Integrated Cross Section of J/ψ Production at Low x

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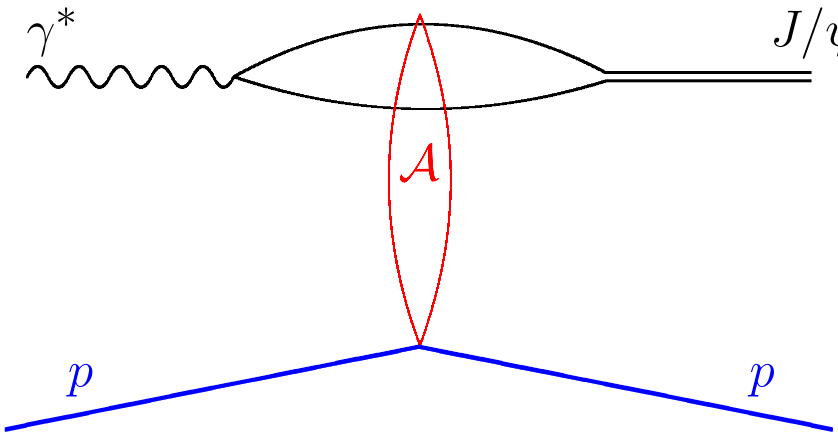
E. Gotsman, E. Levin, M. Lublinsky, U. Maor, & E.N., hep-ph/0302010

Outline

- Nonlinear evolution and the production amplitude
- Impact parameter dependence
- Integrated cross section for proton target
- Integrated cross section for nuclear target
- Summary

The cross section for the production of J/ψ vector meson in a process of γ^*-p scattering:



$$\sigma_{J/\psi}(x,Q^2) = \int d^2b \left| \int dz\, d^2r_\perp\, \Psi_{\gamma^*}(r_\perp, z, Q^2) \mathcal{A}(r_\perp, x; b_\perp) \Psi_{J/\psi}(r_\perp, z) \right|^2$$

- $r_\perp$ the size of the colour dipole
- $\mathcal{A}$ the imaginary part of the production amplitude
- z the fraction of the photon's energy

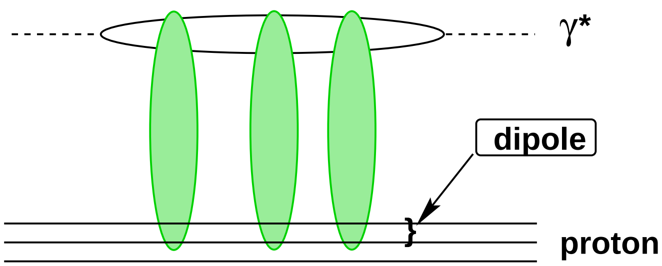
- $\mathcal{A}$ is related to the numerical solution of the NLE equation (the Balitsky-Kovchegov equation).
- The BK equation is for $N(r_\perp, x; b_\perp)$, the ($b_\perp$-dependent) imaginary part of the amplitude for dipole-nucleon elastic scattering.
- The wavefunction of the photon, Ψ_{γ^*}, is well known, and for the J/ψ wavefunction, $\Psi_{J/\psi}$, we approximate $r_\perp = 0$ and $z = \frac{1}{2}$.
- The uncertainty due to this approximation is treated as an overall (constant) normalization.

The relation between N and $\mathcal{A}$

- The numerical solution for the BK equation was fitted to the F_2 data, using a $b_\perp$-dependence ansatz characterized by a nucleon effective radius of 4.5 GeV^{-2} [**Gotsman, Levin, Lublinsky, Maor, 2002**].
- The measured J/ψ differential slope, $B(W)$, is consistent with a radius of ≈ 10 GeV^{-2}.

$\Rightarrow$The relation between N and $\mathcal{A}$ includes an additional profile, which is needed due to the differences between the calculation procedures of total and exclusive cross sections.

Total cross section

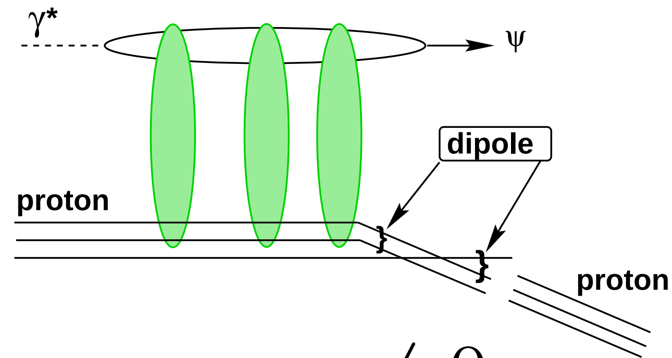


$$q = 0$$

$$\Downarrow$$

$$\mathcal{A}(r_\perp, x; q) = N(r_\perp, x; q)$$

J/ψ production



$$q \neq 0$$

$$\Downarrow$$

$\mathcal{A}$ also depends on $S'(q)$, the probability of finding a second dipole in the recoiled proton.

- In q space:

$$\mathcal{A}(r_\perp, x; q) \propto N(r_\perp, x; q)\, S'(q)\,,$$

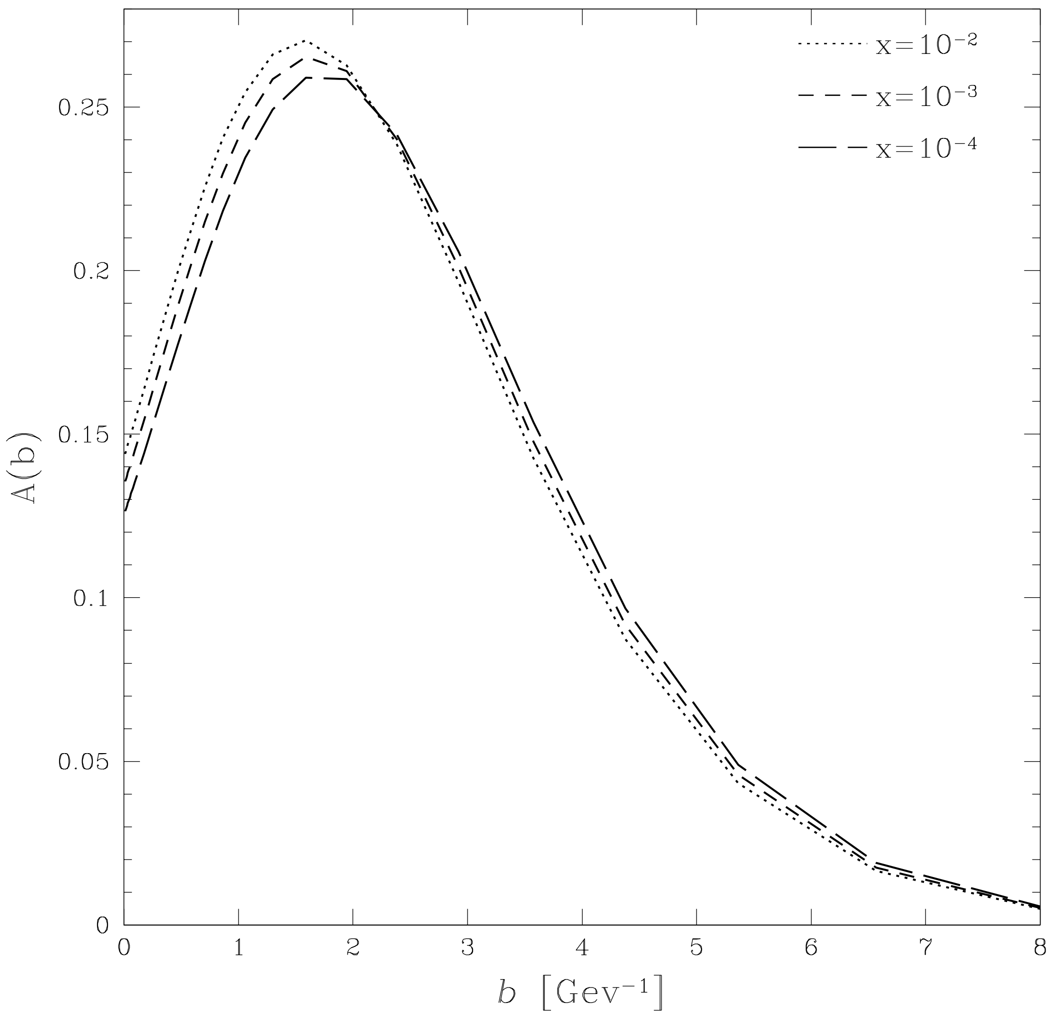
- In b space:

$$\mathcal{A}(r_\perp, x; b) = \int d^2b' N(r_\perp, x; b')\, S'(b - b')\,.$$

- In the Born approximation, assuming a simple factorized form of the proton wave function, $S'(b)$ is characterized by $R = \frac{1}{2} R_{\text{proton}}$.

- The radius of $S'(b)$ can also be extracted from experimental data: $R = 2\left(B_{\text{exp}} - \frac{1}{2}\langle b^2\rangle\right)$.

The resulting b-dependence of $\mathcal{A}$



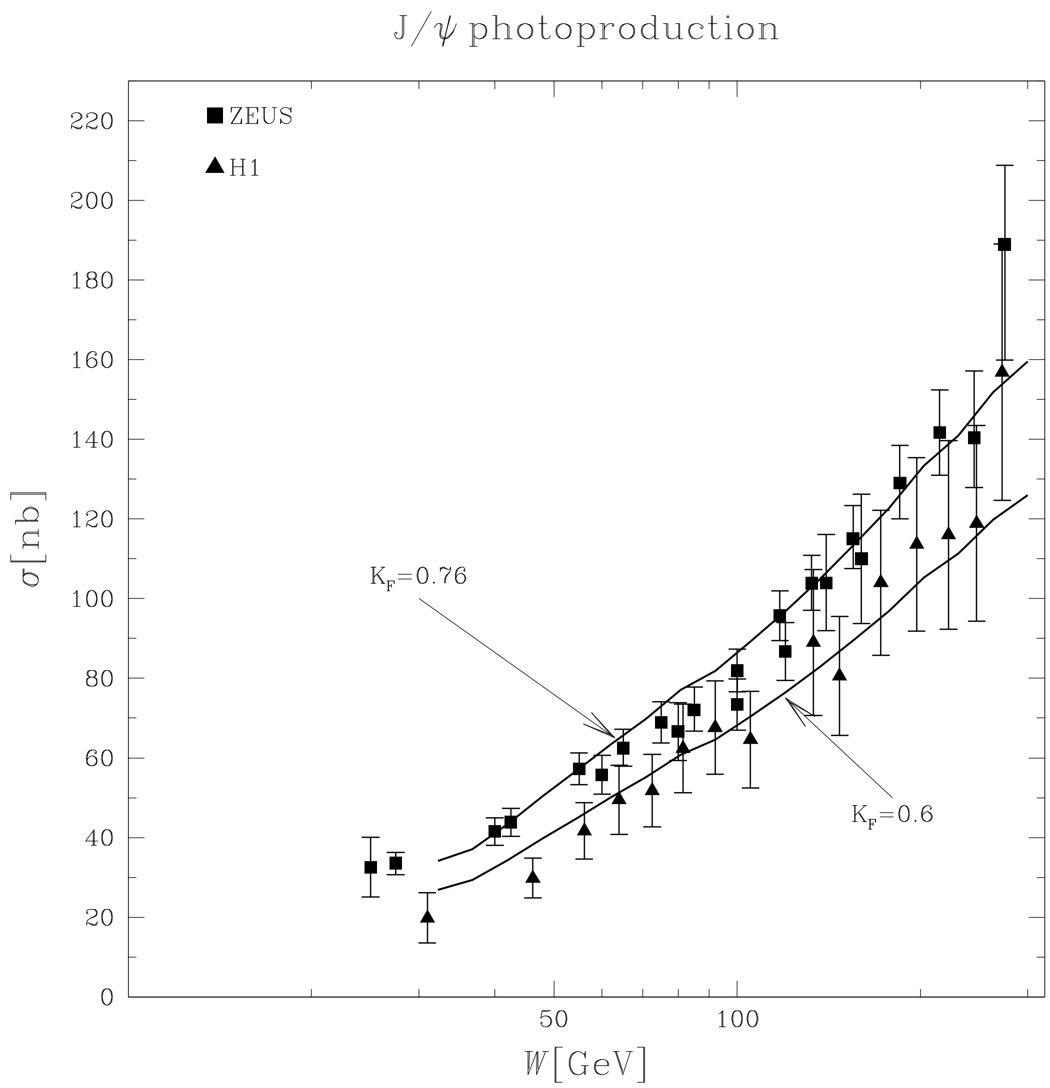
The calculation of $\sigma(\gamma^* p \longrightarrow J/\psi p)$ includes the following modifications:

- Off diagonal contribution: $C_G^2 = \left(\frac{2^{2\lambda+3}\,\Gamma(\lambda+\frac{5}{2})}{\sqrt{\pi}\,\Gamma(\lambda+4)}\right)^2$
  - $\lambda = \partial \ln N / \partial \ln(\frac{1}{x})$.

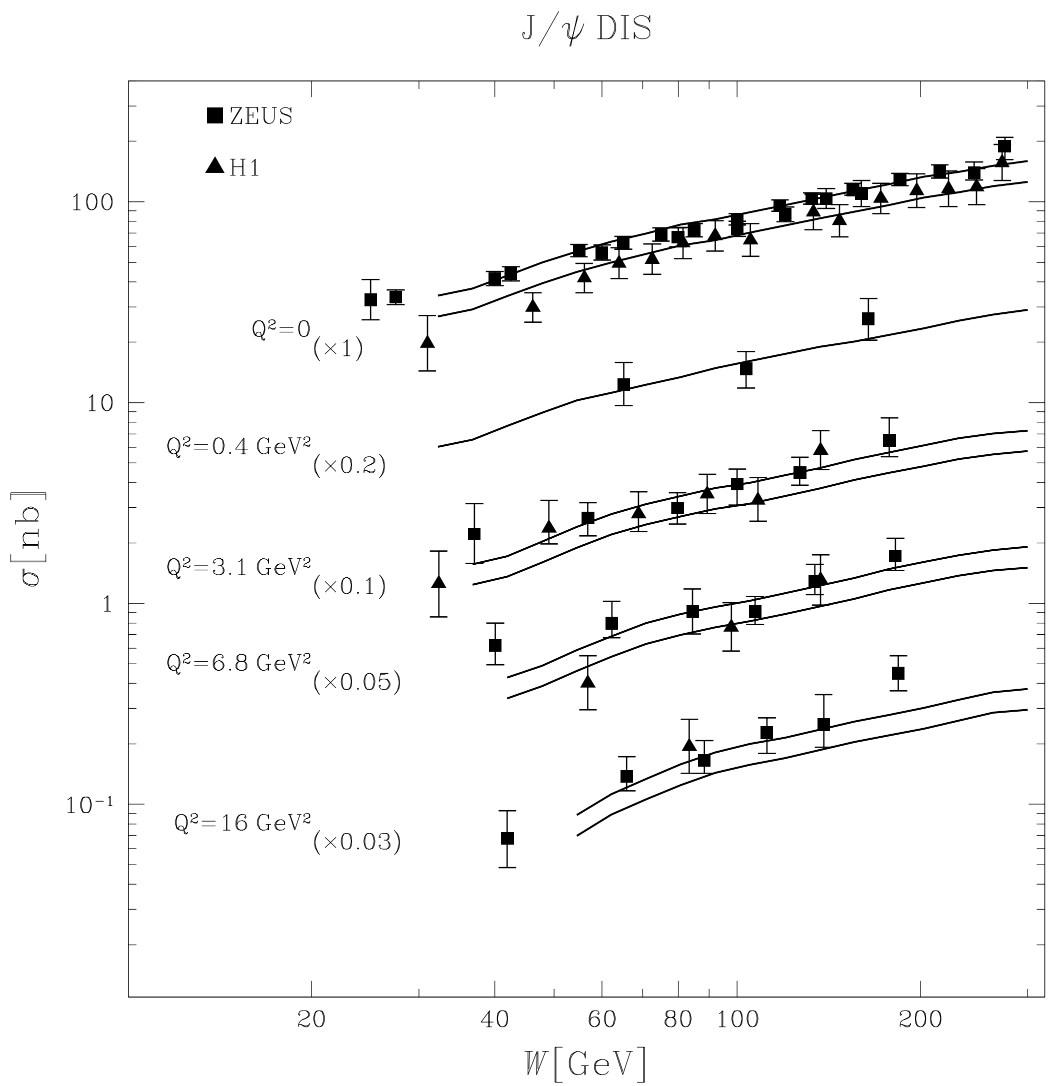
- Real part contribution: $C_R^2 = (1 + \rho^2)$,
  - $\rho = Re\mathcal{A}/Im\mathcal{A} = tg(\frac{\pi\lambda}{2})$.

$$\Rightarrow \sigma(\gamma^* p \rightarrow J/\psi p) = C_G^2\, C_R^2 \int d^2b \left| \int dz\, d^2r_\perp\, \Psi_{\gamma^*}\, \mathcal{A}\, \Psi_{J/\psi} \right|^2$$

Comparison With Experimental Photoproduction Data



Comparison With Experimental DIS Data



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J/ψ Production on a Nuclear Target

We predict $\sigma(\gamma^* A \longrightarrow J/\psi A)$ using Glauber rescatterings.

First, we use the pQCD opacities, Ω_q and $\Omega_g = \frac{9}{4}\Omega_q$, derived from linear DGLAP evolution, taking into account only the dipole and the fastest gluon:

1. the interaction of $|q\bar{q}\rangle$ with the nucleus:

$$\sigma_{|q\bar{q}\rangle} \propto 1 - e^{-\frac{1}{2}\Omega_q}$$

2. the interaction of $|q\bar{q}g\rangle$:

$$\sigma_{|q\bar{q}g\rangle} \propto \frac{C_F}{\pi^2}\alpha_s r_\perp^2 \int \frac{dx}{x} \int_{r'_\perp > r_\perp} \frac{d^2 r'_\perp}{r'^4_\perp} \left(1 - e^{-\frac{1}{2}\Omega_g}\right)$$

- Ω_q is related to the gluon distribution, $xG(x, \frac{4}{r_\perp^2})$:

$$\Omega_q(b, r_\perp, x) = \frac{\pi^2}{3} r_\perp^2 \alpha_s \, xG \, S_A(b) \,,$$

- $S_A(b)$ is the number of nucleons in a nucleus interacting with the incoming dipole.

- We use the Wood-Saxon parameterization:

$$S_A(b) = \rho \int \frac{dr_{||}}{1 + e^{\frac{r - R_A}{h}}} \,,$$

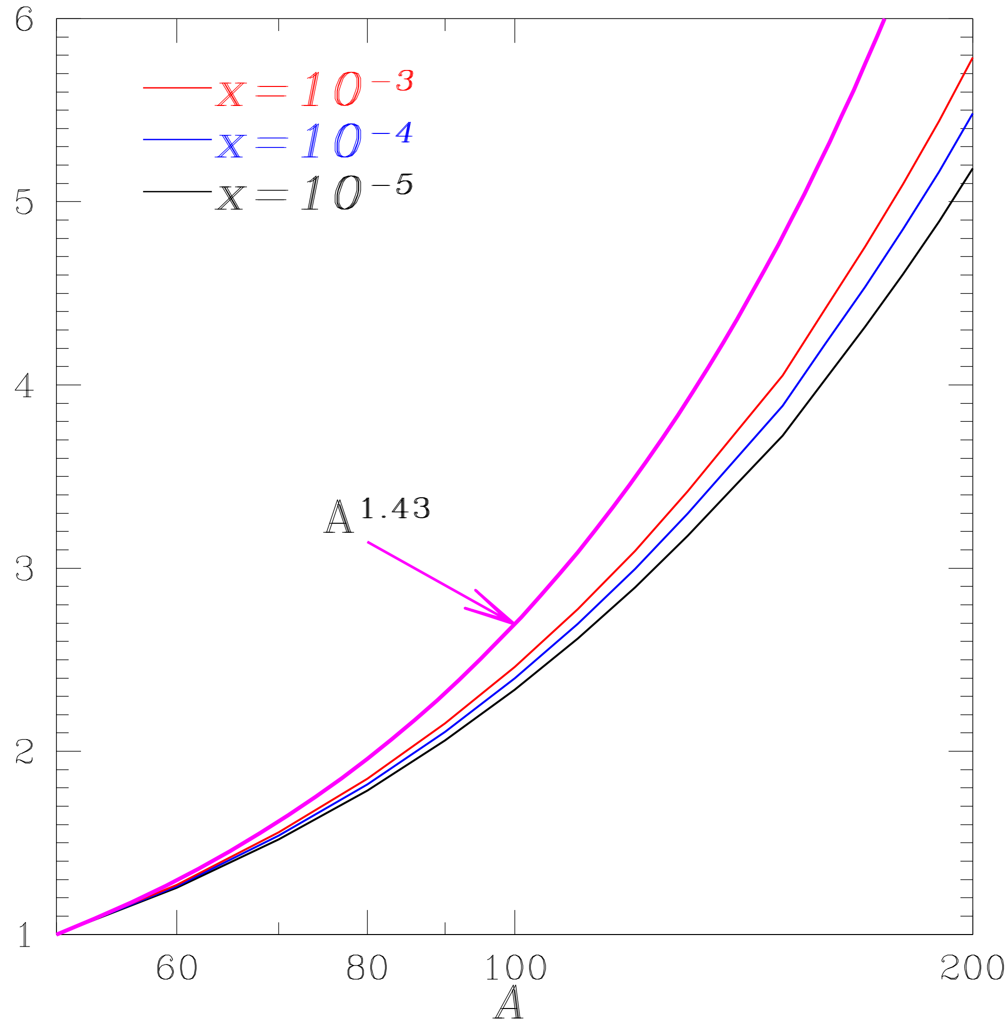
where $r = \sqrt{r_{||}^2 + b^2}$, and $\rho \int \frac{dr_{||} \, d^2 b}{1 + e^{\frac{r - R_A}{h}}} = A$.

The variance between nuclei targets and a nucleon target can be determined by the A dependence of $\sigma(\gamma^* A \to J/\psi A) \propto A^\delta$:

$$\frac{2}{3} \leq \delta \leq \frac{\partial}{\partial \log A} \log \int d^2b \, |S_A(b)|^2 \ .$$

- $\frac{2}{3} \leq \delta \leq \frac{4}{3}$ [for exponential $S_A(b)$];
- $\frac{2}{3} \leq \delta \lesssim 1.43$ [for Wood-Saxon $S_A(b)$].

The A-dependence of $\sigma(\gamma^* A \to J/\psi A)$



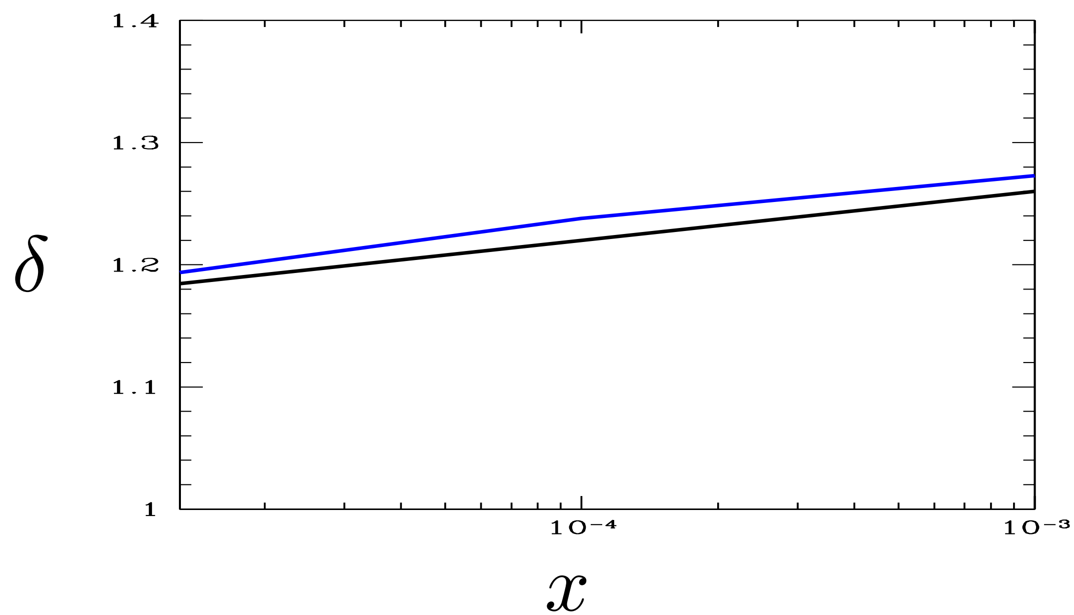
- Recalling that N, the solution of the nonlinear equation, takes into account all possible interactions of partons with the nucleon target, we use N to improve the calculation.
- We consider all rescatterings inside the proton and treat the interactions with different nucleons in the nucleus using the Glauber approach.
- In this approach, the dipole-nucleon cross section is written as:

$$\sigma(\text{dipole-nucleon}) = 2 \int d^2 b_\perp \, N(r_\perp, x; b_\perp)$$

The cross section is written in terms of σ(dipole-nucleon) :

$$\sigma(\gamma^* A \longrightarrow J/\psi A) =$$

$$\int d^2b \left| \int dz\, d^2r_\perp\, \Psi_{\gamma^*} \left(1 - e^{-\frac{1}{2}\sigma(\text{dipole-nucleon})\, S_A(b)}\right) \Psi_{J/\psi} \right|^2$$



- For both approaches, the values of the characteristic exponent, δ, are similar:

$$1.18 \leq \delta \leq 1.28$$

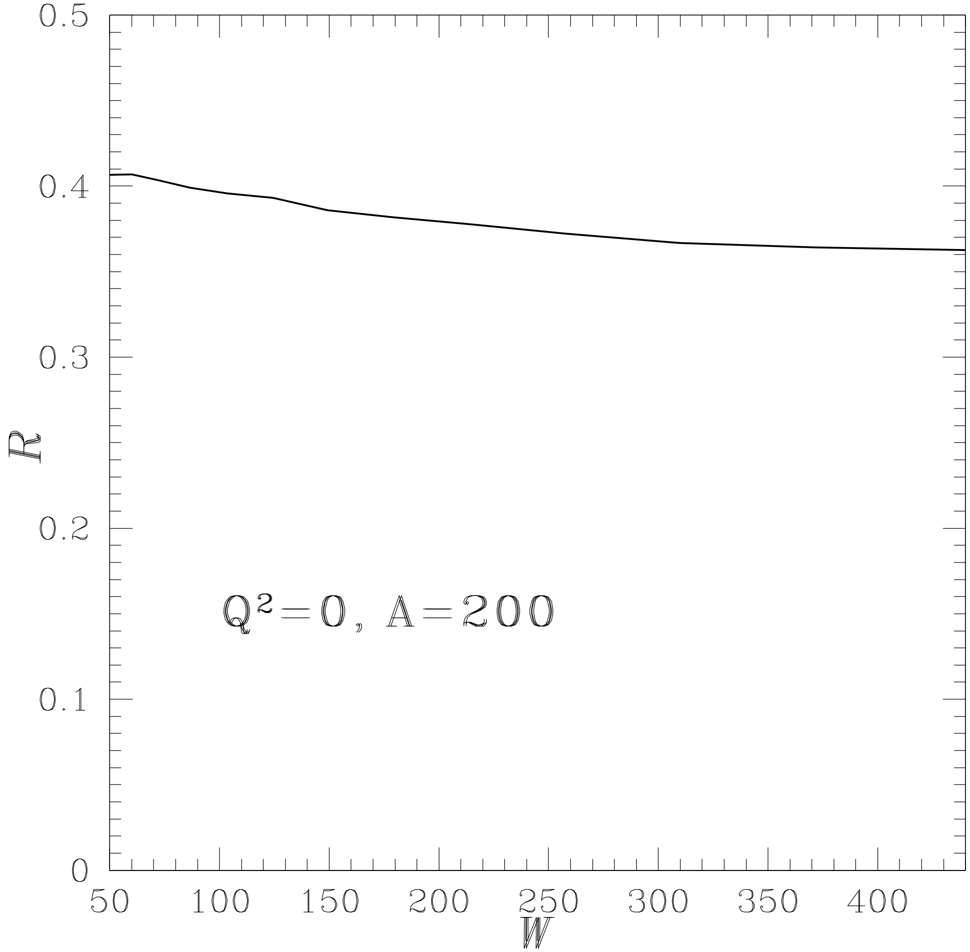
Nevertheless, there is a considerable normalization difference.

- To investigate the normalization difference, define:

$$\mathcal{R} = \frac{\text{dipole+fastest gluon}}{\text{all parton rescatterings}}$$

- A deviation of $\mathcal{R}$ from unity is interpreted as BK nonlinear effects.

Parton Interactions Effects on Gold Target



Summary

- N was used to calculate J/ψ production. The convolution of the b-dependence ansatz of N with the additional profile, $S'(b)$, results in a decrease of $\mathcal{A}$ near $b = 0$. For WS profile, the effect of such convolution is negligible.
- We believe that this decrease is due to the deviation from the linear evolution equations, and is a signature for the onset of unitarity taming effects.
- For nuclear target, unitarity taming effects start to dominate for $x \leq 10^{-3}$.
- We estimate that the effect of all possible interactions of partons with the nucleon, with respect to a contribution of only the parent dipole and the fastest gluon, is $\mathcal{R} \approx 0.4$