J/ψ production in STAR

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/ Lawrence Berkeley National Laboratory

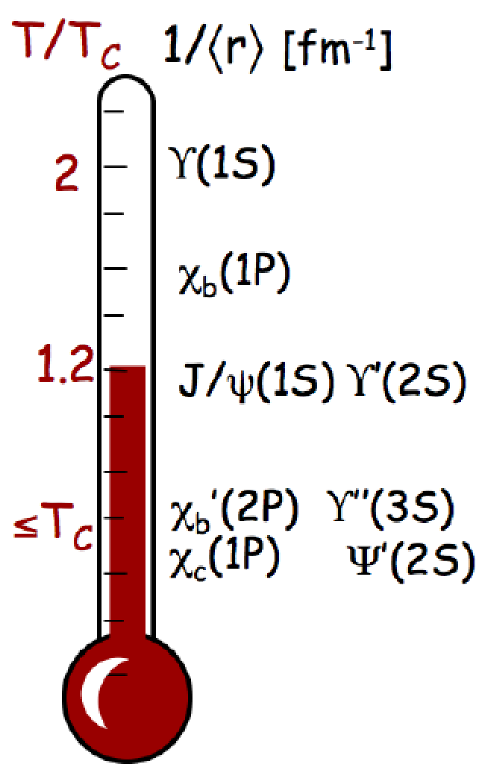
5th International workshop on heavy quark production
in heavy-ion collisions
14-17 November 2012
Utrecht University

Outline

- Motivation
- J/ψ production and polarization in p+p collisions
- J/ψ in d+Au collisions
- J/ψ production and elliptic flow in Au+Au collisions
- Summary

Charmonia at RHIC - Motivation

- ✓ Charmonia suppression in QGP in heavy-ion collisions due to color screening
- ✓ Suppression of different states is determinate by T_C and their binding energy - QGP thermometer

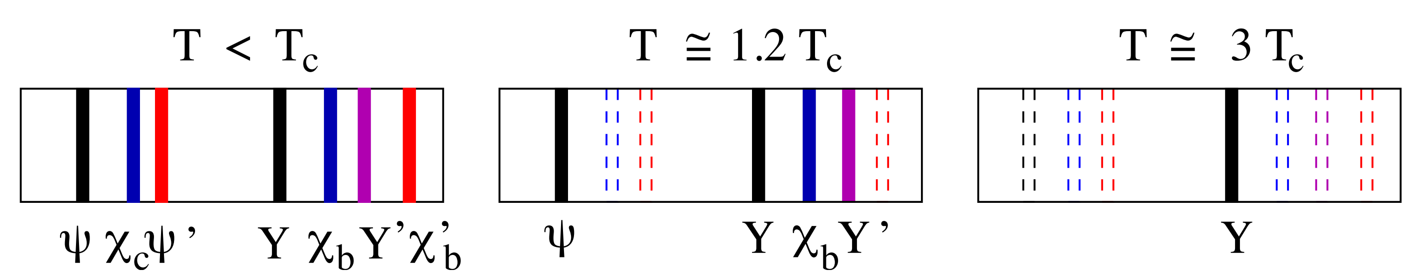


The QGP Thermometer

A .Mocsy, Eur. Phys. J. C61, 705-710 (2009)

Screening radius:

$$r_D(T) \propto 1/T$$



Quarkonia spectral lines as thermometer

H.Satz, Nucl. Phys. A 783, 249 (2007)

Charmonia at RHIC - Motivation (2)

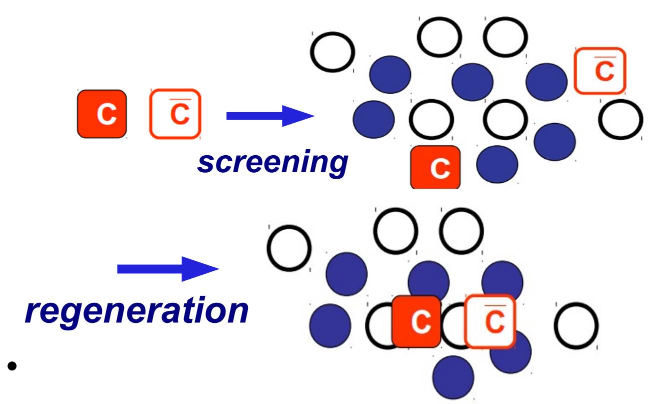
✓ But there are more complications:

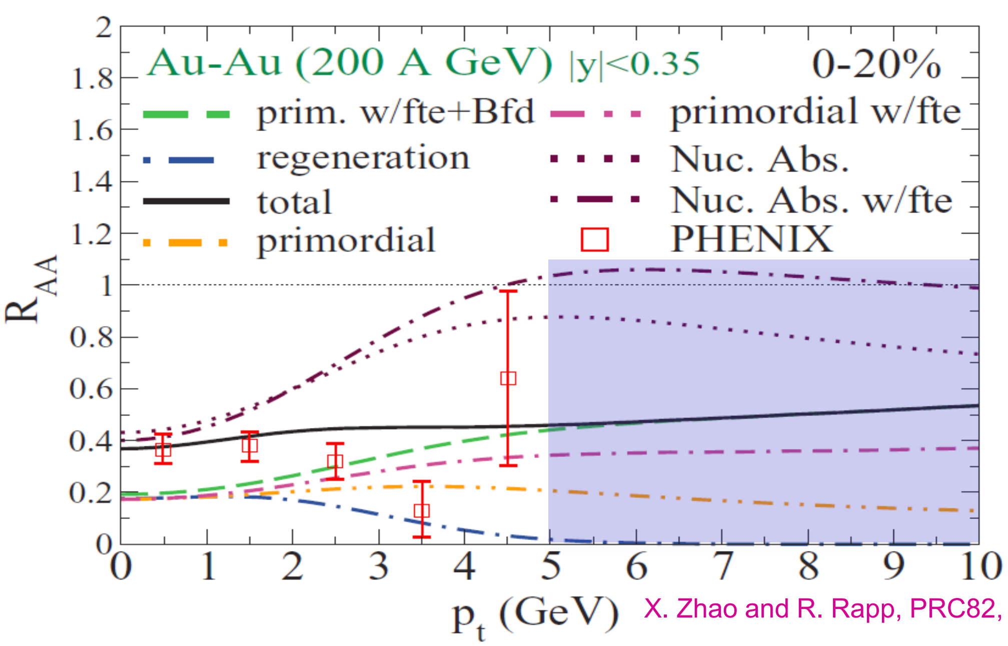
➡ Still unknown production mechanism

➡ Feed-down - direct J/ψ (~60%), ψ' (~10%), χ_C (~30%), B mesons

➡ Cold Nuclear Matter (CNM) effects - nuclear shadowing, Cronin effect, nuclear absorption, ...

➡ Other Hot Nuclear Matter effects - regeneration, ...





X. Zhao and R. Rapp, PRC82, 064905

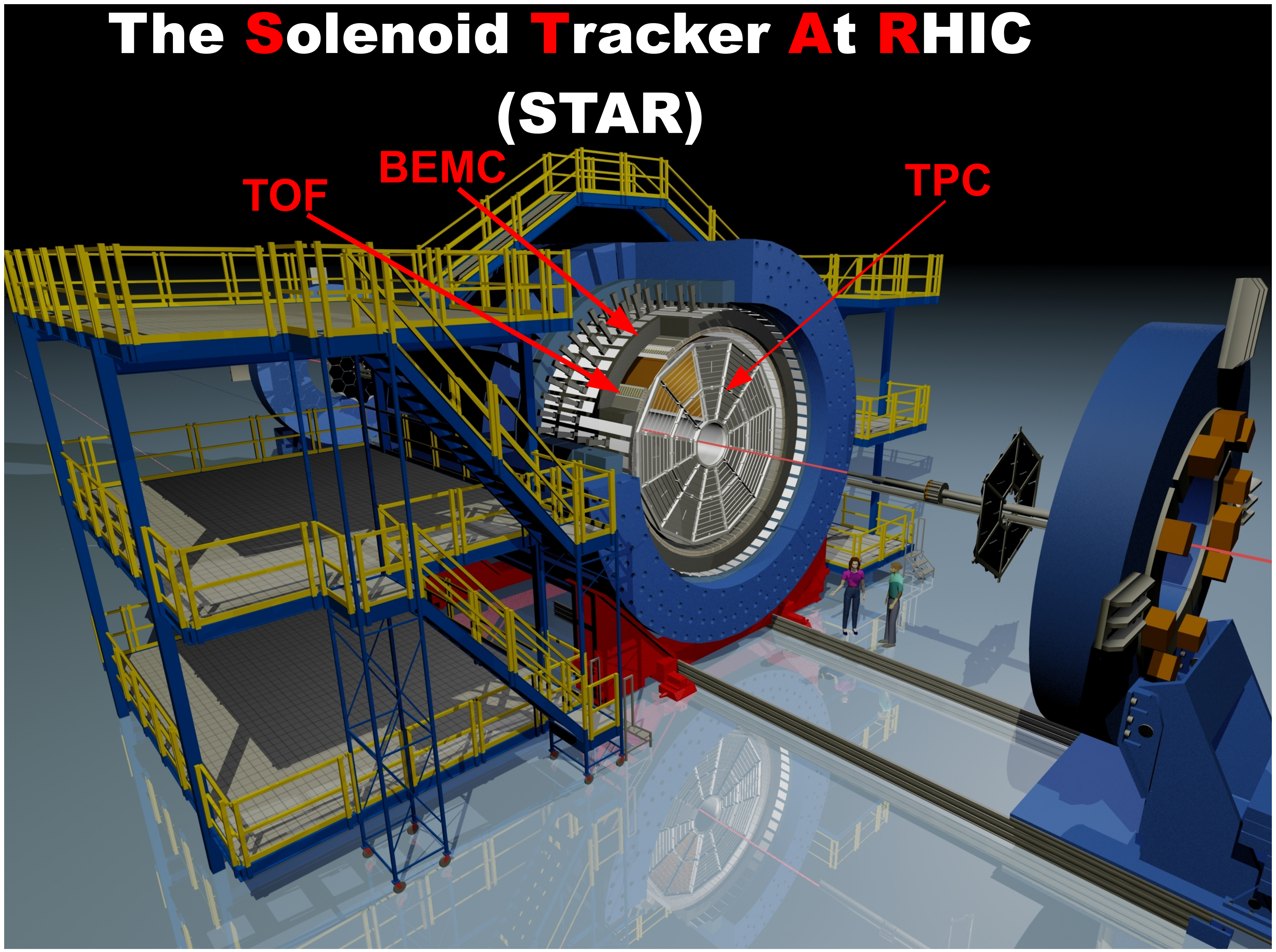
✓ High-p_T J/ψ - almost not affected by Cold Nuclear Matter effects, regeneration, soft processes

$$R_{AA} = \frac{1}{N_{coll}} \frac{dN/dy_{A+A}}{dN/dy_{p+p}}$$

Measure J/ψ p_T spectra, R_{AA}, polarization, elliptic flow ...

STAR EXPERIMENT, PID

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



✓ Large acceptance:

➡ $|\eta| < 1,\ 0 < \phi < 2\pi$

STAR EXPERIMENT, PID

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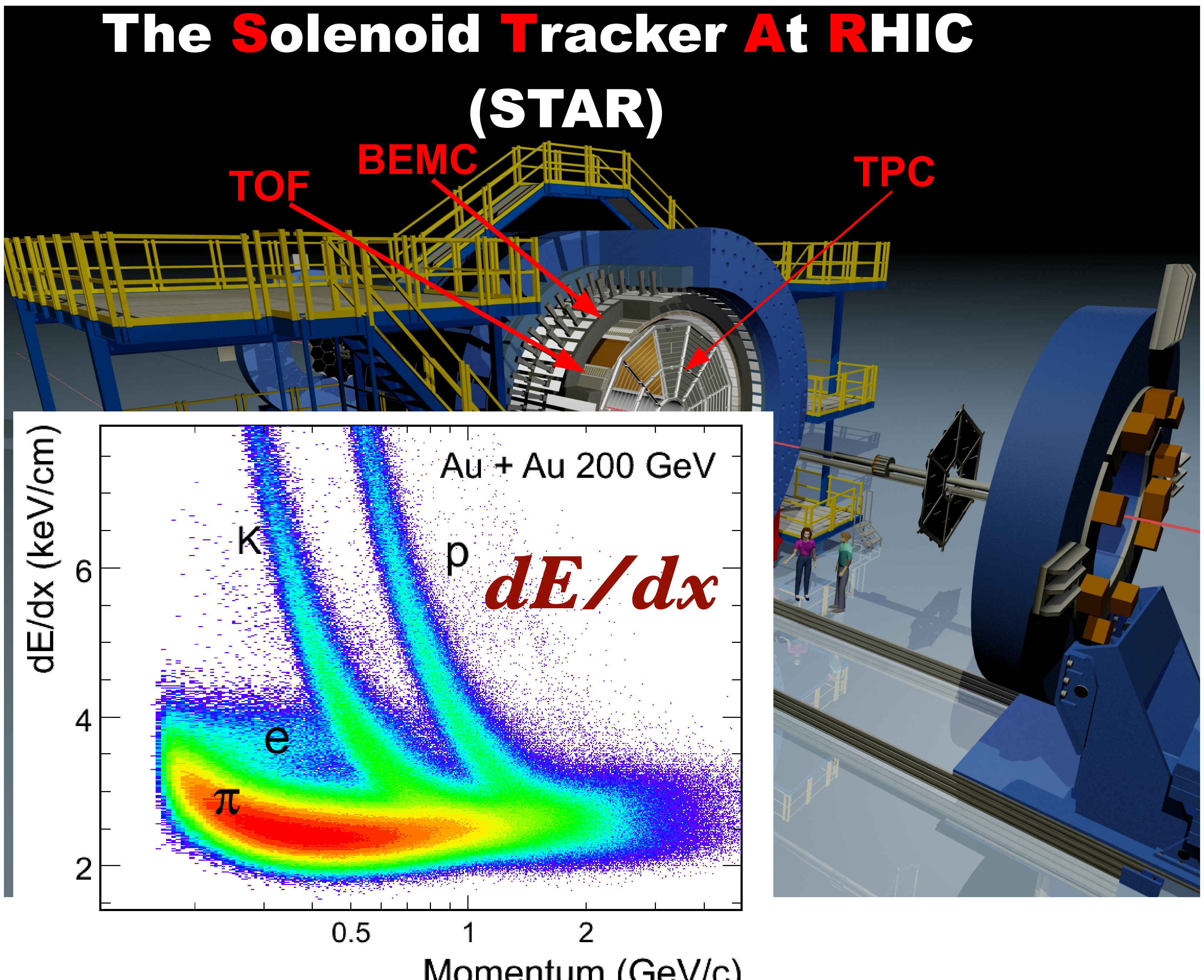

- ✓ Large acceptance:
  - ➡ $|\eta| < 1, 0 < \phi < 2\pi$
- ✓ ***TPC***
  - ➡ Tracking: p_T, η, ϕ
  - ➡ dE/dx: **PID**

STAR EXPERIMENT, PID

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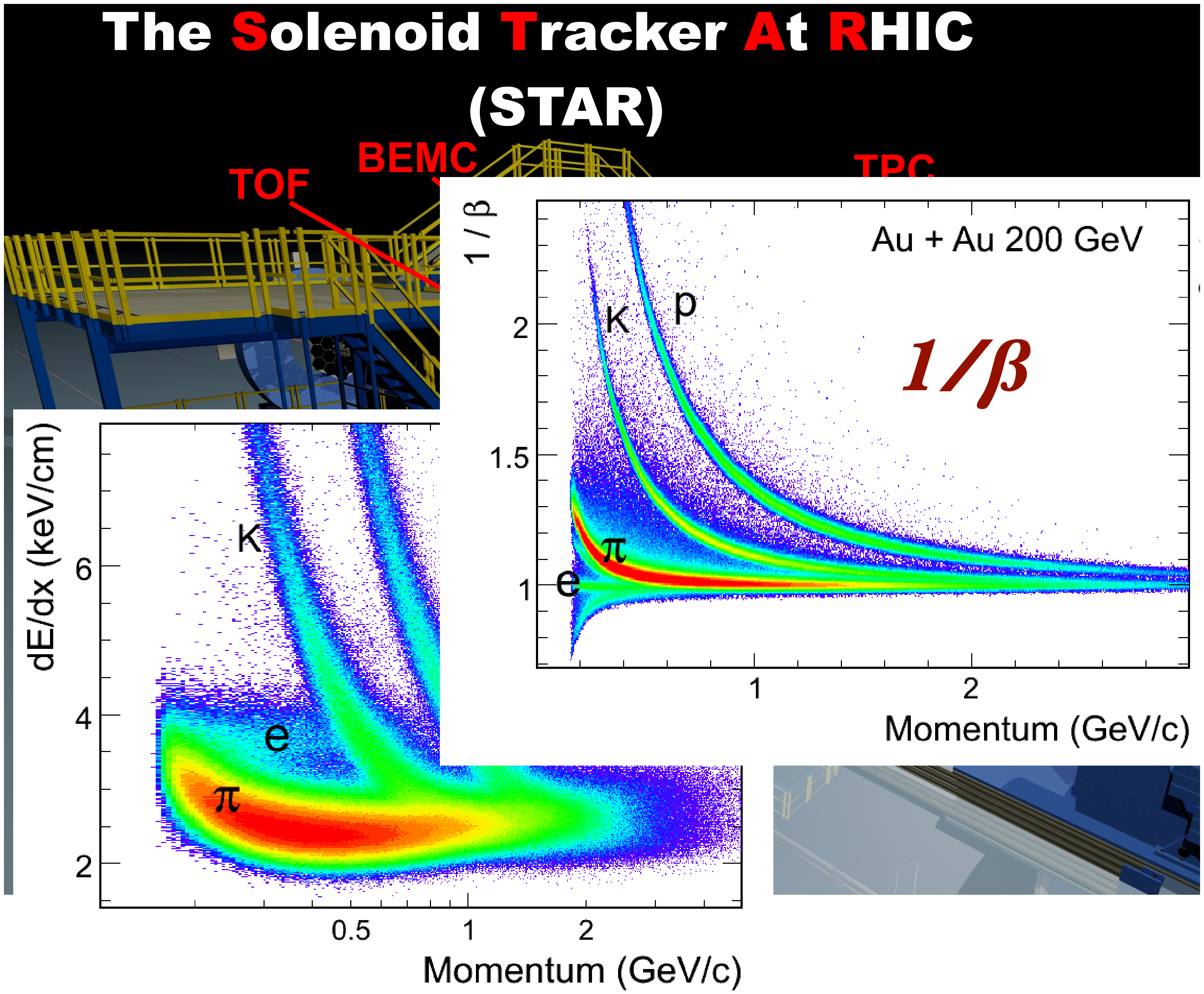
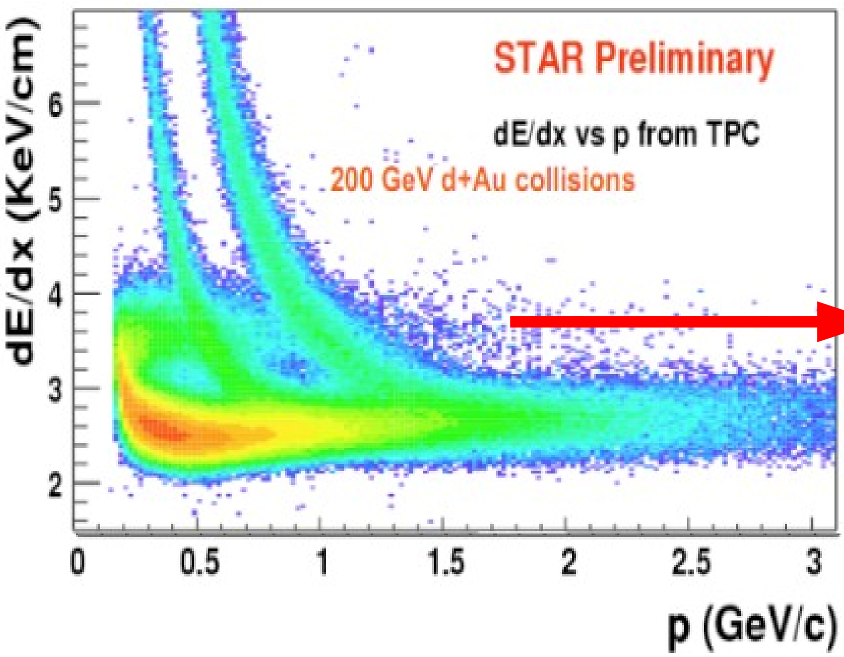
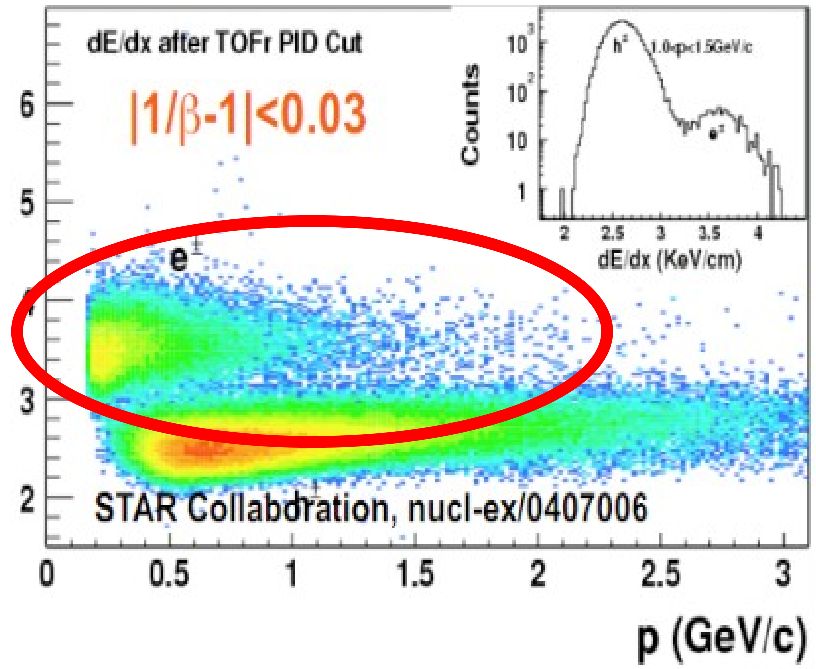


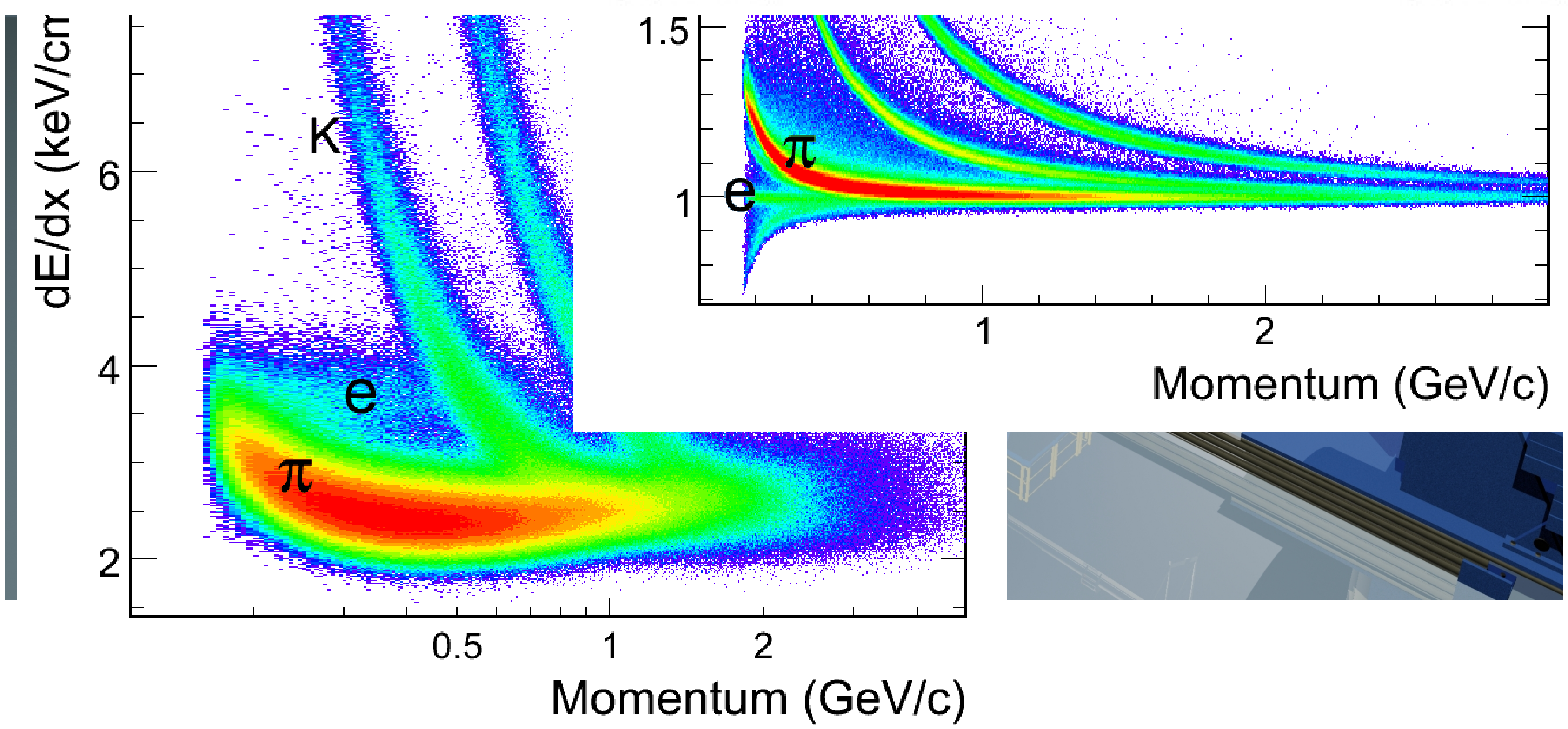
- ✓ Large acceptance:
  - ➡ $|\eta| < 1$, $0 < \phi < 2\pi$
- ✓ ***TPC***
  - ➡ Tracking: p_T, η, ϕ
  - ➡ dE/dx: **PID**
- ✓ ***TOF***
  - ➡ Timing resolution < 100 ps
  - ➡ $1/\beta$: **PID**

STAR EXPERIMENT, PID

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







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STAR EXPERIMENT, PID

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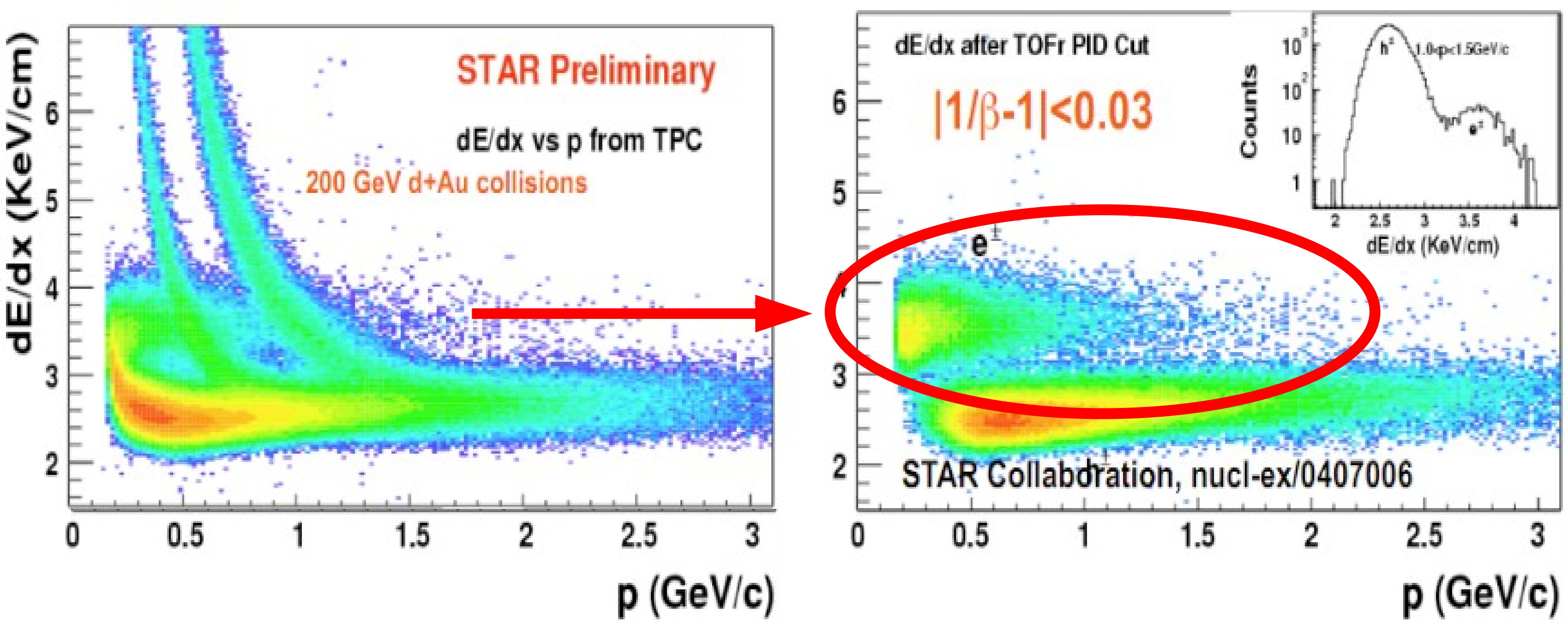
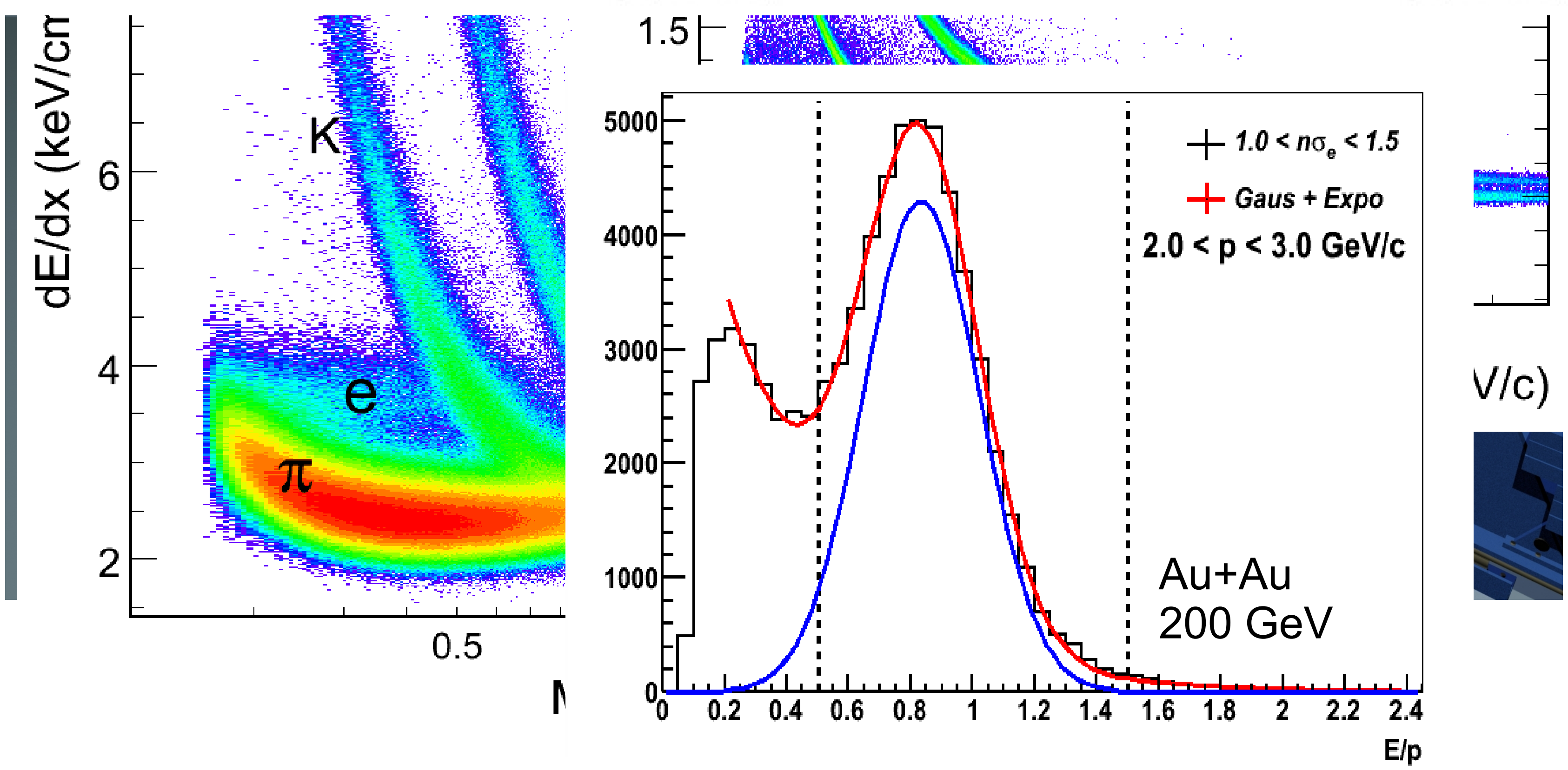
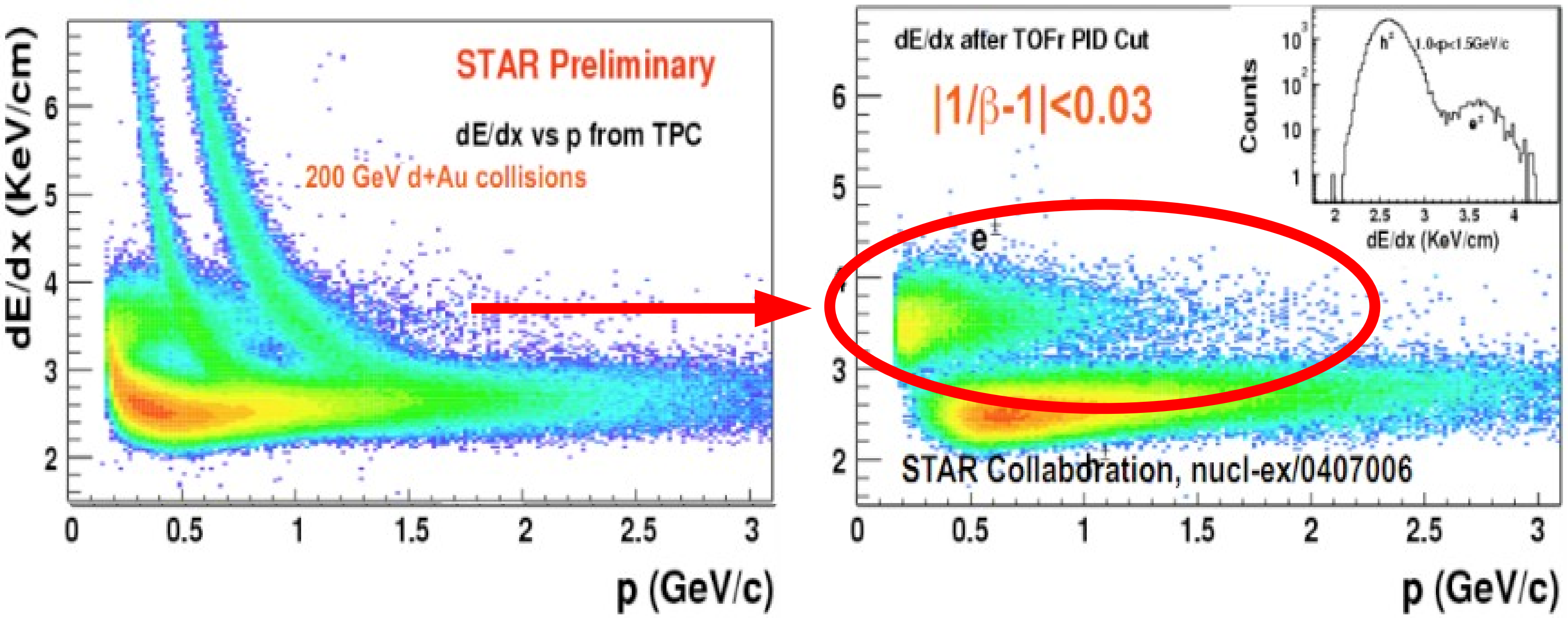


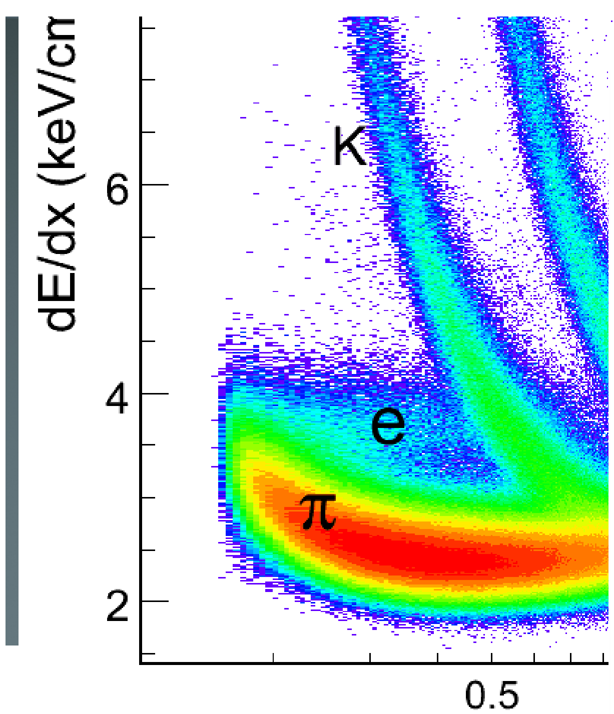


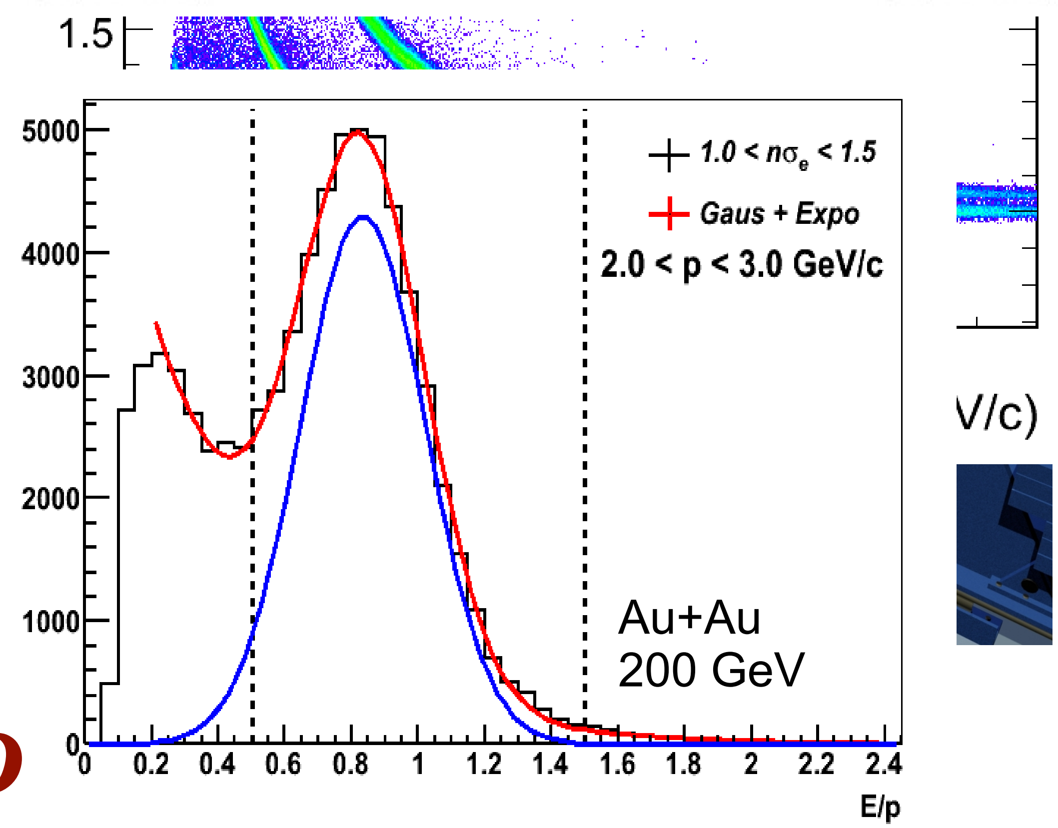
- ✓ Large acceptance:
  - ➡ $|\eta| < 1, 0 < \phi < 2\pi$
- ✓ ***TPC***
  - ➡ Tracking: p_T, η, ϕ
  - ➡ dE/dx: **PID**
- ✓ ***TOF***
  - ➡ Timing resolution < 100 ps
  - ➡ $1/\beta$: **PID**
- ✓ ***BEMC***
  - ➡ Tower $\Delta\eta \times \Delta\phi = 0.05 \times 0.05$
  - ➡ Energy: $E/p \sim 1$ (for electrons) **PID**
  - ➡ **Trigger**

STAR EXPERIMENT, PID

$J/\psi \rightarrow e^{+}e^{-}$ (BR 5.9%)



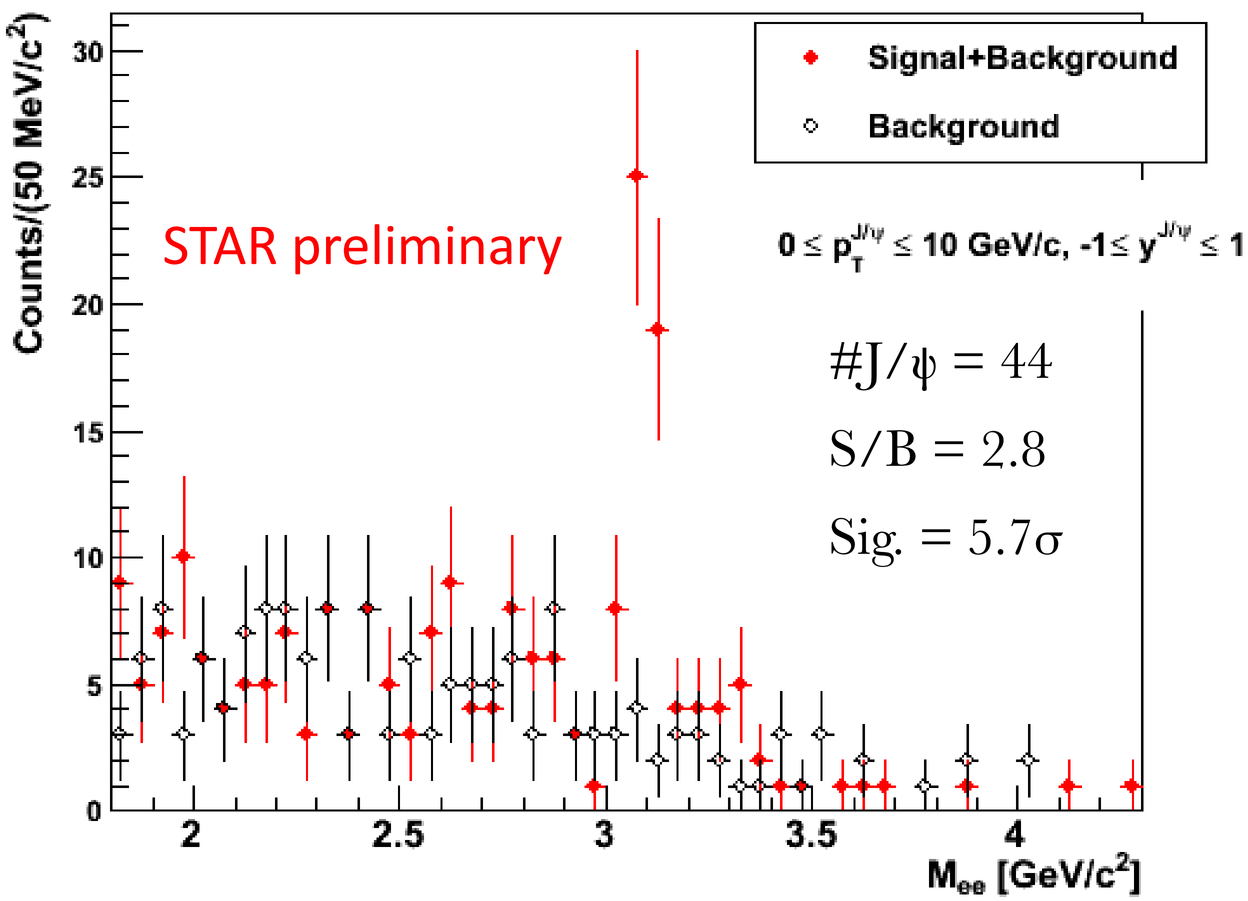




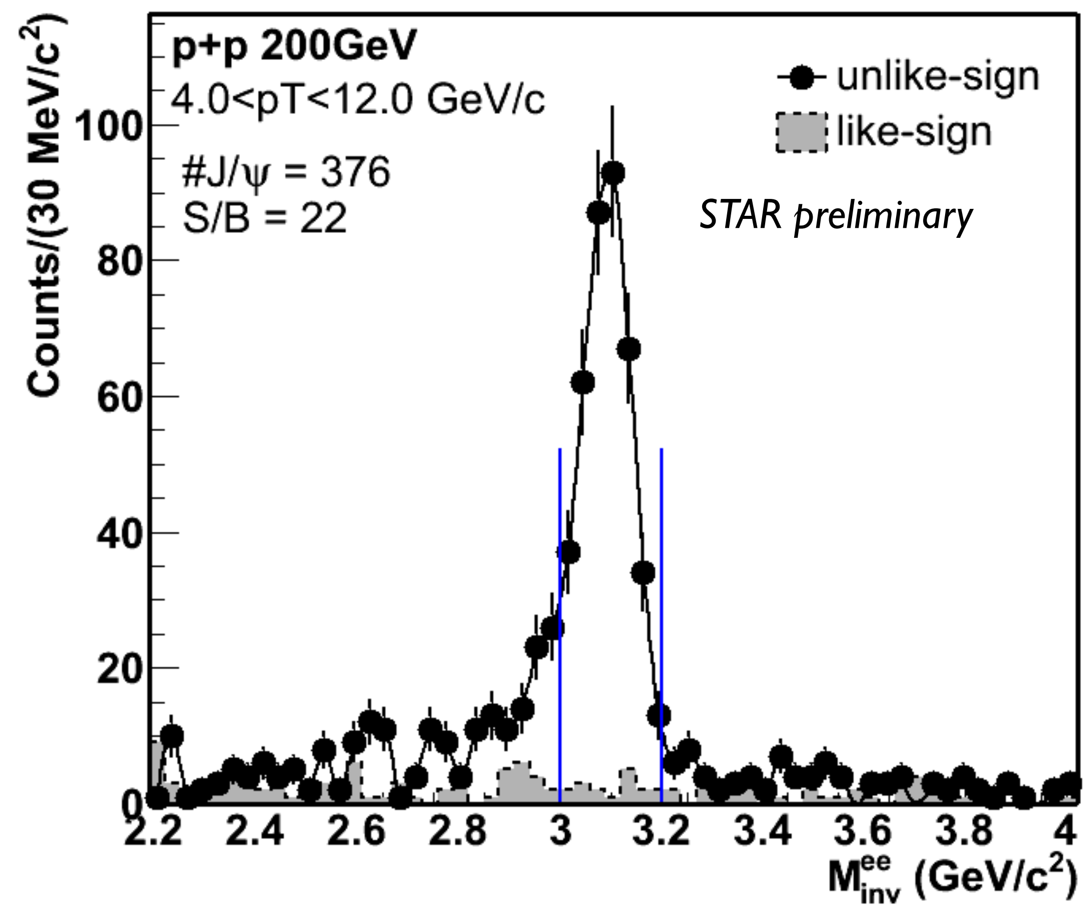
Excellent eID

- ✓ Large acceptance:
  - ➡ $|\eta| < 1$, $0 < \phi < 2\pi$
- ✓ ***TPC***
  - ➡ Tracking: p_T, η, ϕ
  - ➡ dE/dx: **PID**
- ✓ ***TOF***
  - ➡ Timing resolution < 100 ps
  - ➡ $1/\beta$: **PID**
- ✓ ***BEMC***
  - ➡ Tower $\Delta\eta$ x $\Delta\phi$ = 0.05 x 0.05
  - ➡ Energy: E/p ~ 1 (for electrons) **PID**
  - ➡ **Trigger**

J/ψ in p+p collisions at 200 GeV



minimum-bias data

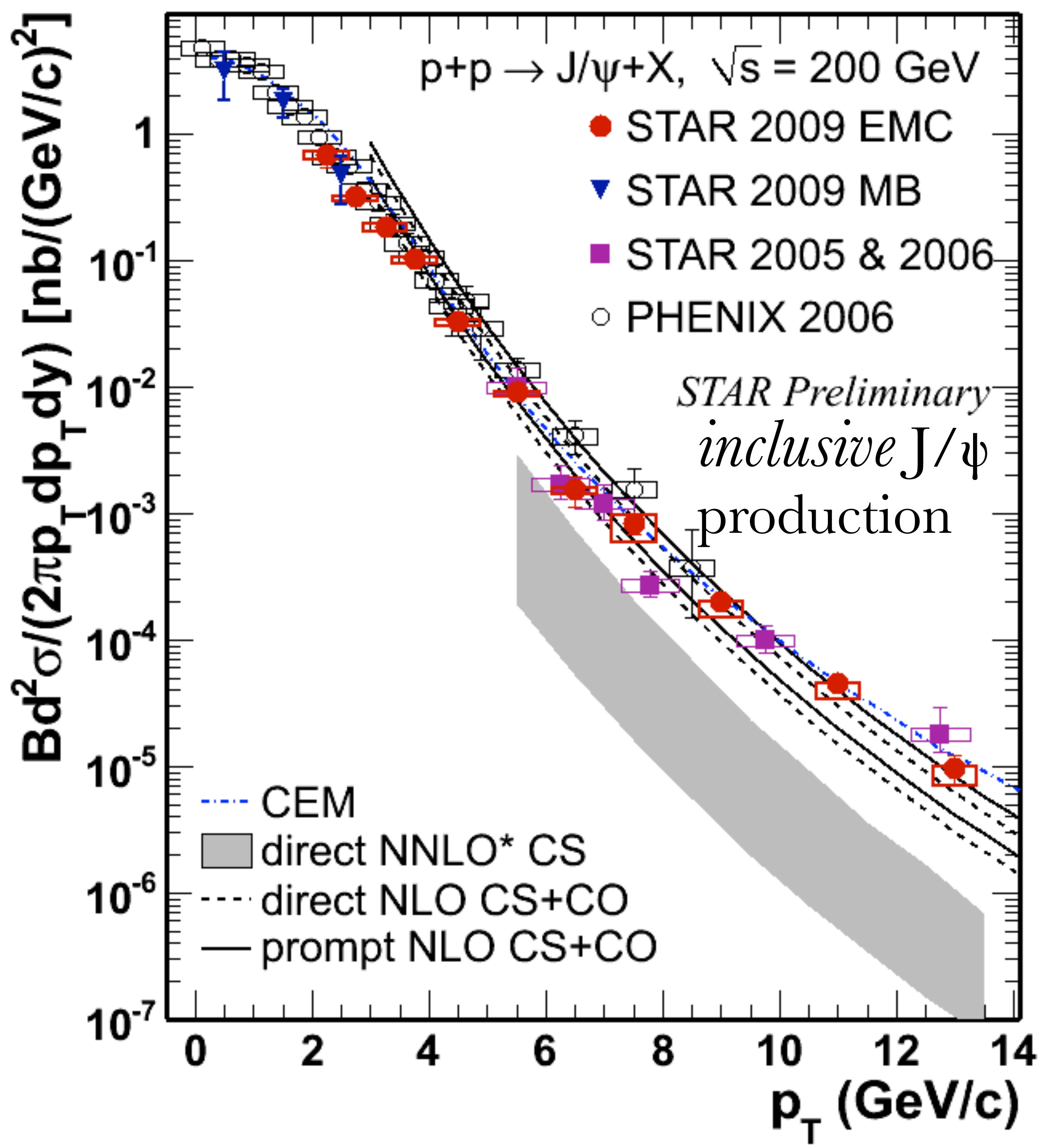


high-tower trigger data

- ✓ New low-p_T p+p baseline from 2009 year with a good significance
- ✓ Used in new R_{AA} measurements for d+Au and low-p_T Au+Au
- ✓ Strong high-p_T signal with high S/B

J/ψ spectra in p+p collisions at 200 GeV

STAR results consistent with PHENIX results
J/ψ p_T range extended to 0-14 GeV/c



PHENIX: *Phys. Rev. D 82, 012001 (2010)*
STAR: *Phys. Rev. C80, 041902(R) (2009)*
STAR high-p_T *: arxiv:1208.2736*
direct NNLO: P.Artoisenet et al., Phys. Rev. Lett. 101, 152001 (2008) and J.P.Lansberg private communication
NLO CS+CO: Y.-Q.Ma, K.Wang, and K.T.Chao, Phys. Rev. D84, 51 114001 (2011)
CEM: M. Bedjidian et al., hep-ph/0311048, and R.Vogt private communication

- ✓ *prompt* NLO CS+CO model describes the data
- ✓ *prompt* CEM model can reasonably well describe the p_T spectra
- ✓ *direct* NNLO* CS model misses high-p_T part

J/ψ polarization

Discrimination power between different J/ψ production models at high-p_T

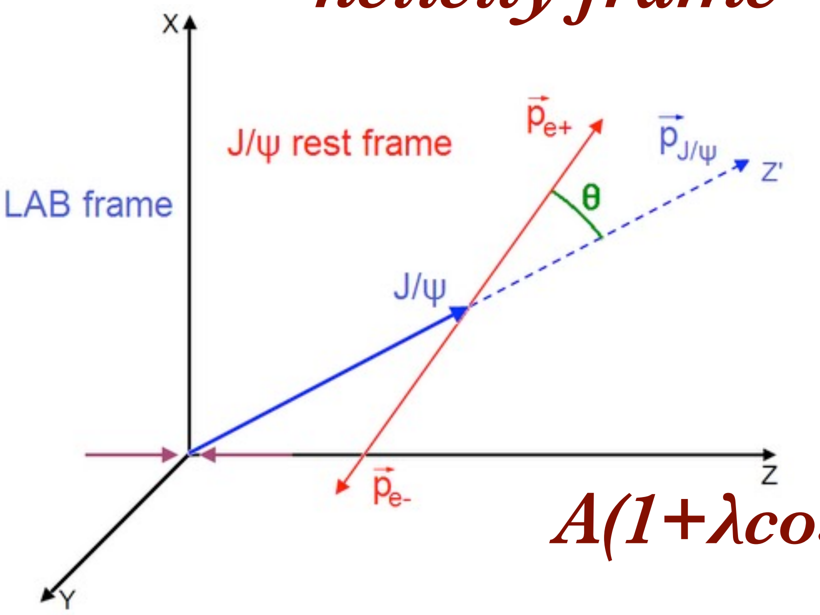
✓ J/ψ polarization is analyzed via the angular distribution of the decay electron pair and is measured in the **helicity frame**

✓ the angular distribution, integrated over the azimuthal angle, can be parametrized:

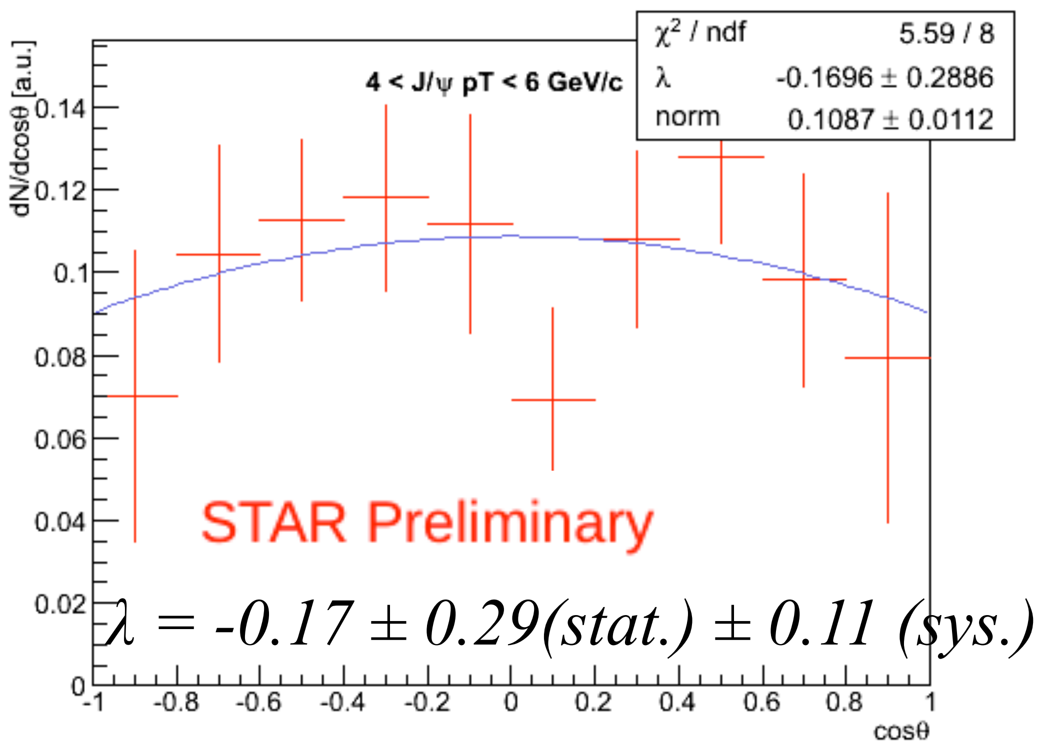
$$\frac{dN}{d\cos\theta} \propto 1 + \lambda \cos^2\theta$$

✓ J/ψ polarization parameter $\boldsymbol{\lambda}$ is obtained by fitting $\boldsymbol{A(1+\lambda\cos^2\theta)}$ function to corrected cosθ distributions without constraints, in 3 J/ψ p_T bins

helicity frame



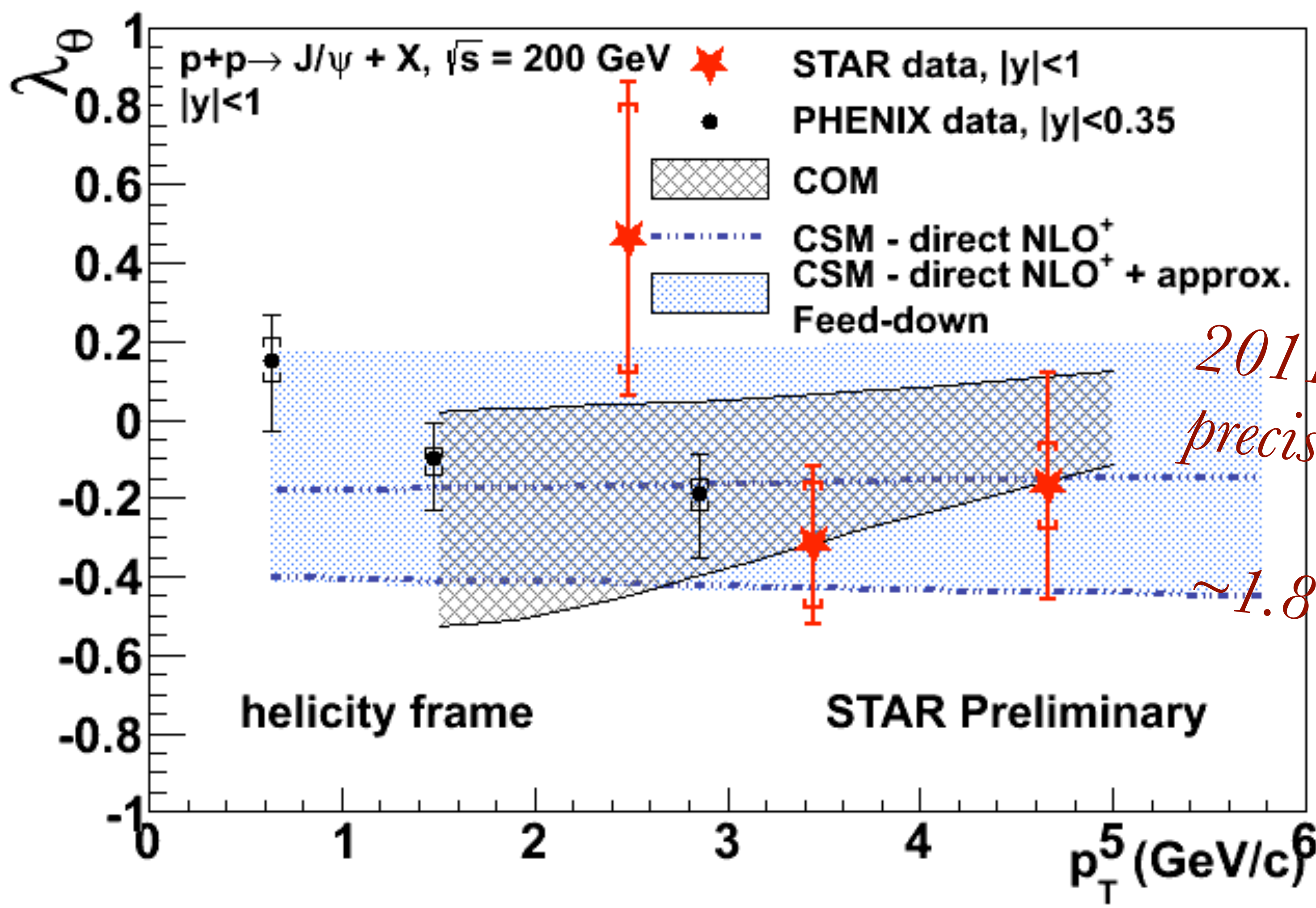
$A(1+\lambda\cos^2\theta)$



$\lambda = -0.17 \pm 0.29(stat.) \pm 0.11\ (sys.)$

corrected cosθ distribution

J/ψ polarization in p+p collisions at 200 GeV



PHENIX: Phys. Rev. D 82, 012001 (2010)
COM: Phys. Rev. D 81, 014020 (2010)
CSM NLO$^+$: Phys. Lett. B, 695, 149 (2011)

2011 500 GeV data can help improve precision of polarization measurement

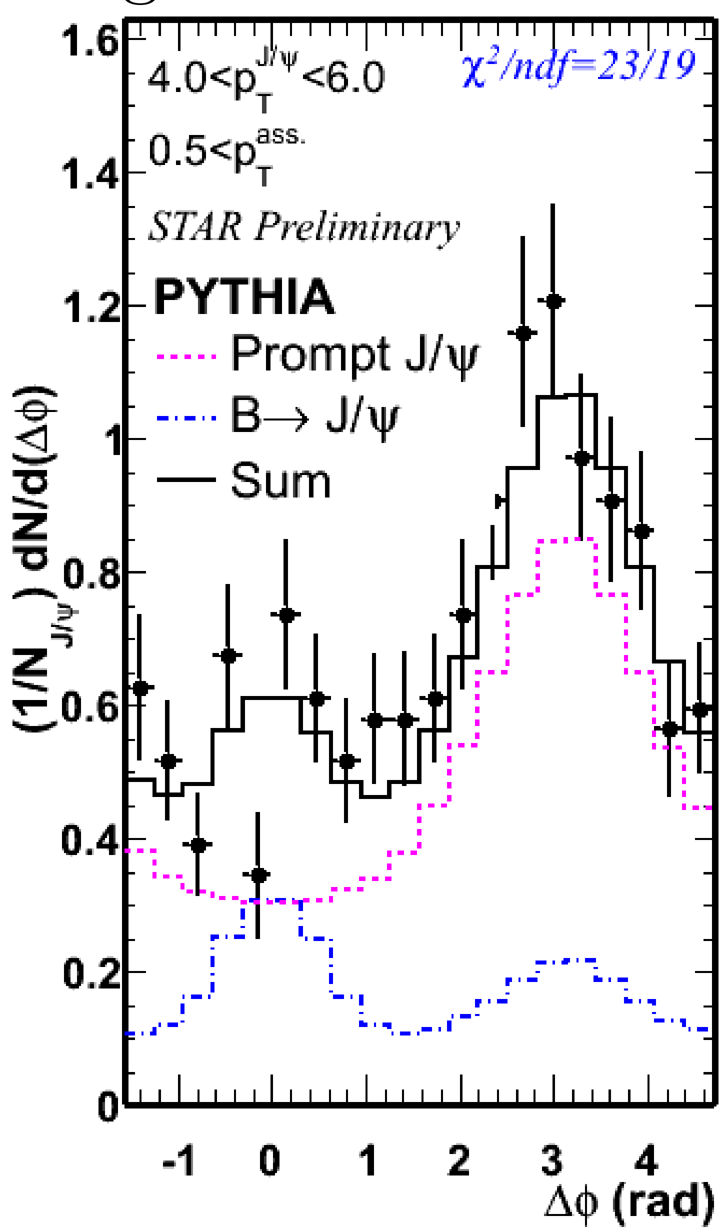
~1.8 pb^{-1} vs ~22 pb^{-1} (triggered events)

- ✓ Polarization parameter λ_θ is measured in helicity frame at $|y| < 1$ and $2 < p_T <$ ~5 GeV/c
- ✓ λ_θ is consistent with NLO$^+$ CSM and COM models predictions, and with no polarization within current experimental and theoretical uncertainties

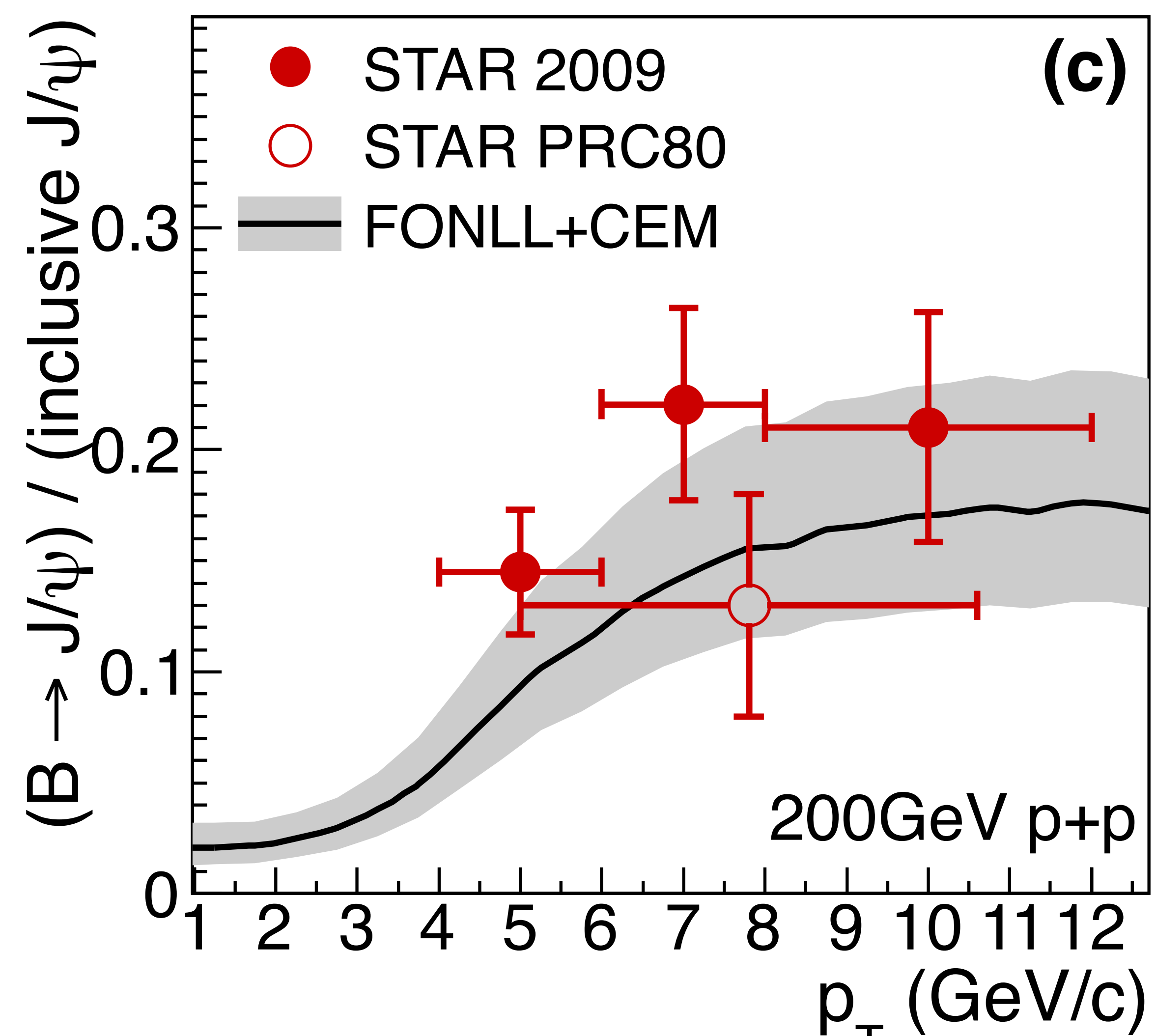
J/ψ-hadron correlations in p+p collisions at 200 GeV

B → J/ψ feed-down

Model based extraction using PYTHIA

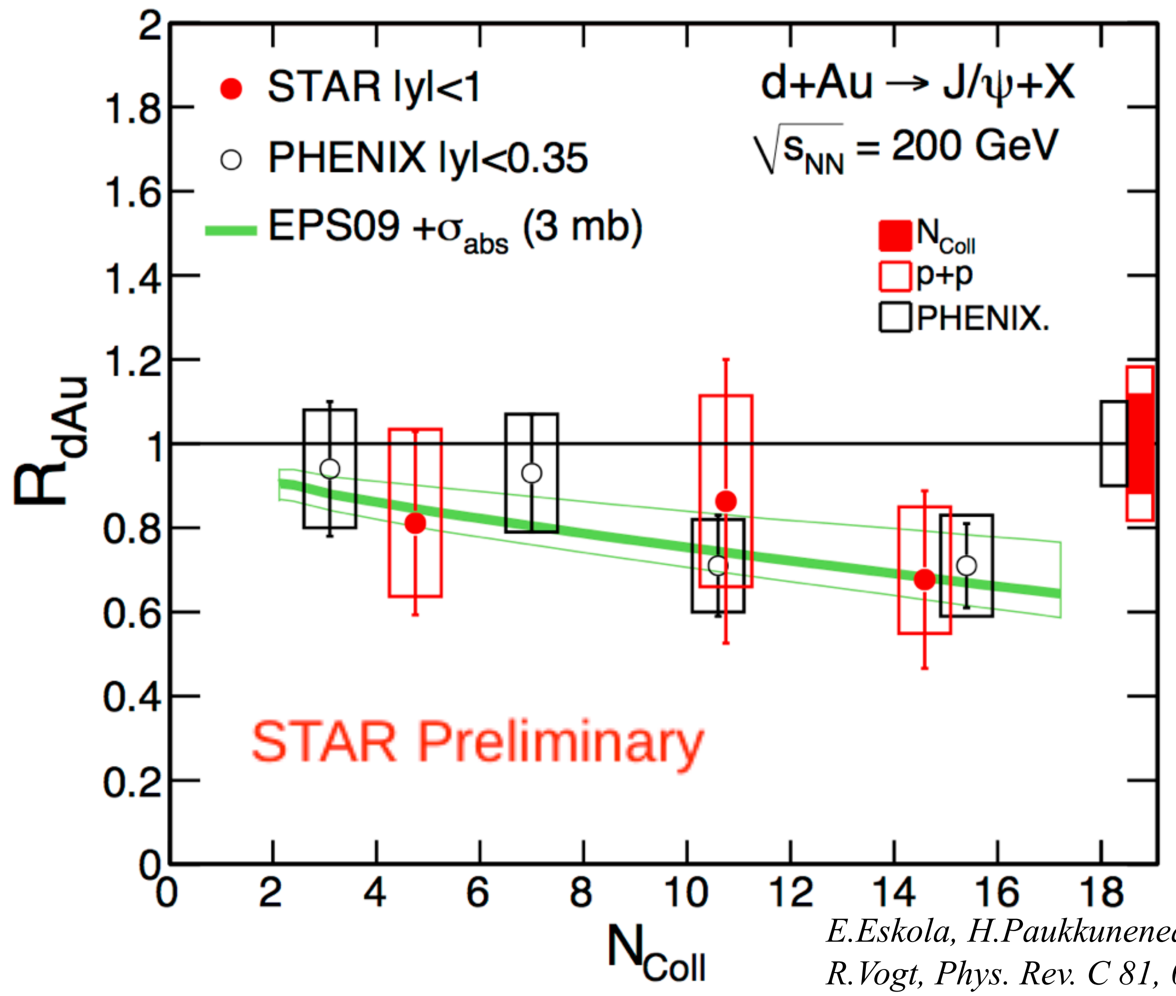


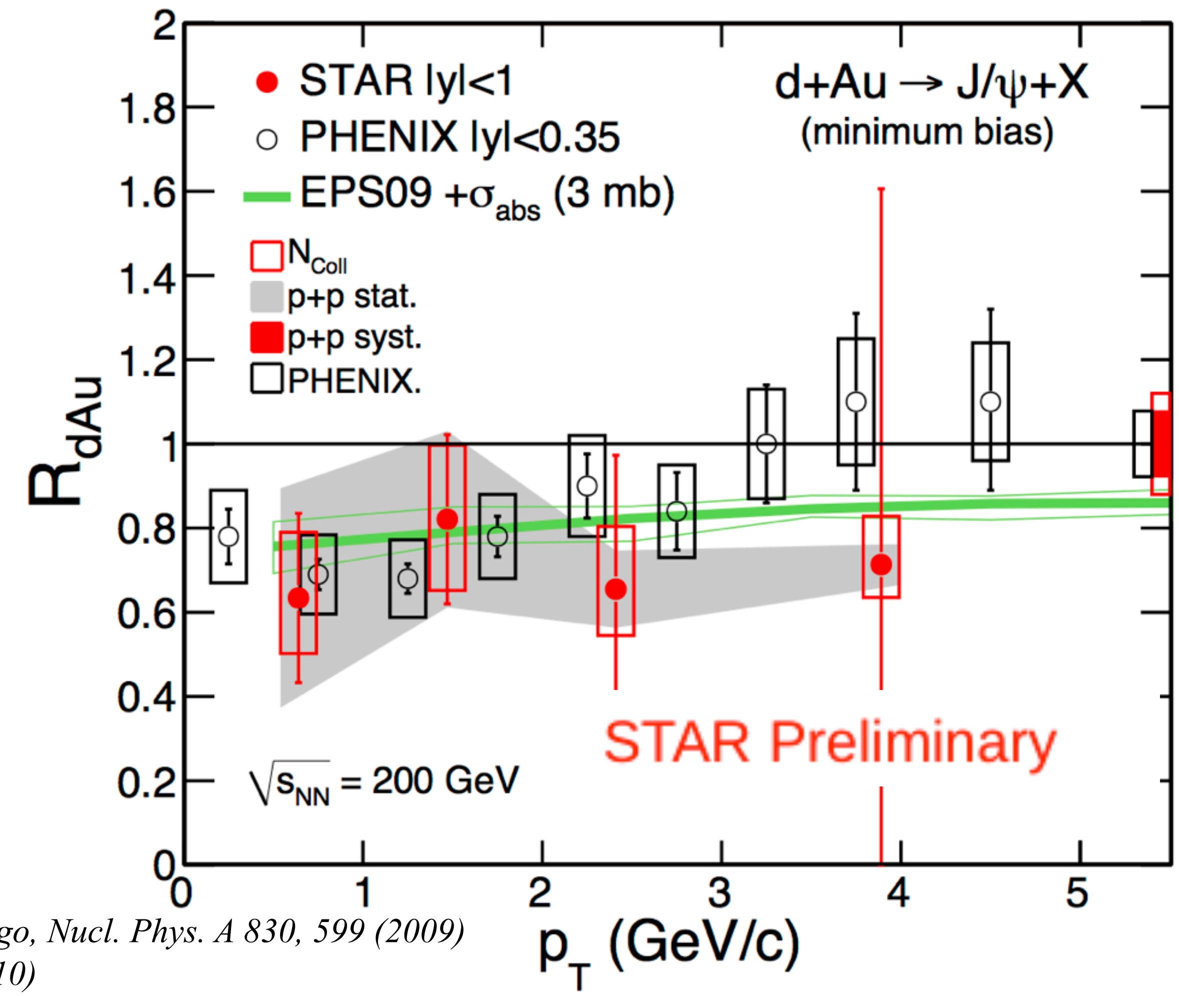
arxiv:1208.2736



- ✓ Extracted from near side J/ψ-h correlation
- ✓ B-hadron feed-down contribution of 10-25% at 4-12 GeV/c
- ✓ Result consistent with FONLL+CEM calculation

J/ψ R_{AA} in d+Au collisions at 200 GeV

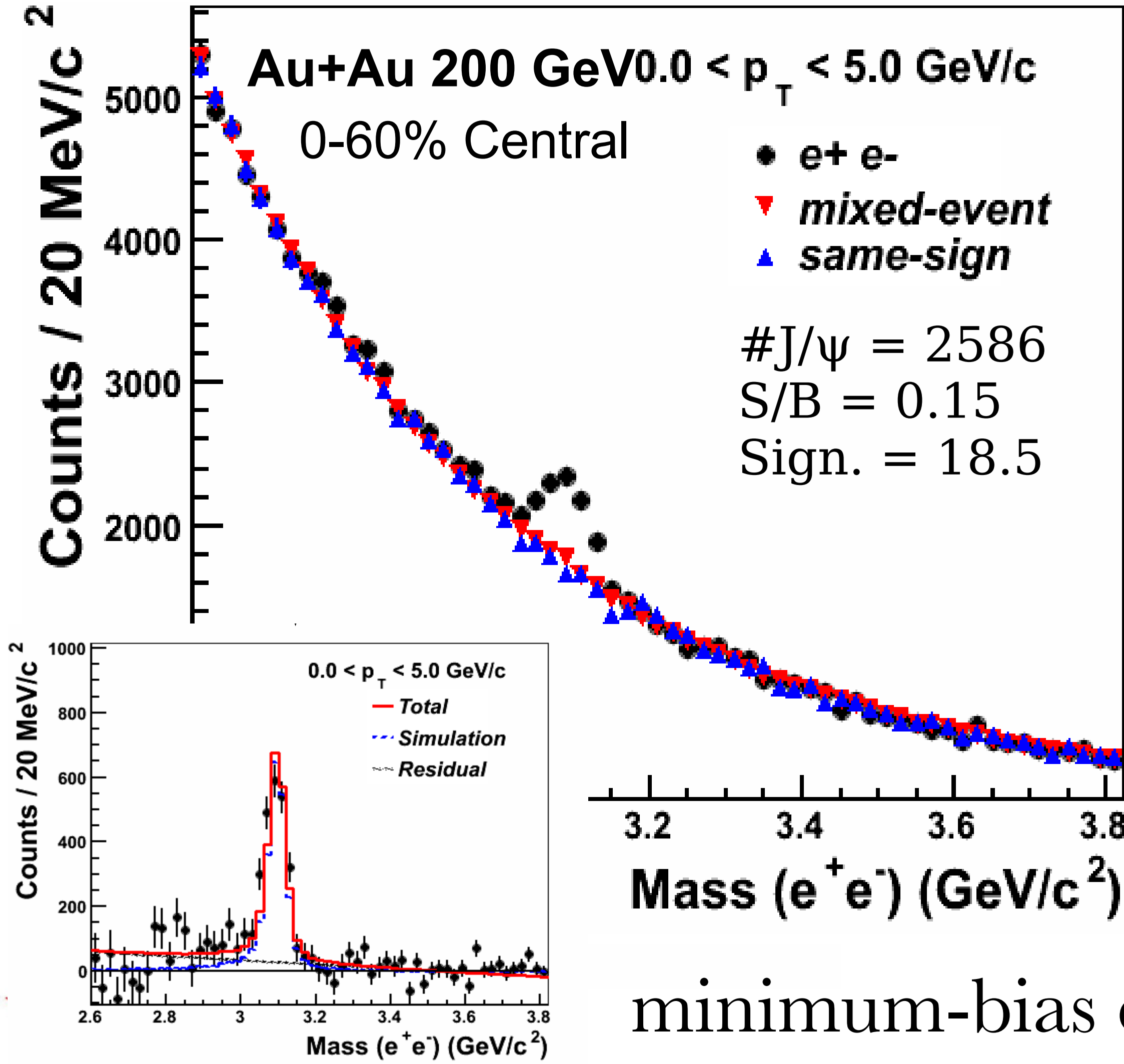




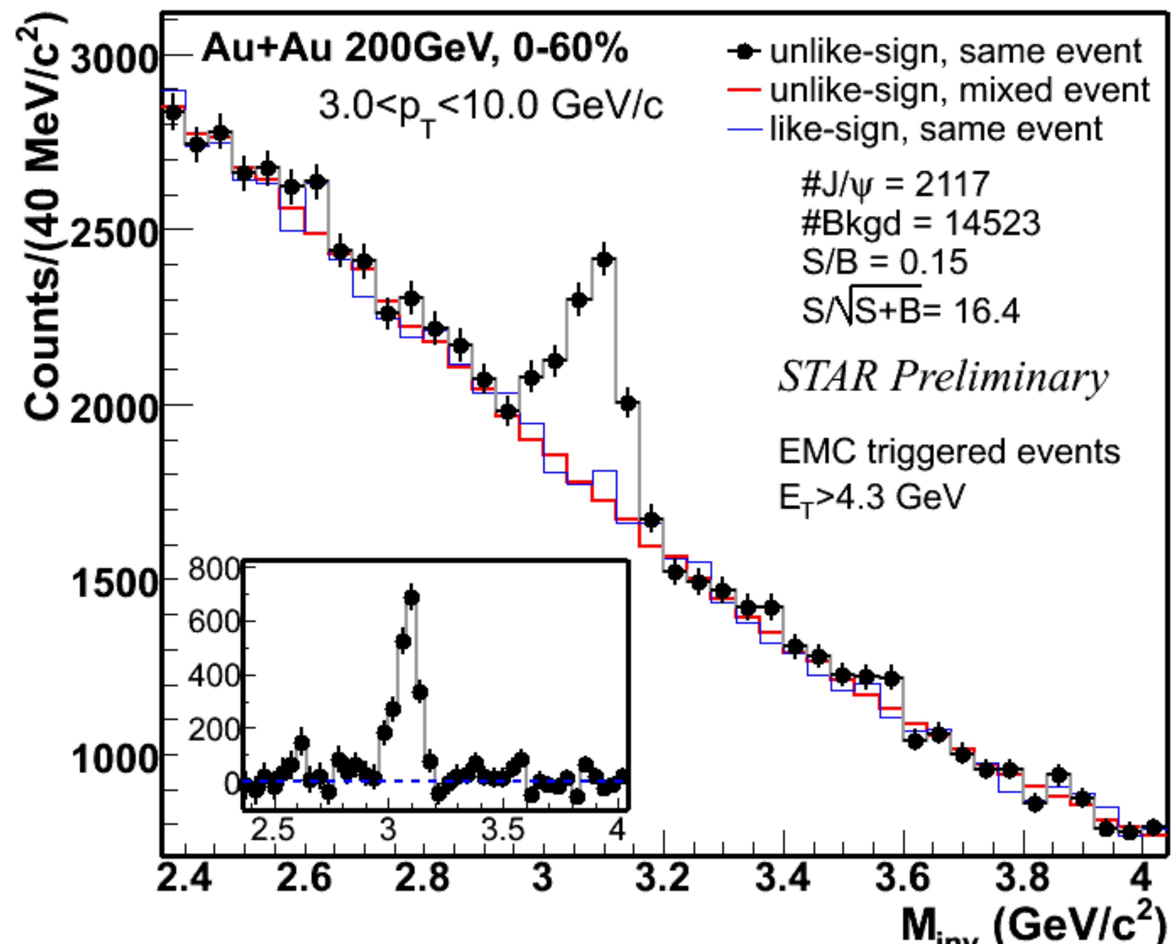
E.Eskola, H.Paukkunenea and C.Salgo, Nucl. Phys. A 830, 599 (2009)
R.Vogt, Phys. Rev. C 81, 044903 (2010)

- ✓ Measurement of J/ψ in d+Au collisions provides information on CNM effects
- ✓ Good agreement with model predictions using EPS09 nPDF parametrization for the shadowing, and J/ψ nuclear absorption cross section $\sigma_{abs}^{J/\psi} = 2.8^{+3.5}_{-2.6}$ *(stat.)*$^{+4.0}_{-2.8}$ *(syst.)*$^{+1.8}_{-1.1}$ *(EPS09)* mb obtained from a fit to the data
- ✓ STAR results consistent with PHENIX measurements

J/ψ in Au+Au collisions at 200 GeV



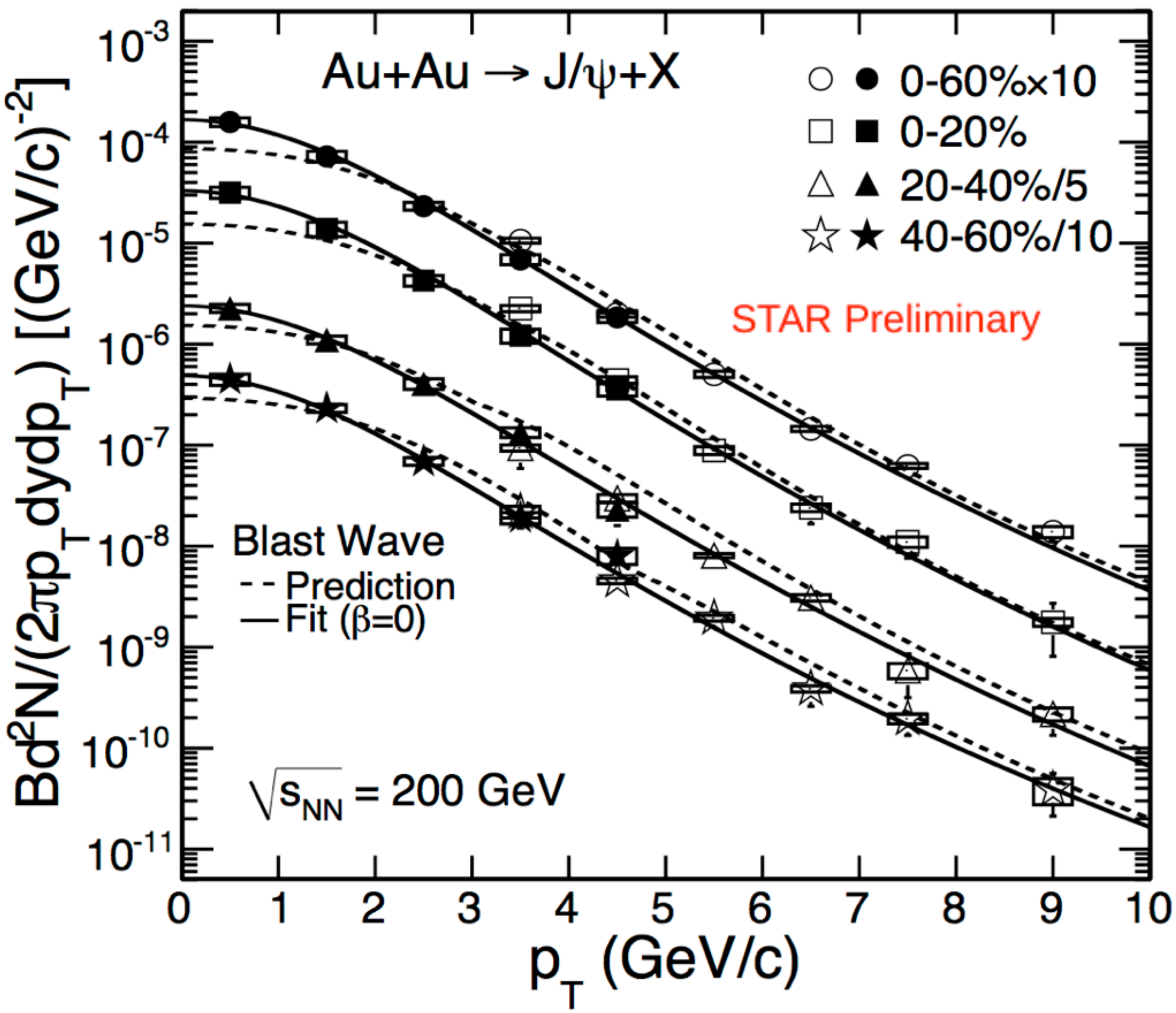
minimum-bias data



high-tower trigger data

- ✓ Very good S/B ~0.15
- ✓ Clean J/ψ signal for low (minimum-bias data) and high p_T (high-tower trigger data)

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



J/ψ p_T range extended to 0-10 GeV/c

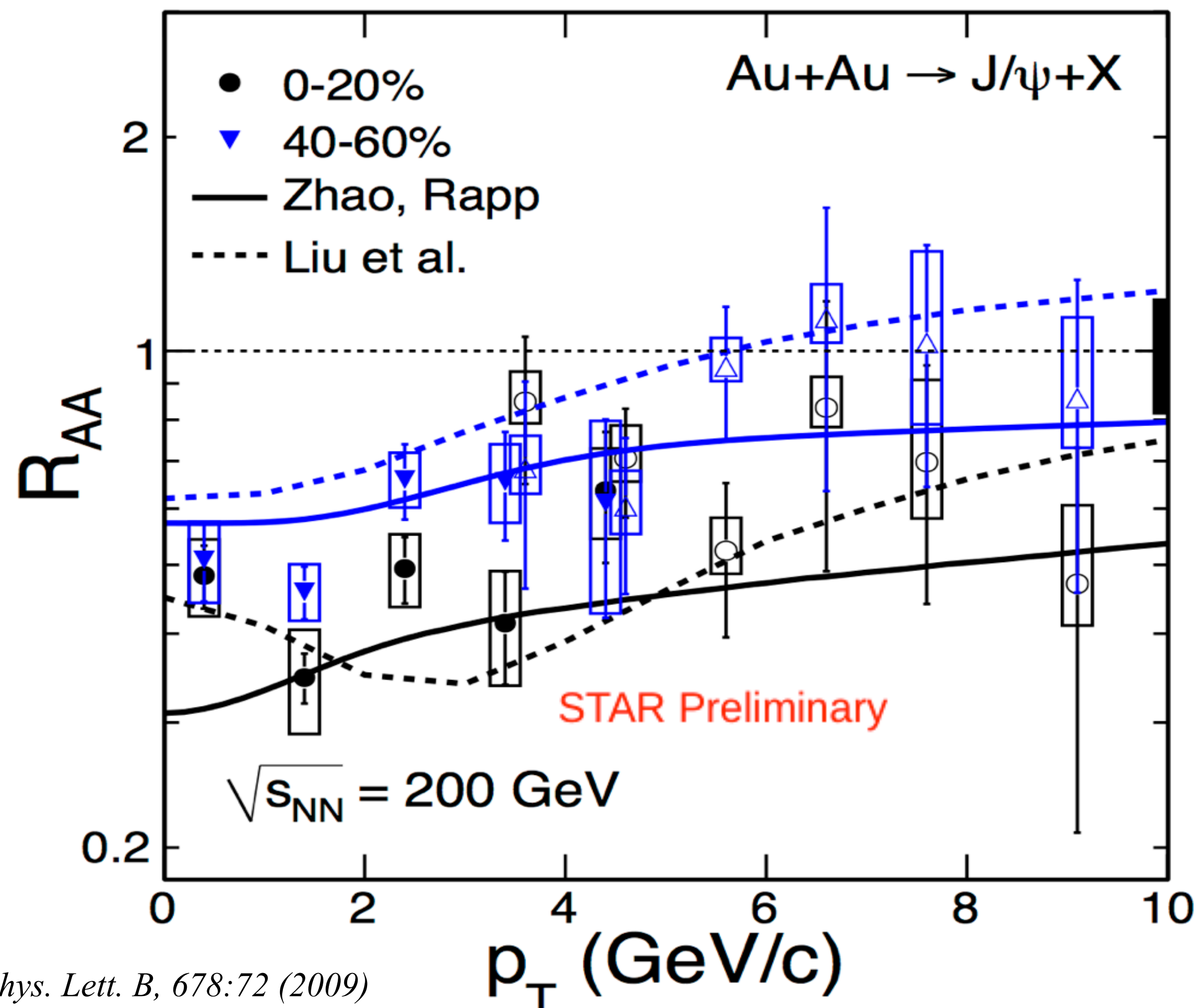
✓ Softer spectra than light hadron prediction at low p_T

smaller radial flow ?

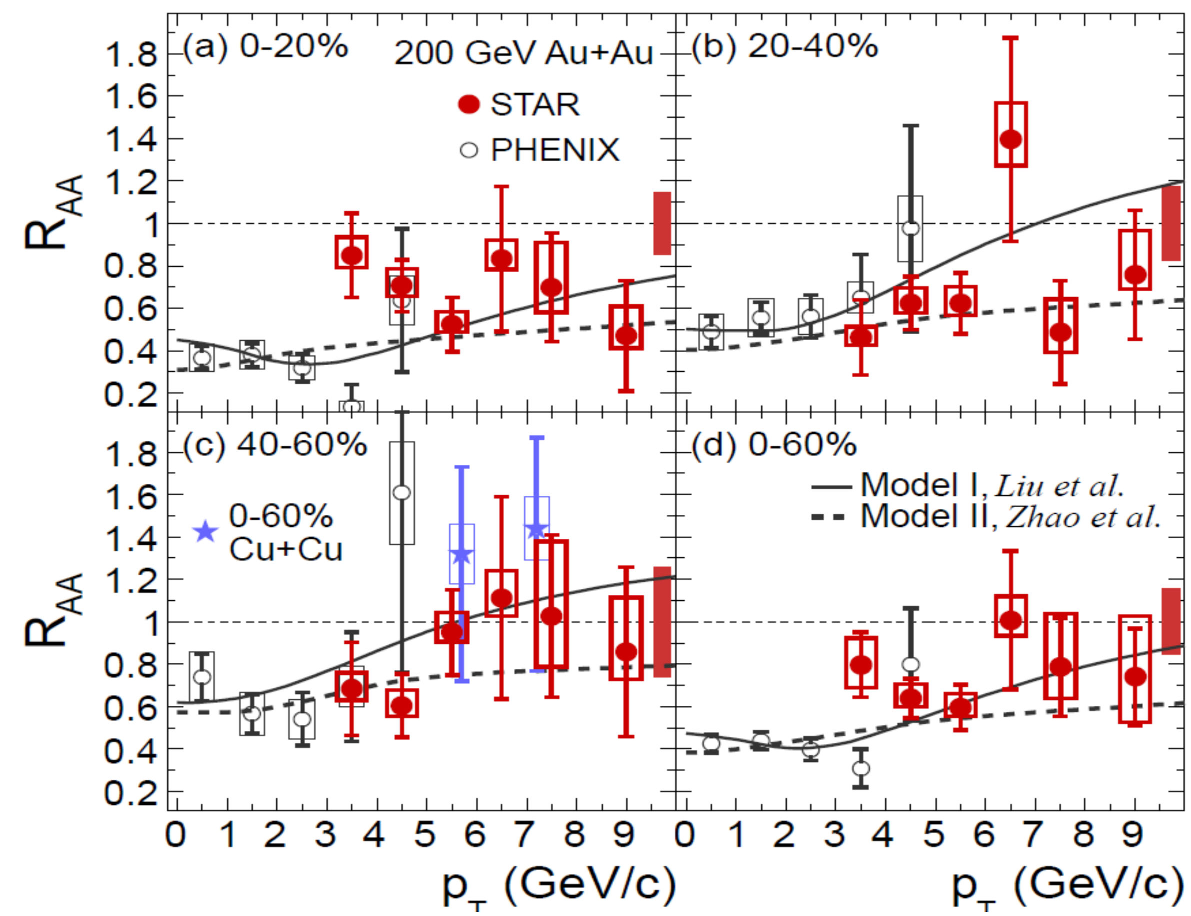
regeneration at low p_T ?

Tsallis Blast-Wave model: Z.Tang et al., arXiv: 1101.1912, JPG 37, 08194 (2010)
STAR high-p_T : arxiv:1208.2736

J/ψ R_{AA} vs p_T in Au+Au collisions at 200 GeV



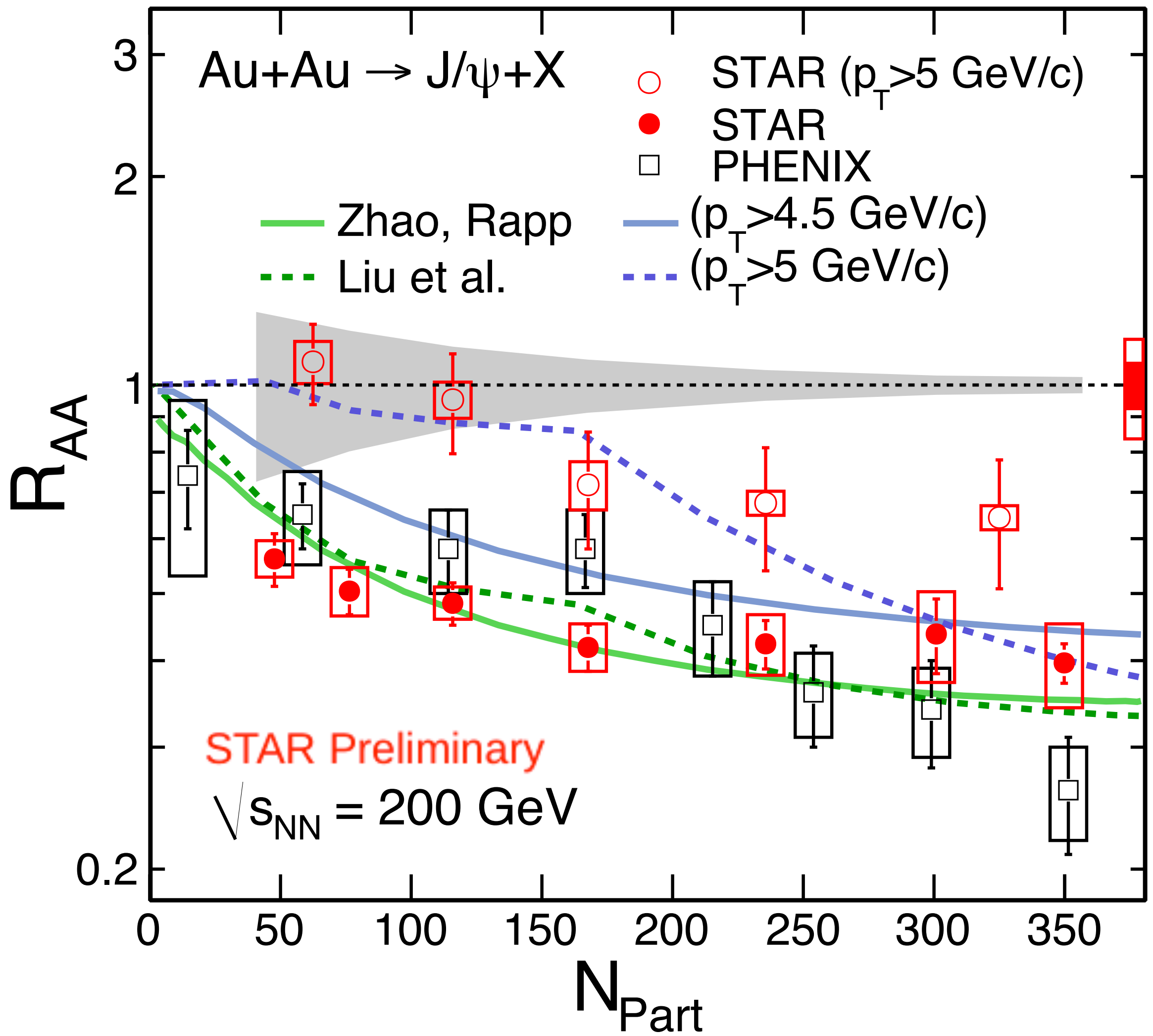
arxiv:1208.2736



Y.Liu et al., Phys. Lett. B, 678:72 (2009)
Zhao, Rapp, Phys. Rev. C 82, 064905 (2010)
STAR high-p_T : arxiv:1208.2736

- ✓ J/ψ suppression decreases with p_T across the centrality range
- ✓ At high p_T suppression for central collisions
- ✓ No suppression at high p_T in (semi-) peripheral collisions

J/ψ R_{AA} vs N_{part} in Au+Au collisions at 200 GeV

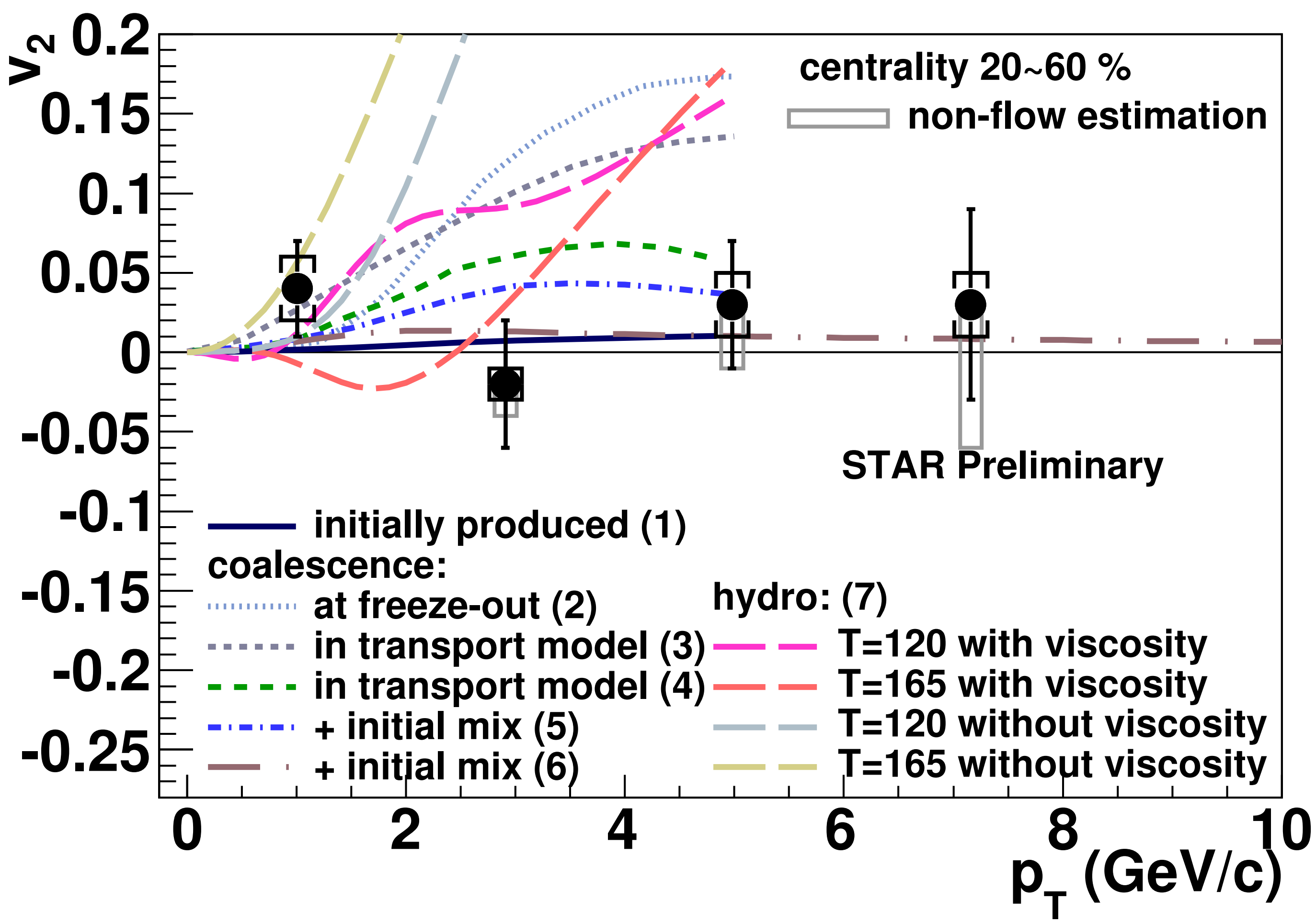


Y.Liu et al., Phys. Lett. B, 678:72 (2009)
Zhao, Rapp, Phys. Rev. C 82, 064905 (2010)
STAR high-p_T : arxiv:1208.2736

- ✓ J/ψ suppression increases with collision centrality
- ✓ Low-p_T data agrees with two models including color screening and regeneration effects
- ✓ At high p_T Liu et al. model describes data reasonable well, while Zhao and Rapp model under-predicts R_{AA} at N_{part} > 70

J/ψ v_2 in semi-central Au+Au collisions at 200 GeV

The J/ψ v_2 measurement is crucial for the test of charm quark recombination effect



(1) (4) Phys. Rev. Lett. 97, 232301 (2006)
(2) Phys. Lett. B595, 202 (2004)
(3) Phys. Lett. B655, 126 (2008)
(5) X.Zhao, R.Rapp, 24th WWND (2008)
(6) Nucl. Phys. A834, 317 (2010)
(7) U.Heinz, C. Shen, private communication

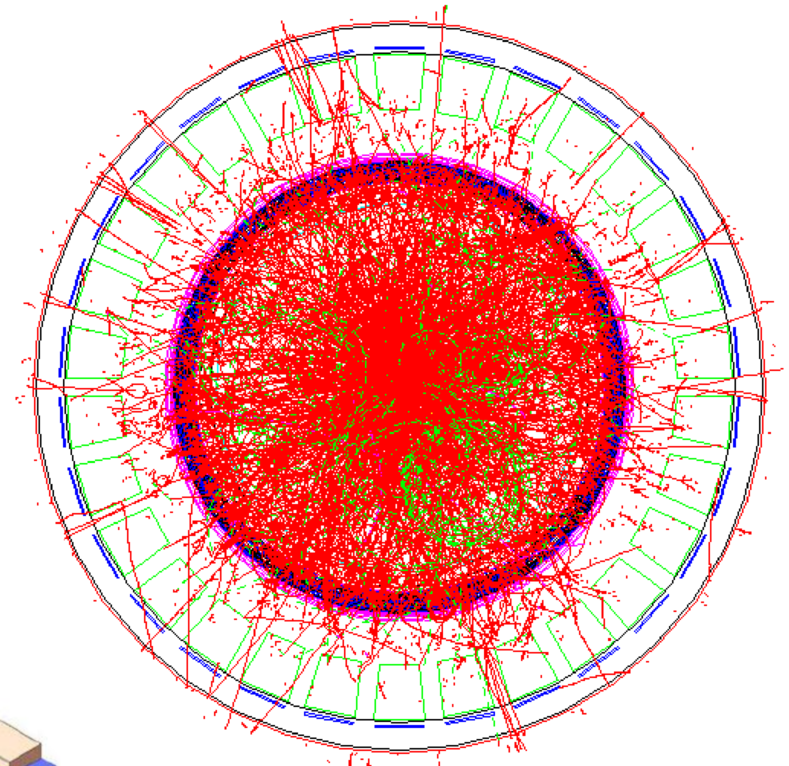
✓ J/ψ v_2 is consistent with non flow at p_T > 2 GeV/c - disfavors the case when J/ψ is produced dominantly by coalescence from thermalized (anti-)charm quarks

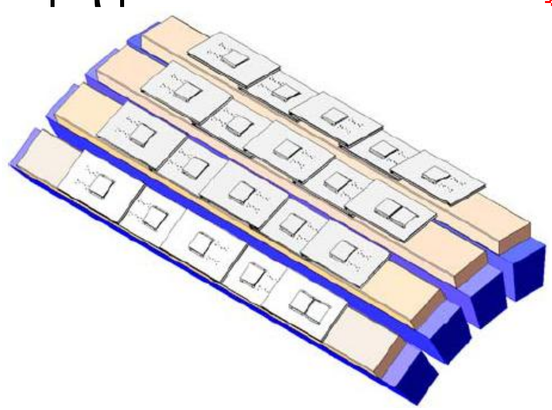
Models	χ^2/ndf	P-value
Initially produced	1.8/3	6.2e-1
Coalescence at freezeout	22.6/3	4.9e-5
Coalescence In transport	13.9/3	3.0e-3
Coalescence In transport	4.8/3	1.8e-1
Coalescence +initial mix	2.9/3	4.0e-1
Coalescence +initial mix	1.8/4	7.7e-1
Hydro T=120 w/viscosity	16.5/3	9.2e-4
Hydro T=165w/ viscosity	14.9/3	1.9e-03
Hydro T=120 w/o viscosity	191.6/3	2.7e-41
Hydro T=165w/o viscosity	237.3/3	0.0

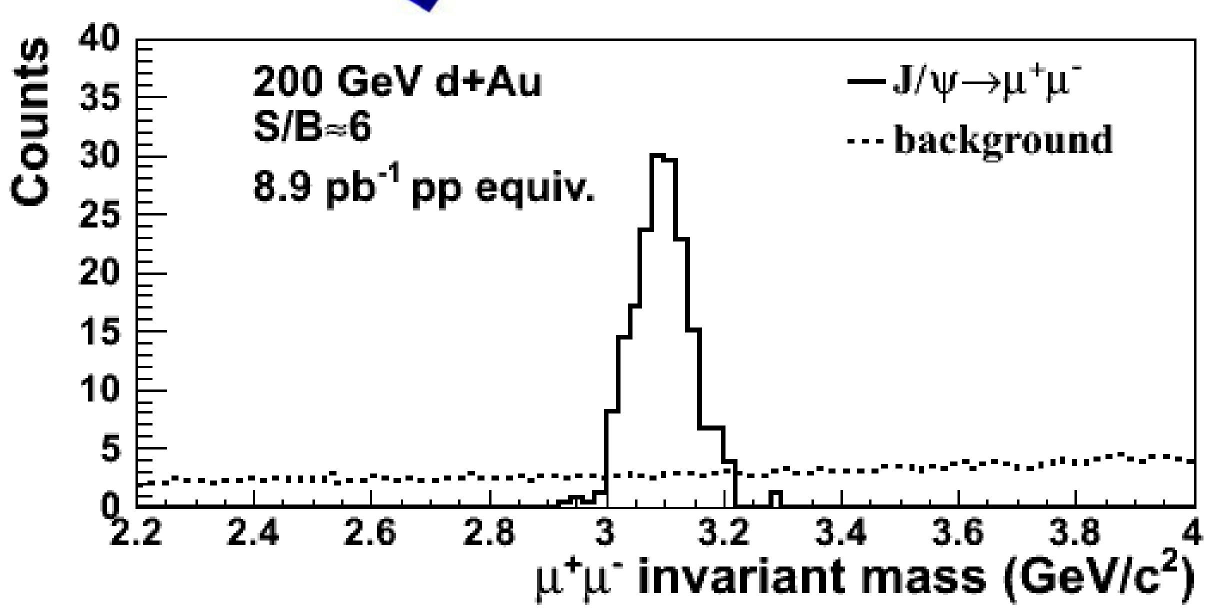
Muon Telescope Detector

Multi-gap Resistive Plate Chamber (MRPC) - gas detector

Acceptance: 45% at $|\eta| < 0.5$







- No γ conversion
- Much less Dalitz decay contribution
- Less affected by radiative looses in the materials

- Trigger capability for low and high p_T J/ψ in central Au+Au

- S/B=6 in d+Au and S/B=2 in central Au+Au
- Excellent mass resolution

- With *HFT*, B→J/ψ + X decays possible to study

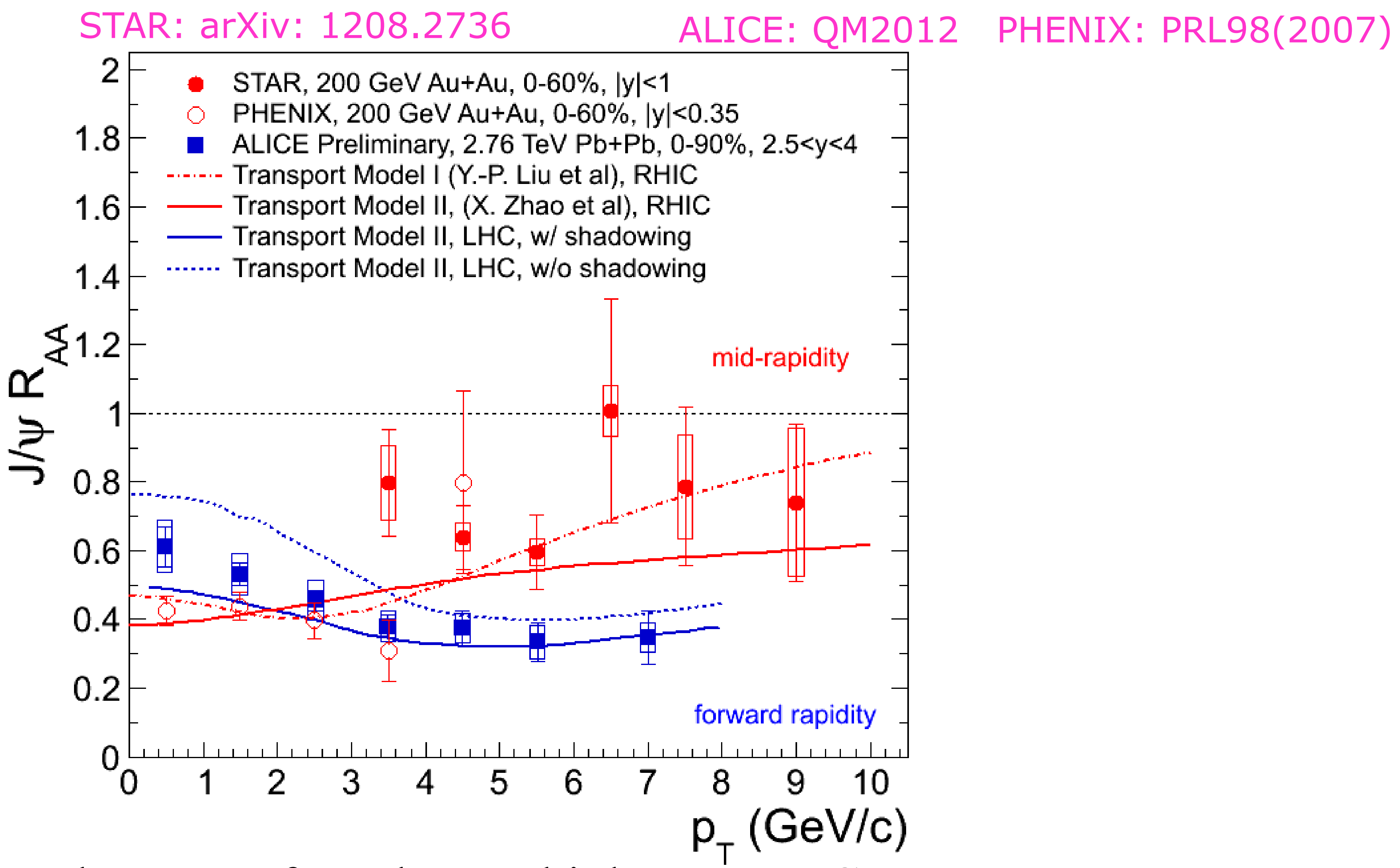
Summary

- NLO CS+CO and CEM models describe J/ψ p_T spectrum in p+p
- J/ψ polarization in p+p collisions consistent with NLO$^+$ CSM and COM models predictions, and with no polarization
- B-hadron feed-down contribution 10-25% at 4 < p_T < 12 GeV/c in p+p
- J/ψ R_{dAu} consistent with the model using EPS09+ $\sigma_{abs}^{J/\psi}$ (3 mb - obtained for a fit to the data)
- J/ψ suppression in Au+Au increases with centrality and decreases with p_T - at high p_T suppression for central collisions
- J/ψ v_2 measurement disfavors the case when J/ψ is produced dominantly by coalescence from thermalized (anti-)charm quarks for p_T > 2 GeV/c

Thank you !

Backup

Compare to LHC - J/ψ R_{AA} vs p_T



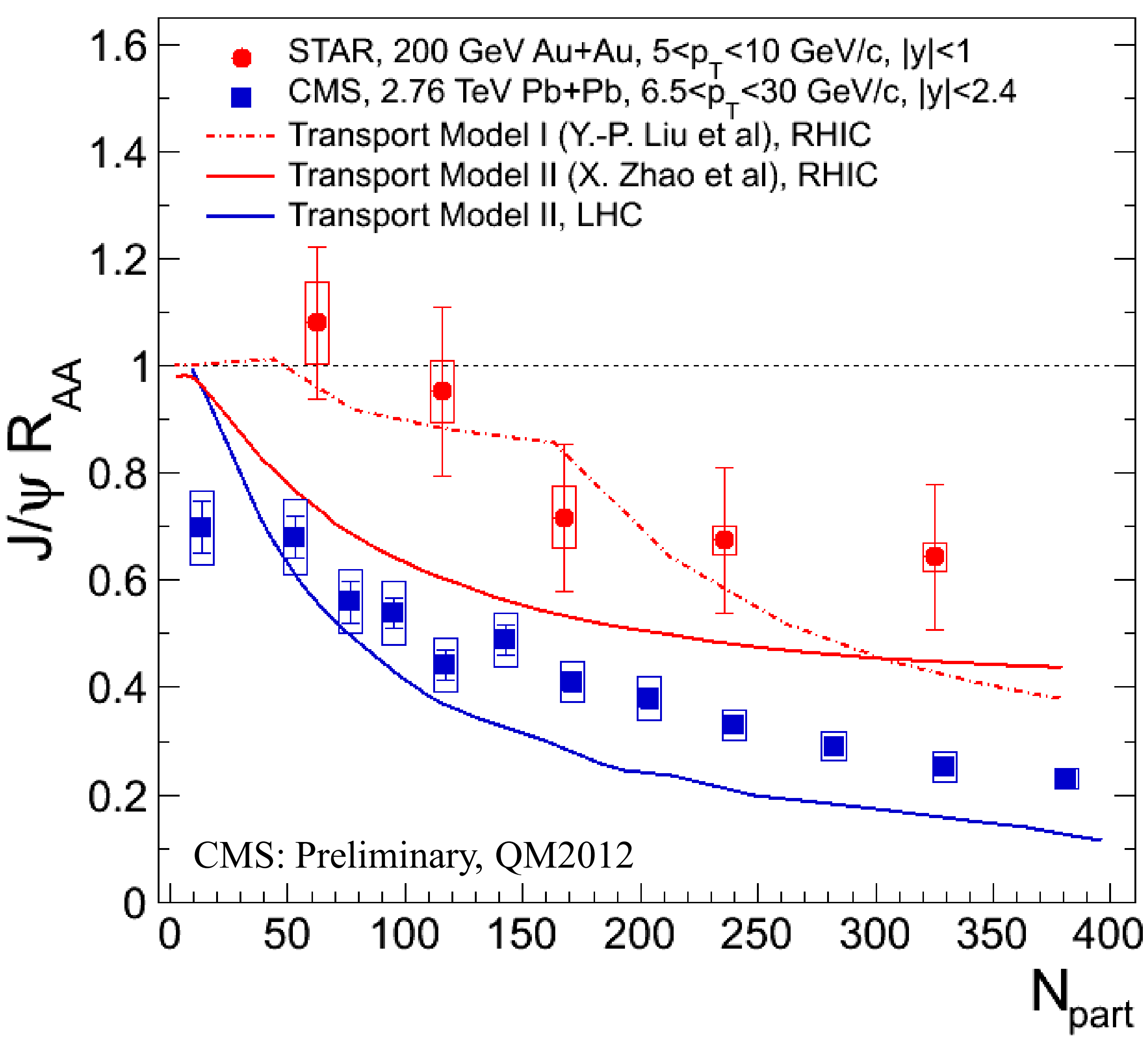
J/ψ R_{AA} decreases from low to high p_T at LHC.

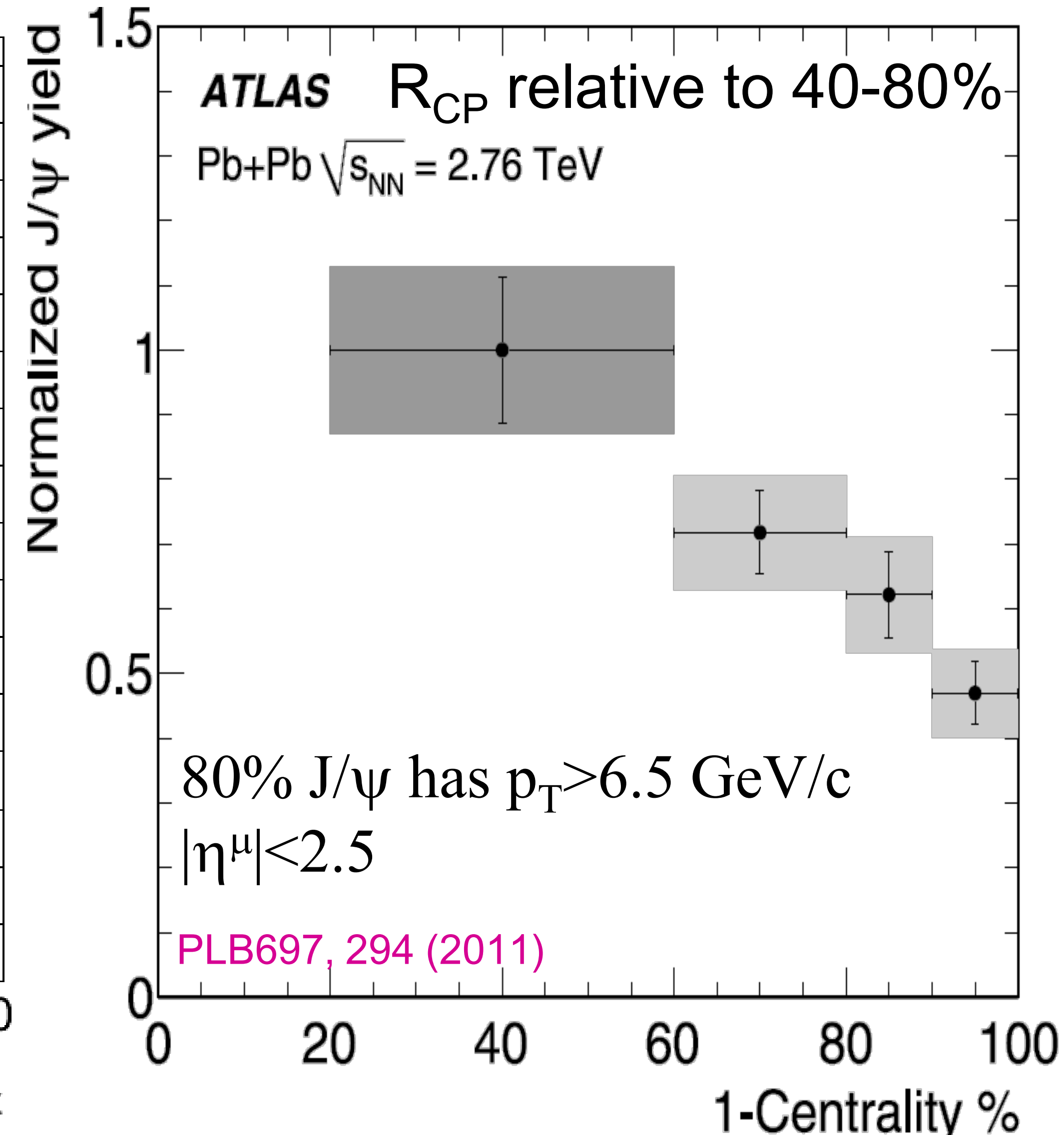
J/ψ R_{AA} increases from low to high p_T at RHIC.

At high p_T, J/ψ more suppressed at LHC.

Models incorporating color screening and recombination can consistently describe the J/ψ suppression pattern.

STAR Compare to LHC - J/ψ R_{AA} vs N_{part}





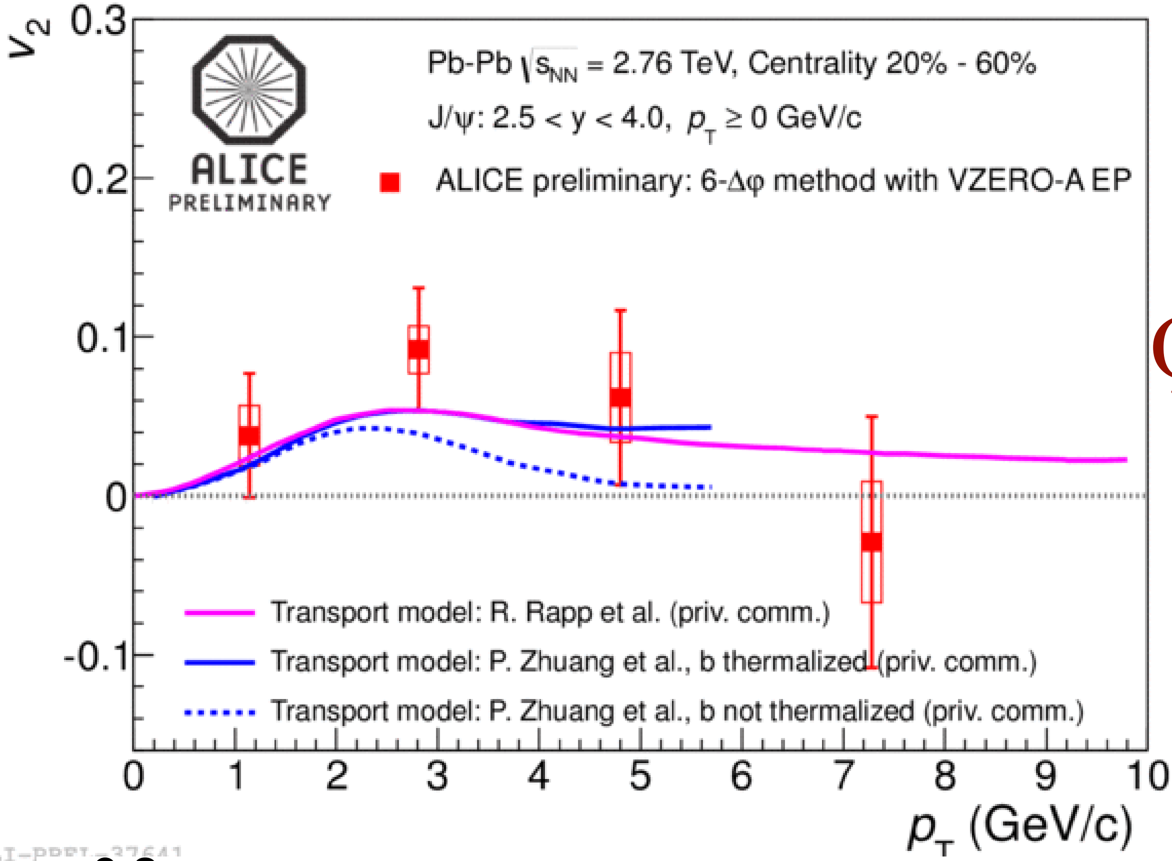
Stronger suppression at CMS than STAR, even in peripheral collisions

R_{CP}~1/3 for CMS, 0.45 for ATLAS and 0.5 for STAR,

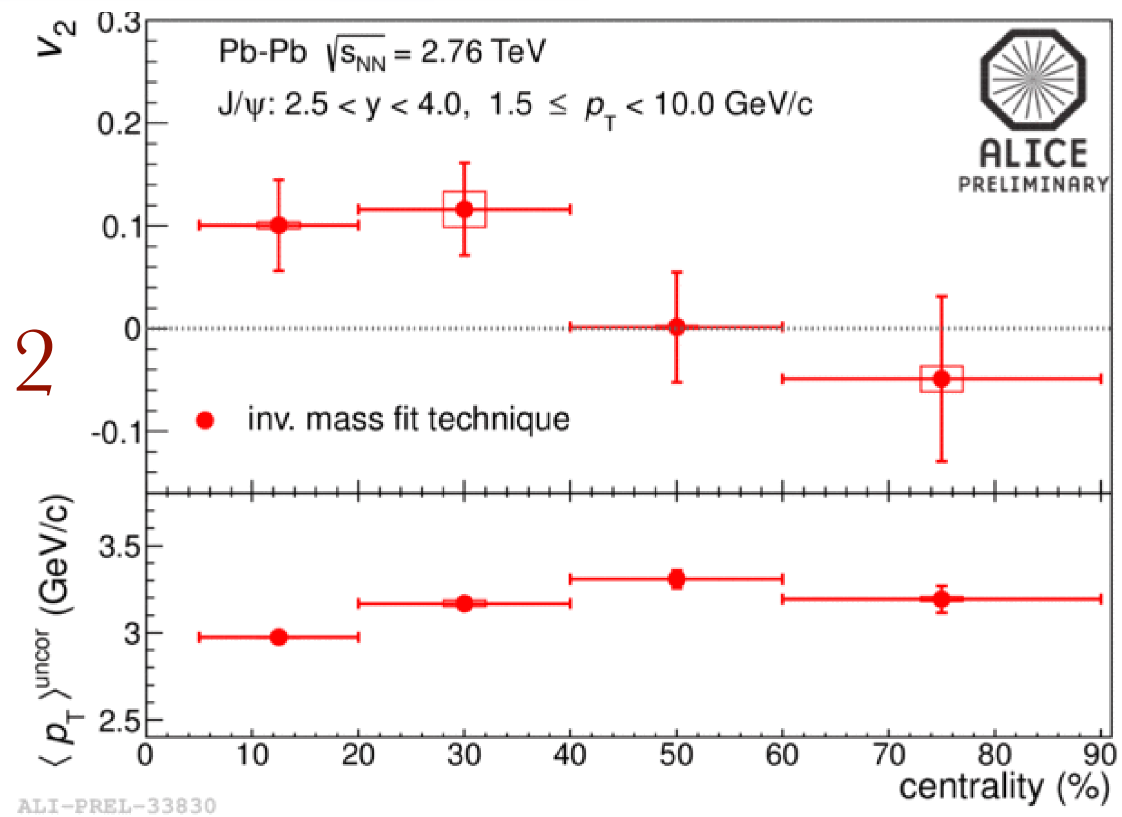
Similar at RHIC and LHC if take the uncertainty into account

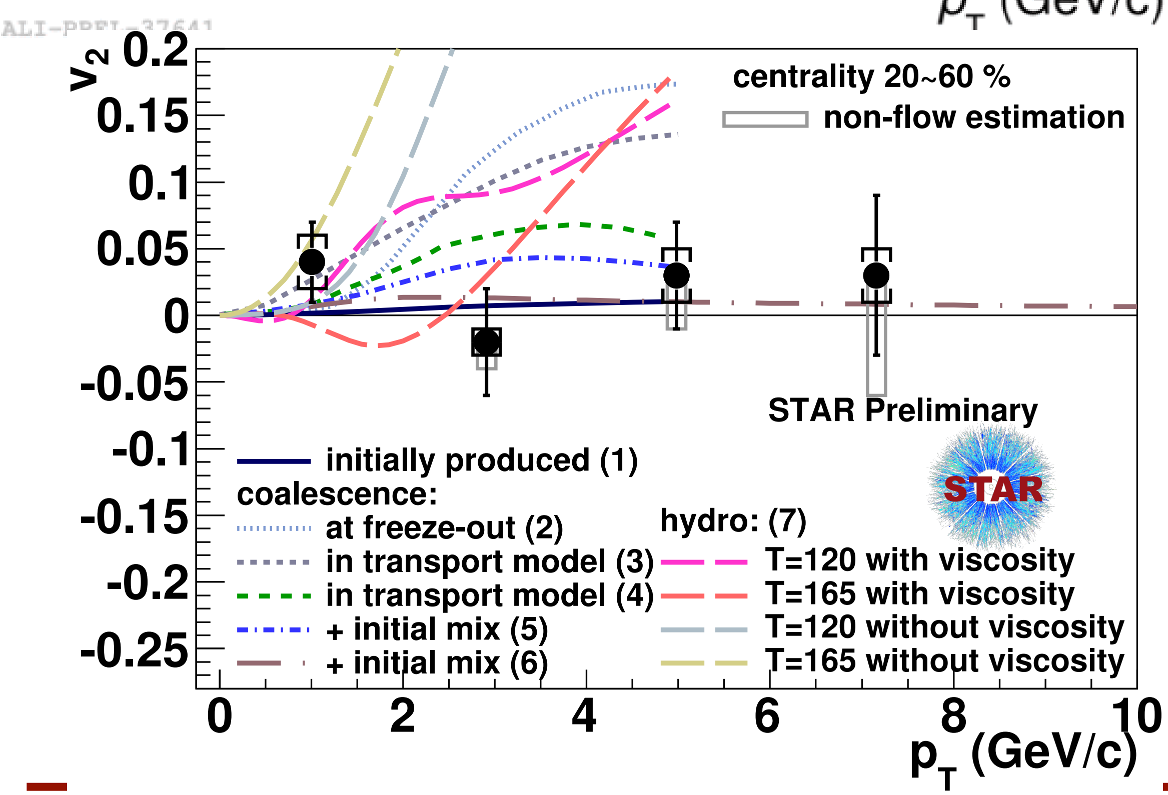
CNM and regeneration is less important at high p_T at RHIC. ➔ Is it true for LHC?

Compare to LHC - J/ψ v_2



QM12





- ✓ ALICE hint for non-zero v_2 in:
  - 20-60% central events in $2<p_T<4$ GeV/c
  - 5-20% and 20-40% central events for $1.5<p_T<10$ GeV/c
- ✓ Significance up to 3.5σ for chosen kinematic/ centrality selection
- ✓ Qualitative agreement with transport models including regeneration