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QCD RESULTS FOR NUCLEON COMPTON SCATTERING[1]

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Abstract

We present QCD results for the exclusive processes $\gamma N \to \gamma N$ (N = p, n) at large momentum transfer and compare them to data for the proton.

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The amplitude for a wide-angle exclusive process is given by the convolution of distribution amplitudes ϕ summarizing soft, hadronic physics and a hard-scattering amplitude T of collinear, constituent partons.[1] For nucleon Compton scattering

$$\mathcal{M}_{hh'}^{\lambda\lambda'}(s,t) = \sum_{d,i} \int [dx][dy]\, \phi_i(x_1,x_2,x_3) T_i^{(d)}(x,h,\lambda;y,h',\lambda') \phi_i^*(y_1,y_2,y_3), \qquad (1)$$

where x_a (y_a) are momentum fractions of the quarks in the initial (final) state proton, the λ's and h's are helicities, and i and d label proton Fock states and Feynman diagrams. Both ϕ and T depend on a factorization scale μ, but since we work to lowest order, we shall neglect this dependence. The integral in eq. (1) is somewhat like a loop integral. In particular, internal partons can go on mass shell for certain (x,y), producing an imaginary part. The amplitude is still infrared safe,[2] because on-shell internal partons move in a direction that tears the nucleon apart.

This paper summarizes our results for the cross sections for nucleon Compton scattering,[3] which is the simplest experimentally accessible process with an imaginary part. The predictions for polarized cross sections and phase of the amplitude can be verified in ep collisions,[4] because Compton scattering with a virtual incident photon also contributes to the reaction $e\mathrm{N} \to e\mathrm{N}\gamma$. This would be interesting, because the non-zero phase is a non-trivial prediction of perturbative QCD. For unpolarized proton Compton scattering there is wide-angle data[5] with center-of-mass energy-squared $4.6\,\mathrm{GeV}^2 < s < 12.1\,\mathrm{GeV}^2$. Since the distribution amplitude is not known, we will present results using four distribution amplitudes suggested by QCD sum rules.[6, 7, 8, 9] These ϕ's implicitly assume that all moments except the first six vanish. The validity of such an assumption at accessible values of s remains to be tested.

The space allotted permits no discussion of the calculation. The difficult aspects of the calculation are technical, especially coping with the on-shell singularities in the momentum-fraction integrals. Wherever possible, we integrate singular integrands analytically. For some diagrams poles remain in the domain of numerical integration, and we use the technique developed in Ref. 10. For details, please consult Ref. 3.

Polarized cross sections and phases are presented in Ref. 3. Here we present only unpolarized cross sections. Our results for $s^6 d\sigma/dt$ are plotted in Fig. 1 for the proton and neutron. Four different distribution amplitudes are shown, CZ[6] (dashed lines), COZ[7] (solid lines), KS[8] (dotted lines), and GS[9] (dot-dashed lines). Fig. 1(a) also includes the experimental data.[5] The agreement is encouraging, especially in light of the uncertainties discussed below.

According to the dimensional counting rules,[11, 1] $s^6 d\sigma/dt$ should be independent of s. In QCD several effects lead to deviations from this rule. First, there is the running of the QCD coupling constant, which we have fixed at $\alpha_\mathrm{S} = 0.3$, as in other calculations.[12, 4] The cross section is sensitive to this choice, because it is proportional to α_S^4. Second, there is the running of the distribution amplitude. The spread of the curves gives a qualitative estimate of this effect. Third, there are mass effects; the nucleon masses is not negligible compared to the photon energies in Ref. 5. Finally,

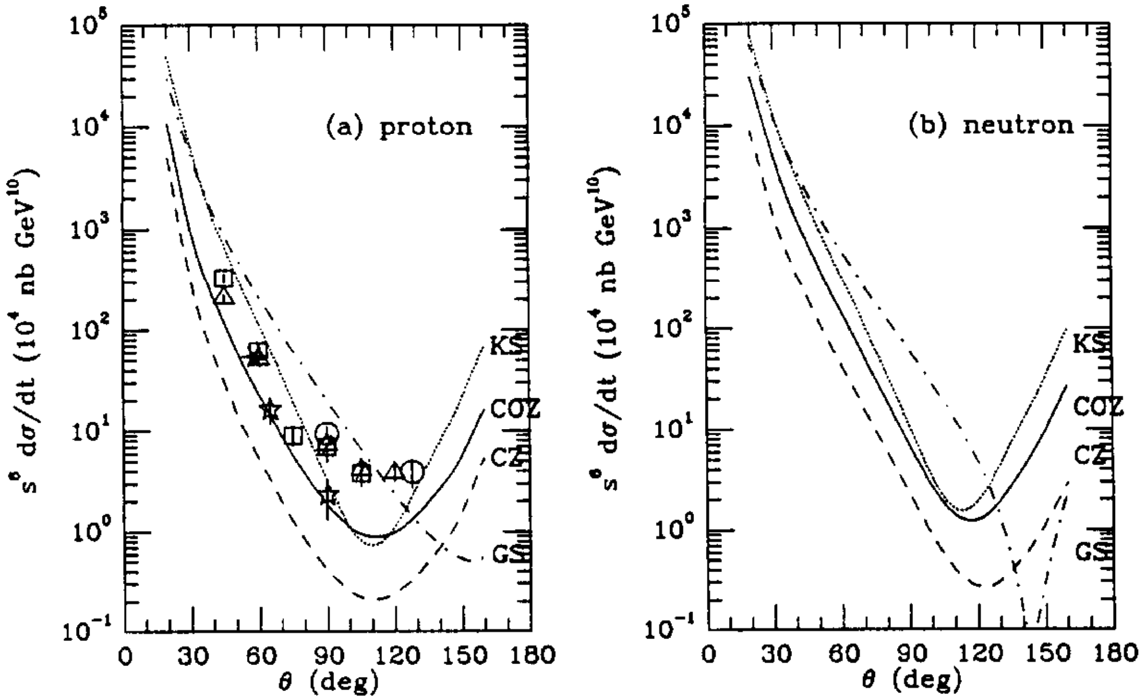

Figure 1: Differential cross sections for (a) protons and (b) neutrons. The experimental data[5] in (a) are at $s = 4.63$ GeV (circles), $s = 6.51$ GeV (triangles), $s = 8.38$ GeV (squares), $s = 10.26$ GeV (five-pointed stars), and $s = 12.16$ GeV (asterisk).

there are higher twist effects, coming from scattering of non-valence Fock states.

The largest systematic uncertainty in our predictions comes from the nucleon decay constant. The cross section is proportional to f_{N}^4, and we have used the value $f_{\mathrm{N}} = (5.2 \pm 0.3) \times 10^{-3}$ GeV^2 suggested by QCD sum rules.[6,8] Accepting the error estimate at face value yields a 23% uncertainty in the cross sections. On the other hand, using the value suggested by quenched lattice QCD,[13] $f_{\mathrm{N}} = (2.9 \pm 0.6) \times 10^{-3}$ GeV^2, would reduce the cross section by a factor of 9.

Since Ref. 3 was finished, there have been theoretical and experimental developments of interest. Neglecting the transverse size of the hadron suggests the factorization scale[1] $\mu = \min\{x_i\}Q$, which is problematic near $x_a = 0$. Better estimates of the soft regime[14] show that the transverse size introduces a natural infrared cutoff to factorization, $\mu = \max\{q_g(x,y), 1/|b_\perp|\}$. Calculations taking these "Sudakov" effects into account exist for the proton form factor[15] and $\gamma\gamma \to \mathrm{p}\bar{\mathrm{p}}$ (Ref. 16). A proposed experiment at SLAC[17] promises to acquire high statistics at high energy for $\gamma\mathrm{p} \to \gamma\mathrm{p}$ and $\gamma\mathrm{p} \to \pi\mathrm{N}$. It makes sense, therefore, to improve our results along the lines of Ref. 15, 16 and to extend the calculations to exclusive pion photoproduction.

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