Particle Physics II

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Exercise sheet VII

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Dec 16, 2011

In-class exercises

Exercise 40 *Discovery of neutral currents*

The process $\bar{\nu}_\mu e^- \to \bar{\nu}_\mu e^-$, investigated by the Gargamelle experiment at CERN, provided the first evidence for the existence of neutral currents (NC). We will read and discuss the seminal paper, and sketch the setup of the Gargamelle experiment.

Note that another neutral-current process investigated by Gargamelle — with neutrinos scattering off nuclei, producing hadrons – produced evidence for neutral currents almost at the same time, handed in for publication only two months later. Since for this process a closely related charged-current (CC) process exists, producing a muon and hadrons, the ratio NC/CC could be measured, allowing the determination of the Weinberg angle more accurately.

Links to the original papers (only available within the university network):

$\bar{\nu}_\mu e^- \to \bar{\nu}_\mu e^-$: "Search for elastic muon-neutrino electron scattering",
F J Hasert et al. 1973a Phys. Lett. 46B 121:
`http://www.sciencedirect.com/science/article/pii/0370269373904942`

$\bar{\nu}_\mu N \to \bar{\nu}_\mu +$ hadrons: "Observation of neutrino-like interactions without muon or electron in the Gargamelle neutrino experiment",
F J Hasert et al. 1973b Phys. Lett. 46B 138:
`http://www.sciencedirect.com/science/article/pii/0370269373904991`
F J Hasert et al. 1974 Nucl. Phys. B73 1:
`http://www.sciencedirect.com/science/article/pii/0550321374900388`

Home exercises

Exercise 41 *Discovery of neutral currents* **5 Punkte**

(i) What are neutral currents?

(ii) Which inconsistency of V-A theory was the main theoretical reason for predicting the existence of neutral currents?

(iii) The process $\bar{\nu}_\mu e^- \to \bar{\nu}_\mu e^-$ produced the first experimental evidence for neutral currents. Motivate why this process was optimal for this purpose - for example, why use neutrinos at all? What is the advantage of anti-neutrinos over neutrinos? Of muon neutrinos over electron neutrinos?

(iv) What were the backgrounds? Explain how the contribution of the main background source was estimated.

(v) Sketch the signature of the process of interest in a bubble chamber (label the tracks).

(vi) How does a bubble chamber work (basic principle in a few sentences)?

Exercise 42 *Ratio of D^0 meson decay widths* **5 Punkte**

D^0 mesons can decay in several ways; for example,

- $D^0 \to K^-\pi^+$
- $D^0 \to \pi^-\pi^+$
- $D^0 \to K^+\pi^-$

The quark contents of these particles are: $D^0 = c\bar{u}$, $K^- = s\bar{u}$, $\pi^- = d\bar{u}$.

(i) Draw the Feynman diagrams for the three processes and assign Cabibbo factors to the vertices.

(ii) Determine the ratio of the decay widths of these three channels.

(iii) Compare to the ratio of the literature values of the branching ratios of these three channels: BR($D^0 \to K^-\pi^+$)=0.038, BR($D^0 \to \pi^-\pi^+$)=0.0014, BR($D^0 \to K^+\pi^+$)=0.00014. The agreement is good, but not perfect. List possible reasons for the discrepancy - which effects have been neglected in this simple calculation?

Exercise 43 *Decay width of $D^0 \to K^-e^+\nu_e$* **3 Punkte**

The decay width $K^+ \to \pi^0 e^+\nu_e$ is $\Gamma = 4 \times 10^6 \mathrm{s}^{-1}$. Draw the Feynman diagram of this process, and of the decay $D^0 \to K^-e^+\nu_e$. Use the relation

$$\Gamma = \frac{G_F^2}{30\pi^3}(\Delta m)^5 V_{qq'}^2$$

to determine the decay width for $D^0 \to K^-e^+\nu_e$. Here, Δm is the mass difference of the mesons in the initial and final state, G_F the Fermi constant, and $V_{qq'}$ the Cabibbo factor.

Exercise 44 *W propagator* **7 Punkte**

Consider electron-neutrino scattering $\nu_\mu(p_1)e^-(p_2) \to \mu^-(p_3)\nu_e(p_4)$ in the context of the intermediate vector boson model. Remember that during the lectures, the W propagator has been introduced as

$$\frac{-i\left(g^{\mu\nu} - \frac{q^\mu q^\nu}{m_W^2}\right)}{p^2 - m_W^2}$$

(i) Draw the Feynman diagram and show that the matrix element of this process can be written as

$$\mathfrak{M} \sim \mathfrak{M}' = \bar{u}(p_3)\gamma_\mu(1-\gamma^5)u(p_1)\frac{-i\left(g^{\mu\nu} - \frac{q^\mu q^\nu}{m_W^2}\right)}{q^2 - m_W^2}\bar{u}(p_4)\gamma_\nu(1-\gamma^5)u(p_2)$$

(omitting constant factors).

(ii) Show that terms proportional to $\frac{q^\mu q^\nu}{m_W^2}$ (with $q^\mu = (p_1 - p_3)^\mu$ and $q^\nu = (p_4 - p_2)^\mu$) can be written as

$$\mathfrak{M}'' = \frac{m_\mu m_e}{m_W^2}\frac{1}{q^2 - m_W^2}\bar{u}(p_3)(1-\gamma^5)u(p_1)\bar{u}(p_4)(1-\gamma^5)u(p_2)$$

(iii) Explain why this term can be neglected.

Hint: Use the covariant form of the Dirac equation, $(\not{p} - m)u = 0$ and $\bar{u}(\not{p} - m) = 0$, and that the neutrinos are massless in the Standard Model.