Measurement of J/ψ production in p+p collisions at $\sqrt{s}$ = 500 GeV at STAR experiment

Rongrong Ma (BNL)

Hard Probes 2015
McGill University, Montreal, Canada
June 29 – July 3, 2015

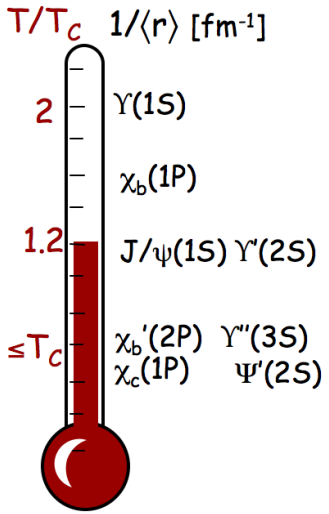
BROOKHAVEN NATIONAL LABORATORY

Outline

- Motivation
- STAR experiment
- J/ψ measurements
  - Cross section
  - Yield ratio of ψ(2s) to J/ψ
  - J/ψ yield vs. event activity
- Summary

J/ψ measurements in heavy-ion collisions

- Quarkonia are predicted to be sequentially melted in Quark Gluon Plasma due to color-screening of the parton constituents →a thermometer of the medium.
- Suppression of J/ψ was proposed as a direct probe of deconfinement.

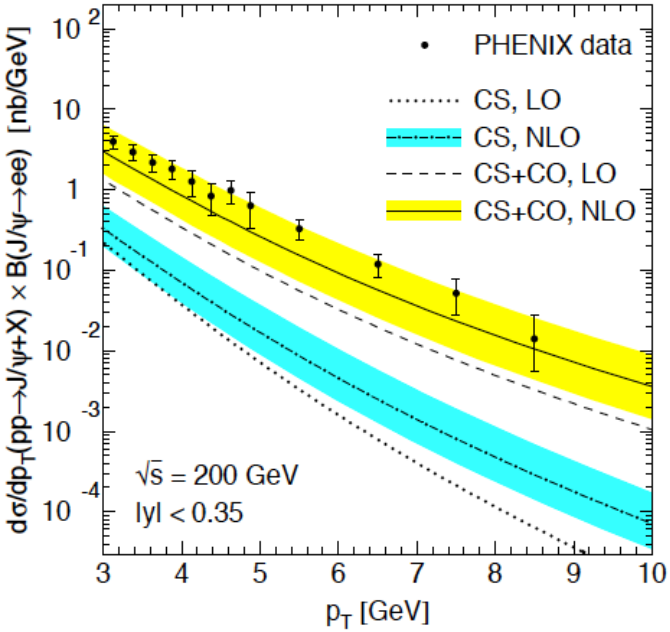


- The pp results serve as a reference for the same measurements in heavy-ion collisions.
- Need to fully understand the production mechanism in pp collisions.

Do we understand J/ψ in pp?

- NRQCD long-distance matrix at Next-to-Leading Order from world-data fitting.

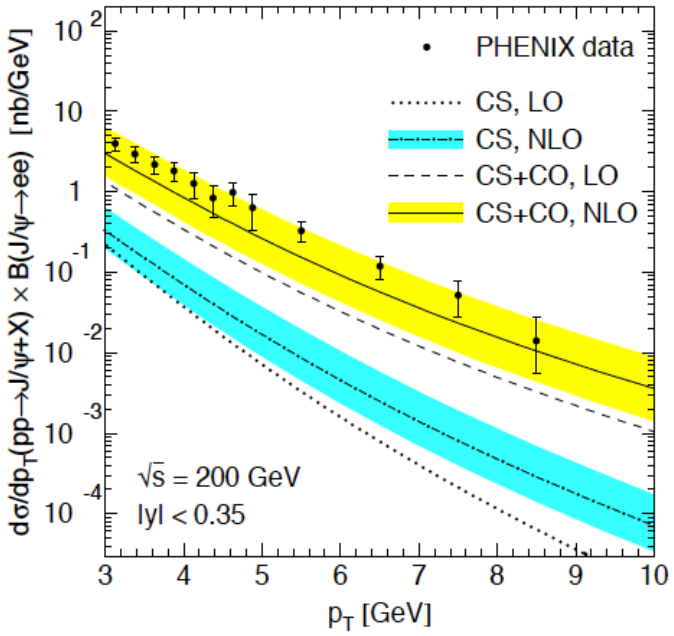
Phys. Rev. D84 (2011) 051501



Do we understand J/ψ in pp?

- NRQCD long-distance matrix at Next-to-Leading Order from world-data fitting.

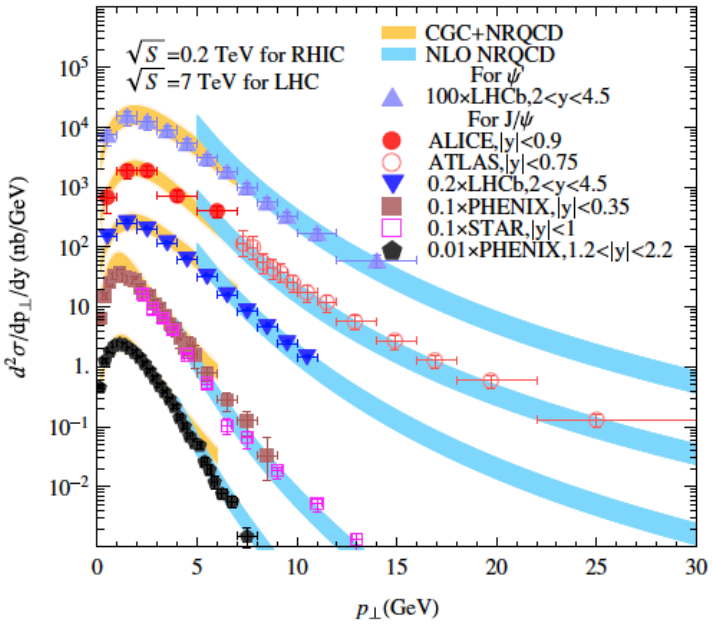
Phys. Rev. D84 (2011) 051501



Low p_T

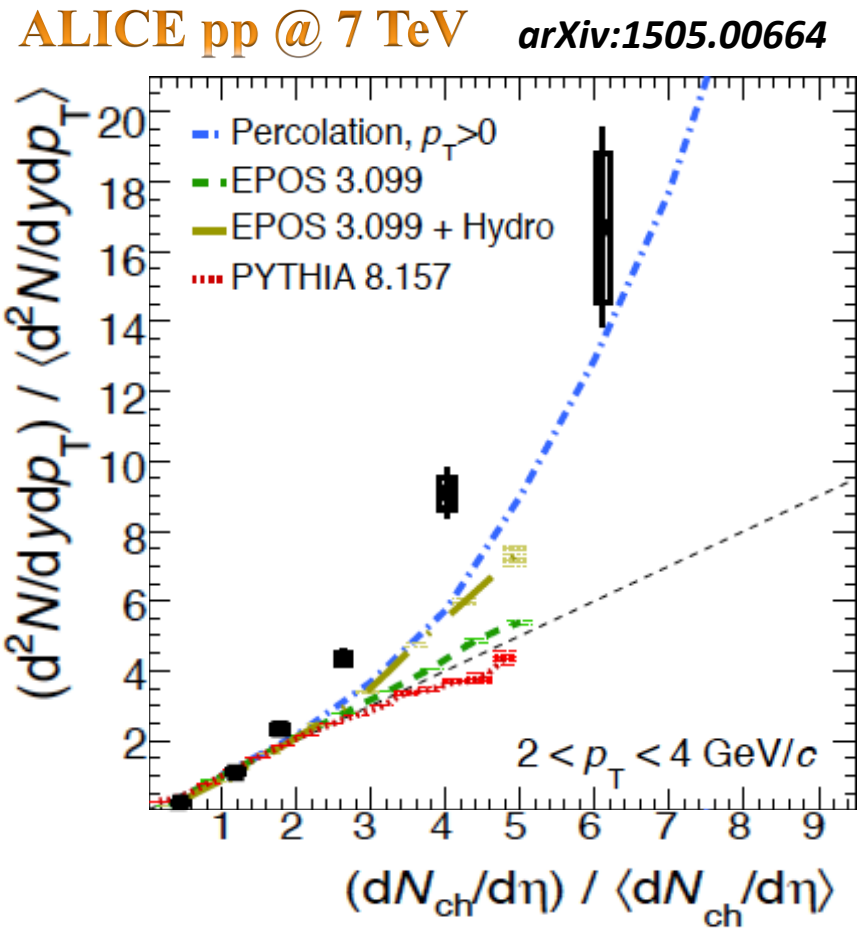
- Color Glass Condensate effective theory to calculate cross section at low p_T

Phys.Rev.Lett. 113 (2014) 192301



- **Good data-theory agreement over $0 < p_T < 30$ GeV/c**

A closer look: event multiplicity dependence

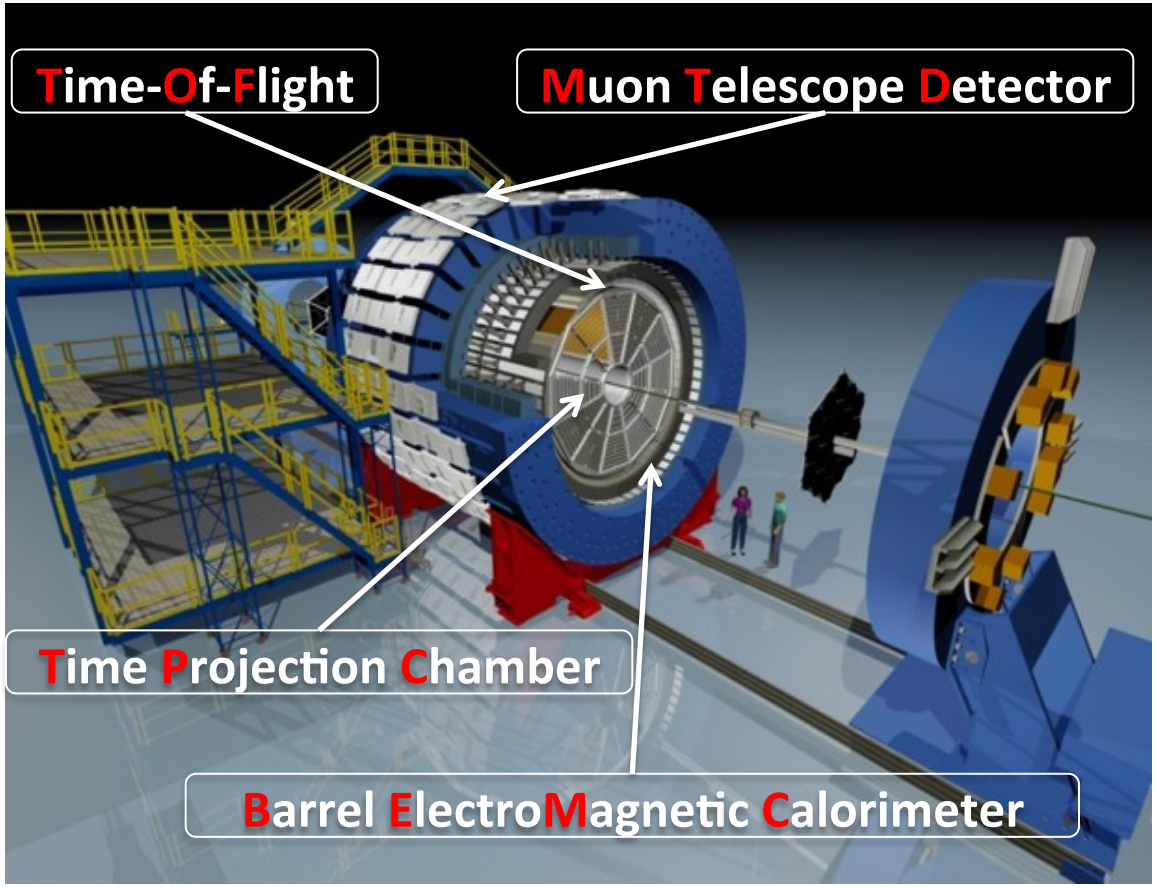


- Stronger-than-linear rise of open charm production vs event activity.
- Similar behavior seen for inclusive J/ψ at both mid- and forward-rapidity.
- Several ideas on the market:
  - PYTHIA 8: c and b quarks produced in Multi-Parton-Interaction -> **underestimate yield at large multiplicity**
  - Percolation model: string screening -> **quadratic rise at high multiplicity**
  - Hard process is associated with larger gluon radiation

- Collective effects in high-multiplicity pp collisions?
- Do we see similar or different behavior at RHIC?

The Solenoid Tracker At RHIC (STAR)

- Mid-rapidity detector: $|\eta| < 1$, $0 < \varphi < 2\pi$



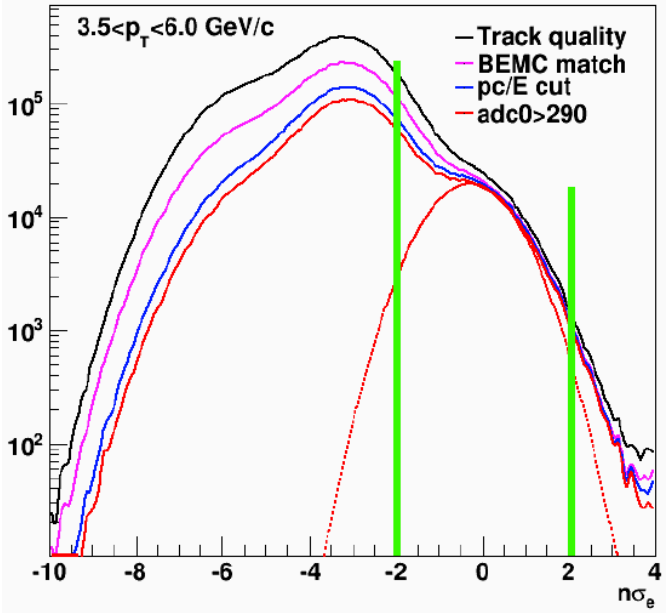
- **TPC**: precise momentum and energy loss
- **TOF**: fast detector
- **BEMC**: trigger on and identify electrons
- **MTD**: trigger on and identify muons
  - Cover 45% geometrical acceptance within $|\eta|<0.5$

J/ψ measurements at high p_T

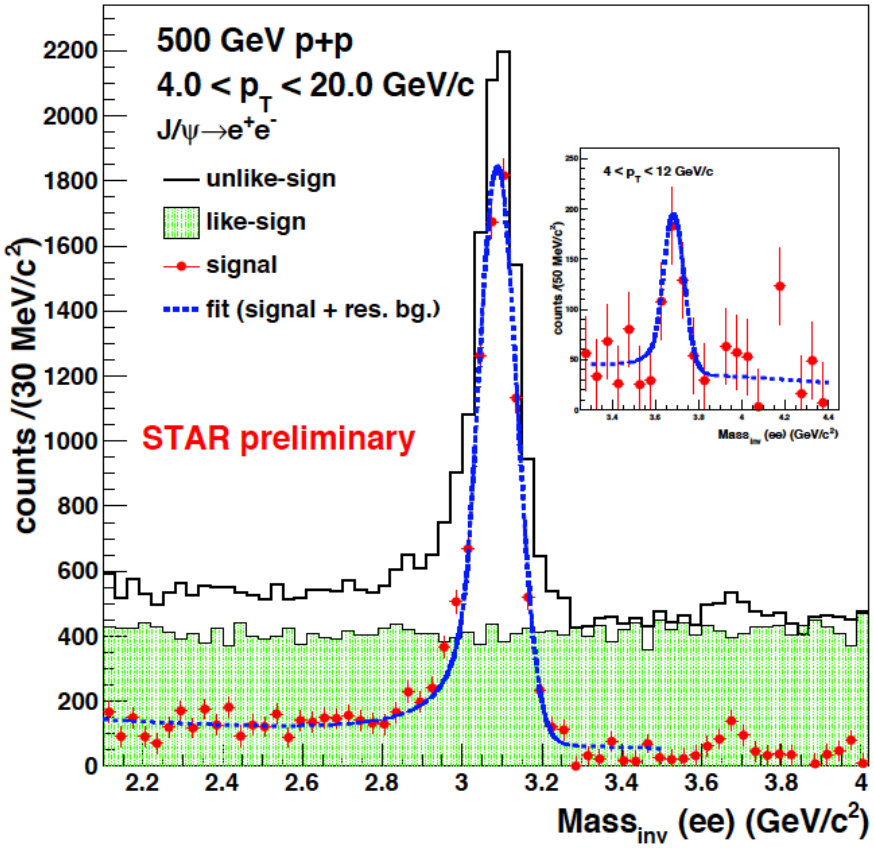
- Decay channel: J/ψ → $e^+ + e^-$
- Data set: p+p collisions at 500 GeV taken in 2011
- High Tower (HT) trigger with a threshold of 3.5 GeV/c using BEMC
  - *Sampled integrated luminosity* ~ 22 pb^{-1}

- **Electron identification**
  - One decay electron fire trigger
  - $0.3 < p_{track}/E_{cluster} < 1.5$
  - $|n\sigma_e|<2$

$$n\sigma_e = \frac{1}{R}\log\frac{(dE/dx)_{\text{measured}}}{(dE/dx)_{\text{electron}}}$$



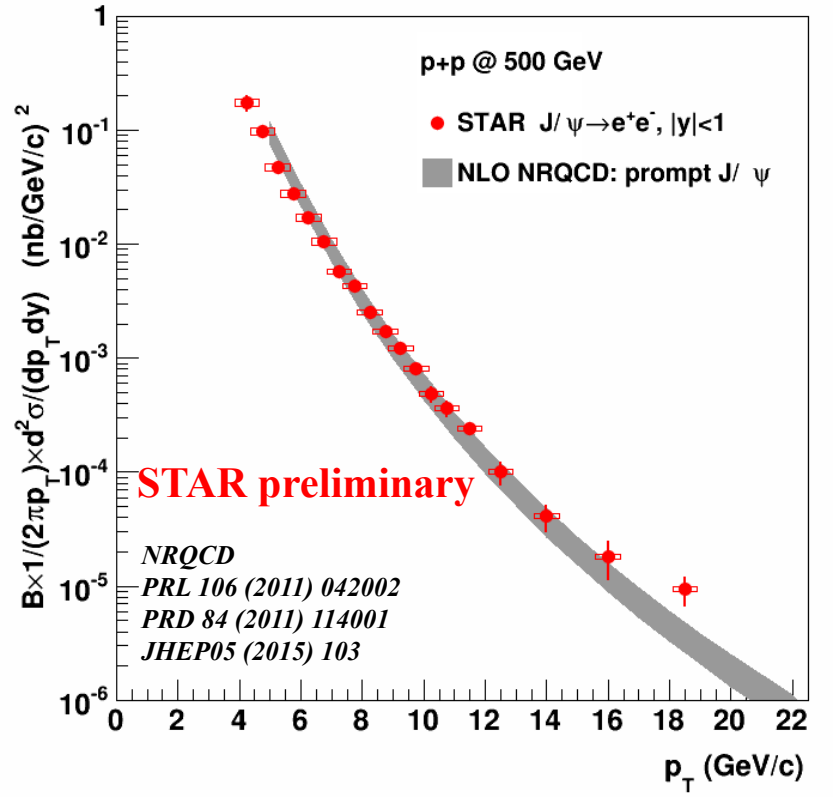
Extract J/ψ yield



- Clear signals for $\psi(2s)$ and J/ψ
- Combinatorial background: estimated by like-sign pairs and subtracted.
- Correlated background: estimated by fitting Crystal ball function (signal) + exponential function

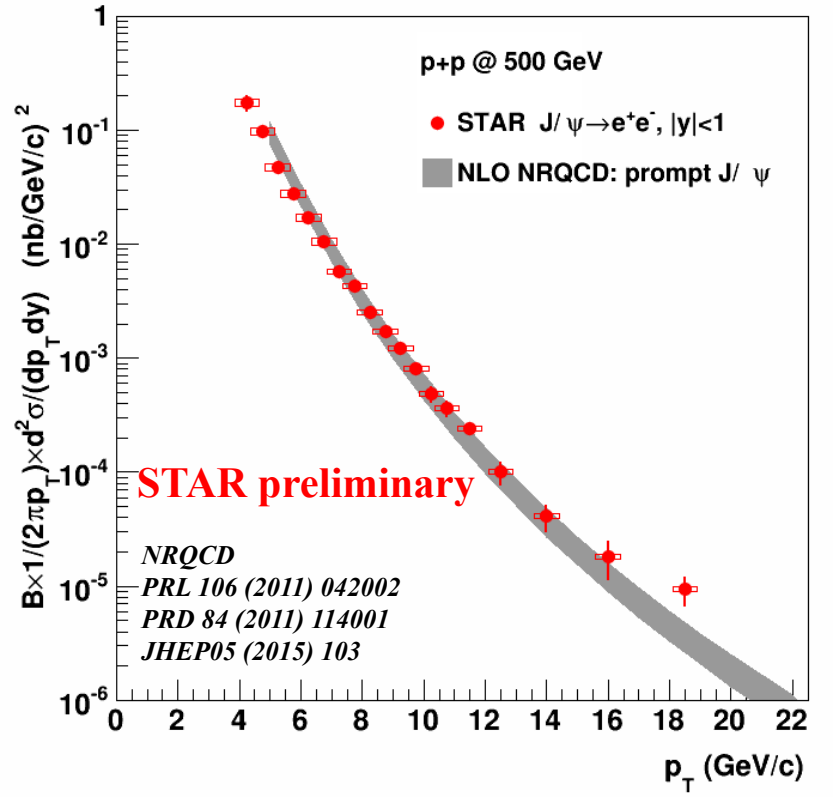
➢ Signal extraction: bin counting within [2.7,3.2] GeV/c^2

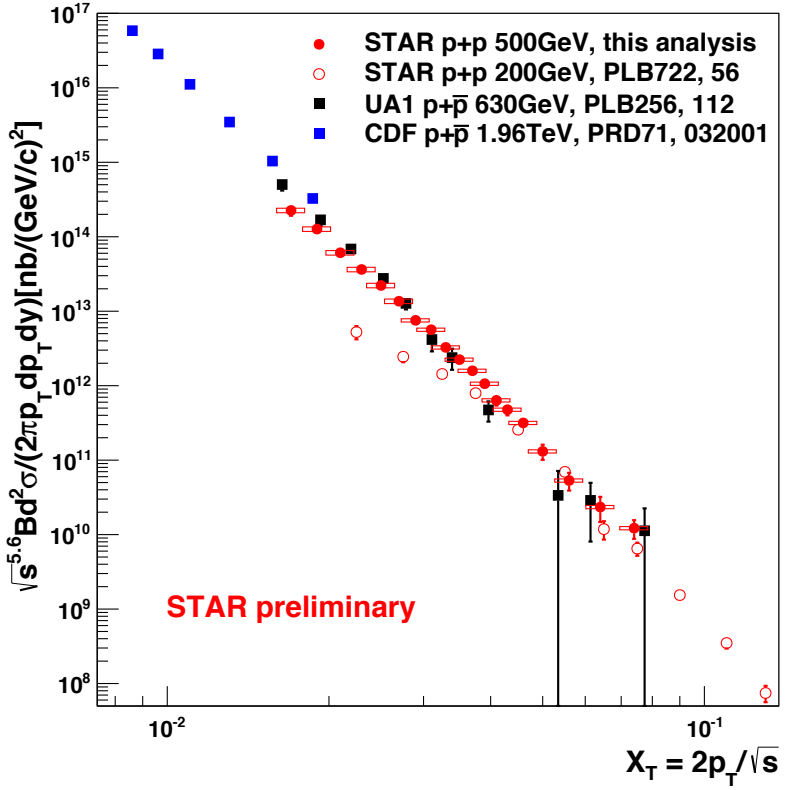
J/ψ cross section above 4 GeV/c



- **Cross section measured within $4 < p_T < 20$ GeV/c**
- **NRQCD prediction agrees well with data**

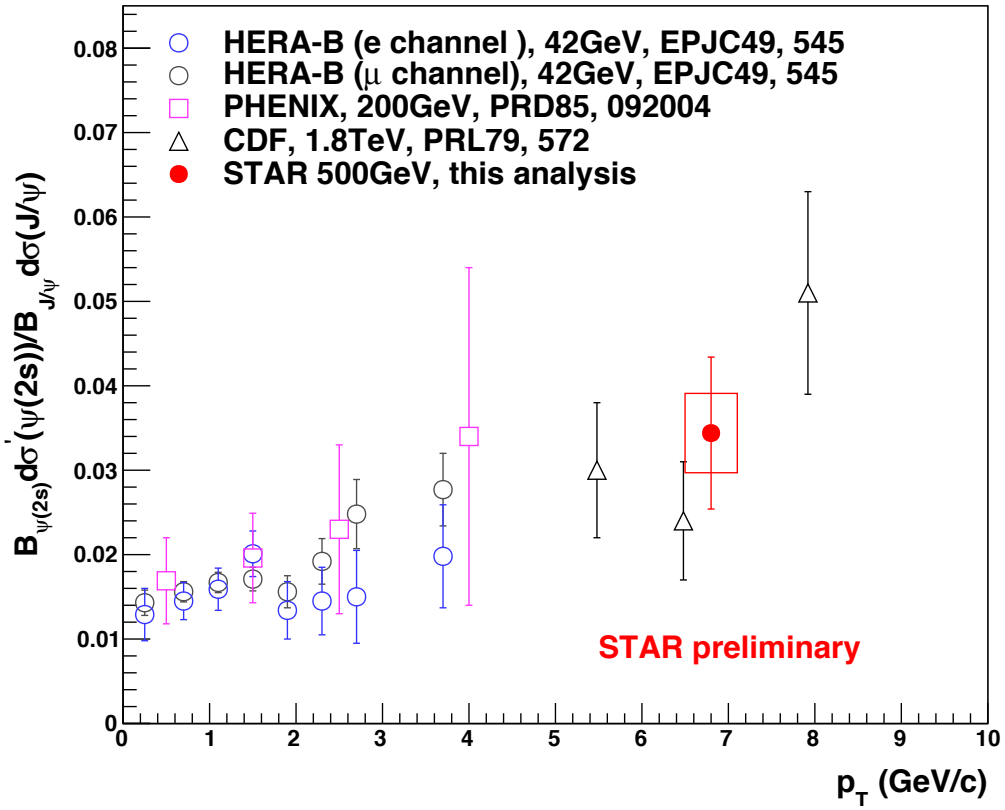
J/ψ cross section above 4 GeV/c





- **Cross section measured within $4 < p_T < 20$ GeV/c**
- **NRQCD prediction agrees well with data**
- Follows x_T scaling with n ~ 5.6, which reflects number of active partons in J/ψ production

Yield ratio of ψ(2s) to J/ψ

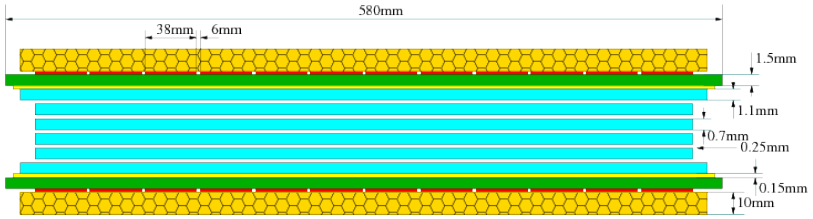


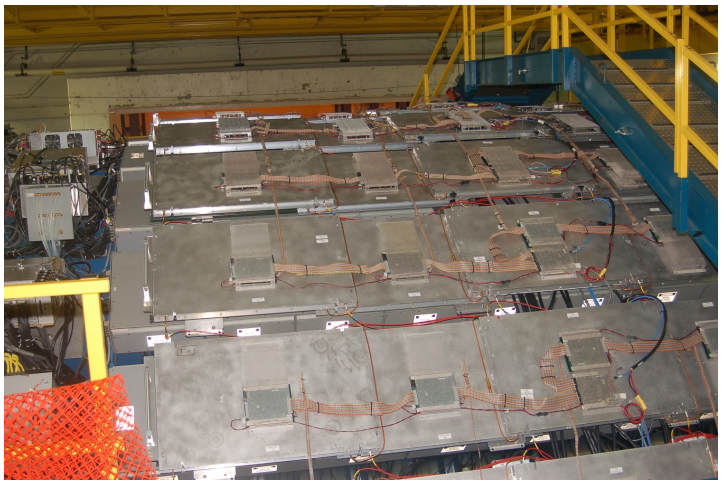
~18% of systematic uncertainty

- **Follows world data trend with p_T, and no obvious collision energy dependence**
- Help to pin down the feed-down contribution from ψ(2s) to J/ψ

J/ψ measurements at low p_T

- **Enabled by the new Muon Telescope Detector**





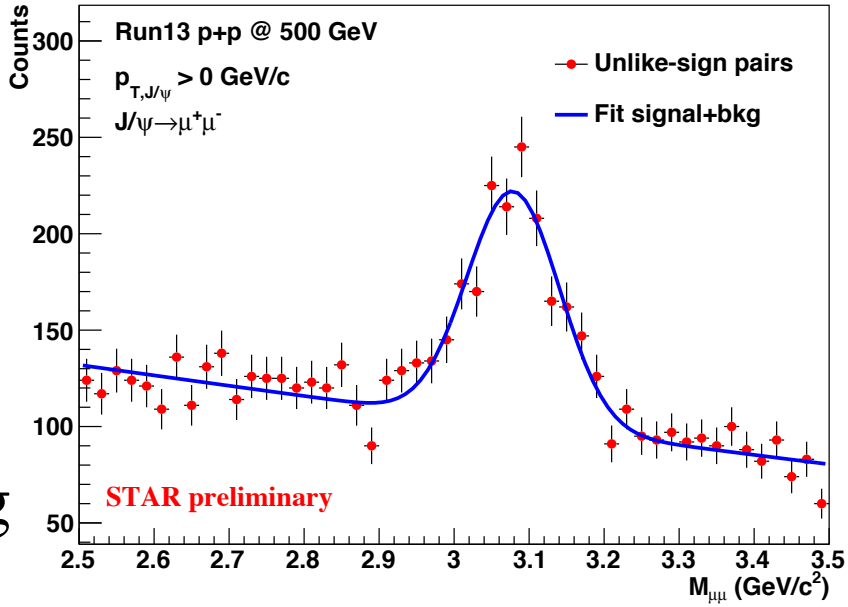
- Multi-gap Resistive Plate Chamber (MRPC)
  - gas detector, avalanche mode
- Installed behind the return iron bars of the magnet
  - 5 interaction length
- Muon identification utilizing precise timing measurement.
- Double-end readout -> measure hit position along the beam direction.

- **In 2013, 63% of MTD was installed. MTD trigger commissioned in May.**
- **Installation completed in early 2014**
  - 122 trays, 1439 readout strips and 2878 readout channels

Extract J/ψ yield

- Decay channel: J/ψ → $\mu^+ + \mu^-$
- Data set: p+p collisions at 500 GeV taken in 2013
- MTD dimuon trigger: two hits in MTD
  - *Sampled integrated luminosity* ~ 7.7 pb^{-1}
- **Muon identification**
  - Match TPC tracks to MTD
  - Require z residual below 20 cm
- Background: fitting Gaussian (signal) & expo+pol0

➢ Signal extraction: bin counting within [2.8,3.3] GeV/c^2

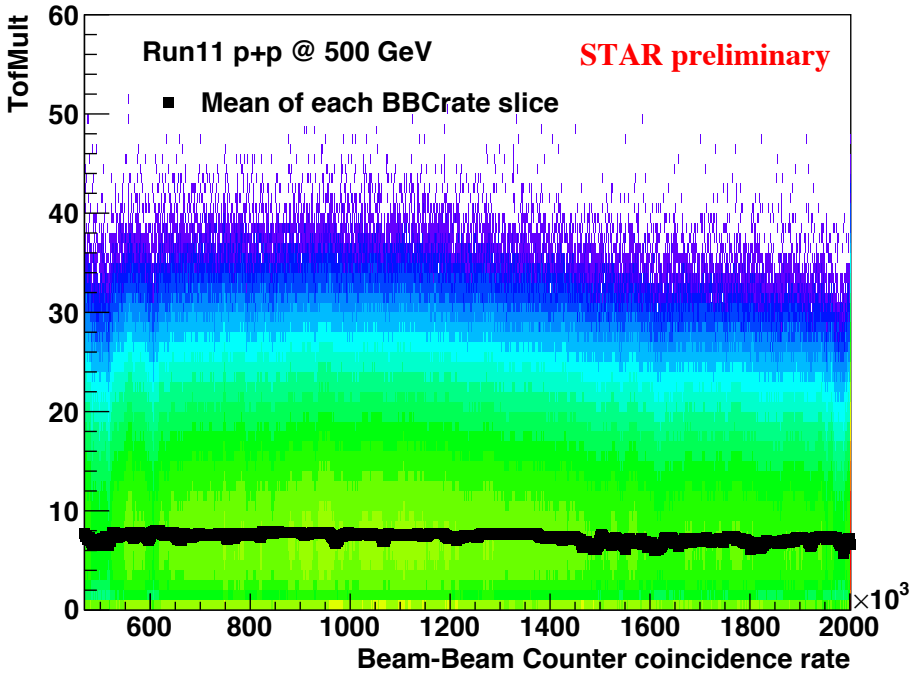


Characterize event activity

Multiplicity of TOF matched tracks

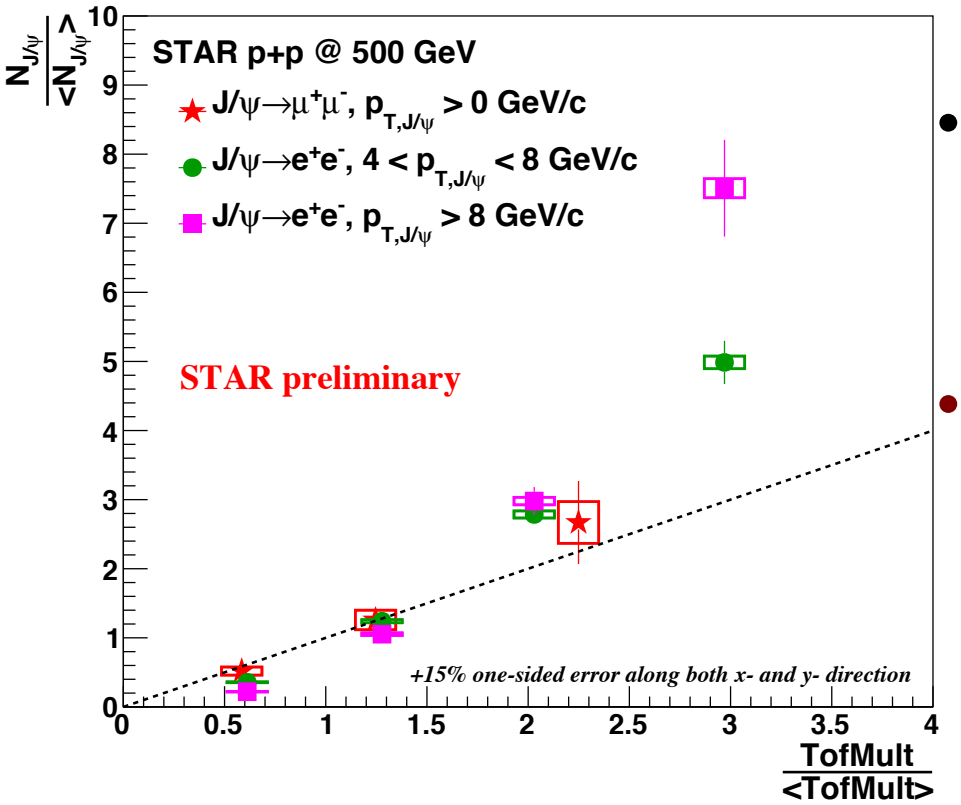
$|\eta| < 0.9$

$$\frac{\text{TofMult}}{<\text{TofMult}>}$$



- **Insensitive to pile-up effects**

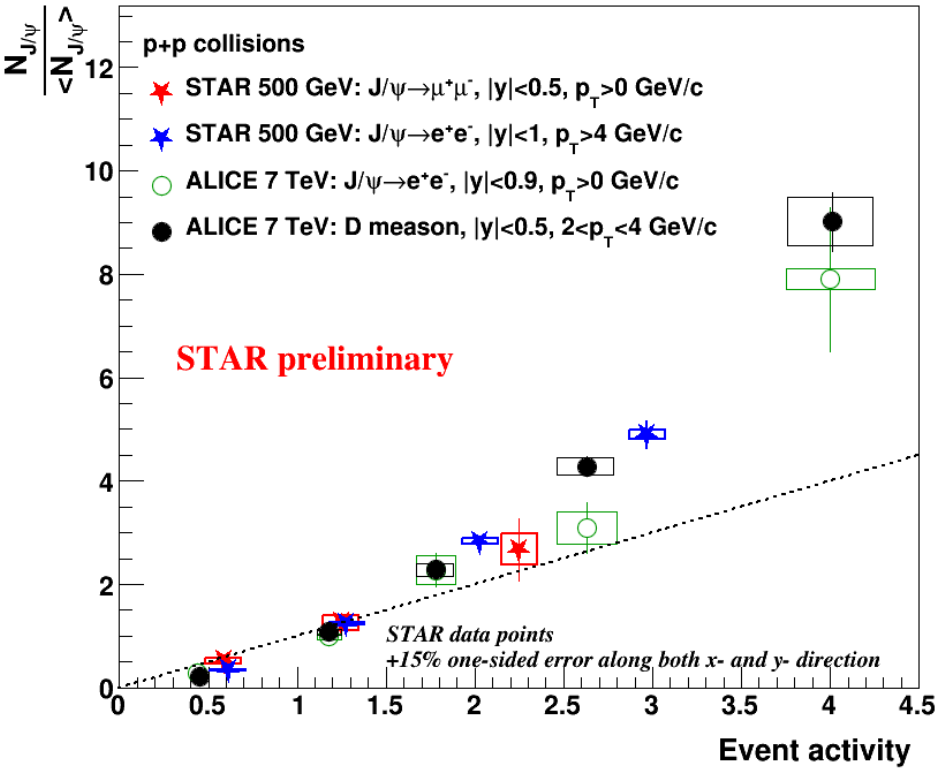
J/ψ yield vs. event activity



- +15% one-sided global errors along both x- and y- directions
  - Work in progress to reduce it
- **Clear correlation between soft and hard processes**
  - Different trends for J/ψ yield vs. event activity at low and high p_T

- **Stronger-than-linear growth in high multiplicity events**

Compare to LHC



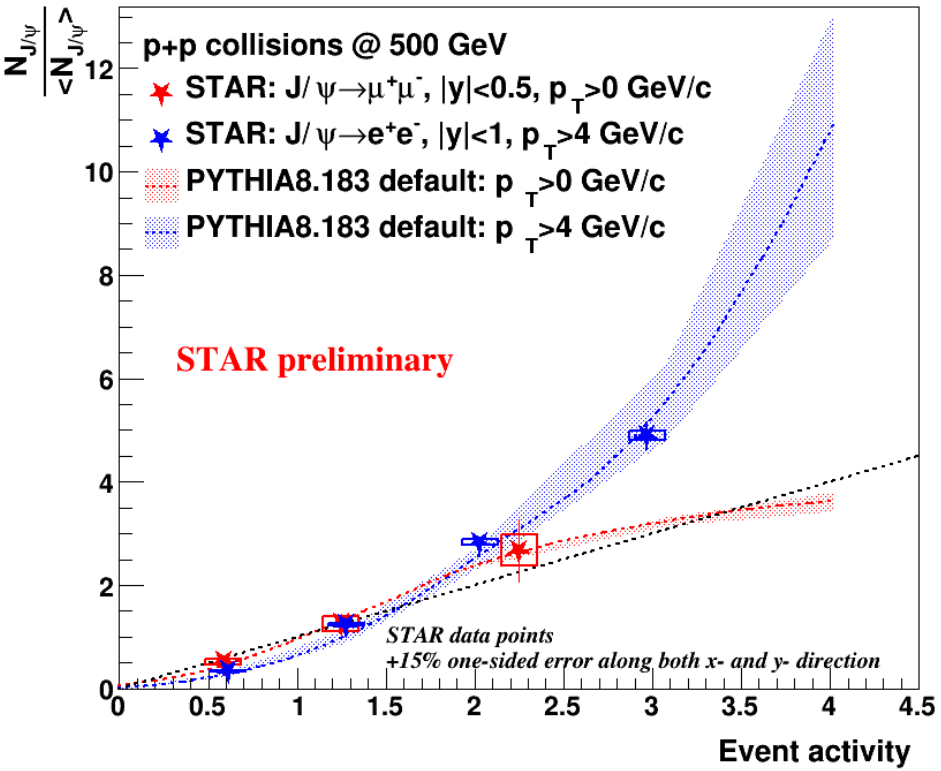
The rising trend is similar at RHIC compared to LHC

- Universal dependence of relative J/ψ yield on event activity at different energy?

ALICE J/ψ: Phys.Lett. B712 (2012) 165-175
ALICE D-meson: arXiv:1505.00664

Data vs PYTHIA

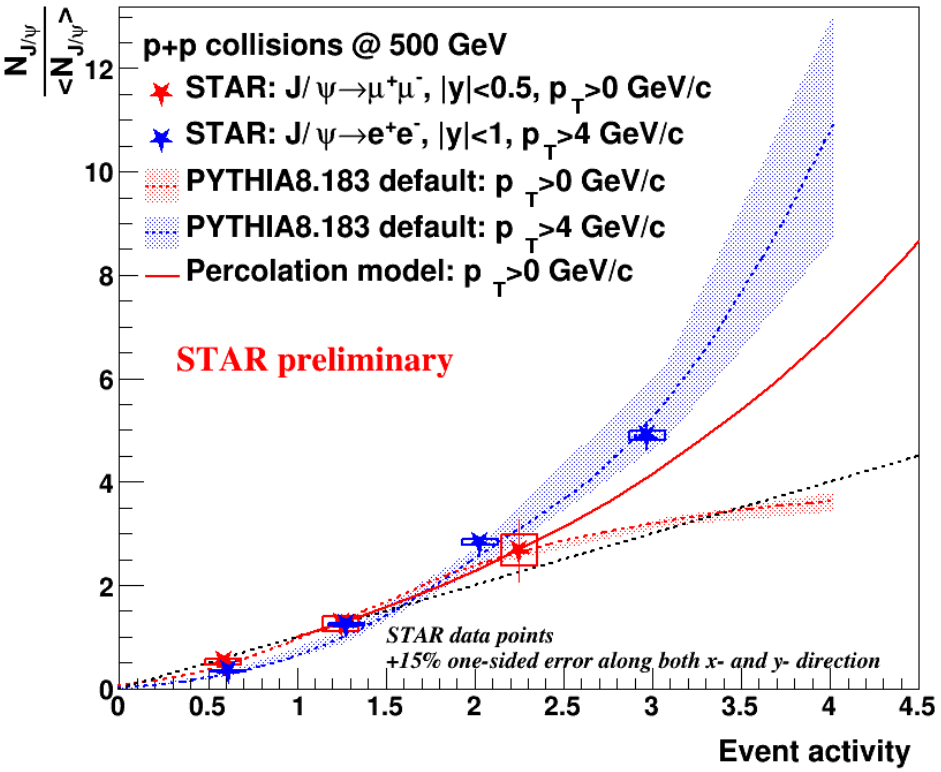
Default tune of PYTHIA 8.183



- Both the rising trend and p_T dependence observed in data can be reasonably reproduced by PYTHIA8
  - It seems to do a better job at RHIC than LHC

Data vs Percolation model

Percolation model: PRC 86 (2012) 034903
private communication



- Both the rising trend and p_T dependence observed in data can be reasonably reproduced by PYTHIA8
  - It seems to do a better job at RHIC than LHC
- The trend is also qualitatively reproduced by percolation model.
  - Stronger rise at large multiplicity than PYTHIA8

- Test with larger multiplicity bins is important

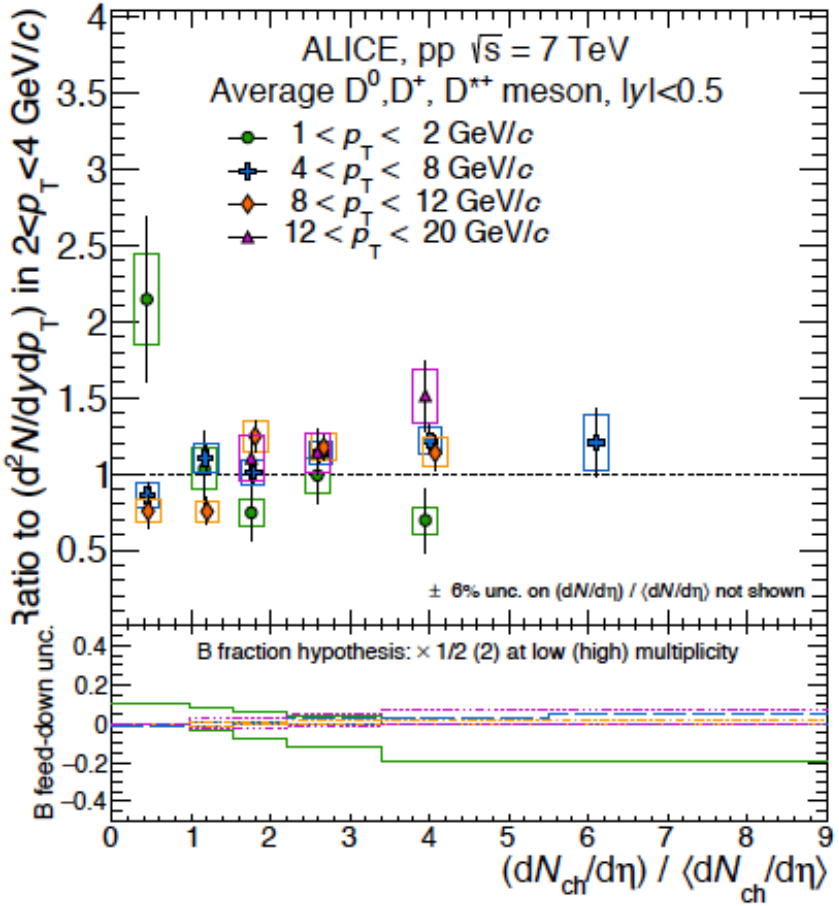
Summary

- Inclusive J/ψ cross section are measured above 4 GeV/c via the di-electron channel.
  - Agrees with NRQCD calculation.
- For the first time, J/ψ is reconstructed via the di-muon channel at STAR using the new MTD.
- The relative J/ψ yield grows rapidly as the event multiplicity increases, and the high p_T J/ψ grows even faster than the low p_T J/ψ.
  - Work in progress to reduce the systematic uncertainties.
- PYTHIA8 and percolation model can reproduce the rising trend of the J/ψ. PYTHIA8 can also describe the high p_T range.
  - Test with even higher multiplicity bins is important.

Theoretical inputs are very welcome.

Backup

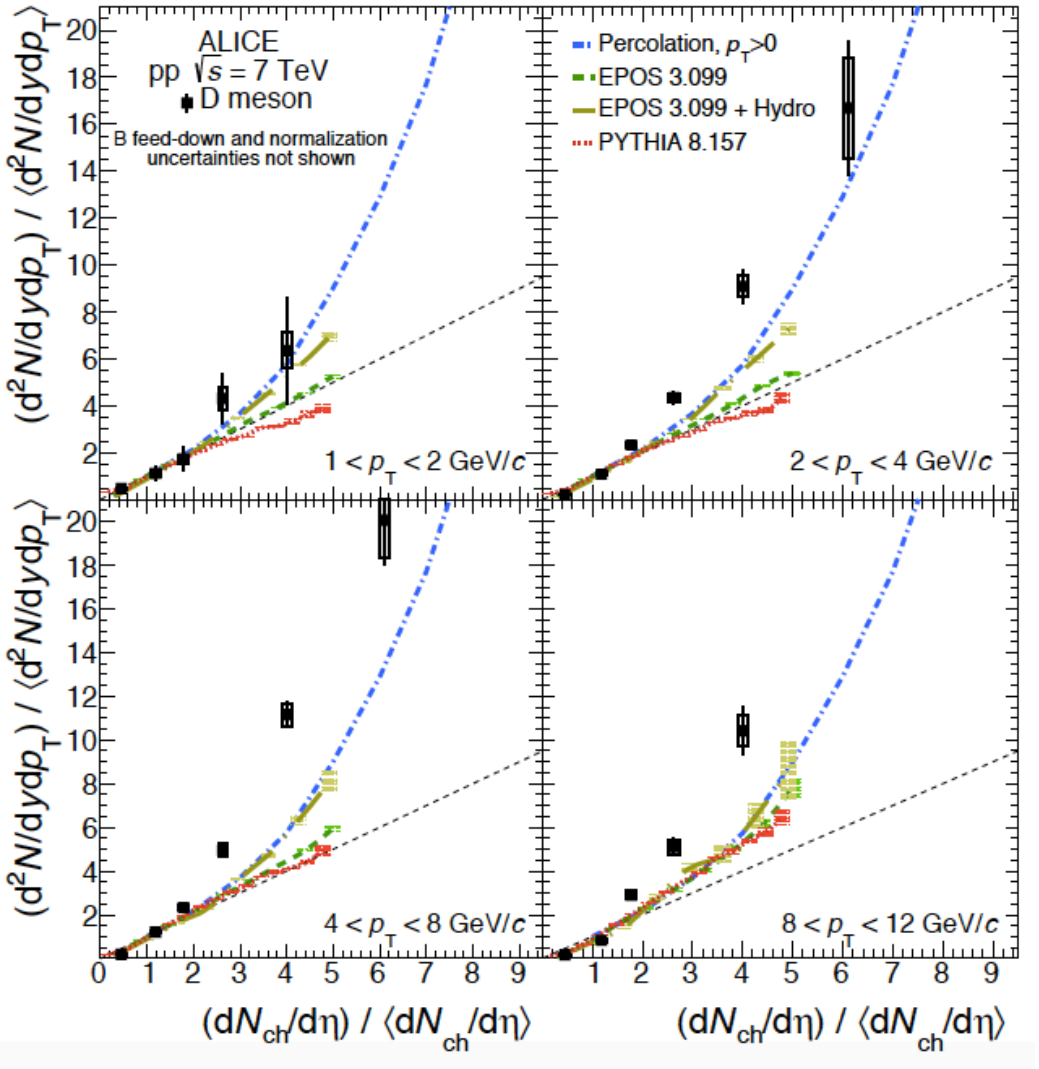
p_T dependence at the LHC



(b) Ratios of p_T intervals vs the $2 < p_T < 4$ GeV/c.

- Clear p_T dependence of the trend.
- Almost a factor 2 of difference between low p_T and high p_T J/ψ at lowest and highest multiplicity bins

Comparison with models at LHC



- Both PYTHIA and EPOS underestimate the yield
- The percolation model agrees better with data.