Experimental results for charmless hadronic B decays

James G. Smith*
University of Colorado
E-mail: jgsmith@pizero.colorado.edu

We present experimental result for charmless hadronic B decays. We discuss some aspects of the theory but for the most part these are covered in other contributions to this conference.

Flavor Physics and CP Violation 2009,
May 27 - June 1, 2009,
Lake Placid, NY, USA

*Speaker.

PoS(FPCP2009)025

1. Introduction

Since the first observation of charmless B meson decays about 15 years ago [1], there has been enormous progress in the field. There are now measurements for about 240 branching fractions; approximately 100 decays have been observed (significance $> 4\sigma$) and charge asymmetries sensitive to direct *CP* violation have been measured for most of these decays (Fig. 1 shows about 20 modes with a precision of 10% or better). We also have measurements of longitudinal polarization fractions (f_L) for 17 of these decays. Most of these observations have been by the BABAR and Belle experiments running at B Factories at SLAC and KEK during the past decade. A few important contributions have been made by the CDF experiment running at FNAL. Though CLEO made many measurements, most were published about a decade ago and they have small weight in the latest world averages.

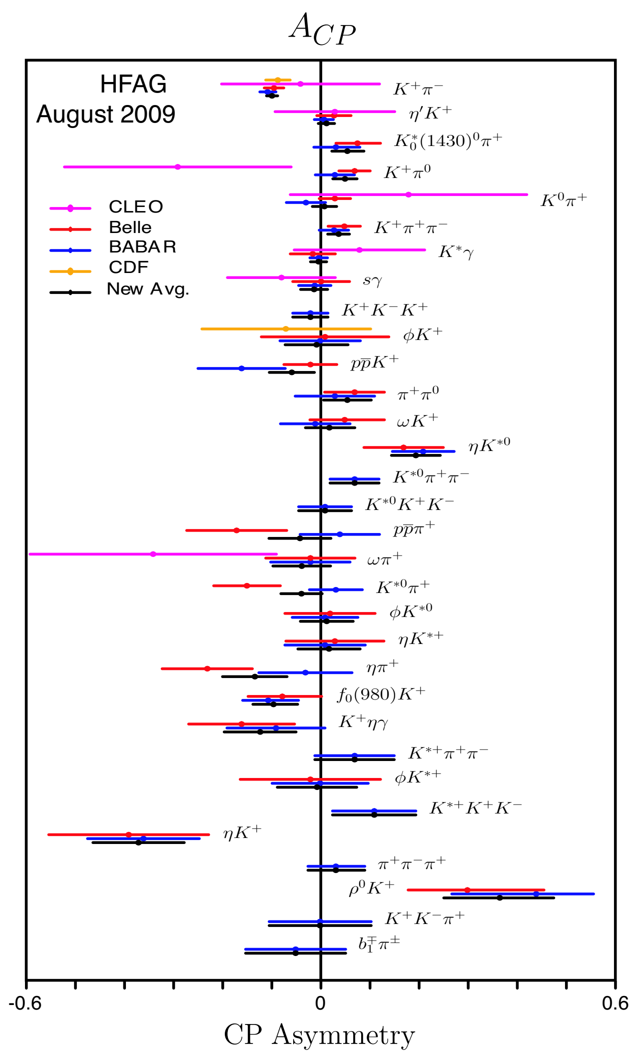

Figure 1: Measured charge asymmetries for modes where the uncertainty is less than 0.1. Though BABAR and Belle currently dominate this and subsequent plots, note that the CDF measurement for $K^+\pi^-$ is nearly as precise as the others and is using only one-quarter of the available data.

There are too many results shown here to give references for all of them. The full list of references (along with the detailed measurements) can be obtained from the Heavy Flavor Averaging Group (HFAG) active gif plots at http://www.slac.stanford.edu/xorg/hfag/rare/index.html. We will include only references for new or historically important results.

2. Two-body decays

While the 2-body charmless B decays to pions and kaons are among the most important, there have been no new measurements of these decays in the last year. The important issues for these modes are likely covered in the theory contributions to this session so we limit ourselves to the status of the measurements as shown in Fig. 2. The $K\pi$ decay modes are dominated by penguin amplitudes and have larger branching fractions than the tree-dominated $\pi\pi$ final states. We have now even observed two of the three decays to two kaons, which are CKM suppressed. The decay $B^0 \to K^+\pi^-$ remains the only decay with a clearly demonstrated charge asymmetry different from zero, indicating direct CP violation (see Fig. 1).

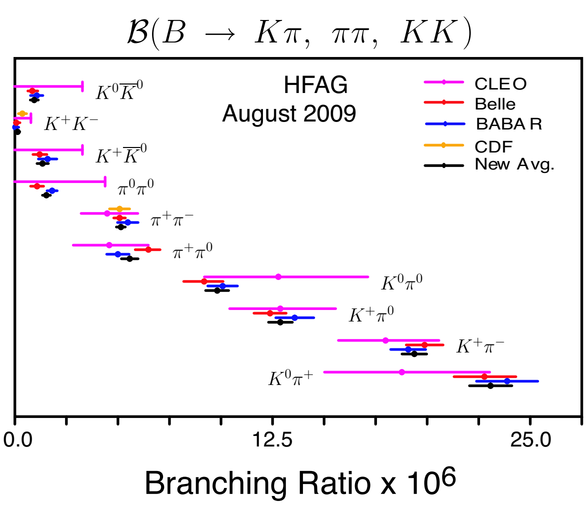

Figure 2: Branching fraction measurements for the 2-body charmless B decays.

3. Three-body decays

There continues to be substantial activity in measurements of 3-body decays. In Fig. 3, we show the status of these measurements. There are now 16 decays that have been observed, with many measurements within the past year. Belle led the way with many measurements about five years ago but more recently BABAR has caught up. In particular, BABAR observed $B^+ \to K^+K^-\pi^+$ recently [2]. The branching fraction for modes with even numbers of kaons is expected to be suppressed so this observation with a branching fraction of $(5.0\pm0.5\pm0.5)\times10^{-6}$ was surprisingly large. Also of note is the very large branching fraction for the K^*KK and $K^*\pi\pi$ final states observed by BABAR[3]. There have been no amplitude analyses or theoretical predictions for these final states, though their branching fractions are among the largest for charmless B decays.

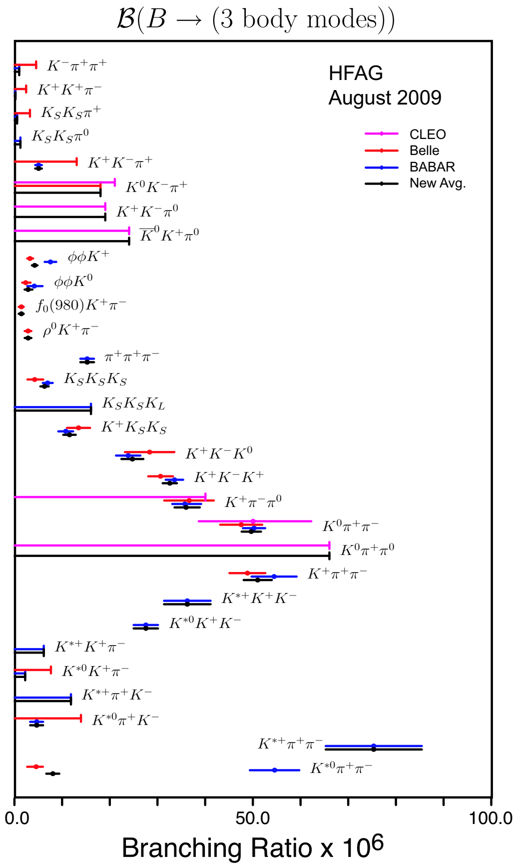

Figure 3: Branching fraction measurements for the 3-body charmless B decays.

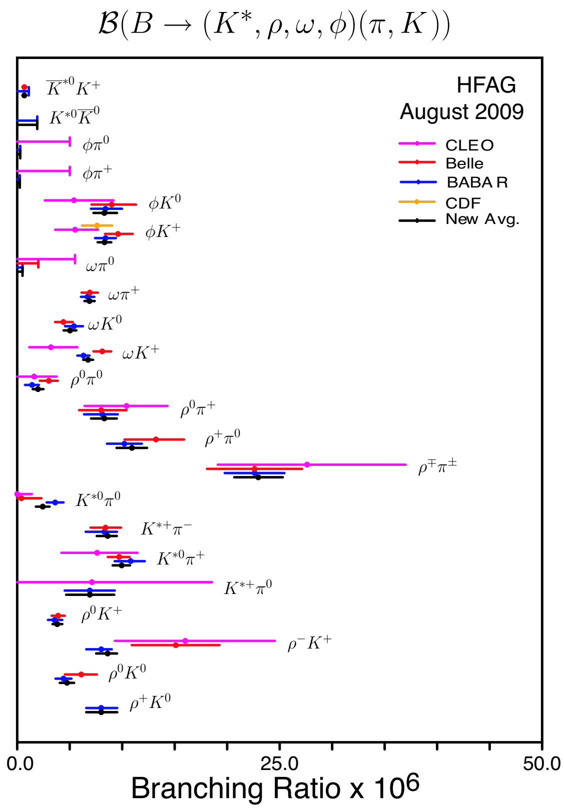

Figure 4: Branching fraction measurements for *PV* modes where P is π or K and V is ρ, ω, K^*, or ϕ.

There are Dalitz-plot analyses of most of these 3-body decays, the most recent being the analysis of the decay $B^+ \to \pi^+\pi^-\pi^+$ by BABAR [4]. From these Dalitz-plot and other analyses, we know that there are large quasi-2-body (Q2B) contributions with most involving pseudoscalar-vector (*PV*) final states containing the ρ, ω, ϕ, and K^* vector mesons. A summary of these measurements is given in Fig. 4. Note that we now have observations of almost all of these decays in all charge states. A notable exception is the $B \to \phi\pi$ decays which have no penguin or tree amplitudes. There are also some measurements where the vector meson is replaced by a scalar such as $f_0(980)$ or $K_0^*(1430)$. These decays are discussed in Sec. 6.

4. Decays with η or η' mesons

There have been many studies of the Q2B decays with η or η' mesons. These decays attracted a lot of interest when the decay $B \to \eta' K$ was observed by CLEO in 1998 [5] with a rate much larger than had been expected. It took several years before improved calculations were able to accommodate this large rate. We have now conclusively verified the pattern, resulting from $\eta - \eta'$ mixing, that the rate for $\eta' K$ and ηK^* are both large and ηK and $\eta' K^*$ are both small. This can be seen in Fig. 5 along with other branching fraction measurements of modes with η or η' mesons; more than a dozen of these decays have now been observed.

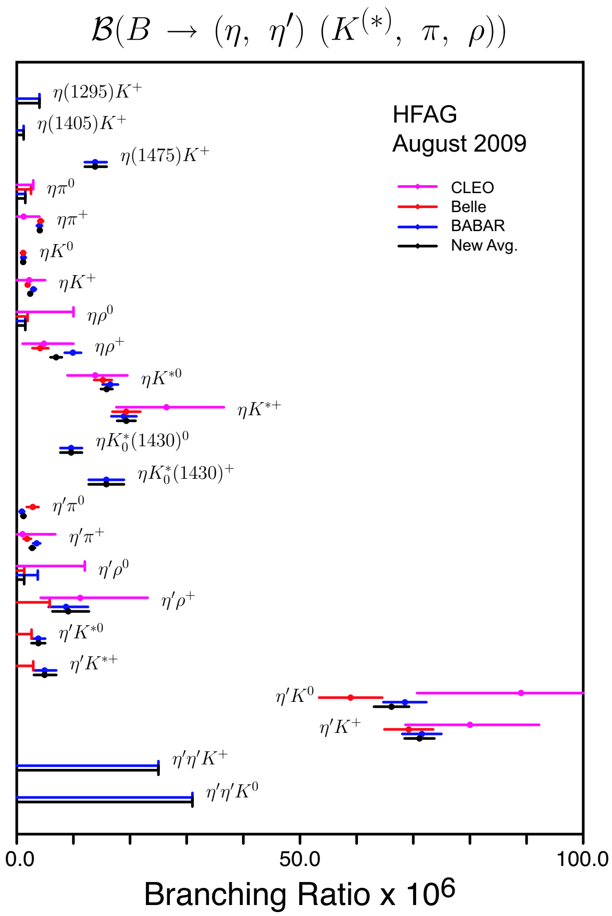

Figure 5: Branching fraction measurements for charmless B decays with an η or η' meson.

5. Vector-vector and similar decays

If both daughters of the B meson have non-zero spin, there are additional complications because there are several possibilities concerning the polarization of the mesons. The simplest, and most common case, is for two vector mesons. Simple spin arguments show that for these decays, the vector spins are expected to be aligned such that the decay is longitudinally polarized, i.e. the longitudinal spin fraction f_L is near 1. Specifically one finds that the transverse component is suppressed by $(m_V/m_B)^2$, where m_V is the mass of the vector meson (this is simply extended if the two mesons have rather different masses). Thus f_L is expected to be >0.9 for final states such as $\rho\rho$, $\omega\rho$, ρK^*, ωK^*, and ϕK^*. All of these have now been measured and only the first two agree with the simple prediction. In 2003, BABAR and Belle measured f_L for ϕK^* and both found values near 0.5 [6]. Further measurements of this final state with a precision as small as 0.04 now confirm this. Similarly small values have been measured for final states such as $\rho^+ K^{*0}$ and ωK^*. In fact all penguin-dominated decays now seem to have a value of f_L consistent with 0.5. The measurements of f_L are summarized in Fig. 6.

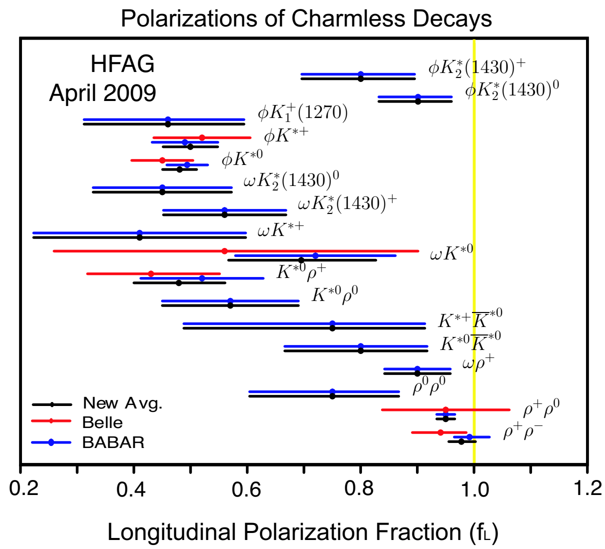

Figure 6: Measurements of the longitudinal spin fraction f_L for VV and similar decays.

The small value of f_L for ϕK^* came as a surprise when it was first observed. Kagan [7] first suggested a solution due to large penguin annihilation contributions; this conjecture is now thought to be at least part of the answer. More recently, authors of two papers have used QCD factorization including nonfactorizable corrections and penguin annihilation [8, 9] to improve the predictions for f_L while simultaneously predicting the branching fractions. From the point of view of experimentalists, these papers were a substantial advance since they make predictions for all charmless VV modes. The agreement between these predictions and data is generally very good. The measurements of these branching fractions are given in Fig. 7. There are new results from Belle for ωK^{*0} [10] and $\rho^0 K^{*0}$ [11]. BABAR has recently measured both ωK^* charge states and $\omega\rho$ [12], all K^*K^* charge states [13], and $\phi\phi$ and $\phi\rho$ [14]; there are also new results for $\rho\rho$ covered in the contribution by Bill Gary.

In the past year, BABAR has gone beyond VV decays in measurements of f_L. First there were the measurements of the VA decay $B \to \phi K_1(1270)$ and the VT decay $B \to \phi K_2^*(1430)$ [15]. The only predictions for these decays have rather large errors or use less reliable methods. The measurement for $\phi K_1(1270)$ is consistent with 0.5 and inconsistent with 1 (see Fig. 6) while the reverse is true for $\phi K_2^*(1430)$. The recent measurements of $B \to \omega K_2^*(1430)$ [12] have made the situation even more interesting since f_L is near 0.5 and inconsistent with 1, in contrast with the $\phi K_2^*(1430)$ case. Improved theoretical calculations for these VA and VT modes would be useful.

6. Decays with 0^+, 1^+ or 2^+ mesons

As alluded to in previous sections, we now have many measurements of B decays to final states with scalar, axial-vector, or tensor mesons. In Fig. 8, we summarize the decays involving scalar mesons. A few decays involving $f_0(980)$ or $K_0^*(1430)$ have been clearly observed, most recently

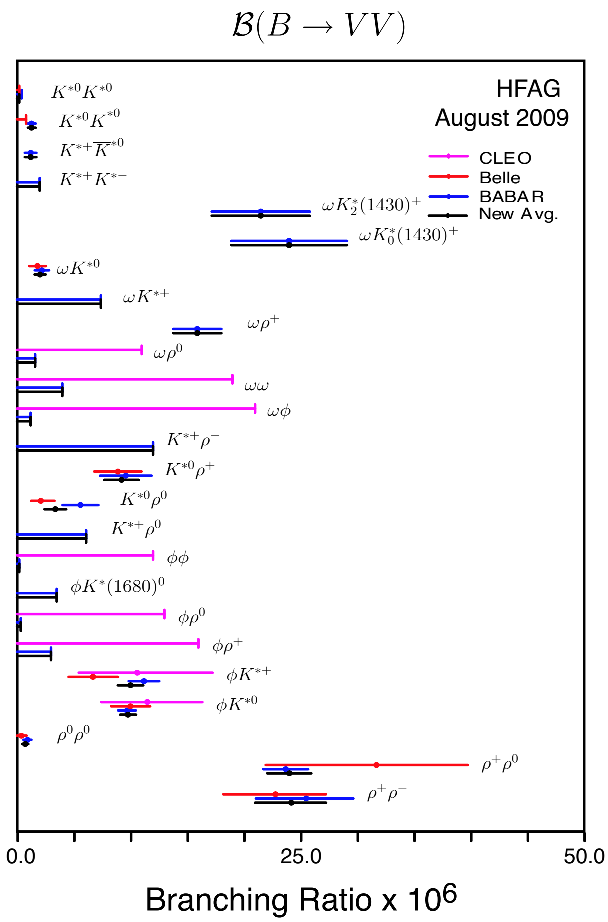

Figure 7: Branching fraction measurements for VV modes.

the $B \to \omega K_0^*(1430)$ decays observed by BABAR [12]. The theoretical predictions for these decays are sparse. One of the more complete calculations uses QCD factorization [16] and is in reasonable agreement with the available measurements.

There have been 11 B decays involving axial-vector mesons observed in the past two years, most by BABAR, as seen in Fig. 9. These represent both a_1 and b_1 mesons as well as the $\phi K_1(1270)$ measurement mentioned earlier. The predictions [17, 18] for these modes are mixed though most are in reasonable agreement with measurements.

There have been only a dozen measurements of decays involving a tensor meson but significant signals have been seen for eight of them (see Fig. 10). Two of these are for $f_2(1270)$ and the rest involve $K_2^*(1430)$. The only theoretical prediction uses naive factorization so it is not surprising that the agreement with the measurements is poor.

7. Decays with baryons

B decays involving baryons have been known for several years, with Belle leading the way. There are now 11 decays that have been observed with significant signals as shown in Fig. 11 for decays that include strange particles and in Fig. 12 for decays without strange particles. There is a

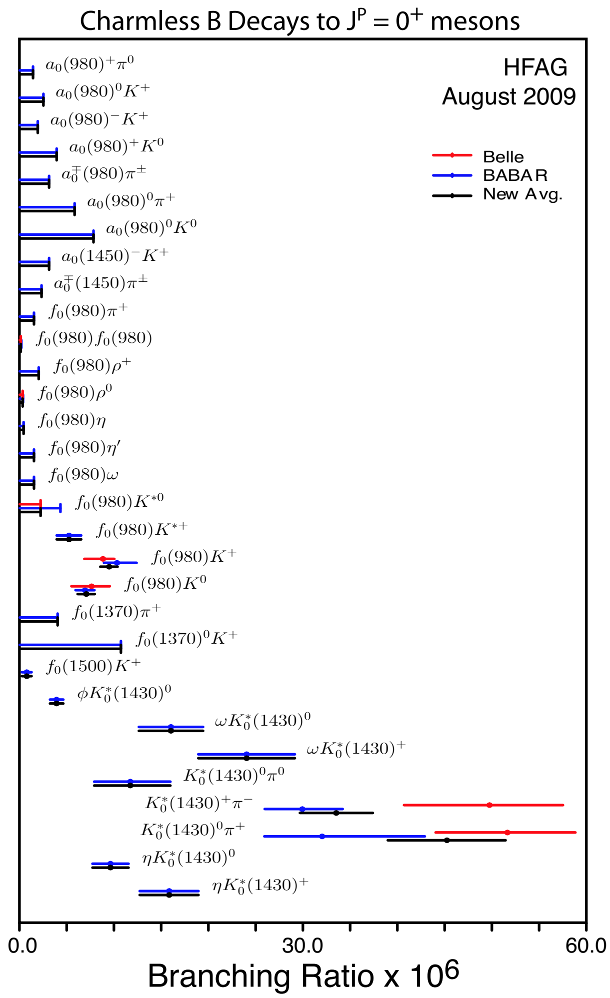

Figure 8: Branching fraction measurements for modes with a scalar meson.

new measurement of $p\bar{\Lambda}\pi$ by BABAR [19] and a new measurement of the modes $\Lambda\bar{\Lambda}K$ and $\Lambda\bar{\Lambda}K^*$ from Belle [20].

There are a variety of interesting features of these decays. As seen in the figures, only 3-body decays have been observed. This is the result of a kinematic effect known as the threshold enhancement [21] which says that the decays are dominated by low-mass baryon-antibaryon pairs accompanied by a fast recoil meson. This conjecture has been verified experimentally in multiple decay channels.

Another interesting feature of these decays with baryons involves angular correlations, in the dibaryon rest frame, between one of the baryons and the meson. The predicted correlation has been observed for the $p\bar{p}\pi^+$ final state but not for $p\bar{p}K^+$. Belle has also observed a correlation in the decay $B^+ \to p\bar{\Lambda}\pi^+$ [22] while no correlation is expected theoretically. Clearly our understanding of these decays with baryons is incomplete.

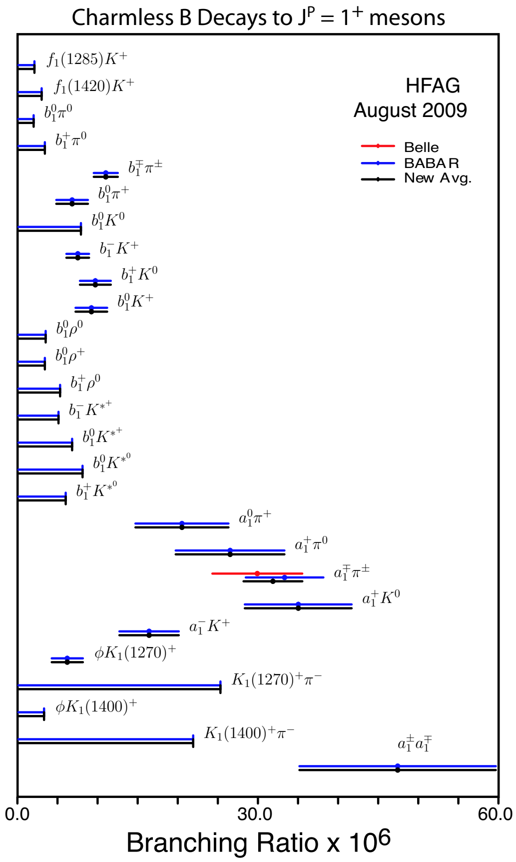

Figure 9: Branching fraction measurements for modes with an axial-vector meson.

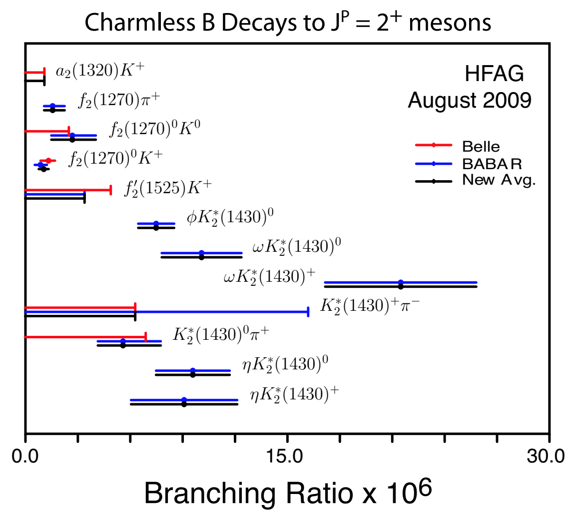

Figure 10: Branching fraction measurements for modes with a tensor meson.

8. Conclusions

The field of charmless hadronic B decays is now quite mature. There have been more than two billion B mesons produced by Belle and BABAR. The sophistication of the measurements with these samples has grown considerably in the past two years. We now have quite precise measurements of the 2-body and simple Q2B decays and they are generally in good agreement with theoretical expectations. There are many new measurements of f_L in the VV and similar decays and the theoretical predictions have improved such that a more complete understanding may be in sight. We have many new measurements that include scalar, axial-vector, or tensor mesons and the experimental results are leading theory in this area. Finally, there have been many measurements of decays with baryons; some simple theoretical ideas have been verified but some puzzles remain.

9. Acknowledgments

We would like to thank the Heavy Flavor Averaging Group, in particular Rob Harr, for the plots that have been used in this review. We also thank our colleagues on CLEO, BABAR, Belle, and CDF for the multitude of measurements that have made this such a mature field.

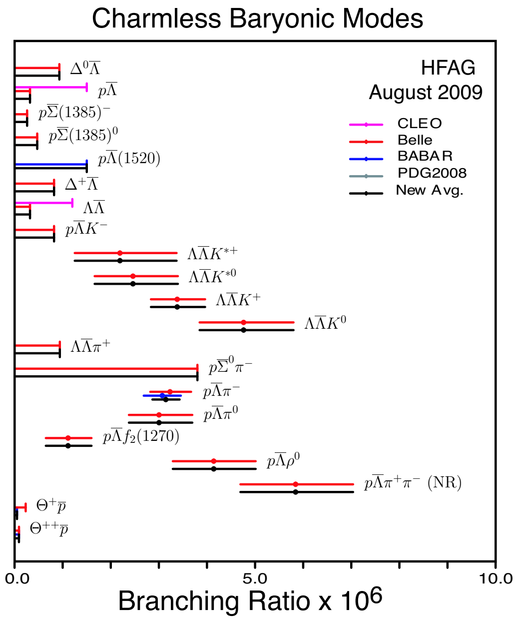

Figure 11: Branching fraction measurements for modes with strange baryons.

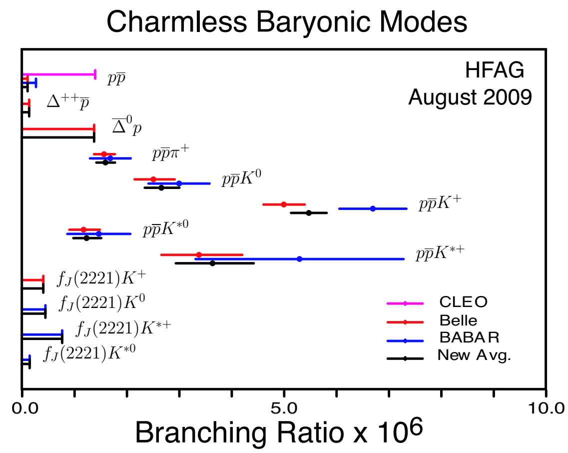

Figure 12: Branching fraction measurements for modes with non-strange baryons.

References

[1] M. Battle, et all. (CLEO Collaboration), *Phys. Rev. Lett.* 71, 3922 (1993); G. Godang, et al. (CLEO Collaboration), *Phys. Rev. Lett.* 80, 3456 (1998).

[2] B. Aubert, et al. (BABAR Collaboration), *Phys. Rev. Lett.* 99, 221801 (2007).

[3] B. Aubert, et al. (BABAR Collaboration), *Phys. Rev. D* 74, 051104 (2006); B. Aubert, et al. (BABAR Collaboration), *Phys. Rev. D* 76, 071104 (2007).

[4] B. Aubert, et al. (BABAR Collaboration), *Phys. Rev. D* 79, 072009 (2009).

[5] B. Behrens, et al. (CLEO Collaboration), *Phys. Rev. Lett.* 80, 3710 (1998).

[6] B. Aubert, et al. (BABAR Collaboration), *Phys. Rev. Lett.* 91, 171802 (2003); K. F. Chen, et al. (Belle Collaboration), *Phys. Rev. D* 91, 201801 (2003).

[7] A. L. Kagan, *Phys. Lett. B* 601151 (2004).

[8] M. Beneke, J. Rohrer, D.S. Yang, *Nucl. Phys. B* 77464 (2007).

[9] H.-Y. Cheng, K.-C. Yang, *Phys. Rev. D* 78094001 (2008).

[10] P. Goldenzweig, et al. (Belle Collaboration), *Phys. Rev. Lett.* 101, 231801 (2008).

[11] S.-H. Kyeong, Y.-J. Kwon, et al. (Belle Collaboration), arXiv:0905.0763 (2009).

[12] B. Aubert, et al. (BABAR Collaboration), *Phys. Rev. D* 79, 052005 (2009).

[13] B. Aubert, et al. (BABAR Collaboration), *Phys. Rev. Lett.* 100, 081801 (2008); B. Aubert, et al. (BABAR Collaboration), *Phys. Rev. D* 78, 051103 (2008); B. Aubert, et al. (BABAR Collaboration), *Phys. Rev. D* 79, 051102 (2009).

[14] B. Aubert, et al. (BABAR Collaboration), *Phys. Rev. Lett.* 101, 201801 (2008).

[15] B. Aubert, et al. (BABAR Collaboration), *Phys. Rev. Lett.* 102, 161801 (2008); B. Aubert, et al. (BABAR Collaboration), *Phys. Rev. D* 79, 092008 (2008).

[16] H.-Y. Cheng, C.-K. Chua, K.-C. Yang, *Phys. Rev. D* 73, 014017 (2006).

[17] H.-Y. Cheng, K.-C. Yang, *Phys. Rev. D* 76, 114020 (2007).

[18] W. Wang, R.-H. Li, C.-D. Lu, *Phys. Rev. D* 78, 074009 (2008).

[19] B. Aubert, et al. (BABAR Collaboration), *Phys. Rev. D* 79, 112009 (2009).

[20] Y.-W. Chang, M.-Z. Wang, et al. (Belle Collaboration), *Phys. Rev. Lett.* 79, 052006 (2009).

[21] W.-S. Hou, A. Soni, *Phys. Rev. Lett.* 86, 4247 (2001).

[22] M.-Z. Wang, Y.-J. Lee, et al. (Belle Collaboration), *Phys. Rev. D* 76, 052004 (2007).