Safety 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 $\theta_{cm} = 5° - 70°$. 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 $\mu g/cm^2$ 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 Safety Concerns

3.1 Radiation

Since ^{12}C is a stable nucleus there will be no concerns regarding radiation levels from a RIB. Radiation will only be a concern if the beam can produce radiation while interacting with the target or can activate portions of the beam line and experimental apparatus via the beam striking any component. In this case both beam on and beam off radiation could be a concern. However at the beam energies being considered for this experiment, the ^{12}C beam should not produce measureable activation because the projectile energy will be well below the coulomb barrier of any nuclei it should encounter. To overcome the coulomb barrier for the ^{12}C-^{12}C interaction would require a beam energy of 17.4 MeV. The maximum beam energy that will be required for this experiment is 8 MeV. Hence no significant radiation is expected.

However when beam is delivered, as a precaution, monitors will be used to note radiation levels, if any, and areas tagged and roped off as required. However the necessity for the latter is not expected.

It should be noted that the E_{cm} range we plan to use for this experiment is above the threshold for the $^{12}C(^{12}C,n)^{23}Mg$ reaction. Even though the cross section for this reaction is miniscule due to the coulomb barrier[5], there still should be measureable

[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.

[5] In fact the event rate should be equivalent to the event rate of the reactions we will be studying

amounts of this reaction because of the beam intensities we plan to use. The neutron can pentrate the TUDA chamber and ^{23}Mg is a radioisotope. However ^{23}Mg decays in 11.317 sec. via electron capture to ^{23}Na, hence there is no concern here. Neutrons could be a concern if there were enough of them, but this is not expected to be the case. If required, neutrons levels will be monitored when the beam is first brought on. DRAGON has used ^{12}C beams at higher energies for the $^{12}C(\alpha,\gamma)^{16}O$ experiment without incident.

There will be two 3kBq α sources on the target ladder. Both sources will be triple Am-Cm-Pu sources. One of the sources has been used in several other TUDA experiments. The other source is new. A label will be placed on the TUDA chamber to notify personnel of the presence of these sources. When not in use, the sources are placed in their containers and secured inside the TUDA shack.

3.2 Other Concerns

On June 19, 2004 the coolant lines to the LEDA preamps burst and sprayed the coolant ethylene-glycol onto the LEDA detectors causing major damage to the detectors and electronics. This problem was caused by overheating of the coolant lines by the electronics because the coolant flow was off and the preamps were on. This situation was inadvertently initiated on June 11, 2004. It took 8 days to fail. As one can see inattentiveness was the main source of the problem. In order to ensure against future occurances of this fault, procedures have now been initiated that will not allow TUDA to be operated unattended in an unsafe state. An unsafe mode has been defined as when one or more of the following systems are on:

- FTS RS44 Recirculating cooler
- ±15V Preamplifier PSU
- CAEN SY403 HV Mainframe

Futhermore warning labels will be attached to the ±15V Preamplifier PSU's and FTS RS44 Recirculating Cooler to ensure that under vacuum they are both ON or both OFF.

As all procedures are subject to human frailty, we will, in addition, install a mains interlock to guard against future occurrences of this incident. The interlock will be mounted on the 19" electronics rack by the TUDA chamber which houses the ±15V Preamplifier PSU's and the CAEN SY403 HV Mainframe. The 115VAC power for the ±15V preamplifier PSUs will be supplied from the rear panel of the unit. A type K thermocouple (bonded to one of the preamplifiers in the TUDA chamber) will also be connected to the rear panel.

The unit is designed so that if there is an ac power dip/cut, or if the thermocouple temperature exceeds c. 60° C, then ac power to the rear panel connectors (±15V preamplifier PSUs) will be removed and an audible/visual alarm will be triggered. To restore ac power to the rear panel and disable the audible/visual alarms requires a manual (key triggered) reset.

If the alarm is triggered, the procedure would be to check:

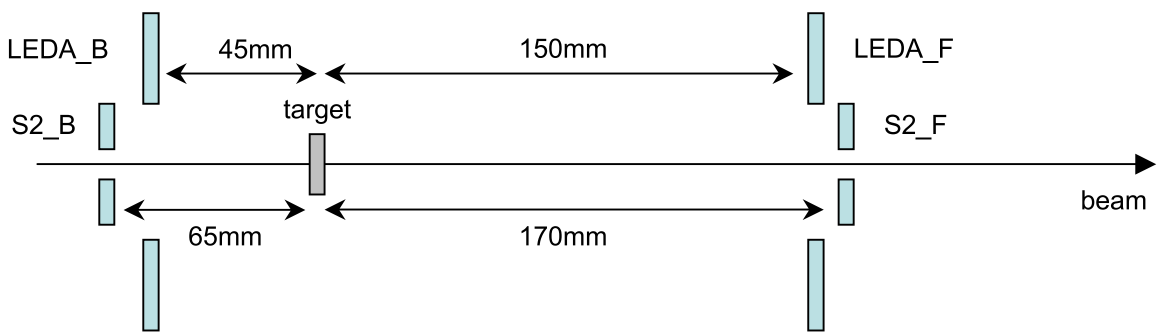
- vacuum pressure OK
- FTS RS44 on and at selected process temperature
- CAEN SY403 on, HV bias on

··· if OK, reset interlock.

The above incident, while an expensive lesson, was not a safety concern as there was no danger to any individual at any time. However, it was noted that ethylene-glycol while supposedly an innocuous compound actually degrades quite readily into a mildly corrosive substance. If it adheres to the skin, a good scrub gets rid of it. However its action on silicon solid state devices is catastrophic. It has therefore been resolved to replace ethylene-glycol with ethanol as the coolant. This substance will not harm the detectors. In fact it has been used to clean the surfaces. However ethanol has some properties which could be dangerous to individuals. The substance is flammable and emits noxious fumes. This coolant has been tested out successfully on the FTS RS44 unit on the TUDA mock up chamber in Edinburgh. The unit uses about a liter of ethanol and is sealed except for a lid on the reservoir in the FTS RS44 unit. Warning labels will be placed on the unit. All supplies of used and unused ethanol will be labelled and stored in the hazardous materials building. When the FTS RS44 unit is not in use for any extended period of time it will be emptied.

If TUDA is not allowed to use the ethanol, we will revert to ethylene-glycol until any outstanding issues are removed.

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)

[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