8.701
Introduction to Nuclear and Particle Physics
Markus Klute - MIT

5. QCD
4. Deep Inelastic Scattering
Proton Structure

The result of ep scattering depends strongly on the wavelength $\lambda=\frac{hc}{E}$

- $\lambda \gg r_p$ - very electron low energies. Scattering is equivalent to that from a point-like object
- $\lambda \sim r_p$ - low electron energies. Scattering with an extended charged object
- $\lambda \ll r_p$ - high electron energies. Scattering resolved sub-structure showing the existence of quarks
- $\lambda \ll r_p$ - very high energies. Proton appears as a sea of quarks and gluons
Proton Structure
Kinematics

\[ x = \frac{Q^2}{2pq} \]

\[ y = \frac{pq}{pl} \]

\[ Q^2 = -q^2 = -(k - k')^2 \]

\[ Q^2 = xys \]
Proton Structure - SLAC-MIT Experiment

5 < \( E_{\text{beam}} < 20 \text{ GeV} \)

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HERA Results

e(30GeV)–p(830GeV) collisions
Parton Distribution Functions

\( f_i(x) \): define as the probability to find a parton in the proton that carries energy between \( x \) and \( x + dx \)

Can be written as:

\[
F_1(x) = \frac{1}{2} \sum_i e_q^2 f_i(x)
\]
\[
F_2(x) = \sum_i x e_q^2 f_i(x)
\]

The partons in the proton are:

- Valence quarks
- Sea quarks and anti-quarks
- Gluons
Sum Rules

PDFs must describe a proton with total fractional momentum $x=1$

$$\int_0^1 dx \, x[u(x) + \bar{u}(x) + d(x) + \bar{d}(x) + s(x) + \bar{s}(x) + \ldots] = 1$$

$$\int_0^1 dx [d(x) + \bar{d}(x)] = 1 \quad \int_0^1 dx [u(x) + \bar{u}(x)] = 2$$

$$\int_0^1 dx [s(x) + \bar{s}(x)] = 0 \quad \int_0^1 dx [c(x) + \bar{c}(x)] = 0$$
Parton Distribution Function

CT10.00 PDFs

$3 \times f(x, \mu=85 \text{GeV})$