PROPOSAL

Indirect study of the $^{12}C(^{12}C,\alpha)^{20}Ne$ *and* $^{12}C(^{12}C,p)^{23}Na$ reactions via the Trojan Horse Method applied to the $^{12}C(^{16}O,\alpha^{20}Ne)^{4}He$ *and* $^{12}C(^{16}O,p^{23}Na)^{4}He$ three-body reactions

1. Astrophysical motivation

Since more than four decades, the ^{12}C+^{12}C system stands out as one of the most interesting subjects to study, from the point of view of fundamental nuclear physics (first clear evidence of quasimolecular structures) as well as because of its astrophysical interest. In particular there is currently a great interest in the fusion channel in the low energy region because of its critical role in studying a wide range of stellar burning scenarios in carbon-rich environments. Indeed, this reaction is important to understand the carbon-burning nucleosynthesis occurring:

- in stars of more than 10 solar masses during their later evolutionary stages [1];
- in intermediate mass stars (8-10 solar masses) which may lead to a detonation wave and a supernova explosion under electron degeneracy [2];
- in binary systems, where a massive carbon-oxygen white dwarf overcomes the Chandrasekhar mass limit by accreting material from its companion star. This is another scenario where the electron degeneracy may detonate explosive carbon burning [3];
- in superbursts from accreting neutron stars [4].

A detailed knowledge of the carbon fusion processes is needed in order to shed light on all these scenarios and to put constraints on the models. The carbon burning temperature ranges from 0.8 to 1.2 GK, corresponding to center-of-mass energies E_{cm} from 1 to 3 MeV.

Considerable efforts have been devoted to measure the ^{12}C+^{12}C cross section at astrophysical energies, involving both charged particle and gamma ray spectroscopy [5]. Nevertheless, it has only been previously measured down to E_{cm} = 2.5 MeV, still at the beginning of the region of astrophysical interest.
As known, measurements at lower energies are extremely difficult. Moreover, in the present case the extrapolation procedure from current data to the ultra-low energies is complicated by the presence of resonant structures even in the low-energy part of the excitation function. Thus, further measurements extending down to 1 MeV would be extremely important. In this proposal we are going to discuss the indirect study of the $^{12}C(^{12}C,\alpha)^{20}Ne$ *and* $^{12}C(^{12}C,p)^{23}Na$ reactions via the Trojan Horse Method (THM) [6-8] applied to the $^{12}C(^{16}O,\alpha^{20}Ne)^{4}He$ *and* $^{12}C(^{16}O,p^{23}Na)^{4}He$ three-body processes in the quasi-free (QF) kinematics regime, where the α particle from the ^{16}O TH nucleus is spectator to the ^{12}C + ^{12}C two-body processes. A number of theoretical as well as experimental works claim that even low lying states of ^{16}O are described in terms of a ^{12}C+α configuration [9-11]. This interpretation is the only one which explains the enhanced electric transition rates and α-widths for those states.

2. Experimental procedure

We plan to investigate a ^{12}C + ^{12}C relative energy region from 3.5 MeV down to 1 MeV, in order to span the Gamow peak together with an extended part at the higher energies where direct data already exist. In this way we can perform a validity test of the THM in the overlap region and check if ^{16}O is a good TH nucleus.
To this aim we need a 28 MeV ^{16}O beam with a spot size on target of about 1 mm and intensities of 1-3 pnA, impinging onto a 100 μg/cm^2 isotopically enriched ^{12}C target. We choose appropriate kinematic conditions where the ^{12}C+α binding energy (7.16 MeV) inside ^{16}O compensates for the ^{16}O +^{12}C relative motion. Thus, the ^{12}C +^{12}C interaction takes place at E_{QF}= $(28 \frac{m_{^{12}C}}{m_{^{16}O}} \frac{m_{^{12}C}}{m_{^{12}C}+m_{^{12}C}} - 7.16)$ MeV= 3.34 MeV. A cutoff in the α momentum distribution of about 65 MeV/c (due to the Fermi motion of the α particle inside ^{16}O), fixes the requested 1 to 3.5 MeV range of ^{12}C-

^{12}C relative energies around E_{QF}. Since the ^{12}C projectile is virtual (initially it is in the bound state of ^{16}O), the Gamow factor does not appear in the $^{12}C+^{12}C$ entrance channel of the binary processes, allowing to extract their cross sections down to the relevant energies without experiencing either the Coulomb suppression or the screening effects. Following theoretical approaches based on the Impulse Approximation (IA), the experimental three-body cross section is factorized in terms of the two-body cross section of interest, of the α momentum distribution inside ^{16}O which is well known, and a kinematic factor [6-8]. Thus the relevant two-body cross section can be easily extracted.

If energy and angle of any two of the three outgoing particles are measured in coincidence, three body kinematic relations will allow us to completely identify the reaction channel. In particular we detect the ejectile of the two-body reactions (either α or p) in coincidence with the spectator α particle.

The heavy counterparts in the two-body reactions have quite low energy and, if detected, their energy reconstruction would be affected by additional uncertainties such as that coming from energy straggling on target.

In order to fulfil the QF requirement for the spectator α particle to be essentially part of the beam (to retain its initial momentum inside ^{16}O), this particle has to be detected at forward angles. Its energy ranges from 4 to 11 MeV. The particle identification will be supplied by a silicon telescope, consisting of 20 μm silicon detector as ΔE- and a 1000 μm Position Sensitive Detector (PSD) as E-stage. It will cover angles from 7° to 22°.

The other coincident particle (either α or p), whose energy ranges from 7 to 17 MeV (for the α) or from 4 to 11 MeV (for the proton), will be detected and identified close to the so called QF angles by means of two telescopes, each consisting of 20 μm silicon detector as ΔE- and a 500 μm Position Sensitive Detector (PSD) as E-stage. They will cover angles from 7° to 60°, which include also a dead region between them of about 5° to 10°, due to their holders.

The selected angular regions correspond to a quite wide angular range for the two-body center of mass angle $\theta_{c.m.}$, which is shown in Figure 1 correlated to the ^{12}C-^{12}C relative energy $E_{c.m.}$, as results from a Monte Carlo calculation.

3. Beam time request

A typical three-body cross section for reactions involving ^{16}O break-up is, in the worst case, of the order of about 1 mbarn/sr^2 MeV and we can also empirically estimate a QF channel contribution

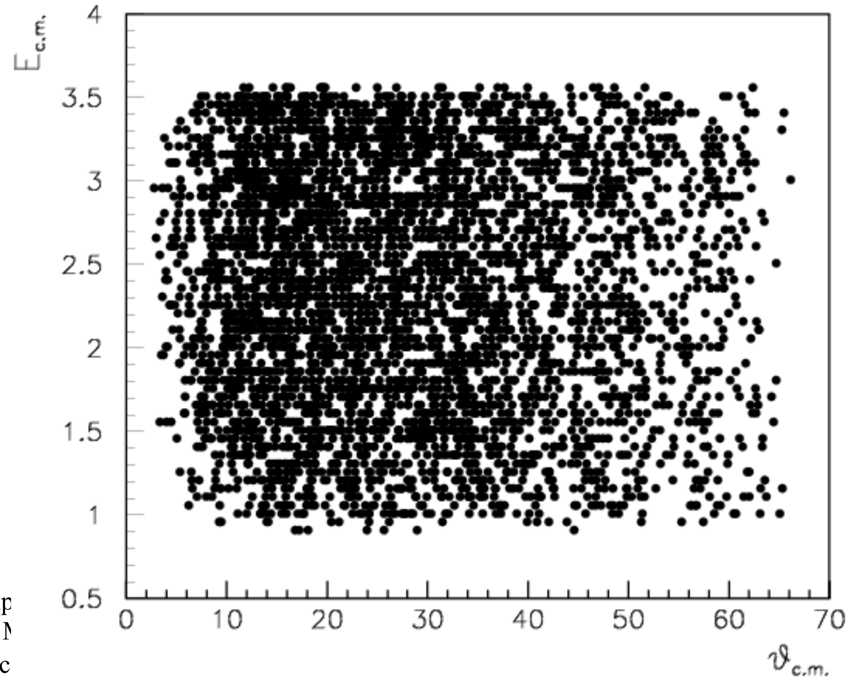

Figure 1. Examp) two-dimensional plot, resulting from a N ntum distribution for the spectator α partic

to this cross-section of as little as 10%. A ^{16}O beam intensity of 1-3 pnA impinging on a 100 μg/cm^2 C target would therefore yield about 0.1 cps for the selected phase space. In order to get a statistical error smaller than 5% for 10 keV bins, about 40000 events/MeV are required to get good statistics in the overall 0.5 - 3.5 MeV energy range. Therefore we require 42 BTU of beam time for the measurement itself (beam energy = 28 MeV).

Including also 3 BTU of beam time for the detector calibration procedure, we ask for a total beam time of 45 BTU.

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