Measurement of the generalized form factors near threshold via $\gamma^* p \to n\pi^+$ at high Q^2

Pion threshold photo- and electroproduction has a long history with continuous interest from both experimental and theoretical sides. These studies are of interest because the vanishing pion mass approximation in chiral symmetry, supplemented by current algebra, allows exact predictions to be made for the threshold cross sections, so-called Low-Energy Theorems (LET). As a prominent example, the LET establish a connection between charged pion electroproduction and the axial form factor of the nucleon. In the real world, the finite pion mass cannot be ignored ($m_\pi/m_N \sim 1/7$). The study of finite pion mass corrections to LET was a topical field in high energy physics in the late sixties and early seventies before the discovery of Bjorken scaling in Deep Inelastic Scattering (DIS) and the advent of Quantum Chromodynamics (QCD).

We report the extraction of the multipole E_{0+} near pion threshold in the charged single pion electroproduction channel ($ep \to e'n\pi^+$) with a nearly 6 GeV electron beam incident on a proton target. This experimental data set allowed us to study near-threshold pion production at photon virtualities Q^2 up to ~ 4.2 GeV^2. This experiment is a major step forward and requires very good energy resolution in order to approach the pion production threshold, where the p-wave contribution of the M_{1+} multipole is suppressed.

In the one-photon-exchange approximation, the single pion electroproduction cross section factorizes as

$$\frac{d^4\sigma}{dQ^2 dW d\Omega^*_\pi} = |J|\Gamma_v \frac{d^2\sigma_u}{d\Omega^*_\pi} ,$$

where

$$|J|\Gamma_v = \frac{\alpha}{2\pi^2 Q^2}\frac{(W^2 - M_p^2)E_f}{2M_p E_i(1-\epsilon)} ,$$

and

$$\frac{d^2\sigma_u}{d\Omega^*_\pi} = \sigma_T + \epsilon\sigma_L + \epsilon\sigma_{TT}\cos 2\phi^*_\pi + \sqrt{2\epsilon(1+\epsilon)}\sigma_{LT}\cos\phi^*_\pi .$$

The parameter ϵ represents the virtual photon polarization and Γ_v is the flux of virtual photons. E_i and E_f are energies of the initial and scattered electrons respectively. The angle ϕ^*_π is the azimuthal rotation of the $n\pi^+$ plane with respect to the electron scattering plane (e, e'), Ω^*_π is the solid angle of pion in the center-of-mass frame, and W is the invariant mass. For an electron beam and a proton target, the center-of-mass differential cross section $d^2\sigma_u$ depends on the virtual photon polarization (ϵ) through four structure functions : $\sigma_T + \epsilon\sigma_L$ and the interference terms σ_{TT} and σ_{LT}.

We extracted the E_{0+} multipole near pion threshold for $W = 1.11 - 1.15$ GeV at high $Q^2 = 2.12 - 4.16$ GeV^2 with vanishing and actual pion masses and by taking into account different G_E^n form factor parametrizations. The results for vanishing pion mass show that E_{0+}/G_D is approximately 0.3 GeV^{-1} and almost Q^2-independent at threshold. This amplitude is larger than the MAID2007 prediction and a little smaller than the LCSR prediction, which has a steeper Q^2 dependence. The Q^2-independent behavior of the data may be caused by the LCSR method, which is based on the chiral limit $m_\pi \to 0$. The results from the multipole fit method are consistent with the LCSR method for the lowest W bin. Independent of pion mass and G_E^n parametrization considerations, the $n\pi^+$ channel is dominated by the transverse s-wave multipole E_{0+}. A lack of asymmetry data near the pion threshold does not allow us to extract the generalized form factor G_2, but the E_{0+} multipole extraction allows us to obtain G_1, and the axial form factor G_A. Figure 1 shows the Q^2-dependent G_1 (left) and G_A (right) near-pion threshold. These data give strong constraints on theoretical developments, especially on the extrapolation away from threshold and away from the chiral limit.

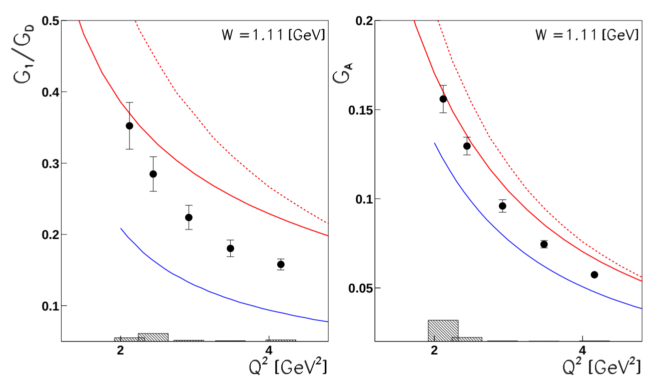

FIG. 1: (Color online) Q^2 dependence for $n\pi^+$ of G_1 normalized by the dipole form factor (left) and axial form factor G_A. Various models are presented, blue solid line: MAID2007 for E_{0+}/G_D, and red solid-dash lines: LCSR (red solid is the LCSR calculation using experimental electromagnetic form factors as input and red dash is pure LCSR). The shaded bars show the estimated systematic uncertainties.

K. Park *et al.*, Phys. Rev. C**85**, 035208 (2012).