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Convener Report of the Session on Rare B Decays

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Searches for rare decays of beauty and charm mesons are producing upper limits which now are approaching the theoretical Standard Model (SM) expectations for branching ratios. Indeed, in some case the measurements have reached those limits. We are approaching the point at which we might expect evidences of New Physics (NP) to become evident. However, in all cases we will need more data to either reach the level of the SM predictions or, in the cases where the measurements are at the SM, to confirm any differences between the observed branching ratio and the SM calculation. We have some reason to expect in the next two years that the experiments at the LHC and other venues will reach this point. In addition, other ways of checking the SM rather than by simple counting experiments are underway. Experiments to measure polarization effects may prove to ultimately be the more sensitive way to look for deviations from the SM rather than using branching ratios. This paper describes the present state of the experimental efforts in several B decay modes and takes a look at future prospects at the LHC.

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[†]A footnote may follow.

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1. Introduction

In this conference, several results were presented for searches or measurements of aspects of rare B Decays. The measurements of rare B decays are beginning to reach the SM predictions. In some cases the searches are already at that level. More data and more precise theoretical estimates of branching ratios will be needed in most cases if NP is to be detected in the rates of these decays since differences with the SM are expected to be small in most cases. It seems obvious now that no large sources of NP appear to be present at the energy scale of the SM. In addition, polarization effects are now being measured and reported on. These polarization effects may be more sensitive to NP and allow earlier detection of NP.

2. Theoretical Perspective on New Physics Evidences

G. IsidoSearch for RaSearri gave a theoretical perspective concerning where a hint of deviations from the SM might be beginning to appear. Isidori's conclusions were that there were no large new sources of flavor symmetry breaking at the TeV scale. However, there were a few anomalies that bore watching. Table 1 below gives a subset of the anomalies and the differences between the SM predictions and the present experimental measurements:

Table 1: Areas where new physics may be beginning to be seen.

Physics Anomaly	Parameter	SM Predictionn	Data	Discrepancy
$A_{\Psi K}$ to $\sin(2\beta)$	$A_{\Psi K}$	0.771±0.036	0.654±0.026	2.7σ
CP Violation in B_s mixing	ϕ_s=-2|β_s|	0.038±0.003	0.7±0.3	$\approx 2\sigma$
$B \to \tau\nu$	10^4BR($B \to \tau\nu$	0.81±0.07	1.72±0.28	3.2σ

Isidori's opinion is that, although there is not really conclusive evidence so far for deviations from the SM, rare decays are the key to finding NP. In addition, he felt that clean lepton and semileptonic decays are the decays with the most potential for discovery of NP in most new physics models.

3. $B \to \mu\mu$

There are several on-going experimental efforts to detect the rare decay $B_s \to \mu\mu$ that were reported in the HQL10 conference. The results of the measurements (or the prospects for such in the case of Atlas, CMS, and the LHCb experiments) were presented. The present value of the SM prediction for $B_s \to \mu\mu$ is $(3.6 \pm 0.3) \times 10^{-9}$ [1]. Table 2 displays the achieved experimental limits to be compared against the SM prediction.

In general, the conclusion to be drawn is that the existing measurements from D0 and CDF are a bit more than a factor of ten away from the SM prediction for $B \to \mu\mu$. It seems that these experiments do not have much chance of reaching the SM level since there may only be a factor of two more data left to analyze. On the other hand, the Atlas, CMS, and LHCb experiments, which expect to accumulate up to 5 fb^{-1} by the end of 2012, have the potential of reaching the SM level by that time.

Table 2: Experimental limits for $B_s \to \mu\mu$

Experiment	Measurement	Prospects for Measurment
D0	$< 5.1 \times 10^{-8}$	-
CDF	$< 4.3 \times 10^{-8}$	-
CMS	-	$\leq 1.6 \times 10^{-8}$ for 1 fb^{-1}
Atlas	-	5.7 signal with 14 background for 10 fb^{-1}
LHCb	-	new physics at 5σ level if $BR_{NP} > 5\times$ SM = 1.7×10^{-8}

4. Branching Ratios for $B \to hl\bar{l}$ Type Decays

There were five measurements and one prospect for measurement reported at this conference for decays of the type $B \to hl\bar{l}$, i.e., decay of a B meson into a hadron plus a lepton pair. These measurements include the report of Babar on the search for $B^{+,0} \to K^{+,0}\nu\bar{\nu}$ and $B^+ \to K^+\tau\bar{\tau}$, the report of CDF on $B_{s,d} \to K^*\mu\mu$, $B_s \to \phi\mu\mu$, and $B^+ \to K^+\mu\mu$. Table 3 summarizes the results of these studies:

Table 3: Experimental Results and Prospects for $B \to hl\bar{l}$ Rare Decays

Experiment	Mode	Measurement	SM Expectation	SM Ref.
Babar	$B^{+,0} \to K^{+,0}\nu\bar{\nu}$	$< 1.4 \times 10^{-5}$ 90% CL	$0.5 \pm 0.7 \times 10^{-5}$	[2]
Babar	$B^+ \to K^+\tau\bar{\tau}$	< 0.0033 90% CL	4.3×10^{-7}	[3]
CDF	$B_{s,d} \to K*\mu\mu$	$(0.81 \pm 0.30 \pm 0.10 \times 10^{-6}$	consistent with SM	[4]
CDF	$B^+ \to K^+\mu\mu$	$(0.59 \pm 0.15 \pm 0.04) \times 10^{-6}$	consistent with SM	[5]
CDF	$B_s \to \phi\mu\mu$	$< 2.3 \times 10^{-6}$ 90% CL	1.61×10^{-6}	[6]

In two of the five cases, the experiment in question (CDF) has made a measurement that reaches the SM level. In those cases, we can say that the branching ratios for $B_{s,d} \to K*\mu\mu$ and $B^+ \to K^+\mu\mu$ are consistent with the SM prediction. More precise data and better theoretical calculations will be needed to determine if there is a discrepancy with the SM. The other three branching ratios that were reported are still some distance away from challenging the SM although there are models such as for $B^{+,0} \to K^{+,0}\nu\bar{\nu}$ [7] that could raise the branching ratios by an order of magnitude.

4.1 NP in Polarization in $B_s \to \phi\phi$ Decay?

In this $B \to VV$ decay studied by CDF, there are three relative angular momentum states that have been decomposed into three independent amplitudes, a longitudinal and two transverse amplitudes, $A_0, A_{||}$ (CP even), and $A_\perp$ (CP odd). The experimental values for the three amplitude are given in Table 4. This result is perplexing and interesting because the SM expectations for these amplitudes are expected naively to be in the following hierarchy, $|A_0| >> |A_{||}| \sim |A_\perp|$. Since this is far from the experimental observation, the question to be answered is whether this discrepancy is due to Penguin effects, final state interactions, or NP.

Table 4: Polarization Amplitudes in $B_s \to \phi\phi$ Decay

Amplitude	Measurement
$\|A_0\|^2$	$0.348 \pm 0.041(stat) \pm 0.021(syst)$
$\|A_\perp\|^2$	$0.287 \pm 0.043(stat) \pm 0.011(syst)$
$\|A_{\|\|}\|^2$	$0.365 \pm 0.044(stat) \pm 0.027(syst)$

5. Prospects for Polarization Measurements at LHCb

5.1 Potential for NP in Forward Backward Asymmetry Measurements in $B_s \to K^*\mu\mu$ at LHCb

LHCb reported in this conference on the prospects for measurement of $B_s \to K^*\mu\mu$ forward-backward asymmetry detection. Fig. 1 shows the present state of the measurement of the forward backward asymmetry (A_{FB}) of the positive μ in the di-lepton center of mass as a function of q^2, the momentum transfer between the initial state B and final state K*. The present state of the Babar and Belle measurements shown in Fig. 1 is consistent (with low statistics) with the SM prediction in the region $1\ GeV < q^2 < 6\ GeV/c$, but, when both experiments are averaged over the entire q^2 range, the centroid of the measurement is lower than the SM at the center of the q^2 range. The value of $A_{FB} \approx -0.2$ at that point. This is lower than the SM prediction by approximately one sigma. Taking this average as indicative of the result of a future measurement, LHCb has shown in Fig. 1 what uncertainty in such a measurement that LHCb could achieve with an integrated luminosity of 2 fb^{-1}. Their belief is that they could reject the SM prediction by 5.4 σ with that integrated luminosity if the value of A_{FB} was -0.2. With an integrated luminosity of 5 fb^{-1} they would, of course, do even better.

5.2 Prospects for Polarization Measurements by LHCb in $B_s \to K^*\gamma$ and $B_s \to \phi\gamma$

These two $B \to V\gamma$ decays are objects of study by the LHCb experiment. The prospects for large new physics effects in them are constrained by the present experimental branching $BR(B^0 \to X_s\gamma) = 3.56 \pm 0.26 \times 10^{-4}$ [8] and the theoretical SM expectation of $BR(B^0 \to X_s\gamma) = 3.15 \pm 0.26 \times 10^{-4}$ [9]. However, even though large NP effects may not appear in the BR's, the polarization of the photon may reveal NP.

6. The Search for $B^0 \to \gamma\gamma$

Babar has searched for the decay mode $B^0 \to \gamma\gamma$ and seems to be on the cusp of an observation hinted at in Fig. 2 by the small mass bump at 5.28 GeV/c^2. If the data shown in Fig. 2 are treated as an upper limit, the result is $BR(B^0 \to \gamma\gamma < 3.3 \times 10^{-7}$. If the data is treated as an observation, a branching ratio $BR(B^0 \to \gamma\gamma$= $(1.7 \pm 1.1(stat) \pm 0.029(syst))x10^{-7}$ at 1.9 sigma significance is

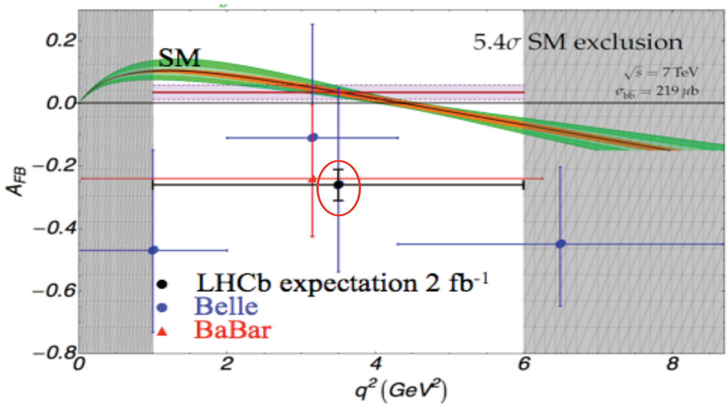

Figure 1: LHCb projections for forward-backward asymmetry measurements in $B_s \rightarrow K^* \mu\mu$.

obtained. The SM expectation for this decay mode is $\approx 3.0 \times 10^{-8}$ [10], well beyond where Babar could expect to see a signal. However, there is a possibility that new physics in which a charged Higgs is substituted in place of the W^- in the SM loop diagram that mediates this decay could increase the branching ration to order of 10^{-7} [11] consistent with the Babar data.

7. Conclusions

A rich set of new data describing searches for new physics in several different rare decay modes of B mesons has been presented at HQL10. Present B decay data nibbles at the edge of challenging the SM predictions. Typically, present day rare B experimental BR results for $B \rightarrow \mu\mu$ are within a factor of 10-15 of reaching the expected SM rates. There is still more data to be analyzed (perhaps a factor of as much as two) from the experiments Babar, Belle, CDF and D0) that presented results at HQL10, but it is unlikely that these experiments will reach the SM level. Expectations for the new LHC experiments LHCb, CMS, and Atlas that are searching for the $B \rightarrow \mu\mu$ decay are much more robust. If the LHC runs to the end of 2012 as anticipated, accumulating 5 fb^{-1}, we might expect to see the SM predictions for decays like $B_s \rightarrow \mu\mu$ reached, opening the chance for a true measurement. We look forward to results in HQL12 in 2012.

For other modes of the type $B \rightarrow hl^+l^-$, the CDF. D0, Belle and Babar are close to the SM limits in some cases. However, with the data remaining to be analyzed, it is unclear if they will be able to make measurements (or, indeed, that the theory predictions will become precise enough) to detect subtle differences due to NP between the SM and the measurement.

Finally, polarization measurements in $B \rightarrow VV$ decays may be more sensitive to NP. At present there are hints of discrepancies between the measurements and the SM expectations. However, these could be due to other than NP and represent an altogether more subtle type of measurement.

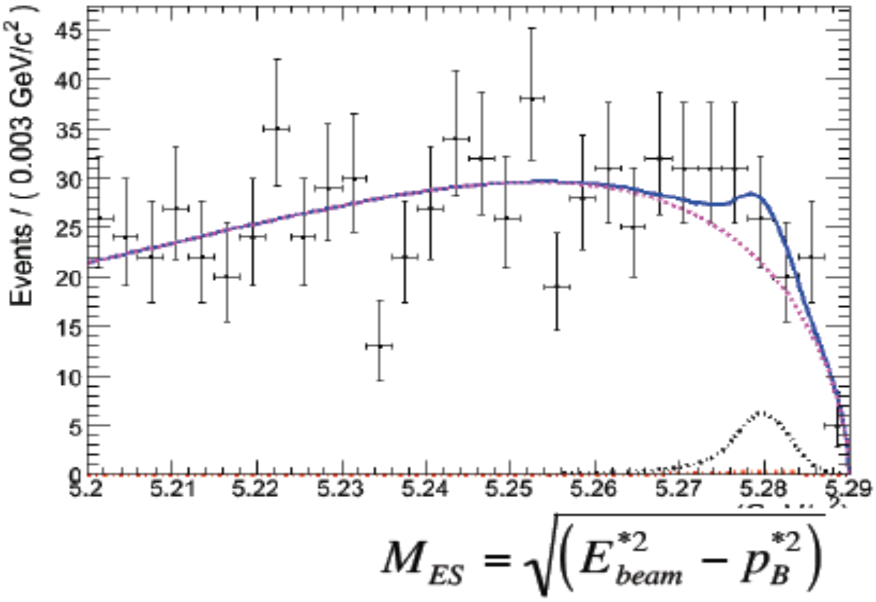

Figure 2: The Babar ES mass spectrum with possible evidence for $B^0 \to \gamma\gamma$.

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