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

Inclusive Features of

Hadron Production in μN Scattering.

Multiparticle Aspects

What questions would we like to see answered by a study of hadron production?

lepton structure:

any thing special about μ^+ vs. μ^- ?

$\mu^\pm$ vs. $e^\pm$?

μ, e vs. ν ?

$\Rightarrow$ At present energies, the answer is disappointing.

Many global features appear to depend on appropriately defined kinematical régime alone.

is the only mechanism of interest

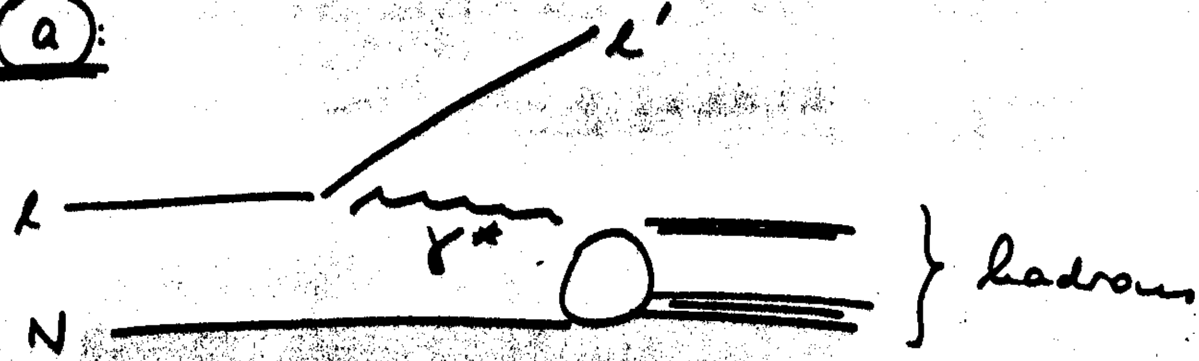
$\boxed{\gamma^* N \to \text{hadrons}}$?

REMEMBER:

If we accept the muon as nothing but a source of virtual photons,

→ THIS IS A **VERY SPECIAL HADRON** source

(a):



$$E_\ell - E_{\ell'} \equiv \boxed{\nu}$$

lab energy of virtual photon

$$q^2 \equiv \boxed{-Q^2}$$

mass-squared of virtual photon

$$= -4 E_\ell E_{\ell'} \sin^2 \frac{\theta_\ell}{2}$$

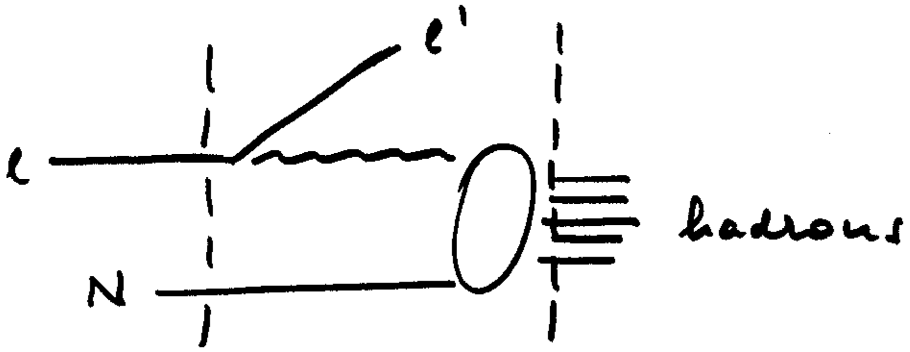
→ by varying kinematical parameters at will,

WE CAN VARY { "MASS" / POLARIZATION } OF BEAM

$$\longrightarrow \epsilon = \left[1 + 2\left(1 + \frac{\nu^2}{Q^2}\right) \tan^2 \frac{\theta_\ell}{2}\right]$$

WHAT CAN BE LEARNED FROM INELASTIC μ-N COLLISIONS ?

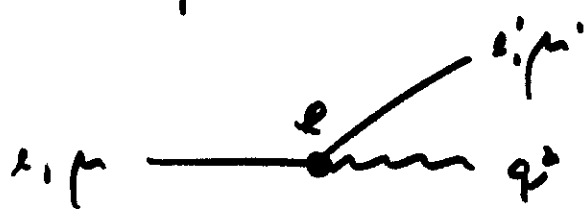
HADRON PRODUCTION:



$\langle N | \quad J_\mu^{had} \quad | \text{hadrons} \rangle$

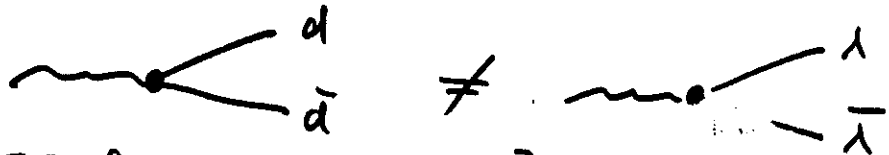
In principle, we can learn about

(1) the lepton:



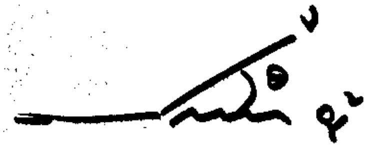
→ is the photon coupling to the $\mu^\pm$
= the photon coupling to the $e^\pm$?

Remember



SUPERSYMMETRIES ?

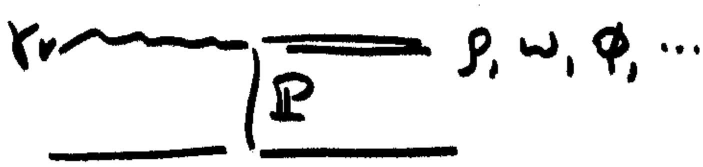
② The photon:

→ 

from variation of "mass" $-q^2$

→ 

from isospin structure

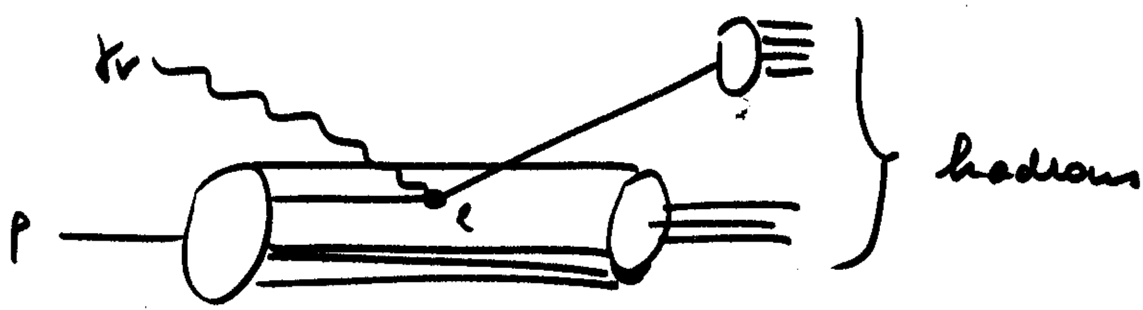
→ 

from "elastic" vector meson production

(size, symmetry structure)

③ the nucleon's structure:

→ γv at high Q^2, ν, "point-like" probe

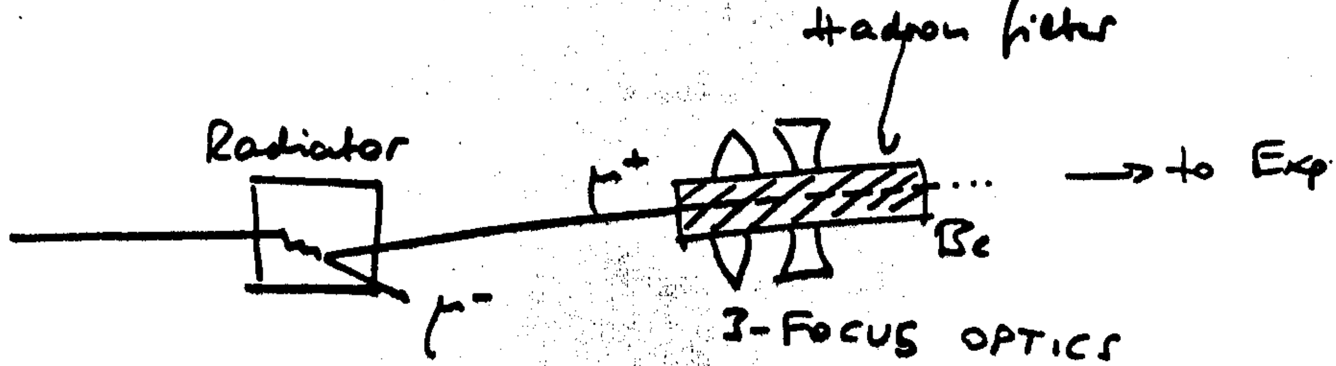


FIRST TASK: BEAM

Optimize experimental conditions

BEAM

→ μ's from SLAC:



YIELD at $E_{\mu^+} \approx 14.$ GeV

Intensity $\left\{ \begin{array}{l} \sim 200-400\ \mu\text{'s per } \underbrace{\text{SLAC pulse}}_{1.5\ \mu\text{sec}} \\ \\ \lesssim 10^5\ /\text{sec} \end{array} \right.$

"Cost" $\{\ \approx 10^{-9}$ per accelerated electron

Special feature: <u>unpolarized</u>.

HADRON PRODUCTION IN μ-N COLLISIONS AT SLAC.

EXPERIMENTAL PROGRAM SINCE 1971

UC Santa Cruz,
SLAC Group D

C. del Papa
D. Dorfan
S. Flatté
C. Heusch
B. Liebermann
H. Meyer
L. Moss
T. Schalk
A. Seiden
K. Bunnell
M. Duong-van
R. Mozley
A. Odian
F. Villa
L.C. Wang.

~~BUT FIRST~~ NEXT: TRY TO OPTIMIZE EXPERIMENT

$$\sigma_{tot}\left(\mu p\big|_{\substack{Q^2>0.3\\ \nu>2.}}\right) \sim 0.3\,\mu b$$

with given μ flux, need thick target,
large solid angle detection

$\Longrightarrow$ 40 cm liquid $\left\{\begin{matrix} H_2 \\ D_2 \end{matrix}\right\}$ target

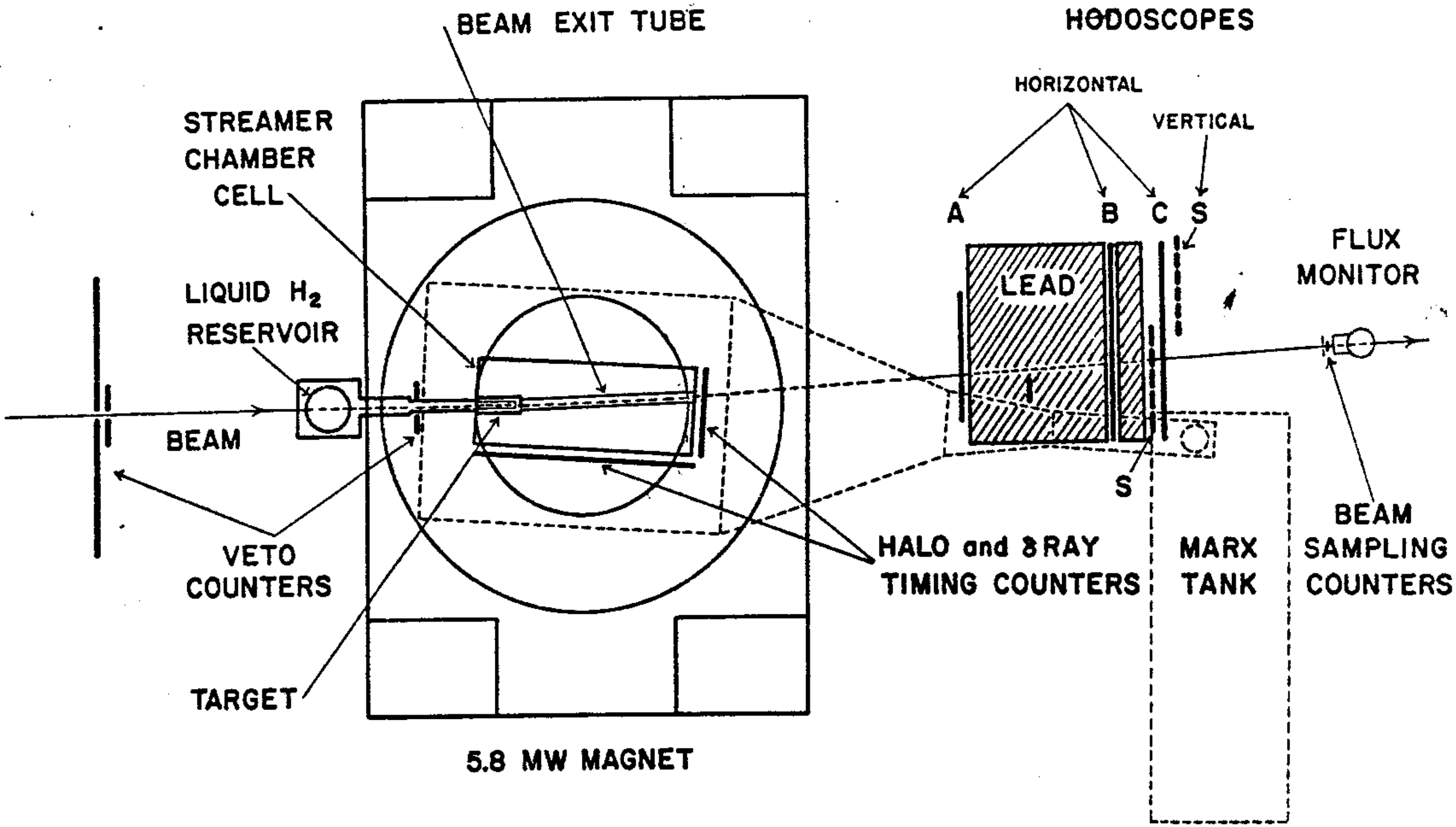
inside streamer chamber

16 k Gauss field

$\sim$ 60 - 75 % trigger efficiency

track finding efficiency $\lesssim 100\%\big|_{cutoff}$.

$\Longrightarrow$ BUT: • NO NEUTRALS DETECTION
LIMITATION • NO PARTICLE IDENTIFICATION.


BEAM EXIT TUBE
HODOSCOPES
HORIZONTAL
VERTICAL
STREAMER CHAMBER CELL
A
B
C
S
LIQUID H_2 RESERVOIR
LEAD
FLUX MONITOR
BEAM
S
VETO COUNTERS
HALO and δ RAY TIMING COUNTERS
MARX TANK
BEAM SAMPLING COUNTERS
TARGET
5.8 MW MAGNET

Experimental difficulties:

1) TRIGGER RESOLVES 10^{-8} sec

BUT: Streamer chamber integrates over full 1.5 μsec SLAC pulse

2) ADDED TRACKS FROM

a → δ RAYS

b → HALO TRACKS

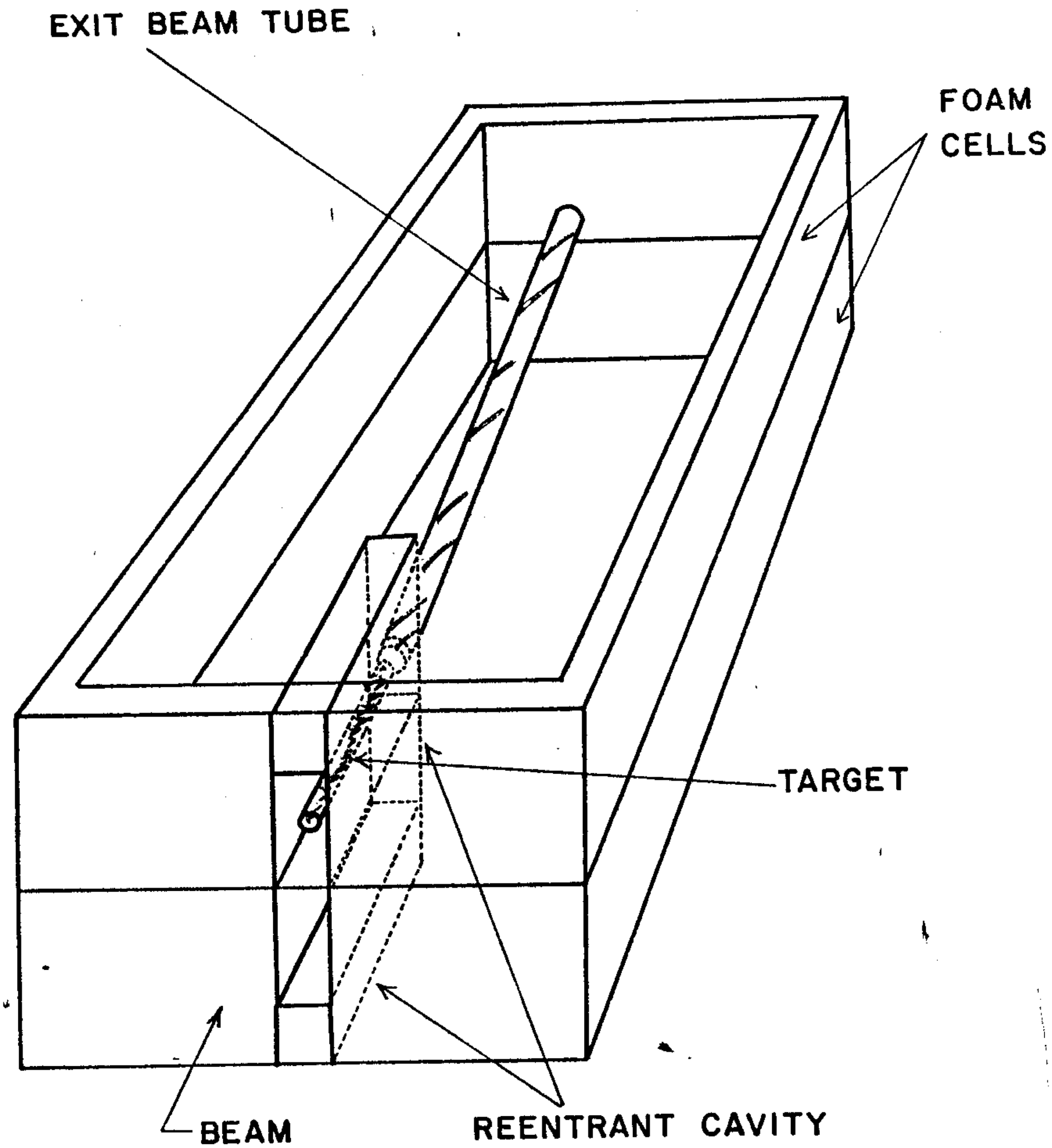
Remedies: a: BOX AROUND TARGET
BEAM EXIT TUBE

a, b: ADDED COUNTERS AROUND CHAMBER (not in trigger)

3) LACKING TRACKS ("prongs") FROM

a → PRESENCE OF TARGET BOX BEAM EXIT TUBE

b → STEEP TRACKS "FLARES"


EXIT BEAM TUBE
FOAM
CELLS
TARGET
BEAM
REENTRANT CAVITY

rimental parameters:

am: μ^+, 14.2 GeV

$\sim$ 200 μ's per SLAC pulse (1.5 μsec)

$\frac{\Delta p}{p} = \pm 1\%$

$\Delta\Theta \approx 2$ mrad

halo: $\sim$ 1% over streamer chamber cross-section

$\frac{\pi}{\mu}$ ratio: $(4 \pm 1.5)\,10^{-5}$

igger: on μ^+ scattered out of beam phase space

by $\sim$ $Q^2 \geq 0.5$ or $\nu \geq 2$

tection efficiency: 60% – 90% depending on W, Q^2

igger efficiency: trigger on $\leq$ 8 μb

ents: $\sim$ 15,000 (8,000 deeply inel.) in H_2

$\sim$ 25,000 (14,000 " ") in D_2

DATA

1

Average charged hadron multiplicity:

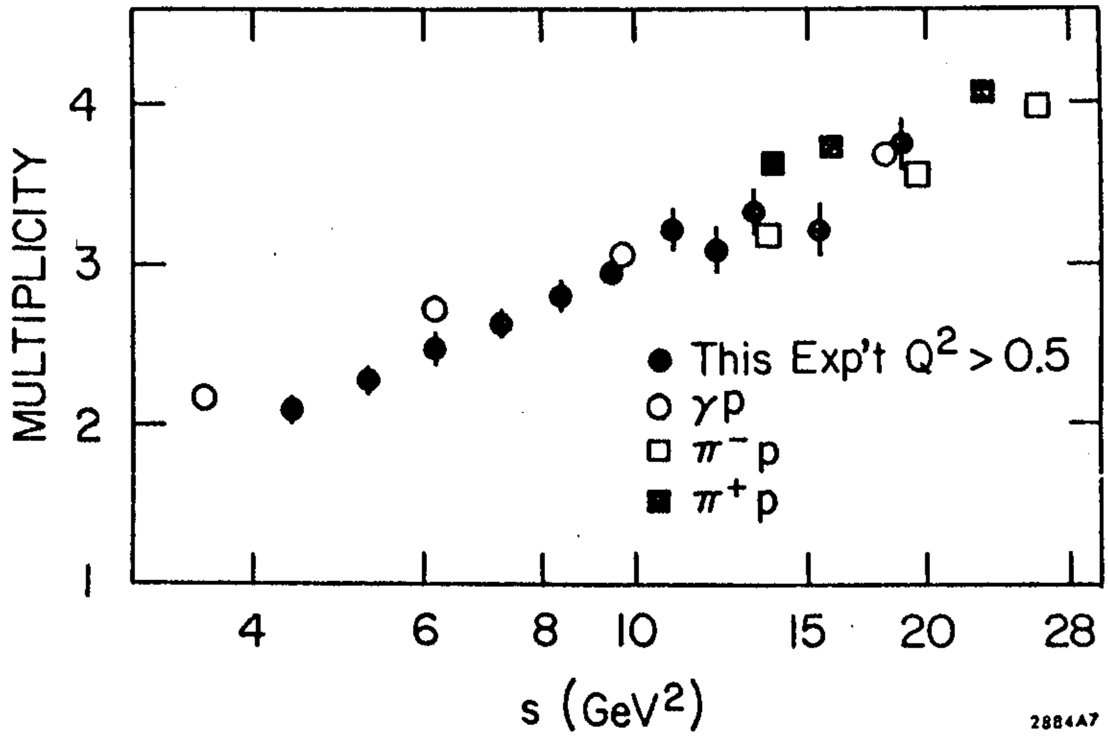


Fig. 9

$\langle n \rangle$ ~ independent of Q^2

follows general hadronic trend

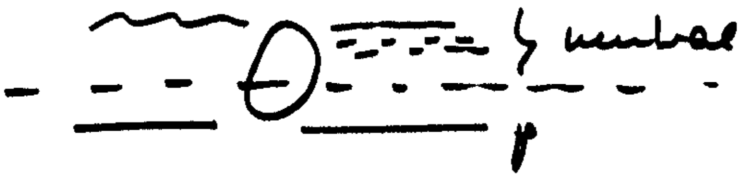
but note ...>

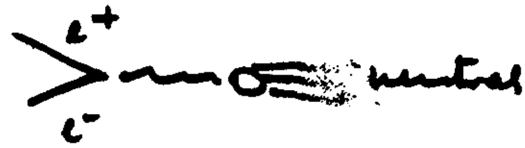
COMPARISON WITH $e^+e^- \to$ HADRONS:

$\Sigma m_i \simeq 0$

① $s = W^2 \Big| = (2E_e)^2$

delete all one-prong events from μp sample



like 

(unseen)

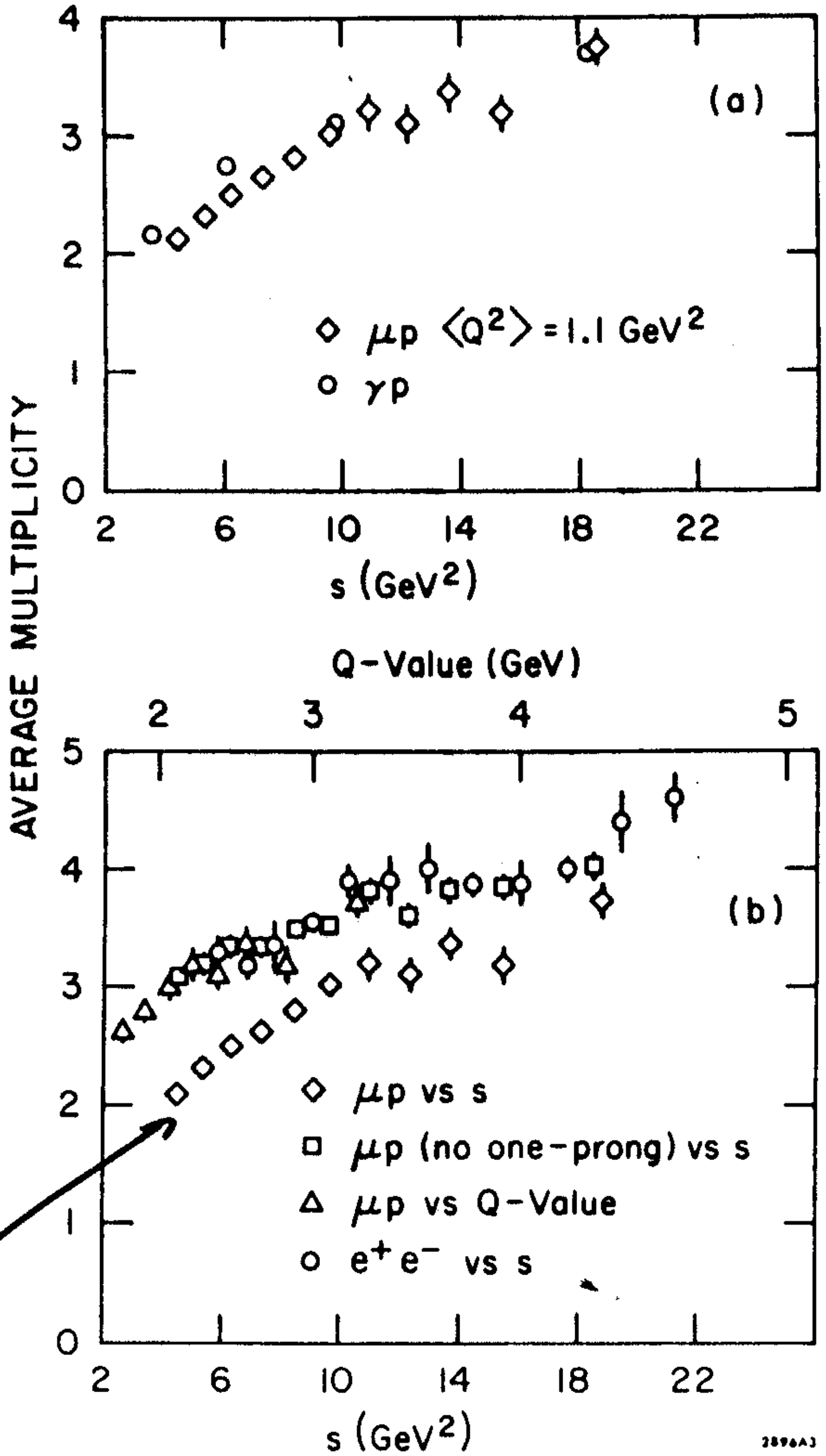
also: "elastic" fragmentation $\gamma \to \pi^0$, η^0 : forbidden by C

②) Choose as energy variable Q value $= \sqrt{s} - \Sigma m_i$

set $m_i\,(\gamma\nu) \approx m_\pi \quad (\dots)$

CONCLUSION: SATISFACTORY AGREEMENT.

$\left\{ \begin{array}{l} \text{light like} \\ \text{space like} \\ \text{time like} \end{array} \right\}$ photons.

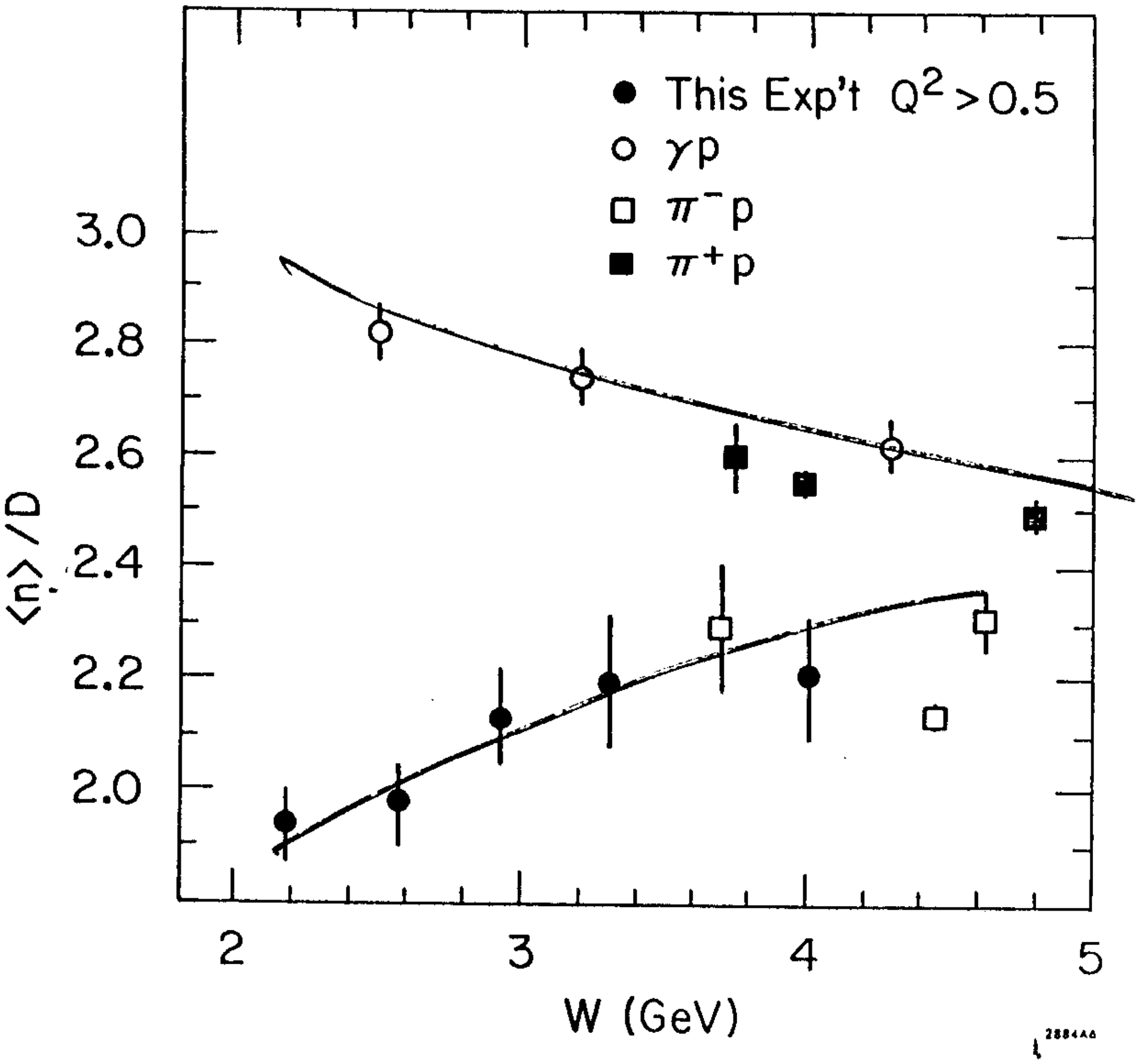


has to be "corrected" for incoming charges (mainly

Fig. 1

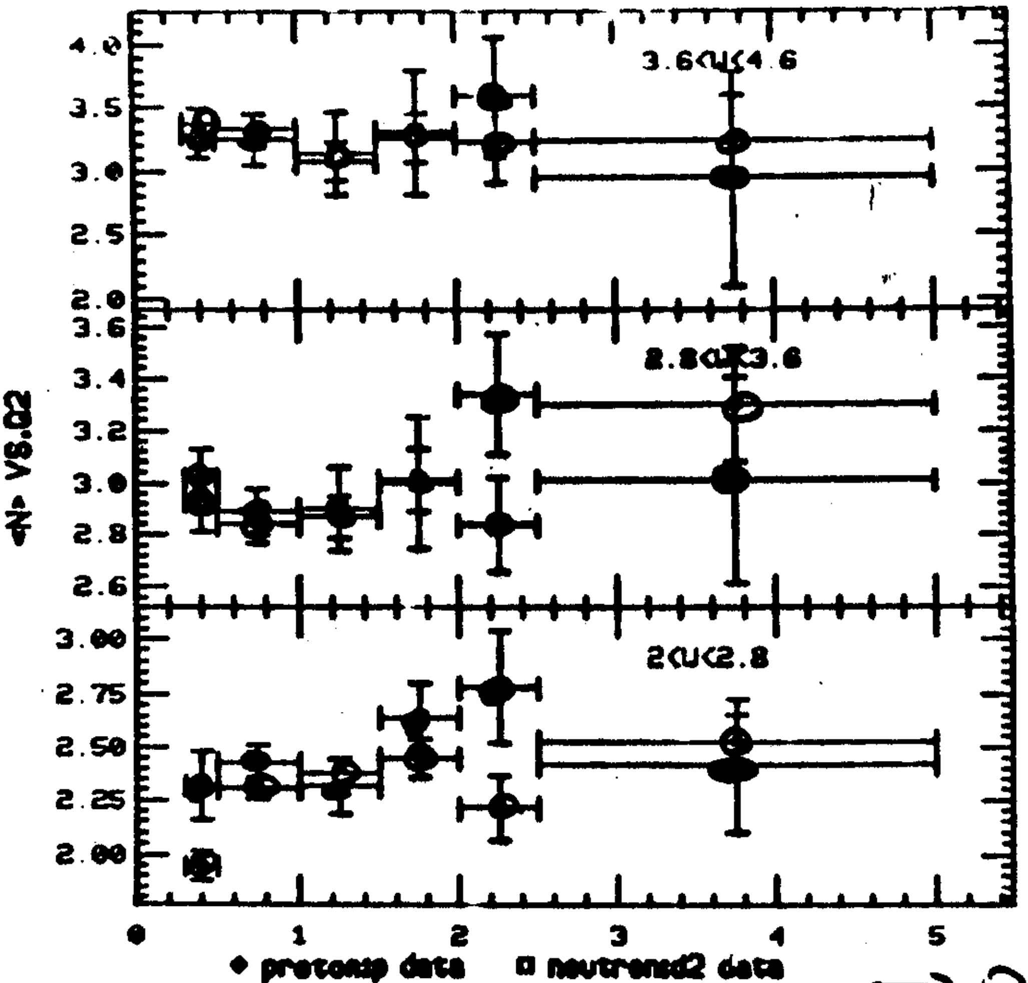
MULTIPLICITY DISTRIBUTIONS

D = DISPERSION



DEPENDENCE ON MASS OF VIRTUAL PHOTON ?

—♦— proton data
—♦— neutron data



$\rightarrow Q^2$

$\gamma^* p$ vs. $\gamma^* n$:

$\rightarrow$ Q^2 dependence ~ flat

$\rightarrow$ no significant difference between $\langle n \rangle_p$, $\langle n \rangle_n$

FRACTIONAL TOPOLOGICAL CROSS-SECTIONS:

HOW OFTEN n CHARGED PRONGS?

$$\gamma^* p \to \boxed{n = 1, 3, 5, \ldots}$$

$$n = 1 \quad \begin{cases} p\pi^0 \ (+\ \ell\pi^0 \ldots) \\ n\pi^+ \ (+\ \ell\pi^0 \ldots) \\ \vdots \end{cases}$$

$$\mathbb{P} \qquad\qquad \pi, \ldots$$

$$n = 3 \quad \begin{cases} p\pi^+\pi^- \ (+\ \ell\pi^0) \\ \vdots \\ \text{but also } n\pi^+\pi^+\pi^- \ldots \end{cases} \quad \begin{cases} p\rho^0 \\ p\omega \\ p\phi \end{cases}, \quad \begin{cases} \Delta^{++}\pi^- \\ \Delta^0\pi^+ \end{cases}$$

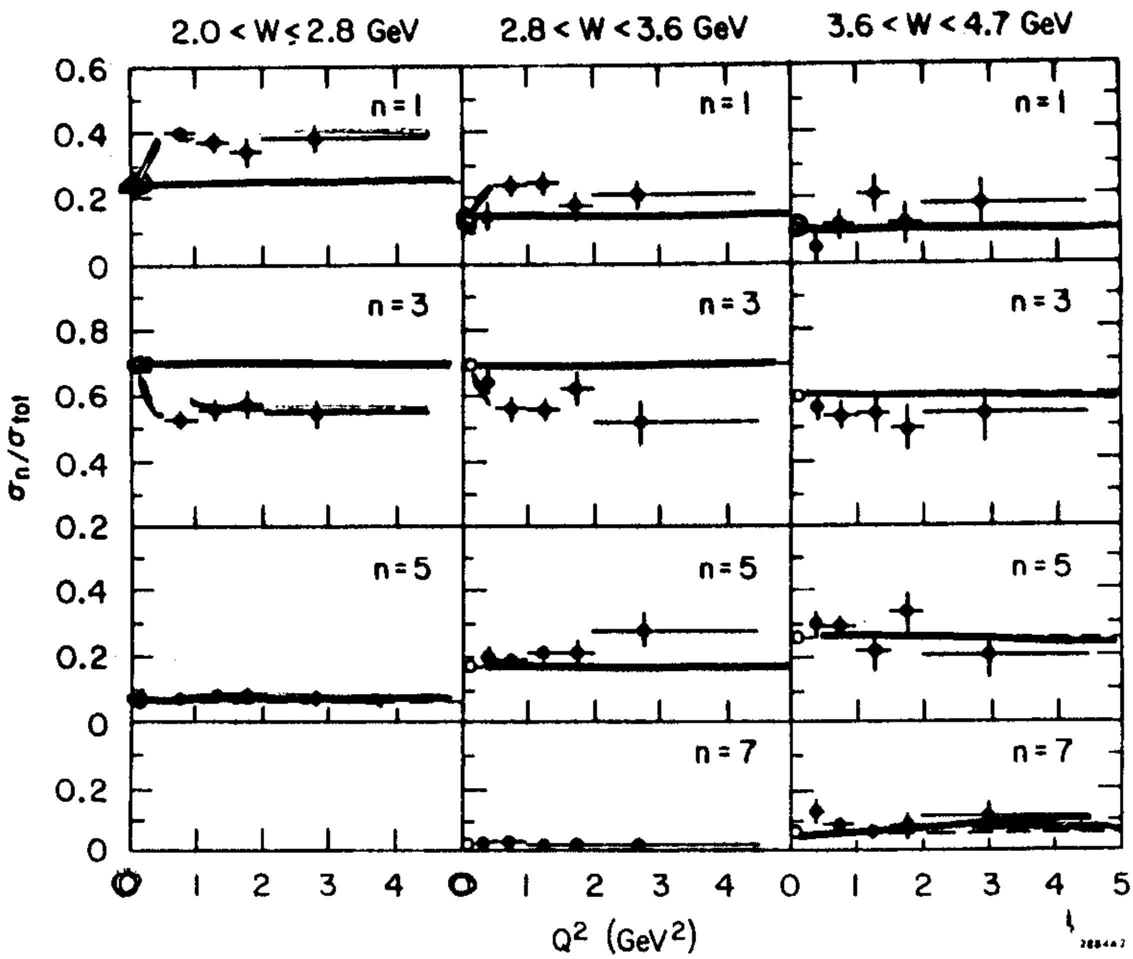
$$n \geq 5 \quad \begin{cases} \ldots \\ \text{phase space} \ \ldots \ (?) \end{cases}$$

$$\gamma^* n \to \boxed{n = 0, 2, 4, 6, \ldots}$$

$$n = 0 \quad \begin{cases} n\pi^0 \ (+\ \ell\pi^0) \\ \vdots \end{cases}$$

$$n = 2 \quad \begin{cases} p\pi^- \ (+\ \ell\pi^0) \Leftarrow \\ n\pi^+\pi^- \\ \end{cases} \qquad \begin{cases} n\rho^0 \\ n\omega^0 \\ n\phi^0 \end{cases} \quad \begin{cases} \Delta^+\pi^- \\ \Delta^-\pi^+ \end{cases}$$

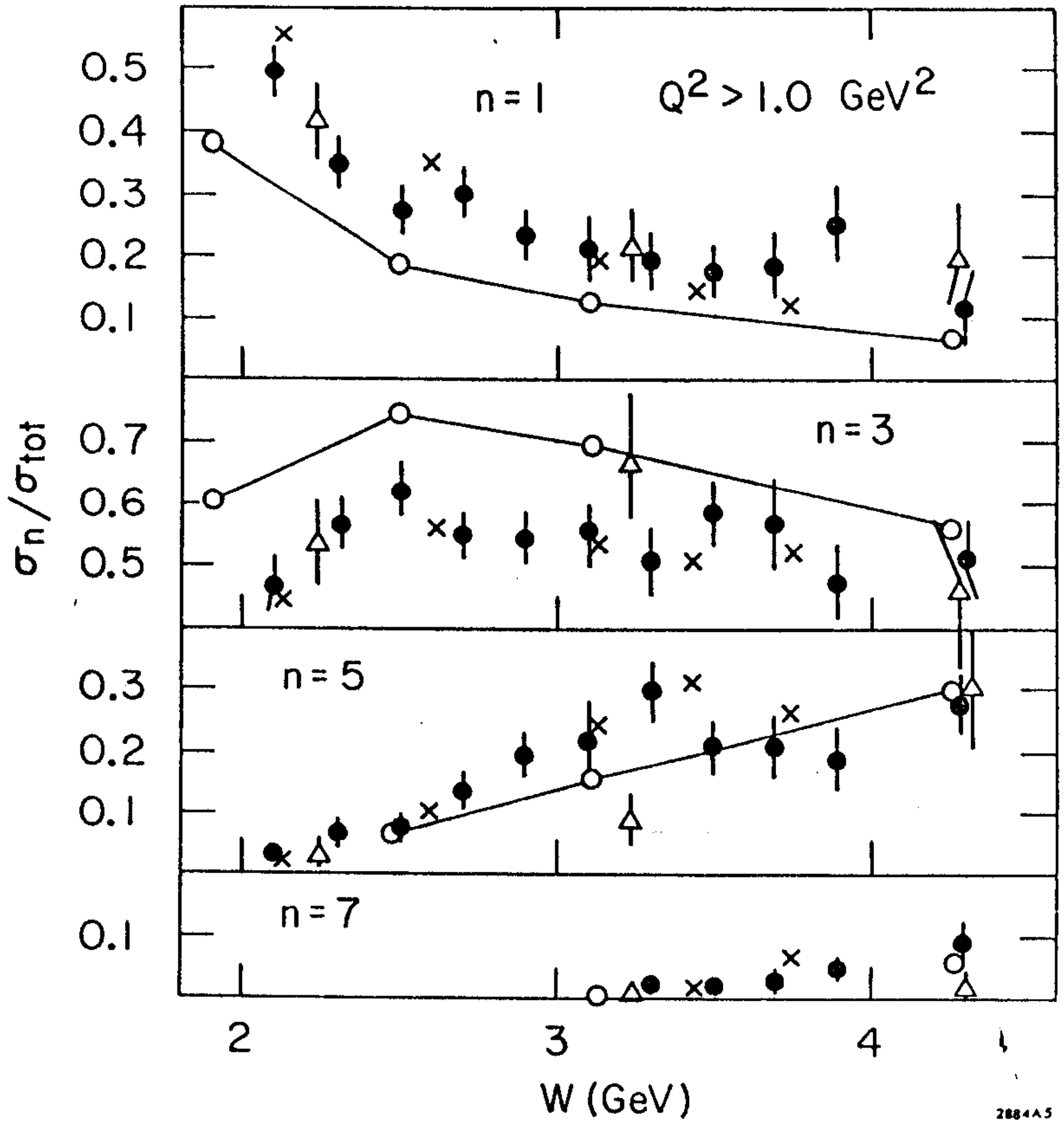
...



Result:

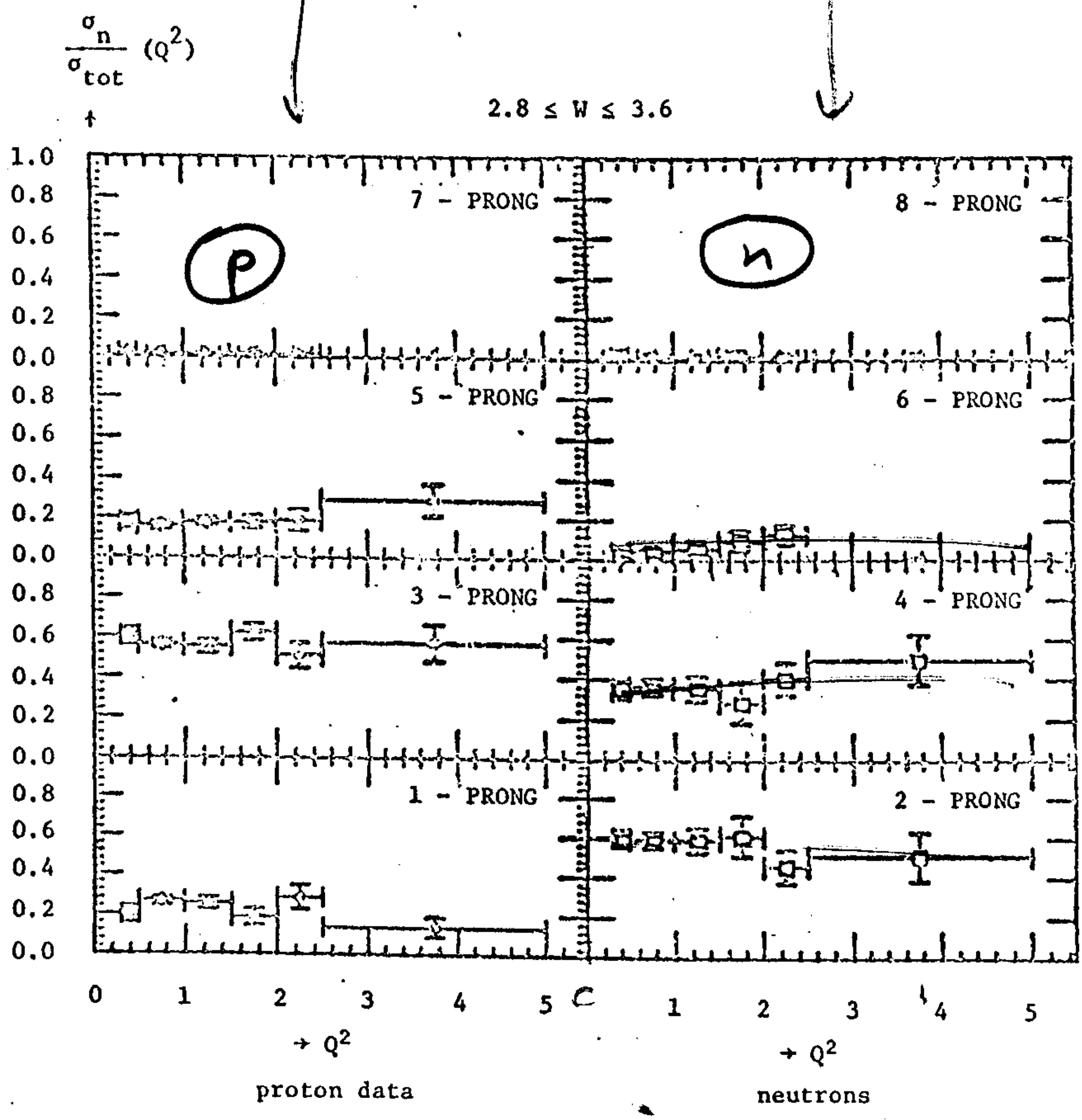
→ Step difference between photoproduction and $Q^2 > 0.2$

→ flat behaviour for $Q^2 > 0.2$.



n = 1
$Q^2 > 1.0\ GeV^2$
n = 3
n = 5
n = 7
σ_n/σ_{tot}
0.5
0.4
0.3
0.2
0.1
0.7
0.6
0.5
0.3
0.2
0.1
0.1
2
3
4
W (GeV)
2884A5

$\gamma^* p$: n = odd $\qquad$ $\gamma^* n$: n = even

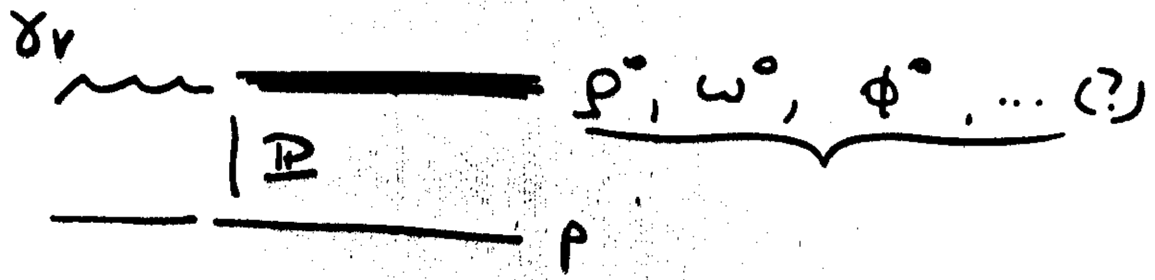


Result: $\gamma^* p$, $\gamma^* n$ qualitatively similar

~~Figure V.13 Fractional Prong Cross Sections vs. Q^2~~

(for γn no good comparison data)

DIFFRACTIVE PHOTON – HADRON DISSOCIATION:



QUESTIONS:

① Clean samples?

(what shape factors, background assumptions?)

② How much contribution to Q^2 dependence of

σ_3/σ_{tot} (p) ; σ_2/σ_{tot} (n) ?

③ $\frac{d\sigma}{dt} \sim e^{b(Q^2)t}$

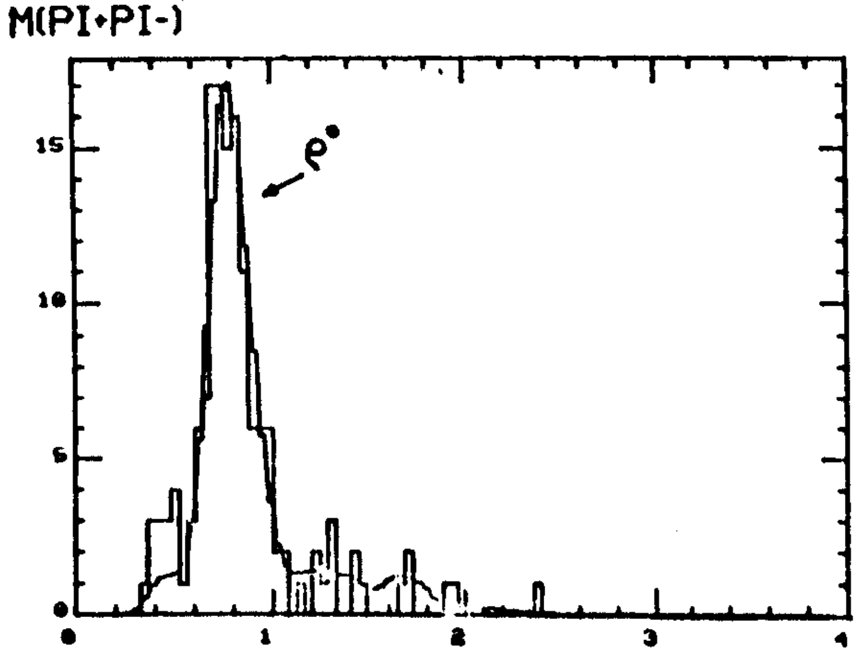
$\rightarrow$ Q^2 dependence of b ?

photon shrinking?

④ ρ decay: $\begin{cases} \text{SCHC} \\ \text{determination of } R = \frac{\sigma_L}{\sigma_T} \end{cases}$

⑤ particle ratio $\rho^\circ / \omega^\circ / \phi^\circ$ in diffraction:

hadronic structure of (<u>bare</u>) photon?



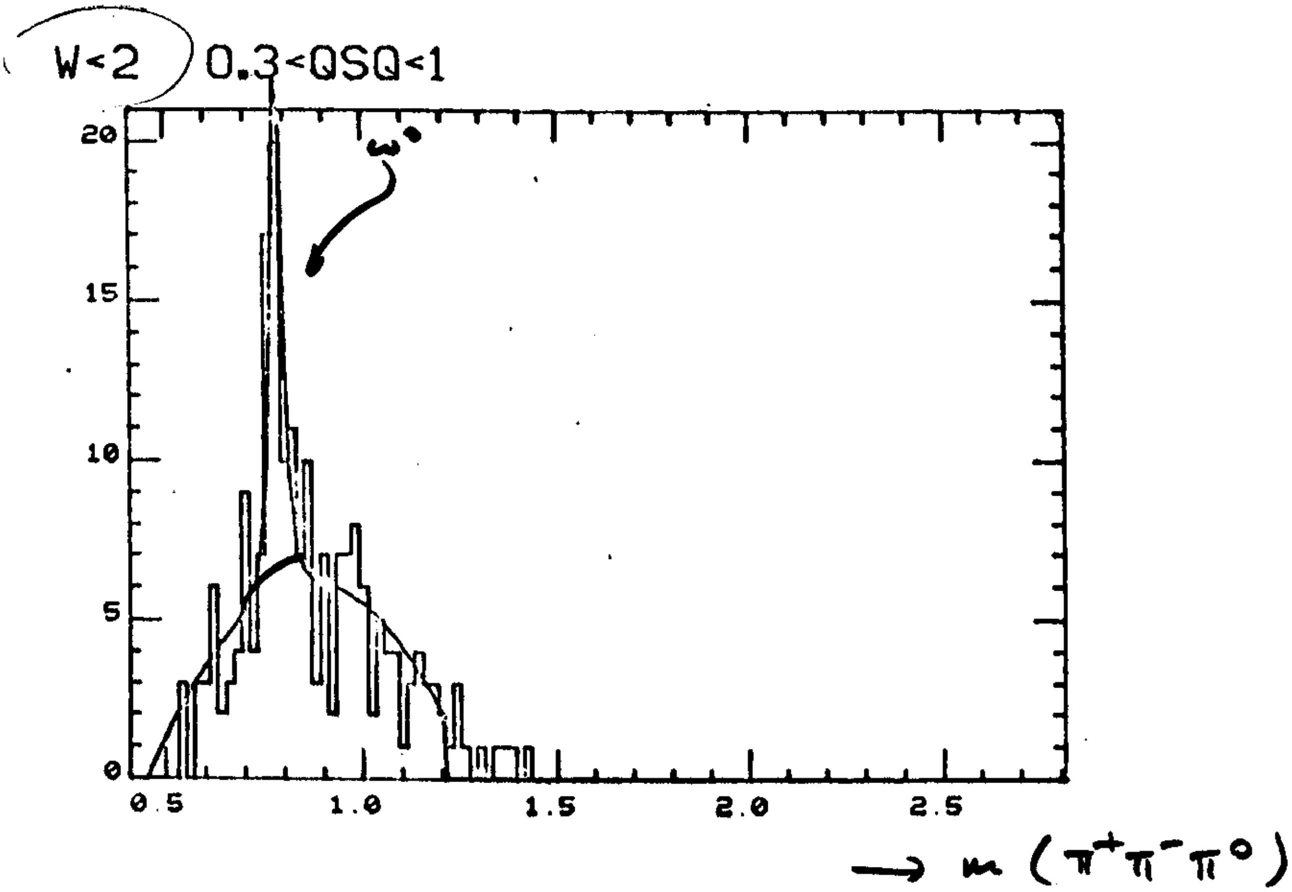
ρ^0 - elastic signal from $\gamma_V p \to \underline{\pi^+ \pi^- p}$

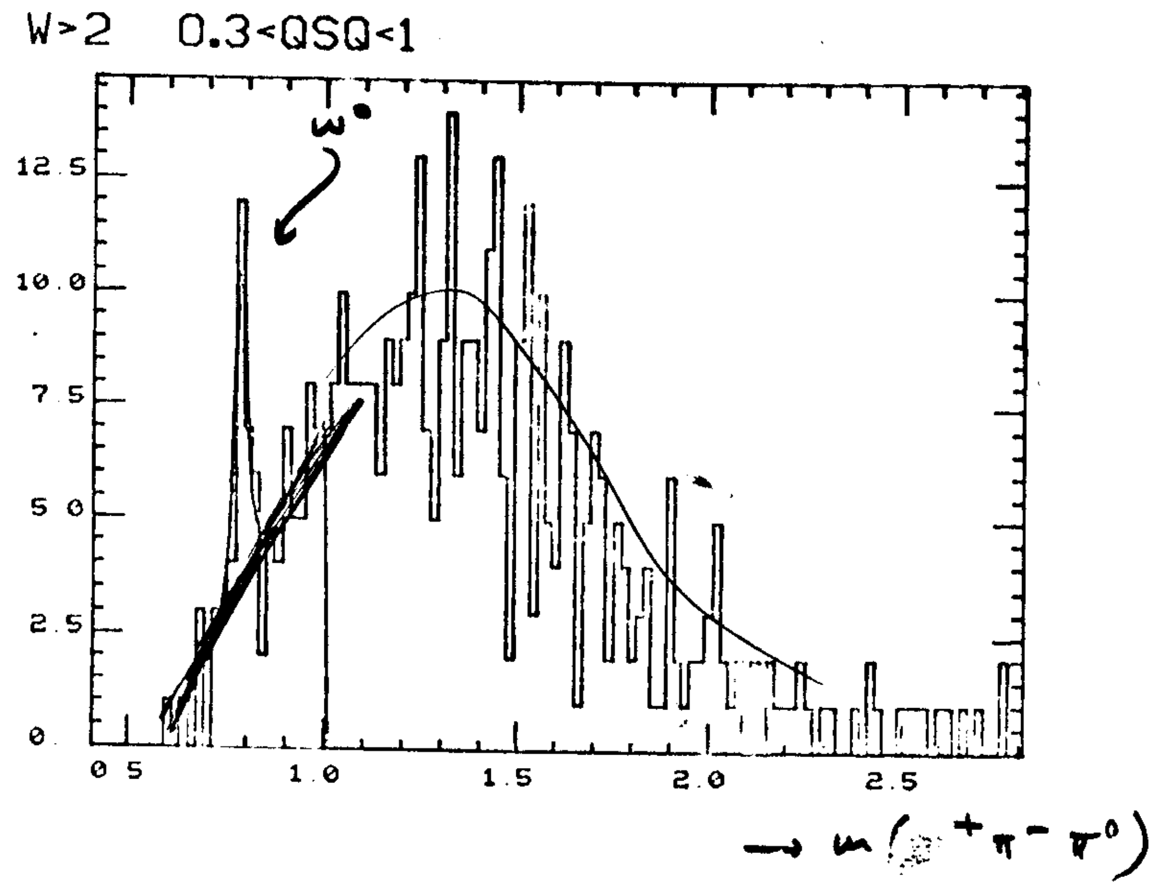
(OPTIME program)

Simultaneous fit to
$\left\{ \begin{array}{l} \rho^0 p \\ \Delta^{++} \pi^- \\ \Delta^0 \pi^+ \\ \quad \hookrightarrow p\pi^- \\ \text{phase space} \end{array} \right.$

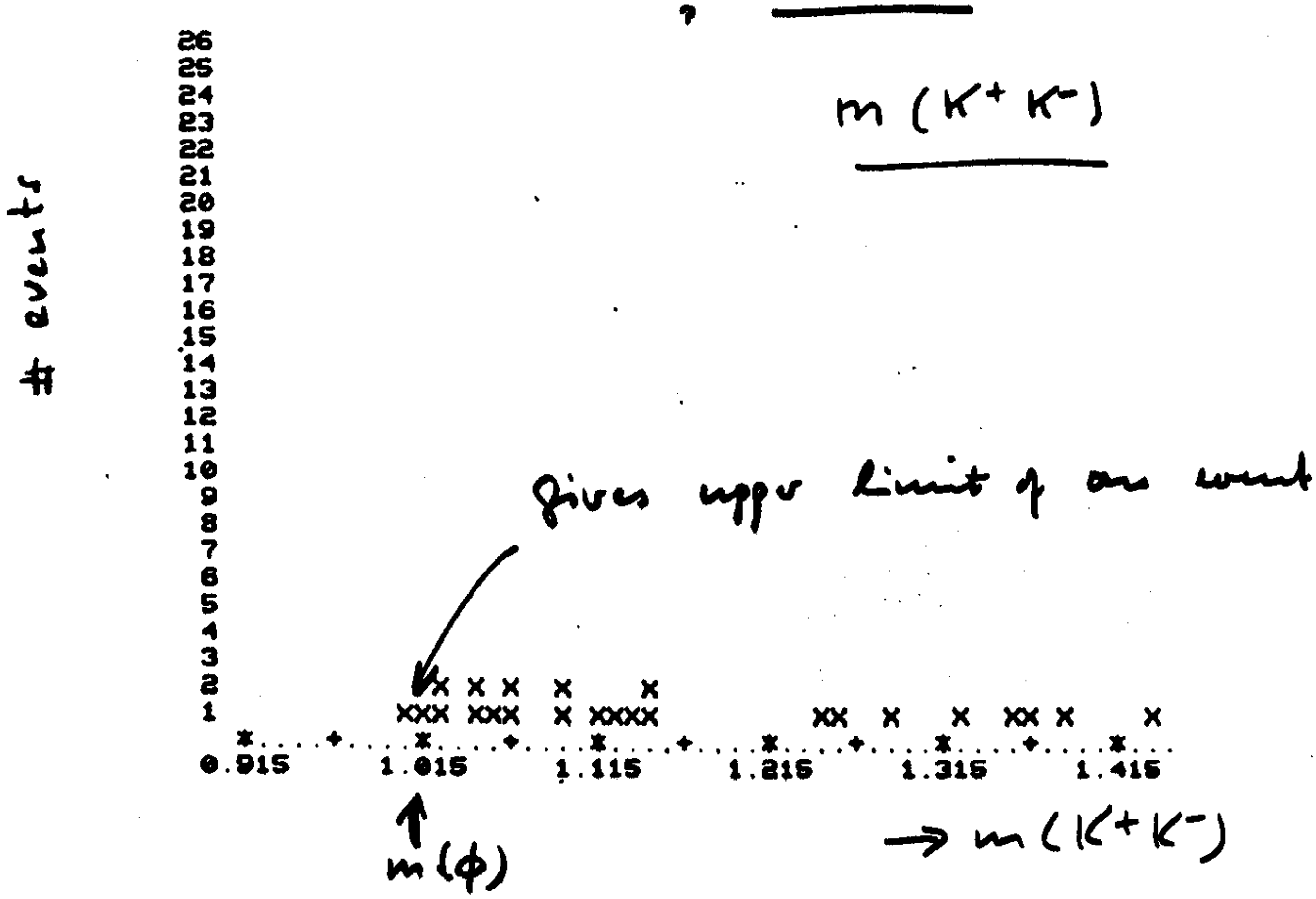
$\langle W \rangle = 2.8$

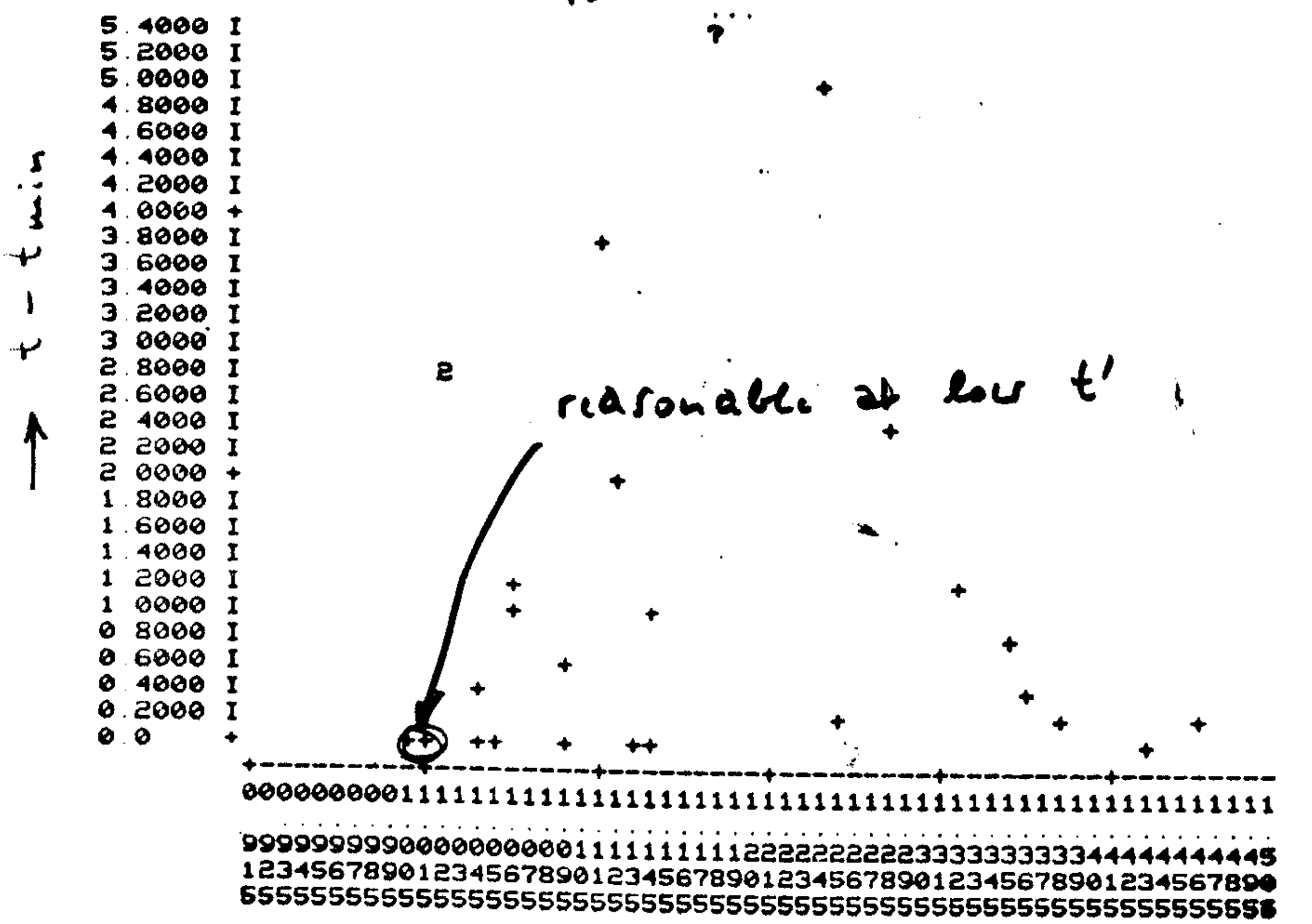
$\langle Q^2 \rangle = 0.8$


W<2 0.3<QSQ<1
ω°
20
15
10
5
0
0.5
1.0
1.5
2.0
2.5
→ m (π⁺π⁻π°)

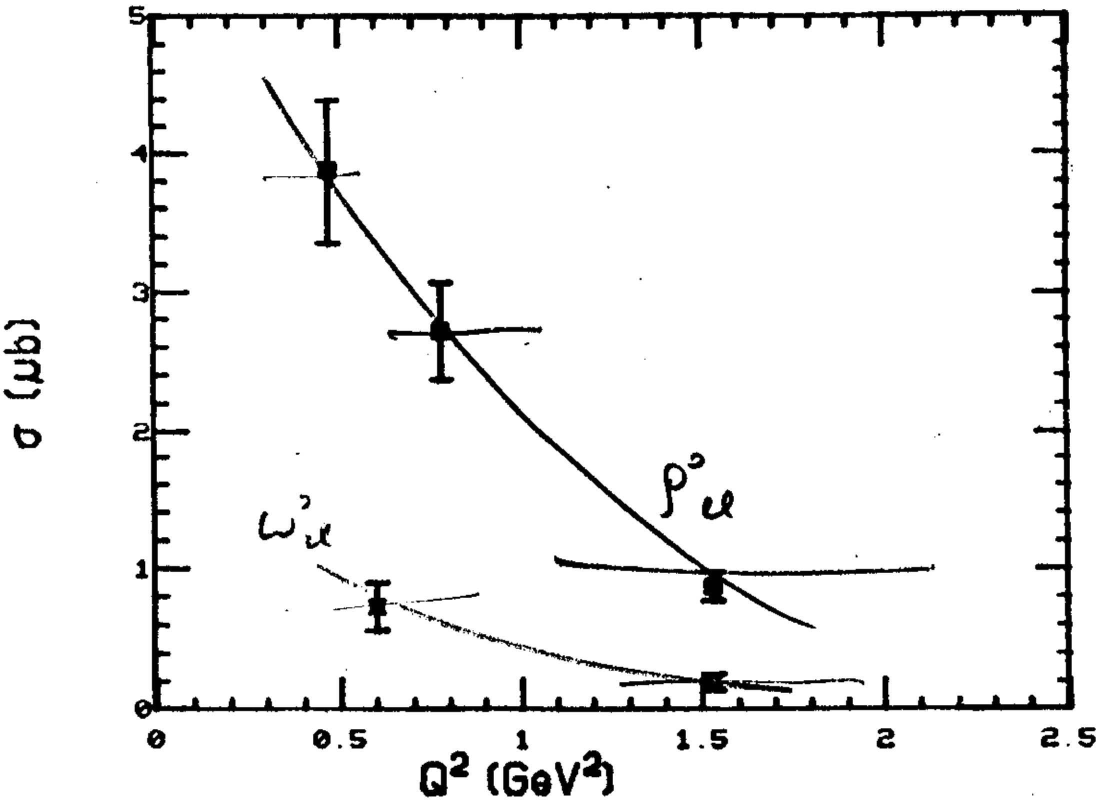

W>2 0.3<QSQ<1
ω°
12.5
10.0
7.5
5.0
2.5
0
0.5
1.0
1.5
2.0
2.5
→ m (π⁺π⁻π°)

SEARCH FOR $\phi \to K^+K^-$, 4C fits

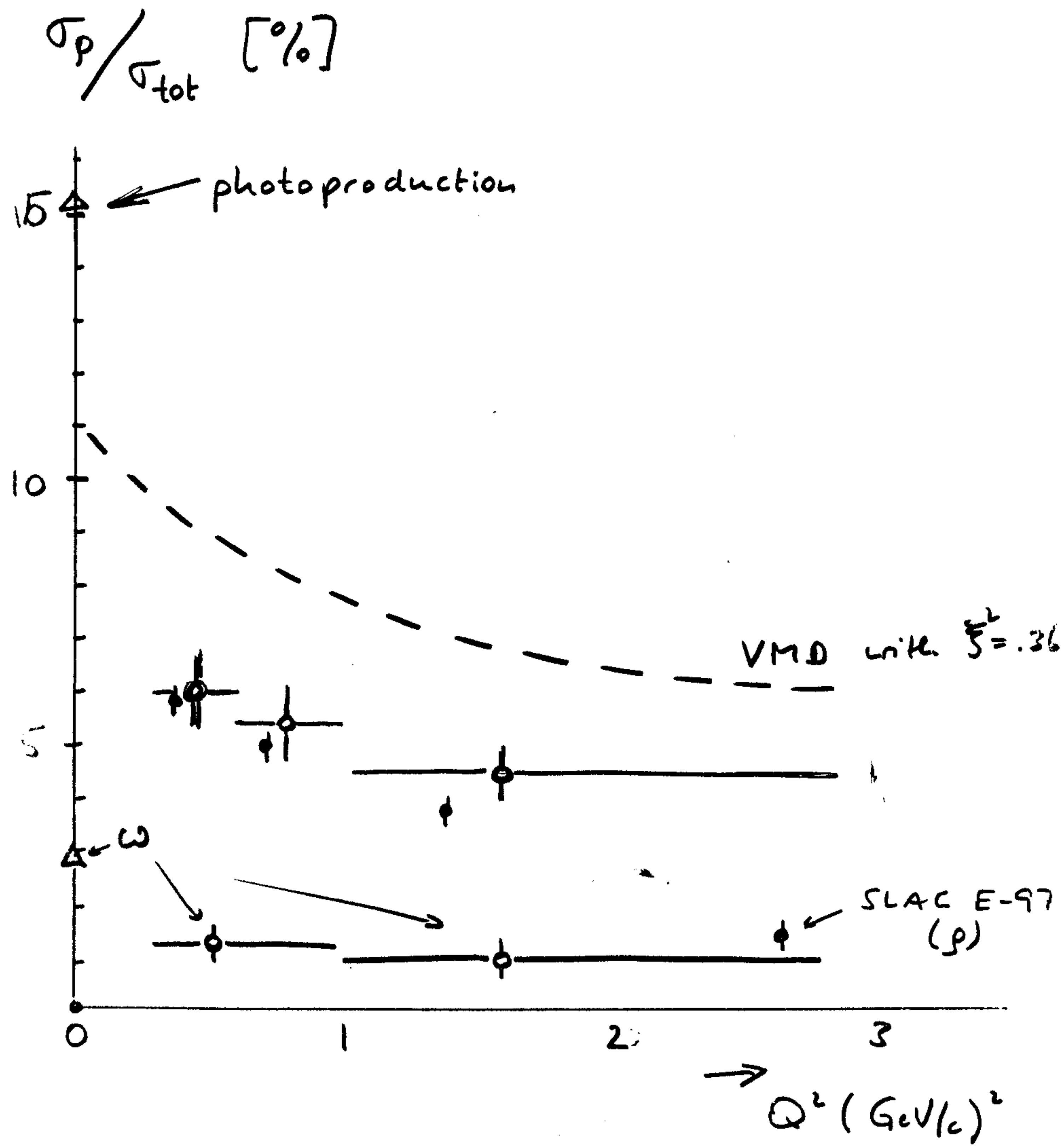




CRØSS SECTIØNS $\gamma_V p \rightarrow pV$

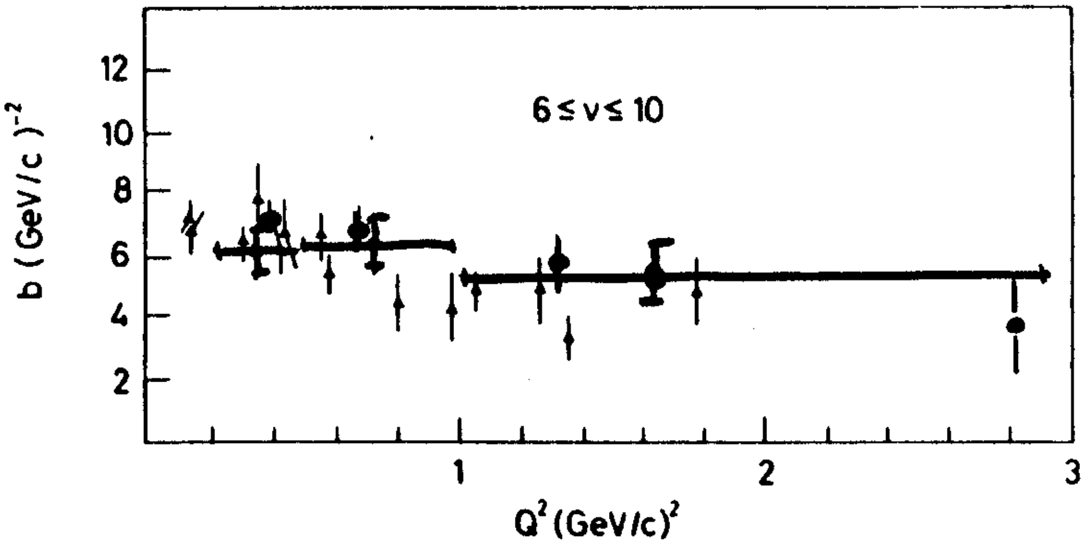


FRACTIONAL VECTOR MESON CROSS-SECTIONS



—●— SANTA CRUZ - SLAC

● SLAC-MIT (1976)



PHOTON "SHRINKING" ?

slope parameter $b(Q^2)$

from $\boxed{\frac{d\sigma}{dt}(\gamma_V p \to p \rho^0) \sim e^{bt}}$

Results on Vector Mesons:

① Clean $\begin{cases} \rho^0 \text{ samples off } p,\ D_2 \\ \omega^0 \text{ samples off } p \end{cases}$

Little trouble with background

② Sudden dropoff of $(\sigma_\rho, \sigma_\omega)/\sigma_{tot}$ for

$$0 \leq Q^2 \lesssim 0.2 \longrightarrow \sigma_\rho/\sigma_{tot}$$

③ Little if any further decrease of $(\sigma_\rho, \sigma_\omega)/\sigma_{tot}(Q^2)$

④ σ_ω behaves similarly to σ_ρ/σ_{tot}, but smaller

⑤ σ_ϕ : only upper limit

⑥ $\sigma_\rho/\sigma_\omega/\sigma_\phi$: accept upper limit as σ_ϕ, then comparison with photoproduction

$\Rightarrow$ $Q^2 = 0$ $\underline{\underline{21/5.3/0.4}}$

$Q^2 > 0.2$ $\underline{\text{flat}}$, $\sim$ $\underline{\underline{\text{same ratio}}}$! $\Big\}$!

Well-remembered symmetry structure!

ENERGY DISTRIBUTION:

"Structure functions" $\underline{F^h_{int}}$

Define (Santa Cruz) $\quad F(z) \equiv \frac{z}{\sigma_{tot}} \frac{d\sigma}{dz}$

μp

with $z \equiv \frac{E_h^{lab}}{\nu}$

(Chicago ...) $\quad F(x') \equiv \frac{x'}{\sigma_{tot}} \frac{d\sigma}{dx'}$

$\mu p, \mu n$

with $x' \equiv \frac{p_{\parallel}^*}{(p_{max}^{*2} - p_{\perp}^{*2})}$;

<u>Results</u>: <u>some</u> ω' dependence for $F^+_{\mu p}$, $F^-_{\mu p}$

almost <u>none</u> for $F^{+,-}_{\mu p}(z)$

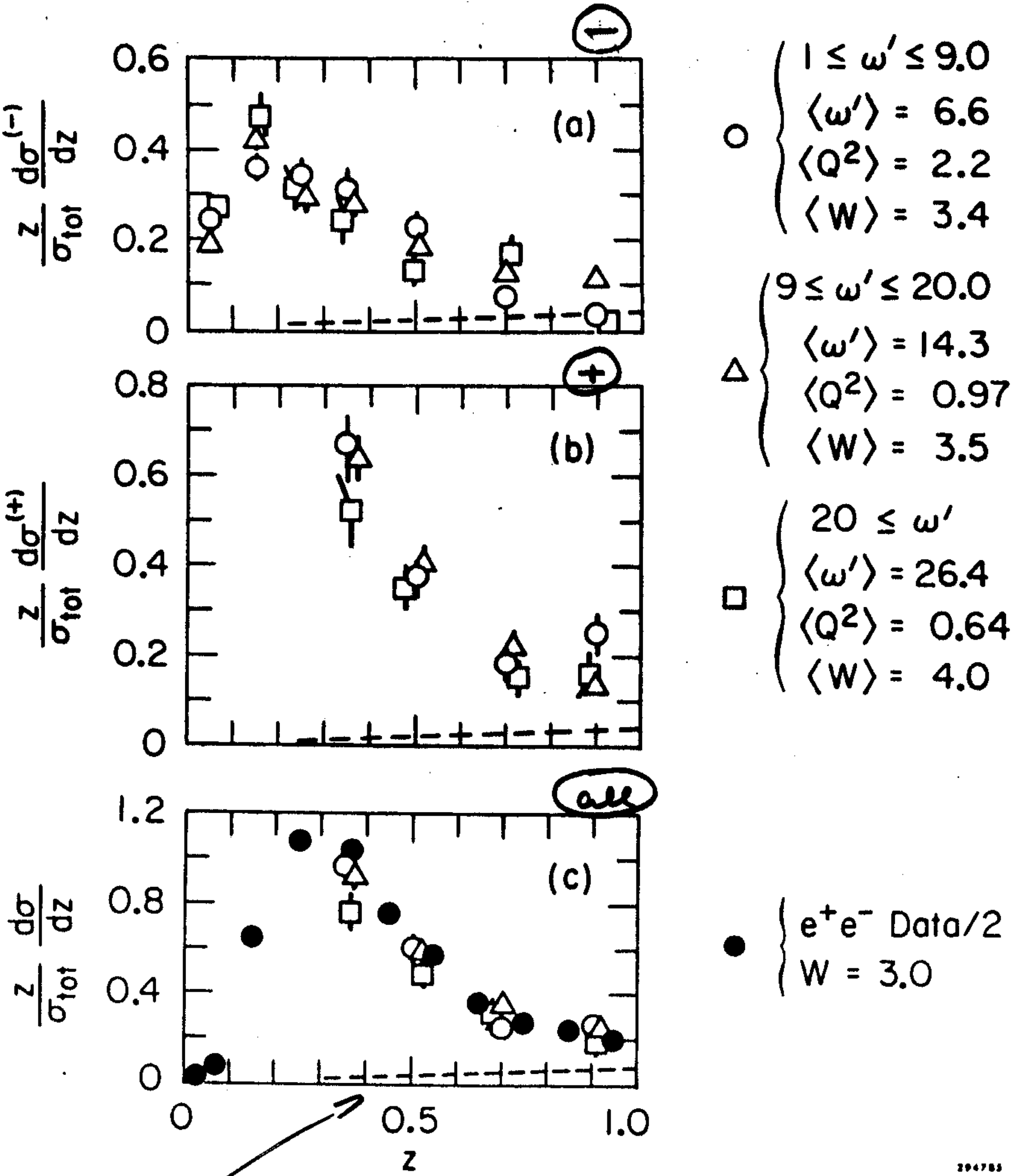
Remark: (+) only for $z > 0.4$, to avoid p-π^+ confusion

all hadrons assumed to be pions.

Comparison with $F^{+,-}_{e^+e^-} = \frac{x}{4\sigma_{tot}} \frac{d\sigma}{dx} \qquad x = \frac{2E_h}{\sqrt{s}}$

$\longrightarrow$ excellent

Comparison with $F_{\nu N}$ ($\rightarrow$ below)



---- elastic ρ^0 fraction

Fig. 7

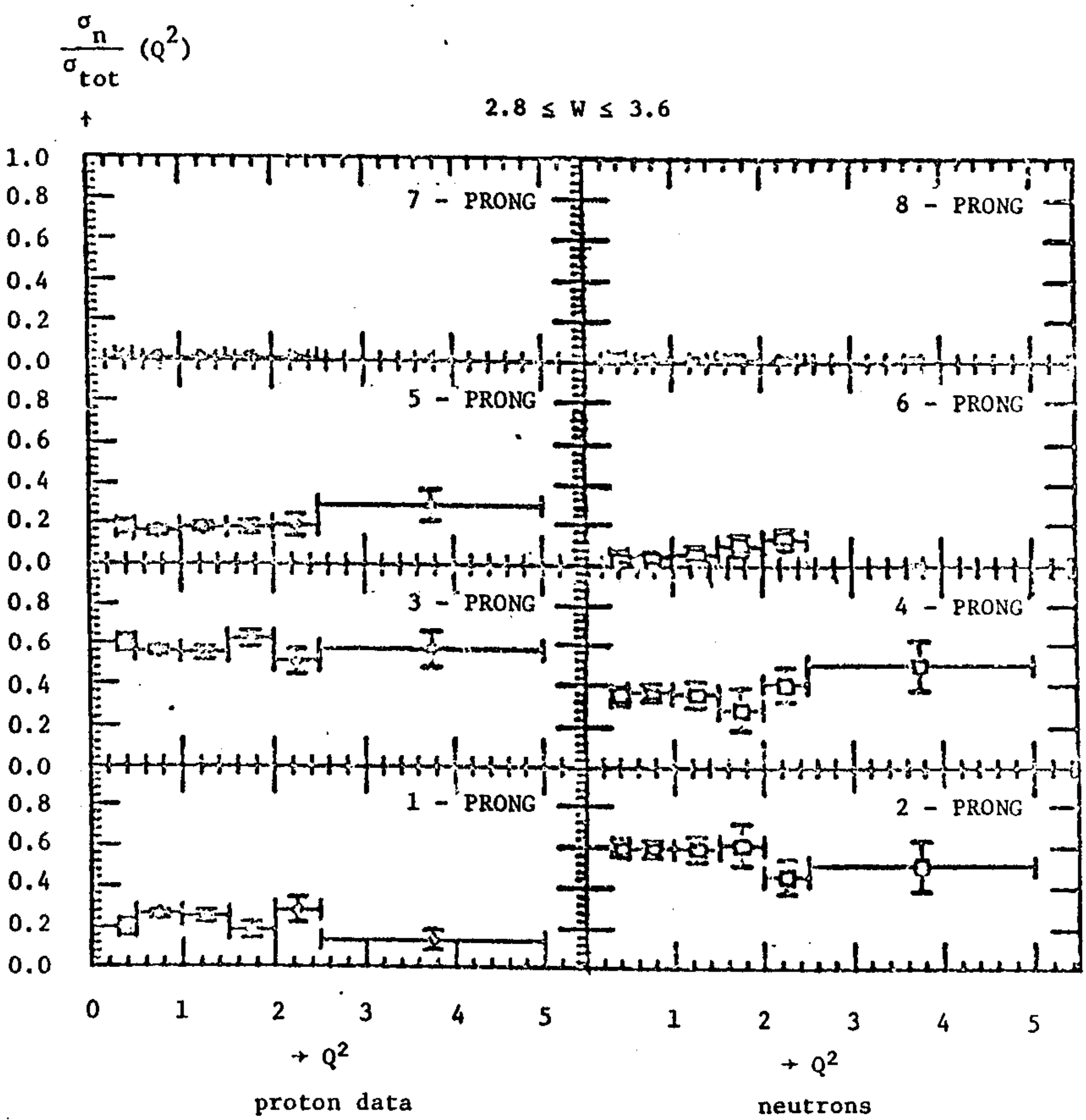
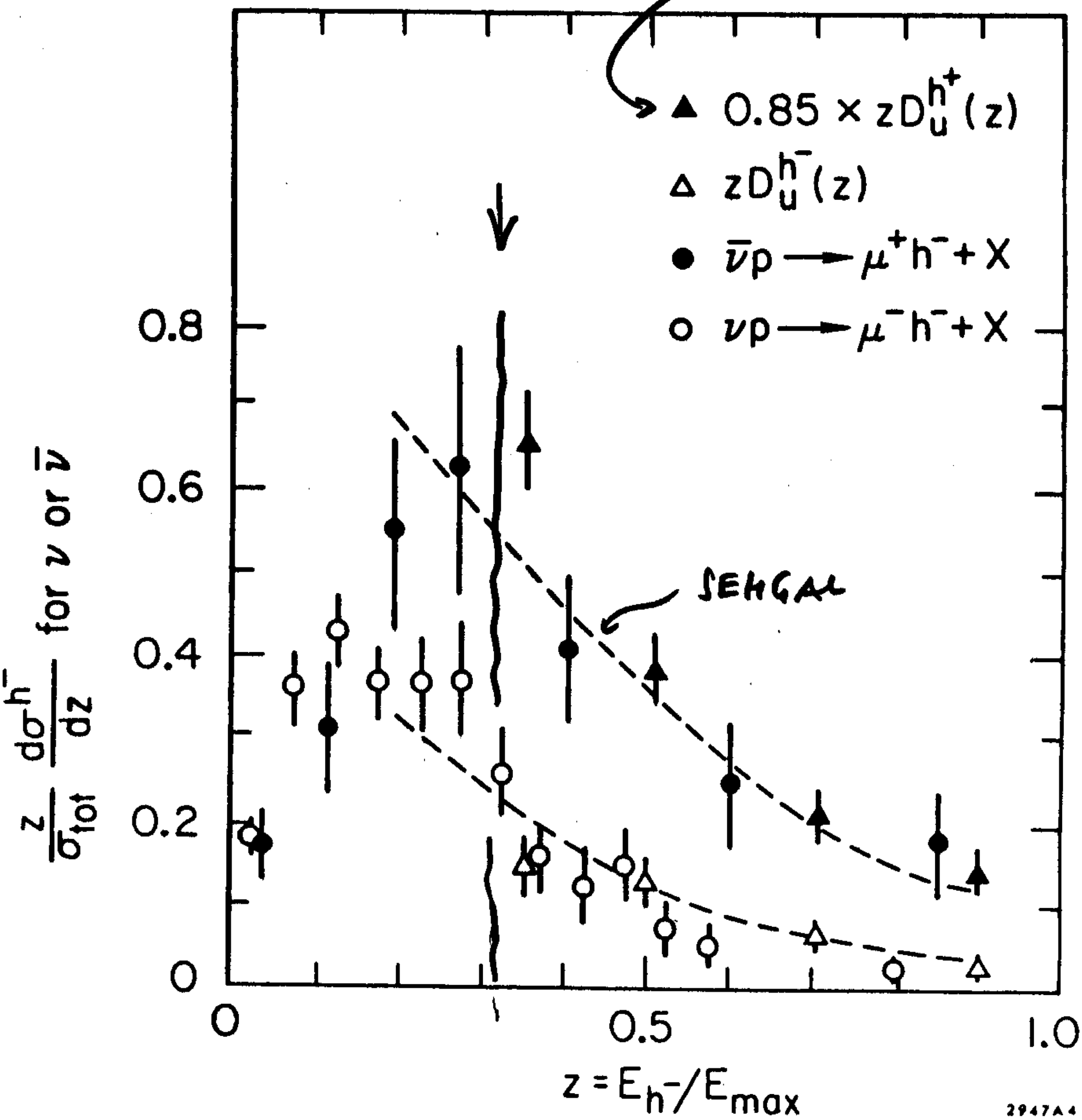


Figure V.13 Fractional Prong Cross Sections vs. Q^2

Comparison with νp, $\bar{\nu} p$

Take p/π^+ ratio of 0.15



RESULT : EXCELLENT AGREEMENT

Fig. 8

CHARGE RATIO FOR LEADING HADRONS

$0.4 \leq z \leq 0.8$

Plot the distribution $\frac{dN}{dz_{max}}$ (one entry per event)

(assumption: only π's)

__Result:__ for $z_{max} \geq 0.4 \rightarrow \left| {}^{"}\pi^+/\pi^-{}^{"} \right| = 2$

for small z, positive excess: proton misidentification

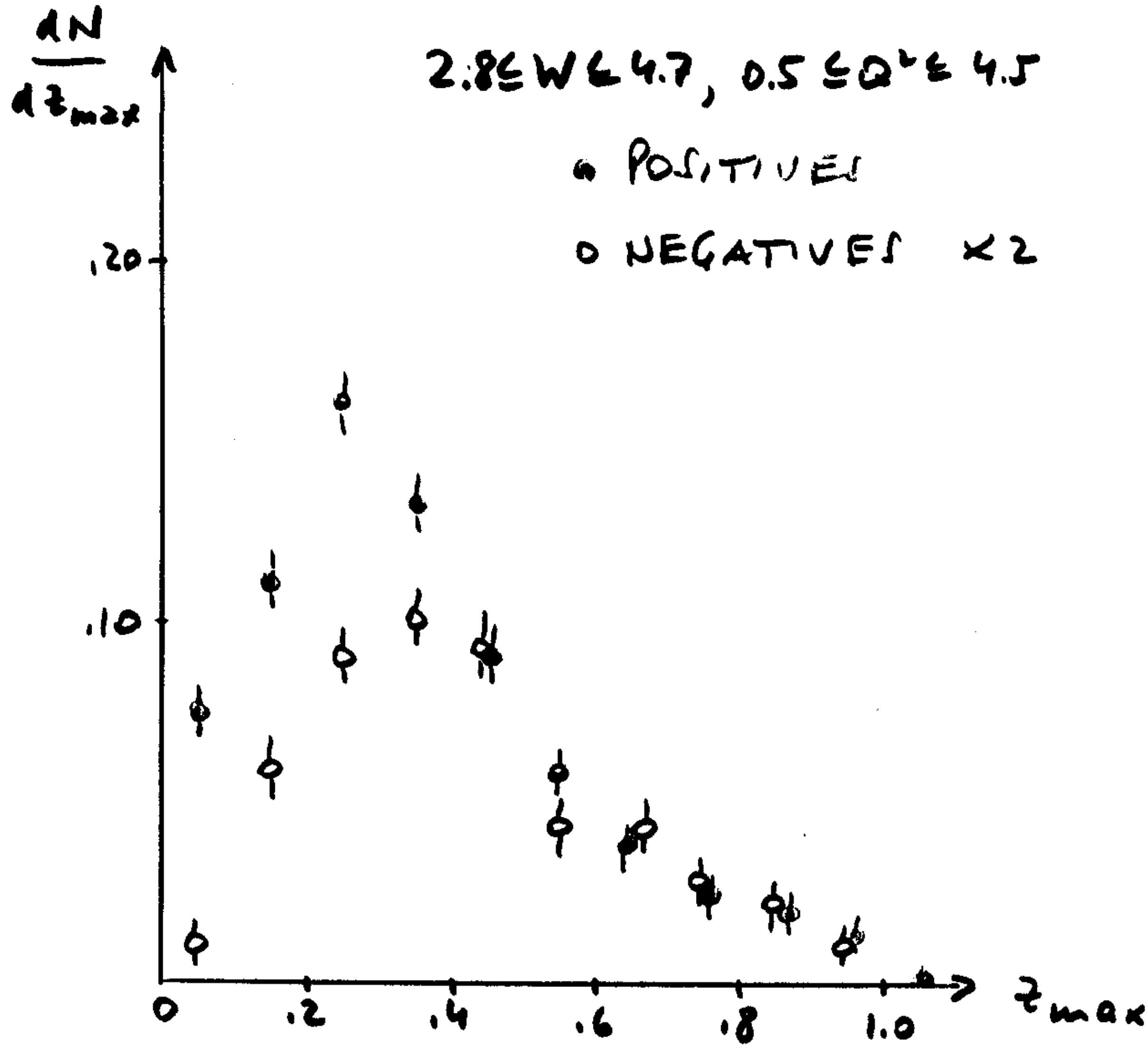
WHY the constant charge ratio?

Plot $\frac{dN}{dz_{max}}$ for all topologies: 1-, 3-, 5- prongs

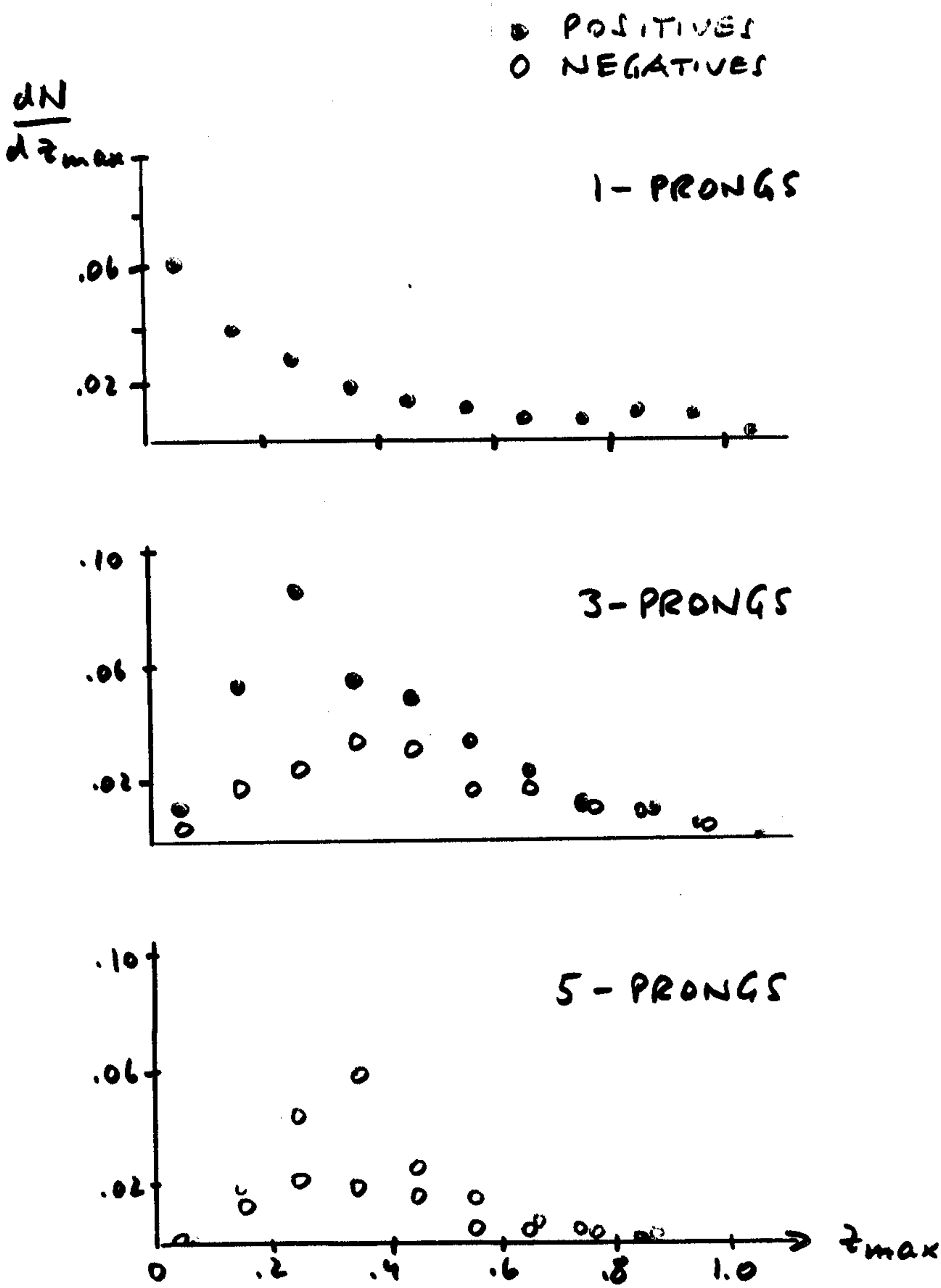
__Result:__ "conspiracy" does it — not true in each topology

2 régimes: $0.4 \leq z \leq 0.7$
$0.7 \leq z \leq 1.$

What individual channels is this due to?

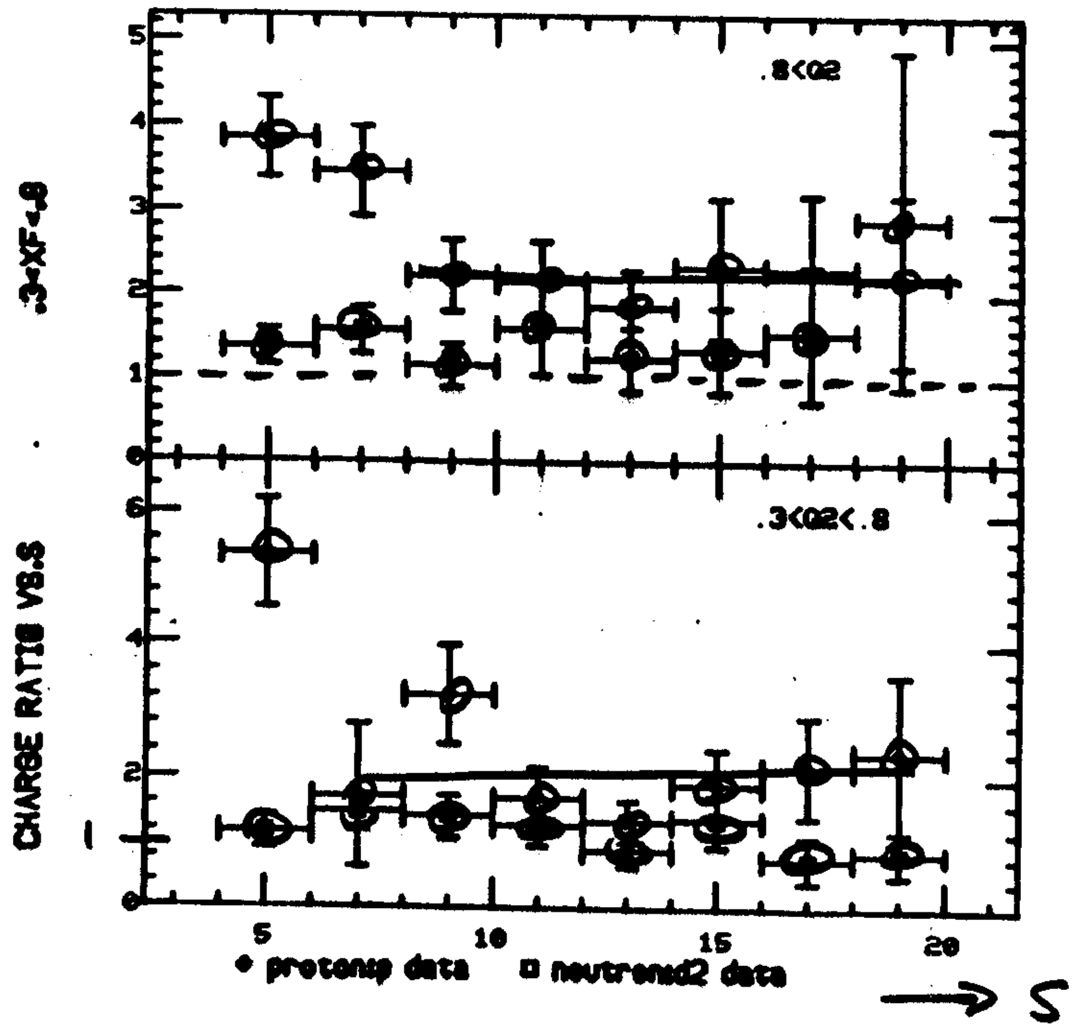


dN
dz max
2.8 ≤ W ≤ 4.7, 0.5 ≤ Q² ≤ 4.5
• POSITIVES
o NEGATIVES ×2
.20
.10
0
.2
.4
.6
.8
1.0
z max



POSITIVES
O NEGATIVES
dN/dz max
1- PRONGS
.06
.02
.10
3- PRONGS
.06
.02
.10
5 - PRONGS
.06
.02
0
.2
.4
.6
.8
1.0
z max

Direct measurement of charge ratio



Result:

$$R_{(p)\,\text{forward}} \approx \pi^+/\pi^- \simeq 2 \text{ for } s \geq 6$$

(see above)

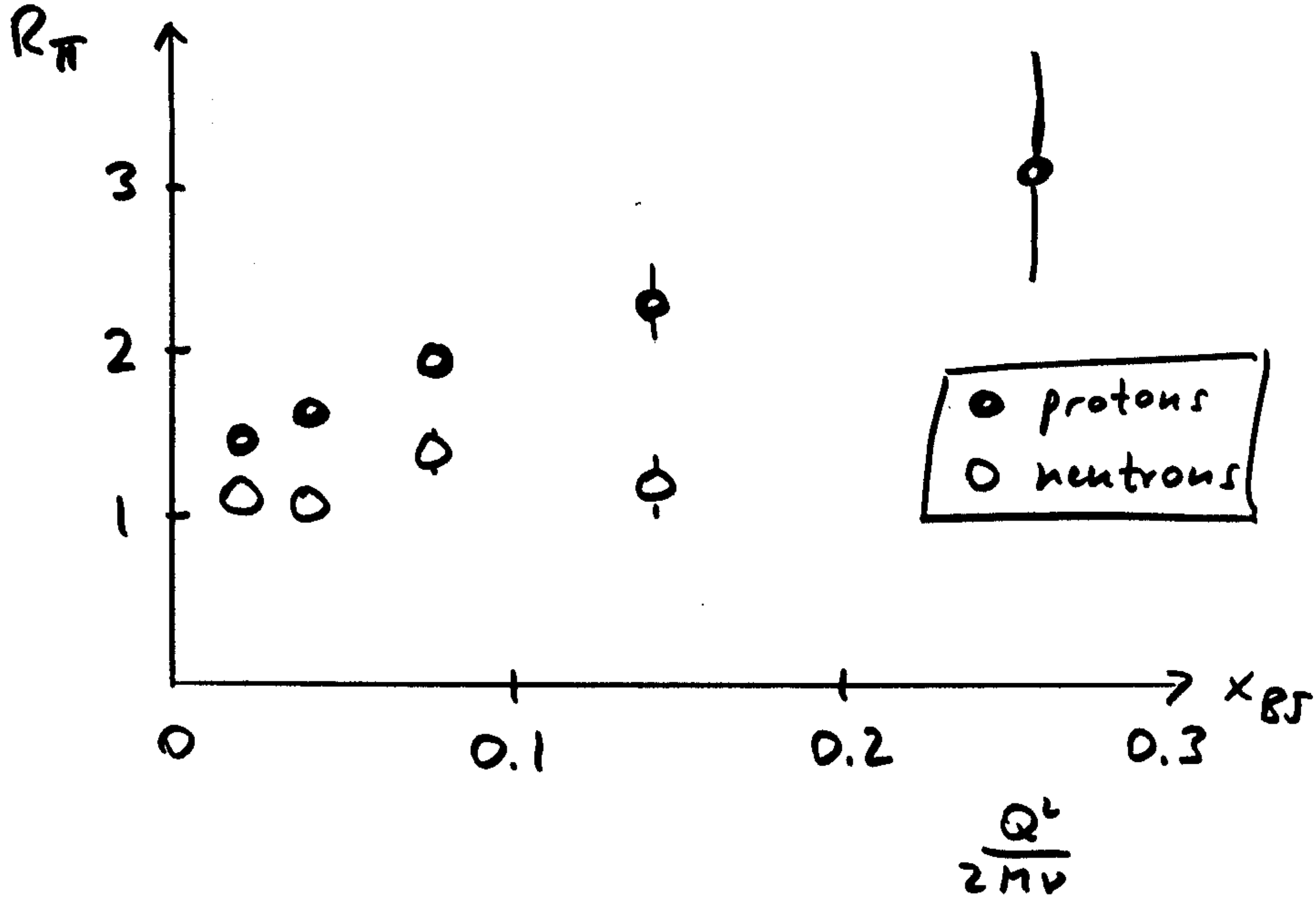
$R_{(n)\,\text{forward}}$ appears to be significantly above 1.

Detailed measurement of charge ratio (SLAC-MIT)

data restricted to region $15 \le s \le 31$

$0.4 \le z \le 0.85$

$0 \le p_\perp^2 \le 0.64$



Result: Claim of a significant deviation from

for $R_\pi(n)$: ± 0.04

→ quark-parton model

LONGITUDINAL MOMENTUM DISTRIBUTION

plot $\quad F^{\pi^-}(x_F, W, Q^2) = E \dfrac{dN^{\pi^-}(W,Q^2)}{d^3p} \dfrac{dp_\perp^2\, d\phi}{2\pi}$

$$x_F = \frac{p_\parallel^*}{p_{\parallel\,max}^*}$$

$$p_{\parallel}^{*}\,max = \frac{W^2 - m_p^2}{2W}$$

<u>Result</u>: no strong W, Q^2 dependence below $x_F \sim 0.5$

$\mu p \to \pi^- \ldots$ contained between
$\pi^- p \to \pi^- \ldots$ and $\pi^+ p \to \pi^- \ldots$

TRANSVERSE MOMENTUM DISTRIBUTION

<u>Results</u>:

→ $\langle p_\perp \rangle$ increases with W
but barely at small $|x_F| < .15$

→ $\langle p_\perp \rangle$ does <u>not</u> depend on Q^2 (<u>now</u>)

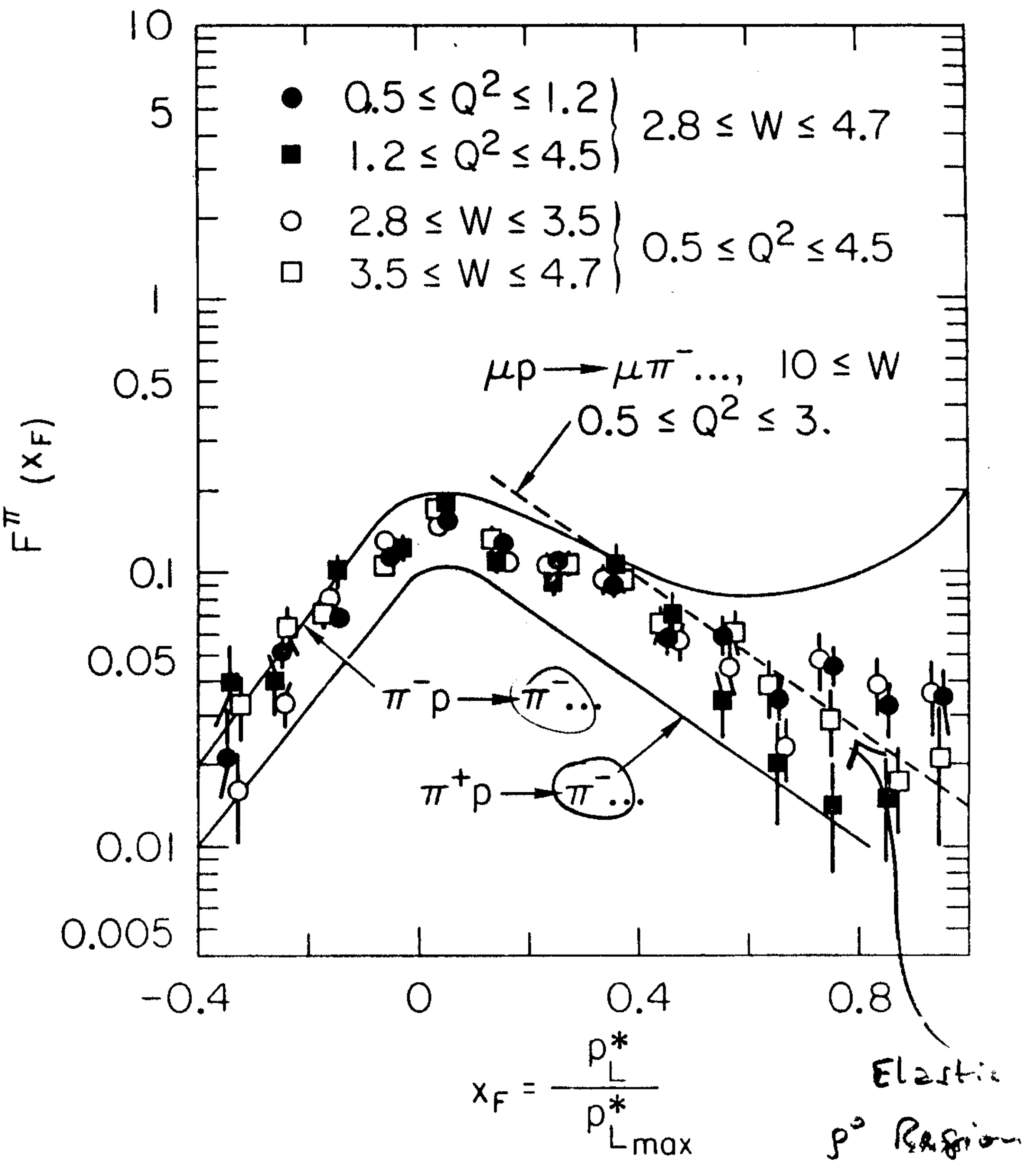
→ $\langle p_\perp \rangle$ has a minimum at $x_F \simeq 0$

→ $\dfrac{dN}{dp_\perp^2}$ distribution shows
two-component system.

Small x_F: $\left(\sim \left(e^{15 p_\perp^2} + a\, e^{5 p_\perp^2} \right) \right)$

Large x_F $\left(\sim e^{5 p_\perp^2} \right)$

maybe <u>direct</u> π production [illegible] like $e^{5 p_\perp^2}$?



10
5
1
0.5
0.1
0.05
0.01
0.005
$0.5 \le Q^2 \le 1.2$
$1.2 \le Q^2 \le 4.5$
$2.8 \le W \le 4.7$
$2.8 \le W \le 3.5$
$3.5 \le W \le 4.7$
$0.5 \le Q^2 \le 4.5$
$\mu p \to \mu \pi^- \ldots, \quad 10 \le W$
$0.5 \le Q^2 \le 3.$
$\pi^- p \to \pi^- \ldots$
$\pi^+ p \to \pi^- \ldots$
$F^{\pi^-}(x_F)$
−0.4
0
0.4
0.8
$x_F = \frac{p_L^*}{p_{L\,max}^*}$
Elastic
ρ^0 Region

fig. 3

W Dependence of $\langle p_\perp \rangle$

$0.5 \leq Q^2 \leq 4.5, \langle Q^2 \rangle = 1.1$

Negatives

○	$-0.4 \leq x_F \leq -0.15$,	$\langle x_F \rangle = -0.23$
△	$-0.15 \leq x_F \leq 0.15$,	$\langle x_F \rangle = 0.$
●	$0.15 \leq x_F \leq 0.4$,	$\langle x_F \rangle = 0.25$
■	$0.4 \leq x_F \leq 0.9$,	$\langle x_F \rangle = 0.57$

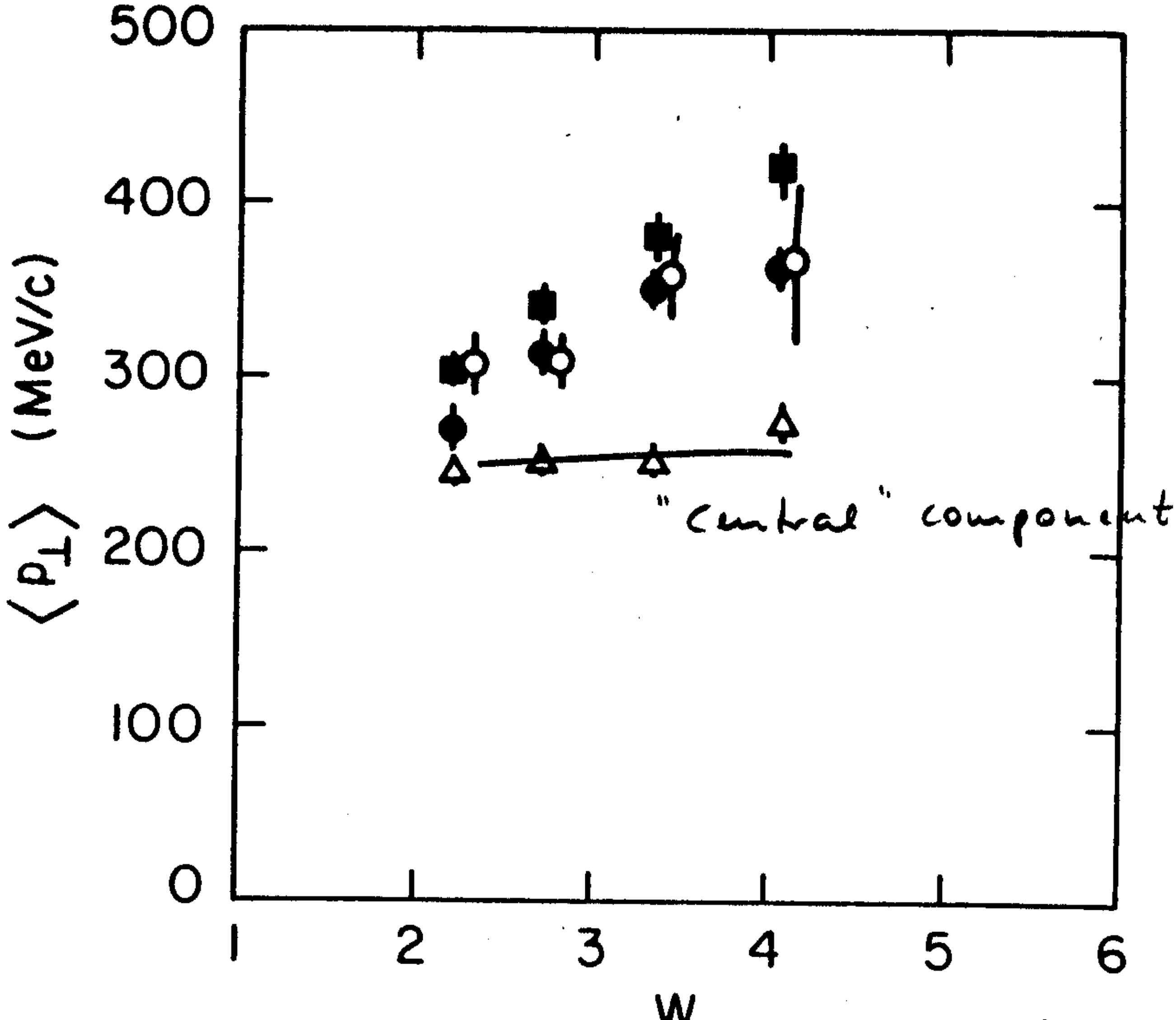


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fig. 4

Q^2 TREND of $\langle p_\perp \rangle$?

x_F dependence of $\langle p_\perp \rangle$, for various $\langle Q^2 \rangle$

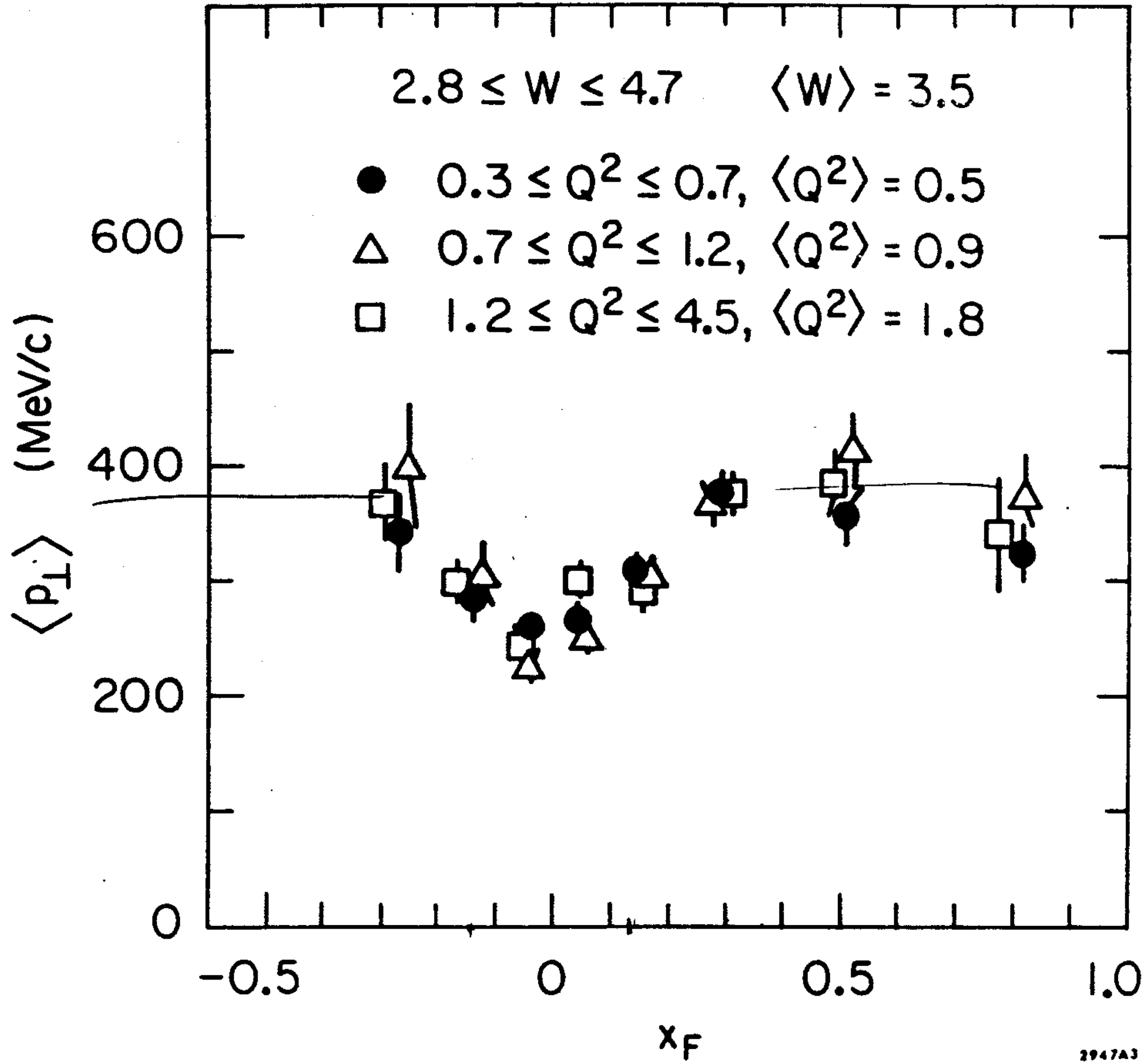

Fig. 7

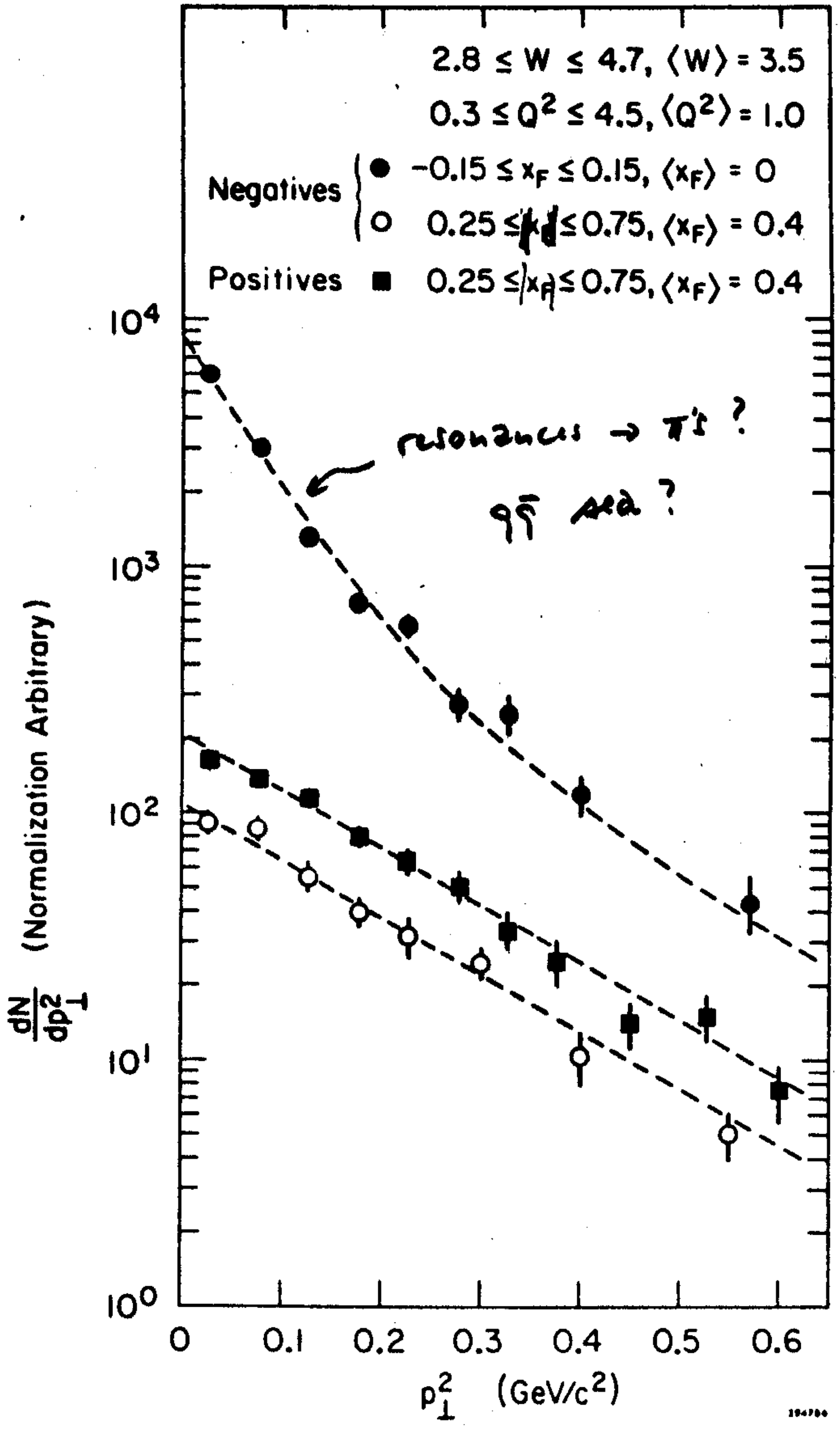
2.8 ≤ W ≤ 4.7, ⟨W⟩ = 3.5
0.3 ≤ Q² ≤ 4.5, ⟨Q²⟩ = 1.0
Negatives
−0.15 ≤ x_F ≤ 0.15, ⟨x_F⟩ = 0
0.25 ≤ |x_F| ≤ 0.75, ⟨x_F⟩ = 0.4
Positives
0.25 ≤ |x_F| ≤ 0.75, ⟨x_F⟩ = 0.4
resonances → π's ?
qq̄ sea ?
dN/dp⊥² (Normalization Arbitrary)
p⊥² (GeV/c²)

fig. 6