B Baryron Spectroscopy at D0

Ronald Lipton, for the D0 Collaboration
Fermilab
P.O. Box 500, Batavia, Illinois - USA

Abstract

We report on the observation of the Ω_b and Ξ_b baryons with the D0 detector at the Fermilab Tevatron. The Ξ_b was observed in the decay mode $\Xi_b \to J/\Psi\Xi$ with a mass of $5.774 \pm 0.011 \pm 0.015$ GeV/c^2. The Ω_b was observed in the analogous decay mode $\Omega_b \to J/\Psi\Omega$ with a mass of $6.165 \pm 0.010 \pm 0.014$ GeV/c^2.

Key words: B Baryon, Baryon mass
PACS: 14.20.Mr, 14.65.Fy

1. Introduction

In the introductory sessions of this conference we heard the history of the beginnings of the "Hadron Physics and Nuclear Structure" conferences, which later became the PANIC meetings, in 1964. That year is also notable because it was the year of the discovery of the Ω^- baryon, the capstone of the quark model, in much the same way the Higgs is considered the capstone of the standard model today. It is particularly pleasing to report on the discovery by D0 of the "cousin" of the Ω^-, the Ω_b. The Ω^- is composed of three s quarks. The Ω_b replaces one of the s quarks with a b quark. We have previously reported observation of the Ξ_b, which combines an s and d quark with a b quark [1].

Both the Ξ_b and Ω_b analyses use $1.3 fb^{-1}$ of data collected by the D0 detector during Run2a at the Fermilab Tevatron. Many of b physics analyses in D0 depend on the dimuon trigger. This trigger provides a pure, unbiassed $J/\Psi \to \mu\mu$ sample which we use as the basis for this analysis. In addition to the muon trigger the D0 tracking system provides excellent secondary vertex identification using the D0 Silicon Microstrip inner tracker and Scintillating Fiber outer tracker. However, the small inner radius of the D0 solenoid limits our mass resolution compared to the CDF detector.

2. Analysis Strategy

Both the Ξ_b and the Ω_b present complex decay topologies. We look for Ξ_b in the mode $\Xi_b \rightarrow J/\Psi\Xi, J/\Psi \rightarrow \mu\mu, \Xi \rightarrow \Lambda\pi, \Lambda \rightarrow p\pi$ and Ω_b in the similar mode $\Omega_b \rightarrow J/\Psi\Omega, J/\Psi \rightarrow \mu\mu, \Omega \rightarrow \Lambda k, \Lambda \rightarrow p\pi$. In our searches we first optimize $signal/\sqrt{background}$ ratios for the well-established states such as B^+, Λ^0, Ξ, and Ω. We then require well reconstructed vertices for the $p\pi, \Lambda\pi$ or K, and $J/\Psi\Xi$ or Ω combinations. Blind optimization of the ratio of $signal/\sqrt{background}$ for the final states is based on Monte Carlo simulation of signal and data-based calculation of background. No particle ID is available for the final states so we use characteristics of the events themselves to establish background levels and select signal (charge conjugate states are implied):

– In the decay $\Lambda \rightarrow p\pi$ the proton is assumed to have the larger momentum
– Ξ^- decays to $\Lambda(\rightarrow p\pi^-)\pi^-$ (pion signs are correlated)
– Ω^- decays to $\Lambda(\rightarrow p\pi^-)K^-$ (pion and kaon signs are correlated)
– Sidebands of the resonance peaks are used to access backgrounds.

The standard tracking algorithms for D0 limit the impact parameters of tracks with respect to the beam spot. This reduces the level of combinatorics and lowers overall processing time. However decay products of long lived particles like the Ω, Ξ, and Λ typically have large impact parameters which would not be reconstructed by the standard algorithms. The J/Ψ candidate data used in these analyses is reprocessed with an algorithm with looser constraints on track impact parameter.

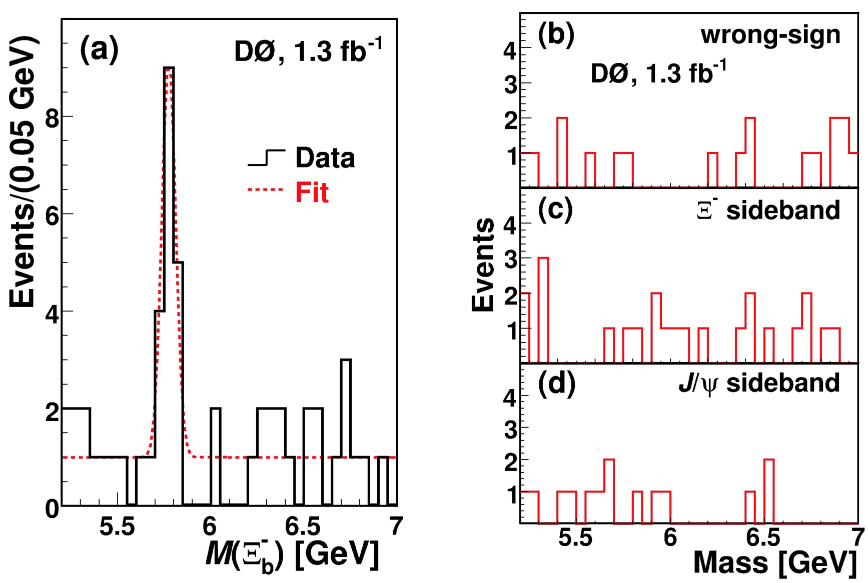

Fig. 1. (a) The invariant mass distribution for Ξ_b candidates . The dotted line is the result of an unbinned likelihood fit to a Gaussian signal and constant background. Mass distributions with wrong sign (b) and sideband (c),(d) backgrounds

3. Ξ_b

Initial cuts for the Ξ_b search are motivated by the topologically similar $\Lambda_b \rightarrow J\Psi\Lambda$ decay. The reconstruction of the Ξ_b signal proceeds by finding dimuon pairs with mass between 2.80 and 3.35 GeV/c^2 and transverse momentum greater than 5 GeV/c. $\Lambda \rightarrow p\pi$ candidates are formed of oppositely charged track pairs which form a secondary vertex and have a mass consistent with the Λ. Lambda candidates are combined with additional tracks which are required to have the same sign as the pion in the Λ and form a vertex with the Λ candidate. Figure 1 shows the distribution of Ξ candidates with both right and wrong sign pions. Finally the Ξ candidates are combined with the J/Ψ candidates and are again required to be consistent with forming a vertex. The cuts are described in more detail in reference [1]. A mass constraint is imposed by subtracting the measured values of the J/Ψ and Ξ masses from the PDG values.

The resulting invariant mass distribution is shown in Figure 1 . We observe a excess of events which corresponds to a yield of 15.2 ± 4.4 events, corresponding to a significance of 5.5σ with a mass of 5.774 GeV/c^2. There is no evidence of peaking in the wrong sign or sideband background distributions. The systematic in the mass error is dominated by the mass shift found when an alternate multivariate technique is used to select events. the resulting mass is: $M(\Xi_b) = 5.774 \pm 0.011 \pm 0.015$ GeV/c^2. We also find the Ξ_b production rate relative to the Λ_b to be $0.28 \pm 0.09^{+0.09}_{-0.08}$. CDF has also reconstructed the Ξ_b in the same mode as well as the mode $\Xi_b^{\pm} \rightarrow \Xi_c^0 \pi^{\pm}$ [2].

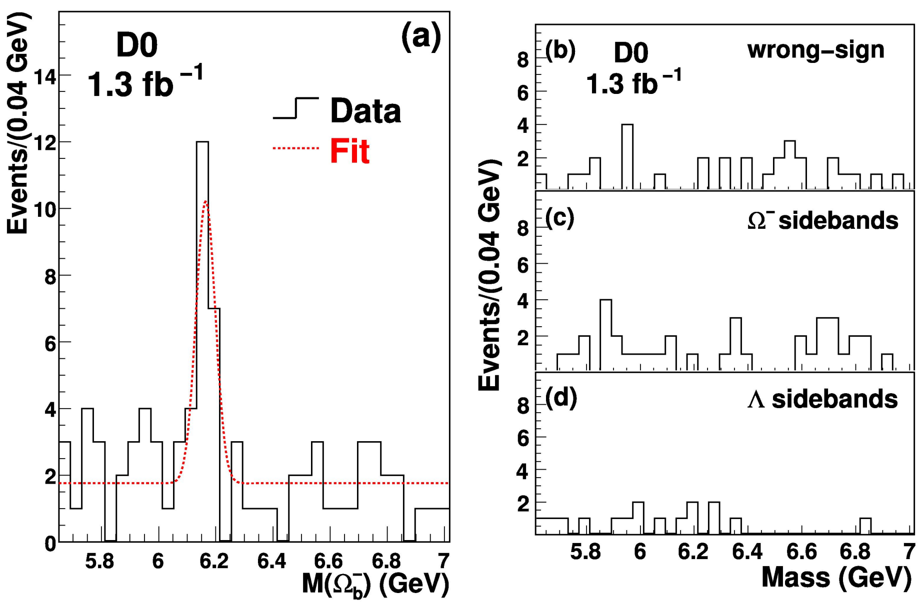

Fig. 2. The invariant mass distribution for Ω_b (left). Mass distributions for wrong sign events, Ω^- sidebands, and Λ sidebands (right).

4. Ω_b

The topology of $\Omega_b \to J\Psi\Omega$ is similar to the Ξ_b decay with the replacement of a pion in the Ξ decay by a kaon in Ω decay. Because we expect a smaller signal/background for the Ω and Ω_b we use a multivariate (boosted decision tree) technique to extract the Ω signal. We also remove events with $\Lambda\pi$ mass less than 1.34 GeV to eliminate Ξ-induced background.

We then apply cuts for the Ω_b based on Monte Carlo generated signal and background extracted from the wrong sign Ω signal. We apply a mass constraint similar to that used for the Ξ_b candidates. This procedure improves the Monte Carlo mass resolution from 80 to 34 MeV/c^2. The resulting mass distribution is shown in Figure 2 . We observe an excess of events near 6.2 GeV, with no evidence of peaking in any of the wrong sign or sideband distributions. A fit using a flat background and Gaussian signal gives a mass of 6.165 ± 0.010 GeV/c^2 with a yield of 17.8 ± 4.9 events and statistical significance of 5.4σ. The signal survives replacement of the multivariate cuts by individual cuts with reduced significance. Varying the selection cuts results in a maximum 0.012 GeV/c^2 shift in mass, which is the major systematic error in the mass determination, giving a measured mass of $6.165 \pm 0.010 \pm 0.013$ GeV/c^2. We note that this mass is significantly above recent theoretical predictions, which cluster near 6.050 GeV/c^2 [4] [5] [6] [7].

5. Conclusions

D0 has observed which we interpret as the Ξ_b(dsb) and Ω_b(ssb) baryons in decays to $J/\Psi\Xi$ or Ω. The reconstructed masses are:
– $M(\Xi_b) = 5.774 \pm 0.011 \pm 0.015$ GeV/c^2
– $M(\Omega_b) = 6.165 \pm 0.010 \pm 0.013$ GeV/c^2
The outstanding performance of the Tevatron should provide final b-physics samples a factor of four larger than the data reported in this analysis by the end of 2009. The prospects are very good for improved precision of the mass measurements and reconstruction of increasingly rare and complex decay modes.

References

[1] V. Abazov, et al. (D0 Collaboration), Phys. Rev. Lett. 99, 052001 (2007).
[2] T. Aaltonen, et al. (CDF Collaboration), Phys. Rev. Lett. 99, 052002 (2007)
[3] V. Abazov, et al. (D0 Collaboration), Phys. Rev. Lett. 101, 232002 (2008).
[4] D. Ebert, R. N. Faustov, V. O. Galkin, Phys. Lett. B 659 (2008) 612.
[5] W. Roberts, M. Pervin, Int. J. Mod. Phys. A23:2817-2860, 2008.
[6] E. E. Jenkins, Phys. Rev. D 77, 034012 (2008).
[7] M. Karliner et al., arXiv:0804.1575,