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Gravitational form factors of the proton from near-threshold vector meson photoproduction

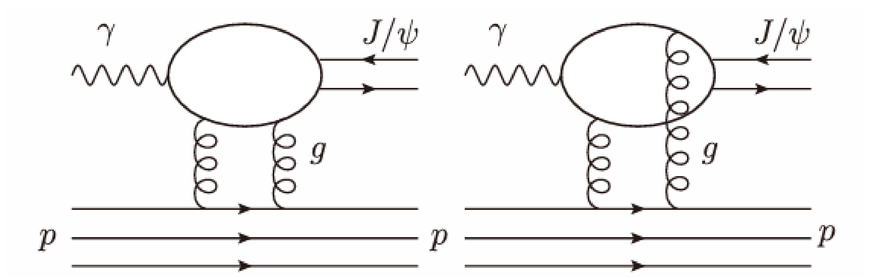
Wang XiaoYun(王晓云)[1]， Zeng Fancong (曾凡聪)[2]

1 Lanzhou University of Technology　　2 Institute of High Energy Physics and University of Chinese Academy of Sciences

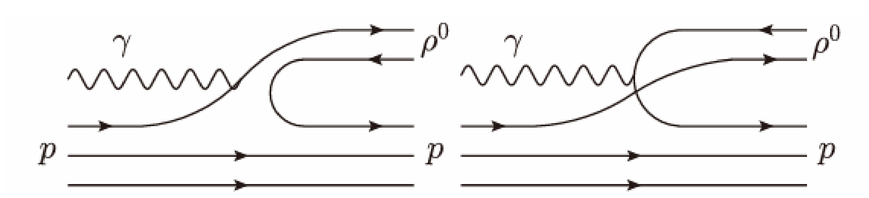
Introduction

The proton, as the most stable hadron, has long been a central focus of research in particle and nuclear physics, particularly regarding its internal structure and properties. The most fundamental aspects of the proton's internal nature can be described through form factors characterizing its electromagnetic, weak, and gravitational interactions. The sum gravitational form factors of the proton, which are divided into quark and gluon contributions, are measurable quantities defined purely for the total system. However, to this day, the GFFs of the proton, which are closely connected to the origin of its mass and internal dynamics, have not been well determined. A major reason for this is that gravitational interactions are extremely weak—far weaker than both electromagnetic and weak interactions—placing them beyond the reach of direct experimental measurement.

To address this problem, we employ an indirect strategy by using vector mesons as probes to investigate the internal structural properties of the proton through the elastic scattering process of vector mesons with protons ($Vp \to Vp$). At low energy scales, the $Vp \to Vp$ process can be connected, via the vector meson dominance model, to the near-threshold photoproduction process ($\gamma p \to Vp$). Indeed, studies indicate that the scalar gluon operator is dominant in the production amplitude of a heavy quarkonium (such as J/ψ) and sensitive to the gluonic structure of the proton [5]; and light vector meson (such as ρ^0) photoproduction mainly reflects the quark part of the GFFs [13] because the exchange of a scalar quark-antiquark pair is not suppressed and far exceeds the contribution of scalar gluon exchange [13, 31]. On the other hand, in the indirect measurement of GFFs in exclusive processes, besides DVCS, $\gamma\gamma^*$ reaction, time-like Compton scattering, and double DVCS [11], vector meson production experiments are regarded as advantageous, and abundant experiment data have been collected by comparison.



(a)The gluon exchange mechanisms



(b)The quark exchange mechanisms

Methods and results

The GFFs of the proton can be written as

$$G(t) = MA(t) - \frac{t}{4M}(A(t) - 2J(t) + D(t))$$

where M is the proton mass. The form factors,$A(t), J(t), D(t)$ can be used to derive the proton mass distribution, angular momentum distribution, and mechanical properties, respectively. The proton GFFs are the sum contributions of the quark and gluon GFFs, which are given as

$$G_{q/g}(t) = MA_{q/g}(t) - \frac{t}{4M}(-B_{q/g}(t) + D_{q/g}(t)) + M\overline{C}_{q/g}(t)$$

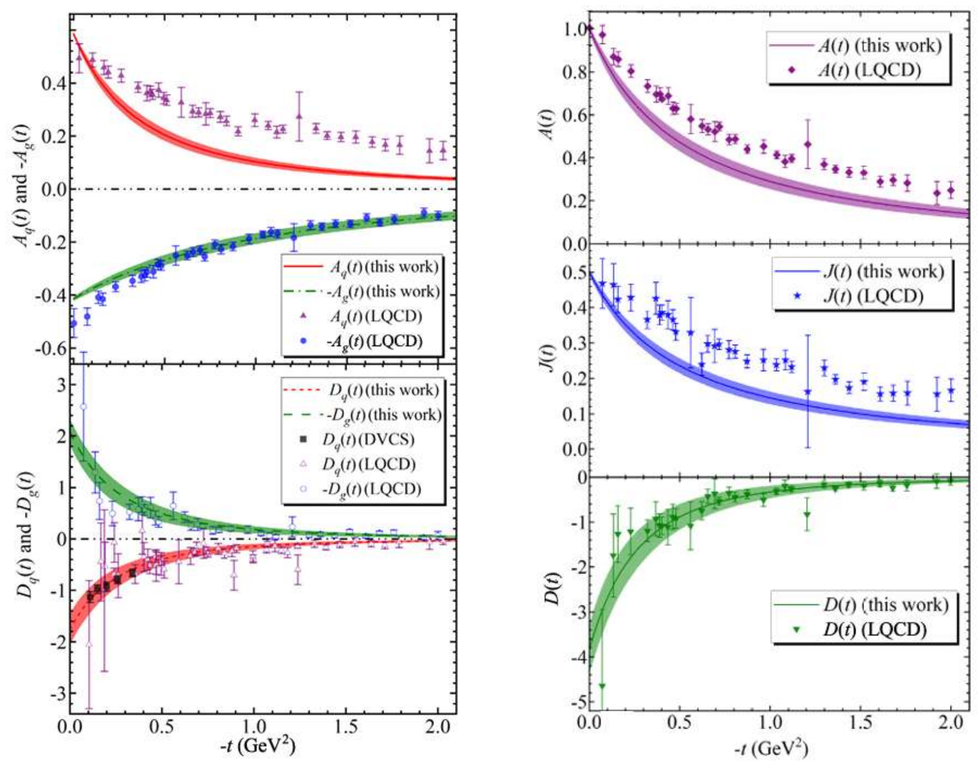
Typically, the photoproduction cross section of the vector meson is given by

$$\frac{\mathrm{d}\sigma_{\gamma p\to Vp}}{\mathrm{d}t} = \frac{1}{64\pi W^2}\frac{1}{|\mathbf{p}_\gamma|^2}|\mathcal{M}_{\gamma p\to Vp}|^2.$$

The amplitudes of light and heavy quarkonia are primarily attributed to the quark and gluon parts of the EMT of QCD, respectively, which can be written as

$$\mathcal{M}_{\gamma p\to Vp} = -Q_e c_2 2Mg^2\left\langle P'\left|T_{00}^{q(g)}\right|P\right\rangle.$$

Three GFFs of the proton, including $A(t), J(t), D(t)$, as functions of t are compared with LQCD results and the result extracted from DVCS experiments.



Summary

We achieve precise determination of the so-called "last global unknown property" of the proton D-term and complete GFFs. The near-threshold vector meson photoproduction (NTVMP) process should be considered as an indispensable method to access the gluon and quark GFFs. A number of other recent studies (e.g., arXiv:2506.07554, 2503.08847, 2502.16689, 2411.13398) agree that the results presented in our work is one of the most important findings in the field of gravitational form factors (GFFs), and have compared their own results with ours.

References

1. Xiao-Yun Wang, Fancong Zeng, Jiyuan Zhang, Gravitational form factors of the proton from near threshold vector meson photoproduction Chinese Phys. C 48 054102 (2024).
2. Xiao-Yun Wang, Fancong Zeng, and Quanjin Wang, Gluon gravitational form factors of protons from charmonium photoproduction, Chin. Phys. C 47, 074101 (2023).
3. Xiao-Yun Wang, Fancong Zeng, Quanjin Wang and Li Zhang, First extraction of the proton mass radius and scattering length |αρ0p| from ρ0 photoproduction, Science China Physics Mechanics and Astronomy 66(3) 232012 2023.