Vol. 35 (2004) *ACTA PHYSICA POLONICA B* No 3

INFLUENCE OF THE COULOMB FIELD ON CHARGED PARTICLE EMISSION IN Ar + Ni REACTION AT 77 MeV/u*

K. Wosińska[a], J. Pluta[a], F. Hanappe[b], L. Stuttge[c]
J.C. Angelique[d], Z. Basrak[e], B. Benoit[b], E. de Goes Brennand[b]
G. Bizard[d], J. Colin[d], G. Costa[c], P. Desesquelles[f], O. Dorvaux[c]
D. Durand[d], B. Erazmus[g], S. Kuleshov[h], R. Lednicky[i]
P. Leszczyński[a], M. Marques[d], Th. Materna[b], K. Mikhailov[h]
G. Papatheofanous[b], T. Pawlak[a], M. Przewłocki[a]
A. Staranowicz[a], A. Stavinskiy[h], A. Sztenkiel[a], B. Tamain[d]
A. Vlasov[h], and L. Vorobyev[h]

[a] Faculty of Physics, Warsaw University of Technology, Koszykowa 75, 00662 Warsaw, Poland
[b] Universite Libre de Bruxelles, CP229, Av. F. D. Roosevelt, 50, B1050, Bruxelles, Belgium
[c] IRES, IN2P3-CNRS / Universite Louis Pasteur, BP28, F67037 Strasbourg Cedex 2, France
[d] Laboratoire de Physique Corpusculaire, IN2P3, CNRS/ISMRA, F-14050 Caen Cedex, France
[e] Ruder Bošković Institute, P.O. Box 180, HR-10 002 Zagreb, Croatia
[f] ISN, IN2P3/CNRS, et Univ. J. Fourier, 53 Av. des Martyrs, F-38026 Grenoble Cedex, France
[g] SUBATECH, UMR Univ., EMN, IN2P3/CNRS, 4 rue A. Kastler, 44307 Nantes, France
[h] Inst. of Theor. and Experim. Physics, B. Cheremushinskaya 25, 117259, Moscow, Russia
[i] Institute of Physics ASCR, Na Slovance 2, 18221 Prague 8, Czech Republic

(Received February 17, 2004)

Ar+Ni collisions at 77 MeV/u were studied in the experiment E286 performed at GANIL. An important advantage of this experiment was an application of the neutron detector DEMON for registration of both neutral and charged particles. This feature allows to compare characteristics of neutrons and protons detected by the same detector and gives a possibility to determine the influence of the Coulomb field on the proton emission. Estimation of a charge of the emitting source was performed by comparing energy spectra of neutrons and protons detected under identical experimental conditions. The experimental results were compared with the prediction of the SIMON model [D. Durand, *Nucl. Phys.* **A541**, 266 (1992)] and Landau–Vlasov model [Z. Basrak, Ph. Eudes, P. Abgrall, F. Haddad, F. Sébille, *Nucl. Phys.* **A624**, 472 (1997)].

PACS numbers: 25.75.–q

---

* Presented at the XXVIII Mazurian Lakes School of Physics, Krzyże, Poland, August 31–September 7, 2003.

1. Introduction

Study of the properties of emitting sources in nucleus–nucleus interactions provides information on the collision dynamics. While the analysis of two-particle correlations allows to estimate the space-time size of the emitting source, the comparison of proton and neutron energy spectra gives information on a source charge. These two independent types of analysis allow to estimate the correlated parameters of the emitting source, namely, its charge and size. The radius of the quasi-projectile in ^{40}Ar+^{58}Ni collision was obtained from the neutron–neutron correlation function [1]. The goal of the present analysis is to estimate the mean charge of the same source.

The experiment (E286) dedicated to investigation of two-particle correlations for different particle systems was performed at GANIL using the modular neutron detector DEMON [2]. The reaction ^{40}Ar+^{58}Ni at 77 MeV/u was studied. Each detector module was of cylindrical form (20 cm long and 16 cm in diameter) filled with liquid scintillator NE213. In front of the main module a thin plastic scintillator was installed to distinguish between neutral and charged particles. This allows to compare characteristics of neutrons and protons detected in the same geometry. The main block of detectors was installed in the forward direction in the angular range 4°–22°. Such arrangement of detectors allows to study the quasi-projectile fragmentation because majority of registered particles, especially those of higher energy, comes from the quasi-projectile [2].

2. Estimation of the charge of the emitting source

Fig. 1 presents kinetic energy for protons and neutrons registered in the same detector module at two different emission angles. The data were corrected for the loss of proton kinetic energy on the way from the reaction chamber to the detector and the efficiency of neutron registration. Differences in the spectra of neutrons and protons resulting from Coulomb repulsion can be used to estimate the mean charge of the emitting source. In so doing, one can assume that the neutron spectrum corresponds to the proton one with the Coulomb interaction switched off. Switching on the Coulomb interaction with the source of a given charge and corresponding radius, one can then estimate the mean source charge by fitting the modified (weighted) neutron spectrum to the experimental proton spectrum. The calculation of the weights resulting from Coulomb interaction between the emitted particle and the source was performed using the model of two-particle and source–particle interactions developed with the aim to calculate the two-particle correlation function [3]. For each detected neutron the weight depending on its kinetic energy and emission point as well as the source charge was determined. The weight was calculated in the source rest frame, thus the Lorentz

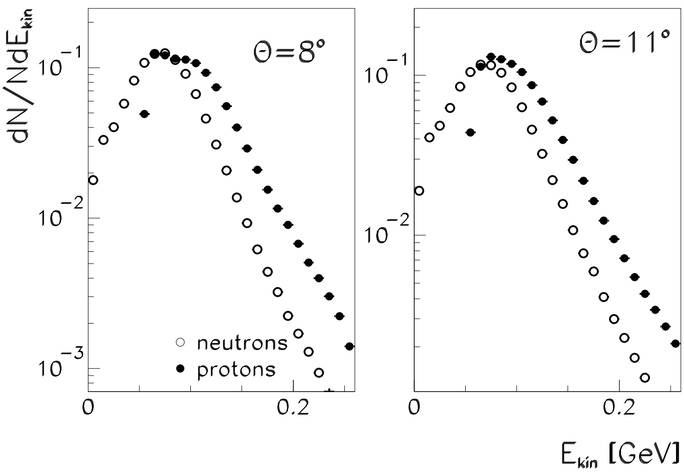

Fig. 1. Proton and neutron energy spectra measured for emission angles: $\theta = 8°$ and $\theta = 11°$.

transformation of each neutron to the quasi-projectile rest frame was performed assuming the quasi-projectile velocity equal to $0.35c$. This velocity relates to the maximum in neutron rapidity distribution [2]. To diminish the error due to the admixture of preequilibrium neutrons, the analysis was performed only for neutrons emitted forward in the quasi-projectile system [4].

While the kinetic energy of neutrons was taken from the experiment, the coordinates of the emission point were sampled from a spherical Gaussian probability distribution with a dispersion $(R_{\rm rms})^2$. The charge of the source and its radius are not independent. The charge Z was calculated from the formula: $Z = k\frac{4}{3}\pi(\sqrt{\frac{5}{3}}R_{\rm rms})^3\rho$, where $R_{\rm rms}$ is the mean square radius, $\sqrt{\frac{5}{3}}R_{\rm rms}$ — the radius of an rms-equivalent sharp sphere, ρ is the density of nuclear matter, $k = \frac{18}{40}$ is the atomic to mass number ratio for the projectile nucleus ^{40}Ar. Calculations were performed for $\rho_0 = 0.17$ nucleons/fm^3 (density of normal nuclear matter), and also for $\rho = 0.75\rho_0$ and $\rho = 0.5\rho_0$ to check whether the density of the source could influence the Coulomb effect. There is an evidence [5] that the density of emitting source could be smaller than the normal nuclear density. The neutron spectra with the Coulomb weights compared to the proton spectrum are shown in Fig. 2. The values of χ^2 per degree of freedom as a function of the radius of the source are presented in Fig. 3 (upper part). The χ^2 test was performed in the energy range 120–260 MeV, because the Coulomb weights calculated for particles of higher energy are not so sensitive to the space parameters of

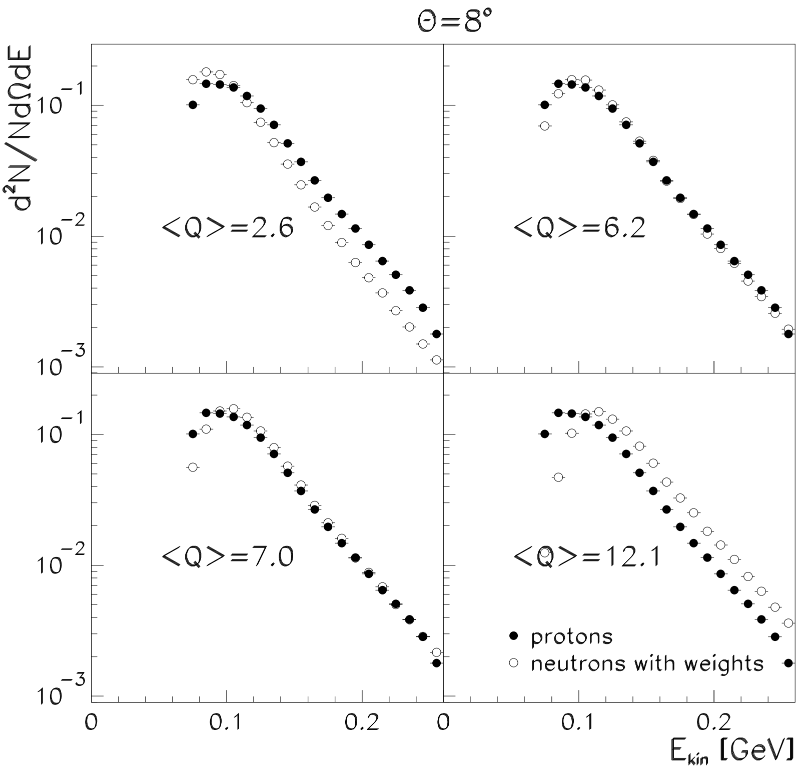

Fig. 2. Proton energy spectrum compared to neutron energy spectra with the Coulomb weights for the emission angle $\theta = 8^{\circ}$ and the source density $\rho_0 = 0.17$ nucleons/fm^3

emission point as for lower energy particles. The lower part of Fig. 3 shows χ^2/d.o.f. as a function of the mean charge of the source. The left part (emission angle $\theta = 8^{\circ}$) presents the values of χ^2/d.o.f. for three values of the source density. The best fit values independent of the assumed density are $6 < Z < 9$. This analysis shows that the calculated Coulomb weights are essentially sensitive to the source charge only. They are not sensitive to other fitting parameters used, *i.e.* the source density and mean radius. The small value of the mean charge of the quasi-projectile corresponds to a small value of the quasi-projectile radius ($2.1 < R_{\rm rms} < 2.4$ fm) estimated from neutron–neutron correlation function in [1]. This result may indicate that in the collision the projectile breaks up into sources with the atomic number close to that of carbon nucleus. The excess of projectile-like fragments with atomic number of about 6 was observed in [6,7].

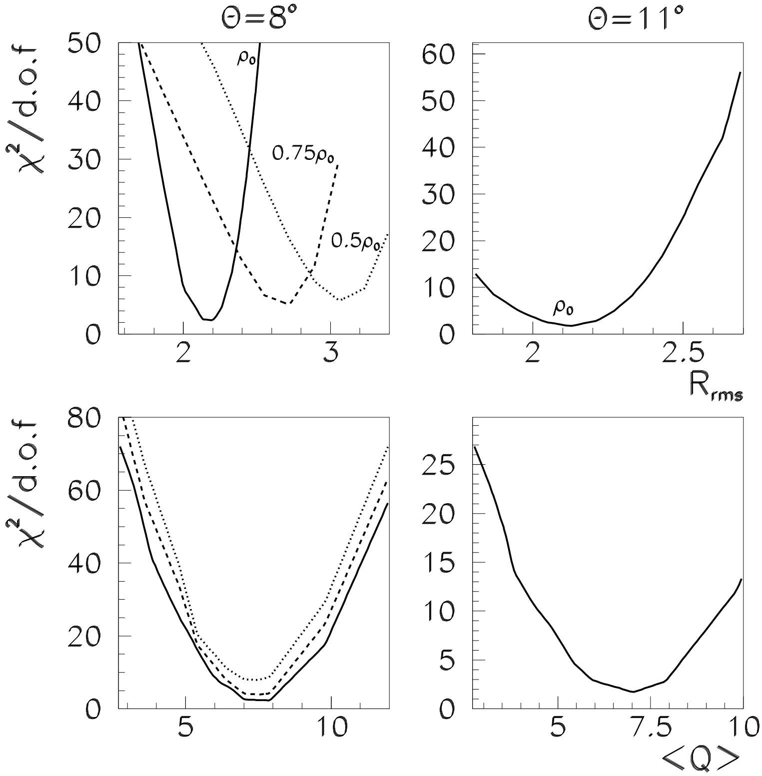

Fig. 3. Upper part: values of χ^2/d.o.f. as a function of the radius of the source. Lower part: values of χ^2/d.o.f. as a function of the mean charge of the source. See details in the text.

3. Comparison to the predictions of theoretical models

Two theoretical models were used to compare to our experimental data: the semiclassical Landau–Vlasov (L–V) transport model [8,9] and the SIMON statistical model [10]. The generated events passed through the experimental filter incorporating the geometry of the detection setup and detector efficiencies.

Fig. 4 shows kinetic energy spectra for protons and neutrons generated in the frame of L–V and SIMON models compared to the experimental ones. The number of particles at high energy is underestimated by both models. The statistical model SIMON assumes the delayed emission as statistical emission from equilibrated sources. The excess of high energy particles in the experiment can indicate that the source is not fully equilibrated. In the case of the transport L–V model underestimation of the amount of high energy particles is not fully understood.

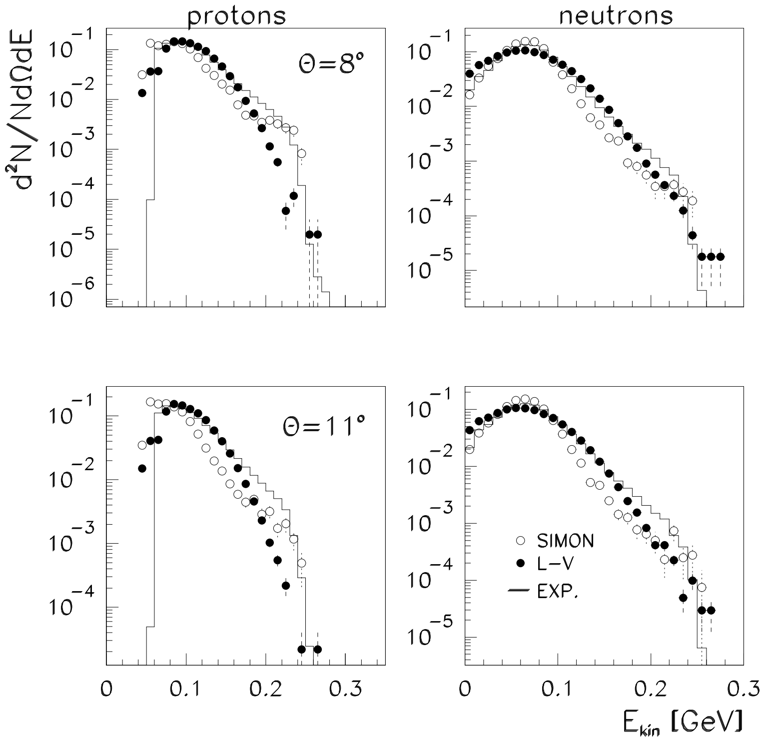

Fig. 4. Kinetic energy spectra for protons and neutrons generated from L–V and SIMON models compared to the experimental data.

The mean values of the quasi-projectile charge from SIMON and L–V models and that estimated from the experiment are presented in Table I. The larger value of the mean quasi-projectile charge in both models may result from the fact that the models do not take into account the fragmentation of the source. Also, in the case of L–V model, the simulation was stopped at 600 fm/c. (It is worth mentioning that the experimentally estimated

TABLE I

The mean quasi-projectile charge from SIMON and Landau–Vlasov models and that estimated from the experiment.

Landau–Vlasov	11.3±1.7
SIMON	13.4±1.6
experiment	7.5±1.5

quasi-projectile time of life is about two times longer [1].) Thus, the L–V residues are not fully cold so that the L–V quasi-projectile charge may be overestimated several charge units. On the other hand, the charge estimated from the experimental neutron and proton spectra may be somewhat underestimated due to the point-like approximation of the source charge used for the Coulomb wave function in the weight calculation. In addition, although the simulation results were filtered to match experimental conditions, the lack of experimental information on the reaction impact parameter may also contribute to the observed discrepancy between simulation and experiment.

4. Conclusions

The mean quasi-projectile charge was estimated from the comparison of the neutron and proton energy spectra. The estimated charge value ($6 < Z < 9$) corresponds (at a normal density of nuclear matter) to the quasi-projectile radius value ($2.1 < R_{\rm rms} < 2.4$ fm) obtained from the neutron–neutron correlation function [1]. This result does not agree with the predictions of SIMON and L–V models which give larger values of the quasi-projectile charge.

REFERENCES

[1] K. Wosińska *et al.*, *Acta Phys. Pol. B* **33**, 507 (2002).

[2] M. Przewłocki *et al.*, *Acta Phys. Pol. B* **31**, 379 (2000).

[3] R. Lednicky, V.L. Lyuboshitz, *Sov. J. Nucl. Phys.* **35**, 770 (1982); *Proc. Int. Workshop on Particle Correlations and Interferometry in Nuclear Collisions, CORINNE 90, Nantes, France, 1990*, ed. D. Ardouin, World Scientific, Singapore 1990, p. 42.

[4] Ph. Eudes, Z. Basrak, F. Sébille, *Phys. Rev.* **C56**, 2003 (1997).

[5] H.A. Gustafsson *et al.*, *Phys. Rev. Lett.* **53**, 544 (1984).

[6] R. Dayras *et al.*, *Nucl. Phys.* **A460**, 299 (1986).

[7] G. Lanzanó *et al.*, *Nucl. Phys.* **A683**, 566 (2001).

[8] Z. Basrak *et al.*, *Nucl. Phys.* **A624**, 472 (1997).

[9] Z. Basrak, *Nukleonika* **43**, 337 (1998).

[10] D. Durand, *Nucl. Phys.* **A541**, 266 (1992).