Measuring $\mathbf{F}_\pi$ at Higher $\mathbf{Q^2}$

The π^+ electric form factor is a topic of fundamental importance to our understanding of hadronic structure. It is well known [1] that the asymptotic behavior is rigorously calculable in perturbative QCD (pQCD), with value

$$F_\pi \rightarrow \frac{8\pi\alpha_s f_\pi^2}{Q^2},$$

where $f_\pi = 133$ MeV is the π^+ axial-vector decay constant. This result is in principle exact and is dependent only on the assumption of quark asymptotic freedom.

The theoretical prediction for F_π at experimentally accessible Q^2 is less certain, as soft scattering contributions, such as gluonic effects, must be explicitly taken into account, making it a difficult and poorly understood region. For example, Jakob and Kroll [2] found that a self consistent treatment of the pQCD contribution to the pion form factor in the few GeV region requires the inclusion of both Sudakov corrections and the transverse momenta of the quarks, leading to an amount which is nonetheless too small with respect to the data, and leaving room for an important role of other processes, such as higher twists. Braun, Khodjamirian, and Maul [8] performed light-cone sum rule calculation up to twist 6, and found that the non-perturbative hard contributions of higher twist strongly cancel the soft components, even at relatively modest Q^2. The models of references [3, 4, 5] obtain good agreement with the experimental data over a broad region of Q^2 by incorporating a confining potential, which dominates at low Q^2, and a QCD-based interaction, which dominates at high Q^2, that takes the form of a one gluon exchange potential or dynamic chiral symmetry breaking. Finally, Maris and Tandy [6] use the Bethe-Salpeter plus Schwinger-Dyson equations to determine the pion form factor. In this case, the model's parameters are adjusted to reproduce m_π, f_π, and $<\bar{q}q>$ and then the predicted F_π is found to have reasonable agreement with the existing data. Reliable experimental data are clearly needed to delineate the role of hard versus soft contributions at intermediate Q^2, and so aid the further development of these models.

The situation for the nucleonic form factors is even more complicated. Firstly, their asymptotic behavior is not predicted in such an unequivocal manner. Secondly, the larger number of valence quarks in the nucleon means that the asymptotic regime will be reached at much higher values of Q^2, at least 100 GeV^2/c^2. Finally, the lower power of Q^2 in the pion form factor means that the relevant cross section will be more easily accessible. Because of these reasons, if one believes that it is worthwhile to pursue the measurement of a hadronic form factor where perturbative effects may become apparent, the pion form factor is the obvious first choice.

Unfortunately, the experimental knowledge of F_π is poor. Many of the experimental difficulties in extracting the pion form factor are well understood. Briefly, one must obtain high quality $p(e,e'\pi^+)n$ data, in which the contribution of the pion pole diagram is optimized by measuring the π^+ in parallel kinematics at the smallest possible $|t|$, and by performing an L/T separation. The complications of the proton target are further taken into account by using a model, such as the one of Ref. [10]. The value of $F_\pi(Q^2)$ is obtained via a fit of the σ_L model to the data. The high quality, continuous electron beam of Jefferson Lab makes

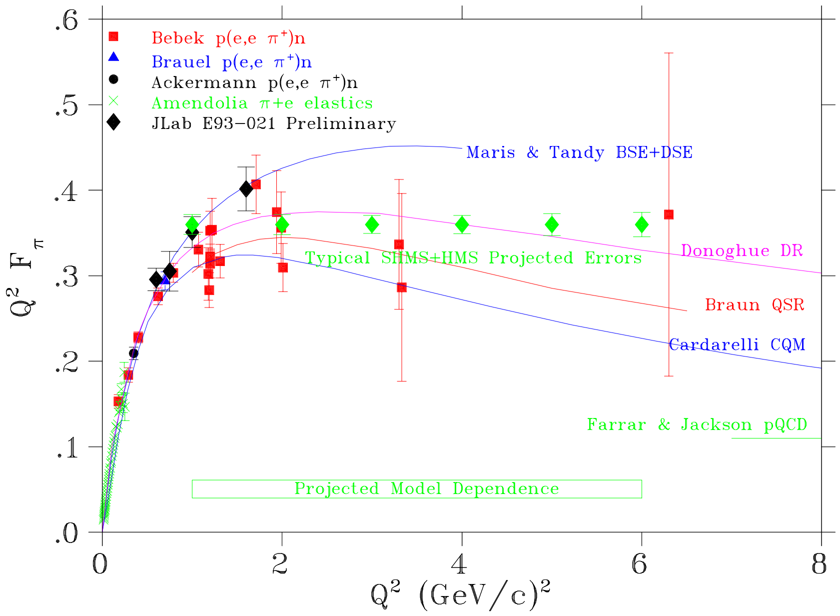

Figure 1: Q^2F_π data that could be obtained with the HMS+SHMS after 100 days of beam, and comparison with existing data and a number of model calculations.

it the only place to seriously pursue these measurements. In 1997, E93-021 obtained data up to $Q^2 = 1.6$ GeV^2/c^2 in Hall C, and we expect to extend these measurements to $Q^2 = 2.6$ GeV^2/c^2 in 2002. However, a challenge of the QCD-based models in the most rigorous manner requires the construction of the SHMS and the electron beam upgrade.

The higher energy of the electron beam will enable one to obtain data at a higher value of the invariant energy W, resulting in lower values of $|t|$, thus enhancing the t-pole part of the cross section and the L/T ratio. Also the models used to extract the pion form factor from data on the proton are believed to be more reliable at higher values of W.

Since the pion will be emitted at rather small angles with the beam, the proposed SHMS spectrometer is essential for this measurement because of its excellent 5.5^o forward angle capability, combined with its good angular resolution (to control systematic errors in the L/T separation) and sufficient missing mass resolution to cleanly separate $p(e, e'\pi^+)n$ events from $p(e, e'\pi^+)n\pi^0$. The figure shows the expected error bars that could be obtained with the SHMS+HMS combination and a 11 GeV beam after 100 days of running time. It is easily seen that the CEBAF upgrade would allow a very significant advance in the understanding of the pion form factor.

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