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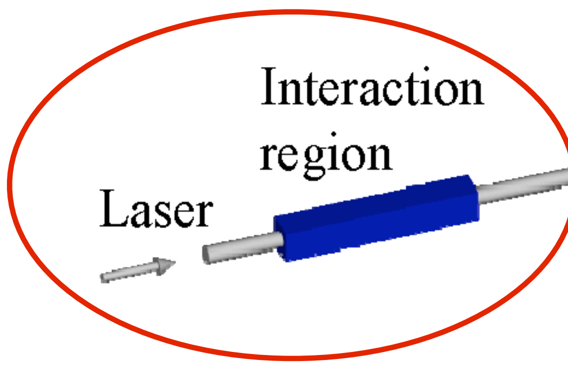
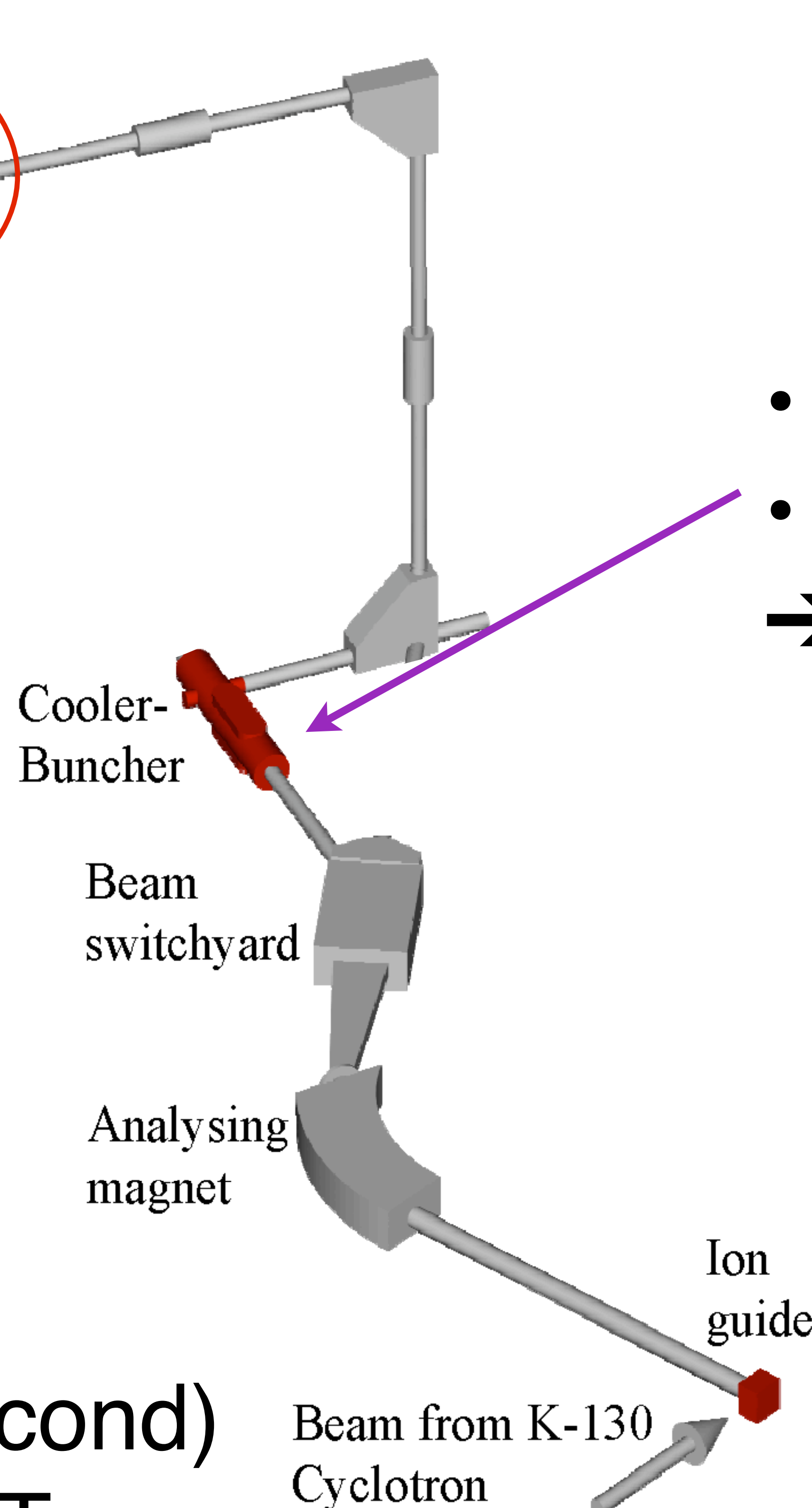
Extending laser spectroscopy with optical pumping

At the university of Jyväskylä, Finland

Laser spectroscopy at JYFL

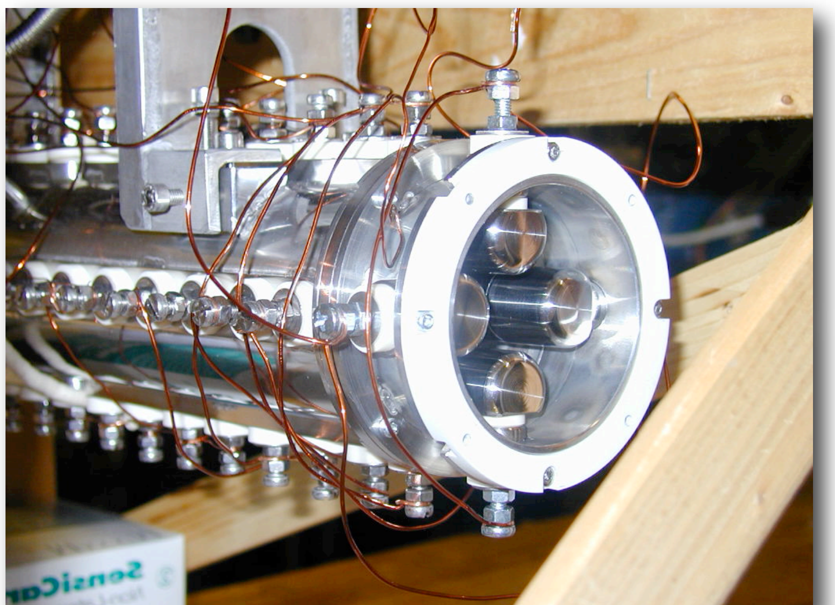


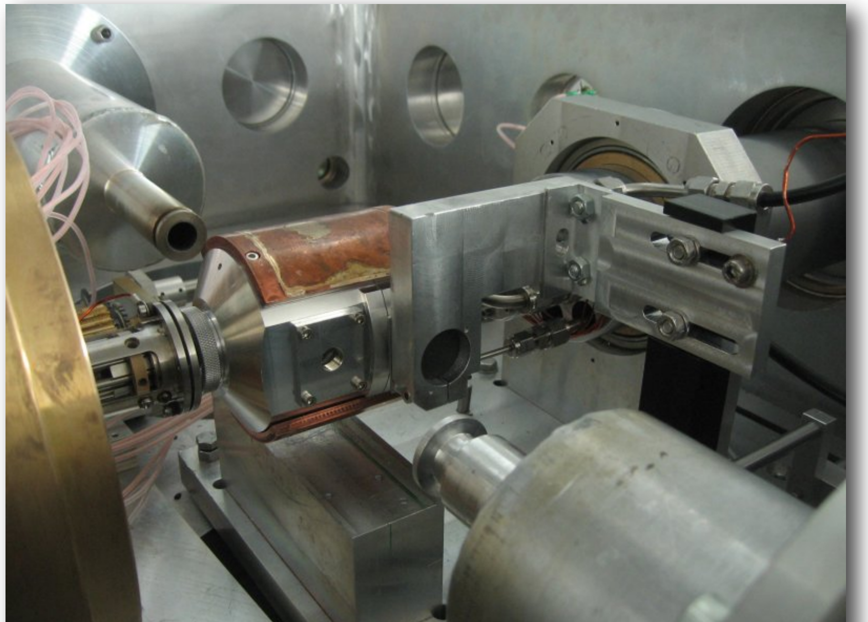


Gas filled RFQ

- Bunched beams
- Reduced emittance

➔ Lower background





IGISOL

- Fast (sub-millisecond)
- Chemistry - Mo, Ta...

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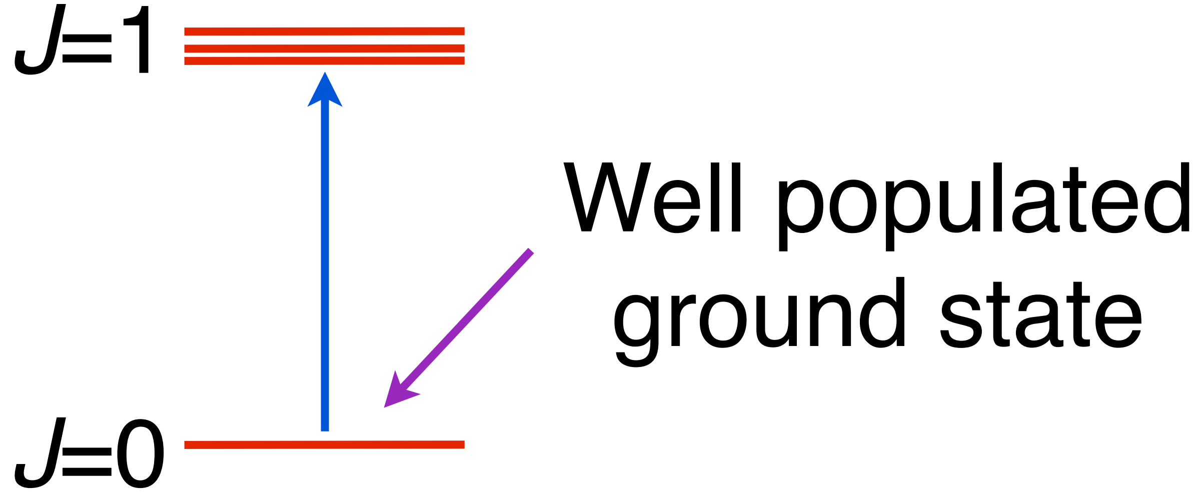
Ground state transitions



But....

- $0 \rightarrow 1$ gives μ, Q_s, $\delta\langle r^2 \rangle$, ~~$I$~~
- Difficult to calibrate atomic factors
- Not necessarily the most efficient
- No accessible transitions (HR, cts)
- Hyperfine anomaly?
- Second order perturbed?

eg.

Y,Nb

Y

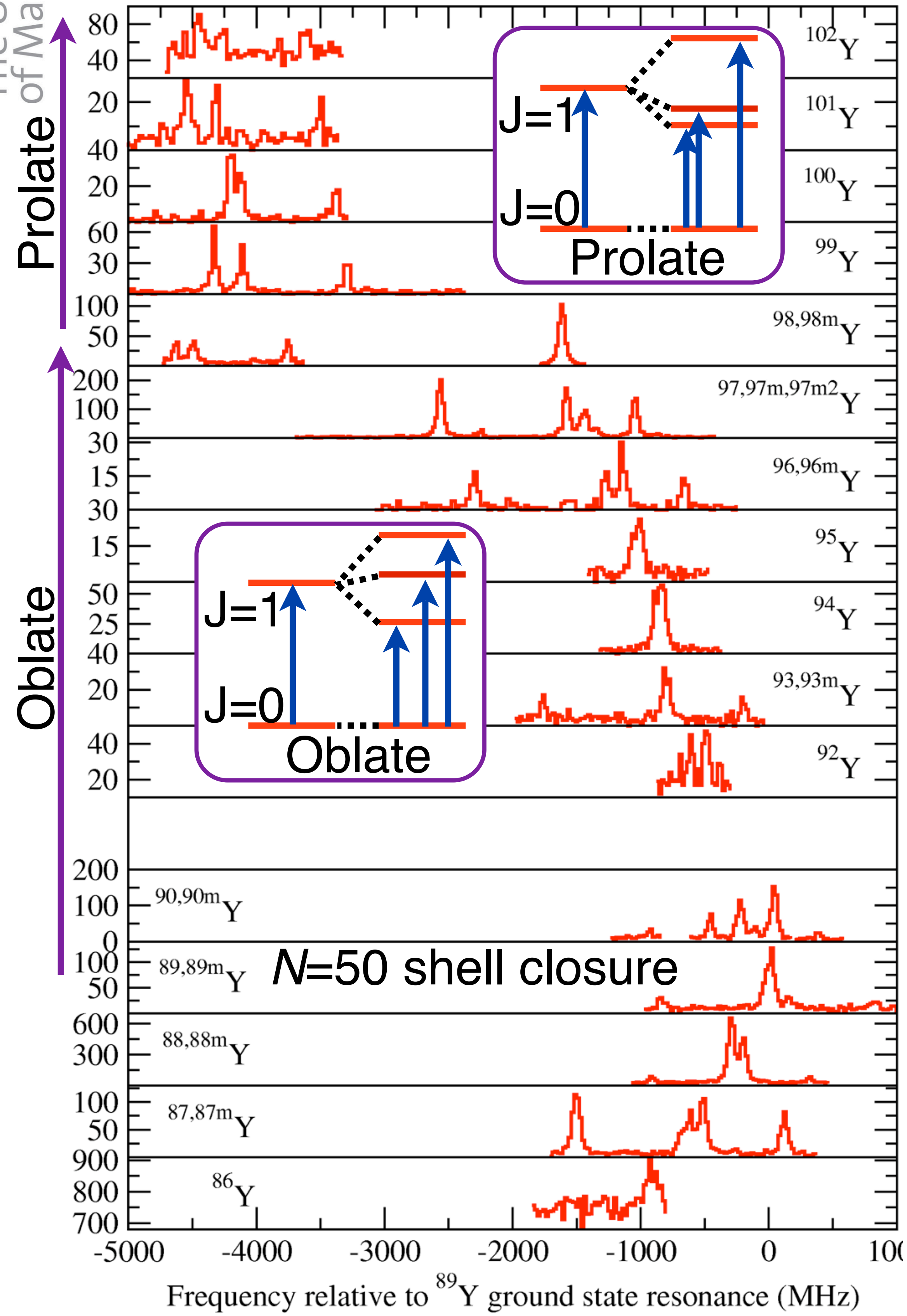
Nb

Mo

Ta

Ta

Case 1: Spectroscopy of yttrium



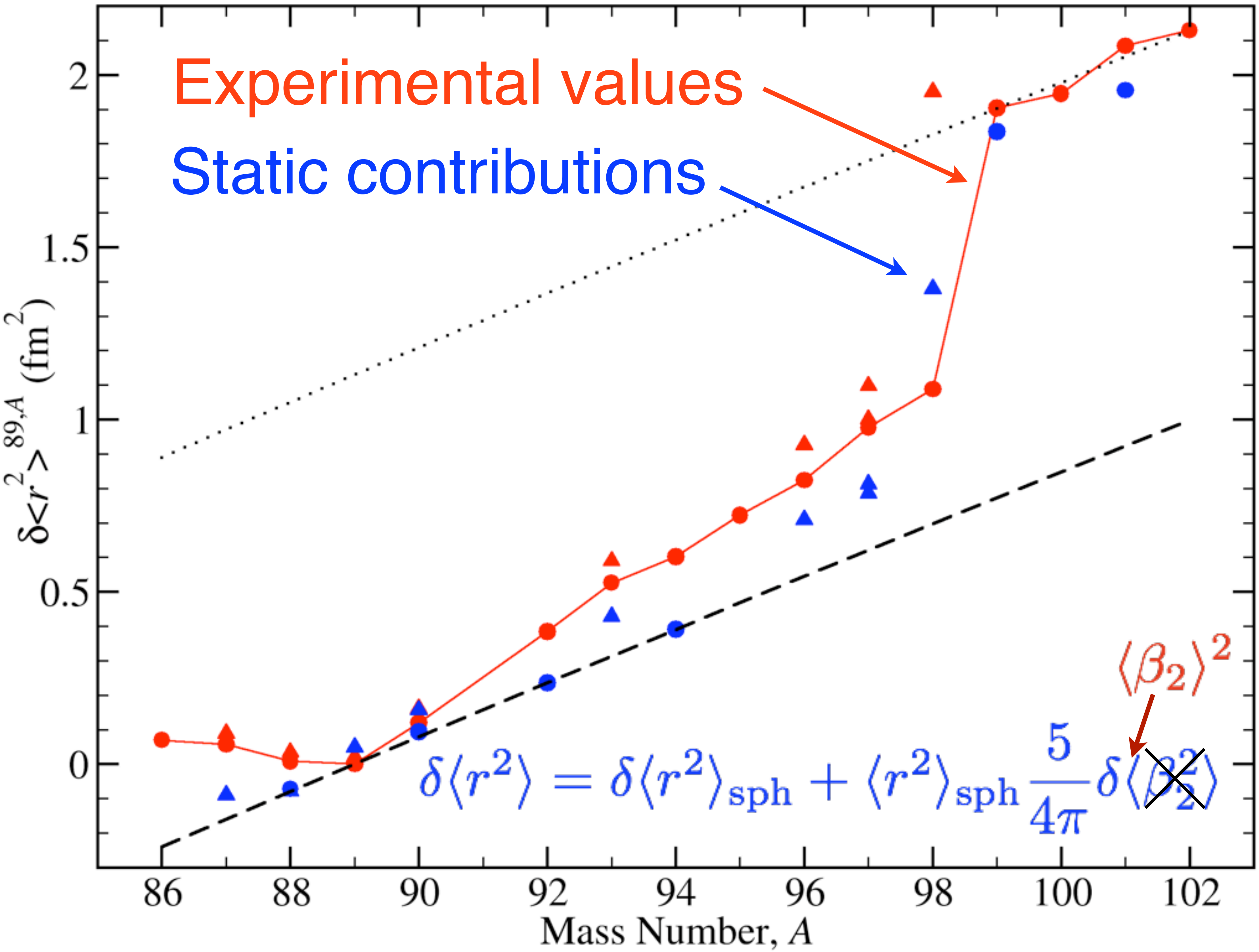
- Rich in isomers $I > 1/2$
- Large onset of deformation

- $J=0 \rightarrow J=1$ electronic transition

➔ 3 peaks (maximum) for each nuclear state

➔ $\delta\langle r^2\rangle$, μ, Q_s (but *not* the spin)

Droplet model analysis



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Potential energy surfaces

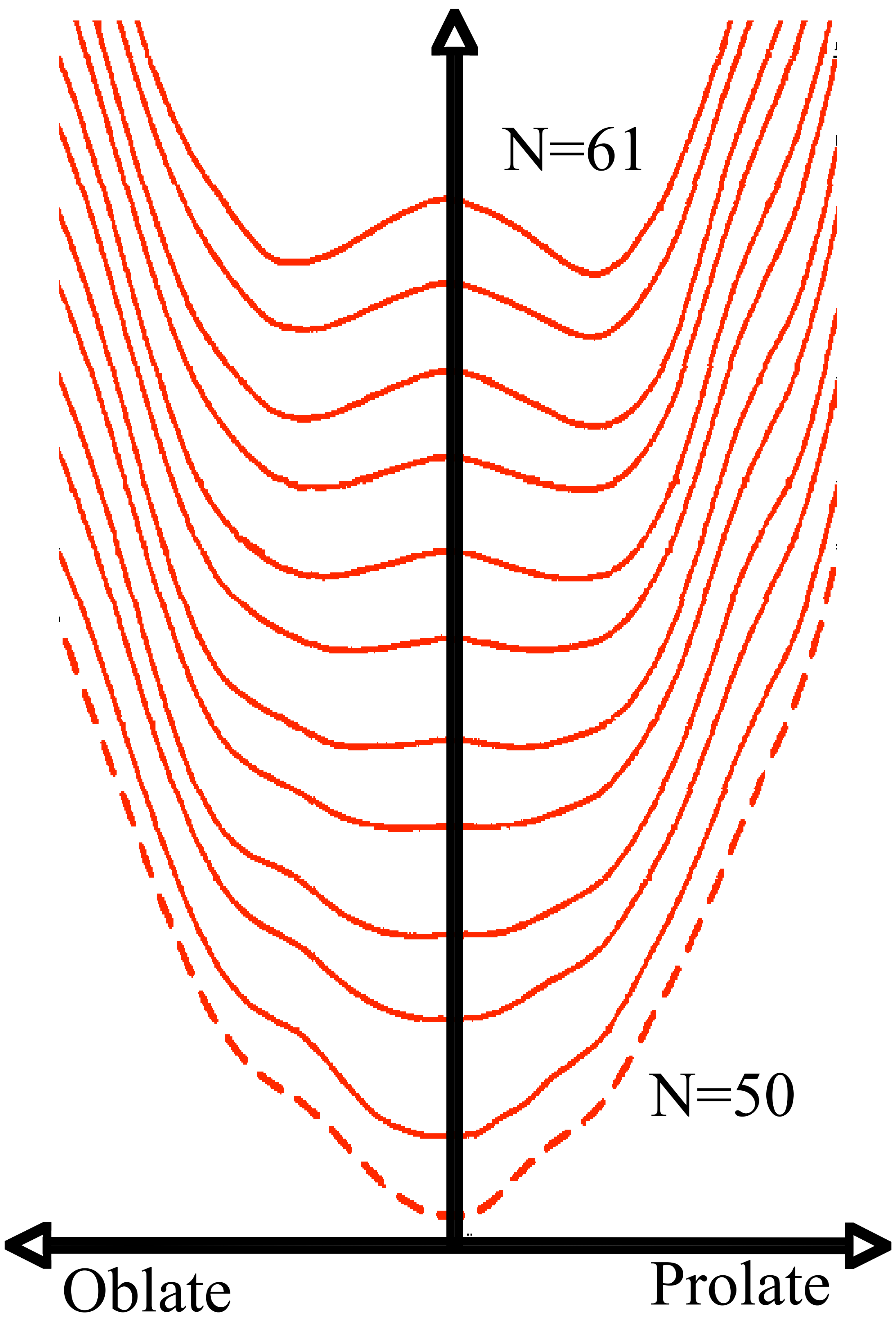
Potential well splits
(strong prolate favourable)

↑

Potential well flattens
(increases β_2-softness)

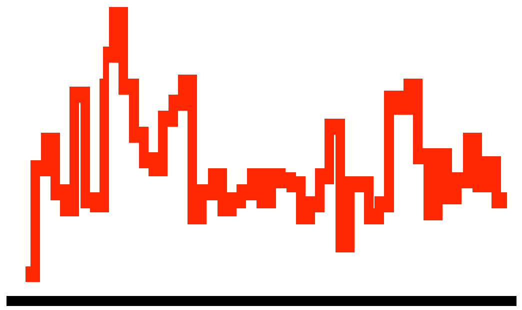
↑

Near-spherical nuclei



Problem of spin determination

A	I^{π}	A_{hf} (MHz)	B_{hf} (MHz)	μ (μ_N)	Q_s (b)	$\delta\nu^{98,98m}$ (MHz)
98m	(4)	−88.3(0.6)	+324.7(4.2)	+2.98(2)	+1.73(19)	−2746(3)
98m	(5)	−73.7(0.4)	+339.1(4.2)	+3.11(2)	+1.80(20)	−2735(3)



Similarly with A=102 and A=100

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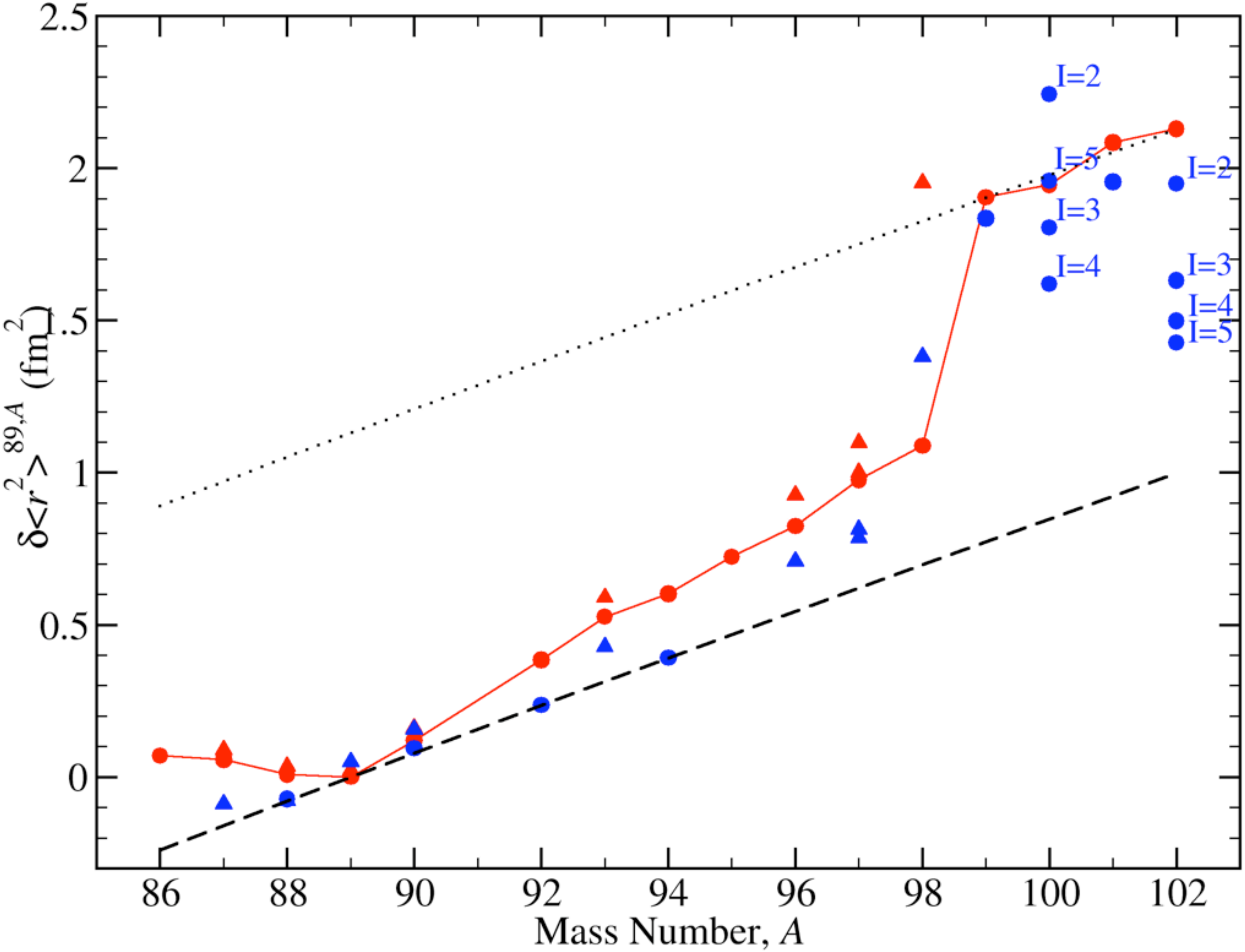
Charge radii (A=100,102)



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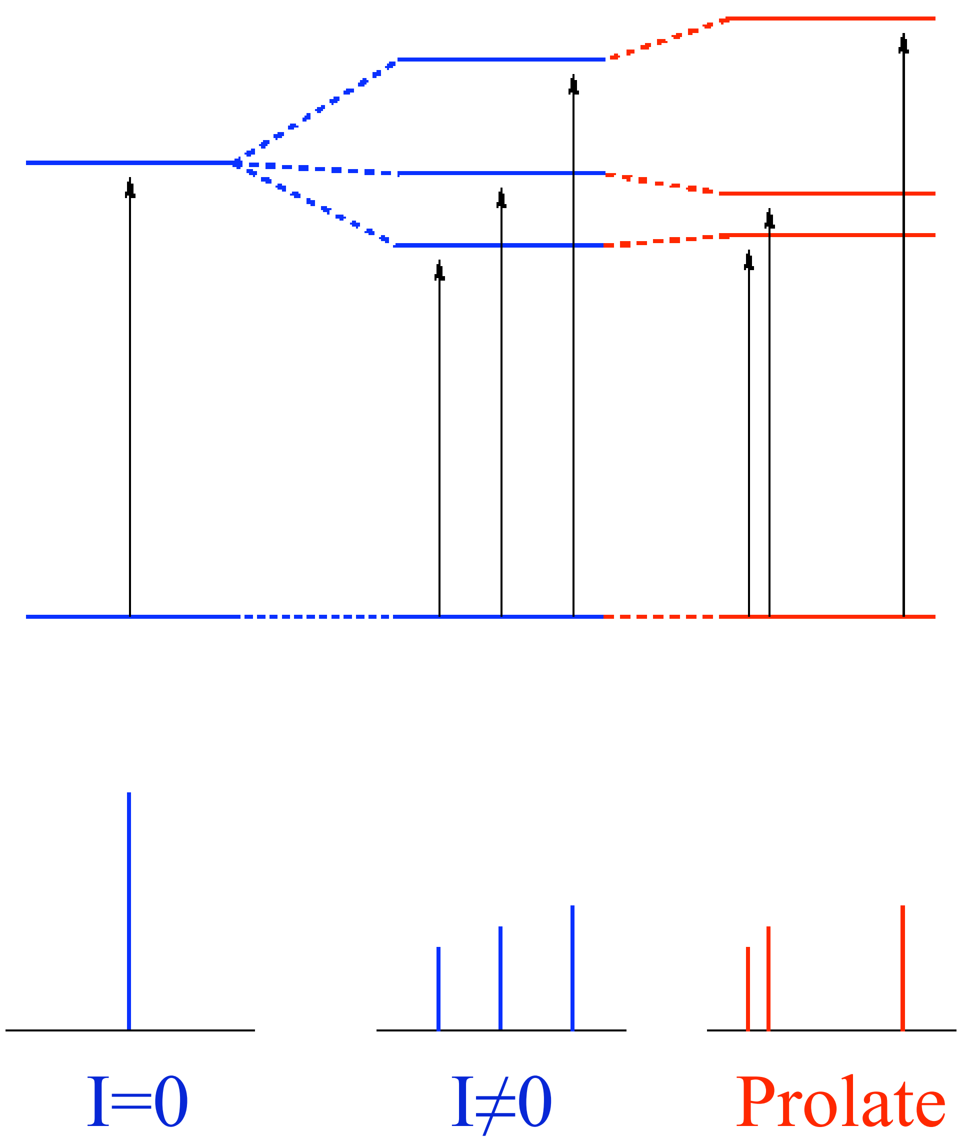
Need for transitions from metastable states

Yttrium (J=0 atomic ground state)



No matter what we'll be limited to J = 1 upper state

Possibilities:

126.9, 138.7, 140.9, 152.8, 154.8, 157.3, 224.3

λ (nm)	log(gf)
311.2	-2.24
349.6	-0.72
363.3	-0.08
420.5	-1.76

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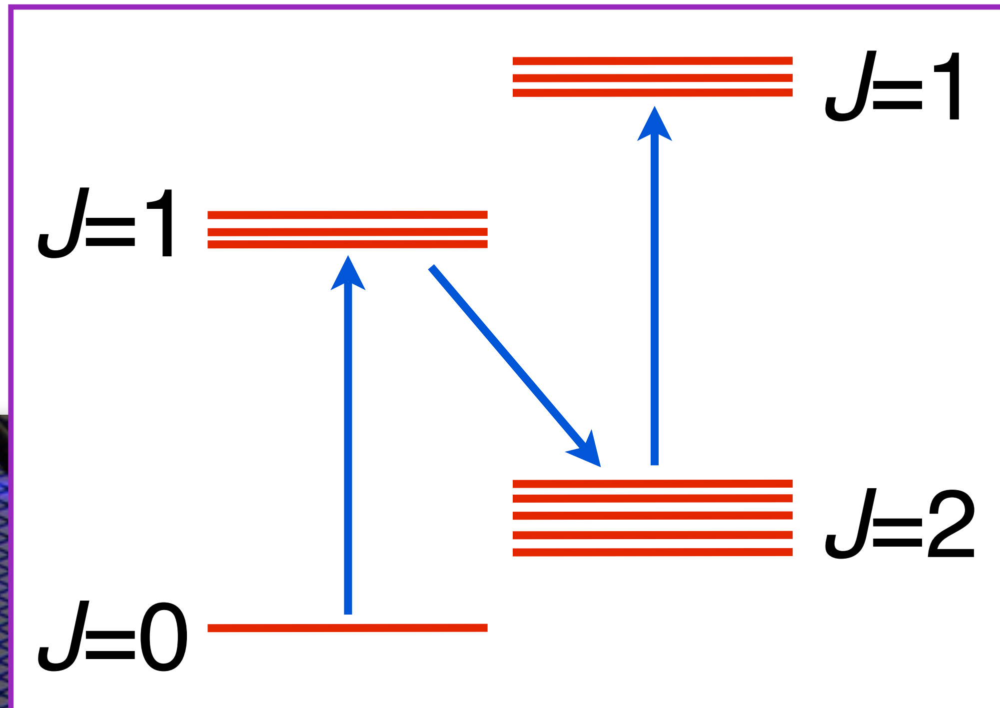
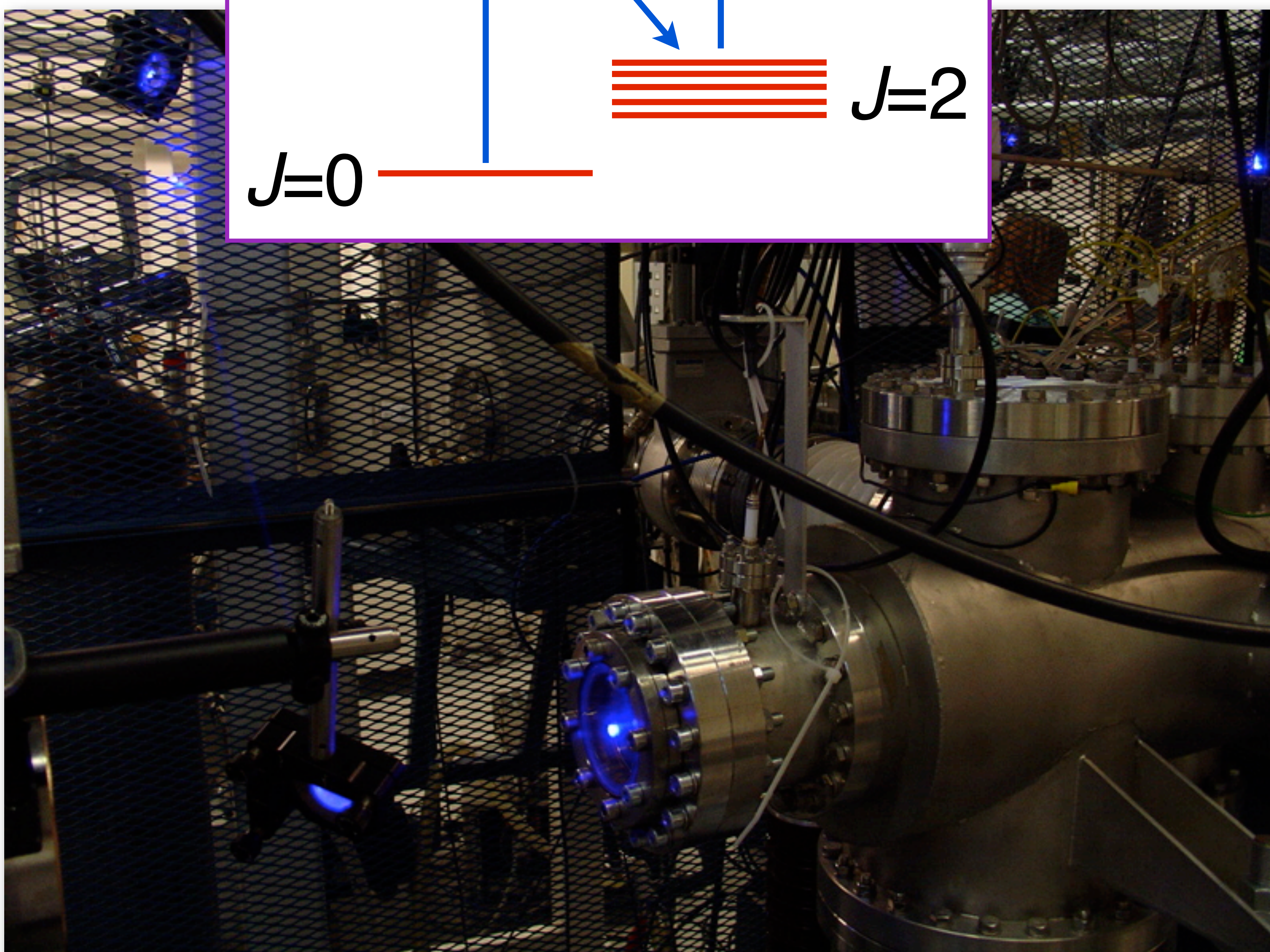
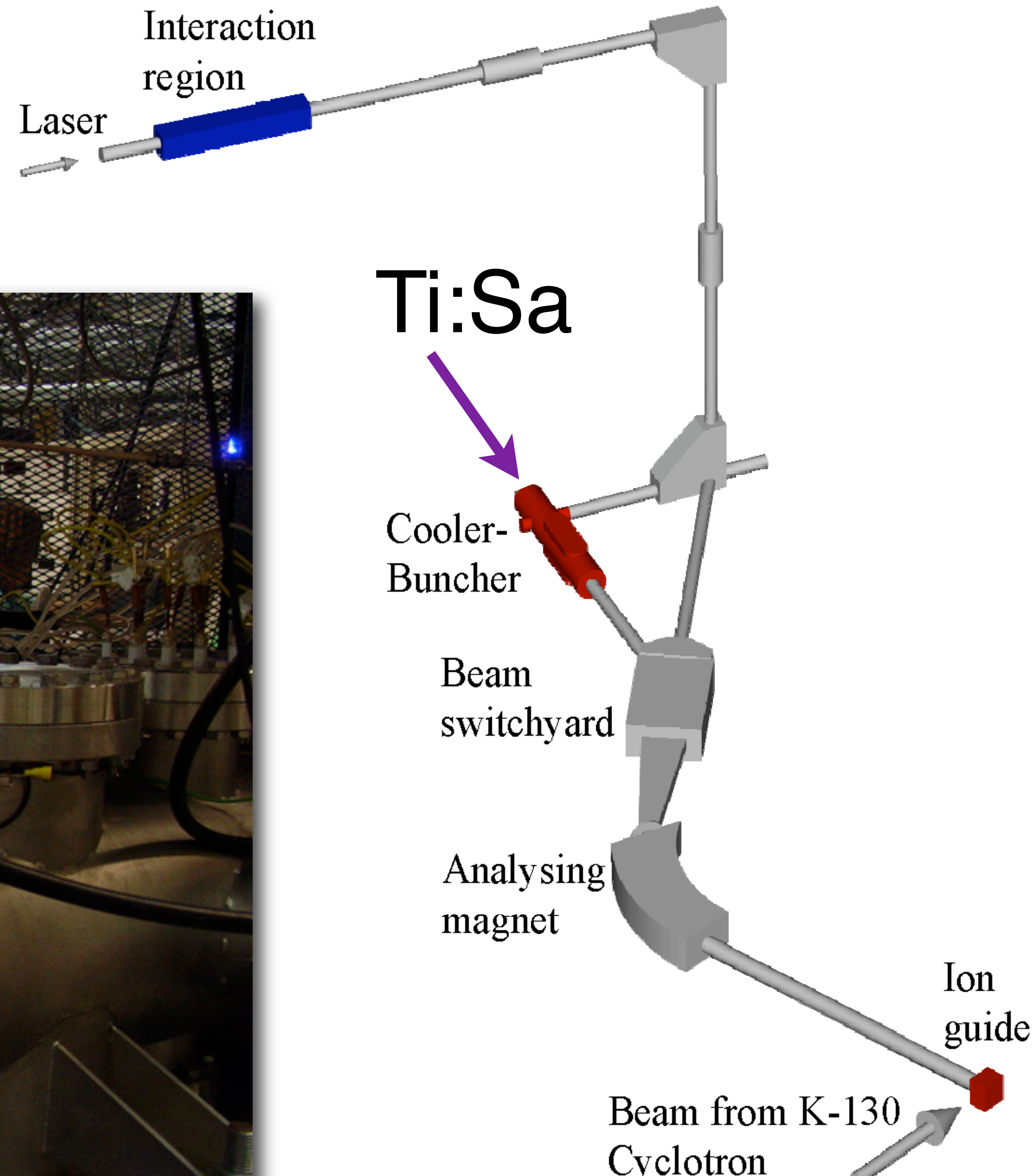
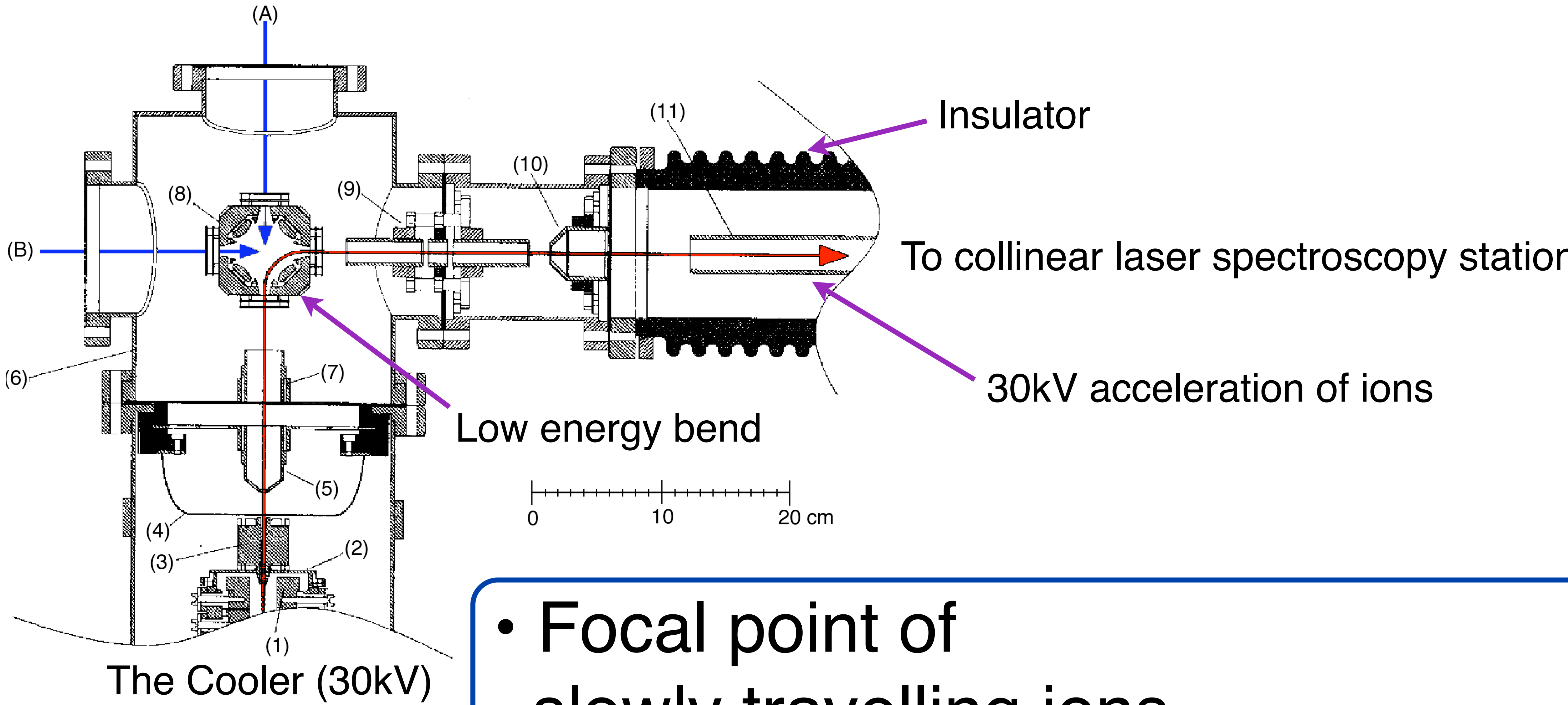
Measuring the J=2→J=1





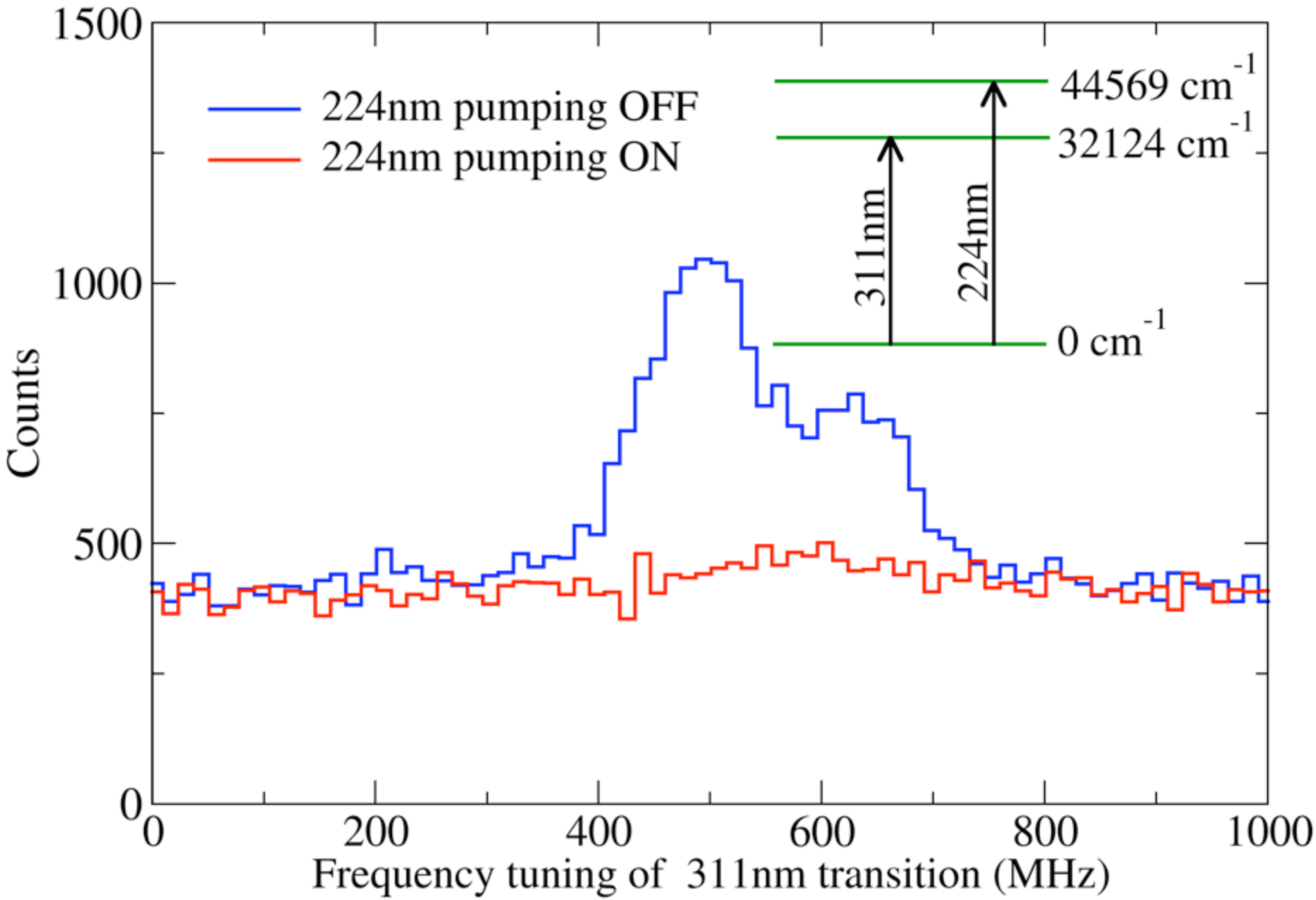


Why at the exit of the cooler?

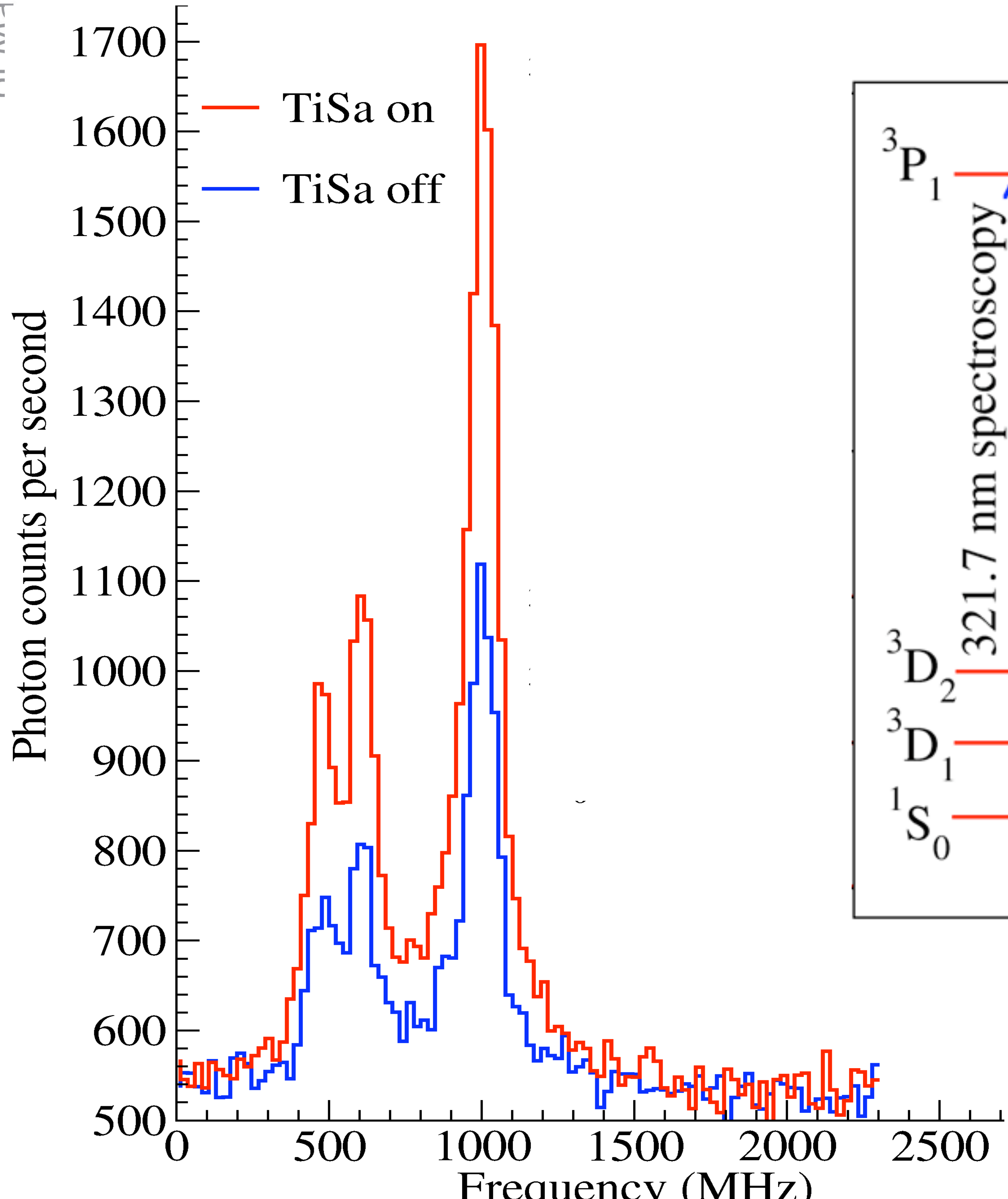


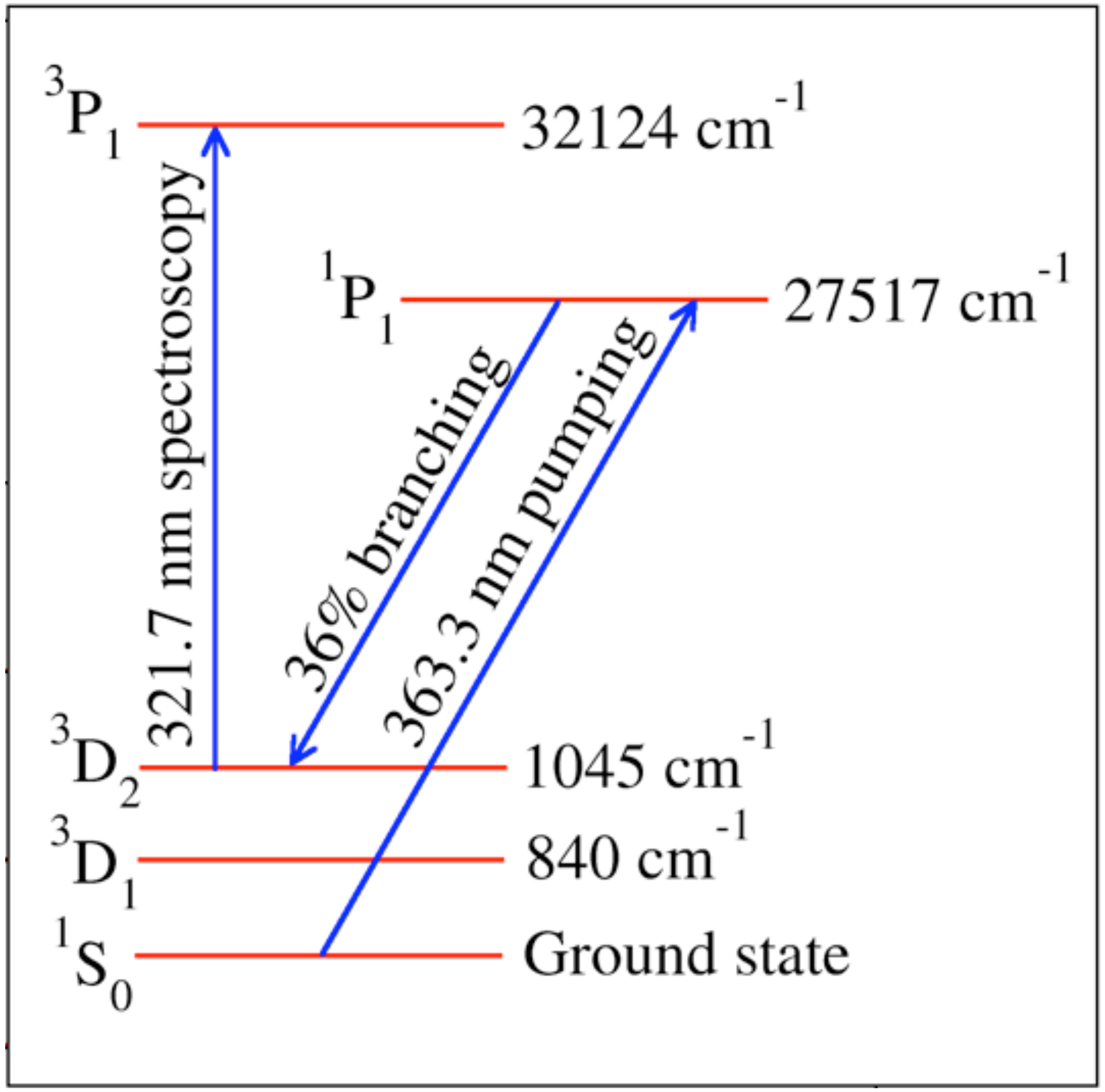
- Focal point of slowly travelling ions
- Can use broadband/pulsed lasers
- Typically a few mW required

Pumping in the cooler: efficiency



363nm pumping of yttrium

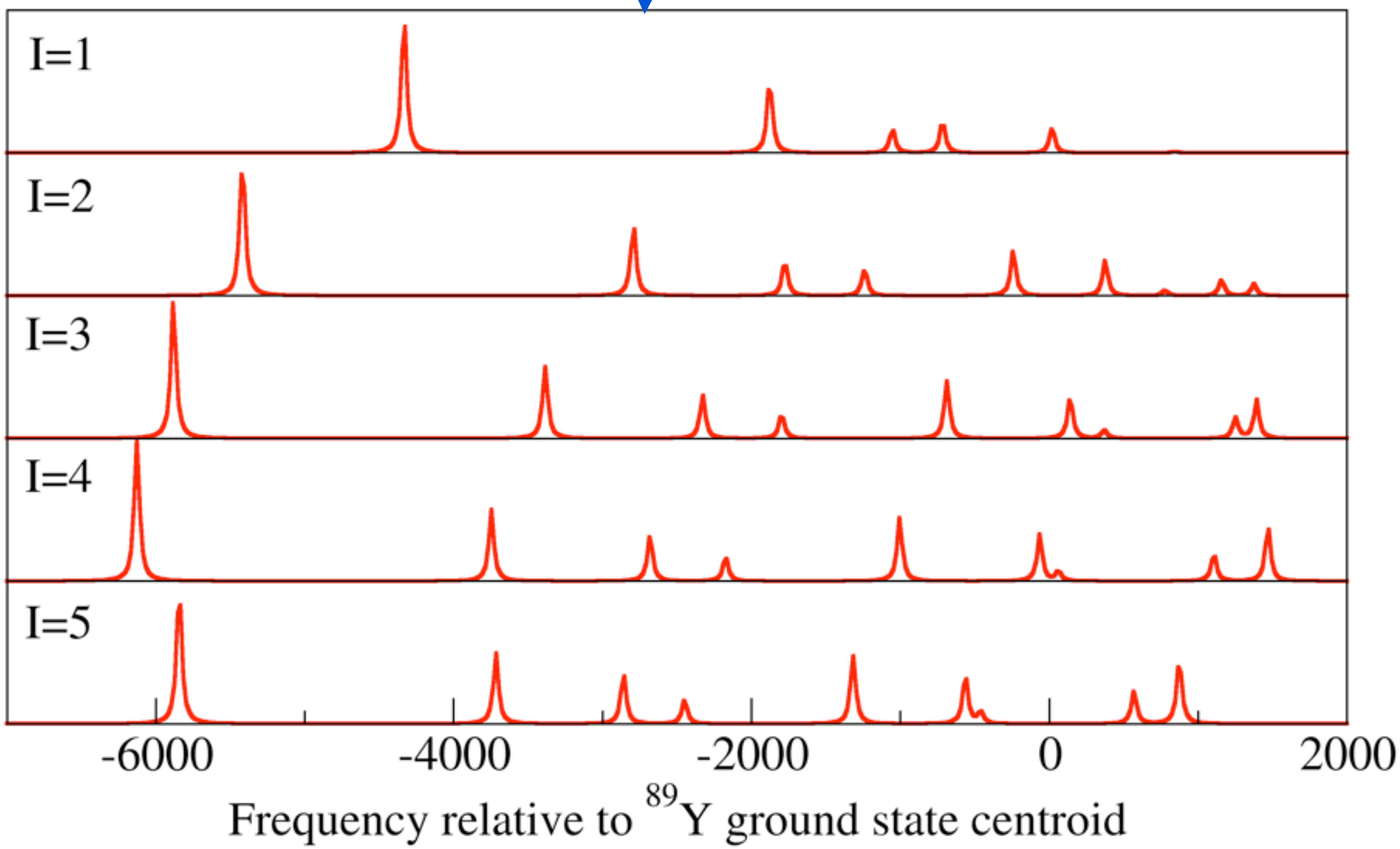




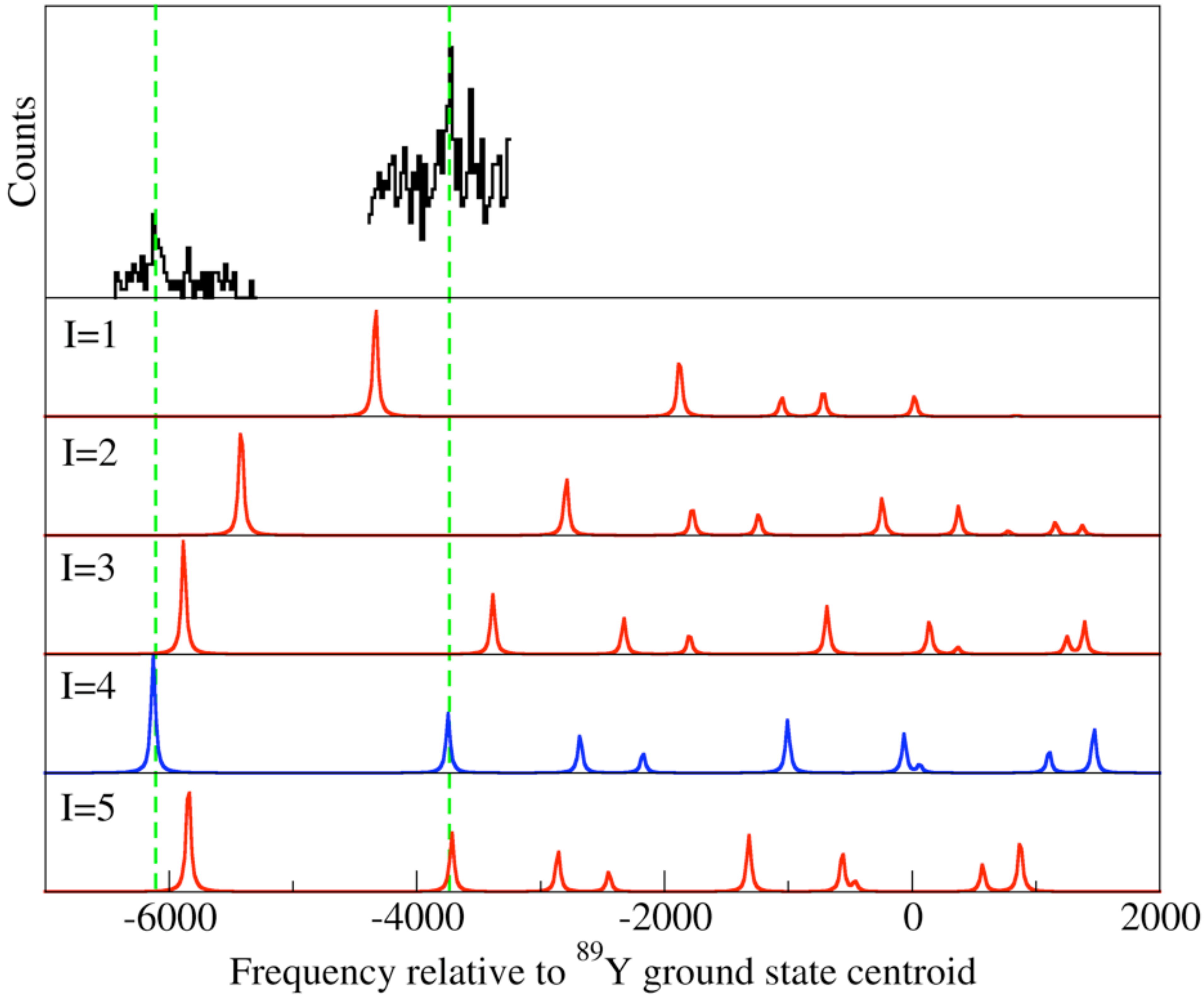
^{100}Y structure for J=2→J=1

Previous data (old transition)

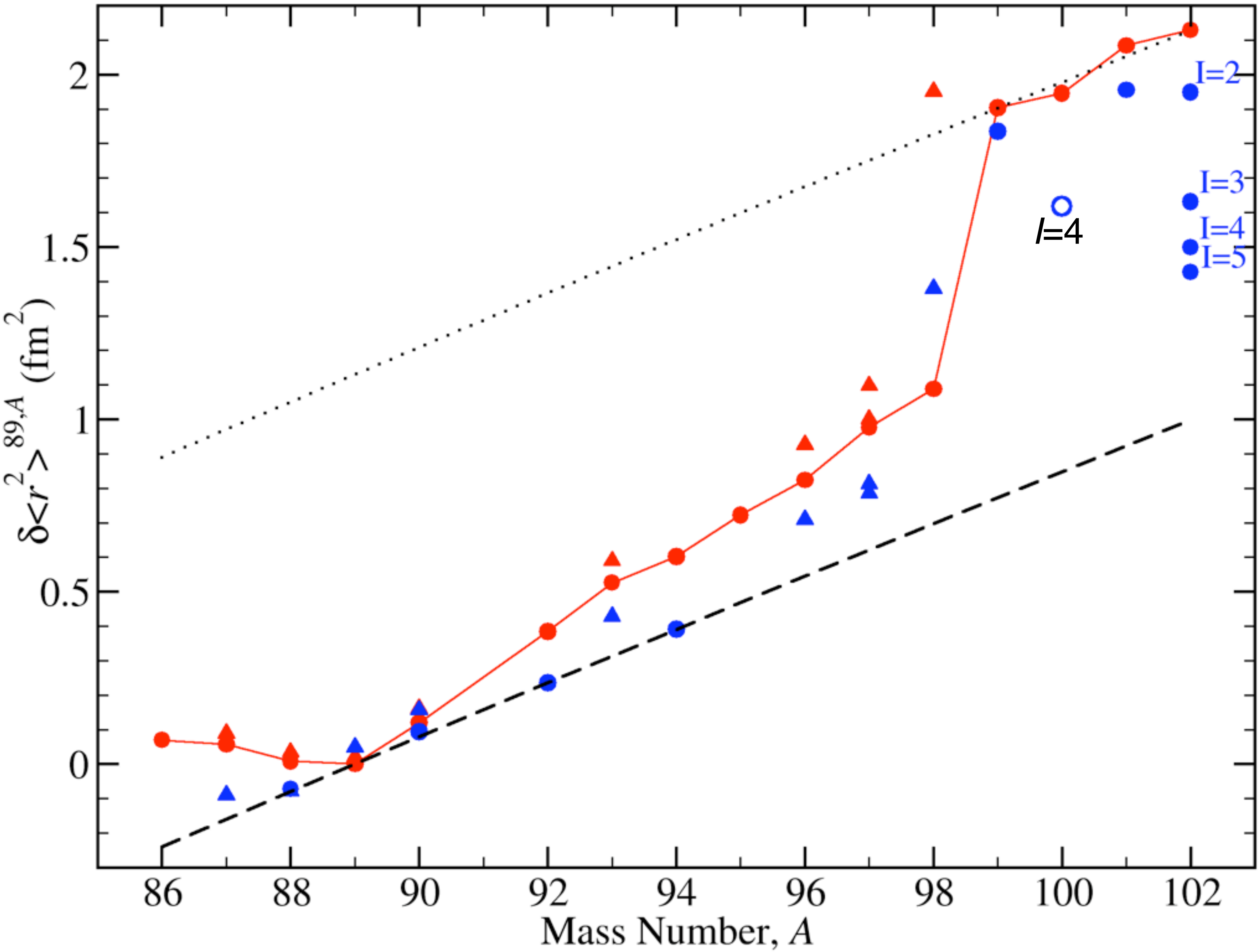
Some easily measured isotopes for calibration



Spin determination of ^{100}Y



Charge radii (A=100,102)



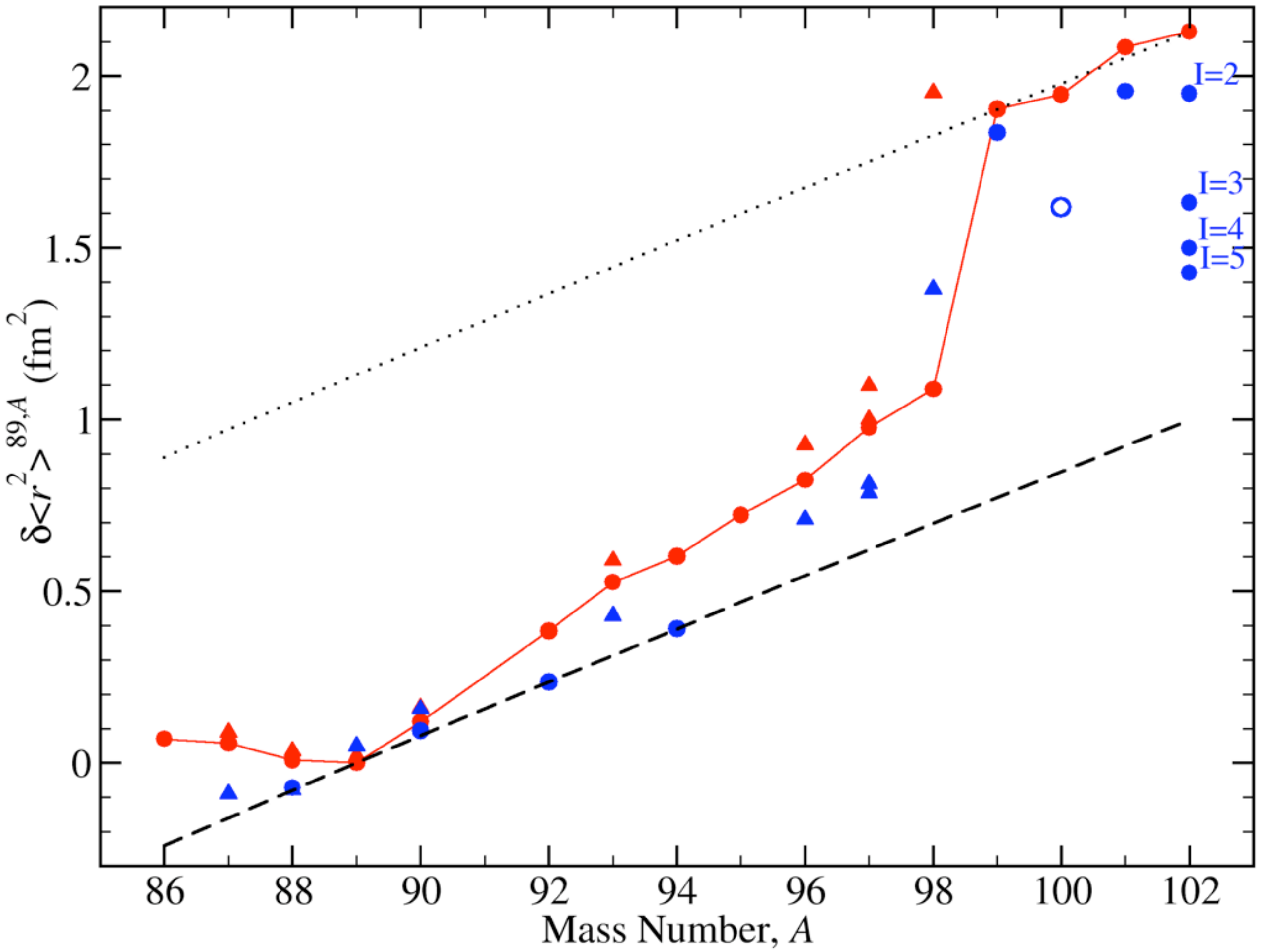
Possibilities....

- Problem with the projection?

$$Q_0 = Q_s \frac{(I+1)(2I+3)}{I(2I-1)}$$

- *A*=100 (and heavier even-*A* isotopes) are 98m-like?

- Has an *isomeric* state been observed instead?



Ongoing....

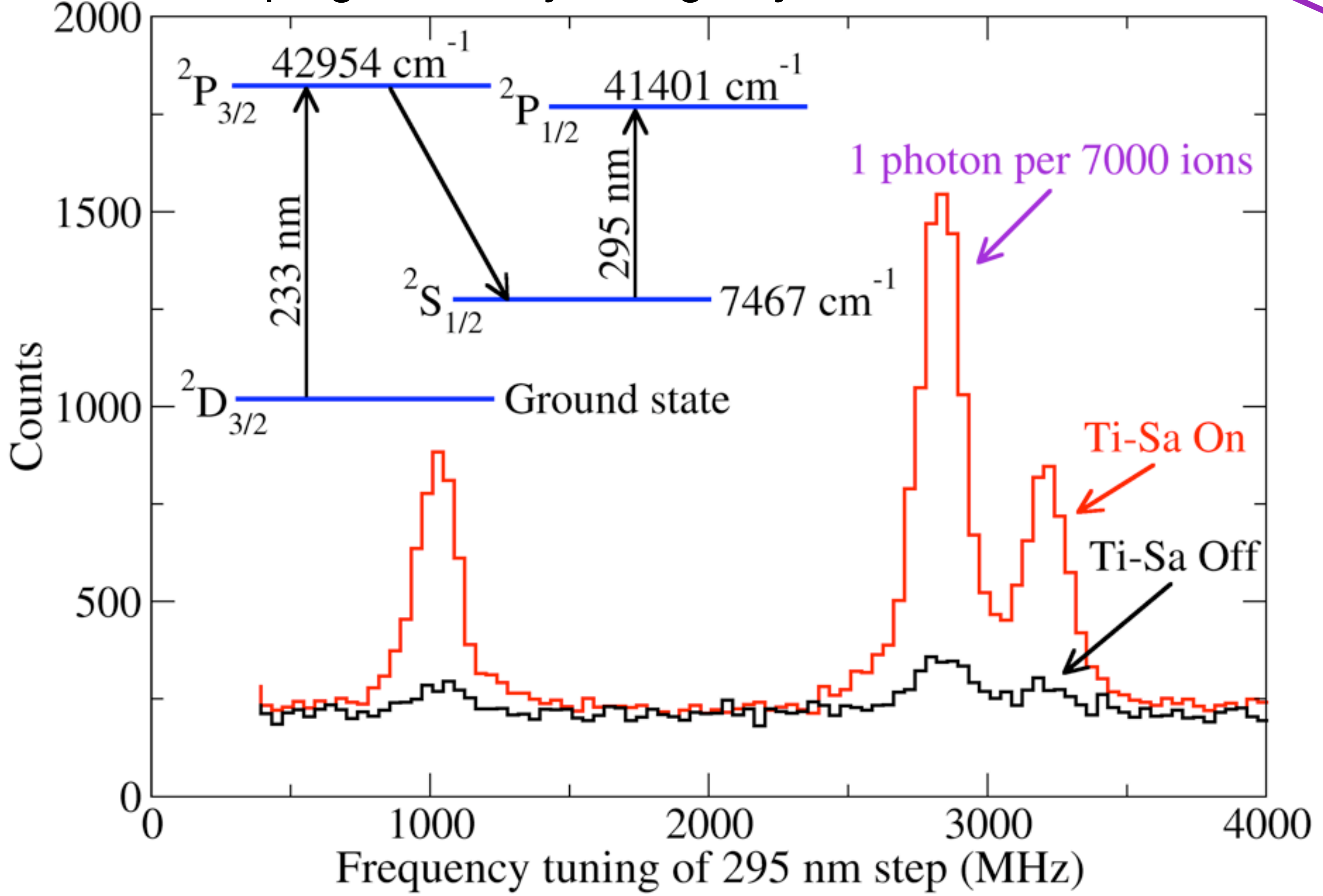
(2) Calibration of atomic factors

Isotope shift

$$\delta\nu^{A,A'} = M_i \frac{A' - A}{AA'} + F_i \delta\langle r^2 \rangle^{A,A'}$$

Atomic factors

Pumping of doubly-charged yttrium



Pure s→p transition

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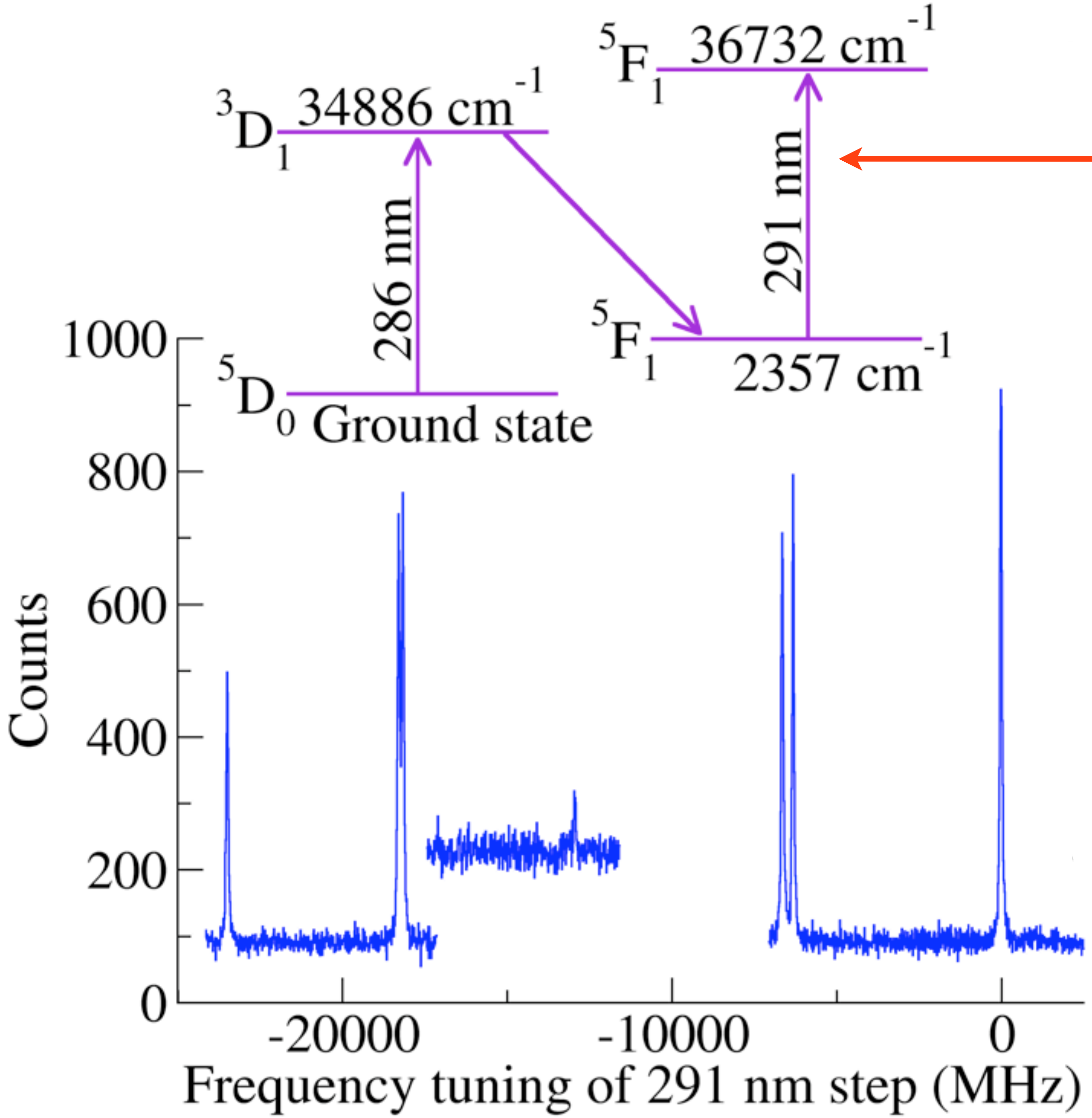
Case 3: niobium

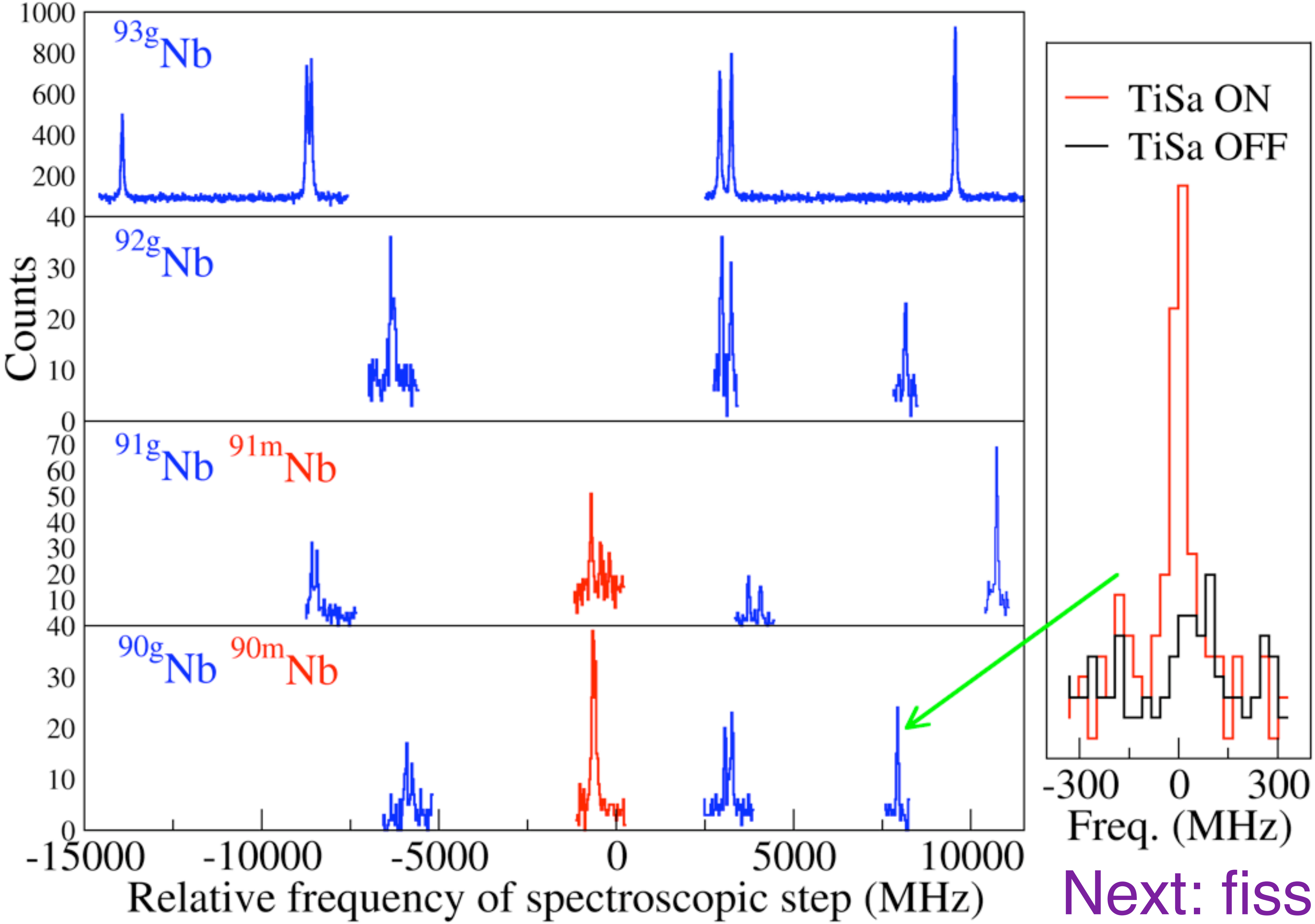


Most efficient transition found

(not 0→1)

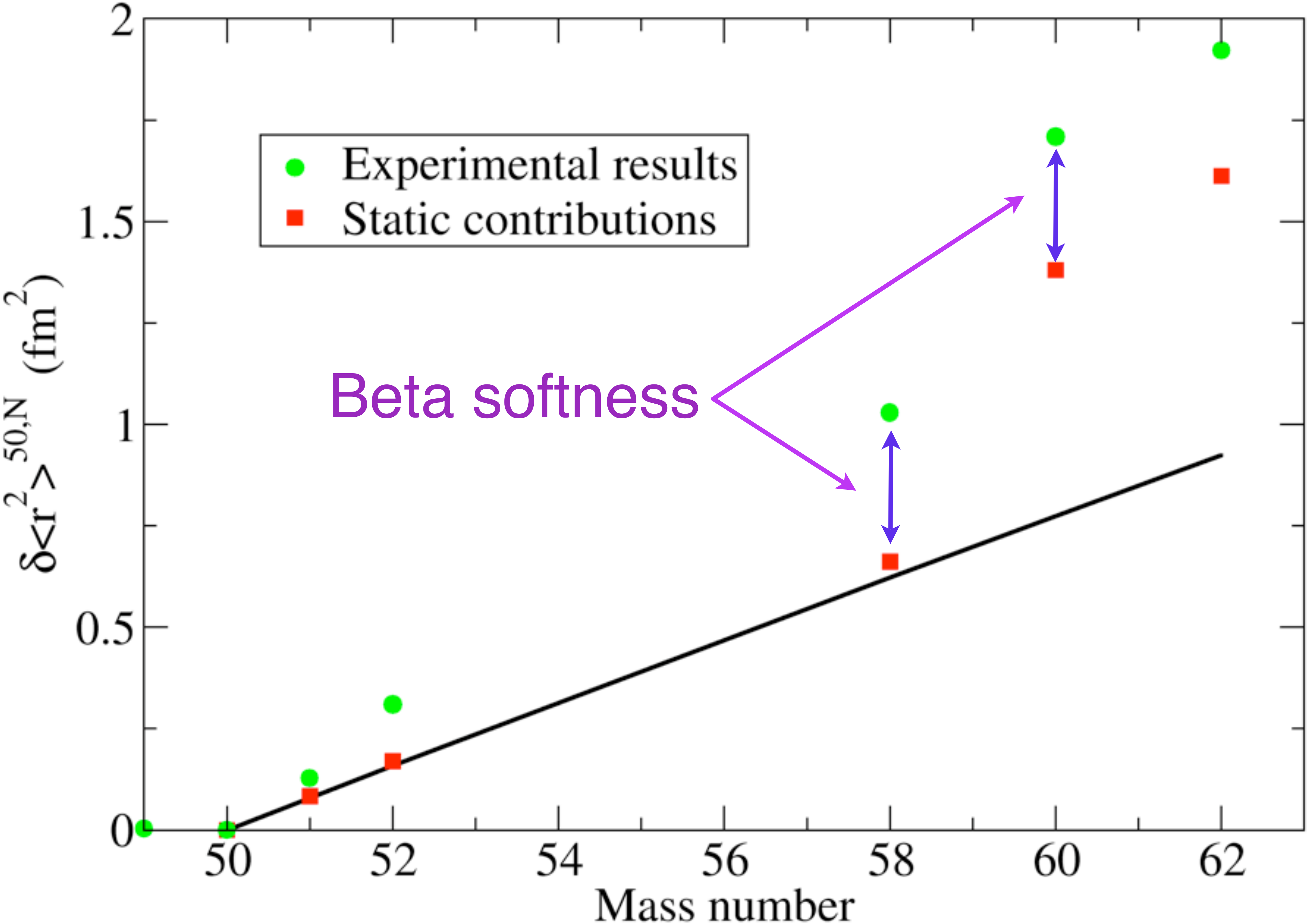
(stronger than pumping step)

Niobium on-line (fusion)

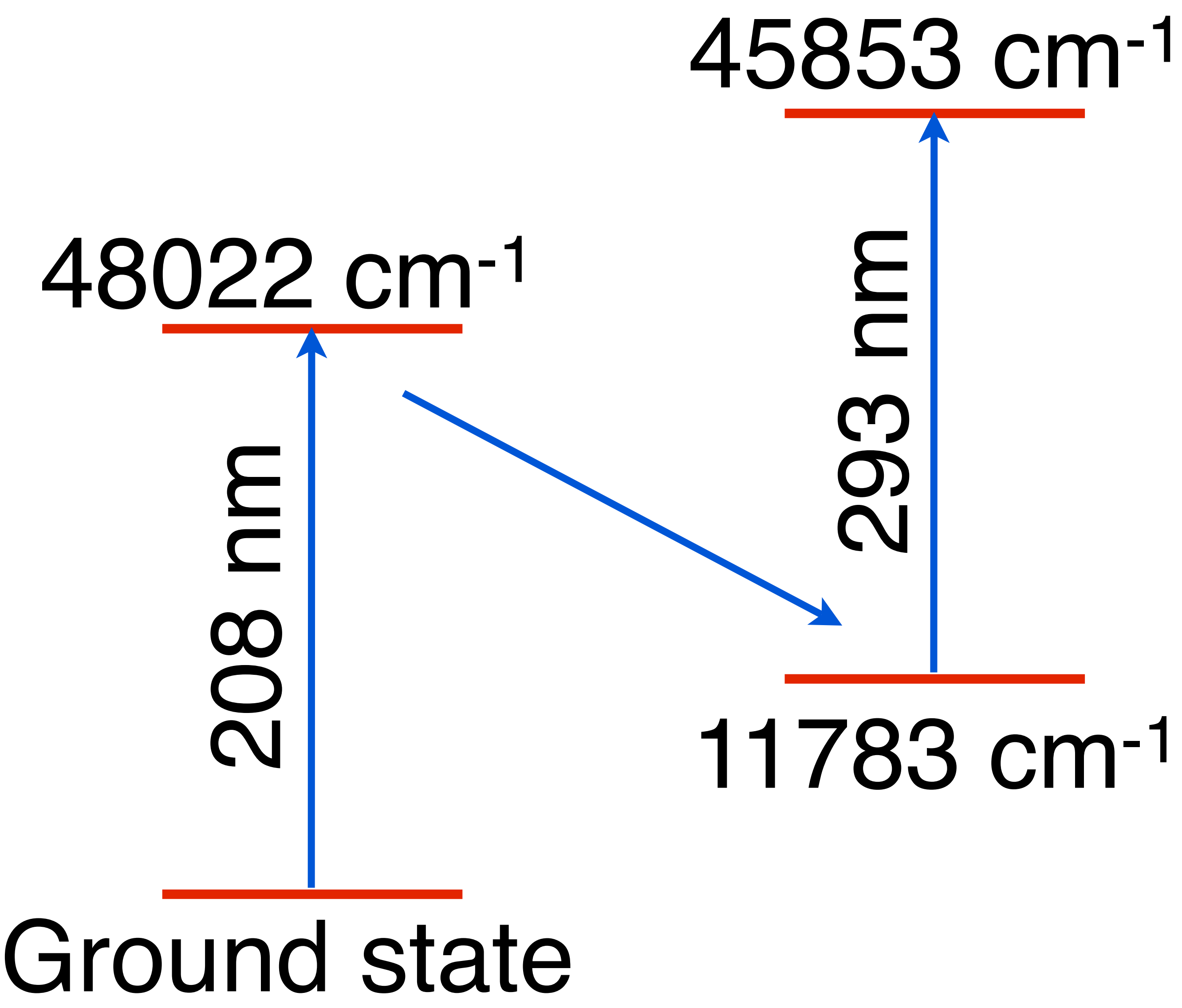


Next: fission

Softness of deformation



Case 4: Molybdenum



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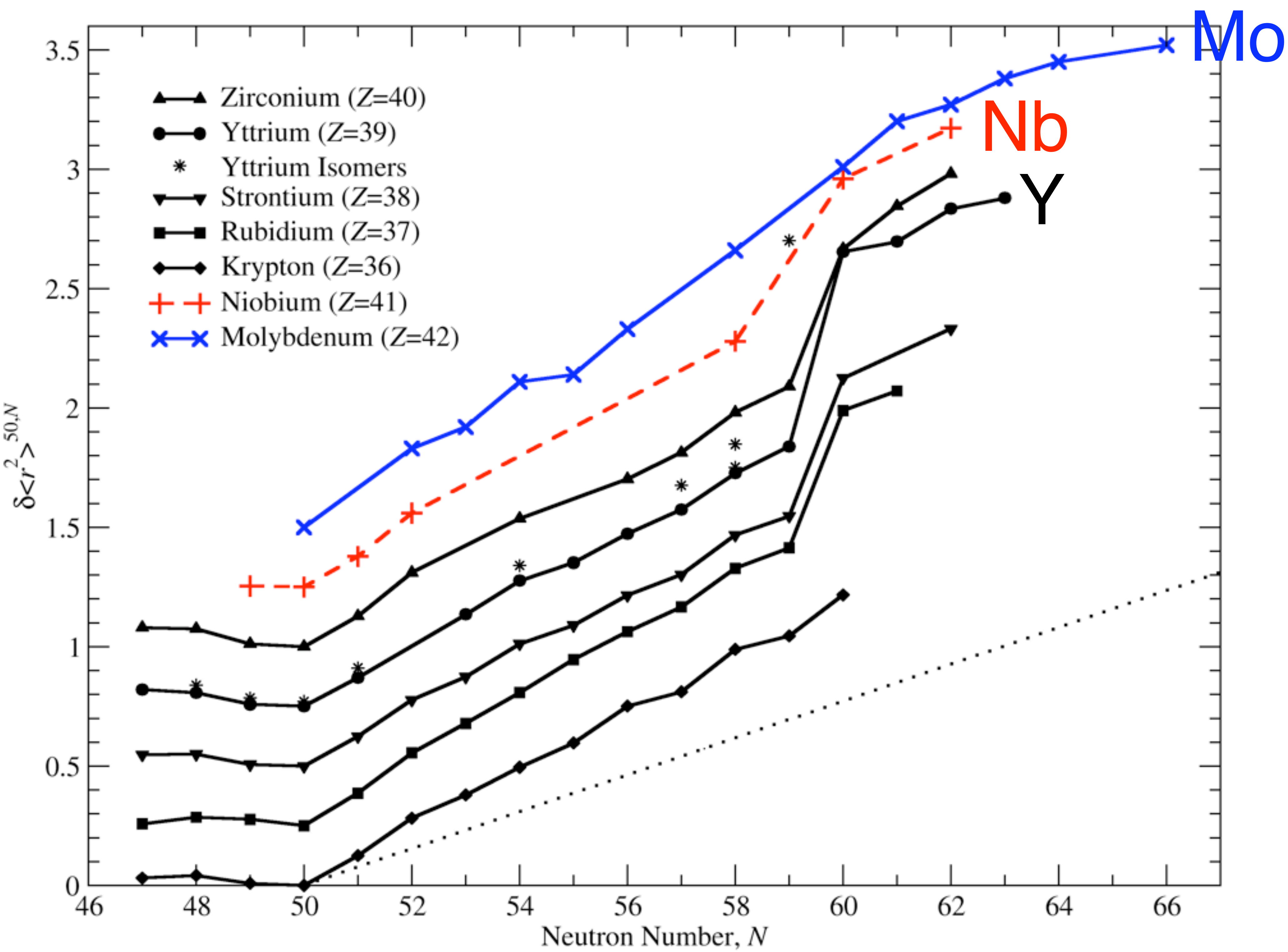
N~60 Mean-Square Charge Radii



β-soft, weakly oblate ⟵ ⟶ static, strongly prolate

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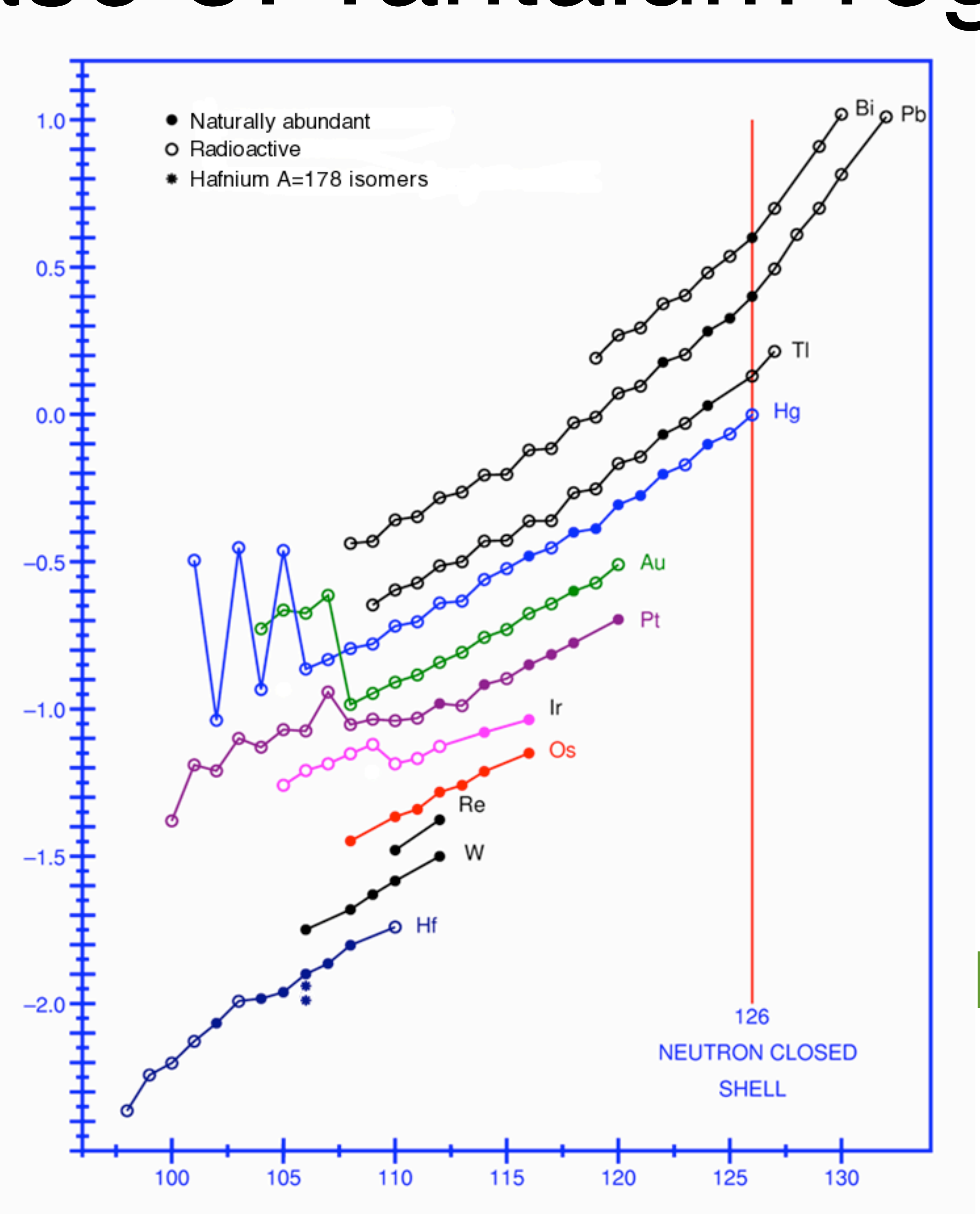
Case 5: Tantalum region



Wealth of MQP isomers in tantalum

Multi quasi particle isomers

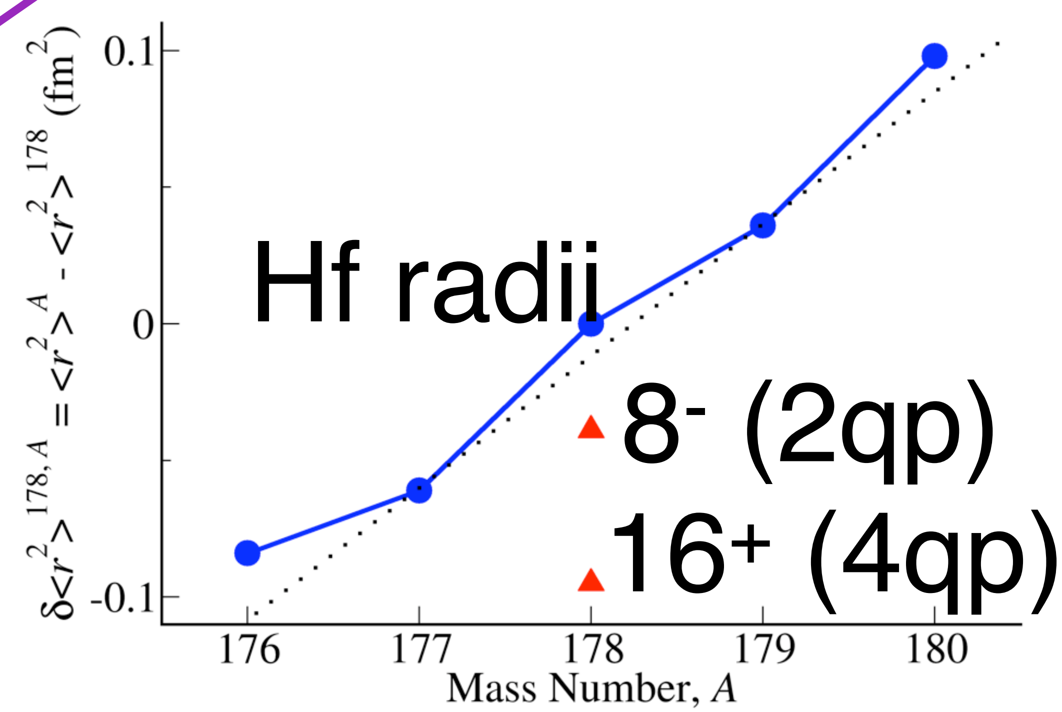
Decrease in ms charge radius despite an *increase* in static quadrupole deformation

$$\langle r^2\rangle = \langle r^2\rangle_{\rm sph}\left(1+\frac{5}{4\pi}(\langle\beta_2^2\rangle+\ldots)+3\sigma^2\right)$$

MQP state is...

More rigid?

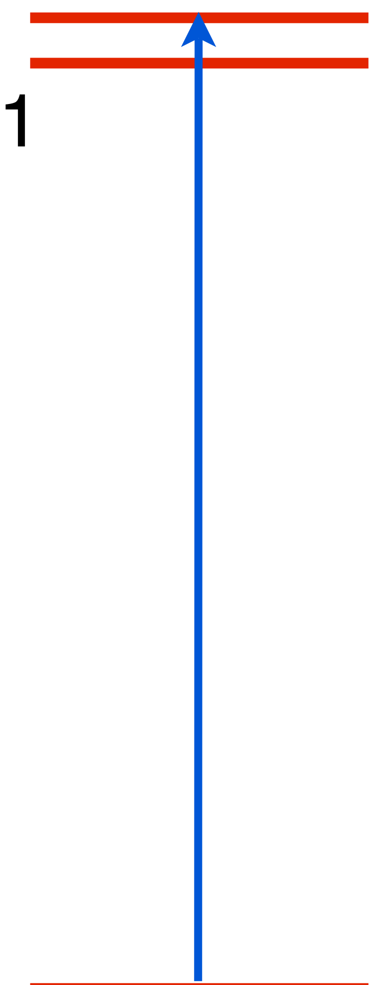
Less diffuse?



$$\beta^2_{\rm rms} = \langle\beta_2\rangle^2 + \left(\langle{\beta_2}^2\rangle - \langle\beta_2\rangle^2\right) = \beta^2_{\rm static} + \beta^2_{\rm dynamic}$$

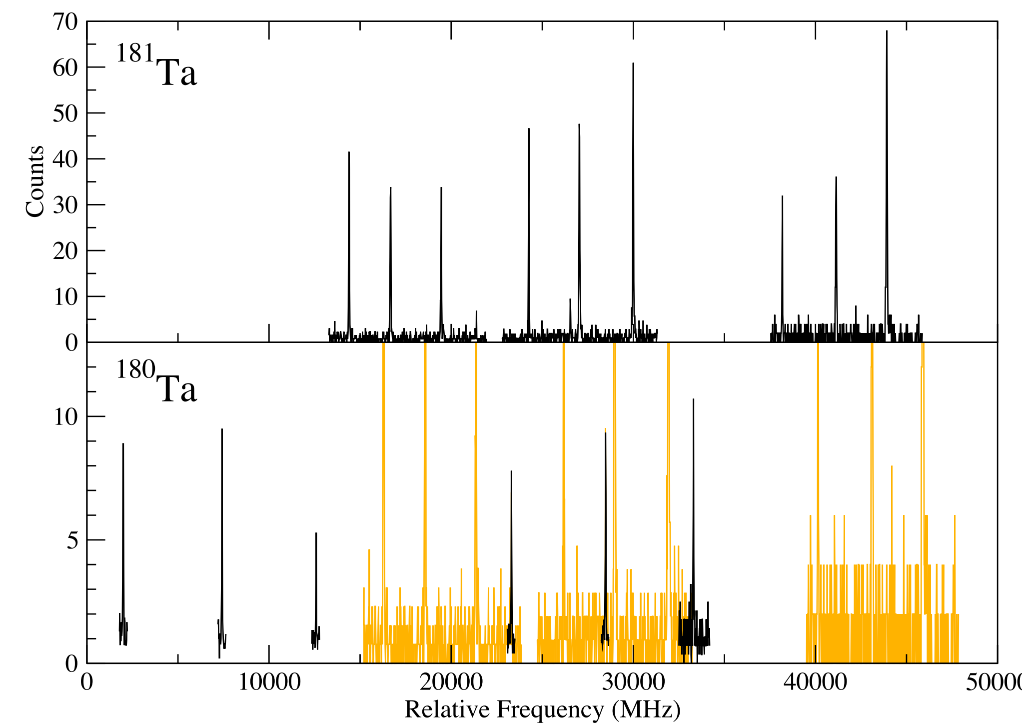
Spectroscopy of tantalum

33715cm^{-1}



Hyperfine Mixing

33706cm^{-1}



Ground state

Hyperfine anomaly

$$\frac{A_1}{A_2} = \frac{\mu_1 I_2}{\mu_2 I_1}(1 + \Delta_{1,2})$$

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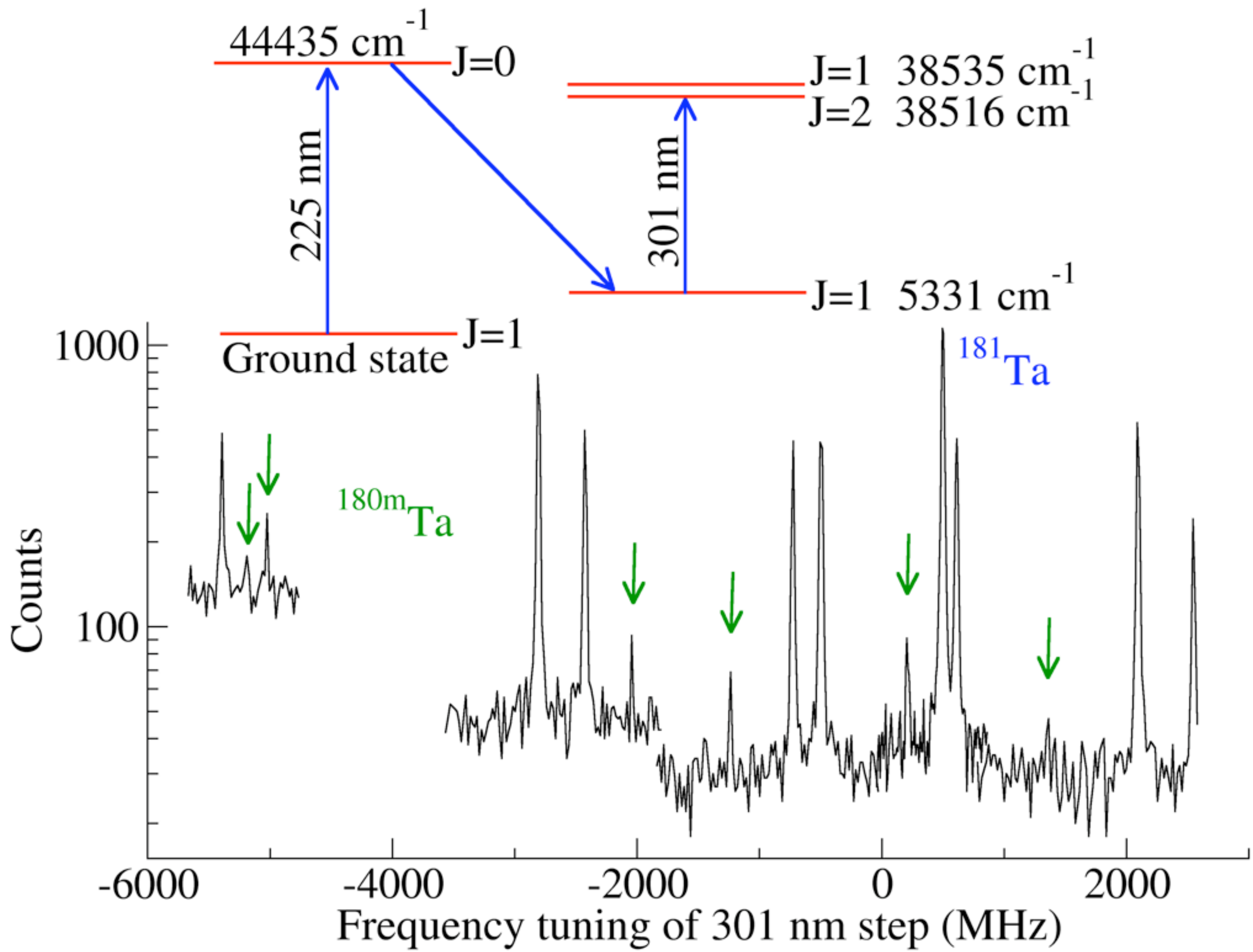
Optical pumping of tantalum



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Pumping in the cooler summary

- Method of enhancing population of metastable states
- More freedom when selecting optical transition
- Chosen because:-
    - Strength
    - More peaks → assignment of nuclear spin
    - Simplicity → calibration of atomic factors
    - Small hyperfine anomaly
    - Manageable or no hyperfine mixing
- Higher wavelength range from broadband lasers
- Being used for Y, Nb, Ta..... and many others to come

Future work

- Finish molybdenum...

- Electronic homologues -

  chromium and manganese

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Particpants

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E.B. Mané

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