Laser Spectroscopy at TRIUMF

McGill

Olivier Shelbaya

TRIUMF

Collinear Laser Spectroscopy

Ions from cyclotron continuously enter RFQ

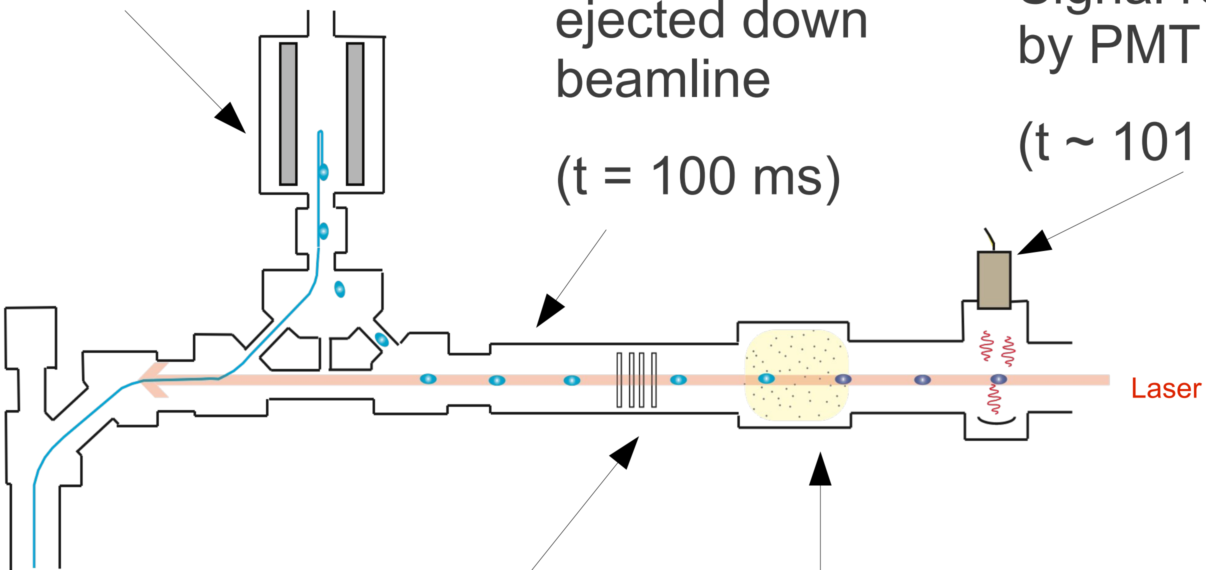
Accumulate 10^5 charges

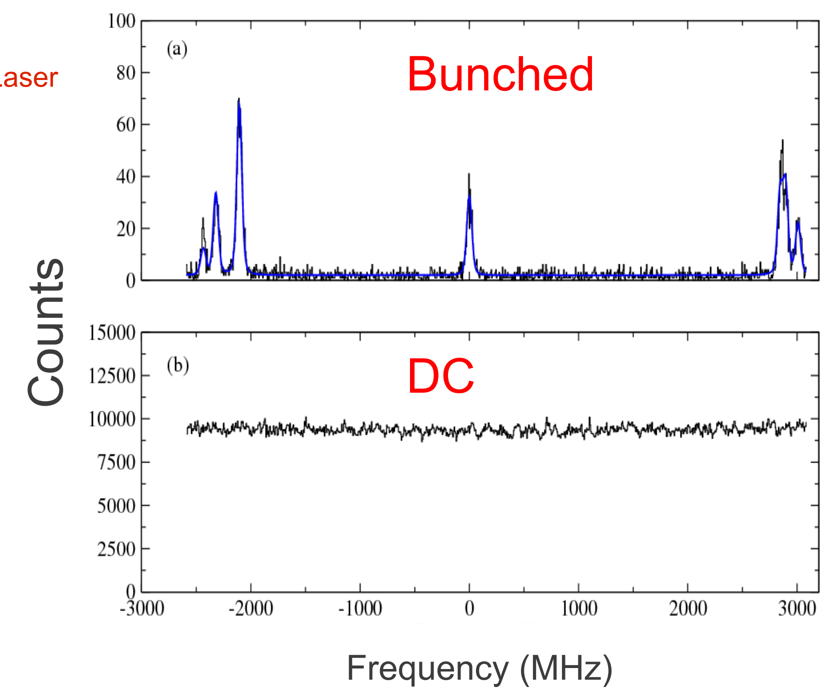
Bunched ions ejected down beamline

(t = 100 ms)

Signal recorded by PMT

(t ~ 101 ms)





Acceleration electrodes

DC ion beam

Neutralization by charge exchange

(floated at electrode potential)

Cutaway of High Vacuum beamline

Hyperfine Structure

Spectral lines break into smaller components, due to:

- e⁻ B-field coupling to Nuclear magnetic moment
- Nuclear electric Quadrupole moment

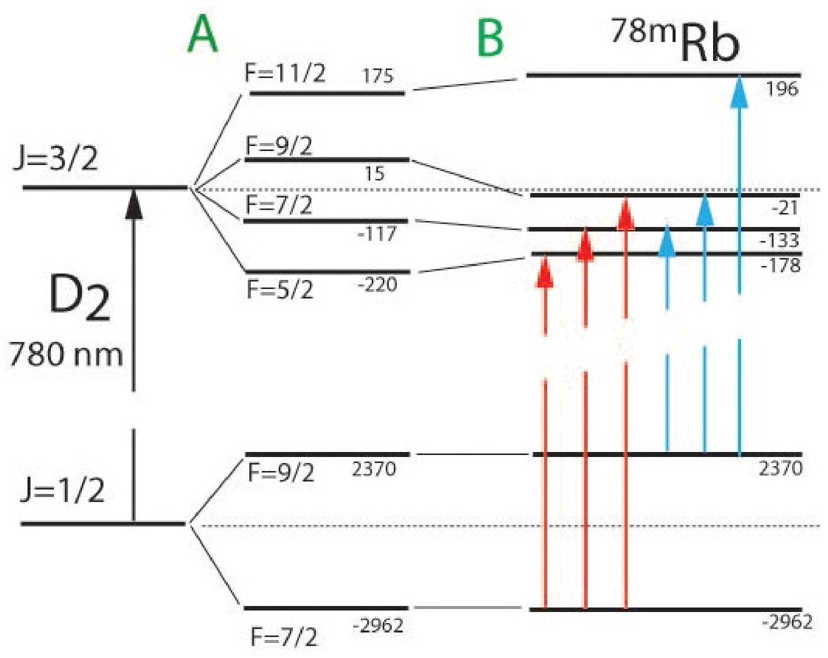
$$\Delta E_{hfs} = \frac{K}{2} A - \frac{3K(K+1) - 4I(I+1)J(J+1)}{8I(2I-1)J(2J-1)} B$$

$$K = F(F+1) - I(I+1) - J(J+1)$$

$$A = \frac{\mu_I}{IJ} B_e(0)$$

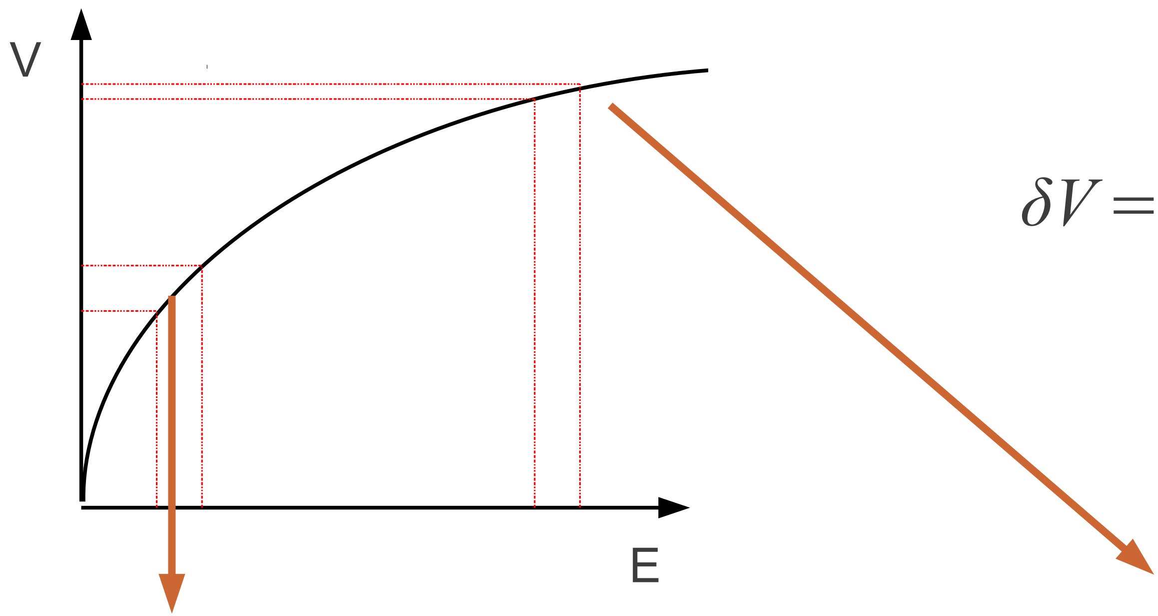
$$B = eQ_s \left\langle \frac{\partial^2 V}{\partial z^2} \right\rangle$$

Spectroscopic quadrupole moment



Fine Structure: meV
Hyperfine structure: μeV

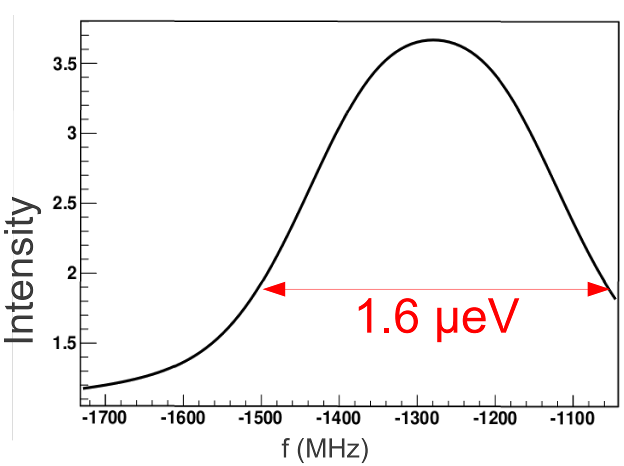
Doppler Broadening of Spectral Lines



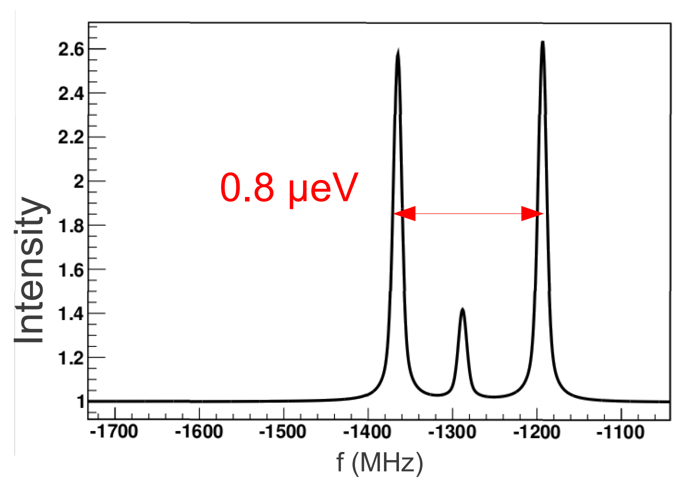
$$\delta V = \frac{\delta E}{mV}$$

δE is finite, only δV may be changed

Higher beam energy, less Doppler broadening



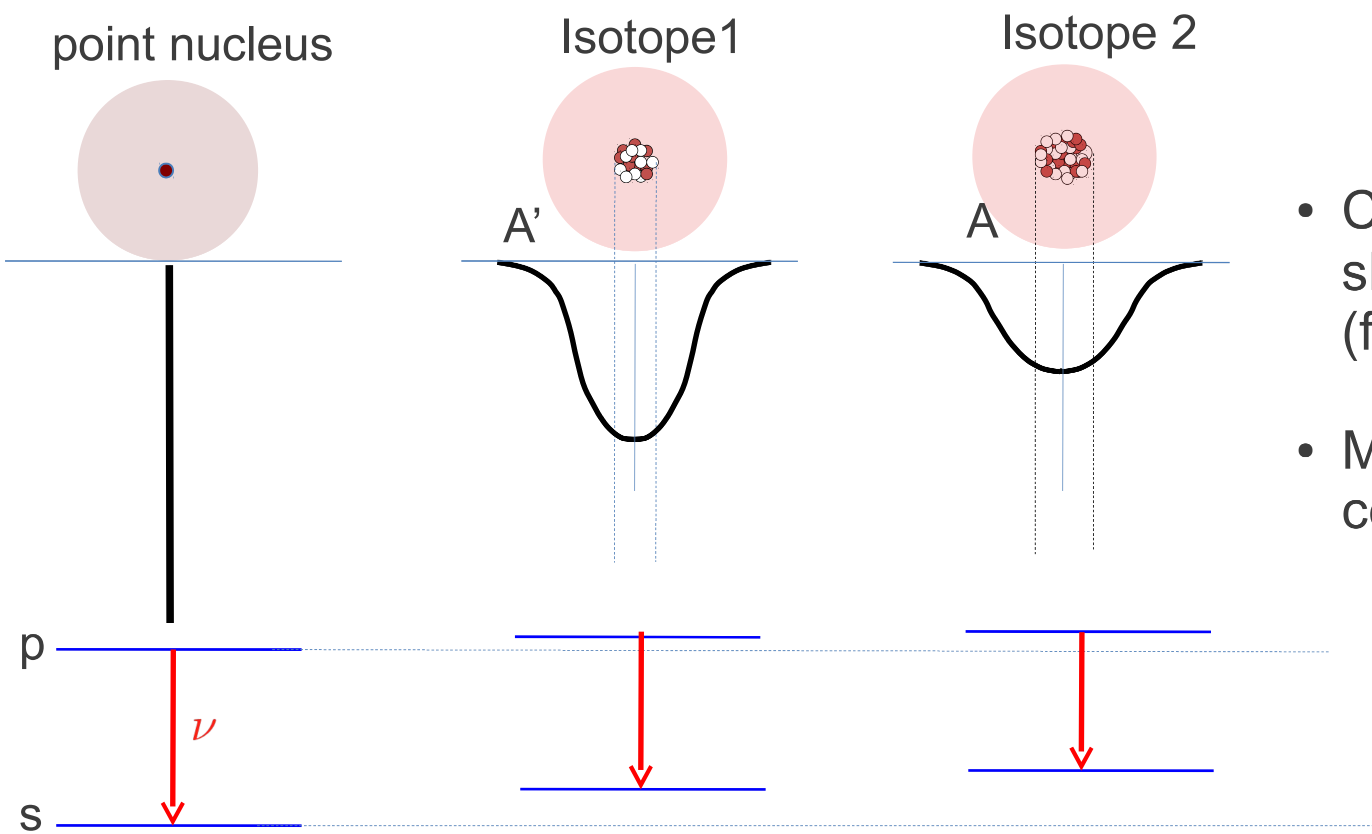
More broadening



Less broadening

^{85}Rb hyperfine lines

Isotope Shifts (δv)



- Change in nuclear potential shifts e^- energy levels (field shift)
- Mass change shifts energy centroid (mass shift)

IS can be lined to variation of nuclear charge radius:

$$\delta v = \delta v_{MS} + F(Z)\,\delta\langle r^2\rangle$$

Measure line shift, get information on change in radius!

$F(Z)$: factor that takes into account e^- and nuclear wavefunction overlap

Gameplan

Produce rare isotopes

Measure HFS → Get nuclear spin I

Get nuclear spin I → Get μ_I, Q_s

Measure HFS → Get $\delta\nu$

Get $\delta\nu$ → Extract $\delta\langle r^2 \rangle$, infer shape of nucleus

Eat doughnuts in here (ISAC-I counting room)

The Rubidium Isotope Chain

Z = 37

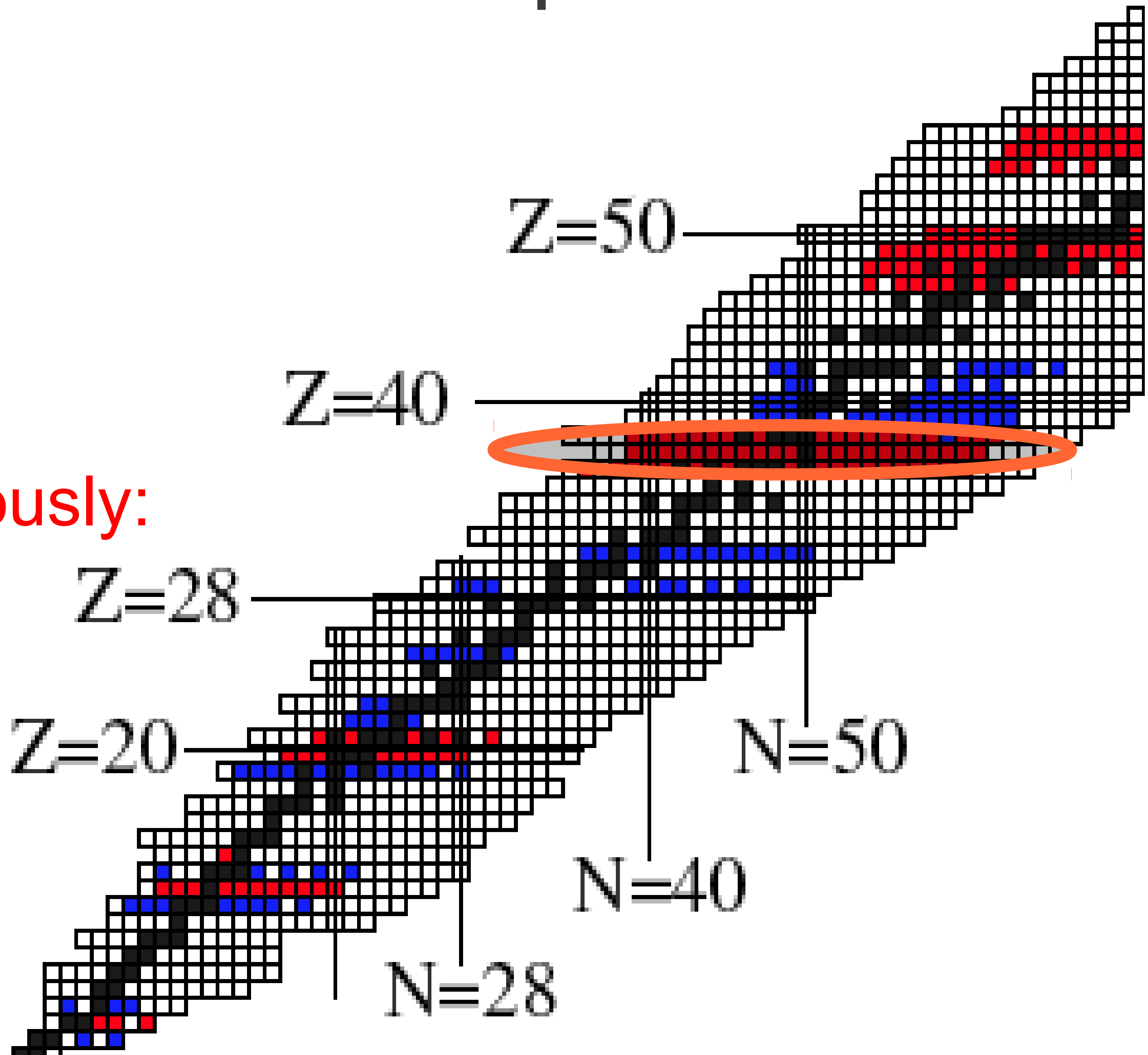
Known:

^{71}Rb to ^{102}Rb

^{85,87}Rb stable

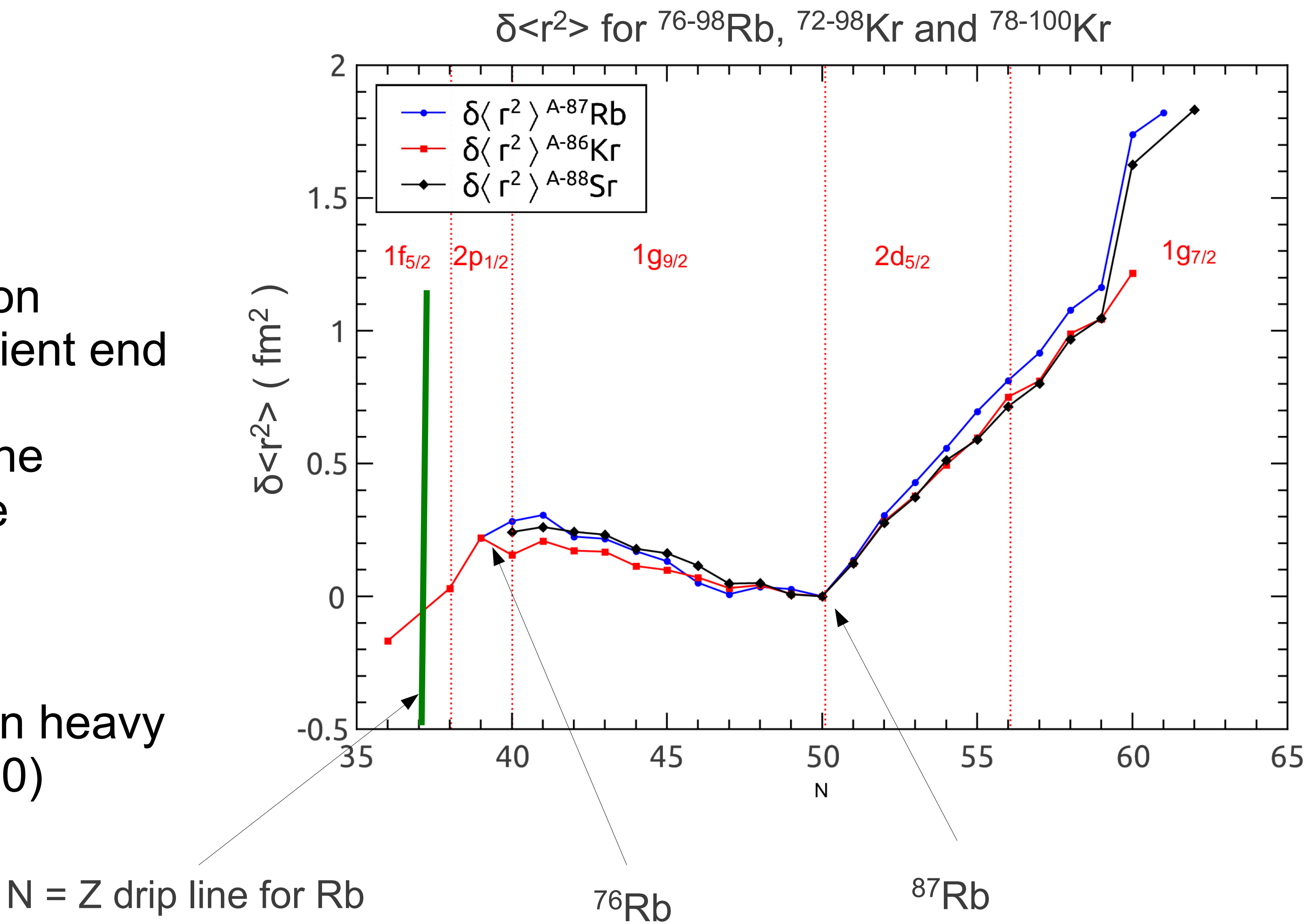
Observed previously:

^{76}Rb to ^{98}Rb



Motivation

- Presence of vibrational deformation on neutron deficient end
- Proton drip line (^{74}Rb) shape coexistence
- Dramatic deformation in heavy Rb's (N=59,60)



$^{74-78}$Rb at TRIUMF late 2010

40 min

2.1x10^9/s

45 min

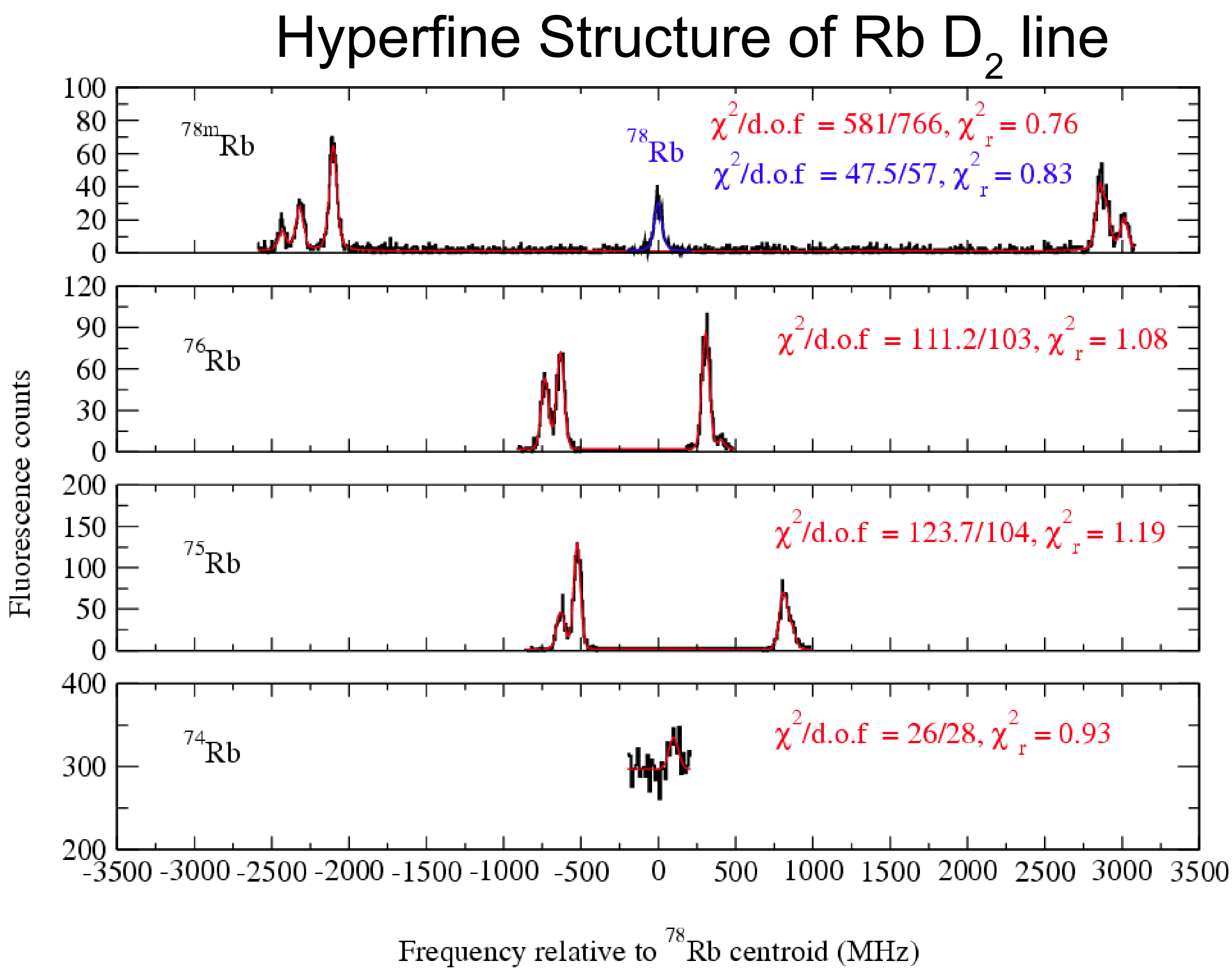
7x10^7/s

35 min

2.1x10^6/s

7h

1.7x10^4/s



Results

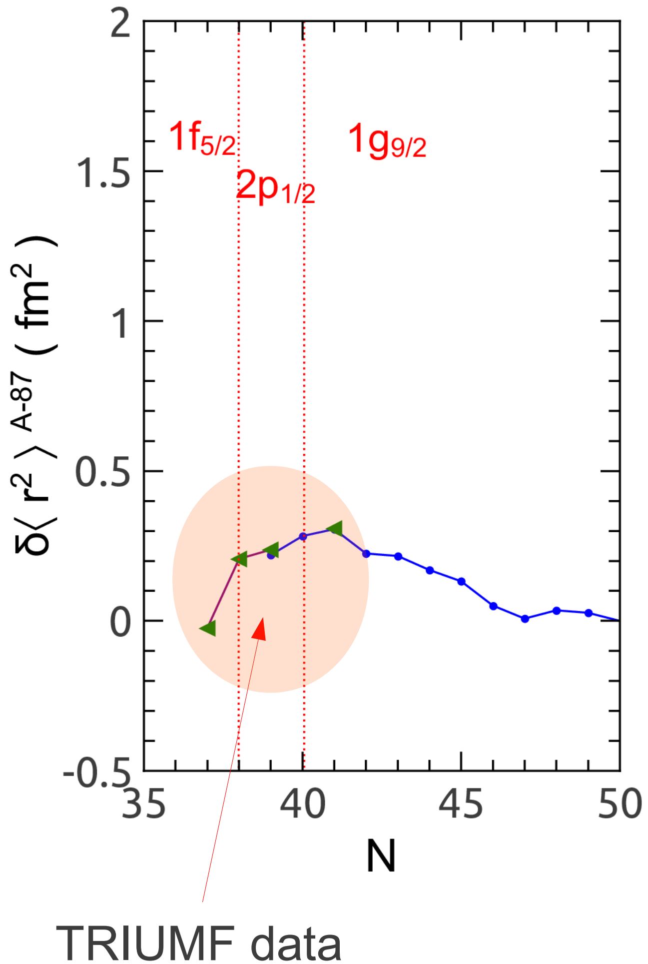
All A,B coefficients in MHz

A	I	$\delta\nu^{A-78}$	$A(S_{1/2})$	$A(P_{3/2})$	$B(P_{3/2})$	χ^2
74	0	+99(10)	-	-	-	0.93
75	3/2	-41.1(17)	+719.6(10)	+17.8(01)	+63(27)	1.18
76	1	-24.3(12)	-693(08)	-17.15(01)	+32(07)	1.08
78m	4	+69.4(21)	+1185.1(05)	+29.3(01)	+83.1(22)	0.76
78	0	0	-	-	-	0.83

- 76Rb: 10x reduction in uncertainty for A,B coeff.
- 75Rb: First nuclear spin assignment (I = 3/2)
- 74Rb: First measurement of isotope shift & Charge radius:

$<r^2>^{74} = 4.18(10)\ fm^2$

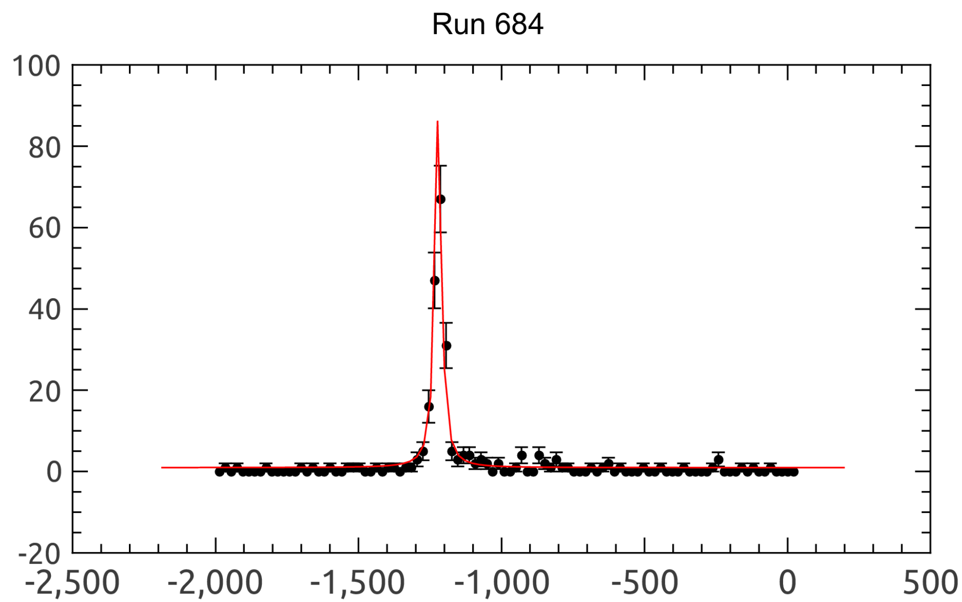
Variations in $\delta\langle r^2 \rangle$ for $^{76-98}$Rb

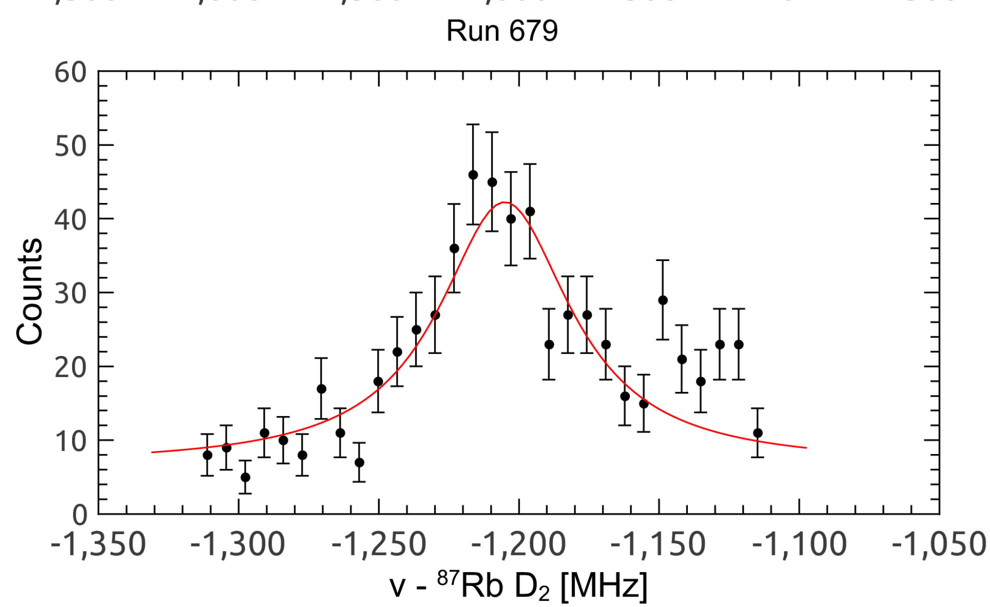


Heavy Rb at TRIUMF, late 2011

Obtained spectra for ^{92}Rb

(10 minute observations)





92 has I = 0 (nuclear spin)

- No hyperfine structure
- Yields of ~ 10^9/s

Conclusion

- Laser spectroscopy probes shape & structure of nuclei
- Extended observations of light Rb's
- Plan to extend on neutron rich end – study dramatic shape change
- Obtained ^{92}Rb spectra late 2011 – First step
- Late April – plans to measure HFS for Rubidium 98-99 and 100
- Observations will reveal whether increase in $\delta<r^2>$ is maintained beyond 97,98 Rb

Laser spectroscopy Collaboration

Dr. Matt Pearson

Dr. Ernesto Mané

Dr. John Behr

TRIUMF

Prof. John Crawford
Dr. Fritz Buchinger
Olivier Shelbaya

McGill

Prof. Jon Billowes
Annika Voss

Manchester