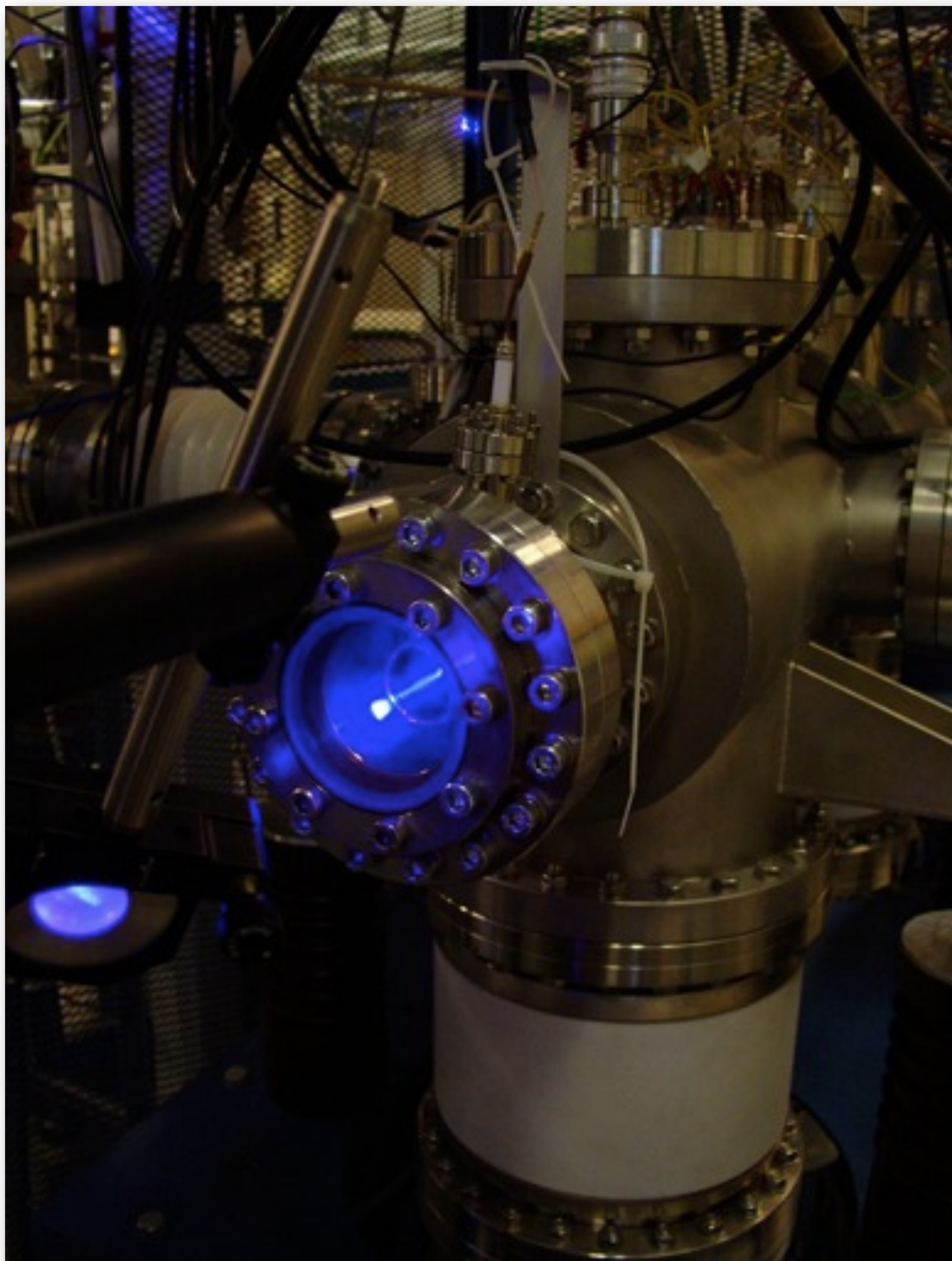
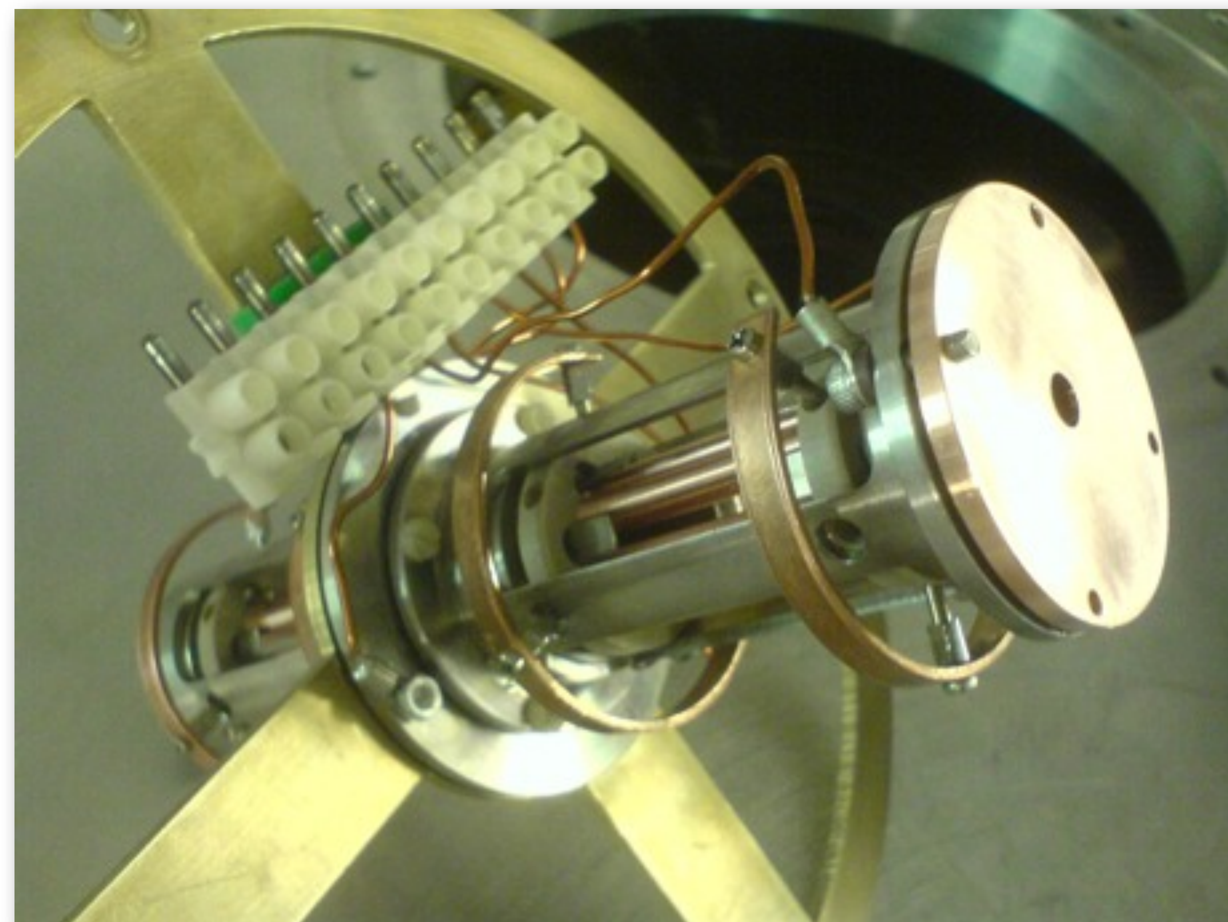
Laser-based ion beam manipulation and preparation





Bradley Cheal

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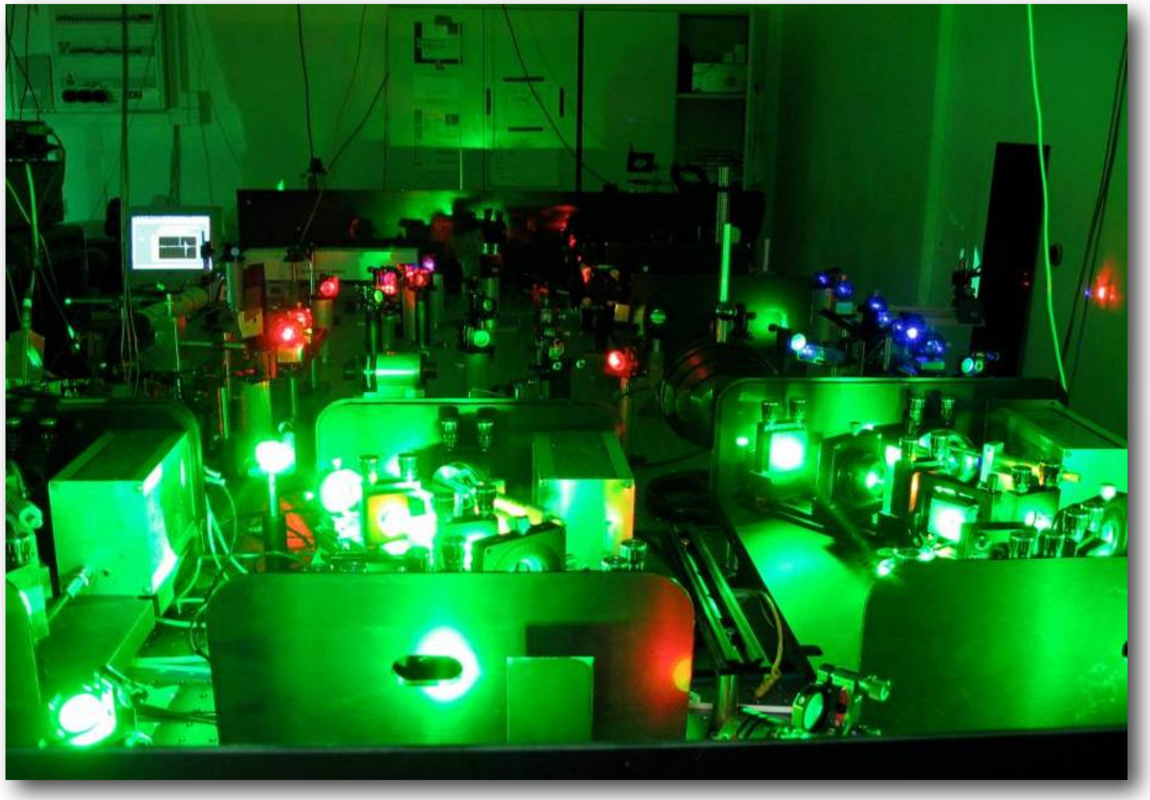
Talk Outline

- Laser spectroscopy - properties obtained
- Experimental methods
- New and proposed techniques



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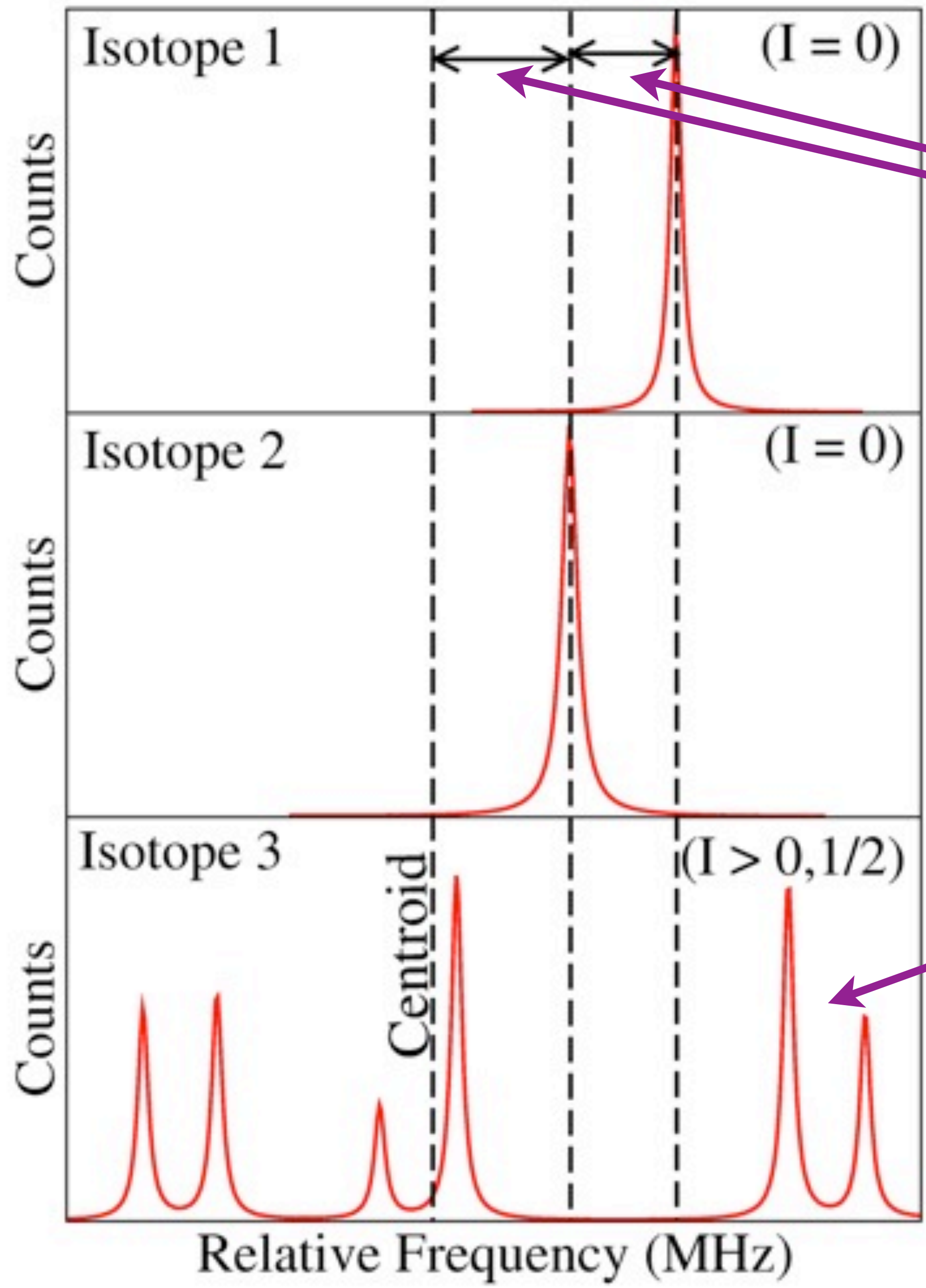
Properties from optical spectra



Isotope Shifts

➔ $\delta\langle r^2 \rangle$

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

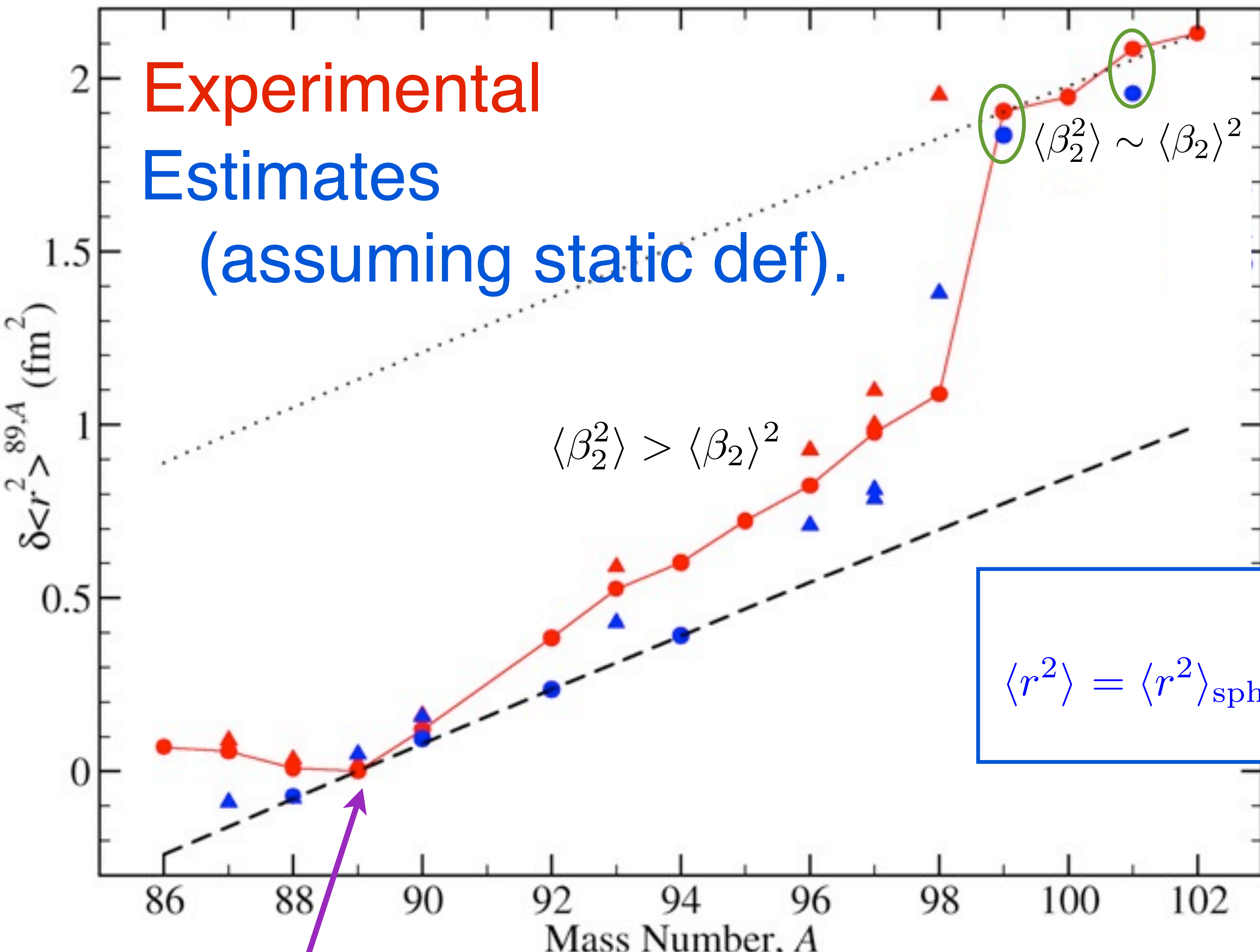
Hyperfine Structure

➔ μ

➔ Q_s ➔ $\langle\beta_2\rangle$

➔ Nuclear spin

Tells us about... deformation



MSCR and Q_s complementary

Q_s

$$\langle r^2\rangle = \langle r^2\rangle_{\text{sph}}\left(1+\frac{5}{4\pi}\Big(\overset{\color{red}{\langle\beta_2\rangle^2}}{\cancel{\langle\beta_2^2\rangle}}+\ldots\Big)\right)+3\sigma^2$$

N=50 shell closure

(Y isotopes, IGISOL 3)

Cheal *et al*. Phys. Lett. B **645**, 133 (2007)

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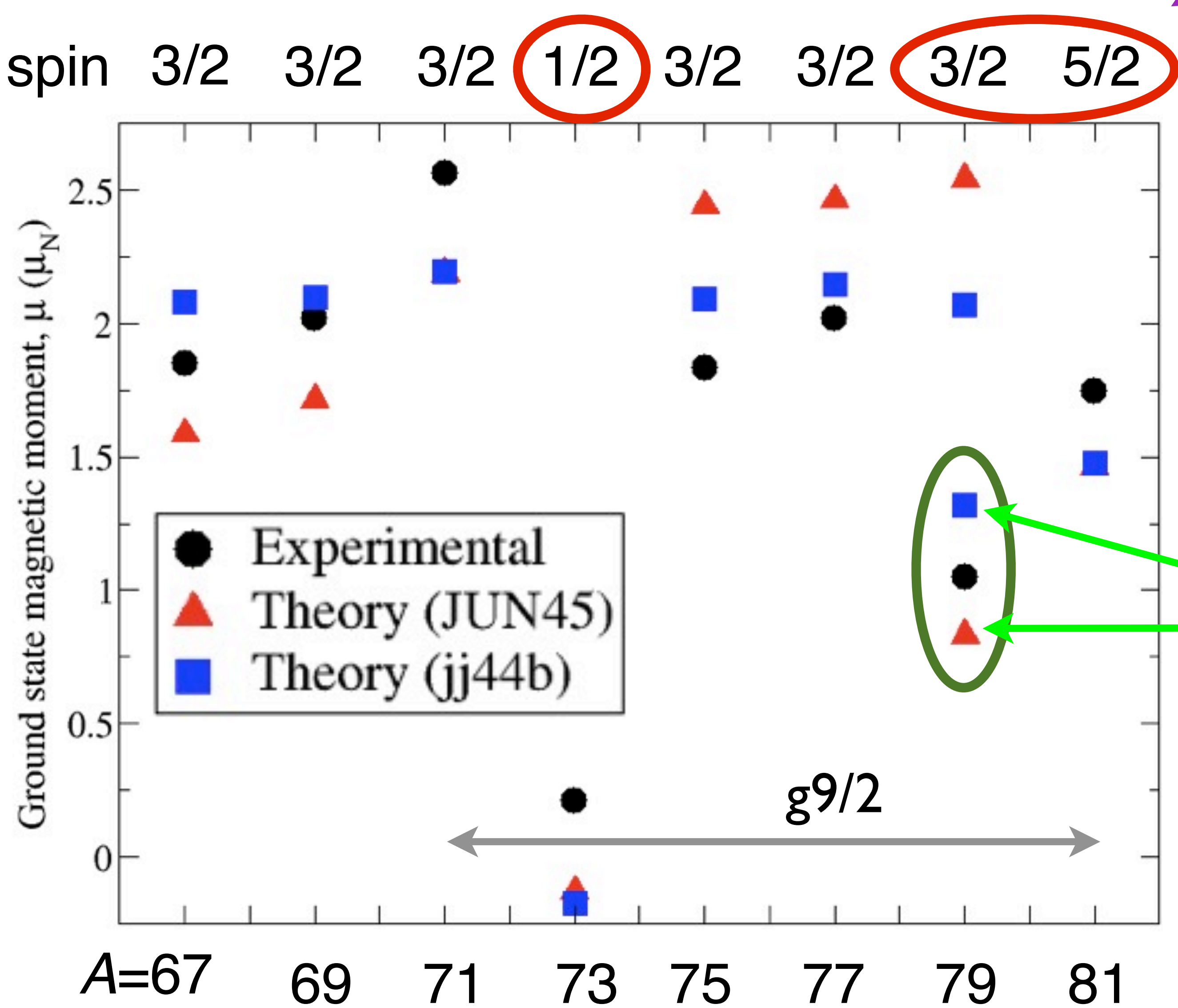
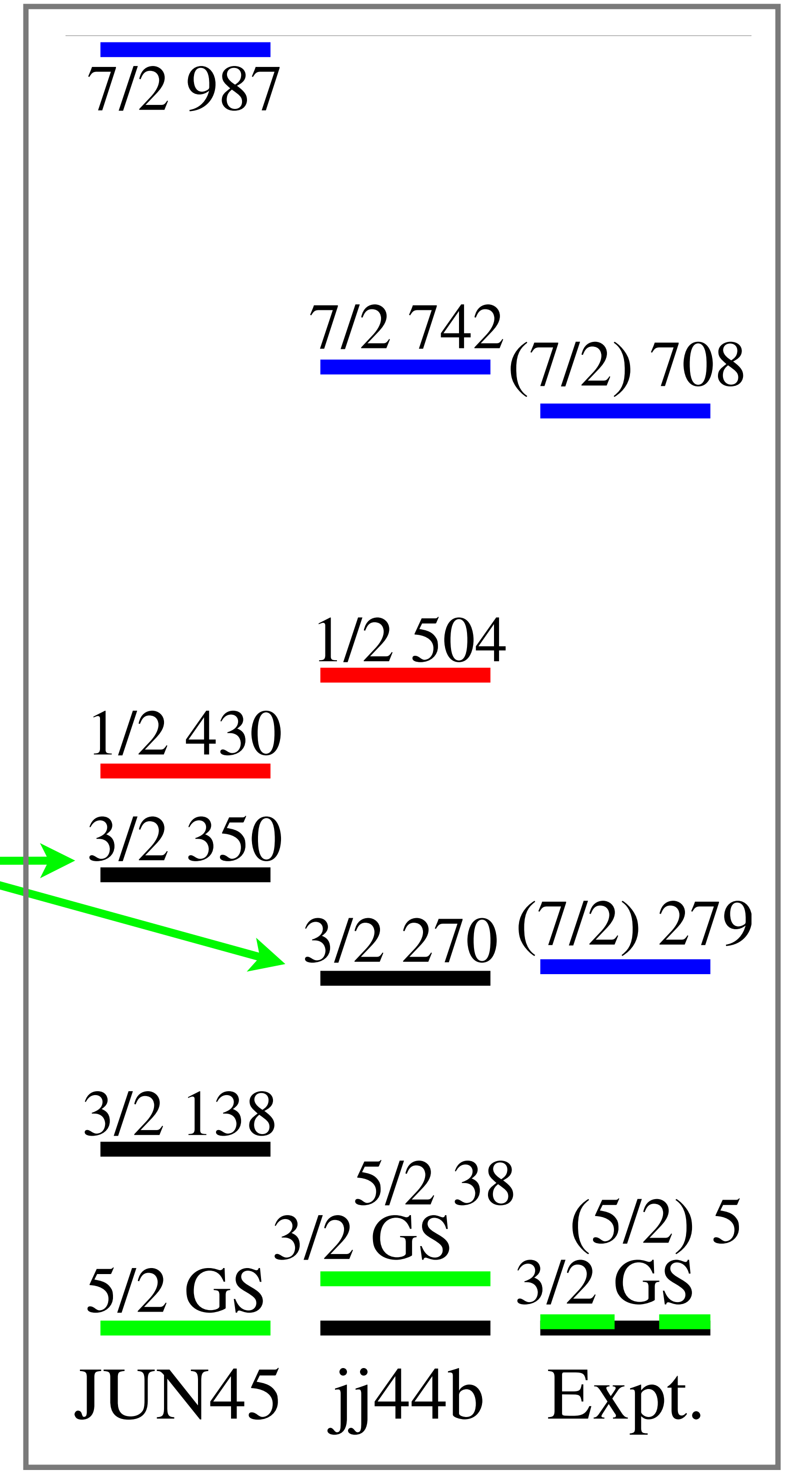
… the nuclear wave function

Determine Ga gs spins

p3/2, f5/2 inversion





One interaction is (accidentally) correct

1st excited 3/2 which matches gs properties ($f^3_{5/2}$ dominated)

(COLLAPS, ISOLDE)

Cheal *et al*. Phys. Rev. Lett. **104**, 252502 (2010)

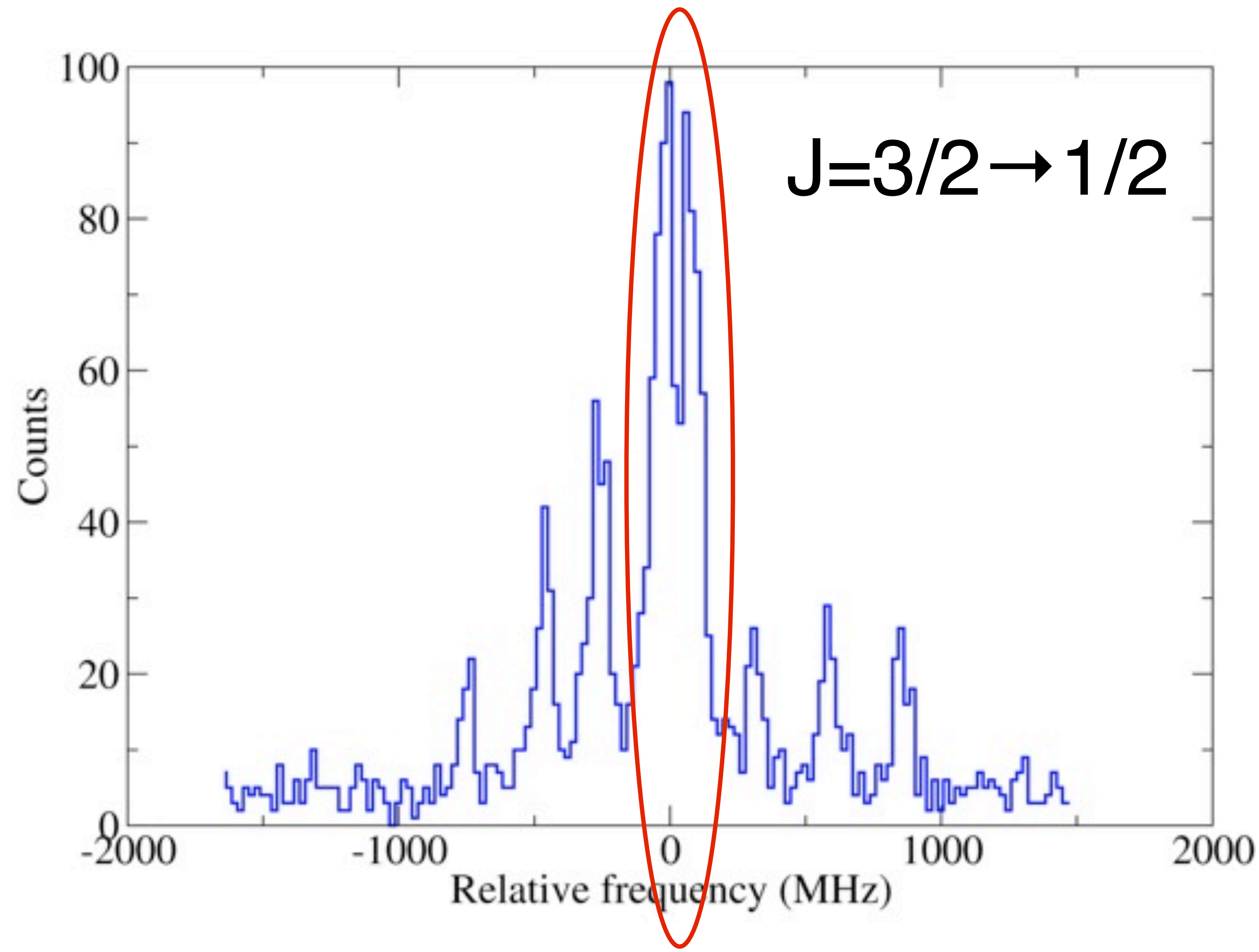
…the very existence of states

A recent example ^{80}Ga:

- Could be too long loved for some decay methods

- Half-life similar to gs

- Too low-lying
  - same mass



Cheal *et al*. Phys. Rev. C **82**, 051302(R) (2010)

Optical spectroscopy is complementary to these methods

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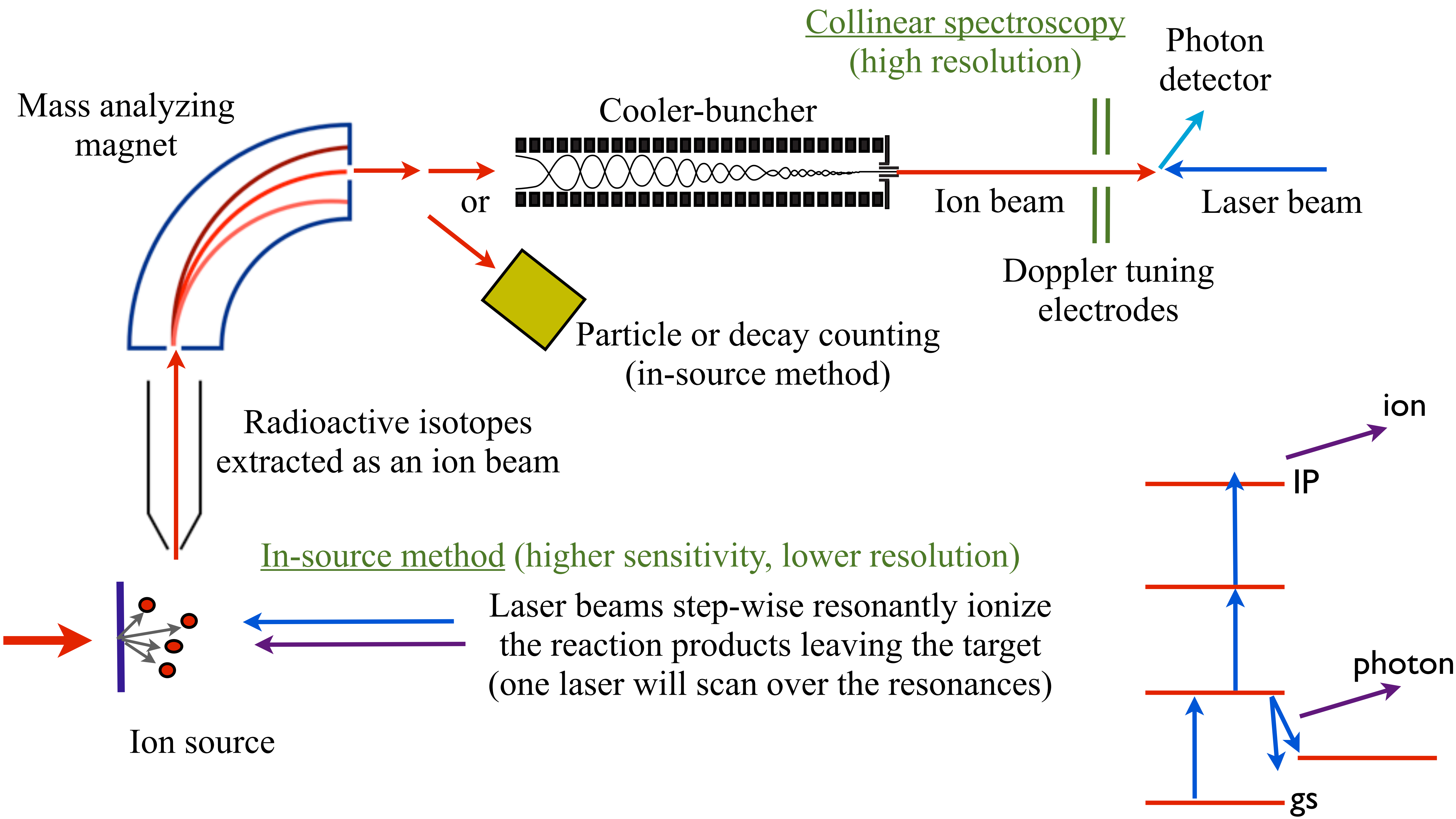
Laser spectroscopy at RIB (ISOL) facilities



Other techniques: eg. CRIS, seeks a compromise between the two

Cheal *et al*. Phys. Rev. A **86**, 042501 (2012)

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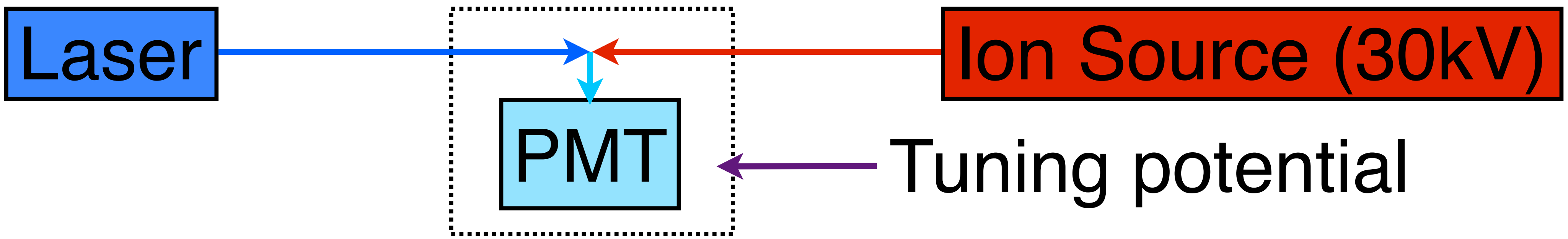
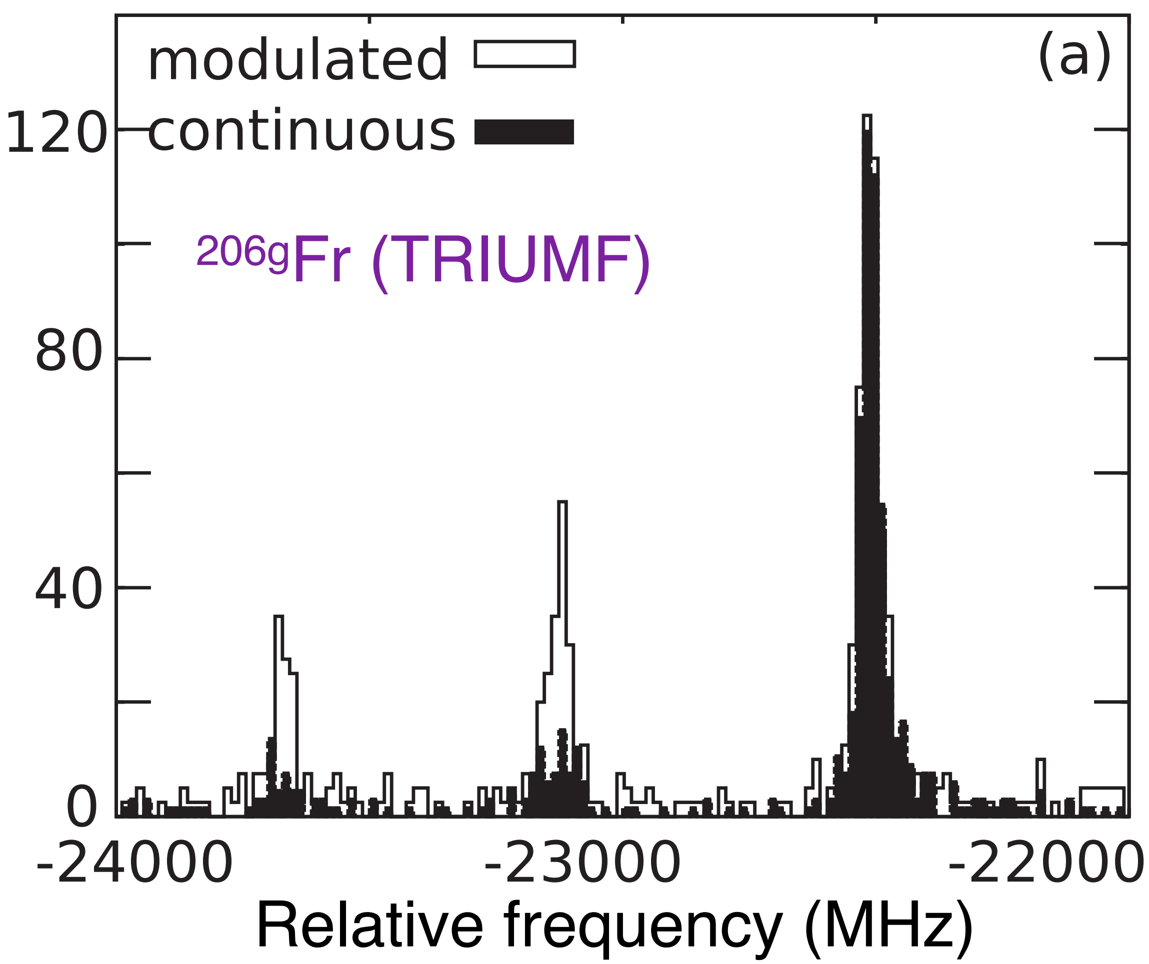
High resolution collinear laser spectroscopy





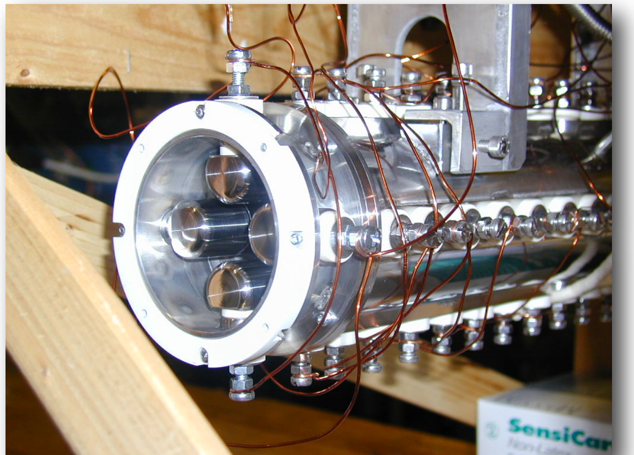
Voss *et al*. Phys. Rev. Lett. **111**, 122501 (2013)

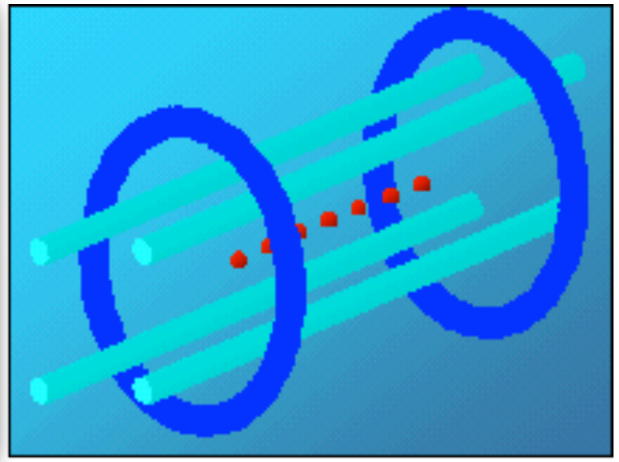
- Used at RIB facilities
- Doppler suppression

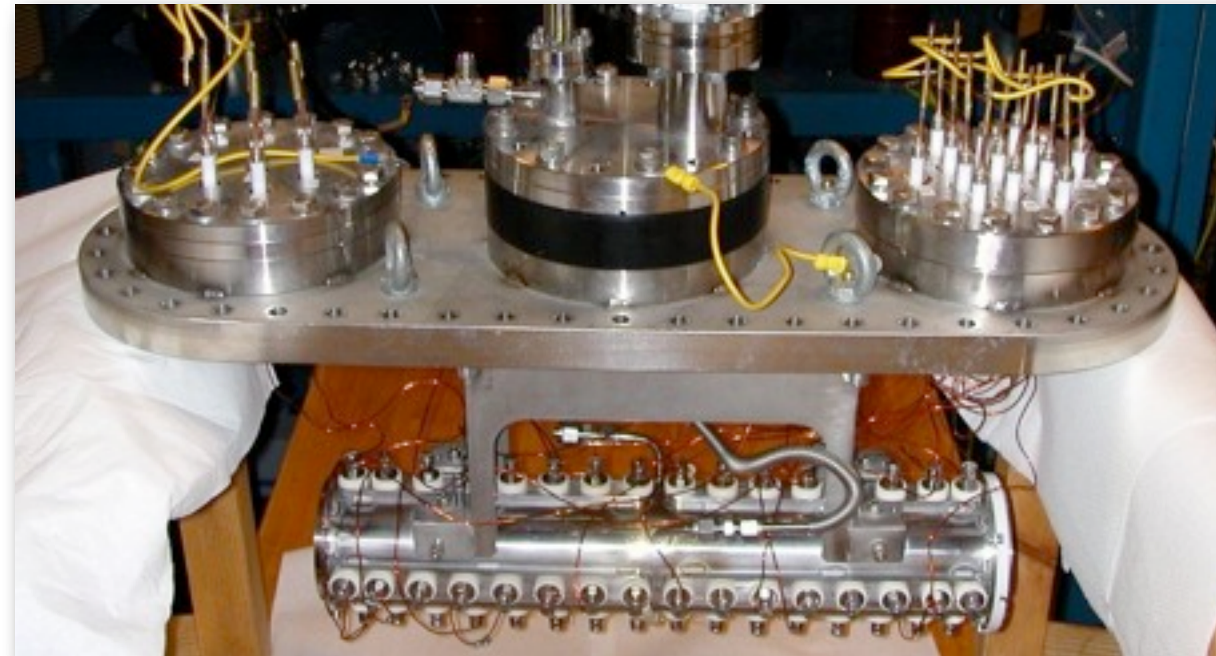
$$E = \frac{1}{2}mv^2$$

$$\Delta v = \frac{\Delta E}{mv}$$

Cooled, bunched beams



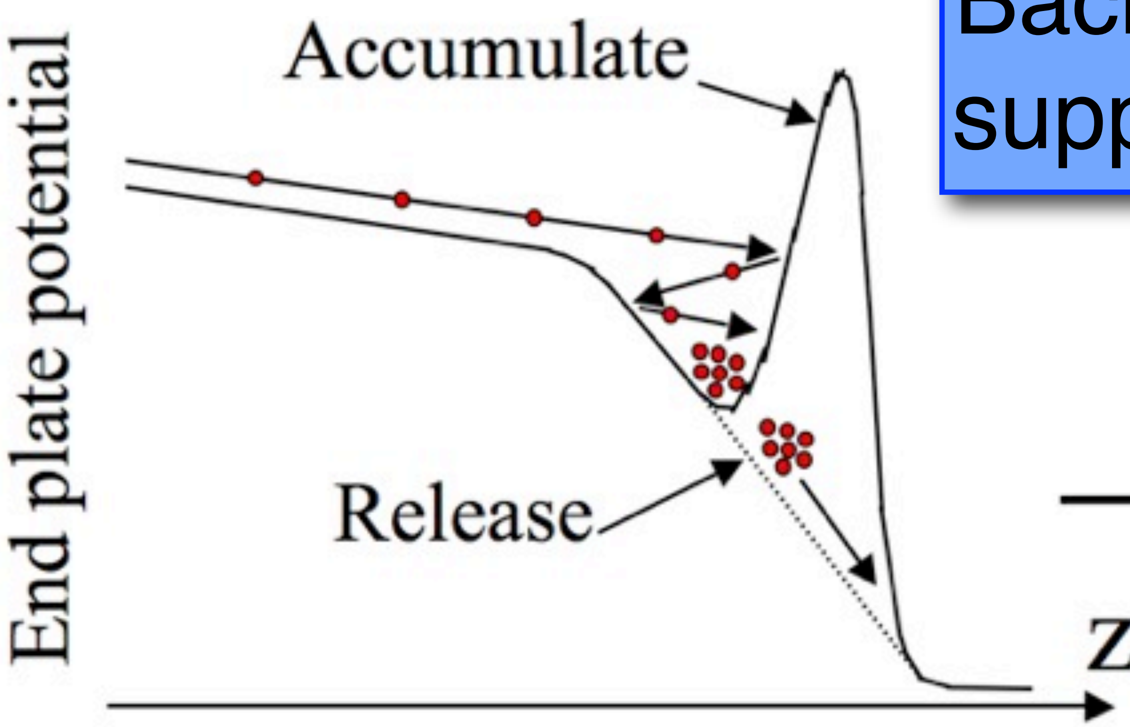


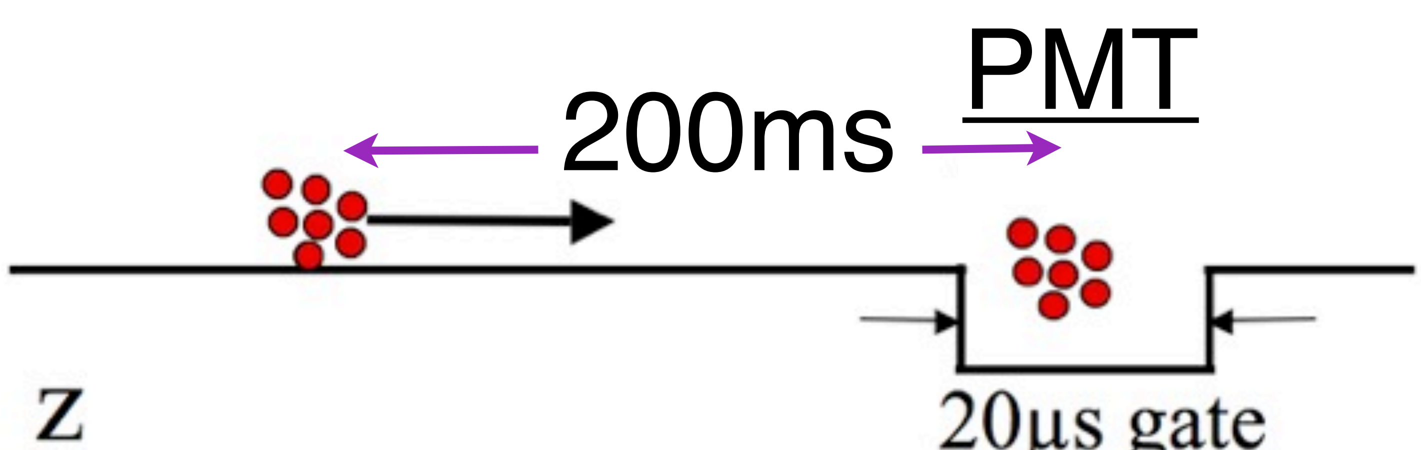


Gas filled RFQ
(→ low emittance)

Photon background dominated by continuous laser scatter

$$\text{Background suppression} = \frac{\text{200ms accumulation}}{\text{20µs gate width}} \sim 10^4$$





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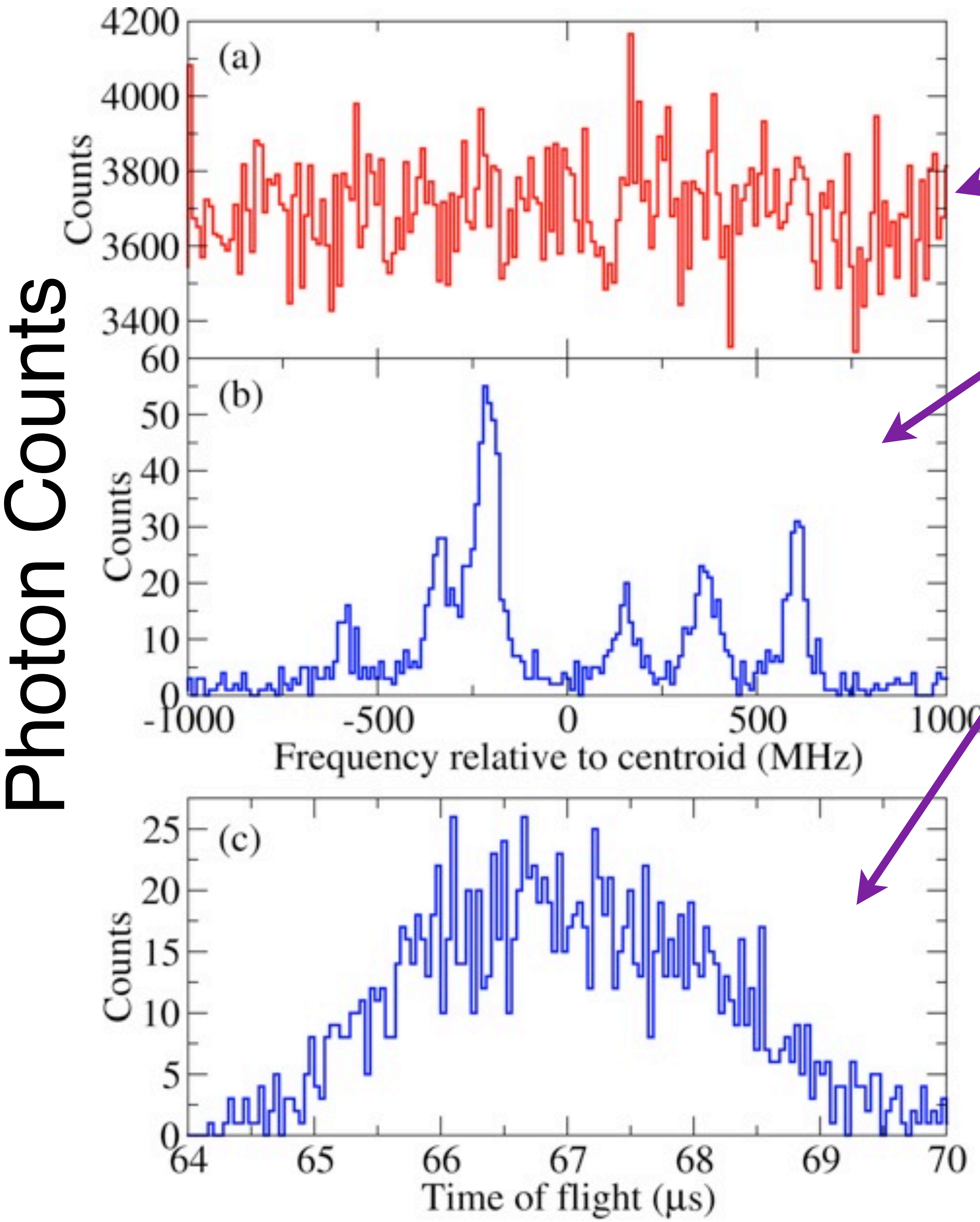
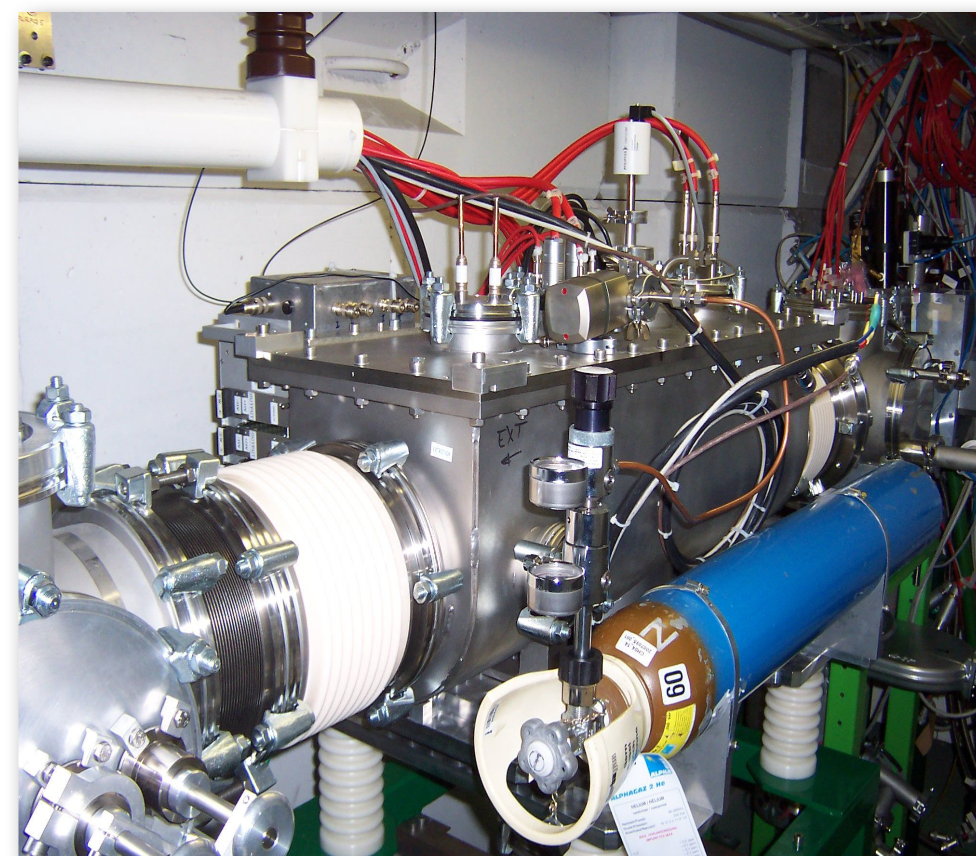
Background suppression



Ungated

Gated (64µs - 70µs)

Time of flight (50ms accumulation)



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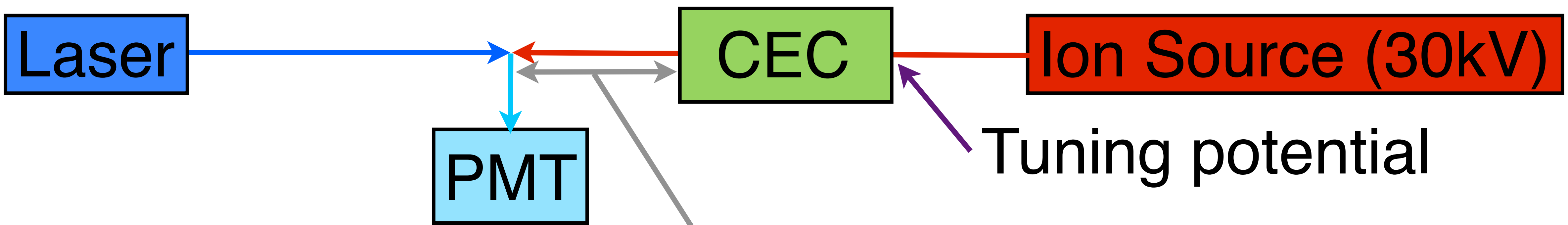
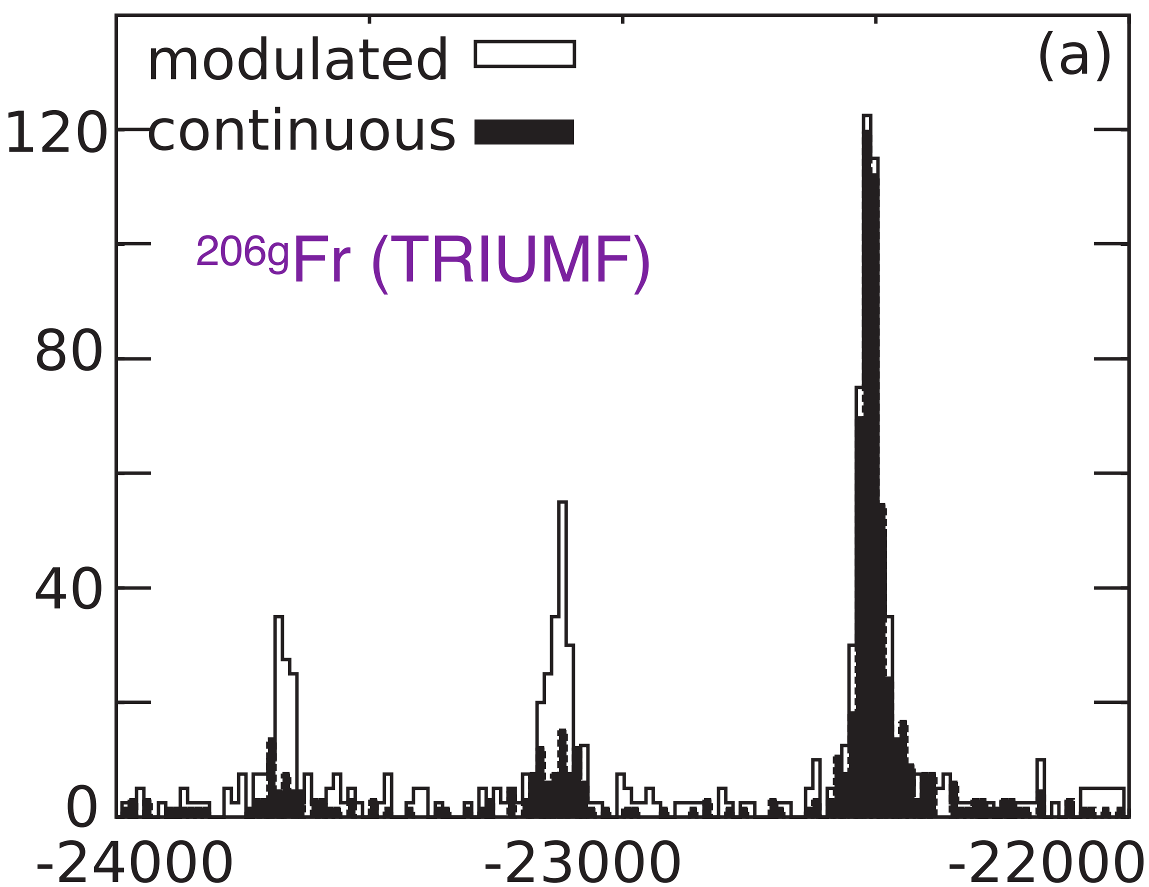
Collinear laser spectroscopy (atom)





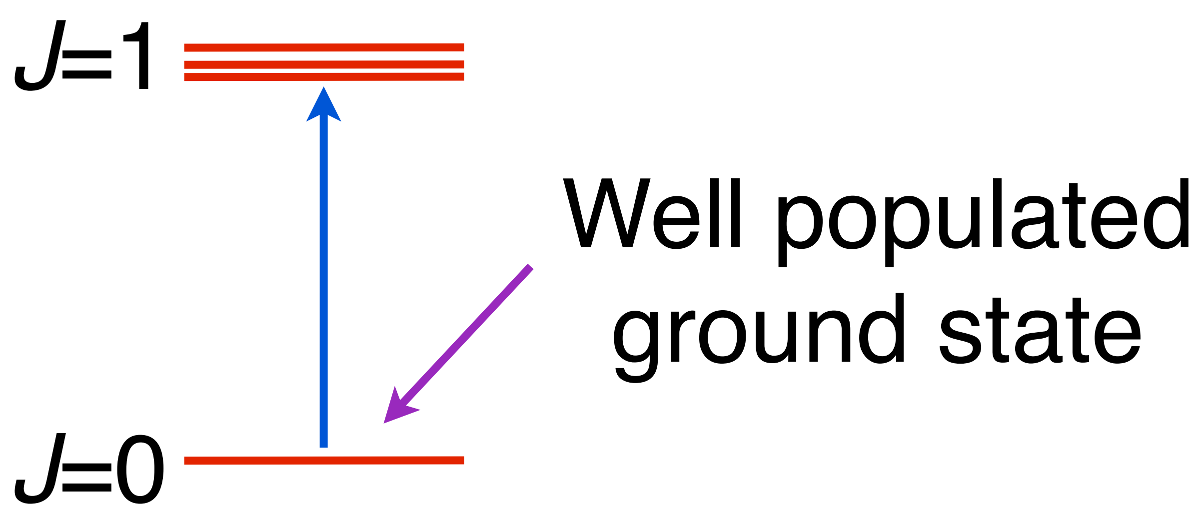
Voss *et al*. Phys. Rev. Lett. **111**, 122501 (2013)

One recent development:-

- Hyperfine pumping between CEC and light collector
- Suppressed by modulating laser intensity with EOM

In other cases however, spectroscopy is performed on the ion....

Spectroscopy from (ionic) ground states



But may present other problems.... eg.

• $0 \rightarrow 1$ gives μ, Q_s, $\delta\langle r^2 \rangle$, $\cancel{I}$	Y,Nb
• No accessible transitions (HR, cts)	Mo,Mn
• Not necessarily the most efficient	Nb,Mn
• Difficult to calibrate atomic factors	Y
• Like to separate laser and detection λ	Ca
• Hyperfine anomaly?	Ta
• Second order perturbed?	Ta

→Transitions from metastable states

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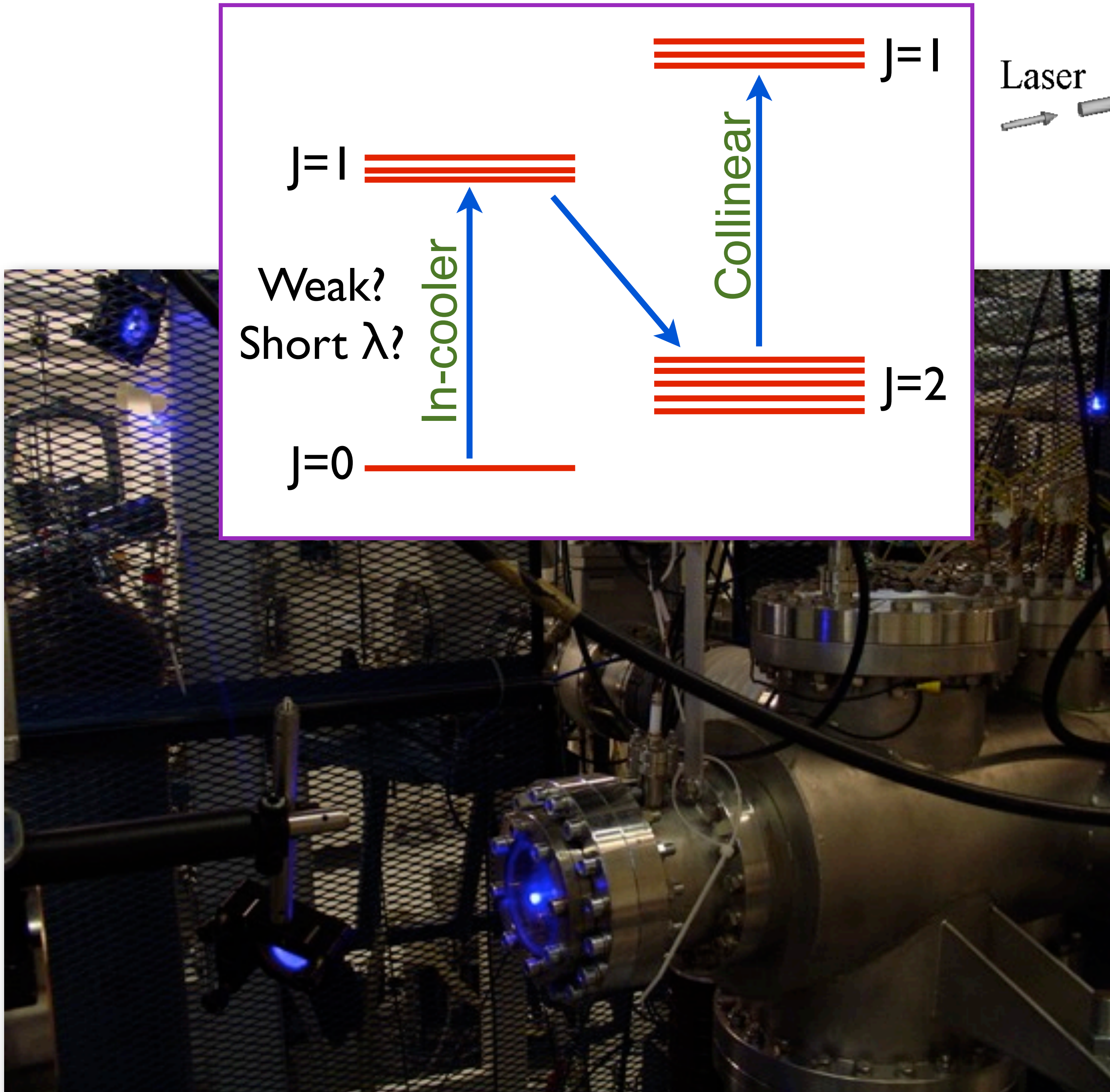
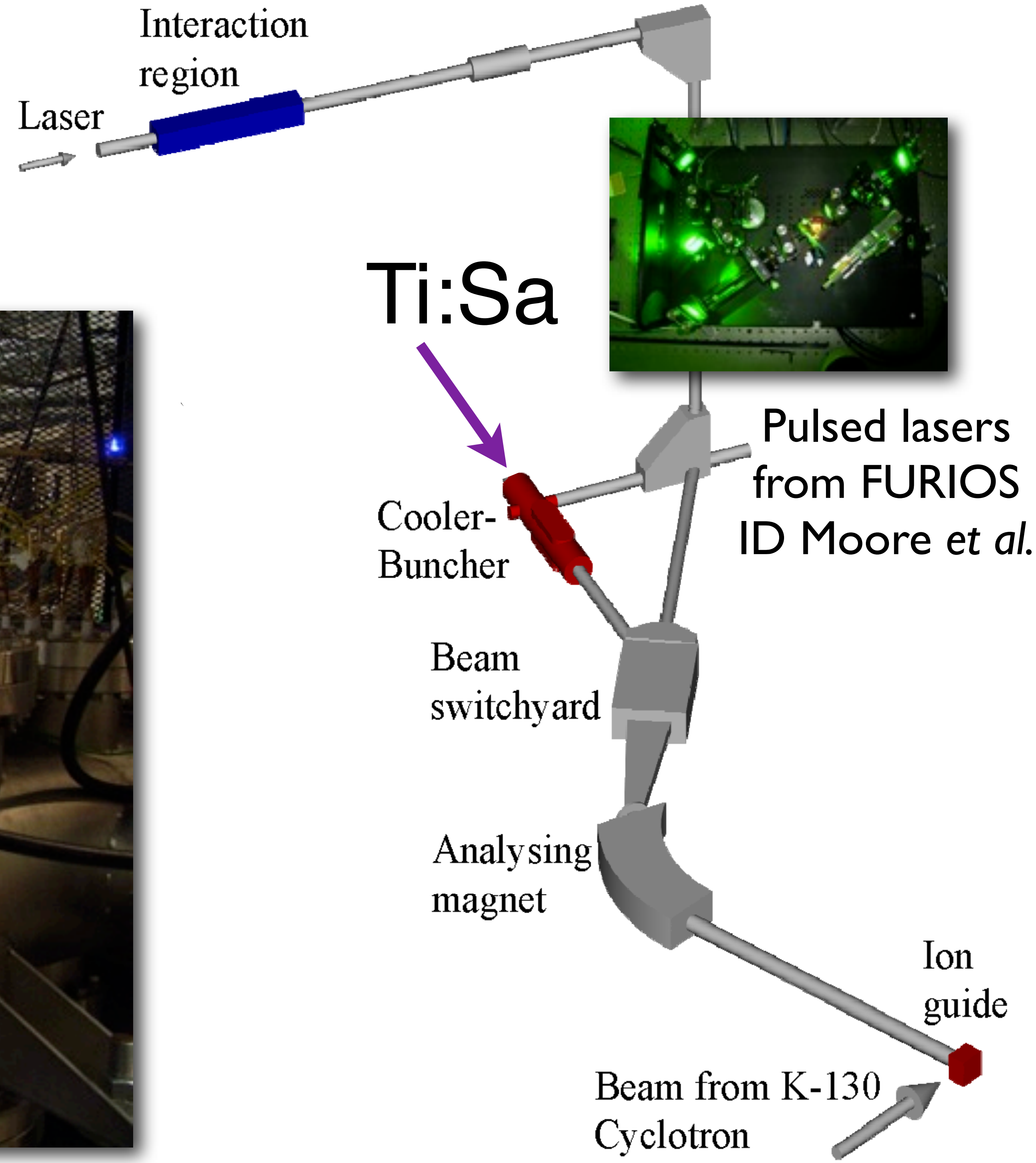
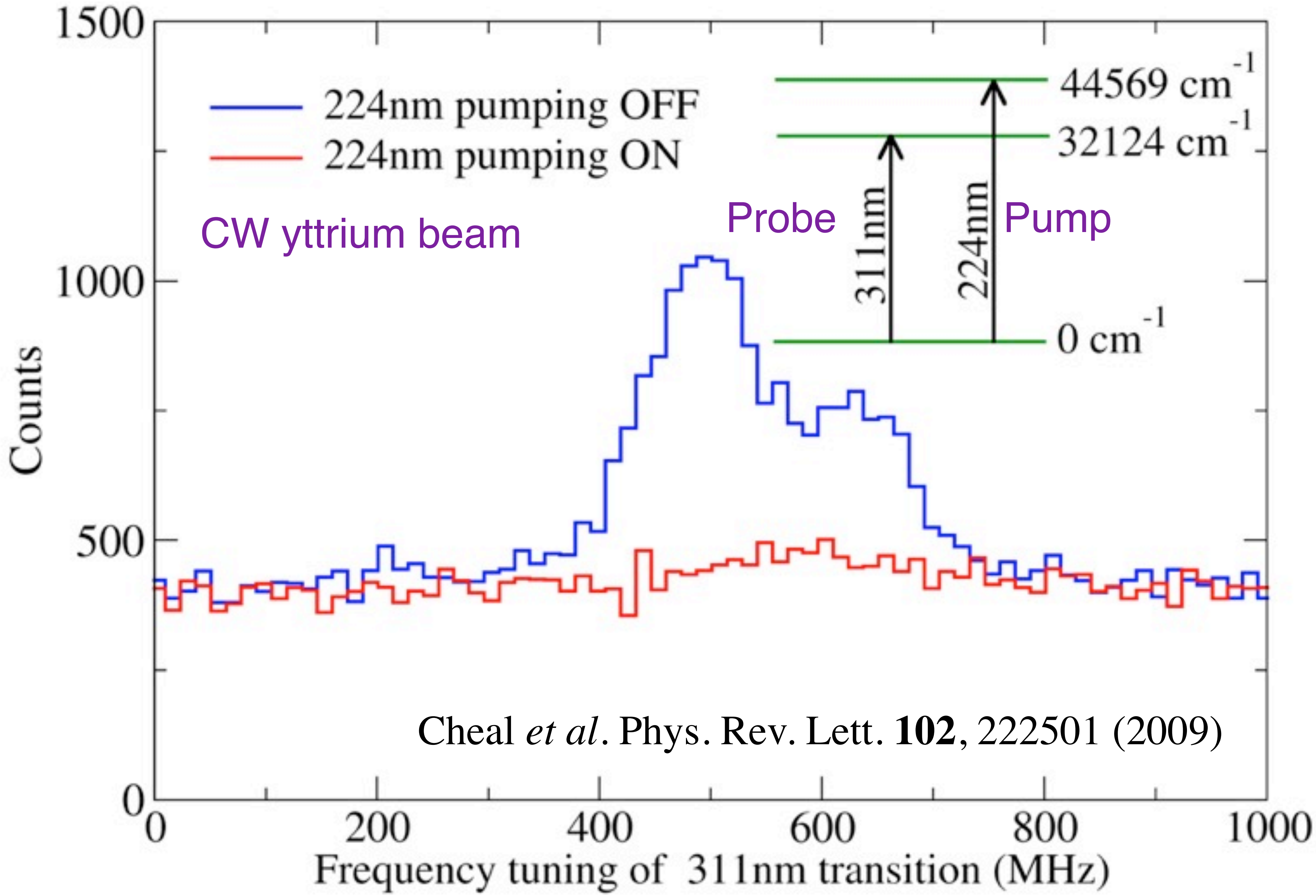
Optical pumping in the cooler





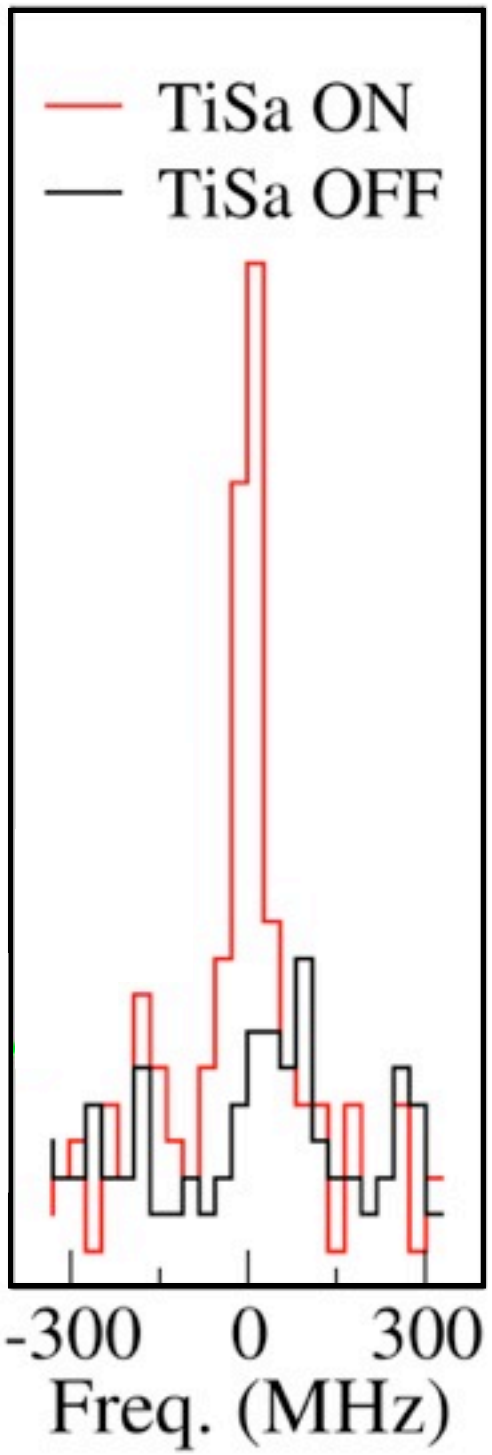
- Focus of slow / trapped ions ➜ always efficient
- Can use broadband/pulsed lasers ➜ large λ range

In-cooler efficiency

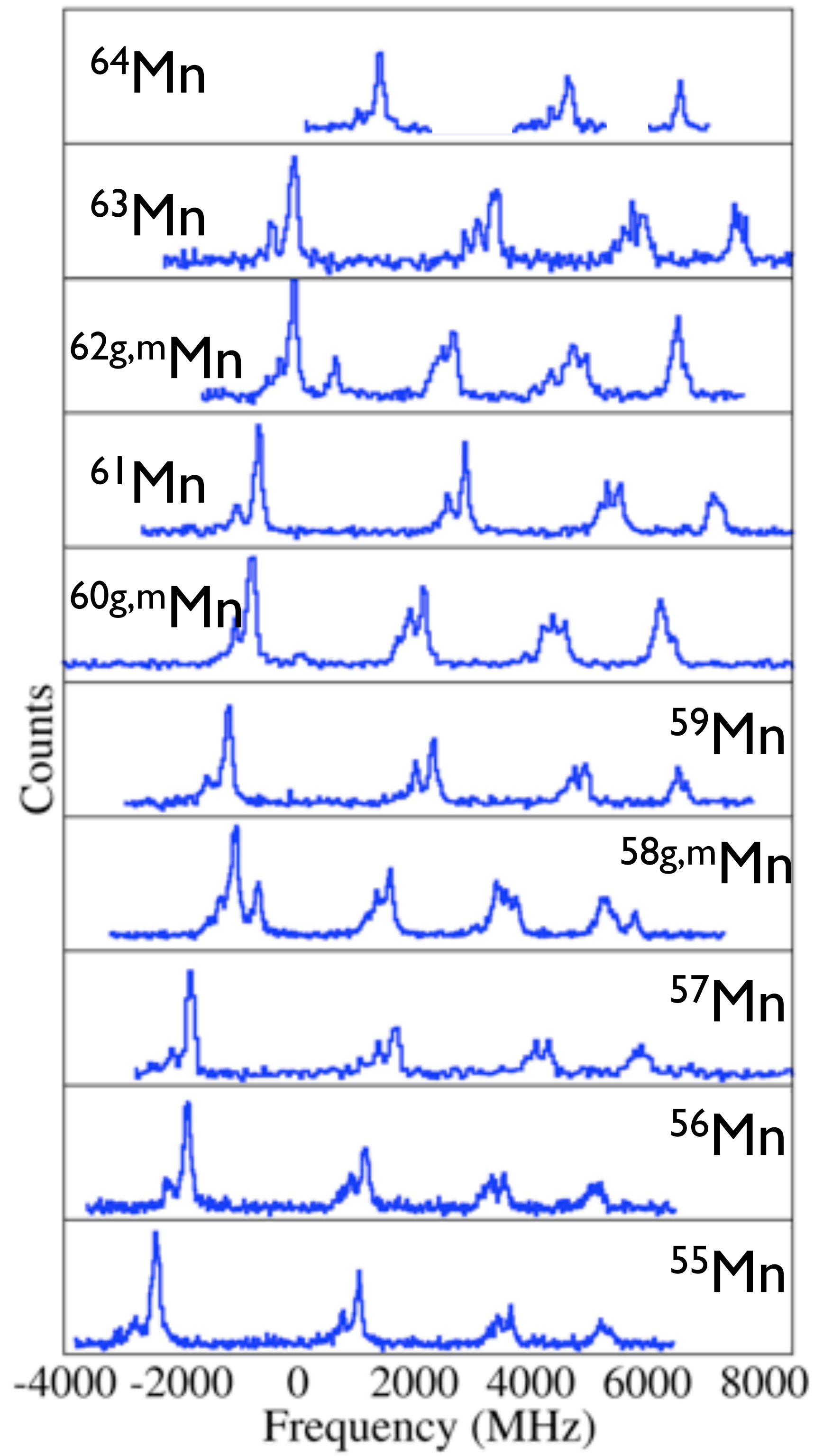


Complete depopulation of the ground state

Applications

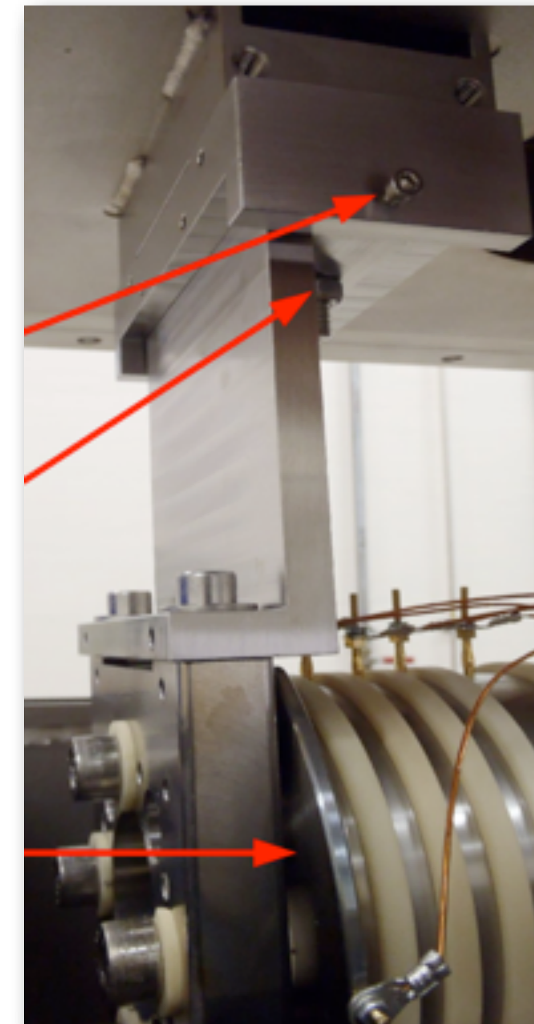


Online resonance
Nb (J=1-1) @JYFL

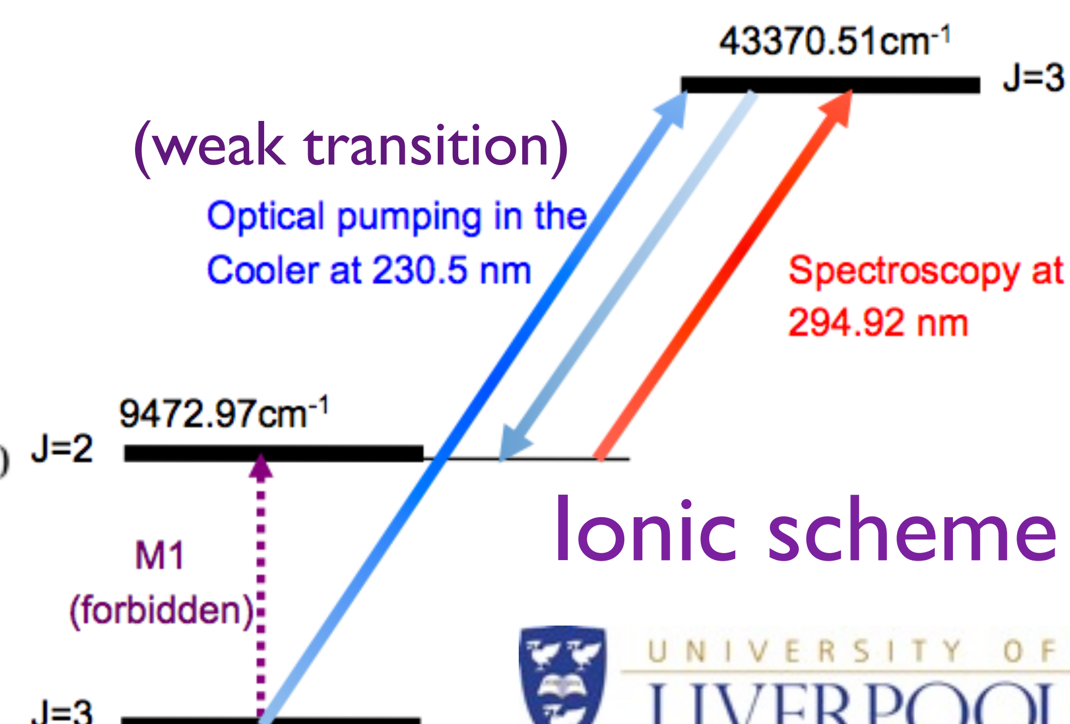


Mn (atomic)
COLLAPS, ISOLDE

Improved alignment of ISCOOL



Carla Babcock



Ionic scheme

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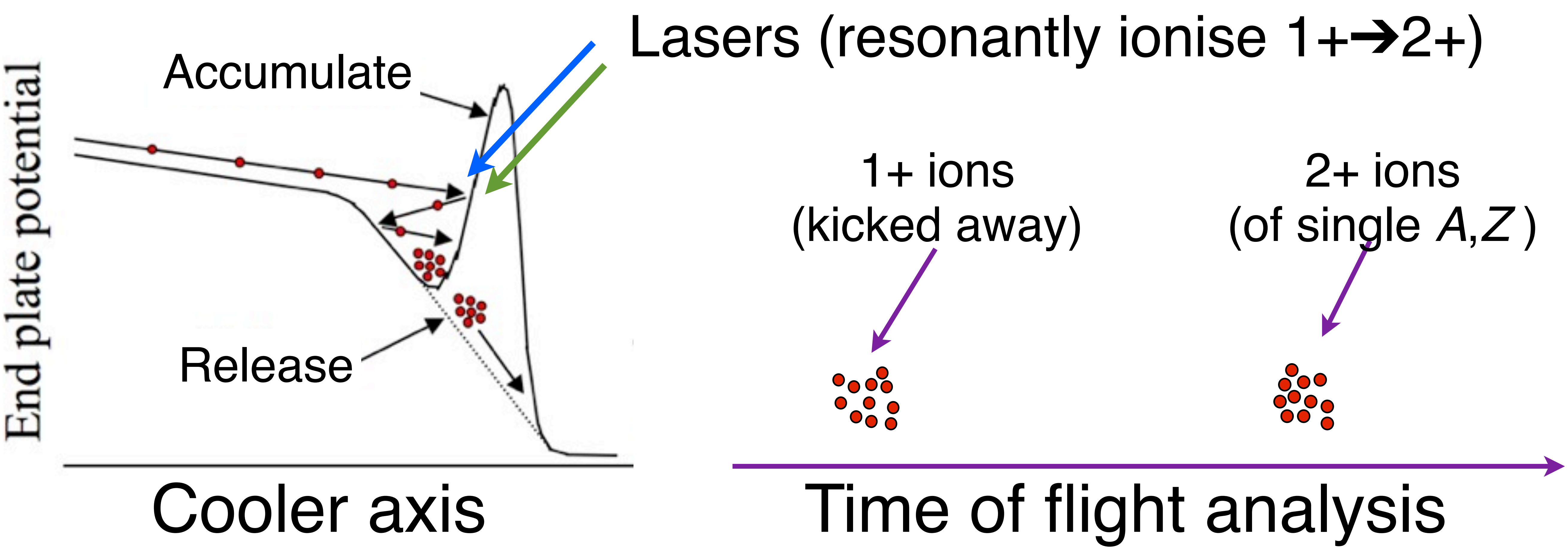
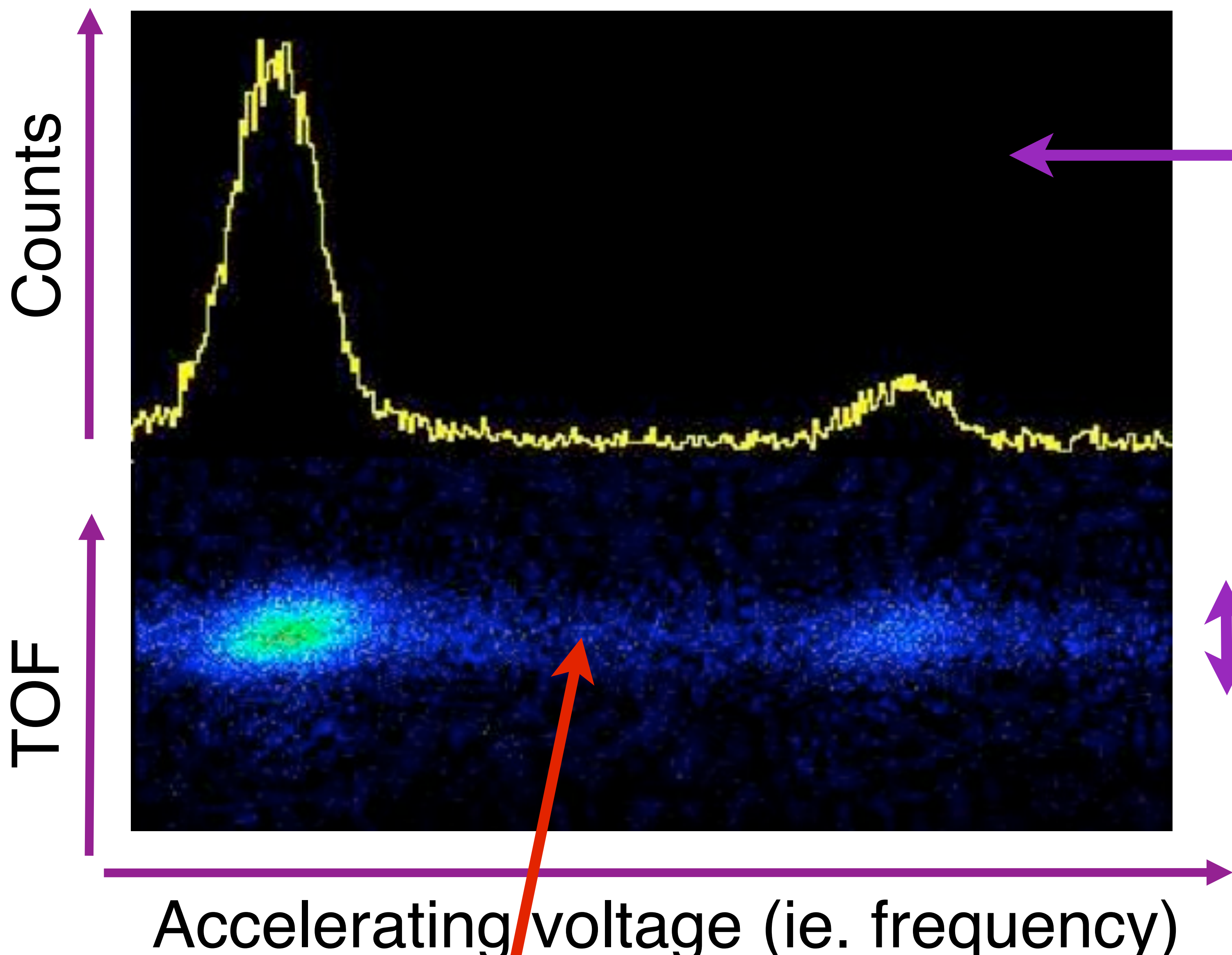
Ion beam purification



- Pure beam of single *A* **and** ***Z***
- No contaminant will have *m*/*q* selected by magnet **and** *m*/(2*q*) selected by TOF (or other device)

Application to laser spectroscopy



Optical spectrum projected

Gate applied

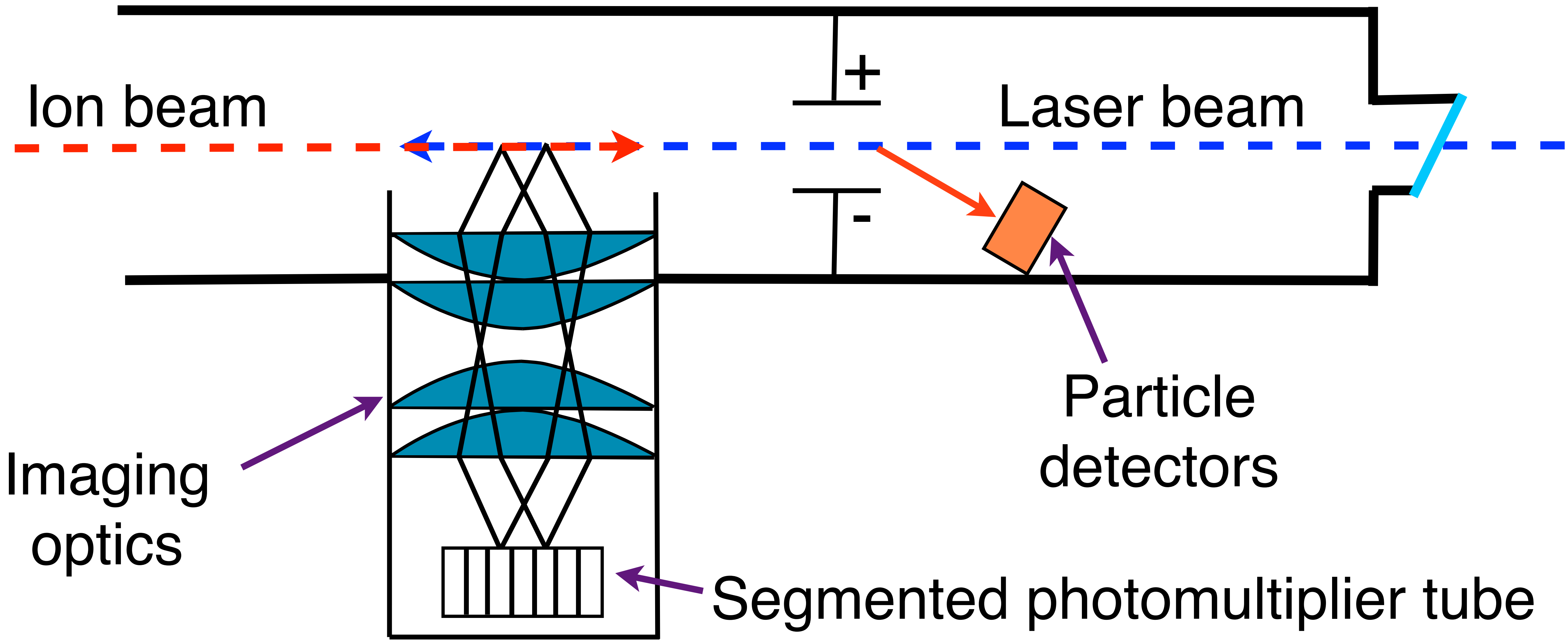
(eg. 10µs of 100ms cycle)

Isobaric contaminants have same TOF (m/q dep.)

➔ Bunching doesn't help remove this

➔ Purity will reduce this background

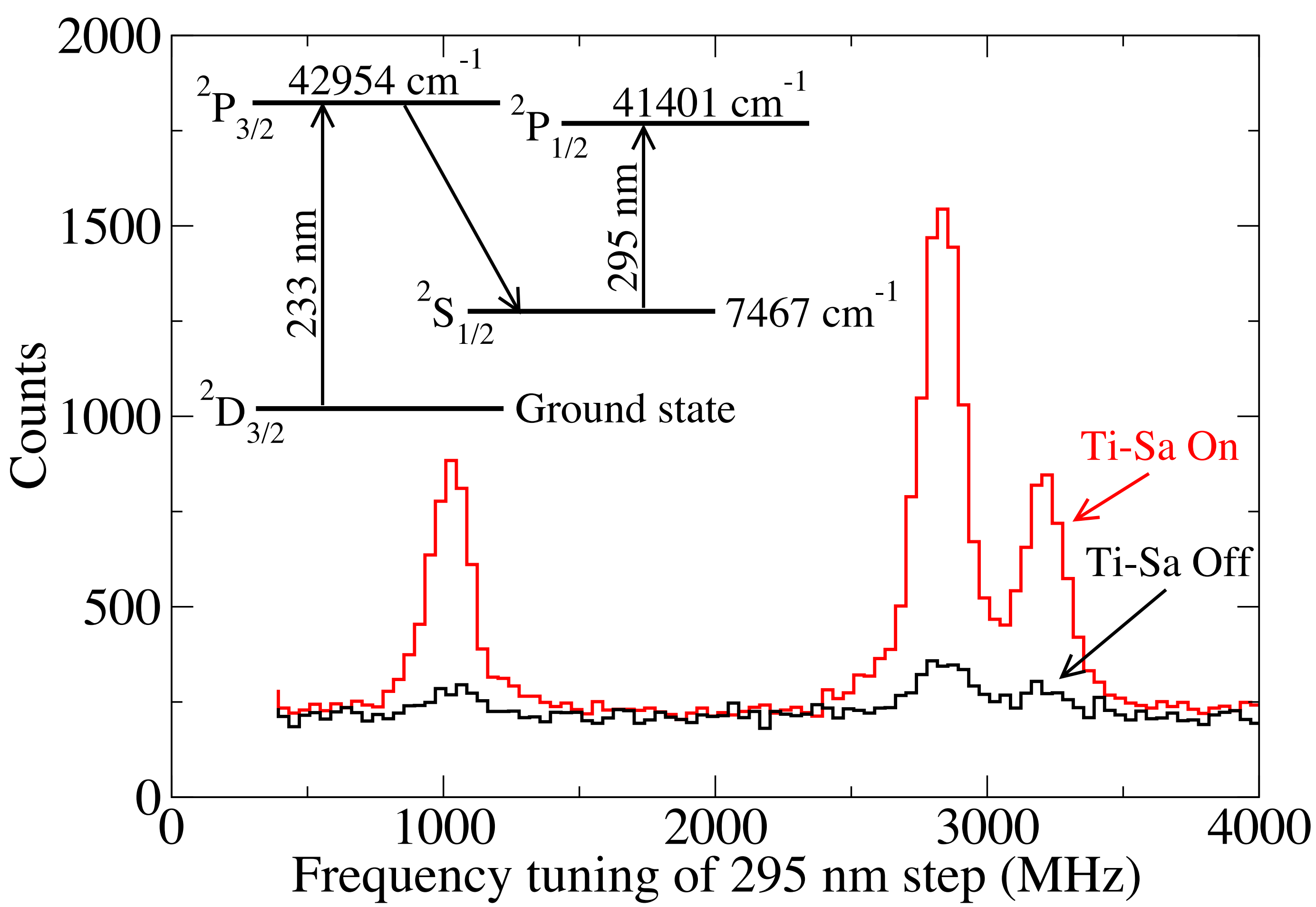
Photon-ion coincidence

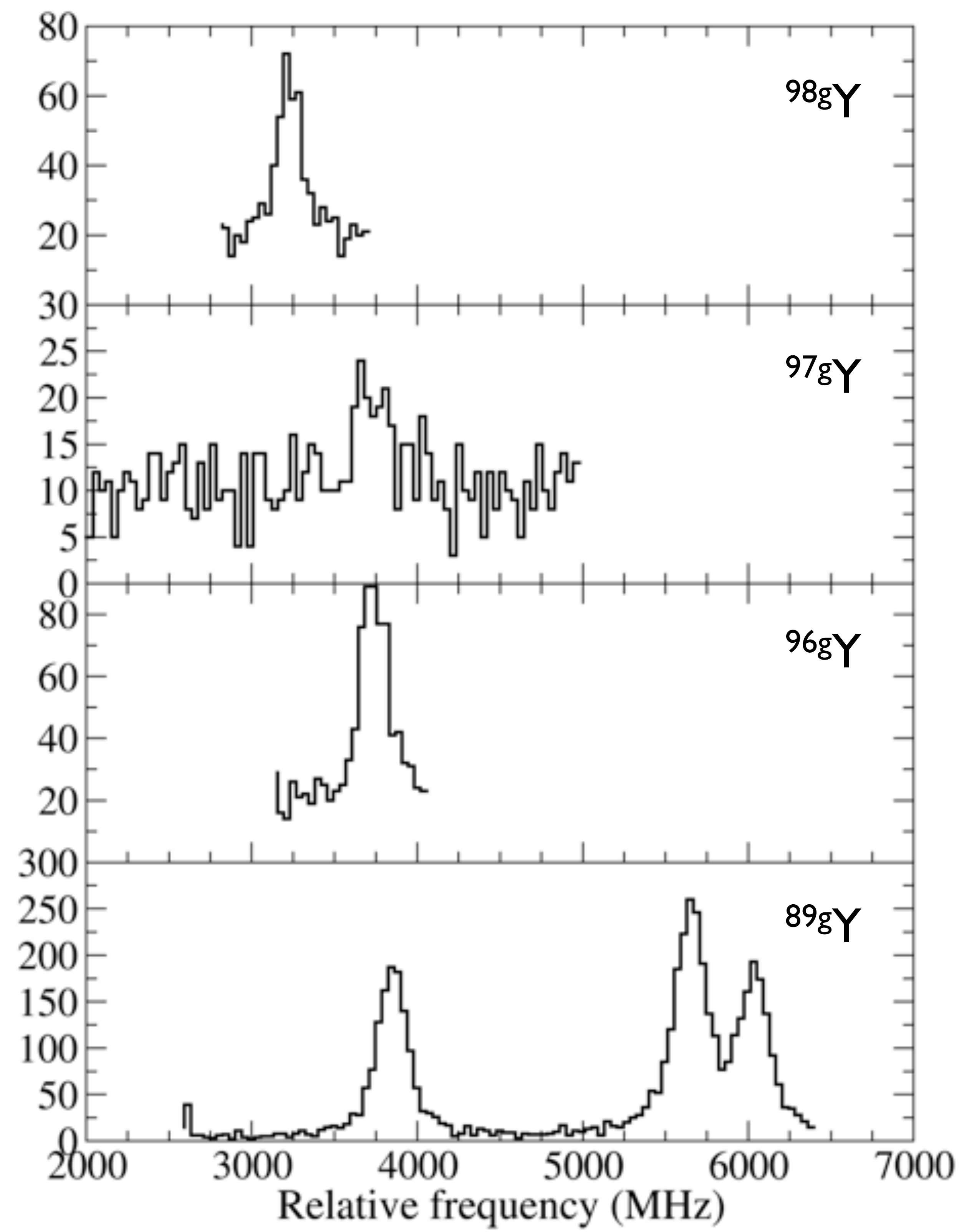


- Requires pure beams
- Cooled beams ➔ ~5 ns resolution ➔ few atoms/s

Doubly-charged spectroscopy

- Y^{2+} spectra (IGISOL 4, JYFL)
- Natural production (10-20%)
- Optical pumping used
- Pure s-p transition for calibration
- For IRIS, tune second step





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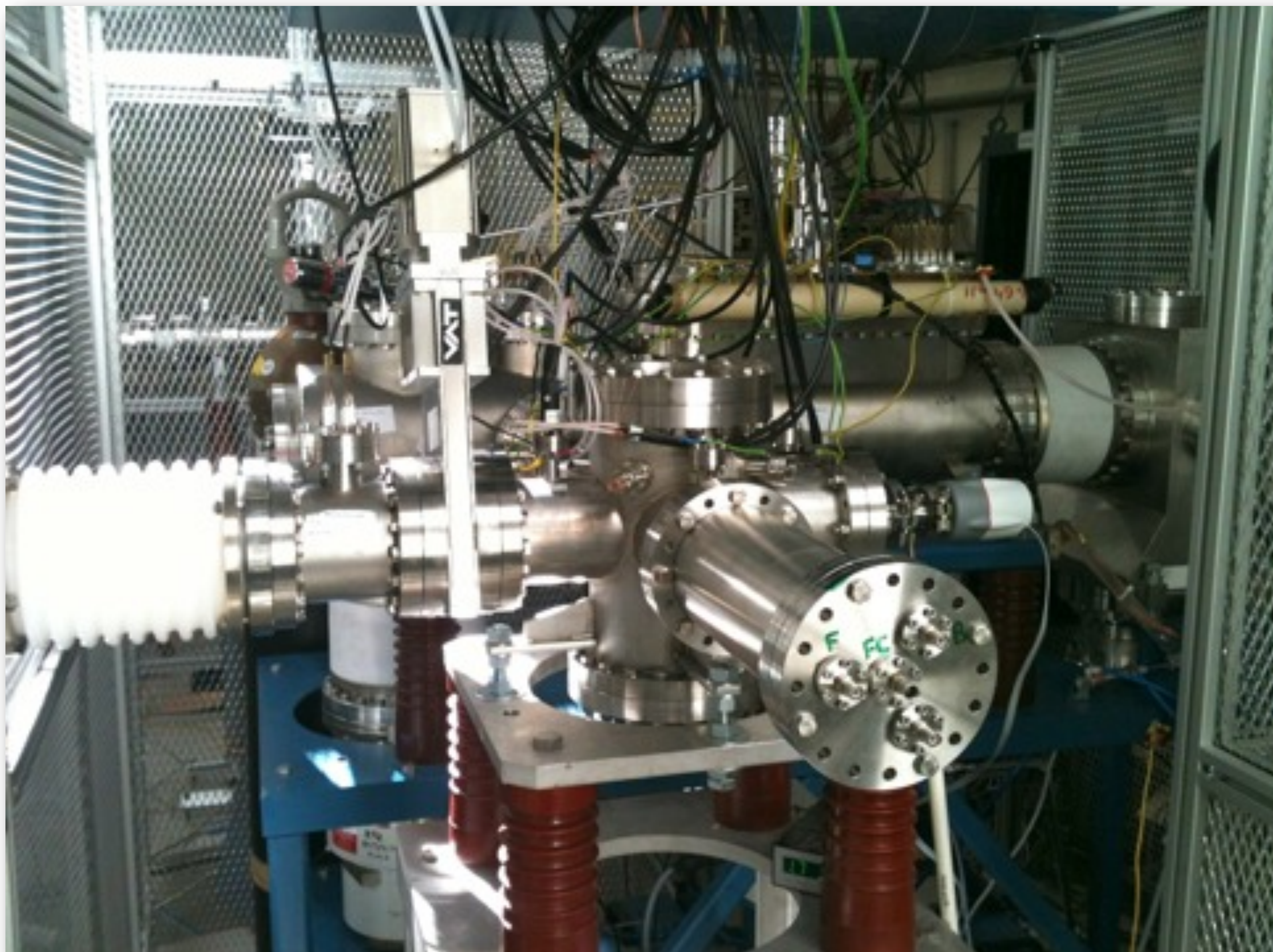
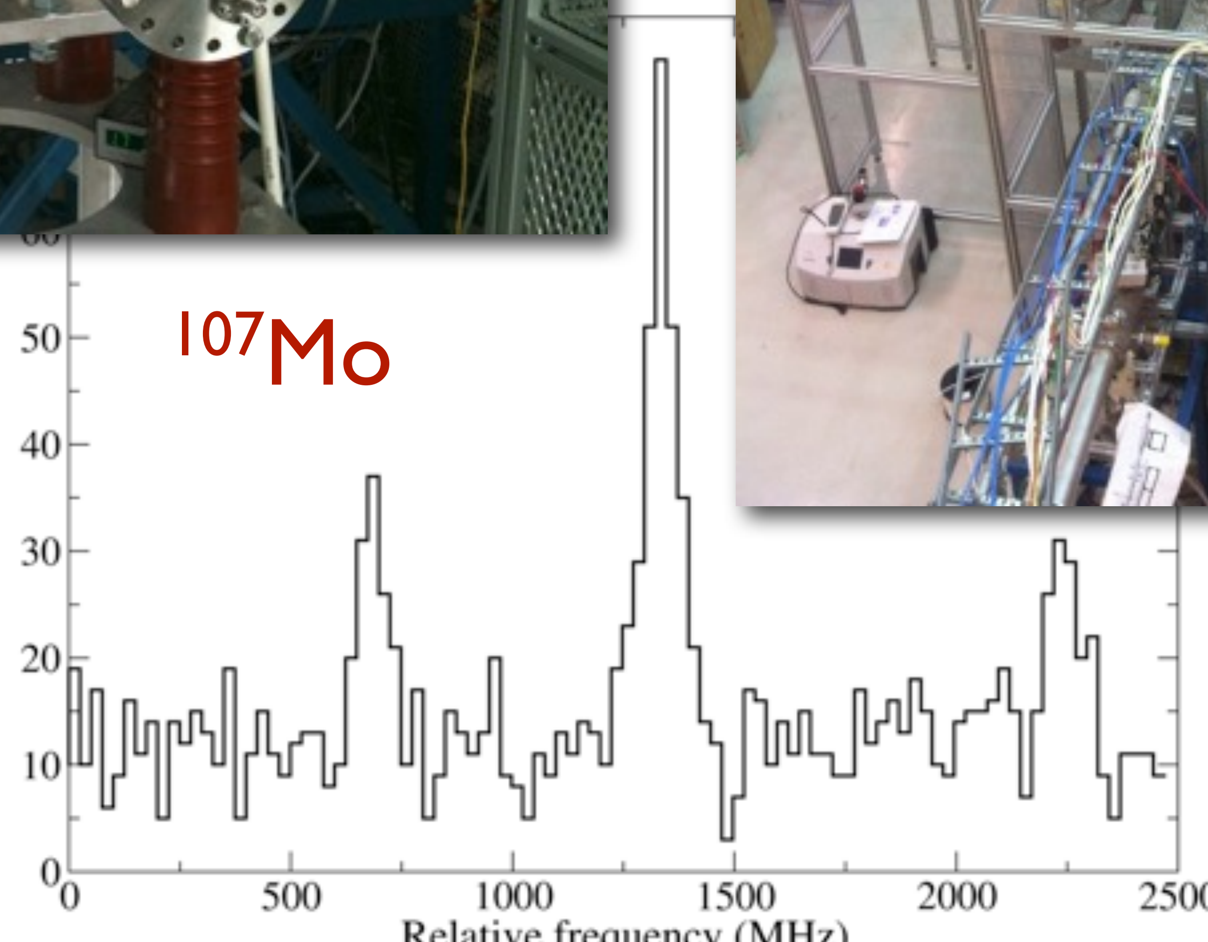
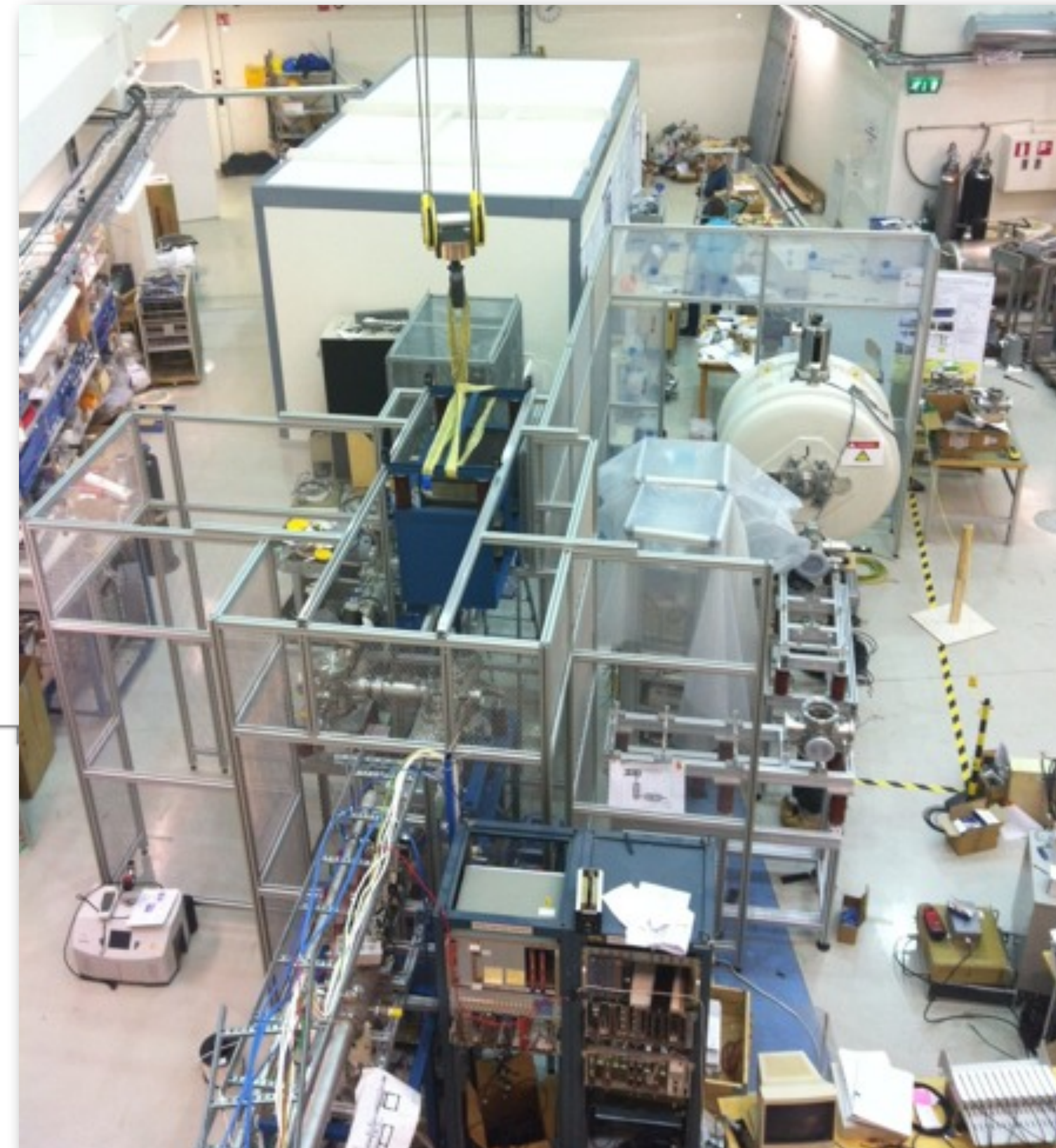
The new IGISOL 4 laboratory



Easy optical access





2012

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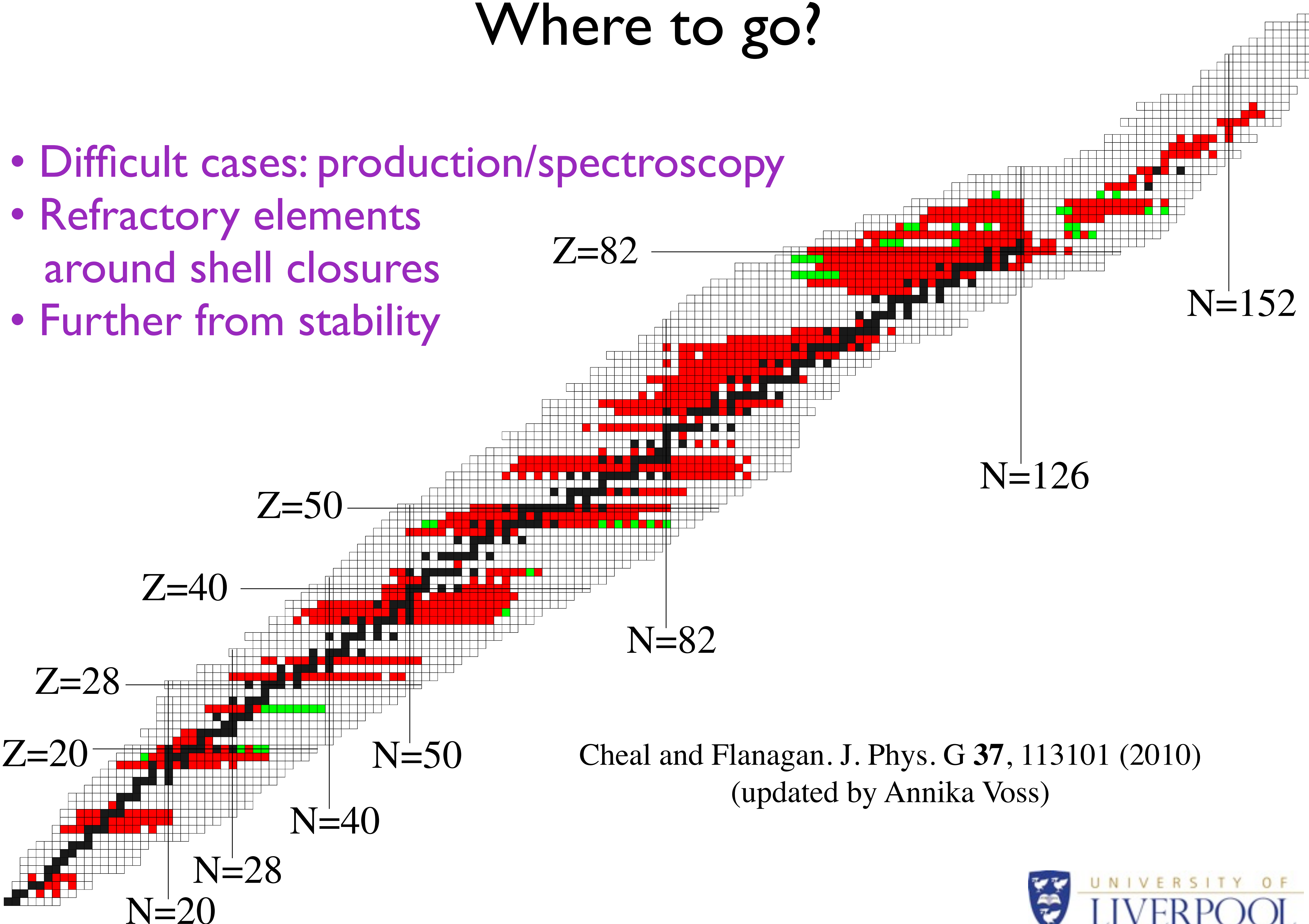
Where to go?

- Difficult cases: production/spectroscopy
- Refractory elements around shell closures
- Further from stability



Cheal and Flanagan. J. Phys. G **37**, 113101 (2010)
(updated by Annika Voss)

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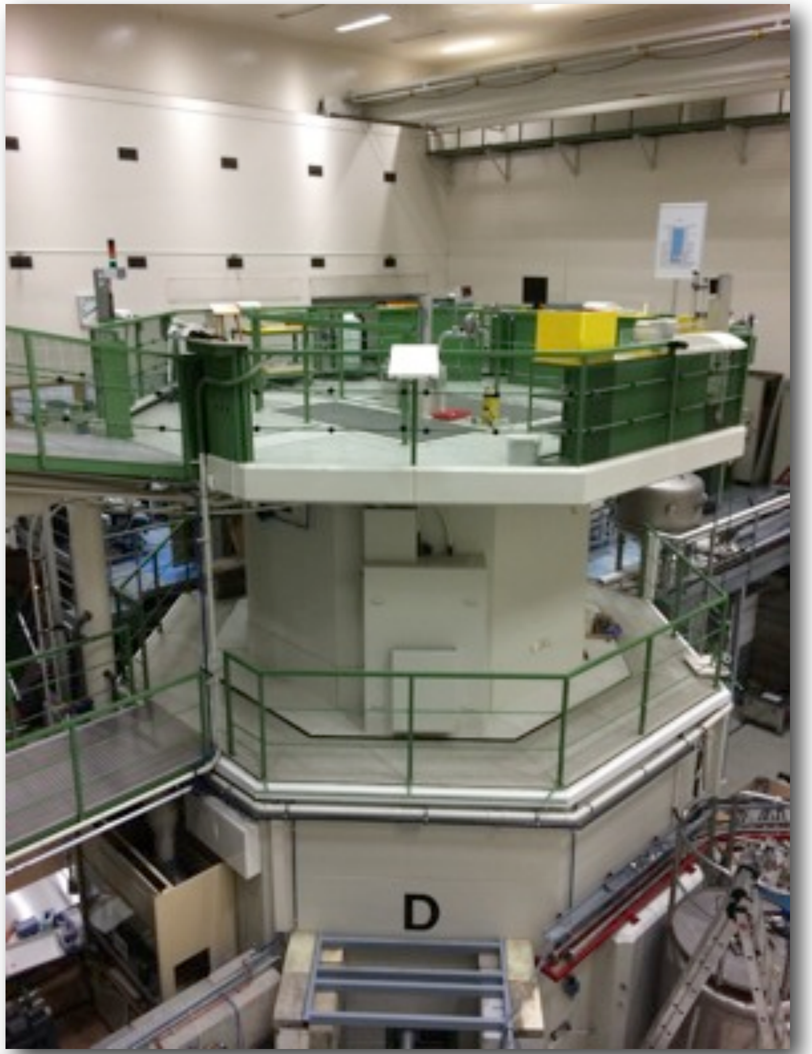
Looking ahead to LaSpec



- Laser spectroscopy provides unique access to several fundamental nuclear properties
- Lasers invaluable for beam preparation
- All new techniques developed now (at JYFL, ISOLDE, TRIUMF, MSU, GSI...) will be immediately applicable at LaSpec
- Prototype/actual LaSpec beamline installed at TRIGA, Mainz
- Much to explore!