

Modelo dos partões :

4

Factores de forma na difusão elástica electrão-quark,
descrita no referencial de momento infinito (CM):



$$\begin{cases} F_1^i(x, Q^2, \xi) = \frac{1}{2} e_i^2 \delta(\xi - x) \\ F_2^i(x, Q^2, \xi) = e_i^2 \xi \delta(\xi - x) \end{cases} \quad \xi = x$$

$q^i(\xi) d\xi$ = número de partões com p/P compreendido
entre ξ e $\xi + d\xi$

$$F_1(x, Q^2) = \sum_i \int F_1^i(x, Q^2, \xi) q^i(\xi) d\xi = \frac{1}{2} \sum_i e_i^2 q^i(x)$$

$$F_2(x, Q^2) = \sum_i \int F_2^i(x, Q^2, \xi) q^i(\xi) d\xi = x \sum_i e_i^2 q^i(x)$$

Relação de Callan-Gross: $F_2^{eN}(x) = 2x F_1^{eN}(x)$

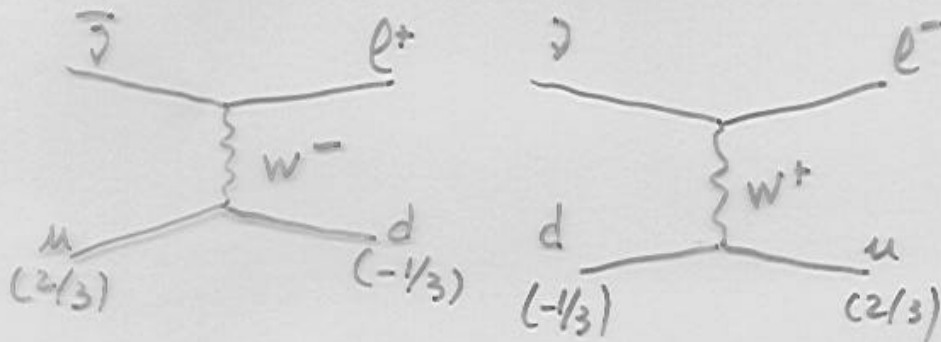
Neutrinos:

$$F_1^{\nu, \bar{\nu}}(x) = \frac{1}{2} \sum_i q_i(x) (\lambda_V^2 + \lambda_A^2)_i$$

$$F_2^{\nu, \bar{\nu}}(x) = x \sum_i q_i(x) (\lambda_V^2 + \lambda_A^2)_i$$

$$F_3^{\nu, \bar{\nu}}(x) = 2 \sum_i q_i(x) (\lambda_V \lambda_A)_i$$

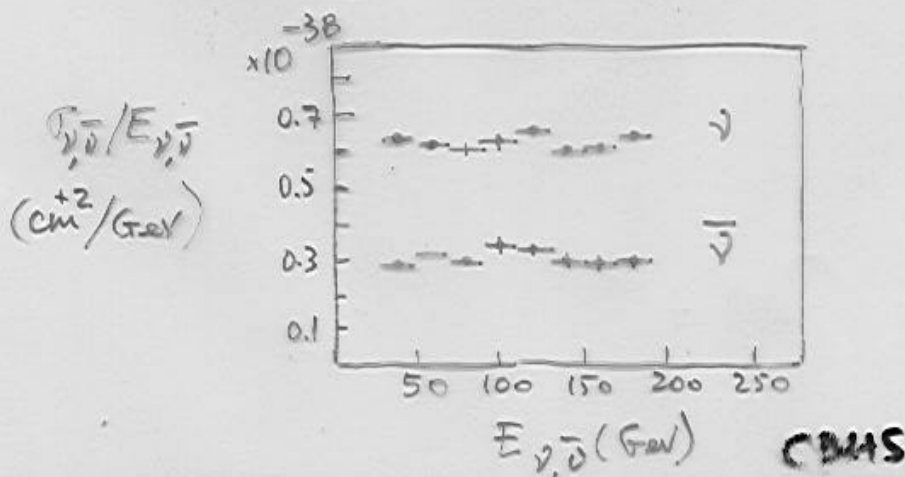
As distribuições $q_i(x)$ intervenientes dependem da partícula incidente (neutrino ou antineutrino):



Secção eficaz:

$$\frac{d^2 \sigma^{\nu, \bar{\nu}}}{dx dy} = \frac{G^2 m_N E}{\pi} \underbrace{\left(\frac{M^2}{M^2 + Q^2} \right)}_{\approx 1} \left[xy^2 F_1^{\nu, \bar{\nu}}(x) + (1-y) F_2^{\nu, \bar{\nu}}(x) \pm \left(y - \frac{y^2}{2} \right) x F_3^{\nu, \bar{\nu}}(x) \right]$$

→ dependência linear na energia incidente E ($Q^2 \ll M^2$)



Define-se:

$$A^{j, \bar{j}}(x) = \left(\frac{2x F_1(x)}{F_2(x)} \right)^{j, \bar{j}} ; \quad B^{j, \bar{j}}(x) = \left(\frac{x F_3(x)}{F_2(x)} \right)^{j, \bar{j}}$$

obtem-se:

$$\frac{d^2 \sigma^{j, \bar{j}}}{dx dy} = \frac{G^2 m_N E}{\pi} F_2^{j, \bar{j}}(x) \left[(1-y) + \frac{1}{2} y^2 A^{j, \bar{j}}(x) \pm (y - \frac{1}{2} y^2) B^{j, \bar{j}}(x) \right]$$

$$\frac{d^2 \sigma^{j, \bar{j}}}{dx} = \frac{G^2 m_N E}{\pi} F_2^{j, \bar{j}}(x) \left[\frac{1}{2} + \frac{1}{6} A^{j, \bar{j}}(x) \pm \frac{1}{3} B^{j, \bar{j}}(x) \right]$$

- modelo dos partões: $A^{j, \bar{j}} = 1$
- acoplamento V-A dos partões a W^+, W^- : $\lambda_V = \lambda_A = 1 \rightarrow B^{j, \bar{j}}(x) = 1$

donde: $\frac{d\sigma^{j, \bar{j}}}{dx} = \frac{G^2 m_N E}{\pi} F_2^{j, \bar{j}}(x) \left(\frac{2}{3} \pm \frac{1}{3} \right)$

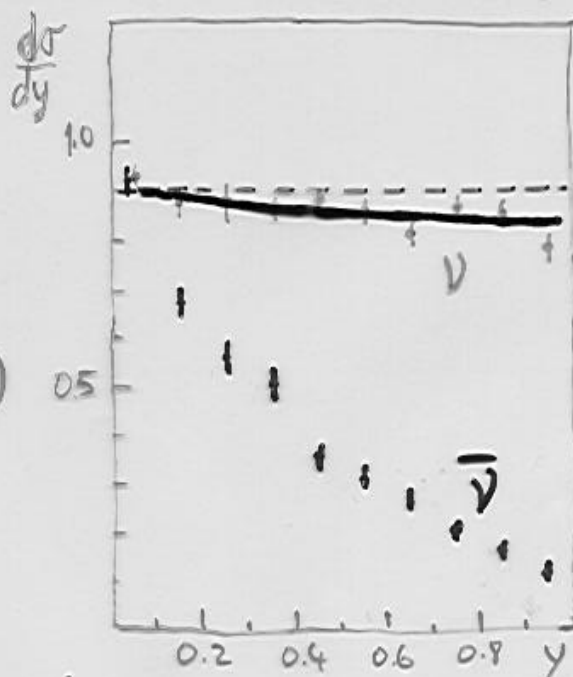
alvo isoscalar ($N=Z$): $F_2^{j, \bar{j}}(x) = F_2^{j, \bar{j}, N}(x)$

$$\Rightarrow \frac{\sigma_{cc}^{j, \bar{j}, N}}{\sigma_{cc}^{j, \bar{j}, N}} = \frac{1}{3} \quad \text{exp: } 0.48 \pm 0.03$$

Se $B^{j, \bar{j}}(x) = 1$:

$$\frac{d^2 \sigma^j}{dx dy} = \frac{G^2 m_N E}{\pi} F_2^j(x)$$

$$\frac{d^2 \sigma^{\bar{j}}}{dx dy} = \frac{G^2 m_N E}{\pi} F_2^{\bar{j}}(x) (1-y^2)$$



há anti-partões no interior dos núcleões!

Acoplamento ao W^\pm :

partões : $\lambda_V = \lambda_A = 1$ $q_i(x)$

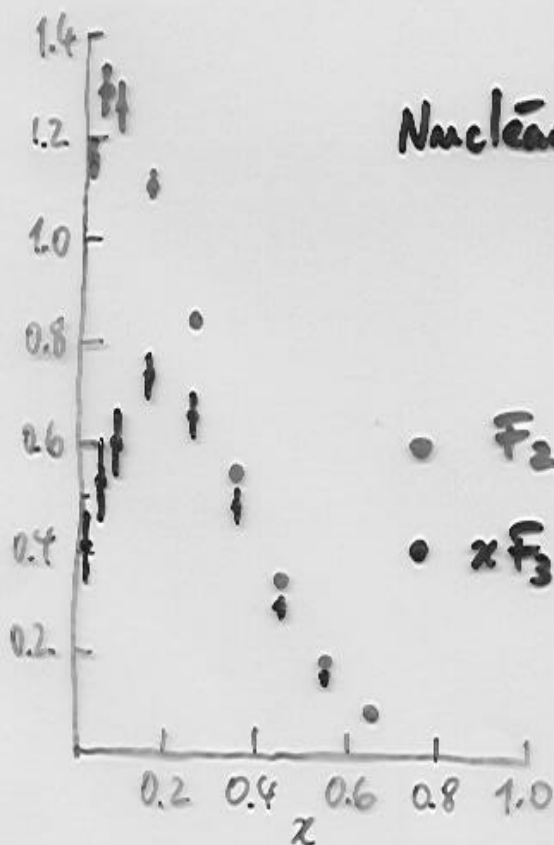
antipartões : $\lambda_V = -\lambda_A = 1$ $\bar{q}_i(x)$

$$F_1^{p,\bar{p}}(x) = \sum_i [q_i(x) + \bar{q}_i(x)]$$

$$F_2^{p,\bar{p}}(x) = 2x \sum_i [q_i(x) + \bar{q}_i(x)]$$

$$F_3^{p,\bar{p}}(x) = 2 \sum_i [q_i(x) - \bar{q}_i(x)]$$

donde : $B^{p,\bar{p}}(x) = \left(\frac{x F_3(x)}{F_2(x)} \right)^{p,\bar{p}} = \frac{\sum_i [q_i(x) - \bar{q}_i(x)]}{\sum_i [q_i(x) + \bar{q}_i(x)]} \neq 1$



Núcleo \equiv quarks de valência +
+ pares quark-antiquark
(mar)

• $F_2 \equiv$ valência + mar

• $x F_3 \equiv$ valência

$$\langle x \rangle_{val} \approx 0.3$$

Partões \equiv quarks

$$\rightarrow \lim_{x \rightarrow 0} F_2^{\nu}(x) \neq 0$$

$$\rightarrow \int_0^1 \frac{\bar{F}_2^{\nu}(x)}{x} dx = n^{\circ} \text{ de quarks} + n^{\circ} \text{ de antiquarks} \\ = \infty$$

\downarrow
 n° infinito de pares quark-antiquark a $x \rightarrow 0$.

• "Ver" os quarks de valência:

$$\int_0^1 \frac{dx}{x} (F_2^{ep} - F_2^{en}) = \left(\sum_{\text{val}} e_i^2 \right)_p - \left(\sum_{\text{val}} e_i^2 \right)_n$$

(mar no próton = mar no neutrão)

$$= \left(\frac{4}{9} + \frac{4}{9} + \frac{1}{9} \right) - \left(\frac{4}{9} + \frac{1}{9} + \frac{1}{9} \right) = \frac{1}{3} \quad \text{exp: } 0.28 \pm 0.06$$

u u d u d d

Distribuições de quarks - antiquarks:

$$u(x), d(x), s(x), c(x) \dots$$

$$\bar{u}(x), \bar{d}(x), \bar{s}(x), \bar{c}(x) \dots$$

Normalização:

$$\text{Protão: } \int_0^1 dx [u(x) - \bar{u}(x)] = 2 ; \int_0^1 dx [d(x) - \bar{d}(x)] = 1 ; \int_0^1 dx [s(x) - \bar{s}(x)] = 0$$

Função de estrutura eletromagnéticas:

Protão:

$$\rightarrow F_2^{ep}(x) = x \sum_i e_i^2 [q_i(x) + \bar{q}_i(x)] =$$

$$= x \left\{ \frac{4}{9} [u(x) + \bar{u}(x) + c(x) + \bar{c}(x) + \dots] \right.$$

$$\left. + \frac{1}{9} [d(x) + \bar{d}(x) + s(x) + \bar{s}(x) + \dots] \right\}$$

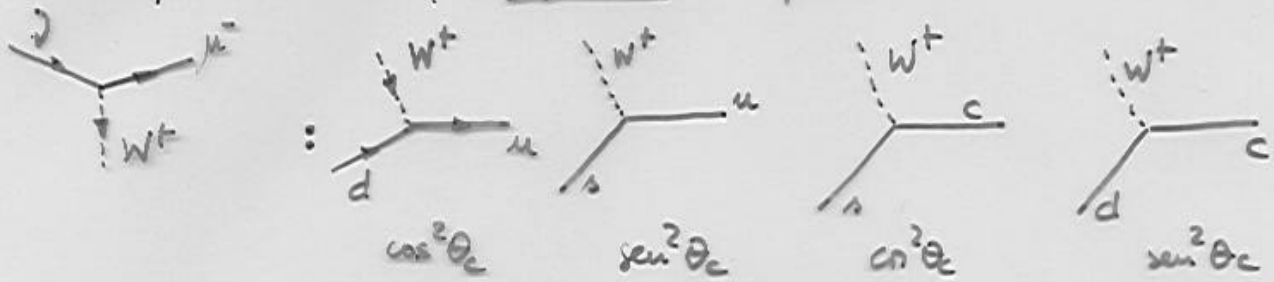
Neutrão:

$$\text{Invariância de isospin: } \begin{cases} u_p(x) = d_n(x) \\ d_p(x) = u_n(x) \end{cases}$$

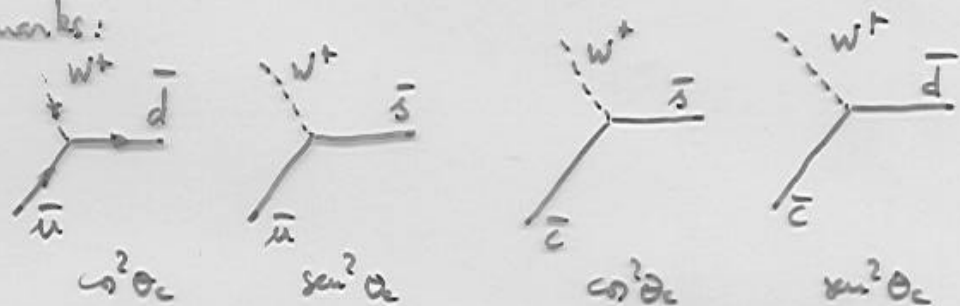
$$F_2^{en}(x) = x \left\{ \frac{4}{9} [d(x) + \bar{d}(x) + c(x) + \bar{c}(x) + \dots] + \frac{1}{9} [u(x) + \bar{u}(x) + s(x) + \bar{s}(x) + \dots] \right\}$$

Funções de estrutura com neutrinos (correntes carregadas):

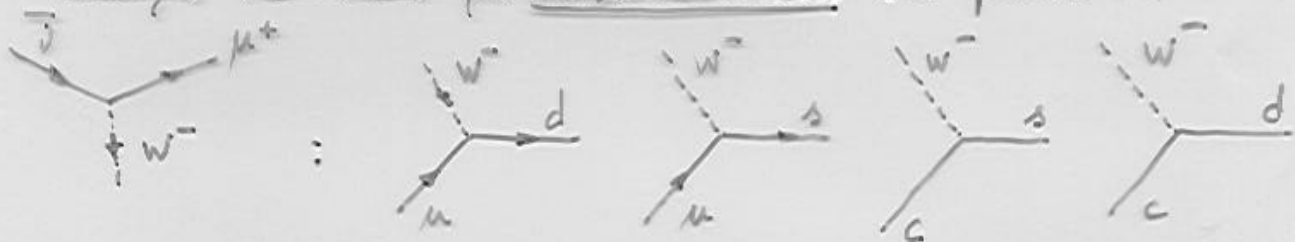
Reações induzidas por neutrinos em quarks:



e em antiquarks:



Reações induzidas por anti-neutrinos em quarks:



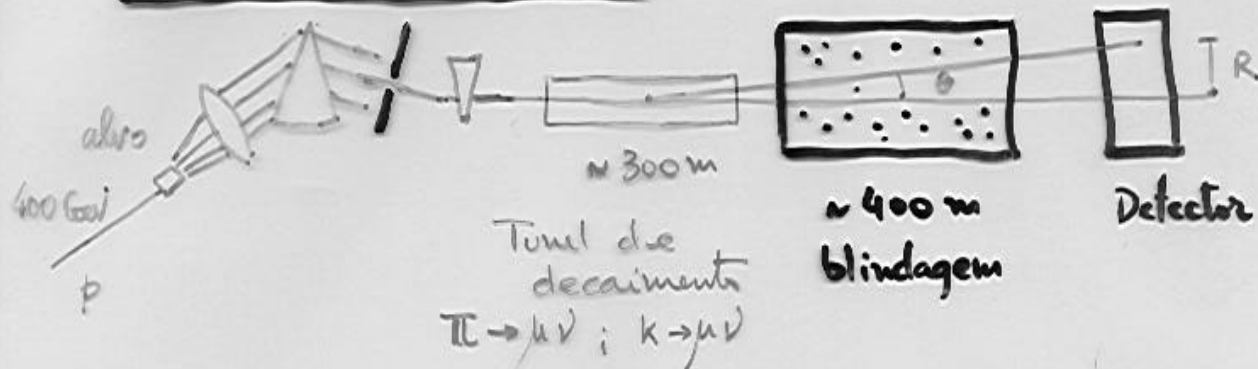
$$\rightarrow \begin{pmatrix} u \\ d \cos \theta_c + s \sin \theta_c \end{pmatrix} ; \begin{pmatrix} c \\ d \cos \theta_c - s \sin \theta_c \end{pmatrix}$$

$$F_1^{\nu p} = \cos^2 \theta_c [d(x) + \bar{u}(x) + s(x) + \bar{c}(x)] + \sin^2 \theta_c [s(x) + \bar{c}(x) + \bar{u}(x) + d(x)] = d(x) + s(x) + \bar{u}(x) + \bar{c}(x) = F_2^{\nu p} / 2x$$

$$F_3^{\nu p} = 2 \cos^2 \theta_c [d(x) - \bar{u}(x) + s(x) - \bar{c}(x)] + 2 \sin^2 \theta_c [s(x) - \bar{c}(x) - \bar{u}(x) + d(x)] = 2 [d(x) + s(x) - \bar{u}(x) - \bar{c}(x)]$$

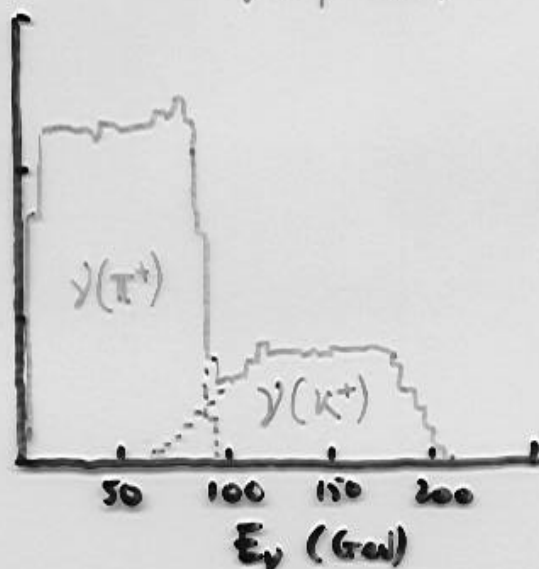
$$\left\{ \begin{array}{l} F_i^{\nu n} \leftrightarrow F_i^{\nu p} : d(x) \leftrightarrow u(x) ; \bar{d}(x) \leftrightarrow \bar{u}(x) \\ F_{1,2}^{\bar{\nu} N} \leftrightarrow F_{1,2}^{\nu N} : q_i(x) \leftrightarrow \bar{q}_i(x) \\ F_3^{\bar{\nu} N} \leftrightarrow F_3^{\nu N} : q_i(x) \leftrightarrow -\bar{q}_i(x) \end{array} \right.$$

Feixes de neutrinos



No referencial do hadrão: E_0, θ_0 (isotrópico)

No Laboratório: $E = \frac{E_0}{\gamma(1-\beta \cos \theta)}$ $\gamma = \frac{E_{had}}{m_{had}}$



Regras de soma:

$$\int_0^1 dx \left[F_1^{\bar{\nu}p} - \bar{F}_1^{\nu p} \right] = \int_0^1 dx \left[-d(x) + \bar{d}(x) + u(x) - \bar{u}(x) - s(x) + \bar{s}(x) + \bar{c}(x) - c(x) \right] = 1$$

$$\int_0^1 dx \left[F_2^{\bar{\nu}n} - \bar{F}_2^{\nu n} \right] = -1$$

$$\int_0^1 dx \left[F_3^{\nu p} + \bar{F}_3^{\bar{\nu}p} \right] = \int_0^1 dx \left[2 \left[d(x) + s(x) - \bar{u}(x) - \bar{c}(x) - \bar{d}(x) - \bar{s}(x) + u(x) + c(x) \right] \right] = 6$$

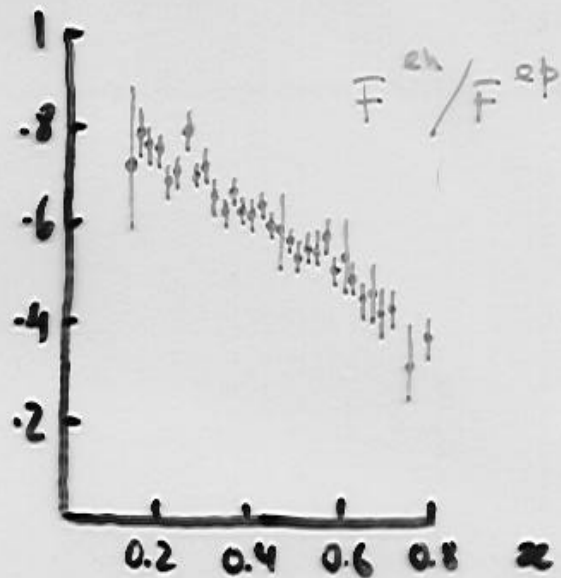
exp: 6.4 ± 1.0

$$\bullet \frac{F_{1,2}^{en}(x)}{F_{1,2}^{ep}(x)} = \frac{u + \bar{u} + s + \bar{s} + 4[d + \bar{d} + c + \bar{c}]}{4[u + \bar{u} + c + \bar{c}] + d + \bar{d} + s + \bar{s}}$$

$$\Rightarrow \frac{1}{4} \leq \frac{F_{1,2}^{en}(x)}{F_{1,2}^{ep}(x)} \leq 4$$

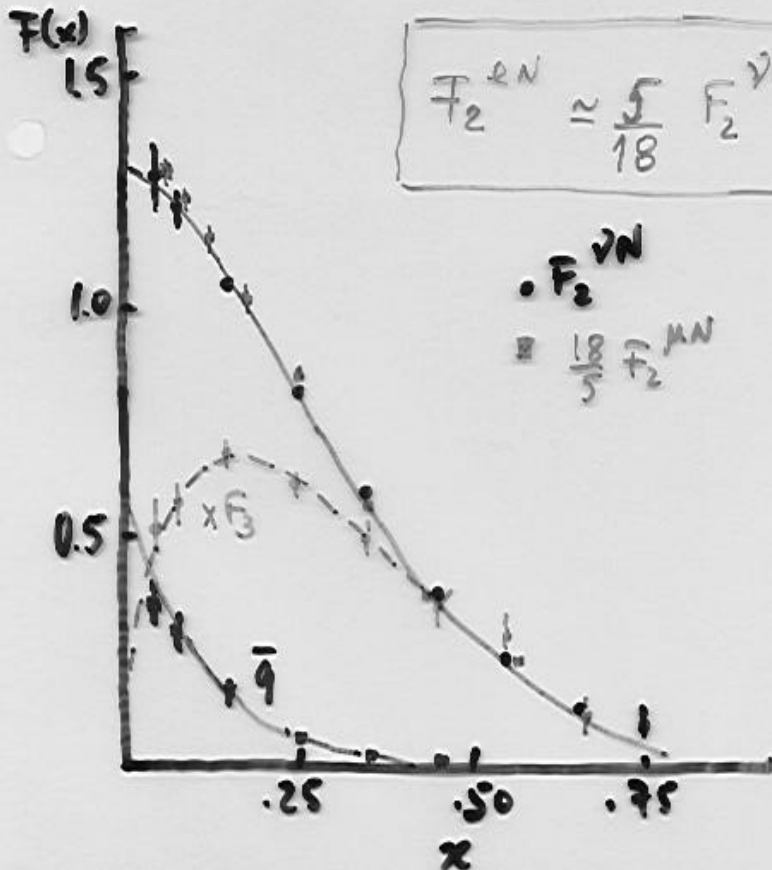
Lim_{x→1} = $\frac{1}{4}$ (predomínio do frank u)

Lim_{x→0} = 1 (predomínio do mar)



$$\Rightarrow [F_2^{vp} + F_2^{vn}] = 2x [u + \bar{u} + d + \bar{d} + 2s + 2c]$$

$$[F_2^{ep} + F_2^{en}] = 2x \left\{ \frac{5}{18} [u + \bar{u} + d + \bar{d}] + \frac{4}{9} [c + \bar{c}] + \frac{1}{9} [s + \bar{s}] \right\}$$

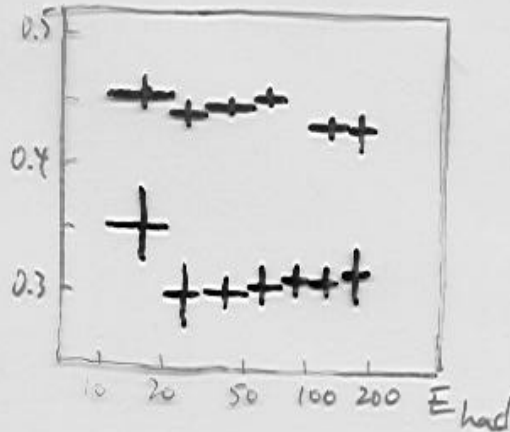


Fracção da impulsão do nucleão transportada pelos quarks e antiquarks :

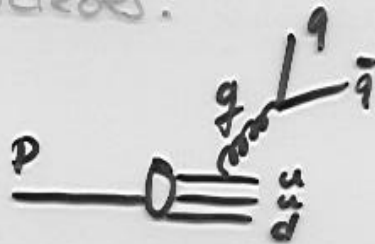
$$F_2^{\nu N} = F_3^{\nu N} = x [u + \bar{u} + d + \bar{d} + s + \bar{s} + c + \bar{c}]$$

• $q + \bar{q} \rightarrow \int_0^1 F_2^{\nu N} dx$

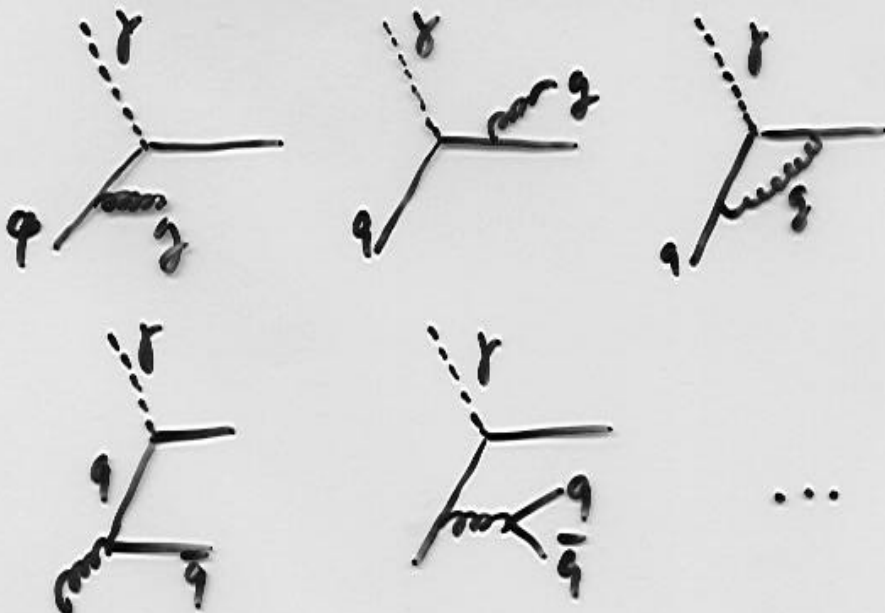
• $q_{val} \rightarrow \int_0^1 x F_3^{\nu N} dx$



⇒ Gluões (campo da interacção forte) no interior dos nucleões.



Cromodinâmica Quântica (QCD) e difusão inelástica

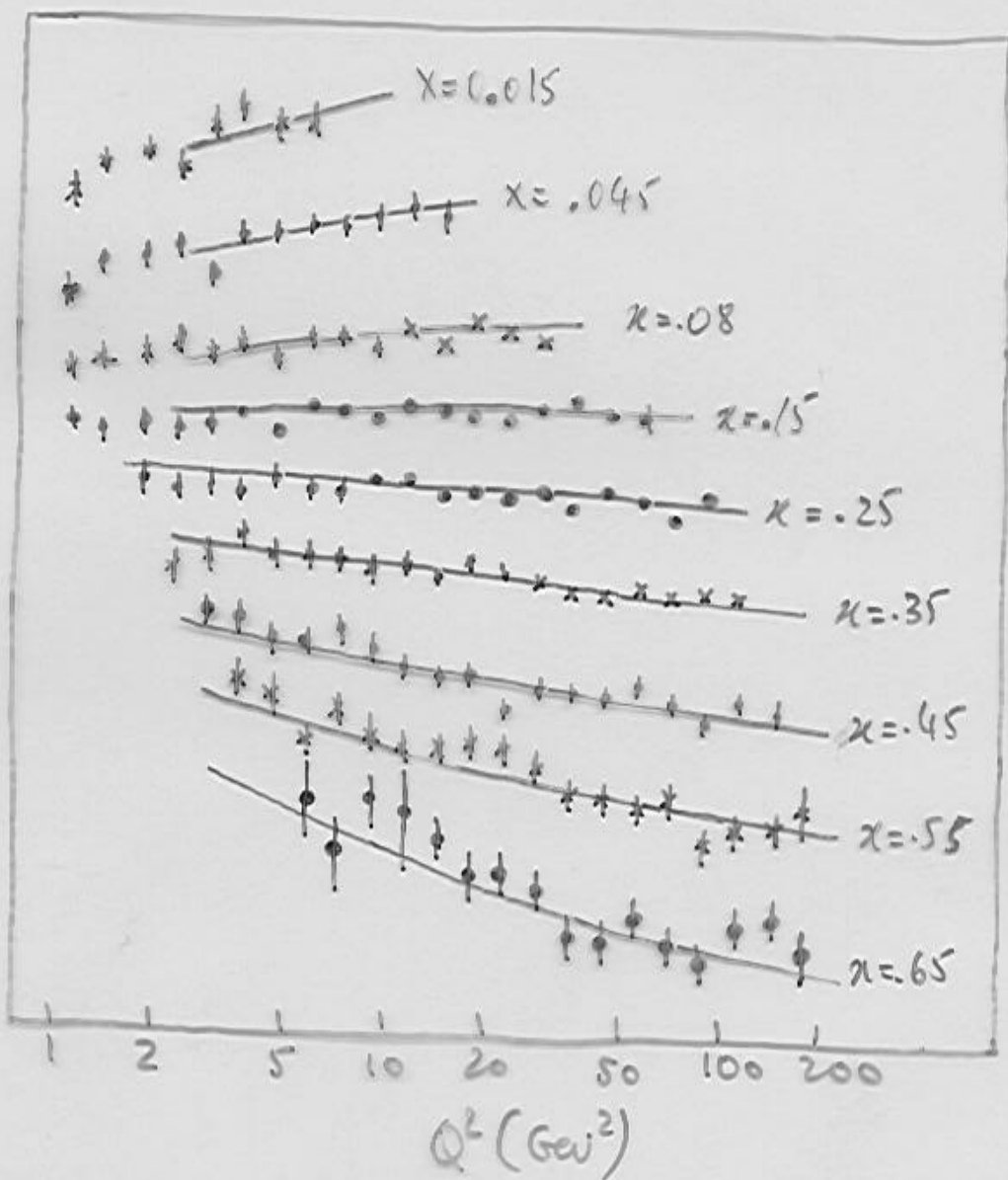


Modelo dos partões \rightarrow QCD

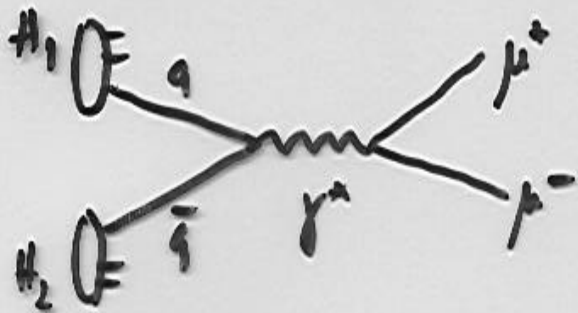
\uparrow
Liberdade assintótica: $\alpha_s(Q^2) \propto \frac{1}{\ln(Q^2/\Lambda^2)}$
 \Rightarrow quarks quasi-livres

Dependência em Q^2 das funções de estrutura:

F_2



Produção de pares de múons em colisões hadrônicas



x_1 (x_2) : fração de impulsão do hadrão H_1 (H_2) transportada pelo quark q (\bar{q}).

$$x_F = 2P_L/\sqrt{S} = x_1 - x_2$$

$$M^2 = x_1 x_2 S$$

Seção eficaz:

$$\sigma = \int dx_1 dx_2 \sum_i \left[q_{H_1}^i(x_1) \bar{q}_{H_2}^i(x_2) + (1 \leftrightarrow 2) \right] \sigma(p_i \bar{p}_i \rightarrow \gamma^*) \delta(M^2 - x_1 x_2 S) dM^2$$

$$\sigma(p_i \bar{p}_i \rightarrow \gamma^*) = \frac{4\pi\alpha^2}{3M^2} e_i^2 \frac{1}{n}$$

n - n° de cores

$$\rightarrow \frac{d^2\sigma}{dx_1 dx_2} = \frac{4\pi\alpha^2}{9M^2} \sum_i e_i^2 \left[q_{H_1}^i(x_1) \bar{q}_{H_2}^i(x_2) + (1 \leftrightarrow 2) \right]$$

Medida das funções de estrutura de partículas instáveis (π , K , \bar{P} ...)