Measurement of $J/\psi$ Elliptic Flow in Au+Au Collisions at $\sqrt{s_{NN}} = 200$ GeV in STAR Experiment

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Outline

- Motivation
- $J/\psi$ identification
- $v_2$ methods
- Results
- Summary and outlook
Motivation

- Charm quarks
  - large mass → produced in the early stage and less influenced by later evolution
  - excellent tool to study properties of the hot and dense matter created in A+A 200GeV collisions

Screening effect
J/ψ suppression → QGP formation

Matsui & Satz 1986

Quarkonia’s suppression patterns → QGP thermometer

A. Mocsy, 417th WE-Heraeus-Seminar, 2008
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Quarkonia’s suppression patterns

\[ \frac{1}{\langle r \rangle} \text{[fm}^{-1}] \]

- \( \Upsilon(1S) \)
- \( \chi_b(1P) \)
- \( J/\psi(1S) \gamma''(2S) \)
- \( \chi_b''(2P) \gamma''(3S) \chi_c(1P) \psi'(2S) \)

\[ \leq T_c \]

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Quarkonia’s suppression patterns ➔ QGP thermometer

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Motivation

We do see suppression, however other hot and cold nuclei effects can influence the yield:

• Recombination
• “comovers”
• Modification of gluon distribution function
• nuclear absorption
• “Cronin effect”

Direct pQCD production + leakage effect

Produced by coalescence of thermalized charm quarks

Limited $v_2$

Large $v_2$
Motivation

- Charm quark is much heavier, thus much more difficult to thermalize than light quarks. So if charm flows, the system dominated by light quarks should be fully thermalized.
- $v_2$ of $J/\psi$ from recombination carries the $v_2$ of charm.
- Precise comparison between model and data is needed to consider the contribution from both direct and recombined $J/\psi$.

- Non-photonic electron $v_2$ measurement favors flowing charm.

http://arxiv.org/abs/1005.1627v2
J/ψ Identification

**J/ψ -> e^+e^-**
Br 5.9 %

Barrel ElectroMagnetic Calorimeter - BEMC
p/E 0.3~1.5
Suppress hadrons at high p_T

Time Of Flight - TOF
|1-1/β|<0.03

Time Projection Chamber - TPC
Measuring p and dE/dx

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J/ψ Identification

- ~14000 J/ψ identified
- prominent signal for $p_T > 6$ GeV/c region
- Data taken in RHIC 200 GeV Au+Au run in 2010

- 350 million minimum bias events
- 270 million central events
- BEMC high tower triggered events equivalent to ~ 7 billion minimum bias in the relatively higher $p_T$ region.
Event Plane

\[ v_2 = \langle \cos[2(\phi - \Psi_{rp})] \rangle \]

\[ v_{2\_obs} = \langle \cos[2(\phi - \Psi)] \rangle \]

\[ v_2 = v_{2\_obs} / R \]

- Event plane resolution is calculated from random sub-event.
**φ–Ψ Method**

- 10 φ–Ψ bins and combine every two bins symmetrical to π/2
- Fix the Gaussian shape, fit only the amplitude and the background.

Scale then with average 1/resolution

yield from fit

yield from raw counts

unlike – like sign

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Invariant Mass Method

- Polynomial: background
- Gaussian: signal

\[ v_{2\text{-overall}}(m) = (v_{2\text{-J}/\psi} * s(m) + v_{2\text{-background}}(m) * b(m)) / (s(m) + b(m)) \]

\[ X^2/\text{ndf} = 52.97/42 \]
\[ A = 505.21 \pm 24.41 \]
\[ \text{mean} = 3.09 \pm 0.00 \]
\[ \sigma = 0.04 \pm 0.00 \] (for background)

\[ X^2/\text{ndf} = 60.25/45 \]
\[ v_2 = -0.03 \pm 0.04 \] (for overall signal)

p_T 2~4 GeV/c, 20~60% centrality by centrality

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Systematic Errors

event plane method fit, standard cuts as central value
Assuming uniform distribution,
1 σ systematic error = (max-min)/√12.
Non-flow Estimation

Near side: Decay like $B \rightarrow J/\psi + X$
Away side: Jet, will be greatly modified by the medium in Au+Au collisions

J/$\psi$-hadron azimuthal correlation in pp 200 GeV collisions
J/$\psi$ $p_T$: 6~10 GeV/c
Hadron $p_T$: 0.15~2 GeV/c

\[
< \Sigma_i \cos^2 (\phi_{p_T} - \phi_i) > = Mv_2(p_T)v_2 + \{\text{non-flow}\}
\]

Assuming $J/\psi$-hadron correlation in pp survive intactly in AuAu,
non-flow effect on calculated $J/\psi$ $v_2 = < \Sigma_i \cos^2 (\phi_{p_T} - \phi_i) >_{pp}/Mv_2$.
A very conservative estimation
Further study by looking at $J/\psi$-hadron correlation in AuAu


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Unlike charged hadrons and φ, J/ψ $v_2$ at higher $p_T$ is found consistent with zero considering errors of the measurement.
Results

- Considering errors, J/ψ $v_2$ at higher $p_T$ is found consistent with zero, which disfavors the case that J/ψ is produced dominantly by coalescence of thermalized charm quarks at higher $p_T$.

- [3] L. Yan, P. Zhuang, N. Xu, PRL 97, 232301. (b=7.8 fm)
- [6] U. Heinz, C. Shen, private communication. (20~60 %)
Summary and Outlook

• Considering errors, J/ψ v₂ measured by STAR is found to be consistent with zero, which disfavors the case that J/ψ is produced dominantly by coalescence of thermalized charm quarks at higher p_T region.

• Finalize systematic uncertainty evaluation.
• J/ψ-hadron correlation in AuAu to help understand the non-flow effect.
• More statistics in Au+Au 200 GeV collisions are expected from data taken in 2011. This measurement can be also extended to different collision energies and collision species like U+U.
Thank you!
$R_{AA}$

**Au+Au 200GeV**

- **0-20%**
  - STAR
  - PHENIX
  - solid lines: Tsinghua U.
  - dashed lines: Zhao+Rapp

- **20-40%**
  - STAR
  - PHENIX
  - solid lines: Tsinghua U.
  - dashed lines: Zhao+Rapp

- **40-60%**
  - STAR
  - PHENIX
  - solid lines: Tsinghua U.
  - dashed lines: Zhao+Rapp

- **0-60%**
  - STAR
  - PHENIX
  - solid lines: Tsinghua U.
  - dashed lines: Zhao+Rapp

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Standard Cuts

• Event cut:
  – abs(vertexZ) < 30. cm
  – vertexR > 0.
  – refMult >= 0

• Electron identification cuts:
  \( (\text{abs}(1./\beta-1.)<0.03 \ \&\& \ p>1.2 \ \text{GeV} \ \&\& \ n\text{SigmaDedx}: \ -0.3\sim3.) \)
  \| (\text{bemc energy}>0.5 \ \text{GeV} \ \&\& \ p/E: \ 0.3\sim1.5 \ \&\& \ p>1.5 \ \text{GeV} \ \&\&
      \text{nSigmaDedx}: \ -0.6\sim3.)
  \| (\text{abs}(1./\beta-1.)<0.03 \ \&\& \ \text{bemc energy}>0.5 \ \text{GeV} \ \&\& \ p/E: \ 0.3\sim1.5 \ \&\& \ p>1.2 \ \text{GeV} \ \&\& \ n\text{SigmaDedx}: \ -1.\sim3.)

• Daughter momentum cuts:
  – P1>1.4 GeV
  – P2>1.2 GeV

• Track quality cuts:
  – nHitsFit > 20
  – nHitsDedx > 15
  – nHitsFit / nHitsPossible > 0.52
  – Global DCA < 1. cm

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Tighter Cuts

- Electron identification cuts:
  \[(\text{abs}(1./\beta-1.)<0.03 \&\& p>1.2 \text{ GeV} \&\& n\text{SigmaDedx}: -0.~3.) \]
  \[|| (\text{bemc energy}>0.5 \text{ GeV} \&\& p/E: 0.3~1.5 \&\& p>1.5 \text{ GeV} \&\& n\text{SigmaDedx}: -0.5~3.) \]
  \[|| (\text{abs}(1./\beta-1.)<0.03 \&\& \text{bemc energy}>0.5 \text{ GeV} \&\& p/E: 0.3~1.5 \&\& p>1.2 \text{ GeV} \&\& n\text{SigmaDedx}: -0.8~3.) \]
Systematic Errors

- Different methods, Different cuts
- Non-flow

Items that are neglected (back-up slides)
- $v_2$ vs. Pt + efficiency and trigger effects vs. Pt
- $v_2$ vs. centrality + trigger effects vs. centrality
- $v_2$ vs. rapidity + efficiency vs. rapidity
$v_2$ vs. Pt + Efficiency and Trigger Effects vs. Pt

Neglected
$v_2$ vs. Centrality + Trigger Effects vs. Centrality

- Efficiency vs. centrality effect is even smaller

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$v_2$ vs. Rapidity + Efficiency vs. Rapidity

• The rapidity distribution is mainly caused by daughter eta acceptance.

• Assume $v_2$ is independent of rapidity within the range of [-1,1].

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