Two-Pion Photoproduction - An Instructive Guide towards Meson Phenomenology

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13. 1. 2020

Outline

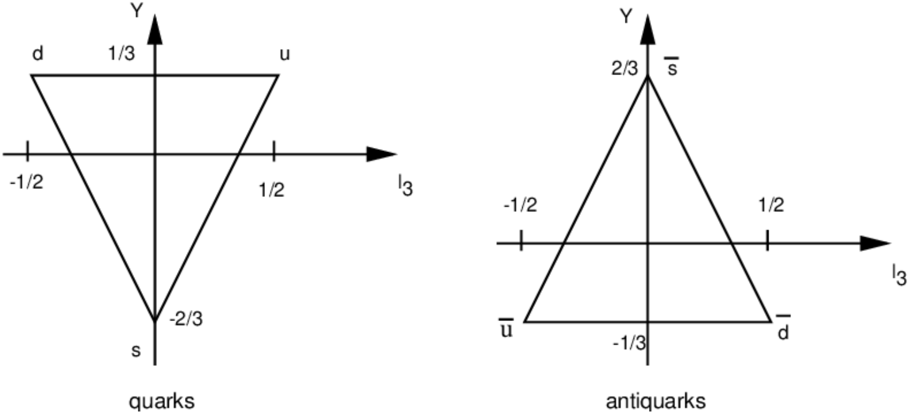
Hadron Nomenclature

- Particles composed of quarks and antiquarks held together by the strong force
- **Quarks:** $q \in \{u, d, s, (c, b, t)\}$
- **Antiquarks:** $\bar{q} \in \{\bar{u}, \bar{d}, \bar{s}, (\bar{c}, \bar{b}, \bar{t})\}$
- **Baryons** qqq**:** $3 \otimes 3 \otimes 3 = 10_S \oplus 8_M \oplus 8_M \oplus 1_A$, **Fermi-Dirac statistics**
- **Mesons** $q\bar{q}$**:** $3 \otimes \bar{3} = 8 \oplus 1$, **Bose-Einstein statistics**

$$f_{FD/BE} = \frac{1}{\exp\left(\frac{E-\mu}{k_B T}\right) \pm 1} \tag{1}$$

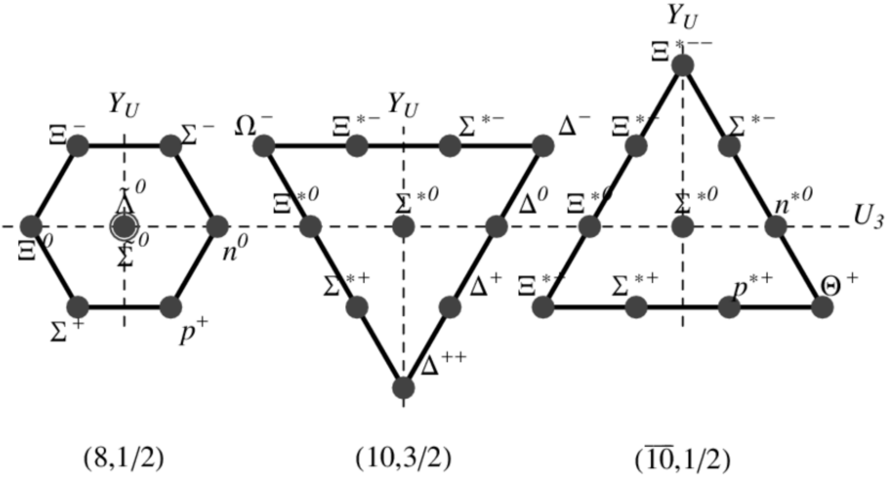
where E is the energy, μ is the chemical potential, k_B is the Boltzmann constant, T is the temperature

(Anti)quark (anti)triplet [1]



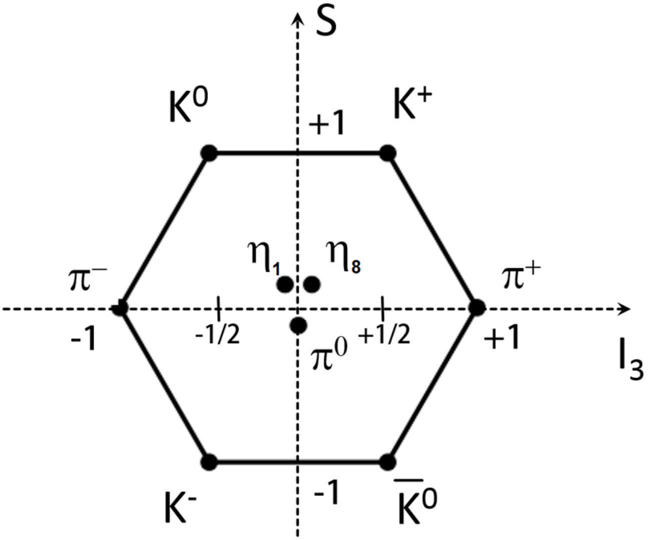
[1] M. Tanabashi et al. (Particle Data Group), Phys. Rev. D 98, 030001 (2018) and 2019 update.

Baryon octet (left), decuplet (centre), antidecuplet (right)[2]



[2] M. Tanabashi et al. (Particle Data Group), Phys. Rev. D 98, 030001 (2018) and 2019 update.

Meson octet [3]



[3] M. Tanabashi et al. (Particle Data Group), Phys. Rev. D 98, 030001 (2018) and

A Brief History of Pions

- First proposal - 1935 - Hideki Yukawa - mesons as the carrier particles of the strong nuclear force
- Mass ($\sim$ 100 MeV) inferred from the radius of the atomic nucleus
- 1936 - discovery of the muon - thought to be THE particle, does not, however, participate in the strong nuclear interaction
- 1947 - Lattes, Occhialini, Powell - discovery of charged pions $\pi^{\pm}$ - photographic emulsions placed for long periods of time in sites located at high altitude mountains and struck by cosmic rays
- 1950 - University of California's cyclotron - discovery of the neutral pion π^0 - decay into two photons

Nobel Prizes:

- 1949 - Hideki Yukawa
- 1950 - Cecil Powell

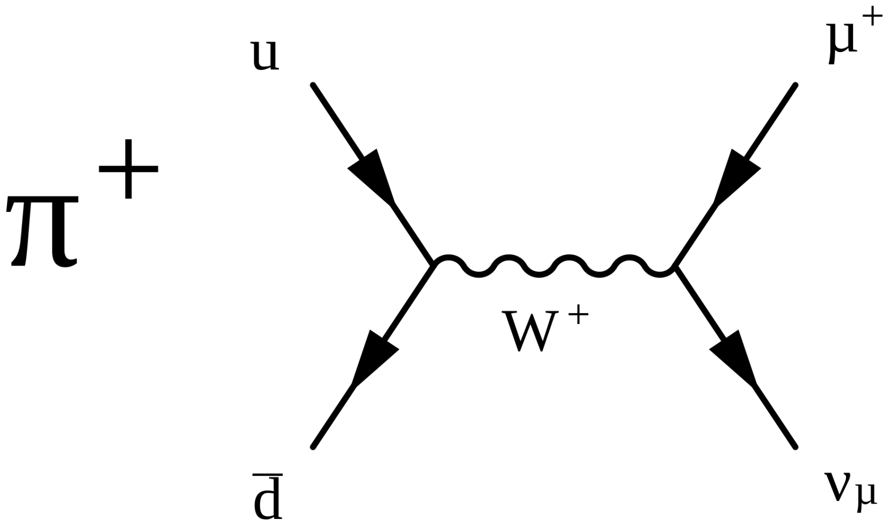
Properties of Pions

- Mass: $m_{\pi^\pm} = 139.57$ MeV, $m_{\pi^0} = 134.9$ MeV
- Mean lifetime: $\tau_{\pi^\pm} = 2.6033 \times 10^{-8}$ s, $\tau_{\pi^0} = 8.4 \times 10^{-17}$ s
- Statistics: Bose-Einstein
- Spin: 0
- Isospin triplet representation
- Parity: -1 - pseudoscalar - couple to the axial vector current; participate in the chiral anomaly
- Decay: charged pions - weak interaction, neutral pion - electromagnetic interaction

$$\pi^+ \to \mu^+ + \nu_\mu$$

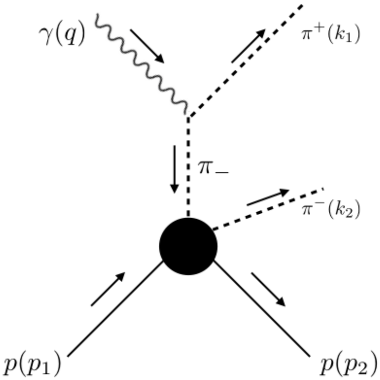
$$\pi^- \to \mu^- + \bar{\nu_\mu}$$

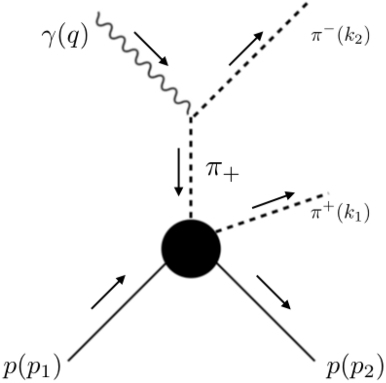
$$\pi^0 \to 2\gamma$$



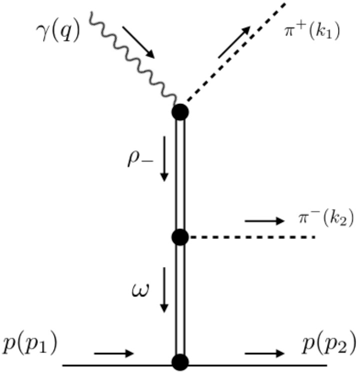
π+
u
μ+
W+
d̄
νμ

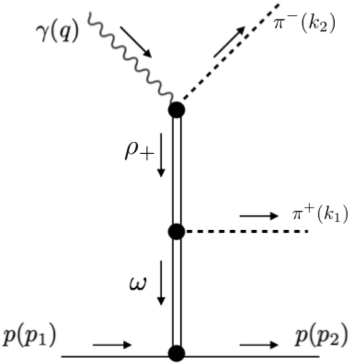
Photoproduction - pion charged channels



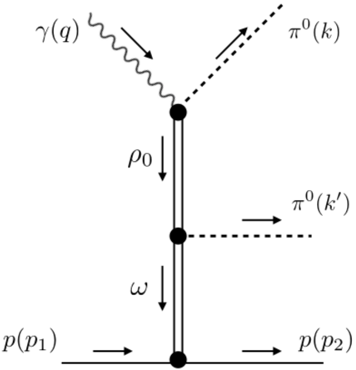


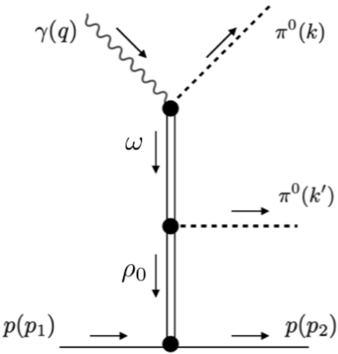
Photoproduction - $\rho\omega$-charged channels





Photoproduction - $\rho\omega$-neutral channels





Vertex factors

$$\Gamma^{\nu\sigma}_{\rho\pi\omega} = g_{\rho\pi\omega}\varepsilon^{\mu\nu\lambda\sigma} l_\mu k_\lambda$$

$$\Gamma^{\mu}_{\pi\pi\gamma} = e(k^\mu + k'^\mu)$$

$$\Gamma^{\nu\sigma}_{\rho\pi\gamma} = g_{\rho\pi\gamma}\varepsilon^{\mu\nu\lambda\sigma} q_\mu k_\lambda$$

$$\Gamma^{\nu\sigma}_{\omega\pi\gamma} = g_{\omega\pi\gamma}\varepsilon^{\mu\nu\lambda\sigma} q_\mu l_\lambda$$

$$\Gamma^{\mu}_{\rho NN} = -\left(G^V_\rho \gamma^\mu + \frac{iG^T_\rho}{2m_N}\sigma^{\mu\nu} k_\nu\right)$$

$$\Gamma^{\mu}_{\omega NN} = -\left(G^V_\omega \gamma^\mu + \frac{iG^T_\rho}{2m_N}\sigma^{\mu\nu} l_\nu\right)$$

Propagators

All propagators take the following form:

$$\Delta_{\mu\nu}(k) = \frac{-g_{\mu\nu} + \frac{k_\mu k\nu}{m^2}}{k^2 - m^2}$$

where μ, ν are vertices, k is the corresponding particle four-momentum, m is the corresponding particle mass, $g_{\mu\nu}$ is the Minkowski metric tensor.

Matrix elements and cross sections

- For each of the mentioned processes, there is a corresponding invariant amplitude M constructed using Feynman rules
- The cross sections are given by

$$\frac{d\sigma}{dt} = \frac{1}{64\pi s} \frac{1}{|p_{1cm}|^2} |M|^2$$

where s is the Mandelstam variable, p_{1cm} is the centre-of-mass four-momentum of the proton.

Thomas Jefferson National Accelerator Facility (JLab)

- Location: Newsport News, Virginia
- Stated Mission: "to provide forefront scientific facilities, opportunities and leadership essential for discovering the fundamental structure of nuclear matter; to partner in industry to apply its advanced technology; and to serve the nation and its communities through education and public outreach
- Main Research Facility: Continuous Electron Beam Accelerator Facility (CEBAF) accelerator
- 2010 - 12 GeV upgrade - Hall D added, which houses the GlueX experiment

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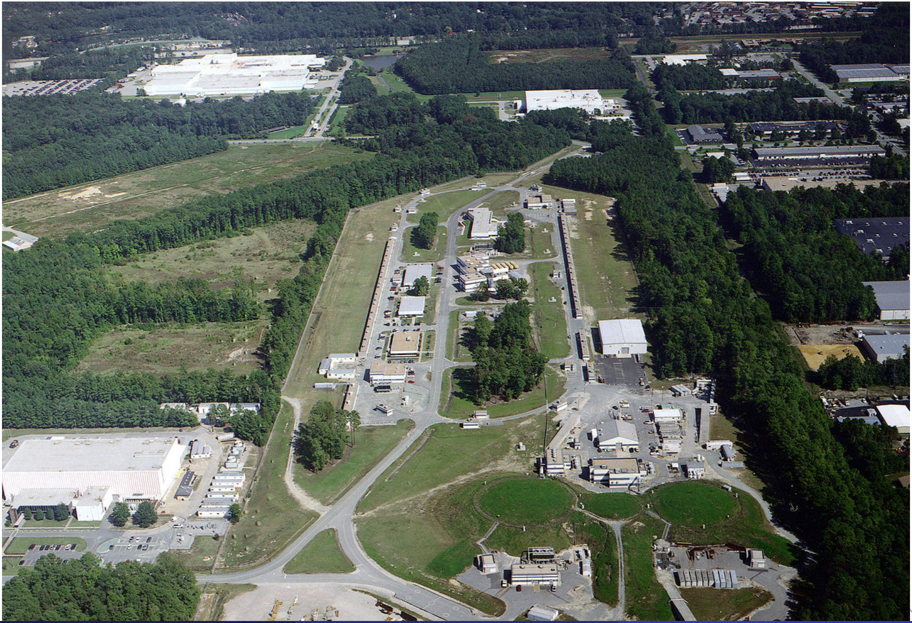

The GlueX experiment

- Primary aim: exploring the nature of confinement in QCD
- This experiment uses photoproduction to produce mesonic states.
- Usage of linearly polarized photons, thus allowing for an analysis of accumulated events
- Scheme: solenoidal hermetic detector optimized for tracking of charged particles (electron, pions, kaons, and protons) and detection of neutral particles (primarily photons)
- Coherent bremsstrahlung technique used to produce a linearly polarized photon beam
- 12 GeV electrons required and provided by the CEBAF accelerator

The GlueX experiment

Conclusion and Outlook

- Feynmann diagrams of chief contributing processes drawn and corresponding matrix elements computed
- Corresponding cross sections in the process of computation, as is the description of the as of now "unknown region".
- Based on data from JLab, the significance of each process will be assessed.

On the count of three...

...you will be wide awake feeling good and well-rested. Thank you for your attention.