CENTRALITY DEPENDENCE OF BARYON AND MESON MOMENTUM DISTRIBUTIONS IN $pA$ COLLISIONS

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The proton and neutron inclusive distributions in the projectile fragmentation region of $pA$ collisions are studied in the valon model. Momentum degradation and flavor changes due to the nuclear medium are described at the valon level using two parameters. Particle production is treated by means of the recombination subprocess. Pion inclusive distributions can be calculated without any adjustable parameters.

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The study of proton-nucleus ($pA$) collisions is important because they are tractable intermediaries between $pp$ and $AA$ collisions, when intense interest exists in discovering the extent to which the dense medium created in an $AA$ collision differ from that of linear superpositions of $pp$ collisions. One of the properties of $pA$ collisions is that the momentum of the leading baryon in the projectile fragmentation region is degraded, a phenomenon commonly referred to, somewhat inappropriately, as baryon stopping. Such a transference of baryon number from the fragmentation to the central region contributes to the increase of matter density at mid-rapidity, thereby raising the likelihood of the formation of quark-gluon plasma. Thus it is important to understand the process of baryon momentum degradation and its dependence on nuclear size or centrality.

Since it is questionable that the concept of color strings can be relevant in heavy-ion collisions where the abundance of color charges in the overlap

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region renders unlikely the development of constricted color flux tubes. Our approach in this paper will be on the various levels of the constituents of the nucleon that are consistent with the parton model. More specifically, we shall use the valon model to keep track of the momenta of the constituents and the recombination model to describe the hadronization of the partons. The valons play a role in the collision problem as the constituent quarks do in the bound-state problem. Thus a nucleon has three valons which carry all the momentum of the nucleon, while each valon has one valence quark and its own sea quarks and gluons. Although soft processes are non-perturbative, the valon model (including recombination) nevertheless provides a systematic way of calculating all subprocesses that contribute to a particular inclusive process. Some of the subprocesses can be identified with certain diagrams in other approaches, e.g., baryon junction and diquark breaking terms.

The valon distributions in the proton will be determined by fitting the parton distributions at low $Q^2$. The effect of the nuclear medium on the valon distribution of the proton projectile will involve two parameters, one characterizing the momentum degradation and the other flavor flipping. The color indices are all averaged over, since multiple gluon interactions, as the projectile traverses the target nucleus, are numerous and uncomputable. Their effects are, however, quantified in terms of the number, $\nu$, of target nucleons that participate in the pA collision. For that reason it is important that the experimental data must have centrality selection expressible in terms of the average $\bar{\nu}$.

In the valon model a proton is considered to consist of three valons ($UUU$), which have the same flavors as the valence quarks ($udd$) that they individually contain. Thus a valon may be regarded as a parton cluster whose structure can be probed at high $Q^2$, but the structure of a nucleon itself in a low-$p_T$ scattering problem is described in terms of the valons. As in the parton model we work in a high-momentum frame so that it is sensible to use the momentum fractions of the constituents. Reserving $x$ for the momentum fraction of a quark, we use $y$ to denote the momentum fraction of a valon. In this paper $y$ never denotes rapidity. Let the exclusive valon distribution function be

$$G_{UUD}(y_1, y_2, y_3) = g(y_1 y_2)^{\alpha} y_3^{\beta} \delta(y_1 + y_2 + y_3 - 1),$$

(1)

where $y_1$ and $y_2$ refer to the $U$ valons and $y_3$ the $D$ valon. The normalization factor $g$ is determined by requiring that the probability of finding these three valons in a proton be one, i.e.

$$\int_0^1 dy_1 \int_0^{1-y_1} dy_2 \int_0^{1-y_1-y_2} dy_3 G_{UUD}(y_1, y_2, y_3) = 1.$$

(2)
Denote $\frac{dz}{z} K_{NS}(z)$ the distribution of the valence quark in a valon, and $\frac{dz}{z} L(z)$ that of the sea quarks, then the distribution for the favored quark (like $u$ quark in a $U$ valon) in a valon is $K(z) = K_{NS}(z) + L(z)$. Thus the parton distribution in the proton can be written as

$$x u(x) = \int \int \int dy_1 dy_2 dy_3 G_{UU} (y_1, y_2, y_3) [2K(x/y_1) + L(x/y_3)], \quad (3)$$

$$x d(x) = \int \int \int dy_1 dy_2 dy_3 G_{UU} (y_1, y_2, y_3) [2L(x/y_1) + K(x/y_3)]. \quad (4)$$

From previous studies, we use

$$K_{NS}(z) = z^a (1-z)^b/B(a,b+1), \quad (5)$$

$$L(z) = \ell_o (1-z)^5, \quad (6)$$

$xu(x)$ and $xd(x)$ have been given by CTEQ. By fitting $xu(x)$ and $xd(x)$ we can get $\alpha, \beta, a, b, \ell_o$

$$\alpha = 0.70, \quad \beta = 0.25, \quad a = 0.79, \quad b = -0.26, \quad \ell_o = 0.083.$$  

If we know the probability, $F(x_1, x_2, x_3)$, of finding a $u$ quark at $x_1$, another $u$ at $x_2$, and a $d$ at $x_3$, and the recombination function, $R_p(x_1, x_2, x_3, x)$, which is the probability for three quarks to form a proton at $x$, the momentum distribution of the produced proton in the projectile fragmentation region can be written as

$$\frac{d\sigma_p}{d^3x} = H_p(x) = \frac{1}{N} \int \int \int \frac{dx_1}{x_1} \frac{dx_2}{x_2} \frac{dx_3}{x_3} F(x_1, x_2, x_3) R_p(x_1, x_2, x_3, x), \quad (7)$$

where $N$ is a normalization constant. From former studies

$$R_p(x_1, x_2, x_3, x) = \frac{x_1 x_2 x_3}{x^3} G_{UU} \left( x, \frac{x_1}{x}, \frac{x_2}{x}, \frac{x_3}{x} \right). \quad (8)$$

To calculate $F(x_1, x_2, x_3)$, we need to consider the physics involved in the passing of the incident proton through the nucleus. During the process, valons in the proton lose their energy and change their flavor contents. We describe the energy loss of valons by $D(z_i, \nu_i)$ through the following equation

$$G'(y_1', y_2', y_3') = \int \int \int \frac{dy_1 dy_2 dy_3}{y_1' y_2' y_3'} G(y_1, y_2, y_3) D(\frac{y_1'}{y_1}, \nu_1) D(\frac{y_2'}{y_2}, \nu_2) D(\frac{y_3'}{y_3}, \nu_3), \quad (9)$$

with $G'(y_1', y_2', y_3')$ depends on $\nu_i$ implicitly. The moments of $D(z_i, \nu_i)$ can be expressed, with a parameter $\kappa$, as

$$\dot{D}(n, \nu_i) = \exp \left[ \dot{Q}(n) \nu_i \right] = \exp \left\{ -\kappa \nu_i [\psi(n) + \gamma_E] \right\}.$$
Assume that the flavor changes at each of the $\nu_i$ collisions are incoherent and the probability for a valon from $U$ to $D$ or from $D$ to $U$ in one valon-nucleon collision is $q$, then the probability for a valon to change its flavor after $\nu_i$ collisions can be proved to be $q_{\nu_i} = \{1 - (1 - 2q)^{\nu_i}\}/2$. Effectively, one can write valons as

$$U \xrightarrow{\nu_i} p_{\nu_i} U + q_{\nu_i} D, \quad D \xrightarrow{\nu_i} p_{\nu_i} D + q_{\nu_i} U,$$

with $p_{\nu_i} = 1 - q_{\nu_i}$, then $F(x_1, x_2, x_3)$ can be calculated. Therefore we can get the momentum distribution of produced proton in the projectile fragmentation region and compare the results with those from experiments. In doing so, one needs to calculate $F(x_1, x_2, x_3)$ for the produced protons and anti-protons and make average over all possible combinations of $\nu_i$, and choose parameters to fit the experimental data on $p - \bar{p}$ production. We can also calculate the distribution for produced neutrons. By simultaneously fitting the experimental data on $p - \bar{p}$ and $n - \bar{n}$ in the proton fragmentation region, we get $\kappa = 0.62, q = 0.37$. This corresponds to an effective degradation length 17fm. From these two parameters, one can predict the momentum distribution for the pions in the same region. In above formulas, we used collision numbers at two different levels: $\nu$ at the nucleon level, and $\nu_i$ at the valon level. We need also to take into account the relation between the number of nucleon-nucleon collisions, $\nu$, and that of valon-nucleon collisions, $\nu_i$. Because of the space limit, the discussion is not contained in this talk, but can be found in Ref. [10]. The fitted results and our prediction can also be found there.

In summary, the general shapes of momentum distribution of hadrons produced in the proton fragmentation region can be reproduced within the valon model with suitably chosen parameters and recombination function.

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