B Baryons at CDF

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Bottom Baryons (I)

- b-baryons are nice laboratory to understand non-perturbative QCD and potential models
  
  • heavy b-quark \( \rightarrow \) sizeable simplification in theoretical description
  
  • basic model: light diquark system \( qq \) surrounding the heavy b-quark "nucleus" \( Q \)
  
  • coupling similar as in hydrogen/helium atom

- Ground states (\( L=0 \))

\[
\begin{align*}
J_{qq} = S_{qq} &= 0 \quad \rightarrow \quad J = J_{qq} + S_Q = 1/2 \quad \{\Lambda^0_b, \Xi_b^-\} \\
J_{qq} = S_{qq} &= 1 \quad \rightarrow \quad J = J_{qq} + S_Q = 1/2 \quad \{\Sigma_b, \Xi_b^*, \Omega_b\} \\
&\quad \rightarrow \quad J = J_{qq} + S_Q = 3/2 \quad \{\Sigma_b^*, \Xi_b^*, \Omega_b^*\}
\end{align*}
\]
Bottom Baryons (II)

- Our knowledge of b-baryons greatly expanded in the last ~2 years
- This is totally a Tevatron field
  - $\Sigma_b^{(*)+}$ and $\Sigma_b^{(*)-}$ observed in 2006
  - $\Xi_b^-$ observed by in 2007
  - $\Omega_b^-$ observed in 2008
The CDF II Detector

Drift chamber in 1.4 T B field

Excellent vertex & mass resolution

Silicon VerteX detector

I.P. resolution: 35 µm @2GeV/c

Muon coverage |η| < 1

DiMuon Trigger

Displaced Vertex Trigger

Primary Vertex

Secondary Vertex

B

Decay Length

L_{xy}

P_T(B) ≥ 5 GeV

L_{xy} ≥ 450µm

d = impact parameter
We search for the $\Xi_b^-$ and $\Omega_b^-$ through the processes

- $\Xi_b^- \rightarrow J/\psi \, \Xi^-, \, J/\psi \rightarrow \mu^+\mu^-, \, \Xi^- \rightarrow \Lambda\pi^-$
- $\Omega_b^- \rightarrow J/\psi \, \Omega^-, \, J/\psi \rightarrow \mu^+\mu^-, \, \Omega^- \rightarrow \Lambda K^-$

The data set is from di-muon trigger
- $J/\psi \rightarrow \mu^+\mu^-$ in the final state

The data set contains many b-meson candidates (useful crosscheck)
$\Xi_b^-/\Omega_b^-$ Reconstruction (I)

5-track, 3-vertex fit

- $\mu^+\mu^-$ constrained to $J/\psi$ mass
- Hadron trajectories constrained to appropriate topologies
- Reconstructed $\Xi^-/\Omega^-$ constrained to originate from the $\mu^+\mu^-$ intersection

The long life of the $\Xi^-$ and $\Omega^-$ opens the possibility of seeing the hits left in the Silicon detector (more on this later)
Selection may be satisfied by

Like sign pairs (p may form a Λ with either)

Both Λ - track intersections

Ambiguities resolved by

Track information in the longitudinal (along beamline) view

Fully constrained 5-track fit

Helix constraint avoids "wrong" intersection
Inclusive $\Xi^-/\Omega^-$ Samples

The base sample is given by:
- $1.1077 < M(p\pi) < 1.1237$
- $P_T(\Xi/\Omega) > 2.0$
- Flight($\Lambda/\Xi^-/\Omega^-$) $> 1$ cm
- Impact($\Xi^-/\Omega^-$) $< 3\sigma$
- $P(\chi^2) > 10^{-4}$
- $P(\chi^2)_{\text{used}} > P(\chi^2)_{\text{swapped}}$
- Veto $1.311 < M(\Lambda\pi) < 1.331$ for $\Lambda K$ sample ($\Xi^-$ reflection)

Yields in the $J/\psi$ sample:
- $\Xi^-$: 41,000
- $\Omega^-$: 3,500

Dashed histograms are WS $\Lambda\pi^+/K^+$
Shaded are selection and SB region
$\Xi_b^-/\Omega_b^-$ reconstructed signals

$M(J/\psi \Xi^-)$ vs. ct

$M(J/\psi \Omega^-)$ vs. ct

$\Xi_b^-$

$\Omega_b^-$

$J/\psi \Xi^-$, $J/\psi \Omega^-$ samples

Obvious $\Xi_b^-$ signal when ct $> 100$ $\mu$m

Cluster in the $J/\psi \Omega^-$ around 6.05 GeV$/$c$^2$

Test of $\Omega_b^-$ significance finds 5.5$\sigma$ (with no ct cut)
Require $\Xi^-/\Omega^-$ hits in SVX

Inclusive $\Lambda\pi$ and $\Lambda K$ with previous selection and additional request of silicon hits on the $\Xi^-/\Omega^-$ track

Obvious $\Xi_b^-$ signal

Just 2 $\Omega_b$ candidates (due to lower $\Omega^-$ lifetime) but mass consistent with the main selection
**Sideband/Wrong-Sign selections**

Same candidate selection, except for the $\Lambda K^-$ pair.
Mass Measurements

$m(\Xi_b^-) : 5790.9 \pm 2.6\text{(stat.)} \pm 0.8\text{(syst.)}\text{ MeV/c}^2$

$m(\Omega_b^-) : 6054.4 \pm 6.8\text{(stat.)} \pm 0.9\text{(syst.)}\text{ MeV/c}^2$

Systematic uncertainty

0.55 MeV from $B^0(K_s)$ error scale by 80% for kinetic energy in the decay

0.5 MeV from $\Lambda_b$ resolution treatment (considered largest possible)

0.3 MeV from $\Omega^-$ mass
$\Xi_b^-/\Omega_b^-$  Lifetime Measurements

Binned lifetime fit distributions
- Each bin comes from an independent fit to the mass distribution
- Dashed lines are fit projections

$\tau(\Xi_b^-): 1.56^{+0.27}_{-0.25}\,(\text{stat}) \pm 0.02\,(\text{syst})\,\text{ps}$
$\tau(\Omega_b^-): 1.13^{+0.53}_{-0.40}\,(\text{stat}) \pm 0.02\,(\text{syst})\,\text{ps}$

Systematic uncertainty
- 2 $\mu$m from $\sigma^{ct}$ treatment
- 5 $\mu$m from binning
We measure ratios of cross section times BR with respect to the $\Lambda^0_b$, only b-baryon with a large sample.

Issues:

- Experiment’s acceptance is $p_T$ dependent
- Cross section is $p_T$ dependent
- Unknown - assume $\Lambda^0_b$ distribution
- Limited data sample requires integration over $p$

Combine acceptance with yields

\[
\begin{align*}
\Lambda^0_b & : 1812 \pm 61 \text{ candidates} \\
\Xi^-_b & : 66^{+14}_{-9} \text{ candidates} \\
\Omega^-_b & : 16^{+6}_{-4} \text{ candidates}
\end{align*}
\]

\[
\frac{\sigma B(\Xi^-_b \to J/\psi\Xi^-)}{\sigma B(\Lambda^-_b \to J/\psi\Lambda)} = 0.167^{+0.037}_{-0.025} \pm 0.012
\]

\[
\frac{\sigma B(\Omega^-_b \to J/\psi\Omega^-)}{\sigma B(\Lambda^-_b \to J/\psi\Lambda)} = 0.045^{+0.017}_{-0.012} \pm 0.004
\]

arXiv:0905.3123
Search for $\Sigma_b^{\pm(*)}$

Decay chain
$\Sigma_b^{-(*)} \rightarrow \Lambda_b^0 \pi^-$
$\Lambda_b^0 \rightarrow \Lambda_c^+ \pi^-$
$\Lambda_c^+ \rightarrow p K^- \pi^+$

Contributions in $\Lambda_b^0$ mass window
86.4 % of $\Lambda_b^0$ (all decays)
9.3 % of B-meson (all decays)
4.3 % combinatorial

PRL 99, 202001 (2007)

$\Lambda_b^0$ yield
3180$\pm$60
Search for resonances in $Q = m(\Lambda_b \pi) - m(\Lambda_b) - m(\pi)$

Exclude $0.03 < Q < 0.10$ GeV region from signal selection procedure (blinding)

Optimize selection based on
- MC simulation for $\Sigma$ signal
- Sidebands from data

Fix background contributions at $m(\Lambda_b^0)$ fit
Observation of $\Sigma_b^{\pm(*)}$

Observed four signals with significance
- $>5.2\sigma$ (4 peaks vs. only BG)
- each peak $>3\sigma$ (except $\Sigma^+_b$)

$$m(\Sigma_{b^-}) = 5808^{+2.0}_{-2.3} \pm 1.7 \text{ MeV}$$
$$m(\Sigma_{b^0}) = 5816^{+1.0}_{-1.0} \pm 1.7 \text{ MeV}$$
$$m(\Sigma_{b^+}) = 5829^{+1.6}_{-1.8} \pm 1.7 \text{ MeV}$$
$$m(\Sigma_{b^{*+}}) = 5837^{+2.1}_{-1.9} \pm 1.7 \text{ MeV}$$

PRL 99, 202001 (2007)
Λ^0_b lifetime

CDF II Preliminary, L=1.1 fb^{-1}

Use ≈3000 ev signal Λ^0_b → Λ^+_cπ from the displaced vertex trigger
cτ(Λ^0) = 420.1 ± 13.7(stat) ± 10.6(syst) μm
Systematics dominated by MC model of trigger efficiency and decay

See Heather Gerberich's talk for details
Resonances in $\Lambda^0_b \rightarrow \Lambda^+_c 3\pi$ (I)

CDF observed resonant semileptonic decay modes and measured

\[
\frac{\text{BR}(\Lambda^0_b \rightarrow \Lambda^+_c (2595)\mu^-\nu)}{\text{BR}(\Lambda^0_b \rightarrow \Lambda^+_c \mu^-\nu)}
\approx 900
\]

\[
\frac{\text{BR}(\Lambda^0_b \rightarrow \Lambda^+_c (2625)\mu^-\nu)}{\text{BR}(\Lambda^0_b \rightarrow \Lambda^+_c \mu^-\nu)}
\approx 45
\]

\[
\frac{\text{BR}(\Lambda^0_b \rightarrow \Sigma^{++}_c (2455)\pi^-\mu^-\nu)+\text{BR}(\Lambda^0_b \rightarrow \Sigma^{+}_c (2455)\pi^-\mu^-\nu)}{2\times \text{BR}(\Lambda^0_b \rightarrow \Lambda^+_c \mu^-\nu)}
\approx 110
\]

Similar resonant decay modes reconstructed in the $\Lambda^0_b \rightarrow \Lambda^+_c \pi^-\pi^+\pi^-$ decay

<table>
<thead>
<tr>
<th>$\Lambda^0_b$ decay mode</th>
<th>Rec. Yields</th>
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<tbody>
<tr>
<td>$\Lambda^0_b \rightarrow \Lambda^+_c \pi^-\pi^+\pi^-$</td>
<td>$\approx 900$</td>
</tr>
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<td>$\approx 110$</td>
</tr>
<tr>
<td>$\Lambda^0_b \rightarrow \Sigma^{++}_c \pi^-\pi^-$</td>
<td>$\approx 85$</td>
</tr>
<tr>
<td>$\Lambda^0_b \rightarrow \Sigma^{0}_c \pi^+\pi^-$</td>
<td>$\approx 35$</td>
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Resonances in $\Lambda^0_b \rightarrow \Lambda^+_c 3\pi$ (II)
First study of CP asymmetry in b-baryon decays (SM predicts DCPV ~10%) Use large sample collected by two displaced track trigger along with $B \rightarrow hh$

We take into account $L_b$ pT spectrum (different from B), $L_b$ polarization (modifies kinematics) and p/K nd p/$\pi$ efficiencies
BRs are in agreement with SM predictions and exclude $O(10^{-4})$ values indicated for R-parity violating Minimal Supersymmetric extensions of the Standard Model \cite{PRD63,056006(2001)}

First DCPV measurements in $b$-baryon decays (statistical uncertainty dominates)

First hint of DCPV in $b$-baryon decays (very interesting to pursue with more data).
Conclusions

Tevatron is giving great contribution to increase our knowledge of b-baryons

Observation of the $\Omega_b$- and $\Xi_b$-
- Measurement of $\Omega_b$- mass and lifetime
- Measurement of $\Xi_b$- mass and lifetime

Observation of the $\Sigma_b^{\pm(*)}$

Improving measurements of $\Lambda_b$ properties
- World best mass and lifetime
- Reconstruction of new decay modes
- BR/CP violation in $\Lambda_b \rightarrow p\pi(K)$