Quarkonium production in the STAR experiment

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Quarkonium - introduction

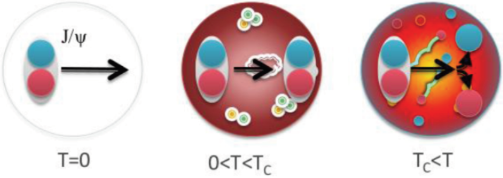
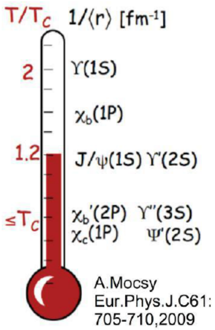
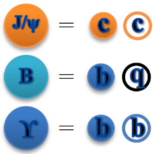


Illustration: A. Rothkopf



Quarkonium: J/ψ, Υ

- Expected to dissociate at high temperature in QGP via color screening (T. Matsui and H. Satz PLB 178 (1986) 416)
- Sequential suppression (lower melting temperatures for excited states)
- Feeddown contributions:
  - Prompt J/ψ: directly produced, decay of $\psi(2S)$ and χ_c
  - Non-prompt J/ψ: $B \to J/\psi$
- Hot nuclear matter (QGP) effects:
  - Dissociation
  - Regeneration
- Cold nuclear matter (CNM) effects

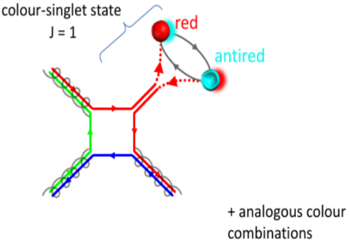


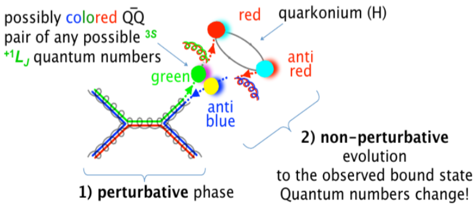
Quarkonium production mechanism

- Still not well understood
- Quarkonium measurements provide tests of production models, help to understand QCD

Models

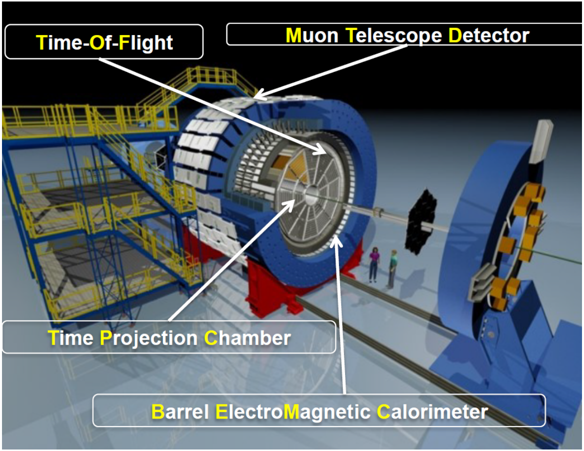
- Color Singlet - $Q\bar{Q}$ produced directly in a color neutral state
- Color Octet - $Q\bar{Q}$ produced in a colored state, gluon emissions needed to neutralize color
- Color Evaporation Model - bound state is produced if $4m_c^2 < m_{c\bar{c}}^2 < 4m_D^2$,color irrelevant (not included), production rates fixed from the data





B. Trzeciak, HQPC 2015

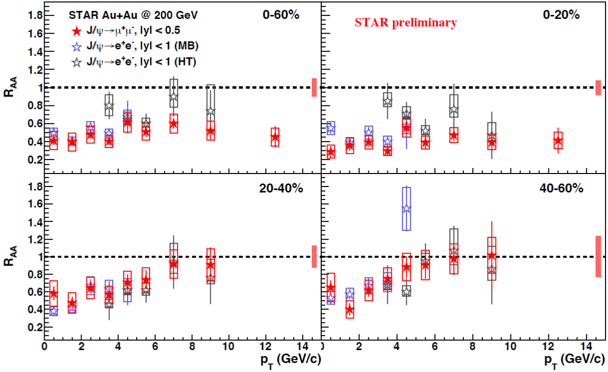
Solenoidal Tracker at RHIC
Large acceptance: $0 < \phi < 2\pi$ $|\eta| < 1$



Detectors used

- TPC - particle tracking and identification
- BEMC - e identification and triggering
- TOF - time of flight measurement
- MTD - μ identification and triggering $|\eta| < 0.5$ (advantage: less bremsstrahlung)

J/ψ from MTD



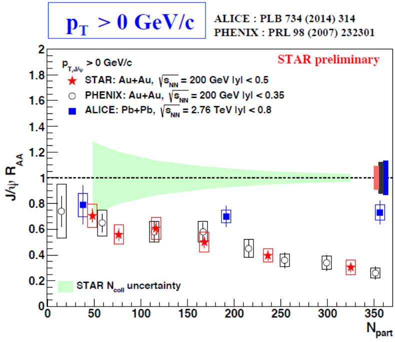
$$R_{AA} = \frac{\sigma_{inel}}{N_{coll}} \frac{d^2 N_{AA}/dydp_T}{d^2 \sigma_{pp}/dydp_T}$$

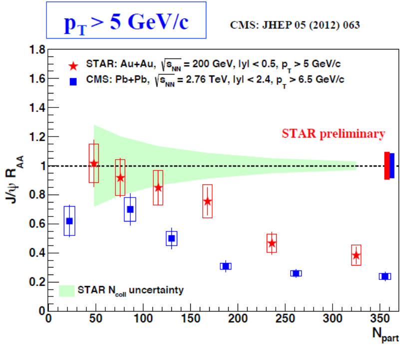
Takahito Todoroki, SQM 2016
STAR PLB 722 (2013) 55
STAR PRC 90, 024906 (2014)

$J/\psi \rightarrow \mu^+\mu^-$

- Suppression at low-p_T
- R_{AA} rises at high-p_T
  - Formation time effect
  - Feeddown from B decays
- Surprise: R_{AA} constant in $0-20\%$ centrality
  - Strong suppression even at high-p_T
  - Consistent with previous results

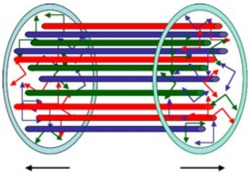
J/ψ from MTD STAR vs. LHC



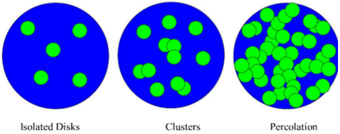


J/ψ R_{AA} vs N_{part} STAR vs. LHC

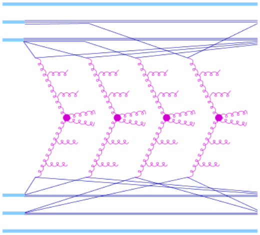
- STAR data consistent with PHENIX
- Larger suppression at RHIC than LHC for $p_T > 0\ GeV/c$ in central events
- Smaller suppression at RHIC than LHC for $p_T > 5\ GeV/c$



Int.J.Mod.Phys. A25 (2010) 5847-5864



arXiv:1501.01524 [nucl-th]



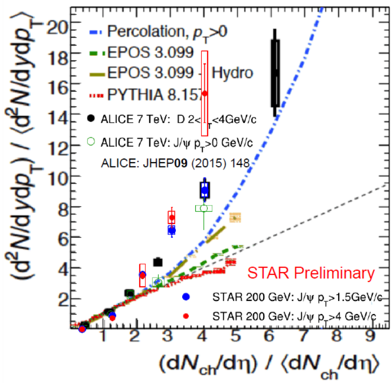
MPI in EPOS3

Klaus Werner, MPI at the LHC 2015

String Percolation

- Many strings of color field are formed during extreme collisions ⇒ many particles produced (high event activity)
- In String Percolation Model overlap between strings dampens particle production (collective effect)
- Multiple Parton Interactions in EPOS3 $N_{hard} \propto N_{MPI} \propto N_{ch}$
- EPOS3+Hydro(3+1D) breaks the proportionality, but includes collective effects

J/ψ vs. event activity

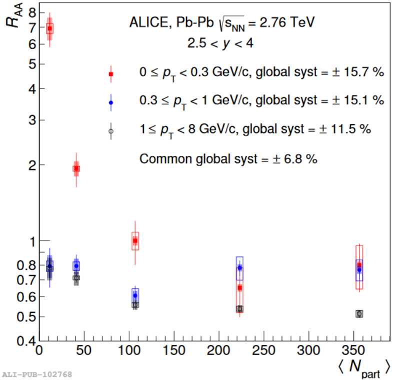


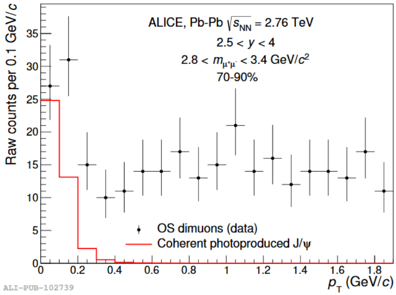
Zhenyu Ye, SQM 2016

$J/\psi \rightarrow e^+e^-$ vs. event activity

- PYTHIA and EPOS3 fail to describe the data, even though they include MPI
- Percolation Model and EPOS3+Hydro(3+1D) describe the data only qualitatively
- Hints of collective effects in $p+p$ both at RHIC and LHC

J. Adam et al. (ALICE Collaboration) Phys. Rev. Lett. 116, 222301

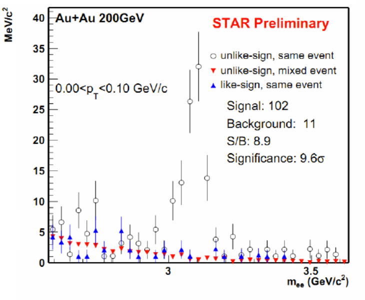


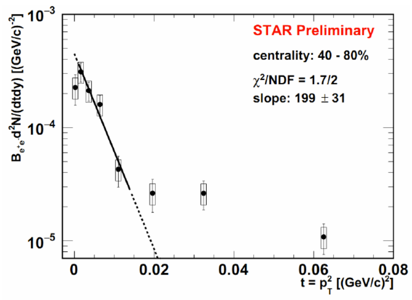


$\gamma\gamma \rightarrow J/\psi \rightarrow e^+e^-$

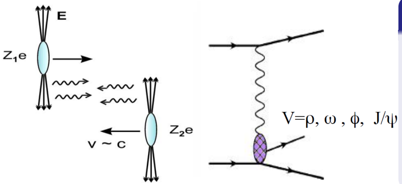
- ALICE has first observed excess of J/ψ at low-p_T
- Origin? Regeneration? Thermal production?

Low-p_T J/ψ excess in $Au+Au$ and $U+U$



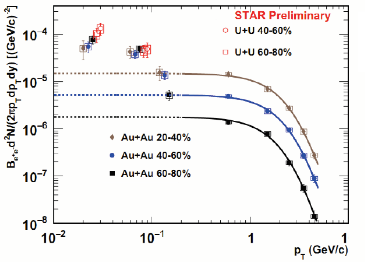


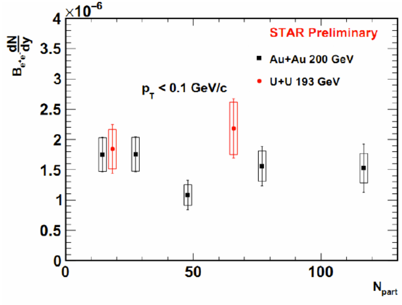
Zhenyu Ye, SQM 2016



$\gamma\gamma \rightarrow J/\psi \rightarrow e^+e^-$

- Excess even at RHIC energy
- Possible explanation is coherent and incoherent photoproduction in ultra-peripheral collisions (UPC)
- New opportunity for QGP studies?

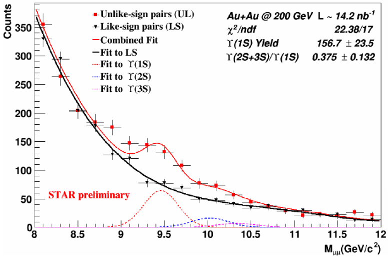


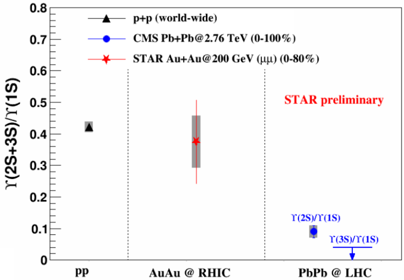


Wangmei Zha, SQM 2016

$\gamma\gamma \to J/\psi \to e^+e^-$

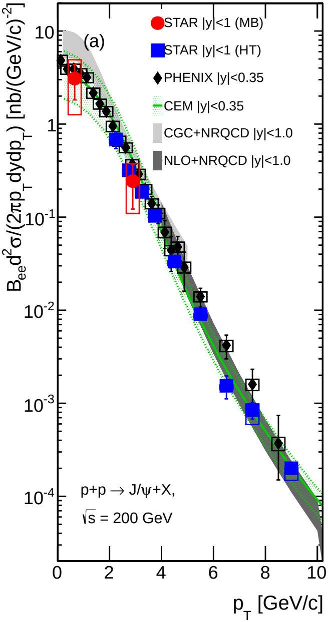
- Effect present in $Au+Au$ and $U+U$
- Constant vs. N_{part}
- Are these really UPC collisions?
- Needs further study especially in $p+p$





$\Upsilon \rightarrow \mu^+\mu^-$ in $Au + Au$ at 200 GeV

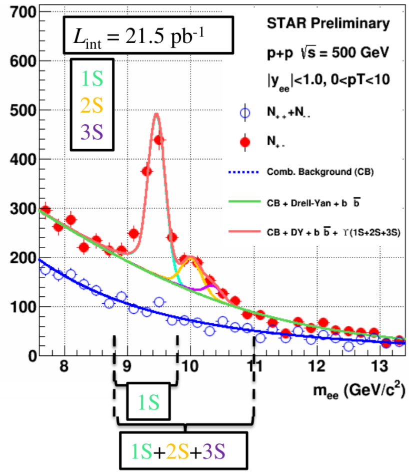
- Υ states separation easier than $J/\psi \rightarrow e^+e^-$ - less bremsstrahlung
- $\Upsilon(2S + 3S)/\Upsilon(1S)$ ratio larger at RHIC than at LHC
- Hints of less melting of $\Upsilon(2S + 3S)$ at RHIC than LHC



$J/\psi \to e^+e^-$ in $p+p$ 200 GeV

- Red points - results of my analysis - Principal Author
- Published: Phys. Rev. C 93 (2016) 064904
- CEM well describes the data
- Both NRQCD CS+CO models at NLO describe the data

My results - Υ in $p+p$ 500 GeV



Υ in $p+p$ 500 GeV

- Large data sample $\Rightarrow$ high precision results
- Visible signal of 1S, 2S and 3S states
- Separation of 1S form 2S+3S possible
- 2S/3S may be hard to separate
- Ongoing analysis goals:
  - Spectra: p_T and $y \Rightarrow$ baseline and constraints for models
  - Event activity studies. Is it the same for Υ as at LHC?

Presented at:

- Hot Quarks 2014
- Zimanyi School 2014
- Quark Matter 2015

- Surprisingly strong J/ψ suppression at high p_T in $0-20\%$ central $Au+Au$
- Smaller suppression at RHIC than LHC for $p_T > 5\ GeV/c$
- J/ψ vs. event activity studies give indication of collectivity in $p+p$ both at RHIC and LHC
- $\Upsilon(2S+3S)/\Upsilon(1S)$ ratio measured by MTD larger at RHIC than at LHC
- Hints of less melting of $\Upsilon(2S+3S)$ at RHIC than LHC
- J/ψ cross section in $p+p$ at 200 GeV in agreement with CEM and NRQCD+NLO models
- Work in progress on Υ vs. event activity studies at RHIC

BACKUP