A Study on the Form Factors of Hadrons

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ABSTRACT

The form factors of the heavy mesons like B_c^+, η_b, B^0_s, F^+, B^0, D, ψ, φ, proton and also deuteron are investigated in the framework of the statistical model for low momentum transfer Q in the range $0.01 \leq Q^2 \leq 0.1$ GeV^2.It has been observed

that the heavy-light flavour mesonic form factors show a scaling behavior in the aforesaid low Q^2 range. The proton form factor also shows almost scaling in the aforesaid range whereas the deuteron form factor shows a clear violation indicating large contribution from sea quarks and gluon sector.

terms/Keywords

Form factor, heavy meson, deuteron, momentum transfer, scaling behaviour.

Academic Discipline And Sub-Disciplines

Physics.

SUBJECT CLASSIFICATION

High Energy Physics

TYPE (METHOD/APPROACH)

Theoretical Study.

INTRODUCTION:

The study of the electromagnetic form factor is an important step towards the interpretation of the internal structure of hadrons.An idea about the form factor relates to probing inside complex hadron internal structure.Deep inelastic scattering experiments (DIS)have been carried out to explore this significant role of the form factors in determining nuclear structure.In a scattering experiment form factor is referred to the Fourier transform of structural distribution of a scattering object from real coordinate r space to momentum Q space.The result of Fourier transform implies that broader the distribution of scatterer in real space narrower is distribution of form factor in momentum space.Measurement of form factor imparts idea about charge distribution of a nucleus and hadron internal structure is revealed from Q^2 evolution of $F(Q^2)$. Different theories studying the form factors are constrained in different Q^2 region. We have studied the form factor in the region of $0.01 \leq Q^2 \leq 0.1$ GeV^2.

Most of the theoretical and experimental attempts towards the interpretation and estimation of the form factor of the hadrons indicates various aspects of mesons [1-7] and nucleons [8-13]. Early study of meson form factor for bare mass has been done by Gell Mann and later advanced studies have been done by number of Drell-Yan processes. Heavy meson form factors have been studied by a number of authors theoretically, particularly for B mesons. Grozin et al [1] have calculated asymptotic behaviour of heavy meson form factors at large recoil and discussed their applications to heavy meson pair production whereas Bakker et al [2] have obtained light front solution of form factor using valence quark contributions. The charmless B_s meson weak decay to strange meson has been studied by Faustov et al [3] in the framework of the relativistic quark model based on quasi potential approach whereas Bo et al [4] have investigated the form factors describing the strong interaction in the semi leptonic decays of mesons in heavy quark limit. Bennich et al[5] have investigated form factor $F(q^2)$ for light and heavy pseudoscalar meson with two covariant constituent quark models from light font. They have observed that ultraviolet properties of QCD dominated form factor of light pseudoscalar meson whereas infrared physics and details of quark confinement appear to be important for heavy meson below $q^2 = 10$ GeV^2. Yiao et al [6] have studied the electromagnetic form factor of kaon in light cone formalism of relativistic constituent quark model whereas Jakob et al[7]have worked on weak axial vector form factors of nucleons, Λ and Σ hyperons.

Form factor of nucleons and deuteron have also been studied by number of authors. Farrar et al [9] have obtained perturbative QCD prediction for leading twist deuteron form factor. Quattan et al [10] have extracted the nucleon form factor from world's data including the low momentum region whereas Ron [11] has analyzed the proton form factor ratio and extracted the proton charge radius using Jafferson data with Q^2 down to $\sim$0.3 GeV^2. Bernauer et al [12]have described a precise measurement of electron scattering off the proton at the momentum transfer $0.003 \leq Q^2 \leq 1$ GeV^2. Gustafson [13] have presented new data on proton form factor obtained at JLab and discussed it's implication on form factor.

Deuteron as two nucleon bound state has been the subject of many theoretical and experimental investigation. Kohl[14] have investigated the deuteron D_2 form factor comparing with that of protons and neutrons. Gilman et al [15] have studied D_2 form factor using its electromagnetic structure. Garcon et al [16] have found D_2 electromagnetic form factor in simple potential model whereas Kolling et al [17] have calculated effective field theory expansion of electromagnetic current operator. They have plotted the deuteron form factor in low Q^2 range < 0.35 GeV^2. Kizukuri [18] have analyzed hard component of D_2 electromagnetic form factor using RHOM model and obtained probability of finding quark configuration in deuteron state. They have plotted $F(Q^2)$ vs Q^2 at high range. Phillips [19] has studied the deuteron form factor ratio as well as the ratios of deuteron to nucleon form factor in chiral effective theory and made a prediction for G_e/G_Q ratio of deuteron at $Q^2 \leq 0.3$ GeV ^{2}. Rezaei et al.[20] have studied the form factors and other basic properties of deuteron using different forms of Wood-Saxon potential and compared their results with other experimental works. They have observed that the results with Wood-Saxon potential closely resemble the results of other form of potential used. Mart et al. [21] have investigated the effect of hadronic form factor on photo production of protons.

Unlike form factor of π and κ mesons, there are relatively fewer experimental information available for other heavy mesons. Hence the theoretical investigations of form factor of heavy light mesons and heavy meson are of great interest. It would be very interesting to investigate the form factor of such mesons and study $F(Q^2)$ behaviour with Q^2. In the present work we have studied the form factor of heavy mesons such as B_c^+, η_b, B^0_s, F^+, B^0, D, ψ, φ for lower values of Q^2 in the range $0.01 \leq Q^2 \leq 0.1$ GeV^2. We have also studied the proton and deuteron form factor and investigated the scaling properties.

FORMALISM:

The form factor of hadron in the ground state can be expressed as:

$$F(Q^2) = \int \Psi(r)|^2 e^{i\,Q.\,r}\, dr \qquad\qquad\qquad\qquad (1)$$

Q being the momentum transfer and r the radius vector with the origin at the center of the scattering system. The wave function for a hadron has been given input from the statistical model [22] which run as:

$$|\Psi(r)|^2 = (8/\pi^2 r_0^6)\,(r_0^2 - r^2)^{3/2}\,\theta(r_0 - r) \qquad\qquad\qquad (2)$$

where r_0 is the radius parameter of the hadron and θ is usual step function. Using this wave function in the expression (1), we come across the expression for $F(Q^2)$ as:

$$F(Q^2) = (32/\pi Q r_0^6) \int_0^{r_0} r(r_0^2 - r^2)^{3/2} \sin(Qr)\, dr \qquad\qquad\qquad (3)$$

Integrating the above expression we arrived at an expression for the form factor for a hadron as:

$$F(Q^2) = 48(Qr_0)^{-3}\, J_3(Qr_0) \qquad\qquad\qquad\qquad (4)$$

where J_3 is the Bessel function of order 3. It may be noted that the form factor here depends only upon the size parameter of the corresponding hadron. Using the radius of the mesons from Castro et al [23] we have estimated the heavy meson

form factors and the results are displayed in the Figure1. The proton form factor has been estimated with the input of proton radius as 0.865fm from the work of Hefter [24] whereas the deuteron radius which equals to 1.96fm has been given

input from the work of Wong [25]. The variation of form factor with Q^2 in the range $0.01 \leq Q^2 \leq 0.1$ GeV2 for proton and the deuteron have been displayed in Figure2.

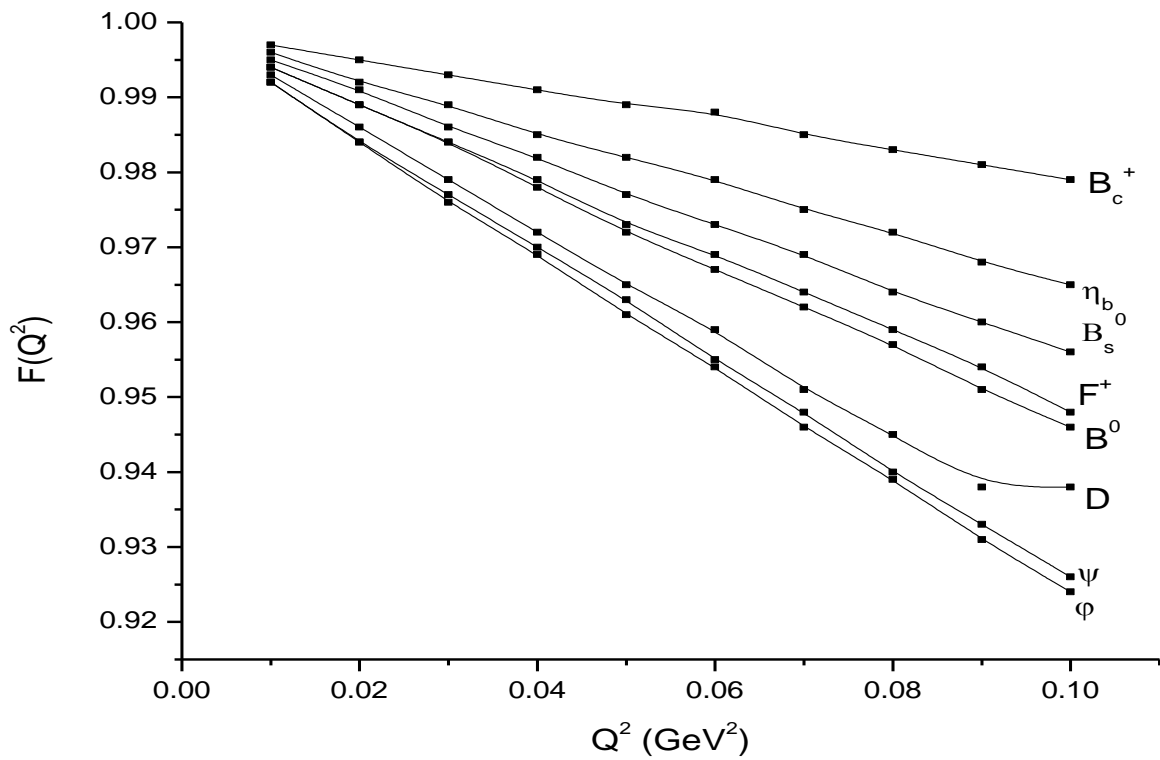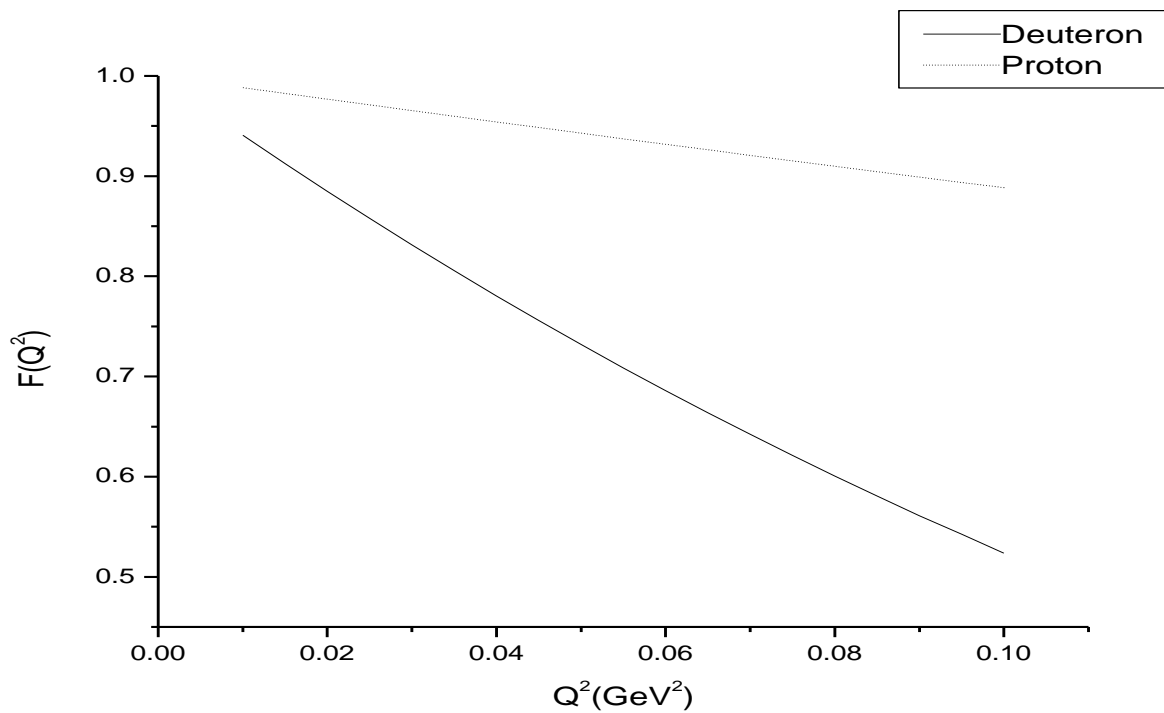**Figure1: Form factor vs Q^2 of heavy mesons**

Figure2: Form factor vs Q^2 for deuteron and proton

RESULTS AND DISCUSSIONS:

In this present work we have studied the form factor of the heavy mesons, proton and deuteron with the input of hadron wave function from the statistical model for the lower values of Q^2 in the range $0.01 < Q^2 < 0.1 \text{GeV}^2$. The model we used in the current investigation enable us to investigate the form factor using only the size parameter of the respective hadrons. It has been observed that for heavy mesons the form factors show scaling behavior to considerable extent. It is well known that the scaling violation is the manifestation of light quark sea asymmetry and gluon contribution to the form factor of a hadron [26]. It may be noted that Avila et al [27] have studied the low Q^2 wave functions of light mesons in terms of expansion in hadron like fork states fluctuation. They have studied the problem of low Q^2 structure of light mesons and have pointed out that the intrinsic valence like sea quark and gluon distribution is needed at low Q^2 scale to describe the experimental data on hadron structure. In the current investigation we have observed that for the heavy meson system like B_c^+, η_b, B^0_s, F^+, B^0, D, ψ, φ shows scaling behaviour whereas the deuteron shows a clear violation. Arnold et al [28] have measured deuteron magnetic form factor at $Q^2 = 1.21, 1.41 \text{ Gev/c}^2$ and found that it decreases rapidly. The proton form factor shows clear scaling in the aforesaid range in the present work whereas the deuteron shows a clear violation. It is interesting to note that deviation from the scaling behaviour which may be attributed to the light quark sea asymmetry has been found to be manifested by the spacial extension of the particles in the present investigation.

ACKNOWLEDGMENTS:

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