Production of Drell-Yan pairs and open and hidden heavy flavor on nuclear targets is examined within perturbative QCD. The effects of modifications of nucleon structure functions inside the nuclear medium are considered. Besides, nuclear dependence of charmonium and bottomium absorption is studied in the framework of the Glauber-Gribov model. The low energy limit of this approach recovers the probabilistic formula usually employed for charmonium and bottomium suppression in nuclear collisions.
1 Introduction

Drell-Yan (DY) and open (Q̅Q) and hidden (Ψ) heavy flavor production in hadron collisions are usually studied in the framework of perturbative QCD \[1, 2\]. The extension to nuclear projectiles and targets is straightforward, provided factorization between partonic densities and parton-parton cross sections is assumed:

\[
\sigma_{AB} \equiv \sigma^{A\rightarrow h\overline{h}} = \sum_{a,b} \int_{x_{a0}}^{1} dx_a \int_{x_{b0}}^{1} dx_b \ f_{a/A}(x_a, \mu^2) f_{b/B}(x_b, \mu^2) \ \hat{\sigma}^{ab\rightarrow h\overline{h}}(\hat{s}, m_h, \mu^2). \tag{1}
\]

In this equation the summation runs over all partons in the projectile and target, \( f_{c/C} \) is the density of parton \( c \) in hadron or nucleus \( C \), \( \hat{\sigma}^{ab\rightarrow h\overline{h}} \) is the parton-parton cross section and factorization and renormalization scales are taken to be equal; \( m_h = m_Q (M_{l+1} - l/2) \) for heavy flavor (Drell-Yan) production, \( x_{a0} = 4m_h^2/s \), \( x_{b0} = 4m_h^2/(sx_a) \), \( \hat{s} = sx_ax_b \) and \( \mu^2 \sim m_h^2 \). The leading order (LO) relation \( x_F = x_a - x_b \) will be used.

In this context, some differences between \( A, B \) being hadrons or nuclei are the following:

- The influence of the nuclear medium on nucleon structure functions or partonic densities (see for example \[3\]), expressed as the ratio:

\[
R_{a/A}(x, \mu^2) = \frac{2 f_{a/A}(x, \mu^2)}{A f_{a/D}(x, \mu^2)} \neq 1. \tag{2}
\]

If we parametrize cross sections on nuclei as \( \sigma_{AB}(x_F) = \sigma_{pp}(AB)^{\alpha(x_F)} \), this effect makes \( \alpha(x_F) \neq 1 \) for all processes, even if isospin effects (i.e. the difference between neutron and proton parton densities) are corrected.

- The scattering of the produced heavy system (absorption by nuclear matter, rescattering with hadronic co-movers and/or deconfinement, see \[4\]), which affects \( \Psi \) production, making \( \alpha^\Psi(x_F) < \alpha^{DY}(x_F) \).

- The elastic scattering of initial partons, which is the accepted explanation of the \( p_T \)-broadening (\( \langle p_T^2 \rangle_{AB} \) greater than \( \langle p_T^2 \rangle_{pp} \) for DY and \( \Psi \) production), being the difference proportional to \( A^{1/3} \) \[4, 5, 6\].
The energy loss of fast partons inside the nuclear medium (the so-called jet quenching), proportional to $A^{2/3}$ and different for cold and hot nuclear matter \cite{5, 7}. It may affect the yield of charm and bottom at high energies \cite{8}.

In this contribution we will examine the two first aspects. It is organized as follows: In Section 2 nuclear structure functions will be briefly discussed, and the parametrizations used in our calculations and results for Drell-Yan, open heavy flavor and charmonium production on nuclear targets will be presented. In Section 3 nuclear absorption of states with hidden heavy flavor will be studied. Finally, in Section 4 some conclusions will be presented.

2 Hard processes on nuclear targets

Since the experiments of the European Muon Collaboration \cite{9}, the modification of nucleon structure functions inside the nuclear medium has been studied by several experiments \cite{3}. While the dependence of $R_{a/A}(x, \mu^2)$ on $\mu^2$ is very small, four regions in $x$ can be described: $R_{a/A} > 1$ for $0.8 < x < A$ (Fermi motion and cumulative regions); $R_{a/A} < 1$ for $0.3 < x < 0.8$ (the original EMC effect); $R_{a/A} > 1$ for $0.1 < x < 0.3$ (antishadowing region); and $R_{a/A} < 1$ for $x < 0.1$ (shadowing region).

We will use the parametrization of Ref. \cite{10, 11} for Au, which was designed to describe the four regions in $x$. This approach follows the conventional techniques for global fits to produce nucleon parton distributions: the ratio $R_{a/A}$ is parametrized at some low virtuality (4 GeV$^2$) and then evolved to higher $\mu^2$ using evolution equations modified for the nuclear case \cite{13}. All parameters are fixed from a comparison to nuclear structure function ratios over deuterium and DY data, using baryon number and momentum sum rules and a $SU(3)$ symmetric sea. This parametrization has a lower limit in $x = 10^{-3}$ ($\equiv \sqrt{s} \simeq 100$ GeV for charm at $x_F = 0$, not enough for predictions for RHIC.

\footnote{An update of this parametrization can be found in \cite{12}; among other modifications, modern sets of nucleon structure functions have been used. Other proposal in the same spirit can be found in \cite{12}.}
and LHC or for high $x_F = x_a - x_b$), so at smaller $x$ we have taken two alternatives:

either frozen or a linear-log extrapolation in the form $x^\beta$. The parametrization for two
different virtualities can be seen in Fig. 1 [14].

Figure 1: Parton densities in $Au$ for $\mu^2 = 5$ and $25$ GeV$^2$: valence quarks (dashed
curve), sea quarks (solid curves) and gluons (dashed-dotted curves); dotted curves are
the results of linear-log extrapolations with $\beta = 0.096$ and $0.040$ at $\mu^2 = 5$ and $25$
GeV$^2$ respectively.

2.1 Open heavy flavor and Drell-Yan

Parametrizing $\sigma_{pA}(x_F) = \sigma_{pp} A^{\alpha(x_F)}$, in Figs. 2-5 results [14] for $\alpha(x_F)$ in $DY$, $c$ and $b$ production in $pAu$ collisions are presented, using GRV HO [15] and MRS A [16]
nucleon structure functions. The $\hat{\sigma}^{ab\rightarrow h\bar{h}}(\hat{s}, m_h, \mu^2)$ are taken at next-to-leading order
in the $\overline{MS}$ renormalization scheme and the following parameters are used:

i) For open heavy flavor [17]: $m_c = 1.5$ GeV and $\mu^2 = 4$ GeV$^2$ for charm, and $m_b = 5$
GeV and $\mu^2 = m_b^2$ for bottom.

ii) For Drell-Yan [18]: $\mu^2 = M_{l^+l^-}^2$. 

4
As stated above, \( x_F = x_a - x_b \) (LO relation), \( x_a x_b s \geq 4m_h^2 \) and the main contribution to the integrals comes from \( x_a x_b s = 4m_h^2 \), \( x_{a/b} = \left[ \sqrt{(16m_h^2/s) + x_F^2} \pm x_F \right]/2 \); this means \( x_{a/b} \approx 3 \cdot 10^{-4} \) for charm at \( \sqrt{s} = 10 \) TeV and \( x_F = 0 \).

Figure 2: Energy dependence of \( \alpha \) for charm and beauty production in \( pAu \) collisions for GRV HO (solid and dashed curves) and MRS A (dotted and dashed-dotted curves) structure functions and using extrapolated (dashed and dashed-dotted curves) and frozen at \( x = 10^{-3} \) (solid and dotted curves) ratios of parton distributions.

\[
\begin{align*}
\sqrt{s_{_{NN}}} (\text{GeV}) & \\
\alpha & \\
\end{align*}
\]

It can be seen in these Figures that the influence of the chosen Set of nuclear parton densities is almost negligible except for the highest energies and \( x_F \). Besides, some difference appears between frozen and extrapolated ratios; as expected, this difference is larger at higher energies or \( x_F \) and for charm or low dilepton masses. Moreover, in the \( x_F \) distributions all regions in nuclear structure functions can be seen from negative to positive \( x_F \) (corresponding to decreasing \( x \)). Related results can be found in Refs. 19, 20.
Figure 3: $x_F$ dependence of $\alpha$ for charm and beauty production in $pAu$ collisions at $\sqrt{s_{NN}} = 39$ GeV (upper figure) and 1800 GeV (lower figure) for GRV HO and MRS A structure functions and using extrapolated and frozen at $x = 10^{-3}$ ratios of parton distributions (with the same conventions as in Fig. 2).

2.2 Hidden heavy flavor

We will concentrate on charmonium production on nuclear targets. Now the formation of the final resonance has to be considered. Usually two models are used to study charmonium production:

i) The Color Evaporation Model (CEM) \cite{21} considers that all color dynamics is contained in the kinematical restriction to Eq. (1): $4m_c^2 \leq \hat{s} = x_ax_bs \leq 4m_D^2$. The projection on different charmonium states is taken into account by numerical coefficients, $\sigma_{AB \rightarrow \Psi} = F_{\Psi} \sigma_{AB \rightarrow \pi}(4m_c^2 \leq \hat{s} \leq 4m_D^2)$, which are universal in this approach.
Figure 4: Mass (upper figure) and energy (lower figure) dependence of $\alpha$ for Drell-Yan pair production in $pAu$ collisions for GRV HO and MRS A structure functions and using extrapolated and frozen at $x = 10^{-3}$ ratios of parton distributions (with the same conventions as in Fig. 2). In the lower figure $M^2$ is in GeV$^2$.

ii) The Factorization Approach (FA), which contains both the Color Singlet Model (CSM) and Color Octet Model (COM), is based on non-relativistic QCD (NRQCD) $[2, 22]$. In this model the parton-parton cross section for production of a charmonium state $\Psi$ is:

\[
\hat{\sigma}^{ab\to\Psi}(\hat{s}, m_c, \mu^2) = \sum_{[n]} C^{ab}_{\bar{c}c[n]} \langle O^\Psi_{[n]} \rangle,
\]

(3)

with $C^{ab}_{\bar{c}c[n]}$ the short distance coefficients for the hard subprocess $ab \to \bar{c}c[n]$ ($[n]$ is the color configuration of the $\bar{c}c$ pair), computable as series in $\alpha_s$, and $\langle O^\Psi_{[n]} \rangle$ the long distance matrix elements taking into account the hadronization $\bar{c}c[n] \to \Psi$, which can
Figure 5: $x_F$ dependence of $\alpha$ values for heavy lepton pair production in $pAu$ collisions at $\sqrt{s_{NN}} = 39$ GeV (upper curves in each figure) and 1800 GeV (lower curves in each figure) and different masses for GRV HO and MRS A structure functions and using extrapolated and frozen at $x = 10^{-3}$ ratios of parton distributions (with the same conventions as in Fig. 2). Note that at $\sqrt{s_{NN}} = 39$ GeV all curves coincide.

be classified in powers of the relative velocity $v$ of $Q$ and $\overline{Q}$ and are obtained from a fit to data [23, 24, 25]. We will use the fit to fixed target data obtained in Ref. [23].

While in CEM different resonances have the same energy and $x_F$ behavior, in FA we consider different contributions and take into account the most important decays from charmonium states into $J/\psi$:

$$\sigma_{J/\psi}^{tot} = \sigma_{J/\psi}^{dir} + B(\psi' \rightarrow J/\psi) \sigma_{\psi'} + \sum_{J=0,1,2} B(\chi_{cJ} \rightarrow J/\psi) \sigma_{\chi_{cJ}},$$

being $\sigma_{J/\psi}^{dir}$ the direct $J/\psi$ production, i.e. not coming from decays, and $B(H \rightarrow J/\psi)$ the branching ratios for particle $H$ to decay into a $J/\psi$. Experimentally it is found
that direct $J/\psi$ contribution is about 60 % of the total $J/\psi$ cross section, $\psi'$ decay gives less than 10 % and all $\chi_{cJ}$ contribute with more than 30 %. Decays into $\psi'$ are not important, and then $\psi'$ production is dominated by direct production.

One important point is the contribution of the different color states to the production of these particles, i.e. the color content of the pre-resonant state. In fact, the FA gives that direct $J/\psi$ production is almost completely produced in color octet state, $\psi'$ is also predominantly (about 90 % or more) produced in color octet, and the main contribution of the $\chi_{cJ}$ states to $J/\psi$ comes from color singlet matrix elements. Then, a separate study of the effect of nuclear structure functions on different particles and color states is possible in this approach. As we will see, the color octet and color singlet contributions to the production of charmonium have different suppression.

In Figs. 6 and 7 we present results for energy and $x_F$ dependence of charmonium production [26]. Computations have been done taking $m_c = 1.5$ GeV and $\mu = 2m_c$, and using CTEQ3L [27] and GRV HO [15] nucleon parton distributions in FA and CEM respectively. Different color contributions and charmonium states are taken into account defining

$$\alpha_{i}^{\Psi}(x_F) = \frac{\ln [\sigma_{AB}^{\Psi,i}(x_F)/\sigma_{pp}^{\Psi,i}(x_F)]}{\ln A},$$

for $i = \text{CSM, COM, CSM+COM=FA, CEM, and } \Psi = \text{total } J/\psi, \text{ direct } J/\psi, \psi'$, $\sum B(\chi_{cJ} \rightarrow J/\psi) \sigma_{\chi_{cJ}}$. It can be observed that both FA and CEM give very similar results except for $\chi$’s at very high energies or $x_F$. The behavior of the different color contributions (and hence of the $S$ wave and $P$ wave states) is also different at high energies or $x_F$.

3 Nuclear absorption

Nuclear absorption of the pre-resonant $cc$ state in its path through nuclear matter is usually taken into account in $pA$ collisions, at fixed impact parameter $b$, by two formulae (which neglect nuclear effects on structure functions, assumed very small at
Figure 6: Center of mass energy dependence of $\alpha$ for $pAu$ collisions. Different lines are: FA total contribution (solid), singlet contribution (dotted), octet contribution (dashed) and CEM (dashed-dotted).

fixed target energies in the central rapidity region):

i) Taking into account the path $L(b)$ across the nucleus [28], Fig. 8:

$$\sigma_{pA}^\Psi(b) \propto \exp[-\rho_0 \sigma_{abs} L(b)], \quad \rho_0 \simeq 0.17 \; \text{fm}^{-3}. \quad (6)$$

ii) The Glauber probabilistic formula [29]:

$$\sigma_{pA}^\Psi = \sigma_{pN}^\Psi A \int d^2b \int_{-\infty}^{+\infty} dz \rho(z, \vec{b}) \exp \left[ -\sigma_{abs} A \int_{z}^{+\infty} dz' \rho(z', \vec{b}) \right]$$

$$= \frac{\sigma_{pN}^\Psi}{\sigma_{abs}} \int d^2b \left[ 1 - e^{-\sigma_{abs} A T_A(b)} \right]; \quad (7)$$

this formula can be easily understood (Fig. 8): the pre-resonant $c\bar{c}$ state is created at some point $z$ in the nucleus (in an amount proportional to the density of nuclear
matter $\rho(z, \vec{b})$ at that point) and is absorbed in its path through the nucleus from $z$ to $+\infty$ with some absorption cross section.\footnote{The meaning of this absorption cross section is not clear. In some proposals (e.g. \cite{30}) it has been related to the color structure of the pre-resonant state: absorption is much stronger in octet than in singlet configuration. Observation of little absorption for $\chi$'s (see Subsection 2.2) and variation of absorption with $p_T$ of the produced resonance in some defined way would support this point of view and the validity of the NRQCD approach.} For open charm ($\sigma_{abs} = 0$), $\sigma_{pA} = \sigma_{pN} N$.

Eqs. (6) and (7), with their longitudinal ordering, are only valid in the low energy limit. A formula valid at all energies has been derived \cite{31} in a fully relativistic Glauber-Gribov approach, using finite energy Abramovsky-Gribov-Kancheli (AGK) cutting rules \cite{32}. Considering $n$ nucleon-nucleon interactions taken in some arbitrary
Figure 8: Representation of the absorption mechanism at low energies in the rest frame of the nucleus; $z$ is the creation point of the pre-resonant $c\bar{c}$ pair.

Longitudinal ordering $z_1 \leq z_2 \leq \cdots \leq z_n$, these rules imply (besides the usual AGK prescription [33]) to change $T^n_A(b)$, $T_A(b) = \int^{+\infty}_{-\infty} dz \rho(z, b)$, by

$$T^{(j)}_n(b) = n! \int^{+\infty}_{-\infty} dz_1 \int^{+\infty}_{z_1} dz_2 \cdots \int^{+\infty}_{z_{n-1}} dz_n \exp \left[ i \Delta(z_1 - z_j) \right] \prod_{i=1}^{n} \rho(z_i, b),$$

for $j$ the first interaction either cut or to the right of the cut (see Fig. 9) and

$$\Delta = \frac{m_N M^2}{sx_a}, \quad M = 2m_h \text{ or } m_\Psi.$$  

This is nothing but the $t_{\min}$ effect [34], i.e. the nuclear form factor suppresses interactions which require a minimum momentum transfer (e.g. those in which heavy flavor is produced).

Both an external contribution (corresponding to the heavy system being produced in the interaction) and internal contributions (corresponding to the heavy system already present in the projectile or target, which turn out to be very small) are included. Modifications of the nucleon structure functions due to the nuclear medium naturally appear in this framework, which is valid at not very high $x$. The results for the low and high energy asymptotic limits are:

\footnote{Not to be confused with intrinsic charm [35], which can be important at high $x$.}
Figure 9: Position of the cut to the left of the $j$-th interaction (dotted line) or cut in the $j$-th interaction (crossed solid line).

i) For low energies, $\Delta \rightarrow \infty \Rightarrow$ only $j = 1$ contributes, the shadowing of structure functions disappears and we recover the probabilistic formula (7). To our knowledge it is the first time that this equation has been derived in a fully relativistic approach.

ii) For $s \rightarrow \infty$, $\Delta = 0$ and $T_n^{(j)}(b) = T_A^n(b)$, the shadowing of the structure functions factorizes and we get for the external part:

$$\sigma_{pA}^\Psi = \sigma_{pN}^\Psi \frac{2}{\sigma} \int d^2 b \ e^{-\tilde{\sigma} T_A(b)/2} \left[ 1 - e^{-\sigma T_A(b)/2} \right]$$

$$\Rightarrow \sigma_{pN}^\Psi A \int d^2 b \ T_A(b) \ e^{-\tilde{\sigma} T_A(b)/2} \quad \text{(if no shadowing).} \quad (11)$$

$\sigma$ ($\tilde{\sigma}$) is the light (heavy) particle-nucleon cross section and $\sigma_{abs} = (1 - \epsilon)\tilde{\sigma}$ ($\epsilon$ can be interpreted as the probability for the heavy particle to survive in one interaction, $\epsilon = 1$ ($\approx 0$) for open charm (charmonium)). Terms with $\sigma$ correspond to the modification (shadowing) of nucleon structure functions inside nuclei; in Eq. (10) it has been described by an eikonal model using a multi-pomeron factorized vertex, although other models could be used (as a sum of fan diagrams, i.e. the Schwimmer model, see [34, 36]).

The consequences of this approach, neglecting the modifications of nucleon structure functions inside nuclei, are the following: at high energies open charm and charmonium are equally absorbed (no $\sigma_{abs}$ appears in Eqs. (10) and (11)), see also [34]); the low
and high energy formulae differ for charmonium up to 20% at the highest energies (being the difference of order \( \tilde{\sigma} A/R_A^2 \), \( \tilde{\sigma} \simeq \sigma_{\text{abs}} \)); and the exact and probabilistic results differ \( \sim 1 \div 2 \% \) at \( \sqrt{s} = 20 \text{ GeV} \).

These results can be interpreted as follows: At low energies only the first interaction is effective for producing heavy flavor (so production is proportional to \( A \)), subsequent interactions can only absorb it. At high energies all interactions are simultaneous, so the absorption mechanism of subsequent interactions is no longer effective; instead the full multiple interaction formalism, which suppresses equally both hidden and open heavy flavor production, has to be considered. Usual factorization (i.e. separation between partonic densities and parton-parton cross sections, Eq. (31)) is broken and an additional suppression factor is always present (except for open heavy flavor production at low energies). While at finite energies it is not possible to separate in this additional factor the modification of nucleon parton densities inside nuclei from the scattering of the heavy partons, this separation is recovered at low energies (Eq. (7), where there is no modification of nucleon parton densities) and also, for fixed impact parameter \( b \), at asymptotically high energies (Eq. (10)).

Results for \( pPb \) collisions [31], in the form of the variation with energy of \( A_{\text{eff}} = A^\alpha \), are presented in Figs. 10 and 11. We use \( \tilde{\sigma} \propto (xs)^{0.08} \) (normalized to 7 mb at \( p_{\text{lab}} = 200 \text{ GeV/c} \) [3], \( \epsilon = 1 \) (0.001) for open (hidden) charm and a standard Woods-Saxon nuclear density. Just to give some estimation, the effect of nuclear structure functions has been taken into account considering it factorized and computed following [14, 26], see Section 2. It can be observed that the exact result provides a smooth transition between the low energy and the high energy regimes (the latter already reached at \( \sqrt{s} = 200 \text{ GeV} \) and that the effect of the nuclear modification of structure functions varies, at \( x_F = 0 \), from antishadowing at low energies to shadowing at high energies.

Turning back to the \( x_F \) dependence of charmonium nuclear absorption, it is clear (see for example [37]) that the modification of the nucleon parton distributions inside nuclei cannot reproduce the data: for different energies, there is no scaling of absorption
Figure 10: $A_{eff}$ versus $\sqrt{s}$ for $x_F = 0$ for charmonium and open charm production in $pPb$ collisions: exact result [31] (solid line), probabilistic formula (Eq. (7), dotted line), asymptotic formula (Eq. (11), dashed line) and exact result with nuclear modifications of structure functions as explained in the text (dashed-dotted line).

in $x_b$ (corresponding to the target nucleus), while there is approximate scaling in $x_F = x_a - x_b$. Nevertheless nuclear structure functions have to be taken into account. In Fig. 12 calculations [26] of $\alpha$ versus $x_F$ for $pW$ collisions at $p_{lab} = 800$ GeV/c are presented, with the same parameters as in Subsection 2.2; normalization is obtained using Eq. (7) with $\sigma_{abs} \simeq 6$ mb (taken constant with $x_F$). Clearly the modification of the nucleon parton distributions inside nuclei accounts for part of the effect, except at the highest $x_F$. More data, both at 800 GeV/c, as those from [38], and at lower energies, have to be examined (following e.g. the proposals of [31, 34, 39]) in order to explain the behavior of the absorption with $x_F$.

As a comment, let us stress that $\alpha$ is a misleading variable. For example, in terms
of $\alpha$ the experimental results of [37] and [38] seem to indicate some anomalous behavior at $x_F \simeq 0$ in $pA$ collisions at 800 GeV/c: absorption increases going from $x_F \simeq 0.15$ to $x_F \simeq 0.65$ and also from $x_F \simeq 0.15$ to $x_F \simeq 0$. If one expresses these results in terms of the ratio $W/C$, which can be done both for the E772 [37] and E789 [38] data, this ratio turns out to be monotonically decreasing with $x_F$ from $x_F \simeq 0$ to 0.65 ($0.780 \pm 0.074, 0.776 \pm 0.059, 0.746 \pm 0.046, 0.741 \pm 0.020, 0.729 \pm 0.034, 0.649 \pm 0.051, 0.604 \pm 0.084, 0.571 \pm 0.155$ for $x_F = -0.023, 0.032, 0.16, 0.26, 0.36, 0.46, 0.55, 0.65$ respectively, with only statistical errors taken into account). So, it follows the trend that can be seen in Fig. 12 and no strange behavior can be deduced.

4 Conclusions

Effects on heavy flavor and Drell-Yan [14] and charmonium [26] production of the modification of nucleon structure functions inside nuclei have been examined. They
are relatively small at low $x_F$, low $\sqrt{s}$ but become very important at high $x_F$ and for RHIC and LHC energies. Thus, more experimental and theoretical effort is needed to reduce the uncertainties in the extrapolation to small $x$. For charmonium nuclear absorption is, at low energies and $x_F \sim 0$, of greater importance than nuclear effects on parton densities; for higher energies or larger $x_F$ both effects have to be taken into account.

Figure 12: Comparison of $x_F$ dependence of nuclear corrections by modifications of parton densities inside nuclei with experimental data of 800 GeV/c protons incident on a tungsten target from [37]. Theoretical calculations have been normalized to one of the less shadowed experimental points (see text). Lines follow the same convention as in Fig. 6.

![Graphs showing comparison of nuclear corrections](image_url)

Formulae for nuclear production of open and hidden heavy flavor have been presented [31], using a relativistic Glauber-Gribov formalism in which the standard probabilistic formula for charmonium absorption has been derived as a low energy limit of an exact expression valid at all energies. The numerical accuracy of the probabilistic formula at available energies has been checked. A striking prediction of this approach [31, 34] is that, at high energies, open charm will asymptotically be as suppressed as charmonium.
New data [10] on $J/\psi$ suppression in $PbPb$ collisions at SPS energies have produced great excitement as a possible signal of new physics (i.e. Quark-Gluon Plasma). In view of all the uncertainties commented in this contribution, detailed tests of all our conventional ideas about open and hidden heavy flavor production off nuclei are needed before any quantitative statement on the existence of new physics in heavy ion collisions can be made.

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