Evidence for a bottom baryon resonance Λ_b^{*0} in CDF data

Prabhakar Palni
(On behalf of CDF Collaboration)

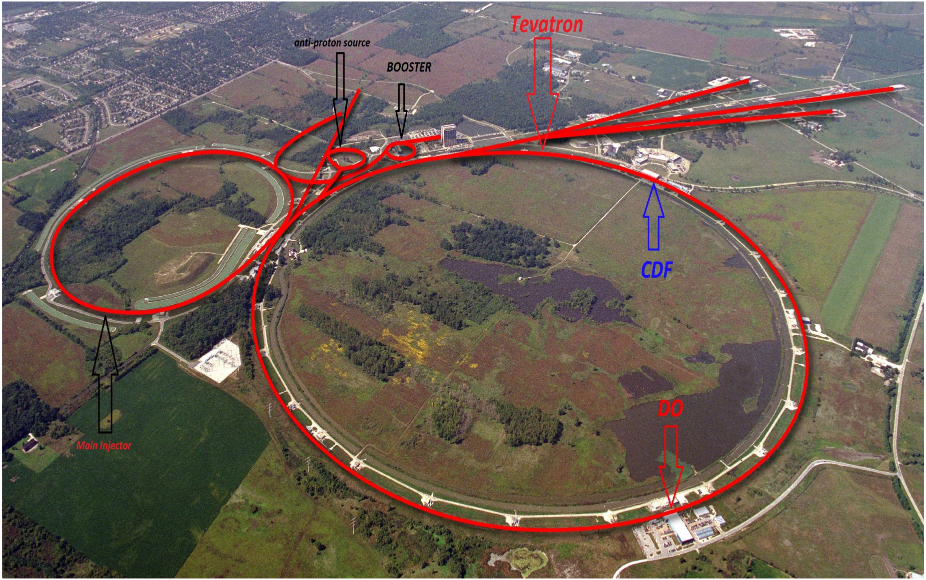
Department of Physics & Astronomy,
University of New Mexico, USA

DPF 2013 Meeting
University of California, Santa Cruz
12-17 August 2013

Outline of the talk

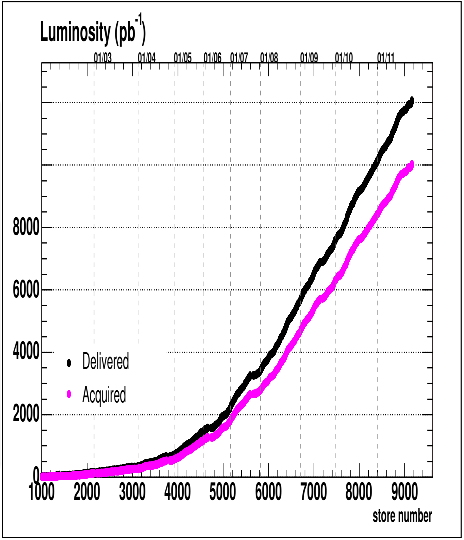
- The Tevatron and the CDF II Detector
- Motivation and Bottom Baryon Resonance states Λ_b^{*0}
- Data Sample and Trigger
- Analysis and Fit Model
- Systematic Uncertainties
- Results and Conclusions

The Tevatron Accelerator at Fermilab near Chicago

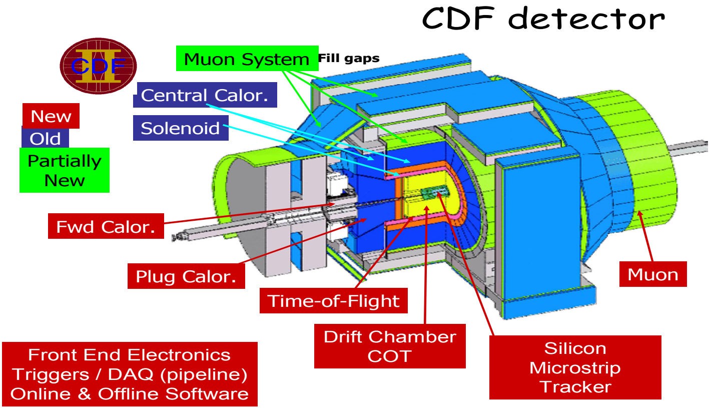


Statistics

- The Tevatron collided p with $\overline{p}$ at 1.96TeV center of mass energy from 2001-2011
- Instantaneous Luminosity upto 4x$10^{32}cm^{-2}s^{-1}$
- $\int \mathcal{L}\, dt \simeq 12.0\,\mathrm{fb}^{-1}$ delivered
- $\int \mathcal{L}\, dt \simeq 10.0\,\mathrm{fb}^{-1}$ on tape, accessible for **CDF II**



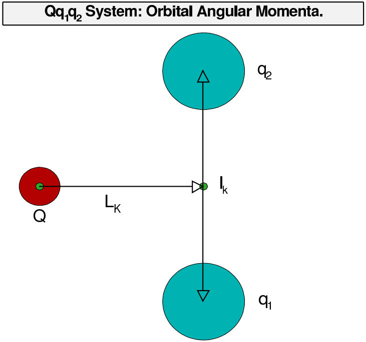
CDF Detector



- Silicon Vertex Detector, Drift Chamber and Muon Detectors.
- B=1.4T and the transverse momentum resolution of the tracking system is $\sigma(p_T)/p_T^2 \simeq 0.07\%/(\mathrm{GeV}/c)$

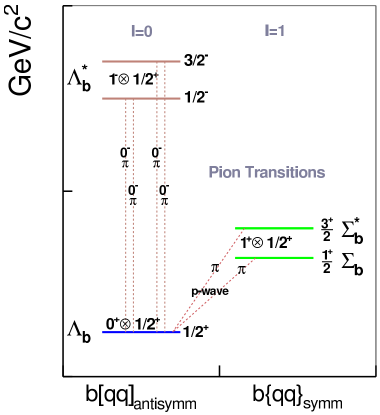
Motivation

- Baryons with a heavy quark Q and a light diquark $q_1 q_2$ (Helium atoms of QCD) are useful for probing QCD in its confinement domain.
- Observing a new HQ baryons, measuring properties provides constraints to QCD models
    - Quark potential models: non-relativistic, relativistic
    - HQET framework at LO and NLO in $1/m_Q$, $1/N_c$ combined expansions
- **Goal of the analysis: search for the resonant states in $\Lambda_b^0 \pi^- \pi^+$ modes.**



- $m_Q \gg \Lambda_{QCD} \gg m_{qq}$
- $m_Q \simeq 4.8\,GeV$, $Q \equiv b$
- HQET: S_Q decouples from $(q_1 q_2)$ degrees of freedoms.

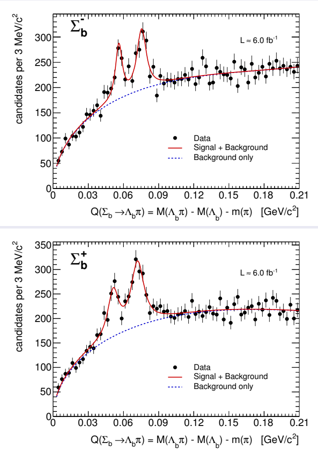
Pion Transitions into Λ_b^0 Singlet.



- HQET: pion transitions are governed by the light diquark.
- Resonant, S-wave, Σ-like states: $\Sigma_b^{(*)\pm} \to \Lambda_b^0 \pi^\pm$
  - single-pion $\pi^\pm$ in P-wave with $qq(1^+) \to qq(0^+) + \pi^\pm_{0^- \otimes 1^-}$
- Orbital excitations, P-wave, Λ-like states: $\Lambda_b^{*0} \to \Lambda_b^0 \pi^+\pi^-$ **given sufficient phase space.**
  - single-pion π^0 forbidden due to:
    - isospin conservation,
    - parity conservation (strong decays)
  - di-pion $\pi^+\pi^-$ are soft and emitted in P-wave with $qq(1^-) \to qq(0^+) + (\pi^+\pi^-)_{1^-}$

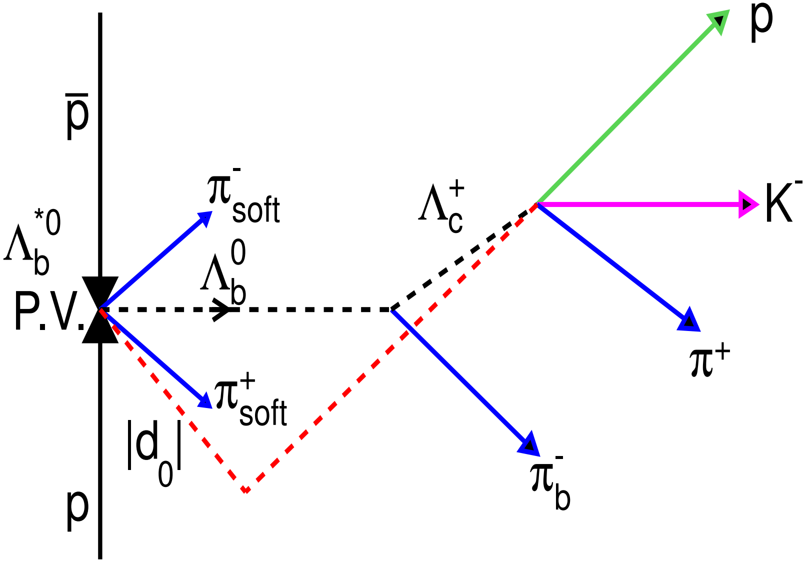
Experimental Status

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



- CDF first observation, then measurements: $\Sigma_b^{(*)\pm}$ resonances
- LHCb observation: $\Lambda_b^{*0}(5912)$ and $\Lambda_b^{*0}(5920)$, interpreted as $J^P = \frac{1}{2}^-$ and $J^P = \frac{3}{2}^-$ resonant states.
- CMS observation: bottom-strange Ξ_b^{*0}, interpreted as $J^P = \frac{3}{2}^+$ resonant state.
- CDF, D0 observations: ground bottom-strange Ξ_b^-
- CDF, D0 observations: ground bottom doubly-strange Ω_b^-
- CDF observation: ground neutral bottom-strange baryon Ξ_b^0

Decay Chain of Λ_b^{*0}



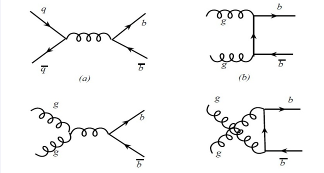
Two Displaced Track Trigger

b-Triggers at @1.96 TeV

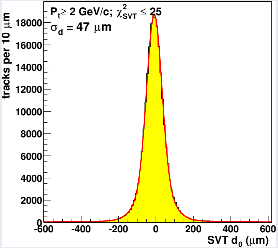
- Enormous inelastic total cross-section of $\sigma_{\mathbf{tot}}^{\mathbf{inel}} \sim \mathbf{60}\,\mathrm{mb}$
- $\sigma_{\mathbf{b}} \approx \mathbf{20}\,\mu\mathrm{b}\,(|\eta| < \mathbf{1.0})$, **@1.96 TeV**

- **Trigger on Hadronic Modes: CDF Two Track Trigger**
  - Exploit long $c\tau$ (b-hadrons)
  - $p_T \geq 2$ GeV/c for each of the two tracks
  - Trigger on ≥ 2 tracks with large $|d_0|$

(b production in $p\bar{p}$)

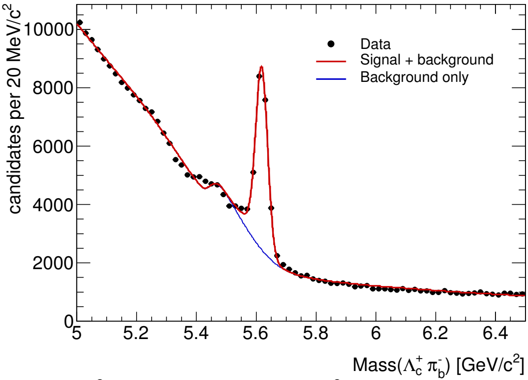


$|d_0|$ Resolution $\oplus$ beam-line = 47 μm



Analysis Criteria

- **Total CDF Luminosity of $\int \mathcal{L}\,\mathbf{dt} \approx$ 9.6 fb^{-1}**
- Reconstruct inclusive base Λ_b^0 signal in $M(\Lambda_c^+ \pi_b^-)$, a pion π_b^- produced in the weak decay $\Lambda_b^0 \rightarrow \Lambda_c^+ \pi_b^-$.
- Combine Λ_b^0 signal candidates with two soft pions to reconstruct $\Lambda_b^{*0} \rightarrow \Lambda_b^0 \pi_s^- \pi_s^+$ candidates.
- require $p_\mathrm{T}(\Lambda_b^0)$ to be large to get soft $\pi_s^\pm$ **within** the detector kinematical **acceptance**



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

Signal Model and Scale

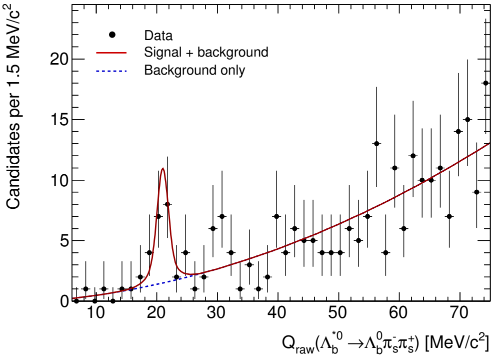
We reconstruct Λ_b^{*0} candidates in a mass difference spectrum: Q value

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

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 $D^{*+} \rightarrow D^0 \pi_s^+$ sample to analyze the soft pions momentum scale for $\Lambda_b^{*0} \rightarrow \pi_s^- \pi_s^+$ candidates.
    - **Adjust scale:** $\mathbf{Q}(\Lambda_b^{*0}) = \mathbf{Q}(\Lambda_b^{*0}) - \mathbf{0.28}, \mathrm{MeV}/c^2$,
    - set 100% syst. uncertainty: $-0.28 \pm 0.28(\mathrm{syst})\ \mathrm{MeV}/c^2$

Q- Spectrum and Results: Λ_b^{*0}



Λ_b^{*0}	
Parameters	**Value**
Q, MeV$/c^2$	20.96 ± 0.35
N, evts	$17.3^{+5.3}_{-4.6}$
Scale Adjusted *Q*-value	
Q, MeV$/c^2$	20.68 ± 0.35

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

Significance of the Signal

Significance Estimated with toy MC expts.

- Generate Null Hypothesis $\mathcal{H}_0$, fit with $\mathcal{H}_1$
- Parameter of interest , N_{cands}
- Signal position Q left floating within [6.0, 45.0] MeV/c^2 search window
- Signal shape fixed
- Background shape floating
- p-value = $2.3 * 10^{-4}$ or 3.5σ

Systematic Uncertainties

- Momentum Scale:
  - B field knowledge,
  - Uncertainty due to detector material on the dE/dx correction.
- Detector resolution model and its parameters.
- Choice of the background model.
- Systematics propagated from the previous CDF measurement of the Λ_b^0 mass.

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 $\int \mathcal{L}\, dt \approx 9.6\,\mathrm{fb}^{-1}$.

Value	MeV/c^2
Q	$20.68 \pm 0.35(\mathrm{stat}) \pm 0.30(\mathrm{syst})$
ΔM	$299.82 \pm 0.35(\mathrm{stat}) \pm 0.30(\mathrm{syst})$
$M(\Lambda_b^{*0})$	$5919.22 \pm 0.35\,(\mathrm{stat}) \pm 0.30\,(\mathrm{syst}) \pm 0.70\,(\mathrm{PDG})$
$\mathbf{M}(\Lambda_b^{*0})$	$\mathbf{5919.22 \pm 0.84}$

To determine the absolute masses for Λ_b^{*0},
$m(\Lambda_b^0) = 5619.4 \pm 0.7,\ \mathrm{MeV}/c^2$ (PDG 2012).

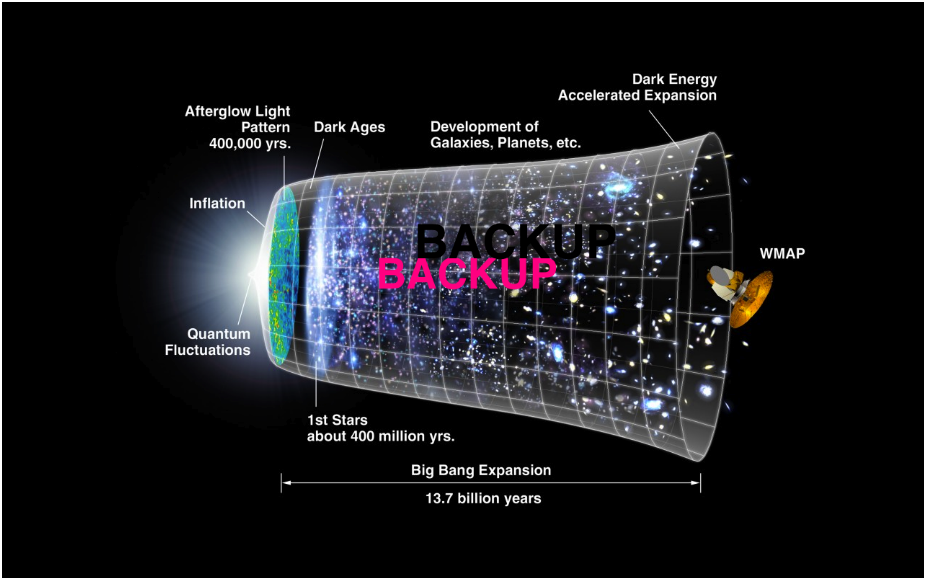
Comparison with LHCb

- Result is consistent with the higher state $\Lambda_b^{*0}(5920)$ found with $\int \mathcal{L}\, dt = 1.0\,\mathrm{fb}^{-1}$ at $\sqrt{s} = 7\,\mathrm{TeV}$ (year 2011) by LHCb
- LHCb reports also a state at $\approx 5912\,\mathrm{MeV}/c^2$ (same data)
- Assume
  - similar $\sigma \cdot B(\Lambda_b^{*0}(5912)) \,/\, \sigma \cdot B(\Lambda_b^{*0}(5920))$
  - similar $\epsilon(\Lambda_b^{*0}(5912)) \,/\, \epsilon(\Lambda_b^{*0}(5920))$, i.e ≈ 1
- Then the lack of a visible $\Lambda_b^{*0}(5912)$ signal in the CDF II is statistically consistent within 2σ with the $\Lambda_b^{*0}(5912)$ reported by LHCb

Conclusions

- We conduct a search for the $\Lambda_b^{*0} \rightarrow \Lambda_b^0\pi^-\pi^+$ resonance state in its Q value spectrum
- A narrow structure is identified at 5919.22 ± 0.84 MeV/c^2 mass.
- The significance of the signal is 3.5σ.
- The signal is attributed to the orbital excitation of the bottom baryon Λ_b^0
- The result supports similar findings by LHCb


THANK
YOU


Dark Energy
Accelerated Expansion
Afterglow Light
Pattern
400,000 yrs.
Dark Ages
Development of
Galaxies, Planets, etc.
Inflation
BACKUP
BACKUP
WMAP
Quantum
Fluctuations
1st Stars
about 400 million yrs.
Big Bang Expansion
13.7 billion years

Masses and Q-values of Λ_b^{*0} Resonance States

- $Q \equiv$ M($\Lambda_b^{*0} \rightarrow \Lambda_b^0 \pi^+ \pi^-$) - M($\Lambda_b^0$) - 2m($\pi^\pm$)
  i.e the amount of energy released by the decay reaction
- Various theoretical models predict that the mass of the first excited state $\Lambda_b^{*0}, (1/2)^-$ lies very close to the hadronic three-body mode threshold with Q$\equiv$[20...47] MeV/c^2
- The higher excited state, $\Lambda_b^{*0}(3/2)^-$has Q$\equiv$[2...17] MeV/c^2 higher than the lower state.