2.
1.

BNL-36658

CONF-8410224--11.

~~OC-838~~

Presented at Conf. on Neutrino Mass and Low Energy Weak Interactions, Telemark Lodge, Cable, WI
Oct. 25-27, 1984

Received by OSTI

JUL 2 9 1985

Limits on Likesign Dilepton Production in ν_μ Interactions

BNL--36658

DE85 015179

N.J. Baker, P.L. Connolly[a], S.A. Kahn, M.J. Murtagh, R.B. Palmer, N.P. Samios and M. Tanaka
Brookhaven National Laboratory, Upton, NY 11973

C. Baltay, M. Bregman[b], M. Hibbs[b], J.T. Liu, J. Okamitsu[c], A.C. Schaffer[d] and K. Shastri
Columbia University, New York, NY 10027

E.B. Brucker[e], P.F. Jacques, M. Kalelkar, E.L. Koller[e], R.J. Plano and P.E. Stamer[f]
Rutgers University, New Brunswick, NJ 08903

May 21, 1985

a) Deceased.
b) Present address: IBM Research Center, Yorktown Heights, NY.
c) Present address: Princeton University, Princeton, NJ.
d) Present address: CERN, CH-1211 Geneva 23, Switzerland.
e) Permanent address: Stevens Institute of Technology, Hoboken, NJ.
f) Permanent address: Seton Hall University, South Orange, NJ.

LIMITS ON LIKESIGN DILEPTON PRODUCTION IN ν_μ INTERACTIONS

N.J. Baker, P.L. Connolly[a], S.A. Kahn, M.J. Murtagh,
R.B. Palmer, N.P. Samios and M. Tanaka
Brookhaven National Laboratory, Upton, NY 11973

C. Baltay, M. Bregman[b], M. Hibbs[b], J.T. Liu, J. Okamitsu[c],
A.C. Schaffer[d] and K. Shastri
Columbia University, New York, NY 10027

E.B. Brucker[e], P.F. Jacques, M. Kalelkar, E.L. Koller[e],
R.J. Plano and P.E. Stamer[f]
Rutgers University, New Brunswick, NJ 08903

ABSTRACT

We have searched for the production of likesign dilepton events (ν_μ + Ne $\rightarrow \mu^-$ + e^- + ...) in a wideband neutrino beam at FNAL using the 15' bubble chamber. We observe no signal above the background arising from conventional sources. We set 90% confidence level upper limits for the production rates of (ν_μ + Ne $\rightarrow \mu^-$ + e^- + ...)/(ν_μ + Ne $\rightarrow \mu^-$ + ...) $\leq 8 * 10^{-5}$ and (ν_μ + Ne $\rightarrow \mu^-$ + e^- + ...)/(ν_μ + Ne $\rightarrow \mu^-$ + e^+ + ..) $\leq 6 * 10^{-2}$.

INTRODUCTION

The observation of neutrino interactions containing two leptons with the same electric charge is very interesting since it is not expected in the simplest diagrams of the standard GIM mechanism[1] describing neutrino interactions. This mechanism has been very successful in describing the opposite sign dilepton (μ^-e^+, $\mu^-\mu^+$)[2] events as being due to the excitation and subsequent (semi-) leptonic decay of a charmed hadron produced in a ν_μ charged current event. Both the production rate and the kinematic parameters of these events are well described by the GIM mechanism; in particular, the results from the bubble chamber experiments indicate that the dilepton events contain an excess of strange particles, as is expected from the Cabbibo favored decay of the charmed hadrons.

Several experiments have now published results on likesign dilepton (μ^-e^-, $\mu^-\mu^-$) events.[3] However, there is no convenient explanation for the production of likesign dilepton events within the framework of the standard model, at the production rates implied

a) Deceased.
b) Present address: IBM Research Center, Yorktown Heights, NY.
c) Present address: Princeton University, Princeton, NJ.
d) Present address: CERN, CH-1211 Geneva 23, Switzerland.
e) Permanent address: Stevens Institute of Technology, Hoboken, NJ.
f) Permanent address: Seton Hall University, South Orange, NJ.

by some of these experiments. In general the results from counter experiments on likesign dimuon production have a large background due to ν_μ charged current events, in which a π^- (or k^-) decays to a μ^- ($+\nu_\mu$). The search for $\mu^- e^-$ pairs does not suffer from this background since the corresponding electronic decays of the pion and kaon are heavily suppressed. The dominant backgrounds for this latter case are due to Compton electrons and asymmetric Dalitz pairs in ν_μ interactions and fake muons from π^- or k^- decays in the rarer ($\approx$ 1/100) ν_e interactions.

EXPERIMENTAL ARRANGEMENT

We report here on a new experiment conducted at FNAL using the 15' bubble chamber exposed to the wideband neutrino beam. This experiment was an improved version of an earlier experiment. For the new experiment the bubble chamber was equipped with an External Muon Identifier (EMI). The EMI greatly enhances the rejection of hadronic backgrounds to the ν_μ induced charged current interactions. The beam used was a single horn focused wideband neutrino beam with an average of approximately $1.1 * 10^{13}$ protons per pulse on target. The ν_μ event energy spectrum peaks near 25 GeV and extends to 200 GeV; the average is 48 GeV. The chamber operates in a 30 kG magnetic field, allowing precise momentum determination and charge assignment of charged tracks. It was filled with a 64% atomic neon/hydrogen mixture, density 0.8 $gmcm^{-3}$ giving a radiation length of 40 cm and a pion interaction length of 125 cm. The short radiation length affords excellent electron identification while the small (relative to the chamber dimensions) interaction length aids in muon/hadron discrimination.

The EMI consisted of two planes of multiwire proportional chambers; the first plane was wrapped cylindrically around the vertical axis of the bubble chamber at a distance of 3.6 m, the second plane was mounted perpendicular to the beam axis, 3 m downstream of the first plane. Muons produced in the chamber passing through both EMI planes traversed 3 to 5 pion absorption lengths upstream of the first plane and a further 5.5 pion absorption lengths between the first and second planes. Raw data from the EMI chamber was read out after each spill and recorded on magnetic tape. The raw data from the individual EMI chambers were reconstructed into spatial hits offline using the program EMIKE.[4] The EMI was constantly monitored during the experiment using cosmic rays and muons produced in the beam shielding. The performance of the EMI was calibrated using muons from upstream neutrino interactions which traversed the whole length of the bubble chamber within 10° of the beam direction. Muons with a momentum greater than 5 GeV/c were extrapolated through both planes of the EMI using the program XTRAP.[4] An association chisquare was calculated for the extrapolated track and the reconstructed chamber hits in both planes. For the extrapolated track to be identified as a muon the hits in each plane had to be within 30 ns of each other and the probability for observing this chisquare had to be greater than 10^{-3}. The total background due to π,k decay in flight, hadronic punchthrough and random associations is calculated to be $(2.0 \pm 1.7)\%$ per leaving hadronic track. The geometrical acceptance of the EMI, integrated over the fiducial volume, was $(89 \pm 1)\%$ for muons with momentum greater than 5 GeV/c. The electronic efficiency for a two plane hit was calculated to be $(95 \pm 1)\%$.

DATA SELECTION

The total exposure containing 264,000 pictures, of which 245,000 had good EMI data. The film was scanned for events with an electron or positron coming from the primary vertex. A minimum ionizing track was identified at the scanning stage as an $e^{\pm}$ candidate if it exhibited two or more of the following signatures: spiralling, radiation with observed photon conversion, abrupt change of curvature, large δ ray or trident and annihilation (e^{+} only). Events containing both an electron and a positron with zero opening angle were recorded separately as candidates for the Dalitz decay of π°'s. The events containing a single $e^{\pm}$, or an $e^{\pm}$ together with an e^{+}/e^{-} pair ('tridents') were measured and reconstructed by the program TVGP. Only events which occured in the restricted fiducial volume were considered further. The events were then examined by physicists to verify the $e^{\pm}$ identification and endtype assignments given to each track, and to search for any additional photon conversions, neutron interactions and neutral decays of strange particles which were missed in the first measurement. Since the geometric acceptance of the EMI falls sharply for muon momentum less than 5 GeV/c, those events with no muon candidate (a leaving negative track) having a momentum greater than 5 GeV/c were excluded from further analysis. Similarly, to reduce the background from Compton electrons and asymmetric Dalitz pairs or external photon conversions close to the primary vertex, the electron momentum was required to be greater than 1 GeV/c.

After these initial requirements 109 events remain, of which 91 have muon candidates which extrapolate through both planes of the EMI. These events were further analyzed to resolve ambiguities and to remove backgrounds to the electron, arising from conventional sources. Five events contain an electron and an additional e^{+}/e^{-} pair; these are resolved using the trident test developed for distinguishing single electrons with a trident, from photon conversions with a delta ray close to the vertex.[5] All five events fail the test and are removed from the sample. Background from Dalitz pairs or external photon conversions close to (and indistinguishable from) the primary vertex were removed by requiring the invariant mass between the electron and any noninteracting (excluding identified protons) positive track to be greater than the π° mass; six events are removed by this cut. Electrons were identified as δ-rays if they occured close to, and appeared to originate at, the primary vertex. The angle between the electron and any track had to be greater than 4°, for those tracks in which the electron energy was less than 50% of the maximum possible δ ray energy; this removed twelve events. In two events the apparent electron candidates were identified as $K^- \to \pi^\circ e^- \nu_e$ decays. In both cases the electron candidate travelled greater than three radiation lengths with no observable energy loss and the converted photons from the π° decay pointed to the decay point rather than being tangential to the primary track as one would expect for true electrons (a Monte Carlo calculation predicted (5.3 ± 1.5) semileptonic K^- decays without placing any restriction on the angle between the K^- and electron trajectories). One event was a trilepton candidate. In addition to the $\mu^-(P_\mu = 11$ GeV/c) and the identified $e^-(P_{e^-} = 13$ GeV/c) there is a spiraling positive track (P = 0.8 GeV/c) with significant energy loss. The effective mass of the e^-e^+ pair is consistent with the ϕ mass ($m_{e^+e^-} = 1$ GeV/c^2). Other experimental results on likesign dilepton production exclude possible contributions from trilepton sources since they are most likely due to Drell Yan or vector meson decay backgrounds. Consequently this event is removed from the sample. A total of 65 μ^-e^- candidates remained after all these cuts were imposed.

We have reported[6] a result on likesign dilepton production from an earlier run of this experiment which had essentially the same statistics as the new run discussed in this paper. In that earlier run the EMI data were not useful. With tighter cuts of $P_e > 2$ GeV/c and $P_\mu > 10$ GeV/c, we had 20 events, with an estimated background of 9 events. We thus had a signal of 11 ± 6 events, which we did not consider significant. If, to show consistency, we analyze our new data in the same way without using the EMI, we have 28 events with $P_e > 2$ GeV/c and $P_\mu > 10$ GeV/c, with an estimated background of 16 events. The remaining signal of 12 ± 7 events is again not significant and is quite consistent with the earlier run.

At this point in the analysis we make use of the EMI data to identify those events with true muons. Using the identification criteria described earlier, we find that only 12 out of the 65 events have an identified μ^-. The momentum distribution for the electrons in these events are shown in Fig. 1. None of the 12 events have an electron with momentum greater than 4 GeV/c.

BACKGROUND CALCULATIONS

In addition to a signal of likesign (μ^-e^-) events arising from some new physics, there are conventional sources producing background events. There are two types of background; one due to fake μ^- (from π^- and k^- decays) produced in ν_e charged current interactions; and a second due to electrons arising from asymmetric Dalitz pair and photon conversions, and Compton electrons, produced in ν_μ charged current interactions.

The background due to fake μ^- was calculated using the 65 events in which the electron momentum was greater than 1 GeV/c and the muon candidate momentum was greater than 5 GeV/c. Applying the above fake muon probability to this sample yields an expected background of 1.1 ± 0.9 events (0.9 ± 0.8 events with $P_{e^-} \geq 4$ GeV/c).

The background due to asymmetric conversions and delta rays can be calculated using the Dalitz pair sample. The observed Dalitz pair rate in ν_μ events with a muon greater than 5 GeV/c is (6.9 ± 0.6)%. Assuming (1.5 ± 0.3) π° per event (the average of π^+ and π^- multiplicities), the observed Dalitz pair rate can be broken down into true Dalitz pairs (1.8 ± 0.4)% and external photon conversions (5.1 ± 0.7)%. The calculated background per charged current event from both asymmetric Dalitz pairs and external photon conversions is (4.3 ± 0.5) * 10^{-5} for electron momenta greater than 1 GeV/c, given that the other arm of pair has an energy less than 5 MeV, the limit of visibility in the chamber. The background due to Compton electrons arises only from external photons. Using the external photon conversion rate calculated above, (17.8 ± 2.7) * 10^{-5} Compton electrons with a momentum greater than 1 GeV are expected per charged current event. Using the measured number of ν_μ interactions we then obtain the sum of the asymmetric pairs plus Compton electron background to be 8.4 ± 1.4 events with $P_e > 1$ GeV/c. (This background reduces to 0.7 ± 0.1 events for $P_e \geq 4$ GeV/c.)

The total background of (9.5 ± 1.7) events is to be compared with our observed 12 events. Fig. 1 displays the shape of the expected background distribution compared to the observed P_{e^-} distribution.

We thus conclude that there is no significant signal for likesign dilepton production with P_{e^-} between 1 and 4 GeV/c, and emphasize that there are no dilepton events observed (regardless of background considerations) with $P_{e^-} \geq 4$ GeV/c. To compare with previous experiments which typically use lepton momentum cuts of 4 or 5 GeV/c, we will give upper limits for the likesign dilepton rates for $P_{e^-} \geq 4$ GeV/c and $P_{\mu^-} \geq 5$ GeV/c, relative to both the total charged current rate and the opposite sign dilepton rate. For these cuts the backgrounds discussed above reduce to (0.9 ± 0.8) fake muon events and (0.7 ± 0.1) events from asymmetric pairs and Comptons, or a total expected background of 1.6 ± 0.8 events.

EXPERIMENTAL EFFICIENCY

The observed events have to be corrected for several inefficiencies and losses: i) the scanning efficiency for finding events containing an electron was measured to be (77 ± 2)%, from a double scan of 25% of the film; ii) the probability that an electron exhibits two independent signatures was (94.0 ± 1.5)%; iii) the effect of the cut to remove delta rays was estimated by applying the same cut on the μ^-e^+ sample; (93 ± 2) of the events were retained; iv) the effect of the invariant mass cut was estimated in a similar manner, all the events were retained and no correction is made for this cut; v) the criteria to reduce the trident ambiguity retains (97 ± 3)% of electrons. In addition a small correction has to be made for confused events, in which an electron would not be identified, even if present; the efficiency for identifying electrons in events is (95.5 ± 1.5)%. The overall efficiency is (0.62 ± 0.03) with respect to the normal charged current event rate. When comparing the likesign events to the opposite sign event rate, efficiencies i), ii), iv) and the inefficiency for confused events all cancel, leaving an overall efficiency of (0.85 ± 0.03).

RESULTS

The normalization samples were subjected to the same fiducial volume cuts, and were required to have a good EMI muon with $P_{\mu^-} > 5$ GeV/c using the identical criteria as were used for the likesign dilepton sample so that the EMI efficiencies cancelled out. This resulted in 48,800 ± 3,300 total ($\nu_\mu + Ne \rightarrow \mu^- + \ldots$) events. In the $\mu^- e^+$ sample, the e^+ tracks wre selected with the same criteria as the e^- tracks; there were 51 ± 8 ($\nu_\mu + Ne \rightarrow \mu^- + e^+ + \ldots$) events with $P_{e^+} \geq 4$ GeV/c.

Since we observe no $\mu^- e^-$ events with $P_e > 4$ GeV/c and $P_\mu > 5$ GeV/c the 90% confidence level upper limit is < 2.3 events.

We thus obtain the 90% confidence level upper limits of:

$$\frac{\nu_\mu + Ne \rightarrow \mu^- + e^- + \ldots}{\nu_\mu + Ne \rightarrow \mu^- + \ldots} \leq 8 * 10^{-5}$$

$$\frac{\nu_\mu + Ne \rightarrow \mu^- + e^- + \ldots}{\nu_\mu + Ne \rightarrow \mu^- + e^+ + \ldots} \leq 6 * 10^{-2}$$

Figure 2 displays the rate for likesign dilepton production compared to normal charged current events for this and other experiments. Figure 3 displays the rate compared to opposite sign dilepton production. These latter results allow a more accurate comparison between experiments since the systematic errors in the acceptance largely cancel. One of the experiments, which has a positive result, is directly comparable with our experiment. They have used a similar beam (400 GeV WBB) and have applied similar momentum cuts on the leptons. We are in disagreement with this result. Assuming their production rate and our efficiencies, we should expect 6.0 events in addition to our 1.6 background events. The probability for observing no events is $7 * 10^{-3}$, when the appropriate experimental errors are taken into account.

In conclusion, we observe no likesign dilepton events above background arising from conventional sources.

We would like to thank the staff of the accelerator division at Fermilab and the 15' bubble chamber and the scanning staff at the individual institutions.

This research was supported by the U.S. Department of Energy and the National Science Foundation.

REFERENCES

1. S.L. Glashow, J. Iliopoulos, L. Maiani, Phys. Rev. D2, 1285 (1970).
2. For a list of experimental results see
   N.J. Baker et al. Phys. Rev. D, to be published.

3.1 M. Holder et al., Phys. Lett. 70B, 396 (1977);
3.2 A. Benvenuti et al., Phys. Rev. Lett. 41, 725 (1978);
3.3 J.G.H. de Groot et al., Phys. Lett. 86B, 103 (1979);
3.4 T. Trinko et al., Phys. Rev. 23D, 1889 (1981);
3.5 K. Nishikawa et al., Phys. Rev. Lett. 46, 1555 (1981); and Errata, Phys. Rev. Lett. 54, 1336 (1985).
3.6 M. Jonker et al., Phys. Lett. 107B, 241 (1981).
3.7 H.C. Ballagh et al., Phys. Rev. 24D, 7 (1981).
3.8 A. Haatuft et al., Nucl. Phys. B222, 365 (1983).

4. See R. Cence et al., Nucl. Instr. and Meth. 138, 245 (1976). The programs, EMIKE and XTRAP, were written by the University of Hawaii group and Group A at LBL.
5. A.M. Cnops et al., Phys. Rev. Lett. 41, 357 (1978).
6. M. Murtagh, Proceedings of the Fermilab Lepton-Photon Symposium, p 277 (1979).

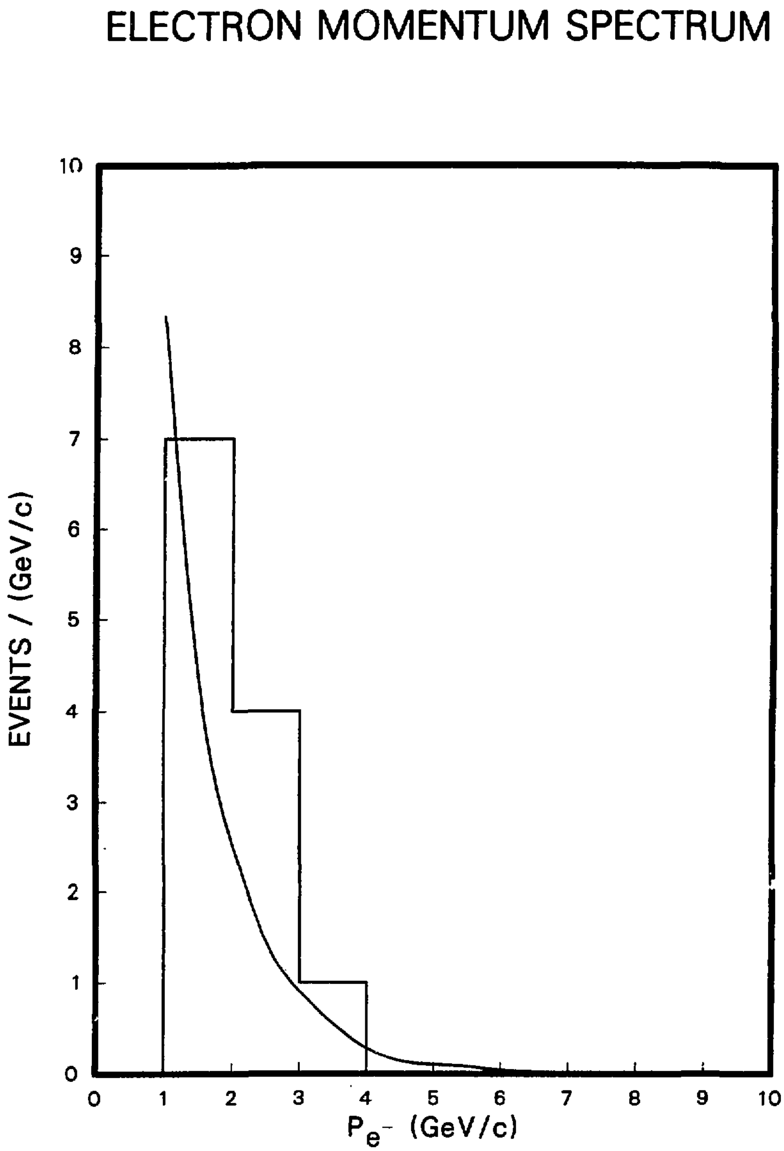

Fig. 1. The electron momentum distribution for those events with a muon identified in the EMI. The smooth curve displays the expected electron momentum distribution for charged current events in which the electron arises from conventional sources.

PRODUCTION RATE OF LIKESIGN DILEPTON EVENTS COMPARED TO CHARGED CURRENT EVENTS

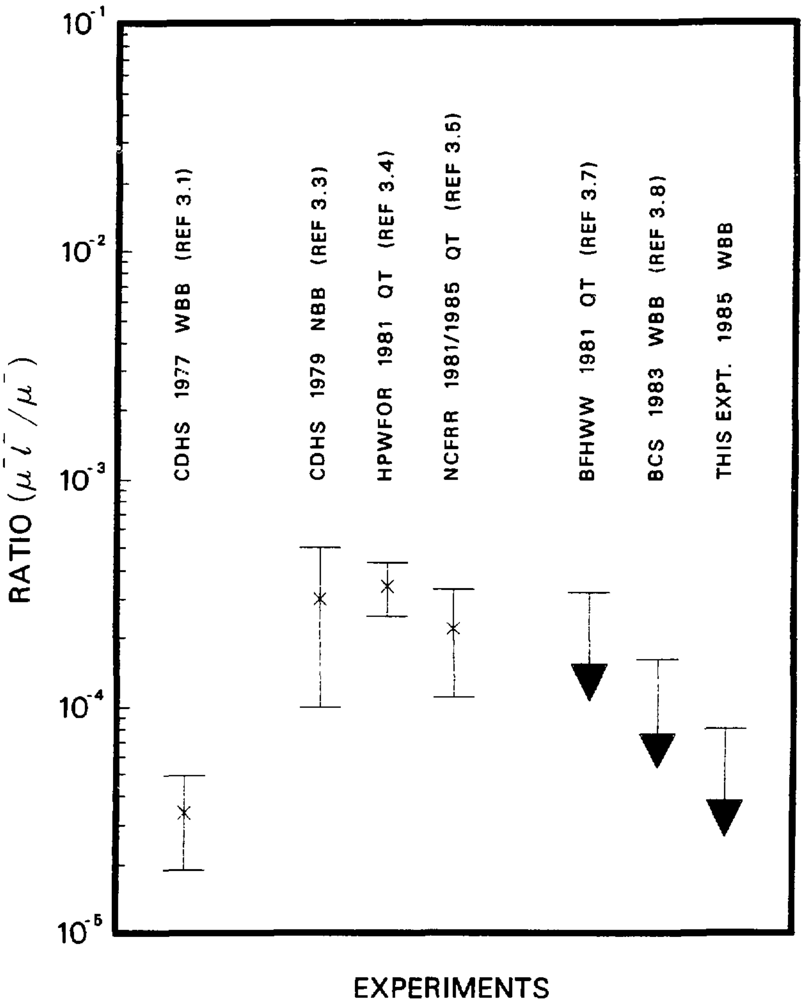

Fig. 2. The rate for likesign dilepton production for this and other experiments, compared to the normal charged current events.

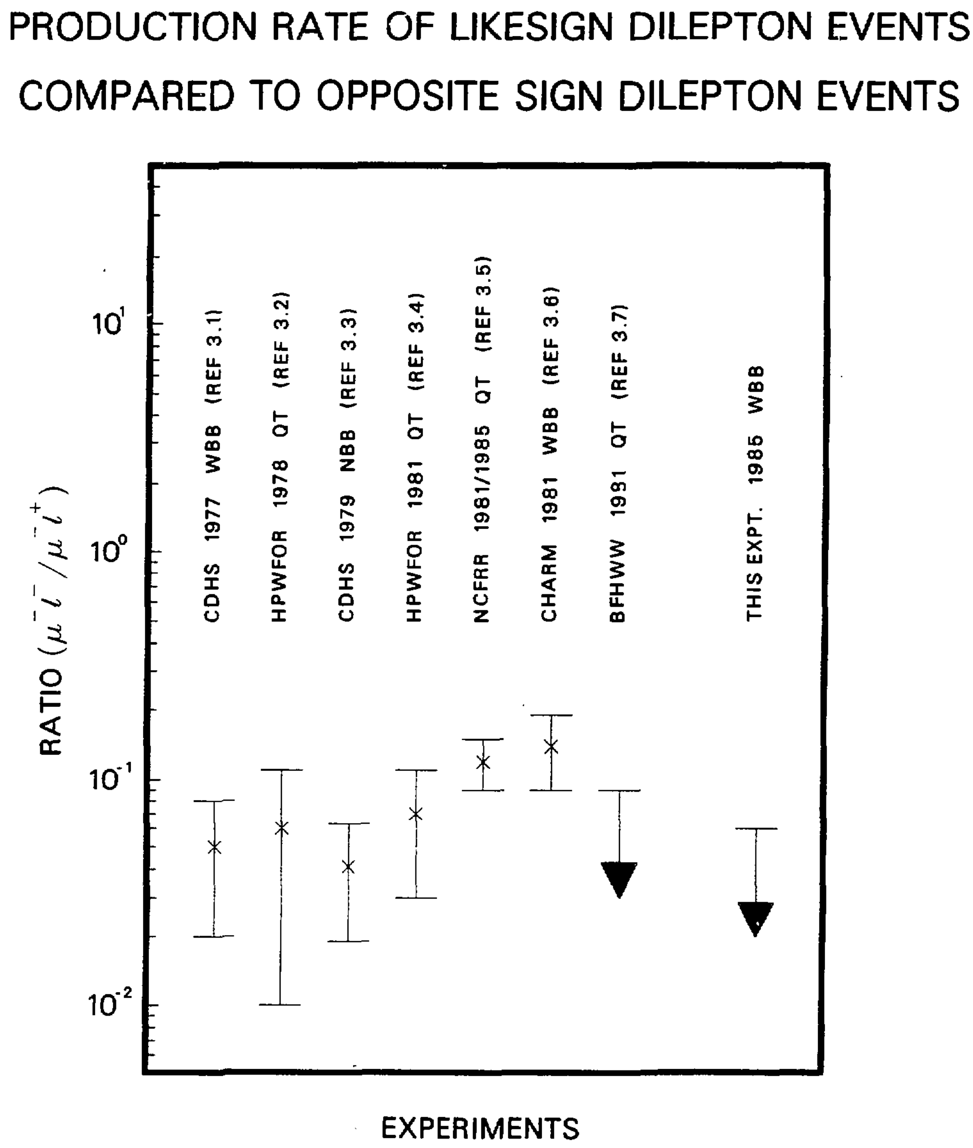

Fig. 3. The rate for likesign dilepton production for this and other experiments, compared to opposite sign dilepton events.