The Fast-Timing Technique for Neutron-Rich Lanthanides

FAYE ROWNTREE

UNIVERSITY OF LIVERPOOL

What is the fast-timing technique?

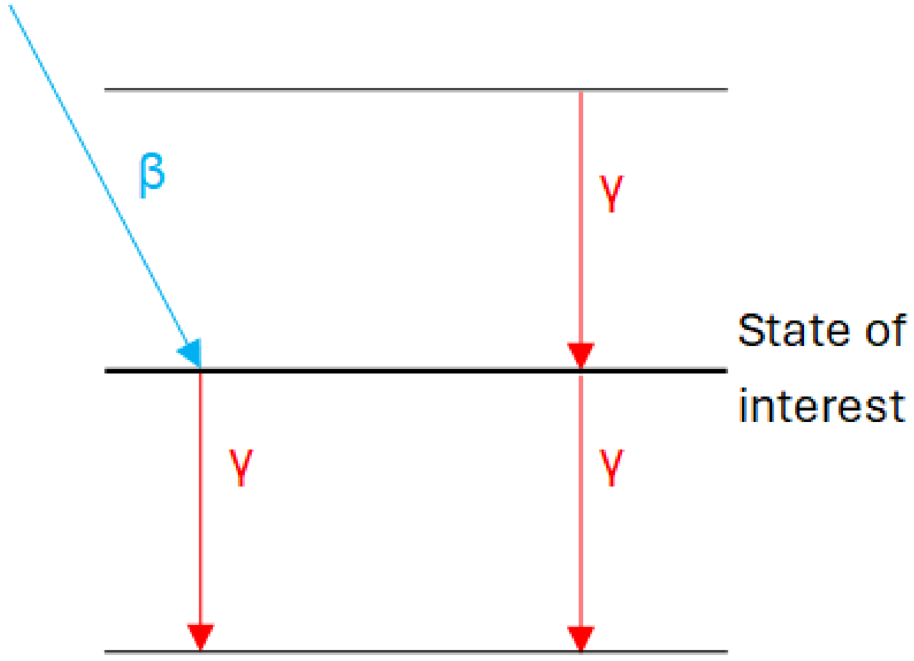
- Measuring the lifetime of excited states within the nucleus

- “short” lifetime < 100ps

- **“long” lifetime > 100ps**

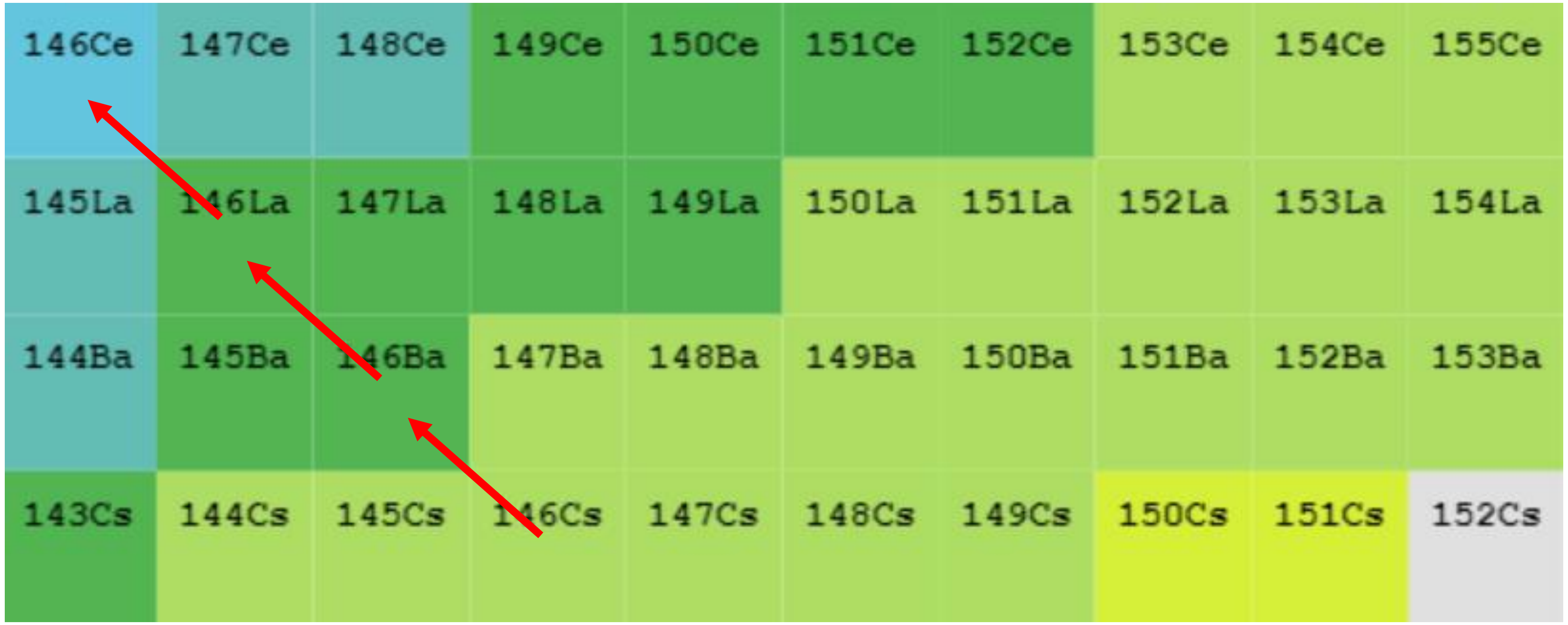
What is the fast-timing technique?

- Detection of **γ-rays** emitted after transitions in the nucleus
- Can also use **electrons** emitted in β^- decay
- Requires **γ-γ** or **β-γ** coincidences



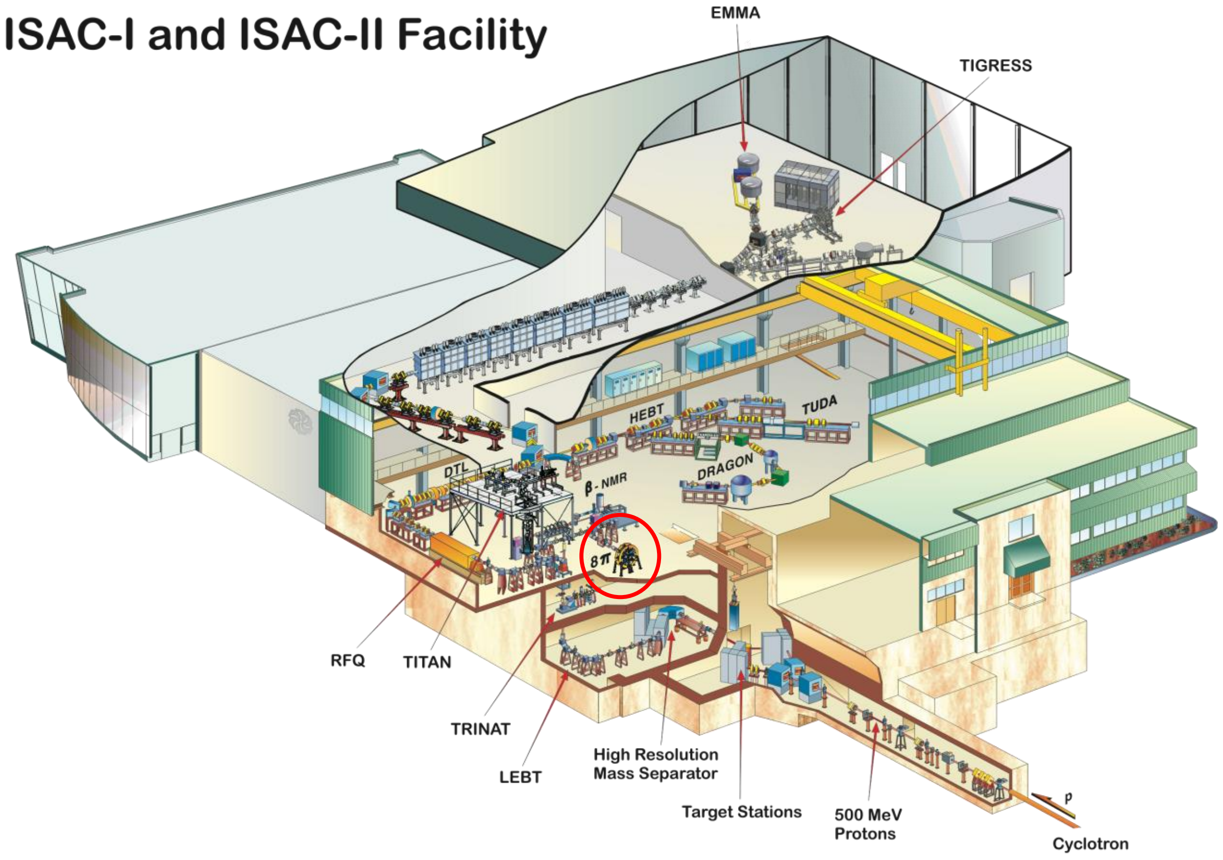
The Decay Chain

$$^{146}\mathrm{Cs} \rightarrow {}^{146}\mathrm{Ba} \rightarrow {}^{146}\mathrm{La} \rightarrow {}^{146}\mathrm{Ce}$$



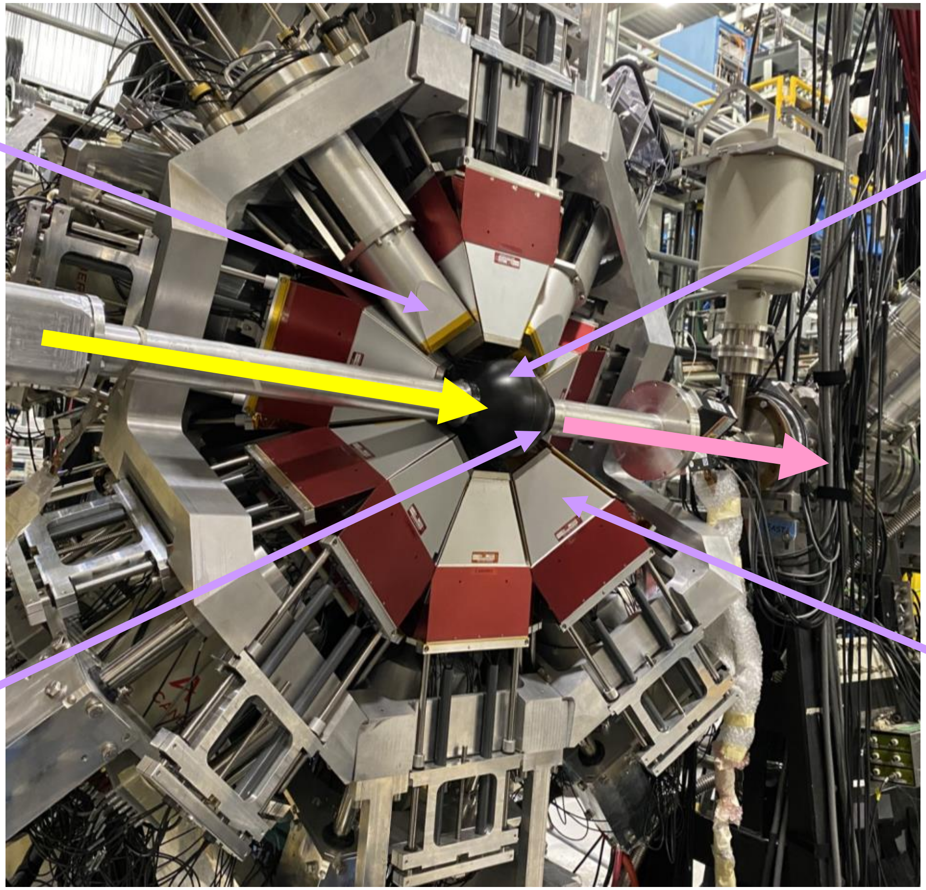
146Ce	147Ce	148Ce	149Ce	150Ce	151Ce	152Ce	153Ce	154Ce	155Ce
145La	146La	147La	148La	149La	150La	151La	152La	153La	154La
144Ba	145Ba	146Ba	147Ba	148Ba	149Ba	150Ba	151Ba	152Ba	153Ba
143Cs	144Cs	145Cs	146Cs	147Cs	148Cs	149Cs	150Cs	151Cs	152Cs

TRIUMF



ISAC-I and ISAC-II Facility
EMMA
TIGRESS
HEBT
TUDA
DTL
β - NMR
DRAGON
8π
RFQ
TITAN
TRINAT
LEBT
High Resolution
Mass Separator
Target Stations
500 MeV
Protons
p
Cyclotron

GRIFFIN Spectrometer



Unstable Cs beam hits target…

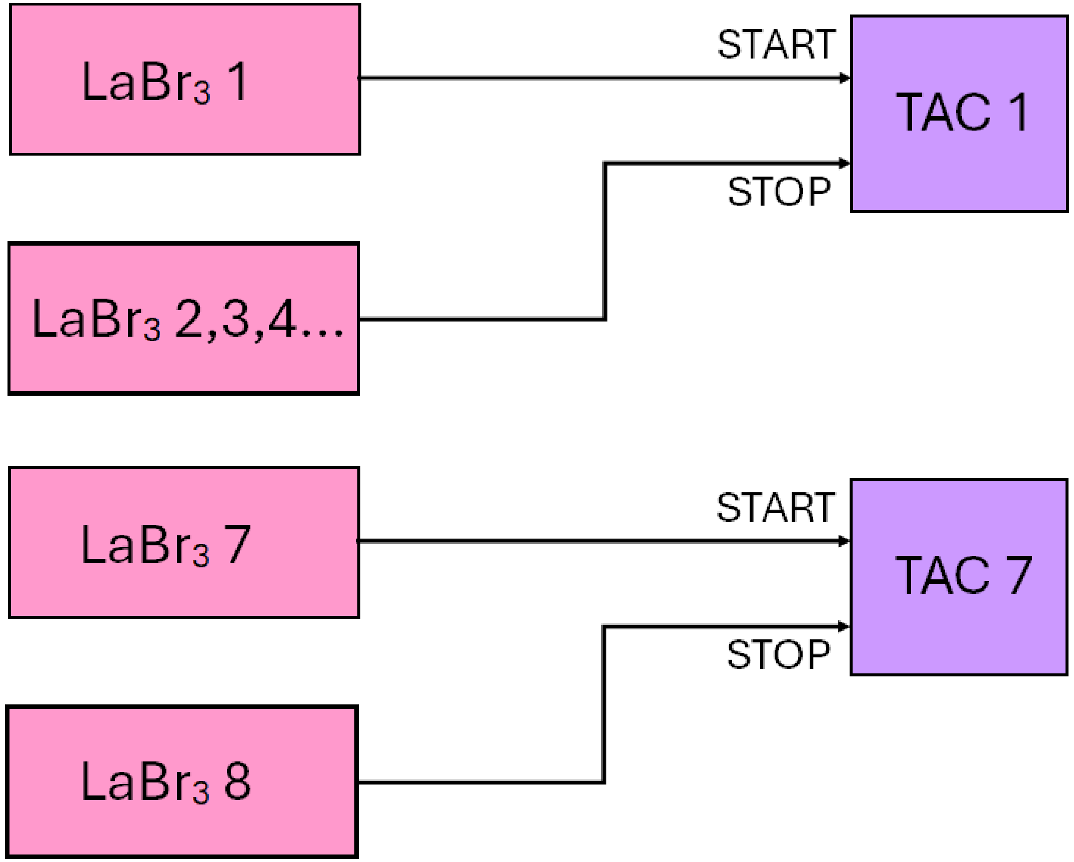
…tape removes material

Time to Amplitude Converters (TACs)

- Each $LaBr_3$ detector is connected to the **START** and **STOP** inputs of corresponding TACs

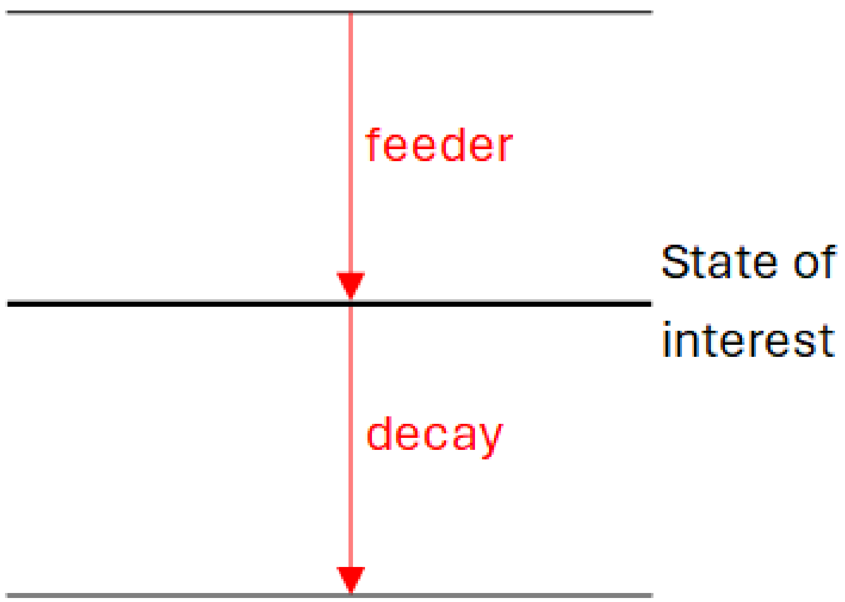
- STOP signal has a set **delay**

- There are 7 TACs in total (+1 for the ZDS)

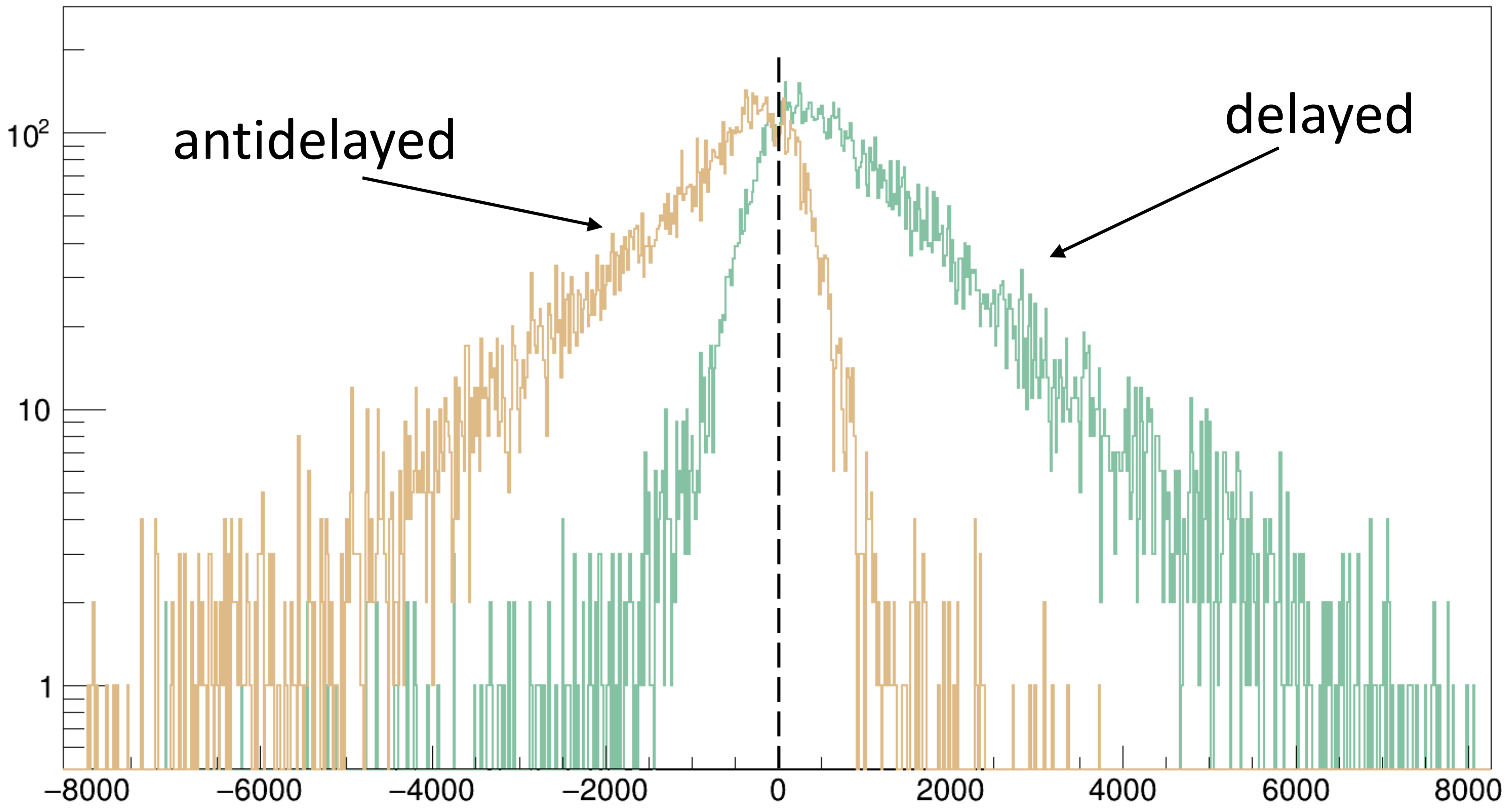


Delayed/Antidelayed

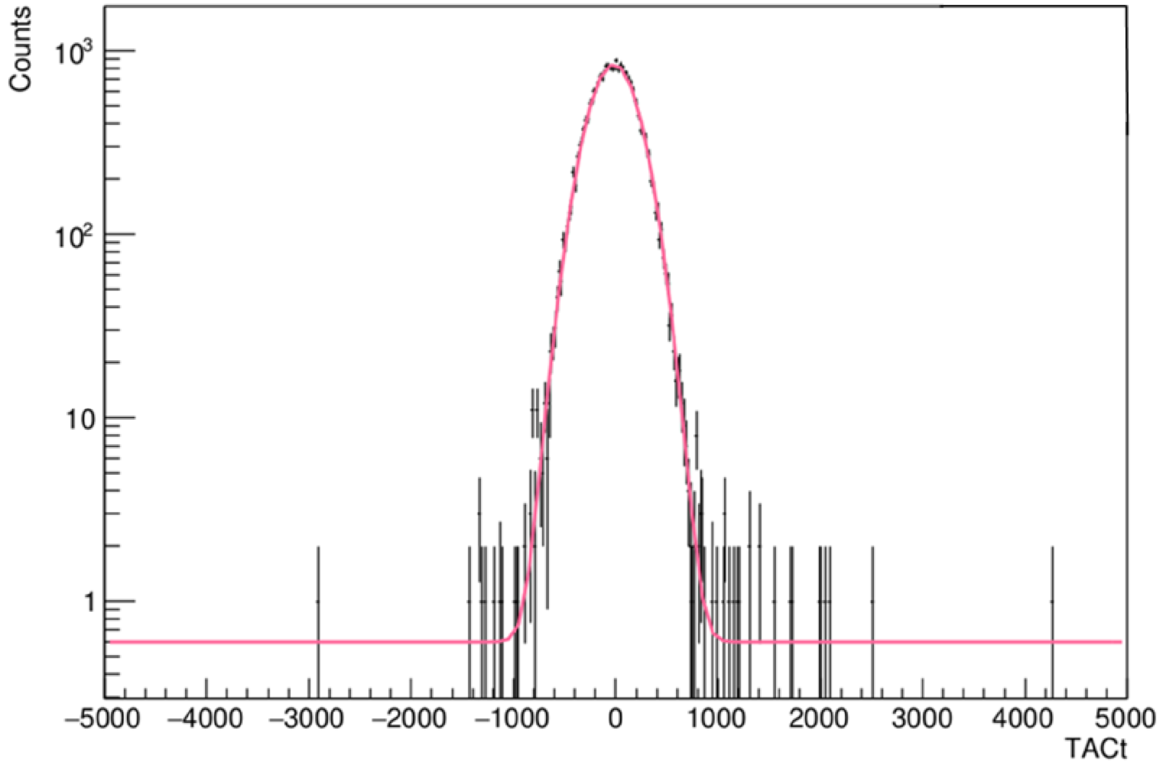
- TAC signal is produced using **START** and **STOP**
- If feeder is detected before decay, configuration is **delayed**
- If decay is detected before feeder, configuration is **antidelayed**



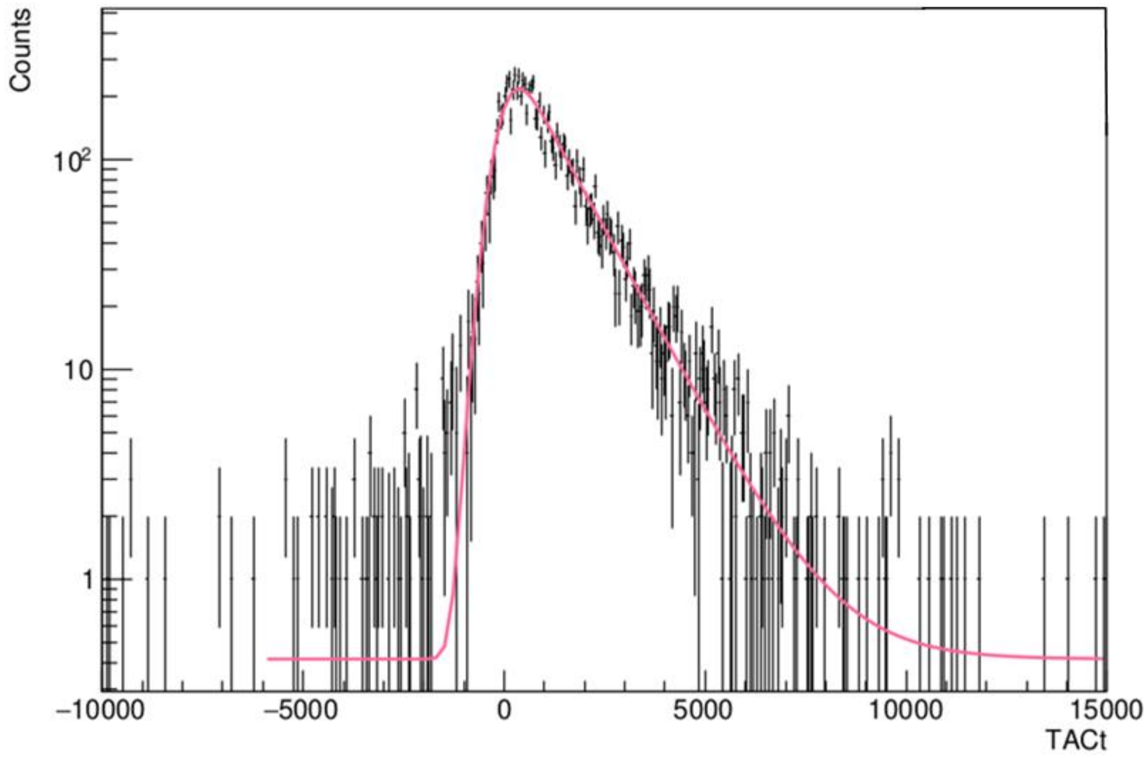
Delayed/Antidelayed



What is a convoluted gaussian?

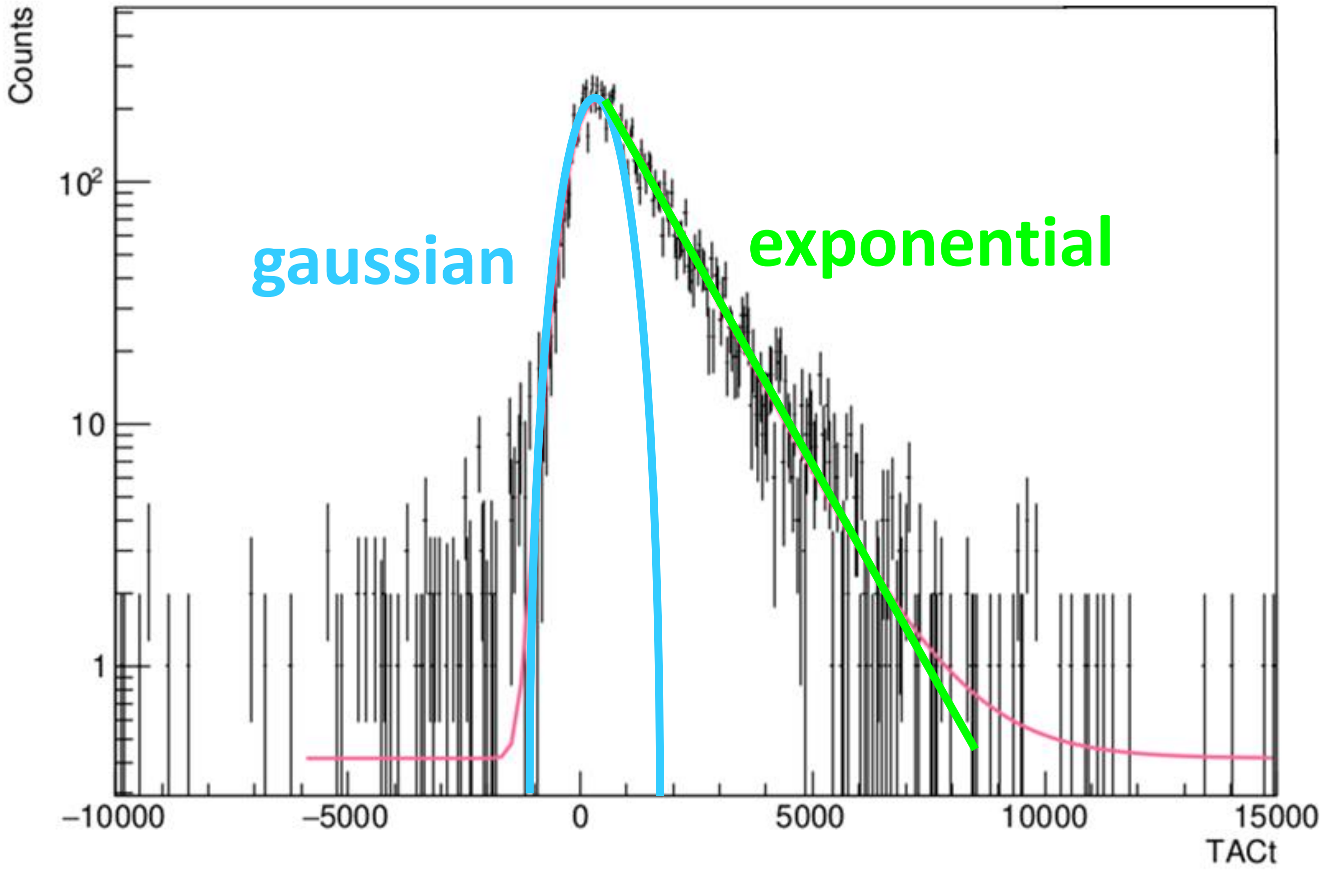


gaussian



gaussian + exponential

What is a convoluted gaussian?



decay constant

γ-ray energy

$$\sqrt{\pi} n \frac{\lambda}{2} \exp\left\{ \frac{\lambda}{2}(2C + \lambda\sigma^2 - 2E \frac{C + \lambda\sigma^2 - E}{\sqrt{2}\sigma} \right\} + bg$$

centroid

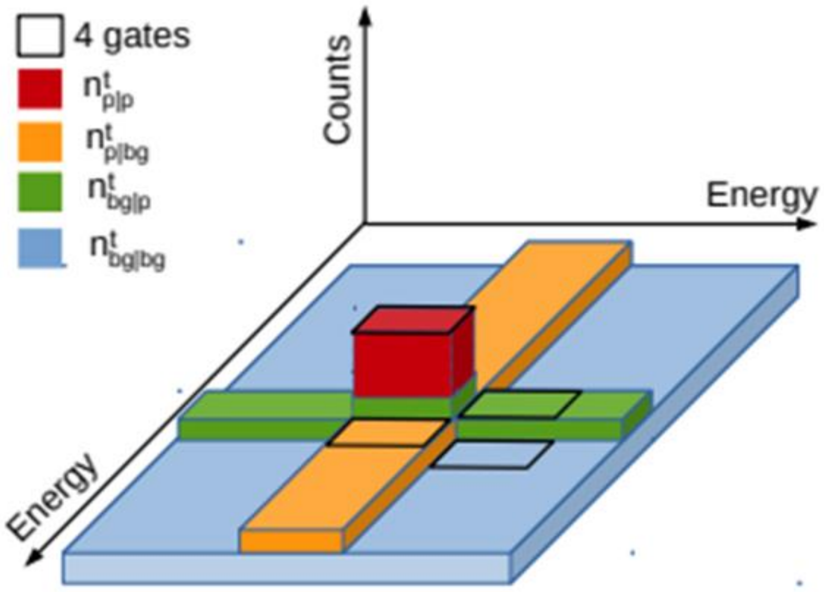
background count

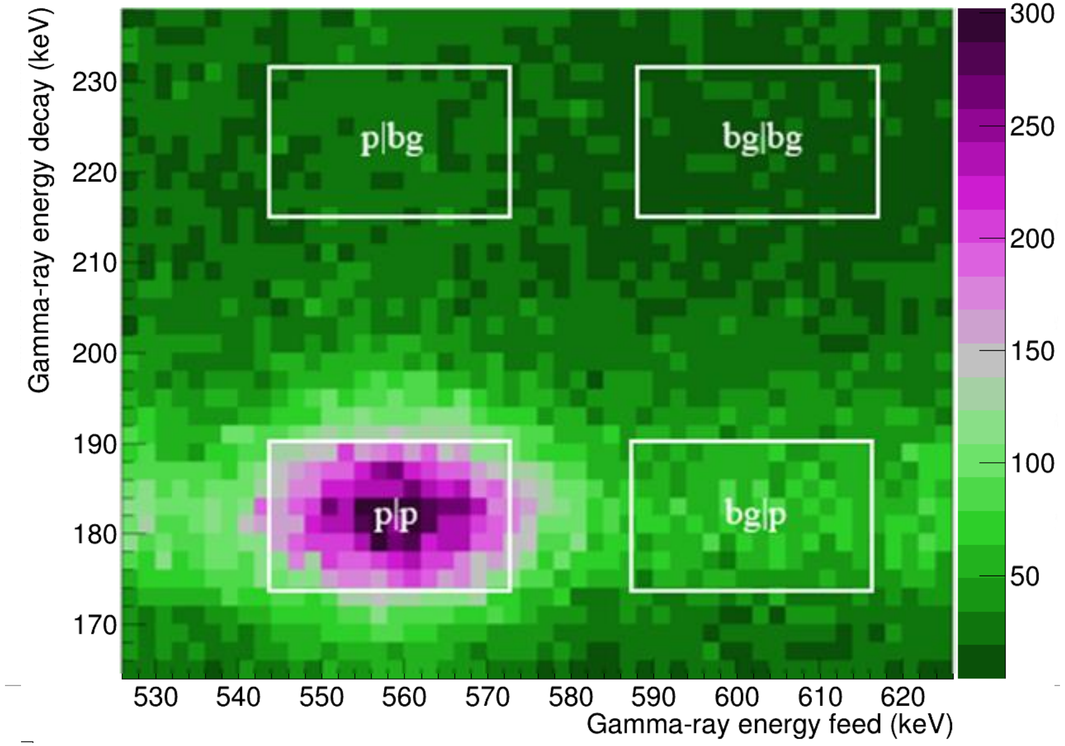
Fitting

- Fitting model is a convoluted gaussian
- Apply energy gating on $LaBr_3$ detectors
- Least-squares minimisation fitting routine
- $t_{1/2}$ can be calculated directly from λ

Background Subtraction

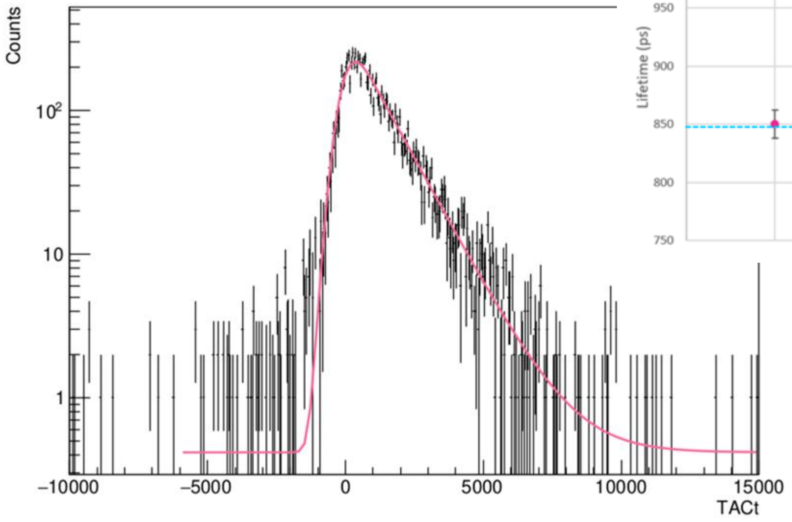
$$p|p_{total} = p|p - p|bg - bg|p + bg|bg$$

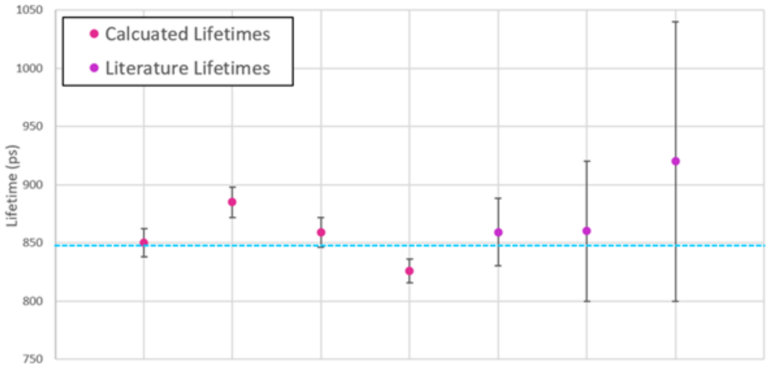


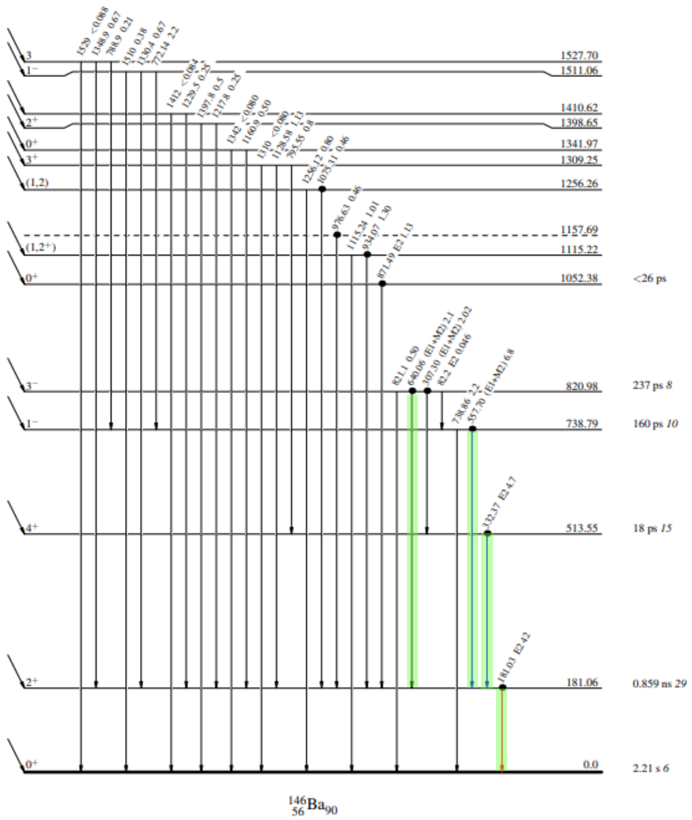


Results so far: 2^+ in ^{146}Ba

- Accepted $t_{1/2}$ = 859(29) ps
- Measured $t_{1/2}$ = **848(6) ps**

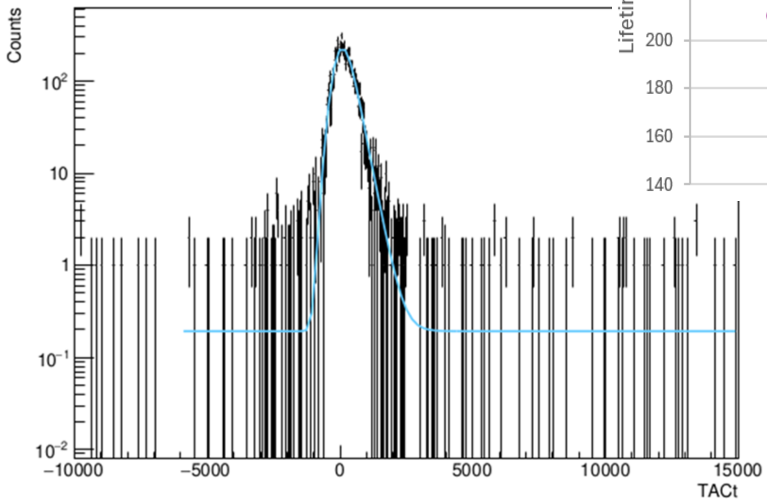


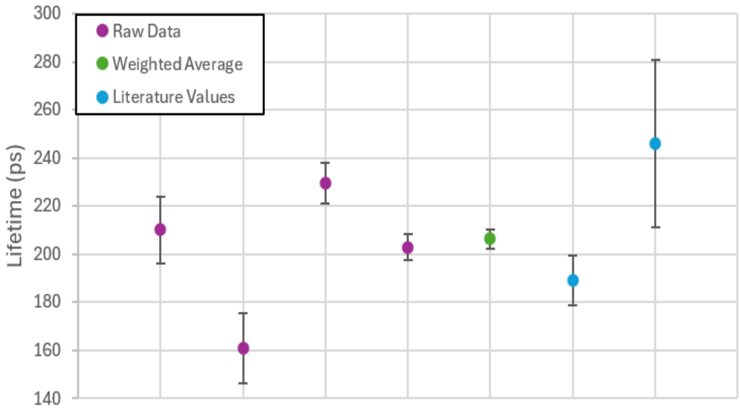


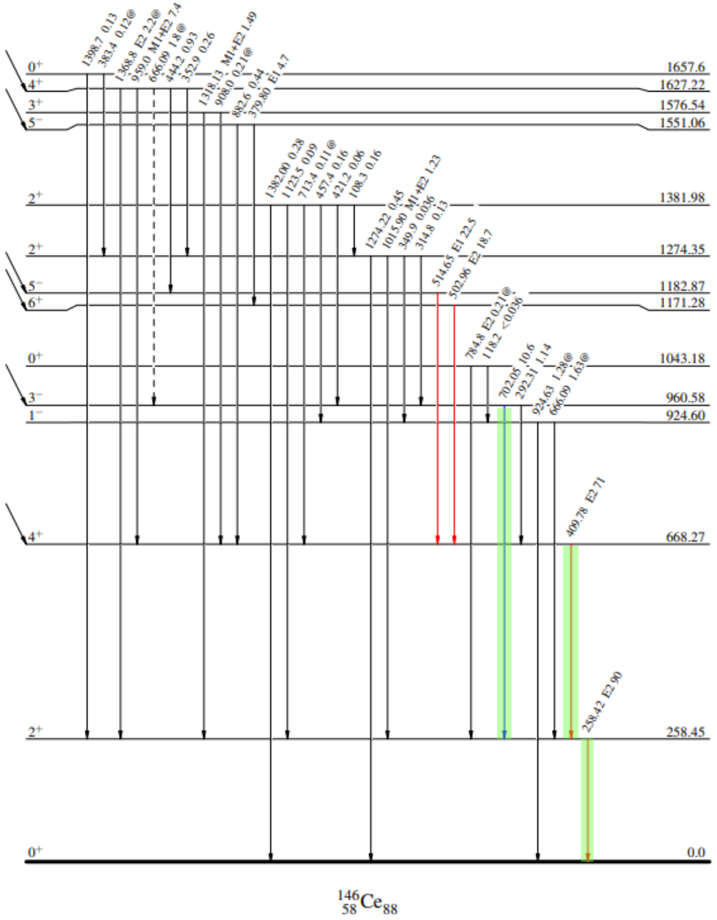


Results so far: 2^+ in ^{146}Ce

- Accepted $t_{1/2}$ = 189(15) ps
- Measured $t_{1/2}$ = **206(4) ps**







Context

PHYSICAL REVIEW C **104**, 044324 (2021)

Evolution of octupole deformation and collectivity in neutron-rich lanthanides

K. Nomura[1,*] R. Rodríguez-Guzmán[2] L. M. Robledo[3,4] J. E. García-Ramos[5,6] and N. C. Hernández[7]
[1]Department of Physics, Faculty of Science, University of Zagreb, HR-10000 Zagreb, Croatia
[2]Physics Department, Kuwait University, 13060 Kuwait, Kuwait
[3]Departamento de Física Teórica and CIAFF, Universidad Autónoma de Madrid, E-28049 Madrid, Spain
[4]Center for Computational Simulation, Universidad Politécnica de Madrid, Campus de Montegancedo, Bohadilla del Monte, E-28660-Madrid, Spain
[5]Departamento de Ciencias Integradas y Centro de Estudios Avanzados en Física, Matemática y Computación, Universidad de Huelva, E-21071 Huelva, Spain
[6]Instituto Carlos I de Física Teórica y Computacional, Universidad de Granada, Fuentenueva s/n, 18071 Granada, Spain
[7]Departamento de Física Aplicada I, Escuela Politécnica Superior, Universidad de Sevilla, E-41011 Seville, Spain

(Received 7 June 2021; accepted 4 October 2021; published 21 October 2021)

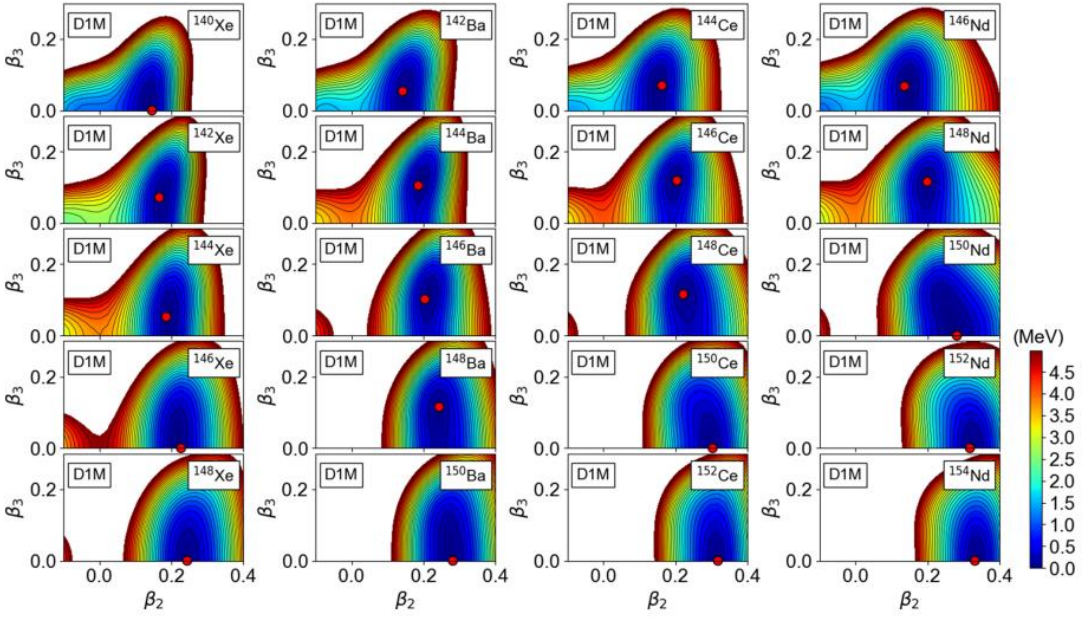


FIG. 1. The SCMF-PESs obtained for $^{140-148}$Xe, $^{142-150}$Ba, $^{144-152}$Ce, and $^{146-154}$Nd are plotted as functions of the quadrupole β_2 and octupole β_3 deformation parameters. The color code indicates the total HFB energies (in MeV) plotted up to 5 MeV with respect to the global minimum. The energy difference between neighboring contours is 0.2 MeV. For each nucleus, the global minimum is indicated by a red solid circle. Results have been obtained with the Gogny-D1M EDF.

Context

Nuclear Instruments and Methods in Physics Research A280 (1989) 49–72 49
North-Holland, Amsterdam

A METHOD FOR PICOSECOND LIFETIME MEASUREMENTS FOR NEUTRON-RICH NUCLEI (1) Outline of the method

H. MACH [1,2)]*, R.L. GILL [2)] and M. MOSZYŃSKI [2,3)]
[1)] *Clark University, Worcester, MA 01610, USA*
[2)] *Brookhaven National Laboratory, Upton, NY 11973, USA*
[3)] *Institute for Nuclear Studies, PL 05-400, Świerk-Otwock, Poland*

Received 6 March 1989

Nuclear Inst. and Methods in Physics Research, A 1052 (2023) 168279
Contents lists available at ScienceDirect
Nuclear Inst. and Methods in Physics Research, A
journal homepage: www.elsevier.com/locate/nima

Full Length Article

Improving fast-timing time-walk calibration standards: Lifetime measurement of the 2_1^+ state in ^{152}Gd

L. Knafla *, A. Harter, M. Ley, A. Esmaylzadeh, J.-M. Régis, D. Bittner, A. Blazhev, F. von Spee, J. Jolie
Universität zu Köln, Institut für Kernphysik, Zülpicher Str. 77, 50937 Köln, Germany

PRL **118**, 152504 (2017) PHYSICAL REVIEW LETTERS week ending 14 APRIL 2017

Direct Evidence for Octupole Deformation in ^{146}Ba and the Origin of Large $E1$ Moment Variations in Reflection-Asymmetric Nuclei

B. Bucher,[1,2,*] S. Zhu,[3,†] C. Y. Wu,[1] R. V. F. Janssens,[3] R. N. Bernard,[4] L. M. Robledo,[4] T. R. Rodríguez,[4] D. Cline,[5] A. B. Hayes,[5] A. D. Ayangeakaa,[3] M. Q. Buckner,[1] C. M. Campbell,[6] M. P. Carpenter,[3] J. A. Clark,[3] H. L. Crawford,[6] H. M. David,[3,‡] C. Dickerson,[3] J. Harker,[3,7] C. R. Hoffman,[3] B. P. Kay,[3] F. G. Kondev,[3] T. Lauritsen,[3] A. O. Macchiavelli,[6] R. C. Pardo,[3] G. Savard,[3] D. Seweryniak,[3] and R. Vondrasek[3]
[1]*Lawrence Livermore National Laboratory, Livermore, California 94550, USA*
[2]*Idaho National Laboratory, Idaho Falls, Idaho 83415, USA*
[3]*Argonne National Laboratory, Argonne, Illinois 60439, USA*
[4]*Departamento de Física Teórica, Universidad Autónoma de Madrid, E-28049 Madrid, Spain*
[5]*University of Rochester, Rochester, New York 14627, USA*
[6]*Lawrence Berkeley National Laboratory, Berkeley, California 94720, USA*
[7]*University of Maryland, College Park, Maryland 20742, USA*
(Received 13 January 2017; published 12 April 2017)

PRL **116**, 112503 (2016) PHYSICAL REVIEW LETTERS week ending 18 MARCH 2016

Direct Evidence of Octupole Deformation in Neutron-Rich ^{144}Ba

B. Bucher,[1,*] S. Zhu,[2] C. Y. Wu,[1] R. V. F. Janssens,[2] D. Cline,[3] A. B. Hayes,[3] M. Albers,[2] A. D. Ayangeakaa,[2] P. A. Butler,[4] C. M. Campbell,[5] M. P. Carpenter,[2] C. J. Chiara,[2,6,†] J. A. Clark,[2] H. L. Crawford,[7,‡] M. Cromaz,[5] H. M. David,[2,§] C. Dickerson,[2] E. T. Gregor,[8,9] J. Harker,[2,6] C. R. Hoffman,[2] B. P. Kay,[2] F. G. Kondev,[2] A. Korichi,[2,10] T. Lauritsen,[2] A. O. Macchiavelli,[5] R. C. Pardo,[2] A. Richard,[7] M. A. Riley,[11] G. Savard,[2] M. Scheck,[8,9] D. Seweryniak,[2] M. K. Smith,[12] R. Vondrasek,[2] and A. Wiens[5]
[1]*Lawrence Livermore National Laboratory, Livermore, California 94550, USA*
[2]*Argonne National Laboratory, Argonne, Illinois 60439, USA*
[3]*University of Rochester, Rochester, New York 14627, USA*
[4]*University of Liverpool, Liverpool L69 7ZE, United Kingdom*
[5]*Lawrence Berkeley National Laboratory, Berkeley, California 94720, USA*
[6]*University of Maryland, College Park, Maryland 20742, USA*
[7]*Ohio University, Athens, Ohio 45701, USA*
[8]*University of the West of Scotland, Paisley PA1 2BE, United Kingdom*
[9]*SUPA, Scottish Universities Physics Alliance, Glasgow G12 8QQ, United Kingdom*
[10]*CSNSM, IN2P3-CNRS, bâtiment 104-108, F-91405 Orsay Campus, France*
[11]*Florida State University, Tallahassee, Florida 32306, USA*
[12]*University of Notre Dame, Notre Dame, Indiana 46556, USA*
(Received 5 October 2015; revised manuscript received 18 December 2015; published 17 March 2016)

PRL **118**, 152504 (2017) PHYSICAL REVIEW LETTERS week ending 14 APRIL 2017

Direct Evidence for Octupole Deformation in ^{146}Ba and the Origin of Large $E1$ Moment Variations in Reflection-Asymmetric Nuclei

B. Bucher,[1,2,*] S. Zhu,[3,†] C. Y. Wu,[1] R. V. F. Janssens,[3] R. N. Bernard,[4] L. M. Robledo,[4] T. R. Rodríguez,[4] D. Cline,[5] A. B. Hayes,[5] A. D. Ayangeakaa,[3] M. Q. Buckner,[1] C. M. Campbell,[6] M. P. Carpenter,[3] J. A. Clark,[3] H. L. Crawford,[6] H. M. David,[3,‡] C. Dickerson,[3] J. Harker,[3,7] C. R. Hoffman,[3] B. P. Kay,[3] F. G. Kondev,[3] T. Lauritsen,[3] A. O. Macchiavelli,[6] R. C. Pardo,[3] G. Savard,[3] D. Seweryniak,[3] and R. Vondrasek[3]
[1]*Lawrence Livermore National Laboratory, Livermore, California 94550, USA*
[2]*Idaho National Laboratory, Idaho Falls, Idaho 83415, USA*
[3]*Argonne National Laboratory, Argonne, Illinois 60439, USA*
[4]*Departamento de Física Teórica, Universidad Autónoma de Madrid, E-28049 Madrid, Spain*
[5]*University of Rochester, Rochester, New York 14627, USA*
[6]*Lawrence Berkeley National Laboratory, Berkeley, California 94720, USA*
[7]*University of Maryland, College Park, Maryland 20742, USA*
(Received 13 January 2017; published 12 April 2017)

Despite the more than 1 order of magnitude difference between the measured dipole moments in ^{144}Ba and ^{146}Ba, the octupole correlations in ^{146}Ba are found to be as strong as those in ^{144}Ba with a similarly large value of $B(E3; 3^- \to 0^+)$ determined as $48(^{+21}_{-29})$ W.u. The new results not only establish unambiguously the presence of a region of octupole deformation centered on these neutron-rich Ba isotopes, but also manifest the dependence of the electric dipole moments on the occupancy of different neutron orbitals in nuclei with enhanced octupole strength, as revealed by fully microscopic calculations.

DOI: 10.1103/PhysRevLett.118.152504

^{145}Ba and ^{145,146}La structure from lifetime measurements

B. Olaizola,[1,*] A. Babu,[1] R. Umashankar,[1,2] A. B. Garnsworthy,[1] G. C. Ball,[1] V. Bildstein,[3] M. Bowry,[1,†] C. Burbadge,[3] R. Cabellero-Folch,[1] I. Dillmann,[1,4] A. Diaz-Varela,[3] R. Dunlop,[3] A. Estradé,[5] P. E. Garrett,[3] G. Hackman,[1] A. D. MacLean,[3] J. Measures,[1,6] C. J. Pearson,[1] B. Shaw,[1] D. Southall,[1,‡] C. E. Svensson,[3] J. Turko,[3] K. Whitmore,[7] and T. Zidar[3]
[1]*TRIUMF, 4004 Wesbrook Mall, Vancouver, British Columbia V6T 2A3, Canada*
[2]*Department of Physics and Astronomy, University of British Columbia, Vancouver, British Columbia V6T 1Z4, Canada*
[3]*Department of Physics, University of Guelph, Guelph, Ontario N1G 2W1, Canada*
[4]*Department of Physics and Astronomy, University of Victoria, Victoria, British Columbia V8P 5C2, Canada*
[5]*Department of Physics, Central Michigan University, Mount Pleasant, Michigan 48859, USA*
[6]*Department of Physics, University of Surrey, Guildford, Surrey GU2 7XH, United Kingdom*
[7]*Department of Chemistry, Simon Fraser University, Burnaby, British Columbia V5A 1S6, Canada*

(Received 11 February 2021; revised 15 March 2021; accepted 10 August 2021; published 9 September 2021)

The occurrence of octupole shapes in even-mass neutron-rich Ba isotopes has been well established. However, the situation with the odd-mass Ba and odd or odd-odd La nuclei around them is not so clear. In order to shed light on these less-studied isotopes, a fast-timing experiment was performed using the GRIFFIN spectrometer at TRIUMF-ISAC. A wealth of excited-state lifetimes in the 100 ps to few ns range have been measured in ^{144,145,146}Ba and ^{145,146}La populated in the β^- and β^--n decay of ^{145,146}Cs. The results do not allow one to draw firm conclusions about the possible octupole deformation of these nuclei but suggest different spin and parity assignments than previous works. This work highlights the need for more detailed study of the odd and odd-odd isotopes in this region to properly understand their structure.

DOI: 10.1103/PhysRevC.104.034307