

Lifetime measurements and shape coexistence in ^{97}Sr

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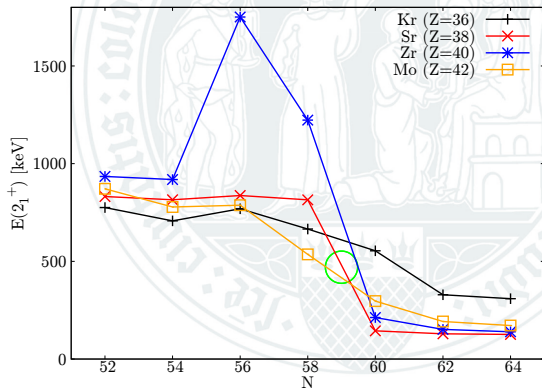
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July 13, 2022

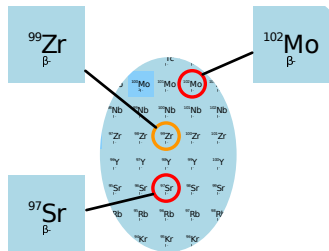


Motivation

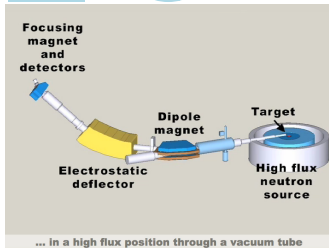
- $N=58$ (^{96}Sr) spherical
- $N=60$ (^{98}Sr) strong deformation
- what is happening at the spherical-deformed border $N=59$?



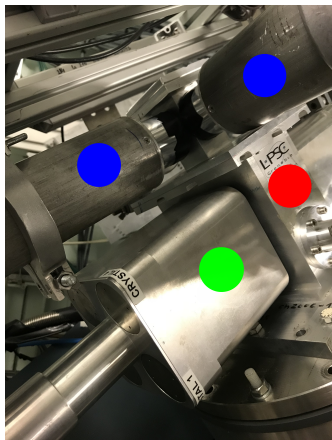
'Shape coexistence region'



- Measurement of delayed γ -rays for mass $A = 97$, $A = 99$ at Lohengrin mass spectrometer, ILL Grenoble
- $^{235}\text{UO}_2$ target with thickness of $363\mu\text{g}/\text{cm}^2$
- flight time of ions is about $0.6\mu\text{s}$

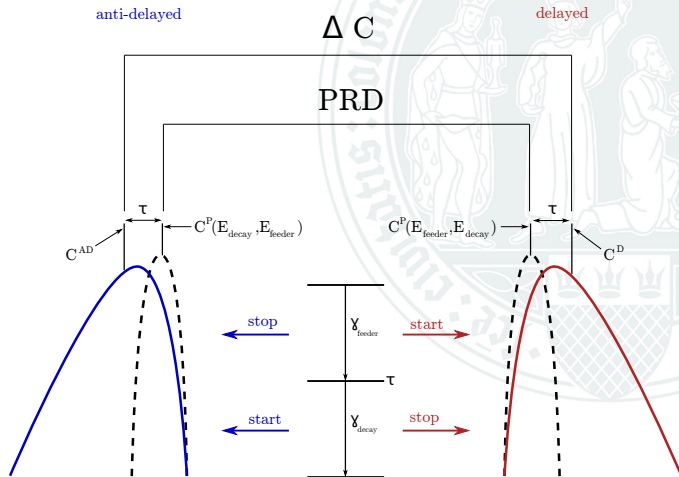


Experimental details

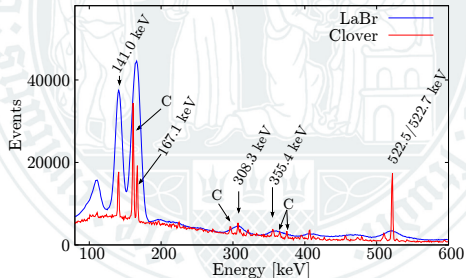
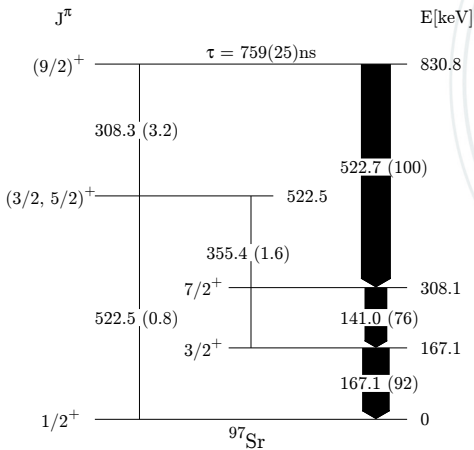


- Selection via mass- and energy-to-ionic-charge ratio in ionization chamber (ΔE - E detection)
- Installation of four $1.5'' \times 1.5''$ $\text{LaBr}_3(\text{Ce})$ detectors to perform fast timing
- Additional two four-segmented Clover detectors

Fast-timing method

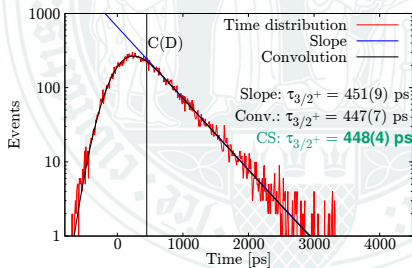
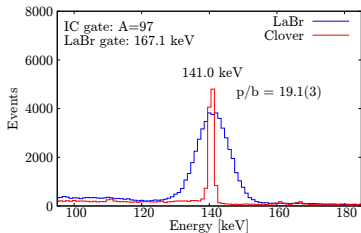
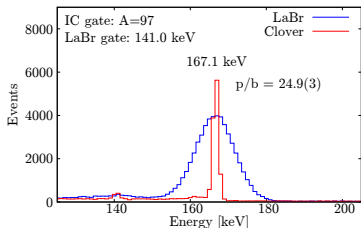


Analysis ^{97}Sr



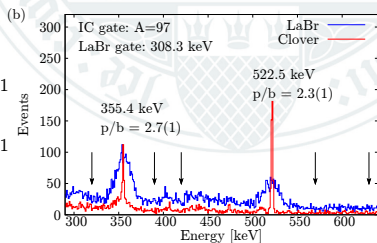
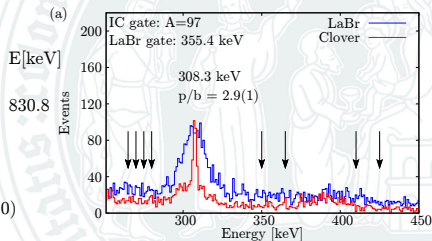
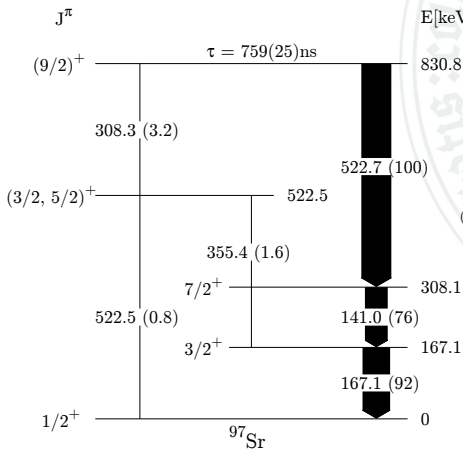
Analysis ^{97}Sr

Lifetime of $3/2^+$ state



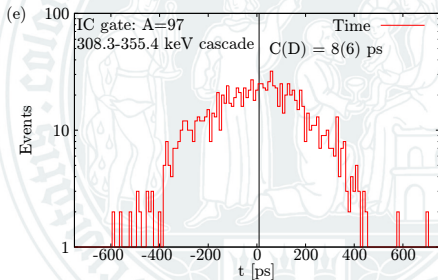
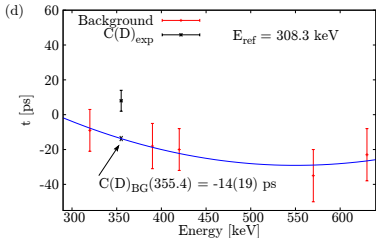
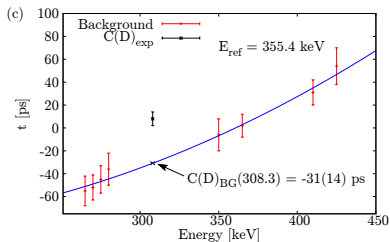
Analysis ^{97}Sr

Lifetime of $(3/2, 5/2)^+$ state



Analysis ^{97}Sr

Lifetime of $(3/2, 5/2)^+$ state



- $\Delta C_{\text{FEP}} = \Delta C_{\text{exp}} + \overline{t_{\text{cor}}}$
- $\overline{t_{\text{cor}}} = \frac{1}{2} (t_{\text{cor}}(E_{d(f)}) + t_{\text{cor}}(E_{d(f)}))$
- $t_{\text{cor}}(E_{d(f)}) = \frac{\Delta C_{\text{exp}} - \Delta C_{\text{bg}}}{p/b_{d(f)}}$



Results ^{97}Sr

State	$E_{\text{Level}}[\text{keV}]$	τ	τ_{Lit}
$3/2^+$	167.1	448(4) ps	317(57) ps ^a , 1.5 ns ^b
$(3/2, 5/2)^+$	522.5	14(6) ps	-
$7/2^+$	308.1	252(10) ns	245(14) ns ^b , 238(36) ns ^c 238(6) ns ^d
$9/2^+$	830.8	759(25) ns	382(39) ns ^e , 368(43) ns ^c 727(12) ns ^f , 759(19) ns ^g , 750 ⁺²³¹ ₋₁₇₃ ns ^h , 743(14) ns ⁱ ,

^a H. Ohm et al., Z. Phys. A 327, 483 (1987), ^b K. L. Kratz et al., Z. Phys. A 312, 43 (1983)

^c J. K. Hwang et al., PRC 73, 044316 (2006), ^d M. Czerwinski et al., PRC 92, 014328 (2015)

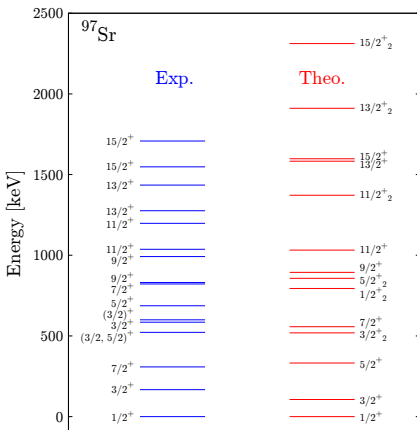
^e J. K. Hwang et al., PRC 67, 054304 (2003), ^f T. Rzaca-Urban et al., PRC 98, 064315 (2018)

^g A. Zlomaniec et al., PRC 72, 067302 (2005), ^h D. Kameda et al., PRC 86, 054319 (2012)

ⁱ M. Rudigier et al., PRC 87, 064317 (2013)



Calculations of mapped IBFM for ^{97}Sr



- For calculations the even-even core ^{96}Sr with a weakly oblate deformation ground state is used
- The Hamiltonian is for ^{96}Sr completely from microscopic EDF calculation^a

^aK. Nomura et al., PRC 94, 044314 (2016)

E_{Level} [keV]	$J^{\pi^2} \rightarrow J^{\pi^1}$	Multipolarity	Experimental results from this work		Theory
			$\tau(J^{\pi^2})$	$B(\sigma\lambda; J^{\pi^2} \rightarrow J^{\pi^1})$	$B(\sigma\lambda)$
167.1	$3/2^+ \rightarrow 1/2^+$	M1	448(4) ps	$260(2) \times 10^{-4} \mu_N^2$	$52 \times 10^{-3} \mu_N^2$
308.1	$7/2^+ \rightarrow 3/2^+$	E2	252(10) ns	$45(2) e^2 \text{fm}^4$	$740 e^2 \text{fm}^4$
522.5 ¹	$5/2^+ \rightarrow 1/2^+$	E2	14(6) ps	$450^{+330}_{-140} e^2 \text{fm}^4$	$313 e^2 \text{fm}^4$
	$\rightarrow 3/2^+$	M1		$60^{+40}_{-20} \times 10^{-3} \mu_N^2$	$120 \times 10^{-3} \mu_N^2$
	$\rightarrow 7/2^+$	E2*		$3300^{+2700}_{-1300} e^2 \text{fm}^4$	$128 e^2 \text{fm}^4$
522.5 ²	$3/2_2^+ \rightarrow 1/2^+$	M1*		$11^{+9}_{-4} \times 10^{-3} \mu_N^2$	$96 \times 10^{-3} \mu_N^2$
		E2*	14(6) ps	$450^{+330}_{-140} e^2 \text{fm}^4$	$33 e^2 \text{fm}^4$
		M1*		$9^{+6}_{-3} \times 10^{-3} \mu_N^2$	$29 \times 10^{-3} \mu_N^2$
	$\rightarrow 3/2^+$	M1		$60^{+40}_{-20} \times 10^{-3} \mu_N^2$	$17 \times 10^{-3} \mu_N^2$
	$\rightarrow 7/2^+$	E2		$3300^{+2700}_{-1300} e^2 \text{fm}^4$	$4 e^2 \text{fm}^4$
830.8	$9/2^+ \rightarrow 5/2^{+3}$	E2	759(25) ns	$12^{+7}_{-5} \times 10^{-3} e^2 \text{fm}^4$	$398 e^2 \text{fm}^4$
	$\rightarrow 7/2^+$	E2*		$27(1) \times 10^{-3} e^2 \text{fm}^4$	$31 e^2 \text{fm}^4$
		M1*		$51(2) \times 10^{-8} \mu_N^2$	$102 \times 10^{-3} \mu_N^2$

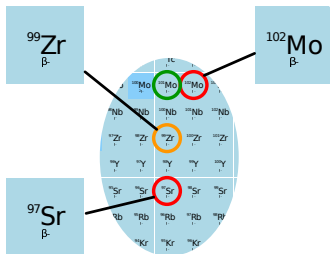
¹By assuming it is a $5/2^+$ state.

²By assuming it is a $3/2^+$ state.

³A $5/2^+$ state is preferred, because a $3/2^+$ would suggest a M3/E4 transition which is unlikely.



Conclusion & Outlook



- Measurement of lifetimes in ^{97}Sr
- Suggestion of $5/2^+$ spin for state at 522 keV (lifetime, multipolarity and calculations)
- Description of spherical-deformed border at $N = 59$ for ^{97}Sr
- Further investigation of $N = 59$ isotones (^{101}Mo , ^{95}Kr , etc)

PHYSICAL REVIEW C **100**, 064309 (2019)

Lifetime measurements and shape coexistence in ^{97}Sr

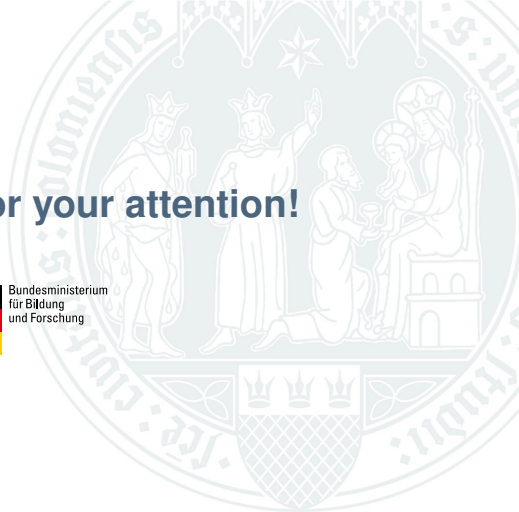
A. Esmaylzadeh,^{1,*} J.-M. Régis,¹ Y. H. Kim,² U. Köster,² J. Jolie,¹ V. Karayonchev,¹ L. Knafla,¹ K. Nomura,³ L. M. Robledo,^{4,5} and R. Rodríguez-Guzmán⁶



Thank you for your attention!



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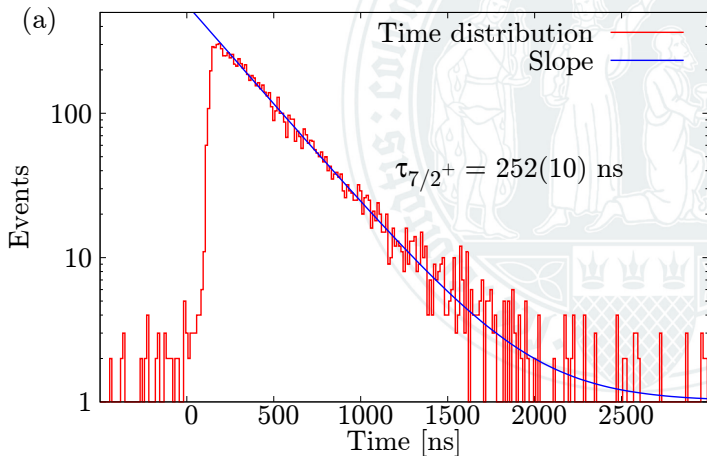


Backup ^{97}Sr



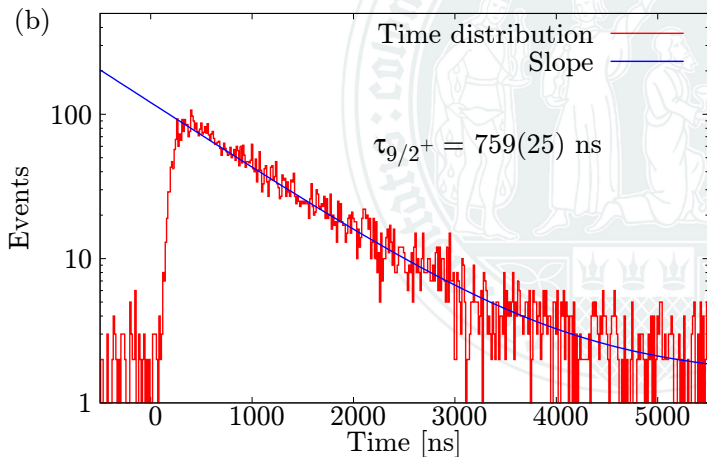
Analysis ^{97}Sr

Lifetime of $7/2^+$ state



Analysis ^{97}Sr

Lifetime of $9/2^+$ state



Experiment

Fast-timing setup

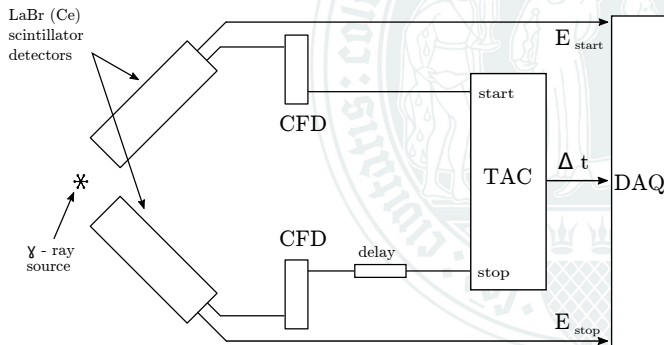
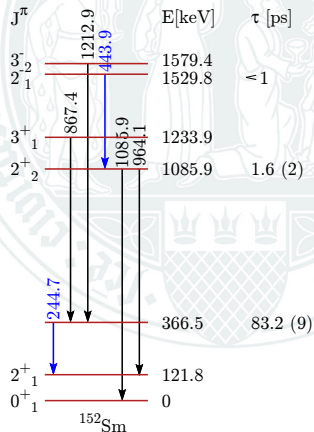
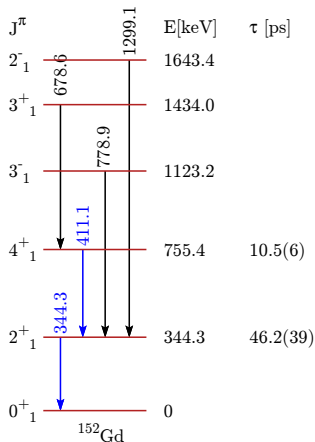
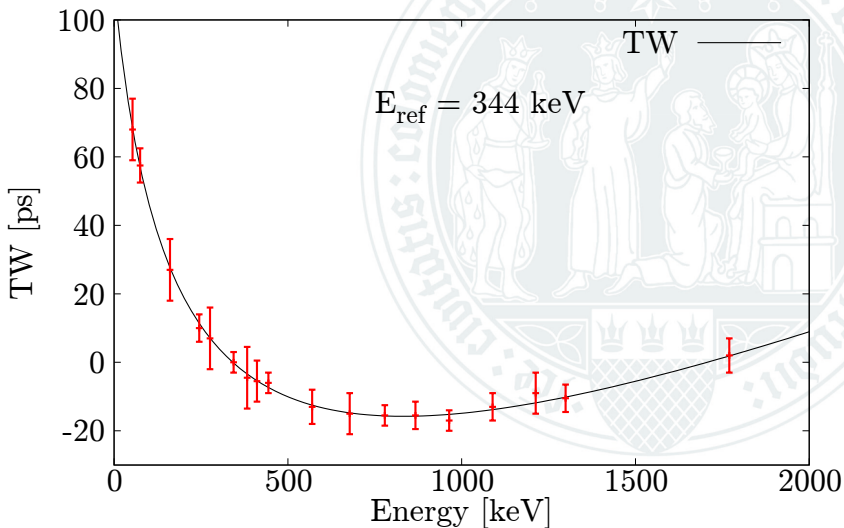


Figure: General fast-timing setup with two $\text{LaBr}_3(\text{Ce})$ detectors

The GCD method

Calibration of the PRD curve





Symmetrization procedure

- mirror the anti-delayed time distribution according to a reference time t_0
- Lifetime is then measured like in centroid shift with $\tau = C(D) - t_0 - TW(E_{\text{feeder}}, E_{\text{decay}})$
- $TW(E_{\text{feeder}}, E_{\text{decay}})$ is similar to the known PRD, where $TW(E_{\text{feeder}}, E_{\text{decay}}) = PRD(E_{\text{feeder}}, E_{\text{decay}}) / 2^4$

⁴J.-M. Régis, NIM A 897 (2018)



IBFM calculation

- $\hat{H}_{\text{IBFM}} = \hat{H}_{\text{B}} + \hat{H}_{\text{F}} + \hat{H}_{\text{BF}}$
 - \hat{H}_{B} IBM-2 Hamiltonian
 - \hat{H}_{F} single-particle fermion Hamiltonian ($3s_{1/2}$, $2d_{3/2}$, $2d_{5/2}$ and $1g_{7/2}$ neutron orbitals)
 - \hat{H}_{BF} boson-fermion interaction term



Arguments for $5/2^+$ state

- Calculation describes $5/2^+$ better than $3/2^+$
- $3/2^+$ calculation near by 522 keV state, but could also be assigned to $3/2^+$ state at 585 keV/600 keV
- Partial lifetime from β -decay $\approx 17 \mu\text{s}$ ⁵, which is favored by an E2 transition from the $9/2^+$ and not by M3 (if state would be $3/2^+$)

⁵M. Rudigier et al., PRC 87, 064317 (2013)

