EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CERN-EP/81-48
27 April 1981

CROSS-SECTION ESTIMATES FOR ASSOCIATED "BEAUTY" PRODUCTION IN (pp) INTERACTIONS AND COMPARISON WITH "CHARM"

M. Basile, G. Cara Romeo, L. Cifarelli, A. Contin,
G. D'Alì, P. Di Cesare, B. Esposito, P. Giusti, T. Massam,
F. Palmonari, G. Sartorelli, G. Valenti and A. Zichichi

CERN, Geneva, Switzerland
Istituto di Fisica dell'Università di Bologna, Italy
Istituto Nazionale di Fisica Nucleare, Bologna, Italy
Istituto Nazionale di Fisica Nucleare, Laboratori Nazionali di Frascati, Italy
Istituto di Fisica dell'Università, Perugia, Italy

SUMMARY

Estimates are given for the associated "beauty" production cross-section ($pp \to \Lambda_b^0 + M_{\bar{b}}$ + anything). Analogous estimates are given for the "charm" case ($pp \to \Lambda_c^+ + \bar{D}$ + anything). A comparison between the two cases is presented.

(Submitted to Nuovo Cimento)

1. INTRODUCTION

We have recently reported[1] the first proof of the associated production of the "beauty"-flavoured baryon, Λ_b^0, in the reaction

$$pp \to \underset{\displaystyle \hookrightarrow pD^0\pi^- \;(D^0 \to K^-\pi^+)}{\Lambda_b^0} + \underset{\displaystyle \hookrightarrow e^+ + \text{anything}}{\underbrace{\text{"antibeauty"-flavoured state}}} + \underset{\displaystyle \hookrightarrow \geq 4 \text{ charged particles}}{\text{anything}} \tag{1}$$

at $\sqrt{s}$ = 62 GeV (pp) c.m. energy.

The partial cross-section for the observation of the final state (1), as specified in the same paper[1], has also been given to be

$$\Delta\sigma_1 = (3.8 \pm 1.2) \times 10^{-35}\ \text{cm}^2 \ .$$

The purpose of the present paper is to elaborate on different possibilities for estimating the cross-section for the process

$$pp \to \Lambda_b^0 + M_{\bar{b}} + \text{anything} \ , \tag{2}$$

where $M_{\bar{b}}$ is the "antibeauty"-flavoured meson, produced in association with the Λ_b^0.

Moreover, the cross-section for reaction (2), σ_2, will be compared with analogous calculations on the estimate for the cross-section of the following process

$$pp \to \Lambda_c^+ + \bar{D} + \text{anything} \ , \tag{3}$$

which was in fact observed via the study of the reaction

$$pp \to \underset{\displaystyle \hookrightarrow pK^-\pi^+}{\Lambda_c^+} + \underset{\displaystyle \hookrightarrow e^- + \text{anything}}{\underbrace{\text{anticharm-flavoured state}}} + \text{anything} \ . \tag{4}$$

The experimental set-up used for the observation of reactions (1) and (4) was the same. We refer the reader to previously published papers[1,2] for details on the detectors used.

2. ESTIMATE OF THE Λ_b^0 PRODUCTION CROSS-SECTION

In order to proceed further, from our value of $\Delta\sigma_1$, it is necessary to know the source of the positive electron. In fact the e^+ is coming from the semileptonic decay of an "antibeauty"-flavoured state which can be either an antibaryon or an antimeson. However, the following points must be emphasized: i) an antibaryon needs three antiquarks, while an antimeson needs an (antiquark-quark) pair, to be made; ii) the experimental results on associated production of flavour-antiflavour states in (pp) interactions favour the baryon-antimeson with respect to the baryon-antibaryon-flavoured pairs. This is why, in order to estimate the associated production cross-section (2), we have chosen the antimeson as the associated state produced with the Λ_b^0.

In order to derive, from our measurement of $\Delta\sigma_1$, the production cross-section for the process (2), it is necessary to know the production and decay distributions for Λ_b^0 and $M_{\bar{b}}$, and the following branching ratios:

$$B_1(D^0 \to K^-\pi^+) = \frac{D^0 \to K^-\pi^+}{D^0 \to \text{all}}$$

$$B_2(M_{\bar{b}} \to e^+ + \text{anything}) = \frac{M_{\bar{b}} \to e^+ + \text{anything}}{M_{\bar{b}} \to \text{all}}$$

$$B_3(\Lambda_b^0 \to pD^0\pi^-) = \frac{\Lambda_b^0 \to pD^0\pi^-}{\Lambda_b^0 \to \text{all}} .$$

Two are measured, B_1 and B_2; B_3 is obviously unknown.

To distinguish, in the successive steps, the relevance of the different information needed from other sources outside our experiment, we will first assume that all the branching ratios (B_1, B_2, and B_3) are equal to one. In this case, to go from reaction (1) to reaction (2) it is necessary to know the production and decay distributions of the Λ_b^0 and the M_b.

For the "antibeauty"-flavoured meson $M_{\bar{b}}$, the production distributions were taken to be

$$\left(E\frac{d\sigma}{dx}\right)_{M_{\bar{b}}} \propto (1 - |x|)^3 \ ,$$

$$\left(\frac{d\sigma}{dp_T}\right)_{M_{\bar{b}}} \propto p_T \cdot \exp(-2.5\ p_T) \ ,$$

in analogy with our previous study of associated charm production[2].

For the decay process of $M_{\bar{b}} \to \bar{D}e^+\nu_e$, a $K_{\ell 3}$ matrix element has been used.

For the Λ_b^0, three models have been taken. However, the transverse momentum production distribution has been taken the same in all three models

$$\left(\frac{d\sigma}{dp_T}\right)_{\Lambda_b^0} \propto p_T \cdot \exp(-2.5\ p_T) \ ,$$

as suggested by the heavy-flavour (charm) baryon production Λ_c^+, measured under the same experimental conditions[3].

Model I: The "leading" baryon conditions

The x production distribution has been chosen according to the "leading" baryon effect, i.e.

$$\left(\frac{d\sigma}{dx}\right)_{\Lambda_b^0} = \text{const}$$

as observed in the Λ_c^+ production studies[2,4], and working out the apparatus acceptance under the same conditions, $x_F > 0.32$ and $|y_{pK^-\pi^+\pi^-}| > 1.4$, which allows us to see the Λ_b^0. The result will not be the "total" cross-section for reaction (2); rather, it will be the partial cross-section according to the experimental cuts used for the experimental observations. This procedure is justified for three reasons:

i) because it is important to evaluate a cross-section (even if only a partial one) without extrapolations, where it is not possible to see anything;

ii) because the same procedure will be adopted for the Λ_c^+ case; the ratio of the two cross-sections will be free from extrapolation uncertainties, and will allow a straightforward comparison between the Λ_b^0 and the Λ_c^+ production cross-section, using the same set-up and the same models for production and decay;

iii) because other models will be adopted, where extrapolations will be allowed.

For the Λ_b^0 decay process, Lorentz-invariant phase space, with the "leading" proton condition $x_F \geq 0.32$ in the laboratory system, has been assumed.

The result is

$$\sigma_2 \text{ (Model I)}_{\substack{\text{(assuming all}\\ \text{branching ratios = 1)}}} = (13.7 \pm 3.5) \times 10^{-33}\ \text{cm}^2 .$$

Model II: Minimum leading conditions

The x production distribution for the Λ_b^0 is taken to be

$$\left(\frac{d\sigma}{dx}\right)_{\Lambda_b^0} = \text{const}$$

without any further "leading" baryon conditions.

For the Λ_b^0 decay, we have again taken Lorentz-invariant phase space and less stringent "leading" proton conditions: $p_p > p_{D^0}$, $p_p > p_{\pi^-}$.

The result is

$$\sigma_2 \text{ (Model II)}_{\substack{\text{(assuming all}\\ \text{branching ratios = 1)}}} = (45.7 \pm 11.7) \times 10^{-33}\ \text{cm}^2 .$$

Model III: Isotropic, no "leading" proton conditions

Here the x production distribution for the Λ_b^0 has been taken as in Model II. The decay distribution has been taken according to phase space, i.e. isotropic. Therefore, in this model there is no "leading" proton condition.

The result is

$$\sigma_2 \text{ (Model III)}_{\substack{\text{(assuming all}\\ \text{branching ratios = 1)}}} = (137 \pm 35) \times 10^{-33}\ \text{cm}^2 .$$

So far, we have taken the branching ratios B_1, B_2, and B_3 all equal to one. As already mentioned, two of them are known, even if with large uncertainties

$$B_1(D^0 \to K^-\pi^+) = (3.0 \pm 0.6)\% \qquad \text{(Ref. 5)}$$

$$B_2(M_{\bar{b}} \to e^+ + \text{anything}) = (13 \pm 6)\% \qquad \text{(Ref. 6)} .$$

The use of these branching ratios allows the estimate of σ_2, under the hypothesis specified in the three models described above.

As $B_3(\Lambda_b^0 \to pD^0\pi^-)$ is unknown, the result will be σ_2 times this branching ratio, i.e.

$$\sigma_2 \cdot B_3(\Lambda_b^0 \to pD^0\pi^-) .$$

The three models provide the following values:

$$\left.\begin{aligned} \sigma_2 \cdot B_3(\Lambda_b^0 \to pD^0\pi^-)_{I} &= (3.5 \pm 2.0) \times 10^{-30}\ \text{cm}^2 \\ \sigma_2 \cdot B_3(\Lambda_b^0 \to pD^0\pi^-)_{II} &= (11.7 \pm 6.6) \times 10^{-30}\ \text{cm}^2 \\ \sigma_2 \cdot B_3(\Lambda_b^0 \to pD^0\pi^-)_{III} &= (35 \pm 20) \times 10^{-30}\ \text{cm}^2 \end{aligned}\right\} \text{(A)}$$

3. COMPARISON WITH THE Λ_c^+ PRODUCTION CROSS-SECTION

We have used the above models to compute the Λ_c^+ production cross-section, under conditions identical to those for the Λ_b^0. As mentioned above, for the Λ_c^+ the reaction studied was (4):

$$pp \to \Lambda_c^+ + \bar{D} + \text{anything}$$
$$\Lambda_c^+ \hookrightarrow pK^-\pi^+ \qquad \bar{D} \hookrightarrow e^- + \text{anything}$$

at the same (pp) c.m. energy and using the same set-up.

In order to calculate the cross-section for the "charm" reaction (3)

$$pp \to \Lambda_c^+ + \bar{D} + \text{anything} ,$$

the knowledge of two branching ratios is needed:

$$B_4 \frac{(\bar{D} \to e^- + \text{anything})}{(\bar{D} \to \text{all})} = (0.08 \pm 0.01) \qquad \text{(Ref. 7)}$$

$$B_5 \frac{(\Lambda_c^+ \to pK^-\pi^+)}{(\Lambda_c^+ \to \text{all})} = (0.022 \pm 0.01)\ . \qquad \text{(Ref. 8)}$$

The results are:

$$\left.\begin{aligned} \sigma_3\ (\text{Model I}) &= (106 \pm 64) \times 10^{-30}\ \text{cm}^2 \\ \sigma_3\ (\text{Model II}) &= (137 \pm 83) \times 10^{-30}\ \text{cm}^2 \\ \sigma_3\ (\text{Model III}) &= (263 \pm 159) \times 10^{-30}\ \text{cm}^2 \end{aligned}\right\} \text{(B)}$$

We are now in a position to compare the results (A) and (B). The interest in this point is the flavour dependence of the (pp) production processes. Some theoretical estimates[9,10] on quasi-diffractive production predict a ratio between heavy flavour cross-sections of the order of the ratio of the produced flavour masses squared, i.e. ∿ 1/8. The direct comparison of (A) and (B) has, as the unique unknown, the branching ratio $B_3(\Lambda_b^0 \to pD^0\pi^-)$. If we take as the guiding value

$$\frac{\sigma(pp \to \Lambda_b^0 + M_{\bar{b}} + \text{anything})}{\sigma(pp \to \Lambda_c^+ + \bar{D} + \text{anything})} = 10^{-1}\ , \qquad (4)$$

the three models will give different predictions on $B_3(\Lambda_b^0 \to pD^0\pi^-)$. This is illustrated in Table 1, where we have reported the values of $B_3(\Lambda_b^0 \to pD^0\pi^-)$ obtained from the above condition (4). Table 1 shows that Model I is compatible with the ratio (4), for the Λ_b^0 and the Λ_c^+ production cross-section; for $B_3(\Lambda_b^0 \to pD^0\pi^-)$ it predicts a value which can be as low as a few percent. Models II and III, affected like Model I by the uncertainties in all the required branching ratios, can accommodate any value of $B_3(\Lambda_b^0 \to pD^0\pi^-)$ and larger cross-section ratios than (4). The most reliable comparison is, as expected, the one based on the first model.

4. CONCLUSIONS

Assuming some production and decay properties, and taking into account the various branching ratios, the "beauty" cross-section estimates, for the associated $(\Lambda_b^0 M_{\bar{b}})$ production, are given. These estimates are also compared with the "charm" production cross-section $(\Lambda_c^+ \bar{D})$. It is found that the "beauty" production cross-section is compatible with being below that for $(\Lambda_c^+ \bar{D})$ production by the ratio of the produced flavour masses squared.

REFERENCES

1) M. Basile, G. Bonvicini, G. Cara Romeo, L. Cifarelli, A. Contin, G. D'Ali, P. Di Cesare, B. Esposito, P. Giusti, T. Massam, R. Nania, F. Palmonari, G. Sartorelli, G. Valenti and A. Zichichi, preprint CERN-EP/81-38, submitted to Nuovo Cimento Letters, April 1981.

2) M. Basile, G. Cara Romeo, L. Cifarelli, A. Contin, G. D'Ali, P. Di Cesare, B. Esposito, P. Giusti, T. Massam, F. Palmonari, G. Sartorelli, G. Valenti and A. Zichichi, preprint CERN-EP/80-214 (1980), submitted to Nuovo Cimento Letters.

3) M. Basile, G. Cara Romeo, L. Cifarelli, A. Contin, G. D'Ali, P. Di Cesare, B. Esposito, P. Giusti, T. Massam, F. Palmonari, G. Sartorelli, G. Valenti and A. Zichichi, preprint CERN-EP/81-23 (1981), submitted to Nuovo Cimento Letters.

4) M. Basile, G. Cara Romeo, L. Cifarelli, A. Contin, G. D'Ali, P. Di Cesare, B. Esposito, P. Giusti, T. Massam, F. Palmonari, G. Sartorelli, G. Valenti and A. Zichichi, preprint CERN-EP/81-22 (1981), submitted to Nuovo Cimento Letters.

5) R.H. Schindler, M.S. Alam, A.M. Boyarski, M. Breidenbach, D.L. Burke, J. Dorenbosch, J.M. Dorfan, G.J. Feldman, M.E.B. Franklin, G. Hanson, K.G. Hayes, T. Himel, D.G. Hitlin, R.J. Hollebeek, W.R. Innes, J.A. Jaros, P. Jenni, R.R. Larsen, V. Lüth, M.L. Perl, B. Richter, A. Roussarie, D.L. Scharre, R.F. Schwitters, J.L. Siegrist, H. Taureg, M. Tonutti, R.A. Vidal, J.M. Weiss, H. Zaccone, G. Abrams, C.A. Blocker, A. Blondel, W.C. Carithers, W. Chinowsky, M.W. Coles, S. Cooper, W.E. Dieterle, J.B. Dillon, M.W. Eaton, G. Gidal, G. Goldhaber, A.D. Johnson, J.A. Kadyk, A.J. Lankford, R.E. Millikan, M.E. Nelson, C.Y. Pang, J.F. Patrick, J. Strait, G.H. Trilling, E.N. Vella and I. Videau, SLAC-PUB-2507; LBL-10905, May 1980 (T/E), submitted to Phys. Rev. D.

6) C. Bebek, J. Haggerty, J.M. Izen, W.A. Loomis, F.M. Pipkin, J. Rohlf, W. Tanenbaum, Richard Wilson, A.J. Sadoff, D.L. Bridges, K. Chadwick, P. Ganci, H. Kagan, R. Kass, F. Lobkowicz, A. Melissinos, S.L. Olsen, P. Poling, C. Rosenfeld, C. Rucinski, E.H. Thorndike, G. Warren, D. Bechis, J.J. Mueller, D. Potter, F. Sannes, P. Skubic, R. Stone, A. Brody, A. Chen, M. Goldberg, N. Horwitz, J. Kandaswamy, H. Kooy, P. Lariccia, G.C. Moneti, M.S. Alam, S.E. Csorna, R.S. Panvini, J.S. Poucher, D. Andrews, K. Berkelman, R. Cabenda, D.G. Cassel, J.W. DeWire, R. Ehrlich, T. Ferguson, T. Gentile, M.G.D. Gilchriese, B. Gittelman, D.L. Hartill, D. Herrup, M. Herzlinger, D.L. Kreinick, N.B. Mistry, E. Nordberg, R. Perchonok, R. Plunkett, K.A. Shinsky, R.H. Siemann, A. Silverman, P.C. Stein, S. Stone, R. Talman, H.G. Thonemann and D. Weber, preprint CLNS-80/4/5 (1980).

7) G. Goldhaber and J.E. Wiss, preprint LBL/10652, March 1980.

8) G.S. Abrams, M.S. Alam, C.A. Blocker, A.M. Boyarski, M. Breidenbach, D.L. Burke, W.C. Carithers, W. Chinowski, M.W. Coles, S. Cooper, W.E. Dieterle, J.B. Dillon, J. Dorenbosch, J.M. Dorfan, M.W. Eaton, G.J. Feldman, M.E.B. Franklin, G. Gidal, G. Goldhaber, G. Hanson, K.G. Hayes, T. Himel, D.G. Hitlin, R.J. Hollebeek, W.R. Innes, J.A. Jaros, P. Jenni, A.D. Johnson, J.A. Kadyk, A.J. Lankford, R.R. Larsen, M.J. Longo, V. Lüth, R.E. Millikan, M.E. Nelson, C.Y. Pang, J.F. Patrick, M.L. Perl, B. Richter, A. Roussarie, J.J. Russell, D.L. Scharre, R.H. Schindler, R.F. Schwitters, J.L. Siegrist, J. Strait, H. Taureg, M. Tonutti, G.H. Trilling, E.N. Vella, R.A. Vidal, I. Videau, J.M. Weiss and H. Zaccone, Phys. Rev. Lett. 44, 10 (1980).

9) G. Gustafson and C. Peterson, Phys. Rev. Lett. B67, 81 (1977).

10) A. Martin, preprint CERN Th. 2980 (1980), and private communication.

Table 1

Branching ratio $B_3\left[(\Lambda_b^0 \rightarrow pD^0\pi^-)/(\Lambda_b^0 \rightarrow \text{all})\right]$ for different values of the ratio: $\sigma_b/\sigma_c =$ $= (pp \rightarrow \Lambda_b^0 + M_{\bar{b}} + \text{anything})/(pp \rightarrow \Lambda_c^+ + \bar{D} + \text{anything})$ and for the different models, as specified in the text.

	σ_b/σ_c		
	0.1	0.2	0.3
Model I	0.33 ± 0.27	0.17 ± 0.14	0.11 ± 0.09
Model II	0.85 ± 0.71	0.43 ± 0.35	0.28 ± 0.24
Model III	1.34 ± 1.11	0.67 ± 0.55	0.45 ± 0.37