PHENIX Quarkonium Results

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Di-leptons measured in $y = (-2.2, -1.2) (-0.35, 0.35) (1.2, 2.2)$

- No triggering required in Au+Au
- Efficient triggers in p+p, (p,d,$^3$He)+A
Introduction

Recent quarkonium analyses in PHENIX have focused on small systems results for J/ψ and Ψ(2S).

p+Al, p+Au and 3He+Au data from the 2014 and 2015 RHIC runs have been added to our d+Au data from 2008.

The recent quarkonium data are all at forward and backward rapidity (no new central arm data).

In the in-medium program, we measure modifications of quarkonia production in p+A or A+A collisions relative to p+p collisions.

- Interested in low/medium p_T, where modifications are largest.
- Not sensitive to production mechanism.
- Not sensitive to some experimental systematic uncertainties.
Motivation for studying light systems

- Interest in p+A partly motivated by the A+A program
- p+A is sensitive to initial state effects that are not theoretically well understood.
- Assumed for a long time only initial state effects present in p+A.
- But:
  - Unexpectedly strong suppression of the $\psi(2S)$ observed in d+Au collisions at RHIC, and then in p+Pb collisions at LHC.
  - The observation of flow in small systems, observed first at LHC and then at RHIC.
  - Final state effects on quarkonia production in p+A?

ψ(2S) results

Strong suppression at backward rapidity relative to J/ψ
• Not explained by CNM effects
• Suggestive of a final state effect

Mid-rapidity data are well described by calculations involving comovers or a short lived plasma phase
RHIC + LHC $\psi(2S)$ data compared

Pattern not so clear when plotted against rapidity

But it makes more sense when plotted vs $dN/d\eta$
Hmm…

Not clear what mechanism would produce strong differential suppression at \(\sim 0.5 - 1 \text{ fm/c}\).

forward/backward rapidity measurements in PHENIX would help a lot to fill this in!

ALICE, JHEP 1606 (2016) 050

\[
\frac{\sigma_{\psi(2S)}}{\sigma_{J/\psi}} \frac{dN_{\psi(2S)}}{d\eta}\frac{dN_{J/\psi}}{d\eta} = \frac{c}{p_{T}}\text{ analysis (JHEP 06(2015)55)}
\]

\[\langle \tau_{c} \rangle (\text{fm/c})\]
An attempt to put p+A charmonium together

Du and Rapp (JHEP 1903 (2019) 015) have adapted their transport model, used to describe heavy ion collisions, for small systems. They try to describe all available charmonium J/ψ and ψ(2S) data from RHIC and LHC, including the J/ψ $v_2$.

The transport model uses
- A rate equation approach within a fireball model
- Initial geometry of the fireball from a Monte-Carlo event generator
- Initial anisotropies are caused by fluctuations
- Includes corrections for CNM effects

The results for J/ψ, ψ(2S) centrality dependence and J/ψ $v_2$ are shown on the next slide.
- The calculations also provide a good description of the $p_T$ dependence — not shown here.
200 GeV

\~20\% effect at RHIC beyond CNM on J/\psi

5.02 TeV

8.16 TeV

J/\psi v_2 not explained
J/ψ results

Explore in detail the effect of projectile size on inclusive J/ψ modification in p/d/\(^3\)He+Au collisions.

Expect any such effects to be largest at backward rapidity.

**Note** that backward rapidity J/ψ in PHENIX experience a significant breakup cross section from collisions with target nucleons (in addition to substantial anti-shadowing).

- However there is no reason to expect either shadowing or breakup to be different for these three light projectiles.

J/ψ Measurement

Dimuon invariant mass spectra for p+Al, p+Au and $^3$He+Au

With fitted J/ψ peak and various background sources shown

- Red: combinatoric from like-sign.
- Green: non-combinatoric (physics) background estimate.

![Graphs showing dimuon invariant mass spectra for p+Al, p+Au, and $^3$He+Au with fitted J/ψ peak and various background sources.](image)
\[ p_T \] integrated \( J/\psi \) vs centrality

No apparent scaling with \( N_{\text{part}} \) at forward rapidity.

Hard to tell at backward rapidity, since \( N_{\text{coll}} \) is relatively flat.
These data were recorded 7 years apart

- Different p+p references.
- Significant changes to the detector between these runs.
- So the systematic errors (boxes) are not strongly correlated between runs.

0-100% centrality

These data were recorded with the same detector 1 year apart

- Same p+p reference
- Same simulations model
- The systematic errors have significant correlations between runs
The p+Al data show little modification in 0-100% centrality data.
New: centrality selected J/ψ results

New preliminary results

- For p+Au and $^3$He+Au, released only at backward rapidity for now.
- Forward rapidity p+Au and $^3$He+Au almost done.
- p+Al analysis is still underway.

Four centrality bins for p+Au
- 0-20, 20-40, 40-60, 60-84%

Three centrality bins for $^3$He+Au (statistics limited in peripheral data)
- 0-20, 20-40, 40-84%
p+Au vs d+Au centrality selected

Inclusive $J/\psi$ $\sqrt{s_{_{NN}}} = 200$ GeV
-2.2<y<-1.2 (A-going)

0-20% 20-40% 40-60% 60-84%

PHENIX preliminary

p+Au, d+Au, Phys. Rev. C 87, 034904
p+Au vs $^3$He+Au centrality selected

$^3$He+Au produces three times as much energy in the collision.

No significant difference observed in modification between the two projectiles.
• Indicates dominance of CNM effects over those due to energy production in the collision.
$p+Au$ vs $^3He+Au$ $<p_T^2>$ vs $N_{coll}$

Limited to $p_T < 4$ GeV/c because of $^3He+Au$ statistics.

- No evidence of any effects due to projectile size.
Summary

We report preliminary new centrality selected data on inclusive J/ψ modifications studied in two small systems - p/³He+Au.

• Only backward rapidity data are available as yet.

The new centrality selected data are compared with each other, and with existing d+Au data.

We observe no difference in modification between the p+Au and ³He+Au systems.

To come:

• p+Au and ³He + Au at forward rapidity
• p+Al at forward and backward rapidity
• Possibly J/ψ v₂ in Au+Au (dimuons, 2014 run)
• We are also considering whether we can extract ψ(2S) centrality dependent data at forward/backward rapidity for p+Au.
Backup
J/ψ centrality and $p_T$ integrated $y$ dependence

Inclusive J/ψ $\sqrt{s_{NN}}=200$ GeV

$R_{AB}$ vs. rapidity

- p+Au
- $^3$He+Au

PHENIX preliminary
Combine PHENIX d+Au J/ψ data at 12 rapidities, and J/ψ data from 6 fixed target experiments

All cross sections parameterized with EKS98 or EPS09 shadowing plus absorption parameter $\sigma_{\text{abs}}$

Plot absorption parameter vs nuclear crossing time ($\tau$) for p+A or d+Au at 17.3A - 200A GeV CM collision energy

For Au + Au collisions: fold forward & backward rapidity CNM effects together in $1.2 < \eta < 2.2$
- Stronger CNM suppression than at mid rapidity
Fit region above $\tau \sim 0.05$ fm/c with model of **expanding color neutral meson**

- Suggests we really have breakup at backward rapidity (large $\tau$), **something else** at forward rapidity (small $\tau$)

The suppression at forward rapidity (small $\tau$) seems to be well explained by energy loss in cold nuclear matter

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