EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

Clarification letter to the ISOLDE and Neutron Time-of-Flight Committee related to INTC-P-508

Fusion hindrance at sub-barrier energies for weakly bound nuclei on heavy targets: the ^{8}B + ^{208}Pb case

October 5, 2017

A. Pakou[1], I. Martel[2], A. M. Sánchez-Benítez[2], N. Keeley[3], K. Rusek[4], N. Alamanos[5], R. Raabe[6], F. Cappuzzello[7,8], L. Acosta[9], A. Assimakopoulou[10], Ch. Betsou[11], D. Carbone[7], M. Cavallaro[7], M. La Commara[12,13], R. Lică[14,15], M. Mazzocco[16,17], N. G. Nicolis[1], A. K. Orduz[18], D. Pérez Álvarez[18], D. Pierroutsakou[12], J. S. Segovia[18], O. Sgouros[1], F. M. de Sola[18], V. Soukeras[1], G. Souliotis[10], A. Trzcinska[4], M. Wolinska-Cichocka[4], B. Zalewski[4], K. Zerva[1].

[1] Department of Physics and HINP, The University of Ioannina, Ioannina,Greece.
[2] Departamento de Ciencias Integradas, Universidad de Huelva, Huelva
[3] National Center for Nuclear Research, Otwock, Poland
[4] Heavy Ion Laboratory, University of Warsaw, Warsaw, Poland
[5] CEA-Saclay, DAPNIA-SPhN, 91191, Gif-sur-Yvette, France
[6]Instituut voor kern-en Stralingsfysica, KU Leuven, B-3001 Leuven, Belgium
[7] INFN-Laboratori Nazionali del Sud, Catania
[8] Dipartimento di Fisica e Astronomia, Universita di Catania, via S. Sofia 64, 95125, Catania, Italy
[9]Instituto de Fisica, Universidad Nacional Autonoma de Mexico, Mexico
[10]Department of Chemistry and HINP, National and Kapodistrian University of Athens, Greece
[11]Department of Physics and HINP, Aristotle University of Thessaloniki, Greece
[12] INFN-Sezione di Napoli, Napoli, Italy.
[13] Department of Physical Science, University of Napoli, Napoli, Italy.
[14]CERN, CH-1211 Geneva 23, Switzerland.
[15]Horia Hulubei National Institute of Physics and Nuclear Engineering, RO-077125 Bucharest, Romania
[16]Department of Physics and Astronomy, University of Padova, Padova, Italy.
[17] INFN-Sezione di Padova, Padova, Italy.
[18]C.H.U.H. Juan Ramn Jímenez, 21005 Huelva, Spain

Spokesperson: Athena Pakou - apakou@cc.uoi.gr
Local Contact: Razvan Lică - razvan.lica@cern.ch

Abstract:

This is a response to the reviewer comments of proposal P-508: Fusion hindrance at sub-barrier energies for weakly bound nuclei on heavy targets: the ^{8}B + ^{208}Pb case. Points related with the statistics of the experiment and the status of the present measurement in relation with an already approved proposal IS616 are clarified.

Requested shifts: 21 shifts - 7 days
Installation: 2nd beamline of HIE-ISOLDE

1 CLARIFICATION LETTER

Reviewer comment
" In addition, IS616 is an already-approved experiment exploring ^{8}B but with a ^{64}Zn target. The authors should address where the current proposal stands in relation to this other proposal. The committee felt that the case for the new proposal was not sufficiently clear in its objectives with regard to the other experiment. "

Our response
Both studies, the present proposal and the approved IS616, include:

1) Angular distribution measurements for elastic scattering and the ^{7}Be reaction product
2) Research in the area of reaction dynamics and channel coupling effects

HOWEVER

they address different physics cases: IS616 will be performed at an energy above the Coulomb barrier with a medium mass target and the present proposal is for an incident energy below the Coulomb barrier on a heavy target. In more detail the differences in the goals of these cases are:

In the area of reaction dynamics, IS616 aims to separate breakup and p-transfer production of the ^{7}Be reaction product in relation to the suppression of the Coulomb-nuclear interference effect (rainbow peak) in the elastic scattering. It will investigate the origin of the rainbow suppression (nuclear versus Coulomb origin) as was done by the same group for the neutron rich ^{11}Be projectile. It is also proposed to measure the core (^{7}Be) elastic scattering from the same target since it is believed that the implementation of the core excitation will be very important in the theoretical analysis of the ^{8}B data. This is a complicated but very interesting and challenging subject. From the elastic scattering the total reaction cross section will also be determined and therefore the fusion cross section at an above barrier energy, with the aim of resolving contradictions observed in previous measurements of fusion cross sections in the ^{8}B+^{58}Ni (E. F. Aguilera et al.) and ^{8}B+^{28}Si (A. Pakou et al.) systems at near barrier energies.

On the other hand the present study focuses on a simple but concrete and physically sound subject, namely an indirect fusion measurement for a weakly bound projectile at an incident energy BELOW the nominal Coulomb barrier where a fusion hindrance effect is expected from systematics; the ratio of direct to total reaction cross section should tend towards 1.0 for sub-barrier energies. This effect is ONLY predicted for heavy targets (see Fig. 1 of the proposal) but remains to be confirmed due to the difficulties of measuring the low direct reaction cross sections for most systems of this type involving stable weakly bound projectiles at these energies. Due to the large expected breakup channel, concentrated in a limited angular range, which is expected completely to dominate the ^{7}Be yield p-stripping should make a very small contribution, less than 5% , the ^{8}B+^{208}Pb system gives us the unique possibility to measure with a low flux beam the direct cross section below the barrier with sufficient precision (the ^{7}Be yield may safely be equated for our purposes with the direct reaction cross section in this system). We also propose simultaneously to measure the elastic scattering angular distribution which, in addition to being used for normalization purposes, will enable the necessary determination of the total reaction cross section. It will also be used as a tracer of the deviation of the elastic scattering from Rutherford scattering predicted by CDCC calculations; we predict a maximum deviation of about 20% at backward angles (see Fig. 2 of the proposal) although the calculations suggest that this is a static effect due to the influence of the halo structure of ^{8}B on the bare optical potential, the effect of coupling to the ^{8}B $\rightarrow$ ^{7}Be + p breakup being entirely negligible in the model used (difference of 1 to 2% in the calculation with and without coupling to continuum around the area of 50^{0} to 110 ^{0}). A study of a rainbow suppression is not intended since below the barrier no rainbow peak is predicted, even in the no-coupling calculations. We should mention that our group has already performed an elastic scattering and reaction dynamics experiment for the ^{7}Be+^{208}Pb system at near barrier energies at LNL, with the analysis in progress, and the EXOTIC group, has performed a measurement of the ^{8}B+^{208}Pb elastic scattering at above barrier energies at RIKEN with the analysis also in progress.

These two proposals, the present and the already approved IS616, are complementary from the point of view of the determination of total reaction cross section and fusion cross section and together with the results of the EXOTIC group from RIKEN, if appropriately reduced, could solve the contradictions of previous measurements on various targets as well as give more insight into the behaviour of a proton halo nucleus compared to the well studied neutron halo nuclei.

Last but not least we underline that the proposed measurement will be the first breakup measurement to be performed below the barrier for ^{8}B, enabling the predictions of large sub barrier breakup cross sections to be confirmed.

Reviewer comment

“ The proposers have substantial theoretical support and the calculations show some small differences between the different models that are shown. The discrepancies between the models are not meant to distinguish between different theories, but rather should be used as a guide as to whether any of the existing theories are valid for the magnitude of the

elastic and breakup cross-sections. Based on the theoretical aspects, the motivation of the proposal is convincing. However, there are questions regarding the statistical precision, which is being requested: the authors should make the case more clearly for the 1% precision that they state is needed. "

Our response

It is true that the measurement is not meant to distinguish between calculations with or without coupling to the continuum, the effect of which is of the order of 1 to 2% around the angular range of 50 to 110 degrees (the maximum predicted effect) and negligible elsewhere. This would be a difficult task even with a stable beam since the statistical error is not the only contribution to the experimental uncertainty. However, we do not claim to require a statistical error of 1%. In the proposal it is stated on page 6, 12 lines from the foot of the page, that with the beam time requested we should be able to obtain a statistical error of less than 1% for the measured elastic scattering at angles less than 38 degrees. This is the safe angular range where the scattering is expected to be Rutherford and since this cross section will be used for normalization purposes it is desirable to obtain it with as small an error as possible, although an error of less than 1% is by no means necessary. During the same beam time the errors for angles around 90, 130 and 160 degrees, where it will be easier to trace the predicted deviation from Rutherford scattering, will be 7, 8 and 12% respectively. This will be sufficient to trace the expected moderate deviation. However, the proposed statistics for the elastic scattering measurement are set by the requirements for an accurate determination of the total reaction cross section. According to the proposed beam time request, an error of 6% will be assigned to the total reaction cross section which will have to be combined with the breakup cross section determined with 10% error, and give finally an error on the fusion cross section of 40 mb taking into account the theoretical reaction and breakup cross sections. This is less than the predicted difference between the total reaction cross section and the breakup cross section (which may be equated to the direct reaction cross section to a good approximation in our case) of 55 mb (415-360 = 55 mb). Therefore, the requested uncertainty is suitable for discussing the subject of a possible trend for fusion hindrance; we will be able to determine whether the fusion cross section is small compared to the direct reaction cross section with sufficient accuracy.

The goal of our proposal was to obtain the above statistics taking into account a beam flux of $5x10^3$ pps and a target thickness of 1.5mg/cm^2. As the technical report for a ^{8}B beam gives at 43 MeV a beam flux of 2 to $3x10^3$ pps we have made in a simulation the optimization of our system in respect with the energy resolution as a function of the target thickness and found that instead of a 1.5mg/cm^2 thick target, a 2.5mg/cm^2 thick target can marginally be used. This does not fully recover the proposed statistics but does not dramatically change our conclusions, therefore we remain with our request for 21 BTU beam time.