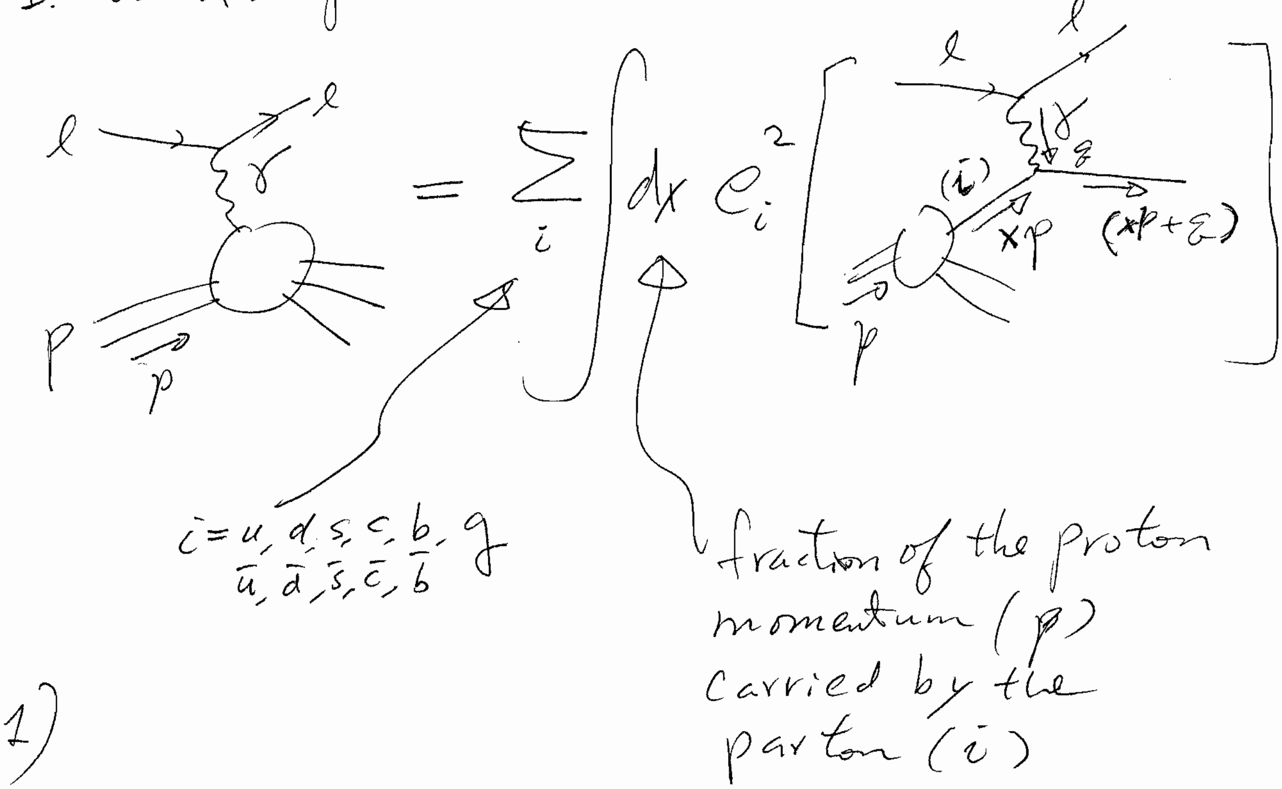
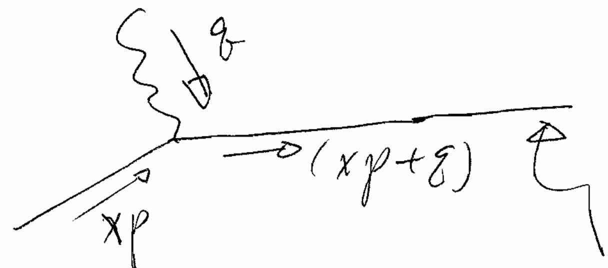
Parton Model

1. What's parton?



1)

Since



and $(xp+q)^2 = 0$ (for producing on-shell, massless quark)

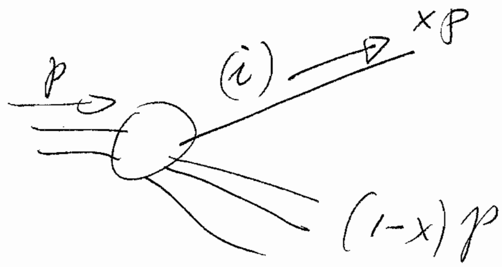
$= x^2p^2 + 2xp\cdot q + q^2$

For $\left(Q^2 \equiv -q^2\right) \gg \left(p^2 = M_p^2\right)$,

then $x = \dfrac{-q^2}{2p\cdot q} = \dfrac{Q^2}{2p\cdot q}$

2) Parton distribution function (PDF)

$f_i(x) \equiv$



↑ The probability for the struck parton (i) to carry a fraction x of the proton momentum.

$$\sum_i \int dx \cdot \left[x f_i(x) \right] = 1 \qquad \left(\text{Total Momentum of proton.} \right)$$

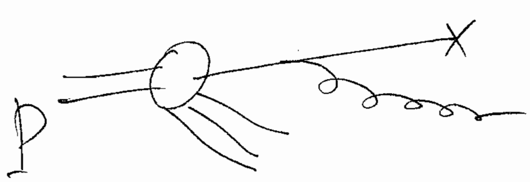
↑ $i = u, \bar{u}, d, \bar{d}, s, \bar{s}, b, \bar{b}, g$

3) In parton model,

$$F_2(x) = \sum_i (e_i)^2 \, x \cdot f_i(x) \qquad (1969)$$

which is independent of Q ⟹ Bjorken scaling $\left(x = \frac{1}{\omega} \right)$

<u>Note</u>: In QCD parton model, the violation of Bjorken scaling is logrithmic, and is a signature of gluon emission.

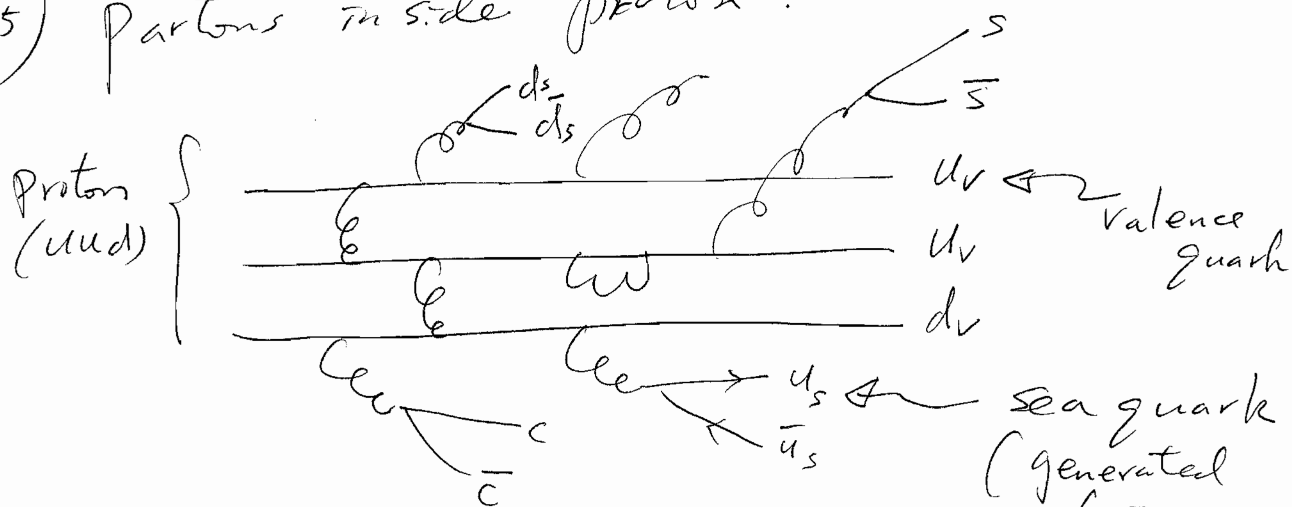


4) $F_1(x) = \frac{1}{2x} F_2(x)$ (Callan-Cross relation)

proves quark is spin-$\frac{1}{2}$ parton.

[For a spin-0 parton, $F_1(x) = 0$.]

5) Partons inside proton.



$u(x) = u_v(x) + u_s(x)$

$d(x) = d_v(x)\, d_s(x)$

$\begin{pmatrix} \bar{u}_s = u_s \\ \bar{d}_s = d_s \end{pmatrix}$

$s, \bar{s}, c, \bar{c}, b, \bar{b}$ are "assumed" to be all coming from gluon splitting (i.e. sea quarks).

$$\int_0^1 dx \left[u(x) - \bar{u}(x) \right] = \int_0^1 dx \left[u_v(x) \right] = 2$$

$$\int dx \left[d(x) - \bar{d}(x) \right] = \int_0^1 dx \left[d_v(x) \right] = 1$$

because $P = (uud)$

6) Where are the gluons?

For $Q \gtrsim 1.5$ GeV, Charm quark is a "heavy" quark.

Hence, the total momentum of proton gives

$$P = \int_0^1 dx \cdot (xp)\left[u+\bar{u}+d+\bar{d}+s+\bar{s}+g\right]$$

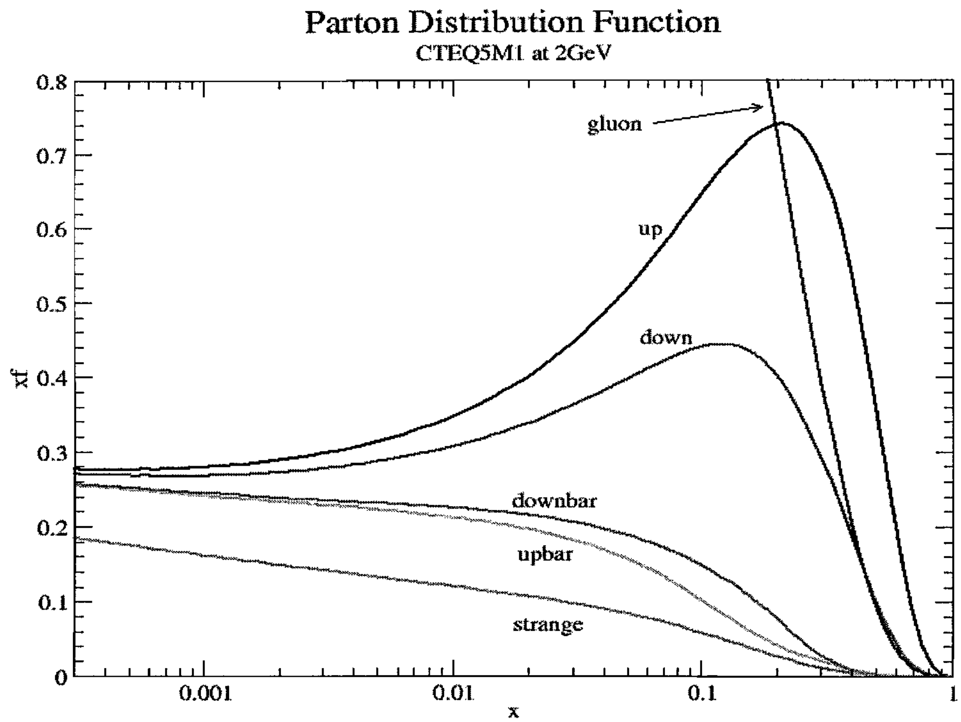
$$\Rightarrow \int_0^1 dx.\, x.\left(u+\bar{u}+d+\bar{d}+s+\bar{s}\right) = 1 - \varepsilon_g,$$

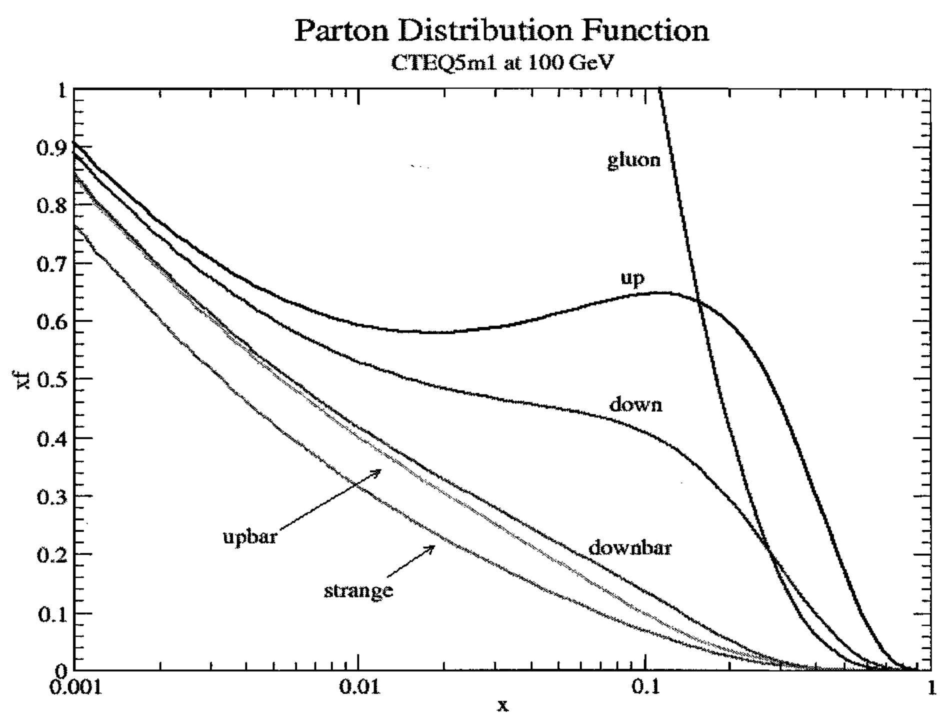
$$\varepsilon_g \equiv \frac{P_g}{P} \equiv \frac{\text{total amount of momentum carried by gluon}}{\text{the momentum of proton}}$$

Experimental data tells us

$$\varepsilon_g \simeq 0.46$$

Hence, gluon carries about 50% of the proton momentum.


Parton Distribution Function
CTEQ5M1 at 2GeV
gluon
up
down
downbar
upbar
strange
xf
x
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0.001
0.01
0.1
1


Parton Distribution Function
CTEQ5m1 at 100 GeV
gluon
up
down
upbar
downbar
strange
xf
x
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0.001
0.01
0.1
1