$J/\psi$ polarization measurement in $p+p$ collisions at $\sqrt{s} = 200$ GeV at STAR

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Motivation

Charmonia Study

1. Help to understand quarkonium production mechanism in QCD possibly colored $Q\bar{Q}$ pair of any possible $3s^+L_J$ quantum numbers

2. Help to understand the interaction with Quark-Gluon Plasma, to probe the properties of QGP.
Motivation

Different models can well describe measured cross-sections

- Color Evaporation Model
- NRQCD approach – applicable at high $p_T$
- Color Glass Condensate+NRQCD – applicable at low $p_T$

Measurements of $J/\psi$ polarization can help understand $J/\psi$ production mechanism in hadron collisions and distinguish between different models.

$P+P \rightarrow J/\psi + X$

**J/ψ polarization**

J/ψ polarization can be analyzed via the angular distribution of the decayed leptons

\[
\frac{d\sigma}{d \cos \theta d\varphi} \propto 1 + \lambda_\theta \cos^2 \theta + \lambda_{\theta \varphi} \sin(2\theta) \cos \varphi + \lambda_\varphi \sin^2 \theta \cos(2\varphi)
\]

In helicity frame the *z axis* is defined along the J/ψ momentum in the center of mass frame.

θ: Polar angle between momentum of positron in J/ψ rest frame and the polarization axis z

φ: Azimuthal angle

Polarization angular distribution follows:

\[
w(\cos \theta) \propto 1 + \lambda_\theta \cos^2 \theta
\]

\[
w(\varphi) \propto 1 + \frac{2\lambda_\varphi}{3 + \lambda_\theta} \cos 2\varphi
\]

4/18/2016

S. Luo, APS April Meeting, Salt Lake City
Solenoidal Tracker At RHIC

Time Projection Chamber:
- Tracking
- eID via energy loss.
Solenoidal Tracker At RHIC

Time-Of-Flight Detector:
- eID at low $p_T$ (<1.5 GeV/c)

TPC

[Graph showing data points and distributions]
Solenoidal Tracker At RHIC

Barrel Electro-Magnetic Calorimeter:
- $e\text{ID}$ at high $p_T$ (>1.5 GeV/c)
- Trigger
Previous measurement

Can not really distinguish different models within precision and kinematic reach of STAR 2009 data.

To make improvement:
- Need more data sample.
- Need to extend measurements to higher $p_T$.

From STAR p+p 200 GeV collisions:

<table>
<thead>
<tr>
<th>EMC Trigger</th>
<th>Threshold</th>
</tr>
</thead>
<tbody>
<tr>
<td>HT0</td>
<td>$E_e &gt; 2.5$ GeV</td>
</tr>
<tr>
<td>HT1</td>
<td>$E_e &gt; 3.6$ GeV</td>
</tr>
<tr>
<td>HT2</td>
<td>$E_e &gt; 4.3$ GeV</td>
</tr>
</tbody>
</table>

Measurement of better precision can be made to higher $p_T$.
**J/ψ signal**

HT2 J/ψ Invariant Mass 1eID

- Unlike = 3521.00 +/- 59.34
- Like = 1886.00 +/- 43.43
- No. J/ψ = 1635.00 +/- 73.53
- S/B = 0.87

HT2 J/ψ Invariant Mass 2eID

- Unlike = 783.00 +/- 27.98
- Like = 68.00 +/- 8.25
- No. J/ψ = 715.00 +/- 29.17
- S/B = 10.51

1eID: 1 track requires strict electron identification → has more J/psi signals.

2eID: both tracks require strict electron identification → provide better signal background ratio.

Strict electron identification requires track satisfy the TOF or EMC electron identification cut.
Raw J/ψ cosθ distribution and efficiency

\( \lambda_\theta \) measurement is feasible up to 14 GeV/c.

The triggers applied in Run9 and Run12 are different, which lead to different shapes. Compared with Run9 data, Run12 has more statistics.
Raw $J/\psi$ $\varphi$ distribution and efficiency

Efficiency extracted from Geant detector simulation

$\lambda_\varphi$ measurement is feasible up to 14 GeV/c.
Conclusion

• $J/\psi$ polarization can help understand quarkonium production mechanism and distinguish different models.

• Raw $J/\psi \cos \theta$ and $\varphi$ distributions have been measured from STAR 2012 $p+p$ 200 GeV data, and efficiency corrections are under way.

• Expect to have more precise measurements on $\lambda_{\theta}$, $\lambda_{\varphi}$ compared with published STAR 2009 data. Measurements can be extended up to 14 GeV/c.
Backup
**J/ψ signal**

1eID: 1 track requires strict electron identification->more J/ψ signals.

2eID: both tracks require strict electron identification->better signal background ratio.

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1eID:

- Unlike = 2373.00 +/- 48.71
- Like = 1223.00 +/- 34.97
- No. J/ψ = 1150.00 +/- 59.97
- S/B = 0.94

2eID:

- Unlike = 586.00 +/- 24.21
- Like = 33.00 +/- 5.74
- No. J/ψ = 553.00 +/- 24.88
- S/B = 16.76

STAR preliminary
Invariant mass lineshape with 1eID requirement

- HT2 $0 \text{ GeV/c} < \text{Pt} < 2 \text{ GeV/c}$ 1eID
  - Unlike-Sign
  - Like-Sign
  - $J/\psi$ signal

- HT2 $2 \text{ GeV/c} < \text{Pt} < 3 \text{ GeV/c}$ 1eID

- HT2 $3 \text{ GeV/c} < \text{Pt} < 4 \text{ GeV/c}$ 1eID

- HT2 $4 \text{ GeV/c} < \text{Pt} < 6 \text{ GeV/c}$ 1eID

- HT2 $6 \text{ GeV/c} < \text{Pt} < 8 \text{ GeV/c}$ 1eID

- HT2 $8 \text{ GeV/c} < \text{Pt} < 14 \text{ GeV/c}$ 1eID
Invariant mass lineshape with 2eID requirement

HT2 0 GeV/c < Pt < 2 GeV/c 2eID
- Unlike-Sign
- Like-Sign
- J/ψ signal

HT2 2 GeV/c < Pt < 3 GeV/c 2eID

HT2 3 GeV/c < Pt < 4 GeV/c 2eID

HT2 4 GeV/c < Pt < 6 GeV/c 2eID

HT2 6 GeV/c < Pt < 8 GeV/c 2eID

HT2 8 GeV/c < Pt < 14 GeV/c 2eID