Opportunities for CLAS12 experiments on exclusive π^0,η and ϕ electroproduction.

•Scheduled Jlab CLAS 12 program “deep” exclusive reactions
•Variety of spin, parity, quark flavors
•Different aspects of the intrinsic parton structure of the nucleon.

$\gamma * + p \rightarrow p + \gamma$ — $\begin{cases} \text{Chiral even GPDs.} \\ \text{Quark tomagraphic density distributions} \end{cases}$

$\gamma * + p \rightarrow p + \pi$
$\gamma * + p \rightarrow p + \eta$ — $\begin{cases} \text{Chiral odd GPDs.} \\ \text{Quark transverse spin distributions.} \end{cases}$

$\gamma * + p \rightarrow p + \phi$
$\gamma * + p \rightarrow p + \psi$ — $\begin{cases} \text{Gluon GPDs.} \\ \text{Gluon ditributions} \end{cases}$

Two approaches to exclusive mesonelectroproduction:

Regge: Jean-Marc Laget

GPD: $\begin{cases} \text{Gary Goldstein, Simoneta Liuti} \\ \text{Sergey Goloskokov, Peter Kroll} \end{cases}$

Generalized Form Factors

DVCS: measure Compton form factors - CFF:

$$\left\langle H_{Re} \right\rangle \equiv \mathcal{H}_{\mathrm{Re}} = \mathcal{P}\int_0^1 dx\; H_+\; K \qquad K = \frac{1}{x-\xi} + \frac{1}{x+\xi}$$

$$\left\langle H_{Im} \right\rangle \equiv \mathcal{H}_{Im} = H_+(\xi,\xi,t) = H_q(x,\xi,\; t) - H_q(x,\xi,\; t)$$

Meson: Measure generalized form factors-GFF:

(Notation of Goloskokov and Kroll (GK))

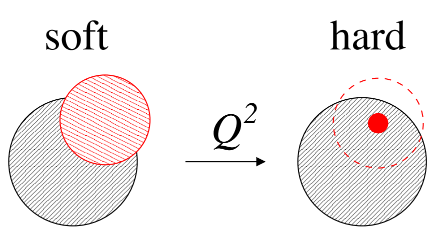
$$\langle F \rangle = \sum_{\lambda} \int_{-1}^{1} dx\; \mathcal{H}_{\mu'\lambda'\mu\lambda} F \quad = \quad \int_{-1}^{1} dx\; KF$$

$$F = H,\;\; E,\;\; \tilde{H},\;\; \tilde{E},\;\; H_T,\;\; E_T$$

Analogy of $\mathcal{H}$ in DVMP for mesons with K for DVCS.

DVCS: $K = \frac{1}{x-\xi} + \frac{1}{x+\xi}$ elementary DVCS process weighted by nucleon structure..

DVMP: two convolutions involving strong processes: meson structure and nucleon structure.



Projectile size: $r_\perp \sim \frac{1}{Q}$ Target size: $r_\perp \sim \frac{1}{\Delta_\perp}$

t-slope: $\sigma \propto e^{Bt}$ $r_\perp^2 =\sim 1/B$

$$\frac{d\sigma_L}{dt} \propto \left|\mathcal{M}_V\right|^2 \qquad \mathcal{M}_V^g = \sum e_a \mathcal{C}_V^a \int_0^1 d\bar{x}\ \mathcal{H}_V^g(\bar{x},\xi,Q^2,t'=0)\ H_g(\bar{x},\xi,t) \qquad \mathcal{C}_\phi^s = 1$$

$$\mathcal{H} = \iint dx_p d^2b\ \ \psi_V(\tau,-b,\mu_F)\mathcal{F}(b,\tau,x,\xi,\mu_R)\ \alpha_s(\mu_R)\ e^{-S(\tau,\xi,b,Q^2,\mu_R,\mu_F)}$$

Helicity amplitudes:

$$\frac{d\sigma}{dt} \propto \left| \mathcal{M}_{\mu'\lambda',\, \mu\lambda} \right|^2$$

Gluon helicity: $\lambda \;\; \lambda'$ Photon/Meson helicities: μ and μ'

Proton helicity non-flip:

$$\mathcal{M}_{\mu',\mu} = \frac{e}{2} \mathcal{C}_V^a \int_0^1 \frac{d\bar{x}}{(\bar{x}+\xi)(\bar{x}-\xi+i\varepsilon)} \left\{ \left(\mathcal{H}_{\mu'+,\,\mu+} + \mathcal{H}_{\mu'-,\,\mu-} \right) \left(H_g(\bar{x},\xi,t) + \tilde{H}_g(\bar{x},\xi,t) \right) \right\}$$

Proton helicity flip:

$$\mathcal{M}_{\mu',\,\mu} = -\frac{e}{2} \mathcal{C}_V^a \kappa \frac{\sqrt{-t}}{2m} \int_0^1 \frac{d\bar{x}}{(\bar{x}+\xi)(\bar{x}-\xi+i\varepsilon)} \left\{ \left(\mathcal{H}_{\mu'+,\,\mu+} + \mathcal{H}_{\mu'-,\,\mu-} \right) \left(E_g(\bar{x},\xi,t) + \xi \tilde{E}_g(\bar{x},\xi,t) \right) \right\}$$

Vector meson production:

$$\frac{d\sigma_L}{dt} \propto \left| \mathcal{M}_V \right|^2 \qquad \mathcal{M}_V^g = \sum e_a \mathcal{C}_V^a \int_0^1 d\bar{x}\; \mathcal{H}_V^g(\bar{x},\xi,Q^2,t'=0)\, H_g(\bar{x},\xi,t) \qquad \mathcal{C}_\phi^s = 1$$

We never will directly measure a GPD. Therefore…

DVMP much more complicated than DVCS, Therefore…

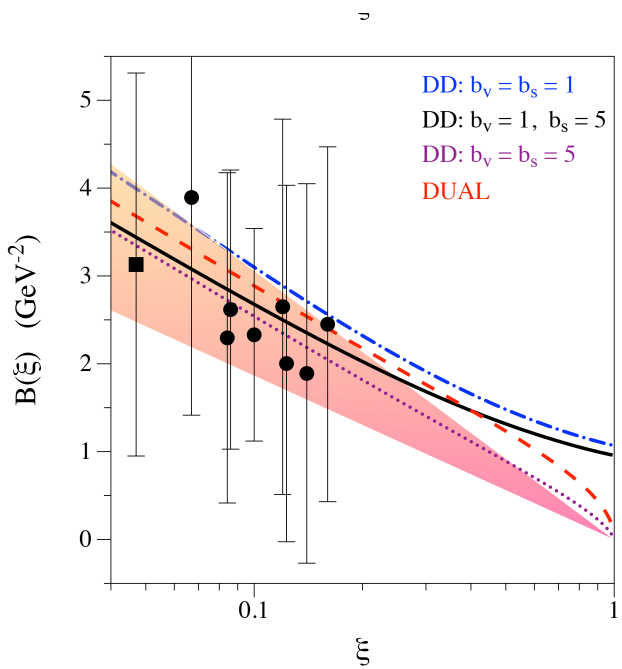
Recent interesting examples of each genre

Charge density of nucleon from CFF:

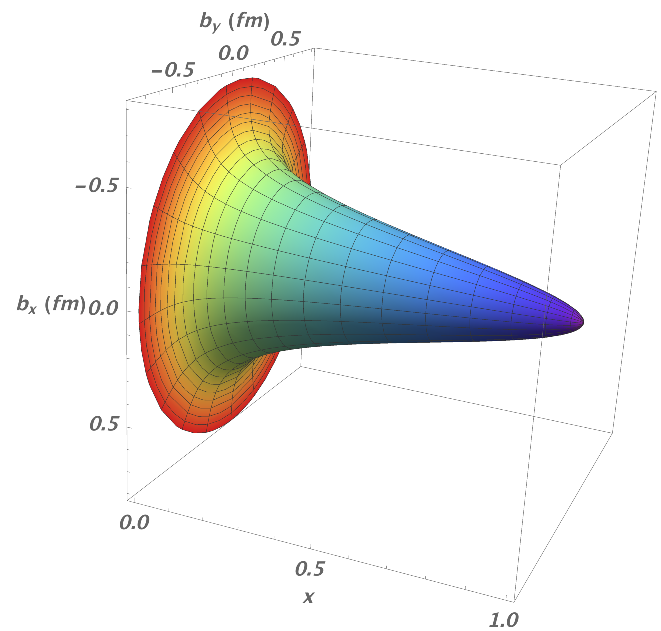
Dupre, Guidal, Vanderhaeghen (hep-ph:1606.07821v1)

$$\text{Cross sections data} \rightarrow \mathcal{H}_{Im} \equiv \langle H_{Im} \rangle$$

$$\text{Expand:} = \mathcal{H}_{Im} = A(\xi)e^{\boldsymbol{B}(\xi)t} \qquad A(\xi) = a_A(1-\xi)/\xi$$



$$\text{fit } \boldsymbol{B}(\xi) = a_B ln(1/\xi).$$



π^0 and η electroproduction experiment

Spokespersons:
V. Kubarovsky, K. Joo, M.Ungaro, C. Weiss and P.S.

Transversity spin distributions: π^0 and η production

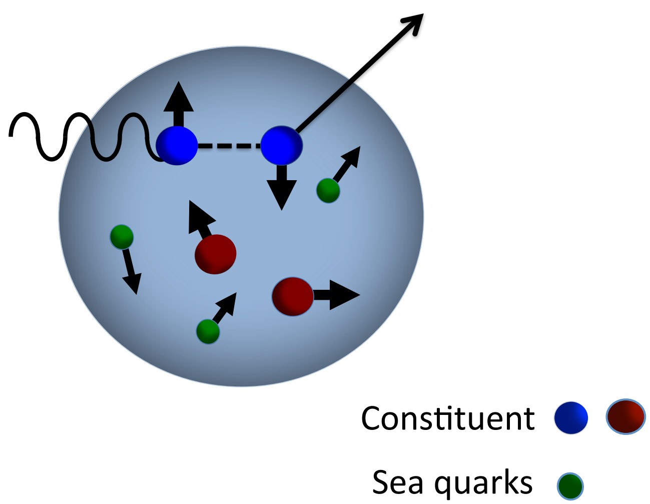
Generalized form factors (GFF)

$$\langle H_T \rangle = \int_{-1}^{1} dx \mathcal{H}_{0\lambda'\mu\lambda} H_T \qquad \langle \bar{E}_T \rangle = \int_{-1}^{1} dx \mathcal{H}_{0\lambda'\mu\lambda} \bar{E}_T$$

H_T and E_T - transversity GPDs. Quark helicity-flip.

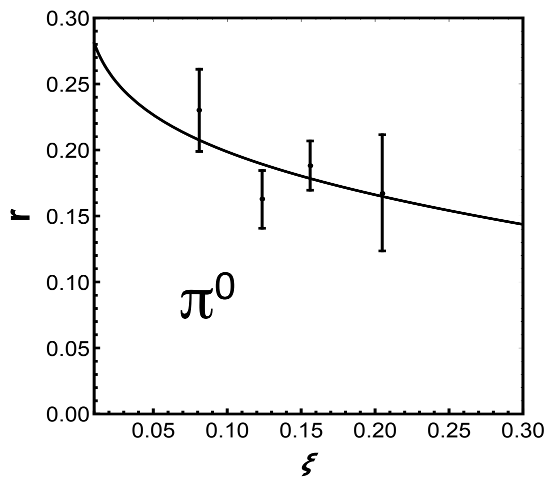
H_T nucleon helicity flip. E_T nucleon helicity non-flip

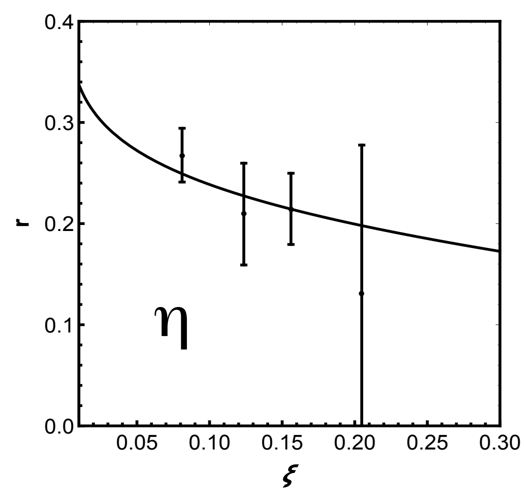
E_T : distribution of guark spins transverse to probe in unpolarized nucleon.



π^0 and η Electroproduction
(Bedlinskiy et al)

Fit $t \rightarrow r_\perp \quad \langle \bar{E}_T \rangle = A\, e^{-Bt} \quad B = b / \ln\xi$ and $r_\perp(x_B) = \sqrt{B}\, hc$ vs. x_B





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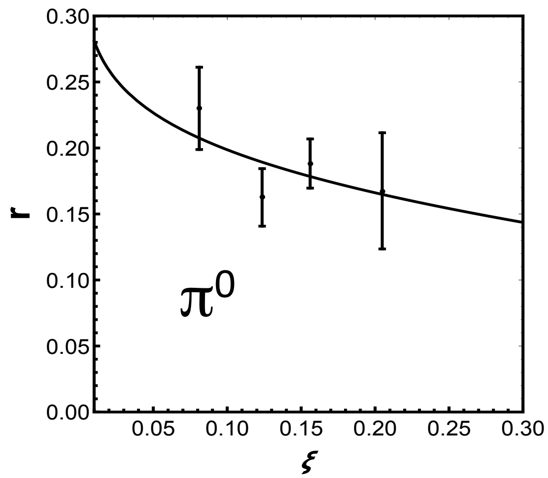
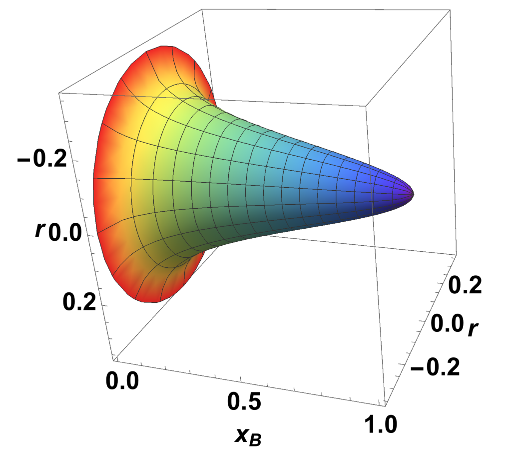
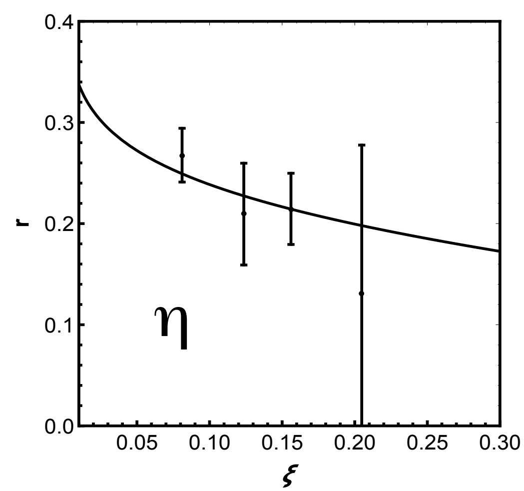
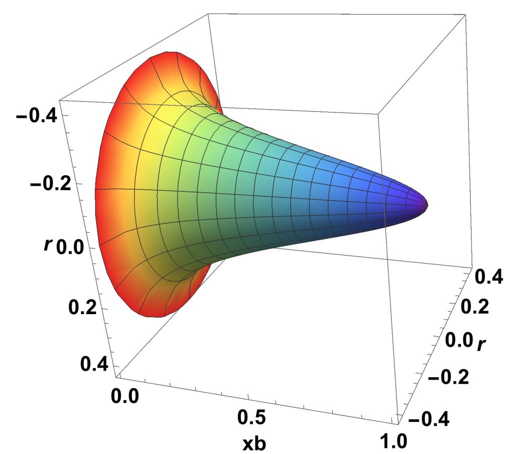








Extracting GPDs for individual quark flavors.

π^0 and η are members of the same meson multiplet.

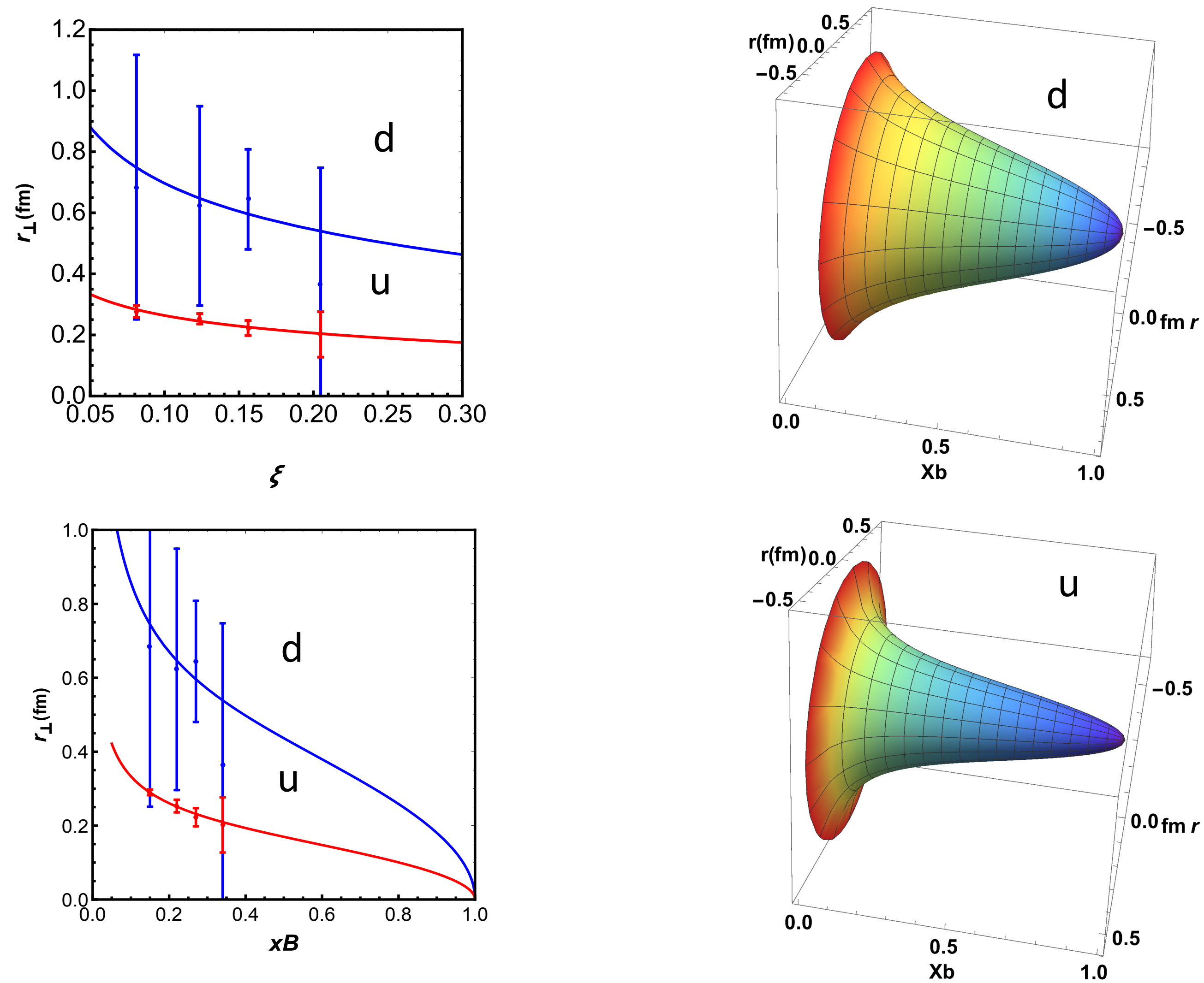
Deconvolute π^0 and η to get contributions from quark flavors with various approximations. (V. Kubarovsky, ArXiv: 1601.04367v2)

π^0 | η

$$H_T^{\pi^0} \approx (e_u H_T^u - e_d H_T^d) / \sqrt{2}, \qquad H_T^{\eta} \approx (e_u H_T^u + e_d H_T^d) / \sqrt{6},$$

$$\bar{E}_T^{\pi^0} \approx (e_u \bar{E}_T^u - e_d \bar{E}_T^d) / \sqrt{2} \qquad \bar{E}_T^{\eta} \approx (e_u \bar{E}_T^u + e_d \bar{E}_T^d) / \sqrt{6}$$

Deconvolution of u and d quarks

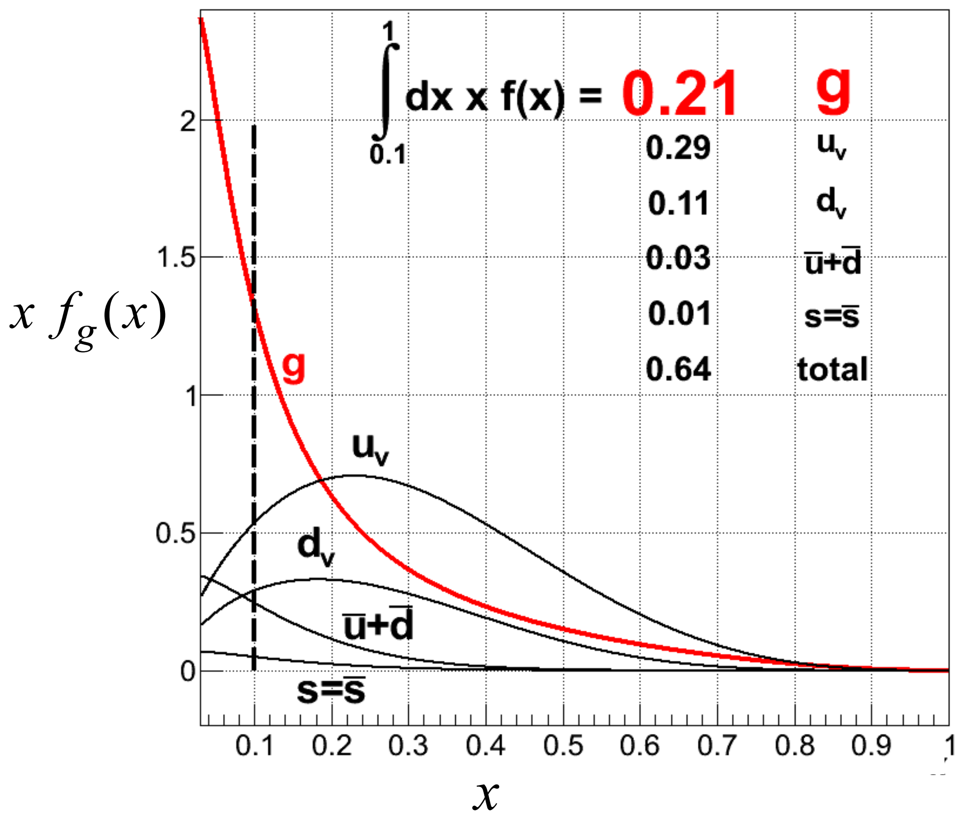


ϕ electroproduction experiment

Spokespersons:
F.-X. Girod, M. Guidal, K. Joo, V. Kubarovsky, C. Weiss, P.S.

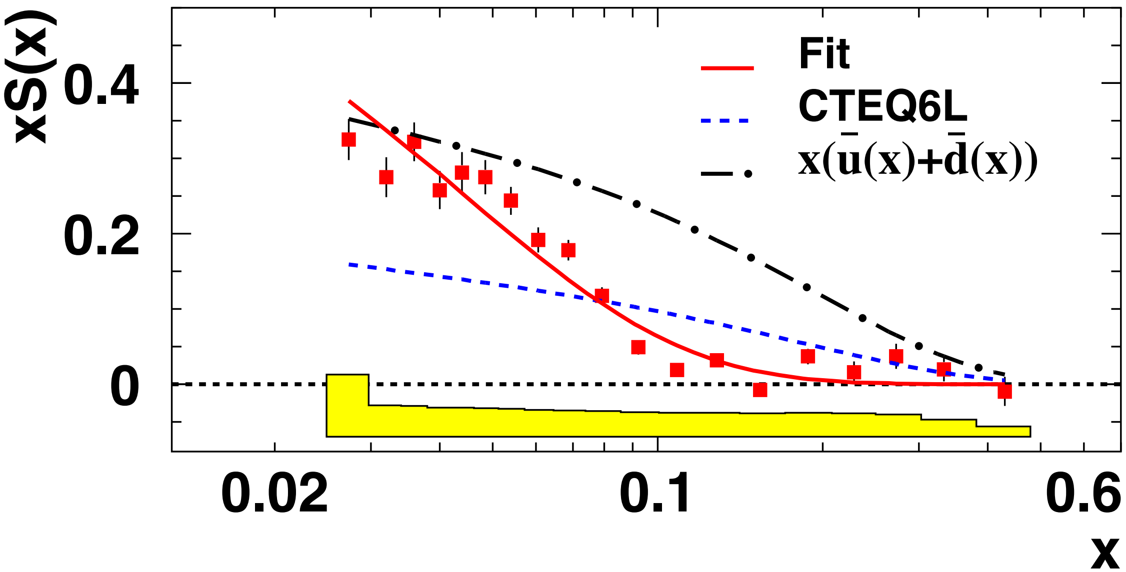
Disclaimer 2: I have never done a phi experiment

PDF - CTEQ6M

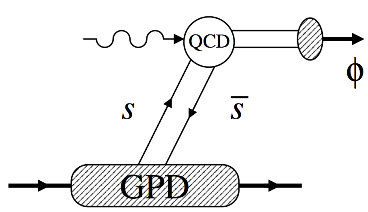


J. Pumplin, et al.
arXiv:hep-ph/0201195v3

Hermes data: A. Airapetian et al
Phys. Lett. B 666 (2008)



High *x*: intrinsic s-$\overline{s}$ knockout?



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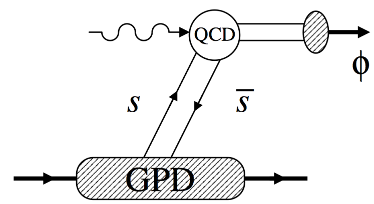
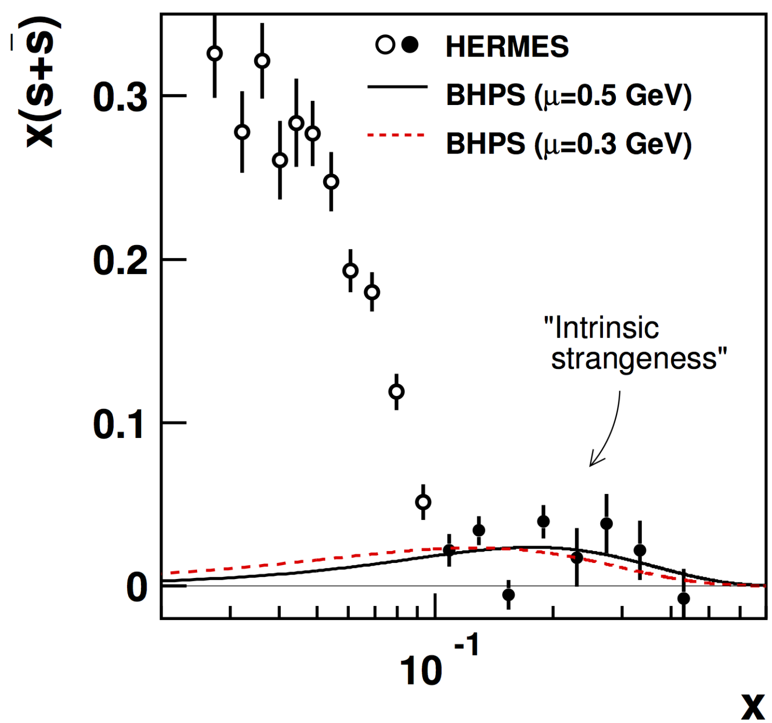




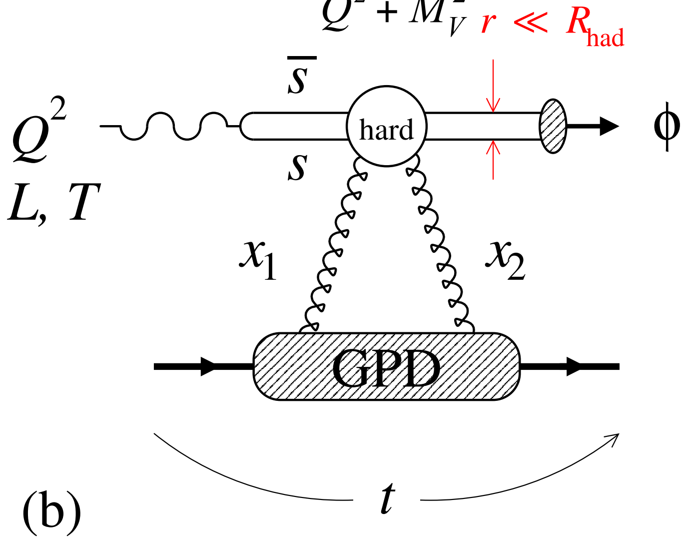
Hermes data: A. Airapetian et al
Phys. Lett. B 666 (2008)

BHPS: S. J. Brodsky, P. Hoyer, C. Peterson
and N. Sakai, Phys. Lett. B 93, 451 (1980)

ϕ Electroproduction and gluon GPDs

Transverse gluon density, $r_\perp$ vs x_g

Coherence time: $\Delta\tau = \dfrac{2\nu}{Q^2 + M_V^2}$ Coherence length: $l = c\Delta\tau$



Projectile size: $r_\perp \sim \dfrac{1}{Q}$

Target size: $r_\perp \sim \dfrac{1}{\Delta_\perp}$ $(\Delta_\perp^2 \sim t$ for large $\theta_e)$

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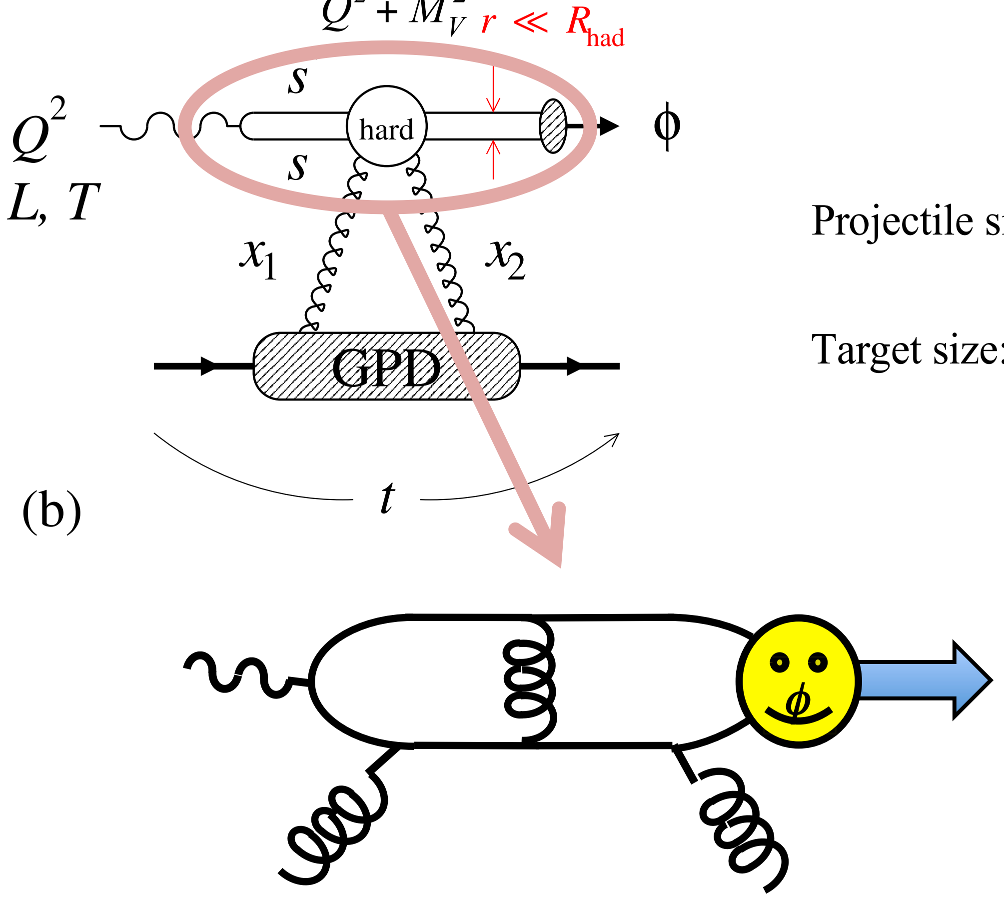

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Gluon GPD: $H_g(x,\xi,t)$

(Following G-K)

$$\frac{d\sigma_L}{dt} = \frac{\alpha_{em}}{Q^2}\frac{x_B^2}{1-x_B}(1-\xi^2)\,|\langle H_g\rangle|^2 + \text{ terms in}\langle Eg\rangle$$

$$\langle H_g\rangle = \int_{-1}^{1} dx\, H_g\, \mathcal{H} \;\rightarrow\; \text{Generalized Form Factor (GPP)}$$

$\mathcal{H}$= convolution of elementary process $\gamma_L + g \rightarrow \varphi_L + g$ by the nucleon distribution of gluons H_g

Relate $f_g(x)$ to $f_g(x,b)$ and GPDs

$$x\, f_g(x,b) = \int \frac{d^2\,\Delta_T}{(2\pi)^2} e^{ib\Delta} H_g(x,0,-\Delta_T^2)$$

$$x\ f_g(x) = \int d^2b\ x\, f_g(x,b) = H_q(x,0,\ 0)$$

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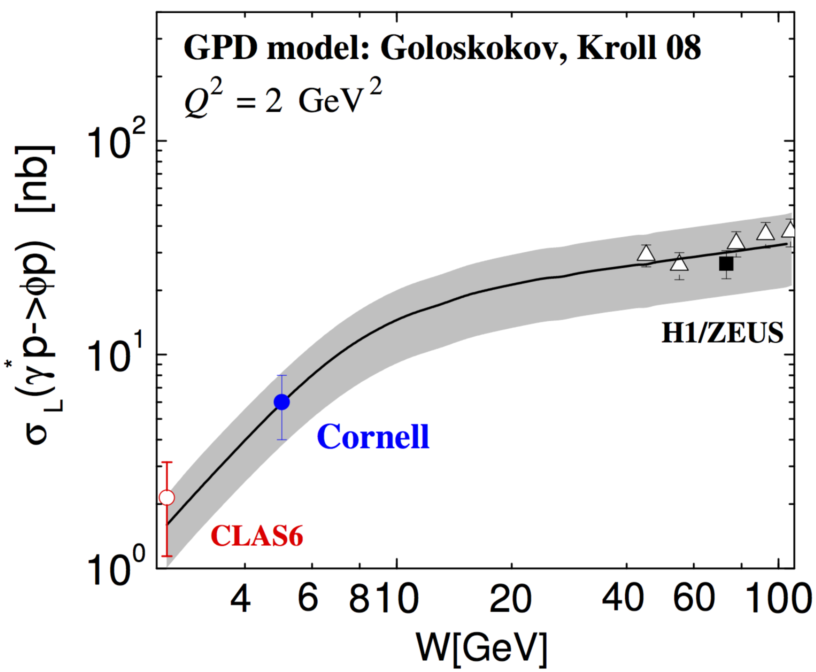
$$x\ f_g(x) = \int d^2b\, x\, f_g(x,b) = H_q(x,0,\ 0)$$

$$\rho_g(x,b) \equiv \frac{f_g(x,b)}{f_g(x)} = \text{normalized distribution.}$$

$$\int d^2b\ \rho_g(x,b) = 1$$

G-K GPD model



GPD model: Goloskokov, Kroll 08
$Q^2 = 2\ \mathrm{GeV}^2$
10^2
10^1
10^0
$\sigma_L(\gamma^* p \to \phi p)$ [nb]
Cornell
CLAS6
H1/ZEUS
4
6
8
10
20
40
60
100
W[GeV]

Experience at Jlab CLAS:

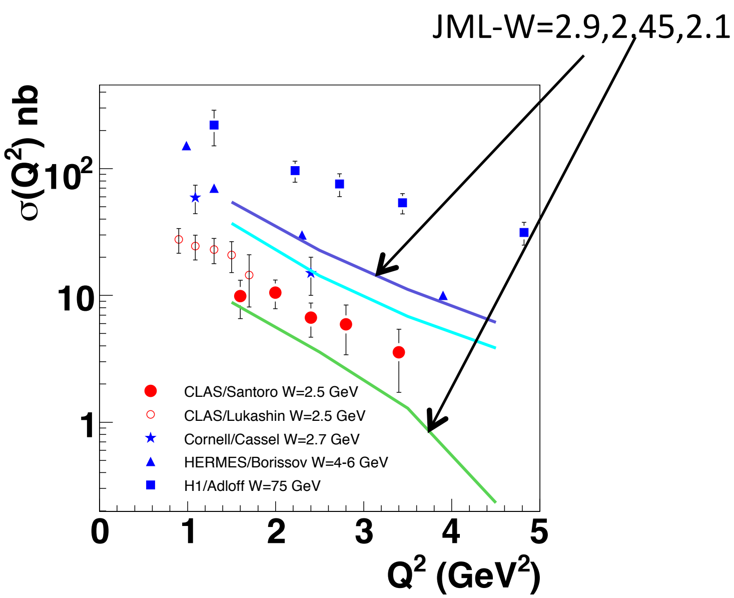
J.P. Santoro, et al. Phys.Rev.C78:025210,2008

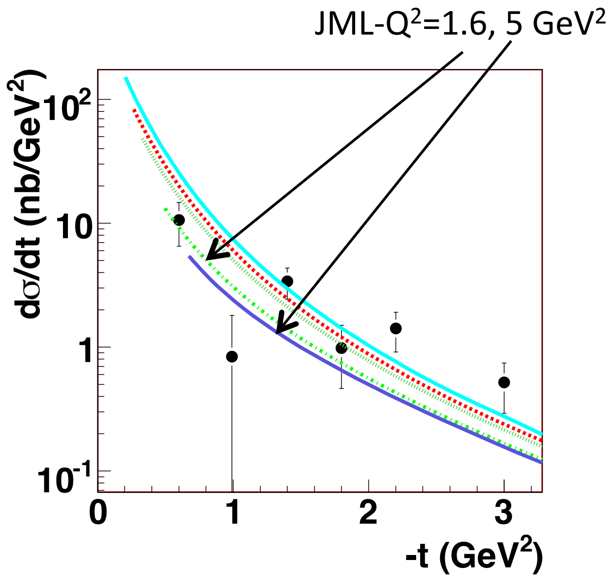
K. Lukashin et al. Phys. Rev. C63.065205,2001

Theory, in terms of Regge trajectories with dressed Gluons produce data successfully.

(J-M. Laget, Phys. Rev. D 70, 054023 (2004)).

Santoro et al.





To find gluon density, need σ_L

$$\frac{d\sigma}{d\Phi} = \frac{1}{2\pi}\left(\sigma + \varepsilon\sigma_{TT} cos 2\Phi + \sqrt{2\varepsilon(1+\varepsilon)}\sigma_{LT}\ cos\ \Phi\right)$$

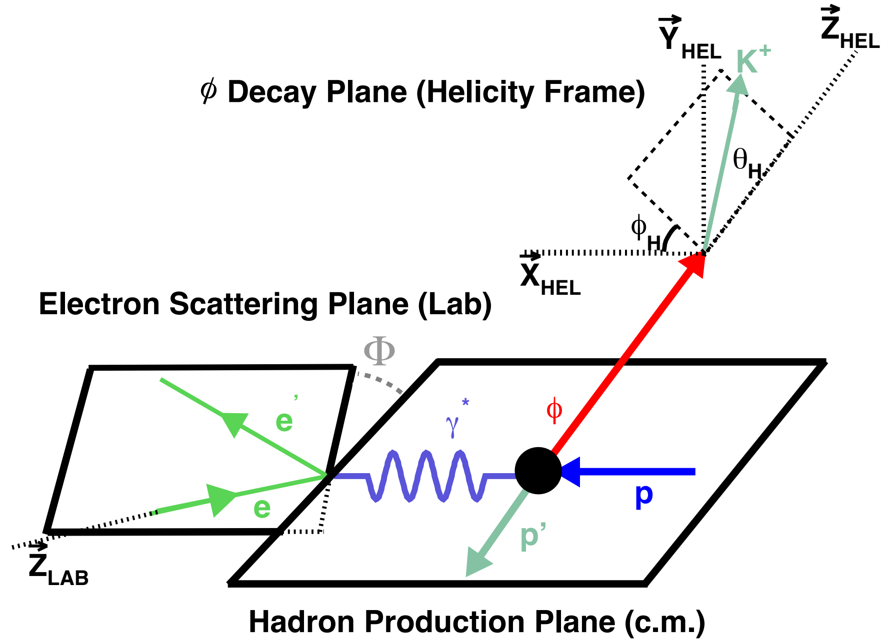
Helicity conservation: $\sigma_{TT}, \sigma_{LT} = 0 \quad \rightarrow \quad d\sigma = \frac{1}{2\pi}\sigma$

Extraction of L/T requires either do Rosenbluth plot or working in **helicity frame**

Helicity matrix element:

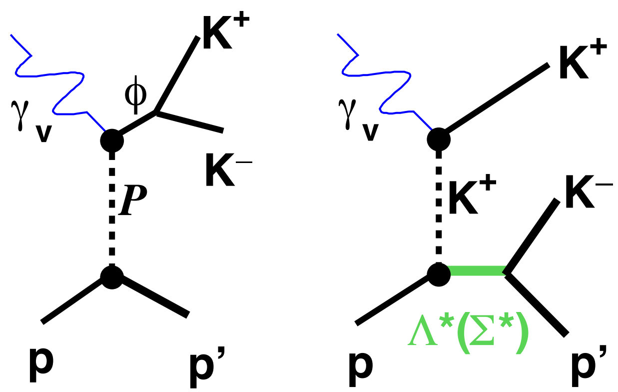
$$r_{00}^{04} = \frac{\varepsilon R}{1+\varepsilon R} \quad \text{were} \quad R = \frac{\sigma_L}{\sigma_T}$$

$$W(cos\theta) = \frac{3}{4}\left[\left(1 - r_{00}^{04}\right) + \left(3r_{00}^{04} - 1\right)\cos^2\theta_H\right]$$



Main background:

Pomeron exchange. Λ electroproduction



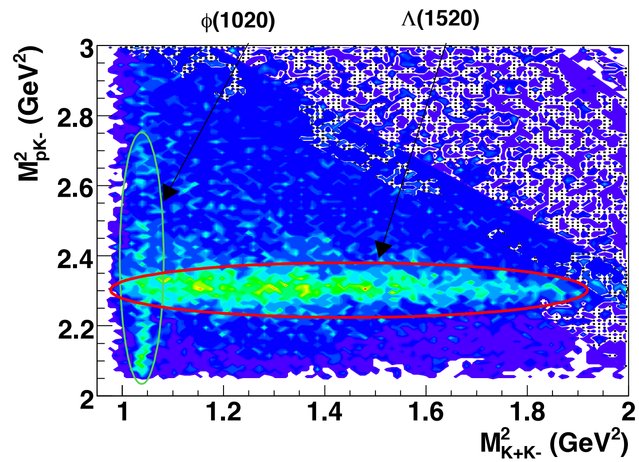
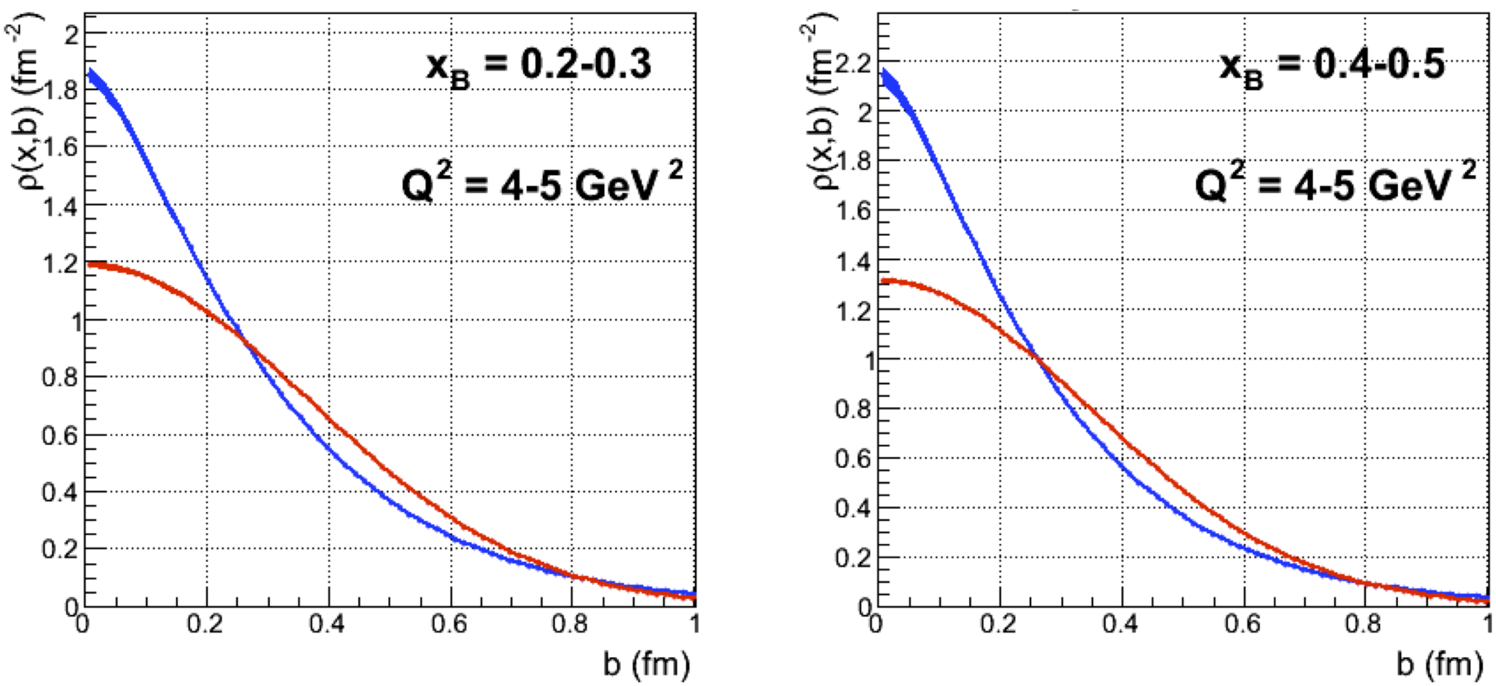


FIG. 7: Dalitz plot of M^2_{pK} versus M^2_{KK}. The well-defined horizontal strip is the $\Lambda(1520)$ band. The vertical strip is the $\phi(1020)$ band.

CLAS, Santoro et al

Extensive simulations done.
Sample of simulated results.

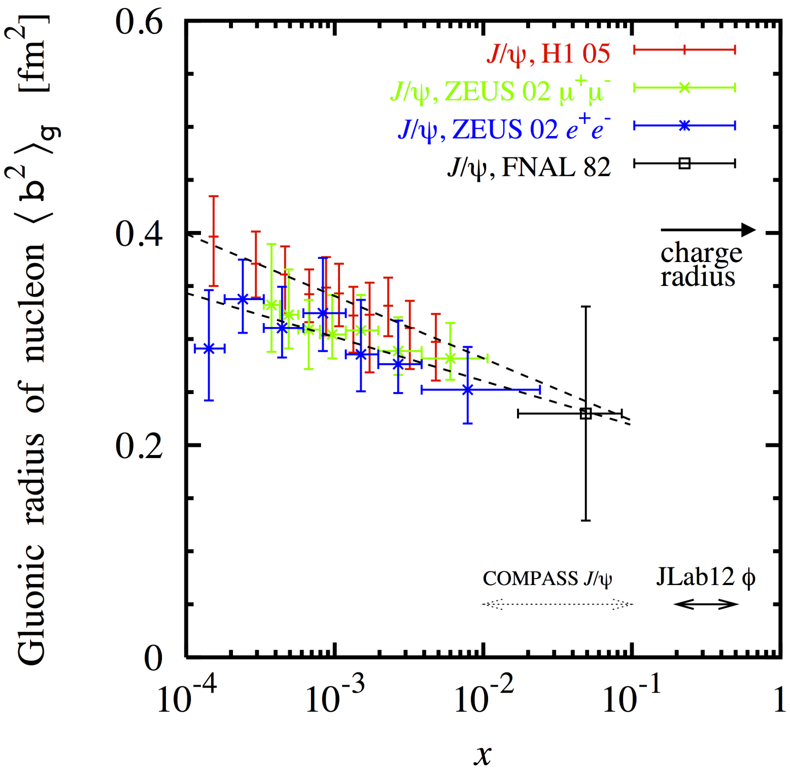


Bands represent statistical

Exponential
t dependence

Linear
t dependence

Status of $r_\perp$ measurements:



CLAS12 Experiment: fill gap in $r_\perp$ in range $x > 0.1$