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

THEORETICAL SCHEMES FOR NEW PARTICLES SITAR CONCERT

J.C. Pati

Department of Physics and Astrophysics, University of Maryland,
College Park, Md. 20742, USA.

Pati.

From the Point of View of a Unified Theory of Quarks and Leptons, THE MOST IMPORTANT QUESTION:

ARE THE BASIC CONSTITUENTS - QUARKS - ABSOLUTELY CONFINED } Perhaps? But, ...

or

ARE THEY LIBERATED? (TUNNELLING THROUGH A FINITE BARRIER) } Certainly Allowed.

PREDICTIONS OF A UNIFIED THEORY WITH

UNCONF QUARKS & UNCONF. COLOR:

(A) LEPTON-HADRON-PHENOMENA: (eN, μN, νN, e^-e^+)

(i) FLAVOR VERSUS COLOR CHARGE CONTRIBUTIONS :	VERY DIFFERENT ... A HAN-NAMBU THEORY OF INT. CH. ...
(ii) SCALING VIOLATIONS	$(\log)_{AF}$ + (Color ...)
(iii) (σ_L/σ_T)	$f(x) \neq 0$
(iv) $\mu^-\mu^+$, $\mu^-\mu^-$	charm $\sim$ ($\frac{1}{...}$ to ...) Color $\sim$ (... to ...) Dissociation $\rightarrow (\mu^-\mu^-)_{\nu N}$
(v) $(\sigma_{\bar{\nu}}/\sigma_\nu)$; $\langle Y \rangle_{\bar{\nu}}$	Non Asympt. ... Contrib.
(vi) $\mu e K$ - Events	($c\bar{\lambda}$) - ... + $D\bar{K}$ - P...
(vii) $e^-e^+ \rightarrow$ (a) μe (b) JETS	$e^-e^+ \rightarrow$ (...) $\rightarrow \mu e$ ... JETS $\Leftrightarrow$ ...

Unified Theory of Quarks & Leptons

Basic Ingredients

1. Quarks (flavors ⊗ Three Colors)
2. Leptons
3. $V(\underset{\sim}{8})$ gluons
4. (W, X, ...)

P8s
('72, '73)

↓

(spont. Symm. Breaking of SAME Local Symm G)

The Unconfined Quark

$\boxed{Q = Q_{flav} + Q_{col}}$

1. Quarks Int. Ch.
2. Gluons Massive ~ 1 to Few GeV
3. quarks → leptons

   Proton Rather stable

4. No Need To Assume Confinement

Central Dogma of Confinement

$\boxed{Q = Q_{flav}}$

1. quarks Fr. charged
2. Gluons Massless
3. MUST Assume quark & Color Confinement

Motivation (P)

G Essentially Unique

$= G_{flav} \otimes G_{color}$

G not unique

Either Simple or Semisimple

COMMON ADVANTAGES.

1. Temp. ASYMP. Freedom - Scaling
2. Parity & strangeness Viol Natural ~ $O(G_F)$
3. Same "SHORT" DISTANCE BEHAVIOUR

Unconfined Quarks

Ⓐ Finite Barrier ⟺
PARTIAL CONF.

Ⓑ or "Equivalently"

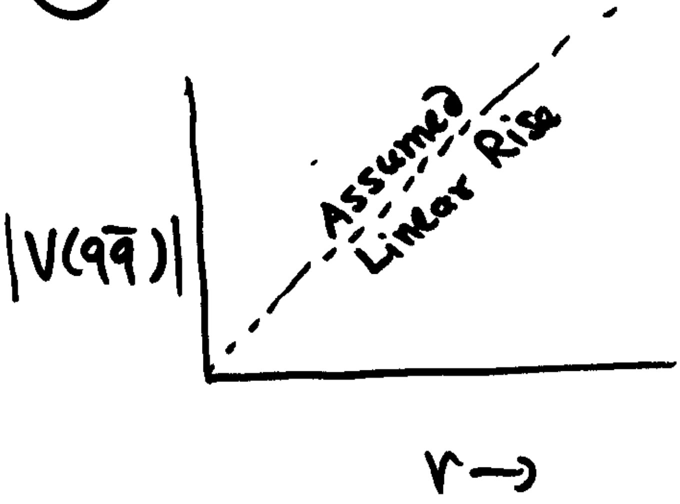
$(m_q^{out}) \sim 2$ to 4 GeV $\longrightarrow$ $(m_q^{out}) \longrightarrow \infty$

$(m_q^{in}) \sim 100$ to 500 MeV $\longrightarrow$ Same
(p, n, λ)

(ARCHIMEDES EFFECT)

Confined Quarks

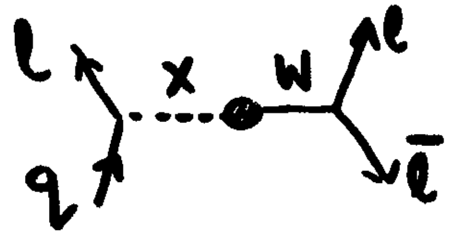
Ⓐ Infinite Barrier.



Ⓒ Common upto Certain Energy $\Big\}$ $\boxed{(q\bar{q})\text{-SPECTROSCOPY}}$

Some Exotic Consequences of B & L Violations

For The case of Int. ch. quarks:

$F = \{q, \ell\}$  $\Delta B = -\Delta L = -1.$

① $q \to \ell + \text{mesons}$, $\to \ell + \ell + \bar{\ell}$ $\Big\}$ $\tau_q \sim 10^{-11}$ to 10^{-12} sec. $m_q \sim 2$ to 3 GeV

② $\text{PROTON} = 3q \longrightarrow 3\ell + \text{Pions}$

$$\boxed{\tau_{\text{proton}} \sim 10^{28} \text{ to } 10^{32} \text{ Yrs.}}$$

③ $p + p \to q + \bar{q} + \text{Hadrons}$ $\sim 10^{-30}$ to 10^{-32} cm

$q \to \ell^- + \cdots$, $\bar{q} \to \ell^+ + \cdots\cdots$ ($\ell = e$ or

④ $\nu_\mu + N \longrightarrow \mu^- + (q^-_{\text{red}} + q_{\text{yel}} + q_{\text{blue}})$

$q^-_{\text{red}} \to \mu^- + \nu + \bar{\nu}$, $q_{\text{yel}} \to \nu + \pi$, $q_{\text{blue}} \to \bar{\nu} + \pi$

⑤ $e^- e^+ \longrightarrow q^-_{\text{red}} + q^+_{\text{red}}$

$q^-_{\text{red}} \to \mu^- \nu \bar{\nu}$, $q^+_{\text{red}} \to \mu^+ \nu \bar{\nu}$

NOTATIONS: BASIC MODEL (FERMIONS)

$$F_{L,R} = \begin{bmatrix} p_r^0 & p_y^+ & p_b^+ & \nu_e \\ n_r^- & n_y^0 & n_b^0 & e^- \\ \lambda_r^- & \lambda_y^0 & \lambda_b^0 & \mu^- \\ c_r^0 & c_y^+ & c_b^+ & \nu_\mu \end{bmatrix}_{L,R}$$

(P & Salam)

Red Yellow Blue Lilac

Minimal NonAbelian Symm. (g, f) $\Big\}$ → $SU(2)_L \times SU(2)_R \times SU(4)'_{L+R}$ $\Big\{$ Desirable MilliWeak Th of CP viol WITH ONLY 4 Flavors. (M, P)

↓

One Coupling Constant $\Big\}$ → $SU(4)_A \times SU(4)_B \times SU(4)'_A \times SU(4)'_B$

↓

MUST POSTULATE MIRROR FERMIONS $\Big\}$ $\boxed{F'_{L,R} \longleftrightarrow F_{R,L}}$ Heavy quarks Heavy Leptons

↓

VECTOR LIKE THEORY, BUT NEUTRAL CURRENTS NOT PURE VECTOR:

↓

No. of Flavors = TWICE NO. of Colors
LEPTON NUMBER = FOURTH COLOR

Gauge Mesons (BASIC MODEL)

$$(W_L^{\pm}, W_L^3);\ (W_R^{\pm}, W_R^3);\quad V(\underset{\sim}{15}) = \left[\begin{array}{ccc:c} V_{11} & V_{\rho+} & V_{K*}^{+} & X^0 \\ V_{\rho-} & V_{22} & V_{K*}^{0} & X^- \\ V_{K*}^{-} & \bar{V}_{K*}^{0} & V_{33} & X'^- \\ \hdashline \bar{X}^0 & X^+ & X'^+ & \sqrt{\tfrac{3}{4}}\, S^0 \end{array}\right]$$

$$(V_{11}, V_{22}, V_{33}) \rightarrow (V_3, V_8, V_{15} = S^0)$$

Neutral

$$A = \frac{fW + gU^0}{\sqrt{\ }}, \quad \tilde{U} = \frac{fU^0 - gW}{\sqrt{\ }}, \quad Z^0$$

$$U^0 = \frac{\sqrt{3}\,V_3 + V_8}{2}, \quad V^0 = \frac{V_3 - \sqrt{3}\,V_8}{2}, \quad S^0$$

Masses:

PHOTON	--->	Massless	EM
Gluons $V(\underset{\sim}{8})$	--->	1 to Few GeV	STRONG qq
Weak Bosons W_L	--->	~ 100 GeV	V−A
Weak Bosons W_R	--->	$\gtrsim 300$ GeV	V+A
"Strong" Boson S^0	--->	$\gtrsim 1000$ GeV	Neutral Current
strong Bosons X	--->	$\gtrsim 10^5$ GeV.	Exotic (K-{ik})

MIXINGS:

$$K^2 \{ V_\rho^+ W^- \cos\alpha + V_{K*}^+ W^- \sin\alpha \}$$

FEATURES OF S.Broken GAUGE TH

$$\Delta^2 \{ X^+ W^- \cos\alpha + X'^+ W^- \sin\alpha \}$$

No $X^0 W$ (Basic Model)

I. Lepto-Production of Color

$$Q = Q_{flav} \quad \text{(Fr. ch. quarks)}$$

$$= Q_{flav} + Q_{col} \quad \text{(Int. ch. quarks)}$$

A. Phenomenological Th. of Color, Familiar Expectns.

Above Threshold for Color Prod Expect :

(i) Large Rise In $F_i(q^2, \nu)$ ~ 100 %

(ii) Charged spin 1 gluons → (σ_L/σ_T) should grow with $|q^2|$

} NOT SEEN

(iii) Sum Rules $(eN/\nu N) = 1/2$ Int. ch
$= 5/18$ Fr. ch.
} Expt ≈ 5/18

∴ Within a phenomenological Theory would deduce:

Either (i) Quarks are Fr. ch. ($Q = Q_{flav}$)

or (ii) Quarks are Int. ch., but Color Th $\gtrsim$ 10 GeV.

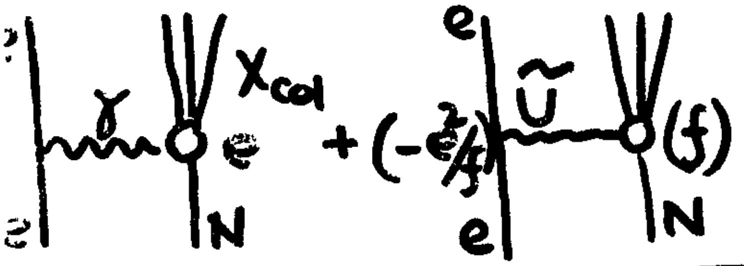
HAS BEEN THE STANDARD INTERPRET.

But Within a Unified Gauge Th. Approach

To "Colored" Photon, Photon Can not Come alone

$$A = \frac{f W_3 + g U^0}{\sqrt{}} \quad , \quad \tilde{U} = \frac{f U^0 - g W_3}{\sqrt{}}$$

THE PHOTON - GLUON CANCELLATION THM: (P & S, R & R 1975)



$$\propto \frac{e^2}{q^2} - \frac{e^2}{q^2 - m_U^2} = \frac{e^2}{q^2}\left(\frac{m^2 \text{[illegible]}}{q^2 - \text{[illegible]}}\right)$$

$$\boxed{F_i(q^2,\nu) = F_i^{flav}(q^2,\nu) + \left(\frac{m_U^2}{|q^2| + m_U^2}\right)^2 F_i^{col}(q^2,\nu)}$$

For eN sex

$$\Delta^2(q^2) < 1$$

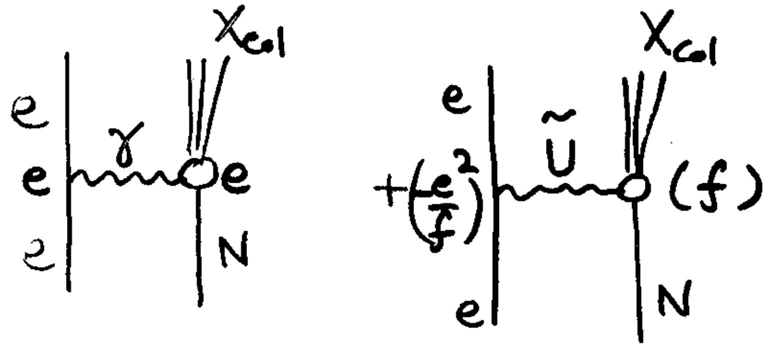
$$\xrightarrow{|q^2| \gg m_U^2} 0$$

This factor $\Delta^2(q^2)$ suppresses Color-brightening Effect both for Space like and time like $(q^2 > 0)$ - R...

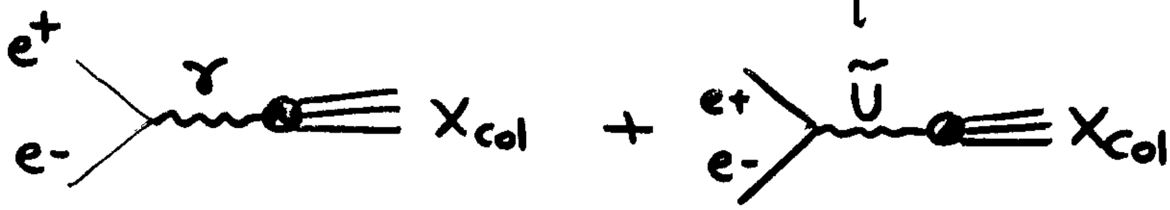
Color Suppression :

$$A = \frac{fW + gU^\circ}{\sqrt{\quad}} \,, \quad \tilde{U} = \frac{fU^\circ - gW}{\sqrt{\quad}}$$

The Photon - Gluon - Cancellation Thm : (P & S
 Roy & Rajasekharan)



$$\propto \frac{e^2}{q^2} - \frac{e^2}{q^2 - m_U^2}$$
$$= \frac{e^2}{q^2}\left(m_U^2 / q^2 - m_U^2\right)$$



$$\boxed{R = \sum_i R_{flav}(q_i \bar{q}_i) + \left[\frac{m_U^2}{q^2 - m_U^2}\right]^2 \left\{\sum_i R_{col}(q_i \bar{q}_i) + \sum_{\substack{\alpha \\ \text{(gluons)}}} R(V_\alpha \bar{V}_\alpha)\right\}}$$

$$e^- e^+ \longrightarrow q_i \, \bar{q}_i$$
$$\longrightarrow V_\rho^+ \, V_\rho^-$$
$$\longrightarrow V_{K^*}^+ \, V_{K^*}^-$$

$$Q_{\text{quarks}} = \begin{array}{c} \\ p \\ n \\ \lambda \\ c \\ \end{array}\!\!\begin{array}{c} \\ \left[\begin{array}{ccc} 0 & + & + \\ - & 0 & 0 \\ - & 0 & 0 \\ 0 & + & + \end{array}\right] \\ \begin{array}{ccc} \text{red} & \text{yel} & \text{blue} \end{array} \end{array} = \begin{bmatrix} 2/3 & 2/3 & 2/3 \\ -1/3 & -1/3 & -1/3 \\ -1/3 & -1/3 & -1/3 \\ 2/3 & 2/3 & 2/3 \end{bmatrix} + \begin{bmatrix} -2/3 & 1/3 & 1/3 \\ -2/3 & 1/3 & 1/3 \\ -2/3 & 1/3 & 1/3 \\ -2/3 & 1/3 & 1/3 \end{bmatrix}$$

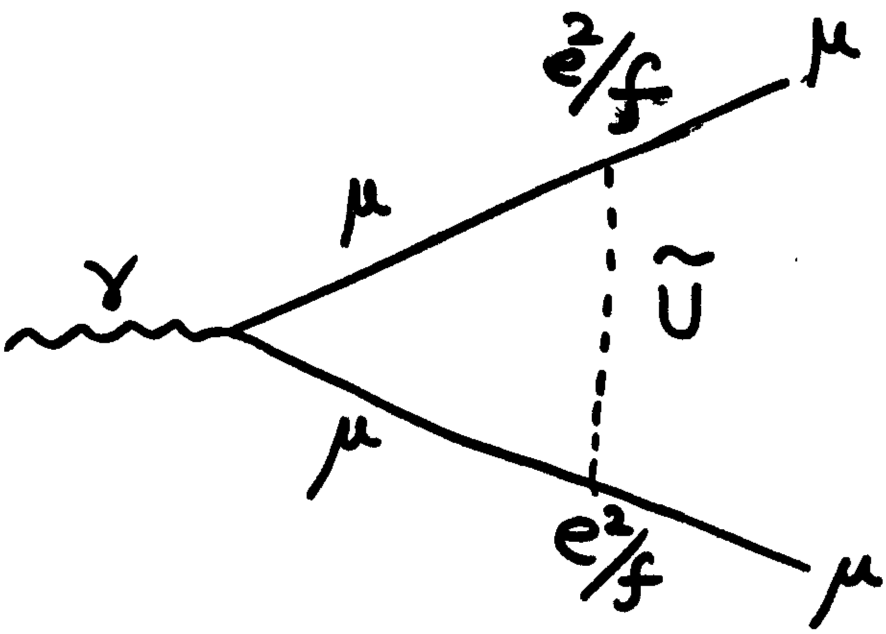
$$= \Big[Q_{\text{flav}} + \underset{F'_{15}}{\underset{\uparrow}{Q_0}} \Big] + Q_{\text{col}}(SU(3)')$$

{ Asymp. Does Not Contribute To R

$\Rightarrow$ PARTON PAIRS

$$\begin{cases} R(p_r^0 \bar{p}_r^0) = R(p_y^+ p_y^-) = R(p_b^+ p_b^-) = \dfrac{4}{9} \\ R(n_r^- n_r^+) = R(n_y^0 \bar{n}_y^0) = R(n_b^0 \bar{n}_b^0) = \dfrac{1}{9} \\ R(\lambda_r^- \lambda_r^+) = R(\lambda_y^0 \bar{\lambda}_y^0) = R(\lambda_b^0 \bar{\lambda}_b^0) = \dfrac{1}{9} \\ R(c_r^0 \bar{c}_r^0) = R(c_y^+ c_y^-) = R(c_b^+ c_b^-) = \dfrac{4}{9} \\ R(V_\rho^+ V_\rho^-) = R(V_{K*}^+ V_{K*}^-) = \dfrac{1}{16} \end{cases}$$

Familiar q.e.d. Tests are not affected

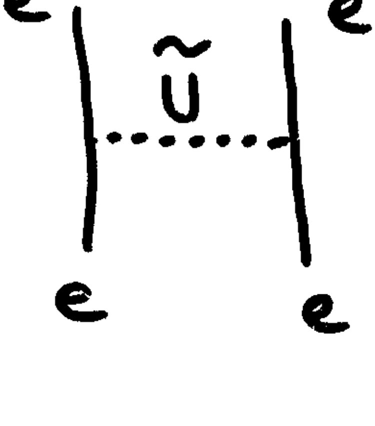


$$(g-2) \longrightarrow (e^2/f)^2 \, (m_\mu/m_U)^2 \left(\frac{1}{12\pi^2}\right)$$

$$= \left\{ \alpha^2/(f^2/4\pi) \right\} \left(\frac{1}{3\pi}\right) (m_\mu/m_U)^2$$

$$= 10^{-8} \qquad \left(\text{for } m_U = 1 \text{ GeV} \quad f^2/4\pi = 5 \right)$$

imilary



$$(e^2/f)^2 \, \frac{1}{k^2 - m_U^2}$$

The Novel Results For The Gauge Th. APP. To Color:

① Asymptotically (For $|q^2| \gg m_U^2$)

$$\text{INT. CH. QUARK PARTONS} \;\underset{\substack{e^-e^+ \to X \\ \nu N \to \mu X}}{\overset{\substack{\text{For} \\ eN \to eX}}{\longleftrightarrow}}\; \text{FR. CH. QUARK PARTONS}$$

② Virulent spin 1- gluons become gentle and Contribute scale Invariantly

$$F_2(x) \neq 2x F_1(x)$$

$$\boxed{(\sigma_L/\sigma_T) = f(x) \neq 0}$$

③ Including (quarks + gluons); we obtain color Can not brighten on Par with flavor eventhough Photon is Colored & Color Th. is low ($\sim$ 1 to Few GeV).

For presently explored (q^2, ω), we obtain

$$\boxed{\left(\sigma_{col}/\sigma_{flav}\right)_{\substack{eN \to ex \\ \nu N \to \mu x}} \sim 10 \text{ to } 20\,\%}$$

④ Small Modification of Sum Rules, e.g.

$$\boxed{\left(eN/\nu N\right) = \frac{5}{18} \pm .03}$$

⑤ Conclude → Lepto-Production data consistent with the hypothesis of integer charge quarks and low-mass Color Threshold (~ 1 to Few GeV) provided we accept the gauge Th. Approach To Color.

FLAVOR & Color- Contrib.

$$F_1^{eN} = \frac{1}{2} \sum_{q=p,n,\lambda,c} Q^2_{flav}(q) \left[q(x) + \bar{q}(x) \right] \rho_{flav}(q^2,\nu)$$

$$+ (1+\xi)^{-2} \left[\frac{1}{3} \sum_q \left(q(x) + \bar{q}(x) \right) + \frac{16}{3}\left(1+\frac{\xi}{4}\right) v(x) \right] \rho_{col}(q^2,\nu)$$

(Color Suppression Factor)

$$F_2^{eN} = \sum_q x\, Q^2_{flav}(q) \left[q(x) + \bar{q}(x) \right] \rho_{flav}(q^2,\nu)$$

$$+ (1+\xi)^{-2} \left[\frac{2x}{3} \sum \left(q(x) + \bar{q}(x) \right) + x\, v(x) \left(4 + \frac{4}{3}\xi + \frac{\xi^2}{3}\right) \right]$$

(Color-Suppression) $\times\ \rho_{col}(q^2,\nu)$

Gluon Distr. Function

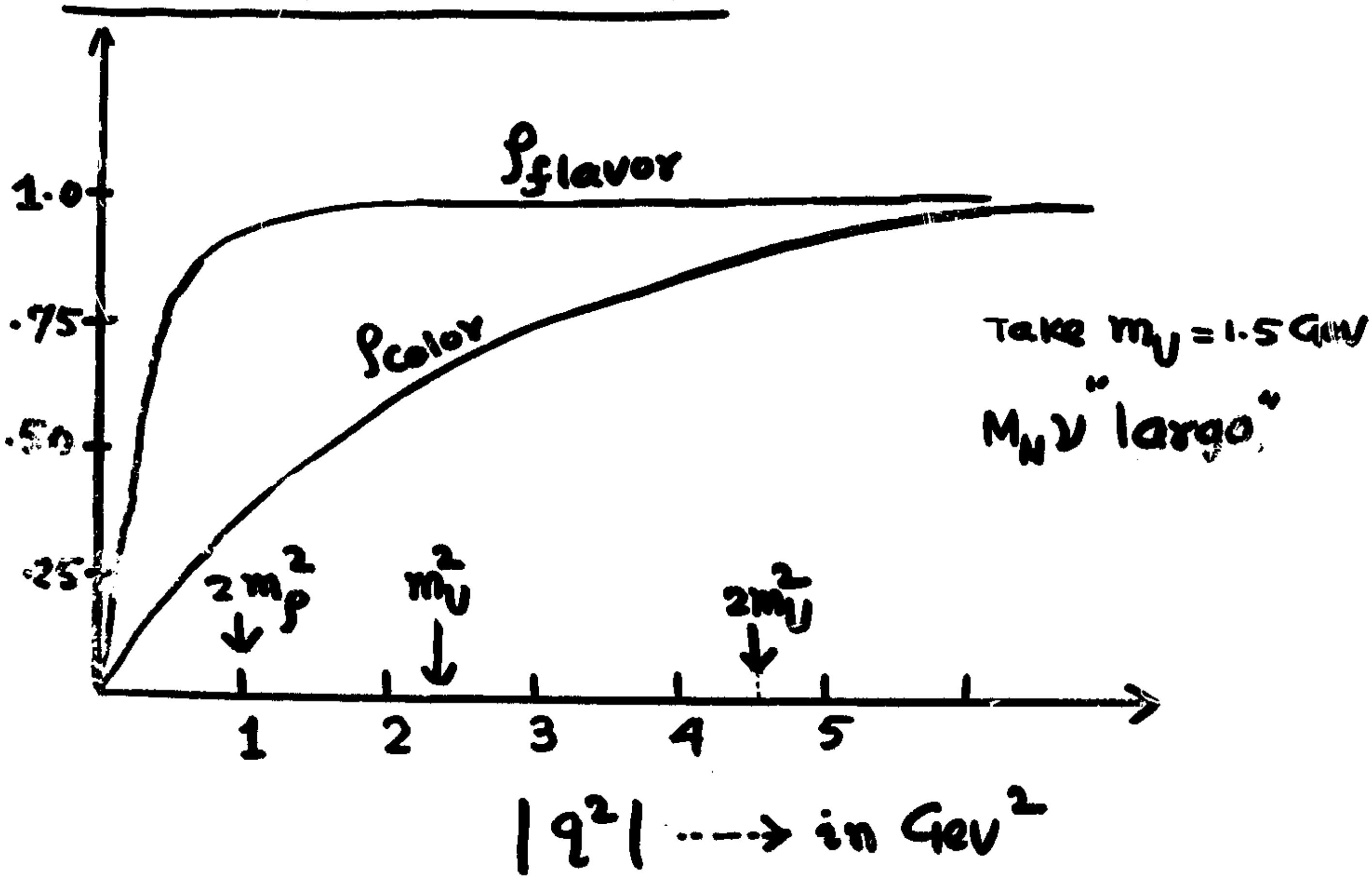
$$R = 3 \sum_q Q^2_{flav}(q) + (1-\xi)^{-2} \left[(2/3) \times (\text{No. of flavors}) + (1/8)\left(1-\frac{4}{\xi}\right)^{3/2} (12 + 20\xi + \xi^2) \right]$$

(Color-Suppression)

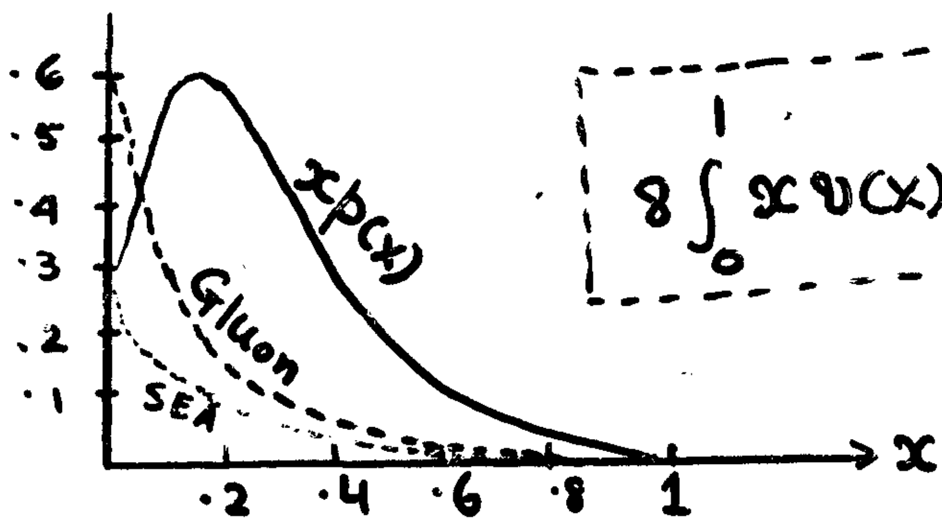
$$\xi = |q^2| / m_\nu^2 \,, \quad x = 1/\omega = |q^2| / 2M_N \nu$$

$$\boxed{\begin{aligned} F_1^{col} &\xrightarrow{\xi \gg 1} 0 \\ F_2^{col} &\longrightarrow (1/3)\, x\, v(x) \\ R^{col} &\longrightarrow (1/8) \end{aligned}}$$

Scale-Threshold Factors



MODEL FOR GLUON-Distrib.



$$8\int_0^1 x\,v(x) \approx 0.5$$

Characteristic Features of Color Prodn.

(1) For $|q^2| \gtrsim 3m_U^2$ (i.e. $\xi \gtrsim 3$), $F_i^{Col}(q^2, \nu)$ <u>decrease</u> with $|q^2|$ (for fixed ω) before settling to scale Inv. values.

(2) Approach to Scaling in $|q^2|$-Variable VERY VERY SLOW DUE TO LARGE NUM. COEFFS OF NON LEADING TERMS in ξ. e.g.

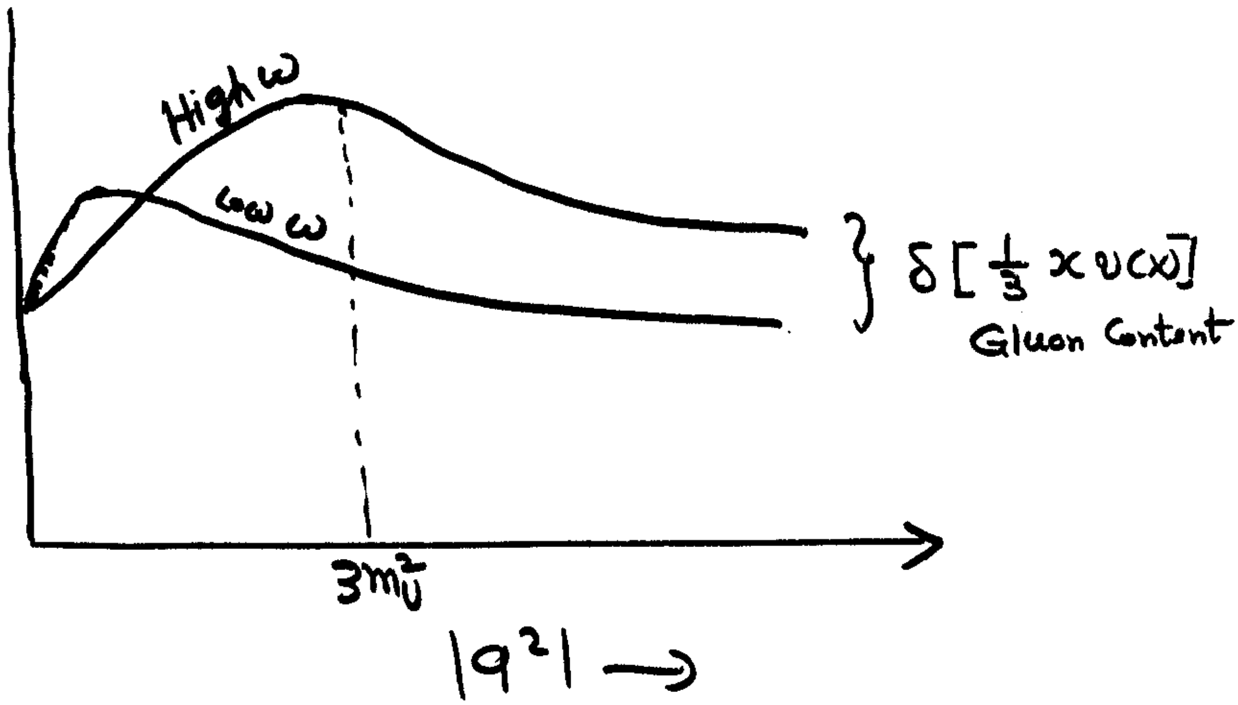
$\left(F_2^{Col} / F_2^{flav}\right) \rightarrow$

	$\xi = 3$	$\xi = 5$	$\xi = 10$
$x = .5$	.14	.10	.07
$x = .2$	.20	.14	.10

$$\xi = 10 \longrightarrow \begin{cases} |q^2| = 22.5 & \text{for } m_U \approx 1.5 \text{ GeV} \\ |q^2| = 160 & \text{for } m_U \approx 4.1 \text{ GeV.} \end{cases}$$

(3) For $|q^2| < 3m_U^2$ and high ω (i.e. high gluon Content) F_i^{Col} may rise with $|q^2|$ temporarily due to rise in $\rho_{Col}(q^2, \nu)$

Qualitatively



Compute

$$\left(\sigma_L/\sigma_T\right) = .15 \rightarrow .2$$

$$\text{for } x = .2 \rightarrow .5 = \frac{1}{\omega}$$

$$\xi = |q^2|/m_V^2 = 2 \rightarrow 5$$

In Summary

① FR. CH. QUARKS (CONFINED BY ASSUMPTION) } Consistent ...
eN, μN, νN
(σ_L/σ_T) ---> ...

② INT. CH. QUARKS (UNIF. GAUGE THEORY) } Consistent ...
eN, μN, νN
$(\sigma_L/\sigma_T) \neq 0$

③ INT. CH. Quarks (Han-Nambu Theory) + Low Mass Color ($\lesssim 5$ GeV) } Incompatible !
(i) $\frac{eN}{\nu N} \neq \frac{1}{2}$
(ii) No large ...
(iii) (σ_L/σ_T) ...

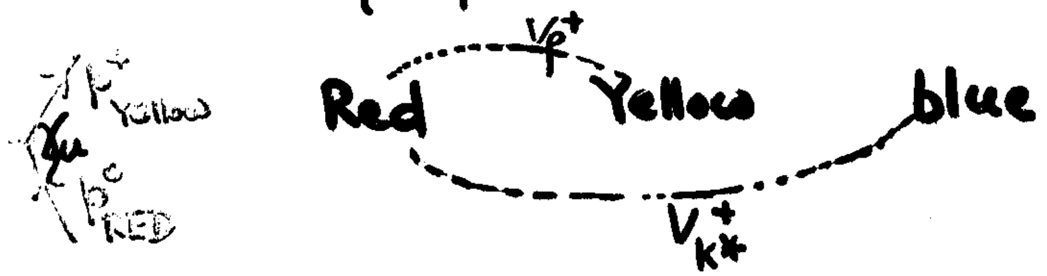
To distinguish between ① & ②

Ⓐ (σ_L/σ_T) - Measurement Crucial

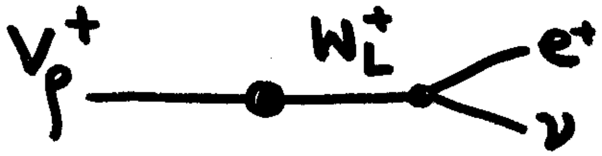
(B) Does Rising F_2 (for high ω) → fall?

Charged Gluon Decays

$$V(\underset{\sim}{8}) = \{ V_\rho^\pm , V_{K^*}^\pm , V_{K^*}^0 , \bar{V}_{K^*}^0 , \tilde{U} , \tilde{V} \}$$



(Nearly Degenerate octet).

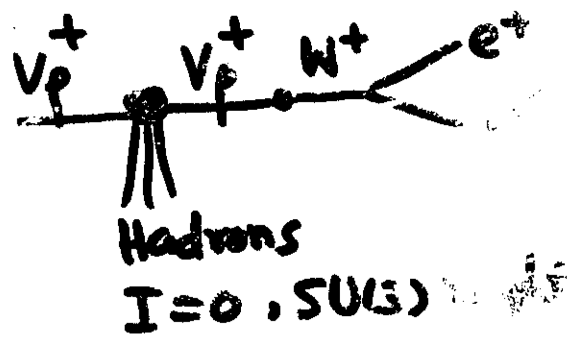


$\}$ $(\mu^+\nu)$; $\pi\pi$, $K\bar{K}$, 3π

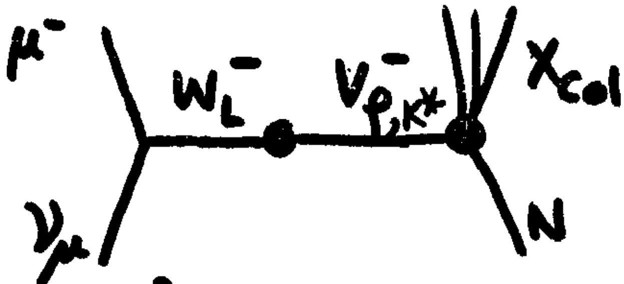
		BR. RATIO $m_U = 1.5$	$m_U = 4$
$V_\rho^+ \to \mu\nu$	---------->	30 %	~20 %
$\to e\nu$	----->	30 %	~20 %
$\to \pi\pi, 3\pi, 5\pi, K\bar{K}\ldots$	-->	30 %	~60 %
$\to \pi\pi e\nu, K\bar{K}e\nu$	-->	Few %	~ Few %

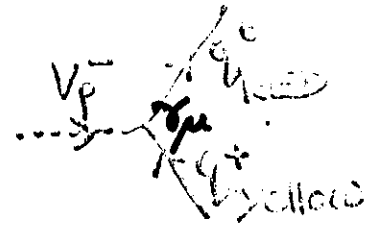
$\not\to \pi\mu\nu, K\mu\nu, \eta\mu\nu$ (CLEAR DISTINCTION FROM D & F)

$$\boxed{\begin{array}{l} \tau(V_\rho^+) \sim 10^{-13} \text{ to } 10^{-15} \text{ sec} \\ m_V \sim 1.2 \text{ to } 3 \text{ GeV} \end{array}}$$



Charged $W^{\pm}$ Must Mix With $(V_{\rho}^{\pm}, V_{K^*}^{\pm})$





$$= \frac{G_F}{\sqrt{2}} \boxed{\left(\frac{m_V^2}{q^2 - m_V^2}\right)} \left[\bar{\mu}\,\gamma_\mu (1+\gamma_5)\,\nu\right] \langle X_{col} \,|\, J_\mu^{V_\rho^-} \,|\, N \rangle$$

SAME Δ-Factor

PURE VECTOR
$(1, \underset{\sim}{8})$ - CURR

$\Rightarrow$ (i) No Contrib From Color To F_3

(ii) Color Contrib To Neutrino & Antineutrino Scatt are identical

$$\boxed{d\sigma^{\nu}_{col} = d\sigma^{\bar{\nu}}_{col}}$$

⑥ NEUTRINO SCATT ($\nu N \to \mu + X$)

$$\begin{pmatrix} F_1^{\nu N} \\ F_1^{\bar{\nu} N} \end{pmatrix}_{C.C.} = \frac{1}{2}\left[\begin{matrix} p(x)+n(x) \\ +\bar{p}(x)+\bar{n}(x) \end{matrix} + 2\left\{\begin{pmatrix} \bar{c}(x) \\ c(x) \end{pmatrix} + \begin{pmatrix} \lambda(x) \\ \bar{\lambda}(x) \end{pmatrix}\right\}\rho_{\text{Charm}}(q^2,\nu)\right.$$

$$+ (1+\xi)^{-2}\Big[\frac{1}{2}\sum_{q=p,n,\lambda,c}(q(x)+\bar{q}(x))$$

$$+ 8\,(1+\xi/4)\,v(x)\Big]\,\rho_{\text{Col}}(q^2,\nu)$$

(Color Suppression Factor)

gluon-dist[illegible]

y^2-distrib.

$$\begin{pmatrix} F_2^{\nu N} \\ F_2^{\bar{\nu} N} \end{pmatrix}_{C.C.} = x\left[\begin{matrix} p(x)+n(x) \\ +\bar{p}(x)+\bar{n}(x) \end{matrix} + 2\left\{\begin{pmatrix} \bar{c}(x) \\ c(x) \end{pmatrix} + \begin{pmatrix} \lambda(x) \\ \bar{\lambda}(x) \end{pmatrix}\right\}\right]\rho_{\text{Charm}}(q^2,\nu)$$

$$+(1+\xi)^{-2}\Big[x\sum_{q}(q(x)+\bar{q}(x))$$

$$+ 2x v(x)(3+\xi+\xi^2/4)\Big]\,\rho_{\text{Col}}(q^2,\nu).$$

Color Suppression Factor

$(1-y)$ dist.

$$\begin{pmatrix} F_3^{\nu N} \\ F_3^{\bar{\nu} N} \end{pmatrix} = (\text{Flavor Part only}).$$

Nonleading Kinematic Terms [illegible]
in Semi Asymp. R[illegible]

(7) As in eN, Nonleading Terms important for $\xi \lesssim 5$, Corresponds To

$|q^2| \lesssim 12 \text{ GeV}^2$ of gluon light $\longrightarrow$ ($m_V \sim 1.5$ GeV)

$\lesssim 80 \text{ GeV}^2 \longrightarrow$ ($m_V \sim 4.1$ GeV)

Use

$$\langle q^2 \rangle_\nu \sim \frac{1}{5} M E_\nu$$

$$\langle q^2 \rangle_{\bar\nu} \sim \left(\frac{1}{8} \text{ to } \frac{1}{10}\right) M E_{\bar\nu}$$

Thus, e.g. for the case of light gluons nonleading Terms important for

$$\boxed{\begin{array}{l} E_\nu \lesssim 60 \text{ GeV} \quad (\text{For } \nu N \to \mu X) \\ \text{and} \quad E_{\bar\nu} \lesssim 108 \text{ GeV} \quad (\text{For } \bar\nu N \to \bar\mu X) \end{array}}$$

$\Rightarrow$ For a given incident energy, the nonleading terms more important for $\bar\nu N$ ...

(8) Low x High y - Anomaly & $(\sigma_{\bar{\nu}}/\sigma_{\nu})$ etc.

For $|q^2| \lesssim 5\, m_U^2$, Color-gluon Contribution still significant especially at low x (with sea-like distrib of gluons).

$$\boxed{F_1^{\text{Col. gluons}} \longrightarrow y^2} \quad (\text{For } \nu \ \& \ \bar{\nu})$$

$$F_2^{\text{Col. gluons}} \longrightarrow (1-y) \quad (\text{For } \nu \ \& \ \bar{\nu})$$

$$F_{1,2}^{\text{Col. quarks}} \longrightarrow \frac{1}{4}\left\{1+(1-y)^2\right\} \Delta^2 \quad (\nu \ \& \ \bar{\nu})$$

$$d\sigma^{\nu}_{\text{flav}} \longrightarrow q(x) + (1-y)^2\, \bar{q}(x)$$

$$\boxed{d\sigma^{\bar{\nu}}_{\text{flav}} \longrightarrow q(x)(1-y)^2 + \bar{q}(x)}$$

Color Production Effects much more imp for $\bar{\nu}$ than ν especially at low x & High y.

The y^2-term superposed on $(1-y)^2$

can provide the nearly flat distrib.

for $\bar{\nu}$.

For ν the effect is not as important

relatively speaking

(i) Already dominant Flat y

(ii) $\langle q^2 \rangle_\nu \sim 2 \langle q^2 \rangle_{\bar{\nu}}$

For a given incident Energy.

Thus Color-Contrib has all the qualitative features to help understand the

(i) <u>Low x - high y Anomaly on the one hand (Also $\langle y \rangle_{\bar{\nu}}$ Threshold)</u>

and (ii) $\left(\sigma_{\bar{\nu}}/\sigma_\nu\right)_{c.c.} \to (0.4 \to .6)$

<u>Provided</u> we interprete these results as

<u>non asymptotic</u>

Asymptotically $(\xi \gg 1)$

$$\frac{(\sigma\bar{\nu})_{cc}}{(\sigma\nu)_{cc}} = \frac{\int_0^1 dx\, x\left[q(x) + 3\bar{q}(x) + \frac{1}{4}v(x)\right]}{\int_0^1 dx\, x\left[3q(x) + \bar{q}(x) + \frac{1}{4}v(x)\right]}$$

$\longrightarrow \approx 0.4$

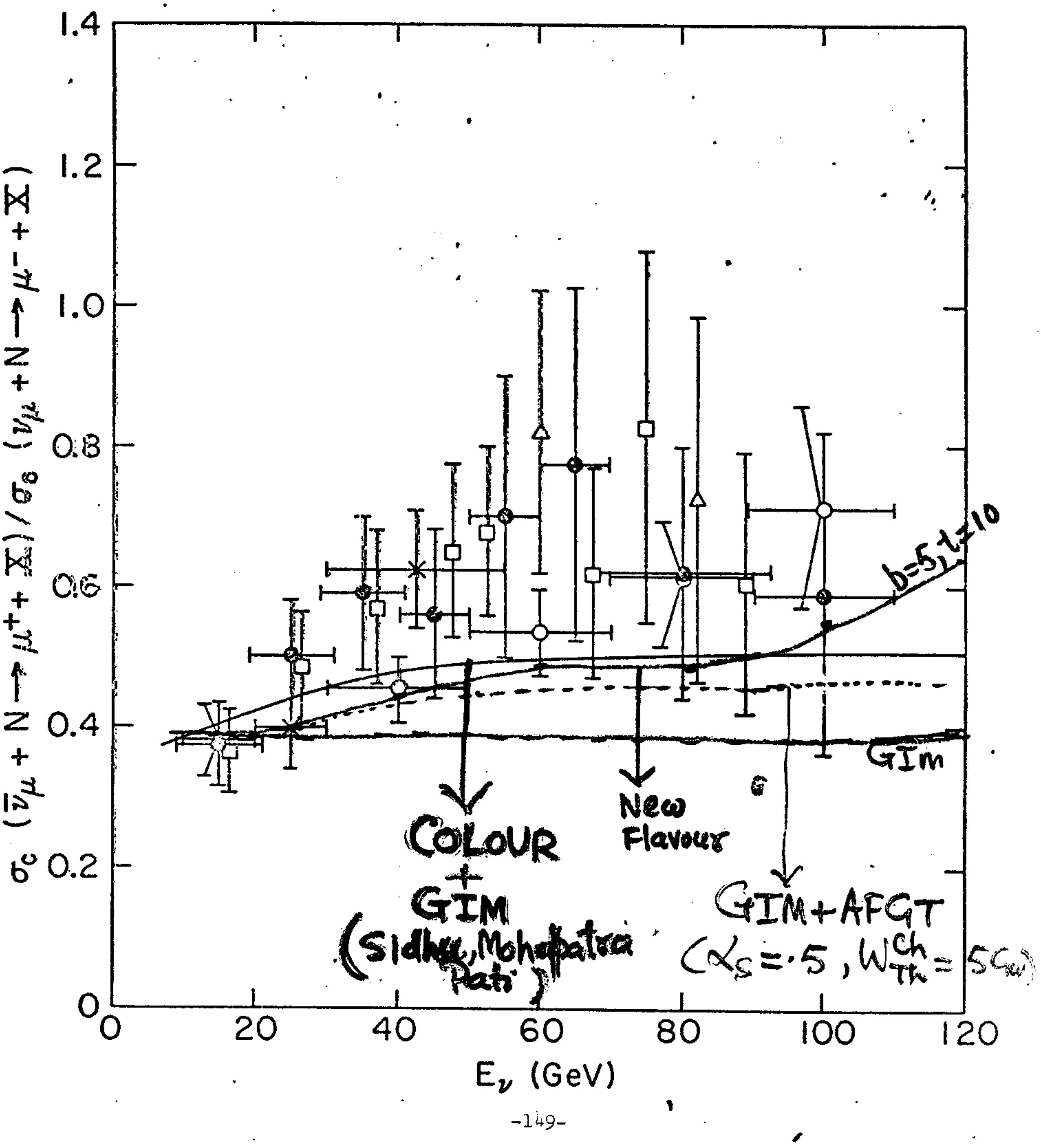
To Summarise

① Color and charm Contrib Can account For the New phenomena in Neutrino Physics ····> (Non Asymp.)

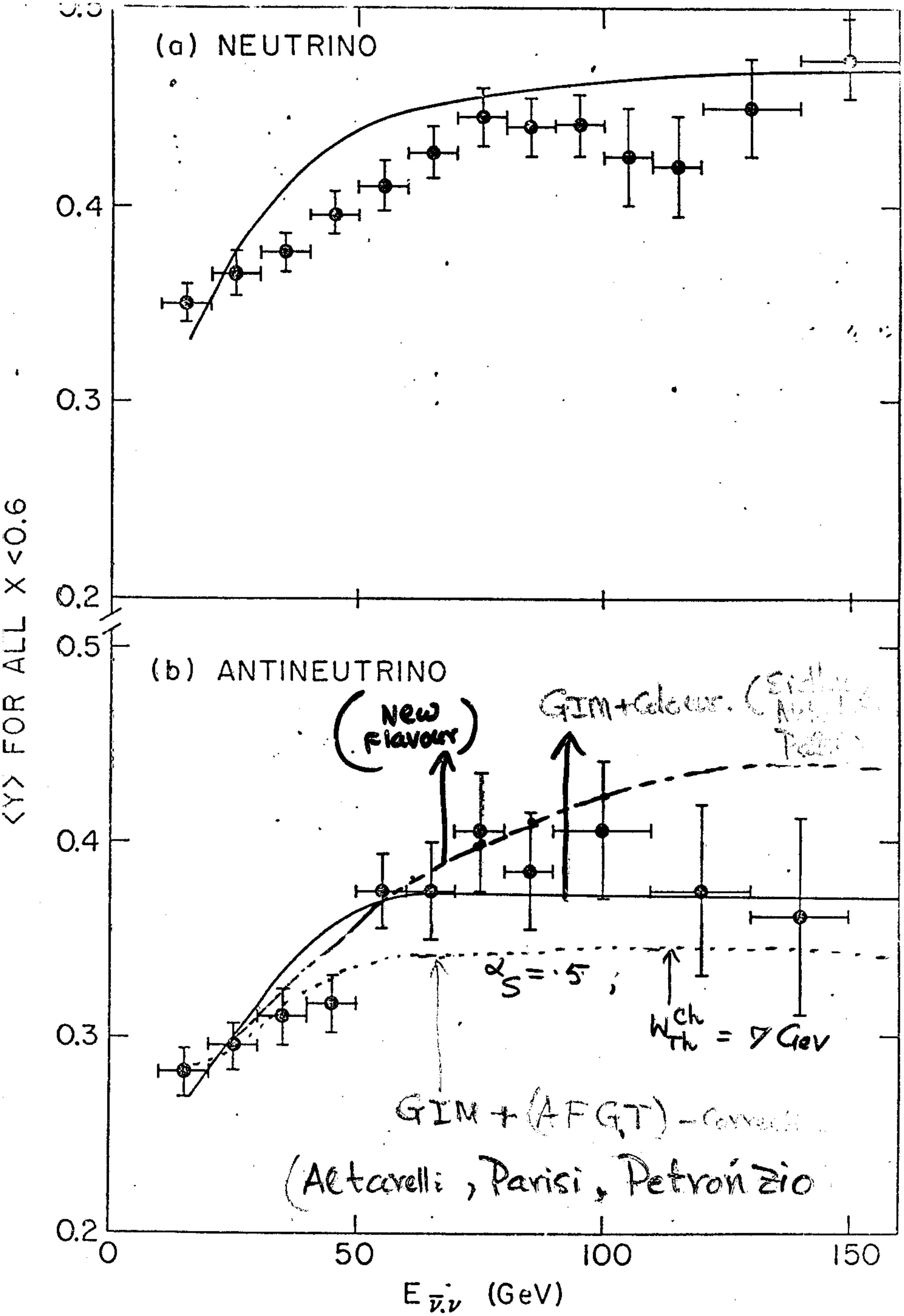
② Several Tests : (Predict)

(i) $(\sigma_L/\sigma_T) \longrightarrow f(x) \neq 0.$

(ii) Many of the New phenomena – low x high y-anomaly, $(\sigma_{\bar{\nu}}/\sigma_{\nu})_{cc}$ and Scaling viol are non-asymp. phenomena $\longrightarrow$ Will change trend at Energies higher still.



1.4
1.2
1.0
0.8
0.6
0.4
0.2
0
0
20
40
60
80
100
120
E_ν (GeV)
$\sigma_c\ (\bar{\nu}_\mu + N \rightarrow \mu^+ + X)/\sigma_c\ (\nu_\mu + N \rightarrow \mu^- + X)$
b=5, t=10
GIM
COLOUR
+
GIM
(Sidhu, Mohapatra
Pati)
New
Flavour
GIM+AFGT
(α_S = .5, W_{Th}^{Ch} = 5 Gev)



(a) NEUTRINO
(b) ANTINEUTRINO
⟨Y⟩ FOR ALL X <0.6
0.2
0.3
0.4
0.5
0
50
100
150
$E_{\bar{\nu},\nu}$ (GeV)
(New Flavour)
GIM+Colour.
$\alpha_S = .5$,
$W_{Th}^{Ch} = 7$ GeV
GIM + (AFGT) –
(Altarelli , Parisi , Petronzio

Quark Decays: (Let us Confine To The Basic Model)

$$W \left[\begin{array}{l} p^0_{red} \xrightarrow{X^0} \nu_e \\ n^-_{red} \longrightarrow e^- \end{array} \right. \qquad \begin{array}{l} p^+_{y,b} \xrightarrow{X^+, X'^+} \nu_e \\ n^0_{y,b} \longrightarrow e^- \end{array}$$

$$W \left[\begin{array}{l} \lambda^-_{red} \longrightarrow \mu^- \\ c^0_{red} \longrightarrow \nu_\mu \end{array} \right. \qquad \begin{array}{l} \lambda^0_{y,b} \longrightarrow \mu^- \\ c^+_{y,b} \longrightarrow \nu_\mu \end{array}$$

(X^+, X'^+) MIX WITH W^+

BUT X^0 CAN NOT MIX WITH W^0 (GROUP PROP OF BASIC MODEL)

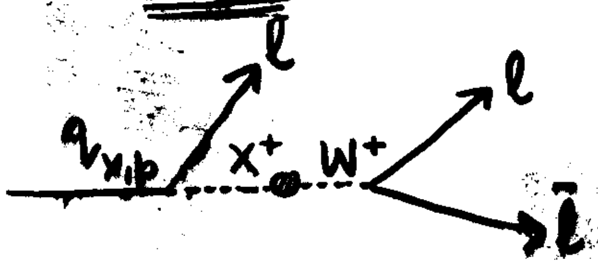
$\Rightarrow$ Yellow & Blue Quarks Decay Very DIFFERENTLY THAN THE RED.

$\boxed{\text{RED IS VERY SPECIAL}}$

3 Mechanisms For Yellow & Blue Quark Decays:

(P, S & Sakakibara)

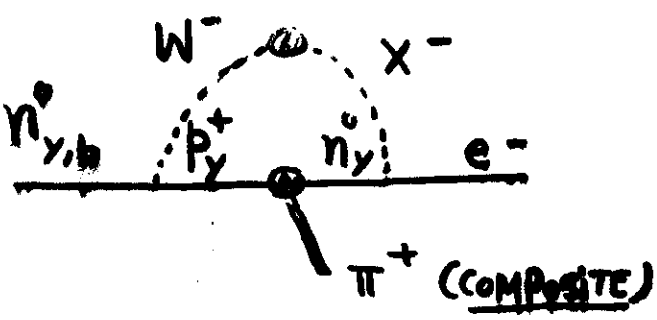
Fig. 1



$O(\Delta^2/m_X^2\, m_W^2)$

$$\begin{cases} p^+_{y,b} \to \nu_e + (e^+ \nu_e) \\ n^0_{y,b} \to e^- + (e^+ + \nu_e) \\ \qquad \to e^- + (\mu^+ \nu_e) \\ \lambda^0_{y,b} \to \mu^- + (e^+ + \nu_e) \end{cases}$$

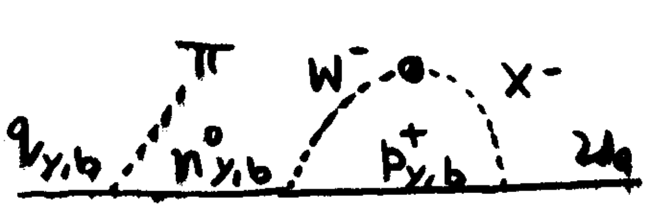
Fig. 2



$O(\Delta^2/m_X^2)(m_q^2/m_W^2)$

$$\begin{cases} p^+_{y,b} \to e^- + \pi^+ + \pi^+ \\ n^0_{y,b} \to e^- \pi^+ \\ \lambda^0_{y,b} \to \overline{K^0} + e^- + \pi^+ \end{cases}$$

Fig. 3



$O(\Delta^2/m_X^2)$

~ Fig 2

$$\begin{cases} p^+_{y,b} \to \nu_e + (\pi, K, \eta) \\ n^0_{y,b} \to \nu_e + (\pi, K, \eta) \\ \lambda^0_{y,b} \to \nu_\mu + \eta \,;\, \nu_e + \overline{K^0} \\ C^+_{y,b} \to \nu_e D^+, \nu_\mu F^+ \quad (?) \\ \qquad \to \lambda_{y,b} + \pi^+ \\ \qquad \to p^+_{y,b} + \pi \end{cases}$$

In Summary:

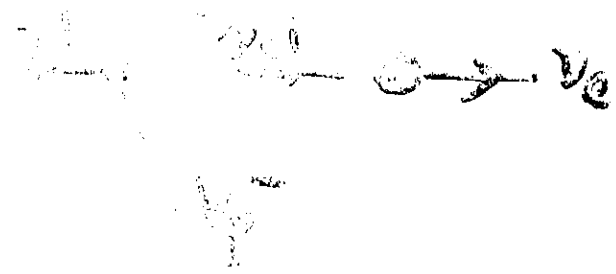
$$\boxed{\begin{aligned} q_{\text{yellow, blue}} &\longrightarrow \text{NEUTRINO} + \underset{(\pi, K, \eta, \cdots)}{\text{Mesons}} \\ &\not\longrightarrow (e^{\pm} \text{ or } \mu^{\pm}) + \cdots \end{aligned}}$$

$$\boxed{\tau_{\text{yel, blue}} \sim 10^{-11} \text{ to } 10^{-12} \text{ sec}} \quad (m_q \sim 2\,\text{GeV})$$

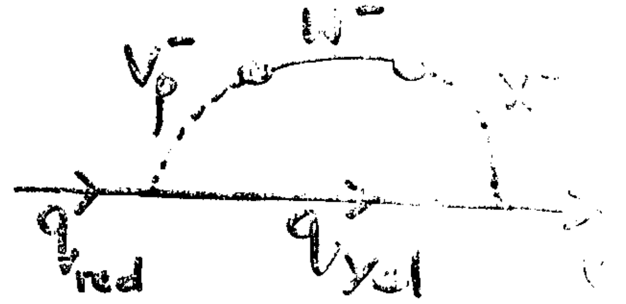
(Basic Model).

Red. Quarks

$m_q > m_{gluon}$



$m_q < m_{gluon}$



suppressed rate

unless consider Ext. Symm.

or $m_{red} - m_{yel} > m_\pi$

For the Case $m_q > m_{gluon}$

$\boxed{p^0_{red} \to n^0_{yel} + \gamma}$; $V_\rho^- + \pi^+ + \nu_e$

$n_{red} \to V_\rho^- + \nu_e$; $V_\rho^- + \pi^+ \pi^- + \nu_e$

$\lambda^-_{red} \to V_\rho^- + \nu_{\mu}$; $V_\rho^- +$ Mesons $+$

$\boxed{\lambda_{red} \to \lambda^0_y + \gamma}$; $p^0_r + \pi^-$, λ_{red}

$$\boxed{\tau_{red,\,yel,\,blue} \sim 10^{-11} \text{ to } 10^{-12} \text{ sec } (m_q \sim 2 \text{ GeV})}$$

$$e^- e^+ \to q\bar{q} \;\; ; \;\; V_\rho^+ V_\rho^-, \; V_{K^*}^+ V_{K^*}^-$$

<u>Real</u> Pairs.

<u>SPEAR $\bar{\mu}e$- events:</u>

$$e^-e^+ \to n^-_{real} + n^+_{real}$$

$$n^+_{real} \to V_\rho^+ + \bar{\nu}_e \leftarrow \text{(Real 2 body)}$$

$$n^-_{real} \to \cdots \nu_e, \qquad \to e^- \bar{\nu}_e$$

$$V_\rho^+ \to \mu^+ \nu_\mu$$

Somewhat like 3 body leptonic decay.

$$R(n_r^- n_r^+)_{real} + R(\lambda_r^- \lambda_r^+)_{Real}$$

$$= (2/9)\, |f_{qq\gamma}(s)|^2 \quad \text{quark e.m. form fact.}$$

$$R(\mu^+ e^-)_{q\bar{q}} = (2/9)\, \rho(s) \left(\tfrac{1}{3} \text{ to } 1/4\right)^2$$

$$\approx \rho(s)\,(1.6 \text{ to } 2.5)\,\%$$

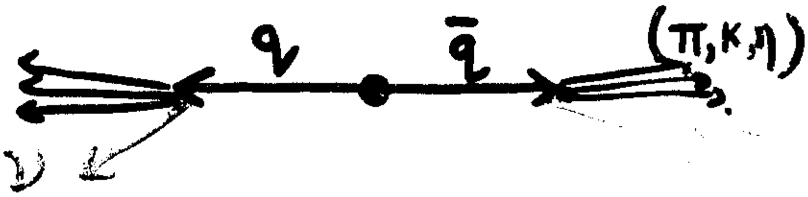
$$R(\mu^+ e^-)_{V\bar{V}} = \rho(s)\,(.8 \text{ to } 1.4)\,\%$$

$R(\mu^+ e^-)_{\text{observed}} \sim (1 \text{ to } 2)\%$ (correcting for Mom. Cut & Solid angle)

$\Rightarrow$ Quark-hypoth. Can explain the signal <u>if</u>

$$\rho(s) = |f_{q\bar{q}\gamma}(s)|^2 \sim \left(\tfrac{1}{2} \text{ to } 1\right)$$ Hard or Point like Form Factor at SPEAR energies.

<u>PREDICT</u>:

(1) <u>JET STRUCTURE</u>: 

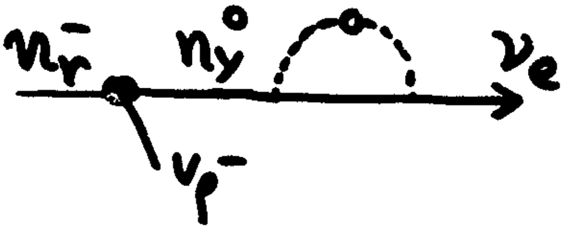
A Large Part of Had. c.s. is due to Real $q\bar{q}$-Pair Prod.

$$\frac{\text{Ch. Jets}}{\text{Neutral Jets}} \rightarrow \frac{3}{1}$$

(2) <u>Missing Energy & Momentum Carried away by Neutrinos</u>

Depletion of charged energy

(3) V+A - Eff. Coupling



$$\left[\bar{\nu}_e \gamma_\mu (1-\gamma_5) n_r^- \right] V^+_{\rho\mu}$$

(4) PARTIAL OR TOTAL Nonappearance of D & F in e^-e^+-annihilation

$$R\,(\chi\bar{\chi})_{Real} = (4/3)\,\rho(s)$$

$\chi \to \lambda + \pi$ rather than $(\nu + D)$ & $(\nu + F)$ If D & F Heavy.

$\lambda \to \nu +$ (Known mesons)

(5) [illegible] signals

$$e^-e^+ \to n_r^- + n_r^+$$

$n_r^- \to V_\rho^- \nu_e$, $V_\rho^- \to \pi^+\pi^- e^- \bar{\nu}_e$

$n_r^+ \to V_\rho^+ \bar{\nu}_e$, $V_\rho^+ \to \mu^+ + \nu_\mu$

$e^-e^+ \to (\pi^+\pi^- \mu^+ e^-) +$ [illegible]

Such semileptonic signal can not come from heavy lepton L^+L^- decays

Charmed Particles $D\bar{D}$, $F\bar{F}$ will give semileptonic signals, but preferentially involving K.

6 Neutral Quark-Pair Prod.

$$\sigma(e^-e^+ \to q_i\bar{q}_i) = \left| Q_{flav}(q_i) + \left(\frac{m_U^2}{q^2-m_U^2}\right) Q_{col}(q_i) \right|^2$$

$$\to Q^2_{flav}(q_i)$$

e.g. $\left.\begin{array}{l} \sigma(e^-e^+ \to P^0_{red}\bar{P}^0_{red}) \\ \text{or} \\ \sigma(e^-e^+ \to C^0_{red}\bar{C}^0_{red}) \end{array}\right\} = 4\,\sigma(e^-e^+ \to n^-_r n^+_r)$

$\boxed{P^0_r \to n^0_y + \gamma}$ $(m_{P_r} - m_{n_y} \gtrsim 10\,\text{GeV}$

↓

Low Energy "Mono Energetic γ-Ray (10 to 100 MeV).

(7) Inclusive Muon Prodn Expt. (Maryland-Pavia, Princeton) expt.

Snow Test:

$$e^- e^+ \to U^+ + U^-$$

$U^+ \to \mu + \ldots$, $U^- \to n_{ch} + \ldots$

$$\frac{U \to n_{ch} \gtrsim 3}{U \to n_{ch} = 1} < .33$$

Snow used this test to eliminate Charmed particles as the major source of (μe)..

For quark and gluon decays

$$V_\rho^+ \to \pi^+\pi^0,\ K^+K^0,\ \pi^+\pi^0\pi^0,\ \pi^+\pi^+\pi^-,\ 4\pi,\ 5\pi \quad \Big\}\ \text{Total} \approx 30\%$$

$$\boxed{\frac{V \to n_{ch} \geqslant 3}{V \to n_{ch} = 1} \lesssim 20\ \%}$$

Summary

(1) Quark-decays can be source of (μe) events only provided there exist a nearly degenerate octet of Colored Vector mesons lighter than 1.8 GeV.

(Pati, Sucher & Woo) Consistency

SEARCH FOR

$e^-e^+ \longrightarrow \tilde{U}$ (Narrow Prominent Peak like ψ') $\rightarrow$ FRASCATI

$$\gamma + p \longrightarrow \tilde{U} + \text{Hadrons}, \quad \tilde{U} \to e^-e^+, \mu^-\mu^+ \qquad \frac{\sigma(\gamma \to \tilde{U} \to e^-e^+)}{\sigma(\gamma \to \rho \to e^-e^+)} \sim \left(\frac{1}{500} \text{ to } \frac{1}{20}\right)$$

(2) Search for ch. gluons (Distinct Signatures)

$$\left.\begin{aligned} \mu^- + p &\rightarrow \mu^- + \text{Had} + \tilde{U} \\ &\rightarrow \mu^- + \text{Had} + V_\rho^+ + V_\rho^- \end{aligned}\right\} \text{Net } 10 \sim 20\% \text{ c.s.}$$

$V_\rho^+ \to \mu^+\nu$, $V_\rho^- \to \mu^-\bar{\nu}$

STUDY TRIMUONS $\rightarrow$ Emulsions

$\mu^-\mu^+\mu^-$

(3) SEARCH FOR QUARKS:

(i) Study Semileptonic (μe)-Signals

(ii) Emulsions.

PROTON - DECAY

$$\text{Proton} = (q_{red}\, q_{yel}\, q_{bl}) \dashrightarrow F = B + L = 3$$

$$\left.\begin{aligned} \text{Proton} &\rightarrow 3\nu + \text{Mesons} \\ &\rightarrow 3\nu + (e^- + \bar{\nu}_e) + \text{Mesons} \\ &\rightarrow 3\nu + (\mu^- + \bar{\nu}_\mu) + \text{Mesons} \end{aligned}\right\} \text{Basic Model}$$

$$\tau(\text{proton}) \sim (10^{29} \text{ to } 10^{32}) \text{ Years}$$

$$\text{For } \tau(\text{quark}) \sim 10^{-11} \text{ to } 10^{-12} \text{ Sec.} \quad m_q \sim 2\,\text{GeV}$$

Note PROTON LIFE TIME CONSTRAINED

WITHIN THE HYPOTH. OF UNCONF. QUARKS

(2) SOURCES OF MULTILEPTONS :

(i) charm - Production - Conventional

(ii) Color - Production

(iii) quark - Production $\longrightarrow$ leptons
($\Delta B \neq 0$, $\Delta L \neq 0$)

Conventional Mechanisms:

$\nu_\mu + N \longrightarrow \mu^- + D + X$ (Charm Prod n $\approx 10\,\%$) (A)
$\quad\quad D \to \mu^+$ or e^+

$\longrightarrow \mu^- + V^+_{color} + X$ (Color Prodn $\approx$ 10 to 15 %) (B)
$\quad\quad V^+_{color} \to \mu^+ \nu$

- -

$\longrightarrow \mu^- + D + \bar{D} + X$ (C)
$\quad D \to (\ell^+$ or Had$)$, $\bar{D} \to (\ell^-$ or Had$)$

$\longrightarrow \mu^- + \xi^+ + V^- + X$ (D)

$\longrightarrow \mu^- + q_R^- + q_R^+ + X$ (E)
$\quad q_R^- \to \ell^- \bar{\nu} \nu$ or (Had $+ \nu$)
$\quad q_R^+ \to \ell^+ \bar{\nu} \nu$ or (Had $+ \bar{\nu}$)

Expect Ⓐ, Ⓑ dominate

νN: $\langle E_{\mu^-} \rangle \gg \langle E_{\mu^+} \rangle$

large Inelasticity

$$\frac{\sigma(\mu^-\mu^+)_{\text{charm}}}{\sigma(\mu^-)} = (\text{Prod.}) \times (\text{B.R.})$$

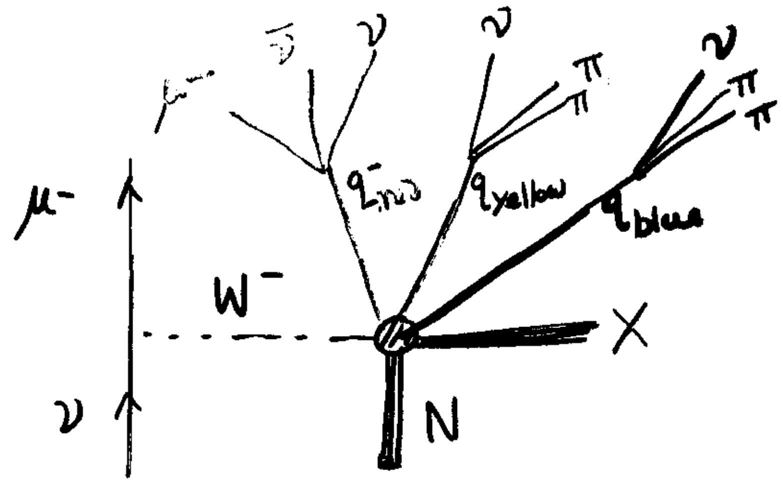
$$\approx (10\ \%) \times (5 \text{ to } 10)\%$$

$$\approx (\tfrac{1}{2} \text{ to } 1)\ \%.$$

$$\frac{\sigma(\mu^-\mu^+)_{\text{Color}}}{\sigma(\mu^-)} = \text{Prod.} \times \text{B.R.}$$

$$= (10 \text{ to } 15)\% \times (20 \text{ to } 30)\%$$

$$\approx (2 \text{ to } 4)\ \%$$



Dissociation of Nucleon In DEEP INELASTIC REGION INTO 3 QUARKS

$$\nu + N \to \mu^- + \mu^- + X$$

$$\nu + N \to \mu^- + (\underset{\hookrightarrow \mu^- \bar{\nu}}{q_{red}} + \underset{\hookrightarrow \nu\pi}{q_{yel}} + \underset{\hookrightarrow \nu\pi}{q_{blue}}) + X$$

From the obs. rate of like sign Dimuons being $\approx (1/1000)$, we would conclude that

$$\left.\frac{d\sigma\,(\nu N \to \mu^- + (q + q + q) + X)}{d\sigma\,(\nu N \to \mu^- + X)}\right|_{\text{deep inelastic}} \approx \frac{1}{1000}$$

MANY TESTS :

(i) Since μ^+ is AntiFermion, Same Mechanism not available for $(\mu^+\mu^+)$ Produ by $\bar{\nu}$.

$\therefore$ Expect $\boxed{(\bar{\nu} N \to \mu^+\mu^+ + X) \ll \nu N \to (\mu^-\mu^- + X)}$

$\mu^+\mu^+$ signal may still come from $q\bar{q}$-Produ.

or From Assoc. Prod. of Charmed Particles.

Unconventional: (Nucleon-Dissociation)

$$\nu + \text{neutron} \rightarrow \mu^- + (q_R^- + q_y^0 + q_b^+)$$

$$q_R^- \rightarrow \mu^- \bar{\nu} \nu \qquad q_y^0 \rightarrow \nu + \pi \qquad q_b^+ \rightarrow \nu + \pi$$

$$\Rightarrow \mu^- \mu^-$$

Obs. Rate $\Rightarrow \dfrac{d\sigma\,(\text{dissoc.})_{\text{deep Inel}}}{d\sigma\,(\text{non dissoc.})} \sim 10^{-3}$

TESTS:

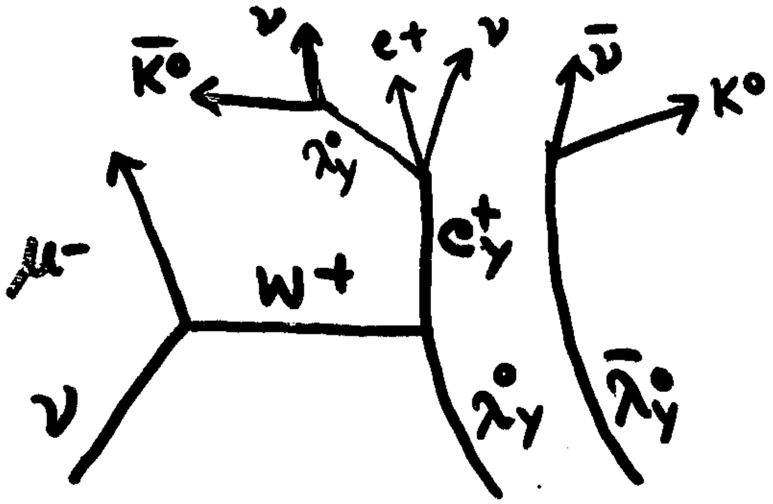
1) $$\boxed{\sigma^{\bar{\nu}}(\mu^+\mu^+)_{\text{Dissoc.}} = 0}$$

Compare $\dfrac{\sigma(\bar{\nu} \rightarrow \mu^+\mu^+)}{\sigma(\nu \rightarrow \mu^-\mu^-)}$

Pair Prodn $\Rightarrow (\frac{1}{3} \text{ to } 3)$

$$\boxed{\frac{\nu + N \rightarrow \mu^-\mu^- X}{\nu + N \rightarrow \mu^- X} \approx \frac{\nu + n \ (\text{from} \rightarrow \mu^-\mu^- X)}{\nu + \text{neutron} \rightarrow \mu^- + X}}$$

⑨ $\mu^- e^+ K$ - Events



$$\lambda^0_{y,b} \longrightarrow \nu + \bar{K}^0$$

$$\lambda^-_{red} \longrightarrow \mu^- + \nu + \bar{\nu} \quad (2\text{ step})$$

$$\text{or} \rightarrow e^- \nu \bar{\nu} \quad (2\text{ step}).$$

$$\boxed{\frac{C_y^+ \rightarrow \lambda e^+ \nu}{C_y^+ \rightarrow \text{All}} \sim \frac{1}{10}} \times (10\ \%\ \text{Sm})$$

(Nearly right)
from Apriori
Calculation of $\frac{C \rightarrow \lambda e \nu}{C \rightarrow \lambda \pi}$.

N+N - Collision - Dissociation

$$N + N \rightarrow \bar{q}_R + q_y + q_B + N$$

$\hookrightarrow e^-$ or μ^- (but not e^+ or μ^+ in basic model)

$$\Rightarrow \boxed{\frac{\ell^-}{\ell^+} \neq 1}$$

CLEAREST TESTS

1. $(\sigma_L/\sigma_T) = f(x) \neq 0$

2. Scale Viol ; $F_i \rightarrow$ Fall to Scale Inv. Values

3. $(\sigma_{\bar{\nu}}/\sigma_\nu)$, $\langle y\rangle_{\bar{\nu}}$ $\longrightarrow$ Fall

   $\hookrightarrow .4$ for $E_{\bar{\nu}} > 200$ GeV
   If Light gluon.

4. a) $e^- e^+ \longrightarrow \mu e + \pi\pi$

   b) missing energy

5. $\sigma(\nu N \rightarrow \mu^- \mu^-) / \sigma(\bar{\nu} N \rightarrow \mu^+ \mu^+)$

6. Search Narrow Light Gluons $\tilde{U}^0$

   (1 to 2 GeV)

   $\boxed{\text{Frascati , Orsay}}$, Novosibirsk,

   (Desy $\rightarrow$ Photo Production)