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BOSE-EINSTEIN CORRELATIONS IN NEUTRINO AND ANTINEUTRINO INTERACTIONS IN DEUTERIUM

WA 25 Collaboration

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Abstract - Bose-Einstein correlations between pions of equal charge have been observed in Charged Current and Neutral Current (anti)neutrino-deuterium interactions in the BEBC bubble chamber exposed to the SPS wide band beam. The pion emission region is found to be essentially spherical with a mean radius of (0.48 ± 0.07) fm; the chaoticity parameter is 0.36 ± 0.04.

1. Introduction

In this paper are presented the results of a study of the Bose-Einstein (BE) correlations between identical pions produced in (anti)neutrino-deuteron interactions. The BE correlations are second order intensity interference effects, arising from the bosonic nature of the pion; consequently there is an ambiguity in the paths of two identical pions. The amplitude arising from the pion produced by the source a (b) hitting the detector A (B) interferes with the amplitude arising from the pion produced by the source b (a) hitting the detector A (B). The interference depends on the distribution of the pion sources in space and in time and on their degree of coherence. The main feature of the observed interference pattern is the enhancement in the number of pion pairs close in phase space.

Bose-Einstein two-photon correlations were first used by Hanbury-Brown and Twiss to determine angular stellar sizes (1). The application of the method to identical pions for the determination of the space-time structure of hadronic production was developed by Kopylov and Podgoretsky (2) and by Cocconi (3); the first measurements were performed by Goldhaber et al in low energy $\bar{p}p$ annihilations (4).

Measurements of the pion emission regions have been made in hadron-hadron (4-21), positron-electron (22-24) and muon-proton (25) collisions. These measurements gave sizes of slightly more than 1 fm in hadron-hadron collisions and smaller than 1 fm in $e^+ e^-$ and μp collisions. This difference may arise from the relatively simpler situation in positron-electron and lepton-nucleon interactions than in hadron-hadron interactions: in the first two cases the Bose-Einstein effects arise from hadronization of relatively simple parton configurations, while this is not the case in hadron-hadron interactions, which also need not be limited to single primordial quark interactions.

Our analysis concerns mainly Charged Current (CC) (anti)neutrino-deuteron interactions; results for Neutral Current (NC) interactions are also presented. It is the first time that BE correlations are observed in neutrino interactions.

A brief phenomenological description of BE correlations is given in Section 2, while experimental details are given in Section 3. Results are described in Sections 4 and 5 for CC and NC interactions, respectively. Conclusions are given in Section 6.

2 - Bose-Einstein correlations

Various types of parametrizations of Bose-Einstein correlations are found in the literature, usually in the overall c.m. reference frame. We shall consider in the hadronic c.m. system a pair of pions with three momenta $\vec{p}_i$ and $\vec{p}_j$ and energies E_i, E_j and define the two vectors $\vec{p} = \vec{p}_i + \vec{p}_j$ and $\vec{q} = \vec{p}_i - \vec{p}_j$. The independent variables most commonly used are

$$q_o = |E_i - E_j| \qquad (1a)$$
$$q_t = |\vec{q} \times \vec{p}| \; / \; |\vec{p}| \; . \qquad (1b)$$

q_t is the relative transverse momentum of the two pions with respect to the direction of their sum, $\vec{p} \;/\; |\vec{p}|$.

The interference distribution, between like sign pions, assuming independent space and time distributions, is given by

$$I = 1 + a\, F_1(q_t)\; F_2(q_o). \qquad (2)$$

a = 1 for complete BE interference from completely chaotic sources; otherwise $0 < a < 1$; $F_1(q_t)$ and $F_2(q_o)$ are the Fourier transforms of the emitting source distribution functions $F_1(\vec{r})$ and $F_2(t)$, respectively. Different kinds of functions F_1 and F_2 have been used in previous analyses:

$$F_1\;(q_t) = 4\, J_1^2\,(q_t R)\; / \;(q_t R)^2 \qquad (3)$$
$$F_1\;(q_t) = \exp(-q_t^2 R^2) \qquad (4)$$
$$F_2\;(q_o) = [1 + (q_o \tau)^2]^{-1} \qquad (5)$$
$$F_2\;(q_o) = \exp\,[-\,(q_o \tau)^2]. \qquad (6)$$

J_1 is the Bessel function of order 1; R may be considered to be the radius of the space emitting region; the parameter τ multiplied by the speed of light c may be interpreted as the effective thickness of the space emitting source. There is no real justification to prefer one or another of these parametrizations. It has also to be remembered that the parameters R and τ have different interpretations in the different parametrizations; moreover fits to the data with different parametrizations usually yield different numerical values of R and τ . Finally the above descriptions are not Lorentz invariant.

Most of the analyses have been performed as function of q_t only, using data at relatively small values of q_o , because the data are usually not statistically adequate to perform simultaneously a two dimensional fit to F_1 and F_2 ; furthermore one should also have a good knowledge of the correlations between q_t and q_o .

An alternative and Lorentz invariant parametrization is the following

$$I = 1 + a \exp\left[-\,M^2 R^2\right] \qquad (7)$$

where $M^2 = M_{\pi\pi}^2 - 4\, m_\pi^2$ and $M_{\pi\pi}$ is the invariant mass of the pion pair. R is now a space-time radius. For $q_o \rightarrow 0$ the form (7) becomes identical to (2) with expressions (4) and (5) (or (6)).

In the following we shall use both form (7) and form (2), with (4) and (5), at relatively low values of q_o . In the last form the source, of radius R, emits pions with an intensity decreasing with the distance from the centre as $\exp\,[-(r/R)^2]$.

3 - Experimental data

The data were obtained in exposures of the bubble chamber BEBC filled with deuterium to the CERN-SPS wide band neutrino and antineutrino beams produced by 400 GeV protons. The chamber was equipped with an External Muon Identifier (EMI) and, in the last two runs, with an Internal Picket Fence (IPF) of vertical proportional tubes. Experimental details of the exposures, of the scanning and measuring procedures, of the neutrino energy determination for Charged Current events and of the event selection have already been published (26-28); the selection of Neutral Current events is discussed in ref (29-31).

3.1 - Charged Current (CC) events

In the present work a total of 16155 antineutrino (CC^+) and 26390 neutrino (CC^-) raw events were used. The main selection of Charged Current events was based on the two-plane EMI. A cut on the muon lab momentum, $p_\mu > 4$ GeV/c, was applied. All secondary charged hadrons were assumed to be pions, unless otherwise identified by energy loss, range, interaction or decay. Only a small fraction, about 10%, of the tracks have been identified. The relatively small contamination by kaons, protons and antiprotons should decrease the observed interference, more so for positive pairs than for negative ones. Events were weighted as in ref.27, the mean global correction factor being 1.09.

The analysis of Bose-Einstein correlations requires the study of the intensity distribution of identical pions, I, relative to an ideal uncorrelated distribution, I_o. The ratio of the two distributions, I/I_o, may be studied as function of the variable q_t for a given range of q_o.

The distribution $I(q_t)$ may be approximated with the q_t-distribution of particles of the same charge, $I_l(q_t)$, for "like" pairs. The following cuts were applied to the data in order to obtain a clean sample of like pairs.

(a) Only CC events with a hadronic mass square $W^2 > 4$ GeV^2 are considered. This cut eliminates low energy events for which an insufficient number of pions are produced.

(b) Only events in which there are at least two positive pions or two negative pions in the final state are retained.

(c) Since two identical pions can interfere only when they are close in phase space (that is when q_o is small) we include only pairs with small q_o. Our limited statistics forces us to use a relatively large interval in q_o ($q_o < 0.6$ GeV).

(d) We require that the c.m. angle between the two pions of a pair be smaller than 90° ($\cos\vartheta > 0$).

(e) For each track we require $\Delta p < 0.15$ GeV/c, where Δp is the measurement error on each track momentum in the lab frame. It has to be noted that the average value of Δp is 0.12 GeV/c. The cut on the absolute uncertainty, which removes poorly measured tracks, seems more appropriate than a cut on the relative uncertainty (20). We have checked that in our case there is no noticeable difference in the results obtained applying the absolute or relative cut.

Table 1 gives the number of events and the number of combinations for different experimental cuts.

An approximation of the ideal uncorrelated distribution $I_o(q_t)$ is given by the distribution of charged particles of opposite charge (unlike pairs), $I_u(q_t)$. This distribution does not include Bose-Einstein correlation effects, but it is different from the ideal uncorrelated distribution because:

(a) The inclusive single particle distributions for negative and positive hadrons are different; this effect is reduced when using neutrino and antineutrino events together.

(b) $I_u(q_t)$ contains the effect of resonances. The effect is minimized with the use of the variable q_t, instead of the variable M (or $M_{\pi\pi}$). Fig. 1 shows the effective dipion mass distributions for (++)+(--) and (+-) pairs. Notice the ϱ^o contribution; it is visible only in the $M_{\pi\pi}$ distribution of unlike pairs; it is not present in the q_t-distribution of (+-) pairs (32).

Because of the above uncertainties in the $I_u(q_t)$ distribution determined from (+-) pairs, many authors have tried other approximations for I_o (20,25), all of which suffer from some problem. In the present experiment the main limitation arises from the statistics available and not from the choice of the background.

Fig.2 shows the ratio N_l/N_u of like-pairs to unlike-pairs versus q_t.

3.2 Neutral Current (NC) events.

The selection of NC events is considerably more difficult than that of CC events. The selection was based on the EMI and IPF systems using the program EMI-PICKET (30,31). The IPF was not available before 1981. We thus used only the 1981 and 1983 runs for the analysis of NC events.

The outgoing tracks of a given event were extrapolated to the IPF and to the EMI. The space extrapolations were mapped onto the electronics timing informations. It was thus possible to assign a space-time point to each event. This information is then used to classify events in Charged Current (CC), Neutral Current (NC) and Hadron induced Events (HA).

The obtained CC sample is a clean sample, but does not contain all the CC events. The obtained NC sample contains true NC events and a number of unidentified CC events and hadron induced (HA) events. In order to reduce the contamination of CC and HA events in the NC sample, the following cuts were applied:

1) Events with one or more tracks with transverse momentum (in the visible hadronic system) $p_t > 1.5$ GeV/c were rejected (this cut removes CC events with high momentum muons not registered by the EMI).
2) Events with a total transverse momentum $p_{t,tot} < 0.5$ GeV/c were rejected (this cut removes HA events and CC events with low energy muons not registered by the EMI).

More details of the NC selection are given in ref. (29-31).

Since the final state neutrino is not observed, one does not have all the information on the final state. One possible way out is to systematically use the visible hadronic system in its own c.m. frame and apply in this frame the same type of cuts as for CC events, namely (all variables in the c.m. of the visible hadronic system have an apostrophe, W', q'_0, ϑ', ...):

a) $W'^2 > 4$ GeV^2.

b) Use only events with at least two positive or two negative tracks.

c) $q'_0 < 0.6$ GeV.

d) $\cos\vartheta' > 0$.

e) Require for each track $\Delta p < 0.15$ GeV/c in the lab frame.

After all these cuts we are left with 2610 weighted NC events (see Table 2).

For the approach based on eq. (7) one must compute the invariant effective mass squared, M^2, for each pair of particles and then fit the distribution to eq. (7).

Because of our limited statistics either approach is adequate. Fig. 3 shows the ratio of like-pairs to unlike pairs versus M^2.

4 - Results for CC events

In Fig. 2 the ratio of the distributions for like-pairs to that of unlike-pairs is plotted versus q_t for all q_0 and for $q_0 \leqslant 0.6$ GeV. The data show the expected behaviour, with a Gaussian like maximum at small values of q_t, and a background constant in q_t. Fits were made using the function

$$N_l/N_u = \gamma\,(1 + \alpha e^{-\beta q_t^2}) \qquad (8)$$

where γ is a normalization constant, the radius R is R (fm) = $0.197\sqrt{\beta\ (\mathrm{GeV/c})^{-2}}$ and α is the chaoticity parameter. Eq. 8 is an approximation of Eq. (2) with formula (4); α replaces eq. (5). The fits, given in table 3, have acceptable χ^2/DoF. The chaoticity parameter α is considerably smaller than 1. This may arise from the presence of hadrons other than pions in the sample, from the large range of q_0 used and from the limited precision in the particle momenta and angles. This reduction in α does not alter the value of R (20). We checked that fits with $\gamma = \gamma'(1 + \delta q_t)$ yield values of δ equal to zero, within errors, and that the quality of the fits is not significantly improved. We also checked that different cuts, for instance using only events with one like pair, do not change the parameters, within errors.

For $q_0 \leqslant 0.6$ GeV (and $\Delta p < 0.15$ GeV/c, $\cos\vartheta \geqslant 0$) we obtain R =(0.48± 0.07) fm, a value smaller than the values obtained in hadron-hadron collisions and consistent with the values from e^+e^- and μp collisions.

Cut in cos ϑ

The effect of the cut in cos ϑ was verified performing fits with and fits without the cut. The Bose-Einstein interference is less visible if there is no cut in cos ϑ. The $\cos\vartheta \geqslant 0$ cut focusses on those pairs which go in the same hemisphere and which may have physically similar conditions; for these pairs the Bose-Einstein correlation should be maximum.

Dependence on q_o

Our limited statistics does not really allow to perform an analysis for different bins of q_o. We have nevertheless performed such fits for the three ranges $q_o \leq 0.3$, $0.3 < q_o \leq 0.6$, $q_o > 0.6$ GeV. The chaoticity parameter decreases slowly and monotonically from 0.38 to 0.24, allowing a very rough estimate of $c\tau$, which comes out to be approximately 0.1 fm, with an uncertainty of essentially 100%. The slow decrease of α with increasing q_o justifies the analyses made for a large q_o interval.

Dependence on multiplicity

The data may be compatible with a small increase of the radius with increasing multiplicity.

Shape of the emission region

We computed the differences in the three momenta of the pions, $\Delta p_x = |p_{ix} - p_{jx}|$, $\Delta p_y = |p_{iy} - p_{jy}|$, $\Delta p_z = |p_{iz} - p_{jz}|$. Pion pairs were selected according to the largest value of Δp_x, Δp_y, Δp_z, thus yielding information on the 3 radii in the x, y, z directions with respect to the intermediate boson ($W^{\pm}$) direction. For instance the selection $\Delta p_x \geqslant \Delta p_y$, $\Delta p_x \geqslant \Delta p_z$ should select those pairs which give the best estimate of the dimension in the x-direction. We find (table 3) that the three radii R_x, R_y, R_z are equal within large errors, suggesting a spherical emission region, in agreement with other data at relatively low energies.

Forward and backward pions

The selection of forward going pions in the hadronic c.m. system selects those particles coming from the current jet, while backward pions should come preferentially from the spectator jet. Forward pions may give more direct information about the Charged Current-quark interaction. An analysis was performed in the c.m.s. of the selected forward pions. The fit indicated a value of R around 0.3 fm, but the value of the chaoticity parameter has such a large an error that no conclusion may be reached.

5 - Results for NC events

After all the cuts described in Section 3.2, we are left with 2610 weighted NC events. The $\pi^+\pi^-$ and $\pi^-\pi^- + \pi^+\pi^+$ effective mass combinations are plotted in Fig. 3. The ratio of the distributions of like-pairs to that of unlike-pairs is plotted versus M^2 for $q'_0 \leq 0.6$ GeV in Fig 4 (the variable q'_0 refers to the value in the c.m. of the visible hadronic system). The fits of the distributions to equation (7) yield the values given in table 4. In particular we have $R = (0.53 \pm 0.14)$ fm, compatible, within its large error, with the value obtained from the CC sample.

We checked that we obtain similar values from the q'_t distribution.

6 - Conclusions

Our data show the existence of Bose-Einstein interference effects in high energy (anti)neutrino-deuteron interactions in both Charged and Neutral Current interactions. The interference is only partial, with a chaoticity parameter equal to 0.36 ± 0.04. The radius of the emitting region is 0.48 ± 0.07 fm, a value considerably smaller than the value found in hadron-hadron interactions, and approximately equal to those found in e^+e^- and μp interactions (33,34). This difference may be related to the simpler parton configuration of $e^+ e^-$ and μp interactions.

In CC interactions there may be some dependence on charged hadron multiplicity.

Within our limited statistics there is no difference in BE correlation for CC and NC interactions.

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REFERENCES

1 - R.Hanbury Brown and R.Q. Twiss, Phil.Mag. 45 (1954) 663;
R.Hanbury Brown and R.Q. Twiss, Nature 177 (1956) 27;
R.Hanbury Brown and R.Q. Twiss, Nature 178 (1956) 1447;
R.Hanbury Brown and R.Q. Twiss, Nature 178 (1956) 1046.

2 - G.I.Kopylov and M.I.Podgoretskii, Sov.J.Nucl.Phys. 19 (1974) 215.

3 - G.Cocconi, Phys. Lett. 49B (1974) 459.

4 - G.Goldhaber et al., Phys.Rev.Lett. 3 (1959) 181.

5 - A.Firestone et al., Nucl.Phys. B101 (1975) 19.

6 - E.Calligarich et al., Nuovo Cim.Lett. 16 (1976) 129.

7 - M.Deutschmann et al., Nucl.Phys. B103 (1976) 198.

8 - N.N.Biswas et al., Phys.Rev.Lett. 37 (1976) 175.

9 - G.Borreani et al., Nuovo Cim. 36A (1976) 245.

10 - F.Grard et al., Nucl.Phys. B102 (1976) 221.

11 - C.Ezell et al., Phys.Rev.Lett. 38 (1977) 873.

12 - H.Kirk et al., Nucl.Phys. B128 (1977) 397.

13 - C.Angelini et al., Nuovo Cim.Lett. 19 (1977) 279.

14 - E.De Wolf et al., Nucl.Phys. B132 (1978) 383.

15 - C.De Marzo et al. Phys.Rev. D29 (1984) 363.

16 - T.Akesson et.al., Phys.Lett. 129B (1983) 269.
T.Akesson et al., Phys.Lett. 155B (1985) 128.

17 - S.Y.Fung et al., Phys.Rev.Lett. 41 (1978) 1592.

18 - M.Deutschmann et al., Nucl.Phys. B204 (1982) 333.

19 - D.Drijard et al., Nucl.Phys. B155 (1979) 269.

20 - A.Breakstone et al., Phys.Lett. 162B (1985) 400.

21 - B.V.Barynya et al., Czech. J. Phys. B31 (1981) 475.

22 - H.Aihara et al., Phys.Rev. D31 (1985) 996.

23 - M.Althoff et al., Z.Phys. C29 (1985) 347.

24 - P.Avery et al., Phys.Rev. D32 (1985) 2294.

25 - M.Arneodo et al., Z.Phys. C32 (1986) 1.

26 - D.Allasia et al., Nucl.Phys. B224 (1983) 1.

27 - D.Allasia et al., Z.Phys. C24 (1984) 119.

28 - D.Allasia et al., Nucl.Phys. B268 (1986) 1.

29 - D.Allasia et al., Phys.Lett. 133B (1983) 129.

30 - D.Allasia et al., (Determination of the Neutral Current chiral coupling constants u_L^2, u_R^2, d_L^2 and d_R^2 from an (anti)neutrino deuterium experiment), to be published.

31 - N.Van Eijndhoven, NIKHEF-H 87-6 (1987).

32 - D.Allasia et al., (Inclusive ρ^0 production in (anti)neutrino-deuteron Charged Current and Neutral Current interactions), to be published.

33 - M.I.Podgoretski, Sov.J.Nucl.Phys. 37 (1983) 272.

34 - A. Giovannini et al., Riv. Nuovo Cimento 2 (1979) 1.

Table 1 - Number of unweighted and weighted CC events for various cuts. The last line gives the number of combinations of like and unlike pairs.

		$\bar{\nu}D$	νD	$\bar{\nu}D + \nu D$
unweighted CC events	$p_\mu \geq 4$ GeV/c	16155	26390	42545
	$p_\mu \geq 4$ GeV/c, $W^2 \geq 4$ GeV^2	12693	22825	35518
weighted CC events	$p_\mu \geq 4$ GeV/c, $W^2 \geq 4$ GeV^2	13740	25080	38820
	and 1 like pair	8571	19620	28191
	and $\cos\vartheta \geq 0$, $q_0 \leq 0.6$ GeV	7729	17331	25060
	Number of combinations			like = 40210 unlike=54620

Table 2 - Number of unweighted and weighted NC events with various cuts.

		$\bar{\nu}D + \nu D$
unweighted NC events		3464
	$W'^2 > 4\ GeV^2$	2927
weighted NC events	$W'^2 > 4\ GeV^2$	3085
	and 1 like pair	2790
	and $\cos\vartheta' > 0, q_0' < 0.6$ GeV	2610
	Number of combinations	Like = 5208 unlike=7306

Table 3 - CC fits. Values of the parameters obtained from the fits of $N_l(q_t)/N_u(q_t)$ to Eq. 8. Only statistical errors are considered. One should add a systematic uncertainty, which is at least of the same order of the statistical uncertainty. All fits are relative to the cuts $p_\mu \geqslant 4$ GeV/c, $W^2 > 4$ GeV^2, $\Delta p < 0.15$ GeV/c, $\cos\vartheta \geqslant 0$, $\geqslant 1$ like pair. Further cuts are indicated in the table. N_{ch} is the number of charged hadrons produced. The last fit refers to the M^2 distribution, eq. 7. (q_o is in GeV).

Condition	α	R (fm)	γ	χ^2/DoF
All q_o	0.32 ± 0.03	0.51 ± 0.06	0.63 ± 0.02	1.7
$q_o \leqslant 0.6$	0.36 ± 0.04	0.48 ± 0.07	0.61 ± 0.02	2.2
$q_o \leqslant 0.6$; $N_{ch} \leqslant 6$	0.31 ± 0.07	0.40 ± 0.09	0.56 ± 0.03	1.9
$q_o < 0.6$; $N_{ch} > 6$	0.36 ± 0.05	0.58 ± 0.09	0.69 ± 0.02	0.7
$q_o \leqslant 0.3$	0.38 ± 0.04	0.53 ± 0.09	0.61 ± 0.02	2.7
$0.3 < q_o \leqslant 0.6$	0.34 ± 0.15	0.35 ± 0.11	0.60 ± 0.07	1.2
$q_o > 0.6$	0.24 ± 0.06	0.58 ± 0.14	0.65 ± 0.03	1.0
$q_o \leqslant 0.6$, $\Delta p_x > \Delta p_y, \Delta p_z$	0.07 ± 0.08	0.38 ± 0.40	0.72 ± 0.05	1.2
" $\Delta p_y > \Delta p_x, \Delta p_z$	0.50 ± 0.06	0.55 ± 0.09	0.59 ± 0.03	2.1
" $\Delta p_z > \Delta p_x, \Delta p_y$	0.54 ± 0.04	0.62 ± 0.07	0.59 ± 0.02	1.6
M^2 $q_o \leqslant 0.6$	0.39 ± 0.04	0.49 ± 0.06	0.62 ± 0.02	2.2

Table 4 - NC fits. Values of parameters obtained from the fits of N_l/N_u to eq.7. All fits are relative to the cuts: $W'^2 \geqslant 4$ GeV^2, $\Delta p < 0.15$ GeV/c, $\cos\vartheta' \geqslant 0$, $\geqslant 1$ like pair. The last line gives a fit of CC events with cuts similar to those used for NC events (q'_o is in GeV).

Condition	α	R (fm)	γ	χ^2/DoF
NC all q'_o	0.43 ± 0.12	0.57 ± 0.19	0.61 ± 0.04	1.2
NC $q'_o \leqslant 0.6$	0.42 ± 0.11	0.53 ± 0.14	0.58 ± 0.04	1.2
CC $q'_o \leqslant 0.6$	0.48 ± 0.06	0.41 ± 0.05	0.58 ± 0.03	1.0

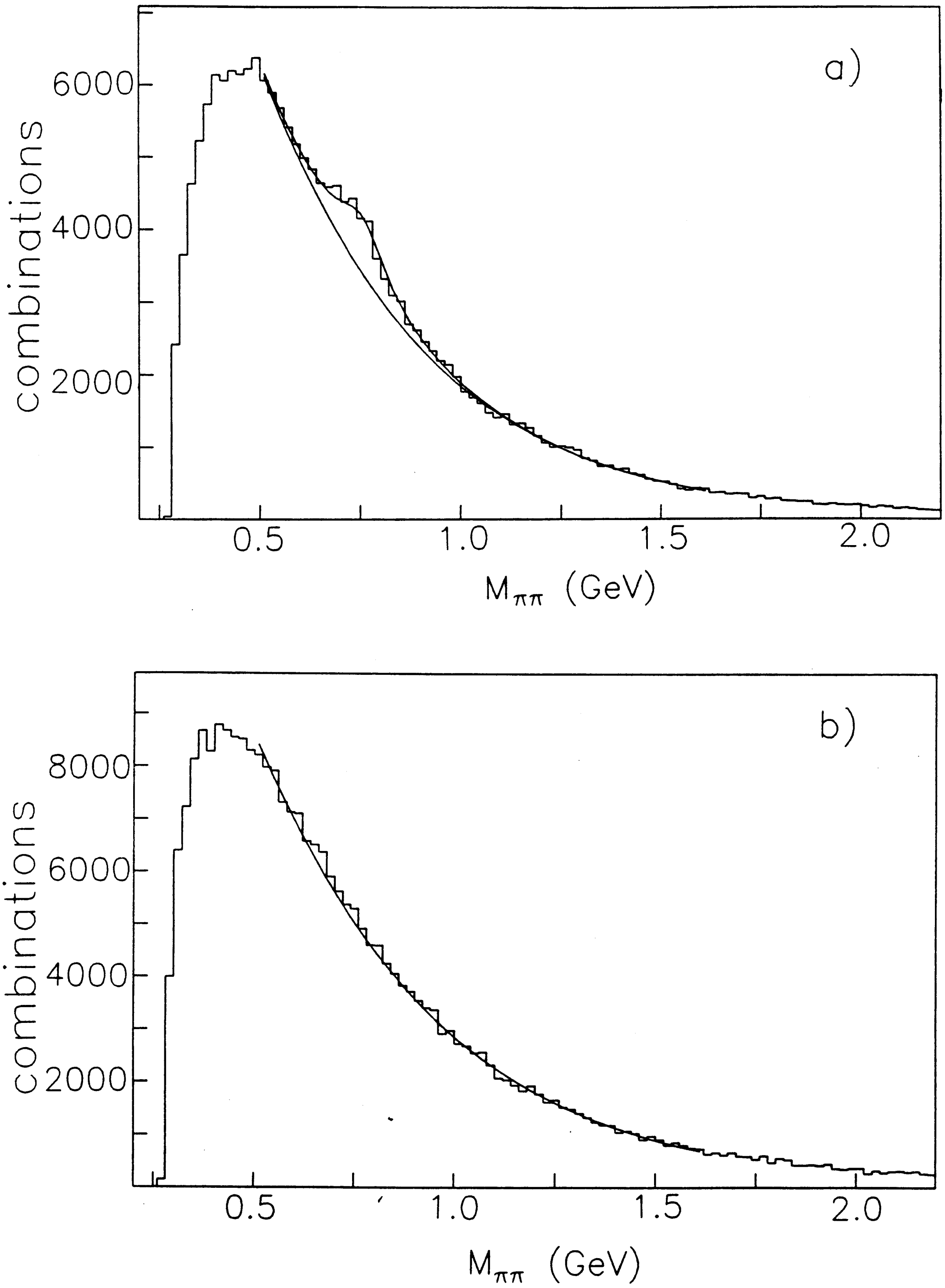
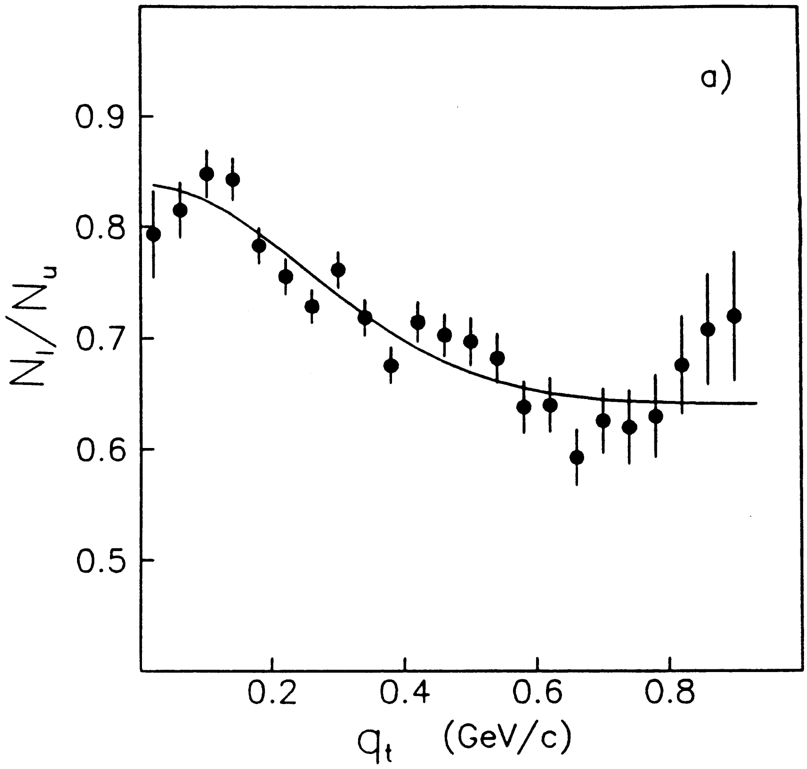


Fig 1 - Invariant dipion mass distribution for (a) $\pi^+\pi^-$ and (b) $\pi^-\pi^-$ and $\pi^+\pi^+$ pairs produced in Charged Current ν_μ D and $\bar{\nu}_\mu$ D interactions. The lines are the results of fits to a Breit-Wigner plus background contributions (32).



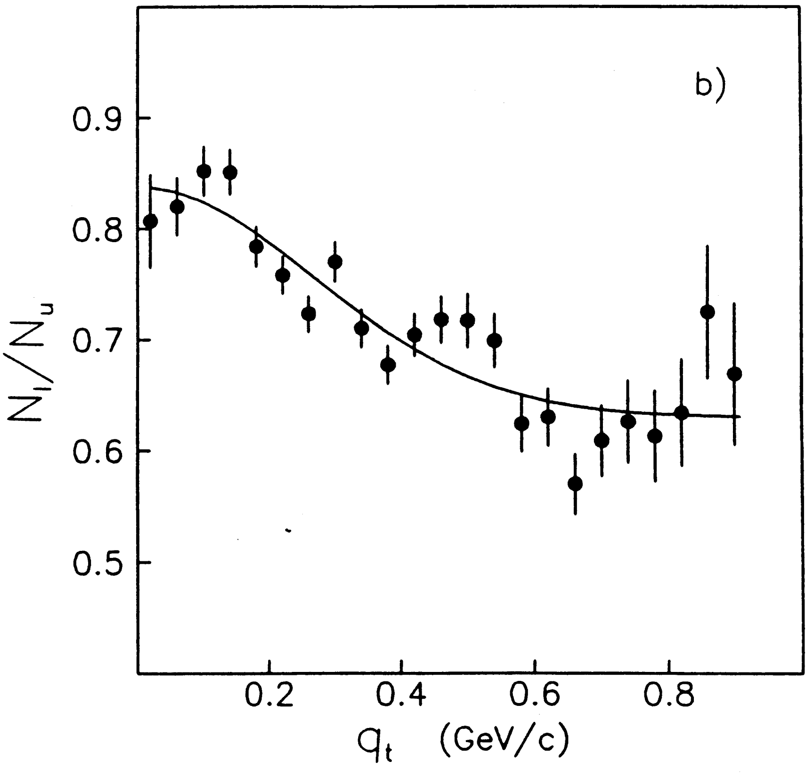


Fig 2 - Ratio of like-pairs to unlike pairs versus q_t for $W^2 > 4$ GeV^2, $\cos\vartheta > 0$, $\Delta p < 0.15$ GeV/c. (a) all pair combinations; (b) for all pairs with $q_0 < 0.6$ GeV. (CC events).

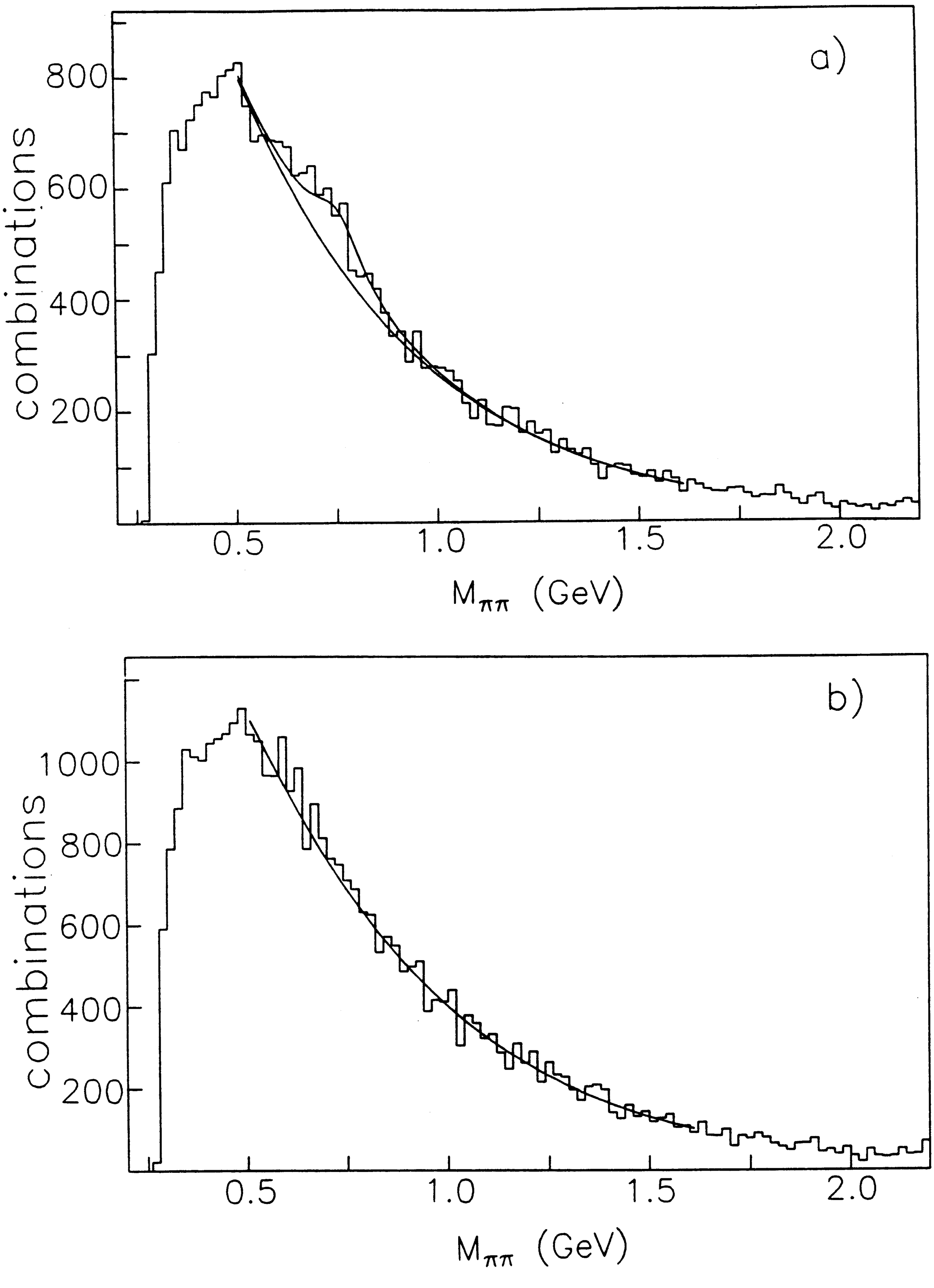


Fig. 3 - Invariant dipion mass distribution for a) $\pi^+\pi^-$ and b) $\pi^-\pi^-$ and $\pi^+\pi^+$ pairs produced in Neutral Current ν_μ D and $\bar{\nu}_\mu$ D interactions. The lines are the results of fits to a Breit-Wigner plus background contribution (32).

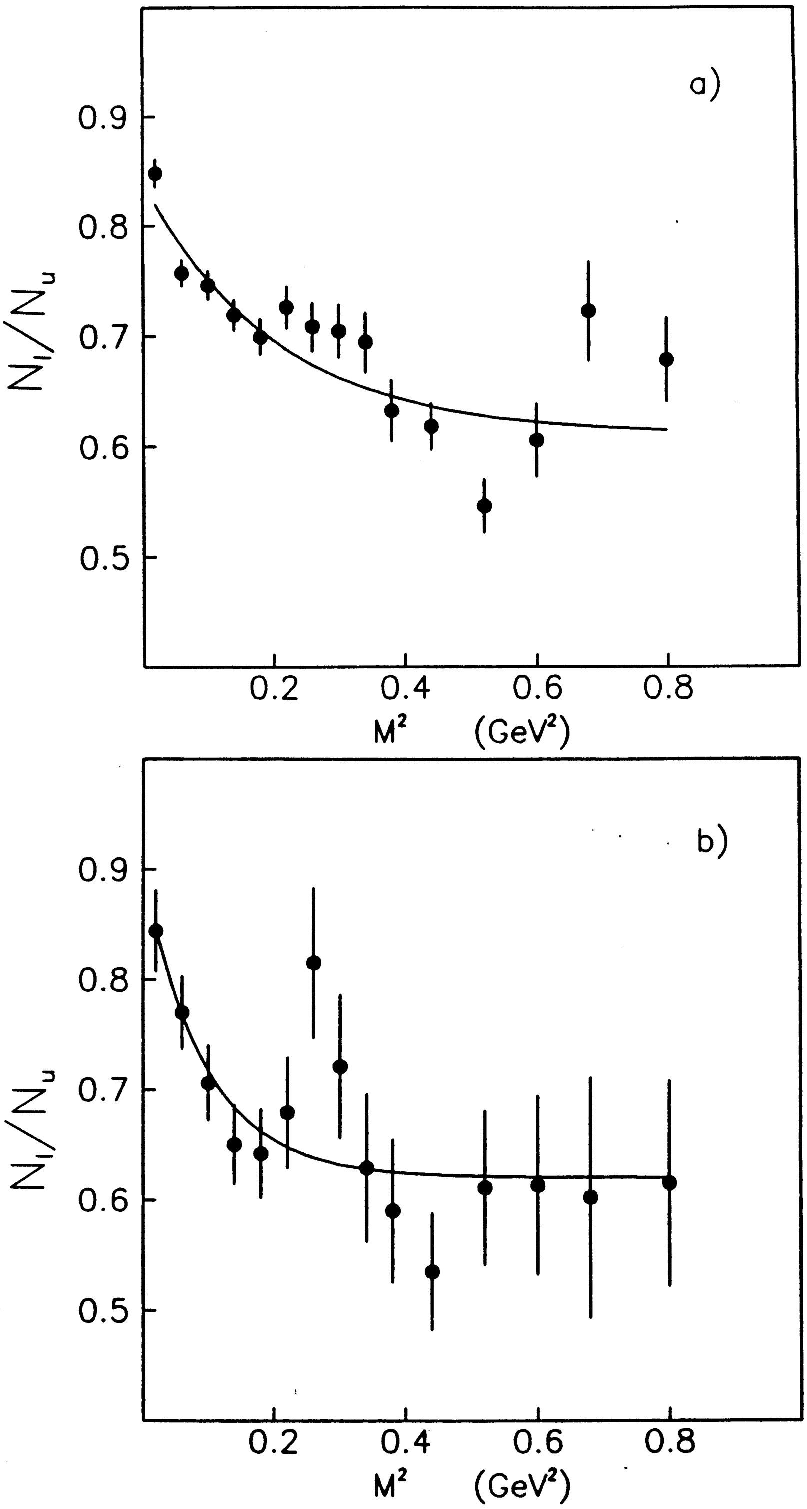


Fig 4 - Ratio of like-pairs to unlike pairs versus M^2 for a) CC events with $W^2 > 4$ GeV^2, $\cos\vartheta > 0$, and b) NC events with $W'^2 > 4$ GeV^2, and $\cos\vartheta' > 0$ (see text).