J/ψ Production in Proton+Proton and Heavy-Ion Collisions at STAR

24 September 2016
Hard Probe 2016 @ Wuhan

Yi Yang
National Cheng Kung University

On Behalf of the STAR Collaboration
Outline

- Motivation
- Relativistic Heavy Ion Collider
- The STAR detector
- $J/\psi$ production in $p+p$ collisions at $\sqrt{s} = 200 & 500$ GeV
- $J/\psi$ production in $Au+Au$ collisions at $\sqrt{s_{NN}} = 200$ GeV
- Summary
Motivation

- Quarkonium production mechanisms are still not fully understood in p+p collisions

- Some popular models on the market:
  - Color Singlet Model (CSM)
  - Color Octet Mechanism (COM) / NRQCD
  - Color Evaporation Model (CEM)
  - $k_T$ factorization
  - ...

- Studying the suppression of quarkonium states in heavy-ion collisions can provide deep insights into the properties of QCD and Quark-Gluon Plasma
Relativistic Heavy-Ion Collider

- One of the most powerful heavy-ion colliders in the world!
The STAR Detector

**Barrel ElectroMagnetic Calorimeter (BEMC)**
- Trigger on and identify electrons
- $|\eta| < 1$

**Time Projection Chamber (TPC)**
- Precise momentum and dE/dx measurements
- $|\eta| < 1$

**Time of Flight (ToF)**
- Particle identification
- $|\eta| < 1$

**Muon Telescope Detector (MTD)**
- Trigger on and identify muons
- $|\eta| < 0.5$
Luminosity: 25.4 pb$^{-1}$ (2012 Run)

Track selection:

- Basic track qualities
- $p_T > 2.5/3.6/4.3$ GeV/c for trigger electrons from $J/\psi$
- $p_T > 0.2$ GeV/c for partner electrons from $J/\psi$
- $|\eta_e| < 1$
- $|y_{J/\psi}| < 1$
**J/ψ → e⁺e⁻/μ⁺μ⁻ in p+p @ 500 GeV**

**Dielectron:**
- Luminosity: 22 pb⁻¹ (2011 Run)
- Track selection:
  - Basic track qualities
  - \(|\eta| < 1\)
  - \(p_T > 1\) GeV/c for electrons from J/ψ

**Dimuon:**
- Luminosity: 28 pb⁻¹ (2013 Run)
- Track selection:
  - Basic track qualities + MTD matching
  - \(|\eta| < 0.5\)
  - \(p_T > 1.3\) GeV/c for muon candidates
  - Additional muon ID selection

(More details can be found in T.C. Huang’s poster)

---

STAR preliminary

Yi Yang 2016 September 24 @ HP2016
J/ψ Invariant Cross-Section in p+p @ 200 GeV

- Precision measurement of J/ψ production cross-section from 0 to 14 GeV/c of \( p_T^{J/\psi} \)
- Data are in a good agreement with CGC+NRQCD & NLO+NRQCD calculations, except that model calculations seem to be above data at low \( p_T \)
- CEM can describe data very well

NLO NRQCD: Ma et al., PRL106 (2011) 042002
CGC+NRQCD: Ma, Venugopalan, PRL113 (2014) 192301
NLO NRQCD: Ma, Venugopalan, PRL113 (2014) 192301
CEM: Nelson, Vogt, Frawley, PRC 87 (2013) 014908
J/ψ Invariant Cross-Section in p+p @ 500 GeV

- Precision measurement of J/ψ production cross-section from 0 to 20 GeV/c of $p_T^{J/ψ}$ ($μμ$ for low $p_T$ and $ee$ for high $p_T$)
- Consistent with CGC+NRQCD & NLO NRQCD calculations. Similar discrepancy at low $p_T$ as seen in p+p @ 200 GeV
- Broken scaling at low $x_T$ is due to soft processes

NLO NRQCD: Ma et al., PRL106 (2011) 042002
CGC+NRQCD: Ma, Venugopalan, PRL113 (2014) 192301

PRC 80 (2009) 041902
ψ(2s) to J/ψ Ratio

- To help determine the feed-down contribution of ψ(2s) to J/ψ
- Result from STAR is consistent with other experiments
  ➜ No obvious collision energy dependence
J/ψ Yield vs. Event Activity

- Event activity = charged-particle multiplicity
- Relative J/ψ yield rises faster than a linear function
  - Similar global trend at different collision energies and as for the D meson
- PYTHIA and Percolation model can qualitatively describe the rising behavior

ALICE: JHEP 09 (2015) 148

* p_T > 0.2 GeV/c for tracks

Yi Yang 2016 September 24 @ HP2016
Luminosity: 14 nb\(^{-1}\) (2014 Run)

Track selection:
- Basic track qualities + MTD PID
- \( |\eta| < 0.5 \)
- \( p_T^{\text{leading}} > 1.5 \text{ GeV/c} \)
- \( p_T^{\text{subleading}} > 1.2 \text{ GeV/c} \)

Yi Yang 2016 September 24 @ HP2016
J/ψ Invariant Yield

- First precision measurement of J/ψ invariant yield via the dimuon channel at mid-rapidity covering $0 < p_T < 15$ GeV/c at STAR


- Tsallis Blast-wave (TBW) function with the assumption of zero J/ψ velocity can describe data very well (Ref: Phys. Rev. C 79 051901, 2009)
No obvious $p_T$ dependence in $R_{AA}$ in 0 - 20% centrality bin
Rising $R_{AA}$ with $p_T$ in 20 - 40% and 40 - 60% centrality bins
Suppression at low $p_T$: dissociation, Cold Nuclear Matter (CNM) effect, regeneration
Rising trend at high $p_T$ could be due to formation time effects, B-hadron feed-down
Strong suppression at high $p_T$ in central collisions is a clear sign of dissociation since regeneration contribution and CNM effects are small
RHIC vs. LHC
- $p_T > 0$ GeV/c: less suppressed in central collisions at the LHC
  - larger regeneration contribution due to higher charm quark cross-section
- $p_T > 5$ GeV/c: more suppressed in central collisions at the LHC
  - larger dissociation rate due to higher medium temperature

Data vs. transport models (dissociation + regeneration effects)
- $p_T > 0$ GeV/c: both models can describe the centrality dependence at RHIC, but tend to overestimate suppression at LHC
- $p_T > 5$ GeV/c: there is tension among data and models

Transport model:
- Model I at RHIC: PLB 678 (2009) 72
- Model I at LHC: PRC 89 (2014) 054911
- Model II at RHIC: PRC 82 (2010) 064905
- Model II at LHC: NPA 859 (2011) 114

Yi Yang 2016 September 24 @ HP2016

ALICE: PLB 734 (2014) 314
PHENIX: PRL 98 (2007) 232301

CMS: JHEP 05 (2012) 063
Two main production mechanisms for $J/\psi$:
- Primordial: close to zero $v_2$
- Regenerated: inherit $v_2$ from constituent charm quarks

First measurement of $J/\psi$ $v_2$ in dimuon decay channel in STAR
- Consistent with the dielectron channel

For $p_T$ above 2 GeV/c, $v_2$ is consistent with zero
→ Contribution of regenerated $J/\psi$ is small
Summary

- The MTD allows STAR to study $J/\psi$ production over a broad kinematic range down to zero $p_T$ via the dimuon decay channel in both $p+p$ and $Au+Au$ collisions

- $J/\psi$ production in $p+p$ @ 200 & 500 GeV
  - Differential $J/\psi$ invariant cross-section from 0 – 20 GeV/c of $p_T^{J/\psi}$ is consistent with CEM, CGC + NRQCD and NLO NRQCD predictions
  - $\psi(2s)$ to $J/\psi$ ratio is consistent with other experiments and no obvious dependence on collision energy is seen
  - $J/\psi$ yield vs. charged-particle multiplicity increases faster than a linear function

- $J/\psi$ production in $Au+Au$ @ 200 GeV
  - Differential $J/\psi \rightarrow \mu^+\mu^-$ invariant yield is consistent with $J/\psi \rightarrow e^+e^-$ result
  - Strong $J/\psi$ suppression at high $p_T$ in central collisions
  - Dissociation in effect
  - Transport models including dissociation and regeneration contributions can describe centrality dependence at RHIC for $p_T > 0$ GeV/c, but there is tension among models and data for $p_T > 5$ GeV/c
  - $J/\psi v_2$: consistent with 0 above 2 GeV/c, favoring the scenario of small regeneration contribution

- Stay tuned for more $J/\psi$ results from STAR