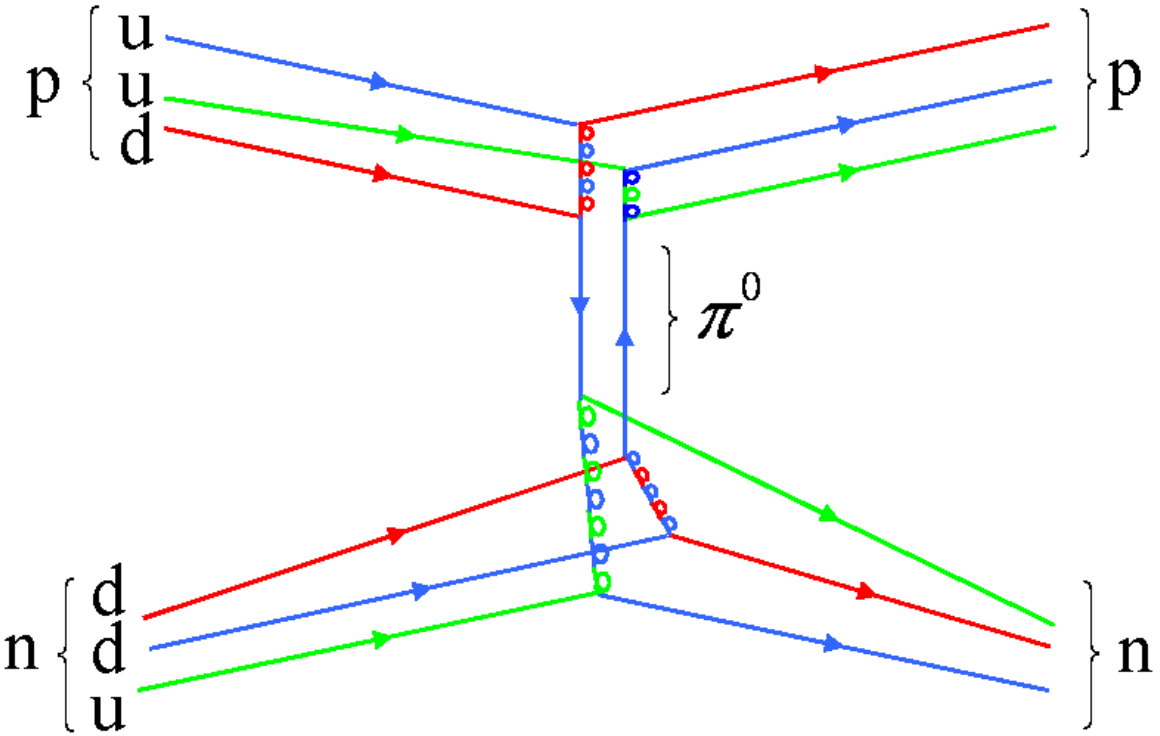
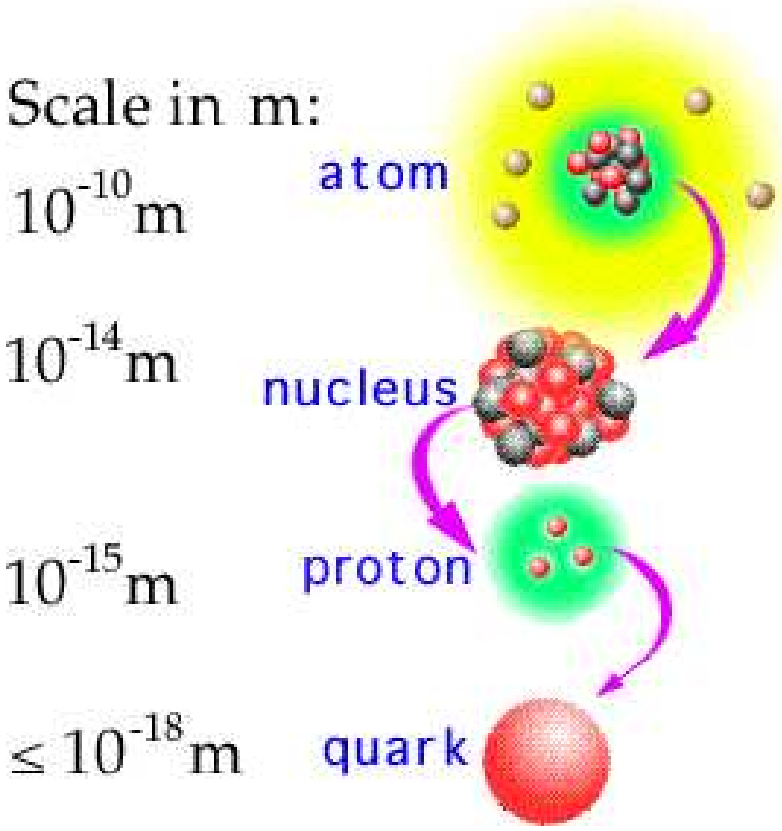
Evidence for the Strong Interaction



Scott Wilbur

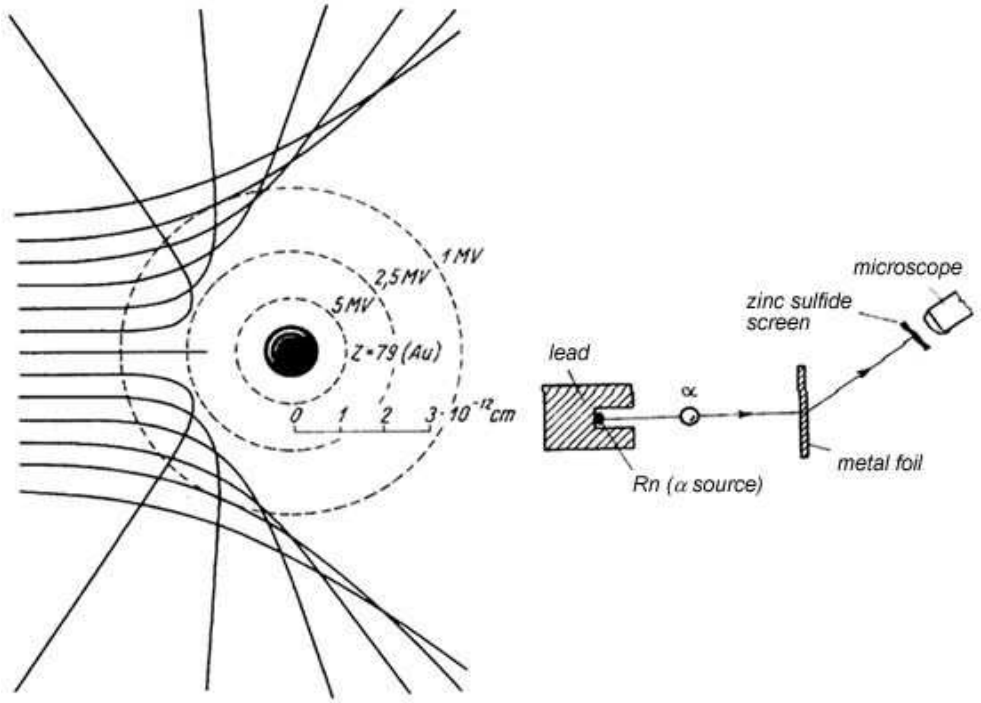
Overview

Continuing search inside "fundamental" particles



Discovery of Nucleus

- Plum pudding model (Thompson)
- 1911: Rutherford observes hard scattering of α particles off of gold atoms
- Atoms must have a small, dense nucleus



Discovery of Protons

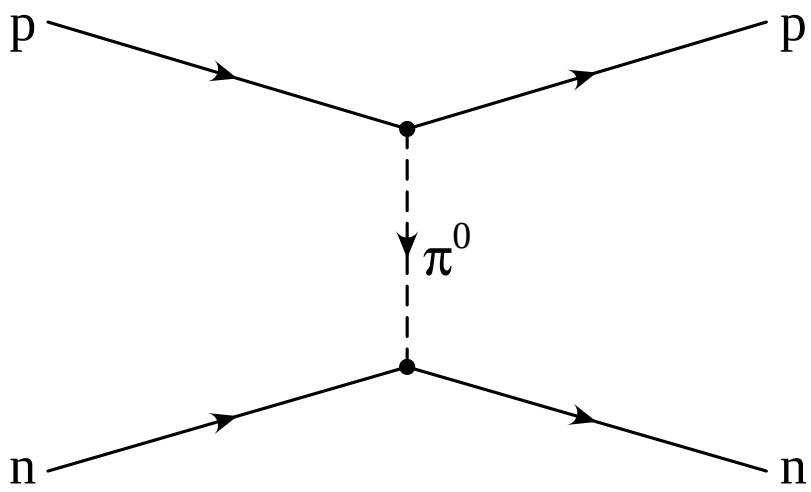
- 1918: Rutherford shoots α particles into nitrogen, sees hydrogen nuclei produced
- Nitrogen must contain hydrogen nuclei
- Since hydrogen has atomic number 1, assume it is an elementary particle

Discovery of Neutrons

- 1930: Walther Bothe and H. Becker notice that α particles hitting light elements produces a new, penetrating radiation
- 1932: Irène Joliot-Curie and Frédéric Joliot notice that if this radiation hits a compound containing hydrogen, it ejects high-energy protons
- 1932: James Chadwick rejects γ ray hypothesis, proposes that new radiation is an uncharged particle with same mass as proton

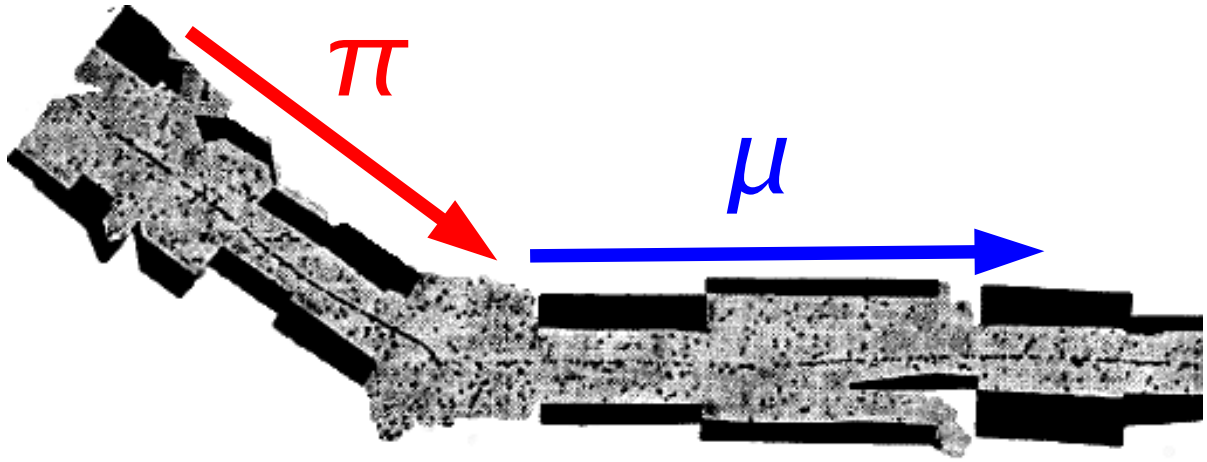
Strong Nuclear Force

- All nucleons are either positive or neutral: need another force to hold them together
- 1935: Hideki Yukawa proposes a mechanism: nucleons exchange massive bosons (mesons)
    - Mesons must have mass ∼100 MeV



Discovery of Pions

- 1947: Cecil Powell, Cèsar Lattes and Giuseppe Occhialini at the University of Bristol observe cosmic rays using photographic emulsions
    - Charged particles leave tracks
    - Pions identified by "double meson" tracks ($\pi^{\pm} \rightarrow \mu^{\pm}\nu_{\mu}$)



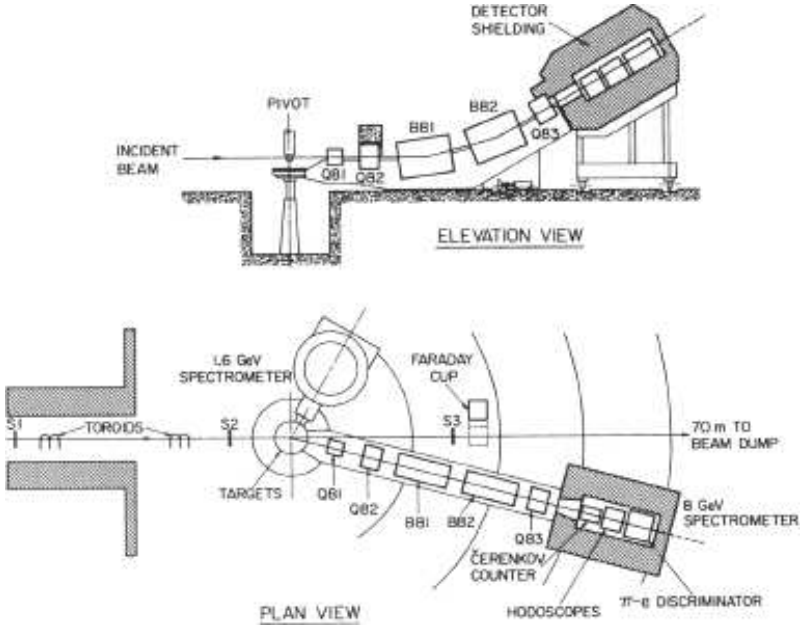
The Eightfold Way

1961: Murray Gell-Mann develops classification scheme for hadrons

- $SU(3)$ flavor symmetry (quantum numbers: isospin, hypercharge)
- Spin-0 mesons, spin-1 mesons, and spin-$\frac{1}{2}$ baryons in **8**, spin-$\frac{3}{2}$ baryons in **10**
    - Leads to discovery of new baryon: Ω^-
- Proposes "quarks" (up, down, strange) as underlying triplet

Electron – Proton Scattering

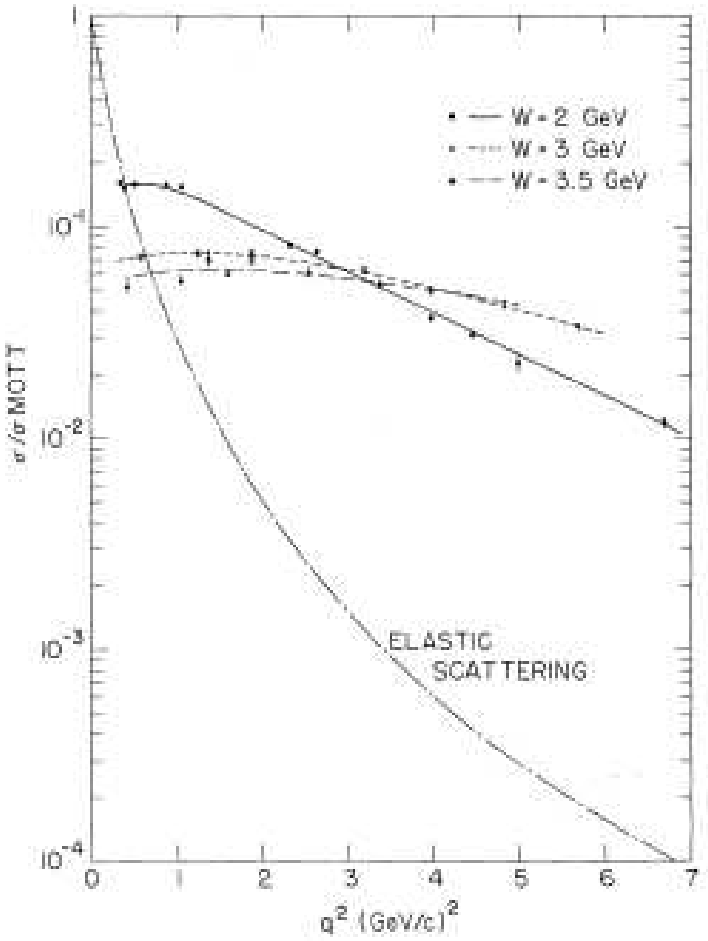
- The MIT-SLAC Collaboration performed $e^- + p$ scattering experiments at 20 GeV in 1966
- Analysis of elastic scattering showed no evidence for structure



Deep Inelastic Scattering

Inelastic scattering analyzed in 1967

- Much larger cross sections than expected
- Electrons were exciting the protons (or breaking them up)
- First actual evidence that protons were composite

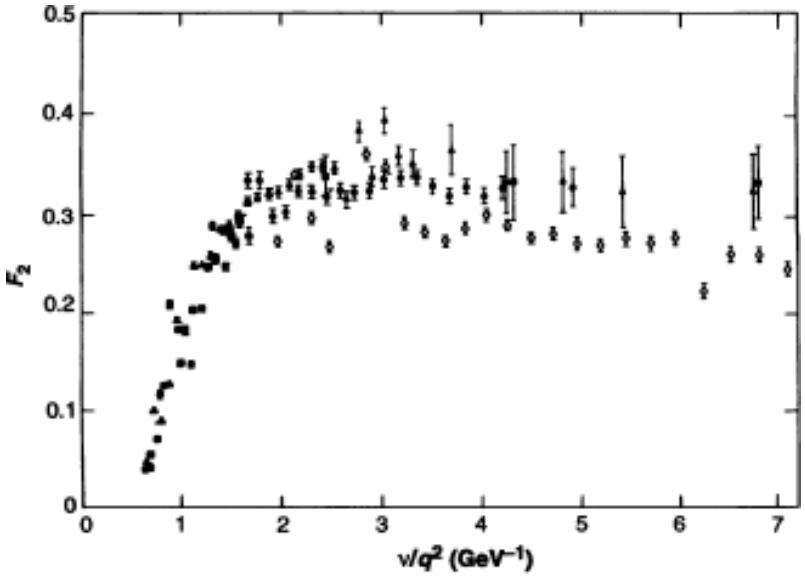


Deep Inelastic Scattering

- Cross section for scattering is

$$\sigma(E, E', \theta) = \frac{4e^4 E'^2}{q^4} \left[W_2(v, q^2) \cos^2 \frac{\theta}{2} + 2W_1(v, q^2) \sin^2 \frac{\theta}{2} \right]$$

- Bjorken predicts (and finds) scaling: $vW_2 = F_2(v/q^2)$, implying pointlike constituents



The Parton Model

- Feynman visited SLAC in 1968, sees inelastic scattering data and fits to Bjorken scaling
- Identifies $x = \frac{q^2}{2mv}$ with the fraction of momentum carried by parton
- According to Friedman:

  "Feynman came up with a simple dynamical model which experimenters could really understand. It was another way of saying what Bjorken was saying except it gave it a sort of physical structure."

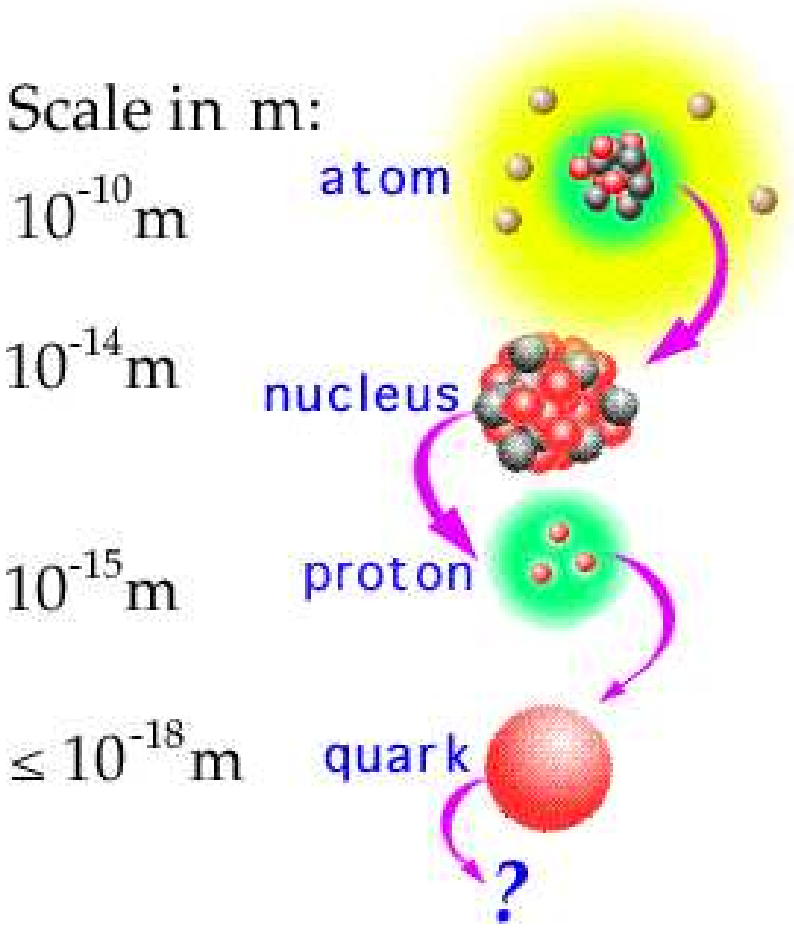
Asymptotic Freedom

- Seems that Gell-Mann's "quarks" are the partons, and are loosely bound inside proton
- If quarks actually exist inside proton, why has no one seen one come out?
- David Gross, David Politzer, and Frank Wilczek formulate QCD
    - Asymptotic freedom
    - Quarks are loosely bound, but "trapped" inside hadrons

Quark Theory Accepted

- Logarithmic scaling violations observed (as predicted) at Fermilab and CERN
- Nobel Prizes for all involved
    - Yukawa – Explaining strong force by meson exchange
    - Powell – Discovering pions
    - Gell-Mann – Proposing "The Eightfold Way"
    - Friedman, Kendall, Taylor – Discovering quarks
    - Gross, Politzer, Wilczek – Discovering QCD

Summary



- The strong interaction was discovered by continually looking for constituents of "fundamental" particles
- Currently, it looks like quarks and gluons are the fundamental particles
- Could there be something else?