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Abstract

We present some reasons for studying beauty baryons (N_b) produced in pN interactions. We also investigate the possibilities of using a suggested HERA experiment with an internal target in order to observe the beauty baryons. Their triggering process allows the study of N_b decays having a J/Ψ in the final state. The estimates of the N_b production rates and branching ratios give the possibility of analyzing $\Lambda_b \to \Lambda J/\Psi$ and $\Xi_b \to \Xi J/\Psi$ channels as well as their charged conjugated processes. The measurements of the decay parameter and the polarization of N_b have been considered. It was also suggested to measure the $\Lambda_b \to l^- \nu p$ $(b \to u)$ and $\Lambda_b \to l^- \nu \Lambda_c^+$ $(b \to c)$ channels in order to have a new estimate of the ratio of the CKM matrix elements $|V_{ub}/V_{cb}|$.

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1 - Introduction

During the recent years, great efforts have been made to evaluate the possibilities of studying the decay of B mesons produced in pN interactions. In particular, the LHC and SSC projects (fixed-target or collider experiments) have been widely considered[1] for the B-physics. A letter of intent concerning the search for CP violation in the B system with pN interactions at HERA has also been presented[2]. Usually, the search for CP violation in B decay is considered as one of the most important aspects of B-physics. Recently, however, some reasons for studying the production and decay of the beauty baryon produced in pN interactions[3,4] have been discussed. Decay and production rates of the beauty baryon have been roughly estimated for the LHC and SSC projects[3]. In the following, we will attempt to evaluate the possibilities of studying beauty baryons with the experiment proposed at HERA using an internal target at the HERA proton ring. We assume here that the incident proton beam has a momentum of 900 GeV/c, corresponding to a c.m. energy of $\sqrt{s} \simeq 41$ GeV.

In Table 1, we present various beauty baryons that could be produced in pN interactions. Excited baryon states are not presented in this table. The masses of the various cases are those used in the PYTHIA Monte Carlo program[5]. For the present discussion we use the following notation. The baryon with isospin $I = 1$ will be denoted by Σ whereas Ξ will be taken for baryons having $I = 1/2$. For $I = 0$, we use Λ unless each quark forming a baryon has $I = 0$. In this case the notation will be Ω. The subscripts of Σ, Ξ, Λ, and Ω indicate the number and the type of the heavy quarks ($Q \equiv b, c$) contained in the considered baryon (the light quarks will be denoted by $q \equiv u, d, s$). In the present discussion we consider only baryons having one heavy quark ($N_b \equiv bq_1q_2$ or $N_c \equiv cq_1q_2$).

The N_b and $\overline{N}_b$ production cross-section [$\sigma(N_b)$ and $\sigma(\overline{N}_b)$, respectively] are estimated from the ratios $R(N_b) = \sigma(N_b)/\sigma(b\bar{b})$ and $R(\overline{N}_b) = \sigma(\overline{N}_b)/\sigma(b\bar{b})$ calculated with the PYTHIA Monte Carlo program at the c.m. energies corresponding to HERA and to the LHC and SSC projects (Table 2). Here $\sigma(b\bar{b})$ is the $pN \to b\bar{b}X$ cross-section (X meaning anything) at the considered c.m. energy. We see from this table that the calculated R values do not depend strongly on $\sqrt{s}$. As discussed previously[6,7], the N_b and $\overline{N}_b$ do not appear to be produced in equal amounts in pN interactions. This difference, mainly due to the the valence quarks of the incoming nucleons, is expected to decrease with increasing $\sqrt{s}$. Nevertheless, the important difference expected at $\sqrt{s} \sim 41$ GeV will not complicate the study of the production and decay of the beauty baryons, in contrast to the search for CP violation in the $B^0_{s,d}$ decay.

Table 1 - Various beauty baryons using the notation explained above. The charge and the quarks forming the baryons are also given. The mass values are those used in the PYTHIA Monte Carlo program.

	Quarks	Charge	Mass (GeV)
Λ_b	bud	0	5.62
Σ_b	buu	+1	5.80
	bdu	0	"
	bdd	−1	"
Ξ_b	bsu	0	5.84
	bsd	−1	"
Ξ_{bc}	bcu	+1	7.01
	bcd	0	"
Ξ_{2b}	bbu	0	10.42
	bbd	−1	"
Ω_b	bss	−1	6.12
Ω_{bc}	bcs	0	7.19
Ω_{b2c}	bcc	+1	8.31
Ω_{2b}	bbs	−1	10.60
Ω_{2bc}	bbc	0	11.71
Ω_{3b}	bbb	−1	15.11

In Section 2 we present some physics interests for studying the production and decay of beauty baryons. The subjects that we will discuss are:

- search for CP violation in the N_b, $\overline{N}_b$ decays;
- beauty-baryon (N_b and $\overline{N}_b$) polarization;
- decays allowing the measurement of CKM matrix elements.

Section 3 is devoted to the estimates of the number of events that can be obtained for specific N_b and $\overline{N}_b$ decay channels in the case of 5 years of running. We also discuss the importance of measuring some quantities related to the production and the decay of the beauty baryons that could be measured with the HERA experiment. Some conclusions are presented in Section 4.

Table 2 - The $R(N_b) = \sigma(N_b)/\sigma(b\bar{b})$ and $R(\overline{N}_b) = \sigma(\overline{N}_b)/\sigma(b\bar{b})$ ratios at various $(\sqrt{s})$ c.m. energies as obtained from PYTHIA. The first (second) line corresponds to the $R(N_b)$ $[R(\overline{N}_b)]$ rate.

$\sqrt{s}$ (TeV)	$R(\Lambda_b)$ / $R(\overline{\Lambda}_b)$	$R(\Sigma_b)$ / $R(\overline{\Sigma}_b)$	$R(\Xi_b)$ / $R(\overline{\Xi}_b)$	$R(\Omega_b)$ / $R(\overline{\Omega}_b)$
0.04	$(2.8 \pm 0.1)\ 10^{-2}$	$(3.1 \pm 0.3)\ 10^{-3}$	$(2.9 \pm 0.3)\ 10^{-3}$	$\sim 2\ 10^{-5}$
	$(1.8 \pm 0.1)\ 10^{-2}$	$(1.8 \pm 0.2)\ 10^{-3}$	$(1.9 \pm 0.2)\ 10^{-3}$	-
0.12	$(6.1 \pm 0.1)\ 10^{-2}$	$(9.2 \pm 0.4)\ 10^{-3}$	$(8.8 \pm 0.4)\ 10^{-3}$	$\sim 6\ 10^{-5}$
	$(4.4 \pm 0.1)\ 10^{-2}$	$(6.4 \pm 0.1)\ 10^{-3}$	$(5.6 \pm 0.1)\ 10^{-3}$	$\sim 10^{-4}$
16	$(8.4 \pm 0.3)\ 10^{-2}$	$(1.5 \pm 0.1)\ 10^{-2}$	$(1.1 \pm 0.1)\ 10^{-2}$	$\sim 2\ 10^{-4}$
	$(8.2 \pm 0.3)\ 10^{-2}$	$(1.4 \pm 0.1)\ 10^{-2}$	$(1.0 \pm 0.1)\ 10^{-2}$	$\sim 10^{-4}$
40	$(8.6 \pm 0.2)\ 10^{-2}$	$(1.4 \pm 0.1)\ 10^{-2}$	$(1.3 \pm 0.1)\ 10^{-2}$	$\sim 2\ 10^{-4}$
	$(8.4 \pm 0.2)\ 10^{-2}$	$(1.4 \pm 0.1)\ 10^{-2}$	$(1.2 \pm 0.1)\ 10^{-2}$	$\sim 10^{-4}$

2 - Physics interest

2.1 - Search for CP violation in the N_b and $\overline{N}_b$ decays

Similarly to the search for CP violation in the $B^{\pm}$ decay, the study of beauty-baryon decays does not need tagging processes of the associated beauty hadron produced in the same event. As in the case of the $B^{\pm}$, the measurement of an asymmetry parameter will, in principle, depend on the final-state interactions (FSI). In the following we will first discuss the beauty baryons of spin 1/2 decaying into two hadrons having spin 1/2 and 0 $(1/2 \to 1/2 + 0)$, a situation similar to $\Lambda \to p\pi$ and $\Xi \to \Lambda\pi$. Afterward, we will consider the $N_b \to Y'J/\Psi$ (Y' denoting here a hyperon or an N_c baryon) where the spin configuration is $1/2 \to 1/2 + 1$.

a) The $1/2 \to 1/2 + 0$ decay

The weak decays will be described here by S and P waves (corresponding to relative orbital momenta of $l = 0, 1$, respectively). The partial width Γ and the decay parameters[8], α, β, and γ of N_b $(\alpha^2 + \beta^2 + \gamma^2 = 1)$ as well as those related to $\overline{N}_b$ (having a bar sign on the parameters) can be used to search for CP violation by testing the non-zero values of the following ratios[8,9]

$$\Delta = \frac{\Gamma - \overline{\Gamma}}{\Gamma + \overline{\Gamma}}, \tag{1}$$

$$A = \frac{\Gamma\alpha + \overline{\Gamma}\overline{\alpha}}{\Gamma\alpha - \overline{\Gamma}\overline{\alpha}} \simeq \frac{\alpha + \overline{\alpha}}{\alpha - \overline{\alpha}}, \tag{2}$$

$$B = \frac{\Gamma\beta + \overline{\Gamma}\overline{\beta}}{\Gamma\beta - \overline{\Gamma}\overline{\beta}} \simeq \frac{\beta + \overline{\beta}}{\beta - \overline{\beta}} \, . \tag{3}$$

Note that for a given CP violation effect we expect[9] that $|B| \gg |A| \gg |\Delta|$, indicating that the measurements of β and $\overline{\beta}$ might be useful. In fact, even with CP violation, $\Delta \neq 0$ can only occur when more than one isospin transition (between the initial and final state) will lead to final states with a non-unique isospin value.

The non-zero values of the β or $\overline{\beta}$ parameters are related to the violation of the time reversal (T) applied to the considered decay process, and hence to the CP violation (CPT rule). However, final-state interactions can also lead to $\beta, \overline{\beta} \neq 0$ (Ref. 9). Table 3 indicates the relation between β and $\overline{\beta}$ which could indicate the violation of time reversal[3,9]. The table also give the relations between the other decay parameters.

In the example of $pN \to \Lambda_b X$, where $\Lambda_b \to \Lambda m$ (m being a meson of spin 0) and $\Lambda \to p\pi^-$, the measurement of the $\alpha \equiv \alpha(\Lambda_b)$ and $\beta \equiv \beta(\Lambda_b)$ parameters [$\overline{\alpha} \equiv \overline{\alpha}(\overline{\Lambda}_b)$ and $\overline{\beta} \equiv \overline{\beta}(\overline{\Lambda}_b)$] can be made in the following way. The angular distributions of the p in the Λ rest frame with respect to the coordinate system shown in Fig. 1 (Ref. 3) are:

$$I(\theta_3) \propto 1 + \alpha(\Lambda_b)\alpha(\Lambda)\cos\theta_3 \, , \tag{4}$$

$$I(\theta_2) \propto 1 - \frac{\pi}{4} P(\Lambda_b)\beta(\Lambda_b)\alpha(\Lambda)\cos\theta_2 \, , \tag{5}$$

$$I(\theta_1) \propto 1 - \frac{\pi}{4} P(\Lambda_b)\gamma(\Lambda_b)\alpha(\Lambda)\cos\theta_1 \, , \tag{6}$$

where $\alpha(\Lambda) = 0.64$ is here the $\Lambda \to p\pi^-$ decay parameter. Once $\alpha(\Lambda_b)$ is determined from the $I(\theta_3)$ measurement, the Λ angular distribution can be used in the pN rest frame with respect to the Λ_b polarization [$\vec{P}(\Lambda_b)$, modulus $P(\Lambda_b)$] definined in the Λ_b rest frame (see Fig. 1),

$$I(\Theta) \propto 1 + \alpha(\Lambda_b)P(\Lambda_b)\cos\Theta \, , \tag{7}$$

in order to obtain the $P(\Lambda_b)$ value. If $P(\Lambda_b) \neq 0$, we could (in principle) determine $\beta(\Lambda_b)$ and $\gamma(\Lambda_b)$ by measuring the $I(\theta_2)$ and $I(\theta_1)$ distributions. By applying the same method for the $\overline{N}_b$ decay we would be able to obtain the A and B parameters [of course, the latter ones only if $P(\Lambda_b), P(\overline{\Lambda}_b) \neq 0$].

Table 3 - The Γ, α and β relations between the N_b and $\overline{N}_b$ decays for CP conservation or violation. In each case final-state interactions (FSI) were assumed or neglected.

CP conservation		CP violation	
FSI	No FSI	FSI	No FSI
$\Gamma = \overline{\Gamma}$	$\Gamma = \overline{\Gamma}$	$\Gamma \neq \overline{\Gamma}^*$	$\Gamma = \overline{\Gamma}$
$\alpha = -\overline{\alpha}$	$\alpha = -\overline{\alpha}$	$\alpha \neq -\overline{\alpha}$	$\alpha = -\overline{\alpha}$
$\beta = -\overline{\beta}$	$\beta, \overline{\beta} = 0$	$\beta \neq -\overline{\beta}$	$\beta = \overline{\beta}$

* With only one isospin transition, $\Gamma = \overline{\Gamma}$ (see text).

Remark

Models have been used to describe the $\Lambda_b \to \Lambda_c^+ m$ and $\Lambda_c^+ \to \Lambda\pi^+$ decays[10–13]. By using only spectator diagrams (factorizable contribution), it is found that $\alpha(\Lambda_b)$, $\alpha(\Lambda_c) \simeq \pm 1$ [and $\overline{\alpha}(\overline{\Lambda}_b), \overline{\alpha}(\overline{\Lambda}_c) \simeq \mp 1$]. No time reversal violation could then be measured with β as $\beta(\Lambda_b), \beta(\Lambda_c) \simeq 0$. In the case of $\Lambda_c^+ \to \Lambda\pi^+$, the $\alpha(\Lambda_c)$ parameter has been measured yielding -0.96 ± 0.42 (Ref. 14) and $-1^{+0.4}_{-0.0} \pm 0.1$ (Ref. 15), in agreement with the theoretical predictions. Nevertheless, the situation might be changed by non-factorizing contributions (e.g. non-spectator diagrams) for the Λ_b decay that could lead to $|\alpha(\Lambda_b)|, |\alpha(\overline{\Lambda}_b)| < 1$. In any case, the decay parameters have to be measured for various N_b and $\overline{N}_b$ decay channels.

b) The $1/2 \to 1/2 + 1$ decay

For the HERA experiment, it is necessary to consider N_b (or $\overline{N}_b$) decays having a J/Ψ in the final state decaying into l^+l^-, ($l \equiv \mu, e$). This is because these J/Ψ decays are entering into the trigger process developed to detect primarily the $B_d^0, \overline{B}_d^0 \to J/\Psi K_s^0$ channel. Some of the $N_b \to Y J/\Psi$ channels are given in Table 4 where Y denotes here the Λ or the Ξ hyperon. These cases will be somewhat more complicated as there is here a spin 1/2 particle decaying into two particles having spin 1/2 and 1 ($1/2 \to 1/2 + 1$). Note that also here, the contribution of only one isospin transition between the initial and final state leads to the equality of the partial widths of the considered N_b and $\overline{N}_b$ decays ($\Gamma = \overline{\Gamma}$) yielding $\Delta = 0$. The decay channels given in Table 4 will then all have $\Delta = 0$. Let us, therefore, consider another possibility to search for CP violation in these decay channels.

The angular distribution of the hyperon with respect to the polarization direction of the N_b in its rest frame (angle Θ) has a form similar to formula (7), namely

$$I(\Theta) \propto 1 \pm \alpha'(N_b)\ P(N_b)\ \cos\ \Theta\ . \quad (8)$$

The α' parameter depends on the various orbital momenta between J/Ψ and Y and can be expressed by

$$|\alpha'(N_b)| = \frac{|2\ \mathrm{Re}\ (S^*_{1/2}\ P_{1/2} + D^*_{3/2} P_{3/2})|}{|S_{1/2}|^2 + |P_{1/2}|^2 + |P_{3/2}|^2 + |D_{3/2}|^2}\ . \quad (9)$$

The indices indicate the sum of the spins of the J/Ψ and the hyperon, namely 3/2 or 1/2. For the present case ($1/2 \to 1/2 + 1$), the angular distribution of one of the Y daughter particles in the Y rest frame is also linear in $\cos\theta_3$ (Ref. 11),

$$I(\theta_3) \propto 1 \pm \alpha''(N_b)\alpha(Y)\cos\theta_3\ . \quad (10)$$

Here, however, the coefficient α'' is different from that appearing in formula (8) (in contrast to the $1/2 \to 1/2 + 0$ case). Therefore $\alpha'(N_b)$ can only be measured with distribution (8) if the polarization $P(N_b)$ is known. The comparison of α' with $\overline{\alpha}'$ or α'' with $\overline{\alpha}''$ through the parameters

$$A' = \frac{\alpha' + \overline{\alpha}'}{\alpha' - \overline{\alpha}'} \quad \text{or} \quad A'' = \frac{\alpha'' + \overline{\alpha}''}{\alpha'' - \overline{\alpha}''}$$

could be used to search for CP violation.

Note that there are several models[12] predicting the $\alpha'(\Lambda_b)$ value for the $\Lambda_b \to \Lambda J/\Psi$ decay. With the free quark decay $b \to c\bar{c}s$, constraining the $c\bar{c}$ effective mass to be near the J/Ψ mass, the estimate is $\alpha'(\Lambda_b) \sim 0.43$. By using an exclusive model[12], the estimate becomes $\alpha'(\Lambda_b) \simeq 0.19 - 0.26$.

2.2 - Beauty-baryon polarization

There are several interests for measuring the production of beauty baryons in pN interactions. The comparison between N_b ($\overline{N}_b$) and hyperon (antihyperon) production at a similar c.m. energy could certainly improve the understanding of the production mechanism. Another aspect related to the production process would consist in observing the polarization of the beauty baryon produced.

Let us remember that in the $pN \to N_b(\overline{N}_b)X$ interactions, the polarization of N_b (or $\overline{N}_b$) in its rest frame can only be along $\hat{n}$, the normal to the production plane (see Fig. 1). This plane is defined here by the momenta of the incident proton ($\vec{p}_{inc}$) and the N_b or $\overline{N}_b$ ($\vec{p}_{out}$) produced in the laboratory (or in the c.m.) system i.e. $\hat{n} = \vec{p}_{inc} \times \vec{p}_{out}/|\vec{p}_{inc} \times \vec{p}_{out}|$. The polarization of the hyperons Λ, Σ, Ξ has been measured in several p-target experiments[16–18] with p incident momentum around $400 - 800$ GeV/c. The polarization of Λ [$P(\Lambda)$] has been observed in the $pN \to \Lambda X$ production, in contrast to $P(\overline{\Lambda}) = 0$ measured in the same type of interaction[17]. For the Ξ^- and $\overline{\Xi}^+$ the situation is different as both have nearly the same polarization[16,18] in the pN production with an incident momentum around 800 GeV/c. The polarization measurement of beauty baryons will certainly be useful for a better understanding of the production mechanism.

2.3 - Decays allowing the measurement of the CKM matrix elements

The QCD effects are expected to be smaller in beauty baryons than in B mesons[4] as the binding of light quarks is smaller in the first case. This difference may facilitate the measurement of CKM matrix elements (V_{ij}) in the N_b decays.

In Ref. 4 a list was presented of some beauty baryon decays corresponding to the $b \to c$ and $b \to u$ processes and which could be measured easily. As these processes lead to different final states for a given N_b decay, different QCD effects are expected. Nevertheless, the measurements of the following ratios

$$\frac{BR(\Omega_b^- \to \pi^-\Xi^0)}{BR(\Omega_b^- \to \pi^-\Omega_c^0)} \simeq \frac{|V_{ub}|^2}{|V_{cb}|^2}\frac{\phi(u)}{\phi(c)}$$
$$\frac{BR(\Xi_b^0 \to \pi^-\Sigma^+)}{BR(\Xi_b^0 \to \pi^-\Sigma_c^+)} \simeq \frac{|V_{ub}|^2}{|V_{cb}|^2}\frac{\phi(u)}{\phi(c)}$$
$$\frac{BR(\Xi_b^0 \to \pi^-\Lambda)}{BR(\Xi_b^0 \to \pi^-\Xi_c^0)} \simeq \frac{|V_{ub}|^2}{|V_{cb}|^2}\frac{\phi(u)}{\phi(c)}$$
$$\frac{BR(\Lambda_b \to \pi^- p)}{BR(\Lambda_b \to \pi^-\Lambda_c)} \simeq \frac{|V_{ub}|^2}{|V_{cb}|^2}\frac{\phi(u)}{\phi(c)}$$

would allow the comparison of QCD effects in the various decay channels and to estimate the $|V_{ub}/V_{cb}|$ ratio. Here $\phi(u)$ [$\phi(c)$] is the phase-space factor corresponding to the $b \to u$ ($b \to c$) transition for a specific final state.

For this purpose, events having two identical leptons ($\mu^+\mu^-$ or e^+e^-) in the final state could be considered in order to benefit from the trigger process. Therefore, we considered the N_b semileptonic decays shown in Table 5. This lepton as well as the one coming from the semileptonic decay of the associated beauty hadron produced in the same event could be utilized for the trigger (see Section 3). Note that by using semileptonic decay, the QCD effect occuring in the N_b decay will be further reduced with respect to the examples given above. .

3 - Production and efficiencies

The HERA project proposes to use an internal Copper target[2]. With the actual HERA beam intensity, and the estimates of the $pN \to b\bar{b}$ cross-section[2] [$\sigma(b\bar{b}) \sim 15$ nb at $\sqrt{s} \simeq 41$ GeV], we obtain that $\sim 4 \times 10^8$ $pN \to b\bar{b}X$ events will be produced in one year (10^7 s) of running. The production rates of the beauty baryons are then obtained by using the $\sigma(N_b)/\sigma(b\bar{b})$ and $\sigma(\overline{N}_b)/\sigma(b\bar{b})$ ratios given in Table 2.

Apart from the semileptonic decays, we consider N_b and $\overline{N}_b$ decay having the J/Ψ and only charged particles in the final state. This is because the charged particles could be detected by the proposed spectrometer with a good momentum accuracy. Based on the preliminary works made for a possible detector[2] at the HERA proton ring we use the following efficiencies (ϵ_j) for the event detection:

- charged track reconstruction, $\epsilon_c = 0.8$;
- additionnal losses of the $e^\pm$ because of momentum reduction due to bremsstrahlung, $\epsilon_e = 0.8$;
- detection of the $K^0 \to \pi^+\pi^-$ ($\Lambda \to p\pi^-$) decay in the suggested spectrometer, $\epsilon_v = 0.5$ (0.8);
- the flight length of the beauty-baryon candidates have to be larger than their average length yielding $\epsilon_f = 0.5$.

3.1 - The measurement of the decay parameters

With the above efficiencies we obtain the rough estimates of the number of events corresponding to the Λ_b and Ξ_b decays indicated in Table 4. These results show that measurements of α'' could be obtained from the $\Lambda_b \to \Lambda J/\Psi$ and $\Xi_b^- \to \Xi^- J/\Psi$ processes. By fitting the meson angular distribution coming from the hyperon Y ($\Lambda \to p\pi^-$ or $\Xi^- \to \Lambda\pi^-$) in its rest frame with formula (10), the error on α'' will be given by

$$\Delta\alpha'' = \frac{1}{\alpha}\left[\frac{3}{N}\left(1 - \frac{(\alpha\alpha'')^2}{3}\right)\right]^{1/2} \qquad (11)$$

[$\alpha'' \equiv \alpha''(N_b)$, $\alpha \equiv \alpha(Y)$] where N is the number of events contributing to the angular distribution. Using the above expression we calculate the minimum value

α''_{min} of $|\alpha''|$ that could be measured with N events and n_s standard deviations, i.e.

$$\alpha''_{min} = \frac{1}{\alpha}\left(\frac{3n_s^2}{N + n_s^2}\right)^{1/2} . \qquad (12)$$

Based on the number of events given in Table 4, we obtain the α''_{min} and $\overline{\alpha}''_{min}$ values that could be measured with $n_s = 3$ and a run of 5 years (Table 6). We also present in Fig. 2 the $\Lambda_b \to \Lambda J/\Psi$ example showing the number of events as a function of α'' needed to measure this parameter with $n_s = 3$.

From Table 6 we note the small values obtained for the Λ and $\overline{\Lambda}_b$ decay because of the large statistics expected for these channels. Let us, therefore, estimate for this case, the values of the asymmetry parameter

$$A'' = \frac{\alpha'' + \overline{\alpha}''}{\alpha'' - \overline{\alpha}''}$$

that could be measured for the Λ_b decay. Practically, one measures the $\alpha''\alpha \equiv \alpha''(\Lambda_b)\alpha(\Lambda)$ and the $\overline{\alpha}''\overline{\alpha} \equiv \overline{\alpha}''(\overline{\Lambda}_b)\overline{\alpha}(\overline{\Lambda})$ quantities that can be compared by using the ratio

$$A_m = \frac{\alpha''\alpha - \overline{\alpha}''\overline{\alpha}}{\alpha''\alpha + \overline{\alpha}''\overline{\alpha}} \simeq \frac{\alpha'' + \overline{\alpha}''}{\alpha'' - \overline{\alpha}''} + \frac{\alpha + \overline{\alpha}}{\alpha - \overline{\alpha}} .$$

Assuming that there is no CP violation in the Λ decay ($\alpha + \overline{\alpha} = 0$), $A_m = A''$. The calculated error on A'' (see Appendix) will then give[19],

$$(\alpha'' A'')_{min} \simeq \frac{n_s}{\alpha}\left(\frac{3}{2N}\right)^{1/2} .$$

Considering still a five-year run and $n_s = 3$, we get $(\alpha''A'')_{min} \simeq 5.5\ 10^{-2}$ (see also Fig. 2).

3.2 - Polarization information

For N_b decay with the spin configuration of $1/2 \to 1/2 + 0$, the polarization $P(N_b)$ could be measured (see Section 2.1 a). In the case of $\Lambda_b \to \Lambda J/\Psi$ and $\Xi_b^- \to \Xi^- J/\Psi$ it is only possible to measure the $\alpha'(N_b)P(N_b)$ quantity with the angular distribution given by formula (8),

$$I(\Theta) \propto 1 \pm \alpha'(N_b)P(N_b)\cos\Theta .$$

Let us recall that Θ represents the angle between one of the N_b daughter momentum expressed in the c.m. system and the N_b polarization (defined in the N_b rest frame). By fitting the experimental data with the above equation for the N_b and $\overline{N}_b$, we could compare $\alpha'(N_b)P(N_b)$ and $\overline{\alpha}'(\overline{N}_b)P(\overline{N}_b)$. Assuming that $\alpha' \simeq \overline{\alpha}'$, one obtains some information about the relation between $P(N_b)$ and $P(\overline{N}_b)$. The error on $\alpha'(N_b)P(N_b)$ and the estimate of its minimum value that can be measured, can be obtained in the same way as was done in Section 3.1 [equations (11) and (12)], yielding

$$\Delta\left[\alpha'(N_b)P(N_b)\right] = \left[\frac{3}{N}\left(1 - \frac{[\alpha'(N_b)P(N_b)]^2}{3}\right)\right]^{1/2}$$

$$\left[\alpha'(N_b)P(N_b)\right]_{min} = \left[\frac{3n_s^2}{N + n_s^2}\right]^{1/2} .$$

The minimum values for the two considered decay channels given in Table 6 are obtained with $n_s = 3$ and a 5 years of run. If we use the theoretical estimates[12] of $\alpha'(\Lambda_b) \simeq \overline{\alpha}'(\Lambda_b) \simeq 0.20 - 0.40$, the corresponding minimum values of the polarization will be $P(\Lambda_b) \simeq P(\overline{\Lambda}) \simeq 0.1 - 0.2$.

3.3 - Estimates of CKM matrix elements

Following the previous discussion (Section 2.3) we consider the possibility of using the channels $\Lambda_b \to l^-\nu p$ and $\Lambda_b \to l^-\nu\Lambda_c^+$ with $\Lambda_c^+ \to pK^+\pi^-$ for estimating the $|V_{ub}/V_{cb}|$ ratio. As stated above, the lepton in the final state in addition to that coming from the semileptonic decay of the associated beauty hadron will be used for the trigger. Here, the effective mass $M(l^+l^-)$ of the two leptons can be very different from the J/Ψ mass as shown by Fig. 3. The effective mass cut, $M(l^+l^-) > 2.5$ GeV, required to decrease the background will lead to an additional loss of events. Taking this efficiency into account ($\epsilon' \sim 0.4$) and that the Λ_b decay channels can be added to their charge-conjugated ones, we obtain the number of events indicated by Table 5 (for one year of running). No efficiecy occurring in the event reconstruction was taken into account. If we assume that such an efficiency will be of the order of 0.5, we could obtain an error on the $|V_{ub}/V_{cb}|$ measurement of the order of $\sim 2 \times 10^{-2}$ after 5 years of running.

It might be that the mass cut will also be applied to leptons having the same charge in order to estimate background effects. In this case the number of events for the proposed channels will increase. This is because the cascade decay of the associated beauty hadron $B \to D \to l$ will also be used for triggering the $\Lambda_b \to l^-\nu p$ and $\Lambda_b \to l^-\nu\Lambda_c^+$ channels. Based on a Monte Carlo calculation, we estimate that the number of events given in Table 5 will increase by a factor of ~ 1.3.

4 - Conclusions

For the present discussion we evaluate the order of magnitude of the various beauty baryons produced in pN interactions at $\sqrt{s} \simeq 39$ GeV. The triggering of the suggested pN experiment at HERA is based on the presence of two leptons in the final state in order to detect the $J/\Psi \to l^+l^-$ coming from the B meson decay. Therefore, we essentially consider beauty-baryon decay having a $J/\Psi \to l^+l^-$ in the final state. From our production and decay estimates, the channels $\Lambda \to \Lambda J/\Psi$ and $\Xi_b^- \to \Xi^- J/\Psi$ could be studied as well as their charged-conjugated ones. The production rates of Λ_b (Ξ_b) and $\overline{\Lambda}_b$ ($\overline{\Xi}_b$) could be compared. This measurement might be useful to understand the importance of the unequal amount of beauty hadrons and anti-beauty hadrons produced in pN interactions.

The α'' ($\overline{\alpha}''$) decay parameters could be measured easily for $\Lambda_b \to \Lambda J/\Psi$ ($\overline{\Lambda}_b \to \overline{\Lambda} J/\Psi$) as the statistics will be the most important ones. For the Ξ_b^- case, only values of $\alpha'' > 0.38$ could be measured with 3 standard deviations and 5 years of running. Information about the difference between the decay parameter α'' and $\overline{\alpha}''$ (CP violation) could be measured with the asymmetry parameter $A'' = (\alpha'' + \overline{\alpha}'')/(\alpha'' - \overline{\alpha}'')$ for the channel with large statistics. Even in this case it would be possible to only measure A'' with 3 standard deviations and a 5 year run if $\alpha''A'' > 4.5 \times 10^{-2}$.

We also mention the possibility of having information about the polarizations of Λ_b, $\overline{\Lambda}_b$ as well as those of Ξ_b^-, $\overline{\Xi}_b^+$. This might be useful for a better understanding of the strong production mechanism. Finally we also suggest to measure the ratio of CKM matrix elements, $|V_{ub}/V_{cb}|$. To this end we propose to use the channels, $\Lambda_b \to l^-\nu p$ ($b \to u$) and $\Lambda_b \to l^-\nu\Lambda_c^+$ ($b \to c$) where QCD effects are expected to be small.

To summarize, we think that the study of beauty baryons, production and decays, would give additional posibilities to the proposed experiment. These results will be useful for further experiments on beauty-baryon decay searching for CP violation in these cases. In any case, beauty-baryon decays will be among the data of the proposed experiment and should, therefore, be investigated.

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Table 4 - The branching ratios (BR) for various cascades of the N_b decays are given in the table as well as the final states. The $BR(J/\Psi \to l^+l^-)$=0.12, $BR(\Xi \to \Lambda\pi) \sim 1$, and $BR(\Lambda \to p\pi^-) = 0.64$ are not indicated. The total branching ratio $BR(tot)$ as well as the number of events expected in one year of running are also given. For the latter values the efficiencies indicated in the text are taken into account.

Channel	BR	$BR(tot)$	Final state	Events/year
$\Lambda_b \to \Lambda J/\Psi$	$\sim 2\ 10^{-2}$	$\sim 1.5\ 10^{-3}$	$p\pi^- l^+ l^-$	~ 2640
$\Xi_b^0 \to \Lambda J/\Psi$	$\sim 9\ 10^{-4}$	$\sim 6.9\ 10^{-5}$	$p\pi^- l^+ l^-$	~ 10
$\Xi_b^- \to \Xi^- J/\Psi$	$\sim 2\ 10^{-2}$	$\sim 1.5\ 10^{-3}$	$p\pi^-\pi^- l^+ l^-$	~ 110

Table 5 - Rough estimates of the semileptonic branching ratios (BR) for some N_b cascade decays that do not contain π^0 in the final state. As above, $BR(\Xi \to \Lambda\pi)$ and $BR(\Lambda \to p\pi^-)$ are not indicated. The number of events per year have been calculated by taking into account that the semileptonic decay of the associated beauty hadron should lead to 2μ or $2e$ in the final state. To estimate the $b \to u$ events we used $|V_{ub}/V_{cb}| = 0.10$.

$b \to q$	Decays	BR	$BR(tot)$	Final state	Events/year
$b \to u$	$\Lambda_b^0 \to l^-\nu p$	$2.4\ 10^{-3}$	$2.4\ 10^{-3}$	$pl^-\nu$	~ 450
$b \to c$	$\Lambda_b^0 \to l^-\nu\Lambda_c^+$	$2\ 10^{-1}$	$6.4\ 10^{-3}$	$p\pi^+\pi^- l^-\nu$	~ 770
	$\Lambda_c^+ \to pK^+\pi^-$	$3.2\ 10^{-2}$			

Table 6 - The minimum of the absolute values of α'', $\overline{\alpha}''$, $\alpha' P(N_b)$ and $\overline{\alpha}' P(\overline{N}_b)$ that could be measured with 3 standard deviations in 5 years of running.

Channel	α''_{min}	$\overline{\alpha}''_{min}$	$[\alpha' P(N_b)]_{min}$	$[\overline{\alpha}' P(\overline{N}_b)]_{min}$
$\Lambda_b \to \Lambda J/\Psi$	~ 0.04	~ 0.05	0.05	0.06
$\Xi_b^- \to \Xi^- J/\Psi$	~ 0.28	~ 0.34	0.22	0.27

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Appendix

Let us estimate the error in the measurement of the asymmetry parameter A'' depending on the decay parameters α'' of the various beauty-baryon channels. For simplicity let us take the example of $\Lambda_b \to \Lambda J/\Psi$ where $\Lambda \to p\pi^-$ and

$$\alpha'' \equiv \alpha''(\Lambda_b) \; ; \quad \alpha \equiv \alpha(\Lambda)$$

($\overline{\alpha}''$ and $\overline{\alpha}$ will denote the decay of the conjugated particles). The angular distribution of the meson in the Λ rest frame [formula (10)]:

$$I(\theta_3) \propto 1 - \alpha''\alpha \cos\theta_3$$

allows the measurement of $x = \alpha''\alpha$ whereas $\overline{x} = \overline{\alpha}''\overline{\alpha}$ will be obtained from the $\overline{\Lambda}_b$ cascade decay. The difference between these measured quantities, i.e.

$$A_m = \frac{\alpha''\alpha - \overline{\alpha}''\overline{\alpha}}{\alpha''\alpha + \overline{\alpha}''\overline{\alpha}} \simeq \frac{\alpha'' + \overline{\alpha}''}{\alpha'' - \overline{\alpha}''} + \frac{\alpha + \overline{\alpha}}{\alpha - \overline{\alpha}} ,$$

could be used to search for CP violation in the Λ_b decay. By neglecting CP violation in the Λ decay, we would have $A_m = A''$ The error on the A'' measurement will then be given by

$$\Delta A'' = \frac{2}{(x + \overline{x})^2} \sqrt{x^2 \, (\Delta\overline{x})^2 + \overline{x}^2 \, (\Delta x)^2} \, .$$

From the measurement of the angular distributions $I_3(\theta)$ coming from the Λ_b decay [formula (4)], the error on $x = \alpha\alpha''$ is then given by

$$(\Delta x)^2 = \frac{3}{N}\left(1 - \frac{x^2}{3}\right) \simeq \frac{3}{N} ,$$

where N is the number of events used for the measurement of the angular distribution. In the expression used to determine $\Delta A''$ we use the approximations that $\Delta x \simeq \Delta\overline{x}$ and $x \simeq \overline{x}$. This leads to

$$(\Delta A'')^2 \simeq \frac{3}{2N} \, \frac{1}{(\alpha''\alpha)^2}$$

and to the minimum value that can be measured

$$(\alpha'' A'')_{min} = \frac{n_s}{\alpha} \left(\frac{3}{2N}\right)^{1/2}$$

with N being the number of events and n_s the number of standard deviations.

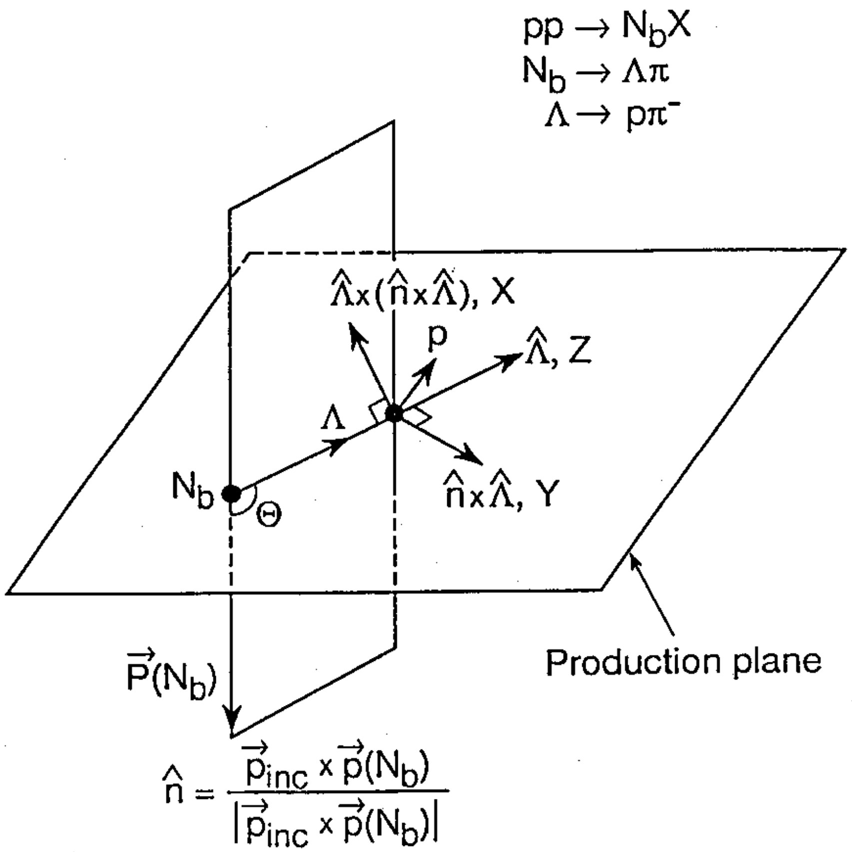

Fig. 1 - The production plane of the $pp \to N_b X$ reaction and the $\vec{P}(N_b)$ polarization normal to this plane. The X, Y, Z represent the coordinate system used in the Λ rest frame for defining the p angular (θ_{1-3}) distributions coming from the $\Lambda \to p\pi$ decay. Here Θ is the Λ emission angle with respect to the $P(N_b)$ direction in the N_b rest frame.

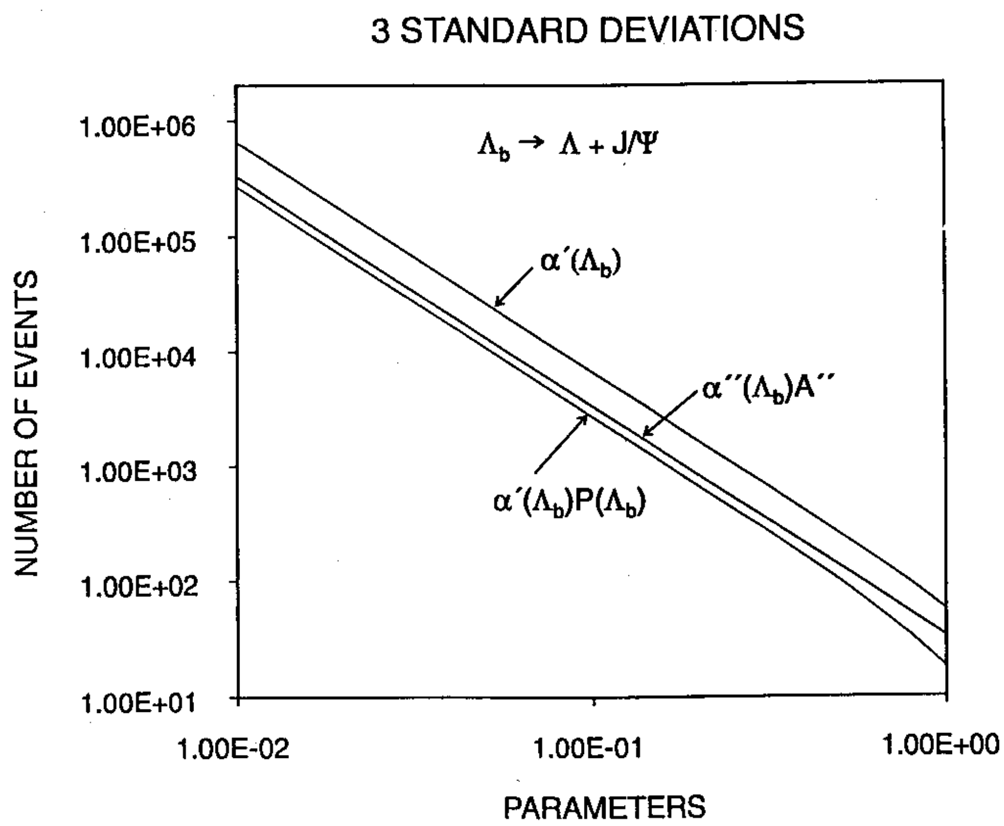

Fig. 2 - The number of $\Lambda_b \to \Lambda J/\Psi$ events needed to measure the α', $\alpha' P(\Lambda_b)$ and $\alpha'' A''$ parameters with 3 standard deviations. For the latter case, about the same number of $\overline{\Lambda}_b \to \overline{\Lambda} J/\Psi$ events is necessary.

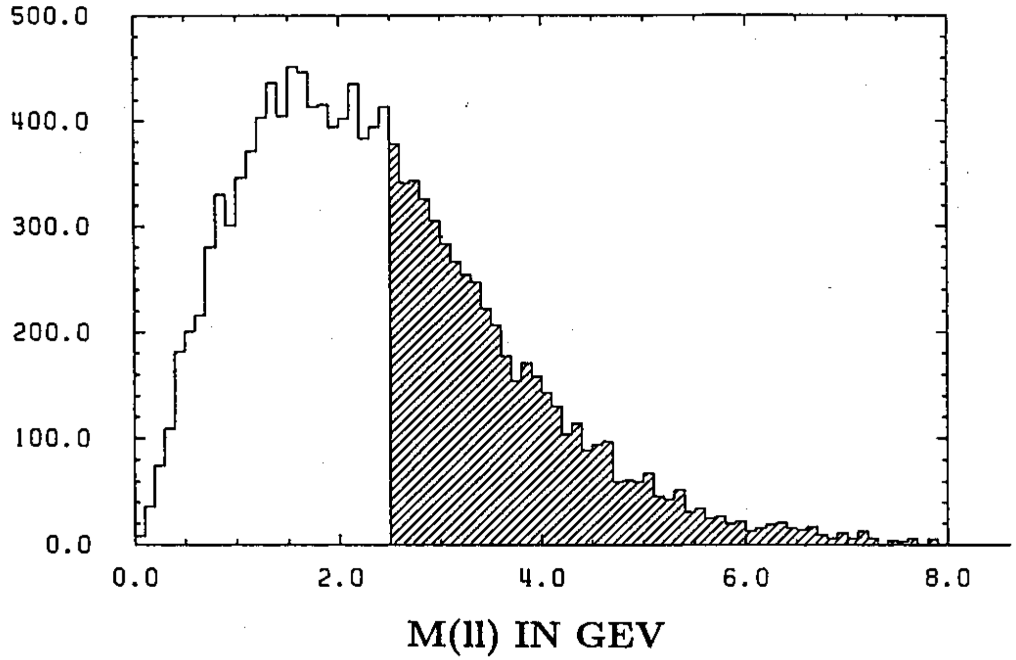

Fig. 3 - The effective l^+l^- mass $[M(l^+l^-)]$ distribution from leptons coming from the semileptonic decay of beauty hadrons produced in the same event. The shaded area corresponds to events having $M(l^+l^-) > 2.5$ GeV.