Pion Electroproduction at Large Q^2

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Abstract

Measurements of the charged pion electric form factor are a sensitive means of testing the validity of a variety of QCD-inspired models, and so are of considerable importance. The combination of a 12 GeV electron beam and a pair of high momentum spectrometers will allow its extraction at fairly high Q^2 with dramatically smaller error bars than the existing Cornell measurements.

The π^+ electric form factor at large Q^2 has been a topic of interest for quite some time. Farrar and Jackson [1] showed in 1979 that at asymptotic Q^2, the spacelike pion form factor is linked to the pion decay constant $f_\pi = 132$ MeV via

$$F_\pi(Q^2) \to \frac{2f_\pi^2}{bQ^2 ln|Q^2|.}$$

This is an exact pQCD result, provided that one believes in asymptotic freedom. There has been much theoretical interest in finding the Q^2 value at which this asymptotic value will be reached, especially because the smaller number of valence quarks in the pion means that the asymptotic regime will be reached at lower values of Q^2 than for the nucleon form factors. However, it is generally expected that the asymptotic region is well beyond the capabilities of Jefferson Lab, even after the energy upgrade [2].

The most interesting question then, as far as Jefferson Laboratory is able to address, is the description of $F_\pi(Q^2)$ in the gap between the “soft” and “hard” regions. This is a difficult and poorly understood region. For example, Jakob and Kroll [3] 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. The models of reference [4] 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. However, Munz et al. [5]

Table 1: Possible parallel kinematics for an extraction of the pion form factor via the $p(e,e'\pi^+)n$ reaction with the HMS and SHMS.

E_e	$E_{e'}$	$\theta_{e'}$	ϵ	$\|t\|$	p_π	θ_π
$Q^2 = 1.00$ (GeV/c)^2, W=2.60 GeV						
4.500	0.834	29.906	0.327	0.022	3.650	-6.285
5.750	2.084	16.607	0.619	0.022	3.650	-9.020
$Q^2 = 2.00$ (GeV/c)^2, W=3.00 GeV						
6.500	1.107	30.556	0.301	0.043	5.367	-5.798
8.250	2.857	16.747	0.598	0.043	5.367	-8.494
$Q^2 = 3.00$ (GeV/c)^2, W=3.20 GeV						
8.000	1.414	29.840	0.313	0.068	6.548	-5.930
10.000	3.414	17.047	0.590	0.068	6.548	-8.451
$Q^2 = 4.00$ (GeV/c)^2, W=3.20 GeV						
8.500	1.381	33.936	0.282	0.110	7.058	-5.985
11.750	4.631	15.582	0.661	0.110	7.058	-9.685
$Q^2 = 5.00$ (GeV/c)^2, W=3.30 GeV						
9.500	1.501	34.432	0.274	0.142	7.920	-5.869
12.000	4.001	18.568	0.576	0.142	7.920	-8.826
$Q^2 = 6.00$ (GeV/c)^2, W=3.20 GeV						
9.500	1.315	40.541	0.232	0.212	8.070	-5.743
12.000	3.815	20.856	0.548	0.212	8.070	-9.148
$Q^2 = 7.00$ (GeV/c)^2, W=3.00 GeV						
9.250	1.193	46.926	0.205	0.331	7.878	-5.900
12.000	3.943	22.175	0.559	0.331	7.878	-10.108

find that their results at Q^2 above a few (GeV/c)^2 depend strongly on the covariant treatment of the boost of the outgoing meson, and lead to a large uncertainty in the momentum transfer at which the asymptotic prediction is reached.

Until 1978, the pion form factor in the spacelike region was, experimentally, an active and mature field, after which time it went into dormancy due to the limitations of the existing electron accelerators. The high quality CEBA beam provides the means to revive this important field of study, especially after the energy upgrade, provided that a new high momentum magnetic spectrometer is constructed.

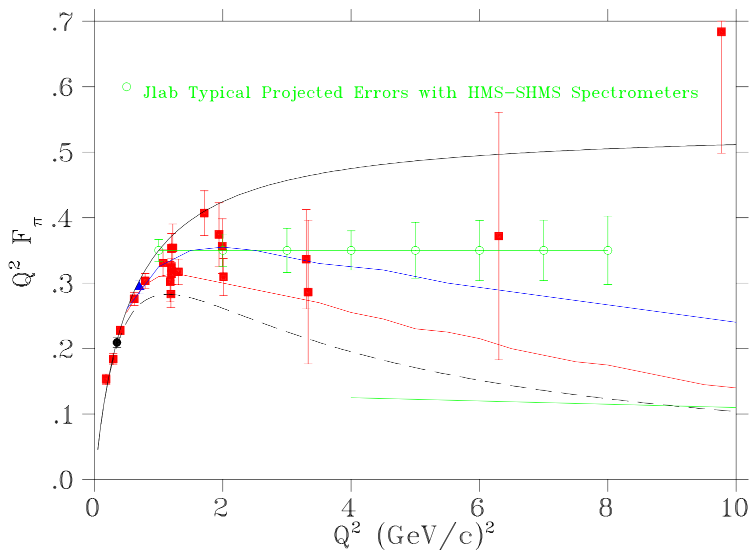

Figure 1: The existing and proposed Q^2F_π data and comparison with a number of model calculations. From top to bottom, the models are: monopole, Isgur & L.Smith, Jacob & Kisslinger, dipole, and the pQCD asymptotic prediction of Farrar & Jackson.

Many of the experimental difficulties in extracting the pion form factor are well understood. Briefly, one requires a high quality electron beam and two moderate resolution magnetic spectrometers to study the $p(e, e'\pi^+)n$ reaction. The contribution of the pion pole diagram is optimized by measuring the π^+ in parallel kinematics at the smallest possible $|t|$, and by performing a L/T separation. The complications of the proton target are further taken into account by using a model, such as the one of Ref. [6], to extrapolate the data to the pion pole at the experimentally inaccessible value of $t = m_\pi^2$.

The table shows the parallel kinematics possible assuming a 12 GeV beam in Hall C with the existing HMS and the proposed SHMS in small angle mode. In order to be as close to the pion pole as possible (maximizing the contribution of the pole diagram and minimizing the error in the extrapolation) the pion momenta are always higher than the corresponding electron momenta, and so the SHMS is used to detect the π^+ and the HMS the recoil electron. An accurate measurement, therefore, requires that the focal plane instrumentation of these spectrometers is kept as flexible as possible, so that proper particle identification can be performed with the spectrometers in these roles.

Because of error magnifications in the extraction of the form factor, it is necessary that the proposed SHMS have good angular resolution (to control systematic errors in the L/T separation) and that the combination of the two spectrometers have sufficient missing mass resolution to cleanly separate $p(e,e'\pi^+)n$ events from $p(e,e'\pi^+)n\pi^0$. Superimposed on the figure are the error bars anticipated from such a measurement, assuming that the L/T ratio drops not quite as rapidly as $1/Q^2$, that experimental systematic error can be controlled to the 3% level, and a 1% statistical error. Theoretical systematic error in the form factor extraction is not included.

It is easily seen that the CEBAF upgrade would allow a very significant advance in the understanding of the pion form factor, with only a moderate beamtime investment. From the table, it is clear that the high Q^2 limitation to the proposed measurements is due primarily to the assumed 12 GeV beam energy, and not the two spectrometers. In fact, measurements utilizing 16 GeV electron beam could be profitably obtained with the HMS+SHMS combination up to approximately $Q^2 = 10$ (GeV/c)^2.

References

[1] G.R. Farrar, D.R. Jackson, Phys. Rev. Lett. **43** (1979) 246.

[2] J.F Donoghue, E.S. Na, Phys. Rev. D **56** (1997) 7073.

[3] R. Jakob, P. Kroll, Phys. Lett. **315B** (1993) 463.

[4] O.C. Jacob, L.S. Kisslinger, Phys. Lett. **243B** (1990) 323.
P.C. Tiemeijer, J.A. Tjon, Phys. Lett. **277B** (1992) 38.
H. Ito, W.W. Buck, F. Gross, Phys. Lett. **287B** (1992) 23.

[5] C.R. Munz et al., Phys. Rev. C **52** (1995) 2110.

[6] M. Vanderhaeghen, M. Guidal, J.-M. Laget, Phys. Rev. C **57** (1998) 1454.