Charge and energy flow in $\pi^+ p$, $K^+ p$ and $pp$ interactions at 250 GeV/c

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Abstract. We present data on the flow of energy and charge in $\pi^+ p$, $K^+ p$ and $pp$ interactions at 250 GeV/c. The energy and charge flow in the beam c.m. hemisphere is analysed in terms of the cluster-invariant Bialas-Ochs-Stodolsky variable $\lambda = \cot \theta_{jet}/E_{jet}$. The profile functions $dQ/d\lambda$ and $dE/d\lambda$ indicate a widening in $p_T$ of jets between 32 and 250 GeV/c incident laboratory momentum, whereas the ratio $dQ/dE$ is energy independent. The data are compared to the single-string LUND model, the Dual Parton Model and the two-string LUND model (FRITIOF).

1 Introduction

It has often been suggested that energy and quantum-number flow can provide valuable information for the study of hadronic jet phenomena. Energy and quantum-number flow has also been considered as a tool to discriminate between parton models for soft processes. Already in 1977, Ochs and Stodolsky advocated the use of calorimetry for the study of deep-inelastic scattering processes and jet fragmentation [1]. Being decay products of numerous resonances, a large fraction of the stable hadrons in multiparticle final states are not promptly produced. The authors, therefore, argue that calorimetric and cluster-invar-
iant measures of hadronic production might reveal novel dynamical characteristics. Specifically, they consider the average flow of energy and of additive quantum numbers (e.g. charge) into a given angular region $\Delta \Omega$ with respect to the direction of the hadronizing parton, in a parton jet, or to the incident beam direction, in hadron-hadron collisions.

The first data on energy-, charge, strangeness- and baryon number flow have been obtained for proton jets in $pp$ collisions at 12 and 24 GeV/c beam momentum [2]. In contrast to the single particle spectra near c.m. rapidity $y=0$, these data show no evidence for scale breaking and thus support the conjecture that cluster-invariant jet-measures are of fundamental importance. Moreover, it has been noted that the energy- and charge flow distributions are nearly equal, implying that the fraction of jet charge equals the fraction of jet energy in any given angular region $\Delta \Omega$. For a single quark jet, Andersson and Gustafson subsequently have proven [3] that the latter property is a natural consequence of the recursive nature of quark cascades. Ochs and Shimada [4] have extended these ideas to the case of meson and proton jets. These authors point out that, particularly for meson jets, the ratio of charge to energy flow in a given angular region is sensitive to the momentum distribution of the valence quarks and could thus help to discriminate between various models.

The first results for meson beams have been obtained by the Mirabelle and BEBC (WA27) collaborations in $K^+p$ and $\pi^+p$ interactions at 32 and 70 GeV/c [5]. These experiments confirm the absence of energy dependence of angular charge and energy flow in the incident momentum range studied. More recently, a similar analysis of $\pi^+p$, $K^+p$ and $pp$ interactions at 147 GeV/c has been presented [6]. It is concluded that the charge and energy flows are beam independent and scale between 32 and 147 GeV/c.

In spite of their potential interest, only few data are available on angular charge and energy flow in other than hadron-hadron interactions. In $\nu(\bar{\nu})p$ collisions, the ABCMO collaboration successfully used the method to determine average quark charges [7]. These data are compared to meson and proton jets in [5] and reveal interesting similarities, although the statistics of the $\nu(\bar{\nu})$-data is poor. Recently, high precision results on energy flow in $\mu p$ collisions have been presented by the EMC collaboration for the hadronic energy range $4<W<20$ GeV [8]. Interestingly, the data exhibit sizeable scale breaking in $dE/d\lambda$, which is another manifestation of the $p_T$-broadening of the forward (quark) jet. This is shown to be due to hard QCD contributions and multiple soft gluon radiation. To our knowledge, no data exist for $e^+e^-$ annihilations.

In this paper, we extend the previous analyses of $\pi^+p$, $K^+p$ and $pp$ collisions to the energy of 250 GeV/c, the presently highest beam momentum for positive meson proton collisions. In Sect. 2 we discuss the variables used. In Sect. 3 we describe the experimental results, compare these to lower energy results and to $\mu p$ data. Predictions of various models for soft hadron-hadron collisions are discussed in Sect. 4. Our main conclusions are summarized in Sect. 5.

2 The variable $\lambda$

To describe the flow into an angular region, the authors of [1] define the variable

$$\lambda = \frac{\cot \theta}{E_{jet}},$$

where $\theta$ is the polar angle with respect to the jet axis and $E_{jet}$ the jet energy. For the case of exact Feynman scaling of the single particle inclusive spectrum for particles of type $k$

$$E \frac{d\sigma_k}{d^3p} = f_k(x, p_T),$$

it is shown that the fraction of jet energy $d\epsilon = dE/E_{jet}$ radiated into the angular interval $d\lambda$ obeys the scaling law

$$\frac{d\epsilon}{d\lambda} = \rho(\lambda),$$

with

$$\rho(\lambda) = \frac{2\pi}{\sigma_{inel}} \int dp_T p_T \sum_k f_k(\lambda p_T, p_T).$$

In terms of pseudo-rapidity $\eta = -\ln \tan (\theta/2)$, one has

$$\frac{d\epsilon}{d\lambda} \approx \frac{dm_T}{d\eta} = \sum_k m_T^2(\eta) \frac{d\epsilon}{d\lambda}.\tag{5}$$

Consequently, $d\epsilon/d\lambda$ is equal to the pseudo-rapidity density $d\epsilon/d\eta$ of particles, weighted by their transverse mass $m_T = \sqrt{m^2 + p_T^2}$. From (4) and (5) one deduces the limiting behaviour

$$\lim_{\lambda \to \infty} \frac{d\epsilon}{d\lambda} = 0, \quad \lim_{\lambda \to 0} \frac{d\epsilon}{d\lambda} = M.\tag{6}$$

The mass parameter $M$ is interpreted as the average transverse mass in the central rapidity plateau at $\lambda = 0$ (or rapidity $y = 0$).

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