Shape-changes and Isomers in neutron-rich Zr-Mo-Ru nuclei

kondev@anl.gov

AFC-11 Workshop, Argonne National Laboratory, April 14-16 2011
Introduction & Motivation

P. Moller et al., ADNDT 94 (2008) 758

- what is the size of deformation and how it changes with A and Z?
- which are the single-particle orbitals near the Fermi level and what role do they play in building deformation, e.g. identification of the “intruder” orbitals?
K-Isomers

- deformed with axially symmetric shape
- high-$\Omega$ orbitals near the proton and neutron Fermi surfaces

**protons**
(prolate): $5/2[422] (g_{9/2})$ & $5/2[303] (f_{5/2})$
(oblate): $7/2[413] (g_{9/2})$ & $5/2[413] (g_{7/2})$

**neutrons**
(prolate): $5/2[532] (h_{11/2})$ & $5/2[413] (g_{7/2})$
(oblate): $7/2[523] (h_{11/2})$ & $5/2[512] (h_{9/2})$

- existence of K-Isomers (with K=5 and 6)
- information about the pairing and residual spin-dependent interactions in deformed neutron-rich nuclei
Size of deformation with $10^4$ ions/sec beam

→ **reactions**: Coulex, DSAM & plunger → usually rates are lower than the room background!

→ **radioactive decay**: a blazing source for decay spectroscopy → the issue is if the state of interest is populated, depends on the properties of the parent

**direct (electronic) timing** – well developed in the past, e.g. $\beta\gamma(t)$, plastic scintillators for $\beta$ – good!, but for gammas Ge (down to ~1 ns) or BaF2 (good timing, but compromised energy resolution) → need for efficient detectors with good energy and time resolutions → e.g. LaBr(Ce) approaching limits down to ~ 40 ps!
Populating states of interest in $\beta^-$ decay

- odd-odd Y-Nb-Tc parent nuclei $\rightarrow$ existence of both low and high spin $\beta^-$ decaying states
- use CPT to determine the excitation energy
- access to variety of states, both intrinsic and collective
  - gamma-ray spectroscopy with X-array would be a powerful tool, including $\beta\gamma$ coin
  - using LaBr$_3$(Ce) detectors in conjunction with X-array to measure fast (ps) lifetimes

what CARIBU can offer?

- **Tc (Z=43):** 112 (610$^4$), 114 (100), 116 (0.012)
- **Nb(Z=41):** 108 (310$^4$), 110 (~100)
- **Y(Z=39):** 102 (210$^5$), 104 (410$^3$), 106 (~100)
β− counting station with GS

GAMMASPHERE

plastic scint. (β−)

high resolution & sensitivity
powerful β−γ−γ coin – resolving weak cascades & isomers!

134Sb

GS as a calorimeter


with a modest upgrade – suitable for β− decay studies – HRGS & TAGS
Shape measurements using TAGS

Ground state of $^{76}$Sr prolate ($\beta_2 \sim 0.4$) as indicated by in-beam studies by Lister et al., PRC 42 (1990) R1191

Ground state of $^{74}$Kr: (60\pm 8)\% oblate, in agreement with other exp results and with theoretical calculations (A. Petrovici et al.)

E. Nácher et al. PRL 92 (2004) 232501

E. Poirier et al. PRC 69 (2004) 034307
GS-LaBr$_3$(Ce) coincidences

2 x LaBr$_3$(Ce) + GS

collaborators Univ. Sofia

177Lu

177Hf
Fast (ps) timing measurements

Direct (electronic) timing - $\gamma-\gamma\gamma(\Delta t)$

GS & 2 LaBr$_3$(Ce)

500-690 ps in NDS

$T_{1/2}=760$ (65) ps

760 (65) ps

520-700 ps in NDS
Direct (electronic) timing – $\gamma-\gamma(\Delta t)$

$\gamma$-ray coincidence and fast-timing measurements using LaBr$_3$(Ce) detectors and gammasphere

S. Zhu$^{a,*}$, F.G. Kondev$^{a}$, M.P. Carpenter$^{a}$, I. Ahmad$^{b}$, C.J. Chiara$^{a,b}$, J.P. Greene$^{a}$, G. Gurdal$^{a}$, R.V.F. Janssens$^{b}$, S. Lalkovski$^{c}$, T. Lauritsen$^{a}$, D. Seweryniak$^{a}$

Promt:
GS: 208 keV
LaBr: 153 - 174 keV

Lifetime: 58 (4) ps
GS: 113 keV
LaBr: 105 - 128 keV

Counts

Time (ps)

$40 \pm 4$ ps
$\delta = -0.36$

$720 \pm 25$ ps

$\delta = -4.4$

$760 \pm 65$ ps
Precise lifetime measurements

\[ K^\pi = 16^+ \]
\[ T_{1/2} = 31 \text{ yr} \]

\[ \begin{align*}
16^+ & \quad 310 \quad 13 \quad 297 \quad 574 \quad 231 \quad 13^- \\
587 & \quad 12^- \quad 277 \quad 535 \quad 258 \quad 495 \quad 11^- \\
10^- & \quad 237 \quad 454 \quad 9^- \quad 217 \quad 8^- \\
8^+ & \quad 89 \quad (515) \quad 454 \\
6^+ & \quad 326 \\
4^+ & \quad 213 \\
2^+ & \quad 93 \\
0^+ & \quad \text{stable}
\end{align*} \]

\[ K^\pi = 8_1^- \quad T_{1/2} = 4.0 \text{ s} \]

\[ K^\pi = 8_2^- \]

\[ 178\text{Hf} \]

\[ \tau(2+) = 2155 (33) \text{ ps} - \text{NDS} \]

S. Zhu et al.
Conclusions

- Fast-timing capabilities - a valuable addition to the CARIBU decay station
  - good physics and a simple concept: LaBr$_3$(Ce) scintillator array in conjunction with Ge hi-res detectors (X-array)

- Shape changes and quantification of deformation in neutron-rich Zr-Mo-Ru nuclei
  - combination between TAGS and HRGS would be very powerful tool

- Identification of single-particle structures and K-Isomers

- Utilizing the high sensitivity and calorimetric capabilities of Gammasphere in decay of neutron-rich nuclei