EXPERIMENTAL STUDY OF OPPOSITE SIGN AND SAME SIGN DIMUON EVENTS PRODUCED IN WIDE BAND NEUTRINO AND ANTINEUTRINO BEAMS

A. BARONCELLI

Istituto Superiore di Sanità

Sezione I N F N

Rome - Italy

Abstract

This contribution reports on a study of 495 ± 32 (290 ± 29) prompt opposite sign dimuons observed at the CERN SPS in a wide band neutrino (antineutrino) exposure of the CHARM counter detector. The momentum cut applied to both muons is $P_\mu > 4$ GeV/c.

The features of the prompt opposite sign signal are represented by charmed D meson production and its semileptonic decay.

In the same experiment 75 ± 17 (52 ± 14) $\mu^-\mu^-$ ($\mu^+\mu^+$) prompt dimuon events with a momentum cut of 4 GeV/c on both muons were collected. The relative ratios $\mu^-\mu^-/\mu^-\mu^+$ $\mu^+\mu^+/\mu^+\mu^-$ were found to be: .14 ± .04 and .19 ± .06 respectively.

Opposite sign and same sign dimuon events were collected with the CHARM counter detector exposed to the WBB $\nu,\bar{\nu}$ beams. A detailed description of the experimental set-up is given in Ref. 12. The detector consists of a segmented ionization calorimeter having a cross section of 300 x 300 cm^2, surrounded by a magnetized iron frame and followed by a muon spectrometer. The calorimeter is a sandwich of marble plates, 8 cm thick, of plastic scintillators, 3 cm thick 15 cm wide 300 cm long, and of proportional drift tubes, 3 cm thick 3 cm wide and 400 cm long. Each marble plate is surrounded by a magnetic iron frame, 45 cm wide and 8 cm thick and the target calorimeter is followed by 4 toroidal iron magnets used to momentum analyse the forward going muons.

The fine granularity of the calorimeter allows an efficient pattern recognition of charged tracks of momenta as low as 1 GeV/c (in about 90% of dimuon events both tracks are fully reconstructed), a good reconstruction of track direction (about 3 mrad HWHM above 4 GeV) and an accurate determination of the vertex of the hadronic shower (few cm above 20 GeV).

Out of 271000 (181000) events in ν_μ ($\bar{\nu}_\mu$) wide band beams, a sample of opposite sign dimuons candidates was found satisfying the following criteria:

1 - The vertex of the shower was required to be in a fiducial volume having a cross section of 240 x 240 cm^2 and from plane 3 to plane 55 of the calorimeter. (This means about 80 tons of target material).

2 - Two tracks were found by automatic pattern recognition.

3 - Out of the two tracks one (defined as the leading muon) was required to be fitted in the magnetic system with the sign expected from the nature of the beam (μ^- for ν_μ , μ^+ for $\bar{\nu}_\mu$) and with momentum $p_{\mu 1} >$ 4 GeV/c. The $\bar{\nu}_\mu$ events contamination in the ν_μ beam is estimated from 1 μ events to be

about 9% in this sample. The ν_μ events contamination in the $\bar{\nu}_\mu$ beam is more important but was reduced by the rejection of all those events in which the second muon had more than twice the energy of the leading muon; the expected contamination after this cut is of the order of 4%.

4 - A minimum momentum of 4 GeV/c was required for the non leading track. If the non leading μ was not fitted in the magnetic system its charge was assumed to be opposite to that of the leading muon, the fraction of unidentified prompt same sign events being about 5% - 10%.

An eye scan of the selected candidates was made in order to reject random superposition of two different events occurring in the time gate of the trigger (double events) as well as those events in which one of the tracks showed a shower at the end of its range (punch through hadrons). Also the contamination of trimuon events with a momentum of the third muon above 1 GeV/c was rejected during the scan.

The number of events after this selection is 749 (467) per ν_μ ($\bar{\nu}_\mu$) expositions.

The correction applied to take into account the efficiency of the pattern recognition is a function of the hadronic energy and of the momentum of the second muon. It is tipically of the order of 95%. After this correction the number of events becomes 798 for and 491 for ν and $\bar{\nu}$.

The main beackground to the prompt dimuons signal is due to charged current events with a non prompt muon originating from a pion or kaon decay in flight.

This background has been evaluated in previous experiments using Monte Carlo calculations or using different target densities.

In the present experiment the projected distances dx, dy on two orthogonal axis between the two muons in a plane perpendicular to the beam direction containing the hadronic vertex, was used to separate the prompt from non prompt events. The non prompt events are expected to be more widely distributed in this variable because of the development of the shower.

The distribution of the projected distances of prompt events was obtained by substituting in real dimuon events the 2 found muons with two Monte Carlo generated muons emerging from the hadronic vertex and reprocessing these pseudo-events through the analysis program. This procedure also gives the probability of finding both muons by automatic pattern recognition.

Furthermore we obtain the distribution of the projected distances dx, dy for the hadronic tracks of the shower from a sample of 891 identified punch through particles. The distribution in the same variable for muons from pion and kaon decay was obtained from the latter after applying corrections for the decay probability. Fig. 1 shows the distribution of the projected distance of the dimuon sample. The continuous line comes from a Chi-square fit of this distribution described as a sum of the obtained prompt and non prompt (dashed line) distributions and in which the free parameter is the fraction α of prompt event over the total.

The fit gives for the ν_μ case ($\bar{\nu}_\mu$) $\alpha = .62 \pm .04 (.59 \pm .06)$ for $p_{\mu 2} > 4$ GeV/c.

To obtain the distribution of the prompt signal in any variable (E ,x, y, z, etc.) the shape of the background measured at large distances (where the prompt signal is negligible) was subtracted after normalization to the number of background events obtained by the fit.

In Fig. 2a, 2b we give the relative rate of prompt 2 μ to 1 μ events for the ν_μ and $\bar{\nu}_\mu$ beam respectively as a function of visible total energy.

The solid line is from a Monte Carlo simulation in which the efficiencies of the various cuts applied and the resolutions are taken into account; the threshold effect, due to the fact that a heavy quark is produced in the final state, are taken into account by using a redefined value of x ("slow rescaling" variable x').

$$x' = x + \frac{M_c^2}{(s \cdot y)}$$

where $M_c = 1.5$ GeV

The x distribution of the valence quarks was parametrized as

$$f(x) = x \cdot (1 - x)^{3.5}$$

The shape of the sea distribution was parametrized as

$$f(x) = (1 - x)^B$$

and the Monte Carlo predictions for different values of B were compared with experimental data. From this comparison we obtain

$$B = 7.0 \pm 1.0 \quad \text{(stat)}$$

were the statistical error corresponds to a variation of 1 in the Chi-square value.

Fig. 3 shows the x and y distribution of dimuon events for ν_μ and $\bar{\nu}_\mu$ interactions respectively for the cut $p_{\mu 2}>4$ GeV/c. These distributions are in good agreement with the predictions of the Monte Carlo program (solid line).

In the same experiment 167 $\mu^-\mu^-$ and 103 $\mu^+\mu^+$ events in ν_μ and $\bar{\nu}_\mu$ beams respectively were also collected.

After correction for the finding efficiency the number of events is 176 and 107 for ν_μ and $\bar{\nu}_\mu$ respectively.

The selection criteria were the same as for opposite sign dimuons except that the second muon was also required to be fitted in the magnetic system with a momentum cut of 4 GeV/c (due to the magnetic fit efficiency the effective momentum cut is about 4.5 GeV/c).

The major problem in the interpretation of these events comes from the fact that the expected non prompt background is as large as the signal itself.

We performed the prompt/non-prompt separation on the same-sign samples using the same procedure as for the opposite sign case. The fractions of prompt signal which correspond to a minimum in the Chi-square are: $\alpha = .43 \pm .10$ (stat) for $\mu^- \mu^-$ and $\alpha = .49 \pm .12$ (stat) for $\mu^+ \mu^+$, corresponding to a prompt signal of 75 ± 17 $\mu^- \mu^-$ and 52 ± 14 $\mu^+ \mu^+$ events. The corresponding prompt opposite sign dimuons selected with the same criteria are 424 ± 33 $\mu^- \mu^+$ and 223 ± 25 $\mu^+ \mu^-$.

To obtain the ratios

$$R_{\nu_\mu} = \frac{\mu^- \mu^-}{\mu^- \mu^+} \quad ; \quad \bar{R}_{\bar{\nu}_\mu} = \frac{\mu^+ \mu^+}{\mu^+ \mu^-}$$

from these measured numbers we have still to apply a correction factor $\eta = .80 \pm .15$ due to the different fitting efficiency in the magnetic system for muons of opposite charge and to subtract the contribution of the punch through particles in the opposite sign sample (5% ± 3%). After these corrections we obtain

$$R_{\nu_\mu} = .14 \pm .04 \text{ (stat)}$$

$$\bar{R}_{\bar{\nu}_\mu} = .18 \pm .06 \text{ (stat)}$$

The systematic errors on these ratios are mainly due to the imperfect knowledge of the shape of prompt and non prompt distribution of the indicator d and they have been estimated to be ± .03 in both cases.

This rate is larger by a factor of about 10 than expected for associated charm production.

In conclusion we have studied 749 (467) opposite sign dimuon events with $p_{\mu 2} > 4$ GeV/c produced by ν_μ ($\bar{\nu}_\mu$) and found their properties in agreement with single c production according to the expectations of the GIM mechanism.

The existence of like sign dimuon pairs is established at the level of 4.5σ in the neutrino case and 4.0σ in the antineutrino one.

References

1) Benvenuti A. et al.: Phys. Rev. Lett. 34 (1975) 419.
2) Benvenuti A. et al.: Phys. Rev. Lett. 35 (1975) 1199, 1203, 1249.
3) Holder M. et al.: Phys. Lett. 69B (1977) 377.
4) Barish B.C. et al.: Phys. Rev. Lett. 36 (1976) 939.
5) Murphy C. et al.: Proc. XII Rencontre de Moriond (1977) 301.
6) Bosetti P.C. et al.: Phys. Lett. 73B (1978) 380.
7) Loveless R.J. et al.: Proc. of Neutrino '79 Conf. Bergen.
8) Armenise N. et al.: CERN EP/79 48.
9) Armenise N. et al.: Proc. of Neutrino '79 Conf. Bergen.
10) Odorico R., Roberto V.: Nucl. Phys. B136 (1978) 333.
11) Roberto V.: Z. Phys. C. Particles and Fields 2 (1979) 315.
12) Diddens A.N. et al.: Nucl. Inst. Meth. 178 (1980) 27.
13) Holder et al.: Phys. Lett. 70B (1977) 396.
14) Benvenuti et al.: Phys. Rev. Lett. 41 (1978) 725.
15) Albright et Smith: Phys. Lett. 77B (1978) 9.

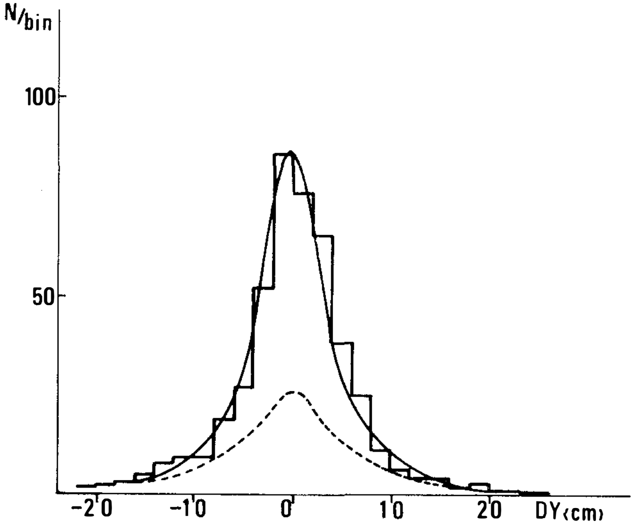

Fig.1 - Shows the distribution of the projected distance of the neutrino dimuon sample. The continuous line comes from a chi square fit of this distribution described as a sum of a prompt and non prompt distributions. The dotted line shows the shape of the background normalized to the number of events predicted by the fit.

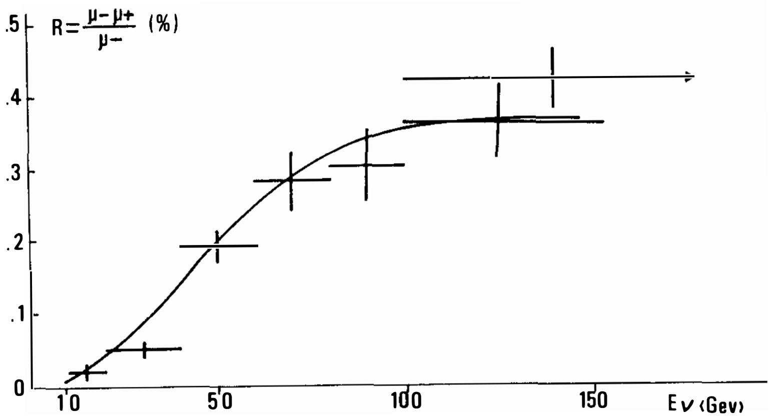

FIG. 2a

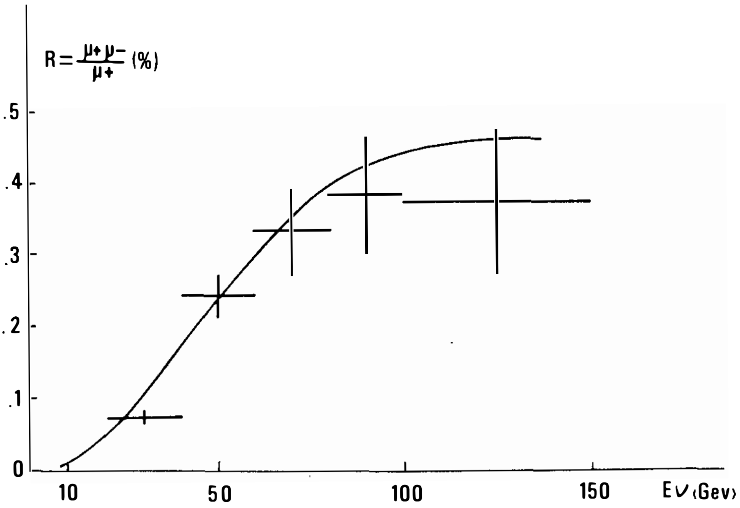

FIG. 2b

Fig.2a- Show the relative ratio of dimuon events to 1μ events
2b as a function of the total visible energy for the neutrino and anti-neutrino samples respectively. The solid lines are Monte Carlo predictions.

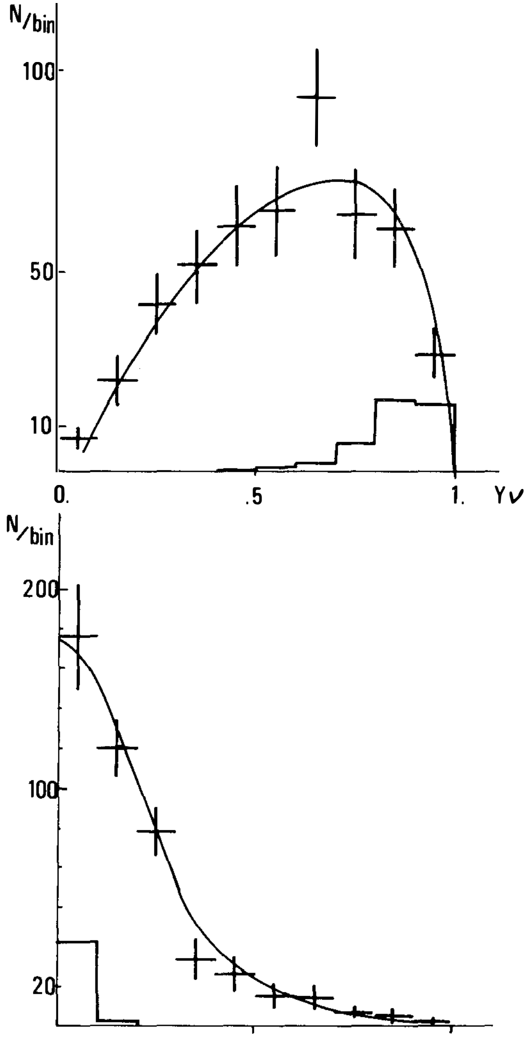

FIG. 3a

Fig.3a- Show the distribution of the x and y variables for the
3b neutrino and anti-neutrino case respectively. Solid lines are Monte Carlo predictions. The contamination of anti-neutrino (neutrino) events in the two samples is also indicated.

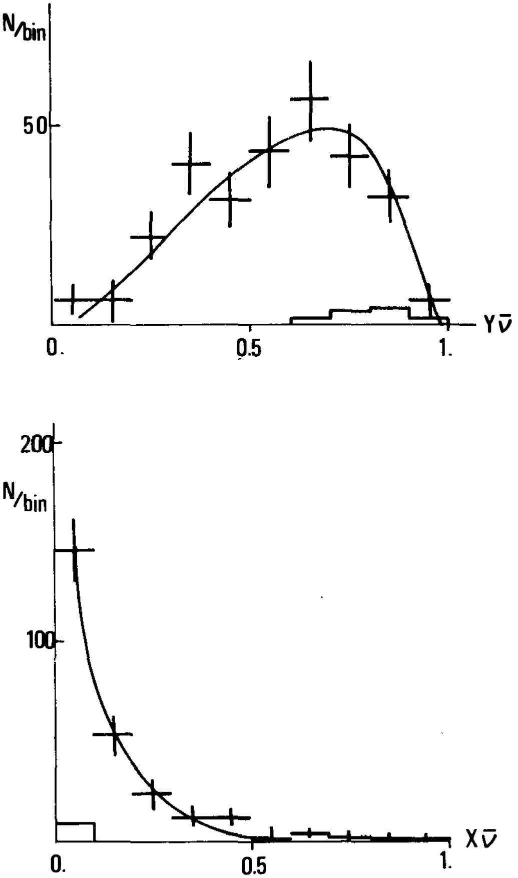

FIG. 3b