Available online at www.sciencedirect.com

ScienceDirect

Nuclear Physics A 920 (2013) 20–32

NUCLEAR PHYSICS A

www.elsevier.com/locate/nuclphysa

Scaling relations for hadron charge exchange continuum scattering from carbon

R.J. Peterson [1]

Department of Physics, University of Colorado, Boulder, CO 80309-0390, United States

Received 14 August 2013; received in revised form 16 September 2013; accepted 17 September 2013

Available online 17 October 2013

Abstract

Two scaling relations, familiar from analyses of electron scattering and successful over limited kinematic ranges for hadron scattering, are applied to 45 charge exchange spectra from beams of protons and pions on carbon. As with scattering without charge exchange, the conditions that underlie scaling analyses of quasifree scattering are in doubt for intermediate energy hadron beams, and scaling analyses are tests of strong assumptions. Scaling for charge exchange reactions is found in the sense that scaled responses for both beam species and all beam energies are in near agreement over a limited but useful range of momentum transfers, especially at small energy losses where nucleon dynamic effects are strong.

Keywords: Scaling; Continuum scattering; Charge exchange; Quasifree

1. Scaling

Five schemes for converting continuum scattering spectra into scaling systems have been a staple of inclusive electron scattering spectra [1]. In these schemes two kinematic variables (energy transfer ω and three-momentum transfer q to a single struck nucleon) are combined into a single scaling variable. These scaling systems have also been examined for inclusive hadron scattering spectra from carbon without charge exchange (NCX) [2]. The goals in that work were to evaluate which scaling system best organizes a wide range of hadron data into a single response function, such that the consistency of the extracted responses can be evaluated, and to determine the momentum transfer, beam energy, and angular limits of the validity of such scaling systems

E-mail address: jerry.peterson@colorado.edu.

[1] Tel.: +1 303 492 1686.

0375-9474/$ – see front matter
http://dx.doi.org/10.1016/j.nuclphysa.2013.09.004

for hadrons. If scaling is found to be reliable, the obtained responses can provide valuable insight into the dynamics of nucleons within nuclei, as has been the case for continuum scattering of electrons. The scattering data considered were obtained with beams of protons, K^+, and pions (of both signs) scattered without charge exchange from carbon. One of the justifications for seeking such scaling systems is the desire to extract single nucleon responses of nuclei to scattering probes interacting with a range of spin and isospin couplings, as discussed in Ref. [2]. Such scattering without charge exchange (NCX) is driven by both isoscalar ($\Delta T = 0$) and isovector ($\Delta T = 1$) interactions between the beam and the struck nucleon, with relative strengths that differ only slightly from among the hadron scattering probes. Isoscalar responses dominate NCX spectra in general.

Charge exchange (CX) spectra for hadrons are driven only by an isovector ($\Delta T = 1$) interaction with nuclei, or in the case of quasifree scattering, with single nucleons within nuclei. A number of inclusive (p, nx) reactions have been used in attempts to extract nuclear isovector spin responses, using polarized beams and measuring the polarization of the emerging neutrons [3–6]. These studies were evaluated for only a single beam energy in each such study.

The kinematic conditions and reaction assumptions required for scaling analyses to be valid were discussed in Ref. [2], and five scaling systems were defined, described, and tested for a range of inclusive (single-arm) hadronic NCX spectra. In the present work, only two of the same scaling systems will be used to transcribe proton and pion CX continuum spectra, over a range of beam energies similar to that considered for the NCX work. Conclusions drawn from use of the ψ-scaling and the little-used West scaling systems are much the same as those to be drawn from the use here of only the y-scaling and Bjorken scaling systems. Since the Nachtmann scaling system [1] did not generate similar responses over a wide range of momentum transfers for hadronic NCX, no such analysis is reported here. Again only carbon will be considered, as the most commonly used target nucleus. The data to be treated are listed in Table 1 [4–13]. One of these studies used a large acceptance neutral particle detector to select one-and-only-one outgoing neutral pion, adding an exclusive experiment to the array of inclusive studies sensing any final hadron [8].

Since scaling cannot be assumed for hadron scattering to the continuum, and since longitudinal and transverse electron scattering spectra do not scale in the same manner [1], hadron CX spectra need a careful study for scaling to complement the NCX study of Ref. [2]. This work uses the same framework for CX data as was used for NCX data, with very similar hadron beams incident upon carbon.

The differences in usage between NCX and CX analyses for scaling will be presented in Section 2. Then will follow exhibitions of a common array of data in two of the five scaling systems used in Ref. [2], in Sections 3 and 4. The figures will be similar to those in which the NCX scaling results of Ref. [2] were exhibited. Section 5 will evaluate the successes of the two scaling systems for CX on carbon, and will draw comparisons between the two classes of reaction, scattering and charge exchange, and to transverse electron scattering closely related to hadronic charge exchange.

A number of other measurements of inclusive neutron spectra from carbon have been reported with proton beam energies suited to a scaling analysis, but with inadequate resolution for scaling tests [14–19]. Two other measurements of neutral pion spectra from $(\pi^-, \pi^0 x)$ reactions considered only energy losses beyond the range of the present scaling analyses [20,21]. A cascade model has been used to understand these reactions at very large energy losses [22].