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GeV PARTONS AND TeV HEXONS FROM A TOPOLOGICAL VIEWPOINT*

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Abstract

An elementary TeV topological hadron supermultiplet breaks into GeV-scale mesons, baryons and baryoniums and TeV-scale "hexons" (extremely-heavy bosons corresponding to six topological constituents). Phenomena on the GeV scale are describable by parton graphs which give meaning to constituent quarks of QCD type. Hexons are responsible --through mixing-- for electroweak-boson masses, may be responsible for cosmic-ray Centauro events, and promise novel TeV accelerator phenomena.

A. INTRODUCTION

Recent application of topological bootstrap theory to electroweak interactions[1,2] has confirmed the capacity of embellished Feynman graphs (graphs with added structures) to overcome the usual arbitrariness of particle theory. The standard Weinberg-Salam model of electroweak interactions has become interpreted as relevant to the lower portion of a unique boson spectrum springing from a Feynman momentum line accompanied by fermion and antifermion lines whose intrinsic and inherited orientations correspond to spin, chirality and isospin. Physical leptons stem from a parallel electroweak pattern where one fermion line is replaced by a boson line. (Separate continuity of boson and fermion lines explains proton stability ; a fourth generation of leptons is predicted.) The present paper considers the hadronic content of topological bootstrap theory, one of our aims being to contact the QCD portion of standard theory.

By "QCD" we mean not the local Lagrangian field theory that so far remains untestable but rather the collection of parton models, sharing certain quark degrees of freedom, which are described as "QCD inspired". The bag model[3] and the quark-antiquark potential model[4] are examples, as are the Lund model[5] and representations of inclusive cross sections through quark distribution functions. A major goal is to explain the QCD meaning of a hadronic-constituent spin-1/2 quark -- carrying momentum as well as flavor, chirality, color and fractional electric charge. We will identify aspects of topological bootstrap theory which play a role parallel to QCD gluons.

QCD-parton degrees of freedom will emerge from topological particle theory as those characteristic of a renormalized and contracted planar approximation which suppresses degrees of freedom whose threshold is $\gtrsim$ 1 TeV. The feasibility of using QCD-parton models to represent GeV data becomes understandable if masses of certain 6-constituent hadrons called "hexons" are larger than the lowest 2-constituent (meson) and 4-constituent (baryon) masses by a factor $\gtrsim 10^3$. We shall identify a candidate mechanism for such a difference. Above the hexon threshold QCD-partons will lose meaning -- phenomena unrepresentable by QCD being anticipated. Centauro cosmic-ray events[6] will be considered as candidate examples. We also will discuss hexons as the source of mass for electroweak bosons.

Low-mass baryoniums in the GeV range are expected but are shown to bear little relation to hexons. "Quarks" building the former are of QCD type while those building the latter have non-QCD electric charges and other "exotic" features associated with the TeV mass scale.

B. TOPOLOGICAL "QUARKS" AND "DIQUARKS"

In topological bootstrap theory any elementary particle --hadron or nonhadron-- corresponds to a cluster of fermion and boson line ends that accompany a Feynman-line end, all lines being embedded in an abstract 2-dimensional surface[7]. Only a small collection of such line-end clusters is allowed by the consistency with unitarity of topological contraction rules. Each fermion-boson elementary-particle cluster of line ends divides into "half" and "antihalf" clusters, separated by a momentum-carrying Feynman-line end. All particle properties beside momentum reside in half and antihalf. There are two families of hadron halves, a fermionic family called "quark" halves and a bosonic family called "antidiquark" halves. Our use here of quotation marks calls attention to the fact that "quark" halves and "diquark" antihalves do not carry momentum --they are topological constituents and automatically "confined". (Furthermore they carry integer, not fractional, electric charge.) A main object of this paper is to relate topological "quark" with QCD quark.

There are four families of elementary hadron : "quark-antiquark" ($q\bar{q}$), "antidiquark-diquark" ($\bar{d}d$), "quark-diquark" (qd) and "antidiquark-antiquark" ($\bar{d}\bar{q}$). Elementary hadrons all share a single nonzero mass m_0, which we shall argue is much larger than the mass of the familiar physical hadrons (such as the proton). The parameter m_0 sets the energy scale for all of particle physics. Elementary hadrons, like elementary leptons and electroweak bosons in topological theory, constitute a finite family (spin 0,1/2,1, 3/2, 2) whereas physical hadrons are indefinite in number. We shall nevertheless find those physical hadrons corresponding to a planar topological approximation to be divisible into $q\bar{q}$, $\bar{d}d$, qd and $\bar{d}\bar{q}$ families.

A shorthand notation for any strong-interaction embellished Feynman graph[8], generalizing the Harari-Rosner scheme[9], employs an oriented "quark line" which carries an 8-valued flavor index f and whose ends each carry a 4-valued Dirac spinor index α . (A quark line is a fermion line with extra inherited orientations corresponding to 4 quark generations.) The four elementary hadrons are representable by the clusters of line ends shown in Fig.1. A "diquark" antihalf is seen to be a cluster

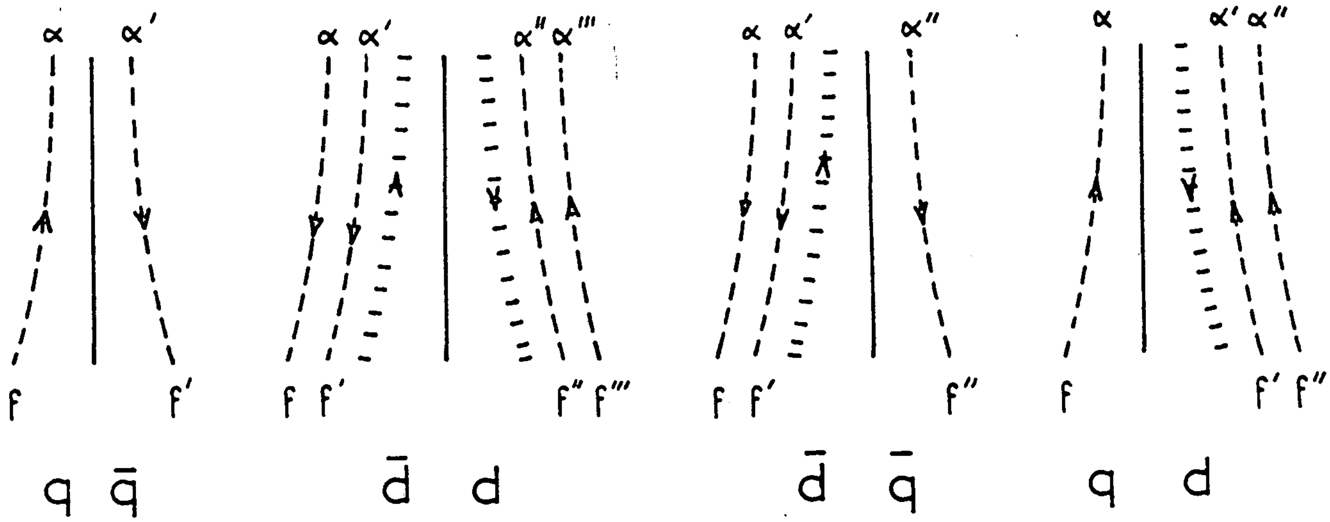

Fig. 1 Elementary hadrons (here --➤- is a quark line, ' ' '➤' ' ' is a boson line and ——— is a Feynman (momentum) line).

of 3 line ends -- 2 quark-line ends plus the end of a boson line. The boson line in strong-interaction topologies has all orientations frozen[7)] and consequently can be ignored in quantum-number bookkeeping[(*)]. The shorthand notation nevertheless can be ambiguous if the boson line is dropped ; we keep it here to clarify the subtle but vital feature of bootstrap theory that quark and antidiquark halves of elementary hadrons maintain permanent identities even though individual quark lines switch between quark and diquark halves. The boson line never crosses the Feynman line, and the boson line always is accompanied by 2 quark lines in a diquark cluster. Whenever a quark line crosses from quark half to diquark antihalf, another must cross from diquark antihalf to a quark half, as shown in the embellished Feynman graph of Fig.2 where there are 5 quark lines, two of which exchange positions

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[(*)] The effective electric charge carried by one of the two quark-line ends within the diquark half is affected by its proximity to the boson-line[10)]. See Sect.E.

on quark and diquark sides of an intermediate qd.

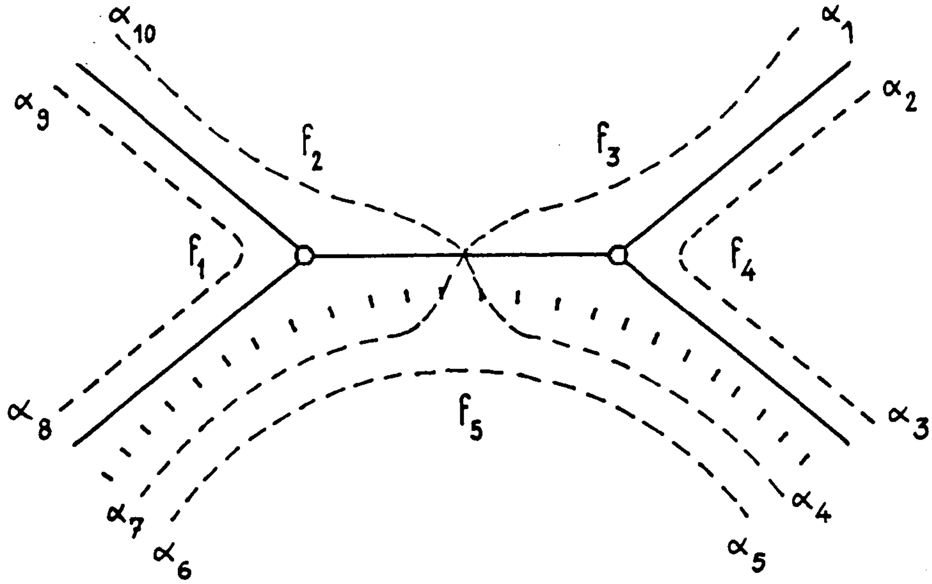

Fig. 2 A 1 $\leftrightarrow$ 2 topological color switch.

We have here an example of a topological color switch, whose significance is described in Ref.11. Topological "color" describes the location of a quark line with respect to the Feynman line which it accompanies. If immediately adjacent to the Feynman line the quark line is said to have "color" #1. A glance at Fig.1 shows that both the quark-line end and the antiquark-line end building an elementary $q\bar{q}$ have "color" #1, while none of the quark-line ends and antiquark-line ends building an elementary $\bar{d}d$ have "color" #1.

"Color" # 2 is carried by a quark-line end adjacent to the boson line, while "color" #3 is carried by a quark-line end adjacent neither to Feynman line nor boson line. Thus Fig.2 represents a 1 $\leftrightarrow$ 2 "color switch". Although sharing the quality of "threeness" with QCD color, topological "color" is not identifiable with color in QCD, as one can see from the unsymmetrical status of "color" #1. The amplitudes accompanying strong-interaction embellished Feynman graphs exhibit 2 $\leftrightarrow$ 3 "color" symmetry (broken by electroweak interactions of hadrons as discussed below in Sect.E), but the distinguished status of topological color # 1 is fundamental. Nevertheless we propose in this paper to elucidate a <u>low-energy approximation</u> to bootstrap theory where all 3 "colors" become equivalent so that contact can be made with QCD. The approximation also will provide a meaning for valence quark momentum.

We repeat now certain rules about "color switching" that were developed in Ref.8) : No more than a single "color switch" may occur between any two adjacent Feynman vertices (switches never occur at a vertex), but trivial vertices --with 2 incident lines-- must be included. The result is that between adjacent nontrivial Feynman vertices there may occur an indefinite number of "color switches". Five different "color switches" are possible at an intermediate point along a qd line, as shown in Fig. 3 a while 3 different color switches (only involving "colors" #2 and #3) are possible along a $\bar{d}d$ line, as shown in Fig. 3 b . Four of the five qd switches connect quark half with diquark-antihalf. None of the $\bar{d}d$ switches connects half with antihalf. "Color switches" are impossible along a $q\bar{q}$ line. Although there is no SU(3) topological color symmetry, Fig.3 shows that topological color is conserved.

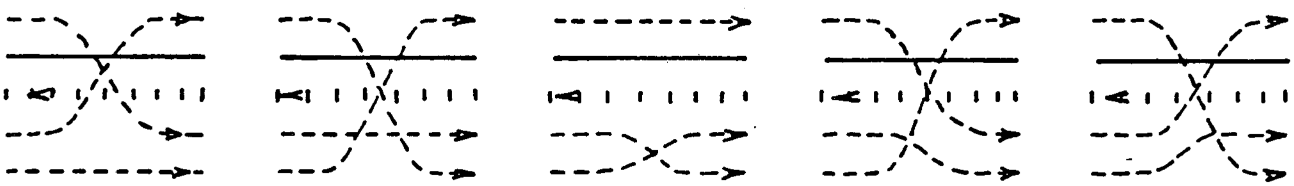

Fig. 3a) "Color" switches along a qd line.

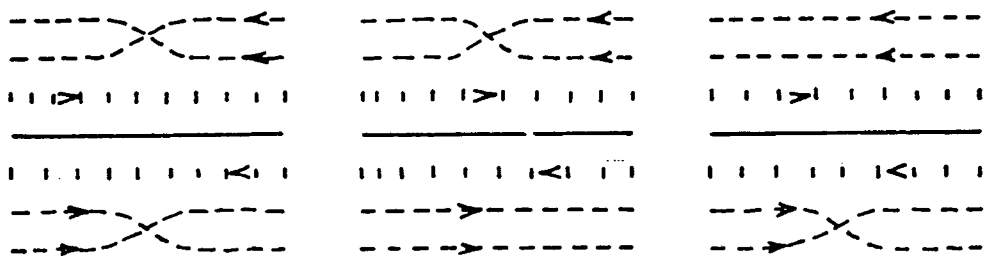

Fig. 3b) "Color" switches along a $\bar{d}d$ line.

The 4-valued spin-chirality (Dirac) index on the end of each quark line is not conserved ; spin-chiral switches --corresponding to $\gamma.p$ propagator factors-- may occur between Feynman vertices[8]. This paper will focus on the dynamics of topological color switching which, with no counterpart in Lagrangian field theory , provides unprecedented features. Spin-chiral switching from $\gamma.p$ propagator factors along quark lines is a dynamical element familiar from QCD. We remark, nevertheless, that the nonzero mass m_o of elementary hadrons follows from the requirement that graphs <u>without</u> complexity --"zero entropy"[7)] graphs-- have neither "color" nor spin-chiral switching. The concept of zero entropy finds no QCD counterpart.

C. MAXIMAL-PLANAR HADRON TOPOLOGIES

Because the multiplicity of a quark line is 32 = 2 spins × 2 chiralities × 8 flavors, the largest components of the topological expansion are those where each Feynman closed loop is accompanied by two closed quark-line loops ; loss of any quark-line loop costs a factor 32. Only planar topologies with a boson-line loop "inside" each Feynman loop have a chance to achieve the maximum number of quark-line loops. An example is given in Fig.4. Notice that in such a "maximal" topology only a <u>perimeter</u> Feynman

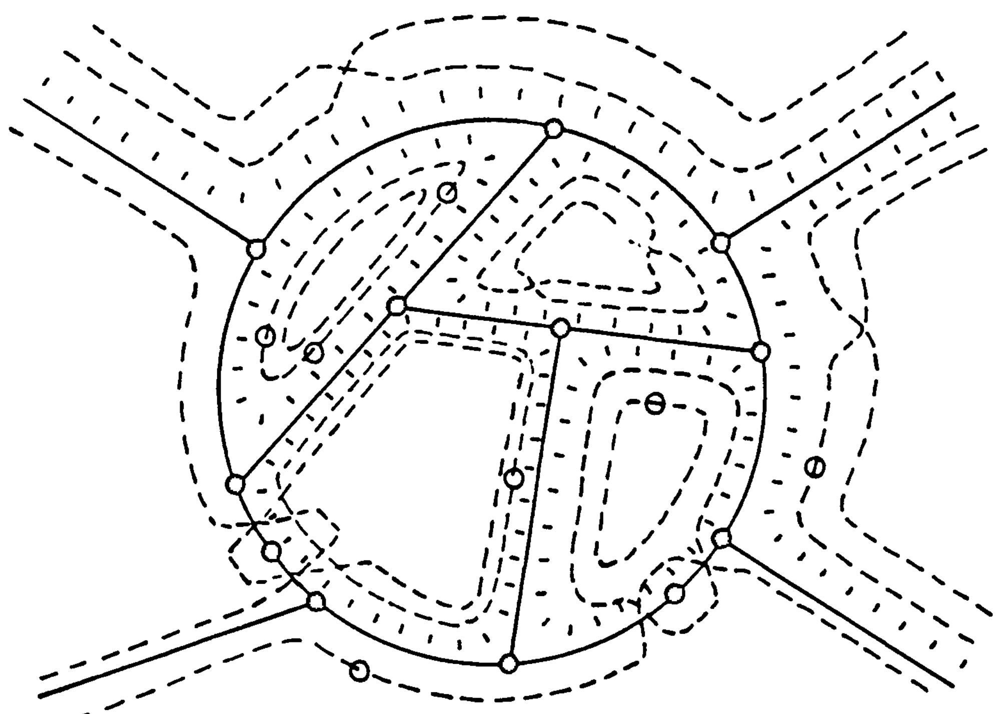

Fig. 4 A maximal-planar graph. Open circles on quark lines indicate chiral switches.

line can be crossed by a quark line and then only when the perimeter line is a qd whose "quark" half lies outside the Feynman perimeter.

Because a boson line never crosses a Feynman line, one may distinguish any planar Feynman loop as one of two types : "quark" or "diquark". Maximal topologies, such as that of Fig.4, contain only Feynman loops of the "diquark" type. In the following section we consider the "maximal-planar" approximation to the topological expansion --the sum over all planar topologies where every Feynman loop not only is of the "diquark" type but contains two closed quark-line loops. In this approximation any "valence quark line" --not part of a closed loop-- passes all nontrivial Feynman-perimeter vertices on the outside. In other words valence quark lines are "stuck" to the Feynman perimeter. The graphs in question are $\bar{d}d$ "fishnets" with a fishnet perimeter which may be either qd or $\bar{d}d$.

Feynman rules for strong-interaction graphs are given in Ref.8). The rules parallel familiar Feynman rules and imply Landau-Cutkosky discontinuity formulas corresponding to unitarity order by order within the topological expansion. In this paper we present heuristic arguments for the result that could emerge from a maximal-planar calculation. The conjecture is motivated partly by the sum of ladder graphs --a sum that can be performed by solving either a Bethe-Salpeter or an ABFST equation. We do not propose that such a partial sum of maximal-planar graphs is quantitatively adequate, but certain qualitative features are suggestive and we recall that many general features of Regge theory became ›preciated via ladder models.

D. MAXIMAL-PLANAR SUM OF LADDER GRAPHS

Using the ABFST equation[12] Espinosa[13] has studied the ladder sum of "zero-entropy" Landau-Cutkosky discontinuities indicated by the Fig.5 graphs,

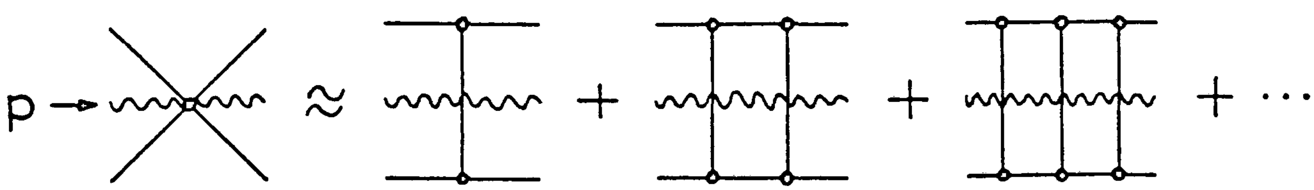

Fig. 5 Sum of zero-entropy discontinuities.

making the further approximation that the cubic-vertex function is a constant $2m_o g_o$. When the Regge boundary condition connects discontinuities with amplitudes, this computation is equivalent to solving a Bethe-Salpeter equation --i.e. to summing a ladder series of amplitudes-- although at zero entropy, because of contraction, it is not generally meaningful to sum amplitudes.

"Zero-entropy" means absence of "color" switches or spin-chiral switches. The bootstrap condition is that real poles of zero-entropy amplitudes correspond to elementary hadrons[7,13,14]. Absence of spin-chiral or "color" switching allows quark lines to be factored out of zero-entropy graphs, each quark line being decoupled not only from other quark lines but also from the momentum-carrying Feynman graph. Zero-entropy supersymmetry between all four families of elementary hadron is a consequence[15].

The effective multiplicity of each closed Feynman loop is

$$N_o = (32)^2 - 32 \qquad (1)$$

because a bosonic (diquark) loop has multiplicity $(32)^2$ while each fermionic (quark) loop, with its minus sign, has multiplicity 32. Espinosa[13] found that to generate a single real pole (bound state) at $p^2 = m_o^2$, by the sum of Fig.5, requires

$$N_o \frac{g_o^2}{16\pi^2} \approx 1 \qquad (2)$$

Although the correct zero-entropy vertex function rather than being constant is expected to decrease asymptotically, the scale of decrease is set by $(2m_o)^2$ --the location of the lowest-lying singularity in the vertex functions. Because propagator poles in the ladder locate at m_o^2, the principle of "nearest-singularity" dominance allows hope for a rough approximation through constant vertex functions. The ladder sum, in any event, mistreats singularities at $(3m_o)^2$, $(4m_o)^2$...(*).

Corrections to zero entropy are sums of planar and non-planar Feynman graphs where each internal line contains at least one spin-chiral

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(*)Indication of the error involved is given by the residue of Espinosa's zero-entropy bound-state pole at m_o, which corresponds to a value of g_o about twice that of formula (2). On the other hand a more elaborate zero-entropy bootstrap model with consistent input-output coupling strength, studied by Balázs, Gauron and Nicolescu[14], gave a g_o value 3 times smaller than formula (2). The latter model is not easily adapted to the needs of the present paper.

or "color" switch. Suppose we sum the planar Feynman graphs of Fig.6, where internal-line "color" switches are compatible with "maximality" --2 closed quark-line loops for each Feynman loop. The first two terms of this series

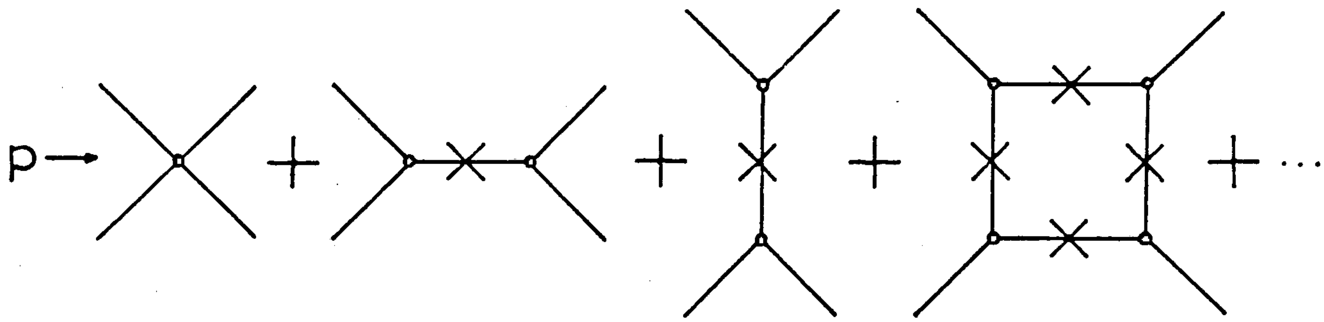

Fig. 6 Schematic sum of maximal-planar graphs. Crosses indicate quark-line switches.

have poles at $p^2 = m_o^2$, Ref.8) showing how the net residue is symmetric in "color" permutations. The remaining terms individually have no p^2 poles but, if the coupling associated with maximal-planar switching corresponds to a sufficiently-attractive Bethe-Salpeter kernel (potential), the infinite sum will diverge at isolated values of p^2, say

$$p^2 = (m_1^{q\bar{q}})^2 \;,\quad (m_1^{qd})^2 = (m_1^{\bar{d}\bar{q}})^2 \;,\quad (m_1^{\bar{d}d})^2 \;, \qquad (3)$$

corresponding to bound-state poles of the S matrix. We now show that the spectrum of such "first-stage renormalized" non-elementary hadrons abandons supersymmetry between $q\bar{q}$, qd, $\bar{d}\bar{q}$ and $\bar{d}d$ and may extend down to masses close to zero on the m_o scale.

Although valence quark lines remain stuck to the sides of the Bethe-Salpeter ladder, they are allowed to cross the Feynman perimeter if they return before reaching the next rung of the ladder (see Fig.4). Such excursions, however, are impossible for any valence quark line accompanied by a valence boson line (see Fig.3b). Thus no such crossings occur in a ladder that might generate an $m_1^{\bar{d}d}$ bound state, and fewer crossings occur for qd (and $\bar{d}\bar{q}$) than for $q\bar{q}$. Supersymmetry is broken.

Can the "switching potential", if attractive, generate bound states of mass close to zero ? Here we need to keep in mind that, although a Bethe-Salpeter ladder sum produces poles at <u>negative</u> p^2 (tachyons) for sufficiently-large attractive coupling, the <u>full</u> planar sum respects unitarity in the "crossed" channel (whose momentum runs vertically in Fig.6). Negative-p^2 poles would violate unitarity in the crossed channel. One may say that vertical ladders not included in Fig.6 contribute a "repulsion" which prevents lowering of bound-state energies below zero. Let us nevertheless assume that the Fig.6 ladder provides an estimate of how large a maximal-planar switch coupling is needed to give an m_1 close to zero. Since Espinosa[13) found that for couplings in the neighborhood of g_o

$$g_o^2 \frac{d}{dg^2} \left(\frac{m^2}{4m_o^2} \right) \approx -1 \ , \qquad (4)$$

any g_1^2 larger than about 1.2 g_o^2 can be expected to generate an m_1 near zero.

Such switch coupling strengths are easily achievable at the maximal planar level where the multiplicity of each Feynman loop is $(32)^2 \approx N_o$, especially if valence quark lines cross the Feynman perimeter. In the absence of a believable maximal-planar calculation, we lean on a collection of qualitative experimental facts explained in the following section to infer that for $q\bar{q}$ and qd or $\bar{d}\bar{q}$ the switch coupling is attractive and generates masses $m_1^{q\bar{q}}$ and $m_1^{qd} = m_1^{\bar{d}\bar{q}}$ much smaller than m_o. For $\bar{d}d$ we infer, on the contrary, that the maximal-planar switch coupling is insufficiently attractive to generate a value of $m_1^{\bar{d}d}$ much smaller than m_o.

We shall describe the low-mass m_1 poles as "bare" mesons and baryons. Although not elementary (with mass m_o), these m_1 poles are still far from physical hadrons because of their residues. The associated vertex functions still correspond to a "radius" m_o^{-1} even though the mass has shifted. Bare mesons and baryons are "small" and will be associated with Feynman's idea of a "parton"[16). Section F will discuss approximations to physical mesons and baryons generated by the next level of the topological expansion --which we shall associate with the thoroughly-GeV domain of QCD-parton models.

Baryonium $\bar{d}d$ states will appear at the GeV level of parton models but must not be confused with $\bar{d}d$ physical hadrons of mass $m_1^{\bar{d}d}$; these latter we shall call "hexons" so as to emphasize their lack of connection with baryon-antibaryon bound states. The name "hexon" is remindful that in the corresponding elementary hadron there are 6 line ends (6 topological constituents) accompanying the Feynman-line end. Hexons are closer to elementary hadrons than are physical mesons and baryons.

What has happened to elementary hadrons as a result of maximal-planar switching ? The graphical summation of Fig.6 leaves m_o poles (present in the first two terms) unshifted but there will be coupling between Bethe-Salpeter m_1 poles and m_0 poles of the same "quark" content, corresponding to graphs such as Fig.7. Such interaction will shift the poles originally at m_1 and m_0

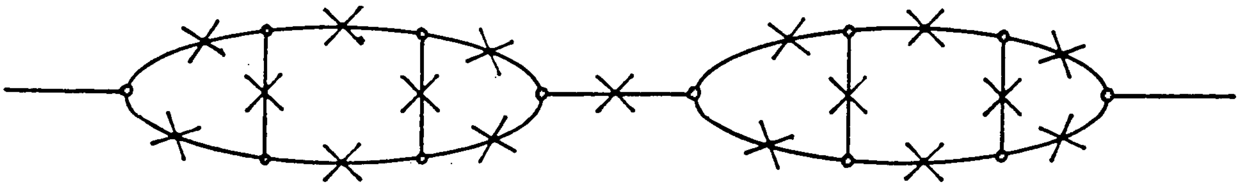

Fig. 7 Example of coupling between Bethe-Salpeter ladder and elementary hadron.

but, further, the shifting of channel thresholds in a complete sum over maximal-planar graphs will cause the more massive of a pair of communicating poles to become complex. In other words the higher state will be unstable already at the maximal planar level --meaning a width comparable to the mass. Only the lower state need be recognized as a "parton". We shall understand m_1 to denote the lower mass after all maximal-planar graphs have been summed.

E. TOPOLOGICAL COLOR AND ELECTRIC CHARGE OF QUARK LINES ACCOMPANYING "BARE" FEYNMAN LINES

Summing planar topologies can only produce poles labellable as $q\bar{q}$, qd, $\bar{d}\bar{q}$, or $\bar{d}$d, but the topological color content of the poles is generally different from that of elementary hadrons because of the "color" switching that contributed to the pole formation. If quark lines are added to Fig.6 and Fig.7 in the sense of Figs.2,3 and 4, one sees that each of the flavors f and f', belonging to a bare meson ($q\bar{q}$) $m_1^{f,\bar{f}'}$, spends equal portions of its line history in each of the 3 "color" locations with respect to a Feynman line. A similar statement applies to all three flavors f,f',f" belonging to a bare baryon (qd) $m_1^{f,f'f''}$. Now Ref.10) has shown that "quarks" with color # 1 or #3 have the "normal" connection between electric charge and isospin :

$$Q = 1 \qquad I_3 = +1/2$$
$$\quad\;\; 0 \qquad\quad\;\; -1/2 \tag{5}$$

whereas for color # 2 the connection is "abnormal" :

$$Q = \begin{matrix} 0 \\ -1 \end{matrix} \qquad I_3 = \begin{matrix} +1/2 \\ -1/2 \end{matrix} \tag{6}$$

Taking an average, all valence "quarks" building bare mesons and baryons have electric charge 2/3 of (5) plus 1/3 of (6), or

$$Q = \begin{matrix} 2/3 \\ -1/3 \end{matrix} \qquad I_3 = \begin{matrix} +1/2 \\ -1/2 \end{matrix} \tag{7}$$

This is the familiar QCD rule.

The story, however, is different for the valence quark lines of bare hexons. Each of the 4 flavors f,f',f",f"' belonging to $m_1^{\bar{f}\bar{f}',f''f'''}$ spends equal portions of its history in "colors" #2 and #3 but none of its history in "color" #1. The consequence is an electric charge 1/2 of (5) plus 1/2 of (6) :

$$Q = \begin{matrix} +1/2 \\ -1/2 \end{matrix} \qquad I_3 = \begin{matrix} +1/2 \\ -1/2 \end{matrix} \tag{8}$$

The "quarks" building bare hexons in this sense are "exotic".

Although the boson line for a bare baryon continues to distinguish the "diquark" side of the Feynman line from the "quark" side, all quark lines accompanying (renormalized) bare meson or baryon Feynman lines must be understood as uniformly superposing the 3 topological colors. In contrast quark lines accompanying bare hexon lines are 50/50 mixtures of "colors" #2 and # 3, with no admixture of "color" # 1.

F. PHENOMENOLOGY

Seven distinct phenomenological considerations support the assumption of bare meson and baryon masses much smaller than m_0 (with lowest bare masses after flavor-symmetry breaking being $\lesssim$ 1 GeV), while bare hexon masses remain of order $m_0 \gg 1$ GeV. The considerations are as follows :

1) The observed dependence of physical-hadron mass on quark flavor : the experimental lower bounds for the top-quark mass[17)] has shown the difference between lowest and highest physical baryon or meson mass squared to be $\gtrsim 10^4$ GeV². In topological theory, because flavor symmetry is sustained

by all strong-interaction graphs, symmetry breaking --by electroweak interactions of hadrons-- should be at the 1 % level. To understand the observed degree of symmetry breaking we thus need $m_0^2 \gtrsim 10^6$ GeV² (or $m_0 \gtrsim 1$ TeV).

2) The approximate chiral symmetry observed in some GeV hadronic phenomena (e.g., PCAC). Topological theory exhibits no chiral symmetry at the elementary-hadron m_0 level, but a zero-mass solution of a fermion-antifermion Bethe-Salpeter equation enjoys a special Lorentz symmetry which includes part and perhaps all of the content of PCAC[18)].

3) The observed $\sim$100 GeV mass of $W^\pm$ and Z_0 bosons[19)], together with the inference from weak-interaction data that right-handed boson masses are $\gtrsim$ 400 GeV[20)]. (Topological theory predicts both right and left-handed vectors[1)].) Ref.10) shows how the coupling of massless elementary electroweak bosons to diquark halves breaks parity and SU(2) isospin symmetry. Mass will thereby be given to all physical electroweak bosons except the photon. The dynamics here may alternatively be described as a mixing between electroweak bosons and hexons of corresponding quantum numbers, which "attracts" the former toward the latter. (Because hexons are much more numerous than electroweak bosons, the center of gravity of their mass distribution does not shift much.) Consistency requires physical hexon masses to exceed physical electroweak-boson masses, although not by an enormous factor. Hexon masses in the TeV range are indicated.

4) Lack of evidence for hexons in data from the CERN $p\bar{p}$ collider[21)]. Hexon masses $\lesssim$200 GeV thereby appear to be unlikely.

5) Centauro cosmic-ray events[6)], with hadron multiplicity $\sim$ 100 but few π^0's. In Sect.H we interpret such events as production and decay of hexons with TeV masses.

6) The success achieved by QCD-parton models in representing GeV-range electroweak-hadron data by assigning $\binom{2/3}{-1/3}$ electric charge to quarks. This charge pattern we have seen to be understandable in topological theory to the extent that bare-hexon partons are suppressed by their large mass.

7) The success of QCD-parton models in describing purely strong-interaction GeV-range data[22)]. In the following section we show how renormalized Feynman graphs from topological theory, with lines corresponding to bare mesons and baryons of masses extending down to $\lesssim$ 1 GeV, but with no bare hexon lines, promise to reproduce and extend successes of QCD-parton models.

Bootstrap theory in its extreme form is not supposed to rely on experimental data, being based on internal consistency, but in practice hints from experiment are always helpful in formulating partial bootstrap approaches. So let us proceed, in the temporary absence of reliable methods for summing fishnet graphs, to take from experiment the following qualitative properties for maximal-planar corrections to zero-entropy :

$$m_1^{q\bar{q}} , m_1^{qd} << m_o, m_1^{\bar{d}d} \tag{9}$$

$$m_o, \quad m_1^{\bar{d}d} \gtrsim 1 \text{ TeV} \tag{10}$$

We furthermore assume that, after flavor symmetry breaking, the lowest bare hadron masses are $\lesssim$ 1 GeV. We assume, in other words, that remaining components of the topological expansion, such as planar graphs containing Feynman loops with a single quark-line loop, will generate effects less drastic than that of maximal planar topologies. Higher-order corrections are nonetheless essential for quantitative physics on the 1-GeV scale, and we shall argue that QCD-parton models represent an approximation to the next level of the topological expansion --just above the maximal planar level, where the controlling parameters are bare-meson and bare-baryon masses. These quantities will determine both the constituent quark mass and the equivalent of the QCD scale parameter. We shall also find meaning for constituent diquark mass.

We have described in Section D a ladder-graph mechanism for the bare-hadron mass pattern (9),(10) in which the switch coupling strength exceeds zero-entropy coupling by a factor greater than 1.2 for $q\bar{q}$ and qd while less than 1.2 for $\bar{d}d$, but we do not depend on this mechanism for the remainder of our reasoning. What is important is the "bare" hadron (i.e., parton) mass pattern.

G. CONTRACTED PLANAR PARTON GRAPHS FOR GeV-SCALE STRONG INTERACTIONS

We now conjecture meaning for renormalized planar graphs where all lines correspond to partons --bare (m_1) hadrons. For GeV-scale physics it is further an appropriate simplifying approximation to contract all nonperimeter Feynman lines whose masses are >> 1 GeV. Bare hexon lines then disappear, and to maximize simplicity of discussion let us suppose all noncontracted internal lines to be bare mesons carrying flavors u,d,s and with a single (bare) mass μ_1. All Feynman loops then contain single closed quark-line loops, double quark loops which accompany a boson-line loop having been contracted into lines and vertices. Although for simplicity we ignore internal boson lines as well as "heavy-flavor" internal quark lines, a perimeter Feynman line may or may not be accompanied by a valence boson line, and valence quark lines may carry any of the 8 flavors.

Even though lines and vertices of such renormalized graphs reveal elementary-hadron substructure if examined on the m_o scale, we may regard the lines as structureless "partons" for phenomena at energies well below m_o. Suppose we are interested in properties of physical mesons carrying flavors f and f'. The example of Fig.8 reveals general features of any relevant renormalized planar graph.

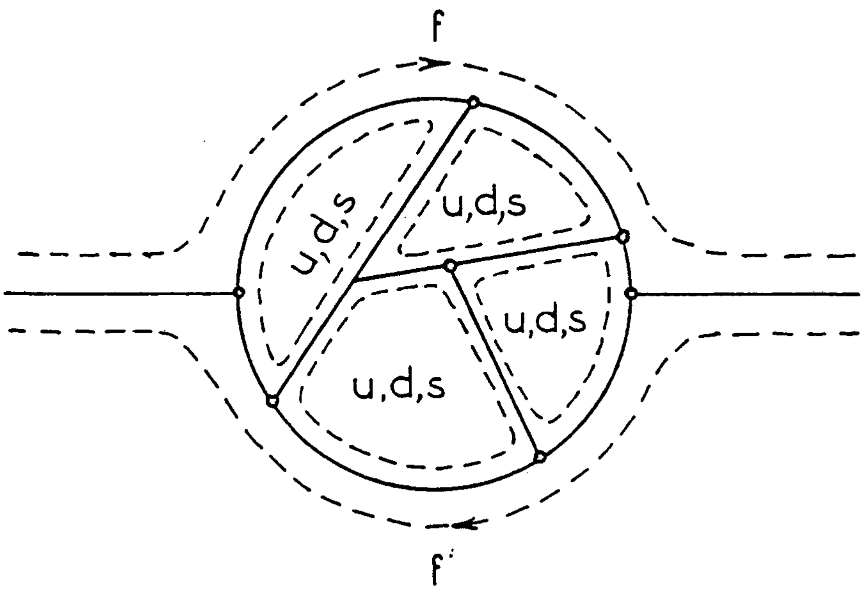

Fig. 8 Renormalized graph for meson dynamics.

One sees firstly how valence quark lines associate with Feynman-perimeter momentum lines ; meaning is thereby given to <u>constituent-quark momentum</u>. The mass of a constituent quark of flavor f is the mass of a bare meson one of whose flavors is f while the other is u,d or s.

Fig.8 further shows that the "potential" acting between constituent quark and antiquark is <u>independent</u> of flavor. We also see how the sum over all planar graphs parallels the large-N_{color} approximation to QCD --which has been argued to yield features of the "potential" needed for fitting "soft" data[23]. The low-mass flavors in topological renormalized planar graphs function similarly to the colors of QCD. The bare-meson mass μ_1 may be regarded as the analogue of the QCD scale parameter and we note that, although bare mesons have both spin 0 and spin 1, vector mesons will be the more important contributors to the "potential". In short, we expect flavored bare vector mesons carrying a symmetrical superposition of 3 topological "colors" to do the job of colored QCD gluons.

If we are interested in baryon properties, a typical planar graph is that of Fig.9(*), which corresponds to a "potential" acting between

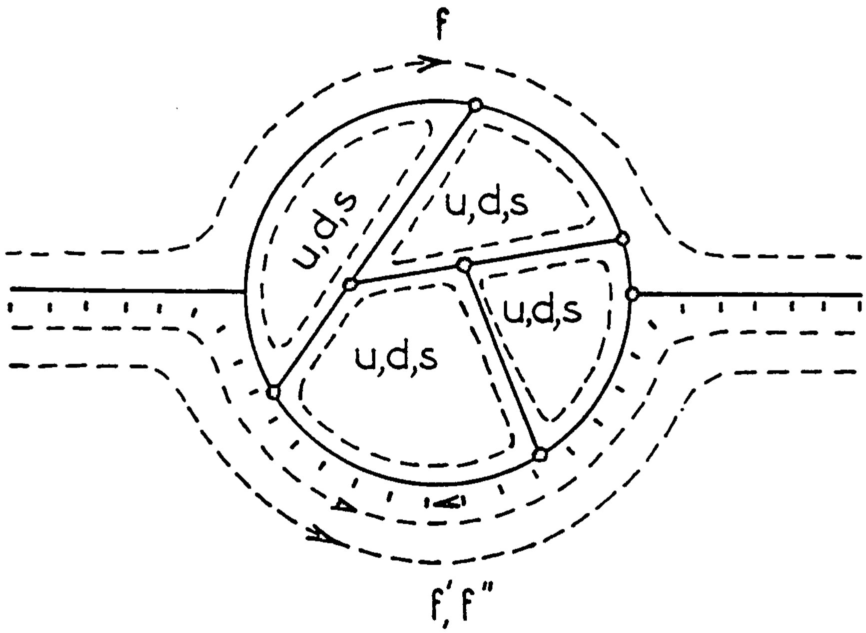

Fig. 9 Renormalized graph for baryon dynamics.

constituent quark of flavor f and constituent diquark of flavors f',f".(**) The mass of the latter is that of a bare baryon with flavors f',f" and u,d, or s. The potential is the same (up to a calculable factor) as between constituent quark and antiquark.

Figure 10 exhibits the third type of planar renormalized graph, this one corresponding to a "potential" between constituent diquark and antidiquark. We expect such a potential to generate bound states whose lower members have spin, parity $0^+, 1^+$ and 2^+. Notice that such quantum numbers do not correspond to $\ell = 0$ physical baryon-antibaryon bound states, a fact reflecting the difference between the planar dynamics of bare hadrons and

(*) Remember that, despite the way quark lines here are drawn, both valence and internal lines are "color" symmetric. The two lines on the diquark side are not ordered.

(**) The physical baryon with flavors f,f',f" is the lowest state of a coupled 3-channel dynamics. Each channel is characterized by the flavor of the constituent quark and that pair of flavors carried by the constituent diquark.

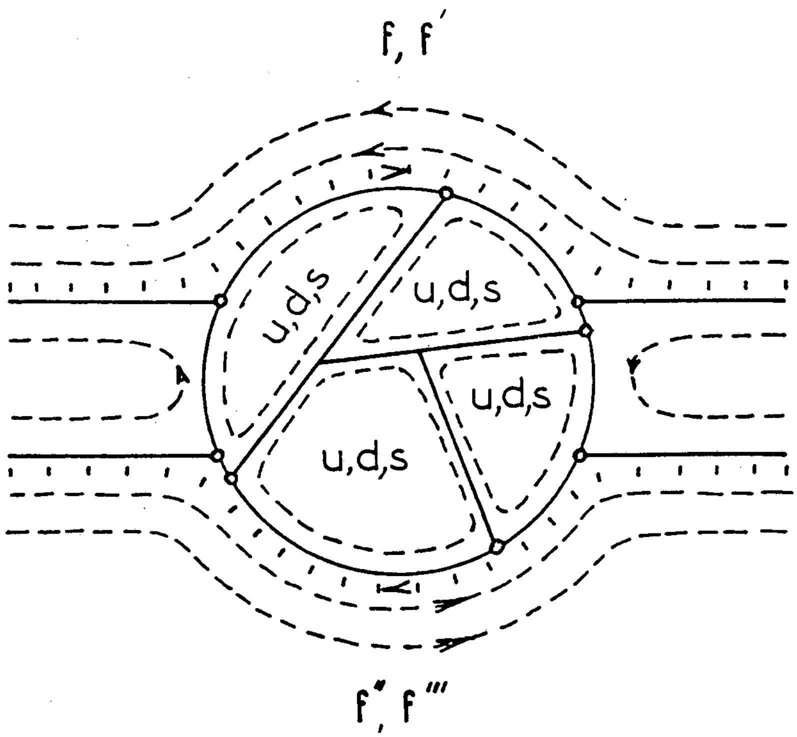

Fig. 10 Renormalized graph for baryonium dynamics.

the ordinary nuclear-physics dynamics of physical baryons. Although the physical hadrons corresponding to Fig.10 --usually called "baryoniums"-- have status parallel to that of physical mesons (Fig.8) and physical baryons (Fig.9), they must not be confused with hexons. Baryoniums are part of GeV-scale strong interactions.

Recently a very narrow state of mass 1.620 ± 0.001 GeV (below the nucleon-antinucleon threshold) has been reported by the LEAR experiment PS 183 [24]. From the topological viewpoint the most probable interpretation is an $I = 2$, $J^P = 1^+$ baryonium. A previous calculation in the planar approximation has predicted such baryonium states near the reported mass[25].

We see no reason why the phenomenologically-successful features of "hard" QCD (e.g., in deep inelastic scattering)[22] should fail to be sustained by renormalized-contracted Feynman graphs from topological theory. We shall, however, not here pursue this issue --which requires detailed examination of how electroweak bosons couple to bare hadrons.

H. HEXONS

We have seen how topological bootstrap theory, in conjunction with certain experimental facts, predicts a large family of 0^+, 1^+, 2^+ hexons with masses in the TeV range. Thorough understanding of electroweak-boson coupling to hadrons will eventually allow 0^+ and 1^+ hexon masses to be calculated from a knowledge of electroweak-boson masses (such as $W^{\pm}$ and Z_o). In the present absence of such capability, certain observations may still be made :

a) SU(8) flavor symmetry of hexon masses and couplings should be broken by only a few percent. There will be three 1296-plets --of $2^+, 1^+$ and 0^+ hexons, one 2016-plet of 1^+ and one 784-plet of 0^+.

b) For a hexon unable to decay into 2 other hexons, a preliminary estimate of a typical width/mass ratio is 1/32. This statement will be elaborated below.

c) The primary hexon decay should be to 2 bare baryons as shown in Fig.11, with subsequent cascade development of 2 large jets of physical hadrons.

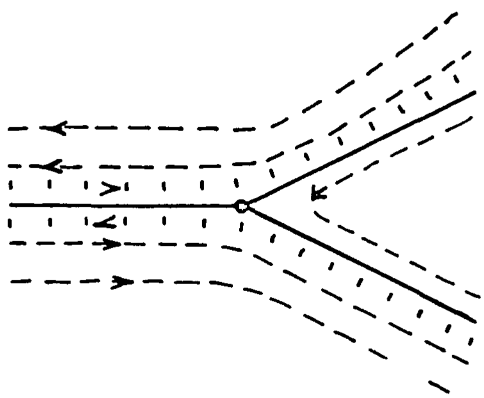

Fig. 11 Hexon decay into $(qd)_1$, plus $(\bar{q}\bar{d})_1$.

The cascade will favor physical baryons over physical mesons because there are more bare baryons than bare mesons, smaller mass for bare mesons being of less consequence than multiplicity with so much energy in the jet. (Analogously to QCD-parton models[22], we expect hadrons in the cascade to remain "bare" until their p^2 has dropped to the GeV level.)

If we associate hexons with the Centauro events of cosmic radiation[6] (characterized by sparcity of π^o's), the observed total hadron multiplicity $\sim$ 100 agrees with our rough estimate of hexon mass if we use the Lund model[5] as a guide.

d) The vertex of Fig.11 (interpreted as "bare", not elementary) also appears in the mechanism for hexon production by a "soft" collision of a high-energy baryon with some other physical hadron. One may say that a valence bare-baryon constituent of the physical baryon at sufficientlyhigh energy emits a hexon before colliding with the other hadron --as shown in Fig.12. The impact parameter is controlled by the bare baryon mass,

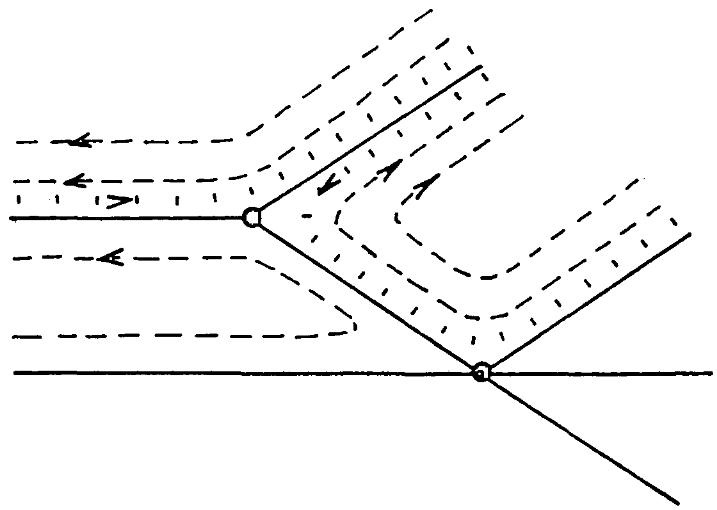

Fig. 12 Hexon production in baryon-hadron collision.

not by the hexon mass, so the cross section can reach the millibarn range as soon as the p^2 of the intermediate bare baryon reaches the GeV range. Such will be possible when the center of mass energy is a few times larger than the hexon mass. Thus we expect a large collection of novel events to appear in Tevatron experiments.

It may seem contradictory to expect a "large" cross section for hexon production while the width for hexon decay is "small", since both depend on the vertex of Fig.11. In the production process of Fig.12, however, one sums over 2 quark lines in the final state while in the decay process of Fig.11, one sums over only 1 final quark line. Hence a factor of 32 suppresses decay relative to production. Alternatively the effect is attributable to there being more hexons than baryons : the production cross section sums over different produced hexons while the decay rate sums over different baryons.

SUMMARY

This paper has suggested that, because quark multiplicity is large (32), two widely-separated scales--TeV and GeV-- develop for strong interactions. The TeV scale associates with planar Feynman loops that carry 2 closed quark loops, while the GeV scale associates with single quark loops(*). Parton models for GeV-scale phenomena are thereby explained, the partons being 3-"color"-symmetrized "bare" mesons and baryons. Partons along the perimeters of planar Feynman graphs are interpretable as valence quarks and diquarks ; we have explained the origin of standard fractional charges for quarks as well as the meaning of constituent-quark mass.

We predict a large new family of "almost-elementary" hadrons called hexons, with masses in the TeV range. With respect to the "classical bootstrap" idea that hadrons are bound states of each other, held together by a hadron-exchange "force", the following simplified summary of planar dynamics is possible :

Hadrons ("radius")	Constituents	"Force"
hexon (TeV^{-1})	hexon plus hexon	hexon
bare baryon (TeV^{-1})	hexon plus bare baryon	hexon
bare meson (TeV^{-1})	bare baryon plus bare antibaryon	hexon
physical baryon (GeV^{-1})	bare meson plus bare baryon	bare meson
physical meson (GeV^{-1})	bare meson plus bare meson	bare meson
physical baryonium (GeV^{-1})	bare baryon plus bare antibaryon	bare meson

The role of the gluon in QCD-parton models is played in topological bootstrap theory by the bare meson, symmetrized in topological color, the gluon color degree of freedom being replaced by bare-meson flavor.

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(*)The MeV scale of classical nuclear physics associates with nonplanar Feynman loops where there are no closed quarks loops.

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