Nuclear effects imitating color transparency

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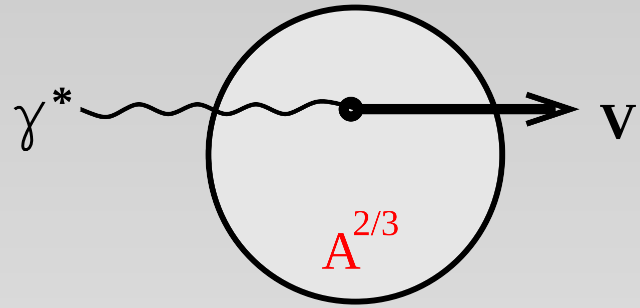
Electroproduction of vector mesons

Classically one might view this process as:



Expected signals of color transparency (CT) would be a nuclear transparency,

$$\boldsymbol{Tr = \frac{\sigma(\gamma^* A \rightarrow V A^*)}{A\sigma(\gamma^* N \rightarrow V N)}},$$

rising as function of either Q^2 at fixed ν, or ν at fixed Q^2.

- The single channel Glauber model is usually believed to predict constant transparency:

Not correct!

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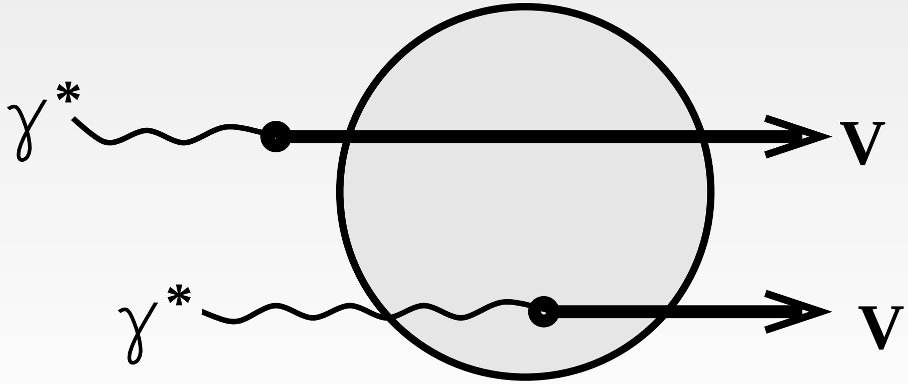
CT or coherence?

Warning: at medium energies one can easily misinterpret coherence time effects as a signal of CT.

VDM/Glauber model: the lifetime (coherence time) of a fluctuation $\gamma^* \to V$ depends on energy ν and virtuality Q^2.

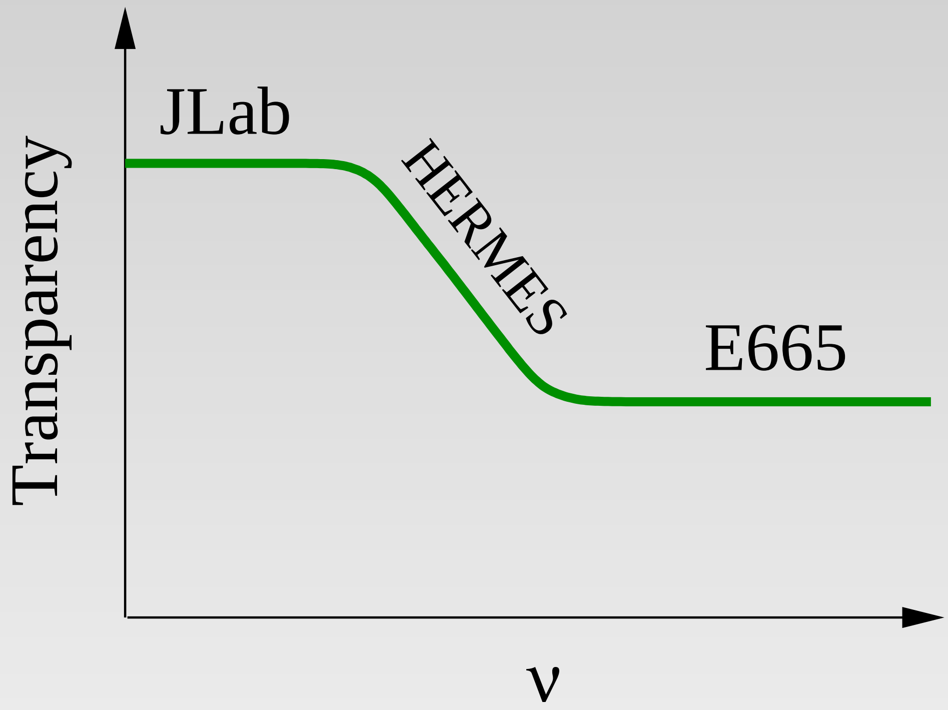
$$t_c = \frac{2\,\nu}{Q^2 + m_V^2} \qquad \left(t_f = \frac{2\,\nu}{{m_V^*}^2 - m_V^2} \right)$$



$t_c >> R_A$ $\quad A^{1/3}$

$t_c << R_A$ $\quad A^{2/3}$

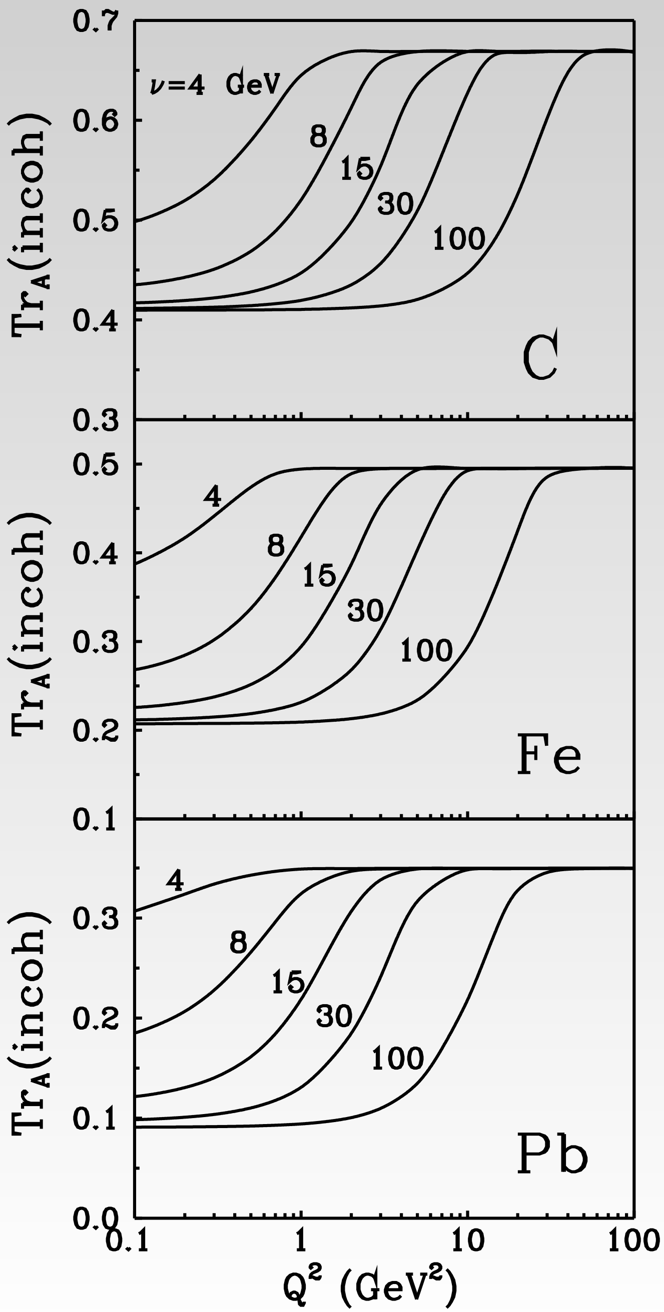
CT or coherence?



Transparency is controlled by the coherence length l_c which rises with energy ν, but shrinks with virtuality Q^2.

In Glauber model transparency may steeply rise with Q^2, imitating CT.

CT or coherence?



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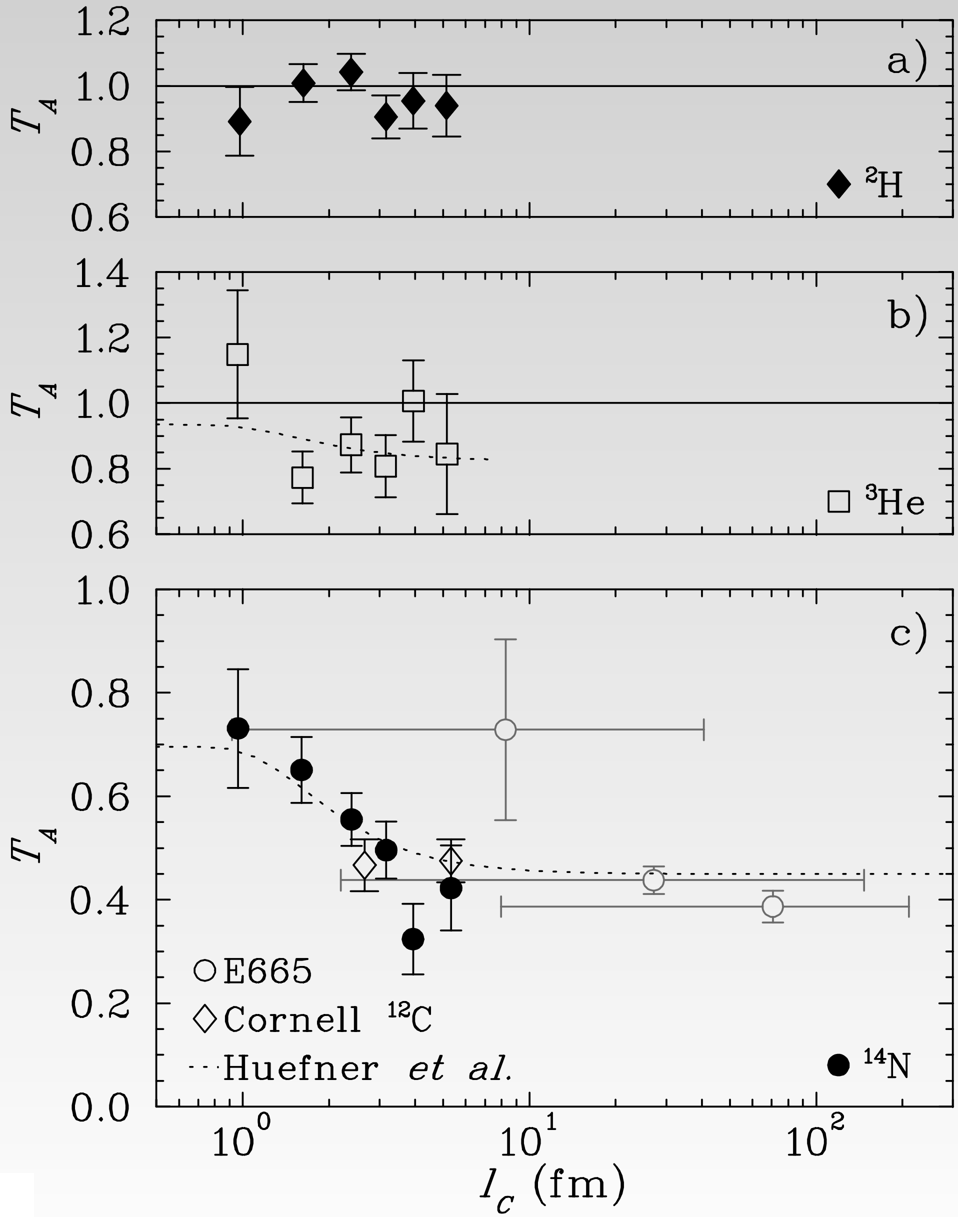
CT or coherence?

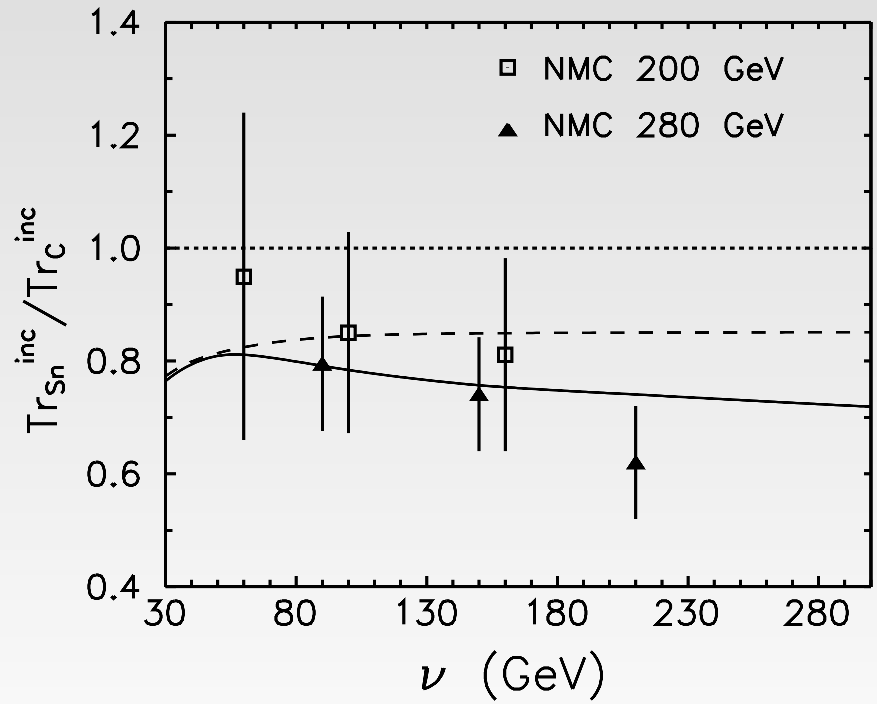


HERMES data

$$eA \to e'\rho A^*$$

NMC data

$$\gamma A \to J/\Psi A^*$$



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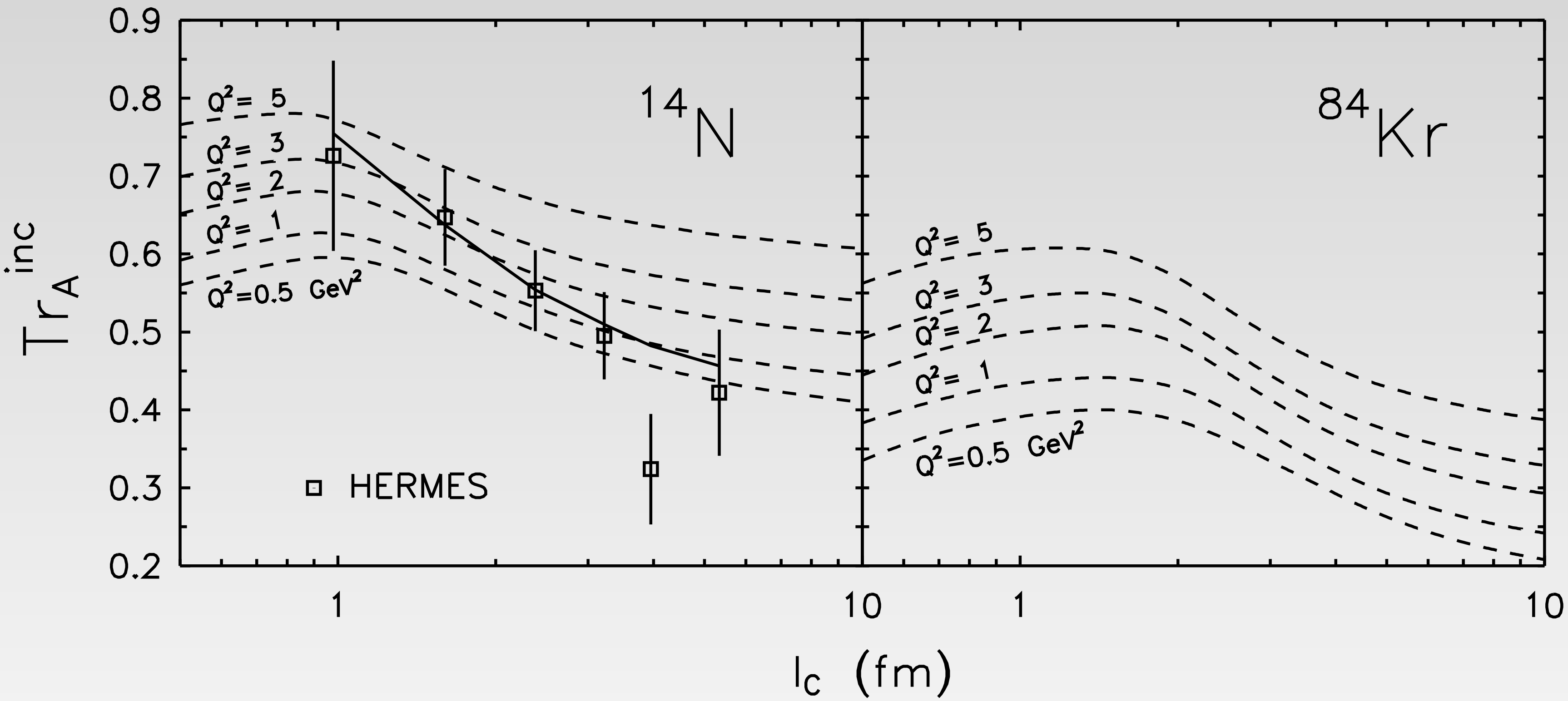
CT or coherence?

The data agree with CT as well:



A global fit to data binned in l_c helps to prove a signal of CT.

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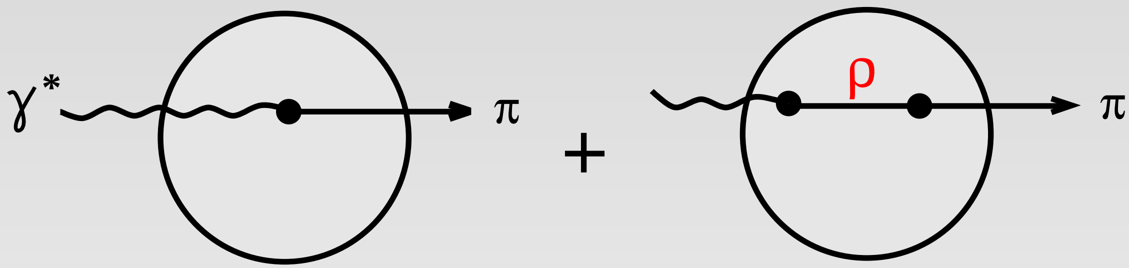
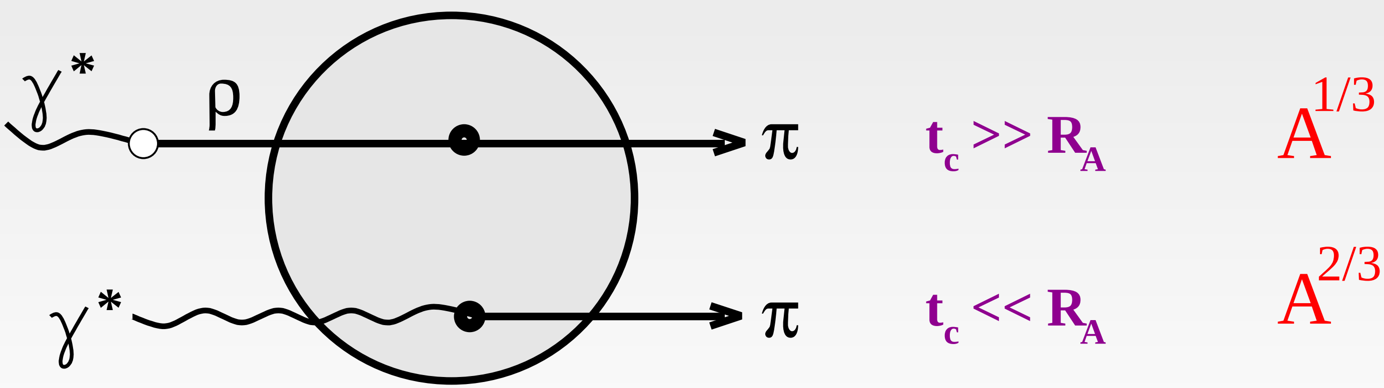
Electroproduction of pions

Similar effects are expected for electroproduction of pions $A(e, e'\pi)A^*$. Transparency in the Glauber model varies with Q^2, energy (even if $\sigma^{\pi N} = const$), and t.

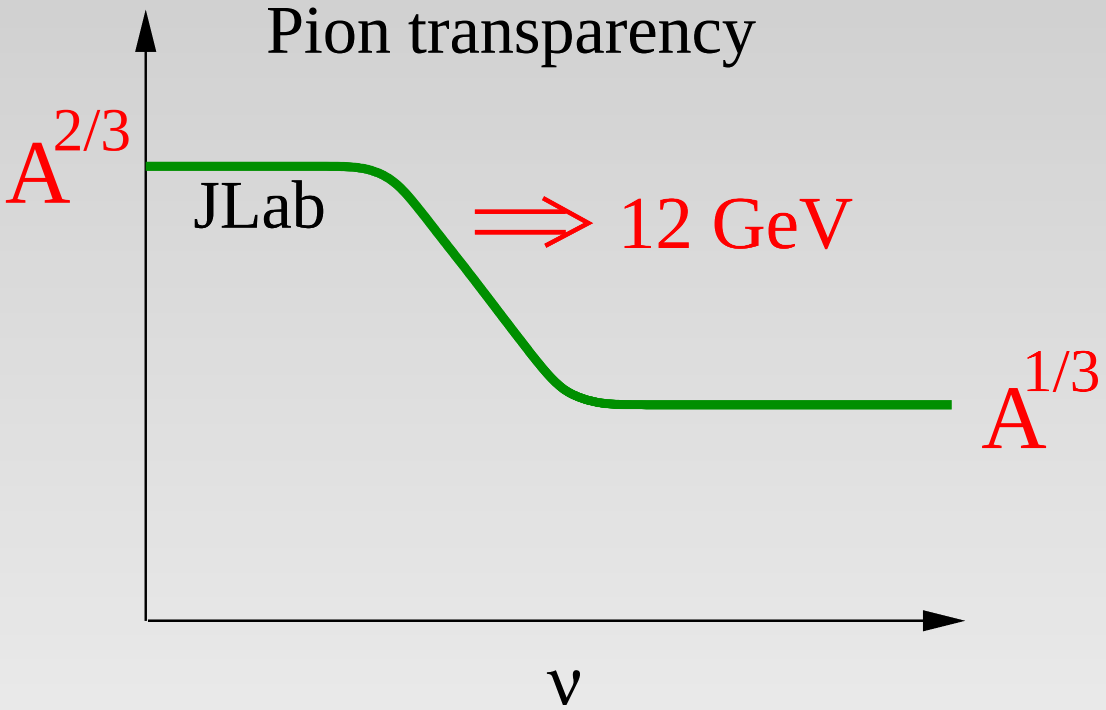


Missed graph

Space−time picture of pion production



Electroproduction of pions



Pion transparency was predicted [Larson, Miller, Strikman] to rise with energy. On the contrary, I expect it to drop down, similar to what already has been observed for vector mesons.

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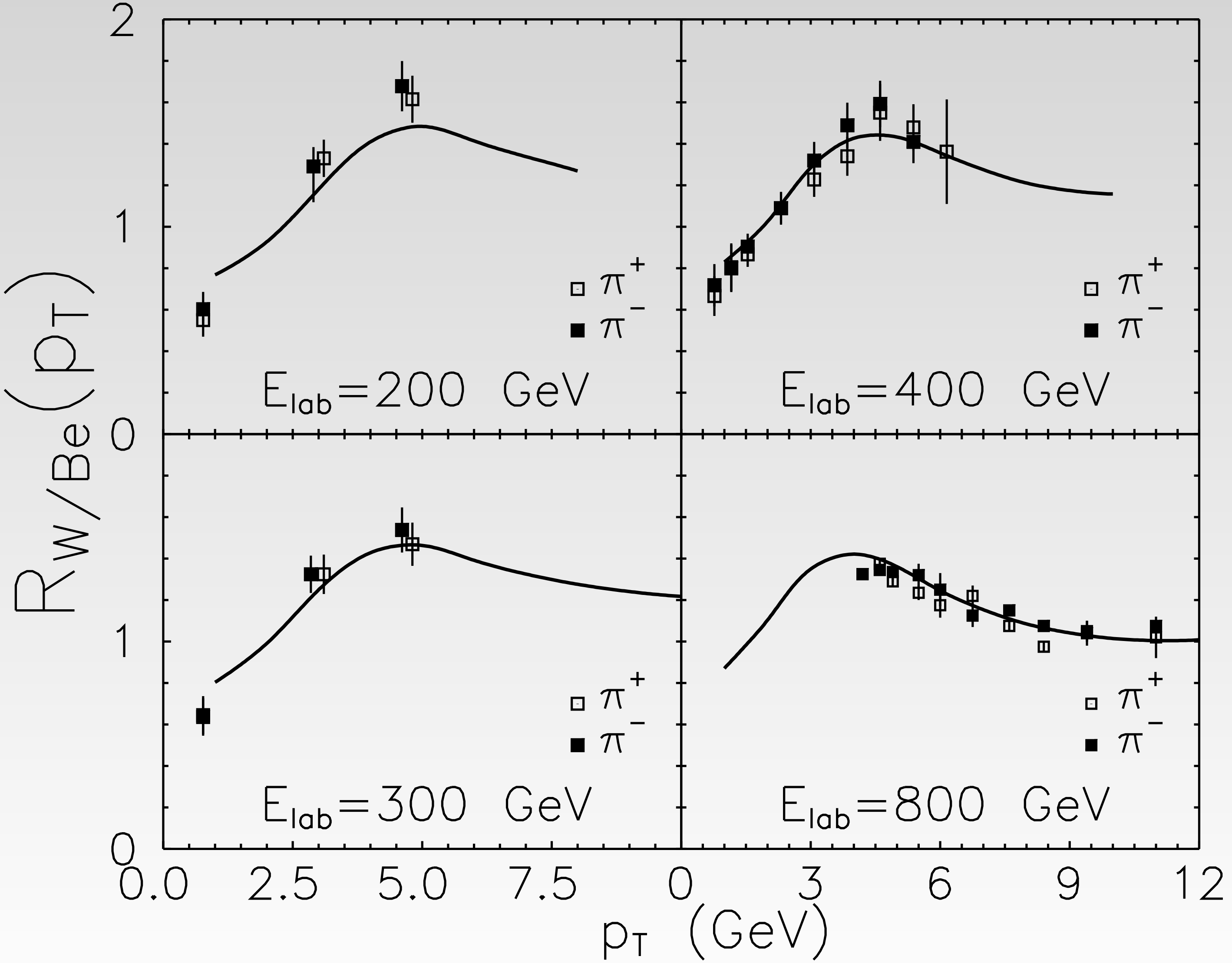
p_T-dependence: Cronin effect

Multiple interactions enhance high-p_T production



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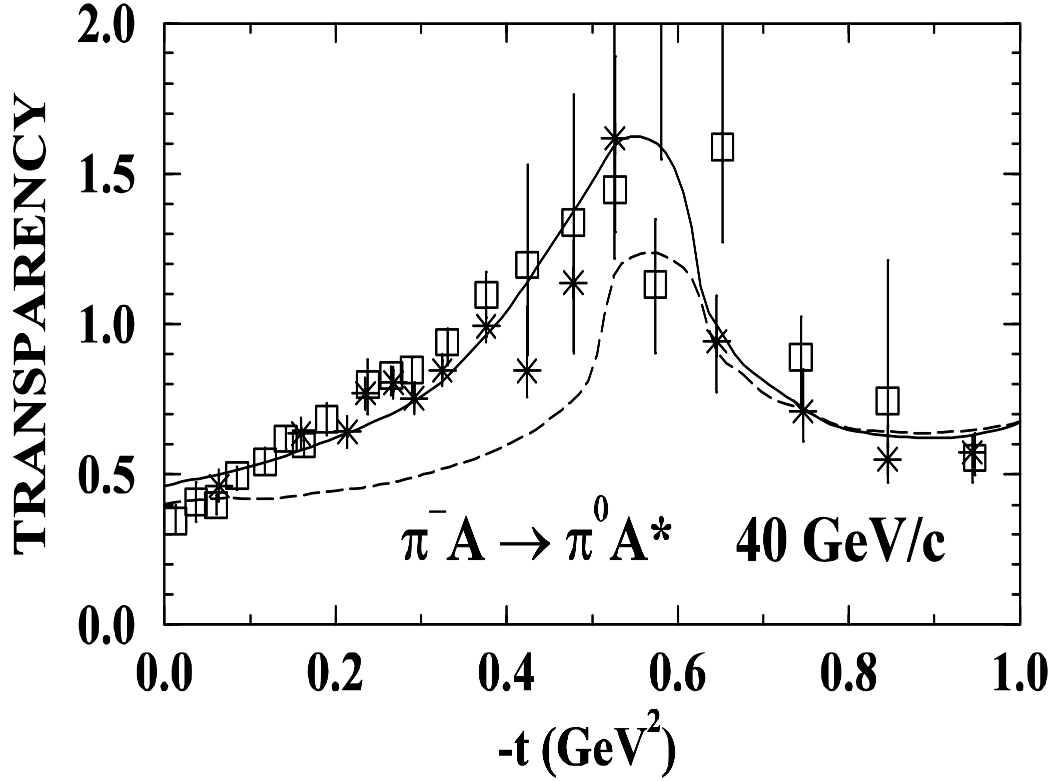

TRANSPARENCY
2.0
1.5
1.0
0.5
0.0
0.0
0.2
0.4
0.6
0.8
1.0
-t (GeV^2)
$\pi^- A \rightarrow \pi^0 A^*$ 40 GeV/c

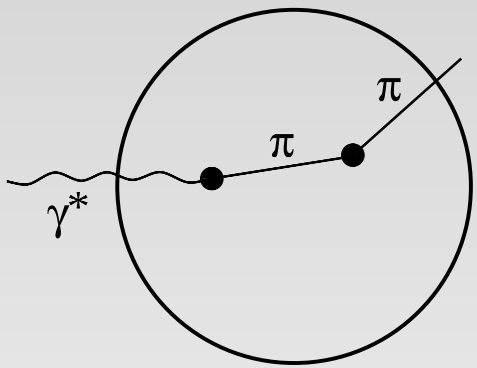
Exclusive electroproduction of pions

$A(e, e'\pi)$ experiment at JLab

Q^2 correlates with t:

Q^2 $(\mathrm{GeV/c})^2$	$-t$ $(\mathrm{GeV/c})^2$
1.10	0.050
2.15	0.158
3.00	0.289
3.91	0.413
4.69	0.527

Cronin effect



Glauber approximation

($l_c \ll R_A$, neglecting interferences),

$$Tr = \int d^2b \int_0^{T_A(b)} dT'_A \, e^{-\sigma_{in}^{\pi N} T'_A}$$

$$\times \left[1 + \frac{1}{2} \sigma_{el}^{\pi N} T'_A \frac{B_{\gamma\pi}}{B_{\gamma\pi} + B_{\pi N}} \exp\left(\frac{B_{\gamma\pi} B_{\pi N}}{B_{\gamma\pi} + B_{piN}} |t| \right) \right]$$

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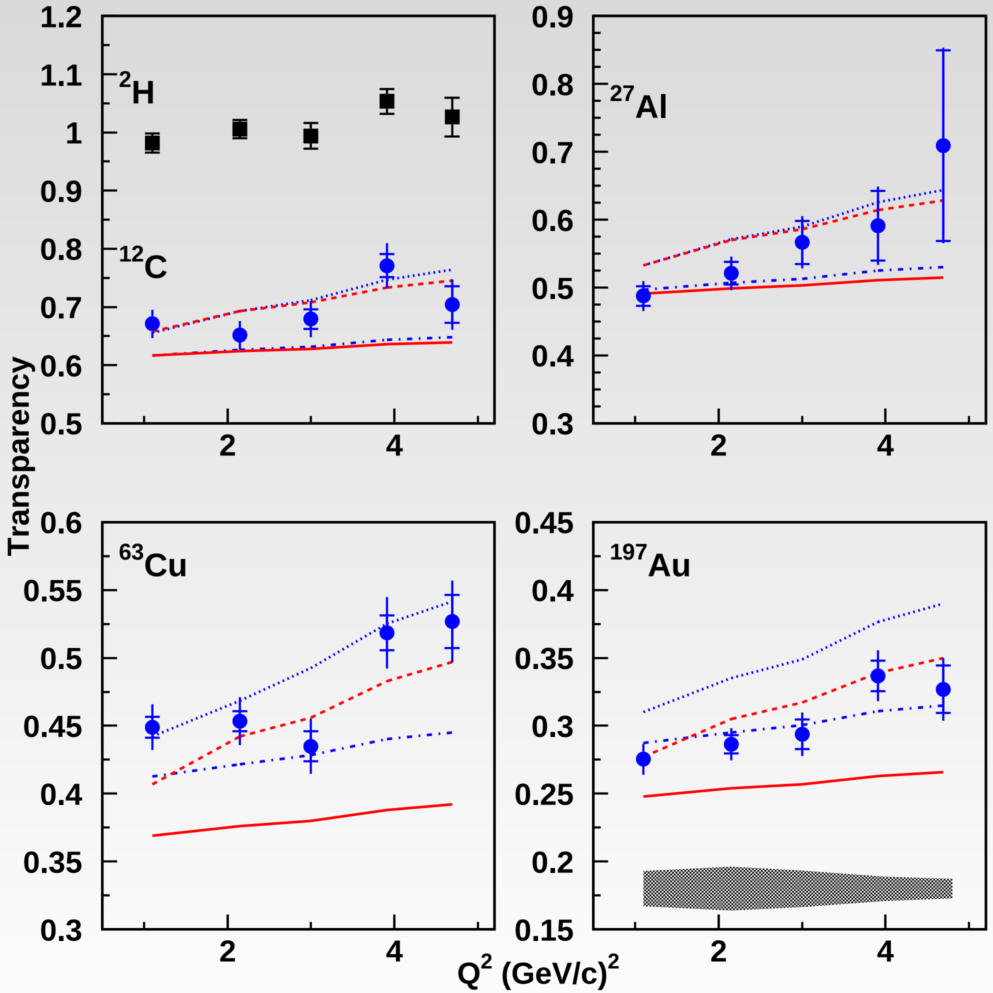
Exclusive electroproduction of pions

With $B_{\gamma\pi} \approx 2\,\mathrm{GeV}^{-2}$, $B_{\pi N} \approx 7\,\mathrm{GeV}^{-2}$, $\sigma_{el}^{\pi N} \approx 7\,\mathrm{mb}$ transparency increases by about 20%, similar to what is observed.



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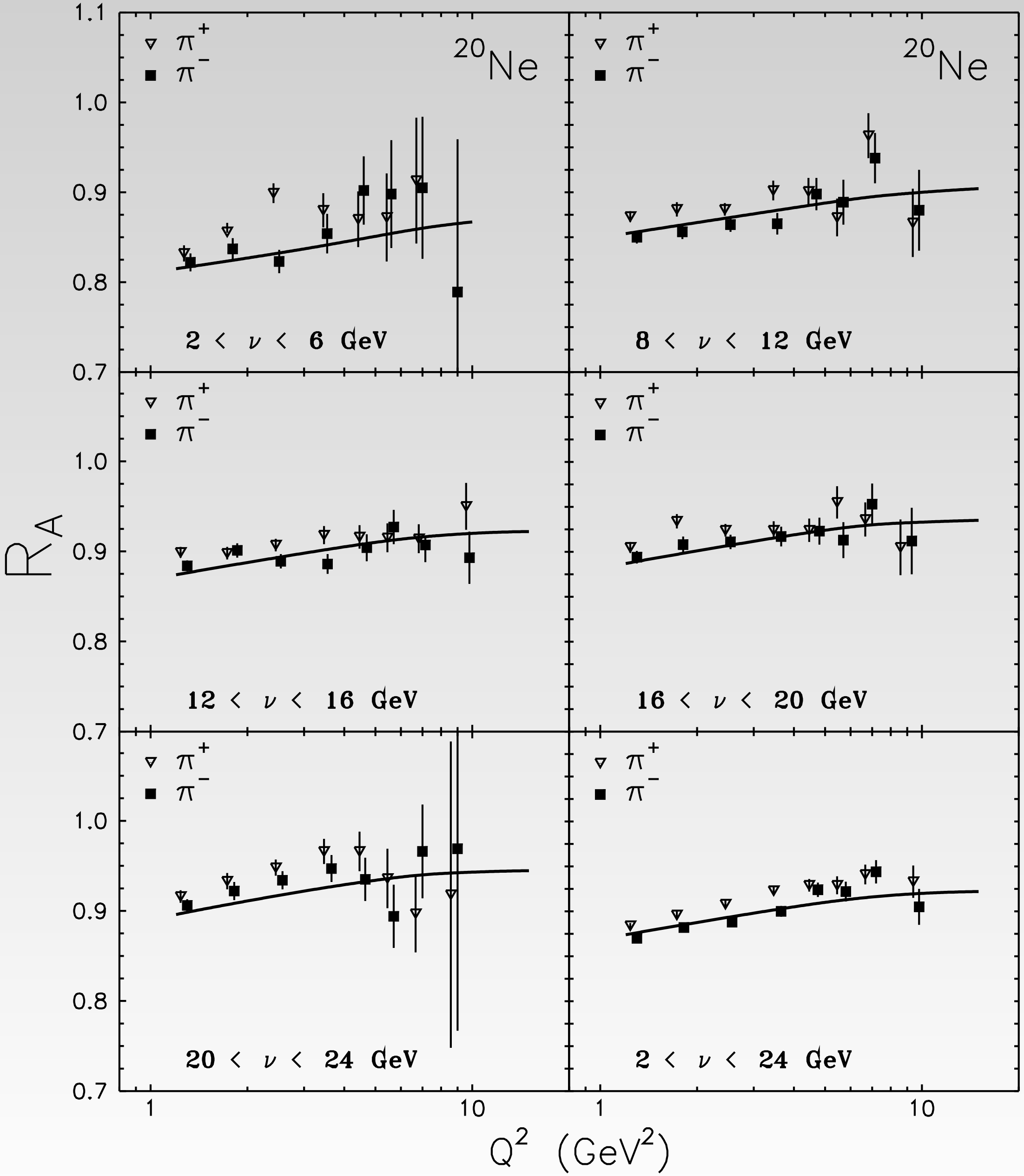
Inclusive electroproduction of pions

Nuclear attenuation of leading pions produced inclusively in DIS is also subject to CT. Transparency should rise with Q^2. [NPA740(2004)211]. Confirmed by data from HERMES.



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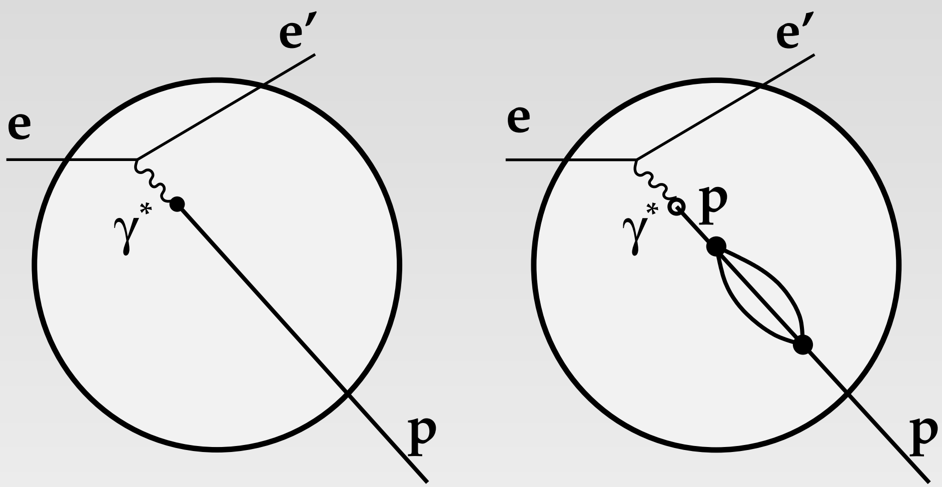
CT vs inelastic shadowing

- Nuclear transparency is known to rise with energy due to inelastic shadowing. [P.V.R. Murthy et al. NPB92(1975)269]

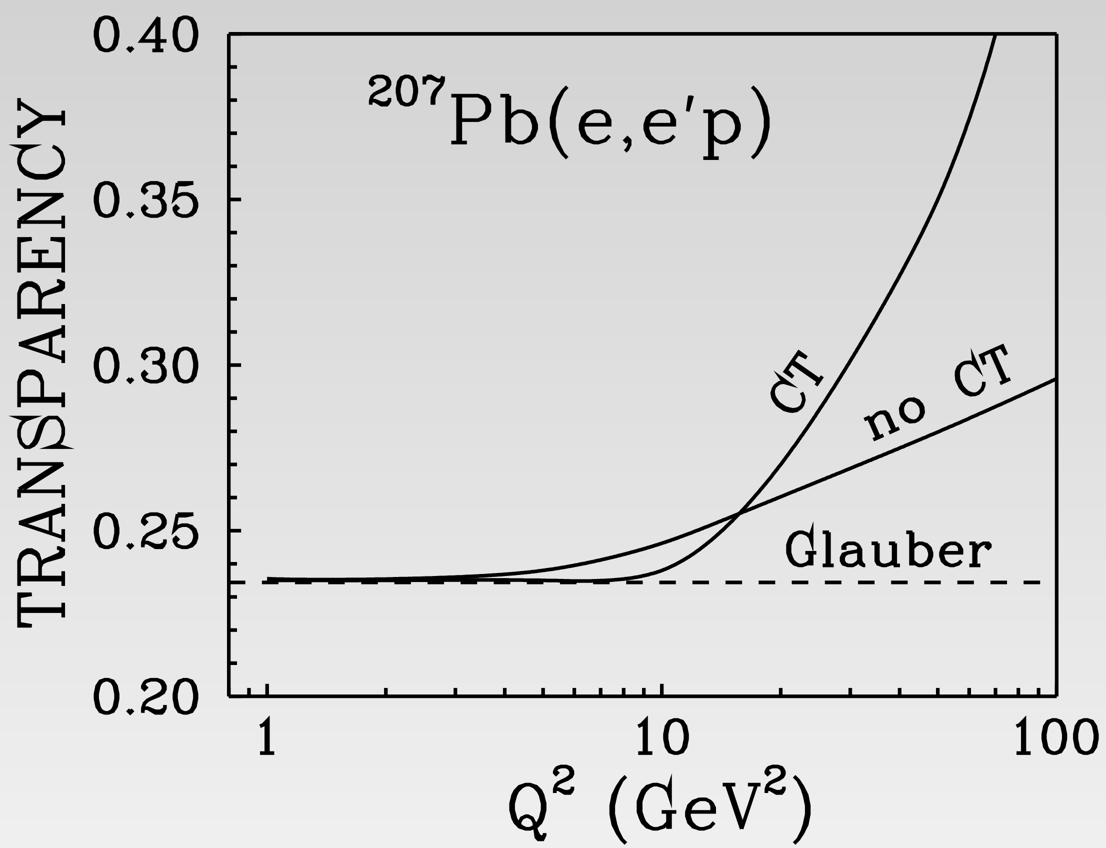


In quasielastic $A(e,e'p)$ the proton energy rises $E_p \approx Q^2/2m_N$. [PLB368(1996)187].

$$Tr(Q^2) \;=\; \int d^2b \int\limits_{-\infty}^{\infty} dz\, \rho_A(b,z) \exp\left[-\sigma_{in}^{NN} \int\limits_{z}^{\infty} dz'\rho_A(b,z')\right.$$

$$\times \;\left[1 + 4\pi \int dM^2 \frac{d\sigma}{dM^2dt}\Big|_{t=0}\, F_A^2(b,z,q_L)\right]^2$$

CT vs inelastic shadowing



One cannot reliably disentangle between CT and the standard inelastic shadowing unless Q^2 is as large as few tens of GeV^2.

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Discussion

- Glauber model is not a probabilistic, but a quantum-mechanical description of multiple interactions. Interferences are important and may cause a strong variation of nuclear transparency as function of kinematic variables. These effects can be easily misinterpreted as a signal of CT.
- The current JLab results for exclusive electroproduction of pions do not say much about CT, and should be analysed differently.
- On the other hand, CT is a rather obvious effect, unless we are going to challenge QCD. A more interesting task would be to study QCD dynamics of production and formation of hadrons. This needs better data and more developed theoretical tools.

BACKUP

Glauber formula for incoherent exclusive production

$\gamma^* + A \to \rho + X$

[J.Hüfner, B.K. & J.Nemchik PLB383(1996)362]

$$Tr_{inc} = \frac{1}{A}\int d^2b \left\{ \int_{-\infty}^{\infty} dz\ \rho_A(b,z)\ e^{-\sigma_{in}^{VN} T_A(b,z)} \right.$$

$$+ \quad \frac{1}{2}\,\frac{\sigma_{tot}^{VN}}{\sigma_{el}^{VN}}\,(\sigma_{in}^{VN} - \sigma_{el}^{VN}) \int_{-\infty}^{\infty} dz_1\ \rho_A(b,z_1) \int_{z_1}^{\infty} dz_2\ \rho_A(b,z_2$$

$$\times \quad \cos\left[q_L(z_2 - z_1)\right]\ e^{-\frac{1}{2}(\sigma_{in}^{VN} - \sigma_{el}^{VN})T_A(b,z_2) - \frac{1}{2}\sigma_{tot}^{VN} T_A(b,z_1)}$$

$$\left. - \quad \frac{\left(\sigma_{tot}^{VN}\right)^2}{4\sigma_{el}^{VN}} \left| \int_{-\infty}^{\infty} dz\ \rho_A(b,z)\ e^{iq_L z}\ e^{-\frac{1}{2}\sigma_{tot}^{VN}\ T_A(b,z)} \right|^2 \right\}$$

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