The 16th International Workshop on Heavy Quarkonium at IISER Mohali

Heavy-flavor Production in p+p Collisions Measured by the STAR

Md. Nasim (For the STAR Collaboration)
Department of Physical Sciences
Indian Institute of Science Education and Research, Berhampur

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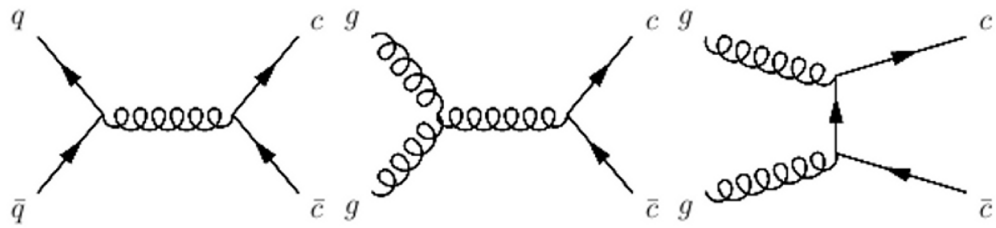
Outline

- Introduction
- The STAR Detector
- Results
  - Heavy-flavor decay electron
  - J/ψ Production (Charm)
  - ϒ Production (Bottom)
- Summary

Heavy-Flavor Measurement in p+p

- Test of Perturbative QCD Calculations.

  - Due to their large mass heavy quarks are primarily produced in initial hard scatterings



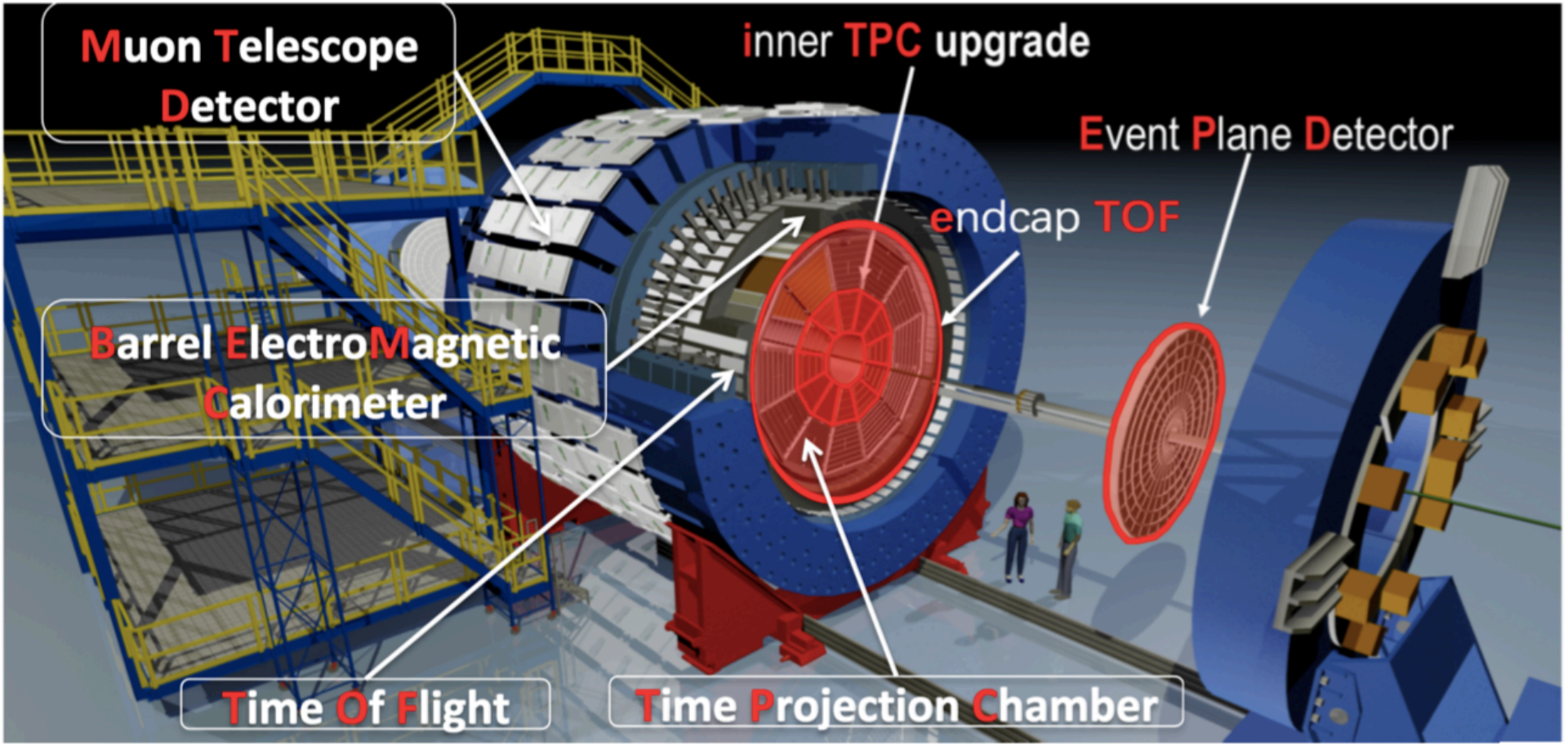
  - Production rates can be calculated by pQCD

- Baseline of Heavy-ion Measurements.

  - Heavy quarks can be used as a probe of QGP in Au+Au collisions.

  - Measurement in p+p collisions is essential to understand the effect of hot QCD medium formed in Au+Au collisions

The STAR Experiment



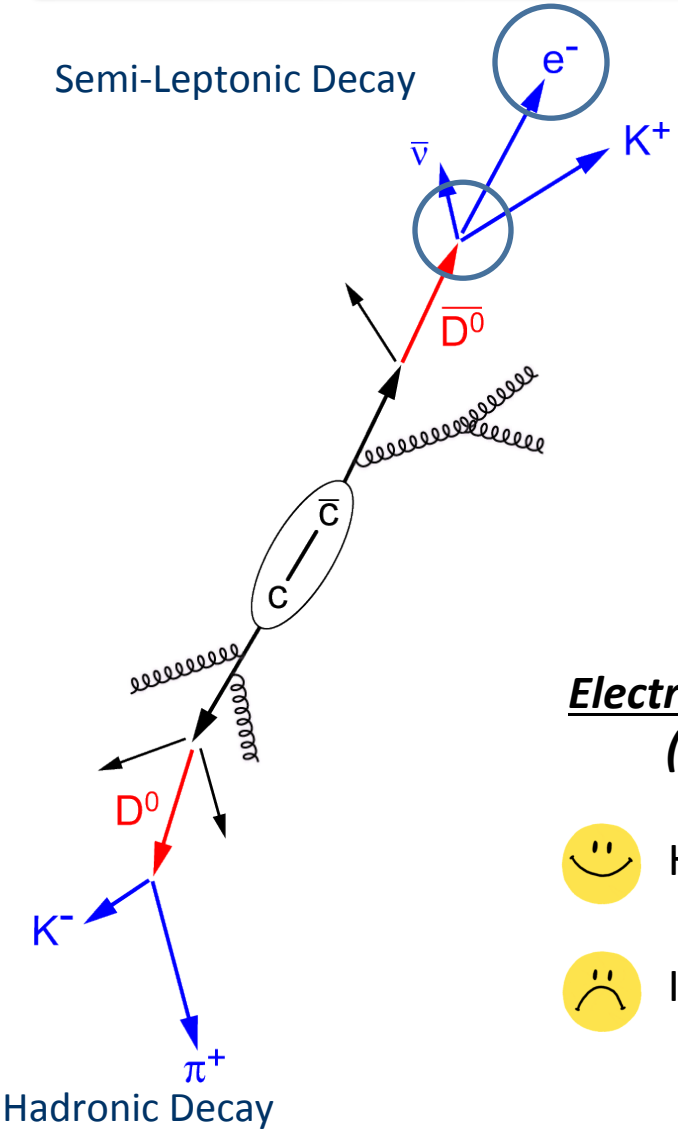
TPC : Tracking (momentum measurement, particle identification) ($|\eta| < 1$, $0 < \varphi < 2\pi$)

BEMC : Triggering and identification of high-p_T electrons ($|\eta| < 1$, $0 < \varphi < 2\pi$)

MTD : Triggering and identification of muons ($|\eta| < 0.5$, 45% in φ)

Heavy-Flavor Decay Electrons

Heavy-flavor Decay Electron



Charm Decay

$$D^0 -> e^+ + X(BR = 6.5\%)$$

$$D^+ -> e^+ + X(BR = 16.1\%)$$

Bottom Decay

$$B^0 -> e^+ + X(BR = 10.1\%)$$

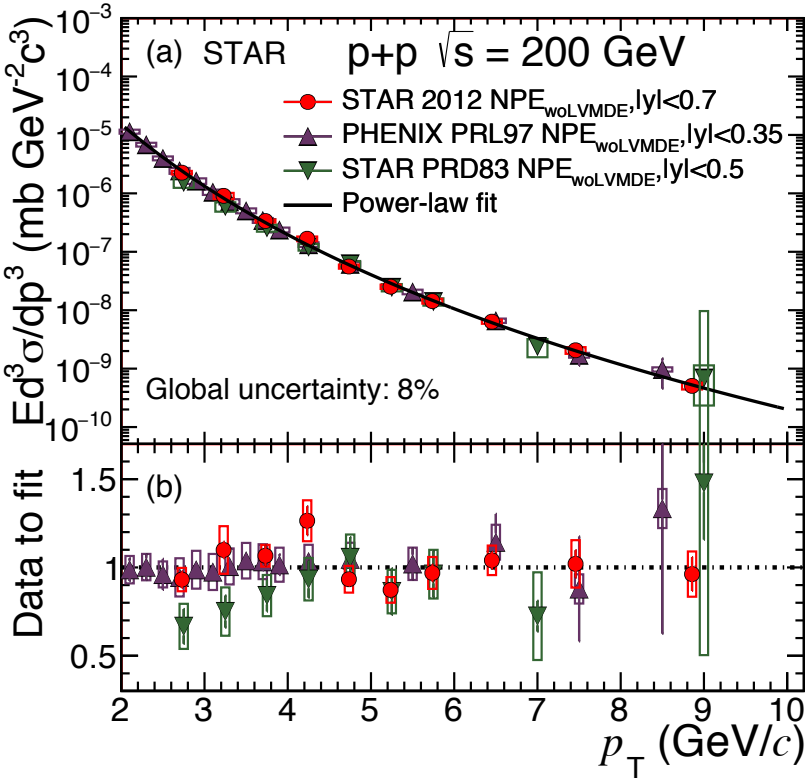
$$B^+ -> e^+ + X(BR = 10.8\%)$$

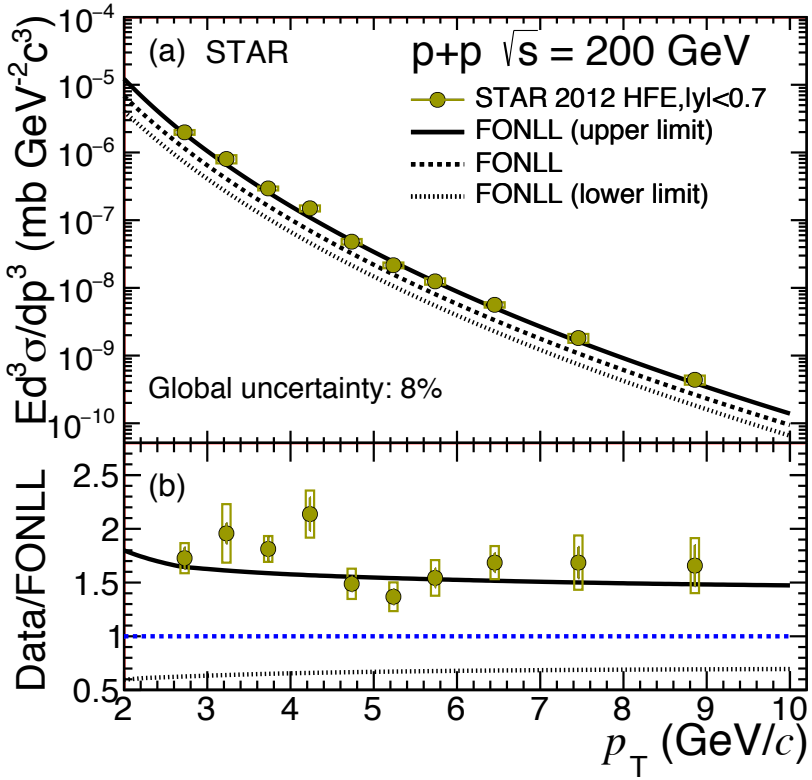
Semi-Leptonic decay of D and B mesons

<u>Electrons from decays of heavy-flavor hadrons (known as NPE)</u>
(proxies to measure heavy quarks)

- Higher branching ratios than the hadronic decays
- Incomplete kinematic information of parent hadrons

Heavy-flavor Decay Electron

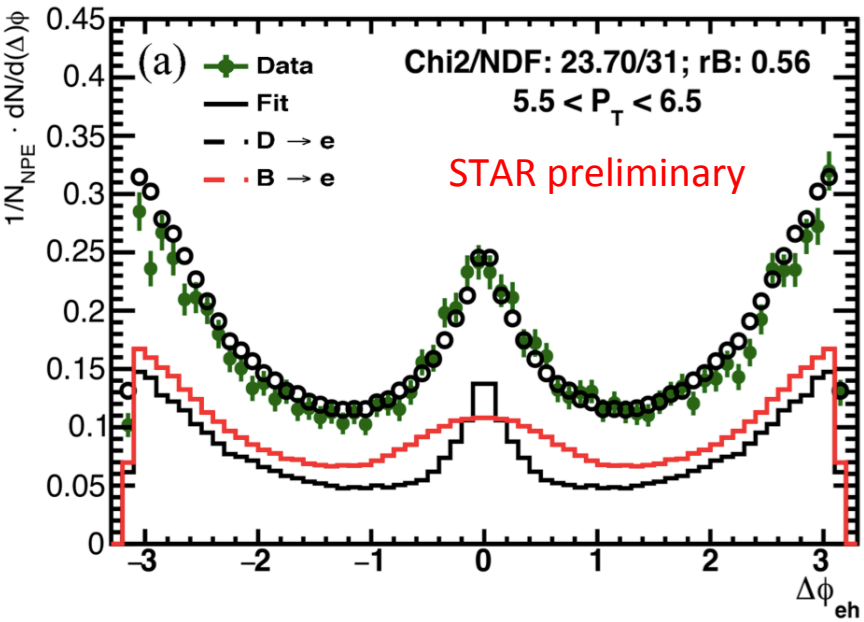


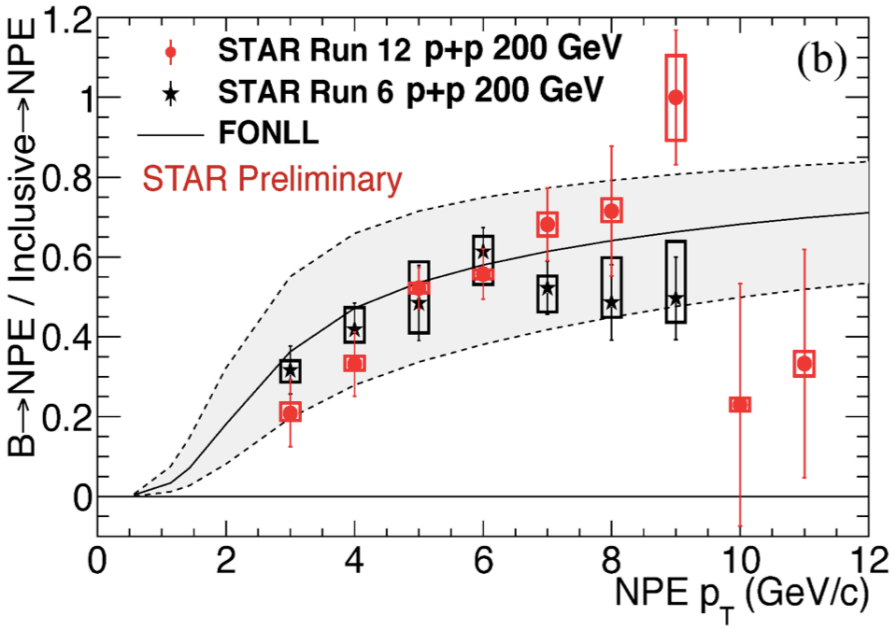


- Results are consistent with FONLL in p+p 200 GeV collisions
- Provides a precise reference for nuclear modification factor measurements in A+A

STAR : Phys. Rev. D **105** (2022) 32007

Charm vs Bottom Contribution to the NPE





Azimuthal correlations between NPE and charged hadrons has been used to separate out charm and bottom contribution

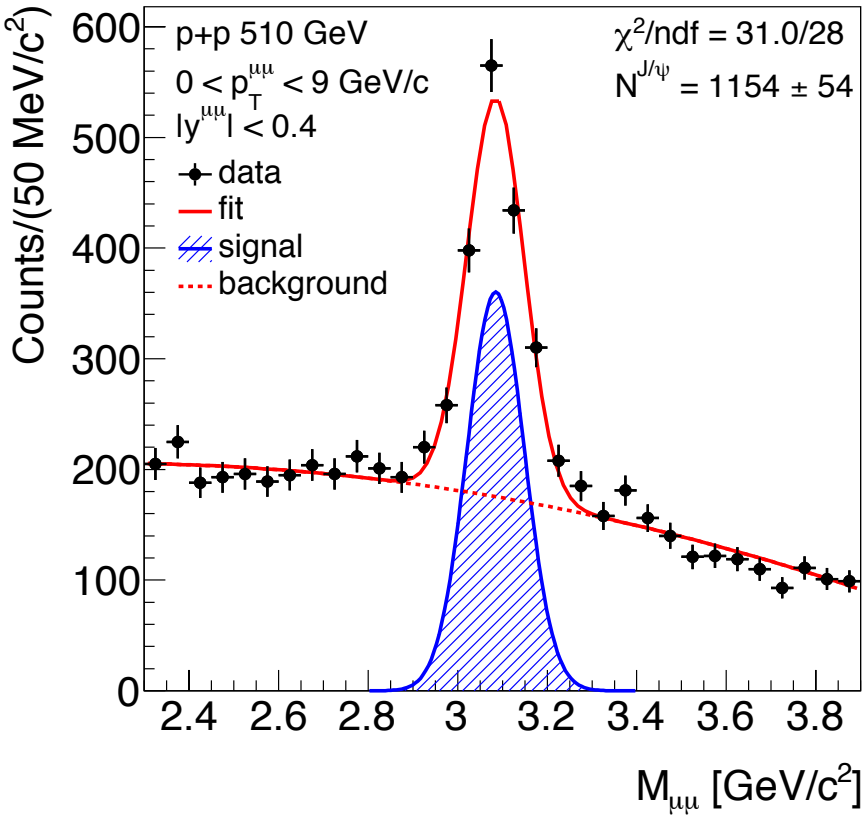
- The B decay contribution increases with p_T
- The B contribution to NPE is about 60% at high p_T

STAR: Phys.Rev.Lett.105,202301(2010)

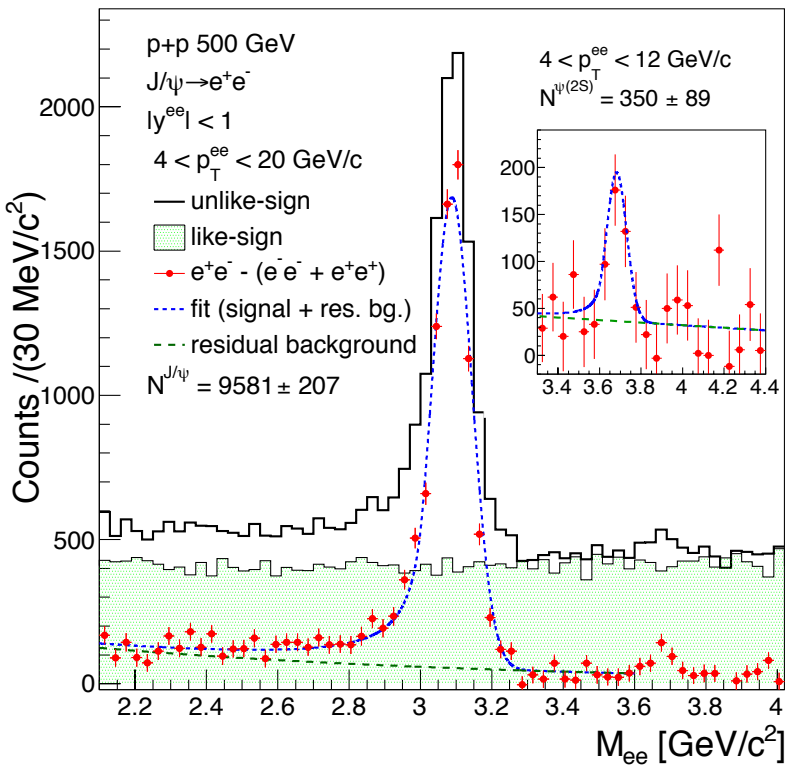
J/ψ ($c\bar{c}$) Production

J/Ψ Reconstruction

$$J/\psi -> \mu^+ + \mu^-(BR = 5.9\%)$$



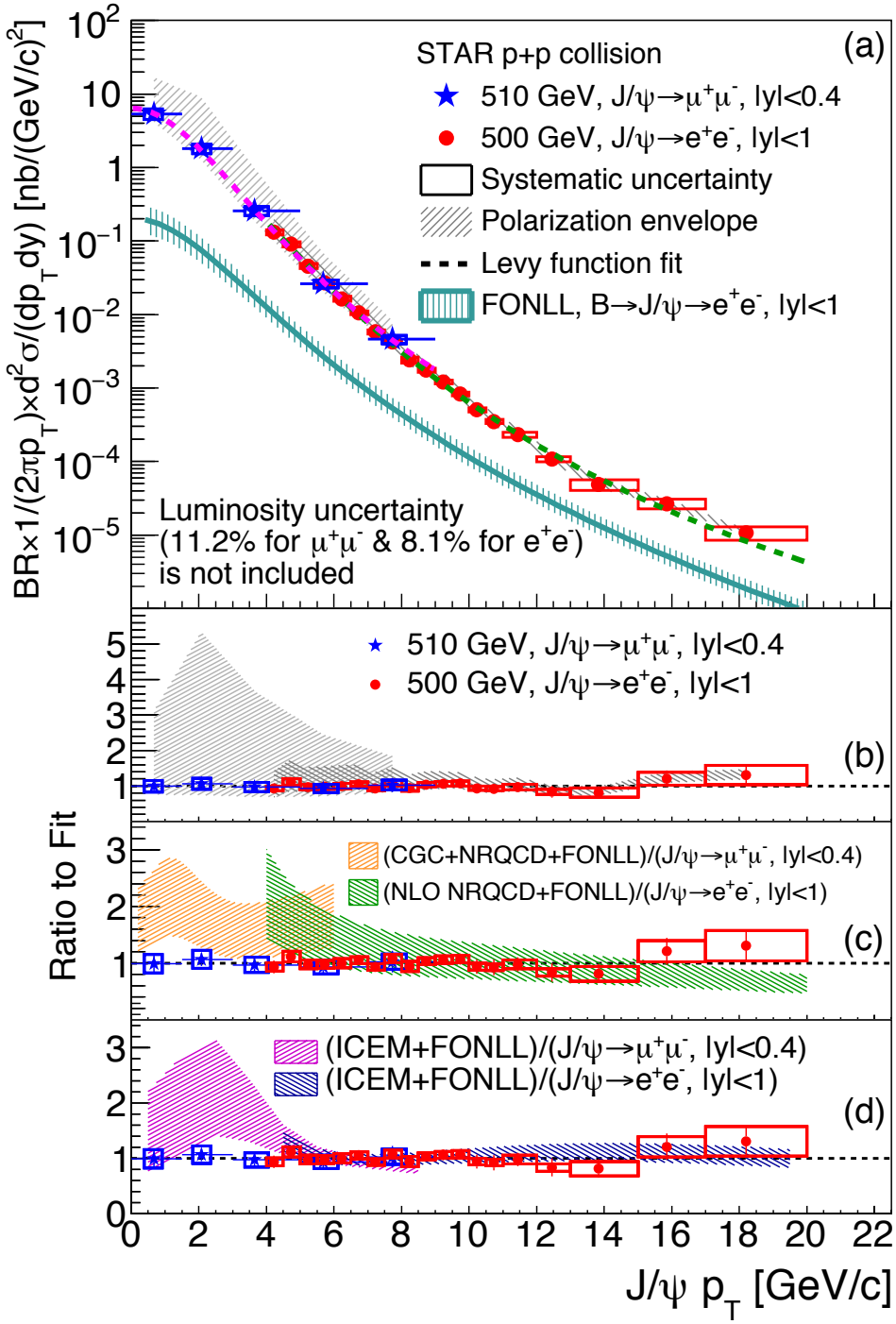
$$J/\psi -> e^+ + e^-(BR = 5.9\%)$$



J/Ψ are reconstructed in both dimuon and di-electron decay channel

STAR : Phys. Rev. D **100** (2019) 52009

J/ψ Cross-Section



- Precise measurement of J/Ψ cross-section up to p_T =20 GeV/c
- Low p_T reach is extended through dimuon channel

Available model calculation

NRQCD : non-relativistic QCD approach

PRL 113, 192301 (2014); PRL 106, 042002 (2011)

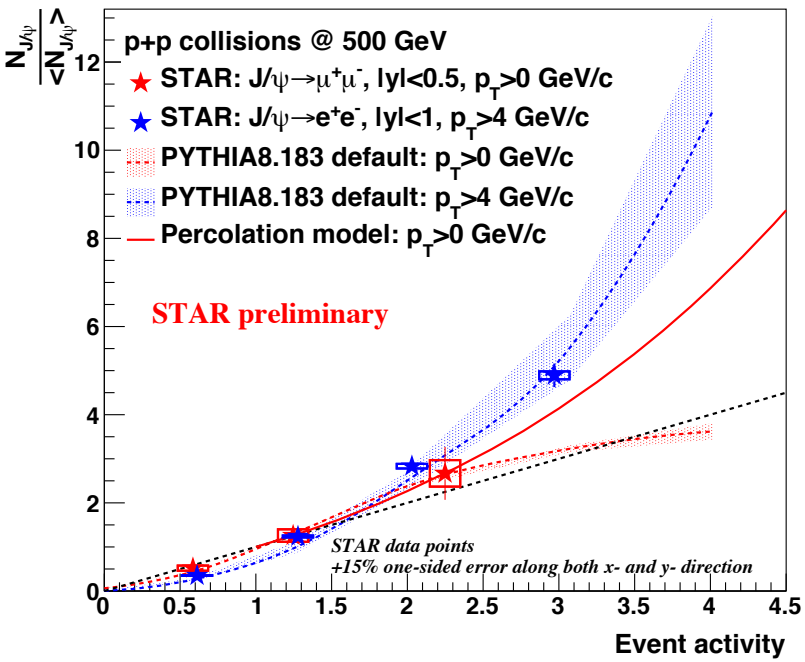
ICEM: Improved Color Evaporation Model

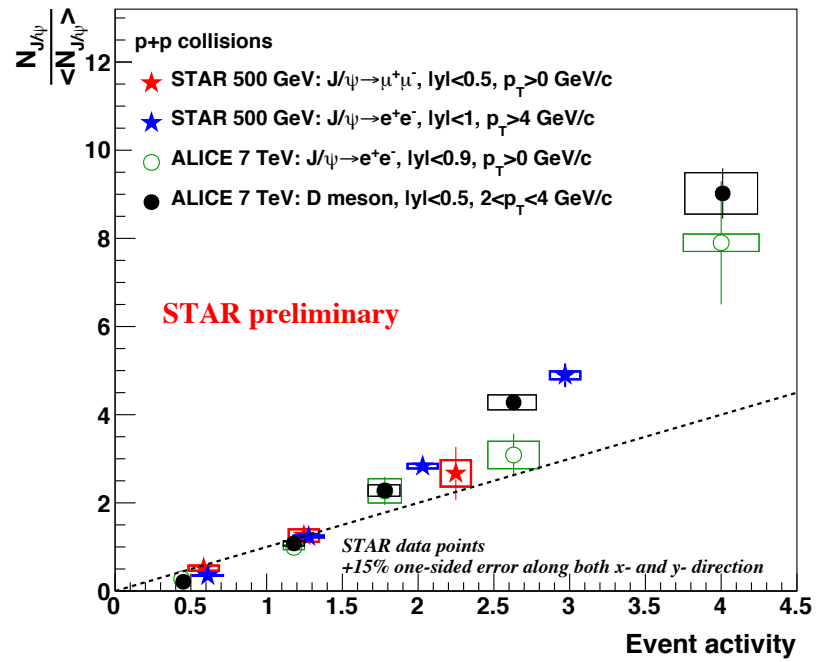
Phys. Rept. 462, 125 (2008)

All models give reasonable description for the data, mainly at high p_T

STAR : Phys. Rev. D **100** (2019) 52009

J/ψ Production Vs Event Activity





- Correlation between soft and hard processes
- Stronger-than-linear growth in high mult. events
- Both PYTHIA and Percolation model explain data,
  - measurement in larger multiplicity bins is important

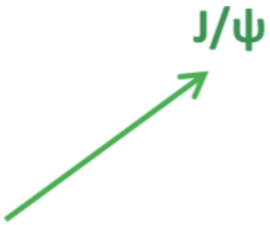
- Similar trend at RHIC and LHC

Percolation: PRC 86 (2012) 034903

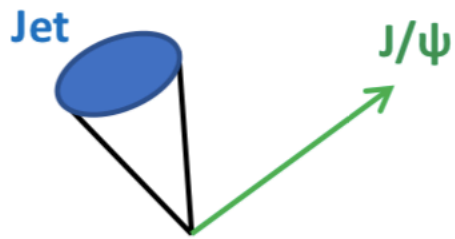
ALICE : PLB 712 (2012) 165-175 and JHEP 09 (2015) 148

J/ψ ($c\bar{c}$) Production Associated with Jet

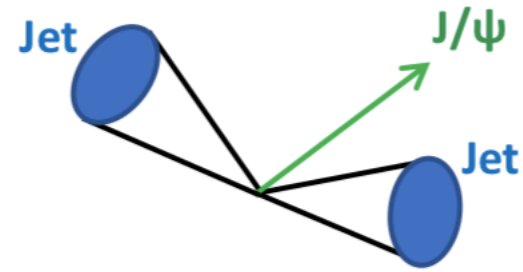
J/ψ Production Associated with Jet



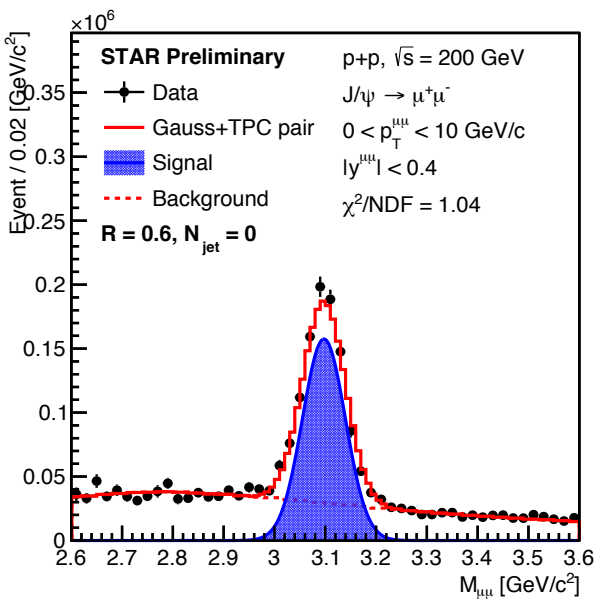
• J/ψ with 0 jet

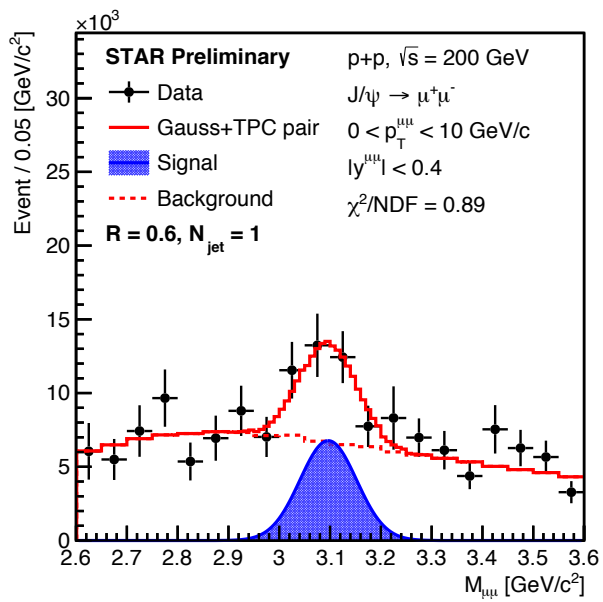


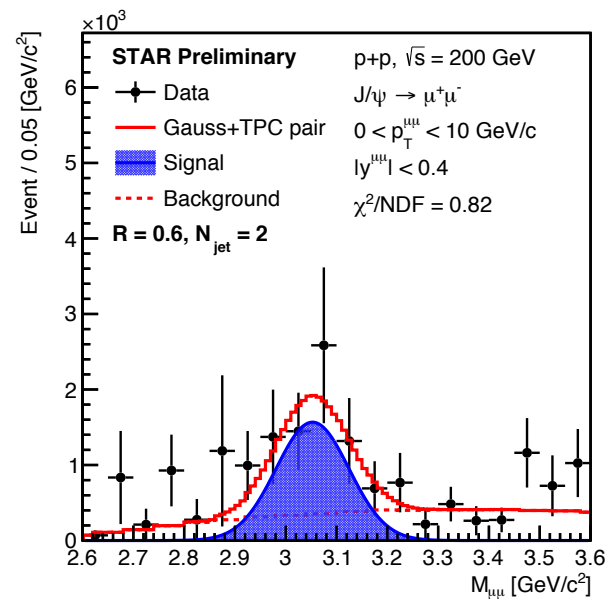
• J/ψ with one jet



• J/ψ with two jets

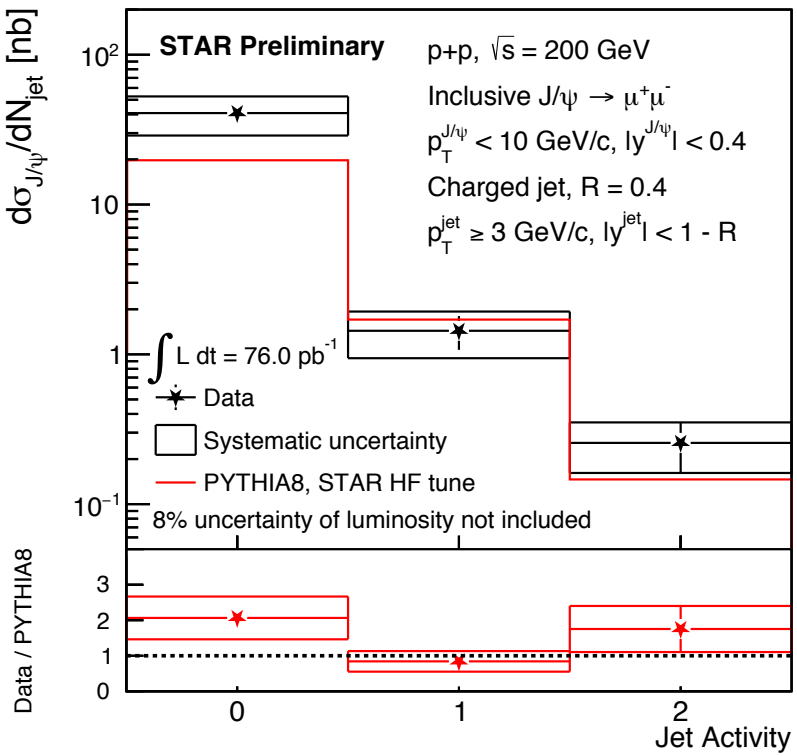


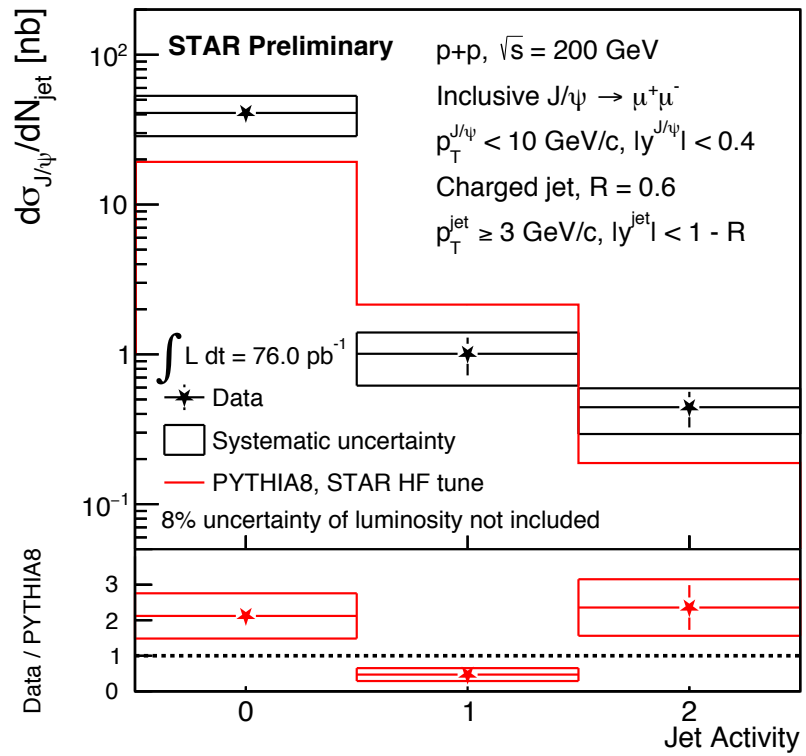




Reconstructed J/ψ in different jet activity categories (left to right: N_{jet} = 0 to N_{jet} = 2)

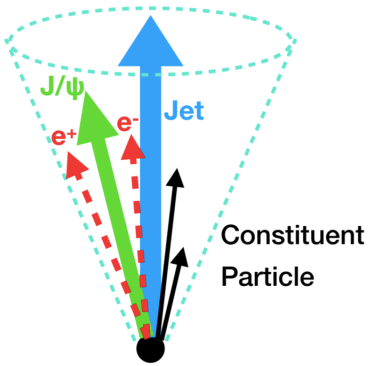
J/ψ Production Vs Jet Activity

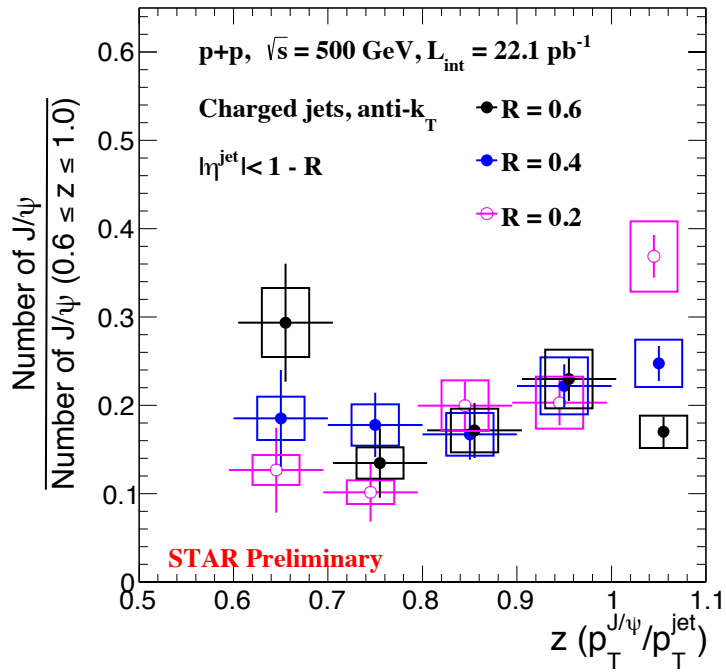


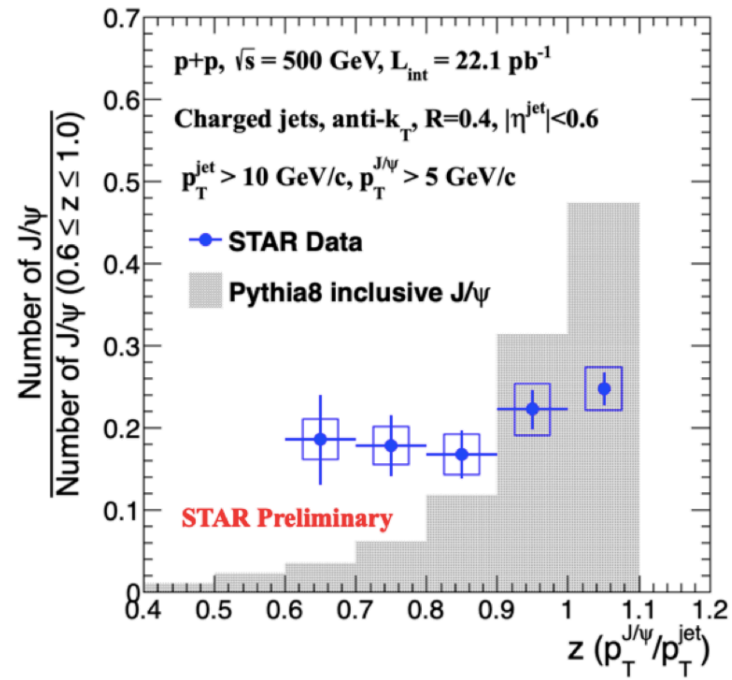


- Production cross section of J/ψ as a function of jet activity (number of jets per event)
- PYTHIA fails to explain the data

J/ψ Production in Jets





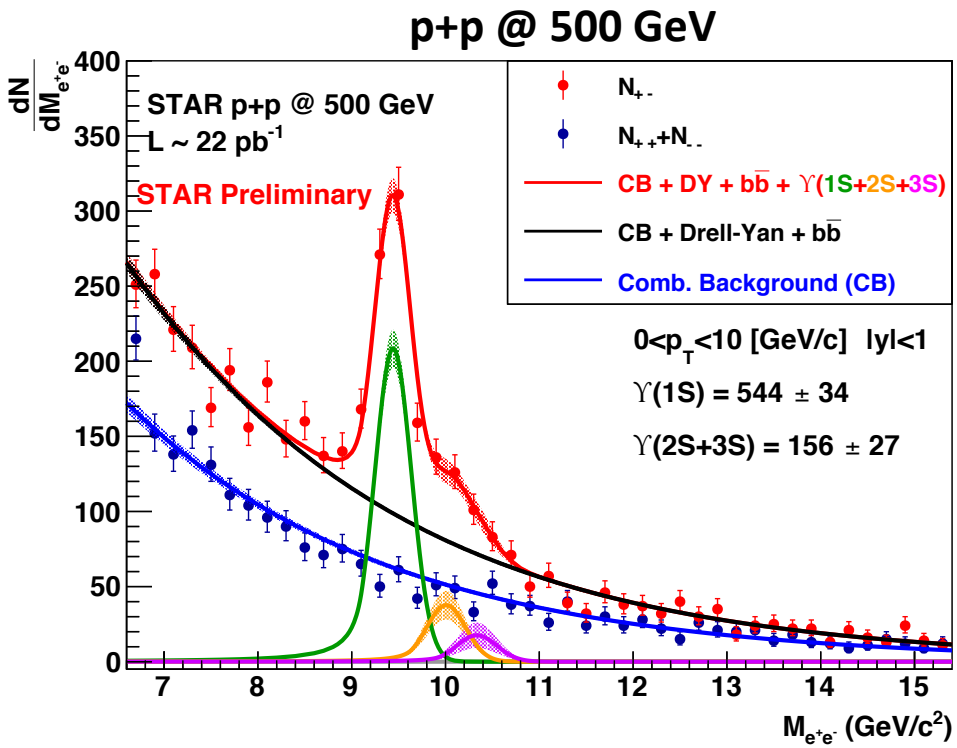


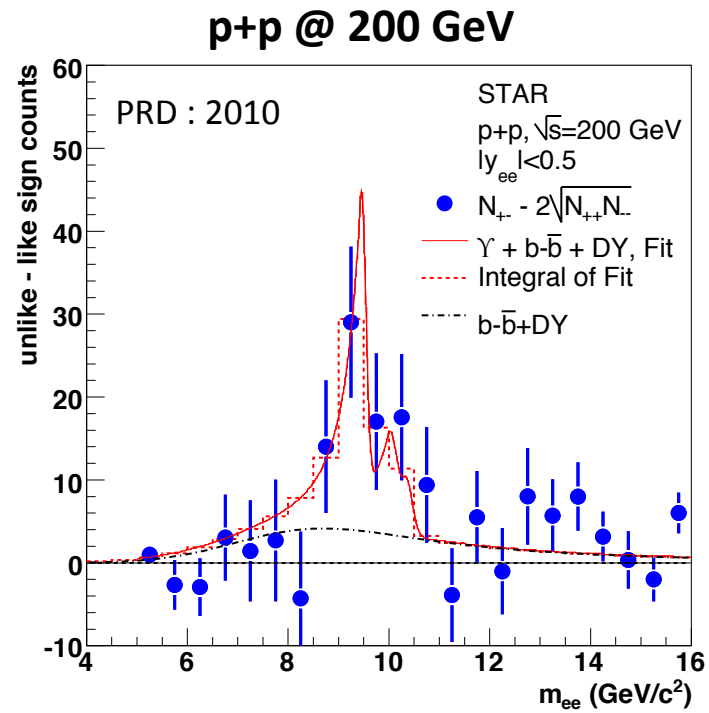
- First measurement of J/ψ production in jets at RHIC
- Unlike PYTHIA, no significant z dependence observed within uncertainties for z <1
- Provide further constrain on models

Upsilon($b\bar{b}$) Production

Upsilon Reconstruction in p+p @ 500 GeV

$$\Upsilon -> e^{+} + e^{-}[BR = 2.3(1S), 1.9(2S), 2.1(3S)]$$

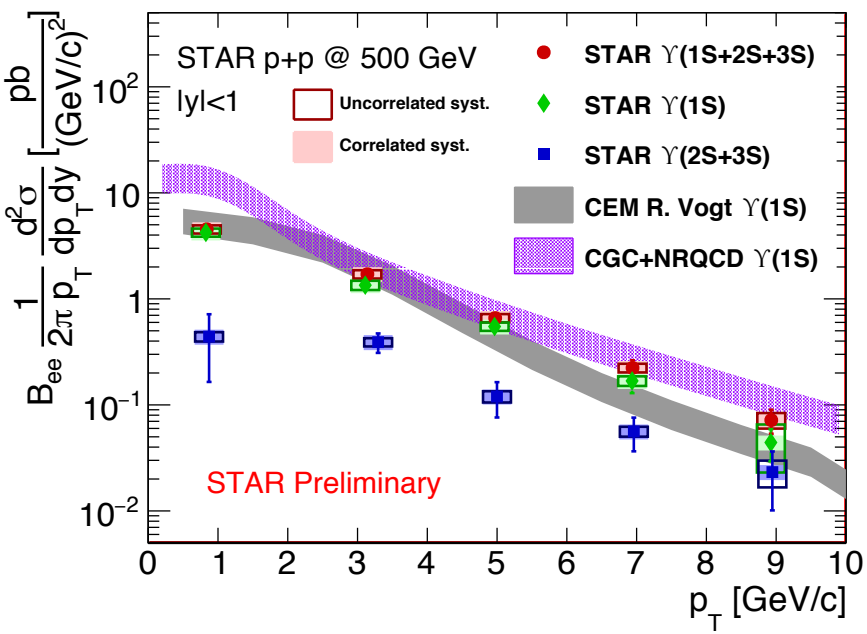


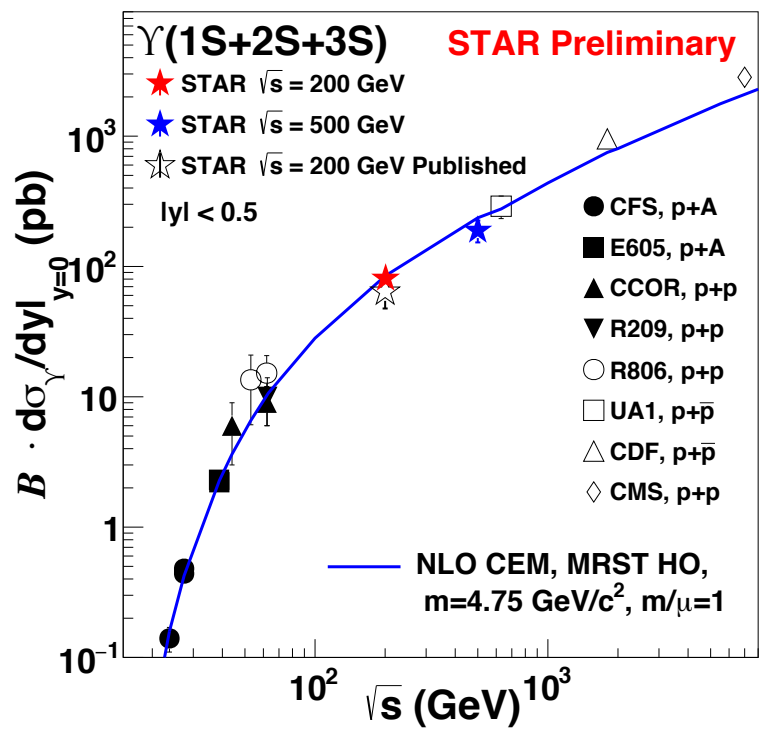


Upsilon are reconstructed in di-electron decay channel in p+p 500 GeV, more precise compared to published result in p+p 200 GeV

STAR :Phys. Rev. D **82** (2010) 12004

Upsilon cross section in p+p collisions



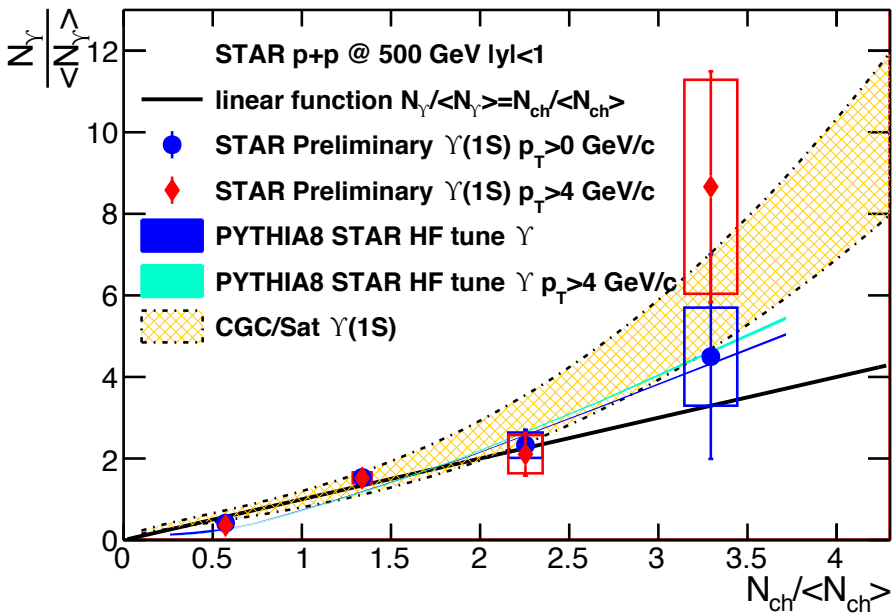


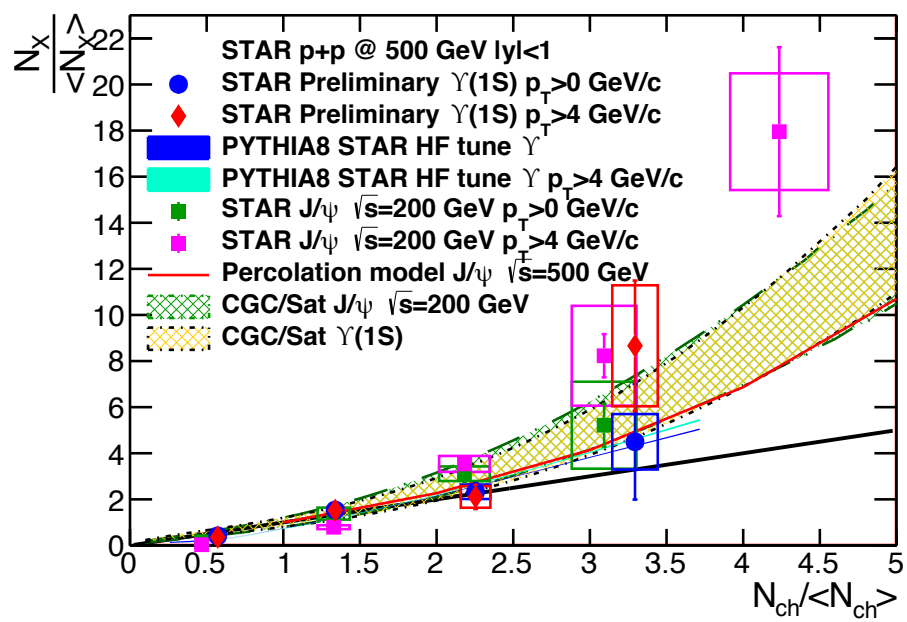
- Spectra for Y(1S) and Y(2S+3S)
- Models agree with data reasonably well, CGC+NRQCD model seems to over predicts at low pT

- STAR results follow the world data trend
- Consistent with the Color Evaporation Model calculation

R. Vogt, PRC 92 034909(2015); H. Han, et al., PRD 94, 014028(2016); Y. Ma, et al., PRL 113, 192301(2014)

Upsilon Production Vs Event Activity





- PYTHIA, CGC model reproduce the trend in the data
- Upsilon shows similar trend like J/ψ when plotted against event activity

Outlook: More precise measurement will be available soon using runs 2017+2022 data

E. Levin, M. Siddikov, EPJC, 97(5), 376(2019);

Summary

The recent results on heavy-flavor production in p+p collisions from STAR are presented

Heavy-flavor Decay Electron :

- Measurement at 200 GeV is consistent with FONLL

J/Ψ Production:

- Precise and more differential measurement of J/Ψ cross-section.
- Current measurement along with model calculation could provide better understanding on J/Ψ production mechanism in p+p collisions

ϒ Production:

- More precise measurement at 500 GeV compared to published results at 200 GeV.
- Upsilon cross section (186± 14(stat) ± 33(sys) pb) at 500 GeV follow world data trend predicted by Color Evaporation Model.


Thank you!