Magnetic Field Effect on Charmonium Formation in High Energy Nuclear Collisions

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Abstract

We study the effect of the magnetic field on the charmonium formation and anisotropic distribution in Pb+Pb collisions at the LHC energy. The time dependent Schrödinger equation is employed to describe the motion of $c\bar{c}$ pairs. We compare our model prediction of non-collective anisotropic parameter v_2 of J/ψs with CMS data at high transverse momentum. This is the first attempt to measure the magnetic field in high energy nuclear collisions.

Motivation

Magnetic field at the early stage of heavy ion collisions:

- $B \sim (1-100)m_\pi^2$
- $\tau \sim 0.1fm$

High p_T charmonia as an ideal probe of the field:

- Created at very early stage
- Sensitive to the magnetic field
- Able to survive the QGP

Hamiltonian in the Magnetic Field

Consider an averaged magnetic field **B** along the $y-$axis in the space-time region determined by the colliding energy and nuclear geometry

$$\mathbf{B} = \begin{cases} B\mathbf{e}_y, & 0 < t < t_B, \quad \frac{x^2}{(R_A-b/2)^2} + \frac{y^2}{(b/2)^2} + \frac{\gamma_c^2 z^2}{(b/2)^2} < 1, \\ 0, & \text{others.} \end{cases}$$

The Hamiltonian:

$$\hat{H} = \frac{(\vec{p}_c - q_c\vec{A}_c)^2}{2m_c} + \frac{(\vec{p}_{\bar{c}} - q_{\bar{c}}\vec{A}_{\bar{c}})^2}{2m_c} - \frac{(q_c\vec{s}_c + q_{\bar{c}}\vec{s}_{\bar{c}})\cdot\vec{B}}{m_c} + V_{c\bar{c}}(r)$$
$$= \hat{H}_0 + \hat{H}_B$$

The magnetic field dependent part:

$$\hat{H}_B = -\frac{q_c}{m_c}(\vec{S}_a - \vec{S}_b)\cdot\vec{B} - \frac{q_c}{2m_c}\vec{P}_{ps}\times\vec{B}\cdot\vec{r} + \frac{q^2}{4m_c}(\vec{B}\times\vec{r})^2$$

$$V_{c\bar{c}}(r) \neq V_{cornell}(r) = -\frac{\alpha}{r} + \sigma r$$

However $\frac{eBP}{2m_c}/\sigma \sim 10$ for $B = 25m_\pi^2$ and $P = 10GeV$.
So magnetic interaction dominates the $c\bar{c}$ evolution!

Initial Wave Function

We take a compact Gaussian wave package as initial wave function:

$$\Phi_r(0) \sim e^{-\frac{(\mathbf{r}-\mathbf{r}_0)^2}{\sigma_0^2}}$$

The parameters r_0 and σ_t is determined by fitting charmonium fractions in p+p collisions with:

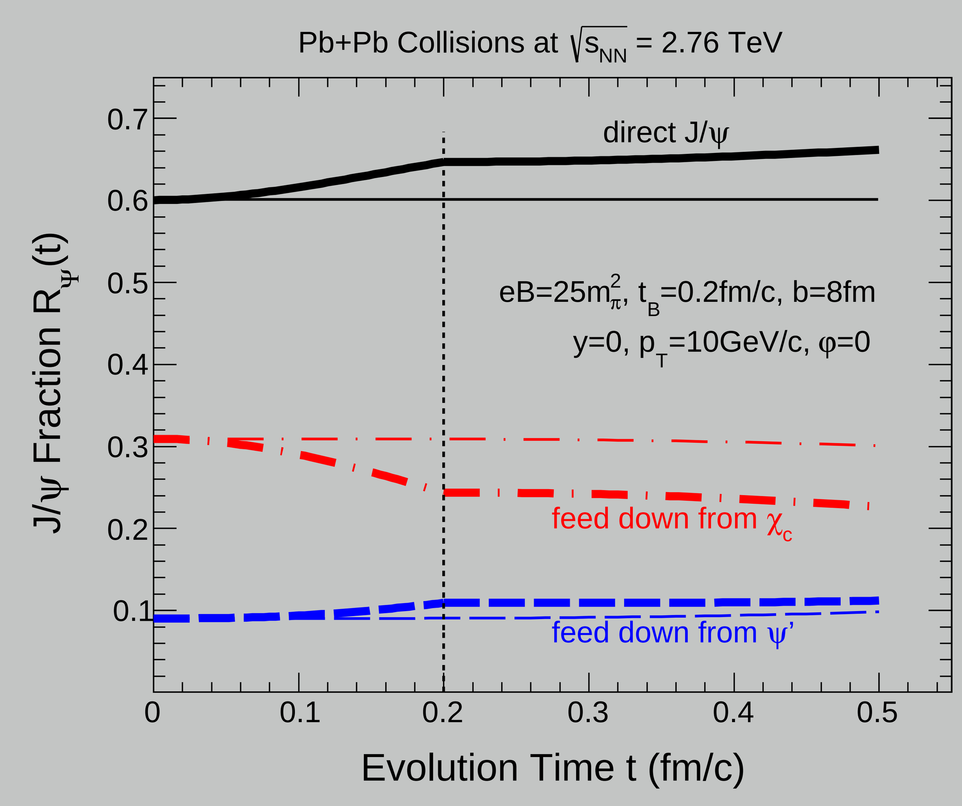
$$\Phi_r(t) \sim \int d^3\mathbf{r}' e^{-\frac{(\mathbf{r}'-\mathbf{r}_0)^2}{\sigma_0^2}} e^{-\frac{(\mathbf{r}-\mathbf{r}')^2}{v^2t^2}} \sim e^{-\frac{(\mathbf{r}-\mathbf{r}_0)^2}{\sigma_t^2}}$$

Conclusions

- The strong magnetic field changes significantly the $c\bar{c}$ evolution in the very initial stage.
- The magnetic field causes strong and anisotropic enhancement or suppression to charmonium states.
- The anisotropic formation leads to a non-collective v_2 at high p_T that explains recent CMS data.

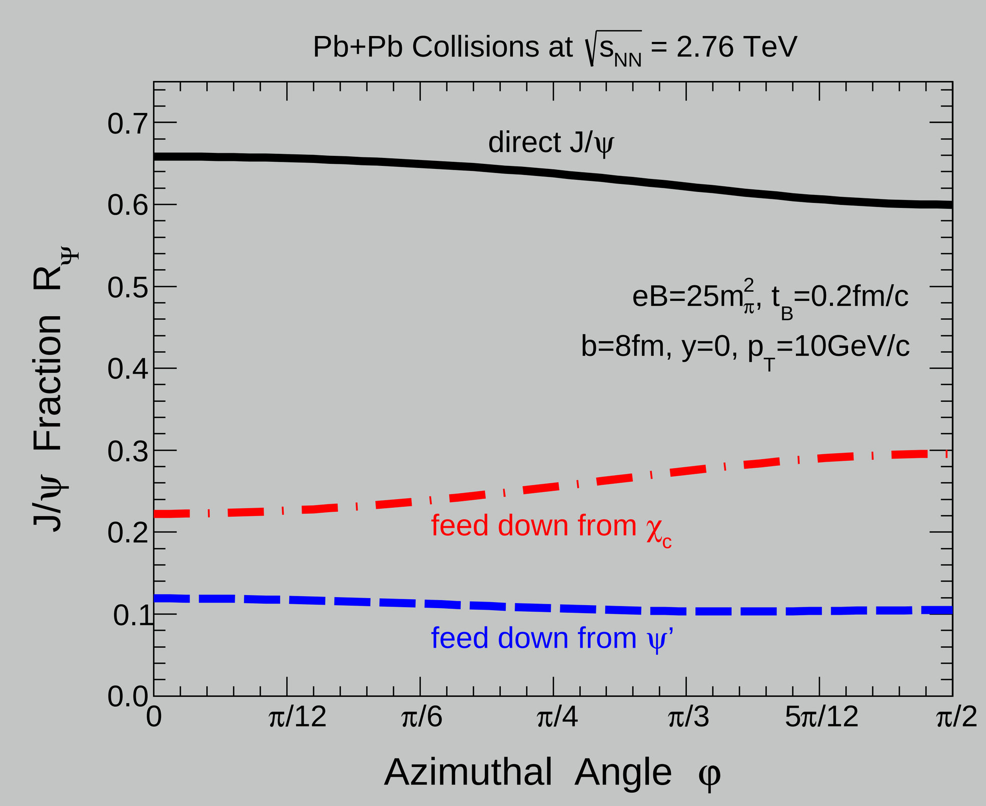
Time Evolution of Charmonium Fractions in A+A Collisions

We focus on the central rapidity region in Pb+Pb collisions with impact parameter $b = 8$ fm and at LHC energy $\sqrt{s_{NN}} = 2.76$ TeV.



The time evolution of J/ψs from direct production (solid lines) and feed down from ψ' (dashed lines) and χ_c (dot-dashed lines). The results with and without the external magnetic field are displayed by thick and thin lines, respectively. As indicated by the vertical short-dashed line, the magnetic field only lasts during the time $t < t_B = 0.2$ fm/c.

Angular Dependence and Non-collective v_2



The anisotropic production of J/ψ will result in an non-collective v_2 of high momentum J/ψ, as shown in the figure below, which explains the CMS data.