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PROPOSAL FOR FURTHER STUDY OF PROMPT NEUTRINO PRODUCTION IN A PROTON BEAM DUMP EXPERIMENT

J.G.H. de Groot, J. Knobloch, J. May, P. Palazzi, F. Ranjard,
J. Steinberger, H. Taureg, J. Rothberg, W. von Rüden,
H. Wahl and J. Wotschack

CERN, Geneva, Switzerland

J. Duda, F. Eisele, H.P. Klasen, K. Kleinknecht, D. Pollmann,
B. Pszola and B. Renk

Institut für Physik* der Universität Dortmund, Dortmund, Germany

J.P. Berge, W. Cooper, R. Hanft, J. Malko and F.A. Nezrick
Fermilab, Batavia, Ill., U.S.A.

I. Becker, F. Dydak, T. Flottmann, C. Geweniger, V. Hepp,
R. Herden and K. Tittel

Institut für Hochenergiephysik* der Universität Heidelberg,
Heidelberg, Germany

C. Guyot, J.P. Merlo, B. Peyaud, J. Rander, J.P. Schuller and R. Turlay
D.Ph.P.E., CEN-Saclay, France

H. Abramowicz, J. Królikowski, A. Para, M. Szczekowski and M. Szeptycka
Institute for Nuclear Research, Warsaw, Poland

J.T. He, T.Z. Ruan and W.M. Wu
Institute of High Energy Physics, Peking, China

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1. INTRODUCTION

The first beam dump experiment carried out at the CERN SPS, has demonstrated[1] the existence of a prompt ν_e flux originating in the collisions of 400 GeV protons with copper nuclei. This flux has been attributed to the production and subsequent semileptonic decay of charmed D mesons. While the expected flux ratio of neutrinos to antineutrinos is not obvious because of the possible contribution from charmed baryons, one expects equality of ν_e and ν_μ fluxes from charmed particle decays. Therefore, a second beam dump experiment was carried out in 1979, mainly to establish the prompt ν_μ flux, but also to clear some discrepancy in the prompt ν_e rate between the CERN-Dortmund-Heidelberg-Saclay (CDHS) counter experiment and the BEBC and GGM bubble chambers.

The analysis of the 1979 beam dump run is completed. The results from the CDHS experiment may be summarized as follows:

i) The prompt $\nu_e + \bar{\nu}_e$ rate as measured previously by the CDHS experiment has been confirmed (note that a calorimetric device cannot separate ν_e from $\bar{\nu}_e$). The number of prompt $CCe^+ + e^-$ events with $E_{tot} > 20$ GeV, at the position of the CDHS detector, normalized to 1.10^{18} protons and 1 ton of detector, is 1.00 ± 0.09 (stat.) ± 0.09 (syst.)[2]. This rate is in good agreement with the results of the BEBC group[3] and the CHARM group[4].

ii) The anomalous excess of muonless events for shower energies below 20 GeV as reported by the CHARM group[5] has not been confirmed by our experiment.

iii) A prompt ν_μ flux has been established by using two copper dumps of relative densities 1 and 1/3, and extrapolating to infinite density. Table 1 gives the normalized rates for $CC\mu^-$ events with $E_{tot} > 20$ GeV for both densities. The prompt rate obtained by extrapolation agrees within errors with the prompt rate obtained by subtraction of the predicted[6] non-prompt background. The agreement with the results of the BEBC and CHARM groups is good, as can be seen in Fig. 1a.

	$\rho = 1/3$	$\rho = 1$
total rate	10.86 ± 0.33	4.56 ± 0.13
prompt rate (extrapolated)		1.23 ± 0.25 ± 0.32
prompt rate (subtracted)		1.35 ± 0.13 ± 0.48

Table 1

$CC\mu^-$ rates for $E_{tot} > 20$ GeV, corrected for losses and acceptance, at the CDHS position, normalized to 1.10^{18} protons and 1 ton of detector.

iv) No significant signal of prompt $\bar{\nu}_\mu$ has been found. Moreover, the agreement between the results from the extrapolation and subtraction methods is poor, as can be seen from Table 2. Taking into account the ratio of ν and $\bar{\nu}$ cross sections, the prompt $\bar{\nu}_\mu$ flux falls below the prompt ν_μ flux with a significance of three standard deviations. While this effect cannot yet be considered as established, it may point to a contribution from charmed baryon production on top of $D\bar{D}$ production. Also the agreement with the rates obtained by the BEBC and CHARM groups is poor, as can been in Fig. 1b.

	$\rho = 1/3$	$\rho = 1$
total rate	2.50 ± 0.16	0.91 ± 0.06
prompt rate (extrapolated)		0.07 ± 0.12 ± 0.07
prompt rate (subtracted)		0.38 ± 0.06 ± 0.08

Table 2

$CC\mu^+$ rates for $E_{tot} > 20$ GeV, corrected for losses and acceptance, at the CDHS position, normalized to 1.10^{18} protons and 1 ton of detector.

v) Table 3 gives the normalized rates of prompt $CCe^+ + e^-$ events, and of prompt $CC\mu^+ + \mu^-$ events, for $E_{tot} > 20$ GeV. The ratio is less than unity for both methods to determine the prompt $CC\mu^+$ and $CC\mu^-$ events. While the result from the extrapolation technique is compatible with unity within errors, the result from the subtraction shows a more pronounced asymmetry. The results from the BEBC and CHARM groups are included in Table 3. They favour an asymmetry rather than equality of the fluxes.

	CDHS	BEBC	CHARM
$CCe^+ + e^-$	1.00±0.09	1.16±0.27	0.98±0.17
$CC\mu^+ + \mu^-$ (extrapolated)	1.30±0.28		2.06±0.64
$(CCe^+ + e^-)/(CC\mu^+ + \mu^-)$ extrap.	0.77±0.18±0.24		0.49±0.21
$CC\mu^+ + \mu^-$ (subtracted)	1.73±0.14	2.35±0.68	1.83±0.32
$(CCe^+ + e^-)/(CC\mu^+ + \mu^-)$ subtr.	0.58±0.07±0.19	0.49±0.20	0.48±0.12±0.10

Table 3

Prompt rates of $CCe^+ + e^-$ and $CC\mu^+ + \mu^-$ events, for $E_{tot} > 20$ GeV (BEBC: $E_{tot} > 10$ GeV), at the CDHS position, normalized to 1.10^{18} protons and 1 ton of detector.

vi) The opposite sign dimuon events collected in all beam dump runs performed so far, show poor agreement with the expected distribution in the projected angle $\Delta\phi$ between the two muons (Fig. 2). However, the small statistics do not permit a firm conclusion.

2. PURPOSE OF THE NEW EXPERIMENT

In the list of results given in Section 1, there is one fundamental question which must be pursued further, namely the equality of the prompt ν_e and ν_μ fluxes. It is clear from the results given above that the central problem is the determination of the prompt ν_μ flux. Contrary to the ν_e case, the background from trivial $\pi \to \mu\nu_\mu$ and $K \to \mu\nu_\mu$ decays is large. The method of extrapolation to infinite density is in principle safe, but requires large statistics and a precise normalization of the runs at different densities. Note that the systematic error quoted in Table 3 reflects a normalization uncertainty of only 5%. The method of subtracting the calculated non-prompt background is more involved, since it is dependent on the production spectra of π and K produced by 400 GeV protons on copper nuclei, and on the neutrino total cross section. The systematic error quoted in Table 3 reflects an overall uncertainty of 15% for the calculated non-prompt background. Since the two methods agree poorly in the prompt $CC\mu^+ + \mu^-$ rate, we content ourselves at the moment to quote both results.

The new experiment aims at a 1% precision (as compared to 5% assumed at present) in the relative normalization of the two runs at different dump densities, and an improvement in the statistical error by a factor two. This precision will allow a decisive test of whether the presently observed asymmetry is real or not.

The problem in the determination of the prompt ν_μ flux is possible proton beam scraping upstream of the dump, since the secondaries produce ν_μ only. In the 1979 beam dump run, the non-prompt ν_μ flux was increased by 5% due to some beampipe windows and beam monitors upstream of the dump. The effect of these materials are taken into account in the analysis.

Suppose, the proton beam has a loss of 10^{-3}, with a decay path of 20 m, as compared to the typical decay path of 20 cm in solid copper. This increases the non-prompt background by 10%, and amounts to a 20% correction of the prompt ν_μ flux, since the prompt ν_μ flux is about one third of the total ν_μ flux. Since such a correction cannot be made reliably, proton beam losses have to be kept below the level of 10^{-4}.

In the 1979 beam dump run, ionization chambers have been installed along the external proton beam in order to have an experimental check on proton beam scraping. It is believed that this was done correctly.

The improvement in the monitoring of proton beam losses, the improvement in the normalization of the proton flux, and the improvement in statistical accuracy are the central aims of the proposed new experiment.

3. DETECTOR

The unique properties of our detector are its large fiducial target mass (500 t of iron) and its excellent muon detection and measurement capability. Both features are indispensable for a precise determination of the prompt $\overset{(-)}{\nu}_\mu$ flux by measuring $CC\mu^-$ and $CC\mu^+$ events.

Our detector will also give a more precise value for the prompt $\nu_e + \bar{\nu}_e$ flux by measuring the excess of muonless events above the expected level of neutral current events. However, no positive identification of $\overset{(-)}{\nu}_e$ induced CC events on an event to event basis will ever be possible in our detector.

We plan to use for the new beam dump experiment the improved version of the WA1 detector[7]. This version provides essentially the same fiducial target mass, but due to a finer sampling an improvement in the hadron energy resolution and in the reconstruction of the muon momentum will be possible.

4. BEAM CONDITIONS

In two earlier documents submitted by the BEBC group (CERN/SPSC/80-34, SPSC/P143) and the CHARM group (CERN/SPSC/80-31, SPSC/P142) it has been proposed to locate the dump at the end of the decay tunnel of the SPS neutrino facility. This location increases the geometrical acceptance of the detectors by approximately a factor four, reducing the statistical error by a factor two with the same 1.10^{18} protons on the target as compared to the 1979 beam dump run.

Together with the new geometry, we consider 1.10^{18} protons sufficient to give a statistically decisive answer on the question of the equality of the prompt ν_e and ν_μ fluxes. The question of the asymmetry of the prompt $\bar{\nu}_\mu$ and ν_μ fluxes should also be resolved by the reduction of the statistical error by a factor two. Of the requested total of 1.10^{18} protons, about 30% should be used on the 1/3 density dump. A third dump of 1/2 density will be prepared, but it should not be used for neutrino detection, but for measurements of the muon flux only.

Our request for 1.10^{18} protons is in contrast to the request of 4.10^{18} protons from the BEBC and CHARM groups. We think that the allocation of protons after the SPS shutdown has to be seen in the context of the whole neutrino programme. We have a strong interest in the precision determination of the nucleon structure functions in high energy narrow band beams, with a reasonable share of protons. We believe that the requested number of 1.10^{18} protons should answer all questions opened up by the 1979 beam dump run. In the event that the analysis will show the need for more than 1.10^{18} protons, the SPSC could still allocate more protons at a later stage.

Both the 1977 and 1979 beam dumps have worked with 400 GeV protons. Since the SPS is scheduled for 450 GeV operation in 1982, we consider it preferable to use 450 GeV protons in the next beam dump run. One expects several factors to increase proportionally to the proton energy: the amount of charm production ($\propto E$), the geometrical acceptance of the detectors due to the increased longitudinal momentum of the secondaries ($\propto E^2$), and the neutrino cross section ($\propto E$), yielding an E^4 dependence of the rates. The gain from 450 GeV over 400 GeV amounts to a factor 1.6. More important, in our opinion, is the possibility that if in fact there are new and not yet understood phenomenae at play, higher energy may increase the effect.

In order to keep proton beam losses under control, ionization monitors with full azimuthal coverage will be placed along the whole external proton beam line. 70 μ thick Alu foils will be put 20 m upstream of these ionization monitors, in order to sense beam losses down to the level of 10^{-4}. A second beam current transformer, operated by the physics groups, will be installed.

The pressure in the decay tunnel has to be decreased considerably below the typical present level of 0.2 Torr. In order to keep the increase of the non-prompt ν_μ flux due to proton-gas interactions at the 1% level, a decay tunnel pressure of 0.05 Torr is needed. This can be achieved by installing a plunger pump with better pumping capacity.

5. TIME SCALE

We propose to carry out the new beam dump experiment as soon as 450 GeV protons from the SPS are routinely available. We expect this at the beginning of 1982. We consider the improvement in the signal to background ratio due to 450 GeV protons sufficiently interesting that we are prepared to accept the half year delay with respect to the earliest possible start immediately after the shutdown.

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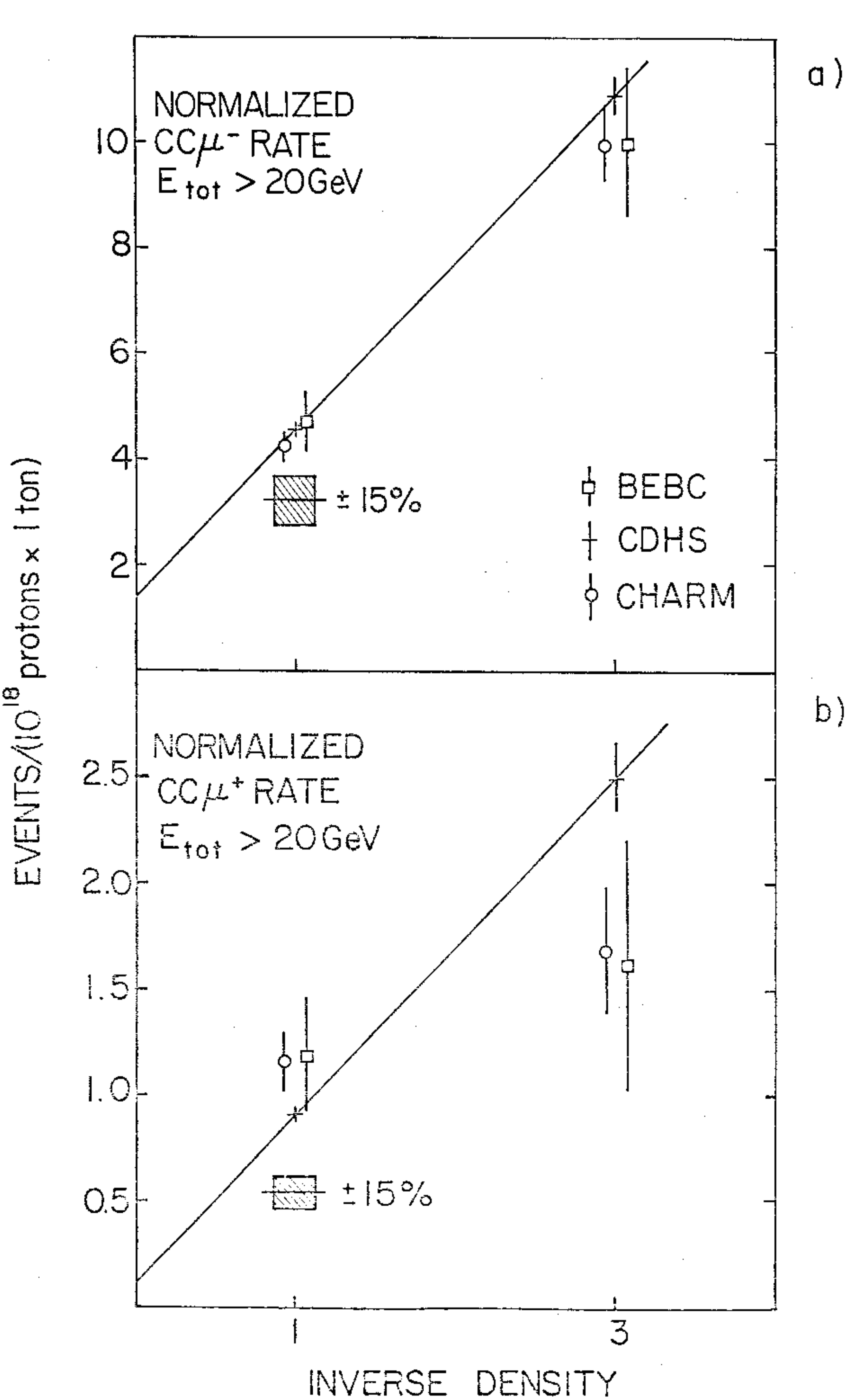
FIGURE CAPTIONS

Figure 1 : CCμ rates for $E_{tot} > 20$ GeV from the BEBC, CDHS and CHARM groups as a function of the inverse dump density. The rates are normalized to 1.10^{18} protons and 1 ton of detector at the position of the CDHS apparatus. Also shown is the predicted rate from the non-prompt π, K decay background (Ref. 6).

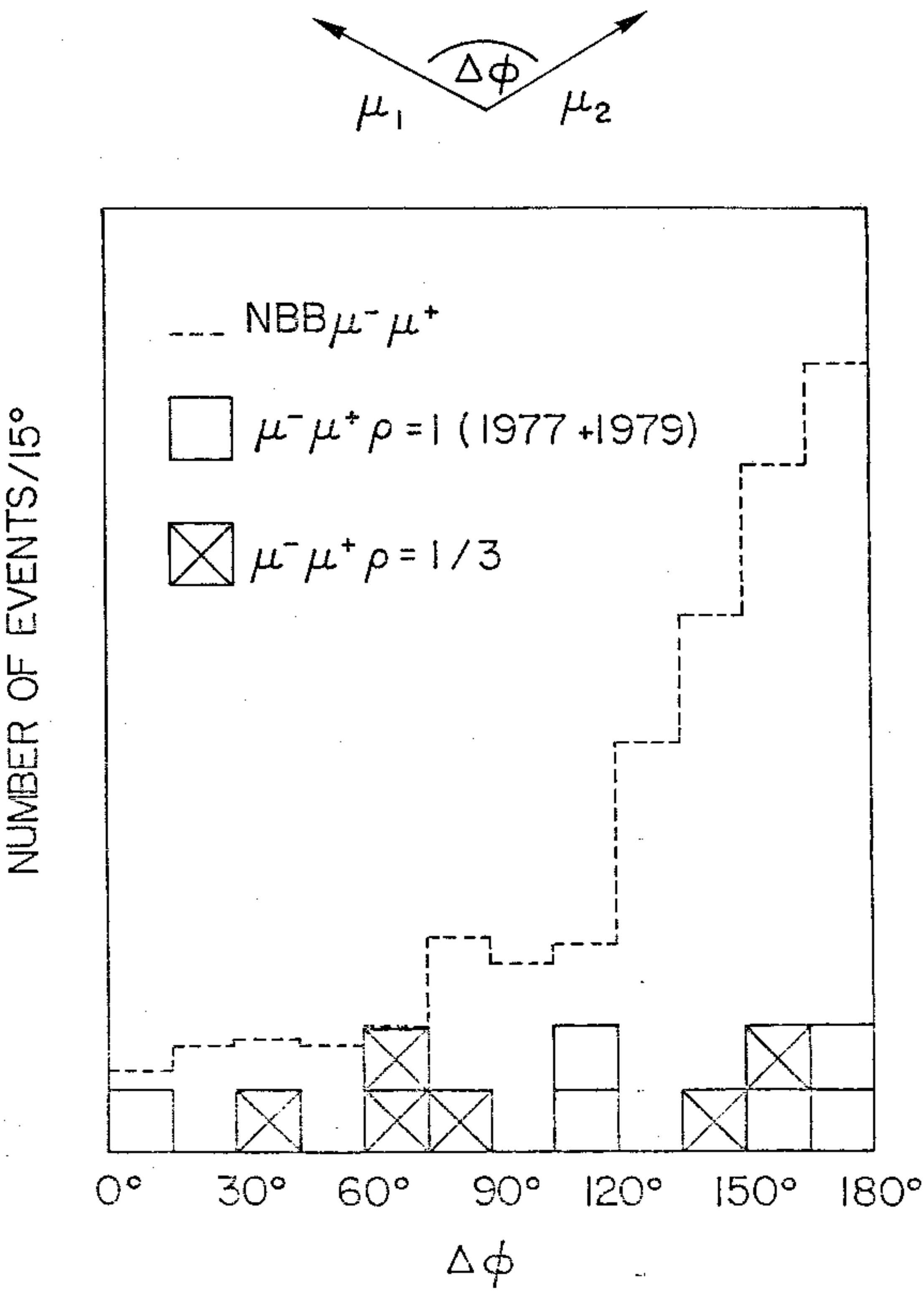
Figure 2 : $\Delta\phi$ distribution of all opposite sign dimuon events with muon momenta above 5 GeV. $\Delta\phi$ is the azimuthal angle between the two muons, projected onto the plane perpendicular to the incident neutrino momentum. The dotted line represents the $\Delta\phi$ distribution of a larger sample of dimuon events recorded in a narrow band neutrino beam.

Fig. 1



a)
NORMALIZED
CCμ⁻ RATE
E tot > 20GeV
10
8
6
4
2
± 15%
BEBC
CDHS
CHARM
b)
NORMALIZED
CCμ⁺ RATE
E tot > 20GeV
2.5
2.0
1.5
1.0
0.5
±15%
EVENTS/(10^18 protons × 1 ton)
1
3
INVERSE DENSITY

Fig. 2



Δφ
μ1
μ2
NBB μ⁻μ⁺
μ⁻μ⁺ ρ = 1 (1977 +1979)
μ⁻μ⁺ ρ = 1/3
NUMBER OF EVENTS/15°
0°
30°
60°
90°
120°
150°
180°
Δφ