Color Coherent Phenomena with Hadron Beams [*]

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We outline major ideas involved in discussion of color coherence phenomena (CCP) at intermediate energies. We point out that the recent advances in calculating cross sections of hard exclusive processes off light nuclei allow to use the lightest nuclei for sensitive tests of CCP. Consistency of the results of the measurements of color transparency in quasielastic A(p,2p) and A(e,e'p) processes is emphasized. Evidence for presence of significant color fluctuations in nucleons and pions emerging from the study of diffractive processes is summarized. A new class of hard processes leading to three particle final state is suggested for electron and hadron projectiles. A number of new experiments are suggested to probe color fluctuations in hadrons.

1. Introduction

In this talk we concentrate on the intermediate energy Color Coherence phenomena (CCP) ($E_{inc} \leq 50$ GeV) relevant for TJNAF, HERMES and KEK hadron facility (JHF) energies. These studies would be complementary to the studies of CCP at high energies where a number of such phenomena were recently been observed both in the scattering of protons - vector meson production at HERA, see the recent discussion in [1], and in coherent diffraction of a pion to two jets [2].

Intermediate energy phenomena are more complicated situation - dispersion over the size of the produced quark-gluon system is likely to be larger, interaction of the produced system with the target is more complicated. Also the produced system is not frozen during passage of the nucleus, leading to dependence of the absorption on the distance from the interaction point. One can treat this as a mere complication - but in fact this is a separate aspect of QCD which we miss in high-energy processes and which deserves dedicated studies.

2. Color transparency phenomena

To describe cross sections of hard processes in QCD one has to introduce the Fock space decomposition of the light-cone hadron wave function over configurations containing

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different number of constituents. Probably the most interesting components in hadrons are those which contain minimal number of constituents. They determine asymptotic behavior of various exclusive hard processes such as electromagnetic form factors. One can expect that at very large momentum transfers point-like (small size components) (PLC) of the hadron wave function should dominate in the scattering. To check this assumption it was suggested by Brodsky [3] and Mueller [4] to study quasi-exclusive hard reactions $l(h) + A \rightarrow l(h) + p + (A - 1)^*$. If the energies and momentum transfers are large enough one expects that projectile and ejected nucleon travel through the nucleus in point-like (small size) configurations, resulting in a cross section proportional to A.

In accessing the range of applicability of this approximation one has to address two questions: (i) Can PLC be treated as a frozen during the passage of the nucleus, (ii) At what momentum transfer PLC's dominate in the elementary amplitude.

2.1. Expansion effect

The current color transparency experiments are performed in the kinematics where expansion of the produced small system is very important (essential longitudinal distances are not large enough) and strongly suppresses color transparency effect [5,7].

The maximal longitudinal distance for which coherence effects are still present is determined by the minimal characteristic internal excitation energies of the hadron h. The estimates [5,7] show that for the case of a nucleon ejectile coherence is completely lost at the distances $l_c \sim (0.3 \div 0.5) \cdot p_h$ fm, where p_h is measured in GeV/c.

To describe the effect of the loss of coherence two complementary languages were suggested. In Ref. [5] based on the quark-gluon representation of PLC wave function it was argued that the main effect is quantum diffusion of the wave packet so that

$$\sigma^{PLC}(Z) = (\sigma_{hard} + \frac{Z}{l_c}[\sigma - \sigma_{hard}])\theta(l_c - Z) + \sigma\theta\left(Z - l_c\right). \tag{1}$$

This equation is justified for hard stage of time development in the leading logarithmic approximation when perturbative QCD can be applied [5,6,9,8]. One can expect that Eq.(1) smoothly interpolates between the hard and soft regimes. A sudden change of σ^{PLC} would be inconsistent with the observation of an early (relatively low Q^2) Bjorken scaling [9]. Eq.(1) implicitly incorporates the geometric scaling for the PLC-nucleon interactions which for the discussed energy range include nonperturbative effects. However the discussed approximation for the expansion effects is oversimplified, see discussion in section 2.3.

The time development of the PLC can also be obtained by modeling the ejectile-nucleus interaction using a baryonic basis for the wave function of PLC:

$$|\Psi_{PLC}(t)\rangle = \Sigma_{i=1}^{\infty}a_i \exp(iE_it)\,|\Psi_i\rangle = \exp(iE_1t)\Sigma_{i=1}^{\infty}a_i \exp\left(\frac{i(m_i^2 - m_1^2)t}{2P}\right)|\Psi_i\rangle, \tag{2}$$

where $|\Psi_i\rangle$ are the Hamiltonian eigenstates with masses m_i, and P is the momentum of PLC which satisfies $P \gg m_i$. As soon as the relative phases of the different hadronic components become large (of the order of one) the coherence is likely to be lost. It was however suggested by B.Pire and J.Ralston that coherence may be sustained over much larger distances, see contribution of B.Pire [10] and references therein. One rather special

example when coherence is sustained indefinitely is the harmonic oscillator - in this case coherence is sustained due to the equidistance of the energy levels.

Color transparency requires that the amplitude of $PLC-N$ interaction is small, leading to a number of constraints on the amplitudes of $i + N \rightarrow j + N$ scattering [7,11–14]. If many intermediate states are included in the hadron-basis model, the numerical results of two approaches for σ_{eff} turn out to be quite similar.

It is worth emphasizing that though both approaches model certain aspects of dynamics of expansion, a complete treatment of this phenomenon in QCD is missing so far. In particular, the phenomenon of spontaneously broken chiral symmetry may lead to presence of two scales in the rate of expansion, one corresponding to regime where quarks can be treated as massless, and another where virtualities become small enough and quarks acquire effective masses of the order of 300 MeV.

2.2. Are small configurations been made?

Current pQCD analyses indicate that the leading twist approximation for the pion form factor could become applicable (optimistically) at $Q^2 \geq 10 - 20 GeV^2$, for the recent analysis see Ref. [15]. For the nucleon case even larger Q^2 are likely to be necessary. However this does not preclude PLC from being relevant for smaller Q^2. In fact, in a wide range of models of a nucleon, such as constituent quark models with singular (gluon exchange type) short-range interaction, pion cloud models, the configurations of sizes substantially smaller than the average one dominate in the form factor at $Q^2 \geq 3-4GeV^2$, see discussion in Ref. [16]. Message from the QCD sum rule model calculations of the nucleon form factor is more ambiguous.

Theoretical expectations for the large angle hadron-hadron scattering are even less clear. Irregularities in the energy dependence of the pp scattering for $\theta_{c.m.} = 90^o$, and large spin effects have lead to suggestion of presence of two interfering mechanisms in this process [17,18] corresponding to interaction of nucleon in configurations of small and large sizes.

2.3. Cross section of PLC-nucleon interaction

The cross section of high-energy PLC-nucleon interaction can be expressed in pQCD through the gluon density in the nucleon. In particular for the interaction of the $q\bar{q}$ pair of the transverse size $b = r_q^t - r_{\bar{q}}^t$ [19]

$$\sigma_{q\bar{q},N}(E_{inc}) = \frac{\pi^2}{3}b^2\alpha_s(Q^2)xG_N(x, Q^2 \equiv \frac{\lambda}{b^2}), \qquad (3)$$

where $\lambda(x \approx 10^{-3}) \approx 9, x = \frac{Q^2}{2m_N E_{inc}}$. At intermediate energies the gluon density enters at rather large x, leading to a further suppression of this cross section as compared to higher energies. All this indicates that the geometrical scaling - $\sigma \propto b^2$ - could be violated at intermediate energies leading to a lack of smooth connection between cross section of interaction of hadrons in average and in PL configurations. Emission of gluons in the process of expansion, and hence interaction of the wave package in configurations containing extra gluons could become important. Also the dominance of the two gluon coupling to a PLC is not obvious for such energies - a competing mechanism of interaction of PLC could be emission of a pion in PLC which contains similar suppression factor as the the coupling to PLC via two gluons [20]. Furthermore at the last stage of the expansion and formation of the outgoing hadron the spontaneous chiral symmetry breaking can

affect both the rate of expansion and the interaction of the wave packet with the target. Overall one can expect that interaction of PLC with nucleons at these energies is more complicated than, for example, in the case of the high-energy vector meson production by longitudinally polarized photons.

2.4. Experimental data

The current data on $A(p, 2p)$ reaction [21] seem to support increase of transparency at $p_{inc} = 6, 10 GeV/c$ as compared to that observed at $T_p = 1 GeV$, see discussion in [22]. The magnitude of the effect can be easily described in the color transparency models which include the expansion effect. Description of the 12 GeV/c data where a drop of the transparency is indicated requires invoking interplay of contributions of PLC and large size configurations as suggested in [17,18]. Such a description was achieved in Ref.[14]. The first data of the EVA experiment at BNL[23] confirmed a significantly larger value of transparency than the one expected in the Glauber approximation. At the same time the data indicate a strong variation of the transparency as a function of the center of mass scattering angle in the studied angular range of $90^o \geq \theta_{c.m.} \geq 84^o$ for $p_{inc} = 5.9 GeV/c$. Such a variation poses a challenge to all models since the elementary pp reaction does not show any variation of the energy dependence in this angular range.

First electron $A(e, e'p)$ experiment, NE-18, aimed at looking for color transparency was performed at SLAC [24]. Maximum Q^2 in this experiment is $\approx 7 GeV^2$ which corresponds to $l_{coh} \leq 2 fm$. In this kinematics the color transparency models which included expansion effects predicted a rather small increase of the transparency, see for example [9]. This prediction is consistent with the NE-18 data. However these data are not sufficiently accurate either to confirm or to rule out color transparency on the level predicted by the realistic color transparency models, for the detailed discussion see review [16]. It should be pointed out that the energy resolution of this experiment was insufficient to separate the levels, which further complicates interpretation of this experiment since the theoretical uncertainties are larger in this case. Also the restricted recoil energy range of the experiment leads to potential complications due to the nuclear quenching effects see discussion in [25].

3. High-momentum transfer exclusive processes at JHF

i) Fixed t color transparency studies.

At high energies cross section of the elastic pp scattering at fixed $\theta_{c.m.}$ drops rapidly with s $(d\sigma/dt \propto s^{-10})$. As a result measurements at $\theta_{c.m.} \sim 90^o$ would be hardly possible. At the same time it is expected that PLC will dominate in the interaction already at $-t \geq -t_0 \sim$ few GeV^2. This corresponds to the kinematics when both the projectile and the leading scattered proton are very fast and can be considered as nearly frozen in the interaction process. Only the recoiling nucleon is rather strongly absorbed. Its absorption should be similar to the one in the $A(e, e'p)$ reaction at the corresponding Q^2. Hence one expects that nuclear transparency should strongly increase as a function of incident energy for fixed t, see Fig.1.

Such studies would require a detector with momentum resolution $\Delta p/p \sim 1\%$ and angular acceptance of $5^o \leq \theta_{lab} \leq 30^o$.

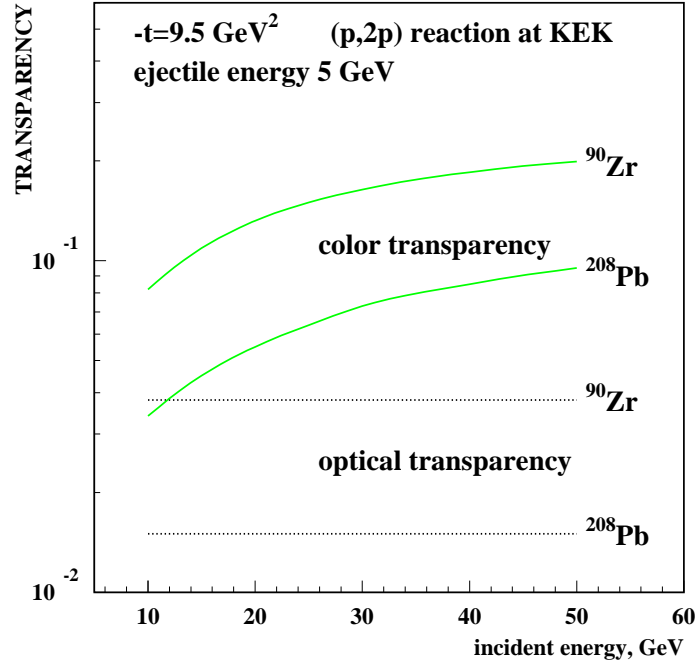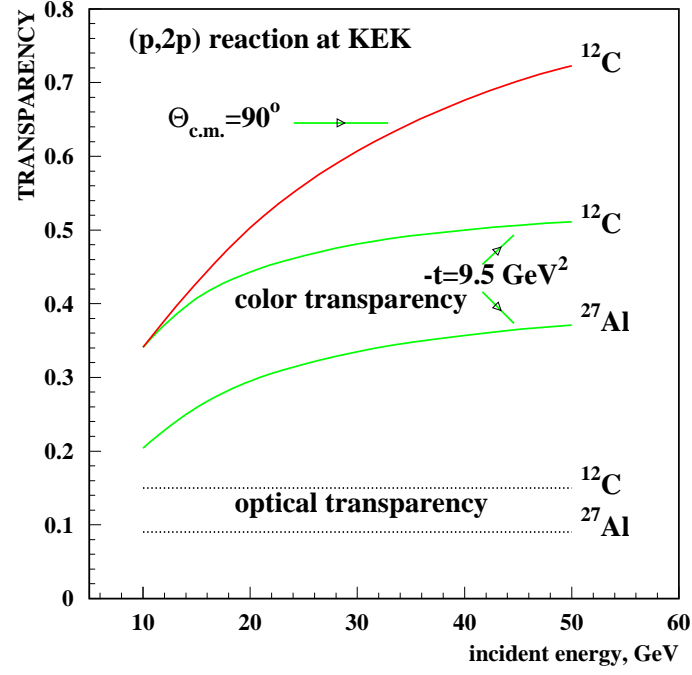ii) Use of different projectiles is necessary, since different hadrons have different PLC

Figure 1. *Energy dependence of the nuclear transparency calculated in the quantum diffusion model with $\Delta m^2 = 0.7 GeV^2$ as compared to the expectations of the Glauber model.*

probabilities. Furthermore, the relative importance of various reaction mechanisms may vary with the projectile. In particular, experimental studies of two-body large angle reactions [26] have demonstrated that reactions where quark exchange is allowed have substantially larger cross sections than reactions where quark exchanges are forbidden. The diagrams corresponding to the quark counting rules are expected to be dominated by small interquark distances, while the dominance of the small interquark distances arises in the diagrams with multiple gluon exchanges due to Sudakov form factor effects only. Thus the energy dependence of the nuclear transparency in different channels may be quite different. Consequently, the experimental study of the reactions like $p + A \rightarrow \Delta^o + p + (A - 1)^*$ would be extremely important.

It would be also very interesting to study nuclear transparency with kaon, and antiproton projectiles. In particular, this may help to understand why the elastic $\bar{p}p$ cross section is suppressed as compared to the elastic pp cross section at least by a factor of 100 at $p_{inc} = 6$ GeV/c.

iii) One important consequence of the CT picture is that cross sections for production of excited states in high-energy wide angle reactions [7,11] are large. So it is important to look for the processes like $p + A \rightarrow N^*(N\pi, N\pi\pi) + N + (A - 1)^*$. Knowledge of the relative abundance of resonances and continuum would help in building more realistic models for the expansion of PLC.

4. Probing the PLC in the high energy scattering from the lightest nuclei

To investigate the implication of the QCD physics for nuclear reactions at not extremely high energies one has to find a way to fight effects of space-time evolution of the the quark-gluon system produced in a hard $\gamma^*(h)N$ scattering. As we discussed above this evolution results in an expansion of a PLC (assuming that it was produced in the hard interaction) to an average size configuration before it could reach another nucleon. In this case one would not be able to observe any color coherence/transparency effects.

Hence an optimal strategy seems to be to select the processes where propagating system may interact with a residual system close to the primary interaction point. This minimizes expansion effects and therefore allows to investigate the PLC at an earlier stage of formation of the final state. However, theoretical methods which were successful in the medium-energy nuclear physics should be upgraded in order to describe processes where energies transferred to a nuclear target are $\geq few\ GeV$.

Hence a new theoretical approach for calculation of the high energy hard semi-exclusive reactions off the lightest nuclei has recently been developed [27,28]. In the nucleus lab. frame these reactions correspond to the kinematics where the momentum transferred to the nucleus $q = p_{inc} - p_{fin.proj}$ and the momentum of one of the hadrons in the final state p_f (the fast hadron) are: $q, p_f \sim\ few$ GeV/c and $(q \approx p_f)$ while the excitation energy of the residual nuclear system E_r is $\sim\ hundreds$ MeV:

$$\frac{q_-}{q_+} \quad , \quad \frac{p_{f-}}{p_{f+}} \ll 1. \tag{4}$$

Here $k_\pm = k_0 \pm k_z$ ($k = q, p_f$) and z is in the $\vec{q}$ direction. The condition (4) provides the small parameter for our calculations. Using this condition it is straightforward to demonstrate that within the accuracy $O(\frac{q_-}{q_+}, \frac{p_{f-}}{p_{f+}})$ the sum of all possible Feynman diagrams

which describe the particular hard semi-exclusive reaction off nuclei could be reduced [29,30,28] to the sum of the restricted number of diagrams where the soft rescattering of the fast hadron (h) with slow nucleons of the target can be described by the invariant amplitude of the elastic hN scattering, f_{hN}. Thus one ends up with a set of covariant diagrams for rescatterings where usual Feynman rules are applied and vertices f_i correspond to above mentioned phenomenological amplitudes.

The diagrams of this type has two crucial features which reflect the high-energy nature of the scattering process and the "soft" nature of rescattering of fast hadrons with the slow nucleons of the target:

• For each vertex f_i, the " $-$ " component of the scattered particle's momentum is conserved up to the factor $O(\frac{q_-}{q_+}, \frac{p_{f-}}{p_{f+}})$. Indeed the energy-momentum conservation for the f_k vertices implies that the " $-$ " components of the rescattered slow k nucleons are proportional to $\frac{p_{f-}}{p_{f+}} \approx \frac{m_f^2}{p_{f+}^2}$.

• The propagator of the fast hadron (knocked-out nucleon - $D(p_1 + q)^{-1}$) decouples from the slow (nuclear) part of the reaction. Such a decoupling allows to use the closure over the intermediate nuclear states, and thus to reduce the covariant nuclear vertices to the nuclear wave functions. As a result of relativistic kinematics we we find that at fixed $-t/s$ and high energy transfer limit, amplitude depends only on the p_{1-} component of the struck nucleon momentum. Therefore at fixed p_- we found effective factorization of the high-energy propagator from low energy intermediate nuclear part whose excitation energy on light cone is defined by the p_{1+} [31,9]. Such a decoupling is valid for any values of the target nucleon Fermi momenta and not restricted to the nonrelativistic limit $\frac{p_1^2}{2m^2} \ll 1$.

These are two of the major differences of the Feynman diagram approach from the conventional Glauber approximation [32], which is applicable only for the case when the Fermi motion of the spectator nucleons is neglected.

Two applications of the Feynman diagram formalism are (i) the knock-out $(e, e'p)$ reaction from the lightest nuclei, and (ii) large angle $^2H(p, 2p)$ reaction [33].

High t knock-out reaction from the deuteron is described by eight diagrams: the plane wave impulse approximation (IA) diagram F_A (where knocked-out fast nucleon does not interact with spectator nucleon), and by rescattering diagrams F_B (Fig.2) where projectile scatters off both nucleons or the final state rescatterings of the scattered nucleon off the would be spectator occur. The diagrams with single soft interaction lead to the screening of the impulse approximation diagram, while the diagrams with two soft interaction have the same sign as the impulse approximation diagram. Applying the Feynman rules for the rescattering diagram and switching to the coordinate space representation we obtain an expression which resembles familiar expression from the Glauber approach (for simplicity we give expression for the $^2H(e, e'pn)$ process where only one rescattering diagram is present:

$$F^{(B)} = - \int d^3x \phi_d(x) F_1^{em}(Q^2) \Theta(z) \Gamma_{NN}(x, \Delta). \tag{5}$$

The key distinction is emergence of the modified profile function $\Gamma_{NN}(x, \Delta)$ which differs from the conventional Glauber profile function as follows

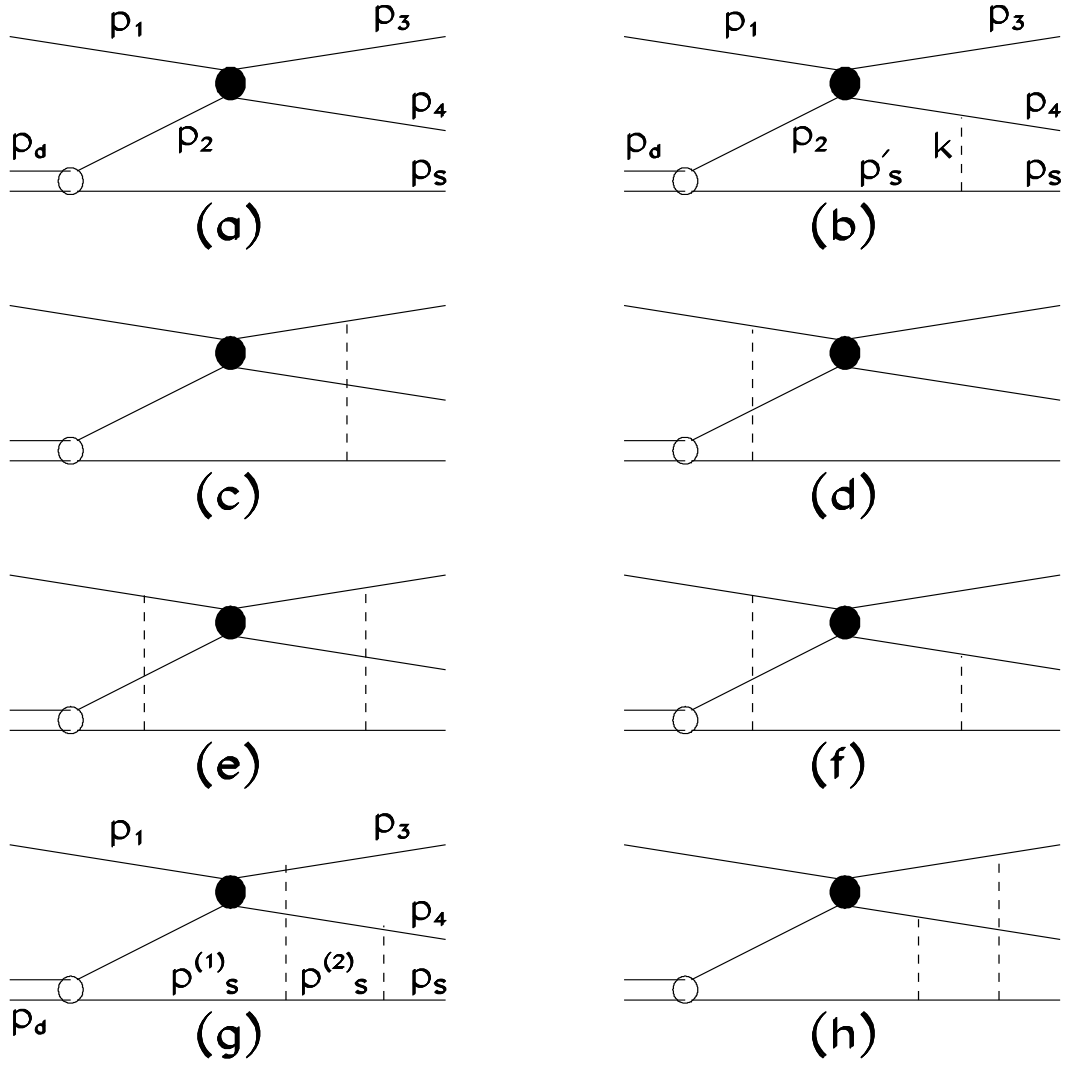$$\Gamma_{NN}(x, \Delta) = e^{i\Delta z} \Gamma_{NN}^{(GA)}(x). \tag{6}$$

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Figure 2. *Feynman diagrams of the eikonal approximation for $^2H(p,pp)n$ scattering. The dashed lines describe the amplitude of NN scattering, the full circles represent the hard pp scattering amplitude.*
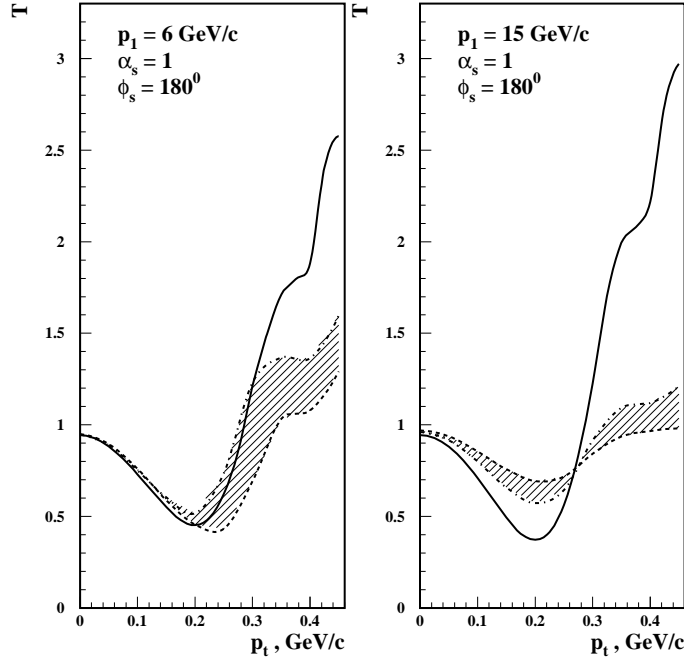
Figure 3.   *The p_t dependence of T at $\alpha_s = 1$. The solid line is for the elastic eikonal approximation which neglects color transparency effects. The shaded area corresponds to T calculated within the quantum diffusion model of CT. Dashed and dash-dotted curves correspond to QDM calculation with $\Delta M^2 = 0.7$ and $\Delta M^2 = 1.1$ GeV^2 respectively.*

Here Δ is given by defined according to

$$\Delta = (E_s - m)\frac{E_f}{p_{fz}} - (p_{st} - p'_{st})\frac{p_{ft}}{p_{fz}}. \tag{7}$$

and describes the excitation of the residual nuclear system (spectator nucleon in the case of the deuteron target). Here subscripts s and f refer to the spectator system and the knocked out nucleon. Due to the steep momentum dependence of the deuteron wave function, the factor $e^{i\Delta z}$ in Eq.(6) results in a significant difference between the predictions of the conventional Glauber approach and the present approach based on the Feynman diagram technique, see comparison in Ref. [27].

One finds that the $^2H(p, pn)$ reaction is very sensitive to the effects of color transparency and can provide a detailed mapping of the pattern of the expansion. The expected effects are large, see e.g. Fig.3. Strong effects are also predicted for the out of plane kinematics.

Overall we now have a reliable formalism for the treating final interaction of the knock out nucleons in electron and hadron nucleus reactions. Hence a set of experiments with lightest and medium size nuclei could allow to perform a detail mapping of the space-time evolution of the wave packet produced in the elementary hard process.

5. Color Fluctuations in Hadrons and Diffraction

Since coherent length in high-energy processes is large, a fast hadron can be considered as a superposition of constituents frozen during such collisions. Therefore existence of parton configurations within hadrons having small interaction cross section (as confirmed by the diffractive electroproduction of $\rho-$meson production) implies that significant fluctuations should be present in the intensity of interaction of fast hadrons with targets. It is convenient to introduce a bulk characteristic of these fluctuations - the probability for a hadron to interact with certain intensity, $P(\sigma)$, see review in [16]. One can describe $P(\sigma)$ in terms of its moments: $\langle \sigma^n \rangle = \int \sigma^n P(\sigma) d\sigma$. The zeroth moment is unity, by conservation of probability, and the first corresponds to the total hadron-nucleon cross section σ_{tot}. The second and third moments has been determined from available diffractive dissociation data for scattering off protons and deuterons as well as from the measurements of inelastic shadowing for $\sigma_{tot}(hD)$. Different determinations [34] give consistent values for the variance of the distribution: $\omega_\sigma \equiv (\langle \sigma^2 \rangle - \langle \sigma \rangle^2)/\langle \sigma^2 \rangle$, with $\omega_\sigma(p) \sim 0.25$ and $\omega_\sigma(\pi) \sim 0.4$, near 200 GeV/c momenta. The behavior of $P(\sigma)$ for $\sigma \to 0$ is determined by the interaction with minimal Fock configurations in the hadrons, leading to $P(\sigma) \propto \sigma^{n-2}$ where n is number of constituents in the hadron. $P(\sigma)$ estimated from data is broad; in line with the view that different size configurations interact with widely varying cross sections. Several analyses seem to confirm this picture.

- For the pion projectile it is possible to calculate $P(\sigma)$ for small σ along the same lines as for the $\rho-$meson production [19],

$$P(\sigma \ll \langle \sigma \rangle) = \frac{6 f_\pi^2}{5 \alpha_s(4k_t^2) \bar{x} G_N(\bar{x}, 4k_t^2)}, \tag{8}$$

where $\alpha_s(4k_t^2)$ is the QCD running coupling constant, and $G_N(\bar{x}, 4k_t^2)$ is the gluon distribution in the nucleon; $\bar{x} = 4k_t^2/s_{\pi N}$; $k_t^2 \approx 1/b^2$ where f_π is the constant for $\pi \to \mu\nu$ decay. This result is in a reasonable agreement with determination from diffractive data.

Nuclear inelastic coherent diffractive hadron production provides another nontrivial experimental test of the concept of color fluctuations.

- The total diffractive cross section can be computed using $P(\sigma)$ [35]. Results of the calculations agree reasonably with available data for the A-dependence of the semi-inclusive production for pion and proton projectiles.
- Coherent diffractive cross section emulsion data [36] for 400 GeV protons on $\langle A \rangle \approx 50$ nuclei give large cross sections consistent with the color fluctuation expectations [35].
- It was shown in Ref. [37] that the color fluctuation cross section expectations are in good agreement with the forward angle cross section data for $p +^4 He \to X +^4 He$ data [38].

Obviously much more detailed experimental studies are necessary to check the details of the picture.

6. Star dust processes

So far the studies of hard exclusive processes were concentrated on two-body reactions. It is natural to move one step further and ask a question whether collapsing of 3 valence quarks to a small size configuration in a nucleon or of valence $q\bar{q}$ in a meson would result
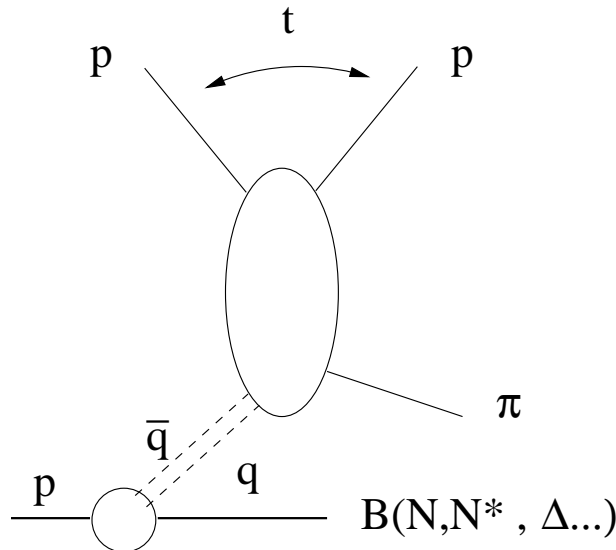
Figure 4. *Production of fast pion and recoiling baryonic system.*

in disappearance of other constituents? Such scenario would be natural in quantum electrodynamics for the case of positronium - the photon field disappears in the case when electron and positron are close together. However in QCD where interactions at large distances are strong it is possible that non-minimal Fock components of the hadron contain configurations with small color singlet clusters. To investigate this question we suggest a study of a new class of hard exclusive processes where large momentum is transfered to subsystem of the hadron and residual system has a finite mass not increasing with hardness of the process [39]. Examples of such reactions include $e + p \to e + M + B$, $h + p \to h' + M + B$ where M is a meson carrying most of the transfered momentum, while B is recoil system which mass and momentum are kept fixed in the target rest frame (or in the projectile rest frame),see for example Fig.4.

The discussed limit is

$$\alpha_B = \frac{E_B - p_{3B}}{m_N} = const, \frac{s_{N_{fin}M}}{s} = 1 - \alpha_B, s \to \infty, -t/s = const \qquad (9)$$

Reverse processes are also possible when a fast baryon is ejected from the target: $e + p \to e + B + M$, $h + p \to h' + B + M$ - Fig.5.

Processes of both kinds emerge naturally in the pion cloud picture of the nucleon (a baryon) as scattering of the nucleon core with a pion been a spectator or visa versa scattering of a pion with a nucleon (Δ-isobar) spectator. Within the pion cloud model cross section of these reactions should have cross section comparable to the cross section of two body large angle process.

Generally one could expect comparable cross sections for production in a recoil of a pion and heavier states. Investigation of these reactions is important also for study of
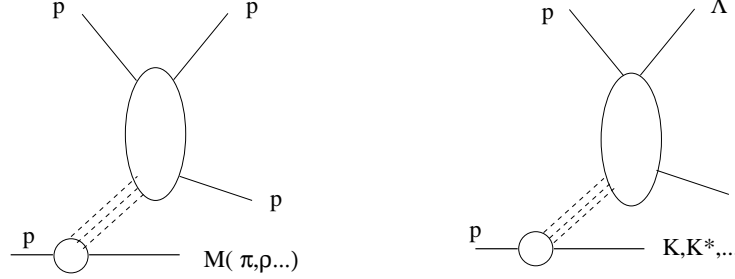
Figure 5. *Production of fast baryon and recoiling mesonic system.*

$(e, e'p), (p, 2p)$ reactions where they produce a background for high excitation energies $\geq (200 \div 300) MeV$.

Recently the QCD factorization theorem was proven for the DIS exclusive processes initiated by the $\gamma_L + T \rightarrow M + B$ [40]. The cross section is expressed through the convolution of the $q\bar{q}$ component of the meson wave function, hard blob, and the skewed parton densities in the nucleon. The quark skewed parton densities are defined as:

$$f_{ij/p}(x_1, x_2, t, \mu) = \int_{-\infty}^{\infty} \frac{dy^-}{4\pi} e^{-ix_2 p^+ y^-} \langle p'| T\bar{\psi}(0, y^-, \mathbf{0}_T)\gamma^+ \mathcal{P}\psi(0) |p\rangle, \tag{10}$$

where $\mathcal{P}$ is a path-ordered exponential of the gluon field along the light-like line joining the two operators for the quarks of flavors i, j and the final state could be any baryon allowed by the quantum numbers. x_1, x_2 are the light-cone fractions of the quark and antiquark. For the process under discussion x_i satisfy

$$x_1 - x_2 = 1 - \alpha_B. \tag{11}$$

Recently calculations of some of these densities were performed in the QCD chiral model [41]. They indicate that probabilities to find a $q\bar{q}$ pair in the nucleon in a PLC configuration is comparable to the expectations of the pion model in a wide range of α_B.

If the corresponding two-body process is dominated by the the scattering in PLC we may expect a scaling relation between the cross sections of the processes induced by longitudinally polarized photons and hadrons:

$$\frac{\frac{d\sigma^{pp \rightarrow p+\pi+B}}{d\alpha_B d^2 p_{tB} d\theta_{c.m.}(p\pi)}}{\frac{d\sigma^{p\pi \rightarrow p+\pi}}{d\theta_{c.m.}}(s_{p\pi})} = \frac{\frac{d\sigma^{\gamma_L^* + p \rightarrow \pi+B}(Q^2)}{d\alpha_B d^2 p_t}}{\sigma^{\gamma_L^* + \pi \rightarrow \pi}(Q^2)}. \tag{12}$$

Similar scaling relations are expected for various hadronic projectiles.

Studies of the "star dust" processes provide a unique way to study parton color singlet correlations in nuclei. To be able to reach the scaling region incident energies of the order 20 GeV are necessary to insure that the energy in the hard blob is large enough.

To summarize, a diverse program of studies of dynamics of hard coherent processes is possible at JHF energies. One would be able to get a better insight into the properties

of point-like configurations in the hadrons, investigate the space time evolution of small quark-gluon wave packages, and also to start investigation of small color singlet clusters in hadrons.

Acknowledgments

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