

Regge behavior in DVCS: non-factorizability and $J = 0$ fixed pole

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XVII International Workshop
on Deep Inelastic Scattering and Related Subjects



Outline

- 1 Regge behavior: the loophole in DVCS factorization
- 2 Fixed pole in DVCS

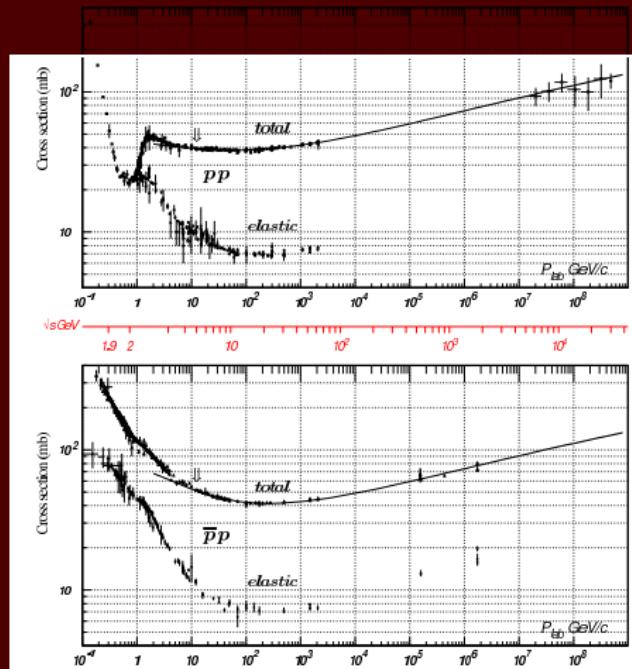
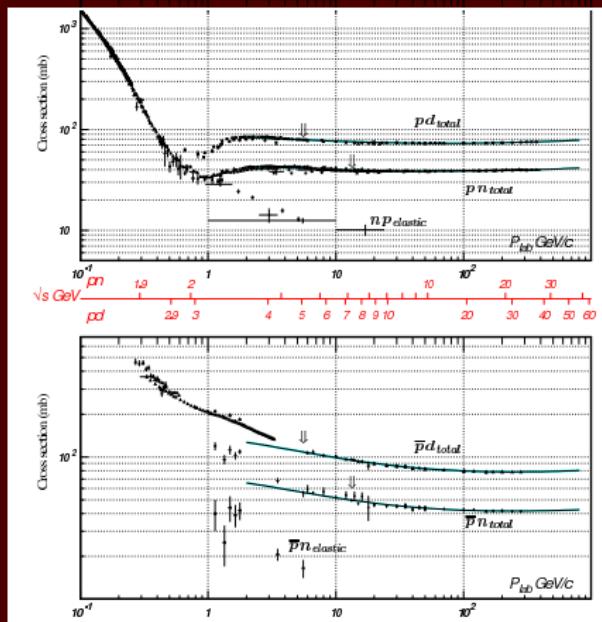


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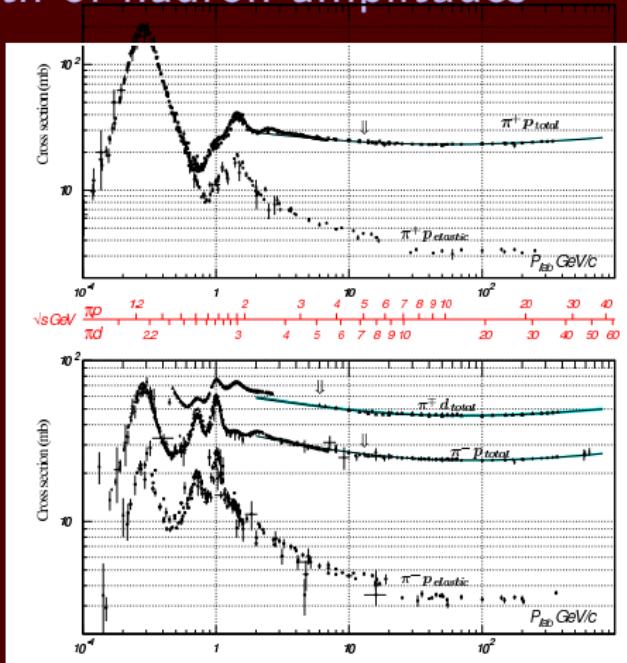
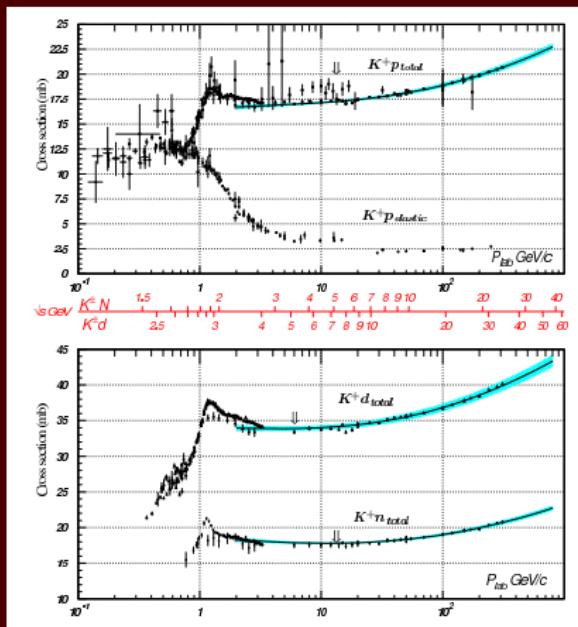
Phenomenology: Regge growth of hadron amplitudes



Abundant data on high-energy hadron cross-sections
(see Particle Data Group Reviews)



Phenomenology: Regge growth of hadron amplitudes



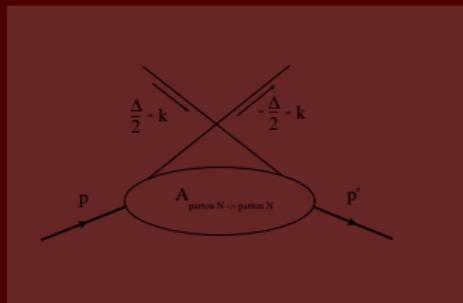
Flat cross section $\sigma \rightarrow s^0$
 implies growing amplitude $A \propto s^{\alpha(t)}$



Quark-Nucleon Scattering Amplitude

- Regge behavior independent of number of quarks...
- ASSUME Regge behavior also for the quark-nucleon scattering amplitude

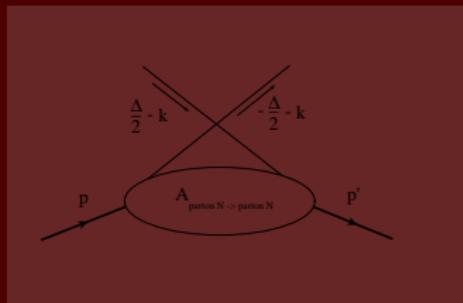
$$A(s, u, k_1^2, k_2^2) = \dots + \frac{k_{\beta\alpha}}{4} \delta_{\lambda'\lambda} (2\pi)^4 \int dm^2 \\ \left\{ \left[\frac{\rho_s(m^2)}{m^2 - s - i\epsilon} - \frac{\rho_{s,R}(m^2)}{m^2 - i\epsilon} \right] + (s \rightarrow u) \right\} I_n \frac{1}{(\mu^2 - k_1^2 - i\epsilon)(\mu^2 - k_2^2 - i\epsilon)},$$



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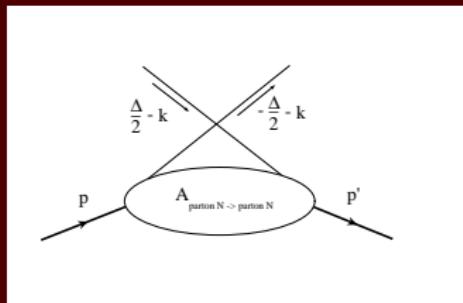
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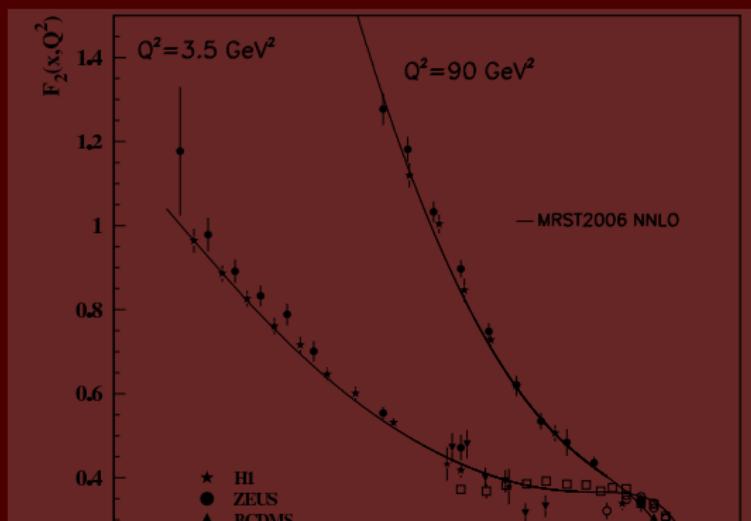
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Consequence: Regge behavior of structure functions

$$f(x) = \frac{\pi^2}{2} \mu^2 \theta(1-x) \int dm^2 \rho_s(m^2) I_{n-1} \frac{x(1-x)^2}{[xm^2 + (1-x)\mu^2]^2} = f_V(x) + f_R(x)$$

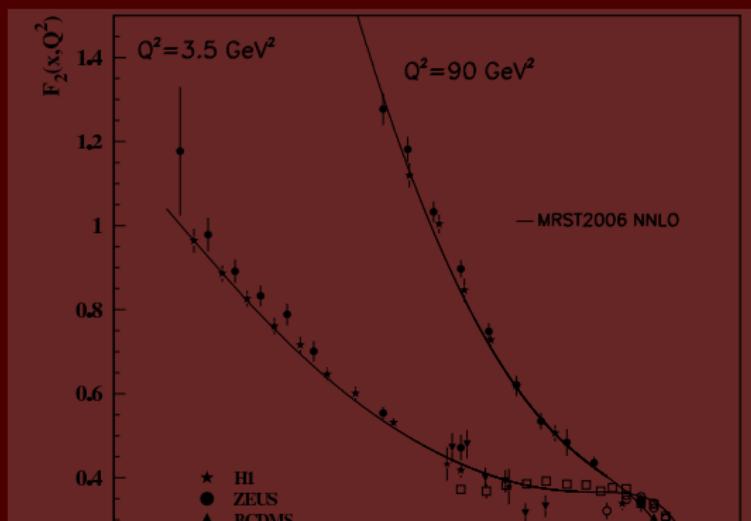
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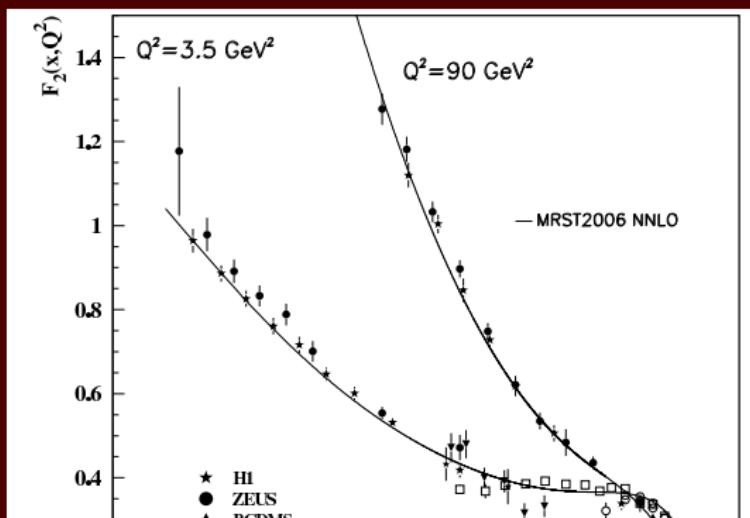
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GPD's and Parton-nucleon amplitude

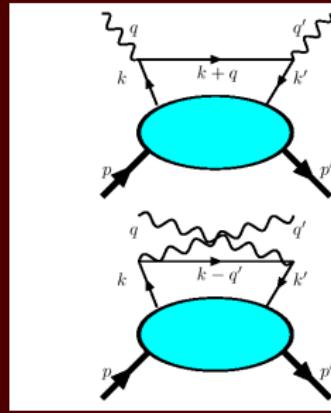
$$H(x, \xi, t) = p^+ \int \frac{d^4 k}{(2\pi)^4} \delta(xp^+ - k^+) A + \dots$$



Consequence: Regge divergence at break-points

$$H(x \sim -\xi) \propto \frac{1}{(x + \xi)^\alpha}$$

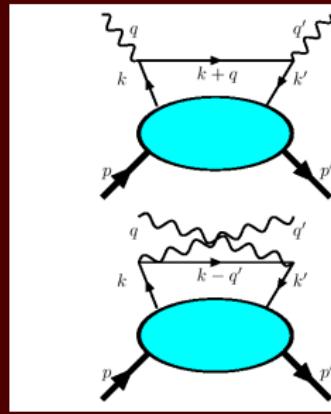
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Consequence: Breakdown of collinear factorization

$$T_1(\xi, t) = - \int_{-1}^1 dx H(x, \xi, t) \left[\frac{1}{x + \xi - i\epsilon} + \frac{1}{x - \xi + i\epsilon} \right] \rightarrow \infty$$

Loophole in factorization theorems:

They ASSUME that the parton-nucleon amplitude vanishes at large s



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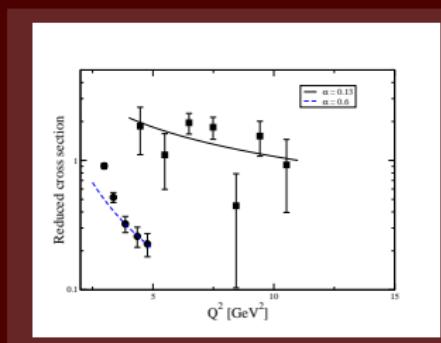
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Consequence: Non-scaling of exclusive amplitudes

$$T^{\mu\nu} = -\delta_{\lambda'\lambda} e_q^2 [n^\mu \tilde{p}^\nu + n^\nu \tilde{p}^\mu - g^{\mu\nu}(n \cdot \tilde{p})] \\ \left[\left(\frac{Q^2}{x_B \mu^2} \right)^{\alpha_s} F_s(x_B) + \left(\frac{Q^2}{x_B \mu^2} \right)^{\alpha_u} F_u(x_B) \right]$$

Meson electroproduction does not seem to scale well



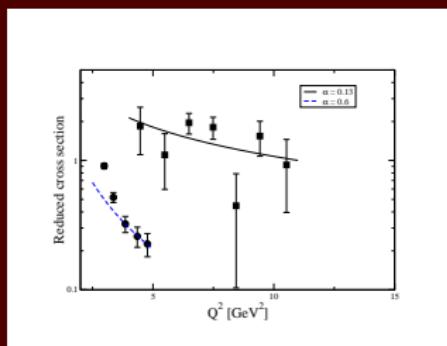
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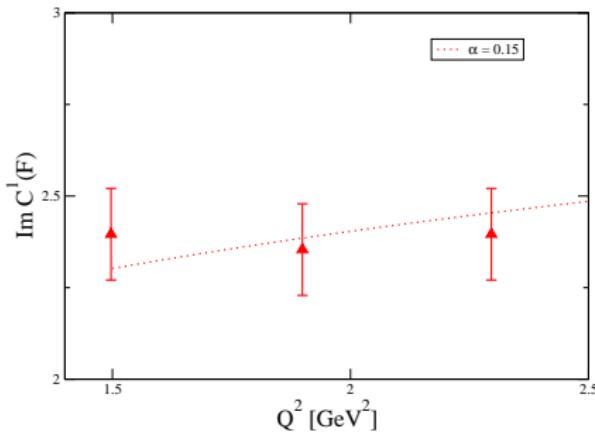
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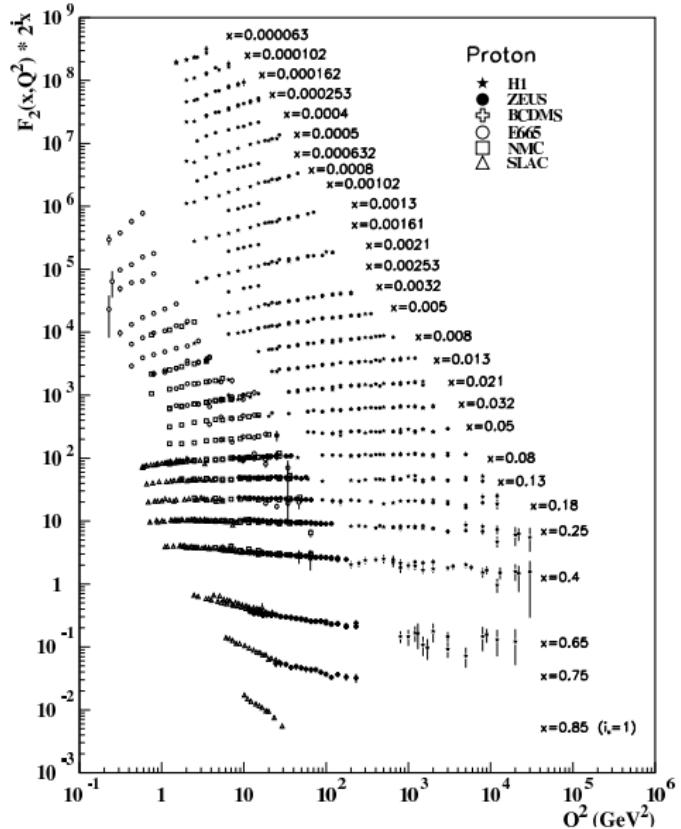
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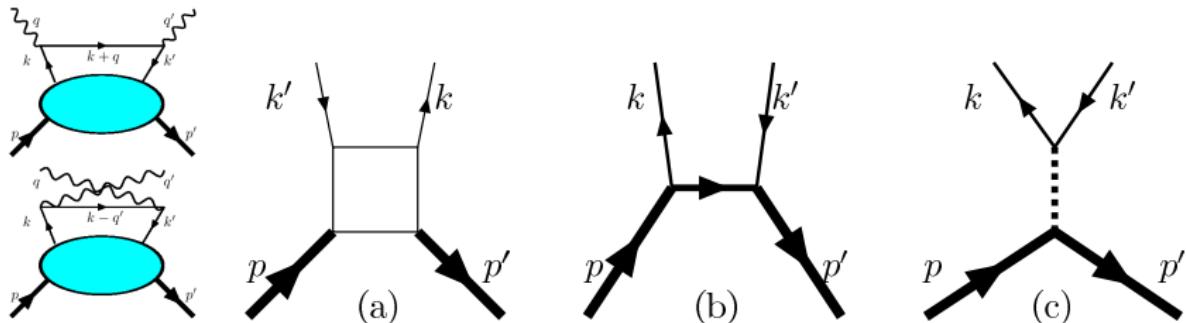
Consequence: Good-bye positivity

$$\left| \sum_{k=1}^2 b_\lambda^k \int \frac{dy^-}{2\pi} e^{iy^- x_k P^+} \Psi_\alpha(y^-) |P_k, \lambda\rangle \right|^2 \geq 0$$

$$|H(x, \zeta, t)| \leq \sqrt{f(x)f\left(\frac{x-\zeta}{1-\zeta}\right) \left(\frac{(1-\zeta/2)^2}{(1-\zeta)(1-t_0/t)} \right)}$$

P. Pobylitsa, PRD65, 077504

Not well defined with continuum quark-nucleon intermediate states



Consequence: GPD's cannot be extracted at low $-t$

- Exclusive data requires process-dependent Regge amplitudes
- Reggeons recede at high $-t$
- GPD's accessible for kinematics $M_N^2 < -t \ll Q^2$



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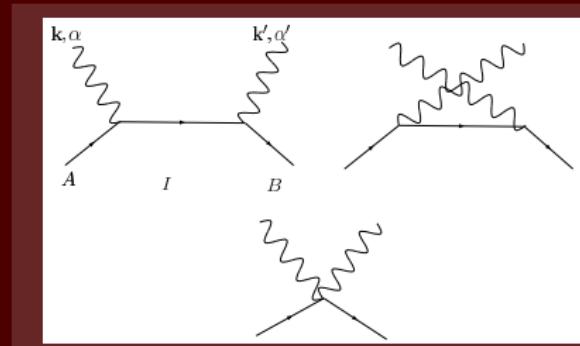
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$J = 0$ Fixed pole: constant contribution to Compton Dispersive representation of Compton amplitude

$$T_1(Q^2, \nu, t) = C_\infty(t) + \frac{1}{\pi} \int_{\nu_{th}^2}^{\infty} \frac{d\nu'^2}{\nu'^2 - \nu^2 - i\epsilon} \text{Im } T_1(Q^2, \nu', t)$$

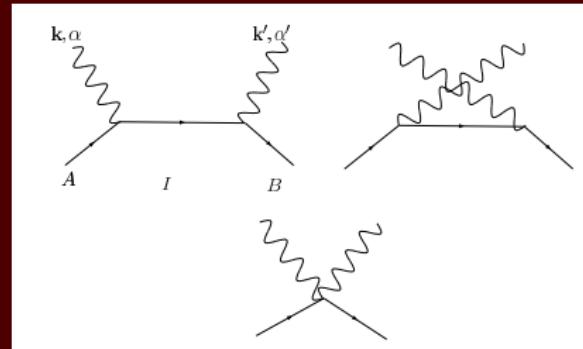
Pointlike seagull coupling
Non-relativistic analog: Kramers-Heisenberg



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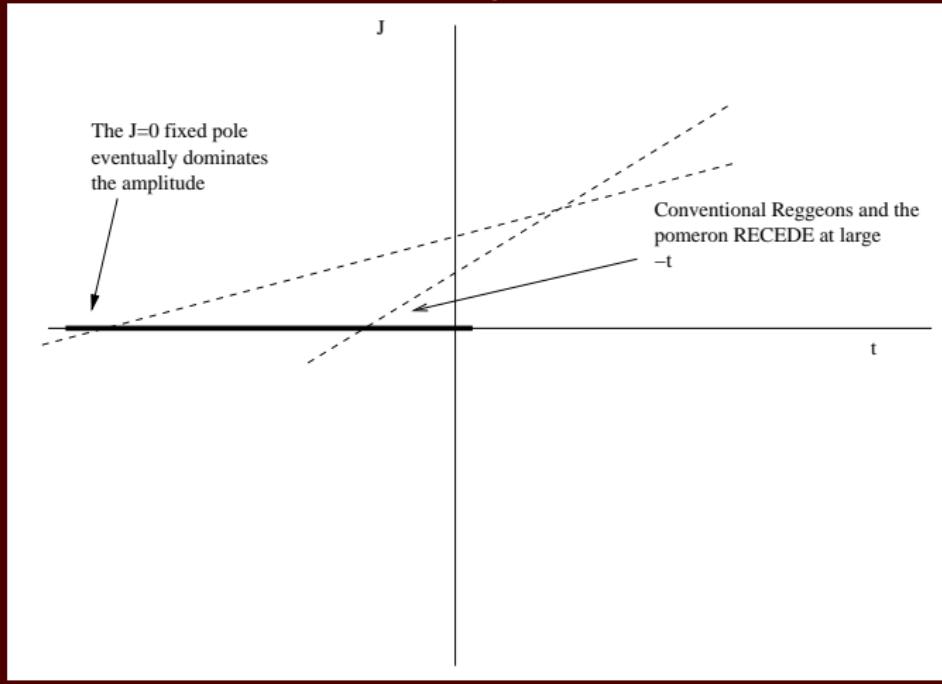
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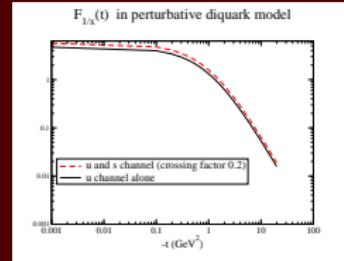
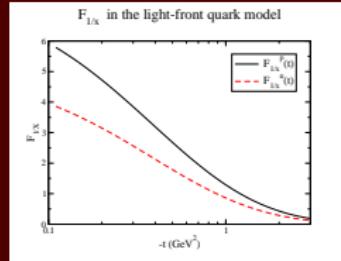
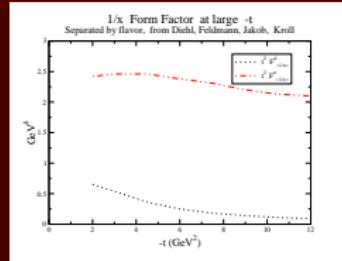


Fixed $J = 0$ pole

Dominates the Compton amplitude for $s \gg -t > M_N^2$
(other Reggeons have receded)



t -dependence: $1/x$ form factor $F_{1/x}(t)$



$$\begin{aligned} C_\infty(t) &= T_1^{J=0}(t) = \\ &-2 \int_{-1}^1 \frac{dx}{x} H_v(x, 0, t) + 2 \sum_{\alpha>0} \frac{\gamma_\alpha(t)}{\alpha(t)} + 2 \sum_{\bar{\alpha}>0} \frac{\bar{\gamma}_{\bar{\alpha}}(t)}{\bar{\alpha}(t)} \end{aligned}$$



Fixed $J = 0$ pole in Real Compton Scattering

Can be expressed in terms of $\text{Im}(\text{Compton})$

$$T_1^{J=0} = T_1(0) - 2 \int_0^1 \frac{dx}{x} f_v(x) + 2 \sum_{\alpha > 0} \frac{\gamma_\alpha}{\alpha}$$

$$f_v(x) \equiv \frac{1}{\pi} \text{Im } T_1(x) - \sum_{\alpha \geq 0} \frac{\gamma_\alpha}{x^\alpha}$$

At large Q^2 , pdf interpretation



Weisberger relation

$$\frac{\delta M_N^2}{\delta m_i^2(\mu)} = \frac{1}{e_i^2} \int_0^1 \frac{dx}{x} [f_{v,i}(x)_\mu + \bar{f}_{v,i}(x)_\mu]$$

The valence part of the $1/x$ moment of pdf's appears in the dependence of the nucleon mass with the quark mass (W. Weisberger, PRD 1972)



Forward limit of GPD

- Often quoted:

$$\lim_{t \rightarrow 0} H(x, 0, t) = f(x)$$

- With Regge subtraction:

$$\lim_{t \rightarrow 0} H(x, 0, t) = f(x) + cx\delta(x)$$

- Additional term not visible in DIS $\int dx x\delta(x) = 0$
- Experimental access:
extrapolate $1/x$ form factor to $t = 0$



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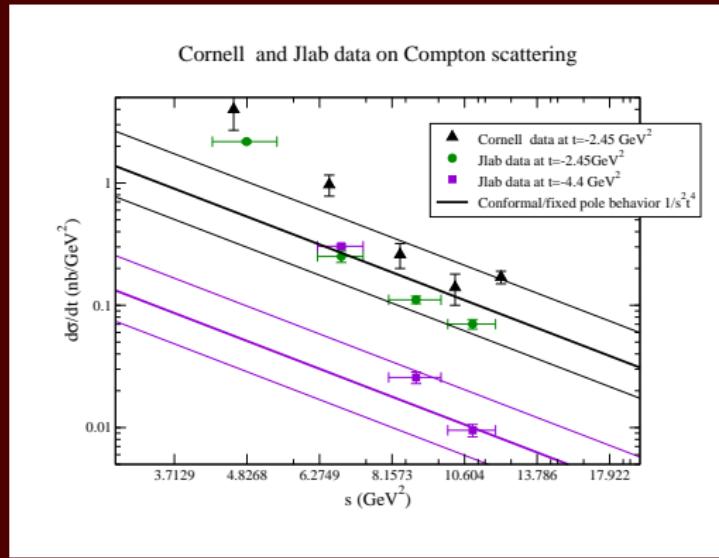
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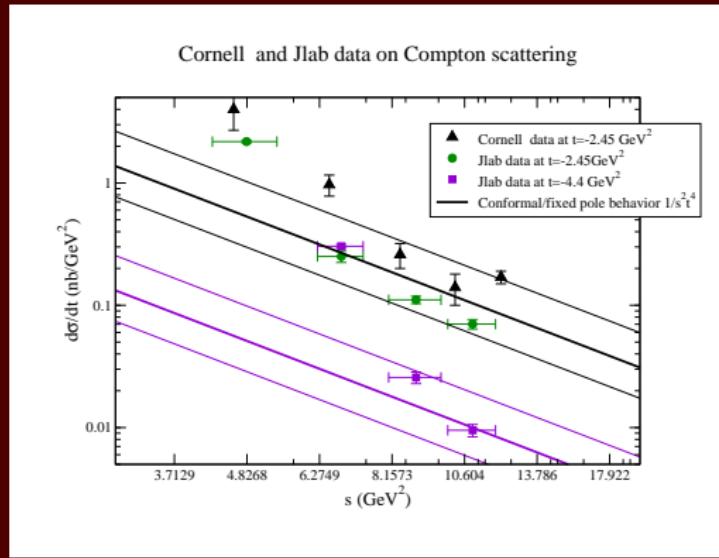
Marginal evidence in Real Compton Scattering



Kinematics for fixed pole: $s \gg Q^2 \gg -t > M_N^2$
Task for Jlab@12GeV, e-RHIC, LHeC...



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Breakdown of collinear factorization in DVCS

- Quark-Nucleon scattering amplitude should show Regge-behavior $s^{\alpha(t)}, u^{\alpha(t)}$.
- GPD's then diverge at breakpoints
 $H(x \rightarrow \xi, \xi, t) \rightarrow (x - \xi)^{-\alpha(t)}$
- Loophole in DVCS factorization theorem!

$$\int_{-1}^1 dx \left[\frac{1}{x + \xi - i\epsilon} + \frac{1}{x - \xi + i\epsilon} \right] H(x, \xi, t) \rightarrow \infty$$

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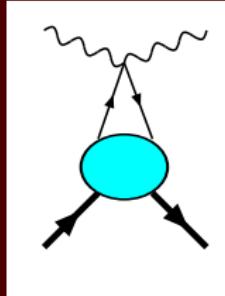
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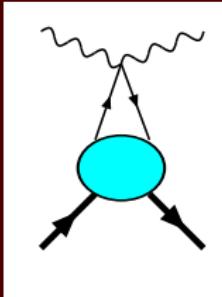
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Szczepaniak, Lonergan, Llanes-Estrada, arXiv:0707.1239 (APB)

Brodsky, Llanes-Estrada, Szczepaniak, arXiv:0812.0395 (PRD)



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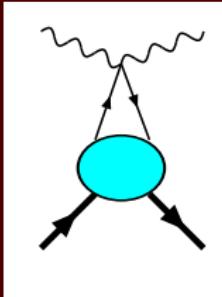
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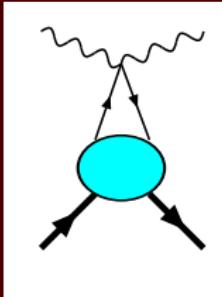
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$J = 0$ fixed pole in DVCS



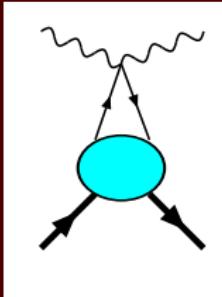
- $\gamma\gamma$ seagull coupling dominant for $s \gg -t > M_N^2$
- Real, s and Q^2 -independent contribution to DVCS
- t -dependence at large $-t$ accepts GPD interpretation
 $F_{1/x}(t) = \int_{-1}^1 \frac{dx}{x} H(x, 0, t)$
- Kinematics accessible at upgraded Jlab, LHeC...
- Extrapolation of data to $t = 0$: Weisberger's
$$\frac{\delta M_N^2}{\delta m_i^2(\mu)} = \frac{1}{e_i^2} \int_0^1 \frac{dx}{x} [f_{v,i}(x)_\mu + \bar{f}_{v,i}(x)_\mu]$$

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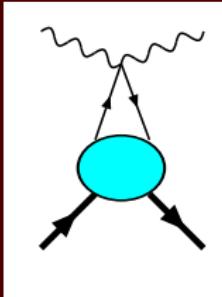
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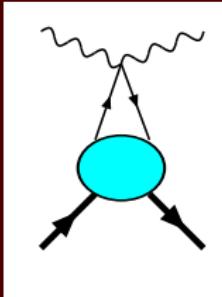
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