More Cold Nuclear Matter Absorption

R. Vogt

Lawrence Livermore National Laboratory, Livermore, CA 94551, USA
Physics Department, University of California, Davis, CA 95616, USA

based on:
RV, Nucl. Phys. A 700 (2002) 539-554

Figure 1: This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344 and supported by the U.S. Department of Energy, Office of Science, Office of Nuclear Physics (Nuclear Theory) under contract number DE-SC-0004014.

Singlet Absorption Model

All $c\bar{c}$ pairs assumed to be produced in small color singlet states

Assume quadratic growth of cross section with proper time until formation time τ_F (Blaizot and Ollitrault)

Strongest at low to negative x_F where J/ψ can form in the target

Asymptotic ψ' and χ_c cross sections proportional to the final state meson size, *e.g.* $\sigma^{\rm s}_{\psi' N} = \sigma^{\rm s}_{J/\psi N}(r_{\psi'}/r_{J/\psi})^2$ (Povh and Hüfner)

$$\sigma_{\rm abs}(z'-z) = \begin{cases} \sigma^{\rm s}_{CN}\left(\dfrac{\tau}{\tau^C_F}\right)^2 & \textbf{if } \tau < \tau^C_F \\ \sigma^{\rm s}_{CN} & \textbf{otherwise} \end{cases} .$$

$$\begin{aligned} \tau_F^{J/\psi} &= 0.92 \text{ fm} & \sigma^{\rm s}_{J/\psi N} &\sim 2.5 \text{ mb} \\ \tau_F^{\psi'} &= 1.5 \text{ fm} & \sigma^{\rm s}_{\psi' N} &= 3.7\,\sigma^{\rm s}_{J/\psi N} \\ \tau_F^{\chi_c} &= 2 \text{ fm} & \sigma^{\rm s}_{\chi_c N} &= 2.4\,\sigma^{\rm s}_{J/\psi N} \end{aligned}$$

A Dependence of 'Color Transparency'

All states produced outside target for $x_F \geq 0$ at 920 GeV (no absorption)

Strong decrease at negative x_F expected in this model for all states but need high statistics to distinguish between them

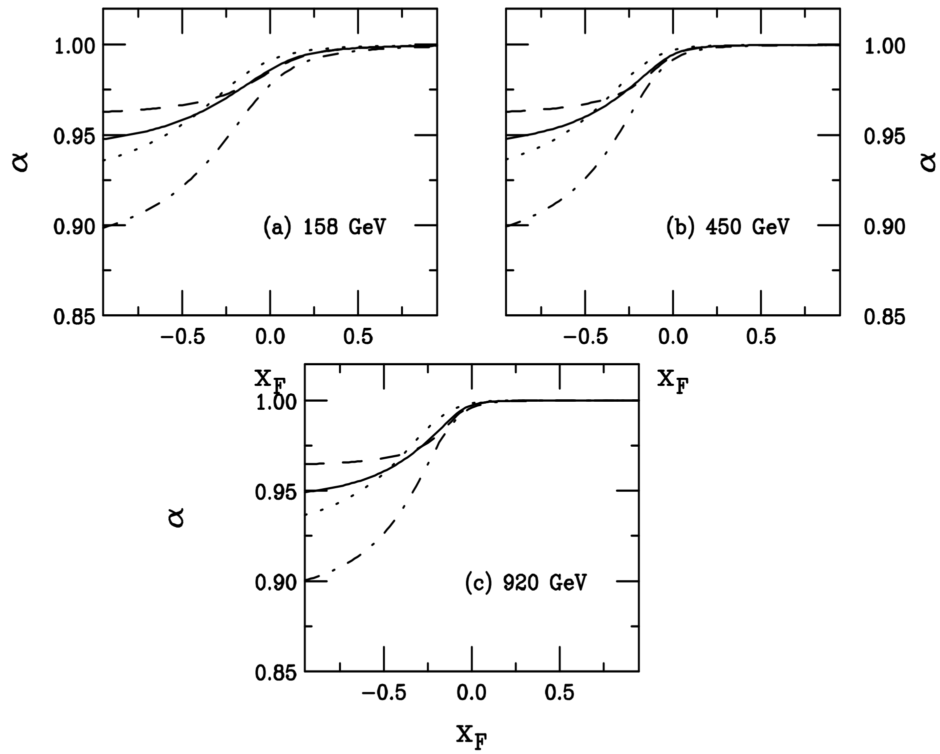

Figure 2: **The A dependence of singlet absorption is shown for 158 (a), 450 (b), and 920 (c) GeV interactions. The total J/ψ (solid), direct J/ψ (dashed), ψ' (dot-dashed) and χ_c (dotted) dependencies are shown. [From R.V., Nucl. Phys. A700 (2002) 539.]**

Octet Absorption Model

Pre-resonant $c\overline{c}$ pairs travel through the nucleus as $|(c\overline{c})_8 g\rangle$ color octet states

Characteristic octet lifetime $\tau_8 \sim 0.25$ fm

For $x_F \geq -0.1$, path length of $|(c\overline{c})_8 g\rangle$ through the target from its production point is greater than maximum path length

These fast states pass through nucleus in color octets so that the pre-resonant A dependence is the same for J/ψ, ψ' and χ_c (Kharzeev and Satz) — $\sigma_{\rm abs}^{\rm o} = 3$ mb agrees with E866 forward A dependence

Universal constant absorption cross section usually assumed for nuclear collision studies (NA38, NA50) where $0 < x_F < 0.18$

At negative x_F, path length is shorter and octet state can neutralize its color inside target and be absorbed as color singlet

Only J/ψ likely to be fully formed inside target even though color neutralization may occur for all states

A Dependence of Octet Absorption

Dependencies different at large negative x_F where neutralization occurs

All values of α identical when state passes through target as octet

As energy increases, color neutralization occurs at more negative x_F

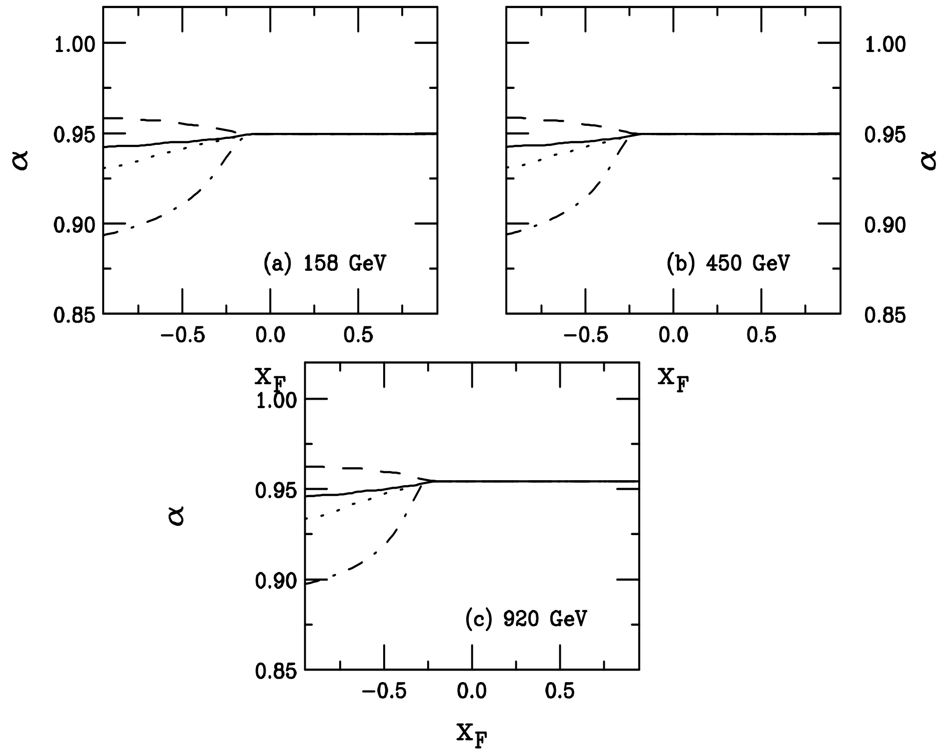

Figure 3: **The A dependence of octet absorption at 158 (a), 450 (b), and 920 (c) GeV interactions. The total J/ψ (solid), direct J/ψ (dashed), ψ' (dot-dashed) and χ_c (dotted) dependencies are shown. [From R.V., Nucl. Phys. A700 (2002) 539.]**

Singlet + Octet Absorption

Relative contributions of singlet and octet production set by NRQCD (Zhang *et al.*)

Equal absorption cross sections for all octet states

Singlet cross sections set by final state size

$$\frac{d\sigma_{pA}^{\psi}}{dx_F} = \int d^2b \left[\frac{d\sigma_{pp}^{\psi,\,\rm oct}}{dx_F} T_A^{\psi,{\rm eff\,(oct)}}(b) + \frac{d\sigma_{pp}^{\psi,\,\rm sing}}{dx_F} T_A^{\psi,{\rm eff\,(sing)}}(b) \right] ,$$

$$\frac{d\sigma_{pA}^{\chi_{cJ}\to J/\psi X}}{dx_F} = \int d^2b \sum_{J=0}^{2} B(\chi_{cJ} \to J/\psi X) \left[\frac{d\sigma_{pp}^{\chi_{cJ},\,\rm oct}}{dx_F} T_A^{\chi_{cJ},{\rm eff\,(oct)}}(b) + \frac{d\sigma_{pp}^{\chi_{cJ},\,\rm sing}}{dx_F} T_A^{\chi_{cJ},{\rm eff\,(sing)}}(b) \right] ,$$

$$\frac{d\sigma_{pA}^{J/\psi,\,\rm tot}}{dx_F} = \int d^2b \left\{ \left[\frac{d\sigma_{pp}^{J/\psi,\,{\rm dir,\,oct}}}{dx_F} T_A^{J/\psi,{\rm eff\,(oct)}}(b) \right.\right.$$
$$+ \sum_{J=0}^{2} B(\chi_{cJ} \to J/\psi X) \frac{d\sigma_{pp}^{\chi_{cJ},\,\rm oct}}{dx_F} T_A^{\chi_{cJ},{\rm eff\,(oct)}}(b) + B(\psi' \to \psi X) \frac{d\sigma_{pp}^{\psi',\,\rm oct}}{dx_F} T_A^{\chi_{cJ},{\rm eff\,(oct)}}(b) \Bigg]$$
$$+ \left[\frac{d\sigma_{pp}^{J/\psi,\,{\rm dir,\,sing}}}{dx_F} T_A^{J/\psi,{\rm dir,eff\,(sing)}}(b) + \sum_{J=0}^{2} B(\chi_{cJ} \to \psi X) \frac{d\sigma_{pp}^{\chi_{cJ},\,\rm sing}}{dx_F} T_A^{\chi_{cJ},\,{\rm eff\,(sing)}}(b) \right.$$
$$\left.\left. + B(\psi' \to \psi X) \frac{d\sigma_{pp}^{\psi',\,\rm sing}}{dx_F} T_A^{\psi',\,{\rm eff\,(sing)}}(b) \right] \right\}$$

$$T_A^{\rm eff}(b) = \int_{-\infty}^{\infty} dz\, \rho_A(b,z) \exp\left\{ - \int_z^{\infty} dz' \rho_A(b,z') \sigma_{\rm abs}(z'-z) \right\}$$

A Dependence of Combination Model

Total J/ψ and ψ' A dependence very similar for $0 < x_F < 0.5$ (previously measured region)

Strong octet component of direct J/ψ makes α nearly constant

Singlet contribution to χ_c means $\alpha \sim 1$ for $0 < x_F < 0.5$

$\alpha(x_F)$ depends on relative octet/singlet contributions

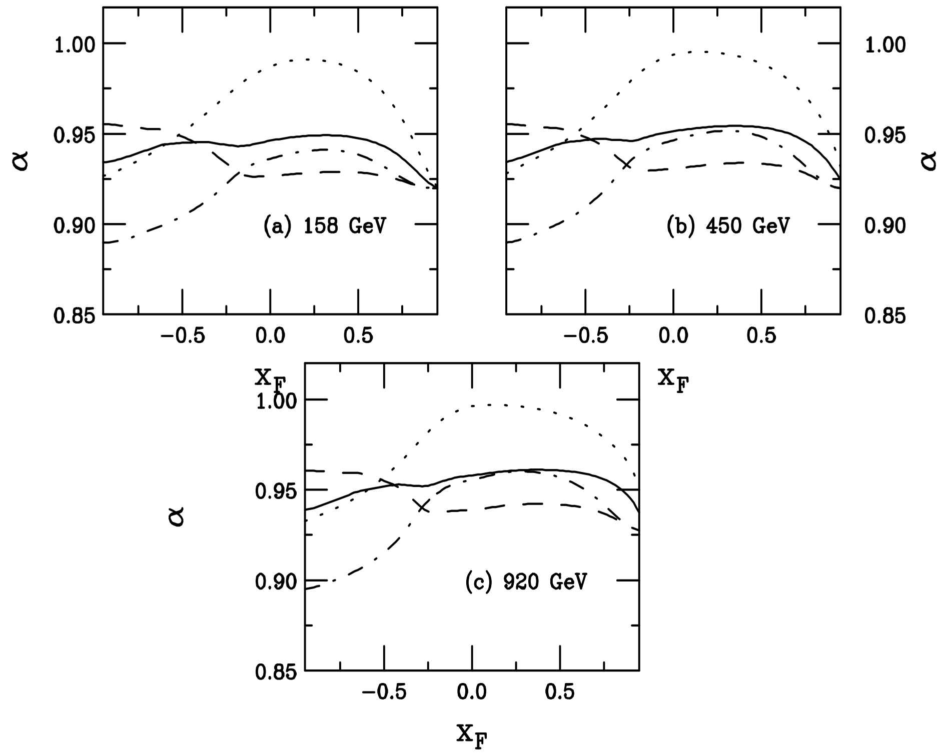

Figure 4: **The A dependence of singlet and octet absorption is shown at 158 (a), 450 (b), and 920 (c) GeV. The total J/ψ (solid), direct J/ψ (dashed), ψ' (dot-dashed) and χ_c (dotted) dependencies are shown. [From R.V., Nucl. Phys. A700 (2002) 539.]**

Including Absorption with Shadowing at RHIC

Effect of changing $\sigma_{\rm abs}$ is shown for the various absorption models

Little difference between constant and growing octet, only at large negative rapidity, singlet absorption only effective for $y < -2$

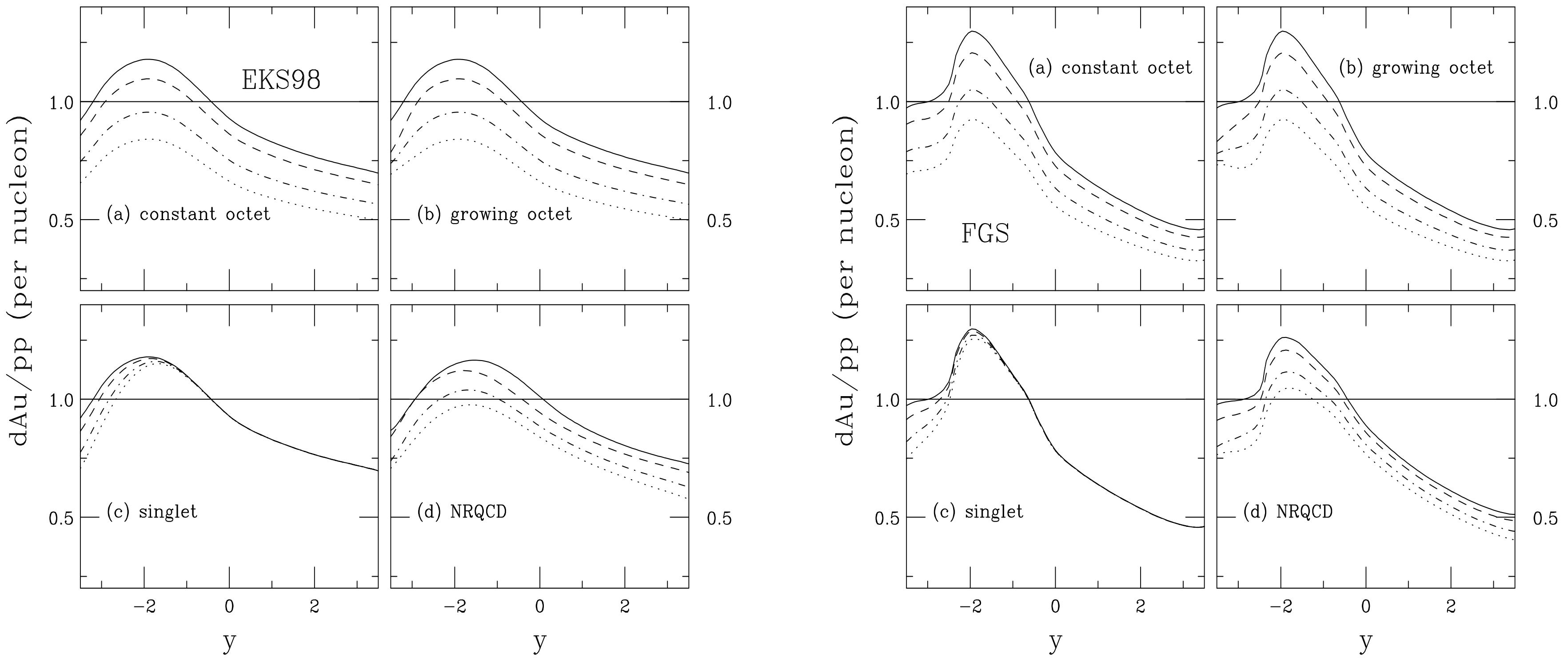

Figure 5: **The J/ψ dAu/pp ratio at 200 GeV with EKS98 (left) and FGS (right) shadowing as a function of rapidity for (a) constant octet (assuming all states have a constant cross section and do not hadronize in the nucleus), (b) growing octet (states behave as singlets if they materialize in the medium), (c) singlet, all calculated in the CEM and (d) NRQCD with a combination of octet and singlet matrix elements. For (a)-(c), the curves are no absorption (solid), $\sigma_{\rm abs} = 1$ (dashed), 3 (dot-dashed) and 5 mb (dotted). For (d), the results are shown for no absorption (solid, note slight difference relative to the CEM), 1 mb octet/1 mb singlet (dashed), 3 mb octet/3 mb singlet (dot-dashed), and 5 mb octet/3 mb singlet (dotted).**

Including Absorption and Shadowing at the LHC

J/ψ not produced inside nucleus except for $y < -5$, no difference between constant and growing octet

Potentially very large J/ψ suppression at $y > -2$, particularly for FGS, even without absorption

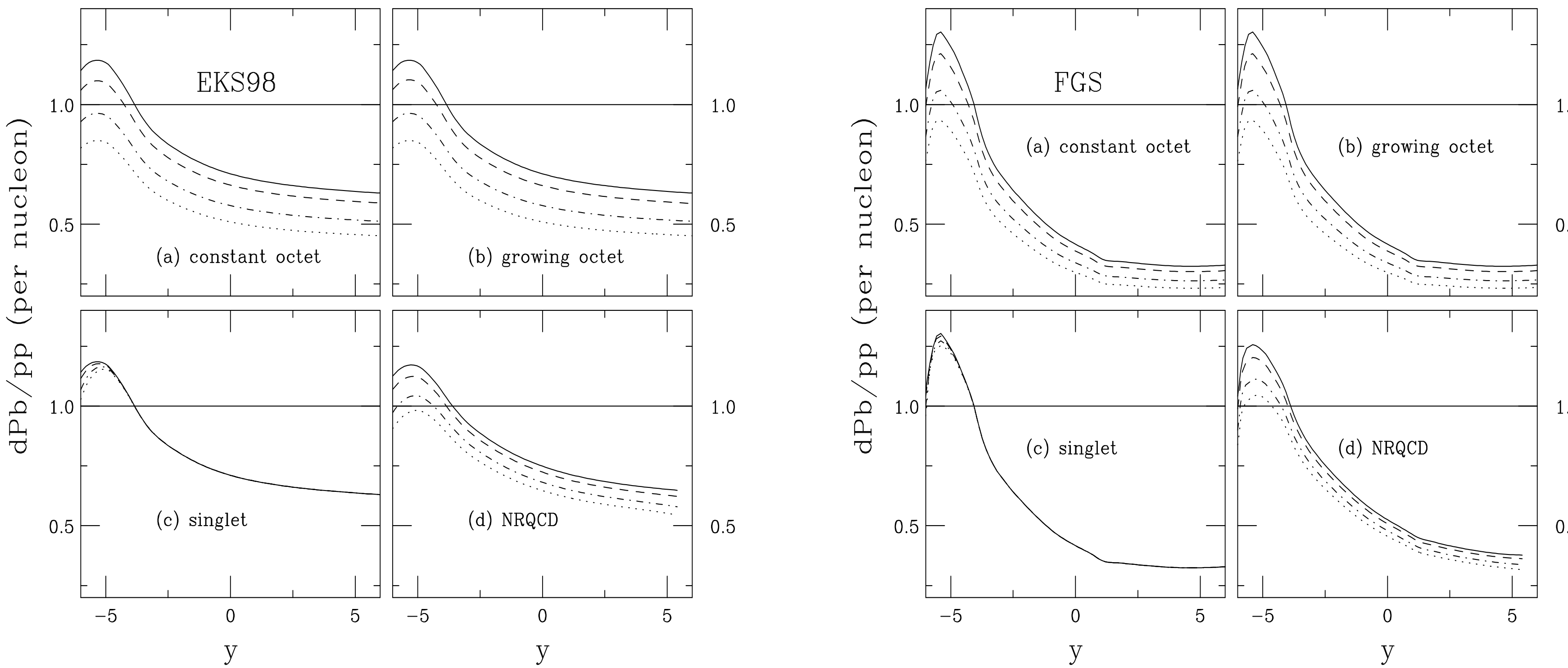

Figure 6: **The J/ψ dAu/pp ratio at 5.5 TeV with EKS98 (left) and FGS (right) shadowing as a function of rapidity for (a) constant octet (assuming all states have a constant cross section and do not hadronize in the nucleus), (b) growing octet (states behave as singlets if they materialize in the medium), (c) singlet, all calculated in the CEM and (d) NRQCD with a combination of octet and singlet matrix elements. For (a)-(c), the curves are no absorption (solid), $\sigma_{\rm abs} = 1$ (dashed), 3 (dot-dashed) and 5 mb (dotted). For (d), the results are shown for no absorption (solid, note slight difference relative to the CEM), 1 mb octet/1 mb singlet (dashed), 3 mb octet/3 mb singlet (dot-dashed), and 5 mb octet/3 mb singlet (dotted).**