Upsilon production in the STAR experiment

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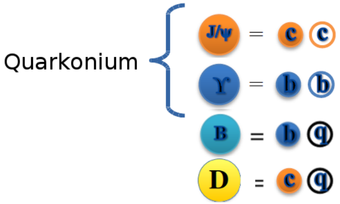
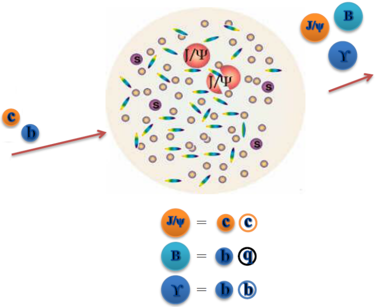
Outline

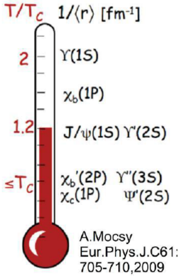


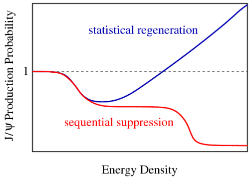
$m_c = 1.28 \pm 0.03\ GeV/c^2$
$m_b = 4.18^{+0.04}_{-0.03}\ GeV/c^2$
$m_{J/\psi} = 3096.900 \pm 0.006\ MeV/c^2$
$m_{\Upsilon(1S)} = 9460.30 \pm 0.26\ MeV/c^2$
$m_{\Upsilon(2S)} = 10023.26 \pm 0.31\ MeV/c^2$
$m_{\Upsilon(3S)} = 10355.2 \pm 0.5\ MeV/c^2$
[Chinese Physics C 2016 vol: 40(10) 100001]

Upsilon

- Part of quarkonium family ($Q\bar{Q}$)
- Upsilons are much heavier than $J/\psi \Rightarrow$ very rare
- Heavy quarks are produced in hard collisions of partons (hard processes, early stages of a collision $\tau < 1\ fm/c$)







[Nucl.Phys.B (Proc.Suppl.) 214, 3-36(2011)]

Upsilon in QGP

- J/ψ suppression is a signature of Quark-gluon plasma (QGP) formation [T. Matsui, H.Satz, Phys.Lett.B 178(4),416-422(1986)]
- Υ melt in QGP at high temperature or energy density $\Rightarrow$ suppression due to Debye-like screening similar to J/ψ
- Each of the quarkonium states has different binding energy $\Rightarrow$ dissociates at different temperature $\Rightarrow$ sequential suppression [Phys.Lett B 637(1-2),75-80(2006)]
- Less recombination for Υ than for J/ψ
- Feeddown from excited states and cold nuclear matter effects complicate the picture

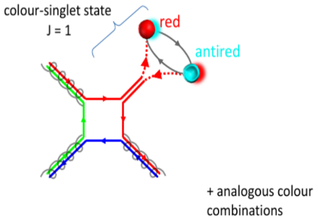
Quarkonium production mechanism

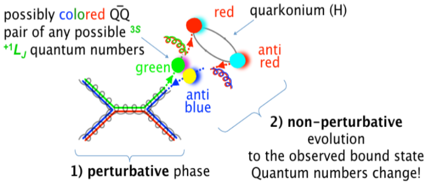
Quarkonium production mechanism

- Still not well understood: hard scattering+non-perturbative hadronization
- Quarkonium measurements provide tests of production models, help to understand QCD
- Provide insight to overall particle production by event activity-dependent studies

Quarkonium production models

- Color Singlet - $Q\bar{Q}$ produced directly in a color neutral state
- Color Octet - $Q\bar{Q}$ produced in a color state, gluon emissions needed to neutralize color - described by long-distance matrix elements (LDMEs), assumed universal
- Color Evaporation Model - color irrelevant (not included), production rates fixed from the fit to the world data

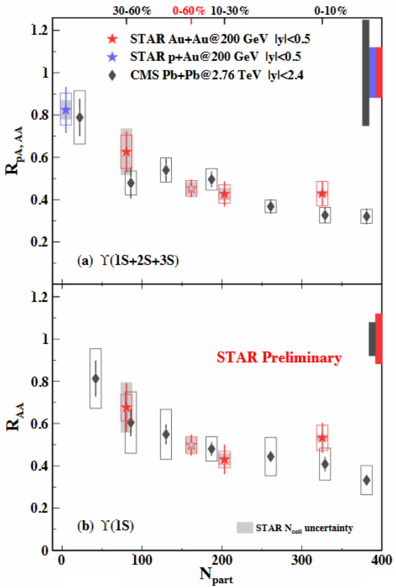




[B. Trzeciak, HQPC 2015]

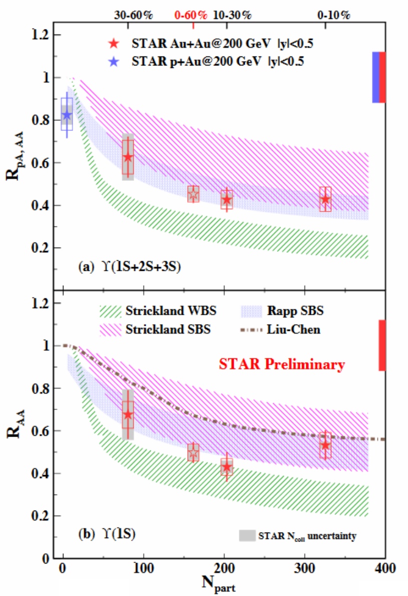
Υ in $Au + Au$ at $\sqrt{s_{NN}} = 200\,GeV$

- $R_{AA} = \frac{1}{N_{coll}} \frac{\text{Invariant yield}_{A+A}}{\text{Invariant yield}_{p+p}}$ - measures suppression
- Newest results with MTD shown at Quark Matter 2017 by Zaochen Ye
- Similar suppression at RHIC and LHC for $\Upsilon(1S + 2S + 3S)$ and $\Upsilon(1S)$
- Data trend indicates more suppression in central collisions



[Phys. Lett. B 770, 357–379]
[Phys. Rev. Lett. 109, 222301]

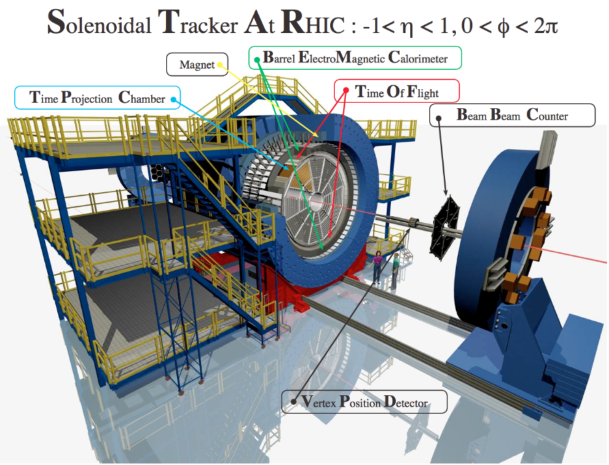
Υ R_{AA} - models



Comparison with models

- Data consistent with Emerick, Zhao, Rapp model [Eur. Phys. J. A 48 (2012) 72]
  - Cold Nuclear Matter (CNM) effects included - modified nPDFs
  - Absorption: $\sigma_{abs} = 0 - 3\ mb$
- Data favor model with Strong Binding Scenario (SBS)
- Strickland, Bazov [Nucl. Phys. A 879 (2012) 25]
  - No CNM effects
  - Feeddown included
  - SBS - internal energy used as heavy quark potential
  - WBS - free energy used as heavy quark potential
- Model by Liu, Chen, Xu, Zhang [Phys. Rev. Lett. 697, (2011) 32]
  - No CNM effects
  - Feeddown included
  - Only excited states dissociate

STAR experiment - detectors used



TPC

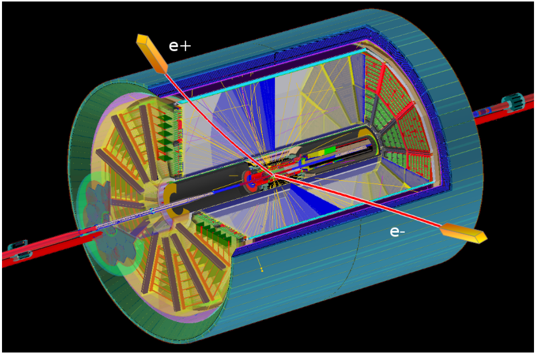
Particle identification via dE/dx and tracking

BEMC

Particle identification via E/p and shower shape, also provides online High Tower trigger

TOF

Particle identification via time of flight, fast detector used to characterize event activity

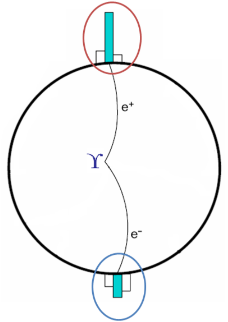


Dataset

Analyzed 160M p+p 500 GeV events triggered by High Tower trigger ($\mathcal{L} \approx 21.5\ pb^{-1}$), 92M passing event cuts

Event cuts

$|V_z| < 40\ cm$ - same as embedding (MC simulation) V_z range



Υ decay reconstruction

$\Upsilon(1S) \rightarrow e^+e^-\ B_{ee}^{\Upsilon(1S)} = 2.38 \pm 0.11\%$
$\Upsilon(2S) \rightarrow e^+e^-\ B_{ee}^{\Upsilon(2S)} = 1.91 \pm 0.16\%$
$\Upsilon(3S) \rightarrow e^+e^-\ B_{ee}^{\Upsilon(3S)} = 2.18 \pm 0.20\%$

[Chinese Physics C 2016 vol: 40(10) 100001]

Track selection and PID

Track, which fired the trigger:

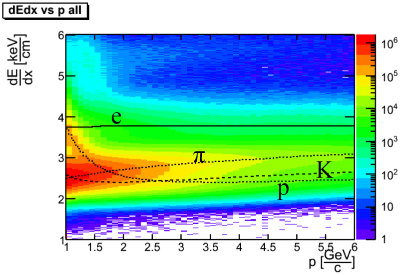
Match to L0 tower required

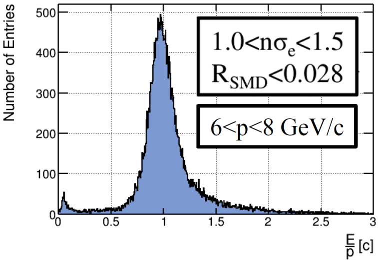
Partner track:

$p > 1\,\mathrm{GeV/c}$

Both tracks:

$$-1.2 < n\sigma_e < 3$$
$$\frac{E_{TOW}}{E_{CLU}} > 0.5$$
$$0.55 < \frac{E_{CLU}}{pc} < 1.45$$
$$R_{SMD} < 0.028$$





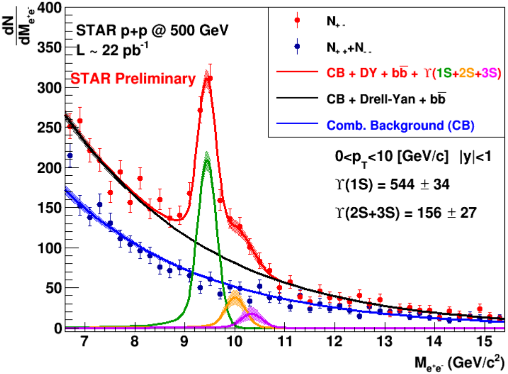
J. Phys.: Conf. Ser. 612 012022

Normalized dE/dx:

$$n\sigma_e = \ln\left(\frac{\frac{dE}{dx}|_{Measured}}{\frac{dE}{dx}|_{Expected}}\right)/\sigma$$

Distance between a track projection on BEMC SMD and center of a cluster:

$$R_{SMD} = \sqrt{\Delta\eta^2 + \Delta\phi^2}$$



- Simultaneous fit of like-sign and unlike-sign histograms using RooFit
- Upsilon (1S+2S+3S) signal modeled by 3 Crystal-Ball functions
- Unlike-sign model (red) consists of:
  - 3 Crystal-Ball functions (1S,2S,3S states)
  - $b\bar{b}$+DY correlated background (black): $f_{b\bar{b}} = N \frac{m^A}{(1+\frac{m}{B})^C}$
  - Combinatorial backround (blue) - exponential simultaneously fitted to like-sign histogram : $f_{CB} = N \cdot exp(\frac{-m}{Exp1})$

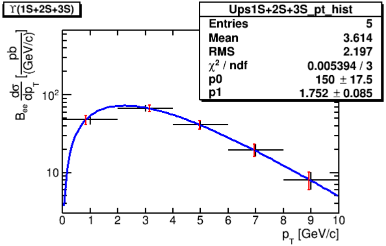
Fit strategy

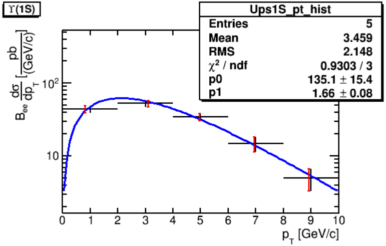
- Use as wide range as possible to get the most information
- Keep the fit function simple

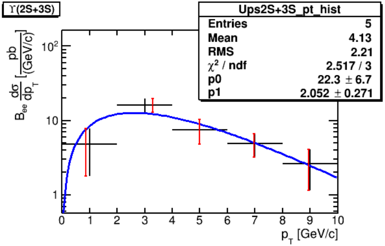
Presented at Quark Matter 2017

[Zaochen Ye, Quark Matter 2017]

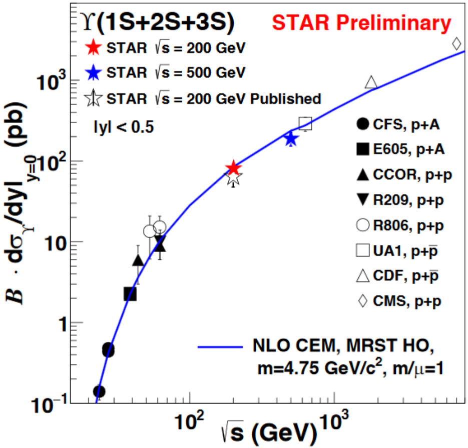
Point placement correction





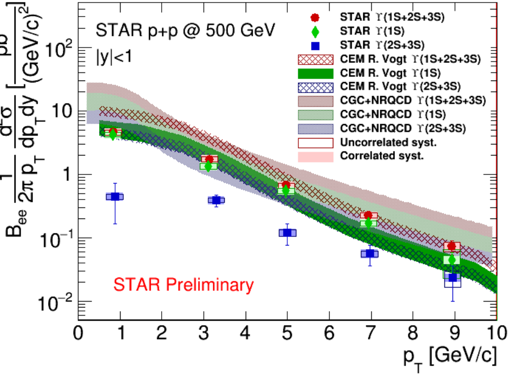


- Fitted a function: $f(p_T) = \frac{A \cdot p_T}{e^{p_T/T}+1}$ $(p0 = A,\ \text{p1} = \text{T})$
- Red points are placed in p_T^{corr}, where $f(p_T^{corr}) = \frac{1}{\Delta p_T} \int_{p_T^{lo}}^{p_T^{hi}} f(p_T) dp_T$

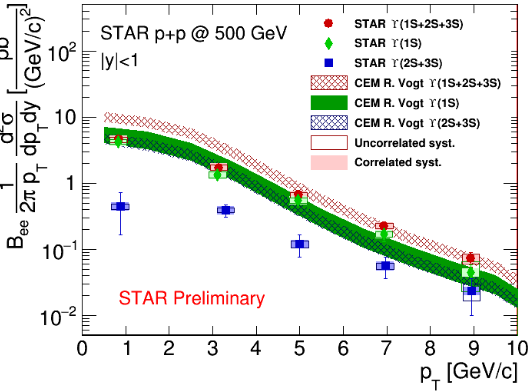


- $B_{ee}\frac{d\sigma}{dy}||_{|y|<0.5} = 186 \pm 14(stat) \pm 33(syst)\ pb$ at $\sqrt{s} = 500\ GeV$
- Integrated cross section consistent with Color Evaporation Model
- Plot from [Zaochen Ye's Quark Matter 2017 talk]

Invariant cross section



- Color Evaporation Model (CEM) calculation for $1S$ from [R. Vogt, Phys.Rev. C92 (2015) 034909]
- $2S$ and $3S$ calculated from $\frac{2S}{1S} = 0.51$ and $\frac{3S}{1S} = 0.35$ extracted at $\sqrt{s} = 7$ TeV
- Color-glass condensate and Non-relativistic Quantum Chromodynamics (CGC+NRQCD) [PRD 94, 014028 (2016)] [PRL 113, 192301 (2014)]
- CGC+NRQCD authors warning: Sudakov resummation needed at low p_T
- $1S$ consistent with both, except with CGC+NRQCD at low p_T, rest below



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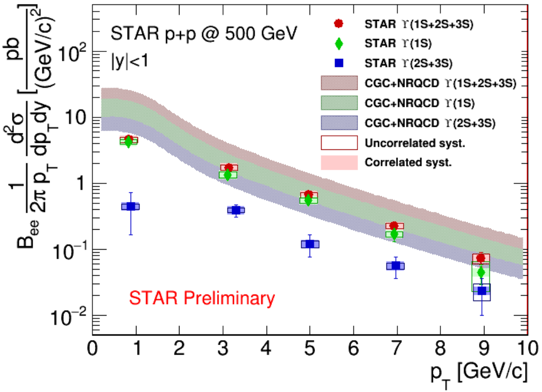
- $2S$ and $3S$ calculated from $\frac{2S}{1S} = 0.51$ and $\frac{3S}{1S} = 0.35$ extracted at $\sqrt{s} = 7\ TeV$
- $1S$ data consistent with CEM, rest consistent at high p_T mostly



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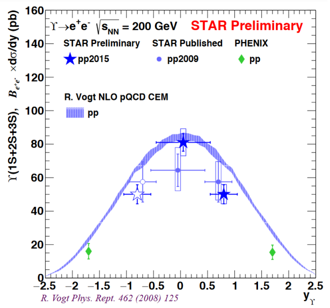
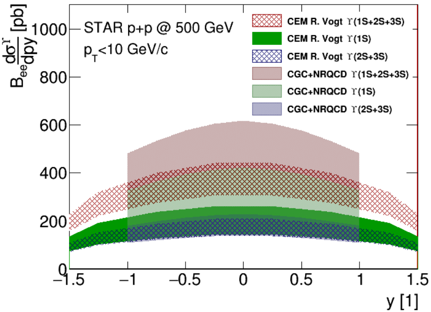
- CGC+NRQCD authors warning: Sudakov resummation needed at low p_T
- $1S$ and $1S + 2S + 3S$ consistent with model, except at low p_T
- $2S + 3S$ below model

Rapidity dependence

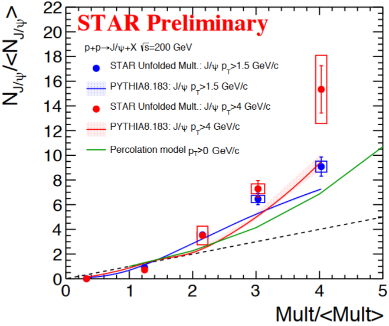


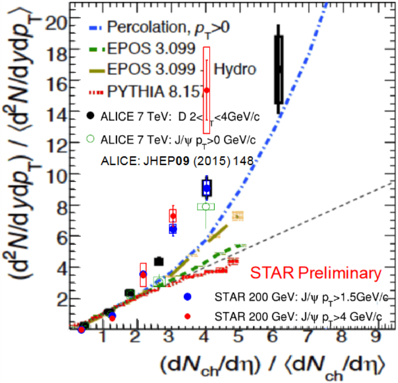
[Zaochen Ye, QM 2017 talk]



- STAR data slightly narrower than CEM model
- Rapidity spectrum more flat at $\sqrt{s} = 500\ GeV$ compared to $\sqrt{s} = 200\ GeV$
- STAR results coming soon!

Quarkonium production vs. event activity

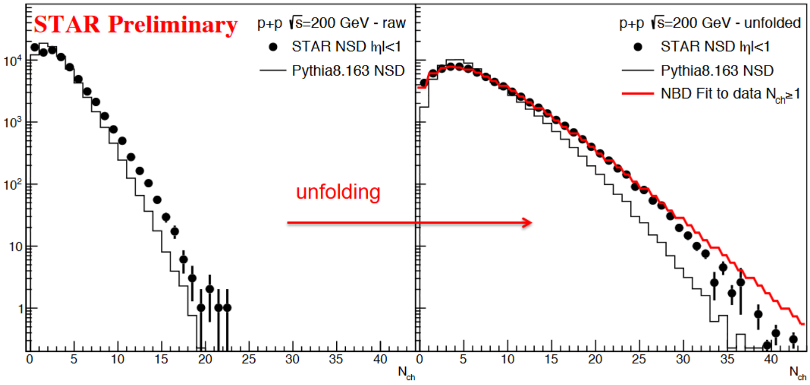




[Zhenyu Ye, MPI2016]

Quarkonium production vs. event activity

- Provides insight into particle production models
- Investigate multiple parton interactions (MPI)
- Strong dependence on normalized mult
- Check behavior for Υ - results at $\sqrt{s} = 500\ GeV$ coming soon!
- Plan to study production vs. forward activity using FMS or EEMC



[Zhenyu Ye, MPI2016]

Unfolding method used for event activity studies

- Advanced correction for multiplicity distribution
- Same method applied to correct J/ψ and Υ
- PYTHIA does not describe the data
- Work in progress

Summary

- Presented preliminary Υ p_T spectrum at $\sqrt{s} = 500$ GeV
- $\Upsilon(1S)$ p_T spectrum consistent with both CEM and CGC+NRQCD models, except at low p_T
- Event activity and rapidity dependence coming soon!
- Interesting to compare with EPOS (event activity, p_T, y dependence)
- Next, finalize the results and prepare for publication

BACKUP - links

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