Heavy Flavour Hadro-Production Cross-Sections

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Abstract. Hadro-production data on charm and beauty absolute cross-sections, collected by experiments at CERN, DESY and Fermilab, are reviewed. The measurements, corrected for the ‘time evolution’ of the branching ratios, are compared to calculations done with Pythia, as a function of the collision energy, using the latest parametrizations of the parton densities. We then estimate some charm and beauty production cross-sections relevant for future measurements, including nuclear effects in the PDFs. We finish by briefly addressing the relevance, in heavy-ion collisions, of beauty production as feed-down for J/ψ production.

In the near future, several heavy-ion experiments (at the SPS, RHIC and LHC) will be sensitive to the production of open charm and open beauty production. It is, therefore, timely to review what is known today about production yields and estimate what can be expected for these future measurements.

The data used in this study were obtained with proton and pion beams at energies from $E_{\text{lab}} = 200$ to 920 GeV and from $\sqrt{s} = 0.63$ to 1.96 TeV, being summarized in Table 1. The reported beauty production values refer to a global *mixture* of beauty hadrons, mostly measured by looking at high p_T single muons, dimuons or even trimuons, except for CDF which gives B^+ cross-sections. While most experiments had full coverage in the positive x_F region, the E789 experiment covered a rather small window. All experiments using nuclear targets assumed a *linear* dependence of heavy flavour production on the mass number of the target nucleus, to derive the cross-section per nucleon. The different measurements on charm production cross sections were normalized to common branching ratios, using the PDG 2002 tables [1], to remove the ‘time evolution’ of these values. We have also updated the systematic errors of the published values, to reflect the smaller uncertainties of the most recent branching ratios. If the D mesons were searched in more than one decay channel, the performed corrections were weighted according to the number of observed events in each of the channels. While the data on D meson production collected with pion beams were published for the positive x_F range, data obtained with proton beams were mostly published for the full x_F range. To ease their comparison, all measurements were normalized to the positive x_F range. The very recent CDF charm measurement was done for $p_T > 5.5$ GeV/c.

After having collected the available charm and beauty cross-sections we can compare their $\sqrt{s}$ dependence with calculations performed with Pythia [26], a Monte-Carlo event generator used by many experiments. The calculations used version 6.208, with its default settings. In particular, the c and b quark masses are 1.5 and 4.8 GeV/c², respectively. The neutral and charged D meson production cross-sections in π^-p and pp collisions are compared in Fig. 1 with the Pythia curves obtained with different PDFs [27]. After normalizing the curves to the data (not including the CDF point), fitting

an empirical K-factor, none of the curves can be excluded.

While in pion induced collisions the D^+/D^- and $D^0/\overline{D}^0$ data require similar K-factors, of around 1.5, in p-A collisions the calculated charged D meson cross-sections are much lower than the measured values. Figure 2 (left) shows the charged to neutral D meson ratio measured in proton induced reactions. Their average is two times higher than the value given by Pythia, 0.32, and expected assuming equal production probabilities of the D and D^* states and using known D^* branching ratios. It is worth noting that the data collected with pion-induced collisions do not show such a strong discrepancy.

TABLE 1. Charm and beauty measurements used in this study.

	Exp. / Publication	Target(s)	$D^0 + \overline{D}^0$ events	$D^+ + D^-$ events	acc. window
p-A	NA16 [2] 1984	p	5	10	$x_F > -0.1$
	NA27 [3] 1988	p	98	119	$x_F > -0.1$
	E743 [4] 1988	p	10	46	$x_F > -0.1$
	E653 [5] 1991	emulsion	108	18	$x_F > -0.2$
	E789 [6] 1994	Be, Au	> 4000	—	$0.00 < x_F < 0.08$
	E769 [7] 1996	Be, Al, Cu, W	136	159	$x_F > -0.1$
$p\overline{p}$	CDF [8] 2002	$p\overline{p}$	36804	28361	$p_T > 5.5 \text{ GeV}/c$
π -A	NA16 [2] 1984	p	4	9	$x_F > -0.1$
	NA27 [9] 1986	p	49	14	$x_F > 0.0$
	NA32 [10] 1988	Si	75	39	$x_F > 0.0$
	NA32 [11] 1991	Cu	543	249	$x_F > 0.05$
	E653 [12] 1992	emulsion	328	351	$x_F > 0.0$
	E769 [7] 1996	Be, Al, Cu, W	62/353	73/414	$x_F > -0.1$
	WA92 [13] 1997	Cu, W	3873	3299	$x_F > 0.0$
	E791 [14] 1999	C, Pt	88990	—	$x_F > -0.1$
	E706 [15] 1997	Be, Cu	—	110	$x_F > -0.2$

	Exp. / Publication	Target(s)	$B\overline{B}$ events	acceptance window
π -A	NA10 [16] 1988	W	43	$x_F > 0$
	WA78 [17] 1989	U	12	$x_F > 0$
	E653 [18] 1993	emulsion	9 ± 3	$x_F > -0.3$
	E672/E706 [19] 1995	Be	8 ± 3.3	$x_F > 0$
	WA92 [20] 1998	Cu	26	$-0.5 < x_F < 0.6$
p-A	E789 [21] 1995	Au	19 ± 5	$0 < x_F^{J/\psi} < 0.1, p_T^{J/\psi} < 2 \text{ GeV}/c$
	E771 [22] 1999	Si	15	$x_F > -0.25$
	HERA-B [23] 2002	C, Ti	$10.5^{+13.1}_{-9.2}$	$-0.25 < x_F^{J/\psi} < 0.15$
$p\overline{p}$	UA1 [24] 1991	$p\overline{p}$	2859	$ y < 1.5, p_T^\mu > 6 \text{ GeV}/c$
	CDF [25] 2002	$p\overline{p}$	387 ± 32	$ y < 1.0, p_T^\mu > 6 \text{ GeV}/c$

Figure 3 shows the energy dependence of the total $c\overline{c}$ production cross-section, derived by adding the measured neutral and charged D meson values, and considering that the production of other charmed hadrons (Λ_c , D_s , etc) is 20 % of the total yield. Before being included in this figure, the CDF value was extrapolated down to zero p_T , using the distributions given by Pythia with the $\langle k_T^2 \rangle$ parameter varied between 1 and 2 $(\text{GeV}/c)^2$. An error of 40 % was added to account for the uncertainty in this extrapolation. Once Pythia is normalized to the available data we can estimate the charm production cross-sections

FIGURE 3. $c\bar{c}$ production cross-sections versus collision energy.

FIGURE 4. $b\bar{b}$ production cross-sections in pion (left) and proton (right) induced collisions.

Figure 4 shows the few available measurements of beauty production cross-sections in pion (left) and proton (right) induced collisions. Unfortunately, the data points are considerably spread around, with factors of 5 between measurements made at essentially the same energy (NA10 and WA78; E771 and E789). To minimize the number of standard deviations between the data points and the normalized curves, the pion induced collisions prefer K-factors below 1.4 while the proton data can accommodate values between 1 and 3. Therefore, rough estimates for the $b\bar{b}$ production cross-sections, per nucleon-nucleon collision, for the heavy-ion collider experiments are $\sim 2 \mu\text{b}$ at RHIC and $\sim 350 \text{ mb}$ at the LHC. These values include nuclear effects in the PDFs, assuming Pb colliding nuclei. Clearly, better data is needed in the beauty sector, including a measurement of the nuclear effects in proton-nucleus collisions.

At collider energies, beauty production is a very important source of J/ψ mesons. CDF observed that beauty decays represent more than 15 % of the total J/ψ yield [30], at $\sqrt{s} = 1.8$ TeV, and for J/ψ mesons of p_T above 5 GeV/c. Since beauty production is expected to scale linearly with the mass number of the colliding nuclei, while J/ψ production scales as $A^{0.92}$, due to the normal nuclear absorption, in Au-Au collisions the relative fraction of J/ψ mesons resulting from beauty decays should be 2.3 times higher. If direct J/ψ production is further suppressed in heavy-ion collisions (NA50 measured a factor 2 in central Pb-Pb collisions at the SPS), beauty production might account for more than 50 % of the observed J/ψ yield, maybe already at RHIC energies. This observation underlines the importance of upgrading the RHIC experiments with vertexing detectors, in view of a proper interpretation of the measured J/ψ suppression pattern.

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REFERENCES

1. K. Hagiwara *et al.* (PDG), Phys. Rev. **D66** (2002) 010001.
2. M. Aguilar-Benitez *et al.* (NA16 Coll.), Phys. Lett. **B135** (1984) 237.
3. M. Aguilar-Benitez *et al.* (NA27 Coll.), Z. Phys. **C40** (1988) 321.
4. R. Ammar *et al.* (E743 Coll.), Phys. Rev. Lett. **61** (1988) 2185.
5. K. Kodoma *et al.* (E653 Coll.), Phys. Lett. **B263** (1991) 573.
6. M.J. Leitch *et al.* (E789 Coll.), Phys. Rev. Lett. **72** (1994) 2542.
7. G.A. Alves *et al.* (E769 Coll.), Phys. Rev. Lett. **77** (1996) 2388.
8. D. Acosta *et al.* (CDF Coll.), hep-ex/0307080.
9. M. Aguilar-Benitez *et al.* (NA27 Coll.), Z. Phys. **C31** (1986) 491.
10. S. Barlag *et al.* (NA32 Coll.), Z. Phys. **C39** (1988) 451.
11. S. Barlag *et al.* (NA32 Coll.), Z. Phys. **C49** (1991) 555.
12. K. Kodoma *et al.* (E653 Coll.), Phys. Lett. **B284** (1992) 461.
13. M. Adamovich *et al.* (WA92 Coll.), Nucl. Phys. **B495** (1997) 3.
14. E.M. Aitala *et al.* (E791 Coll.), Phys. Lett. **B462** (1999) 225.
15. L. Apanasevich *et al.* (E706 Coll.), Phys. Rev. **D56** (1997) 1391.
16. P. Bordalo *et al.* (NA10 Coll.), Z. Phys. **C39** (1988) 7.
17. M.G. Catanesi *et al.* (WA78 Coll.), Phys. Lett. **B 231** (1989) 328.
18. K. Kodoma *et al.* (E653 Coll.), Phys. Lett. **B 303** (1993) 359.
19. R. Jesik *et al.* (E672 and E706 Coll.), Phys. Rev. Lett. **74** (1995) 495.
20. M. Adamovich *et al.* (WA92 Coll.) Nucl. Phys. **B519** (1998) 19.
21. D.M. Jansen *et al.* (E789 Coll.), Phys. Rev. Lett. **74** (1995) 3118.
22. T. Alexopoulos *et al.* (E771 Coll.), Phys. Rev. Lett. **82** (1999) 41.
23. I. Abt *et al.* (HERA-B Coll.), Eur. J. Phys. **C26** (2002) 345.
24. C. Albajar *et al.* (UA1 Coll.), Phys. Lett. **B256** (1991) 121.
25. D. Acosta *et al.* (CDF Coll.), Phys. Rev. **D65** (2002) 052005.
26. T. Sjöstrand *et al.*, Comp. Phys. Comm. **135** (2001) 238.
27. H. Plochow-Besch, Comp. Phys. Comm. **75** (1993) 396; J. Pumplin *et al.*, JHEP 0207 (2002) 012; A.D. Martin *et al.*, Phys. Lett. **B531** (2002) 216; Eur. Phys. J. **C23** (2002) 73.
28. NA60 Proposal, CERN/SPSC 2000-010; <http://cern.ch/na60>
29. K.J. Eskola *et al.*, Eur. Phys. J. **C9** (1999) 61.
30. F. Abe *et al.* (CDF Coll.), Phys. Rev. Lett. **79** (1997) 572.