Comparison of Resonance Ionization in High- and Low-Voltage Mass Separators

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Laser Resonance Ionization Spectroscopy for Selected Applications

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Motivation

Use of different type offline mass separators for similar purposes:

- Search for excitation schemes
- Ion source developments
- Resonance ionization spectroscopy on stable isotopes

General goal is the achievement of

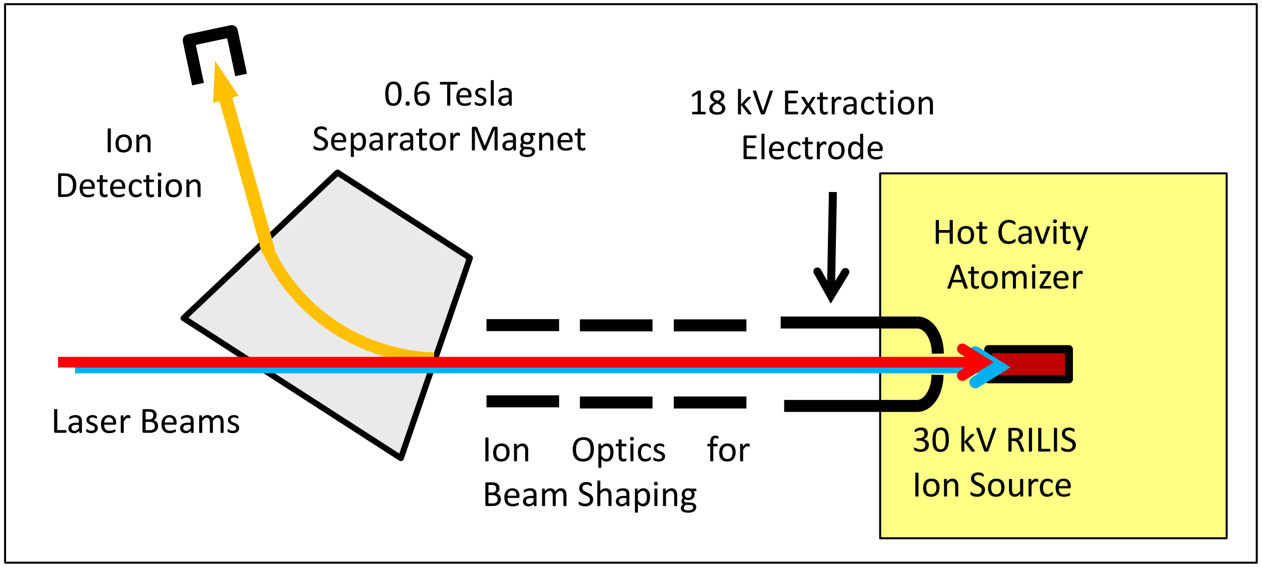
- Highest ionization efficiency
- High spectral resolution
- Optimum background suppression

But: How do the characteristics of the mass separator affect these parameters?

The Mainz RISIKO Mass Separator

(RISIKO – Resonance **I**onization **S**pectroscopy in **KO**llinear Geometry)

- 30 kV ion energy
- Two step acceleration (ISOLDE 2 design) - intermediate extraction electrode on 18…22 kV
- Atomizer oven: Tantalum, up to 2500 K
- Ion detection with current readout of a Faraday Cup or ion pulse counting from SEM
- Source region identical to present ISOLDE sources



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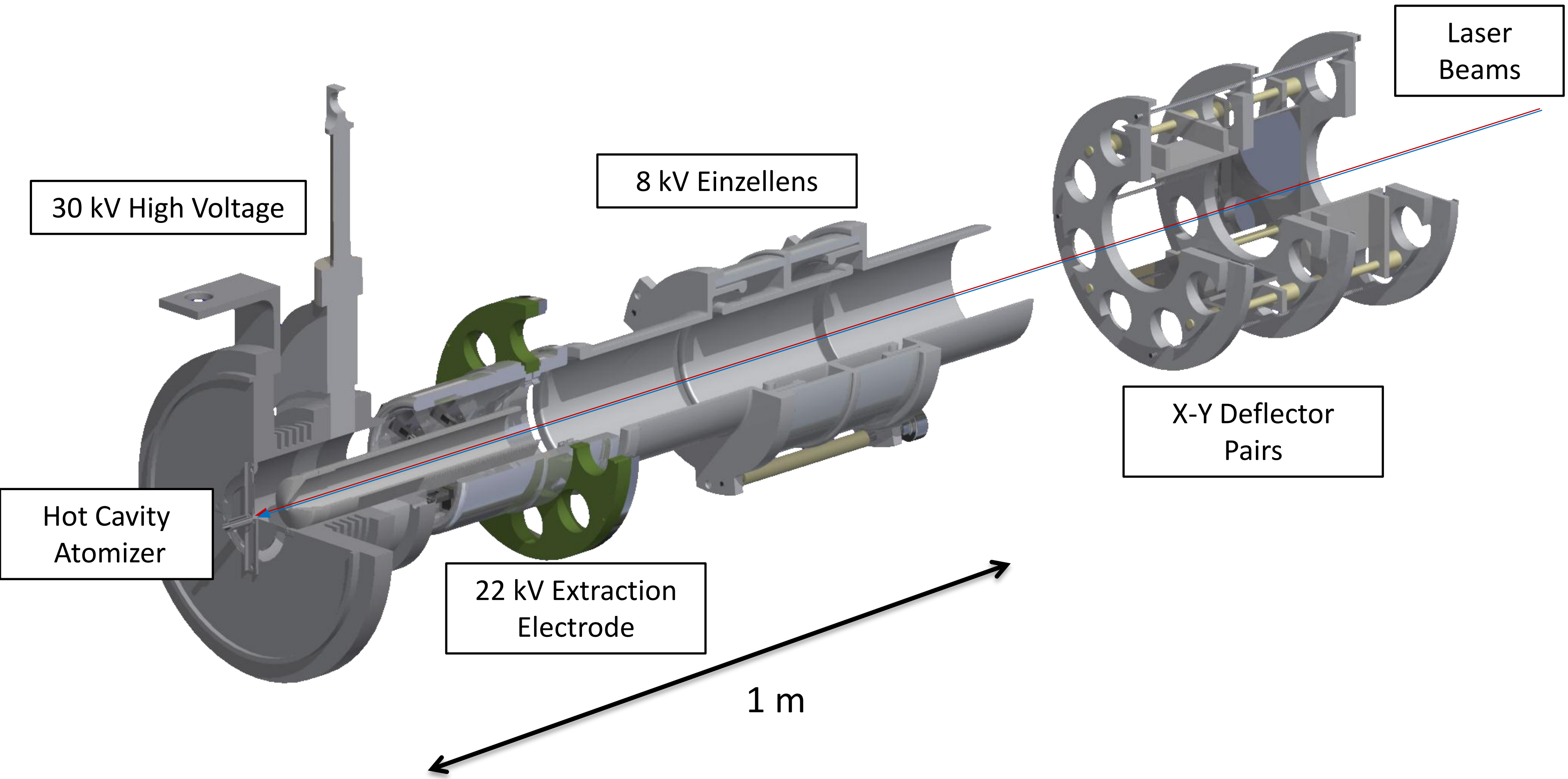
RISIKO Mass Separator

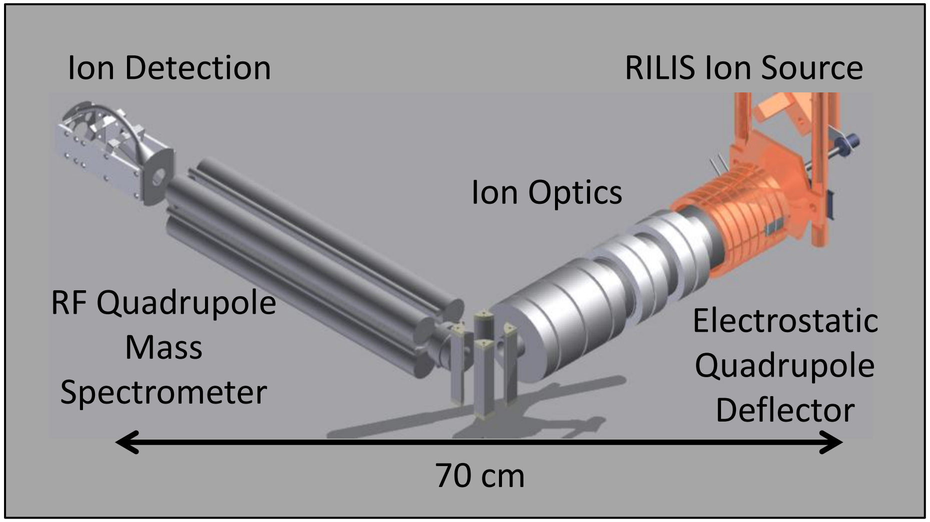


Offline Mass Separators

Compact mass separator

MABU – Mainz Atomic Beam Unit:

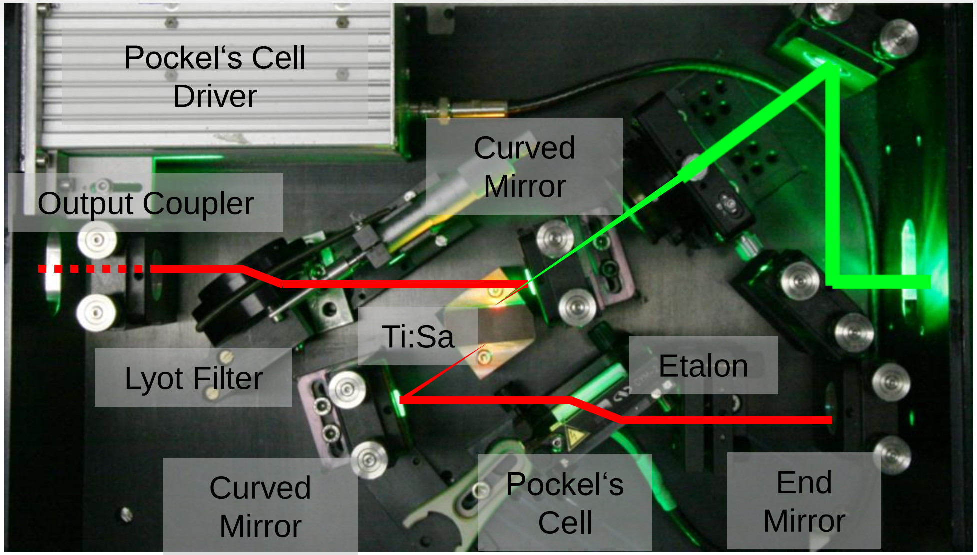
- 30 V ion energy
- Atomizer oven: Graphite, up to 2300 K – cheaper to change
- Mass separation with a RF quadrupole
- Very compact and simple – no HV needed
- High resolution spectroscopy possible with transversal excitation

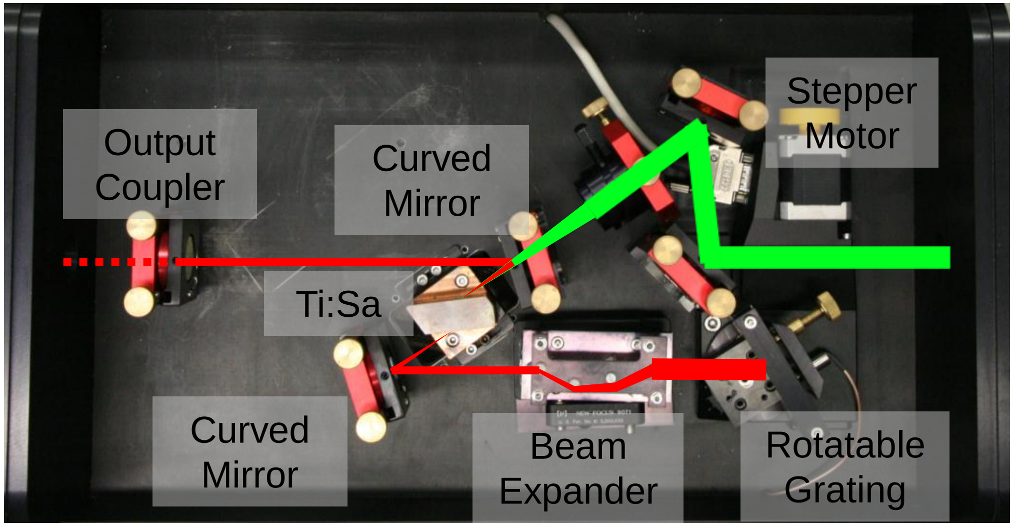


Laser System

Tunable Titanium-Sapphire Lasers:

- Pulse length of 30 ns with a repetition rate of 10 kHz
- Wide tuning range from 700 to 1000 nm
- High output power, up to 4 W
- Pumped by commercial frequency doubled Nd:YAG with 12..20 W





Grating tuned Titanium-Sapphire Laser:

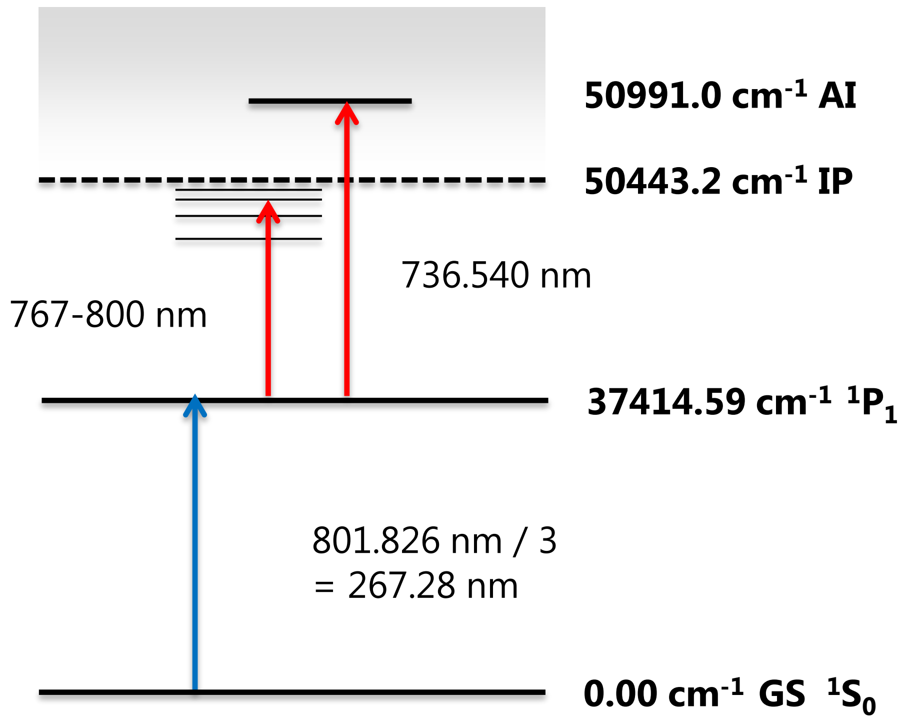
- For spectroscopy purposes
- Wavelength selection using a grating
- Lower output power
- But allows automated, mode-hop free scans of the complete tuning range

Ytterbium

Ytterbium as test candidate:

- Evaporates at intermediate temperatures
- RIS possible with high efficiency, as high as 35% reported by Alkhazov et al. (1989) – using a three step resonant scheme
- Undisturbed spectrum due to closed shells
- Measurements on most abundant isotope ^{174}Yb

Excitation Scheme



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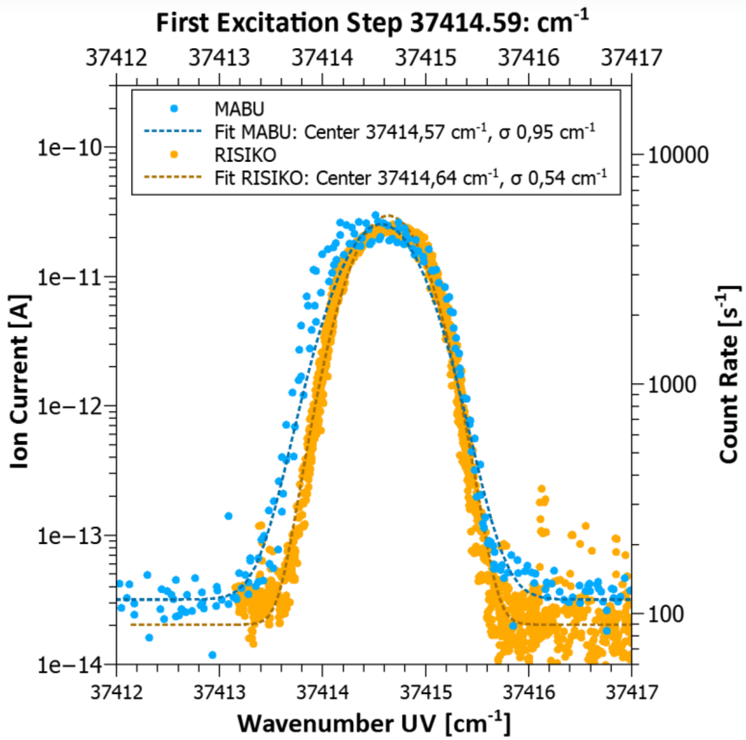
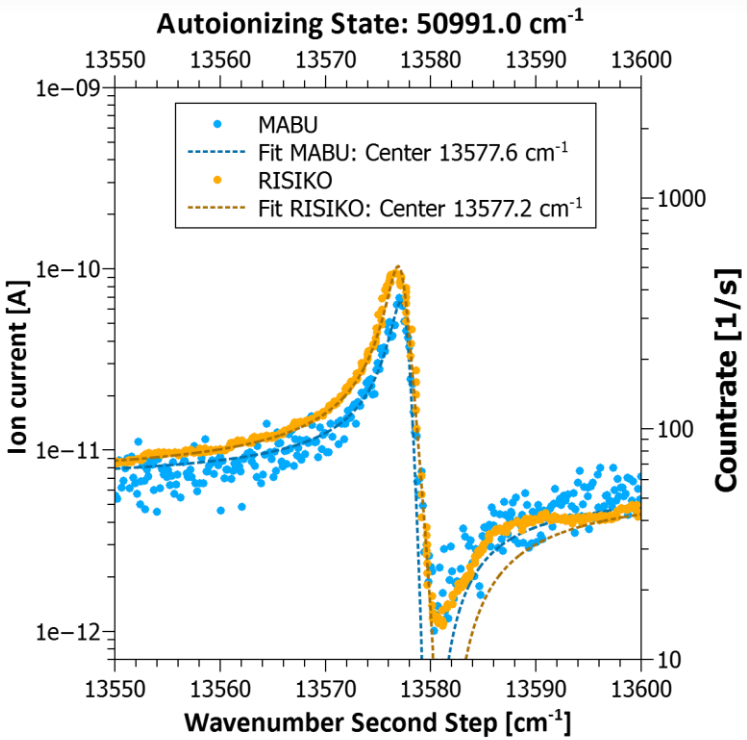
Spectral Scans





- Very similar spectra in the two step excitation using an AI transition
- Here the AI ion signal is about 10 times stronger than non-resonant ionization

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Performance Comparison

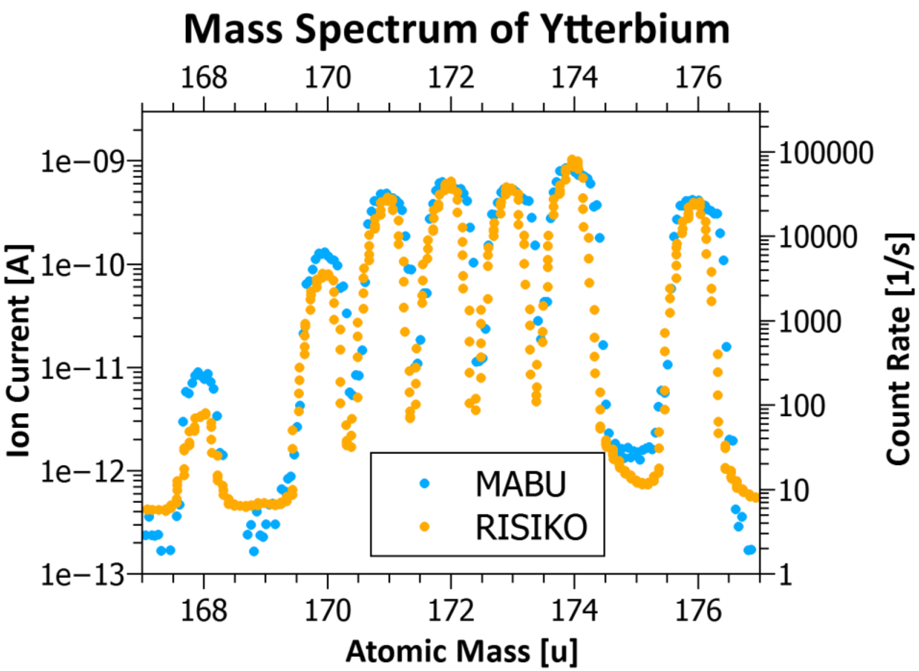
Machine performance:

RISIKO:

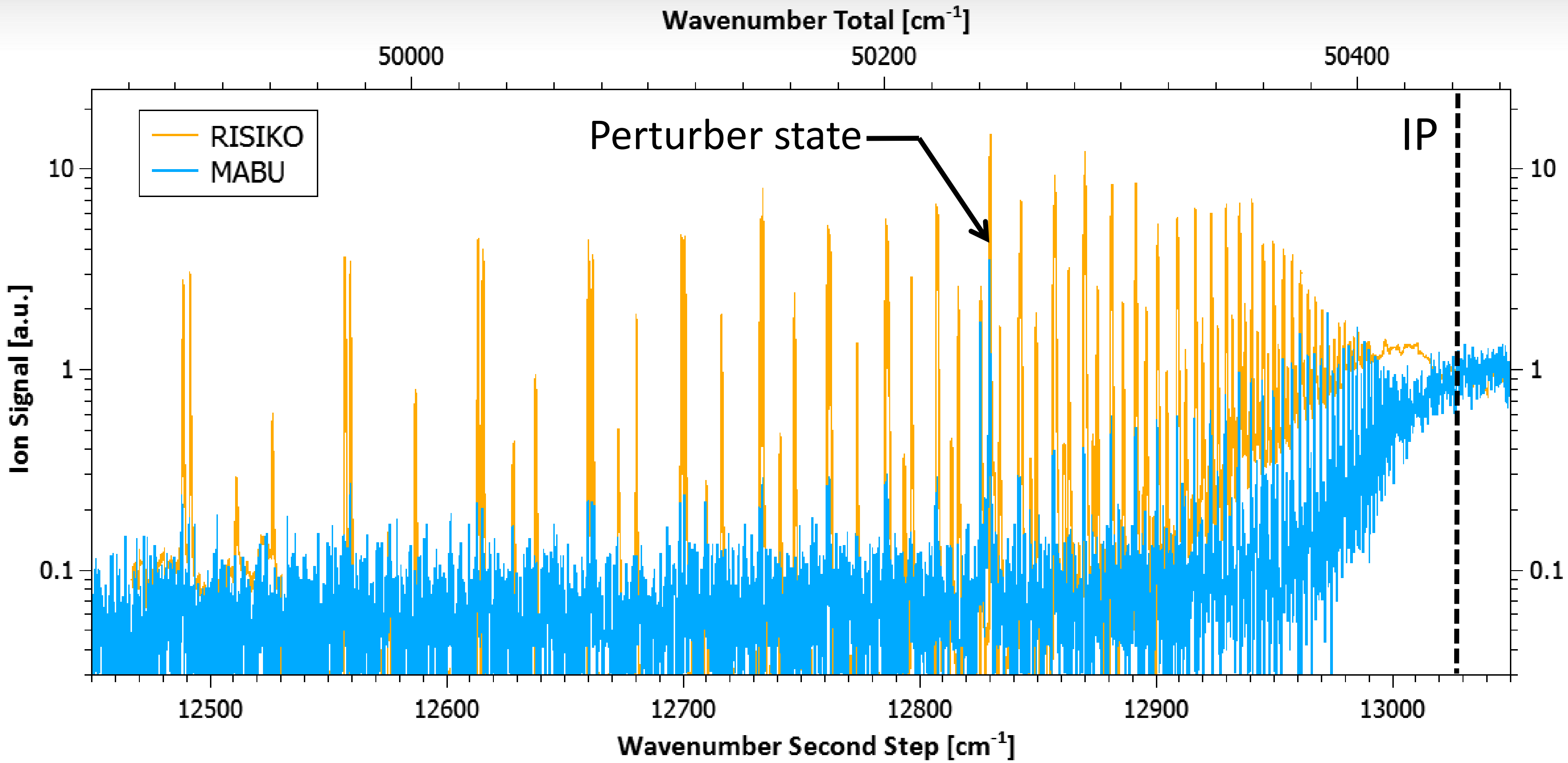
- Overall efficiency of **25%**, including separator magnet transmission and ion detection efficiency of 70%
- Mass resolution of 400

MABU:

- Overall efficiency of **0.9%**, translates to an efficiency of the QMS system of about 2.5%
- Similar mass resolution, even for masses > 240 u

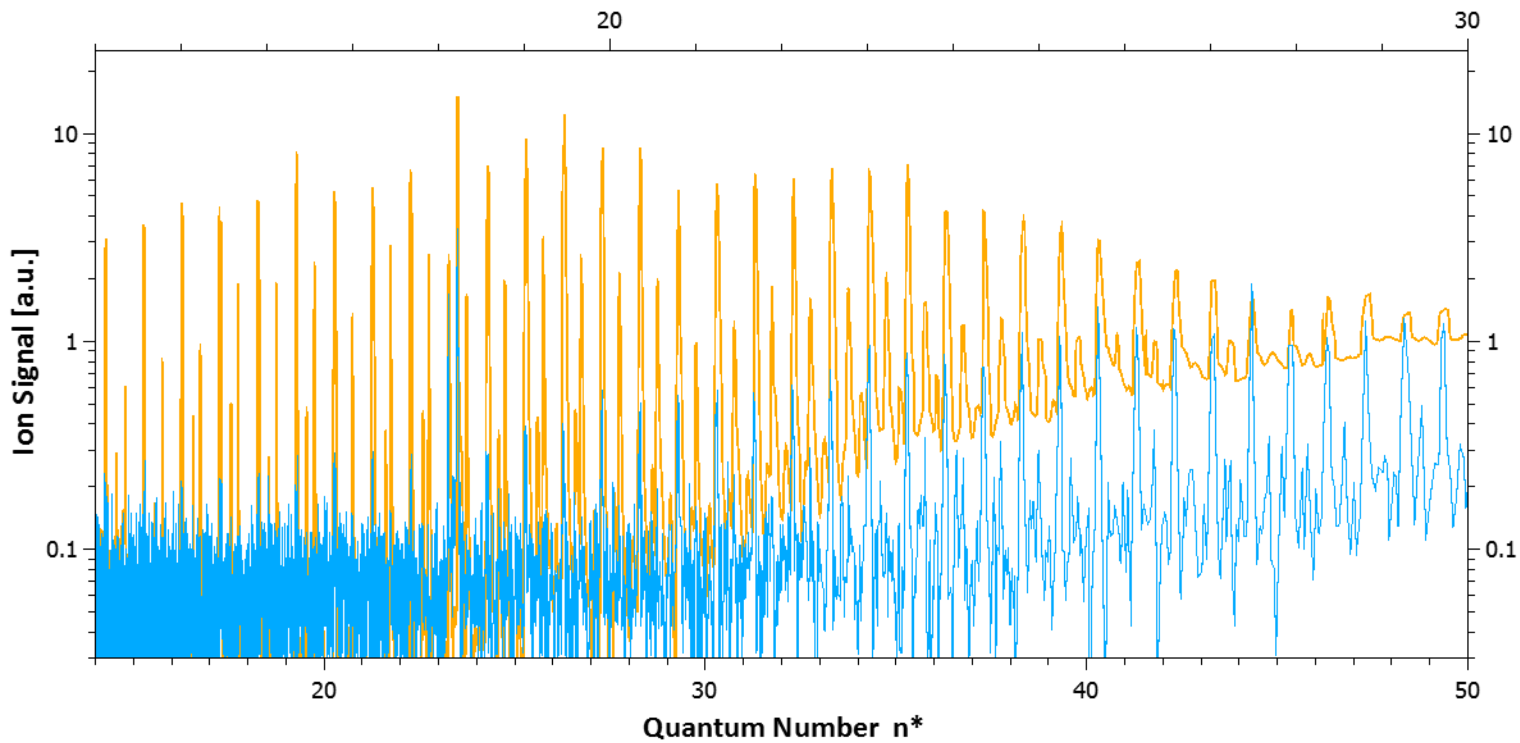


Rydberg Spectroscopy



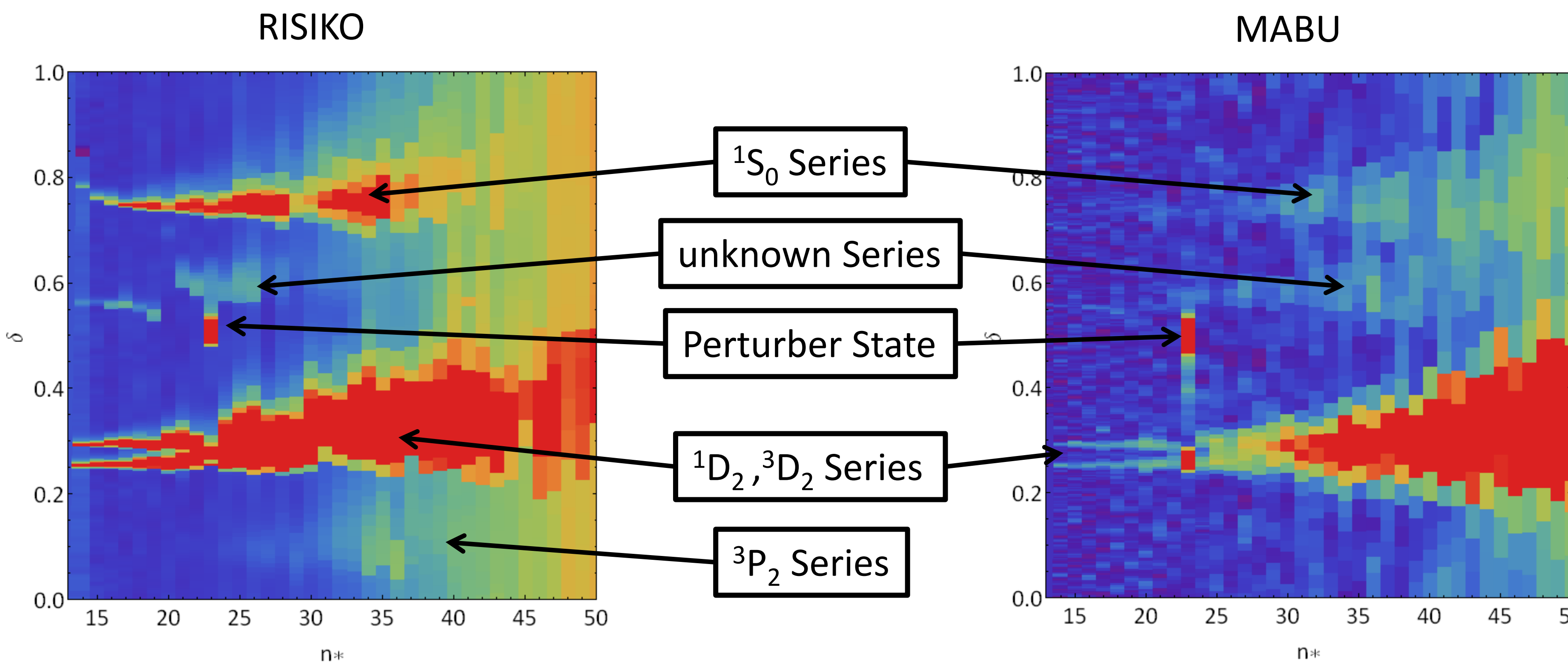
- Long range scan with low laser power using the grating tuned Ti:sapph
- Several Rydberg series visible, strongly enhanced in RISIKO spectrum
- Very strong perturber state at 50244.3 cm^{-1}

Rydberg Series Analysis



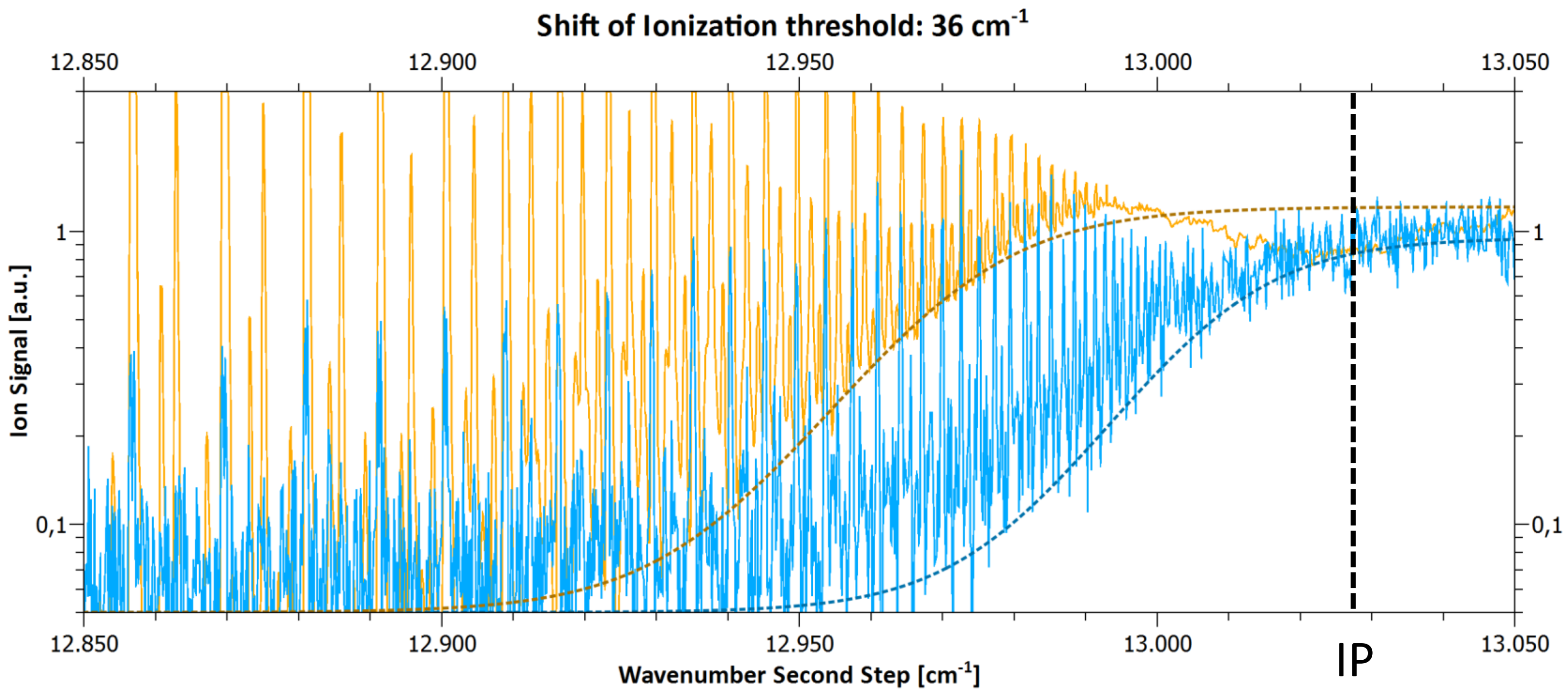
- Same data plotted against prinicipal quantum number
- Peak positions converge to the same ionization potential in both spectra
- Any shift in the resonances is smaller than the laser linewidth (~8 GHz)

Rydberg Series Analysis



- Both measurements are in reasonable agreement with literature values for $^1D_2$, $^3D_2$ and $^1S_0$ Rydberg series
- Some weak peaks belonging to $^3P_2$ series visible in the RISIKO data
- An additional series is visible, that is unknown in the literature

Non-Resonant Ionization



- Distinct shift in the behaviour for non resonant ionization between the spectra
- Amounts to a threshold of 36 cm^{-1} lower in RISIKO than in MABU
- But no absolute shift assignable

Electric Field

Most likely cause:

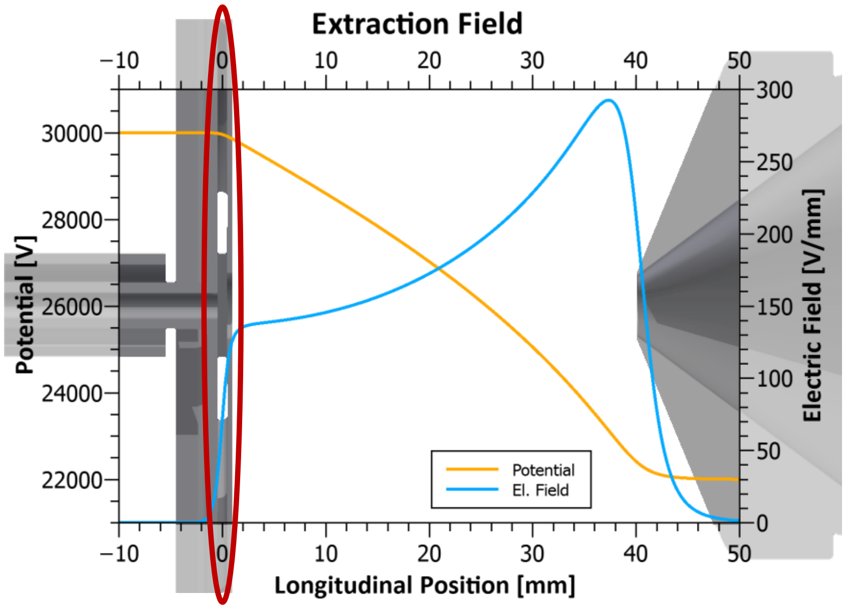
Lowering the ionization threshold by the electric field of the extraction

RISIKO:

- Extraction Field Strength: 150…300 V/mm

MABU:

- Extraction Field Strength: 2…5 V/mm
- Field does not penetrate into the oven region



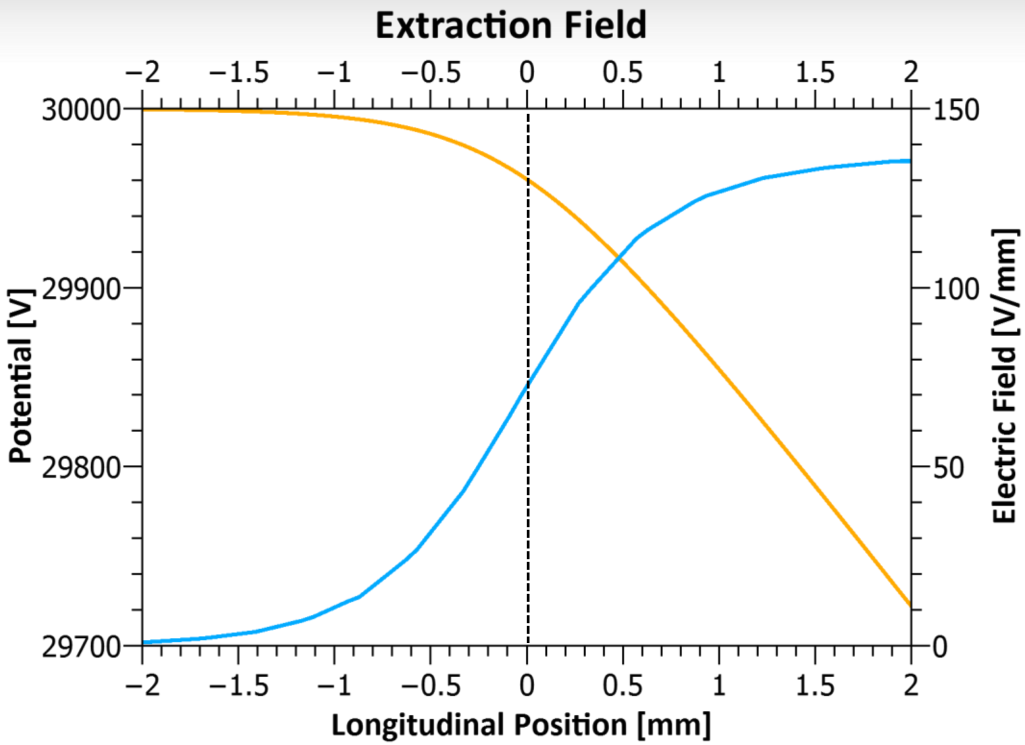
Oven

Extraction Electrode

Field Penetration

Maximum field in the oven:

70 V/mm



Considerations:

- Ions with E < 29900 eV are detected on a lower mass
- Range of rydberg atoms before decay is only some mm
- Mean thermal velocity: 0.5 mm/µs, radiation lifetime 5 µs for n=20

Conclusion

Resonance ionization spectroscopy results are transferable between both machines:

- Nearly identical excitation spectra for the first excited step and the auto ionizing state
- Very similar mass spectra

But in case of Rydberg excitation they strongly differ

- The penetrating extraction field of 70 V/mm allows field ionisation effects
- Increased signal on Rydberg states, even for energies more than 500 cm^{-1} below the IP
- Decreased non-resonant ionization threshold by 40 cm^{-1}

Depending on the specific ion source schemes with Rydberg states have to be considered among the most efficient schemes

Thank you very much for attention!

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