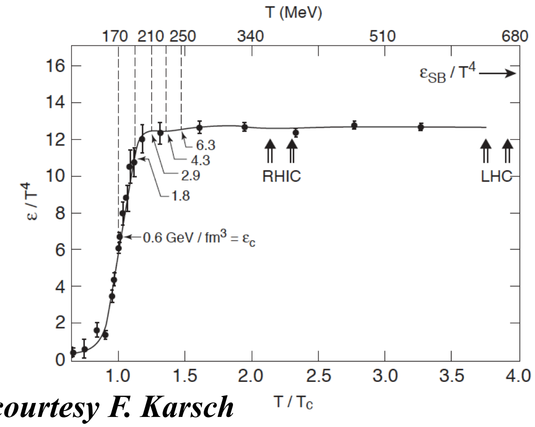
J/ψ R_{AA} and v_2 via the di-muon channel in Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV from STAR Experiment

Takahito Todoroki (BNL)
for the STAR Collaboration

Quarkonium Working Group 2016
PNNL, Richland, WA
June 6th – 10th, 2016

Quark-Gluon Plasma

- QCD predicts **a phase transition** from confined hadrons to Quark-Gluon Plasma (QGP) where ***partons are the relevant degrees of freedom***



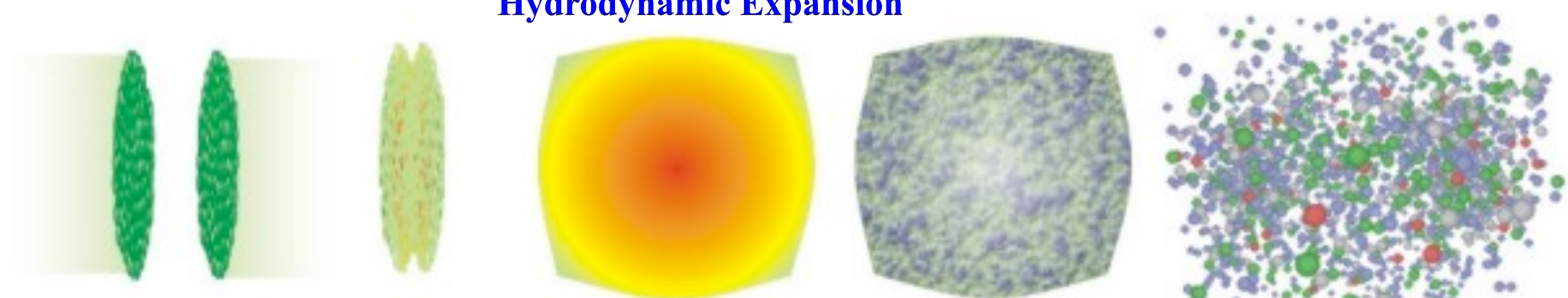
Contemp.Phys. 42 (2001) 209, courtesy F. Karsch

- Form QGP with relativistic heavy ion collisions

Initial Collision

QGP & Hydrodynamic Expansion

Freeze-out



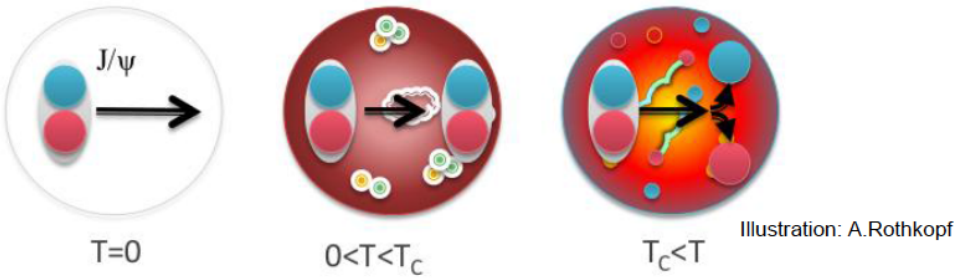
Pre-Equilibrium

Hadronization & Hadron Gas Phase

http://www.phy.duke.edu/research/NPTheory/

Probe QGP with J/ψ

- **Color-screening**: J/ψ dissociate in the medium



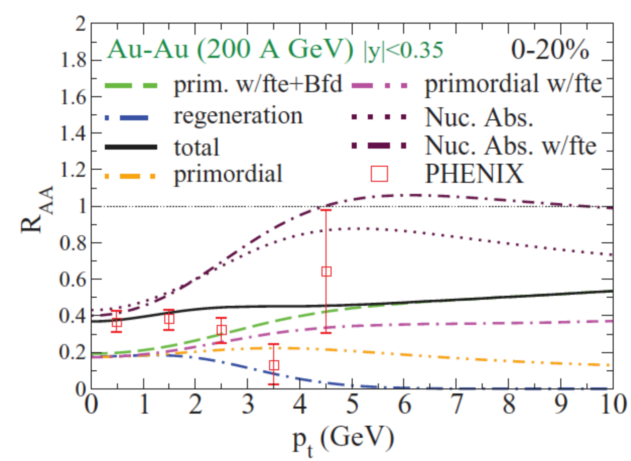
J/ψ suppression was proposed as a direct proof of deconfinement

T. Matsui and H. Satz PLB 178 (1986) 416

HOWEVER

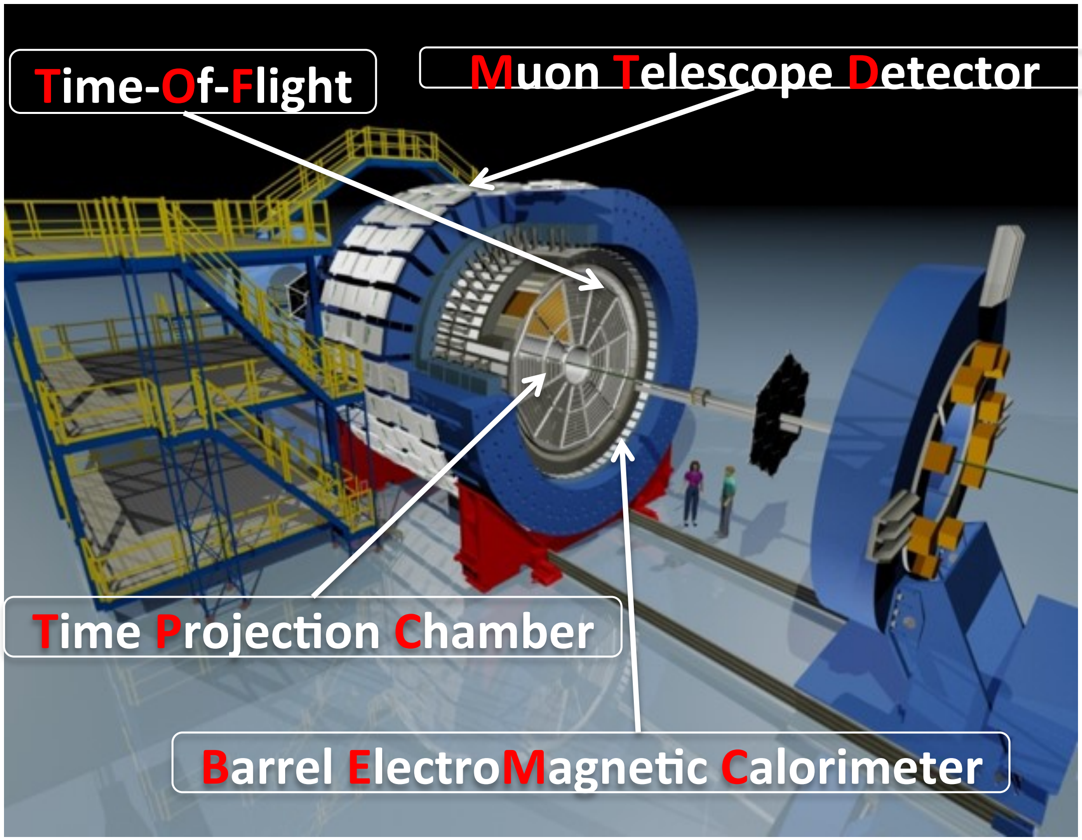
- **Various production mechanisms**
  - Prompt: direct production; decay of ψ(2S) and χ_c (40%)
  - Non-prompt: B-meson decay (Up to 20% at high p_T)
- **Different effects in play**
  - Hot nuclear matter effects
    - *Dissociation*
    - Regeneration from uncorrelated quarks
    - Medium-induced energy loss
  - Cold nuclear matter effects

Phys. Rev. C 82, 064905



The Solenoid Tracker At RHIC (STAR)

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



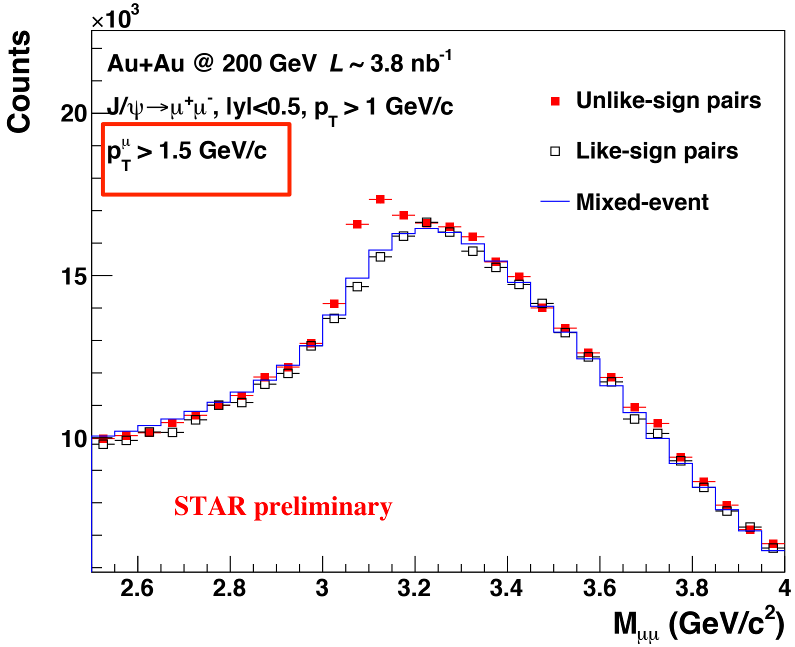
- **TPC**: precise momentum and energy loss
- **TOF**: measure time-of-flight
- **BEMC**: trigger on and identify electrons
- **MTD**: trigger on and identify muons
  - **Fully installed in 2014** behind magnet
  - ***Precise timing measurement (σ~100 ps)***
  - ***Relatively high efficiency for J/ψ at low p_T*** → cover wide kinematic range

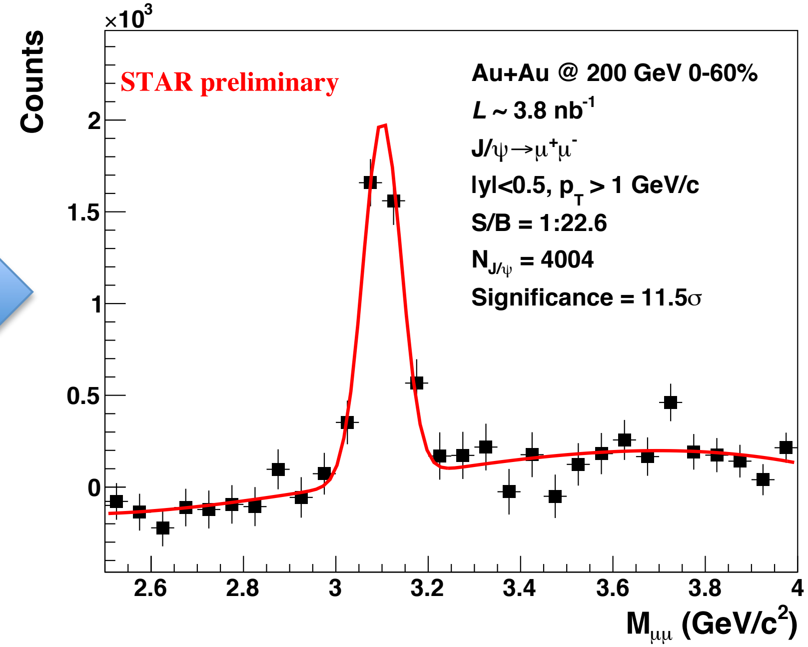
Analysis details

- Decay channel: $J/\psi \rightarrow \mu^+ + \mu^-$
- **Dimuon trigger**: two hits in MTD
- 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 have been taken in 2016 experiment!!

- **Muon identification cuts**
  - Energy loss measurement by TPC
  - Match TPC tracks to MTD
    - Distance between MTD hits and projected TPC tracks along both z and φ directions
    - Time difference between MTD measured time and expected travel time of muons

Extract J/ψ yield



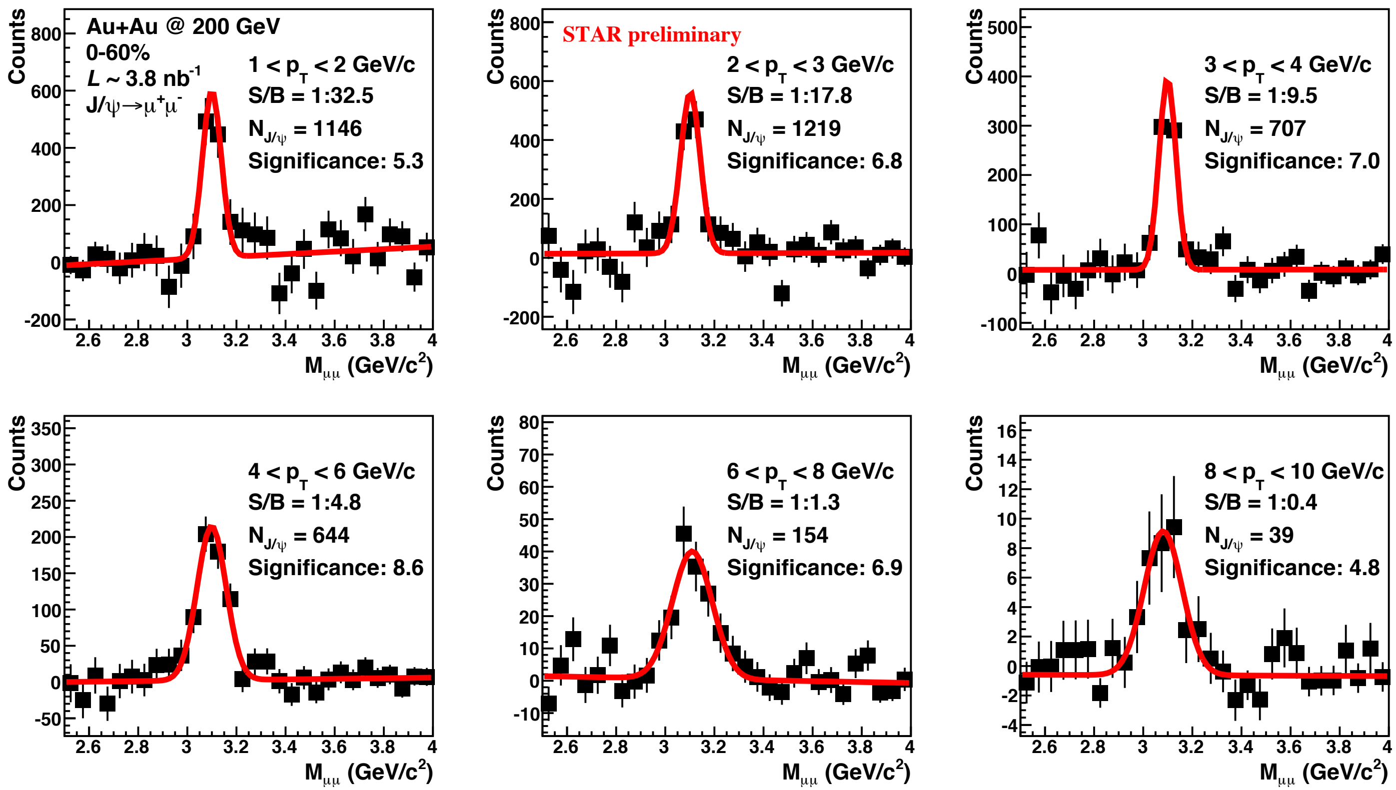


Signal extraction

- Mixed-event → combinatorial background.
- Fit background-subtracted unlike-sign with Gaussian+pol3
- Signal = (counting in [2.9,3.3] GeV/c²) – (residual background)

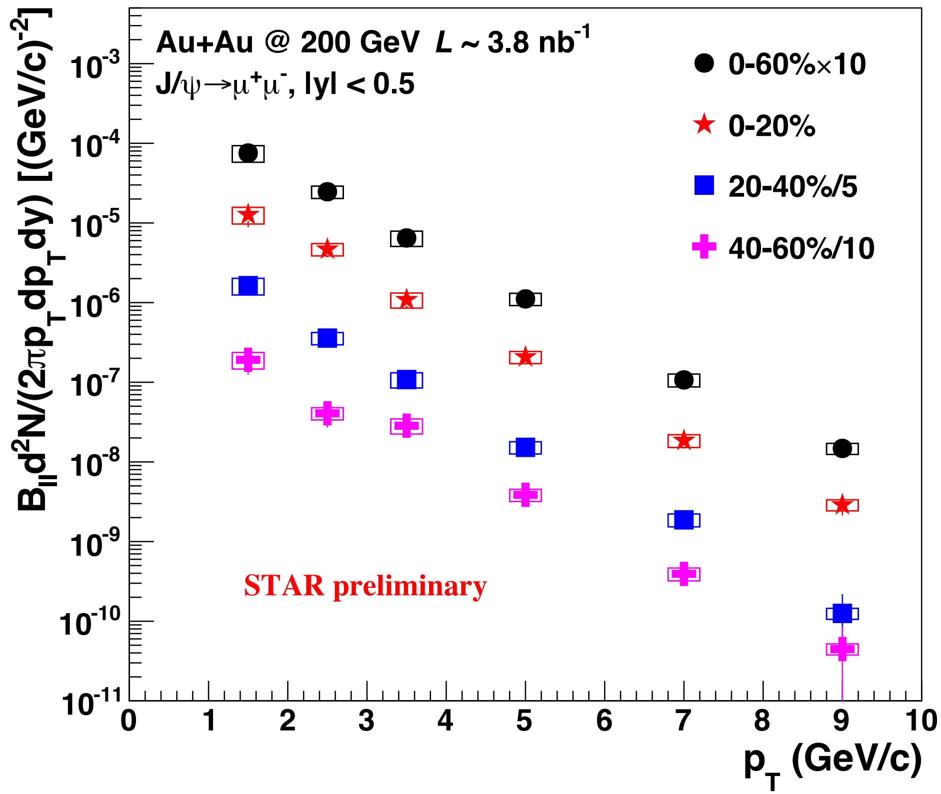
No bremsstrahlung tail
S/B = 1:23
N ~ 4000
Sig ~ 11.5σ

J/ψ yield in p_T bins



- Good significance in each p_T bin
- Larger J/ψ p_T → larger S/B, wider J/ψ peak and fewer signal counts

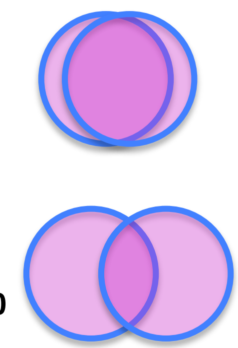
Invariant yield of J/ψ



Collision Centrality

0%: head-head collisions

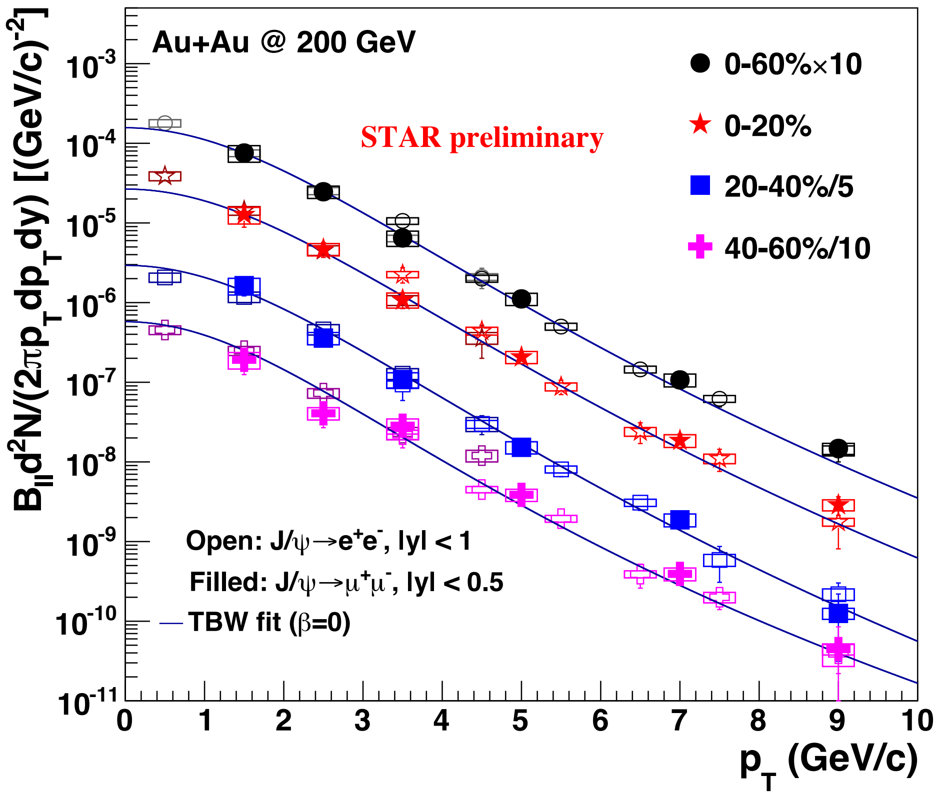
100%: peripheral collisions



B_{ll}: branching ratio to di-lepton

- First mid-rapidity measurement of J/ψ yield in Au+Au collisions via the di-muon channel for $1 < p_T < 10$ GeV/c

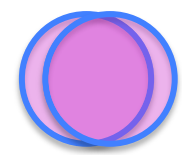
Invariant yield of J/ψ

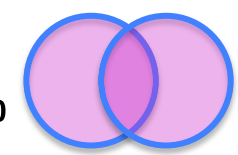


Collision Centrality

0%: head-head collisions

80%: peripheral collisions



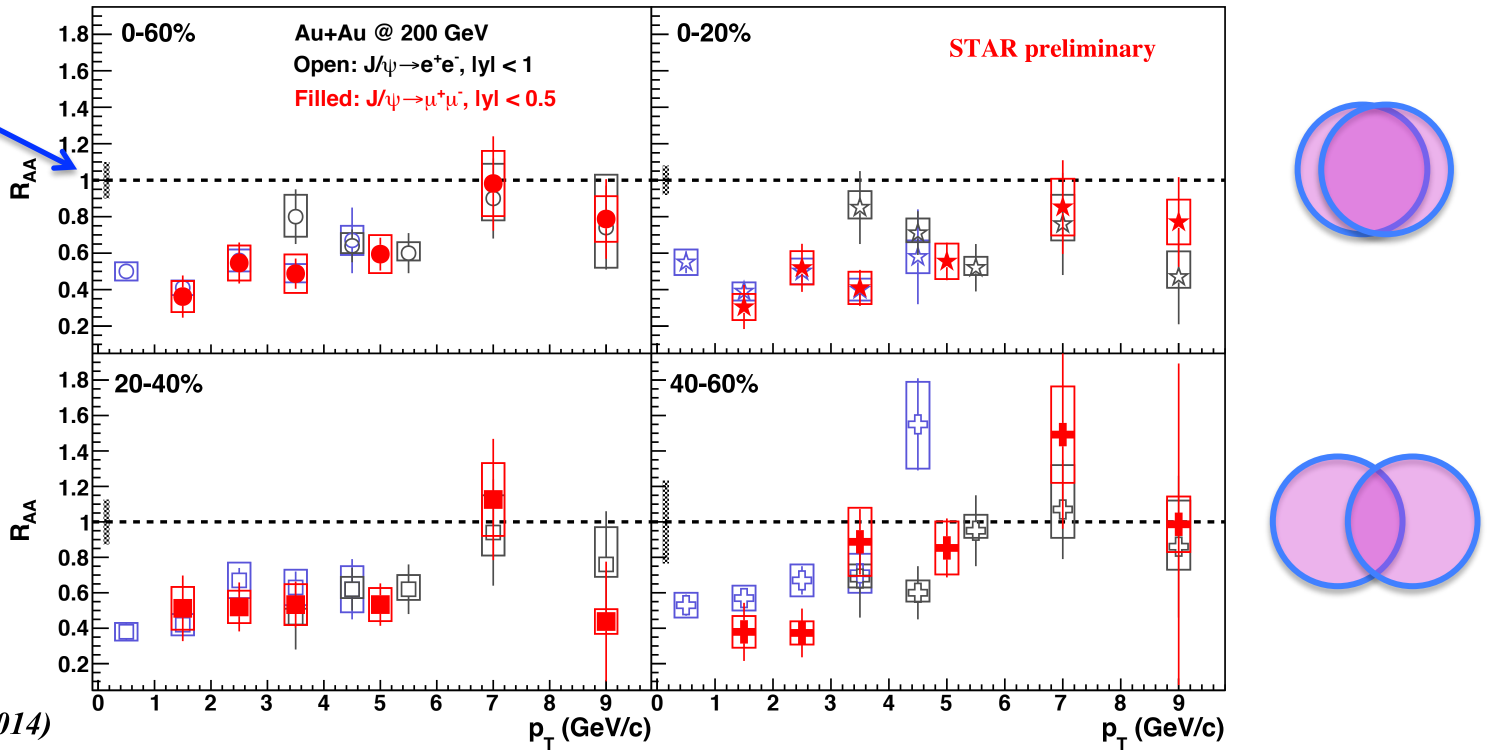


Di-electron:
STAR PLB 722 (2013) 55
STAR PRC 90, 024906 (2014)

- Consistent with the published di-electron results using Run10 data over the entire kinematic range.

J/ψ suppression: $R_{AA} = \frac{\sigma_{inel}}{\langle N_{coll} \rangle} \frac{d^2N_{AA}/dydp_T}{d^2\sigma_{pp}/dydp_T}$

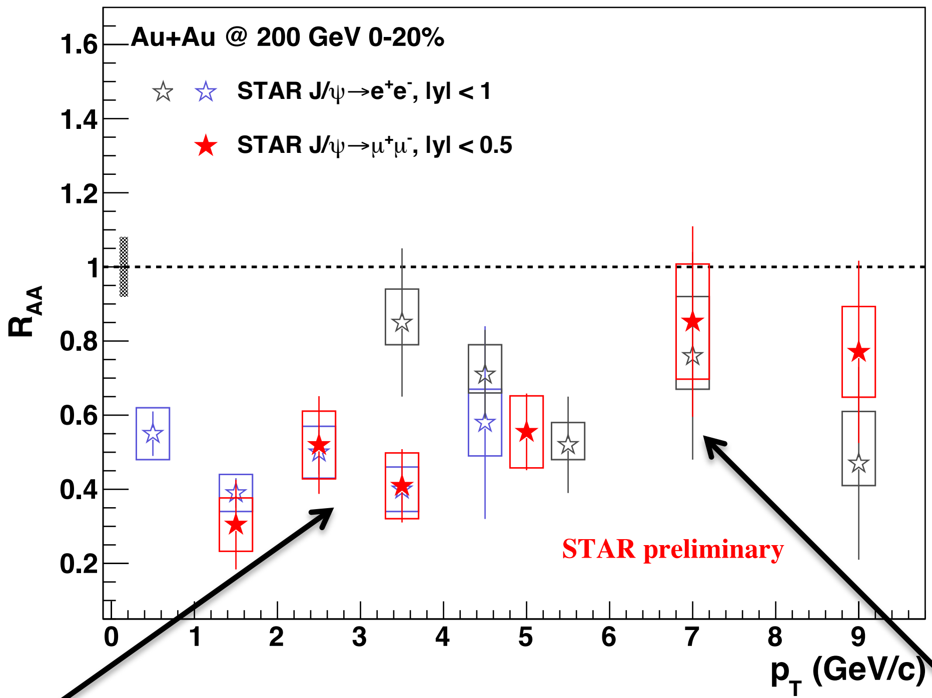
Scale uncertainty for σ_{inel} and N_{coll}



Di-electron:
STAR PLB 722 (2013) 55
STAR PRC 90, 024906 (2014)

- Confirm the rising R_{AA} with p_T seen in the di-electron channel

Closer look at the 0-20% central collisions



Di-electron:
STAR PLB 722 (2013) 55
STAR PRC 90, 024906 (2014)

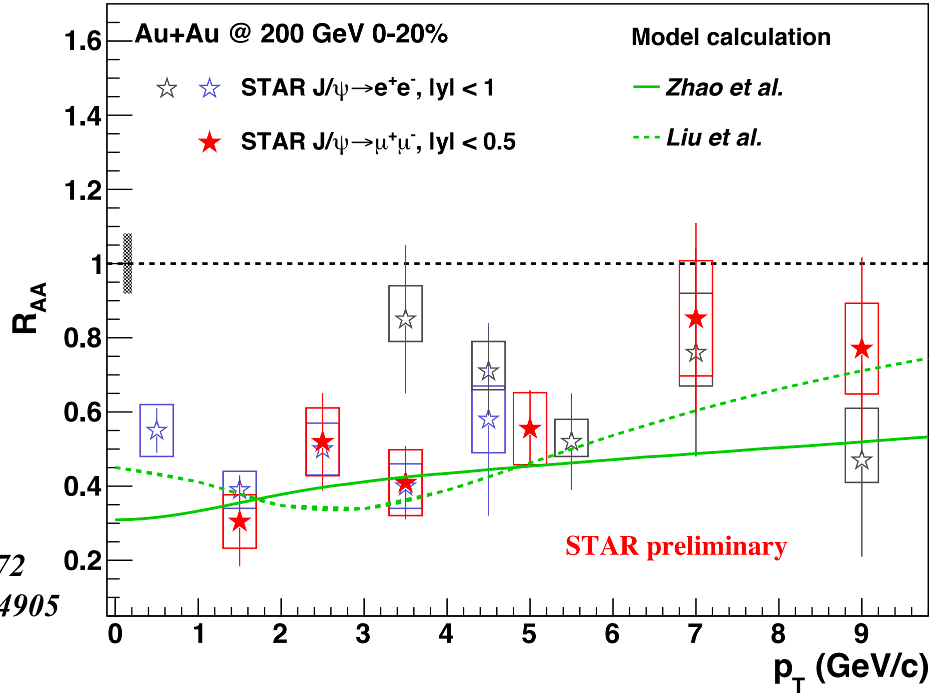
Strong suppression at low p_T

- Dissociation
- Cold nuclear matter effect

Less suppression at high p_T

- Dissociation
- Formation time effect
- Feed-down from B-hadrons

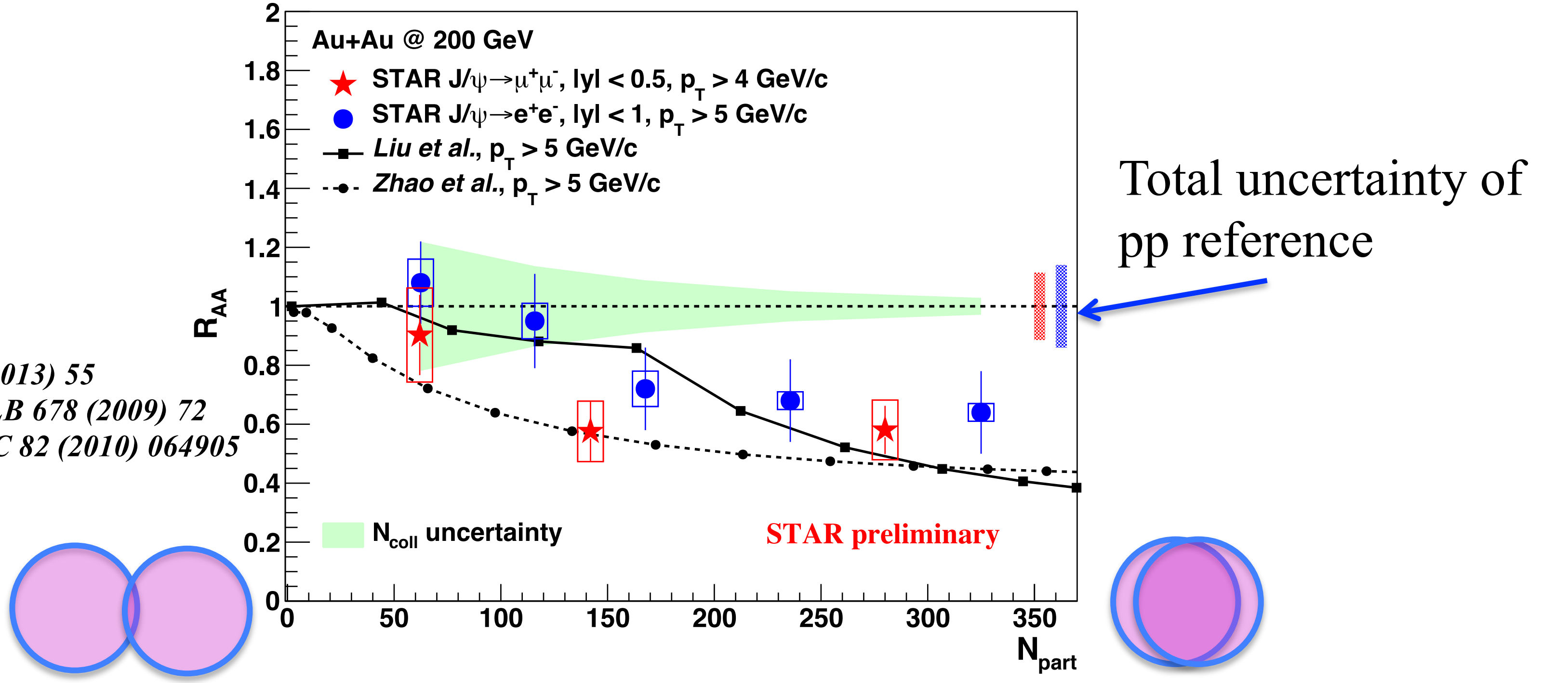
Compare with model calculations



STAR PLB 722 (2013) 55
STAR PRC 90, 024906 (2014)
Y.-p. Liu, et al. PLB 678 (2009) 72
X. Zhao et al. PRC 82 (2010) 064905

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

J/ψ R_{AA} vs N_{part}

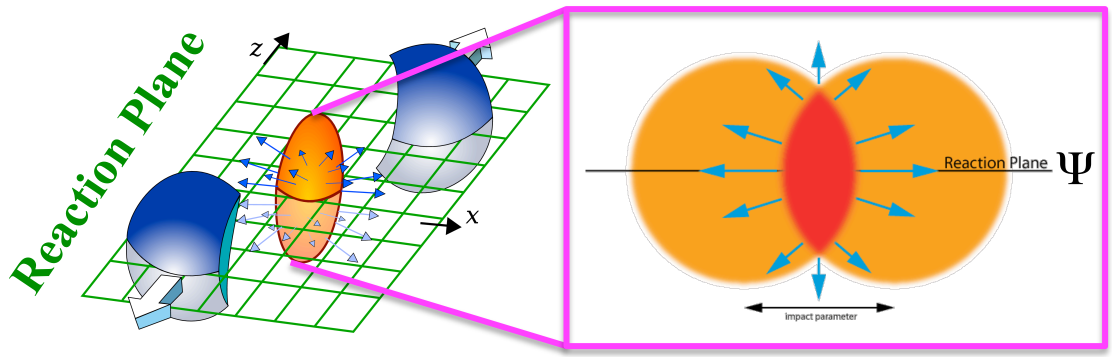


STAR PLB 722 (2013) 55
Y.-p. Liu, et al. PLB 678 (2009) 72
X. Zhao et al. PRC 82 (2010) 064905

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

Collective Flow

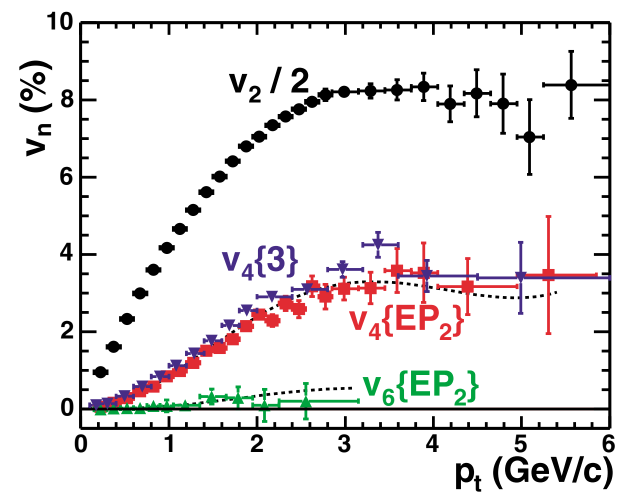
- Anisotropies in momentum space originate from initial-geometry ***via hydrodynamic expansion***



$$\frac{dN}{d\phi} \propto 1 + 2\sum_n v_n \cos\left[n(\phi - \Psi)\right]$$

Voloshin and Zhang, Z.Phys.C70, 665

Charged hadron

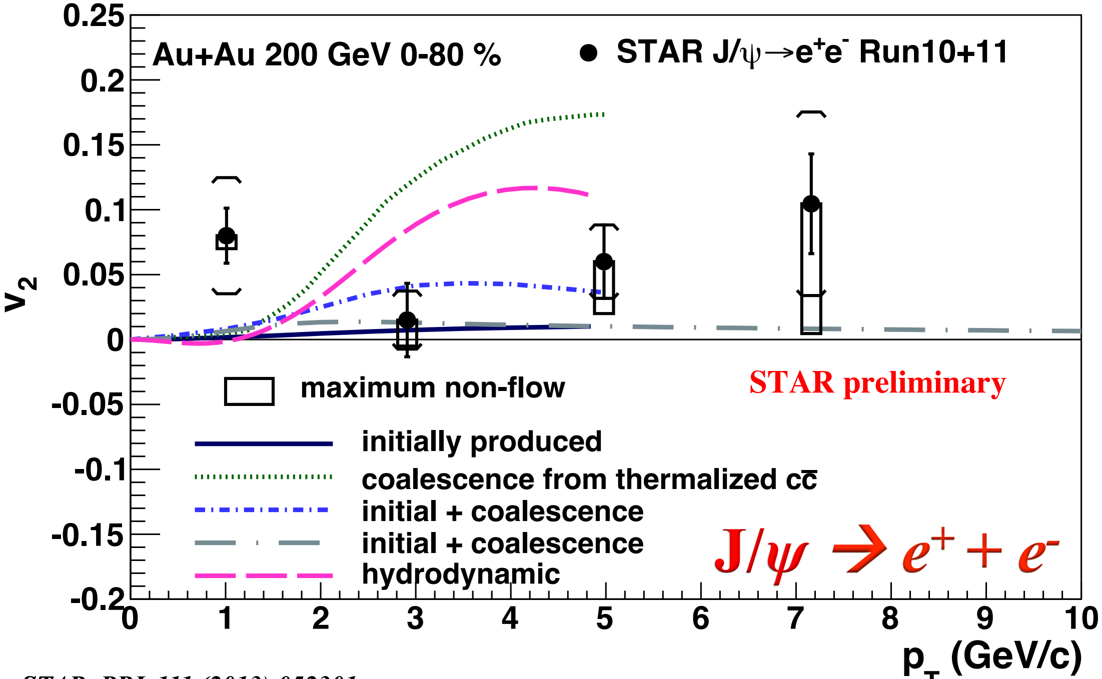


STAR, PRL.92.062301

- Elliptic flow (v_2) :
  - Low p_T : sensitive to medium viscosity
  - High p_T : sensitive to energy loss

Does J/ψ flow?

- Measure elliptic flow v_2
  - Primordial J/ψ : little or zero v_2
  - Regenerated J/ψ : inherit v_2 from the constituent charm quarks

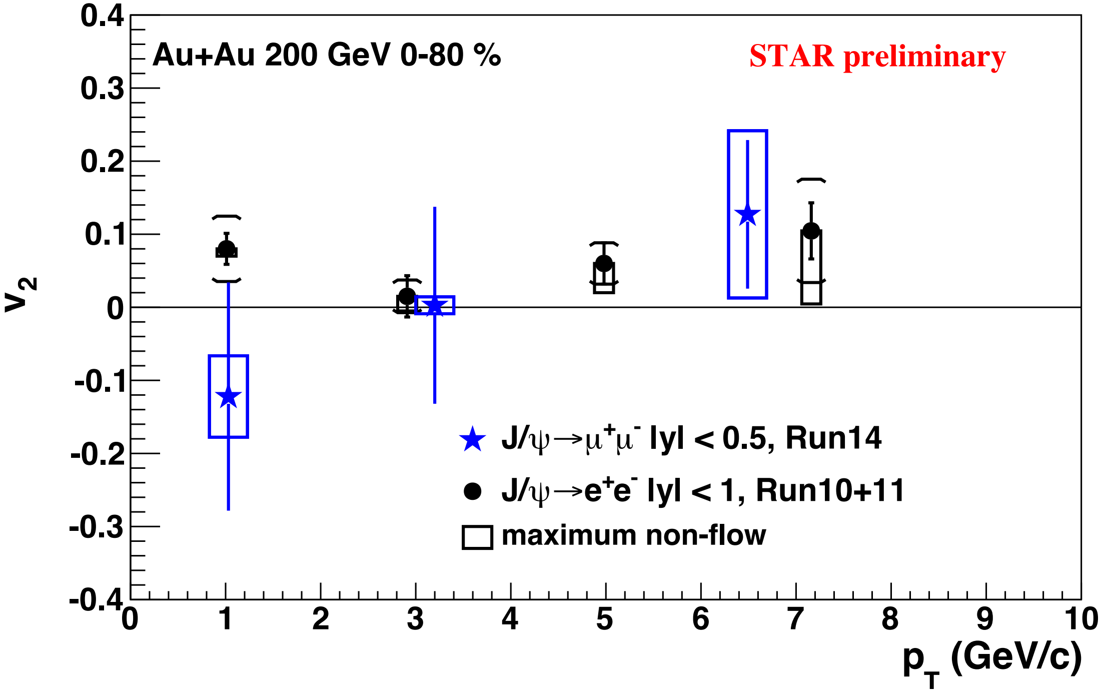


STAR, PRL 111 (2013) 052301
L. Yan, P. Zhuang, and N. Xu, PRL 97 (2006) 232301
V. Greco, C.M. Ko, and R. Rapp, PLB 595 (2004) 202
X. Zhao and R. Rapp, arXiv: 0806.1239
Y. Liu, N. Xu and P. Zhuang, NPA 834 (2010) 317
U.W. Heinz and C. Shen, (private communication)

- For p_T above 2 GeV/c, v_2 is consistent with zero → *contribution of regenerated J/ψ is small*
  - Non-flow effects estimated using J/ψ-h correlation in pp collision can account for possible deviation of v_2 from zero at high p_T

Does J/ψ flow?

- Measure elliptic flow v_2
  - Primordial J/ψ : little or zero v_2
  - Regenerated J/ψ : inherit v_2 from the constituent charm quarks



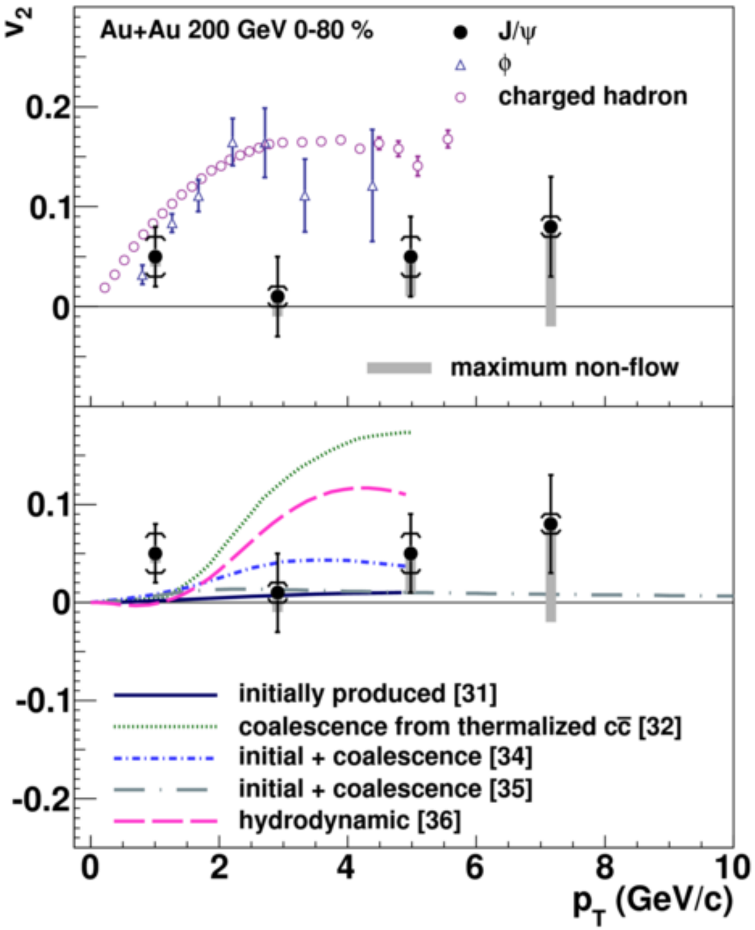
- Consistent results from di-muon channel within large error bars
- 7 times more statistics are yet to come!!

Summary

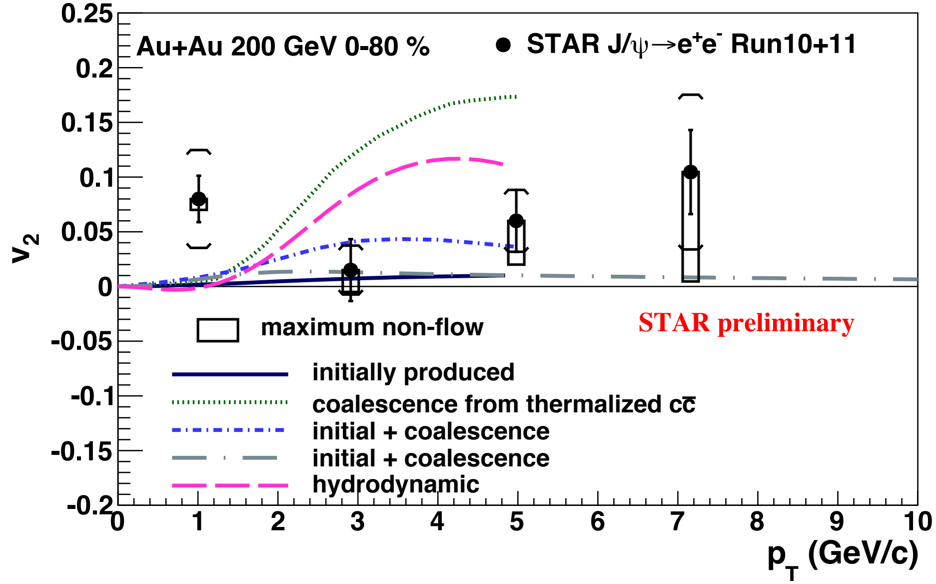
- First J/ψ measurements via di-muon channel at mid-rapidity by the STAR experiment in Au+Au collisions
- Invariant yield of J/ψ is obtained, and R_{AA} rises with p_T
  - Significant suppression in central collisions above 4 GeV/c → dissociation
  - Measure J/ψ in pA (Run15) to quantify CNM, especially at low p_T
- Updated J/ψ v_2 in di-electron channel combining Run10 and Run11 data → favors small contribution from regeneration above 2 GeV/c
  - Results in di-muon channel with 7 times more statistics are yet to come and can shrink uncertainties!!

Backup

Compare J/ψ v_2



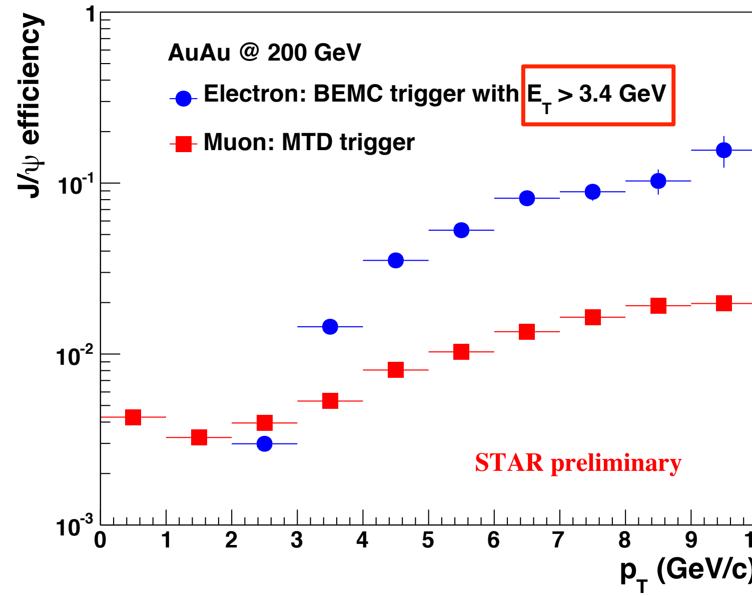
STAR, PRL 111 (2013) 052301



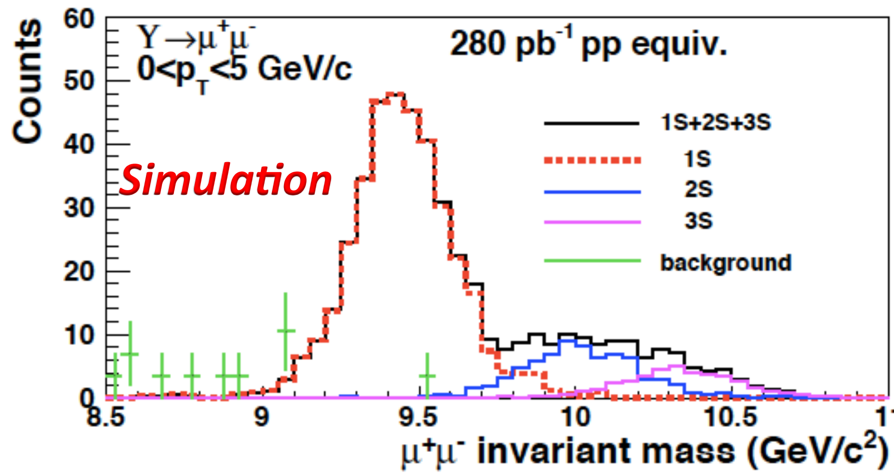
- By combining published results with Run11 analysis, the statistical error bar is reduced by a factor of $\sqrt{2}$.
- Additional systematic uncertainty is assigned due to J/ψ yield extraction.

Muon Telescope Detector (MTD)

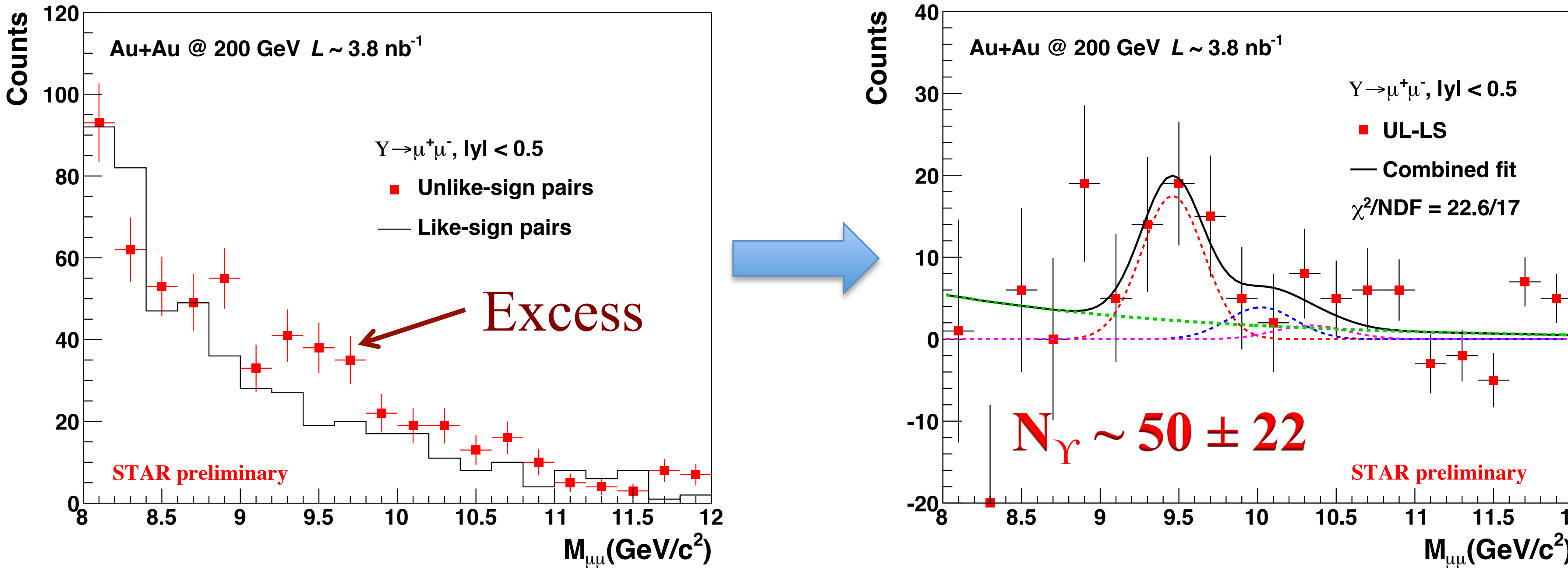
- **Relatively high efficiency for J/ψ at low p_T** → cover wide kinematic range



- **Separate ϒ(2S+3S) from ϒ(1S)**
- **Potential to separate ϒ(2S) and ϒ(3S)** states as muons suffer less from bremsstrahlung



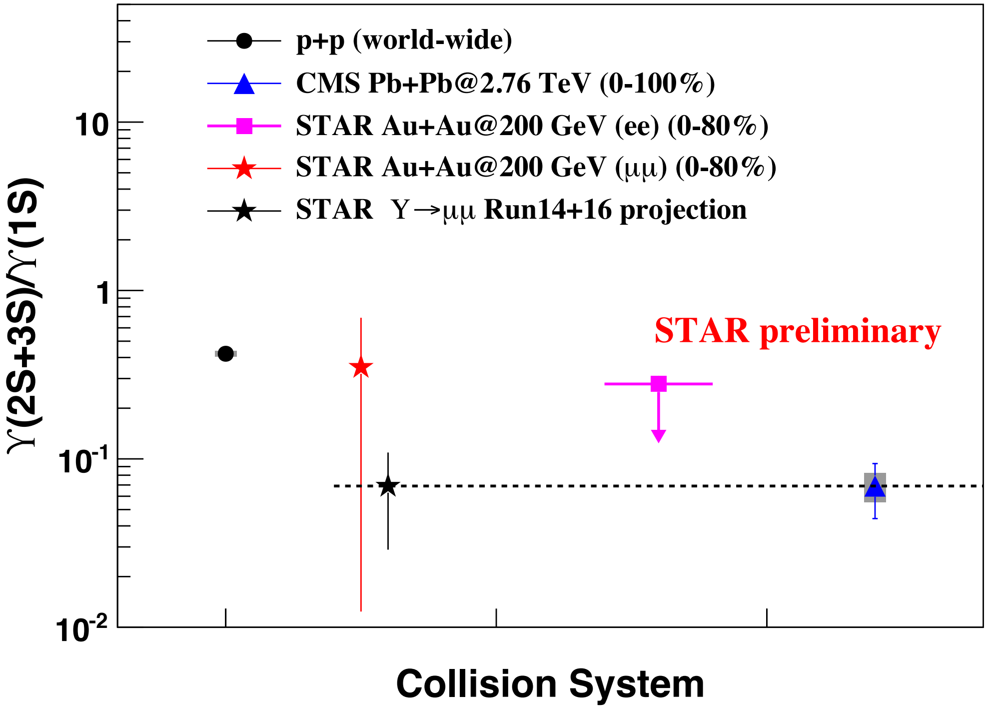
ϒ measurement



- Fit signal distribution after background subtraction:
  - Mean of ϒ is fixed to PDG value, while width is determined from simulation.
  - Ratio of ϒ(2S)/ϒ(3S) is fixed to pp value, and shape of bb and Drell-Yan background is estimated using PYTHIA

Υ(2S+3S)/Υ(1S) ratio

PLB 735 (2014) 127
PRL 1029(2012) 222301



- 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
  - Usage of mix-event can reduce statistical error by √2