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Observation of the Doubly Strange b–Baryon Ω_b^- with the DØ Detector

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We report the first observation of the doubly strange b–baryon Ω_b^- in the decay channel

$$\Omega_b^- \to \overbrace{J/\psi(1S)}^{\mu^+\,\mu^-}\ \underbrace{\Omega^-}_{\underbrace{\Lambda^0}_{p\,\pi^-}\ K^-}$$

in $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV.

Using approximately 1.3 fb^{-1} of data collected with the DØ detector at the Fermilab Tevatron Collider, we observe 17.8 ± 4.9 (stat) $\pm$ 0.8 (syst) Ω_b^- signal events at a mass of 6.165 ± 0.010 (stat) $\pm$ 0.013 (syst) GeV/c^2 with a significance of 5.4 σ, meaning that the probability of the signal coming from a fluctuation in the background is 6.7×10^{-8}.

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1. *b*–Baryon Observation

Before Tevatron RunII, the only *b*–baryon observed was the Λ_b^0. Since then, the CDF collaboration reported the observation of Σ_b^+ and Σ_b^{*+} in 2006 [1], and the DØ Collaboration presented the Ξ_b^- in 2007 [2] followed by its confirmation by CDF the same year [3]. In 2008, DØ reported the observation of another *b*–baryon: the Ω_b^- [4]. Since 2002, Tevatron have produced a large amount of data, approximately 6 fb^{-1} of integrated luminosity, and it is expected to increase until at least 10 fb^{-1}. This makes Tevatron a unique environment for *b*–baryon observation and gives both collaborations room for the search of some of the remaining *b*–baryons.

2. Search of Ω_b^- at DØ

Due to the maximum IP of 2.5 cm used in the standard reconstruction of tracks in the DØ data, final products of long–lived particles may lie in a region of non–standard–reconstruction, decreasing the efficiency in the identification of long–lived particles, like in this case the Λ^0. A special tracking reconstruction –which increases the efficiency in the identification of long–lived particles–, was used in this analysis[1]. The most important characteristics of this special tracking are: (*i*) the increment of the maximum IP for accepted tracks from 2.5 cm to 10 cm and (*ii*) the modification of the minimum radius of curvature to allow the reconstruction of tracks with lower curvature compared with the standard reconstruction, Fig. 1.

The search for the Ω_b^- (and its charge conjugate modes) was made in 1.3 fb^{-1} of data collected with the DØ detector [5] and processed with the special tracking; following the decay channel $\Omega_b^- \to J/\psi(1S)\,\Omega^-$, with $J/\psi(1S) \to \mu^+\,\mu^-$ and $\Omega^- \to \Lambda^0\,K^-$, where Λ^0 decays to $p\,\pi^-$, schematically shown in Fig. 1.

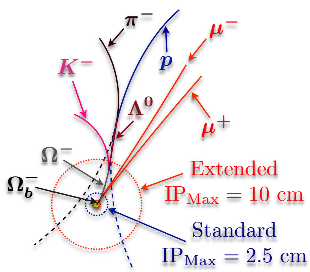


Figure 1: Special Tracking Reconstruction. Dotted tracks are the extrapolation of tracks missed by the Standard Reconstruction.

3. Decay Reconstruction and Optimization

In a sample containing $J/\psi(1S) \to \mu^+\,\mu^-$ events, we look for $\Lambda^0 \to p\,\pi^-$ candidates to combine them with charged tracks identified as K's. These combinations are divided in two sets: K and π with same–sign charge are known as *Correct–sign* and *Wrong–sign* when their charges are opposite. Correct–sign combinations show a resonance around the Ω^- PDG–mass mean value

[1]The same tracking reconstruction in which the Ξ_b^- was observed.

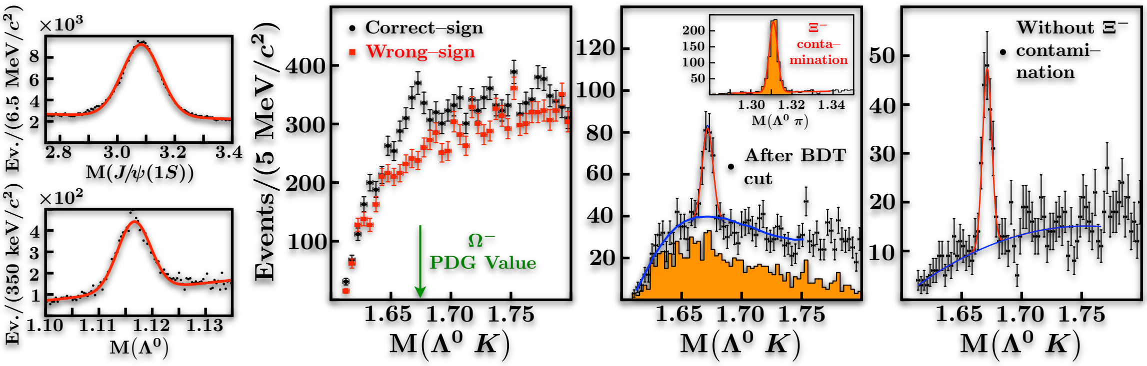


Figure 2: Intermediate particle reconstruction.

(1,672.45 MeV/c^2), while wrong–sign seem to represent a good description of the background, Fig. 2. In order to clean the $\Lambda^0 K$ signal, a twenty–variable BDT classifier [6], is used to distinguish between signal and background. Information of $\Omega^- \to \Lambda^0\, K^-$ from a MC sample of $\Omega_b^- \to J/\psi(1S)\; \Omega^-$ decays is used as training–signal and wrong–sign combinations as training–background. Another source of background is the cross–feed contamination from $\Xi^- \to \Lambda^0\; \pi^-$ decays which may appear as the result of identification of the charged track as a π instead of K. Events which consistently reconstruct a Ξ^- appear distributed as background in the Ω^- mass window and are removed to produce a cleaner Ω^- signal, Fig. 2, rightmost histogram.

The combination of the $J/\psi(1S)$ with the final Ω^- candidates was optimized in a blind way looking at the rejection fraction obtained with cuts on the $p_T(J/\psi(1S)\; \Omega^-)$ and the uncertainty in the proper decay length, $\sigma\left(\lambda_{J/\psi(1S)\;\Omega^-}\right)$, comparing MC as signal and wrong–sign as background to decide the cut points which give the best compromise between removing most of the background without the elimination of possible signal events. These cuts are: $p_T(J/\psi(1S)\; \Omega^-) > 6.0$ GeV/c and $\sigma\left(\lambda_{J/\psi(1S)\;\Omega^-}\right) < 0.03$ cm.

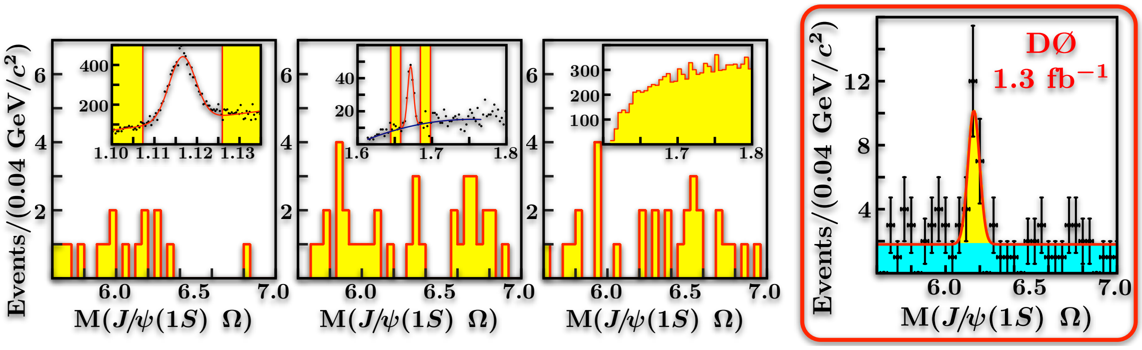
In order to improve the mass resolution of the final combination, the following definition for the mass is used: $M_{\Omega_b^-} \equiv M_{J/\psi(1S)\;\Omega^-} - M_{J/\psi(1S)} - M_{\Omega^-} + M^{\rm PDG}_{J/\psi(1S)} + M^{\rm PDG}_{\Omega^-}$.

The mass window for the search of the Ω_b^- was chosen taking as reference for its lower limit the mass of the lightest b–baryon, the Λ_b^0, and approximately 1 GeV/c^2 above the predicted mass for the Ω_b^- [7] as the upper limit, setting the window between 5.6 and 7.0 GeV/c^2.

This method applied to a MC sample of $\Omega_b^- \to J/\psi(1S)\; \Omega^-$ events, was able to reproduce the input value for the mass used to generate the sample itself.

4. Control Samples

Before the method previously described was applied to the right–sign sample, it was used over different control samples to discard possible artificial generation of signal events due to the method itself. Λ^0 and Ω^- sidebands, wrong–sign combinations, as well as high statistics MC samples for similar topology decays like $\Xi_b^- \to J/\psi(1S)\; \Xi^-$ and $B^- \to J/\psi(1S)\; K^*(892)^-$ were analyzed. None of these control samples showed any excess of events, Fig. 3a.



(a) Left to right: Λ^0 sidebands, Ω^- sidebands and wrong–sign combinations. (b) Right–sign combinations.

Figure 3: $J/\psi(1S)$ combined with control samples and right–sign.

5. Right–Sign Combinations

The method applied to right–sign combinations result in 79 events inside the given mass window with an excess of events around 6.2 GeV/c^2, Fig. 3b. An unbinned extended log–likelihood fit with a Gaussian function as signal[2] plus a flat function as background was made over this distribution. The fit gives a mass for the $J/\psi(1S)\ \Omega^-$ combination of $6.165 \pm 0.010(\text{stat})$ GeV/c^2 with $17.8 \pm 4.9(\text{stat})$ events. A systematic error in the mass measurement of 13 MeV/c^2 is estimated from the sources summarized in Table 1. The significance of the signal is evaluated taking the logarithmic likelihood ratio $\sqrt{2\ln(\mathscr{L}_{S+B}/\mathscr{L}_B)}$, being $\mathscr{L}_{S+B}$ the likelihood of the hypothesis Gaussian signal plus flat background and $\mathscr{L}_B$ the likelihood which corresponds to the only–background contribution. The significance of this signal is 5.4 σ, equivalent to a probability of 6.7×10^{-8} to come from a fluctuation in the background.

Source	Contribution (MeV/c^2)
Linear Background	Negligible
Variation in Gaussian width	3
Momentum Scale Correction	4
Event Selection	12

Table 1: Sources of systematic error in the mass measurement of Ω_b^-.

6. Crosschecks

A series of crosschecks support the signal found. A harder cut on the $p_T(J/\psi(1S)\ \Omega^-)$ distribution, this time above 7.0 GeV/c, result in a signal with consistent mass and significance of 6.0 σ. The replacement of multivariate techniques with a selection of Ω^- candidates based on cuts reduces the significance of the signal to 3.9 σ because of the presence of a higher background, but still yields a consistent mass and number of events. The combination of events obtained from both selections:

[2] The width of the Gaussian is fixed to that of the MC $\Omega_b^- \to J/\psi(1S)\ \Omega^-$ sample, 34 MeV/c^2.

the BDT–based plus the cuts–based, gives a signal with significance 5.4 σ, 25.5 ± 6.5 (stat) events and consistent mass –after the removal of event double counting–.

7. Production Ratio

The last part of the analysis consists on the evaluation of the production ratio between the Ω_b^- and the Ξ_b^- [2]. This was estimated to be:

$$\mathscr{R} = \frac{f(b \to \Omega_b^-) Br(\Omega_b^- \to J/\psi(1S)\ \Omega^-)}{f(b \to \Xi_b^-) Br(\Xi_b^- \to J/\psi(1S)\ \Xi^-)} = \frac{\varepsilon(\Xi_b^-) N(\Omega_b^-)}{\varepsilon(\Omega_b^-) N(\Xi_b^-)} = 0.80 \pm 0.32\ (\text{stat})^{+0.14}_{-0.22}\ (\text{syst})$$

with $\varepsilon(\Xi_b^-)/\varepsilon(\Omega_b^-) = 1.5 \pm 0.2$ (stat) and $N(\Omega_b^-)$, $N(\Xi_b^-)$ the corresponding yields.

8. Conclusion

Using approximately 1.3 fb^{-1} of data collected with the DØ detector at the Fermilab Tevatron Collider, we observe 17.8 ± 4.9 (stat) $\pm$ 0.8 (syst) Ω_b^- signal events at a mass of 6.165 ± 0.010 (stat) $\pm$ 0.013 (syst) GeV/c^2 with a significance of 5.4 σ. The production ratio $\mathscr{R}$ relative to the previously measured Ξ_b^- is 0.80 ± 0.32 (stat)$^{+0.14}_{-0.22}$ (syst). This observation represent the first experimental evidence of the b–baryon Ω_b^-.

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