Multiplicities and J/ψ suppression at the LHC

Elena G. Ferreiro

Universidad de Santiago de Compostela, Spain

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with Alfons Capella

Multiplicies: Shadowing corrections

$$\frac{dN_{AA}}{dy}(b) = a(y,b)N_{part}(b) + c(y,b)N_{coll}(b).$$

• $N_{part}(b) \propto A$: number of participant nucleons, valence-like contribution.
• $N_{coll}(b) \propto A^{4/3}$: number of inelastic nucleon-nucleon collisions, dominant at asymptotic energies.

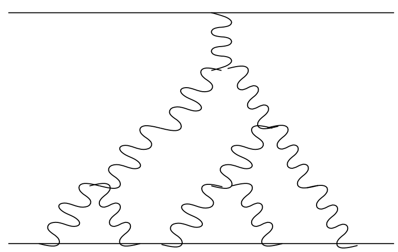
To get the right multiplicities at RHIC $\Rightarrow$ **Shadowing:**
Mechanisms that makes the nuclear structure functions in nuclei different from the superposition of those of their constituents nucleons
It increases with decreasing x and decreases with increasing Q^2

Physical meaning:

• **In the rest frame on the nucleus:** consequence of multiple scattering
(Capella, Kaidalov; Frankfurt, Strikman)

• **In a frame in which the nucleus is moving fast:** gluon recombination
Overlap of the gluon clouds from different nucleons reduces the gluon density in the nucleus

Shadowing



Dynamical, non linear shadowing
It is determined in terms of diffractive cross sections
It would lead to saturation at $s \to \infty$
Controled by triple pomeron diagrams
Contribution to diffraction: positive
Contribution to the total cross-section: negative

Reduction of multiplicity from shadowing corrections in AB collisions:

$$S_{sh} = \frac{\int d^2 s f_A(s) f_B(b-s)}{T_{AB}(s)} \; , \; f_A(b) = \frac{T_A(b)}{1 + AF(s)T_A(b)}$$

Function F: Integral of the triple P cross section over the single P one:

$$F(s) = 4\pi \int_{y_{min}}^{y_{max}} dy \frac{1}{\sigma_P(s)} \left. \frac{d^2\sigma^{PPP}}{dydt} \right|_{t=0} = C \left[\exp\left(y_{max}\right) - \exp\left(y_{min}\right) \right]$$

$y = \ln(s/M^2),\ M^2 =$ squared mass of the diffractive system
$y_{max} = \frac{1}{2}\ln(s/m_T^2),\ y_{min} = \ln(R_A m_N/\sqrt{3}),\ C =$ triple pomeron coupling

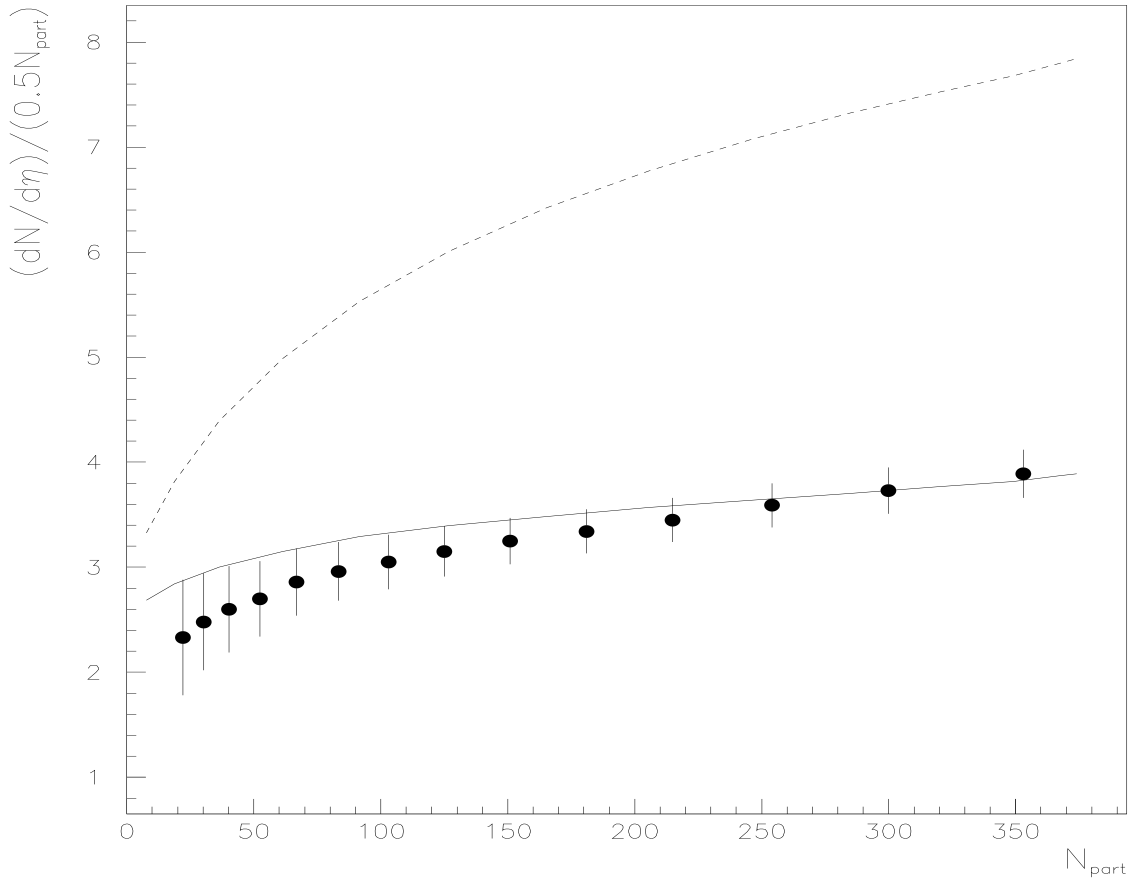
b (fm)	$Shadow(ch)$	$Shadow(J/\psi)$
0.	0.4959	0.7482
1.	0.4962	0.7485
2.	0.4973	0.7493
3.	0.5003	0.7513
4.	0.5058	0.7550
5.	0.5145	0.7607
6.	0.5268	0.7687
7.	0.5423	0.7792
8.	0.5649	0.7928
9.	0.5954	0.8109
10.	0.6318	0.8321
11.	0.6830	0.8599
12.	0.7447	0.8909
13.	0.8072	0.9200

Shadowing corrections for Au+Au collisions at RHIC

b (fm)	$Shadow(ch)$	$Shadow(J/\psi)$
0.	0.2663	0.3888
1.	0.2665	0.3889
2.	0.2674	0.3899
3.	0.2698	0.3926
4.	0.2743	0.3976
5.	0.2815	0.4055
6.	0.2920	0.4169
7.	0.3065	0.4327
8.	0.3255	0.4528
9.	0.3549	0.4829
10.	0.3908	0.5186
11.	0.4395	0.5660
12.	0.5113	0.6315
13.	0.6003	0.7071

Shadowing corrections for Pb+Pb collisions at LHC

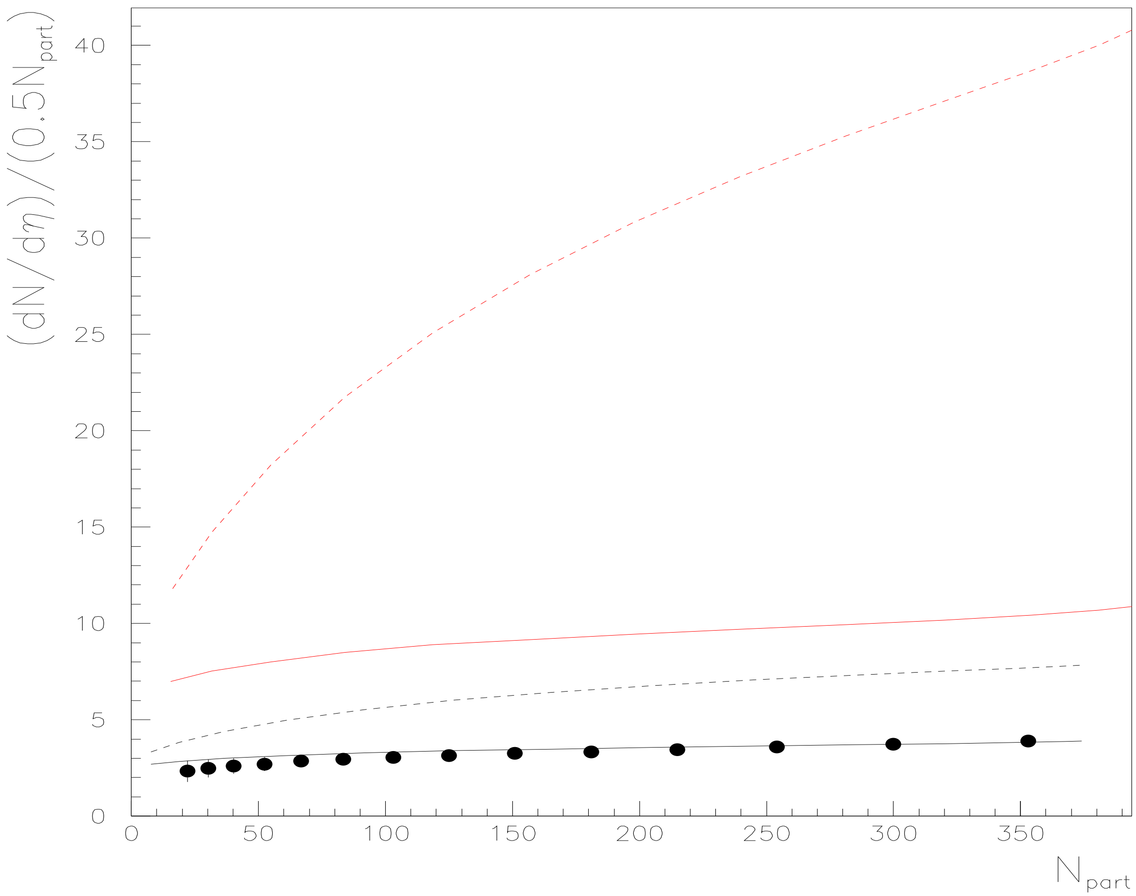
Results at RHIC



- **Maximal multiplicity in absence of shadowing:** $dN_{AA}/dy = A^{4/3}$

- **Multiplicity with shadow corrections:** $dN_{AA}/dy = A^{\alpha}$
  $\alpha = 1.13$ at RHIC
  $\alpha = 1.1$ at LHC

Predictions for LHC



Multiplicities with shadowing corrections in central Au-Au collisions at RHIC and Pb-Pb collisions at LHC energies

- - - - **LHC wo shadow**

——- **LHC w shadow**

- - - - **RHIC wo shadow**

——- **RHIC w shadow**

LHC wo shad: 6800-6000

LHC w shad: 1800-1600

J/ψ suppression: A little bit of history...

• The J/ψ production in proton-nucleus collisions is suppressed with respect to the characteristic A^1 scaling of lepton pair production (Drell-Yan pairs).

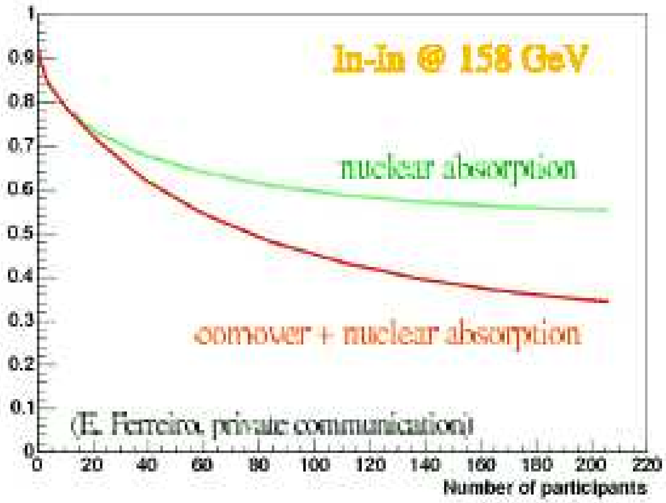
•This suppression is interpreted as a result of the multiple scattering of a pre-resonance $c\bar{c}$ with the nucleons of the nucleus: nuclear absorption.

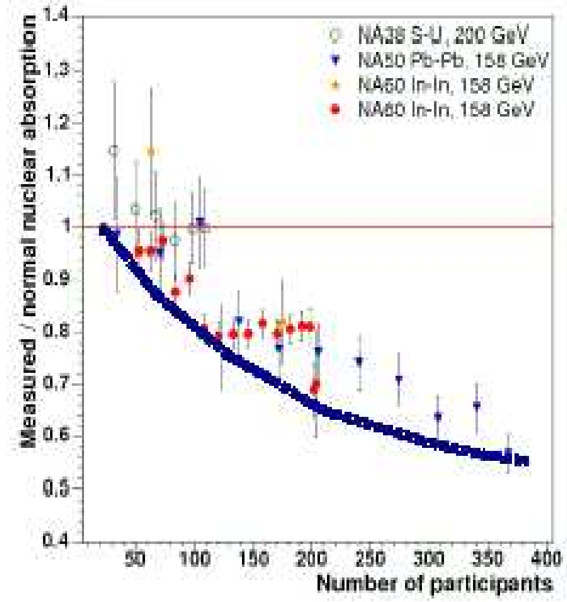
• Anomalous J/ψ suppression in $Pb - Pb$ collisions at SPS:
The suppression clearly exceeds the one expected from nuclear absorption.

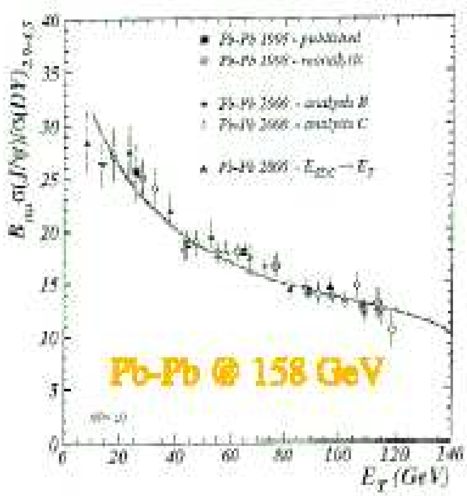
Different causes for the yield suppression:

• Such a phenomenon was predicted by Matsui and Satz as a consequence of **deconfinement in a dense medium**.

• It can also be described as a result of final state interaction of the $c\bar{c}$ pair with the dense medium produced in the collision: **comovers interaction**.







We have described the results at SPS using nuclear absorption + comovers interaction:

$\sigma_{abs} = 4.18$ mb , $\sigma_{co} = 0.65$ mb

The model

• Ratio of the J/ψ yield over the average number of binary nucleon-nucleon collisions in AB collisions:

$$R_{AB}^{J/\psi}(b) = \frac{dN_{AB}^{J/\psi}(b)/dy}{n(b)} = \frac{dN_{pp}^{J/\psi}}{dy} \frac{\int d^2s\ \sigma_{AB}(b)\ n(b,s)\ S^{abs}(b,s)\ S^{co}(b,s)}{\int d^2s\ \sigma_{AB}(b)\ n(b,s)}$$

$\sigma_{AB}(b) = 1 - \exp[-\sigma_{pp} AB T_{AB}(b)]$ where $T_{AB}(b) = \int d^2 s T_A(s) T_B(b-s)$, $T_A(b)$= profile function obtained from Wood-Saxon nuclear densities

$n(b)$= number of binary nucleon-nucleon collisions at fixed impact parameter b

• S^{abs}= survival probability due to nuclear absorption
• S^{co}= survival probability due to comovers interaction

• J/ψ yield in the absence of interactions ($S^{abs} = S^{co} = 1$) scales with the number of binary nucleon-nucleon collisions.

NUCLEAR ABSORPTION

From the probabilistic Glauber model:

$$S^{abs}(b,s) = \frac{[1-\exp(-A\ T_A(s)\ \sigma_{abs})][1-\exp(-B\ T_B(b-s)\sigma_{abs})]}{\sigma_{abs}^2\ AB\ T_A(s)\ T_B(b-s)}$$

$$S^{abs} \sim \exp[-N\sigma_{abs}L]$$

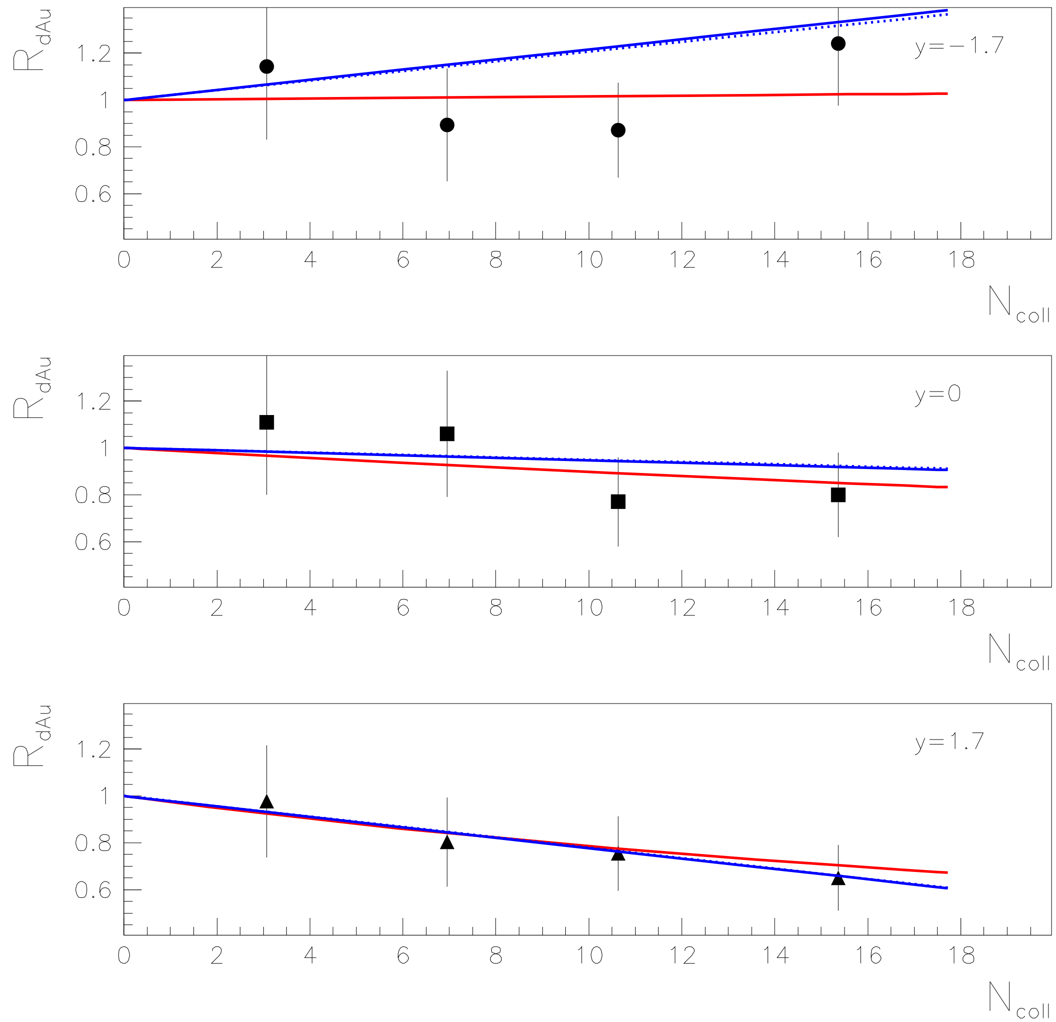
where N is the nuclear density and L denotes the path of the $c-\bar{c}$ in the nuclear medium

At SPS energies: $\sigma_{abs} = 4.18$ mb

At RHIC energies: $\sigma_{abs} = 0$ mb

Data on on dAu collisions favorize a small σ_{abs}

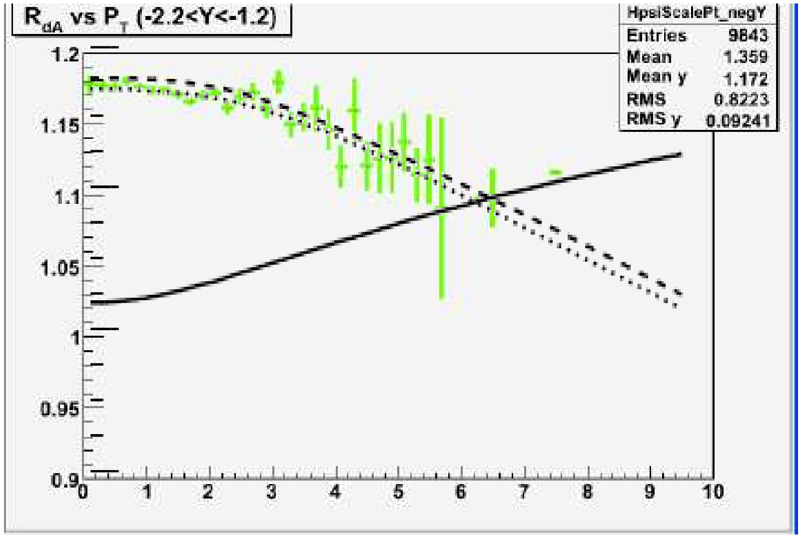
Results on J/ψ suppression for dAu collisions at RHIC

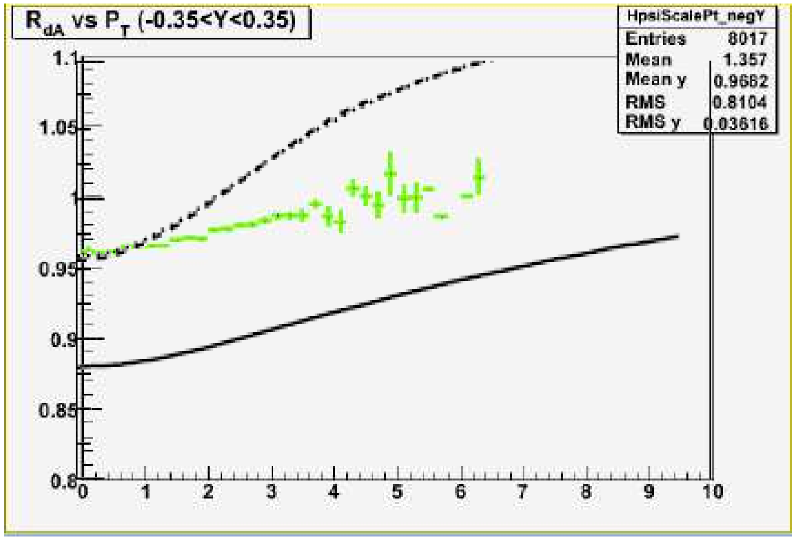


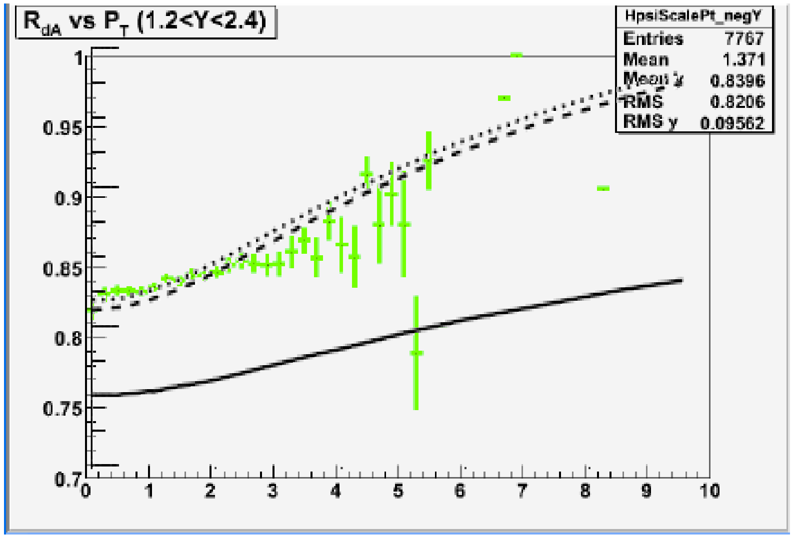
—— Results from pomeron shadowing $\sigma_{abs} = 0$

—— Results from EKS $\sigma_{abs} = 0$

RdA vs pT







Continuous line: Results from
Pomeron shadow
Discontinous lines: Results
for EKS
- - - at fixed y
……. Integrated in y

Interesting:EKS at y<0 decreases with pT

WORK IN PROGRESS (F. Fleuret, A. Rakotoza ndrabe)

COMOVERS INTERACTION

The interaction of a particle or a parton with the medium is described by the gain and loss differential equations which govern the final state interactions:

$$\tau \frac{d\rho^{J/\psi}(b,s,y)}{d\tau} = -\sigma_{co} \; \rho^{J/\psi}(b,s,y) \; \rho^{medium}(b,s,y)$$

$\rho^{J/\psi}$ and ρ^{co} are the densities of J/ψ and comovers (charged + neutral)

• We neglect a gain term resulting from the recombination of c-$\overline{c}$ into J/ψ.

The possibility of such a recombination, giving sizable effects at RHIC energies, has been considered by several authors

It will be most interesting to see whether the LHC data confirm or reject such an effect.

• Our equations have to be integrated between initial time τ_0 and freeze-out time τ_f.

• The solution depends only on the ratio τ_f/τ_0.

• We use the inverse proportionality between proper time and densities, $\tau_f/\tau_0 = \rho(b,s,y)/\rho_{pp}(y)$

$\rho_{pp}(y)$= density per unit rapidity for mb pp collisions

$\rho(b,s,y)$ = density produced in the primary collisions

• Our densities can be either hadrons or partons:

σ_{co}: **effective cross-section averaged over the interaction time**

• **Survival probability** $S_{co}(b,s)$ **of the** J/ψ **due to comovers interaction:**

$$\boxed{S^{co}(b,s) \equiv \frac{N^{J/\psi(final)}(b,s,y)}{N^{J/\psi(initial)}(b,s,y)} = \exp\left[-\sigma_{co}\ \rho^{co}(b,s,y)\ell n\left(\frac{\rho^{co}(b,s,y)}{\rho_{pp}(0)}\right)\right]}$$

The shadowing produces a decrease of the medium density

$$\rho^{co}(b,s,y) \to \rho^{co}(b,s,y)\ S^{ch}_{sh}(b,s,y)$$

Two effects:

- Shadowing corrections on comovers **increase** J/ψ survival probability S^{co}
- Shadowing corrections on J/ψ **decrease** the J/ψ yield

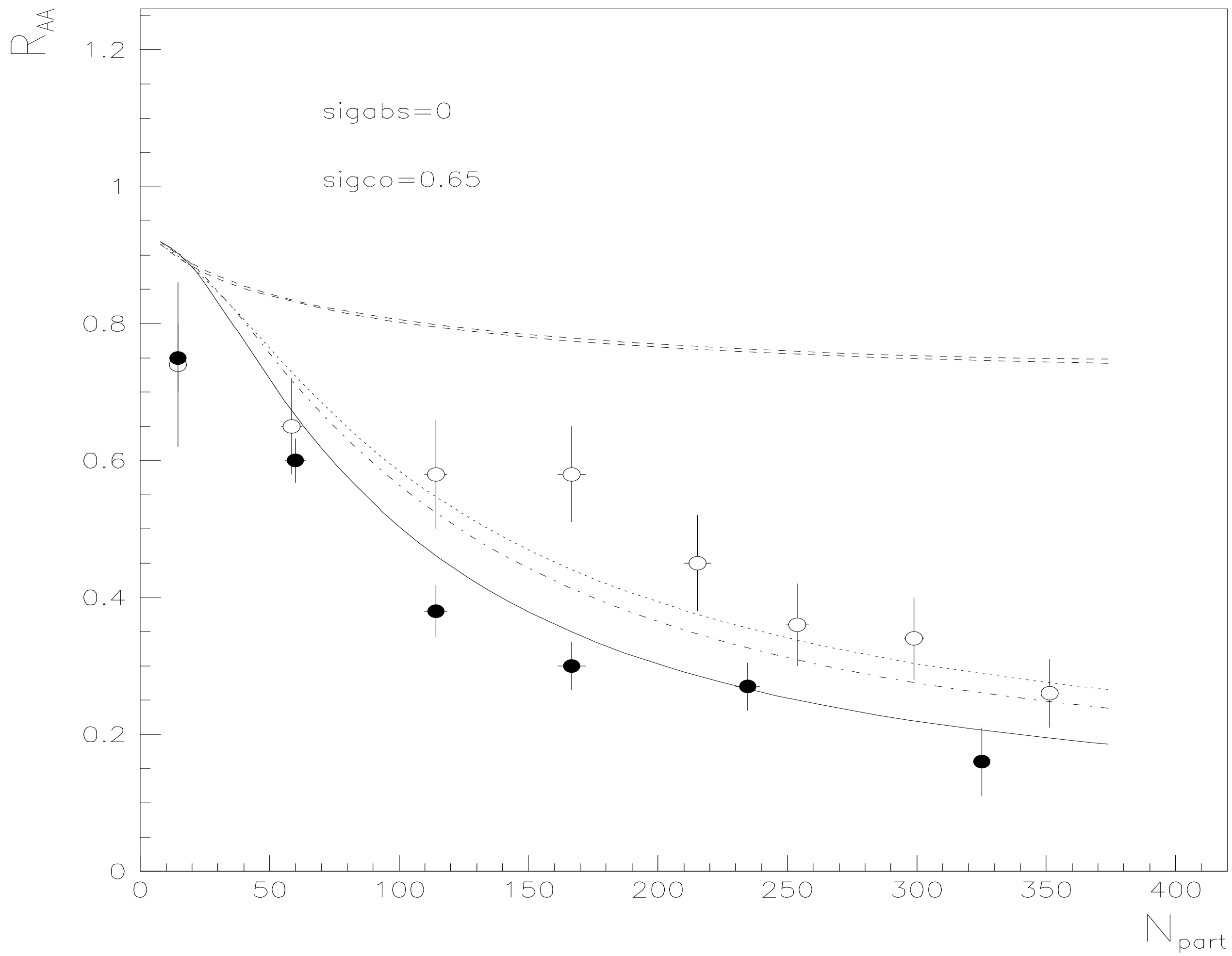
The J/ψ suppression is given by

$$\boxed{R^{J/\psi}_{AB}(b) = \frac{dN^{J/\psi}_{AB}(b)/dy}{n(b)} = \frac{dN^{J/\psi}_{pp}}{dy} \frac{\int d^2s\ \sigma_{AB}(b)\ n(b,s)\ S^{abs}(b,s)\ S^{co}(b,s)}{\int d^2s\ \sigma_{AB}(b)\ n(b,s)}}$$

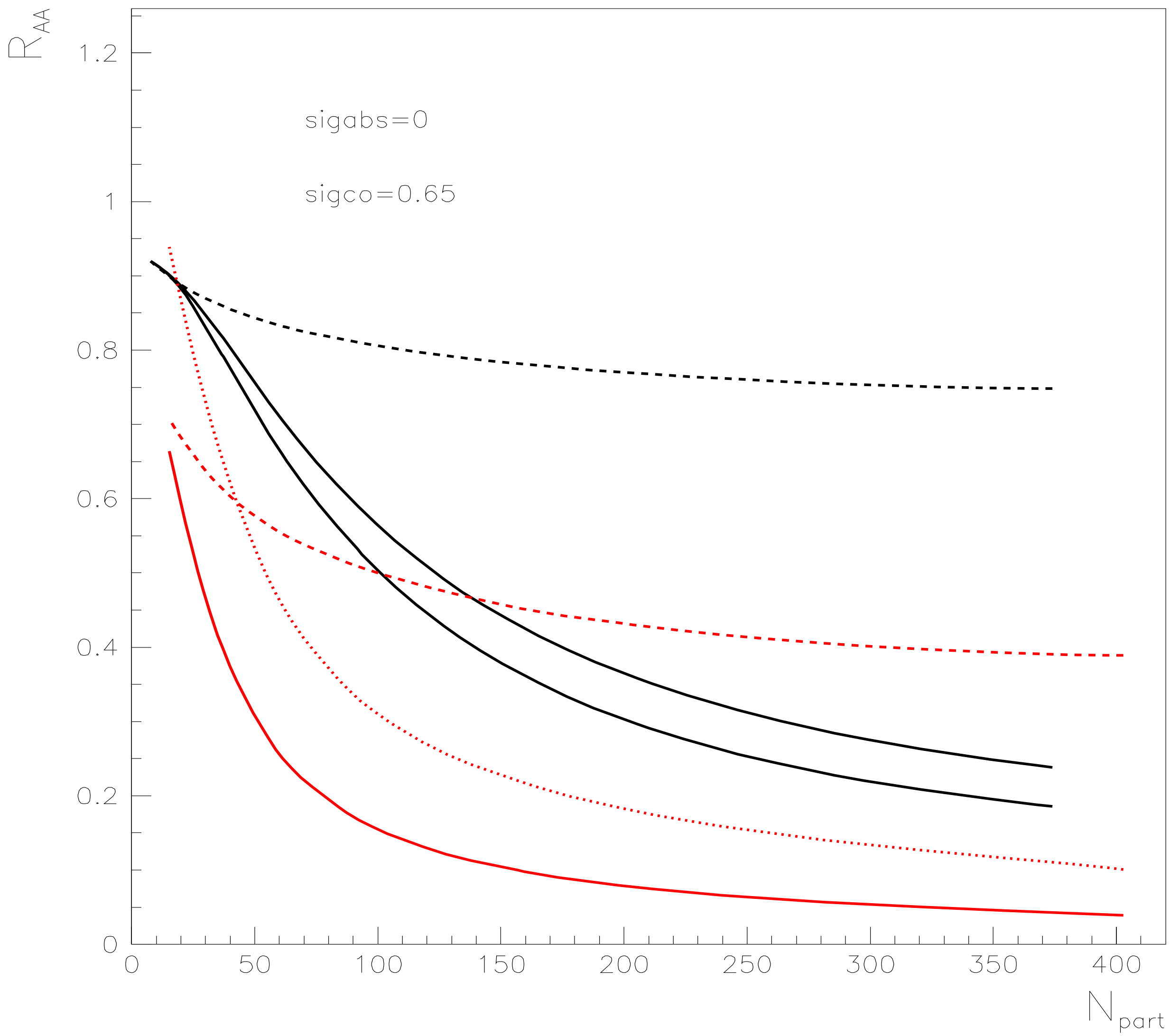
with the replacement $n(b,s) \to n(b,s)\ S^{J/\psi}_{sh}(b,s,y)$ in its numerator

Shadowing $\Rightarrow$ The J/ψ yield in the absence of interactions ($S^{abs} = S^{co} = 1$) does not longer scales with the number of binary collisions.

Results at RHIC



Predictions for LHC



- **We use the same value of the comovers cross-section, $\sigma_{co} = 0.65$ mb**

- **We neglect the nuclear absorption, $\sigma_{abs} = 0$ mb**

- **Shadowing is introduced in both the comovers and the J/ψ yields**

- **We do not include rescatering of the $c\bar{c}$ pair**

DETAILS

i) Comovers density in the dual parton model

In order to compute the survival probability S^{co} we need the comovers density N^{co} at initial time τ_0.

In the DPM

$$N^{co}_{NS}(b,s,y) = \frac{3}{2}\,\frac{dN^{ch}_{NS}}{dy}(b,s,y) = \frac{3}{2}\left[C_1(b)\ n_A(b,s) + C_2(b)\ n(b,s)\right] \quad (1)$$

$n_A(b,s) = A\ T_A(s)\left[1-\exp\left(-\sigma_{pp} B\ T_B(b-s)\right)\right]/\sigma_{AB}(b)$
$n(b,s) = AB\ \sigma_{pp}\ T_A(s)\ T_B(b-s)/\sigma_{AB}(b)$
The factor 3/2 takes care of the neutrals.

The coefficients $C_1(b)$ and $C_2(b)$ are obtained from string multiplicities which are computed in DPM as a convolution of momentum distributions functions and fragmentation functions.

These functions are universal, i.e. the same for all hadronic and nuclear processes $\Rightarrow$ We use the same expressions as at CERN energies.

b	C_1^{AuAu}	C_2^{AuAu}	C_1^{CuCu}	C_2^{CuCu}	C_1^{PbPb}	C_2^{PbPb}	C_1^{InIn}	C_2^{InIn}
0	1.0274	1.7183	1.0330	1.8196	0.7102	0.3975	0.7480	0.4312
1	1.0276	1.7206	1.0334	1.8239	0.7115	0.3987	0.7485	0.4317
2	1.0278	1.7228	1.0338	1.8320	0.7152	0.4020	0.7527	0.4357
3	1.0286	1.7340	1.0342	1.8437	0.7208	0.4070	0.7599	0.4428
4	1.0293	1.7448	1.0347	1.8592	0.7283	0.4136	0.7696	0.4526
5	1.0302	1.7574	1.0352	1.8787	0.7376	0.4218	0.7810	0.4646
6	1.0310	1.7722	1.0357	1.9014	0.7488	0.4320	0.7945	0.4793
7	1.0320	1.7908	1.0361	1.9258	0.7617	0.4445	0.8112	0.4985
8	1.0330	1.8121	1.0364	1.9505	0.7764	0.4597	0.8290	0.5198
9	1.0340	1.8374	1.0364	1.9754	0.7929	0.4776	0.8475	0.5430
10	1.0349	1.8665	1.0363	2.0006	0.8112	0.4985	0.8664	0.5681
11	1.0357	1.8990	1.0360	2.0259	0.8308	0.5220	0.8855	0.5949
12	1.0362	1.9308	1.0356	2.0515	0.8503	0.5466	0.9046	0.6235
13	1.0364	1.9580	1.0349	2.0772	0.8673	0.5698	0.9233	0.6536

Table 1: Values of C_1 and C_2 in eq. (1) as a function of the impact parameter b. The second and third columns correspond to $AuAu$ collisions and the forth and fifth to $CuCu$ collisions both at $\sqrt{s} = 200$ GeV. The values, calculated in the range $-0.35 < y^* < 0.35$, are given per unit rapidity. The following columns refer to $PbPb$ and $InIn$ at $p_{lab} = 158$ GeV/c and are computed in the rapidity range of the NA50 dimuon trigger $0 < y^* < 1$.

• We see from Table 1 that C_2 is significantly larger than C_1 at RHIC energies.

⇒ DPM multiplicities: closer to a scaling with the number of binary collisions rather than to a scaling with the number of participants.

• With increasing energies the ratio C_2/C_1 increases and one obtains a scaling in the number of binary collisions.

This is a general property of Gribov's Reggeon Field Theory which is known as AGK cancellation – analogous to the factorization theorem in perturbative QCD and valid for soft collisions in the absence of triple Pomeron diagrams.

It is well known that this behaviour is inconsistent with data which show a much smaller increase with centrality.

Such a discrepancy is due to **shadowing** which is important at RHIC energies and has not been taken into account in eq. (1). This is precisely the meaning of label NS (no shadowing) in this equation.

Due to coherence conditions, shadowing effects for partons take place at very small x, $x \ll x_{cr} = 1/m_N R_A$ where m_N is the nucleon mass and R_A is the radius of the nucleus.

Partons which produce a state with transverse mass m_T and a given value of Feynman x_F, have $x = x_\pm = \frac{1}{2}(\sqrt{x_F^2 + 4m_T^2/s} \pm x_F)$

Our shadowing applies to soft and hard processes. Nevertheless, for large p_T these effects are important only at very high energies, when $x \sim \frac{m_T}{\sqrt{s}}$ satisfies the above condition.

At fixed initial energy (s) the condition for existence of shadowing will not be satisfied at large transverse momenta: In the central rapidity region $(y^* = 0)$ at RHIC and for p_T of jets (particles) above 5(2) GeV/c the condition for shadowing is not satisfied and these effects are absent.

If the triple pomeron coupling is small:

$[1 + AF(s)T_A(b)]^{-1} \sim 1 - AF(s)T_A(b) \Rightarrow$ Only the contribution of the triple P graph is involved in the shadowing

If the triple pomeron coupling is large:

One needs to sum all of fan diagrams with Pomeron branchings (Schwimmer model) $\Rightarrow [1 + AF(s)T_A(b)]^{-1}$

In the limit of large triple pomeron coupling:

$[1 + AF(s)T_A(b)]^{-1} \sim [AF(s)T_A(b)]^{-1}$

A-dependence: $\frac{dN_{AA}}{dy} \sim A^{4/3}$ changes to $\frac{dN_{AA}}{dy} \sim A^{2/3}$

Our result for AA at RHIC energies: $\frac{dN_{AA}}{dy} \sim A^{1.13}$

Comparison with the saturation model

In the saturation regime ($\Lambda_{QCD} << p_T < Q_s$:)

$$\frac{dN}{dyd^2p_T} \sim \frac{A^{2/3}}{\alpha_s(Q_s^2)}$$

Same result as for maximal shadowing

First correction: Integrating over d^2p_T up to Q_s and assuming a p_T broadening corresponding to $Q_s^2 \sim A^{1/3}$:

$$\frac{dN}{dy} \sim xG(x, Q_s^2) = \frac{\pi R_A^2 Q_s^2(x, A)}{\alpha_s(Q_s^2)} \sim \frac{A}{\alpha_s(Q_s^2)}$$

Second correction: $\alpha_s^{-1}(Q_s^2) \sim log A^{1/3}$

Problem: a p_T broadening in $A^{1/3}$ is too large

Third correction: $\alpha_s^{-1} \sim log[(0.61 + 0.39(\frac{N_{part}(b)}{N_{part_{max}}})^{1/3})/0.6]$

b (fm)	$Shadow$
0	0.656
2	0.657
4	0.664
6	0.681
8	0.712
10	0.763
12	0.843

Shadowing corrections, integrated over p_T, for Au+Au collisions at RHIC

Diffraction

The total cross section:

$$\begin{aligned}
\sigma_{tot}(x,Q^2) &= \int_0^{r_0} d^2r \int_0^1 d\alpha\, |\Psi^{T,L}_{\gamma^* q}(\alpha,r)|^2\, \sigma^{dipole}_{CFKS}(x,r) \\
\sigma^{dipole}_{CFKS}(x,r) &= 4 \int d^2b\ \sigma^{n\,I\!P}(x,Q^2,b,r) \\
\sigma^{n\,I\!P}(x,Q^2,b,r) &\simeq 1 - \exp[-\,r^2 \chi^{n\,I\!P}(x,Q^2,b)\,]
\end{aligned}$$

Single Pomeron exchange amplitude:

$$\chi^{I\!P}(s,b,Q^2) \simeq \frac{C_{I\!P}}{R(x,Q^2)} \left(\frac{Q^2}{s_0+Q^2}\right)^{\varepsilon_{I\!P}} x^{-\varepsilon_{I\!P}} \exp[-b^2/R(x,Q^2)]\,.$$

The resummation of the triple-Pomeron branches is encoded in the denominator of the amplitude $\chi^{n\,I\!P}$, i.e. the Born term in the eikonal expansion.

$$\chi^{n\,I\!P}(x,Q^2,b) = \frac{\chi^{I\!P}(x,Q^2,b)}{1 + a\chi_3(x,Q^2,b)}$$

where the constant a depends on the proton-Pomeron and the triple-Pomeron couplings at zero momentum transfer ($t=0$).

Diffractive cross section:

$$\sigma_{diff}(x, Q^2) \quad = \quad 4 \int d^2b(\sigma_{tot}(b, x, Q^2))^2$$

We assume longitudinal boost invariance. Therefore, the above picture is not valid in the fragmentation regions.

We assume that the dilution in time of the densities is only due to longitudinal motion: Transverse expansion is neglected. The fact that HBT radii are similar at SPS and RHIC and of the order of magnitude of the nuclear radii, seems to indicate that this expansion is not large. The effect of a small transverse expansion can presumably be taken into account by a small change of the final state interaction cross-section.

The logarithmic factor in Eq. 3 is the result of an integration in the proper time τ from the initial time to freeze-out time. (One assumes a decrease of densities with proper time in $1/\tau$.) A large contribution to this integral comes from the few first fm/c after the collision – where the system is in a pre-hadronic stage. Actually, Brodsky and Mueller introduced the comover interaction as a coalescence phenomenon at the partonic level.

At RHIC $N_{pp}(0) = 2.24$ fm^{-2}. This density is about 90 % larger than at SPS energies. Since the corresponding increase in the AA density is comparable, the average duration time of the interaction will be approximately the same at CERN-SPS and RHIC, about 5 to 7 fm.

We neglect transverse expansion.

We assume a dilution in time of the densities due to longitudinal motion which leads to a τ^{-1} dependence on proper time τ.

The solution is invariant under the change $\tau \rightarrow c\tau$
$\Rightarrow$ the result depends only on the ratio τ_f/τ_0 of final over initial time.

Using the inverse proportionality between proper time and densities:

$$\tau_f/\tau_0 = N^{co}(b,s,y)/N_{pp}(y)$$

$\Rightarrow$ we assume that the interaction stops when the densities have diluted, reaching the value of the pp density at the same energy.

At $\sqrt{s} = 200$ GeV and $y^* \sim 0$, $N_{pp}(0) = \frac{3}{2}\frac{(\frac{dN^{ch}}{dy})^{pp}_{y^*=0}}{\pi R_p^2} \sim 2.24$ fm^{-2}.
At CERN-SPS $N_{pp}(0) \sim 1.15$ fm^{-2}

The corresponding increase in the $AuAu$ densities is the same
$\Rightarrow$ the average value of τ_f/τ_0 is about the same at the two energies $\sim 5 \div 7$

Derivation of the suppression factor S_{π^0}

Gain and loss diferential equation for pions:

$$\frac{d\rho_{\pi^0}(x,p_T)}{d^4x} = -\widetilde{\sigma}\ \rho_{medium}\left[\rho_{\pi^0}(x,p_T) - \rho_{\pi^0}(x,p_T+\delta p_T)\right]$$

This is equivalet to the loss equation for the J/ψ suppression due to its interaction with comovers:

$$\frac{d\rho_{J/\psi}(x)}{d^4x} = -\sigma_{co}\ \rho_h(x)\rho_{J/\psi}(x),\ \text{where } dx^4 = \tau d\tau dy ds^2$$

Since $\rho(\tau,y,s) = \rho(y,s)\frac{\tau_0}{\tau}$ –dilution on time of densities–:

$$\frac{\tau d\rho_{\pi^0}}{d\tau} = -\widetilde{\sigma}\ \rho_{medium}\ \rho_{\pi^0}(b,s,y,p_T) + \widetilde{\sigma}\ \rho_{medium}\ \rho_{\pi^0}(b,s,y,p_T+\delta p_T)$$

Putting $\rho(y,s,b) = dN/dyds^2db$, we obtain:

$$\tau \, \frac{dN_{\pi^0}(b,s,y,p_T)}{d\tau} = -\widetilde{\sigma} N_{medium}(b,s,y) N_{\pi^0}(b,s,y,p_T) \left[1 - \frac{N_{\pi^0}(b,s,y,p_T+\delta p_T)}{N_{\pi^0}(b,s,y,p_T)}\right]$$

$$dN_{\pi^0}(b,s,y,p_T) = -\widetilde{\sigma} N_{medium}(b,s,y) N_{\pi^0}(b,s,y,p_T) \left[1 - \frac{N_{\pi^0}(b,s,y,p_T+\delta p_T)}{N_{\pi^0}(b,s,y,p_T)}\right] \frac{d\tau}{\tau}$$

After integration:

$$N_{\pi^0}(b,s,y,p_T)|_{\tau_f} - N_{\pi^0}(b,s,y,p_T)|_{\tau_0} =$$

$$-\widetilde{\sigma} N(b,s,y) N_{\pi^0}(b,s,y,p_T) \left[1 - \frac{N_{\pi^0}(b,s,y,p_T+\delta p_T)}{N_{\pi^0}(b,s,y,p_T)}\right] \ell n \left(\frac{\tau_f}{\tau_0}\right)$$

All densities in the r.h.s. are at initial time, τ_0, so:

$$N_{\pi^0}(b,s,y,p_T)|_{\tau_f} =$$

$$N_{\pi^0}(b,s,y,p_T)_{\tau_0} \left[1 - \widetilde{\sigma} \left[1 - \frac{N_{\pi^0}(b,s,y,p_T+\delta p_T)}{N_{\pi^0}(b,s,y,p_T)}\right] N(b,s,y) \ell n \left(\frac{\tau_f}{\tau_0}\right)\right]$$

and for a finite formation time,

$$N_{\pi^0}(b,s,y,p_T)|_{\tau_f} =$$

$$N_{\pi^0}(b,s,y,p_T)_{\tau_0} \exp\left\{-\widetilde{\sigma}\left[1-\frac{N_{\pi^0}(b,s,y,p_T+\delta p_T)}{N_{\pi^0}(b,s,y,p_T)}\right] N(b,s,y)\ell n\left(\frac{\tau_f}{\tau_0}\right)\right\}$$

$$= N_{\pi^0}(b,s,y,p_T)_{\tau_0}\widetilde{S}\ ,$$

where the suppression factor is:

$$\widetilde{S}_{\pi^0}(b,s,y,p_T) = \exp\left\{-\widetilde{\sigma}\left[1-\frac{N_{\pi^0}(b,s,y,p_T+\delta p_T)}{N_{\pi^0}(b,s,y,p_T)}\right] N(b,s,y)\ell n\left(\frac{\tau_f}{\tau_0}\right)\right\}\ .$$

Since $N \sim 1/\tau \Rightarrow \tau_f = 1/N_f = 1/N_{pp},\ \tau_0 = 1/N(b,s,y) = 1/N_{medium}$

$$\widetilde{S}_{\pi^0}(b,s,y,p_T) = \exp\left\{-\widetilde{\sigma}\left[1-\frac{N_{\pi^0}(b,s,y,p_T+\delta p_T)}{N_{\pi^0}(b,s,y,p_T)}\right] N(b,s,y)\ell n\left(\frac{N(b,s,y)}{N_{pp}(y)}\right)\right\}\ .$$

Comovers interactions: Partons or hadrons?

We can divide our suppression factor

$$S^{co}(b,s) \equiv \frac{N^{J/\psi(final)}(b,s,y)}{N^{J/\psi(initial)}(b,s,y)} = \exp\left[-\sigma_{co}\, N^{co}(b,s,y)\ell n\left(\frac{N^{co}(b,s,y)}{N_{pp}(0)}\right)\right]$$

where the log term corresponds to:

$$\ell n\left(\frac{N(b,s,y)}{N_{pp}(y)}\right) = \ell n\left(\frac{\tau_f}{\tau_0}\right)$$

in two parts:

Partonic: From initial density $N(b,s,y) = \frac{dN/dy}{\pi R_A^2} \sim \frac{1000}{\pi R_A^2}$ to $\frac{dN/dy}{\pi R_A^2} \sim \frac{300}{\pi R_A^2}$, or equivalently from $\tau_0 = 1$ fm to $\tau_p = 3.36$ fm

Hadronic: From partonic density $\frac{dN/dy}{\pi R_A^2} \sim \frac{300}{\pi R_A^2}$ to $N_{pp}(y) = \frac{dN/dy}{\pi R_{pp}^2} = 2.24$ fm^{-2}, or equivalently from $\tau_p = 3.36$ fm to $\tau_f = 5 - 7$ fm

We find that:

75% of the effect takes place in the partonic phase

25% of the effect takes place in the hadronic phase