Asymmetry of the missing momentum distribution in (e,e′p) reactions and color transparency

A. Bianconi, S. Boffi and D.E. Kharzeev

Dipartimento di Fisica Nucleare e Teorica, Università di Pavia, and
Istituto Nazionale di Fisica Nucleare, Sezione di Pavia, Pavia, Italy

Abstract

We suggest the measurement of the integrated asymmetry of the missing momentum distribution in (e,e′p) reactions to check color transparency effects at intermediate momentum transfers.

Exclusive (e,e′p) experiments are considered as one of the best tools to study the phenomenon of Color Transparency (CT) (see, e.g., [1,2] and references therein). Within various models it has been shown [3-7] that in (e,e′p) reactions a complete transparency can be expected at momenta of the ejected nucleon p′ ∼ 20 GeV or more. This region is at present far from experimental possibilities. Present experiments [see, e.g., [8]] can however explore the region p′ ∼ 2 ÷ 10 GeV where a nontrivial and irregular behaviour of CT is foreseen. It has been recently shown that Fermi motion plays a crucial role in the onset of CT [4,5]. In particular, at intermediate energies CT is strongly affected by the longitudinal component of the missing momentum of

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1 On leave from Moscow University, Moscow, Russian Federation
the reaction [6,7]: $p_m \equiv (\vec{p}' - \vec{q}) \cdot (\vec{q}/q)$, where $\vec{q}$ is the momentum transferred by the virtual photon. Measurements of nuclear transparency as a function of both $q$ and $p_m$ should, in principle, afford seeing CT effects at relatively low energies.

However, three problems are present:

1) At $p, q \sim 5 \div 10$ GeV it is difficult to measure $p_m$ with good precision, taking into account that the useful values of $p_m$ range from $-200$ to $200$ MeV.

2) CT effects must be disentangled from nuclear effects. Traditionally, in the theoretical works this is accomplished by defining a transparency coefficient $T$ as the ratio between the calculated yield and a PWBA evaluation. But the real number of events as a function of $p_m$ is largely dominated by the PWBA distribution, which is strongly peaked and changes by at least one order of magnitude in the range $0 \leq p_m \leq 200$ MeV. It is hard to determine experimentally the ratio $T$ in the tails of the momentum distribution, where the rate of events is low. In addition, one needs to divide the number of events by a PWBA calculation, which is model dependent.

3) On the experimental side one usually defines transparency as the ratio of the measured nuclear cross section to the summed elementary cross section of $Z$ (incoherent) protons. This is useful when applied to integrated cross sections, but cannot give too much information on anomalous transparency when looking at a $p_m$ distribution. Indeed, such a distribution is dominated by the PWBA behaviour. So plotting such a ratio one would just more or less see a PWBA shape.

A possible way out of these problems is to remember that the PWBA
distribution is symmetric under the exchange $p_m \rightarrow -p_m$, when $\vec{q}$ and the transverse component $p_t$ of the missing momentum are kept fixed. At high momenta even the DWBA calculation performed in the Glauber formalism approximately shows the same symmetry, if one neglects any CT effects. On the contrary, CT effects are largely dependent on the sign of $p_m$ [6,7]. The reason is the following: if it exists, CT is due to the formation of a compact (ideally pointlike) baryonic state when the virtual photon is absorbed by a proton in the nucleus. This compact state cannot be of course a proton on its mass-shell, but it is a superposition of many baryon states with different mass: the proton, its resonances, the continuum. It is well known that the threshold for the production of each of these states depends on $p_m$ in an asymmetric fashion. As an example we show in fig. 1 the loci of maximum probability for excitation of some intermediate states with given mass as a function of $q$ and $p_m$ (see also ref. [7]). It is evident that all the excited baryon states are produced preferentially at positive $p_m$. So a compact state is better realized at positive $p_m$, since one can simultaneously produce both a real proton and states with $m^* > m_p$.

Let us define $N_+ (N_-)$ as the number of events in the region $x < p_m < y$ ($-y < p_m < -x$) at given $q$ and $p_t$. The threshold $x$ can be zero, or some tens of MeV; $y \sim 100 \div 200$ MeV. We suggest to measure the asymmetry

$$A = \frac{N_+ - N_-}{N_+ + N_-}.$$  

The values of $A$ calculated in parallel kinematics ($p_t = 0$) as a function of $q$ at different $x$ are shown in figs. 2 and 3 at $y = 100$ and 200 MeV,
respectively. The adopted model is the same as in refs. [4,6], improved by the three-channel calculation [7].

The reason to have a central window \((-x, x)\) of lost events is to exclude the region where the symmetric PWBA peak dominates the distribution. As one can clearly see in figs. 2 and 3 the larger is \(x\) the larger is \(A\). At the same time, a large value of \(x\) restricts the statistics to a very small number of events. An optimal choice depends on the values of the fixed variables, \(q\) and \(p_t\), and on the experimental acceptances.

An upper threshold between 100 and 200 MeV is needed to exclude those regions (in the tails of the nuclear Fermi distribution) where the validity of impulse approximation may be questionable and an asymmetry might arise from other mechanisms than CT.

The clear advantages of this measurement are:

1) One is not restricted to measure the missing momentum \(p_m\) with a good precision: it is possible to choose just two wide \(p_m\) regions (e.g.: \(x = 0, y = 150\) MeV). Ideally, the proposed measurement is to be performed in parallel kinematics. However, concerning the transverse component \(p_t\) one can always choose either a given \(p_t\), or a wide \(p_t\) region to integrate it over.

2) The normalization is model-independent.

The estimated magnitude of the asymmetry (figs. 2 and 3) hopefully should allow to observe it in present or coming experiments. However, in the experimental conditions of current NE18 experiment at SLAC [8] the kinematics is close to perpendicular and only a very limited range of \(p_m\) can be explored [8,9]. Therefore we think that specially dedicated experiments are desirable.
We would like to stress that the origin of the asymmetry in the missing momentum distribution is largely model-independent. Its appearance only requires that the compact state is a superposition of different mass eigenstates with similar couplings. This is a straightforward consequence of the foundations of the CT theory.

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Figure captions

Fig. 1. The maxima of the production probability of an intermediate state with given mass $m^*$ for the $^{12}$C(e,e'p) reaction as a function of three-momentum transfer $q$ (GeV) and longitudinal missing momentum $p_m$ (in units of Fermi momentum $p_F = 221$ MeV). Solid (dotted) line for $m^* = 1.44 (1.8)$ GeV.

Fig. 2. The asymmetry of the number of events in the $^{12}$C(e,e'p) reaction as a function of three-momentum transfer $q$ (GeV) integrated over the longitudinal missing momentum $p_m$ in the region $x \leq p_m \leq y = 100$ MeV. Solid, dashed and dotted lines refer to $x = 10, 30, 50$ MeV, respectively.

Fig. 3. The same as in fig. 2, but with $y = 200$ MeV.
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