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Nuclear Physics A 940 (2015) 53–66

NUCLEAR PHYSICS A

www.elsevier.com/locate/nuclphysa

Mechanisms for hadron continuum scattering from complex nuclei

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Received 20 February 2015; received in revised form 25 March 2015; accepted 27 March 2015

Available online 1 April 2015

Abstract

The continuum spectra of hadrons scattered from complex nuclei are influenced by several features of the strong interaction, even at beam energies and momentum transfers where an incoherent quasifree mechanism is formally valid. These hadrons may suffer multiple scattering, they may interact with nucleons in correlated motion with other bound nucleons, and the spectra may become contaminated with events including pion production. In this work, nuclear spectra at energy losses less than those for free beam-nucleon scattering are compared as ratios to similar spectra for deuterium, an idea recently used for simpler electron scattering spectra, and as ratios to scattering from free nucleons, as the single-nucleon responses in scaling formats. A large array of data is organized to distinguish among the possibilities leading to hadron continuum spectra from complex nuclei, and the relative contributions of single-nucleon responses and other mechanisms are distinguished. It is concluded that for a range of three-momentum transfers near 500 MeV/c it is correlations among bound nucleons that generate the hadron spectra.

Keywords: Continuum scattering; Quasifree; Multiple scattering; Charge exchange

1. Introduction

At sufficiently high beam energies and momentum transfers, an incident hadron interacting with complex nuclei can be considered as interacting with the individual nucleons, in a quasifree

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http://dx.doi.org/10.1016/j.nuclphysa.2015.03.013

0375-9474/

process [1]. This scattering will lead to characteristic features of the continuum spectra, which are indeed observed in a general sense. Can this seemingly simple mechanism be exploited to learn about nuclear dynamics, as has proven possible for data from electron scattering, but with a wider range of couplings to nuclear responses with hadron beams? The use of scaling phenomena provides a useful means to make comparisons of a wide range of data, as has been used for electron scattering [2]. A common way to present data is as responses, which are basically ratios of measured continuum cross sections to the expectations of an incoherent beam-nucleon interaction, based on known beam-nucleon data. Definitions and results for electron beams have been presented recently [3], and several recent publications have presented hadron-nucleus data in these formats, as cited below.

In particular, it is desired to use quasifree scattering to sense correlations among nuclear nucleons. In principle, single-nucleon responses of hadrons with nuclei could sense six modes of correlations (isoscalar/isovector; nonspin, spin transverse $\sigma x q$, and spin longitudinal $\sigma \cdot q$), whereas electrons may couple only to two spin/isospin responses. Hadron scattering both with (CX) and without (NCX) hadron charge exchange is considered, giving access to differences between isovector ($\Delta T = 1$) and isoscalar ($\Delta T = 0$) modes. Several studies of inclusive (p, nx) reactions with spin observables have demonstrated the methods to extract all three isovector spin responses [4,5], assuming a quasifree reaction mechanism.

Recent work with high energy electron beams has demonstrated another powerful way to investigate the role of correlations among nucleons in complex nuclei. This method plotted the ratios of measured doubly differential inclusive continuum cross sections from a nucleus to the similar cross sections for deuterium, where correlations are expected to have little role [6–8]. This is a simpler example of other work that took similar ratios to ^{3}He [9,10]. These studies plotted the ratios as functions of the Bjorken x scaling variable, a measure of the fraction of the momentum of a nucleus held by the one struck nucleon in a quasifree collision. These insights were made possible because of the simple, not-strong, interactions of the probing electron beam and the responding nuclei, and are interpreted as sensitive to inter-nucleon correlations within the complex nuclei. The strong interactions between hadron beams and bound nucleons may complicate the simple single-nucleon responses examined with electrons, especially by multiple scattering, with incoherent collisions with several bound nucleons. The assumptions of the impulse approximation [1] may also be in doubt for intermediate energy hadrons. At large energy losses pion production can also complicate the continuum spectra. These possible reaction complications will be examined below.

In the present work, this ratio method is extended to similar ratios to deuterium of measured continuum doubly differential cross sections for reactions induced by intermediate energy hadrons (protons, K^+, and pions), at beam energies from 345 MeV to 795 MeV. Older data extend these ratios to higher beam energies. Response data, not ratios to deuterium, are available for additional beam energies.

Limitations on the data and on the relevant kinematic conditions limit most of this hadron work to four-momentum transfers with $Q^2 = q^2 - \omega^2$ from about 0.08 to 0.54 $(\mathrm{GeV}/c)^2$ for the intermediate energy beams, with q the three-momentum transfer and ω the energy transfer to the struck nucleon. The recent electron data [6–8] are for much larger Q^2. Data cases for which reliable and relevant hadron spectra are available for complex nuclei and deuterium are listed in Table 1.

After defining some usages and demonstrating that the Bjorken scaling system is appropriate for intermediate energy spectra in the deuterium denominator of ratios, the available data, both NCX and CX, will be presented as they depend on the scaling variables x and y [2], on nuclear