Combined analysis of charm-quark fragmentation-fraction measurements

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Introduction and goals

New-born quarks participate in the fragmentation process producing more quarks. The process is difficult for modelling, so the comparison to experiment is essential. An important parameter of the fragmentation is a probability to form a given hadron in the end of the process, **fragmentation fraction**. The subject of this analysis is the **charm-quark fragmentation fractions** $f(c\to H_c)$ to specific charm hadrons H_c.

The definition of fragmentation fraction enforces to check:

- The total probability of charm quark to form one of the long-living hadrons, S, is unity.
- The independence of fragmentation fractions from the process produced the charm quark (**fragmentation universality**).

Measurements and selection

The measurements of charm-hadron production in $p^{\pm}p^{\pm}$, e^+e^-, $p^{\pm}N$, $e^{\pm}p$, $e^{\pm}N$, NN, πN and KN collisions are considered and selected with the criteria:

- $\sqrt{s}\gg 2m_c\approx 3$GeV
- well-understood set-up
- minimal model dependence
- sufficient precision
- sufficient number of states
- availability as a publication

Selected results form **five** groups of measurements:

★ e^+e^-, B-factories: $\sigma(H_c)$, $\sigma(H_c)\cdot\mathcal{B}$, and $\sigma(H_c)/\sigma(\text{hadrons})\cdot\mathcal{B}$ from BELLE, BaBar, ARGUS and CLEO.

★ e^+e^-, Z decays: $f(c\to H_c)$, $\Gamma_{c\bar{c}}/\Gamma_{\text{hadrons}}\cdot f(c\to H_c)$ and $\Gamma_{c\bar{c}}/\Gamma_{\text{hadrons}}\cdot f(c\to H_c)\cdot\mathcal{B}$, from OPAL, ALEPH and DELPHI.

★ $e^{\pm}p$, DIS: $\sigma_{\text{restricted}}(H_c)$ from H1 and ZEUS.

★ $e^{\pm}p$, PHP: $\sigma_{\text{restricted}}(H_c)$ and $f(c\to H_c)$ from ZEUS.

★ pp: $\sigma_{\text{restricted}}(H_c)$ from LHCb.

Here σ is production cross-section, $\mathcal{B}$ decay branching ratio and Γ width of Z.

Combination procedure

The combination is a χ^2 fit with all known correlations included. The fit parameters are total charm cross-sections and fragmentation fractions. For the combination the measurements are corrected for the most precise decay branching ratios $\mathcal{B}$ of charm hadrons, theoretical up-to-dated values of $\sigma(e^+e^-\to c\bar{c})$ and $\Gamma_{c\bar{c}}/\Gamma_{\text{hadrons}}$ and contribution of $\Xi^{+,0}$ and Ω^0_c baryons. The combination is done separately for each group as well as for all the measurements simultaneously. From the combination results the following quantities are calculated:

$$S=\sum_{H_c=D^0,D^+,D_s^+,\Lambda_c^+,\Xi_c^{+,0},\Omega_c^0} f(c\to H_c),\quad R_{u/d}=\frac{f(c\to c\bar{u})}{f(c\to c\bar{d})},\quad P_V^d=\frac{\sum f(c\to D^*)}{\sum f(c\to D)},\quad \gamma_{s(1)}^{(*)}=\frac{f(c\to D_{s(1)}^{(*)})}{f(c\to D_{(1)}^{(*)})}.$$

The measurements of the excited states $D_1^{0,+}$,$D_2^{*0,*+}$, D_{s1}^+ from ALEPH, OPAL and ZEUS are combined in a simple averaging procedure.

Results of combinations

e^+e^-, B-factories

	Fix $\sigma(e^+e^-\to c\bar{c})$	Constrained S
$f(c\to D^{*+})$	0.2470 ± 0.0137	0.2525 ± 0.0155
$f(c\to D^{*0})$	0.2241 ± 0.0304	0.2291 ± 0.0316
$f(c\to D_s^{*+})$	0.0532 ± 0.0082	0.0544 ± 0.0085
$f(c\to D^+)$	0.2639 ± 0.0139	0.2698 ± 0.0125
$f(c\to D^0)$	0.5772 ± 0.0241	0.5901 ± 0.0140
$f(c\to D_s^+)$	0.0691 ± 0.0045	0.0707 ± 0.0048
$f(c\to \Lambda_c^+)$	0.0526 ± 0.0031	0.0611 ± 0.0060
χ^2	19.2	17.0
n_{dof}	21	20
S	0.9701 ± 0.0284	1.0000 ± 0.0005
$R_{u/d}$	0.9508 ± 0.0752	0.9508 ± 0.0752
P_V^d	0.5601 ± 0.0432	0.5601 ± 0.0431
γ_s	0.1644 ± 0.0121	0.1644 ± 0.0121
γ_s^*	0.2257 ± 0.0385	0.2257 ± 0.0385

e^+e^-, Z decays

	Fix $\frac{\Gamma_{c\bar{c}}}{\Gamma_{\text{hadrons}}}$	Constrained S
$f(c\to D^{*+})$	0.2369 ± 0.0064	0.2454 ± 0.0071
$f(c\to D_s^{*+})$	0.0545 ± 0.0144	0.0547 ± 0.0145
$f(c\to D^+)$	0.2267 ± 0.0100	0.2429 ± 0.0102
$f(c\to D^0)$	0.5470 ± 0.0215	0.5894 ± 0.0132
$f(c\to D_s^+)$	0.0925 ± 0.0082	0.0996 ± 0.0083
$f(c\to \Lambda_c^+)$	0.0555 ± 0.0065	0.0600 ± 0.0066
χ^2	6.7	7.8
n_{dof}	13	13
S	0.9292 ± 0.0261	1.0000 ± 0.0005
$R_{u/d}$	0.9987 ± 0.0627	1.0348 ± 0.0580
P_V^d	0.6119 ± 0.0185	0.6000 ± 0.0177
γ_s	0.2390 ± 0.0224	0.2394 ± 0.0223

$e^{\pm}p$, DIS

	Constrained S
$f(c\to D^{*+})$	0.2261 ± 0.0179
$f(c\to D^+)$	0.2115 ± 0.0201
$f(c\to D^0)$	0.5975 ± 0.0343
$f(c\to D_s^+)$	0.0903 ± 0.0125
$f(c\to \Lambda_c^+)$	0.0887 ± 0.0307
χ^2	1.0
n_{dof}	3
S	1.0000 ± 0.0007
$R_{u/d}$	1.2191 ± 0.1316
P_V^d	0.6201 ± 0.0438
γ_s	0.2233 ± 0.0325

$e^{\pm}p$, PHP

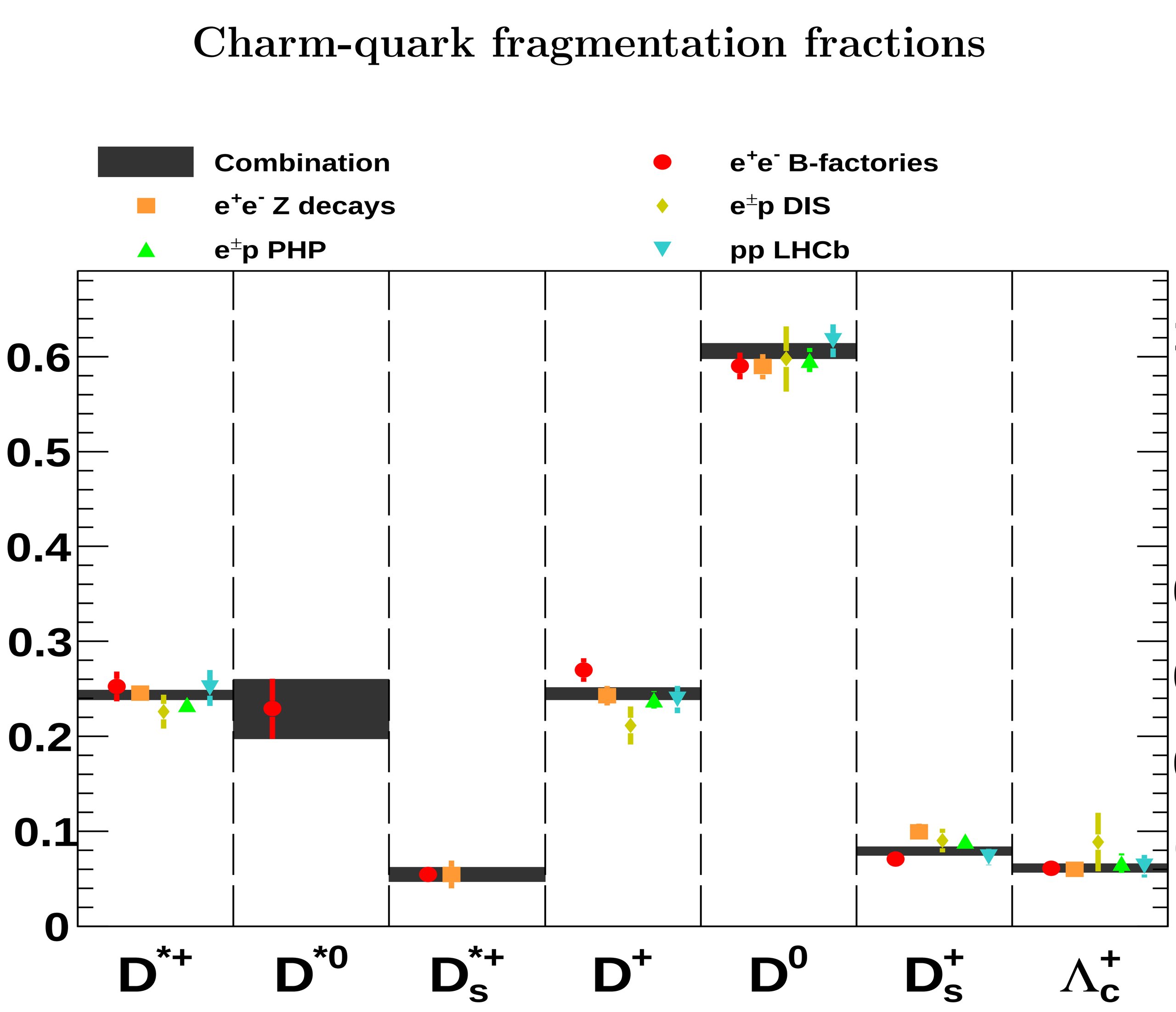
	Constrained S
$f(c\to D^{*+})$	0.2335 ± 0.0081
$f(c\to D^+)$	0.2384 ± 0.0092
$f(c\to D^0)$	0.5963 ± 0.0127
$f(c\to D_s^+)$	0.0898 ± 0.0066
$f(c\to \Lambda_c^+)$	0.0665 ± 0.0105
χ^2	5.2
n_{dof}	4
S	1.0000 ± 0.0005
$R_{u/d}$	1.1054 ± 0.0532
P_V^d	0.5890 ± 0.0175
γ_s	0.2152 ± 0.0172

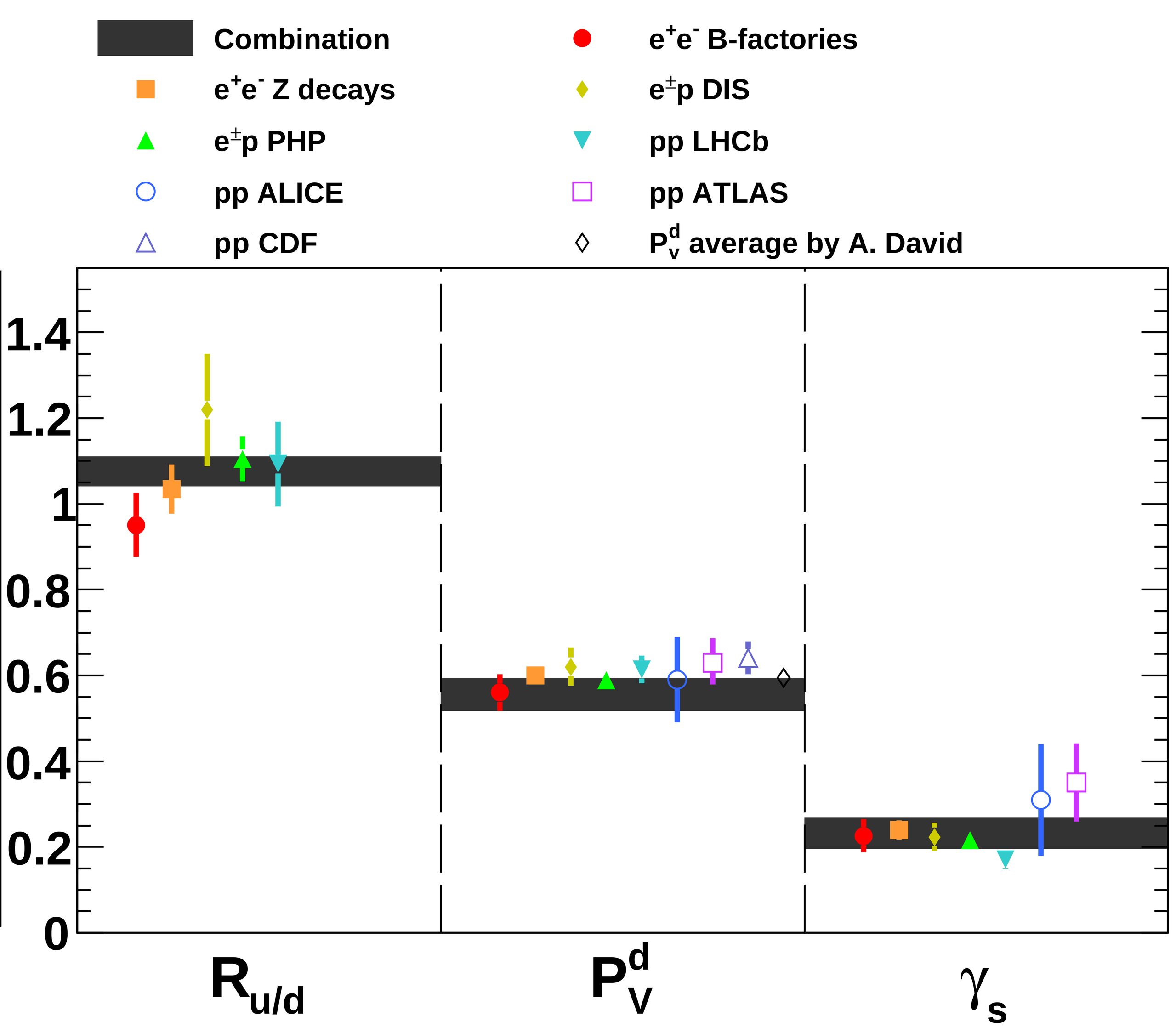
pp

	Constrained S
$f(c\to D^{*+})$	0.2510 ± 0.0190
$f(c\to D^+)$	0.2388 ± 0.0141
$f(c\to D^0)$	0.6166 ± 0.0171
$f(c\to D_s^+)$	0.0729 ± 0.0087
$f(c\to \Lambda_c^+)$	0.0631 ± 0.0119
χ^2	0.0
n_{dof}	0
S	1.0000 ± 0.0005
$R_{u/d}$	1.0928 ± 0.0984
P_V^d	0.6140 ± 0.0324
γ_s	0.1705 ± 0.0219

Results of global combination

	Constrained S	Constrained S, fix $\sigma(e^+e^-\to c\bar{c})$, $\frac{\Gamma_{c\bar{c}}}{\Gamma_{\text{hadrons}}}$.
$f(c\to D^{*+})$	0.2436 ± 0.0050	0.2411 ± 0.0048
$f(c\to D^{*0})$	0.2286 ± 0.0313	0.2270 ± 0.0304
$f(c\to D_s^{*+})$	0.0548 ± 0.0076	0.0549 ± 0.0076
$f(c\to D^+)$	0.2449 ± 0.0065	0.2451 ± 0.0064
$f(c\to D^0)$	0.6058 ± 0.0079	0.6130 ± 0.0075
$f(c\to D_s^+)$	0.0794 ± 0.0047	0.0803 ± 0.0048
$f(c\to \Lambda_c^+)$	0.0615 ± 0.0046	0.0542 ± 0.0030
χ^2	60.0	74.6
n_{dof}	57	60
S	1.0000 ± 0.0005	1.0000 ± 0.0004
$R_{u/d}$	1.0757 ± 0.0341	1.1017 ± 0.0335
P_V^d	0.5551 ± 0.0372	0.5455 ± 0.0357
γ_s	0.1866 ± 0.0120	0.1872 ± 0.0123
γ_s^*	0.2321 ± 0.0356	0.2344 ± 0.0361
$f(c\to D_1^+)$	$0.0460^{+0.0269}_{-0.0182}$	
$f(c\to D_2^{*+})$	$0.0320^{+0.0094}_{-0.0082}$	
$f(c\to D_1^0)$	0.0297 ± 0.0038	
$f(c\to D_2^{*0})$	0.0394 ± 0.0068	
$f(c\to D_{s1}^+)$	0.0109 ± 0.0014	
γ_{s1}	$0.287^{+0.079}_{-0.109}$	





The physical implications of reduced uncertainties can be illustrated with other fit results, e.g.:
$\sigma(pp\to c\bar{c})_{\sqrt{s}=7\text{TeV},\text{restricted}}=1366\pm103$ pb vs. LHCb: 1419 ± 134 pb
$\sigma(ep\to c)_{\text{DIS},\text{restricted}}=13.1\pm0.6$ pb vs. ZEUS (correlated systematics): $13.7^{+1.6}_{-1.0}$ pb
The application of the obtained values can significantly reduce uncertainties in future analyses and already published results.

Conclusions

- A summary of measurements of the charm quark fragmentation fractions and related quantities is given.
- The averages of the fragmentation fractions are presented and recommended for the tuning of Monte Carlo event generators.
- The results support the hypothesis of fragmentation universality.
- The hypothesis that the sum of fragmentation fractions of all known weakly decaying charm hadrons is equal to unity is holds within three standard deviations.

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See also

http://arxiv.org/abs/1509.01061