Observation of the Ξ_b^0 baryon

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for the CDF Collaboration

The first observation of the heavy baryonic state Ξ_b^0 is reported by the CDF Collaboration. A new decay mode of the established state Ξ_b^- is also observed. In both cases the decay into a Ξ_c plus a charged pion is seen, with an equivalent statistical significance of above 6.8σ.

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1. Introduction

The quark model of elementary particles is well established and has a impressive history of success in its account of hadronic states. Nevertheless, it is important to continue to test it by searching for hitherto unobserved particles that are predicted to exist, both to provide continued confirmation of the quark model, and to provide a background for the possible discovery of unusual types of particle. In this presentation we report the first observation, by the CDF Collaboration, of a new baryonic state, the Ξ_b^0 [1]. This consists of a bsu quark combination and fills an important gap in the set of baryons containing a b quark.

One possible search strategy would be to look for decays of a hypothesized b state into the easily-identifiable J/ψ meson. This will not succeed in the present case because of the unavoidable presence of a π^0 in the decay chain, which is hard to vertex precisely. Instead, we have made use of the decay $\Xi_b^0 \to \Xi_c^+ \pi^-$, which has the merit that the previously unobserved decay $\Xi_b^- \to \Xi_c^0 \pi^-$ can also be sought using a parallel search scheme. The Ξ_b^- is a known state, and its observation provides a check on the methodology employed here.

The decay chains that are used in the present study are as follows. (Throughout this account, the corresponding charge conjugate states are also implied.)

$$
\begin{array}{rcl}
\Xi_b^0 & \to & \Xi_c^+ \pi^- \\
\Xi_c^+ & \to & \Xi^- \pi^+ \pi^+ \\
\Xi^- & \to & \Lambda \pi^- \\
\Lambda & \to & p \pi^-
\end{array}
\qquad\qquad
\begin{array}{rcl}
\Xi_b^- & \to & \Xi_c^0 \pi^- \\
\Xi_c^0 & \to & \Xi^- \pi^+ \\
\Xi^- & \to & \Lambda \pi^- \\
\Lambda & \to & p \pi^-
\end{array}
$$

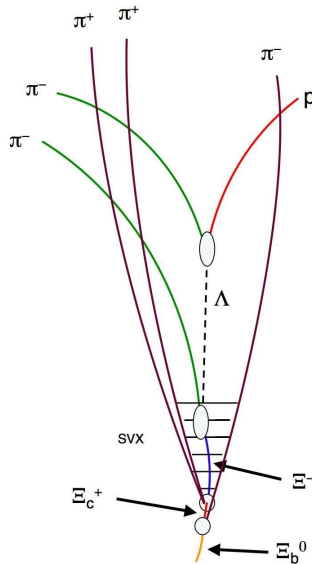The Ξ_b^0 decay chain is depicted in figure 1.

Figure 1: Schematic depiction of the Ξ_b^0 decay chain in the mode studied here.

2. Search method

The CDF II detector is a multi-purpose detector situated at the Fermilab Tevatron. Inside a solenoid that provides a 1.4 T axial magnetic field, an array of coaxial silicon detector layers (SVX) is surrounded by the Central Outer Tracker, which is a drift detector containing axial and angled layers of wires. It is these detector systems that are used in the present analysis. A displaced track trigger, using silicon and COT information, is used to record suitable events for analysis by requiring two charged tracks that do not point to the beam line. A data sample of integrated luminosity 4.2 fb^{-1} formed the basis of the present search.

The reconstruction method starts with an identification of Λ candidates by plotting the invariant mass of track pairs of opposite charge and transverse momentum (p_T) greater than 0.4 GeV/c. The higher-momentum track is taken as a proton and the lower as a π^-. The tracks must form a good vertex more than 1 cm from the beamline. Mass cuts around the Λ peak select suitable candidates with good efficiency.

The Λ candidates are then paired with charged tracks to form Ξ^- candidates, taking the charged track as a π^- and requiring a good quality $\Lambda\pi^-$ intersection at a vertex point. The flight distance of the Λ from the Ξ^- vertex and the flight distance of the latter from the beamline must both exceed 1 cm. Silicon detector hits are now demanded on the postulated Ξ^- track, and a new vertex fit is performed. This procedure improves the quality of the Ξ^- peak-to-background ratio dramatically, as seen in figure 2.

The third step in reconstruction is to combine the Ξ^- candidates with one or two positive tracks, taken as π^+, to form Ξ_c candidates (figure 3a, b). The pion tracks must have more than two silicon detector hits for precise vertexing, a p_T of at least 2 GeV/c, and an impact parameter of at least 100 μm relative to the beam line. The combination must have a well-fitted vertex, a total p_T of at least 4 GeV/c, and a calculated decay *ct* value of at least 100 μm. This procedure yields well-characterised Ξ_c mass peaks at the expected values (figure 3a,b). A selection broadly covering the peaks is made to maximise efficiency, retaining 2110 $\pm$70 Ξ_c^0 candidates and 3048 $\pm$67 Ξ_c^+.

Finally, the Ξ_c candidates are each paired with a further negative track, taken as a π^-. This must satisfy $p_T > 6$ GeV/c, and a fully constrained vertex fit is performed using the extrapolated Ξ_c direction, enforcing all the previously assumed baryon masses. The position of the fitted vertex
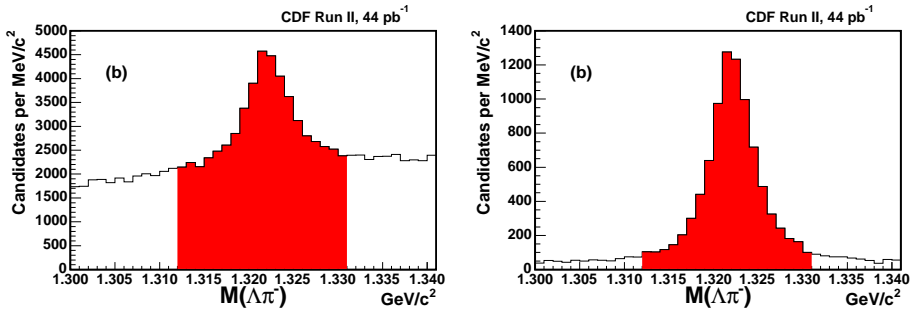

Figure 2: Illustrations of $\Lambda\pi^-$ invariant mass distribution (a) without and (b) with the requirement of silicon detector hits on the expected Ξ^- track.
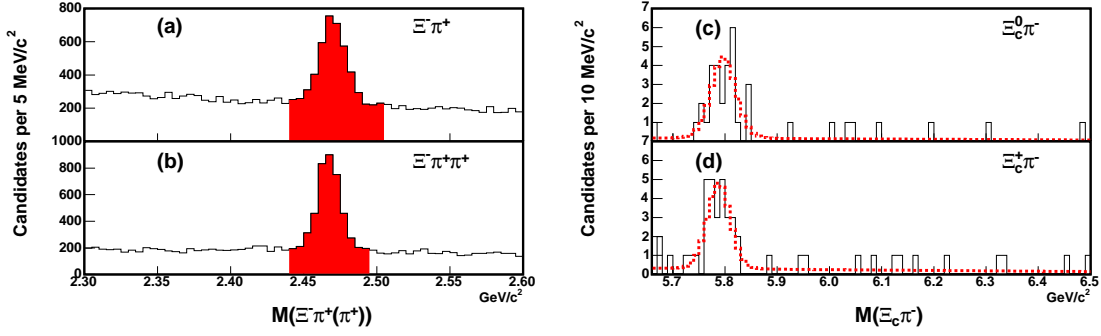
Figure 3: (a) $\Xi^- \pi^+$ and (b) $\Xi^- \pi^+ \pi^+$ invariant mass distributions showing Ξ_c^0 and Ξ_c^+ peaks; (c) $\Xi_c^0 \pi^-$ and (d) $\Xi_c^+ \pi^-$ invariant mass distributions, showing Ξ_b^- and Ξ_b^0 peaks.

must correspond to a subsequent Ξ_c decay time that satisfies $-2\sigma < t < 3t + 2\sigma$, using the measurement uncertainty σ and the known mean decay time t of the Ξ_c. This formalism takes account of the very different decay distances, 440 μm and 110 μm, of the Ξ_c^+ and Ξ_c^0 respectively. At least one of the charged pions used at this stage and also at the previous stage must satisfy the displaced track trigger requirements.

3. Results

The results of the final stage are shown in figure 3c, 3d, where the invariant masses of the $\Xi_c \pi^-$ combinations are plotted. In both combinations, a clear mass peak is seen. In the $\Xi_c^0 \pi^-$ case the peak is interpreted as the established Ξ_b^- state at this mass, of which this is an expected decay channel, thus providing a check on the present procedure. We interpret the peak in the $\Xi_c^+ \pi^-$ combination as an observation of the predicted Ξ_b^0 state, seen here for the first time. The two peaks are of similar magnitude, consistent with general expectations. When an unbinned likelihood fit is performed to a Gaussian peak on a linear background, an equivalent significance of 6.8σ is found in both cases using a likelihood ratio test.

Systematic uncertainties are estimated by comparing particle masses measured in the present fit process with their standard values. The fit gives peaks contining $25.8^{+5.5}_{-5.2}$ Ξ_b^- baryons and $25.3^{+5.6}_{-5.4}$ Ξ_b^0. The fitted mass of the Ξ_b^0 is 5787.8 $\pm$5.0 (stat.) $\pm$1.3 (sys.) GeV and that of the Ξ_b^- is 5796.7 $\pm$5.1 (stat.) $\pm$1.4 (sys.) GeV, in agreement with the value of 5791 $\pm$3 GeV measured in the $J/\psi \Xi^-$ decay channel [2]. Using the latter Ξ_b^- mass value, we obtain a mass difference $m(\Xi_b^-) - m(\Xi_b^0)$ between the two states of 3.1 $\pm$5.6 (stat.) $\pm$1.3 (sys.) GeV.

In summary, measuring $\Xi_c \pi^-$ decay modes using the CDF II detector, we have made the first observation of the Ξ_b^0 state, and also the first observation of the Ξ_b^- state in this decay mode.

References

[1] CDF Collab., T. Aaltonen et al., Phys. Rev. Lett. 107 (2011) 031104 [hep-exp/1107.4015].

[2] CDF Collab., T. Aaltonen et al., Phys. Rev. D 80 (2009) 072003 [hep-exp/0905.3123].