IC/76/78
INTERNAL REPORT
(Limited distribution)

International Atomic Energy Agency

and

United Nations Educational Scientific and Cultural Organization

INTERNATIONAL CENTRE FOR THEORETICAL PHYSICS

TOPICAL MEETING

ON LEPTON INTERACTIONS AND NEW PARTICLES

6 - 9 July 1976

PART I

(Contributions)

MIRAMARE - TRIESTE

July 1976

NEUTRINO PHYSICS AT FNAL

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I. NAIVE COMPARISON OF e^+e^- PHYSICS AND $\nu(\bar{\nu})$ PHYSICS

A. $e^+ + e^-$ SCATTERING.

(i) $\psi(J)$, ψ', ... spectroscopy

(ii) $e\mu$ final states - heavy lepton ~1.8 GeV

(iii) Mass peaks in $K\pi$, $K(n\pi)$ at 1.86 GeV

(iv) Dual thrust in ~2 GeV mass region

B. $\nu(\bar{\nu}) + N$ SCATTERING

(i) More difficult to obtain significant data samples: $\sigma \approx 10^{-37}\,cm^2$ not $10^{-33}\,cm^2$

(ii) Compromise $\Longrightarrow$ maximal info per event vs mass for high event rate

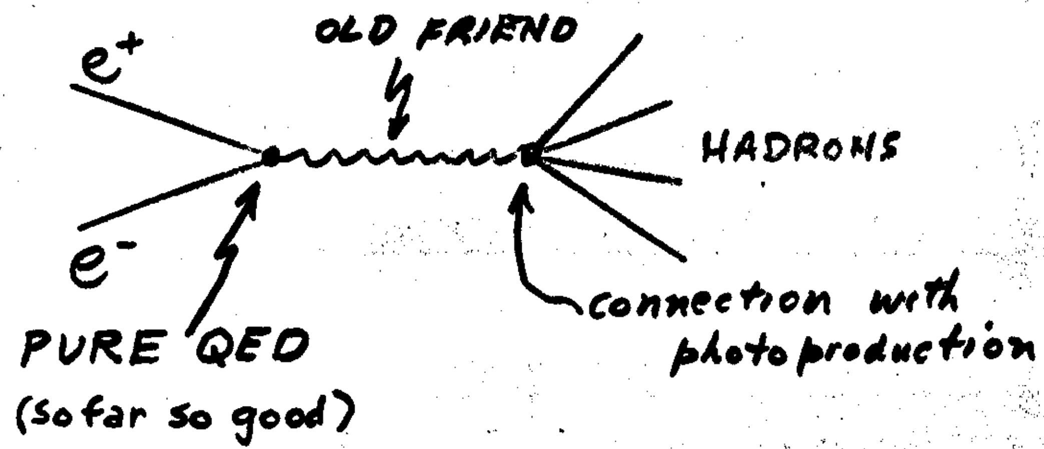
(iii) Incisiveness

Limitations due to (i) and (ii)

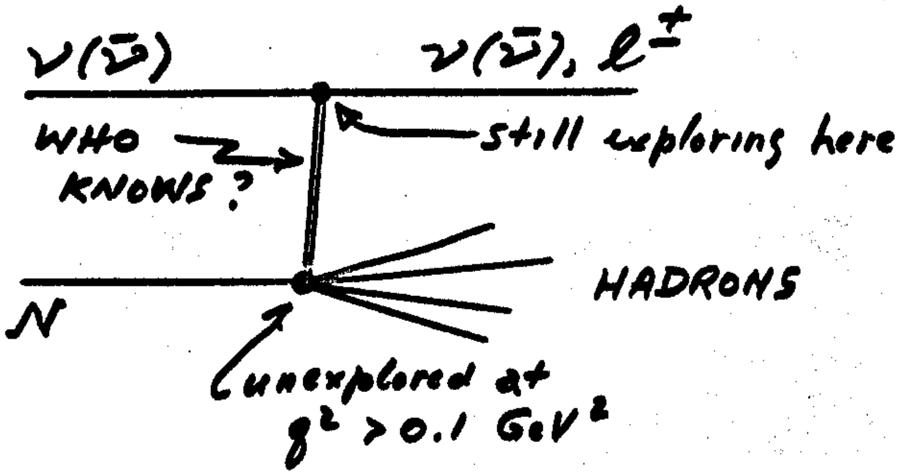
Continuous $\nu, \bar{\nu}$ spectra

Higher laboratory energy

(iv) Diversity of unexplored phenomena, e.g.,



VS



Best of both worlds.

II WHAT IS THRUST OF PRESENT $\nu(\bar{\nu})$ DATA ?

Many questions, some answers, gross overexposure

(i) Quickly, how are the experiments done?

(ii) Zero-Mu Physics: leave mostly to next speaker, but two salient points here

(iii) Two-Mu (One-Mu, One-Electron) Physics

(iv) One-Mu Physics

Thence to

III SOME TENTATIVE CONCLUSIONS

and

IV THE IMMEDIATE FUTURE

EXP. 1A HPWF

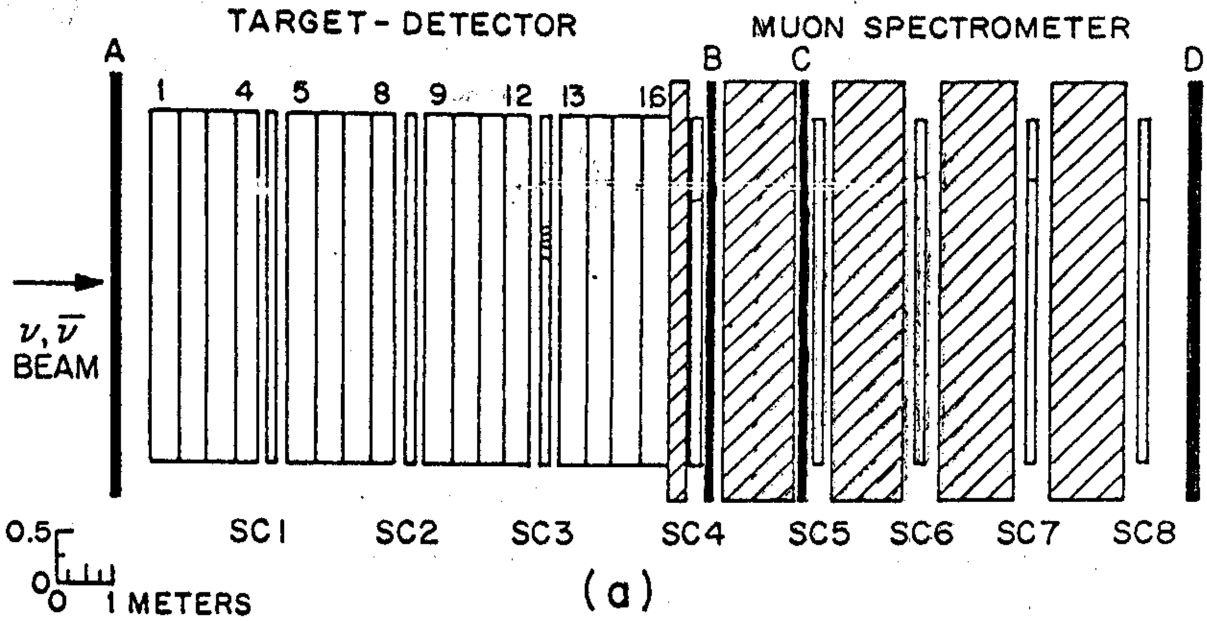
HARVARD — C. RUBBIA, L. SULAK

PENNSYLVANIA — W. FORD, T.Y. LING, F. MESSING*, A.K. MANN

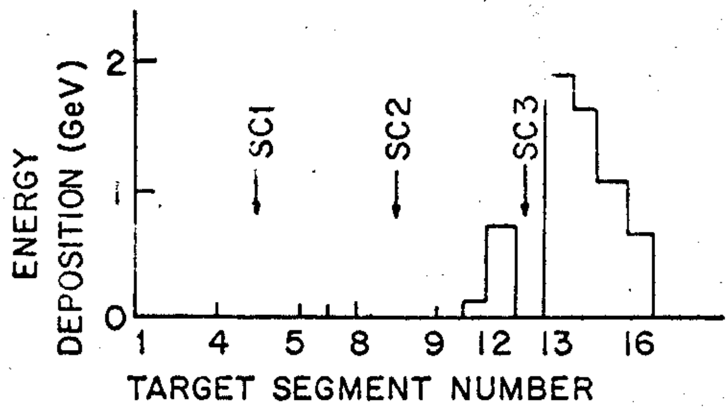
WISCONSIN — A. BENVENUTI, D. CLINE, R. IMLAY+, D. REEDER, P. WANDERER#

FERMILAB — R. STEFANSKI

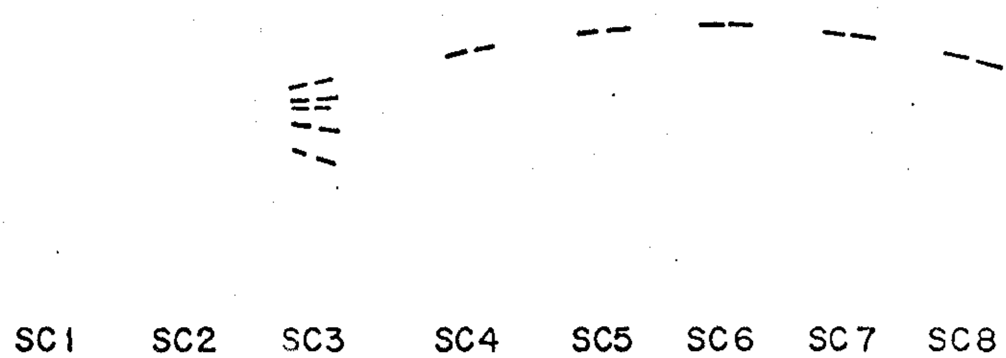
* CORNELL
\+ RUTGERS
\# BNL


TARGET - DETECTOR
MUON SPECTROMETER
A
B
C
D
1
4
5
8
9
12
13
16
ν, ν̄
BEAM
SC1
SC2
SC3
SC4
SC5
SC6
SC7
SC8
0.5
0
0
1 METERS

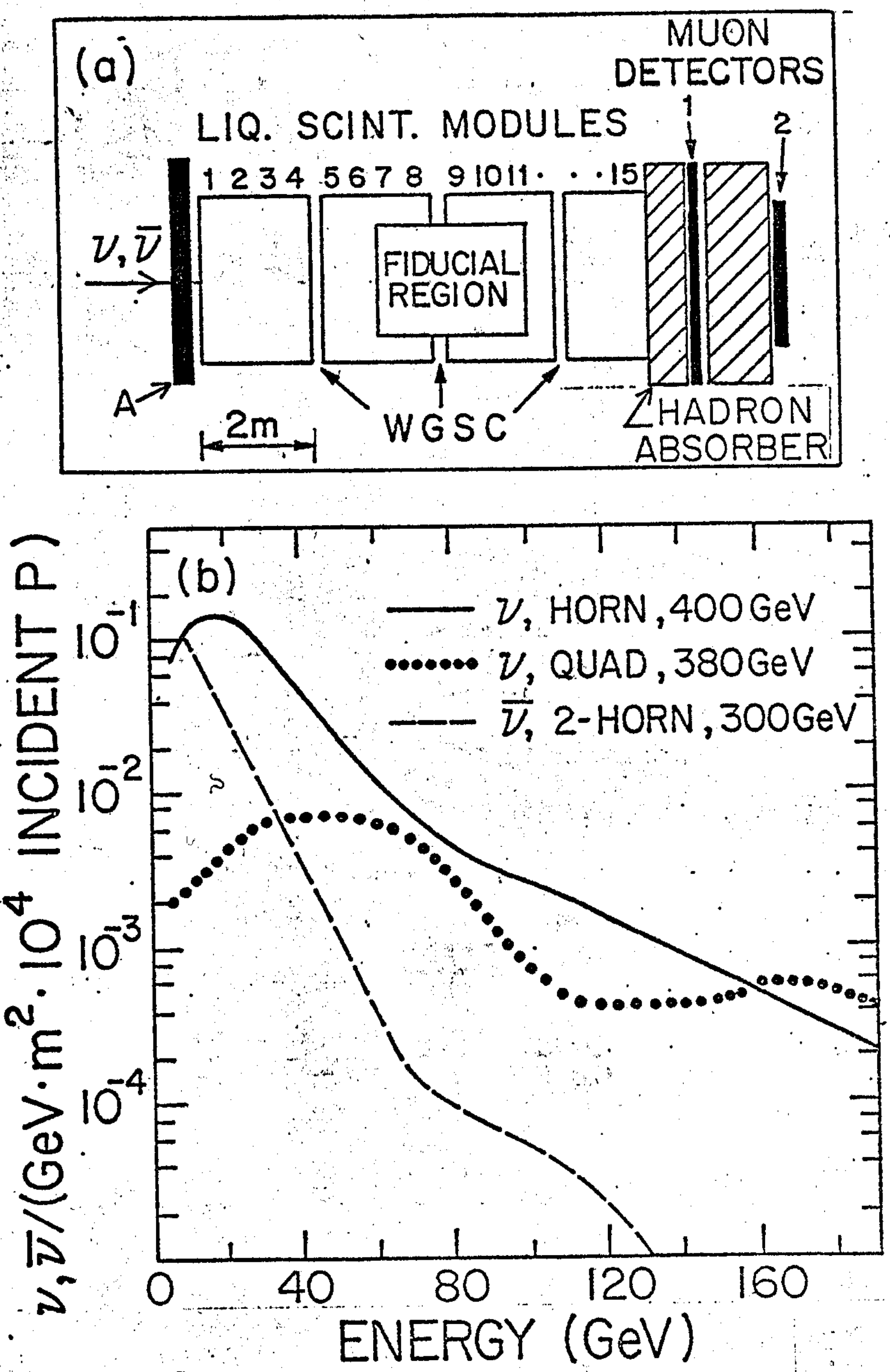
(a)


ENERGY
DEPOSITION (GeV)
2
1
0
SC1
SC2
SC3
1
4
5
8
9
12
13
16
TARGET SEGMENT NUMBER

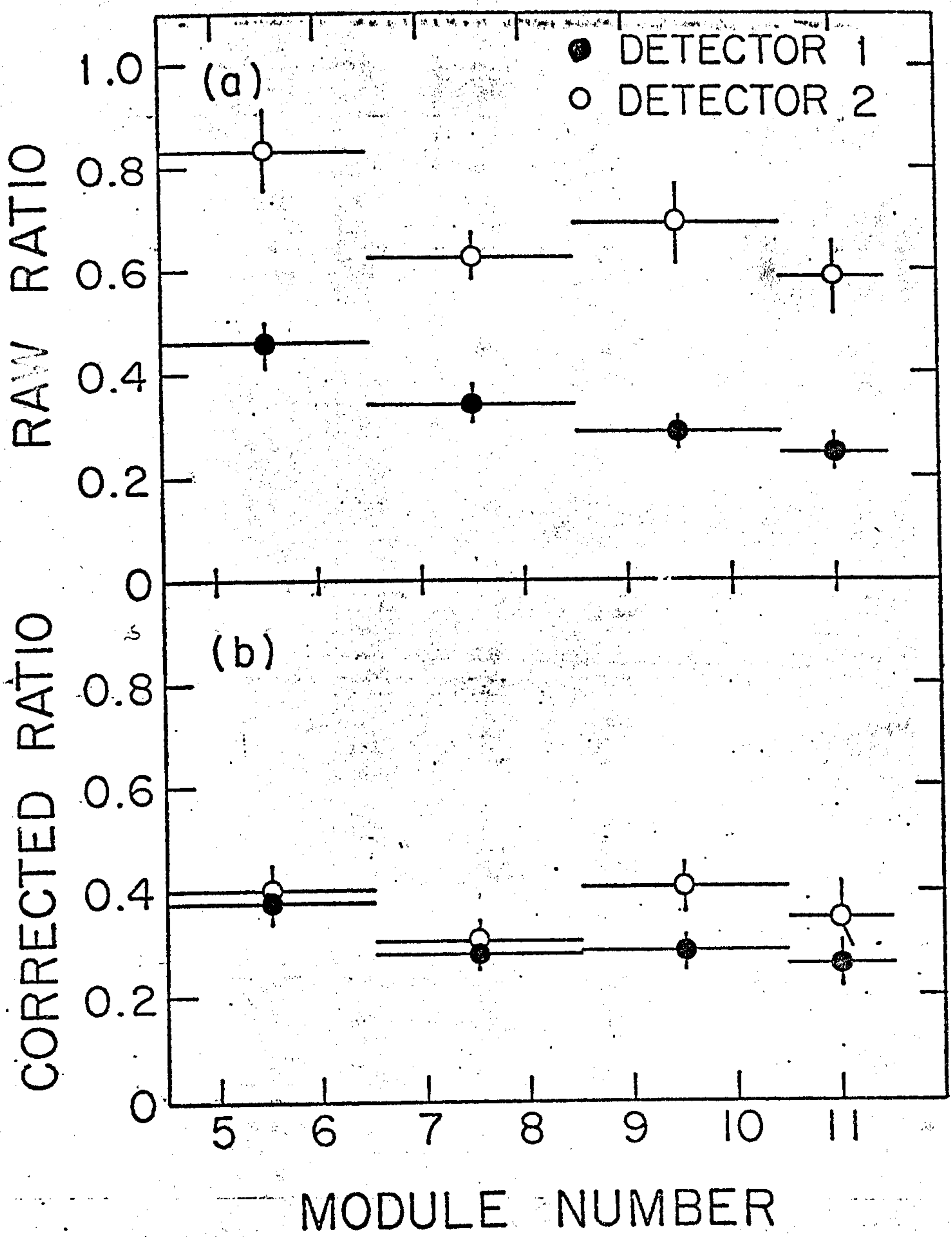
(b)


SC1
SC2
SC3
SC4
SC5
SC6
SC7
SC8

(c)



(a)
MUON DETECTORS
1
2
LIQ. SCINT. MODULES
1 2 3 4 5 6 7 8 9 10 11 · · · 15
ν, ν̄
FIDUCIAL REGION
A
2m
WGSC
HADRON ABSORBER
(b)
ν, HORN, 400 GeV
ν, QUAD, 380 GeV
ν̄, 2-HORN, 300 GeV
ν, ν̄/(GeV·m²·10⁴ INCIDENT P)
10⁻¹
10⁻²
10⁻³
10⁻⁴
0
40
80
120
160
ENERGY (GeV)


DETECTOR 1
DETECTOR 2
(a)
(b)
RAW RATIO
CORRECTED RATIO
1.0
0.8
0.6
0.4
0.2
0
5
6
7
8
9
10
11
MODULE NUMBER

BEAM	COMMENT	R^{ν}	$R^{\bar{\nu}}$
SINGLE HORN	PURE ν BEAM $\langle E_{\nu} \rangle = 53$ GeV	0.31 ± 0.06	
QUAD TRIPLT (1974)	MIXED BEAM $\langle E_{\nu} \rangle = 78$ GeV	0.24 ± 0.06	
QUAD TRIPLT (1975)	MIXED BEAM $\langle E_{\nu} \rangle = 85$ GeV	0.29 ± 0.04	
DOUBLE HORN WITH PLUG	PURE $\bar{\nu}$ BEAM $\langle E_{\bar{\nu}} \rangle = 41$ GeV		0.39 ± 0.10

– for $E_H > 4$ GeV –

TEST OF THE FORM OF NC

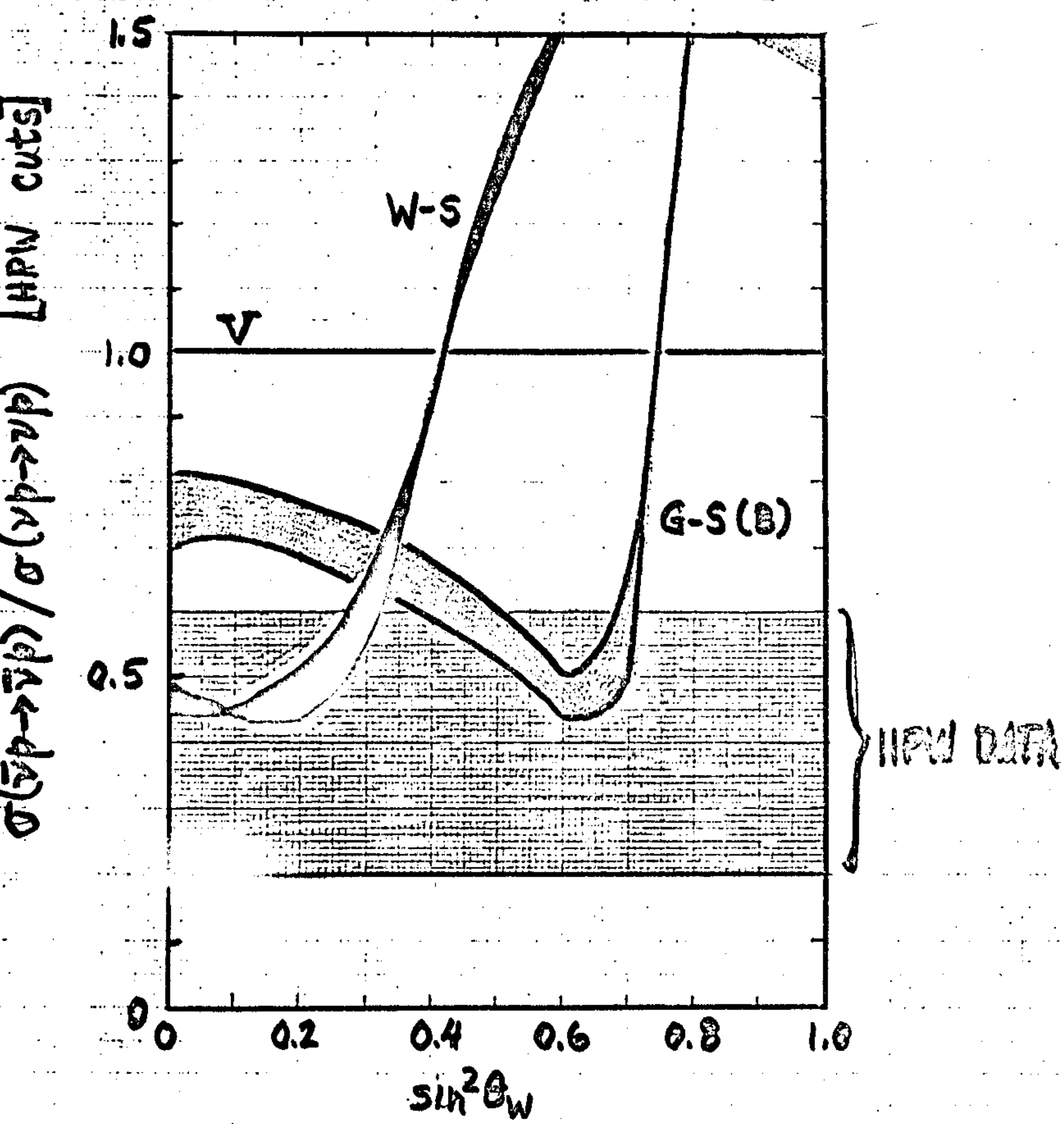
If we write

$$\frac{d\sigma_N^{\nu}}{dy} = a + b(1-y)^2$$

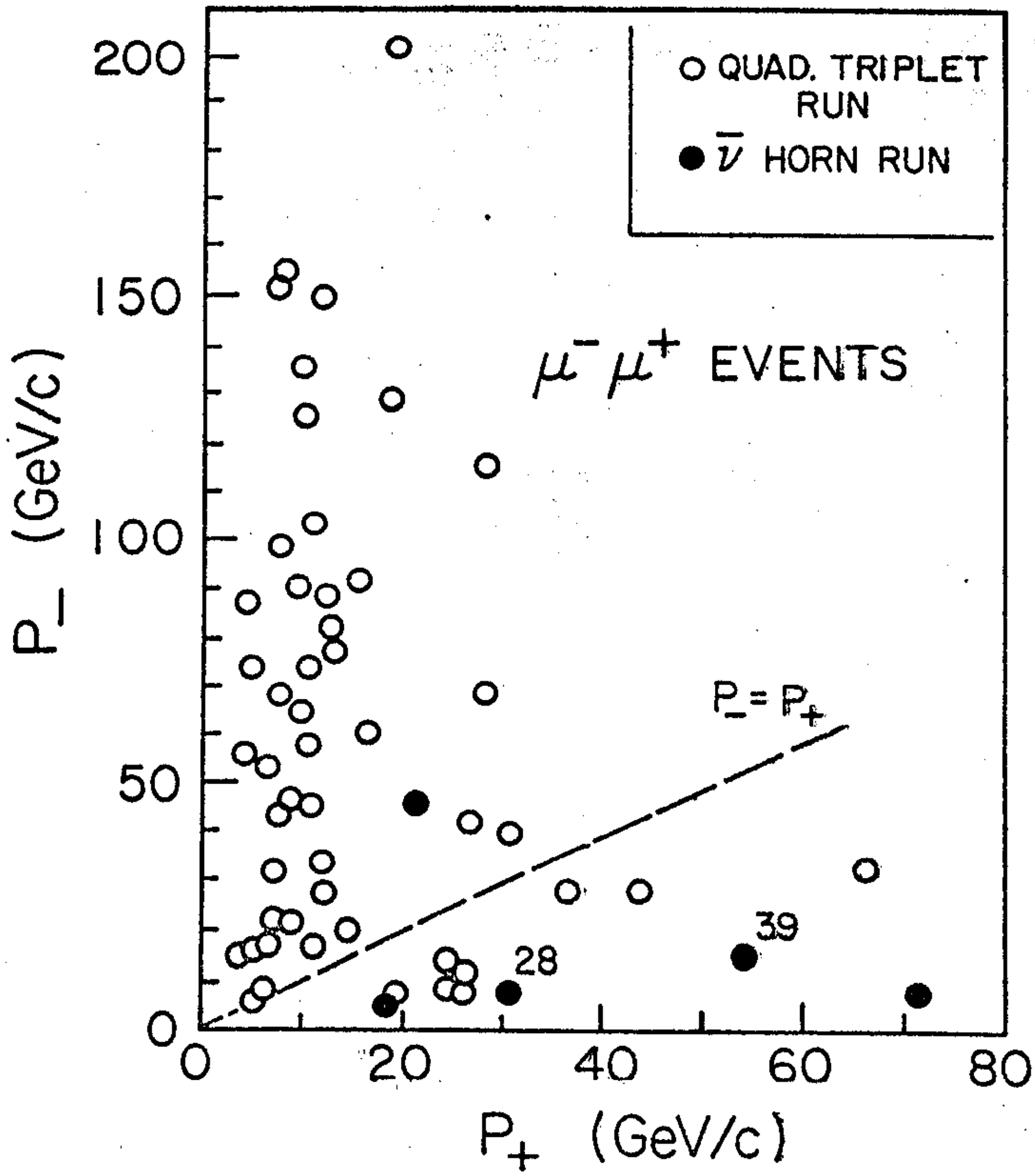
$$\frac{d\sigma_N^{\bar{\nu}}}{dy} = b + a(1-y)^2$$

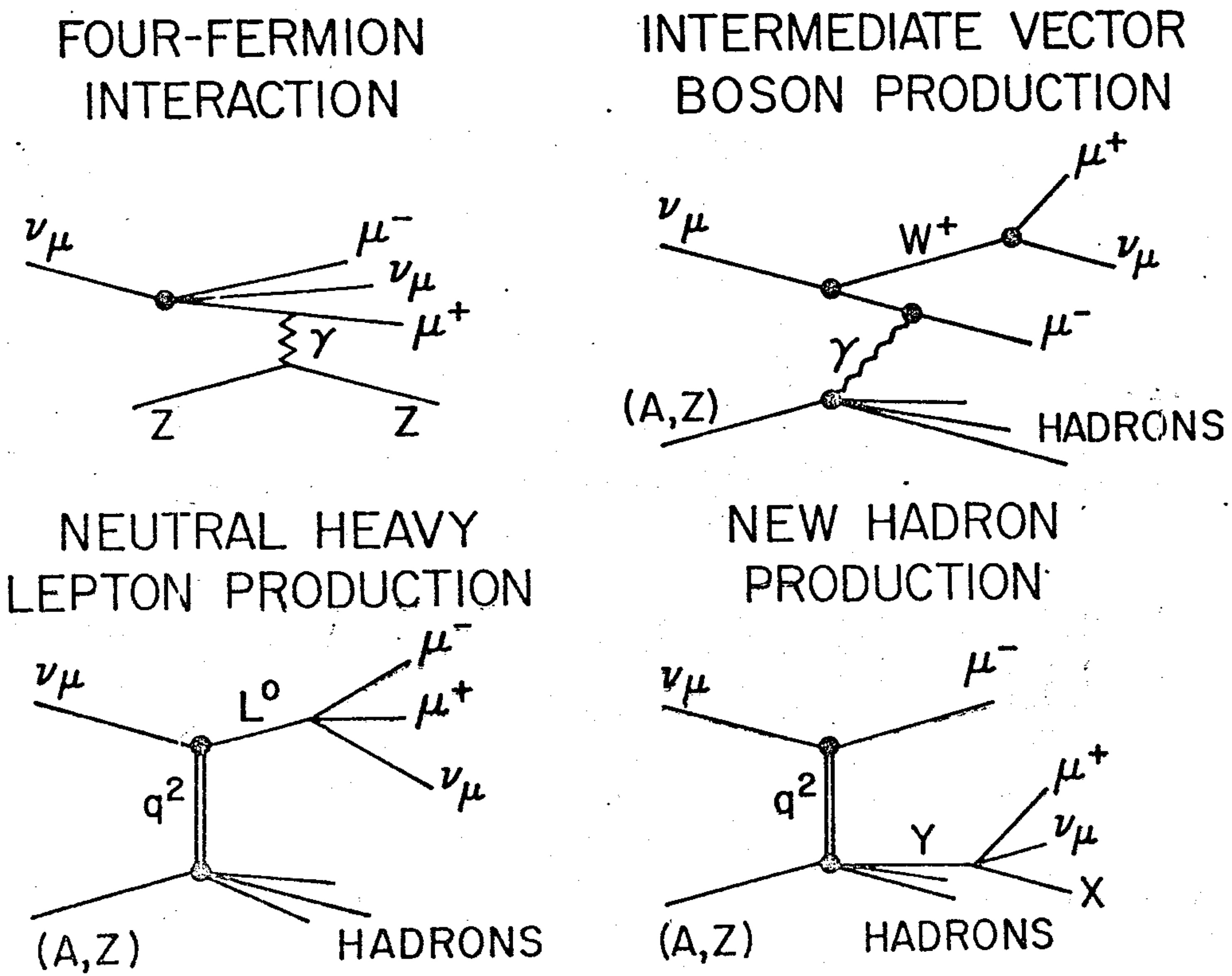
FORM OF THE WEAK NEUTRAL CURRENT	$\sigma_N^{\bar{\nu}}/\sigma_N^{\nu}$	
	CORRECTED EXP. VALUE	EXPECTED
$a=1; b=0$ V−A	0.61 ± 0.25	0.38
$a=b=\frac{1}{2}$ V; A	0.40 ± 0.17	1.00
$a=0; b=1$ V+A	0.37 ± 0.16	2.65
$a=0.9; b=0.1$	0.48 ± 0.20	0.48

BNL.



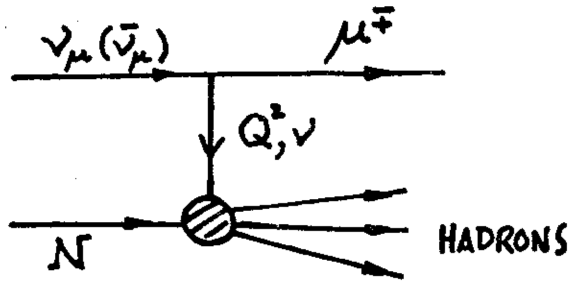
Albright
Quigg
Schrock
Smith


200
150
100
50
0
0
20
40
60
80
P_ (GeV/c)
P+ (GeV/c)
QUAD. TRIPLET RUN
$\bar{\nu}$ HORN RUN
$\mu^-\mu^+$ EVENTS
$P_- = P_+$
28
39


FOUR-FERMION INTERACTION
ν_μ
μ^-
ν_μ
μ^+
γ
Z
Z
INTERMEDIATE VECTOR BOSON PRODUCTION
ν_μ
W^+
μ^+
ν_μ
μ^-
γ
(A,Z)
HADRONS
NEUTRAL HEAVY LEPTON PRODUCTION
ν_μ
L^o
μ^-
μ^+
ν_μ
q^2
(A,Z)
HADRONS
NEW HADRON PRODUCTION
ν_μ
μ^-
q^2
Y
μ^+
ν_μ
X
(A,Z)
HADRONS

DEEP INELASTIC SCATTERING

- SINGLE MUON -



$$\nu \equiv E_\nu - E_\mu$$

$$Q^2 \equiv 2E_\nu E_\mu (1-\cos\theta_\mu)$$

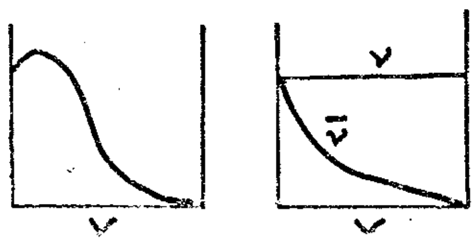
$$X = Q^2/2M\nu$$

$$Y = \nu/E_\nu \quad , \quad V = XY$$

EXPECT :

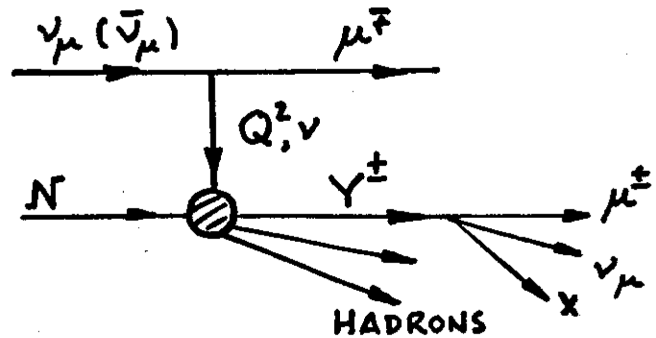
$$\frac{d^2\sigma}{dx\,dY} = F_2(x) \quad ; \quad \nu_\mu$$

$$F_2(x)(1-Y)^2 \quad ; \quad \bar{\nu}_\mu$$



Y- PARTICLE PRODUCTION

- DIMUON -



FINAL STATE ν_μ ENERGY MISSING

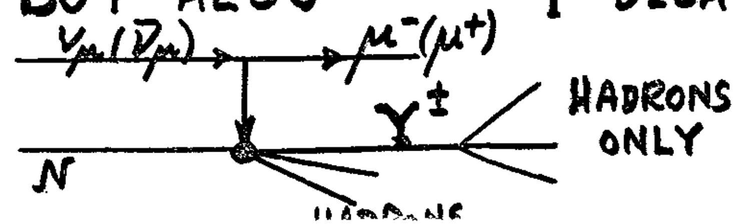
MEAS. ONLY $\quad E_{VIS} = E_H + E_+ + E_-$

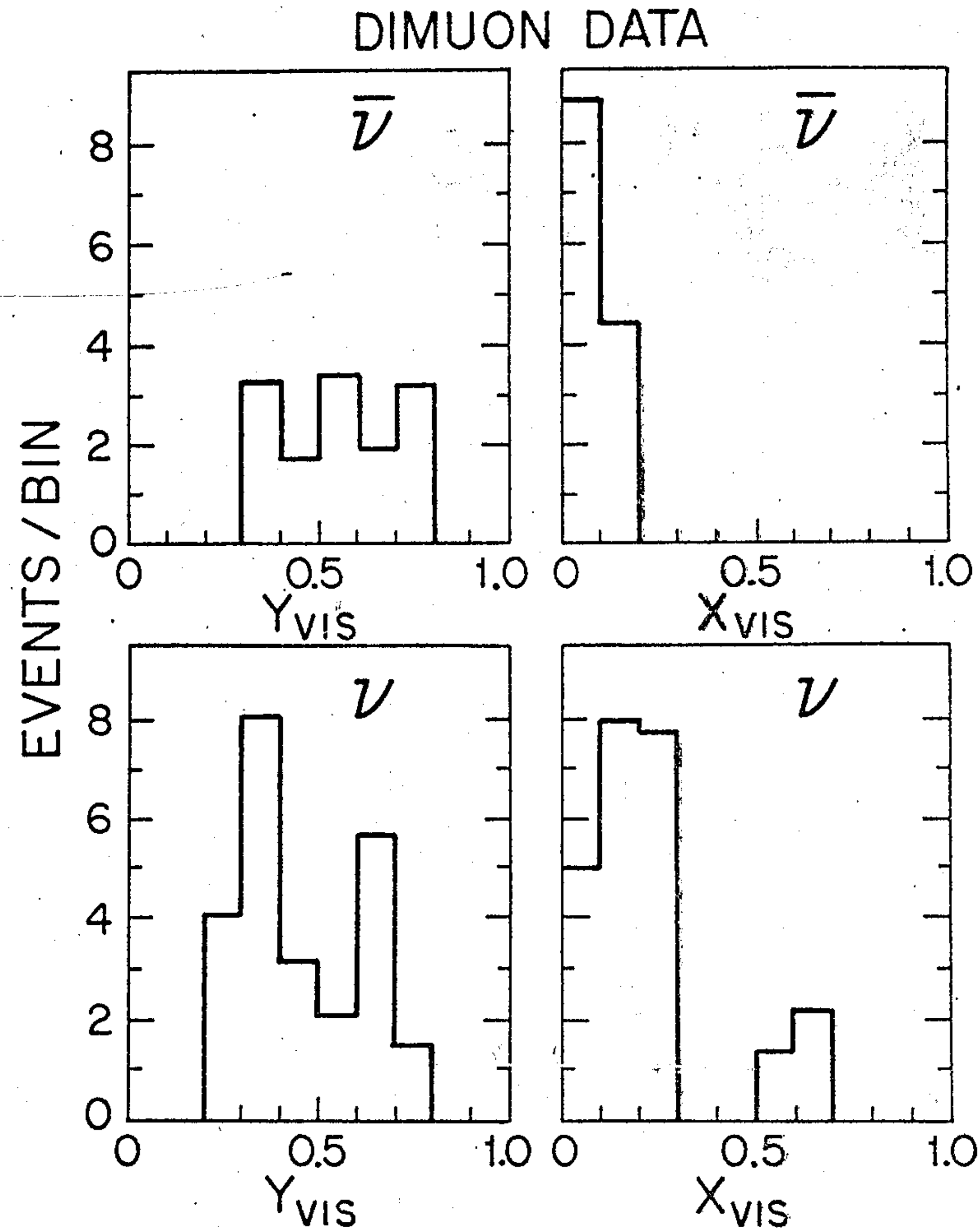
$$Y^\mp_{VIS} = (E_{VIS} - E_\mp)/E_{VIS}$$

$$X^\mp_{VIS} = V^\mp / Y^\mp_{VIS}$$

$Y_{VIS} \leq Y$
$X_{VIS} \geq X$; $V^\mp$ MEASURABLE

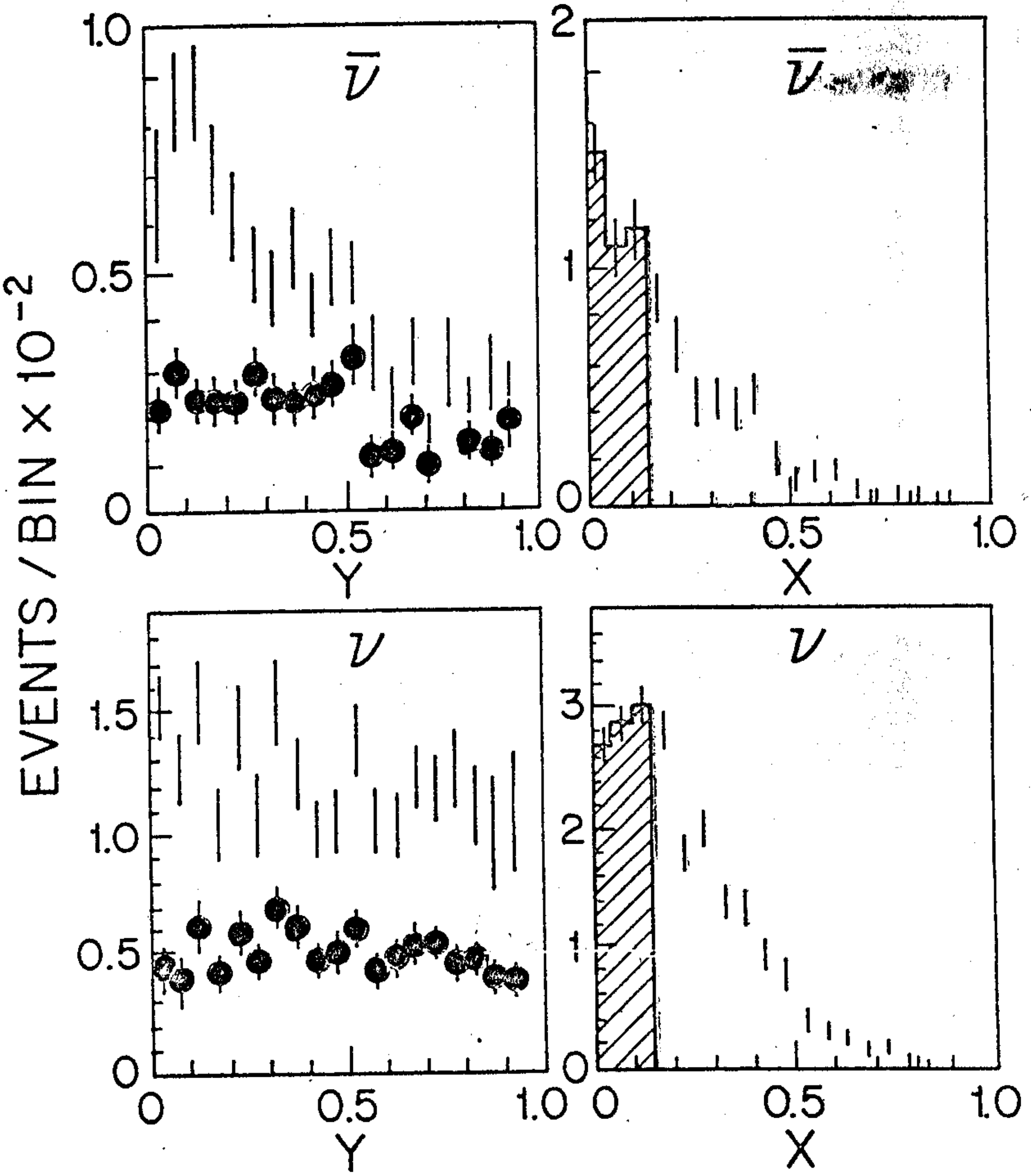
BUT ALSO - NONLEPTONIC Y- DECAY

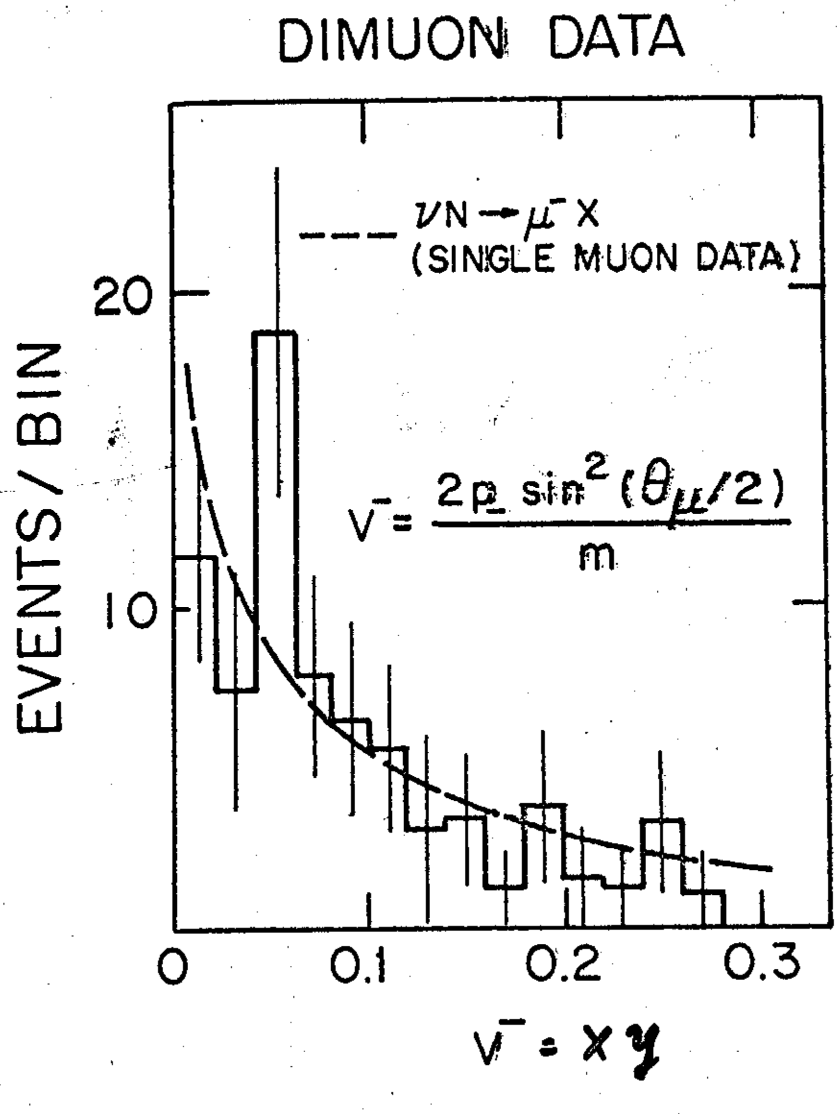



DIMUON DATA
EVENTS / BIN
$\bar{\nu}$
$\bar{\nu}$
ν
ν
0
2
4
6
8
0
0.5
1.0
Y_{VIS}
X_{VIS}

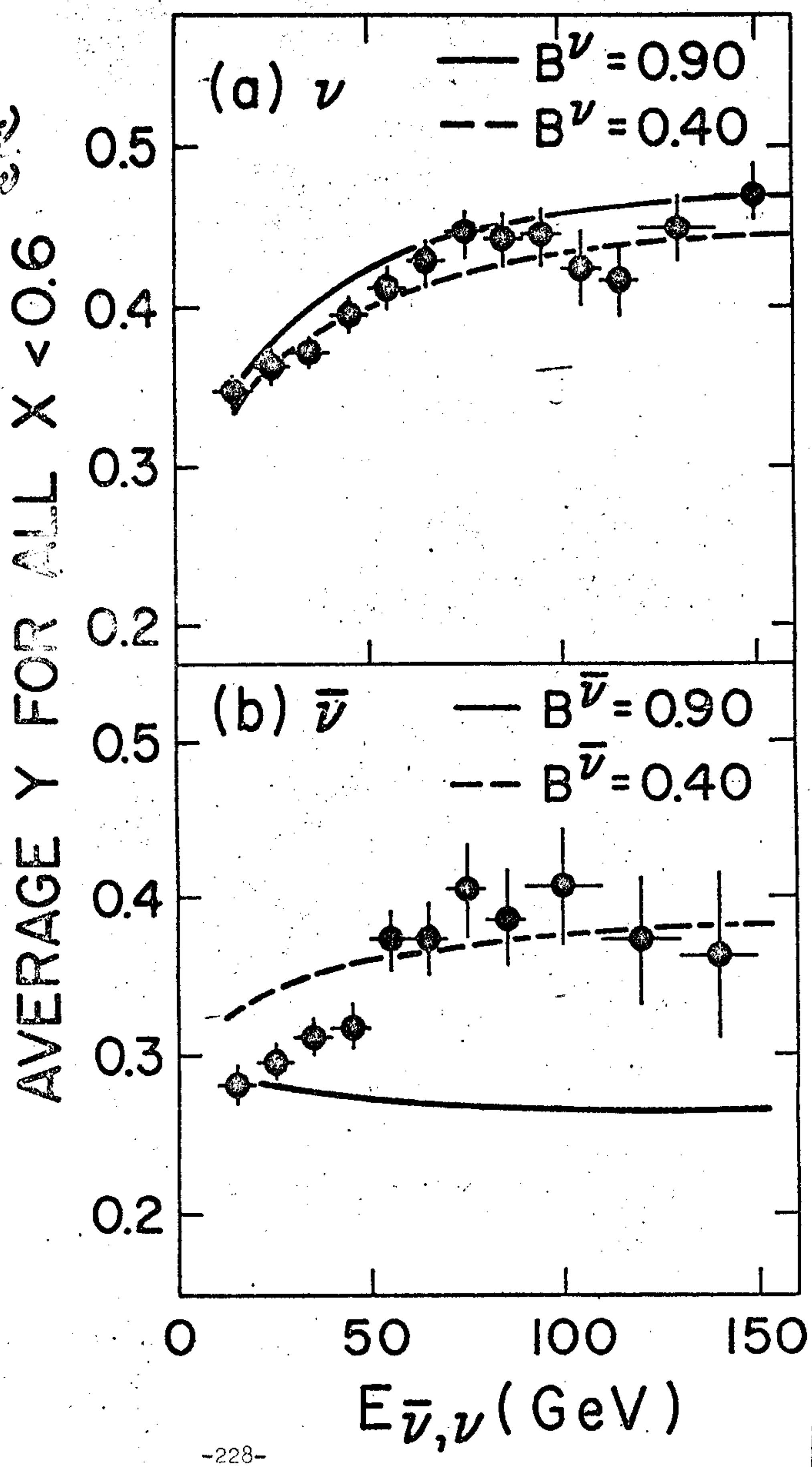
SINGLE MUON DATA

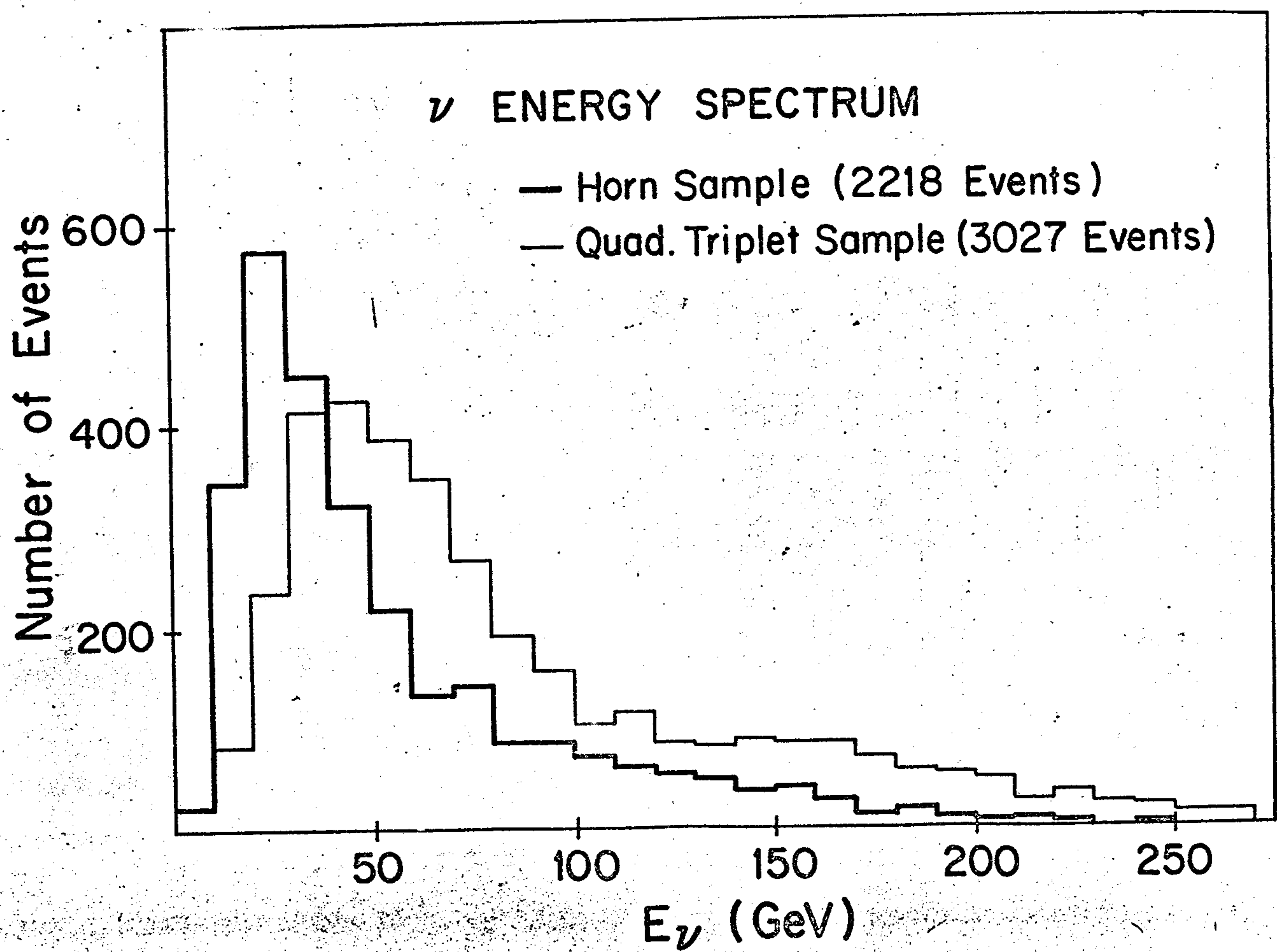
$E_{\nu,\bar{\nu}} > 30$ GeV




DIMUON DATA
$\nu N \to \mu^- X$
(SINGLE MUON DATA)
EVENTS / BIN
20
10
$V^- = \frac{2p_- \sin^2(\theta_\mu/2)}{m}$
0
0.1
0.2
0.3
$V^- = xy$

$B = -\frac{xF_3(x)}{F_2(x)}$





ν ENERGY SPECTRUM
Horn Sample (2218 Events)
Quad. Triplet Sample (3027 Events)
Number of Events
600
400
200
50
100
150
200
250
E_ν (GeV)

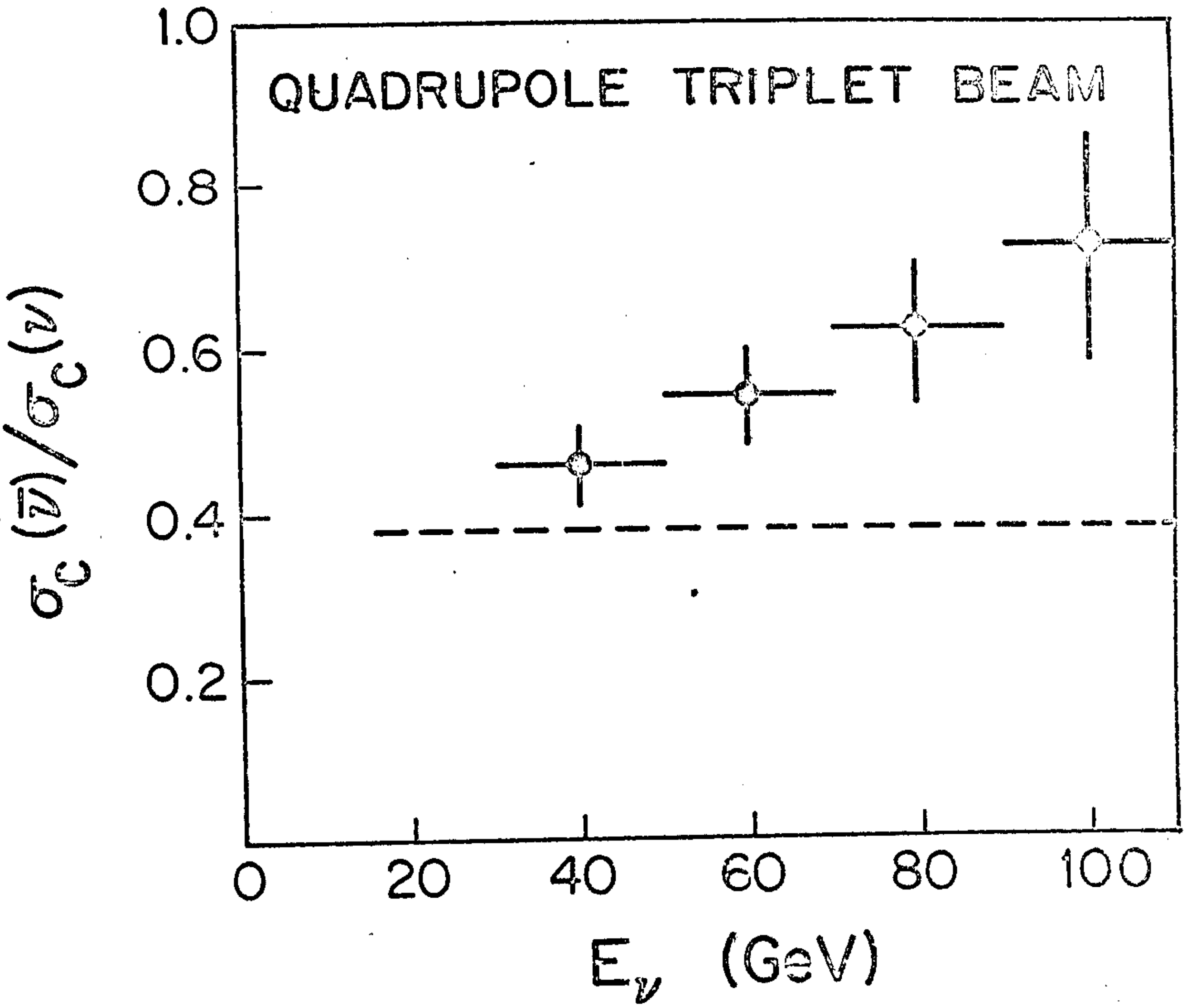

QUADRUPOLE TRIPLET BEAM
1.0
0.8
0.6
0.4
0.2
$\sigma_c(\bar{\nu})/\sigma_c(\nu)$
0
20
40
60
80
100
E_ν (GeV)

Fig. 2

1. QUASI ELASTIC AND N^* PRODUCTION

FOR $E_{\nu,\bar{\nu}} \gtrsim 3\,\text{GeV}$, KNOW EMPIRICALLY

$$\sigma(\nu_\mu + N \rightarrow \mu^- + N \text{ OR } N^*)$$
$$= \sigma(\bar{\nu}_\mu + N \rightarrow \mu^+ + N \text{ OR } N^*)$$

2. IN GENERAL, (Lee AND Yang, 1962)

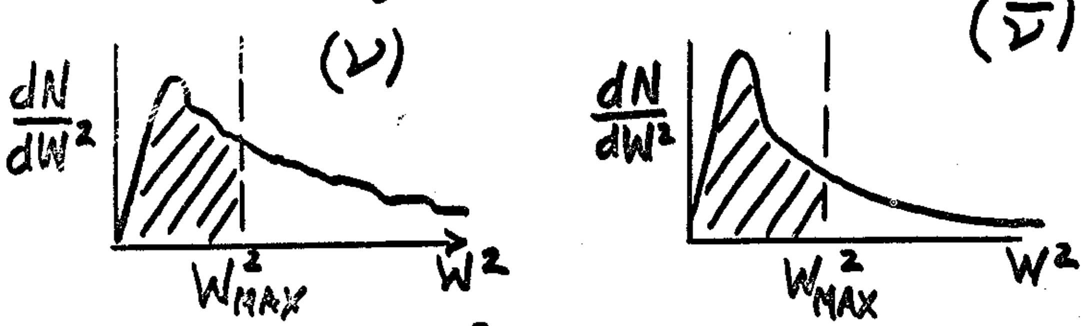
$$\lim_{E\to\infty} \frac{d\sigma}{dW^2}\left[\nu_\mu + \binom{T=0}{\text{tgt}} \rightarrow \mu^- + \text{hadrons}\right]$$

$$= \lim_{E\to\infty} \frac{d\sigma}{dW^2}\left[\bar{\nu}_\mu + \binom{T=0}{\text{tgt}} \rightarrow \mu^+ + \text{hadrons}\right]$$

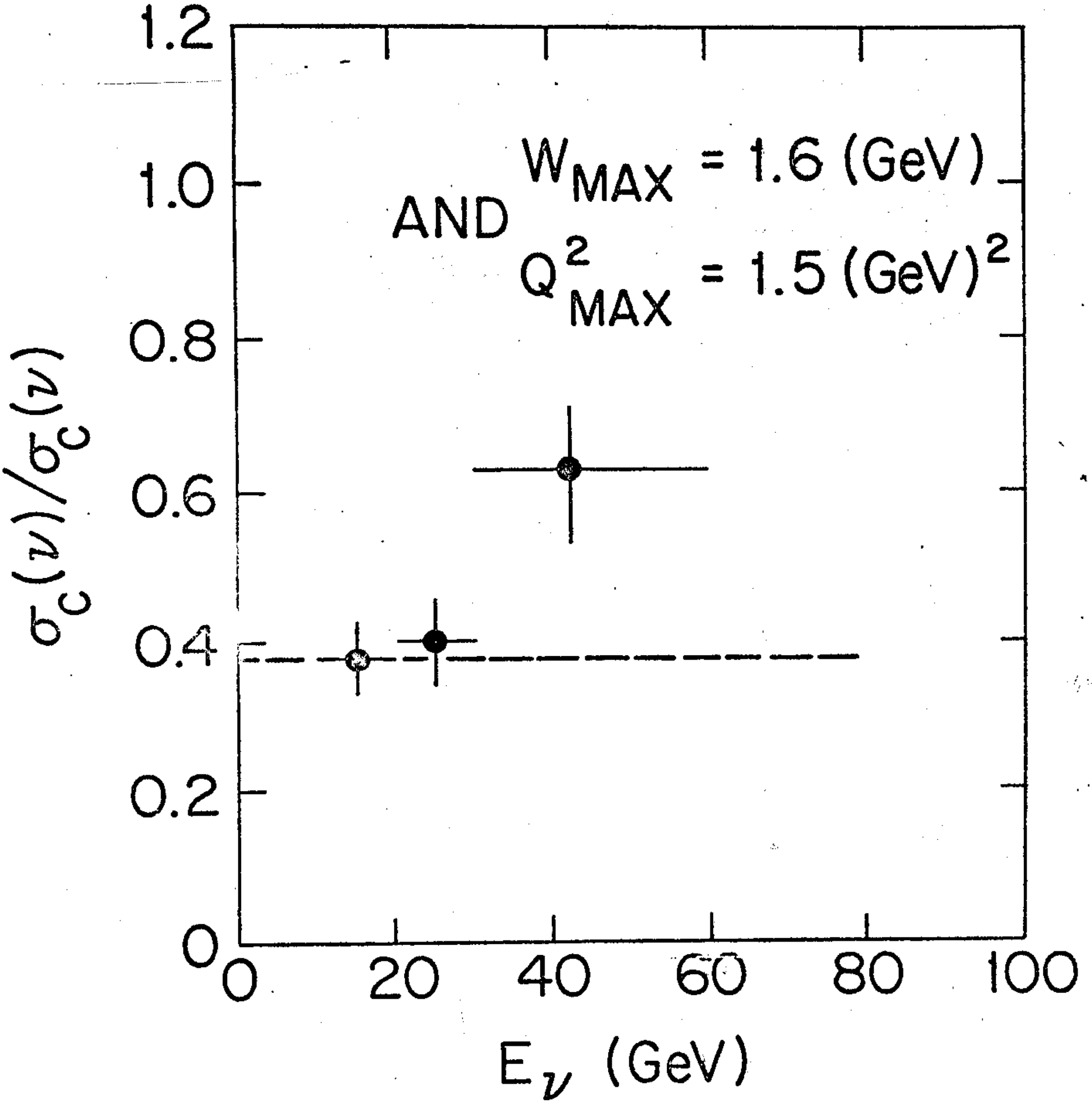
$\left[\lim E\to\infty \frac{d\sigma}{dW^2 dq^2} = \text{const}\, W_2(q^2, W^2) \text{ AND CSI}\right]$

3. PROCEDURE (Sakurai, 1973)

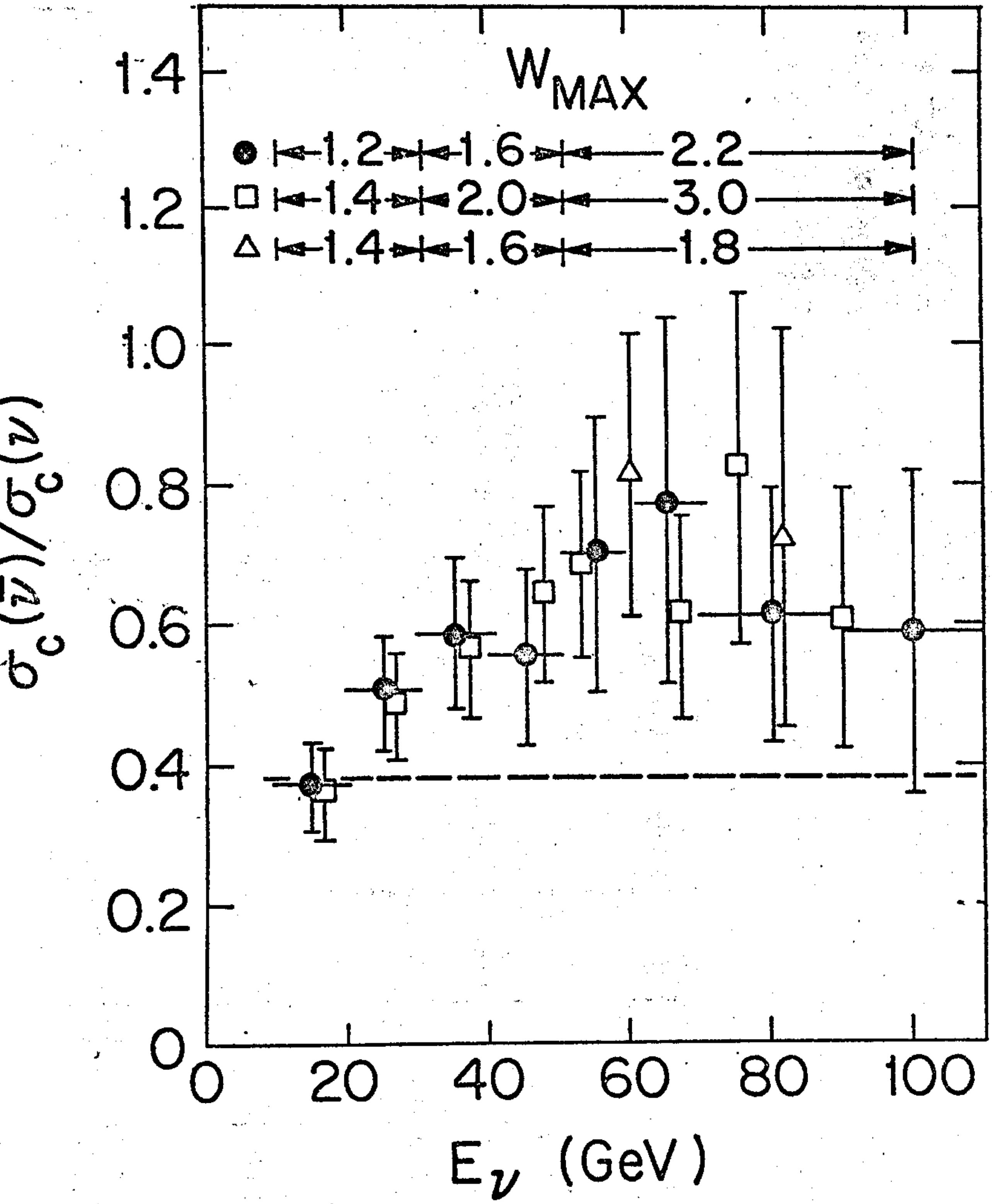
e.g., $E = 50\,\text{GeV}$



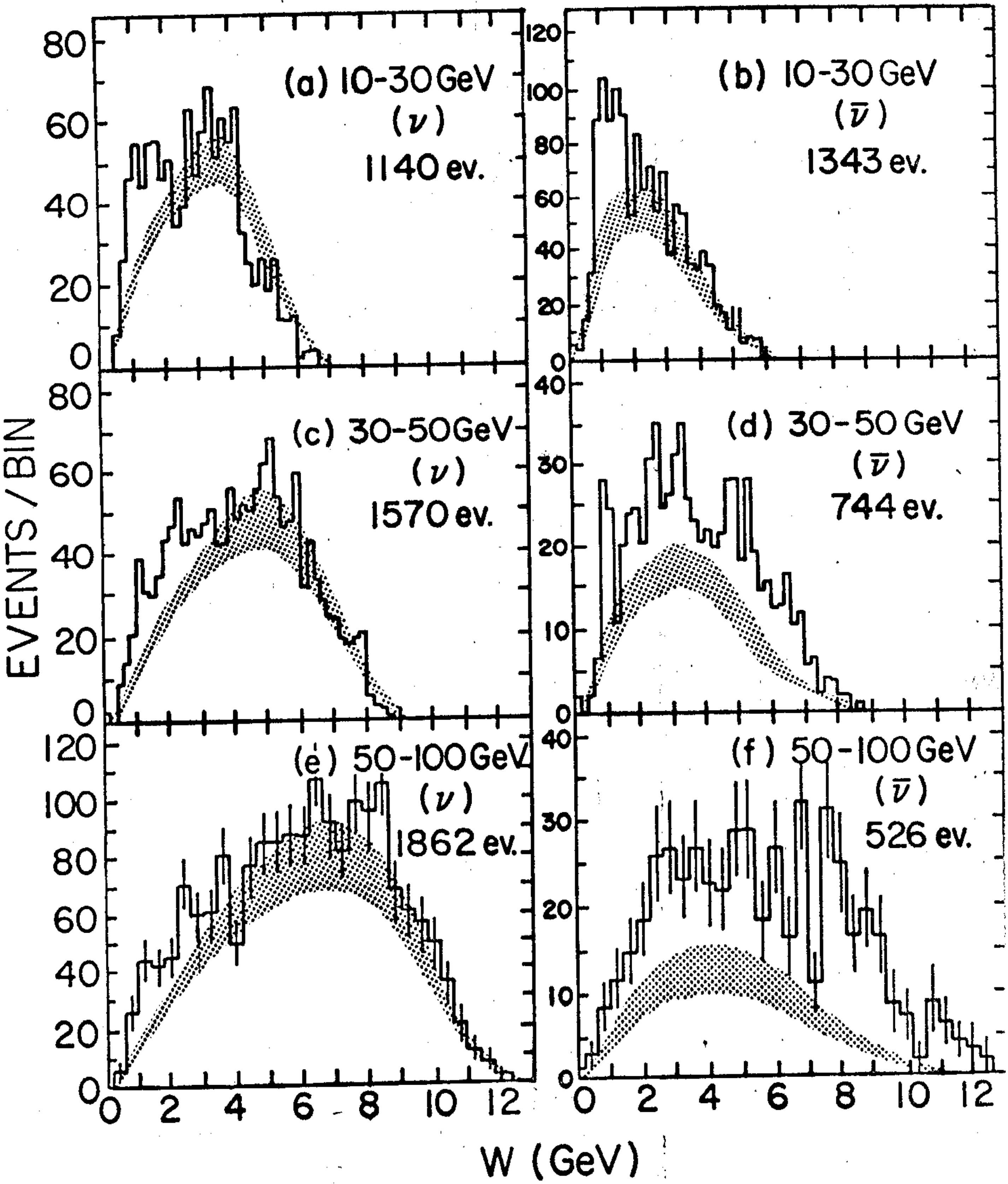
$$\int_0^{W^2_{MAX}} \frac{d\sigma}{dW^2}\, dW^2$$



$W_{MAX} = 1.6$ (GeV)
AND
$Q^2_{MAX} = 1.5$ (GeV)^2
$\sigma_c(\bar{\nu})/\sigma_c(\nu)$
E_ν (GeV)
1.2
1.0
0.8
0.6
0.4
0.2
0
0
20
40
60
80
100



W_{MAX}
1.2
1.6
2.2
1.4
2.0
3.0
1.4
1.6
1.8
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0
0
20
40
60
80
100
$\sigma_c(\bar{\nu})/\sigma_c(\nu)$
E_ν (GeV)



(a) 10-30 GeV
(ν)
1140 ev.
(b) 10-30 GeV
($\bar{\nu}$)
1343 ev.
(c) 30-50 GeV
(ν)
1570 ev.
(d) 30-50 GeV
($\bar{\nu}$)
744 ev.
(e) 50-100 GeV
(ν)
1862 ev.
(f) 50-100 GeV
($\bar{\nu}$)
526 ev.
EVENTS / BIN
W (GeV)

Table I. Values of the average detection efficiency ϵ and the flux factor f (in number of events) for ν and $\bar{\nu}$ in each energy interval ΔE.

ΔE (GeV)	ϵ^{ν}	$\epsilon^{\bar{\nu}}$	f^{ν}	$f^{\bar{\nu}}$
10-30	0.56	0.88	233	435
30-50	0 75	0.96	145	95
50-100	0.84	0.98	92	29

For $\bar{\nu}$,

$$\frac{A^{\bar{\nu}}(E)}{A^{\nu}(E)} = \frac{\sigma_c^{\bar{\nu}}(E)}{\sigma_c^{\nu}(E)} \cdot \frac{f^{\bar{\nu}}(E)}{f^{\nu}(E)} \cdot \frac{\epsilon^{\bar{\nu}}(E)}{\epsilon^{\nu}(E)}$$

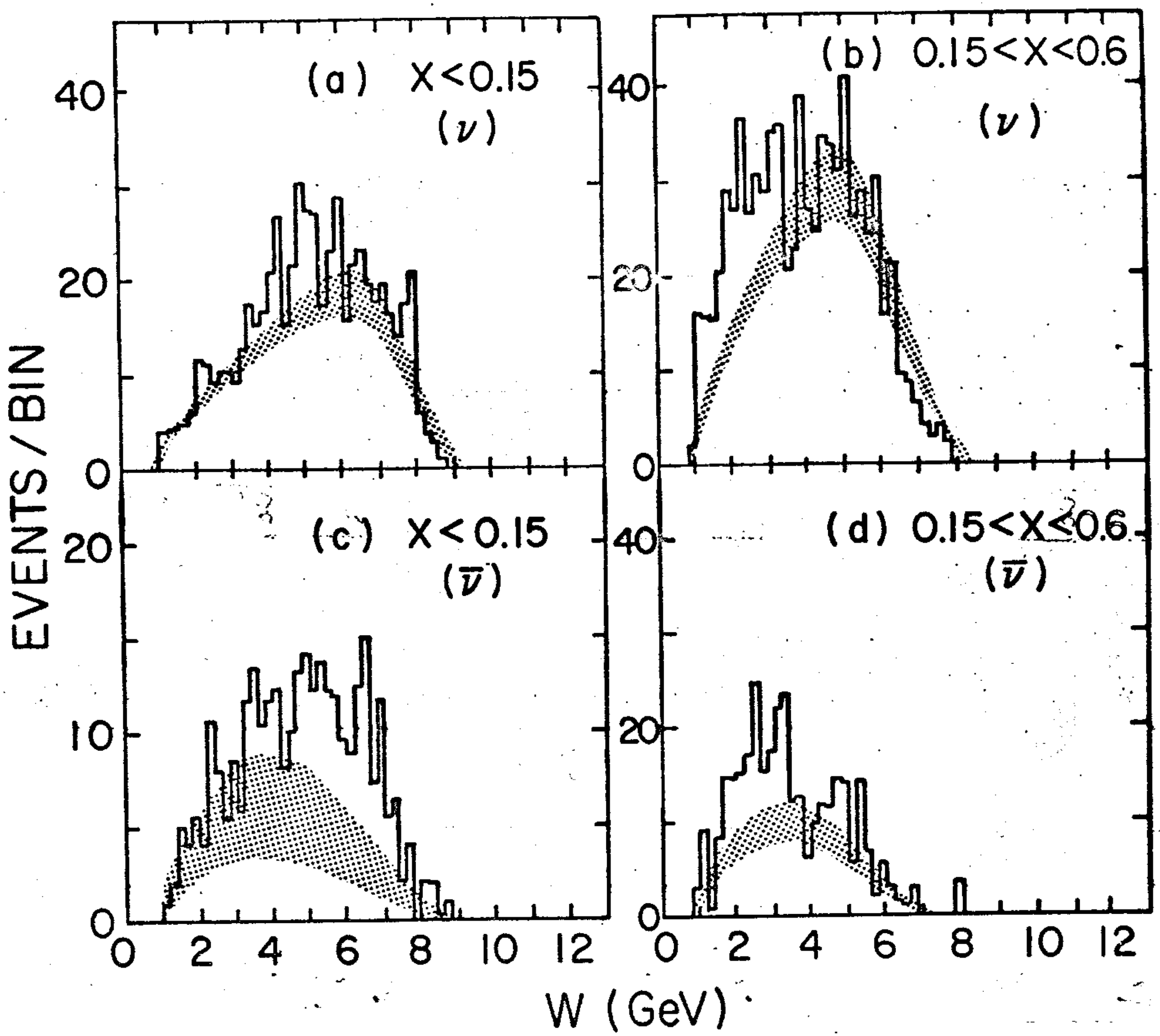
with $\sigma_c^{\bar{\nu}}(E)/\sigma_c^{\nu}(E) = 0.38 \pm 0.06$, all E

(charge symmetry invariance)

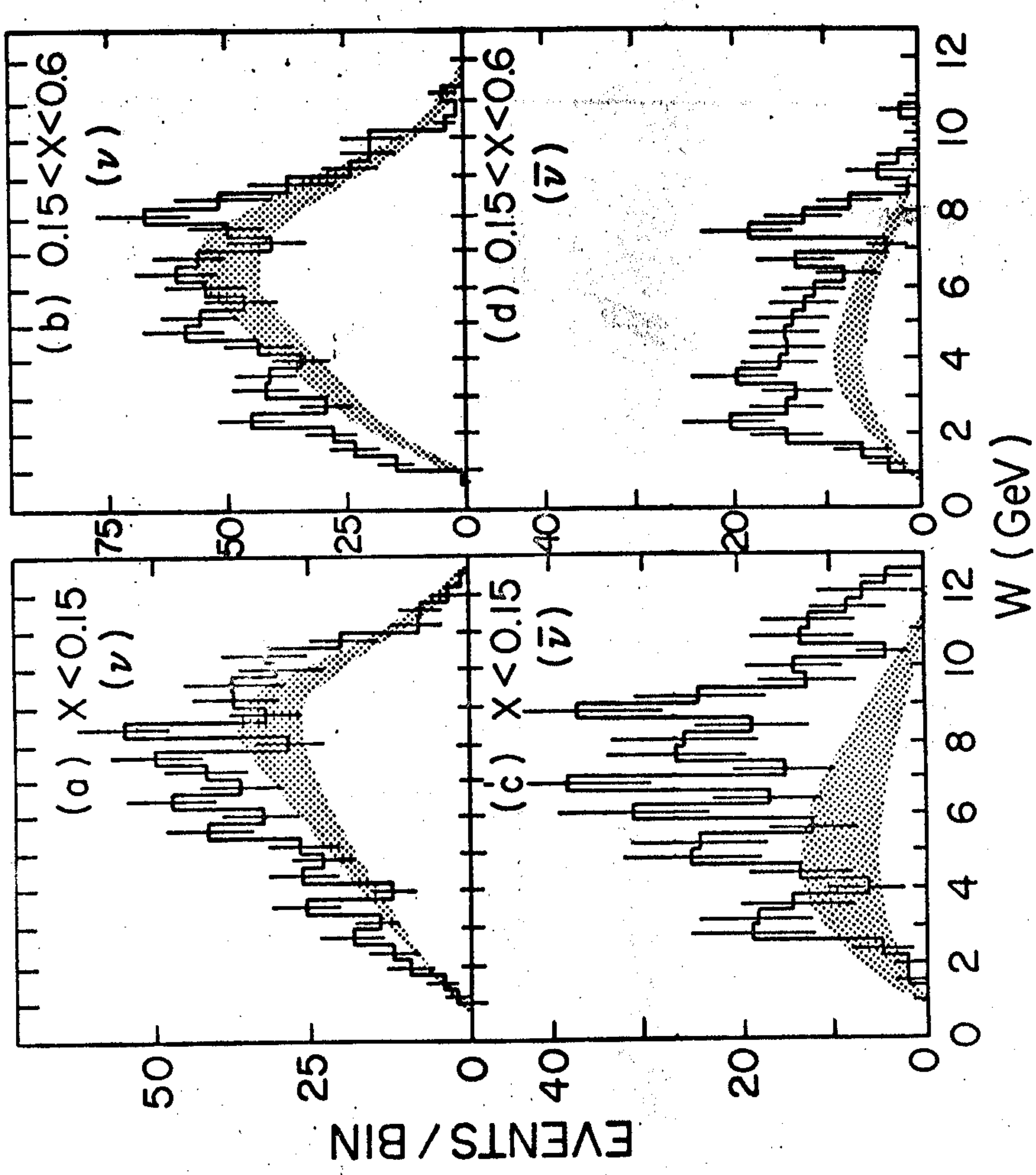
For ν,

$$\frac{A^{\nu}(E_1)}{A^{\nu}(E_2)} = \frac{E_1}{E_2} \cdot \frac{f^{\nu}(E_1)}{f^{\nu}(E_2)} \cdot \frac{\epsilon^{\nu}(E_1)}{\epsilon^{\nu}(E_2)}$$

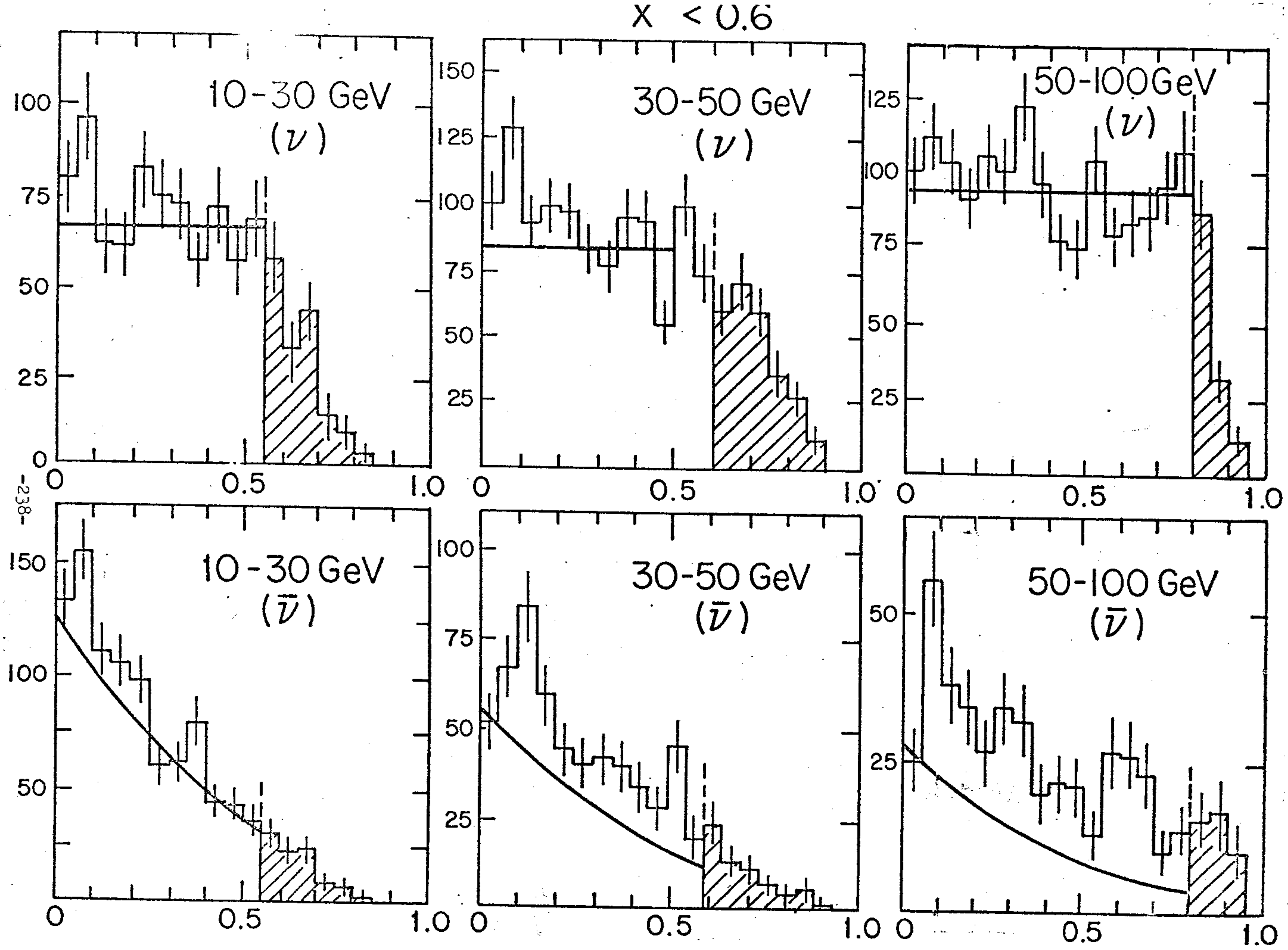
(scale invariance)

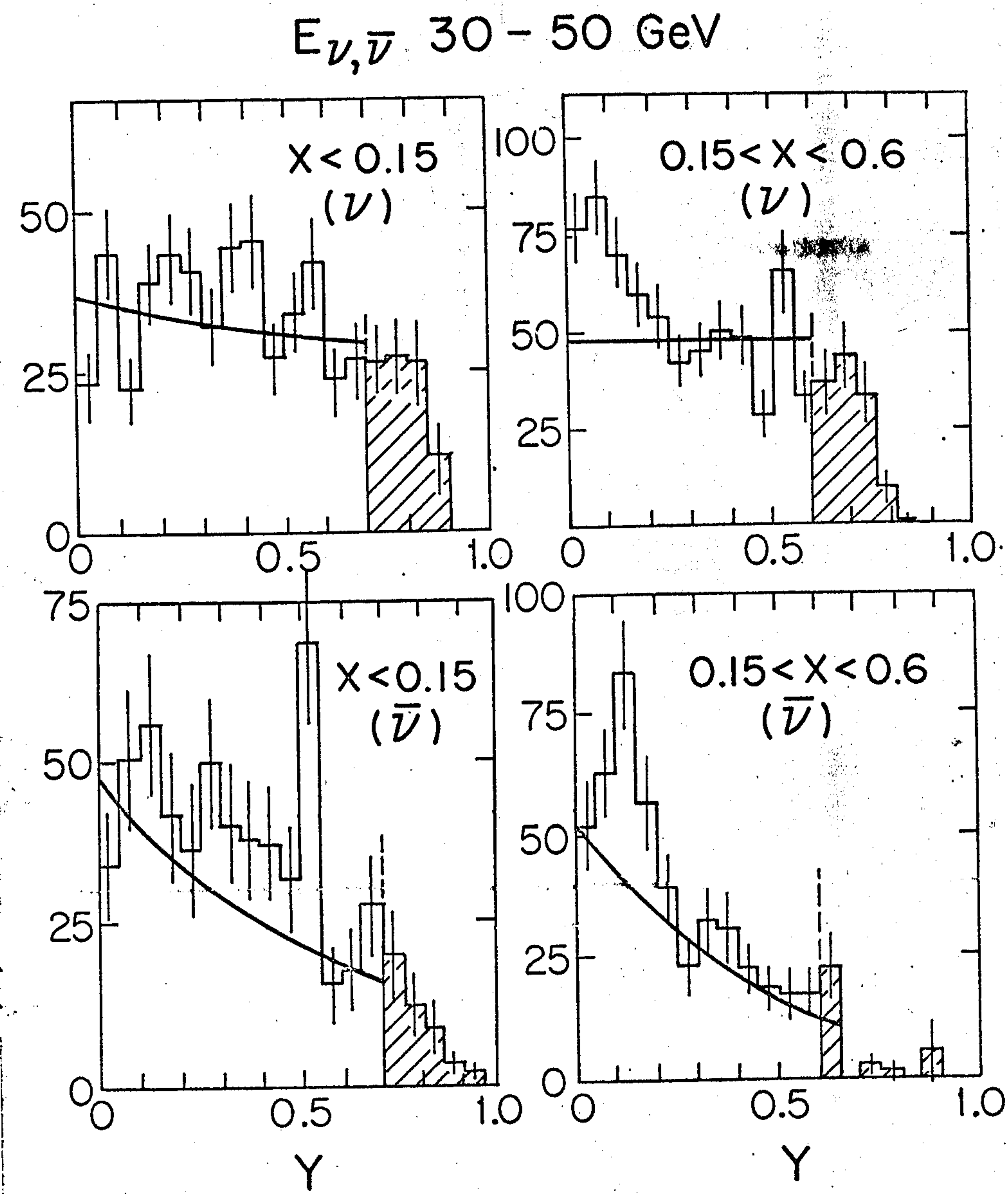


$30 < E_{\nu,\bar{\nu}} < 50$ GeV

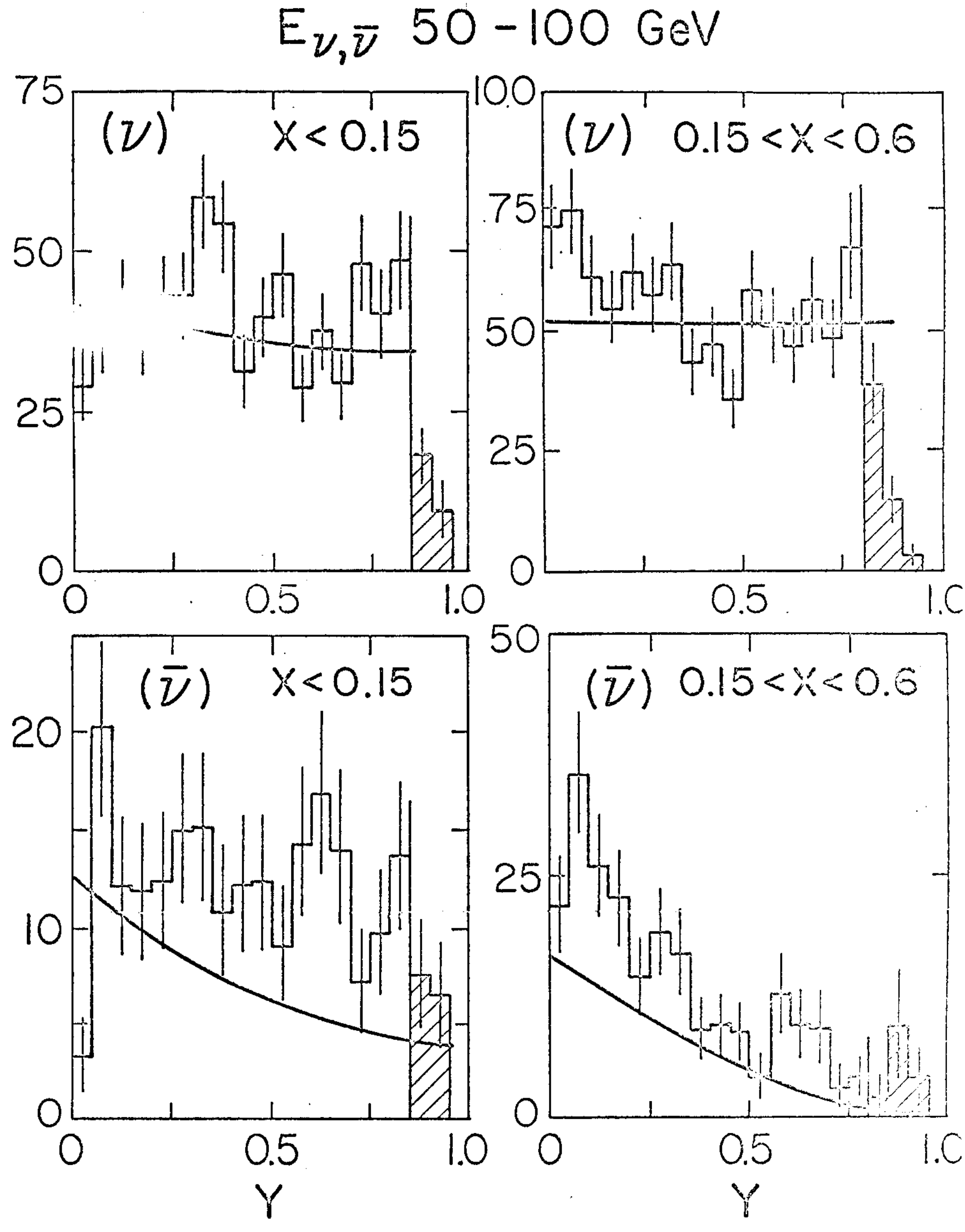


$50 < E_{\nu,\bar{\nu}} < 100$ GeV


X < 0.6
10-30 GeV
(ν)
30-50 GeV
(ν)
50-100 GeV
(ν)
10-30 GeV
($\bar{\nu}$)
30-50 GeV
($\bar{\nu}$)
50-100 GeV
($\bar{\nu}$)
0
0.5
1.0
0
25
50
75
100
125
150



$E_{\nu,\bar{\nu}}$ 30 - 50 GeV
X < 0.15
(ν)
0.15 < X < 0.6
(ν)
X < 0.15
($\bar{\nu}$)
0.15 < X < 0.6
($\bar{\nu}$)
0
25
50
75
100
0.5
1.0
Y
Y



$E_{\nu,\bar{\nu}}$ 50 - 100 GeV
(ν) X < 0.15
(ν) 0.15 < X < 0.6
($\bar{\nu}$) X < 0.15
($\bar{\nu}$) 0.15 < X < 0.6
0
25
50
75
100
10
20
0.5
1.0
Y
Y

III. SOME TENTATIVE CONCLUSIONS

A. Is there a new degree of freedom of hadronic matter, ie, Is number of quarks > 3 ?

$\left.\begin{array}{l}\nu, \bar{\nu} \text{ data} \\ e^+, e^- \text{ data}\end{array}\right\}$ unequivocal YES

B. Is number of quarks > 4 ?

$\nu, \bar{\nu}$ data $\Longrightarrow$ YES

e^+, e^- data $\Longrightarrow$?

(i) From single muon data: y- and W-distbns $E_{\nu,\bar{\nu}} \gtrsim 40$ GeV

Measure $\left(\dfrac{\sigma_Y^{\nu}}{\sigma_X^{\nu}}\right)_{\mu} \lesssim 0.15$

$$\boxed{\begin{array}{l}\sigma_Y^{\nu} \equiv \sigma(\nu_\mu + N \to \mu^- + Y + X)_{in} \\ \sigma_X^{\nu} \equiv \sigma(\nu_\mu + N \to \mu^- + X)_{in}\end{array}}$$

compatible with

$$\left.\begin{array}{l}(1)\ \nu_\mu + d \to \mu^- + c, \quad \sin\theta_c, \text{ sea + valence} \\ (2)\ \nu_\mu + s \to \mu^- + c, \quad \cos\theta_c, \text{ sea}\end{array}\right\} 0.1\sigma_X^{\nu}$$

Measure also $\left(\dfrac{\sigma_Y^{\bar\nu}}{\sigma_X^{\bar\nu}}\right)_\mu \approx 1.0\ (\pm 0.2)$

which is <u>not</u> compatible with

(3) $\bar\nu_\mu + \bar s \to \mu^+ + \bar c$, $\cos\theta_c$, sea, $\sim 0.15\,\sigma_X^{\bar\nu}$

(ii) <u>From dimuon data</u> ($E_{\nu,\bar\nu} \gtrsim 40$ GeV)

we measure

$$\frac{R_{\mu\mu}^{\bar\nu}}{R_\mu^{\bar\nu}} = (2+1)\times 10^{-2}\ ;\quad \frac{R_{\mu\mu}^{\nu}}{R_\mu^{\nu}} = (0.9\pm 0.3)\times 10^{-2}$$

which yield

$$\left(\frac{\sigma_Y^{\bar\nu}}{\sigma_Y^{\nu}}\right)_{\mu\mu} \approx 2\,(2.2\pm 1.3)\left(\frac{\sigma_X^{\bar\nu}}{\sigma_X^{\nu}}\right)\left(\frac{BR^\nu}{BR^{\bar\nu}}\right)$$

because ½ of $R_\mu^{\bar\nu}$ was due to Y-production (didn't know it then).

$$\boxed{BR^\nu \equiv \frac{\Gamma(Y\to\mu+\text{anything})}{\Gamma(Y\to\text{all})}}$$

(iii) <u>To make 1-μ and 2-μ data yield same $\sigma_Y^{\bar\nu}/\sigma_Y^{\nu}$</u> requires $\left[\left(\dfrac{\sigma_Y^{\bar\nu}}{\sigma_Y^{\nu}}\right)_\mu \geq 6.7\left(\dfrac{\sigma_X^{\bar\nu}}{\sigma_X^{\nu}}\right)\right]$

$$\frac{BR^\nu}{BR^{\bar\nu}} \geq \frac{6.7}{(4.4\pm 2.6)} \approx 1.5\pm 0.9$$

which means

$$\left(\frac{\sigma_Y^{\bar{\nu}}}{\sigma_Y^{\nu}}\right)_{\mu} = \left(\frac{\sigma_Y^{\bar{\nu}}}{\sigma_Y^{\nu}}\right)_{\mu\mu} \approx 2.7 \quad \text{for } \frac{\sigma_X^{\bar{\nu}}}{\sigma_X^{\nu}} = 0.4$$

ie, again incompatible with reactions (1), (2), (3) which yield

$$\frac{\sigma_Y^{\bar{\nu}}}{\sigma_Y^{\nu}} \approx \frac{0.15\,\sigma_X^{\bar{\nu}}}{0.10\,\sigma_X^{\nu}} = 0.6$$

(iv) Conclusion: need at least another $Q = -\frac{1}{3}$ quark (beside d and s) in addition to c-quark, or color excitation, or asymptotic freedom effects, or .... ANOTHER DEG. of FREEDOM

C. Is there a right handed component of WCHC?

Again, $\nu, \bar{\nu}$ data $\Longrightarrow$ YES (qualified)

(i) Single muon data require coupling of new $Q = -\frac{1}{3}$ quark (to u) be right handed to get observed $\sigma_Y^{\bar{\nu}}/\sigma_Y^{\nu}$. Energy dependence of $\langle y^{\bar{\nu}} \rangle$.

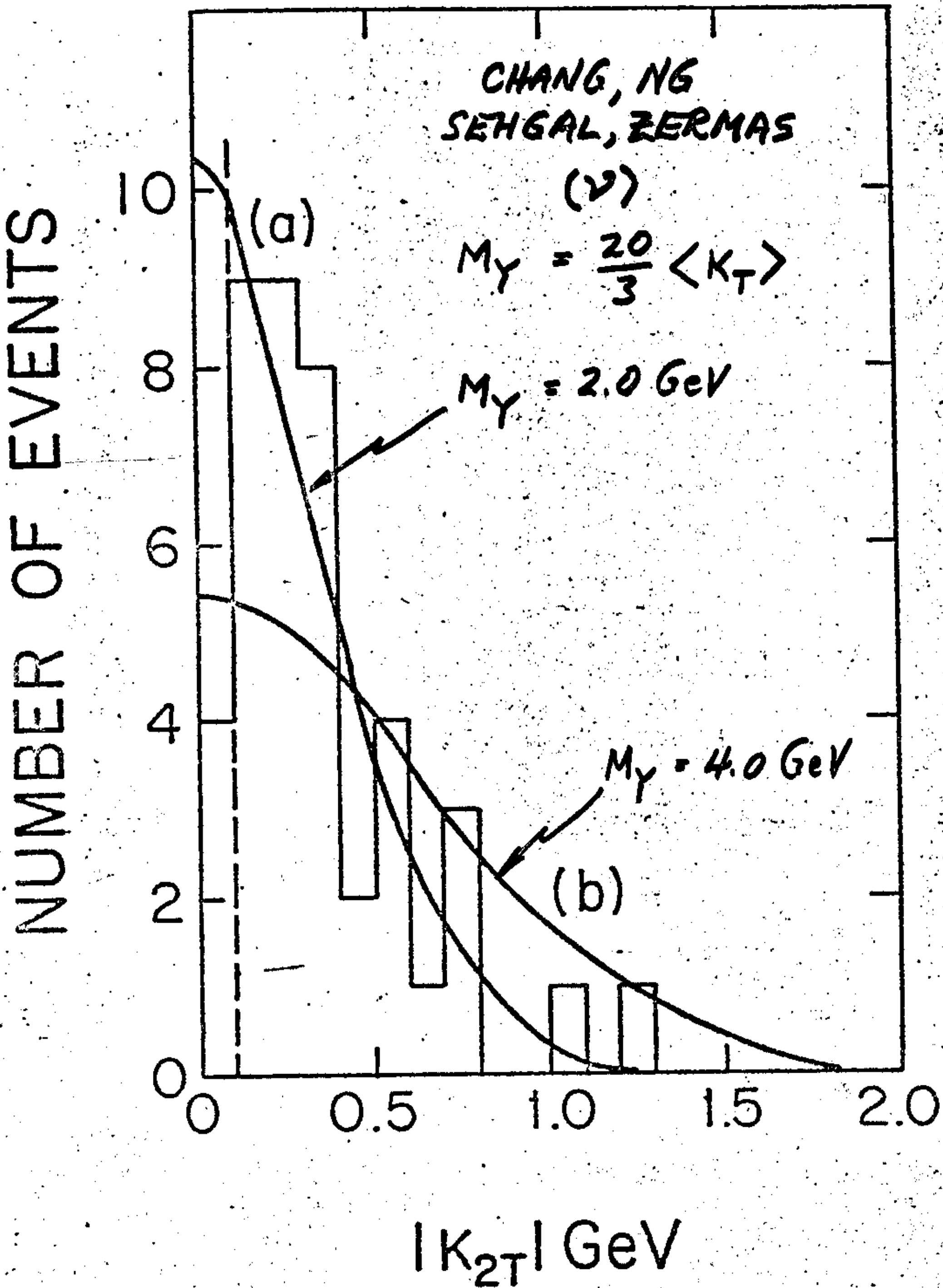
(ii) Dimuon data

Compare p_t and $\frac{p_+ - p_-}{p_+ + p_-}$ distbns for $\nu, \bar{\nu}$

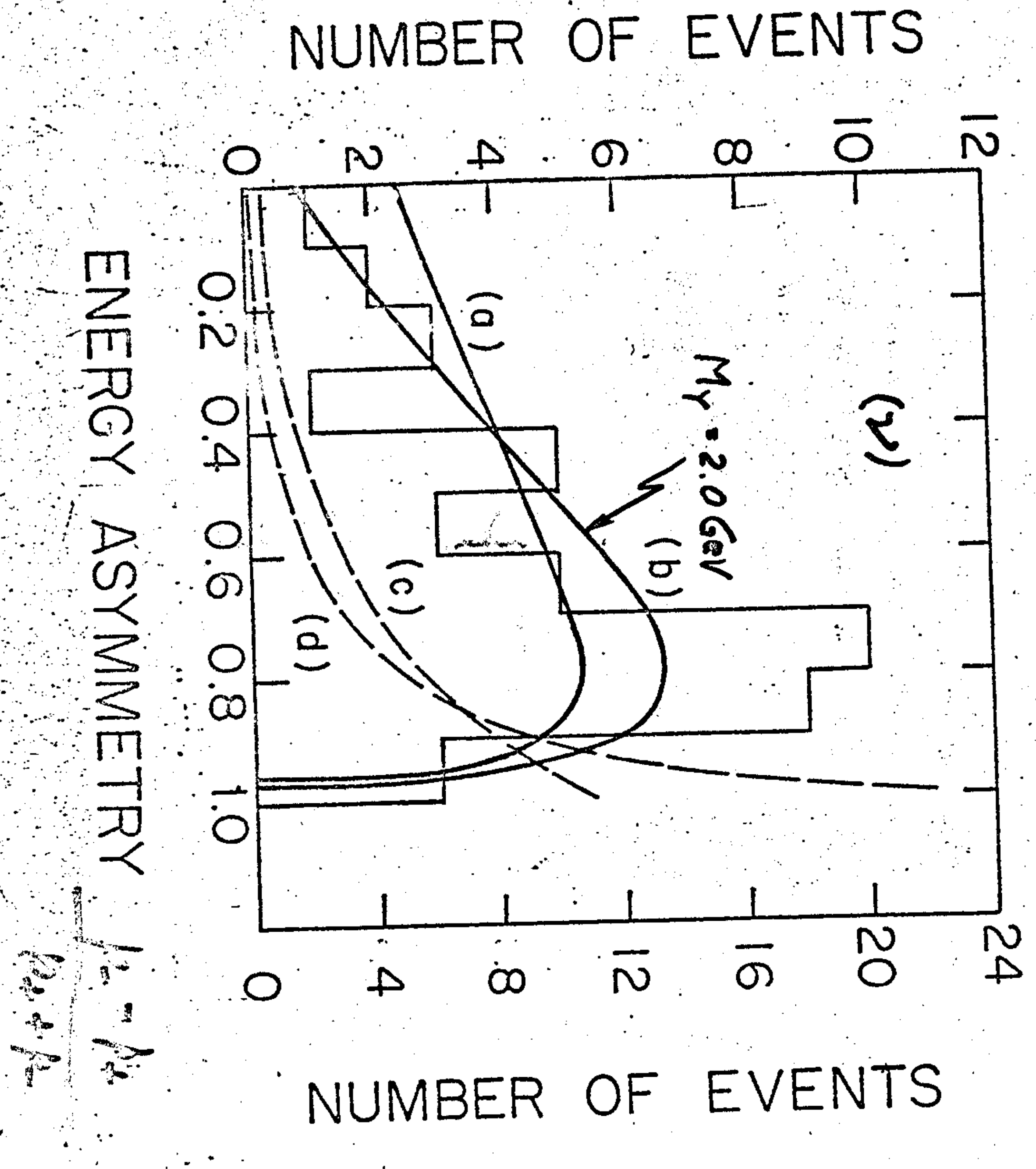
$$d\sigma = \frac{G^2 s}{2\pi} F_2(x)\, f(y)\, D(p_c)\, d\Gamma_Y/\Gamma_Y$$

use K-decays as guide

from electroproduction or low energy ν data including $\exp[-6\, p_c^{\perp 2}]$ cutoff



k_{2T} is $p_\perp$ of 2nd [illegible]


NUMBER OF EVENTS
ENERGY ASYMMETRY
NUMBER OF EVENTS
(ν)
(a)
(b)
(c)
(d)
$M_Y = 2.0$ GeV

CHANG, NG

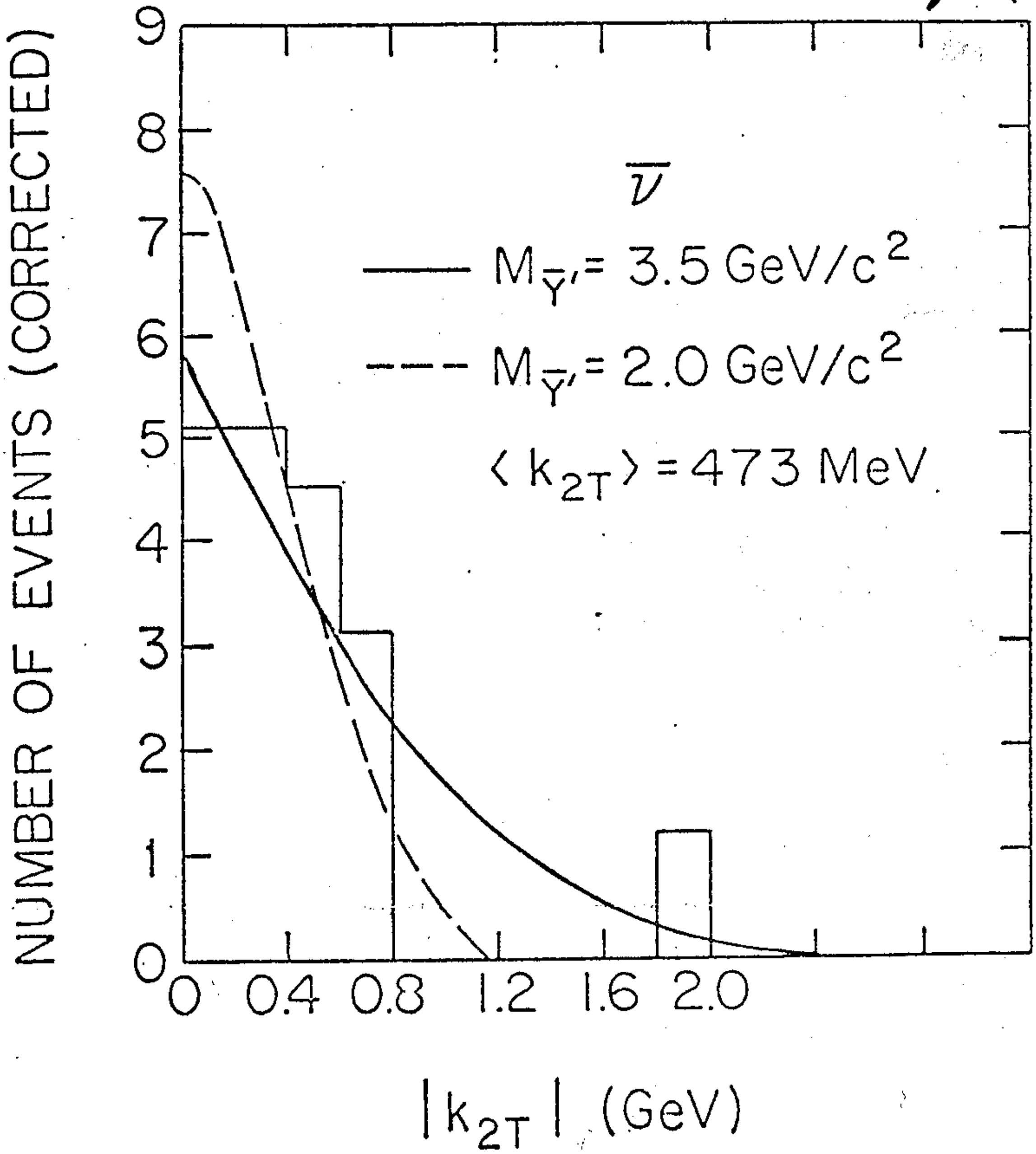
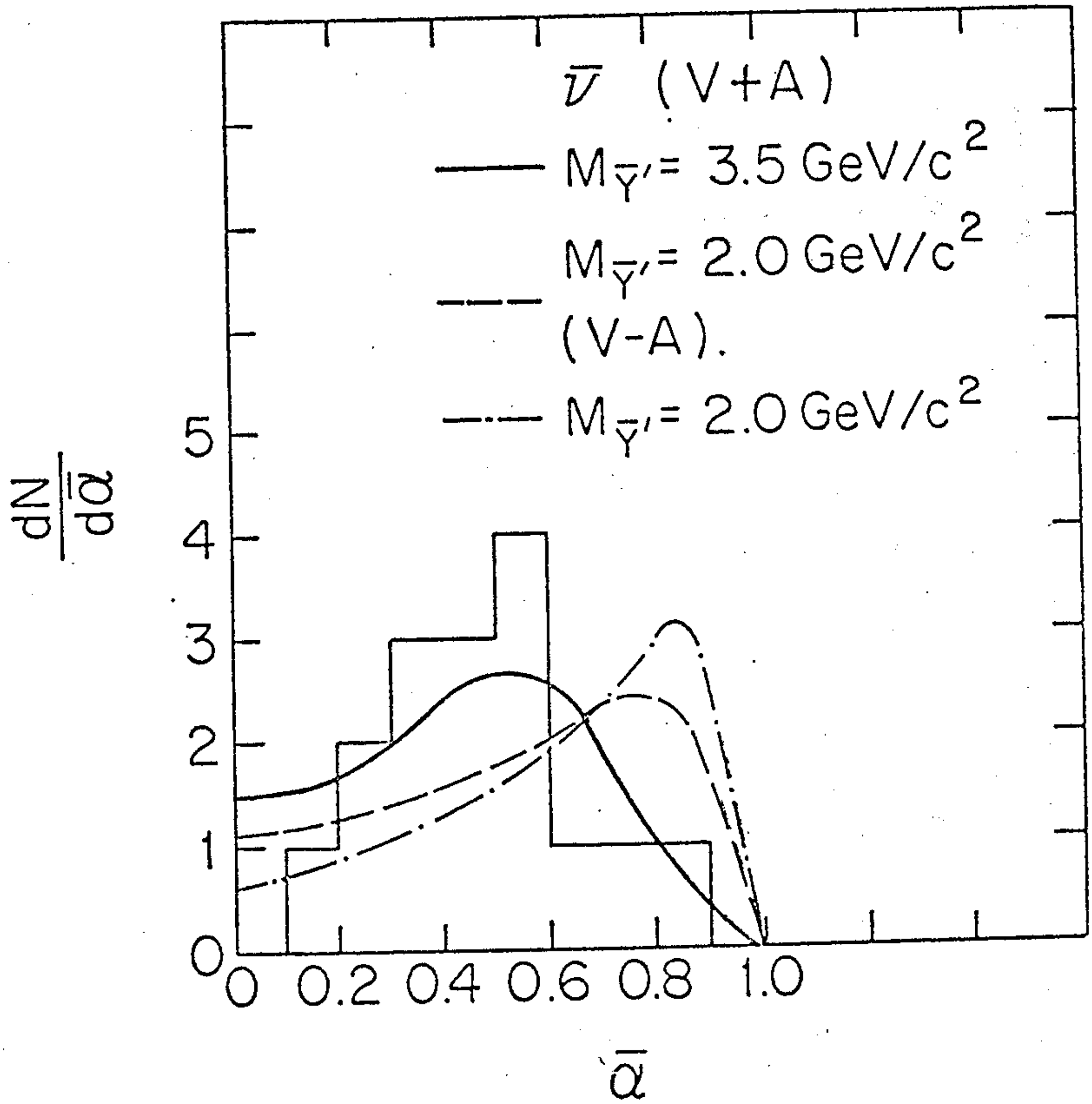


Fig. 2



$\bar{\nu}$ (V+A)
$M_{\bar{Y}'}$ = 3.5 GeV/c^2
$M_{\bar{Y}'}$ = 2.0 GeV/c^2
(V-A).
$M_{\bar{Y}'}$ = 2.0 GeV/c^2
$\frac{dN}{d\bar{\alpha}}$
0
1
2
3
4
5
0 0.2 0.4 0.6 0.8 1.0
$\bar{\alpha}$

Fig. 1

D. <u>Is there a new current form or a new particle channel (or both) in the WNC ?</u>

(i) space-time structure

R^{ν}_{inel}, $R^{\bar{\nu}}_{inel}$

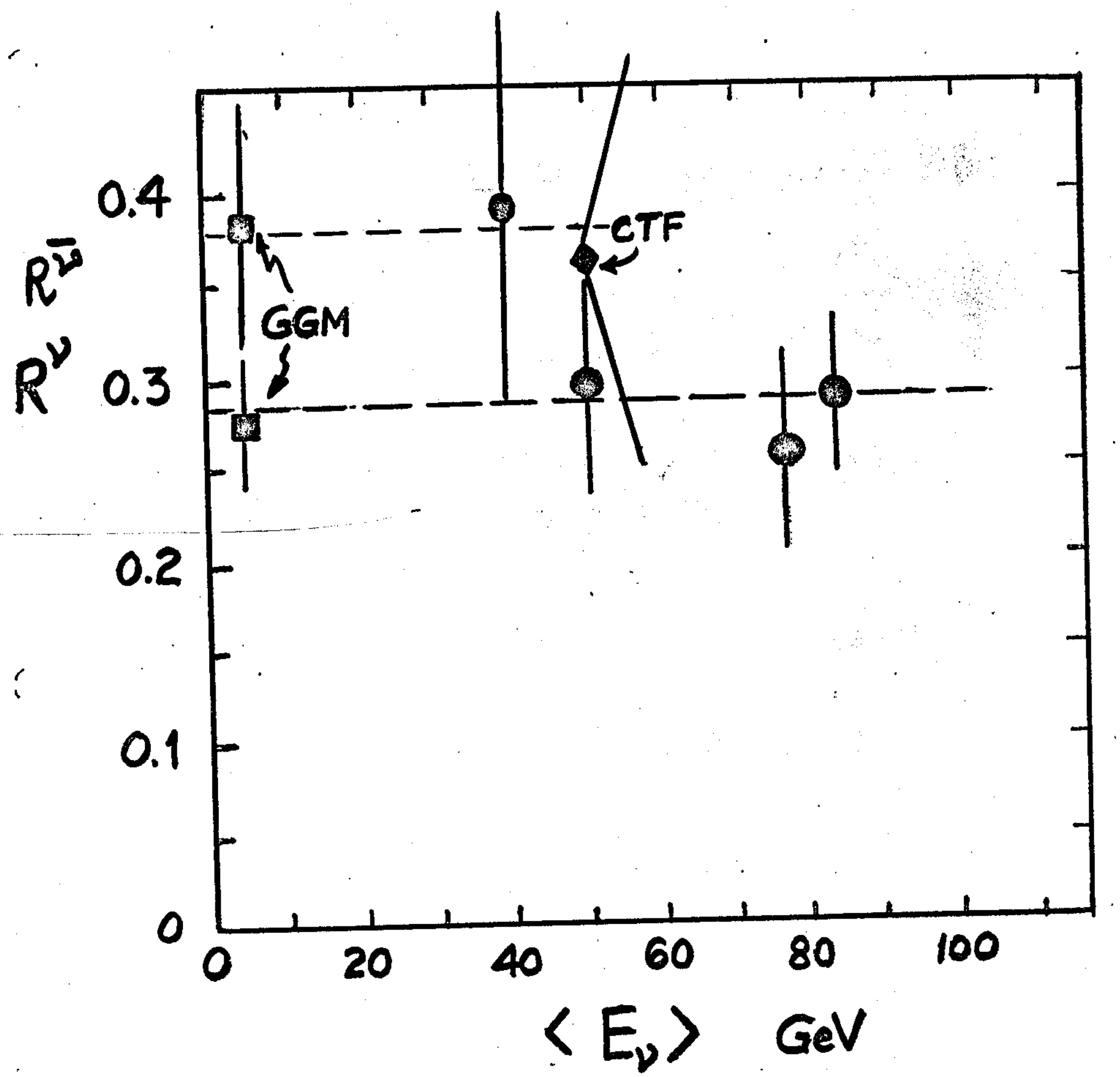
$R^{\nu}_{elastic}$, $R^{\bar{\nu}}_{elastic}$ (qualified)

atomic physics expts
(Seattle, Oxford)

all consistent with parity violation $\Rightarrow$ (V-A)

(ii) dependence of $R^{\nu}_{inel.}$ and $R^{\bar{\nu}}_{inel.}$ on $\langle E_{\nu,\bar{\nu}} \rangle$

what is happening in $\bar{\nu}$ channel ?



Since σ^{ν}_{cc} linear in E_ν (within 15%) up to 100 GeV, we conclude

$$\boxed{\sigma^{\nu}_{NC} \text{ (roughly) linear in } E_\nu}$$

$\sigma^{\bar{\nu}}_{NC}$?

IV THE FUTURE

A. Second generation HPWF expt.

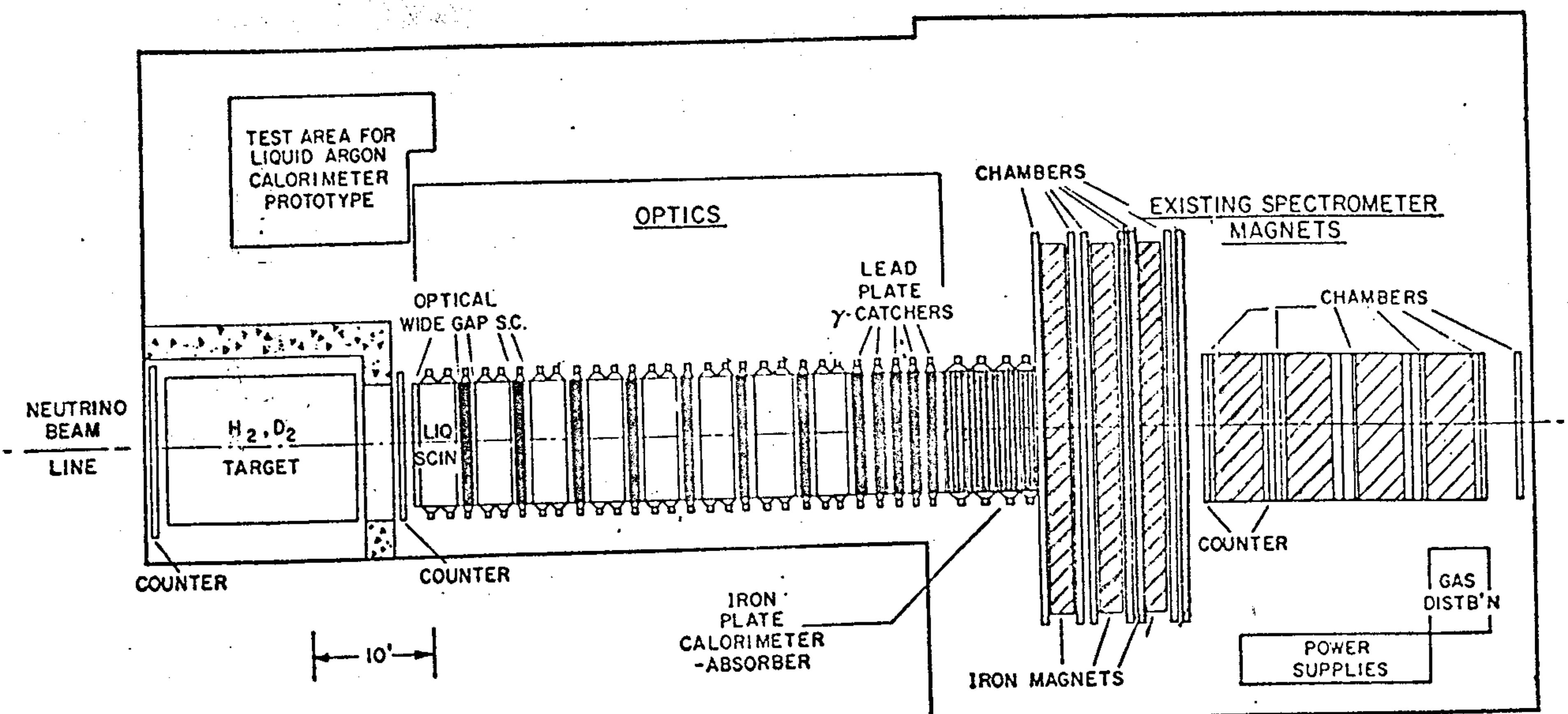
(i) Rate : ν_μ- induced events $\Rightarrow$

30 events/(ton-hour) $\Rightarrow$ 6×10^3 events/hr

$\Downarrow$

Neutrino Oscillation
Expt at 10^3 km

(ii) Flexibility



PLAN VIEW OF APPARATUS

EARLY, 1975