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Searches for New Physics in the Flavor Sector

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Abstract. Looking for deviations from the Standard Model in measurements from the flavor sector can be a powerful probe for the indications of new physics. In this proceeding we discuss the potential of lifetime measurements, CP asymmetry measurements and searches for rare decays of B hadrons as probes for new physics and present results from the Tevatron experiments.

Keywords: HEP, Flavor Physics, B Physics

INTRODUCTION

Traditionally searches for particles predicted by extensions of or alternatives to the Standard Model(SM) have been performed by looking for direct production of the particles. The simplest example of a direct search is particle anti-particle annihilation leading to the production of single or pairs of new particles. However, another way to search for the evidence of new particles is to look at the decay properties of hadrons. In this scenario the new physics particles occur virtually in the decay diagrams and can lead to branching ratios or decay distributions not predicted by the SM. The best place to look for non SM effects is in decays that are low probability. For instance, in weak decays B hadron decays that can only occur via loop diagrams the predicted contribution from the SM can be on order the contributions from new physics models.

Searching for these rare decays or small deviations from the SM distributions required large statistics. The Tevatron experiments, CDF and D0, are acquiring very large samples of B decays using dedicated triggers. Promising areas for looking for new physics effects include examining B lifetimes, measuring direct charge parity(CP) asymmetries and searching for very rare decays.

In the following sections we will briefly comment on the Tevatron detectors and the properties that make them well suited for the indirect searches discussed above. Then we will review current and in progress measurements of interest.

THE CDF AND D0 DETECTORS

The CDF and D0 detectors are typical high energy physics multipurpose devices. They consist inner and outer trackers immersed in a magnetic field and designed for precession interaction or decay vertex finding and high efficiency track finding; calorimeter systems for measuring the energy of electromagnetic and hadronic particles; and muon chambers. The CDF tracking detector has a large radius which allows for high precision measurements of the mass of B hadrons while the D0 detector is lower radius but has efficient track finding to higher pseudorapidity which is well matched to the large coverage of its muon chambers. The CDF detector collects interesting physics events by selecting possible B events based on finding muons and displaced tracks. D0 primarily relies on it's large muon coverage though they are upgrading their trigger to also include lifetime information.

NEW PHYSICS IN $\Delta\Gamma_{B_S^0}$

Particle-antiparticle oscillation occurs in the B_s^0 meson system resulting in two eigenstates with definite masses and widths. Also in the SM the CP eigenstates of the B_s^0 meson are expected to be nearly identical to the mass eigenstates. This makes it possible to directly measure the decay width difference, $\Delta\Gamma_{B_s^0}$, by measuring the lifetime of states with known CP content. In the SM the mass difference, Δm_s, which can be measured in a B_s^0 oscillation analysis, is related to $\Delta\Gamma_{B_s^0}$ by a simple ratio [1]. Where observing B_s oscillations may be challenging at the Tevatron for higher oscillation frequencies, a $\Delta\Gamma_{B_s}$ measurement would be feasible. In new physics models $\Delta\Gamma_{B_s}$ is related to the SM value by the expression $\Delta\Gamma_{B_s} = \Delta\Gamma_{B_s}^{(CP\ conserving)} cos(\phi^{(SM)} + \phi^{(New\ physics)})$. In this expression the SM phase is expected to be zero and new physics contributions would reduce $\Delta\Gamma_{B_s}$ from the SM expectation.

There are several interesting ways to probe $\Delta\Gamma_{B_s^0}$. Examples of such analysis are: measuring the CP eigenstate lifetimes by disentangling the eigenstates using angular information in $B_s^0 \to J/\psi\phi$ decays; measuring the lifetime in modes that are expected to be primarily one eigenstate such as the decay $B_s^0 \to KK$ which is 97% CP even; or considering a decays such as $B_s^0 \to D_s D_s$ which is expected to account for most of the decay width and lifetime difference.

The $\Delta\Gamma_{B_s^0}$ analysis using $B_s^0 \to J/\psi\phi$ has been performed by both CDF and D0. The CDF analysis is performed in the transversity angle basis [2], which defines three decay amplitudes corresponding to linear combinations of the two eigenstates [3]. The D0 analysis is similar except in that they integrates over two of the three transversity angles [4]. The CDF and D0 experiments extract values of $\Delta\Gamma_{B_s^0} = 00.65^{+0.25}_{-0.33} \pm 0.01$ and $\Delta\Gamma_{B_s^0} = 00.21^{+0.33}_{-0.45}$ respectively. The measured values of $\Delta\Gamma_{B_s^0}$ are plotted relative to the SM value and world average constraints in Figure 1. Both values are high, which would not be expected in new physics scenarios, but are compatible with each other and the SM expectations.

Measurements of the lifetime in $B_s^0 \to KK$ decays or the lifetime and decay branching fraction in $B_s^0 \to D_s D_s$ have not been performed yet. However, the CDF experiment has observed the decay $B_s^0 \to KK$ [5] as well as the first B decay to two charmed hadrons at a proton anti-proton collider $B^0 \to D_s D^+$ [6] and is working on extending these analysis.

NEW PHYSICS IN CP ASYMMETRIES

Many models of new physics predict enhancements of the CP asymmetries (A_{CP}) of B decays [7]. At hadron colliders the most promising measurements are of direct A_{CP} or

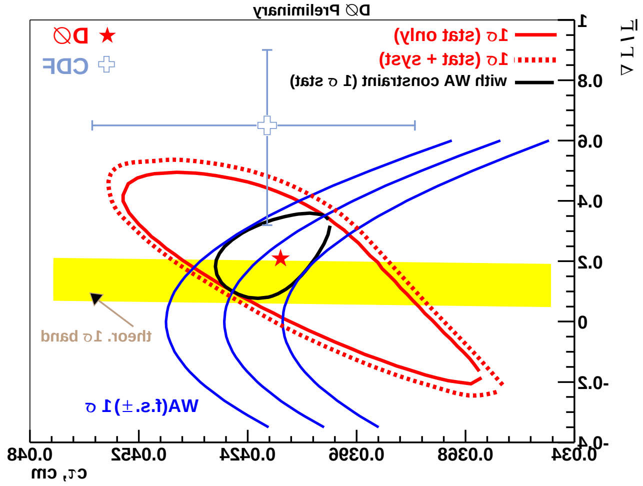

FIGURE 1. $\Delta\Gamma_{B_s^0}$ vs. B_s^0. Also plotted is the standard models predicted range for $\Delta\Gamma_{B_s^0}$ and the range allowed by the world average lifetime results.

differences in the time integrated decay rate of the CP eigenstates. These measurements are simplest when the decays of the eigenstates are flavor specific(when the eigenstate can be identified by the decay products). Examples of flavor specific decays are $B^+ \to J/\psi K^\pm$ or $B^0 \to \pi^+ K^-$ vs. $\bar{B}^0 \to \pi^- K^+$. Another possibility is to look at angular information in decays such as $B_s^0 \to \phi\phi$.

The CDF experiment has recently performed CP asymmetry measurements in the $B^+ \to J/\psi K^+$ [8] and $B^0 \to \pi^+ K^-$ [5] modes. The measured asymmetries, $A_{CP}(B^+ \to J/\psi K^+) = -0.07 \pm 0.17^{+0.03}_{-0.02}$ and $A_{CP}(B^0 \to \pi^+ K^-) = -0.04 \pm 0.08 \pm 0.006$, are of comparable accuracy to world average measurements.

In the mode $B_s^0 \to \phi\phi$ CDF has published an observation[8] based on 12 events with 1.98 ± 0.62 background and preliminarily found that 44 events are present in the data set up to August 2004. This larger amount of events approaches the number necessary to perform an A_{CP}.

NEW PHYSICS IN RARE DECAYS

Searching for rare decays can give one of the least ambiguous signals for new physics. For instance, the decays $B_s^0 \to \mu^+\mu^-$and $B_d^0 \to \mu^+\mu^-$are highly suppressed in the SM with expected branching ratios of $\mathrm{BR}(B_s^0 \to \mu^+\mu^-) = 3.5 \times 10^{-9}$ and $\mathrm{BR}(B_d^0 \to \mu^+\mu^-) = 1.0 \times 10^{-10}$. However, it has been noted [9] that the decay $B_s^0 \to \mu^+\mu^-$can be enhanced by up to 3 orders of magnitude in supersymetric extensions to the SM(SUSY) making it observable at the Tevatron. An observation of this decay would be a clear indication of new physics. In addition, the enhancement of this decay is proportional to $tan^6\beta/m_A^4$ and an observation would give interesting information on the $tan\beta$, the ratio of the vacuum expectation values of the SUSY Higgs' and the mass of the pseudoscaler Higgs [10].

The D0 and CDF collaboration have recently put limits on these processes. The D0 experiment expected 4.3 events and observed 4 and sets a limit of of $\mathrm{BR}(B_s^0 \to \mu^+\mu^-) = 3.7 \times 10^{-9}$ at 95% confidence level(CL) [11]. The CDF experiment expects 1.47 evens and observes none and sets limits of $\mathrm{BR}(B_s^0 \to \mu^+\mu^-) = 2.0 \times 10^{-9}$ and $\mathrm{BR}(B_s^0 \to \mu^+\mu^-) = 4.9 \times 10^{-10}$ at 95% CL [12]. These measurements are twice as sensitive as previous published measurements [13]. In addition, CDF and D0 they have recently produced a combined limit of $\mathrm{BR}(B_s^0 \to \mu^+\mu^-) = 1.6 \times 10^{-9}$ at 95% CL [14]. This combined limit starts to severely constrain the phase space of SUSY variants such as SO(10) gauge unification models [15].

CONCLUSION

Indirect searches for the evidence of new physics in the flavor sector is a promising avenue of investigation. The Tevatron experiments, CDF and D0, have performed a number of new measurements using the large samples of B hadron decays they have collected. No evidence of new physics is yet seen and limits are set on various new physics scenarios.

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