DIFFRACTIVE DISSOCIATION OF TOP HADRONS AT COLLIDER ENERGIES

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In an optical model in which heavy-flavour production is described as coherent scattering within the nucleon, the total heavy-flavour cross-section is expected to obey a m_q^{-2} dependence, whilst the partial differential cross-section $d\sigma/dp_T$ for top hadrons is expected to show a broad plateau above ~ 20 GeV/c in transverse momentum. The expected top hadron signal $d\sigma/dp_T$ is 60 nb for $m_t = 20$ GeV/c^2 appearing in the angular range $\langle\theta\rangle \approx 10°$–$20°$.

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Diffractive dissociation of charmed hadrons observed at the CERN Intersecting Storage Rings (ISR) [1] has been successfully described by the "intrinsic" charm model [2] in which heavy-flavour quark pairs ($Q\overline{Q}$) appear in the Fock-state decomposition of the proton. The most striking property of this model is the large forward production of charmed hadrons, generated by colour-singlet eigenstates $|uudQ\overline{Q}\rangle$ at the 1–2% content level whose heavy constituents tend to carry the largest fraction of the hadron momentum. Within the context of diffraction excitation in QCD [3], these intrinsic Fock-states pass through the nucleus without interacting, as a result of their small transverse dimension.

At the CERN $\bar{p}p$ Collider, where the available c.m. energy $\sqrt{s} = 540$ GeV far exceeds the observed charmed and beauty quark mass, searches for the top quark with masses in excess of 18 GeV/c^2 (the current upper limit from PETRA) are immediately accessible; in the energy region where $m_q \ll \sqrt{s}$, perturbative QCD calculations [4] predict a m_q^{-2} dependence of the total heavy-flavour cross-section. Given the surprisingly large charmed hadron cross-section observed at the ISR, the diffractive cross-section for open top hadrons is then expected to be ~ 3 μb for $m_t = 20$ GeV/c^2.

The presumably large mass of the top quark leads to distinguishing kinematic features in transverse momentum that suggest a simple experimental separation from the more abundant charmed and beauty backgrounds produced at relatively low p_T. This p_T separa-

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tion, however, differs from previous calculations [5] which exclude the intrinsic transverse momentum of the given top hadrons. Our calculations show that this separation occurs above 20 GeV/c, and that the shape of this spectrum is very broad, persisting out to high values of p_T. It should also be pointed out that whilst conventional QCD calculations [6] predict a top signal that is completely dominated by charm and beauty production at high values of p_T, the absolute cross-sections for these reactions are less than 1 pb and also exclude the intrinsic heavy-flavour component.

We begin by defining our optical model of heavy-flavour diffractive production which also leads to the same scaling law in mass. Optical parameters describing the different heavy--flavour production cross-sections are then derived, along with the expected distributions in p_T.

In the high-energy diffractive dissociation process,

$$p+p \rightarrow p'+M, \tag{1}$$

a high-mass excited state M is produced which can then dissociate into a heavy-flavour baryon Λ_q and an antimeson pair; p′ is a quasi-elastic proton recoiling against M. In the framework of an intrinsic heavy-flavour model, diffractive dissociation provides a natural mechanism for these heavy-flavour states to appear as real heavy-flavour hadrons once the state M has crossed mass threshold and the $(Q\bar{Q})$ pairs are then on the mass shell, as illustrated in Fig. 1. At Collider energies of $\sqrt{s} = 540$ GeV, a top quark mass of 20 GeV/c^2 implies a kinematic limit in Feynman x for the recoiling proton of $x = 0.995$, extremely close to the elastic limit.

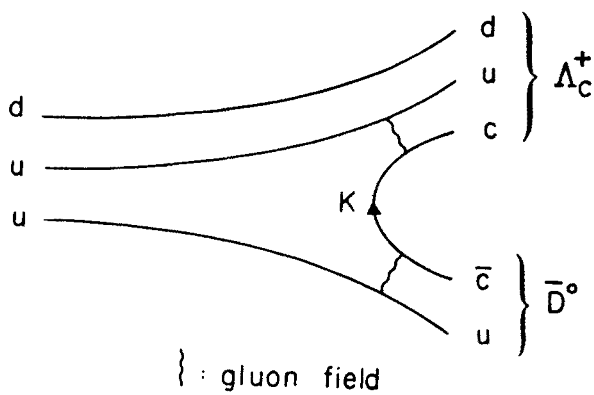

Fig. 1. Diffractive dissociation of the state M into a charmed $c = +1$ baryon and a charmed $c = -1$ meson

The transparency of the nucleus to short-range components suggests that diffractive production of heavy flavours in nucleon-nucleon interactions can be treated as quasi-elastic scattering of intrinsic short-range components whose cross-section depends on the geometric scale of the interaction. The transverse dimension of the $(Q\bar{Q})$ heavy-flavour pairs appearing in the Fock-state decomposition is characterized by the Compton wavelength, with a range of separation inversely proportional to the quark mass:

$$R_q \propto \frac{1}{m_q}. \tag{2}$$

In the limit that reaction (1) is a quasi-elastic scattering process of one proton off intrinsic components with a transverse dimension characterized by formula (2), heavy-flavour production can be treated as coherent wave scattering from scattering centres of radius R_q. The total heavy-flavour cross-section in this case is given by the optical theorem, $\sigma_{tot} = 2\pi R_q^2$. From the relationship between transverse extent and mass, the total heavy--flavour cross-section then obeys the scaling law

$$\sigma_{tot} \propto m_q^{-2}, \tag{3}$$

also as expected on the basis of perturbative QCD calculations.

Table I summarizes the optical parameters of heavy flavours at Collider energies. The reactions are scaled to a total charmed hadron cross-section of 1 mb observed at the ISR [7], where $\sigma_{tot}(\Lambda_c^+) \sim$ 200–400 μb and $\sigma_{tot}(D^0+D^+) \sim$ 0.8–0.9 mb.

TABLE I

Optical parameters of heavy flavours

	Total m_q (GeV/c^2)	c 1.2	b 4.0	t 20	t 50
R (fermi)	1.0	0.16	4.74×10^{-2}	9.5×10^{-3}	3.8×10^{-3}
σ_{tot}	62.8 mb	1.6 mb	141 μb	5.7 μb	0.9 μb

The intrinsic transverse momentum of each quark in a Fock-state generally increases with m_q, a result which is also expected on the basis of decay kinematics. The high-mass excited state M in reaction (1) is known to follow the empirical law [8]

$$\frac{d\sigma}{dm^2} \propto \frac{1}{m^2}, \tag{4}$$

and, given the large available c.m. energy at the Collider, the resulting mean mass $\langle m \rangle$ can then impart a large fraction of its energy through strong decay into heavy-flavour hadrons. In the diffractive region [1] $x \gtrsim 0.85$, the mass m is given by $m^2 = s(1-x)$, and for a top-quark mass of 20 GeV/c^2, the mean excited mass, integrated between threshold $\approx 2\,m_q$ and the diffractive limit, is

$$\langle m \rangle \approx 100 \text{ GeV}/c^2. \tag{5}$$

In the limiting case that the state M decays into two heavy-flavour hadrons of comparable mass, the resulting maximum transverse momentum of each particle is given by $(p_T)^2_{max} = (m^2/4) - m_q^2$, corresponding to a mean upper limit of

$$\langle p_T \rangle_{max} \approx 55 \text{ GeV}/c. \tag{6}$$

Additional particles accompanying the decay of M will reduce the available energy appearing in p_T, whilst those events near $x \approx 0.85$ provide increasing energy which may then appear as increasing p_T.

The partial differential cross-section in momentum transfer for heavy flavour is likewise expected to show an enhanced p_T behaviour. For a mean mass $\langle m \rangle \approx 100$ GeV/c^2 the implied mean x for the recoiling proton is $\langle x \rangle \approx 0.97$, which in our optical model is

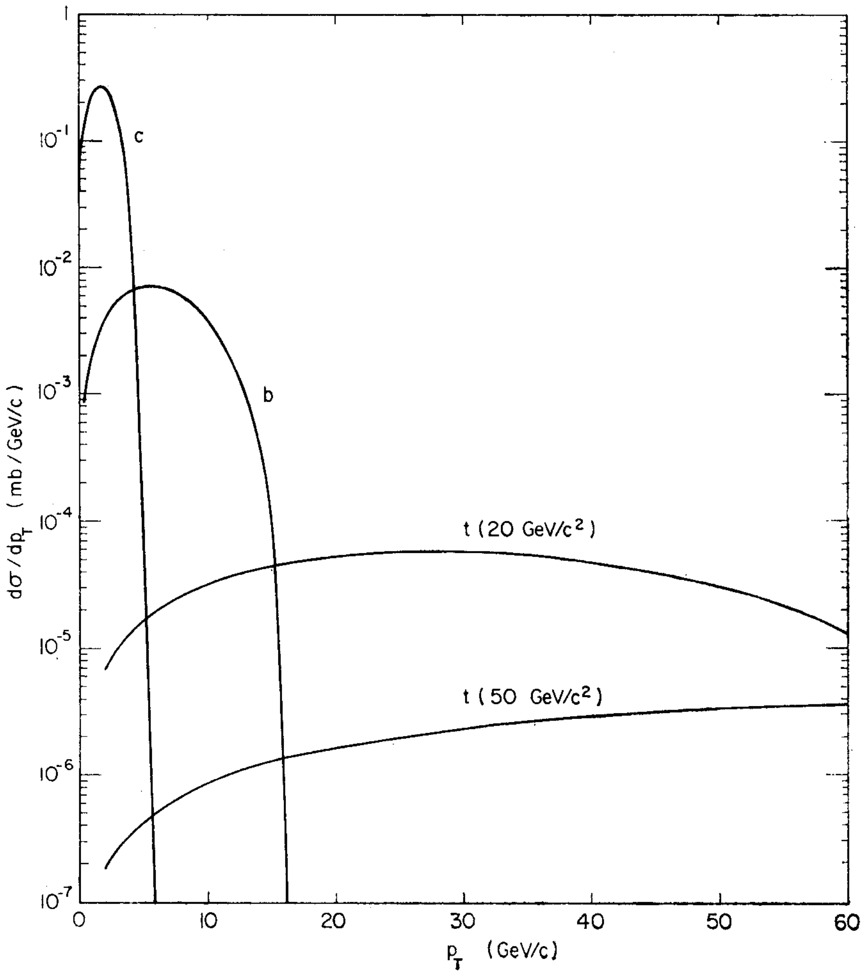

Fig. 2. $d\sigma/dp_T$ (mb/GeV/c) as a function of transverse momentum

approximated as being elastic. The heavy-flavour hadrons appearing in the decay of M are produced together, with a total transverse momentum equal to that of the recoiling proton. Each hadron, however, has a much larger transverse momentum if arising from a near-elastic scattering from a small interaction region within the nucleon, i.e. both hadrons being coherently scattered. In the optical picture of diffractive scattering, the elastic differential cross-section is then given by:

$$\frac{d\sigma}{dp_T} = \sigma_{tot} \frac{J_1^2(p_T R)}{p_T}, \tag{7}$$

which describes ISR elastic scattering data [9] well up to the first minima near $t \approx -1$ $(\mathrm{GeV}/c)^2$. The absolute normalization is given by σ_{tot} (Table I), which in turn is normalized for different heavy flavours by m_q^{-2} and the value of R given by formula (2).

The partial differential cross-sections for different heavy flavours are shown in Fig. 2. For charmed hadrons the predicted mean for p_T is ~ 1.5 GeV/c, to be compared with the observed $\langle p_T \rangle$ of $\sim$ 1 GeV/c for the Λ_c^+ seen at ISR energies [10] and the rise in $\langle p_T \rangle$ from $\sim$ 350 MeV/c to $\sim$ 430 MeV/c at Collider energies [11]. In the p_T region near the zero of the Bessel function J_1 where the p_T dependence is no longer expected to hold, the next higher flavour contribution dominates. Owing to the expected high-mass difference between the top quark and the beauty quark, the corresponding distribution in p_T is much broader, and completely dominates the high-p_T region above $\sim$ 20 GeV/c.

On the basis of Fig. 2, the most direct way of detecting the top hadron is suggested by looking in the single prompt lepton p_T spectrum above 20 GeV/c. Note that the mean p_T of top hadrons in this model is quite large, with $\langle p_T \rangle \sim$ 20 GeV/c for m_t = 20 GeV/c^2. The laboratory emission angle of leptons is therefore dominated by the production characteristics of the parent top hadrons, since in the decay rest frame of the top hadron, the mean transverse momentum from three-body decay is $\langle p_T \rangle \approx m_t/3$.

The laboratory emission angle is given by

$$\langle \theta \rangle \approx \frac{\langle p_T \rangle}{\langle p_L \rangle}. \tag{8}$$

Heavy-flavour baryon production of Λ^0, Λ_c^+ [12] and, presumably, Λ_b^0 [13] at the CERN ISR has been shown to be forward, with $d\sigma/dx \propto (1-x)^\alpha$ and $\alpha \approx 1$, whilst the x-distribution for the accompanying heavy-flavour antimesons is expected to be much softer [5, 7], with $d\sigma/dx \propto (1-x)^n$, $n = 3$. Based on what has been observed at the ISR, similar production characteristics of top hadrons are therefore expected at the $\bar{\mathrm{p}}\mathrm{p}$ Collider. In view of the high background conditions expected in the very forward region where diffractive Λ_t states are also expected to be found, it is suggested, rather, to look for the top mesons produced at larger opening angles. For $\langle p_L \rangle = 270/(n+2)$ (GeV/c), the resulting emission angle is then $\langle \theta \rangle = 20°$ for $n = 3$, or $\langle \theta \rangle = 9°$ in the case of dissociation into two heavy hadrons equally sharing the mean longitudinal momentum $\langle x \rangle = 0.5$. For a leptonic branching ratio of $\sim 10\%$, the expected top signal $\sigma \cdot B$ is 176(36) nb for m_t = 20(50) GeV/c^2 at $p_T \gtrsim 20$ GeV/c.

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