Forward $J/\psi \rightarrow \mu\mu$ production in Cu+Au collisions at PHENIX

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Overview

- Motivation
- Past measurements
  - Tests of hot and cold nuclear matter
- Why CuAu collisions?
- J/ψ measurement in PHENIX
- Results
Why measure J/ψ?

- Hard collision product
  - Dominated by gluon fusion
- Loosely bound ccbar state
  - 'Melt' in a QGP?
  - Modification was an initial signature of QGP formation
- Complex interplay between hot and cold nuclear matter … need more variables to disentangle effects
What has been measured: Hot nuclear matter

- Au+Au and Cu+Cu collision data
  - Suppression turns on with centrality
  - Similar dependence with overlap volume ($N_{\text{part}}$)
What has been measured: Cold nuclear matter

- $d+Au$
  - Forward/backward asymmetry
  - “suppression” at forward rapidity
- See K. Lee's talk for details
Observational Summary

- $J/\psi \rightarrow$ modified by both hot and cold nuclear matter

- Cold nuclear matter:
  - Shadowing, anti-shadowing, and Cronin
    - Evaluated where these are active, but hot nuclear matter is absent
  - Suppression or enhancement

- Hot nuclear matter, or final state effects
  - Color screening in the hot, dense medium

- Current interpretation needs both hot and cold
  - True relative contribution is difficult to disentangle
  - Colliding different systems, at the same energy, provides additional insight into the relative importance of such mechanisms
Add more geometrical variation: Cu+Au collisions

- Why CuAu (more details from A.Iordanova's talk)
  - Forward/backward momentum asymmetry (like d+Au, but also includes hot nuclear matter)
  - Left-right asymmetry – test of possible core/corona effects
  - Natural triangularity – is this borne out in data?

- Summary: different geometrical controls
  - Next: test them
CuAu Collisions –
Exploiting the flexibility of RHIC

• Why interesting?
  • Naturally odd harmonics
    – Possibility to investigate a “true v3”
  • Large “corona” on Au-side
    – Giving rise to more detailed investigation of it's size
    – “v₁-like” azimuthal dependence
  • Completely swallowed Cu-nucleus in central collisions
    – Cu-going corona vanishes

Participant density (log-z scale)

Glauber model CuAu, b=4fm
CuAu Collisions – Exploiting the flexibility of RHIC

Why interesting?

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Global observations

- BBC asymmetry → forward/backward asymmetry in bulk
Global observations

- $v_1$ at mid-rapidity → left/right asymmetry

Centrality: 30–40%

$p_T$: 2–3 GeV/c

$\Delta \phi = \phi - \psi_{SMD}$

$v_1 \rightarrow (3.1 \pm 0.3) \times 10^{-3}$
$v_2 \rightarrow (4.6 \pm 0.3) \times 10^{-3}$
$v_3 \rightarrow (0.2 \pm 0.3) \times 10^{-3}$
Global observations

- Geometrical effects are borne out in charged hadrons,
  - What about more hard scatterings?
Measuring $J/\psi$ in PHENIX
Measuring J/$\psi$ in PHENIX

- Three pieces:
  - **Tracking**
    - In the muon tracker
  - **Identification**
    - In the MuID (short road through all planes)
  - **Match**
    - Track pieces to ID
    - Track to vertex
Measuring $J/\psi$ in PHENIX

- **Tracks**: small $\chi^2$ and extrapolate back to vertex
- **Identification**: must transcend full MuID steel
- **Matching**: requires spatial position and track/road slopes to be similar
- **Non-matching tracks**: characteristic of hadronic background with larger multiple scattering (or in-flight decay)
Combinatorics

- Combinatorics form a large background
  - Background estimated from mixed event subtraction

- Central data:
  - Peak visible, but atop a large background
Combinatorics

- Combinatorics form a large background
  - Background estimated from mixed event subtraction

- Central data:
  - Peak visible, but atop a large background

- Peripheral data:
  - Clear peak, little background

![Diagram showing Au-going direction with raw counts and invariant mass in GeV/c^2]
Nuclear Modification Factor

- Comparison between particle yields in AA to pp (scaled by the expected number of collisions)
- CuCu and AuAu
  - CNM and final-state effects
  - Suppression observed
  - Independent of collision system

![Graph showing comparisons between J/ψ and μμ distributions for different collision systems and number of participants.]
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- CuAu collisions
  - Same suppression as AuAu/CuCu measured in the Au-going direction
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- CuAu collisions
  - Same suppression as AuAu/CuCu measured in the Au-going direction
  - More suppressed in the Cu-going direction
  - J/ψ not significantly more suppressed in completely swallowed-Cu (top 5%) events
Nuclear Modification Factor

- One example of CNM effects
  - Can partially explain forward / backward difference
  - Final state effects must account for additional suppression

- Similar CNM observations in AuAu collisions

- Model:
  - 4mb break-up cross-section
    - Best describes dAu data
  - Center line → best EPS09 fit
    - Band limits → outer limit of EPS09 nPDFs
  - Linear thickness dependence on shadowing
    - No centrality dependence

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Relative Suppression

- Ratios of yields at fixed centrality
- Relative suppression observed forward/backward
- Centrality-independent

Presents a challenge to theories trying to describe the data
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Energy Density

- Reminder
  - CuAu energy density higher than symmetric systems
  - Effect on $J/\psi$ suppression?
Bulk Asymmetry

- Reminder:
  - Bulk forward/backward asymmetry
  - Affects $J/\psi$ suppression?

- More studies are needed
  - Have a large $J/\psi$ dataset from CuAu collisions
  - Reaction plane dependence
  - $p_T$ dependence

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Conclusion and Outlook

First measurements of $J/\psi$ CuAu collisions at RHIC

- Similar suppression of Au-going $J/\psi$'s
- Stronger suppression observed in forward (Cu-going) direction for $J/\psi$
- Further studies to test for reaction plane dependent production underway