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Study of elastic α-scattering from ^2H and ^{12}C at $E_\alpha = 4.2$ GeV

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Abstract

Elastic scattering of α-particles from deuterium and ^{12}C has been investigated using α-particles from SATURNE. The differential cross sections have been analysed within an optical model description using a folding potential. Matter radii extracted at this energy are consistent with radii deduced from electron scattering.

Recently, the scattering of α-particles in the few GeV region has been used to investigate the properties of baryons related to their "scalar" (non-spin-flip and isoscalar) structure[1,2]. Using a folding model approach, scalar radii may be extracted from elastic scattering, whereas spectroscopic information on dynamical properties of baryons may be deduced from inelastic excitation of baryon resonances. In the present paper we present elastic α-scattering data for deuterium and carbon and use the same theoretical description to test the validity of this approach for nuclear systems. "Scalar" radii extracted from the data should be identified with the matter radii of these systems which can be compared with radii deduced from electron scattering.

The present investigation is part of a program to study α-scattering at intermediate energies on light nuclei. In these systems the excitation of the Roper resonance is of interest to study nuclear medium effects on the compression mode of the nucleon. Preliminary results[3] indicate that this resonance is observed in both systems, α-d and α-^{12}C.

The experiment has been performed using a ^{4}He-beam from SATURNE with a momentum of 7 GeV/c and the SPES IV spectrometer. The experimental conditions are quite similar to those described in ref.1. A liquid D_2 target of 4 cm thickness as well as solid targets of carbon and mylar of a thickness of 2-4 mm were used. For angles up to about 5^o the elastic line was very pronounced and could be isolated easily from inelastic reactions including the quasielastic continuum (with a ratio of elastic to inelastic events of $\geq$3-5). The subtraction of the quasielastic component gives rise to the uncertainties indicated in the figures, the statistical errors being very small. From subsequent measurement of the position of the elastic lines for ^{12}C, CH_2, and ^{2}D targets in the focal plane of the spectrometer the effective scattering angle was deduced with a precision of 0.1^o. The resulting differential cross sections as a function of the momentum transfer for α-^{12}C scattering are given in fig.1, the corresponding data for α-d scattering are given in fig.2.

For the deuteron old data (also taken at SPES IV) exist[4] which cover a large momentum transfer region. In our experiment we concentrated on the measurement at small momentum transfers, as these are more sensitive to the determination of radii (see below). In the overlapping region a reasonable agreement between the two data sets is found. Only one point, at about 0.3 $(GeV/c)^2$ is lower in the present results. For a consistency check of the results we measured simultaneously the elastic line for ^{1}H with a mylar foil, the derived cross sections are in good agreement with the data of ref.4.

Table 1: Summary of the results. I_{V_o}, I_{W_o}, and I_{tot} present normalized volume integrals of the real, imaginary and total potential, $I_V = \frac{1}{A}\int V d\tau$.

System α-A	E_α [GeV]	I_{V_o}	I_{W_o} [MeV fm^3]	I_{tot}	$< r_A^2 >$ [fm^2]	$< r_A^2 >^*$ [fm^2]
α-^{12}C	4.2	140	269	303	5.4±0.2	5.43±0.17
α-^{2}H	4.2	129	336	360	3.6±0.4	3.77±0.07

* mean square charge radius deduced from (e,e') unfolding an isoscalar nucleon form factor.

The data have been analysed within the optical model approach, the details of the calculations are given in ref.2. In the fits the radius of the target density and the potential depths V and W were adjusted to the data. The other parameters concerning the α-particle density and the effective interaction were used from ref.2.

The experimental differential cross sections for ^{12}C are well described up to -t values of about 0.2 (GeV/c)^2 using a mean square radius $< r^2_{^{12}C} >$ of 5.4±0.2 fm^2. The volume integrals of the potentials V_o and W_o, normalized to one nucleon, are given in table 1. They are about a factor of two smaller than those obtained for α-p scattering. This can be interpreted by an effective number of nucleons participating in the scattering process ($A_{eff} \leq 12$). The comparison with the results for α-p scattering[2] ($\bar{I}_{V_o}$=292 MeV fm^3, $\bar{I}_{W_o}$=559 MeV fm^3) yields $A_{eff} \sim 6$.

The matter mean square radius derived from the fit can be compared with radii for ^{12}C obtained from[5] electron scattering and muonic atoms, giving a charge root mean square radius $< r^2_{^{12}C} >^{1/2}_{ch}$ of 2.46±0.03 fm. To derive a matter radius from the charge density the nucleon form factor should be unfolded. Using the proton mean square radius $< r_p^2 >_{ch}$=0.74±0.02 fm^2, this gives $< r^2_{^{12}C} >$ = 5.31±0.15 fm^2. Using instead an isoscalar nucleon form factor with $< r_N^2 > = < r_p^2 >_{ch} + < r_n^2 >_{ch}$=0.62±0.04 fm^2 yields $< r^2_{^{12}C} >$ = 5.43±0.17 fm^2. The comparison with the mean square radius extracted from α-scattering shows a good agreement.

It should be noted, that for α-^{12}C scattering a similar study has been performed[6] at a lower energy of 1.37 GeV. In this study a comparison has been made between different theoretical approaches using densities from electron scattering. However, at this lower energy the condition of hard scattering is not satified, necessary for the extraction of scalar radii.

Concerning the scattering from the deuteron, the simple folding model is not expected to give a good description at large momentum transfers. Emphasizing on a description of the small momentum transfers measured in our experiment, the results are given by the solid line in fig.2. In this description the diffractive structure beyond the first minimum is not well described. The mean square radius derived is $< r_d^2 > = 3.6 \pm 0.4$ fm^2. The normalized volume integrals of the central potential are given in table 1, the spin-orbit potential was used with a geometry r=1.5 fm and a=0.5 fm and potential depths V_{ls}=0.9 MeV and W_{ls}=1.8 MeV. The comparison of the potential strengths with α-p scattering gives $A_{eff} \sim 1$. This appears to be very reasonable for scattering from the very extended A=2 system.

From electron scattering a deuteron charge root mean square radius $< r_d^2 >_{ch}^{1/2}$ of 2.095 ± 0.006 fm is obtained[7]. Unfolding the nucleon form factor gives a matter mean square radius $< r_d^2 >$ of 3.65 ± 0.05 fm^2 and 3.77 ± 0.07 fm^2, by using the proton or the isoscalar form factor, respectively. This is again in good agreement with our result.

In summary, the present investigation has shown that a good description of the small momentum transfer behaviour of elastic α-scattering in the few GeV region is obtained within the optical potential approach which gives reliable information on matter radii. Therefore, the relative wave functions obtained may be used with reasonable confidence to describe the inelastic process.

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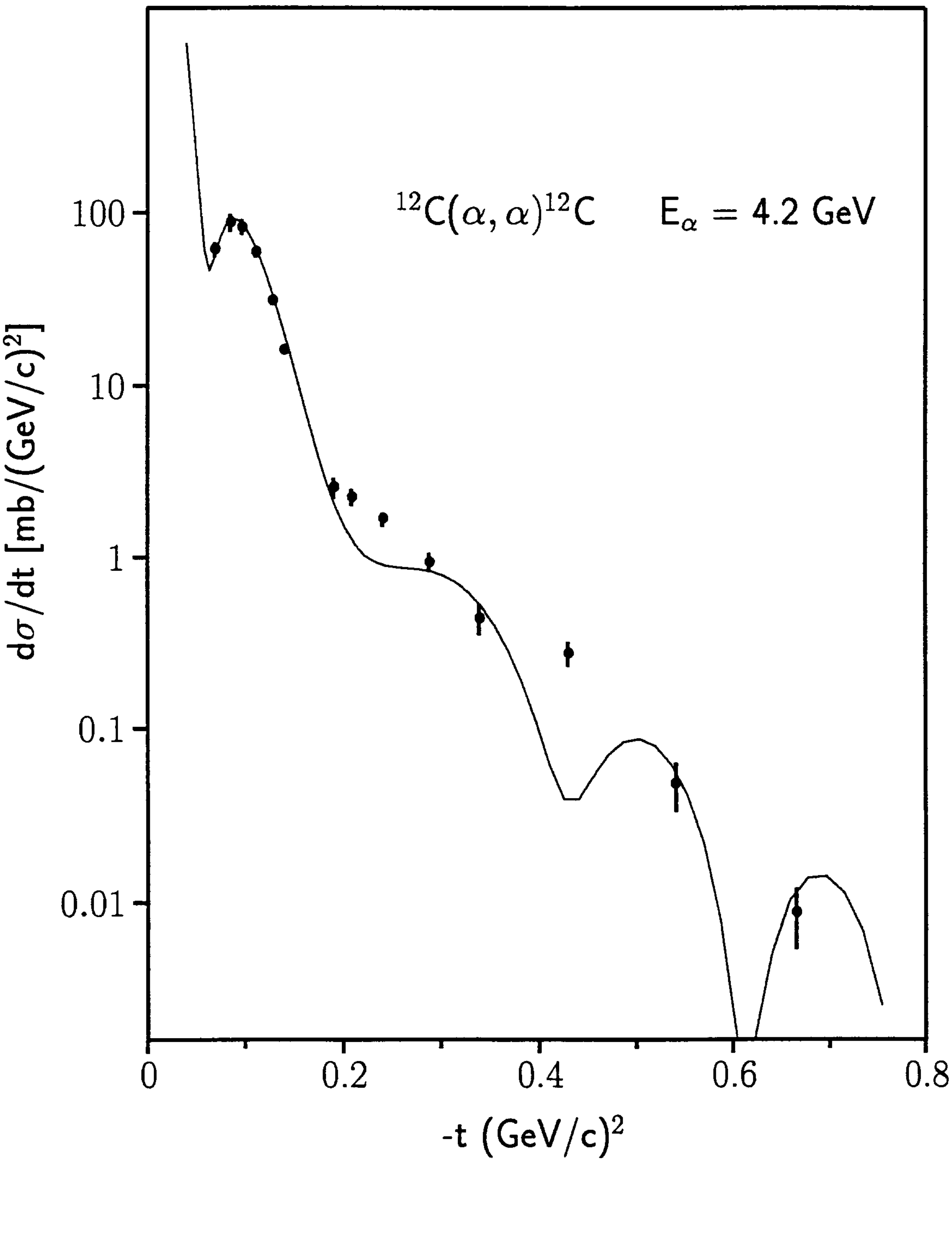
FIGURE CAPTIONS:

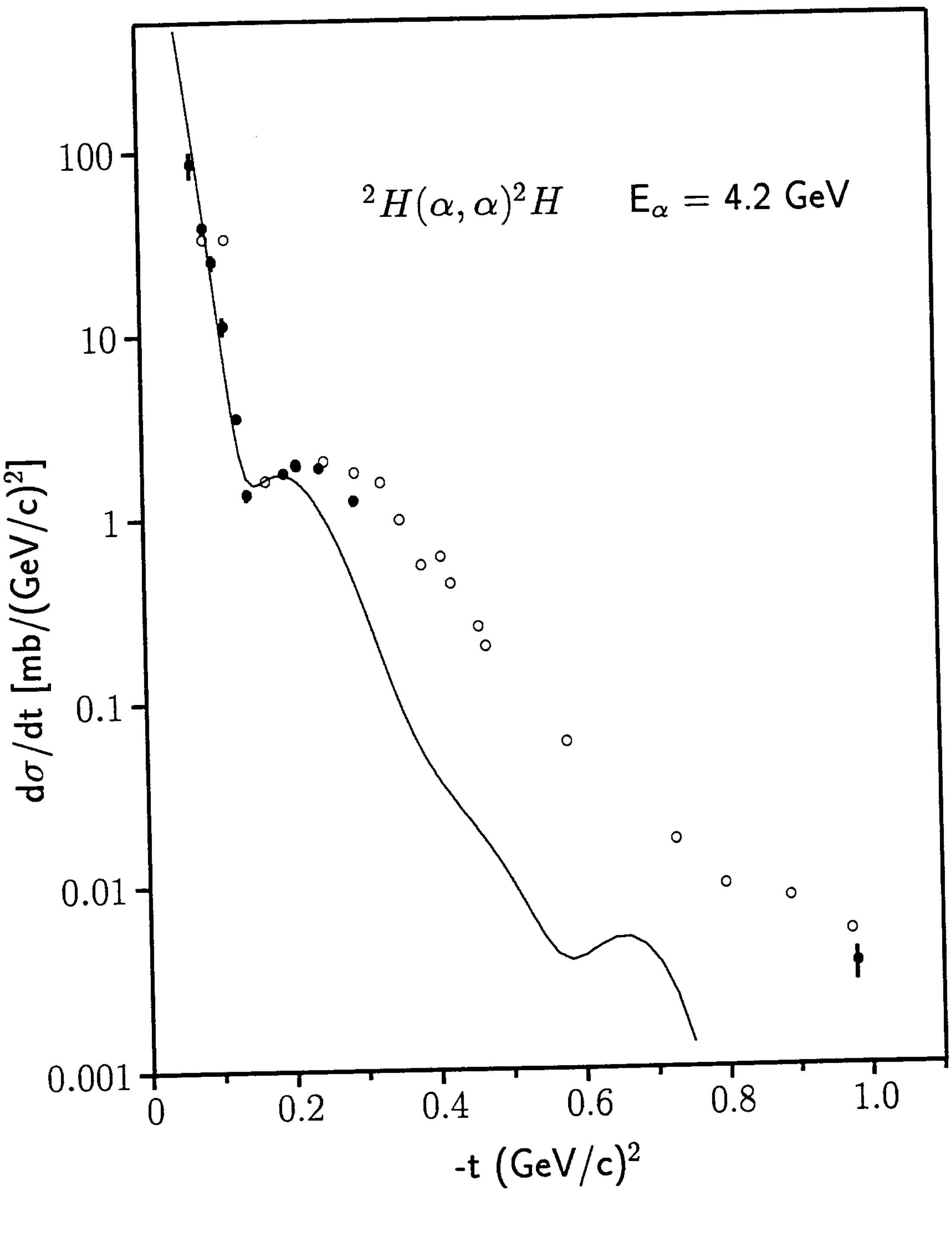
Figure 1: Differential cross section for elastic α-^{12}C scattering as a function of momentum transfer. The solid line represents an optical model calculation discussed in the text.

Figure 2: Differential cross section for elastic α-d scattering and optical model calculations. The present data are given by the closed points, those of ref.4 by the open points.



$^{12}C(\alpha,\alpha)^{12}C$ $E_\alpha = 4.2$ GeV
100
10
1
0.1
0.01
$d\sigma/dt$ [mb/(GeV/c)^2]
0
0.2
0.4
0.6
0.8
-t (GeV/c)^2

Fig. 1



$^2H(\alpha,\alpha)^2H$ $E_\alpha = 4.2$ GeV
$d\sigma/dt$ [mb/(GeV/c)^2]
100
10
1
0.1
0.01
0.001
0
0.2
0.4
0.6
0.8
1.0
-t (GeV/c)^2

Fig. 2