Probing the nucleon meson cloud in semi-inclusive deep inelastic scattering: Tagging of ^{3}He

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Abstract: It is proposed to study the pion cloud component in the nucleon using semi-inclusive deep inelastic scattering on light nuclear targets in which the recoiling target nucleus is detected.

1 Introduction

The meson cloud model provides a convenient phenomenological model for treating the non-perturbative sea effects. It has been applied successfully to explain both the SU(2) sea, $(\bar{d}-\bar{u})$ as well as the SU(3) flavor symmetry breaking $(2\bar{s}-\bar{u}-\bar{d})$ effects in the nucleon, observed in inclusive dis and DY experiments. More detailed tests of the pion cloud model can be addressed in exclusive scattering, as originally proposed by Lusignoli [1] to determine the pion structure function. This can be achieved in principle by detecting the slow recoiling proton (or isobar) after dis on a proton target. However, it has been pointed out [2, 3] that the semi-exclusive cross section at all but the smallest x values is dominated by background contributions from di-quark (target) fragmentation.
Several ideas to isolate the meson process from the fragmentation contribution have been suggested. First the measurement of polarization transfer using a polarized proton target [3].
In this note we discuss the semi-inclusive dis on a nuclear target [4] $A(N,Z)$

$$e + A(N,Z) \to e' + A(N',Z') + X.$$

We argue that in this case the target fragmentation process in which one nucleon is destroyed will in general lead to breakup of the A system whereas in the meson cloud in principle there is a chance to leave the recoiling nucleus A in the ground state. The deuteron has isospin $T=0$ and does not couple elastically to pions and neither does ^{4}He. Therefore it is natural to consider the process on a ^{3}He target in which either ^{3}He (corresponding to an interaction with a π^0), or ^{3}H (interaction with π^+) is detected.

2 The semi-inclusive cross section

For simplicity we neglect final state interactions between spectators and debris of hit hadron.

2.1 Kinematics

We define the variables in the target rest frame and take $\vec{q}$ along the z axis.
Kinematics is defined by the l.c. variables $x = \frac{Q^2}{2m\nu}$, $Q^2 = 4EE' \sin^2(\theta/2)$, $y = \frac{E-E'}{E}$ for the photon, and $p_T^2 = \vec{p}^2 \sin^2\alpha$, $z = p^-/m_A$, for the observed nucleus ($m \equiv m_N$).
Then the four-momentum of the hit pion $t(z, p_T) = t_{\max} - p_T^2/z$, where $t_{\max} = -m_A^2(1-z)^2/z$.
In terms of t the three-momentum of the recoiling nucleus is $|p| = \frac{1}{2m_A}\sqrt{t^2 - 4m_A^2 t}$.
Therefore the slowest recoil (in the trf) occurs when t is maximal ($t = 0$), i.e. if $z = 1$.
Also for given z no particles with target mass (m_A) are produced beyond the kinematical limit $x > \frac{m_A}{m}(1-z)$, i.e. for $t_{\min} = t_{\max} = -mx^2/(1 - \frac{m}{m_A}x)$.
In the trf the polar angle is $\cos\alpha = \frac{2m^2(1-z)-t}{\sqrt{t^2-4m^2t}}$ with a maximum value $\alpha_{\max} = \arccos\sqrt{1-z^2}$.

2.2 Cross section

The semi-inclusive cross section for the reaction $e + A \to e' + X + A$ is given by (after integrating over the azimuthal angle ϕ)

$$\frac{d\sigma}{dx\,dy\,dz\,dp_T^2} = \frac{4\pi\alpha^2 s}{Q^4}\left(xy^2 H_1 + (1-y)H_2\right),$$

where $H_i(x, z, p_T)$ are the semi-inclusive structure functions.
Using the pion cloud model for H_2, the Bjorken limit, $H_1 = H_2/2x$, and integrating over y one finds

$$\frac{d\sigma}{dx\,dz\,dp_T^2} = \frac{4\pi\alpha^2 s}{Q^4}\frac{g_{\pi AA}^2}{16\pi^2}\frac{(-t)|F_{\pi AA}(t)|^2 F_2^\pi(x_\pi)}{(t-m_\pi^2)^2},$$

where the effective pion lc momentum is $x_\pi = \frac{m}{m_A}\frac{x}{1-z}$.
The nuclear pion form factor, $F_{\pi AA}(t)$, can be related to the axial form factor $F_A^5(t)$, $F_{\pi AA}(t) = F_{\pi AA}(0)F_A^5(t)/F_A^5(0)$. We may assume that the t dependence of the axial nuclear form factor is the equal to that of the vector one.
We note that the cross section is a delicate tradeoff between the t dependence of the nuclear form factor $F_A(t)$ which favors small values of $|t|$ (and hence $z \approx 1$, p_T small) and the pion structure function $F_2^\pi(\frac{x}{3(1-z)})$ which decreases rapidly with increasing $z \to 1 - \frac{m}{m_A}x$.

3 Estimates

Let us discuss the special case of a ^{3}He target. The magnetic form factor for ^{3}He is parametrized as [5] $F_A(t) = (\exp At + Bt \exp Ct)$, with $A = 0.48$ fm^2, $B = 0.18$ fm^2, and $C = 0.85$ fm^2.
For concreteness let us consider $x = 0.1$ and a kinetic energy of the recoil of $T = 10(25)$ MeV, at $\alpha = 30^o$ (in practice the smallest angle).
Then $|\vec{p}| = 237(375)$ MeV/c, $p_3 = 205(325)$ MeV/c, $p_T = 119(188)$ MeV/c, $z = 0.93(0.89)$ Then the corresponding values of t, x_π are $t = -(237\ \text{MeV/c})^2$ and $t = -(374\text{MeV/c})^2$, $x_\pi = 0.48$ and $x_\pi = 0.30$, respectively.
As an example we show in figure 1 the differential cross section as a function of z and α for $x = 0.10$ and $x = 0.15$.

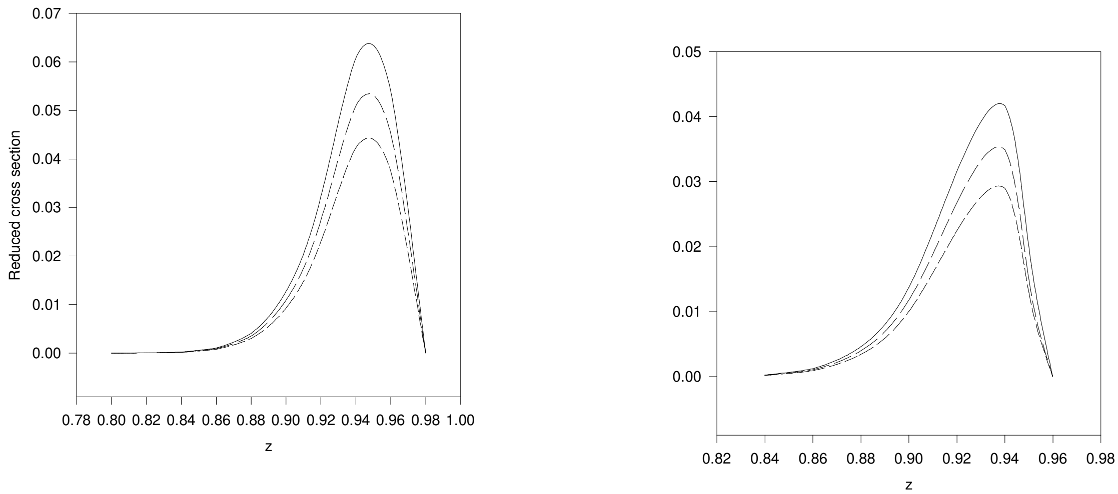

Figure 1: Semi-inclusive cross section for $x = 0.10$ (left) and $x = 0.15$ (right). The angle $\alpha = 30, 40, 50^o$ (top to bottom)

4 Discussion

The reaction discussed above can be considered as one example of deep inelastic diffractive scattering on a nucleus in which the nucleus as a whole emerges intact. At smaller values of x, ($x \leq 0.1$) one would expect that heavier mesons or reggions will dominate the reaction. Of particular interest are σ meson exchange, and at very small x one could even speculate on a 'nuclear pomeron' exchange, characterized by vacuum quantum numbers. In principle one could distinguish between the various processes by detecting different iso-spin T_3 members of recoiling nuclei or by using targets with various isospin T.
For example on a $A = 3$ target the ratio of ^{3}He and ^{3}H in the final state, or ^{4}He and d targets ($T = 0$) to check pion isospin selection rule.
In addition the dependence on Q^2, the photon-target center of mass energy, $W^2 = (P + q)^2 = m_A^2 + Q^2(1/x - 1)$, or $M_X^2 = (P + q - p)^2$ is expected to be different for the various processes.

References

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