8.701

Introduction to Nuclear and Particle Physics

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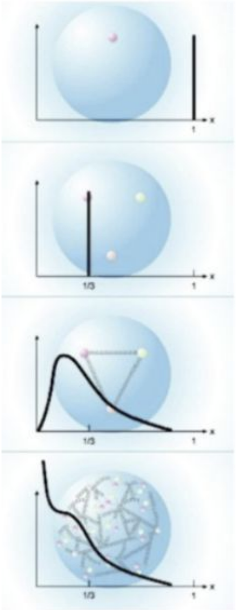
5. QCD

4. Deep Inelastic Scattering

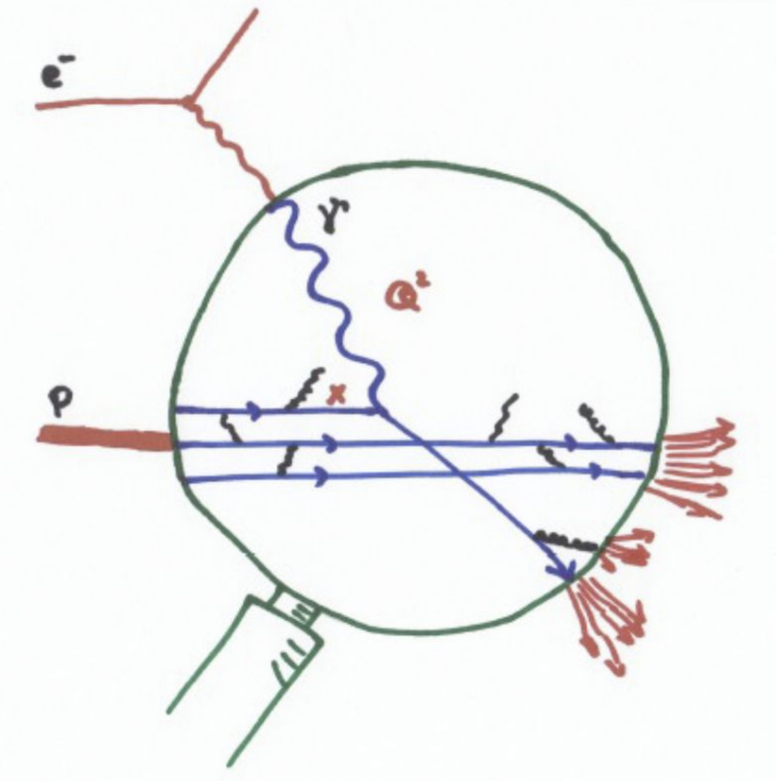
Proton Structure

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

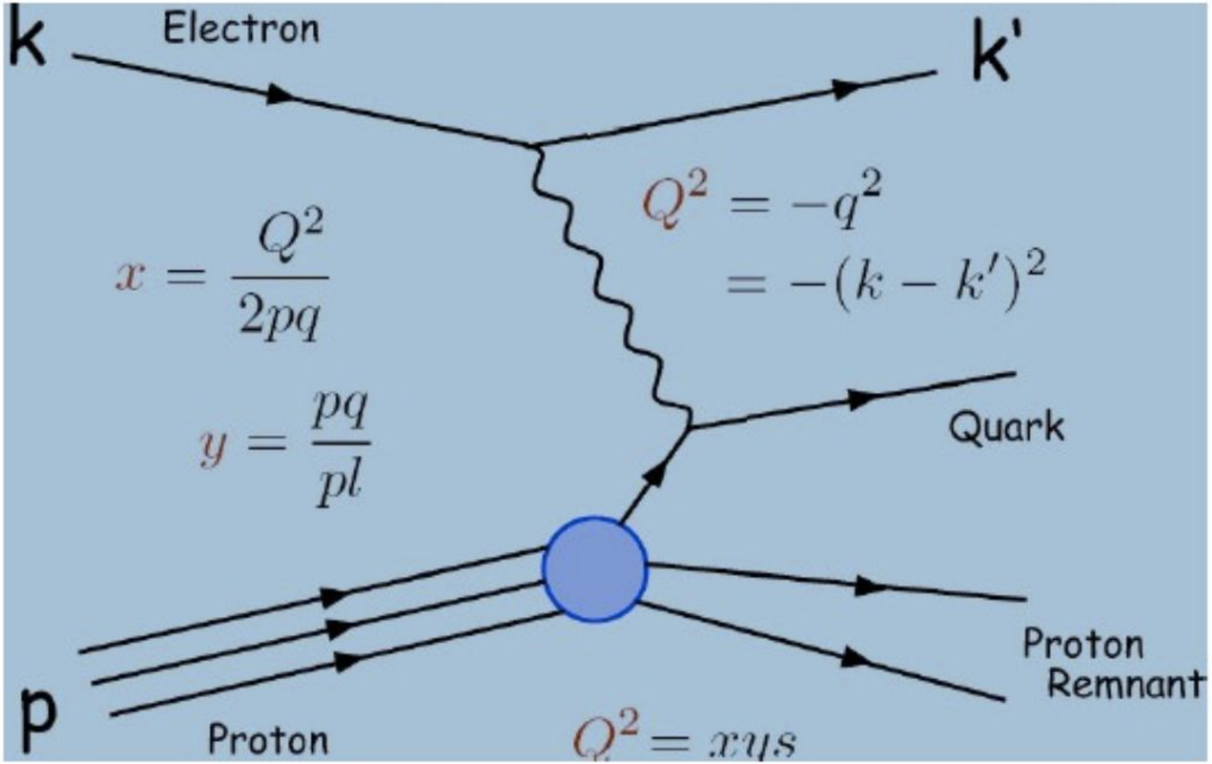
- **$\lambda \gg r_p$ - very electron low energies.** Scattering is equivalent to that from a point-like object
- **$\lambda \sim r_p$ - low electron energies.** Scattering with an extended charged object
- **$\lambda < r_p$ - high electron energies.** Scattering resolved sub-structure showing the existence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



Proton Structure



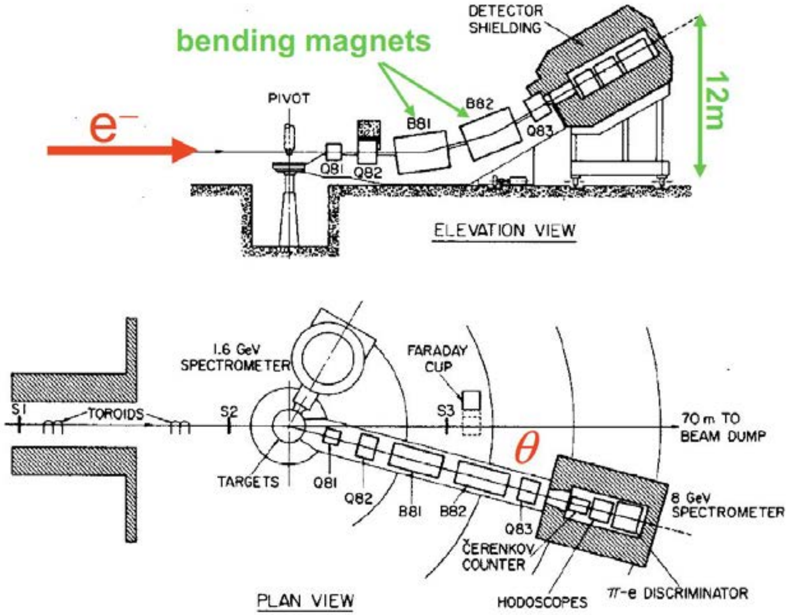
Kinematics



k
Electron
k'
$Q^2 = -q^2$
$= -(k - k')^2$
$x = \frac{Q^2}{2pq}$
$y = \frac{pq}{pl}$
Quark
Proton
Remnant
p
Proton
$Q^2 = xys$

Proton Structure - SLAC-MIT Experiment

$5 < E_{beam} < 20$ GeV



HERA Results

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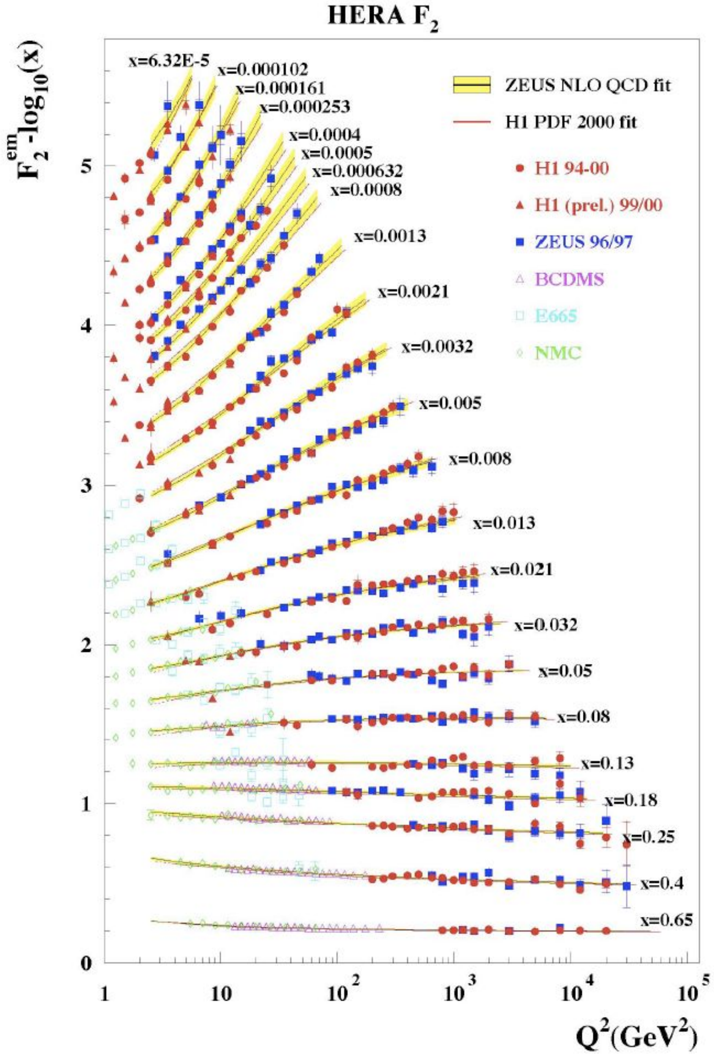
e(30GeV)-p(830GeV)

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

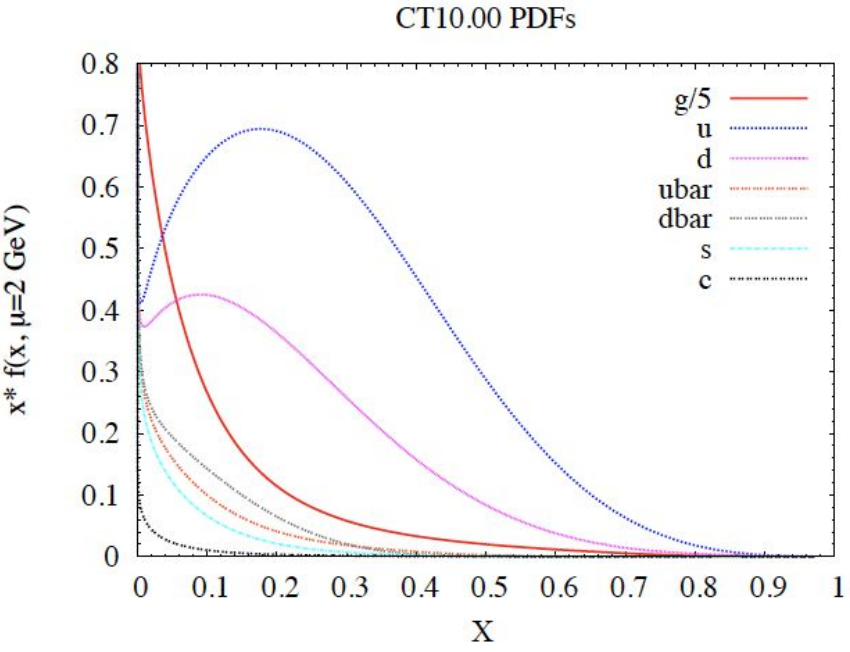
PDFs must describe a proton with total fractional momentum x=1

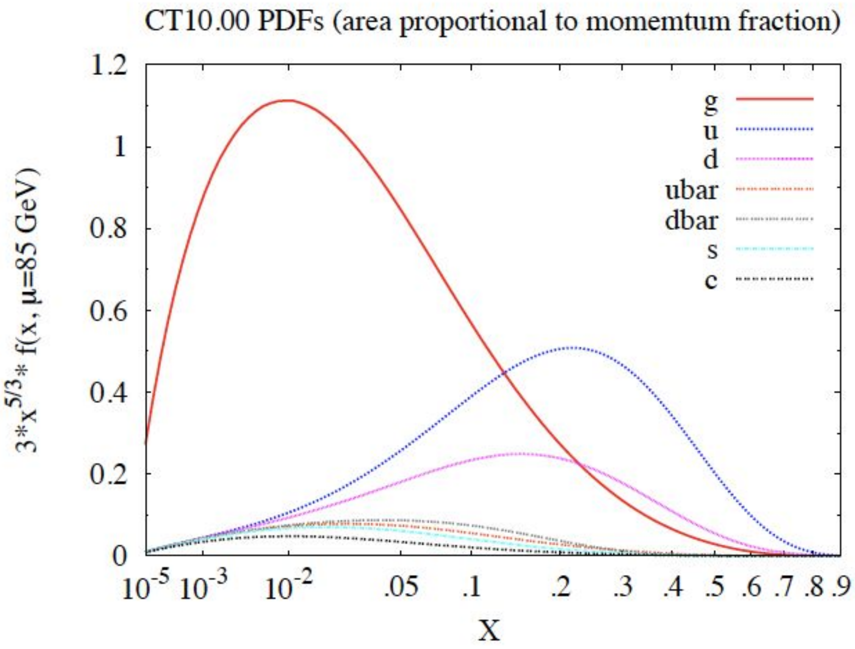
$$\int_0^1 dx\; x[\mathrm{u}(x) + \bar{\mathrm{u}}(x) + \mathrm{d}(x) + \bar{\mathrm{d}}(x) + \mathrm{s}(x) + \bar{\mathrm{s}}(x) + \ldots] = 1$$

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

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

Parton Distribution Function





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