THE STATUS OF THE SEARCH FOR MUONLESS EVENTS IN THE BROAD BAND NEUTRINO BEAM AT NAL

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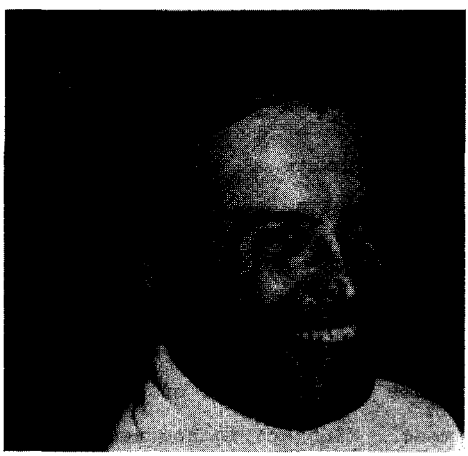
Abstract: The current status and results of the search for muonless events in the broad band neutrino beam at NAL are presented. An excess of events unaccompanied by muon is observed which cannot be explained by instrumental effects. The ratio of the unaccompanied events to the customary charged current events is 0.20 ± 0.05 for the mixture of ν and $\bar{\nu}$ in this beam.

Résumé : On présente la situation actuelle et les résultats de la recherche d'événements sans muons avec le faisceau de neutrinos de large bande à NAL. On observe un excès d'évènements non accompagnés de muons qui ne peut pas être imputé aux instruments. Le rapport des évènements non accompagnés sur les évènements habituels à courant chargé est de 0.20 $\pm$ 0.05 pour le mélange de ν et $\bar{\nu}$ dans ce faisceau.



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The deep inelastic scattering of neutrinos described by the usual phenomenological theory results in events of the type

$$\binom{\nu}{\bar{\nu}} + N \rightarrow \binom{\mu^-}{\mu^+} + X(E_H, \vec{p}_H) \qquad 1)$$

where X represents the produced hadrons which have total energy E_H and momentum $\vec{p}_H$. The object of our search is to find events of the type

$$\binom{\nu}{\bar{\nu}} + N \rightarrow X(E_H, \vec{p}_H) \text{ only} \qquad 2)$$

The experimental apparatus and arrangement has been described by Benvenuti[1] and is shown in Fig. 1. The presence of reaction 2) is signaled by the absence of a count in anti-counter A and the deposition of energy $E > E_{threshold}$ in the calorimeter.

The "muon" can be identified as a track appearing after a large number of collision lengths in the calorimeter and iron (eg. in counter C). The events without such a characteristic compose the raw sample of muonless events.

Possible backgrounds which could contribute to this sample of events are:

a) Cosmic ray showers.

b) Neutral hadrons interacting in the calorimeter.

c) Events of reaction 1) for which the muon is not identified.

The cosmic ray background was monitored by activating the apparatus for a time equal to that of the gate containing the beam spill ($\sim$1 msec). Subject to the requirements made in the analysis described below, the contribution of cosmic rays to the sample was measured to be completely negligible.

The elimination of neutral hadrons requires a further restriction of the data sample. The tracks produced by the hadron shower are measured in the wide gap spark chambers imbedded in the calorimeter and extrapolated to their common vertex. The vertex measurements in the various stereo views are combined to locate the vertex in space. The sample can then be required to have the primary interaction within a protected fiducial volume. The mean angle of the shower is also measured and almost all events have a mean angle within 15° of the ν beam direction. This means that no neutral hadron can enter from the side, miss the A counter, and remain in the sample. The distribution of vertices of hadron interactions should then show the characteristic exponential distribution as a function of distance along the ν beam. To the extent that the distribution is uniform (i.e. expected for ν interactions) the hypothesis that muonless events arise from hadron interactions must be discarded.

Finally, the sample of muonless events must be corrected for events of reaction 1) whose muon escapes detection; primarily those whose muon is produced at such a large angle that it is outside the angular acceptance of the muon spectrometer. This calculation is done by Monte Carlo techniques

The result of a preliminary search completed in July 1973 was that a true unaccompanied signal was observed. Let R (R_{obs}) be the true (observed) ratio of the cross section for reaction 2) to that of reaction 1). Then the equation which relates them is:

$$R_{obs} = \frac{R + (1 - \varepsilon)}{\varepsilon}$$

where ε is the fraction of events of reaction 1) identified as a muon. We found

$$R = 0.29 \pm .09 \text{ (error is statistical only).}$$

(Subsequent reanalysis in the light of our repetition of the experiment reduced the value to $R = 0.22 \pm .08$.)

In the course of completing this preliminary experiment we discovered the limitations of our apparatus, and we made two significant changes to reduce or eliminate possible sources of error. These were:

a) To increase the solid angle acceptance of the muon identifier. About 14" of iron was added between calorimeter module 16 and SC4. The size of counter C was increased from 8' × 8' to ∿12' × 12' and the size of spark chamber 5 from 8' × 8' to ∿10' × 10'.

b) To increase the precision with which the interaction vertex was located. We supplemented the narrow stereo angle views (15°) with a 90° view. We then were able to locate the vertex within a couple of inches in both dimensions.

In the fall of 1973 we obtained data with the improved detector exposed to an anti-neutrino enriched magnetic horn focussed beam produced by 300 GeV primary protons.[2] We tentatively signal the presence of a muon by a count in counter B. We observe about 3000 raw triggers ($\bar{A}E$) whose distribution along ν beam axis is shown in Fig. 2. Note that the $\bar{A}E$ distribution shows deviations from uniformity only in a slight enhancement in module 1 which is consistent with a known 5% inefficiency in the anti-coincidence counter A, and in a depletion of events beginning in module 13 caused by incomplete containment of the hadronic shower and consequent failure to satisfy the trigger requirement $E > E_{th} \simeq 2$ GeV. These effects were eliminated by retaining only those events between modules 5 and 12. The non-uniform behavior of the $\bar{A}EB$ sample is due to the changing solid angle acceptance of the muon identifier.

About 1410 events survive this z axis cut. The hadron shower was measured and the vertex was required to lie within $|x|, |y| < 1.2$ m. About 800 events have vertices which can be reconstructed and about 538 pass the 1.2 m cut. The events which fail are mainly those with low energy deposition in the calorimeter and consequently too few tracks to determine the vertex or to hadrons entering the calorimeter from the side. The effect of the latter is eliminated by a fiducial volume cut on vertex position. The extra muon in the $\bar{A}EB$ sample allows more efficient vertex measurement. This effect vanishes above $E_H \cong 15$ GeV.

The sample which remains has <u>no bias depending on the presence of the muon</u> except this slight difference in efficiency below $E_H = 15$ GeV. (This would act to reduce our signal R.) Furthermore, the uniform distribution of events throughout the calorimeter indicate <u>no significant contamination of neutral hadrons</u>.

It remains to identify the muon. Three signatures of the presence of a muon were used

Type	Solid Angle (sr.)
μ_1 = Spark chamber 4 or Counter B	0.45
μ_1' = Spark chamber 4 only	0.29
μ_2 = Spark chamber 5 or Counter C	0.27

A new problem was discovered in analyzing the muon signatures μ_1 and μ_1'. This was the possibility that hadrons could "punch through" the limited shielding and appear as tracks in SC4 or as counts in counter B. This was quantitatively studied by scanning events which had a clearly identified muon (i.e. one which passed through several magnet modules) and measuring the number with > 1 track in SC4. This experimentally determined probability is plotted in Fig. 3 and Fig. 4 as a function of vertex position and hadron energy. The amended formula relating R_{obs} and R_{true} then becomes

$$R_{obs} = \frac{(1 - \varepsilon_p)[R + (1 - \varepsilon)]}{\varepsilon_p R + [\varepsilon + \varepsilon_p - \varepsilon_p]}$$

where ε_p is the punch through probability and ε is the efficiency for identifying the muon (angular acceptance).

The angular acceptance can now be determined experimentally with the improved apparatus. In Fig. 5 the polar angular distribution of identified muons is shown. This distribution has been corrected for the azimuthal acceptance of the apparatus, assuming a uniform azimuthal distribution of the primary ν interactions. The distribution is not measured for angles > 500 mr. The implication of this blind spot is shown in Fig. 6. The shaded region indicates the portion of the x-y plot unmeasured. Note that since this region is basically a strip along the x axis, no bizarre x distribution could be responsible for the muonless events and remain unseen. Shown in Fig. 6 is the shape of the y distribution which would be necessary to "explain" the excess of muonless events. Although the "explanation" cannot be ruled out is would be at least as interesting and as unexpected as other explanations. We estimate the correction for the unseen region by extrapolating the observed y distribution uniformly into the region y = 0.85 to 1.0.

Using the value of ε so determined we plot the calculated ratio of unaccompanied events to charged current events as a function of transverse distance from the beam axis and as a function of hadron energy in Figs. 7-8. The stability of the result and the agreement between the various muon signatures with substantially different corrections indicates the improbability of attributing the result to an instrumental effect.

Finally the results are

Signature	μ_1	μ_1'	μ_2
R_{obs}	$\frac{85}{332} = 0.26$	$\frac{116}{301} = 0.39$	$\frac{185}{350} = 0.53$
ε	0.89	0.80	0.79
ε_p	0.26	0.16	0.0
R	0.19 ± 0.04	0.19 ± 0.04	0.22 ± 0.04

$$R = 0.20 \pm 0.05$$

where the error includes our estimate of systematic error. This result together with the measured ratio of μ^+/μ^- in the apparatus is shown in Fig. 9 with the CERN result. The result is <u>not</u> corrected for ν_e contamination of the beam which is expected to be $\sim$1.5%.

In summary, we confirm our earlier observation that an anomalous signal of events of reaction 2). The necessary corrections are <u>completely</u> determined experimentally excepting the assumption of azimuthal symmetry. There is <u>no</u> assumption concerning form factors flux etc.

References

1. A. Benvenuti, Recent Results on ν, $\bar{\nu}$ Charged Current Interactions at NAL, this conference.

2. A Benvenuti et al., Phys. Rev. Letters (to be published).

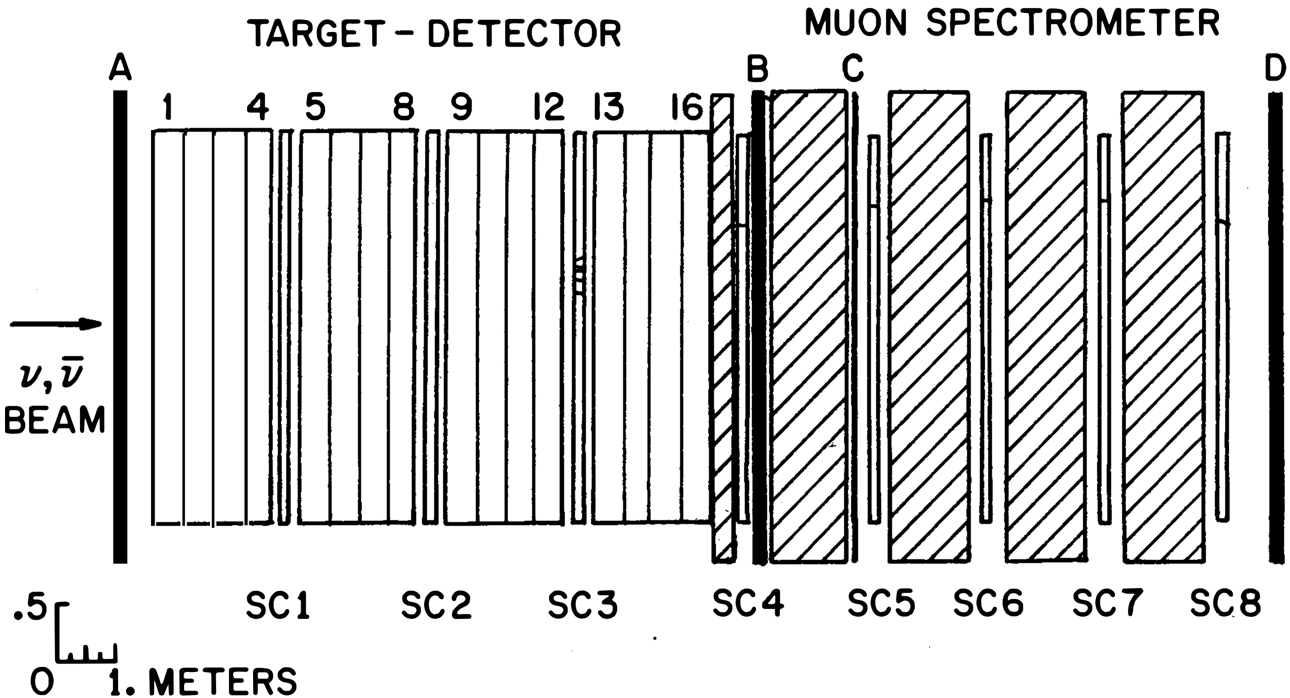
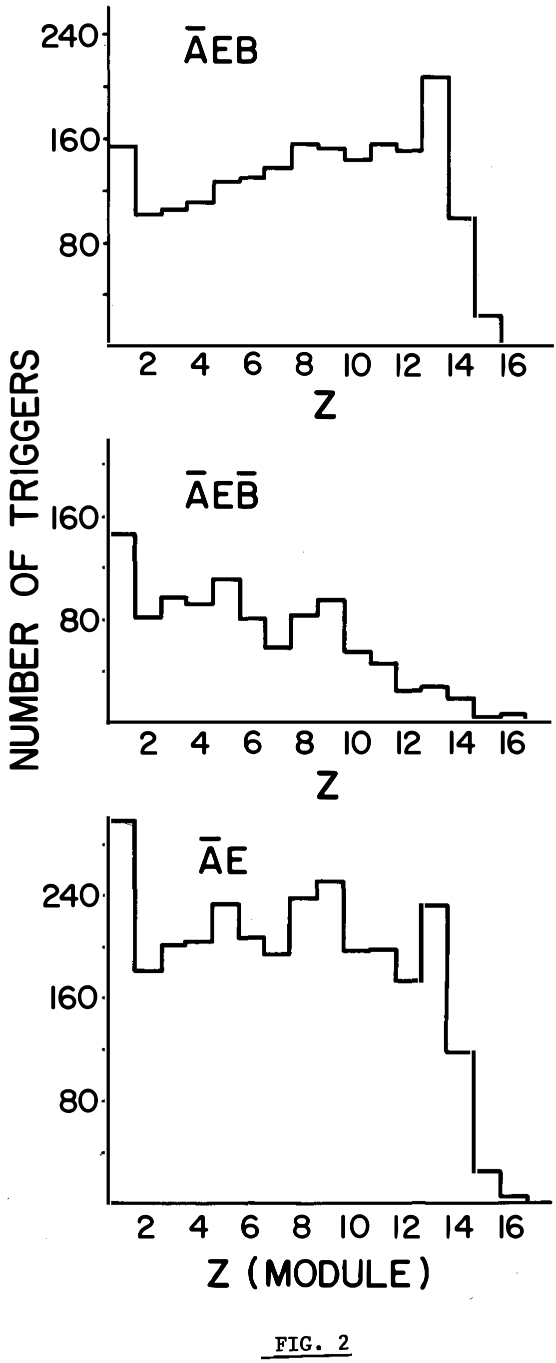

TARGET - DETECTOR
MUON SPECTROMETER
A
B
C
D
1
4
5
8
9
12
13
16
$\nu, \bar{\nu}$
BEAM
SC1
SC2
SC3
SC4
SC5
SC6
SC7
SC8
.5
0
1. METERS

FIG. 1



NUMBER OF TRIGGERS
ĀEB
240
160
80
2 4 6 8 10 12 14 16
Z
ĀEB̄
160
80
2 4 6 8 10 12 14 16
Z
ĀE
240
160
80
2 4 6 8 10 12 14 16
Z (MODULE)

FIG. 2

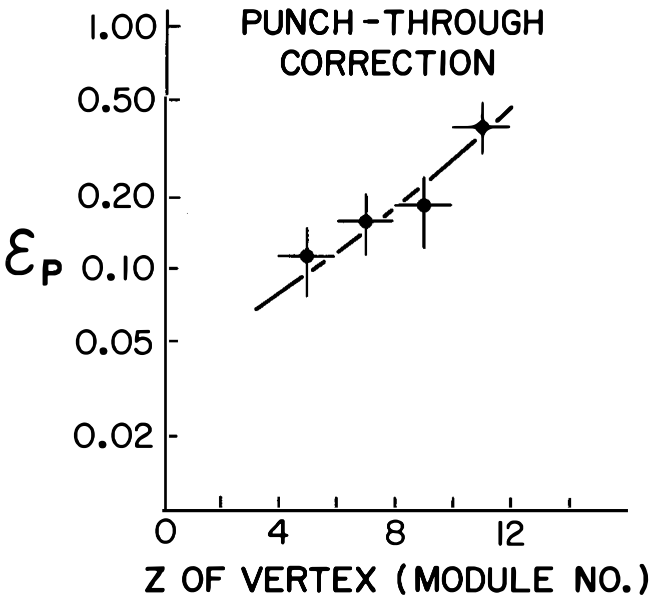

PUNCH-THROUGH
CORRECTION
1.00
0.50
0.20
$\mathcal{E}_P$
0.10
0.05
0.02
0
4
8
12
Z OF VERTEX (MODULE NO.)

FIG. 3

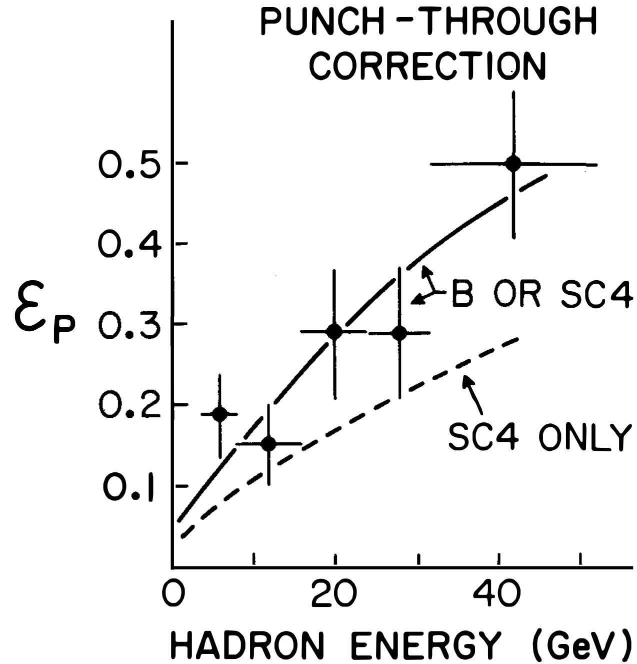

PUNCH-THROUGH
CORRECTION
0.5
0.4
$\mathcal{E}_P$
0.3
0.2
0.1
B OR SC4
SC4 ONLY
0
20
40
HADRON ENERGY (GeV)

FIG. 4

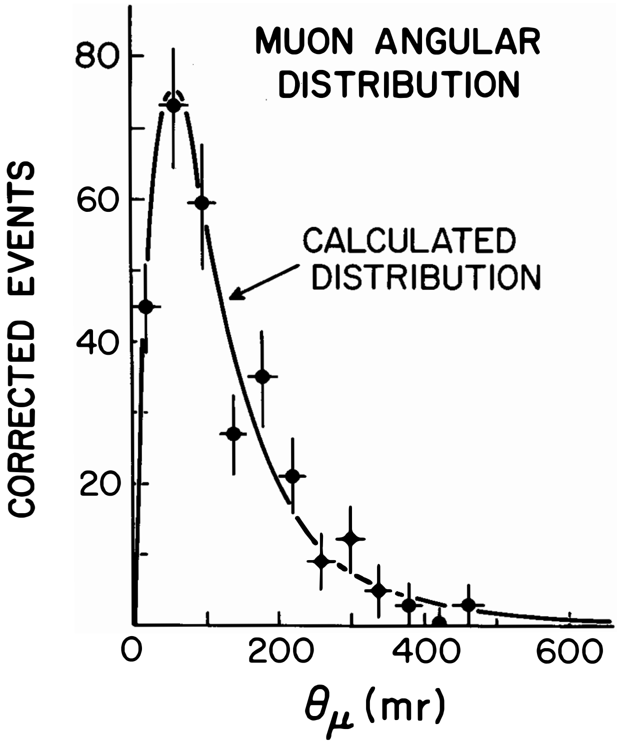

MUON ANGULAR DISTRIBUTION
CALCULATED DISTRIBUTION
CORRECTED EVENTS
80
60
40
20
0
200
400
600
θ_μ (mr)

FIG. 5

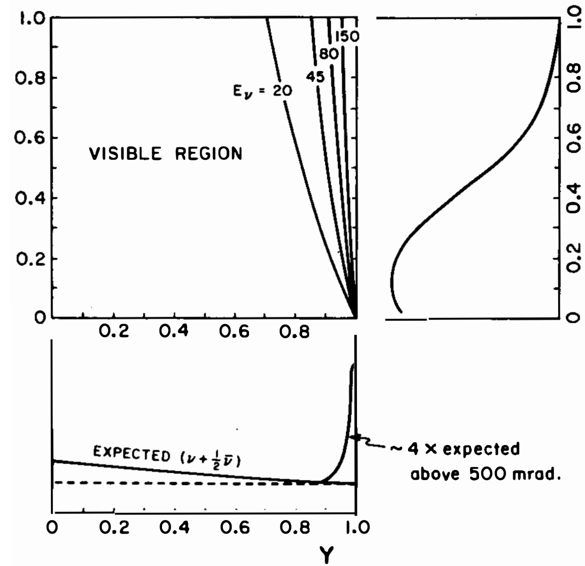

1.0
0.8
0.6
0.4
0.2
0
VISIBLE REGION
E_ν = 20
45
80
150
X
EXPECTED $(\nu + \frac{1}{2}\bar{\nu})$
~ 4 × expected above 500 mrad.
0.2
0.4
0.6
0.8
1.0
Y

FIG. 6

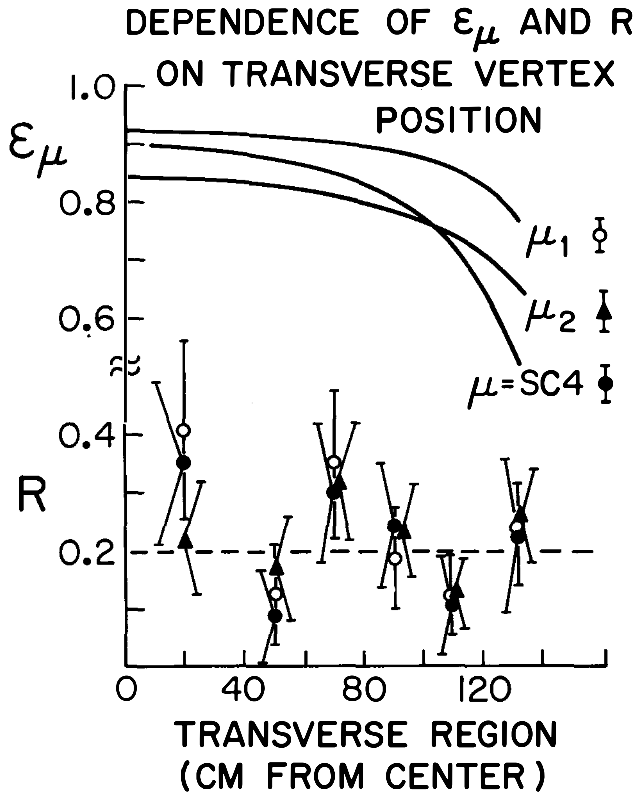

DEPENDENCE OF ε_μ AND R ON TRANSVERSE VERTEX POSITION
ε_μ
R
1.0
0.8
0.6
0.4
0.2
0
40
80
120
μ_1
μ_2
μ=SC4
TRANSVERSE REGION
(CM FROM CENTER)

FIG. 7

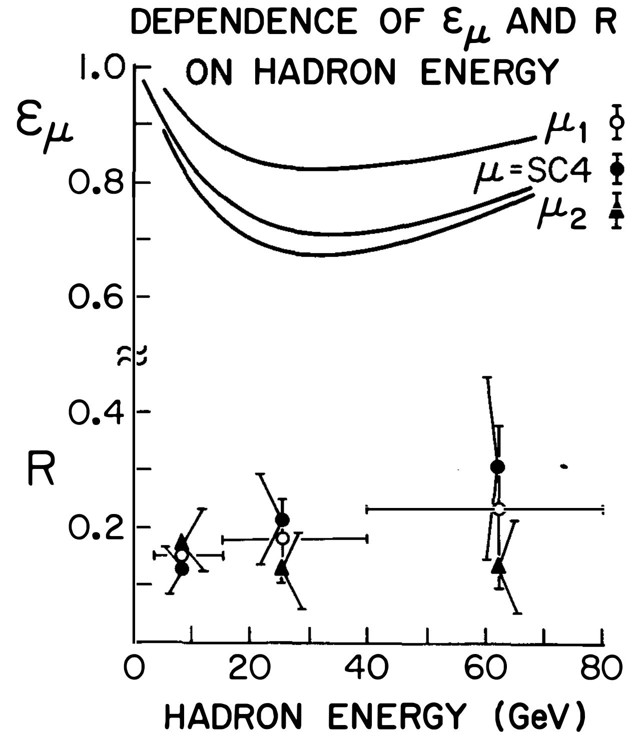

DEPENDENCE OF ε_μ AND R ON HADRON ENERGY
ε_μ
R
1.0
0.8
0.6
0.4
0.2
0
20
40
60
80
μ_1
μ=SC4
μ_2
HADRON ENERGY (GeV)

FIG. 8

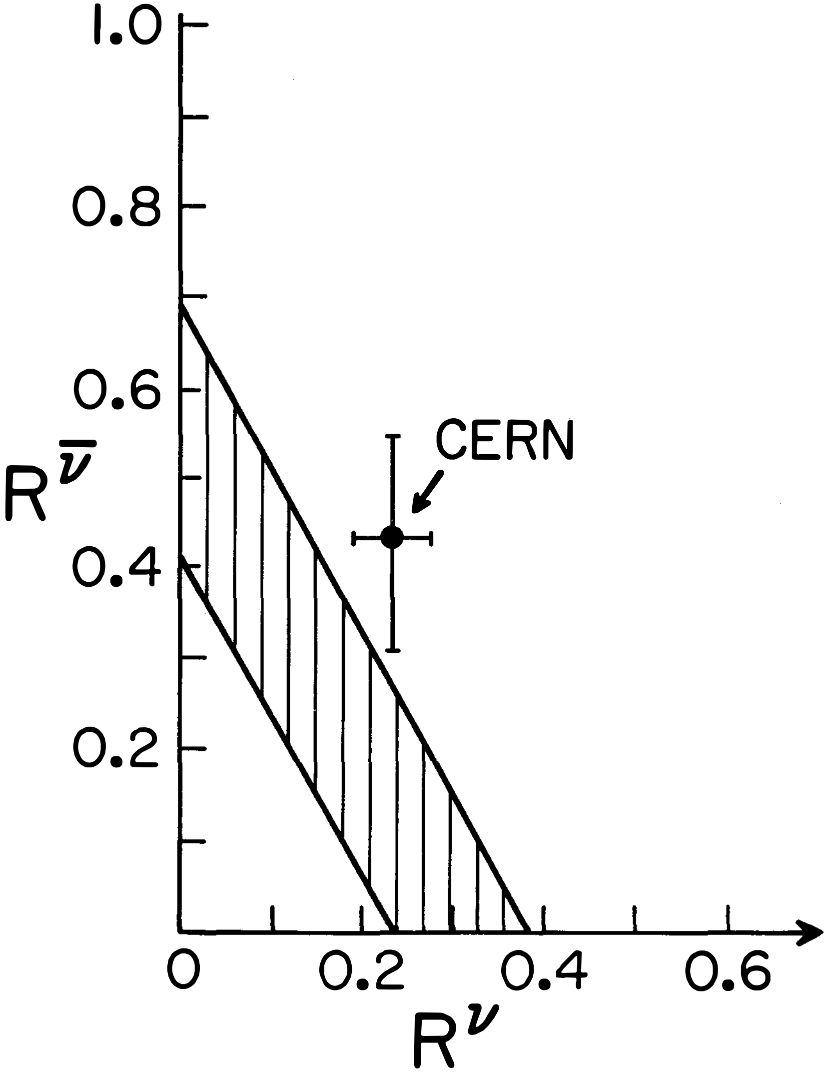


FIG. 9