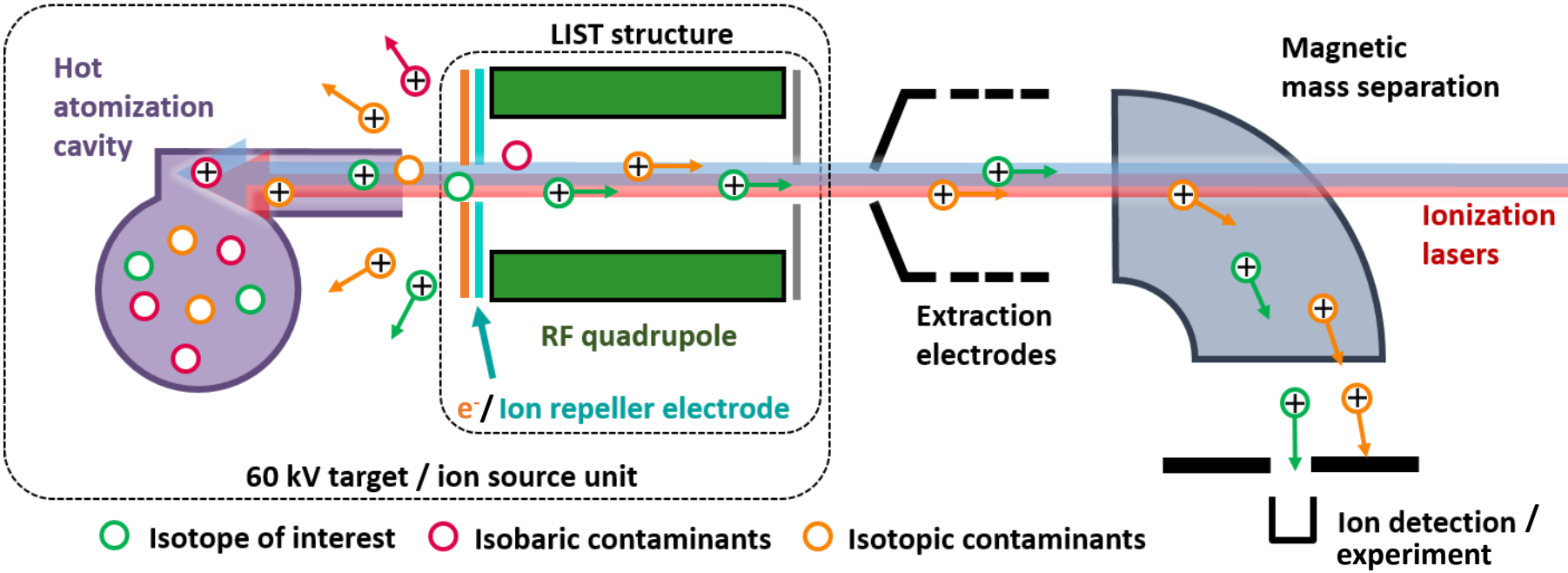
- Effusion of reaction products provided as

  hot atomic vapor (> 2000°C)
- Highly efficient laser ionization of **element of choice**

  as function of laser wavelength ➔ in-source spectroscopy (<< 1pps)
- Extraction and mass separation as **ion beam**
- **Beam purity influenced by competing ionization mechanisms**



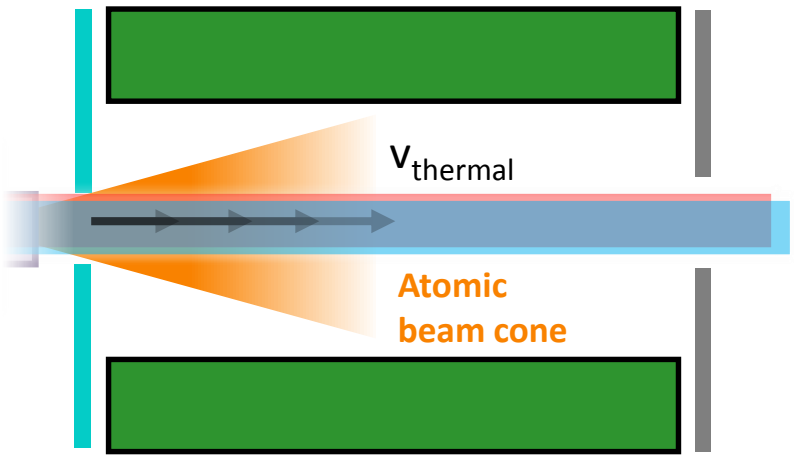
The Laser Ion Source and Trap LIST

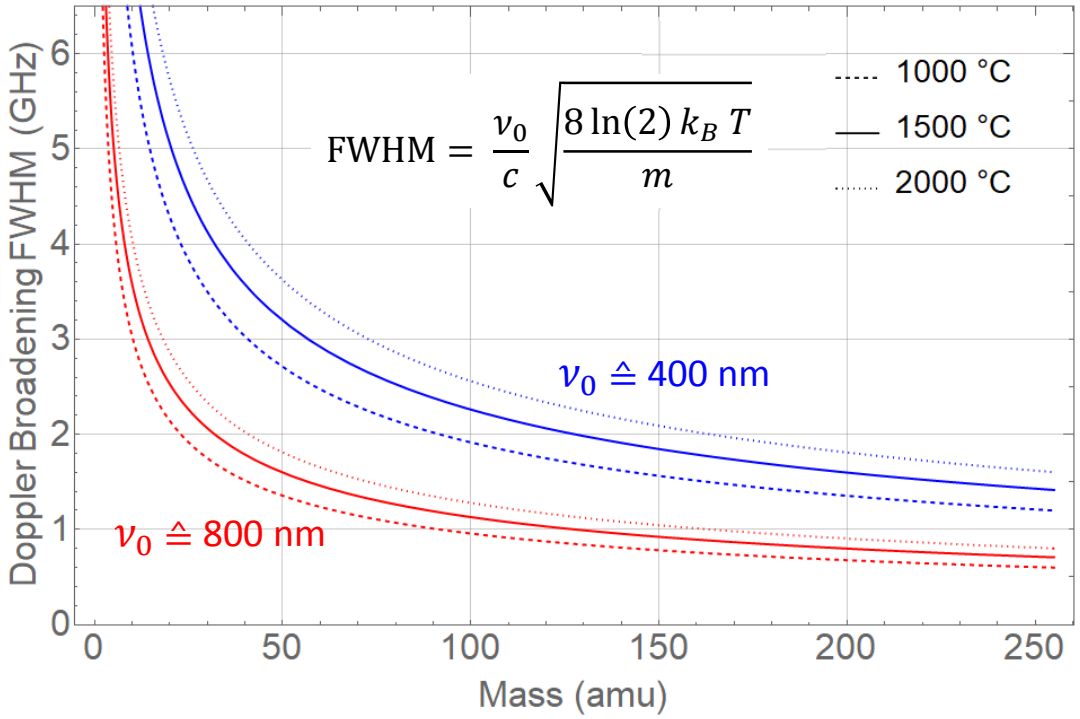


- **Spatial separation:** hot cavity ↔ laser ionization volume
- **Suppression** of surface ionized species
- **Pure laser ionization** inside RF quadrupole structure
- On-line @ CERN-ISOLDE 2018 – Production of Na-free Mg beams:

  Factor 20 – 50 reduction in beam intensity / Factor up to 10^6 in suppression
- IG-LIS routinely used at TRIUMF Secondment TRIUMF M15-16

Spectroscopic Limitations



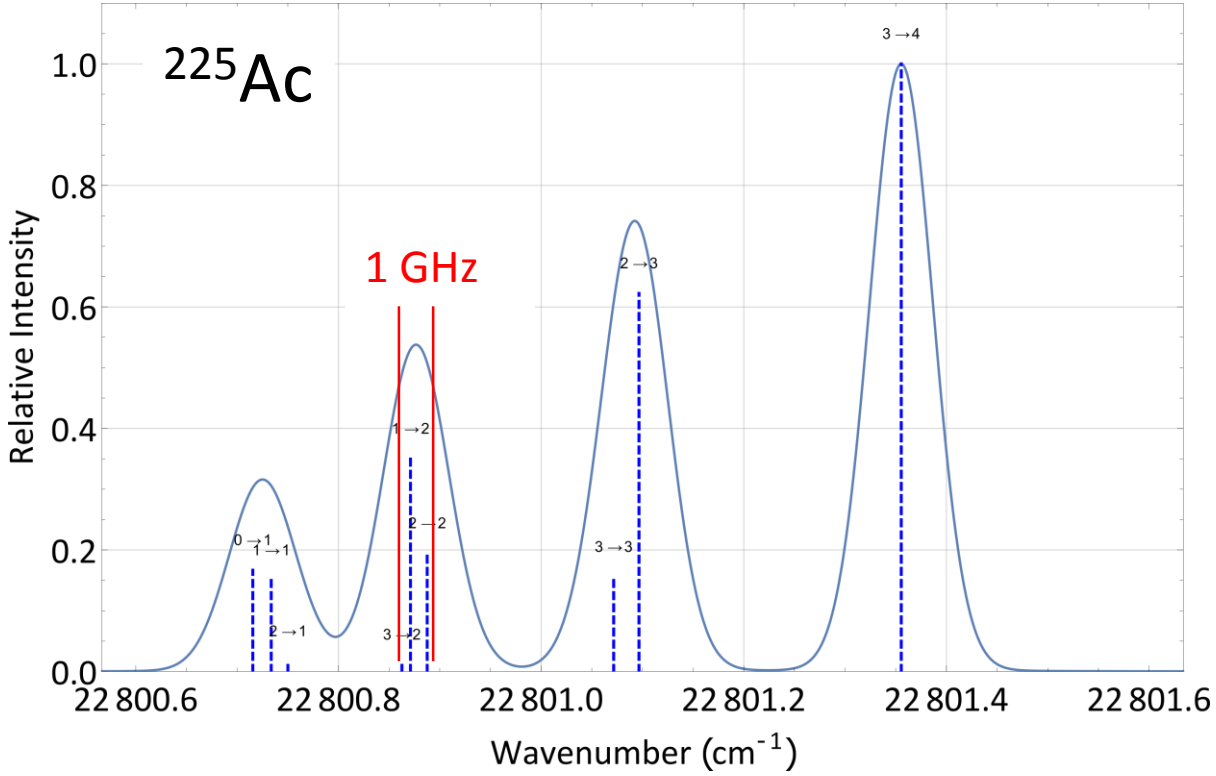


- **Doppler broadening** as ultimate limit for hot atomic vapor spectroscopy

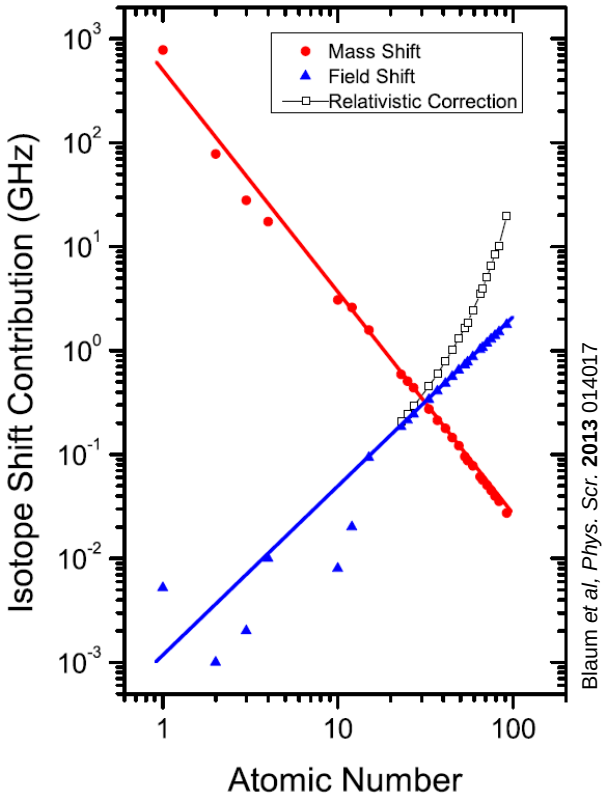
➔ Resolution intrinsically limited to > 1 GHz FWHM

High Resolution Spectroscopy

Hyperfine structure ➔ I, μ_I, Q_s

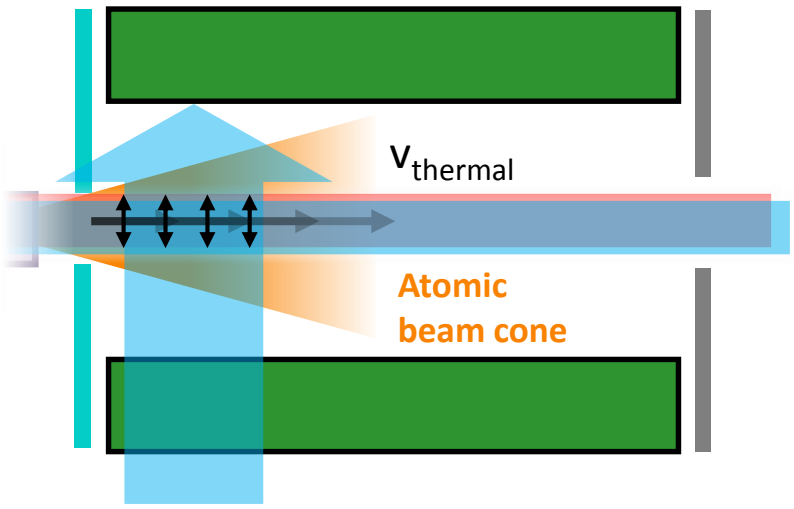


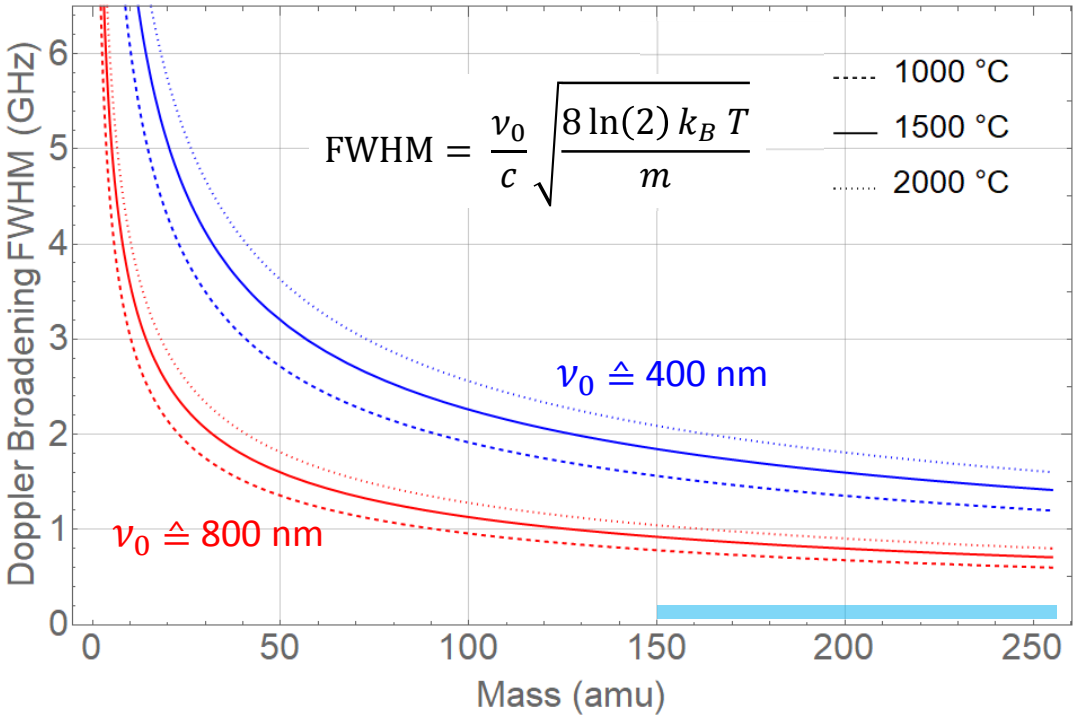
Isotope shift ➔ $\delta\langle r^2 \rangle$



➔ Sub-GHz resolution mandatory for
- Extraction of nuclear structure information
- Laser-based element/isomer selectivity

Sub-Doppler Spectroscopy: The PI-LIST

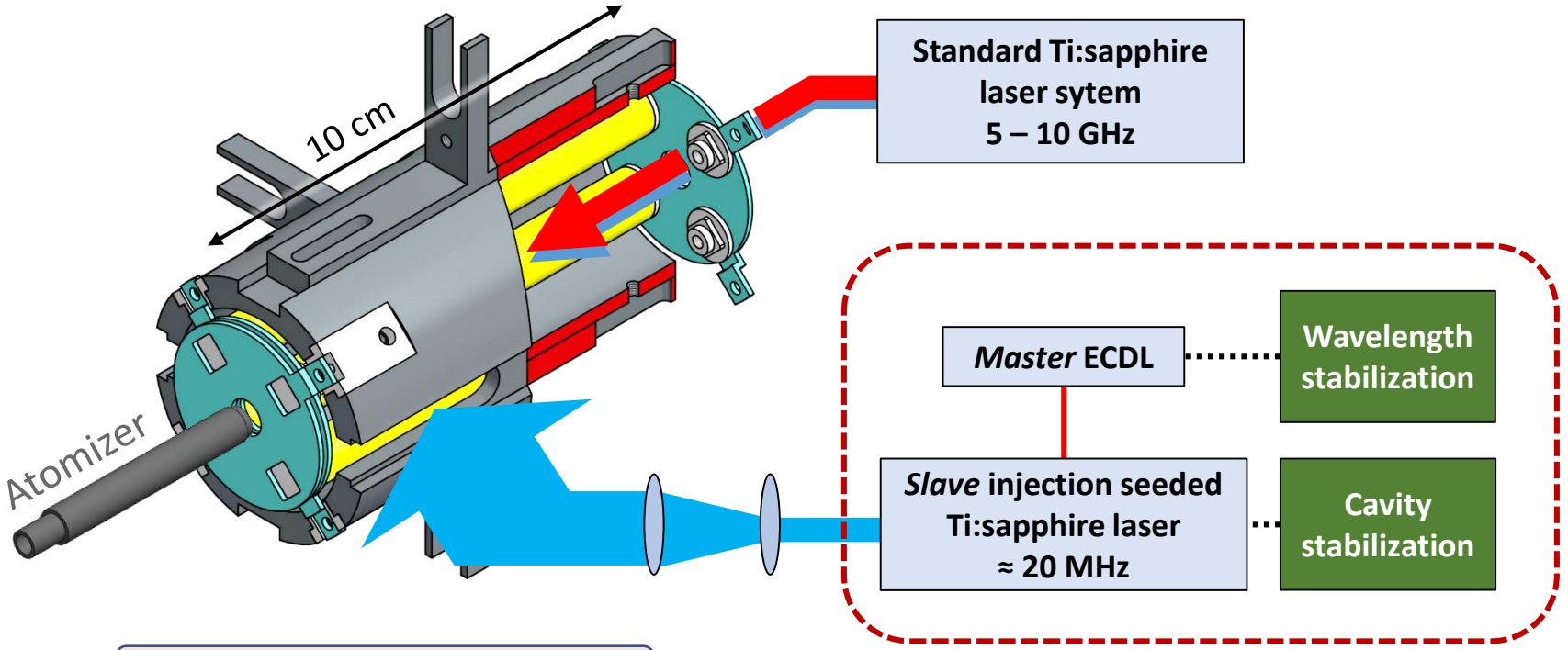




- **Doppler broadening** as ultimate limit for hot atomic vapor spectroscopy
- Selection of **reduced Doppler ensemble** in laser intersection volume
  - Resolution improvement by 1 order of magnitude

➡ The ***P**erpendicularly **I**lluminated **L**aser **I**on **S**ource and **T**rap* ***PI-LIST***

The PI-LIST at Mainz University

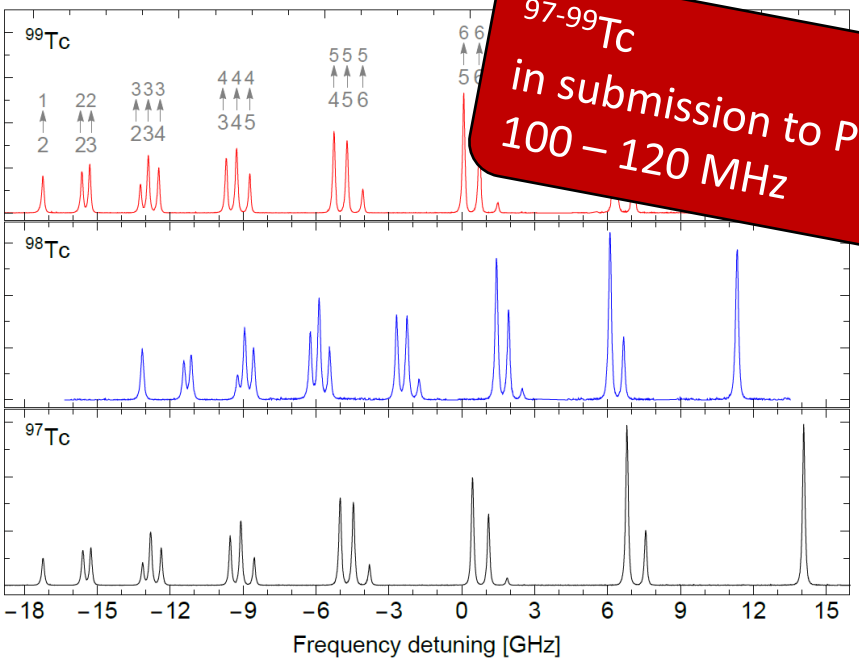


Secondment JGU M9-10

Narrow-band laser system at ISOLDE:
RILIS + CRIS + JYU + JGU

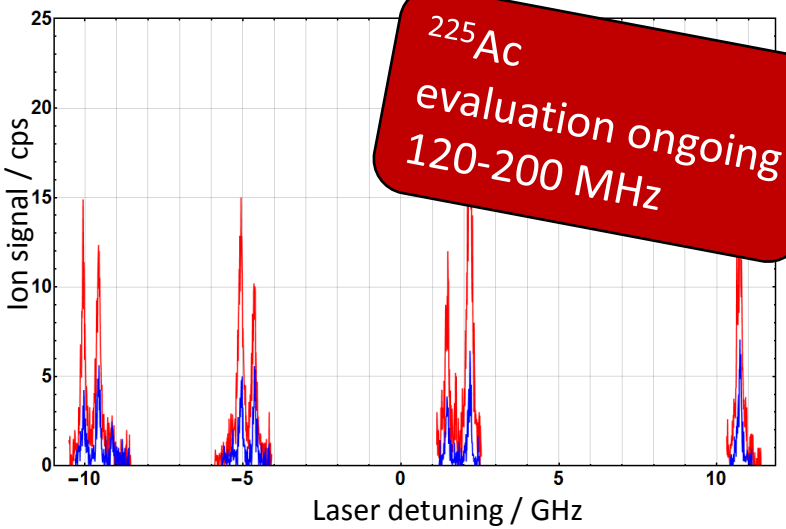
ESR9 (WP2): Development of narrow-linewidth pulsed Ti:Sa Amplifier

PI-LIST Off-line Highlights @ JGU

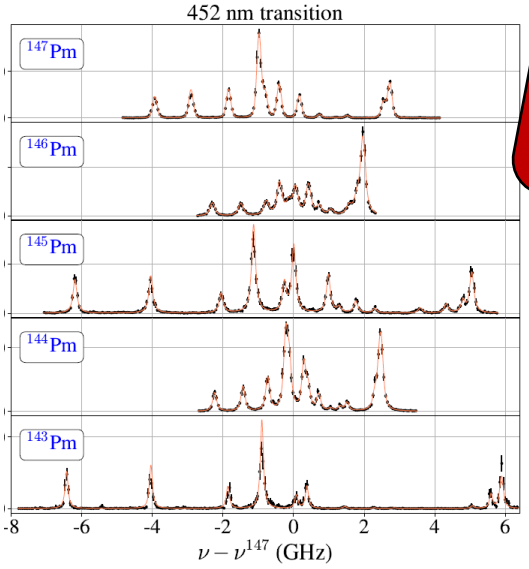


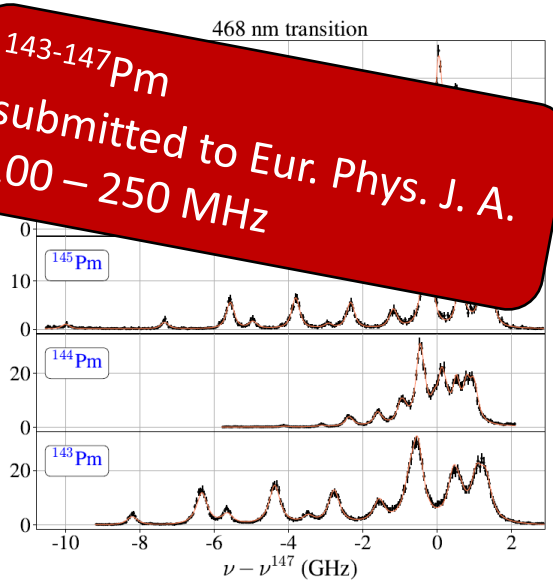
97-99Tc
in submission to PRC
100 – 120 MHz

Secondment JGU M21-22



225Ac
evaluation ongoing
120-200 MHz





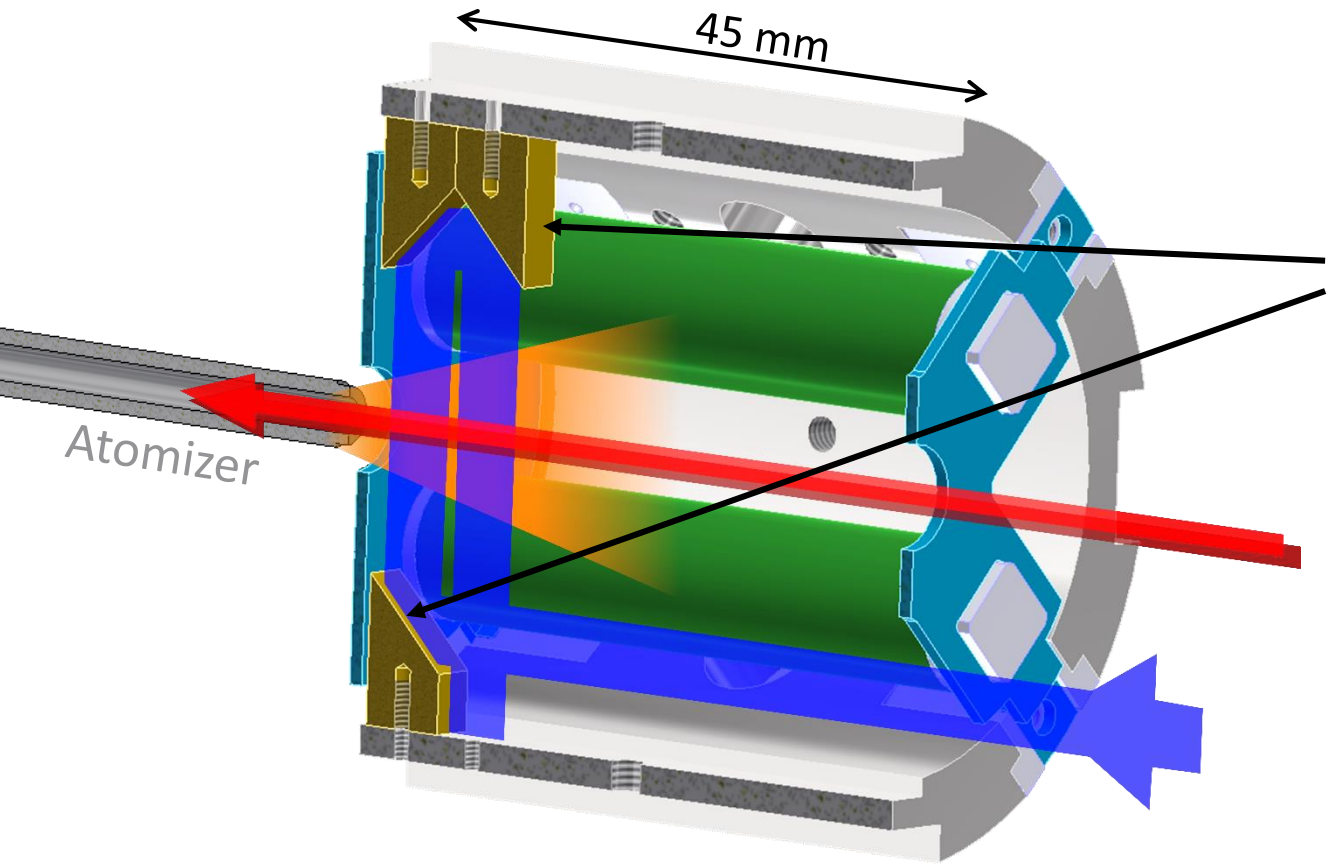
143-147Pm
submitted to Eur. Phys. J. A.
100 – 250 MHz

Resolution benchmark:
- 60 MHz @ U, Rb

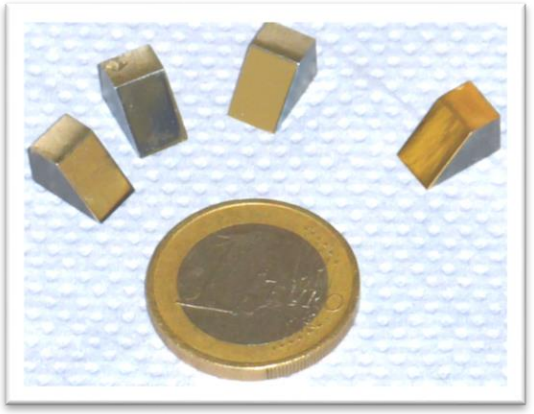
Overall efficiency:
- 10^{-4} … 10^{-5}

No lateral laser access at ISOLDE

PI-LIST on-line



Metallic mirrors

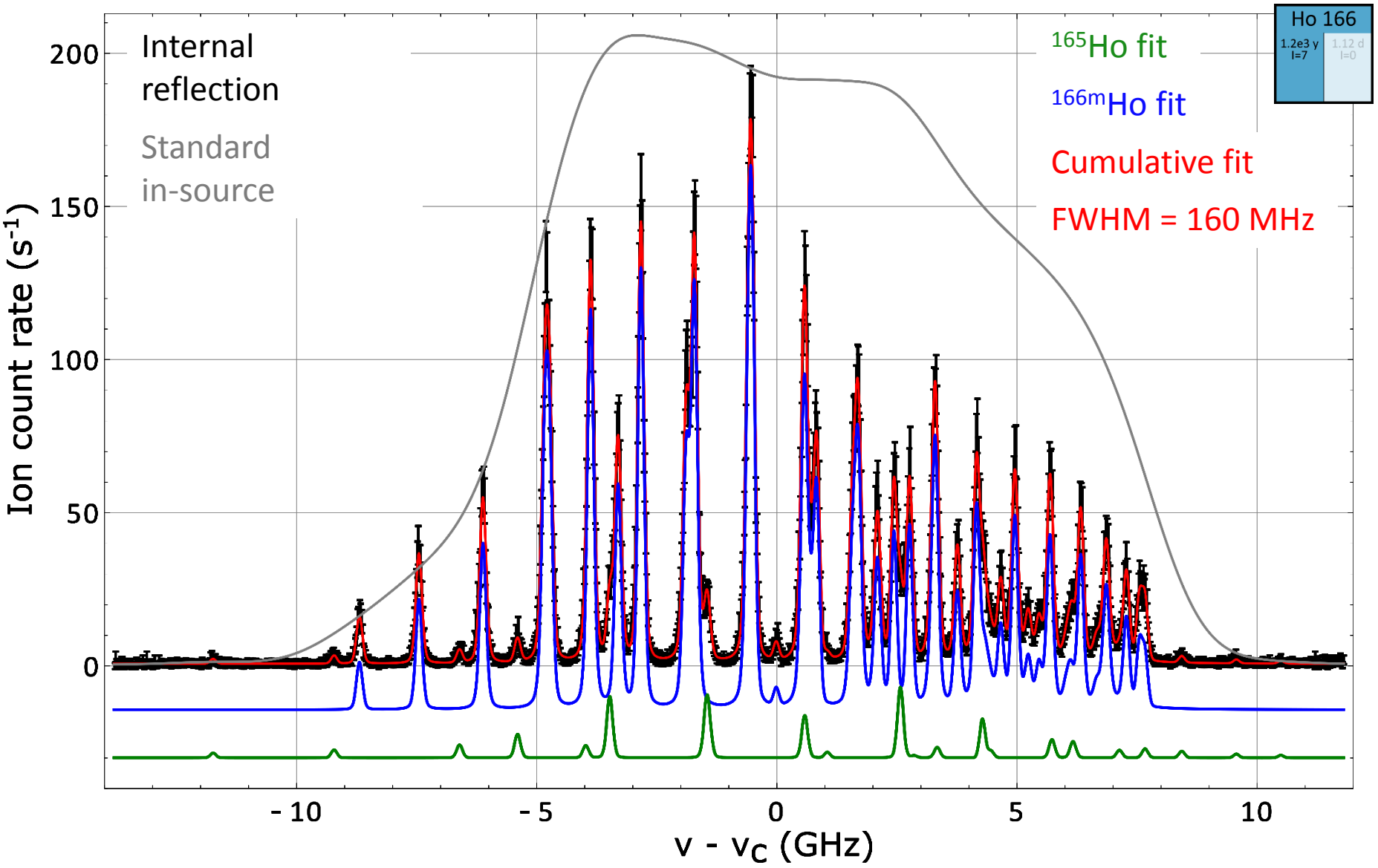


Machined at
JGU mechanical workshop

Optional surface treatment
by pulsed laser deposition

- Transversal reflection by **robust metallic mirror** surfaces
- **Off-axis guiding** of spectroscopy laser through ion beam line

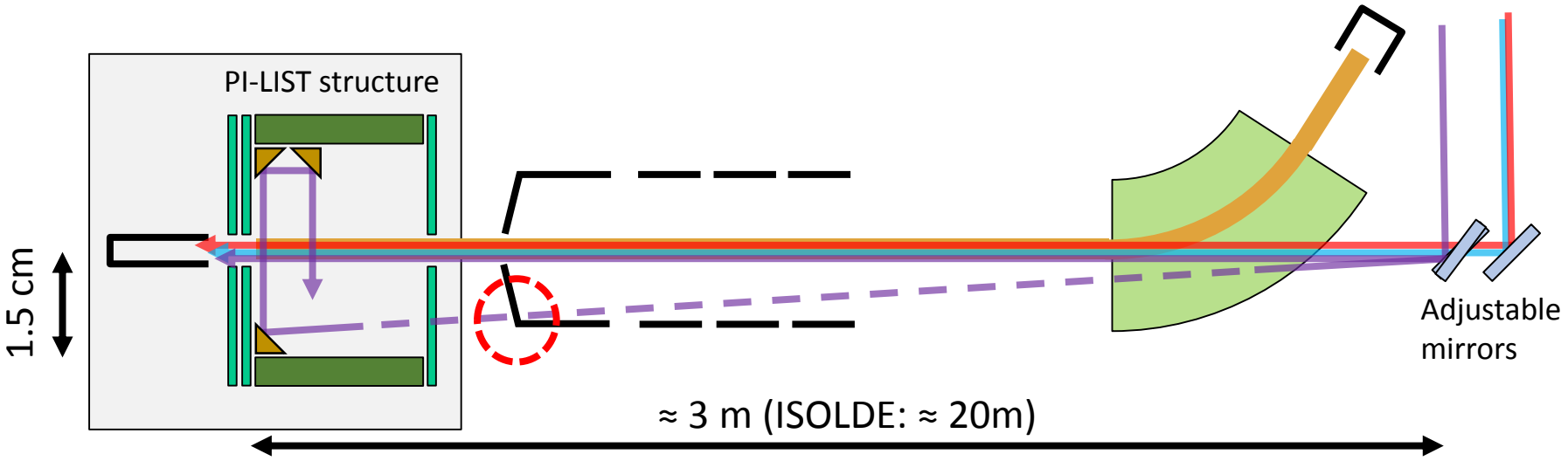
High Resolution Spectroscopy on Holmium

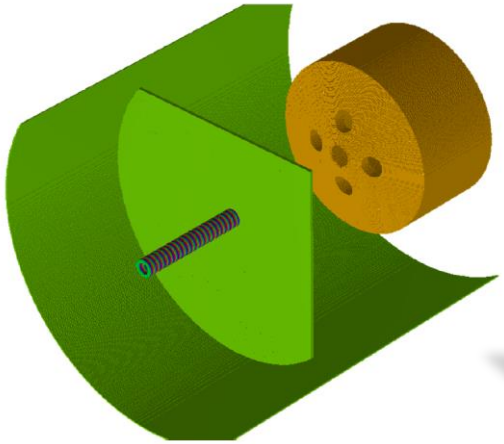


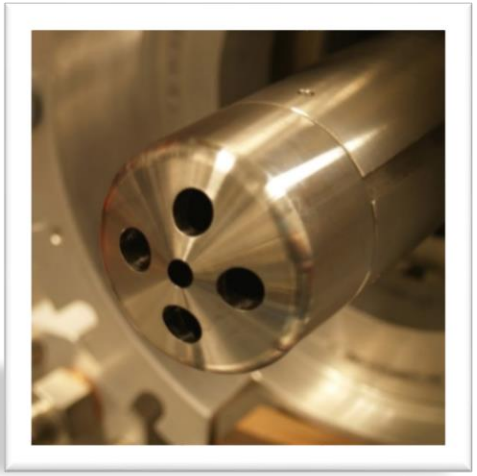
Implementation of the PI-LIST at ISOLDE

Use of existing laser infrastructure - easy mode switching by mirror adjustment

- Full conservation of „classical“ operation modes





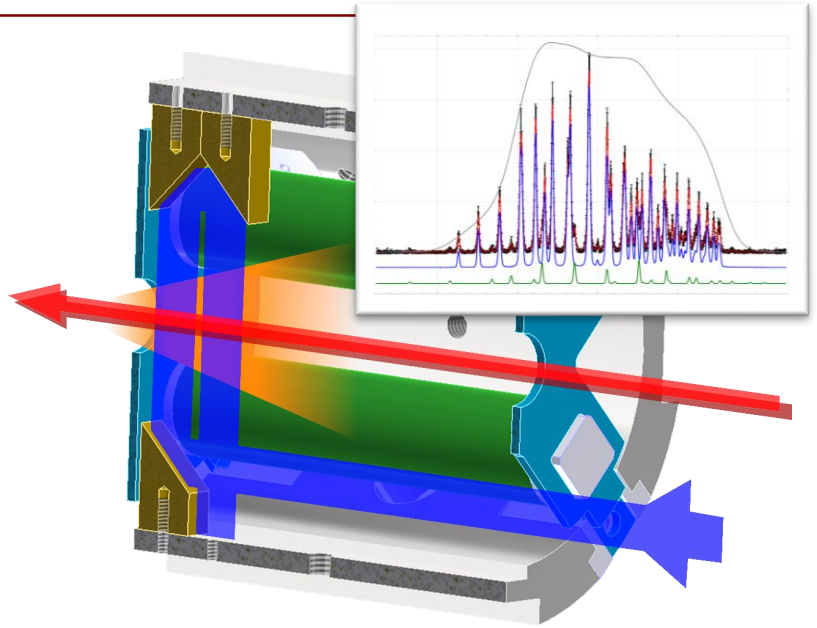


Simulation and implementation successful at JGU for > 1 year

Implementation at ISOLDE:

- Simultaneous change of target and extractor?
- Design change – meshed holes?
- …

Overview and Prospects



- The PI-LIST as tool for Sub-Doppler resolution

  at on-line hot-cavity RILIS systems

  - ✓ Extraction of nuclear parameters on actinides
  - ✓ Additional purification and isomer selectivity
  - ✓ Success in various off-line experiments at JGU

- Implementation at ISOLDE (ESR2 – based at CERN, enrolled at JGU (Prof. K. Wendt))

  - ➢ Realization of lateral laser access / off-center guidance through beam line
  - ➢ Validation of perfomance: resolution and efficiency
  - ➢ Long-term behavior under harsh conditions (radiation, heat, and outgassing)
  - ➢ High resolution spectroscopy on actinides / production of isomer-pure ion beams

ESR2	**CERN**	**Y**	**Start: M6**	**Duration: 36**	**D2.2**
Project title: Development of high-resolution in-source hot-cavity RILIS methods for actinides. (**WP2**: Novel techniques and technologies for actinide research)					
Objectives: Combining the unparalleled sensitivity of in-source resonance ionization spectroscopy with the resolution required to resolve sub 1 GHz hyperfine structures and isotope shifts in atomic transitions of actinides. For this goal, the work towards the implementation of the PI-LIST device (perpendicular-illuminated Laser Ion Source Trap) shall be performed at ISOLDE. This will include the design and setup of infrastructure required for the on-line PI-LIST operation followed by characterization of its performance and high-resolution laser spectroscopy studies using the PI-LIST. Optimal ionization schemes for actinium (together with ESR1) and protactinium shall be established in the frame of this project. The eventual application of PI-LIST for actinide elements at ISOLDE will rely on the successful extraction of actinium and protactinium isotopes from an ISOLDE target (ESR3). The two fellows will closely collaborate to ensure the complementarity of these development projects. Development of optimal ionization schemes of actinides for ISOLDE will be performed via laser spectroscopy of actinide elements in close collaboration with JGU (ESR5). Such links are already established and will be further enhanced in the course of the proposed ITN.					
Expected results: Implementation of the PI-LIST at ISOLDE on-line isotope separation facility [D2.2]; demonstration of sub-Doppler resolution and enhanced isomer selectivity using the PI-LIST; selection of the optimal laser ionization schemes for actinium and protactinium; new experimental results on IS and HFS of atomic transitions in actinides (WP4&5).					
Planned secondment(s): JGU (Klaus Wendt) – M9-10 – training and study of PI-LIST at RISIKO mass separator; TRIUMF (Jens Lassen) – M15-16 – training and study of LIST operation at the ISAC facility; JGU (Klaus Wendt) - M21-22 – laser ionization studies of actinides.					
Enrolment in Doctoral degree: JGU Institute of Physics under the supervision of Prof Klaus Wendt					

- Necessity of high res: Doppler limit vs. HFS size, isomer selectivity
- LIST as ion source, PI-LIST upgrade (off-line at RISIKO)
- Successful experiments + resulting papers
  - Special remark holmium
  - Pm, Tc, Ac
- Benchmarks?
- Technical integration, obstacles
  - Laser system existing at RILIS
  - Freshly made units (and support) from Mainz
  - Mirror performance in radioactive/outgassing environment/high temperature/long term
  - Laser beam path! Extraction electrode -> permament, changeable
  - Validation of operating parameters (efficiency, purity esp. isomer, tradeoff linwidth efficiency)
- Alternative 2-photon? Doublecheck with RILIS…