TRIUMF - RESEARCH PROPOSAL	**Experiment no.**	**Sheet** 1 **of** 19

Title of proposed experiment

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

Name of group

TUDA

Spokesperson for group

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Members of group (name, institution, status)

(For each member, include percentage of research time to be devoted to this experiment over the time frame of the experiment)

M. Aliotta	University of Edinburgh	Lecturer	30 %
A. M. Laird	University of York	Lecturer	30 %
C. J. Barton	University of York	Lecturer	10 %
L. Buchmann	TRIUMF	Senior Research Scientist	20 %
T. Davinson	University of Edinburgh	Senior Research Fellow	30 %
S. P. Fox	University of York	Scientific Officer	10 %
B. R. Fulton	University of York	Professor	10 %
J. José	UPC/IEEC Barcelona	Associate Professor	10 %
P. Mumby-Croft	University of York	Student	20 %
A. Murphy	University of Edinburgh	Lecturer	30 %
G. Ruprecht	TRIUMF	Research Associate	10 %
A. C. Shotter	TRIUMF	Full Professor	10 %
K. Vaughan	University of York	Student	20 %
P. Walden	TRIUMF	Research Scientist	50 %
D. Watson	University of York	Lecturer	10 %

Date for start of preparations: now

Date ready: June 2005

Completion date: June 2006

Beam time requested:

12-hr shifts	**Beam line/channel**	**Polarized primary beam?**
28 (Stage 1)	ISAC	No
28 (Stage 2)	ISAC	No

SUMMARY	Sheet 2 of 19

Do not exceed one page.

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 $^{12}C(^{12}C,\alpha)^{20}Ne$ 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} < 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 ΔE_{cm} = 100 keV energy steps. Silicon strip detector arrays will be placed downstream and upstream so as to cover an effective total angular range $\theta_{cm} = 5^o - 70^o$. Particle identification will be achieved via TOF (upstream detectors) and ΔE-E (downstream detectors) techniques. Mott elastic scattering will be measured with a monitor detector placed at a forward angle, thus allowing for absolute cross section normalisation. The monitor will also provide information on the combined effect of beam intensity and target thickness.

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, eg 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 detector. Background sources, arising mainly from H and D contaminations on the target, will be kept at a minimum by using cryopumps and target heating (if required).

BEAM and SUPPORT REQUIREMENTS	

Experimental area

ISAC-HE, TUDA

Primary beam and target (energy, energy spread, intensity, pulse characteristics, emittance)

OLIS, 12C 50enA

Secondary channel

Secondary beam (particle type, momentum range, momentum bite, solid angle, spot size, emittance, intensity, beam purity, target, special characteristics)

TRIUMF SUPPORT:
Summarize all equipment and technical support to be provided by TRIUMF. If new equipment is required, provide cost estimates.

NOTE: Technical Review Forms must also be provided before allocation of beam time.

High intensity bunched ^{12}C beam (1mm beam spot)
Operational support

NON-TRIUMF SUPPORT:
Summarize the expected sources of funding for the experiment.
Identify major capital items and their costs that will be provided from these funds.

The TUDA scattering facility, targets, electronics and detectors, as well as manpower, will be provided by the Universities of Edinburgh and York.

SAFETY	

Summarize possible hazards associated with the experimental apparatus, precautions to be taken, and other matters that should be brought to the notice of the Safety Officer. Details must be provided separately in a safety report to be prepared by the spokesperson under the guidance of the Safety Report Guide available from the Science Division Office.

Low voltage detectors and electronics.

Standard alpha particle calibration.

1. Astrophysical motivation and current status

The astrophysical importance of the $^{12}C+^{12}C$ fusion reaction is well known and arguably second only to that of the $^{12}C(\alpha,\gamma)^{16}O$ rate. It plays a crucial role in many stellar environments, both quiescent and explosive, and consequently the implications of the current uncertainty in this rate affect many astrophysical models, including super-AGB stars, super-bursts in X-ray bursts models and type Ia supernovae [1].

For most purposes, such as energy generation or the general course of nucleosynthesis, it is only the total fusion reaction cross section that is needed. The reason being that the alpha particles, protons and neutrons liberated in the reactions are readily captured by the fusion residues themselves. Thus, for example, the reactions

$$
\begin{aligned}
^{12}C + ^{12}C &\rightarrow ^{20}Ne + ^{4}He \qquad (1)\\
&\rightarrow ^{23}Na + ^{1}H \qquad (2)\\
&\rightarrow ^{23}Mg + n \qquad (3)
\end{aligned}
$$

lead quickly to $^{12}C+^{12}C \rightarrow ^{24}Mg + \gamma$. However, partial cross sections such as (1-3) are needed as inputs for the nucleosynthesis codes in which the flow of nuclear reactions involving hundreds of nuclei is followed [2].

In standard stellar models, the $^{12}C+^{12}C$ fusion reaction is one of the key factors differentiating between the evolutionary paths leading to either white dwarfs or heavy element burning stages. In fact it is the uncertainty in this rate that is responsible for the present uncertainty in the cut-off mass (~ 8 M_{sun}) separating these two paths [1]. In type Ia supernovae, carbon-carbon fusion initiates a thermonuclear runaway on the white dwarf once the Chandrasekhar mass has been exceeded. Changes in the reaction rate imply that carbon will ignite elsewhere (i.e. at different densities) with important consequences for the resulting nucleosynthesis [3].

For standard stellar models and for carbon ignition in type Ia supernovae, the relevant temperature range T = 0.8 – 1.2×10^9 K corresponds to E_{cm} = 1.7 – 3.3 MeV. In the case of super-bursts, the relevant regime extends up to T ~ 2.5×10^9 K (E_{cm} = 5.7 MeV).

To date, the $^{12}C + ^{12}C$ fusion reaction has been measured down to E_{cm} = 2.45 MeV using both γ-ray spectroscopy and charged particle detection [4-12]. Yet, the agreement between the various data sets is far from perfect. At very low energies the discrepancy is likely to be caused by errors in the energy scales and, to a lesser extent, by target thickness effects. Indeed, at sub-Coulomb energies where cross sections drop by several orders of magnitude, the accurate determination of the interaction energy is as important as the cross-section measurements themselves. As an example of the current disagreement between data sets, the $\hat{S}(E)$ factor for the α-particle (a) and proton (b) exit channels of the $^{12}C+^{12}C$ fusion reaction is shown in Figure 1. Here $\hat{S}(E)=E\sigma(E)\exp(2\pi\eta+gE)$ where η is the usual Sommerfeld parameter and g = 0.46 MeV^{-1} [12]. The summed contribution from both exit channels is shown in the bottom panel (c) together with results from previous work [5]. While it is apparent that strong resonant structures persist down to the lowest energies investigated and may continue to exist at even lower beam energies, it is clear that the two data sets disagree below $E_{cm} \sim 5$ MeV. Additional investigations in this energy region, as well as an extension to $E_{cm} < 3$ MeV are clearly needed.

Currently, the reaction rate used in the astrophysical models is based on the value S(E) = $3x10^{16}$exp(-0.46E) MeV-b as quoted in [13] from the evaluation of three data sets [12, 4 and 6]. The reference, however, does not quote any uncertainty. This is not altogether surprising considering the difficulty of extrapolating from the existing data down to astrophysical energies. Clearly strong resonance contributions (or indeed their absence) in the lower energy region could significantly change existing predictions.

In summary, a better understanding of the $^{12}C+^{12}C$ fusion reaction is critically needed for a wide range of astrophysical models. In particular, accurate cross-section data in the energy range E_{cm} = 1.7 – 5.7 MeV are required to base astrophysical implications on firmer ground.

It is proposed to re-investigate the charged-particle contribution to the $^{12}C+^{12}C$ fusion reaction in the energy range E_{cm} = 3.0 – 4.0 MeV. The extension of these measurements to energies below E_{cm} = 3.0 MeV will require an experimental setup substantially different from the one envisaged here. As briefly outlined in section 5, such a setup will make use of the TACTIC detector (currently under development) in order to overcome the problems which would otherwise hamper investigations at these low energies. A related proposal will be submitted in due course to EEC, upon successful completion of the presently proposed investigation.

2. The experiment

2.1 Objectives and Methodology

The present proposal addresses the investigation of the $^{12}C(^{12}C,p)^{23}Na$ and $^{12}C(^{12}C,\alpha)^{20}Ne$ reaction channels in two stages.

Stage 1 will cover the energy range $E_{cm} \sim 3.3 – 4.0$ MeV; and

Stage 2 will cover the energy range $E_{cm} \sim 3.0 – 3.3$ MeV.

The measurements will be carried out using self-supporting enriched ^{12}C targets (typical thickness ~20 μg/cm^2) in ΔE_{cm} = 100 keV energy steps. In regions where resonances are expected, finer energy steps will be used.

The motivation to study the above energy ranges is twofold. Firstly we aim to resolve the present discrepancy in the total cross section by using improved detection techniques. This will both be relevant to astrophysical issues and will prove crucial to lower energy measurements as the experience gained will highlight critical issues for future studies optimisation. Secondly, we will address the outstanding issue of the extent to which resonances contribute to the astrophysical S(E) factor in this energy region, where indeed only one data point ($E_{cm} \sim 3$ MeV) seems to indicate the presence of a strong resonance [12] not seen in the other data set [5].

In the range E_{cm} = 3.0 – 4.0 MeV, several excited states in ^{23}Na and ^{20}Ne can be accessed as shown in Figure 2. For the minimum beam energy E_{lab} = 6 MeV (E_{cm} = 3 MeV) the kinematical curves of the emitted protons and alpha particles leading to various excitation energies in the respective residual nuclei are shown in Figure 3. It should be noted that states above the alpha threshold in ^{20}Ne can also be populated leading to sequential (or simultaneous) emission of two alpha particles. If not properly taken into account, this effect may lead to double-counting problem and in some cases might have been a source of discrepancy between data sets in the high energy region. Owing to the much larger solid angle coverage in this experiment (see below) it will be possible to quantitatively measure this effect, thereby achieving an improvement with respect to previous measurements.

For both reaction channels, excitation functions and angular distributions will be obtained by detecting the ejectiles over a wide angular range by means of highly segmented silicon detector arrays. Particle identification will be obtained by time-of-flight with respect to a pulsed carbon beam and $\Delta E/E$ telescope technique. Angular distributions will be normalized to the ^{12}C+^{12}C elastic scattering, which follows Mott scattering at $E_{cm} \leq$ 6.5MeV, thus allowing for absolute total cross section determination for each exit channel.

2.2 Experimental Setup

The experimental setup is sketched in Figure 4. It will consist of three silicon strip detector arrays placed downstream and upstream of a self-supporting enriched ^{12}C target at the distances shown in the figure. The overall angular range corresponds to $\theta_{cm} \cong 5^o - 30^o$ and $\theta_{cm} \cong 110^o - 150^o$ with angular resolution $\Delta\theta_{cm}$=2° (most forward detector) and $\Delta\theta_{cm}$=1.3° (most backward detector). Since the particles in the entrance channel are identical, the angular distributions of all reaction products will be symmetric around $\theta_{cm} = 90^o$. Hence, the above angular ranges will effectively correspond to $\theta_{cm} \cong 5^o - 70^o$ (with some overlap around $\theta_{cm} = 30^o$) with little loss of information in the total $\theta_{cm} = 0^o - 90^o$ range. Such an arrangement will allow for a consistency check of the relative cross section magnitude above and below 90°.

Due to the high event rate at small angles, foils will be placed in front of the downstream detectors to stop the elastically scattered beam particles (max θ_{lab} = 90°).

The normalization of the solid angle (here ~ 38% of 4π) will be carried out by using an α source and the elastic scattering from a gold foil. In addition, a well collimated monitor detector (not shown in Figure 4) will be placed at forward angles to monitor the combination of target thickness and beam intensity via the ^{12}C+^{12}C elastic scattering yield, which at sub-Coulomb energies can be described by pure Mott scattering. A Faraday cup placed at the end of the TUDA chamber will be used to stop the beam and to monitor beam intensity variations during the measurement. This combination will allow the monitoring of target thickness changes (eg. due to carbon build-up) during runs. If needed rotating targets will be used to minimise such an effect. The energy calibration (detector/electronics) for both protons and alphas will be performed using a triple-line α source and proton elastic scattering from CH_2 foils.

2.3 Beam Energy Calibration, Target Thickness and Background Issues

The discrepancies in existing data sets have highlighted the need for a high accuracy beam energy determination. The reaction cross sections to be studied are extremely sensitive to the interaction energy and so both the initial beam energy and the beam energy loss through the target must be accurately known. In order to determine our initial beam energy, we propose to use the DRAGON separator which has been calibrated using a variety of reactions and can measure the beam energy to 0.1-0.2%.

The beam energy loss depends on the target thickness which may increase due to carbon build-up during runs. Previous measurements seem to suggest that this is not a limiting effect. However, once the beam energy is known, the target thickness can be determined in-situ, from the elastic scattering data. In addition, checks of target thickness will be performed both before and after runs using a triple-line α source.

The main source of background arises from water contamination of the carbon targets. At low energies the elastically scattered protons dominate the reaction cross section, whereas higher energy protons can be produced by the $D(^{12}C,^{13}C)p$ reaction on deuterium contamination in water. It is expected that both contaminants can be significantly reduced by using a cryopump recently installed in the TUDA chamber. If this does not prove satisfactory, the target will be heated during the runs to reduce water vapour condensing on its surface.

2.4 Data Analysis

The TUDA acquisition system is VME based and capable of acquiring data from up to 512 electronic channels, which is more than enough for our proposed set up (max. 320). The VME DAQ is also capable of handling up to 20 kHz event rate and again this should be more than sufficient for our purposes. 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.

2 Beam Request

The total beam time requested is 56 shifts of ^{12}C beam to be delivered in two stages. Stage 1 will cover the energy region E_{cm} = 4.0 – 3.3 MeV (28 shifts) and Stage 2 will cover the energy range E_{cm} = 3.3 MeV – 3.0 MeV (28 shifts) as indicatively summarised in Table 1. The regions will typically be covered in 100 keV energy steps with smaller step sizes in the region of expected resonances. The above request is based on the following:

- beam intensity $i = 10^{11}$ pps (eg 50nA, $^{12}C^{3+}$)
- target thickness $dx = 20\ \mu g/cm^2$
- total efficiency $\eta = 10\%$ (conservative estimate)
- cross sections values as given in [12] for the alpha channel only

The requested number of shifts reflects the importance of acquiring enough statistics over a large angular range to accurately determine the total cross section at each energy.

It is expected that there will be a period of several months between stages 1 and 2 to allow for data analysis and for any necessary improvements to be implemented. Additional beam time of 10 shifts is requested, in advance of stage one, to investigate the extent of carbon build up and water contamination of the target, in the relevant energy region.

3 Readiness

The TUDA scattering facility and the necessary manpower will be available for preparation as of January 2005. The required detectors are available and the recently installed VME data acquisition is capable of handling the number of channels as well as the predicted event rate. The rotating target should be ready to be installed by this time. It is therefore expected that the TUDA facility will be capable of running the initial phase of the proposed experiment as of June 2005.

It should be highlighted that the measurements proposed here rely on present beam capabilities and existing equipment. The TUDA group have extensive experience of such measurements and the analysis, interpretation and publication of these data can be foreseen on relatively short timescales.

4 Future direction

From the astrophysical standpoint, it is extremely important to extend these measurements to even lower energies, i.e. below 3 MeV. This however would not be possible using the technique presented. Therefore, in order to push the measurements to lower energies, we intend to submit a related proposal to a future EEC based on the use of the TACTIC detector.

TACTIC is a gas-based detector and would have several significant advantages over the current set up. The cylindrical design of TACTIC would increase the geometrical efficiency to approximately 80%. In addition, since TACTIC uses a gas target, the background issues related to water contamination of the target foils, which limited the precision of previous measurements, will be severely reduced. Background protons kicked out from the entrance window can also be rejected offline using trajectory reconstruction. Measurements with TACTIC will initially cover the energy region around 3 MeV in order to provide a comparison with data from the measurement proposed here and to validate calibrations and normalisations. Once the operation of TACTIC has been verified, the measurements will be extended to as low energies as possible using the new set up and available beam intensities. It is expected that TACTIC will be ready to take beam by 2006.

5 References

[1] G. Wallerstein et al.: Rev. Mod. Phys. 69(4) (1997) 995

[2] C. Barnes et al.: *Heavy-Ion Reactions in Nuclear Astrophysics* in: Treatise on Heavy-Ion Science, Vol 6 – Ed. D. Allan Bromley

[3] J. José: private communication (2004)

[4] J.R. Patterson et al: Astrophys. J. 157 (1969) 367

[5] M.G. Mazarakis and W.E. Stephens: Phys. Rev. C7 (1973) 1280

[6] H. Spinka and H. Winkler: Nucl. Phys. A 233 (1974) 456

[7] K.U. Kettner et al.: Phys. Rev. Lett. 38 (1977) 337

[8] W. Galster et al.: Phys. Rev. C15 (1977) 950

[9] M.D. High and B. Čujec: Nucl. Phys. A 282 (1977) 181

[10] H.W. Becker: Diplomarbeit, Institute fuer Kernphysik, Muenster (1978)

[11] K.U. Kettner et al.: Z. Phys. A 298 (1980) 65

[12] H.W. Becker et al.: Z. Phys. A 303 (1981) 305-312

[13] G.R. Caughlan and W.A. Fowler: Atomic Data and Nucl. Data Tables 40 (1988)

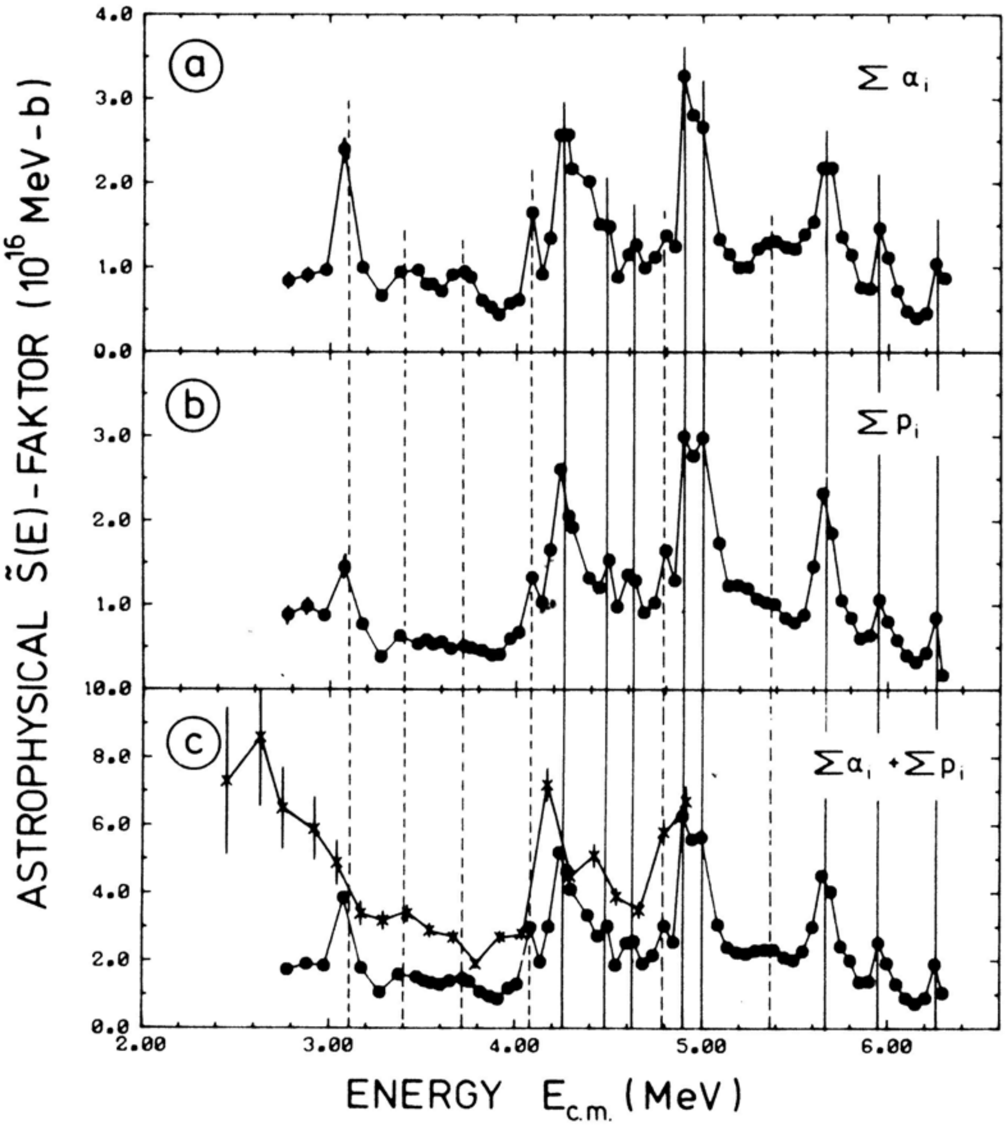


Figure 1: Summed Ŝ(E) values for the α-particle (a) and proton (b) exit channels of the 12C+12C fusion reaction. The summation of both exit channels is shown in (c) together with the results from previous work [Mazarakis et al.](cross symbols). The vertical solid lines represent the reported energetic locations of the intermediate resonance structures [Galster et al], while the dashed lines indicate the presence of possible additional resonances. (From Becker et al. 81)

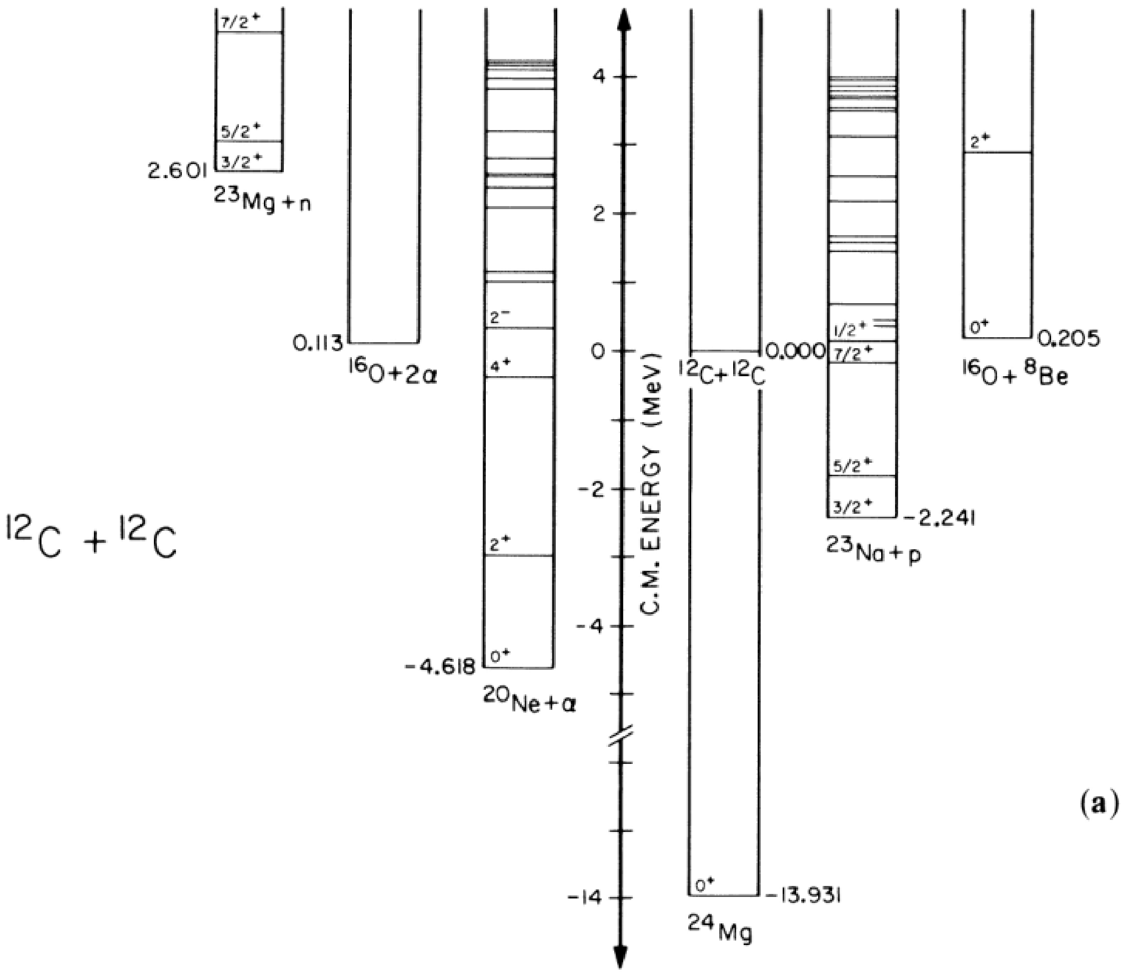
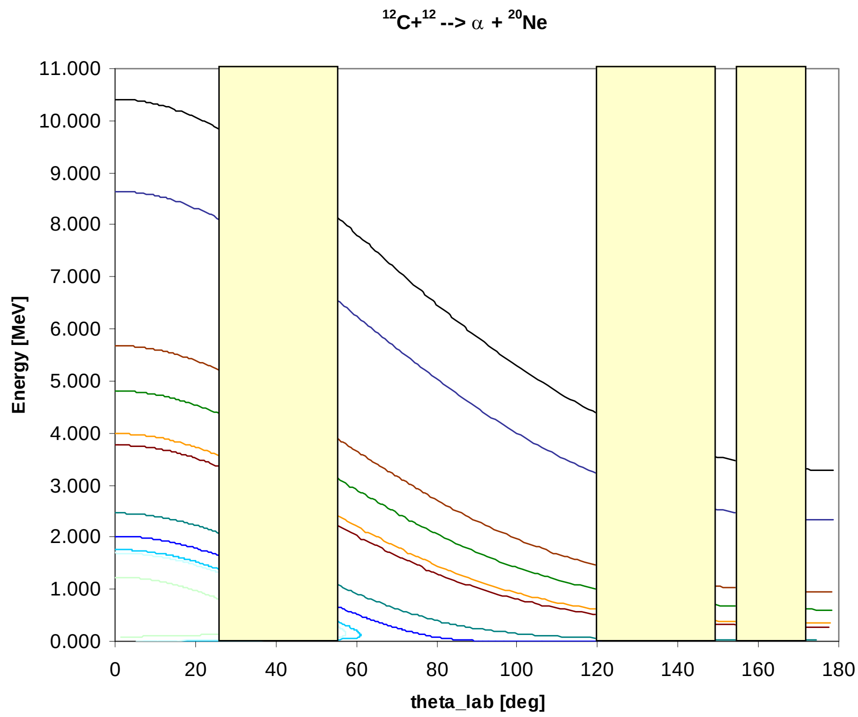


Figure 2: Q-value diagram indicating open channels



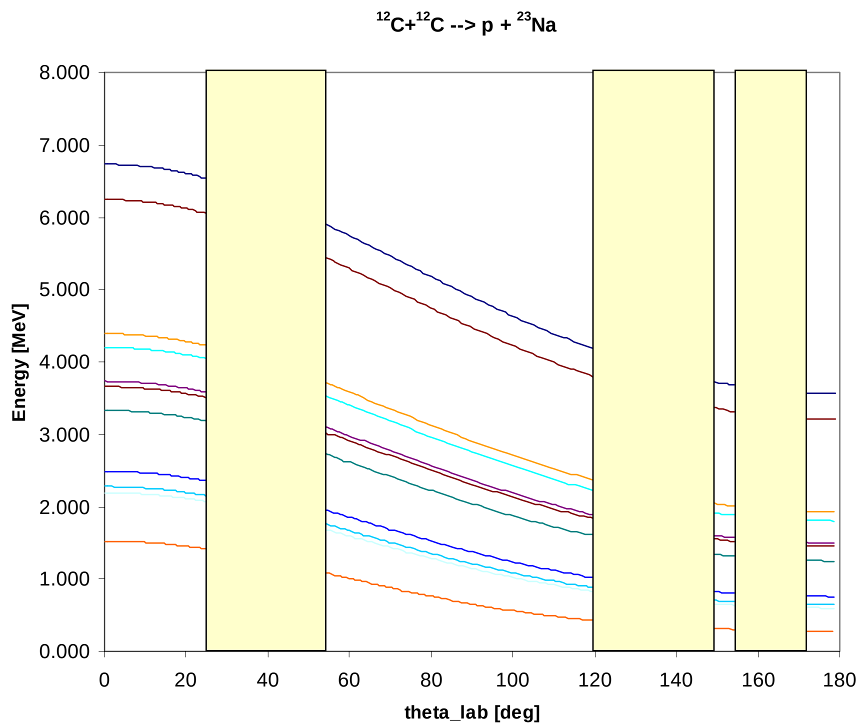


Figure 3: Kinematics for alpha (top) and proton (bottom) exit channels at Elab = 6 MeV. Lines correspond to various excitation energies of the residual nuclei ^{20}Ne and ^{23}Na respectively. Rectangles indicate the angular ranges covered by the detectors (see text for details).

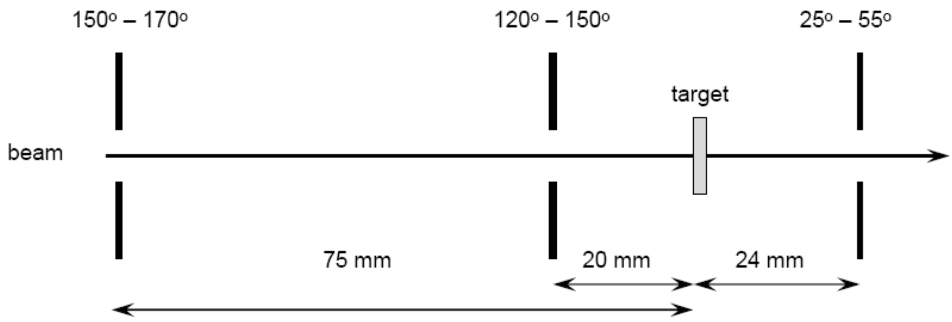


Figure 4: Sketch of the experimental setup.

The monitor for the elastic scattering is not shown.

	E_cm [MeV]	sigma [ub]	rate [counts/s]	# shifts [12 h]	total counts	precision %
stage 2	3.0	0.015	1.5E-04	14	90.7	10.5
	3.1	0.040	4.0E-04	6	103.7	9.8
	3.2	0.035	3.5E-04	8	121.0	9.1
	3.3	0.050	5.0E-04	6	129.6	8.8
stage 1	3.4	0.300	3.0E-03	2	259.2	6.2
	3.5	0.700	7.0E-03	2	604.8	4.1
	3.6	0.700	7.0E-03	2	604.8	4.1
	3.7	2.000	2.0E-02	2	1728.0	2.4
	3.8	2.500	2.5E-02	2	2160.0	2.2
	3.9	2.500	2.5E-02	2	2160.0	2.2
	4.0	5.500	5.5E-02	2	4752.0	1.5

Table 1: Indicative breakdown of beam time request. The8 shifts unaccounted for in stage 1 will be used for finer energy step measurements where resonances are expected (see text for details).

Spokesperson's (A. Laird) List of Publications.

J.M. D'Auria *et al.,* Phys. Rev. C 69 (2004) 065803
The $^{21}Na(p,\gamma)^{22}Mg$ *reaction from* $E_{c.m.}$*=200 to 1103 keV in novae and x-ray bursts*

O.R. Kakuee, Nucl. Phys. A *in press*
Elastic scattering of the halo nucleus ^{6}He *from* ^{208}Pb *above the Coulomb barrier*

R. Raabe *et al*., Phys. Rev. C 67 (2003) 044602,
2n-transfer contribution in the $^{4}He(^{6}He,^{6}He)^{4}He$ *cross section at* E_{cm} *= 11.6 MeV*

A.R. Junghans *et al*., nucl-ex/0308003, 8/5/2003,
Precise measurement of the $^{7}Be(p,\gamma)^{8}B$ *S-factor*

S. Bishop *et al.,* astro-ph/0303285, 3/13/2003
The $^{21}Na(p,\gamma)^{22}Mg$ *Reaction and Oxygen-Neon Novae*

S. Bishop *et al*., Phys. Rev. Lett 90 (2003) 162501; Erratum Phys. Rev. Lett 90 (2003) 229902
The $^{21}Na(p,\gamma)^{22}Mg$ *Reaction and Oxygen-Neon Novae*

D.A. Hutcheon *et al*., NIM A498 (2003) 190
The DRAGON facility for Nuclear Astrophysics at TRIUMF-ISAC: Design, Construction and Operation

U. Greife *et al*., submitted to NIM B
Energy loss of stable and radioactive ions in hydrogen gas

A. Olin *et al*., Proceedings of the International Conference on Classical Nova Explosions, AIP Conf. Proc. 637 (2002) 119
Nuclear Astrophysics at ISAC with DRAGON: Initial Studies

D. Groombridge *et al*., Phys. Rev. C 66 (2002) 055802
Breakout from the hot CNO cycle via the $^{18}Ne(\alpha,p)^{21}Na$ *reaction. II. Extended energy range* $E_{c.m.}$ *approx 1.7-2.9 MeV*

A.M. Laird *et al*., Phys. Rev. C 66 (2002) 048801
Indirect study of the astrophysically important $^{15}O(\alpha,\gamma)^{19}Ne$ *reaction through* $^{2}H(^{18}Ne,^{19}Ne)^{1}H$

A. Lepine-Szily *et al*., Phys. Rev. C65 (2002) 054318
Observation of the Particle-Unstable Nucleus ^{10}N

T. Davinson *et al*., Nucl. Phys A701 (2002) 188c
Louvain-Edinburgh Detector Array (LEDA): A silicon detector array for use with radioactive nuclear beams

S. Cherubini *et al*., Nucl. Phys A701 (2002) 632c
New Developments and Recent Results in Nuclear Astrophysics at Louvain-la-Neuve

A.N. Ostrowski *et al*., Nucl. Phys A701 (2002) 621c
Break-Out from the Hot-CNO Cycle Studied with Radioactive Beams

R. Raabe *et al*., Nucl. Phys A701 (2002) 387c
Measurement of the ^{4}He(^{6}He,^{6}He)^{4}He Cross Section with a ^{4}He-Implanted Al Target

A.N. Ostrowski *et al*., NIM A480 (2002) 448
CD: A double sided silicon strip detector for radioactive beam experiments

A.N. Ostrowski *et al.,* Phys. Rev. C63 (2001) 024605
Borromean Nucleus Reactions Induced below the Breakup Threshold: ^{6}He + p

A.M. Laird *et al*., Nucl. Phys A688 (2001) 134c
Hot CNO Breakout: Status of the d(^{18}Ne,p)^{19}Ne(α)^{15}O Reaction*

D. Groombridge *et al*., Nucl. Phys A688 (2001) 472c
Breakout from the Hot-CNO Cycle via the ^{18}Ne(α,p)^{21}Na Reaction

S. Cherubini *et al*., Nucl. Phys A688 (2001) 465c
The ^{15}O(α,γ)^{19}Ne Reaction using a ^{18}Ne Radioactive Beam*

T. Davinson *et al*., NIM A454 (2000) 350
Louvain-Edinburgh Detector Array (LEDA): a silicon detector for use with radioactive nuclear beams

J.M. Oliveira *et al*., Phys. Rev. Lett 84 (2000) 4056
Observation of the ^{11}N Ground State

A.M. Laird *et al*., Proceedings of the Experimental Nuclear Physics in Europe Conference, AIP Conference Proceedings 495 (1999) 367
A study of the ^{15}O(α,γ) reaction via the α-decay of ^{19}Ne

R. Raabe *et al*., Proceedings of the Experimental Nuclear Physics in Europe Conference, AIP Conf. Proc. 495 (1999) 9
Elastic 2n-transfer in the ^{4}He(^{6}He,^{6}He)^{4}He scattering

A.M. Laird *et al*., Proceedings of the Nuclei in the Cosmos V Conference, Edition Frontier (1998) 415
The d(^{18}Ne,^{19}Ne)p Reaction: A way to measure ^{15}O(α,γ) ?*

W. Bradfield-Smith *et al*., Proceedings of the Nuclei in the Cosmos V Conference, Edition Frontier (1998) 419
Break-Out from the Hot CNO Cycle via ^{18}Ne(α,p)^{21}Na

R. Raabe *et al*., Phys. Lett. B458 (1999) 1
Elastic 2n-Transfer in the ^{4}He(^{6}He,^{6}He)^{4}He Scattering

A.N. Ostrowski *et al*., Phys. Rev. C60 (1999) 064603

Nuclear Forward Glory, σ_R and $f_N(0°)$ in the Scattering of ^{6}He by Carbon

W. Bradfield-Smith *et al*., Phys. Rev. C59 (1999) 3402
Breakout from the Hot CNO Cycle via the $^{18}Ne(\alpha,p)^{21}Na$ Reaction

W. Bradfield-Smith *et al.,* NIM A425 (1999) 1
Investigation of (α,p) Reactions using a Radioactive Beam

A.N. Ostrowski *et al*., J. Phys. G24 (1998) 1553
Low-Energy Radioactive Ion Beam Induced Nuclear Reactions

Spokesperson's (M. Aliotta) List of Publications.

Indirect $^7Li(p,\alpha)^4He$ reaction at astrophysical energies

C. Spitaleri, M. Aliotta, S. Cherubini, M. Lattuada, Đ. Miljanić, S. Romano, N. Soić, M. Zadro, R.A. Zappalà
Physical Review C60 (1999) 55802 – 1.

The $^6He+^6Li$ reactions and exotic states of ^{10}Be

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