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

NEUTRAL CURRENTS AND CHARM AT CERN

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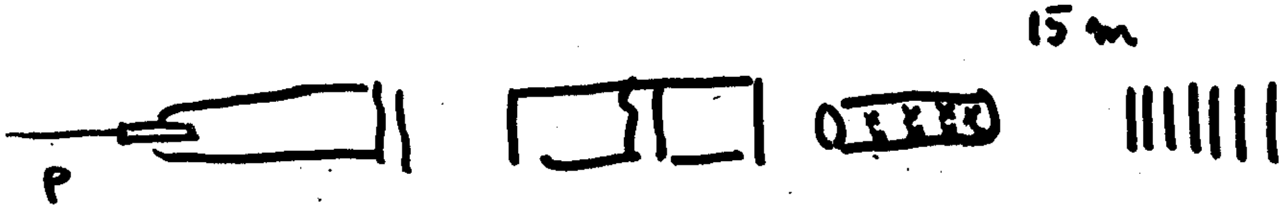
New results at CERN



Gargamelle 1971 - 1975

$\Phi = 1.9$ m $L = 4.5$

$B \simeq 20.000$ gauss.

Propane

Freon CF_3Br $X_0 = 11$ cm $X_{int} = 60$ cm
$d = 1.5$ gr cm^{-3}

Aachen - Brux - CERN - E.P. - Orsay - Milan - UCL

S.C. Aachen-Padova Jul. 74 - Nov. 75

141 bigap Al $\Rightarrow$ 282 gaps

$2 \times 2\ m^2$ $\underline{0.5} - 1 - \underline{1}$

Last 12 chambers with 12 Fe 4 cm

Total Target mass : 50 tons

Fiducial Volume : 19 tons

X_{rad} in Al $\underline{9\,cm}$ $\Rightarrow$ 22 cm in space

— • —

a) SEARCH FOR NEW PARTICLE

b) LEPTON N.C.

c) STRUCTURE OF SEMILEPTON NEUTRAL CURRENTS.

a) SEARCH FOR N.P.

Discovery of $\mu\mu$ events in neutrin

nd antineutrino interactions

and of $\mu^\pm e^\mp$ pairs in e^+e^-

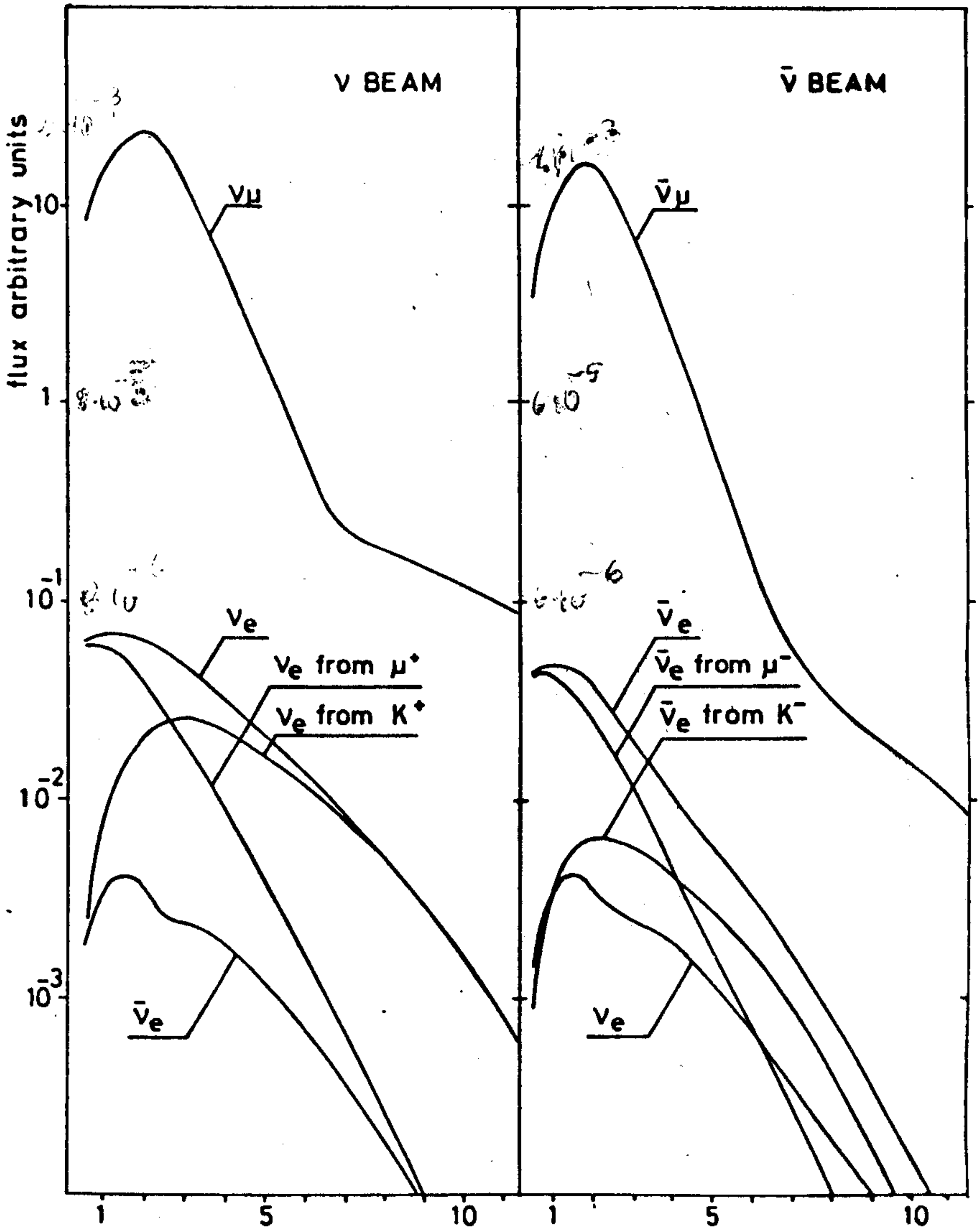


Fig.1

Neutrino and antineutrino spectrum in the Gargamelle experiment.

225_525_4

ν_μ + nucleon $\rightarrow \mu^- + X^+$ + hadrons

$\bar{\nu}_\mu$ + " $\rightarrow \mu^+ + X^-$ + hadrons

$\sin^2\theta_c$ $S=0$ $C=+1$ $\boxed{X}$ $q=+1$ valence

$\cos^2\theta_c$ $S=+1$ $C=+1$ $q=+1$ sea

Gargamelle $X^+ \rightarrow K^0 e^+ \nu_e$

$\rightarrow V^0$ + pions + p

1971–72 1975 4 – 6.3 factor

Results on neutrino $\mu^- e^+ (V^0)$

i) Leptonic Decays $\underline{\nu}$

560.000 pictures $\Rightarrow 1.7 \cdot 10^{18}$ protons

$\nu_\mu + N \rightarrow \mu^- + e^+ + (V^0)$ + hadrons

3 m^3

Scanning for e^+, e^-, e^+e^-, strange part

$\Downarrow$

After reconstruction $\Rightarrow$

1) $E_{vis} > 1$ GeV 2) $\Sigma P_L > .6$ GeV/c

3) $E_e > 200$ MeV single < 5 mm $\Rightarrow$ 4–8 m

4) charged decays of V^0 only if $L < 3 L_{1/2}$

$Eff_{\Lambda_0} = (0.52 \pm .04)$ $Eff_{K^0} = (0.26 \pm 0.03)$

Events with $E_{vis} > 1 GeV \Rightarrow 40.6\%$

Energy	1-2	2-3	3-4	4-6	6-8	8-10	10-[illegible]
%	30.5	31.5	17.8	12.1	4.3	2.5	1.[illegible]

Topology	# ev	Background e^+e^-	$\bar{\nu}_e(\nu_e)$	$\Rightarrow$ Total
$\mu^- e^+ V^0$	3 (+1)	.10	.01	0.11 ± .
$\mu^- e^+$	19	6.4	.3	6.7 ± 3
$\mu^- e^-$	25	19.2	7.5	26.7 ± 7
$\cancel{B}^- V^0$	6	—	2.5	2.5 ± .
$e^+ X$	4	—	4.8	4.8 ± 2

Details

1080 γ

asymmetric e^+e^-

attachement prob : $(4.1 \pm 0.7)\%$

$(1.5 \pm 0.4)\%$

asymmetry " : $(4.4 \pm 0.6)\%$

ν_e (ν_e)

$\bar{\nu}_e + N \to e^+ + \pi^-(K^-) + \text{hadrons}$

$\bar{\nu}_\mu + N \to \mu^+ + \pi^-(K^-) +$ "

Difference between $\bar{\nu}_e$ and $\bar{\nu}_\mu$ spectra

$\nu_e + N \to e^- + \pi^-(K^-) + \text{hadrons}$

$\nu_\mu + N \to \mu^- + \pi^-(K^-) +$ "

Presence of a V^0 in about 0.5 ...

events

If $\mu^- V^0 e^+$ from $e^+e^- \Rightarrow 9\ \mu^- V^0 e^- \Rightarrow 0$

" $\mu^- V^0 e^+$ " $\bar{\nu}_e \Rightarrow 10^2$ more $\mu^- e^+ \Rightarrow 10$

Other interactions

$\mu^- e^+ V^0$ hadrons $\quad E_{vis} = 4.6\text{ GeV} \quad E_e = 200^{+15}_{-10}$

$\Downarrow$

K^0

$\mu^- \Sigma^- e^+$ hadrons $\quad E_{vis} = 9.75\text{ GeV} \quad E_e = 2.6$ G

$\hookrightarrow K^0_s$

$\mu^- e^+$ hadron  $\quad$ " $\quad 4.38$ " $\quad 220 \pm 50$

$\Lambda^0 \to \pi^0 n$

Topology	$e^+V^0D^-(\mu^-)S^-$ Σ^+ 2p 2n	$e^+V^0L^-(\mu^-)\Sigma^+p$	$e^+\Lambda^0L(\mu^-)\Sigma^+p$
E_{vis}	3.6	3.9	6.1
P_{e^+}	250 ± 50	900 ± 250	170 ± 170
P_μ	150 ± 2	1060 ± 145	895 ± 35
P_{V^0} K^0	1.8	1.9	–
P_{V^0} Λ^0	2.1	1.1	3.7
X_{vis}	0.1	0.35	0.87
y_{vis}	0.94	0.72	0.85
$M(\Lambda e)$	1.24	1.91	1.99
$M(Ke)$	.65	1.57	–

μ^-e^+

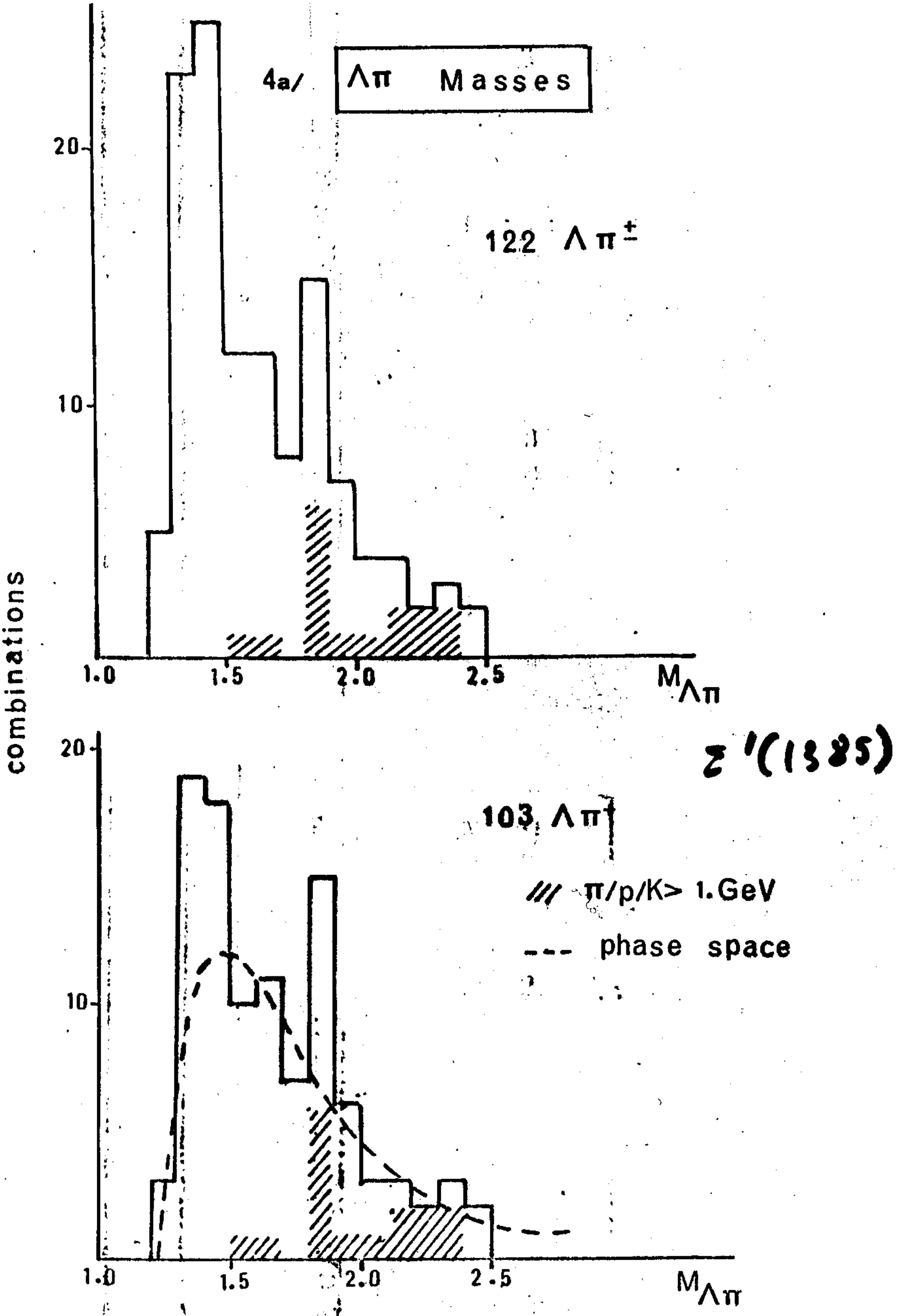
3+1 $\mu^-V^0e^+$ <u>12.3</u> ± 8.7 with or withou

ALL CONSISTENT WITH THE PRESENCE OF A STRANGE PAR

ii) Hadron decay-

Brookhaven Φ 2m h = 3 m

	Pict	Events	Strange Part
H_2	204,000	~400	6
D_2	278000	686	4



4a/
Λπ Masses
20
10
122 Λπ±
combinations
1.0
1.5
2.0
2.5
MΛπ
Σ'(1385)
20
10
103 Λπ∓
/// π/p/K> 1.GeV
--- phase space
1.0
1.5
2.0
2.5
MΛπ

Figure 4

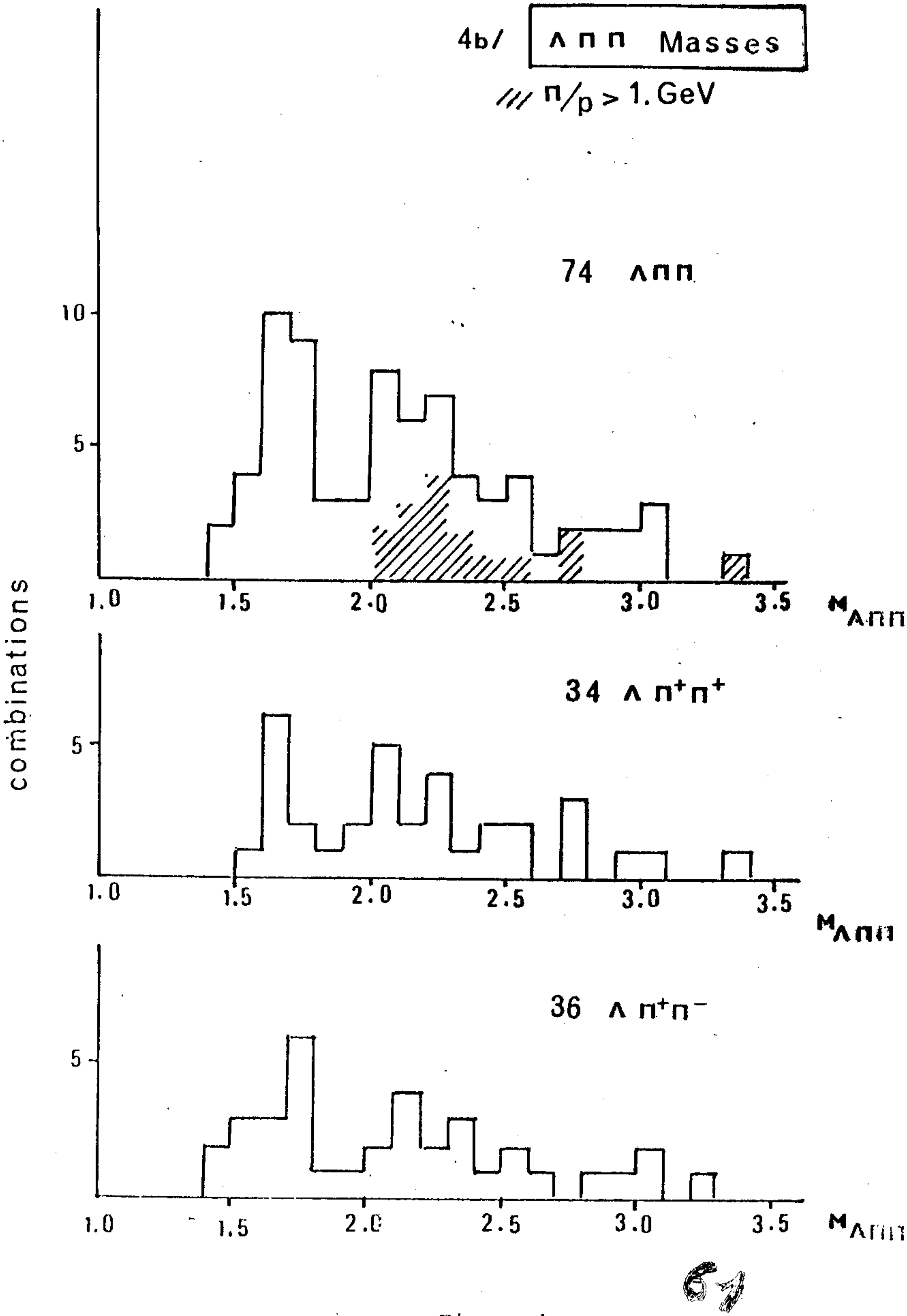

4b/
Λ π π Masses
/// π/p > 1. GeV
74 Λππ
10
5
1.0
1.5
2.0
2.5
3.0
3.5
$M_{\Lambda\pi\pi}$
combinations
34 Λ π⁺π⁺
36 Λ π⁺π⁻
67

Figure 4

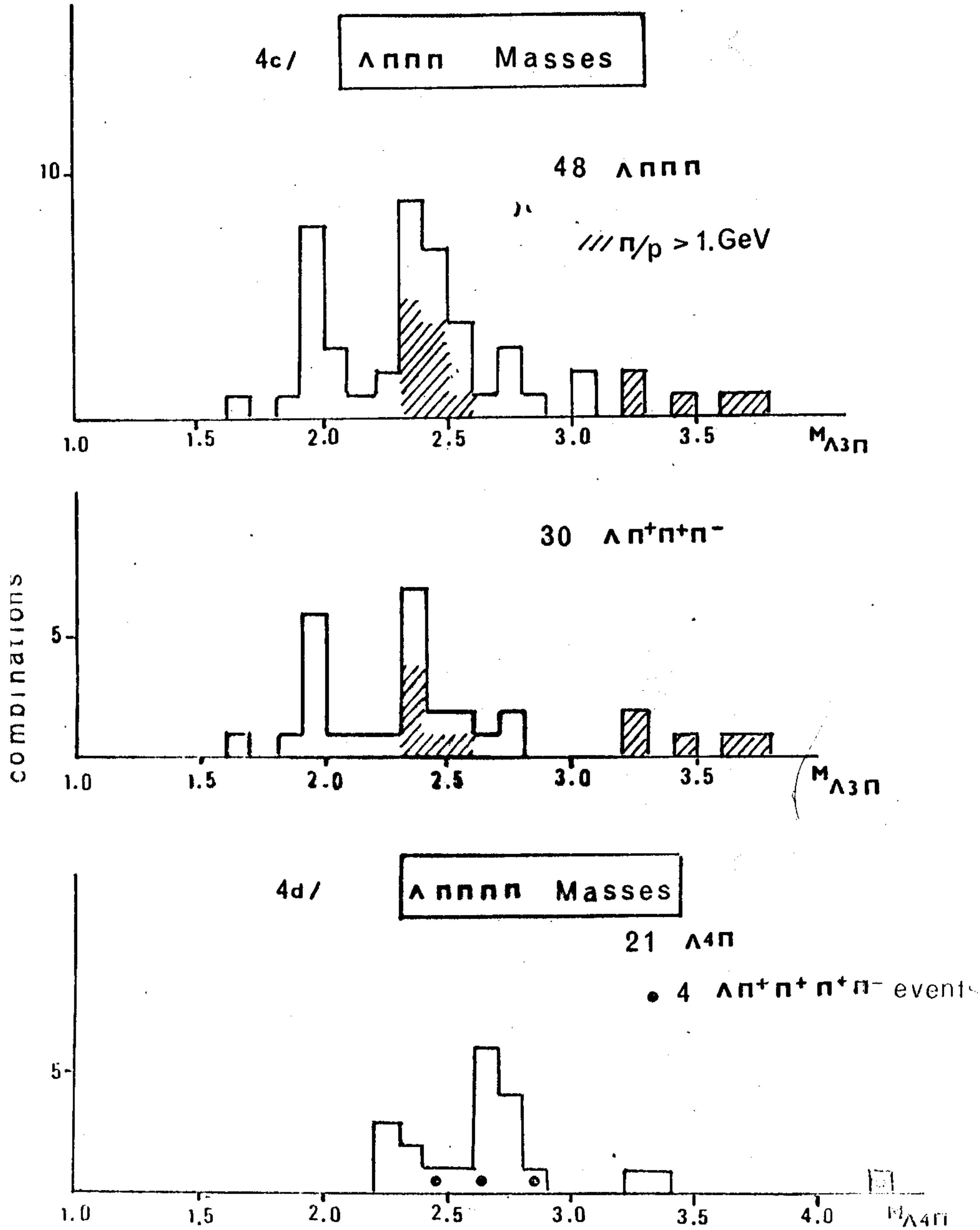

4c/
Λπππ Masses
10
48 Λπππ
/// π/p > 1.GeV
1.0
1.5
2.0
2.5
3.0
3.5
$M_{\Lambda 3\pi}$
combinations
30 Λπ⁺π⁺π⁻
5
1.0
1.5
2.0
2.5
3.0
3.5
$M_{\Lambda 3\pi}$
4d/
Λππππ Masses
21 Λ4π
4 Λπ⁺π⁺π⁺π⁻ events
5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
$M_{\Lambda 4\pi}$

Figure 4

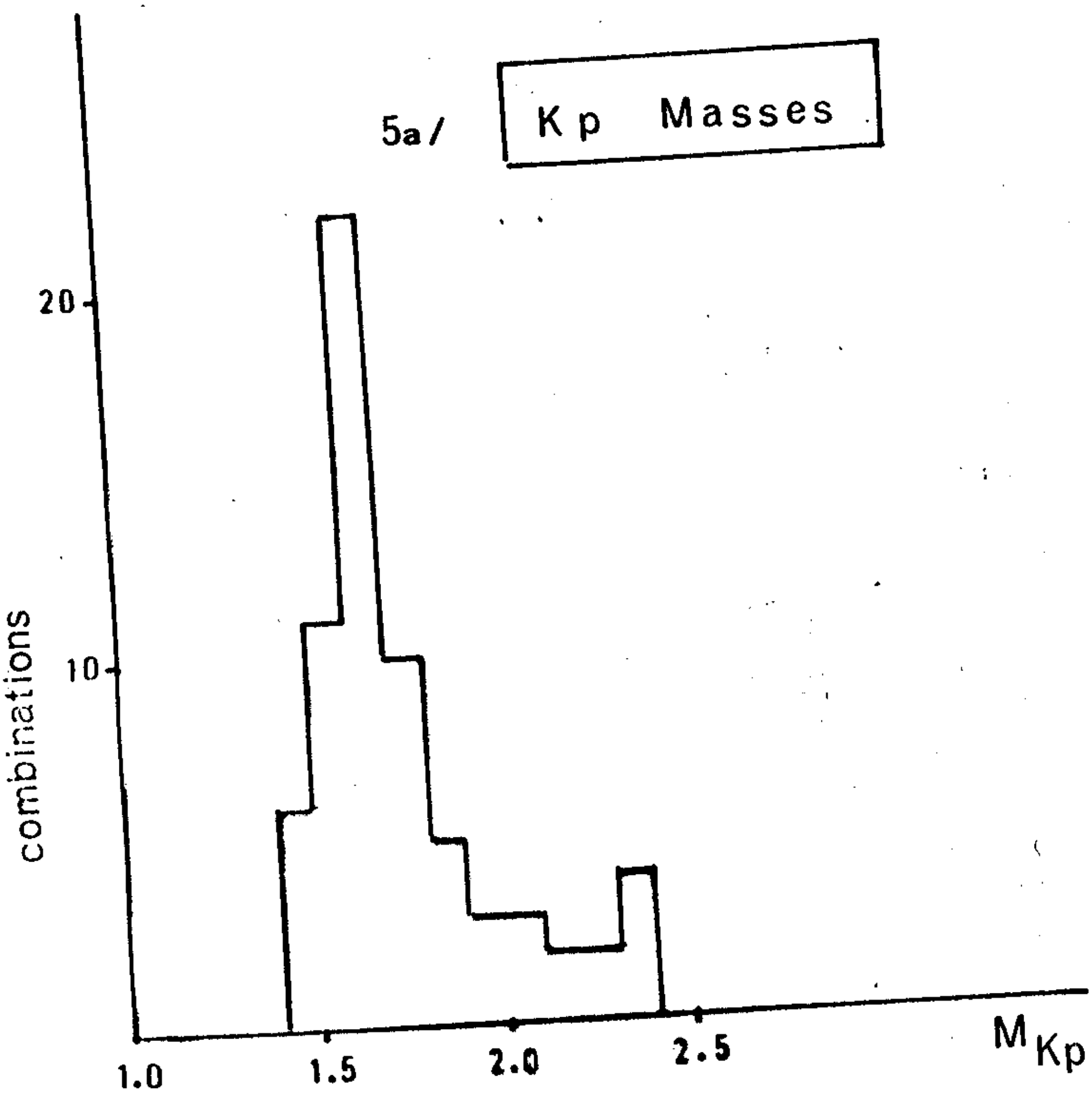


Figure 5

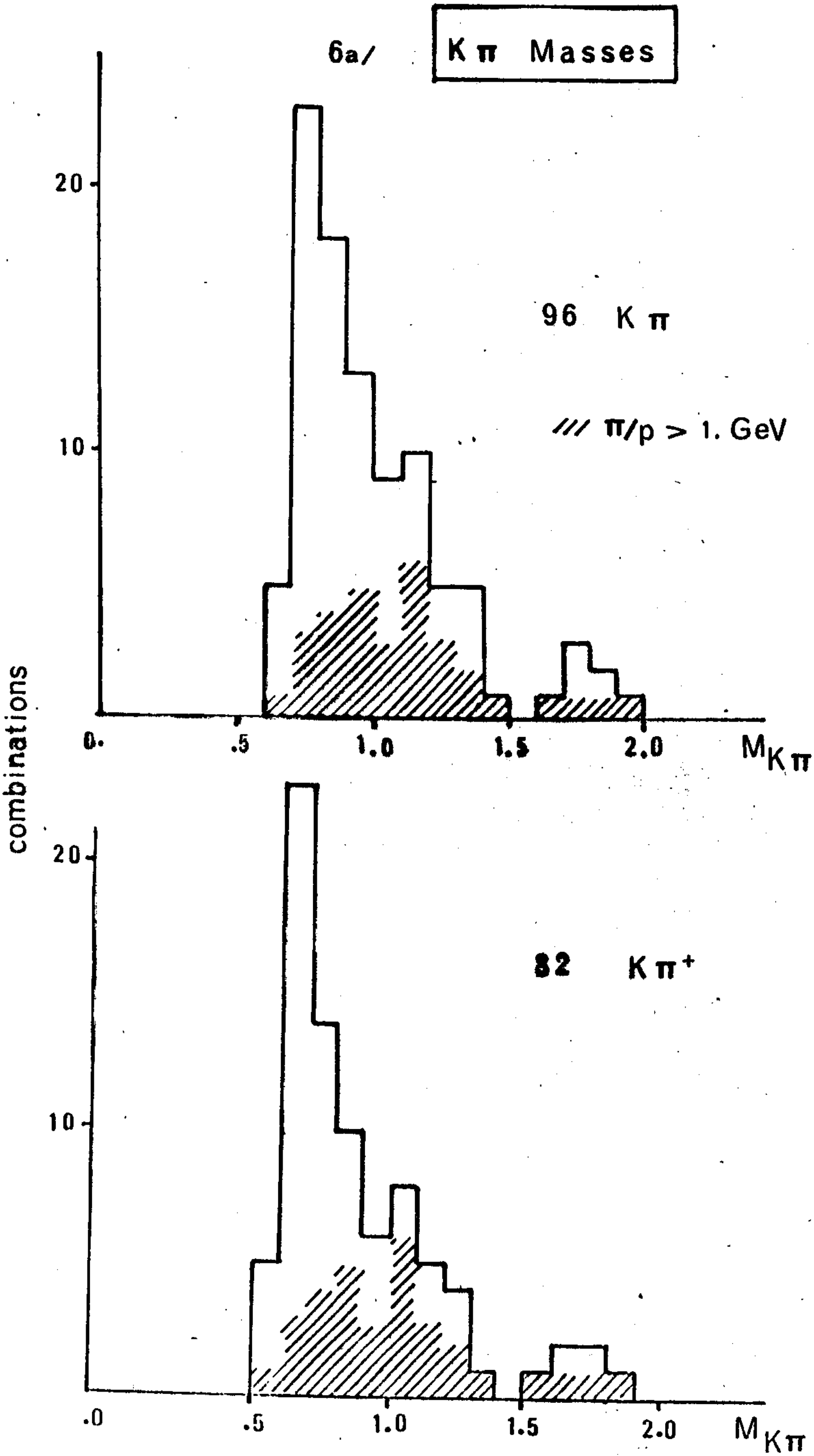

6a/
Kπ Masses
96 Kπ
/// π/p > 1. GeV
82 Kπ⁺
combinations
20
10
0.
.5
1.0
1.5
2.0
$M_{K\pi}$
.0

Figure 6

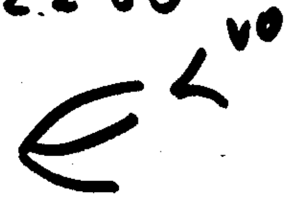
Energy similar to Gargamelle exp.

1 $\nu p \to \mu^- \Lambda^0 \pi^+ \pi^+ \pi^+ \pi^-$ $\Delta S = -\Delta Q$

$E_\nu = 13.5$ GeV

$M(\Lambda^0 \pi^+ \pi^+ \pi^+ \pi^-) = 2.426 \pm 0.013$ GeV

$M(\Lambda^0 \pi^+ \pi^+ \pi^-)$ 2090 — 2260



Gargamelle

60% of events

V^0 with fit > 1% and $L < 3 L_{1/2}$

69 Λ, 40 K^0, 34 $K^0 V^0$ 13 associated V^0's

$\Lambda\pi$, $\Lambda\pi\pi$, $\Lambda\pi\pi\pi$, $\Lambda\pi\pi\pi\pi$ $K\pi$ and Kp

$\pi^+ p$ ambiguity

No peak apart $\Sigma'(1385)$ in $\Lambda\pi^\pm$

Three events with $(\Lambda \pi^+\pi^+\pi^+\pi^-)$ compatible with 2.5 GeV $\Rightarrow$ 15 times Brookhaven

Ratio (extreme) all events with $E_{vis} > 3$ GeV with V^0 due to charm and $\Gamma_e \mp \Gamma_\mu$

$$\frac{\Gamma_{lept.}}{\Gamma_{hadronic}} > 7\%$$

Other BC experiments

Berkeley - CERN - HAWAII - Wisc.

$15'$ 20% Neon 110 cm X_{rad} WB

$X_{int} = 200$ cm EMI 5000 events

15 candidates $\mu^- e^+$

11 with [illegible] 8 K_s^0, 2 Λ, 1 [illegible]

4 without $V^0 \Rightarrow$ [illegible] $K_s^0 \rightarrow \pi^0 \pi^0$

Background ≈ 1 event -

Many K_s^0 per event.

Columbia - Brookhaven $\nu_\mu / \bar{\nu}_\mu / \nu_e / \bar{\nu}_e \sim 100/3/1/$

$15'$ 64% Ne $d = 0.8$ $X_{rad} = 40$ cm $X_{int} = 100$ cm

50.000 pictures 1 ev./pict. (all)

41 events with $E_e > 300$ MeV

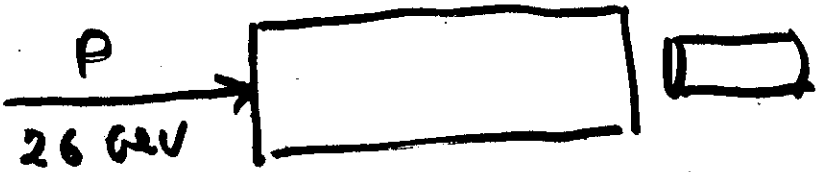
$\Downarrow$

30 with μ^- Background

$\frac{1}{4000}$ $e^+ e^-$ $\frac{1}{3000}$ $K^+_{3} e^+ \pi^0 \nu$ $\frac{1}{3000}$ $\bar{\nu}_e$ int

Heavy leptons

$L^{\pm} \to L^{0}$ long lifetime $10^{-3} - 10^{-6}$ seconds



ν from decay of π or K $\Rightarrow \frac{1}{500}$

~30.000 pictures with beam

~18.000 " Cosmic Rays

CF_3Br
$3\ m^3$

i) one or more protons ($L_{proj.} > 1$ cm)

ii) one p or π, K

selection

a) 2^{nd} half of chamber

b) $\Sigma p_x > .3$ GeV/c

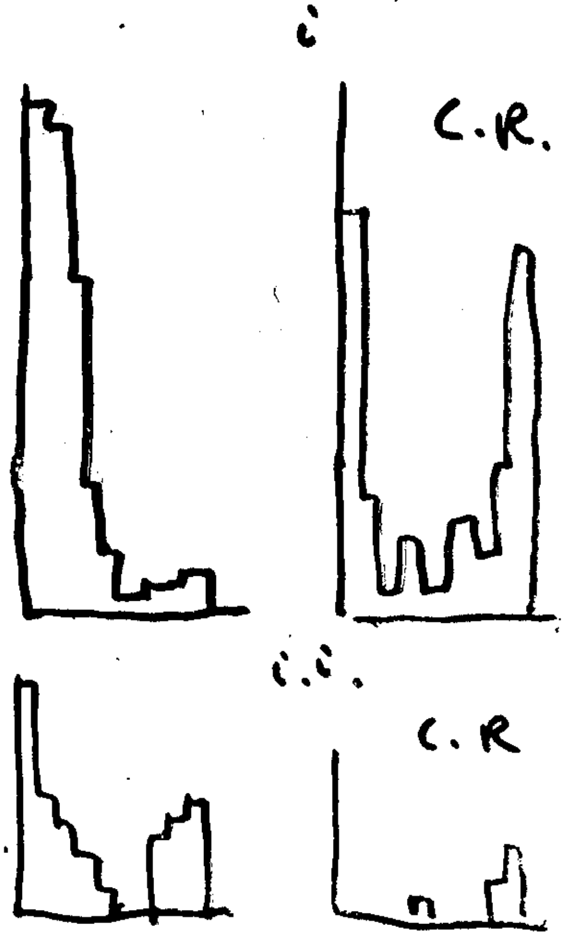
$\Downarrow$

		E_{vis}
2 events	$p\, \pi^0\, \mu^+ (\pi^+$	2.9
	$p\, p\, \mu^+ (\pi^+)$	1.2

1 " in R.c.

expected 1.5 ± 0.5 neutrino events

$\sigma_{prod}\, \sigma_{int} < 10^{-64}\ cm^4$



ii) LEPTONIC NEUTRAL CURRENT

$\bar{\nu}_\mu + e^- \longrightarrow \bar{\nu}_\mu + e^-$ $\nu_\mu + e^- \rightarrow \nu_\mu + e^-$

Gargamelle

350.000 + 350.000 pictures CF_3Br $\bar{\nu}$

4.7×10^{18} protons on target ▲ ν_e

F.V. 6.3 m^3 - Scanning for

a) $e^-, e^+, e^\pm$ b) e^+e^-

some events are ambiguous $E_e > 300$ MeV

$E_e < 2$ GeV $\vartheta < 3°$ $\vartheta < 5°$ 1.5° -

$3e^-$ 1 e^-/γ 6 → 5 γ's $3e^+$ $3e^\pm$

In kinematic region $3e^-$ and $5e^+e^-$ / $1e^\pm/\gamma$

0.39 ± 0.13   0.50 ± 0.12   0.80 ± 0.25

Background:

a) e^+e^- $(3.4 \pm 0.7)\%$ from 700 events

for γ's with $E_\gamma > 300$ MeV

5 + 1 event ⇒ 0.2 events

b) $\nu_e + n \rightarrow e^- + p$

$\nu_\mu + p \rightarrow \mu^- + \text{m.protons}$ ⇒ 890 ⇒ 10 (< 5°

$$\frac{e^-(\vartheta < 5^\circ,\ E_{e^-} < 2\,\mathrm{GeV}) + 0p}{e^- + mp} = (0.1 \pm 0.05)\ \%$$

0.07 ± 0.04 events $\quad \nu_e(\bar\nu_e) + e^- \to \nu_e \ldots$

$\Rightarrow$ 0.11 events

$\vartheta > \vartheta > 5^\circ \quad 69\ e^+e^- \Rightarrow \left.\begin{matrix} 2.34 \pm 0.54 \\ 0.38 \pm 0.06 \end{matrix}\right\} 2$

Losses: scanning efficiency, $e^- + e^+e^-$ ambiguity - $e^\pm$ ambiguity - Determined experimentally -

$$\frac{d\sigma}{dy} = \frac{2G^2 m}{\pi} E_{\bar\nu}\left[\left(\frac{G_V+G_A}{2}\right)^2(1-y)^2 + \left(\frac{G_V-G_A}{2}\right)^2\right]$$

$$0.1 < \sin^2\vartheta_{W} < 0.4 \quad 90\%$$

integrating on y and using data on $\nu_\mu e \to \nu_\mu e$

Aachen-Padova - ν and $\bar\nu$

no magnetic field. $e \Rightarrow$ shower - (also γ)

1.700.000 $\Rightarrow$ 1.100.000 pictures election:

a) shower not pointing to a visible vertex

b) $.2 < E_e < 2.0$ GeV

c) $\vartheta < 5$

d) below kinematical curve

	ν	$\bar{\nu}$
	25 e^-	19 e^-
Backgr.	11.8	2.9
	13 ± 5.3	16 ± 4.5
P	$3.4 \cdot 10^{48}$	$3.45 \cdot 10^{18}$

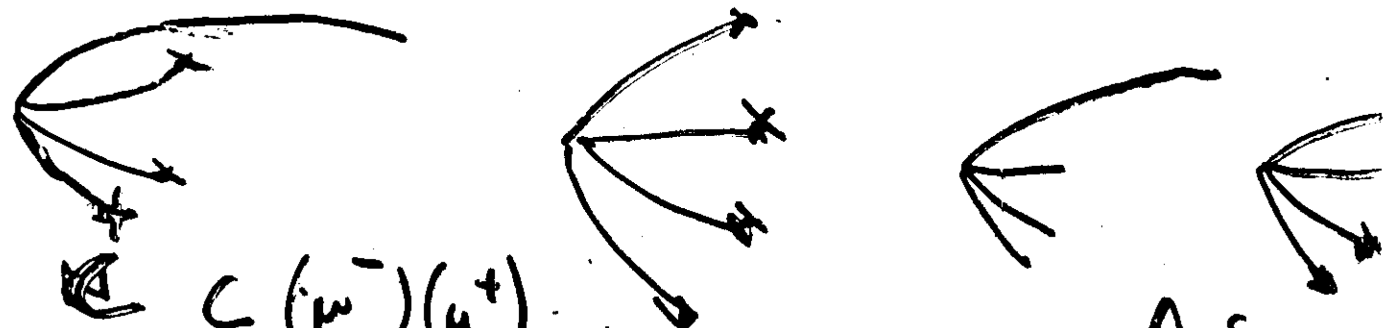
Background:

0.4	0.04	$\nu_e n(p) \to e^- p(\ldots$
10.6±1.7	2.8±1.1	$\overset{(-)}{\nu}_\mu n \to \overset{(-)}{\nu} n\pi^0$ $\overset{(-)}{\nu}_\mu p \to \overset{(-)}{\nu}_\mu p\pi^0$
0.9	0.06	incoming γ-ray

$$\frac{\sigma(\nu_\mu e)}{\sigma(\bar{\nu}_\mu e^-)} = 0.44 \pm 0.26$$

INCLUSIVE N.C.

Definition of events



S^+, I^-, J^+

Selection:

a) F.V. $3\,m^3$ b) $E_H > 1$ GeV c) $\Sigma p_x > 0$

x, R, ϑ, $\frac{1}{\lambda}$, E_H distribution symila multiplicity for C.C. and N.C.

Background:

a) in NC n and K^0_L inter. 2 methods

$\frac{B}{AS}$ and λ 9.2 % NC_ν 7.3 % $NC_{\bar{\nu}}$

3

b) C.C. events

μ^-

NC simulating CC "false C.C. μ^+ and" μ^- "

		ν uncorr.	n false CC		ν cont.	CORR
ν	NC	175	16	—	—	159
	CC(μ^-)	658	—	27	—	631
$\bar{\nu}$	NC	151	11	—	9	131
	CC(μ^+)	273	—	38	—	235

$$R_\nu = 0.25 \pm 0.03 \qquad R_{\bar{\nu}} = 0.56 \pm 0.07$$

Experimental biases

a) missing energy

$$\frac{\text{n° events with } E_{meas} > 1\,GeV}{\text{" " } E_{true} > 1\,GeV}$$

ν	$\frac{d\sigma}{dy} \div E$	$\frac{d\sigma}{dy} \div (1-y)^2 E$
ν CC	0.81	0.72
ν NC	0.82	0.78
$\bar{\nu}$ CC	0.80	0.75
$\bar{\nu}$ NC	0.81	0.77

b) detection efficiency (is the same?)

each NC weighted for detection probability and to simulate NC

$R_\nu = 0.21 \pm 0.02$ $\quad R_{\bar{\nu}} = 0.55 \pm 0.04$

c) ambigous tracks

p $\quad R_\nu = 0.27 \pm 0.03$ $\quad R_{\bar{\nu}} = 0.52 \pm 0.07$

π^+ $\quad 0.22 \pm 0.03$ $\quad = 0.59 \pm 0.07$

$$\boxed{R_\nu = 0.25 \pm 0.04 \qquad R_{\bar{\nu}} = 0.56 \pm 0.10}$$

Theoretical evaluation -

$E_H > 1\,\mathrm{GeV}$ expecially for $\bar{\nu}$ $\quad y_{min} = \frac{}{E}$

$$R_\nu^{obs} = \frac{\int \Phi(E)\left[\int_{y_{min}}^{1} \frac{d\sigma^{NC}}{dy}\, dy\right] dE}{\int \Phi(E)\left[\int_{y_{min}}^{1} \frac{d\sigma^{cc}}{dy}\, dy\right] dE}$$

a) scaling is valid

b) CC $V-A$

c) NC $(V-A)$ and $(V+A)$

$$\boxed{\text{C.C.}}$$

$$\frac{d\sigma^{cc}}{dy}\nu = \frac{G^2 ME}{\pi}\left[a_1 + a_2(1-y)^2\right] \qquad \frac{d\sigma^{cc}}{dy}\bar{\nu} = \frac{G^2 ME}{\pi}\left[a_1(1-y)^2 + a\right.$$

0.76 ± 0.08 $\quad 0.28 \pm 0.03$ $\quad 0.98 \pm 0.05$ $\quad 0.02 \pm 0$

$$r = \frac{\sigma_{\bar{\nu}}^{cc}}{\sigma_{\nu}^{cc}} = \frac{1+3\varepsilon}{\varepsilon+3} \qquad \varepsilon = \frac{a_2}{a_1} \qquad \varepsilon = 0.053 \pm 0.023$$

$\boxed{NC}$

$$\frac{d\sigma_{\nu}^{NC}}{dy} = \frac{G^2 ME}{\pi}\left[A_L + A_R(1-y)^2\right] \qquad A_L \to V-A$$

$$\frac{d\sigma_{\bar{\nu}}^{NC}}{dy} = \frac{G^2 ME}{\pi}\left[A_L(1-y)^2 + A_R\right] \qquad A_R \to V+A$$

$$R_{\nu}^{obs} = \frac{\int E\,\Phi_{\nu}(E)\,dE\left\{\int_{y_{min}}^{1}\left[A_L + A_R(1-y)^2\right]dy\right\}}{\int E\,\Phi_{\nu}(E)\,dE\left\{\int_{y_{min}}^{1} a_1\left[(1+\varepsilon(1-y)^2\right]dy\right\}}$$

$$A_R = 0.036 \pm 0.010 \qquad A_L = 0.11 \pm 0.02$$

$$\Downarrow$$

$$\boxed{\begin{aligned} R_{\nu}^{corr} &= 1.05\,R^{obs} = 0.26 \pm 0.04 \\ R_{\bar{\nu}}^{corr} &= 0.76\,R_{\bar{\nu}}^{obs} = 0.39 \pm 0.06 \end{aligned}}$$

$$A_R = A_L \qquad R_{\bar{\nu}} = 2.6\,R_{\nu} \qquad \sigma_{\nu}^{NC} = \sigma_{\bar{\nu}}^{NC}$$

P.C. Models

$$A_L - A_R = 0.74 \pm 0.023$$

$$2.6\,R_{\nu} - R_{\bar{\nu}} = 0.26 \pm 0.08$$

A_L and A_R as a function of $\sin^2\vartheta_{SW}$

$$\sin^2\vartheta_{SW} = 0.33 \pm 0.05$$

$R^{obs}_{\nu(\bar{\nu})}$ as function of $\sin\vartheta_W$

ν 0.31 ± 0.07 $\bar{\nu} = 0.33 \pm^{0.07}_{0.10}$

Exclusive N.C.

Gargamelle 120000 ν and $\bar{\nu}$ $3\,m^3$

$$\nu_\mu(\bar{\nu}_\mu) + N \to \nu_\mu(\bar{\nu}_\mu) + N' + \pi^0$$

NC π^0 origin with protons 1γ, 2γ
without " 2γ

CC π^0 1 and only 1 $\mu^\pm$ 1γ, 2γ

Corrected for 1γ, protons leaving, π-p amb., 2γ with $m_{\gamma\gamma} > 0.4$

ν NC 146 ± 13
CC 338 ± 27 $\boxed{\nu}$

$\bar{\nu}$ NC 176 ± 14
CC 199 ± 15 $\boxed{\bar{\nu}}$

$$0.10 < \frac{\sigma(\to \nu_\mu N'\pi^0)}{2\sigma(\mu^- N'\pi^0)} < 0.20 \qquad .26 < \frac{\sigma(\bar{\nu}_\mu N'\pi^0)}{2\sigma(\mu^+ N'\pi^0)} < .48$$

AACHEN - PADOVA on ^{27}Al

$\pi^0 \to 2\gamma$ $1\gamma \to$ shower μ, p

Corrections: μ/p, additional π^0, dditional π^+, π^-, neutron background

ν N C 125.8

C C 122.2

$\bar{\nu}$ N C 88.6

C C 65.4

$$\frac{\bar{\sigma}_0}{\sigma_0} = 0.49 \pm 0.14$$

$$0.25 < \sin^2\theta_{sW} < 0.55$$

ISOSPIN PROPERTIES OF N.C.

Bertrand - Coreman et al - $\Delta I = 0, \Delta I = 1$

- $\nu(\bar{\nu}) + p \to \nu(\bar{\nu}) + p + \pi^0$ $\quad \nu(\bar{\nu}) + p \to \nu(\bar{\nu}) + n + \pi^+$
- $\nu(\bar{\nu}) + n \to \nu(\bar{\nu}) + p + \pi^-$ $\quad$ • $\nu(\bar{\nu}) + n \to \nu(\bar{\nu}) + n + \pi^0$

Exp. eff. π^0 $(1-2\gamma)$ $\quad \pi^-$ (int. prob. and $\mu^+\pi^-$)

$\frac{\pi^0}{\pi^-}$	Exp	Theor. $(\Delta I = 0)$	$\Delta I = 1/2$ ws
ν	1.4 ± 0.2	0.9	1.8
$\bar{\nu}$	2.1 ± 0.4		

effects of neutrons

a) Parity violation

b) $\Delta I = 0, \Delta I = 1$

Elementary particles: existence of pseudoscalar terms

$\Downarrow$

Nuclei: parity forbidden transitions have been found, as well as $\vec{\sigma}_N \cdot \vec{k}$ and P_γ correlations. Can be explained by c.c. with large nuclear effects. Nuclear currents explain everything.

$\Downarrow$

Muonic atoms: presence of pseudoscalar terms can be due only to weak nuclear currents. Experiments are very difficult.

$\Downarrow$

Atoms: as above, but experiments look possible. Rotation of the polarization plane of laser light. Experiments on Bi vapour at Oxford and Seattle.

Published: $< 10^{-6} \div 3.5 \cdot 10^{-7} \rightarrow 2 \cdot 10^{-7}$

Rumours of effect 1-1.5 times the S.W. predictions