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Abstract

Using the ARGUS detector at the e^+e^- storage ring DORIS II at DESY, we have searched for decays $b \to s\ gluon$ through full reconstruction of a whole event. Two $B\bar{B}$ decays were found with one of B meson decaying into a final state without charmed particles. We also obtained an upper limit for $Br(B^+ \to \tau^+ \nu_\tau)$ of 1.04% @ 90% CL.

1 Search for $b \to s\ gluon$ decays

The smallness of the semileptonic branching ratio in B decays and the still possible charm deficit [1] result in numerous theoretical speculations. In particular in some extensions of the Standard Model the decay of a b quark through a virtual charged Higgs boson is competitive to weak decays of b quarks. Such decays can lead to an enhancement of the branching ratios of $B \to D\tau^-\bar{\nu}_\tau$ and $b \to s\ gluon(\gamma)$, depending on which Higgs doublet acquires the larger vacuum expectation value [2, 3]. Although the experimental study of the former process excluded the explanation of the lepton and charm deficit in the charged Higgs approach, there is thus far no experimental limit on the latter process. Therefore the search for the decay $b \to s\ gluon$ is an important test of extensions of the Standard Model.

The inclusive branching ratio for $b \to s\ gluon$ transition is predicted by the Standard Model at a level of $(1-2)\%$ [4]. According to theoretical expectations, the products of the reaction $b \to s\ gluon$ materialize dominantly as multibody final states with an averaged multiplicity only slightly lower than for B decays into charmed final states [5, 6]. The composition of $b \to cW^-$ and $b \to s\ gluon$ final states is also very similar. In most cases both of them contain K^+ [1] or K^0 mesons and pions. Therefore it is difficult to discriminate $b \to s\ gluon$ from $b \to cW^-$ reactions which are expected to have two orders of magnitude larger branching ratio.

In this paper, we report a search for B mesons decaying via the $b \to s\ gluon$ transition, reconstructed in final states containing a K^+ or K^0_S and n charged pions with $1 \leq n \leq 7$. The other B meson in the event was required to be completely reconstructed either in hadronic or in semileptonic decay modes. This requirement not only significantly reduces the continuum and $\Upsilon(4S)$ combinatorial backgrounds but also allows to separate the hadronic charm and non-charm B decays. Such an approach for searching for rare B decays was successfully used in previous ARGUS analyses [7, 8] where events unambiguously interpreted as $B^0 - \bar{B}^0$ mixing and semileptonic $b \to u$ transitions were found.

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[1] References in this paper to a specific charged state are to be interpreted as also implying the charged-conjagate state

The data used for this analysis were taken on the $\Upsilon(4S)$ resonance using the ARGUS detector at the e^+e^- storage ring DORIS II. The integrated luminosity of the sample is 246 pb^{-1}, corresponding to about 209000 ± 10000 $\Upsilon(4S)$ decays. The ARGUS detector, its trigger requirements and particle identification capabilities have been described in detail elsewhere [9].

Charged particles are required to originate from the main vertex with a polar angle, θ, in the range $|\cos(\theta)| < 0.92$. Each particle is used as pion or kaon if the corresponding likelihood ratio exceeds 1%. A K^0_S candidate is defined as a $\pi^+\pi^-$ pair forming a secondary vertex and having an invariant mass within ± 30 MeV$/c^2$ of the K^0_S mass. Leptons (electrons and muons) are identified with standard criteria [?], requiring the corresponding likelihood to be greater than 70%. Photons are identified as clusters in the electromagnetic calorimeter which are not associated with a charged track and have energy larger than 50 MeV.

For the B meson reconstruction into the $K^{+(0)}n\pi^{\pm}$ final state, the standard selection criteria were applied:

(1) The energy of the B candidate, $E(K^{+(0)}n\pi^{\pm})$, has to coincide with the beam energy within two σ.

(2) The angle between the thrust axes for the $K^{+(0)}n\pi^{\pm}$ combination and the rest of the event, θ_{thrust}, has to fulfill the requirement $|\cos(\theta_{\mathrm{thrust}})| < 0.8$. This cut reduced strongly background from continuum events.

In order to further suppress background from continuum events as well as combinatorial background from the $\Upsilon(4S)$ decays, the complete reconstruction of the other B in the event was required in addition to the selection criteria (1-2). The tagging B meson was reconstructed both in hadronic and semileptonic decays modes into final states containing D^0, D^+, D^{*+} or D^{*0} mesons, namely:

$$\begin{array}{lll} B & \rightarrow & D^{(*)}\ell^-\bar{\nu} \\ & & D^{(*)}\pi^- \\ & & D^{(*)}\rho^- \ (\rho^- \rightarrow \pi^-\pi^0, \text{ with } |M_{\pi^-\pi^0} - M_{\rho^-}| < 150 \text{ MeV}/c^2) \\ & & D^{(*)}a_1^- \ (a_1^- \rightarrow \pi^-\pi^-\pi^+, \text{ with } \left|M_{\pi^-\pi^-\pi^+} - M_{a_1^-}\right| < 300 \text{ MeV}/c^2) \end{array}$$

$D^{(*)}$ mesons were reconstructed in the channels:

$$\begin{array}{lllllll} D^0 & \rightarrow & K^-\pi^+(\pi^0) & \quad & D^+ & \rightarrow & K^0_S\pi^+(\pi^0) \\ & & K^0_S\pi^+\pi^-(\pi^0) & & & & K^-\pi^+\pi^+(\pi^0) \\ & & K^-\pi^+\pi^+\pi^- & & & & \end{array}$$

$$\begin{array}{lll} D^* & \rightarrow & D\pi \\ & & D\gamma \end{array}$$

The two photons from the π^0 decay may either form two separated neutral clusters or merge into one cluster. π^0 candidates were accepted if the invariant mass of the two photons coincided with the nominal π^0 mass within 3 σ. All neutral clusters with the energy of more than 700 MeV were also considered as π^0.

All D^0, D^+, D^{*+} and D^{*0} candidates were required to be consistent with the appropriate mass hypothesis within 3 σ. All charged tracks in the event were required to be assigned to one of the B meson candidates. Since there is a non-negligible probability to have fake photons, additional photons in the event were allowed.

The momentum of leptons from the tagging B meson was required to be larger than 1.4 GeV$/c$, and the absolute value of the recoil mass squared against the $D^{(*)}\ell^-$ system calculated by the formula

$$M^2_{\mathrm{recoil}} = (E_{\mathrm{beam}} - E_{D^{(*)}} - E_{\ell^-})^2 - (\vec{p}_B - \vec{p}_{D^{(*)}} - \vec{p}_{\ell^-})^2$$

was required to be less than 1 GeV$^2/c^2$.

With hadronic tags, the sum of energies of the two B mesons (tagging and tagged) was required to lie within 2 σ from the E_{cms} energy, and the total momentum in the event to be zero within 2 σ. The total number of photons in the event was required to be less than five, including photons used in the reconstruction of the tagging B meson.

Figure 1 shows the combined B signal in the $K^{+(0)}n\pi^{\pm}$ decay channels. Since the identification of kaons and pions is often ambiguous, one combination of charged tracks can produce several entries to the mass distribution when the kaon hypothesis is assigned to different charged tracks. The masses of all such candidates would be essentially the same. Therefore, in order to avoid multiple counting, only combinations with the maximum probability, calculated from the χ^2 contributions of particle identification and fit to the beam energy, in the mass range $M_{K^{+(0)}n\pi^{\pm}} > 5.1$ GeV$/c$ were counted. We observed 7 candidates in the B mass region with practically no background. This demonstrates the power of this method for background suppression.

In order to estimate continuum contribution to the 7 completely reconstructed events observed at $\Upsilon(4S)$ energy, we have studied the data collected in the continuum below the $\Upsilon(4S)$ resonance. The continuum data have been analyzed in the same way as the $\Upsilon(4S)$ sample. No events with $M_{K^{+(0)}n\pi^{\pm}} > 5.1$ GeV$/c^2$ have been found. In order to get more confidence in the estimation of the continuum contribution the cut (1^a) was relaxed to a 40 σ_E difference between the energy of $K^{+(0)}n\pi^{\pm}$ system and the beam energy. Five events have been found in the mass interval $M_{K^{+(0)}n\pi^{\pm}} > 5.1$ GeV$/c^2$, four events with hadronic tag and one event with semileptonic tag. Assuming a uniform distribution of continuum events both in bins of σ_E and $M_{K^{+(0)}n\pi^{\pm}}$, we extrapolate the observed five events into the B signal region. Taking into account the scaling factor 2.3 for the continuum, which includes the difference in cross sections and integral luminosities for the $\Upsilon(4S)$ and continuum data, the estimate of continuum background

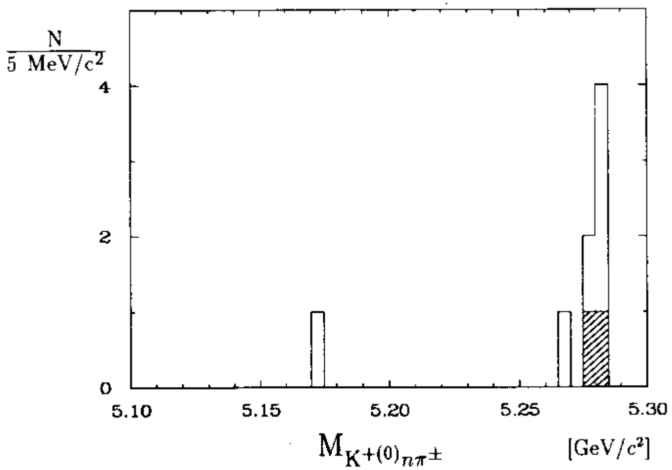

Figure 1: Invariant mass distribution for $K^{+(0)} n\pi^\pm$ combinations. The hatched histogram corresponds to $b \to s$ *gluon* candidates.

is 0.07 ± 0.03 event. Thus the probability of seven events observed in $\Upsilon(4S)$ decays to be a fluctuation of continuum background is negligible.

Seven of the eight combinations from figure 1 were obtained with the second B meson in the event being reconstructed in the semileptonic decay mode. In order to estimate the contribution from hadrons misidentified as leptons, the analysis was repeated for $K^{+(0)} n\pi^\pm$ combinations tagged by $D^{(*)}hadron^-$ combination with the same criteria as for the semileptonic tag analysis. One event in the B mass signal region was observed. Taking into account a misidentification rate of 2.2%, this results in a contribution from faked semileptonic tags of 0.02 ± 0.02 events.

The observed B candidates in figure 1 could result both from $b \to cW^-$ and non-charm transitions. Five B candidates in the signal can be interpreted as $b \to cW^-$ decays. Their specific reconstruction channels are listed in table 1. The number of found $b \to cW^-$ candidates is consistent with the number of reconstructed hadronic B meson decays in the previous paper [10] taking into account the tagging efficiency. Moreover, relying on the Monte Carlo efficiency for $b \to cW^-$ decay we conclude that the expected number of reconstructed $b \to cW^-$ decays is equal to 6, assuming a 100% branching ratio for $b \to cW^-$. This demonstrates that the efficiencies are correctly calculated.

For the remaining two events there is no possibility to find any subcombination of the charged particles assigned to these B meson candidate consistent with a D^0, D^+, D_s^+, J/ψ, ψ', η_c or χ_c hypothesis within 4 σ of the corresponding masses. The investigated subcombinations include Cabibbo suppressed D decays and D decays into final states with three kaons. The explanation of these candidates as decays of B mesons into baryons is also impossible, because the assignment of a proton mass hypothesis to any two particles from B candidate leads to increasing of its energy by more than 4 σ_E. The hatched histogram in figure 1 represents two events which failed to be reconstructed as $b \to cW^-$ decay. They are shown on figures 2 and 3 and their kinematical features are presented in tables 2 and 3.

Table 1: Decay channels of full reconstructed $b \to cW^-$ decays and tagged B mesons.

#	Tagged $B \to K^{+(0)} n\pi^\pm$	Tagging B meson decay
1	$B^+ \to D^0 5\pi^\pm$ $D^0 \to K^-\pi^+$	$B^- \to \bar{D}^{*0} e^- \bar{\nu}$ $\bar{D}^{*0} \to \bar{D}^0 \gamma$ $\bar{D}^0 \to K^+\pi^-\pi^0$
2	$B^0 \to D^-\pi^-\pi^+\pi^+$ $D^- \to K_s^0\pi^-$	$\bar{B}^0 \to D^{*+}\mu^-\bar{\nu}$ $D^{*+} \to D^+\pi^0$ $D^+ \to K^-\pi^+\pi^+$
3	$B^- \to D^0\pi^-\pi^-\pi^+$ $D^0 \to K^-\pi^+$	$B^+ \to \bar{D}^0\mu^+\nu$ $\bar{D}^0 \to K^+\pi^-\pi^0$
4	$B^+ \to \bar{D}^0\pi^-\pi^+\pi^+$ $\bar{D}^0 \to K^+\pi^-$	$B^- \to D^{*0}\mu^-\nu$ $D^{*0} \to D^0\gamma$ $D^0 \to K^-\pi^-\pi^+\pi^+$
5	$B^+ \to \psi' K^{*+}$ $\psi' \to \pi^+\pi^+\pi^-\pi^-$ $K^{*+} \to K_S^0\pi^+$	$B^- \to D^{*0} e^- \nu$ $\bar{D}^{*0} \to \bar{D}^0\pi^0$ $\bar{D}^0 \to K^+\pi^+\pi^-\pi^-$

The missing momentum vector in the first event points into the barrel region of the detector where no interactions were observed. The missing momentum and the missing energy coincides within errors. These facts lead to the conclusion that the missing particle is a neutrino.

As was discussed above, the continuum contribution is small. It is suppressed further for the two $b \to s$ *gluon* candidates by the requirement of not observing charm in the final state. Only two out of five continuum events satisfied this requirement when the energy cut was relaxed down to 40 σ_E. Thus the continuum background to the the two candidates of $b \to s$ *gluon* decays is estimated to be 0.03 ± 0.02 and the probability of continuum fluctuation is equal to $8 \cdot 10^{-4}$.

A B candidate can be formed in principle by combining tracks belonging to different

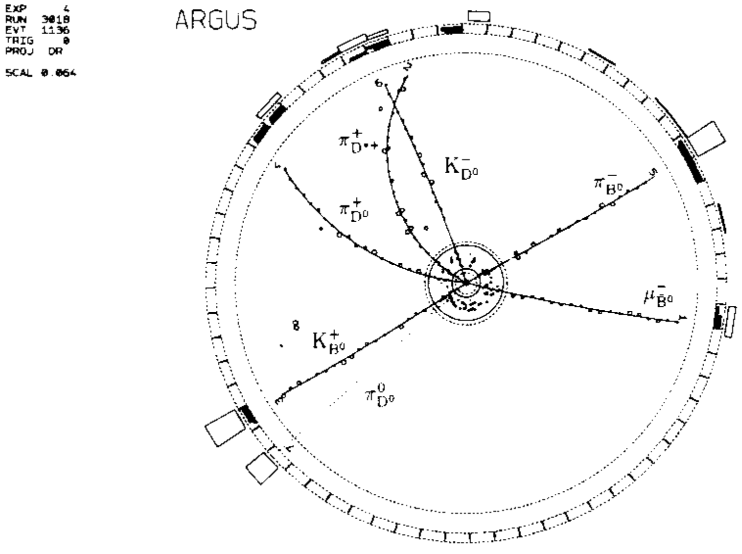

Figure 2: The completely reconstructed event with a $B^0 \to K^+\pi^-$ candidate.

B mesons in the $\Upsilon(4S)$ decay. Some of these wrong combinations could lead to fake B candidates without charm. Such situation is rather unprobable because all other tracks in the event should form the other B candidate decaying into final state with D meson. This probability was evaluated by Monte Carlo simulations of $b \to cW^-$ decays with 10 times more statistics. No B candidate decaying into $K^{+(0)}n\pi^\pm$ without charm was observed in the Monte Carlo sample. Moreover, relying on the specific kinematic of these two observed events, we are able to exclude their interpretation as $b \to cW^-$ decays. The reconstructed charged tracks in both events cannot be recombined in a way that they form two B candidates decaying into charm states even if some particles are not reconstructed in the events. Technically this was proven by adding neutral and possibly missing particles to the events by hand. The vectors of momenta of all added particles were varied in the whole kinematically allowed interval. Note that for both events the phase space for variation is rather small. In the first event this is due to high momentum of both K^+ and π^- from the B candidate. For the second event practically all energy is distributed among charged particles and only a small window (0.4 GeV) remains for neutral and possibly unreconstructed particles. For all steps of variation

Table 2: Kinematical quantities of the event with $B^0 \to K^+\pi^-$ candidate.

Decay	P (GeV/c)	E (GeV)	Mass (GeV/c^2)	$\cos\theta$
$B^0 \to K^+\pi^-$	0.308 ± 0.014	5.308 ± 0.057	5.280 ± 0.004	0.58
K^+	2.664 ± 0.035			-0.40
π^-	2.595 ± 0.030			0.34
$\bar{B}^0 \to D^{*+}\mu^-(\bar{\nu})$				
$D^{*+} \to D^0\pi^+$	1.818 ± 0.024	2.711 ± 0.017	2.011 ± 0.001	0.67
π^+	0.146 ± 0.003			0.44
$D^0 \to K^-\pi^+\pi^0$	1.799 ± 0.058	2.719 ± 0.095	2.039 ± 0.079	0.70
K^-	1.414 ± 0.015			0.62
π^+	0.203 ± 0.002			-0.08
π^0 (*one cluster*)	0.990 ± 0.093			0.40
μ^-	2.017 ± 0.023			-0.58
$\bar{\nu}$	0.561 ± 0.050	0.547 ± 0.028		-0.26

of missing particles vectors the interpretation of the two events with both B mesons decaying into charmed states was excluded within 4 standard deviations. Thus, the expected combinatorial background from $\Upsilon(4S)$ decays is less than 0.01 events in the signal region, and the probability of fluctuation of this background to 2 events is less than 10^{-4}.

In fact, both non-charm candidates can also be interpreted as a result of $b \to u$ transitions, although this interpretation has smaller probability. The relative probability for $b \to u$ interpretation versus $b \to s$ *gluon* was calculated taking into account the identification of the particles and the difference between the energy of B candidate and energy of the beam. The first event could be completely reconstructed assuming the decay $B^0 \to \pi^+\pi^-$, with a relative probability 8% with respect to the $K^+\pi^-$ hypothesis. The second event can be interpreted as $B^- \to 5\pi^\pm$ with practically the same probability as for $K^-4\pi^\pm$. Note also that $b \to u$ decays are expected on the level of 1%, while their probability to be reconstructed in the studied final state is 4 time smaller than for $b \to s$ *gluon* as shown by Monte Carlo simulations.

The tagging efficiency was found to be 0.9% using Monte Carlo simulated $\Upsilon(4S)$ decays. The main contribution is due to semileptonic tags (0.7%). This calculation was checked to be consistent with the data where the clean decay channel $B^0 \to D^{*-}\ell^+\nu$ was reconstructed in the same way. Two such events were found, while 2.3 events were expected. The suppression factor for the continuum contribution was found to

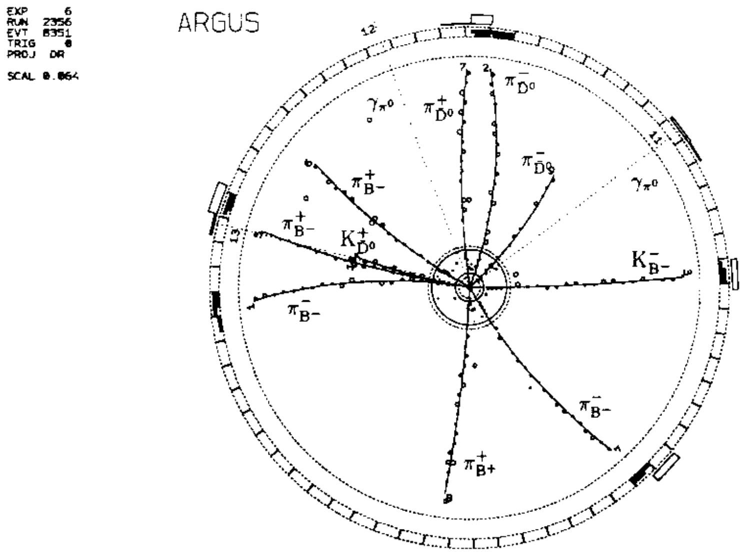

Figure 3: The completely reconstructed event with a B$^-$ → K$^-4\pi^\pm$ candidate.

be $3 \cdot 10^5$, while the combinatorial $\Upsilon(4S)$ background was suppressed by 10^{-5}. These evaluations are based on the continuum analysis described above and on Monte Carlo simulations of $\Upsilon(4S)$ decays.

The reconstruction efficiency of B decays into $K^{+(0)}n\pi^\pm$ via the $b \rightarrow s$ *gluon* reaction was estimated by Monte Carlo simulations. The $b \rightarrow s$ *gluon* reaction has been modeled using the approach of [5]. B mesons were generated to decay into two jets: s+spectator and $q\bar{q}$ with Q^2 for $q\bar{q}$ as predicted by the Standard Model [5]. The hadronization of both jets was performed using the Lund string fragmentation model [11]. According to the model used, the final states, produced in $b \rightarrow s$ *gluon* decays, do not contain neutral particles in 12% of the events. The average charged pion multiplicity is 4. The probability to find no charm in the final state of $b \rightarrow s$ *gluon* decay was estimated to be 60%. Taking into account these factors, the overall efficiency of $b \rightarrow s$ *gluon* decay reconstruction is found to be 2%. The inclusive branching ratio $BR(b \rightarrow s\ gluon)$ was obtained to be equal to 2.6 %, which is consistent with the prediction of the Standard Model. For an estimation of the systematic errors in the efficiency the average pion multiplicity in $b \rightarrow s$ *gluon* decays was varied within ±1.

Table 3: Kinematical quantities of the event with B$^-$ → K$^-4\pi^\pm$ candidate.

Decay	P (GeV/c)	E (GeV)	Mass (GeV/c^2)	$\cos\theta$
$\Upsilon(4S) \rightarrow B^-B^+$	0.029 ± 0.031	10.514 ± 0.067		
$B^- \rightarrow K^-\pi^-\pi^-\pi^+\pi^+$	0.314 ± 0.032	5.253 ± 0.046	5.280 ± 0.004	-0.68
K^-	2.182 ± 0.032			-0.65
π^-	0.605 ± 0.006			-0.75
π^-	0.564 ± 0.005			-0.66
π^+	0.971 ± 0.013			0.50
π^+	0.821 ± 0.012			0.80
$B^+ \rightarrow \bar{D}^{*0}\pi^+$	0.310 ± 0.018	5.261 ± 0.045	5.280 ± 0.004	0.62
π^+	2.185 ± 0.035			-0.78
$\bar{D}^{*0} \rightarrow \bar{D}^0\pi^0$	2.325 ± 0.018	3.071 ± 0.013	2.007 ± 0.002	0.82
$\pi^0 \rightarrow \gamma\gamma$	0.102 ± 0.020	0.173 ± 0.030	0.140 ± 0.025	0.78
γ	0.104 ± 0.024	0.104 ± 0.024		0.76
γ	0.111 ± 0.034	0.111 ± 0.034		0.68
$\bar{D}^0 \rightarrow K^+\pi^-\pi^-\pi^+$	2.218 ± 0.028	2.893 ± 0.023	1.859 ± 0.011	0.83
K^+	0.941 ± 0.022			0.91
π^-	0.587 ± 0.010			-0.88
π^-	0.497 ± 0.005			-0.72
π^+	0.697 ± 0.006			-0.14

As a result the efficiency changed by a factor of two. We are also able to put an upper limit for the $b \rightarrow s$ *gluon* decay of 8% at the $90\%CL$.

It should be mentioned that the efficiency for $b \rightarrow s$ *gluon* decays to be detected in a final state with only charged particles is about 20 times larger than that of for $b \rightarrow cW^-$ transition. This fact can be explained by the following reasons. Hadronization of s quark leads mainly to K, K* or K** mesons, while the product of c quark hadronization are D, D* or D** mesons. The latter process results in the studied final state with about 10 times smaller probability than the former one. Another factor of about two of suppression of $b \rightarrow cW^-$ is due to semileptonic and baryonic B decays and B decays into $D_s^{(*)+}$ because they cannot result in the studied final states. So the similar numbers of reconstructed $b \rightarrow cW^-$ and $b \rightarrow s$ *gluon* decays are not surprising.

2 Search for the decay $B^+ \to \tau^+\nu_\tau$

The decay $B^+ \to \tau^+\nu_\tau$ in the Standard Model can only proceed via a CKM-suppressed annihilation diagram and is predicted to be of the order of 10^{-4}. Additional contributions to this decay can arise in some extensions of the Standard Model, for example in the models with extra Higgs doublets [2, 4]. For the decay $B^+ \to \tau^+\nu_\tau$ CLEO recently obtained the upper limit of $Br(B^+ \to \tau^+\nu_\tau) < 0.22\%$ at the 90% CL [12]. In this chapter we present our search for this decay.

The decay $B^+ \to \tau^+\nu_\tau$ followed by $\tau^+ \to \ell^+\bar{\nu}_\tau\nu_\ell$ has a signature with only one lepton from the τ^+ in the final state and provides a high reconstruction efficiency. The leptons from the τ^+ decays are allowed to have any momentum where lepton identification is possible ($P > 0.4$ GeV/c for electrons and $P > 0.9$ GeV/c for muons). The reconstruction efficiency for the lepton from τ^+ decay was found to be 44% from Monte Carlo simulation.

The reconstruction of the tagging B^- was performed using the criteria described in the previous chapter for both semileptonic and hadronic decay modes. In contrast to the previous analysis the tagged $B^+ \to \tau^+\nu_\tau$ meson in the event is not completely reconstructed. Background from B decays with the only lepton and several photons detected in the event can arise. In order to suppress this background we required in addition to the previous reconstruction criteria that all photons in the event with energy more than 100 MeV be assigned to the tagging B^- meson candidate. This cut has a high efficiency (85%) for the decay under study even in presence of possible fake photons in the event which usually have momentum less than 100 MeV. In the case of semileptonic tags the B^+ momentum in the recoil mass squared calculation is unknown. If we ignore this small momentum the resolution in M^2_{recoil} against the system $D^{(*)0}\ell^-$ gets worse. Thus, in order to have high efficiency M^2_{recoil} was required to be larger than -1 GeV$^2/c^4$. The total tagging efficiency was found to be $(0.60 \pm 0.07)\%$ for semileptonic tagging and $(0.16 \pm 0.01)\%$ for hadronic tagging.

No events satisfying all requirements listed above were found. Taking into account the systematic errors, the upper limit for the branching ratio was calculated to be $Br(B^+ \to \tau^+\nu_\tau) < 1.04\%$ at the 90% CL.

In summary, we observed two completely reconstructed events with one of B meson in the event decaying into a non-charm hadronic state. The continuum and $\Upsilon(4S)$ combinatorial backgrounds were found to be small. Both events can be interpreted either as $b \to s$ *gluon* or $b \to u$ transitions, although the former interpretation is more preferable. Assuming that the observed events are result of the $b \to s$ *gluon* transition and using the simple model describing these decays, the evaluated branching ratio of $b \to s$ *gluon* decays is about 3% which is in agreement with the Standard Model expectation. An upper limit for $Br(B^+ \to \tau^+\nu_\tau)$ was set of 1.04% at the 90% CL.

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