DEUTSCHES ELEKTRONEN-SYNCHROTRON DESY

DESY 89-163
December 1989

Search for Rare Semileptonic B-Meson Decays

The ARGUS Collaboration

ISSN 0418-9833

NOTKESTRASSE 85 · 2 HAMBURG 52

DESY 89-163
December 1989

ISSN 0418-9833

Search for Rare Semileptonic B-Meson Decays

The ARGUS Collaboration

H. Albrecht, R. Gläser, G. Harder, A. Krüger, A. Nippe, T. Oest, M. Reidenbach, M. Schäfer, W. Schmidt-Parzefall, H. Schröder, H. D. Schulz, F. Sefkow, R. Wurth
DESY, Hamburg, Germany

R. D. Appuhn, A. Drescher, C. Hast, G. Herrera, H. Kolanoski, A. Lange, A. Lindner, R. Mankel, H. Scheck, G. Schweda, B. Spaan, A. Walther, D. Wegener
Institut für Physik[1], Universität Dortmund, Germany

M. Paulini, K. Reim, U. Volland, H. Wegener
Physikalisches Institut[2], Universität Erlangen-Nürnberg, Germany

W. Funk, J. Stiewe, S. Werner
Institut für Hochenergiephysik[3], Universität Heidelberg, Germany

S. Ball, J. C. Gabriel, C. Geyer, A. Hölscher, W. Hofmann, B. Holzer, S. Khan, J. Spengler
Max-Planck-Institut für Kernphysik, Heidelberg, Germany

C. E. K. Charlesworth[4], K. W. Edwards[5], W. R. Frisken[6], H. Kapitza[5], P. Krieger[4], R. Kutschke[4], D. B. MacFarlane[7], K. W. McLean[7], R. S. Orr[4], J. A. Parsons[4], P. M. Patel[7], J. D. Prentice[4], S. C. Seidel[4], J. D. Swain[4], G. Tsipolitis[7], T.-S. Yoon[4]
Institute of Particle Physics[8], Canada

R. Davis
University of Kansas[9], Lawrence, KS, USA

T. Ruf, S. Schael, K. R. Schubert, K. Strahl, R. Waldi, S. Weseler
Institut für Experimentelle Kernphysik[10], Universität Karlsruhe, Germany

B. Boštjančič, G. Kernel, P. Križan[11], E. Križnič, M. Pleško
Institut J. Stefan and Oddelek za fiziko[12], Univerza v Ljubljani, Ljubljana, Yugoslavia

H. I. Cronström, L. Jönsson, A. W. Nilsson
Institute of Physics[13], University of Lund, Sweden

A. Babaev, M. Danilov, B. Fominykh, A. Golutvin, I. Gorelov, V. Lubimov, A. Rostovtsev, A. Semenov, S. Semenov, V. Shevchenko, V. Soloshenko, V. Tchistilin, I. Tichomirov, Yu. Zaitsev
Institute of Theoretical and Experimental Physics, Moscow, USSR

R. Childers, C. W. Darden
University of South Carolina[14], Columbia, SC, USA

1 Supported by the German Bundesministerium für Forschung und Technologie, under contract number 054DO51P.
2 Supported by the German Bundesministerium für Forschung und Technologie, under contract number 054ER11P(5).
3 Supported by the German Bundesministerium für Forschung und Technologie, under contract number 054HD24P.
4 University of Toronto, Toronto, Ontario, Canada.
5 Carleton University, Ottawa, Ontario, Canada.
6 York University, Downsview, Ontario, Canada.
7 McGill University, Montreal, Quebec, Canada.
8 Supported by the Natural Sciences and Engineering Research Council, Canada.
9 Supported by the U.S. National Science Foundation.
10 Supported by the German Bundesministerium für Forschung und Technologie, under contract number 054KA17P.
11 Supported by Alexander v. Humboldt Stiftung, Bonn.
12 Supported by Raziskovalna skupnost Slovenije and the Internationales Büro KfA, Jülich.
13 Supported by the Swedish Research Council.
14 Supported by the U.S. Department of Energy, under contract DE-AS09-80ER10690.

Abstract

Using the ARGUS detector at the e^+e^--storage ring DORIS II at DESY, we have searched for rare semileptonic decays of B mesons. No signals are found, leading to upper limits $BR(B^- \to \rho^0 l^- \overline{\nu}) < 1.1 \cdot 10^{-3}$ and $BR(\overline{B}^0 \to \pi^+ l^- \overline{\nu}) < 0.9 \cdot 10^{-3}$ at the 90% confidence level. The comparison with theoretical predictions of the corresponding decay widths results in upper limits on the Cabibbo-Kobayashi-Maskawa matrix element $|V_{ub}|$.

Our present knowledge of particle interactions can be described by the minimal standard model with 18 free parameters, which have to be determined by experiments. One of these parameters is the Cabibbo-Kobayashi-Maskawa (CKM) matrix element $|V_{ub}|$ which describes the weak coupling of a b-quark to a u-quark. A measurement of its value would test the unitarity of the CKM matrix and could check if CP-violation in neutral kaon decays can be explained in the framework of the standard model.

Semileptonic decays play a particular role for the determination of $|V_{ub}|$. Upper limits have been obtained previously [1] from the inclusive lepton momentum spectrum in e^+e^--annihilations at the center-of-mass energy of the $\Upsilon(4S)$ resonance. This method relies on good lepton identification and a precise knowledge of the continuum background. In addition, the expected momentum spectra for $b \to c$ and $b \to u$ transitions are model dependent. Exclusive semileptonic decays such as $B \to \pi\, l\nu$ and $B \to \rho\, l\nu$ have different systematic uncertainties and therefore offer an alternative method for the determination of $|V_{ub}|$.

The analysis presented here is based on a data sample corresponding to an integrated luminosity of 174 events/pb at the $\Upsilon(4S)$ energy and 47 events/pb at continuum energies below the $B\overline{B}$ threshold. The total number of produced B mesons is 291000 ± 23000. Details about the ARGUS detector, its trigger conditions and the particle identification procedures can be found elsewhere [2].

Hadronic events are selected by requiring at least three reconstructed charged particles originating from the interaction region with transverse momentum larger than $50\, MeV/c$ and $|\cos\vartheta| < 0.9$, where ϑ is the angle between the beam axis and the momentum of the particle. We further require an identified electron or muon with a momentum between $1.5\, GeV/c$ and $2.7\, GeV/c$. A cut on the combined multiplicity of charged and neutral particles is used to reduce contributions from continuum events; we require

$$N_{ch} + \frac{1}{2} N_\gamma(0.1\, GeV < E < 1.0\, GeV) + N_\gamma(E > 1.0\, GeV) \geq 5.5 \qquad (1)$$

The semileptonic decays $B^- \to \rho^0\, l^- \overline{\nu}$ and $\overline{B}^0 \to \pi^+\, l^- \overline{\nu}$ can be identified by the mass of the missing neutrino:

$$\tilde{M}^2 = (E_B - E_{\rho,\pi} - E_l)^2 - (\vec{p}_B - \vec{p}_{\rho,\pi} - \vec{p}_l)^2 \quad (2)$$

Because of the low Q-value of the decay $\Upsilon(4S) \to B\overline{B}$ one can neglect the unknown B meson momentum, $\vec{p}_B \approx 0$. The B meson energy is given by the beam energy. This method was first used successfully to reconstruct the semileptonic decay $\overline{B}^0 \to D^{*+}\, l^- \overline{\nu}$ [3]. The approximation of neglecting the B meson momentum leads to a resolution of the missing mass squared of about $0.7\, GeV^2/c^4$.

All selected events are investigated for $\rho^0 l^-$ and $\pi^+ l^-$ pairs[1]. The ρ meson is reconstructed by its decay into a $\pi^+\pi^-$ pair, using all $\pi^+\pi^-$ combinations with an invariant mass between $0.62\, GeV/c^2$ and $0.92\, GeV/c^2$. For each $\rho^0\; l^-$ and $\pi^+\; l^-$ pair, the angle α between the lepton momentum and the thrust axis of the rest of the event is calculated, where rest of the event includes all particles which are not contributing to the semileptonic decay searched for. For continuum events the thrust axis and the lepton momentum are almost parallel due to the twojet structure of the event as shown in fig. 1. For Υ(4S) events, the two B mesons decay independently and there is no correlation expected between these two vectors. Consequently, a cut on $|\cos\alpha| < 0.7$ is used to suppress the continuum background. Because of kinematical limits, no momenta greater than $2.8\, GeV/c$ can occur in B mesons decays. Therefore, the maximum momentum of all combinations of any number of particles in the rest of the event is calculated. Fig. 2 shows the distributions obtained for continuum events and direct Υ(4S) decays compared to the distribution expected for the decay of a single B meson. For further analysis only events with $p_{max} < 2.5\, GeV/c$ are accepted. In order to suppress combinatoric background from Υ(4S) events, a cut on the opening angle β between the lepton and the ρ^0 or π^- candidate is used (fig. 3); we require $\cos\beta < -0.5$.

The resulting missing mass distributions with these cuts for $\rho\, l$ and $\pi\, l$ pairs are shown in figure 4 and 5. No signal at $M^2 = 0$ is observed. For a determination of the upper limits of signal events a fit to the missing mass distribution with the shape of an expected signal and a polynomial of second order for the background is applied. In addition, the background function is constrained to fit the distribution of the wrong charge combinations ($\pi^\pm\pi^\pm\, l^-$, $\pi^-\, l^-$) which describes the background very well (fig. 4 and 5). Here each entry is weighted with the appropriate ratio of right charge combinations to wrong charge combinations depending on the charged multiplicity of the event [4].

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

From the fit procedure one obtains the likelihood as a function of signal events. The value where the integrated likelihood function has reached 90% of the total integral defines the upper limit on the number of detected decays. We find $N(B^- \to \rho^0\, e^-\overline{\nu},\, \rho^0\, \mu^-\overline{\nu}) < 47$ and $N(\overline{B}^0 \to \pi^+\, e^-\overline{\nu},\, \pi^+\, \mu^-\overline{\nu}) < 40$.

The efficiency to reconstruct the above decays is calculated with a detailed Monte-Carlo simulation of the ARGUS detector. We assume equal numbers of B^+B^- and $B^0\overline{B}^0$ pairs. The error on the number of produced B mesons and the uncertainty of the acceptance estimation is taken into account. The efficiencies together with the upper limits on the branching ratios are given in table 1.

To calculate the upper limits on the matrix element $|V_{ub}|$ we use absolute predictions of several models [5,6,7,8], listed in table 1, together with the mean B lifetime of $(1.18 \pm 0.14) \cdot 10^{-12} s$ [9]. The combined results of the $B^- \to \rho^0\, l^-\overline{\nu}$ and $\overline{B}^0 \to \pi^+\, l^-\overline{\nu}$ decays are given in table 3. The best limits are derived from the models of Körner and Schuler [7] and Wirbel, Stech and Bauer [6], both of which yield approximately $|V_{ub}| < 0.0071$ at the 90% confidence level; whereas the model of Grinstein, Isgur, Scora and Wise [5] yields the most conservative upper limit of $|V_{ub}| < 0.0135$.

In conclusion, we have obtained upper limits on the CKM matrix element $|V_{ub}|$ which are competitive with the results of the inclusive method. The limits are strongly model dependent. Future experiments with improved detector resolution and considerably increased data samples may be able to distinguish between the various theoretical models by investigating the phase space distributions of reconstructed $B^- \to \rho^0\, l^-\overline{\nu}$ and $\overline{B}^0 \to \pi^+\, l^-\overline{\nu}$ decays.

It is a pleasure to thank U. Djuanda, E. Konrad, E. Michel and W. Reinsch for their competent technical help in running the experiment and processing the data. We thank Dr. H. Nesemann, B. Sarau, and the DORIS group for the excellent operation of the storage ring. The visiting groups wish to thank the DESY directorate for the support and kind hospitality extended to them.

References

[1] C. Klopfenstein et al. (CUSB), Phys. Lett. **130B** (1983) 444;
S. Behrends et al. (CLEO), Phys. Rev. Lett. **59** (1987) 407;
K. Wachs et al. (Crystal Ball), Z. Phys. **C42** (1989) 33;
J. C. Gabriel (ARGUS), Ph.D.Thesis, Heidelberg, IHEP–HD/89-01 (1989).

[2] H. Albrecht et al. (ARGUS), Nucl. Instr. and Meth. **A275** (1989) 1.

[3] H. Albrecht et al. (ARGUS), Phys. Lett. **197B** (1987) 452.

[4] T. Ruf (ARGUS), Ph.D.Thesis, Karlsruhe, IEKP–KA/89-5 (1989).

[5] N. Isgur, D. Scora, B. Grinstein and M. B. Wise, Phys.Rev. **D39** (1989) 799.

[6] M. Wirbel, B. Stech and M. Bauer, Z. Phys. **C29** (1985) 637.

[7] J. G. Körner and G. A. Schuler, Z. Phys. **C38** (1988) 511.

[8] C. A. Dominguez and N. Paver, DESY 88-063.

[9] K. R. Schubert, ICTP Series in Theoretical Physics 5 (1988) 523.

	GISW [5]	WSB [6]	KS [7]
acceptance: $\frac{1}{2}(\eta_e + \eta_\mu)$	18%	14.5%	16.7%
$BR(B^- \to \rho^0 l^- \overline{\nu})$	$< 0.92 \cdot 10^{-3}$	$< 1.14 \cdot 10^{-3}$	$< 0.99 \cdot 10^{-3}$
acceptance: $\frac{1}{2}(\eta_e + \eta_\mu)$	15.3%	20.7%	20.6%
$BR(\overline{B}^0 \to \pi^+ l^- \overline{\nu})$	$< 0.94 \cdot 10^{-3}$	$< 0.70 \cdot 10^{-3}$	$< 0.70 \cdot 10^{-3}$

Table 1: Efficiencies and upper limits at 90% CL on the branching ratios of $B^- \to \rho^0 l^- \overline{\nu}$ and $\overline{B}^0 \to \pi^+ l^- \overline{\nu}$ for different models

	GISW [5]	WSB [6]	KS [7]	DP [8]
$\Gamma(B^- \to \rho^0 l^- \overline{\nu})$	4.2	13.1	16.5	
$\Gamma(\overline{B}^0 \to \pi^+ l^- \overline{\nu})$	2.1	7.4	7.3	14.5

Table 2: Theoretical predictions of the semileptonic decay widths in units of $|V_{ub}|^2 \cdot 10^{12} s^{-1}$

	GISW [5]	WSB [6]	KS [7]	DP [8]
$\lvert V_{ub} \rvert$	$< 13.5 \cdot 10^{-3}$	$< 7.1 \cdot 10^{-3}$	$< 6.7 \cdot 10^{-3}$	$< 7.6 \cdot 10^{-3}$

Table 3: Upper limits on the CKM-matrix element $|V_{ub}|$ at 90% CL from the combination of $B^- \to \rho^0 l^- \overline{\nu}$ and $\overline{B}^0 \to \pi^+ l^- \overline{\nu}$ decays

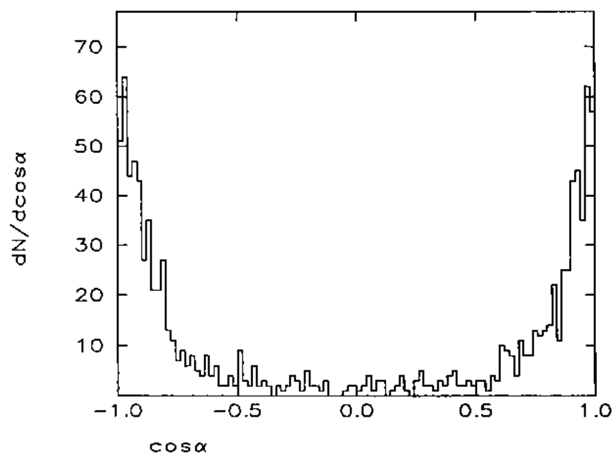

Figure 1: The angle between the lepton momentum and the thrust axis of the rest of the event in continuum events.

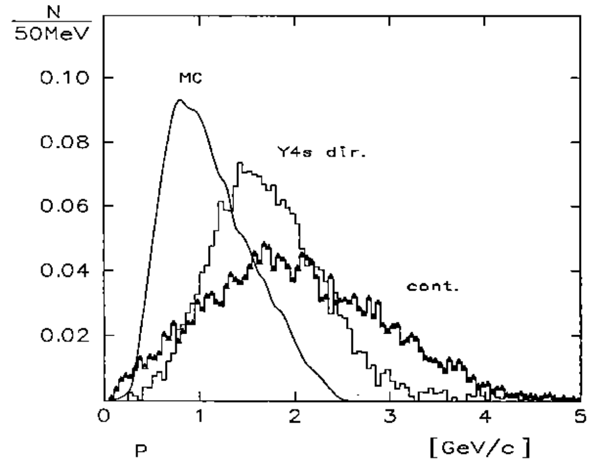

Figure 2: Maximum momentum of charged particles in the rest of the event for direct $\Upsilon(4S)$ decays and continuum events compared to a Monte Carlo simulation for a single B decay. Because of using tracks of different B mesons the maximum momentum in direct $\Upsilon(4S)$ events could be higher than for single B meson decays.

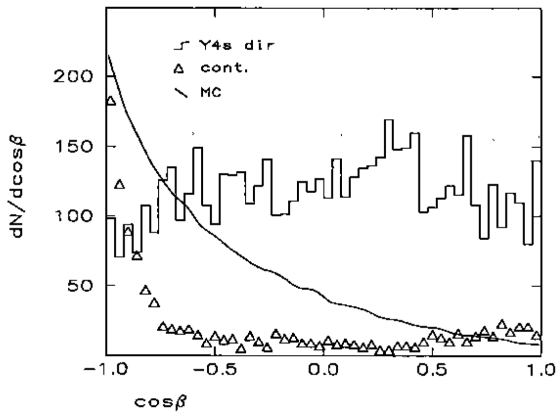

Figure 3: Opening angle between lepton and ρ^0 candidates in $\Upsilon(4S)$ and continuum events compared to the expected distribution in the WSB [6] model.

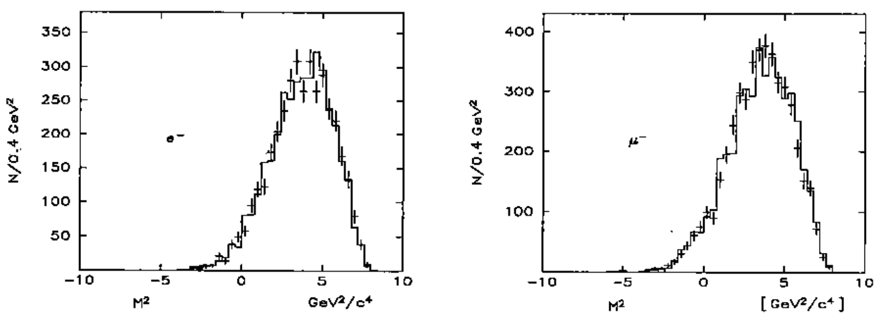

Figure 4: Missing-mass distribution for $\rho^0 e^-$ and $\rho^0 \mu^-$ pairs (crosses) together with the distribution of wrong charge combinations (histogram).

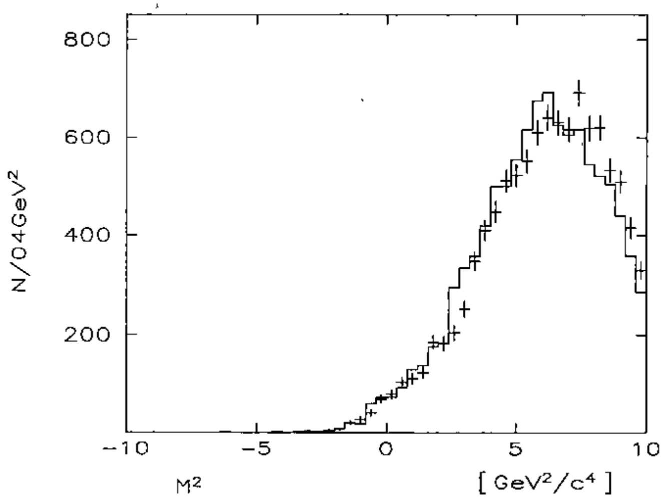

Figure 5: Missing-mass distribution for $\pi^+ l^-$ pairs (crosses) together with the distribution of wrong charge combinations (histogram).