Lecture 16 Deep Inelastic ep Scattering and Partons

ICPY473 Nuclear Physics, MUIC, 3-Trimester, 2021

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Monday 21, 2021

Today Topics

- Strange particles
- DIS program
- Partons
- Parton distribution function

Strange Particles

- K^0 was first observed strange particle by Rochester and Butler in 1964 from the decay

$$K_S^0 \to \pi^+ + \pi^- \quad \tau = 9 \times 10^{-11} s$$

where the index "S" indicate the short life time kaon. Since it is also observe the same particle ($M = 497.7 MeV/c^2$) having different decay mode with a longer life time

$$K_L^0 \to \pi^+ + \pi^- + \pi^0 \quad \tau = 5 \times 10^{-8} s$$

Then it was indexed by "L" for long life time.

- "Strangeness" was introduced by Murray Gell-Mann, Abraham Pais and Kazuhiko Nishijima, to explain their curios properties (preserve under their reactions).
- The kaons are thought to be *composite particle*, first was initiated by *Shoichi Sakata* and later were completed and *Murray Gell-Mann* and *George Zweig*

- Shoichi Sakata (1964)

Prog. Theor. Phys. 16 (1956), 686

On a Composite Model for the New Particles*

Shoichi Sakata

Institute for Theoretical Physics, Nagoya University, Nagoya

September 3, 1956

Recently, Nishijima-Gell-Mann's rule[1] for the systematization of new particles has achieved a great success to account for various facts obtained from the experiments with cosmic rays and with high energy accelerators. ...

... It seems to me that the present state of the theory of new particles is very similar to that of the atomic nuclei 25 years ago. At that time, we had known a beautiful relation between the spin and the mass number of the atomic nuclei. Namely, the spin of the nucleus is always integer if the mass number is even, whereas the former is always half integer if the latter is odd. But unfortunately we could not understand the profound meaning for this even-odd rule. ...

- Murray Gell-Mann (1964)

Volume 8, number 3 PHYSICS LETTERS 1 February 1964

A SCHEMATIC MODEL OF BARYONS AND MESONS *

M. GELL-MANN
California Institute of Technology, Pasadena, California

Received 4 January 1964

If we assume that the strong interactions of baryons and mesons are correctly described in terms of the broken "eightfold way" [1-3], we are tempted to look for some fundamental explanation of the situation. A highly promised approach is the purely dy-

ber $n_t - n_{\bar{t}}$ would be zero for all known baryons and mesons. The most interesting example of such a model is one in which the triplet has spin $\frac{1}{2}$ and $z = -1$, so that the four particles d^-, s^-, u^0 and b^0 exhibit a parallel with the leptons.

- George Zweig (1964)

CERN Report No.8182/TH.401

AN SU_3 MODEL FOR STRONG INTERACTION SYMMETRY AND ITS BREAKING

G. Zweig *)

CERN - Geneva

A B S T R A C T

Both mesons and baryons are constructed from a set of three fundamental particles called aces. The aces break up into an isospin doublet and singlet. Each ace carries baryon number $\frac{1}{3}$ and is consequently fractionally charged. SU_3 (but not the Eightfold Way) is adopted as a higher symmetry for the strong interactions. The breaking of this symmetry is assumed to be universal, being due to mass differences among the aces. Extensive space-time

DIS Project at SLAC with MIT and CalTech Physicists

- The first electron-proton scattering experiment at SLAC, 1966, in which electrons with energies up to 20 GeV (1 GeV equals 1 billion electron volts) recoiled elastically from the proton (that is, without breaking.it up), gave noevidence for quark substructure.

PROPOSALS FOR INITIAL ELECTRON SCATTERING EXPERIMENTS
USING THE SLAC SPECTROMETER FACILITIES

Submitted
By
SLAC-MIT-CIT Collaboration

Particle physicists actively participating in the collaboration at this time:

Stanford Linear Accelerator Center (Group A)

W.K.H. Panofsky, D. H. Coward, H. DeStaebler, J. Litt, L. W. Mo and R. E. Taylor.

Massachusetts Institute of Technology

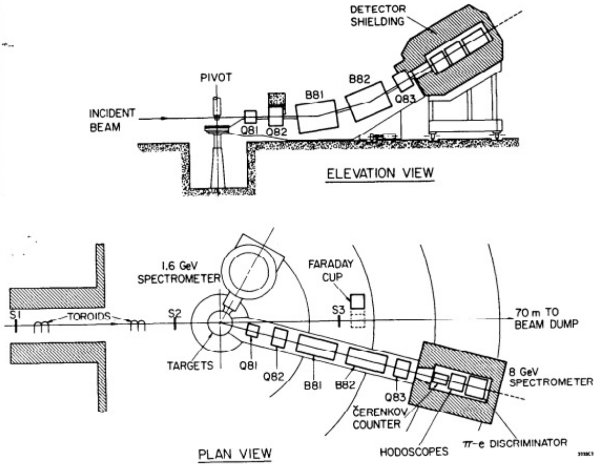
J. I. Friedman, H. W. Kendall and L. Van Speybroeck.

California Institute of Technology

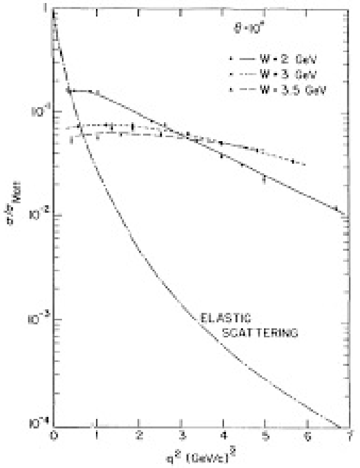
C. Peck and J. Pine.

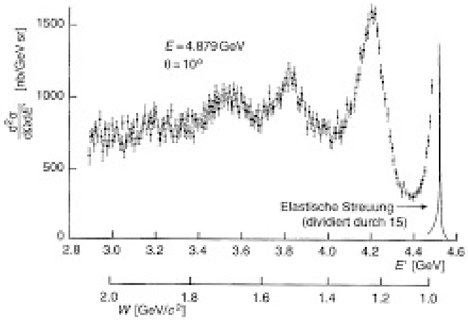
SLAC-linear accelerating machine

SLAC-end station



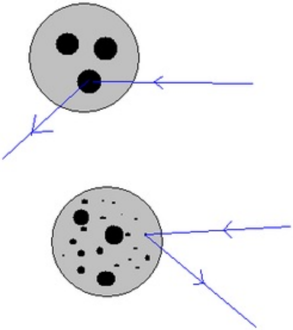
SLAC-observe point-like structure (1968)



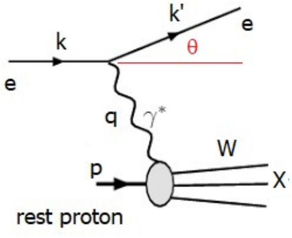


Partons

- The parton model was proposed by Richard Feynman in 1969 as a way to analyze high-energy hadron collisions. *The scattering particle only sees the valence partons. At higher energies, the scattering particles also detects the sea partons.*



- Parton kinematics (LAB frame)



$$k^\mu = (E, k\hat{z}), \quad k'^\mu = (E', k'\hat{n}), \;\; \hat{n}\cdot\hat{z} = \cos\theta \tag{1}$$

$$p^\mu = (m_p, 0), \;\; W^\mu = (q+p)^\mu, \;\; q^\mu = (k-k')^\mu \tag{2}$$

Importance quantities:

$$Q^2 = -q^2 \text{ transfer energy}, \;\; y = \frac{q\cdot p}{k\cdot p} \text{ inelasticity} \tag{3}$$

$$x = \frac{Q^2}{2p\cdot q} \text{ Bjorken scaling variable} \tag{4}$$

- Parton kinematics (cont.)

$$x = \frac{Q^2}{2p \cdot q} = \frac{Q^2}{2m_p \nu}, \quad \nu = E - E', \; y = \frac{q \cdot p}{k \cdot p} = \frac{\nu}{E} \qquad (5)$$

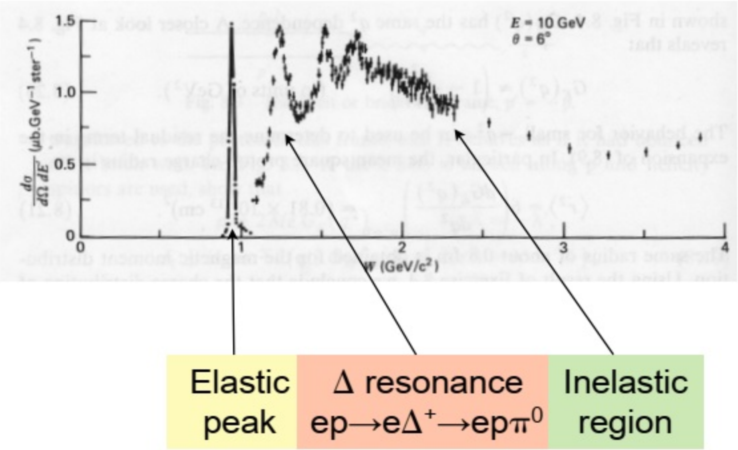
$$\rightarrow Q^2 = Sxy = 2m_p Exy, \quad S = 2(p \cdot k) \qquad (6)$$

$$W^2 = (q+p)^2 \rightarrow M_x^2 = m_p^2 + 2p \cdot q + q^2 = m_p^2 + \frac{Q^2}{x} - Q^2$$

$$\rightarrow M_x^2 = m_p^2 + \frac{Q^2}{x}(1-x) \qquad (7)$$

  - Elastic scattering: $M_x = m_p, \; x = 1$
  - Resonance: $M_x = M_R, \; \omega = x^{-1} = 1 + \frac{MR^2 - m + p^2}{Q^2}$
  - Inelastic scattering: $M_x > m_p, \; x < 1$

- Character of ep-scattering, $W > 1.8 Gev$ for inelastic scattering (continuum region)



- DIS cross section

$$\frac{d\sigma}{d\Omega dE'} = \frac{\alpha_{em}^2}{4m_p E^2 sin^4(\theta/2)} \left\{2W_1(x, Q^2)\sin^2(\theta/2) \right.$$
$$\left. + W_2(x, Q^2)\cos^2(\theta/2)\right\} \tag{8}$$

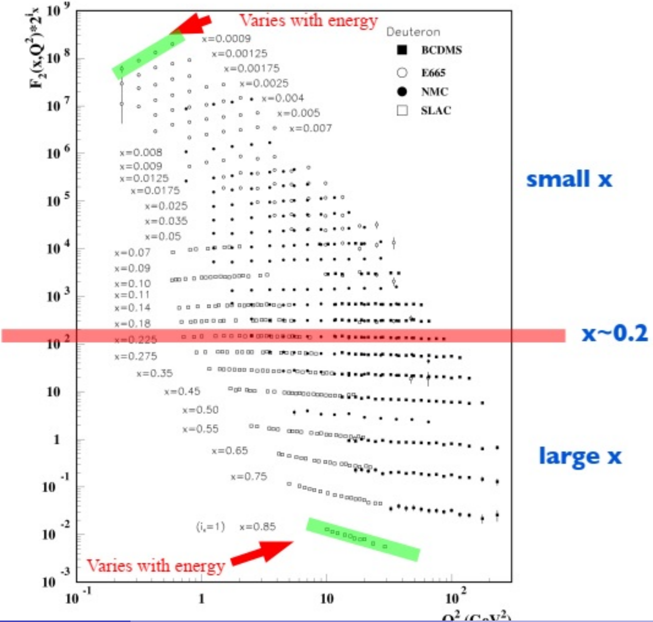
- Define *scaling structure functions* or *form factor*

$$\{F_1(x, Q^2), F_2(x, Q^2)\} = \left\{W_1(x, Q^2), \frac{Q^2}{2xm_p^2} W_2(x, Q^2)\right\}$$

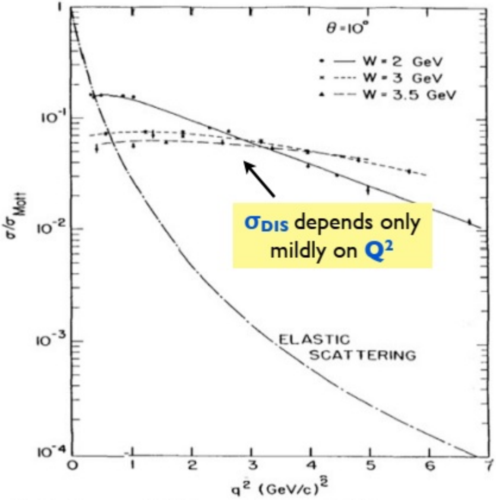
where $\{F_1, F_2\}$ result from longitudinal or transverse photon momentum transfer, respectively. So that

$$\frac{d\sigma}{d\Omega dE'} = \frac{\alpha_{em}^2}{4m_p E^2 sin^4(\theta/2)} \left\{2F_1(x, Q^2)\sin^2(\theta/2) \right.$$
$$\left. + \frac{2xm_p^2}{Q^2} F_2(x, Q^2)\cos^2(\theta/2)\right\} \tag{9}$$

- DIS form factor



- DIS cross section



Early data on DIS from the SLAC-MIT experiment [PRL23(1969)935]