Technical Report

Experiment 1031

Charged-particle exit channels from the ^{12}C+^{12}C fusion reaction at astrophysical energies

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1 Introduction

Carbon-carbon burning plays an important role in many astrophysical sites, both explosive and non-explosive. Current data not only show discrepancies in the derived astrophysical S-factors but also the presence of resonant structures which make the extrapolation to lower energies difficult with any degree of confidence. Improvements in our understanding of this reaction, therefore, will have widespread implications for many stellar models.

The aim of this proposal is to re-investigate the charged-particle reaction channels ^{12}C(^{12}C,α)^{20}Ne and ^{12}C(^{12}C,p)^{23}Na in the energy region E_{cm} = 3.0 - 4.0 MeV where existing data differ typically by a factor of 2. This experiment represents a necessary first step before extending the measurements to E_{cm} below 3.0 MeV where little experimental information is available at present.

The measurement will be undertaken in two stages at the TUDA facility using a pulsed ^{12}C beam and self-supporting enriched ^{12}C targets. Angular distributions and excitation functions will be measured for both exit channels in the range E_{cm} = 4.0 - 3.3 MeV (Stage I) and E_{cm} = 3.3 - 3.0 MeV (Stage II) in E_{cm} = 100 keV energy steps. Silicon strip detector arrays will be placed downstream and upstream so as to cover an effective total angular range $\theta_{cm} = 5^\circ$ - 70°. Particle identification will be achieved via TOF vs. total deposited energy techniques. Mott elastic scattering will be measured with a monitor detectors placed at 45° in the lab thus allowing for absolute cross section normalisation.

While standard nuclear physics techniques and instrumentation will be employed for this measurement, the precise knowledge of the interaction energy is critical at these low energies. Therefore, the accurate determination of the incident beam energy and of its energy loss in the target are essential. The beam energy calibration will be carried out using the DRAGON facility to an accuracy of at least 0.2%. The beam energy loss is affected by changes in the target thickness for example due to carbon build-up during runs. These will be monitored and corrected for by combining together information on the beam intensity (Faraday cup) and the elastic scattering data from the monitor detectors. Background sources, arising mainly from H and D contaminations on the target, will be kept at a minimum by using the cryopump.

2 Description of the Experiment

The setup up the experiment can be seen in the accompanying figure. There will be 4 detector arrays, 2 LEDAs and 2 S2s, 384 channels in total. This will be the largest number of channels ever run in the TUDA chamber in one experiment. The LEDA arrays are composed of 8 equal pie shaped sectors with 16 concentric strips each. Each pie shaped sector spans an arc of $360 \div 8 = 45$ degrees, the centre of which is concentric with the beam axis. The inside radius of each LEDA sector is 50mm with the width of each of each strip being 5mm. This gives $16 \times 8 \times 2 = 128$ channels for each LEDA array. The S2 detectors are are single chips, each with 48 continuous 360 degree concentric strips on the front face and 16 azimuthal strips on the rear face. The axis of the detectors are on the beam line. The inside radius of an S2 is 11.5mm and the outside radius is 35.5mm.

Not shown on the figure are two solid state devices which are placed at 45 degrees with respect to the beamline and target. The target and the two detectors will be co-planar such that the detectors will observe ^{12}C-^{12}C elastic scattering. From the beam energy as measured with the DRAGON facility, the beam intensity as measured with the regular TUDA faraday cup, and the known cross section from theory, the thicknes of the ^{12}C can be determined. The Mott formula can be applied to calculate the cross section since at the energies being requested the amplitude for nuclear interactions will only result in a very minor perturbation in the calculated cross section.

The solid state devices will detect both α's and protons from the incipient fusion reactions. The beam will be pulsed such that both the particle energy and time-of-flight with respect to the beam RF signal will be measured. This is sufficient for particle ID and to resolve which ^{23}Na or ^{20}Ne excited state is involved. The energy, particle type, and scattering angle are all that is needed to resolve the missing mass (excited state) of each nucleus. The detectors will cover c.m. scattering angles from 5 to 62 degrees for the ^{12}C(^{12}C,p)^{23}Na reaction and from 5 to 54 degrees for the ^{12}C(^{12}C,α)^{20}Ne reaction. Use is made that the cross sections are symmetric about 90 degrees in the c.m. frame such that the use of both forward and backward scattering events can cover a fair sized chunk of the total solid angle.

In order to prevent the downstream detectors from being swamped by heavy ions from elastic scattering, the detectors will be shielded with 8μ Aluminum foils. The heavy ions will stop in the foils, but not the α's and the protons. Heavy ions cannot be scattered into the backward hemisphere, hence the upstream detectors need no such protection.

The target ladder will be the one used in previous TUDA experiments, E879 and

E928. The targets will be self supported enriched foils of ^{12}C, 20 μg/cm^2 thick. The target ladder will also have the usual collimators to assist in focussing the beam, a small Faraday cup [1], CH$_2$, foils[2], more C foils but with a Au splash[3], and two triple α sources [4].

The TUDA acquisition system is VME based and capable of acquiring data from up to 512 electronic channels, which is more than enough for the proposed setup (max. 384). The VME DAQ is also capable of handling up to 20 kHz event rate and again this should be more than sufficient for this experiment. The data will be acquired online event by event allowing cuts and coincidence requirements to be applied offline as necessary. The data being acquired will be monitored online using a Sun workstation to verify beam and target status and detector/electronics stability. The electronics and the data aquisition system that will be used is the fairly standard TUDA setup, and except for some minor modifications and upgrades, has been used for all the previous TUDA experiments. The present electronics setup and DAQ was used as recently as May 2005 for the E1030 ^{11}Li decay experiment.

3 Technical Assistance from TRIUMF

There is little technical development required from TRIUMF. E1031 requires a 50 enA ^{12}C beam from OLIS. This is not a new beam and has been run before for the DRAGON ^{12}C$(\alpha, \gamma)^{16}$O experiment. The experiment will require fairly frequent beam energy changes of 100 keV in order to cover the E$_{cm}$ energy region of 3.3 MeV to 4.0 MeV. When scanning over a resonance, smaller energy changes will be required. There is a concern that these energy changes be done quickly and efficiently. The beam energies corresponding to this energy range is 6.6 to 8.0 MeV or 0.55 to 0.666 MeV/u.

Because we use the TOF with the beam RF signal for particle ID purposes, we will require a tightly bunched beam, on the order of 1ns.

To provide the operators with signals to indicate beam intensity and stability our Faraday Cup signal and event rate counter will be provided to the control room as usual. We will also provide the signal from our Mott scattering device. There will also be the usual 2 4-vane monitors, collimators, and the target ladder Faraday cup for tuning porposes. Care must be taken with the beam steering as to have beam directed right along the TUDA chamber axis as the S2 counters are just 11.5mm from the axis. A procedure will have to be worked out with the beam tuners as to how to determine when the beam is on axis.

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[1] This cup is for tuning purposes only. This is not the large downstream cup which will monitor beam current during the experiment

[2] for elastic scattering of protons to use in detector calibration

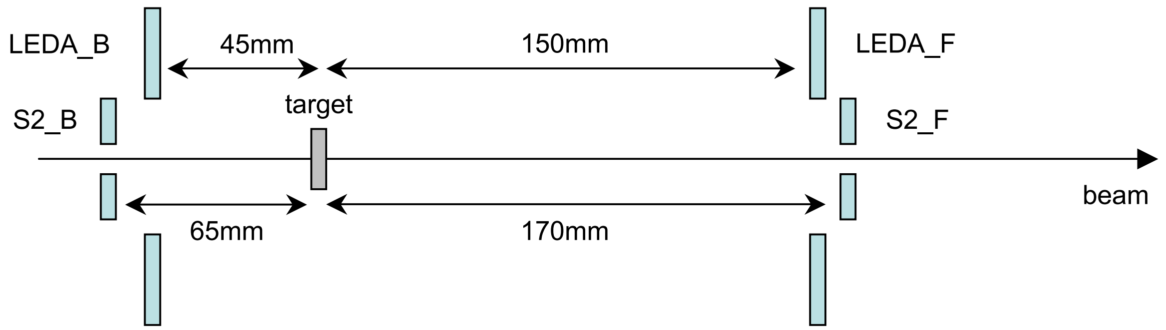
[3] for comparing ^{12}C - Au Rutherford scattering to Mott scattering

[4] These are Pu-Am-Cm sources for detector calibration. We need two, one for the upstream detectors and one for the downstream detectors.

As mentioned in the above text, it is essential to determine the exact energy of the ^{12}C beam. To do this we require to use the DRAGON facility. We should have sufficient personnel in our experimental group who know how to run DRAGON, hence this should not be too much of a problem, as long as the DRAGON group are aware of our intensions. Some of our personnel are also part of the DRAGON group, thus the communications with the DRAGON group should be excellent.

We are not aware of any other technical issues that need to be addressed that concern both TRIUMF and our experimental group.

SETUP
E1031



	Distance [mm]	lab_angle [deg]	Dtheta_cm[1] protons [deg]	Dtheta_cm[1] alphas [deg]	dtheta[2] [deg]	DToF [ns]
S2_F	170	4-12	5-14	5-15	±0.5	not needed[3]
LEDA_F	150	18-41	21-47	23-52	±1.1	4.3
LEDA_B	-45	109-132	118-139 (41-62)[4]	126-145 (35-54)[4]	±3.4	1.5
S2_B	-65	152-170	157-172 (8-23)[4]	160-173 (7-20)[4]	±1.0	2.7 (but almost not needed)

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[1] Values given here refer to p0 or a0 with respective recoils in their ground states

[2] Taking into account beam spot size effects

[3] In this angular range there are no interceptions between protons' and alphas' kinematics curves, hence no ToF discrimination is required

[4] Because of symmetry around theta=90º in cm system