PoS PROCEEDINGS OF SCIENCE

B baryons at D-Zero

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The observation of the *b* baryons Ξ_b^- and Ω_b^- in high energy proton-antiproton collisions in the D-Zero Detector at Fermilab's Tevatron Collider are presented, along with measurements of the masses and production rates of these states.

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[1] Speaker

1.Introduction

Within the standard model a total of 15 *b* baryons are predicted (counting quark content only). Taking into consideration intrinsic angular momentum, there are 10 charmless *b* baryons in J=1/2 and J=3/2 muliplets. These states are unique to hadron colliders since the B factories operate at insufficient energy to produce them, and they are expected to be produced copiously at the Tevatron. There are interesting mass predictions for these states from various theoretical models but the experimental challenge to observe them is very substantial.

At the start of Tevatron Run II (~2003) only the Λ_b had been observed (first by the UA1 collaboration in 1991 [1]). However, in the past three years at the Tevatron, another four of the predicted J=1/2 states containing just one *b* quark have been observed.The Σ_b^+ (uub) and Σ_b^- (ddb) were recorded by the CDF collaboration in the $\Sigma_b \rightarrow \pi\, \Lambda_b \rightarrow \pi\, (\Lambda_c\, \pi)$ channel [2] whilst at D-Zero the Ξ_b^- (bds) [3] and Ω_b^- (bss) [4] states were observed. The measurements leading to the identification of the latter two states are the subject of the remainder of this presentation.

2.Experimental Apparatus

The D0 detector is described in detail elsewhere [5]. The components most relevant to this analysis are the central tracking system and the muon spectrometer. The central tracking system consists of a silicon microstrip tracker (SMT) and a central fiber tracker (CFT) that are surrounded by a 2 T superconducting solenoid. The SMT is optimized for tracking and vertexing for the pseudorapidity region $|\eta| < 3$ ($\eta = -\ln[\tan(\theta/2)]$ and θ is the polar angle) while the CFT has coverage for $|\eta| < 2$. Liquid-argon/uranium calorimeters in a central and two end-cap cryostats cover the pseudorapidity region $|\eta| < 4.2$. The muon spectrometer is located outside the calorimeters and covers the pseudorapidity region $|\eta| < 2$. It comprises a layer of drift tubes and scintillator trigger counters in front of 1.8 T iron toroids followed by two similar layers behind the toroids. An integrated luminosity of 1.3 fb^{-1} was used in these analyses.

3.Optimization of event reconstruction

In this analysis, we have sought to identify *b* baryons containing a $J/\psi \rightarrow \mu^+\mu^-$ candidate, to take advantage of D-Zero's excellent muon acceptance and trigger efficiency. The decays of *b* baryons yield various long lived baryons (Λ,Ξ) and mesons (K_S) which decay in flight far from the proton-antiproton collision vertex (typically from a few cm to tens of cm). The D-Zero offline event reconstruction algorithms are not optimized for these objects. When tracks are reconstructed, a maximum impact parameter is required to increase the reconstruction speed and lower the rate of fake tracks. But for particles like the Ξ_b^-, this requirement could result in missing the pion and proton tracks from Λ and Ξ^- decays. To overcome this inefficiency, all events containing a $J/\psi \rightarrow \mu^+\mu^-$ candidate were reprocessed with a much looser impact parameter cut. The resulting improvement in reconstruction efficiency is shown in Figure 1.

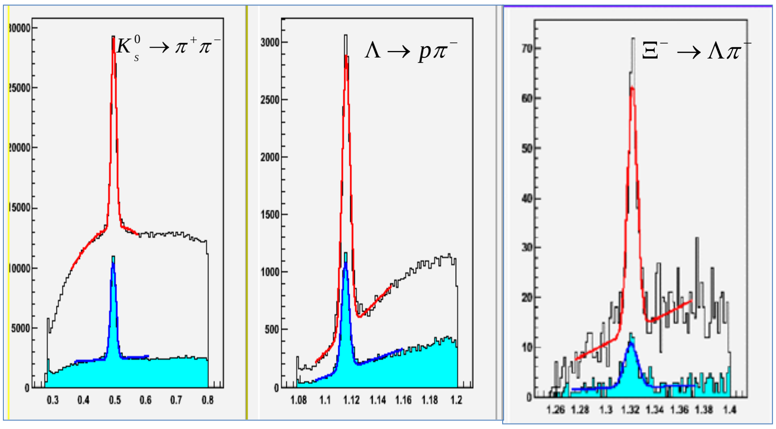
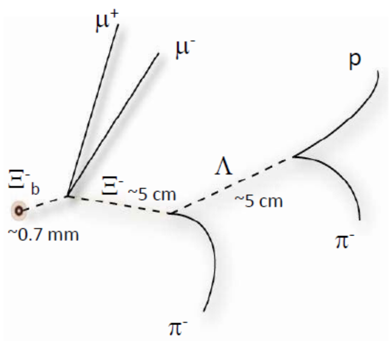


Figure 1. The improvement in reconstruction efficiency of long-lived mesons and baryons. The red curves are for reprocessed data (looser impact parameter cut on reconstructed tracks) and the blue curves are for the standard track reconstruction algorithm. The number of reconstructed events is shown as a function of the invariant mass (GeV) of the daughter pair.

4.Observation of the Ξ_b^-

The search strategy for this state is based on the typical event topology illustrated in Figure 2a. The Ξ_b^- decays in flight after about 0.7 mm into a J/ψ and a Ξ^-. The J/ψ decays immediateley into a muon pair whilst the Ξ^- decays after about 5 cm of flight into a Λ and a charged pion. After a further 5cm of flight the Λ decays into a proton and a pion. The beauty baryon therefore decays into 5 charged particles with three distinct vertices. The events were selected by attempting to reconstruct J/ψ mesons from opposite charge dimuons, and Λ baryons decaying into opposite charged tracks (assuming proton and pion masses respectively). Using cuts on the appropriate mass windows, if an event contained a J/ψ and a Λ, an additional track



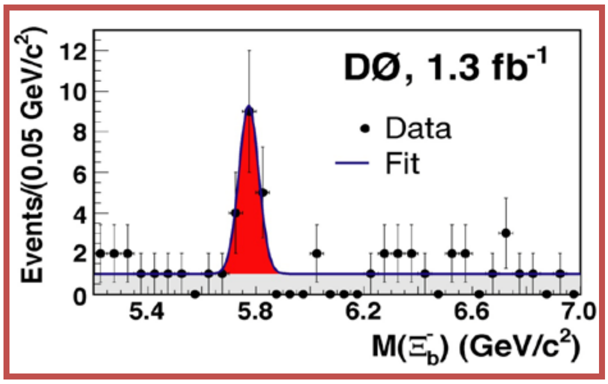


Figure 2a (left hand) – the typical event topology of the Ξ_b^- decay.
Figure 2b (right hand) – invariant mass distribution of reconstructed Ξ_b^- candidates.

was sought which could be combined to form a Ξ^- candidate and if this was successful the invariant mass of the Ξ^- and the J/ψ was computed (Figure 2b). Several optimization cuts were applied during this procedure to improve the signal to noise ratio and a full description of these may be found in [3]. An unbinned extended log likelihood fit was performed on the Ξ_b^- candidates, yielding a 5.5. standard deviation signal (15.2 ± 4.4 events) above a flat background.

The fit also determined the mass (5.774 ± 0.011 (stat) GeV) and width (0.037 ± 0.008 GeV) of this state. Finally, using a previously determined production rate for Λ_b baryons, the following ratio

$$R = \frac{\sigma(\Xi_b^-) BR(\Xi_b^- \to J/\psi\, \Xi^-)}{\sigma(\Lambda_b) BR(\Lambda_b \to J/\psi \Lambda)}$$

was determined to be 0.28 ± 0.09 (stat) ± 0.09 (syst).

5.Observation of the Ω_b^-

The search for the Ω_b^- followed a very similar strategy to the Ξ_b^- analysis with the main difference being the use of a kaon mass hypothesis for the single track combined with the Λ candidate to test for the existence of an Ω baryon in the event. If the J/ψ, Λ and Ω candidates fell within appropriate mass windows, the invariant mass of the resultant J/ψ and Ω was calculated to determine if there was any evidence for the production of Ω_b^- baryons.

Due to the relatively poor signal to background ratio in the ΛK invariant mass distribution (Figure 3a), a Boosted Decision Tree (BDT) selection based on 20 kinematic variables was applied to the data. The BDT selection retains 87% of the Ω_b^- signal while rejecting 89% of the background. Furthermore, a cut on the invariant mass of the Λπ system (> 1.34 GeV), assuming a pion mass hypothesis instead of a kaon, was applied to remove residual contamination from $\Xi \to \Lambda\pi$ decay. The resulting ΛK mass distribution (Figure 3b) reveals a much larger signal to background ratio for the Ω baryons. Additonal optimization cuts were used to further enhance

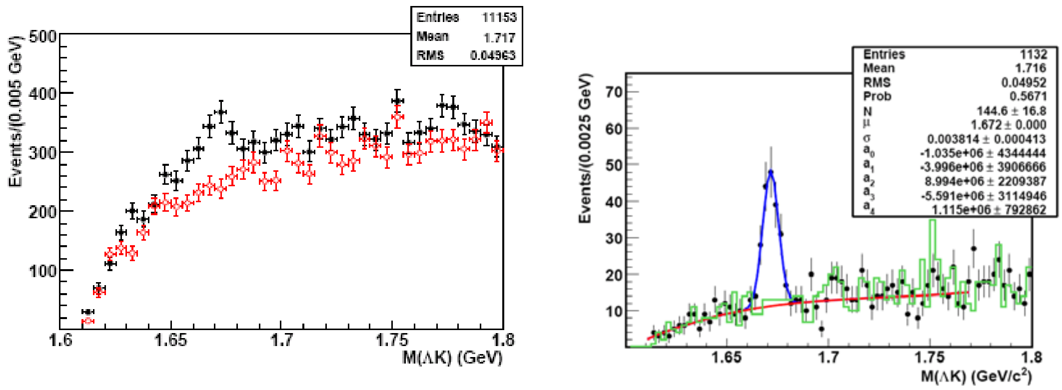


Figure 3a (left) – the ΛK mass distribution for correct (black) and wrong (red) charge combinations.
Figure 3b (right) – the ΛK mass distribution after all optimization cuts described in the text.

the Ω_b^- signal over the combinatorial background: the uncertainty of the Ω_b^- proper decay length was required to be less than 0.03 cm and we imposed a minimum p_T cut of 6 GeV on the Ω_b^- candidates. Finally, we required the J/ψ and the Ω^- candidates to be in the same event hemisphere (due to kinematic boosts). We applied the above selection to right-sign events in the data to search for the Ω_b^- in the mass window 5.6 – 7.0 GeV. We calculate the Ω_b^- candidate mass using the formula

$$M = M_{J/\psi\Omega} - M_{J/\psi} - M_{\Omega} + M_{J/\psi}^{PDG} + M_{\Omega}^{PDG}$$

where the first three terms on the right hand side are the reconstructed masses whilst the latter two are taken from the PDG. This calculation improves the Ω_b^- mass resolution from 0.080 to 0.034 GeV. In the mass search window we observe 79 candidates in the data with mass distribution shown in Figure 4d. An excess of events near 6.2 GeV is apparent. No such structure, however, is seen in the corresponding mass distributions of the wrong-sign ΛK events, events reconstructed using the Λ sidebands or events reconstructed using the Ω^- sidebands (Figures 4a, 4b and 4c respectively).

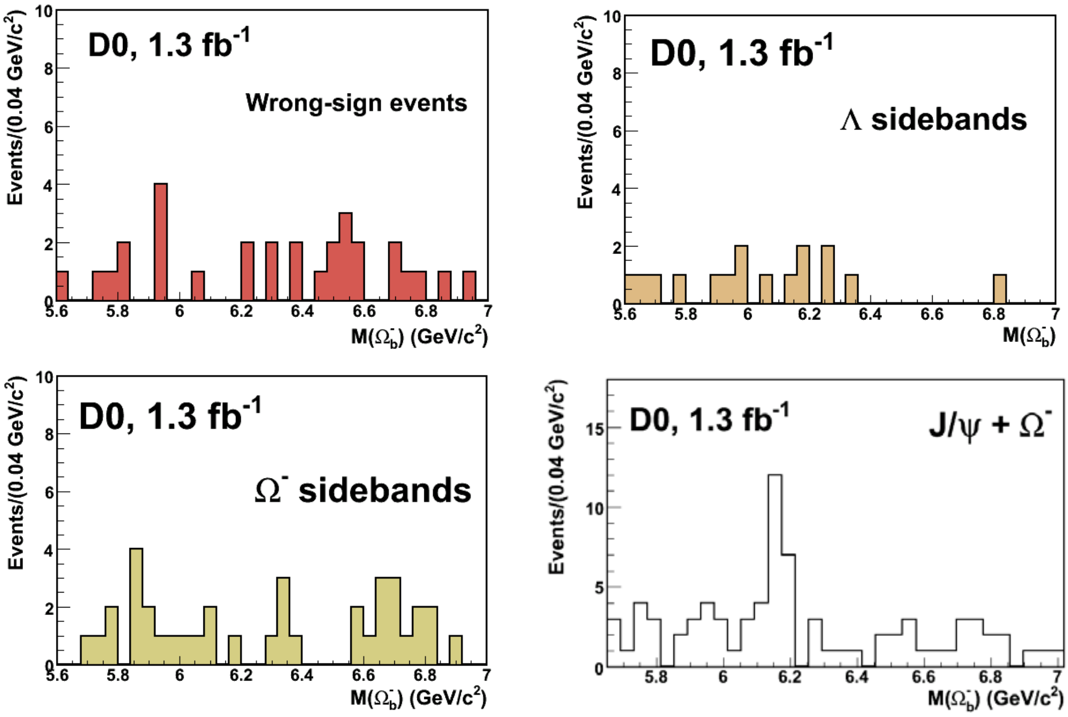


Figure 4a (top left) – the $J/\psi\ \Omega$ invariant mass distribution for wrong-sign ΛK events;
Figure 4b (top right) – the $J/\psi\ \Omega$ invariant mass distribution for events reconstructed using Λ sidebands;
Figure 4c (bot left) – the $J/\psi\ \Omega$ invariant mass distribution for events reconstructed using Ω^- sidebands;
Figure 4d (bot right) - the $J/\psi\ \Omega$ invariant mass distribution for right-sign ΛK events.

Assuming the excess of right-sign combinations is due to Ω_b^- production, we fit the Ω_b^- candidate masses with the hypothesis of a Gaussian signal plus a flat background using an unbinned likelihhod method. We fix the Gaussian width to 0.034 GeV, the width of the MC Ω_b^- signal. The fit gives an Ω_b^- mass of 6.165 ±0.010 (stat) GeV and a yield of 17.8 ± 4.9 (stat) signal events – with a statistical significance of 5.4 standard deviations (Figure 5a). A systematic uncertainty of 0.013 Gev was assigned to the mass determination with the principal sources being variations in the Gaussian width, the momentum scale and the event selection procedure. The proper decay length distribution of the Ω_b^- candidates within a $\pm 3\sigma$ mass window around the fitted Ω_b^- mass is consistent with the expectations of a Monte Carlo signal with 1.54 ps lifetime and a background distribution (Figure 5b).

A recent measurement of the Ω_b^- mass by the CDF collaboration (elsewhere in these proceedings) yielded a value about 0.11 GeV lower than the D-Zero value (a difference of about 6 standard deviations). This difference is approximately ten times the systematic uncertainty

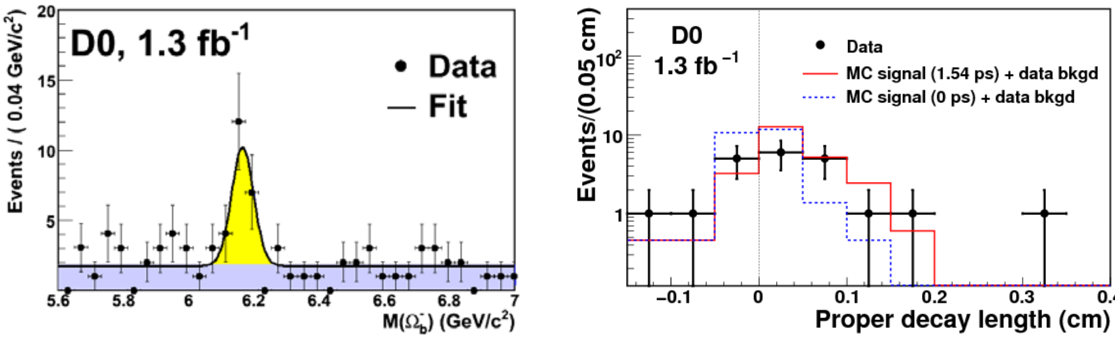


Figure 5a (left) – the fit of the Ω_b^- candidates and background;
Figure 5b (right) – the proper decay length distribution of the signal and MC expectations.

assigned to the D-Zero Ω_b^- mass measurement. However, the measurements of the masses of the Λ_b and Ξ_b baryons are consistent between the experiments. Furthermore, the reconstructed D-Zero Ω_b^- mass in MC events is consistent with the input value. The uncertainties in theoretical predictions for the mass of the Ω_b^- baryon fall in the range 0.05-0.10 GeV. The D-Zero measurement of the Ω_b^- mass is 1.5-2.0 standard deviations higher than the theoretical predictions and is therefore consistent with them. The D-Zero analysis is based on the Run 2A detector configuration (i.e. no SMT layer-0), the same as used for the Ξ_b^- discovery. A new analysis with five times more integrated luminosity, based on the full Run 2 data sample, is currently underway. This requires reprocessing of the raw data (to loosen the impact parameter cut) and further optimization of the event selection criteria.

The production rate of the Ω_b^- relative to the Ξ_b^- is determined from the relation

$$\frac{f(b\to\Omega_b^-)Br(\Omega_b^-\to J/\psi\,\Omega^-)}{f(b\to\Xi_b^-)Br(\Xi_b^-\to J/\psi\,\Xi^-)}=\frac{\varepsilon(\Xi_b^-)}{\varepsilon(\Omega_b^-)}\frac{N(\Omega_b^-)}{N(\Xi_b^-)}$$

and using the experimentally determined reconstruction efficiency ratio of 1.5 ± 0.2 (stat) yields a relative Ω_b^- / Ξ_b^- production rate times branching ratio of 0.80 ± 0.32 (stat) ${}_{-0.22}^{+0.14}$ (syst). Combining this measurement with a theoretical estimate of the partial decay width ratio of these baryons (9.8), the experimental value of the Ξ_b^- lifetime ($1.42_{-0.24}^{+0.28}$ ps) and the theoretical range of the Ω_b^- lifetime (0.83-1.67 ps), gives the ratio of production rates

$$\frac{f(b\to\Omega_b^-)}{f(b\to\Xi_b^-)}\approx 0.07-0.14$$

References

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