Lifetime measurements in the even-even $^{\text{104-108}}\text{Cd}$

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Longest isotopic chain between two experimentally accessible doubly-magic nuclei.

Unique opportunity for systematic studies of the basic nuclear properties.

Balance between the closed-shell effects and evolving collectivity.
Z=48 PHYSICS CASE

Vibrational…?

Vibrational-like character

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P.E. Garrett and J.L. Wood have proposed a reinterpretation of the stable Cd nuclei:

- Shape coexistence between rotational deformed structures

Reduced transition probabilities and quadrupole moments

Unobserved transitions between the three-, two- and one-phonon states

Courtesy of P.E. Garrett
Z=48 PHYSICS CASE

Vibrational…?
Deep-inelastic reaction to investigate the neutron-deficient Cd isotopes:

- Stable beam with **higher intensity** than previous experiment with radioactive beams

**Beam:** $^{106}$Cd @ 770 MeV

**Target:** $^{92}$Mo 0.715 mg/cm$^2$

**Degrader:** $^{24}$Mg 1.6 mg/cm$^2$
RESULTS

Lifetimes in $^{106}$Cd

- Verify the experimental procedure
- Lifetime measurement via both DDCM and DCM to check the real target-degrader distances (i.e. plunger zero-offset)

$\tau_{\text{NNDC}}(2^+) = 10.5(1)$ ps

$\tau_{\text{DCM}}(2^+) = 10.7(4)$ ps

$\tau_{\text{DDCM}}(2^+) = 10.4(2)$ ps

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RESULTS
Lifetimes in $^{106}$Cd

$$R_{TOT}(\tau) = \frac{\sum_{j=1}^{n} I_{u,j}}{\sum_{j=1}^{n} (I_{u,j} + I_{s,j})} = \sum_{j=1}^{n} n_j e^{-\frac{1}{\tau} \frac{x_j}{\beta_{TD} c}}$$


$\tau_{NNDC}(2^+) = 10.5(1)$ ps

$\tau_{TOT}(2^+) = 10.1(3)$ ps

RESULTS
Lifetimes in $^{108}\text{Cd}$

$\tau_{\text{NNDC}}(2^+) = 9.9(1) \text{ ps}$

$\tau_{\text{TOT}}(2^+) = 10.1^{+2.8}_{-2.0} \text{ ps}$

**RESULTS**

Lifetimes in $^{104-108}$Cd

\[ \tau_{\text{lit}}(2^+) = 8.5(12) \text{ ps} \]

\[ \tau_{\text{TOT}}(2^+) = 10.0^{+0.6}_{-0.5} \text{ ps} \]


\[ \tau_{\text{lit}}(4^+) = 1.5(5) \text{ ps} \]

\[ \tau_{\text{TOT}}(4^+) = 1.44^{+0.33}_{-0.24} \text{ ps} \]


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RESULTS
Reduced Transition Probability

(a) $B(E2; 4^+ \rightarrow 2^+)$ [e$^2$ fm$^4$]

(b) $B(E2; 2^+ \rightarrow 0^+)$ [e$^2$ fm$^4$]

Neutrons vs. $B(E2)$ values for $^{104-108}$Cd.

- Adopted
- Milner1969
- Esat1976
- Najib1977
- Pitarinen1993
- Lobach1999
- Muller2001
- Harissopulos2001
- Boalert2007
- Ekstrom2009
- Siciliano2019
THEORETICAL INTERPRETATION
Quadrupole-Pairing Interplay

Large-scale shell-model calculation, performed by the Strasbourg group, to explain the systematic of the reduced transition probability in the neutron-deficient Cd isotopes.

- Realistic potential: N3LO (CD-Bonn and AV18 provide same results)
- Renormalization: 30% for quadrupole force, 40% for pairing force
- Monopole-free
  $^{100}\text{Sn}$ single-particle spectrum, given by GEMO
- Full $gds$ valence space
  1p-1h excitations in the $(g_{9/2})^\pi$

Deformed structures
CONCLUSIONS

• Deep-inelastic collisions are a powerful tool for populating the region close to $^{100}$Sn. Thanks to the direct population of the states, electromagnetic properties of the low-lying states can be investigated.

• **Lifetime of $2^+_1$ states** has been measured in the even-even $^{104-108}$Cd. **Lifetime of $4^+_1$ state** has been measured for $^{104}$Cd. The results confirm the values obtained in previous experiments.

• The extracted B(E2) values have been compared with LSSM calculations in the full $gds$ valence space to explain the trend of neutron-deficient Cd isotopes.

FUTURE...?

Further investigation of neutron-deficient Cd nuclei via Coulomb excitation or lifetime measurements, to study the nature of side bands.
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THANKS FOR YOUR ATTENTION
The nuclear reaction takes place in the thin target and then the reaction products are slowed down by the degrader foil. Because of the two different velocities, per each γ-ray transition two components are observed. The γ-ray energy is Doppler corrected for $\beta_u$ (measured by VAMOS++), so in the spectrum a second under-corrected shifted peak appears.

The relative intensity of the two peaks depends on the target-degrader TOF ($\beta_s$, distance) and lifetime.

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Information of the shell gap and collectivity evolution can be experimentally obtained from
- the excitation energy of the low-lying states
- the reduced transition probability
Due to the almost symmetric reaction, the recoils energy was at the limit for the identification in the IC.

The identification of the fragments is challenging because of the high atomic number, close to the resolution limit of the IC.

- Empirical corrections to improve the resolution
- A systematic investigation was performed to identify the Z=50 channel

A good estimation for the even-even nuclei yield is given by the efficiency-corrected area of the peak related to $2^+_1 \rightarrow 0_{g.s.}^+$ transition.

- Yields asymmetry for $Z \geq 48$
- Yields symmetry for $Z \leq 46$

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The VAMOS++ spectrometer allows the **complete identification** of the reaction products, providing the atomic number \( Z \) and mass \( A \).

- Light ions with \( Z \sim 28 \) were populated via the fusion-fission reaction of the beam with the degrader material.
- Beam-like ions with \( Z \sim 48 \) were obtained via both multi-nucleon transfer reactions and deep-inelastic collisions of the beam with the target.

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*M. Siciliano et al., INFN-LNL Annual Report 2017 (2018) 57*
Theoretical Interpretation
Quadrupole-Pairing Interplay in Sn

- Realistic potential: N3LO (CD-Bonn and AV18 provide same results)
- Renormalization: 30% for quadrupole force, 0-40% for pairing force
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  $^{101}$Sn single-particle spectrum, given by GEMO
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Pairing force takes its revenge on quadrupole correlation

Results in $^{108}$Sn allow to firmly define the pairing force

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