High-resolution laser spectroscopy of $^{76-78}$Cu with CRIS

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Outline

- Motivation: study of the magicity of ^{78}Ni
- Laser spectroscopy with CRIS
- Experimental results
    - Magnetic moments
    - Quadrupole moments
    - Charge radii
- Conclusions

Motivation: structure of neutron-rich Cu

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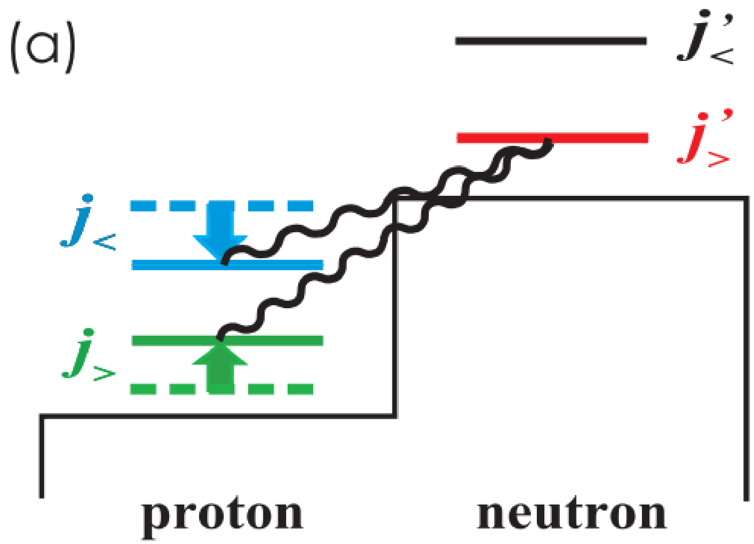
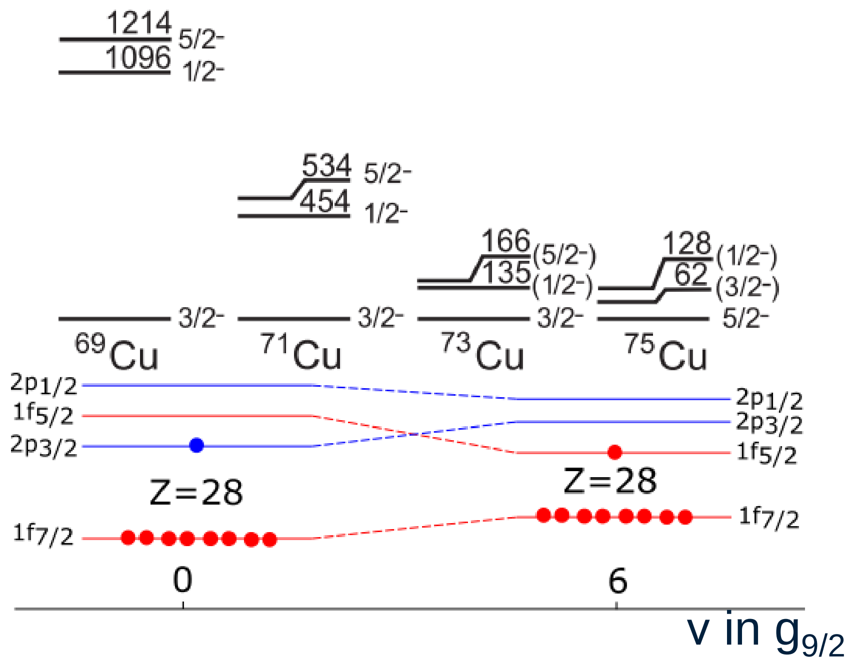
Context: shell evolution

- Nucleon-nucleon interaction: single-particle energies evolve as function of nucleons in an orbit
- Away from stability, this can lead to (dis)appearance of shell closures
- Cu chain: *Z*=29: probe for the magicity of *Z*=28 and *N*=28,40,50



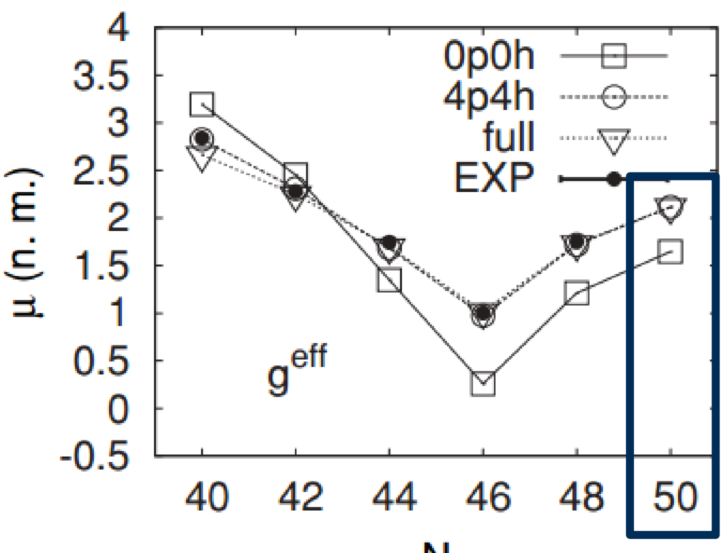
T. Otsuka et al, PRL **104**, 012501 (2010)



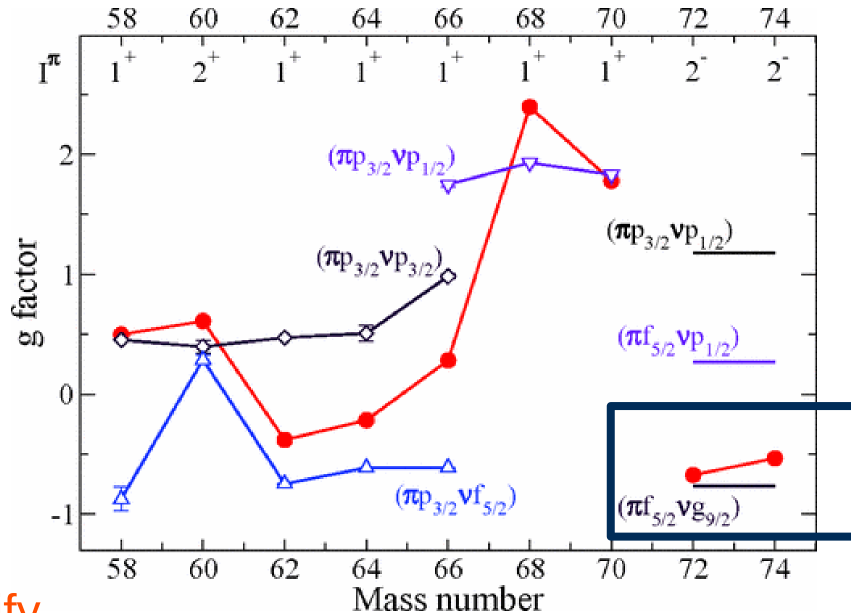
K.T. Flanagan et al, PRL **103**, 142501, 2009

Moments of neutron-rich Cu (Z=29)

Magnetic moments: sensitive to details of wavefunction



Can we verify this prediction?



$\pi f_{5/2}\ \nu g_{9/2}$

Does the deviation increase?

- Theoretical reproduction: excitation across *Z*=28 required
- Moment confirms dominant $\pi f_{5/2}$ contribution for ^{72,74}Cu

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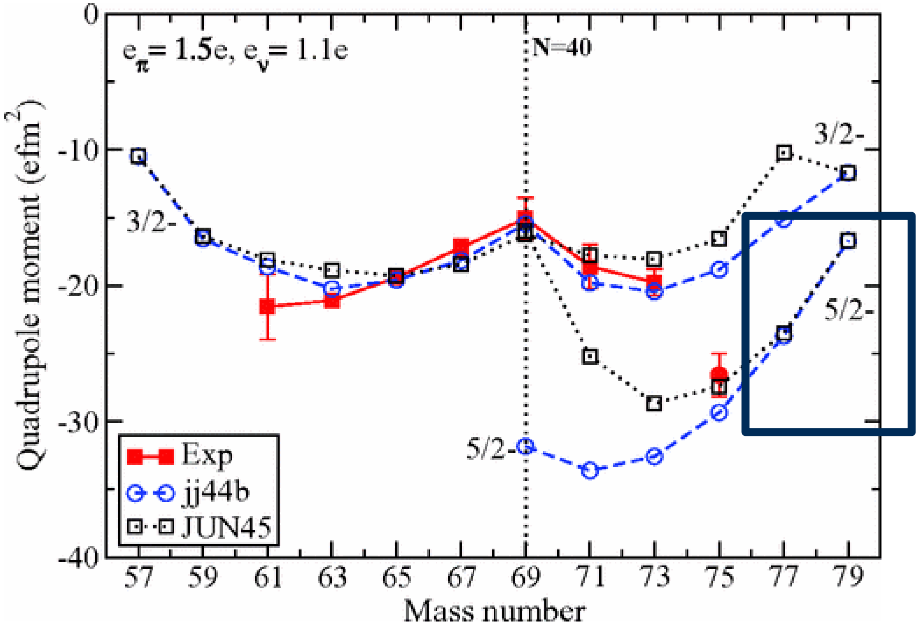
K. Sieja and F. Nowacki, PRC 81, 061303(R) , 2010
P. Vingerhoets et al, Phys. Rev. C 82, 064311, 2010

Moments of neutron-rich Cu (Z=29)

Quadrupole moments: collectivity and deformation



Will the reproduction continue for A > 75?

- Quadrupole moment is sensitive to E2 transitions
- Neutrons across N=50 (not included in jj44b/JUN45) not required up to A=75

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P. Vingerhoets et al, Phys. Rev. C 82, 064311, 2010

Goals of our experiments

Perform laser spectroscopy on $^{76-78}$Cu

- Determine g-factors: probe excitations across Z=28
- Determine quadrupole moments: determine deformation; probe E2 collectivity
- Determine changes in mean-squared charge radii
- Determine nuclear spins

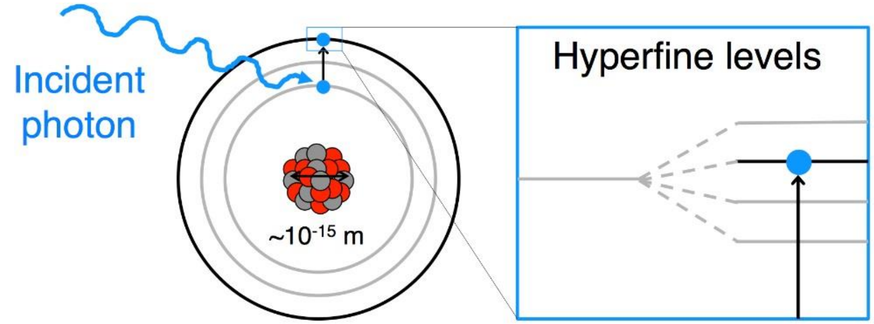
Determine feasibility of future experiments on ^{79}Cu

Laser spectroscopy with CRIS

Laser spectroscopy

Hyperfine interaction of nucleus and electrons

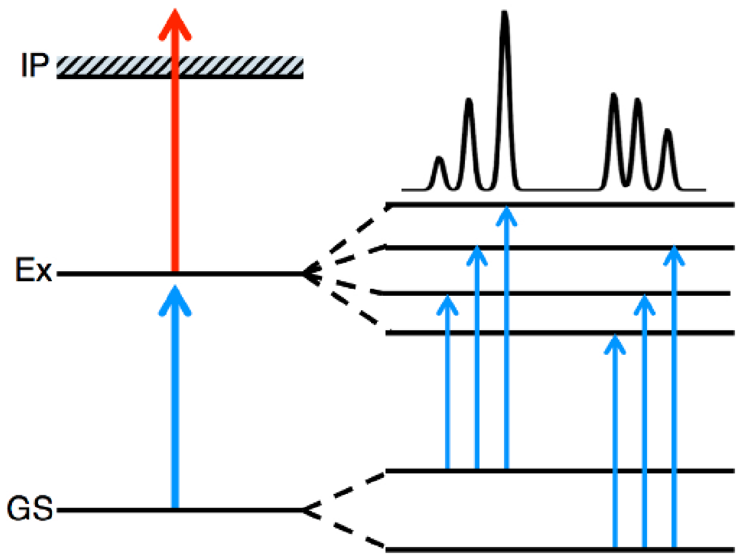
- Energy splitting – μ, Q, I
- Energy shift – $\delta\langle r^2\rangle$



$$W_F = \frac{1}{2}AC + B\,\frac{\frac{3}{4}C(C+1) - I(I+1)J(J+1)}{2I(2I-1)J(2J-1)},$$

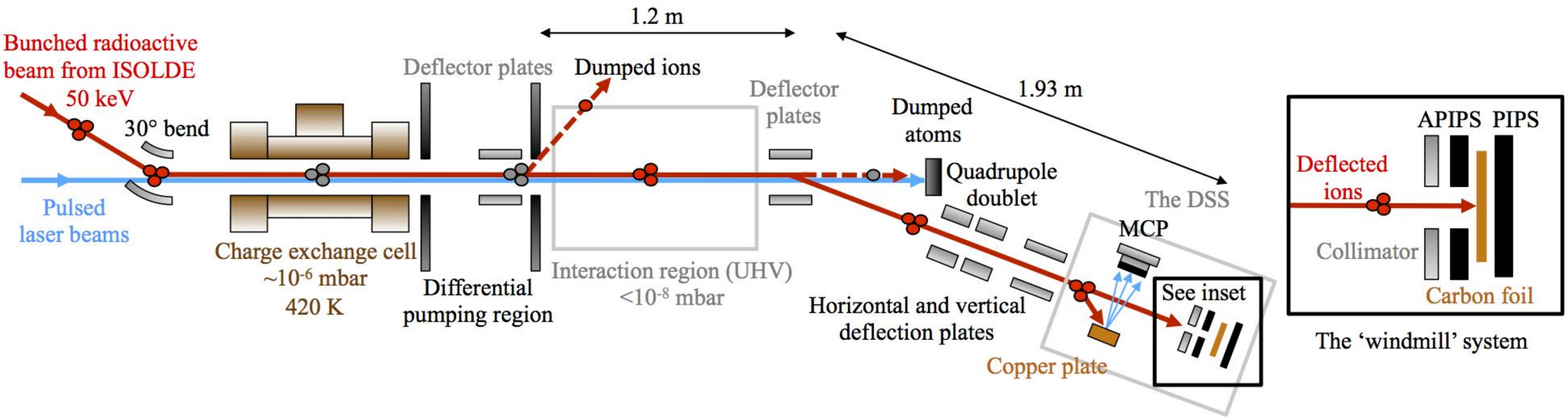
$$C = F(F+1) - I(I+1) - J(J+1).$$

Laser spectroscopy: probing these energy perturbations with lasers



Pictures courtesy of Kara Lynch

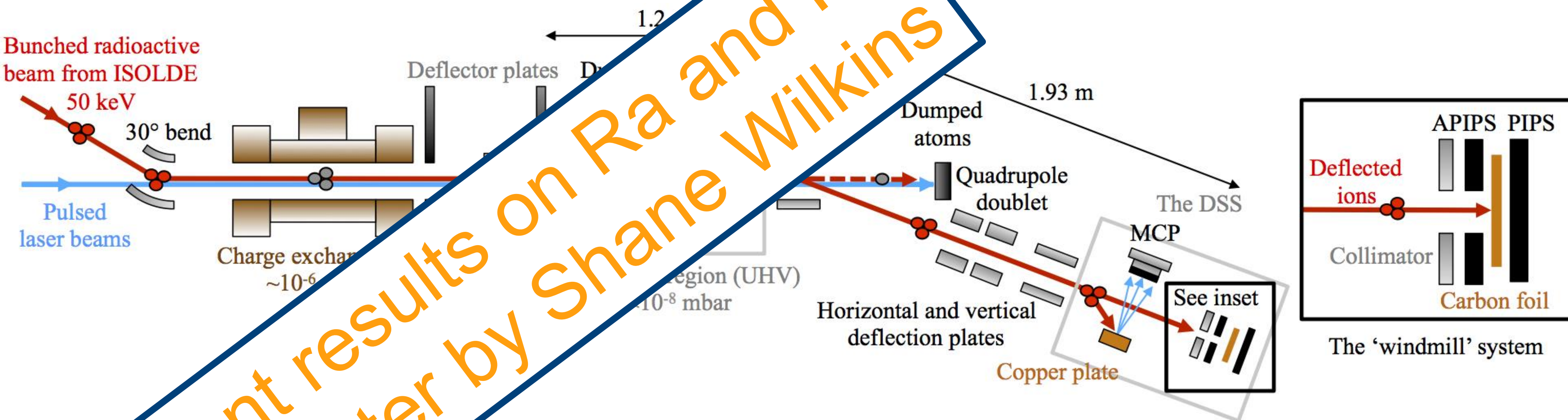
Collinear resonance ionization spectroscopy



- Accelerated beam (30-60 keV) + collinear geometry: reduced doppler broadening
- Bunched beam from ISCOOL: match pulsed laser duty cycle
- UHV: suppression of unwanted collisional ionization
- MCP: efficient ion detection

Pictures courtesy of Kara Lynch

Collinear resonance ionization spectroscopy



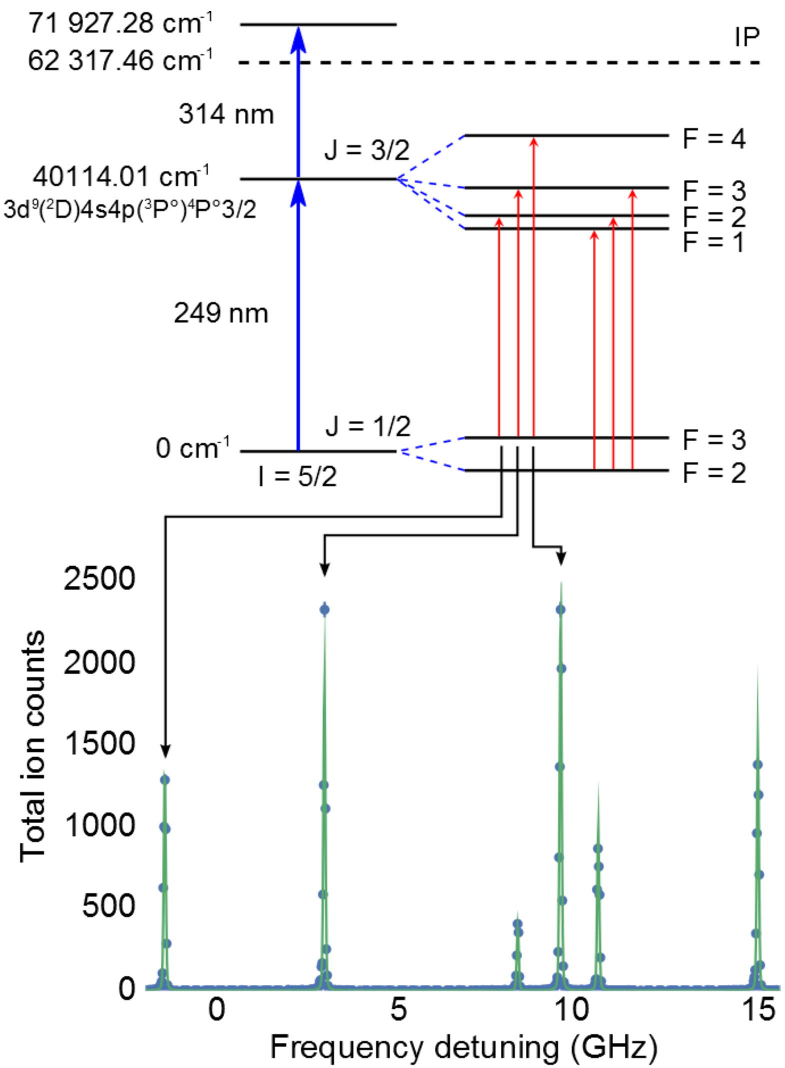
Recent results on Ra and Fr:
See poster by Shane Wilkins

- beam + collinear geometry: reduced doppler ng
- ched beam from ISCOOL: match pulsed laser duty cycle
- UHV: suppression of unwanted collisional ionization
- MCP: efficient ion detection

Pictures courtesy of Kara Lynch

CRIS of copper

- Laser ionization scheme: 249 nm + 314 nm
- Laser system: injection locked pulsed ti:sapphire laser (Jyvaskyla/Mainz) and pulsed dye laser
- High efficiency (total ε~1%)
- High resolution (70 MHz linewidth)
- High background suppression



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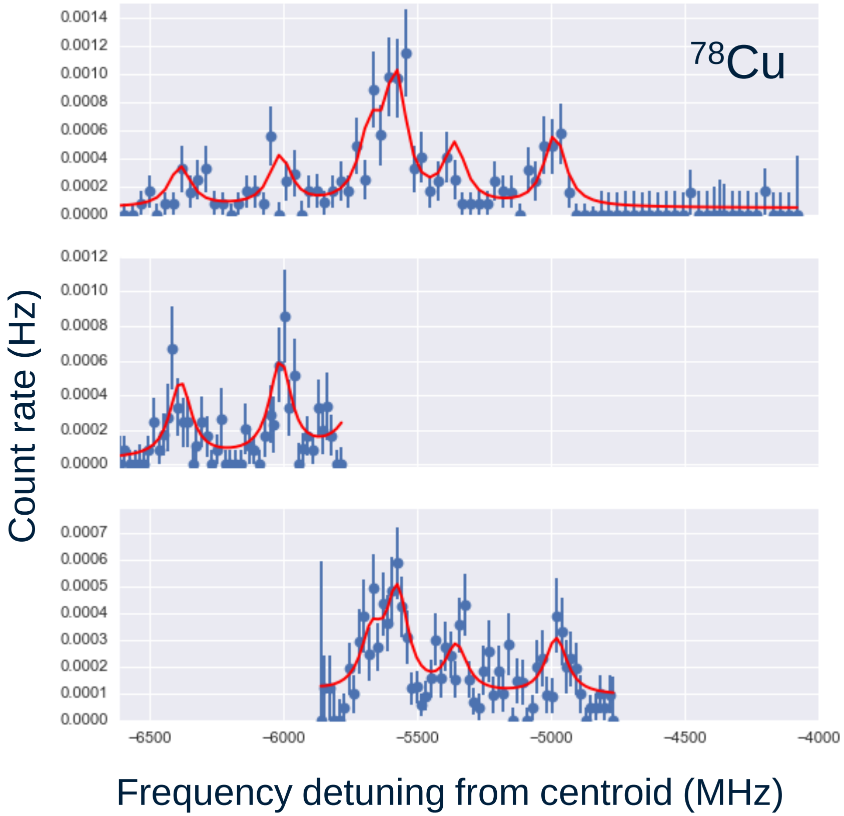
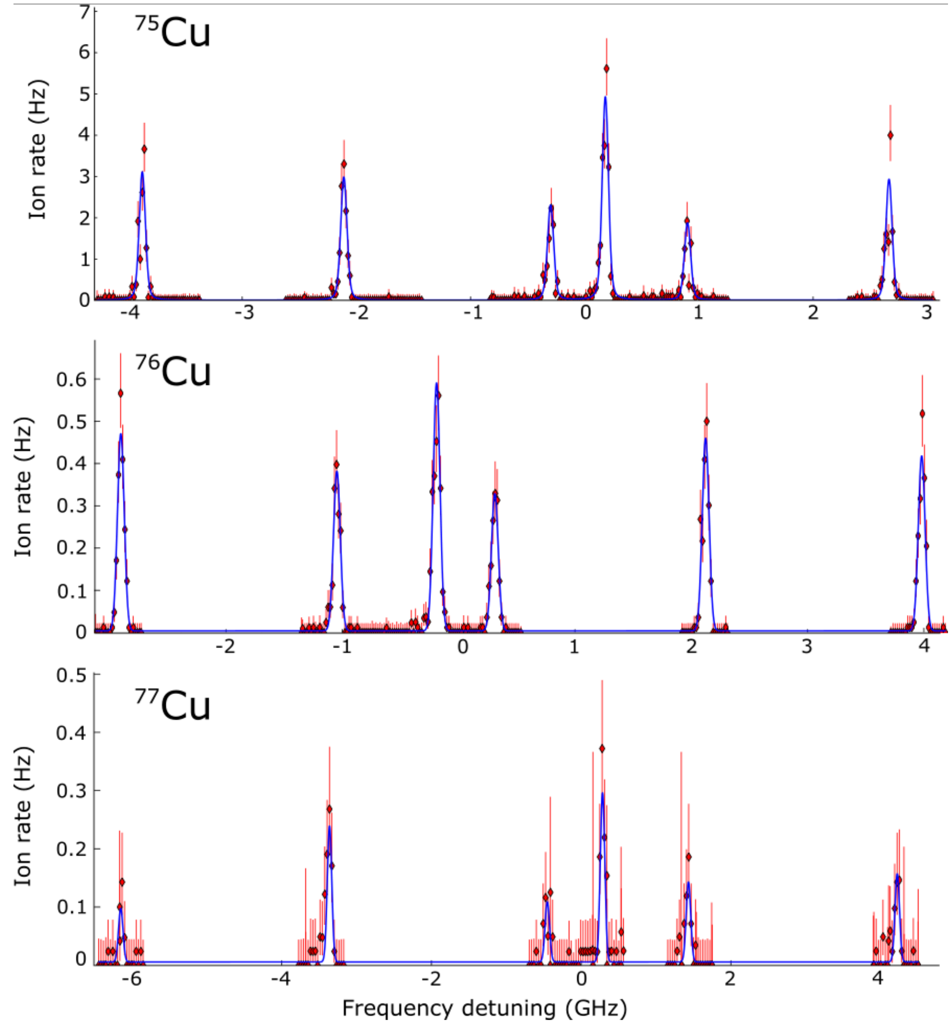
Experimental results

Experimental spectra

- Data on $^{63\text{-}78}$Cu
- 80hrs total of data taking





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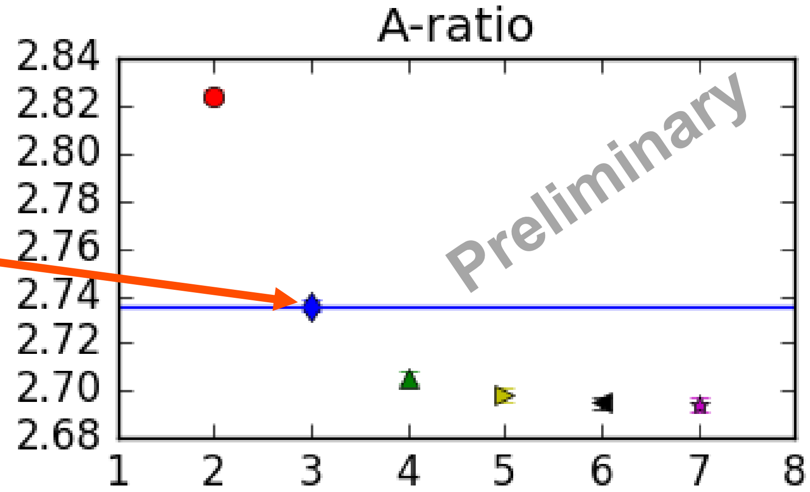
Results

Spin assignments

- Literature spins from previous laser spectroscopy confirmed
- **^{76}Cu: I = 3**



- ^{78}Cu: I = 6??
  - Ratio of A: I>1
  - g-factor: I = 5,6,7

→ We cannot make a spin assignment…

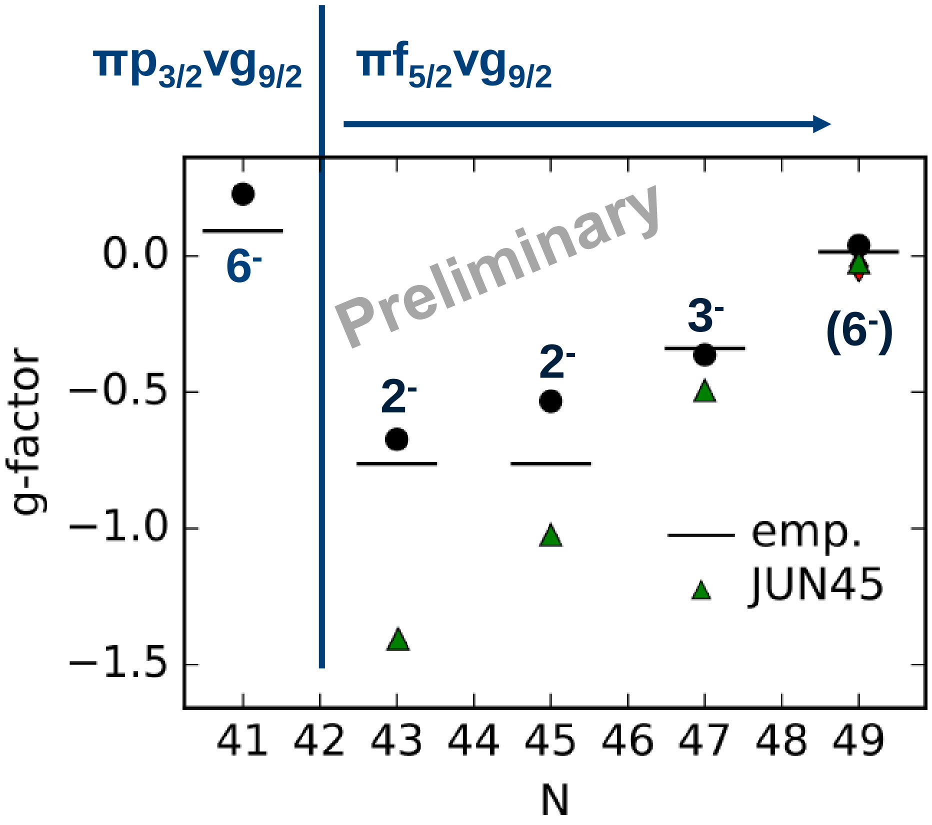
Results

g-factors of even Cu isotopes

- Empirical g-factors confirm $\pi f_{5/2} \nu g_{9/2}$ dominates the wavefunction for N>43

- Shell model calculations improve with increasing N

- Opening cross-shell excitation could improve reproduction



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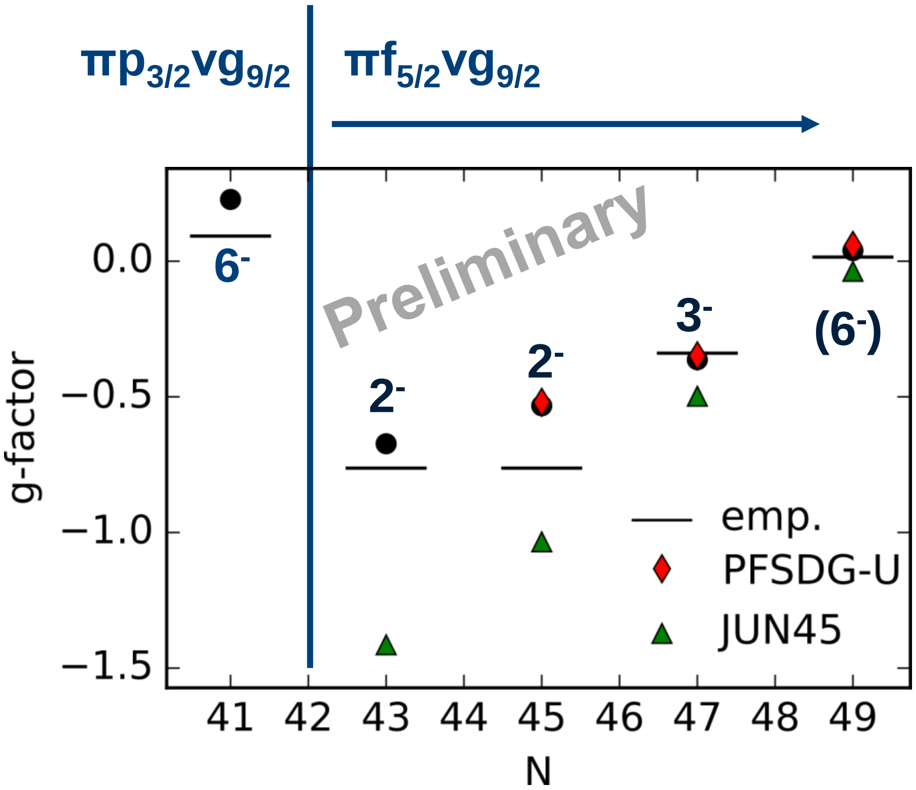
Results

g-factors of even Cu isotopes

- Empirical g-factors confirm $\pi f_{5/2} \nu g_{9/2}$ dominates the wavefunction for N>43
- Shell model calculations improve with increasing N
- Opening cross-shell excitation could improve reproduction
    - Recent calculations by Strasbourg group show promising agreement!



Quenching 0.75

ν: g_s = -2.8695 g_l = -0.1

π: g_s = 4.1895 g_l = 1.1

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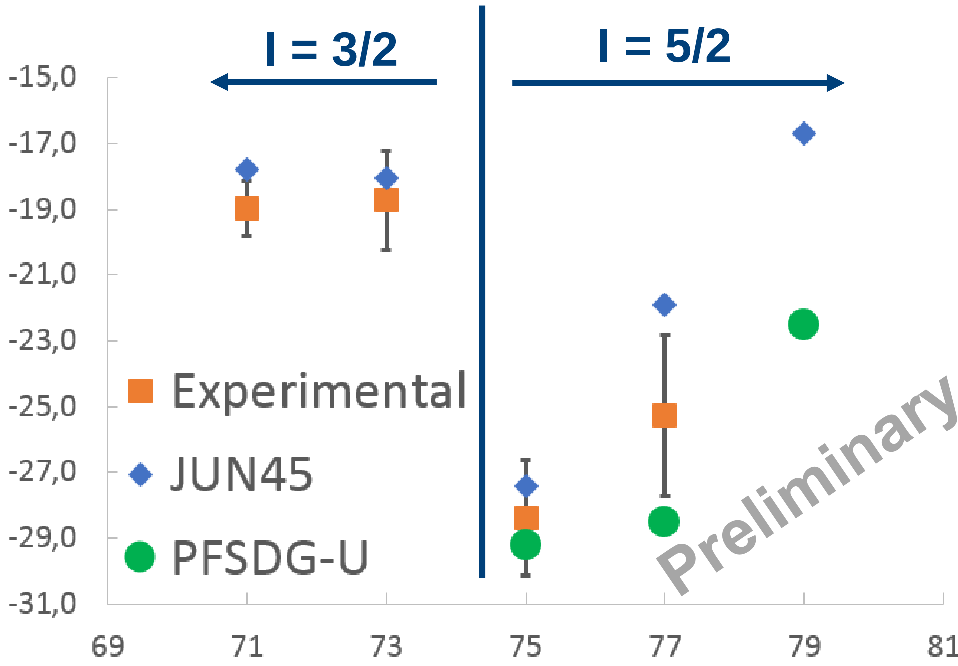
Results

Q-moments of odd Cu isotopes

- Uncertainties on Q-moment of ^{77}Cu unfortunately too large to draw conclusions
- ^{79}Cu will be a key case for the future
- Interpretation of shell model calculations in progress



$e_p = 1,5 \quad e_n = 1,1$

$e_p = 1,31 \quad e_n = 0.46$

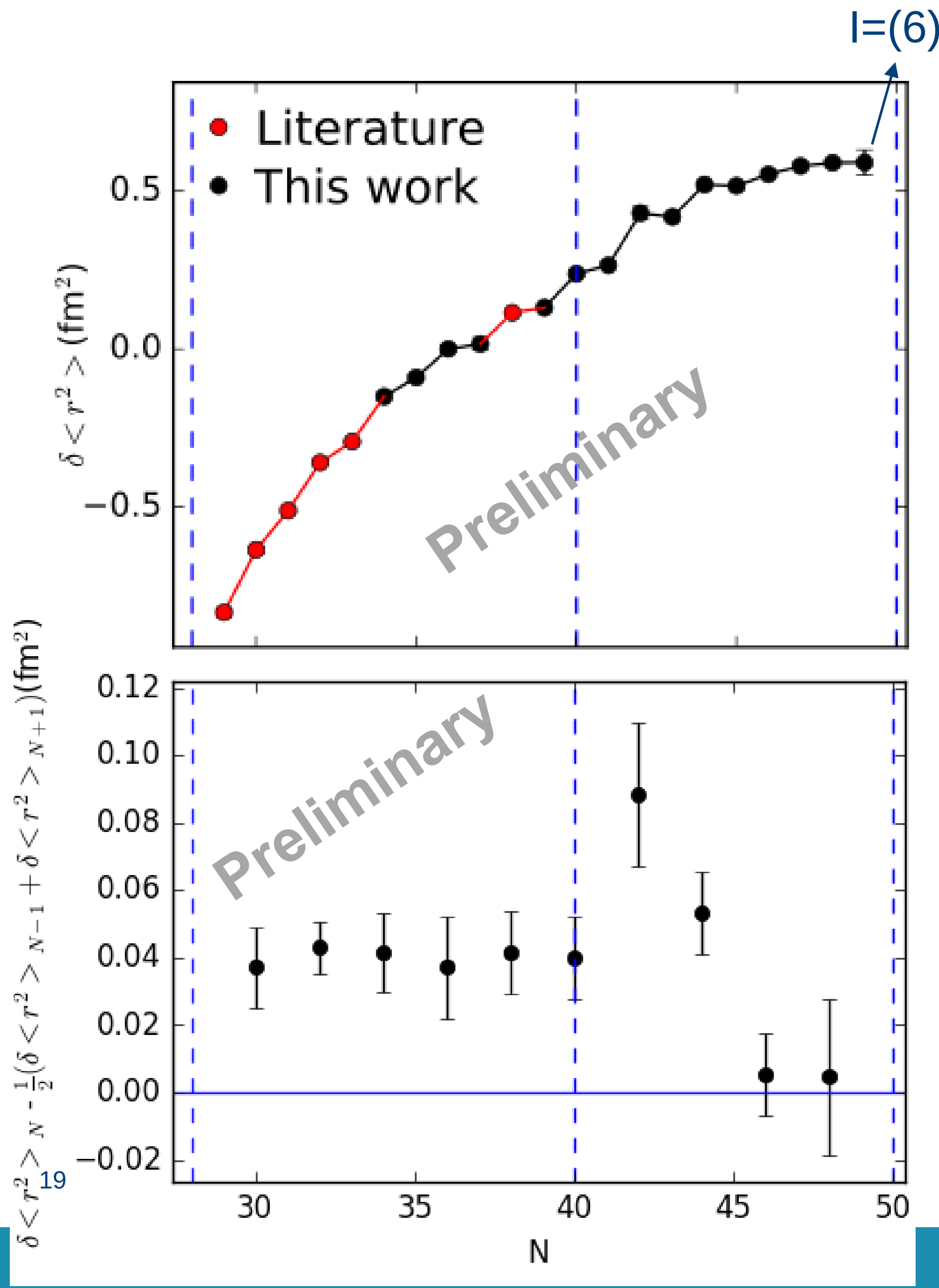
Results

Charge radii

- King plot analysis:
  M_k = 2296(23) GHz u
  F_k = 490(50) MHz fm^{-2}

- Radii flatten out as
  N = 50 is approached

- Reduction of odd-even staggering?



Conclusions

Conclusions

- Laser spectroscopy performed on $^{65-78}Cu$
- Preliminary analysis points to
  - Continued inversion of $\pi p_{3/2}$ and $\pi f_{5/2}$
  - Need for proton excitations across $Z = 28$ to reproduce odd-Cu g-factors
  - Odd-even staggering of charge radii seems to reduce significantly
  - Measurement of g, Q of ^{79}Cu will be key
- Comparison with large scale shell model calculations in underway

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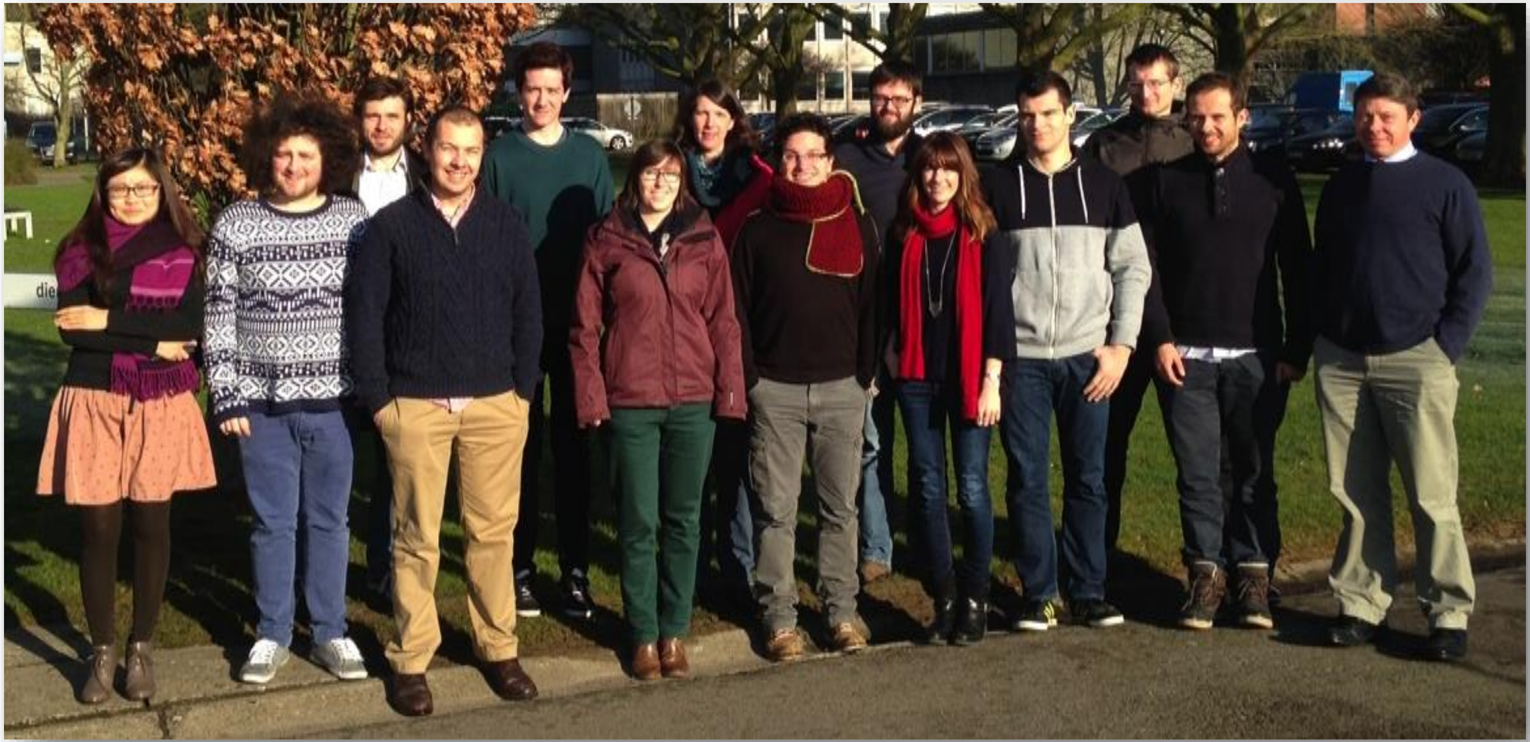
Thanks for your attention!



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Feasibility of ^{79}Cu

- Yield: 10x less than ^{78}Cu

  → efficiency boost required!

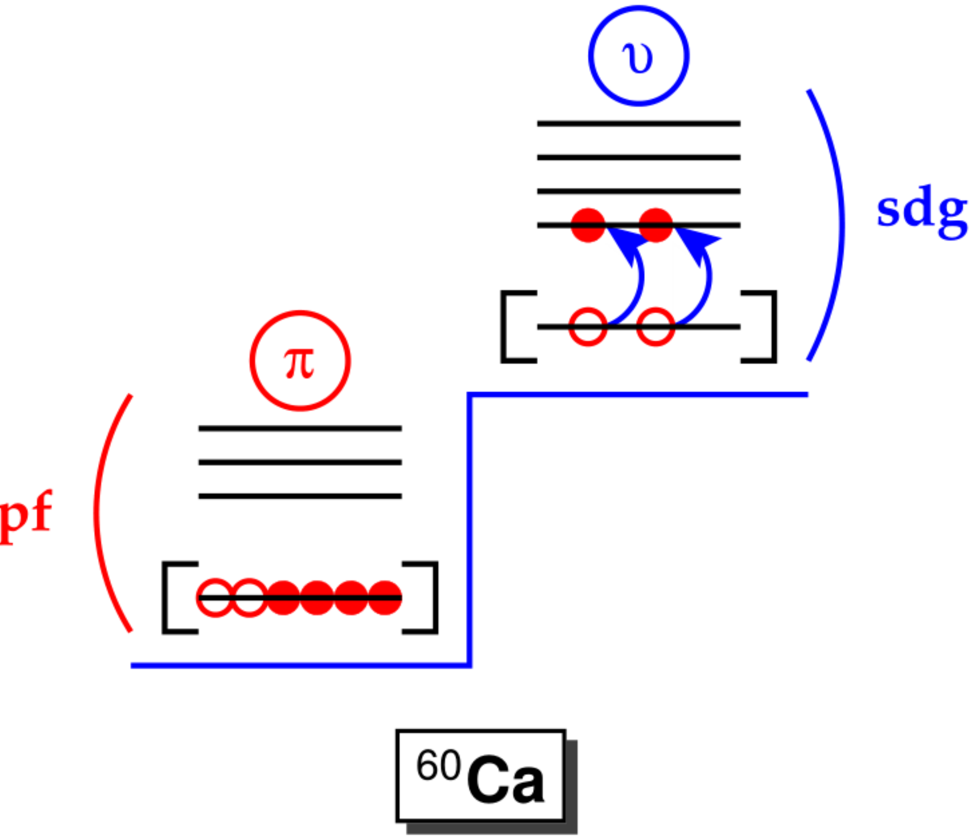
  → We think a factor of 3 is possible (laser ionization + transmission)
- Background: 10x more than ^{78}Cu

  → Reducing pressure by a factor of 10 in progress

  → fast beam gate: factor 3
- Stability of the system needs to be guaranteed

- With all this, we expect a result similar to ^{77}Cu

Slide by F. Nowacki, SSNET'16 International Workshop, November 7 th -11 th 2016



PFSDG-U interaction:

- realistic TBME
- pf shell for protons and gds shell for neutrons
- monopole corrections (3N forces)
- proton and neutrons gap ^{78}Ni fixed to phenomenological derived values

Calculations:

- excitations across Z=28 and N=50 gaps
- up to $2*10^{10}$ Slater Determinant basis states
- m-scheme code ANTOINE (non public version)
- J-scheme code NATHAN (parallelized version): $0.5*10^9$ J basis states