Latest Results on Bottom Spectroscopy and Production with CDF

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Abstract

Using data collected with the CDF Run II detector, new measurements on bottom production cross-sections are presented. The latest achievements in bottom hadron spectroscopy are discussed. The results are based on a large sample of semileptonic and hadronic decays of bottom states made available by triggers based on the precise CDF tracking system.

1 First Observation of the Baryons $\Sigma_b$ and $\Sigma_b^*$ in CDF

The bottom $\Sigma_b^{(*)}$ states decay strongly into $\Lambda_b^0$ by emitting soft pion as shown in Figure 1. Our results are based on data collected with the CDF II detector [2] and corresponding to an integrated luminosity of $\sim 1.1 \text{ fb}^{-1}$. The trigger used in this study is based on displaced tracks. It reconstructs with the central tracker a pair of $p_T \gtrsim 2.0 \text{ GeV}/c$ tracks at Level 1 and enables secondary vertex selection at Level 2 requiring each of these tracks to have impact parameter measured by the CDF silicon detector SVX II larger than 120 $\mu$m. The signals of $\Sigma_b^{(*)\pm}$ states were sought in the decay chain $\Sigma_b^{(*)\pm} \to \Lambda_b^0 \pi^{\pm}_{\text{soft}}, \Lambda_b^0 \to \Lambda_c^+ \pi^-, \Lambda_c^+ \to pK^-\pi^+$. To remove the contribution due to a mass resolution

of each $\Lambda_b^0$ candidate and to avoid absolute mass scale systematic uncertainties, the $\Sigma_b^{(*)\pm}$ candidates were reconstructed in the mass difference $Q$-value spectra defined as $Q = M(\Lambda_b^0 \pi^{\pm}_{\text{soft}}) - M(\Lambda_b^0) - M_{\text{PDG}}(\pi^{\pm})$ for every charge state of $\Sigma_b^{(*)\pm}$ candidates. Here we assume also that the width of the weakly decaying $\Lambda_b^0$ candidate is determined by the corresponding detector mass resolution. The fitted experimental spectra are shown at Figure 2 and fit results are summarized in Tables 1 and 2 [3].

Figure 1: The low lying $\Sigma_b$- and $\Lambda_b$-like $b$-baryons and their strong decays with pion emissions.
2 Observation and Mass Measurement of the Baryon $\Xi_b$

The bottom cascade baryons $\Xi_b$ consist of a single bottom quark, one strange quark and one light quark. Theoretical predictions for these heavy baryons are outlined in Table 3. We consider the lowest lying $\Xi_b$ states that decay weakly and the $\Xi_b^{(*)}$ states that decay radiatively or strongly via pion emission. The $\Xi_b$ candidates are reconstructed in the decay chain $\Xi_b \rightarrow J/\psi \Xi^-$ with secondary states $J/\psi \rightarrow \mu^+\mu^-$ and $\Xi^- \rightarrow \Lambda^0\pi^-$, $\Lambda^0 \rightarrow p\pi^-$ (see Figure 3). Since experiments with bubble chambers the strange cascade, given its long decay path of $c \cdot \tau = 4.91$ cm, is identified as a charged track with a 1-track decay vertex at the end formed by a kinked soft pion track as shown at Figure 3. The subse-

Table 1: The masses resulting from the simultaneous fit of both spectra [9].

| State | $Q$ or $\Delta\Sigma^+$ (MeV/c²) | Mass (MeV/c²) |
|-------|----------------------------------|---------------|
| $\Sigma^+_b$ | $Q_{\Sigma^+_b} = 48.5^{+2.0+0.2}_{-2.2-0.3}$ | 5807.8$^{+4.0}_{-2.2}$ ± 1.7 |
| $\Sigma^-_b$ | $Q_{\Sigma^-_b} = 55.9 \pm 1.0 \pm 0.2$ | 5815.2 ± 1.0 ± 1.7 |
| $\Sigma^0_{b*}$ | $\Delta\Sigma^+ = 21.2^{+0.0+0.4}_{-1.9-0.3}$ | 5829.6$^{+1.6+1.7}_{-1.8-1.8}$ |

Table 2: The fitted yields [9] of the identified $\Sigma^0_{b*}$ states. The combined significance of all four peaks relative to the null hypothesis well exceeds 5 Gaussian standard deviations.

Table 3: Theoretical expectations for properties of bottom cascade baryons containing a single $b$- quark [9]. The lowest lying states have a light quark pair with momentum $j_{sq} = 0$ while the next ones have light quarks aligned with $j_{sq} = 1$. 

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3 Correlated $b\bar{b}$ Production in CDF II Detector

In this chapter we cover briefly a unique analysis on a paired $b\bar{b}$ production measurement. As leading order (LO) processes dominate $b\bar{b}$ production, $\sigma_{b\bar{b}}$, while next-to-leading (NLO) processes are essential for inclusive $\sigma_{b\bar{b}}$ studies, the measurement of $\sigma_{b\bar{b}}$ will help to disentangle LO and NLO contributions and to resolve the controversy between the Run I DØ and CDF measurements [8]. We select dimuon events with invariant masses $5 < M(\mu^+\mu^-) < 80 \text{ GeV}/c^2$, outside of the domain populated by sequential decays of single $b$-quarks and $Z^0$ modes, and extract $\sigma(b \rightarrow \mu^- + X, \bar{b} \rightarrow \mu^+ + X)$, subtracting contributions from $c\bar{c}$, prompt Drell-Yan pairs, $\gamma$- and $b$-onium prompt decays, $\pi^-$, $K$-decays, and misidentified dimuon candidates. The signal and background contributions are determined by fitting the experimental 2-dimensional impact parameter $d_0(\mu_1), d_0(\mu_2)$.

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distribution to corresponding templates expected for various dimuon sources. The method exploits the fact that the shape of the $d_0(\mu)$ distribution is largely determined by the lifetime of its parent heavy hadron. The analysis is based on a data sample of total luminosity $L = 740 \pm 10 \text{pb}^{-1}$ collected with the CDF dimuon trigger [2] having no biases with respect to $d_0(\mu)$ distribution. The projection of the 2-dimensional fit onto $d_0(\mu)$ comprising various background contributions is shown in Figure 6. The extracted experimental cross-section is found to be $\sigma(b \rightarrow \mu^-, \bar{b} \rightarrow \mu^+) = 1549 \pm 133 \text{pb}$. The errors include statistical and systematic uncertainties added in quadratures. From this measurement we derive $\sigma(b\bar{b}, p_T \geq 6 \text{GeV}/c, |y| \leq 1) = 1618 \pm 148 \text{nb}$. The systematic uncertainty due to choice of the fragmentation model is $\sim 25\%$.

4 Summary

CDF announces the first observation of four bottom baryon $\Sigma_b^{(*)\pm}$ resonance states. CDF has also observed the strange bottom cascade baryon $\Xi^-_b$, and our measurements are in agreement with the DØ observation and with theoretical predictions. CDF II detector has measured the correlated production cross-section of $b\bar{b}$ pairs with $b$-quarks identified in their muonic semileptonic modes. The measurement is consistent with theoretical expectations. Using NLO Monte-Carlo production cross-section in the kinematic domain $(p_T \geq 6 \text{GeV}/c, |y| \leq 1)$ has been derived.

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