GUMP: GLUON GPD FROM DV$J/\psi$P

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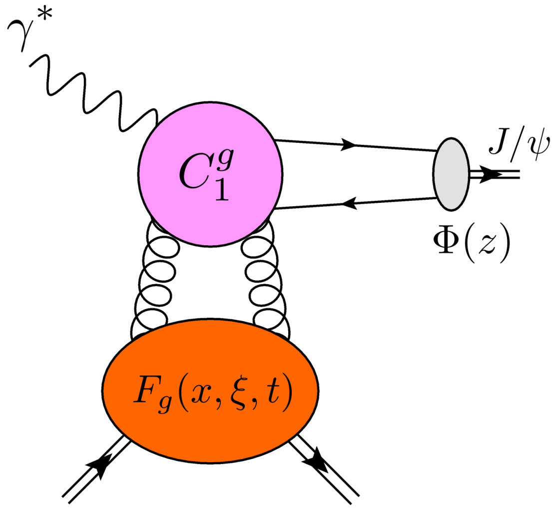
Theory Framework

- Want to constrain gluon GPDs from exclusive production data – need heavy mesons!
- We study deeply virtual J/ψ production (DV J/ψ P) using collinear factorization at NLO with mass corrections from the NRQCD framework

$$\mathcal{A}_{\text{Hyb.}} = \sum_{i=q,\bar{q},g,\cdots} \frac{e_q f_{J/\psi}}{N_C} \frac{Q}{Q^2+M_{J/\psi}^2} \int_0^1 \mathrm{d}z \int_{-1}^{1} \mathrm{d}x C^i(x,\xi,z,Q,\mu_R,\mu_{f,\text{GPD}},\mu_{f,\text{DA}}) \times F^i(x,\xi,t,\mu_{f,\text{GPD}}) N_{\text{amp}} \Phi_{\text{asym}}(z,\mu_{f,\text{DA}})$$



GUMP Framework

- Parameterizing GPDs in terms of their conformal moments

$$F(x,\xi,t)=\frac{1}{2i}\int_{c-i\infty}^{c+i\infty}\mathrm{d}j\,\frac{p_j(x,\xi)}{\sin(\pi[j+1])}\mathcal{F}_j(\xi,t)$$

(*D. Mueller and A. Schafer* 2006)

- We can write the DV J/ψ P amplitude in conformal moment space using a Mellin Barnes integral

$$\mathcal{A}_{\mathrm{Hyb.}}=\frac{e_q f_{J/\psi}C_F}{N_C}\frac{Q}{Q^2+M^2_{J/\psi}}\sum_{i=u,\bar{u},\dots}\frac{1}{2i}\int_{c-i\infty}^{c+i\infty}\mathrm{d}j\,\xi^{-j-1}\left[i+\tan\left(\frac{\pi j}{2}\right)\right]$$
$$\times\left[C_k^{i,LO}E_{kj}^{LO}F_j^i(\xi,t)+C_k^{i,NLO}E_{kj}^{LO}F_j^i(\xi,t)+C_k^{i,LO}E_{jk}^{NLO}F_j^i(\xi,t)\right]$$

Details discussed in Yuxun's talk!

Moment Parameterization

- We are only looking at the gluon GPD H_g in the small-x_B kinematics probed by HERA data, so we can just take the first few terms in the polynomial expansion for the moments

$$\mathcal{F}_j^g(\xi,t) = \mathcal{F}_{j,0}^g(t) + \xi^2 R_{\xi^2}^g \mathcal{F}_{j,0}^g(t) + \xi^4 R_{\xi^4}^g \mathcal{F}_{j,0}^g(t)$$

- The generalized form factor $\mathcal{F}_{j,0}^g$ we take to have the forward limit given by a simple PDF ansatz and t-dependence from a Regge trajectory multiplied with a residual exponential term

$$\mathcal{F}_{j,0}^g(t) = N^g B(j+1-\alpha_g, 1+\beta_g)\frac{j+1-k-\alpha_g}{j+1-k-\alpha_g(t)}e^{b^g t}$$

As explained in Fatma's talk

Input For Fits

- We use 17 t-dependent cross section points from H1 (2006) data
  - $< \mathrm{Q}^2 >$ in range $7.0 - 22.4\ \mathrm{GeV}^2$, $\mathrm{x_B}$ in range $9\times10^{-4} - 6\times10^{-3}$, and |t| in range $0.04\ - 0.64\ \mathrm{GeV}^2$
  - The data has negligible sensitivity to the GPD E, so we only fit parameters coming from the GPD H: $\mathrm{b^g}$, $\mathrm{R_{\xi^2}}$, $\mathrm{R_{\xi^4}}$ as well as the amplitude normalization parameter $\mathrm{N_{amp}}$
- Given the small values of x_B, we redo the fit of our forward gluon PDF parameters in a simultaneous fit, using 9 points from the JAM22 global analysis with $Q^2 = 4\ GeV^2$ and $x_B = 10^{-4} - 10^{-3}$ to constrain N^g, α^g, β^g
  - Limited number of points constraining forward limit since we have a limited number of off-forward data points
- The NLO corrections require input from the quark GPDs, so we take the best fit results from our previous u and d quark global analysis (*Guo et al* 2023) as input

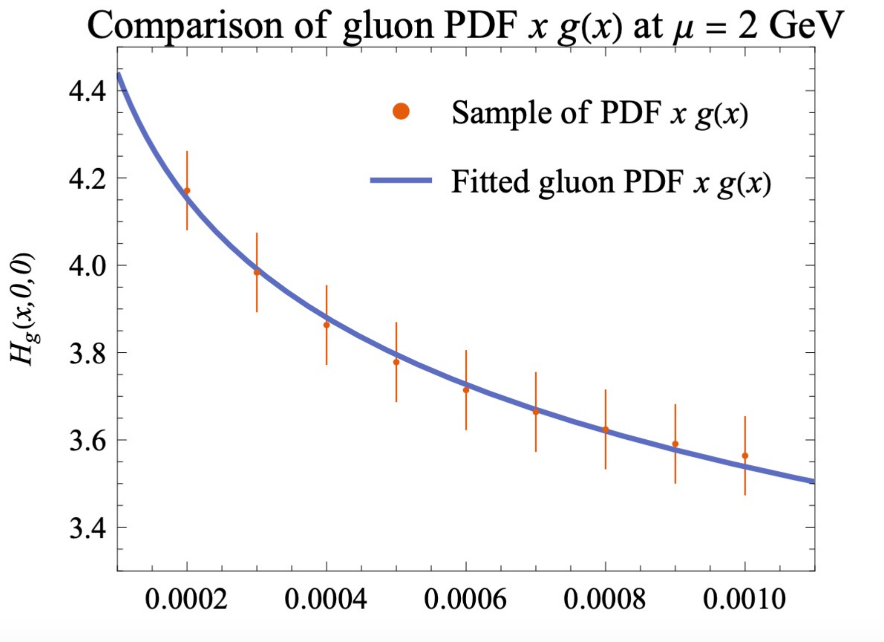
Fit Results

- Minimizing with Minuit2 gives $\chi^2/dof \approx 1.03$
- Only statistical uncertainties from fit, full error propagation left for future work

Best-Fit Parameters		
Parameter	Best-Fit Value	Statistical Uncertainty
N^g	1.84	0.22
α^g	1.096	0.016
α'^g	0.0	0.06
$R^g_{\xi^2}$	1.4	0.5
$R^g_{\xi^4}$	-0.45	0.21
b^g	1.91	0.11
N_{amp}	0.50	0.04

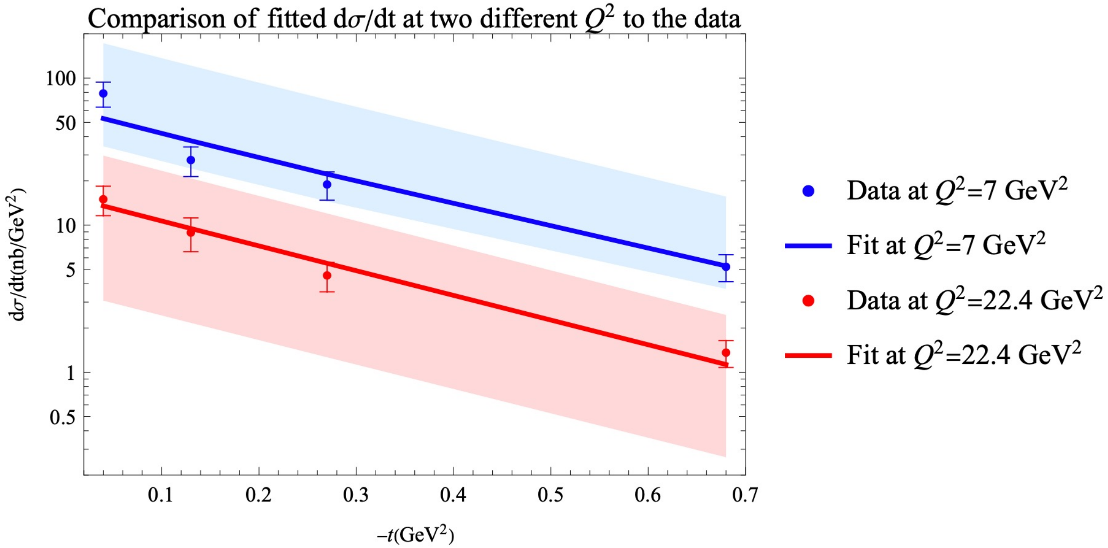
PDF Fit Results

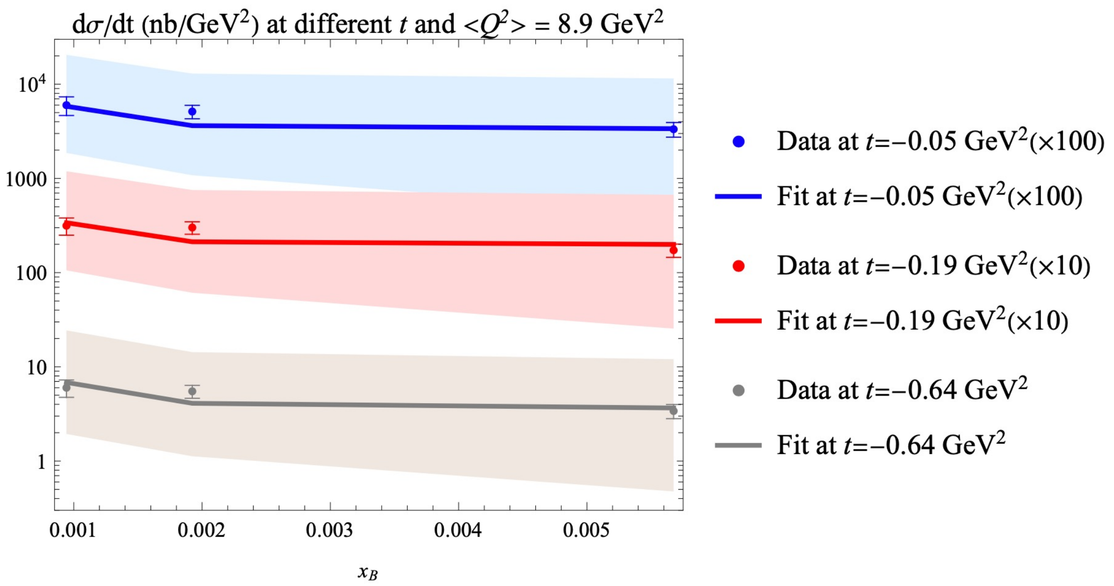
- Simple forward limit ansatz is sufficiently flexible to replicate small-x_B PDFs from JAM22 global analysis while being consistent with DV J/ψ P HERA data



Cross Section Fit Results

- For $Q^2 \sim M_{J/\psi}^2$ or larger virtualities we can describe the data relatively well
  - Lower Q^2 would bring in higher-twist effects and necessitate use of a full NLO NRQCD treatment due to mass corrections
- Note that the x_B dependence seen in the data strongly relies on NLO corrections in our framework

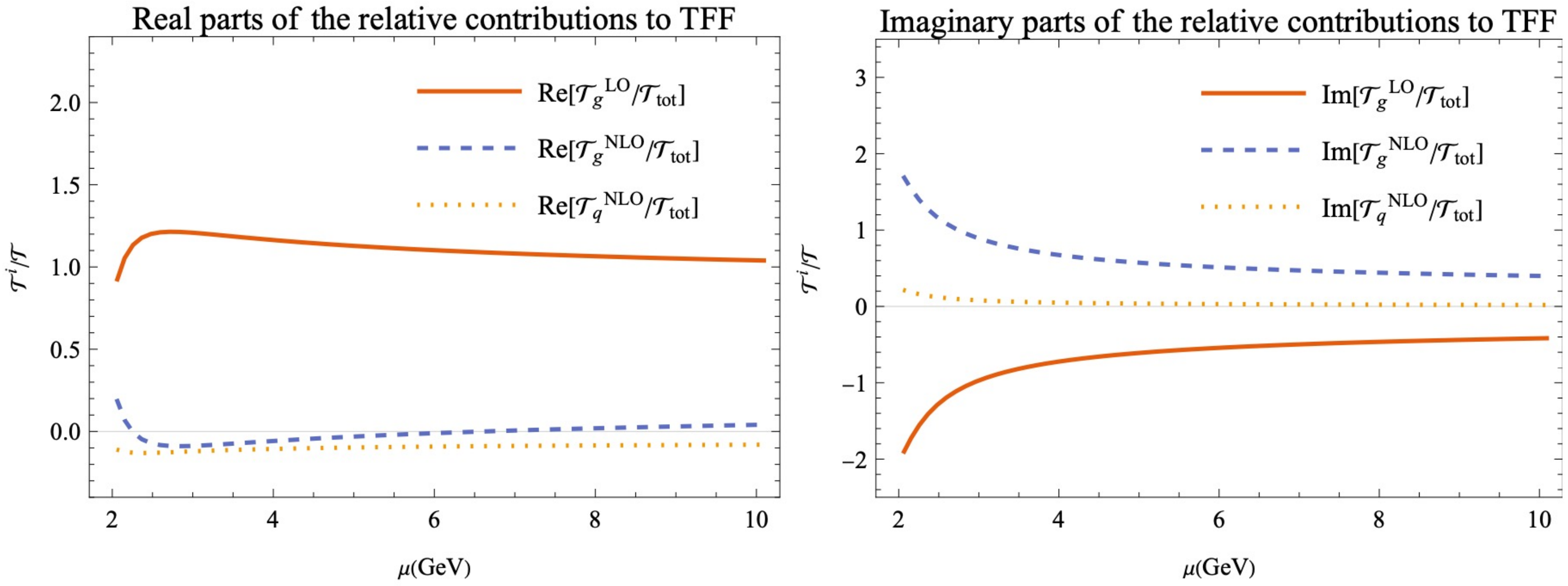




*Bands show uncertainty from varying the renormalization scale within $\mu \in [1/2, 2] \times \mu_F$ as Yuxun discussed, hinting at large higher order corrections!

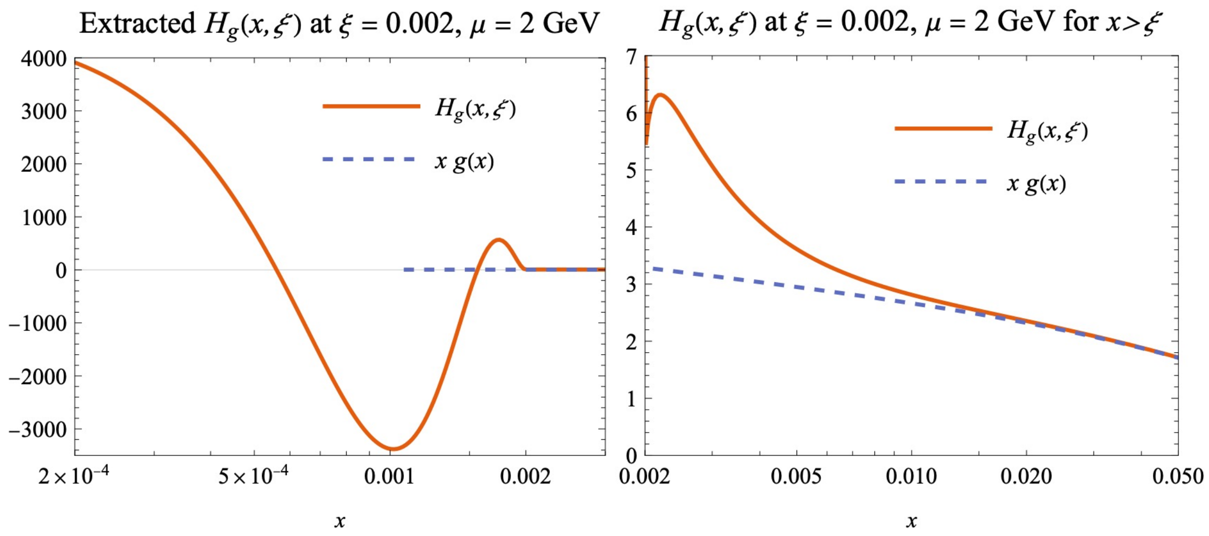
Comparison of LO and NLO Contributions

- We see strong cancellations between the LO and NLO gluon contributions to the TFFs
  - A similar cancellation was seen between the NLO quark and gluon contributions to DVCS *(Čuić et al* 2023*)*
- The quarks enter only at NLO, and overall provide a small background effect relative to the gluon contributions



Extracted Gluon GPDs

- The combination of DV$J/\psi$P data and gluon PDF global analysis input only constrain the GPD along the $x = \pm\xi$ lines and in the forward limit, so the functional form is only well controlled in the PDF region $|x| > \xi$
- We see that the for fixed ξ the GPD approaches the PDF as x becomes large, as expected from the forward limit
- The DA like region $|x| < \xi$ shows large unphysical fluctuations due to the form of the Gegenbauer polynomials and the lack of constraints in this region
  - Need lattice input!

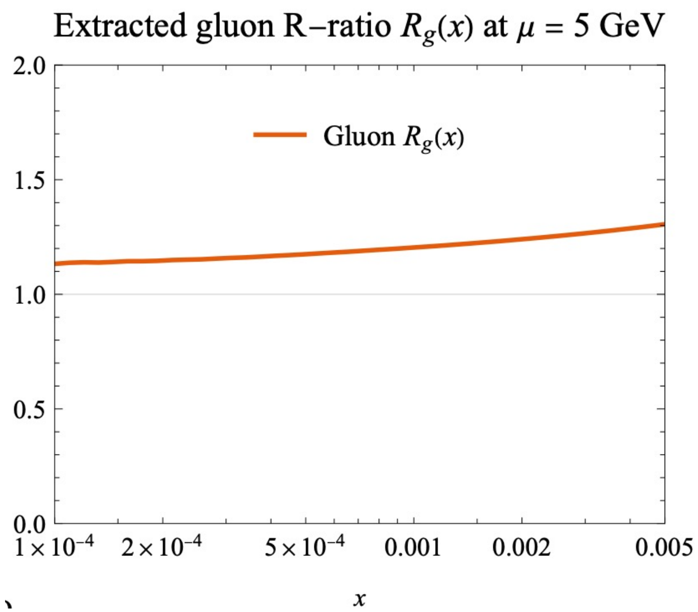


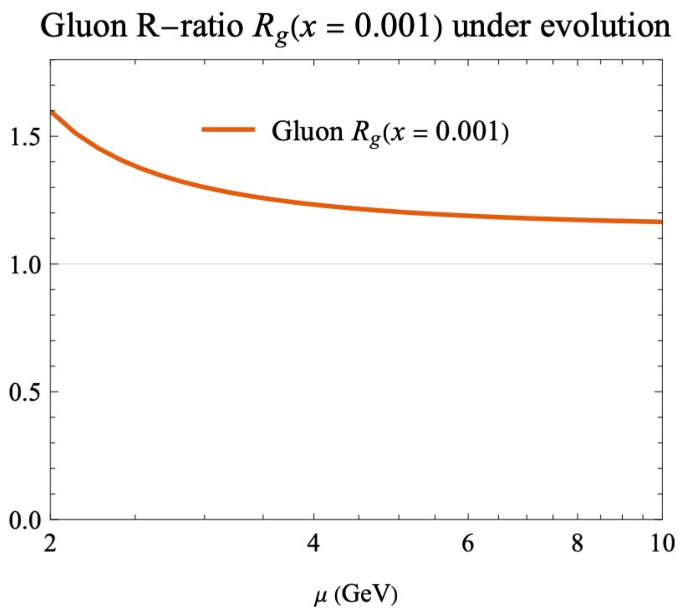
Skewness Ratio - R

- At small-x_B it is common to approximate the GPD by a PDF multiplied by a skewness correction factor

$$R_g(x, \mu) \equiv \frac{H_g(x, \xi = x, 0, \mu)}{H_g(x, 0, 0, \mu)}$$

- For both small-x and large Q^2 our extracted R_g tends toward ~1.1-1.2, deviating from unity and implying a significant skewness effect even at HERA kinematics
  - This is a similar sized correction as found in other frameworks (*Martin, Ryskin and Teubner* 2000, *Mäntysaari and Schenke* 2016, *Čuić et al* 2023)





Future Developments

- Full NLO implementation of DVCS and light vector meson DVMP for simultaneous fits
- Additional observables such as DVϕP, J/ψ photoproduction, threshold J/ψ, etc. to supply further constraints and bring in more quark flavors
- Full NLO NRQCD treatment for DV J/ψP
- Full uncertainty propagation

Conclusions

- We have performed a simultaneous fit of DV J/ψP HERA data and gluon PDF input to constrain the gluon GPD H_g in a collinear factorization / GPD based framework
- See clear signs that higher order α_s corrections and skewness effects are important, even at fairly large Q^2 and small-x_B kinematics!
- Have NLO evolution and Wilson coefficient corrections implemented into GUMP framework – can apply to other processes!