

# 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  $120 \mu\text{m}$ . The signals of  $\Sigma_b^{(*)\pm}$  states were sought in the decay chain  $\Sigma_b^{(*)\pm} \rightarrow \Lambda_b^0 \pi_{soft}^\pm$ ,  $\Lambda_b^0 \rightarrow \Lambda_c^+ \pi^-$ ,  $\Lambda_c^+ \rightarrow p K^- \pi^+$ <sup>a</sup>. To remove the contribution due to a mass resolution

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<sup>a</sup>Unless otherwise stated all references to the specific charge combination imply the charge conjugate combination as well.

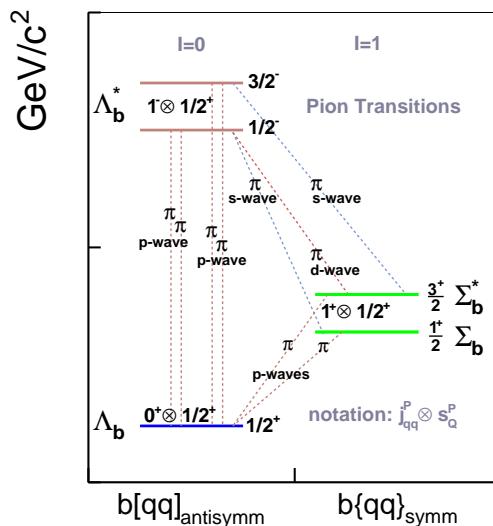


Figure 1: The low lying  $\Sigma^-$ - and  $\Lambda^-$ -like  $b$ -baryons and their strong decays with pion emissions.

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  $Q = M(\Lambda_b^0 \pi_{soft}^\pm) - M(\Lambda_b^0) - M_{\text{PDG}}(\pi^\pm)$  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].

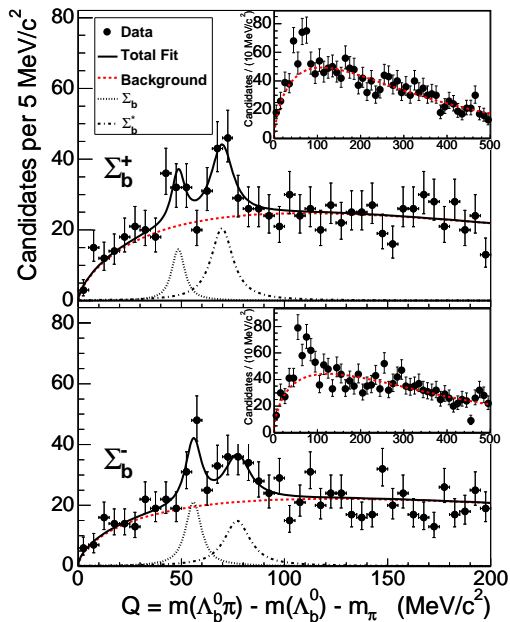


Figure 2: The experimental mass difference spectra [3] for the candidates of both charged partners,  $\Sigma_b^{(*)\pm}$ . Double peak signatures are observed in every case.

## 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 [4]. 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 [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 subse-

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

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

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

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.

quent  $V^0$  decay vertex of the  $\Lambda^0$  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  $\Xi^-$  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  $\Xi^-$ , see Figure 4. The analysis [6] uses a data sample of integrated  $\mathcal{L} = 1.9 \text{ fb}^{-1}$  collected by the CDF dimuon trigger [2] which saves events with two oppositely charged tracks reconstructed in the CDF cen-

State	$b$ $sq$	$J^P$	$I_3$	$j_{sq}$	$M, \text{ GeV}/c^2$
$\Xi_b^0$	$b\{su\}$	$1/2^+$	$1/2$	0	5.80
$\Xi_b^-$	$b\{sd\}$	$1/2^+$	$-1/2$	0	5.80
$\Xi_b^{0'}$	$b\{su\}$	$1/2^+$	$1/2$	1	5.94
$\Xi_b^{-'}$	$b\{sd\}$	$1/2^+$	$-1/2$	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  $j_{sq} = 1$ .

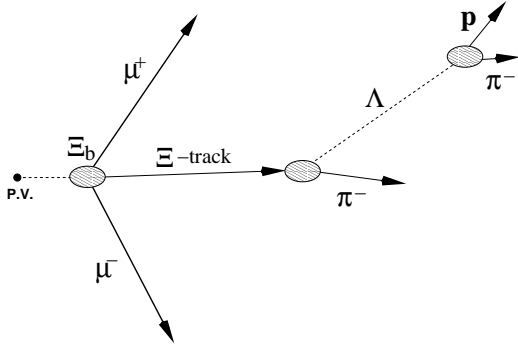


Figure 3: Topology of the  $\Xi_b^- \rightarrow J/\psi \Xi^-$  decay.

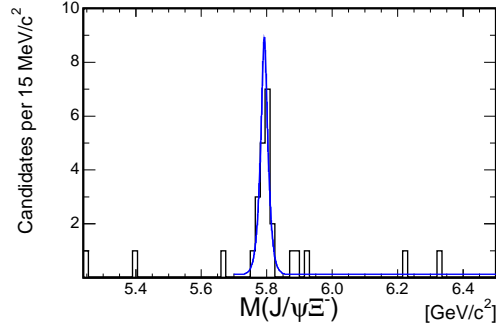


Figure 5: The invariant mass distribution of  $J/\psi \Xi^-$  candidates after optimized selection criteria have been applied. The profile of the unbinned fit is superimposed. A clear signal is observed [6].

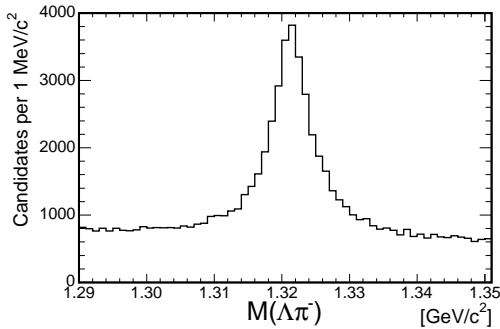


Figure 4: The  $\Xi^-$  signal [6] when the cascade track has at least 2 hits in the CDF SVX II tracker.

tral tracker, matched to hits in the CDF muon chambers and selected in the mass window  $M(\mu^+\mu^-) \in [2.7, 4.0] \text{ GeV}/c^2$  around the mass of the  $J/\psi$  [5]. The sample yields  $\sim 15 \times 10^6$   $J/\psi$  and  $\sim 23500$   $\Xi^-$  candidates. The final selection criteria for  $\Xi_b^-$  candidates have been studied using  $\sim 31000$   $B$ -mesons in the mode  $B^+ \rightarrow J/\psi K^+$  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]  $17.5 \pm 4.3(\text{stat}) \Xi_b^-$  candidates at a mass of  $5792.9 \pm 2.5(\text{stat}) \pm 1.7(\text{syst}) \text{ MeV}/c^2$  and with a significance of 7.7 of Gaussian standard de-

viations. The results [6] are in good agreement with theoretical predictions and with the observation made by the DØ Collaboration [7].

### 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  $\sigma_b$  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  $5 < M(\mu_1\mu_2) < 80 \text{ GeV}/c^2$ , 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,  $c$ - 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  $d_0(\mu_1), d_0(\mu_2)$

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-

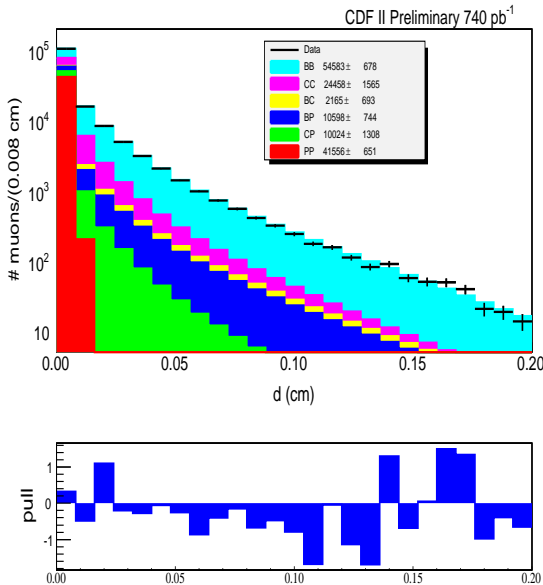


Figure 6: The projection of the 2-dimensional fit of  $d_0(\mu_1), d_0(\mu_2)$  with background templates summed up and data superimposed. The notations used are “B” as  $b$ -source, “C” as  $c$ -source and “P” as the source of prompt muons.

imental cross-section is found to be  $\sigma(b \rightarrow \mu^-, \bar{b} \rightarrow \mu^+) = 1549 \pm 133 \text{ pb}$ . 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  $R2(b \rightarrow \mu^-, \bar{b} \rightarrow \mu^+) = 1.20 \pm 0.21$ . 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  $\Xi_b^-$ , 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 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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