Recent $J/\psi$ results measured with PHENIX

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52nd ISMD
PHENIX Run History

Accomplished 16 years of operation with 9 collision species and 9 collision energies

Results from the recorded data are still coming out.

Progresses from larger systems to smaller systems

<table>
<thead>
<tr>
<th>Species</th>
<th>Run Year</th>
</tr>
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<tbody>
<tr>
<td>Cu+Cu</td>
<td>2005</td>
</tr>
<tr>
<td>U+U</td>
<td>2012</td>
</tr>
<tr>
<td>Cu+Au</td>
<td>2012</td>
</tr>
<tr>
<td>$^3$He+Au</td>
<td>2014</td>
</tr>
<tr>
<td>p+Au</td>
<td>2015</td>
</tr>
<tr>
<td>p+Al</td>
<td>2015</td>
</tr>
</tbody>
</table>
**Muon Arms**

- Rapidity coverage: $1.2 < |y| < 2.2$
- Muon Tracking followed by Muon Identifier
  - Stainless steel and copper absorbers for hadron rejection
- BBC measures collision vertex along beam axis

**Central Arms**

- Rapidity coverage: $|y| < 0.35$
- Charged particle tracks and momentum – pad and drift chambers
- Ring Imaging Cherenkov detector for pion rejection
- Energy / momentum matching of charged particles using EMCal clusters
Small Systems Results
CNM Effects

• Gluon Shadowing/Anti-Shadowing:
Modification (suppression/enhancement) of heavy quark cross section due to modifications of the gluon structure function

• Parton Energy Loss:
The projectile gluon experiences multiple scattering while passing through the target before $J/\psi$ production, reducing the rapidity of the $J/\psi$

• Cronin Effect:
Modification of the $J/\psi$ $p_T$ distribution due to multiple elastic scattering of partons

• Nuclear Break-Up:
The break up of the bound $J/\psi$ (or precursor state) in collisions with other target nucleons that pass through $J/\psi$ production point

• Co-Movers Break-Up:
Final state break up of the $J/\psi$ through interactions with produced partons
• Forward rapidity: $J/\psi$ suppression similar to open charm suppression
  • Consistent with shadowing and/or parton energy loss

• Backward rapidity: $J/\psi$ suppressed relative to open charm
  • Expect open charm enhanced by anti-shadowing
  • $J/\psi$ suppression consistent with absorption from collisions with nucleons in target
  • Possible contribution also from co-movers

• Predictions for $p/ ^3\text{He}+\text{Au}$ based on Bayesian reweighting method using $J/\psi$ constraints from $p+\text{Pb}$ data at the LHC

• Added PHENIX nuclear absorption estimate at backward rapidity
Charmonia Nuclear Modification in $p$+Au Collisions

- At forward rapidity, $J/\psi$ and $\psi(2S)$ modification well described by shadowing models
  - Consistent with cold nuclear matter effects
- At backward rapidity, charmonium modification inconsistent with shadowing effects alone
Large Systems Results
J/ψ Suppression puzzle

- $R_{AA}^{Fwd} < R_{AA}^{mid}$, contrary to expectation
- ~20 cū pairs in collisions at RHIC (mostly at mid-rapidity)

Can we attribute this significant difference in J/ψ $R_{AA}$ to regeneration of J/ψ from cū pairs at mid-rapidity?
Coalescence as the solution

- $R_{AA}^{LHC} > R_{AA}^{RHIC}$
- Greater $J/\psi$ suppression predicted at higher $T$
- $\sim 200$ $c\bar{c}$ pairs at LHC
- Coalescence increases $R_{AA}$
**J/ψ Reconstruction**

**J/ψ Signal Mass Distribution**
- Run 14
- Centrality: 10 – 60%
- Rapidity: [-2.2, -1.2]
- $p_T$: [2, 3]
- $\Delta \Phi$: [0, $\pi/4$]

$\bar{x} = 3.118 \pm 0.004$ GeV/$c^2$
$\sigma = 0.160 \pm 0.002$ GeV/$c^2$
$\alpha = 1.00$
$n = 4.06$

$N_{J/\psi} = 1001 \pm 46$

**J/ψ simulated with PYTHIA embedded in Au+Au data**

- Obtain Crystal Ball fit parameters

**Constructing the signal and fit**
- Crystal Ball function ($J/ψ$)
- Crystal Ball function ($ψ(2S)$)
- Exponential (residual background)
J/ψ ν₂ measurement

- PHENIX J/ψ ν₂ at forward rapidity is consistent with zero
- Forward and mid-rapidity results at RHIC are consistent, but the uncertainties are large
- The ALICE nonzero result is different from our measurement
Summary

• Small systems
  • Large enhancement seen in open heavy flavor decays at backward rapidity
  • $J/\psi \ R_{AA}$ suppression at backward rapidity consistent with nuclear absorption effects
  • $\psi(2S)$ modification at backward rapidity consistent with final state effect

• Large systems
  • Forward rapidity $J/\psi \ R_{AA}$ slightly more suppressed than mid-rapidity results
  • Data at forward rapidity suggests little to no coalescence effects
  • $J/\psi \ \nu_2$ measurements consistent with zero

Thank you for your attention!
Back up
\( \frac{J/\psi \text{ Modification Ratio for } ^3\text{He}+\text{Au to } p+\text{Au} (0-20\%)}{ } \)

- Stronger suppression in \(^3\text{He}+\text{Au}\) than \(p+\text{Au}\) at bkwd rapidity with significance 1.3\(\sigma\)
- No final state effect at fwd rapidity, small final state effect at bkwd rapidity
The $\psi(2S)$ to $J/\psi$ ratio in $p+p$ collisions at RHIC, LHC show no clear energy dependence.

Comparison of the $p+A$ to $p+p$ ratio strongly suggests the presence of final state effects in $p+A$ collisions at backward rapidity, as initial state effects expected to largely cancel.