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Shapes and Collectivity in Neutron Deficient Even-mass $^{188-198}$Pb Isotopes

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The neutron deficient $^{188-198}$Pb isotopes have been studied in a Coulomb excitation measurement employing the Miniball spectrometer and radioactive beams from REX-ISOLDE, CERN. These isotopes are of particular importance as they lie in a transitional region, where the intruding structures, associated with different deformed shapes, come down in energy close to the spherical ground state. For detailed analysis of the Coulomb excitation data, the understanding of the beam composition is essential.

KEYWORDS: Nuclear structure, in-beam γ-ray spectroscopy, Coulomb excitation, radioactive beams

1. Introduction

One of the goals of modern nuclear physics research is to understand the origin of coexisting nuclear shapes and exotic excitations and their relation to the fundamental interactions between the nuclear constituents. These subjects can be investigated particularly well in the Pb isotopes close to neutron mid-shell N=104, where a relatively small proton shell gap, together with a large valence neutron space, provides fertile ground for studies of shape transitions within a small energy range [1]. A whole arsenal of spectroscopic techniques, including β-decay studies [2], α-decay fine structure measurements [3], in-beam γ-ray experiments using fusion-evaporation reactions [4] and laser spectroscopy [5], to name but a few, have been carried out in order to verify and understand the shape coexistence phenomenon in this region. For more detailed understanding, it is important to measure transition probabilities between the coexisting nuclear states. Transition probabilities are very sensitive to the details of a nuclear wave function and, consequently, information about nuclear shape and configuration mixing can be inferred.

2. Experimental technique

The experiment was performed at the REX-ISOLDE facility, CERN [6]. The nuclei of interest were produced by bombarding a high temperature UC_x target with 1.4GeV, up to 2μA proton beam provided by PS-Booster and extracted employing the RILIS laser ion source [7]. Subsequently, they were mass selected utilising the high resolution separator before being delivered to the REXTRAP-REXEBIS for charge breeding. Finally, the REX-ISOLDE post-accelerator was employed to deliver radioactive ion beams of 2.82MeV/u (^{188,190,194,196,198}Pb) and 2.84MeV/u (^{192}Pb) to the Miniball spectrometer [8]. At Miniball, the radioactive beam was impinging on a 2mg/cm^2 thick ^{112}Cd target. The beam intensity on the Miniball target varied between 2×10^5-1.4×10^6pps. The scattered projectile- and target-like nuclei were detected with the CD detector at ~30mm downstream from the target. The γ rays from the decay of the Coulomb excited states were recorded with the Miniball Ge-detector array [8]. The relatively high granularity of Miniball and the CD detector allowed for kinematic correction to be made.

3. Subtracting the γ-ray background arising from the beam impurities

One of the main challenges in the present work was to address the amount of the isobaric impurities in the beam. The analysis of the decay data obtained after the mass separation stage revealed contamination of Tl, being the only unwanted component of the beam. While the Pb atoms were ionised with lasers, the Tl atoms were surface ionised in the Ta hot cavity in which laser ionisation takes place. The primary ISOLDE yields at PS-Booster, achieved when system was optimised for production of either Pb or Tl, are plotted in Figure 1. The Pb yields peak at ^{194}Pb and drop rapidly when

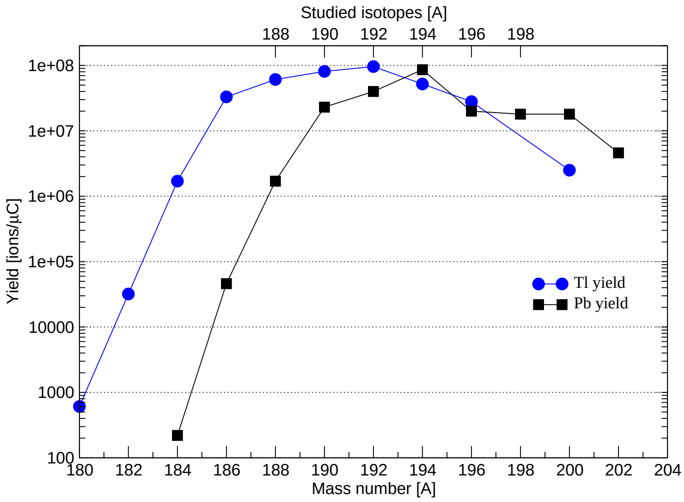

Fig. 1. The ISOLDE yields at PS-Booster relevant to the present work. Yields are given with respect to incident proton beam current on the primary UC_x target. The top X-axis points out the isotopes studied in the present work.

moving towards lighter isotopes, whereas the Tl yields remain relatively high throughout the studied isotopes 188≤A≤198. Consequently, the lowest beam purity of ~55% was obtained for ^{188}Pb. The beam properties, together with purity, accumulated Pb dose on the Miniball target and data collection times are summarised in Table I.

Table I. The radioactive Pb beams delivered to Miniball. Beam energy, yields at Miniball including the beam impurities, purity of the Pb beam, the accumulated dose on the Miniball target and data collection times have been listed.

Isotope	E_{Beam} [MeV/u]	Average yield [pps]	Purity [%]	Pb dose [particles]	Data collection time Laser on [min]	Data collection time Laser off [min]
^{188}Pb	2.82	3.2E+05	55.1±5.5	2.05E+10	1955	1127
^{190}Pb	2.82	2.2E+05	86.3±2.0	2.37E+10	451	72
^{192}Pb	2.84	5.0E+05	96.9±0.8	6.13E+10	1736	137
^{194}Pb	2.82	7.8E+05	97.0±0.7	9.64E+10	241	97
^{196}Pb	2.82	5.0E+05	98.7±0.5	6.19E+10	256	15
^{198}Pb	2.82	2.5E+05	98.6±0.7	3.09E+10	233	21

In the analysis of the Coulomb excitation data, the $2^+_1 \rightarrow 0^+_1$ transition strength in ^{112}Cd (target) was used as a normalisation in determination of the $2^+_1 \rightarrow 0^+_1$ transition strength in the Pb projectiles. The target excitation cross section depends on the atomic number and energy of the beam, i.e. it is approximately the same for excitation caused by Tl (Z=81) and Pb (Z=82). Therefore, it is essential to establish the amount of the target excitations associated with the beam impurities impinging on the target. This can be inferred by using a laser on–laser off technique that enables to determine the beam composition precisely by measuring the amount of scattered particles in the CD detector in laser on (both Pb and Tl present) and laser off (solely Tl in the beam) runs. The laser on–off technique has been used successfully e.g. in Coulomb excitation study of ^{68,70}Cu isotopes [9].

In Figure 2, the CD detector count rates in two laser on–laser off sequences recorded in the ^{188}Pb measurement are shown. The straggling is due to the time structure of the beam, hence 60s running averages have been plotted for better visualisation. The presence of the beam impurities when lasers were turned off is apparent. The beam purities listed in Table I were extracted using this technique.

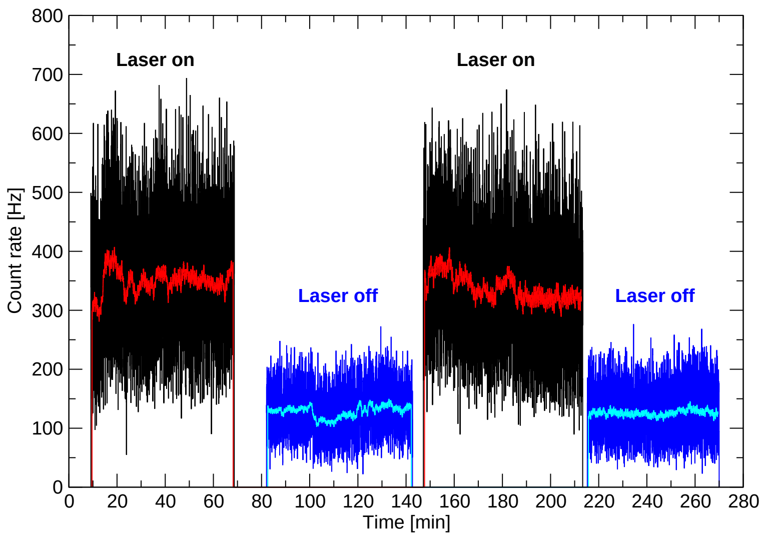

Fig. 2. Typical count rates of the Miniball CD detector in the ^{188}Pb experiment. The black curve visualises runs when the RILIS lasers were set on, while the blue curve represents the laser off runs. Red and cyan curves represent the corresponding running averages (60s) of the laser on and laser off runs, respectively.

Alternatively, in the presence of γ rays associated with the beam impurities, a different approach can be used to eliminate the target excitations arising from the beam impurities. The γ-ray energy spectra in coincidence with prompt particles obtained in the ^{188}Pb measurement are shown in Figure 3. The γ rays present in the laser off runs (Figure 3a) can be associated with excitations of the ^{188}Tl

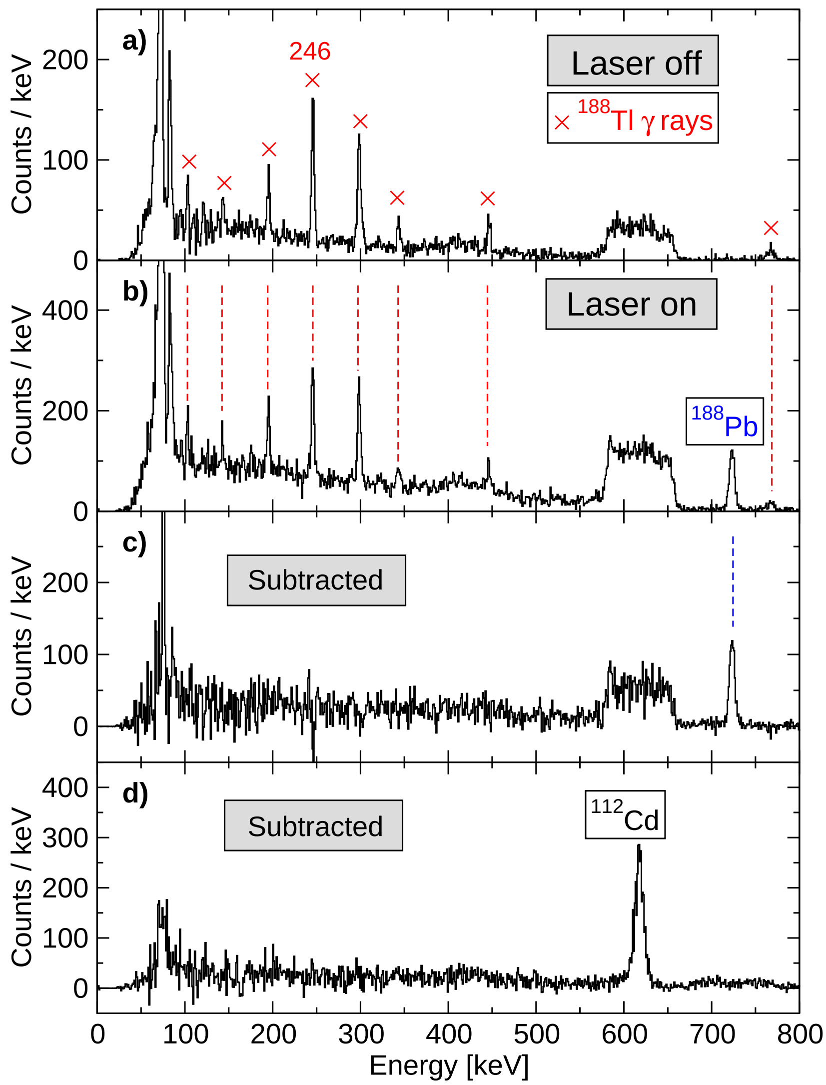

Fig. 3. Prompt particle gated γ-ray energy spectra obtained in ^{188}Pb measurement. Panels a) and b) show the laser off and laser on data, respectively, Doppler corrected for projectile. In panels c) and d), laser off runs subtracted from laser on runs, Doppler corrected for the projectile- and target-like nuclei, respectively, are shown. γ rays associated with ^{188}Tl, ^{188}Pb and ^{112}Cd nuclei have been labelled.

impurities of the beam. In the γ-ray energy spectrum collected with lasers on (Figure 3b), both transitions in ^{188}Tl and the known $2^+_1 \rightarrow 0^+_1$ transition in ^{188}Pb are evident. As shown in Figure 3c, a pure ^{188}Pb γ-ray energy spectrum was obtained by subtracting the laser off runs from the laser on runs, using the 246keV γ-ray transition associated with ^{188}Tl for normalisation. Figure 3d shows the same as previous, but Doppler corrected for the target-like nuclei.

The two techniques described above to subtract the amount of the target excitations associated with the beam impurities were validated in the analysis of ^{188}Pb data and the results obtained were consistent.

4. Summary

The neutron deficient $^{188-198}$Pb isotopes have been studied in a Coulomb excitation experiment employing the Miniball spectrometer. These exotic radioactive beams are only available at REX-ISOLDE, CERN. In this paper, we have reported on the beam properties, essentially the beam composition, that plays important role in the analysis of the Coulomb excitation data. Preliminary analysis suggests that these data will allow us to extract the transition strengths for the first excited 2^+ state in $^{188-198}$Pb isotopes. The results will shed more light on collectivity and configuration mixing in Pb isotopes close to the neutron N=104 midshell.

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