Collectivity of the $4^+_1$ states in heavy Zn isotopes and the first HIE-ISOLDE experiment

Andres Illana Sison$^{1,4}$, Magda Zielińska$^2$, Elisa Rapisarda$^3$, Piet Van Duppen$^1$

$^1$ KU Leuven, Belgium; $^2$IRFU/DPhN, CEA Saclay, France; $^3$ PSI Villigen, Switzerland; $^4$ INFN Legnaro, Italy

and the IS557 – MINIBALL collaboration

- Motivation
- Lifetime measurements in heavy Zn isotopes
- Coulomb excitation measurements
  - First HIE-ISOLDE experiment
- What have we learnt so far?
Vicinity of $^{68}$Ni

- High excitation energy of the $2^+$ state and low B(E2) in $^{68}$Ni
- Weakness of the N=40 shell gap: rapid onset of collectivity when moving away from $^{68}$Ni
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- polarisation of the $Z=28$ proton core in $^{70}\text{Ni}$
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Experimental methods to measure transition probabilities around $^{68}$Ni

- Lifetime measurements after deep-inelastic reactions
  - yrast states
  - problem of unknown feeding

- Coulomb excitation
  - collective states
  - Coulex cross-sections depend on quadrupole moments

Combination of both methods should in principle give information on quadrupole moments, provided that the measurements are precise and accurate
Transition probabilities in Zn isotopes: status five years ago

- $B(E2)$'s for stable Zn isotopes: Coulex, RDDS, DSAM: some important discrepancies ($^{64,66}$Zn)
- neutron-rich Zn isotopes: low-energy Coulex, relativistic Coulex for $2^+$

- $B(E2; 4^+ \rightarrow 2^+)$ better test for theories than $B(E2; 2^+ \rightarrow 0^+)$
- collectivity overestimated by beyond-mean-field calculations
Lifetime measurements in $^{70-74}\text{Zn}$

- RDDS measurement with AGATA (Legnaro)
- new lifetimes for the $2^+$ states in agreement with previous $B(E2; 2^+ \rightarrow 0^+)$ values
- good agreement with model calculations for the $2^+$

- discrepancy of the new lifetimes for $4^+$ states with low-energy Coulex results (especially for $^{74}\text{Zn}$)
Lifetime measurements in $^{70,72}\text{Zn}$


- plunger measurement at GANIL: EXOGAM+VAMOS
- $^{238}\text{U}$ beam (6.8 MeV/u) on $^{70}\text{Zn}$
- confirmation of the RDDS results from Legnaro
Coulomb excitation of exotic Zn nuclei at ISOLDE

gamma-ray detection array:
MINIBALL
8 triple clusters, 8% efficiency

particle detection setup:
annular DSSD detector at forward angles
(+ sometimes C-REX Barrel Si)
detection of scattered Zn
and recoiling target nuclei

deexcitation $\gamma$ rays measured in coincidence with particles (Zn and target recoils)
laser ionisation to suppress strong Ga contamination
beam intensities: $3 \times 10^7$ pps ($^{72}$Zn), $1 \times 10^6$ pps ($^{74}$Zn), $5 \times 10^5$ pps ($^{76}$Zn), $3 \times 10^4$ pps ($^{78}$Zn)
Coulomb excitation of $^{72}$Zn

PhD S. Hellgartner, TU Munich (2015)

- low-energy Coulex at ISOLDE
- C-REX setup
  - broad range of CM angles
- large statistics
  - differential cross sections
  - high-precision measurement
  - consistency check

![Graph showing B(E2; 4$^+$ → 2$^+$) vs. energy for $^{72}$Zn](image)

![Graph showing angular distribution for $^{72}$Zn](image)

![Graph showing energy spectrum for $^{72}$Zn](image)
Coulomb excitation of $^{74,76}$Zn: the first HIE-ISOLDE experiment

October 2015, $^{74}$Zn on $^{196}$Pt: analysis by A. Illana Sison

- increased probability of multi-step excitation
- higher sensitivity to quadrupole moments
- max 6 hours of 4MeV/A beam per day, only on weekdays
- bad beam time structure (150 $\mu$s bursts) – high particle multiplicity
Coulomb excitation of $^{74,76,78}$Zn: preliminary results

- **October 2016:**
  - 5 days of $^{78}$Zn (4.3 MeV/u) on $^{196}$Pt/$^{208}$Pb
- Analysis in the final stage (A. Illana Sison)
What have we learnt so far?

- systematic disagreement between RDDS and Coulex results for $4^+$ states
- DSAM result (states populated in non-safe Coulex) seems consistent with Coulex
- ...but the RDDS result from GANIL, also with states populated in non safe Coulex, is not!
- better control of possible sources of systematic errors needed
  - feeding in lifetime measurements
  - second-order effects in Coulex \[ \rightarrow \text{higher statistics necessary} \]
- too early to make comparisons with theory
Collectivity of $4^+$ states

Z<40 nuclei

40<Z<80 nuclei


- Small $B(E2;4^+ \rightarrow 2^+)/B(E2;2^+ \rightarrow 0^+)$ ratio for all Zn isotopes → indication of a non-collective character of the $4^+$ states
Description of the region south of $^{68}$Ni

- Interaction between neutron $g_{9/2}$ and proton fp shell causes lowering of the $f_{5/2}$ and raising of the $f_{7/2}$
- collectivity increases with filling of the $g_{9/2}$
- transition probabilities important to test validity of model descriptions
Lifetime measurements in $^{70-74}$Zn

Deep inelastic reaction: $^{76}$Ge (7.6 MeV/u) + $^{238}$U
PRISMA spectrometer at grazing angle ($55^\circ$)

Cologne plunger

Target: 1.4 mg/cm$^2$
Degrader: Nb – 4.2 mg/cm$^2$
5 plunger distances: 100, 200, 500, 1000, 1900 µm
(20 hours each)
Lifetime measurements in $^{70-74}\text{Zn}$

C. Louchart, PRC 87 (2013) 054302
Transition probabilities in $^{70}\text{Zn}$

D. Mücher et al PRC 79 (2009)

- DSAM measurement, excited states in $^{70}\text{Zn}$ populated by non-safe Coullex on $^{12}\text{C}$

- $4^+ \rightarrow 2^+ (901 \text{ keV})$ and $2^+ \rightarrow 0^+ (885 \text{ keV})$ close in energy

- Coulomb excitation seems a more appropriate method to measure B(E2)'s in $^{70}\text{Zn}$ (no double peaks/tails)
Coulomb excitation of $^{70}$Zn

M. Zielińska et al, HIL Warsaw

48 PIN diodes ($120^\circ$ – $155^\circ$)

EAGLE: 15 ACS Ge detectors

$^{32}$S beam (68 MeV), $^{70}$Zn target (0.7 mg/cm$^2$)
5 days of data-taking