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Searches for Rare and Forbidden B and Charm Decays at the BABAR experiment.

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A review of recent results of searches for rare decays with new physics sensitivity from the analysis of the data recorded at the *BABAR* experiment at the Stanford Linear Accelerator Center PEP-II B-Factory, is presented. In particular, results of searches for the Standard Model (SM) rare B meson decays, such as $B \to \gamma\gamma$ and $B \to K\nu\bar{\nu}$, as well as for the SM forbidden lepton and baryon number violating mode $B \to \Lambda_{(c)} l$ are shown. We also describe recent searches for the corresponding similar charm meson decays $D \to \gamma\gamma$ and $X_c^+ \to h^\pm l^\mp l^{(\prime)-}$.

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1. Introduction.

The so-called B meson factories, such as the *BABAR* experiment at SLAC PeP-II collider, produce actually almost as much $c\bar{c}$ quark (and $\tau^+\tau^-$ lepton) pairs as $b\bar{b}$ quark pairs. Therefore studying very suppressed, within the Standard Model (SM), beauty and charm meson decay modes, to search for any possible unexpected enhancement of their respective branching fraction (BF), is an excellent place to look for hints of new physics (NP) processes, beyond the SM, that provide extra contributions to the otherwise very suppressed decay amplitudes. Processes like $B \to \gamma\gamma$, $B \to K\nu\bar{\nu}$, $D \to \gamma\gamma$ and $X_c^+ \to h^\pm\, l^\mp l^{(\prime)-}$, where X_c is a charm hadron (D^+, D_s^+ , or Λ_c^+) , $l^{(\prime)\pm}$ is an electron or muon, and h^{-1} can be either a pion, a kaon or a proton; when the oppositely charged leptons of the same lepton flavor, are examples of flavor-changing neutral processes (FCNP) , which are expected to be very rare because they cannot occur at tree level in the SM.

Additionally, searching for processes that are directly forbidden by the SM, such as those violating baryon (BNV) or lepton number conservation (or both) like $B \to \Lambda_{(c)} l$, would, if found, be unequivocally a signature of physics beyond the SM. Another example would be the charm meson decay $X_c^+ \to h^\pm\, l^\mp l^{(\prime)-}$, which with the two oppositely charged leptons of different flavor would correspond to lepton-flavor violating (LFV) decays, which are essentially forbidden in the SM because they can occur only through lepton mixing. The former decay mode but with two leptons of the same charge are lepton-number violating (LNV) decays and are also forbidden in the SM.

2. The *BABAR* detector and dataset.

The *BABAR* detector is described in detail [1] . Charged particle tracks are measured with a five-layer silicon tracker (SVT) and a 40-layer drift chamber (DCH). Measurements of the ionization energy loss, dE=dx, in the tracking system together with the Cherenkov angle obtained from a ring imaging Cherenkov detector (DIRC) are use to provide the identification of charged hadrons. The calorimeter system (EMC) is based on CsI(TI) crystals that measure the energy deposition of electrons and photons. All the above detectors are inside a superconducting solenoidal magnet, which provides a 1.5 T magnetic field. This flux return of this magnetic field is instrumented (IFR) allowing further discrimination of muons from pions.

The searches for the above mentioned decay modes are performed using data collected by the *BABAR* experiment at the SLAC PeP-II asymmetric e^+e^- collider. A total of approximately 530fb^{-1}, most of them at (and near) a centre-of-mass energy of the $\Upsilon(4S)$ resonance (10.58 GeV), but also at the $\Upsilon(3S)$ and $\Upsilon(2S)$, were collected during its operation. The event yield contains around 470 milion B meson pairs, 690 milion charmed meson pairs and 500 milion τ lepton pairs.

3. Rare B meson decays: $B \to \gamma\gamma$ and $B \to K\nu\bar{\nu}$

The SM decay $B^0 \to \gamma\gamma$ occurs through a FCNC transition involving eletroweak loop diagrams. The leading order calculation for the BF of $B^0 \to \gamma\gamma$ produces an estimate of $(3.1^{+6.4}_{-1.6}) \times 10^{-8}$ [2]. NP scenarios beyond the SM (e.g., extended Higgs sectors [3] or R-parity violating supersymmetry [4]) can enhance this BF due to new contributions of non-SM heavy particles occurring in the loop of the leading-order Feynman diagrams. Previous measurements [5] [6] [7] have reached a best upper limit (UL) on this BF at 90 % confidence level (CL) of BF($B \to \gamma\gamma$) $< 6.2\times 10^{-7}$ set by the Belle experiment [7] using a dataset recorded at the $\Upsilon(4S)$ resonance with an integrated luminosity of 104 fb^{-1} .

The most recent *BABAR* analysis is based on 429 fb^{-1} of data recorded at the $\Upsilon(4S)$ resonance [8]. The $B \to \gamma\gamma$ signal yield is extracted by means of 2-dimensional likelihood fit to the m$_{ES}$ and ΔE variables. The beam energy substituted mass is defined as m$_{ES} \equiv \sqrt{E^{*2}_{beam} - c^2\vec{p}^{*2}_B}/c^2$ and the energy difference is $\Delta\text{E} \equiv E^*_B - E^*_{beam}$, where E^*_{beam} is the beam energy, and $\vec{p}^*_B$ and E^*_B are the three momentum and energy of the B candidate, respectively. The BF is calculated from the signal yield to be $\mathscr{B}(B^0 \to \gamma\gamma) = (1.7 \pm 1.1 \pm 0.2) \times 10^{-7}$, where the first error is statistical and the second is systematic, which corresponds to a 1.8σ significance. The corresponding 90% CL is set to $\mathscr{B}(B^0 \to \gamma\gamma) <(3.2) \times 10^{-7}$ (90% CL).

Similarly the $B \to K\nu\bar{\nu}$ decay arise from FCNC. NP models foresee extra contributions that allow for up to five-fold BF increase with respect to the SM [9] [10] [11] [12] [13]. The latest SM prediction for the total $B \to K\nu\bar{\nu}$ rate is $(4.5 \pm 0.7)\times10^{-6}$ [14], while previous measurements [15] have established the best UL for the $B^+ \to K^+\nu\bar{\nu}$ decay to be 1.4×10^{-5}, and the UL for the $B^0 \to K^0\nu\bar{\nu}$ to be 1.6×10^{-4} both at 90% CL [15]. The *BABAR* analysis is based on 418fb^{-1} of on-peak ($\Upsilon(4S)$) data [16]. The difficulty to directly reconstruct kinematically this channel, forces to recontruct the other B meson in the event (though a semi-leptonic decay), and look for the signal among the remaining particles of the event. The result of this search fails to find any significant signal evidence, and the corresponding UL at 90% CL are set for the neutral and charged decay channels to be $\mathscr{B}(B^0 \to K^0\nu\bar{\nu}) < 5.6\times10^{-5}$ and $\mathscr{B}(B^+ \to K^+\nu\bar{\nu}) < 1.3\times10^{-5}$ respectively.

4. Searches for lepton and baryon number violation B decays: $B \to \Lambda_{(c)}l$

The search is performed for the decay lepton and baryon number violating $B \to$ baryon lepton , where the baryon is either a Λ_c or a Λ_0, and the lepton is a muon or electron, is performed on 429 fb^{-1} of data collected at the $\Upsilon(4S)$ peak [17]. This beyond the SM process is generally interpreted as being mediated by a boson which carries both color and lepton number and is fractionally charged and is a signature of some SU(5) theories. The analysis technique followed a "blind" approach in order to avoid bias in the results. The signal yield was obtained by means of an unbinned extended maximum likelihood fit to the m$_{ES}$ and ΔE (and the neural network output for the Λ_c mode) variables. No significant excess event above the background expectations were observed and the corresponding UL at 90% CL are set to be of the order of 10^{-6} for the Λ_c modes and of the order of 10^{-8} for thr Λ_0 modes [17].

5. Rare charm meson decays: $X_c^+ \to h^{\pm}\, l^{\mp}l^{(\prime)-}$, $D \to \gamma\gamma$.

In the charm meson sector, the decay $D \to \gamma\gamma$ is an example of FCNC [18] whose BF is suppressed within the SM at levels of 10^{-8}-10^{-11} [19] [20], and that could be enhanced by NP contributions [21]. A preliminary analysis [22] has been performed over a sample of 407fb^{-1} and no signal yield is found beyond the expected background events. The corresponding UL on the BF has been set to $\mathscr{B}(D \to \gamma\gamma) < 2.4\times10^{-6}$ at 90% CL.

The rare or forbidden charm decays of the form $X_c^+ \to h^\pm\, l^\mp l^{(\prime)-}$, where X_c is a charm hadron (D^+, D_s^+ , or Λ_c^+) , $l^{(\prime)\pm}$ is an electron or muon, and $h^\pm$ can be either a pion, a kaon or a proton. The SM rare but allowed cases (not considering the resonant l^+l^- vector resonances like ρ, ω and ϕ) are predicted to have a BF of the order of 10^{-8} [19]. A search has been performed on 384 fb^{-1} of e^+e^- annihilation data collected at or close the $\Upsilon(4S)$ resonance[23]. Although no signal evidence is found, the corresponding UL at 90 % CL represent an improvement with respect to the previous experimental limits, and in many modes by more than one oerder of magnitude.

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