Search for exotic new Physics at BABAR

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Abstract. We present the recent BABAR results for direct new physics searches. In particular we describe searches in the $\tau$ sector, with new results concerning lepton flavor violation searches, and in the $\Upsilon(nS)$ sector, where light Higgs and dark matter candidates are sought after and searches for lepton flavor violating decays are performed. We also present precise tests of lepton universality in $\Upsilon(nS)$ decays.

1. Introduction

BABAR operated for the last ten years, having been shut down in April 2008, during its long data-taking period it recorded events at different center of mass energies. The largest part of the BABAR data sample consists of 486 fb$^{-1}$ taken around $\Upsilon(4S)$ resonance energy. To broaden its reach for new physics and in order to study $\Upsilon$ decays, the PeP-II asymmetric storage rings were operated also around $\Upsilon(3S)$ and $\Upsilon(2S)$ resonances, recording 30 fb$^{-1}$ and 14 fb$^{-1}$ around each resonance, respectively. A complete description of the BABAR detector can be found in [1].

2. Direct search for light Higgs and Dark Matter candidates

The Higgs mechanism, leading to the electroweak breaking, predicts an Higgs boson mass which is unstable after radiative corrections. Some new physics (NP) models solve this instability with the presence of a CP-odd Higgs singlet $A^0$, as predicted by Next to Minimal Supersymmetric Standard Model (NMSSM) [2], or an axion-like particle [3]. The former solution would solve the Higgs instability, while the latter would provide also a solution for the dark matter puzzle. Such a pseudoscalar particle can be searched in the decays of $\Upsilon(nS)$, which hence provides a great probe for direct NP searches and could be of paramount importance for the understanding of two of the most sought after answers in particle physics.

BABAR recorded one of the largest samples of $\Upsilon(3S)$ and $\Upsilon(2S)$, with seven times the statistics of the combined CLEO and Belle datasets for the former and half of the combined statistics for the latter. Searches were performed in three different channels: $\Upsilon(2S,3S) \rightarrow \gamma A^0, A^0 \rightarrow \mu^+\mu^-$ [4], $\Upsilon(3S) \rightarrow \gamma A^0, A^0 \rightarrow \tau^+\tau^-$ [5], and $\Upsilon(3S) \rightarrow \gamma A^0, A^0 \rightarrow$ invisible [6].

2.1. $\Upsilon(2S,3S) \rightarrow \gamma A^0, A^0 \rightarrow \mu^+\mu^-$

The $A^0 \rightarrow \mu^+\mu^-$ event signature is characterized by two charged tracks, of which at least one should be identified as a $\mu$, forming the $A^0$ candidate, and an energetic $\gamma$ which should have an energy $E_\gamma > 200$ MeV in the center of mass (CM) frame. A kinematic fit of the $\gamma\mu\mu$ vertex is performed in order to select the $\Upsilon$ candidate, the background shapes and yields are estimated on a subsample of the data which is then removed from the final selection and fit. A fit to the
invariant mass of the two reconstructed $\mu$ is done in order to look for a peak produced by $A^0$, the fit is performed in the $0.212 \text{ GeV}/c^2 < m_{A^0} < 9.3 \text{ GeV}/c^2$ range by looking at 300 MeV/c$^2$-wide windows that are moved by 2–5 MeV/c$^2$ steps, excluding the $J/\Psi$ and $\Psi(2S)$ peak regions from the fit due to the large peaking backgrounds, resulting in 1951 fitting points. The possible bias in the fitted value of the signal yield is tested with a large number of pseudo-experiments, and is consistent with zero for all $m_{A^0}$ values. The significance of any positive fluctuation is estimated through a likelihood ratio variable. Including the systematics the largest significances observed are $3.1\sigma$ ($\Upsilon(2S)$) and $2.8\sigma$ ($\Upsilon(3S)$), consistent with null hypothesis. The limits on $B(\Upsilon(nS) \to \gamma A^0) \times B_{\mu\mu}$ are shown in Fig. 1 and Tab. 1.

![Figure 1](image-url)

**Figure 1.** 90% Confidence Level (C.L.) upper limits on (a) $B(\Upsilon(2S) \to \gamma A^0) \times B_{\mu\mu}$, (b)$B(\Upsilon(3S) \to \gamma A^0) \times B_{\mu\mu}$, and (c) effective coupling $f_\Upsilon^2 \times B_{\mu\mu}$ as a function of $m_{A^0}$

The branching fractions (BFs) $B(\Upsilon(nS) \to \gamma A^0)$ are related to the effective coupling $f_\Upsilon$ of the bound $b$ quark to the $A^0$ through [7]:

$$
\frac{B(\Upsilon(nS) \to \gamma A^0)}{B(\Upsilon(nS) \to \ell^+\ell^-)} = \frac{f_\Upsilon^2}{2\pi\alpha} \left(1 - \frac{m_{A^0}^2}{m_{\Upsilon(nS)}^2}\right)
$$

where $\ell = e, \mu$ and $\alpha$ is the fine structure constant. \textit{BABAR} computed the experimentally accessible quantity $f_\Upsilon^2 B_{\mu\mu}$, averaging on the $\Upsilon(2S)$ and $\Upsilon(3S)$ samples, taking into account both correlated and uncorrelated uncertainties, the results are shown in Fig. 1(c).

2.2. $\Upsilon(3S) \to \gamma A^0, A^0 \to \text{invisible}$

The decays of the light Higgs boson depend on its mass and couplings, as well as on the low-energy particle spectrum of the underlying theory. In certain NMSSM scenarios, particularly those in which the mass of the lightest supersymmetric particle (LSP) is larger than $m_\tau$ or if the Higgs mass is less than $2m_\tau$, the dominant decay of $A^0$ could be invisible: $A^0 \to \chi^0\chi^0$, where the neutralino $\chi^0$ is the LSP. The cleanest experimental signature of such decays is production of
monochromatic single photons in decays $T \to \gamma A^0$, accompanied by a significant missing energy and momentum.

BABAR performed a search for a monochromatic peak in the missing mass distribution of events with a single high energy photon. The decay width of $A^0$ is assumed to be negligibly small compared to experimental resolution, and it is assumed that a single $A^0$ state exists in the range $0 < m_{A^0} \leq 7.8 \text{ GeV}/c^2$; or if two or more states are present, they do not interfere.

Detection of the low-multiplicity single photon events requires dedicated trigger and filter lines. The BABAR detector offers two different trigger lines for such events: a high energy line requiring an isolated electromagnetic calorimeter (EMC) cluster with a CM energy $E_\gamma > 2 \text{GeV}$, and no tracks originating from the interaction region, which is refined at reconstruction level to have a photon energy $E_\gamma \geq 3 \text{GeV}$ and no tracks reconstructed in the drift chamber (DCH) with $p^* > 1 \text{ GeV}/c$; and a low energy line which require $E_\gamma > 1.5 \text{GeV}$ and no tracks reconstructed in the DCH with $p^* > 0.1 \text{ GeV}/c$. The two triggers present different backgrounds: the high energy line backgrounds are dominated by $e^+e^- \to \gamma\gamma$ events, especially in the energy region $E_\gamma \sim E_{cm}/2$, where the photon energy shows a peak; on the other hand for the low energy line backgrounds are dominated by low angle radiative Bhabha events $e^+e^- \to \gamma e^+e^-$, where the two charged tracks are not reconstructed.

A limited number of variables can be used to select these very low multiplicity event samples, in particular the selection is focused on the photon quality requirements (number of crystals in the neutral clusters, and cluster shape), polar angle of the photon (which is distributed in the CM polar angle as $1 - \cos^2 \theta^\ell$ and peaked forward and backward for backgrounds), veto of extra particle in the event, and a Instrumented Flux Return (IFR) veto in the muon system, which suppress the $e^+e^- \to \gamma\gamma$ events where one of the photon is lost in the dead regions of the EMC but is reconstructed as an IFR cluster. The selection is optimized to maximize $\varepsilon_S/\sqrt{\varepsilon_B}$ where $\varepsilon_S$ is the signal selection efficiency and $\varepsilon_B$ is the background efficiency. MC events are used to estimate the signal efficiency, while the background is estimated using a data sub sample (about 10%) which is later included in the final fit.

The signal is extracted from an unbinned maximum likelihood fit to $m^2_{A^0}$, in steps of 0.1 GeV$^2$/c$^4$, the resolution on $m^2_{A^0}$ is estimated from simulated and reconstructed $e^+e^- \to \gamma\gamma$, and ranges between 1.5 GeV$^2$/c$^4$ (for $m_{A^0} = 0$) and 0.7 GeV$^2$/c$^4$ (for $m_{A^0} = 8 \text{ GeV}/c^2$). The largest systematic uncertainties arise from the estimate of $e^+e^- \to \gamma\gamma$ peaking background yield (only in the high energy region) and its shape (affecting both regions). No signal excess was observed in the fit, and an Upper Limit (UL) was set for $\mathcal{B}(T(3S) \to \gamma A^0) \times \mathcal{B}(A^0 \to \text{invisible}) < (0.7 - 31) \times 10^{-6}$ (90% CL). The limits as a function of $m_{A^0}$ are shown in Fig.2.

2.3. $T(3S) \to \gamma A^0, A^0 \to \tau^+\tau^-$ channel

The $T(3S) \to \gamma A^0, A^0 \to \tau^+\tau^-$ channel is reconstructed only in the case both $\tau$ leptons decay leptonically (i.e. $\tau \to e\nu_e\nu_\tau$ or $\tau \to \mu\nu_\mu\nu_\tau$). The selected events are required to contain at least one energetic photon candidate with $E_\gamma > 100 \text{ MeV}$, and exactly two charged tracks, which should be identified as leptons (either an electron or a muon). After this preliminary selection most of the background retained is due to radiative $\tau$ pair production and higher order QED processes, like two photon processes, leading to four tracks with low transverse momenta in the final state.

The backgrounds are reduced using 8 kinematic variables: the total CM energy calculated from the two tracks and the candidate photon; the squared missing mass; the aplanarity, which is the cosine of the angle between the photon direction and the plane identified by the two tracks momenta; the cosine of the angle between the photon and the tracks; the total transverse momentum of the event calculated in the CM frame; the polar angle of the missing momentum; and the cosine of the polar angle between the tracks in the photon recoil frame. The final selection is optimized to maximize $S/\sqrt{B}$, where $S$ and $B$ are the expected number of signal and of background events respectively. Since the background may vary as a function of the photon
energy, the optimization is performed in five $E_\gamma$ regions, which partially overlaps in order to reduce the discontinuity in the efficiency. The backgrounds after the selection are dominated by $e^+e^- \rightarrow \gamma\tau^+\tau^-$ events, with larger contribution observed for low $E_\gamma$ values.

The analysis looks for an excess in a narrow region in the $E_\gamma$ spectrum, since any peak in the recoil mass ($m_{\tau\tau}$) indicating the presence of a new particle decaying in two $\tau$'s, translates to a peak in the photon energy distribution. To extract the signal and background yields a two-step binned likelihood fit is made simultaneously for $\tau\tau \rightarrow ee, e\mu,$ and $\mu\mu$ samples. In the first step of the fit a no signal hypothesis is assumed and the background function is fitted, in the second step a search for $\Upsilon(3S) \rightarrow \gamma A^0, A^0 \rightarrow \tau^+\tau^-$ is performed, assuming the $A^0$ to have a negligible width and the signal distribution is parametrized with a Crystal Ball function. The search for such signal is performed scanning for peaks in the $E_\gamma$ distribution in steps equal to half the photon energy resolution. In total 307 scan points are examined and for each scan point the yield and its statistical uncertainty are obtained from the fit. The yield significance from the data is shown in Fig.3. The data points are consistent with the normal distribution and no significant evidence for any signal is found, and an UL is set: $B(\Upsilon(3S) \rightarrow \gamma A^0, A^0 \rightarrow \tau^+\tau^-) = (1.5 - 16) \times 10^{-5}$.

A review for all Higgs and dark matter candidate searches can be found in Tab. 1.

**Table 1.** Results for Higgs and Axion-like particle searches performed by the BABAR Collaboration.

| Process | Energy Range | Upper Limit |
|---------|--------------|-------------|
| $T(2S,3S) \rightarrow \gamma A^0, A^0 \rightarrow \mu^+\mu^-$ | $0.212 GeV/c^2 < m_{A^0} < 9.3 GeV/c^2$ | $(0.26 - 8.3) \times 10^{-5}$ |
| $T(3S) \rightarrow \gamma A^0, A^0 \rightarrow \tau^+\tau^-$ | $0.212 GeV/c^2 < m_{A^0} < 9.3 GeV/c^2$ | $(1.5 - 16) \times 10^{-5}$ |
| $T(3S) \rightarrow \gamma A^0, A^0 \rightarrow invisible$ | $m_{A^0} \leq 7.8 GeV/c^2$ | $(0.7 - 31) \times 10^{-6}$ |

3. Lepton Flavor Violation in $\tau$ decays

Lepton Flavor Violation (LFV) involving charged leptons has never been observed, and stringent experimental limits exist for both $\tau$ and $\mu$ decays [8, 9]. On the other hand, experimental observation of neutrino oscillations [10] implies that, within the Standard Model (SM), there are
amplitudes contributing to LFV in the neutral sector, which would contribute to LFV in charged sector, albeit with effects well below the current experimental sensitivity [11]. Many descriptions of physics beyond the SM predict enhanced LFV in $\tau$ decays over $\mu$ decays, with branching fractions within or at least very close to the present experimental sensitivities [12, 13, 14]. An observation of LFV in $\tau$ decays would be a clear signature of NP, while improved limits would further constrain models.

We will present in the following results for $\tau^-(\rightarrow \ell^- \gamma)$ and $\tau^- \rightarrow \ell_1^- \ell_2^- \ell_3^- \ell_4^- \ell_5^- \ell_6^- \ell_7^- \ell_8^-$ ($\ell_i = e, \mu$) searches: these two channels are two of the most studied $\tau$ LFV decays and have analogues in the $\mu \rightarrow eee$ and $\mu \rightarrow e\gamma$ decays. The observation of signal in more than one channel, among the eight decays we will present, would not only imply NP, but by looking at the ratios of the measured branching ratios (BR) it would be possible to obtain important information about the flavor structure of the NP leading to the LFV processes (a review of possible branching fraction ratios can be found in Ref. [15]).

In order to look for LFV in $\tau$ decays, events with low charged particle multiplicity are selected, the event space is divided in two non-overlapping hemispheres by a plane containing the interaction region and orthogonal to the thrust axis, calculated from both charged tracks and neutral energy deposit. Each track and reconstructed photon is associated to one of the two hemispheres. The two hemispheres are called the tag side (where a SM $\tau$ decay is observed) and the signal side (where the LFV decay candidate is observed). For $\tau^- \rightarrow \ell^- \gamma$ searches the signal candidate is expected to have an energetic photon with $E_\gamma > 1$ GeV and only one charged track in the signal side, in the tag side the decay is categorized in five broad classes: $e$, $\mu$, and $\pi$ tags, where only one track is present, $\rho$ tags where a candidate $\pi^0$ is observed along the tag
side track, and 3h tag, where there are three tracks in the tag hemisphere. On the other hand in \( \tau^- \to \ell^- \ell^- \ell^- \) the signal hemisphere is required to contain exactly three tracks, while the tag side is required to have only one track and no neutral deposits corresponding to photons with \( E_\gamma > 100 \) MeV. Both analyses are performed in a blind way, in order to reduce biases introduced by the analysts, and the data are observed only after the selection is optimized and systematics are estimated.

The selection is optimized independently for each channel. For both searches the background is reduced by using particle identification (PID), kinematic information, and for \( \tau^- \to \ell^- \gamma \) analysis also multivariate algorithms. The optimization is made in order to obtain the best expected UL, the number of expected background events in the blinded signal region is extrapolated from unblinded sidebands, using MC samples or data enriched control samples. The signal efficiency is estimated using MC. The UL is determined using a modified frequentist approach accounting for systematics errors.

The results for \( \tau^- \to \ell^- \gamma \) are shown in Fig. 4, the main background contribution comes from radiative SM \( \tau \) decays such as \( \tau^- \to \ell^- \nu_\tau \bar{\nu}_\ell \gamma \), which constitute an irreducible background in the case the \( \nu_\tau \)s have low momenta.

**Figure 4.** Sidebands and signal region for \( e\gamma \) channel (left) and \( \mu\gamma \) channel (right) in the \((m_{EC}, \Delta E)\) plane. Data events are shown as dots, and contours containing 90\% (50\%) of signal MC are shown as light- (dark-) shaded regions.

\( \tau^- \to \ell^- \ell^- \ell^- \) decays present smaller backgrounds due to the clear signature of the signal candidates, the main systematics associated to the analysis arise from the background model which have large errors, reflecting on large errors on background yields due to the lack of data events in the sidebands. Results are shown in Fig. 5, and a resume of the 90\% CL ULs for both LFV searches in \( \tau \) decays is reported in Tab. 2.

### 4. Lepton Flavor Violation in \( \Upsilon \) decays

The large \( \Upsilon(3S) \) and \( \Upsilon(2S) \) samples available for \( B\bar{B}A\bar{R} \) made it possible to reach unprecedented sensitivities for the searches for rare decays of such resonances. \( \Upsilon(nS) \) decays have been used to search for LFV in \( \Upsilon(nS) \to \ell^+ \ell^- \) decay, which are as sensible as \( \tau \) decays to NP. Four channels have been studied, looking at \( e\tau \) and \( \mu\tau \) final states for both \( \Upsilon(3S) \) and \( \Upsilon(2S) \). The LFV event signature is composed of one energetic lepton (either \( e \) or \( \mu \)) and a \( \tau \) reconstructed through leptonic or hadronic \((\tau \to \pi^+ \pi^- \pi^0)\) decays, the selection is partially common to the four channels with differences regarding mainly PID and \( \tau \)-daughters kinematics.
The main discriminating variable $x$ is defined as the ratio between the primary lepton momentum (i.e., the electron or muon produced in the $\Upsilon(nS)$ decay) and the CM beam energy. An unbinned maximum likelihood fit is performed on this variable to determine the signal and background yields. The PDF shapes of $x$ are different for the signal and each background class: signal events are expected to peak at $x = x_{\text{max}} \sim 0.97$, $\tau$-pair, which constitute the main background source, present a smooth distribution with an end-point at $x_{\text{max}}$, QED events peak at $x \sim 1$ since no missing energy is present, and hadrons have a shape similar to the $\tau$ pairs. The BF is calculated as $\text{BF} = N_{\text{SIG}}/(\epsilon_{\text{SIG}} \times N_{\Upsilon(nS)})$. The main systematic uncertainties on BF measurement arise from the choice of the PDF shapes, due to the limited statistics in the selected sample. No signal evidence is found in any of the four channels under study, so ULs are set, the results are reported in Tab. 3 [18].
Table 3. Results for LFV searches in \( \Upsilon \) decays, statistical error is noted first followed by systematic error, the last column shows the improvement with respect to previous measurements made by CLEO collaboration. UL for \( \Upsilon (2S) \to e^+e^-\tau^+\tau^- \) and \( \Upsilon (3S) \to e^+e^-\tau^+\tau^- \) were measured for the first time

| \( B(10^{-6}) \) | UL \( (10^{-6}) \) | Improvement |
|------------------|------------------|-------------|
| \( B(\Upsilon (2S) \to e^+e^-\tau^+\tau^-) \) | \( 0.6^{+1.5+0.5}_{-1.4-0.6} \) | \( < 3.2 \) | First |
| \( B(\Upsilon (2S) \to \mu^+\mu^-\tau^+\tau^-) \) | \( 0.2^{+1.5+1.0}_{-1.3-1.2} \) | \( < 3.3 \) | \( \times 5.5 \) |
| \( B(\Upsilon (3S) \to e^+e^-\tau^+\tau^-) \) | \( 1.8^{+1.7+0.8}_{-1.4-0.7} \) | \( < 3.2 \) | First |
| \( B(\Upsilon (3S) \to \mu^+\mu^-\tau^+\tau^-) \) | \( -0.80^{+1.3+1.4}_{-1.5-1.3} \) | \( < 3.3 \) | \( \times 3.7 \) |

5. Lepton Flavor Universality
In the SM the couplings of the gauge bosons to leptons are independent of the lepton flavor, and, aside from small mass effects, the decay width for \( \Upsilon (1S) \to \ell^+\ell^- \) should be identical for all leptons. Hence in the SM one expect the quantity:

\[
R_{\ell\ell'} \Upsilon (1S) = \frac{\Gamma_{\Upsilon (1S) \to \ell\ell'}}{\Gamma_{\Upsilon (1S) \to \ell'\ell'}}
\]

with \( \ell, \ell' = e, \mu, \tau \) and \( \ell \neq \ell' \) to be close to one, in particular the value for \( R_{\tau\mu} \Upsilon (1S) \) is predicted to be \( \sim 0.992 \) [19]. In the next-to-minimal supersymmetric extension of the SM, deviation from the SM expectation may arise due to a light CP-odd Higgs boson, \( A^0 \) [20], among other hypothetical particles, \( A^0 \) may mediate the following processes: \( \Upsilon (1S) \to \gamma A^0 \to \gamma \ell^+\ell^- \) or \( \Upsilon (1S) \to \gamma \eta_b (1S) \), with \( \eta_b (1S) \to A^0 \to \ell^+\ell^- \).

If the photon remains undetected, the lepton pair would be ascribed to the \( \Upsilon (1S) \) and the proportionality of the coupling of the Higgs to the lepton mass would lead to an apparent violation of the lepton universality, and this effect should be larger for decays to \( \tau \) pairs, and enhanced for higher mass resonances. The deviation of \( R_{\tau\mu} (\Upsilon (1S)) \) may be as large as \( \sim 4\% \), depending on the \( A^0 \) mass.

\( \text{BaBar} \) performed a measurement of \( R_{\tau\mu} (\Upsilon (1S)) \), in the decays \( \Upsilon (3S) \to \Upsilon (1S)\pi^+\pi^- \), with \( \Upsilon (1S) \to \ell\ell', \) and \( \ell = e, \mu, \). Only events with \( \tau \) decaying in one charged particle are selected. One tenth of the data is used to validate the analysis method and the signal extraction procedure, the validation sample is then discarded from the final result to avoid biases. The selection requires exactly four charged tracks, and the \( \Upsilon (1S) \to \ell\ell' \) is formed by selecting two oppositely-charged tracks, constrained to come from a common vertex, while the other two tracks are used to reconstruct the \( \Upsilon (3S) \to \Upsilon (1S)\pi^+\pi^- \) candidate. Different selection procedures are applied for \( \mu \) and \( \tau \) channel selection due to the presence of neutrinos in the latter case, which leads to larger background contributions arising from non-leptonic \( \Upsilon (1S) \) decays and \( \tau \) decays.

In the \( \Upsilon (1S) \to \mu^+\mu^- \) channel PID is used to identify muons, and the \( \Upsilon (3S) \) is reconstructed by selecting tracks compatible with being produced in the \( \Upsilon (3S) \to \Upsilon (1S)\pi^+\pi^- \) decay. For the \( \tau \) channel tighter selection criteria are applied, due to the presence of large missing energy, so only events with a visible energy in the CM frame larger than 5 GeV are selected, and further selection is applied on the di-pion momenta along with a multivariate algorithm taking as input event shape and kinematic variables. Finally in order to select \( \Upsilon (3S) \to \Upsilon (1S)\pi^+\pi^- \) the invariant mass difference between the two resonance candidates is required to be less than 2.5 GeV/\( c^2 \), and the di-pion invariant mass is required to be between 0.28 and 0.90 GeV/\( c^2 \).

The final selection efficiency is estimated from MC simulated events and are measured to be \( \varepsilon_{\mu\mu} = (44.57 \pm 0.04)\% \) and \( \varepsilon_{\tau\tau} = (16.77 \pm 0.03)\% \). An extended unbinned maximum likelihood fit, applied to the two disjoint datasets is used to extract \( R_{\tau\mu} \). The \( \mu \) data sample is fitted with
a two dimensional PDF, based on the invariant mass of the $\mu$ pair and on $M_{reco}^{\pi^+\pi^-}$, defined as the invariant mass of the system recoiling against the pion pair. The $\tau$ data sample is modeled with a one dimensional PDF of $M_{reco}^{\pi^+\pi^-}$. The data taken 30 MeV below the $\Upsilon(3S)$ resonance are used to model the background shapes. The result of the simultaneous fit is $R_{\tau\mu} = 1.006 \pm 0.013$, where the error is statistical only. Fig. 6 shows the projection of the fit for the three variables.

Figure 6. Fit projection for $\mu$ pair invariant mass (left) and $M_{reco}^{\pi^+\pi^-}$ (middle) in the $\mu$ sample, and for $M_{reco}^{\pi^+\pi^-}$ (right) in the $\tau$ sample. The dashed lines represent the background shape, while the solid line is the sum of signal and background contribution to the fit, and data are represented by the dots.

Several systematic errors cancel out in the ratio, however the residual systematics are related to the differences between data and simulation in the efficiency of event selection, PID, and the trigger efficiency. There is also a systematic uncertainty on signal and background yields due to the imperfect knowledge and the particular choice of the PDFs used in the fit. The total systematic uncertainties is estimated to be 2.2%.

Including all the systematic corrections, the ratio $R_{\tau\mu}$ is found to be [21]:

$$R_{\tau\mu} = 1.005 \pm 0.013 \pm 0.022$$

(3)

where the first error is statistic only and the second is systematic. This result is the most precise test for this ratio and is consistent with the SM expectation, excluding the hypothesis of an $A^0$ with mass lower than 9 GeV/c$^2$ at 90% confidence level.

6. Conclusion

$\textsc{Babar}$ has proven to be a very versatile detector for the search for NP in rare and exotic decays, thanks to a very large data sample recorded, and the energy range exploited, with samples taken at $\Upsilon(4-3-2S)$ resonances, leading to a large production of $b\bar{b}$ bound states, $\tau$ pairs and hadronic decays. The high luminosity achieved and the constant development of new analysis tools and techniques made it possible to greatly improve the sensitivities for such rare processes over the years, with improvements far better than the ones provided by the increase in statistics only.

Many new results have been presented in this paper, and thanks to these improved limits many bounds to NP models could be set. The great number of searches for indirect NP effects of non SM particles demonstrate how a flavor factory can be a key infrastructure for seeking new answers even in the LHC era.

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