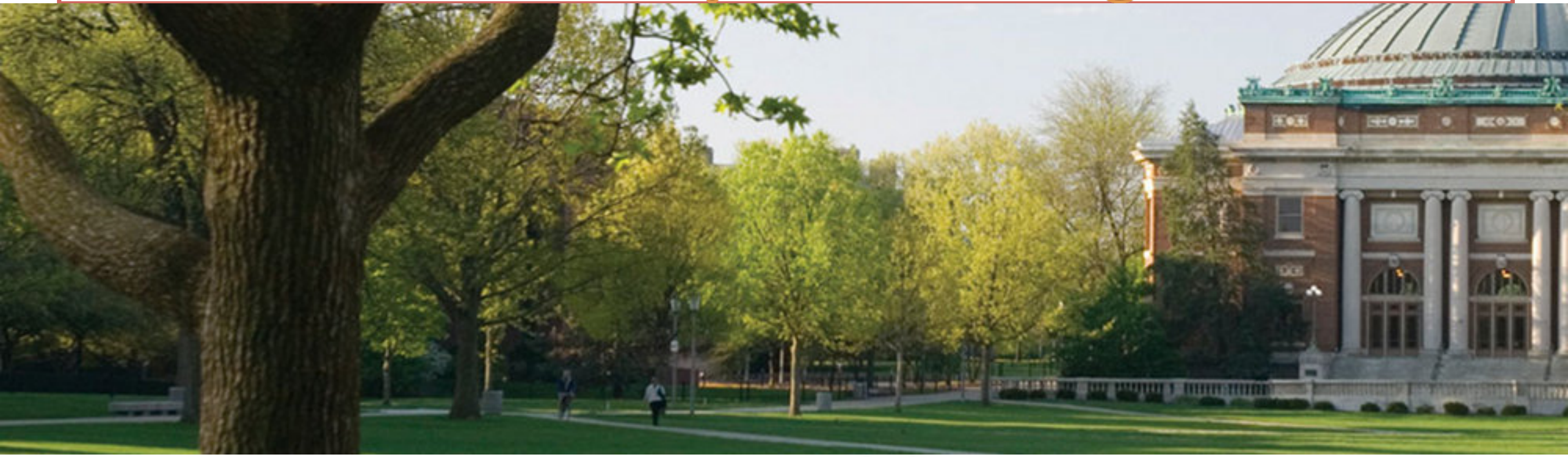
The Flexible Spectator Model of Spin Dependent Quark and Gluon GPDs: Implications for Deeply Virtual Lepton Scattering



Gary R. Goldstein
Tufts University

SPIN 2016
U. Illinois

Abstract

The "flexible" parametrization of quark and gluon Generalized Parton Distributions (GPDs), based on spectator models and Regge behavior, will be presented. The Chiral Even GPDs, constrained by nucleon form factors and PDFs, determine deeply virtual Compton scattering amplitudes and are compared with cross section and polarization data. The Chiral Odd GPDs, including "transversity", contribute to pseudoscalar leptoproduction and are compared to recent experimental data. The **spectator scheme is extended to new quark-sea and gluon GPDs**. Predictions for an array of spin-dependent angular distributions and asymmetries in Deeply Virtual Scattering processes related to these distributions is explored.

GPDs, Extension to Sea and Gluons

Collaborators: S. Liuti, O. Gonzalez Hernandez, A. Rajan, J. Poage

- GRG, O. Gonzalez-Hernandez, S.Liuti, PRD(2015) arXiv:1311.0483
- GRG, O. Gonzalez-Hernandez, S.Liuti, arXiv:1401.0438
- Ahmad, GRG, Liuti, PRD79, 054014, (2009)
- Gonzalez, GRG, Liuti PRD84, 034007 (2011)
- GRG, Gonzalez, Liuti, PRD91, 114013 (2015)
- GRG, Gonzalez Hernandez, Liuti, J. Phys. G: Nucl. Part. Phys. **39** 115001 (2012)
- Gonzalez Hernandez, Liuti, GRG, Kathuria, PRC88, 065206 (2013)

OUTLINE

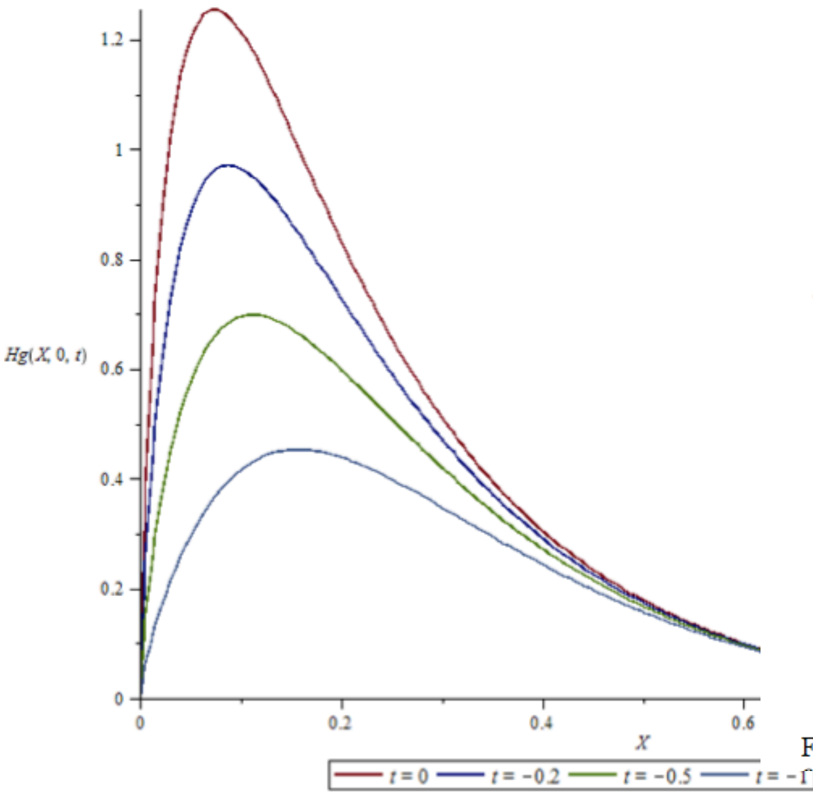
Collaborators: S. Liuti, O. Gonzalez Hernandez, J. Poage

- **GPDs, Model– Reggeized spectator “flexible parameterization”**
- **Recall Valence quarks: Chiral Even & Odd**
- **Gluons & sea quarks - spectator “flexible”**
- **Preliminary results**
- **Some Observable quantities**

Preview

Gluon GPDs – extending the model

Preliminary: x and t dependence of $H_g(x, 0, t)$ for input scale



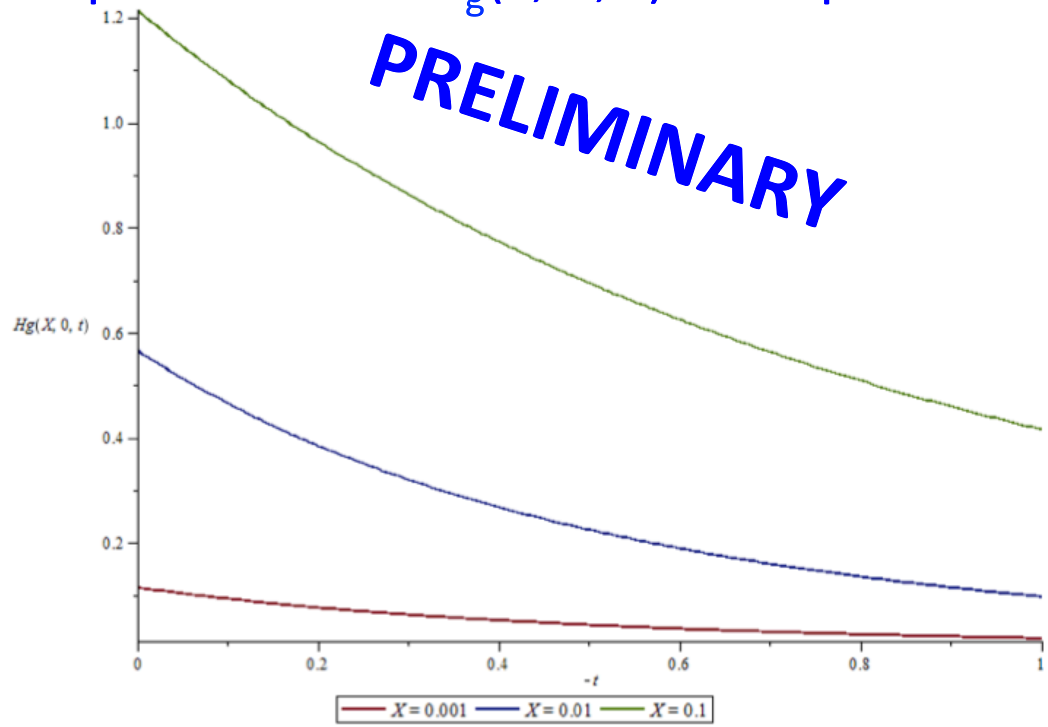


Figure 10: The plot above displays the distribution H_g(X,0,t) as a function of t, for several

'igure 9: The plot above displays the distribution H_g(X,0,t) for a range of t values.

GG, Gonzalez Hernandez, Liuti, Poage, in progress

GPD definitions – 8 quark + 8 gluon (twist 2)

Momentum space nucleon matrix elements of quark field correlators

see, e.g. M. Diehl, Eur. Phys. J. C 19, 485 (2001).

$$\frac{1}{2}\int \frac{dz^-}{2\pi}\, e^{ixP^+z^-} \langle p',\lambda'|\,\bar\psi(-\tfrac{1}{2}z)\,\gamma^+\psi(\tfrac{1}{2}z)\,|p,\lambda\rangle\Big|_{z^+=0,\,\mathbf{z}_T=0}$$

$$= \frac{1}{2P^+}\bar u(p',\lambda')\left[H^q\gamma^+ + E^q\frac{i\sigma^{+\alpha}\Delta_\alpha}{2m}\right]u(p,\lambda),$$

$$\frac{1}{2}\int \frac{dz^-}{2\pi}\, e^{ixP^+z^-} \langle p',\lambda'|\,\bar\psi(-\tfrac{1}{2}z)\,\gamma^+\gamma_5\,\psi(\tfrac{1}{2}z)\,|p,\lambda\rangle\Big|_{z^+=0,\,\mathbf{z}_T=0}$$

$$= \frac{1}{2P^+}\bar u(p',\lambda')\left[\tilde H^q\gamma^+\gamma_5 + \tilde E^q\frac{\gamma_5\Delta^+}{2m}\right]u(p,\lambda),$$

Chiral even GPDs
-> Ji sum rule

$$\left\langle J_q^x\right\rangle = \tfrac{1}{2}\int dx\left[H(x,0,0)+E(x,0,0)\right]x$$

$$\frac{1}{2}\int \frac{dz^-}{2\pi}\, e^{ixP^+z^-} \langle p',\lambda'|\,\bar\psi(-\tfrac{1}{2}z)\,i\sigma^{+i}\,\psi(\tfrac{1}{2}z)\,|p,\lambda\rangle\Big|_{z^+=0,\,\mathbf{z}_T=0}$$

$$= \frac{1}{2P^+}\bar u(p',\lambda')\left[H_T^q\, i\sigma^{+i} + \tilde H_T^q\,\frac{P^+\Delta^i - \Delta^+P^i}{m^2} + E_T^q\,\frac{\gamma^+\Delta^i - \Delta^+\gamma^i}{2m} + \tilde E_T^q\,\frac{\gamma^+P^i - P^+\gamma^i}{m}\right]u(p,\lambda$$

Chiral odd GPDs
-> transversity
How to measure and/or parameterize them?

Normalizing & constraining quark GPDs – Chiral even

Form factor, Forward limit

$$\int_0^1 H_q(x,\xi,t)\,dx = F_1^q(t), \quad H_q(x,0,0) = q(x)$$

Integrates to charge

$$\int_0^1 E_q(x,\xi,t)\,dx = F_2^q(t)$$

→Anomalous magnetic moments

$$\int_0^1 \tilde{H}_q(x,\xi,t)\,dx = g_A^q(t), \quad \tilde{H}_q(x,0,0) = \Delta q(x) = q_{\Rightarrow}^{\rightarrow}(x) - q_{\Rightarrow}^{\leftarrow}(x)$$

Integrates to axial charge

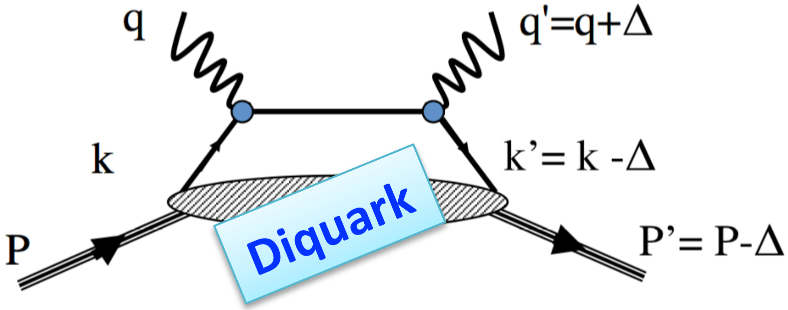
$$\int_0^1 \tilde{E}_q(x,\xi,t)\,dx = g_P^q(t)$$

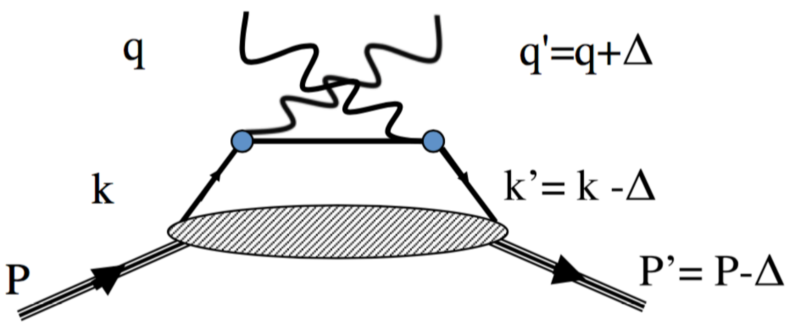
The Model for valence quarks– Reggeized Diquarks

The Model – first for Chiral Even –
Reggeized Diquark Spectator
Diquark: Color anti-3, scalar & axial vector

"flexible" covariant model

Gonzalez, GG, Liuti PRD84, 034007 (2011)





$$H = \mathcal{N}\frac{1-\zeta/2}{1-X} \times \int d^2k_\perp \frac{[(m+MX)(m+M\frac{X-\zeta}{1-\zeta}) + \mathbf{k}_\perp \cdot \tilde{\mathbf{k}}_\perp]}{(k^2-M_\Lambda^2)^2(k'^2-M_\Lambda^2)^2} + \frac{\zeta^2}{4(1-\zeta)}E, \tag{27}$$

$$E = \mathcal{N}\frac{1-\zeta/2}{1-X}\int d^2k_\perp \times \frac{-2M(1-\zeta)[(m+MX)\frac{\tilde{k}\cdot\Delta}{\Delta_\perp^2} - (m+M\frac{X-\zeta}{1-\zeta})\frac{k_\perp\cdot\Delta}{\Delta_\perp^2}]}{(k^2-M_\Lambda^2)^2(k'^2-M_\Lambda^2)^2}, \tag{28}$$

$$\tilde{H} = \mathcal{N}\frac{1-\zeta/2}{1-X} \times \int d^2k_\perp \frac{[(m+MX)(m+M\frac{X-\zeta}{1-\zeta}) - \mathbf{k}_\perp \cdot \tilde{\mathbf{k}}_\perp]}{(k^2-M_\Lambda^2)^2(k'^2-M_\Lambda^2)^2} + \frac{\zeta^2}{4(1-\zeta)}\tilde{E}, \tag{29}$$

$$\tilde{E} = \mathcal{N}\frac{1-\zeta/2}{1-X}\int d^2k_\perp \times \frac{-\frac{4M(1-\zeta)}{\zeta}[(m+MX)\frac{\tilde{k}\cdot\Delta}{\Delta_\perp^2} + (m+M\frac{X-\zeta}{1-\zeta})\frac{k_\perp\cdot\Delta}{\Delta_\perp^2}]}{(k^2-M_\Lambda^2)^2(k'^2-M_\Lambda^2)^2}, \tag{30}$$

Reggeizing diquark model

Diquark+quark & fixed masses (e.g. at ξ=0)

$$H^{M_\Lambda^q}_{M_X^q, m_q} = \mathcal{N}_q \int \frac{d^2k_\perp}{1-x} \frac{[(m_q + Mx)(m_q + Mx) + \mathbf{k}_\perp \cdot \tilde{\mathbf{k}}_\perp]}{[\mathcal{M}_q^2(x) - k_\perp^2/(1-x)]^2 [\mathcal{M}_q^2(x) - \tilde{k}_\perp^2/(1-x)]^2},$$

$$E^{M_\Lambda^q}_{M_X^q, m_q} = \mathcal{N}_q \int \frac{d^2k_\perp}{1-x} \frac{-2M/\Delta_\perp^2 [(m_q + Mx)\tilde{\mathbf{k}}_\perp \cdot \mathbf{\Delta}_\perp - (m_q + Mx)\mathbf{k}_\perp \cdot \mathbf{\Delta}_\perp]}{[\mathcal{M}_q^2(x) - k_\perp^2/(1-x)]^2 [\mathcal{M}_q^2(x) - \tilde{k}_\perp^2/(1-x)]^2},$$

Diquark mass "spectrum"
as in Brodsky, Close & Gunion
Phys. Rev. D8, 3678 (1973)

$$F_T^q(X,\zeta,t) = \mathcal{N}_q \int_0^\infty dM_X^2 \rho(M_X^2) F_T^{(m_q, M_\Lambda^q)}(X,\zeta,t; M_X).$$

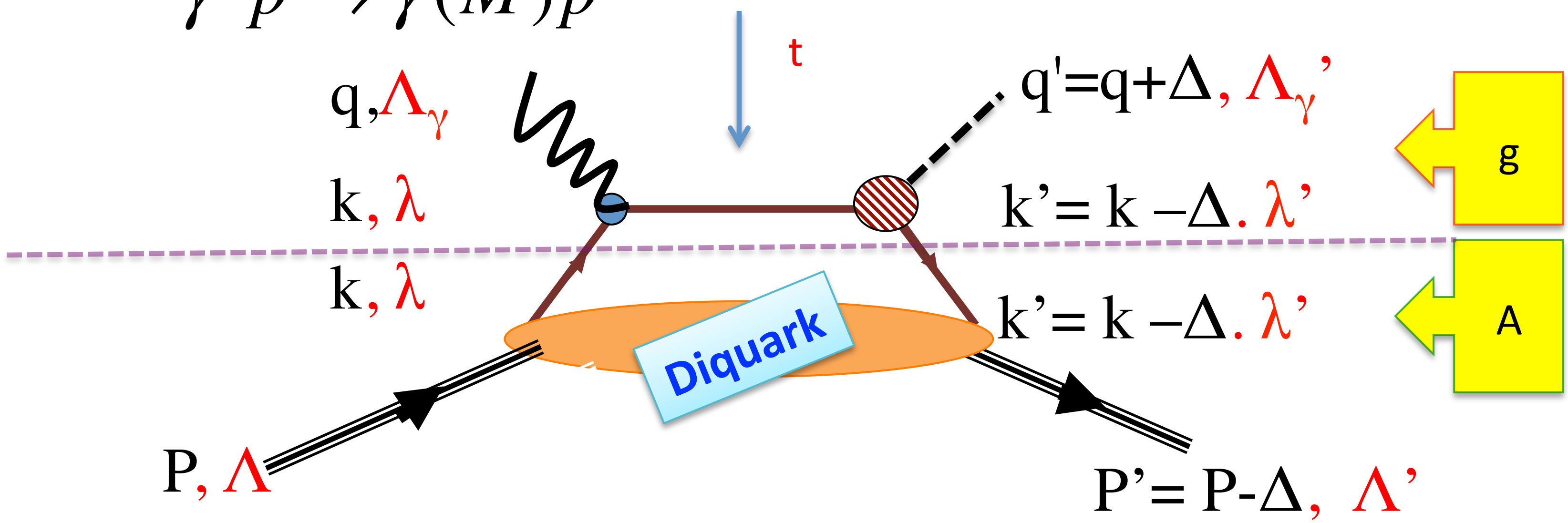
$$\rho(M_X^2) \approx \begin{cases} (M_X^2)^\alpha & M_X^2 \to \infty \\ \delta(M_X^2 - \overline{M}_X^2) & M_X^2 \text{ few GeV}^2 \end{cases}$$

$$F_T^q(X,\zeta,t) \approx \mathcal{N}_q X^{-\alpha_q + \alpha_q'(X)t} F_T^{(m_q, M_\Lambda^q)}(X,\zeta,t; \overline{M}_X) = R_{p_q}^{\alpha_q, \alpha_q'}(X,\zeta,t)\, G_{M_X, m}^{M_\Lambda}(X,\zeta,t)$$

R✖Dq

Factorization in exclusive processes (DVCS, DVMP…)

$$\gamma^* p \rightarrow \gamma(M) p'$$



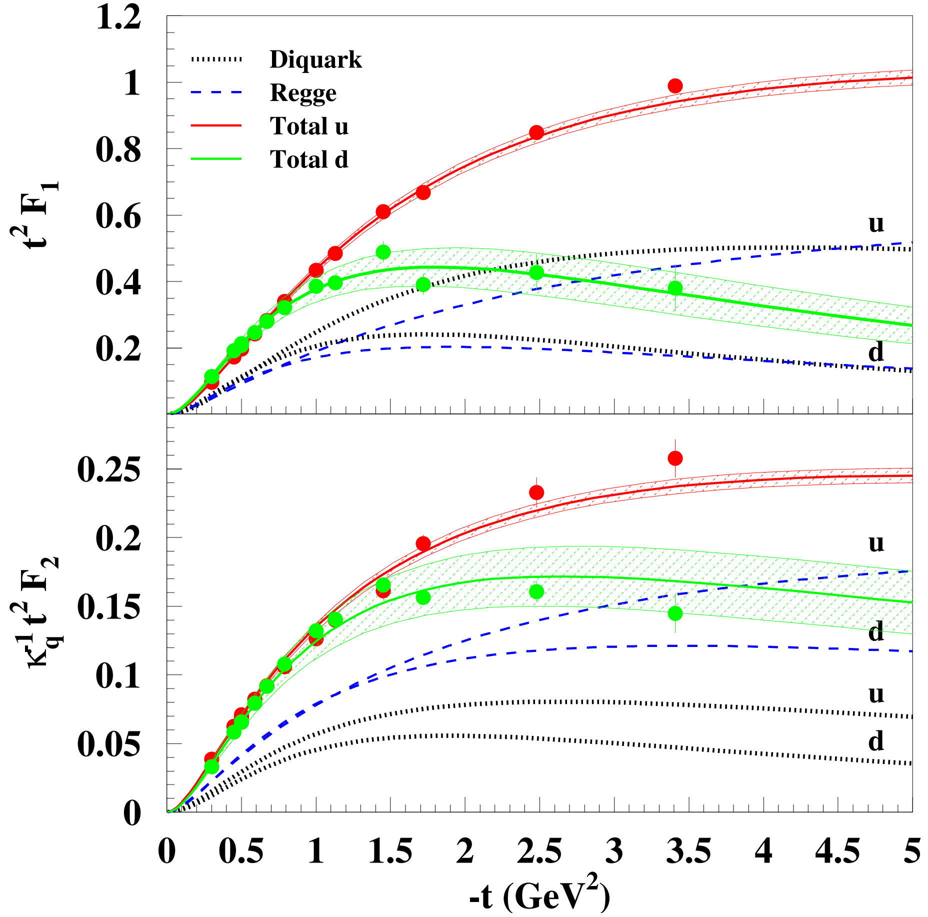
Convolution of "hard part" with quark-proton **Helicity** amplitudes

$$f_{\Lambda_\gamma,\Lambda;\Lambda'_\gamma,\Lambda'} = \sum_{\lambda,\lambda'} g_{\lambda,\lambda'}^{\Lambda_\gamma,\Lambda'_{\gamma(M)}}(x, k_T, \zeta, t; Q^2) \otimes A_{\Lambda',\lambda';\Lambda,\lambda}(x, k_T, \zeta, t),$$

λ= +(-) λ' chiral even (odd)
See Ahmad, et al. PRD75, 0904003 (2007); ibid, EPJC63, 407 (2009) .

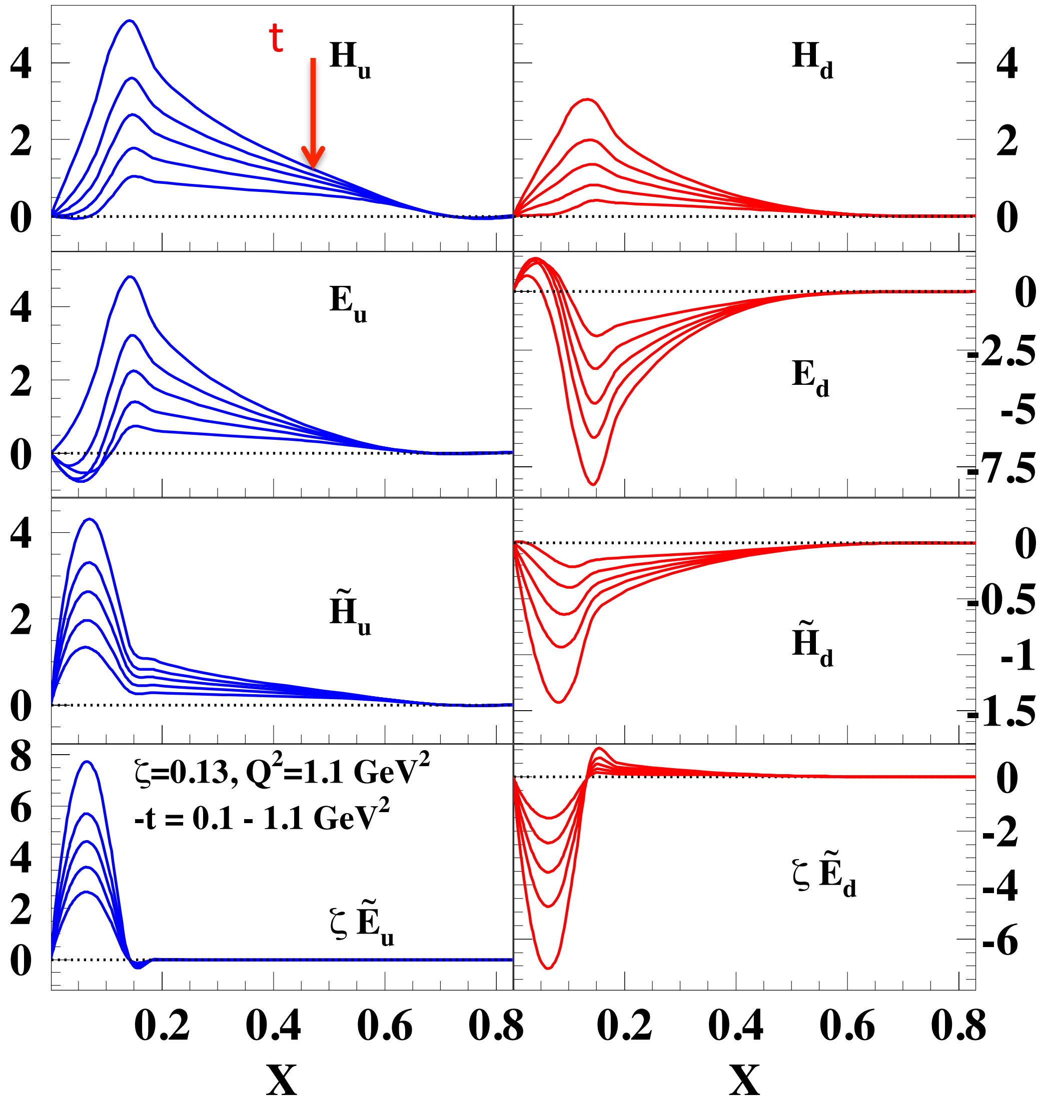
see Ahmad, GG, Liuti, PRD79, 054014, (2009)
for first chiral odd GPD parameterization
Gonzalez, GG, Liuti PRD84, 034007 (2011) chiral even GPD

EM Form Factors (t dependence) precision mesurements→tighter parameters



O.Gonzalez, GRG, S.Liuti, K.Kathuria PRC88, 065206(2013)
data: G.D. Cates, et al. PRL106,252003 (2011).

Chiral even GPDs



From GPDs with evolution to Compton Form Factors

↓

CFFs to helicity amps

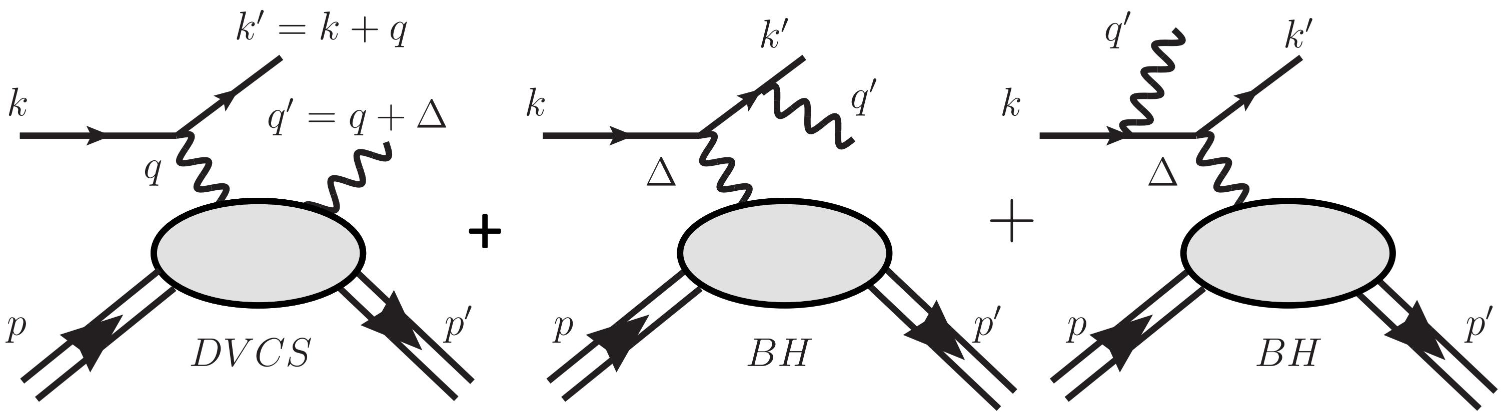
↓

helicity amps to observables

↓

<-> parameters

DVCS: "golden" GPDs

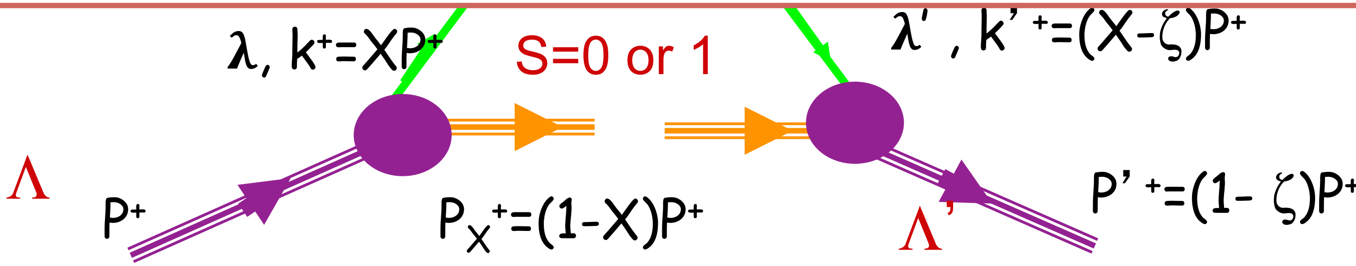


BH Interference with DVCS/GPDs

Successful comparison with data

see: Gonzalez, GRG, Liuti PRD84, 034007 (2011)

Procedure to construct **Chiral Even GPDs** & observables
Spectator color anti-3 diquark model & Reggeization



Product of diquark l.c.w.f.'s $\rightarrow A_{\Lambda\lambda;\Lambda'\lambda'=\lambda}$

↓

$A_{\Lambda\lambda;\Lambda'\lambda}$ → chiral even GPDs + Evolution

↓

$g \otimes A \rightarrow$ exclusive process helicity amps

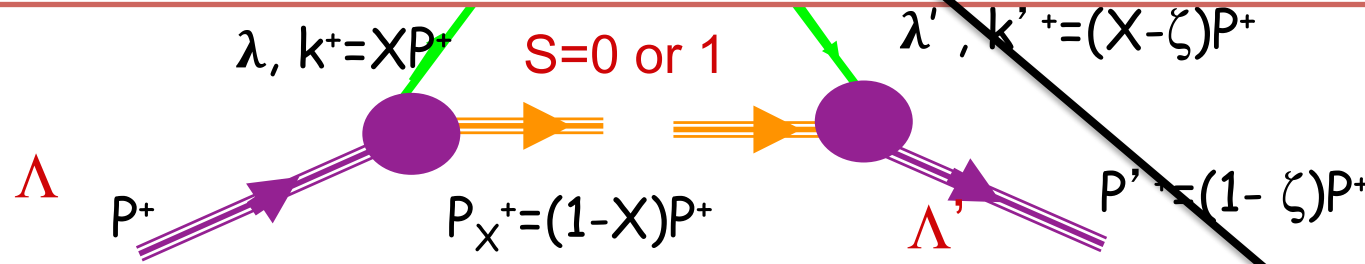
↓

pdf's, FF's, $d\sigma/d\Omega$ & Asymmetries: parameters & predictions

↓

$A_{\Lambda\lambda;\Lambda'\lambda}$→ all chiral even GPDs→DVCS, DVMP

Procedure to construct **Chiral Even GPDs** & observables
Spectator color anti-3 diquark model & Reggeization



Product of diquark l.c.w.f.'s $\rightarrow A_{\Lambda\lambda;\Lambda'\lambda'=\lambda}$ ← **Odd**

↓

$A_{\Lambda\lambda;\Lambda'\lambda}$ → chiral even GPDs + Evolution

↓

$g \otimes A \rightarrow$ exclusive process helicity amps

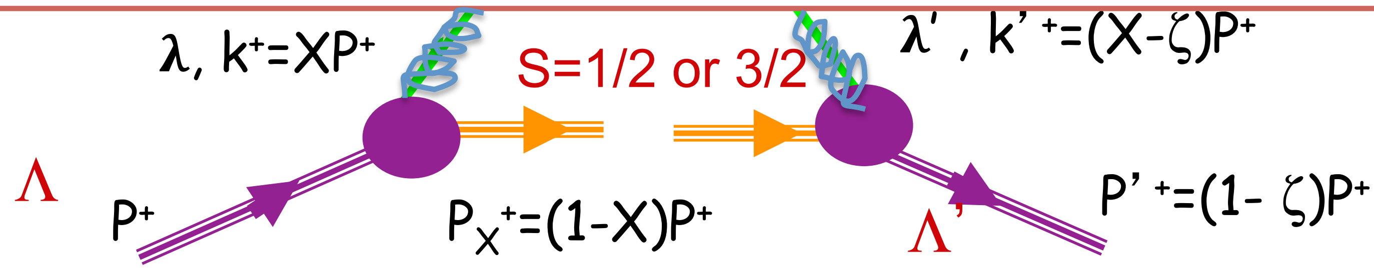
↓

pdf's, FF's, $d\sigma/d\Omega$ & Asymmetries: parameters & predictions

↓

$A_{\Lambda\lambda;\Lambda'\lambda}$ → all chiral even GPDs → DVCS, DVMP

Procedure to construct **Gluon** GPDs & observables
Spectator color octet "nucleon" model & Reggeization



Product of baryon l.c.w.f.'s $\rightarrow A_{\Lambda\lambda;\Lambda'\lambda'=\lambda}$

↓

$A_{\Lambda\lambda;\Lambda'\lambda} \rightarrow$ gluon GPDs

↓

$g \otimes A \rightarrow$ exclusive process helicity amps

↓

pdf's, FF's, $d\sigma/d\Omega$ & Asymmetries: parameters & predictions

↓

vertex parity?$\rightarrow A_{\Lambda\lambda;-\Lambda'-\lambda'} \rightarrow$ "transversity" gluon GPDs ?

Gluon GPDs

$$\frac{1}{\bar{P}^+}\int \frac{dz^-}{2\pi} e^{ix\bar{P}^+z^-}\langle P',\Lambda'|G^{+i}(-\frac{1}{2}z)G^{+i}(\frac{1}{2}z)|P,\Lambda\rangle\Big|_{z^+=0,\vec{z}_T=0} =$$

$$\frac{1}{2\bar{P}^+}\bar{U}(P',\Lambda')[H^g(x,\xi,t)\gamma^+ + E^g(x,\xi,t)\frac{i\sigma^{+\alpha}(-\Delta_\alpha)}{2M}]U(P,\Lambda)$$

Even parity & Gluon helicity conserving

$$\frac{-i}{\bar{P}^+}\int \frac{dz^-}{2\pi} e^{ix\bar{P}^+z^-}\langle P',\Lambda'|G^{+i}(-\frac{1}{2}z)\tilde{G}^{+i}(\frac{1}{2}z)|P,\Lambda\rangle\Big|_{z^+=0,\vec{z}_T=0} =$$

$$\frac{1}{2\bar{P}^+}\bar{U}(P',\Lambda')[\tilde{H}^g(x,\xi,t)\gamma^+\gamma_5 + \underset{\sim}{E}^g(x,\xi,t)\frac{\gamma_5(-\Delta^+)}{2M}]U(P,\Lambda)$$

Odd parity & Gluon helicity conserving

- **Gluon & Sea quark distributions**
  Spectator Model
  – generalize Regge-diquark spectator model

- N→ ***g*** + "color octet N" spectator ($8 \otimes 8 \supset 1$)
  (could be spin ½ or 3/2)
- (N→ ***anti-u*** + color 3 "tetraquark"uuud)

- How to normalize?
  $H_g(x,\xi,t)_{Q^2} \rightarrow H_g(x,0,0)_{Q^2} = xG(x)_{Q^2}$
- Evolution & small x phenomenology
- Sea quark distributions $H_{anti\text{-}u}(x,0,0)$ . . .

- Use pdf's to fix x dependence

- Small x ~ Pomeron

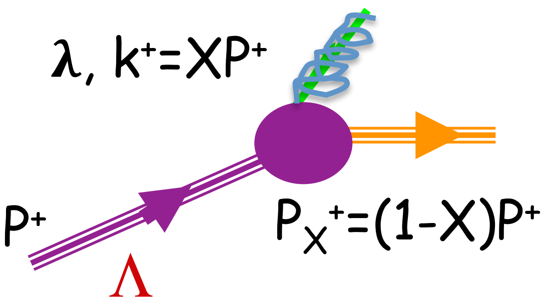
Gluon distribution model?

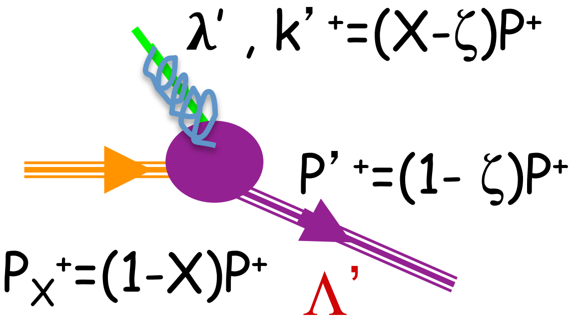
- What to expect for H_g , $E_g(x,\xi,t)$, . . . ?
- Begin with normalization

$$H_g(x,0,0) \rightarrow xG(x)|_{Q^2} \text{ unpolarized}$$

- Parametrize via “spectator” model by pdf’s
- Follow same procedure as for valence quark chiral even GPDs

Gluon 'vertex functions' $\mathcal{G}_{\Lambda x\,;\,\Lambda g,\,\Lambda}$





$\mathcal{G}_{+++}(x,\vec{k}_T^2)$	$-\frac{2}{\sqrt{2(1-X)}}\frac{(k_x-ik_y)}{X}$
$\mathcal{G}_{-++}(x,\vec{k}_T^2)$	$-\frac{2}{\sqrt{2(1-X)}}(M(1-X)-M_x)$
$\mathcal{G}_{++-}(x,\vec{k}_T^2)$	0
$\mathcal{G}_{-+-}(x,\vec{k}_T^2)$	$-\frac{2}{\sqrt{2(1-X)}}(1-X)\frac{(k_x-ik_y)}{X}$
$\mathcal{G}^*_{+++}(x,\vec{k}_T'^2)$	$-\frac{2}{\sqrt{2(1-X')}}\frac{(\tilde{k}_x+i\tilde{k}_y)}{X'}$
$\mathcal{G}^*_{-++}(x,\vec{k}_T'^2)$	$-\frac{2}{\sqrt{2(1-X')}}(M(1-X')-M_x)$
$\mathcal{G}^*_{++-}(x,\vec{k}_T'^2)$	0
$\mathcal{G}^*_{-+-}(x,\vec{k}_T'^2))$	$-\frac{2}{\sqrt{2(1-X')}}(1-X')\frac{(\tilde{k}_x+i\tilde{k}_y))}{X'}$

$$X'=\frac{X-\zeta}{1-\zeta},\ \tilde{k}_{i=1,2}=k_i-\frac{1-X}{1-\zeta}\Delta_i$$

GG, Gonzalez Hernandez, Liuti, Poage, in progress

Spectator model gluon GPDs

$$H_g = \mathcal{N}\frac{1}{(1-X)^2}\Big[X(X-\zeta)((1-X)M-M_X)((\frac{1-X}{1-\zeta})M-M_X)\mathcal{I}_2$$
$$+(1-\zeta)(1+\frac{(1-X)^2}{(1-\zeta)})(\mathcal{I}_3-\frac{(1-X)\Delta_\perp^2}{(1-\zeta)}\mathcal{I}_1)\Big]+\frac{\zeta^2}{4(1-\zeta)}E_g$$

$$\tilde{H}_g = \mathcal{N}\frac{1}{(1-X)^2}\Big[X(X-\zeta)((1-X)M-M_X)((\frac{1-X}{1-\zeta})M-M_X)\mathcal{I}_2$$
$$+(1-\zeta)(1-\frac{(1-X)^2}{(1-\zeta)})(\mathcal{I}_3-\frac{(1-X)\Delta_\perp^2}{(1-\zeta)}\mathcal{I}_1)\Big]+\frac{\zeta^2}{4(1-\zeta)}\tilde{E}_g$$

$$E_g = \mathcal{N}\left(\frac{-2M(1-\zeta)}{(1-X)}\right)\frac{1}{1-\zeta/2}\Big[X((1-X)M-M_X)(\mathcal{I}_1-\frac{1-X}{1-\zeta}\mathcal{I}_2)-(X-\zeta)((\frac{1-X}{1-\zeta})M-M_X)\mathcal{I}_1\Big]$$

$$\tilde{E}_g = \mathcal{N}\left(\frac{-2M(1-\zeta)}{(1-X)}\right)\frac{2}{\zeta}\Big[X((1-X)M-M_X)(\mathcal{I}_1-\frac{1-X}{1-\zeta}\mathcal{I}_2)+(X-\zeta)((\frac{1-X}{1-\zeta})M-M_X)\mathcal{I}_1\Big]$$

$\mathcal{I}_{1,2,3}$ are $k_\perp$ integrations & M_X is spectator mass

pdf's fix x dependence

Gluon

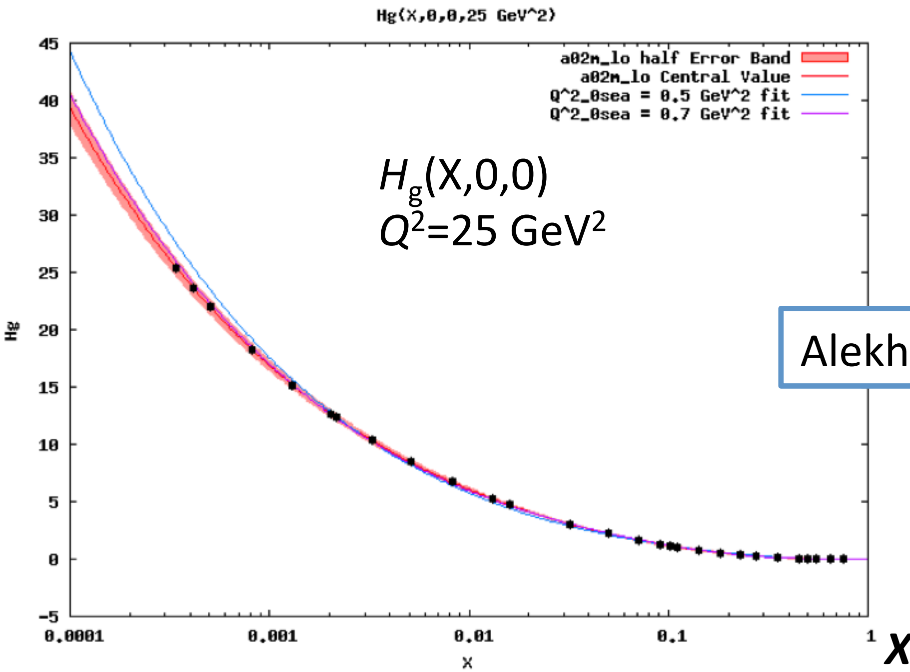


Figure 6: The plot above shows the distribution $H_g(X,0,0,25\ \mathrm{GeV}^2)$ for the two fits. Alekhin's distribution Xg(X) used in the fit procedure is included with an error band of one half of the error for the set a02m_lo. The X points used in the fit procedure are indicated by black dots.

anti-u

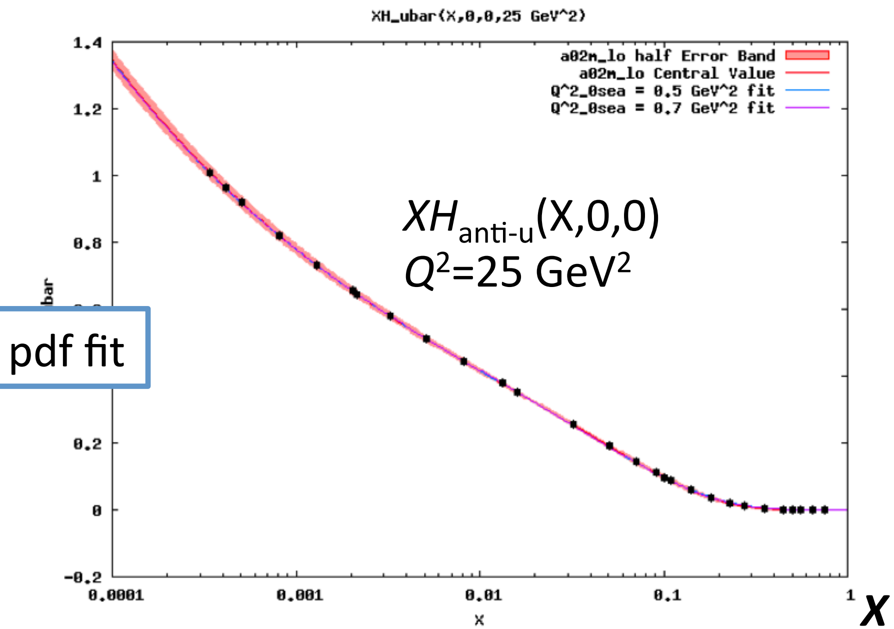


Figure 3: The plot above shows the distribution $XH_{\bar{u}}(X,0,0,25\ \mathrm{GeV}^2)$ for the two fits. Alekhin's distribution $X\bar{u}(X)$ used in the fit procedure is included with an error band of one half of the error for the set a02m_lo. The X points used in the fit procedure are indicated by black dots.

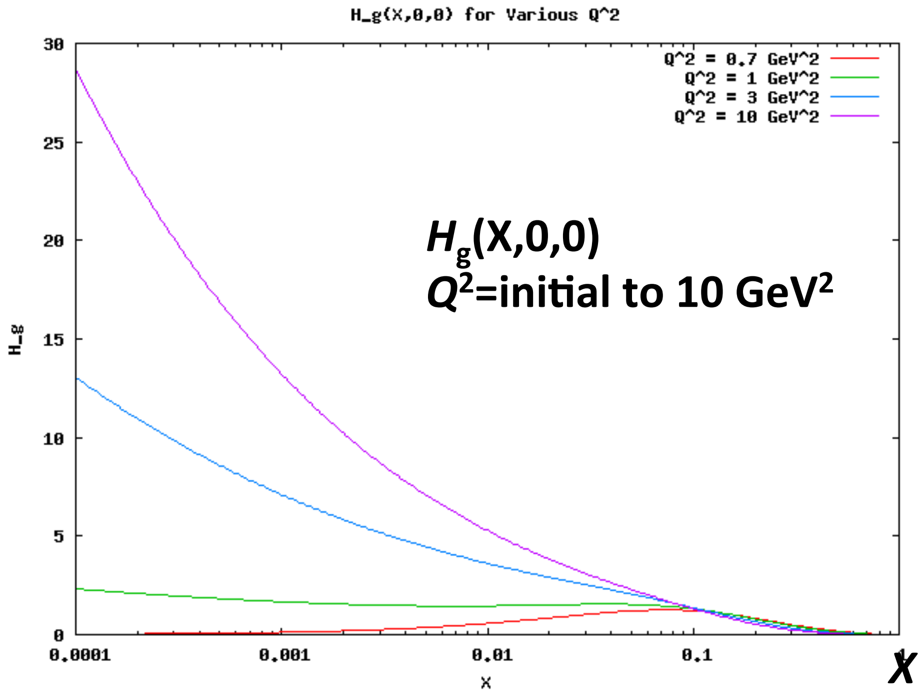
Alekhin pdf fit

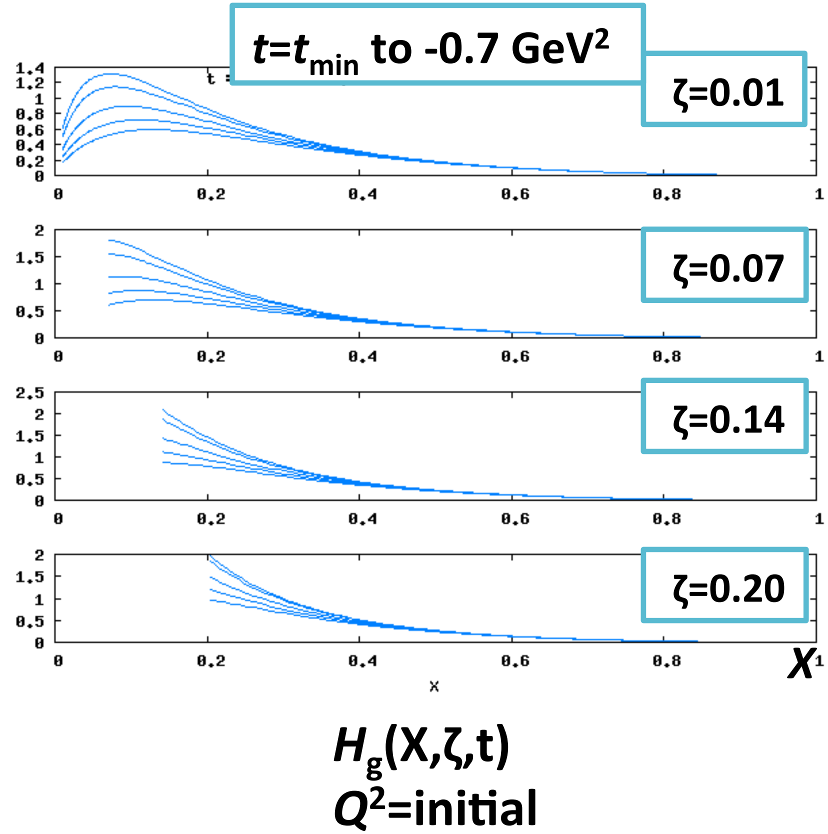
Single Q^2 value shown --- fit known pdf's all Q^2

from J. Poage

GG, Gonzalez Hernandez, Liuti, Poage, in progress

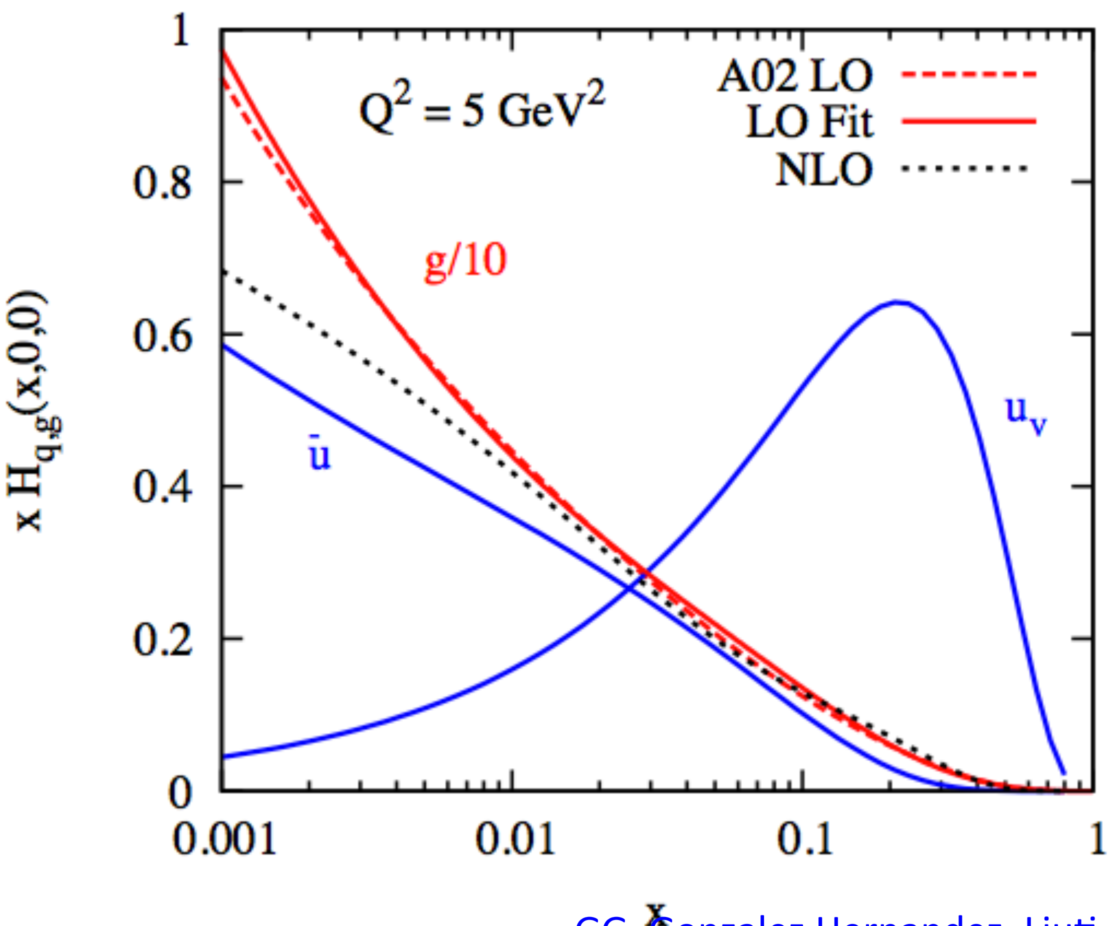
After pdf's vs. Q^2 → fix x dependence
Regge behavior determines *t* dependence
Spectator determines ζ dependence





Fitting gluon pdf's

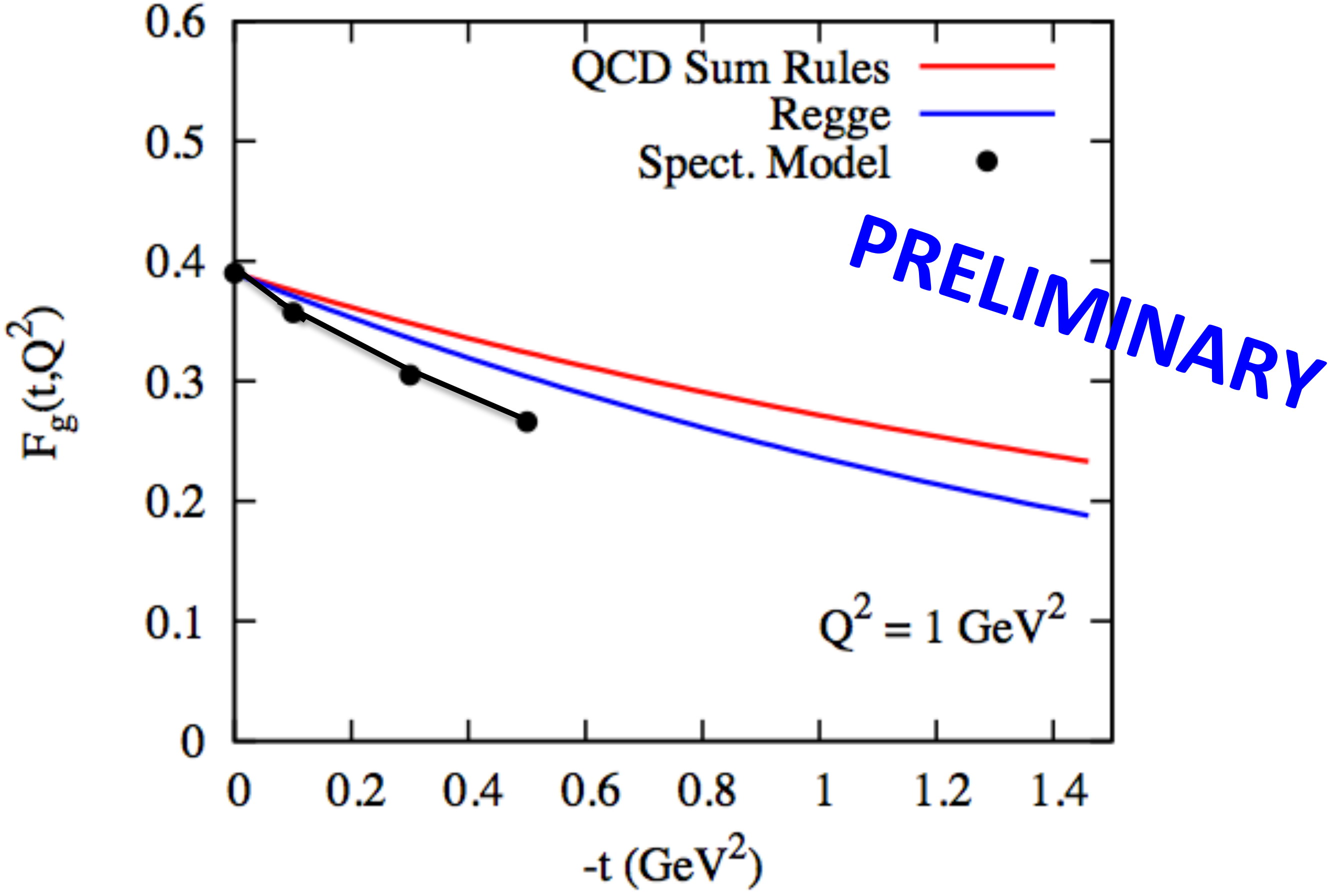
c.f. Alekhin, .. etc.



GG, Gonzalez Hernandez, Liuti, Poage, in progress

$H_g(x,0,t)$ What constrains t-dependence?

Spectator t-dependence w/o Regge small x behavior:
& hybrid Regge-Spectator model combines



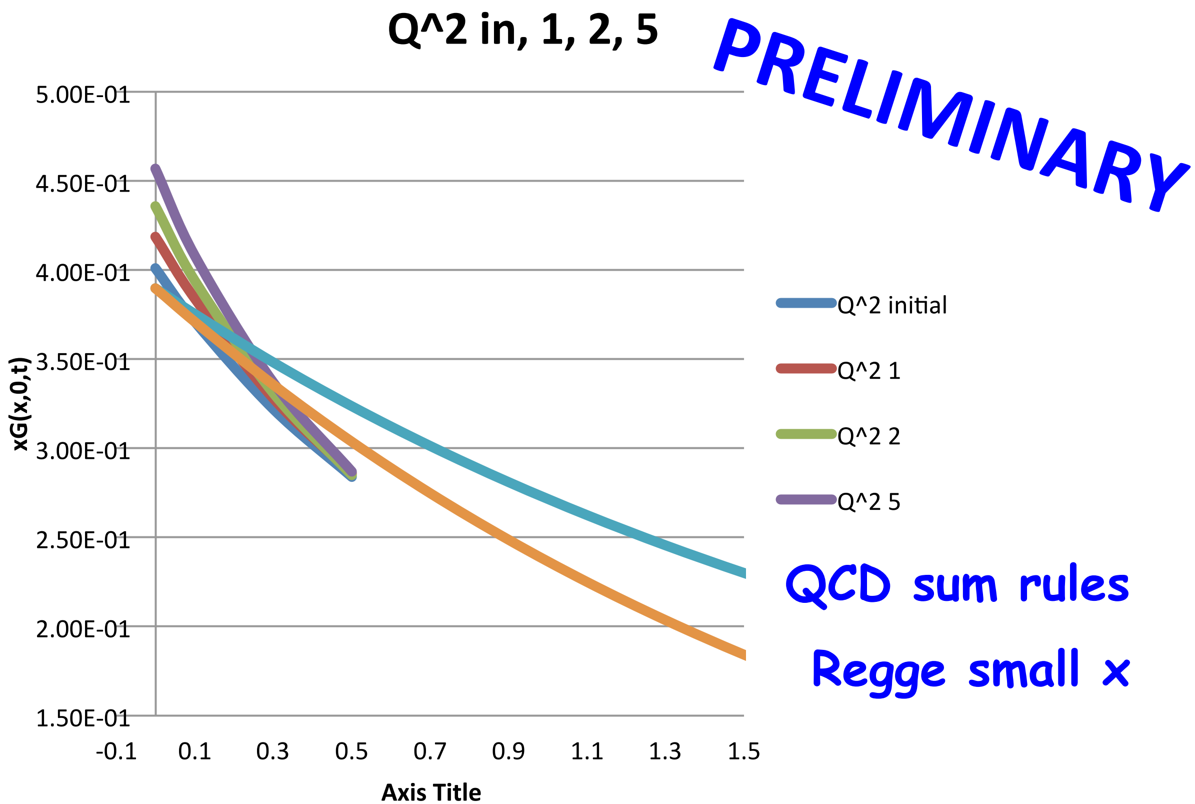
Compare Gluon form factor via QCD sum rules

Braun, Gornicki, Mankiewicz, Schaefer, Phys.Lett.B302, 291 (1993)

GG, Gonzalez Hernandez, Liuti, Poage, in progress

Compare Gluon form factor via QCD sum rules

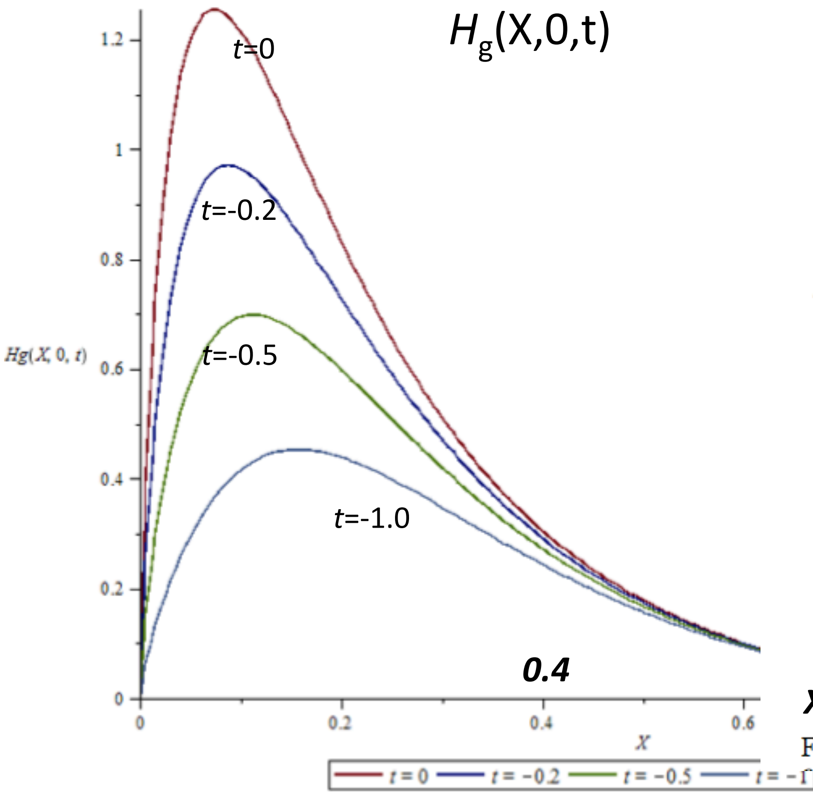
Braun, Gornicki, Mankiewicz, Schaefer, Phys.Lett.B302, 291 (1993)



Spectator t-dependence w/o Regge small x behavior:
hybrid Regge-Spectator model combined

GG, Gonzalez Hernandez, Liuti, Poage, in progress

Preliminary: x and t dependence of $H_g(x, 0, t)$ for input scale



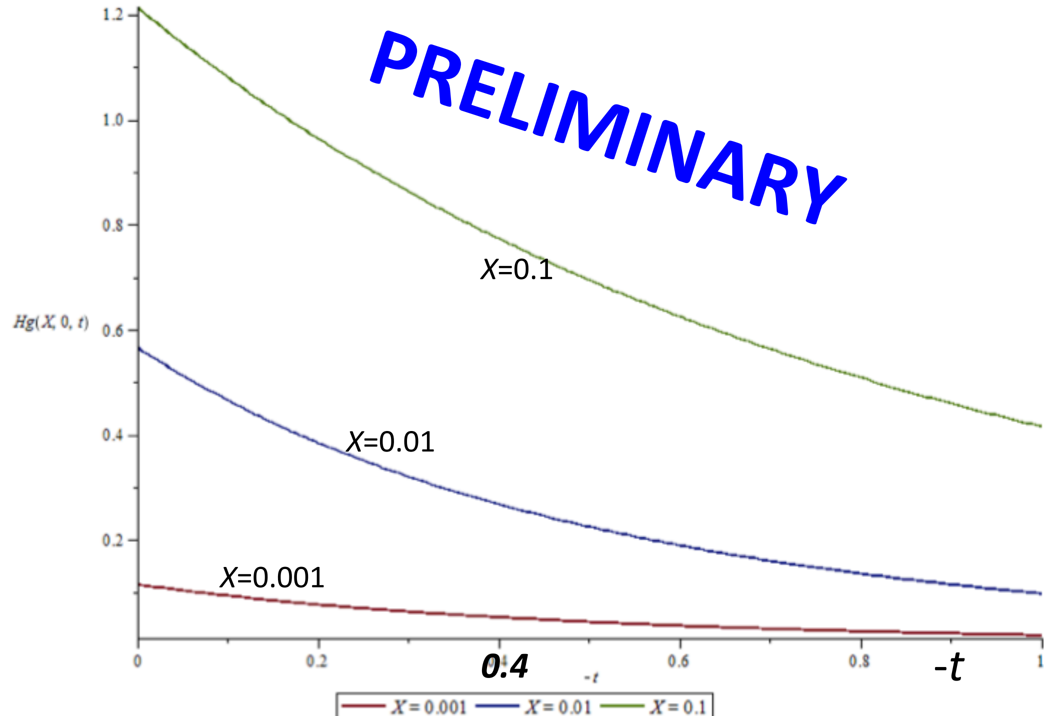


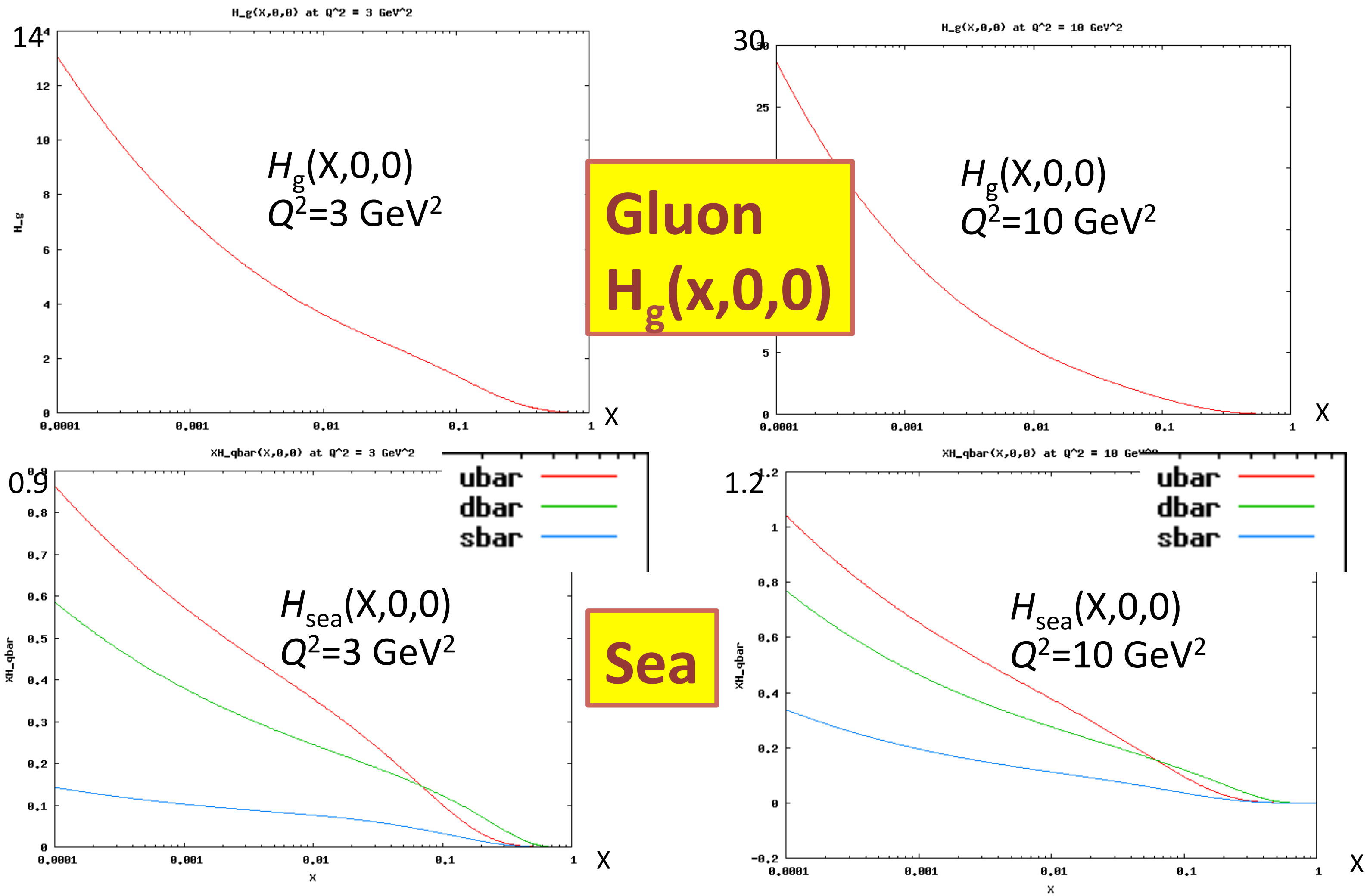
Figure 10: The plot above displays the distribution H_g(X,0,t) as a function of t, for several

'igure 9: The plot above displays the distribution H_g(X,0,t) for a range of t values.

GG, Gonzalez Hernandez, Liuti, Poage, in progress

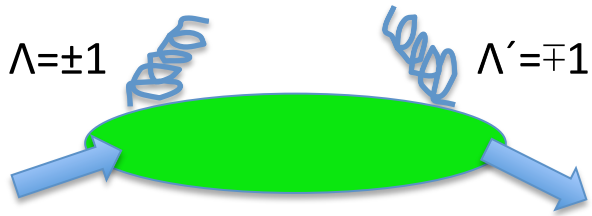
Gluon & sea distributions

J. Poage



GG, Gonzalez Hernandez, Liuti, Poage, in progress

Extension to Gluon "Transversity"



$$-\frac{1}{P^+}\int\frac{dz^-}{2\pi}\,e^{ixP^+z^-}\langle p',\lambda'|\,\mathbf{S}F^{+i}(-\tfrac{1}{2}z)\,F^{+j}(\tfrac{1}{2}z)\,|p,\lambda\rangle\Big|_{z^+=0,\,\mathbf{z}_T=0}$$

$$= \mathbf{S}\,\frac{1}{2P^+}\,\frac{P^+\Delta^j-\Delta^+P^j}{2mP^+}$$

$$\times\;\bar{u}(p',\lambda')\left[H_T^g\,i\sigma^{+i}+\tilde{H}_T^g\,\frac{P^+\Delta^i-\Delta^+P^i}{m^2}\right.$$

$$\left.+\,E_T^g\,\frac{\gamma^+\Delta^i-\Delta^+\gamma^i}{2m}+\tilde{E}_T^g\,\frac{\gamma^+P^i-P^+\gamma^i}{m}\right]u(p,\lambda).$$

4 GPDs: M.Diehl, EPJC19, 485 (2001)

What about Gluon "transversity"?

Transversity for on-shell gluons or photons : no |0> helicity

$$|+1)_{trans} = \{|+1> + |-1>\}/2 = |-1)_{trans}$$

$$|0\ )_{trans} = \{|+1> - |-1>\}/\sqrt{2}$$

$$\text{helicity } |\pm 1> = \{-/+\hat{x} - i\hat{y}\}/\sqrt{2}$$

$$\hat{x} = -|0)_{trans} = P_{parallel}$$

Linear polarization in the plane

$$\hat{y} = i\sqrt{2}\,|+1)_{trans} = P_{normal}$$

Linear polarization normal to the plane

GG&M.J.Moravcsik, Ann.Phys.195,213(1989).

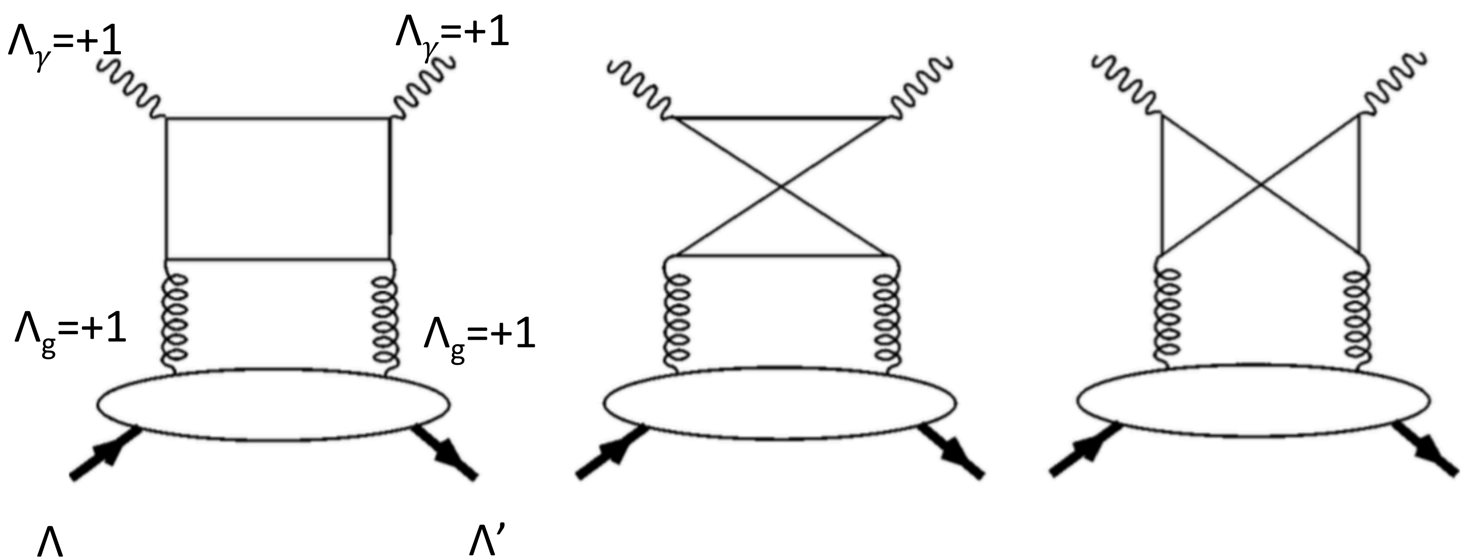
Using the Reggeized Spectators Model

How to Measure? What Processes?

$A_{\Lambda',\Lambda g';\,\Lambda,\Lambda g}$ contributes to DVCS at order α_S

$$M_{\Lambda',\Lambda'\gamma=\Lambda\gamma';\Lambda,\Lambda\gamma} = -\frac{\alpha s}{2\pi}\sum_q e_q^2 \int_{-1}^{+1} dx \frac{A_{\Lambda',\Lambda' g=\Lambda\gamma;\Lambda,\Lambda g=\Lambda\gamma}(x,\xi,t)}{(\xi - x - i\varepsilon)(\xi + x - i\varepsilon)} C(x,\xi,Q^2)$$

DVCS cross sections: $d\sigma/dt \propto \sum |M_{\Lambda'\ldots}|^2$



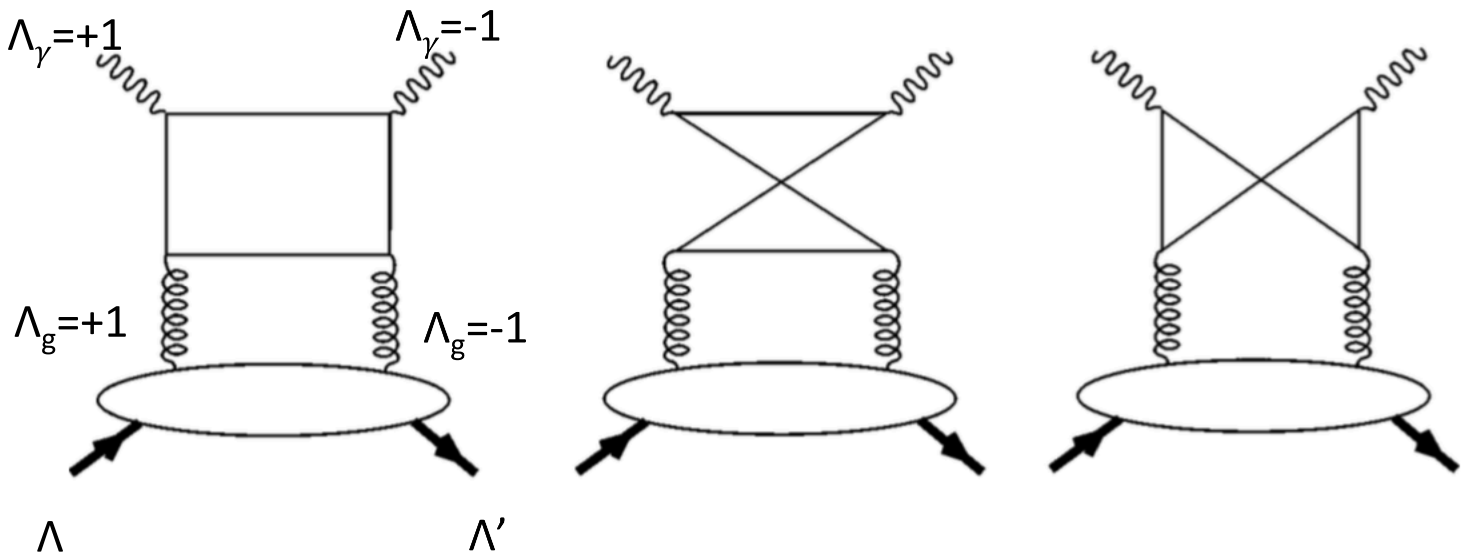
See Hoodbhoy & Ji, PRD58, 054006 (1998)

$A_{\Lambda',-1;\,\Lambda,+1}$ Gluon Transversity contributes to DVCS order α_S

$$M_{\Lambda',\Lambda'\gamma=-1;\Lambda,\Lambda\gamma=+1} = -\frac{\alpha s}{2\pi}\sum_q e_q^2 \int_{-1}^{+1} dx \frac{A_{\Lambda',\Lambda' g=-1;\Lambda,\Lambda g=+1}(x,\xi,t)}{(\xi - x - i\varepsilon)(\xi + x - i\varepsilon)} \; C'(x,\xi,Q^2)$$

DVCS cross sections: $d\sigma/dt \propto \sum |M_{\Lambda' \ldots}|^2$

***Interference with Bethe-Heitler contains *cos3φ* modulation to distinguish from (leading twist) quark contribution ***



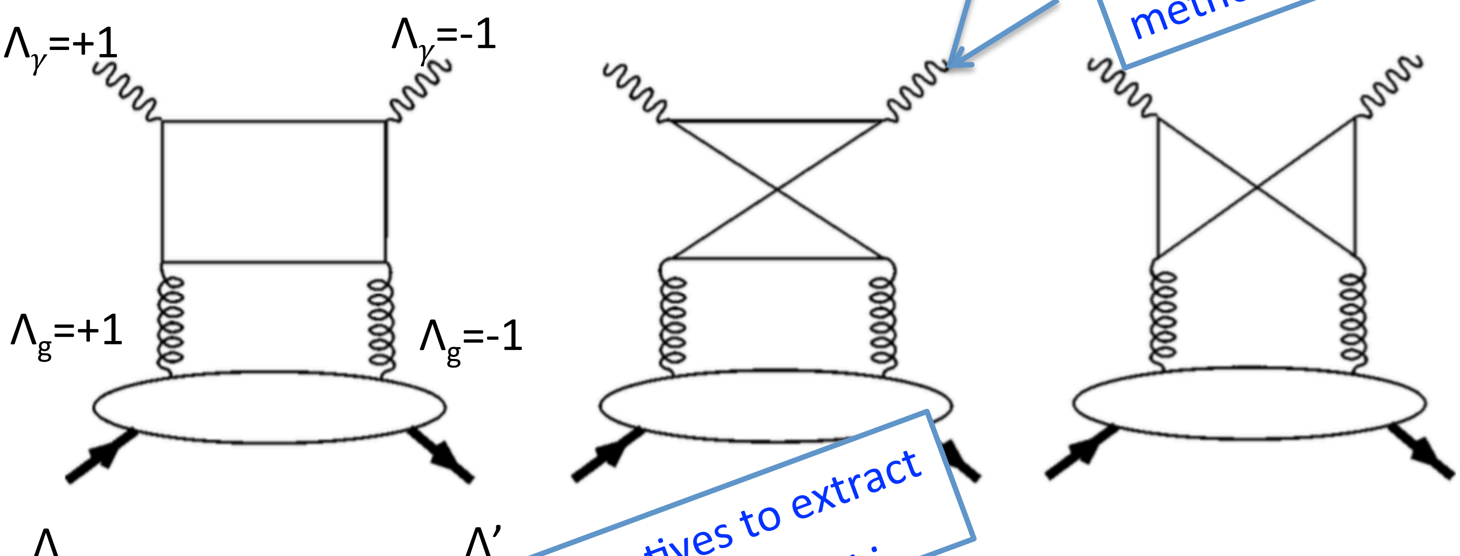
See Hoodbhoy & Ji, PRD58, 054006 (1998)

$A_{\Lambda',-1;\Lambda,+1}$ contributes to DVCS at order α_S

$$M_{\Lambda',\Lambda'\gamma=-1;\Lambda,\Lambda\gamma=+1} = -\frac{\alpha s}{2\pi}\sum_q e_q^2 \int_{-1}^{+1} dx \frac{A_{\Lambda',\Lambda' g=-1;\Lambda,\Lambda g=+1}(x,\xi,t)}{(\xi - x - i\varepsilon)(\xi + x - i\varepsilon)} \; C'(x,\xi,Q^2)$$

Interference with Bethe-Heitler contains *cos*3φ modulation to distinguish from (leading twist) quark contribution

$\mu^- \mu^+$ alternative method to extract



other alternatives to extract J/Ψ production; jets . . . .

See Hoodbhoy & Ji, PRD58, 054006 (1998)

Measuring Gluons in Nucleons

DVCS

$$\frac{d^5\sigma}{dx_{Bj}dQ^2d|t|d\phi d\phi_S} = \frac{\alpha^3}{16\pi^2(s-M^2)^2\sqrt{1+\gamma^2}}|T|^2$$

$$T(k,p,k',q',p') = T_{DVCS}(k,p,k',q',p') + T_{BH}(k,p,k',q',p'),$$

$$|T|^2 = |T_{\rm BH} + T_{\rm DVCS}|^2 = |T_{\rm BH}|^2 + |T_{\rm DVCS}|^2 + \mathcal{I}\ .$$

$$\mathcal{I} = T^*_{BH}T_{DVCS} + T^*_{DVCS}T_{BH}.$$

For unpolarized e+p→e'+γ+p' cross section depends on azimuthal angle ϕ. cos3ϕ term in interference dσ measures gluon transversity GPDs (CFF's)

$$\frac{\sqrt{t_0-t}^3}{8M^3}\left[H_T^g F_2 - E_T^g F_1 - 2\tilde{H}_T^g\left(F_1 + \frac{t}{4M^2}F_2\right)\right]\cos 3\phi$$

$\mathcal{H}_T{}^g \sim \int dx\, H^g_T/(x-\xi)(x+\xi)$ CFF's

See Diehl, *et al*. PLB411, 193 (1997);
Diehl, EPJC25, 223 (2002);
Belitsky, Mueller, PLB486, 369 (2000).

Summary

- Flexible parameterization for chiral even valence quarks from form factors, pdfs & DVCS **R**✖Dq
- Extended **R**✖Dq to **R**✖Spectator
- **New Extension to gluons & the sea**
- Considered Gluon sector
  - Helicity conserving & Helicity →gluon ***Transversity***
- Measurements?
- **More phenomenology to come**