Nuclear moments, spins and charge radii of copper isotopes from N=28 to N=50 by collinear fast-beam laser spectroscopy

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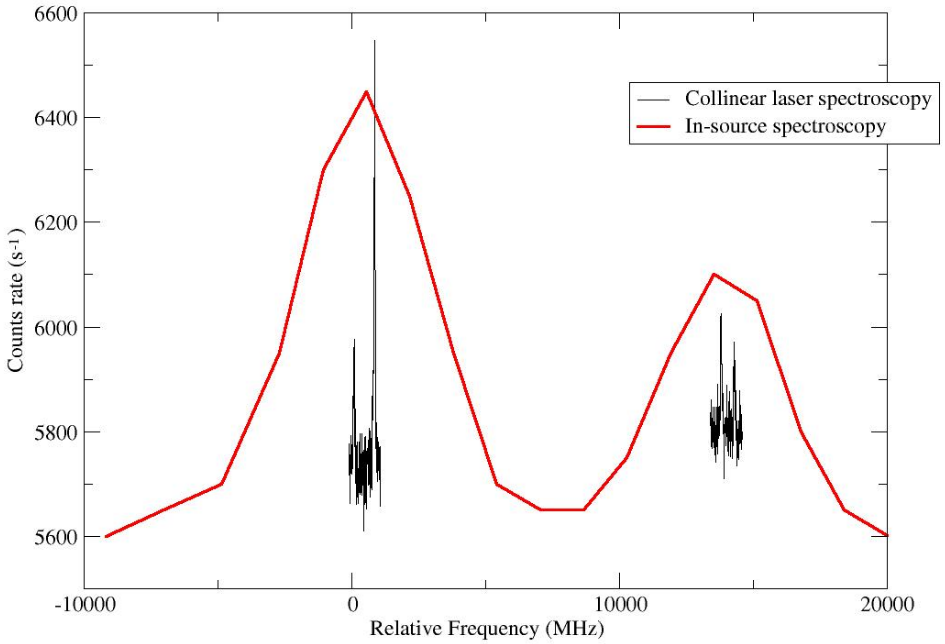
B. Cheal.

Laser spectroscopy at ISOLDE

- An atomic probe that extracts model independent nuclear information (spin, nuclear moments, charge radii).
- Several approaches (in-source, trapped, collinear…)
- Efficiency vs resolution
- Background (radioactive isobars, scattered light…)

Collinear and in-source laser spectroscopy



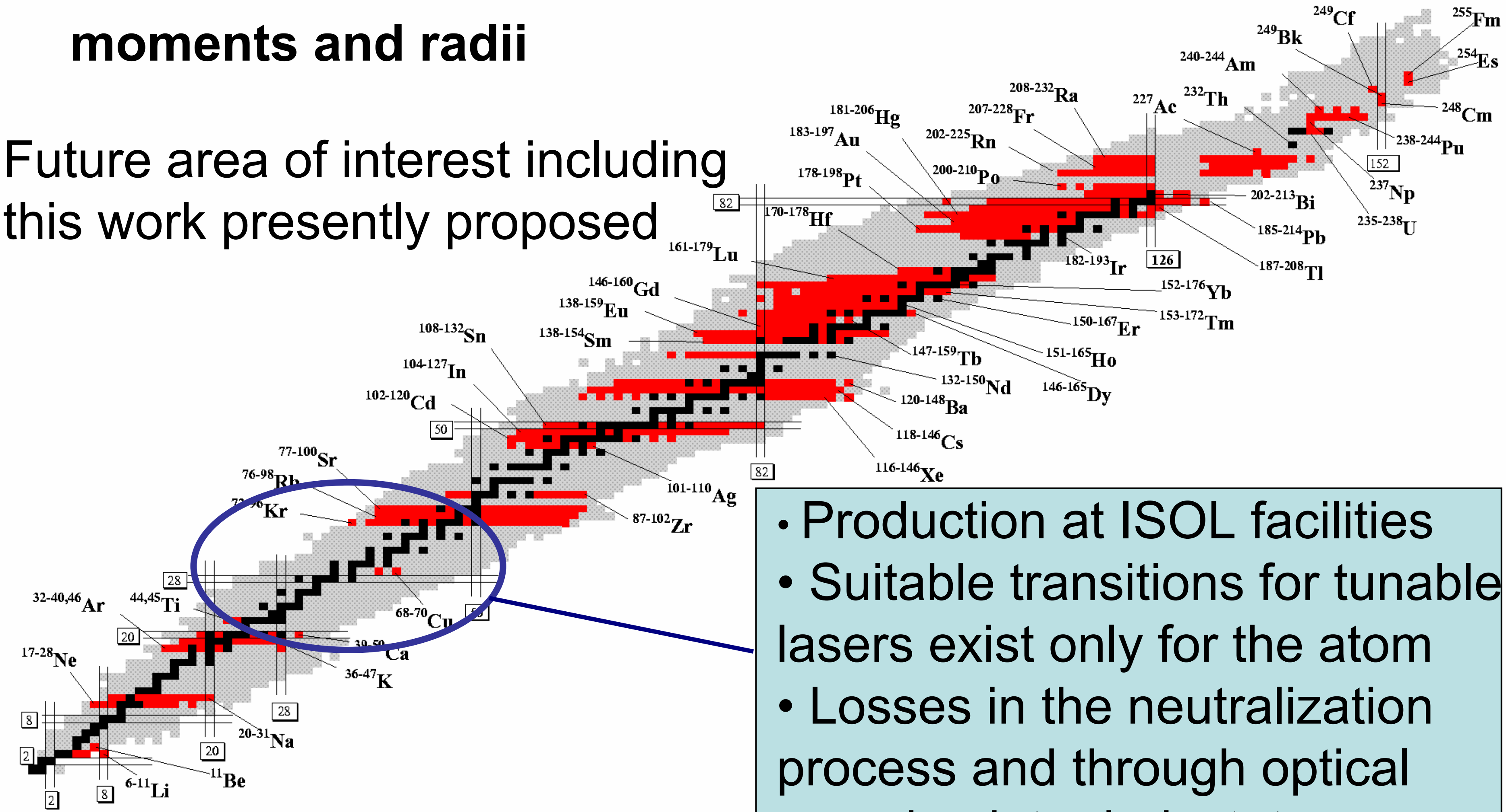
Sensitivity of collinear laser spectroscopy has a limit of ~1:100. Typically 1:10 000.

Resolution ~ MHz, resulting from the velocity compression of the line shape through acceleration.

With this resolution quadrupole moments and accurate isotope shift measurements are possible

Status of laser measurements of moments and radii

Future area of interest including this work presently proposed



- Production at ISOL facilities
- Suitable transitions for tunable lasers exist only for the atom
- Losses in the neutralization process and through optical pumping into dark states

Kluge & Nörtershäuser 2003

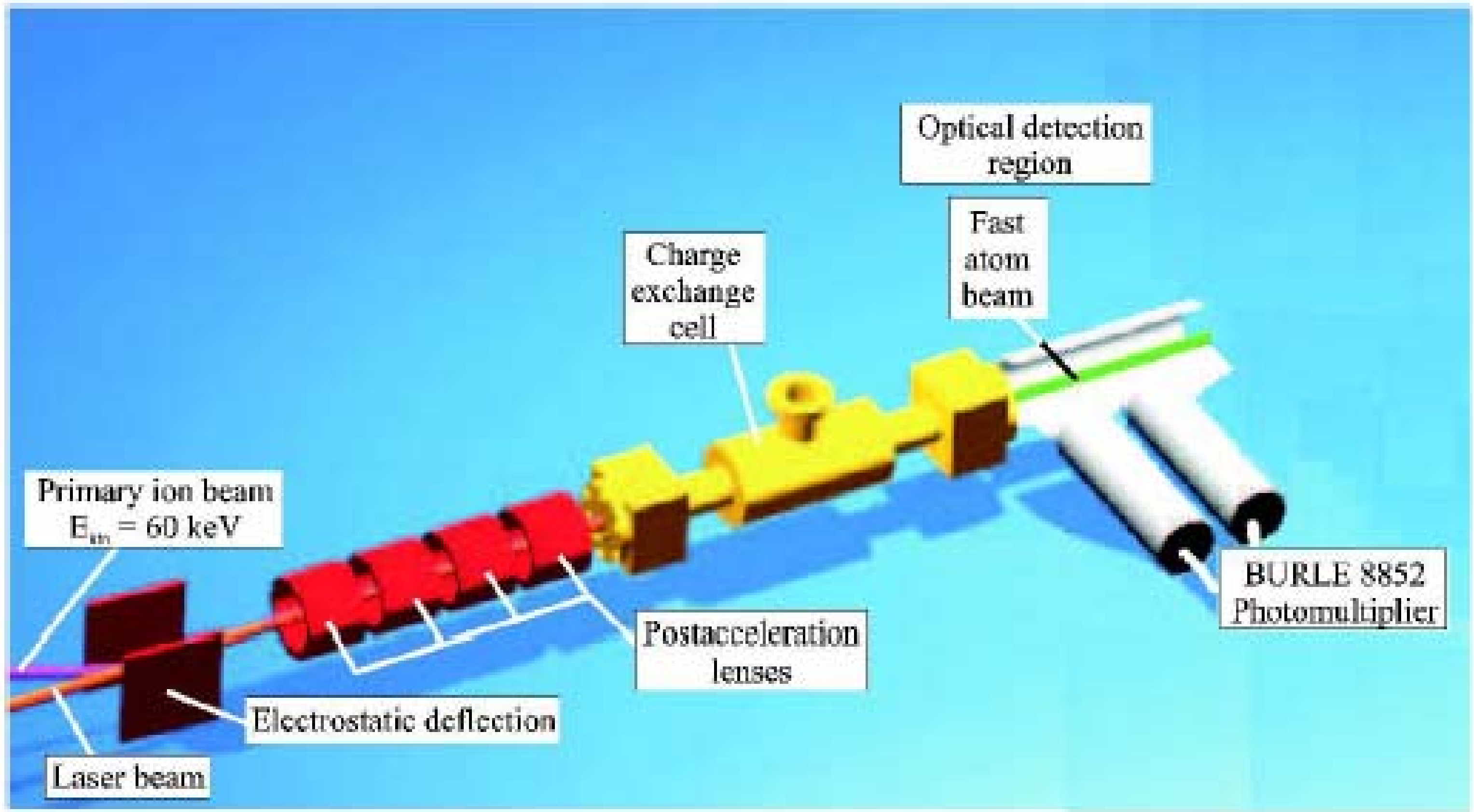
Physical motivation

			28																						50	
		Zn 57	Zn 58	Zn 59	Zn 60	Zn 61	Zn 62	Zn 63	Zn 64	Zn 65	Zn 66	Zn 67	Zn 68	Zn 69	Zn 70	Zn 71	Zn 72	Zn 73	Zn 74	Zn 75	Zn 76	Zn 77	Zn 78	Zn 79	Zn 80	30
	Cu 55	Cu 56	Cu 57	Cu 58	Cu 59	Cu 60	Cu 61	Cu 62	Cu 63	Cu 64	Cu 65	Cu 66	Cu 67	Cu 68	Cu 69	Cu 70	Cu 71	Cu 72	Cu 73	Cu 74	Cu 75	Cu 76	Cu 77	Cu 78	Cu 79	29
Ni 53	Ni 54	Ni 55	Ni 56	Ni 57	Ni 58	Ni 59	Ni 60	Ni 61	Ni 62	Ni 63	Ni 64	Ni 65	Ni 66	Ni 67	Ni 68	Ni 69	Ni 70	Ni 71	Ni 72	Ni 73	Ni 74	Ni 75	Ni 76	Ni 77	Ni 78	28

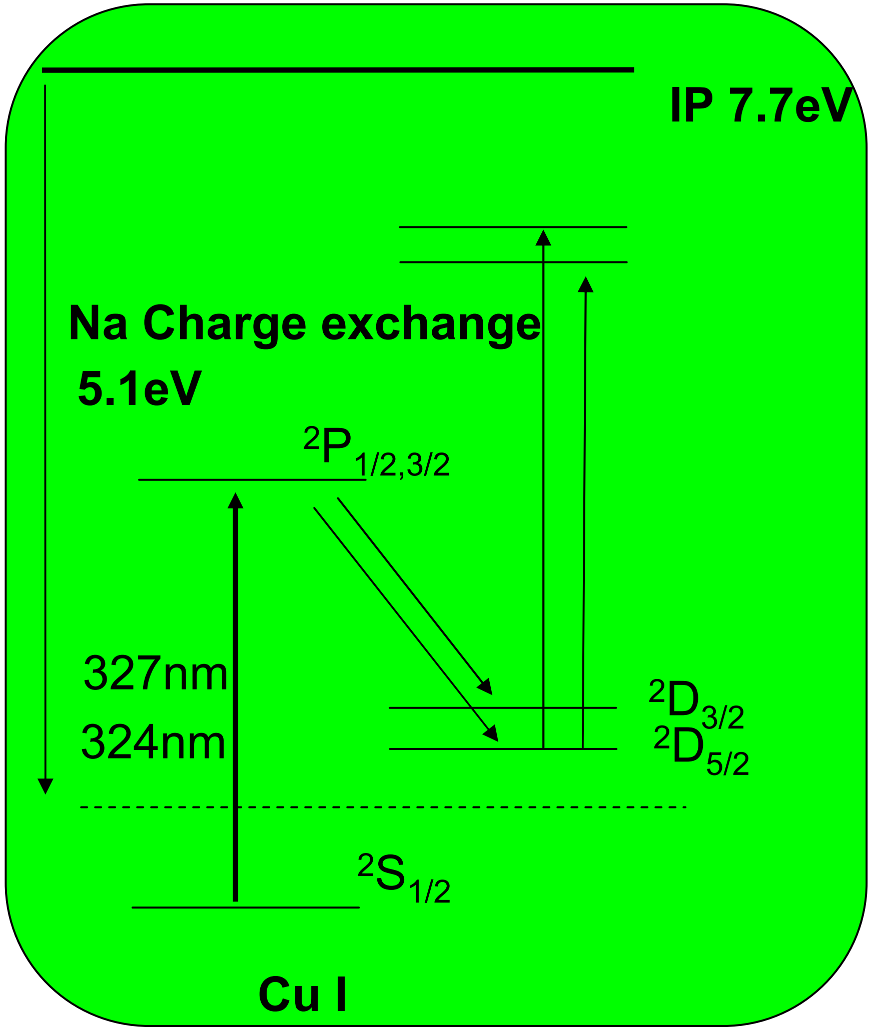
- Magnetic moments, high sensitivity to the migration of the 5/2- level with neutron excess
- Spin assignment of ground and isomeric states
- Quadrupole moments
- Changes in the mean square charge radii.
- Evolution of nuclear structure towards N=50 and the onset of deformation

Experimental technique

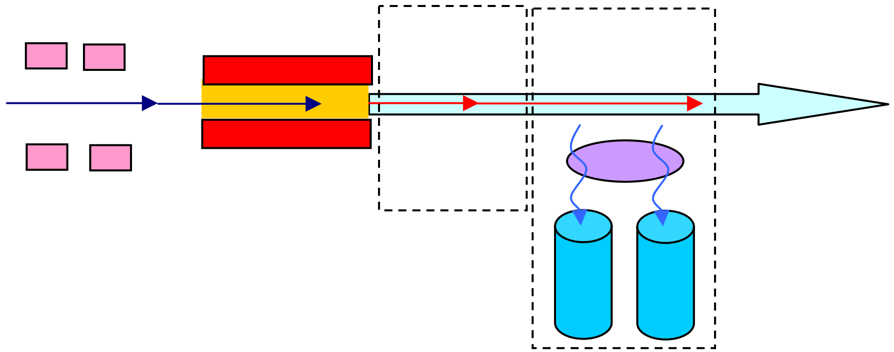
- **Collinear laser spectroscopy at ISOLDE with the COLLAPS setup**



Collinear spectroscopy of copper

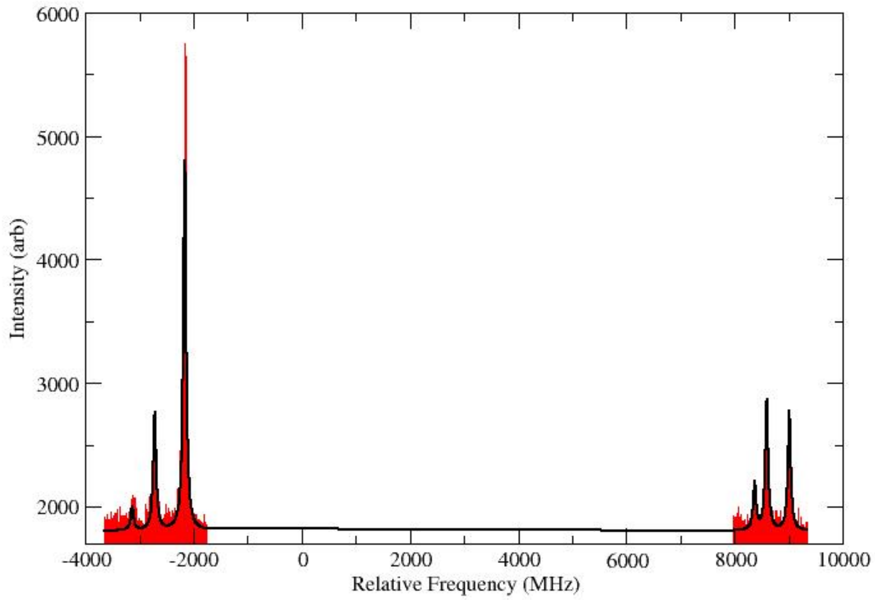


1. Voltage tuning of the ion beam
2. Neutralization within Na or Li vapor
3. Transit of atomic beam between vapor cell and light collection region.
4. Detection of resonant fluorescence in the light collection region

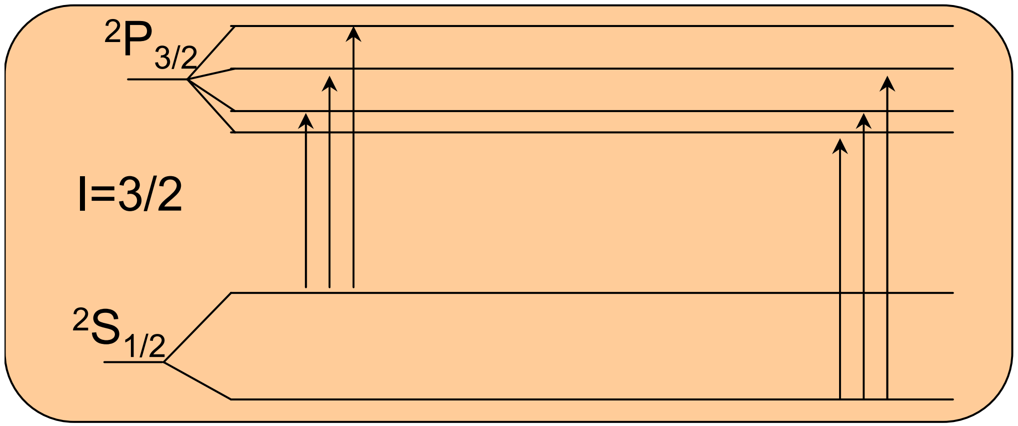


Stable beam test, March 2006

Alkali-like $^2S_{1/2}$-$^2P_{3/2}$ (D2) transition ^{63}Cu



a



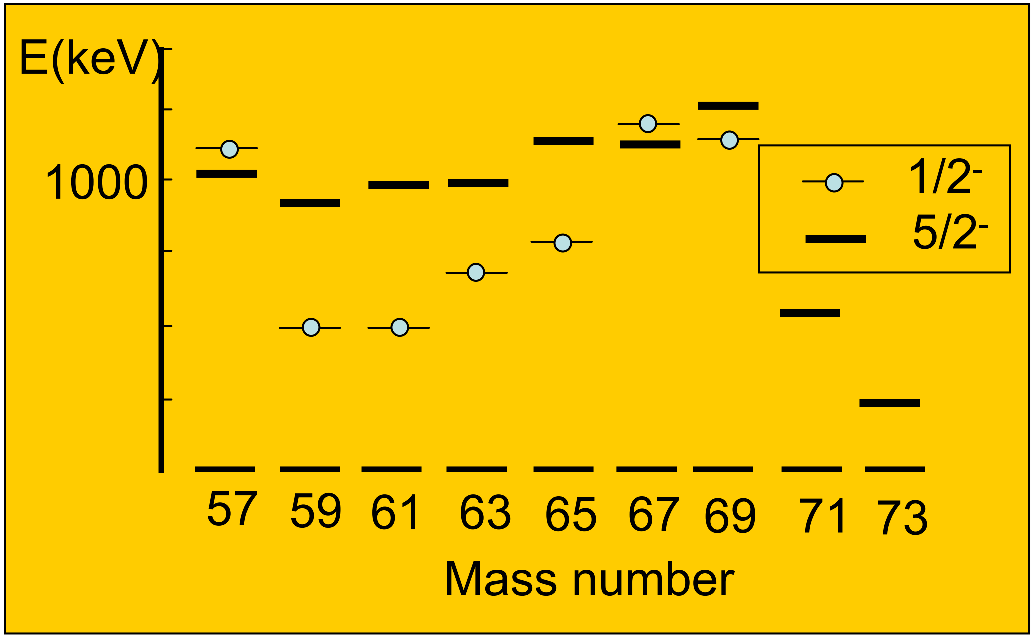
March 2006
$A_{1/2}$=5865(2), $B_{3/2}$=-28(2)

Literature (RF measurements and level mixing)
$A_{1/2}$=5866.915(5), $B_{3/2}$=-28.8(6)

March 2006
A detection efficiency 1:30 000 for the strongest component of the hyperfine structure.

Systematic migration of nuclear states in copper isotopes

•5/2- level associated with the π(*f*5/2) orbital



S. Franchoo et al. Phys. Rev. C 64 054308

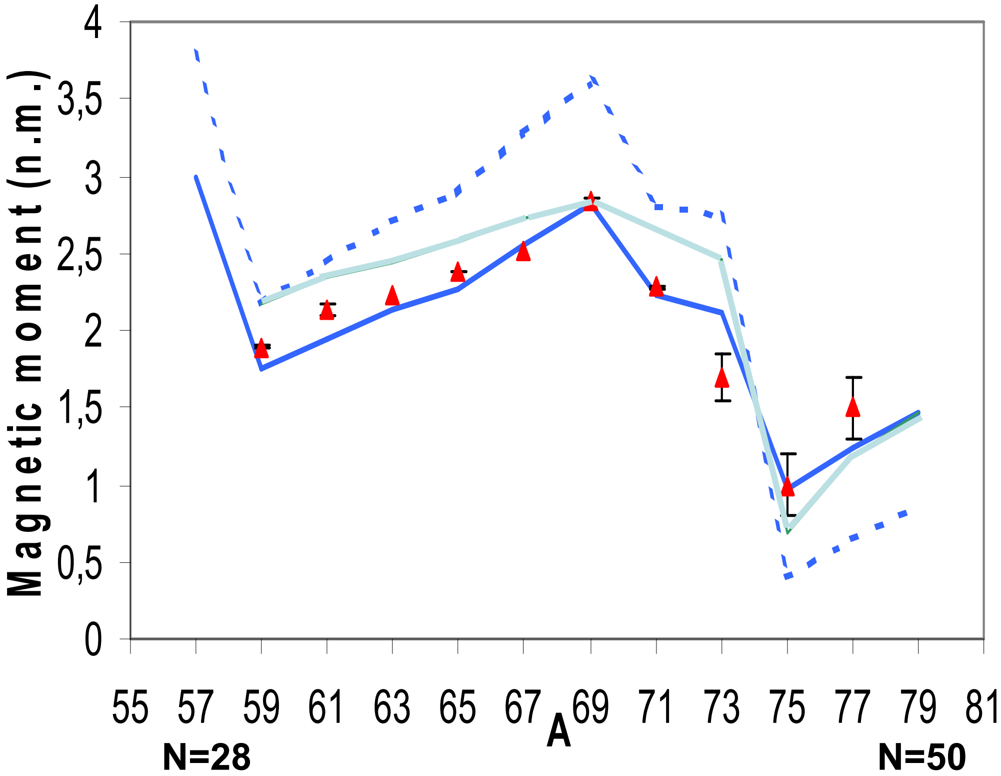
A.F. Lisetskiy et al. Eur. Phys. J. A, 25:95, 2005
N.A. Smirnova et al. Phys. Rev. C, 69:044306, 2004

I=5/2$^-$ level:

- **Remains static between $^{57-69}$Cu at ~1MeV**
- **Systematically drops in energy as the ν(g9/2) shell begins to fill**
- **Predictions on the inversion of the ground state lie between ^{73}Cu and ^{79}Cu.**
- **Experimental evidence for the inversion to occur at ^{75}Cu.**

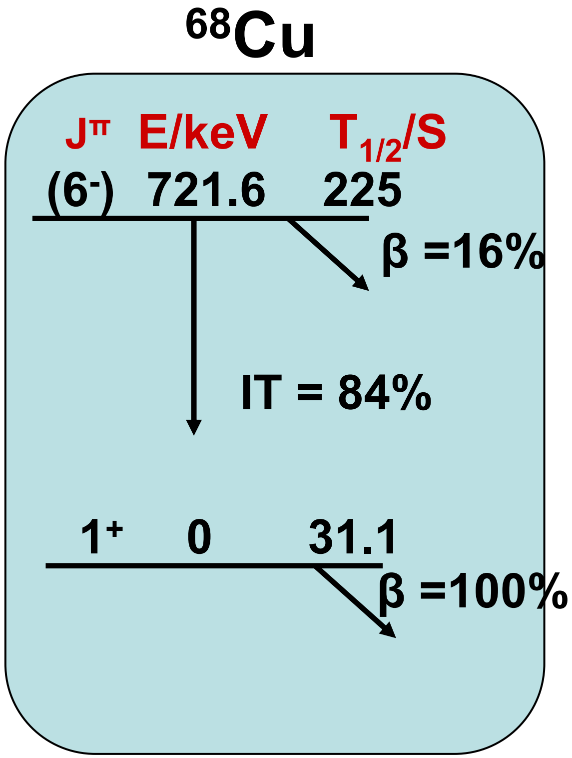
Shell model with realistic interaction (G-matrix) and different monopole modifications

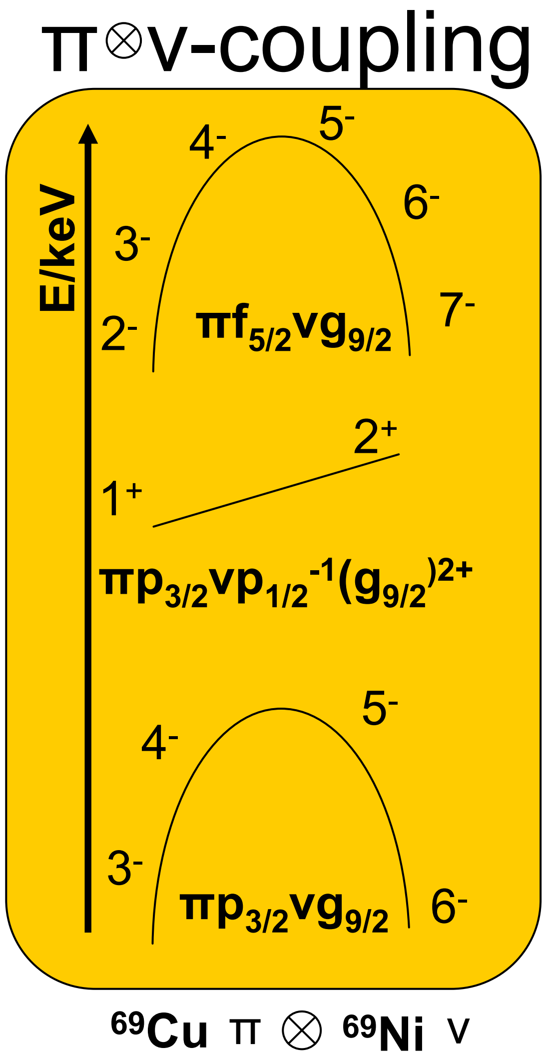
- **High sensitivity to the monopole shift in measured magnetic moments.**
- **Magnetic moment calculations assuming a 5/2⁻ ground state in ^{75}Cu and beyond show reasonable agreement with experimental data.**
- **Higher resolution data required.**

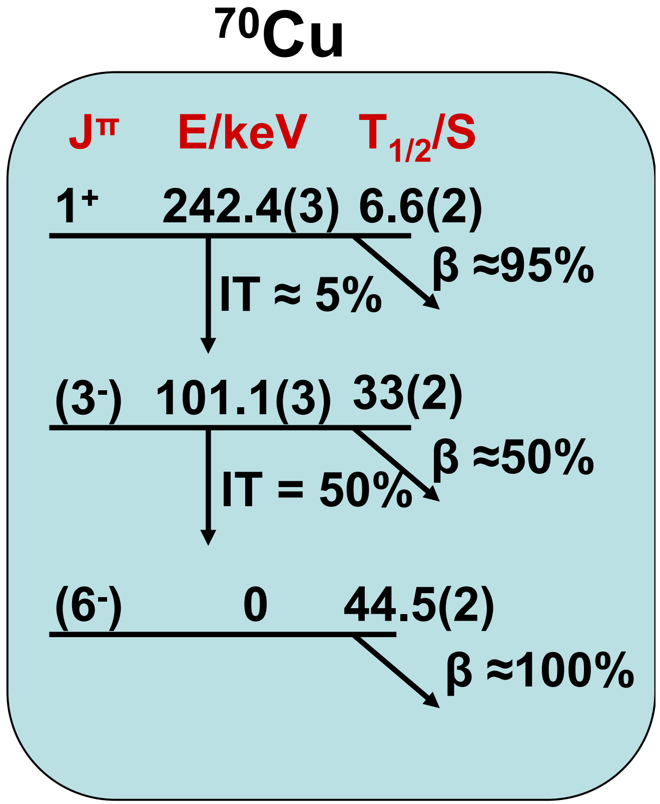


A. Lisetskiy (OXBASH) ...... **no quenching**
— **$0.7g_s$**
N. Smirnova (ANTOINE), monopole by Nowacki

Ground and excited state spin assignment



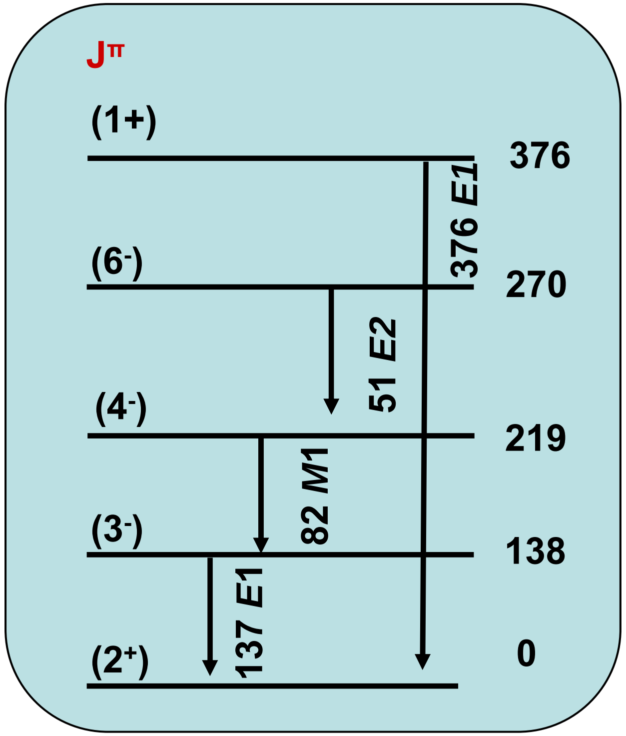




J. Van Roosbroeck
Phys. Rev. Lett. 92:112501 2004

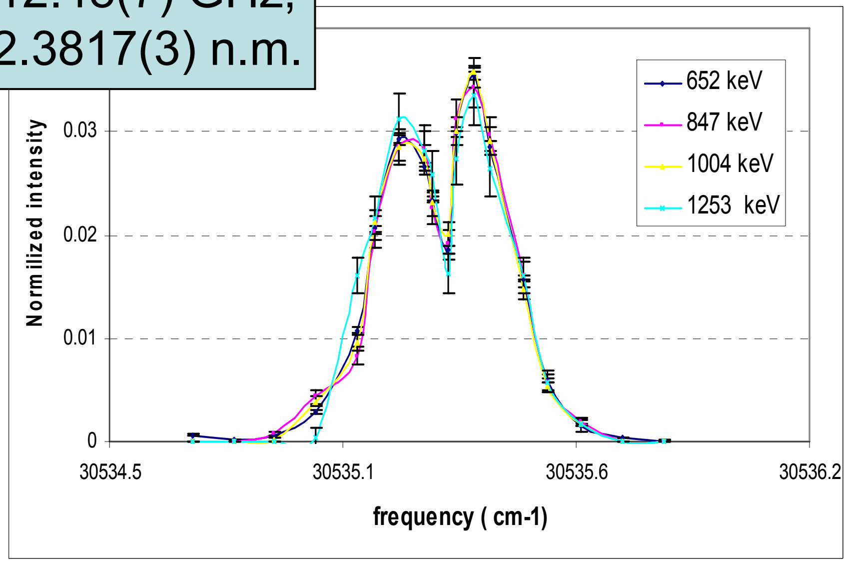
J. Van Roosbroeck
Phys. Rev. C 69:034313 2004

^{72}Cu



A(^{72}Cu) = 5.4(1) GHz
A(^{65}Cu) = 12.48(7) GHz,
μ(^{65}Cu) = 2.3817(3) n.m.

Cu I $S_{1/2} – P_{1/2}$



β-decay and γ-ray spectroscopy studies

This proposal aims to resolve this inconsistency.

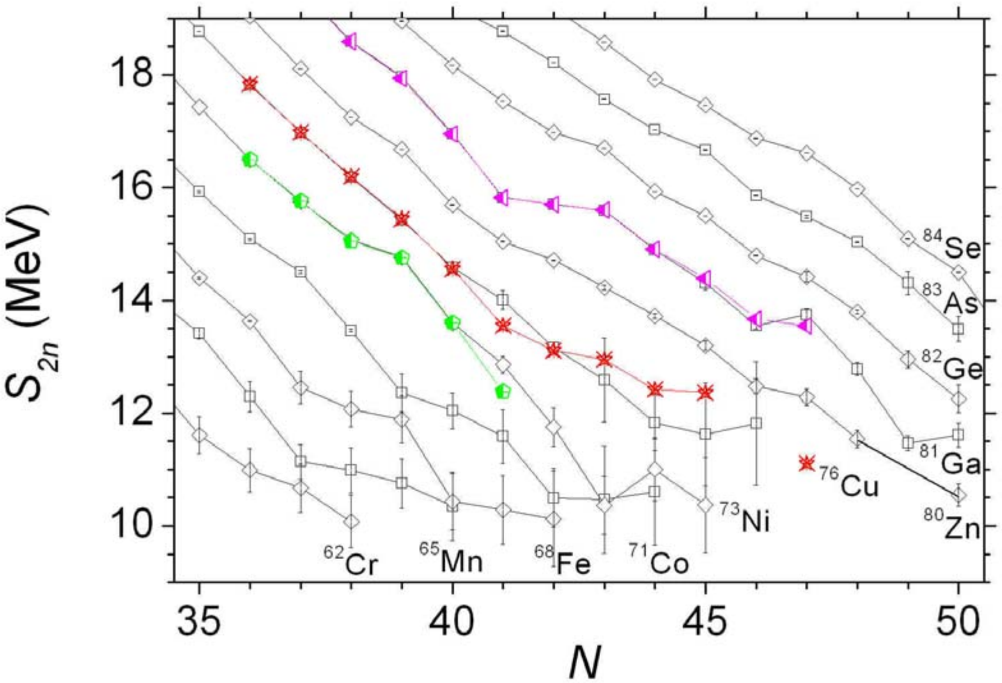
Contrary to results from in-source laser spectroscopy!

I	$\mu(\mu_{nm})$ Exp.	$\mu(\mu_{nm})$ Cal.
1	±0.92	±2.03
2	±1.10	+2.76
3	±1.18	-2.74
4	±1.22	-0.99
5	±1.25	+0.43
6	±1.27	+1.66

H. Mach, Symposium on Nuclear Structure Physics University of Göttingen, 2001
M. Stanoiu, PhD thesis, Université de Caen 2003
J.C Thomas, et al. Submitted to Phys. Rev. C

Onset of deformation

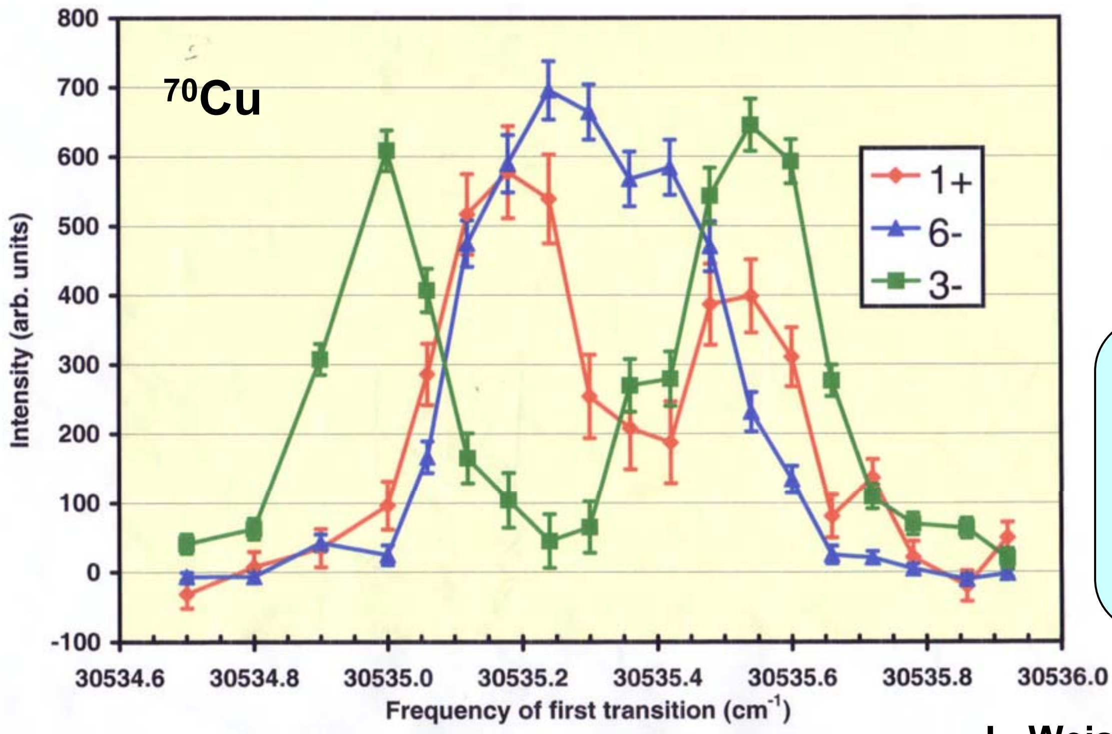
- **Evidence from ISOLTRAP.**
- **Upward kink in the plot of S_{2N}.**
- **Further confirmation will be obtained from the model independent measurements of Q and $\delta\langle r^2\rangle$.**



C. Guénaut et al., submitted to Phys. Rev. C.

Further evidence for large deformation from isomeric shift data

- No mass shift in system
- Pure field effect
- Sensitivity to isomer shift in low resolution in-source spectroscopy



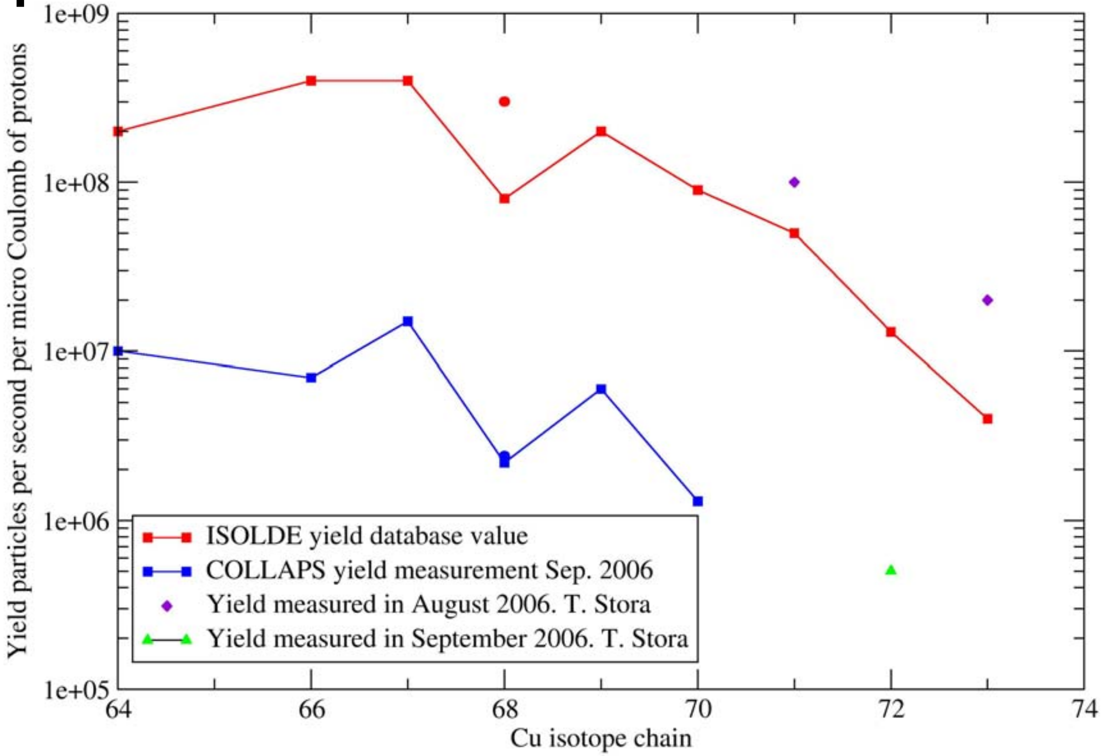
Isomer shift in ^{68}Cu~390(250)MHz

- **Enhanced Isomeric shift observed in ^{70}Cu**
- **$\delta\nu^{70g,70m1} \sim$ 900(230)MHz**
- **$\delta\nu^{70g,70m2} \sim$ 1100(220)MHz**

L. Weissman et al. Phys. Rev. C, 65:024315, 2002
S. Gheysen et al. Phys. Rev. C, 69:064310, 2004

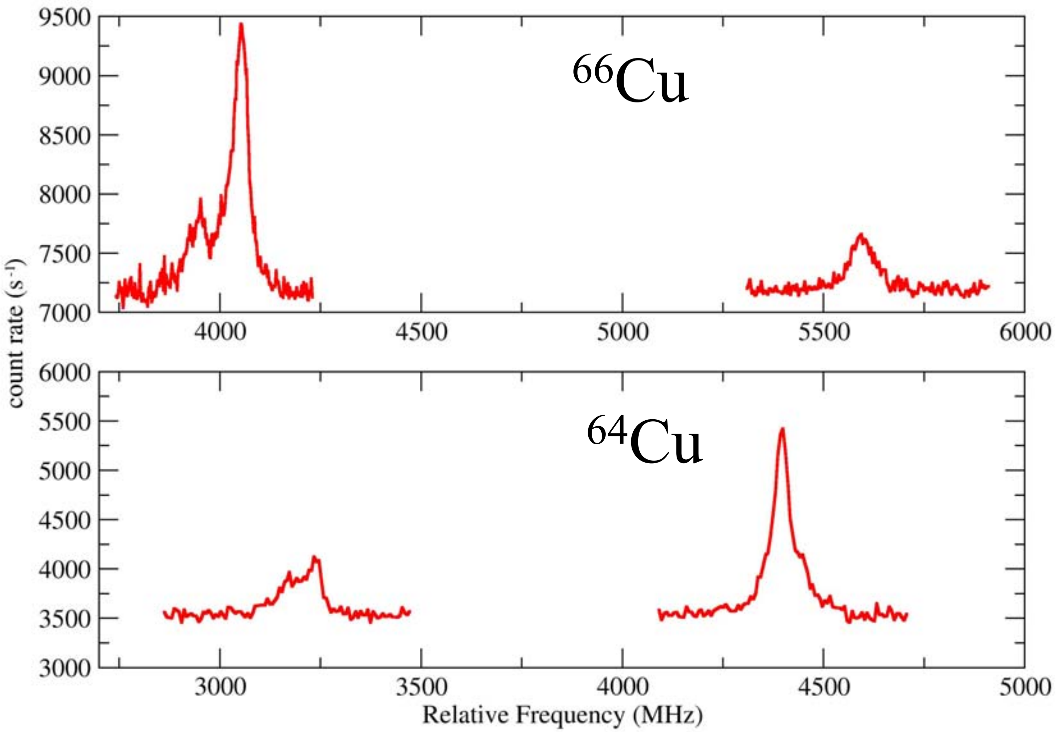
September 2006

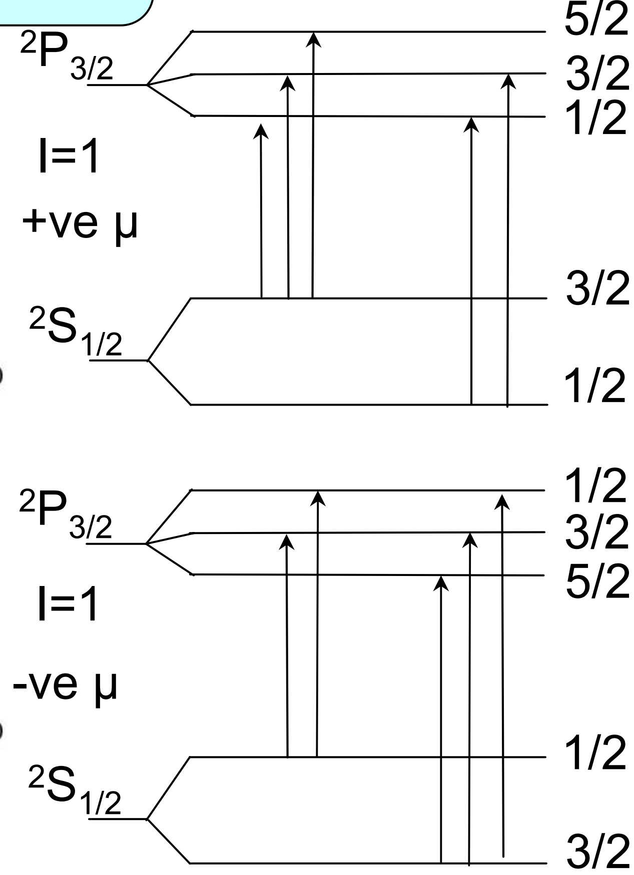
- First on-line run for IS439 on neutron rich copper.
- Primary goal was to measure the ground state spin of ^{72}Cu.



Sign of the magnetic moment of ^{66}Cu

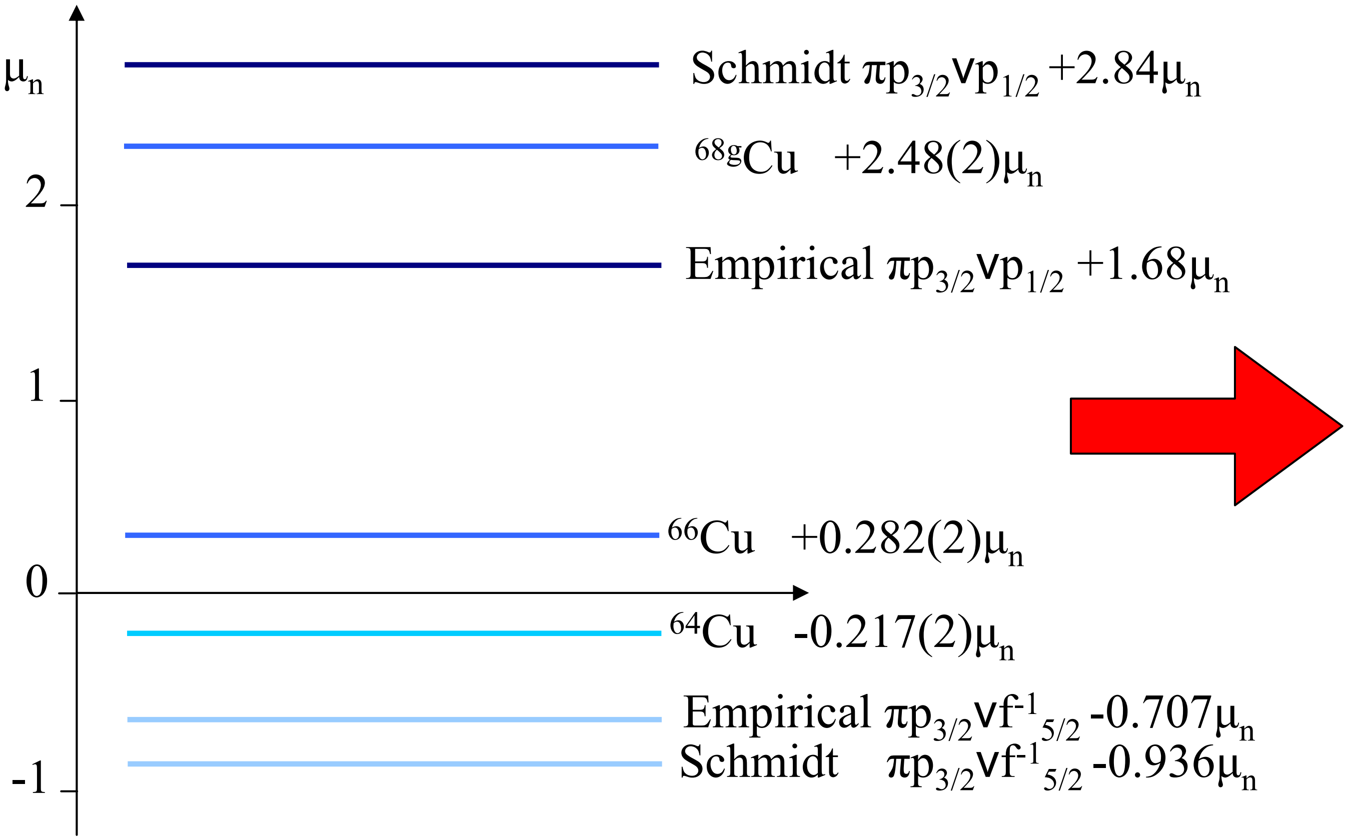
First measurements were made in 1966 and 1969 and have had little attention paid to them since. Both ^{64}Cu and ^{66}Cu have $I=1^{+}$ ground states.





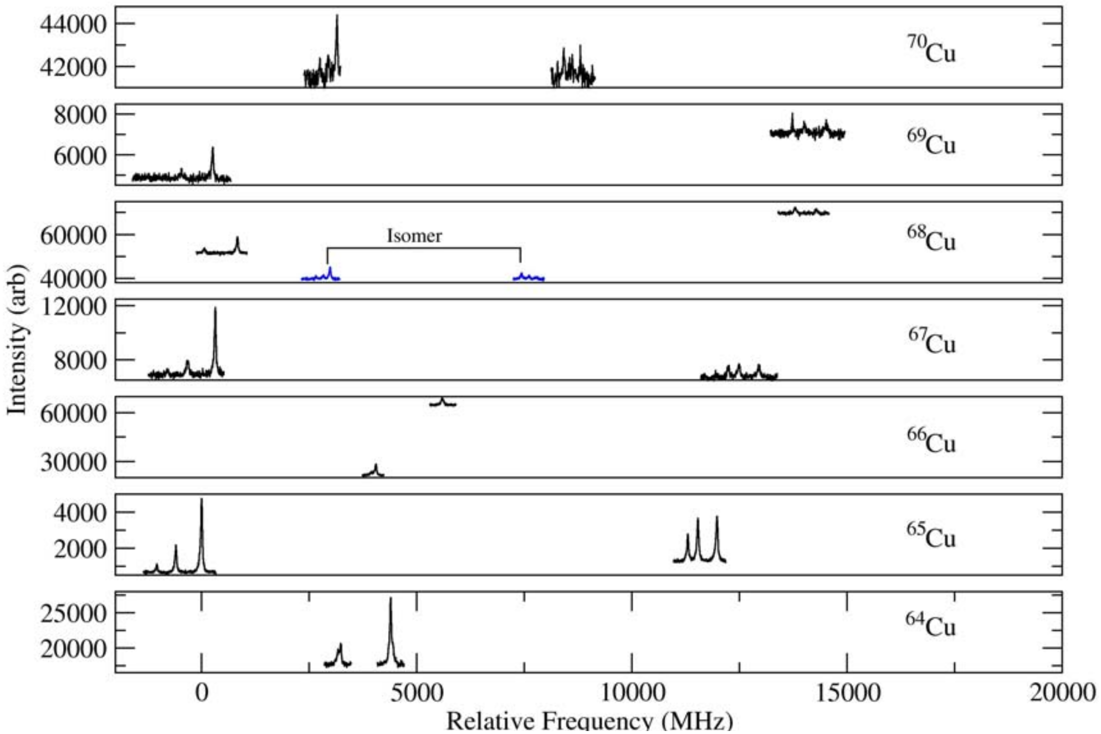
C.J. Cussens et al. J. Phys. A, 2:658, 1969
G.K. Rochester et al. Phys. Lett. B, 8:266, 1964

1^+ Ground state of $^{64,66,68}Cu$



Currently under investigation

Summary of results

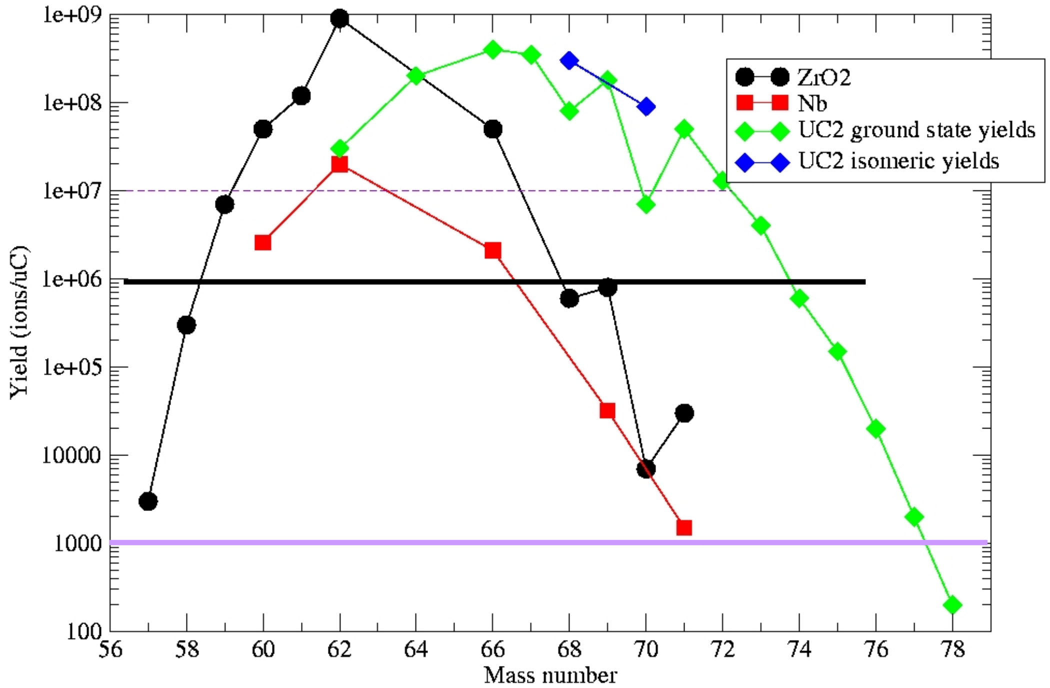


Isotope/Isomer	A factor ($S_{1/2}$) (MHz)	B factor($P_{3/2}$) (MHz)	Isotope Shift (A=65 ref)
63	+5866.9(5)	-28.1(3)	**-570.0(4)**
64	-856(2)	**+9.8(7)**	**-244.6(9)**
65	+6282.2(5)	-25.8(4)	0
66	**+1104.4(3)**	**+9.9(11)**	**293.5(10)**
67	+6632.7(12)	**-22.8(13)**	**554.4(9)**
68	+9476.4(14)	**-10.3(13)**	**856.3(9)**
68m	+761.2(5)	**-59.1(30)**	**804.3(12)**
69	+7487.1(15)	**-19.2(18)**	**1071.4(10)**
70	+901.1(11)	**-41.0(40)**	**1334.8(23)**

Negative isomer shift

- **New quadrupole moments**
- **New isotope shifts**
- **Higher accuracy magnetic moments**
- **Sign confirmation (+ve ^{70g}Cu)**
- **Isomer shift $^{68g-68m}$Cu**

Experimental requirements for fluorescence spectroscopy on the COLLAPS beam line



Low noise on the separator voltage

•Suppression of Isobaric contamination

Current limit for optical detection continuous ion beam: 10^6 ions/μC

• Further optimization of light collection region, at best an order of magnitude improvement.

•RFQ cooler: Improved beam emittance.

Bunched beam spectroscopy, background suppression by a factor up to 10^4

2007

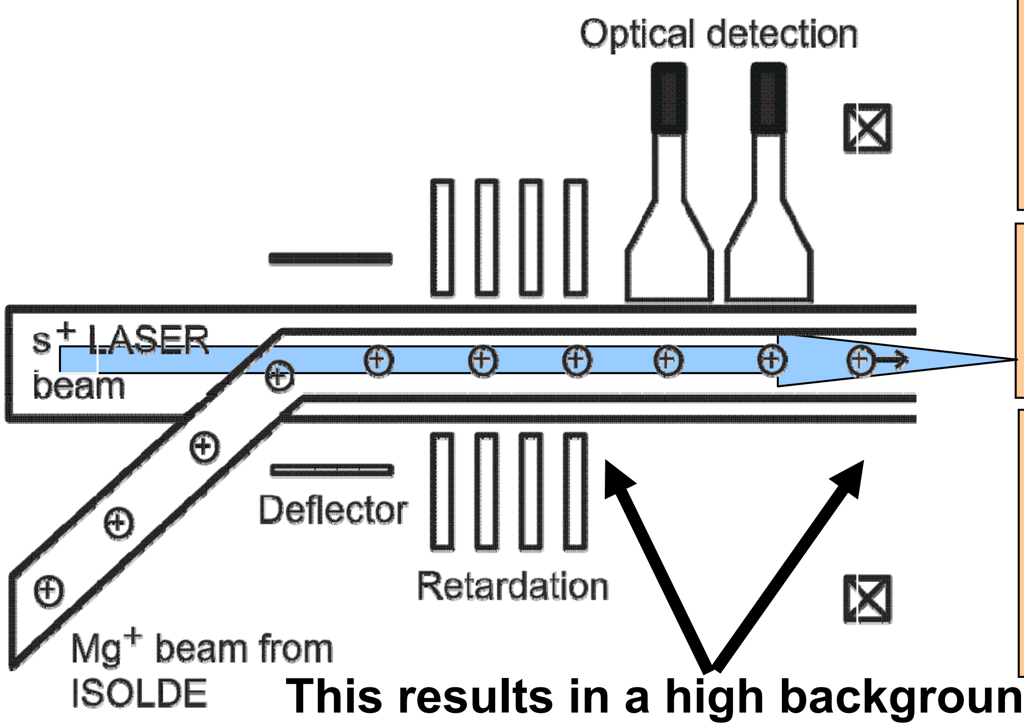
- $^{70m1,70m2}Cu$ Isomer shifts and quadrupole moments
- ^{72}Cu Ground-state spin
- $^{73\text{-}75}Cu$ monopole migration of $f_{5/2}$ with $p_{3/2}$

All possible before the RFQ cooler is installed

Effect of improved ion beam for fluorescence spectroscopy on the COLLAPS beam line

Current limiting factors for laser spectroscopy

- **Background of scattered laser light detected by PMT ~2000/s.**
- **Detection efficiency within the light collection region.**
- **Broadening of lineshape due to voltage ripples.**



Within the light collection region the ion beam should have zero divergence (parallel beam)

Currently the minimum ion beam diameter reached is ~5mm

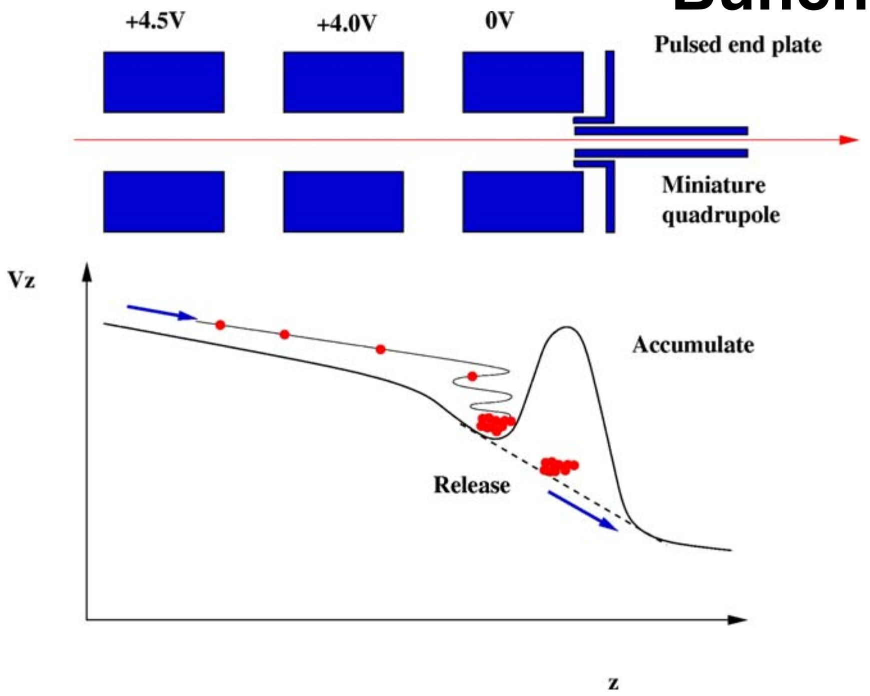
In order to maximize the detection efficiency good overlap between laser and ion beams is necessary

This results in a high background level from scattered light

Effect of improved ion beam for fluorescence spectroscopy on the COLLAPS beam line

- **A reduction in the ion beam diameter will allow the laser to be reduced in diameter (and therefore power) with no detrimental effect on the detection efficiency.**
- **Immediate consequences for the detected background**

Bunching ions in the RFQ cooler

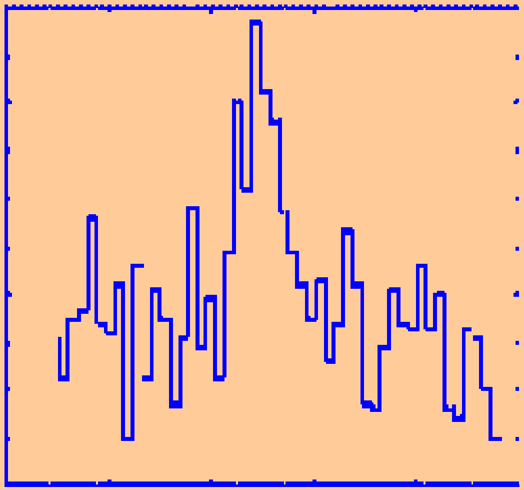


Trap and accumulates ions – typically for 300 ms

Releases ions in a 15 μs bunch

Background suppression equal to the ratio of the trapping time to the bunch width 300ms/15 μs ~ 10^4

BEFORE



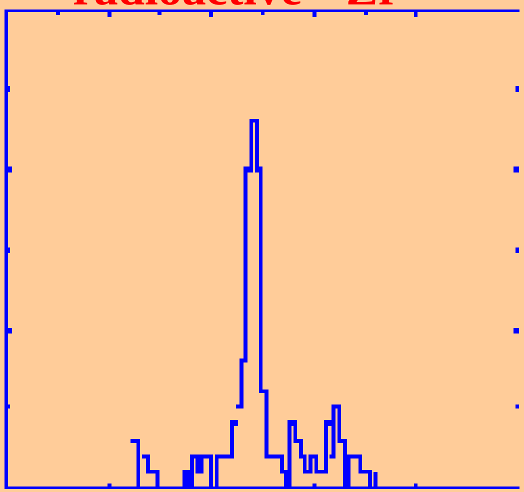
8000 ions/sec

5.3 hours

(Photon-ion coincidence method)

Photons from laser-excitation of radioactive ^{88}Zr

AFTER



2000 ions/sec

48 minutes

Data from work at Jyvaskyla JYFL J.Billowes

Compare to COLLAPS

For optical measurements the minimum ion beam intensity is 10^6/s