Near-threshold photon-proton production of J/ψ and Υ

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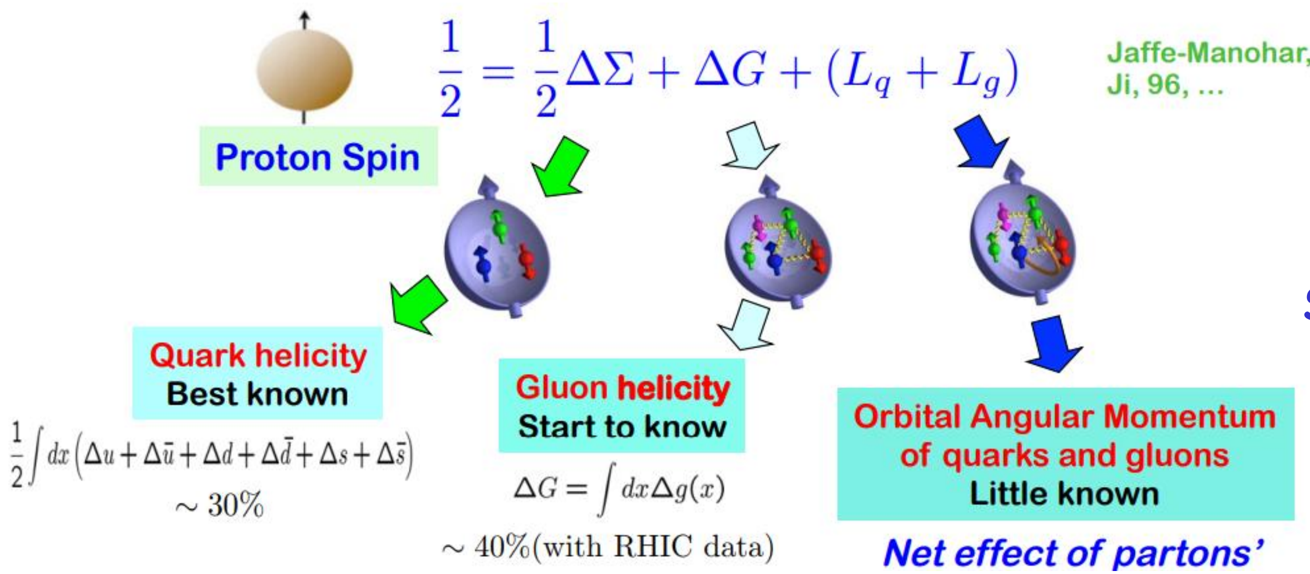
outline

- GPD factorization framework
- Gluon GPDs in a spectator model
- Parameter determination, derived quantities, and cross sections
- Summary

proton spin structure



spin decomposition

classification

Phys. Rev. Lett. 113, 012001 (2014)

$$l_z = -\int dx d^2\boldsymbol{k}_\perp \frac{\boldsymbol{k}_\perp^2}{M^2} F_{1,4}(x,0,0,\boldsymbol{k}_\perp^2,0;\mathcal{W}_{\text{straight}}/\mathcal{W}_{\text{LF}})$$

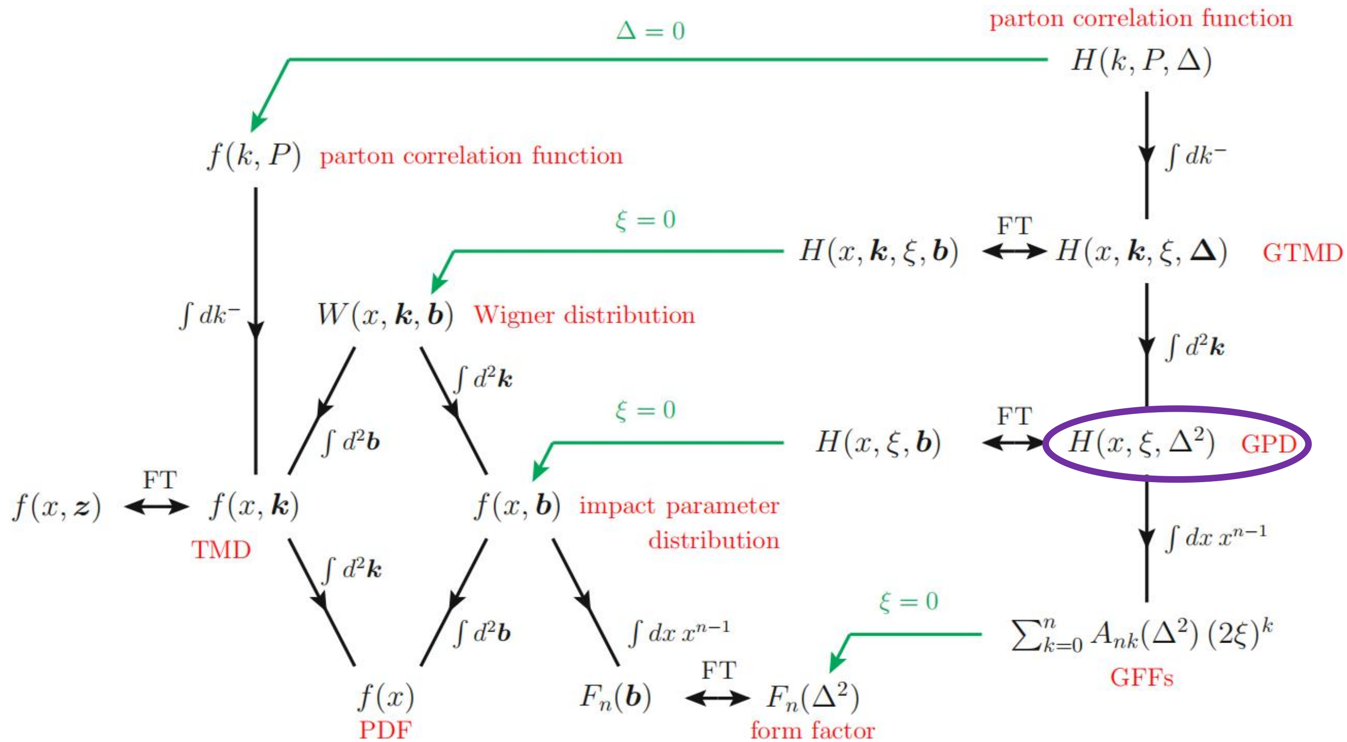
$\vec{J}^q_{\text{Bel}}$		$\vec{J}^g_{\text{Bel}}$	
$\vec{S}^q_{\text{Ji}}$	$\vec{L}^q_{\text{Ji}}$	$\vec{J}^g_{\text{Ji}}$	
$\vec{S}^q_{\text{gik}}$	$\vec{L}^q_{\text{gik}}$	$\vec{L}^g_{\text{gik}}$	$\vec{S}^g_{\text{gik}}$
$\vec{S}^q_{\text{gic}}$	$\vec{L}^q_{\text{gic}}$	$\vec{L}^g_{\text{gic}}$	$\vec{S}^g_{\text{gic}}$

kinetic orbit
angular momentum
(OAM)

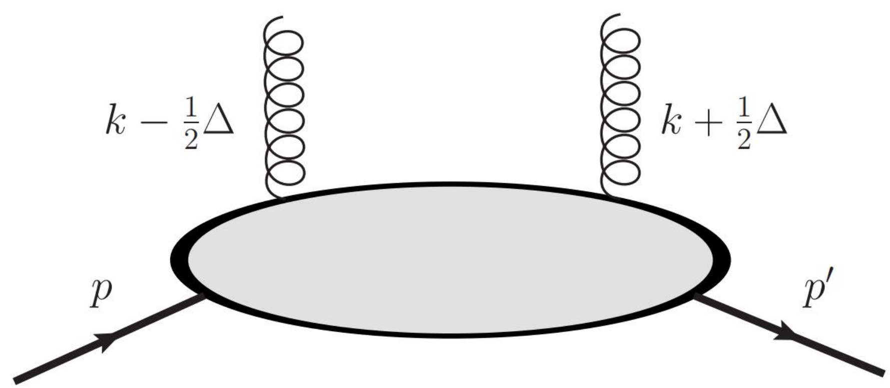
canonical OAM

$$L_z = \frac{1}{2}\int dx\{x[H(x,0,0)+E(x,0,0)] - \tilde{H}(x,0,0)\}$$

in a most generalized picture

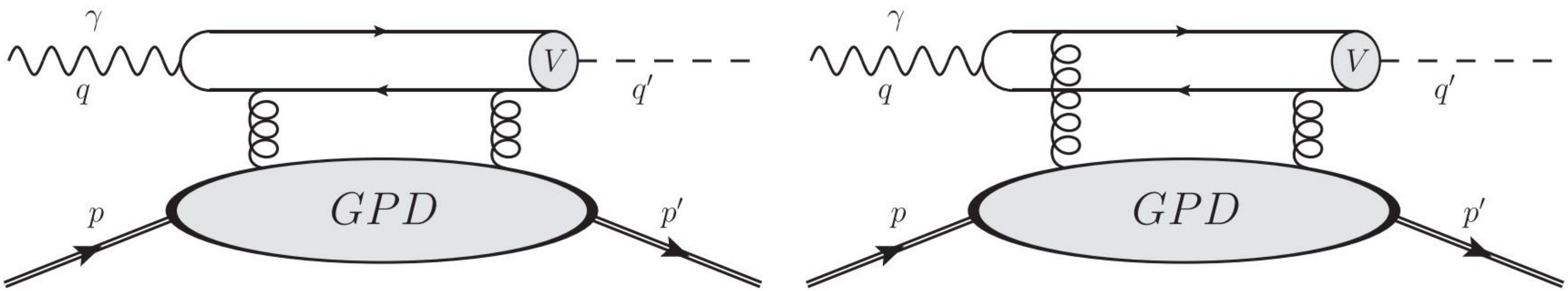


off-forward matrix element of a bilocal operator



$$F^{g[ij]}(x, \Delta; \lambda, \lambda') = \int \frac{dz^-}{2\pi} e^{ik\cdot z} \langle p'; \lambda' | F_a^{+j}\left(-\frac{z}{2}\right) \times \mathcal{W}_{ab}\left(-\frac{z}{2}; \frac{z}{2}\right) F_b^{+i}\left(\frac{z}{2}\right) | p; \lambda \rangle |_{z^+=0^+, \boldsymbol{z}_\perp = \boldsymbol{0}_\perp}$$

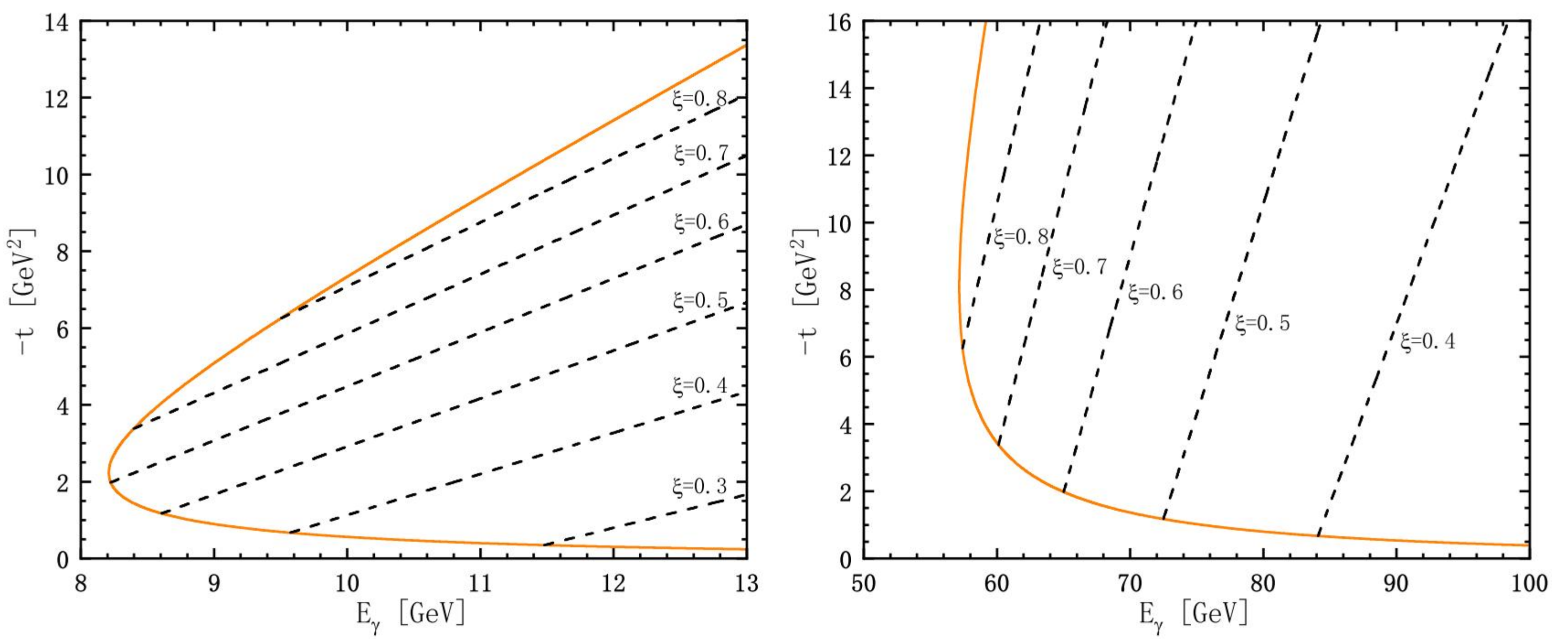
exclusive photoproduction of heavy quarkonium



JLab, EIC, EicC...

$$q^2 = -Q^2 = 0$$

kinematically allowed regions



GPD framework for near-threshold photoproduction of heavy quarkonium

differential cross section

Phys. Rev. D 103, 096010 (2021)

$$\frac{d\sigma}{dt} = \frac{\alpha_{\mathrm{EM}} e_{\mathrm{Q}}^2}{4(W^2 - M^2)^2} \frac{(16\pi\alpha_S)^2}{3M_V^3} |\psi_{\mathrm{NR}}(0)|^2 |G(t,\xi)|^2$$

$$|G(t,\xi)|^2 = \frac{4}{\xi^4}\left\{\left(1 - \frac{t}{4M^2}\right)E_2^2 - 2E_2(H_2 + E_2) + (1-\xi^2)(H_2+E_2)^2\right\},$$

second Mellin moments of GPDs

$$\int_0^1 dx x H^g(x,\xi,t) = A^g(t) + (2\xi)^2 C^g(t) \equiv H_2(t,\xi)$$

$$\int_0^1 dx x E^g(x,\xi,t) = B^g(t) - (2\xi)^2 C^g(t) \equiv E_2(t,\xi)$$

twist-2 gluon GPDs for an unpolarized proton

$$F^g(x,\Delta;\lambda,\lambda') = \delta_\perp^{ij} F^{g[ij]}(x,\Delta;\lambda,\lambda') = \frac{1}{2}\bar{u}(p',\lambda')\left(\gamma^+ H^g(x,\xi,t) + \frac{i\sigma^{+\mu}\Delta_\mu}{2M} E^g(x,\xi,t)\right) u(p,\lambda)$$

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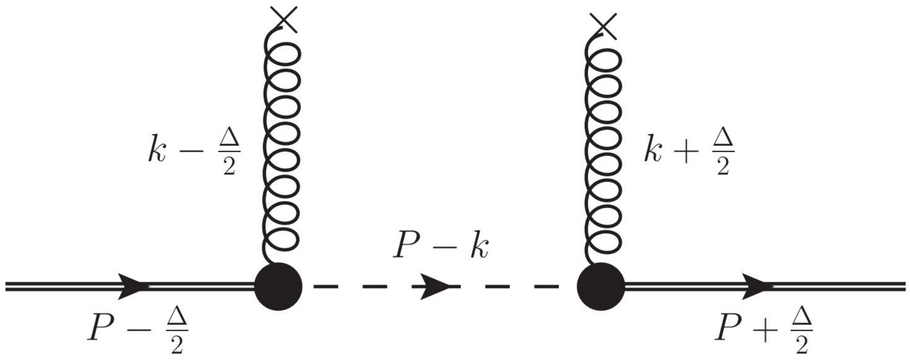
The spectator model



kinematics for gluon GPDs in the spectator model

nucleon-gluon-spectator vertex

Eur. Phys. J. C (2020) 80:733

$$\mathcal{Y}^{\pm}_{\mu,bc} = \delta_{bc}\left[g_1^{\pm}\gamma_\mu + g_2^{\pm}\frac{i}{2M}\sigma_{\mu\nu}p^\nu\right]$$

$$g^{\pm}_{1,2} \equiv g_{1,2}\left(\boldsymbol{k}_\perp \pm \frac{\boldsymbol{\Delta}_\perp}{2}\right) = \kappa_{1,2}\frac{(k\pm\frac{\Delta}{2})^2}{|(k\pm\frac{\Delta}{2})^2-\Lambda_X^2|^2}$$
$$= -\kappa_{1,2}\frac{(1-x)[(\boldsymbol{k}_\perp\pm\frac{\boldsymbol{\Delta}_\perp}{2})^2+L_X^2(0)]}{[(\boldsymbol{k}_\perp\pm\frac{\boldsymbol{\Delta}_\perp}{2})^2+L_X^2(\Lambda_X^2)]^2},$$

analytical expressions

$$H(x,\xi,t) = \begin{cases} \frac{1}{64M^2\pi^3\boldsymbol{\Delta}_\perp^2}\int d^2\boldsymbol{k}_\perp \frac{N_H^{0\leq x\leq\xi}}{D_{\mathrm{SM}}^{0\leq x\leq\xi}}, & 0\leq x\leq\xi, \\ \frac{1}{16M^2\pi^3\boldsymbol{\Delta}_\perp^2}\int d^2\boldsymbol{k}_\perp \frac{N_H^{\xi<x\leq 1}}{D_{\mathrm{SM}}^{\xi<x\leq 1}}, & \xi<x\leq 1, \end{cases}$$

$$E(x,\xi,t) = \begin{cases} \frac{1-\xi^2}{8M\pi^3\boldsymbol{\Delta}_\perp^2}\int d^2\boldsymbol{k}_\perp \frac{N_E^{0\leq x\leq\xi}}{D_{\mathrm{SM}}^{0\leq x\leq\xi}}, & 0\leq x\leq\xi, \\ \frac{1-\xi^2}{4M\pi^3\boldsymbol{\Delta}_\perp^2}\int d^2\boldsymbol{k}_\perp \frac{N_E^{\xi<x\leq 1}}{D_{\mathrm{SM}}^{\xi<x\leq 1}}, & \xi<x\leq 1, \end{cases}$$

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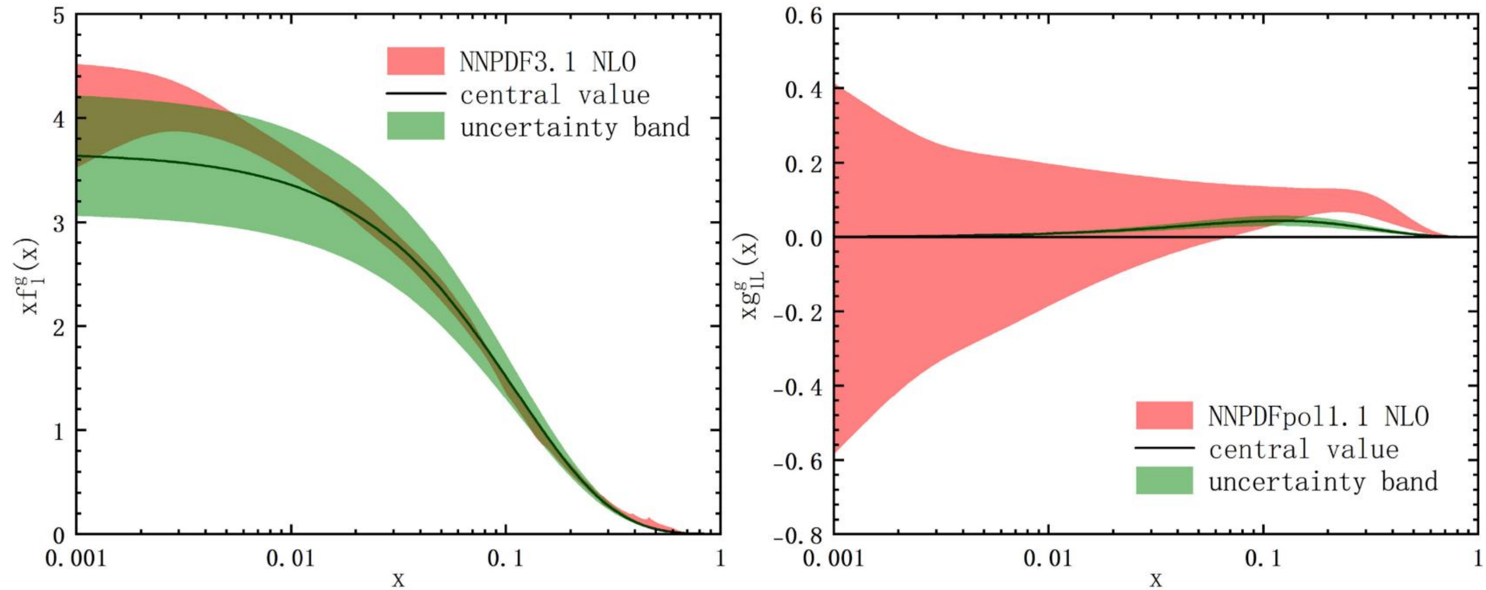
Parameter determination

simultaneous fit



parameter values with uncertainties

Parameter	Central value	Uncertainty
κ_1	6.503	± 0.388
κ_2	3.591	± 0.199
M_X	1.341	± 0.028
Λ_X	0.474	± 0.014

derived quantities

average longitudinal momentum fraction

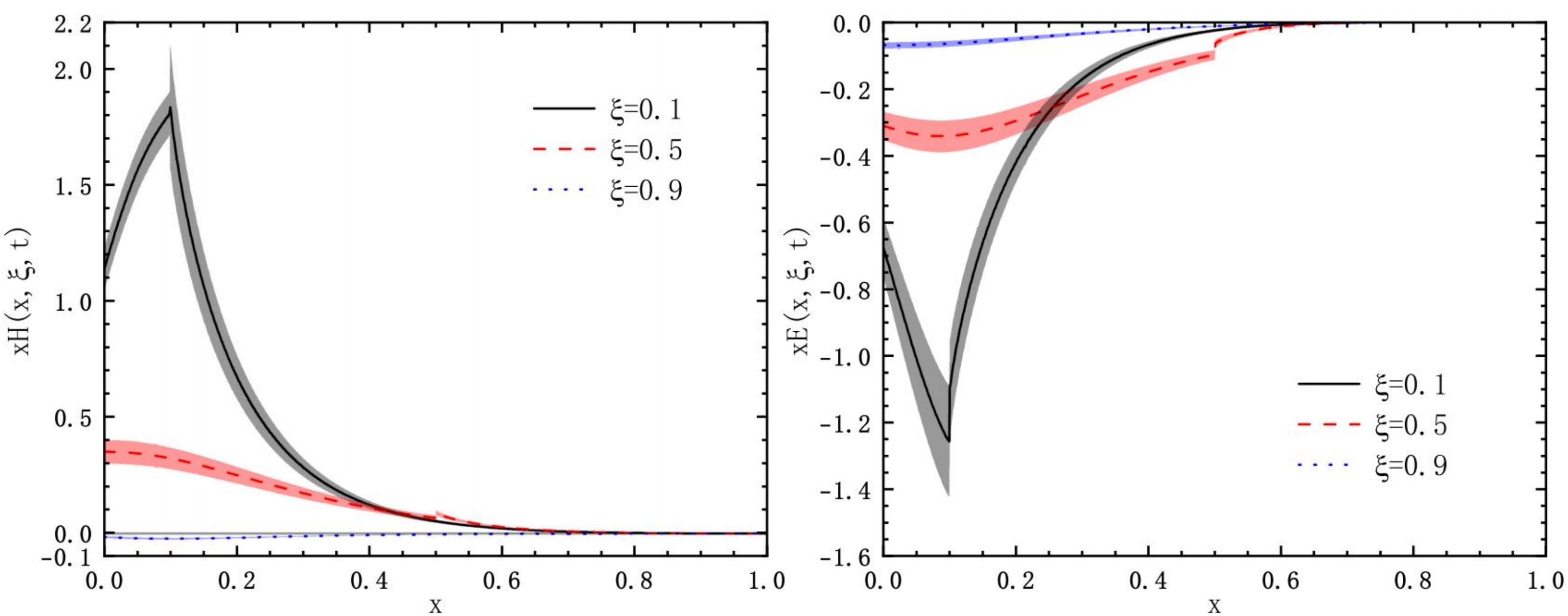
$$\langle x \rangle_g = \int_0^1 dx x\, f_1^g(x) = 0.421 \pm 0.060$$

total gluon angular momentum

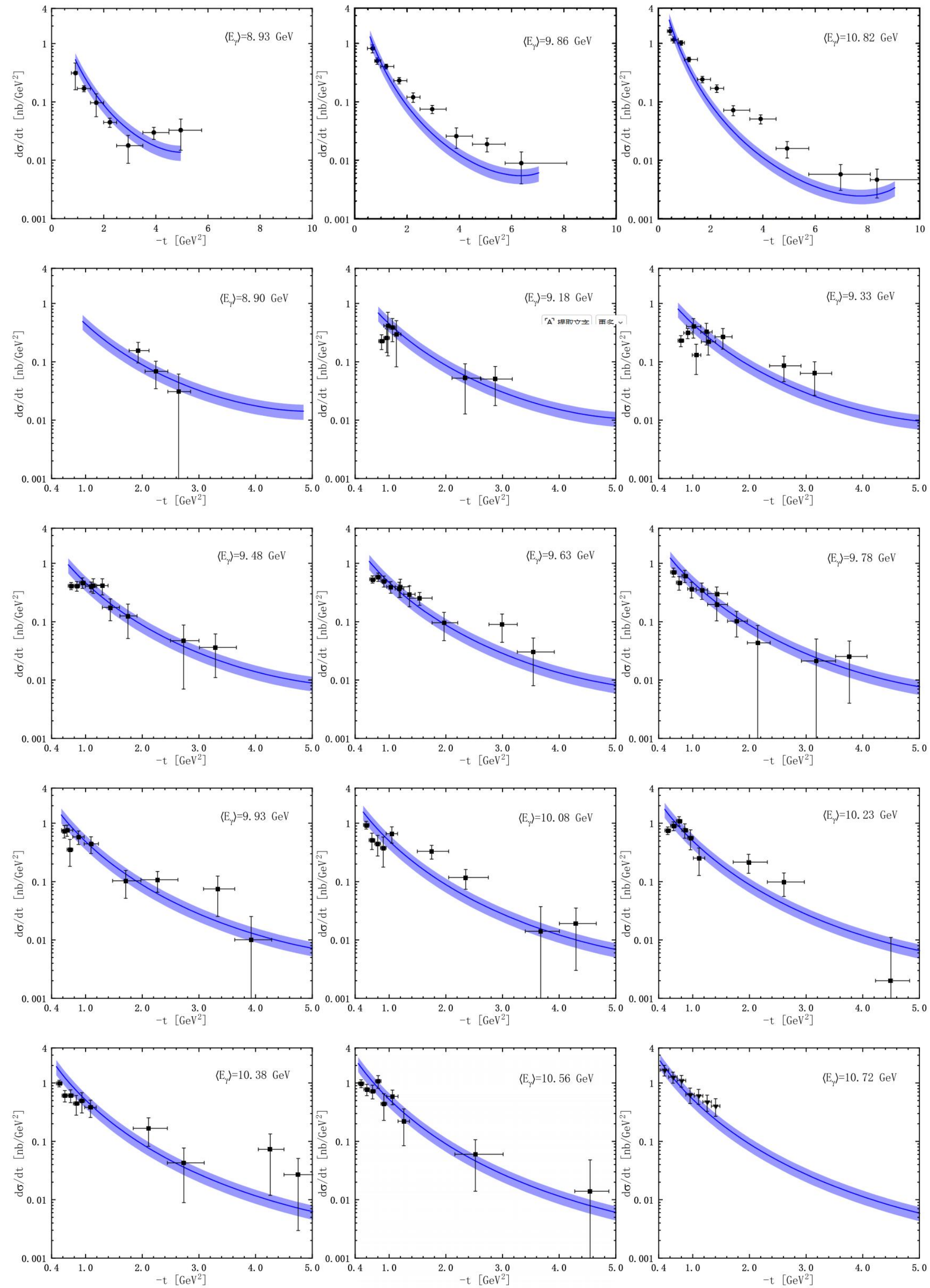
$$J_z^g = \frac{1}{2}\int_0^1 dx x [H^g(x,0,0) + E^g(x,0,0)] = 0.090 \pm 0.015$$

	$\langle x \rangle$	J	$\frac{1}{2}\Delta\Sigma$	L
u^+	0.359(30)	0.211(22)(5)	0.432(8)	−0.221(26)(5)
d^+	0.188(19)	0.050(18)(5)	−0.213(8)	0.262(20)(5)
s^+	0.052(12)	0.016(12)(5)	−0.023(4)	0.039(13)(5)
c^+	0.019(9)	0.009(5)(0)	−0.005(2)	0.014(10)(0)
g	0.427(92)	0.187(46)(10)		
Tot.	1.045(118)	0.473(71)(14)	0.191(15)	0.094(51)(9)

Phys. Rev. D 101, 094513 (2020)

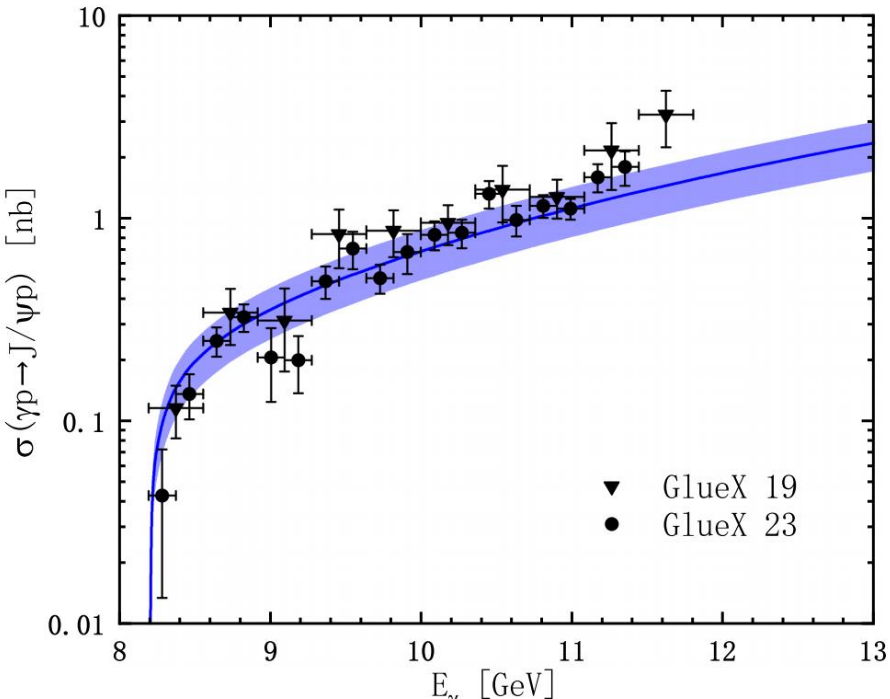


cross sections for $\gamma\, p \to J/\psi\, p'$



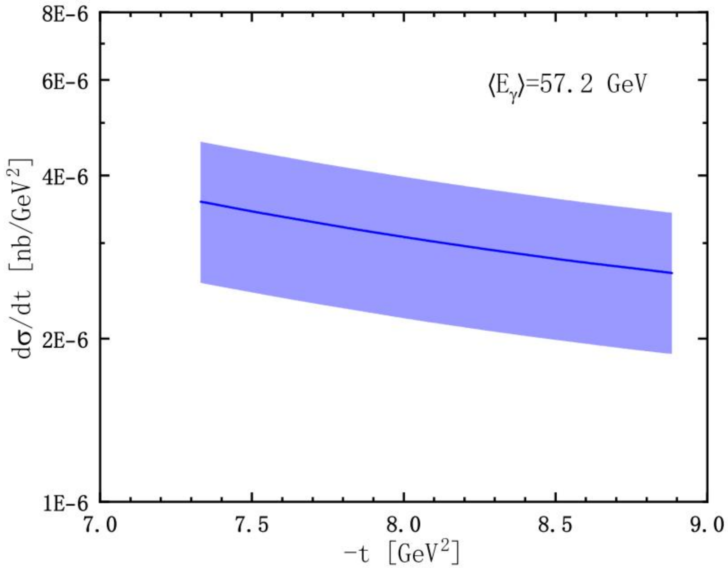
differential cross sections

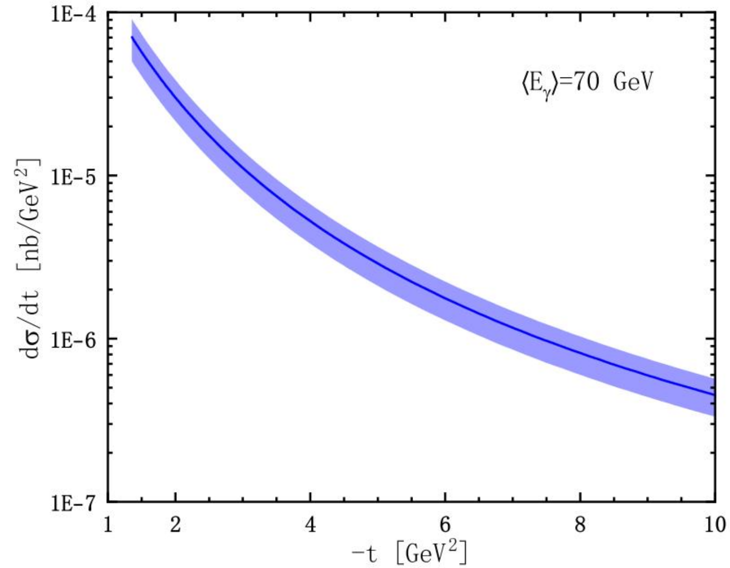
total cross section



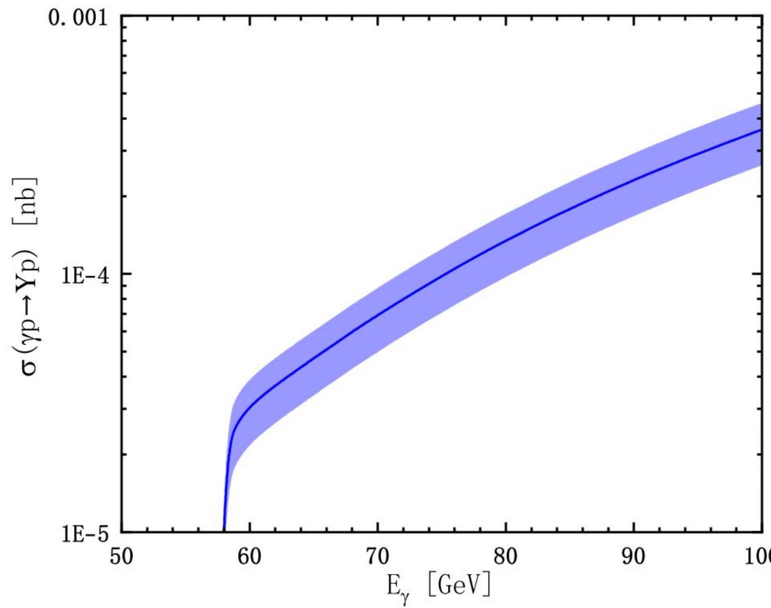
cross sections for γ p→Υ p′

differential cross sections





total cross section



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summary

- Unlike the cases of angular momentum, study on GPDs at nonzero skewness is necessary for comparisons with related observables

- The near-threshold photoproduction of heavy quarkonium is dominated by the second Mellin moments of gluon GPDs, offering a reliable probe of gluon distributions at large skewness

- Future measurements combined with phenomenological analysis can provide more precise information on the gluon structure inside hadrons and improve the model calculation method of gluon GPDs

Thank you

谢谢大家！