First observation of the beauty baryon Λ_b in the decay channel $\Lambda_b \rightarrow J/\psi \Lambda$ at the CERN proton-antiproton collider

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Abstract

We report on the first observation of the beauty baryon Λ_b in the decay channel $\Lambda_b \rightarrow J/\psi \Lambda$ at the CERN proton antiproton collider. Using 4.7 pb^{-1} of muon data collected in the 1988/89 collider runs we reconstruct (16 ± 5) Λ_b 's in the decay mode $\Lambda_b \rightarrow J/\psi \Lambda$ above a background of (9 ± 1) events, corresponding to a significance of about five standard deviations. We measure the Λ_b mass to be $m_{\Lambda_b} = (5640 \pm 50 \pm 30) \text{ MeV}/c^2$. Using the beauty cross-section measured by UA1 we deduce for the product of the production fraction and branching ratio $f_{\Lambda_b} \cdot \text{Br}(\Lambda_b \rightarrow J/\psi \Lambda) = (1.8 \pm 1.1) 10^{-3}$. Our sample contains a three-muon event in which the beauty particle opposite to the $\bar{\Lambda}_b$ is tagged by the third muon. We also observe an indication of a signal in the decay channel $B^0 \rightarrow J/\psi K^{0*}$ with a significance of three standard deviations.

1. Introduction

The CERN $p\bar{p}$ collider is a prolific source of beauty particles. The total $b\bar{b}$ cross-section measured by UA1 is $\sim 20 \mu\text{b}$ at $\sqrt{s} = 630 \text{ GeV}$. The measured p_t spectrum of the beauty particles is in excellent agreement in shape and magnitude with theoretical calculations [1]. Semi-leptonic decays of b-quarks are the largest source of high- p_t muon pairs dominating over charm because of the decay properties and, more importantly, the harder fragmentation of the b-quarks compared to the c-quarks. The large b-production rate enabled the UA1 collaboration to report, in 1986, the first observation of $B^0-\bar{B}^0$ mixing via the measurement of the ratio of numbers of like-sign and unlike-sign muon pairs [2] and, more recently, to give significant new limits on exotic B-decays into muon pairs [3].

In the absence of a microvertex detector, the reconstruction of exclusive decay channels is difficult due to the huge combinatorial background and the many existing multiparticle decay channels with branching ratios on the percent level. Furthermore, it is exceedingly difficult to trigger on such decay topologies. Single and dimuon triggers are possible and present a good inclusive signature for semi-leptonic decays of beauty particles, but the presence of neutrino(s) rules out the reconstruction of mass peaks. In this analysis we have therefore chosen to use J/ψ 's for beauty tagging (see also ref. [4]).

An earlier UA1 analysis has demonstrated that about 1/3 of the J/ψ 's originate from beauty decays, the rest coming dominantly from χ decays [5]. The inclusive branching ratio of beauty decays into J/ψ has been measured to be $1.12 \pm 0.18 \%$ [6]. As examples, the following exclusive decay channels are in principle well suited for beauty particle reconstruction at hadron colliders :

$$B \rightarrow J/\psi + (K^0, K^+, K^{0*}, K^{+*}, \phi)$$

$$\Lambda_b \rightarrow J/\psi + \Lambda$$

and charge conjugated.

Whenever a particle is mentioned, the charge conjugate state has been treated accordingly. The Λ is easily identified even without any particle identification due to its characteristic decay pattern and the long decay length. We therefore concentrate in this paper on the search for the beauty baryon. Previous claims for the observation of the beauty baryon [7] have been highly contested [8] or are inconclusive [9].

To search for the beauty meson we have chosen the decay into $J/\psi + K^{0*}$ rather than K^0 for the following reasons: (i) the beauty branching ratio is larger, (ii) there is less combinatorial background since there are fewer K^{0*} 's than K^0 's produced in the underlying event, (iii) there is no loss of a factor 2 due to undetected K_L^0 's.

2. Detector

The commissioning of the Antiproton Collector (ACOL) increased the luminosity of the CERN $p\bar{p}$ collider by an order-of-magnitude. With a mean luminosity of $1.5 \cdot 10^{30} \text{ cm}^{-2}\text{s}^{-1}$ UA1 collected 4.7 pb^{-1} of muon data at $\sqrt{s} = 630 \text{ GeV}$ in the 1988/89 collider runs. A more detailed description of the UA1 detector can be found elsewhere^[10]. In brief, we mention the changes made for the 1988/89 runs that affect this analysis. The muon chambers in the forward directions were rearranged resulting in a forward pseudorapidity coverage of $|\eta| < 2.3$. The capability of the muon trigger was improved by the addition of 820 tonnes of iron shielding in the forward directions. Thus, triggering was possible for single muons up to $|\eta|$ of 1.5 and for muon pairs over almost the full pseudorapidity acceptance of the detector. The electromagnetic calorimeters had been removed increasing the decay path length by about 15%. None the less, the background from pion and kaon decays in the dimuon sample considered is almost negligible. In order to cope with the higher currents induced by the increased collider luminosity, the wire gain of the central detector (CD) was reduced, which was compensated by an increase of the amplifier gain. This resulted in a degradation of the charge division resolution by 50% but did not much affect the accuracy of the muon momentum measurement, which combines the informations from the CD and from the muon chambers.

3. Data selection

3.1 The $J/\psi \rightarrow \mu^+\mu^-$ sample

Muons are identified as high p_t tracks in the CD, which when extrapolated through the iron shielding (at least 8 interaction lengths) match with tracks reconstructed in the muon chambers. The analysis presented here is based on a sample of unlike-sign dimuon events in the mass range $2 < m_{\mu\mu} < 5 \text{ GeV}/c^2$, which includes the J/ψ and its neighbouring guard bands. Transverse momentum cuts of $p_t > 3 \text{ GeV}/c$ for the first muon and $p_t > 2 \text{ GeV}/c$ for the other muon have been applied. The dimuon system is required to have $p_t > 5 \text{ GeV}/c$ and rapidity $|\eta| < 2$.

The dimuon invariant mass spectrum from this selection is shown in fig.1 together with a fit of the line-shape. For more details on the fitting procedure of the signal and the background see reference[5]. The fitted J/ψ mass is $m_{J/\psi} = 3.098 \pm 0.005(\text{stat}) \text{ GeV}/c^2$ in excellent agreement with the PDG value. We define as the J/ψ signal region the mass interval from 2.8 to $3.4 \text{ GeV}/c^2$ and the background region as the two guard bands from 2 - 2.7 and 3.5 - 5 GeV/c^2 . The signal region contains 1596 events out of which 1372 ± 39 are estimated to be real J/ψ 's and 224 ± 9 are background. From the study of the topology of these events [5] it was established that the J/ψ 's originate from mainly two sources: $31 \pm 12 \%$ from beauty decays and the rest from χ decays.

3.2 The Λ sample

The Λ can be identified by its V^0 decay in the charged decay mode $\Lambda \rightarrow p\pi^-$. The pattern recognition methods for V^0 type decays are described in ref. [11]. The mean decay length of a Λ with a momentum of 1 GeV/c is 7.1 cm. Another important characteristic of the Λ decay is the momentum imbalance between the proton and the pion. If, as here, the Λ momentum is large compared to the Q-value of the decay, the proton momentum is on average larger than the pion momentum by a factor m_p/m_π . This feature has important consequences for the analysis. Firstly, there are essentially no mass assignment ambiguities because the proton is always the particle with the higher momentum. Furthermore, on average the proton carries 87 % of the Λ momentum and, consequently, it will be orientated almost in the direction of flight of the Λ and points to the interaction vertex. Finally, only tracks with $p > 0.1$ GeV/c are reconstructed in the CD and the low momentum pion limits the Λ acceptance to $p_t(\Lambda) > 0.5$ GeV/c. Motivated by these decay characteristics we require for the Λ selection:

- i) $b_i/\Delta b_i > 0.5$ for both tracks, where b_i is the track impact parameter at the main vertex and Δb_i is the error on this quantity.
- ii) Decay probability $P_d = 1 - \exp(-d/c\tau\gamma\beta) > 25\%$, where d is the measured decay length.
- iii) $p_t(\Lambda) > 0.5$ GeV/c
- iv) In addition, we require that the Λ lies in a cone around the dimuon direction of $\Delta R^2 < 5$ with $\Delta R^2 = \Delta\phi^2 + \Delta\eta^2$, where ϕ is the azimuthal angle around the beam direction, η is the pseudorapidity and Δ denotes the difference between the Λ and dimuon direction.

The Λ 's from the decay considered lie dominantly in the region $\Delta R^2 < 3$. With the cut $\Delta R^2 < 5$ we include in our selection a guard band above the expected Λ_b mass but reject Λ 's contained in the opposite jet. The $(p\pi)$ mass spectrum selected from the J/ψ sample with the cuts defined above is shown in fig. 2. The line-shape for the Λ is determined by fitting the events in fig. 2 with a Gaussian function and a 4th order polynomial for the background. We define as the Λ signal region the mass interval $1.105 < m(p\pi) < 1.125$ GeV/c². For background studies we use a pair of guard bands from 1.08 to 1.1 GeV/c² and from 1.14 to 1.18 GeV/c². The signal region contains 129 entries from which (69 ± 11) are estimated to be real Λ 's; 38 ± 9 of these Λ 's lie in the J/ψ signal region the rest in the J/ψ guard bands.

3.3 The K^{0*} sample

For the reconstruction of the decay $K^{0*} \rightarrow K^+\pi^-$, we accept all charged tracks associated to the dimuon vertex which have $p_t > 0.1$ GeV/c and which are within a cone of $\Delta R^2 < 5$ around the

dimuon direction. For the calculation of the mass of a particle pair we assign the kaon mass to one track and the pion mass to the other and vice versa. A track combination is selected if :

$$p_t(K\pi) > 1.5 \text{ GeV}/c \text{ and } p(K) > 0.5 p(\pi).$$

The first cut exploits the fact that the K^{0*} 's arising from high- p_t B-decays have a higher average momentum than particles from the rest of the event and the second one takes account of the effect of the Lorentz boost on decay particles of unequal masses.

In fig. 6 we show the invariant mass spectrum for $(K\pi)$ pairs selected with the above cuts from the J/ψ signal region. For this plot only, we require that the $(K\pi)$ system lies within a cone $\Delta R^2 < 1$ around the dimuon direction. With this more restrictive cut we mainly reject random track combinations from the underlying event and optimize the signal to background ratio for the K^{0*} signal. We observe a K^{0*} signal centered at $0.87 \text{ GeV}/c^2$. An estimation of the background shape obtained from like-sign track combinations is shown as a solid line. The mass shift with respect to the PDG value of $0.897 \text{ GeV}/c^2$ is probably due to systematics in the charge division measurement and is consistent with a shift also observed for the K^0_S mass. For the K^{0*} signal region we take the central bins from 0.84 to $0.9 \text{ GeV}/c^2$.

4. The decay channel $\Lambda_b \rightarrow J/\psi \Lambda$

In order to search for the decay mode $\Lambda_b \rightarrow J/\psi \Lambda$ we combine the J/ψ and any Λ in a cone of $\Delta R^2 < 5$ around the J/ψ . Furthermore, we require that the Λ_b candidates have $p_t > 6 \text{ GeV}/c$ and $|y| < 2$ corresponding to the kinematical region where the sensitivity is greatest. The distribution of the invariant $(J/\psi\Lambda)$ mass is shown in fig. 3. We observe a peak centered at $5.6 \text{ GeV}/c^2$ indicating the presence of a Λ_b signal. We perform a fit to the data using a Gaussian function for the signal and the result of a Monte Carlo simulation for the background, which will be discussed in the next paragraph. The fit gives $5590 \pm 50 \text{ MeV}/c^2$ for the mean mass and $120 \pm 40 \text{ MeV}/c^2$ for the width of the Gaussian. To be more precise, we study the distribution of the mass difference $\Delta m = m(J/\psi, \Lambda) - m(J/\psi)$, which has the advantage that the measurement error on the J/ψ mass largely cancels. Fig. 4a shows the resulting distribution in Δm to which we have added the PDG value of the J/ψ mass.

Combinatorial background to the Λ_b signal will come from $(p\pi)$ and $(\mu^+\mu^-)$ backgrounds in the Λ and J/ψ signal region, respectively, and from real J/ψ 's combined with real Λ 's from the underlying event or the beauty quark fragmentation. We used a Monte Carlo simulation to describe the background which contains a simulation of the underlying event, beauty and charm production and decays. More details of the UA1 Monte Carlo production can be found elsewhere^[1,5]. From this study we find that the Δm distributions for the above background processes are of similar

shape. For an independent estimation of the combinatorial background we use the J/ψ and Λ guard bands. In fig. 4b we plot the $\Delta m + m(J/\psi)_{PDG}$ distribution using dimuon pairs selected from the J/ψ guard bands and in fig. 4c using $(p\pi)$ pairs selected from the Λ guard bands. The latter has been normalized to the estimated $(p\pi)$ combinatorial background. Both distributions are approximately flat in the Λ_b signal region. The distribution for the J/ψ guard bands is compared to our Monte Carlo distribution, which we normalize to the data for $\Delta m + m(J/\psi)_{PDG} > 5 \text{ GeV}/c^2$. A small excess is expected at the lower end of the mass distribution from Λ_b cascade decays. We find a good agreement between the Monte Carlo simulation of the background and our experimental background data.

We determine the line shape of the spectrum in fig. 4a by fitting the data with a Gaussian function for the signal and the Monte Carlo shape for the background. The summed contributions are normalized to the number of entries in the histogram. The resulting fit, superimposed in fig. 4a as a solid line, describes well the background and the signal. The fit yields $(16 \pm 5) \Lambda_b$ events. The fitted width of the Gaussian is $\sigma_m = (110 \pm 40) \text{ MeV}/c^2$ consistent with the expected measurement error of $(80 \pm 20) \text{ MeV}/c^2$. The fitted mass of the Λ_b is :

$$m(\Lambda_b) = 5640 \pm 50 \pm 30 \text{ MeV}/c^2,$$

where the first error is statistical and the second one the systematic. The systematic error is an estimation of uncertainties due to systematics in the charge division measurement and due to the background shape assumption ($\pm 10 \text{ MeV}/c^2$). The J/ψ mass was measured $20 \text{ MeV}/c^2$ too low when the muon momenta were only determined in the central detector. The measured mass is consistent with theoretical expectations which range from 5580 to 5640 MeV/c^2 [12]. The number of background events determined in the region $m(\Lambda_b) \pm 2\sigma_m$ is 9 ± 1 and hence the statistical significance of our signal amounts to about five standard deviations.

We note that the signal could in principle contain contributions from the beauty baryons Σ_b , Ξ_b and Ω_b . All theoretical predictions for the Σ_b - Λ_b mass difference [12] and also the extrapolation of the known mass differences $\Sigma - \Lambda = 77 \text{ MeV}/c^2$ and $\Sigma_c - \Lambda_c = 169 \text{ MeV}/c^2$ into the beauty regime indicate that its value is well above the pion mass implying that the Σ_b decays strongly via the emission of a pion into the Λ_b ground state. Ξ_b and Ω_b , however, will decay weakly and a possible decay channel is $\Xi_b (\Omega_b) \rightarrow J/\psi \Xi (\Omega) \rightarrow J/\psi \Lambda X$. Due to strangeness suppression and due to the fact that the decay modes are not fully reconstructed, their contributions to the Λ_b signal are expected to be small. We obtain an estimate of $< 10\%$ for these contributions from Monte Carlo studies.

Among the $\bar{\Lambda}_b$ candidates we found an event which shows several features of the expected $b\bar{b}$ topology. A view of the transverse plane of the event is shown in fig. 5 with a p_t cut of $1 \text{ GeV}/c$ on all particles. Three of them are muons which have been extrapolated towards the muon chambers

and match with the position and direction of reconstructed muon tracks. The $\bar{\Lambda}_b$ candidate is made up of the unlike-sign muon pair with an invariant mass of $(2.95 \pm 0.23) \text{ GeV}/c^2$, consistent with the J/ψ mass, and a $\bar{\Lambda}$ candidate, reconstructed nearby in the central detector. The mass of the $\bar{\Lambda}_b$ candidate is $(5.58 \pm 0.11) \text{ GeV}/c^2$ and its transverse momentum is $9.4 \text{ GeV}/c$. The transverse momentum of the $\bar{\Lambda}_b$ is almost balanced by a third positive charged muon with a p_t of $6.8 \text{ GeV}/c$, which is nearly back-to-back with the $\bar{\Lambda}_b$. The event is thus a candidate for the process:

Since baryons cannot mix, the charge of the other b is determined to $Q=-1/3$. If the positive muon arises directly from semileptonic b -decay, which is probable because of its high transverse momentum, this implies that the opposite b hadronized into a neutral b -meson which mixed into its charge-conjugated partner.

5. Evaluation of the Branching Ratio

The observed number of events in the Λ_b -signal (N_{sig}) is related to the exclusive branching ratio $\text{Br}(\Lambda_b \rightarrow J/\psi \Lambda)$ through

$$N_{\text{sig}} = 2 \cdot \epsilon^{J/\psi} \cdot \epsilon^{\Lambda} \cdot \text{Br}(\Lambda_b \rightarrow J/\psi \Lambda) \cdot f_{\Lambda_b} \cdot \sigma_B \cdot L, \quad (1)$$

where we used the following notation:

$\epsilon^{J/\psi}$	J/ψ reconstruction efficiency
ϵ^{Λ}	Λ reconstruction efficiency
σ_B	B -hadron production cross-section
f_{Λ_b}	Production fraction = Probability of the b -quark to hadronize into a Λ_b or into another beauty baryon decaying to a Λ_b .
L	Integrated luminosity = $4.7 \pm 0.4 \text{ pb}^{-1}$

The factor 2 arises from the fact that quarks are produced as quark-antiquark pairs.

A breakdown of the efficiencies for the reconstruction of the J/ψ and the Λ from the decay $\Lambda_b \rightarrow \Lambda J/\psi$ of a Λ_b with $p_t > 6 \text{ GeV}/c$ and $|\eta| < 2$ is shown in Table 1. We distinguish between branching ratios, the acceptances due to the kinematical cuts, and detection efficiencies determined for this kinematical region. The J/ψ detection efficiency includes the acceptance of the muon p_t cut ($\sim 25 \%$), the geometrical and trigger efficiency (together making $\sim 45\%$) and the two-track reconstruction efficiency ($\sim 50 \%$). The Λ detection efficiency is dominated by the track reconstruction efficiency ($\sim 75 \%$), the cut on the decay probability (75 %) and the geometrical acceptance (70 %). For both efficiencies we assume an overall systematic error of 10 %, which includes a conservative estimate of the uncertainties on the detector simulation.

For the B-hadron production cross section, we use a weighted average of the values obtained by UA1 from the analysis of the J/ψ and high-mass dimuon sample [1] and extrapolate it to the region $|\eta| < 2^1$:

$$\sigma(p\bar{p} \rightarrow B; p_t(B) > 6 \text{ GeV}/c; |\eta_B| < 2) = (2.2 \pm 1.1) \mu\text{b}$$

Values for the production fractions $f_u = f_d = 36\%$, $f_s = 18\%$ and $f_{\text{baryon}} = 10\%$ are suggested by measurements of the K/π ratio of leading particles and the baryon fraction in $p\bar{p}$ collisions [14].

Inserting into equation (1) the number of reconstructed Λ_b 's we obtain for the production fraction times branching ratio:

$$f_{\Lambda_b} \cdot \text{Br}(\Lambda_b \rightarrow J/\psi \Lambda) = 1.8 \pm 0.6 \text{ (stat)} \pm 0.9 \text{ (sys)} 10^{-3}.$$

Assuming a production fraction of $f_{\Lambda_b} = 10\%$ this converts into $\text{Br}(\Lambda_b \rightarrow J/\psi \Lambda) = (1.8 \pm 1.1) \%$.

6. The decay channel $B^0 \rightarrow J/\psi K^{0*}$

The analysis of this decay channel is performed in a manner similar to that for the Λ_b decay. Fig. 7 shows the distribution of $m = m(J/\psi K^{0*}) - m(J/\psi) + m(J/\psi)_{\text{PDG}}$. The background is dominated by combinatorial ($K\pi$) background from the K^{0*} signal region. For the estimation of the background shape we plot the corresponding mass distribution for like-sign ($K\pi$) pairs selected with the same cuts as for the K^{0*} candidates. The resulting spectrum has been normalized to the signal spectrum for $m > 5.5 \text{ GeV}/c^2$ and is superimposed on fig. 6 as a dashed line. We observe an

¹ The J/ψ result was rescaled with the recently improved measurement of the leptonic branching ratio $\text{Br}(J/\psi \rightarrow \mu^+ \mu^-) = (5.9 \pm 0.15 \pm 0.19) \%$ [13].

excess of 14 ± 6 entries over a background of 26 centered at $5.2 \text{ GeV}/c^2$ indicating the presence of a B^0 signal with a significance of about three standard deviations.

A breakdown of the efficiency for the reconstruction of K^{0*} 's from the decay mode considered is given in Table 1. The detection efficiency includes the two-track reconstruction efficiency (75 %) and the cut on the reconstructed K^{0*} mass (68 %). The evaluation of the branching ratio follows the same scheme as already been explained for the Λ_b . For the production fraction times branching ratio we obtain:

$$f_d \cdot \text{Br}(B^0 \rightarrow J/\psi K^{0*}) = 1.4 \pm 0.6(\text{stat}) \pm 0.7(\text{sys}) 10^{-3}.$$

Assuming a production fraction of $f_d = 36\%$ this converts into $\text{Br}(B^0 \rightarrow J/\psi K^{0*}) = (0.4 \pm 0.30) \%$.

Our measured branching ratio is consistent with those obtained from ARGUS ($0.11 \pm 0.06\%$) and CLEO ($0.11 \pm 0.05\%$) at e^+e^- - colliders^[15].

7. Conclusions

During the collider runs in 1988/89 UA1 collected 4.7 pb^{-1} of dimuon data at $\sqrt{s}=630 \text{ GeV}$. Events containing a J/ψ were analyzed to search for beauty decays. In the absence of particle identification we used the mass constraints of the two-body decays of the Λ and K^{0*} particles. The Λ was better identified due to its characteristic decay, giving a large momentum fraction to the proton, and due to its sizeable decay length. A clear Λ_b peak with 16 ± 5 events above a background of 9 ± 1 was observed in the decay channel $\Lambda_b \rightarrow J/\psi \Lambda$. The background underneath the signal was evaluated by using the side bins of the J/ψ and the Λ . Monte Carlo calculations taking into account the underlying event and the beauty decays described well the background data. The error on the background is therefore small. The statistical significance of the signal, determined by fluctuating the background, amounts to 5σ . By fitting a Gaussian distribution above the background we determined the Λ_b mass to be:

$$m(\Lambda_b) = 5640 \pm 50 \pm 30 \text{ MeV}/c^2.$$

From the beauty cross-section, as measured by UA1, and assuming a Λ_b production fraction of 10% we deduced a branching ratio of :

$$\text{Br}(\Lambda_b \rightarrow J/\psi \Lambda) = (1.8 \pm 1.1) \%.$$

A trimuon event with a $\bar{\Lambda}_b$ decay on one side and a high p_t muon on the opposite side, indicating a beauty pair production, was among the signal events.

We also searched for the decay $B^0 \rightarrow J/\psi K^{0*}$ and found indication of a signal with a significance of three standard deviations.

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Figure Captions:

Fig. 1:

The invariant mass distribution of unlike-sign muon pairs. The solid line is the result of a fit to the data. The dashed line is the background shape. The arrows indicate the J/ψ signal region used for the analysis.

Fig. 2:

The invariant (p,π) mass distribution for V^0 's selected from the J/ψ sample showing the Λ peak. A fit to the spectrum with a Gaussian function and a 4th order polynomial for the background is shown as a solid line. The Λ signal region used for the analysis is indicated.

Fig. 3:

The distribution of the invariant mass $m(J/\psi \Lambda) = m(\mu^+\mu^- p^{+(-)} \pi^{-(+)})$ showing the Λ_b signal. A fit to the spectrum using a Gaussian function and the result of the Monte Carlo simulation for the background shape is shown as a solid line.

Fig. 4:

(a) The invariant mass distribution in $m(J/\psi \Lambda) - m(J/\psi) + m(J/\psi)_{PDG}$. A fit to the spectrum using a Gaussian function and the result of the Monte Carlo simulation for the background shape is shown as a solid line.

(b) The corresponding distribution for the J/ψ guard bands. The solid line is the result of a Monte Carlo simulation.

(c) The corresponding distribution, where (p,π) pairs have been selected from the Λ guard bands.

Fig. 5:

View of the transverse plane of the trimuon event containing a $\bar{\Lambda}_b$ decaying into $J/\psi \bar{\Lambda}$, and a muon which almost balances the transverse momentum of the $\bar{\Lambda}_b$. Values for the transverse momenta are given in units of GeV/c. All charged particles with $p_T > 1$ GeV/c are shown.

Fig. 6:

The invariant (K,π) mass distribution for tracks associated to the muon-vertex for J/ψ events. An estimation of the background shape obtained from like-sign track combinations is shown as a solid line. The K^0 signal region used for the analysis is indicated.

Fig. 7:

The invariant mass distribution in $m(J/\psi K^{0*})-m(J/\psi)+m(J/\psi)$ PDG (solid line). The dashed line is an indication of the background spectrum, where like-sign (K,π) pairs have been selected with the same cuts as the K^{0*} 's.

Table 1:

The total efficiencies for the different decay modes which are the products of the branching ratios, the kinematical acceptances and the reconstruction efficiencies. The 10% systematic error on the total efficiency includes a conservative estimate of the uncertainties on the detector simulation.

Mode	Branching Ratio	Kinematical Acceptance		Detection Efficiency	Total Efficiency
$J/\psi \rightarrow \mu^+ \mu^-$	$(5.9 \pm 0.2)\%$	$p_t > 5 \text{ GeV}/c$, $ y < 2$	68%	5.7%	$(0.23 \pm 0.02)\%$
$\Lambda \rightarrow p^+ \pi^-$	$(64.1 \pm 0.5)\%$	$p_t > 0.5 \text{ GeV}/c$	91%	33%	$(19 \pm 2)\%$
$K^{0*} \rightarrow K^+ \pi^-$	68%	$p_t > 1.5 \text{ GeV}/c$	61%	51%	$(21 \pm 2)\%$

Table 1:

Fig. 1

Fig. 2

Fig. 3

Fig. 4a

Fig. 4b

Fig. 4c

Fig. 5

Fig. 6

Fig. 7