The p_T Dependence of J/ψ Production at RHIC

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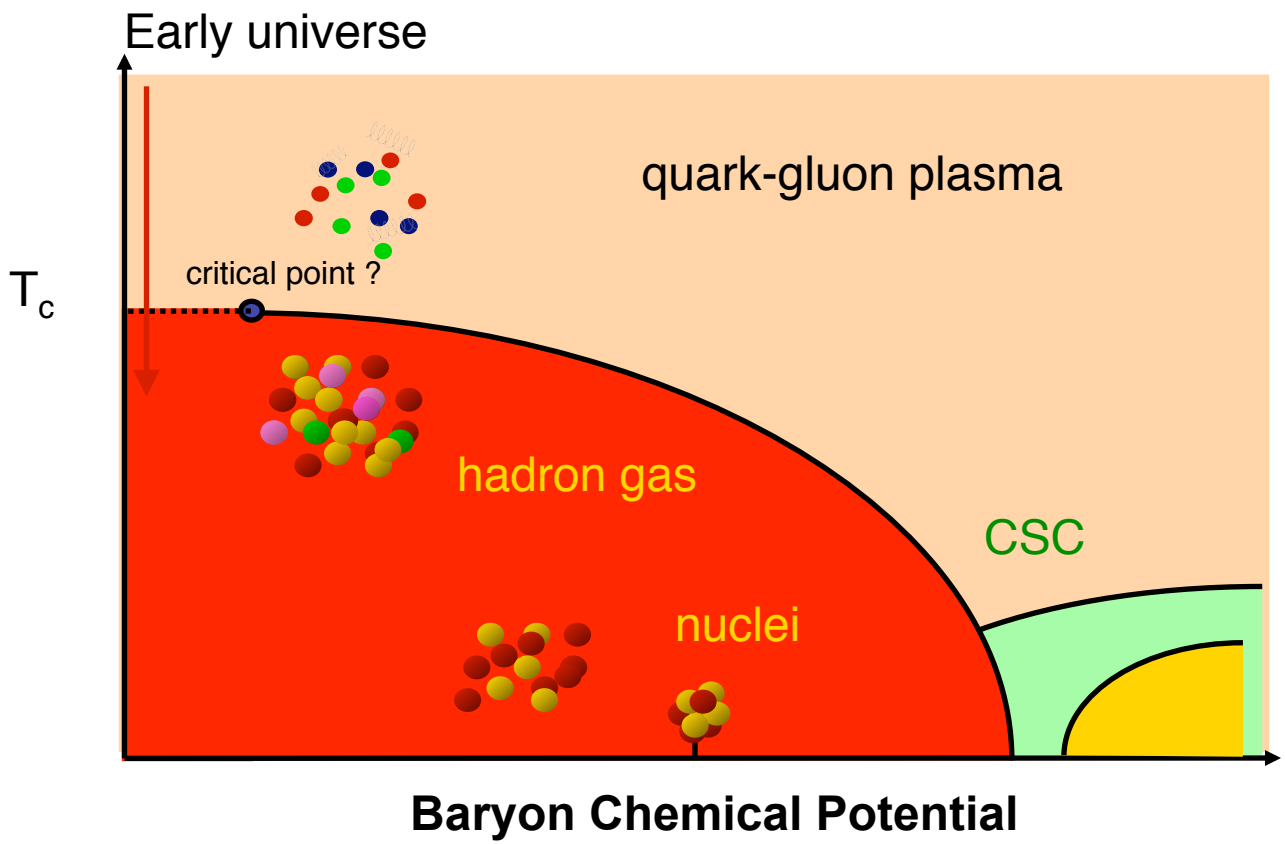
1) Introductions

2) Transport (J/ψ) + hydro (medium)

3) Centrality and p_T dependence

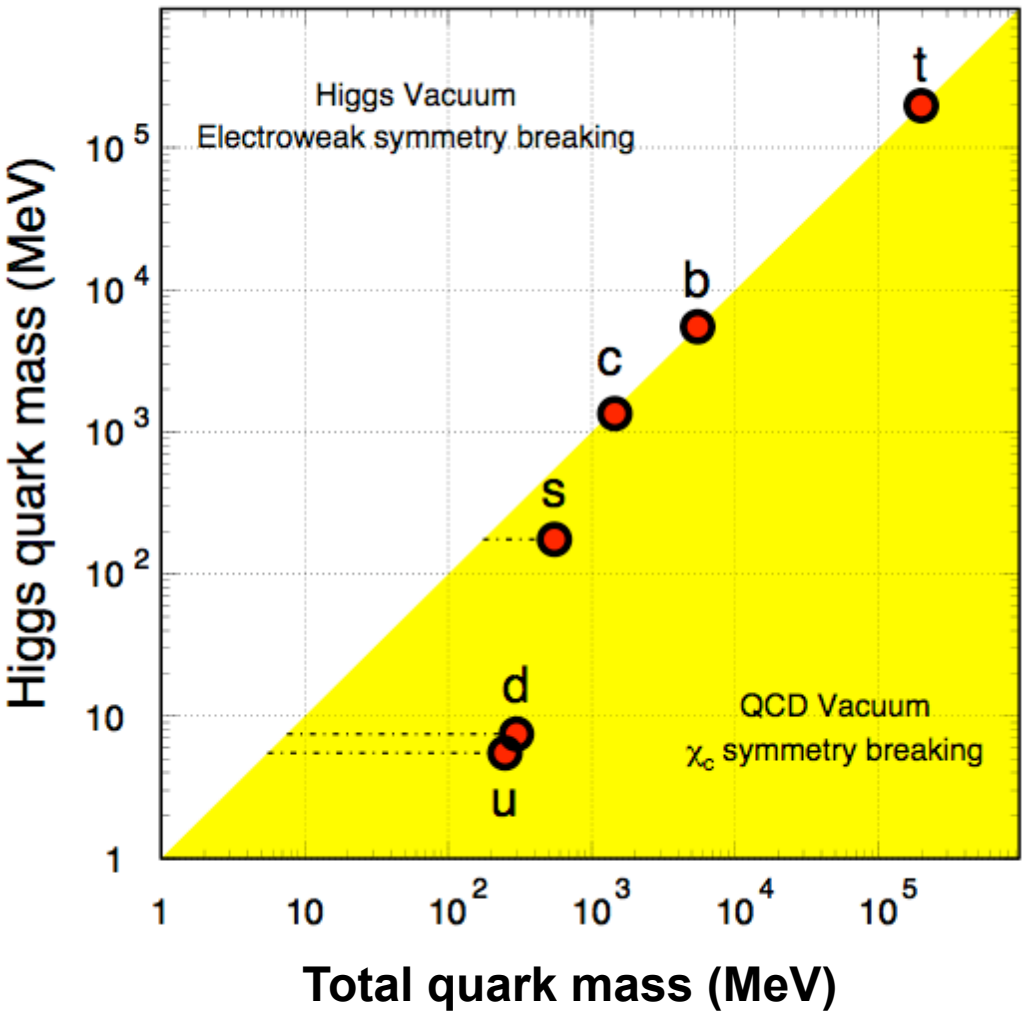
4) Summary and outlook

QCD Phase Diagram



HI Collisions: Explore the QCD landscape, structure of the matter with partonic degrees of freedom.

Quark Masses

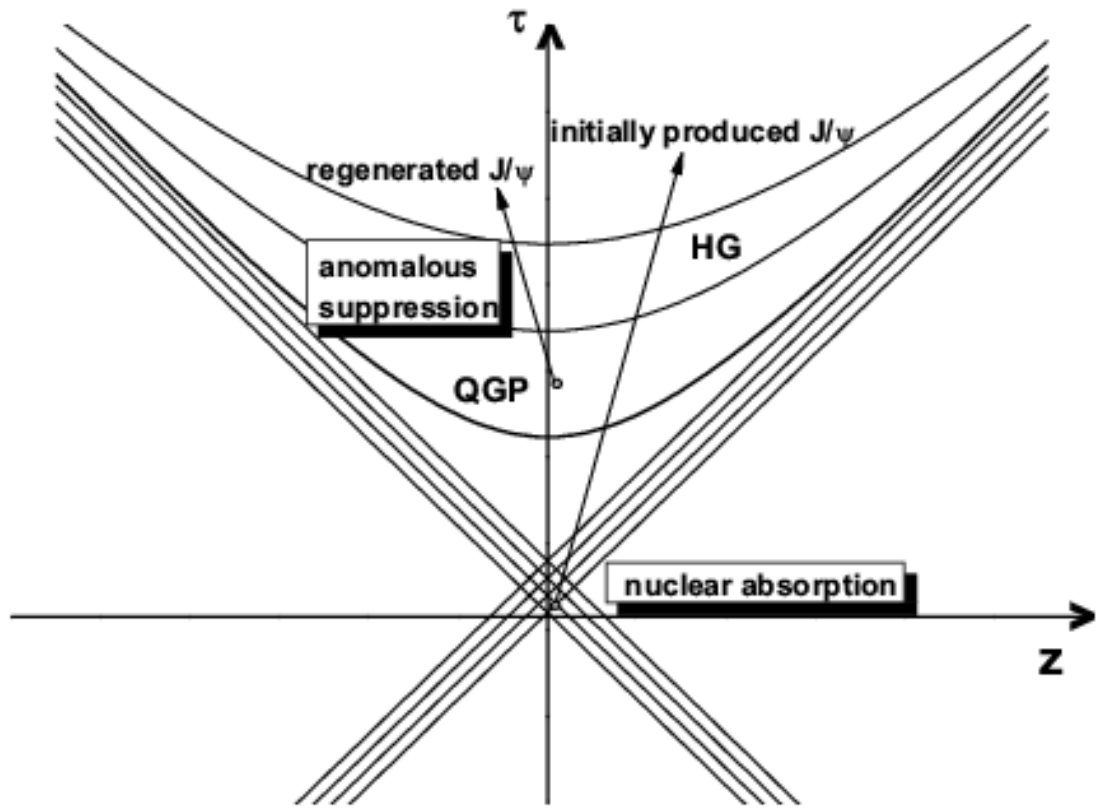


1) Higgs mass: electro-weak symmetry breaking. (current quark mass)
2) QCD mass: Chiral symmetry breaking. (constituent quark mass)

- ⇨ New mass scale compared to the excitation of the system.
- ⇨ Important tool for studying properties of the hot/dense medium at RHIC.
- ⇨ Test pQCD predictions at RHIC.

J/ψ Production in HI Collisions

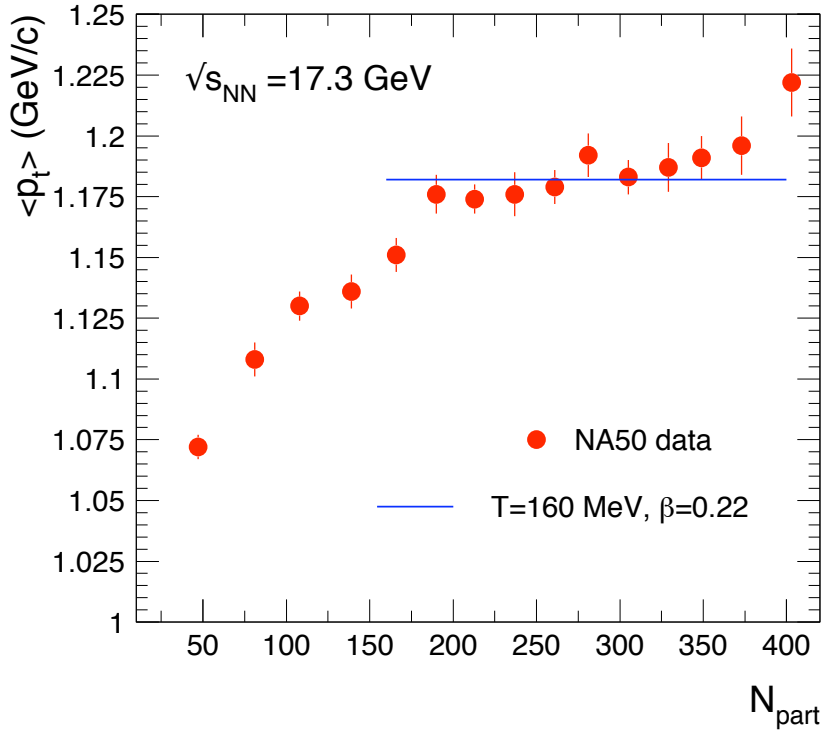
Matsui and Satz PLB178, 416(1986): J/Psi suppression as a signature of QGP formation

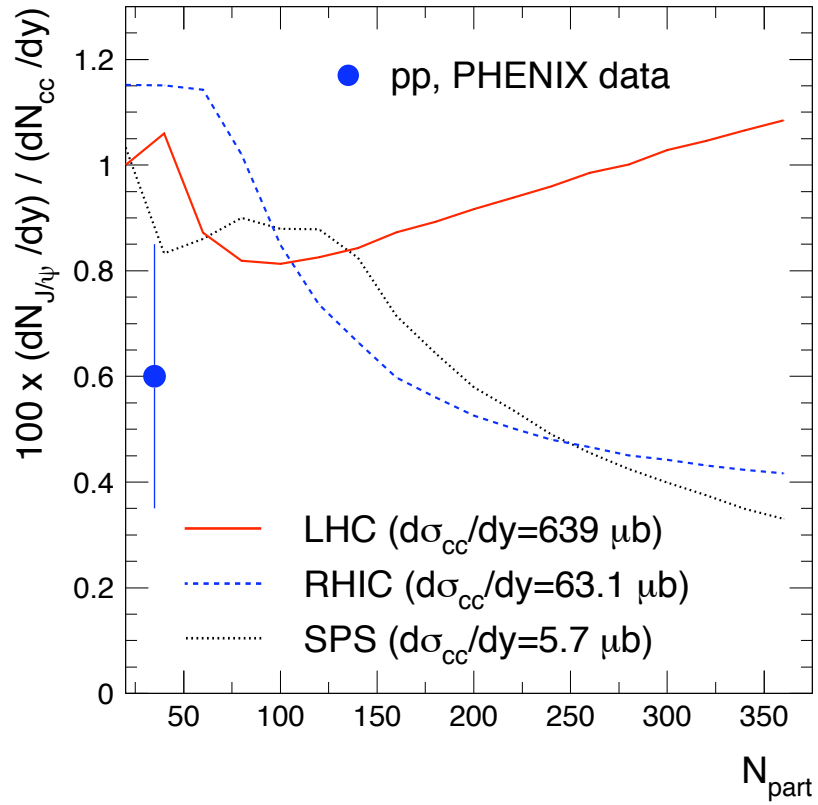


(1) Creation: **initial production and regeneration**
(2) Destroy: **normal suppression and anomalous suppression**

SPS J/ψ Results

arXiv: nucl-th/0611023v2, Andronic et al



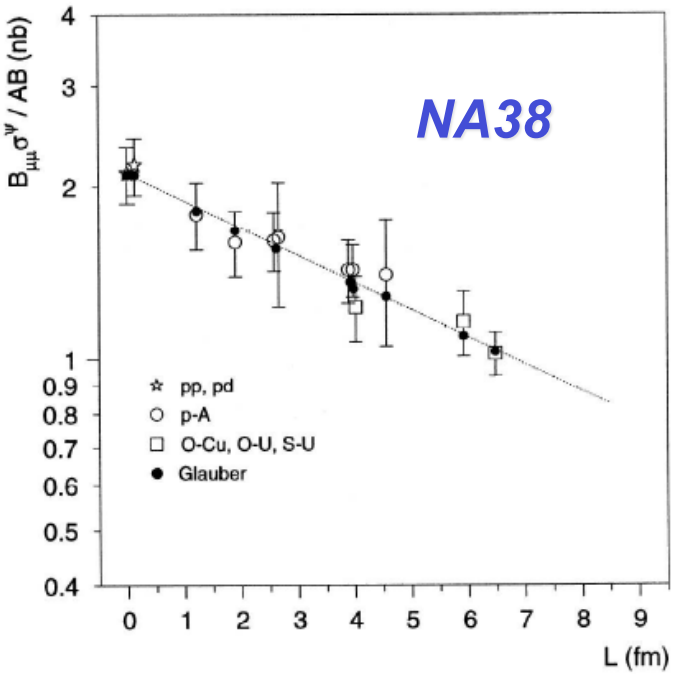


1) The values of <p_T> increase reaching saturation at central collisions

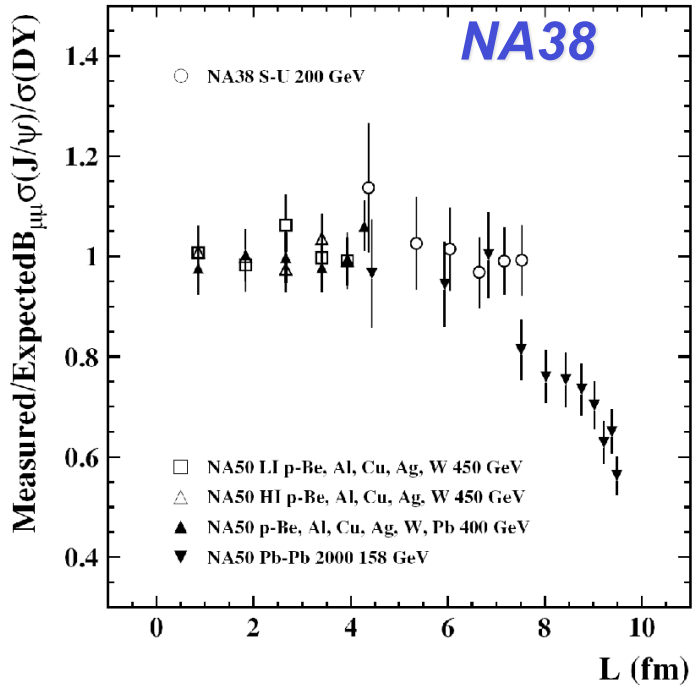
2) In HI collisions J/ψ yields depended on charm total cross sections

Suppressions

Normal



Anomalous



① Debye screening (Matsui, Satz, Karsch, Kharzeev, Asakawa, Hatsuda)

② Threshold model (Blaizot, Dinh, Ollitrault …)

③ Comover interactions (Capella, Feireiro, Kaidalov …)

Regenerations

$$c + \bar{c} \Leftrightarrow J/\psi + g$$

$$D + \bar{D} \Leftrightarrow J/\psi + mesons$$

Model 1: statistical production at T_c, no initial production (Andronic, PBM, Redlich, Stachel)

Model 2: continuous production in QGP, including anomalous suppression, no initial production (Thews, Mangano)

$$\frac{dN_{J/\psi}}{dt} = \frac{\lambda_F N_C N_{\bar{C}}}{V(t)} - \lambda_D N_{J/\psi} \rho_g$$

Model 3: two-component, initial production + sudden regeneration (Grandchamp, Rapp, Brown)

$$N_{J/\psi} = N_{J/\psi}^{dic} + N_{J/\psi}^{thermal}$$

Conclusion: With one or more parameters, most of the model results can account for the yields of J/ψ in heavy ion collisions.

Question: How about the J/ψ transverse momentum distributions?

J/ψ Transport in QGP

The transverse momentum distribution, which depends more directly on the production mechanism, contains additional information about the nature of the medium and J/ψ. Helps to distinguish between different production scenarios.

transport model (Zhu, Yan, Xu and Zhuang)

transport equation for J/ψ and hydrodynamics for QGP

$$\partial_\tau E + \nabla \cdot \mathbf{M} = -(E+p)/\tau \ ,$$
$$\partial_\tau M_x + \nabla \cdot (M_x \mathbf{v}) = -M_x/\tau - \partial_x p \ ,$$
$$\partial_\tau M_y + \nabla \cdot (M_y \mathbf{v}) = -M_y/\tau - \partial_y p \ ,$$
$$\partial_\tau R + \nabla \cdot (R\mathbf{v}) = -R/\tau$$

$$\partial f_\Psi/\partial\tau + \mathbf{v}_\Psi \cdot \nabla f_\Psi = -\alpha_\Psi f_\Psi + \beta_\Psi .$$

leakage **regeneration**

anomalous suppression

initial production and nuclear absorption as initial condition

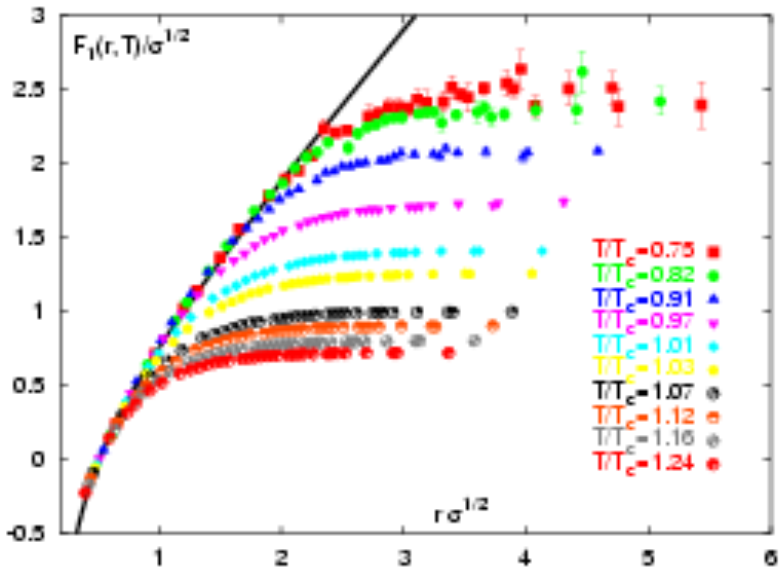
$$f_\Psi(\mathbf{p}_t, \mathbf{x}_t, \tau|\mathbf{b}) = f_\Psi(\mathbf{p}_t, \mathbf{x}_t - \mathbf{v}_\Psi(\tau-\tau_0), \tau_0|\mathbf{b}) e^{-\int_{\tau_0}^{\tau} d\tau' \alpha_\Psi(\mathbf{p}_t, \mathbf{x}_t - \mathbf{v}_\Psi(\tau-\tau'), \tau'|\mathbf{b})}$$
$$+ \int^{\tau} d\tau' \beta_\Psi(\mathbf{p}_t, \mathbf{x}_t - \mathbf{v}_\Psi(\tau-\tau'), \tau'|\mathbf{b}) e^{-\int_{\tau'}^{\tau} d\tau'' \alpha_\Psi(\mathbf{p}_t, \mathbf{x}_t - \mathbf{v}_\Psi(\tau-\tau''), \tau''|\mathbf{b})} .$$

$$\alpha_\Psi(\mathbf{p}_t, \mathbf{x}_t, \tau|\mathbf{b}) = \frac{1}{2E_\Psi} \int \frac{d^3\mathbf{p}_g}{(2\pi)^3 2E_g} W_{g\Psi}^{c\bar{c}}(s) f_g(\mathbf{p}_g, \mathbf{x}_t, \tau) \Theta\left(T(\mathbf{x}_t, \tau|\mathbf{b}) - T_c\right) ,$$

$$\beta_\Psi(\mathbf{p}_t, \mathbf{x}_t, \tau|\mathbf{b}) = \frac{1}{2E_\Psi} \int \frac{d^3\mathbf{p}_g}{(2\pi)^3 2E_g} \frac{d^3\mathbf{p}_c}{(2\pi)^3 2E_c} \frac{d^3\mathbf{p}_{\bar{c}}}{(2\pi)^3 2E_{\bar{c}}} W_{c\bar{c}}^{g\Psi}(s) f_c(\mathbf{p}_c, \mathbf{x}_t, \tau|\mathbf{b}) f_{\bar{c}}(\mathbf{p}_{\bar{c}}, \mathbf{x}_t, \tau|\mathbf{b})$$
$$\times (2\pi)^4 \delta^{(4)}(p + p_g - p_c - p_{\bar{c}}) \Theta\left(T(\mathbf{x}_t, \tau|\mathbf{b}) - T_c\right) ,$$

detailed balance between suppression and regeneration included.

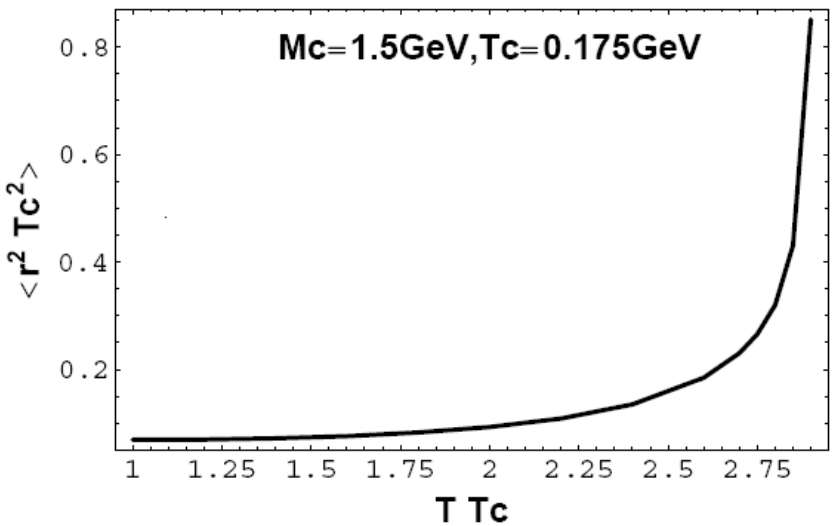
Medium-dependent Dissociation Cross Section



Lattice results

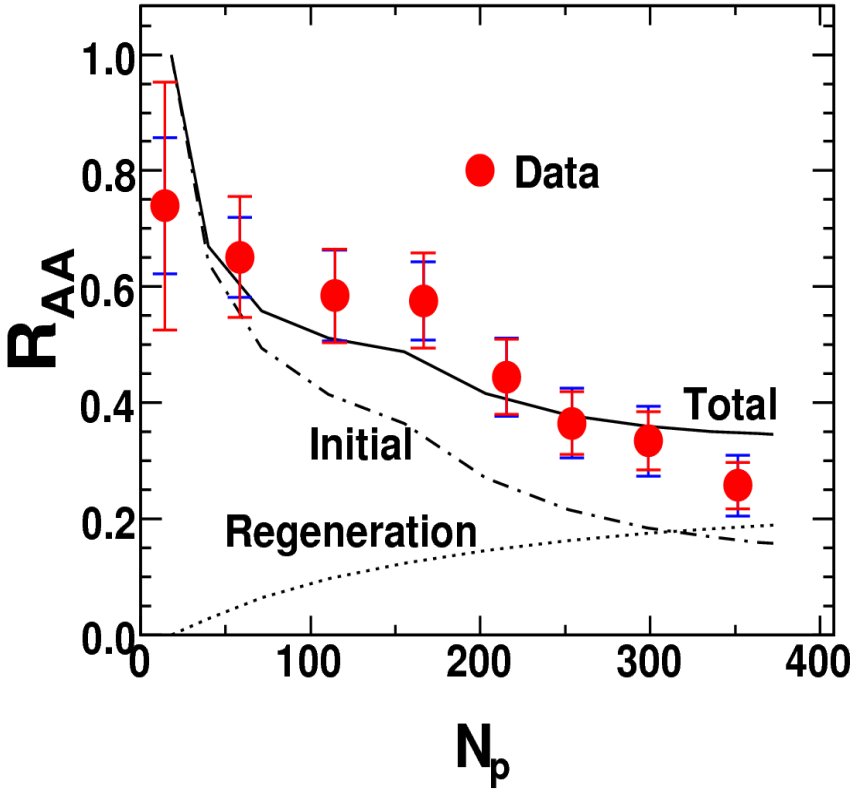
$$\frac{d^2U}{dr^2} = \left(\frac{M_c}{T_c}\cdot V - \frac{2M_c^2 E}{T_c^2} + \frac{l(l+1)}{r^2}\right)U$$

$$U = rR(r)$$



$$\sigma(T) = \sigma(0)\frac{\langle r^2\rangle(T)}{\langle r^2\rangle(0)}$$

Nuclear Modification Factor



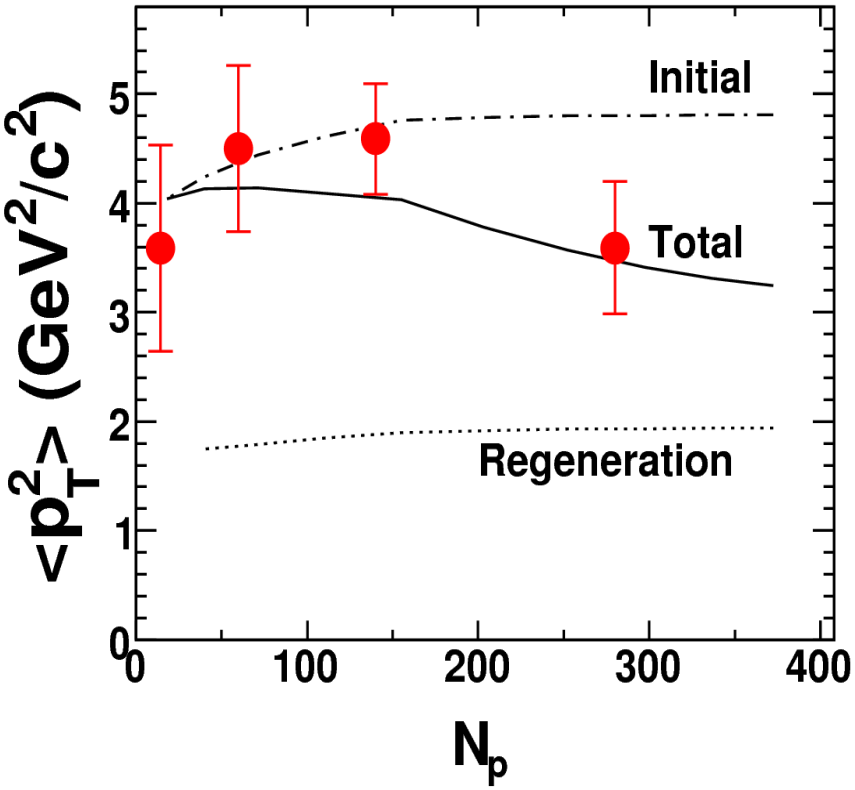
200 GeV Au+Au collisions:

1) Integrated yields

2) The flat structure in semi-central region is well described by the medium-dependent cross sections.

3) At the most central collision, both initial and regeneration are important.

Averaged Transverse Momentum

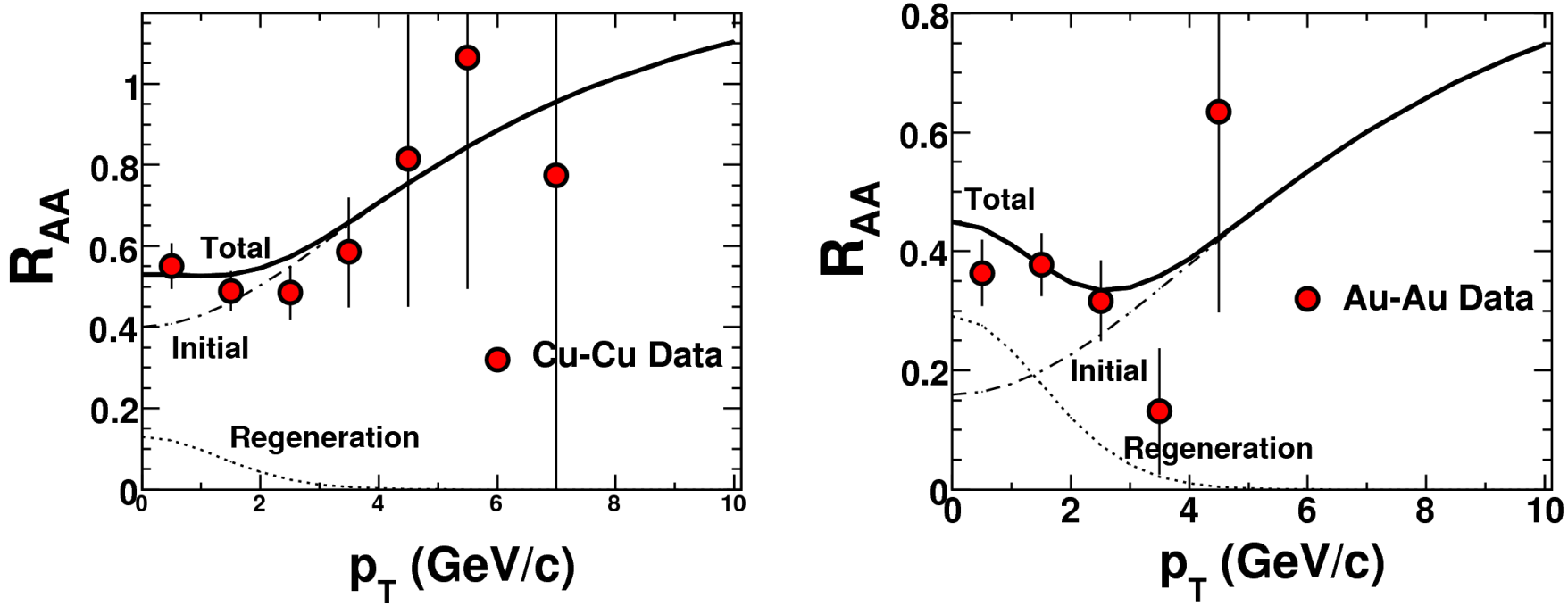


200 GeV Au+Au collisions:

1) Integrated p_T

2) At the most central collision, due to rescatterings and regeneration, the mean p_T is in fact reduced. This is different from that of light quark hadrons.

R_{AA} versus p_T



1) The low p_T region is controlled by both initial production and regeneration, while high p_T region is governed by only initial production.

2) The observed enhancement at high p_T may be caused by the Cronin effect and leakage effect.

Summary

1) A clear signature of regeneration for J/ψ at RHIC is observed from this analysis.

2) The competition between the initial production and regeneration of J/ψ leads to a minimum at low p_T region.

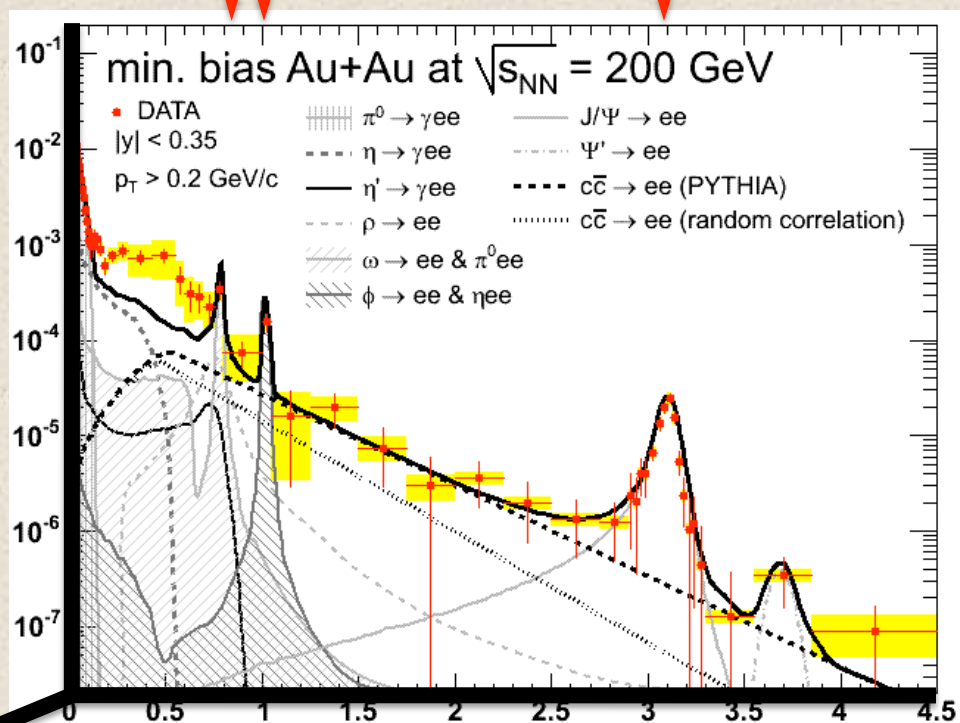
Next step: evaluate the J/ψ rapidity ditributions.

The di-lepton Program at RHIC

(1) σ

(2) v_2

(3) R_{AA}



=> Direct Radiation from The Hot/Dense Medium

=> Large acceptance Is crucial for the physics.