PROPERTIES OF B HADRONS: RESULTS FROM THE TEVATRON*

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The latest B-physics results obtained in the experiments at the Tevatron are presented. They include an observation of new B baryons, new measurements of lifetime of B hadrons, and the properties of B_s^0 meson.

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1. Introduction

B hadrons give a unique possibility to study all kinds of interactions, both at short and long distance. The QCD becomes a precise science for the quark systems involving b quark. For example, the lifetime ratios of different B hadrons are predicted with 1–3% accuracy [1], and the masses of new B baryons are predicted with a few MeV precision [2]. B mesons are ideally suited to study the CP-violation and other fundamental properties of the electroweak interactions. The latest achievement in this field is a precise test of the unitarity of the CKM matrix, and the measurements with B hadrons provide an essential input to it [3]. Many properties of B meson, like the branching fraction of $B_s^0 \to \mu^+\mu^-$ decay, or the CP violation in the B_s^0 system, are sensitive to the new physics, and can be used to set stringent constraints on the new models [4, 5].

In this talk I review the new B-physics results coming from the experiments at the Tevatron (Fermilab, USA). They include an observation of new baryons with b quark, the new measurements of lifetimes of different B hadrons, the study of the mass and lifetime difference of B_s^0 meson, and the CP violation in the B_s^0 system. The search for rare B decays and the contribution of the Tevatron into the Unitarity Triangle test are covered in other talks.

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2. B baryons

Almost no experimental information on B baryons was available until 2007 [6]. Only the Λ_b baryon was established, and the indirect indication of the Ξ_b from the LEP experiments was reported, without any information on its mass. The theory predicts the masses of Σ_b, Ξ_b and Ω_b baryons with the precision of about ten MeV [2], providing an excellent possibility of comparison with experiment.

The CDF experiment reports the observation of Σ_b and Σ_b^* baryons [7]. These particles are searched for in the decay chain $\Sigma_b^{(*)\pm} \to \Lambda_b\pi^\pm$, with $\Lambda_b \to \Lambda_c\pi$ and $\Lambda_c \to pK\pi$. A sample of about 2800 Λ_b decays is reconstructed. Each Λ_b candidate is combined with an additional pion, and the obtained mass difference $Q = M(\Lambda_b\pi) - M(\Lambda_b) - M(\pi)$ is shown in Fig. 1. It is fitted to the expected signals of $\Sigma_b^\pm$ and $\Sigma_b^{*\pm}$ assuming that $M(\Sigma_b^{*-}) - M((\Sigma_b^-) = M(\Sigma_b^{*+}) - M((\Sigma_b^+)$, and fixing the width of Σ_b and Σ_b^* to the theory prediction. The following masses of new B baryons are obtained:

$$m(\Sigma_b^+) = 5808^{+2.0}_{-2.3} \pm 1.7 \text{ MeV}, \quad m(\Sigma_b^{*+}) = 5829^{+1.6}_{-1.8} \pm 1.7 \text{ MeV},$$
$$m(\Sigma_b^-) = 5816 \pm 1 \pm 1.7 \text{ MeV}, \quad m(\Sigma_b^{*-}) = 5808^{+2.1}_{-1.9} \pm 1.7 \text{ MeV}. \quad (1)$$

These results agree well with the theory prediction [2].

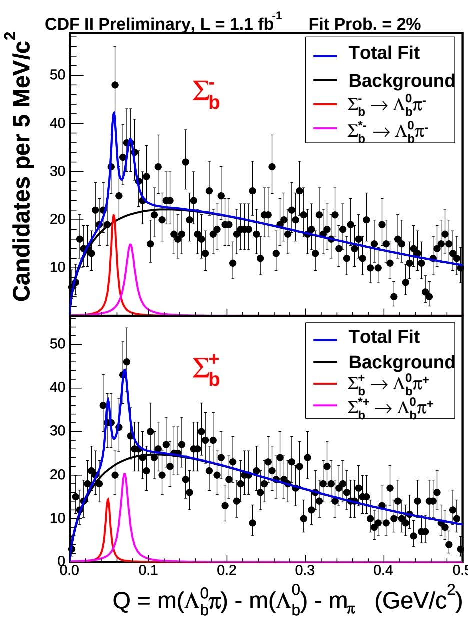

Fig. 1. The mass difference $Q = M(\Lambda_b\pi) - M(\Lambda_b) - M(\pi)$ distribution with the result of the fit with Σ_b and Σ_b^* hypotheses superimposed.

Both the DØ and CDF Collaboration observe for the first time the Ξ_b baryon [8, 9]. It is the first object containing the quarks from all three families. It is searched for in the following decay chain: $\Xi_b \to J/\psi \Xi$, $J/\psi \to \mu^+\mu^-$, $\Xi \to \Lambda\pi$, $\Lambda \to p\pi$. A particular difficulty of this analysis consists in the fact that both Ξ and Λ baryons decay far from the primary interaction point producing the soft tracks with large impact parameters, which are difficult to reconstruct. Special efforts are taken by both collaborations to increase the efficiency of Ξ reconstruction. The mass spectrum of the $J/\psi\Xi$ events obtained by the DØ Collaboration is shown in Fig. 2. The signal of Ξ_b production is clearly seen. The Ξ_b mass measured by both collaboration agree, although the CDF measurement has a much better precision:

$$\begin{aligned} M(\Xi_b) &= 5774 \pm 11 \pm 15 \text{ MeV (DØ Collaboration)}\,, \\ M(\Xi_b) &= 5792 \pm 2.4 \pm 1.7 \text{ MeV (CDF Collaboration)}\,. \end{aligned} \tag{2}$$

Both results agree with the theoretical predictions [2].

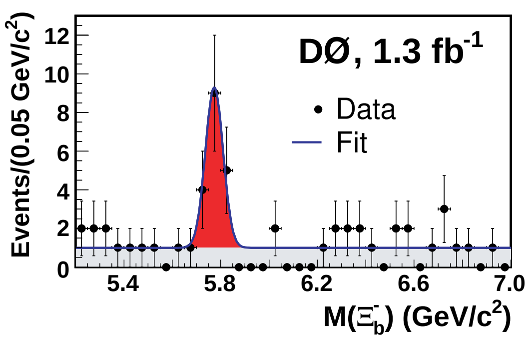

Fig. 2. The $J/\psi\Xi$ mass distribution with the fit of Ξ_b hypothesis superimposed.

3. Lifetime of *B* hadrons

The lifetime of B hadrons is another quantity which allows a direct comparison between theory and experiment. The theoretical predictions are especially precise for the lifetime ratios $\tau(B_X)/\tau(B_0)$, where B_X is either meson or baryon containing the b quark. The following hierarchy of lifetimes is expected:

$$\tau(B_c) << \tau(\Lambda_b) << \bar{\tau}(B_s^0) \simeq \tau(B^0) < \tau(B^+)\,. \tag{3}$$

The precision of Tevatron results for the B_s^0, Λ_b and B_c lifetime is now much better than in all previous measurements [3]. Both CDF and DØ Collaboration report many new results on the lifetime of B hadrons.

The CDF Collaboration selects the decays $B^+ \to J/\psi K^+$, $B^0 \to J/\psi K^{*0}$ and obtains [10]:

$$\begin{aligned} \tau(B^+) &= 1.630 \pm 0.016 \pm 0.011 \text{ ps}, \\ \tau(B^0) &= 1.551 \pm 0.019 \pm 0.011 \text{ ps}, \\ \tau(B^+)/\tau(B^0) &= 1.051 \pm 0.023 \pm 0.004. \end{aligned} \quad (4)$$

This result agrees well with the current world average value $\tau(B^+)/\tau(B^0) = 1.076 \pm 0.008$ ps.

The CDF Collaboration also reports the new measurement of the B_s^0 lifetime in the $J/\psi\phi$ final state [10]:

$$\tau(B_s^0) = 1.494 \pm 0.054 \pm 0.009 \text{ ps}. \quad (5)$$

However, this result should be treated with caution, since the final state $J/\psi\phi$ is the mixture of B_s^L and B_s^H states, which have different lifetimes. Therefore, the translation of this result into the mean B_s^0 lifetime is not straightforward. Currently, the mean B_s^0 lifetime quoted by PDG is based on the flavour specific B_s^0 decays only, where the DØ measurement in the $B_\mathrm{s}^0 \to \mu\nu D_s$ decay [11] still gives the most precise contribution.

The Λ_b lifetime attracted recently a lot of attention, both from theorists and experimenters. Earlier theoretical calculations predicted the $\tau(\Lambda_b)/\tau(B^0)$ ratio around 0.94, while the experimental average, which was dominated by the LEP measurements, was around 0.75. The recent calculations include higher order effects and predict a lower ratio 0.86–0.95 [1]. The precision of the experimental results is also significantly improved, mainly due to the contribution of the Tevatron experiments. It allows to perform a meaningful comparison between the theory and experiment.

Both the CDF and DØ Collaborations measure the Λ_b lifetime in $\Lambda_b \to J/\psi\Lambda$ decay [12, 13]. The measurement technique is similar in both cases, while the CDF has a higher yield because of a larger detector acceptance. The results show $\sim 2.3\sigma$ discrepancy:

$$\tau(\Lambda_b) = 1.580 \pm 0.077 \pm 0.012 \text{ ps (CDF Collaboration)}, \quad (6)$$

$$\tau(\Lambda_b) = 1.218^{+0.130}_{-0.115} \pm 0.042 \text{ ps (DØ Collaboration)}. \quad (7)$$

In addition, the DØ Collaboration reports the new Λ_b lifetime measurement in the semileptonic $\Lambda_b \to \mu\nu\Lambda_c$ decay [14]. The $\Lambda_c \to K_\mathrm{s}^0 p$ decay is used for this analysis. The observed number of semileptonic Λ_b decays is about 4400, but the high background level adds an additional complication for this analysis, prompting a special method of the lifetime measurement to be applied. The Λ_b yield is determined in the different proper decay length bins from the fit of the corresponding $K_\mathrm{s}^0 p$ mass spectrum, and the Λ_b lifetime is extracted from this distribution:

$$\tau(\Lambda_b) = 1.290^{+0.119}_{-0.110} \pm 0.012 \text{ ps}. \quad (8)$$

The new Tevatron results now dominate in the world average Λ_b lifetime. The resulting lifetime ratio $\tau(\Lambda_b)/\tau(B^0) = 0.912 \pm 0.032$ [3] is in a good agreement with the theoretical expectation. Still, some controversy between different experimental results exists, since the most precise CDF measurement is more than 2σ away from all other results. Therefore, additional Λ_b lifetime measurements are required to resolve this ambiguity.

4. Properties of $B_{\rm s}^0$ system

The $B_{\rm s}^0$ meson has many interesting and unique properties. Contrary to any other system, the oscillation frequency in the $B_{\rm s}^0$ system is very high, and two physical states $B_{\rm s}^{\rm H}$ and $B_{\rm s}^{\rm L}$ have distinct masses and lifetimes. In general, this system is described by five parameters: the mass (M_s), the mean lifetime ($\bar{\tau}_s$), the mass and width difference (ΔM_s and $\Delta\Gamma_s$), and the CP violating phase (ϕ_s) [5]. The Tevatron currently is a unique source of information on all these parameters.

The CDF Collaboration is succeeded to measure the mass difference ΔM_s with the significance exceeding 5σ [15]:

$$\Delta M_s = 1.77 \pm 0.10 \pm 0.07 \text{ ps}^{-1}\,. \tag{9}$$

This result sets a milestone of the Tevatron program and provides an essential constraint to the Unitarity Triangle.

The DØ Collaboration reports many new results on the lifetime difference $\Delta\Gamma_s$ and the CP-violating phase ϕ_s. One of them comes from the analysis of the time evolution of the polarization amplitudes in the $B_{\rm s}^0 \to J/\psi\phi$ decay [16]. This final state contains both the CP-even and CP-odd amplitudes, which produce different angular distributions. The lifetime of two CP eigenstates can be determined from the evolution of these amplitudes with time, while the CP-violating phase ϕ_s can be extracted from their interference. If the width difference between $B_{\rm s}^{\rm L}$ and $B_{\rm s}^{\rm H}$ is large enough, the ϕ_s phase can be obtained even without the flavor tagging of the initial $B_{\rm s}^0$ state. The result of DØ experiment is:

$$|\Delta\Gamma_s| = 0.17 \pm 0.09 \pm 0.03 \text{ ps}^{-1}\,, \tag{10}$$

$$|\phi_s| = -0.79 \pm 0.56^{+0.14}_{-0.01}\,. \tag{11}$$

The four-fold experimental ambiguity in $\Delta\Gamma_s$ and ϕ_s values arises because the flavour of the initial $B_{\rm s}^0$ state is not determined in this analysis. This result is consistent with the Standard model prediction $\Delta\Gamma_s = 0.088 \pm 0.017$ ps^{-1}, $\phi_s = 0.0042 \pm 0.0014$, and the experimental precision still needs to be improved for a more meaningful test of consistency with the Standard Model.

Another DØ analysis measures the branching fraction of the $B_{\rm s}^0 \to D_s^{(*)}D_s^{(*)}$ decay [17]. This decay mode contains mainly the CP-even state, and therefore can provide an interesting estimate of the width difference between the CP-even and CP-odd $B_{\rm s}^0$ states $\Delta\Gamma_s^{\rm CP}$:

$$2 \times {\rm Br}(B_{\rm s}^0 \to D_s^{(*)}D_s^{(*)}) \simeq \frac{\Delta\Gamma_s^{\rm CP}}{\Gamma_s}\,. \qquad (12)$$

The following decay chain is selected for this analysis: $B_{\rm s}^0 \to D_s^{(*)}D_s^{(*)}$, $D_s^{(1)} \to \mu\nu\phi$, $D_s^{(2)} \to \phi\pi$. The branching fraction is derived from the correlated production of two D_s mesons:

$${\rm Br}(B_{\rm s}^0 \to D_s^{(*)}D_s^{(*)}) = 0.039^{+0.019}_{-0.017}({\rm stat})^{+0.016}_{-0.015}({\rm syst})\,. \qquad (13)$$

It is a big improvement in precision of this quantity compared to the only previously available result from ALEPH Collaboration [18]. The constraint on the $\Delta\Gamma_s^{\rm CP}$ obtained from this measurement and from (12) is consistent with the other measurements of the related quantities.

The parameters of $B_{\rm s}^0$ system are also related with the semileptonic charge asymmetry $A_{\rm SL}^s$ through the following expression:

$$A_{\rm SL}^s = \frac{N(\bar{B}_{\rm s}^0 \to l^+X) - N(B_{\rm s}^0 \to l^-X)}{N(\bar{B}_{\rm s}^0 \to l^+X) + N(B_{\rm s}^0 \to l^-X)} = \frac{\Delta\Gamma_s}{\Delta M_s}\tan\phi_s\,. \qquad (14)$$

The DØ Collaboration performs two measurements of $A_{\rm SL}^s$. One of them is extracted from the dimuon charge asymmetry [19], where the following quantity is measured:

$$A_{\rm SL}^d + 0.7A_{\rm SL}^s = (-9.2 \pm 4.4 \pm 3.2) \times 10^{-3}\,. \qquad (15)$$

The other is obtained from the charge asymmetry in the semileptonic $B_{\rm s}^0 \to \mu\nu D_s$ decays [20]:

$$A_{\rm SL}^s = (2.45 \pm 1.93 \pm 0.35) \times 10^{-2}\,. \qquad (16)$$

Combining these results with the value of $A_{\rm SL}^d$ measured at B factories [3], the following result is obtained:

$$A_{\rm SL}^s = +0.0003 \pm 0.0093\,. \qquad (17)$$

All results on the parameters of $B_{\rm s}$ system can be combined together [21]. The 1σ contour of the allowed values in the $\Delta\Gamma_s$ versus ϕ_s plane is shown in Fig. 3. Good consistency of different measurements is observed. The combined parameters of the B_s^0 system are:

$$\Delta\Gamma_s = 0.13 \pm 0.09 \text{ ps}^{-1}\,, \tag{18}$$
$$\phi_s = -0.70^{+0.47}_{-0.39}\,. \tag{19}$$

This result is consistent with the Standard Model expectation within 1.3σ.

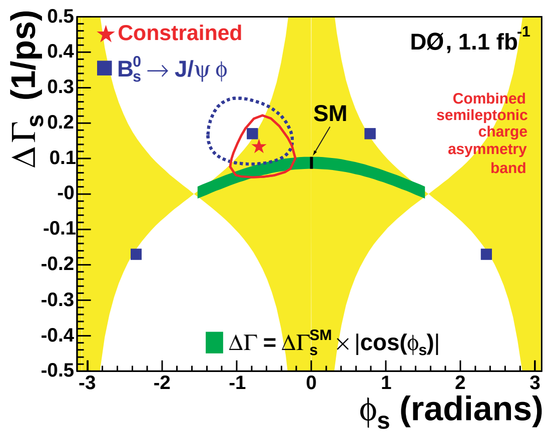

Fig. 3. Combination of all measurement of the parameters of B_s^0 system. The 1σ allowed contour in the $\Delta\Gamma_s$ *versus* ϕ_s plane is also shown.

The CDF Collaboration reports the measurement of CP asymmetry in the $B \to h^+h^-$ decay, where $h^\pm$ can be either $\pi^\pm$, $K^\pm$, or $p^\pm$ [22]. Many different decays contribute in this final state. They are separated using the kinematic and particle ID variables. The obtained results include:

$$A_{\rm CP}(B^0 \to K^+\pi^-) = -0.086 \pm 0.023 \pm 0.009\,, \tag{20}$$
$$A_{\rm CP}(B_s^0 \to K^+\pi^-) = 0.39 \pm 0.15 \pm 0.08\,. \tag{21}$$

The precision of the $A_{\rm CP}(B^0 \to K^+\pi^-)$ is compatible with the results from B factories, while the result on $A_{\rm CP}(B_s^0 \to K^+\pi^-)$ is the first CP asymmetry in $B_{\rm s}$ system deviating from the zero value by 2.5σ. Both results agree with the Standard Model prediction.

In conclusion, the B physics program of Tevatron gives many interesting results, which are complementary to the B factories. Still, much more results can be expected in the future, since the statistics used almost for all measurements corresponds to 1 fb^{-1} per experiment, while at least 4 fb^{-1} per experiment is expected by the end of RunII.

REFERENCES

[1] C. Tarantino, *Eur. Phys. J.* **C33**, S895 (2004) [hep-ph/0310241]; F. Gabbiani, A. Onischenko, A. Petrov, *Phys. Rev.* **D68**, 114006 (2003); *Phys. Rev.* **D70**, 094031 (2004).

[2] E.E. Jenkins, arXiv:0712.0406[hep-ph]; M. Karliner, B. Keren-Zur, H.J. Lipkin, J.L. Rosner, arXiv:0708.4027[hep-ph].

[3] E. Barberio *et al.* [HFAG Group], arXiv:0704.3575[hep-ex].

[4] K.S. Babu, C.F. Kolda, *Phys. Rev. Lett.* **84**, 228 (2000); S.R. Choudhury, N. Gaur, *Phys. Lett.* **B451**, 86 (1999).

[5] I. Dunietz, R. Fleischer, U. Nierste, *Phys. Rev.* **D63**, 114015 (2001).

[6] W.-M. Yao *et al.* [Particle Data Group], *J. Phys. G* **33**, 1 (2006).

[7] T. Aaltonen *et al.* [CDF Collaboration], *Phys. Rev. Lett.* **99**, 202001 (2007).

[8] V. Abazov *et al.* [DØ Collaboration], *Phys. Rev. Lett.* **99**, 052001 (2007).

[9] T. Aaltonen *et al.* [CDF Collaboration], *Phys. Rev. Lett.* **99**, 052002 (2007).

[10] CDF Collaboration, CDF Note 8524 (2007).

[11] V. Abazov *et al.* [DØ Collaboration], *Phys. Rev. Lett.* **97**, 241801 (2006).

[12] A. Abulencia *et al.*, *Phys. Rev. Lett.* **98**, 122001 (2007).

[13] V. Abazov *et al.* [DØ Collaboration], *Phys. Rev. Lett.* **99**, 142001 (2007).

[14] V. Abazov *et al.* [DØ Collaboration], *Phys. Rev. Lett.* **99**, 182001 (2007).

[15] A. Abulencia *et al.* [CDF Collaboration], *Phys. Rev. Lett.* **97**, 242003 (2006).

[16] V. Abazov *et al.* [DØ Collaboration], *Phys. Rev. Lett.* **98**, 121801 (2007).

[17] V. Abazov *et al.* [DØ Collaboration], *Phys. Rev. Lett.* **99**, 241801 (2007).

[18] R. Barate *et al.* [ALEPH Collaboration], *Phys. Lett.* **B486**, 286 (2000).

[19] V. Abazov *et al.* [DØ Collaboration], *Phys. Rev.* **D74**, 092001 (2006).

[20] V. Abazov *et al.* [DØ Collaboration], *Phys. Rev. Lett.* **98**, 151801 (2007).

[21] V. Abazov *et al.* [DØ Collaboration], *Phys. Rev.* **D76**, 057101 (2007).

[22] [CDF Collaboration], CDF Note 8579 (2006).