Helicity-dependent photoabsorption cross sections on the nucleon

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We examine the energy dependence of single-meson photoproduction as it contributes to the Gerasimov-Drell-Hearn (GDH) sum rule. For photon energies above approximately 1 GeV, through the full resonance region, this contribution dominates the proton sum-rule integral. Over the same energy region, our single-pion contribution to the neutron sum rule also qualitatively follows a recent set of GDH data. The predicted neutral-pion contribution to the neutron sum rule is nearly zero above 1 GeV in this result. The SAID and Mainz (MAID) results are very different for a number of observables over this energy region.

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The Gerasimov-Drell-Hearn (GDH) sum rule [1] states that

$$\frac{2\pi^2\alpha}{M^2}(\kappa_{p,n})^2 = \int_{\nu_0}^{\infty} \frac{\sigma_{3/2}(\nu) - \sigma_{1/2}(\nu)}{\nu} d\nu, \qquad (1)$$

where κ_p (κ_n) is the proton (neutron) anomalous magnetic moment, ν is the laboratory photon energy, M is the nucleon mass, and α is the fine-structure constant. The left-hand side represents the single-nucleon contribution to the spin-flip amplitude, whereas the right-hand side involves an integration over the difference of helicity 3/2 and 1/2 γ-nucleon total cross sections. This relation can be derived on the basis of fundamental principles (such as gauge and Lorentz invariance) and is expected to be satisfied exactly. Although early results [2] suggested a possible violation, careful measurements and estimates of the important high-energy contribution have greatly reduced this discrepancy [3]. It now seems unlikely that the sum rule and the fundamental assumptions used in its derivation are violated.

Early estimates of the GDH integral used phenomenological single-pion photoproduction amplitudes and crude estimates for two-pion and other-meson production. Particularly important are the two-pion production contributions, as they dominate the total photoabsorption cross section over much of the resonance region. To illustrate this point, the SAID [4] and MAID [5,6] single-pion contributions to the total photoabsorption cross section have been plotted in Fig. 1. Some of these two-pion channels have been measured separately and would appear to give a significant contribution to the GDH sum rule over much of the resonance region [10]. However, a quite different conclusion results if the measured helicity-dependent total cross section ($\sigma_{3/2} - \sigma_{1/2}$) is compared with its single-pion contribution over the resonance region. Single-pion predictions for the SAID and MAID analyses are again plotted for comparison in Fig. 2. The contribution from η-meson photoproduction is significant near its threshold because of the dominant $N(1535)$, but is expected to contribute little at higher energies. Its contribution, obtained from a SAID fit to η-photoproduction data, is shown in Fig. 3. The contributions from kaon photoproduction are also small, based on fits to the existing data.

In the proton sum rule, both the SAID and MAID single-pion predictions account for almost the entire result for photon energies above 1 GeV. The SAID results extend over a larger energy region, but qualitatively agree with MAID where comparisons are possible. The SAID single-pion contribution to the neutron sum rule also tends to follow the GDH measurement. Here, however, the MAID fit diverges from the data, which (assuming a correct single-pion part) would imply a large and increasing two-pion contribution to the neutron. The dip near 900 MeV is seen in both the SAID and the MAID single-pion contributions to the neutron sum rule and does not appear to be the result of a problem in the multipole analysis. However, other quantities predicted by the SAID and MAID fits are often quite different, particularly above 1 GeV in the photon energy. In Figs. 4(a) and 4(b), we compare the SAID and MAID fits with the $p\pi^0$ differential cross section and $p\pi^-$ Σ data.

Conclusions regarding single-pion contributions to the neutron sum rule are much less solid, as the underlying single-pion photoproduction database is less complete and precise than the available proton-target data. In particular, there are almost no $\gamma n \to n\pi^0$ data of any kind. This component of the neutron sum rule is therefore purely a prediction, based on amplitudes extracted from the $p\pi^0$, $n\pi^+$, and $p\pi^-$ channels. Interestingly, these amplitudes conspire to cancel in the SAID solution, giving a negligible $n\pi^0$ contribution to the neutron sum rule above about 1 GeV. The $n\pi^0$ and $p\pi^-$ contributions from SAID and MAID are compared in Fig. 5. We therefore find that the $p\pi^-$

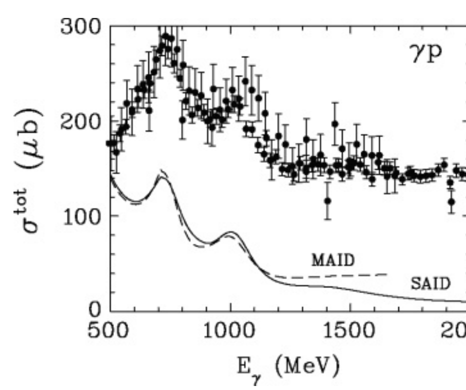

FIG. 1. Single-pion photoproduction contributions to the total cross section for a proton target: SAID SM05 [7] (solid) and MAID2003 [5] (dashed) analyses. Proton photoabsorption data from Ref. [9].

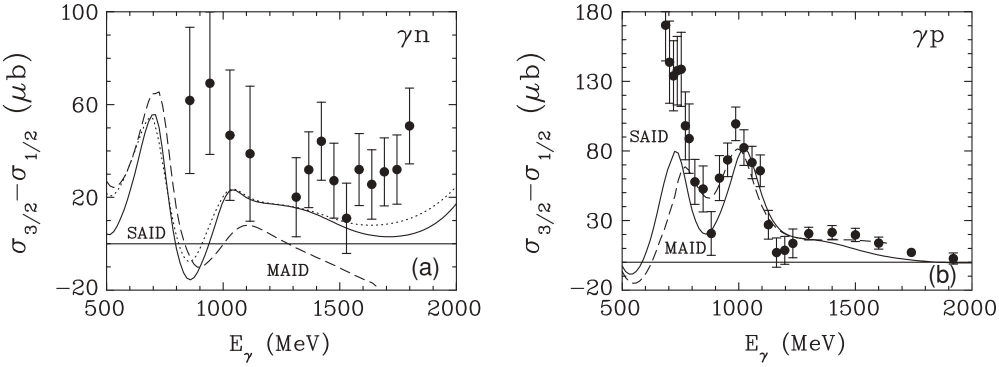

FIG. 2. Single-pion photoproduction contributions to the (a) neutron and (b) proton GDH sum rules from the SAID SM05 [7] (solid), recently published SM02 [4] (dotted), and MAID2003 [5] (dashed) analyses. GDH data from Refs. [3,11].

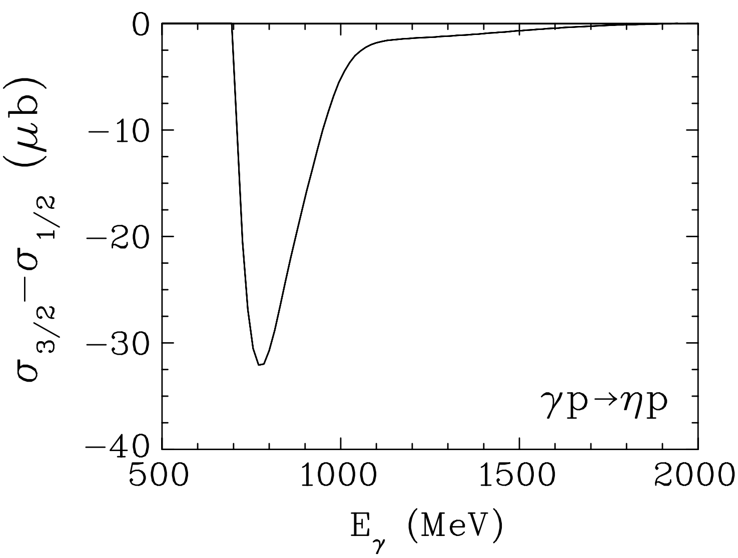

FIG. 3. SAID single-η photoproduction contribution to the proton sum rule.

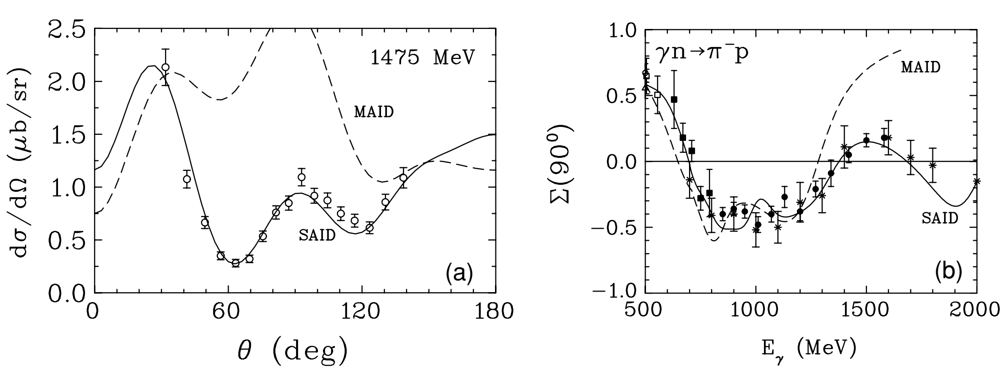

FIG. 4. Single-pion photoproduction above 1 GeV: (a) $p\pi^0$ differential cross section at 1475 MeV and (b) $p\pi^-$ Σ beam asymmetry at 90°. Cross-section data from Ref. [8] and Σ data are from Ref. [12]. Predictions from SAID SM05 [7] (solid) and MAID2003 [5] (dashed) analyses.

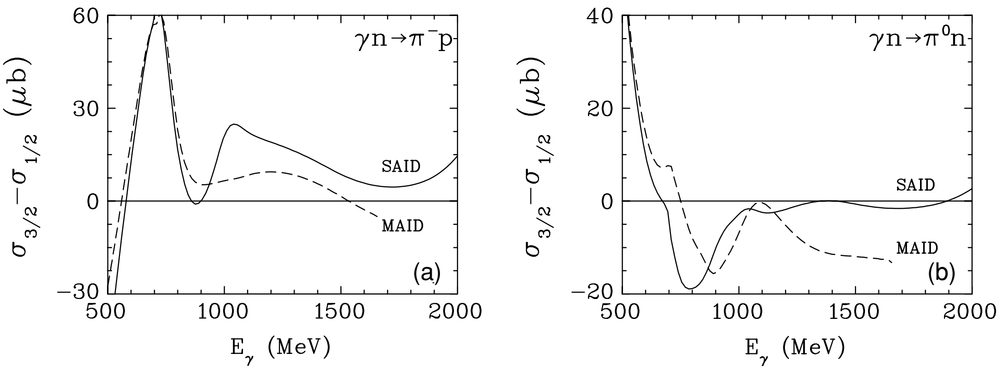

FIG. 5. Single-pion photoproduction for (a) $\gamma n \to \pi^- p$ and (b) $\gamma n \to \pi^0 n$. Predictions are given for the SAID SM05 [7] (solid) and MAID2003 [5] (dashed) analyses.

component is mainly responsible for the qualitative agreement shown in Fig. 2(a). Both the SAID solution and data suggest an upward trend near 2 GeV. Examining the behavior of our fits at the high-energy limit, we cannot claim this to be more than an artifact. Comparing our fits SM02 and SM05, we find that the fit influenced by more recent high-energy ELSA and JLab data (SM05) displays a less pronounced upward trend. If the highest energy measurement is more than a fluctuation, it would signal a resonance contribution not contained in either the SAID pion-nucleon [13] or the pion-photoproduction [4] analyses. Given that a similar trend is not seen in the proton GDH data, this resonance contribution would decay to γn much more readily than γp.

In summary, data that have been measured to verify the GDH sum rule may be equally valuable in understanding both resonance physics and the transition between resonance and Regge-dominated regions. In Ref. [11], the Regge-inspired high-energy parametrization of Bianchi and Thomas [14] was shown to overlap the neutron sum-rule data over much of the resonance region. Here we see that this agreement extends to the single-pion contribution as well. For the proton sum rule, the matching of the data and high-energy fits occurs above 2 GeV. The apparent cancellation of large multipion contributions to the proton GDH sum rule suggests an underlying principle that deserves further investigation. Certainly it would be interesting to extend the single-pion analysis to find out how high in energy the trend of Fig. 2 continues. Work on this project is in progress. The comparison of proton and neutron GDH data, versus the single-pion photoproduction contribution, suggests the existence of states coupling more strongly to γn than γp. However, the sparse neutron-target database is a limiting factor at energies at which the neutron GDH data show an upturn. These features should motivate further measurements of two-pion production and single-meson photoproduction off the neutron.

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