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UPPER LIMITS ON $D^{\pm}$ AND $B^{\pm}$ DECAYS TO TWO LEPTONS PLUS $\pi^{\pm}$ OR $K^{\pm\star}$

A. J. Weir,[1] S. R. Klein,[10,c] G. Abrams,[8] C. E. Adolphsen,[2] C. Akerlof,[9] J. P. Alexander,[10,i] M. Alvarez,[3,a] D. Amidei,[8,g] A. R. Baden,[8,n] J. Ballam,[10] B. C. Barish,[1] T. Barklow,[10] B. A. Barnett,[7] J. Bartelt,[10] D. Blockus,[6] G. Bonvicini,[9] A. Boyarski,[10] J. Boyer,[8] B. Brabson,[6] A. Breakstone,[5] J. M. Brom,[6,j] F. Bulos,[10] P. R. Burchat,[2] D. L. Burke,[10] F. Butler,[8,t] F. Calvino,[3,e] R. J. Cence,[5] J. Chapman,[9] D. Cords,[10] D. P. Coupal,[10] H. C. DeStaebler,[10] D. E. Dorfan,[2] J. M. Dorfan,[10] P. S. Drell,[8,i] G. J. Feldman,[10] E. Fernandez,[3,a] R. C. Field,[10] W. T. Ford,[3] C. Fordham,[10] R. Frey,[9] D. Fujino,[10] K. K. Gan,[10] G. Gidal,[8] L. Gladney,[10,u] T. Glanzman,[10] M. S. Gold,[8] G. Goldhaber,[8] A. Green,[10,s] P. Grosse-Wiesmann,[10] J. Haggerty,[8,b] G. Hanson,[10] R. Harr,[8] F. A. Harris,[5] C. M. Hawkes,[1] K. Hayes,[10] D. Herrup,[8,l] C. A. Heusch,[2] T. Himel,[10] R. J. Hollebeek,[10,u] D. Hutchinson,[10] J. Hylen,[7] W. R. Innes,[10] M. Jaffre,[8,p] J. A. Jaros,[10] I. Juricic,[8,h] J. A. Kadyk,[8] D. Karlen,[10,d] J. Kent,[2] W. Koska,[9] W. Kozanecki,[10] A. J. Lankford,[10] R. R. Larsen,[10] B. W. LeClaire,[10,z] M. E. Levi,[8] A. M. Litke,[2] N. S. Lockyer,[10,u] V. Lüth,[10] J. A. J. Matthews,[7] D. I. Meyer,[9] B. D. Milliken,[1] K. C. Moffeit,[10] L. Müller,[10,q] J. Nash,[10] M. E. Nelson,[1] D. Nitz,[9] H. Ogren,[6] R. A. Ong,[10,g] K. F. O'Shaughnessy,[10] S. I. Parker,[5] C. Peck,[1] A. Petersen,[10,w] M. Petradza,[9] F. C. Porter,[1] P. Rankin,[3] B. Richter,[10] K. Riles,[10] P. C. Rowson,[8,h] D. R. Rust,[6] H. F. W. Sadrozinski,[2] T. Schaad,[4,m] T. L. Schalk,[2] H. Schellman,[8,l] W. B. Schmidke,[8] A. S. Schwarz,[2,r] A. Seiden,[2] P. D. Sheldon,[8,o] J. G. Smith,[3] A. Snyder,[6] E. Soderstrom,[1] D. P. Stoker,[7] R. Stroynowski,[1] R. Thun,[9] G. H. Trilling,[8] R. Tschirhart,[9,v] R. Van Kooten,[10] H. Veltman,[9,y] P. Voruganti,[10] S. R. Wagner,[3] P. Weber,[3] A. J. Weinstein,[1] S. Weisz,[2,f] S. L. White,[3,x] E. Wicklund,[1] D. R. Wood,[8,f] D. Y. Wu,[1] and J. M. Yelton[10,k]

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[1] *California Institute of Technology, Pasadena, CA 91125*
[2] *University of California, Santa Cruz, CA 95064*
[3] *University of Colorado, Boulder, CO 80309*
[4] *Harvard University, Cambridge, MA 02138*
[5] *University of Hawaii, Honolulu, HI 96822*
[6] *Indiana University, Bloomington, IN 47405*
[7] *Johns Hopkins University, Baltimore, MF 21218*
[8] *Lawrence Berkeley Laboratory and Department of Physics, University of California, Berkeley, CA 94720*
[9] *University of Michigan, Ann Arbor, MI 48109*
[10] *Stanford Linear Accelerator Center, Stanford University, Stanford, CA 94309*

Present address:
(a) Universidad Autónoma de Barcelona, Bellaterra, Spain
(b) Brookhaven National Laboratory, Upton, NY 11973
(c) Boston University, Boston, MA 02215
(d) Carleton University, Ottawa, Ontario, Canada, K1S 5B6
(e) Universitat Politecnica de Catalunya, ETSEIB–DEN Barcelona, Spain
(f) CERN, CH–1211, Genève 23, Switzerland
(g) University of Chicago, Chicago, IL 60637
(h) Columbia University, New York, NY 10027
(i) Cornell University, Ithaca, NY 14853
(j) Centre de Recherches Nucleaires, F–67037 Strasbourg, France
(k) University of Florida, Gainsville, FL 32611
(l) Fermilab, Batavia, IL 60510
(m) Université de Genève, CH–1211, Genève 4, Switzerland
(n) Harvard University, Cambridge, MA 02138
(o) University of Illinois, Urbana, IL 61801
(p) Laboratoire de l'Accèlérateur Linèaire, F–91405 Orsay, France
(q) Lab. für Hochenergie Physik Bern, CH–3012 Bern, Switzerland
(r) Max-Planck Institut, München, F. R. Germany
(s) O'Conner and Associates, Chicago, IL 60604
(t) University of Oklahoma, Norman, OK 73019
(u) University of Pennsylvania, Philadelphia, PA 19104
(v) Princeton University, Princeton, NJ 08544
(w) SCS, Hamburg, F. R. Germany
(x) University of Tennessee, Knoxville, TN 37996
(y) University of California, Berkeley, CA 94720
(z) University of Wisconsin, Madison, WI 53706

ABSTRACT

Data taken by the Mark II detector at the PEP storage ring was used to search for exclusive decays of $D^{\pm}$ and $B^{\pm}$ mesons into two charged leptons plus a charged pion or kaon. All possible charge and lepton combinations consistent with charge conservation were considered and no evidence for any signals was found. We obtain upper limits for the various branching ratios ranging from $2.5 \cdot 10^{-3}$ to $9.2 \cdot 10^{-3}$, at a 90% confidence level. Some of these limits can be used to constrain leptoquark masses in various models.

I. INTRODUCTION

Many extensions to the standard model allow for the existence of leptoquarks, particles which can mediate the decay of a quark into a lepton or vice versa.[1] We have previously published results[2] of a search for these leptoquarks as mediators of the decay $D^0 \rightarrow e\mu$. However, this reaction is helicity suppressed[3] by a factor of approximately $(m_\mu/m_D)^2$. For this reason, reactions such as $D^{\pm} \rightarrow e\mu\pi$ are more likely to yield evidence of leptoquarks. More generally, since reactions of this type lie outside the Standard Model they would signal interesting new physics and are therefore worth searching for, independent of the leptoquark hypothesis.

In addition to the potentially leptoquark mediated decays, where the leptons have opposite charges, we also search for final states where both leptons have the same charge. Although these reactions have no obvious theoretical motivation, and the simplest decay schemes do not conserve charge at the quark level, it is possible to construct two-photon-like Feynman diagrams which would allow these decays to proceed, as in Fig. 1.

We present here the results of a search for $D^{\pm}$ and $B^{\pm}$ decays into 14 distinct final states. The $D^{\pm}$ and $B^{\pm}$ were produced in 29 GeV e^+e^- annihilation at the PEP storage ring. The search was based on data taken with the Mark II detector in both the PEP5 and upgrade configurations.

II. DETECTOR DESCRIPTION

The detectors have been described in detail elsewhere.[4] In the PEP5 detector, charged particles were tracked in a 16-layer cylindrical drift chamber and a 7-layer precision vertex drift chamber in a 2.3 kG solenoidal magnetic field. Charged particle momenta p (GeV/c) were measured with a resolution of $\delta p/p = [(0.010p)^2 + (0.025)^2]^{1/2}$. In the upgrade detector, the PEP5 drift chambers were replaced with a 72-layer drift chamber and a 6-layer high precision straw chamber[5] in a 4.5 kG field giving a combined resolution of $\delta p/p = [(0.003p)^2 + (0.014)^2]^{1/2}$. In both configurations, electrons were identified by their energy deposition in a lead-liquid argon calorimeter, which covers 64% of the 4π solid angle. Muons were identified over 45% of the 4π solid angle in a planar, four-layer, iron/proportional tube system.

The total accumulated luminosity was 209 pb^{-1} in the PEP5 configuration, and 28 pb^{-1} in the upgrade configuration. Because of problems with the muon system early in the run, only 15 pb^{-1} of the data with the upgrade detector was used for final states involving a muon.

III. EVENT SELECTION

Hadronic events were selected with a standard set of cuts. We required at least five reconstructed charged tracks which formed a vertex less than 4 cm radially, and within ± 7 cm axially from the expected e^+e^- annihilation point. The scalar sum of the momenta of all charged tracks was required to be at least 3.0 GeV, and the sum of the visible charged and neutral energy was required to be at least 7.5 GeV. Finally, in order for the event to be well contained in the detector, we required that the cosine of the angle between the beamline and the reconstructed thrust axis be smaller in magnitude than 0.7. A total of 89,047 events passed these cuts.

Events were divided into hemispheres on the basis of the event thrust axis. We searched for a hemisphere containing two identified leptons which combined with a third track to form a $D^{\pm}$ or $B^{\pm}$ candidate. Both lepton charge combinations were allowed. Electrons were identified by an algorithm which looked at the energy deposition in the liquid argon calorimeter.[6] Electrons from identifiable γ conversions and Dalitz π^0 decays were removed.[7] Muons were required to have associated hits in all four layers of the muon system. Because multiple scattering can be significant, it is possible for two tracks to share associated hits and both be identified as muons. Such cases are easily detected by a hand scan and were removed. To minimize backgrounds from pion and kaon decays and hadronic misidentification, the electrons and muons were required to have momenta of at least 2.0 GeV/c. The third track was required to have a momentum of at least 500 MeV/c and, when assigned a pion or kaon mass,[8] could be combined with the two leptons to give a charge and mass compatible with a $D^{\pm}$ or $B^{\pm}$. The three-particle combination was required to have a momentum of at least 4.0 GeV/c. The $D^{\pm}$ candidates were required to have a mass between 1.77 and 1.97 GeV/c^2, and the $B^{\pm}$ candidates were required to have a mass between 4.0 and 6.5 GeV/c^2. No statistically significant signal was observed in any channel. Two representative mass distributions are shown in Fig. 2.

IV. MONTE CARLO SIMULATION

The detection efficiency was determined using a Monte Carlo simulation. The simulation is complicated by the presence of a three particle final state. Since the decay mechanism, and hence the matrix element, is unknown, several different decay schemes were tried. To simulate the leptoquark mediated decay we used a weak matrix element with a neutral heavy propagator decaying to two leptons. Schemes where the propagator decayed to a lepton plus a hadron were also considered. Finally, phase space decays were studied. In practice, the exact scheme made little difference; the maximum efficiency variation between the different schemes was less than 5%. For the rest of the event generation we used the Lund model, with second-order QCD matrix element and the Peterson fragmentation function.[9] Version 5.2 of the Lund Model was used, with the following parameters: $\Lambda_{\overline{MS}} = 0.5$ GeV, $y_{min} = 0.02$, $A = 0.9$, $B = 0.7$, $\epsilon_c = 0.05$, $\epsilon_b = 0.005$, $\sigma_q = 0.265$ GeV/c, $P_s = 0.35$, $P_{qq} = 0.09$.

Using the Monte Carlo simulation, we estimated the one standard deviation widths of the $D^{\pm}$ and $B^{\pm}$ mass peaks in the PEP5 detector to be 100 MeV/c^2 and 370 MeV/c^2, respectively. Because the upgrade detector has substantially better mass resolution, narrower search regions could have been used. However, none of the searches yielded any candidate events in the upgrade data and regions of the same width were used in both data samples.

V. RESULTS

The numbers of candidate events for the channels of interest are shown in Table 1. To be conservative, no background subtraction was attempted. However, the numbers of observed events agree well with Monte Carlo background predictions. Systematic errors come from uncertainties in the tracking efficiency (3% per track), lepton identification efficiency (8%), overall $D^{\pm}$ and $B^{\pm}$ reconstruction efficiency (12%), $D^{\pm}$ and $B^{\pm}$ momentum spectra (7%), and luminosity (2%). A correction factor of 0.82 was applied to the Monte Carlo reconstruction efficiency to account for differences in track reconstruction and lepton identification efficiencies between the Monte Carlo simulation and the data.

Calculation of upper limits on the cross section times branching ratios requires a knowledge of the $D^{\pm}$ and $B^{\pm}$ production rates. The inclusive $D^{\pm}$ production rate at $\sqrt{s} = 29$ GeV has been measured by the HRS collaboration to be 0.075 $\pm$0.014 nb.[10] From this measurement, we included radiative corrections to estimate that there are $22,100 \pm 4100$ $D^{\pm}$ in our sample. Unfortunately, there are no measurements of inclusive $B^{\pm}$ production at this energy, so we were forced to rely on Monte Carlo predictions. Two hadronization models were considered: the Lund parton shower model and the Gottschalk model.[11] The predictions of the $B^{\pm}$ production rate for the two models agreed to within 7%. We assigned a 10% systematic error for the uncertainty in the $B^{\pm}$ production rate and used the Lund estimate (which predicted fewer $B^{\pm}$) to estimate that there are 6850 ± 690 $B^{\pm}$ in our sample. The Gaussian distribution associated with these systematic errors was convoluted with the Poisson distribution associated with the number of observed events to find the 90% confidence level limits shown in Table 1.

Table 1. Results for individual channels. Charge conjugate reactions implied. $\sigma \cdot BR$ and BR are the 90% c.l upper limits including the estimated systematic errors.

Reaction	Observed Number	Reconstruction Efficiency (%)	$\sigma \cdot BR$ Limit (pb)	BR Limit (10^{-3})
$D^+ \to e^+e^-\pi^+$	0	4.3 ± 0.4	0.22	2.5
$D^+ \to e^+\mu^-\pi^+$	0	3.5 ± 0.4	0.30	3.3
$D^+ \to e^-\mu^+\pi^+$	0	3.5 ± 0.4	0.30	3.3
$D^+ \to \mu^+\mu^-\pi^+$	1	3.3 ± 0.3	0.55	5.9
$D^+ \to e^+e^-K^+$	1	3.9 ± 0.4	0.52	4.8
$D^+ \to e^+\mu^-K^+$	0	3.3 ± 0.3	0.33	3.4
$D^+ \to e^-\mu^+K^+$	0	3.3 ± 0.3	0.33	3.4
$D^+ \to \mu^+\mu^-K^+$	2	3.0 ± 0.3	0.85	9.2
$D^+ \to e^+e^+\pi^-$	1	3.9 ± 0.4	0.43	4.8
$D^+ \to e^+\mu^+\pi^-$	0	3.0 ± 0.3	0.34	3.7
$D^+ \to \mu^+\mu^+\pi^-$	1	2.9 ± 0.3	0.62	6.8
$D^+ \to e^+e^+K^-$	3	3.6 ± 0.4	0.82	9.1
$D^+ \to e^+\mu^+K^-$	1	2.8 ± 0.3	0.37	4.0
$D^+ \to \mu^+\mu^+K^-$	1	2.6 ± 0.3	0.40	4.3
$B^+ \to e^+e^-\pi^+$	0	8.6 ± 0.9	0.11	3.9
$B^+ \to e^+\mu^-\pi^+$	0	5.6 ± 0.6	0.16	6.4
$B^+ \to e^-\mu^+\pi^+$	0	5.6 ± 0.6	0.16	6.4
$B^+ \to \mu^+\mu^-\pi^+$	0	3.9 ± 0.4	0.24	9.1
$B^+ \to e^+e^-K^+$	1	8.6 ± 0.9	0.19	6.8
$B^+ \to e^+\mu^-K^+$	0	5.6 ± 0.6	0.13	6.4
$B^+ \to e^-\mu^+K^+$	0	5.6 ± 0.6	0.13	6.4
$B^+ \to \mu^+\mu^-K^+$	0	3.9 ± 0.4	0.24	6.4
$B^+ \to e^+e^+\pi^-$	0	8.6 ± 0.9	0.11	3.9
$B^+ \to e^+\mu^+\pi^-$	0	5.6 ± 0.6	0.16	6.4
$B^+ \to \mu^+\mu^+\pi^-$	0	3.9 ± 0.4	0.24	9.1
$B^+ \to e^+e^+K^-$	0	8.6 ± 0.9	0.11	3.9
$B^+ \to e^+\mu^+K^-$	0	5.6 ± 0.6	0.16	6.4
$B^+ \to \mu^+\mu^+K^-$	0	3.9 ± 0.4	0.24	9.1

Many models predict that the branching ratios to leptons should be independent of the final state leptons; in this case, many channels may be combined to form more interesting limits. Several possible combinations are shown in Table 2.

Table 2. Combined results. $\sigma \cdot BR$ and BR are the 90% c.l. upper limits including the estimated systematic errors.

Reaction	Observed Number	Average Reconstruction Efficiency (%)	$\sigma \cdot BR$ Limit (pb)	BR Limit (10^{-3})
$D^+ \to l^+l^-\pi^+$	1	3.8 ± 0.4	0.48	5.2
$D^+ \to l^+l^-K^+$	3	3.4 ± 0.3	0.91	10.1
$D^+ \to l^+l^+\pi^-$	2	3.3 ± 0.3	0.74	8.2
$D^+ \to l^+l^+K^-$	5	2.9 ± 0.3	1.49	16.8
$D^+ \to ll\pi, llK$	11	3.3 ± 0.3	2.38	26.9
$B^+ \to l^+l^-\pi^+$	0	5.7 ± 0.6	0.18	6.2
$B^+ \to l^+l^-K^+$	1	5.7 ± 0.6	0.31	10.9
$B^+ \to l^+l^+\pi^-$	0	5.7 ± 0.6	0.18	6.2
$B^+ \to l^+l^+K^-$	0	5.7 ± 0.6	0.18	6.2
$B^+ \to ll\pi, llK$	1	5.7 ± 0.6	0.31	10.9

The opposite sign lepton limits may be compared with the results published by the CLEO collaboration.[12] Although our inclusive B limits are higher, we have presented previously unpublished limits on electron/muon and same-sign dilepton final states. Also, our analysis is more conservative in that we performed no background subtraction.

It is possible to turn these limits into limits on leptoquark masses. However, this requires a considerable amount of model-dependent theoretical input, and it will not be attempted here.

VI. CONCLUSION

We have presented limits on the production of events in which $D^{\pm}$ and $B^{\pm}$ decay exclusively to two leptons plus a charged pion or kaon.

Note added: After the conclusion of this work, we learned of improved CLEO results on B meson channels.[13]

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FIGURE CAPTIONS

Figure 1. A possible diagram for the process $D^+ \rightarrow \ell^+\ell^+\pi^-$ (the neutrino is required to be a Majorana particle).

Figure 2. Representative invariant mass distributions. Dashed lines indicate limits of B and D signal regions.

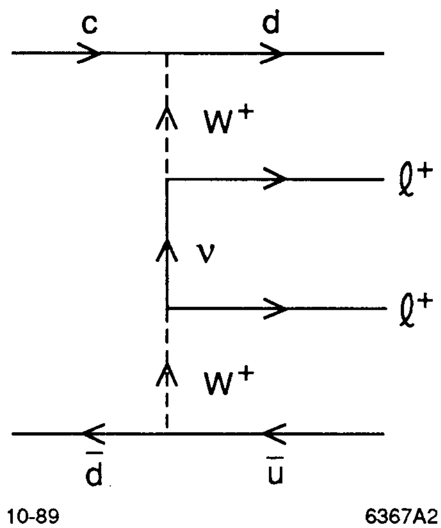

Fig. 1

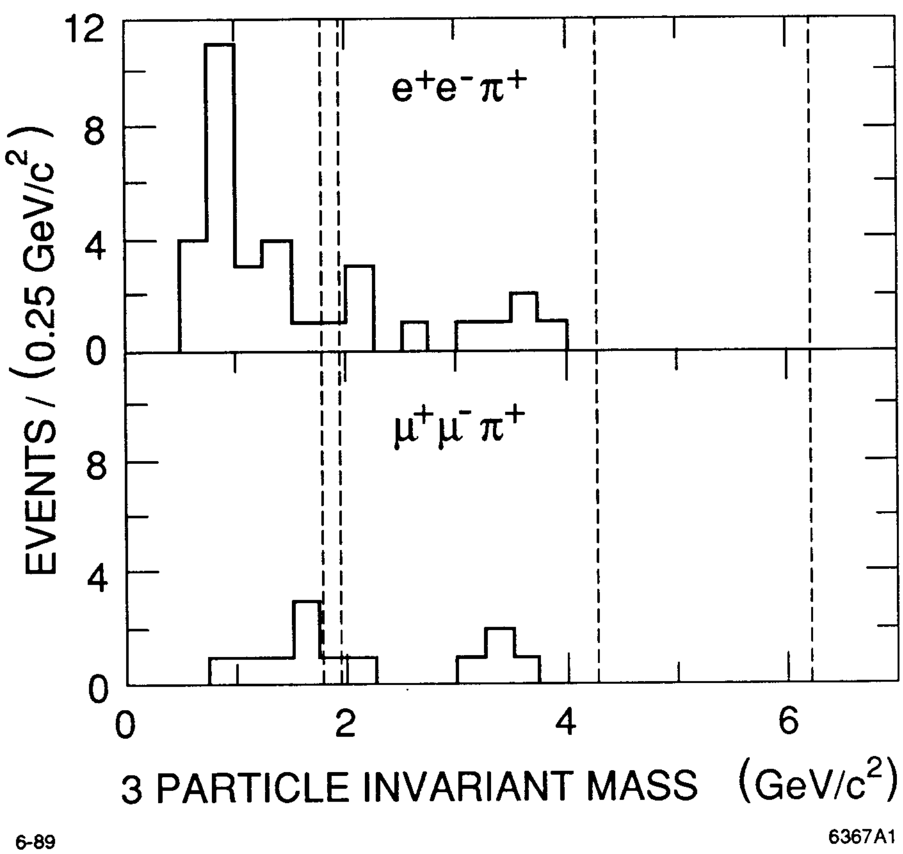
12
8
4
0
8
4
0
$e^+e^-\pi^+$
$\mu^+\mu^-\pi^+$
EVENTS / (0.25 GeV/c^2)
0
2
4
6
3 PARTICLE INVARIANT MASS (GeV/c^2)
6-89
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Fig. 2