Deeply Virtual Exclusive Processes with Charm*

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Outline

- *Motivations*
- *Deeply Virtual π^o and η Production*

  $\Rightarrow$ *A unique access to chiral odd GPDs*

  (S. Ahmad, G. Goldstein, S.L., PRD79, 2008)

- *Deeply Virtual Charmed Mesons Production*

  $\Rightarrow$ *A unique access to intrinsic charm content of nucleons*

- *Physically Motivated Parametrizations*
- *Conclusions/Outlook*

Motivations

The next decade…

- LHC results from multi-TeV CM energy collisions will open new horizons but many "candidate theories" will provide similar signatures of a departure from SM predictions…

- Precision measurements require QCD input → Dual role

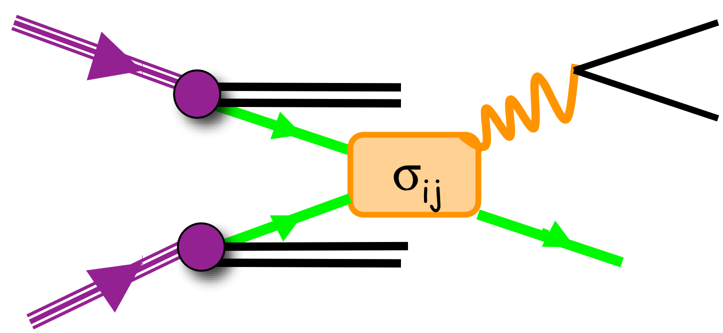
$$\sigma(P_1,P_2)=\sum_{i,j}\int dx_1 dx_2\, f_i(x_1,\mu_F) f_j(x_2,\mu_F)\hat{\sigma}(x_1,x_2,\alpha_S(\mu_R),\mu_F)$$

Factorization scale

Measured x-section

Parton distributions

Hard process x-section



- QCD: A background for "beyond the SM discovery"

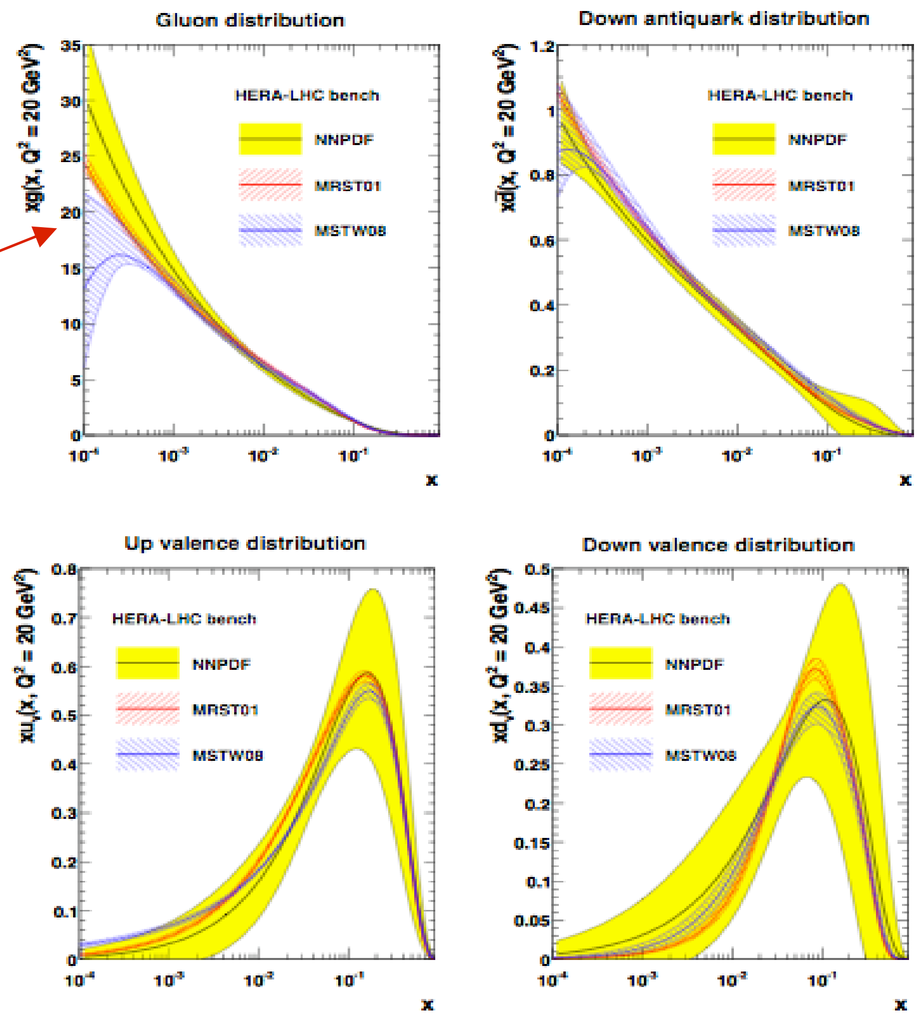
- Interesting dynamical questions for QCD at untested high energies

- Most important point for EIC

…Our understanding of the structure of hadrons is

<u>disconcertingly incomplete</u>

Uncertainties from different evaluations/extractions are smaller than the differences between the evaluations



⇒ Rich dynamics of hadrons can only be accessed and tested at the desired accuracy level in lepton DIS

- Our contribution to EIC physics (S.L. with G. Goldstein and L. Gamberg)

Study heavy quark components → charm, through hard exclusive processe

Why charm?

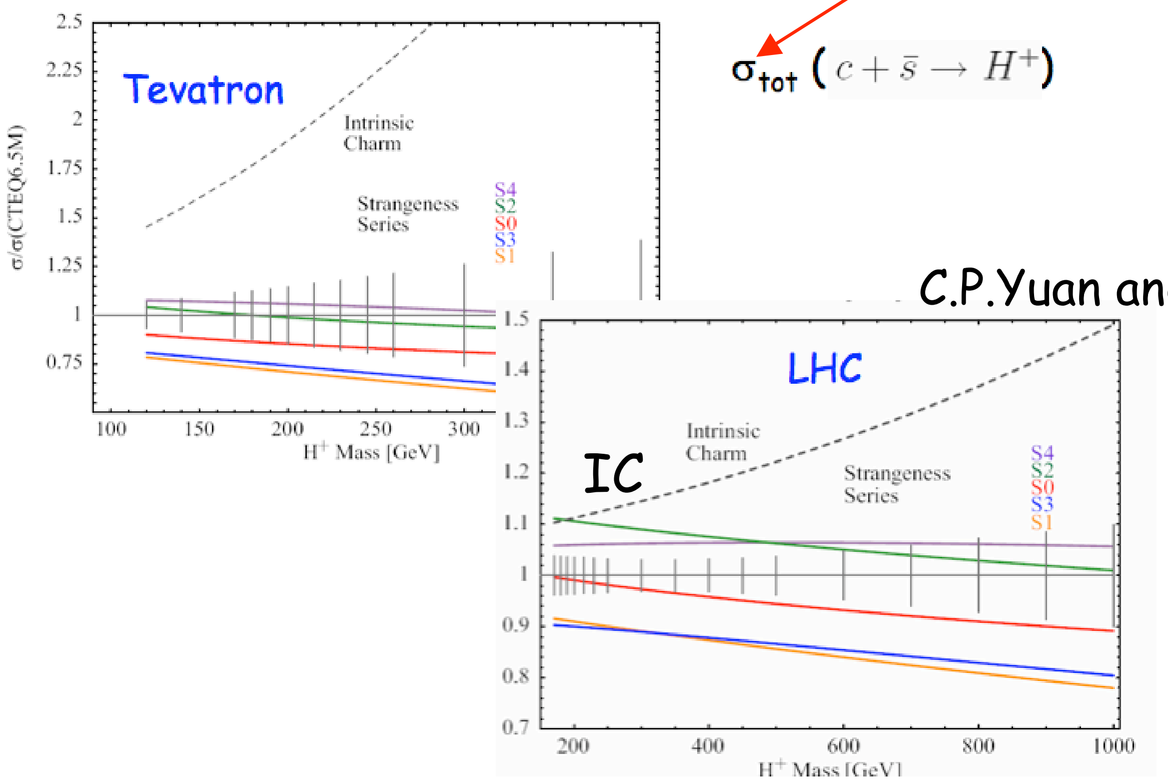
LHC processes are sensitive to charm content of the proton:

⇒ Higgs production: SM Higgs, charged Higgs, $c\bar{s} \rightarrow H^+$

⇒ Precision physics (CKM matrix elements, V_{tb} ....): single top production

Impact of new CTEQ6.5(M,S,C) PDFs

$\sigma_{tot}\,(c + \bar{s} \rightarrow H^+)$



C.P.Yuan and collaborators

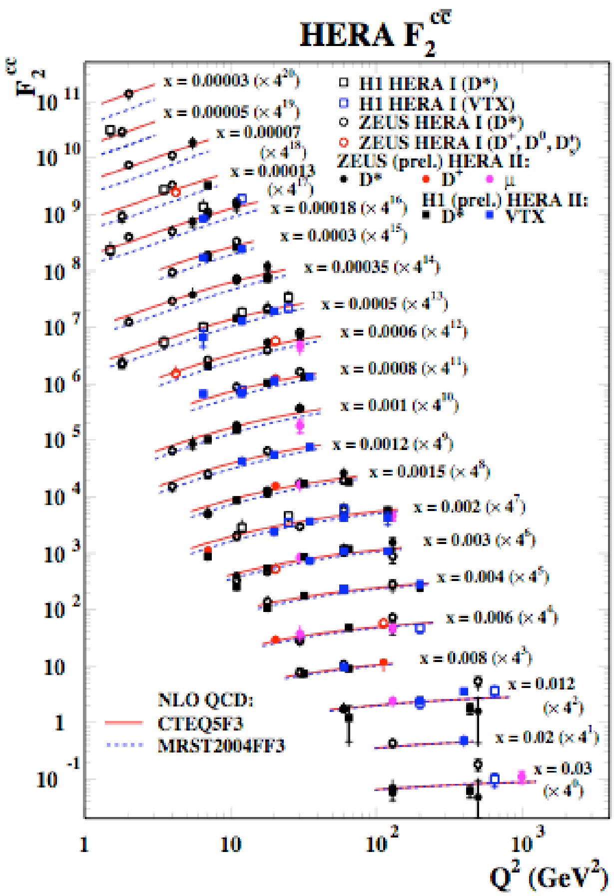
CTEQ 6.6

TABLE V. Relative differences $\Delta_{GM} \equiv \sigma_{6.1}/\sigma_{6.6} - 1$ between CTEQ 6.1 and CTEQ 6.6 cross sections for Higgs boson prodı at the LHC listed at the beginning of Sec. IV, compared to the PDF uncertainties Δ_{PDF} in these processes. The $Ah^{\pm}$ cross section combined production of positively and negatively charged Higgs bosons, with m_h being the mass of the CP-odd boson (m_h = and $m_{h^{\pm}}$ given by $m^2_{h\pm} = m^2_A + M^2_W$.

m_h (GeV)	$\Delta_{GM}(\%)\vert\Delta_{PDF}(\%)$												
	VBF		Z^0h		$Ah^{\pm}$		$gg \to h$		$c\bar{b} \to h^+$		$c\bar{s} \to h^+$		$c\bar{s} + c\bar{b} \to$
100	**−3.8**	**3.1**	**−3.2**	**2.7**	**−3.2**	**4.3**	0.6	4.4	1.5	5.9	**−18**	**10**	**−8.4**
200	−1.8	2.8	−1.6	2.8	−1.9	4.3	1.7	3.2	2.1	4.7	**−16**	**8**	**−6.6**
300	−1.6	2.8	−0.6	3	−0.4	5.3	2.3	2.7	1.9	4.3	**−14**	**7**	**−6.2**
400	−0.1	3.3	0	3.4	0.7	6.6	2.8	3.8	2	4.8	**−13**	**6.3**	**−5.6**
500	0.2	2.8	0.4	3.7	1.1	7.6	3.3	3.9	2.3	6.1	**−12**	**6.3**	**−5**
600	−0.7	3.5	0.7	4.1	1.6	9.2	3.8	5.0	2.8	8	**−11**	**6.8**	−4.2
700	0.2	3.0	0.9	4.4	2.1	11	4.3	6.3	3.4	10	**−9.9**	**7.7**	−3.4
800	2.3	3.5	1	4.8	2.8	13	4.9	7.8	4.1	12	**−8.7**	**9**	−2.4

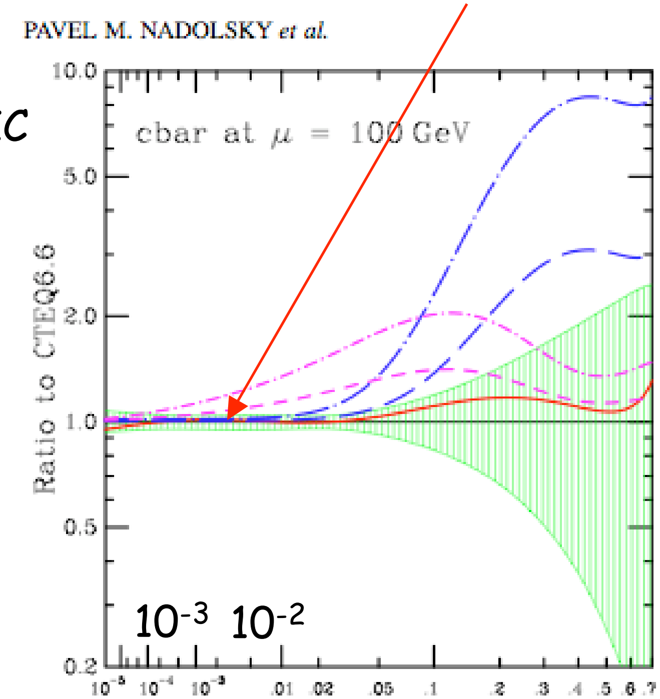
Why charm?

Outstanding question in QCD: is there a “non-perturbative/intrinsic char
component”?



Data are at very low x where they canno
discriminate whether IC is there

IC/no-IC

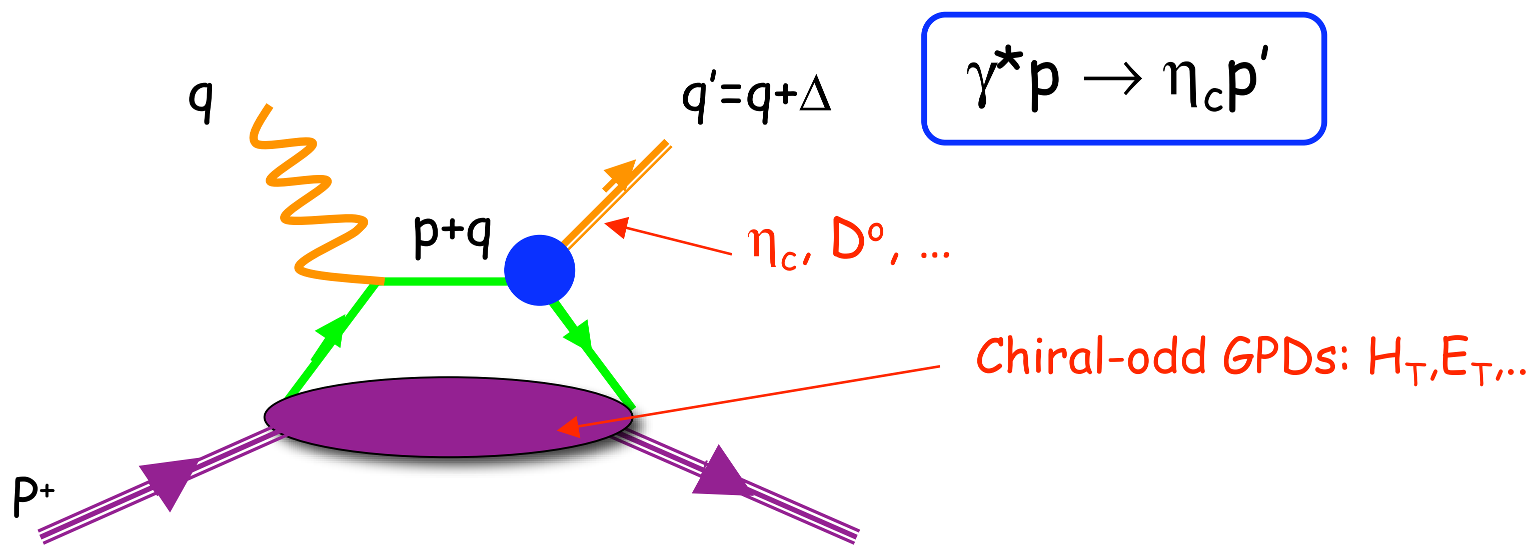


x

Why Exclusive Processes?

η_c, D^0, and $\bar{D}^0$ exclusive production is governed by chiral-odd soft matrix elements ($\Rightarrow$ Generalized Parton Distributions, GPDs) which cannot evolve from gluons!

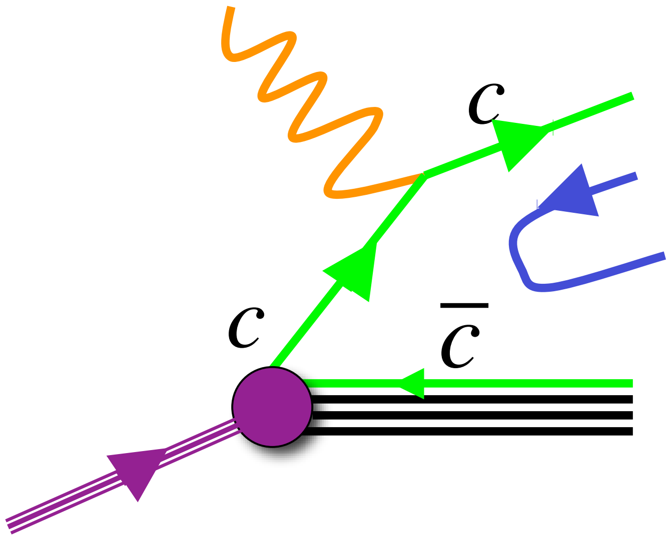
η_c, D^0, and $\bar{D}^0$ used as triggers of "intrinsic charm content"!



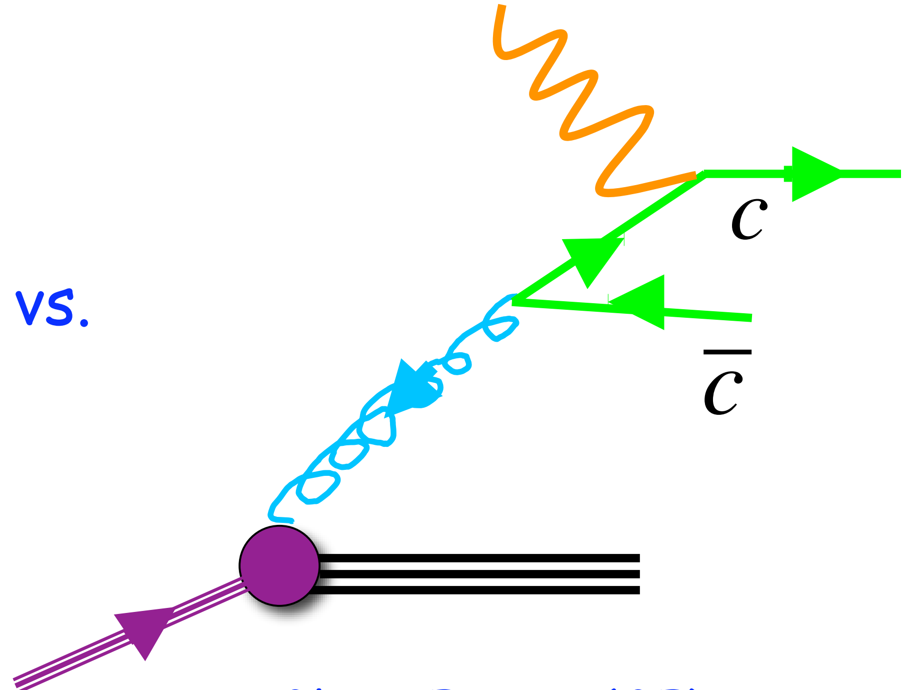
Windows into Heavy Flavor Production at the EIC

Inclusive

Intrinsic Charm (IC)



vs.

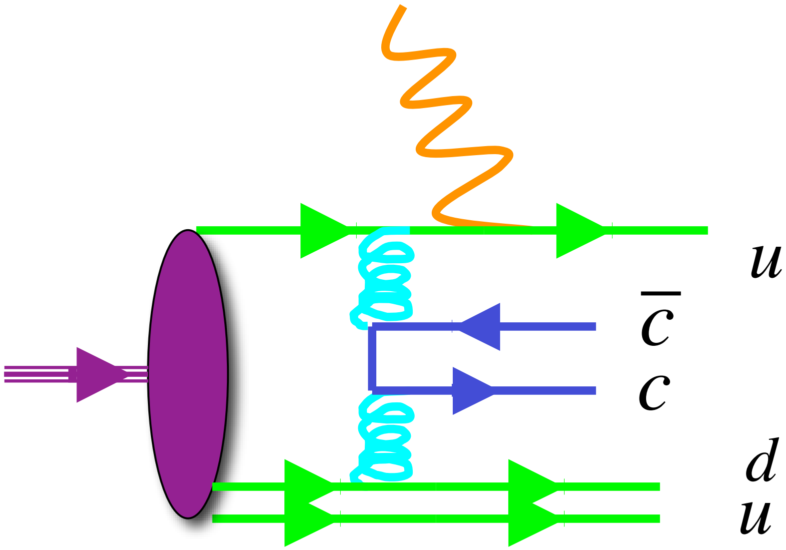


Gluon Fusion (GF)

IC content of proton can be large (up to 3 times earlier estimates) but PDF analyses are inconclusive (J.Pumplin, PRD75, 2007)

Intrinsic Charm (IC)

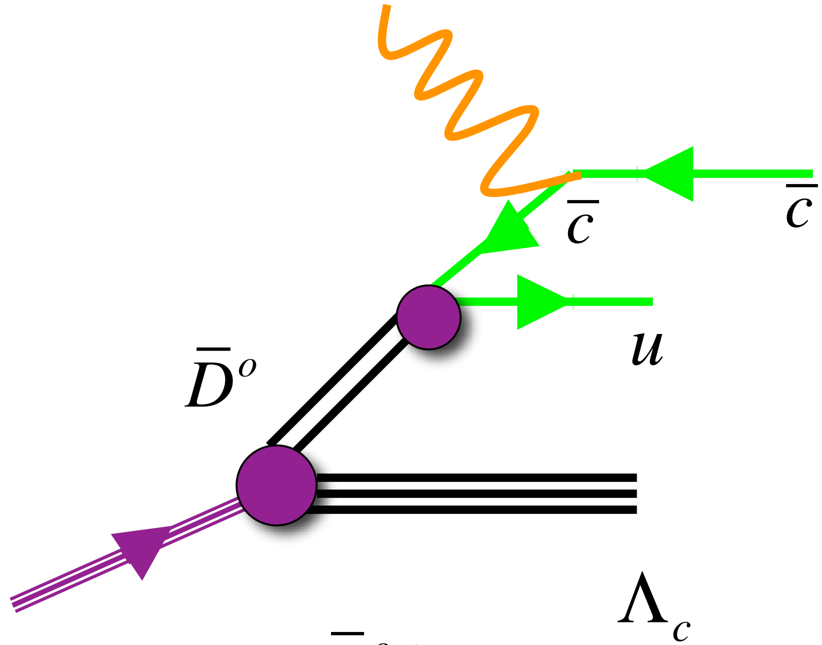
"Light Cone" based Processes



$$|p\rangle \rightarrow |uudc\bar{c}\rangle$$

Brodsky, Gunion, Hoyer, R.Vogt, ...

Hadronic Processes

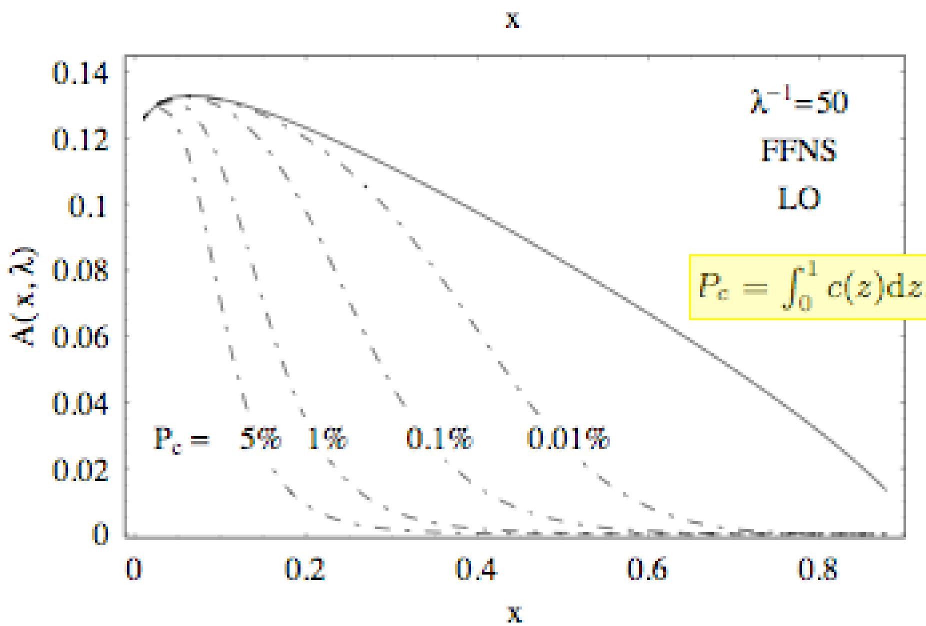


$$p \rightarrow \bar{D}^o \Lambda_c$$

Meson Cloud: Thomas, Melnichouk ...

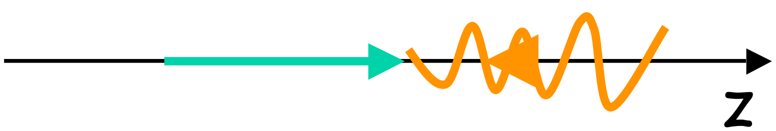
Intrinsic Charm can be "partially" detected by looking at asymmetries in Inclusive Heavy Quark Jets Production

Ananikian and Ivanov, NPB (2008)



$$l(\ell) + N(p) \to l(\ell - q) + Q(p_Q) + X[\overline{Q}$$

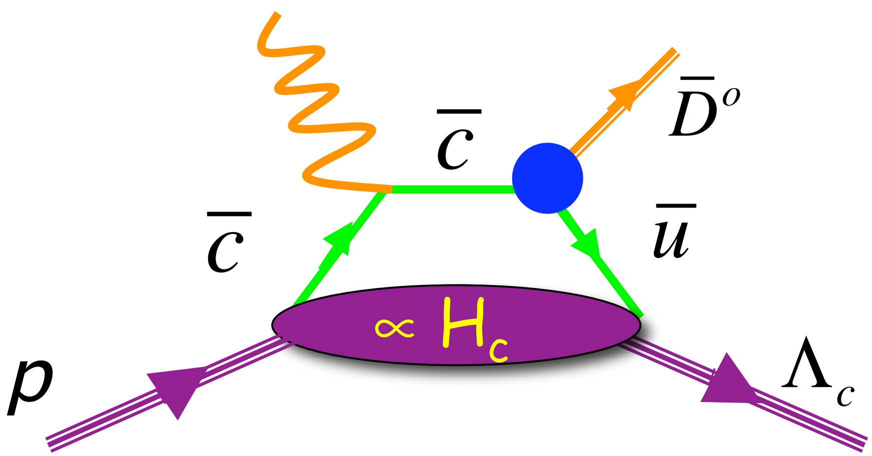
$$A_{2\varphi}(\rho, x, Q^2) = 2\langle\cos 2\varphi\rangle(\rho, x, Q^2) = \frac{\mathrm{d}^3\sigma_{lN}(\varphi=0) + \mathrm{d}^3\sigma_{lN}(\varphi=\pi) - 2\mathrm{d}^3\sigma_{lN}(\varphi=\pi/2)}{\mathrm{d}^3\sigma_{lN}(\varphi=0) + \mathrm{d}^3\sigma_{lN}(\varphi=\pi) + 2\mathrm{d}^3\sigma_{lN}(\varphi=\pi/2)}$$



$A_{IC}^{LO} = 0$

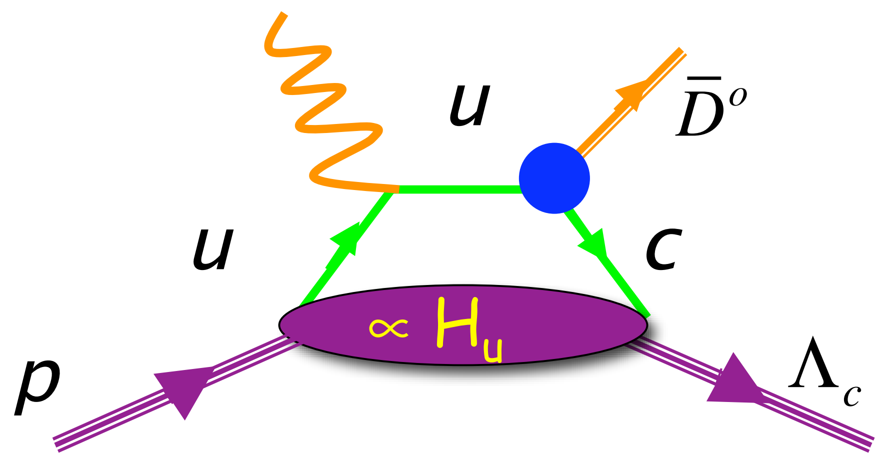
Intrinsic Charm can be singled out more clearly in asymmetries fı
Exclusive Heavy Quark Meson Production!

(1)



$p \to \bar{c}cuud \to (\bar{u}\ u)\ cud = \Lambda_c$

(2)



$p \to u + ud \to cud = \Lambda_c$

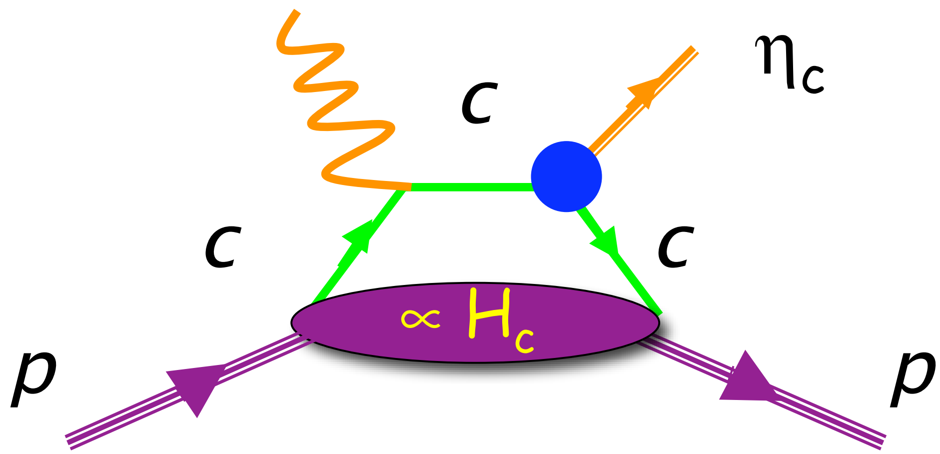
$\gamma^* p \to \bar{D}^o\ \Lambda_c^+ \Rightarrow 2H_u - H_d + H_c$

$\gamma^* p \to D^o\ \Sigma_c^+ \Rightarrow H_d - H_c$

$\gamma^* n \to \bar{D}^o\ \Sigma_c^o \Rightarrow H_u - H_c$

SU(4) relations allow one to extract H_c

(3)



$p \rightarrow \bar{c}cuud \rightarrow (\bar{c}\,c)\,uud = p$

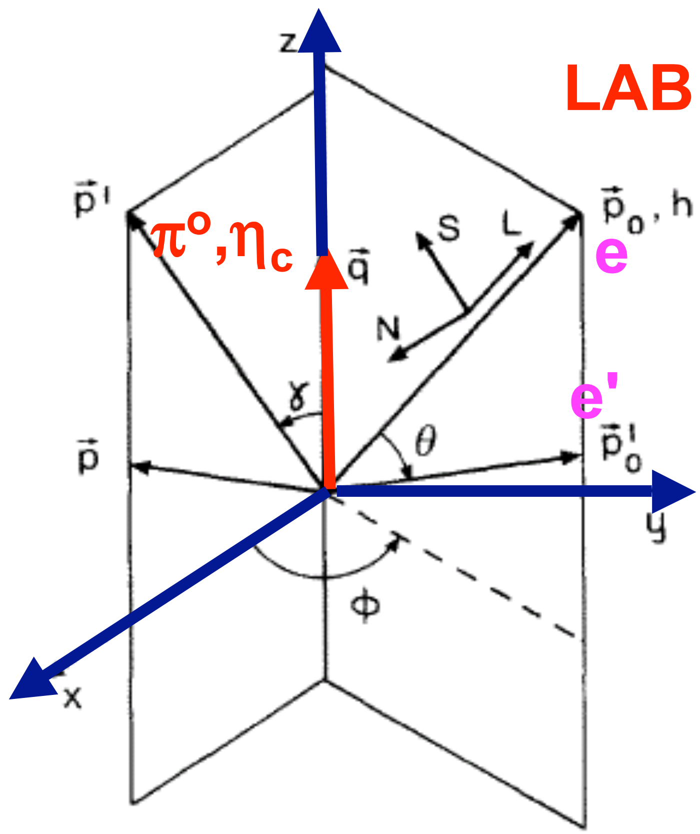
"golden plated signal"

$\eta_c = c\bar{c} \rightarrow J^{PC} = 0^{-+}$

Pseudoscalar Mesons Electroproduction and Chiral Odd GP

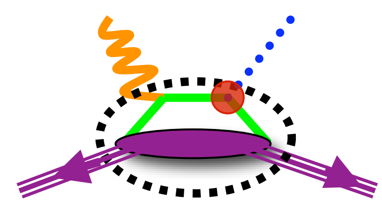
(S. Ahmad, G. Goldstein and S.L., PRD (2008))

Unpolarized Cross Section



$$d\sigma \propto L_{\mu\nu}^{h=\pi^o} W_{\mu\nu}$$

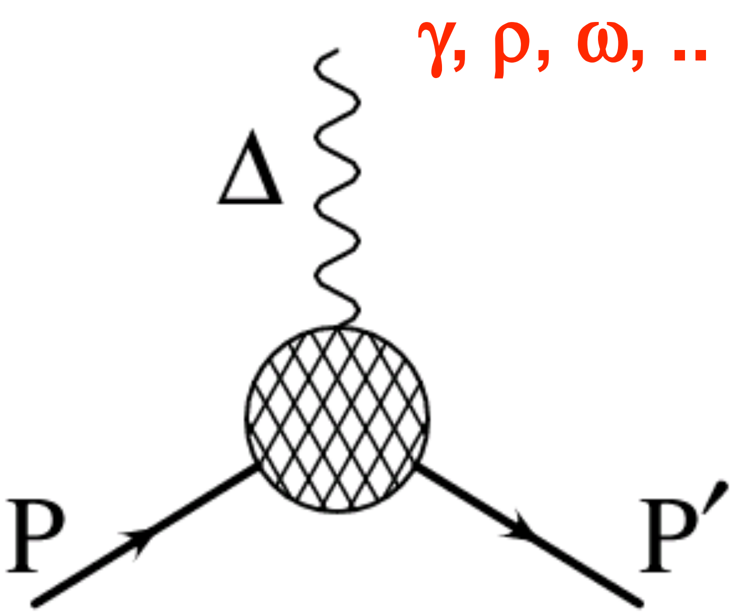
$$L_{\mu\nu}^{h=\pi^o} \approx \gamma^* \text{ polarization density matrix}$$

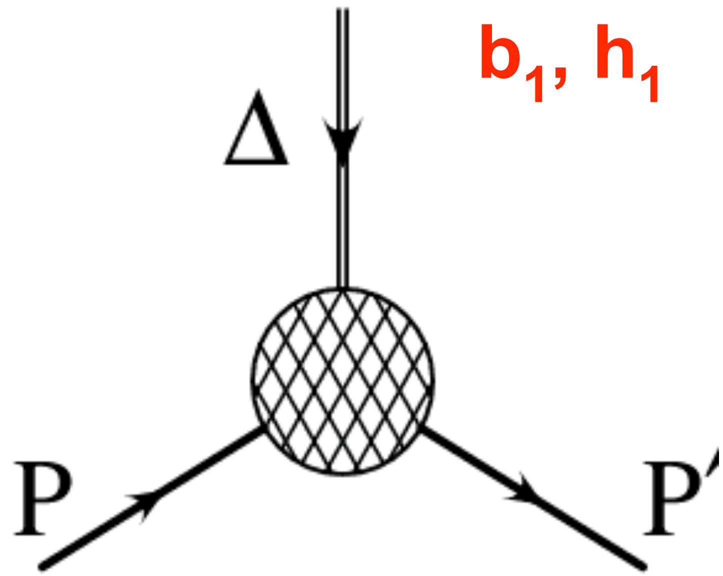


$$W_{\mu\nu} = \sum_f J_\mu J_\nu^* \delta(E_i - E_f) = \text{hadronic tensor}$$

$$\frac{d\sigma}{dt\,d\phi} = \left(\frac{d\sigma_T}{dt} + \epsilon\frac{d\sigma_L}{dt}\right) + \epsilon\frac{d\sigma_{TT}}{dt}\cos 2\phi + \sqrt{2\epsilon(\epsilon+1)}\frac{d\sigma_{LT}}{dt}\cos\phi$$

t-channel J^{PC} quantum numbers for deeply virtual exclusive proce

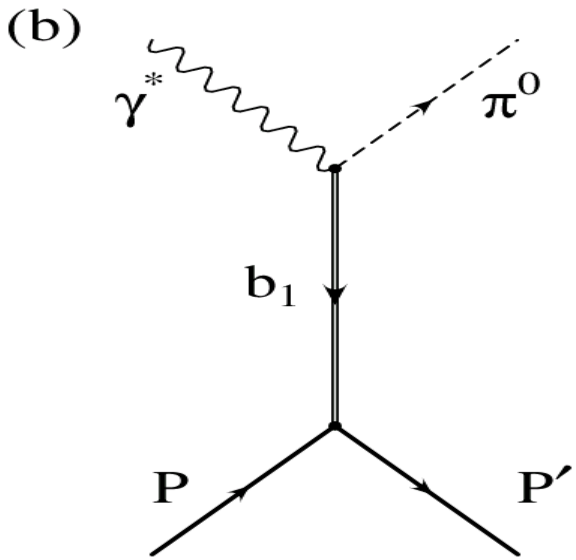




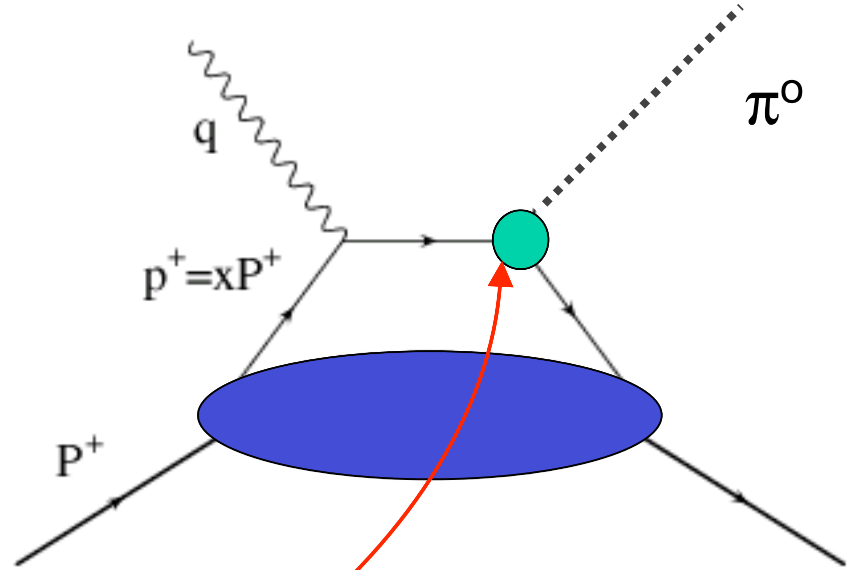
$J^{PC}=1^{--}$

$J^{PC}=1^{+-}$

Duality Picture



$t=\Delta^2$



"Regge factorization"

QCD factorization

chiral-even stru

π^0 vertex is described by current operators: γ_5 or $\gamma_\mu\gamma_5$

GPDs: $\tilde{H}$,

$\gamma_5 \rightarrow$

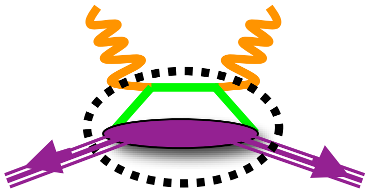
$$\gamma_5(\not k + \not q)\gamma^\mu = (k_\nu + q_\nu)\frac{\gamma_5}{2}\left([\gamma^\nu,\gamma^\mu] + \{\gamma^\nu,\gamma^\mu\}\right) = (k_\nu + q_\nu)\gamma_5\,(i\sigma^{\mu\nu} + g^{\mu\nu})$$

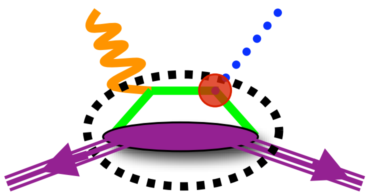
$$\propto i\gamma_5\sigma^{\mu\nu}$$

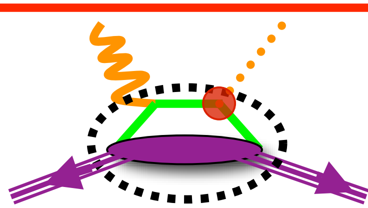
chiral-odd structure

GPDs: H_T, E_T, $\tilde{H}_T$, $\tilde{E}_T$...

t-channel J^{PC} quantum numbers for deeply virtual exclusive proce

DVCS  $J=0,1,\dots$ $PC=++,-+$

$DV\pi^{\pm}P$  $J=0,1,\dots$ $PC=+-,\ -+$

$DV\pi^{o}P$,
$DV\eta_{c}P$  $J=1,\dots$ $PC=--,+-$

$\Rightarrow$ π^{o}, η_{c} <u>electroproduction always occurs with *C*=-1</u> !

J^{PC} quantum numbers & GPDs

$$N\bar{N}: \text{ spin S} = 0\text{ , J} = \text{ L, P} = (-1)^{L+1}\text{, C} = (-1)^{L+S}$$

$$J^{PC}: L = 0 \Rightarrow 0^{-+}$$

$$L = 1 \Rightarrow 1^{+-}$$

$$L = 2 \Rightarrow 2^{-+} \quad \ldots L^{(-1)^{L+1}\,(-1)^{L}}$$

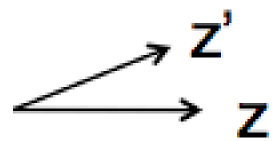
$$\text{spin S} = 1, \quad J^{PC}: L = 0 \Rightarrow 1^{--}$$

$$L = 1 \Rightarrow 0^{++}, 1^{++}, 2^{++}$$

$$L = 2 \Rightarrow 1^{--}, 2^{--}, 3^{--} \quad \ldots .(L-1, L, L+1)^{(-1)^{L+1}\,(-1)^{L+1}}$$

These must match the q+anti-q states' quantum numbers (quarkonium states).
q+anti-q ↔ N+antiN although the S_z totals need not match for $\theta_t \neq 0$.
For z-axis quantization,

$$\langle \lambda\lambda' | \to S_{z'} = \lambda - \lambda' \text{ for } \vec{z}' \text{ along } \vec{k} \text{ similarly for } |\Lambda\Lambda'\rangle$$



$$\text{forward limit } f_1(x) + g_1(x) \sim |\Lambda = + \to \lambda = +|^2 \quad \sim \langle ++|T|++\rangle$$

$$f_1(x) - g_1(x) \sim |\Lambda = + \to \lambda = -|^2 \quad \sim \langle --|T|++\rangle$$

linear combinations for S_Z=0, S=0 or 1

Chiral Even Sector: M. Diehl and D. Ivanov (2008)

distribution	J^{PC}
$H^q(x,\xi,t) - H^q(-x,\xi,t)$	$0^{++}, 2^{++}, \ldots$
$E^q(x,\xi,t) - E^q(-x,\xi,t)$	$0^{++}, 2^{++}, \ldots$
$\widetilde{H}^q(x,\xi,t) + \widetilde{H}^q(-x,\xi,t)$	$1^{++}, 3^{++}, \ldots$
$\widetilde{E}^q(x,\xi,t) + \widetilde{E}^q(-x,\xi,t)$	$0^{-+}, 1^{++}, 2^{-+}, 3^{++}, \ldots$
$H^q(x,\xi,t) + H^q(-x,\xi,t)$	$1^{--}, 3^{--}, \ldots$
$E^q(x,\xi,t) + E^q(-x,\xi,t)$	$1^{--}, 3^{--}, \ldots$
$\widetilde{H}^q(x,\xi,t) - \widetilde{H}^q(-x,\xi,t)$	$2^{--}, 4^{--}, \ldots$
$\widetilde{E}^q(x,\xi,t) - \widetilde{E}^q(-x,\xi,t)$	$1^{+-}, 2^{--}, 3^{+-}, 4^{--}, \ldots$

Only combination good for π^o production

GPDs: $\tilde{H}$, $\tilde{E}$, and Weak Form factors

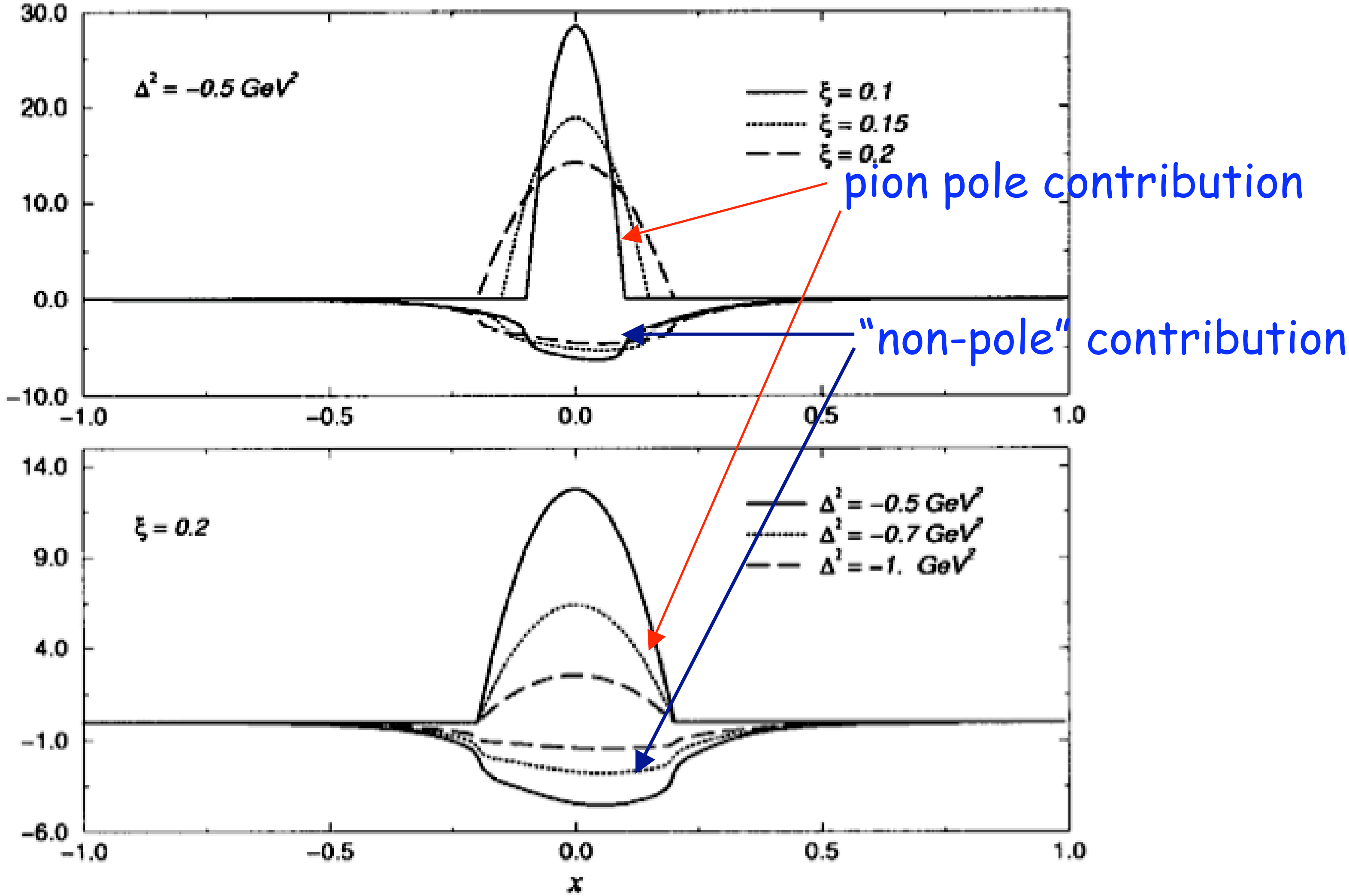
$$\langle N(p')\Lambda' | J_A^{\nu} | N(p)\Lambda \rangle = \overline{U}^{(\Lambda')}(p') \left[g_A(t)\gamma^{\nu}\gamma^5 + \frac{g_P(t)}{m_\mu}\Delta^{\nu}\gamma^5 \right] U^{(\Lambda)}(p)$$

$$g_P(t) = \frac{2m_\mu M}{m_\pi^2 - t} g_A(0)$$

$g_P(t)$ = pseudoscalar form factor → dominated by pion pole

$\tilde{E}$

Goeke et al.



1) For π^0 production the pion pole contribution is absent!

2) The non-pole contribution is very small!

π^o, η_c electroproduction happens mostly in the chiral-odd sector

$\Rightarrow$ it is governed by chiral-odd GPDs

$\Rightarrow$ issue overlooked in most recent literature on the subject

Since chiral-odd GPDs cannot evolve from gluons we have proven that η_c, D^o, and D^o uniquely single out the "intrinsic charm content"!

Transversity

- $|\pm \frac{1}{2})_{\text{Transversity}} = \{|+\frac{1}{2}> \pm(i)\, |-\frac{1}{2}>\}_{\text{helicity}}/\sqrt{2}$ for spin 1/2, etc.
- for p -> 0 this corresponds to spin quantized along normal to scattering plane y-axis
- consider $|N, \pm \frac{1}{2})_T \rightarrow |q, \pm \frac{1}{2})_T$
- $h_1(x) \sim |\, |+\frac{1}{2})_T \rightarrow |+\frac{1}{2})_T\, |^2 - |\, |+\frac{1}{2})_T \rightarrow |-\frac{1}{2})_T\, |^2$

  $\sim H_T(x,0,0) \sim A_{++;--}(x,0,0)$ in helicity basis

  or $<+ -|\mathcal{T}|- +>$

to GPD J^{PC}

$$f_1(x) = H(x,0,0) \sim \left(\langle ++|T|++\rangle + \langle --|T|++\rangle\right)$$

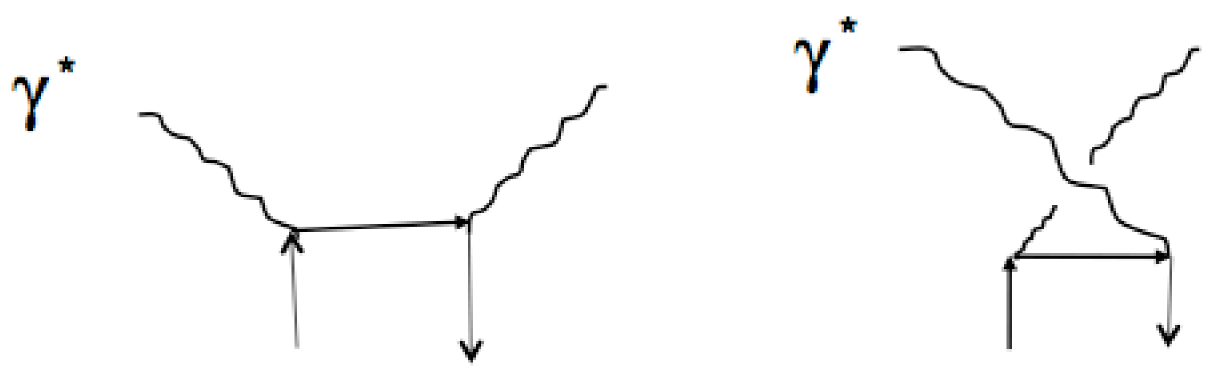
$$g_1(x) = \tilde{H}(x,0,0) \sim \left(\langle ++|T|++\rangle - \langle --|T|++\rangle\right)$$

$$h_1(x) = H_T(x,0,0) \sim \langle -+|T|-+\rangle$$

One more input into J^{PC} assignments for all GPDs

C - parity involves symmetry under $q \leftrightarrow \bar{q}$ & $N \leftrightarrow \bar{N}$

Crossing operation exchanges $x \leftrightarrow -x$

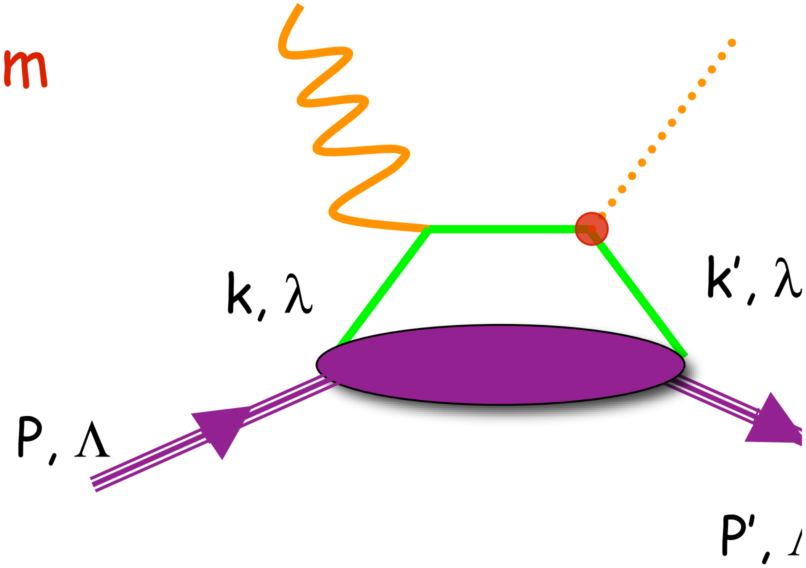


G. Goldstein, INT Workshop, 200

Helicity Amplitudes formalism

$f_{\Lambda_\gamma,\Lambda;0,\ \Lambda'}$

photon → Λ_γ; initial proton → Λ; pion → 0; final proton → Λ'



Factorized form

$$f_{\Lambda_\gamma,\Lambda;0,\Lambda'} = \sum_{\lambda,\lambda'} g_{\Lambda_\gamma,\lambda;0,\lambda'}(X,\zeta,t,Q^2) \otimes A_{\Lambda',\lambda';\Lambda,\lambda}(X,\zeta,t),$$

g: γ quark scattering amp.

A: "quark-proton helicity amp

6 "f" helicity amps

$$\frac{d\sigma_T}{dt} = \mathcal{N}\left(|\, f_{1,+;0,+}\,|^2 + |\, f_{1,+;0,-}\,|^2 + |\, f_{1,-;0,+}\,|^2 + |\, f_{1,-;0,-}\,|^2\right)$$
$$= \mathcal{N}\left(|\, f_1\,|^2 + |\, f_2\,|^2 + |\, f_3\,|^2 + |\, f_4\,|^2\right)$$
$$\frac{d\sigma_L}{dt} = \mathcal{N}\left(|\, f_{0,+;0,+}\,|^2 + |\, f_{0,+;0,-}\,|^2\right)$$
$$= \mathcal{N}\left(|\, f_5\,|^2 + |\, f_6\,|^2\right),$$

Helicity Amplitudes from correlator contracted with $i\sigma^{+i}$

$$\int dk^- \, d^2\mathbf{k} \, \mathrm{Tr}\left[i\sigma^{+i}\Phi\right]_{XP^+=k^+}$$
$$= \frac{1}{2P^+}\overline{U}(P',S')\left[H_T^q \, i\sigma^{+i} + \widetilde{H}_T^q \frac{P^+\Delta^i - \Delta^+ P^i}{M^2} + E_T^q \frac{\gamma^+\Delta^i - \Delta^+\gamma^i}{2M} + \widetilde{E}_T^q \frac{\gamma^+ P^i - P^+\gamma^i}{M}\right] U(P,S)$$

Using LC spinors formalism (Diehl) one obtains

$$A_{+-,++} = -\frac{\sqrt{t_0 - t}}{2M}\left[\widetilde{H}_T + \frac{1+\xi}{2}E_T - \frac{1+\xi}{2}\widetilde{E}_T\right]$$
$$A_{++,--} = \sqrt{1-\xi^2}\left[H_T + \frac{t_0 - t}{4M^2}\widetilde{H}_T - \frac{\xi^2}{1-\xi^2}E_T + \frac{\xi}{1-\xi^2}\widetilde{E}_T\right]$$
$$A_{+-,-+} = -\sqrt{1-\xi^2}\,\frac{t_0 - t}{4M^2}\widetilde{H}_T$$
$$A_{++,+-} = \frac{\sqrt{t_0 - t}}{2M}\left[\widetilde{H}_T + \frac{1-\xi}{2}E_T + \frac{1-\xi}{2}\widetilde{E}_T\right],$$

Rewrite helicity amps. expressions using new GFFs

$$f_1 = f_4 = \frac{g_2}{\mathcal{C}_q} F_V(Q^2) \frac{\sqrt{t_0 - t}}{2M} \left[\widetilde{\mathcal{H}}_T + \frac{1-\xi}{2}\mathcal{E}_T + \frac{1-\xi}{2}\widetilde{\mathcal{E}}_T \right]$$

$$f_2 = \frac{g_2}{\mathcal{C}_q} [F_V(Q^2) + F_A(Q^2)] \sqrt{1-\xi^2} \left[\mathcal{H}_T + \frac{t_0 - t}{4M^2}\widetilde{\mathcal{H}}_T - \frac{\xi^2}{1-\xi^2}\mathcal{E}_T + \frac{\xi}{1-\xi^2}\widetilde{\mathcal{E}}\right.$$

$$f_3 = \frac{g_2}{\mathcal{C}_q} [F_V(Q^2) - F_A(Q^2)] \sqrt{1-\xi^2} \frac{t_0 - t}{4M^2} \widetilde{\mathcal{H}}_T$$

$$f_5 = \frac{g_5}{\mathcal{C}_q} F_A(Q^2) \sqrt{1-\xi^2} \left[\mathcal{H}_T + \frac{t_0 - t}{4M^2}\widetilde{\mathcal{H}}_T - \frac{\xi^2}{1-\xi^2}\mathcal{E}_T + \frac{\xi}{1-\xi^2}\widetilde{\mathcal{E}}_T \right],$$

elementary subprocess

Q^2 dependent pion vertex

GFFs

Q^2 dependence (G. Goldstein and S.L., *to be publi*

Standard approach (Goloskokov and Kroll, 2009)

$\gamma_\mu\gamma_5 \Rightarrow$ leading twist contribution within OPE,
leads to suppression of transverse vs. longitudinal terms
$\gamma_5 \Rightarrow$ twist-3 contribution is possible

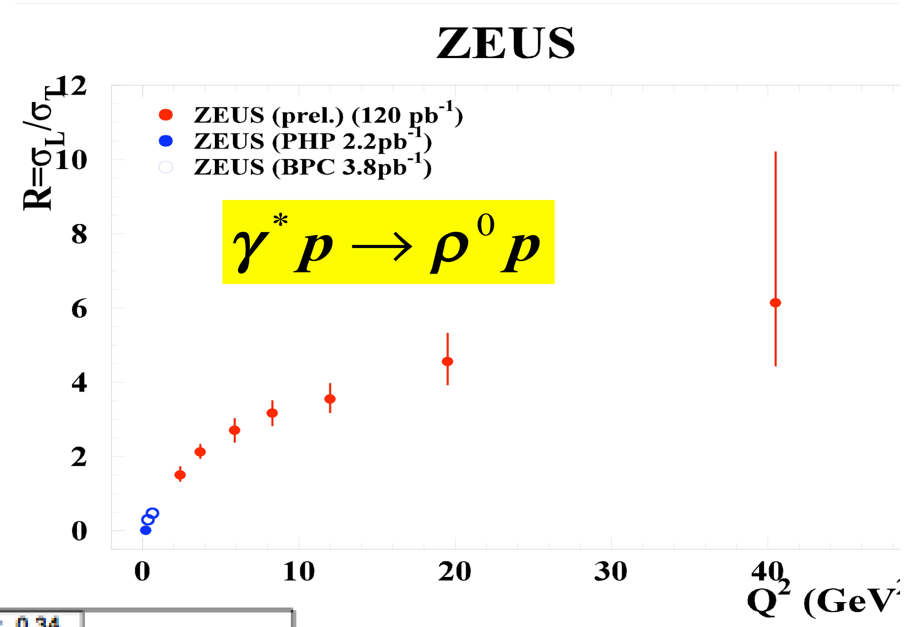
However…
$\Rightarrow$ suppression is not seen in experiments

Need to devise method to go beyond the collinear OPE: consider a mechanism that takes into account the breaking of rotational symmetry by the scattering plane in helicity flip processes (transverse d.o.f.)

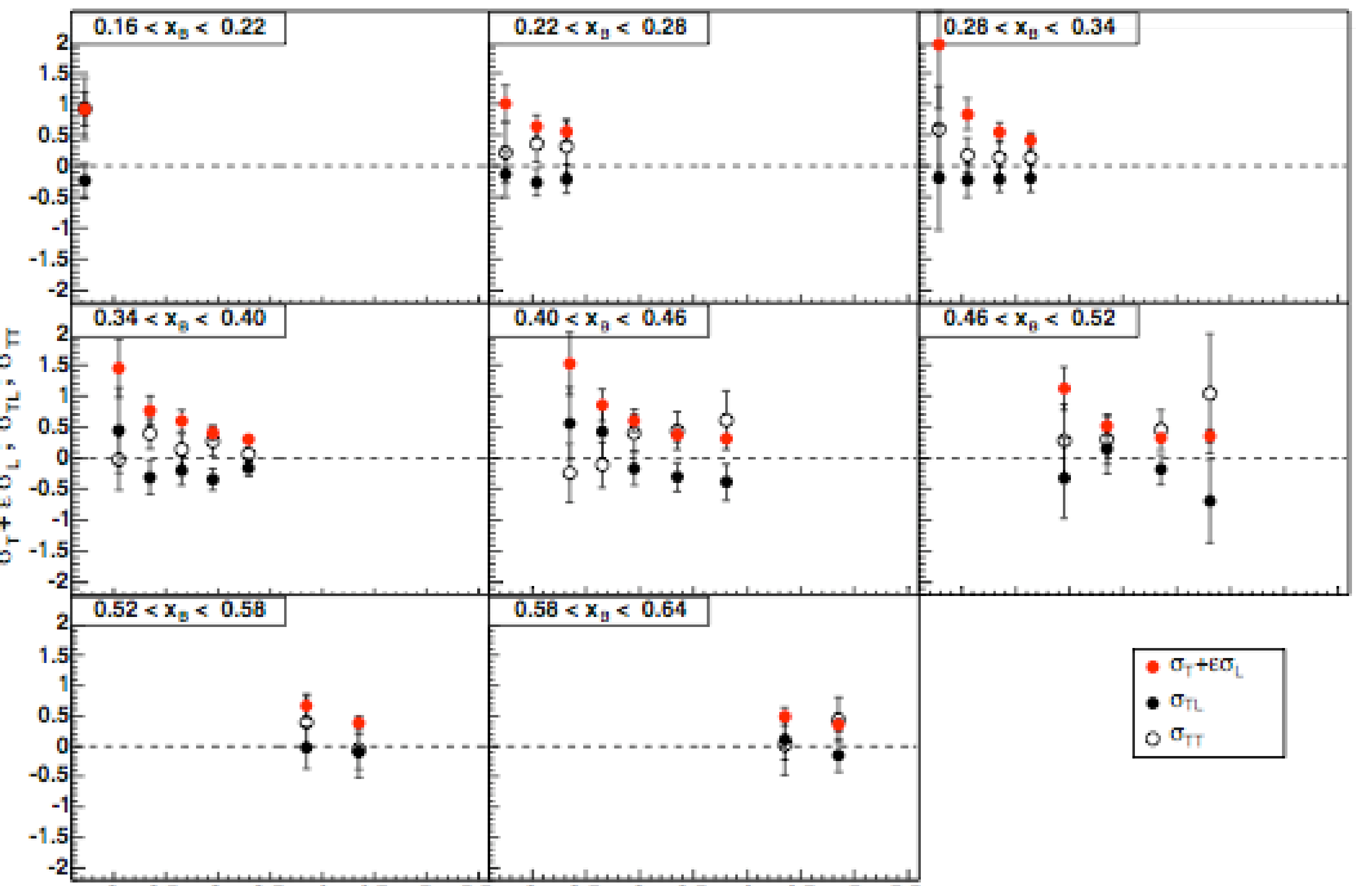
We proposed a possible model

See also T. Gousset, B. Pire and J.P. Ralston, Phys. Rev. D 53, 1202 (1

Q^2 dependence in ρ production

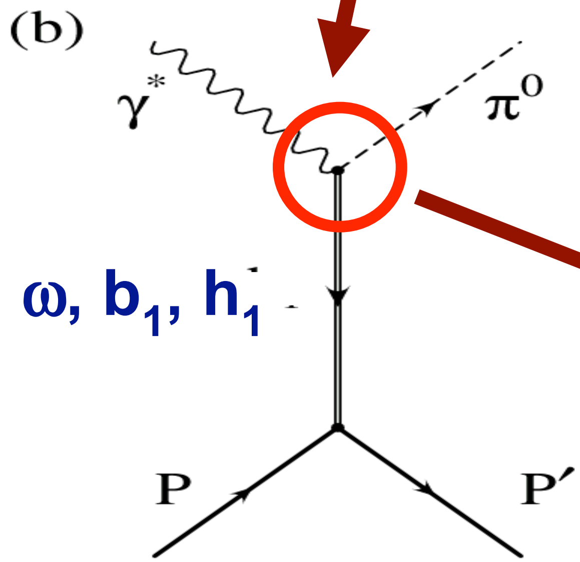


Jlab



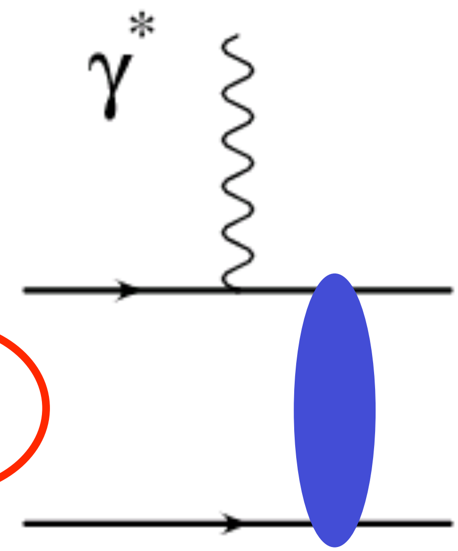
Q^2 dependence

t-channel exchange vertex



ρ, ω, b_1, h_1

modeled as $F_{p\gamma}$ (pseudoscalar-meson transition form factor)



π^o

J^{PC}=

ρ, ω | b_1, h_1

$J^{PC}=1^{--}$ ($^3S_1$)

$J^{PC}=1^{+-}$($^1P_1$)

mesons quark content: $\frac{1}{\sqrt{2}}\left(u\bar{u} \pm d\bar{d}\right)$

Distinction between ω,ρ (vector) and b_1,h_1 (axial-vector)exchar

$J^{PC}=1^{--}$ → transition from ω,ρ(S=1 L=0) to π^0(S=0 L=0) **ΔL =0**

$J^{PC}=1^{+-}$ → transition from b_1,h_1 (S=0 L=1) to π^0(S=0 L=0) **ΔL =1**

"Vector" exchanges no change in OAM

"Axial-vector" exchanges change 1 unit of OAM!

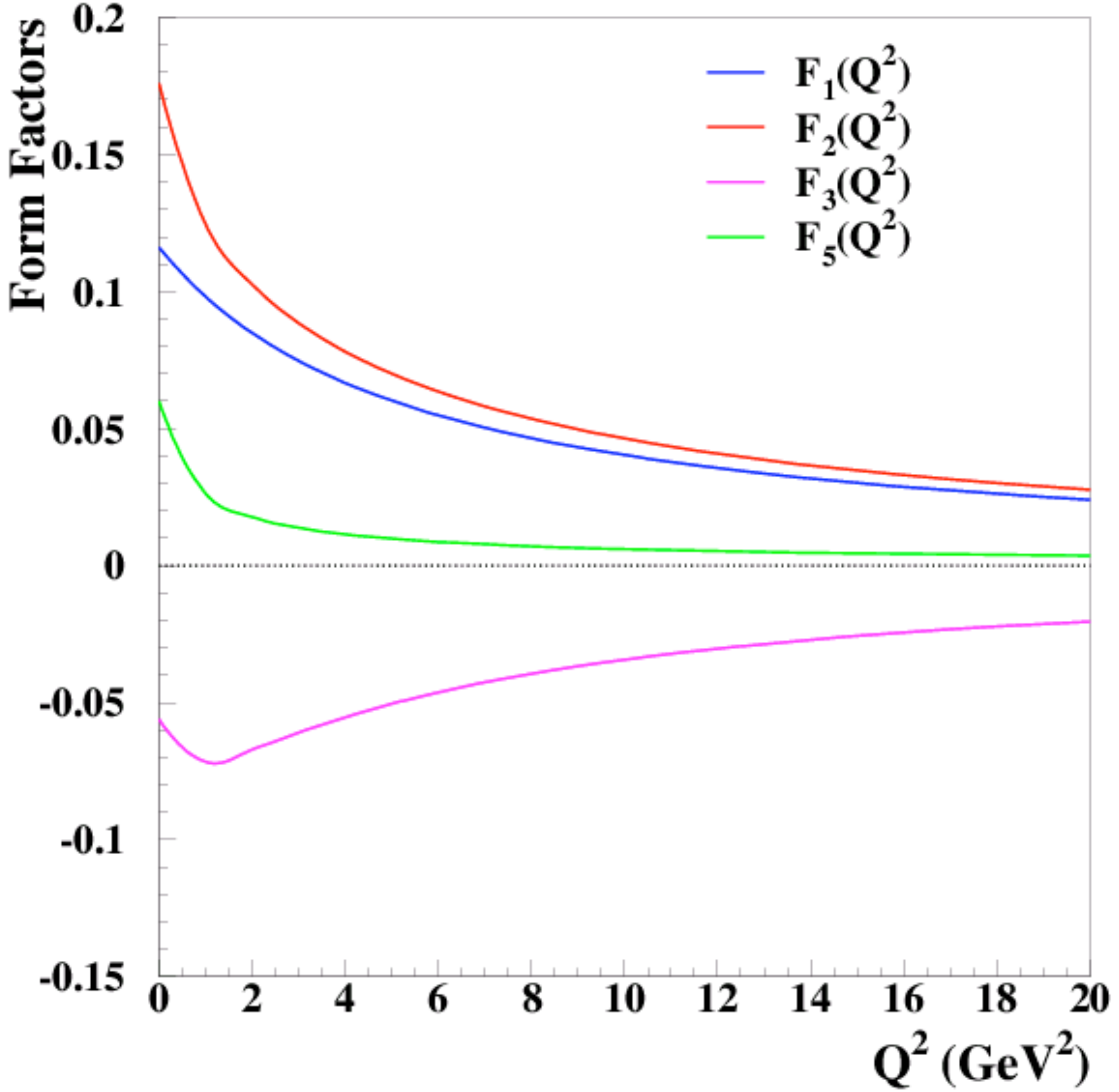
$$F_{\gamma^* V\pi^o} = \int dx_1 dy_1 \int d^2\mathbf{b}\, \psi_V(y_1,b)\, \mathcal{C} K_o(\sqrt{x_1(1-x_1)Q^2}b)\, \psi_{\pi^o}(x_1,b)\, exp(-S)$$

$$F_{\gamma^* A\pi^o} = \int dx_1 dy_1 \int d^2\mathbf{b}\, \psi_A^{(1)}(y_1,b)\, \mathcal{C} K_o(\sqrt{x_1(1-x_1)Q^2}b)\, \psi_{\pi^o}(x_1,b)\, exp(-S)$$

Because of OAM axial vector transition involves Bessel J_1

$$\psi_A^{(1)}(y_1,b) = \int d^2k_T J_1(y_1 b)\psi(y_1,k_T),$$

This yields configurations of larger "radius" in b space (suppressed with G



Form Factors
0.2
0.15
0.1
0.05
0
-0.05
-0.1
-0.15
0
2
4
6
8
10
12
14
16
18
20
Q^2 (GeV^2)
$F_1(Q^2)$
$F_2(Q^2)$
$F_3(Q^2)$
$F_5(Q^2)$

What goes into a theoretically motivated parametrization...?

The name of the game: Devise a form combining essential dynamical elements with a flexible model that allows for a fully quantitative analysis constrained by the data

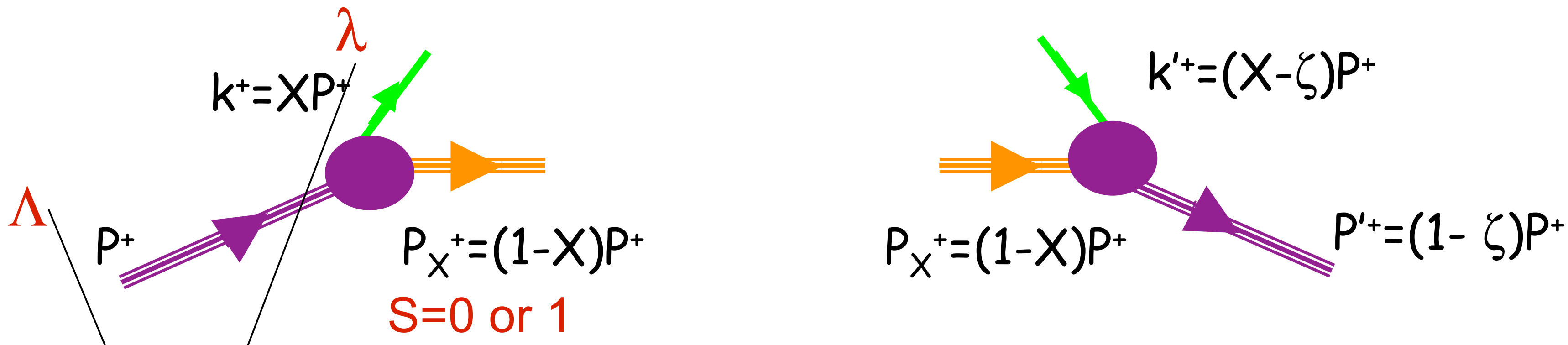
$$H_q(X, \zeta, t) = R(X, \zeta, t)\, G(X, \zeta, t)$$

$R(X, \zeta, t)$ → "Regge"

$G(X, \zeta, t)$ → Quark-Diquark

+ Q^2 Evolution

Vertex Structures



Focus e.g. on S=0

$$H \Rightarrow \varphi^*_{++}(k',P')\varphi_{++}(k,P) + \varphi^*_{-+}(k',P')\varphi_{-+}(k,P)$$

$$E \Rightarrow \varphi^*_{++}(k',P')\varphi_{+-}(k,P) + \varphi^*_{+-}(k',P')\varphi_{++}(k,P)$$

$$\tilde{H} \Rightarrow \varphi^*_{++}(k',P')\varphi_{++}(k,P) - \varphi^*_{-+}(k',P')\varphi_{-+}(k,P)$$

$$\tilde{E} \Rightarrow \varphi^*_{++}(k',P')\varphi_{+-}(k,P) - \varphi^*_{+-}(k',P')\varphi_{++}(k,P)$$

Vertex function Φ

$$\phi(k^2,\Lambda^2) = \frac{k^2 - m^2}{|k^2 - \Lambda^2|^2}.$$

O. Gonzalez Hernandez, S

Fixed diquark mass formulation

DGLAP regio

$$G_{M_X}^{\Lambda^2}(X,\zeta,t) = \int d^2\mathbf{k}_\perp \frac{\phi(k^2,\Lambda^2)}{k^2-m^2}\frac{\phi(k'^2,\Lambda^2)}{k'^2-m^2}\mathcal{N}_{\mathcal{H}(\mathcal{E},\tilde{\mathcal{H}},\tilde{\mathcal{E}})} \quad \zeta \geq X$$

$$k^2 = (XP^+)\left[\frac{M^2}{P^+} - \frac{M_X^2+\mathbf{k}_\perp^2}{(1-X)P^+}\right] - \mathbf{k}_\perp^2$$

$$k'^2 = (XP^+)\left[\frac{M^2+\mathbf{\Delta}_\perp^2}{P^+} - \frac{M_X^2+\mathbf{k}_\perp^2}{(1-X)P^+}\right] - (\mathbf{k}_\perp + \mathbf{\Delta}_\perp)^2$$

ERBL region

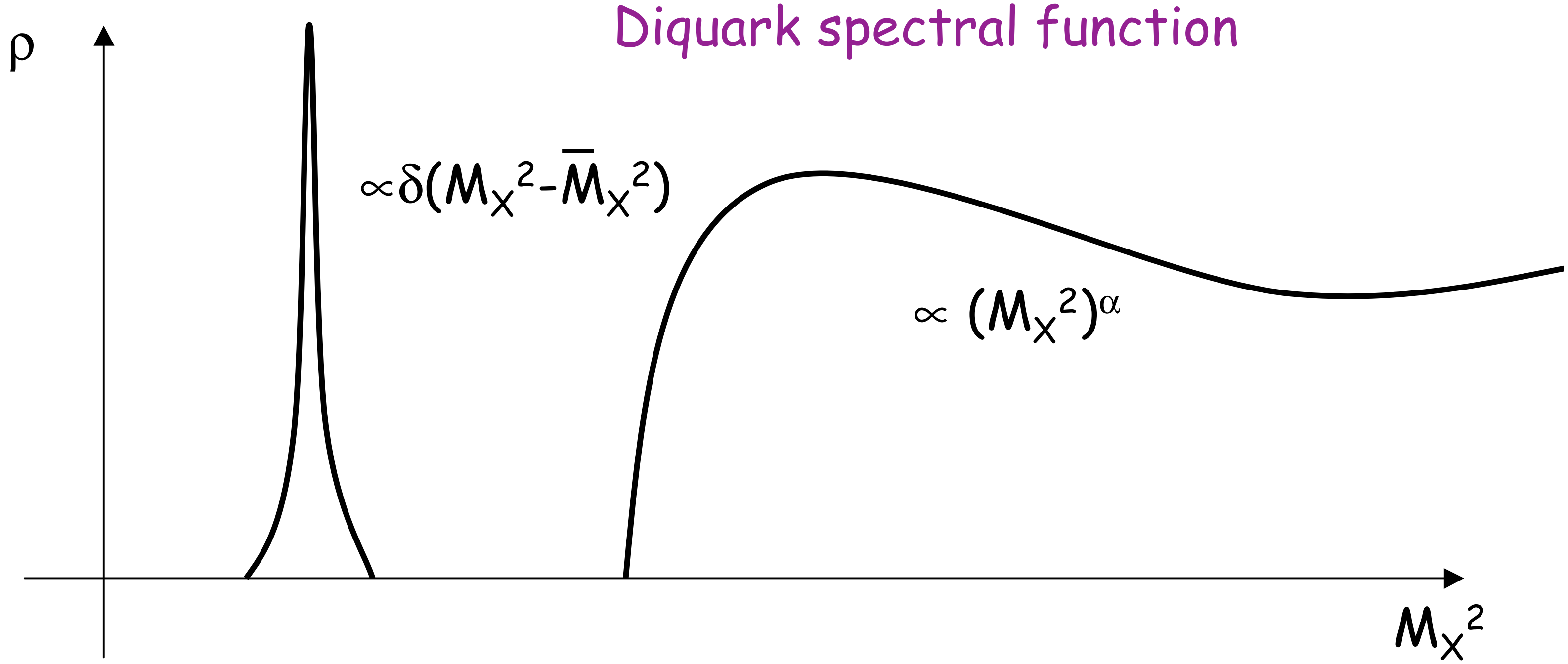
$$G_{M_X}^{\Lambda^2}(X,\zeta,t) = \int d^2\mathbf{k}_\perp \frac{\phi(P_X^2,\Lambda^2)}{P_X^2-M_X^2}\frac{\phi(k'^2,\Lambda^2)}{k'^2-m^2}\mathcal{N}_{\mathcal{H}(\mathcal{E},\tilde{\mathcal{H}},\tilde{\mathcal{E}})} \quad \zeta < X.$$

Reggeized diquark mass formulation

$$G_{M_X}^{\Lambda^2}(X,\zeta,t) = \int d^2\mathbf{k}_\perp \int dM_X^2\, \rho(M_X^2)\, \frac{\phi(k^2,\Lambda^2)}{k^2 - M_X^2}\frac{\phi(k'^2,\Lambda^2)}{k'^2 - m^2}\mathcal{N}_{\mathcal{H}(\mathcal{E},\tilde{\mathcal{H}},\tilde{\mathcal{E}})} \qquad \zeta \geq X$$

$$G_{M_X}^{\Lambda^2}(X,\zeta,t) = \int d^2\mathbf{k}_\perp \int dM_X^2\, \rho(M_X^2)\, \frac{\phi(P_X^2,\Lambda^2)}{P_X^2 - M_X^2}\frac{\phi(k'^2,\Lambda^2)}{k'^2 - m^2}\mathcal{N}_{\mathcal{H}(\mathcal{E},\tilde{\mathcal{H}},\tilde{\mathcal{E}})} \qquad \zeta < X.$$

Diquark spectral function



DIS → Brodsky, Close, Gunion

Fitting Procedure

- Fit at ζ=0, t=0 $\Rightarrow$ $H_q(x,0,0)=q(X)$
  - 3 parameters per quark flavor (M_X^q, Λ_q, α_q) + initial Q_o^2
- Fit at ζ=0, t≠0 $\Rightarrow$

$$\int_0^1 dX H^q(X,t) = F_1^q(t)$$

$$\int_0^1 dX E^q(X,t) = F_2^q(t),$$

  - 2 parameters per quark flavor (β, p)

$$R^I_{1(2)} = X^{-\alpha^I - \beta^I_{1(2)}(1-X)^{p^I_{1(2)}} t}$$

Regge

$$G^\lambda_{M_X}(X,t) = \mathcal{N}\frac{X}{1-X}\int d^2\mathbf{k}_\perp \frac{\phi(k^2,\lambda)}{D(X,\mathbf{k}_\perp)}\frac{\phi(k'^2,\lambda)}{D(X,\mathbf{k}_\perp+(1-X)\mathbf{\Delta}_\perp)}$$

Quark-Diqua

- Fit at ζ≠0, t≠0 $\Rightarrow$ DVCS, DVMP,… data (convolutions of GPDs with Wilson coefficient functions) + lattice results (Mellin Moments of GPDs)
- Note! This is a multivariable analysis $\Rightarrow$ see e.g. Moutarde, Kumericki and D. Mueller, Guidal and Moutarde

ζ=0,t=0

Parton Distribution Functions

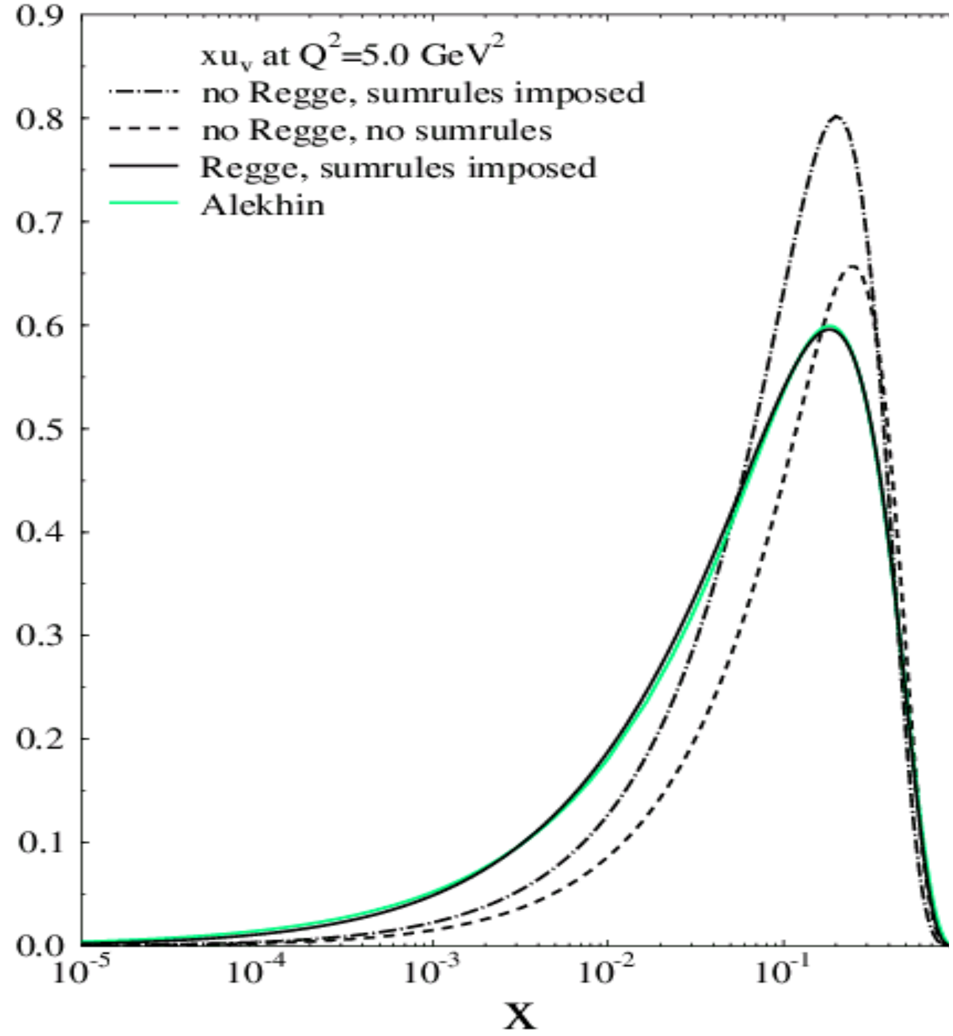
Notice! **GPD parametric form is given at $Q^2=Q_o^2$ and evolved to Q^2 of data.**

Notice! **We provide a parametrization for GPDs that simultaneously fits the PDFs:**

$$H_q(X,z,t)= R(X,z,t)\, G(X,z,t)$$

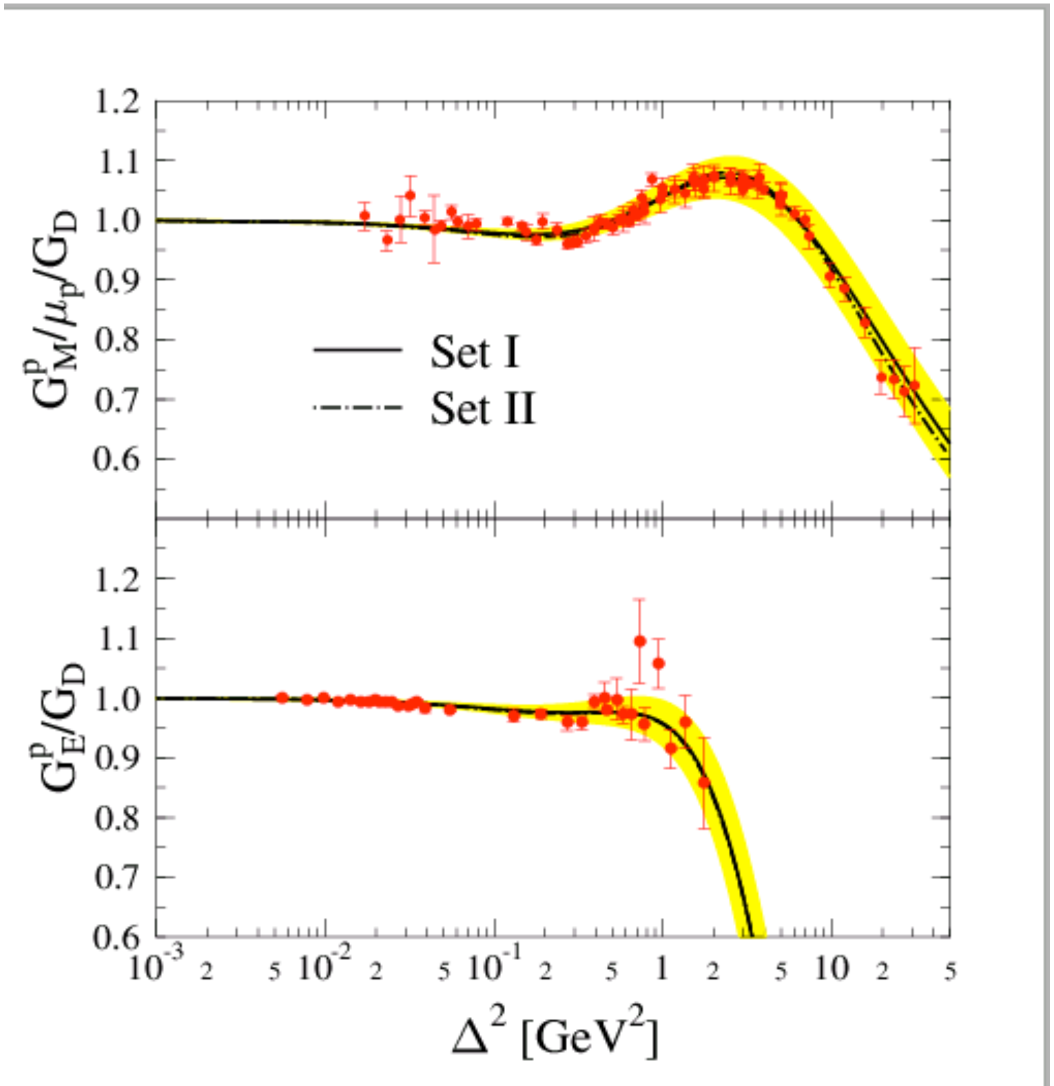
Regge

Quark-Diquark



$\zeta = 0, t \neq 0$

Nucleon Form Factors



$$\int_0^1 dX\, H^q(X,t) = F_1^q(t)$$

$$\int_0^1 dX\, E^q(X,t) = F_2^q(t),$$

Data Set	χ^2/N_{data} Set 1	χ^2/N_{data} Set 2	Data P
G_{E_p}	1.049	0.963	33
G_{M_p}	1.194	1.220	75
G_{E_p}/G_{M_p}	0.689	0.569	20
G_{E_n}	0.808	1.059	25
G_{M_n}	2.068	1.286	24
TOTAL	1.174	1.085	177

S. Ahmad, H. Honkanen, S. L., S.K. Taneja, PRD75:094003,2007

Parameters from PDFs

Flavor	M_X (GeV)	λ (GeV)	α
u	0.4972	0.9728	1.2261
d	0.7918	0.9214	1.0433

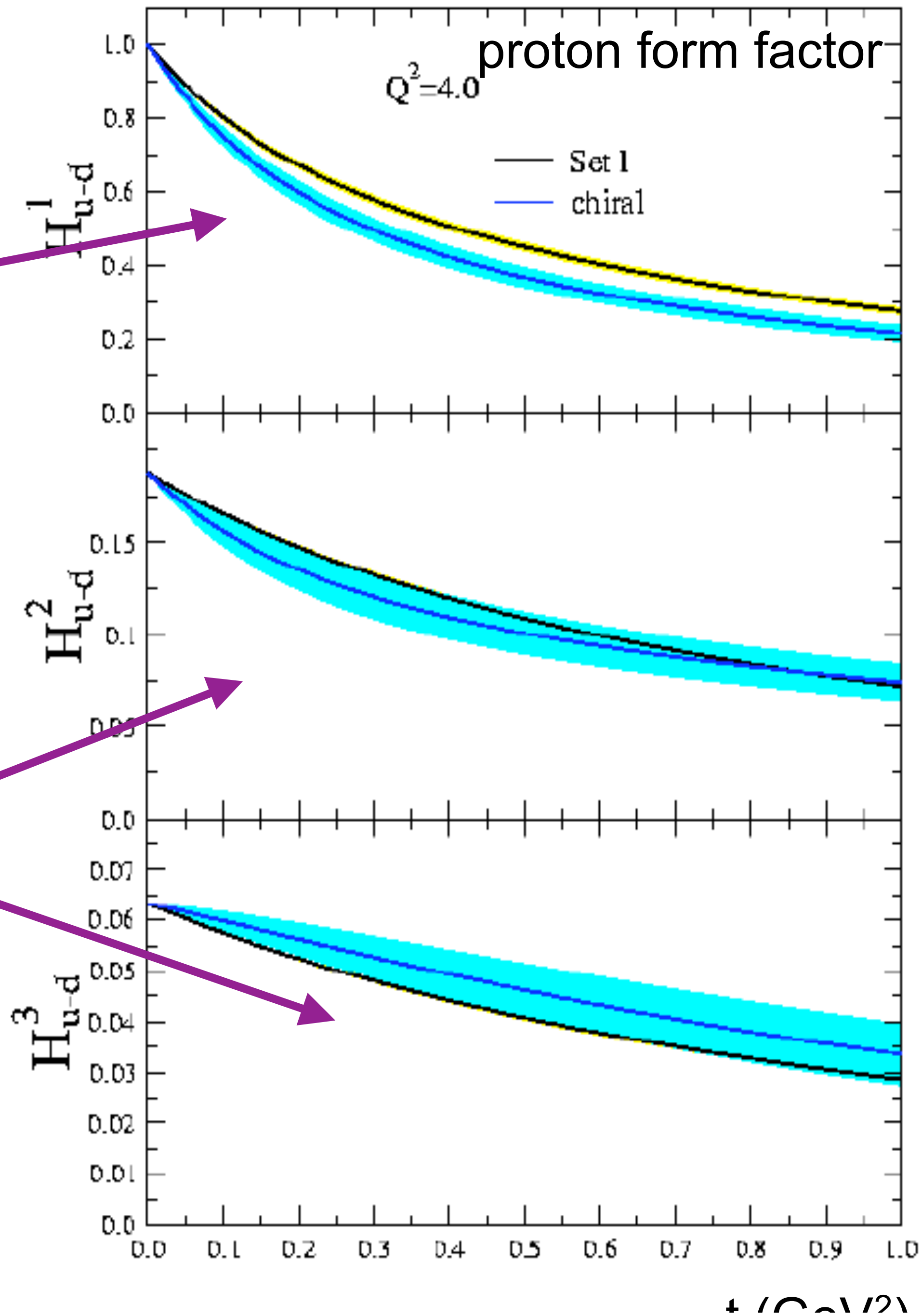
Parameters from FFs

Flavor	β_1 (GeV^{-2})	β_2 (GeV^{-2})	p_1	p_2
u	1.9263 ± 0.0439	3.0792 ± 0.1318	0.720 ± 0.028	0.528 ± 0.[illegible]
d	1.5707 ± 0.0368	1.4316 ± 0.0440	0.720 ± 0.028	0.528 ± 0.[illegible]

Results of Chiral Extrapolations

⇒ Ashley et al. (2003)

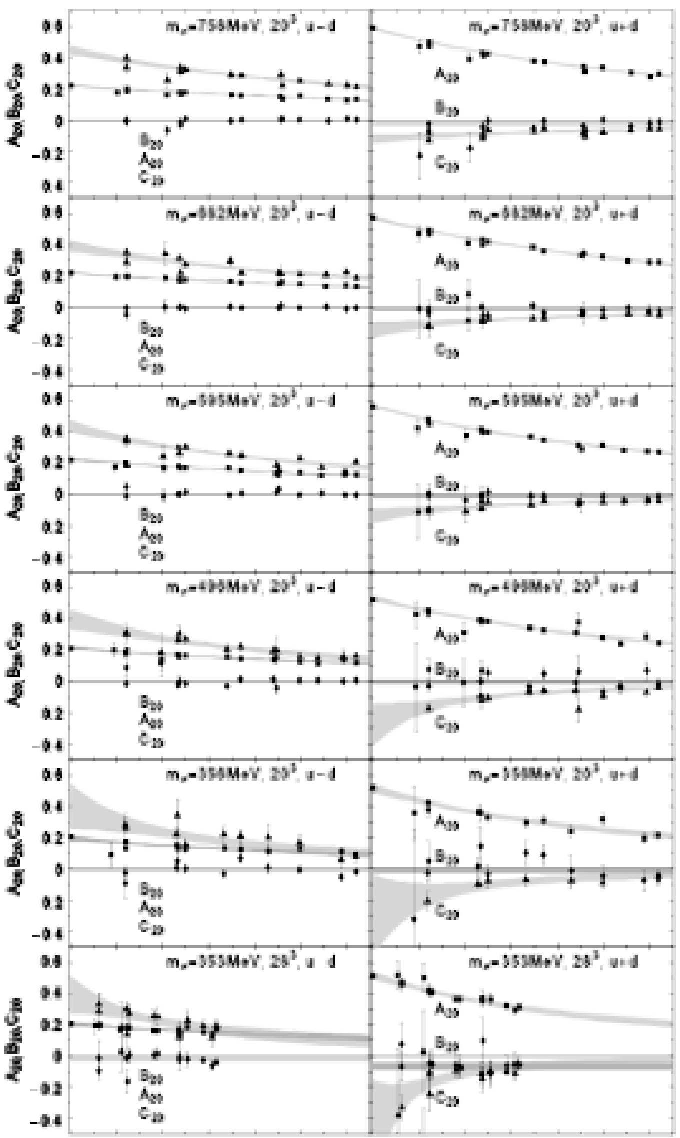
⇒ Ahmad et al. (2008)

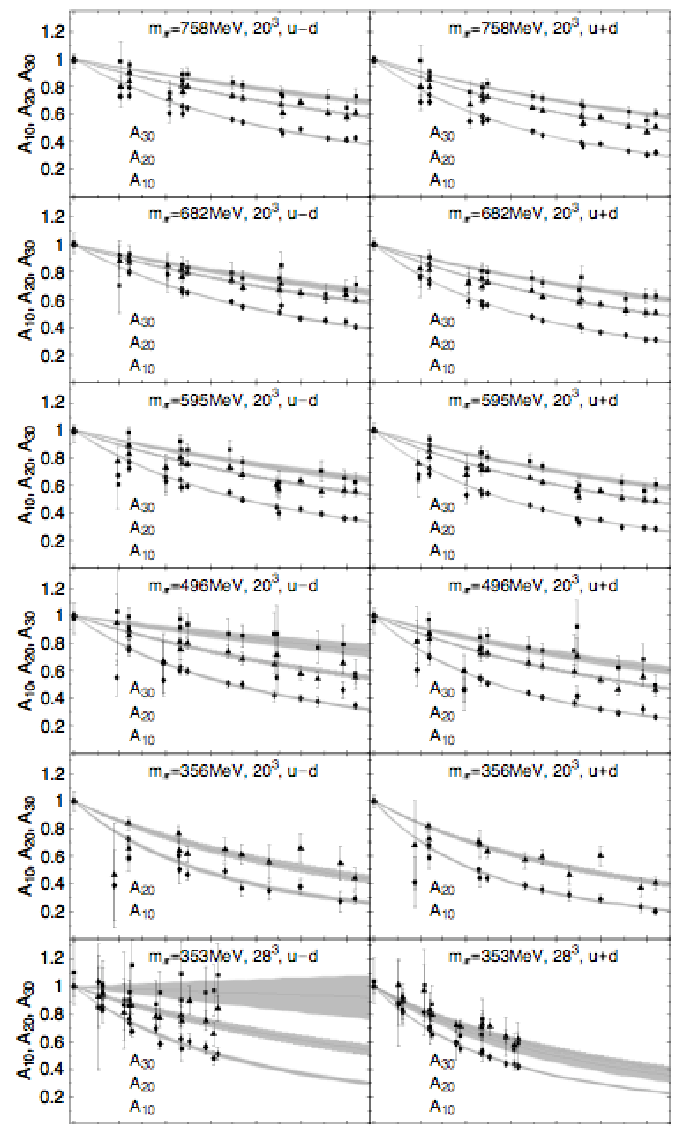


New Developments

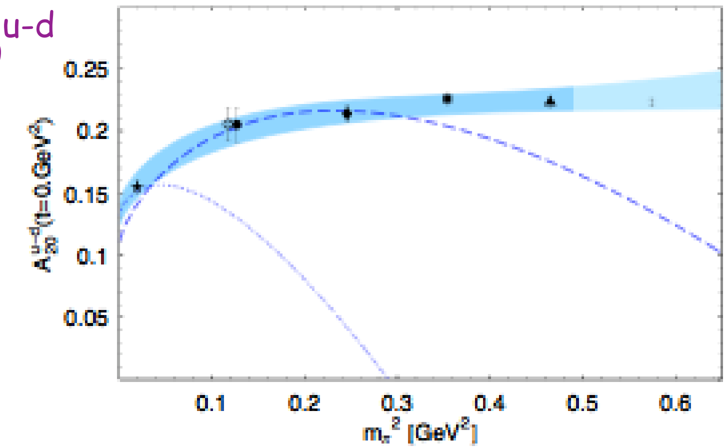
✔We repeated the calculation with improved lattice resul

(Haegler et al., PRD 2007, arXiv:0705:4295)





A_{20}^{u-d}



Results are comparable (up to n=2) to "phenomenological" extrapolation

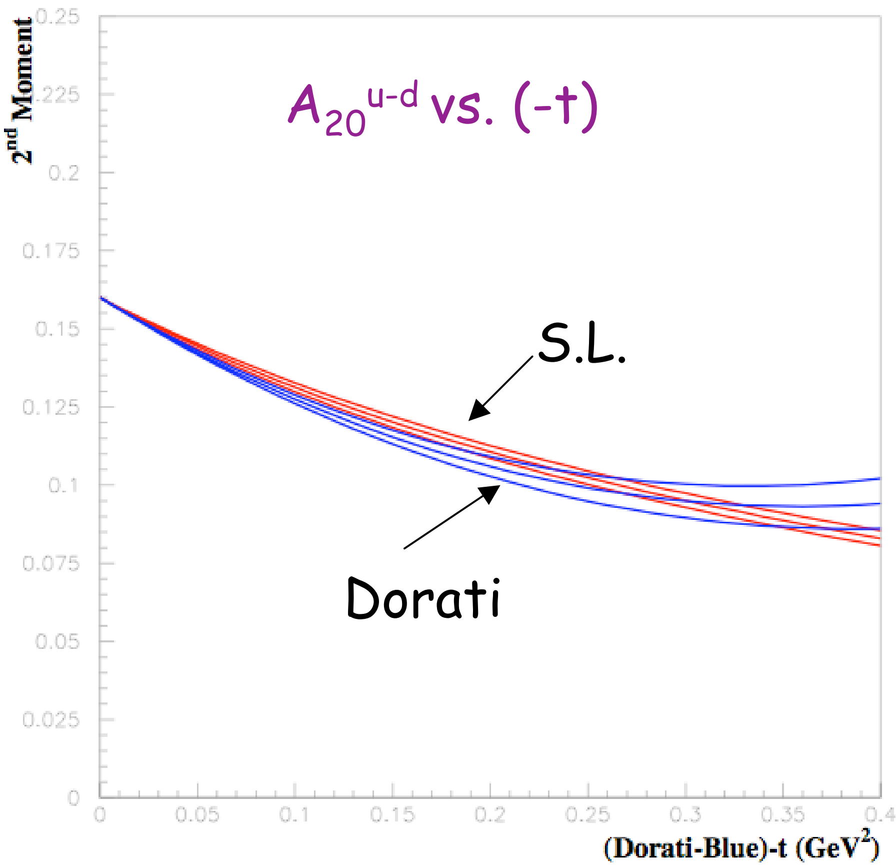
✔We are investigating the impact of different chiral extrapolat methods: "direct" extrapolation applicable up to n=2 only

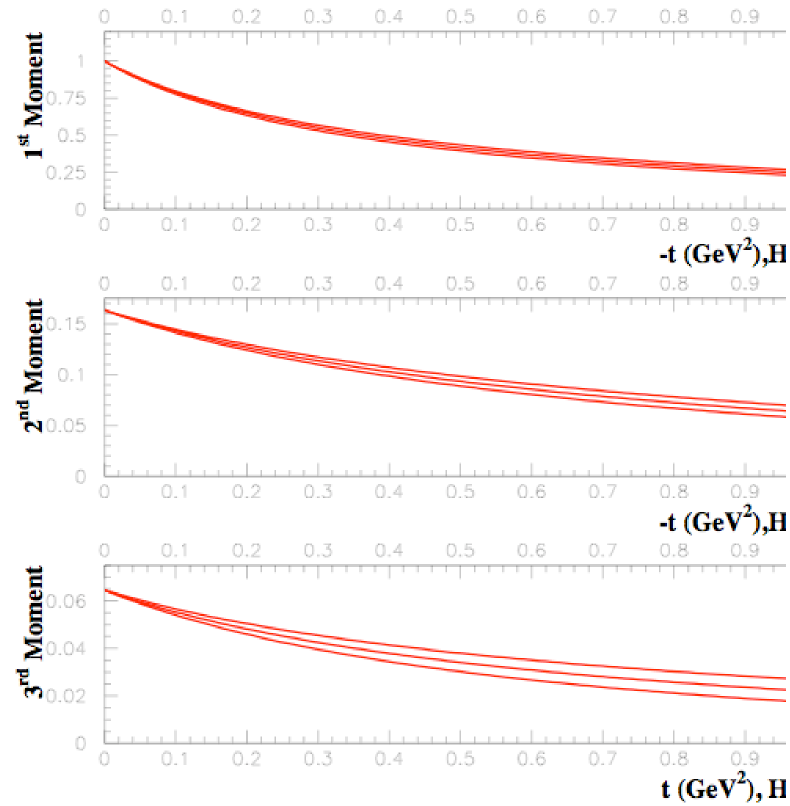
$$A_{20}^{u-d}(t,m_\pi) = A_{20}^{0,u-d}\left(f_A^{u-d}(m_\pi) + \frac{g_A^2}{192\pi^2 f_\pi^2} h_A(t,m_\pi)\right) + \tilde{A}_{20}^{0,u-d} j_A^{u-d}(m_\pi) + A_{20}^{m_\pi,u-d} m_\pi^2 + A_{20}^{t,u-d} t\,,$$

M. Dorati, T. Gail and T. Hemmert (NPA 798, 2008)

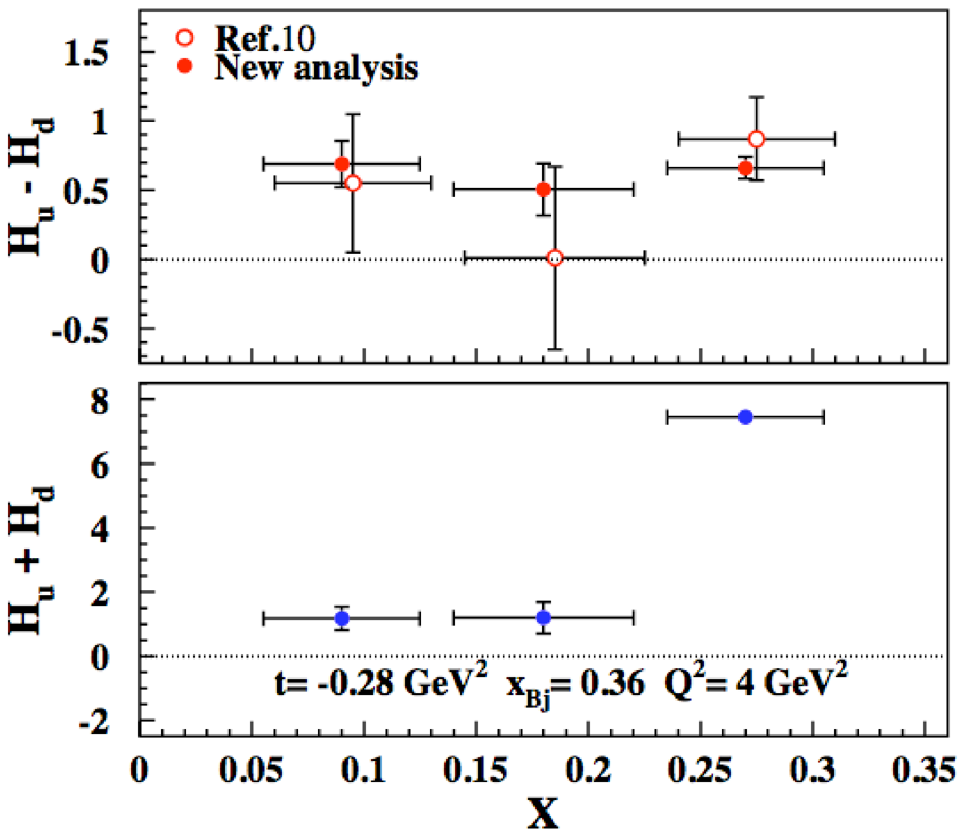
(Also using P. Wang, A. Thomas et al.)

New Results are more precise and compatible with other chiral extrapolat

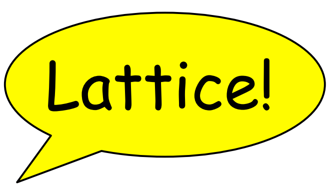




New Analysis



- Results are more accurate ⇒or can see trends
- both isovector and isoscalar te

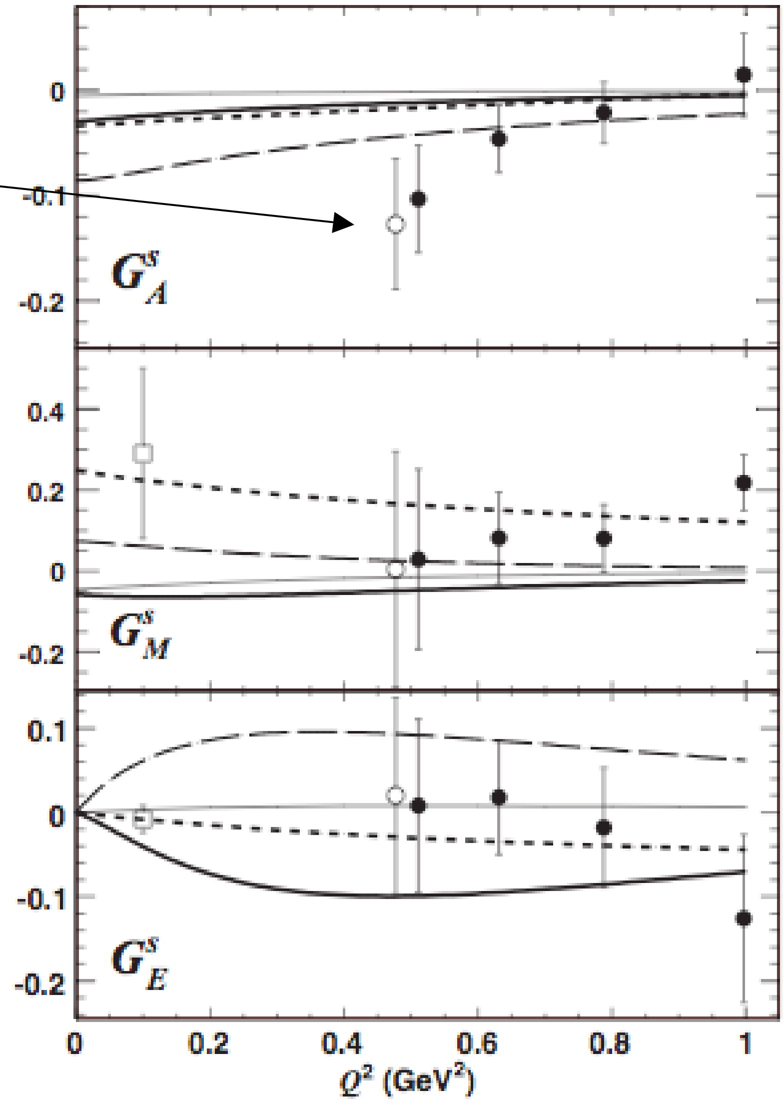


Extend analysis to Strange and Charm Content of nucleon

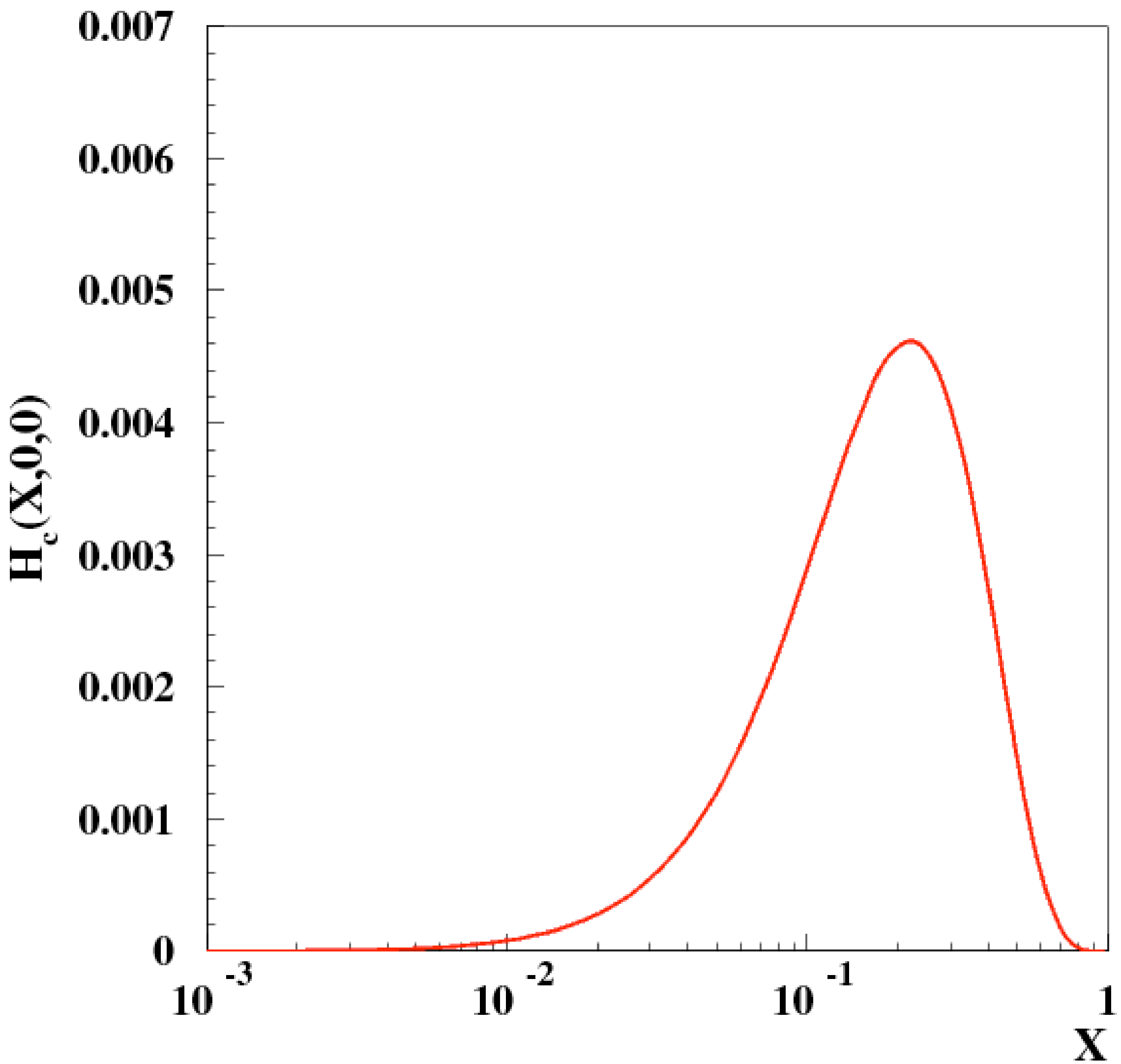
Bali, S.Collins, Schäfer, hep-lat,0911.2704

G0 + BNL E734

HAPPEx+E734

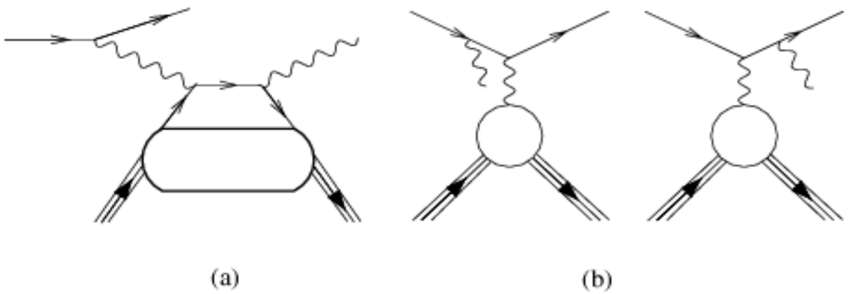


IC distribution

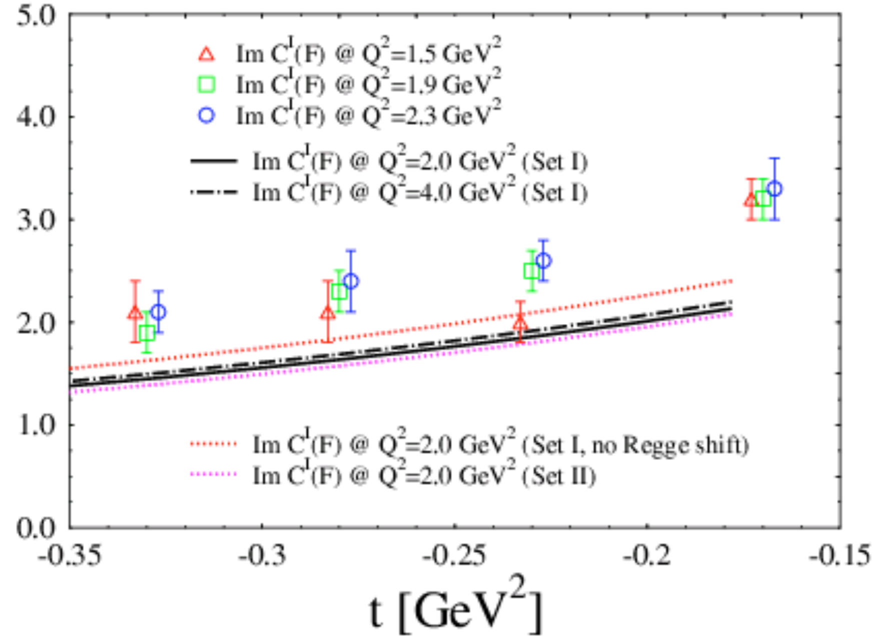


Results

BSA data are predicted at this stage



Munoz Camacho et al., PRL(2006)

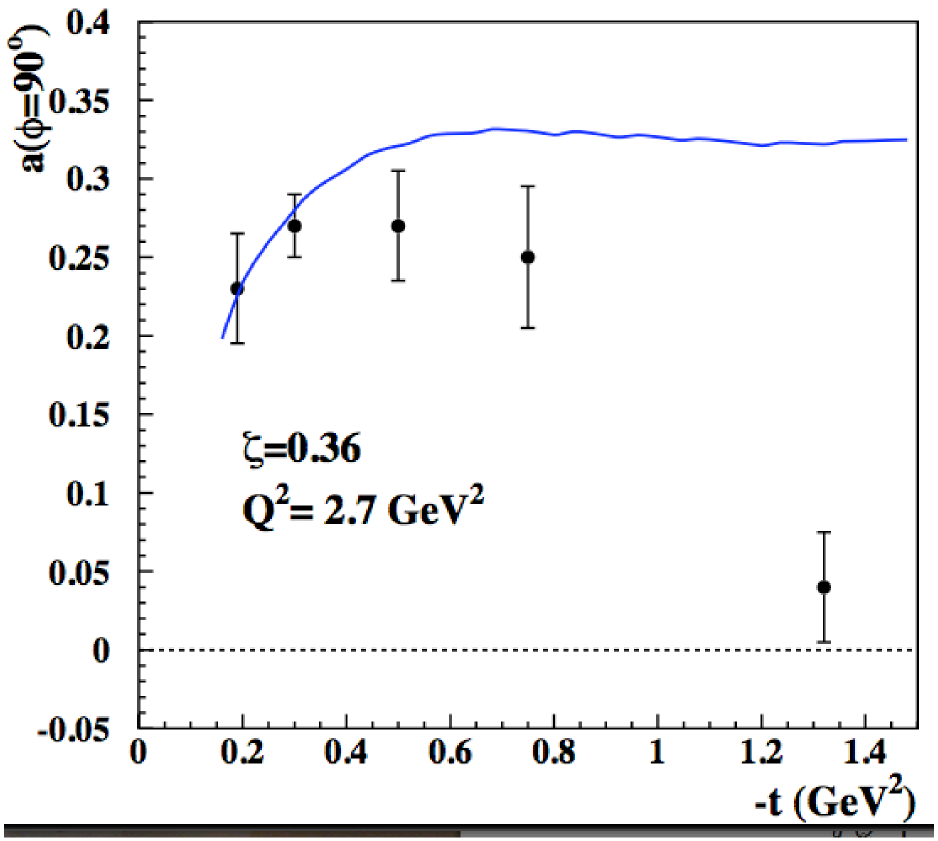


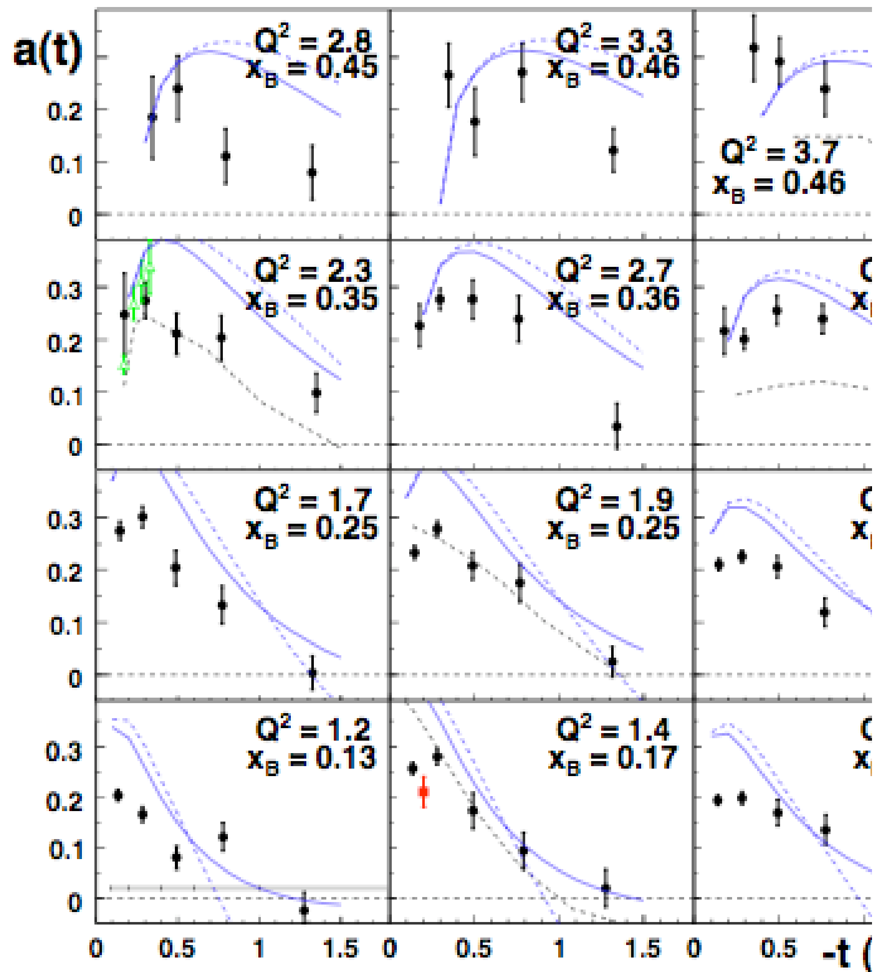
• Observable given by Interference Term between DVCS (a) and BH(b):

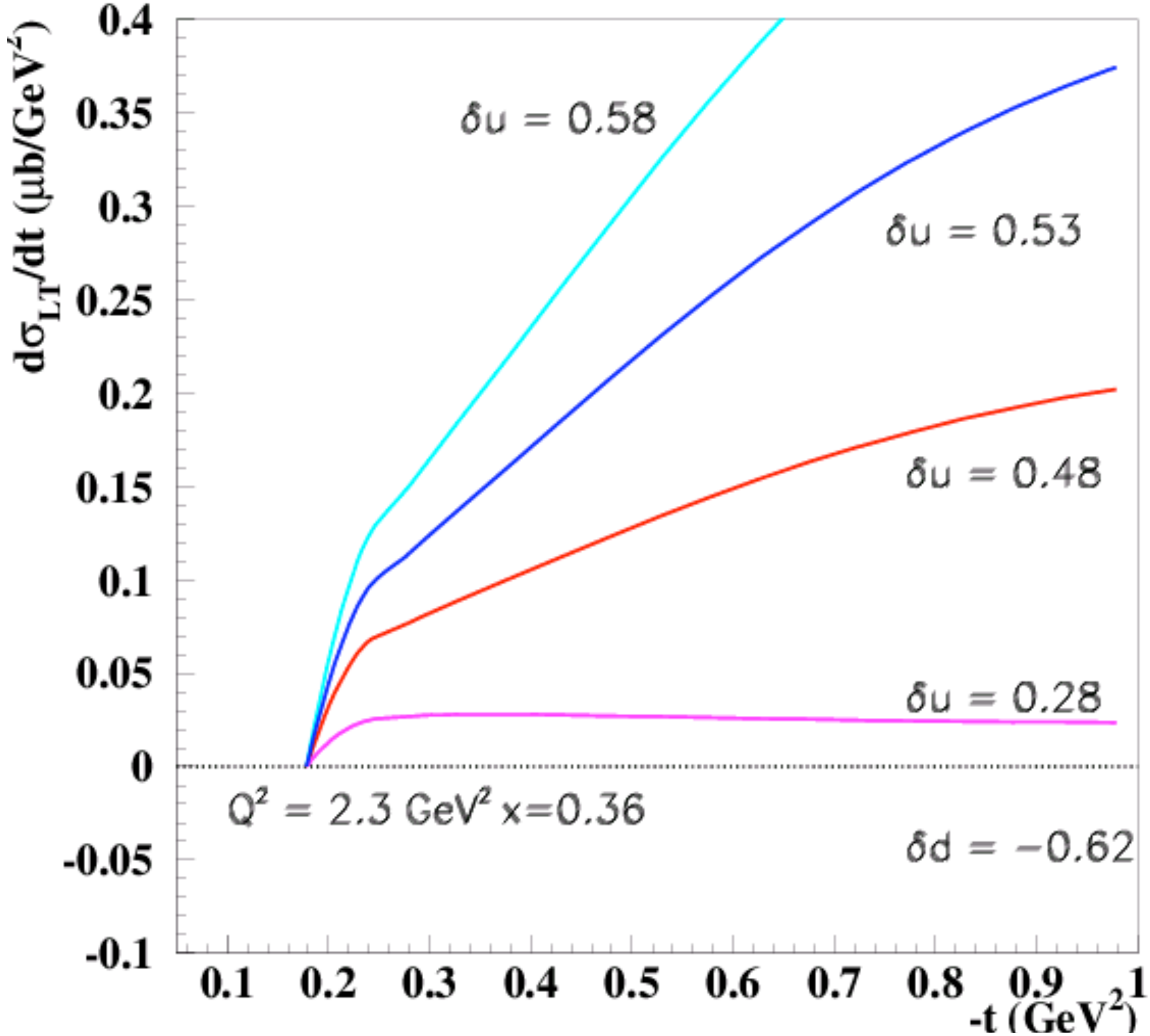
$$d\sigma^{\rightarrow} - d\sigma^{\leftarrow} \propto sin\phi \left[F_1(\Delta^2)\mathcal{H} + \frac{x}{2-x}(F_1+F_2)\tilde{\mathcal{H}} + \frac{\Delta^2}{M^2}F_2(\Delta^2)\mathcal{E} \right]$$

$$\mathcal{H} = \sum_q e_q^2 (H(\xi,\xi,\Delta^2) - H(-\xi,\xi,\Delta^2))$$

Hall B (one binning, 11 more)

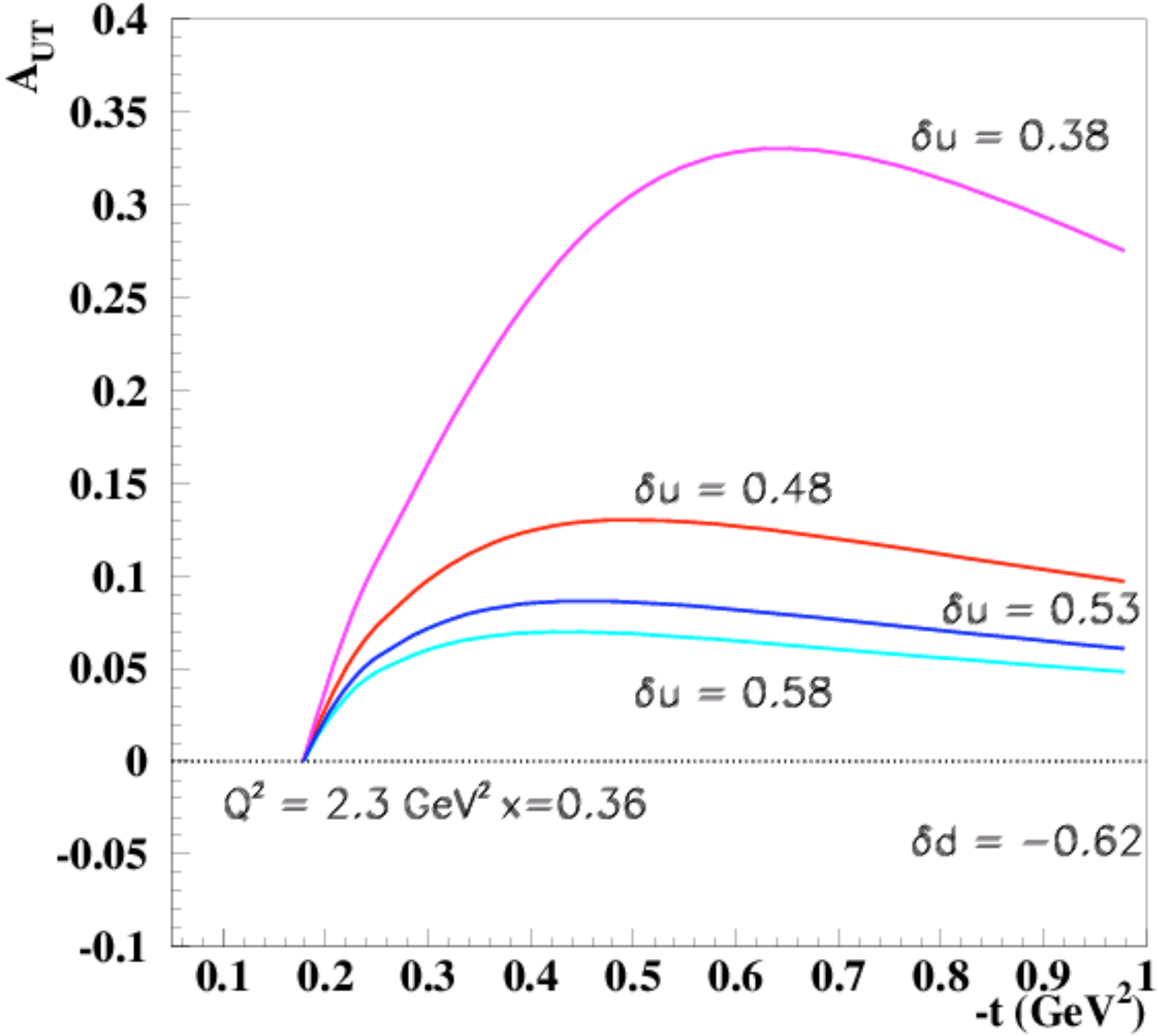






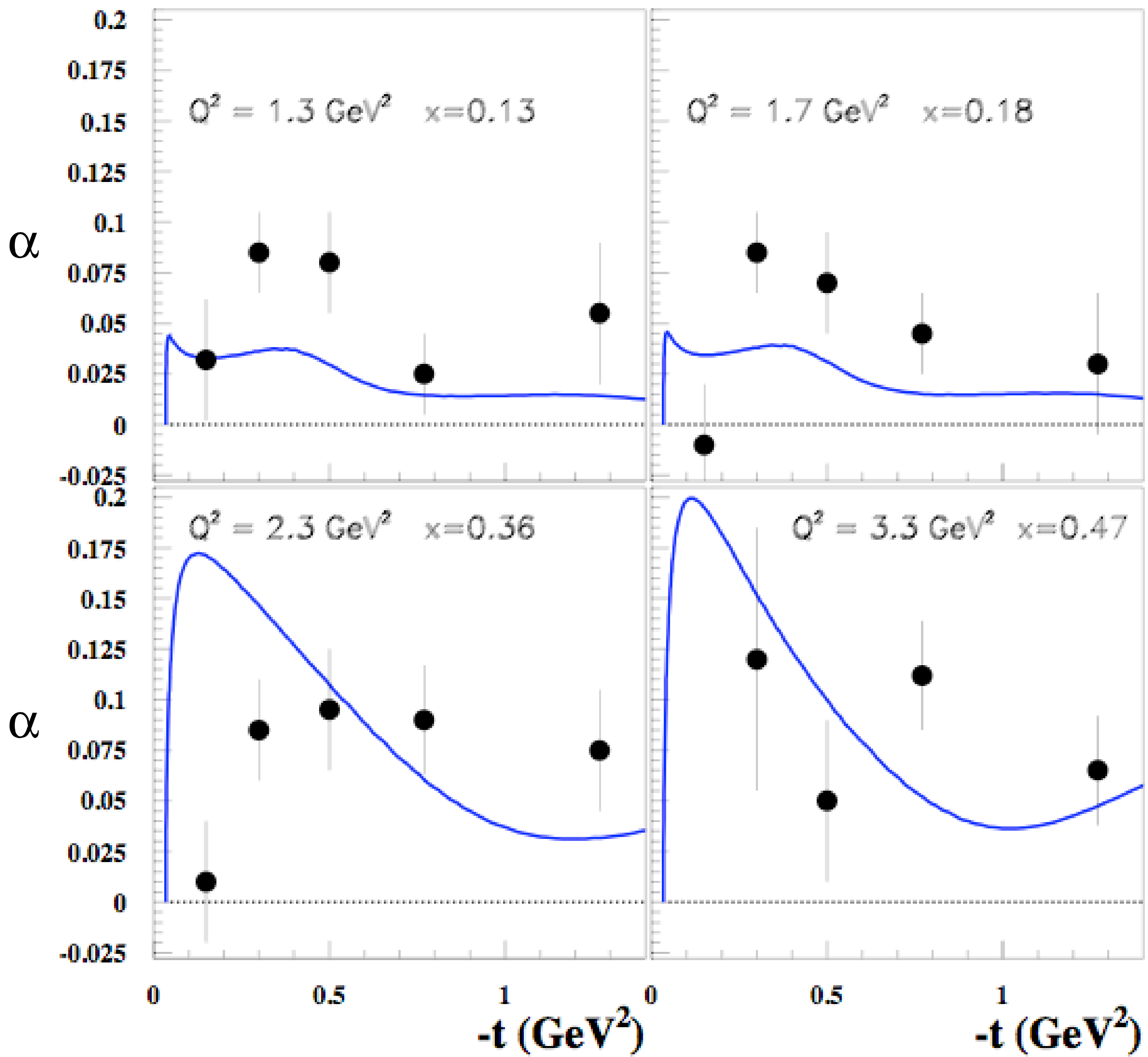
$d\sigma_{LT}/dt$ (μb/GeV²)
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
-0.05
-0.1
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
-t (GeV²)
δu = 0.58
δu = 0.53
δu = 0.48
δu = 0.28
Q² = 2.3 GeV² x=0.36
δd = −0.62

σ_{LT}



A_{UT}
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
-0.05
-0.1
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
-t (GeV^2)
δu = 0.38
δu = 0.48
δu = 0.53
δu = 0.58
Q^2 = 2.3 GeV^2 x=0.36
δd = −0.62

A_{UL} (HallB data)



Conclusions and Outlook

- EIC with an extended kinematical coverage (low to "larger" x_{Bj}) and wide Q^2 range will provide invaluable information on both pdfs (needed for LHC ...!!), and basic hadronic properties: nature of charm content, quark and gluons spin, transversity...

- Through deeply virtual exclusive charmed mesons production we suggested a unique way of singling out the Intrinsic Charm (IC) content of the nucleon:

    - Transversity sensitive observables are key: they cannot evolve from gluons

    - Asymmetries for Pseudoscalar Charmed mesons production will establish a lower limit on the size of IC component