

Decay Spectroscopy of ^{161}Eu with the GRIFFIN Spectrometer



Canadian Association
of Physicists

Association canadienne
des physiciens et physiciennes

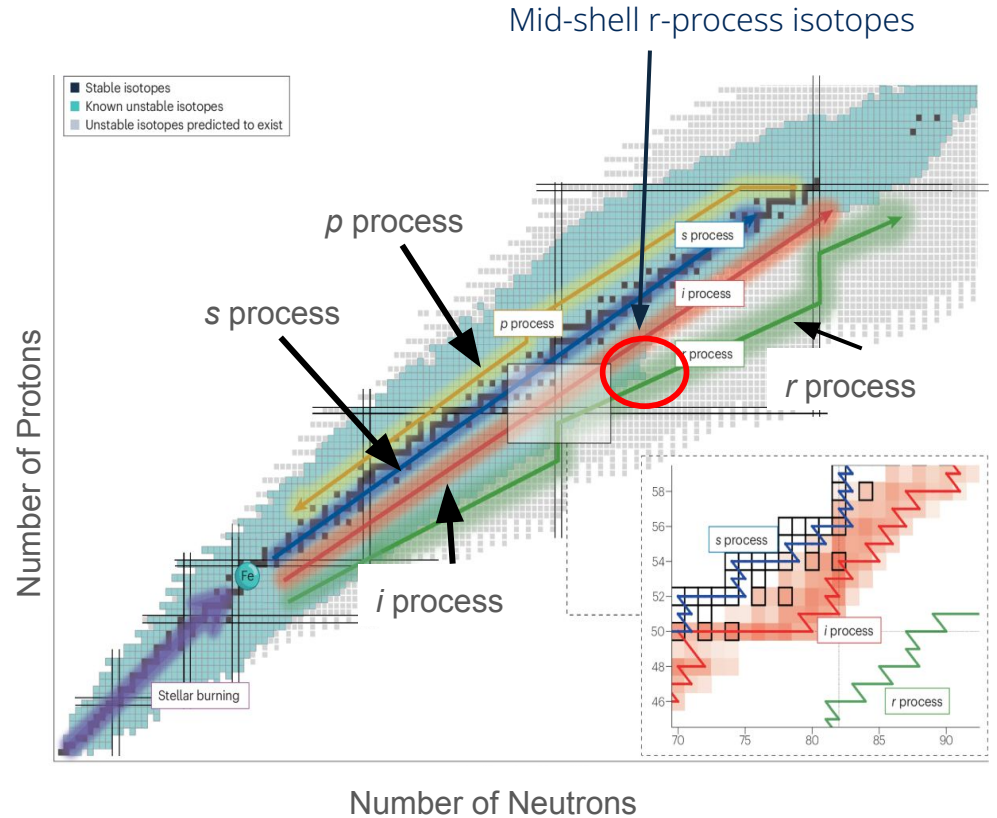
Jizhong Liu
PhD student



University
of Victoria

r-process

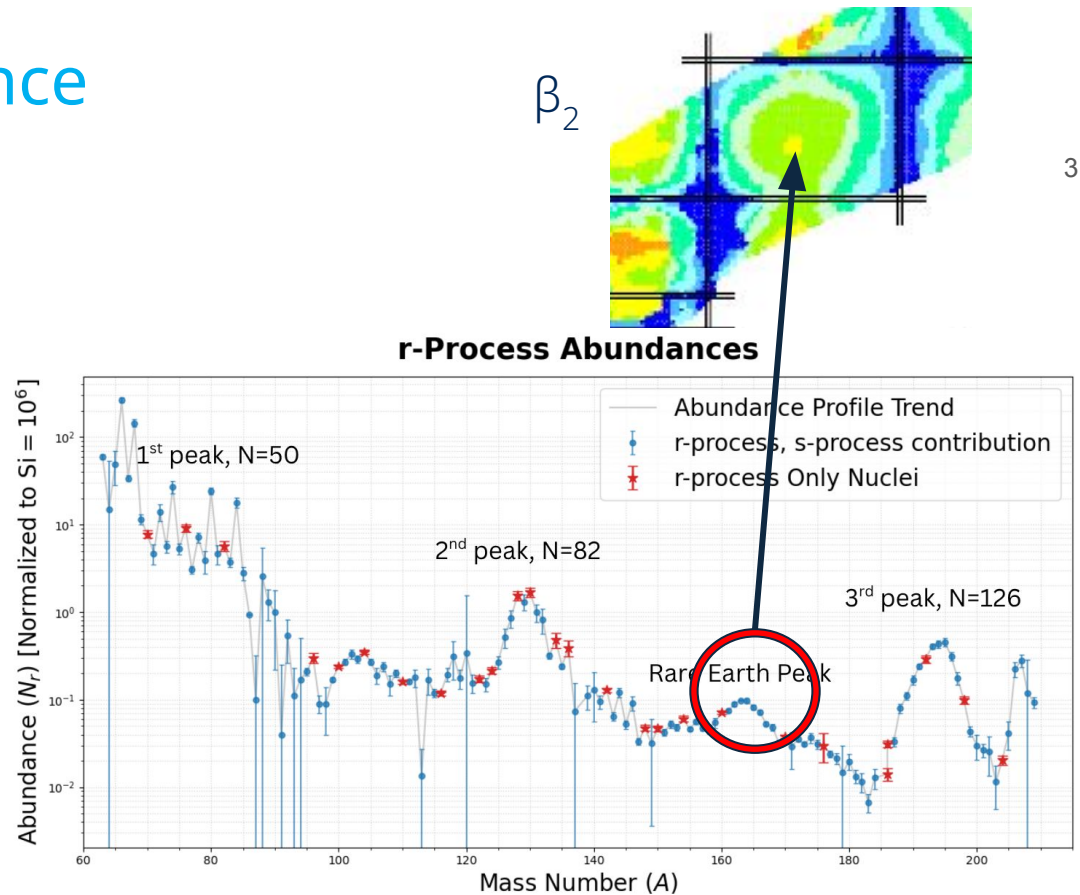
- Rapid neutron capture process
- Creates about 50% of the heavy nuclei
- Astrophysical environment with high neutron densities
- When neutron density and temperature drop, nuclei β -decay back to stability (Freeze-out)



Wiedeking, M., Goriely, S., Guttormsen, M. et al., Nat Rev Phys 7, 696–712 (2025).

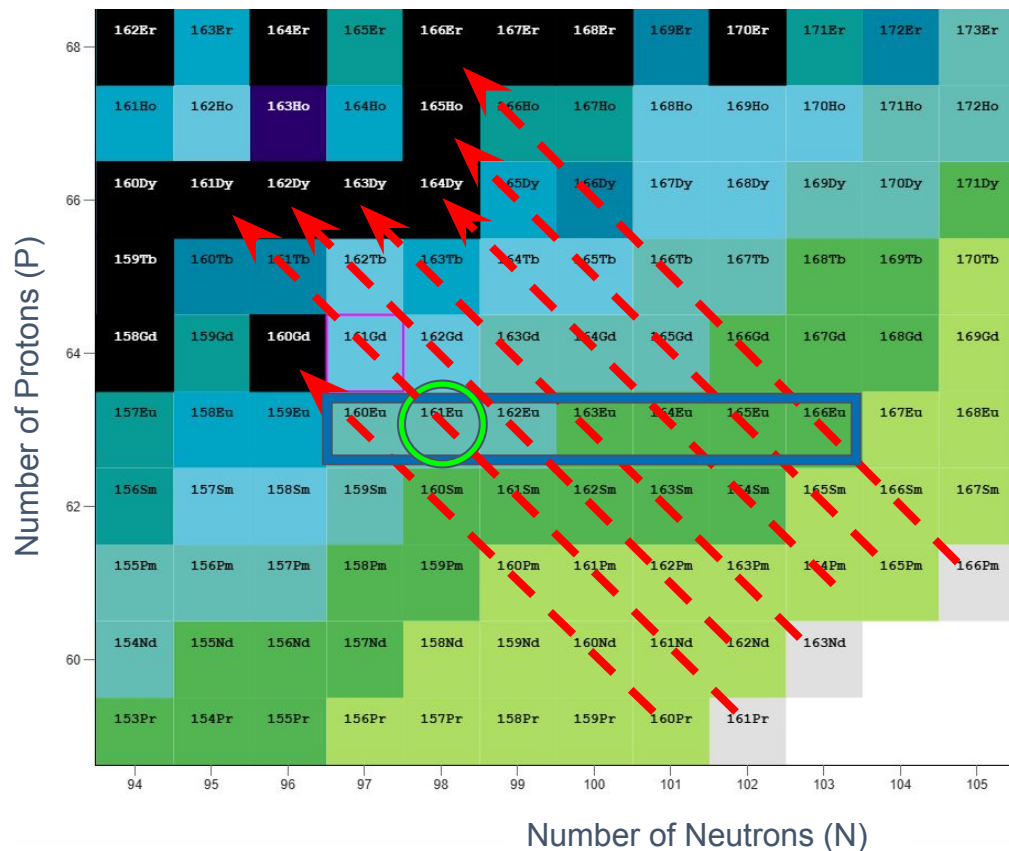
Solar *r*-process abundance

- Major peaks relate to major neutron shell closure around spherical nuclei
- Rare earth peak near mass 165 is connected to mid-shell nuclei
- Nuclei in this region have large quadrupole deformation
- Lack of knowledge in *r*-process nuclei in this region impacts the rare earth peak formation



Motivation

- Eu isotopes mass 160-166 lies on freeze out path
- Detailed studies of Gd isotopes at TRIUMF in 2017
- ^{160}Eu result published by D.Yates
- This work focus on ^{161}Eu
- 1000 pps
- Data taking time ~ 3.33 hours
- single particle and collective excitations
- Details in β -decay properties are important for modeling isotopes involved in r-process

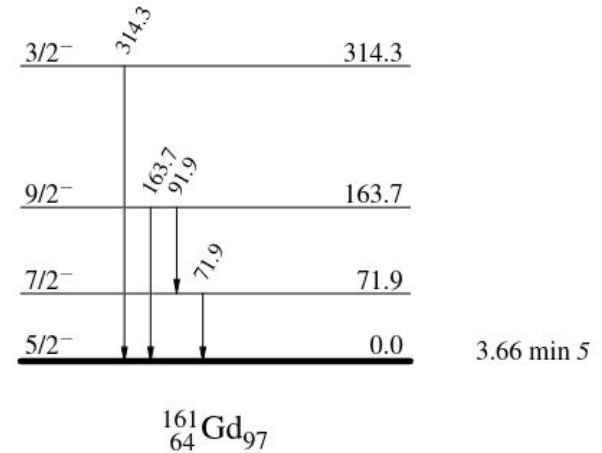
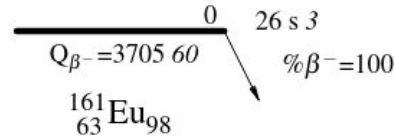


D.Yates, .et.al, Phys. Rev. C 107,
064309, (2023)

Previous Studies of ^{161}Eu and ^{161}Gd

- low-lying single-neutron states in ^{161}Gd have been probed via the $^{160}\text{Gd}(d,p)$ reaction, more states proposed
- excited states of ^{161}Gd via the neutron capture reaction provided very limited information on the γ -ray emissions
- Previous β -decay placed only four transitions in the decay scheme

P.O. Tjøm and B. Elbeck *Mat.-Fys.Medd.*36, No.8, 1967.



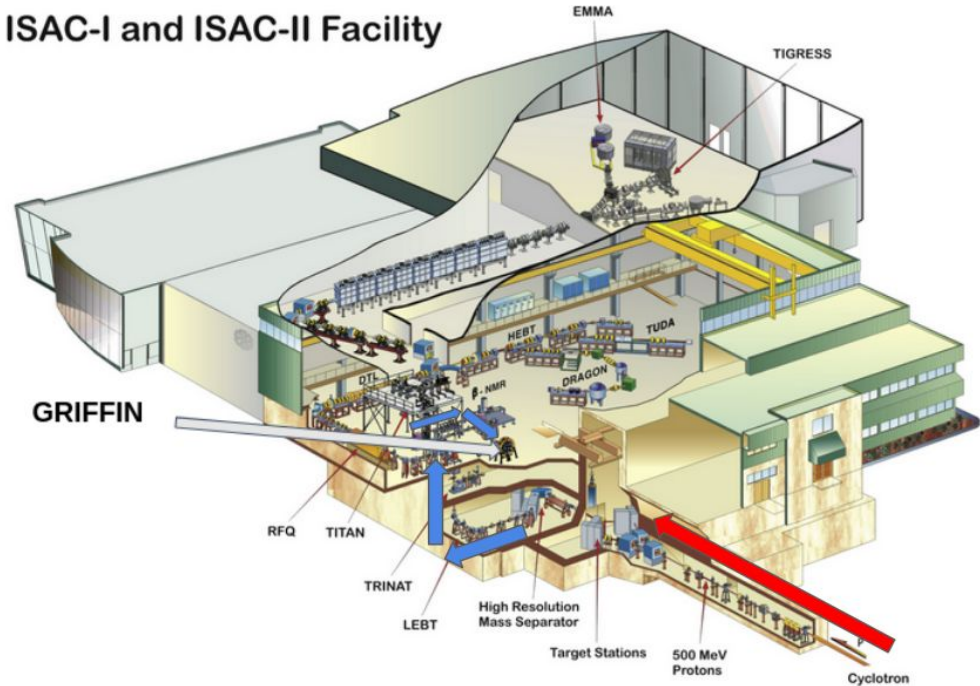
L.V.Groshev, A.M.Demidov, L.L.Sokolovskii *Ser.Fiz.* 35,1644, 1972.

H. Mach et al. *Phys. Rev. Lett.* 56,1547, 1986.

TRIUMF ISAC (Isotope Separator and ACcelerator)

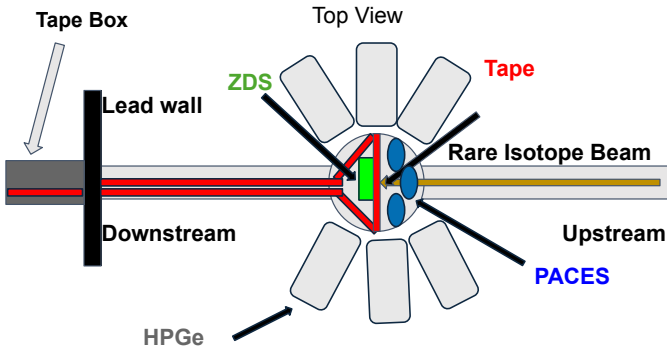
- Located in Vancouver B.C.
- Cyclotron accelerating H⁻ ion up to 520MeV
- Delivery of protons to ISAC target station
- production of isotopes
- High resolution mass separator and laser ionization
- High purity rare isotope beam delivery to GRIFFIN at ISAC 1

ISAC-I and ISAC-II Facility



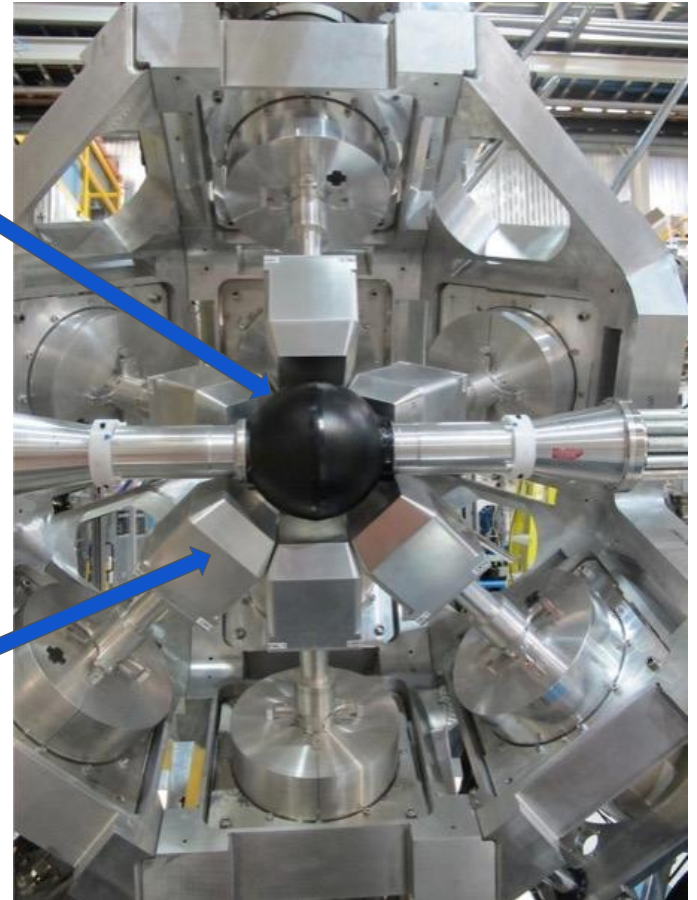
GRIFFIN (Gamma Ray Infrastructure For Fundamental Investigations of Nuclei)

- Nuclear structure studies through beta decay
- 16 clovers with each clover consists of 4 HPGe crystals
- Inside vacuum chamber, upstream using PACES (Pentagonal Array of Conversion Electron Spectrometers), downstream with ZDS (Zero Degree Scintillators) for β tagging



Vacuum Chamber

HPGe



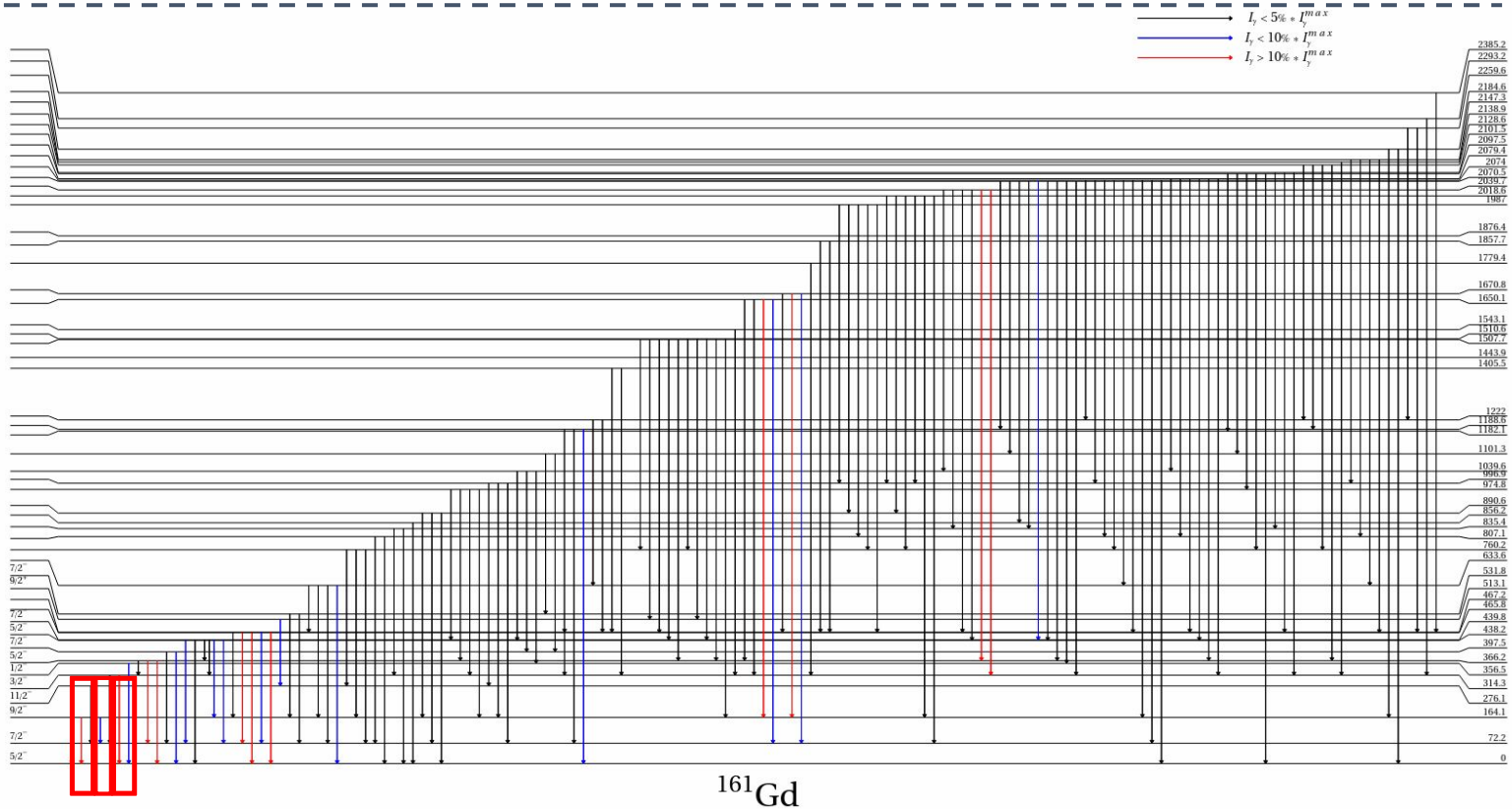
Full Decay Scheme

Previous 4 transitions
3 excited states

87 new gamma-ray transitions,
35 new excited states

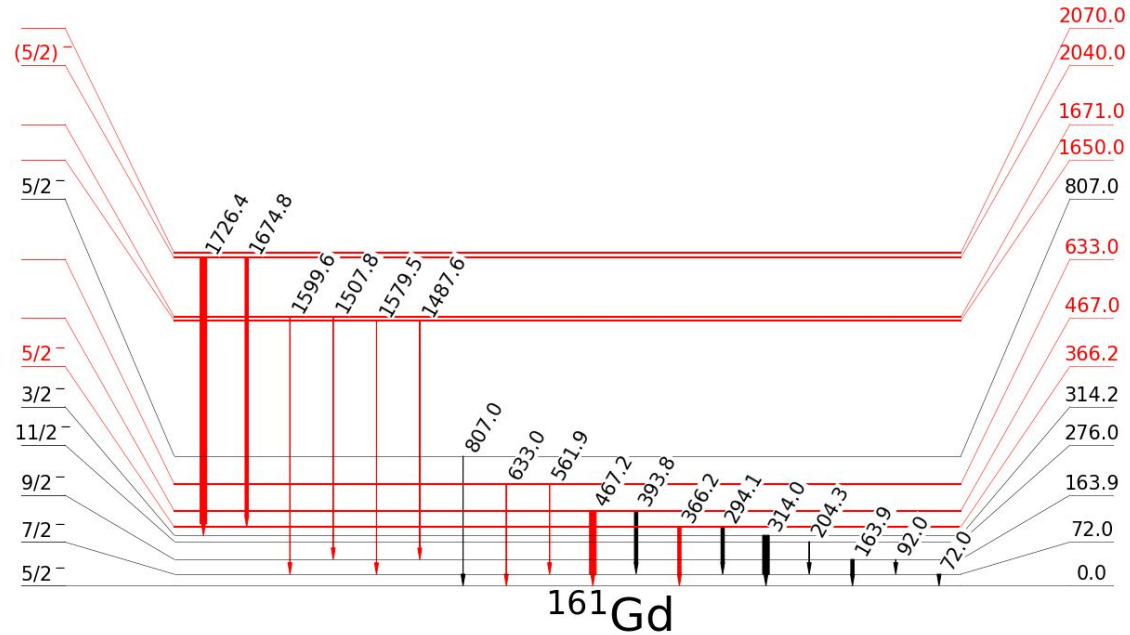
Lowest intensity observed 0.05% I_{max}

S_n 5635 keV



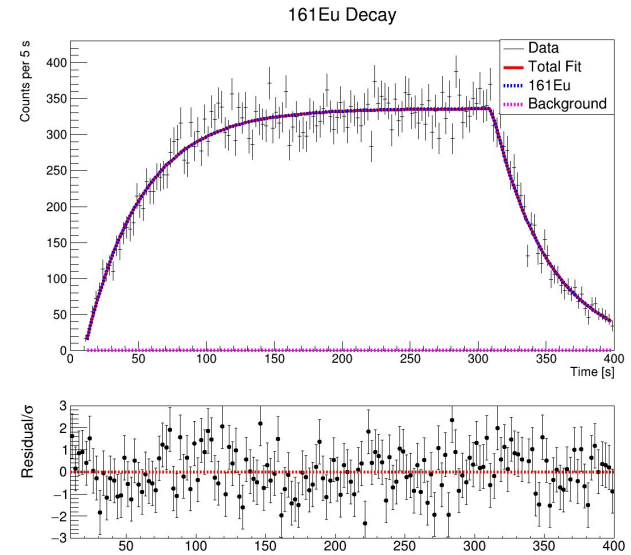
Partial Level Scheme

- 18 γ -ray transitions are selected as a demonstration
- Red indicates newly observed states and transitions
- Width represents intensity



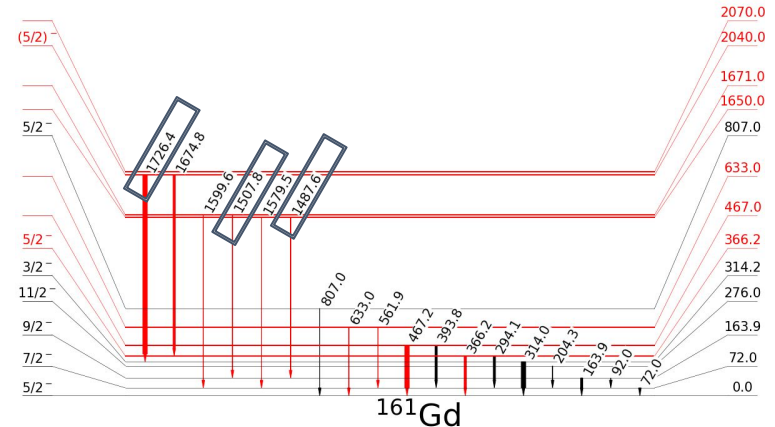
Half-life of Ground State ^{161}Eu

- Gated on pure ^{161}Gd transitions from ^{161}Eu β -decay
- High energy γ -rays at 1488 keV, 1508 keV, 1726 keV
- ^{161}Eu $T_{1/2} = 28.3$ (4) s (only statistical error, systematics uncertainty is in progress)
- Within uncertainty of NNDC adopted value of 26(2)s



10

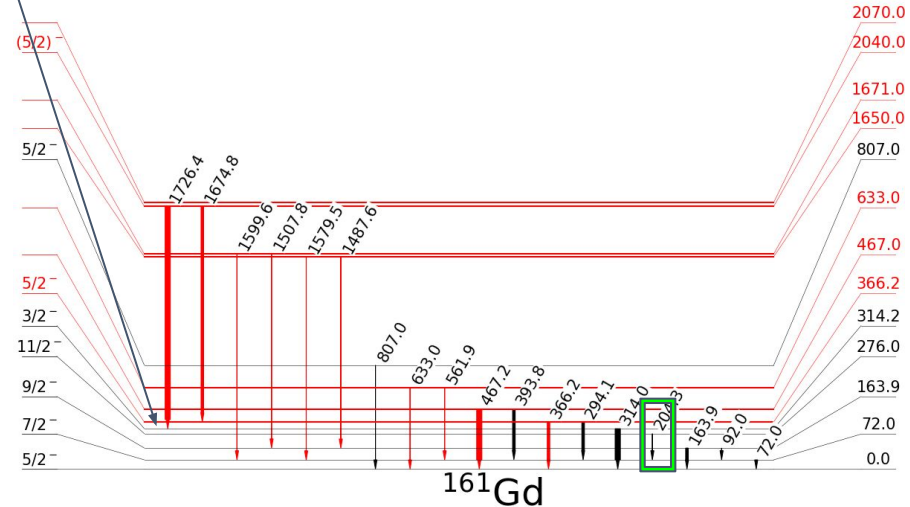
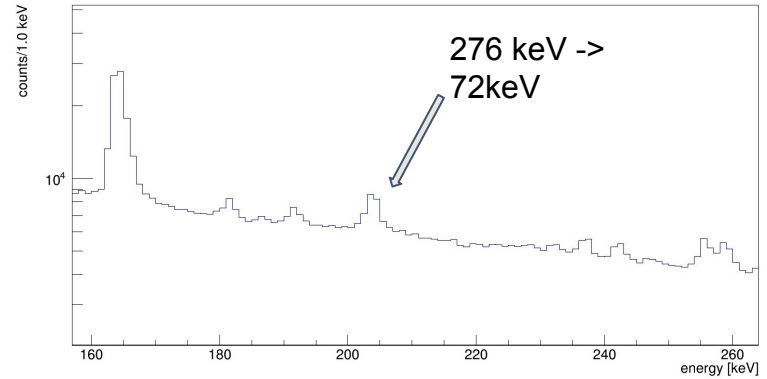
Ref	$T_{1/2}$ (s)
This work	28.3(4+systematics)
H. Mach et al. (1986)	27(3)
R. A. Anderl, R. C. Greenwood (1990)	24(4)
J.Wu., et al. (2017)	30.1(90)



Isomeric state of ^{161}Eu

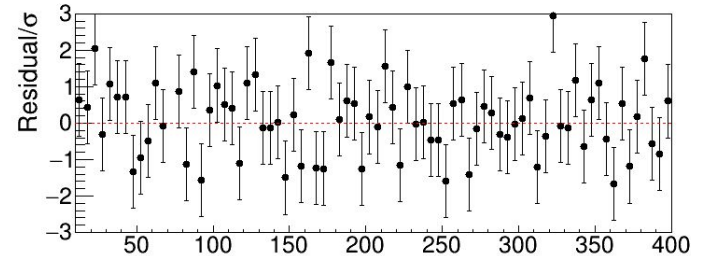
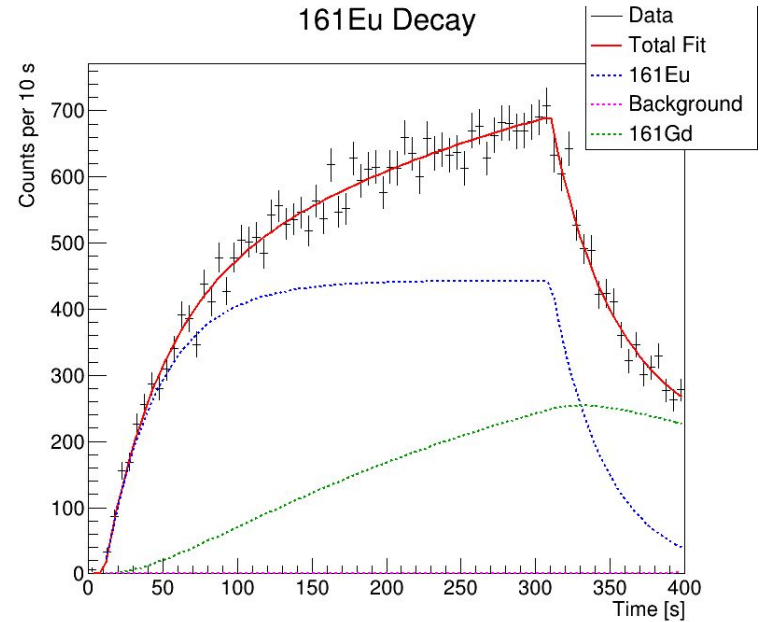
- High intensity of 204 keV gamma-ray observed
- Possible β -decay isomer in ^{161}Eu
- Third forbidden β -decay ($\text{LogFt} = 7.31(5)$) from ground state ^{161}Eu is very unlikely
- More likely to be allowed to first forbidden decay from a higher spin state in ^{161}Eu

^{161}Eu 0.0 (5/2⁺)



Half-life of High Spin Isomeric State ^{161}Eu

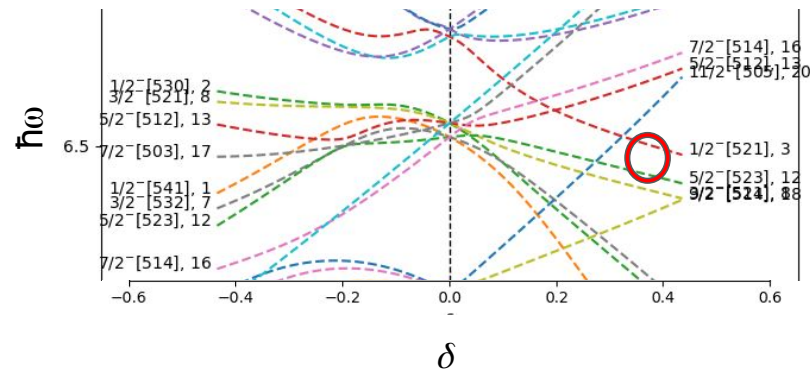
- Isomeric state of ^{161}Eu with potential spin parity assignment of $11/2^+$
- Activity gated on 204 keV transition
- Best fit isomer half-life of 25.4 (5+ systematics)s
- Ground state half-life 28.3 (4+systematics) s



Odd Mass Eu Isotopes Systematics

			25.4 s		
		(11/2 ⁺)	_____		
5/2 ⁺	18.1 min	(5/2 ⁺)	28.3 s	7.7s	2.25s
	0		0	0	0
	¹⁵⁹ Eu		¹⁶¹ Eu	¹⁶³ Eu	¹⁶⁵ Eu

- ¹⁶¹Eu is the only isotope that have been observed with an isomeric state among the odd mass Eu
- Propose configuration due to breaking pair of neutrons causing a three quasi-particle configuration with the single proton
- 3 quasi-particle configuration $\pi(5/2^+[413])\nu(1/2^-[521]5/2^-[523])$



Conclusion

- 87 new γ -ray transitions, constructed a level scheme comprising 35 new excited states
- Detailed structure of the excitations is under study
- High precision half-life measurements and new beta-decaying isomer found in ^{161}Eu , similar half-life

DECAY SPECTROSCOPY OF ^{161}Eu WITH THE GRIFFIN SPECTROMETER

J. Liu^{1,2}, I. Dillmann^{1,2}, A.B. Garnsworthy¹, P.E. Garrett⁵, F.A. Ali^{5,6}, C. Andreoiu^{1,7}, W. Ashfield⁸, G.C. Ball¹, Z. Beadle⁸, N. Bernier^{1,4}, S.S. Bhattacharjee¹, H. Bidaman⁵, V. Bildstein⁵, D. Bishop¹, M. Bowry¹, C. Burbadge⁵, R. Caballero-Folch¹, D.Z. Chaney⁹, D.S. Cross⁷, A. Diaz Varela⁵, M.R. Dunlop⁵, R. Dunlop⁵, L.J. Evitts^{1,10}, F.H. Garcia⁷, S. Georges¹, S.A. Gillespie¹, G. Hackman¹, J. Henderson¹, B. Jigmeddorj⁵, R. Krücken^{1,3,4}, J. Lassen^{1,11}, R. Li¹, B.K. Luna⁹, A.D. MacLean⁵, C.R. Natzke^{1,12}, B. Olaizola¹, C.M. Petrache^{7,13,17}, A.J. Radich⁵, M.M. Rajabali⁹, P.H. Regan^{14,15}, Y. Saito^{1,4}, J. Smallcombe¹, J.K. Smith⁸, D. Southall¹, M. Spieker¹⁶, C.E. Svensson⁵, A. Teigelhöfer^{1,11}, V. Vedia¹, K. Whitmore⁷, D. Yates^{1,4} and T. Zidar⁵

¹TRIUMF, Vancouver, B.C., V6T 2A3, Canada

²Dept. of Physics and Astronomy, University of Victoria, Victoria, B.C., V6T 1Z4, Canada

³Lawrence Berkeley National Laboratory, Berkeley, California 94720, U.S.A.

⁴Dept. of Physics and Astronomy, University of British Columbia, Vancouver, B.C., V6T 1Z4 Canada

⁵Dept. of Physics, University of Guelph, Guelph, Ontario N1G 2W1, Canada

⁶Dept. of Physics, College of Education, University of Sulaimani, Kurdistan Region, Iraq

⁷Dept. of Chemistry, Simon Fraser University, Burnaby, B.C., V5A 1S6, Canada

⁸Dept. of Physics, Reed College, Portland, Oregon 97202, U.S.A.

⁹Dept. of Physics, Tennessee Technological University, Cookeville, Tennessee 38505, U.S.A.

¹⁰Dept. of Physics, University of Surrey, Guildford GU2 7XH, U.K.

¹¹Dept. of Physics and Astronomy, University of Manitoba, Winnipeg, Manitoba R3T 2N2, Canada

¹²Dept. of Physics, Colorado School of Mines, Golden, Colorado 80401, U.S.A.

¹³University Paris-Saclay, CNRS/IN2P3, IJCLab, 91405 Orsay, France

¹⁴School of Mathematics and Physics, University of Surrey, Guildford, Surrey GU2 7XH, U.K.

¹⁵Marine, Medical and Nuclear Dept., National Physical Laboratory, Teddington TW11 0LW, U.K.

¹⁶Dept. of Physics, Florida State University, Tallahassee, FL 32306, U.S.A.

¹⁷Institute of Modern Physics, Chinese Academy of Sciences, Lanzhou 730000, China

Thank you Merci

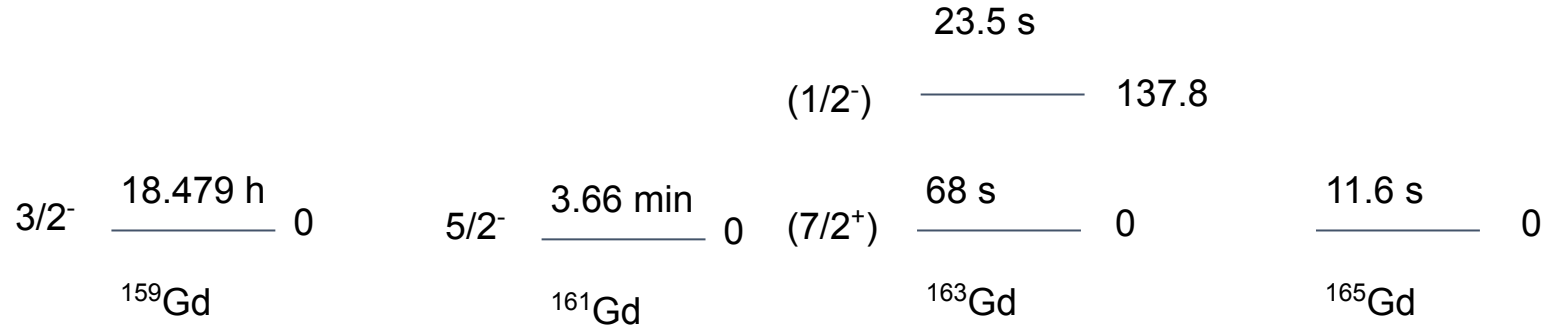


University of Victoria



TRIUMF is located on the traditional, ancestral, and unceded territory of the x̣ẉṃə̣θ̣ḳẉə̣ỵəṃ (Musqueam) People, who for millennia have passed on their culture, history, and traditions from one generation to the next on this site.

Systematics



- No observation of isomeric states in ¹⁶¹Gd