First Online Mass Measurements of Isobar Chains Via MRTOF-MS : Toward Direct Identification of SHE

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Motivation

Theoretical prediction



• Experimental status

- - not determined for non-alpha decay species



Experimental Setup **GARIS-II**



Cryogenic Gas Cell

140 mm

ε: 97 x 90.5% Honeycomb + 0.5 µmt Mylar

Primary beam Target Ta beam dump Q1 **D1** Q2 Q3 Beam envelope of ERs





M. Brodeur et al., IJMS 336 (2013) 53

Present System Performance



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- Macro drift: temperature change of ~0.2 K for Ti
- Micro drift: assuming voltage instabilities

Fr and At Mass Measurements

¹⁶⁹Tm(⁴⁰Ar, xn)^{209-x}Fr, ¹⁶⁵Ho(⁴⁰Ar, xn)^{205-x}At $E_{lab}(^{40}Ar) = 173 \text{ MeV} @tgt center, E_{recoil} ~ 35 \text{ MeV}$

203 87 FF 116	204 87 FF 117	²⁰⁵ 87 FF 118	206 87 FF 119	²⁰⁷ FF 120	208 87 FT 121	209 87 F
550 ms 9/2 [−] # M 876 (6) α≈100% β ⁺ =5#%	$ \begin{array}{c c} 0.8 \ s \ (10^{-}) \\ Eex \ 327 \ (4) \\ a=74 \ (8)\% \\ IT=26 \ (8) \end{array} \begin{array}{c} 2.30 \ s \ (7^{+}) \\ Eex \ 51 \ (4) \\ a=90 \ (2)\% \\ B^{+} \ ? \end{array} \begin{array}{c} 1.75 \ s \ (3^{+}) \\ M \ 607 \ (25) \\ a=96 \ (2)\% \\ B^{+} \ ? \end{array} $	1.15 ms (1/2 ⁺) 80 ns (13/2 ⁺) 3.82 s (9/2 ⁻) M = 1310 (8) α≈100% IT=100% IT=100%	$\begin{array}{c c} 700 \text{ ms} (10^{-}) \\ \text{Eex} 730 (40) \\ \text{IT}=?\% \\ \alpha \approx 5 \#\% \end{array} \begin{array}{c} \sim 16 \text{ s} (7^{+}) \\ \text{Eex} 190 (40) \\ \alpha = 42 (24)\% \\ \beta^{+}? \dots \end{array} \begin{array}{c} \sim 16 \text{ s} (2^{+},3^{+}) \\ \text{M}^{-1}242 (28) \\ \beta^{+}=? \\ \alpha = 42 (24)\% \end{array}$	14.8 s 9/2 ⁻ M ⁻ 2844 (18) α=95 (2)% β ⁺ ?	432 ns (10 ⁻) 59.1 s 7 ⁺ M ⁻ 2666 (11) Eex 827 (18) α=89 (3)% IT=100% β ⁺ =11 (3)%	420 ns 45/2 ⁻ Eex 4659.8 (0.7) IT=100% 50.0 Δ = δ β ⁺ =
²⁰² RN 116	²⁰³ 86 80 117	²⁰⁴ RN 118	²⁰⁵ RN 119	²⁰⁶ 81 120	²⁰⁷ Rn 121	²⁰⁸ 86
2.22 us 11 ⁻ # 9.7 s 0 ⁺ Eex 2310# (50#) M ⁻⁶²⁷⁴ (18) IT=100% β ⁺ ?	$\begin{array}{c c} 26.9 \text{ s } 13/2(^+) \\ \text{Eex } 360 \ (4) \\ \alpha = 75 \ (10)\% \\ \beta^+ ? \end{array} \begin{array}{c} 44 \text{ s } 3/2^- \# \\ M^- 6159 \ (24) \\ \alpha = 66 \ (9)\% \\ \beta^+ ? \end{array}$	1.242 m 0 ⁺ M ⁻ 7983 (15) α=72.4 (9)% β ⁺ ?	>10 s 13/2 ⁺ # Eex 657.1 (0.5) IT≈100% α? α=24.6 (9)%	5.67 m 0 ⁺ M [−] 9115 (15) α=62 (3)% β ⁺ =38 (3)%	$\begin{array}{c} 184.5 \text{ us } 13/2^+ \\ \text{Eex } 899.1 \ (1.0) \\ \text{IT=} 100\% \end{array} \begin{array}{c} 9.25 \text{ m } 5/2^- \\ \text{M} \ ^{-}8635 \ (8) \\ \beta^+ = 79 \ (3)\% \\ \alpha = 21 \ (3)\% \end{array}$	487 ns 8 ⁺ 24.3 Eex 1828.3 (0.4) μ ⁻ IT=100% β ⁺
²⁰¹ At 116	²⁰² At 117	²⁰³ At 118	204 85 At 119	²⁰⁵ At 120	²⁰⁶ At 121	²⁰⁷ At
85.2 s (9/2 ⁻) M ⁻ 10789 (8) α=71 (7)% β ⁺ =29 (7)%	$\begin{array}{c} \mbox{460 ms (10^-)} \\ \mbox{Eex 580 (40)} \\ \mbox{IT} \approx 100 \\ \mbox{a=0.096 (11)\%} \end{array} \begin{array}{c} 182 \ {\rm s} \ (7^+) \\ \mbox{Eex 190 (40)} \\ \mbox{IT} \mbox{P} \\ \mbox{B}^+ \mbox{P} \\ \mbox{B}^+ \mbox{P} \\ \mbox{a=37 (7)\%} \end{array}$	7.4 m 9/2 ⁻ M ⁻ 12163 (11) β ⁺ =69 (3)% α=31 (3)%	$\begin{array}{c} 108 \text{ ms } 10^{-} \\ \text{Eex 587.30 (0.20)} \\ \text{IT=100\%} \end{array} \begin{array}{c} 9.12 \text{ m } 7^{+} \\ \text{M}^{-}11875 (22) \\ \beta^{+}=96.2 (2)\% \\ \alpha=3.8 (2)\% \end{array}$	7.76 us 29/2+ 33.8 m 9/2- Eex 2339.65 (0.23) M - 12970 (15) IT=100% α=10 (2)%	$\begin{array}{c} 813 \text{ ns } (10)^{-} \\ \text{Eex } 810 \ (3) \\ \text{IT=} 100\% \end{array} \xrightarrow[]{30.6 \text{ m}} (5)^{+} \\ M^{-12429} \ (15) \\ \beta^{+} = 99.10 \ (8)\% \\ \alpha = 0.90 \ (8)\% \end{array}$	108 ns 25/2 ⁺ 1.81 Eex 2117.3 (0.6) IT=100% α≈
²⁰⁰ PO 116	²⁰¹ PO 117	²⁰² PO 118	²⁰³ PO 119	²⁰⁴ PO 120	²⁰⁵ PO 121	296 P
268 ns 12 ⁺ 100 ns 11 ⁻ 11.51 m 0 ⁺ Eex 2817 (8) Eex 2596.1 (0.3) M ⁻ 16954 (14) IT=100% IT=100% a=11.1 (3)%	$\begin{array}{c c} 8.96 \text{ m } 13/2^+ & 15.6 \text{ m } 3/2^- \\ \text{Eex } 424.1 \ (2.4) & \text{M}^-16525 \ (6) \\ \text{IT}=\!56.2 \ (12)\% & \beta^+=\!98.87 \ (3)\% \\ \beta^+=\!41.4 \ (7)\% & \alpha=\!1.13 \ (3)\% \end{array}$	110 ns 8+ Eex 1712 (12) IT=100%44.6 m 0+ M $^{-17924}$ (15) $\beta^{+} = ?$ $\alpha = 1.92$ (7)%	$\begin{array}{c} \textbf{>200 ns} \\ \textbf{Eex 21585 (0.6)} \\ \textbf{IT=100\%} \end{array} \begin{array}{c} \textbf{45 s 13/2^+} \\ \textbf{Eex 641.68 (0.17)} \\ \textbf{IT\approx 100\%} \\ \textbf{\alpha=0.04\#\%} \end{array} \begin{array}{c} \textbf{36.7 m 5/2^-} \\ \textbf{M-17311 (9)} \\ \textbf{\beta^+\approx 100\%} \\ \textbf{\alpha=0.11 (2)\%} \end{array}$	$\begin{array}{c} \textbf{158.6 ns 8}^{+} \\ \textbf{Eex 1639.03 (0.06)} \\ \textbf{IT=100\%} \end{array} \begin{array}{c} \textbf{3.519 h 0}^{+} \\ \textbf{M}^{-18341 (11)} \\ \textbf{\beta}^{+=99.33 (3)\%} \\ \textbf{\alpha}=0.67 (3)\% \end{array}$	645 us 13/2 ⁺ 310 ns 1/2 ⁻ $1.74 h 5/2^-$ Eex 880.31 (0.07) Eex 143.166 (0.07) M ⁻ 17509 (20) JT=100% IT=100% g=0.04 (1)%	1.05 us 9 ⁻ # Eex20203 (0.12) EexToo. IT=100% IT=100 >
¹⁹⁹ BI 116	²⁰⁰ Bi 117	²⁰¹ BI 118	²⁰² Bi 119	²⁰³ Bi ₁₂₀	²⁰⁴ Bi ₁₂₁	195 -
$\begin{array}{c} 100 \text{ ns } 25/2^{+}\# \\ \text{Eex } 667 \ (3) \\ \text{IT}=100 \end{array} \begin{array}{c} 24.70 \text{ m} \ (1/2^{+}) \\ \text{Eex } 667 \ (3) \\ \text{B}^{+}=? \\ \text{IT}<2\% \end{array} \begin{array}{c} 27 \text{ m} \ 9/2^{-} \\ \text{M}^{-}20797 \ (11) \\ \text{B}^{+}=100\% \end{array}$	$\begin{array}{c} 400 \text{ ms (10}^{-}) \\ \text{Eex 428.20 (0.10)} \\ \text{IT=100\%} \end{array} \begin{array}{c} 31 \text{ m (2}^{+}) \\ \text{Eex 100\# (70\#)} \\ \beta^{+} < 100\% \\ \text{IT ?} \end{array} \begin{array}{c} 36.4 \text{ m } 7^{+} \\ \text{M}^{-} 20371 (22) \\ \beta^{+} = 100\% \end{array}$	$\begin{array}{c} 118 \text{ ns } 25/2^{+}\# \\ \text{Eex } 846.35 (0.18) \\ \text{Eex } 1973 (23) \\ \text{IT}=100\% \\ \end{array} \begin{array}{c} 57.5 \text{ m } 1/2^{+} \\ \text{Eex } 846.35 (0.18) \\ \beta^{+} > 91.1\#\% \\ \text{IT} < 8.6\% \\ \end{array} \begin{array}{c} 103 \text{ m } 9/2^{-} \\ \text{M}^{-}21415 (15) \\ \beta^{+} = 100\% \end{array}$	310 ns (17 ⁺) 3.04 us 10 ⁻ # 1.72 h 5(⁺ #) Eex 2617 (12) Eex 625 (12) M ⁺ 20741 (15) JT=100% IT=100% a<1e ⁻ 5%	194 ns 25/2 ⁺ 305 ms 1/2 ⁺ 11.76 h 9/2 ⁻ Eex 2041.5 (0.6) Eex 1088.12 (0.12) M - 21524 (13) IT=100% IT=100% β ⁺ =100%		220 ns 25/2 ⁺ Eex 2139.0 (0.7) IT=100% IT=100~



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Th & Pa Mass Measurements



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Th & Pa Mass Measurements



	ME (keV)	Δm (keV)	δ <i>m/m</i>
²²⁴ Th	19864(100)(7)	-130(100)(7)	4.8 x 10 ⁻⁷
²²⁴ Pa	23827(34)(7)	-36(34)(7)	1.6 x 10 ⁻⁷
$C_3H_6NO_2S$		32(66)(7)	3.2 x 10 ⁻⁷
²²³ Th	19262(23)(7)	-124(23)(7)	1.1 x 10 ⁻⁷



D. Neidherr et al., PRL 102 (2009) 112501





- GARIS-II: occupied for new element search after SC-Linac construction
- GARIS-I: no connection to the MRTOF exp. room downstairs

Mini-MRTOF



- Overall system efficiency: ~20% is expected
- More contaminants? due to less selectivity of BN-gate
- GARIS-I transmission: similar efficiency for symmetric reaction products, but less for asymmetric ones



Reference IS



- Direct mass measurements of SHN: not only for nuclear structure studies but also direct identification of SHE
- GARIS + MRTOF configuration: high-efficiency measurement and short measurement time
- GC efficiency: ~30% for Fr and No @room temp., and ~25% for Th @90 K
- Concomitant operation: more accurate and precision measurement of MRTOF
- Mass measurements of A = 201, 205 and 206 isobar chains: masses of ^{201g}Po , ^{201}At and ^{206g}Fr are significantly deviated from SMS@ESR values
- Mass measurements of ^{223,224}Th and ²²⁴Pa: indicate onset of octupole deformation in this region Mini-MRTOF: higher efficiency and possibility coupled with GARIS-I instead of GARIS-II • Proton-rich middle mass region w/ GARIS-II: ⁶⁴Ni, ⁶⁵Cu, ⁶⁴⁻⁶⁷Zn, ⁶⁴⁻⁶⁷Ga, ⁶⁵⁻⁶⁷Ge ⁶⁷As, ⁷⁹Br, ⁷⁹⁻⁸⁰Kr, ⁷⁹⁻⁸⁰Rb, ⁷⁹⁻⁸⁰Sr
- (S. Kimura from KEK)

Collaborators

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Summary

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