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DIFFRACTIVE DISSOCIATION AND NEW QUARKS*

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ABSTRACT

We argue that the chiral limit of QCD can be identified with the strong (diffractive dissociation) coupling limit of reggeon field theory. Critical Pomeron scaling at high energy must then be directly related to an infra-red fixed-point of massless QCD and so requires a large number of flavors. This gives a direct argument that the emergence of diffraction-peak scaling, KNO scaling etc. at $\bar{p}$-p colliders are evidence of a substantial quark structure still to be discovered.

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For some time now I have advocated[1] linking QCD to $\bar{p}$-p collider soft physics by a two-stage process.

1. Show that Critical Pomeron reggeon field theory[2] gives a good phenomenological framework for describing the basic features of collider soft processes. The rising cross-section, scaling diffraction peak, rising central plateau, KNO scaling of the multiplicity distribution are all part of the asymptotic predictions of Critical Pomeron scaling. If approach to scaling terms are added a good phenomenological description of the data seems possible.

2. Study high-energy behavior in QCD by first building up a reggeon description of spontaneously broken (Higgs) theories. Infra-red analysis when an SU(2) unbroken symmetry is restored suggests that the high-energy behavior of QCD with the gauge symmetry broken to SU(2) is that of Super-Critical Pomeron theory. The Critical Pomeron will then be produced when the gauge symmetry is completely restored to SU(3)--provided that there is asymptotic freedom (and hence no transverse momentum cut-off) already present at the SU(2) stage. This last condition implies that QCD saturated with quarks has Critical Pomeron asymptotic behavior.

Combining 1 and 2 we have the result that if a convincing phenomenology of soft collider physics shows that Critical Pomeron asymptotic behavior is emerging then we have evidence that a substantial quark structure remains to be discovered.

To many physicists it seems counter to their intuition that a bulk property of hadronic matter such as diffraction could be sensitive to a "short-distance property" like the number of massive quarks in the theory. However, diffractive dissociation is also counter-intuitive in many ways and it plays a central role in the occurrence of Critical Pomeron behavior. While I strongly believe that 2 is an unavoidable route to establish the connection between QCD and the Critical Pomeron, it has to be admitted that the argument is sophisticated, the analysis complicated and that much further work remains to be done to establish its validity. (I am preparing a Physics Report giving all the theoretical background for both 1 and 2. Goulianos has written a companion experimental report).

In this talk I shall present a relatively simple and direct argument which with plausible assumptions leads to essentially the same conclusions as above. I hope that the argument can be understood by most physicists. I also hope that it illustrates clearly the essential physics of diffraction which reggeon field theory describes. It contrasts sharply with the physics on which many eikonal or impact parameter models of the diffraction peak are based.

We shall see that the central issue is how the mass-scales of QCD can enter the description of an asymptotic diffraction peak which describes rising cross-sections. From the Critical Pomeron formalism it is the scale of diffractive dissociation which determines the width of the diffraction peak (at truly asymptotic energies). The main point of the following argument is that the diffractive dissociation scale is essentially m_π^{-1} or equivalently the (inverse) quark mass-scale in QCD. Consequently the existence and nature of the chiral limit in QCD is a stringent constraint on the emergence of an asymptotic diffraction peak dominated by diffractive dissociation. We shall exploit this in the following argument by considering the chiral limit of zero mass for all quarks.

From an impact parameter or geometric point of view the diffraction pattern simply reflects the matter distribution in a hadron.[3] This distribution is conventionally thought to be determined by the "bag-radius" or "string-tension" or some other confinement scale directly related to Λ_{QCD}. In this case the diffraction peak might be expected to be relatively insensitive to m_π (and to a chiral limit in general). This is probably the simplest situation to understand from an intuitive point of view.

We begin by considering the behavior of the diffraction peak far into asymptopia where only the leading power of $\ell n\ s$ describes the complete differential cross-section and (assumed) rising cross-section. This is illustrated in Fig.1. We have a shrinking, scaling, diffraction peak

$$\frac{d\sigma}{dt} \sim \left[(\ell n\ s)^{\eta}\ f\left(\frac{t(\ell n\ s)^{\nu}}{\rho}\right)\right]^2 \qquad (1)$$

$$= \left[t^{\delta}\ g\left(\frac{t(\ell n\ s)^{\nu}}{\rho}\right)\right]^2 \qquad (2)$$

where $\nu\delta + \eta = 0$. this general form for $\frac{d\sigma}{dt}$ holds both for the case of the Critical Pomeron, where η and ν are critical exponents and for the case of saturation of the Froissart bound when $\eta = 1$ and $\nu = 2$. The function f produces the diffraction pattern (and in general[4] must have an infinite number of complex zeroes). The question we wish to focus on is how the scale factor ρ, which has mass dimensions, depends on the basic mass parameters of a theory.

For the Critical Pomeron there can in principle be an infinity of underlying parameters (this was, of course, a great virtue in its original formulation) while in QCD we have a specific set of parameters. For simplicity let us suppose that we have only the minimum of three bare parameters in the reggeon field theory, that is we have a Pomeron regge pole with a linear trajectory

$$\alpha_P^0(t) = \alpha_0 + \alpha_0' t \qquad (3)$$

and a triple Pomeron coupling r_0 measured in large mass diffractive dissociation. For criticality $\alpha_0 = \alpha_{oc}(r_0, \alpha_0')$ and we are reduced to two bare parameters r_0 and α_0', in terms of which

$$\rho = [\alpha_0']^{-1}[r_0^2/\alpha_0']^{-\nu+1} \qquad (\nu > 1) \ . \qquad (4)$$

α_0' is, of course, the "canonical scale" for a Regge pole diffraction peak, while the dependence on r_0 is an anomalous dimension effect of the critical-point scaling behavior.

Next consider the "strong-coupling limit" $r_0 \to \infty$ with α_0' fixed. From (4) we have $\rho \to 0$ and so the argument of f and g in (1) and (2) goes to infinity. In fact $g(\infty)$ is finite[5] while $f(\infty)$ is not. (Alternately f(0) is finite while g(0) is not and this is used in obtaining the behavior of the total cross-section from (1)). So from (2)

$$\frac{d\sigma}{dt} \underset{r_0 \to \infty}{\sim} [t^{\delta}]^2 . \qquad (5)$$

That is we have "infra-red" singular behavior at $t = 0$ which, since it is energy independent, we can describe as multiple vector exchange (two or more) but with an anomalous dimension. That is the strong coupling limit of the Critical Pomeron diffraction peak is "free vector gluon" behavior with an anomalous dimension.

Moving on to QCD we must first ask if the Critical Pomeron is relevant for any values of the QCD parameters? For this we need to establish that a single Regge pole description of diffraction is uniquely related to an SU(3) gauge group. The analysis of 2 above is, I believe, the only way to prove this. It can be made plausible by observing that SU(3) is the only gauge theory in which closed strings of electric flux have an orientation dependence but have no further multi-valuedness property with respect to their space location in two transverse dimensions. This qualitatively relates SU(3) closed strings to a simple dual string model in which there is a single Pomeron trajectory. Alternatively we could be more phenomenological and note that a single Pomeron trajectory and QCD both fit existing experimental data and so let us assume they go together.

In QCD we have the parameters N_F - the number of flavors (for the moment we take all quarks to be triplets of color), the quark masses $[m_{q_1},\ldots,m_{q_{N_F}}]$ and finally the renormalization scale Λ_{QCD}. We make the following assumptions about the relation of these parameters to those of the Pomeron. As we shall discuss afterwards this is the relationship that emerges from 2 and the assumptions are generally plausible given only that the confining solution of QCD is string-like and multiperipheral as expected. Assume that

A) Criticality depends only on N_F in that if $\alpha_0 = \alpha_{0c}$ for a particular value of N_F, then variation of the scale parameters Λ_{QCD}, $m_{q_1},\ldots m_{q_{N_F}}$ will not disturb this relation.

B) The diffractive dissociation scale is set by

$$r_0 \sim \frac{1}{m_\pi^2} \sim \frac{1}{m_{q_1}} \qquad (\sim \frac{1}{m_{q_i}} \text{ in general}) .$$

C) The bare Pomeron slope scale is set by

$$\alpha_0' \sim \Lambda_{QCD}^{-1} .$$

So we want to identify our three reggeon field theory parameters α_0, α_0' and r_0 respectively with N_F, Λ_{QCD}, and m_q. The exact relationship may be quite complicated but we anticipate that close to the critical point and close to the chiral limit A) – C) represent essentially the correct relationship.

Suppose now that N_F is fixed to give criticality and consider the "maximal" chiral limit

$$m_{q_1} \sim m_{q_2} \sim \ldots m_{q_{N_F}} \rightarrow 0 . \tag{7}$$

From B) we immediately have that this gives the strong-coupling limit $r_0 \rightarrow \infty$. Therefore A) – C) imply that <u>if the Pomeron is Critical the Chiral limit of QCD must give free gluon scaling behavior—with an anomalous dimension</u>.

This result is natural from the point of view of the analysis of <u>2</u> above. There I argue that if the Pomeron is critical a vector is "almost" in the theory. In the sense that an infinitesimal variation of parameters can bring vectors into the theory. In the context of QCD this implies that gluons are almost deconfined at infinite energy when the Pomeron is Critical. We are now saying the same for the chiral limit—it must almost bring gluons into the theory in that multiple gluon exchange must appear in the diffraction peak. But, can we have confinement away from the chiral limit and "deconfinement" at the limit?

QCD with all quarks massless is a single scale theory (Λ_{QCD}) and hence a single β-function--defined suitably for strong coupling--can describe both small and large momenta. In Ret.6 it is argued that the evolution of such a β-function as N_F is increased is as in Fig.2. An expansion around $N_F = N_F^*$--the value of N_F at which asymptotic freedom is lost--shows that an infra-red fixed-point actually appears before asymptotic freedom disappears. ($N_F = 16$ has also been argued[7] to have such a fixed-point by several authors). But an infra-red fixed-point is exactly what we need to produce anomalous dimension gluon scaling for the Critical Pomeron. Thus we are brought to the very attractive connection <u>Critical Pomeron scaling requires an infra-red fixed-point of massless (quarks) QCD</u>.

Since the infra-red fixed-point requires many, if not the maximum, number of quarks allowed by asymptotic freedom we have essentially recovered the result of <u>2</u> above. In fact if the limit (7) is really to take us from a confining theory to a β-function with an infra-red fixed-point, we may actually require a double-zero fixed point as illustrated in Fig.3. This is an even stronger requirement on N_F and in fact it is not obvious that it is satisfied for any integer-value of N_F. As presently understood the argument of <u>2</u> allows three possbilities for quark-structure with which to "saturate" QCD--given the existing five triplets of known quarks--that is

i) 16 color triplets

ii) 6 color triplets and 2 color sextets

iii) 5 color triplets and 1 color sextet plus 1 color octet.

It could very well be that the requirement of a double-zero in the β-function selects definitively one of these three possiblities.

To complete our discussion we must give what justification we can for A) - C) above. Consider A) first--Fig.1 emphasizes that the diffraction peak scaling we are discussing eventually holds for

$$S \gg m_{q_1}, \ldots m_{q_{N_F}}, \Lambda_{QCD}, \; t \ll m_{q_1} \ldots m_{q_{N_F}}, \Lambda_{QCD} \; . \qquad (8)$$

Therefore it would be very singular behavior if a small variation in these scales could effect its occurrence. We expect variation of such scales to determine only how large and small s and t should be respectively to see the scaling behavior.

B) and C) are the vital elements of our argument. Firstly any multiperipheral-like model will give B) as illustrated in Fig.4. The scale for large-mass diffractive dissociation will be set by the lightest particle which can be exchanged in the central region of the rapidity axis. The resulting pion loop models for the triple Pomeron vertex have been phenomenologically successful[8] at producing the right order of magnitude. The simplest model (shown in Fig.4) gives

$$r_0 \sim \int_0 \frac{d^2 k_\perp}{[k_\perp^2 + m_\pi^2]^2} \underset{m_\pi \to 0}{\sim} \frac{1}{m_\pi^2} \; . \qquad (9)$$

Of course, m_π^{-1} could also appear in α_0' but it has long been known[9] that if a finite chiral limit is assumed then $m_\pi \to 0$ gives only a very mild singularity in the trajectory function. In fact if a bare Pomeron trajectory can be related to a clo~ed-string configuration in a string-like description of confinement we expect α_0' to be determined by the universal string-tension. The relation of the string tension to Λ_{QCD} then gives C).

In the detailed analysis of 2, B) and C) emerge since we (indirectly) define a bare Pomeron from a set of graphs which has color-zero but anomalous (negative) color charge parity (a property shared by the imaginary part of a closed-string progagator). This gives a finite result as $m_q \to 0$ and should give a finite trajectory with C) satisfied. The triple Pomeron vertex must violate color charge-parity conservation (off mass-shell) and so depends for its existence on the existence of the pion, whose coupling to the Pomeron violates color charge-parity by a triangle anomaly coupling. It then follows that the triple Pomeron scale is indeed determined by m_π and hence m_q and not Λ_{QCD}. C) then follows.

We hope that the above discussion has made it clear that if we have an asymptotic diffraction peak with the structure built up by diffractive dissociation related processes then it is natural for the peak to shrink to zero width in the chiral limit. This can be consistent with QCD only if there is an infra-red fixed-point and this in turn requires a large number of flavors. Therefore it becomes of central interest to determine whether the various scaling properties of soft diffractive physics that are certainly emerging at the $\bar{p}$-p collider are indeed inter-related with diffractive dissocation processes as we would expect from the Critical Pomeron. We would therefore like to urge as extensive an investigation of diffractive processes at both the CERN and FERMILAB colliders as is consistent with all other priorities. This may give us the best signature we can find that a rich quark structure remains to be discovered.

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FIGURE CAPTIONS

Fig.1 The rising cross-section and asymptotic diffraction peak.

Fig.2. Evolution of the β-function with N_F.

Fig.3 Possible smooth behavior of an effective β-function as $m_{q_i} \to 0$, $i = 1, N_F$

Fig.4 The multiperipheral origin of the triple Pomeron coupling r_0.

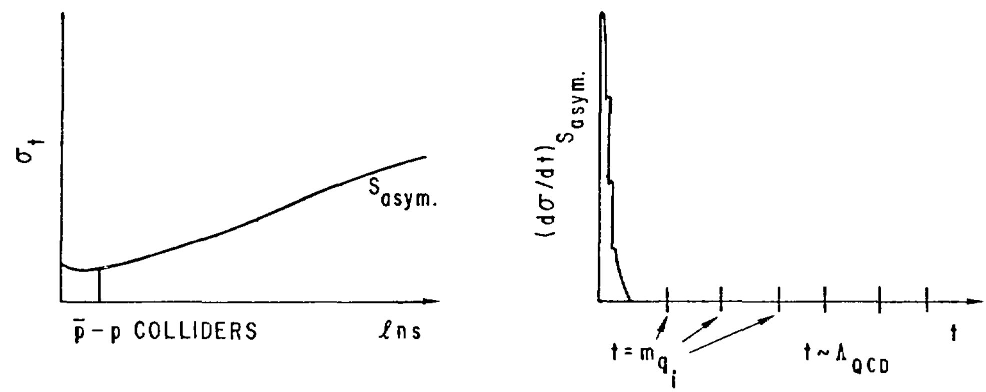
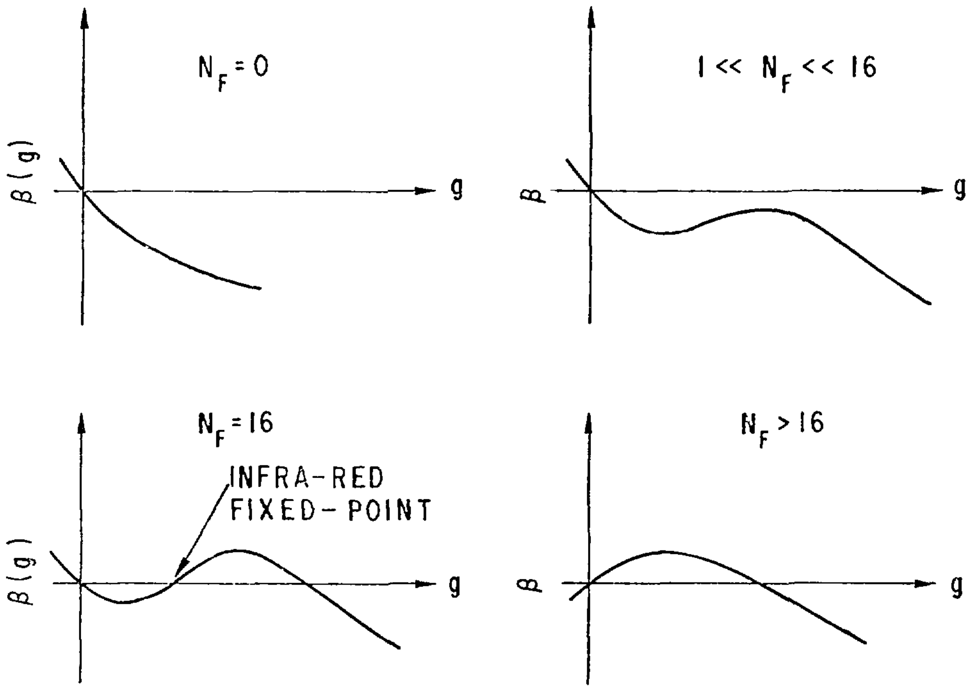


Fig. 1



$N_F = 0$
$\beta(g)$
g
$1 \ll N_F \ll 16$
β
g
$N_F = 16$
INFRA-RED
FIXED-POINT
$\beta(g)$
g
$N_F > 16$
β
g

Fig. 2

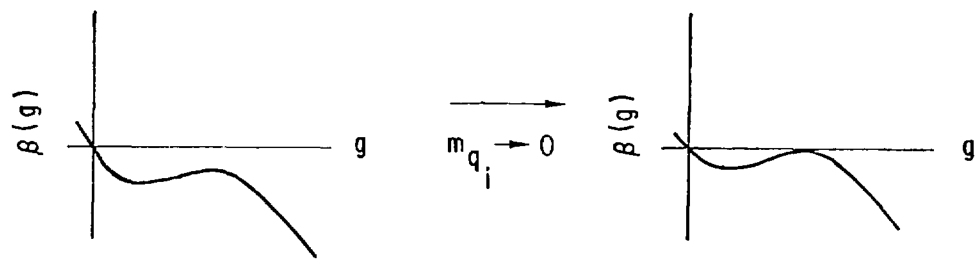


Fig. 3

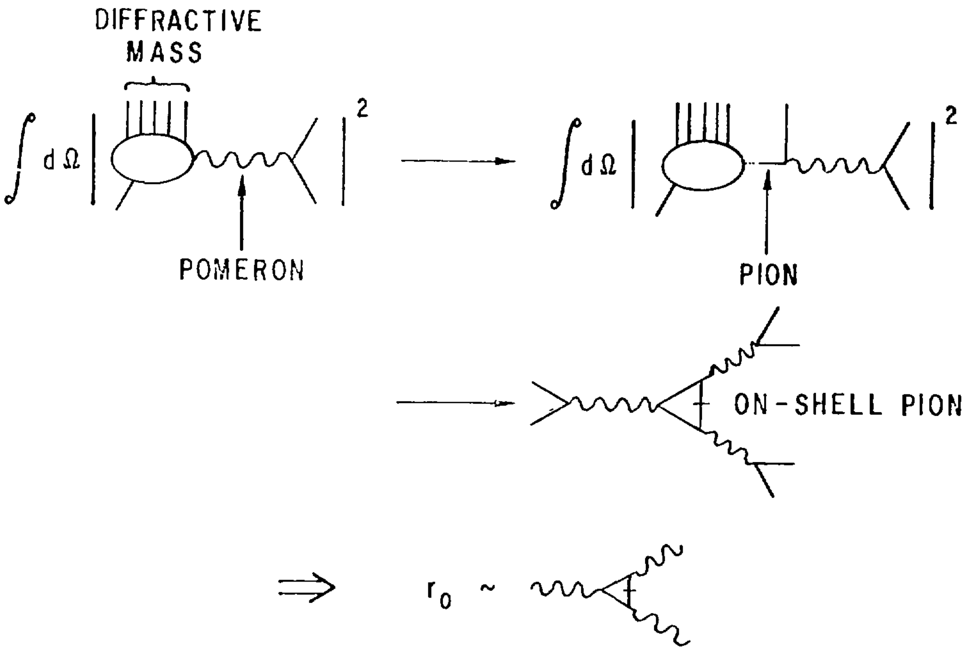


Fig. 4