# Excited State Lifetime Studies in the N=100 Isotone <sup>166</sup>Dy using NUBALL

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### Overview

- Motivation behind the experiment
- Facility at IPN Orsay and the NuBALL spectrometer
- Performing the <sup>166</sup>Dy experiment
- Reaction channel selection
- Half-life measurements
- Future plans

# Motivation to measure $^{166}$ Dy T<sub>1/2</sub>(2<sup>+</sup>)

- <sup>170</sup>Dy is the valence maximum nucleus below <sup>208</sup>Pb
- Energy systematics suggest maximum quadrupole deformation at <sup>164</sup>Dy



Evaluated B(E2)↑ vs. N in the Z=66 Region



• <sup>164</sup>Dy is the most neutron-rich isotope with an established  $B(E2: 2^+ \rightarrow 0^+) = B(E2)\uparrow$ 

$$\begin{aligned} \tau &= 40.81 \times 10^{13} E_{\gamma}^{-5} |\mathsf{B}(\mathsf{E2})^{\uparrow}/e^2 b^2|^{-1} (1+\alpha)^{-1} \\ \beta_2 &\approx \beta_{eff} = (4\pi/3 Z R_0^2) [\mathsf{B}(\mathsf{E2})^{\uparrow}/e^2]^{1/2} \end{aligned}$$

Data from: B. Singh and B. Chen Nucl. Data Sheets 147, 1 (2018); C.M. Baglin Nucl. Data Sheets 109, 1103 (2008); H. Watanabe et. al. Phys. Lett. B 760, 641 (2016); B. Pritychenko et. al. Nucl. Phys. A 962, 73 (2017).

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# IPN Orsay and NuBALL







- 14.8 MV tandem accelerator
- Stable heavy-ion beams: pulsed or continuous
- Hybrid spectrometer: HPGe and LaBr detectors



# IPN Orsay and NuBALL

- 4 detector rings, 184 channels
- 20 LaBr detectors with 1.5x2 inch crystals, no passive shielding, at  $d_{centre} \ge 15.2$  cm
- 24 HPGe clover detectors, surrounded by BGO shielding, at d<sub>centre</sub> = 20.9 cm
- 10 HPGe coaxial detectors, surrounded by BGO shielding, at d<sub>centre</sub> = 18.0 cm
- Hybrid geometry for good energy and time resolution
- FASTER DAQ (fully digitized):
  - 125 MHz, 14 bit ADCs with trapezoid filter for HPGes and BGOs
  - o 500 MHz, 12 bit QDCs with internal pulse-shaping algorithm for LaBrs
- Data collected with a trigger or in triggerless mode



# Experimental Method

- Pulsed <sup>18</sup>O beam: 2 ns pulses, 400 ns period, ~35 enA, charge state 6<sup>+</sup>
- <sup>164</sup>Dy target: 95% purity, 6.3 mg/cm<sup>2</sup>
- Desired reaction: two-neutron transfer <sup>164</sup>Dy(<sup>18</sup>O,<sup>16</sup>O)<sup>166</sup>Dy
- 1 week beam time, 3 beam energies: 71 MeV (2 days), 76 MeV (2 days), 80 MeV (3 days)

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- Contaminants: <sup>164</sup>Dy from Coulomb excitation of the target, <sup>178</sup>W from 4n fusion evaporation
- <sup>166</sup>Dy not visible in total projection spectrum, HPGe gates needed



Total Projections at Different Beam Energies

### **Reaction Channel Selection**

- Multiplicity distribution for different event types, HPGe gate on 4<sup>+</sup> → 2<sup>+</sup> transitions in <sup>164</sup>Dy, <sup>166</sup>Dy and <sup>178</sup>W
- nTot = 2 dominated by Coulomb excitation, 2n transfer peaks at nTot = 2 and 3
- Look at nBGO vs. LaBr E to set a multiplicity condition for 2n transfer selection



#### **Reaction Channel Selection**

Event selection conditions: nGe = 1, nLaBr = 2, nBGO < 2 HPGe gate on 273 keV



LaBr Projection after HPGe gate on 273 keV



#### Time difference measurements:

- $4^+ \rightarrow 2^+$  and  $2^+ \rightarrow 0^+$  gamma rays at 177 and 77 keV
- $4^+ \rightarrow 2^+$  gamma ray and internal conversion x-ray at 177 and 46 keV

#### Lifetime Measurements in <sup>166</sup>Dy



# Summary

- NuBALL hybrid detector array used for gammaray spectroscopy
- Aim to study quadrupole deformation near the mid-shell <sup>170</sup>Dy isotope
- 2n transfer reaction  ${}^{164}$ Dy( ${}^{18}$ O, ${}^{16}$ O) ${}^{166}$ Dy
- Lifetime of 2<sup>+</sup> and 4<sup>+</sup> excited states in <sup>164</sup>Dy successfully re-measured
- Event energy and multiplicity used to select reaction channel
- Half-life of  $2^+$  in <sup>166</sup>Dy measured as  $T_{1/2} = 2.4(4)$  ns
- $B(E2)\uparrow = 5.0(10) e^2 b^2$ , to extract more from the value the 20% uncertainty must be reduced

#### Evaluated B(E2) $\uparrow$ vs. N in the Z=66 Region



# Acknowledgements

- UK Science and Technologies Facility Council (STFC)
- UK Nuclear Data Network
- Marion Redfearn Scholarship Trust
- UK Dept. for Business, Energy and Industrial Strategy (BEIS)
- ENSAR2 transnational accessfunding from the European Commission
- Collaborators at IPN Orsay (Dr. M. Lebois, Prof. J. Wilson, Dr. N. Jovancevic)
- IKP, University of Cologne (for the supply of the <sup>164</sup>Dy target)

# Additional slides



#### P/T Ratio: Add-Back and Compton Veto



- All HPGe are Compton ٠ suppressed
- Add-back used in clover detectors
- Coincidences between ۲ nearest neighbours are excluded for LaBr

Spectrum Type	Peak/Total at Energy:			
(76 MeV data)	107 keV	237 keV	351 keV	447 keV
Raw	0.0054	0.014	0.0098	0.0075
Prompt Gated	0.0039	0.017	0.015	0.013
with Add Back	0.0043	0.019	0.018	0.016
Compton Suppressed	0.0043	0.020	0.019	0.017

### Coincidence Measurements



### LaBr Projections in <sup>166</sup>Dy



### Justification of Results using <sup>164</sup>Dy



[1] B. Singh and B. Chen Nucl. Data Sheets 147, 1 (2018)