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ABOUT MEASURING CHARGES IN HARD JETS

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A B S T R A C T

Infra-red singularities usually associated with charge measurement can be avoided on a suitably defined perturbative level. Under optimistic assumptions about the non-perturbative phase of the interaction this observation can be used to predict correlation between the angular charge and the angular energy flow in jets of known initial charge.

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A number of predictions which are related to the energy flow in hard jets have been made in perturbative quantum chromodynamics and it is tempting to try to extend this method to charge flow related quantities. There is hope that the charge structure in final states will eventually enable a better distinction between various concepts of hadronic production. However, several problems are encountered. Charge distributions are statistically relatively difficult to measure as local fluctuations or misidentifications involve unit charges and are large against the total fractional charge flow. This small "signal-to-noise" ratio requires comparatively strong assumptions about the non-perturbative final state interactions: any unaccounted-for polarization in the distribution of the soft quarks in the final state can completely invalidate perturbative predictions. However, we will find that reasonable assumptions make it possible to treat these non-perturbative effects in an approximate sense. Contrary to previous authors ¹⁾, we see no real problem with infra-red singularities for the perturbative phase of the interaction. As described in the next paragraph, an insignificantly modified angular charge flow is free of infra-red singularities ²⁾.

For angular distributions there is no problem with collinear partons and the point which has to be considered is how infra-red singularities arising from the production of light quark-antiquark pairs can be avoided. Light is meant to be small ($m_q^2 < Q_0^2$) in relation to a preconfinement mass Q_0 ³⁾ down to which perturbative considerations are applicable and it presumably includes up, down and strange quarks. If such pairs lie only partially within the measured cone they are counted in a special way, the cancellation between real and virtual production is affected and mass singularities appears. There is no obvious way out with special kinematic regions ^{*}) as some soft quarks have to occupy the same kinematic regions as the initial hard quarks to neutralize their colours. The infra-red singularities are not automatically cured by a symmetry between soft quarks and antiquarks as the direction of the quark flow can be correlated. However, as light quark masses are neglected, their flavour distribution has to be universal. This allows us to eliminate the special contribution from soft quarks during the summation over the light quark flavours. To accomplish this, one adds to each quark (antiquark) charge the average charge which is carried by the antiquark (quark) needed to neutralize its colour ^{9),8)}, i.e., one observes

*) Suitable weights favouring special kinematic regions are useful to obtain single parameter descriptions. A number of such parameters have been proposed in the literature ⁴⁾⁻⁶⁾. To determine jet charges with best statistics at present energies, it is reasonable to assume that like in soft scattering ^{7),8)} large rapidity gaps tend to involve just ($q\bar{q}$) exchanges and an average of the charges transferred over the gap width in rapidity (i.e., $\sum y_i q_i$) led to best results ⁶⁾.

$$q_{\text{counted}}(\in \Delta\Omega) = \sum_{k \in \Delta\Omega} (q_k - \langle q \rangle) + \sum_{\bar{k} \in \Delta\Omega} (\bar{q}_{\bar{k}} - \langle \bar{q} \rangle);$$

where the summation over k and $\bar{k}$ involves the quarks and antiquarks which enter the observation cone $\Delta\Omega$. With a zero average counting charge of produced soft quarks or antiquarks the cancellation of infra-red singularities is no longer disturbed. For actual measurements this shift in the charges is irrelevant as there is usually ^{*)} the same number of quarks and antiquarks.

Can the absence of infra-red singularities during the perturbative phase be used to predict measurable quantities? It is known from the density of strange particles in final states that the flavour distribution of soft quarks has to be considerably different during the non-perturbative phase of the interaction. Perturbative calculations ³⁾ predict the production of colour singlets with relatively small, Q^2 independent masses. Inspired by soft phenomenology one might somewhat optimistically assume that the decay of these colour singlets is essentially isotropic. In this way charge symmetry eliminates the contribution of soft quarks, except for some smearing out of the initial distribution which will be less and less important with increasing energy.

The result does not critically depend on this optimistic assumption. What happens if the preconfinement scale is larger than the "isotropic cluster" mass and the preconfinement clusters non-perturbatively evolve in several isotropically decaying clusters? One can again neglect the fluctuations which arise from the cluster decay and just consider the charge which is carried by the undecayed clusters into a given angular region. Its value will be determined by the charges of, say, one initial hard quark and n , respectively $n+1$, produced light quarks which enter, and respectively leave, the observed angular region. Because of an approximate ordering ¹⁰⁾ the numbers n will not be very large and from lowest order calculations one can expect a certain degree of symmetry between entering and leaving quarks regarding their perturbative or non-perturbative origin. It seems therefore a safe assumption that this symmetry can be restored if a suitably chosen "colour neutralizing" quark is separated out. The symmetric part then does not contribute to charge and error incurred arises from the possibility that the chosen quark originates in the non-perturbative phase where its charge is not correctly compensated. Let

*) If (anti-) baryons are produced the counted charge corresponds to a linear combination of charge and baryon number.

us consider this mismatch quantitatively. With an equal number of up, down and strange quarks the average perturbative light quark charge happens to be zero, while a reasonable estimate of the non-perturbative, non-isotrope soft quark involves half as many strange quarks as up or down quarks and gives an average charge of 0.06. For up quark jets the derivation from the optimistic prediction therefore maximally amounts to a 10% correction. [Almost exclusively (>90%) up quark jets are produced in deep inelastic scattering off protons and in association with large p_T direct photons in the appropriate region of phase space.] Under the stated reasonable assumptions and after smearing and a small absolute uncertainty ("theoretical error bars") is accounted for, perturbative predictions like the correlation between the angular energy and charge flow in charged jets can therefore be directly compared with experiment.

To account in some way for the smearing from final state fluctuations, it is useful to compare angular charge and angular energy flow distributions¹¹⁾. The energy-charge flow distribution and the corresponding two-energy flow distribution have been calculated to leading order in the jet calculus¹²⁾. The jet calculus describes the evolution of jets with a two parameter (k^2 and $x=k_{||}/Q$) master equation. The relevant jet calculus graphs are depicted in Fig. 1. Two partons which contribute to the observation have a common and a separate evolution. On a leading logarithmic level their relative angle δ is obtained in a single step during the decay of a parent parton of mass $k^2 = \delta^2 Q^2$. As all other angles are neglected the summed over charge or energy flow will not be affected during the separate evolution after this decay. During the common evolution, however, one effectively measures a product of energy and charge flow or, respectively, of energy and energy flow and these quantities decrease in branching processes. Experimentally the fractions of the products which are not lost until masses of the order of k^2 are reached during the evolution, will correspond to the integrals over energy-energy or energy-charge flow for arbitrary angles up to a maximum value of δ . The exact definition of these integrals is :

$$P_{x_a, x_b} = \int_{(\angle \Omega_a \Omega_b) < \delta} \frac{d\vec{P}_a}{2E_a} \frac{d\vec{P}_b}{2E_b} \cdot x_a x_b \cdot g(p_a, p_b) ;$$

or

$$P_{x_a, q_b} = \int_{(\angle \Omega_a \Omega_b) < \delta} \frac{d\vec{P}_a}{2E_a} \frac{d\vec{P}_b}{2E_b} \cdot x_a q_b \cdot g_q(p_a, p_b) ;$$

where $\rho(p_a, p_b)$ is the inclusive two particle spectrum and where x, q and Ω are the energy fraction, charge and angle of the corresponding secondary. Using the solution of the evolution equation¹²⁾ these quantities can be evaluated as :

$$P_{x_a x_b}(\delta) = (1, 1) \eta^{-A_2/(2\pi b)} \begin{pmatrix} 1 \\ 0 \end{pmatrix},$$

and

$$P_{x_a q_b}(\delta) = (q_{jet} - \langle q \rangle) \cdot \eta^{-A_1^{q \leftarrow q}/(2\pi b)}.$$

As a convenient parameter to describe the angles we used :

$$\eta = \ln(\delta Q / \Lambda) / \ln(Q / \Lambda).$$

The constant b is given as $12\pi b = 33 - 2N_f$. The expression for the two energy flow distributions contains a matrix product which involves the anomalous dimension matrix for the second moment :

$$A_2 = \begin{pmatrix} A_2^{q \leftarrow q} & A_2^{q \leftarrow g} \\ A_2^{g \leftarrow q} & A_2^{g \leftarrow g} \end{pmatrix} = \begin{pmatrix} -25/9 & N_f \cdot 7/30 \\ 7/9 & -21/5 - N_f/3 \end{pmatrix};$$

while for the energy-charge flow one has to use the non-singlet component of the anomalous dimension of the first moment :

$$A_1^{q \leftarrow q} = -16/9.$$

The resulting probabilities are plotted in Fig. 2 for $N_f = 3$ and with the parameter $\Lambda = 0.5$. The fact that the angular spread of charges is slightly smaller than that of the corresponding energy flow arises from the dominant emission of not too fast hard gluons. As the transverse momentum is not uniform in x , the prediction of Ref. 11) of an approximate equality of energy and charge width is not applicable. However, the deviation from this relation, which empirically holds for soft jets, is not very large.

The purpose of this note was to point out that an insignificantly redefined charge flow distribution is infra-red safe. Under reasonable assumption this observation can be used to predict measurable quantities. In contrast to the unit charge fluctuations in individual events, uncertainties about flavour averaged charges can be small in comparison with jet charges and perturbative predictions can survive non-perturbative effects.

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FIGURE CAPTIONS

Figure 1 : Illustration of the jet calculus contribution to the two-energy flow distribution and the energy-charge flow distribution.

Figure 2 : The energy-charge flow distribution and the two-energy flow distribution. The angular parameter is defined as $\eta = \ln(\delta Q/\Lambda)/\ln(Q/\Lambda)$. The soft flavour number is $N_f = 3$.

fig. 1

fig. 2