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Recent Searches for Exotic Physics at the BaBar/PEP-II B-factory

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I present three recent results from searches for exotic physics at the *BABAR*/PEP-II B-factory. These results span many of the samples produced at the B-factory, including B mesons, τ leptons, and $\Upsilon(3S)$ mesons. We have searched for CPT-violation in B^0 mixing and find no significant deviation from the no-violation hypothesis. We have also searched for lepton-flavor-violating decays of the τ using $\tau^- \to \omega\ell^-$ and $\tau^- \to \ell^-\ell^+\ell^-$ and their charge conjugates. We find no evidence for these processes and set upper limits on their branching fractions. Finally, we have searched for a low-mass Higgs boson in the decay $\Upsilon(3S) \to \gamma A^0$, where the Higgs decays invisibly. We find no evidence for such a decay and set upper limits across a range of possible Higgs masses.

1. INTRODUCTION

The Standard Model of particle physics has been an extremely successful description of nature. The discovery of neutrino mass, dark matter, the large matter/anti-matter asymmetry in the universe, and other natural phenomena which cannot be accommodated by the Standard Model require a more comprehensive theory of nature.

CPT-conservation is an important principle on which an effective field theory, such as the Standard Model, is built. Observation of CPT violation would require significant changes in our understanding of nature. The large matter/anti-matter asymmetry in our universe requires sources of symmetry violation which are not yet understood, such as the violation of lepton number conservation. Finally, attempts to extend the Standard Model via supersymmetry (e.g. the Minimal Supersymmetric Standard Model, or MSSM) succeed in improving the behavior of the model above the weak scale but introduce new parameters whose values are not determined by the next natural scale, the Planck scale.

I report on recent searches at the *BABAR*/PEP-II B-factory for new physics, including a search for CPT-violation, searches for lepton flavor violation, and a search for a low-mass Higgs boson which is produced in the decay $\Upsilon(3S) \to \gamma A^0$. A detailed description of the *BABAR* detector can be found elsewhere [1].

2. A SEARCH FOR CPT VIOLATION IN B-MIXING

CPT conservation requires that the rate of mixing from $B^0 \to B^0$ and the rate of mixing from $\overline{B}^0 \to \overline{B}^0$ be equal. A violation of CPT invariance in mixing is detectable as a non-zero value for the quantity:

$$\mathcal{A}_{CPT} = \frac{Prob(\overline{B}^0 \to \overline{B}^0) - Prob(B^0 \to B^0)}{Prob(\overline{B}^0 \to \overline{B}^0) + Prob(B^0 \to B^0)} \tag{1}$$

over the course of a sidereal day.

Our measurement of the CPT asymmetry in B^0 mixing is detailed elsewhere [2]. I briefly describe our approach and results. We measure the CPT asymmetry using dilepton events in 232×10^6 $B\overline{B}$ pairs. The charge of the lepton indicates the flavor of the B at the time of decay, and the difference in the decay positions (Δz) of the two B mesons is related to the time between their respective decays, $\Delta z = \beta\gamma c\Delta t$.

In a generic extension of the Standard Model [3] a term z modifies the B^0 mass eigenstates [4], where $z = \beta^\mu \Delta a_\mu/(\Delta m - i\Delta\Gamma/2)$, β^μ is the boost direction of the $\Upsilon(4S)$ system, Δa_μ is the four-vector of the CPT-violating effect, and Δm and $\Delta\Gamma$ are the mass and width differences of the heavy and light B^0 mass eigenstates.

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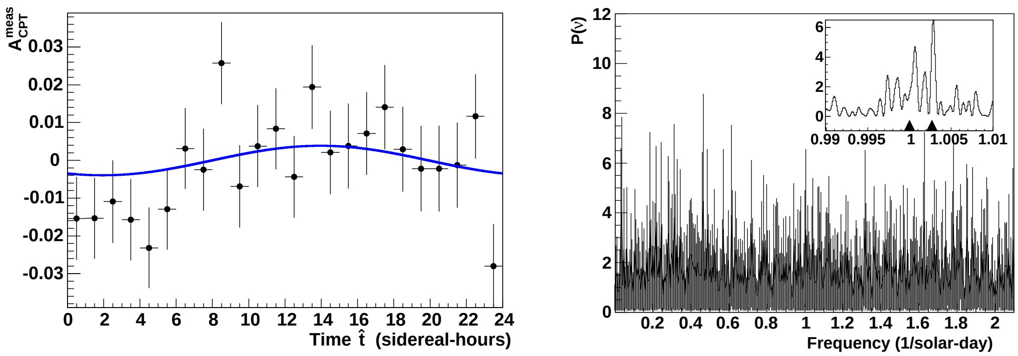

(a) CPT asymmetry vs. sidereal time for opposite-sign dilepton events. The curve is a projection of the two-dimensional maximum likelihood fit.

(b) Periodogram for opposite-sign dilepton events. The solar day and sidereal day frequencies, indicated by the left and right triangles (inset), are well-resolved in our data.

Figure 1: Results from the two methods of analyzing the B^0 mixing data

We search for CPT-violation by measuring the relative numbers of opposite-sign dilepton events as a function of the sidereal day. The B-factory is fixed to the earth, which rotates on its axis and around the sun. We fix the celestial coordinate system on the center of the sun. The z-axis ($\hat{Z}$) of the celestial coordinate system is parallel to the earth's rotation axis, and the z-axis ($\hat{z}$) of the rotating frame is opposite the $\Upsilon(4S)$ boost vector. The axis $\hat{z}$ precesses around $\hat{Z}$ with a period of one sidereal day.

The dilepton events are fitted in two dimensions - Δt and sidereal time - using a maximum likelihood function. The projection of the fit and data in only sidereal time is shown in Fig. 1(a). We find that the data are consistent with the no-CPT-violation hypothesis at the level of 2.8σ.

We perform an alternative measurement of the data by studying the spectral power of periodic variations in z over a wide frequency band using the periodogram method [5] developed to study variable stars. The spectral power at a test frequency ν is $P(\nu) \equiv \frac{1}{N\sigma_w^2}\left|\sum_{j=1}^{N} w_j e^{2i\pi\nu T_j}\right|^2$, where the data, containing N measurements of the weight, w_j, made at times T_j, with variance σ_w^2. Here, T_j is the time elapsed since the Unix epoch for opposite-sign dilepton event j, and the weights $w_j = \Delta m\Delta t_j - \sin(\Delta m\Delta t_j)$ are suited to the study of periodic variations in z according as described by $\mathcal{A}_{CPT}$.

The frequency spectrum is shown in Fig. 1(b). The largest spectral power occurs at nearly half a sidereal day, and assuming no signal we find that the probability of obtaining a larger spectral power is 76%. We find that for events with a frequency of one sidereal day, there are 78 other frequencies (out of 20994 test frequencies) which exceed its spectral power.

The dominant source of uncertainty is due to statistical uncertainty. Therefore, with the remaining half of the BABAR dataset we can expect to improve this measurement by reducing the dominant statistical uncertainties.

3. SEARCHES FOR LEPTON-FLAVOR-VIOLATING τ DECAYS

We use a sample of $\sim 700\times10^6$ τ leptons to search for the lepton-flavor-violating (LFV) decays $\tau^-\to\omega\ell^-$ and $\tau^-\to\ell^-\ell^+\ell^-$ (charge conjugation is implied throughout). Observation of either is an unambiguous sign of physics beyond the Standard Model.

These analyses are described in detail elsewhere [6]. I briefly describe our approach and results. We reconstruct the signal events by separating the event into two hemispheres based on the thrust axis. One hemisphere is required to contain only one charged particle identified as either an electron or muon, while the other is required to contain three charged particles. We require that the three particles pass muon or electron identification for the $\tau^-\to\ell^-\ell^+\ell^-$

final state, while for the $\tau^- \to \omega\ell^-$ final state one track must be identified as either an electron or muon, and the other two must be paired with a π^0 candidate to form an ω candidate.

We find, using Monte Carlo simulations, that the background for each final state is expected to be about one event and that the efficiency for reconstructing the signal varies with final state between $2-10\%$. We find no evidence for these decays in our data and set upper limits on the branching fractions for these decays. Depending on which combination of lepton identification is used, the limits on the branching fraction for $\tau^- \to \ell^-\ell^+\ell^-$ range between $(4-8)\times10^{-8}$. For both lepton final states of $\tau^- \to \omega\ell^-$, the limits are 1×10^{-7}. All limits are at the 90% confidence level. These results are competitive with the best existing limits on these decays.

4. A SEARCH FOR A LOW-MASS, INVISIBLY DECAYING HIGGS BOSON

We use a sample of 122×10^6 $\Upsilon(3S)$ mesons to search for the production of a low-mass CP-odd Higgs boson in the decay $\Upsilon(3S) \to \gamma A^0$. Such a low-mass Higgs boson is possible if the MSSM is extended with an additional chiral Higgs singlet gauge field [7]. The addition of such a singlet yields two additional Higgs bosons, including a CP-odd Higgs which can have a mass below the $b\bar{b}$ threshold, and allows the Higgs vacuum expectation value in the MSSM to be dynamically generated, instead of set by hand to the weak scale.

While the dominant decay of such a low-mass Higgs boson could be to τ leptons, muons, etc. if there is also additionally a low-mass dark matter component then the dominant Higgs decay may be to a completely undetectable final state. We therefore search for a single monochromatic photon recoiling against an invisibly decaying Higgs boson.

This analysis is described in detail elsewhere [8]. I briefly describe the method and results of this search. We select events by requiring they contain a single, well- reconstructed photon within the barrel of the electromagnetic calorimeter. We require that there are no charged particles in the event, and we constrain the additional neutral particles to have very little total energy. The second-highest energy neutral particle cannot be back-to-back with the signal photon; this is done to eliminate part of the significant background from $e^+e^- \to \gamma\gamma$. There is a significant contribution from this background where the second photon escapes detection in the calorimeter but leaves hits in the instrumented flux return. We require that there are no hits in that system correlated with the signal photon.

We search for a signal in the data by performing a maximum likelihood fit to the square of the missing mass,

$$m_X^2 = M^2_{\Upsilon(3S)} - 2E_\gamma M_{\Upsilon(3S)}. \tag{2}$$

We fit the data using several models for backgrounds (a peaking component from $e^+e^- \to \gamma\gamma$ at $m_X^2 = 0\,\mathrm{GeV}^2$, with a long tail extending to large values of m_X^2, and non-peaking components from other sources) and a model for the signal. The signal model represents the resolution function of a photon reconstructed in the calorimeter, and its parameters vary with energy as the calorimeter response varies. We scan the signal model across m_X^2 in steps of $100\,\mathrm{MeV}$ in m_X for $m_X^2 < 40\,\mathrm{GeV}^2$ and in steps of $25\,\mathrm{MeV}$ for $m_X^2 > 30\,\mathrm{GeV}^2$. Due to the different triggers required to select events in these two regions, there is a slight overlap which is handled in the final combination of results.

Two example fits, one from the low-missing-mass region and one from the high-missing-mass region, are shown in Fig. 2. These examples are chosen because they represent the most significant yields in each missing-mass region - (37 ± 15) events in the low-missing-mass region and (119 ± 71) events in the high-missing-mass region. Neither of these is a significant enough deviation from the null-signal hypothesis, with the larger of the two statistical significances being 2.6σ.

We interpret the results of these fits as upper limits on the branching fraction for $\Upsilon(3S) \to \gamma A^0$ as a function of the Higgs mass. The results are shown in Fig. 3. The statistical uncertainty dominates across the mass spectrum, except in the region where the $e^+e^- \to \gamma\gamma$ background peaks. For small Higgs masses, the systematic uncertainty on the shape and yield of this background dominates. These are the most significant constraints on an invisibly decaying low-mass Higgs boson for a Higgs up to $m_{A^0} = 7.8\,\mathrm{GeV}/c^2$.

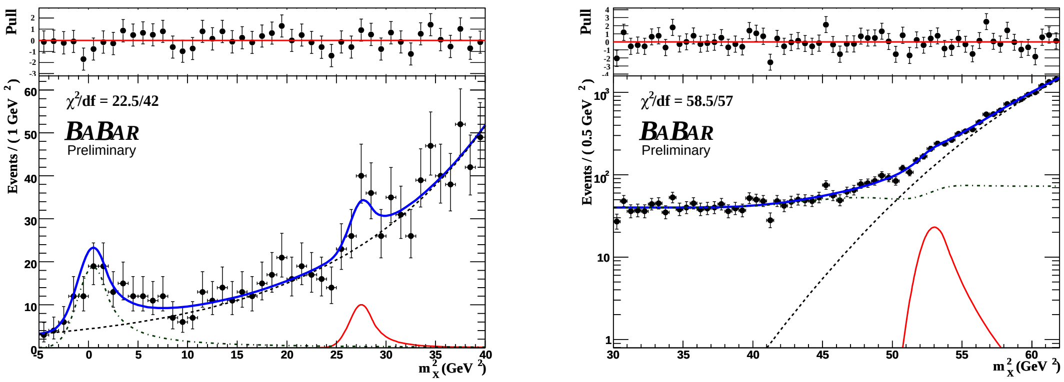

Figure 2: Two example fits from the Higgs scan, one from the low-missing-mass data (left) and one from the high-missing-mass data (right), each representing the most significant yields from each region.

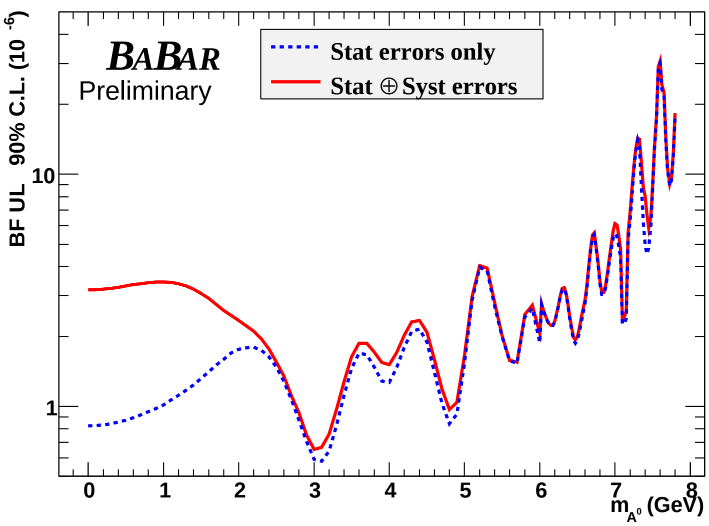

Figure 3: The upper limit on the branching fraction for $\Upsilon(3S) \to \gamma A^0$ as a function of Higgs mass.

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