New Results on Bottom Baryons with CDF II Detector

Igor V. Gorelov
(On behalf of the CDF Collaboration)

Department of Physics & Astronomy,
University of New Mexico, USA

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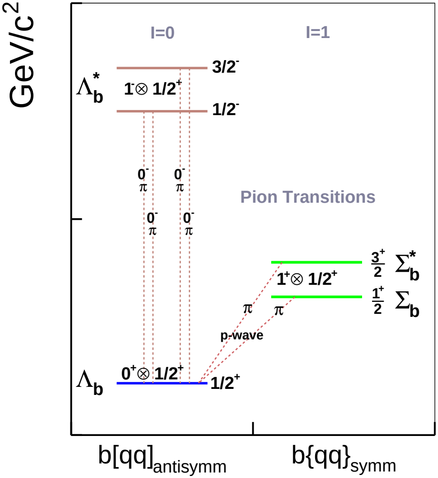
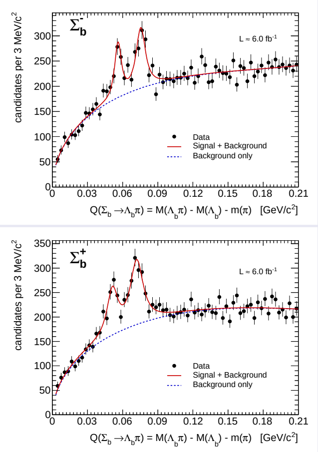
Motivation

- Baryons with a heavy quark Q as the “nucleus” and a light diquark $q_1 q_2$ as the two orbiting “electrons” can be viewed as the “helium atoms” of quantum chromodynamics (QCD).
- Observations of new heavy baryon states, measurements of masses/widths of heavy baryons provide input to critical tests for different non-perturbative QCD approaches to a spectroscopy of bottom hadron states
  - HQET framework
  - Potential models
  - $1/N_c$ expansion methods
  - and finally several large scale projects on Lattice QCD calculations
- **Goal of the analysis: search for the resonant states in $\Lambda_b^0 \pi^- \pi^+$ modes.**

The Bottom Baryon States Decaying into Λ_b^0 Singlet



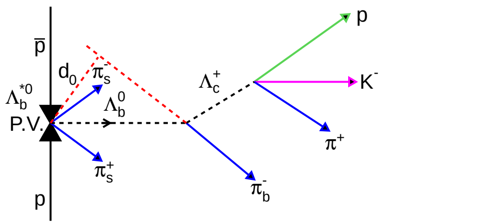
$\Sigma_b^{(*)\pm}$ in CDF: PRD **85**, 092011 (2012)



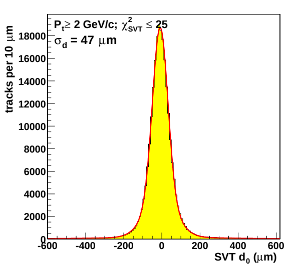
b- Triggers at @1.96 TeV

- Enormous inelastic total cross- section of $\sigma_{\mathbf{tot}}^{\mathbf{inel}} \sim \mathbf{60}\,\mathrm{mb}$ at Tevatron.
- $\sigma_{\mathbf{b}} \approx \mathbf{20}\,\mu\mathrm{b}\,(|\eta| < \mathbf{1.0})$, **@1.96 TeV**
- Selective three-level triggers
- **Trigger on Hadronic Modes: CDF Two Track Trigger** .
    - Exploit long $c\tau$(b-hadrons)
    - Trigger on $\geq$ 2 tracks with large $|d_0|$.

Λ_b^{*0} Decay Chain and Possible Trigger

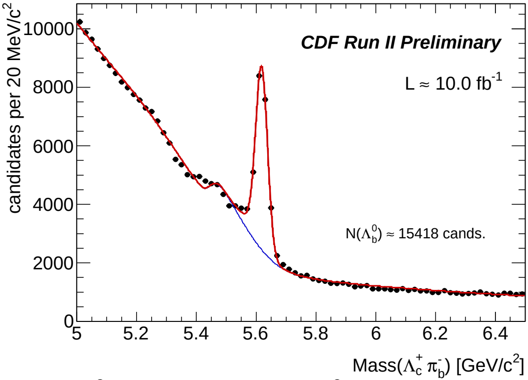


$|d_0|$ Resolution $\oplus$ beam-line = 47 μm



Analysis Criteria

- **Total CDF Luminosity of** $\int \mathcal{L}\,\mathbf{dt} \approx \mathbf{10.0\,fb^{-1}}$
- Reconstruct inclusive base Λ_b^0 signal in $M(\Lambda_c^+\pi_b^-)$, a pion π_b^- produced in the weak decay $\Lambda_b^0 \to \Lambda_c^+\pi_b^-$.
- Combine Λ_b^0 signal candidates with two soft pions to reconstruct $\Lambda_b^{*0} \to \Lambda_b^0\pi_{soft}^-\pi_{soft}^+$ candidates.
- require $p_{\rm T}(\Lambda_b^0)$ to be large to get $\pi_{soft}^{\pm}$ **within** the detector kinematical **acceptance**



- $p_{\rm T}(\Lambda_b^0) > 9.0\,{\rm GeV}/c$, $ct(\Lambda_b^0)/\sigma_{ct} > 6.0$
- $p_{\rm T}(\pi_b^-) > 1.0\,{\rm GeV}/c$ $\quad N(\Lambda_b^0) \approx 15400$
- $p_{\rm T}(\pi_{soft}^{\pm}) > 0.2\,{\rm GeV}/c$, very loose.
- $|d_0/\sigma_{d_0}|(\pi_{soft}^{\pm}) < 3.0$, w.r.t. primary VX.

Fit Model and Scale

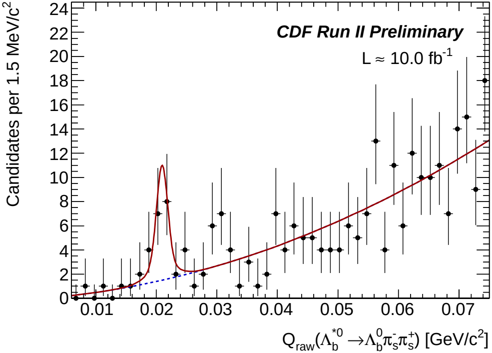
We reconstruct Λ_b^{*0} candidates in a mass difference spectrum: Q value

$$Q = M(\Lambda_b^0 \pi_s^+ \pi_s^-) - m(\Lambda_b^0) - 2 \cdot m(\pi^\pm)$$

The mass resolution of the Λ_b^0 signal and most of the systematic uncertainties cancel in the Q value spectrum.

- The signal: double Gaussian to model the detector resolution; shape fixed from MC; position Q and N_{cands} floating.
- The background: second order polynomial; floating.
- The full model for the Q value spectra: a single narrow structure on top of a smooth background.
- Use high statistics CDF $D^{*+} \to D^0 \pi^+_{soft}$ sample to analyze the soft pions momentum scale for $\Lambda_b^{*0} \to \pi^-_{soft} \pi^+_{soft}$ candidates.
  - **Adjust scale: $\mathbf{Q}(\Lambda_b^{*0}) = \mathbf{Q}(\Lambda_b^{*0}) - \mathbf{0.28}$, MeV/c^2,**
  - set 100% syst. uncertainty: $-0.28 \pm 0.28(\mathrm{syst})\ \mathrm{MeV}/c^2$

Q- Spectrum and Results: Λ_b^{*0}



The projection of the unbinned LH fit onto the binned distribution of the **raw Q** spectrum of Λ_b^{*0} candidates.

Λ_b^{*0}	
Parameters	**Value**, MeV/c^2
Q, MeV/c^2	20.68 ± 0.35
N, evts	$17.3^{+5.3}_{-4.6}$

Q scale adjustment applied.

Significance of the Signal: Λ_b^{*0}

Significance Estimate Based on Exp. Data Fits.

- $\mathcal{H}_1$: signal on top of the background.
- $\mathcal{H}_0$: background, 2-nd order Chebyshev.
- $D = -2 \ln \frac{\mathcal{L}_0}{\mathcal{L}_1} = -2\,\Delta(\ln \mathcal{L})$.
- $2.28 \cdot 10^{-6}$ or 4.6σ, see table below.

$-2 \cdot \Delta(\log \mathcal{L})$	ΔNDF	Prob(χ^2)
$-2 \cdot (-12.99)$	2	$2.28 \cdot 10^{-6}$

Significance Estimate with Stat. Trials

- Generate $\mathcal{H}_0$, fit with $\mathcal{H}_1$
- Search window: $Q \in (0., 50.0)\ \mathrm{MeV}/c^2$
- Parameter of Interest: N_{cands}
- Signal position Q floating
- Signal shape fixed
- Background shape floating
- $p = 2.3 \cdot 10^{-4}$ or 3.5σ

Systematics Uncertainties

Source	**Value**, MeV/c^2	**Comment**
Momentum scale	± 0.28	propagated from high statistics calibration D^{*+} sample; 100% of the found adjustment value.
Signal model	± 0.11	MC underestimates the resolution; choice of the model's parameters
MC resolution stat. uncertainty	± 0.012	finite MC sample size induces the stat. uncertainty of the shape parameters.
Background model	± 0.03	consider 3-rd, 4-th power polynomials
Total:	± 0.30	added in quadrature

Results

Results on Λ_b^{*0} with $\int \mathcal{L}\,dt \approx 10\,\text{fb}^{-1}$.

Value	MeV/c^2
Q	$20.68 \pm 0.35(\text{stat}) \pm 0.30(\text{syst})$
ΔM	$299.82 \pm 0.35(\text{stat}) \pm 0.30(\text{syst})$
$M(\Lambda_b^{*0})$	$5919.5 \pm 0.35\,(\text{stat}) \pm 1.72\,(\text{syst})$

To determine the absolute masses for Λ_b^{*0},
$m(\Lambda_b^0) = 5619.7 \pm 1.2\,(\text{stat}) \pm 1.2\,(\text{syst}),\ \text{MeV}/c^2$ (CDF II).

Conclusions

- We have observed the $\Lambda_b^{*0} \to \Lambda_b^0 \pi^- \pi^+$ resonance state in its Q value spectrum
- The significance of the signal for the search window of $(0., 50)\,\mathrm{MeV}/c^2$ is 3.5σ.
- Our result confirms the higher state $\Lambda_b^{*0}(5920)$ of the two recently observed by the LHCb Collaboration and published in *arXiv:1205.3452 [hep-ex]*.
- The result is consistent with recent theoretical predictions.