Multiplicities, J/ψ suppression, Fixed p_T suppression and Elliptic Flow at the LHC

Elena Ferreiro
Departamento de Física de Partículas
Universidade de Santiago de Compostela, 15782 Santiago de Compostela, SPAIN

1 Introduction

Using a model that takes into account shadowing effects in the initial state and final interactions with the hot medium, we present our results on multiplicities, J/ψ suppression, fixed p_T suppression and elliptic flow at RHIC energies, compared to the existing experimental data. We also show our predictions at LHC energies. Concerning the multiplicities, we obtain 1800 charged particles at LHC and the J/ψ suppression, in absence of recombination effects, increases by a factor 5 to 6 compared to RHIC. The increase in the medium density between these two energies (by a factor close to three) produces an increase of the fixed $p_\perp$ π^0 suppression by a factor 2 at large $p_\perp$ and of v_2 by a factor 1.5. We have used in all calculations the same final state interaction cross-section both at RHIC and at LHC energies.

2 Multiplicities with shadowing corrections

Multiplicities are usually considered as the addition of two contributions: one proportional to number of participant nucleons A and a second one proportional to the number of inelastic nucleon-nucleon collisions $A^{4/3}$, dominant at asymptotic energies. In order to get the right multiplicities at RHIC, different mechanisms in the initial state -*shadowing*-, that lower the total multiplicity, have to be taken into account. The shadowing makes the nuclear structure functions in nuclei different from the superposition of those of their constituents nucleons. Its effect increases with decreasing x and decreases with increasing Q^2. We have included a dynamical, non linear shadowing [1], controlled by triple pomeron diagrams. It is determined in terms of the diffractive cross sections. Our results for charged particles multiplicities at RHIC and LHC energies are presented in Fig. 1. In absence of shadowing we obtain a maximal multiplicity, $dN_{AA}/dy = A^{4/3}$. With shadowing corrections the multiplicity behaves as $dN_{AA}/dy = A^\alpha$, with $\alpha = 1.13$ at RHIC and $\alpha = 1.1$ at LHC.

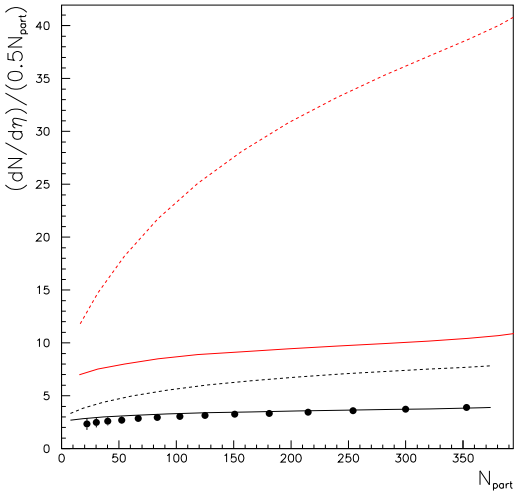

Figure 1: Multiplicities of charged particles with (solid lines) and without (dashed lines) shadowing corrections at RHIC and LHC.

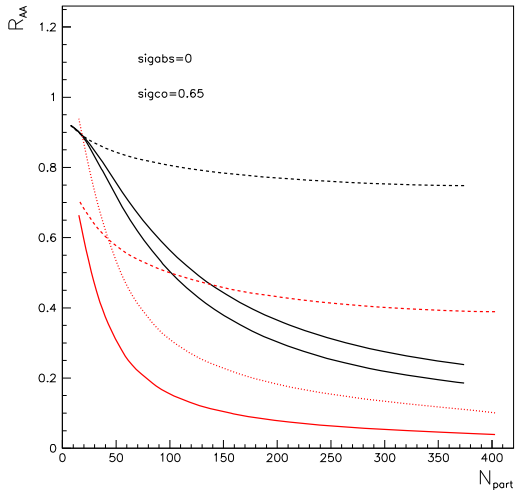

Figure 2: J/ψ production at RHIC and LHC. Dashed: J/ψ shadowing, pointed: comovers suppression, continuous: total suppression.

3 J/ψ suppression

The J/ψ production in proton-nucleus collisions is suppressed with respect to the characteristic A^1 scaling of lepton pair production. This suppression is generally interpreted as a result of the multiple scattering of a pre-resonance $c\overline{c}$ with the nucleons of the nucleus: *nuclear absorption*. An anomalous J/ψ suppression -that clearly exceeds the one expected from nuclear absorption- has been found in $PbPb$ collisions at SPS. 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 $c\overline{c}$ pair with the dense medium produced in the collision: *comovers interaction* [2].

Here we present our results for the ratio of the J/ψ yield over the average number of binary nucleon-nucleon collisions at RHIC and LHC energies:

$$R_{AB}^{J/\psi}(b) = \frac{dN_{AB}^{J/\psi}(b)/dy}{n(b)} = \frac{dN_{pp}^{J/\psi}}{dy} \frac{\int d^2s\ \sigma_{AB}(b)\ n(b,s)\ S^{abs}(b,s)\ S^{co}(b,s)}{\int d^2s\ \sigma_{AB}(b)\ n(b,s)} \ . \qquad (1)$$

S^{abs} refers to the survival probability due to nuclear absorption and S^{co} is the survival probability due to the medium interactions. The data on dAu collisions at RHIC favorize a small $\sigma_{abs} = 0$ mb, so $S^{abs} = 1$ [3]. 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:

$$\tau \frac{d\rho^{J/\psi}(b,s,y)}{d\tau} = -\sigma_{co}\ \rho^{J/\psi}(b,s,y)\ \rho^{medium}(b,s,y)\ , \tag{2}$$

where $\rho^{J/\psi}$ and $\rho^{co} = \rho^{medium}$ are the densities of J/ψ and comovers. We neglect a gain term resulting from the recombination of c-$\overline{c}$ into J/ψ. Our equations have to be integrated between initial time τ_0 and freeze-out time τ_f. We use the inverse proportionality between proper time and densities, $\tau_f/\tau_0 = \rho(b,s,y)/\rho_{pp}(y)$. Our densities can be either hadrons or partons, so σ_{co} represents an effective cross-section averaged over the interaction time. We obtain the survival probability $S_{co}(b,s)$ of the J/ψ due to the medium interaction:

$$S^{co}(b,s) \equiv \frac{N^{J/\psi(final)}(b,s,y)}{N^{J/\psi(initial)}(b,s,y)} = \exp\left[-\sigma_{co}\ \rho^{co}(b,s,y)\ell n\left(\frac{\rho^{co}(b,s,y)}{\rho_{pp}(0)}\right)\right]\ . \tag{3}$$

The shadowing produces a decrease of the medium density. Because of this, the shadowing corrections on comovers increase the J/ψ survival probability S^{co}. On the other side, the shadowing corrections on J/ψ decrease the J/ψ yield. Our results for RHIC and LHC are presented in Fig. 2. We use the same value of the comovers cross-section, $\sigma_{co} = 0.65$ mb that we have used at SPS energies. We neglect the nuclear absorption, $\sigma_{abs} = 0$ mb. The shadowing is introduced in both the comovers and the J/ψ yields.

4 π^0 Fixed $p_\perp$ suppression

Final state interaction (FSI) effects have been observed in AA collisions. They are responsible of strangeness enhancement, J/ψ suppression, fixed $p_\perp$ supression, azimuthal asymmetry, ... The question is if one should consider those observables as the manifestation of the formation of a new state of matter or if they can be described in a FSI model with no reference to an equation of state, hydrodynamics and thermalization. We take the latter view and try to describe all these observables within a unique formalism : the well known gain and loss differential equations, also used to described the J/ψ suppression. We assume [4] that, at least for particles with $p_\perp$ larger than $< p_\perp >$, the interaction with the hot medium produces a $p_\perp$-shift $\delta p_\perp$ towards lower values and thus the yield at a given $p_\perp$ is reduced. There is also a gain term due to particles produced at $p_\perp + \delta p_\perp$. Due to the strong decrease of the $p_\perp$-distributions with increasing $p_\perp$, the loss is much larger than the gain. Assuming boost invariance and dilution of the densities in $1/\tau$ due to longitudinal expansion, we obtain

$$\frac{\tau dN_{\pi^0}(b,s,p_\perp)}{d\tau} = -\sigma N(b,s)\left[N_{\pi^0}(b,s,p_\perp) - N_{\pi^0}(b,s,p_\perp + \delta p_\perp)\right] \tag{4}$$

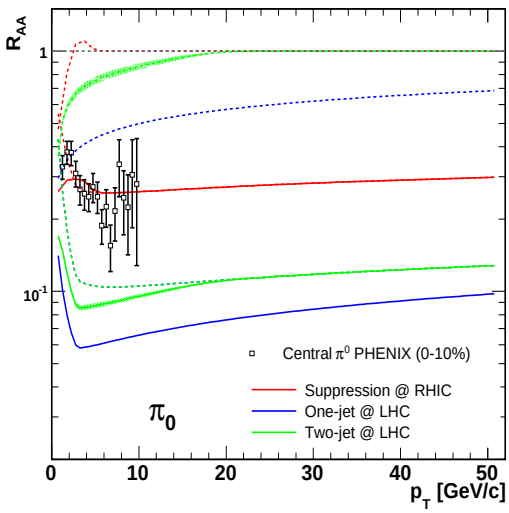

Figure 3: From up to down: RHIC initial, 2 LHC initial, RHIC final, LHC FSI, LHC FSI+shadowing.

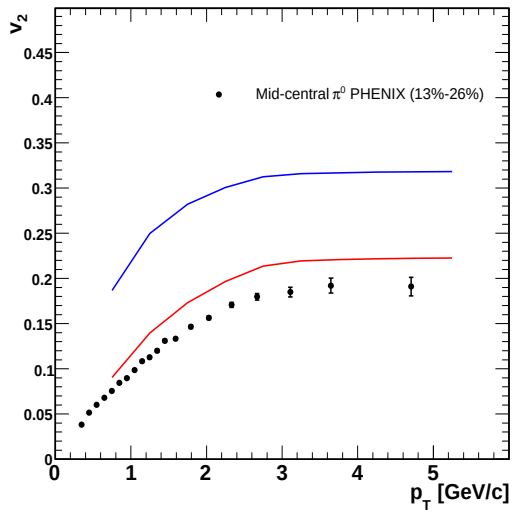

Figure 4: v_2 for π^0 at RHIC (lower curve) and LHC (upper curve).

Here $N \equiv dN/dyd^2s$ is the transverse density of the medium and N_{π^0} the corresponding one of the π^0 [5]. This has to be integrated between initial time τ_0 and freeze-out time τ_f. The solution depends only on τ_f/τ_0. We use $\sigma = 1.4$ mb at both energies and $\delta p_\perp = p_\perp^{1.5}/20$ for $p_\perp < 2.9$ GeV and $\delta p_\perp = p_\perp^{0.8}/9.5$ for $p_\perp > 2.9$ GeV [6]. Eq. (4) at small τ describes an interaction at the partonic level. Indeed, here the densities are very large and the hadrons not yet formed. At later times the interaction is hadronic. Most of the effect takes place in the partonic phase. We use a single (effective) value of σ for all values of the proper time τ.

The results at RHIC and LHC are given in Fig. 3. At LHC only shadowing has been included in the initial state. The suppression is given by the dashed line. It coincides with R_{AA} for $p_\perp$ large enough – when shadowing and Cronin effects are no longer present. The LHC suppression is thus a factor of two larger than at RHIC.

5 Elliptic flow

Final state interaction in our approach gives rise to a positive v_2 [6] (no need for an equation of state or hydro). Indeed, when the π^0 is emitted at $\theta_R = 90°$ its path length is maximal (maximal absorption). In order to compute it we assume that the density of the hot medium is proportional to the path length $R_{\theta_R}(b, s)$ of the π^0 inside the interaction region determined by its transverse position $s$and its azimuthal angle θ_R.

Hence, we replace $N(b,s)$ by $N(b,s)R_{\theta_R}(b,s)/ < R_{\theta_R}(b,s) >$ where R_{θ_R} is the π^0 path length and $<>$ denotes its average over θ_R. (In this way the averaged transverse density $N(b,s)$ is unchanged). The suppression $S_{\pi^0}(b,s)$ depends now on θ_R and v_2 is given by

$$v_2(b,p_\perp) = \frac{\int d\theta_R S_{\pi^0}(b,p_\perp,\theta_R)\cos 2\theta_R}{\int d\theta_R S_{\pi^0}(b,p_\perp,\theta_R)} \tag{5}$$

The results at RHIC and LHC are presented in Fig. 4.

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