

Spin resummation in heavy-quarkonium photoproduction: from gluonic gravitational form factors to the Pomeron

Kiminad A. Mamo

University of Connecticut

With Kemal Tezgin (Virginia Tech)
and Christian Weiss (Jefferson Lab)

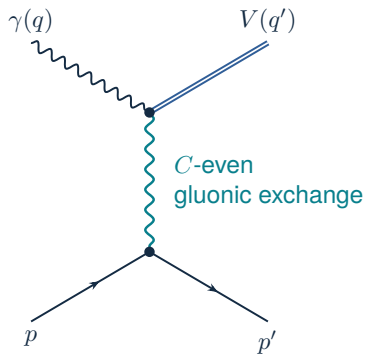
Stony Brook University
Charles B. Wang Center, Room 201

October 22, 2026 | 4:40–5:05 p.m. EDT

Mamo–Tezgin–Weiss, arXiv:2607.25099.



Heavy quarkonium and proton structure



$$\gamma + p \longrightarrow V + p, \quad V = J/\psi, \Upsilon$$

Production dynamics and proton structure

Exclusive J/ψ and Υ :
energy and t dependence probe the reaction mechanism.

Heavy quarkonium as a testing ground

A hard scale from m_Q , even at $Q^2 = 0$.

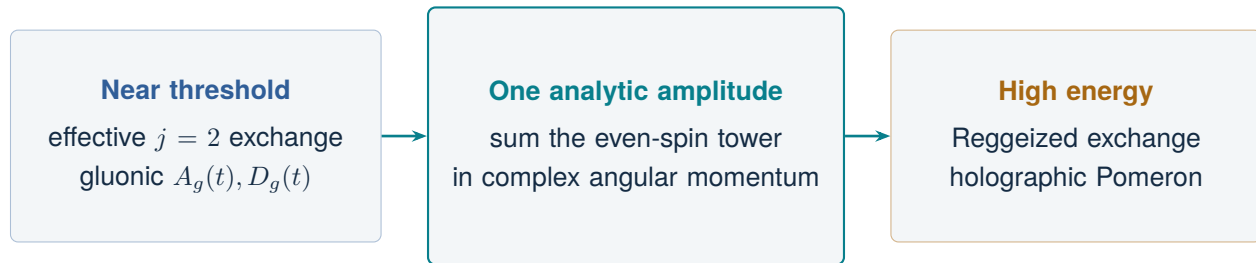
The same process from **JLab to HERA**.

Near threshold: sensitivity to gluonic GFFs.

How reliably can near-threshold production determine **proton structure**?

Hatta–Yang, Phys. Rev. D **98**, 074003 (2018); Mamo–Zahed, Phys. Rev. D **101**, 086003 (2020).

One reaction, two organizing principles



Phenomenology

Describe the energy and t dependence with the same proton input.

Interpretation

Determine what a successful spin-2 fit does—and does not—establish.

Mamo–Tezgin–Weiss, arXiv:2607.25099.

At spin 2, the proton vertex contains gluonic GFFs

$$\langle p' | T_g^{\mu\nu} | p \rangle \longleftrightarrow A_g(t), B_g(t), D_g(t), \bar{C}_g(t)$$

Gluon momentum

$$A_g(t), \quad A_g(0) = \langle x \rangle_g.$$

Scale- and scheme-dependent gluon contribution.

Gluon stress

$$D_g(t)$$

The stress form factor in the spin-2 matrix element.

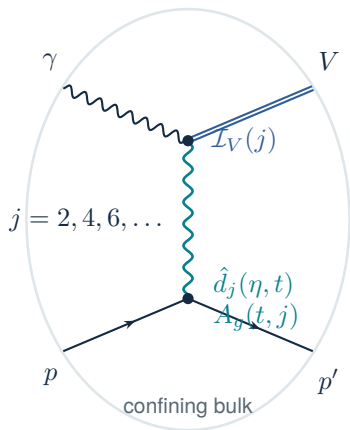
Scalar combination retained in this holographic amplitude

$$A_g(t, 2) + \eta^2 D_g(t, 2) = \hat{d}_2(\eta, t) A_g(t, 2).$$

The GFFs enter through the **proton vertex**; their extraction also needs the production amplitude.

Mamo–Zahed, Phys. Rev. D **106**, 086004 (2022); Guo–Ji–Liu–Yang, Phys. Rev. D **108**, 034003 (2023).

At fixed spin: an upper overlap and a proton moment



Fixed even spin $j = 2, 4, 6, \dots$

$$\mathcal{M}_{V,j} \sim \left(\frac{s}{\kappa_N^2} \right)^j \underbrace{\mathcal{I}_V(j)}_{\gamma \rightarrow V} \underbrace{\hat{d}_j(\eta, t) A_g(t, j)}_{\text{proton moment}}.$$

Upper vertex:

photon–meson overlap and heavy scale.

Lower vertex:

proton structure, t dependence, skewness.

Holographic QCD:

a dynamical continuation from spin 2 to complex j .

The spin-2 GFFs anchor the model; **higher-spin couplings come from the holographic construction.**

Mamo–Zahed, Phys. Rev. D **101**, 086003 (2020); Phys. Rev. D **104**, 066023 (2021); Mamo–Tezgin–Weiss, arXiv:2607.25099.

Skewness preserves the GPD polynomiality structure

Holographic skewness factor

$$\hat{d}_j(\eta, t) = {}_2F_1\left(-\frac{j}{2}, \frac{1-j}{2}; \frac{1}{2} - j; z_S\right),$$

$$z_S = -\frac{4m_N^2\eta^2}{t - m_S^2}, \quad \eta = \frac{M_V^2}{2(s - m_N^2) - M_V^2 + t}.$$

At positive even j :

the series terminates to a polynomial in η^2 .

The spin-2 limit

$$\hat{d}_2 = 1 - \frac{z_S}{3},$$

$$\hat{d}_2 A_g = A_g + \eta^2 D_g,$$

$$D_g(t, 2) = \frac{4m_N^2}{3(t - m_S^2)} A_g(t, 2).$$

The scalar scale m_S is fixed from the lattice $D_g(t)$ input.

Impose the polynomiality structure at even spin, then use the **same model expression at complex j** .

Mamo–Tezgin–Weiss, arXiv:2607.25099. Main text, Eq. (3); Supplemental Material, Eqs. (S35)–(S39).

Reggeization connects spin 2 to the Pomeron

BPST spin–dimension relation

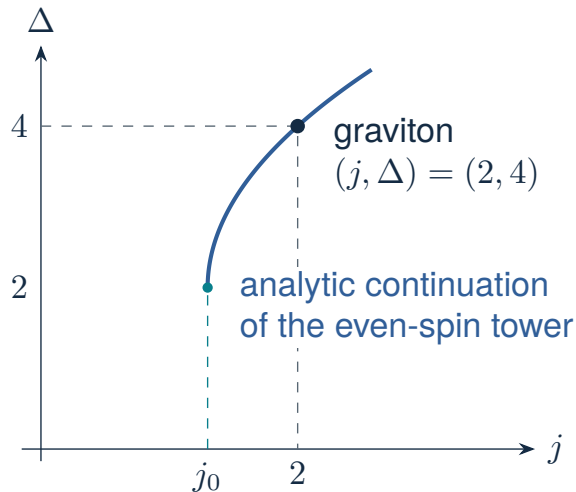
$$\Delta(j) = 2 + \sqrt{2\sqrt{\lambda}(j - j_0)}$$

$$j_0 = 2 - \frac{2}{\sqrt{\lambda}}, \quad \Delta(2) = 4.$$

Square-root branch point at $j = j_0$.

The rightmost cut endpoint controls the leading high-energy growth:

$$\mathcal{M}_V \sim s^{j_0}.$$



Spin 2 and the Pomeron belong to the **same analytically continued exchange dynamics**.

Brower–Polchinski–Strassler–Tan, JHEP **12** (2007) 005; Brower–Strassler–Tan, JHEP **03** (2009) 092.

Resum the even-spin tower before comparing with data

$$\mathcal{M}_V(s, t) = -\frac{\pi}{2} \int_{\mathcal{C}_B} \frac{dj}{2\pi i} \underbrace{\frac{(s/\kappa_N^2)^j + (-s/\kappa_N^2)^j}{\sin \pi j}}_{\text{even signature and energy}} \mathcal{I}_V(j) \hat{d}_j(\eta, t) A_g(t, j).$$

Upper impact factor

$$\mathcal{I}_V(j)$$

Photon $\rightarrow$ quarkonium.

Skewness

$$\hat{d}_j(\eta, t)$$

Polynomiality completion.

Proton moment

$$A_g(t, j)$$

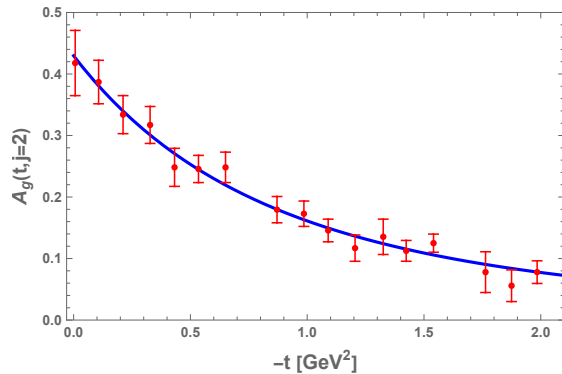
Spin-2 input fixed by lattice QCD.

Direct numerical evaluation: $j = 1.6 + i\nu, \quad -\infty < \nu < \infty.$

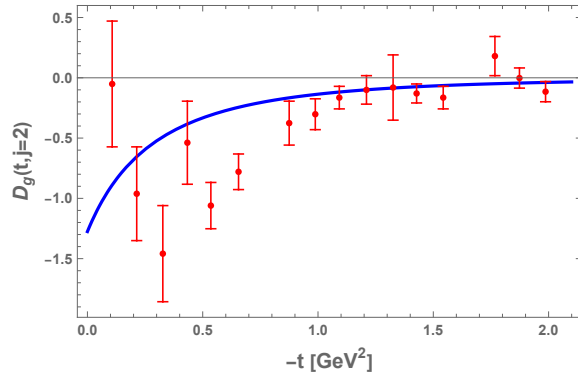
Full Mellin–Barnes integral, beyond the high-energy cut approximation.

Mamo–Tezgin–Weiss, arXiv:2607.25099. Eq. (1); Supplemental Material, Secs. II and VI.

Lattice QCD anchors the spin-2 proton input



$A_g(t, 2)$: gluon momentum form factor



$D_g(t, 2)$: gluon stress form factor

$$A_g(0) = 0.430 \quad \kappa_N = 0.388 \text{ GeV} \quad m_S = 0.630 \text{ GeV}$$

$$\overline{\text{MS}}, \mu = 2 \text{ GeV} \quad | \quad \text{fixed **before** the photoproduction fit.}$$

Lattice: Pefkou–Hackett–Shanahan, Phys. Rev. D **105**, 054509 (2022). Model fits: arXiv:2607.25099, Fig. S3.

Only two parameters are fitted to J/ψ photoproduction

Fixed independently

Proton: $A_g(0)$, κ_N , m_S from lattice GFFs.

Baryon twist: $\tau = 3$.

Meson scale: $\kappa_V = 1.038$ GeV
from earlier J/ψ electroproduction.

Fit observable

$$\sigma(s) = \int_{t_{\max}}^{t_{\min}} dt \frac{|\mathcal{M}_V(s, t)|^2}{16\pi(s - m_N^2)^2}.$$

Fitted to total cross sections

$$\lambda = 8.13$$

$$j_0 = 2 - \frac{2}{\sqrt{\lambda}} \simeq 1.30.$$

One overall normalization

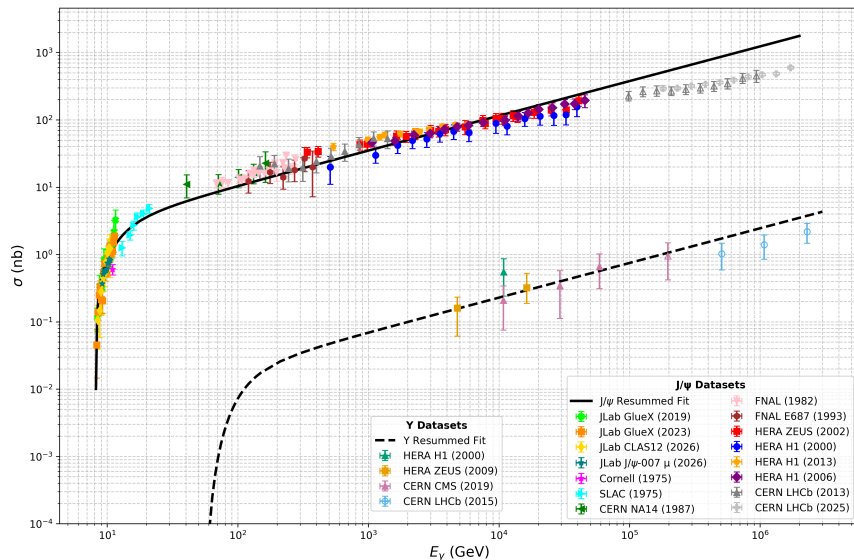
$$N_{J/\psi}^2 = 5.27 \times 10^{-5} [\text{GeV}^2 \text{ nb}].$$

$\chi^2/\text{d.o.f.} \simeq 2.27$; data-set normalizations held fixed.

One common parameter set from **threshold to HERA**; no additional threshold normalization or t slope.

Mamo–Tezgin–Weiss, arXiv:2607.25099. Table S1 and Eq. (S49). Meson scale: Mamo–Zahed, Phys. Rev. D **104**, 066023 (2021).

One resummed curve from JLab to HERA



J/ψ : global fit

The same amplitude follows threshold and Regge energy dependence.

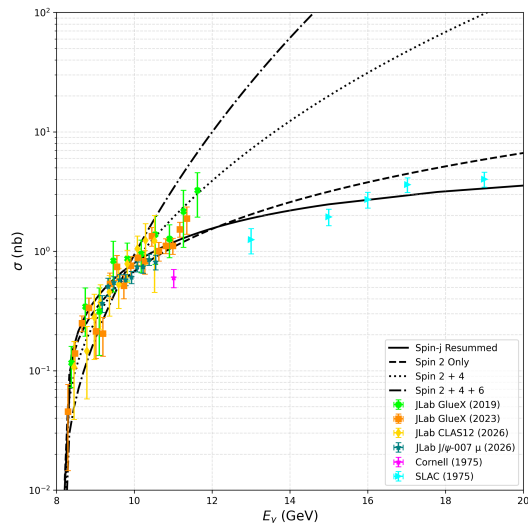
Υ : channel test

Same proton and Regge dynamics; a separate normalization.

Highest-energy LHCb J/ψ points lie outside the fit.

Mamo–Tezgin–Weiss, arXiv:2607.25099. Fig. 1. $E_\gamma = (s - m_N^2)/(2m_N)$ is the equivalent photon lab energy.

Near threshold: compare resummation with fixed-spin models



The comparison

Solid: resummed global fit.

Dashed: spin {2}.

Dotted: spins {2, 4}.

Dash-dotted: spins {2, 4, 6}.

Each fixed-spin model is normalized separately to GlueX.

Spin 2 can work over a limited window.

Mamo–Tezgin–Weiss, arXiv:2607.25099. Fig. 2.

A successful spin-2 fit is not a controlled spin expansion

$$\mathcal{M}_V^{(J)}(s, t) = \sum_{j=2,4,\dots,J} \beta_{V,j}(t) \left(\frac{s}{\kappa_N^2} \right)^j \xrightarrow[\text{fixed } t]{s \rightarrow \infty} \beta_{V,J}(t) \left(\frac{s}{\kappa_N^2} \right)^J.$$



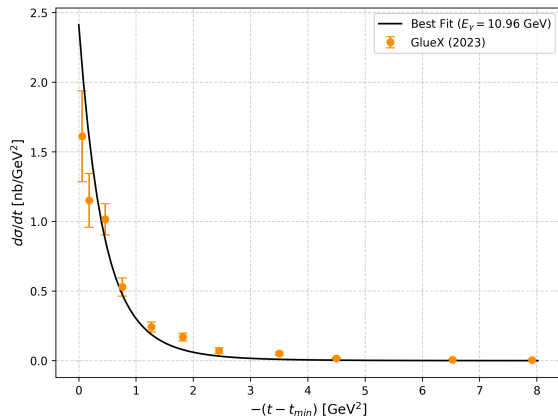
The highest retained power eventually dominates.

Adding $j = 4, 6, \dots$ does not systematically approach the resummed result.

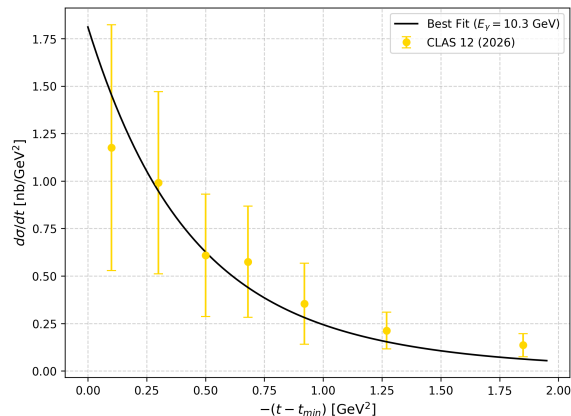
Spin 2 is an **effective near-threshold description**, not the first term of a controlled finite-spin sequence.

Mamo–Tezgin–Weiss, arXiv:2607.25099. Supplemental Material, Eqs. (S12)–(S14); main text, Fig. 2.

The near-threshold t dependence is a post-fit prediction



GlueX: $E_\gamma \simeq 10.96$ GeV

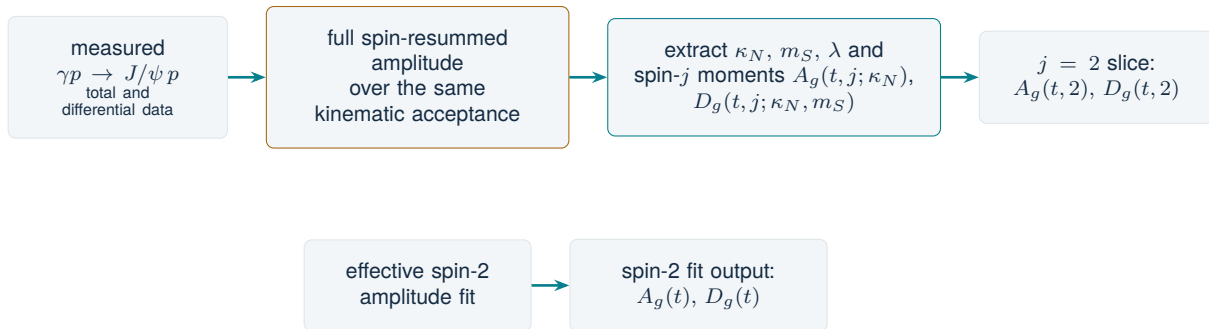


CLAS12: $E_\gamma \simeq 10.3$ GeV

Same λ and $N_{J/\psi}$ from total cross sections. **No fitted differential points, t slope, or bin normalization.**

GlueX, Phys. Rev. C **108**, 025201 (2023); CLAS, Phys. Rev. C **113**, 065203 (2026). arXiv:2607.25099, Fig. S4.

Benchmark a spin-2 extraction against the resummed fit



Proposed extraction test

Fit the measured total and differential data with the full resummed amplitude over the same acceptance and extract $\{\kappa_N, m_S, \lambda\}$.

Benchmark at $j = 2$

Compare the $j = 2$ slice of the extracted spin- j moments with lattice GFFs/spin-2 moments and with the effective spin-2 extraction.

Mamo–Tezgin–Weiss, arXiv:2607.25099. Main text: “Implications for GFF extraction.”

Next: Q^2 dependence and separate photon amplitudes

Extend the upper vertex to electroproduction

$$\mathcal{I}_V(j) \longrightarrow \mathcal{I}_{V,T}(j, Q^2), \mathcal{I}_{V,L}(j, Q^2).$$

JLab and large skewness

Resolve the joint W, t, Q^2 dependence.

Separate longitudinal and transverse dynamics.

Connect to ϕ production and helicity observables.

Higher energy and heavier mesons

Use a larger energy lever arm.

Test Υ production with a larger heavy-quark scale.

Determine where a single Pomeron exchange must be extended.

Combine energy coverage and polarization information to **separate reaction dynamics from proton structure**.

Mamo–Tezgin–Weiss, arXiv:2607.25099. Outlook. Electroproduction: Mamo–Zahed, Phys. Rev. D **104**, 066023 (2021).

One amplitude, two energy limits

1 Resum the exchange tower.

Connect gluonic GFFs to the Pomeron.

2 Test one common amplitude.

Lattice-fixed spin-2 proton input;
two photoproduction fit parameters;
successful differential cross-section tests.

3 Calibrate the GFF interpretation.

Spin-2 success $\neq$ controlled truncation.

Thank you.

Mamo–Tezgin–Weiss, arXiv:2607.25099.



Kiminad A. Mamo University of Connecticut
Kemal Tezgin Virginia Tech
Christian Weiss Jefferson Lab

Supported by the U.S. Department of Energy, Office of Science, Office of Nuclear Physics, under Contracts 89243126CSC000213, DE-SC0023646 (QGT Topical Collaboration), DE-SC0016286 and DE-SC0024644 (EXCLAIM Collaboration); by DOE Grant DE-FG02-04ER41309; and by the U.S. National Science Foundation under Grant 2412625.

Exact two-body kinematics

$$s = W^2, \quad E_\gamma = \frac{s - m_N^2}{2m_N}.$$

$$|\mathbf{q}| = \frac{s - m_N^2}{2\sqrt{s}}, \quad |\mathbf{q}'| = \frac{\sqrt{\lambda_K(s, M_V^2, m_N^2)}}{2\sqrt{s}},$$

$$E' = \frac{s + M_V^2 - m_N^2}{2\sqrt{s}}.$$

$$\lambda_K(a, b, c) = a^2 + b^2 + c^2 - 2ab - 2ac - 2bc.$$

$$t = M_V^2 - 2|\mathbf{q}|E' + 2|\mathbf{q}||\mathbf{q}'|\cos\theta.$$

$$t_{\min} = t(0), \quad t_{\max} = t(\pi),$$

$$t_{\max} \leq t_{\min} \leq 0.$$

Paper convention: $t_{\min}$ is the forward endpoint, with minimum $|t|$.

$$E_{\gamma,\text{th}} = 8.21 \text{ GeV} \quad (J/\psi), \quad E_{\gamma,\text{th}} = 57.2 \text{ GeV} \quad (\Upsilon).$$

At threshold $|\mathbf{q}'| = 0$ and the physical t interval collapses.

Mamo–Tezgin–Weiss, arXiv:2607.25099. Supplemental Material, Eqs. (S1)–(S11).

Full gluon EMT decomposition and the retained combination

$$\langle p' | T_g^{\mu\nu} | p \rangle = \bar{u}(p') \left[A_g(t) \gamma^{(\mu} P^{\nu)} + B_g(t) \frac{P^{(\mu} i \sigma^{\nu)\rho} \Delta_\rho}{2m_N} \right. \\ \left. + D_g(t) \frac{\Delta^\mu \Delta^\nu - g^{\mu\nu} \Delta^2}{4m_N} + \bar{C}_g(t) m_N g^{\mu\nu} \right] u(p),$$

$$P = \frac{p + p'}{2}, \quad \Delta = p' - p, \quad D_g = 4C_g.$$

Photoproduction model

$$A_g(t, 2) + \eta^2 D_g(t, 2).$$

The scalar amplitude uses lattice A_g, D_g ; it does not determine every EMT structure.

Protected holographic point

$$\Delta(2) = 4, \quad \gamma(2) = 0.$$

The protected branch corresponds to the conserved total EMT; renormalized gluon and quark operators mix.

Mamo–Tezgin–Weiss, arXiv:2607.25099. Supplemental Material, Eqs. (S36)–(S39).

Explicit photoproduction impact factor

$$\mathcal{I}_V(j) = \frac{C_V(j)}{\Gamma\left(\frac{j+\Delta(j)+2}{2}\right)},$$

$$C_V(j) = \frac{N_V}{2} \left(\frac{j+\Delta(j)}{2}\right) \frac{\Gamma^2\left(\frac{j+\Delta(j)}{2}\right)}{\Delta(j)} \left(\frac{\kappa_V}{\kappa_N}\right)^{j+10-3\Delta(j)}.$$

Normalization N_V

Photon–meson overlap, wave-function conventions, and the remaining channel normalization.

Heavy-meson scale

$\kappa_V = 1.038$ GeV from the earlier J/ψ electroproduction analysis.

The J/ψ normalization is fitted together with λ ; the Υ normalization is fixed separately.

Mamo–Tezgin–Weiss, arXiv:2607.25099. Supplemental Material, Eqs. (S29)–(S30), Table S1.

The soft-wall proton form factor at complex spin

$$A_g(t, j) = A_g(0) 2^{-2+\Delta} \Gamma\left(a_K + \frac{\Delta}{2}\right) [T_0(t, j) + T_1(t, j)], \quad a_K = -\frac{t}{8\kappa_N^2}, \quad \Delta = \Delta(j).$$

$$\mathcal{F}_n = {}_2\tilde{F}_1\left(2 + a_K - \frac{\Delta}{2}, \frac{j}{2} + \tau - \frac{\Delta}{2} + n; a_K + \frac{j}{2} + \tau + n; -1\right), \quad n = 0, 1.$$

$$T_0 = \frac{2^{1-\Delta}(\tau-1)}{\Gamma(\tau)} \Gamma\left(\frac{j}{2} + \tau - \frac{\Delta}{2}\right) \Gamma\left(\frac{j}{2} + \tau + \frac{\Delta}{2} - 2\right) \mathcal{F}_0,$$

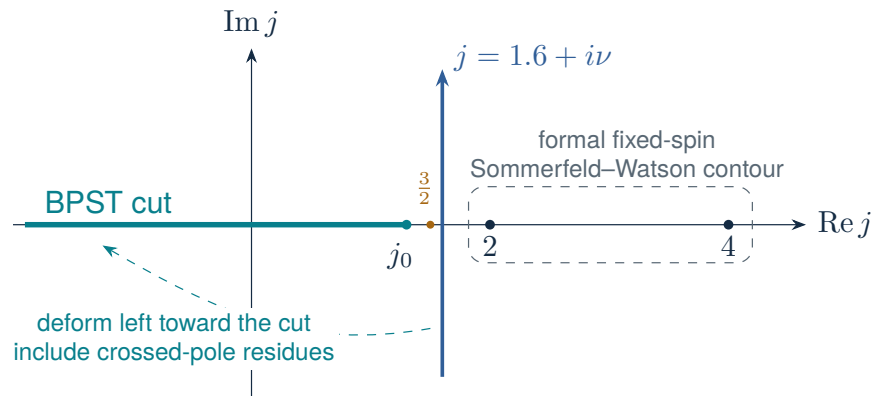
$$T_1 = \frac{2^{1-\Delta}}{\Gamma(\tau)} \Gamma\left(\frac{j}{2} + \tau - \frac{\Delta}{2} + 1\right) \Gamma\left(\frac{j}{2} + \tau + \frac{\Delta}{2} - 1\right) \mathcal{F}_1.$$

$\tau = 3$; ${}_2\tilde{F}_1$ is the regularized Gauss hypergeometric function.

The lattice spin-2 normalization and scale anchor this **model-dependent continuation in j** .

Mamo–Tezgin–Weiss, arXiv:2607.25099. Supplemental Material, Eqs. (S31)–(S34).

Contour prescription and the two kinds of singularity



Numerical amplitude

$j = 1.6 + i\nu$ for $j_0 \simeq 1.30$.

Fixed-spin diagnostics

Residues at $j = 2, 4, 6, \dots$

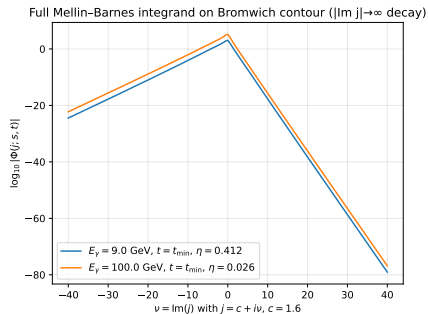
Auxiliary deformations

Include residues of crossed isolated poles; no large right semicircle is used.

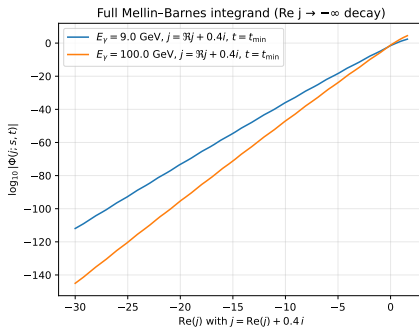
Skewness poles are kinematic: $s^{n+1/2} z_S^{n+1} \sim s^{-n-3/2}$ at fixed t , since $z_S \sim s^{-2}$.

Mamo–Tezgin–Weiss, arXiv:2607.25099. Supplemental Material, Fig. S1 and Eqs. (S18)–(S23).

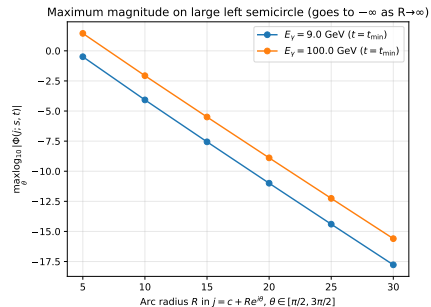
Numerical convergence diagnostics



Bromwich-line decay



Left-half-plane suppression



Large-left-arc diagnostic

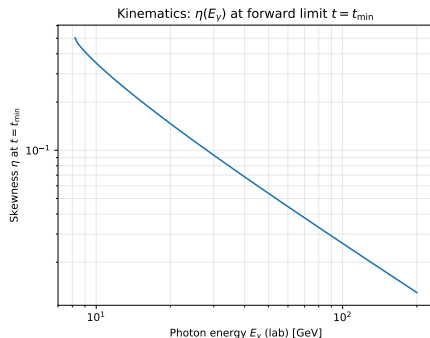
$$|\Phi_V(c + i\nu; s, t)| \lesssim \text{poly}(|\nu|) e^{-\alpha_\pm |\nu|}, \quad \alpha_\pm > 0.$$

Adaptive quadrature; increase the imaginary cutoff and test contour stability within a common analytic strip.

The full Mellin–Barnes integral is evaluated directly; the cut is used for analytic interpretation.

Mamo–Tezgin–Weiss, arXiv:2607.25099. Supplemental Material, Eq. (S28) and Figs. S5–S7.

Physical-region skewness and large-spin damping



Forward-endpoint skewness, $t = t_{\min}(s)$.

Skewness decreases along the physical path; its damping does not turn a finite-spin truncation into a uniform energy expansion.

Physical-region bound

$$\eta^2 \leq \frac{-M_V^4 t}{(4m_N^2 - t)(M_V^2 - t)^2},$$

$$z_S = \frac{4m_N^2 \eta^2}{m_S^2 - t}, \quad 0 \leq z_S < 1.$$

Large real j , fixed $0 < z_S < 1$

$$\hat{d}_j \sim \left(\frac{1 + \sqrt{1 - z_S}}{2} \right)^j,$$

$$\hat{d}_j \sim e^{-jz_S/4} \quad (z_S \ll 1).$$

Mamo–Tezgin–Weiss, arXiv:2607.25099. Supplemental Material, Fig. S2 and Eqs. (S40)–(S47).

The Υ test and the high-energy limit

Transferred from the J/ψ analysis

Proton form factors, skewness prescription, BPST trajectory, and $\lambda = 8.13$.

Channel-specific normalization

$$N_{\Upsilon}^2 = 9.98 \times 10^{-8} [\text{GeV}^2 \text{ nb}].$$

Fitted to HERA Υ data.

The displayed test sets $\kappa_{\Upsilon} = \kappa_{J/\psi}$.

At the highest energies

A single BPST cut gives powerlike growth.

The highest-energy LHCb J/ψ points fall below the curve.

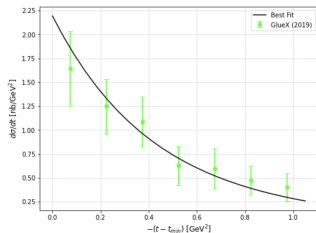
Next ingredients:

multi-Pomeron exchange,
eikonalization and unitarity corrections.

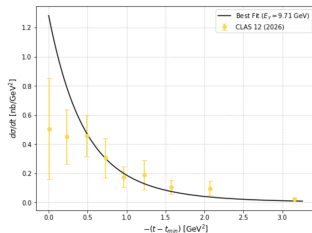
The Υ comparison tests the common Regge/proton dynamics after a new channel normalization is specified.

Mamo–Tezgin–Weiss, arXiv:2607.25099. Fig. 1 and Table S1; Brower–Strassler–Tan, JHEP **03** (2009) 050.

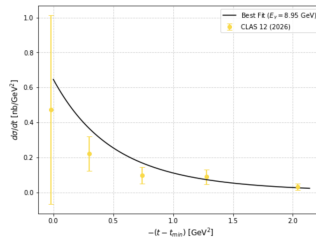
Additional JLab bins: GlueX 2019 and CLAS12



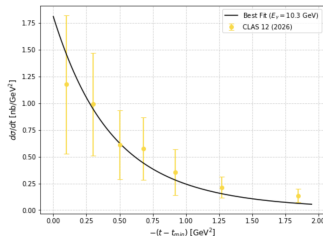
GlueX 2019



CLAS12: $E_\gamma = 9.71$ GeV



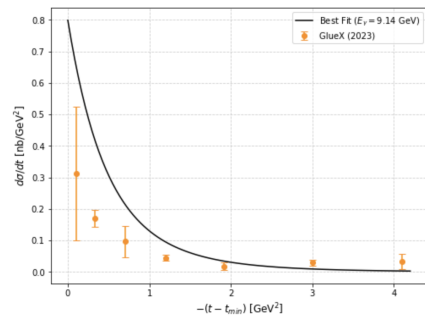
CLAS12: $E_\gamma = 8.95$ GeV



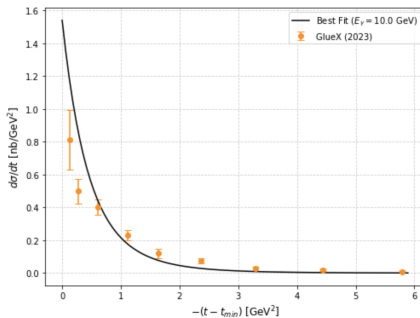
CLAS12: $E_\gamma = 10.3$ GeV

GlueX (2019); CLAS, Phys. Rev. C **113**, 065203 (2026).

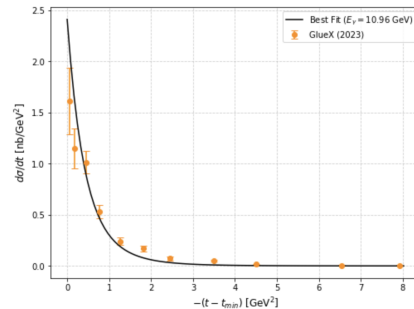
Additional JLab bins: GlueX 2023



$$E_\gamma = 9.14 \text{ GeV}$$



$$E_\gamma = 10.0 \text{ GeV}$$



$$E_\gamma = 10.96 \text{ GeV}$$

The lower-energy bins provide additional leverage on the reaction mechanism and the predicted t dependence.

GlueX, Phys. Rev. C **108**, 025201 (2023).

The fixed-spin current-correlator dictionary

DDVCS: two-current kernel $\times$ proton conformal moment

$$\hat{\mathcal{H}}_j \sim \xi^{-j} K_j^{(\gamma_j)}(\vartheta) H_j(\eta, t), \quad \vartheta = \eta/\xi,$$

$$K_j^{(\gamma)}(\vartheta) = {}_2F_1\left(\frac{j}{2} + \frac{\gamma}{4}, \frac{j+1}{2} + \frac{\gamma}{4}; j + \frac{3}{2} + \frac{\gamma}{2}; \vartheta^2\right).$$

Holographic upper vertex

The leading-twist TT projection of the pure-AdS two-current integral gives the conformal Wilson-kernel family.

Quarkonium production

Replace the current kernel by $\mathcal{I}_V(j)$; retain fixed- j factorization, the proton moment, and the resummation.

A fixed-scale structural dictionary; the photoproduction impact factor is **not** the DDVCS photon kernel.

Mamo–Tezgin–Weiss, arXiv:2607.25099. Main text and Supplemental Material; Nishio–Watari, arXiv:1408.6365.