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Quark decay top to two bodies

Decaimiento del quark top a dos cuerpos

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Abstract: Is investigated the top quark decay (t) two bodies using the spectator model. Is analyzed the decay ($t \rightarrow bW^+$) calculated theoretically the width of decay and decay fraction of the particle whose result is compared with the experimental data of the table Particle Data group. The model prediction on the decay process can be considered good as a first approach to this class of decay. This type of analysis is particularly important because it allows one hand, familiarize students with the decays of particles and on the other, open a space to introduce topics of particle physics in the introductory courses at university level.

Keywords: Decay fraction, Quark, Teaching, Width decay.

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Resumen: Se investiga el decaimiento del quark top a dos cuerpos haciendo uso del modelo espectador. Se analiza particularmente el decaimiento ($t \rightarrow bW^+$) calculando teóricamente el ancho de decaimiento y la fracción de decaimiento de la partícula, cuyo resultado es comparado con el dato experimental dado por la tabla Particle Data Group. La predicción del modelo sobre el decaimiento del quark top puede ser considerado bueno como una primera aproximación. Este tipo de análisis adquiere especial importancia ya que permite, por un lado, familiarizar a los estudiantes con los decaimientos de partículas y sus predicciones, y por otro, abre un espacio para introducir tópicos de física de partículas en los cursos introductorios a nivel universitario.

Palabras clave: Fracción de decaimiento, Quark, Enseñanza, Ancho de decaimiento.

1. Introduction

The most accepted model in the scientific community for the phenomenological description of elementary particles is the so-called standard model. At present, any model that is designed should at least reproduce the phenomenological predictions of the standard model. With the discovery of the top quark in Fermilab in 1995 by CDF and DØ A new field of research was opened for the study of the physics of the top quark. The standard model predicts the decay of the top quark in a quark bottom and a W^+ ($t \rightarrow bW^+$) which allows to carry out a research to this kind of process theoretically calculating the decay width and the decay fraction of the particle. For the theoretical calculation, the spectator model is used to compare it with the experimental data obtained from the Particle Data Group table and thus affirm the prediction of the standard model.

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Hadrons are particles composed of quarks, which are divided into two classes, the baryons and the mesons. Baryons are particles whose structure is given by the combination of a trio of quarks. The mesons they are particles composed by the combination of a quark and an antiquark. The quarks have an intrinsic property called flavor (Scientific American, 1986). This property allows to account for the decays of the mesons with weak interaction. The different flavor combinations of quarks explain the existence of different kinds of hadrons.

For the physical description of the process of decay of the quark top (t) to two bodies, the quark model or free quark model will be used, in which the active quark of the meson decays independently of the other constituents of the particle as shown in the Figure 1.

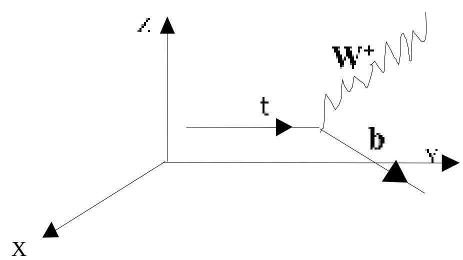

Figure 1. The active quark (t) it decays as if it were isolated from its companion.

Source: own.

2. Decay width

The width of decay of the process is defined by two terms that are the amplitude of Feynman (M) and the phase space [1-2]. Feynman's breadth has the dynamic information of the process [3] and the phase space contains the kinematic information, which depends on the mass, energy and momentum of the particles participating in the interaction [4-5]. The decay width of the top quark to two bodies is by [1].

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$$d\Gamma = \frac{1}{32\pi^2 m_t}\left|M\right|^2\left|\vec{P}_b\right|d\Omega, \tag{1}$$

The Feynman amplitude of the process is defined as:

$$M = \frac{-ig}{\sqrt{2}}V_{tb}\overline{U}(b)\gamma_\alpha\frac{(1-\gamma_5)}{2}U(t)\in^\mu (W^+), \tag{2}$$

which is calculated using the Feynman diagrams and rules for the corresponding interaction. Taking the square of the absolute value of the Feynman amplitude and replacing the spinorial products by the projection operators [6],

$$\begin{aligned}\sum_s U(t)\overline{U}(t) &= \gamma^\mu P_\mu + m_\tau = \not{P}_t + m_\tau \\ \sum_s U(b)\overline{U}(b) &= \gamma^\mu P_\mu + m_b = \not{P}_b + m_b\end{aligned} \tag{3}$$

Is obtained,

$$\left|M\right|^2 = \frac{g^2}{2}\left|V_{tb}\right|^2 Tr\left[(\not{P}_t + m_t)P_R\gamma_\mu(\not{P}_b + m_b)\gamma_\alpha P_L\right]\left[-g_{\mu\alpha} + \frac{W_\mu W_\alpha}{m_w^2}\right], \tag{4}$$

being, $P_R = \frac{(1-\gamma_5)}{2}$ y $P_L = \frac{(1+\gamma_5)}{2}$.

Evaluating the traces of the previous equation, you get the dynamics of the process:

$$\left|M\right|^2 = \frac{g^2}{2}\left|V_{tb}\right|^2\left[P_t \bullet P_b + 2\frac{(P_t \bullet W)(P_b \bullet W)}{m_w^2})\right]. \tag{5}$$

The kinematic contribution of the process, $P_t \bullet P_b; P_t \bullet W; P_b \bullet W$ it is carried out for the conservation of energy and the moment [7-8]:

$$\begin{aligned}&P_t \bullet P_b = \frac{1}{2}(m_t^2 + m_b^2 - m_w^2);\ P_t \bullet W = \frac{1}{2}(m_t^2 + m_W^2 - m_b^2); \\ &P_b \bullet W = \frac{1}{2}(m_t^2 - m_W^2 - m_b^2).\end{aligned} \tag{6}$$

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Replacing the previous equations in (5), the square of Feynman's amplitude finally remains:

$$|M|^2 = \frac{g^2}{2}|V_{tb}|^2\left[m_t^{\,2} + m_b^{\,2} - m_w^{\,2} + \frac{m_t^{\,4} - 2m_t^{\,2}m_b^{\,2} - m_W^{\,4} + m_b^{\,4}}{m_w^{\,2}})\right]. \qquad (7)$$

The decay width of the top quark is obtained by replacing (7) in (1),

$$\Gamma(\tau \to bW^+) = \frac{G_f|V_{tb}|^2}{4\sqrt{2}\,\pi\, m_t^{\,2}}\left[m_W^{\,2}(m_t^{\,2} + m_b^{\,2} - 2m_w^{\,2}) + (m_t^{\,2} - m_b^{\,2})^2\right] \bullet |\vec{P}_b|, \qquad (8)$$

where, $d\Omega = 4\pi, \mathrm{g}^2 = \frac{8m_W^{\,2}G_f}{\sqrt{2}}$ y $|\vec{P}_b| = \left(\frac{m_t^{\,2} - m_W^{\,2} + m_b^{\,2}}{2m_t}\right)^2 - m_b^{\,2}$.

The constant $|V_{tb}| = 0.999146$ is a parametrization element of the Cabibbo-Kobayashi-Maskawa matrix and G_f Fermi's constant [1]. Finally, equation (8) allows calculating the decay width of the top quark to two bodies.

3. Results

Table 1, shows the data that are used to calculate the decay width and the decay fraction of the top quark.

Name	Symbol	Value
Fermi constant	G_f	$1.16639 \times 10^{-5}\,\mathrm{GeV}^{-2}$
quark mass t	m_t	$173.5\,\mathrm{GeV}$
quark mass b	m_b	$4.65\,\mathrm{GeV}$
quark mass W^+	m_W	$80.385\,\mathrm{GeV}$
Average life of t	t	$0.5 \times 10^{-24}\,\mathrm{S}$

Table 1. Experimental data obtained from the table Particle Data Group, [9].

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The theoretical decay width of the top quark is:

$$\Gamma(t \rightarrow bW^{+}) = 1.504453913\ GeV, \tag{9}$$

and the experimental is given by,

$$\Gamma(t \rightarrow bW^{+}) = 1.99\ GeV. \tag{10}$$

In terms of seconds $^{-1}$,

$$\Gamma(t \rightarrow bW^{+}) = 2.286769947 \times 10^{24}\ s^{-1}. \tag{11}$$

The total decay width of the quark is:

$$\Gamma_{total} = \frac{1}{\tau} = \frac{1}{0.5 \times 10^{-24}\ s} = 2 \times 10^{24}\ s^{-1}. \tag{12}$$

and the decay fraction is:

$$\textbf{Decay fraction} = \frac{\Gamma(t \rightarrow bW^{+})}{\Gamma_{total}} = \mathbf{1.143}\%. \tag{13}$$

Table 2, presents a comparative table between the theoretical calculation of the decay of the top quark to two bodies using the spectator model and the experimental data obtained from the Particle Data Group table [1].

Spectator Model (%)	Experimental Data (%)	$\frac{\textbf{M. Espectator} - \textbf{D. Experimental}}{\textbf{Error}}$
1.14	0.91 ± 0.04	5σ

Table 2. The table indicates the fraction of decay predicted by the spectator model and the experimental data obtained from the Particle Data Group table, [9].

The model prediction of the decay process $(t \rightarrow bW^{+})$ It can be considered good. However, the viewer model does not consider the linked states in which the quark is found, leading to a

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limitation of the model. Models that take into account bound states [10], show the equation of the system with a potential of ligature with which results are obtained more precise with respect to the experimental data.

It is important to note that from the elements of the Cabibbo-Kobayashi-Maskawa matrix [1]

$$\mathbf{V_{ij}} = \begin{pmatrix} \mathbf{V_{ud}} & \mathbf{V_{us}} & \mathbf{V_{ub}} \\ \mathbf{V_{cd}} & \mathbf{V_{cs}} & \mathbf{V_{cb}} \\ \mathbf{V_{td}} & \mathbf{V_{ts}} & \mathbf{V_{tb}} \end{pmatrix},$$

the transitions between quarks $q \rightarrow q'$ from the same family, as shown in Table 3, are more likely to occur than those carried out in different families. Experimentally, the magnitudes of the matrix elements are given by [1]:

$$\mathbf{V_{ij}} = \begin{pmatrix} \mathbf{0.97427 \pm 0.00014} & \mathbf{0.22536 \pm 0.00061} & \mathbf{0.00355 \pm 0.00015} \\ \mathbf{0.22522 \pm 0.00061} & \mathbf{0.97343 \pm 0.00015} & \mathbf{0.0414 \pm 0.0012} \\ \mathbf{0.00886 \pm 0.00033} & \mathbf{0.0405 \pm 0.0011} & \mathbf{0.99914 \pm 0.00005} \end{pmatrix},$$

From the experimental data given by the previous matrix, the decay process $(t \rightarrow bW^{+})$, considering the constant $|V_{tb}| \approx 1$, It is more likely to occur than the processes carried out between quarks of different families.

First family	Second family	Third family
u	c	t
d	s	b

Table 3. The table indicates the classification of the different families of quarks according to the standard particle model, [9].

In general, the processes of decay that take place between quarks of the same family are more likely to occur than those that occur between quarks of different families.

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