Fragmentation fractions of heavy quarks

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Outline : **Introduction**

$f(c \to H_c)$ and $f(b \to H_c)$ at LEP

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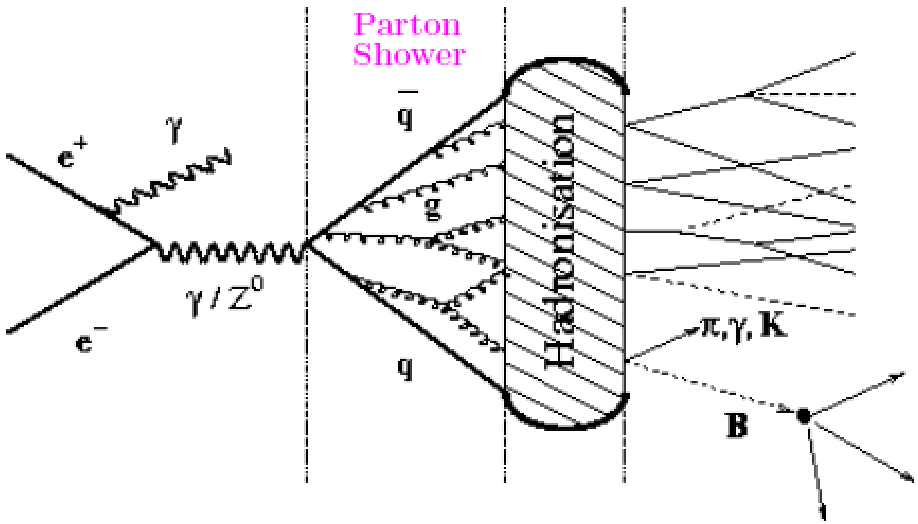
arXiv:1404.388

Hints for non-universality of fragm. Fractions

Summary

Fragmentation Functions and Fragmentation Fractions



HQ fragmentation is hard

harder for larger m_Q

e.g., for Peterson param.:

$$f(z) \propto \frac{1}{z(1-1/z-\epsilon/(1-z))^2}$$

$$\epsilon(b) \sim \frac{m_c^2}{m_b^2}\epsilon(c) \sim 0.1\epsilon(c)$$

Fragmentation Functions are strongly model dependent

pQCD is applicable to "initial" Q-fragmentation: LO, NLO, LL, NLL, ...

anyhow, some parameterisation is needed for the non-perturbative (NP) rest

the NP parameterisation is strongly dependent from the perturbative core

(it is wrong to use MC fragmentation for NLO w/o full retuning the fragm. parameters)

Fragmentation Fractions are less model dependent, often assumed to be universal

f(c⟶D), f(b⟶B), f(b⟶D) = f(b⟶B)*BR(B⟶D)

needed for normalisation of pQCD predictions

Fragmentation fractions of c and b quarks into charmed hadrons at LEP

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Charmed hadron decay	Branching fraction [%]
$D^0 \rightarrow K^- \pi^+$	3.88 ± 0.05 [6]
$D^+ \rightarrow K^- \pi^+ \pi^+$	9.15 ± 0.19 [6]
$D_s^+ \rightarrow \phi \pi^+ \rightarrow (K^- K^+) \pi^+$	2.24 ± 0.10 [6]
$\Lambda_c^+ \rightarrow p K^- \pi^+$	6.71 ± 0.35 [7,8]
$D^{*+} \rightarrow D^0 \pi^+$	67.7 ± 0.5 [6]

[6] PDG 2014.
[7] Belle (2014) : $B(\Lambda_c^+ \rightarrow pK^-\pi^+) = 6.84 \pm 0.24\ ^{+0.21}_{-0.27}$ %
[8] CLEO (2000) : $B(\Lambda_c^+ \rightarrow pK^-\pi^+) = 5.0 \pm 0.5 \pm 1.2$ %

In PDG 2014, $B(\Lambda_c^+ \rightarrow pK^-\pi^+) = 5.0 \pm 1.3$ % (indirect, with large uncertainty due to model dependence

LEP measurements of charm fragmentation fractions

ALEPH, DELPHI and OPAL rate measurements:

H_c	ALEPH [9] $R_c \cdot f(c \to H_c) \cdot \mathcal{B}$ [%]	DELPHI [10] $R_c \cdot f(c \to H_c) \cdot \mathcal{B}$ [%]	OPAL [11,12] $R_c \cdot f(c \to H_c) \cdot \mathcal{B}$ [%]
D^0	$0.370 \pm 0.011 \pm 0.023$	$0.3570 \pm 0.0100 \pm 0.0146$	$0.389 \pm 0.027 ^{+0.026}_{-0.024}$
D^+	$0.368 \pm 0.012 \pm 0.020$	$0.3494 \pm 0.0116 \pm 0.0140$	$0.358 \pm 0.046 ^{+0.025}_{-0.031}$
D_s^+	$0.0352 \pm 0.0057 \pm 0.0021$	$0.0765 \pm 0.0069 \pm 0.0037$	$0.056 \pm 0.015 \pm 0.007$
Λ_c^+	$0.0673 \pm 0.0070 \pm 0.0037$	$0.0743 \pm 0.0155 \pm 0.0078$	$0.041 \pm 0.019 \pm 0.007$
D^{*+}	–	$0.1089 \pm 0.0027 \pm 0.0039$	$0.1041 \pm 0.0020 \pm 0.0040$

$f(c \to D^{*+}) = 0.2333 \pm 0.0102(\mathrm{stat}) \pm 0.0084(\mathrm{syst})$ (← ALEPH rate measurement)

$$R_c = \Gamma(Z \to c\bar{c})/\Gamma(Z \to \mathrm{hadrons})$$

R_c = 0.1723 (SM calculation)

DELPHI and OPAL double-tag measurements:

$f(c \to D^{*+}) = 0.255 \pm 0.015(\mathrm{stat}) \pm 0.006(\mathrm{syst})$ (← DELPHI double-tag measurement)

$f(c \to D^{*+}) = 0.222 \pm 0.014(\mathrm{stat}) \pm 0.014(\mathrm{syst})$ (← OPAL double-tag measurement)

Correct all results with latest branching fractions

Charm fragmentation fractions

All LEP results:

H_c	ALEPH [9] $f(c \to H_c)$ [%]	DELPHI [10, 14] $f(c \to H_c)$ [%]	OPAL [11, 12] $f(c \to H_c)$ [%]
D^0	$55.3 \pm 1.6 \pm 3.4$	$53.4 \pm 1.5 \pm 2.2$	$58.2 \pm 4.0\ ^{+3.9}_{-3.6}$
D^+	$23.4 \pm 0.8 \pm 1.3$	$22.2 \pm 0.7 \pm 0.9$	$22.8 \pm 2.9\ ^{+1.6}_{-2.0}$
D_s^+	$9.1 \pm 1.5 \pm 0.5$	$9.7 \pm 0.9 \pm 0.5$	$7.1 \pm 1.9 \pm 0.9$
Λ_c^+	$5.8 \pm 0.6 \pm 0.3$	$6.4 \pm 1.3 \pm 0.7$	$3.5 \pm 1.6 \pm 0.6$
D^{*+}, rate	$23.3 \pm 1.0 \pm 0.9$	$24.1 \pm 0.6 \pm 0.9$	$23.0 \pm 0.4 \pm 0.9$
D^{*+}, double-tag	–	$25.7 \pm 1.5 \pm 0.6$	$22.4 \pm 1.4 \pm 1.4$

Experiments are in fair agreement

LEP measurements of bottom fragmentation fractions

ALEPH, DELPHI and OPAL rate measurements:

H_c	ALEPH [15] $f(b \to H_c)$ [%]	DELPHI [10] $R_b \cdot f(b \to H_c) \cdot \mathcal{B}$ [%]	OPAL [11,12] $R_b \cdot f(b \to H_c) \cdot \mathcal{B}$ [%]
D^0	$60.5 \pm 2.4 \pm 1.6$	$0.4992 \pm 0.0162 \pm 0.0304$	$0.454 \pm 0.023 \, ^{+0.025}_{-0.026}$
D^+	$23.4 \pm 1.3 \pm 1.0$	$0.4525 \pm 0.0204 \pm 0.0226$	$0.379 \pm 0.031 \, ^{+0.028}_{-0.025}$
D_s^+	$18.3 \pm 1.9 \pm 0.9$	$0.1259 \pm 0.0100 \pm 0.0063$	$0.166 \pm 0.018 \pm 0.016$
Λ_c^+	$11.0 \pm 1.4 \pm 0.6$	$0.0962 \pm 0.0187 \pm 0.0083$	$0.122 \pm 0.023 \pm 0.010$
D^{*+}	–	$0.1315 \pm 0.0035 \pm 0.0053$	$0.1334 \pm 0.0049 \pm 0.0078$

$$R_b = \Gamma(Z \to b\bar{b})/\Gamma(Z \to \text{hadrons})$$

R_b = 0.21579 (SM calculation)

OPAL double-tag measurement:

$f(b \to D^{*+}) = 0.173 \pm 0.016(\text{stat}) \pm 0.012(\text{syst})$ (⟵ OPAL double-tag measurement)

Correct all results with latest branching fractions

Bottom fragmentation fractions

All LEP results:

H_c	ALEPH [15] $f(b \to H_c)$ [%]	DELPHI [10, 14] $f(b \to H_c)$ [%]	OPAL [11, 12] $f(b \to H_c)$ [%]
D^0	$59.7 \pm 2.4 \pm 1.3$	$59.6 \pm 1.9 \pm 3.6$	$54.2 \pm 2.7 \, ^{+3.0}_{-3.1}$
D^+	$23.3 \pm 1.3 \pm 1.0$	$23.0 \pm 1.0 \pm 1.1$	$19.2 \pm 1.6 \, ^{+1.4}_{-1.3}$
D_s^+	$14.4 \pm 1.5 \pm 0.8$	$12.8 \pm 1.0 \pm 0.6$	$16.6 \pm 1.8 \pm 1.6$
Λ_c^+	$7.2 \pm 0.9 \pm 0.6$	$6.6 \pm 1.3 \pm 0.6$	$11.3 \pm 2.1 \pm 0.9$
D^{*+}, rate	–	$23.2 \pm 0.6 \pm 0.9$	$23.5 \pm 0.9 \pm 1.4$
D^{*+}, double-tag	–	–	$17.5 \pm 1.6 \pm 1.2$

Experiments are in fair agreement

LEP fragmentation fractions

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Weighted mean taking correlations into account:

H_c	$f(c \to H_c)$ [%]	$f(b \to H_c)$ [%]
D^0	$54.2 \pm 2.4 \pm 0.7$	$58.7 \pm 2.1 \pm 0.8$
D^+	$22.5 \pm 1.0 \pm 0.5$	$22.3 \pm 1.1 \pm 0.5$
D_s^+	$9.2 \pm 0.8 \pm 0.5$	$13.8 \pm 0.9 \pm 0.6$
Λ_c^+	$5.7 \pm 0.6 \pm 0.3$	$7.3 \pm 0.8 \pm 0.4$
D^{*+}, rate	$23.4 \pm 0.7 \pm 0.3$	$23.3 \pm 1.0 \pm 0.3$
D^{*+}, double-tag	$24.4 \pm 1.3 \pm 0.2$	$17.5 \pm 2.0 \pm 0.1$
D^{*+}, combined	$23.6 \pm 0.6 \pm 0.3$	$22.1 \pm 0.9 \pm 0.3$

1st uncert. - stat.&syst., 2nd uncert. - branching fractions

$f(c \to D^0) + f(c \to D^+) + f(c \to D_s^+) + f(c \to \Lambda_c^+) = 91.6 \pm 3.3(\mathrm{stat} \oplus \mathrm{syst}) \pm 1.0(\mathrm{branching\ fractions})\%$

$f(b \to D^0) + f(b \to D^+) + f(b \to D_s^+) + f(b \to \Lambda_c^+) = 102.1 \pm 3.1(\mathrm{stat} \oplus \mathrm{syst}) \pm 1.1(\mathrm{branching\ fractions})\%$

Too low?

Important to measure fragmentation fractions to Ξ_c^+, Ξ_c^0 and Ω_c^0.

Hints for non-universality of fragmentation fractions

In previous averaging of $f(c \to H_c)$ (arXiv:hep-ex/9912064),
LEP and B-fabric measurements were combined

It is not done in the new averaging, because
$f(b \to H_c)$ are certainly different at LEP and at √s ~ 10 GeV
$f(c \to H_c)$ show hints of non-universality as well:

At LEP, $f(c \to D^{*+}) > f(c \to D^{+})$
At 10 GeV, $f(c \to D^{*+}) < f(c \to D^{+})$

X	Belle $\sigma_{\rm PROD}$ [pb]	$\sigma_{PROD(CLEO'04/BaBar)}$ [pb]
$D^0 \to K^-\pi^+$	$1449 \pm 2 \pm 64 \pm 38$	$1521 \pm 16 \pm 62 \pm 36$
$D^+ \to K^-\pi^+\pi^+$	$654 \pm 1 \pm 36 \pm 46$	$640 \pm 14 \pm 35 \pm 43$
$D_s^+ \to \phi\pi^+$	$231 \pm 2 \pm 92 \pm 77$	$210 \pm 6 \pm 9 \pm 52^{(1)}$
$\Lambda_c^+ \to p^+K^-\pi^+$	$189 \pm 1 \pm 66 \pm 66$	$270 \pm 90 \pm 70^{(2)}$
$D^{*0} \to D^0\pi^0$	$510 \pm 3 \pm 84 \pm 39$	$559 \pm 24 \pm 35 \pm 39$
$D^{*+} \to D^0\pi^+$	$598 \pm 2 \pm 77 \pm 20$	$583 \pm 8 \pm 33 \pm 14$
$D^{*+} \to D^+\pi^0$	$590 \pm 5 \pm 78 \pm 53$	-
$average\ D^{*+}$	$597 \pm 2 \pm 78 \pm 25$	-

Due to, in particular, exclusive production channels, e.g.: $e^+e^- \to D^{(*)+}D^{(\bar{*})-}$

Hints for non-universality of fragmentation fractions

$f(b \to \Lambda_b)$ demonstrates p_T dependance at low p_T:

LHCb, arXiv:1111.2357 (for p_T < 14 GeV):

$$\left[\frac{f_{\Lambda_b}}{f_u + f_d}\right](p_T) = (0.404 \pm 0.017 \pm 0.027 \pm 0.105) \times [1 - (0.031 \pm 0.004 \pm 0.003) \times p_T(\mathrm{GeV})]$$

LEP obtains 0.110 ± 0.019

CDF measures $f_{\Lambda_b}/(f_u + f_d) = 0.281 \pm 0.012^{+0.011+0.128}_{-0.056-0.086}$

Important to measure *$f(b \to \Lambda_b)$* in central LHC range (ATLAS, CMS)

Summary

- Averaging of LEP $f(c\to H_c)$ and $f(b\to H_c)$ measurements performed
  They are intended for normalisation of MC and analytical predictions

- $\Sigma_{w.d.} f(c\to H_c)$ and $\Sigma_{w.d.} f(b\to H_c)$ look somewhat too low
  Important to measure fragmentation fractions to Ξ_c^+, Ξ_c^0 and Ω_c^0

- There are hints for non-universality of fragmentation fractions
  Important to measure $f(b\to \Lambda_b)$ at ATLAS and CMS