Properties of *B* hadrons: results from Tevatron

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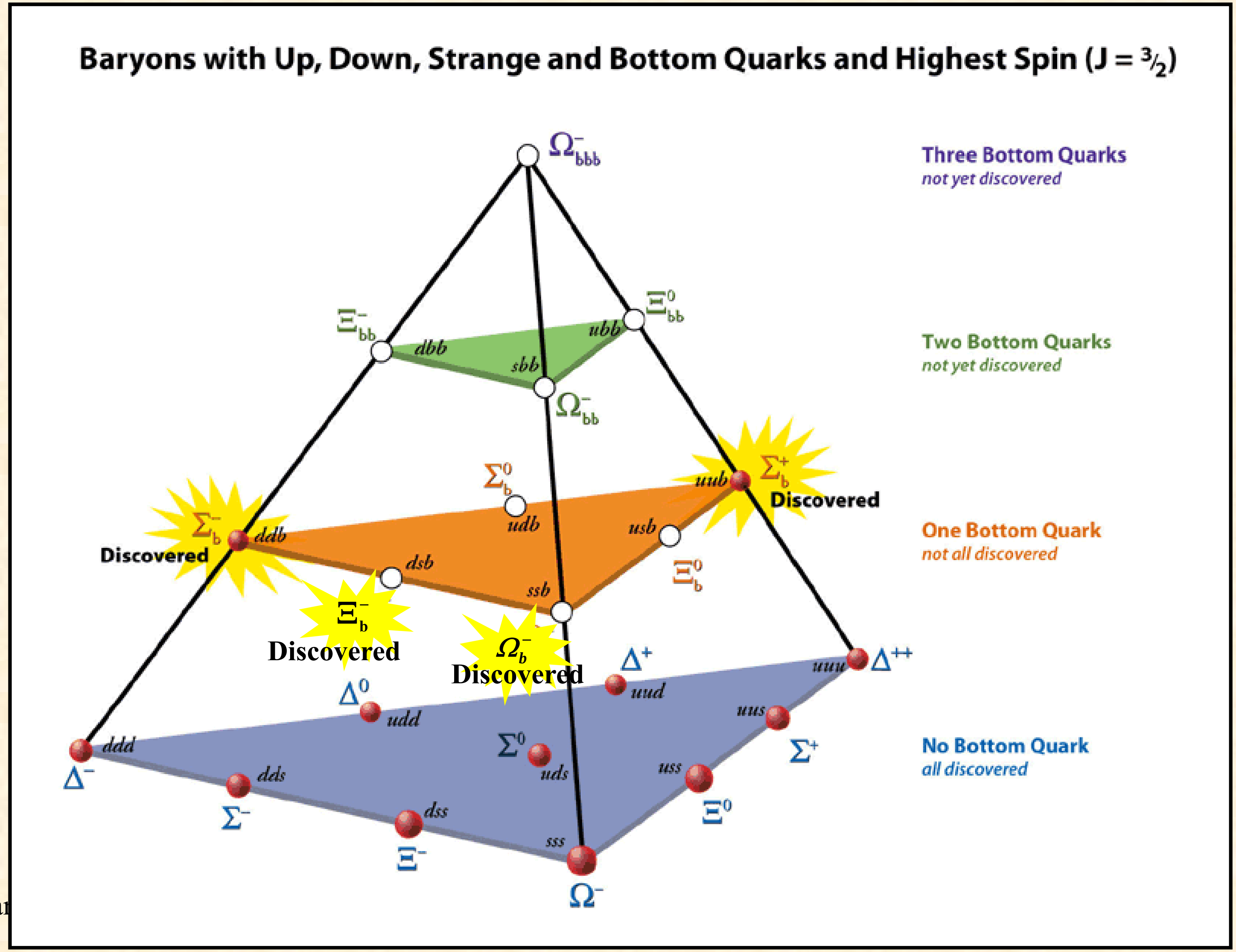
- *B* hadrons allow to study all kinds of interactions, both at short and long distance;
- QCD becomes a precise science for heavy-light quark bound system
  - Ratio of lifetimes of different *B* hadrons are predicted with ~1-3% accuracy;
  - Masses of different *B* baryons are predicted with few MeV precision;
- Experimental measurements have comparable or better precision;
- Meaningful comparison of experiment and theory is possible;
- Experimental input helps a lot to develop theoretical methods
  - Example: initial theoretical estimates of $\tau(\Lambda_b)/\tau(B^0)$ significantly improved following the discrepancy with the experimental results;

- Many new results on properties of *B* hadrons come from Tevatron. In this talk:
  - Masses of particles containing *b* quark;
  - Lifetimes;
- In other talks:
  - B_s: Oscillation, lifetime difference and CP violation;
  - Unitarity triangle, including contributions from Tevatron;
  - Rare decays of *B* mesons and implications for new physics;

B baryon spectroscopy

- Many new results on properties of B baryons were obtained recently;
- Excellent possibility to compare theory and experiment:
  - Precise theoretical predictions of masses (e.g. E. Jenkins, PRD 55, R10-R12 (1997)):
    - $M(\Xi_b) = 5805.7 \pm 8.1$ MeV;
    - $M(\Sigma_b) = 5824.2 \pm 9.0$ MeV;
    - $M(\Sigma_b^*) = 5840.0 \pm 8.8$ MeV;
    - $M(\Omega_b) = 6068.7 \pm 11.1$ MeV;
  - Interesting to note: $M(\Xi_b) < M(\Sigma_b)$ (contrary to baryons with light and charm quarks;

Expected baryons with b quark



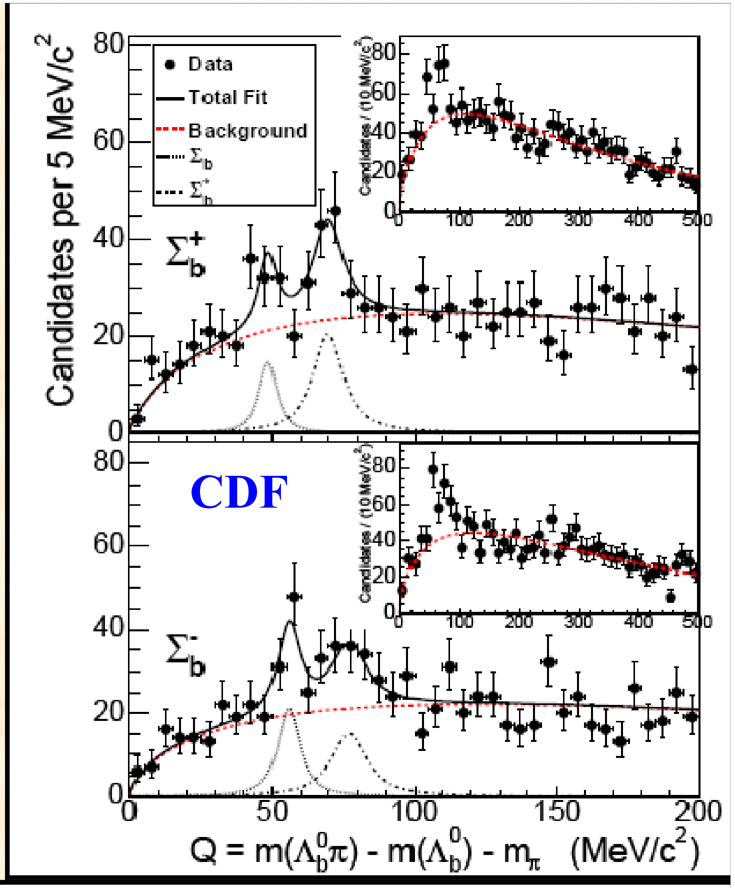
Observed B baryons

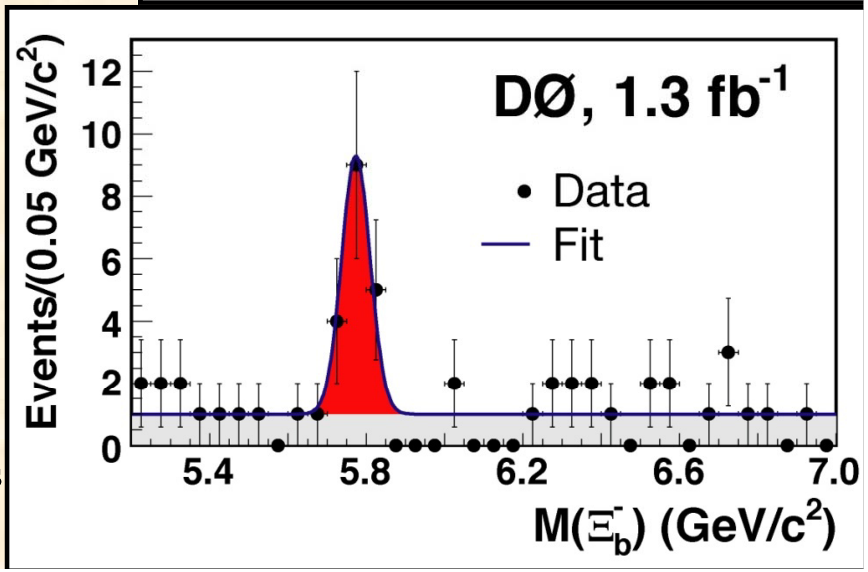
- Σ_b and Σ_b^* (CDF)

$$M(\Sigma_b^+) = 5807.8^{+2.0}_{-2.2} \pm 1.7\ \text{MeV}$$
$$M(\Sigma_b^-) = 5815.2 \pm 1 \pm 1.7\ \text{MeV}$$
$$M(\Sigma_b^{*+}) = 5829^{+1.6}_{-1.8} \pm 1.7\ \text{MeV}$$
$$M(\Sigma_b^{*-}) = 5836.4 \pm 2.0^{+1.8}_{-1.7}\ \text{MeV}$$

- Ξ_b^-

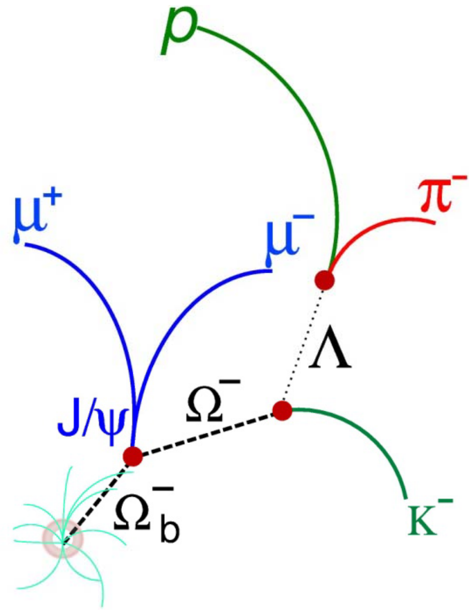
$$M(\Xi_b^-) = 5774 \pm 11 \pm 15\ \ \text{MeV (Dzero)}$$
$$M(\Xi_b^-) = 5792.9 \pm 2.4 \pm 1.7\ \ \text{MeV (CDF)}$$

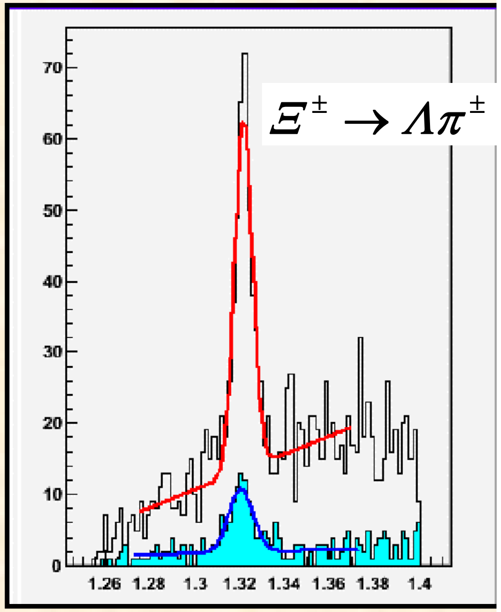




Discovery of Ω_b

- DØ collaboration recently reported the observation of Ω_b (bss):
  - Decay chain $\Omega_b^- \to J/\psi\ \Omega^-$; $\Omega^- \to \Lambda K^-$; $\Lambda \to p\pi^-$ is used;
- The same statistics and the same special processing of data is used:
  - Special reprocessing of data with the increased acceptance of low momentum tracks with large impact parameter allowed to increase the efficiency of Ω^- reconstruction ~6 times;

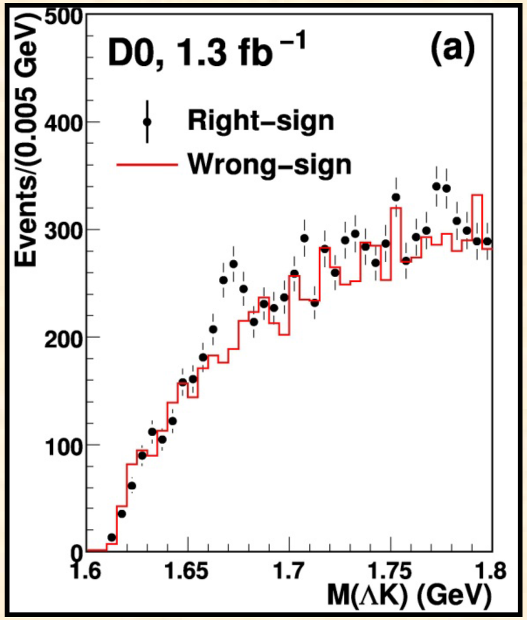


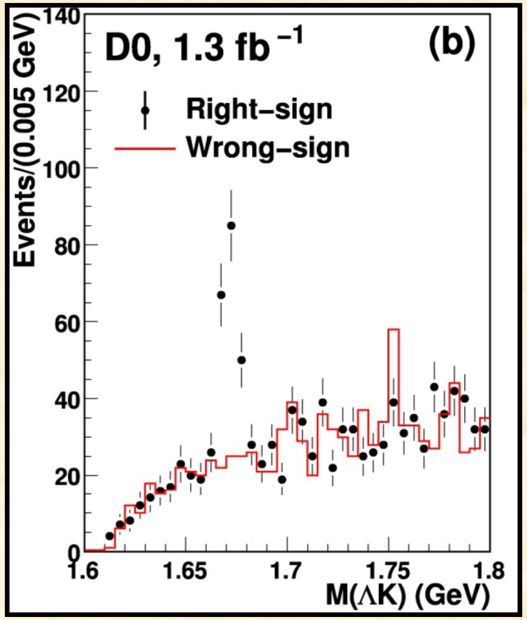


Mass of $\Lambda\pi$ with standard (bottom histogram) and modified tracking algorithm;

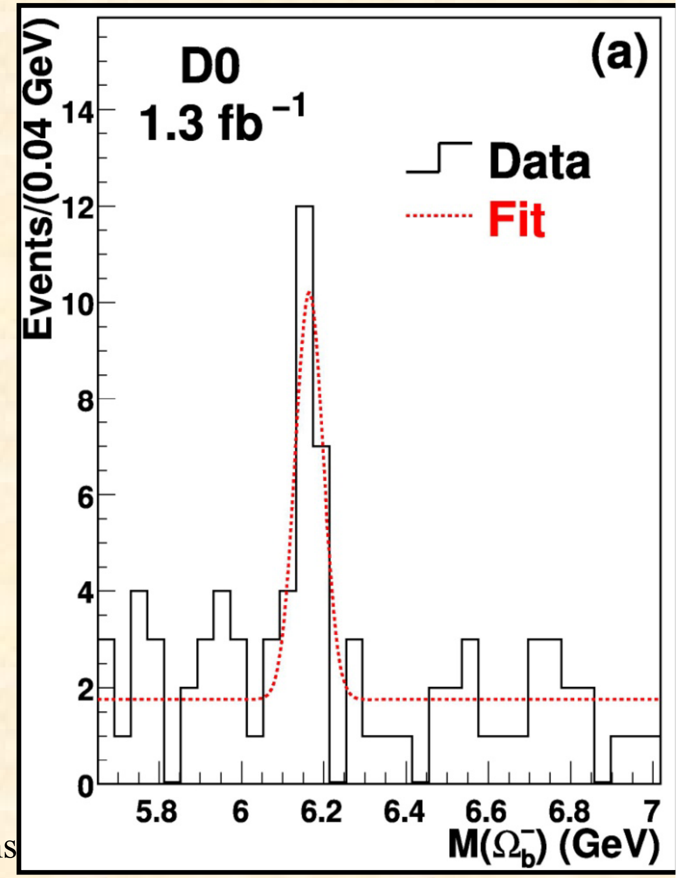
Discovery of Ω_b

- Multivariate technique (BDT) was used to improve the signal selection and suppress background:





The invariant mass distribution of the ΛK pair before and after the BDT selection

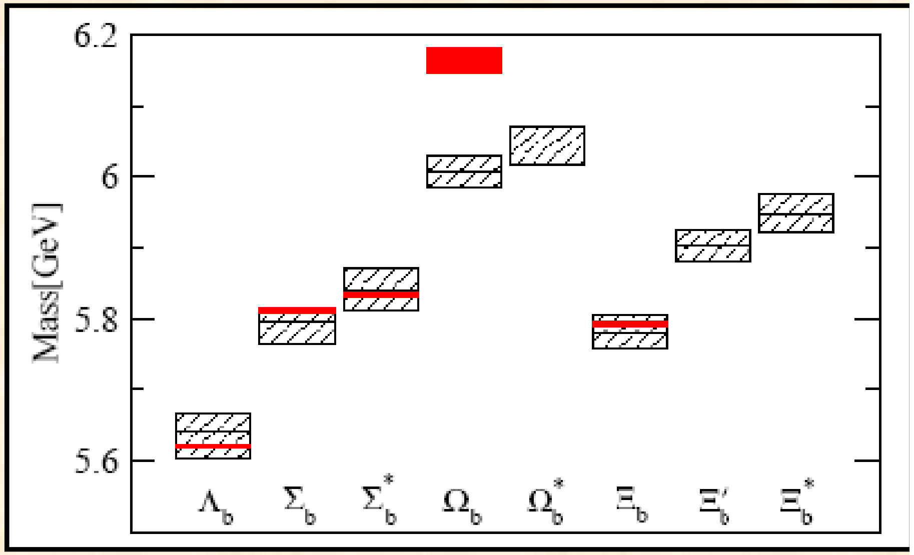


- 17.8 ± 4.9 events observed (5.4 σ statistical significance);

$$M(\Omega_b^-) = 6165 \pm 10 \pm 13 \quad \text{MeV (Dzero)}$$

Comparison with theory

- In general, theory predicts a lower Ω_b mass:
  - 6039 ± 8 MeV
    - E. Jenkins, PR D77, 034012 (2008);
  - 6052.1 ± 5.6 MeV
    - M. Karliner *et al.* arXiv:0804.1575;
  - 6036 ± 81 MeV
    - X. Liu *et al.* , PR D77, 014031 (2008);
  - 6006 ± 22 MeV
    - R. Lewis, R.M. Woloshyn, PR D79, 014502 (2009);



Comparison of theoretical prediction (boxes) and experimental results (red lines). Taken from: R. Lewis, R.M. Woloshyn, PR D79, 014502 (2009);

Additional experimental and theoretical studies are required to resolve this new Ω_b puzzle

B_c mass

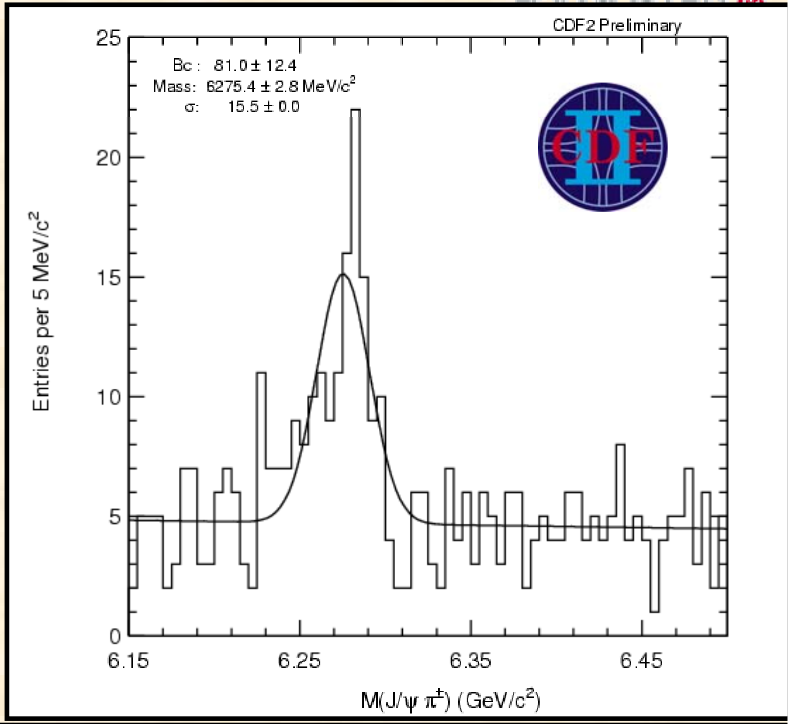
- Now measured by both CDF and DØ collaborations in $B_c \to J/\psi\, \pi$ mode;
- Consistent results are obtained:

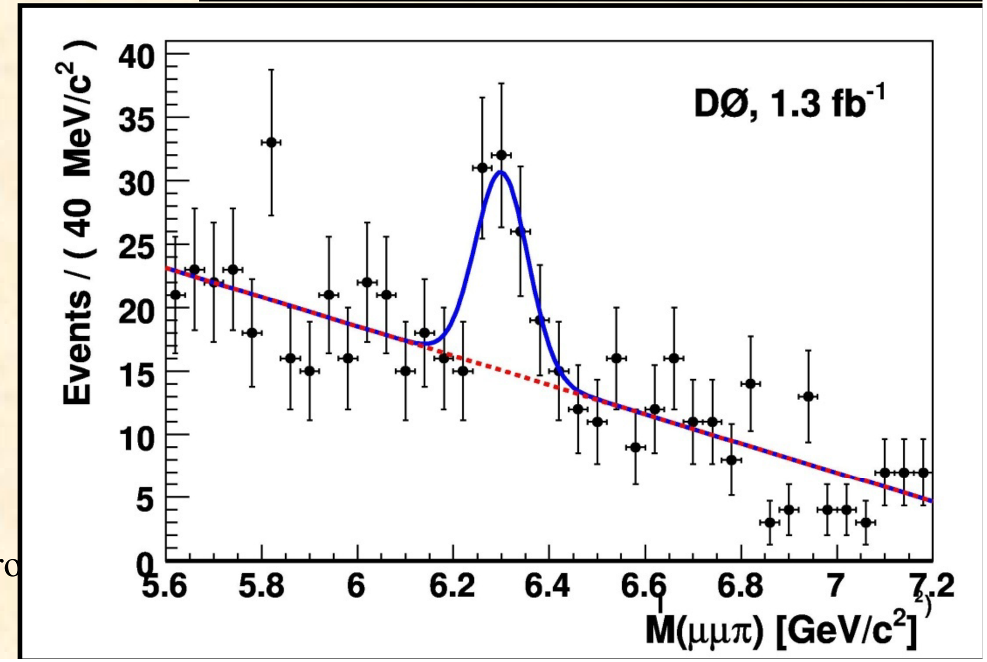
$$M(B_c) = 6275.6 \pm 2.9 \pm 2.5 \quad \text{MeV (CDF)}$$
$$M(B_c) = 6300 \pm 14 \pm 5 \quad \text{MeV (Dzero)}$$

- Agree well with theory prediction:

$$M(B_c) = 6304 \pm 12\ ^{+18}_{-0}\ \text{MeV (Theory)}$$

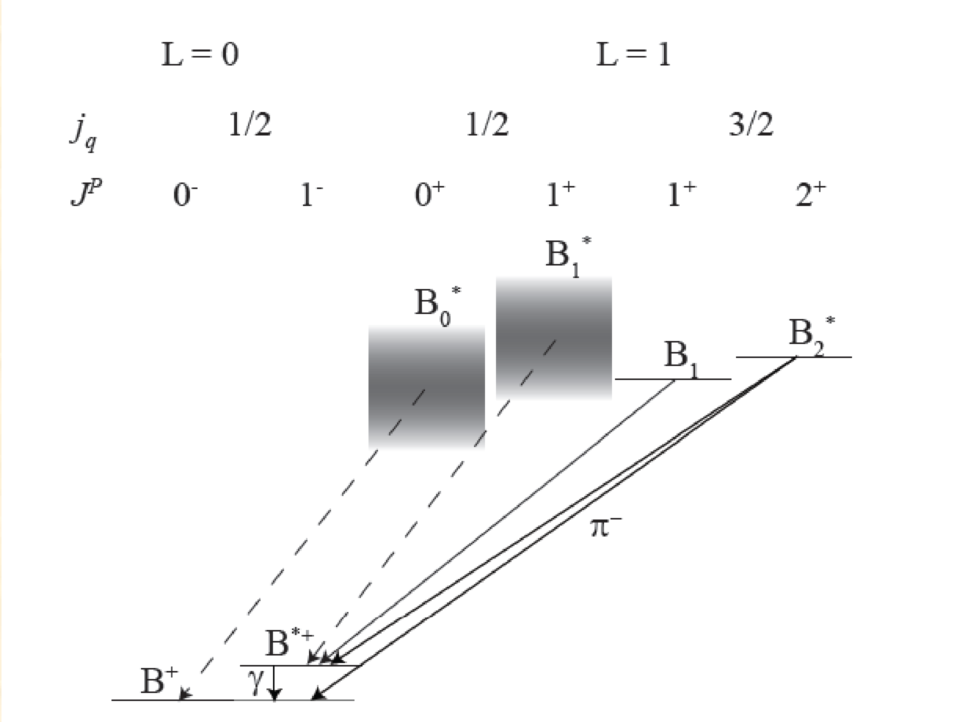
  – (lattice QCD calculations, J. Allison *et al.* PRL 94, 172001 (2005)):





Excited B^{**} mesons

- Tevatron is currently the main source of information on excited ($L=1$) states with *b* quark;
- Theory gives precise predictions on the masses of these states, and especially on the mass splitting between B_2^* and B_1 mesons;
- Good possibility to compare theory and experiment;



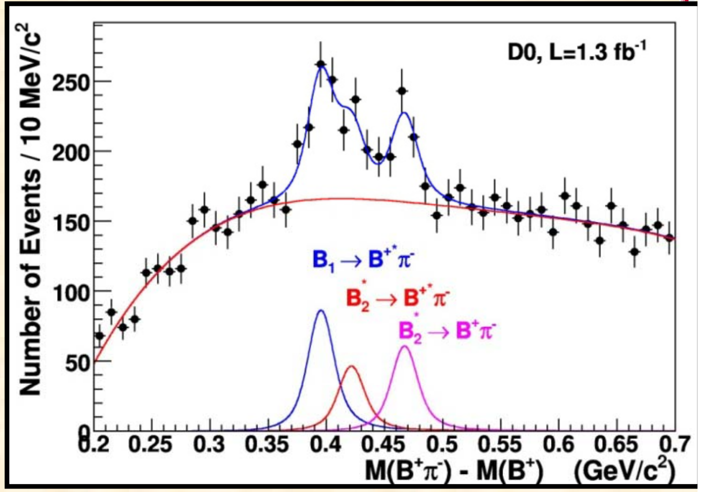
Excited B^{**} mesons

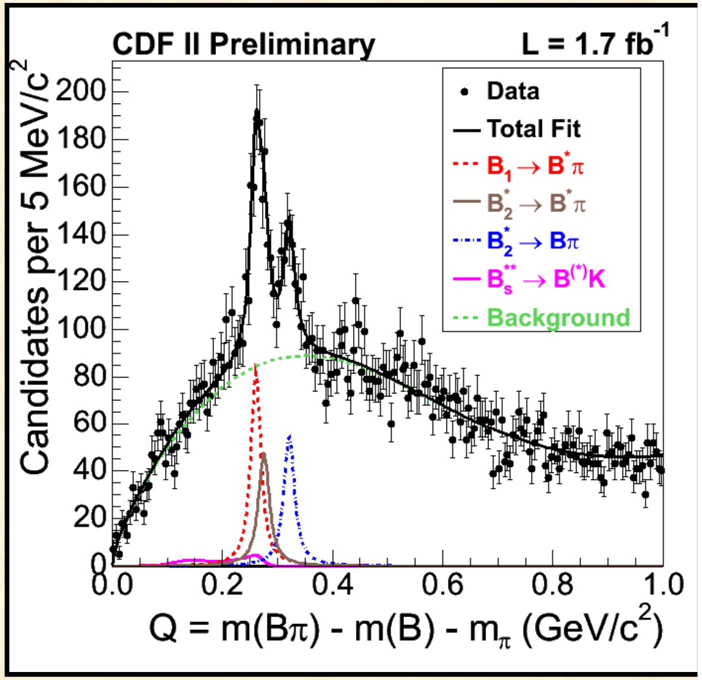
- Decay mode $B^{**} \to B^+ \pi^-$ is used;
- Both CDF and DØ observe B_1 and B_2^* states:

$$M(B_1) = 5720.6 \pm 2.4 \pm 1.4 \text{ MeV (Dzero)}$$
$$M(B_1) = 5725.3^{+1.6\,+1.4}_{-2.2\,-1.5} \text{ MeV (CDF)}$$

$$M(B_2^*) = 5746.8 \pm 2.4 \pm 1.7 \text{ MeV (Dzero)}$$
$$M(B_2^*) = 5740.2^{+1.7\,+0.9}_{-1.8\,-0.8} \text{ MeV (CDF)}$$

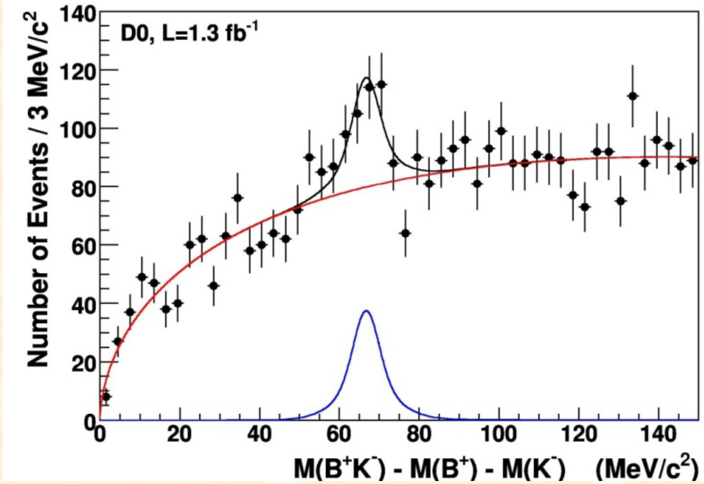
- Maximal difference between results of two collaborations is ~2σ





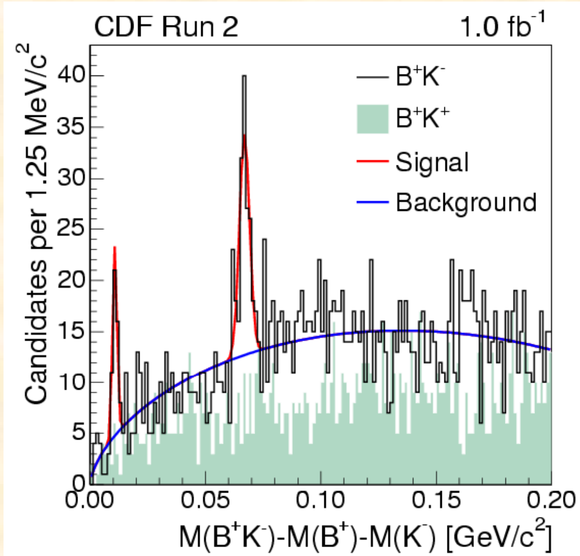
Excited B_s^{**} states

- CDF observes both B_{s2}^* and B_{s1} states, while DØ confirmed only B_{s2}^* meson:
  - Lack of statistics does not allow the DØ collaboration to either confirm or deny B_{s1};



$$M(B_{s1}) = 5829.4 \pm 0.7 \text{ MeV (CDF)}$$

$$M(B_{s2}^*) = 5839.6 \pm 1.1 \pm 0.7 \text{ MeV (Dzero)}$$
$$M(B_{s2}^*) = 5839.6 \pm 0.7 \text{ MeV (CDF)}$$



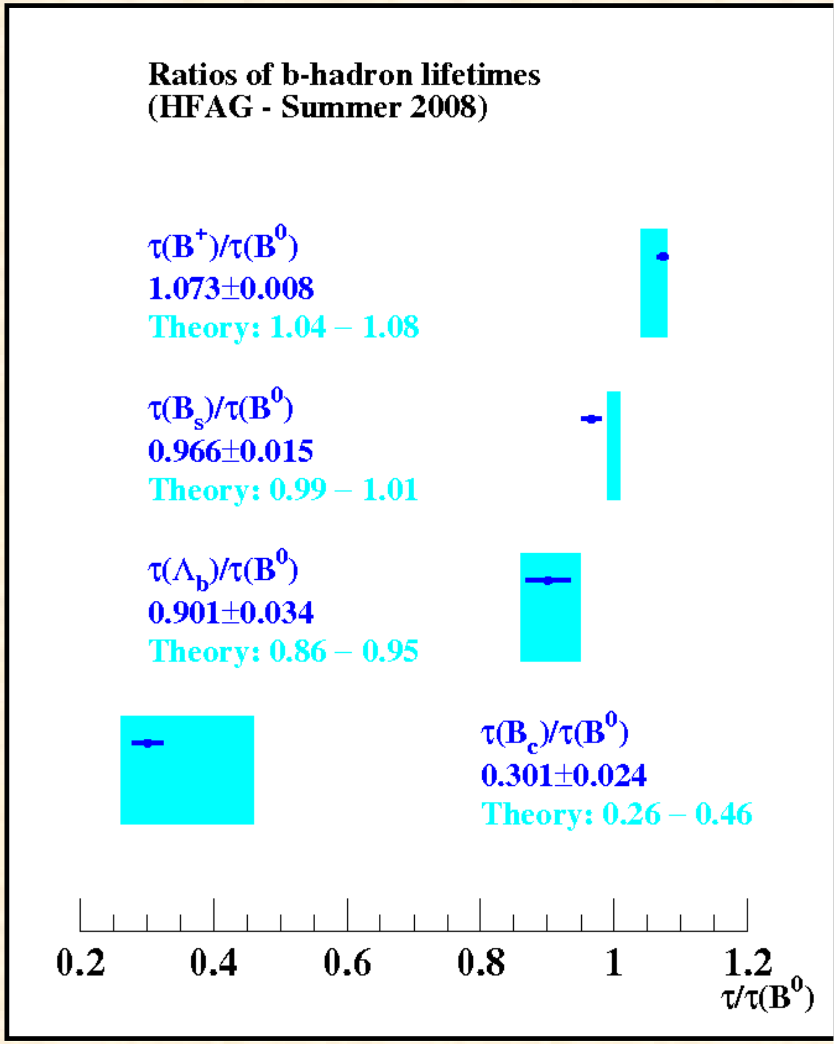
- Measured masses of B^{**} states can be compared with theoretical predictions;

Lifetime of b hadrons

- Lifetime is another quantity which allows direct comparison between theory and experiment;
- Theory predicts the hierarchy:

$$\tau(B_c^+) << \tau(\Lambda_b^0) < \bar{\tau}(B_s^0) \approx \tau(B^0) < \tau(B^+)$$

- Theory predictions are especially precise for lifetime ratios;
- Precision of Tevatron results is now dominant for B_s, Λ_b and B_c lifetimes;
- It is much better than all previous measurements;

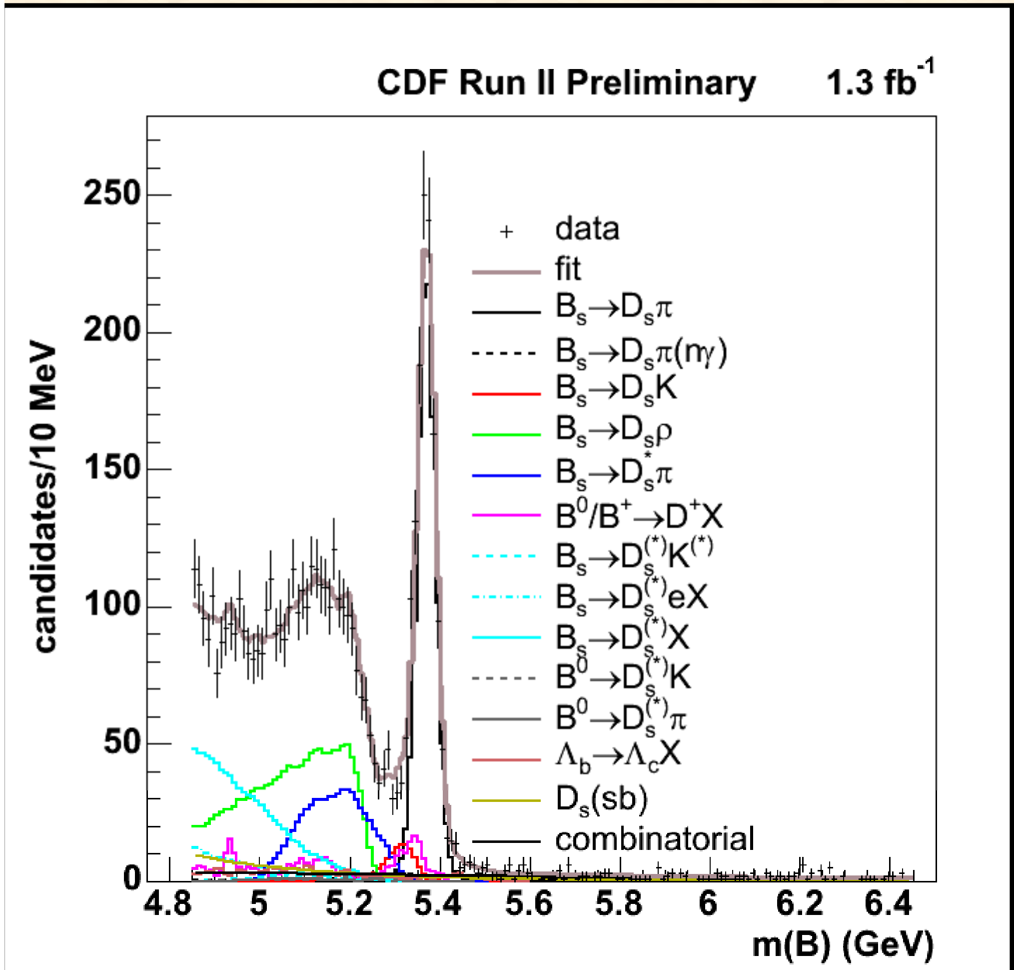


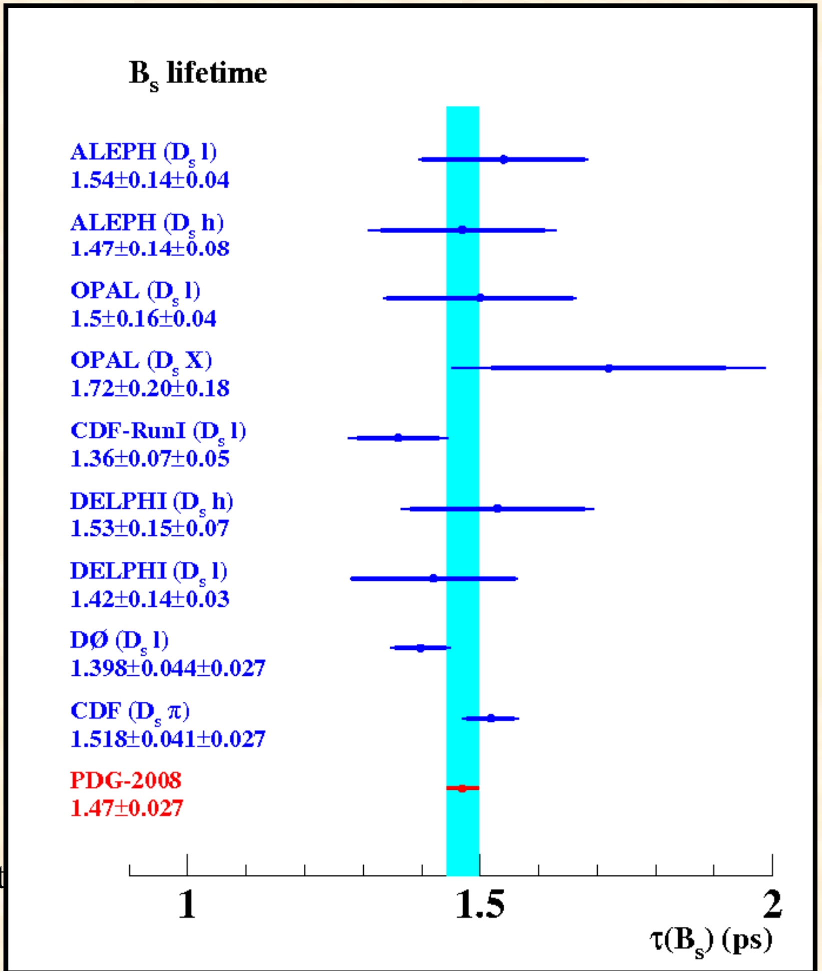
B_s Lifetime (CDF)

- New CDF result in $B_s \to D_s \pi$ channel:

$$\tau(B_s^0) = 1.518 \pm 0.041 \pm 0.027\ \text{ps}$$

$$\text{PDG 2008}: \quad \bar{\tau}(B_s^0) = \frac{2}{\Gamma_L + \Gamma_H} = 1.470^{+0.027}_{-0.026}$$





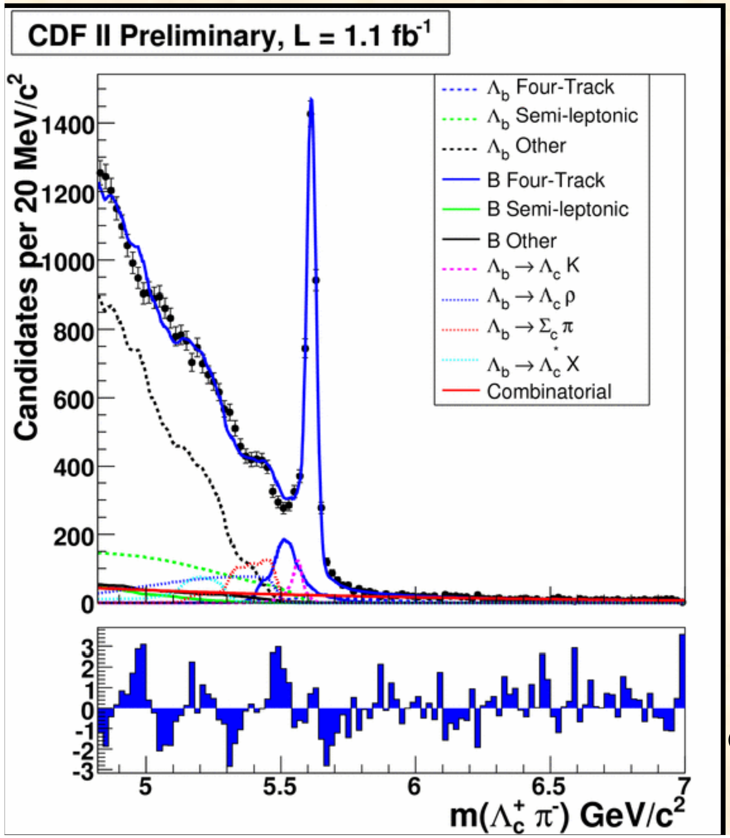
Λ_b Lifetime

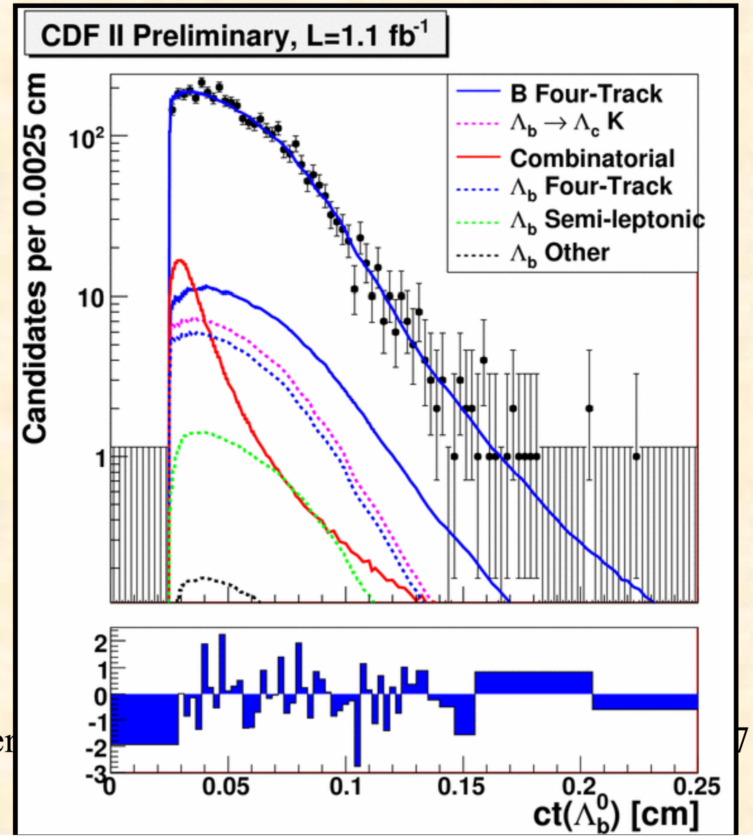
- A lot of discussion of Λ_b lifetime recently ("Λ_b puzzle");
- Earlier theoretical calculations predicted $\tau(\Lambda_b)/\tau(B^0)$ value around 0.94, experimental values (mainly LEP measurements) were around 0.75;
- Recent calculations include higher order effects and predict a lower ratio: 0.86 − 0.95:
  - C. Tarantino, Eur. Phys. J. C 33, S895 (2004);
  - F. Gabbiani et al., Phys. Rev. D 70, 094031 (2004).
- Tevatron results increased the experimental value, but there was some inconsistency between collaborations:
  - CDF measurement in $\Lambda_b \to J/\psi\ \Lambda$:
  - DØ measurement in $\Lambda_b \to J/\psi\ \Lambda$:
  - DØ measurement in $\Lambda_b \to \mu\nu\Lambda_c$:
    - There was ~2.5σ difference between CDF and DØ

$$\tau(\Lambda_b) = 1.580 \pm 0.077 \pm 0.012\ ps \quad \text{(CDF)}$$
$$\tau(\Lambda_b) = 1.218^{+0.130}_{-0.115} \pm 0.042\ ps \quad \text{(D0)}$$
$$\tau(\Lambda_b) = 1.290^{+0.119}_{-0.110} \pm^{+0.087}_{-0.091}\ ps \quad \text{(D0)}$$

Λ_b lifetime (CDF)

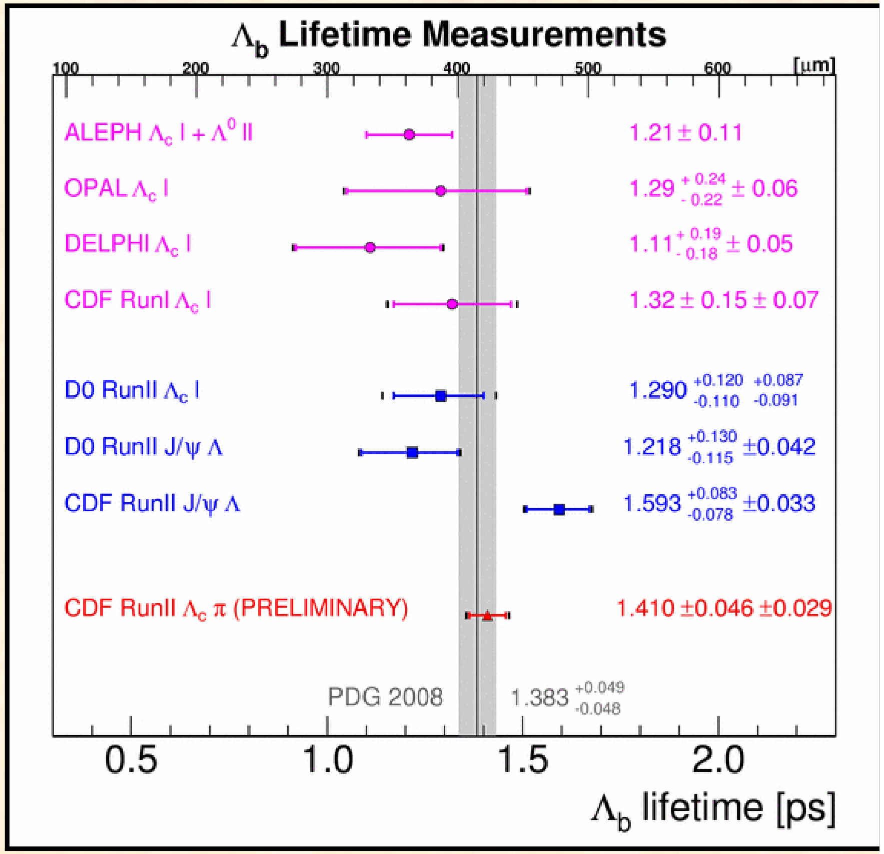
- CDF released a new result on Λ_b lifetime measured in $\Lambda_b \to \Lambda_c \pi$ mode: $\tau(\Lambda_b) = 1.410 \pm 0.046 \pm 0.029$ ps
- The most precise single measurement;
- Excellent description of the mass and lifetime distribution;
- Events are obtained with the lifetime biasing trigger;





Λ_b lifetime (summary)

- New results from Tevatron now dominate in the world average precision of Λ_b lifetime;
- New CDF result (shown in red) eliminates the inconsistency between the experiments;
- World average is now consistent with the theoretical prediction;



B_c lifetime

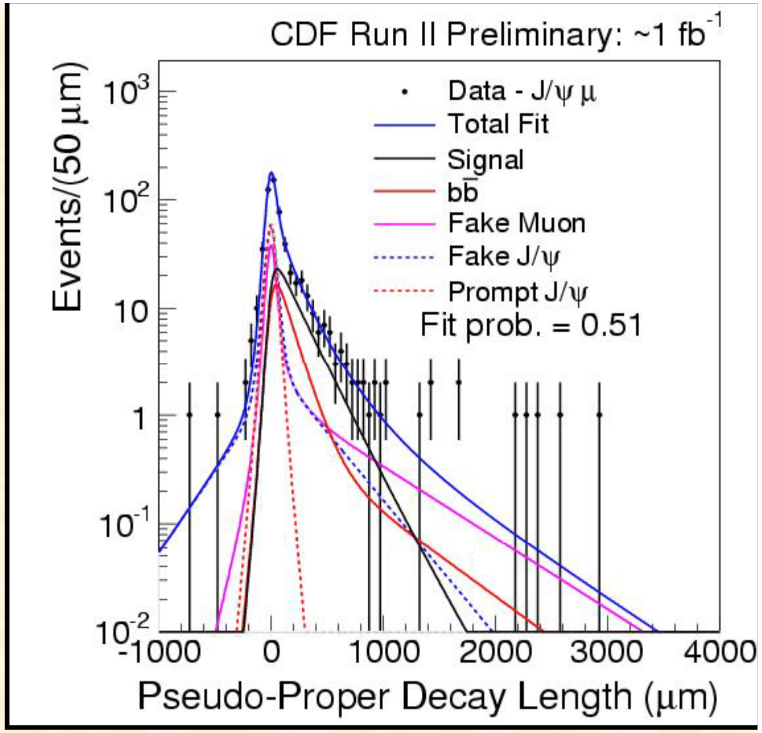
- Now measured by both CDF and DØ collaborations in $B_c \rightarrow J/\psi\ l\ \nu$ mode
  - CDF uses events with $l = \mu, e$; DØ with $l=\mu$ only;
- Results are consistent and precision is similar:

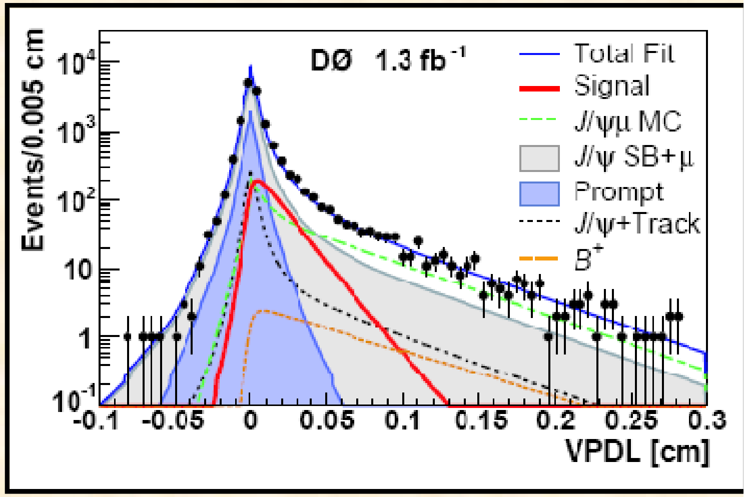
$$\tau(B_c) = 0.475^{+0.053}_{-0.049} \pm 0.018 \text{ ps (CDF)}$$
$$\tau(B_c) = 0.448^{+0.038}_{-0.036} \pm 0.032 \text{ ps (Dzero)}$$

- World average value:

$$\tau(B_c) = 0.461 \pm 0.036 \text{ ps (HFAG)}$$

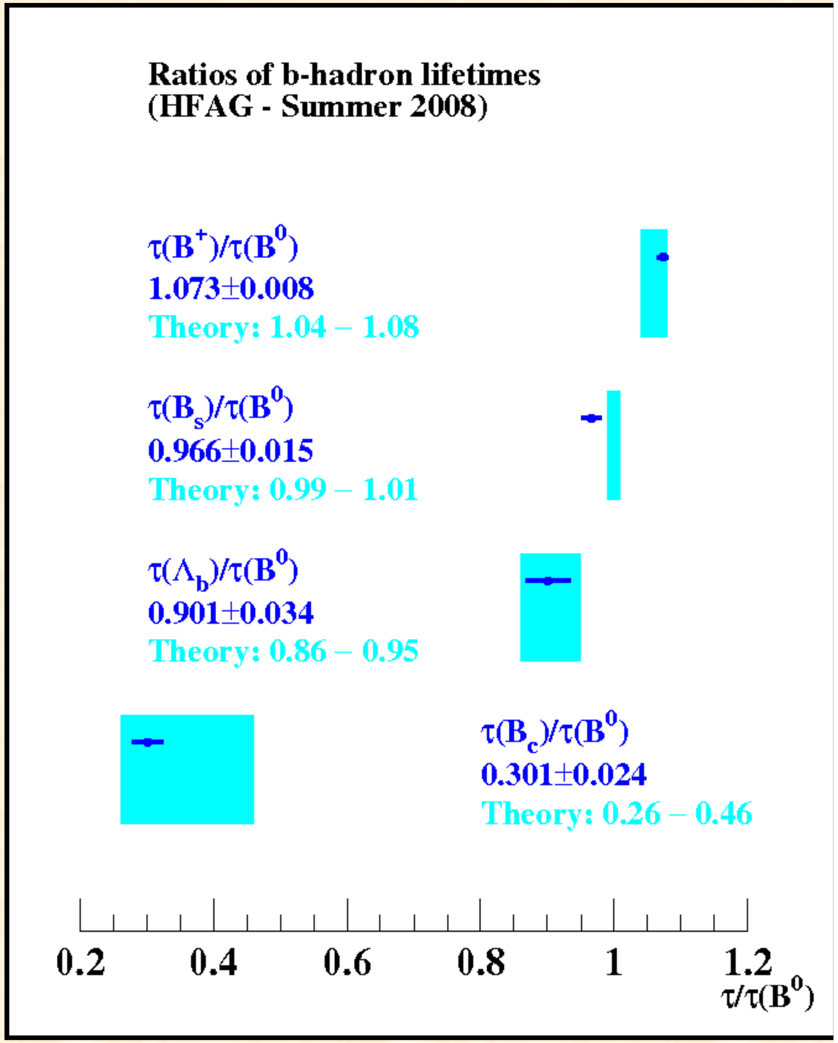
- Experimental precision is now much better than the theoretical:
  - $\tau(B_c) = 0.4 - 0.7$ ps (V.V. Kisilev, hep-ph 0211201)
  - Need the updated theoretical prediction;





Current status of lifetime measurements

- Excellent agreement between experiment and theory;
- Need to improve the theoretical precision for $\tau(B^+)/\tau(B^0)$, $\tau(B_c)$ for a more accurate comparison with experiment;
- Need to measure the lifetime of B baryons – Ξ_b, Ω_b for the new tests of theory;



Conclusions

- *B*-physics program at Tevatron gives rich results:
  - Discovery of new states containing *b* quark;
  - Precise measurement of masses of *B* hadrons;
  - Precise measurement of lifetime of *B* hadrons;
- All these results provide an important input for theoretical computation and help to tune the models describing the quark system;
- Still a lot more is expected in the future:
  - Main results were obtained with 1-2 fb^{-1}/experiment;
  - We already have 5 fb^{-1} / experiment available;
  - We continue the data taking and expect even more statistics;