Seniority conservation along N=50: The neutron-magic $^{90}$Zr, $^{92}$Mo and $^{94}$Ru

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for the AGATA, VAMOS++ and IKP Plunger Collaboration

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Outline

- Physics Motivation
- Production Mechanism
- Experimental Setup
- Analysis
- Results
- Summary and Outlook
Physics Motivation

Seniority in the $g_{9/2}$ shell

- Seniority, $\nu$, can be viewed as a partial dynamical symmetry
- Shell Model orbitals for valence $\pi$ along $N=50$ are the same as for valence $\nu$ along $Z=28$
- $g_{9/2}$, first shell in which seniority might not be conserved
- Same nuclear structures for Valence Mirror Symmetry Partners (?)
- Effective two-body interaction is different along $g_{9/2}$ near $^{100}$Sn and around $^{78}$Ni
- Calculations suggest 4+ in $^{94}$Ru and $^{96}$Pd have $\nu=2$ and 4+ in $^{72,74}$Ni have $\nu=4$
Physics Motivation

Shell model theory in the valence space $f_{5/2}, p_{3/2}, p_{1/2}, g_{9/2}$

Valence Mirror Symmetry Partners

Physics Motivation

Shell model theory in the valence space $f_{5/2}, p_{3/2}, p_{1/2}, g_{9/2}$

Valence Mirror Symmetry Partners

N=50

Production Mechanism

Multi-nucleon Transfer

**Reaction $^{92}Mo + ^{92}Mo$:**
- Beam energy: 716.9 MeV
- Grazing angle LAB: ~23 °
- $E_{CM}/V_B \sim 1.75$

Deep-inelastic reactions used since pioneering work of R. Broda et al. PLB 251 (90) 245

G. Pollarolo (private comm 2015)

Deep-inelastic reactions used since pioneering work of R. Broda et al. PLB 251 (90) 245

~ few mb for $^{94}$Ru
Experimental Setup

GANIL

Experimental Setup

**VAMOS++ Setup:**
- Horizontal Acceptance: ±7°
- Vertical Acceptance: ±10°
- DM/M~1/220
- DZ/Z~1/66
- Angle 23 degrees
- Brho ~ 0.91
- ToF ~ 237.5 ns

**Agata Setup:**
- 23 Crystals
- Counting rate per crystal: 50 kHz
- Shaping 2.5 us
- Position: Nominal (23.5 cm)

**Plunger Setup:**
- 7 distances (μm): 19, 25, 105, 505, 1000, 2000, 4000

**AGATA**
- Target \(^{92}\text{Mo}\) 0.77 mg/cm\(^2\)
- Degrader Mg 1.9 mg/cm\(^2\)
- Plunger R DDS
- Quadrupoles
- VAMOS++
- TOF
- Dipole
- MWPPAC DC
- MWFP & OrGAMMA

**Trigger:** MWPPAC & MWFP & OrGAMMA

\(^{92}\text{Mo} @ 716.9\) MeV
Experimental Setup

**92Mo @ 716.9 MeV**

**Particle ID: A**
- Beam Spot size: 2mmx5mm
- Position resolution: 4mm
- From DPS-MWPC

**Particle ID: Z**
- Z = 42
- Z = 44
- Z = 40

**Target**
- 92Mo
- 0.77mg/cm²

**Trigger**
- MWPPAC & MWFP & OrGAMMA

**VAMOS++**
- Setup:
  - Horizontal Acceptance: ±7°
  - Vertical Acceptance: ±10°
  - DM/M~1/220
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  - Angle 23 degrees
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**Dipole**
- Wien Filter (not used)
Analysis

Total Kinetic Energy Loss (TKEL)

TKEL ↓↓ population of lower excited states
TKEL ↑↑ population of higher excited states
Analysis

$^{92}\text{Mo}$ Gamma Tracked Spectrum

Counts (0.5 keV/ch)

- 244.39 keV (5→4+)
  - 1.55 ns
- 329 keV (6→4+)
  - 1.53 ns
- 773 keV (4→2+)
- 1340 keV (3→2+)
  - 0.27 ps
- 1509 keV (2→0+)
  - 0.35 ps

Inelastic

19 μm

Energy (keV)

G.S. Stable

$^{82}\text{Mo}_{50}$

Isomer

2612.4 keV

2282.6 keV

773.09 keV

1509.5 keV

$^{3+}$

$^{5+}$

$^{6+}$

$^{4+}$

$^{2+}$

$^{0+}$
Analysis

$^{94}$Ru Gamma Tracked Spectrum

- 126.5 keV (5$\rightarrow$6+)
- 0.51 ns
- 437.7 keV (5$\rightarrow$4+)
- 0.51 ns
- 725.3 keV (12$\rightarrow$10+)
- 23.8 ps
- 755.9 keV (4$\rightarrow$2+)
- <3.47 ps
- 1340 keV (10$\rightarrow$8+)
- 1430.7 keV (2$\rightarrow$0+)
- 1033.3 keV (7$\rightarrow$5-)
- 2186.6 keV
- 755.9 keV
- G.S. 51.8 m
- 1430.7 keV
- 94
- 44
- $^{50}$Ru
Analysis

$^{90}$Zr Gamma Tracked Spectrum

- Counts (2 keV/ch)
- Energy (keV)
- MNT -2p 19$\mu$m

- $890.64$ keV ($4^+ \rightarrow 2^+$) $890.64$ keV
- $2186.3$ keV ($2^+ \rightarrow 0^+$) $2186.3$ keV
- $530$ keV ($3^+ \rightarrow 2^+$) $530$ keV
- $437.7$ keV ($4^- \rightarrow 5^-$) $437.7$ keV
- $530$ keV ($6^+ \rightarrow 5^-$) $530$ keV
- $0.14$ ns

- Isomer
  - $8^+$
  - $6^+$

- $90$Zr

- Z=40
- A=90
Analysis

**RDDS technique**
(Recoil Distance Doppler-Shift)

Lifetimes: ~1 to ~500 ps at v/c ≈ 10%

\[ R(t) = \frac{l_u(t)}{l_u(t) + l_s(t)} = e^{-t/\tau} \]

\[ \tau_i(t) = \frac{-R_i(t) + \sum_k R_k(t)}{d R_i(t)/dt} \]

A. Dewald et al. Prog. Part. Nucl. Phys. 63 (3)2012
Results

\[ ^{92}\text{Mo} \, 4^+ \rightarrow 2^+ \, \text{lifetime} \]

Q value to avoid 5\(^+\) & 6\(^+\) feeding

Small feeding from 5\(^+\) taken into account

\[ ^{92}\text{Mo} + ^{92}\text{Mo} \]

716 MeV

4\(^+\) \rightarrow 2^+ \rightarrow 0^+ \, \text{G.S. Stable} \]

Counts

716 MeV

773.09 keV

1509.5 keV

1509.5 keV

Energy (keV)

SM

N=50

4^+ \rightarrow 2^+

Distance (\mu m)

Q value to avoid 5\(^+\) & 6\(^+\) feeding

Small feeding from 5\(^+\) taken into account

DCM

\[ \tau = 35.5 \pm 24 \, \text{ps} \]

DDCM

\[ \tau = 34.6(14) \, \text{ps} \]
Results

$^{94}\text{Ru} \ 4^+ \rightarrow 2^+$ lifetime

Feeding from $5^+$ taken into account

$^{92}\text{Mo} + ^{92}\text{Mo}$

716 MeV

$4^+ \rightarrow 2^+$

2186.6 keV

755.9 keV

1430.7 keV

G.S. Stable

$\tau = 89 (16) \text{ps}$

$\tau = 87 (8) \text{ps}$
Results

\(^{90}\text{Zr} \, 4^+ \rightarrow 2^+ \) preliminary lifetime

\( Q \) value to avoid 6^+ feeding

\[ 0^+ \rightarrow 2^+ \]

\( \text{G.S.} \) Stable

\[ 4^+ \rightarrow 2^+ \]

\( \text{Q-value to avoid feeding} \)

\[ \tau = 4.2(4) \text{ ps} \]

\[ \tau = 4.3(7) \text{ ps} \]

\[ 716 \text{ MeV} \]

\[ 3448.2 \text{ keV} \]

\[ 890.64 \text{ keV} \]

\[ 2186.3 \text{ keV} \]
Results

B(E2)

<table>
<thead>
<tr>
<th>Nucleus</th>
<th>State</th>
<th>$\tau$ (ps)</th>
<th>B(E2) ($e^2fm^4$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{92}$Mo</td>
<td>4$^+\rightarrow$2$^+$</td>
<td>35.3(6)</td>
<td>84.4 (14)</td>
</tr>
<tr>
<td>$^{94}$Ru</td>
<td>4$^+\rightarrow$2$^+$</td>
<td>87 (8)</td>
<td>38(3)</td>
</tr>
<tr>
<td>$^{90}$Zr</td>
<td>4$^+\rightarrow$2$^+$</td>
<td>4.2(4)</td>
<td>300 (30)</td>
</tr>
</tbody>
</table>

Shell model theory in the proton valence space $f_{5/2} p_{3/2} p_{1/2} g_{9/2}$

A. F. Lisetskiy et al. PRC 2004  A. Gargano (private comm 2019)
- Bonn-C
- $e_p=2$
- Bonn-A
- $e_p=1.55$

[3] A. Gargano Private communication
Summary and Outlook

1. Experimental study of the seniority along the N=50 isotones in the vicinity of $^{100}$Sn

2. Successful lifetime measurement of the $4^+ \rightarrow 2^+$ yrast transition in $^{90}$Zr, $^{92}$Mo and $^{94}$Ru at GANIL using AGATA + PLUNGER + VAMOS++ for 7 target-degrader distances (19,25,105,505,1000,2000,4000 μm)

3. The results are being interpreted on the basis of Shell Model predictions for the comparison of the nuclear structure trends between the valence mirror symmetry partners $^{56-78}$Ni Z=28 isotopes and $^{78}$Ni- $^{100}$Sn N=50 isotones

4. Lifetimes and B(E2) for the $4^+ \rightarrow 2^+$ $^{90}$Zr, $^{92}$Mo and $^{94}$Ru allow to eventually confirm the conservation of seniority predicted by the Shell Model calculations
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Thank you to the AGATA, VAMOS++ and the IKP Plunger collaborations and all the e682 collaborators
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Thank you for your attention