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Title :

Large rapidity separation of baryonic number in
hard processes.

thesis for the title of "Magister philosophiae"

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Preface:

The purpose of this work is to provide an understanding of how baryon hairs are produced in electron-positron annihilation processes and deep inelastic scattering involving baryons in the initial state.

Baryons are taken to be Y-shaped and a fundamental role is attributed to the junction line.

parametrisation of the latter is inspired from ordinary hadronic reactions (low p_T)
In deep inelastic scattering, the mechanism responsible for the scattered baryon is that where the observed baryon is connected to the initial one by the junction line - it is shown that this mechanism takes place within a certain range in $t = (P_B - P_A)^2$

in case of high transverse momentum and due to the trigger bias this mechanism is dominant for enough high transverse momentum.

The normalisation for both the junction line model and the conventional parton model is far from the experimental normalisation.

Several people attempted to reduce that discrepancy but without success, QCD suffers from both the slope and the right normalisation.

The present thesis will be organised as follows

notions on duality, the parton model, application of these concepts to high p_T processes, baryons in e+e- annihilation, deep inelastic electron scattering and ends up with discussion, conclusions and references.

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I) General introduction

Section A : the concept of duality

Duality is a very important and profound concept in ordinary hadron physics; because it provides a connection between the direct forces and the exchange forces.

it states that a scattering amplitude can be described either by the resonances formed in the direct channel(s) or by the Regge singularities exchanged in the crossed channel(t).

a) finite energy sum rule

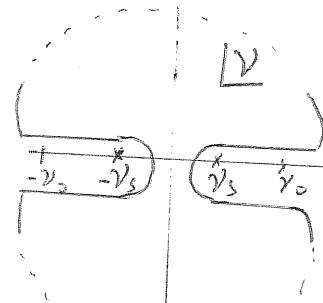
to give a more quantitative status of duality, we use the analyticity properties and the Regge-type behaviour of the scattering amplitude which lead in a trivial way to F.E.S.R

let $F(\nu, t)$ be the probability amplitude

$$\nu = \frac{s-u}{2} \rightarrow F(\nu, t) \text{ is real analytic in the cut } \nu \text{ plane}$$

If for $\nu > \nu_0$, $F(\nu, t)$ obeys
a regge-like expansion

$$(I,1) \quad F(\nu, t) \simeq \sum_i \beta_i(t) \frac{1 + \xi_i e^{-i\pi\alpha_i(t)}}{\sin \pi\alpha_i(t)} \nu^{\alpha_i(t)}$$



where $\beta_i(t)$ and $\alpha_i(t)$ are respectively the residues and the trajectories of the t-channel regge poles with signatures ξ_i .

applying Cauchy's theorem to $\nu^n F(\nu, t)$ one gets

$$(I,2) \quad \int_{\nu_0}^{\nu_0} \nu^{2p} \operatorname{Im} F(\nu) d\nu = \sum_i \beta_i(H) \frac{\nu_0^{d_i+2p+1}}{d_i+2p+1}$$

Now if we suppose that at low energies, the resonances dominate the S channel which is experimentally the case, then

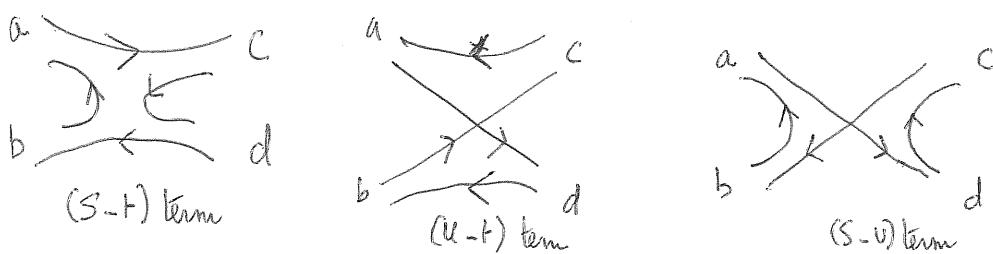
$$(I,3) \quad \int_{\nu_0}^{\nu_0} \operatorname{Im} F_{\text{res}}(\nu, H) d\nu = \sum_i \beta_i(H) \frac{\nu_0^{d_i+1}}{d_i+1}$$

The basic content of (I,3) is a connection of the low energy part of the amplitude with its high energy part. The two descriptions are dual of one another. The Regge pole contribution is a smooth representation of the low energy dynamical effects.

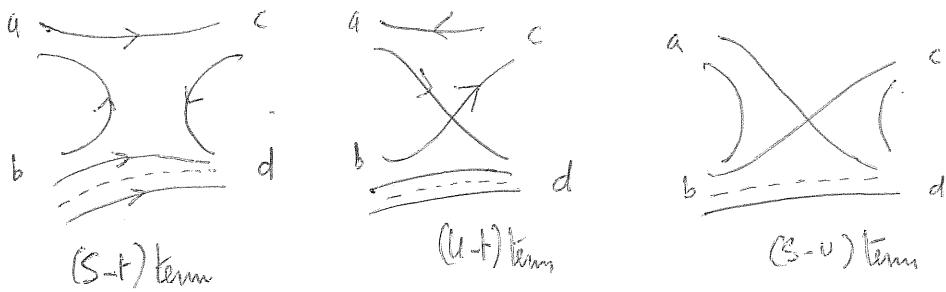
b) Duality diagram = Duality + quarks

A great amount of quark model results can be reproduced within duality, therefore the question of the implication of duality on the quark dynamics is of some relevance.

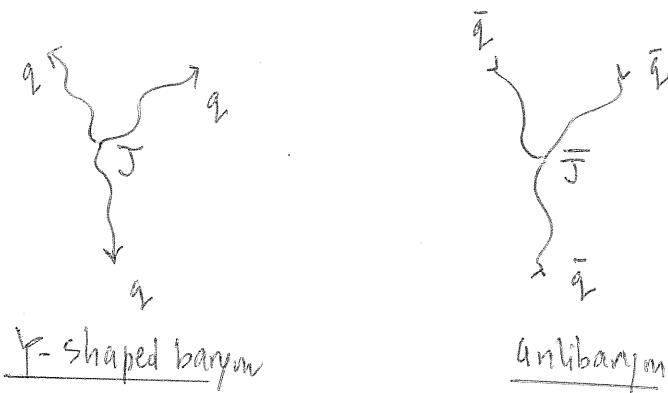
In order to build a diagram, one expresses each particle in terms of its quark content, a quark being an oriented line. In addition one requires the connectedness of the diagram.



Meson-Meson Scattering duality diagram



Meson-Baryon Scattering duality diagrams



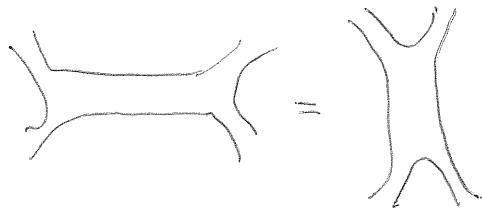
here we stress the fundamental role attributed to the junction line in the following study, in contrast to Q.C.D based models, where such junction is without any existence.

c) local duality and Veneziano formula

local duality states that for each value of S , resonances are equivalent to the t-channel Regge poles. This implies an infinite number of resonances and also an infinite series of poles. The first successful proposal was made by Veneziano who realized that for an $(S-t)$ term, the following expression possesses all the required properties.

$$V(S, t) = \beta \frac{\Gamma(1 - \alpha(s)) \Gamma(1 - \alpha(t))}{\Gamma(1 - \alpha(s) - \alpha(t))}$$

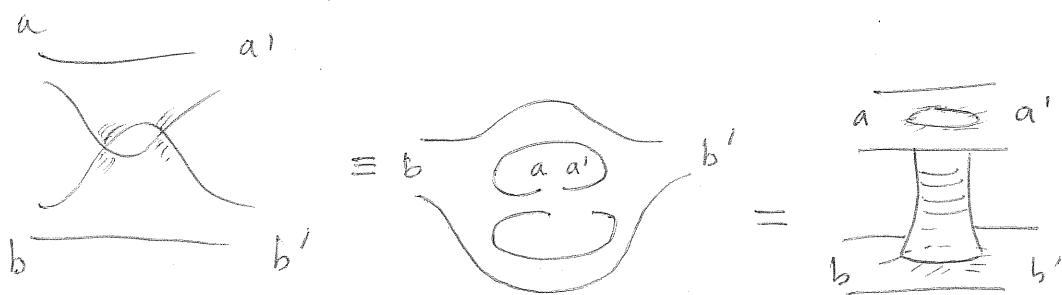
local duality can be represented by the following equality



therefore a dual diagram is invariant under deformations.

d) Pomeron and duality

so far we have not consider the pomeron because of its very peculiar role in duality. its exchange means the non exchange of any quantum number. a good candidate is the following diagram



The last diagram show that the interaction is mediated by a neutral glue tube.

A2: Unitarity and duality

a) Introduction Hadronic processes can be separated into two large classes characterized by very specific properties and quite different dynamical content. the first class includes the non-diffractive mechanism. this refers to the resonance formation and/or the ordinary Regge pole exchanges. the corresponding amplitude has the usual S^R energy dependance. the second class covers all the diffractive phenomena whose dynamics is not clarified. they can be simulated by the pomeron exchange. within the duality framework the pomeron occupies a very peculiar place and is related to the non-resonant background. this decomposition

of scattering amplitudes in two component duality, while clarifying the content of each component does not give any relation among them. The only way to predict the specific properties of the pomeron P starting from that of reggeon R is to use the unitarity condition, which gives a consistency relation to be satisfied by all reaction amplitude

$$\text{Im} \langle i | T | f \rangle = \sum \langle i | T + | n \rangle \langle n | T | f \rangle$$

$$\langle i | = \langle f |$$

$$\text{Im } F_d = R + P = \sum_n S_n$$

- Unfortunately the planar dual model violates unitarity in two ways

- the zero width limit at tree level

- the product of two planar T matrices can generate non planar pieces. The first point must be cured to insure the Regge behaviour and this can be achieved by the introduction of the loop corrections. The second difficulty is in fact attractive if we remember that precisely the pomeron is non planar. Therefore it would be satisfactory to associate these two equations

$$\text{planar} \otimes \text{planar} = \text{planar} \oplus \text{non planar}$$

$$\text{Reggeon} \times \text{Reggeon} = \text{Reggeon} + \text{pomeron}$$

b) Application of Dual ^{Topological} Unitarisation Scheme (D.T.U) to baryons.

In dual topological unitarisation scheme, the unitarity sum is approximated using multiparticle amplitudes which enjoy the following properties.

- Regge behavior
- Semi-local duality
- Exchange degeneracy.

let us sketch the method on the simplest case when the number of intermediate states is 2 and 3

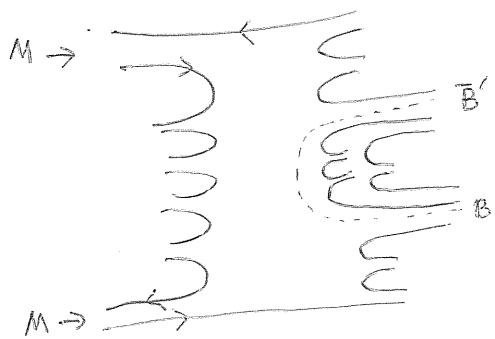
$$\text{Diagram} = \text{Diagram} + \text{Diagram} + \sum_{n>3} \text{Diagram}$$

for $n=2$ one has to square the four point dual amplitude, at the concrete level this amplitude can be represented in two ways : a sum over the S-channel resonances (if any) or a sum over t-channel regge poles. However it is well known that the regge representation is better adapted for S larger than some value $\bar{S} \approx 6 \text{ GeV}^2$.

$$\begin{aligned} \text{Diagram} &= \sum_{S \leq \bar{S}} \text{Diagram} = \text{Diagram} \\ \text{Diagram} &= \text{Diagram} \end{aligned}$$

Different decomposition of the amplitude
All $\rightarrow 123$

In this thesis we are strictly interested in the production of baryons and therefore to this aim we generalise D.T.U to the baryonic sector in the case of very low P_T baryons that is in ordinary hadron physics. We will suppose the dominance of the following diagram for the production of the pair $B\bar{B}$ in meson-meson scattering



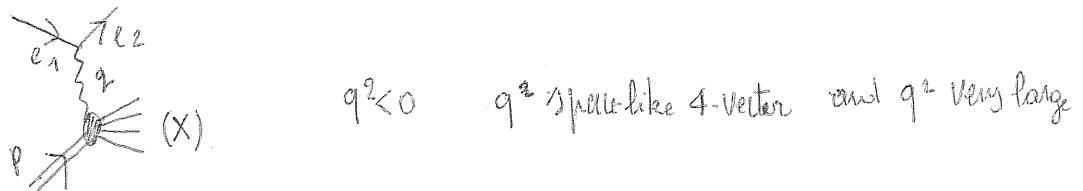
Dominant diagram in the production of $B\bar{B}$ pair (quark lines in the rapidity zone exterior to the pair may be planar or not).

Section B the concept of parton

B1. the parton model

a) Deep inelastic scattering, and scale invariance

Consider the reaction $e p \rightarrow e X$ where X any final hadronic state



the amplitude associated to this diagram is $(\bar{u}_2)_{\mu} u_1 \frac{q \pi e^2}{q^2} \langle X | J_{\mu} | p \rangle$

Where the hadronic current matrix element is unknown. Here the sum is taken over all final states except that of the electron
the kinematical variables of the problem are just

$$q^2 \text{ and } p \cdot q = Mv, \quad v = E/E, \quad M \equiv \text{proton mass}$$

the measured probability is given by

$$M^2 = (\bar{u}_2 \gamma_{\mu} u_1)^* (\bar{u}_2 \gamma_{\mu} u_1) \left(\frac{q \pi e^2}{q^2} \right)^2 K_{VV}$$

$$\text{with } K_{VV} = \sum_X \langle p | J_{\mu}(-q) | X \rangle \langle X | J_{\mu}(q) | p \rangle 2\pi \delta(M_X^2 - (p+q)^2)$$

using Lorentz invariance and gauge invariance, the symmetrical part in $p \cdot v$ of K_{VV} is written as

$$K_{VV} = 4W_2(q^2, v)(p_{\mu} - q_{\mu} \frac{p \cdot q}{q^2})(p_{\nu} - q_{\nu} \frac{p \cdot q}{q^2}) - 4W_1(q^2, v) M^2 \left(\delta_{\mu\nu} - \frac{q_{\mu} q_{\nu}}{q^2} \right)$$

the structure functions depend on q^2 and v

experimentally $W_1(q^2, v)$ and $W_2(q^2, v)$ no longer depend on q^2 in the limit ($Q^2 \rightarrow \infty$, $q^2 = Q^2$, $v \rightarrow 0$, with $\frac{Q^2}{v}$ fixed) that is it's so called Bjorken limit and the Bjorken scale invariance

in fact present-day energies violate this scaling. but this will not be considered here.

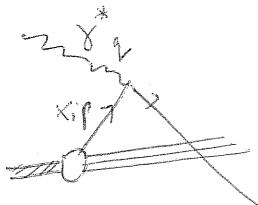
b) the parton model:

the parton model acquires a meaning only in some peculiar system of references the so called "infinite momentum frames" to insure the following conditions.

- 1) photon dissociation into hadrons minimized
- 2) impulse approximation.

the center of mass system at present day energies is one of these infinite momentum frames.

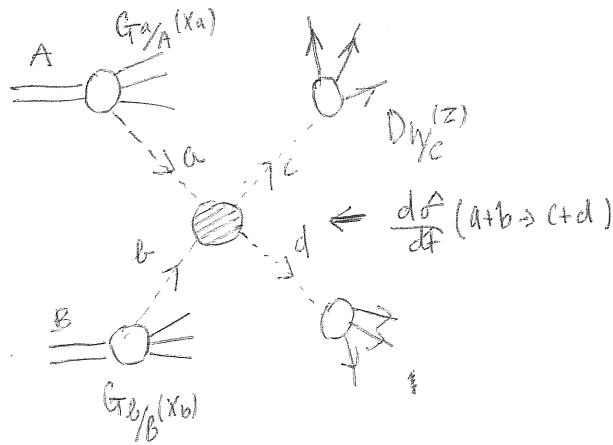
the deep inelastic scattering of an electron off a proton is given in the parton scheme by the following diagram.



Scattering of a virtual photon off a proton

B2. high momenta transverse processes and the partons

when hadrons collide at high energies, the large part of energy appear in the form of many particles moving in the forward direction with a very small transverse momentum $\langle p_T \rangle \approx 0.35 \text{ GeV}_c$. there exist however a few events with a high p_T . we currently assume that these hadrons result from a underlying and fundamental interaction between the hadron constituents "quarks". the collision of quark is assumed to elastic and the diffused quark fragmentates into a cascade of hadrons. this is illustrated by the following picture.



model of producing hadrons at high p_T

a) Structure functions $G_{q/A}(x_a)$

these functions appear already in the deep inelastic scattering, $G_{q/A}(x)$ is the mean number of quarks of type q with the fraction x of momenta between x and $x+dx$ inside the hadron of type A moving with a high velocity.

particularly there exists six functions to describe necessarily the ~~parton~~ the distribution of quarks inside the proton

$$u(x) \equiv G_{u/p}(x)$$

$$d(x) \equiv G_{d/p}(x) \quad \text{with } \bar{u}, \bar{d}, \bar{s}$$

$$s(x) \equiv G_{s/p}(x)$$

these functions verify certain relations:

$$\int_0^1 (u(x) - \bar{u}(x)) dx = 2$$

$$\int_0^1 (d(x) - \bar{d}(x)) dx = 1$$

$$\int_0^1 (s(x) - \bar{s}(x)) dx = 0$$

furthermore, isospin invariance and charge conjugation give extra relationships between $G_{u/p}(x)$ and $G_{b/m}(x)$ etc.. ($m = \text{neutron}$, $p = \text{proton}$)

the structure function $G_{A/A}(x)$ can be deduced from deep inelastic scattering for certain intermediate values of x .

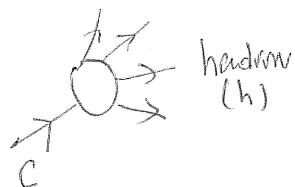
b) fragmentation functions

The offixed quark is assumed to fragmentate into a cascade of observed hadrons (confinement). These latter keep on the same direction with a small p_T relative to the jet axis. This fragmentation function is described by the function $D_{h/c}(z) = \int D_{h/c}(z, k_T) d^2 k_T$ where $D_{h/c}(z, k_T)$ is the number of hadrons of type h getting out of the quark c with a longitudinal fraction of momentum z , $z+dz$ and a transverse part $k_T, k_T + dk_T$.

This function is independent of the way the quark is generated and also of its color, and satisfy certain constraints

$$\sum_h \int_0^1 D_{h/c}(z) dz = 1$$

i.e. the total momentum of all the hadrons must be equal to that of the parent quark c



fragmentation of a quark

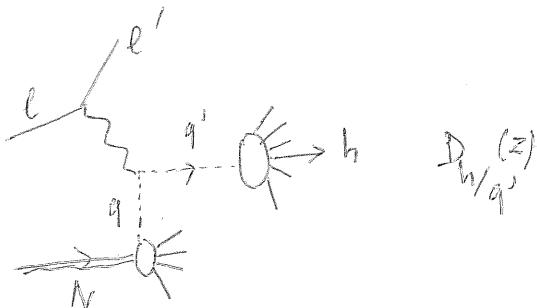
The integral of $D_{h/c}(z)$ is the mean multiplicity of hadrons of type h coming out of the quark c

$$\int_{z_{\min}}^1 D_{h/c}(z) dz = \langle N_h \rangle$$

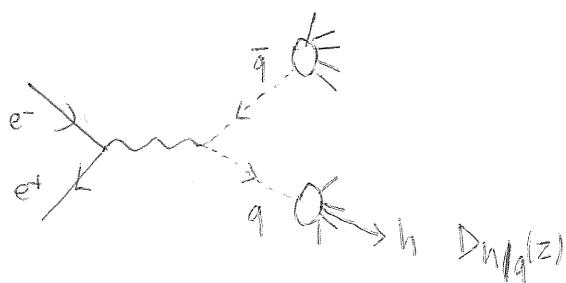
Now experimentally $D_{h/c}(z) \approx \frac{1}{z}$, then the multiplicity

Above a certain fixed momentum p_0 ($Z_{\min} = \frac{p_0}{P}$) increases logarithmically with the quark momentum.

being independant of the origin of the quark c , these functions can be extracted from leptonic Collisions $\ell + N \rightarrow \ell' + h + X$ or $e^+ + e^- \rightarrow h + X$



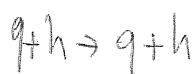
Double-inclusive deeply inelastic diffusion



$e^+ + e^- \rightarrow h + X$, inclusive $e^+ + e^-$ annihilation (one particle)

c) elastic diffusio $q + q \rightarrow q'_a + q'_b$

In the following the basic interaction will be that of the elementary constituents of the initial hadrons. i.e between quarks. Another process where the observed hadron takes place in the hard interaction i.e



or the quark fusion model Q.F.M i.e



will be supposed non-dominant or inexistant's

the hard, fundamental process taken as elastic quark-quark scattering will be described by the quantity $\frac{d\hat{\sigma}}{dt}$, which analytic form depends on the knowledge of the fundamental interaction. Here we adopt a phenomenological parametrisation

at high \hat{s} and \hat{t} we write asymptotically

$$\frac{d\hat{\sigma}}{dt} \approx \hat{s}^{-N} f\left(\frac{\hat{t}}{\hat{s}}\right)$$

We assume also the flavor independence of this cross section

$\frac{d\hat{\sigma}}{dt}$ is the same for
 $u\bar{u} \rightarrow u\bar{u}$
 $u\bar{d} \rightarrow u\bar{d}$
 $u\bar{u} \rightarrow u\bar{u}$

d) the one particle inclusive cross section $\equiv \frac{d\sigma}{dp}$

The cross section for the production of a hadron at high momentum transverse with respect to the beam axis is given by

$$\frac{d\sigma}{dp} (s, t, u, AB \rightarrow h) = \int_{x_a^{\min}}^1 dx_a \int_{x_b^{\min}}^1 dx_b G_{A/x_a} G_{B/x_b} D_{h/c}(z_c) \frac{1}{Z_c \pi} \frac{d\hat{\sigma}}{dt} (\hat{s}, \hat{t})$$

$$\text{with } \hat{s} = (p_A + p_B)^2$$

$$\hat{t} = (p_A - p_h)^2$$

$$\hat{u} = (p_B - p_h)^2$$

$\hat{s}, \hat{t}, \hat{u}$ are the invariants of the subprocess $q_a + q_b \rightarrow q'_a + q'_b$, we have the following relationships

$$\hat{s} = (p_A + p_B)^2 = x_a x_b s$$

$$\hat{t} = (p_A - p_h)^2 = \frac{x_a t}{Z_c}$$

$$\hat{u} = (p_B - p_h)^2 = x_b \frac{u}{Z_c}$$

Z_c and the integration boundaries are determined by the constraints of the elastic clifford

$$\hat{s} + \hat{t} + \hat{u} = 0 \quad \text{and} \quad 0 < x_a, x_b, Z_c < 1$$

putting the asymptotic form of $\frac{d\hat{\sigma}}{d\hat{t}}$ into the inclusive cross section one gets

$$E \frac{d\sigma}{d^3 p} (s, t, u) = p_T^{-2N} I(x_t, \theta_{c.m.})$$

In the following we will take the phenomenological parametrisation of Feynman and Field

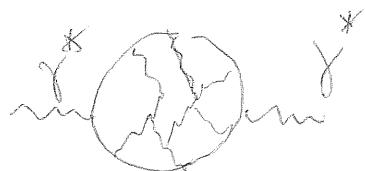
$$\frac{d\hat{\sigma}}{d\hat{t}} = \frac{\hat{A}}{-\hat{s} \hat{t}^3} \quad \text{with} \quad \hat{A} = 2.3 \cdot 10^6 \text{ GeV}^5$$

which gives the correct dependence in p_T ($\frac{1}{p_T^8}$) for the mesons produced at high p_T .

II jet's Universality

t'Hooft derived a topological expansion in $\frac{1}{N_c}$ where $g^2 N_c$, N_f are fixed and $N_c \rightarrow \infty$ (N_c , number of color, N_f number of flavor)

in this limit, the cross section $\gamma^* \rightarrow \text{hadrons}$ which is related to the imaginary part of the amplitude $\gamma^* \gamma^*$ is dominated by the planar diagrams



these diagrams contain no quark loop. this development does not lead to a jet structure, the final state is a $q\bar{q}$ state
 Veneziano, in order to unify dual topological expansion ($\frac{1}{N_f}$) and that of Q.C.D ($\frac{1}{N_c}$) consider the following limits

$$\frac{N_f}{N_c}, g^2 N \text{ fixed for } N \rightarrow \infty$$

the dominant diagrams are still planars, with quark loops in addition.



the jet structure is guaranteed in this picture. in fact

$$DIS \frac{g^*}{N_c} \frac{g^*}{N_c} = \sum_m \left| \frac{g^*}{N_c} \frac{g^*}{N_c} \right|^2$$

we notice that is of the same structure as that of dual topological expansion

the jet Universality postulates a correspondance at the planar level between the dual jets and Q.C.D jets. stated another way we expect the same cut-off in transverse momenta

$\langle p_T \rangle \approx 300 \text{ MeV}/c$ with respect to the jet axis, the same multiplicity

$$N_{jet} \simeq n_{MM}^{(\text{planar})} \quad \text{etc.}$$

We can make precise this statement using the following "kick". We introduce an auxiliary quark \underline{a} (which plays no role and will

$$\left| \begin{array}{c} \text{m} \\ \text{C} \\ \text{C} \\ \text{C} \end{array} \right|^2 = \frac{Q_i^2}{g^2 S^{aa}} \left| \begin{array}{c} \xrightarrow{i} \\ \text{A} \\ \cdots \\ \text{B} \end{array} \right| \left| \begin{array}{c} \xrightarrow{i} \\ \text{C} \\ \cdots \\ \text{C} \end{array} \right|^2$$

where $g^2 S^{aa} = \text{DIS}$

$$\left| \begin{array}{c} \xrightarrow{i} \\ \text{A} \\ \cdots \\ \text{B} \end{array} \right|$$

III Baryon production in deep inelastic $e+B \rightarrow e'+B'+X$ and $e^+e^- \rightarrow B+\bar{B}+X$

(See the article enclosed.)

Baryons at high momentum transverse

i) Comparison of standard parton model with experiment

Experimentally the cross section (1 particle inclusive) Fermilab and ISR)

$$E \frac{d\sigma}{dp^3} \approx \frac{1}{p_T^m} f(x, \theta_{cm})$$

for the production of protons in the reaction $p p \rightarrow p X$ is visibly larger than that of the antiproton in the reaction $p p \rightarrow \bar{p} X$

The inequality of fragmentation functions (for example)

$$D_{p/u}(z) > D_{\bar{p}/u}(z)$$

Could explain this difference, but admits that the proton and antiproton are created in independent pairs. but the slopes are quite different.

$$10 < \eta(\text{proton}) < 14$$

$$\eta(\text{antiproton}) = 8$$

The mechanism proposed (see article), if introduce a free parameter β can be adjusted to account for these inequalities



a mechanism for the production of baryons at high P_T

however the transfer ($|t|=P_T s$ at $\theta_{cm}=90^\circ$) minimal at CERN-ISR and Fermilab is larger than the upper limit of the dominance of this mechanism (comparison made with the independant pair creation mechanism)

$$|t| \geq |t_1| \text{ with } |t_1| \approx 10 \text{ GeV}^2 \quad (\text{see formula 23 of the article})$$

on the other side, the conventional model does not account for the observed slope.

We have nevertheless compute the one particle inclusive cross section at ISR energies as well as at those of Fermilab for the structure function, the following form of Berger and Phillips have been considered.

$$U(x) = 0.534 \bar{x}^{1/2} (1-x^2)^3 + 0.45 \bar{x}^{1/2} (1-x^2)^5 + 0.621 \bar{x}^{1/2} (1-x^2)^7$$

$$d(x) = 0.072 \bar{x}^{1/2} (1-x^2)^3 + 0.206 \bar{x}^{1/2} (1-x^2)^5 + 0.621 \bar{x}^{1/2} (1-x^2)^7$$

and for the fragmentation functions, we have used the parametrisation due to Owens

$$\sum D_{p/q} = \sum D_{\bar{p}/q} = (1-p) \alpha_p \sqrt{z} (1-z)^3 + (1-p) \xi_p (1-z)^3$$

$$\sum D_{q/\bar{q}} = \sum D_{\bar{q}/\bar{q}} = (1-p) \xi_p (1-z)^3$$

where P ($p=0.923$) is the momentum fraction carried by the mesons from a quark jet
and q stands of u, d , or s

in our practical computation we restrict ourselves to up quarks in the proton. In conclusion standard parton model underestimate the experimental result of a factor 10 in average see (fig 17, a,b)

(ii) Remarks concerning quantum chromodynamic predictions.

Certain authors attempted to obtain predictions on baryons produced at high momentum transverse in the Q.C.D framework. To this end the structure functions as well as fragmentation functions take into account scaling violations and of the smearing effect. The transverse component k_T (intrinsic) of the parton is taken to be

$$\langle k_T \rangle \approx 660 \text{ MeV/c}$$

Central collision ($2 \rightarrow 2$) is described to lowest order of perturbative Q.C.D. No higher order diagrams has been considered apart from the logarithmic dependence in Q^2 of the coupling constant $\alpha_s(Q^2)$ and structure and fragmentation functions.

The gluon fragmentation functions used have the following expression.

$$\frac{Z_D}{p/g} = \frac{Z_D}{p/g}(z) = g_N^{2.5} (1-z)^{2.5}$$

$$\text{with } g_N = 0.875(1-p)$$

This parametrisation involves uncertainties due to the impossibility to measure it directly.

The study of Baryons was done in parallel with that of mesons in order to see whether there were any common features.

here we comment their results.

The discrepancy between theoretical predictions and experimental data

is larger for the baryonic sector.

$$p + p \rightarrow p + X$$

$$p + p \rightarrow \bar{p} + X$$

at $P_T = 3 \text{ GeV}/c$, the experimental ratios exceed those of Q.C.D. of a factor 25 and 15 respectively for $\sqrt{s} = 27.4$ and $\sqrt{s} = 53 \text{ GeV}$ for the production of the proton (p) and of a factor 8 and 13 for that of the anti-proton (\bar{p}).

These numbers are to be compared with those for mesons: the factors in this case are respectively 3.3 and 3 at the same values of P_T and \sqrt{s} .

In the other hand fig. 18 and 19 show a certain convergence of these predictions toward experimental data, and this allows to think that at high s and high P_T Q.C.D. born diagrams become dominant. However this is not yet easy to check, for the data for the production of p and \bar{p} in the region $\sqrt{s} > 50 \text{ GeV}$ and $P_T > 5 \text{ GeV}/c$ are not available.

Waiting for the exploitation of these regions, we can try to understand why Q.C.D. does not provide good predictions for low P_T , imagining another competitive mechanisms, mainly, that of the junction line which we have proposed (this mechanism is a natural one but not dominant because of the weakness of the junction normalisation), the mechanism of the junction-pion, the CIM, etc ...

(ii) Remarks on the contributions of CIM (Constituent interchange model).

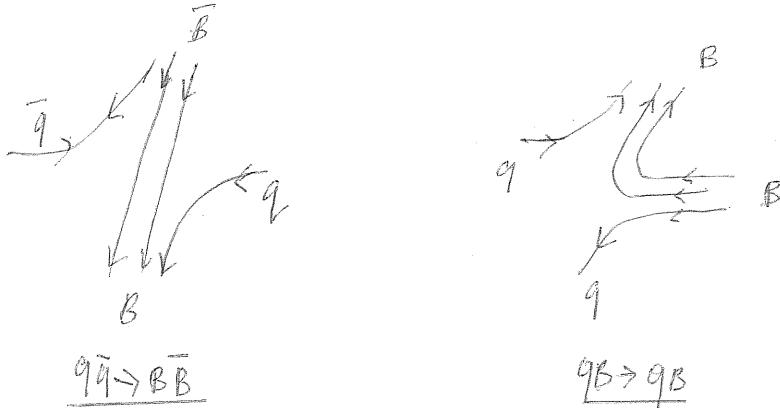
To comprehend the necessity of others competitive mechanisms in the case of the proton we must keep in mind the phenomenon of trigger bias. It's more probable that the detected baryon

carry a large fraction of momentum from the parent quark, ie $Z \rightarrow 1$ now the fragmentation functions behave as power of $(1-Z)$ when $Z \rightarrow 1$. These powers are 1 or 2 for mesons and 2 or 3 for baryons. Then the trigger bias present in the one particle inclusive reactions cause a large suppression of the baryon production with respect to mesons. This implies that a large amount of baryon inclusive cross section at any fixed p_T derive from new mechanisms in CEM. The observed baryons originate from a variety of sub-processes which dependence in p_T is determined from dimensional counting rules ie

$$\frac{d\sigma}{dp^3} = (p_T^2)^{2-N} f(x_T, \eta_{CM})$$

Where N is the number of fundamental fields participating to the hard sub-process.

The dominant CEM sub-process are given by the following diagrams



These two diagrams give a contribution p_T^{-12} which is the observed dependence.

The final state can materialise in a unique hadron or a jet ie

$$D\eta_B(z) = A \delta(1-z) + f(z)$$

$$\text{with } f(z) \approx (1-z)^N \text{ for } z \rightarrow 1$$

The exponent N' is also determined by dimensional counting. both subprocesses involve the vertex quark-diquark-baryon. the magnitude of this coupling α_B determines the global normalization of the CIM contribution.

we we assume, that the underlying mechanism for the production of the proton in $p\bar{p} \rightarrow pX$ is that of the above diagram where the proton is produced either directly

$$q\bar{p} \rightarrow qp$$

or by cascade (disintegration of the baryonic number)

$$qB \rightarrow q\bar{B}$$

$$\downarrow \\ \rightarrow p + X$$

the distribution in p_T (p_T^{-12}) is OK. on the other hand this mode of production is proportional to the valence quark distribution.

In Conclusion the CIM predictions of the proton are in agreement with data. for the production of the anti-proton, the discrepancy is flagrant p_T^{-8} and not p_T^{-12} .

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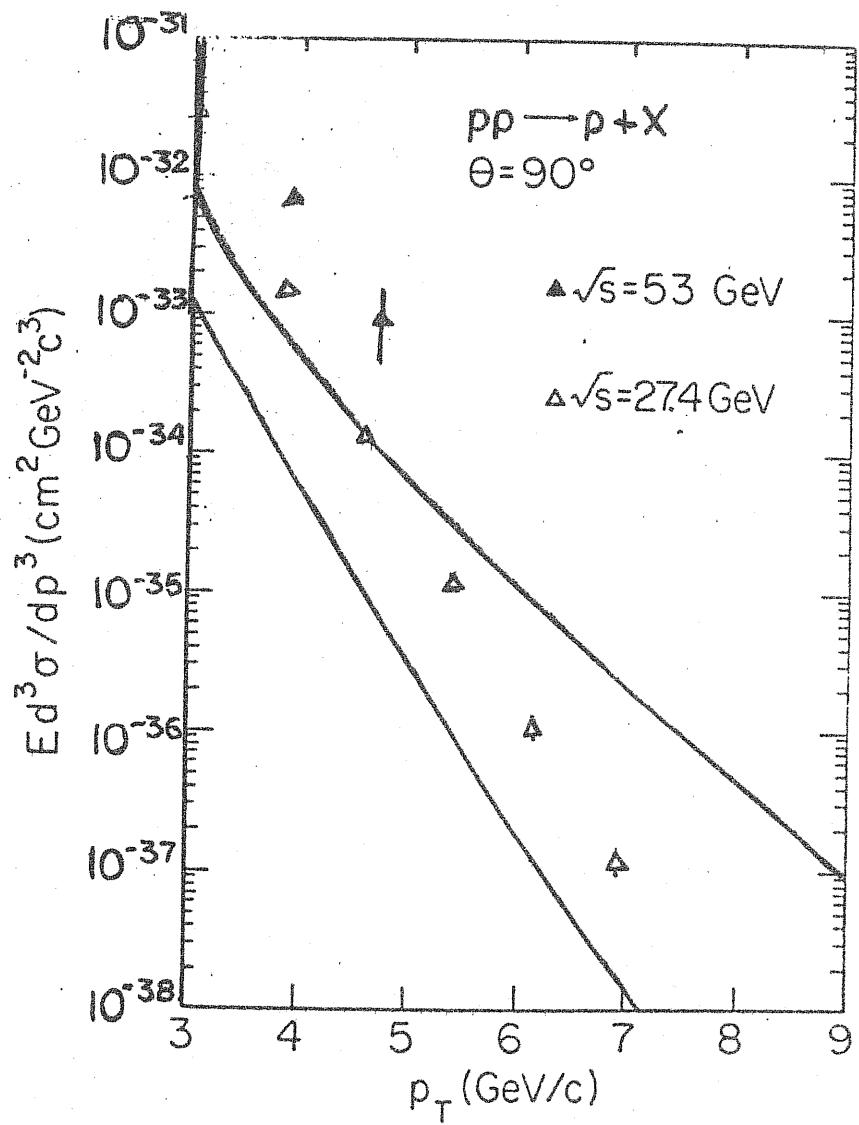


Fig. 18 Prédictions pour les protons à grand p_T (QCD)
predictions for protons at high p_T (QCD)

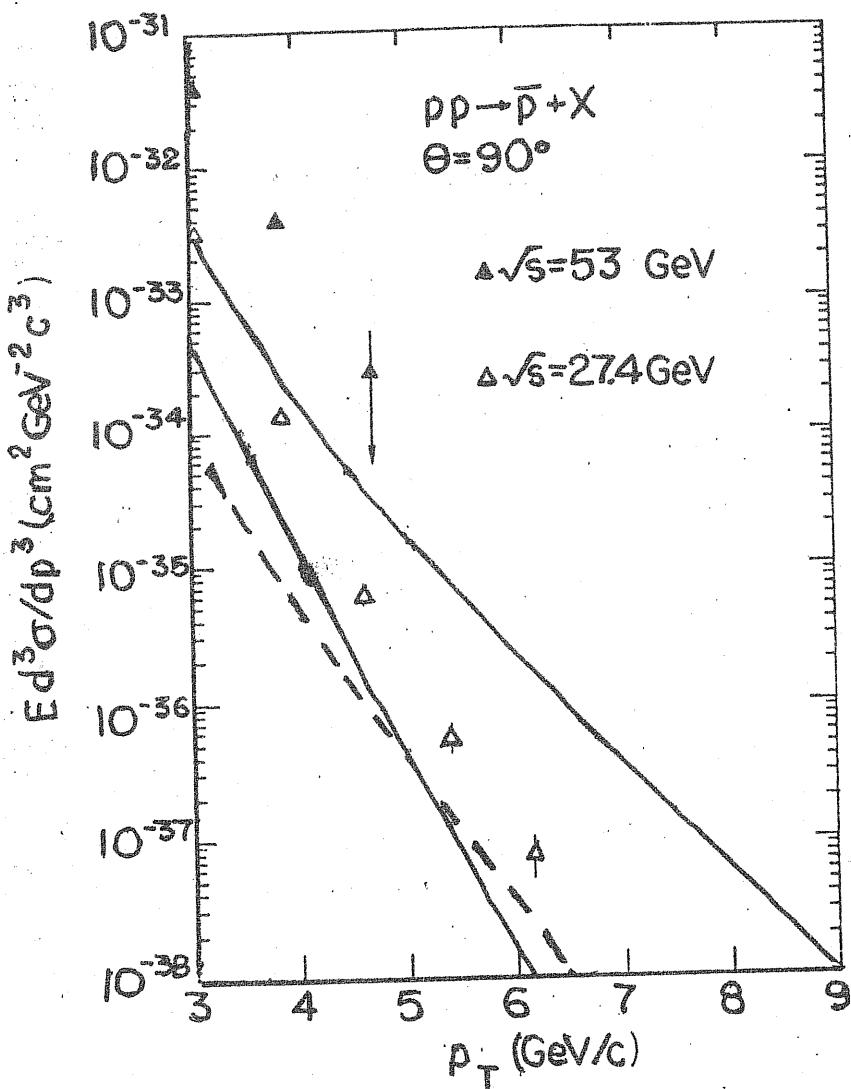


Fig.19: Prédictions pour les antiprotons à grands p_T (QCD).

La courbe discontinue correspond à l'ordre le plus bas du QCD avec invariance d'échelle exacte.

prediction for antiprotons at high p_T (QCD) the dashed curve correspond to the lower Q.C.D order with exact scale invariance .

Large rapidity separation of baryonic number in hard processes

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A mechanism combining the parton scheme and dual topology with Y-shaped baryons is investigated in (a) the production of large- M^2 baryonic pairs in e^+e^- annihilation, (b) deep-inelastic scattering events in which a large momentum is transferred from the incident to the observed baryon, and (c) high- p_T baryon production in hadron + baryon collisions. One junction line is assumed to connect the observed final baryon to the antibaryon [in case (a)] or to the target baryon [cases (b) and (c)]. Accordingly, a Regge-type factor $M^{-2\beta}$ (or $|t|^{-\beta}$) is incorporated in the conventional parton formulas. Double (single) inclusive cross sections are worked out, and the limits of the model are discussed. The possibility of measuring this factor is discussed for cases (a) and (b). In case (c), the mechanism considered here may be larger than the conventional one.

I. INTRODUCTION

In ordinary (low- p_T) hadron-hadron collisions, baryon-antibaryon pairs are believed to be created via a multiperipheral mechanism (Fig. 1) leading to an $(M^2)^{-\beta}$ decrease of the double inclusive cross section at large $B\bar{B}$ invariant mass. This factor, which can also be written in terms of rapidity separation as $e^{-\beta\Delta y}$, represents the price one has to pay for the displacement of the baryonic junction in the dual diagram. In dual topological unitarization (DTU),^{1,2} the exponent β is related to the Regge intercepts of M_0^J and M_2^J (Fig. 2) by the relation

$$\beta = \alpha_2^J - \alpha_M = \alpha_0^J - \alpha_{\text{Pomeron}}. \quad (1)$$

In this paper we will extend this topological approach to baryon production in hard processes such as e^+e^- annihilation (Fig. 3)

$$e^+e^- \rightarrow B\bar{B}' + X, \quad (1a)$$

deep-inelastic electron scattering (Fig. 4)

$$e + B \rightarrow e + B' + X, \quad (1b)$$

and high- p_T collisions (Fig. 5)

$$h + B \rightarrow B'(\text{high } p_T) + X. \quad (1c)$$

In the spirit of jet universality³ we again associate an exponential factor to the migration of the junction in rapidity space,

$$e^{-\beta\Delta y} \sim \left\{ \begin{array}{l} M^{-2\beta} [\text{reaction (a)}] \\ |t|^{-\beta} [\text{reaction (b) and (c)}] \end{array} \right\} \sim (p \cdot p')^{-\beta},$$

where $t = (p_B - \bar{p}_B)^2$. However, jet universality itself is controversial, so the exponent β may not be the same as in low- p_T phenomena. For the moment we leave it as a free parameter, which might be fixed later by a counting rule analogous to those of the constituent-interchange model. This mechanism has been proposed independently

by Aurenche and Bopp⁴ to explain the observed p_T spectrum of protons in proton-proton collisions, with different parametrization and input, however.

In what follows we shall state the power laws in M^2 and t more precisely, work out formulas for cross sections, and discuss the domain in which our mechanism is relevant.

II. $e^+e^- \rightarrow B\bar{B}' + X$

According to the parton model, this reaction is a two-step process: (1) quark pair production $e^+e^- \rightarrow i\bar{i}$, given by QED and (2) jet fragmentation, $i\bar{i} \rightarrow B\bar{B}' + X$. Convenient kinematical variables are (in the center-of-mass frame): $s = q^2 =$ invariant center-of-mass energy squared, $z = 2\vec{p} \cdot \vec{q}/q^2 = 2E/\sqrt{s}$, $\vec{p}_{\parallel i} =$ longitudinal momentum with respect to the jet ($i\bar{i}$) axis, $\vec{p}_{T,i} =$ momentum transverse to the jet axis (supposed to be limited, ~ 0.5 GeV/c), $z_{\pm} = E \pm \vec{p}_{\parallel i}/\sqrt{s}$.

We will describe the jet fragmentation by the following formula [see the Appendix, formula (A6)]:

$$dN = C D_{B/i}(z_+) D_{\bar{B}'/\bar{i}}(z'_-) \frac{dz_+}{z_+} \frac{dz'_-}{z'_-} \times [(1 - z_+)(1 - z'_-) p \cdot p'/m^2]^{-\beta}, \quad (2)$$

where N is the number of pairs per jet, $(1/z)D_{B/i} \equiv D_{B/i}$ the usual single fragmentation function, and C a normalization constant. Integration over \vec{p}_T is understood. This formula is valid only for large $(1 - z_+)(1 - z'_-) p \cdot p'$ and for $z_+ > z'_-$ (rapidity ordering implied by Fig. 3).

We can obtain a rough estimate of the normalization factor C by noting that, when we integrate (2) over z' , we get the single fragmentation function (the probability of finding an antibaryon, once a baryon is detected, is equal to one). For this purpose we make the following approximations

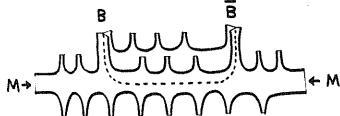


FIG. 1. Multiperipheral mechanism for high mass baryon-antibaryon pair production, in the Y-shaped baryon string model.

[for the threshold in $p \cdot p'$, see (A9)]:

$$z' \ll 1, \int \frac{dz'}{z'} \dots \approx \int_{m^2/(1-z_+)}^{\infty} \frac{d(p \cdot p')}{p \cdot p'} \dots, \quad (3)$$

$$\mathcal{D}_{B'/i}(z') \equiv \mathcal{D}_{B'/i}(z') \simeq \mathcal{D}_B(0), \quad (4)$$

where $\mathcal{D}_B(0)$ is the rapidity density of baryons of type B in the central region. We are led to the normalization constraint

$$1 \sim C \sum_B \mathcal{D}_B(0) \int_{m^2/(1-z_+)}^{\infty} \frac{d(p \cdot p')}{p \cdot p'} \times [(1-z_+)p \cdot p'/m^2]^{-\beta}. \quad (5)$$

Hence

$$C \sim \frac{\beta}{\sum_B \mathcal{D}_B(0)}. \quad (6)$$

We stress that this value of C is only an order of magnitude, due to the fact we have extrapolated an asymptotic form of the double fragmentation function down to the threshold in $p \cdot p'$.

So far we have used kinematical quantities (z^\pm , $\vec{p}_{T/i}$, etc.) which depend on the definition of the jet axis. It is more practical to express the cross section in terms of new variables depending only on \vec{p} and \vec{p}' . To fix the idea, let us suppose $|\vec{p}| \geq |\vec{p}'|$. Then, M^2 being large requires the proton to be relativistic ($|\vec{p}| \gg m$), and the angle between the jet axis and the proton momentum is small:

$$\theta_{p,i} \simeq \frac{\vec{p}_{T/p}}{|\vec{p}|}.$$

Accordingly we will use the new variables $\vec{p}'_{T/p}$ and $p'_{\parallel p}$ relative to the proton axis (Fig. 6). They are related to the old ones by

$$\vec{p}'_{T/p} \simeq \vec{p}'_{T/i} - \frac{\vec{p} \cdot \vec{p}'}{\vec{p}^2} \vec{p}_{T/i}, \quad (7)$$

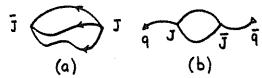


FIG. 2. (a) M_0^J baryonium. (b) M_z^J baryonium.

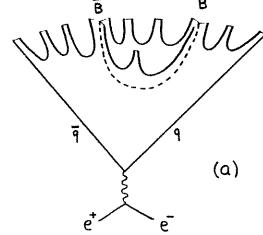


FIG. 3. Massive $B\bar{B}$ pair production in e^+e^- annihilation: (a) without rapidity gap between B and \bar{B} (general case); (b) with a rapidity gap.

$$p \cdot p' \simeq E(E' - p'_{\parallel p}), \quad (8)$$

$$z_+ \simeq z,$$

$$z' \simeq \frac{E' - p'_{\parallel p}}{\sqrt{s}}, \quad (9)$$

$$\frac{dz'}{z'} \simeq -\frac{dp'_{\parallel p}}{E'},$$

and we can write the double inclusive cross section (integrated over $p'_{T/p}$) as

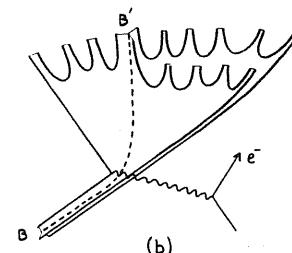
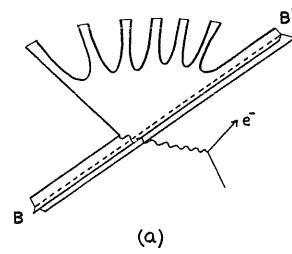


FIG. 4. Deep-inelastic event (valence contribution): (a) ordinary event, with a leading final baryon; (b) rare event, with a high momentum transfer to the baryon.

$$\frac{E' z d\sigma}{dp' dz d\Omega_p} = \left. \frac{d\sigma(e^+e^- \rightarrow \mu^+\mu^-)}{d\Omega} \right|_{\Omega=\Omega_p} 3C[(1-z)(1-z')p \cdot p'/m^2]^{-\beta} \sum_{\text{flavor } i} e_i^2 \mathcal{D}_{B/i}(z) \mathcal{D}_{B'/i}(z'), \quad (10)$$

where e_i stands for the quark charge in electron units, and $p \cdot p'$ and z' are given by (8) and (9). The factor 3 is due to color summation. An order-of-magnitude estimate for C is given by (6).

Until now, we have integrated over the \vec{p}_T 's, assuming them to be small. Their observable effect consists of a noncollinearity between \vec{p} and \vec{p}' , given by (7). Typically, $p'_{T/p} \lesssim 1$ GeV. Now if we assume there is no correlation between $\vec{p}_{T/i}$ and $\vec{p}'_{T/i}$, we have more precisely

$$\langle p'_{T/p} \rangle = \langle p'_{T/i} \rangle + \frac{\vec{p}'^2}{\vec{p}^2} \langle p_{T/i} \rangle. \quad (11)$$

In the case where $|\vec{p}| < |\vec{p}'|$, we just have to switch primed and unprimed quantities in formulas (7)–(10) (with $z' \leftrightarrow z_+$).

III. $e + B \rightarrow e + B' + X$

There is a strong similarity between electroproduction and e^+e^- annihilation, due to crossing. In fact, Fig. 4(b) is the crossed version of Fig. 3(a) when \bar{B} has been pushed to the left-hand edge (i.e., is a leading particle). We shall define, in the laboratory frame,

$q = (\nu, \vec{q})$ = virtual-photon momentum, $q^2 < 0$;
 \vec{p}, \vec{p}' = initial and final baryon momenta;
 k, k' = initial and final momenta of the interacting

quark;

$$x = -q^2/2\vec{p} \cdot q;$$

$$z = \vec{p} \cdot \vec{p}'/\vec{p} \cdot q = E_{B'}/\nu;$$

s = mass squared of the hadronic final state
 $\simeq 2\vec{p} \cdot q(1-x)$.

Again, we have a two-step process: (1) Electron-quark scattering $e^-i \rightarrow e^-i$, given by QED. Each species of quark appears with a probability $G_{i/B}(x)dx$. (2) Jet fragmentation. The probability of finding the scattered baryon at z will be given, for large $\vec{p} \cdot p'$, by [see the Appendix (A13)]

$$dN_B = C \mathcal{D}_{B'/i}(z) \frac{dz}{z} [(1-x)(1-z)p \cdot p'/m^2]^{-\beta}. \quad (12)$$

If one does not have jet universality ($\beta_{\text{hard}} \neq \beta_{\text{soft}}$), one must use this formula only for $x \gtrsim \frac{1}{2}$. If $x \lesssim \frac{1}{2}$ [see, e.g., Fig. 12(a)], one must distinguish a hadronic region in rapidity space of length $\ln(1/x)$ where $\beta = \beta_{\text{soft}}$ and a current region of length $\ln|q^2|$, where $\beta = \beta_{\text{hard}}$. The generalization of the exponential Regge-type factor is

$$\beta e^{-\beta(Y-Y_{\text{threshold})}} \Rightarrow \beta(Y) \exp \left[- \int_{Y_{\text{threshold}}}^Y \beta(Y') dY' \right]. \quad (13)$$

Integrating over \vec{p}'_q , the double inclusive cross section reads

$$\frac{E_B d\sigma}{dE_B dq^2 dx} = \left. \frac{d\sigma(e^- \mu \rightarrow e^- \mu)}{dq^2} \right|_{\hat{s}=2E_B x m_B} C [(1-x)(1-z)E_{B'}/m]^{-\beta} \sum_{\text{flavor } i} e_i^2 G_{i/B}(x) \mathcal{D}_{B'/i}(z). \quad (14)$$

Equivalently, in terms of virtual-photon-nucleon cross section,

$$\frac{1}{\sigma_*} \frac{z d\sigma}{dz} = C \frac{\sum_i e_i^2 G_{i/B}(x) \mathcal{D}_{B'/i}(z)}{\sum_i e_i^2 G_{i/B}(x)} [z(1-z)s/2m^2]^{-\beta}. \quad (15)$$

A formula analogous to Eq. (11) can be found in Ref. 5 for the transverse momentum spreading (with respect to the virtual photon).

IV. $h + B \rightarrow B'(\text{high } p_T) + X$

We assume that the hard subprocess is quark-quark (or quark-antiquark) scattering. Then the experiment is not very different from deep-inelastic electron scattering, except that we have replaced a monoenergetic electron beam by a wide-band beam of quarks with a distribution $G_{a/h}(x)$. Also we take the standard parton formula,¹² but multiply it by our Regge-type factor:

$$\frac{E' d\sigma}{d^3 p'} = \sum_{a, b, c} \int dx_a G_{a/h}(x_a) \int dx_b G_{b/B}(x_b) \frac{1}{\pi z} D_{B'/c}(z) \frac{d\hat{\sigma}}{dt} (a+b \rightarrow c+d; \hat{s}, \hat{t}) C [(1-x_b)(1-z)p_B \cdot p_{B'}/m^2]^{-\beta}. \quad (16)$$

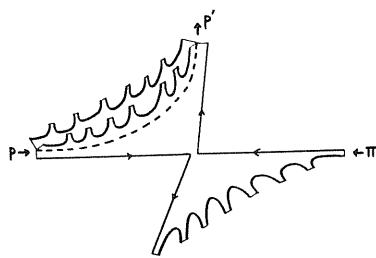


FIG. 5. Mechanism for production of high- p_T baryons in hadron-hadron collision, analogous to Fig. 4(b).

If one does not have jet universality, the integrand must be modified for $x_b \lesssim \frac{1}{2}$ according to (13). The constant C' is the same as in deep-inelastic lepton scattering, approximately given by (6). Assuming that the quark-quark cross section behaves at fixed angle like \hat{s}^{-N} , we get an inclusive cross section at fixed x_T and θ falling down like

$$p_T^{-2N} \text{ for mesons,}$$

$$p_T^{-2N-2B} \text{ for baryons,}$$

i.e., a steeper slope for baryons, as it seems experimentally to be the case.

V. DISCUSSION

A. Limits of the model

In terms of rapidity, Eq. (2) can be rewritten in the central region as

$$dN = 2^B C \hat{D}(y' - y_{\min}) dy' e^{-\beta \Delta y} \hat{D}(y_{\max} - y) dy, \quad (17)$$

with

$$y = y_{\max} + \ln z^+ = y_{\min} - \ln z^-,$$

$$\Delta y = y - y',$$

and

$$C \sim \beta / \hat{D}(\infty).$$

(Flavor indices are omitted and p_T is taken to be zero.) The exponential factor describes the $B\bar{B}$ correlation due to the junction line. \hat{D} takes into account possible extra $B\bar{B}$ pairs on the right- and left-hand sides of the observed one. Thus, our model is not restricted to one single baryonic pair in the final state. It only specifies that no additional pair lies inside the interval $[y, y']$. However, at very large Δy , this is no longer true and there is a critical value Δ_1 (or a critical



FIG. 6. Geometrical construction of transverse momenta in e^+e^- annihilation [Eq. (7)].

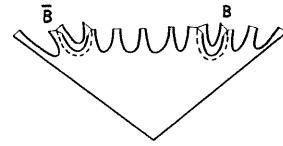


FIG. 7. Inclusive $B\bar{B}$ production coming from independent baryonic pairs.

mass M_1) above which the mechanism shown in Fig. 7 dominates. This new contribution is given by

$$dN^{(\text{independent pairs})} = \hat{D}(y' - y_{\min}) \hat{D}(y_{\max} - y) dy dy'. \quad (18)$$

Thus

$$\frac{d\sigma^{(\text{same})}}{dy dy'} / \frac{d\sigma^{(\text{indep})}}{dy dy'} = 2^B C e^{-\beta \Delta y}, \quad (19)$$

and

$$2^{-B} e^{+\beta \Delta_1} = C \sim \frac{\beta}{\hat{D}(\infty)}, \quad (20a)$$

or, returning to our previous formulation, our mechanism is dominant for

$$\left. \begin{aligned} & (1-z_+)(1-z_-) \\ & \text{or} \\ & (1-x)(1-z) \end{aligned} \right\} \times p \cdot p' / m^2 \leq \cosh \Delta_1 = C^{1/B} \sim \frac{\beta}{\sum_B D_B(0)}^{1/B}. \quad (20b)$$

On the other hand, there is a lower value of the left-hand side of (20b) below which the Regge form in (2) or (12) is not valid due to resonances and threshold effects.

B. Numerical estimates

Little is known about β . If one makes a strong jet universality hypothesis (identity of soft and hard jets), then β is given by (1), according to DTU. For the intercepts we may use the empirical formula^{1,2}

$$\alpha(0) = 1 - n_J / 4 - n_{u,d} / 4 - n_s / 2, \quad (21)$$

which gives (Ref. 6) $\beta = 0.5$. On the other hand, the value $\beta = 2$ could explain the observed p_T^{-12} proton spectrum at large p_T (Ref. 7) provided the mechanism of Fig. 5 is at work. (In fact, there is a large uncertainty in the exponent because neither at CERN ISR nor at Fermilab was the experiment done at fixed x_T .) In fact, there is no compelling reason to believe in the validity of DTU in hard processes. $\beta = 2$ is also a value obtained theoretically in a model where the junction is a parton.¹¹

No precise data are available for the fragmentation function $D_B(z)$. $D_B(z)$ has been measured in e^+e^- annihilation⁸ only for $z \gtrsim 0.5$, $D_\beta(z)$ and $D_{\bar{\beta}}(z)$ in electroproduction⁹ for $z \gtrsim 0.2$. These data are insufficient to give us an estimate of $\sum_B D_B(0)$.

To get an idea about this quantity, we may use its value in ordinary hadron-hadron collisions¹⁰ as jet universality would require:

$$\left. D_{\bar{\beta}}(0) \right|_{e^+e^-} = \frac{1}{2} \left. \frac{dN_{\bar{\beta}}}{dy} \right|_{hh, y=0} \sim 0.05. \quad (22)$$

The factor $\frac{1}{2}$ comes from dual topology: In the hadronic case, there are two superposed jets (the upper one and lower one in Fig. 1). Assuming

$$\sum_B D_B(0) \sim 4 D_{\bar{\beta}}(0), \quad (23)$$

we get

$$\cosh \Delta_1 \sim \begin{cases} 6 & \text{for } \beta = 0.5, \\ 3 & \text{for } \beta = 2. \end{cases} \quad (24)$$

Let us see under what conditions our mechanism can show up in the three reactions that we have considered.

(a) e^+e^- annihilation. If β is large, the $B\bar{B}$ mass spectrum will be peaked near threshold [cf. Eq. (10)] and the independent pair mechanism [Eq. (10) without the Regge-type factor] will take over very soon. In the central region,

$$\beta = 2 \rightarrow M_{B\bar{B}} < M_1 \sim 3 \text{ GeV}$$

[assuming (22)]. Thus, it will be difficult to establish the power law behavior in M^2 (unless one can reject the four- or more-baryon events). Things are easier if β is small, although the mass interval may not be very large:

$$\beta = 0.5 \rightarrow M_{B\bar{B}} < M_1 \sim 4 \text{ GeV}.$$

One should try to test formula (10) with slow baryons of fixed z and z' (varying s).

(b) Deep inelastic electron scattering. Experimentally, the situation is easier because of the larger counting rate. Theoretically also, the power law behavior in t is expected to hold better than the one in M^2 because of the absence of resonant fluctuations. The final baryon energy, in the laboratory frame, at which the pair creation mechanism begins to dominate should be according to (24),

$$(1-x)E_{B'} \sim \begin{cases} 6 \text{ GeV} & \text{for } \beta = 0.5, \\ 3 \text{ GeV} & \text{for } \beta = 2. \end{cases}$$

In fact the crossover is probably at higher energy than the above ones, because the baryonic pair creation mechanism has a threshold effect; Eq. (18) is not valid at $\Delta y < 2$.

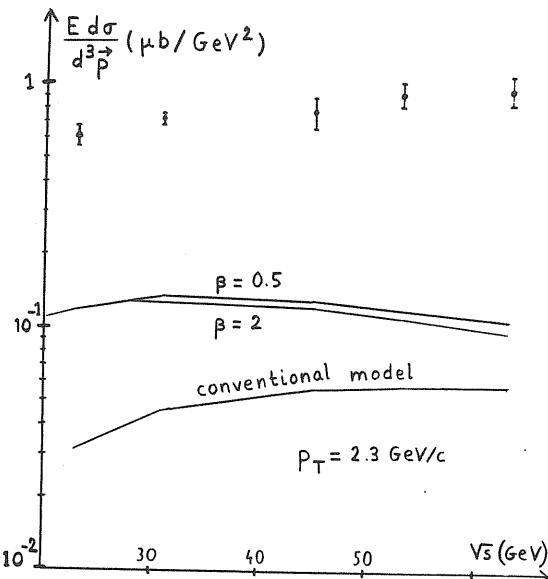


FIG. 8. Inclusive cross section for protons of $p_T = 2.3$ GeV/c at $\theta_{c.m.} = 0$ in the ISR energy range.

It is worth noting that the cross section for electroproduction at small z is insensitive to the absolute values of the $D_B(0)$'s. Formula (15), together with (6), leads to

$$\frac{1}{\sigma_{\gamma^* B}^{\text{tot}}} \frac{z d\sigma}{dz} \sim \frac{D_{B'}(0)}{\sum_B D_B(0)} \beta \left(\frac{z\nu}{m'} \right)^{-\beta} \quad (z \text{ small}). \quad (25)$$

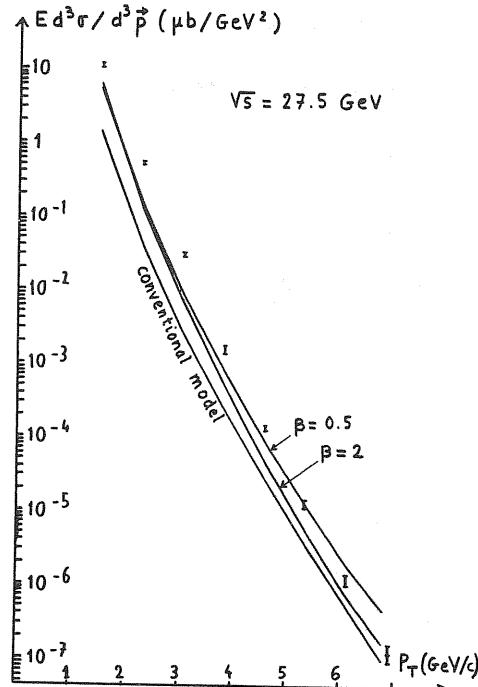


FIG. 9. High- p_T proton spectrum at $\theta_{c.m.} = 0$ and $P_{\text{lab}} = 400$ GeV/c ($\sqrt{s} = 27.5$ GeV).

Before extracting fragmentation functions from electroproduction data, one must be aware of the nonscaling contribution of our mechanism, which is the dominant one at $z \sim 0$, but also, according to (15), at $z \sim 1$.

(c) *Hadron + nucleon - high- p_T baryon + anything.* Here we can compare our formula (16) with existing data at c.m. angles near 90° .⁷ Letting both C and β be free parameters would make it possible to fit any powerlike single-particle spectrum. But the normalization condition [Eqs. (5) and (6)] fixes the order of magnitude of our mechanism. Due to the trigger bias, which makes z close to one, the Regge-type factor does not damp very much the cross section. (We thank Dr. P. Aurenche for pointing out this effect to us.) In Figs. 8–10 we have compared our mechanism with the conventional one for typical ISR and Fermilab experiments. For the structure functions we take¹³

$$G(x) \equiv G_{u/p}^{\text{valence}} = [0.594(1-x^2)^3 + 0.461(1-x^2)^5 + 0.621(1-x^2)^7]x^{-1/2}; \quad (26)$$

for the fragmentation function¹⁴

$$\mathcal{D}(z) \equiv \mathcal{D}_{p/u}^{\text{valence}} = 0.16\sqrt{z}(1-z)^2, \quad (27)$$

$$\mathcal{D}_{p/u}(0) = 0.0276, \quad (28)$$

$$\sum_B \mathcal{D}_B(0) \approx 2\mathcal{D}_{p/u}(0) \approx 0.06, \quad (29)$$

we do not follow (23); we take a factor of 2 instead of 4 because the fragmentation function of Ref. 14 includes the contribution of hyperon decays. For $x_b < \frac{1}{2}$, the integrand of formula (16) was modified

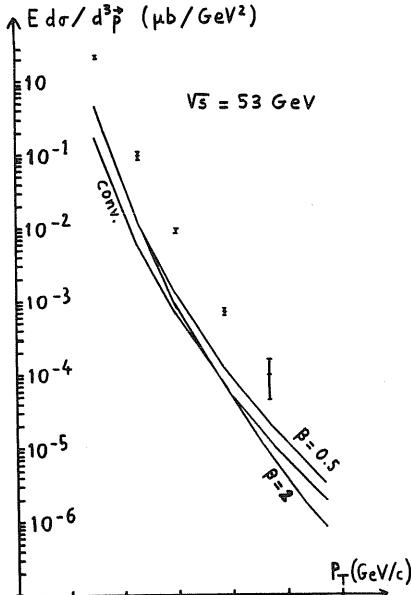


FIG. 10. High- p_T proton spectrum at $\theta_{\text{c.m.}} = 0$ and $\sqrt{s} = 53$ GeV.

to account for the migration of the junction through the soft region [see formula (13)]. The quark-quark cross section was¹²

$$\frac{d\hat{\sigma}}{dt} = 2.3 \times 10^6 \frac{1}{\hat{s}\hat{t}^3} \mu b \text{ GeV}^6.$$

The three curves, $\beta = 0.5$, $\beta = 2$, and the conventional mechanism, are not very far apart. They lie below the experimental points (except at large x_T). Including the contribution of down quarks and of the sea, and adding the two mechanisms could reduce the discrepancy. On the other hand, our choice of D function is probably too optimistic at large z ; $D(z) \sim (1-z)^2$ is not consistent with $G(x) \sim (1-x)^3$. Thus, the difficulty to get the right normalization still remains. (Here we must mention another model with junction which does not have this problem, i.e., the “countable junction model,” in which the junction itself suffers the hard elastic scattering.¹⁵)

VI. CONCLUSION

We have considered a mechanism for baryon production in hard processes which involve a large rapidity shift of baryonic quantum number (of the junction, in the string model). We applied it to three related processes

- (a) $e^+ e^- \rightarrow B\bar{B} + X$,
- (b) $e^- + B \rightarrow B' + X$,
- (c) $h + B \rightarrow B'$ (high p_T) + X .

By analogy with soft processes, the migration of the junction was taken into account by a Regge-type factor in front of the usual parton formula. The normalization was roughly given by baryonic-number conservation. Our formulation is valid in a finite rapidity interval above which the mechanism with independent baryonic-pair creation will take over, restoring the usual parton formulas. The measurement of β in reaction (a) or, more easily, in reaction (b) could settle the question of jet universality between hard and soft processes. In reaction (c), our mechanism is of the same order of magnitude as the standard parton mechanism at present energies. In any case, it has to be considered seriously.

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APPENDIX: REGGE-TYPE FACTOR FOR THE MIGRATION OF THE JUNCTION IN RAPIDITY SPACE

Let us calculate the ratio $R = \sigma_{\text{mig}}/\sigma_{\text{indep}}$ between the migration mechanism and the conventional one for the two processes

$$(a) e^+e^- \rightarrow B \bar{B}' + X ,$$

$$(b) eB \rightarrow e' B' + X$$

in the framework of DTU and jet universality.

In reaction (a), according to jet universality, one can replace the virtual photon by a "resonant" meson-meson system of the same mass. We shall consider two extreme cases

(1) B and \bar{B}' in the central region [Figs. 11(a) and 11(b)]. Applying the Regge-Müller formalism, we get

$$R = C \left(\frac{p \cdot p'}{m^2} \right)^{\alpha_2^J - \alpha_M} \quad (\text{A1})$$

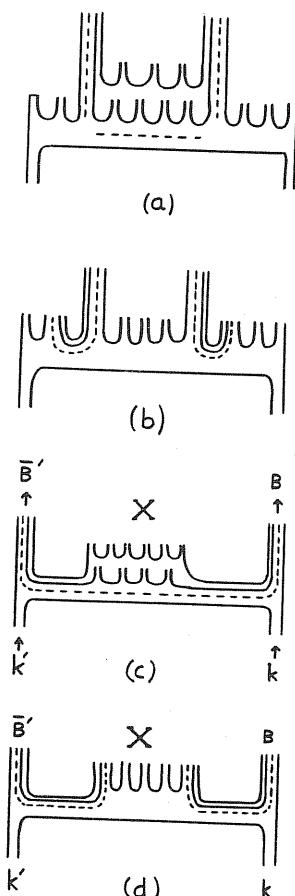


FIG. 11. $B\bar{B}$ production in a planar meson+meson jet: (a), (b) in the central region; (c), (d) at the ends of the spectrum; (a), (c) junction migration; (b), (d) independent baryonic-pair creation.

with

$$C = |g_{BBM_2^J}/g_{BBM}|^2 . \quad (\text{A2})$$

(2) B and \bar{B}' in the opposite ends of the spectrum [Figs. 11(c) and 11(d)]. The right and left triple-Regge vertices $g_{BBM_2^J}$ depends, respectively, on

$$t \equiv (k - p)^2 \simeq -\vec{p}_T^2 \quad (\text{A3a})$$

and

$$t' \simeq -\vec{p}'_T^2 , \quad (\text{A3b})$$

and the missing mass is

$$M_X^2 = q^2(1 - z_+)(1 - z'_-) \simeq 2p \cdot p'(1 - z_+)(1 - z'_-) . \quad (\text{A4})$$

Thus, at fixed p_T and p'_T ,

$$R = \frac{g_{BBM_2^J}(-p_T^2)g_{BBM_2^J}(-p'^2)}{g_{BBM}(-p_T^2)g_{BBM}(-p'^2)} \times [(1 - z_+)(1 - z'_-)p \cdot p'/m^2]^{\alpha_2^J - \alpha_M} . \quad (\text{A5})$$

Formulas (A1) and (A5) join smoothly in one single formula

$$R = C [(1 - z_+)(1 - z'_-)p \cdot p'/m^2]^{\alpha_2^J - \alpha_M} , \quad (\text{A6})$$

if one assumes

$$g_{BBM_2^J}^{(t)} = \sqrt{C} g_{BBM}^{(t)} . \quad (\text{A7})$$

At fixed z_+ , we have a threshold in z'_- , due to the conditions

$$z'_- > z_- > \frac{m^2}{q^2 z_+} , \quad (\text{A8a})$$

$$z'_- > \frac{m^2}{q^2 z'_+} > \frac{m^2}{q^2(1 - z_+)} . \quad (\text{A8b})$$

These two conditions can be summarized in

$$z'_- \gtrsim \frac{m^2}{q^2 z_+(1 - z_+)} ,$$

i.e.,

$$p \cdot p' \gtrsim \frac{m^2}{1 - z_+} . \quad (\text{A9})$$

In reaction (b), we replace the virtual photon by an incoming meson k' plus an outgoing meson k with

$$q = k' - k ,$$

$$x = k^+ / p^+ .$$

In the Regge-Müller analysis, there are many different cases to consider, according to the relative positions of B , B' , k , and k' in rapidity space. We shall give only two examples.

(1) $x \ll 1$, valence contribution, $m^2/s \ll z \ll m^2/|q^2|$ [Fig. 12(a)].

$$\begin{aligned} R &= |g_{BBM} J_2^{(m^2)} g_{MBBM} J_{BBM}^{(m^2)} g_{MBBM}| (p \cdot p' / m^2)^{\alpha_2^J - \alpha_M} \\ &= C (p \cdot p' / m^2)^{\alpha_2^J - \alpha_M} . \end{aligned} \quad (\text{A10})$$

(2) x and z close to one [Fig. 12(b)]. Compare to Fig. 11(c). In a collinear \vec{q}, \vec{p} frame,

$$t \equiv (k - p)^2 \simeq -k_T^2 , \quad (\text{A11a})$$

$$t' \equiv (p' - k')^2 \simeq -(k_T - p'_T)^2 , \quad (\text{A11b})$$

and the missing mass is

$$M_X^2 \simeq s(1-z) \simeq 2p \cdot p'(1-x)(1-z) . \quad (\text{A12})$$

This case is very similar to $e^+ e^- \rightarrow B\bar{B}' + X$ at large z_+ and z_- . Assuming (A7) again, we get

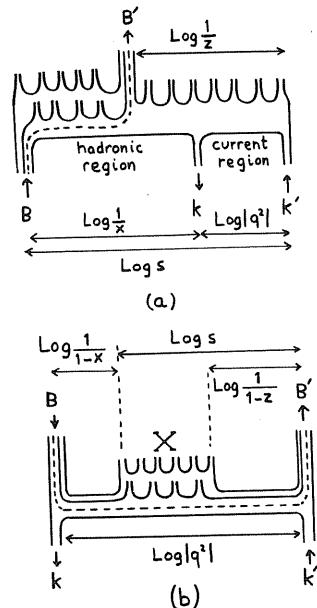


FIG. 12. Junction migration in "deep-inelastic meson scattering": (a) x and $z \ll 1$; (b) $x \sim 1$ and $z \sim 1$.

$$R = C [(1-x)(1-z)p \cdot p' / m^2]^{\alpha_2^J - \alpha_M} . \quad (\text{A13})$$

This formula generalizes (A10) to all (x, z) regions.

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