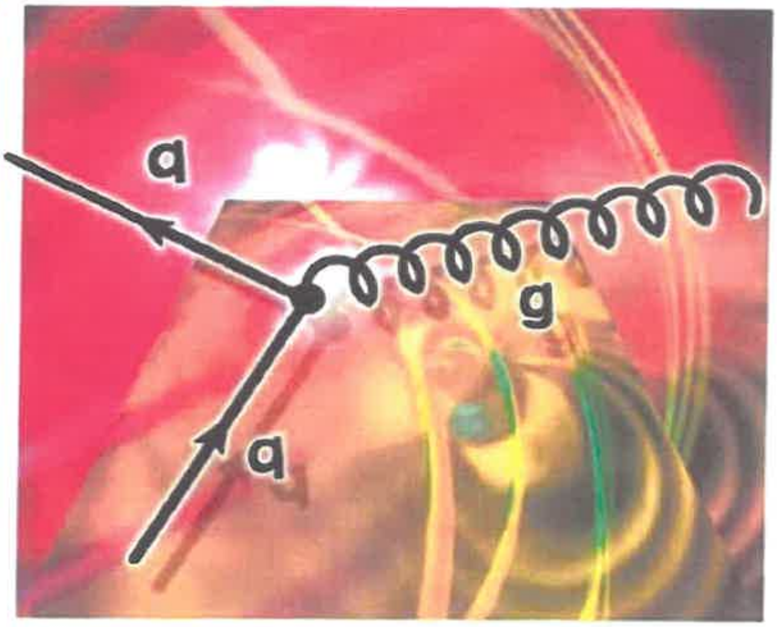
PHYSICS TEXTBOOK

David Griffiths

WILEY-VCH

Introduction to Elementary Particles

Second, Revised Edition



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Introduction to Elementary Particles, Second Edition. David Griffiths

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High Energy Physics

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Text: D. Griffiths: Introduction to Elementary Particles
John Wily & Sons , 2nd Edition(2008)

Reference:

F. Halzen and A.D. Martin: Quarks & Leptons John-Wiley & Sons (1984)

D.H. Perkins: Introduction to High Energy Physics
(4th Edition) Cambridge University Press (2000)

Fayyazuddin & Riazuddin: A Modern Introduction to Particle Physics
(2nd edition) World Scientific Publishing(2000)

Duncan Carlsmith: Particle Physics, Pearson Education (2013)

General Reading:

(1) Brian Greene: The Elegant Universe (1999), QC794.6 Str. Gr.
The Fabric of the Cosmos (2003); The Hidden Reality (2011)

(1) M Veltman: Facts and Mysteries in Elementary Particle Physics (WSPC, 2003)

(2) Leo Lederman: The God Particle : If the Universe is the Answer, What is the question, Boston: Houghton Mifflin (1993), QC793.Bos.L

Websites:

Update of the Particle Listings available on the Web
PDG Berkeley website: http://pdg.lbl.gov/

The Berkeley website gives access to MIRROR sites in:
Brazil, CERN, Italy, Japan, Russia, and the United Kingdom.

Also see the Particle Adventure at: http://ParticleAdventure.org

http://www-ed.fnal.gov/lml/Leon_life.html (Leo Lederman)
http://www-ed.fnal.gov/trc/projects/index_all.html

Particle Physics Labs

- **Laboratories**BNL: The Department of Energy's Brookhaven National Laboratory in Upton, Long Island.
- CERN: Originally "Conseil Européenne pour Recherches Nucléaires," now the European Laboratory for Particle Physics, in Geneva, Switzerland.
- DESY: Deutches Elektronen SYnchrotron laboratory in Hamburg, Germany.
- FNAL: The Department of Energy's Fermi National Accelerator Laboratory in Batavia, Illinois.
- KEK: Koo Energy Ken. The High Energy Research Accelerator Organization in Tsukuba, Japan.
- SLAC: The Department of Energy's Stanford Linear Accelerator Center in Palo Alto, California.

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1.1 Introduction

Elementary Particles = Basic constituents of matter.

A particle can be pointlike and wavelike.

To break matter into its smallest pieces, need high energy

∴ **Elementary particle physics = high energy physics**

Present energy achieved ≈ 1 TeV ≈ 1000 GeV ≈10^{12} eV (Fermilab)

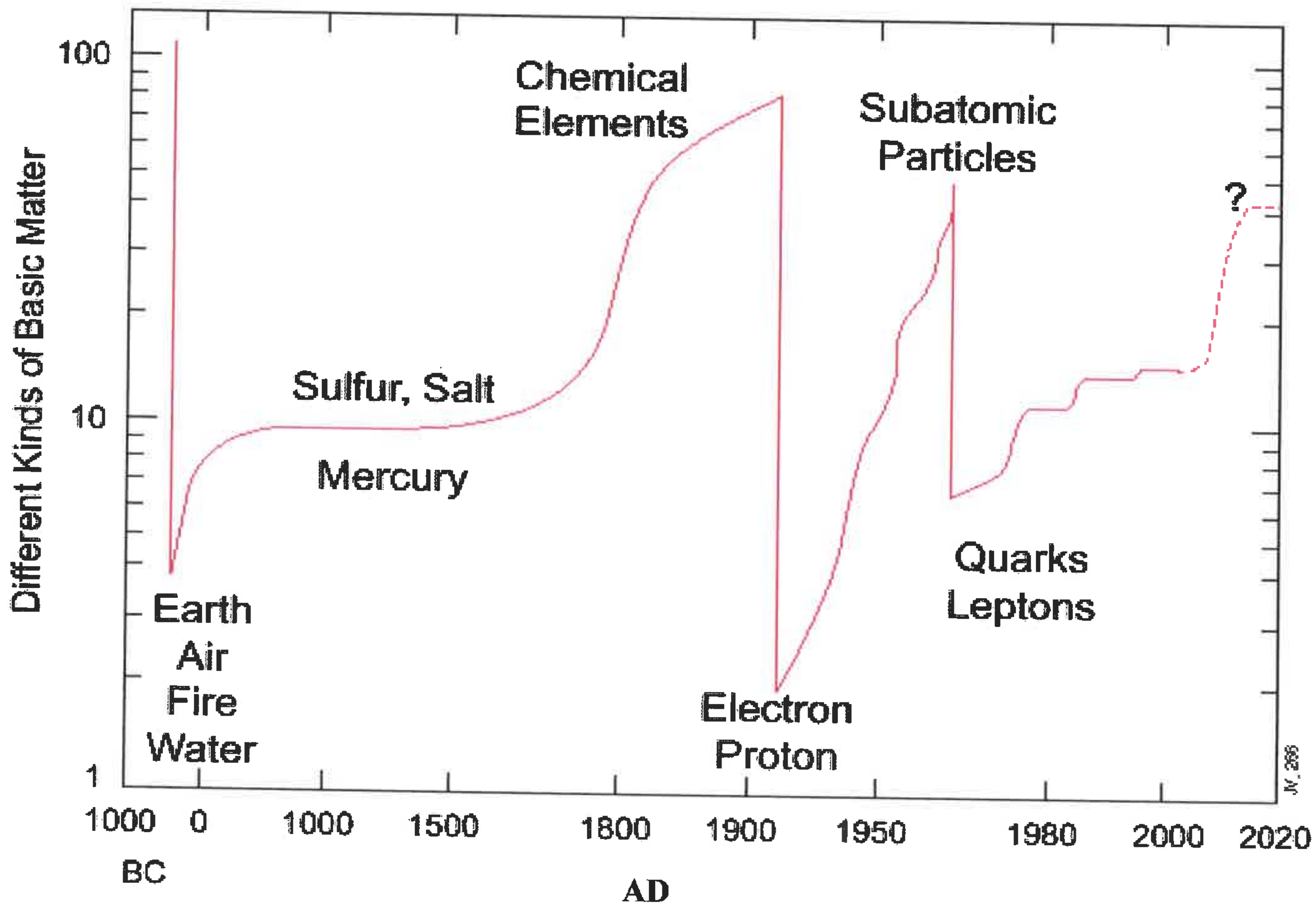
LHC (2007) proton beams 7 TeV + 7 TeV = 14 TeV

Theoretical discussion on the unification of basic forces has reached the Planck energy scale

$$\left(\frac{\hbar c}{G_N}\right)^{1/2} = 10^{-5} gm = 10^{19} GeV = 10^{28} eV$$

Close to the energy scale at which the universe is created.

History of Constituents of Matter



1.2 Particles

Leptons: Particles do not participate in strong interaction.

	Q	L_e	L_μ	L_τ
e	-1	1	0	0
ν_e	0	1	0	0
μ	-1	0	1	0
ν_μ	0	0	1	0
τ	-1	0	0	1
ν_τ	0	0	0	1

Electron pointlike up to

10^{-15} cm = 10^{-2} *fm*

Hadrons(strongly interacting particles)

Baryons: Half-integral spin particles (fermions) involve in all basic interactions, ***st*** (strong), ***wk*** (weak), ***em*** (electromagnetic), e g

$p, n, \Lambda, \Sigma^+, \Sigma^0, \Sigma^-, \Xi^0, \Xi^-, \Delta, \Omega^-$

Mesons: integer spin particles (bosons) involve in all basic interactions ***st, wk, em***

$\pi^+, \pi^\circ, \pi^-, k^\pm, k^\circ, \eta, \omega$

Baryons are made from three quarks

q, q, q

Mesons are made from quark-antiquark

$q, \bar{q}$

Three generations of quarks

	Q	U	D	C	S	T	B
u	$2/3$	1	0	0	0	0	0
d	$-1/3$	0	-1	0	0	0	0
c	$2/3$	0	0	1	0	0	0
s	$-1/3$	0	0	0	-1	0	0
t	$2/3$	0	0	0	0	1	0
b	$-1/3$	0	0	0	0	0	-1

each quark has a nonabelian charge, called colour (**source** of strong interaction); there are three different colours.

Classification symmetry group

The lepton number, like electric charge, is associated with the Abelian U(1) group.

The lepton doublet and also quark doublet are associated with the non-Abelian SU(2), originally from the isospin symmetry of proton and neutron

Baryons and Mesons are bound states of quarks.

e.g.

proton = $u\ u\ d$ antiproton = $\bar{u}\ \bar{u}\ \bar{d}$ neutron = $u\ d\ d$

Pion π^+ = $u\ \bar{d}$ Pion π^- = $\bar{u}\ d$

Kaon k^+ = $u\ \bar{s}$ Kaon k^- = $\bar{u}\ s$

J/ψ = $c\ \bar{c}$

Gauge field particles (force field)

Photon γ	electromagnetic interaction
Graviton	gravitation
Gluons g	strong interaction
Intermediate Vector bosons $W^{\pm}$ Z	weak interaction

Mass: $m_{W^{\pm}} \approx 82GeV/c^2$, $m_Z \approx 92Gev/C^2$

1.3 Basic Interactions (forces)

Type of force:	Gravitational	Weak	Electro-magnetic	Strong
Range:	infinite	$\leq 10^{-16}$cm	infinite	$\leq 10^{-13}$cm
Strength relative to strong force at a distance 10^{-13} cm	10^{-38}	10^{-13}	10^{-2}	1
Decay time for a typical small mass hadron:		10^{-10}s	10^{-20}s	10^{-23}s
Mediator:	Graviton	W^+, W^-, Z^0	Photon γ	gluon
Mass of the mediator:	0	82 GeV/c^2 92 GeV/c^2	0	0

Theories: Strong interaction	**Quantum chromodynamics QCD**
***em* interaction**	**Quantum electrodynamics QED**
***Weak* interaction**	**Weinberg – Salam model (Flavour dynamics)**
Gravitation	**Quantum gravity (?) Einstein's general relativity**

Standard Model in particle physics

(i) Electroweak unification 1967

So called Glashow-Salam-Weinberg Model unifying weak interaction with the electromagnetic interaction. Quantum flavor dynamics

The model is based on quantum field theory. Both the particle (matter lepton) and the interaction are represented by field operators and the interaction term is of the form of current(matter) × gauge field, or $J_\mu^a \times A_a^\mu$. The symmetry group is $U(1) \times SU(2)$

(ii) The strong interaction is described by quantum chromatic dynamics (QCD) ~1973. The symmetry group is $SU(3)$. Again Both the particle (matter quarks) and the interaction are represented by field operators and the interaction term is of the form of current(matter) × gauge field, or $J_\mu^a \times A_a^\mu$.

(iii) The standard model is based on the gauge group is $U(1) \times SU(2) \times SU(3)$. Strictly not a complete unification because it consists of 3 separate gauge group. Ideally unification should be based on one single gauge group.

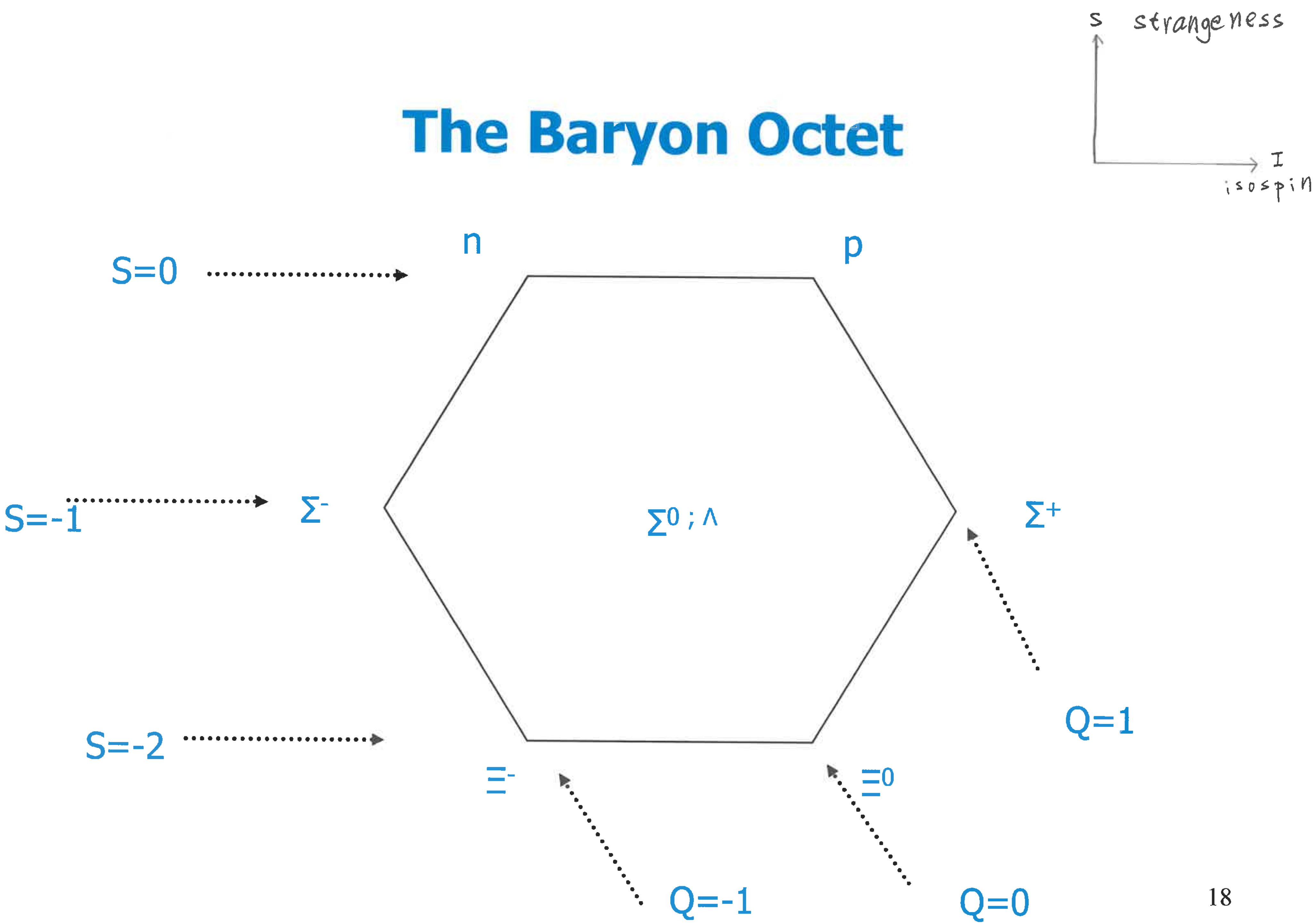
THE EIGHTFOLD WAY

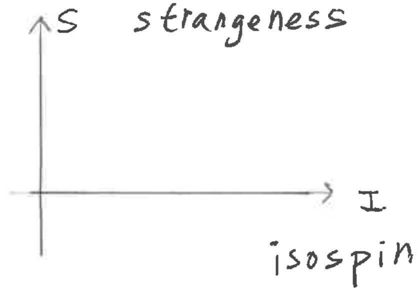
(1961)

classify hadrons
(baryons, mesons)
according to the
multiplets (singlet,
octet, decuplet) of
SU(3) group, so
called unitary symmetry.

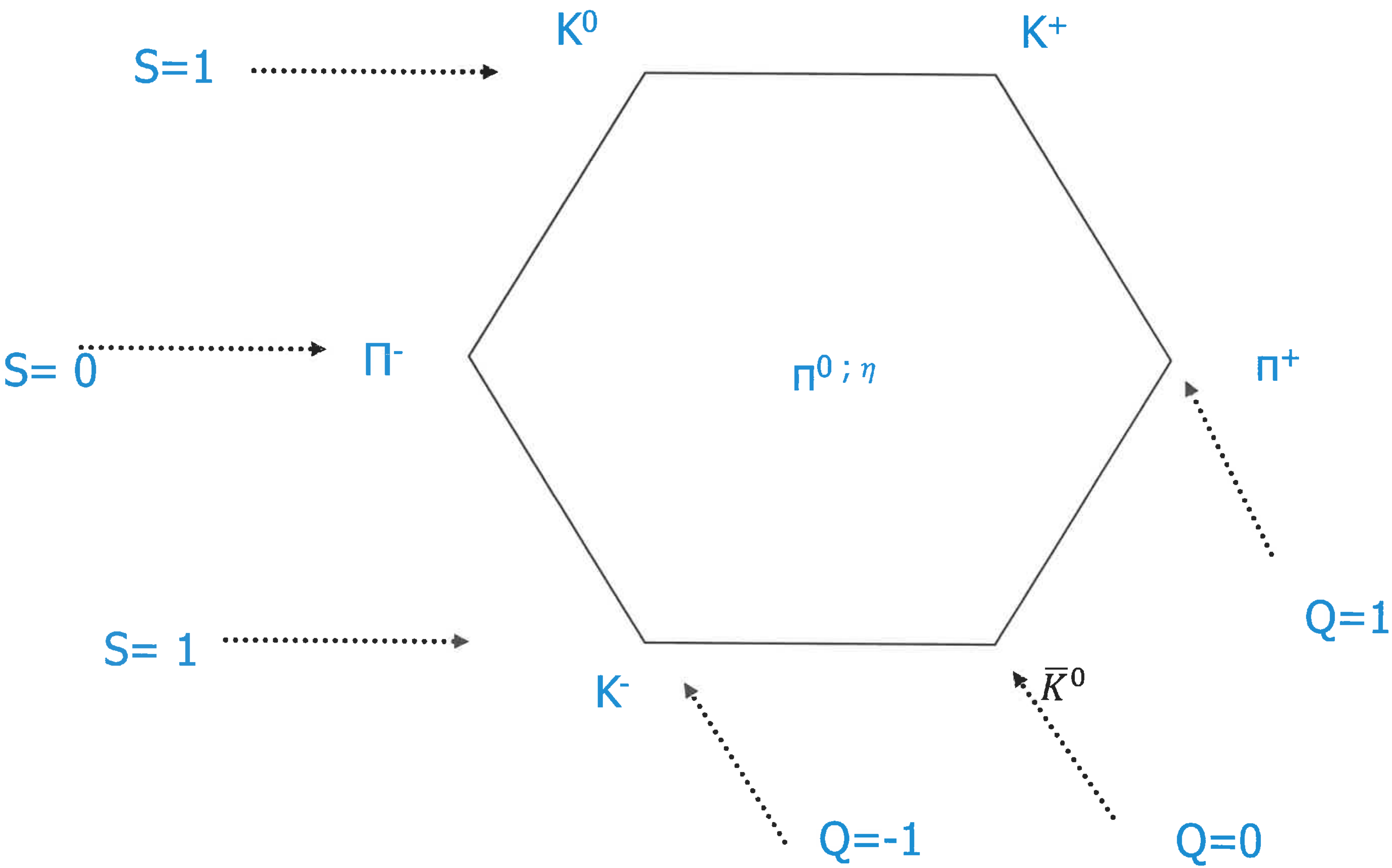
Extension of isospin scheme SU(2)

The Baryon Octet





The Meson Octet



SU(3) Octet and Nonet

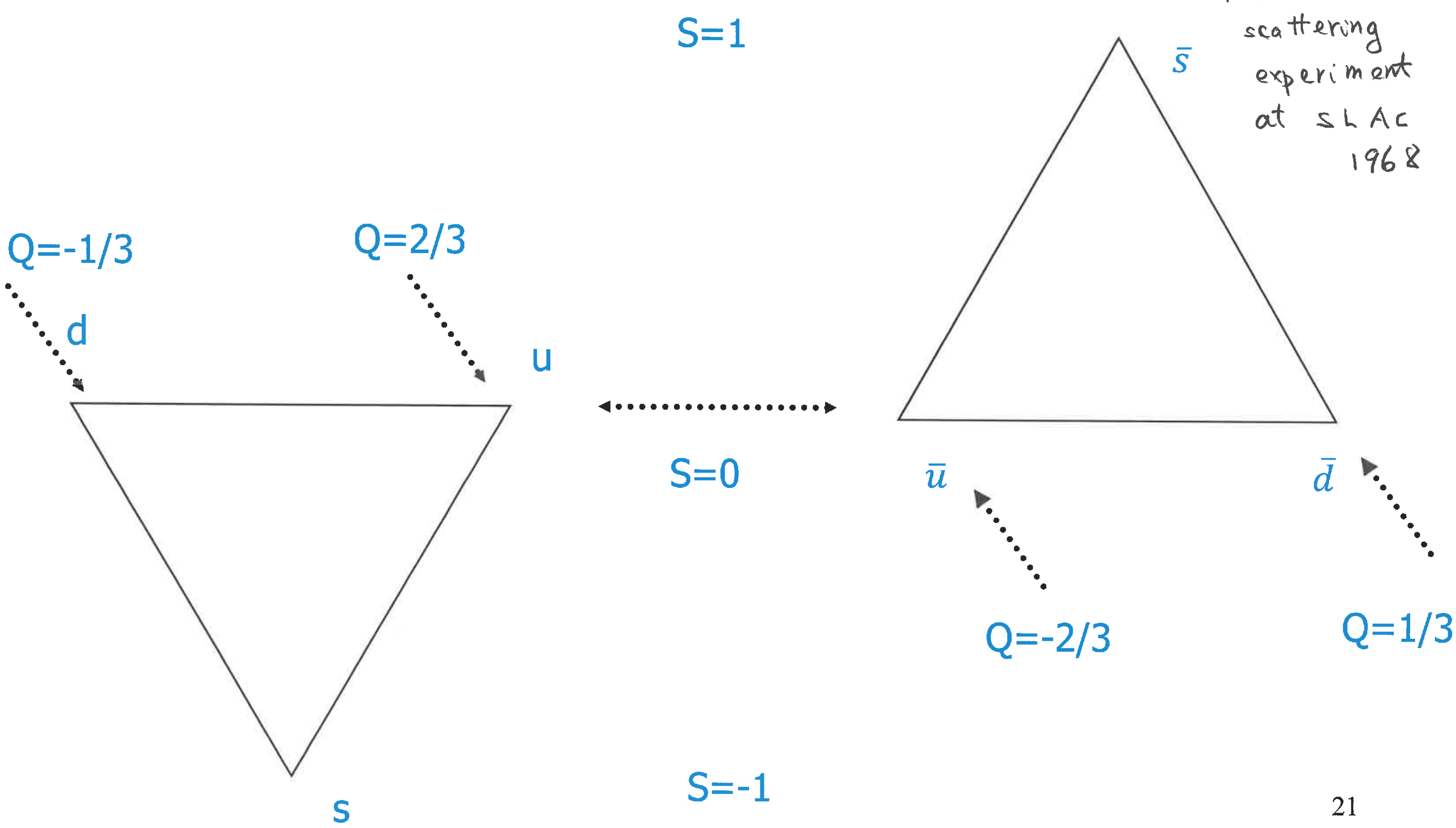
An SU(3) octet consists of 2 isodoublets, 1 isotriplet, and 1 isosinglet. These isomultiplets refer to SU(2).

An nonet consists of an SU(3) octet and an SU(3) singlet.

An nonet is a SU(3) reducible representation, and is equivalent to an irreducible SU(3) octet representation and an irreducible SU(3) singlet representation.

The Quark Model (1964)

Quarks indirectly detected in the deep inelastic $e^- p$ scattering experiment at SLAC 1968



1.4 Theoretical Framework

1.4.1 Quantum field theories

To every elementary particle, we associate a field operator $\psi(\underline{x})$, $x^0 = ct, \underset{\sim}{x} = (x^1, x^2, x^3)$, $\psi(\underline{x})$ acts on state vectors of a Hilbert space. The field operator $\psi(\underline{x})$ obeys equation of motion. For free particles, equations of motion are known. Usually can obtain equation of motion from action S

$$S = \int d^4x \; \mathscr{L}$$ $\mathscr{L}$ = Lagrangian density.

For particles in interaction, interaction terms are usually derived from a symmetry principle, called principle of local gauge invariance.

Two types of interaction terms:

$\overline{\psi}(\underline{x})\psi(\underline{x})\varphi(\underline{x})$	Yukawa
$\overline{\psi}(\underline{x})\gamma^\mu\psi(\underline{x})A_\mu(\underline{x})$	Gauge field theories

In quantum theory, exp (-iS) determines the physics, S= action.