EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

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Letter of Intent to the ISOLDE and neutron Time-of-Flight Experiment Committee

Fast-timing studies from the β-decay of n-rich Cl isotopes

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Abstract

With this letter of intent we would like to request a systematic investigation of yields and release properties of n-rich Cl nuclei at ISOLDE. Once the production and stability of Cl beams is known, we foresee to submit a proposal with the purpose of investigating the structure of nuclei populated in the β-decay of Cl isotopes via the ATD $\beta\gamma\gamma$(t) technique. With this method we will be able to measure dynamic moments in Ar isotopes and their daughter products in order to understand how the structure close to the N=28 shell closure is affected by the interplay between protons filling the $(1d_{5/2}2s1d_{3/2})$ shell and neutrons fill the $1f_{7/2}$ subshell.

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1 Introduction

Understanding the modification of shell structure for nuclei far from stability is one of the main topics of nuclear structure. It is expected that changes in the structure for exotic nuclei may lead to the disappearance of the known stable magic numbers and the appearance of new ones. Extensive theoretical and experimental studies have been carried out in the last years in different regions of the nuclear chart. One of the most conspicuous examples is the weakening and eventual vanishing of the N=20 shell gap in the island of inversion around ^{32}Mg. The structure away from stability, and in particular the presence of deformed ground-state configurations, comes as a consequence of the lowering of states from higher lying shells that, in this exotic conditions, intrude in the normal lower lying shells. This is not only due to shifts in the single particle energies but also to the interaction between the valence nucleons in the proton or neutron shells and to the interaction between valence protons and neutrons. A proper understanding of these effects requires detailed information on the nuclear structure of chains of nuclei across the regions of interest.

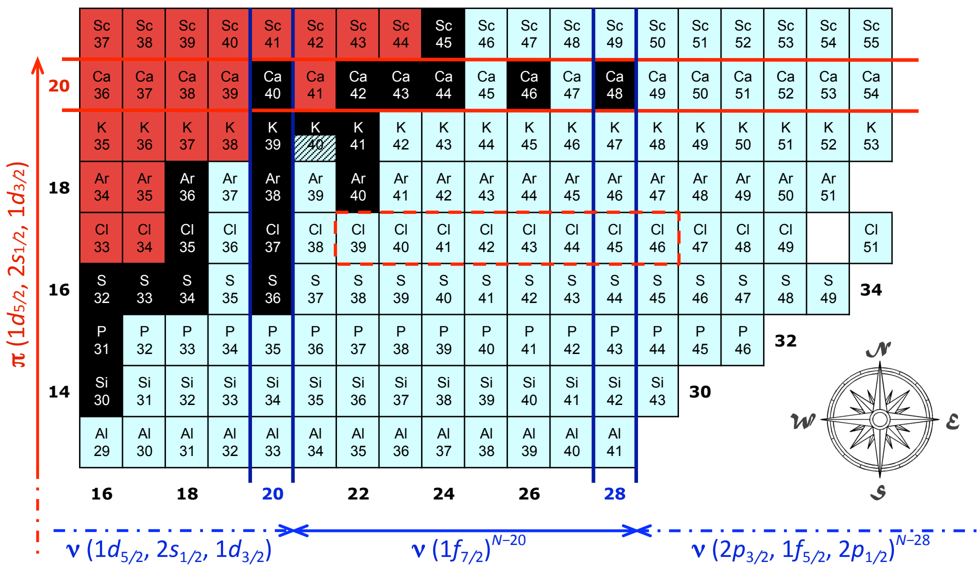

Figure 1: The region of nuclei south-west from ^{48}Ca where the ATD $\beta\gamma\gamma$(t) technique will provide structural information by the determination of dynamic moments.

With this Letter of Intent, we propose to initiate the study of neutron rich nuclei south-west from the doubly-magic $^{48}_{20}$Ca populated in the β-decay of Cl isotopes. We intend to use the Advanced Time-Delayed (ATD) $\beta\gamma\gamma(t)$ technique [1, 2] as to measure dynamic moments in Ar (and daughter nuclei), particularly for odd-A nuclei, for transitions de-exciting states populated in β-decay. The technique has been amply used at ISOLDE and has provided key information on a number of exotic nuclei, helping elucidate their observed low-energy structure. Recent applications include nuclei in the Mg island of inversion and nuclear systems a few nucleons away from the doubly magic ^{132}Sn. We propose to use an array of five detectors: a fast plastic scintillator for beta detection, and two fast $LaBr_3$(Ce) crystals and two large HPGe detectors. The analysis of γ-γ coincidences provides the level scheme, while the lifetimes of the excited states in the nanosecond and subnanosecond range, selected by a particular decay branch, are measured via β-γ-γ coincidences. A precision down to a 1-2 ps is reachable in the most favourable situations.

2 Nuclei below $^{48}_{20}$Ca

The nuclear structure in the region of nuclei south-west from the doubly-magic $^{48}_{20}$Ca is modulated by the onset of deformation and the interplay between protons filling the $(1d_{5/2}2s1d_{3/2})$ shell and neutrons occupying the $1f_{7/2}$ subshell. The observation of strong collectivity in neutron rich S and Ar isotopes by means of intermediate-energy Coulomb excitation [3] originally lead to the interpretation of this new region of deformation in terms of the destruction of the N=28 neutron shell closure or the quenching of the Z=16 proton subshell (see Fig. 2). Shell model calculations with a combined effective interaction built for the *sd* and *pf* shells [4] were able to describe the available data in a satisfactory way, pointing to the persistence of the N=28 shell gap and just a local deformation effect for ^{40,42}S. Nevertheless, the modification of the shell structure and the appearance of deformation was observed in more exotic nuclei by mass measurements of $^{43-46}$Cl and ^{47}Ar [5], which could only be explained by models including prolate deformations in the ground state and coexistence of different configurations. The strength and the extent of the collective effects for very n-rich nuclei remains an open question. Refined shell model calculations in the *sdpf* valence space, which could be tested for Ar isotopes, have been recently presented [6]. We note that the appearance of a new shell gap at N=32 for exotic $_{22}Ti$ and $_{24}$Cr nuclei heavier above Ca has also been discussed [7, 8], see Fig. 2.

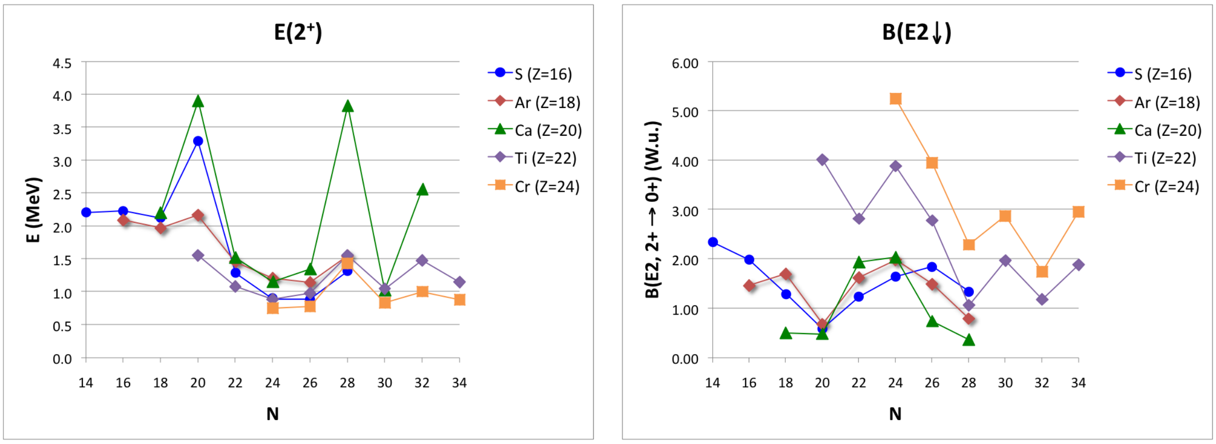

Figure 2: Systematics of the 2^+ energies (in MeV) and B(E2↓; $2^+ \rightarrow 0^+$) values (in W.u.) for S, Ar, Ca, Ti and Cr (Z=16, 18, 20, 22 and 24) as a function of the neutron number (N). The data are taken from [7, 8, 9, 10].

The ATD $\beta\gamma\gamma(t)$ technique can provide good insight into the structure of excited states of nuclei populated in the β-decay of Cl isotopes. The direct β-decay of ^{A}Cl and the β-delayed neutron emission $^{A+1}$Cl will populate complementary levels in the daughter nuclides due to the selection rules. We have recently been able to measure the lifetime of excited states at 167.1, 515.9 and 1867.7 keV in ^{41}Ar by means of the ATD technique [11] in an experiment at ISOLDE. The ^{41}Cl was produced with a standard UC$_x$/graphite target coupled to a FEBIAD-type plasma ion source, and ionized in the molecular ^{128}Xe^{41}Cl^{+} band as a by-product of the main experiment. Good quality results were obtained as illustrated in Fig. 3, even though the beam of ^{41}Cl represented only a very weak impurity.

The reduced transition probabilities obtained confirm the low-lying structure of this ^{41}Ar, with neutron configuration $(f_{7/2})^3$. But the situation may not be so clear for more neutron rich nuclei. The study of the β-decay of ^{43}Cl has recently been reported [12]. A tentative assignment of $5/2^-$ is given for the ground state of ^{43}Ar, with the $7/2^-$ at more than 750 keV in excitation energy, contrary to the theoretical predictions [13]. The measurement of level lifetimes in this nucleus will help clarify this matter. A similar situation is expected for ^{45}Ar, with configuration $\nu(f_{7/2})^{-1}$, $\pi(1d_{5/2}2s1d_{3/2})^{-2}$. The lifetime of the first excited state is of the order of 340 ps. In the β-decay study [14] candidates for intruder neutron states were suggested at ∼1.4 MeV. For ^{47}Ar, a reduction of the N=28 gap and a decreased of the spin-orbit splitting for the p and f neutron orbitals has been claimed from a transfer reaction study [15]. The measurement of lifetimes in these odd-A nuclei, if reached, can certainly shed light on their nuclear structure.

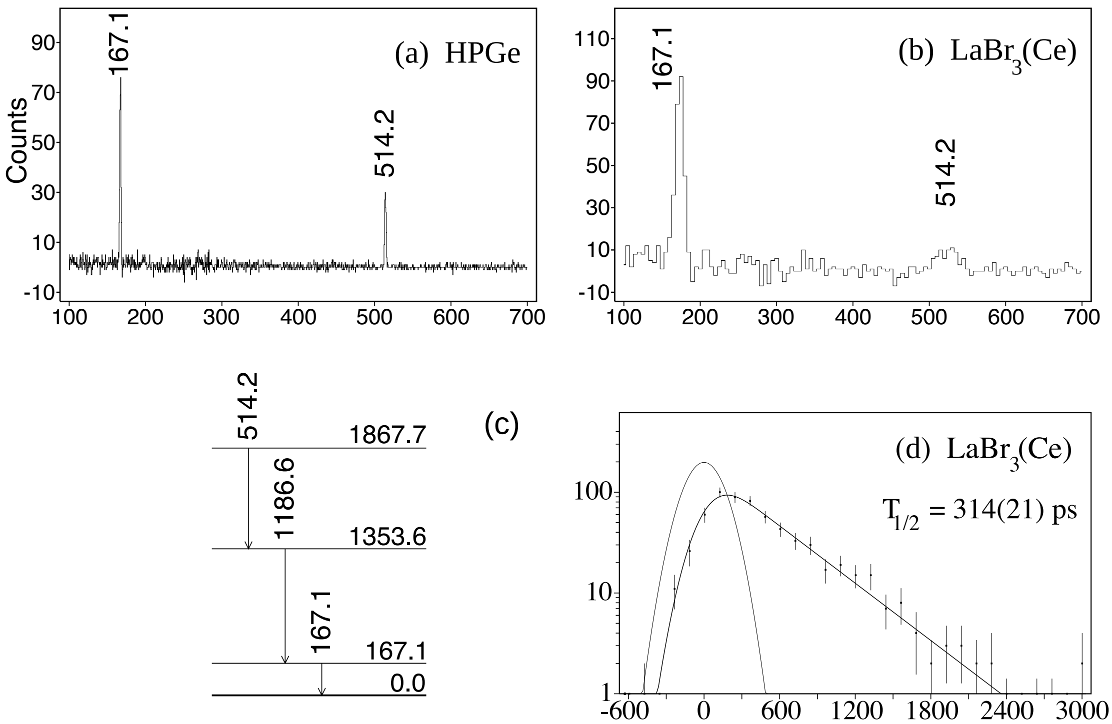

Figure 3: Timing analysis of the β-decay of ^{41}Cl. Partial γ-γ coincidence spectra gated on the 1187 keV transition on a HPGe detector and project into the other HPGe *(a)* and the $LaBr_3$ *(b)* detectors. The decaying gamma cascade is shown in *(c)*. Panel *(d)* shows the time-delayed β-γ-γ(t) spectrum gated by the de-exciting 167 keV transition in the $LaBr_3$, with the slope due to the half-life of the 167.1 keV level in ^{41}Ar. Adapted from [11].

We therefore think that the extension of the study of level lifetimes and dynamic moments to exotic nuclei populated in the decay of chlorine isotopes up to at least ^{45}Cl can provide important nuclear structure information.

3 Request for beam development

There exist at least two alternatives to produce ISOL beams of exotic chlorine, namely molecular beams ionized with positive ion sources and atomic beams ionized with negative ion sources.

As discussed above, in a recent experiment [11] $XeCl^+$ beams originating from a UC_x target coupled to a plasma (Mk5) ion source with Xe support gas were observed. Nevertheless the ratio of the production of a given Cl isotope in all the molecular side bands with stable Xe to the yield atomic Cl^+ was measured to be only ≈1% [16]. Therefore this method, even when using isotopically enriched Xe, does not seem to be very efficient. A more promising scenario is the use of $BaCl^+$ molecules, which can be surface ionized. A test of this production scheme can be easily accommodated in a standard UC_x-Mk7 ISOLDE unit with the addition of a Ba mass marker.

Concerning ionization with Mk4 negative ion source, the ISOLDE yield database [17] quotes yields for n-rich Cl isotopes up to ^{43}Cl from [18] measured for 600 MeV incident protons from the CERN synchrocyclotron (see Fig. 4). The highest yields for ^{43}Cl were obtained from uranium carbide UC_x units and from targets made of a mixture of Ta rolls and graphite (TaC), both coupled to a negative surface ion source, see Fig. 4. The density of uranium was 13 g/cm^2 compared to the standard density of ∼50g/cm^2 used nowadays at the the PS-Booster with 1.4 GeV protons. This may lead to think that Cl yields from PSB with an uranium carbide target coupled to a negative ion source should be higher, but this effect can be balanced by the requirement of running in stable conditions over a sizeable period of time. In a recent measurement at PSB-ISOLDE yields for Cl isotopes up to ^{43}Cl have been obtained [19] for 1.4 GeV protons on a UC_x target coupled to a negative $LaBr_6$ ion source (see Fig. 4). The measured yields were a factor of ∼3 lower (except for ^{43}Cl) than those found for SC. There is still room for research and development with standard negative ion sources and with the negative ion source materials, currently under test at ISOLDE [20]. The combination of thoria fiber targets with a negative ion source should not be excluded.

With this letter of intent we therefore would like request a systematic investigation of the yields and the release properties of n-rich Cl nuclei at ISOLDE and to assess the stability over time of the radioactive beams.

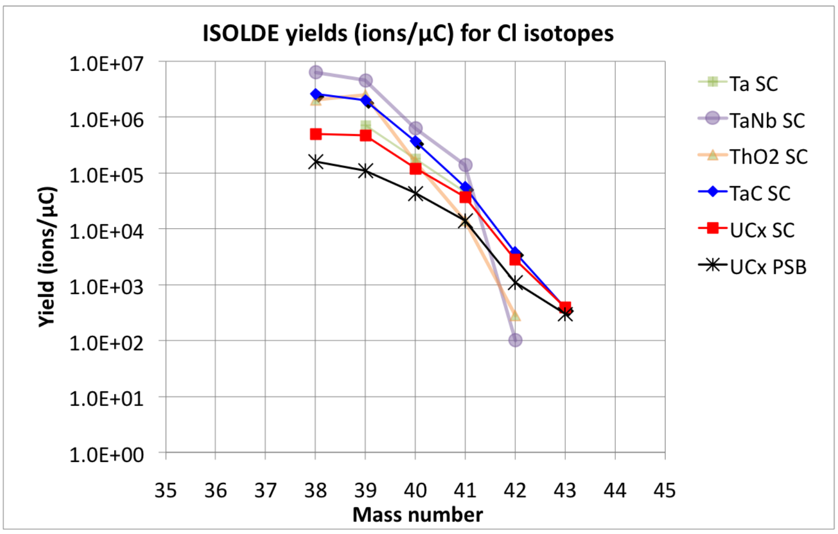

Figure 4: ISOLDE yields for Cl isotopes from [17] and [19]. The ionization was achieved with negative surface ion sources, except for the Ta data where a plasma ion source was used. See text for details.

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