Generalized Parton Distributions and ColorTransparency Phenomena

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Motivation

1. Generalized Parton Distributions (GPDs) provide a theoretical tool for studying the (deeply inelastic) spatial structure of hadrons.

2. Color Transparency and Nuclear Filtering can provide measurements of the spatial extension of different hadronic components.

3. The idea is: Use these two tools in combination $\Rightarrow$ GPDs + CT bring in a whole new dimension in studies at hadronic structure!

However ...

...

1. GPDs are presently substantially unmeasured.

2. Parametrizations purporting to reproduce the spatial structure of hadrons are largely unconstrained.

3. Color Transparency phenomena are hard to disentangle experimentally at present faciltities.

An important goal for the future EIC:
<u>nail down GPDs</u> and <u>nail down CT</u>, simultaneously!

Summary of current findings on GPDs

$\Rightarrow$ First proposed $\approx$ 1997 (*Radyushkin, Ji*)

$\Rightarrow$ Dedicated experiments $\approx$ 2000: HERMES and Jlab measure GPDs through DVCS

$\Rightarrow$ Parametrizations are built with constraints given by:

$$
\begin{aligned}
F_1(\Delta^2) &= \int dx \sum_q e_q H_q(x, \xi, -\Delta^2 \equiv t) \\
q(x) &= H_q(x, 0, 0)
\end{aligned}
$$

$\Rightarrow$ Experiments disentangle DVCS from BH and confirm the presence of Leading Twist type asymmetries (2002).

- *Comparison with theory is a slow process*

Impact parameter space interpretation

Burkardt, Diehl, Belitsky, Ji, and Yuan (2003)

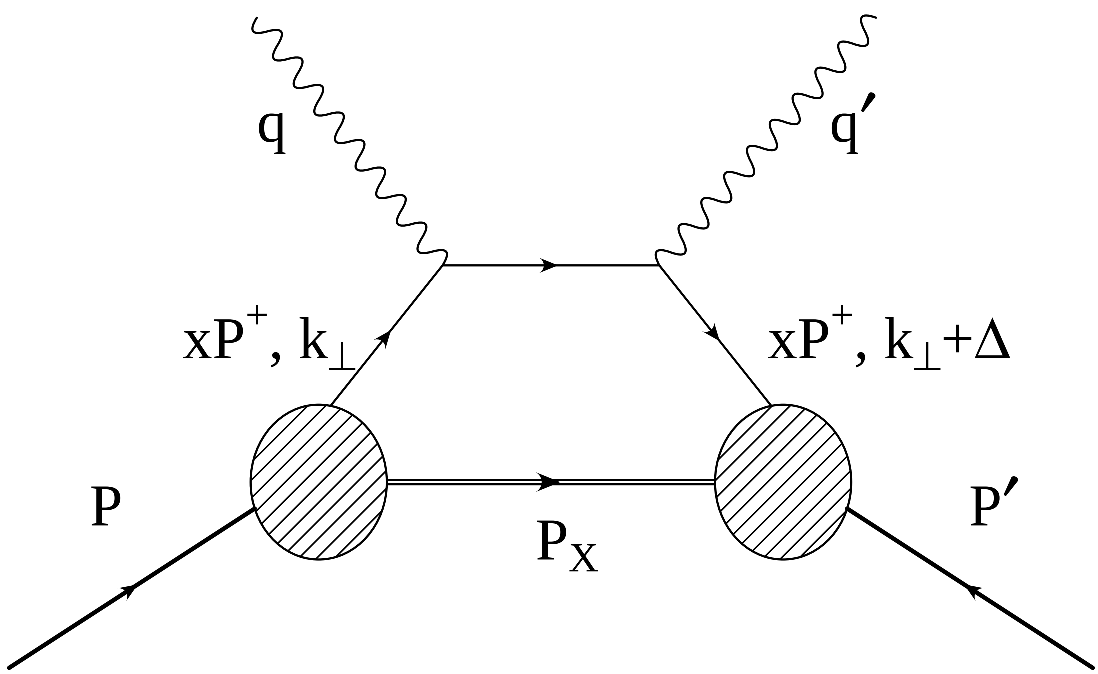
$\Rightarrow$ Connect GPDs to Impact Parameter space dependent PDFs (IPPDFs)
Soper '77

$$\frac{dn_q}{dx d\mathbf{b}} \equiv q(x, \mathbf{b})$$

LC variables:

- $x^\mu \equiv (x^o; \mathbf{x} \equiv \mathbf{b}, x^3) \rightarrow$ space 4-vector
- $x^+ = 1/\sqrt{2}(x^0 + x^3) \rightarrow$ time
- $P^+ = \sum p_i^+ \rightarrow$ system's mass
- $x_i = p_i^+ / P^+ \rightarrow$ Feynman x
- $\mathbf{R} = \sum x_i^+ \mathbf{b}_i \rightarrow$ center of mass
- $P^+ \mathbf{R} \rightarrow$ generator of galilean boosts.

$$q(x, \mathbf{b}) = \int \frac{d^2 \mathbf{\Delta}}{(2\pi)^2} e^{-i \mathbf{b} \cdot \mathbf{\Delta}} H_q(x, 0, -\mathbf{\Delta}^2)$$


q
q′
xP+, k⊥
xP+, k⊥+Δ
P
P′
PX

• Since $q(x, \mathbf{b})$ satisfies positivity constraints and it can be interpreted as a probability distribution, $H_q(x, 0, -\mathbf{\Delta}^2)$ is also a probability distribution.

What is the *radius* of a hadronic configuration?

In a two component model:

Transverse interparton separation (squared)
Soper '77

$$\langle y^2 \rangle = \frac{\langle b^2 \rangle}{(1-x)^2}$$

Radius (squared):

$$MAX\left\{ \langle b^2 \rangle, \left(\frac{x}{1-x} \right)^2 \langle b^2 \rangle \right\}$$

Summary of current findings on CT

$\Rightarrow$ First proposed $\approx$ 1988 (*Brodsky, Mueller*)

$\Rightarrow$ A number of dedicated experiments since then
($pA \to p'p(A-1)$, *Carroll et al., 1988*;
$eA \to e'p(A-1)$, *Makins et al., 1994, O'Neill et al., 1995*; $\gamma^* A \to \rho A$ *HERMES, 2002*;
$\gamma A \to \pi^+ n(A-1)$, *Jlab, 2002* ...)

• *No systematics, no marked trend ... however, none of the experiments does rule out <u>small size configurations</u>.*

Whether or not a pQCD description of hadrons holds at the Q^2 values presently available, or at reach at future experimental programs, it has now become imperative to investigate the basic question of the existence and observability of small size hadronic configurations.

Model

with S.K. Taneja at U.Va., hep-ph/0403...

Consider a **two component** (quark-diquark) picture for the lowest Fock components of the proton.

Assumptions:

- Leading Twist $\Rightarrow$ Relativistic Impulse Approximation: final states are the scattered quark with 4-momentum $k' = k+q$, and diquark with 4-momentum P_X.

- Kinematics $\Rightarrow$ the struck quark is off-shell: $k^2 \neq m^2$, the diquark is on-shell with mass $P_X^2 = \mathbf{M_X}^2$.

- Dynamics $\Rightarrow$ introduce quark-diquark-nucleon vertex functions.

LC function: $\Phi(x, \mathbf{k}) = \dfrac{\mathcal{M}(k^2, P_X^2)}{D(x, \mathbf{k})}$

$$\begin{cases} D(x, \mathbf{k}) = M_X^2\, x - \dfrac{\mathbf{k}^2}{1-x} \\ \mathcal{M} = g^2 \dfrac{k^2 - m^2}{k^2 - \mathbf{\Lambda}^2} \end{cases}$$

DEFINITIONS IN TERMS OF LC W.F.:

$$\boxed{H(x,0,-\mathbf{\Delta}^2) = \int d^2\mathbf{k}\,\Phi^*(x,\mathbf{k})\Phi(x,\mathbf{k}+(1-x)\mathbf{\Delta})}$$

$$\nu W_2(x) = x\int d^2\mathbf{k}\ \mid \Phi(x,\mathbf{k}) \mid^2$$

$$F_1(\Delta^2) = \int d^2\mathbf{k} \int_0^1 dx\,\Phi^*(x,\mathbf{k})\Phi(x,\mathbf{k}+(1-x)\mathbf{\Delta})$$

$$q(x,\mathbf{b}) = \mathcal{F}\left[H(x,\Delta)\right]$$

ROLE OF INTRINSIC $k_\perp$ ($\equiv \mathbf{k}$):

$$f(x,\mathbf{k}) \equiv \mid \Phi(x,\mathbf{k}) \mid^2$$

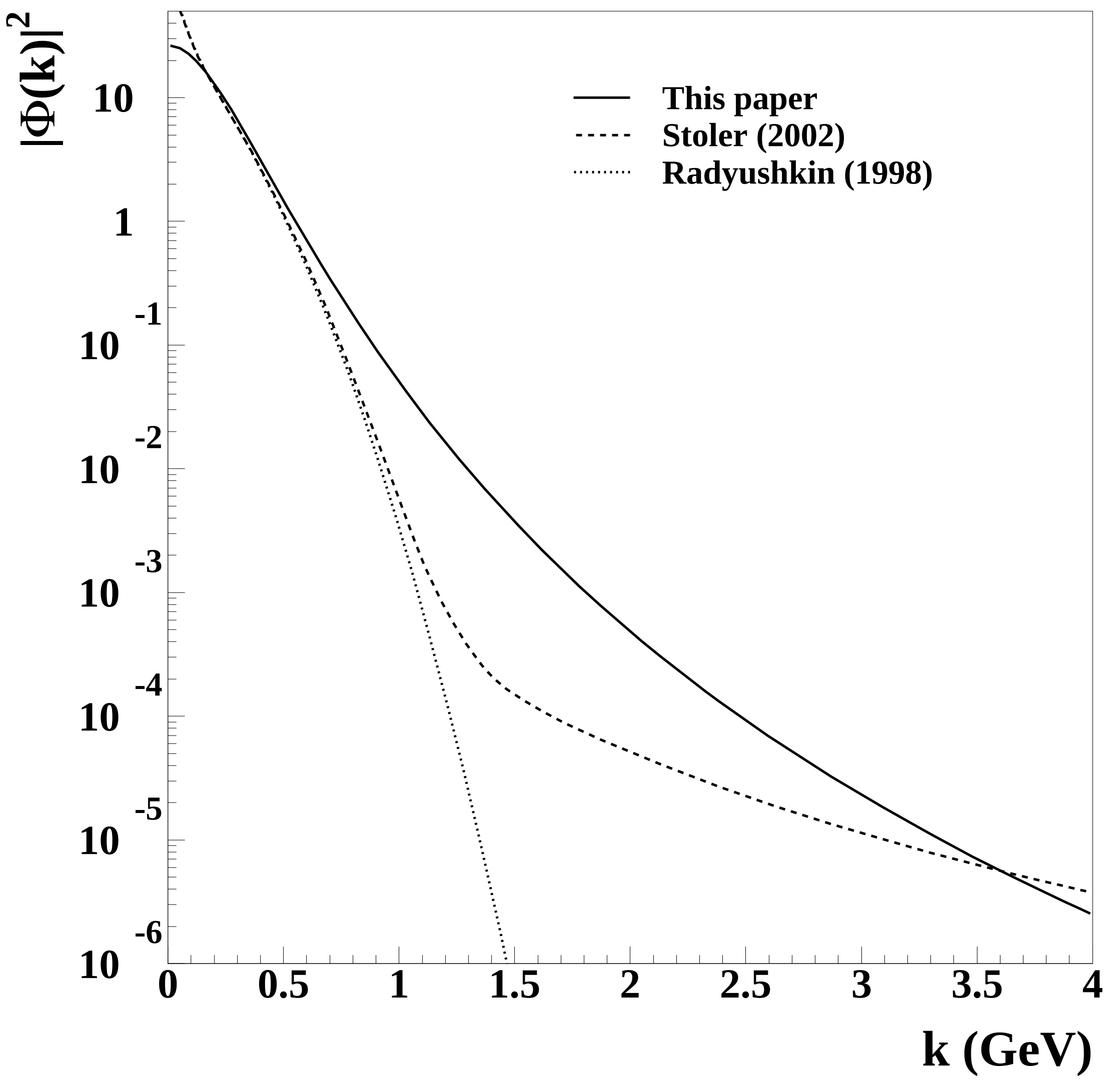
$$f(x,\mathbf{k}) = \int d^2\mathbf{b} \int d^2\mathbf{b}'\, e^{i\mathbf{k}\cdot(\mathbf{b}-\mathbf{b}')}\, q(x,\mathbf{b},\mathbf{b}')$$

intrinsic $k_\perp$ distribution

$$q(x,\mathbf{b},\mathbf{b}') = \Psi^*(x,\mathbf{b}')\Psi(x,\mathbf{b}) \stackrel{\mathbf{b}\to\mathbf{b}'}{\equiv} q(x,\mathbf{b})$$

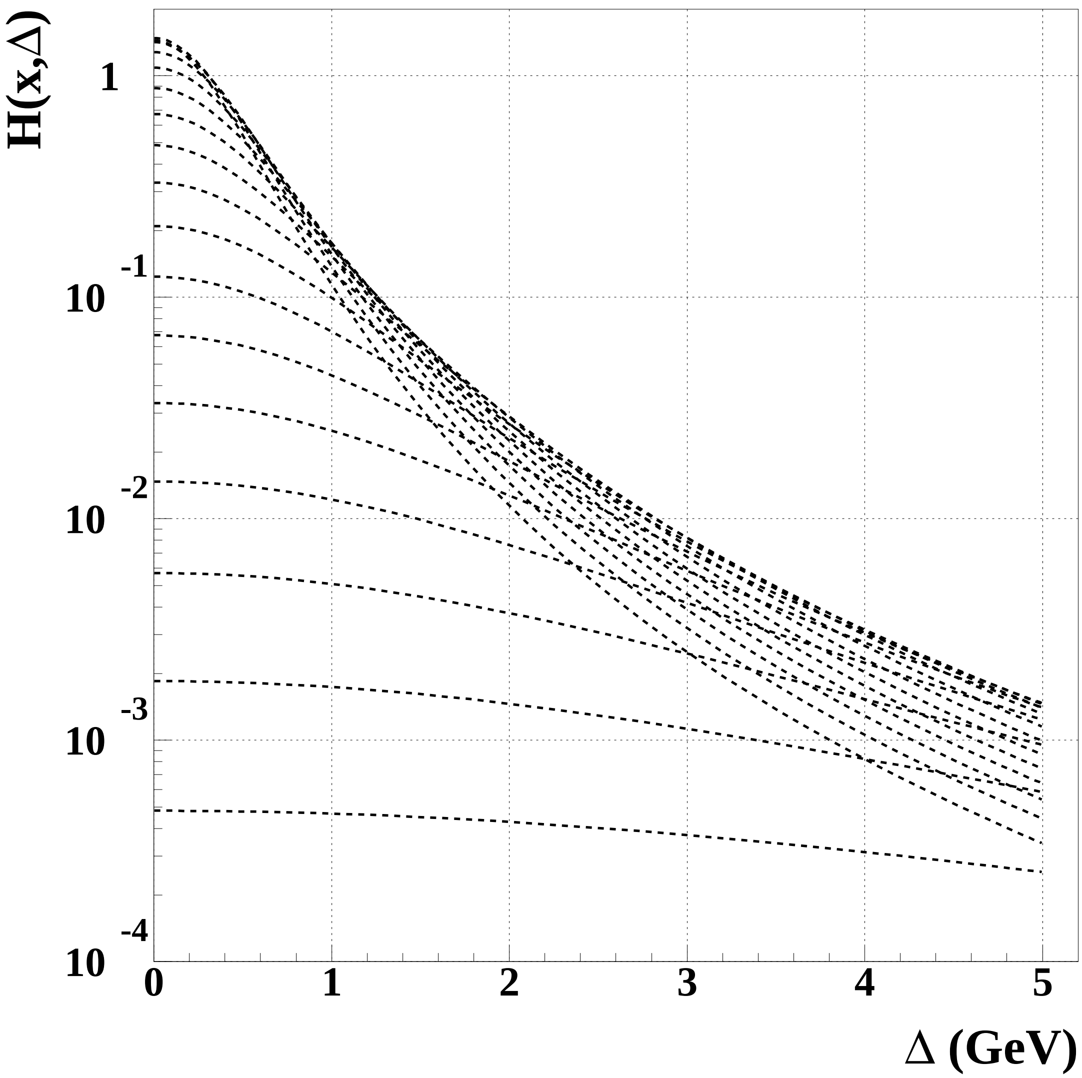
non-diagonal one-body transverse density.

Comparison with existing parametrizations



$$\Phi(\mathbf{k}) = \int dx\, \Phi(x, \mathbf{k})$$

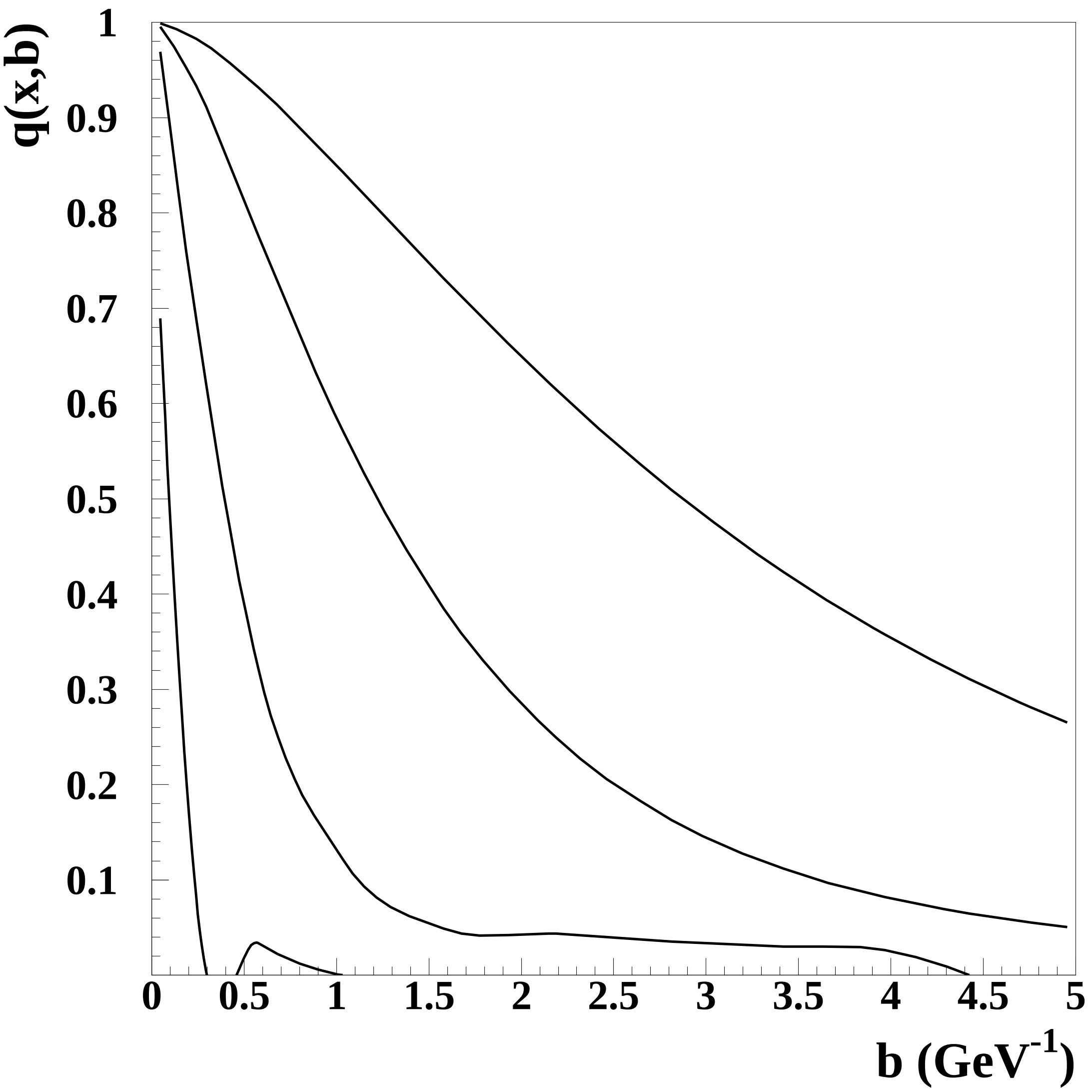
Generalized Parton Distribution



Parametrized as:

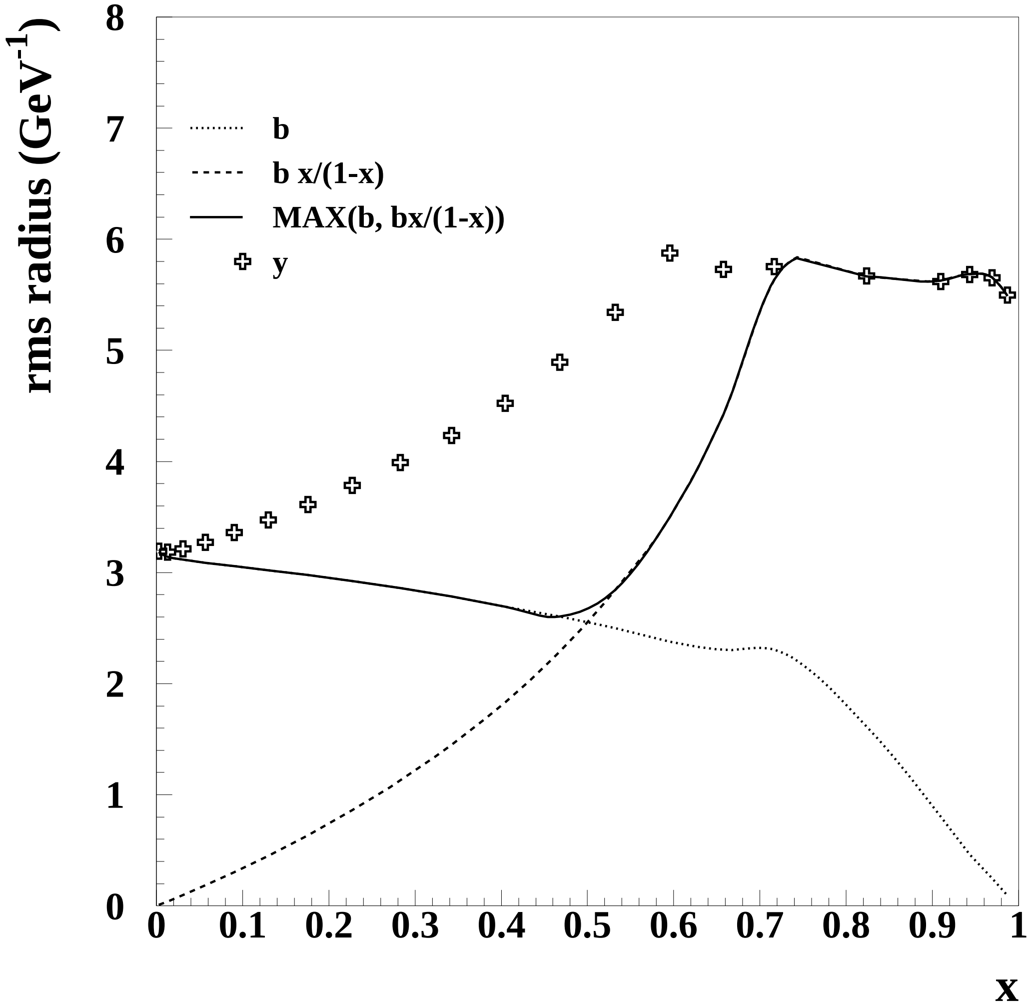
$$H(x, -\mathbf{\Delta}^2) = p_1(x)\frac{1}{p_2(x) + p_3(x)\Delta + p_4(x)\Delta^2}$$

Transverse spatial dependence



$q(x, \mathrm{b}) \rightarrow$ Hankel transform

Radius



$$r_{rms} = MAX\left\{\sqrt{\langle b^2\rangle}, \frac{x}{1-x}\sqrt{\langle b^2\rangle}\right\}$$

Independently from the fine tuning of our result, the radius does not blow up at large x

Discussion:

- In order to describe the form factor, one needs high $k_\perp$ components in the LC wave function.

- These are provided naturally within a two component model.

- High $k_\perp$ components are also responsible for decreasing the hadronic transverse size as x increases.

- This mechanism can be clearly tested by comparing different parametrizations.

- The decrease predicted in $\langle b^2 \rangle$, and consistent with the form factor behavior and measured $\langle k_\perp^2 \rangle$ values, seems to be however not sufficient to guarantee the onset of Color Transparency.

- Main message: Based on a LC description, a range of configurations with varying sizes can be monitored!

About Color Transparency Proper

With this tool in hand – GPDs in terms of IPPDFs – we just have to let our imagination run free.

NUCLEAR AMPLITUDE:

$$\mathcal{A} = \int dz \rho_A(0_\perp, z) \int dx \int d^2b\, e^{-i\mathbf{b}\cdot\boldsymbol{\Delta}} q(x,b)\, f_A(0,b)$$

ATTENUATION FACTOR:

$$f_A(0,b) = e^{-\int dz'\, \sigma[r(b)]\, \rho_A(0,z')}$$

calculated at 0 nuclear impact parameter

Conclusions

- The interplay bewteen $\mathbf{k}_\perp$, x, $\mathbf{b}$ and $\mathbf{\Delta}$ determines the size of hadronic configurations $\Rightarrow$ another important role of GPDs.
- Yet, direct measurements of GPDs are a very slow process.
- Use CT phenomena, specifically Nuclear Filtering to extract information.

Open Questions

- Flavor dependence
- OAM and deformation (role of ξ variable)
- Beyond the nuclear factorized formula:
  - "Passive" role of nucleus: description in terms of both quark and nucleon spectral functions, role of off-shellness ...
  - "Active" role of nucleus: rescattering beyond convolution might yield terms directly proportional to GPDs.