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Recent Developments in Charm Physics

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Recent results in the charm sector are reviewed. In particular I will concentrate on rare processes that provide a possible window onto new physics, and on the spectroscopy of new charmonium-like states.

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1. Introduction

I have only a very limited time to review a subject that frequently fills a whole conference. I have chosen a series of topics that I hope will be of interest to many people working at the LHC. Many of these were first shown at the ICHEP this summer and I refer people to excellent review talks there by David Asner[1] and Galina Pakhlova[2].

1.1 The Experiments

Although the discovery of charm is more than a generation ago, the research in the charm sector is vigorous. There are three different types of experiments that give complementary information. Charm threshold experiments, exemplified by BESII, CLEO-c (that stopped taking data this year), and now BESIII which has just started taking data, are excellent at low-background studies of charmed mesons. However, they only operate at one energy at a time, limiting the physics topics possible in each run. The so called B-factories (for many years CLEO, BaBar from 1998-2008, and BELLE at KEK which is still taking data), detect charm through three mechanisms; continuum production, B-decays to charm, and recently initial state radiation which can be used to scan out the entire charmonium range. Lastly there are experiments at hadron colliders. The cross-section for charm in high energy hadron collisions is huge. However, the charm has to be dug out of a complicated event environment. Recently CDF and D0 have revamped their analysis chains - including the hardware triggers - to enable specific charm studies to be carried out.

2. Rare Processes in Charm Decays

Working at the LHC we are used to the idea that to find New Physics (NP), we need to go to the highest possible energies. However, this is not always the case. Many rare charm decays, as well D-Dbar oscillations and CP violation, proceed in the Standard Model (SM) via loop diagrams involving virtual vector bosons. However NP (for instance SUSY) can introduce new particles into these virtual loops, and may in some cases dominate the SM decay rates. Thus we need to search for these processes. These charm studies are complementary to the study of B and K decays.

2.1 Rare Decays

Results on rare charm decay rates include radiative D decays[3,4], purely leptonic decays[5], GIM suppressed decays such as $D\rightarrow\pi ll$[6,7], lepton-flavor-violating decays[8], and lepton number violating decays[7]. I highlight the results that are new this year, firstly the BaBar measurements[4] $B(D \rightarrow \varphi\gamma\gamma) = (2.72 \pm 0.03 \pm 0.36) \times 10^{-5}$ and $B(D\rightarrow K^*\gamma) = (3.22 \pm 0.20 \pm 0.27) \times 10^{-4}$. These results are significantly non-zero, but do not indicate NP, but rather final state interactions. That does not mean that they are not interesting, however, as it is important to measure the deviations from the basic SM diagrams in order to discriminate between SM and NP in other decays.

Next is the purely leptonic decay $D\rightarrow\mu\mu$. The importance of this mode is clearly known to experimenters – there are 12 successively tighter limits in the Particle Data Book. This is the latest one, courtesy of CDF[5], and it is very tight - 4.3×10^{-7}. However this is much bigger than the SM expectation of 10^{-13}. It is beginning to constrain some SUSY models - particularly those involving R-parity violation - which predict branching fractions of this order.

2.2 Mixing

The subject of D^0D^0-bar mixing is a very complicated one. Mixing happens in a two-state system when the mass eigenstates are not the same as the flavor eigenstates. There are many relevant and inter-related variables, and some experiments are sensitive to one, and others to a different one. Recent measurements include those on the dimensionless mass difference of the states (x), the dimensionless width difference, (y)[9], R, which is a combination of those two[10], and x' and y' which are x and y rotated in some imaginary space[11,12,13]. q/p and the argument of q/p (which is an angle) parameterize the contribution to the mixing that violates CP violation. Short distance, box diagrams, calculations[14] give $x \sim 10^{-5}$ and $y \sim 10^{-7}$, but other, long distance QCD effects can give values orders of magnitude bigger. NP can give contributions to mixing and any CPV in this system would be evidence of NP.

Several individual measurements now show non-zero mixing signals (though no one measurement is compelling). The Heavy Flavor Averaging Group[15] have taken on the tough job of combining the measurements, and find that the composite data lie a full 9.8 σ deviation away from a non-mixing hypothesis. They separately look for CP violation in this sector, and find that it is within the 1 σ contour. In other words, they find no evidence of CP violation.

Thus we conclude that D^0D^0-bar mixing exists, but that it is not necessarily due to NP.

2.3 Direct CP violation

This year BaBar has shown results of an improved search for direct CP violation, by looking at the D^0 decay rate into the singly-Cabibbo-suppressed mode K^+K^- and comparing with the D^0-bar decay rate[16]. They can differentiate between the two by the charge of the slow pion. They find absolutely no asymmetry (literally zero). This compares with BELLE who find a slight deviation from zero[17]. The sensitivity is entering interesting territory!

3. Purely Leptonic Decays

Now let's turn to purely leptonic decays and the measurement of the decay constants f_D and f_{Ds}. In general the SM predicts the width for D to lepton-neutrino in terms of variables which are well known except for f_D. Our job is to measure the decay widths and so find values of f_D.

Analyses exist by CLEO_c for $D_s \to \mu\nu$ and also $\tau\nu$ where the τ decays to a π[18]. BELLE and BaBar have $D_s \to \mu\nu$[19]. CLEO_c also has $D_s \to \tau\nu$ where the τ decays to an electron[20]. Only CLEO_c can measure $D^+ \to \mu\nu$[21]. The basic method for CLEO_c is to run at D or D_s threshold, reconstruct the whole event except for the neutrino and plot the missing mass. For BELLE, the presence of the D_s is inferred from the rest of the event, the μ found, and again the missing mass plotted. BaBar uses B decays near the end-point; they infer the momentum of the neutrino and plot the D_s^*-D_s mass difference.

We can compare the computed decay constants and then with the lattice calculations. The three D_s results are all within 1 σ of each other. However, they are 3 σ from lattice calculations[22], which can reproduce many results including that of the $f_{D.}$ Is this the sign of NP?

One curiosity in rare charm decays is the first observation of a charmed meson decaying into baryons[23]. It is the only possible such decay mode. In a similar manner to $\mu\nu$ the final plot is missing mass peaking at the neutron mass. The measured branching fraction of 1.3 x 10^{-3}, agrees with a theoretical post-diction[24] which invokes final-state interactions as the naïve SM would give a much lower result.

4. Recent Spectrosopy Results

You might think that, 35 years after the discovery of charm, charm spectroscopy would be a dying subject, but on the contrary there is much activity. There are many charmed baryons found in the last few years. Also, a new and unexpected spectroscopy has arisen in the charmonium-like states known as the X,Y and Z particles.

It all started with BELLE finding a signal of the X(3872) decaying to $J/\psi\ \pi\pi$ in B decays. This has been confirmed by BaBar, D0 and CDF. Now CDF[25] have the most accurate mass measurement in their Run II data. It's very important to measure this mass accurately as the DD-bar molecule explanation is popular mostly because the mass is so close to the sum of the masses of D^0 and D^{*0}. However, BaBar have shown radiative decays both into J/ψ and $\psi(2S)$[26]. The latter observation disfavors the molecular interpretation. It is also important to know if it is the same state as the X(3875) found in DD* and $DD\pi^0$. Recent results indicate that it is.

A new state[27] has also been reported by BELLE in $\Lambda_c\Lambda_c$-bar near threshold. It is clearly significant. Is it a new particle or a threshold effect? Is it the same as the Y(4660)[28]? There is also much excitement about a possible charged Z state[29] reported by BELLE in $B\rightarrow KZ$, $Z\rightarrow\pi\psi(2S)$. An extensive study by BaBar[26] has not confirmed this state, although there seems to be a small fluctuation at the BELLE mass. Lastly, BELLE are also showing preliminary results[30] indicating the existence of a pair of Z particles decaying to $\chi_{c1}\pi$. These charges Z states are particularly interesting because they cannot be excited charmonium (ccbar + glue) states.

5. Conclusions

In the area of rare charm decays, experiments are entering interesting territory and should provide constraints on NP soon. In charm mixing, the discovery of D^0D^0-bar mixing points forward to searches for CP violation and NP. CP violation itself has not been observed in this sector, but the precision of measurements is improving. There is growing disagreement between experiment and lattice calculations concerning the value of f_{Ds} . The latest results on the spectroscopy of "XYZ" states produce more questions than answers, and indicate the our view of the quark content of hadrons as being all qqq or qq-bar may be wrong.

We look forward to tighter constraints on NP, more stringent tests of lattice QCD, more precise input from the B-factories, Tevatron and BESIII. In the longer term, possible higher luminosity B-factories as well as charm results from LHC (in particular from LHCb should lead to a better understanding of NP observed at LHC.

References

[1] D.Asner, *Decays of Open Charm,* 34th International Conference on High Energy Physics, Philadelphia, 2008.

[2] G Pakhlova, *Exotic ccbar spectroscopy,* 34th International Conference on High Energy Physics, Philadelphia, 2008, arXiv:0810.4114 [hep-ex].

[3] T. Coan et al. (CLEO Collaboration), Phys. Rev. Lett. 90:101801 (2003).

[4] B.Aubert et al. (BaBar Collaboration), SLAC-PUB-13362, arXiv:0808.1898 [hep-ex].

[5] CDF public note 9226.

[6] V.S.Abazov et al. (D0 Collaboration), Phys. Rev. Lett. 100.101801 (2008).

[7] Q.He et al. (CLEO Collaboration), Phys. Rev. Lett. 95.221802 (2005).

[8] B.Aubert et al., (BaBar Collaboration), Phys. Rev. Lett. 93.191801 (2004).

[9] K. Abe et al. (BELLE Collaboration), Phys. Rev. Lett. 99.131803 (2007).

[10] K.Abe et al. (BELLE Collaboration), Phys. Rev. D77 112003 (2008), B.Aubert et al. (BaBar Collaboration), Phys. Rev. D 76 014018 (2007).

[11] K.Abe et al. (BELLE Collaboration), Phys. Rev. Lett. 92.151801 (2006), B.Aubert et al. (BaBar Collaboration), Phys. Rev. lett. 98 211802 (2007), T.Aaltonen et al. (CDF Collaboration), Phys. Rev. Lett. 100 121802 (2008).

[12] B.Aubert et al. (BaBar Collaboration), arXiv :0807.4544 [hep-ex].

[13] J.L.Rosner et al. (CLEO Collaboration), Phys. Rev. Lett. 100.221801 (2008), D.M.Asner et al. (CLEO Collaboration), Phys. Rev. D78 :012001 (2008).

[14] A. Falk et al., Phys. Rev. D65:054034 (2002).

[15] Heavy Flavor Averaging Group, http://www.slac.stanford.edu/xorg/hfag/index.html

[16] B.Aubert et al. (BaBar Collaboration), Phys. Rev. D100:061803 (2008).

[17] J. Abe et al. (BELLE Collaboration) arXiV:0807.0148 [hep-ex]

[18] M.Artuso et al., (CLEO Collaboration), Phys. Rev.Llett. 99:071802 (2007), T.K.Pedlar et al., (CLEO Collaboration), Phys. Rev. D76:072002 (2007).

[19] K.Abe et al. (BELLE Collaboration), Phys. Rev. lett. 100:241801 (2008), B.Aubert et al. (BaBar Collaboration) Phys. Rev. Lett. 98 :141801 (2007).

[20] K.M.Ecklund et al., (CLEO Collaboration), Phys. Rev. lett. 100:161801 (2008).

[21] B.Eisenstein et al., (CLEO Collaboration), Phys. Rev. D78, 052003 (2008).

[22] E. Follana et al., (HEPQCD+UKQCD Collaboration), Phys. Rev. Lett. 100:062002 (2008).

[23] S.B.Athar et al, (CLEO Collaboration), Phys. Rev. Lett. 100:181802 (2008).

[24] C-H. Chen, H-Y Cheng and Y-K Hsiao, Phys. Lett. B663:326 (2008).

[25] CDF public note 9454.

[26] A. Mokhtar, *Searches for exotic X, Y and Z-state with BaBar*, 34th International Conference on High Energy Physics, Philadelphia, 2008, arXiv:0810.1073 [hep-ex].

[27] K. Abe et al. (BELLE Collaboration), arXiv:0807.4458 [hep-ex].

[28] K. Abe et al. (BELLE Collaboration), Phys. Rev. Lett. 99 :142002 (2007).

[29] K. Abe et al. (BELLE Collaboration), Phys. Rev. Lett. 100 :142001 (2008).

[30] K. Abe et al. (BELLE Collaboration). arXiv :0806.4098 [hep-ex].