ELSEVIER

Nuclear Physics A688 (2001) 549c–551c

NUCLEAR PHYSICS A

www.elsevier.nl/locate/npe

Recoil separator ERNA*: improved measurements of the astrophysical key reaction $^{12}C(\alpha,\gamma)^{16}O$

D. Rogalla[a], M. Aliotta[a†], C.A. Barnes[b‡], L. Campajola[c], A. D'Onofrio[d], L. Gialanella[a], U. Greife[a], G. Imbriani[c], A. Ordine[c], V. Roca[c], C. Rolfs[a], M. Romano[c], C. Sabbarese[d], D. Schürmann[a], F. Schümann[a], F. Strieder[a], S. Theis[a], F. Terrasi[d], H.P. Trautvetter[a]

[a]Institut für Physik mit Ionenstrahlen, Ruhr-Universität Bochum, Germany

[b]California Institute of Technology, Pasadena, USA

[c]Dipartimento di Scienze Fisiche Universita Federico II, Napoli and INFN, Napoli, Italy

[d]Dipartimento di Scienze Ambientali, Seconda Universita di Napoli, Caserta and INFN, Napoli, Italy

The recoil separator ERNA (**E**uropean **R**ecoil Separator for **N**uclear **A**strophysics) for improved measurements of the astrophysical key reaction $^{12}C(\alpha,\gamma)^{16}O$ is being developed at the 4 MV Dynamitron tandem accelerator in Bochum to detect directly the ^{16}O recoils. The total detection efficiency of about 50 % allows direct measurements in a much wider energy range than previously accessible. In addition this technique allows improved measurements not hampered by cosmic background problems when compared to γ-ray detection.

1. INTRODUCTION

The capture reaction $^{12}C(\alpha,\gamma)^{16}O$ takes place during the helium burning stage of Red Giants [1] and is a key reaction of nuclear astrophysics. The cross section at stellar energy E_0 determines not only the nucleosynthesis of elements up to the iron region, but also the subsequent evolution of massive stars the dynamics of supernovae, and the kind of remnants after supernova explosions. For this reason the cross section $\sigma(E_0)$ should be known with a precision of at least 10%. In spite of tremendous efforts over nearly 30 years, one is still far from this goal. ERNA is an approach to improve the situation.

2. EXPERIMENTAL SETUP

Performing the reaction in inverted kinematics $^4He(^{12}C,\gamma)^{16}O$ a carbon beam is guided into a windowless ^4He jet gas target and the kinematically forward directed ^{16}O recoils

*Supported in parts by Deutsche Forschungsgemeindschaft(Ro429/35-1) and the Istituto Nazionale di Fisica Nucleare (INFN)
†Alexander von Humboldt Fellow
‡Alexander von Humboldt Award

PII S0375-9474(01)00784-9

are detected downstream on the beam line (Fig. 1, more detailed description in Ref. [2]). The direct observation of the ^{16}O recoils requires an efficient recoil separator [3–5] to filter out the intense ^{12}C beam particles while the recoils have to be focussed into a detector. In addition an ultra high purity of the incident carbon beam is necessary.

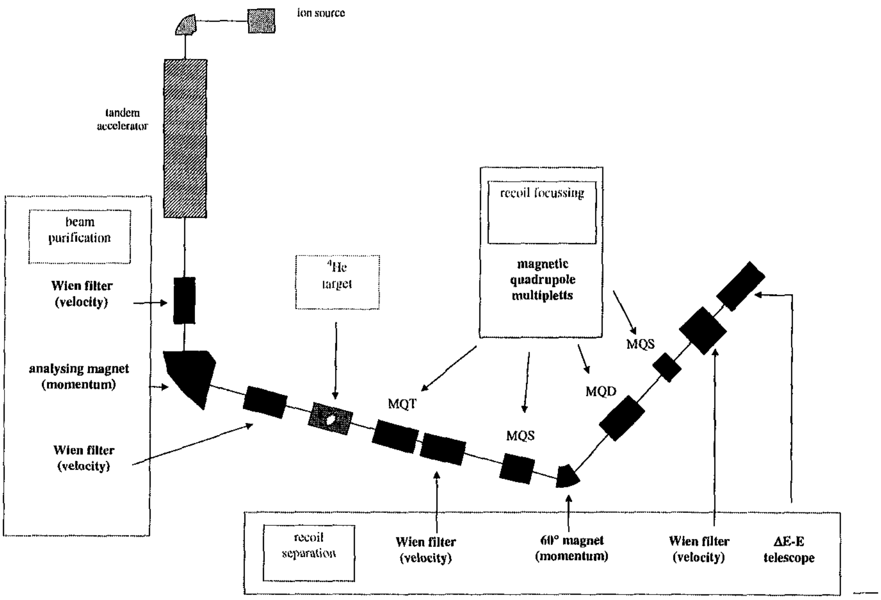

Fig 1: Final layout of the ERNA setup

2.1. Separation

Due to the kinematics of the reaction the carbon and oxygen have the same momentum. Therefore the first filtering element is a velocity filter (Wien filter) followed by a dipole magnet and a second Wien filter. The ratio between carbon ions passing the target and oxygen recoils is of the order of 10^{18} for $\sigma = 1$ pb and a target density n(^{4}He) $= 10^{18}$ atoms/cm^2. If the filtering of the separator is sufficiently effective (with a beam supression factor of the order of $R_{rec} = 10^{-14}$), the ^{16}O recoils can be counted directly in a ΔE-E telescope which allows particle identification and by this an additional separation ($R_{tel} = 10^{-4}$) [5] leading to a total suppresion of $R_{tot}=10^{18}$.

2.2. Acceptance

In separators that includes rigidity analysis (dipole magnet), it is necessary to make a charge state selection [5]. Measurements of charge state distributions had been performed in order to determine the probability of the selected charge state. All recoils of the selected state has to be focussed up to the telescope. An angle and energy spread due to the γ emission of the compound nuclei requires several magnetic multipletts. The transmission of the recoils had been studied by beam optic calculations [6].

2.3. Purification

The carbon beam provided by the accelerator is momentum filtered by an analysing magnet. Therefore contaminants in the beam, e.g. ^{16}O, have essentially the same momentum like the ^{16}O recoils and can not be distinguished by the separator. These contaminats have to be eliminated upstream of the target. A purificaton system consisting of two Wien filters in combination with the analysing magnet is installed. Measurements have shown a presence of contaminants in the unpurified ^{12}C beam of the order of $P_0 = 10^{-11}$ which is reduced to $P_{tot} < 10^{-29}$ when the purification is switched on.

3. STATUS OF THE PROJECT

The purification is installed and tests have shown an exceedingly sufficient supression of the contaminants [7]. The assembling of the elements for the separation is nearly finished and most of them including the ΔE-E telescope specially designed for this project had been already used for test measurements. The design of the ^{4}He jet gas target is finished and is in progress to be assembled. A time-of-flight recoil detection in addition to the telescope will be developed in order to improve the separation performance of the detection at low energies.

4. FURTHER STAGE

For a cross section determination of the different components of the $^{12}C(\alpha,\gamma)^{16}O$ reaction (E1, E2, cascade transitions) an array of γ-ray detectors surrounding the ^{4}He target is planned. Measurements of the γ-ray angular distribution in coincidence with the recoils enables a γ-detection without the usual background problems.

REFERENCES

1. C. Rolfs and W.S. Rodney: Cauldrons in the Cosmos (University of Chicago Press 1988).
2. D. Rogalla, S. Theis, L. Campajola, A. D'Onofrio, L. Gialanella, U. Greife, G. Imbriani, A. Ordine, V. Roca, C. Rolfs, M. Romano, C. Sabbarese, F. Schümann, F. Strieder, F. Terrasi, H.P. Trautvetter,: Nucl. Instr. Meth. A**437** (1999) 266
3. R.M. Kremer, C.A. Barnes, K.H. Chang, H.C. Evans, B.W. Filippone, K.H. Hahn, L.W. Mitchell: Phys. Rev. Let. **60**(1988) 1475
4. M.S. Smith, C. Rolfs, C.A. Barnes: Nucl. Instr. Meth. A**306** (1991) 233
5. L. Gialanella, F.Strieder, K. Brand, L. Campajola, A. D'Onofrio, U. Greife, E. Huttel, F. Petrazzuolo, V. Roca, C. Rolfs, M. Romano, M. Romoli, S. Schmidt, W.H. Schulte, F. Terrasi, H.P. Trautvetter, D. Zahnow : Nucl. Instr. Meth A**376** (1996)174
6. M. Berz: Computational aspects of design and simulation (COSY INFINITY), Nuc. Instr. Meth. A**298**(1990) 473
7. D. Rogalla, M. Aliotta, C.A. Barnes, L. Campajola, A. D'Onofrio, E. Fritz, L. Gialanella , U. Greife, G. Imbriani, A. Ordine, J. Ossmann, V. Roca, C. Rolfs, M. Romano, C. Sabbarese, D. Schürmann, F. Schümann, F. Strieder, S. Theis, F. Terrasi, H.P. Trautvetter: Eur. Phys. J. A**6** 471-477 (1999)