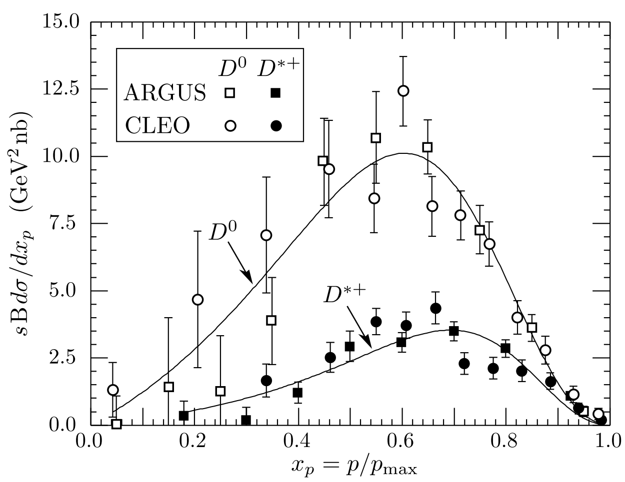
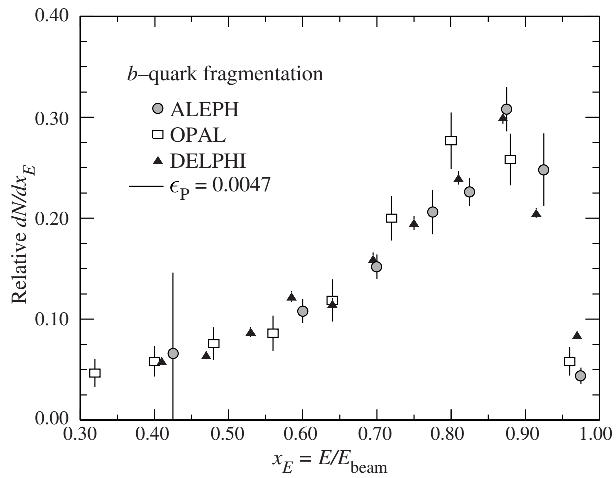
Heavy Quark Fragmentation in e^+e^- Annihilation





Figures 36.14 and **36.15:** Measurements of the fragmentation functions of heavy quarks provide information on the non-perturbative regime of particle production in a variety of experimental environments. The CDF observation of high p_T $J/\psi(1S)$ production at levels far in excess of the extant theoretical predictions prompted the development of the color octet model ($p\overline{p} \to gg \to \chi_c \to \psi$+X, *e.g.*) and highlighted the role of gluon fragmentation in charmonium production. Recent results from both LEP and HERA have also helped elucidate the gluonic contribution to charmed meson production. Current estimates from LEP are that gluon fragmentation accounts for approximately half of the D^* production in the low momentum region ($x_P \leq 0.15$, with $x_P = p/p_{\max}$).

The bulk of the available fragmentation function data on charmed mesons (excluding $J/\psi(1S)$'s) derives from measurements at $\sqrt{s}$=10 GeV. Shown in Fig. 36.14 are the effciency-corrected (but not branching ratio corrected) **CLEO** [1] and **ARGUS** [2] inclusive cross sections ($s \cdot \mathcal{B}d\sigma/dx_p$ in units of GeV^2 − nb, with $x_p = p/p_{\max}$) for the production of pseudoscalar D^0 and vector D^{*+} in e^+e^- annihilations at $\sqrt{s}$ ~10 GeV. For the D^0, $\mathcal{B}$ represents the branching fraction for $D^0 \to K^-\pi^+$; for the D^{*+}, $\mathcal{B}$ represents the product branching fraction: $D^{*+} \to D^0\pi^+; D^0 \to K^-\pi^+$. These inclusive spectra have not been corrected for cascades from higher states, nor for radiative effects. Many functional forms have been suggested to describe these "hard" spectra, characteristic of charmed particles produced in e^+e^- annihilations. The parameterization given by Peterson *et al.* [3] in terms of just one variable ϵ_p has found the most use:

$$\frac{dN}{dx_p} = \frac{1}{x_p[1-(1/x_p)-\epsilon_P/(1-x_p)]^2} \; .$$

Fits to the combined CLEO and ARGUS D^0 and D^{*+} data give $\epsilon_p^{D^0} = 0.135 \pm 0.01$ and $\epsilon_p^{D^*} = 0.078 \pm 0.008$; these are indicated in the solid curves. In the case of charm, the fragmentation functions for a variety of particles has allowed comparisons between mesons and baryons, and particles of different spin structure, as shown in the following table.

We note from the table that the mass dependence of ϵ_P is less marked than the dependence on the orbital angular momentum structure of the charmed hadron being measured. Orbitally excited $L = 1$ charmed hadrons (D_J, $D_{s,J}$, and $\Lambda_{c,J}$) show consistently harder spectra (*i.e.*, smaller values of ϵ_P) than the $L = 0$ ground states, whereas the data for the ground state charmed baryons Λ_c and Ξ_c show agreement with the lighter (by ~400-600 MeV) ground state D and D_s charmed mesons. The harder spectra of $L = 1$ hadrons can, to some extent, be attributed to the fact that all the $L = 1$ charmed hadrons will eventually decay into $L = 0$ hadrons.

Particle	$\sqrt{s}$	ϵ_P
D^0 [1]	10 GeV	0.135 ± 0.01
D^{*+} [1]	10 GeV	0.078 ± 0.008
D_s^* [4]	10 GeV	$0.04^{+0.03}_{-0.01}$
$D_1^0(2420)$ [5]	10 GeV	$0.034^{+0.018}_{-0.012}$
$D_2^0(2460)$ [5]	10 GeV	$0.015^{+0.004}_{-0.004}$
$D_1^+(2420)$ [6]	10 GeV	$0.020^{+0.011}_{-0.006}$
$D_2^+(2460)$ [6]	10 GeV	$0.013^{+0.007}_{-0.007}$
$D_{s1}(2536)$ [7]	10 GeV	$0.06^{+0.035}_{-0.03}$
$D_{s2}(2573)$ [8]	10 GeV	$0.027^{+0.043}_{-0.016}$
Λ_c [9][10]	10 GeV	0.25 ± 0.03
Ξ_c [11][12]	10 GeV	0.23 ± 0.05
Σ_c [13][14]	10 GeV	0.29 ± 0.06
Σ_c^* [15]	10 GeV	$0.30^{+0.10}_{-0.07}$
Ξ_c^{*+} [16]	10 GeV	$0.24^{+0.22}_{-0.10}$
Ξ_c^{*0} [17]	10 GeV	$0.22^{+0.15}_{-0.08}$
$\Lambda_{c,1}$ [18][19]	10 GeV	0.059 ± 0.028
$\Lambda_{c,2}$ [18][20]	10 GeV	0.053 ± 0.012
$\Xi_{c,2}$ [21]	10 GeV	$0.058^{+0.037}_{-0.021}$
b hadrons [22]	90 GeV	$0.0047^{+0.0010}_{-0.0008}$

Bottom-flavored hadrons at LEP have been measured to have an even harder momentum spectrum than charmed hadrons at lower energies - qualitatively, whereas charm spectra peak at x_P ~0.6, the spectra of bottom hadrons peak at x_P ~0.8. This is as expected in the Peterson model, where the value ϵ_P is expected to vary as the ratio of the effective light quark mass to the heavy quark mass in a heavy quark + light (di)quark hadron. In the case of charm, the Peterson functional form provides an acceptable description of the shape of the x_P distribution, provided the appropriate ϵ_P value is independently determined for each separate species of charmed particle. However, unlike charm, the numbers of fully reconstructed b-flavored hadrons is too small to allow a statistically compelling measure of ϵ_P for each separate bottom hadron. Consequently, a b-enriched sample is isolated kinematically, using, *e.g.*, a high p_T lepton and/or a displaced vertex to tag a primary b-quark. The x_P distribution therefore includes all b-flavored hadrons in the sample, and does not allow a straightforward species-by-species ϵ_P extraction. Additional uncertainties in the case of bottom arise from the sensitivity of ϵ_P to the fragmentation model used to non-perturbatively evolve the initial $q\overline{q}$ system into final state hadrons.

In general, the b-quark fragmentation function distribution is found to be somewhat narrower than the shape of the Peterson function; this may be due to a systematic underestimate of soft gluon emission in event generators, and/or uncertainties in the appropriate mix of b-flavored hadrons. The match of a single Peterson function to data is therefore much more difficult for bottom than charm at this time, although there is relatively good agreement from experiment to experiment, as seen in Fig. 36.15, which displays the fragmentation function data from OPAL [22], ALEPH [23], DELPHI [24]. (Courtesy of D. Besson, Univ. of Kansas, 1997.)

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