Quarkonium Production at STAR

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Introduction

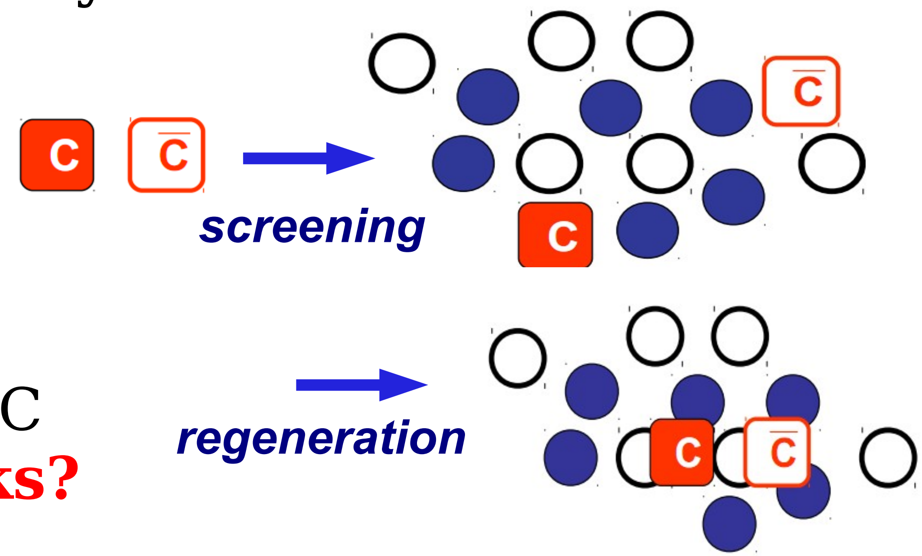
Heavy quarks are created in the initial hard scattering
→ exposed to the evolution of the system.

Quarkonium are used to probe the properties of the hot dense matter created at RHIC.

Expect suppression in a deconfined medium.

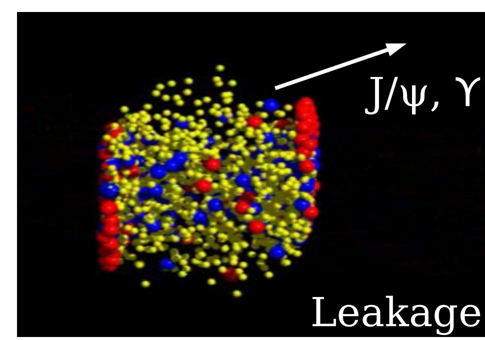
Similar suppression at SPS and RHIC

Regeneration from sea of quarks?



A+A collisions:

- Modification of production due to QGP (e.g. color-screening, regeneration);
- Initial-state gluon multi-scattering;
- Escape from fireball at high-p_T;
- Feed down from excited states;



→ Measure p_T spectra, elliptic flow (v_2), R_{AA} .

Previous Measurements

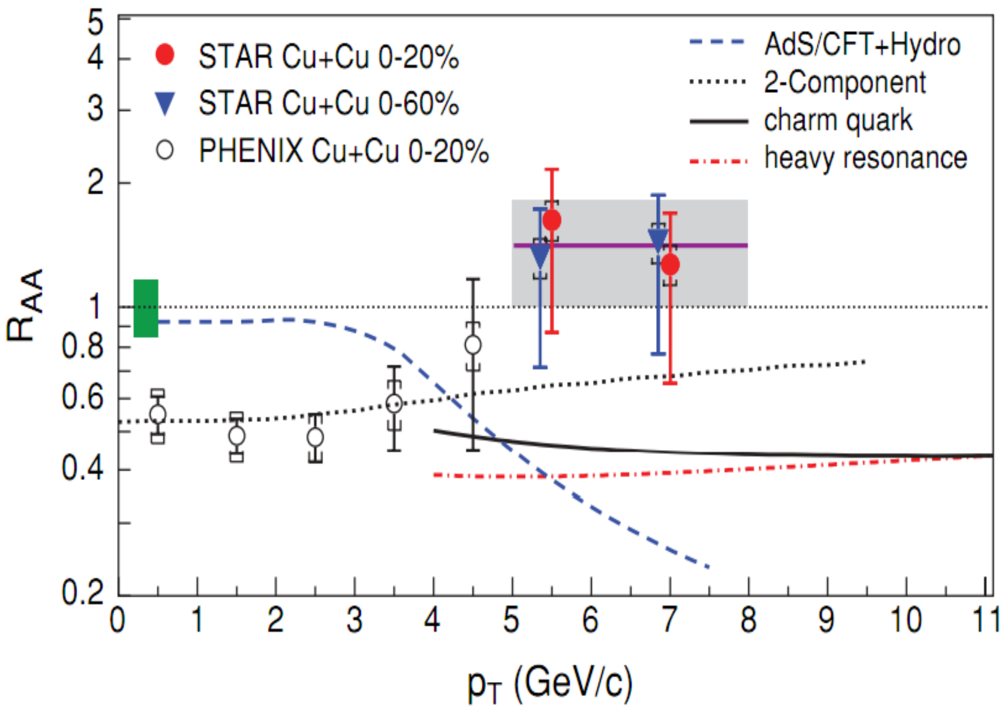
Nuclear modification factor:

$$R_{AA} = \frac{dN/dy|_{A+A}}{N_{coll} \cdot dN/dy|_{p+p}}$$

Look at high-p_T J/ψ to understand system size and formation time effects

J/ψ in Cu+Cu at 200 GeV

Phys.Rev.C80:041902,2009



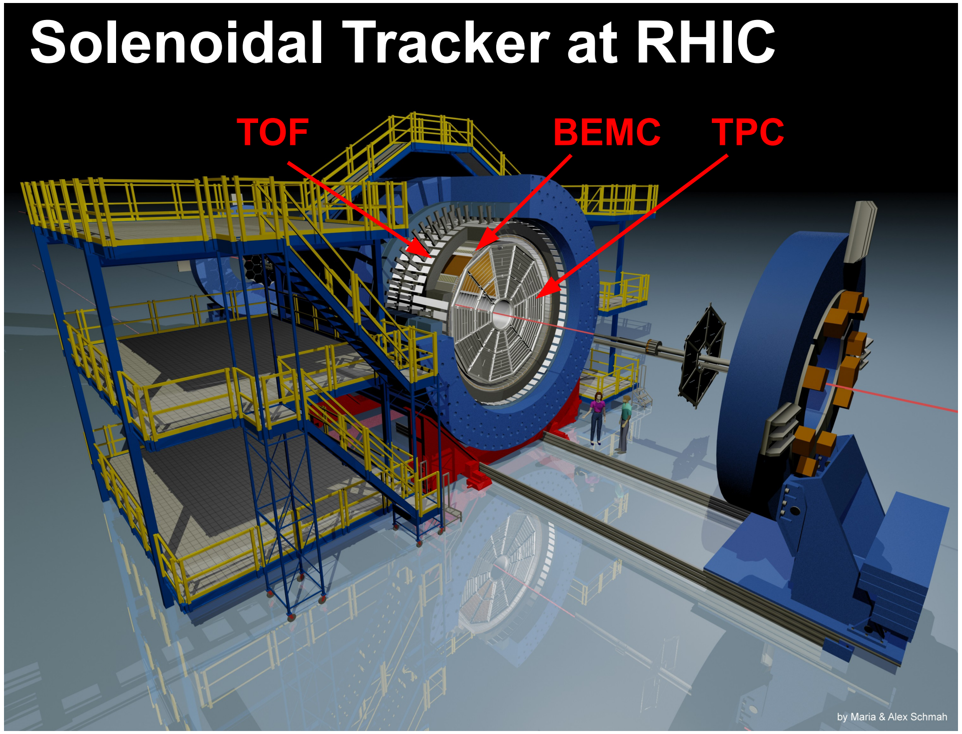
No suppression in Cu+Cu 200 GeV at high-p_T

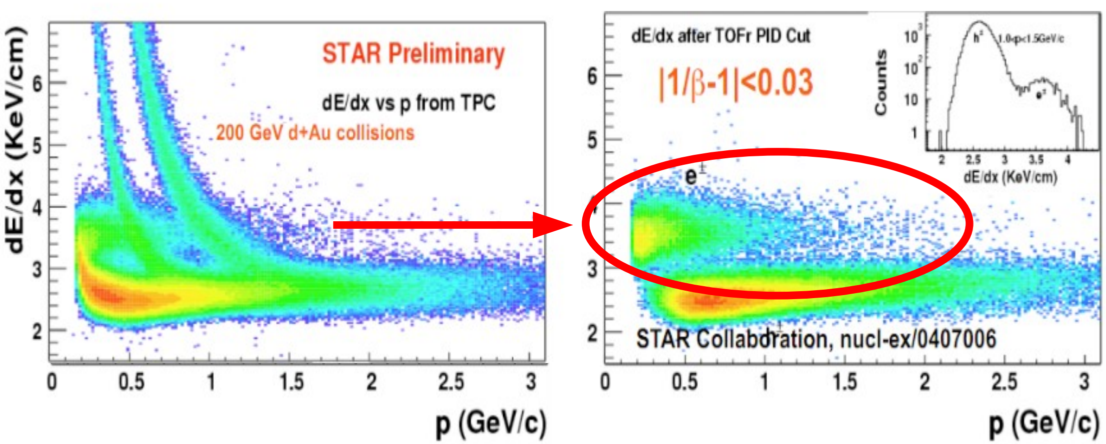
→ leakage / p_T broadening

Data agrees with 2 Component model
(dissociation, regeneration, formation time effects)

STAR Experiment

$J/\psi, \Upsilon \rightarrow e^+ e^-$
(BR = 5.9%, 2.4%)





Large Acceptance:
$|\eta| < 1$, $0 < \varphi < 2\pi$

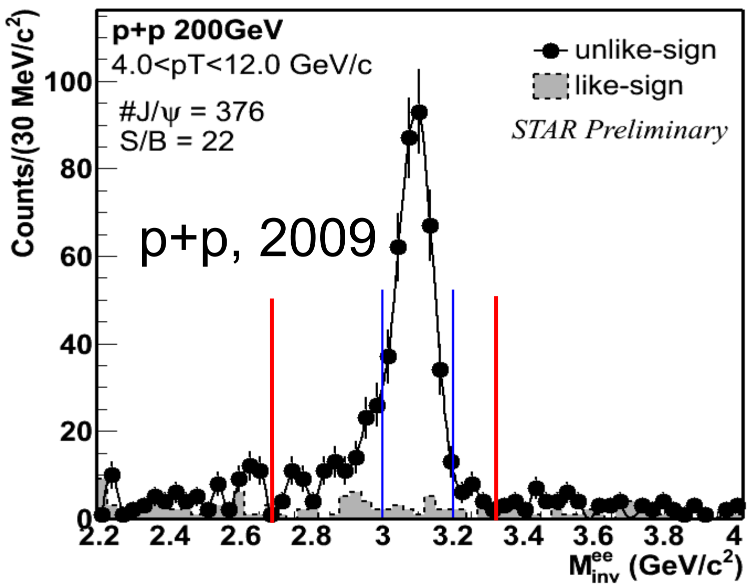
Time Projection Chamber:
Tracking → p_T, η, φ
dE/dx → PID

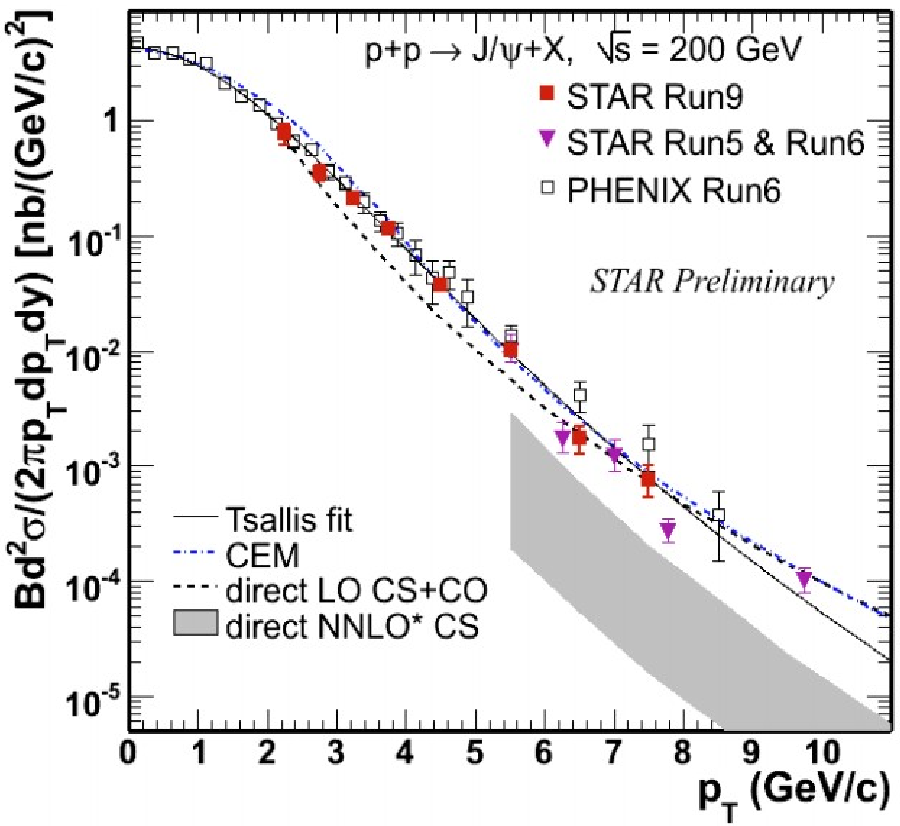
Time Of Flight:
Timing res. < 100 ps
$1/\beta$ → PID

Barrel Electromagnetic Calorimeter:
Tower $\Delta\eta \times \Delta\varphi = 0.05 \times 0.05$
Energy → $E/p \sim 1$ (electrons)

J/ψ Spectra in p+p 200 GeV

Look at p_T spectrum in p+p to understand production mechanism





- Color singlet model: direct NNLO still misses the high-p_T part
- LO CS+CO: leave no room for feeddown at high p_T
- CEM can describe J/ψ in p+p 200 GeV data

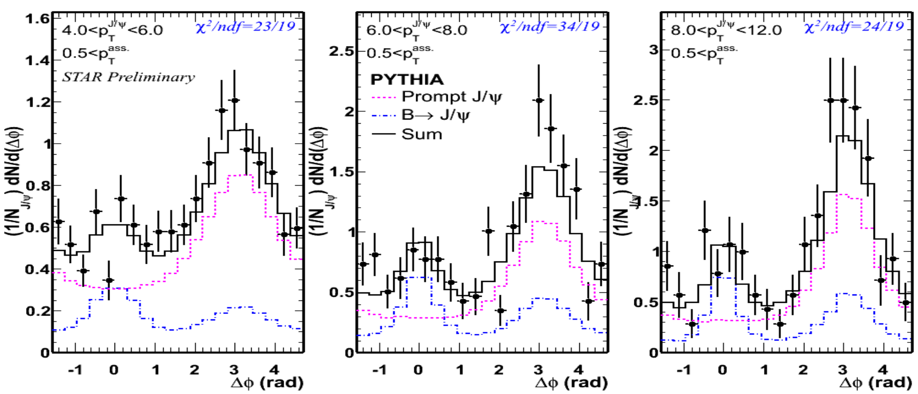
PHENIX: Phys. Rev. D 82, 012001 (2010)
STAR: Phys. Rev. C80, 041902(R) (2009)
Phys. Rev. Lett. 101, 152001 (2008)
Phys. Rev. D68, 034003 (2003)
JPG 37, 085104 (2010)
arXiv: hep-ph/0311048

B → J/ψ (incl.) feed-down

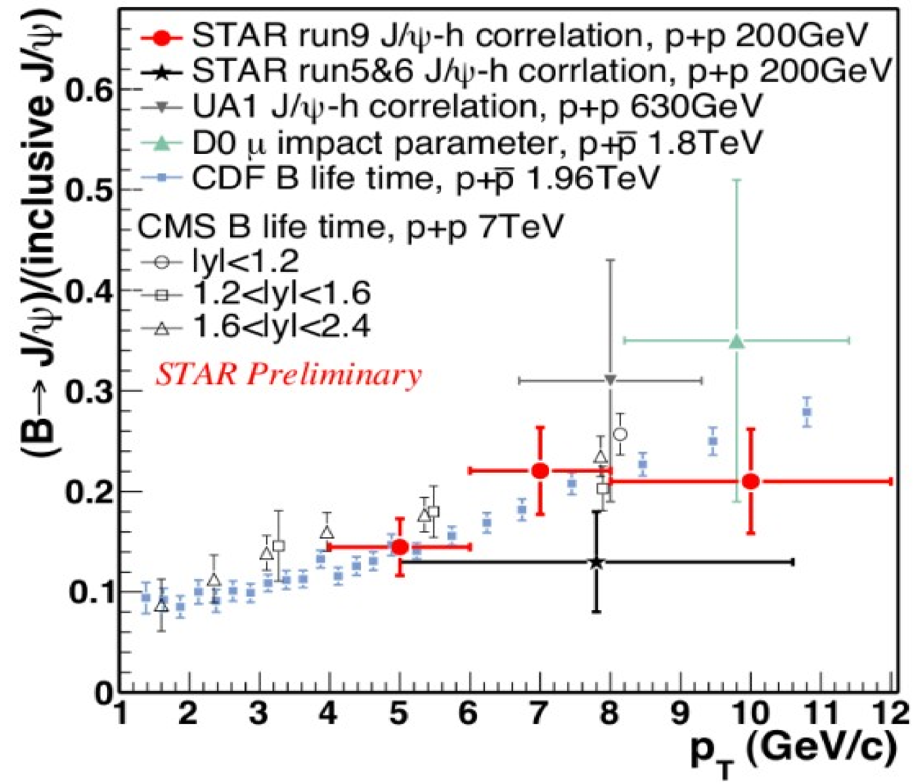
J/ψ-hadron azimuthal correlations

Separate direct J/ψ from
B → J/ψ feed-down:

$\cdot\, J/\psi_{Total} = J/\psi_{Direct} + J/\psi_{B \rightarrow J/\psi}$



Model based extraction using PYTHIA

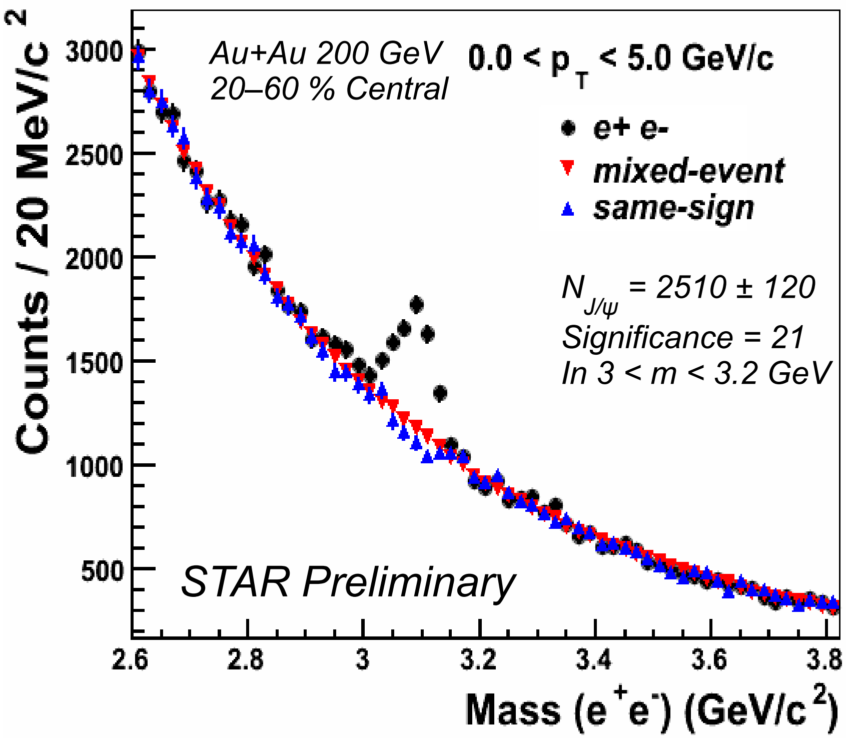


No significant beam energy dependence

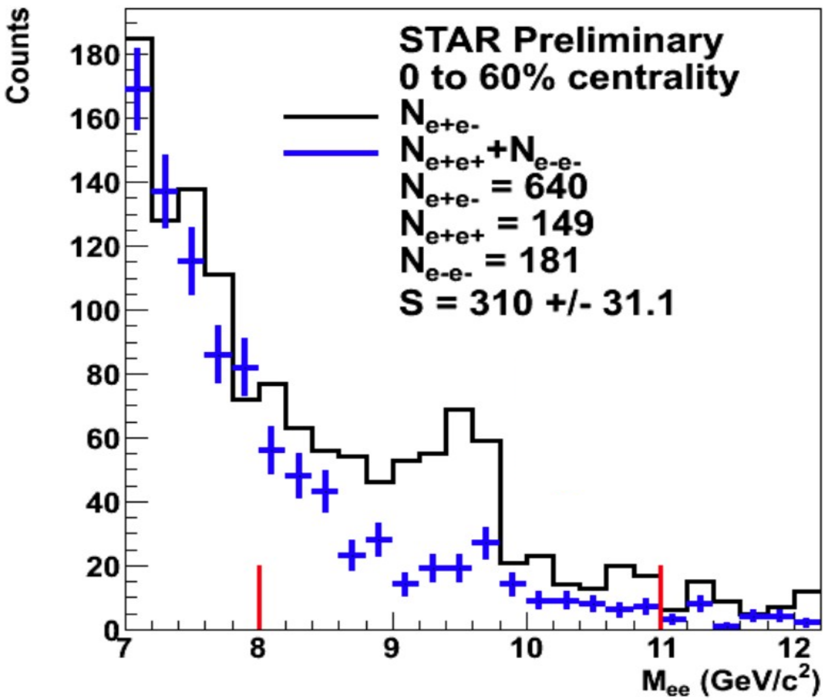
Constrain feed-down contribution:
(B → J/ψ) / (incl. J/ψ) ~ 10 – 25 %

Signal in Au+Au 200 GeV

J/ψ



ϒ(1S+2S+3S)



Clean signal with high significance for J/ψ and ϒ.
First ϒ measurement in heavy ion collisions!

J/ψ Spectra in Au+Au

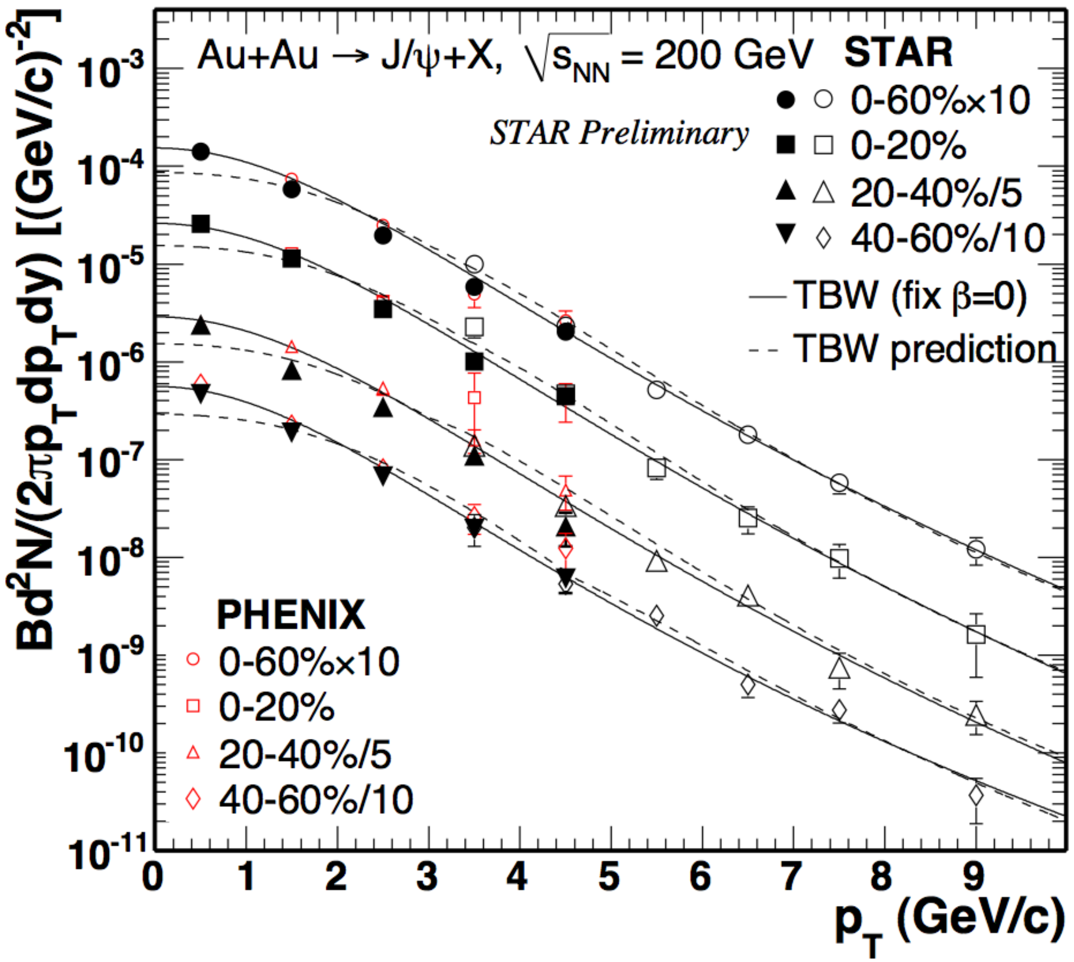
Transverse momentum dependence of J/ψ

Hydro-inspired blast wave fit to data:

· Softer spectra than light hadron prediction → low-p_T regeneration

J/ψ range extended to low and high p_T from 0 - 10 GeV/c

Agreement between STAR (|y| < 1) and PHENIX (|y| < 0.35)

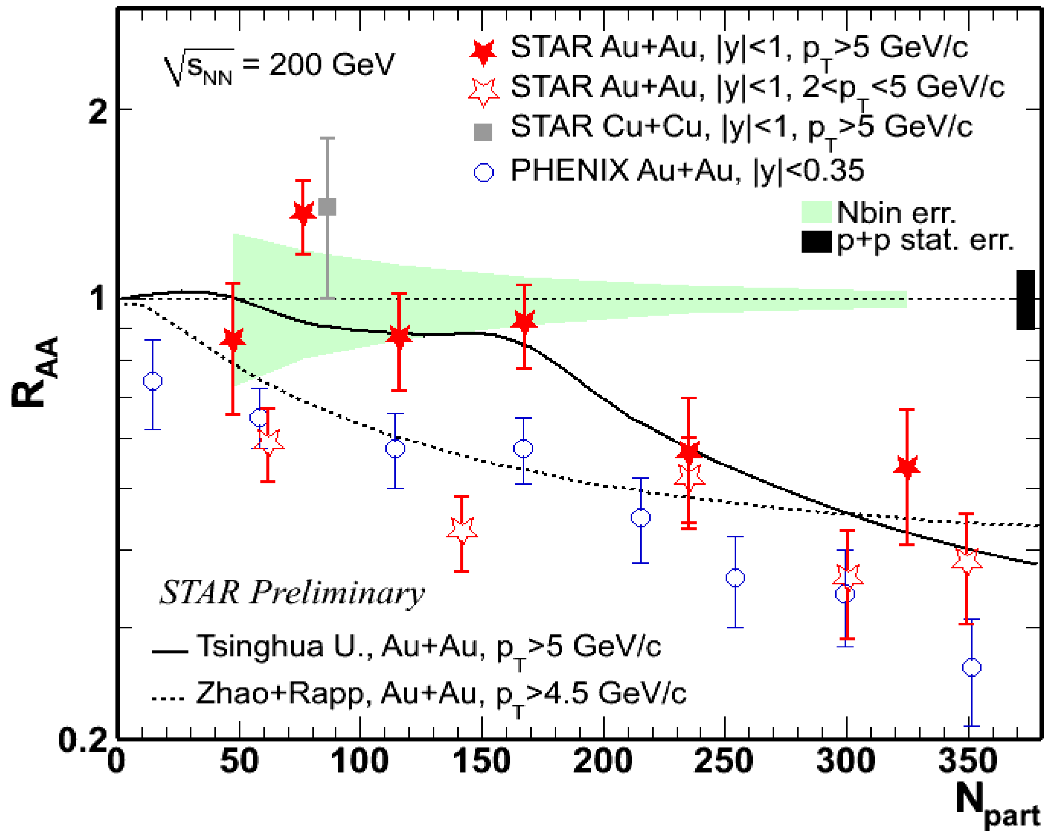


Phys. Rev. Lett. 98, 232301 (2007)
JPG 37, 085104 (2010)

J/ψ R_{AA} in Au+Au

Modification of J/ψ in A+A collisions

- → *suppression, regeneration in central events*
- → *escape from hot medium at high p_T*



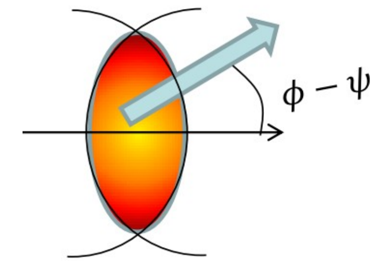
Suppression of J/ψ in central collisions.
Data agrees with 2 Component model
Smaller R_{AA} for lower p_T across the centrality range.

Formation time / system size effect

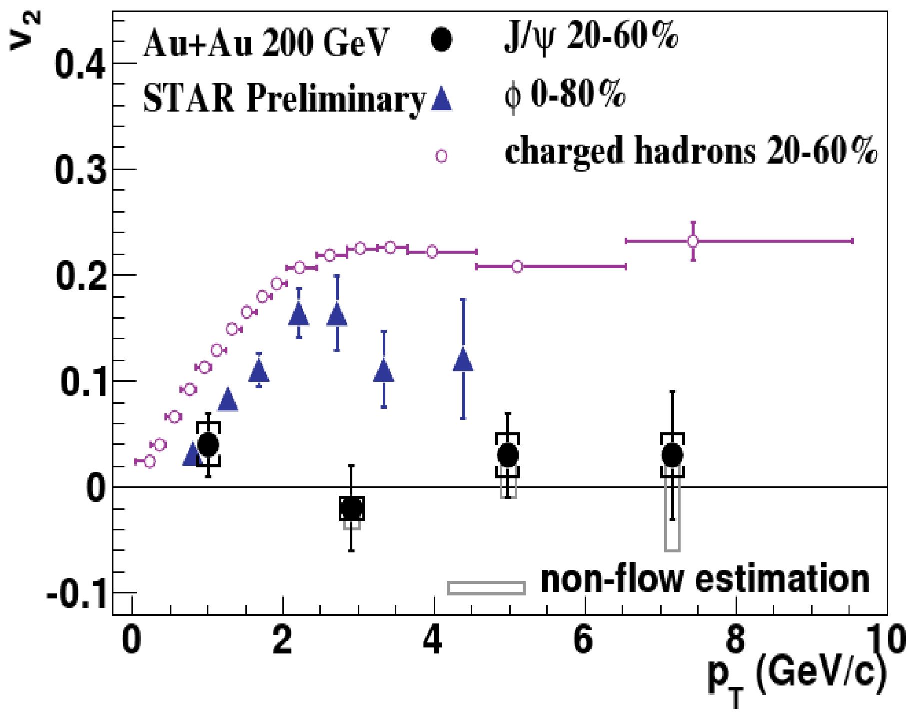
-Y. Liu et. al., PLB 678:72 (2009)
-X. Zhao, R. Rapp, PRC82,064905(2010)

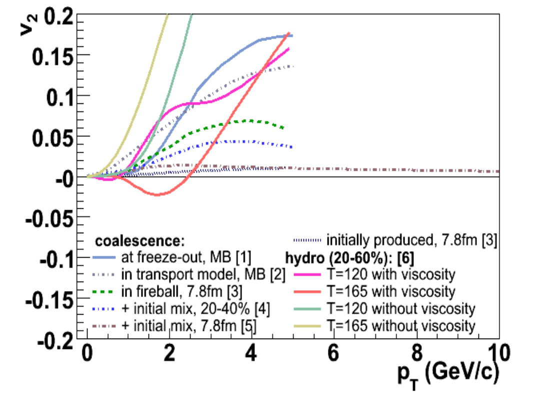
J/ψ v_2 in Au+Au

A new probe of charmonium production
and thermalization from azimuthal anisotropy:
J/ψ elliptic flow v_2



Significant flow of light hadrons and φ ($s\bar{s}$) meson observed.





[1] V. Greco, C.M. Ko, R. Rapp, PLB 595, 202.
[2] L. Ravagli, R. Rapp, PLB 655, 126.
[3] L. Yan, P. Zhuang, N. Xu, PRL 97, 232301.
[4] X. Zhao, R. Rapp, 24th WWND, 2008.
[5] Y. Liu, N. Xu, P. Zhuang, Nucl. Phy. A, 834, 317.
[6] U. Heinz, C. Shen, priviate communication.

J/ψ v_2 is consistent with zero!

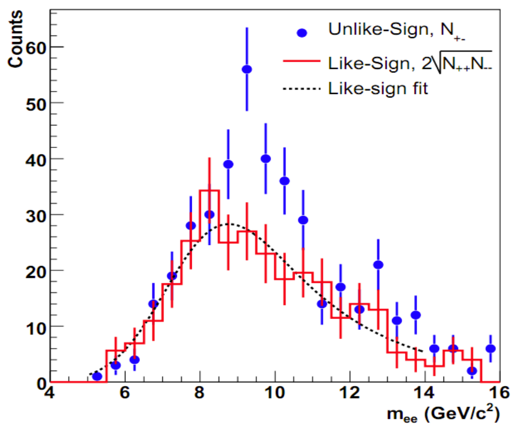
First hadron that does *not* flow.

Disfavor regeneration from thermalized charm quarks in 20 – 60 % central collisions.

Υ(1S+2S+3S) R_{AA} in Au+Au

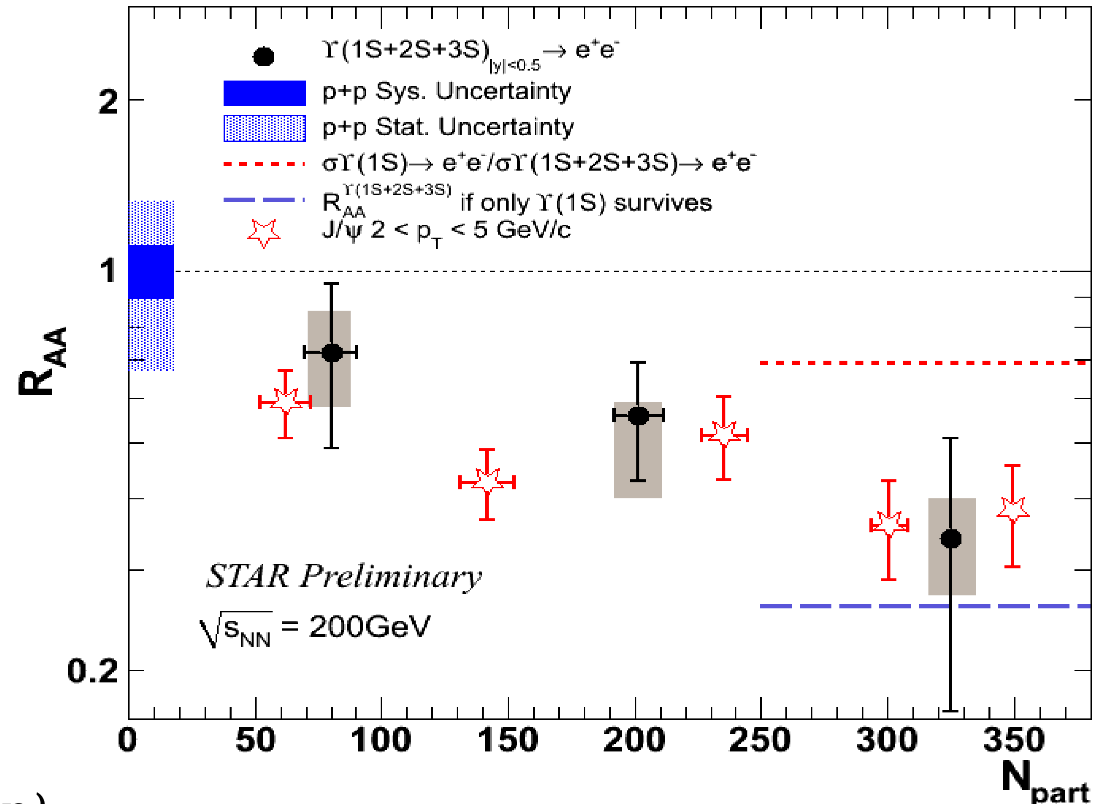
Cleaner probe of deconfinement (negligible regeneration)

Υ in p+p at 200 GeV



Phys. Rev.D82:12004,2010

Comparison lines:
Red: 1S / (1S+2S+3S) (from low energy data)
Blue: 1S direct (no feed-down)



Suppression of Υ(1S+2S+3S) in 0-10%, R_{AA} = 0.34±0.17.

More statistics to come – reduce uncertainty by a factor of 2

Summary

In p+p collisions:

J/ψ p_T spectrum extended to high p_T.

B feed-down to J/ψ measured ~ 10 – 25 %.

In heavy ion collisions:

Suppression of J/ψ and ϒ in central collisions.

No suppression for high-pT J/ψ in Cu+Cu and peripheral Au+Au

→ **formation time / system size effects.**

J/ψ v_2 is consistent with zero

→ **disfavor regeneration of thermalized charm quarks.**

→ **J/ψ is the only meson that does not flow!**

Quarkonium production is very exciting !