Heavy quarkonium production at STAR experiment

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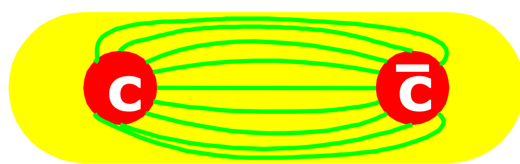
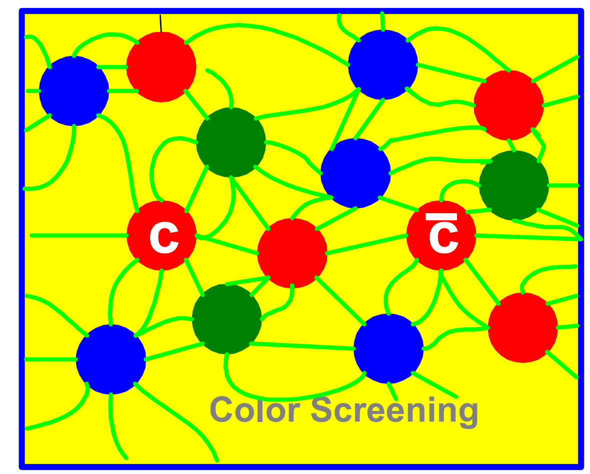
Motivation

Quarkonium Suppression: “Smoking Gun” for QGP



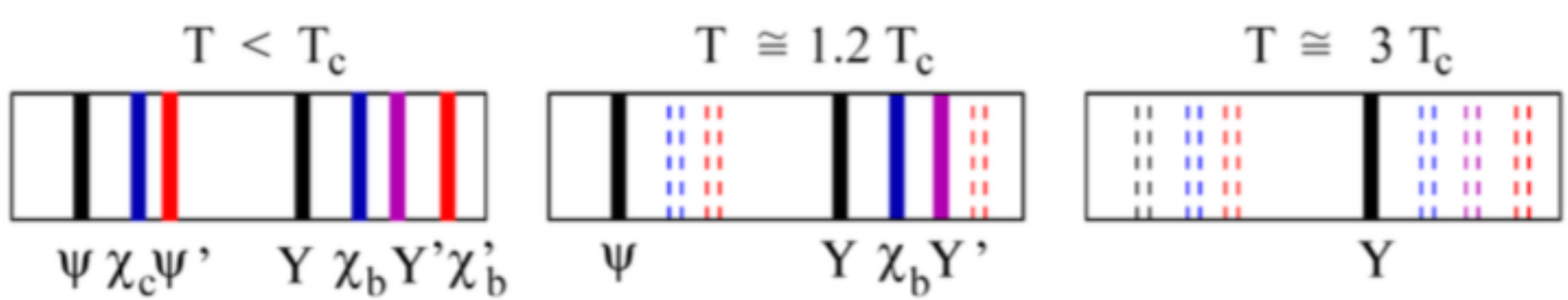
- Low temperature
- Vacuum

- J/ψ production mechanism in p+p is not well understood !!



- High temperature
- High density
  (screening effect takes place)

When do quarkonium states melt?



Sequential melting → a QGP thermometer

Quarkonia production in medium can be complicated

Observed J/ψ is a mixture of prompt production + feeddown:

- prompt J/ψ
  - direct J/ψ(~60%), feed down from ψ(2s)(~10%) and χ_c(~30%) decays.
- non-prompt J/ψ: B-mesons feed-down(10-25% at 4-12 GeV/c)

STAR: Phys. Lett. B772(2013) 55

Suppression and enhancement in medium

- Cold nuclear matter effects, i.e. nuclear absorption, nuclear PDF effects, initial state energy loss, Cronin effect.
- Hot/dense medium effects
  - **J/ψ, ϒ suppression**
  - **J/ψ, ϒ enhancement**

Upsilon: a cleaner probe at RHIC compared to J/ψ

- Co-mover absorption → negligible
- Recombination → negligible (σ_{cc} = ~800μb, σ_{bb} = ~2μb)
- Challenge: low rate → large acceptance detector and efficient trigger

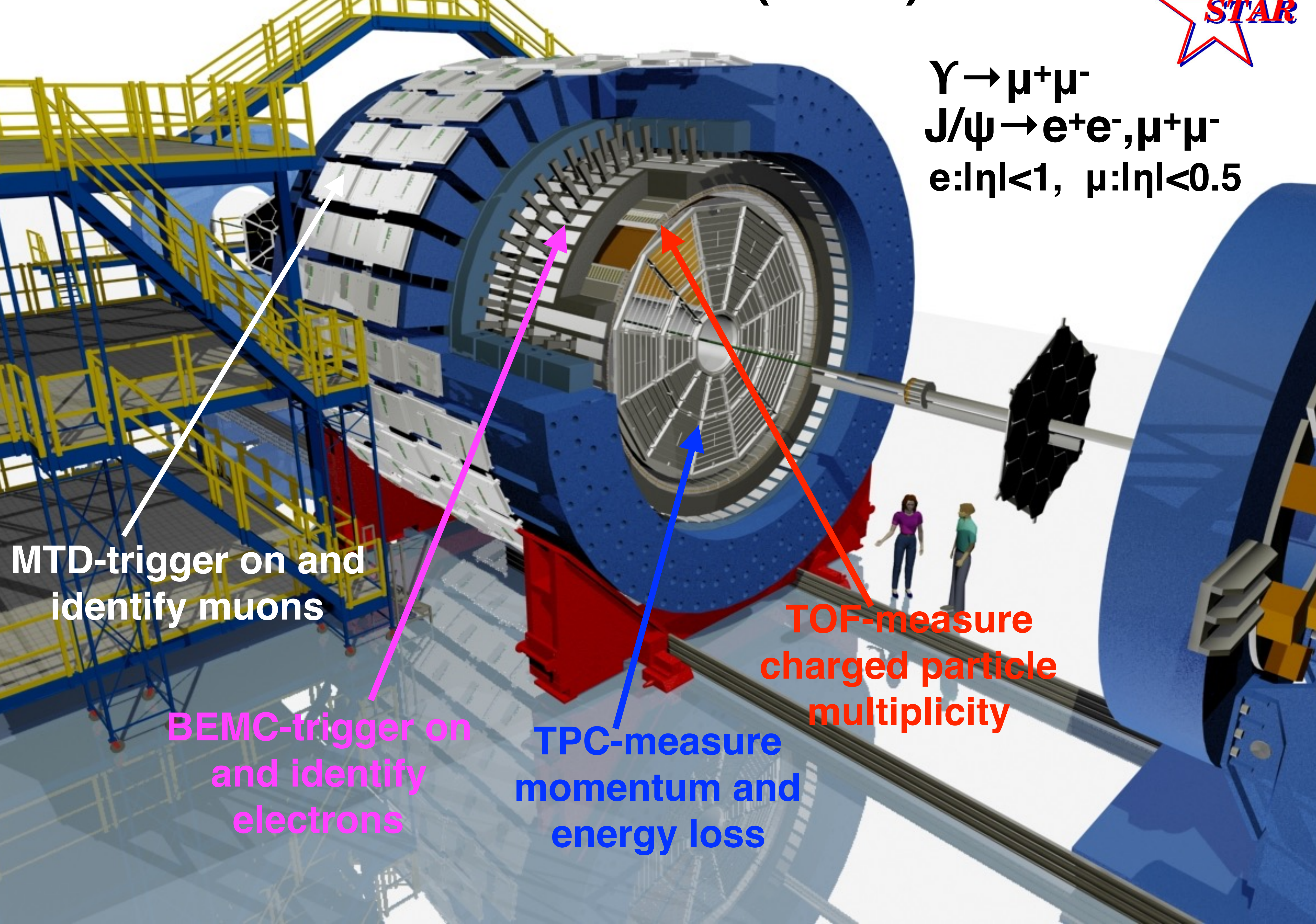
The Solenoid Tracker At RHIC (STAR)

STAR

$\Upsilon \rightarrow \mu^+\mu^-$

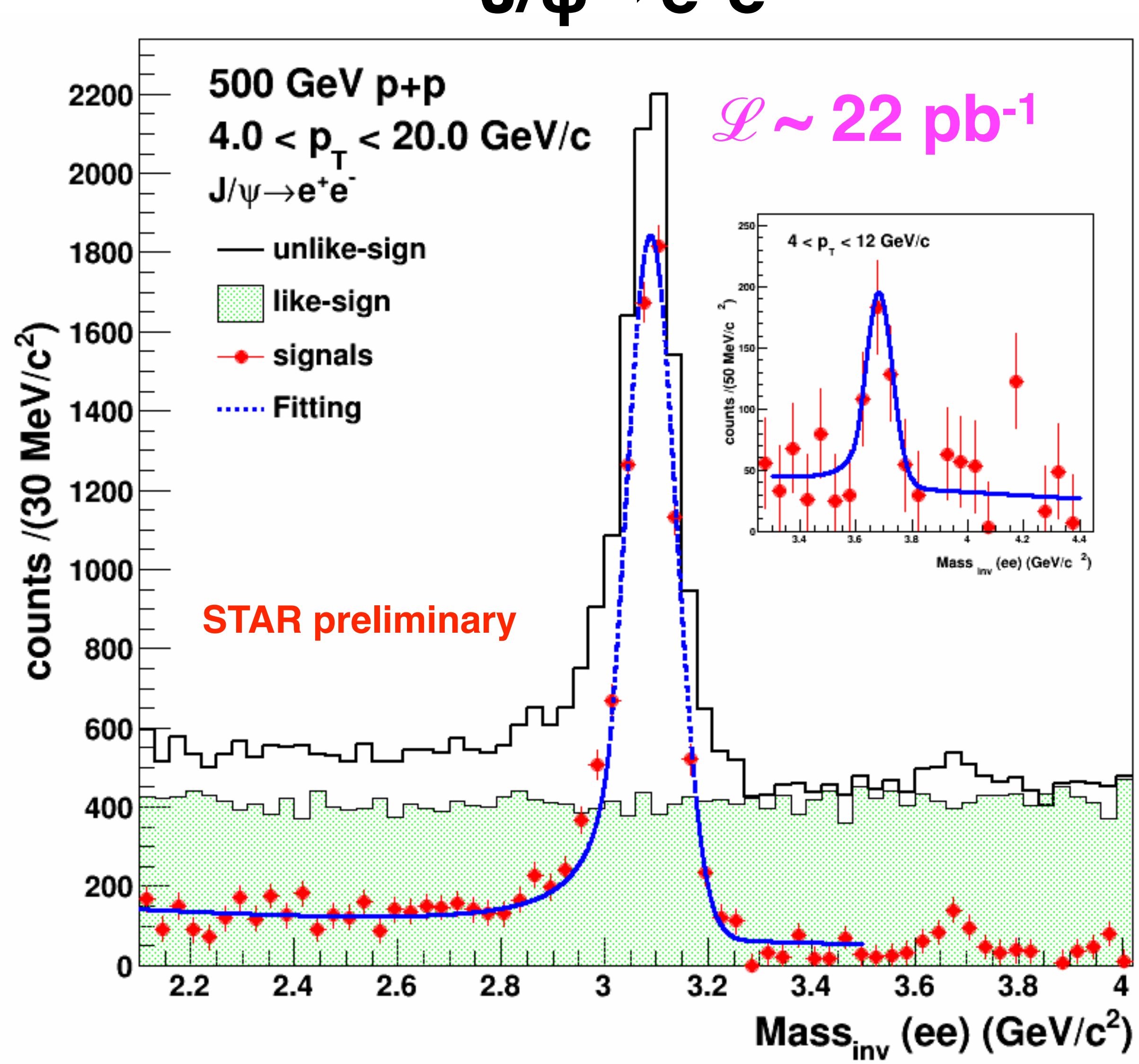
$J/\psi \rightarrow e^+e^-, \mu^+\mu^-$

$e: |\eta|<1, \ \mu: |\eta|<0.5$



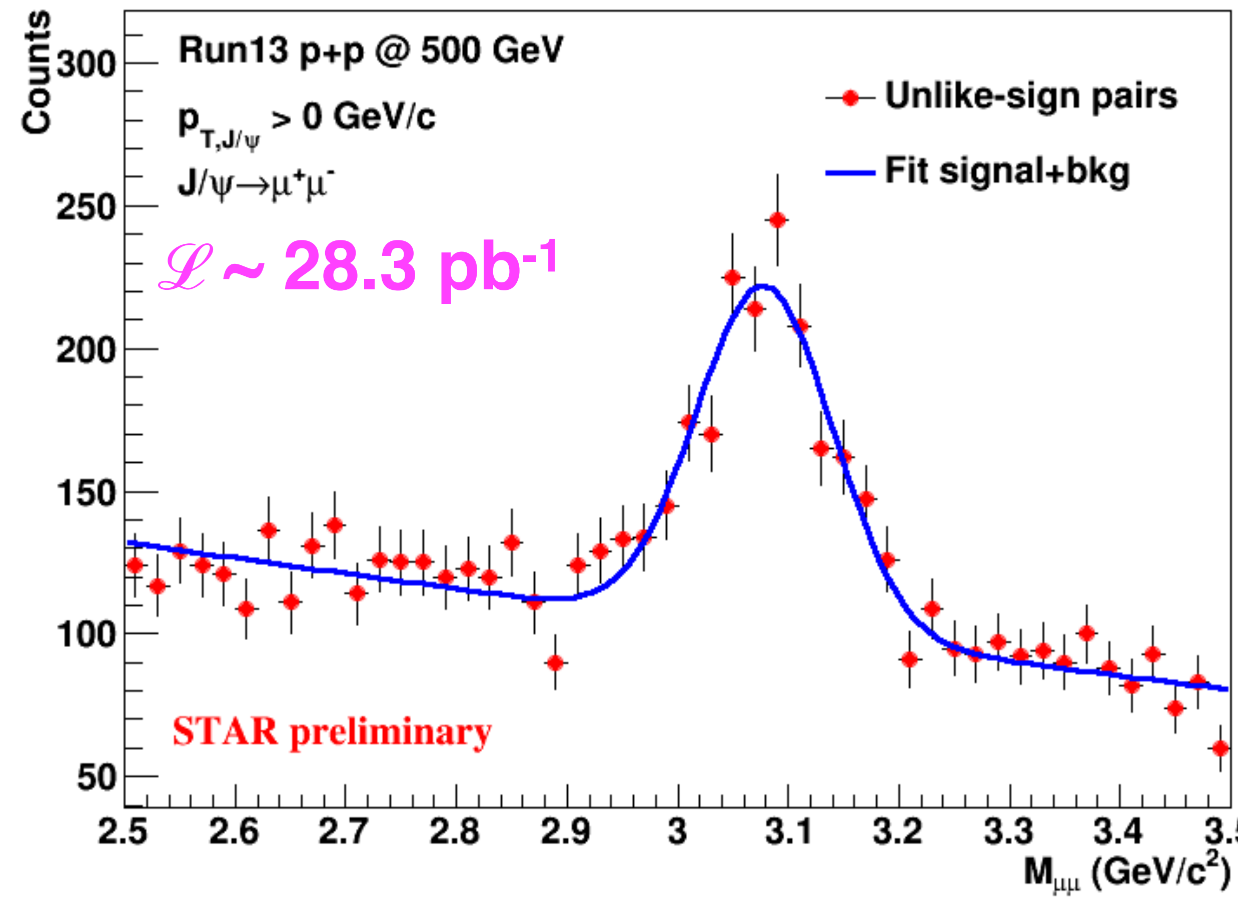
Inclusive J/ψ yield in p+p

High-p_T J/ψ
$J/\psi \to e^+e^-$



- Combinatorial background: **like-sign pairs**
- Residual background: fitting **Crystal ball function**(signal) & **expo**
- Signal extraction: bin counting **[2.7, 3.3]** GeV/c^2

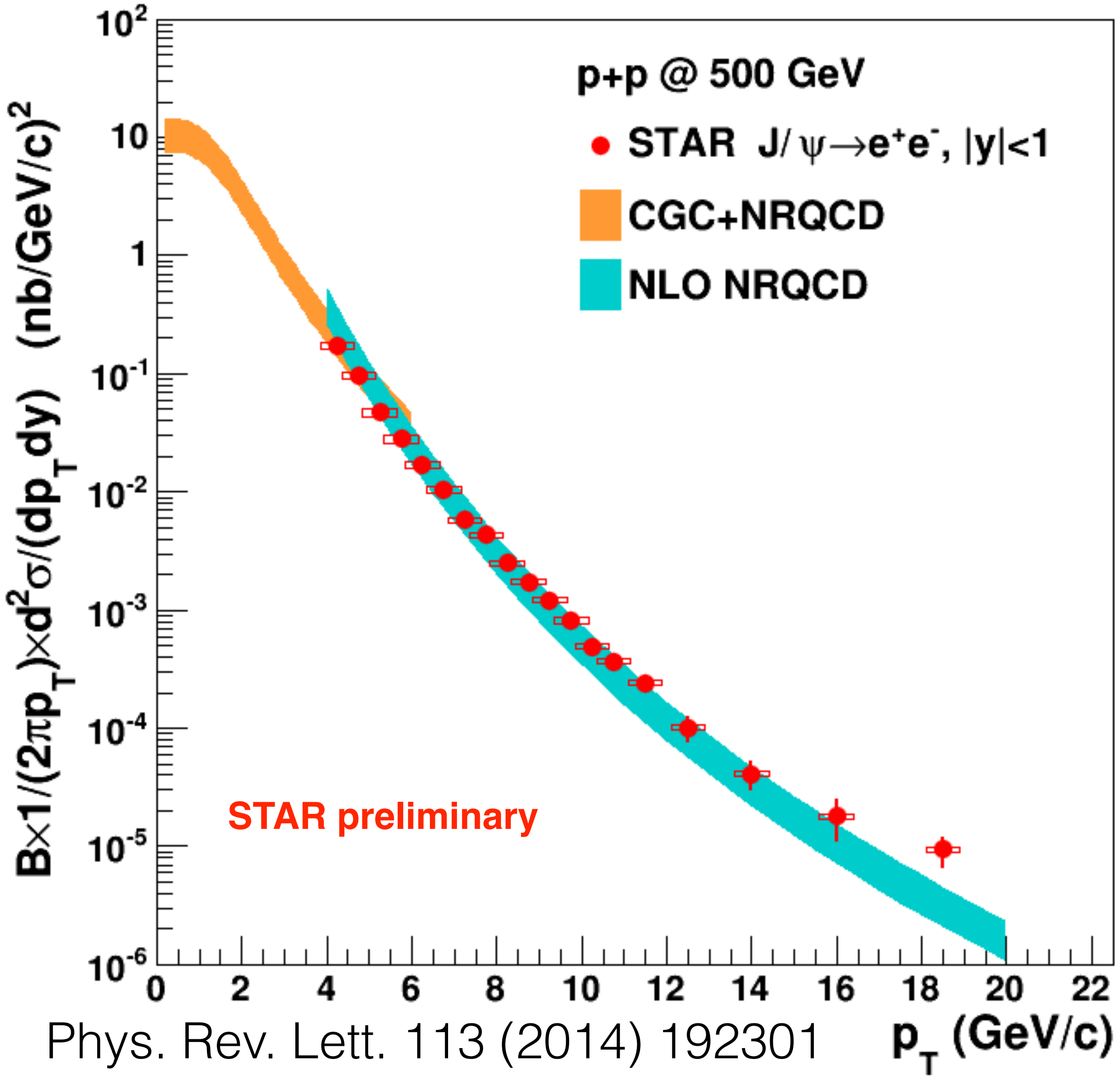
low-p_T J/ψ
$J/\psi \to \mu^+\mu^-$



- Background: fitting **Gaussian** (signal)& **expo+pol0**
- Signal extraction: bin counting **[2.8, 3.3]** GeV/c^2

J/ψ cross section and x_T scaling

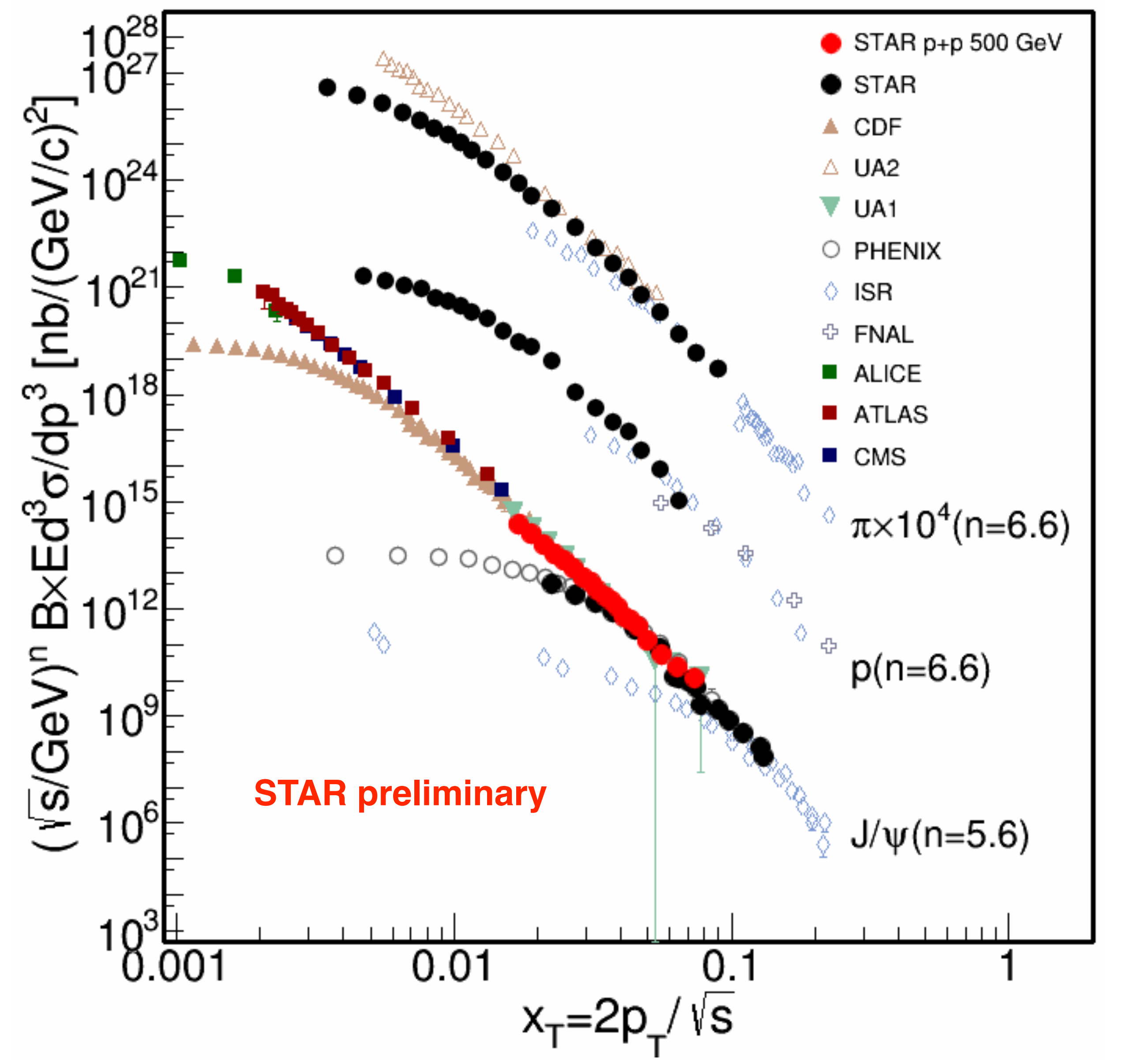
high-p_T J/ψ cross section



Phys. Rev. Lett. 113 (2014) 192301
H. S. Shao et al. JHEP05 (2015) 103

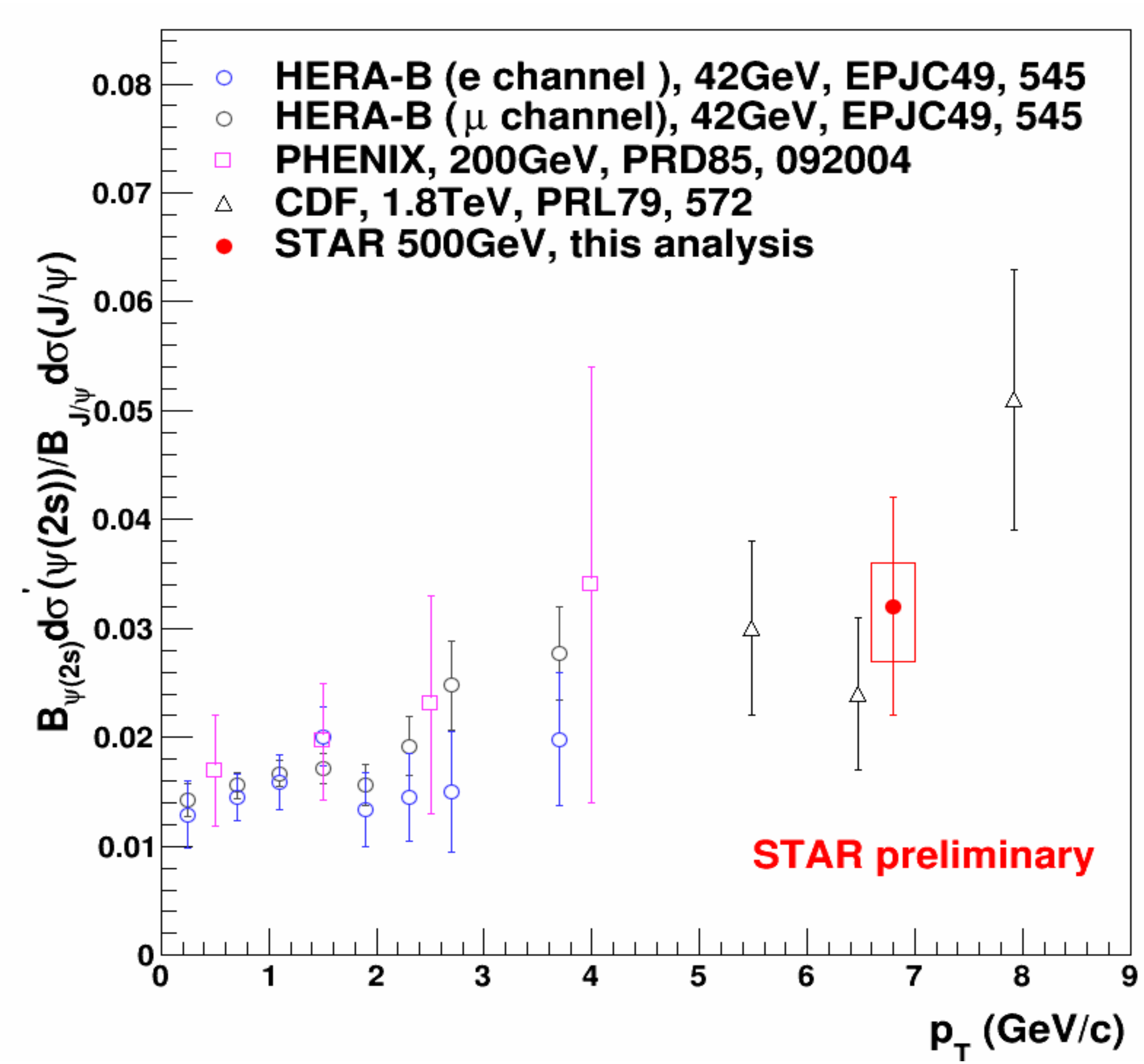
x_T scaling

Phys. Rev. C 80, 041902(2009)



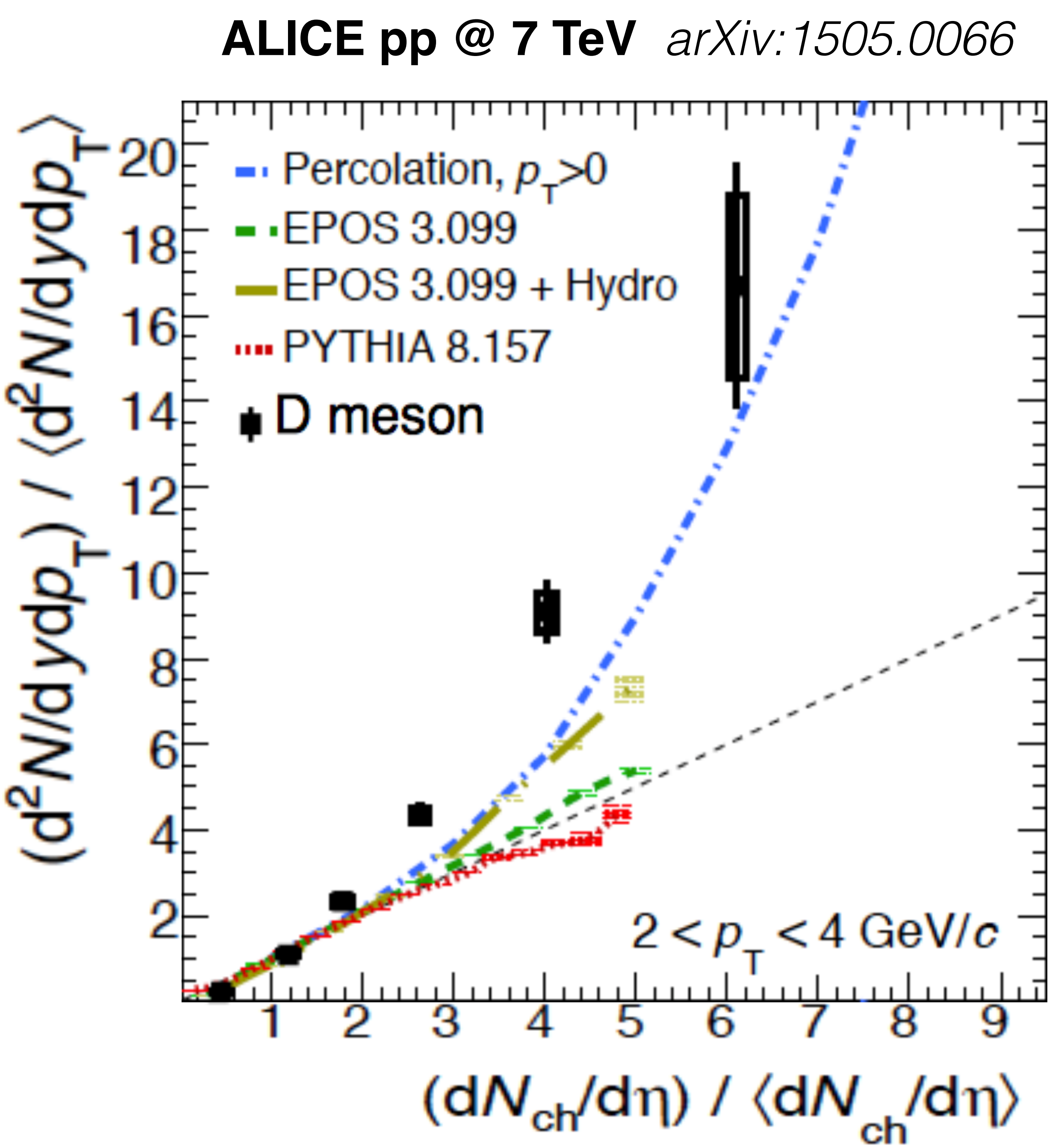
- **Inclusive J/ψ cross section** measured within **$4<p_T<20$ GeV/c**.
  - **NLO NRQCD** prediction **agrees** with data.
- **x_T scaling of high-p_T J/ψ** observed in STAR at **200** and **500** GeV.
  - **x_T scaling breaking** - affected by soft process**.**

Yield ratio of ψ(2s) to J/ψ



- STAR results **consistent with** world data **trend** versus p_T.
- **No collision energy dependence** is seen with current precision.
- Help to **pin down** the feed-down contribution from ψ(2s) to J/ψ.

Charm production vs. event multiplicity



- Stronger-than-linear rise of open charm production vs event activity.
- Similar behavior seen for inclusive J/ψ at both mid- and forward- rapidity in p+p @7 TeV.

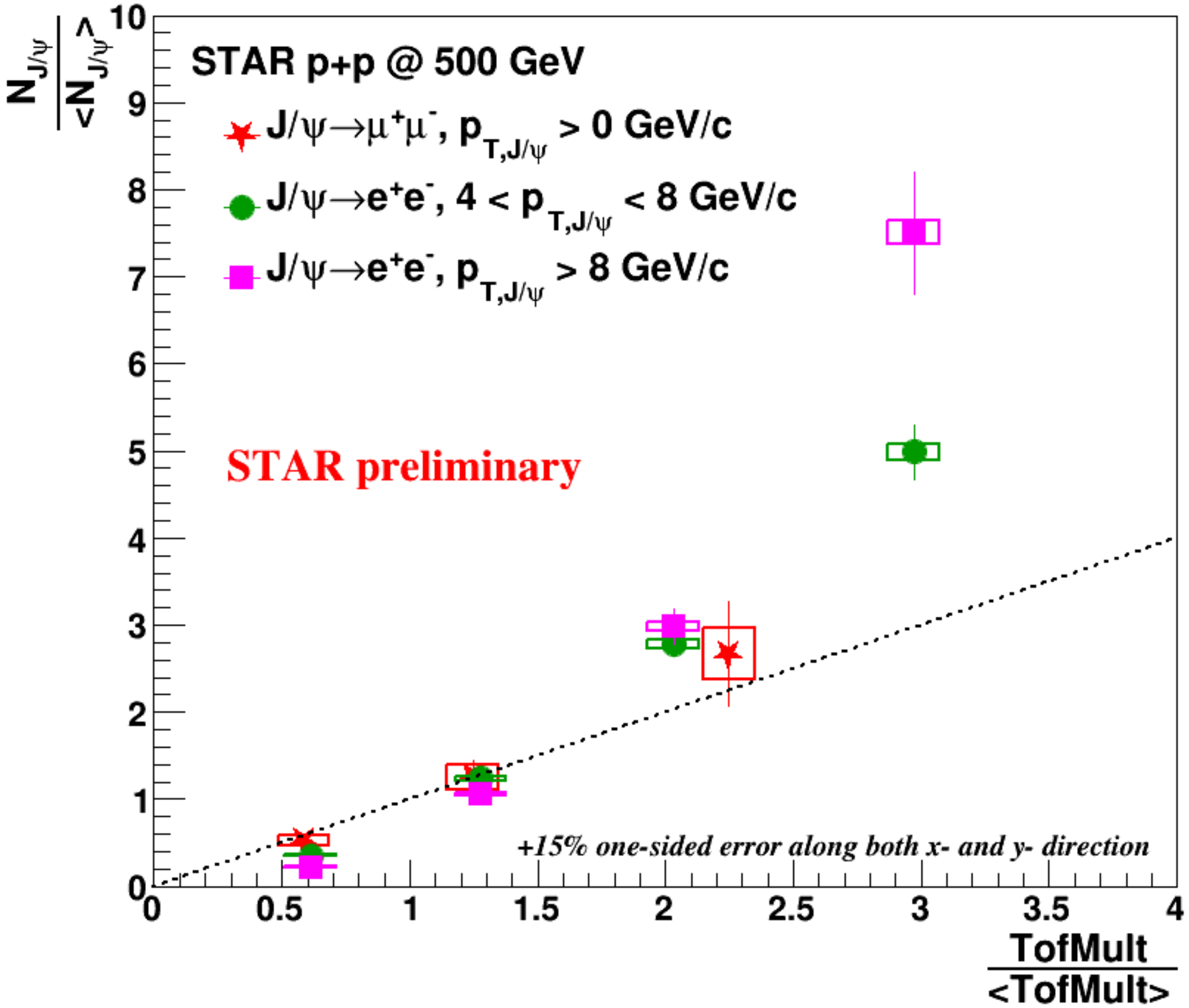
Several models:

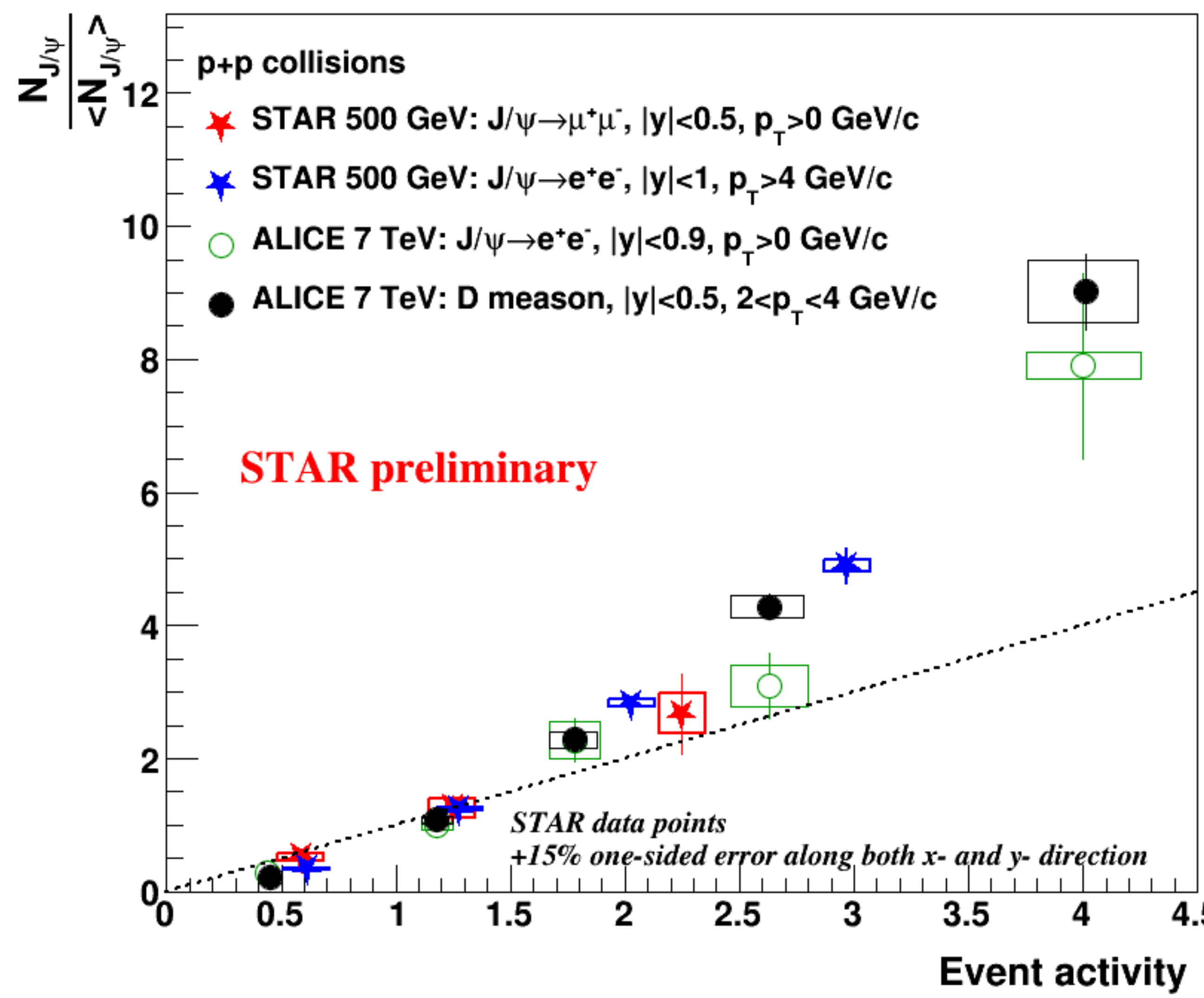
- PYTHIA8 including Multi-Parton-Interaction contributions to c production underestimates yield at large multiplicity
- Percolation model with string screening rises quadratically at high multiplicity.
- EPOS 3 event generator: initial conditions followed by a hydrodynamical evolution

Similar at RHIC energies??

J/ψ yield vs. event activity

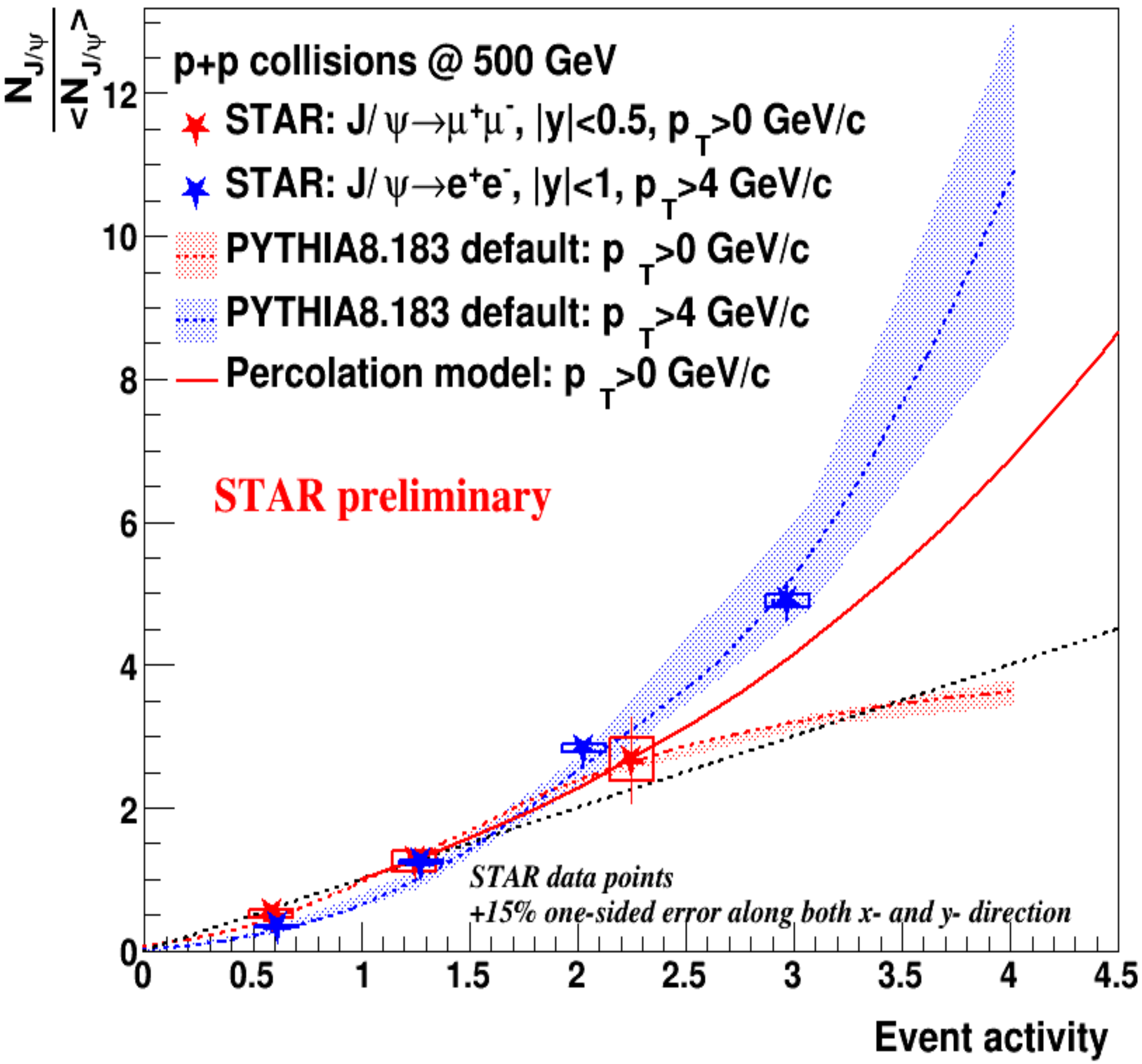
TofMult - Multiplicity of TOF matched tracks, |η|<0.9





- **Stronger-than-linear growth for relative J/ψ yield**.
  - **Soft and hard** processes are **correlated**.
- **Different trends** for low and high p_T J/ψ.
- **Similar trend at LHC and RHIC.**

Compare with models



- **PYTHIA8 describes** the rising **trend** and **p_T dependence** in data.
- **Percolation model** - also qualitatively **reproduces trend in data**.
- Measurement for **higher multiplicity** bins is in progress ➜ important to distinguish between models.

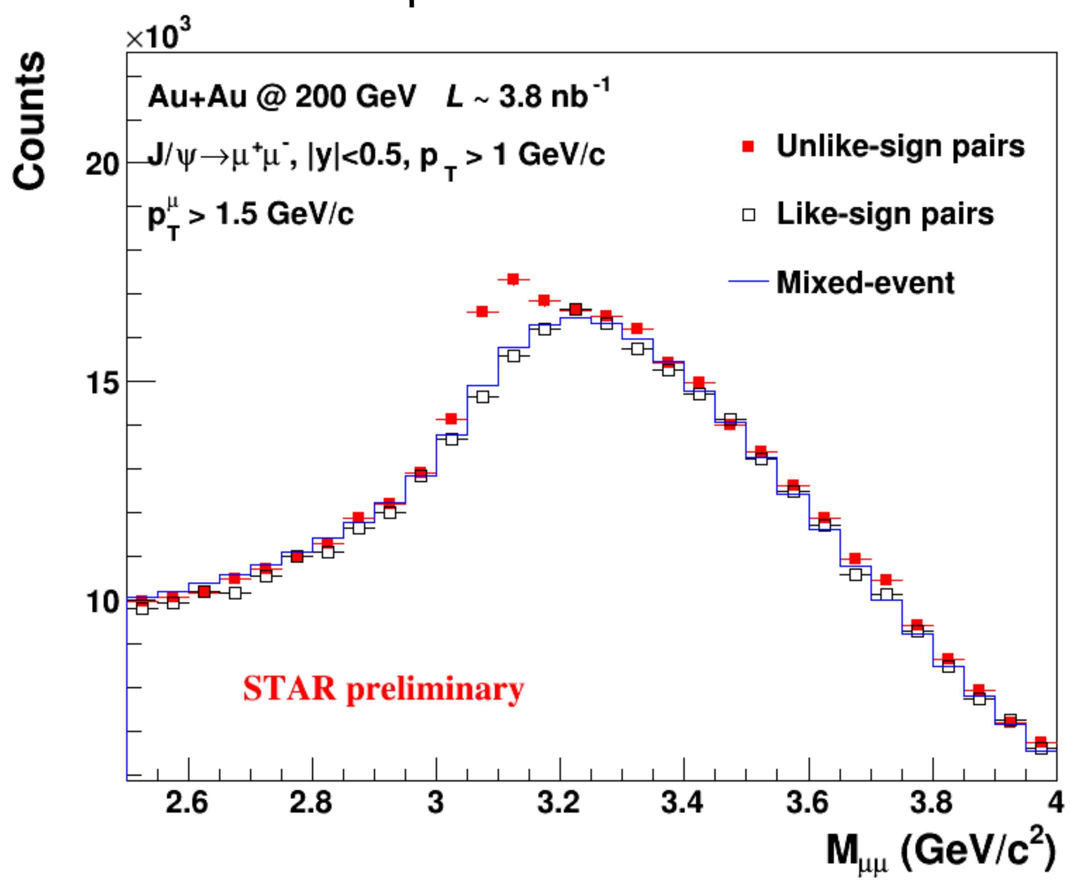
J/ψ production in Au+Au collisions at 200 GeV

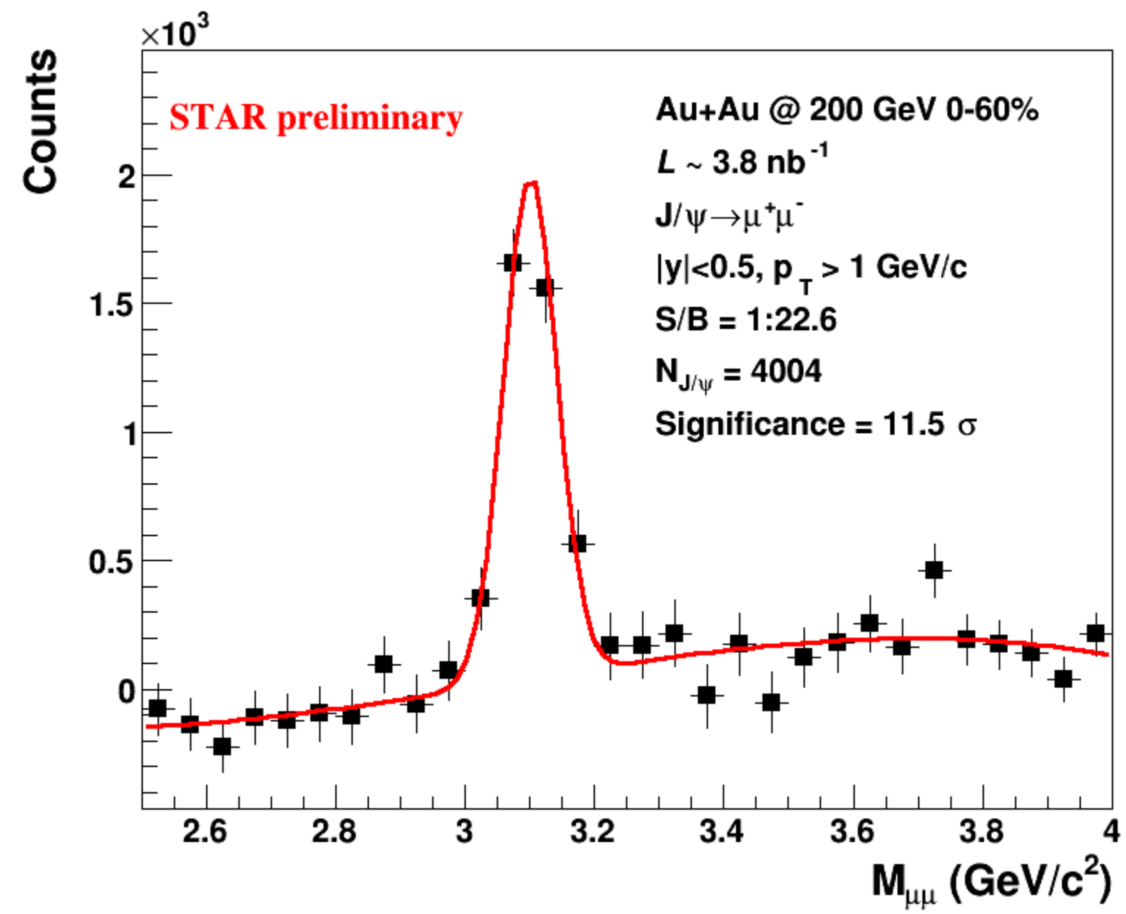
- Decay channel: $J/\psi \rightarrow \mu^+\mu^-$
- Data set: Au+Au collisions at 200 GeV recorded in 2014

  - Integrated luminosity ~14.2 nb^{-1}

  - only 30% is used for the results presented here

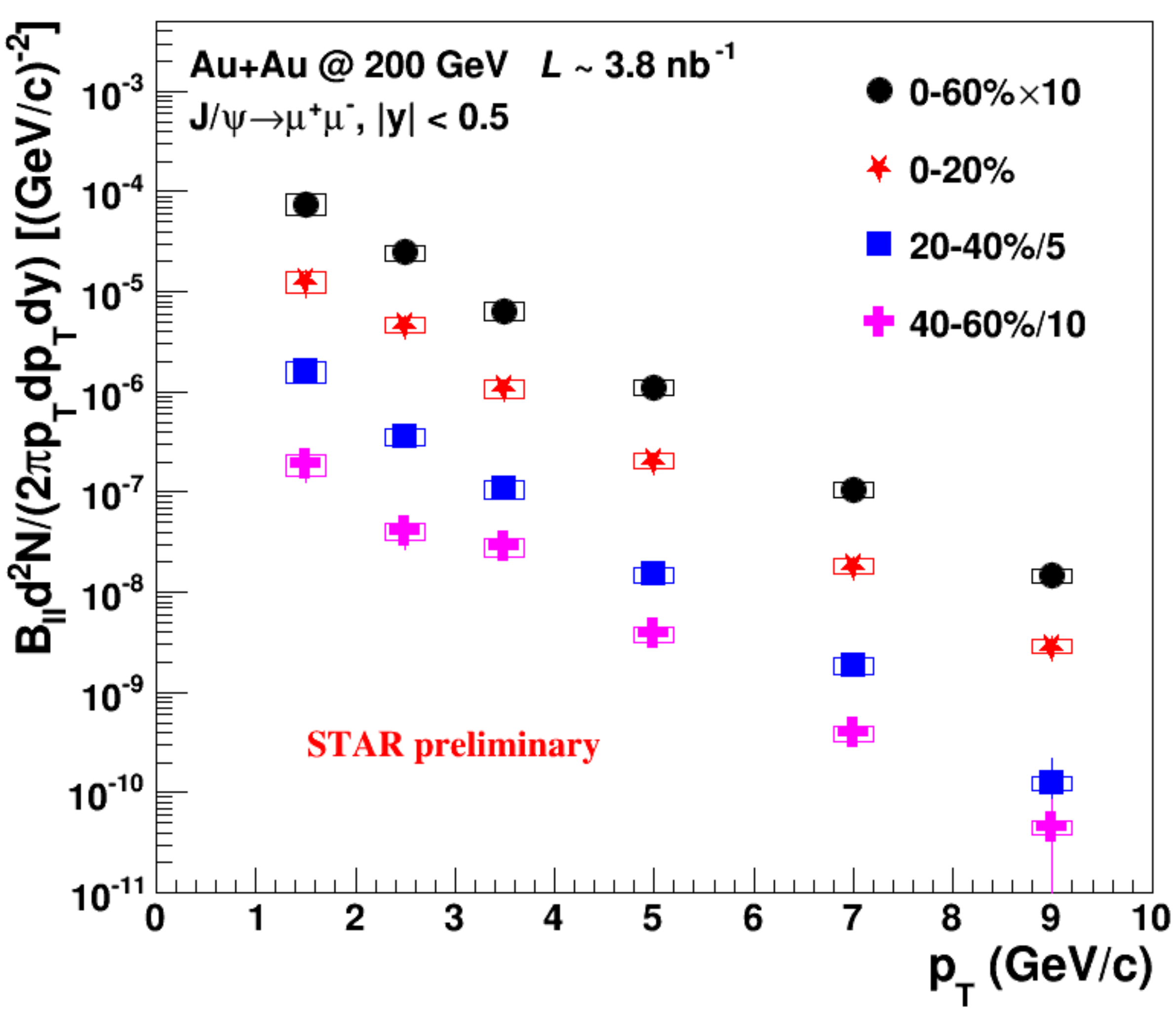
  - Equivalent amount of data as Run14 was taken in Run16

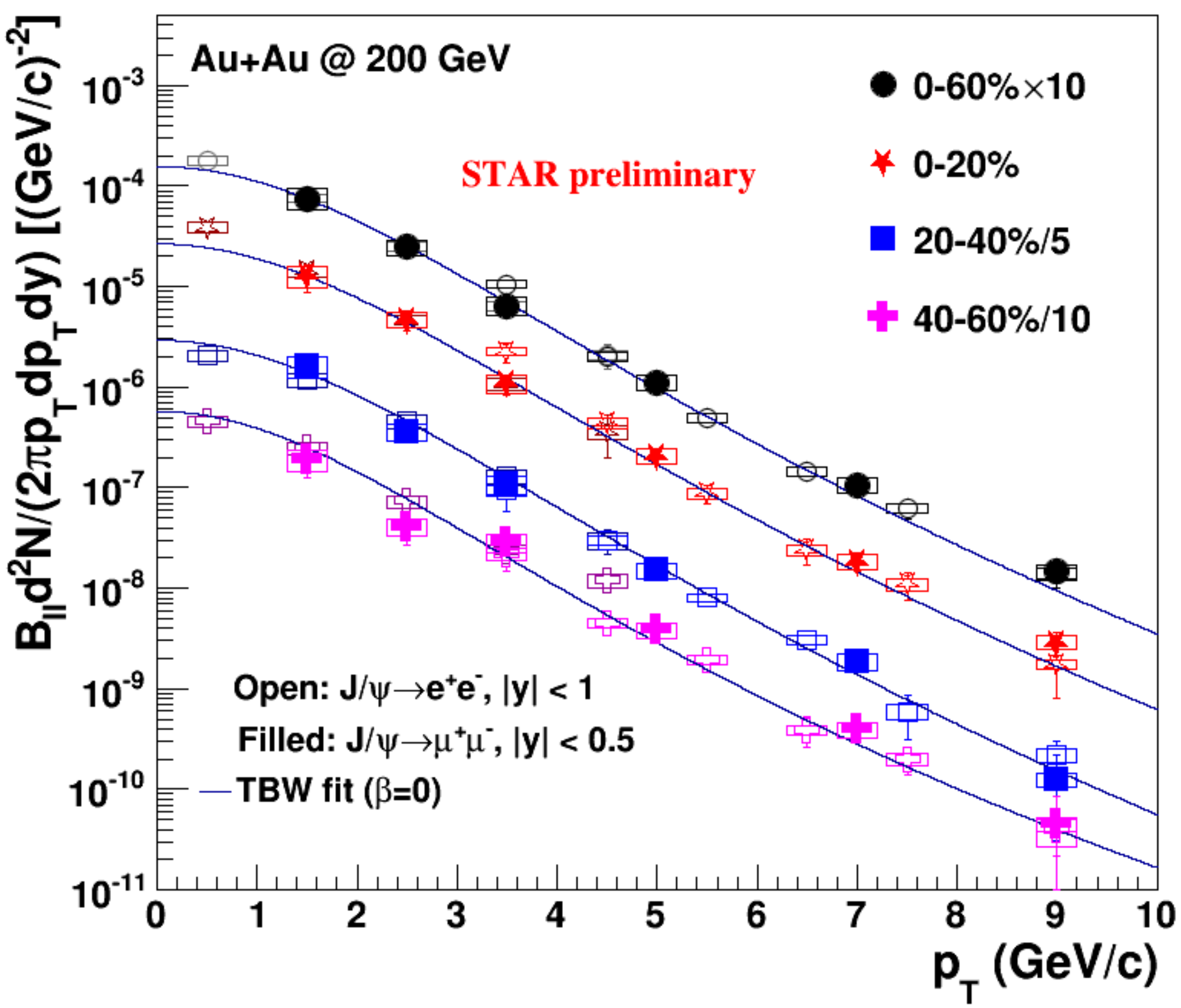




- Combinatorial background: **Mixed-event**
- Signal + residual background fitting: **Gaussian + pol3**
- Signal extraction: bin counting **[2.9, 3.3] GeV/c²**

Invariant yield of J/ψ



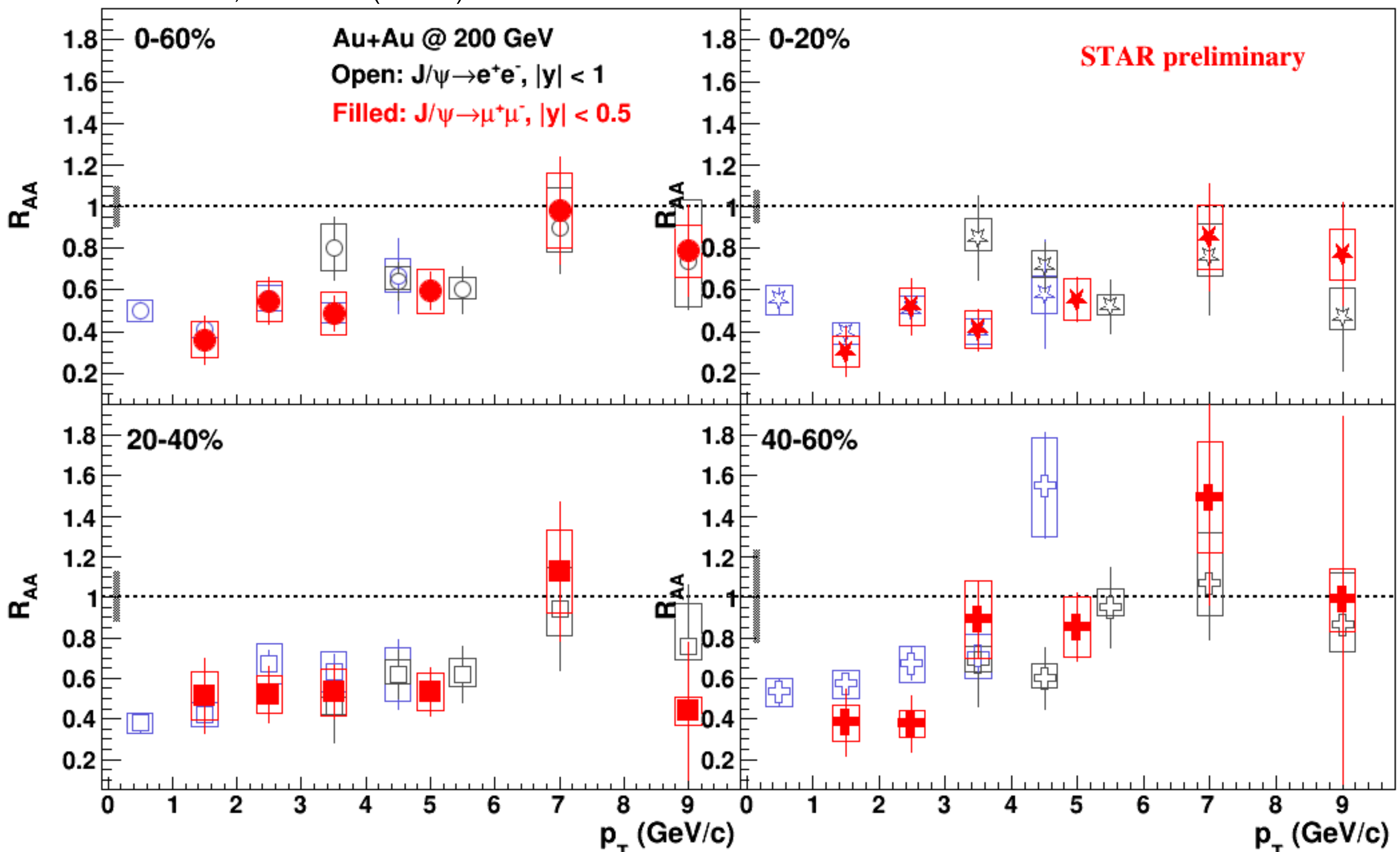


- First mid-rapidity measurement of J/ψ yield in Au+Au collisions via di-muon channel for $1 < p_T < 10$ GeV/c.
- Consistent with the published di-electron results.
- TBW fits to di-electron results assuming zero velocity for J/ψ.

J/ψ suppression

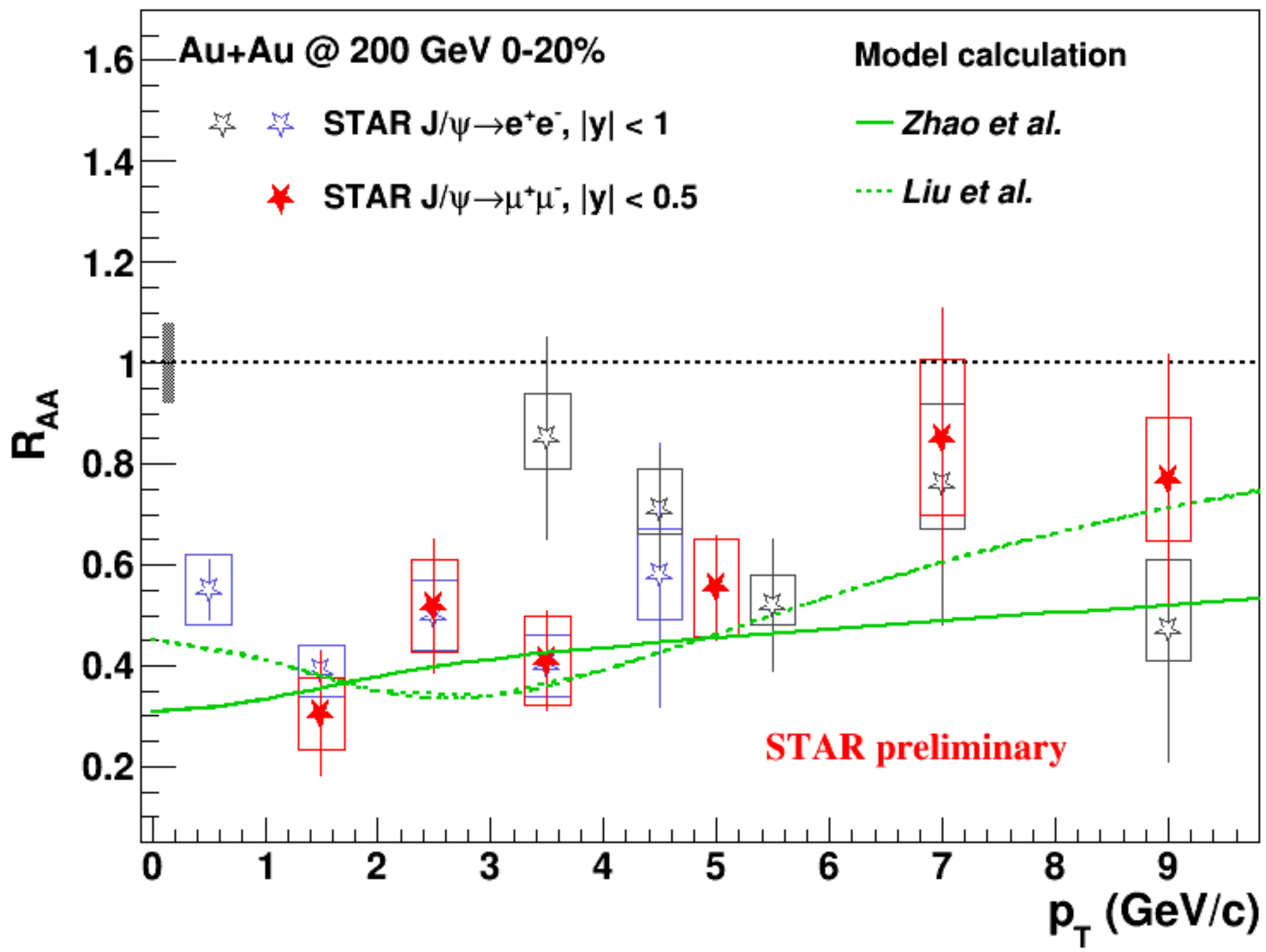
$$R_{AA} = \frac{\sigma_{inel}}{< N_{coll} >} \frac{d^2N_{AA}/dydp_T}{d^2\sigma_{pp}/dydp_T}$$

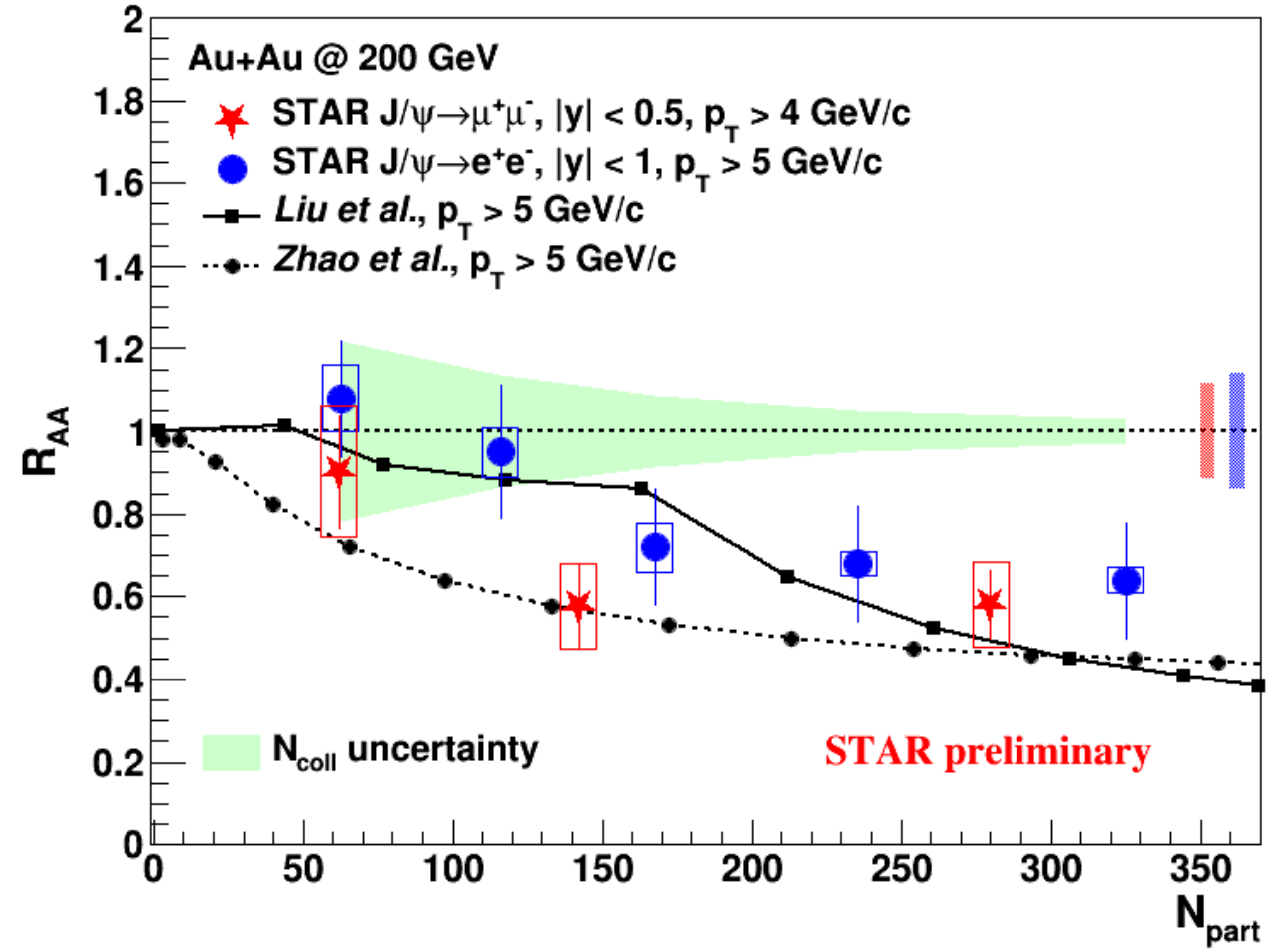
PLB 722 (2013) 55
PRC 90, 024906 (2014)



- Confirm rising R_{AA} with p_T in di-electron channel
- Strong suppression at low p_T.
- Less suppression at higher p_T: dissociation, Cronin effect, longer formation time?

J/ψ suppression compare with model





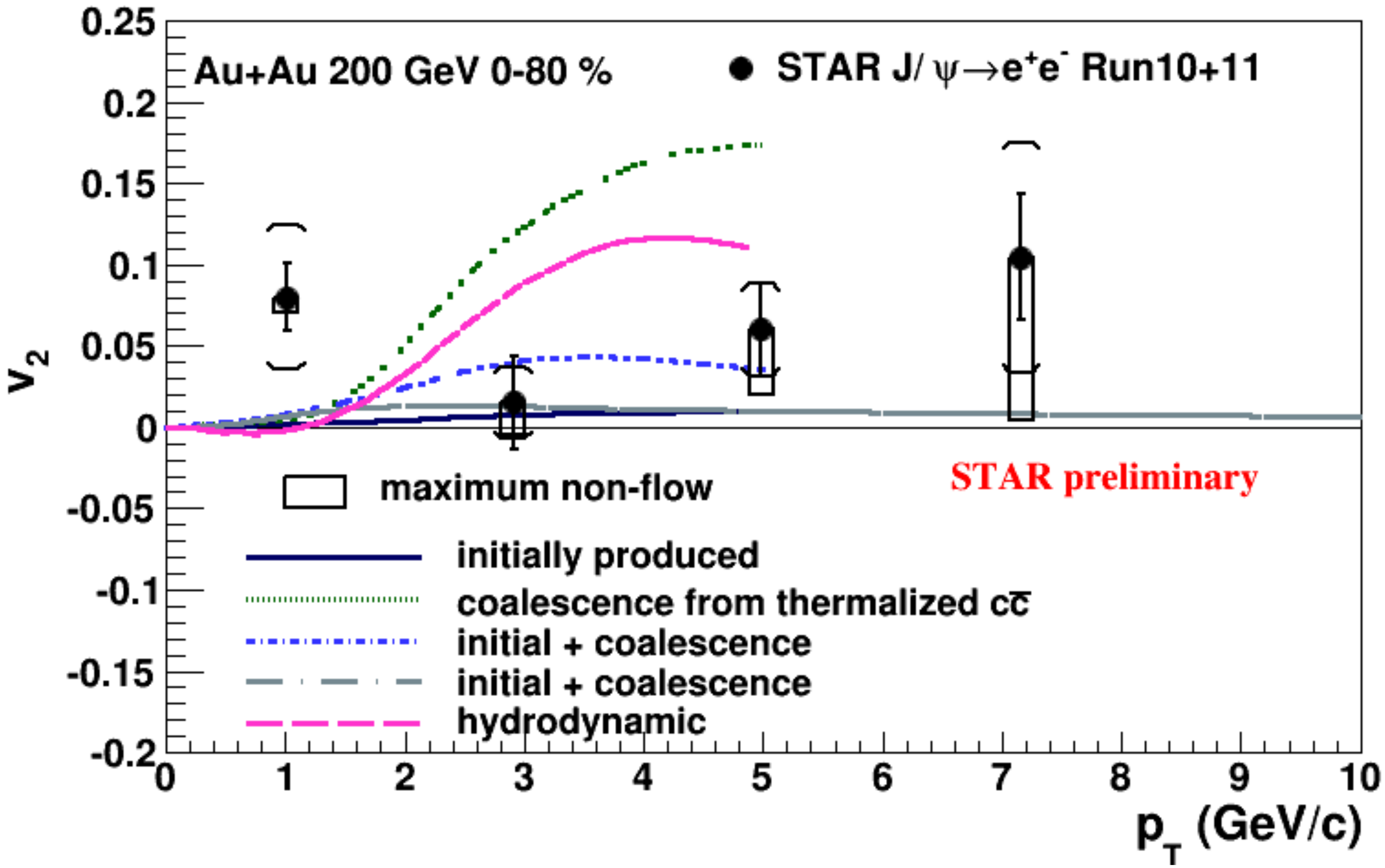
- Both models include dissociation of the prompt J/ψ and contribution of regenerated J/ψ.
  → qualitatively reproduce the rising trend seen in data.

- Significant suppression for J/ψ above 4 GeV/c in 0-20% and 20-40% centralities.
- Both models qualitatively reproduce the centrality dependence.

J/ψ elliptic flow

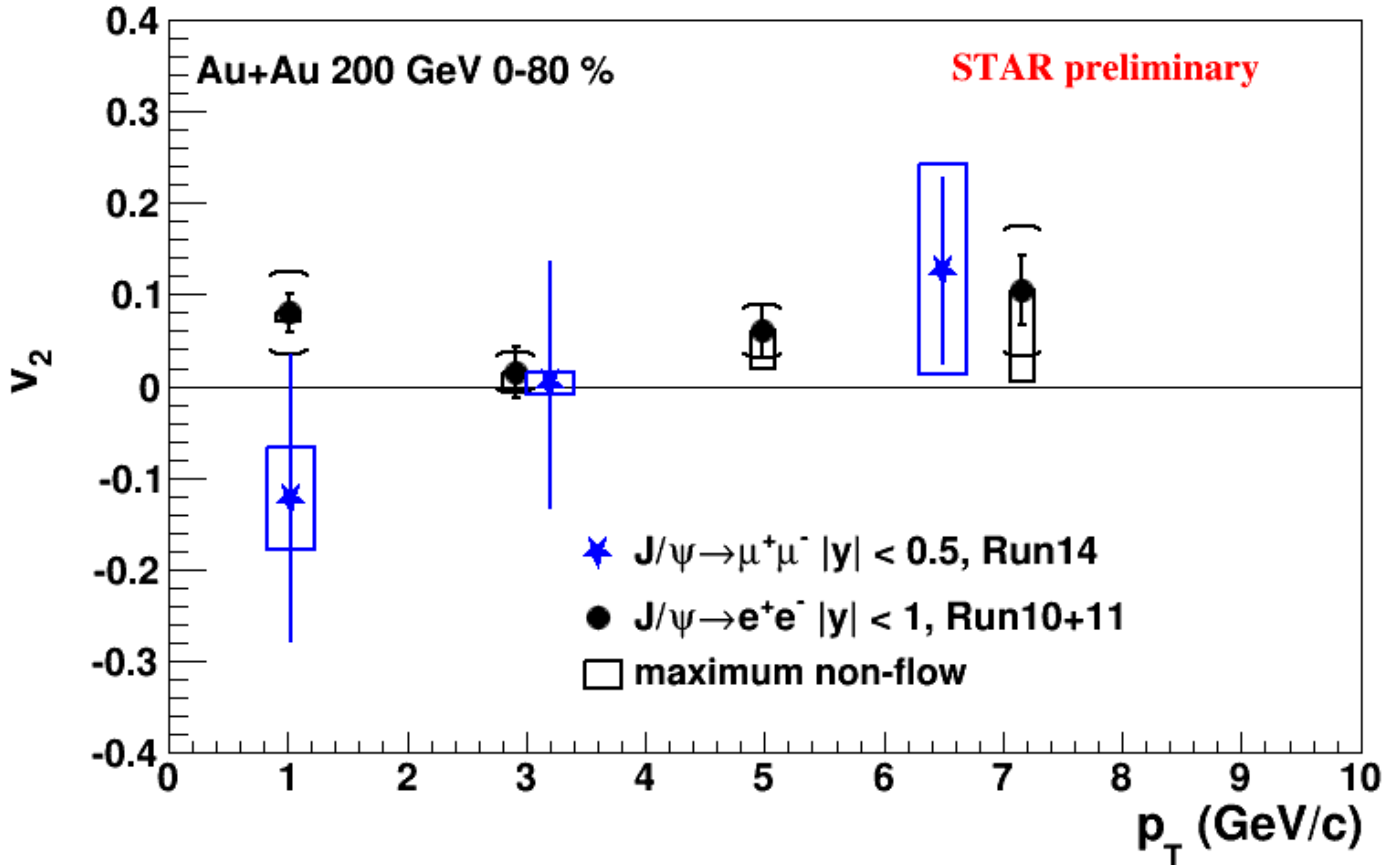
Measure elliptic flow v_2

- Primordial: little or zero v_2
- Regenerated: inherit v_2 from constituent charm quarks



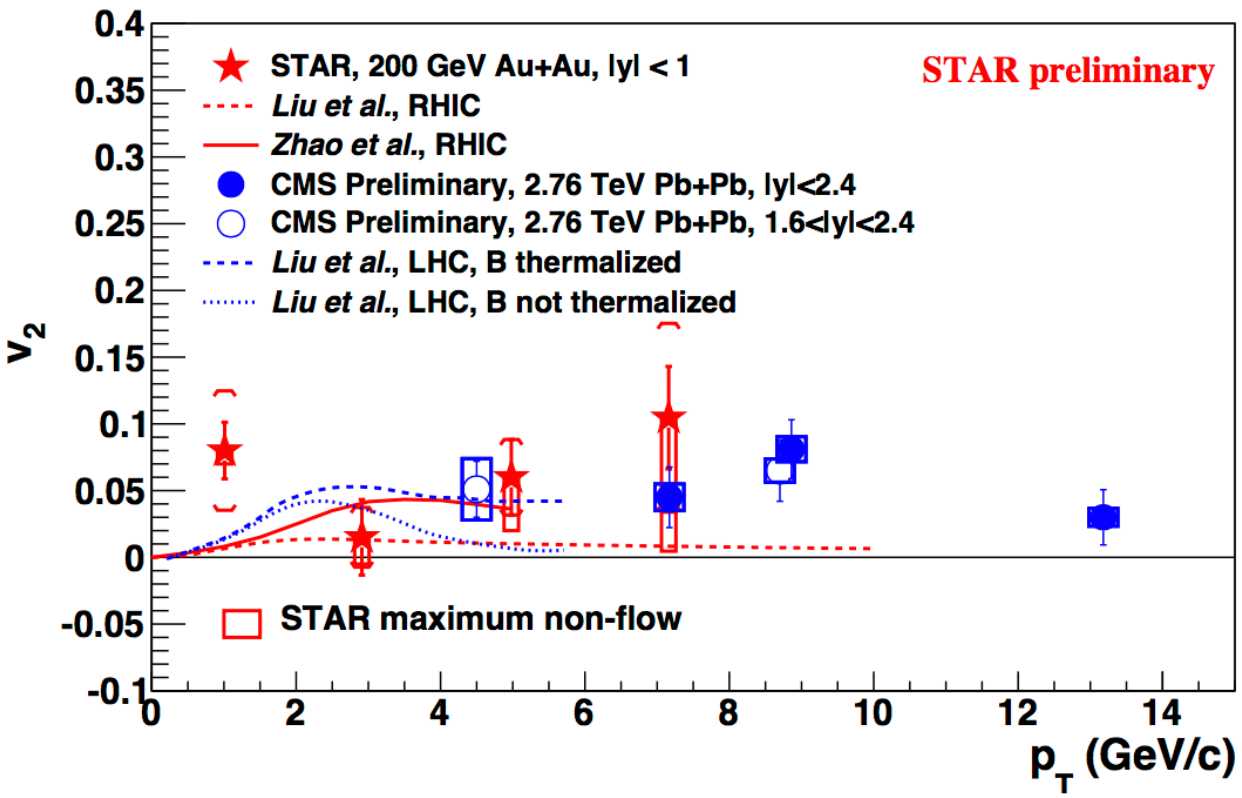
- Disfavors the case that J/ψ with p_T >2.0 GeV/c is produced dominantly from coalescence of thermalized charm and anti-charm quarks.

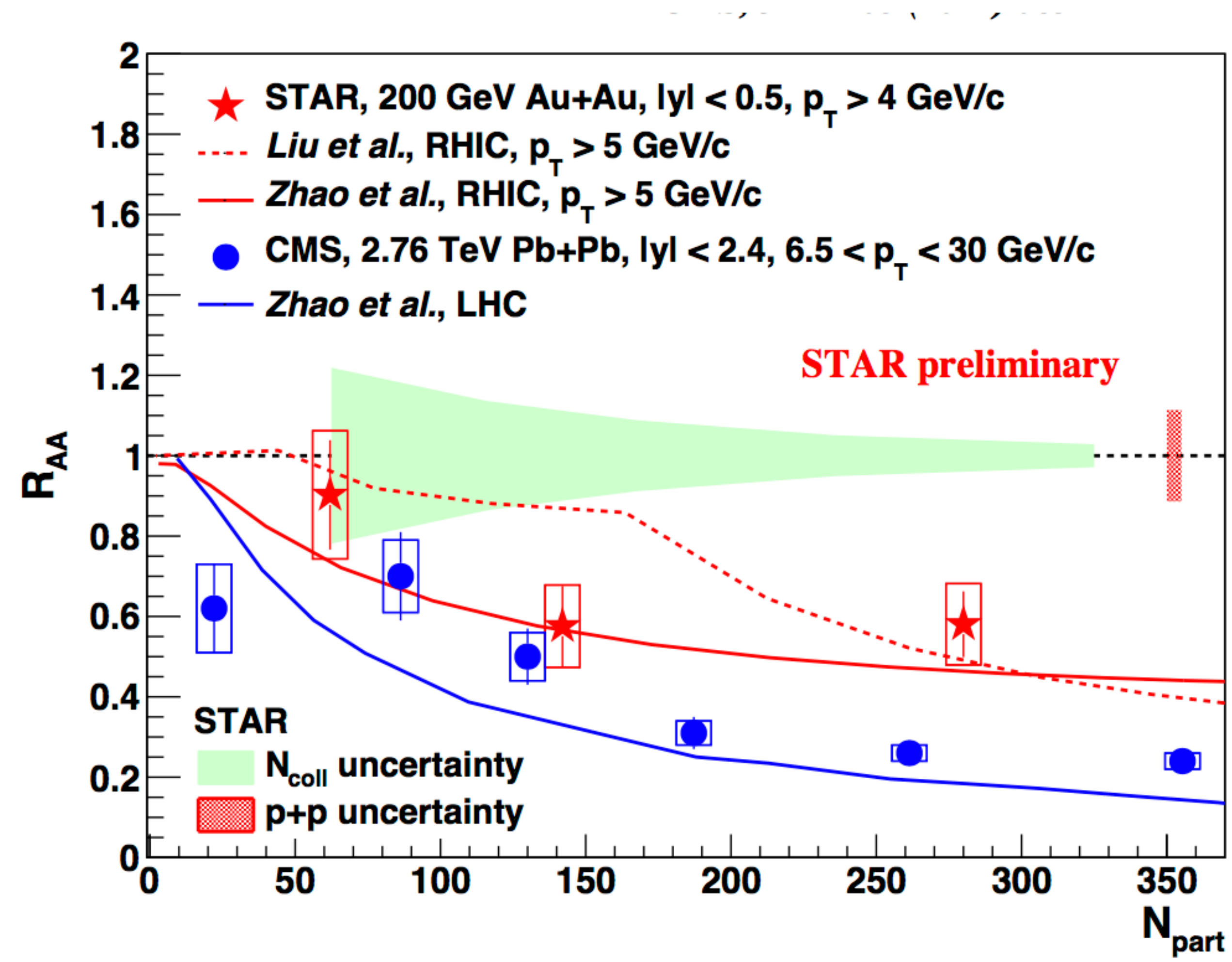
J/ψ elliptic flow



- First attempt to measure J/ψ v2 in dimuon channel .
- The result will be significantly improved with the full Run14+Run16 data.

J/ψ elliptic flow

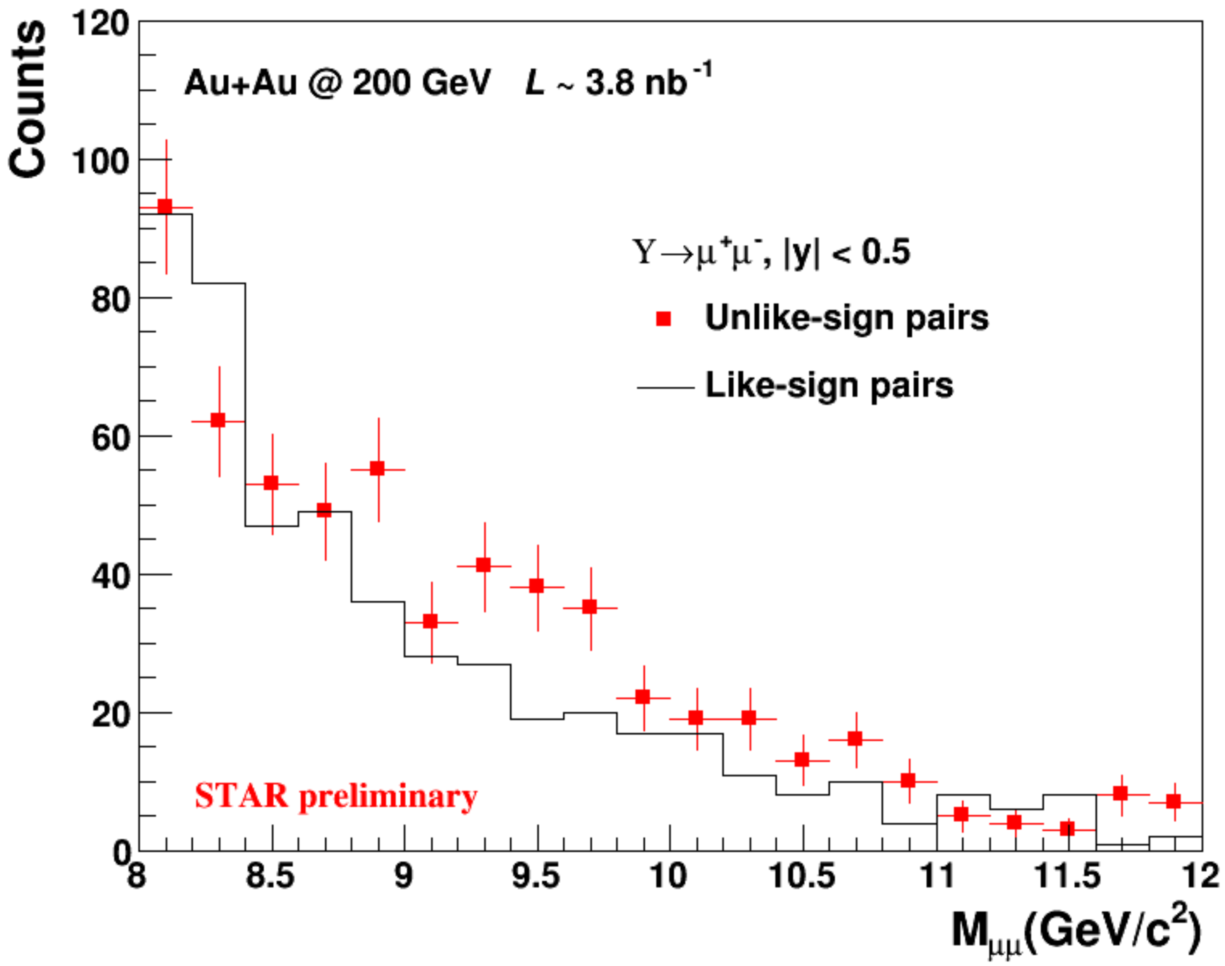


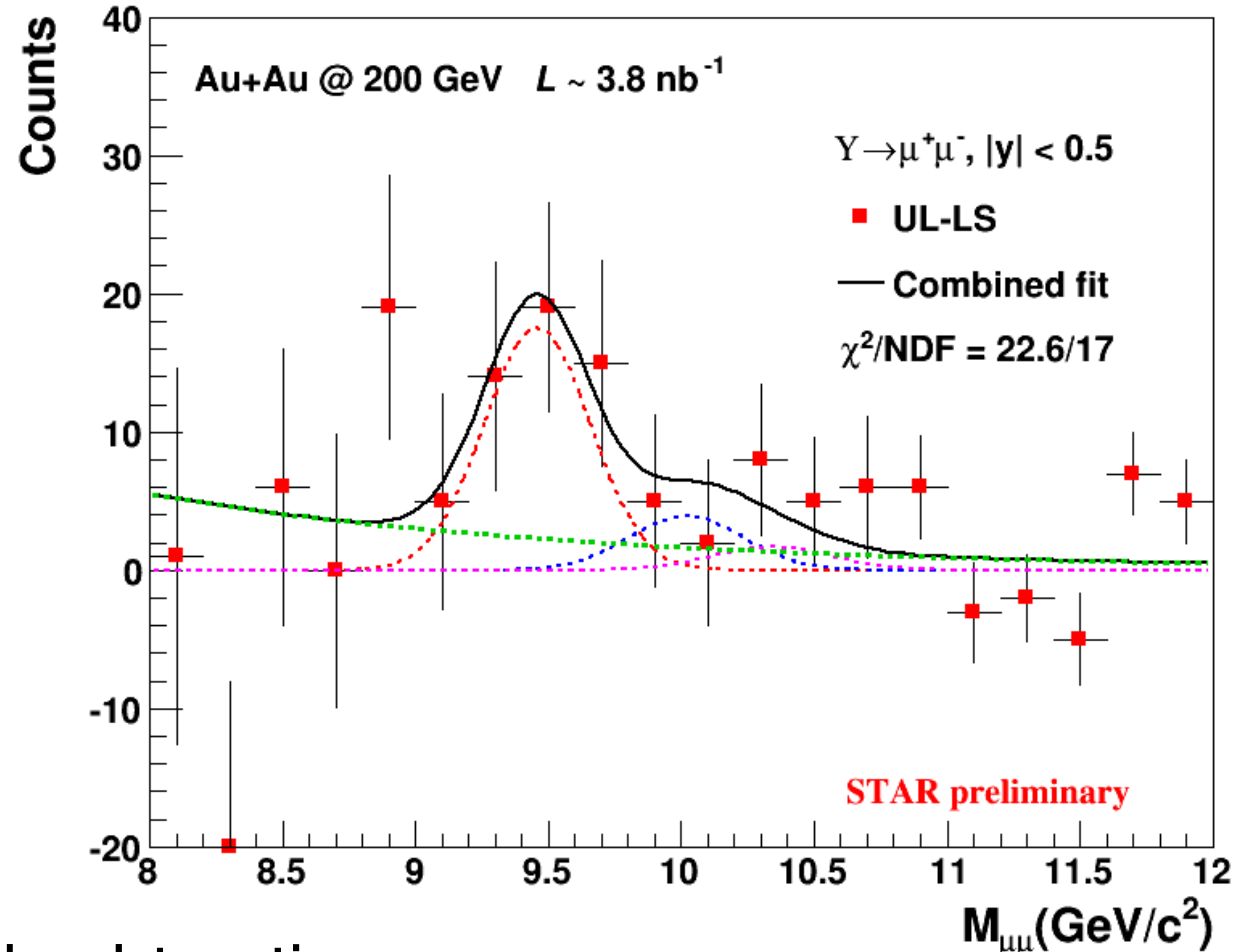


- High p_T J/ψ in central collisions at RHIC, v_2 is consistent with 0 while $R_{AA} \sim 0.5$
  - Small interaction with medium
  - Dissociation dominates
- High p_T J/ψ at LHC exhibits larger suppression.
- Models include recombination and dissociation can qualitatively reproduce R_{AA} at RHIC and LHC simultaneously. Need model calculations for v2 up to p_T = 14 GeV/c.

Upsilon measurement

- Less bremsstrahlung radiation in dimuon channel compared to dielectron channel → potential to separate ϒ states.

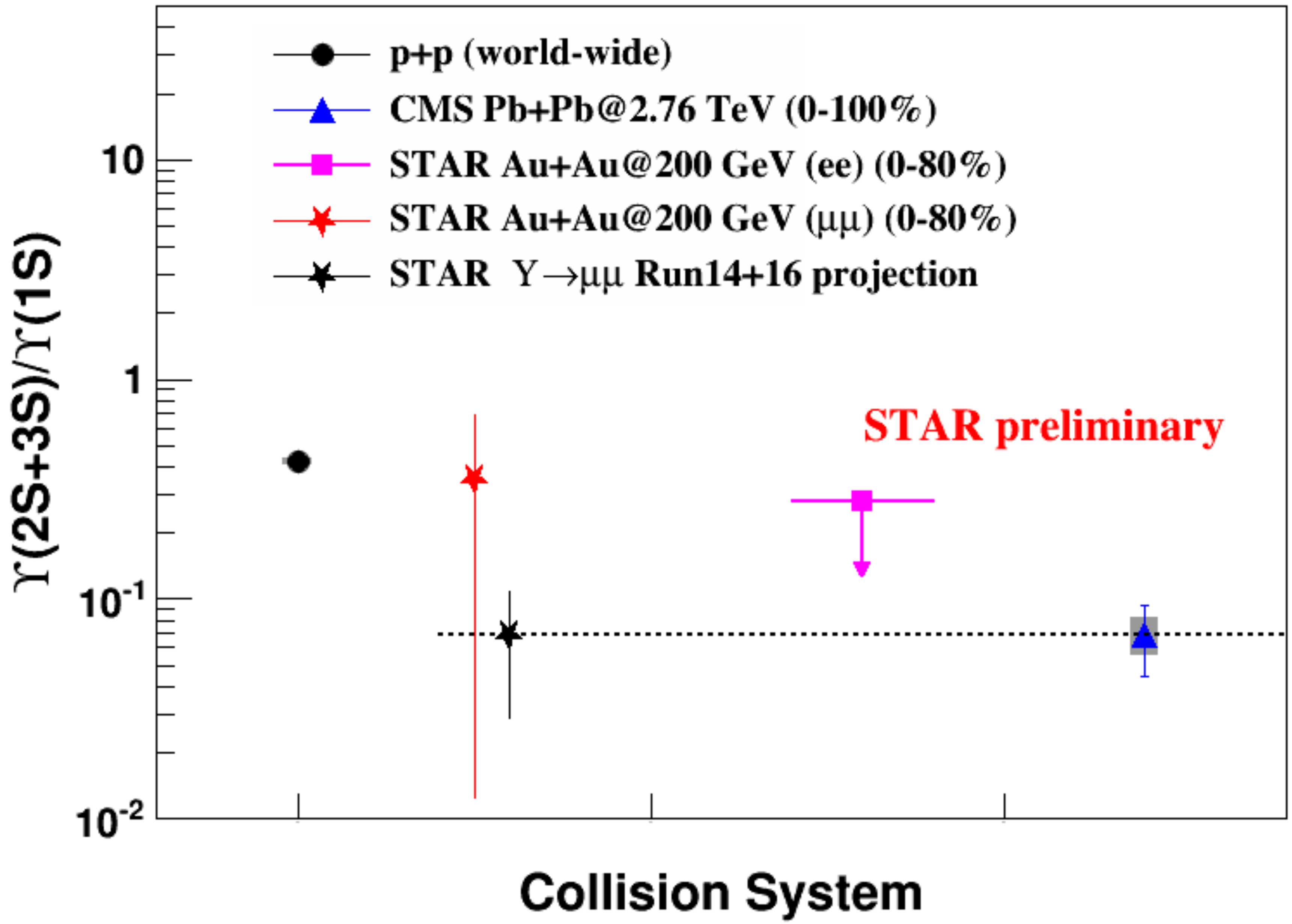




Fit signal distribution after background subtraction:

- Mean of ϒ mass spectrum is fixed to PDG value, width is determined from simulation.
- Ratio of ϒ(2S)/ϒ(3S) is fixed to pp value
- Residual background shape ($b\bar{b}$ and Drell-Yan) is estimated using PYTHIA

Upsilon measurement



- Consistent with di-electron channel within large error bars.
- The statistical error can be further reduced:
- A factor of 7 more statistics with full Run14+16 data

Summary

- Inclusive J/ψ p_T spectrum is measured above 4 GeV/c in p+p collisions at 500 GeV via di-electron channel. The spectra can be well described by NRQCD calculation.

- The relative J/ψ yield grows rapidly as the charged-particle multiplicity increased in p+p collisions at $\sqrt{s}$ = 500 GeV
  - Stronger-than-linear rise at higher multiplicities for $p_T > 4$ GeV/c
  - PYTHIA8 and Percolation model can describe the observed trend in data.
  - Measurement at high multiplicity are needed to distinguish PYTHIA8 and Percolation model.

- First quarkonium measurements via di-muon channel at mid-rapidity, the spectra are consistent with di-electron channel, and precise results are expected with full Run14 + Run16 data.
- Dissociation of high p_T J/ψ at RHIC in central collisions
  - Significant suppression with $R_{AA} \sim 0.5$
  - v_2 is consistent with 0
  - Models with recombination and dissociation can qualitatively reproduce data.