Proposal for an experiment at the IFIN-HH Tandem
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Title: Search for the beta-decay of the 5- isomeric state in ^{38}Cl

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Motivation

The accurate knowledge of beta decay rates of neutron rich nuclei has an important impact on the astrophysics calculations of nucleosynthesis via n-capture process. Though there are global approaches that allow the calculation of beta and beta-n decay probabilities, the results are both model dependent and mass dependent. It is therefore important to have reliable experimental information as much as the experimental conditions to allow it.

Among the recent experimental studies of our group using radioactive beams at large scale facilities, the nucleus $^{34}Al_{21}$, located at the border of the Island of Inversion revealed a very particular feature. Above the 4^- ground state ($T_{1/2}$ = 54 ms) we found a beta-decay isomeric state at an energy yet to be established with a 25 ms halftime, feeding the 0_2^+ state in $^{34}Si_{20}$ [1]. According to extended shell model calculations (both Strasbourg-Madrid [2] and Monte Carlo SM versions [3]) the new state in $^{34}Al_{21}$ is most likely a 1^+ state corresponding to the promotion of a neutron over the N=20 shell gap and therefore a configuration with a neutron pair in $f_{7/2}$ and one neutron hole in *sd* shell, and feeding low spin positive parity states in ^{34}Si. On the contrary, the beta-decay of the ground state will feed negative parity states in ^{34}Si, dominated by *1 hw* intruder configuration.

The situation in $^{38}Cl_{21}$ isotone is similar in many respects. The 2^- ground state has a halftime of $T_{1/2(g.s)}$ = 37.23 m and the 5^- first excited state has a halftime of $T_{1/2(isom)}$=715 ms [4, 5], both belonging mainly to the 2^-, 3^-, 4^-, 5^- quadruplet resulting from the coupling $\pi 1d_{3/2} \otimes \nu 1f_{7/2}$. The currently adopted decay mode of the 5^- isomeric state is 100% internal transition (99.95% gamma plus 0.05% conversion electrons) and no beta decay study for this state was reported so far. **The goal of the proposed experiment is to determine the beta-gamma branching ratio from this isomeric state.** As shown in Fig. 1, the beta decay intensities from the 2^- ground state are experimentally known, 33% going to a 3^- excited state [5, 6] of *1 hw* intruder origin of magic N=20 ^{38}Ar isotope (resulting from coupling of one *sd* neutron and one $f_{7/2}$ neutron). The beta-decay of 5^- isomer is expected to feed significantly only the 5^- and 4^- states in ^{38}Ar, involving configurations and beta energy end point similar to ground state beta-decay to 3^- state. Thus, the expected beta-gamma branching ratios are about $T_{1/2(isom)}/(T_{1/2(g.s)}/0.33) \sim 1.1E{-4}$ for both states of the daughter nucleus.

As sensitive observables to nuclear structure details, the deduced Gamow-Teller strength will provide additional test cases for the new interactions developed for SPDF valence space in order to reproduce the properties of neutron-rich N~20 and N~28 nuclei.

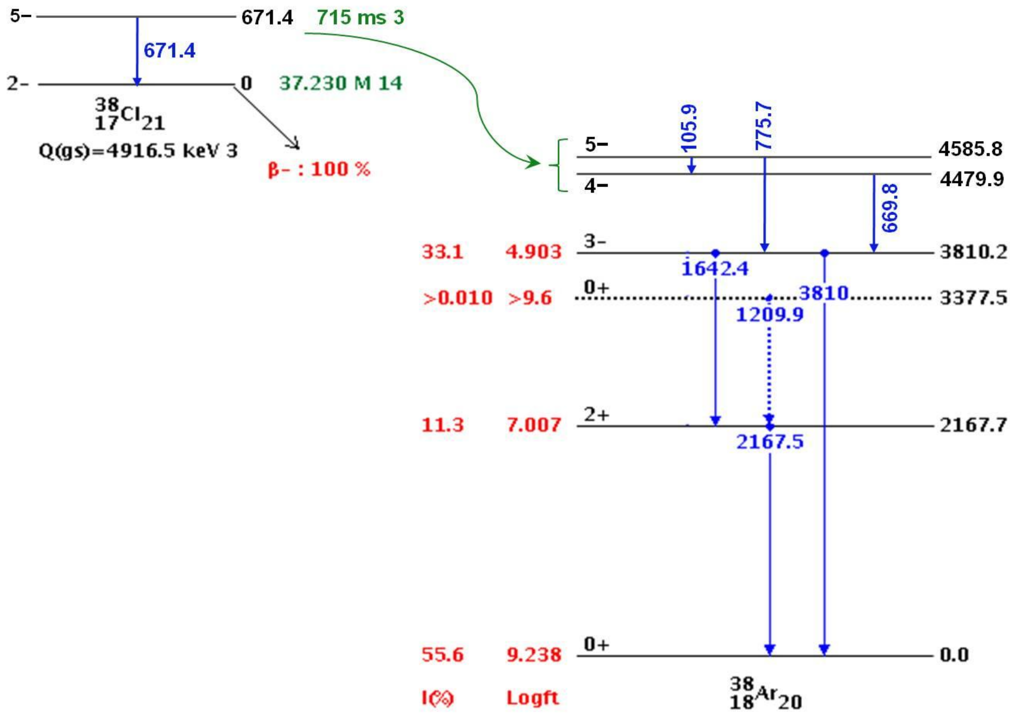

Fig. 1 Beta-decay of ^{38}Cl ground state and the known 4^- and 5^- states expected to be populated in the 5^- isomer beta-decay.

The Experiment

The ^{38}Cl nucleus will be produced via the ^{7}Li(^{36}S,αn)^{38}Cl fusion-evaporation reaction using a ^{36}S of 80 MeV. The cross sections for several residual nuclei are plotted in Fig. 2 generated with CASCADE code [7]. The intensity of ^{36}S beam is supposed 10 pnA (6.2E+10 pps) depending on the isotopic enrichment of the ion-source material. The target is a pure Li foil of thickness larger the 1.6 mg/cm^2 (1.4E+20 at/cm^2). Considering the risk for oxidation in contact with the air, a compound of Li such as LiBr was considered, too. However, due to larger stopping power and stoichiometry, the useful thickness in this case is about 2.8 mg/cm^2 (1.9E+19 at/cm^2 of Li atoms), that is the loss in reaction rate is about one order of magnitude. The option of using ^{7}Li beam implies an expensive target to get the same production rate and low number of contaminants (nuclei with halftimes shorted than one day): highly enriched ^{36}S target of 20 mg/cm^2 thickness.

The average cross section for ^{38}Cl production, as shown in Fig. 2 is 50 mb. We note that experiments with ^{7}Li, due to its cluster structure, have shown an important contribution of incomplete fusion mechanism, especially for the channel (A,Z) + ^{7}Li → (A+1,Z+1) + X. Therefore the above calculation can be considered an underestimation. We suppose also that the yield is equally distributed among the 2^- ground state and the 5^- isomer. With these assumptions we get an isomeric production rate of 2.2E+5 events/sec.

The experiment will make use of the slow pulsing system with beam-on/beam-off periods of 1.4 s and 2.1 s corresponding, respectively, to 2 and 3 halftimes $T_{1/2(isom)}$ of the isomeric state. The measurement of gamma ray emitted during the beam-off period will be done with an array 8 Ge detectors with an efficiency of 1% at 1 MeV. The effective production rate is thus decreased to 2/5=0.4 of the above calculated rate. Moreover, due to decays during beam-on periods an additional factor of 2 is lost. Given also the beta-gamma branching estimated previously we get the effective production rate of desired beta-decay events of 4.8 ev/sec or 4E+5 ev/day.

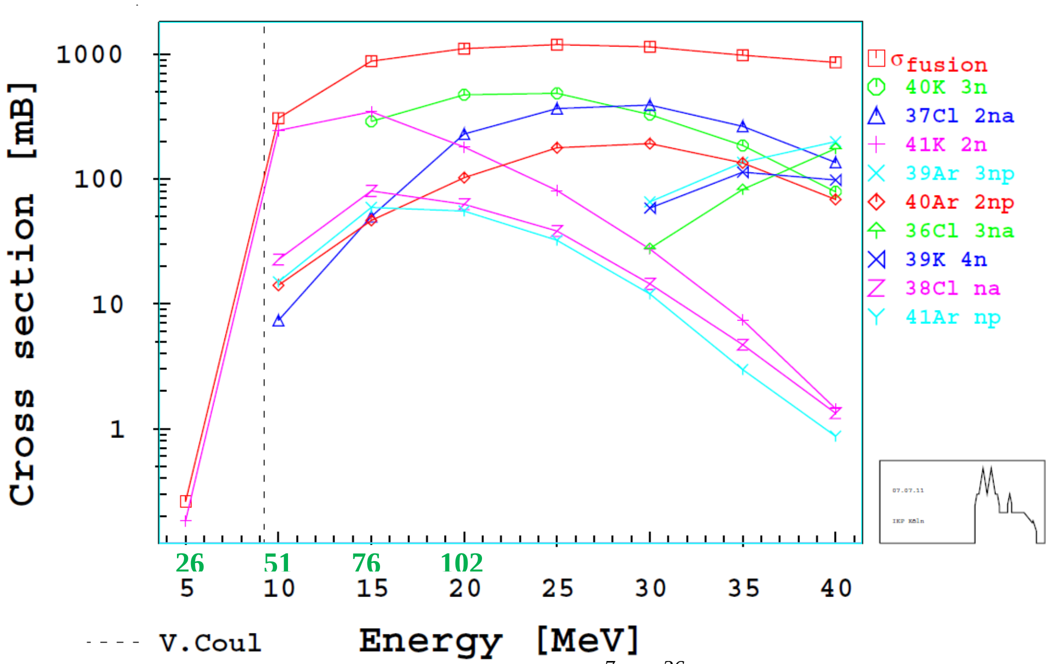

Fig. 2. Fusion evaporation cross section for $^{7}Li+^{36}S$ reaction. The black numbers on horizontal axis are energies for ^{7}Li beam, while the green ones correspond to ^{36}S beam.

In case of beta-decay feeding of the 5^{-} state in the daughter nucleus, a 106 keV gamma is emitted with 90% branching. Considering 3% gamma efficiency at this energy, the expected counting rate is 1.2E+4 γ_{106keV}/day. In order to assess required total beam time (i.e. experiment duration), we denote with *A* the total area of 106 keV peak and estimate *F*, the background under this peak, imposing the condition of $A > 3\sqrt{F}$. A careful analysis of all produced nuclei in the considered fusion-evaporation reaction over the relevant reaction energy range, lead to the conclusion that all nuclei with lifetimes shorter than 1 day have less than one gamma per beta-decay. Moreover, in all these nuclei, this gamma has more than 1 MeV:

^{42}K – 12.3 hours – 18%, 1524 keV,
^{41}Ar – 109 min – 99%, 1293 keV,
^{39}Cl – 56 min – 90%, 1400 keV,
^{38}Cl – 37 min – 33%, 1642 keV + 44% 2167 keV.
^{37}S – 5 min – 95% 3100 keV,
^{34}P – 12 s – 15% 2127 keV.

From the above list, due to production cross section, the most important contribution comes from ^{41}Ar and ground state of ^{38}Cl, as shown in the Fig. 2. Each of the two, will produce in the measured gamma spectrum large peaks of area about $2\times10^{4}\,Ab^{(i)}\varepsilon_{\gamma^{(i)}>1.5MeV}/\varepsilon_{106keV}$ (the factor 2 accounts for the supposed 50% isomeric ratio). Additionally, the 671.4 keV peak corresponding to gamma decay of the isomer will be also present. All these peaks will induce a Compton background having, typically, a magnitude of about 20 less than the peak. Thus, under the 106 keV peak the background is estimated to $F = 500 \div 600\,A$. Therefore, the above condition for peak identification becomes *A* >3.6E+3, which demonstrate that the measurement of 5^{-} beta feeding is feasible even the branching ratio is lower by an order of magnitude compared to what we considered above.

In case of beta-decay feeding of the 4^{-} state, the measurement is more difficult due to the fact that the decay of the state is going only through one gamma of 669.8 keV, very close to 671.4 keV from much stronger isomer gamma decay. A gate on 1642 keV transition eliminates the 671.4 keV line but also decreases the weak 669.8 keV to be observed on the Compton background produced by the strong 2167 keV transition. Therefore, the observation of beta-decay feeding of the 4^- state is less certain in these experimental conditions.

Beam time request

The requested beam time is **21 U.T. (7 days)**. It allows, if the branching ratio has the estimated value, to observe the 715 ms component in decay time spectrum obtained for the 106 keV gate and thus unambiguously assign it to the decay of the 5^- isomer in ^{38}Cl.

[1] F. Rotaru et al., 7th Balkan School on Nuclear Physics Sept.2010, and to be published
[2] E. Caurier et al., Rev. Mod. Phys. 77 (2005) 427
[3] G. Neyens et al., Phys. Lett. B 658 (2008) 203
[4] P. M. Endt, Nucl. Phys.A 521 (1990) 1
[5] E. K. Warburton et al., Phys. Rev. C 34 (1986) 1031
[6] H. Miyahara et al., Nucl. Instr. Meth. A 369 (2002) 494
[7] F. Puehlhofer, Nucl. Phys. A 280 (1977) 267.