Recent CDF results on heavy and exotic baryons in p-pbar collisions at $\sqrt{s} = 1.96\,\mathrm{TeV}$

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1. INTRODUCTION

Since March 2001 a new period of CDF data taking (called Run II) began at the $p\bar{p}$ Tevatron collider. The upgrade of Collider Detector at Fermilab improved the tracking system: the vertexing, triggering and particle identification capabilities. This has allowed a further development of B physics, because the B_s and Λ_b are produced in hadronic collisions. Here measurements of the mass and lifetime of Λ_b in two decay channels are presented. Using particle identification (PID) information from the time of flight and the dE/dx, CDF performed pentaquark searches for Θ^+, $\Xi_{3/2}^{--,0}$ and Θ_c^0, following the recent interest in exotic baryon spectroscopy.

2. BOTTOM BARYONS

2.1. Λ_b mass

Using several exclusive decay modes, CDF measures the B meson masses and at present the measurements of the B_s and Λ_b mass are the world's most precise. For this measurement, CDF uses the J/ψ trigger, which is also important for the momentum scale calibration. The Λ_b mass is measured in the $J/\psi\Lambda$ channel ($5619\pm1.2\pm1.2\,\mathrm{MeV/c^2}$) and it is consistent with the CDF RunI measurement and in excellent agreement with the PDG value ($5624\pm9\,\mathrm{MeV/c^2}$).

2.2. Λ_b lifetime

Using 88$\pm$10.3 $\Lambda_b \to \Lambda J/\psi$ candidates in the J/ψ sample, CDF measures the Λ_b lifetime for the first time in a fully reconstructed mode. The prediction from NLO Heavy Quark Expansion [1] for the Λ_b/B^0 ratio of lifetime is 0.87$\pm$0.05. We use the high statistics $B^0 \to J/\psi K_S^0$ sample, which is topologically similar to the Λ_b decay, as a control sample. We found $\tau(B^0)$=1.38$\pm$0.10 ps, within $1.5\,\sigma$ of current world average. Having validated our method we go on to measure the lifetime of the Λ_b and we measure $\tau(\Lambda_b)$=1.25$\pm$0.26$\pm$0.10 ps which is consistent with the PDG average ($\tau(\Lambda_b)$=1.229$\pm$0.08 ps).

2.3. Measurement of $\Lambda_b \to \Lambda_c\pi$

CDF has made the first observation of $\Lambda_b \to \Lambda_c\pi$ in the so-called Two-Track Trigger (TTT) sample. The TTT sample collect tracks with non zero impact parameter at trigger

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level and is used especially to collect a large sample of B decays. Measurements of the ratios of branching ratios are more precise than absolute measurements since most of systematic errors cancel. We use the large statistics $\bar{B}^0 \to D^+\pi^-$ sample as the reference sample. Figure 1 (center) shows the $\Lambda_c\pi$ mass distribution; the peak contains 96±13 events. Reflections from B meson decays and partially reconstructed B hadrons lie to the left of the peak. Using the 2002 PDG fragmentation ratio (FR) $f_{barions}/f_d = 0.304 \pm 0.053$ to extract the relative branching ratio, the final result is:

$$\frac{BR(\Lambda_b \to \Lambda_c^+\pi^-)}{BR(\bar{B}^0 \to D^+\pi^-)} = 2.2 \pm 0.4(stat) \pm 0.3(syst) \pm 0.7(BR + FR) \qquad (1)$$

2.4. Search for $\Lambda_b \to pK, p\pi$

A large direct CP violation amplitude is expected in the charmless decay $\Lambda_b \to pK, p\pi$. Predictions for the branching ratio are: $Br(\Lambda_b \to pK)$=(1.4-1.9)$\times 10^{-6}$ and $Br(\Lambda_b \to p\pi)$=(0.8-1.2)$\times 10^{-6}$ [6]. The previous upper limit was set by ALEPH $Br(\Lambda_b \to pK + p\pi) < 50\times 10^{-6}$ @90%C.L.. In the plot in Figure 1, the main peak is dominated by $B^0 \to K^-\pi^+$, $B^0 \to \pi^+\pi^-$ and $B_s \to K^+K^-$ decays. Optimization has been performed excluding the signal region. The result is a new upper limit: $Br(\Lambda_b \to pK + p\pi) < 22\times 10^{-6}$ @90%C.L..

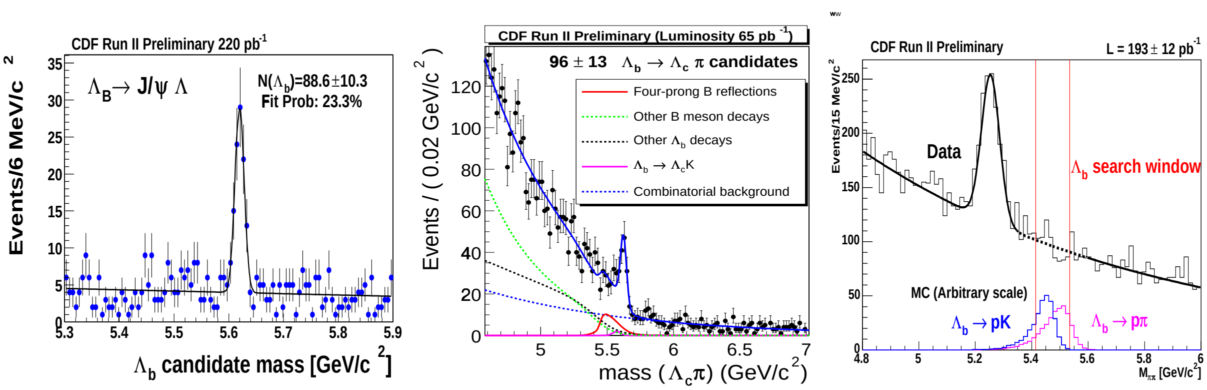

Figure 1. Left: the mass distribution for Λ_b candidates. The result of the log likelyhood fit is superimposed. Center: the $\Lambda_b \to \Lambda_c\pi$ mass fit. Right: invariant mass distribution for 2-body B decays with the pion mass assumption. The two red lines define the search window for $\Lambda_b \to pK$ and $\Lambda_b \to p\pi$. The two MC plots are the mass distribution for the two decay modes using an arbitrary scale.

3. PENTAQUARK SEARCHES

Beginning in the summer of 2003, several experiments have reported evidence for pentaquark states, exotic baryons composed of 5 quarks ($4q$ and $\bar{q}$ of different flavor), predicted in at least 3 models [3–5]. A recent review [2] gives an overview of the experimental situation, citing 13 reports of positive evidence and 16 reports of no observation.

3.1. Search for $\Theta^+ \to pK_S^0$

We look for the lightest member ($uudd\bar{s}$) of the antidecuplet of light exotic baryons. The predicted mass is near 1530 MeV/c^2 and the width $\Gamma \leq 15$ MeV/c^2. The Θ^+ is expected to decay almost immediately into equal fractions of nK^+ and pK^0. No reliable cross-section models exist for Θ^+ production. Therefore, we analyze two different data samples to be sensitive in two different production mechanisms: inelastic collisions with minimal trigger requirements, where hadron production is dominated by soft processes of the beam remnants (`minimum-bias` and `zero-bias` datasets) and inelastic collisions with a high p_T threshold, where hadron production results from the final stages of the fragmentation of high-energy jets (`Jet20` dataset). From both samples K^0_S peaks are clearly reconstructed, removing $\Lambda \to p\pi^-$ contamination and with K^0_S p_T >0.5 GeV/c. For the proton selection we use the TOF system. The pions and kaons span a momentum range of 0.5–1.3 GeV/c and the protons 0.5–2.1 GeV/c. Two tracks, or one track plus a K^0_S, are combined to give high statistic reference signals: $\Lambda(1520)$ and K^{*+} (see Figure 2). The transverse momentum range for which the resonances can be reconstructed is largely determined by the implicit momentum cuts of the TOF separation requirement. The $\Theta^+ \to pK^0_S$ decay acceptance is in the momentum range $1.5 \le p_T \le 4.5$ GeV/c. We did not find any resonance structure in the search window (see Figure 2). In $\sim 22 \times 10^6$ inelastic collisions, collected with a `minimum-bias` trigger, the number of reconstructed $\Lambda(1520)$ is 3276±327 and the limit on Θ^+ yield is <89 @90%C.L.. In a follow-up of this study we will determine the relative efficiency of $\Theta^+ \to pK^0_S$ with respect to other resonances and a limit on the relative production cross-sections.

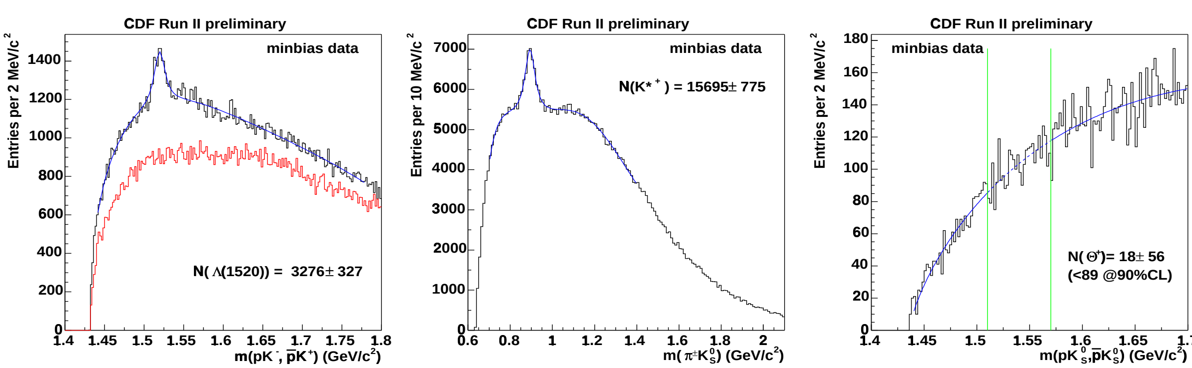

Figure 2. Left: invariant mass spectrum of the pK^- and (pK^+) combinations showing the $\Lambda(1520)$ reference signal. Center: invariant mass spectrum of the $K^0_S\pi^+$ combinations showing the K^{*+} reference signal. Right: invariant mass spectrum of pK^0_S combinations; the two vertical lines indicate the search window (1.51–1.57 MeV/c^2).

3.2. Search for $\Xi^{--,0}_{3/2}$

Manifestly exotic baryons decaying to $\Xi^-\pi^-$ and $\Xi^-\pi^+$ were recently claimed by NA49 experiment. CDF uses standalone silicon tracking of long-lived Ξ hyperons which achieves background reduction and improved momentum and impact parameter resolution. We have used clean sample of Ξ hyperons to search for exotic states decaying to $\Xi\pi$. The normal cascade are long-lived particles which leaves hits in the silicon vertex detector and the decay chain under study is: $\Xi^{--,0}_{3/2} \to \Xi^-\pi^{-,+}, \Xi^- \to \Lambda\pi^-, \Lambda \to p\pi^-$. For the exotic cascade search, two different kind of data were used: the TTT sample and `Jet20` sample.

In both set the Ξ^- is reconstructed, but no narrow resonances around 1860 MeV/c^2 are visible in $\Xi\pi$ combinations (see Figure 3).

3.3. Search for $\Theta_c^0 \to D^{*-}p$

CDF has searched for charmed pentaquarks, which have been reported by H1. Many reference modes for the Θ_c^0 have been reconstructed at CDF: $D^{**} \to D^{*+}\pi^-$, $D^{**} \to D^{*+}\pi$ with $D^{*+} \to D^+\pi^0$ and $D^{**} \to D^{*0}\pi^+$ with $D^{*0} \to D^0\pi^0$. The particle identification is performed using the TOF and the dE/dx energy loss. The PID requirements are optimized on an independent calibration sample ($\Lambda_c \to pK\pi$). The D^0p channel corresponds to the Θ_c^+. The results for all channels ($\Theta_c^0 \to D^{*-}p$, $\Theta_c^0 \to D^-p$, $\Theta_c^0 \to D^0p$, $\Theta_c^+ \to \bar{D}^0p$) are negative: no narrow resonances are seen in the expected mass region (see for example Figure 3).

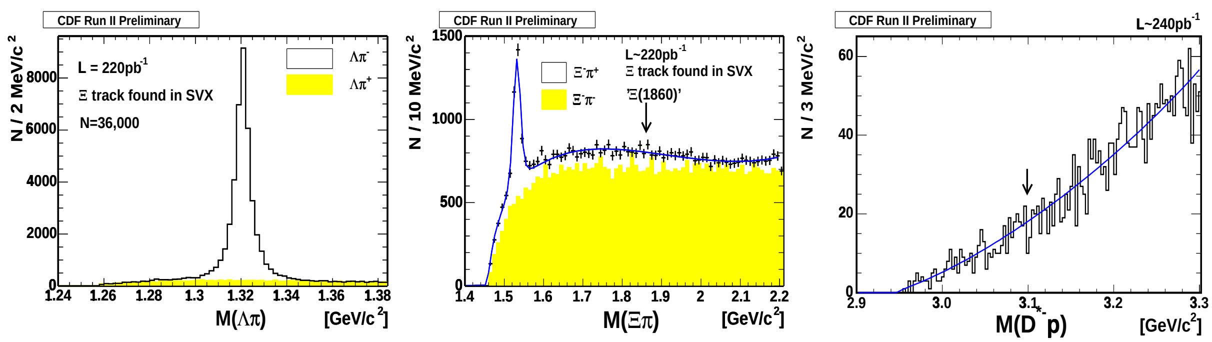

Figure 3. Left: invariant mass spectrum of $\Lambda\pi$ combination showing the Ξ cascade. Center: invariant mass spectrum of $\Xi^-\pi^+$ and $\Xi^-\pi^-$ combinations. The arrows mark the mass at 1862 GeV/c^2. The peak corresponds to the decay $\Xi(1530) \to \Xi^-\pi^+$. Right: m(D^*p) mass spectrum. The arrow indicates the position of the H1 signal.

4. CONCLUSIONS

Recent CDF studies of Λ_b bottom baryon have been presented. Despite good mass resolution, particle identification and high statistic reference signals, CDF does not see evidence for pentaquarks. This may mean that the pentaquark production from fragmentation is severely suppressed.

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