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Latest Results on Bottom Spectroscopy and Production with CDF

Igor V. Gorelov *

Department of Physics and Astronomy,
MSC07 4220, University of New Mexico,
800 Yale Blvd. NE,
Albuquerque, NM 87131, USA

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 Σ_b and Σ_b^* in CDF

The bottom $\Sigma_b^{(*)}$ states decay strongly into Λ_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 $\sim 1.1\,\mathrm{fb}^{-1}$. The trigger used in this study is based on displaced tracks. It reconstructs with the central tracker a pair of $p_T \gtrsim 2.0\,\mathrm{GeV}/c$ 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 $\Sigma_b^{(*)\pm} \to \Lambda_b^0 \pi_{soft}^{\pm}$, $\Lambda_b^0 \to \Lambda_c^+ \pi^-$, $\Lambda_c^+ \to pK^-\pi^{+}$[a]. To remove the contribution due to a mass resolution of each Λ_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 $Q = M(\Lambda_b^0 \pi_{soft}^{\pm}) - M(\Lambda_b^0) - M_{\mathrm{PDG}}(\pi^{\pm})$ for every charge state of $\Sigma_b^{(*)\pm}$ candidates. Here we assume also that the width of the weakly decaying Λ_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].

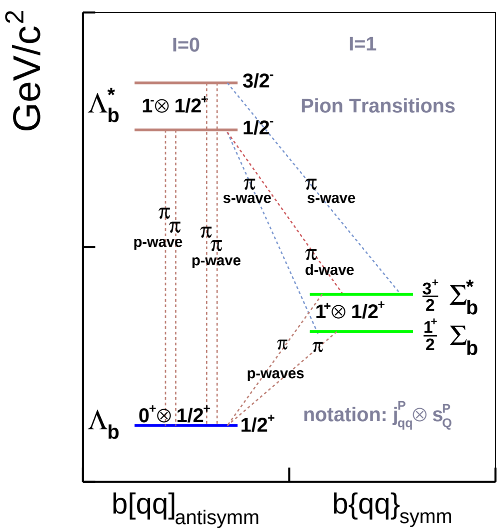

Figure 1: The low lying Σ- and Λ- like b-baryons and their strong decays with pion emissions.

*This talk [1] has been presented on behalf of the CDF Collaboration at a conference "Photon 2007".

[a] Unless otherwise stated all references to the specific charge combination imply the charge conjugate combination as well.

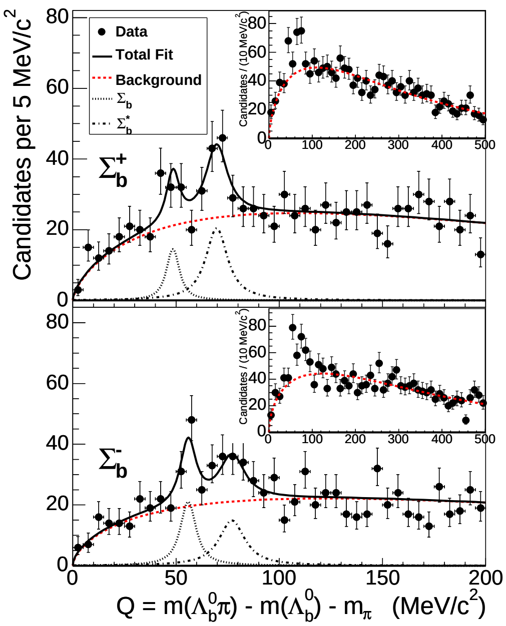

Figure 2: The experimental mass difference spectra [3] for the candidates of both charged partners, $\Sigma_b^{(*)\pm}$. Double peak signatures are observed in every case.

State	Q or $\Delta_{\Sigma_b^*}$ (MeV/c^2)	Mass (MeV/c^2)
Σ_b^+	$Q_{\Sigma_b^+} = 48.5^{+2.0+0.2}_{-2.2-0.3}$	$5807.8^{+2.0}_{-2.2} \pm 1.7$
Σ_b^-	$Q_{\Sigma_b^-} = 55.9 \pm 1.0 \pm 0.2$	$5815.2 \pm 1.0 \pm 1.7$
Σ_b^{*+}	$\Delta_{\Sigma_b^*} = 21.2^{+2.0+0.4}_{-1.9-0.3}$	$5829.0^{+1.6+1.7}_{-1.8-1.8}$
Σ_b^{*-}		$5836.4 \pm 2.0^{+1.8}_{-1.7}$

Table 1: The masses resulting from the simultaneous fit of both spectra [3].

Yields of the signals			
Σ_b^+	Σ_b^-	Σ_b^{*+}	Σ_b^{*-}
32^{+13+5}_{-12-3}	59^{+15+9}_{-14-4}	77^{+17+10}_{-16-6}	69^{+18+16}_{-17-5}

Table 2: The fitted yields [3] of the identified $\Sigma_b^{(*)\pm}$ states. The combined significance of all four peaks relative to the null hypothesis well exceeds 5 Gaussian standard deviations.

2 Observation and Mass Measurement of the Baryon Ξ_b

The bottom cascade baryons Ξ_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 [4]. We consider the lowest lying Ξ_b states that decay weakly and the Ξ_b' states that decay radiatively or strongly via pion emission. The Ξ_b candidates are reconstructed in the decay chain $\Xi_b^- \to J/\psi\,\Xi^-$ with secondary states $J/\psi \to \mu^+\mu^-$ and $\Xi^- \to \Lambda^0\pi^-$, $\Lambda^0 \to p\pi^-$ (see Figure 3) . Since experiments with bubble chambers the strange cascade, given its long decay path of $c \cdot \tau = 4.91$ cm [5], 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 subsequent V^0 decay vertex of the Λ^0 is associated with the 1-track vertex and included in a two-vertex kinematic fit. The key technique in this analysis is the tracking algorithm developed to reconstruct Ξ^- tracks leaving hits in the CDF silicon vertex tracker SVX II. A finest tracking resolution [2] coupled with the custom software provide a clean signal for Ξ^-, see Figure 4. The analysis [6] uses a data sample of integrated $\mathcal{L} = 1.9\,\mathrm{fb}^{-1}$ collected by the CDF dimuon trigger [2] which saves events with two oppositely charged tracks reconstructed in the CDF cen-

State	$b\ sq$	J^P	I_3	j_{sq}	M, GeV/c^2
Ξ_b^0	$b[su]$	$1/2^+$	1/2	0	5.80
Ξ_b^-	$b[sd]$	$1/2^+$	-1/2	0	5.80
$\Xi_b^{0\prime}$	$b\{su\}$	$1/2^+$	1/2	1	5.94
$\Xi_b^{-\prime}$	$b\{sd\}$	$1/2^+$	-1/2	1	5.94

Table 3: Theoretical expectations for properties of bottom cascade baryons containing a single b- quark [4]. The lowest lying states have a light quark pair with momentum $j_{sq} = 0$ while the next ones have light quarks aligned with $j_{sq} = 1$.

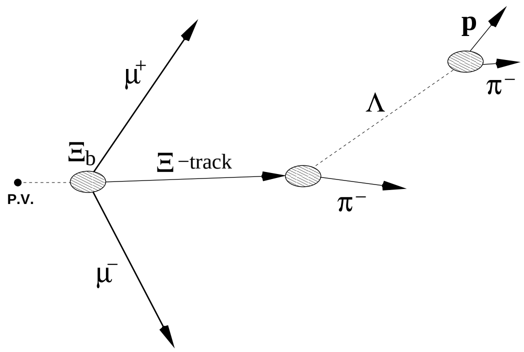

Figure 3: Topology of the $\Xi_b^- \to J/\psi\,\Xi^-$ decay.

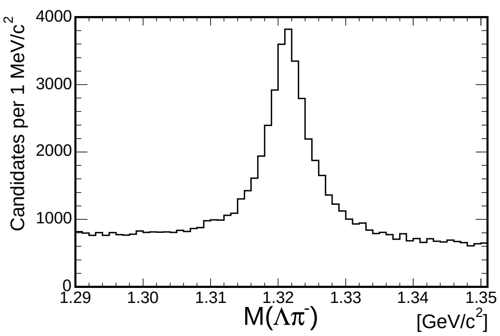

Figure 4: The Ξ^- signal [6] when the cascade track has at least 2 hits in the CDF SVX II tracker.

tral tracker, matched to hits in the CDF muon chambers and selected in the mass window $M(\mu^+\mu^-) \in [2.7, 4.0]\,\mathrm{GeV}/c^2$ around the mass of the J/ψ [5]. The sample yields $\sim 15 \times 10^6$ J/ψ and ~ 23500 Ξ^- candidates. The final selection criteria for Ξ_b^- candidates have been studied using ~ 31000 B-mesons in the mode $B^+ \to J/\psi\ K^+$ as a control sample assuming very similar decay kinematics. The invariant mass of selected $J/\psi\,\Xi^-$ candidates is shown in Figure 5. An unbinned likelihood fit finds [6] $17.5 \pm 4.3(\mathrm{stat})\,\Xi_b$ candidates at a mass of $5792.9{\pm}2.5(\mathrm{stat}){\pm}1.7(\mathrm{syst})\,\mathrm{MeV}/c^2$ and with a significance of 7.7 of Gaussian standard deviations. The results [6] are in good agreement with theoretical predictions and with the observation made by the DØ Collaboration [7].

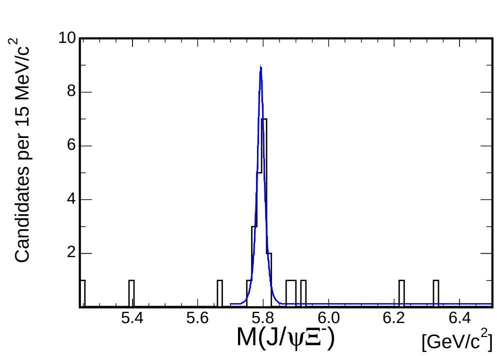

Figure 5: The invariant mass distribution of $J/\psi\,\Xi^-$ candidates after optimized selection criteria have been applied. The profile of the unbinned fit is superimposed. A clear signal is observed [6].

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 σ_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 $5 < M(\mu_1\mu_2) < 80\,\mathrm{GeV}/c^2$, outside of the domain populated by sequential decays of single b- quarks and Z^0 modes, and extract $\sigma(b \to \mu^- + X, \bar{b} \to \mu^+ + X)$, subtracting contributions from $c\bar{c}$, prompt Drell-Yan pairs, c- and b- onium prompt decays, π-, K-decays, and misidentified dimuon candidates. The signal and background contributions are determined by fitting the experimental 2-dimensional impact parameter $d_0(\mu_1), d_0(\mu_2)$

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 $\mathcal{L} = 740\,\text{pb}^{-1}$ 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 exper-

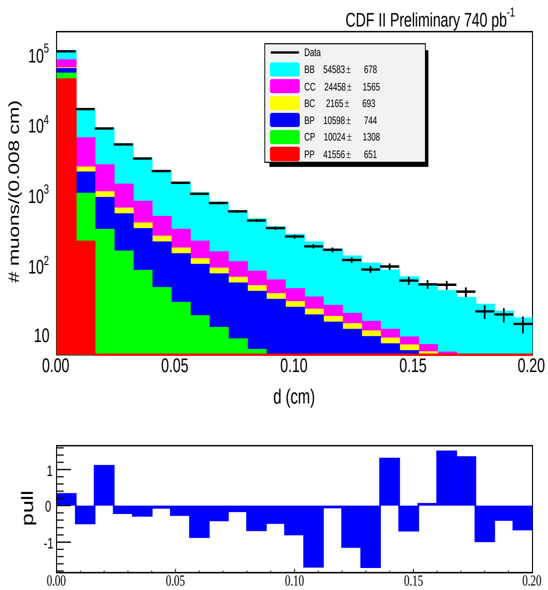

Figure 6: The projection of the 2-dimensional fit of $d_0(\mu_1), d_0(\mu_2)$ with background templates summed up and data superimposed. The notations used are "B" as b-source, "C" as c-source and "P" as the source of prompt muons.

imental cross-section is found to be $\sigma(b \to \mu^-, \bar{b} \to \mu^+) = 1549 \pm 133\,\text{pb}$. The exact NLO predictions are made using Herwig Monte-Carlo program [9], MNR code [10] running with EVTGEN generator [11], parton structure functions from MRST [12] fits and Peterson fragmentation function [13]. The ratio of data to NLO theoretical Monte-Carlo calculation is found to be $R2(b \to \mu^-, \bar{b} \to \mu^+) = 1.20 \pm 0.21$. 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 Ξ_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 cross-section calculations, the full $b\bar{b}$ production cross-section in the kinematic domain ($p_T \geq 6\,\text{GeV}/c, |y| \leq 1$) has been derived.

5 Acknowledgments

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