Proton-Nucleus Scattering in Relativistic Mean Field Theory with Density and Energy Dependent Self Energies ◊

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Detailed information on nuclear matter distributions can be obtained by proton elastic scattering on stable nuclei at intermediate energies up to 1 GeV. Using radioactive beams and inverse kinematics this method can also be applied to the study of exotic nuclei far off stability [1]. The comparison of scattering data with predictions for density distributions of nuclei in their ground state can give additional information on the quality of theoretical models of nuclear structure, especially for instable nuclei. Data on proton scattering on stable nuclei can accurately be described in Dirac phenomenology using scalar and vector optical potentials, which are parametrized as functions of proton energy for different target nuclei [2].

It is worthwhile trying to describe proton-nucleus scattering within the same theoretical model as for bound nuclei. A promising foundation is relativistic mean field theory (RMFT). It is a consistent framework for the description of nuclear matter and finite nuclei based on hadronic field theory [3]. Modern parametrizations of meson-baryon couplings lead to a good quantitative agreement between theory and experiment with respect to ground state properties. One approach is the introduction of a density dependence in the couplings [4]. This parametrization is suggested from Dirac-Brueckner theory of nuclear matter, where the scalar and vector self-energies are density dependent. In the mean field approximation this can be represented as a density dependence of the coupling constants which simulates the effective in-medium interaction.

Above the Fermi energy, scalar and vector self energies from Dirac-Brueckner calculations of nuclear matter are momentum dependent and complex. The imaginary part takes into account inelastic processes in the scattering similar to the occurence of optical potentials in Dirac phenomenology. Starting from self energies, which we obtain from mean field calculations of finite nuclei, we try to parametrize the additional energy dependence in proton-nucleus scattering in a systematic way by fitting to scattering "data" from Dirac phenomenology for a ^{208}Pb target at proton energies between 50 and 1000 MeV.

In Fig. 1 we compare the resulting optical potential for nuclear matter in our parametrization with the optical potential extracted from Dirac phenomenology. In both cases we get a saturation of the real part for energies around 1 GeV and an almost linear increase in the imaginary part. Our potentials are substantially smaller. On the other hand real parts of the optical potential from Dirac-Brueckner calculations and from RMFT without energy dependent coupling constants increase linearly and become much larger at higher energies than potentials obtained from a fit to scattering data. The differences in the optical potential will have significant consequences in calculations of heavy ion collisions with relativistic transport equations, like BUU etc., [5].

Our parametrization of the energy dependence is also successful in describing elastic proton scattering on other targets (cf. Fig. 2). Therefore it is meaningful to extend our model to nucleus-nucleus scattering. Here we will follow the approach to calculate the effective nucleus-nucleus potential from a folding of target self energies and projectile densities. More generally the scattering amplitude can be obtained by folding the individual nucleon amplitudes using a relativistic eikonal approximation.

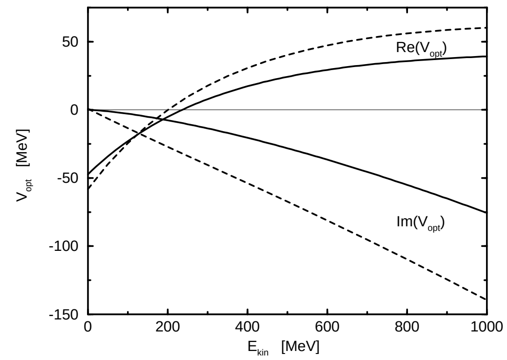

Fig. 1: Real and imaginary part of the optical potential in symmetric nuclear matter as a function of kinetic energy in Dirac phenomenology (dashed lines) and in our parametrization (solid lines).

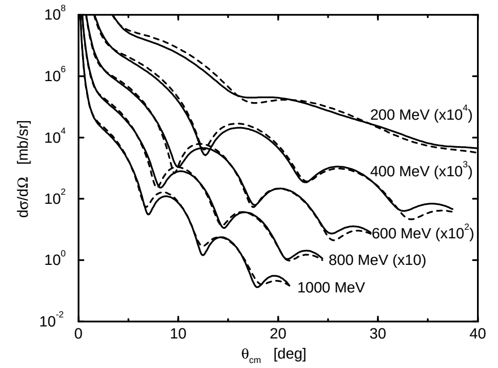

Fig. 2: Differential cross section as a function of the scattering angle for elastic proton scattering on ^{40}Ca for different proton energies in Dirac phenomenology (dashed lines) and in our parametrization (solid lines).

References

[1] G. D. Alkhazov *et al.*, Phys. Rev. Lett. **78** (1997) 2313
[2] E. D. Cooper *et al.*, Phys. Rev. **C47** (1993) 297
[3] B. D. Serot and J. D. Walecka, Adv. Nucl. Phys. **16** (1986) 1
[4] S. Typel and H. H. Wolter, to be published;
[5] T. Gaitanos, C. Fuchs and H. H. Wolter, Nucl. Phys. **A** (1999) in print.

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