EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

Proposal to the ISOLDE and Neutron Time-of-Flight Committee

Letter of Clarification
Probing the ^{11}Li low-lying dipole strength via ^{9}Li(t,p) with the ISS

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We address the comments raised by the INTC at the November 2020 meeting with regards to the proposal P-582 titled "Probing the ^{11}Li low-lying dipole strength via ^{9}Li(t,p) with the ISS".

Comment 1: *"The physics case is interesting. The ^{11}Li system has been studied at length, but important questions remain to be settled regarding its ground state configuration and its continuum spectrum. In this regard, the proposed experiment can provide complementary information to that obtained from previous measurements."*

Response: We appreciate the comments of the INTC. We are aware of several changes in the committee membership since the INTC 65, and therefore, we provide as many details as possible. In addition, we would like to point out that the ISS offers unprecedented capabilities in terms of excitation energy resolution (around 150 keV FWHM for this experiment) that may help to reveal features of the investigated dipole resonance not accessible with other detection setups, both at ISOLDE and elsewhere.

Comment 2: *"The TAC report warns that the actual ^{9}Li intensity might be a factor of 5 lower than requested in the proposal and that the requested activity of the tritium target is substantially larger than the existing one and above the limits of running in a class C lab. This will require the use of a thinner target. These two effects will result in significantly lower statistics. The proponents are requested to clarify how this may compromise the feasibility of the analysis."*

Response: We acknowledge that the beam intensity presented a problem in past measurements of the same reaction. With the updated calculations requested by the committee (see Comment 3), an intensity of about 2×10^5 pps, commensurate with the maximum delivered ^{9}Li intensity at ISOLDE, is sufficient to carry out this experiment successfully. This beam rate is also compatible with the proposed recoil detection system (see Comment 4). We still suggest to follow the recommendation presented in the TAC summary document for INTC 65 to schedule this experiment after P-568 to asses the quality of the beam.

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The target, quoted at nominally 1 Ci (37 GBq), is for a half-inch sized tritiated foil. As was done with previous titanium tritide targets used at ISOLDE, the foil can be cut into a thin strip commensurate with the size of the beam, such that the total activity is 10 GBq, and compliant with a class C lab. The areal density does not change, so there is no impact on the yield.

Overall, the situation in terms of statistics remains the same with a 2×10^5 pps beam and the estimated calculations. Keeping the high resolution and high background rejection capabilities of the ISS is of capital importance for this experiment.

Comment 3: *"Concerning the theoretical interpretation of the data, the proposal seeks for the dipole ^{11}Li structure in the continuum but, in addition to this L=1 mode, the reaction will populate other L values in the continuum (such as L=0, 2). It would be useful to have a realistic estimate of the contribution of these other multipoles, in order to assess whether their shape and magnitude will allow for a clear and unambiguous identification of the required L=1 contribution within the angular coverage of the experiment (10 to 40 deg cm for protons)."*

Response: Motivated by these comments, we have extensively reviewed our theoretical calculations to validate the cross sections previously estimated and to clarify the contributions from other states with different J^π. To our knowledge, these are the most complete calculations performed for the ^{9}Li(t,p)^{11}Li(1^-) reaction. The final 1^- states are described by a QRPA calculation, as in Refs. [1, 2], using single-particle levels calculated in a Saxon-Woods potential. It is to be noted that the dipole mode contributes in an important way to the ground state wavefunction of ^{11}Li and to the stability of the ^{11}Li halo, through RPA ground state fluctuations. The wavefunction of the ^{11}Li ground state has been validated by the good agreement of the calculated absolute cross sections ^{11}Li(p,t)^{9}Li(gs) and ^{11}Li(p,t)^{9}Li($3/2^-$) with the experimental findings [3, 4] . The cross section of the ^{9}Li(t,p)^{11}Li(1^-) reaction has been calculated making use of the same optical potentials in the DWBA approximation, in the prior representation, at a center of mass energy E_{cm}=22.5 MeV, which is the energy of the proposed experiment.

In Figure 1 the excitation function for the ^{9}Li(t,p)^{11}Li(1^-) reaction populating final 1^- states and smoothed out using a Lorentzian function with a width equal to 200 keV, is compared to the background associated with the population of the final states associated with the multipolarities $0^+, 2^+, 3^-$, treated as uncorrelated excitations. These excitation functions were obtained by integrating the corresponding double differential cross sections over the angle interval covered by the ISS (θ_{cm}=[10,40] deg). The dipole cross section integrated between 0 and 2 MeV corresponds to about 0.4 mb and dominates over the $0^+, 2^+$ and 3^- contributions. The differential cross sections (integrated between 0 and 2 MeV) shown in Fig. 2 clearly show that the angular range covered by the ISS contains the most adequate features of the distribution used to infer the spin and parity of the state of interest.

The ISS capabilities make the detection of protons at forward angles with high resolution possible. It is worth pointing out that the outstanding excitation energy resolution of the ISS (150 keV) may unveil characteristic features of the resonance shape that would not be possible to resolve using conventional detection setups.

In summary, the improved calculations show that the dipole resonance dominates over background contributions. The differential cross section also clearly indicates that at forward angles, we will be able to infer the spin and parity of the state without any ambiguity. The new calculations indicate an integrated cross section for the dipole and monopole contributions of about 0.4 mb and 0.1 mb, respectively, with the former being nominally a factor of four larger than previously estimated.

Comprehensive details about the calculations are available upon request.

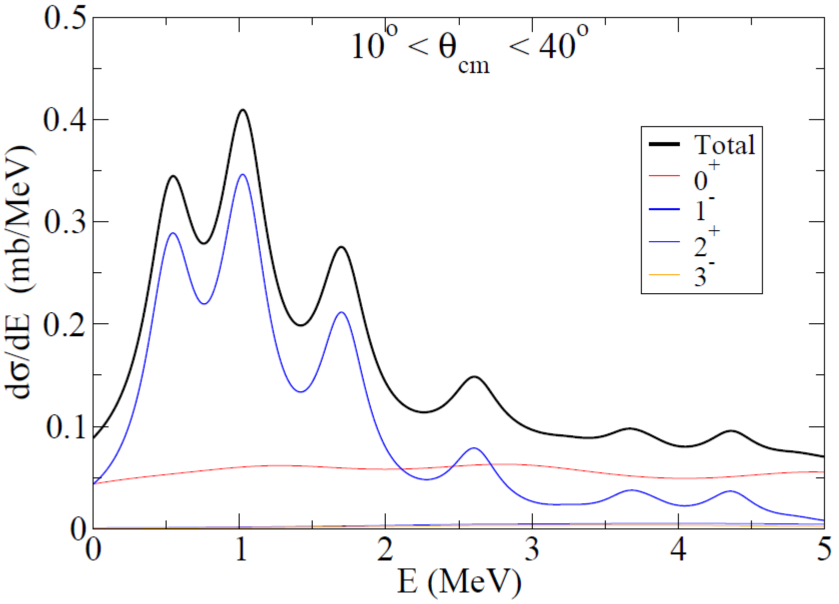

Figure 1: The total excitation function obtained integrating the double differential cross sections over the angle interval (θ_{cm}=[10,40] deg) as well as the contributions from the various multipolarities are shown.

Comment 4: *"From an experimental point of view, coincidences between backward emitted protons and forward emitted ^9Li in the laboratory system are to be detected. Since the 3H in the target is embedded in a Ti substrate, the rate of elastic scattering of 9Li on Ti going at the very small laboratory angles covered by the recoil detector could be a problem. In fact, due to the time structure of the ISOLDE beam, the instantaneous beam intensity is more than two orders of magnitude higher than the average one, and so is the instantaneous rate. A careful estimate of this rate must be done taking into account the beam time structure of ISOLDE."*

Response:

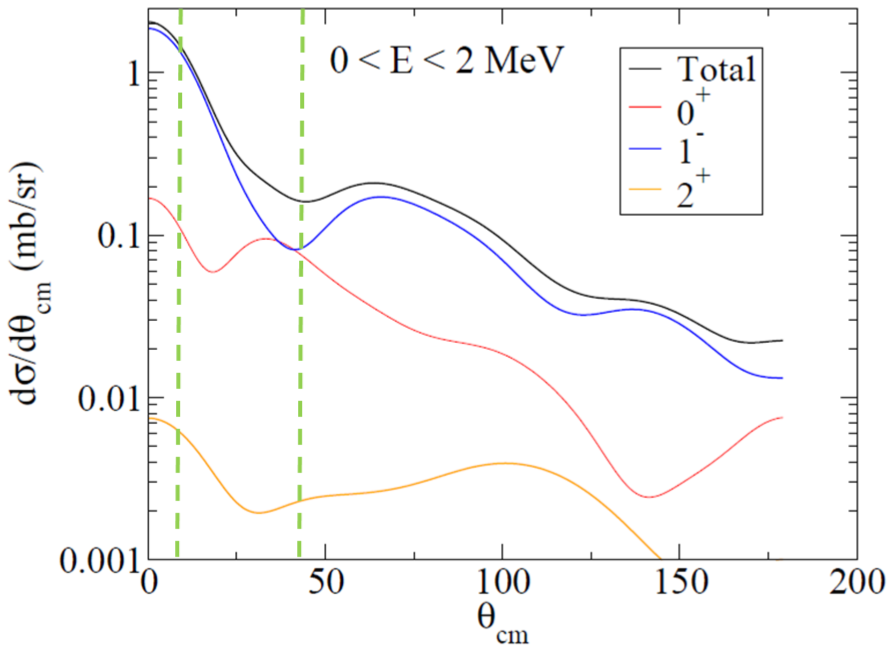

Figure 2: The differential cross sections obtained integrating the double differential cross sections over the energy range between 0 and 2 MeV as well as the contributions from the various multipolarities are shown. The green dashed lines refer to the angular domain covered in this experiment.

This is indeed a problem that any other experiment using tritiated foils will face. One solution is to move the recoil detector away from the target. However, in this particular experiment, and as can be seen in the reported calculations, it is of capital importance to measure at very forward angles. Our goal is to provide high quality data leveraging the outstanding capabilities of the ISS. Following the information provided by the committee, the revised beam intensity of around 2×10^5 pps mitigates any potential problems associated with recoil detection, as commented on below.

For the rate in the recoil detectors, we assume Micron *QQQ* quadrant detectors in a telescope arrangement approximately 600-mm downstream of the target. Their diameters are such that they subtend $\sim$1-5° in the lab frame. The target is assumed to be 450 μg/cm^2 of Ti. For a 10-MeV/u ^{9}Li beam, the integrated cross section over this detector is $\sim 2.5 \times 10^5$ mb, as determined from a simple elastic scattering calculations using the optical model (it is essentially the Rutherford scattering cross section in this case). For a 2×10^5 pps beam this is about 300 Hz over 2π or about 75 Hz per quadrant. Assuming 100 times great instantaneous rate, this is about 7000 Hz. While high, it is not unusual to use these recoil detectors at this rate, with a limit nominally around 10 kHz. We do not consider this an obstacle for this measurement.

References

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[3] G. Potel, F. Barranco, E. Vigezzi, and R. A. Broglia. Evidence for phonon mediated pairing interaction in the halo of the nucleus ^{11}Li. Phys. Rev. Lett., 105:172502, Oct 2010.

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