LBL-11397 c.2

Lawrence Berkeley Laboratory

UNIVERSITY OF CALIFORNIA

Physics, Computer Science & Mathematics Division

Presented at the XXth International Conference in High Energy Physics, Madison, WI, July 17-23, 1980

QCD CORRECTIONS TO HADRONIC LARGE p_T SCATTERING

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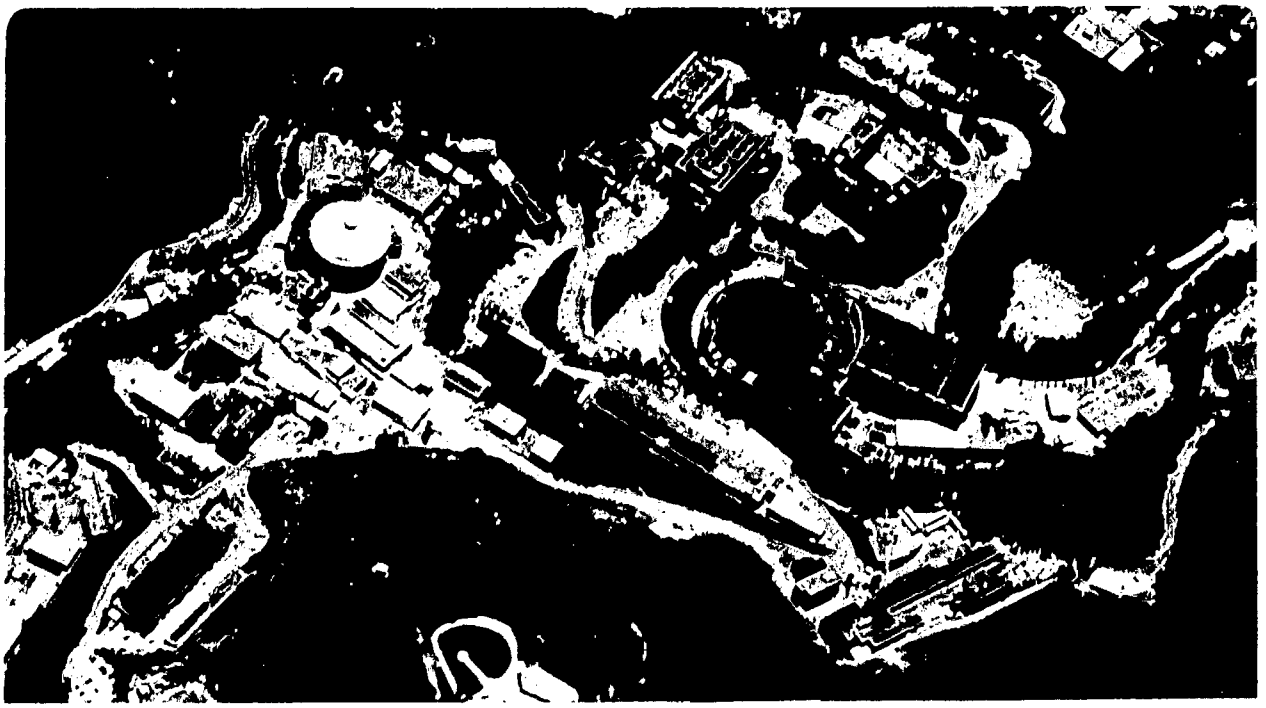

Prepared for the U.S. Department of Energy under Contract W-7405-ENG-48

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QCD CORRECTIONS TO HADRONIC LARGE p_T SCATTERING*

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ABSTRACT

QCD corrections to large p_T scattering are calculated. The status of the perturbation expansion is discussed.

This talk is an account of the work by R.K. Ellis, H. Haber, M. Furman, and myself,[1] however, the contents of this talk reflect my views and not necessarily those of my collaborators.

The aim of this work is to decide whether QCD perturbation theory makes reliable predictions for the production of particles at large transverse momentum in hadron-hadron collisions. I will briefly recall the ingredients of the QCD prediction. The process $h_1 + h_2 \to h_3 + X$ is indicated in Fig. 1. Hadrons h_1 and h_2 of momenta P_1 and P_2 emit constituents of momenta x_1P_1 and x_2P_2 which then scatter at wide angle resulting in parton of momentum p_3 which then fragments into the observed hadron h_3 with momentum P_3. (Throughout upper case letters refer to hadrons and lower case refers to partons.)

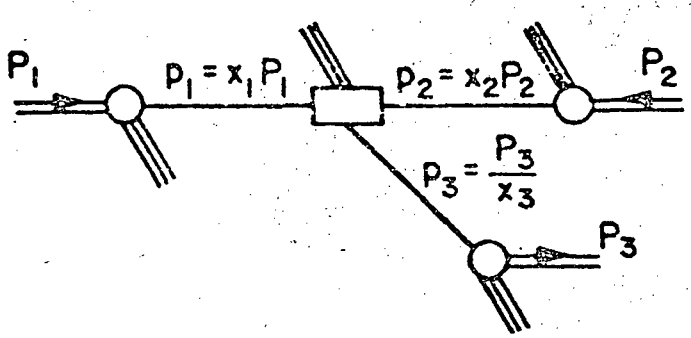

Fig. 1

Defining $t = (p_1 - p_3)^2$, $s = (p_1 + p_2)^2$, $u = (p_2 - p_3)^2$ and $v = 1 + t/s$, $w = -u/(s + t)$, the cross-section for production of h_3 is

$$\frac{1}{SV}\frac{d\sigma}{dVdW} = \sum_{ijk} \int_0^1 dx_1 dx_2 \frac{dx_3}{sx_3^2} \times \left[F_i(x_1,M^2)\, F_j(x_2,M^2)\, D_K(x_3,M^2)\right] \cdot \times \left[\frac{1}{v}\frac{d\sigma_{ij}^K}{dv}(s,v)\,\delta(1-w) + \frac{\alpha_s^3}{2\pi} K_{ij}^K(s,v,w)\right] \tag{1}$$

* This work was supported by the High Energy Physics Division of the U.S. Department of Energy under contract No. W-7405-ENG-48.

where $F_i(x,M^2)\left[D_i(x,M^2)\right]$ is the probability of extracting a parton (hadron) of momentum fraction x from a hadron (parton). $\frac{d\sigma}{dv}$ is the lowest order parton parton scattering cross-section. $\frac{d\sigma}{dv}$ is proportional to α_s^2 and has support only at the elastic limit. The aim of the work I describe is to calculate the quantity $K(s,v,w)$. If it is small then the phenomenology based on the lower order[2] is believable, if it is large then some doubt must be cast on the validity of the phemomenology.

Since only the size of K is relevant we chose[1] the simplest process ($\equiv$ simplest gauge invarient set of diagrams). Consider $q_1 + q_2 \to q_3 + X$ where q_1 and q_2 are quarks of distinct flavour, and we will ignore (initially) incoming gluons. A physical process can be found where this is the dominant process (e.g. $K^+ + \pi^- \to K^+ + X$, at large p_T where valence quarks dominate). In $\frac{d\sigma}{dv}$ there is only one graph, that involving t channel gluon exchange. The calculation of K is tedious and I will merely outline it here (details are given in ref. 1).

1.) Calculate the graphs which contribute through order α_s^3.

2.) Renormalize the ultraviolet divergence.

3.) Remove the mass singularities. The graph shown in Fig. 2, has a mass divergence when the propagator A goes on mass shell. These divergences must be reabsorbed into F and D. We are guaranteed that this proceedure will work by the factorization proof.[3] In order to avoid confusion, one merely has to remember where the F's and D come from. F is extracted from deep inelastic lepton scattering. The structure function

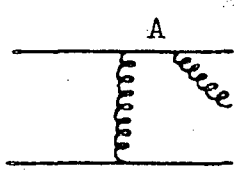

Fig. 2

$$F_2(x,M^2) = \sum_i e_i^2 F_i(x,M^2) \qquad (2)$$

where the sum i runs over quarks of charge e_i and M^2 is the scale at which the structure function is measured. If F_2 is calculated in perturbation theory the same mass divergences are encountered so that one uses F_i defined by equation (2) all the mass singularities cancel. The singularities in D are removed in a similar way by defining it from one particle inclusive $e\bar{e}$ annihilation.

4.) There is a complication associated with gluons of Fig. 3. A singularity arises when the propagator A goes on shell. This process corresponds to the incoming quark decaying into a gluon which then undergoes a hard scattering against the other quark. Now the gluon distribution is not measured in any other process,

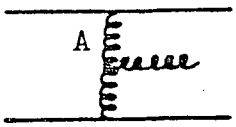

Fig. 3

so we are forced to define it. This leads to a (finite) ambiguity in K. However, the gluon distribution is not totally arbitrary. The singular part is defined and there is a constraint on the finite part from energy momentum conservation.

Having calculated K we now substitute back into equation (1), using some parton distributions and look at the effect of K on $\frac{d\sigma}{dVdW}$. It is important to discuss the ambiguities in K.

1.) The scale M^2 is characteristic of the hard scattering process; a change in M is equivalent to a change in K. In lowest order M is arbitrary (a popular choice is $\frac{2stu}{s^2 + t^2 + u^2}$)[4].

2.) Part of K is the expansion of $\alpha_s^2(\mu)$ which appears in lowest order. Again μ is same scale characteristic of the hard scattering ($\mu = M$ is usually used in lowest order but there is no reason why they should be the same), and a change in μ results in a change in K. There is an additional ambiguity in the prescription used to define α_s. We used the so called $\overline{MS}$ prescription,[5] but one could equally use a momentum space scheme.[6]

3.) There is an ambiguity associated with the gluon distribution $G(x,M^2)$ as discussed earlier.

It is "obvious" that for some values of μ, M^2, and $G(x,M^2)$, K can be made small, and it is also probably true that having found those values somebody will come up with an a posteriori "proof" that these are the natural values. I will try to guess the scales before doing the calculation. $\mu = t$ seems natural since the coupling constant renormalization comes from dressing the lowest order (t channel) graph. We do not know what M is. An obvious upper value is s, and a lower one p_T^2 of the outgoing parton (= tu/s at 90° in the center mass frame). Figure 4 shows the function

$$R = \frac{1}{SV}\frac{d\sigma}{dWdV}\Bigg|_{\text{including } K} \Bigg/ \frac{1}{SV}\frac{d\sigma}{dVdW}\Bigg|_{K=0}$$

at 90° in the center of mass as a function of $x_\perp = 2p_T/\sqrt{S}$. If $R \approx 1$ the correction is small and the perturbation expansion is reliable. The dashed line at $M^2 = tu/s$ illustrates the size of the ambiguity associated with $G(x,M^2)$. It disappears at large p_T where gluons are irrelevant. $M^2 = t$ and $M^2 = \frac{2stu}{s^2 + t^2 + u^2}$ produce curves

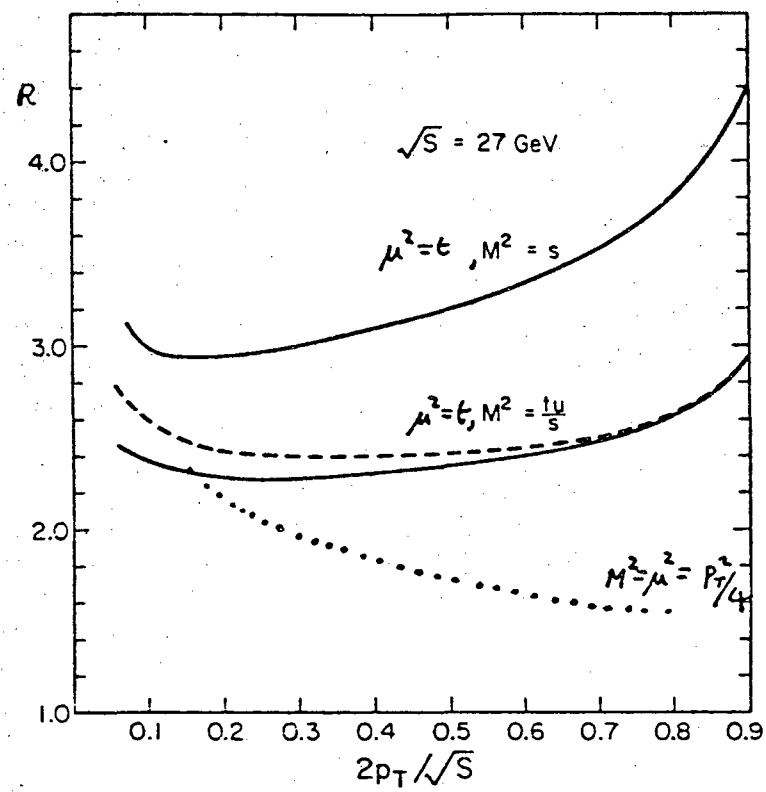

Fig. 4

which lie between the solid lines. I have shown an unnatural value of μ and M in the dotted line on Fig. 4 $\mu^2 = M^2 = p_T^2/4$. The correction is still large. The correction can be reduced by using a momentum space subtracted coupling constant. It will reduce the correction by about 40%. However, even for $p_T^2/4 = \mu^2 = M^2$ the corrections are still substantial.

In conclusion it appears that QCD perturbation theory does not make sound predictions for large p_T hadron scattering at current energies. As the energy increases the corrections reduce but only logarithmically, not until $\sqrt{S} \approx 1000$ GeV do they become reasonably small.

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This report was done with support from the Department of Energy. Any conclusions or opinions expressed in this report represent solely those of the author(s) and not necessarily those of The Regents of the University of California, the Lawrence Berkeley Laboratory or the Department of Energy.

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