Measurement of the production fraction times branching fraction $\mathbf{f(b \to \Lambda_b) \cdot \mathcal{B}(\Lambda_b \to J/\psi \Lambda)}$

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on behalf of the **DØ Collaboration**

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Outline

Λ_b^0 baryon: Experimental Status

- $\Lambda_b^0(udb)$ is the lightest b baryon.
- Only a few decay channels studied and BR uncertainties are large $\sim 30 - 60\%$.
- A measurement of the $\Lambda_b^0 \to J/\psi\Lambda^0$ BR establishes the methods to study $b \to s$ (FCNC) decays such as $\Lambda_b \to \mu^+\mu^-\Lambda$ (where $\Lambda_b^0 \to J/\psi\Lambda^0$ can be used as a normalization channel).
- From PDG (2010):
  - $f(b \to \Lambda_b) \cdot \mathcal{B}(\Lambda_b \to J/\psi\Lambda) = (4.7 \pm 2.3) \times 10^{-5}$.
  - Roughly $f(b \to \Lambda_b) \sim f(b \to b_{baryon}) \sim 0.1$ [1]
    $\to \mathcal{B}(\Lambda_b \to J/\psi\Lambda) \sim 5 \times 10^{-4}$.

[1] $f(b \to b_{baryon}) = (8.5 \pm 2.2) \times 10^{-2}$

$\Lambda_b^0 \to J/\psi\Lambda^0$ branching fraction predictions

- PQCD[2]: $\mathcal{B}(\Lambda_b \to J/\psi\Lambda) \sim (1.7 - 5.3) \times 10^{-4}$.
- Factorization[3]: several (quark) models predict $\mathcal{B}(\Lambda_b \to J/\psi\Lambda) \sim (1.1 - 6.1) \times 10^{-4}$.

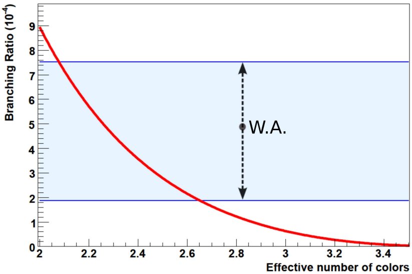


Figure 1: Factorization ansatz introduces an effective color number to take account of the non-factorizable terms in the decay amplitude [PRD **58**, 014016 (1998), figure from LHCb-2008-005 Public Note]

[2] PRD **65**, 074030 (2002).

[3] PRD **58**, 014016 (1998); **80**, 094016 (2009); **57**, 5632 (1998); **56**, 2799 (1997); **53**, 1457 (1996); **55**, 1697(E) (1997) ; Prog. Theor. Phys. **101**, 959 (1999).

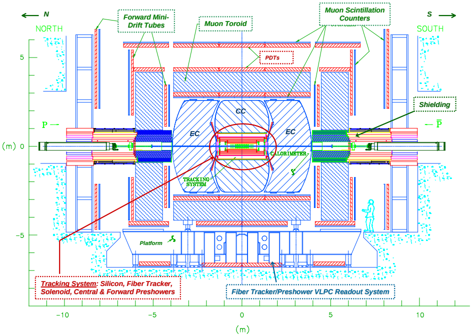
Tevatron and the DØ Detector

Tevatron

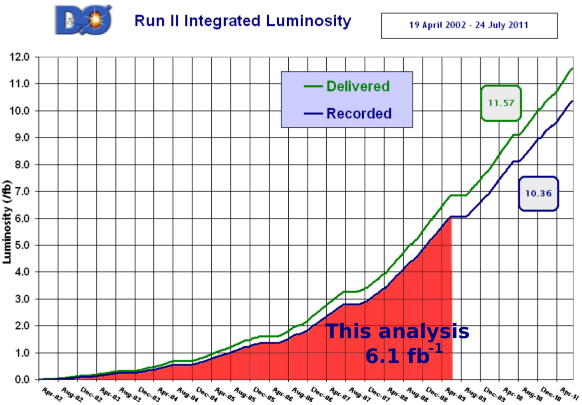
- $\sqrt{s} = 1.96$ TeV.
- 396 ns bunch spacing
- $L_{peak} \sim 4 \times 10^{32}/cm^2/s$

DØ Detector

- Excellent muon detector, $|\eta| < 2.2$.
- Silicon Microstrip Tracker and Central Fiber Tracker in a 2T solenoid allows accurate vertex and track reconstruction.



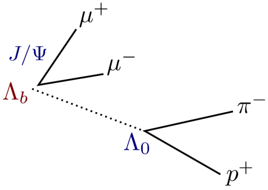
Data – DØRunII



- Data for this analysis is recorded using single muon and dimuon triggers.

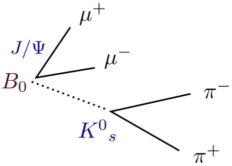
Λ_b^0 reconstruction

- $p_T(\mu) > 2$ GeV/c
- $p_T(\mu^+\mu^-) > 3$ GeV/c
- $p_T(\Lambda) > 1.6$ GeV/c ,
- Λ^0 decay length ($L_{xy}/\sigma_{L_{xy}} > 4$),
- (Λ^0 decay vertex to J/ψ vertex) pointing angle ($< 2.5^\circ$),
  - Due to Λ^0 large lifetime ($c\tau \sim 8$ cm), the p and π are required to have large impact parameter .
  - DØ can not distiguish between protons and pions. From Monte-Carlo, $p_T(p) > p_T(\pi)$. Then assume p is leading.

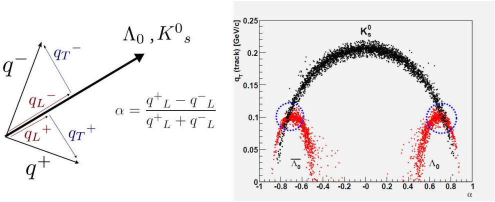


B_d^0 reconstruction

- Similar conditions to reconstruct $K_S^0 \to \pi^+\pi^-$.
- We use $B_d^0 \to J/\psi K_S^0$ as normalization channel for $\Lambda_b^0 \to J/\psi\Lambda^0$.



- Track pairs simultaneously identified as both Λ^0 and K_S^0 due to different mass assignments to the same tracks are removed.



Armeteros-Podolanski technique

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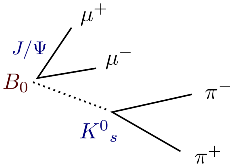

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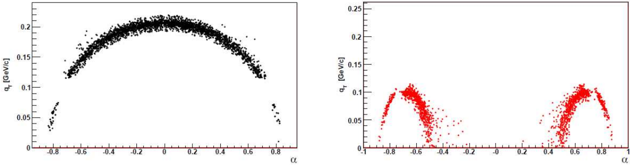
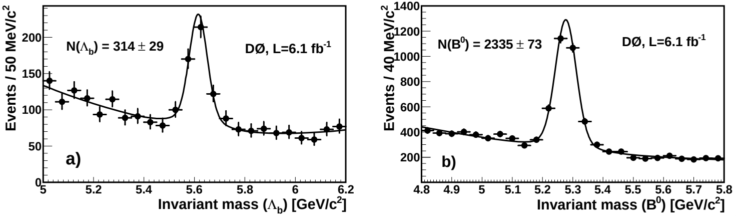


Armeteros-Podolanski plots after removing track pair ambiguities

Λ_b^0 and B_d^0 reconstruction and yields

- Λ_b^0 (B_d^0) are reconstucted by performing a constrained fit to a common vertex for the Λ^0 (K_S^0) and two muon tracks.
- Minimum transverse proper decay length (> 2) to reduce (J/ψ) prompt background.



$\Lambda_b^0 \to J/\psi\Lambda^0$ Branching Fraction measurement: method

$$N_{obs}\left[\Lambda_b \to J/\psi(\mu^+\mu^-)\Lambda^0(p\pi^-)\right] = N_{prod}\left[\Lambda_b \to J/\psi(\mu^+\mu^-)\Lambda^0(p\pi^-)\right] \times \epsilon_R\left[\Lambda_b \to J/\psi(\mu^+\mu^-)\Lambda^0(p\pi^-)\right]$$

where the number of decays produced in collisions is:

$$N_{prod}\left[\Lambda_b \to J/\psi(\mu^+\mu^-)\Lambda^0(p\pi^-)\right] = \mathcal{L}\sigma(p\overline{p} \to b\overline{b})f(b \to \Lambda_b) \times Br\left(\Lambda_b \to J/\psi\Lambda^0\right) Br\left(J/\psi \to \mu^+\mu^-\right) Br\left(\Lambda^0 \to p\pi^-\right)$$

The efficiency ϵ_R (acceptance+detector+reconstruction) can be obtained from simulations. Similar expressions for $B_d^0 \to J/\psi K_S^0$.

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The efficiency ϵ_R (acceptance+detector+reconstruction) can be obtained from simulations. Similar expressions for $B_d^0 \to J/\psi K_S^0$. Then:

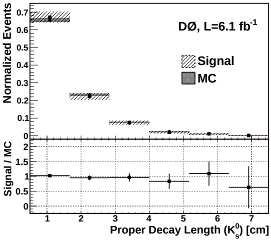
$$\boxed{\sigma_{\text{rel}} = \frac{f(b \to \Lambda_b)\cdot\mathcal{B}(\Lambda_b \to J/\psi\Lambda)}{f(b \to B^0)\cdot\mathcal{B}(B^0 \to J/\psi K_s^0)} = \frac{N_{\Lambda_b \to J/\psi\Lambda}}{N_{B^0 \to J/\psi K_S^0}} \cdot \frac{\mathcal{B}(K_s^0 \to \pi^+\pi^-)}{\mathcal{B}(\Lambda \to p\pi^-)} \cdot \epsilon.}$$

$$\epsilon \equiv \frac{\epsilon_R[B^0 \to J/\psi K_S^0]}{\epsilon_R[\Lambda_b \to J/\psi\Lambda]}$$

(Most systematic errors cancel in this ratio)

$\Lambda_b^0 \to J/\psi\Lambda^0$ Reconstruction efficiencies.

- The relative efficiency ϵ is determined from MC simulation:
  - Pythia (production) + EvtGen[4] (decay) + GEANT (detector).
  - Same reconstruction algorithm as in data.
- Data and Monte Carlo distributions are found to be in good agreement. Below an example.



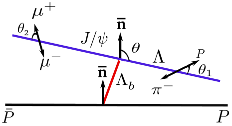
- We found $\epsilon = 2.37 \pm 0.05$.

[4] D.J. Lange, NIM. PRA **462**, 152 (2001).

$\Lambda_b^0 \to J/\psi\Lambda^0$ BR: systematics and polarization effect

- Dominant systematic unc.:
  - Unknown Λ_b^0 polarization, impacts evaluation of ϵ.
- Λ_b^0 initially polarized was implemented in EvtGen, assigning the correct spin density matrix. $\Lambda_b \to J/\psi\Lambda$ is described completely in terms of 5 (helicity) angles.
- Polarization is observed (mainly) through θ:

Test	Systematic uncertainty (%)
Fit Model	5.5
Signal Decay Model for B_0	2.0
Background from B_d^0 and Λ_b^0	2.3
Λ_b^0Polarization ($P_b\alpha_b = +1$)	7.2
Total (in quadrature)	9.6



$$I(\theta) = \frac{1}{2}\left(1 + \alpha_{\Lambda_b} P_{\Lambda_b} \cos\theta\right) \qquad (1)$$

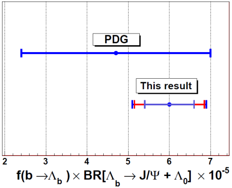
(α_{Λ_b} and P_{Λ_b} are the Λ_b^0 (weak PV) asymmetry parameter and polarization)

$\Lambda_b^0 \to J/\psi\Lambda^0$ Branching Ratio measurement: results

$$\frac{f(b \to \Lambda_b) \cdot \mathcal{B}(\Lambda_b \to J/\psi\Lambda)}{f(b \to B^0) \cdot \mathcal{B}(B^0 \to J/\psi K_s^0)} = 0.345 \pm 0.034\ (\text{stat.}) \pm 0.033\ (\text{syst.}) \pm 0.003\ (\text{PDG})$$

- From the PDG, $f(b \to B^0) \cdot \mathcal{B}(B^0 \to J/\psi K_s^0) = (1.74 \pm 0.08) \times 10^{-4}$. Then:

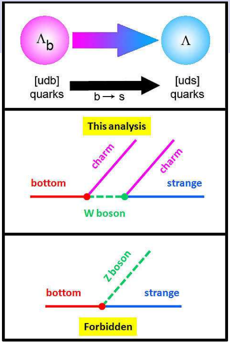
$$f(b \to \Lambda_b) \cdot \mathcal{B}(\Lambda_b \to J/\psi\Lambda)\ \left[\times 10^{-5}\right] = 6.01 \pm 0.60\ (\text{stat.}) \pm 0.58\ (\text{syst.}) \pm 0.28\ (\text{PDG}) = 6.01 \pm 0.88$$



[PDG 2010: $(4.7 \pm 2.3) \times 10^{-5}$]

- arXiv:1105.0690. Accepted in PRD-RC.

Final comments: $\Lambda_b^0 \to \mu^+\mu^- \ \Lambda^0$



- We can use $\Lambda_b \to J/\psi + \Lambda$ to normalize $\Lambda_b \to \mu^+\mu^- + \Lambda$:

$$BR[\Lambda_b \to \mu^+ + \mu^- + \Lambda] =$$
$$\color{red}{BR[\Lambda_b \to J/\psi + \Lambda]} \times BR[J/\psi \to \mu^+\mu^-]$$
$$\times \frac{\varepsilon_{b\to W\to s}}{\varepsilon_{b\to s}} \times \frac{N_{obs}[\Lambda_b \to \mu^+ + \mu^- + \Lambda_{[\pi p]}]}{N_{obs}[\Lambda_b \to J/\psi_{[\mu\mu]} + \Lambda_{[\pi p]}]}$$

- The BR of this rare decay ($\sim 2 - 5 \times 10^{-6}$ in SM) can be enhanced by new physics effects ($\times 10$ in SUSY models).[5]

[5] PRD 64, 074001,(2001); PRD 81,056006 (2010); arXiv:0808.2113.

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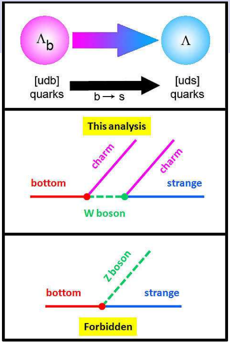

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- The BR of this rare decay ($\sim 2 - 5 \times 10^{-6}$ in SM) can be enhanced by new physics effects ($\times 10$ in SUSY models).[5]
- CDF reported the observation of this decay a few days ago (arXiv:1107.3753v1): using our measurement they found $\mathcal{B}(\Lambda_b \to \mu^+\mu^-\Lambda) = 1.73 \pm 0.42$ (stat) $\pm\, 0.55$ (syst.) and no significant deviation from the SM.

[5] PRD 64, 074001,(2001); PRD 81,056006 (2010); arXiv:0808.2113.

Conclusions

- A new measurement of $f(b \to \Lambda_b) \cdot \mathcal{B}(\Lambda_b \to J/\psi\Lambda)$ has been performed and is found to be:

$$(6.01 \pm 0.60\ (\text{stat.}) \pm 0.58\ (\text{syst.}) \pm 0.28\ (\text{PDG})) \times 10^{-5}$$

- This result represents a reduction by a factor of ~ 3 of the uncertainty with respect to the previous measurement.
- Important measurements such as the branching ratio of FCNC decays ($\Lambda_b \to \mu^+\mu^-\Lambda$) or the Λ_b polarization can be performed with the tools developed in this analysis.

Stay tuned, we are working on that!

Final comments: How can we extract $\mathcal{B}(\Lambda_b \to J/\psi\Lambda)$?

- We need an external measurement of $f(b \to \Lambda_b)$. We are not aware of any direct measurement of this quantity.
- $f(b \to b_{baryon}) \neq f(b \to \Lambda_b)$. Tevatron has observed Ξ_b^-, Σ_b, Ω_b, and recently Ξ_b^0.
- To first aproximation, $f(b \to b_{baryon}) \approx f(b \to \Lambda_b) + f(b \to \Xi_b^-) + f(b \to \Xi_b^0)$.
  - Assume isospin invariance. Then $f(b \to \Xi_b^-) \approx f(b \to \Xi_b^0)$.[6]
  - It's also observed that $f(b \to B_s)/f(b \to B_d) \approx f(b \to \Xi_b^-)/f(b \to \Lambda_b)$.[7]
  - Then: $\mathcal{B}(\Lambda_b \to J/\psi\Lambda) \approx (11.08 \pm 1.09\ (\text{stat}) \pm 1.06\ (\text{syst}) \pm 3.13\ (\text{PDG})) \times 10^{-4} = (11.08 \pm 3.48) \times 10^{-4}$.
  - Same assumptions to the W.A would lead to $(8.67 \pm 4.84) \times 10^{-4}$.
- Experimental results favors models which predict a larger value for this branching ratio.

[6] arXiv:1010.1589v2

[7] PDG note on Production and Decay of b-Flavored Hadrons, Phys. Rev. Lett. 99, 052001 (2007)