# Uncorrelated production of double quarkonium in PbPb collisions

Miles Cochran-Branson[1] and Manuel Calderón de la Barca Sánchez[2]

[1]Department of Physics, Lawrence University, [2]Department of Physics, University of California, Davis

## Objective

Estimate quarkonium yields from the $\sqrt{s_{NN}} = 5.02\,\mathsf{TeV}$, $\mathcal{L}_{int} = 1.7\,\mathsf{nb}^{-1}$, 2018 PbPb run at CMS using:

- Monte Carlo Glauber model for number of nucleon-nucleon collision ($N_{coll}$)
- Monte Carlo particle production simulation, PYTHIA 8.306, for kinematic values to make cuts in acceptance ($\mathcal{A}$) and efficiency ($\mathcal{E}$)
- Estimates of cross-sections for probability of production
- Multinomial model for estimates of production

## Introduction

The study of quarkonium, a heavy meson ($\mathcal{Q}\bar{\mathcal{Q}}$), has long been used as an indicator of the quark gluon plasma (QGP) [1]. The QGP is a state of deconfined quarks and gluons that occurs at high energies and/or pressures and is readily produced in heavy ion (HI) collisions. Quarkonium production is indicative of the QGP because:

- It is produced in both HI and pp collisions
- It is produced in the beginning stages of the collision, i.e. before or soon after the formation of a QGP
- Suppression or enhancement due to color Debye screening and other effects of the QGP can be observed when comparing quarkonium production in pp and HI collisions [2]

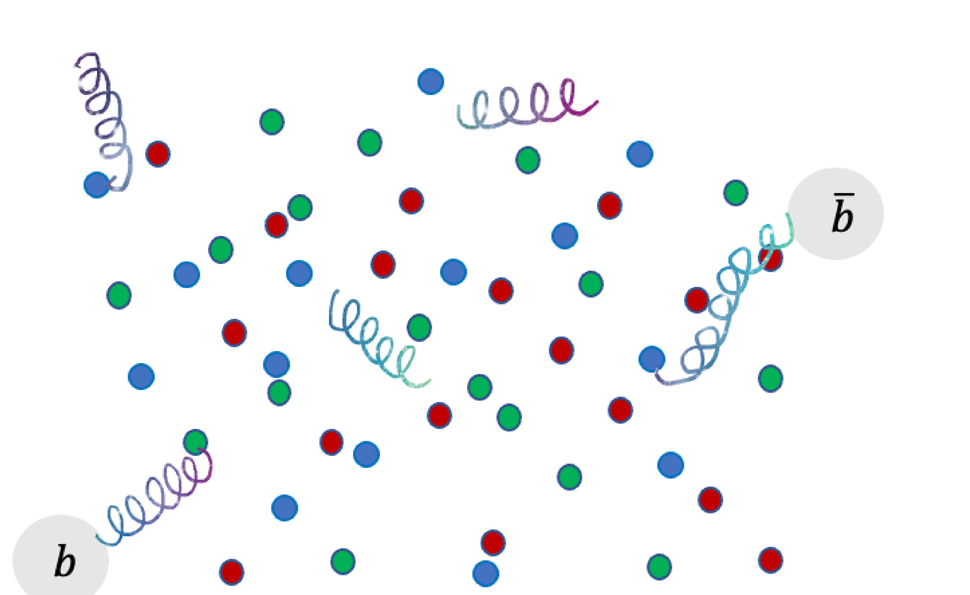



Figure: Suppression of $\Upsilon$ due to the quark-gluon plasma

## Quarkonium

We study *bottomonium* ($b\bar{b}$), specifically the $\Upsilon(1S)$, and *charmonium*, specifically the $J/\psi(1S)$.

- Particles are detected in the $\mathcal{Q} \to \mu^+ + \mu^-$ decay channel which have branching ratios of 6% and 2.5% for the $\Upsilon$ and $J/\psi$ respectively
- In HI collisions quarkonium production should be suppressed
- Our model will not include suppression. It will act as a benchmark for data analysis currently being done by the CMS collaboration

## Acceptance and Efficiency

In order to compare to data, we must include kinematic considerations of our detector, i.e. acceptance and efficiency. We do this by running a Monte Carlo particle production simulation, PYTHIA 8.306. Results for acceptance and efficiency are shown below:

| | $\Upsilon$ | $J/\psi$ |
|---|---|---|
| $\mathcal{A}$ | 0.25 | 0.014 |
| $\mathcal{E}$ | 0.80 | 0.67 |
| $\mathcal{A} \times \mathcal{E}$ | 0.20 | 0.0094 |

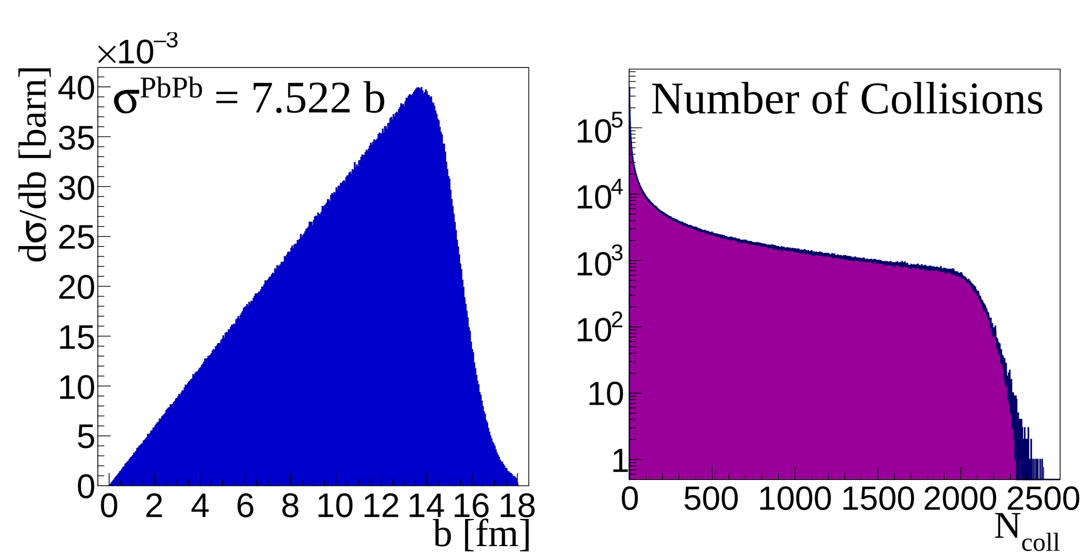
## Backbone of model

For each nucleon-nucleon collision there is some probability of producing a quarkonium. Using a multinomial model we can determine how many $\Upsilon$ and $J/\psi$ single and double productions we should see for PbPb collisions at $\sqrt{s_{NN}} = 5.02\,\mathsf{TeV}$, $\mathcal{L}_{int} = 1.7\,\mathsf{nb}^{-1}$.

## Glauber Model

The Glauber Model is a way of modeling collisions of heavy ions by assuming that each nucleus-nucleus collision is a superposition of nucleon-nucleon collisions [3].

- From impact parameter (b) we can determine number of events by $N_{events} = \sigma^{PbPb} \cdot \mathcal{L}_{int}$
- We use $N_{coll}$ distribution for nucleon-nucleon collisions




(a) (b)

Figure: Distributions from Glauber model. (a) shows the impact parameter normalized to the PbPb cross-section while (b) shows our $N_{coll}$ distribution.

## Probabilities and Multinomial

We use the assumption that the probability of producing a quarkonium is given by

$$Pr(\mathcal{Q}) = \frac{\sigma^{\mathcal{Q}}}{\sigma^{pp}} \quad (1)$$

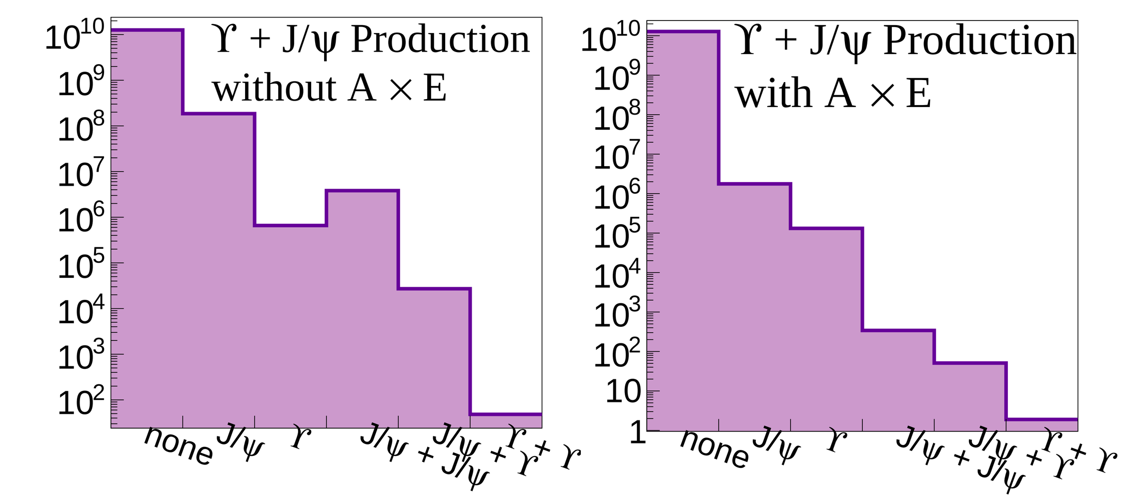
where $\sigma^{\mathcal{Q}}$ is our quarkonium cross-section, and $\sigma^{pp}$ is the proton-proton cross-section. We obtain values of cross-sections from [4] and calculate probability of production as show below.

| | $\Upsilon$ | $J/\psi$ |
|---|---|---|
| $\sigma^{\mathcal{Q}}$ | 9.40 nb | 2.65 μb |
| $Pr(\mathcal{Q})$ | $1.34 \times 10^{-7}$ | $3.78 \times 10^{-5}$ |

We then use a multinomial distribution to obtain estimates for production. We validate this model by running Monte Carlo pseudo-experiments. Results of this model can be found in the following section.

## Results

Combining all of the above we find estimates for production. Below, panel (a) shows values without acceptance and efficiency whereas (b) shows values with acceptance and efficiency.




(a) (b)

## Conclusion

We estimate the production of single and double $\Upsilon$ and $J/\psi$ production without suppression due to the QGP. These values will be compared to data currently being analyzed by the nuclear group at the University of California, Davis as part of the CMS collaboration.

## References

[1] Francesco Becattini.
The quark gluon plasma and relativistic heavy ion collisions in the LHC era.
*Journal of Physics: Conference Series*, 527:012012, jul 2014.

[2] T. Matsui and H. Satz.
$J/\psi$ suppression by quark-gluon plasma formation.
*Physics Letters B*, 178(4):416–422, 1986.

[3] Michael L. Miller, Klaus Reygers, Stephen J. Sanders, and Peter Steinberg.
Glauber modeling in high-energy nuclear collisions.
*Annual Review of Nuclear and Particle Science*, 57(1):205–243, 2007.

[4] Yu Feng, Jean-Philippe Lansberg, and Jian-Xiong Wang.
Energy dependence of direct-quarkonium production in pp collisions from fixed-target to LHC energies: complete one-loop analysis.
*The European Physical Journal C*, 75(7):313, Jul 2015.

## Acknowledgements

We wish to thank the University of California, Davis REU program and NSF grant PHY-1852581 for making this research possible. We would also like to thank the nuclear research group at UCD for all of their support, with a very special thanks to Manuel Calderón de la Barca Sánchez for his invaluable mentorship.

## Contact Information

- Email: cochranm@lawrence.edu