J/ψ production in the STAR experiment

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Czech Technical University in Prague

High Energy Physics in the LHC Era
16-20 December 2013
Valparaiso - CHILE

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Outline

- Motivation
- J/ψ production and polarization in p+p collisions at 200 GeV
- J/ψ production and elliptic flow in Au+Au collisions at 200 GeV
- Energy dependence of J/ψ R_{AA}
- Outlook
- Summary

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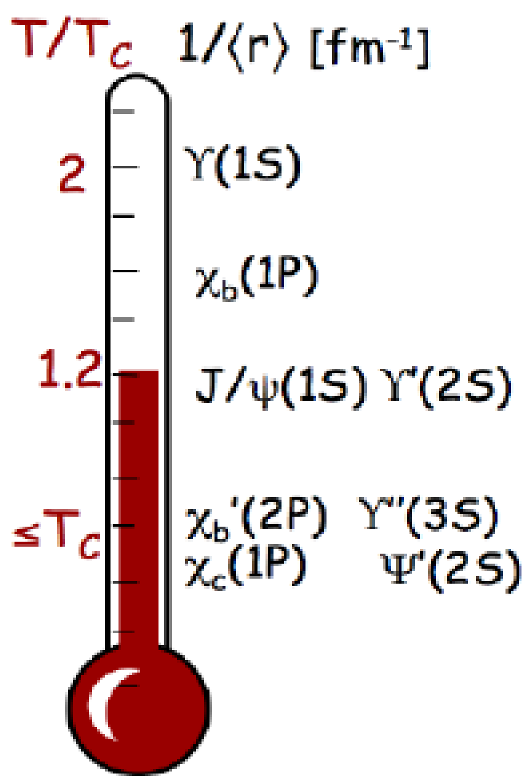
Charmonia at RHIC - Motivation

- ✓ 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

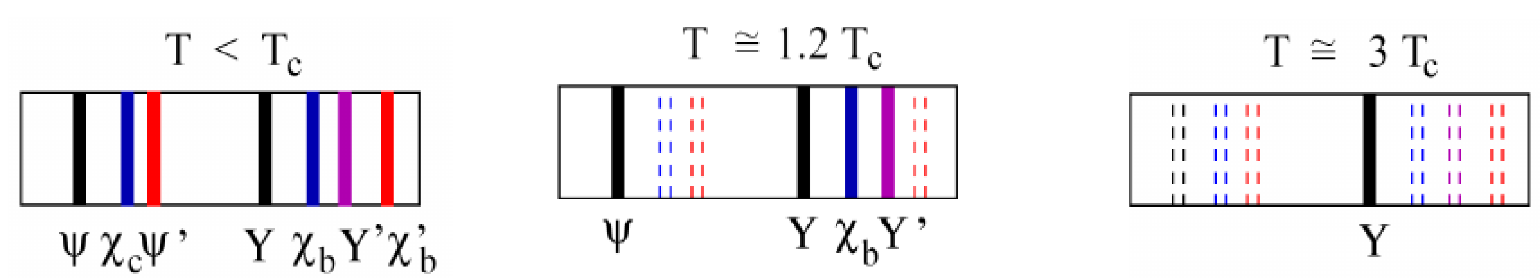
The QGP Thermometer



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)

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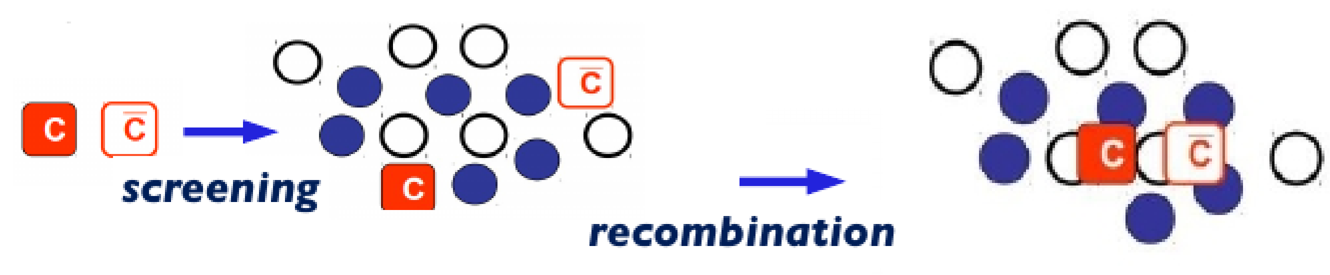
Charmonia at RHIC - other effects

✓ ***But there are more complications:***

- Still unknown ***production mechanism*** in elementary collisions - measure p_T spectra and polarization
- ***Feed-down***
  - prompt J/ψ production:
    - direct J/ψ (~60%)
    - feed down from ψ' (~10%) and χ_C (~30%) decays
  - non-prompt: B-mesons feed-down (10-25% at 4-12 GeV/c, STAR, Phys. Lett. B722 (2013) 55)
- ***Cold Nuclear Matter (CNM) effects*** - nuclear shadowing, Cronin effect, nuclear absorption, ...
- Other ***Hot Nuclear Matter effects*** - recombination, ...



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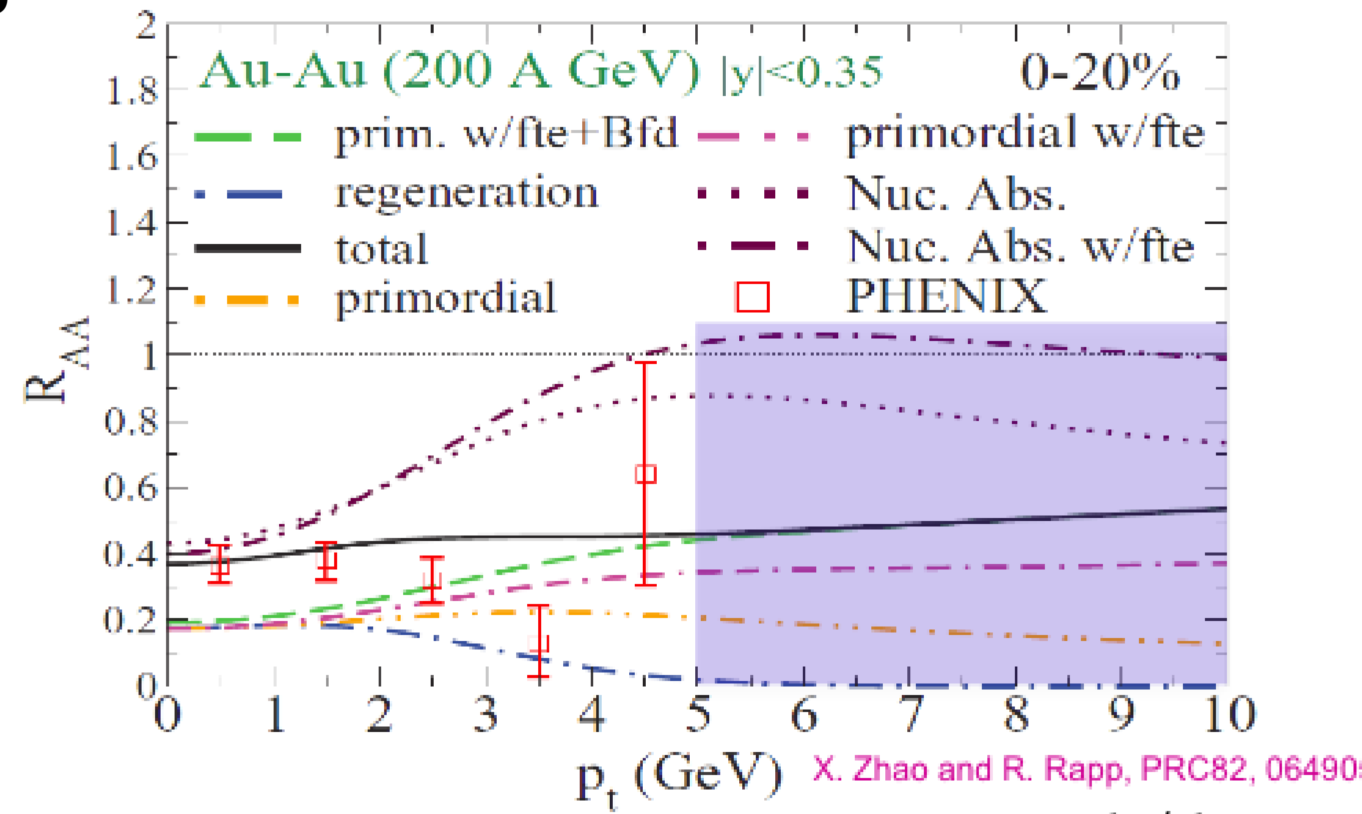
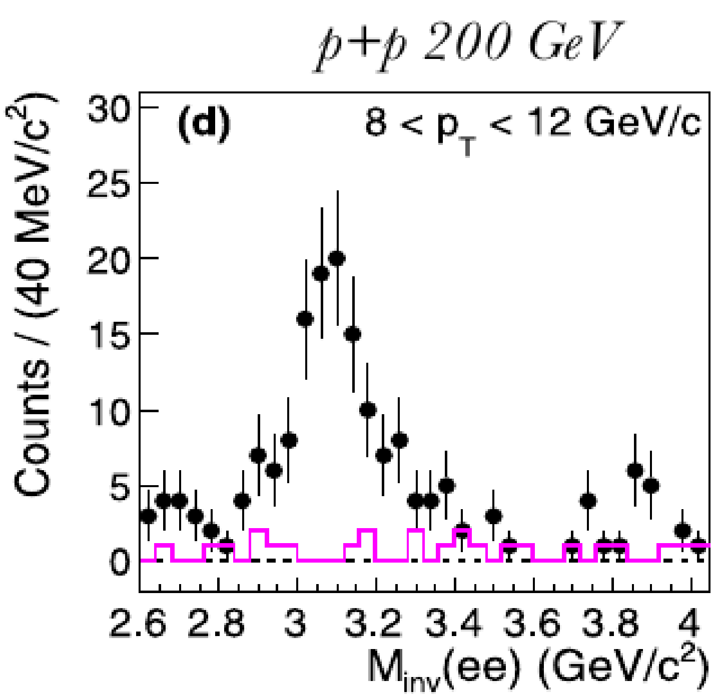
How to disentangle color screening vs CNM effect vs recombination

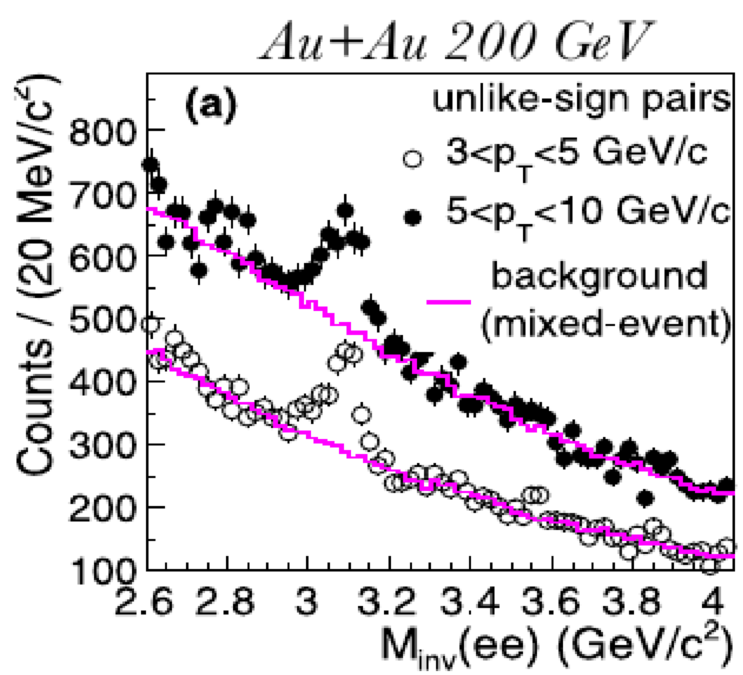
- Energy dependence of the J/ψ production - varying relative contributions
- High-p_T J/ψ - almost not affected by CNM effects and recombination



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

STAR high-p_T signal:





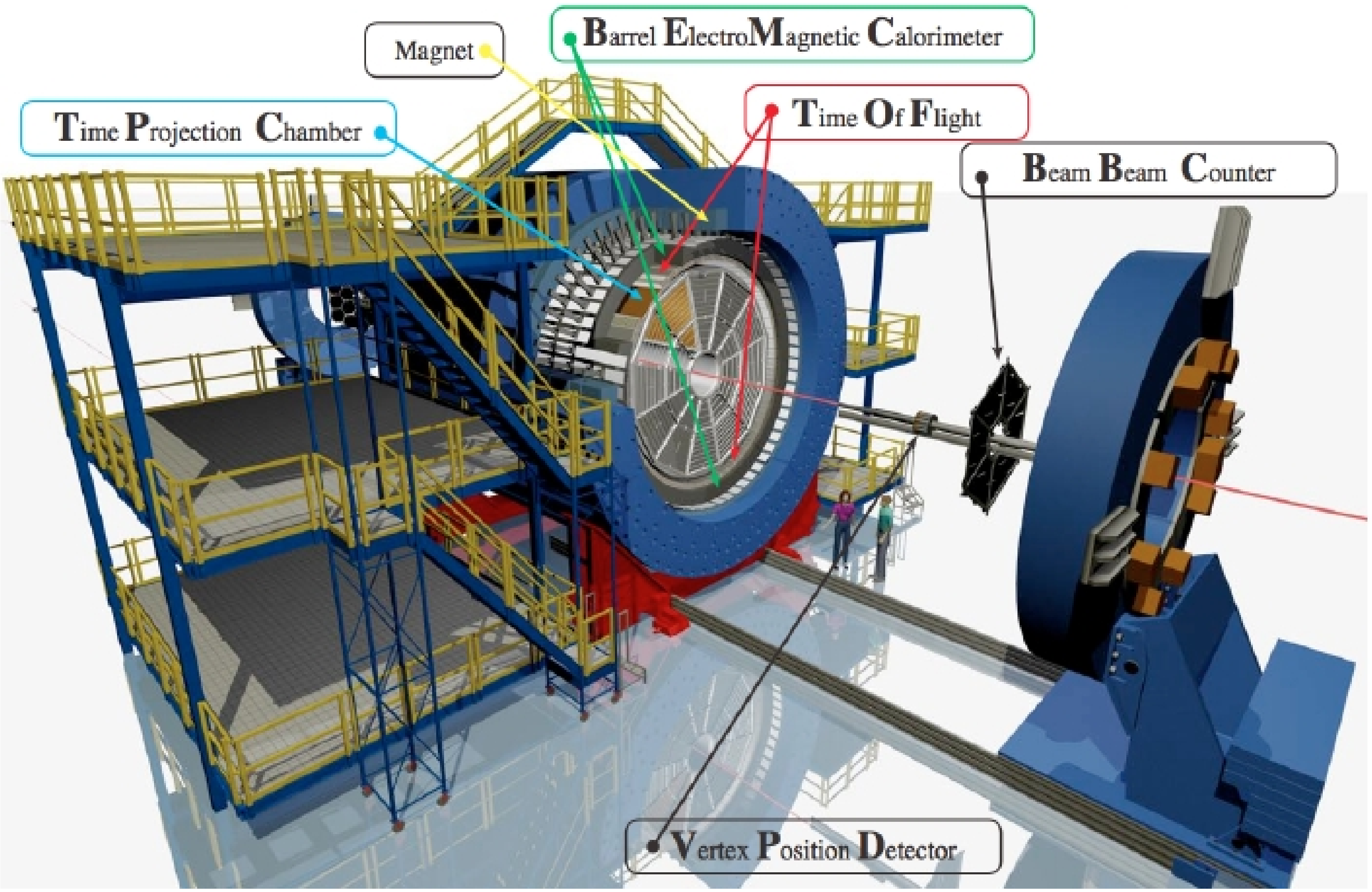
Measure J/ψ p_T spectra, R_{AA}, polarization, elliptic flow ...

Phys. Lett. B 722 (2013) 55

STAR EXPERIMENT, PID

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

Solenoidal Tracker At RHIC : $-1 < \eta < 1, 0 < \phi < 2\pi$



✓ Large acceptance:

- $|\eta| < 1$, $0 < \varphi < 2\pi$

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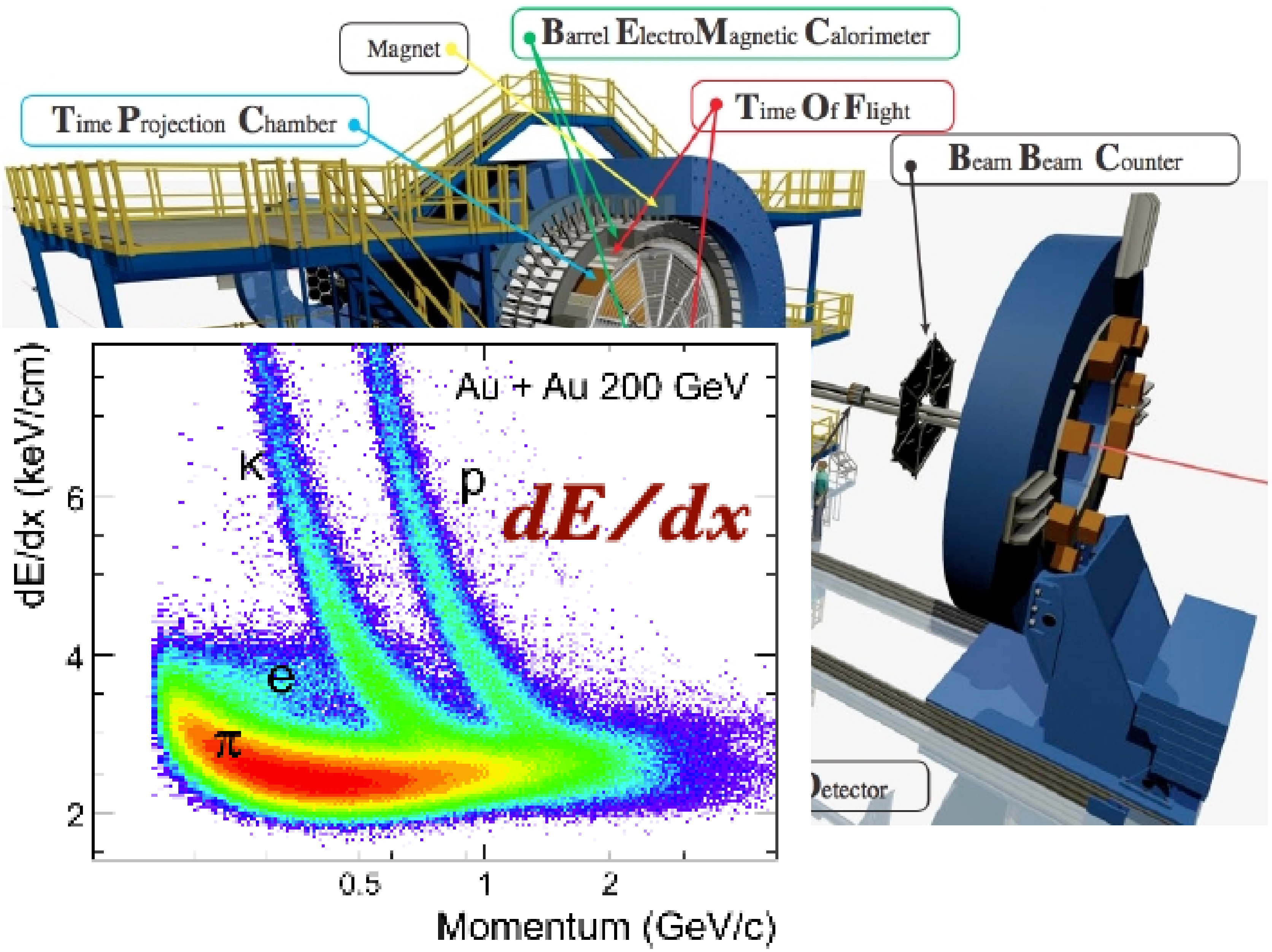

- ✓ Large acceptance:
  - $|\eta| < 1, 0 < \varphi < 2\pi$
- ✓ ***TPC***
  - Tracking: p_T, η, φ
  - dE/dx: **PID**

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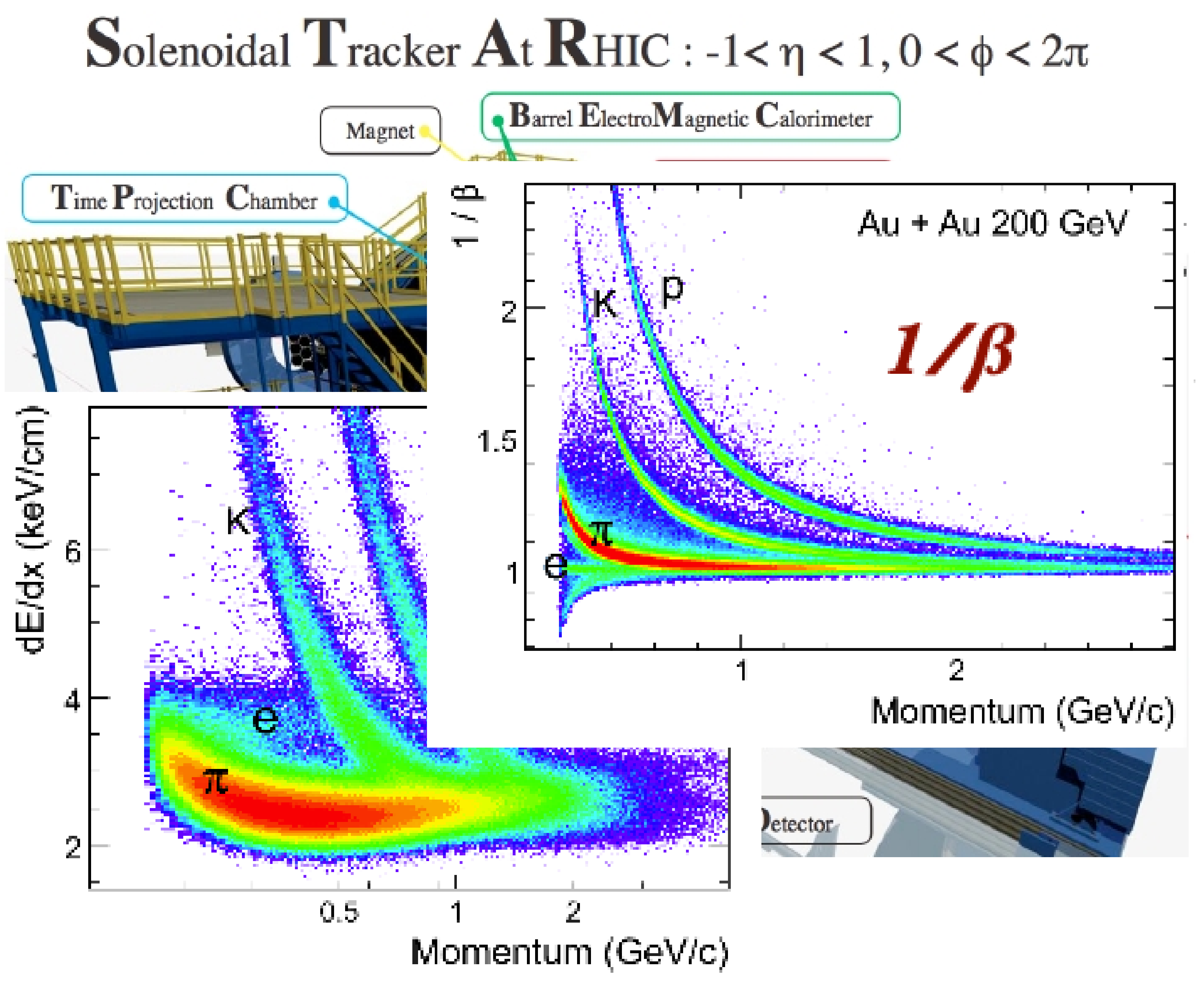

- ✓ Large acceptance:
  - |η| < 1, 0 < φ < 2π
- ✓ ***TPC***
  - Tracking: p_T, η, φ
  - dE/dx: **PID**
- ✓ ***TOF***
  - Timing resolution < 100 ps
  - 1/β: **PID**

STAR EXPERIMENT, PID

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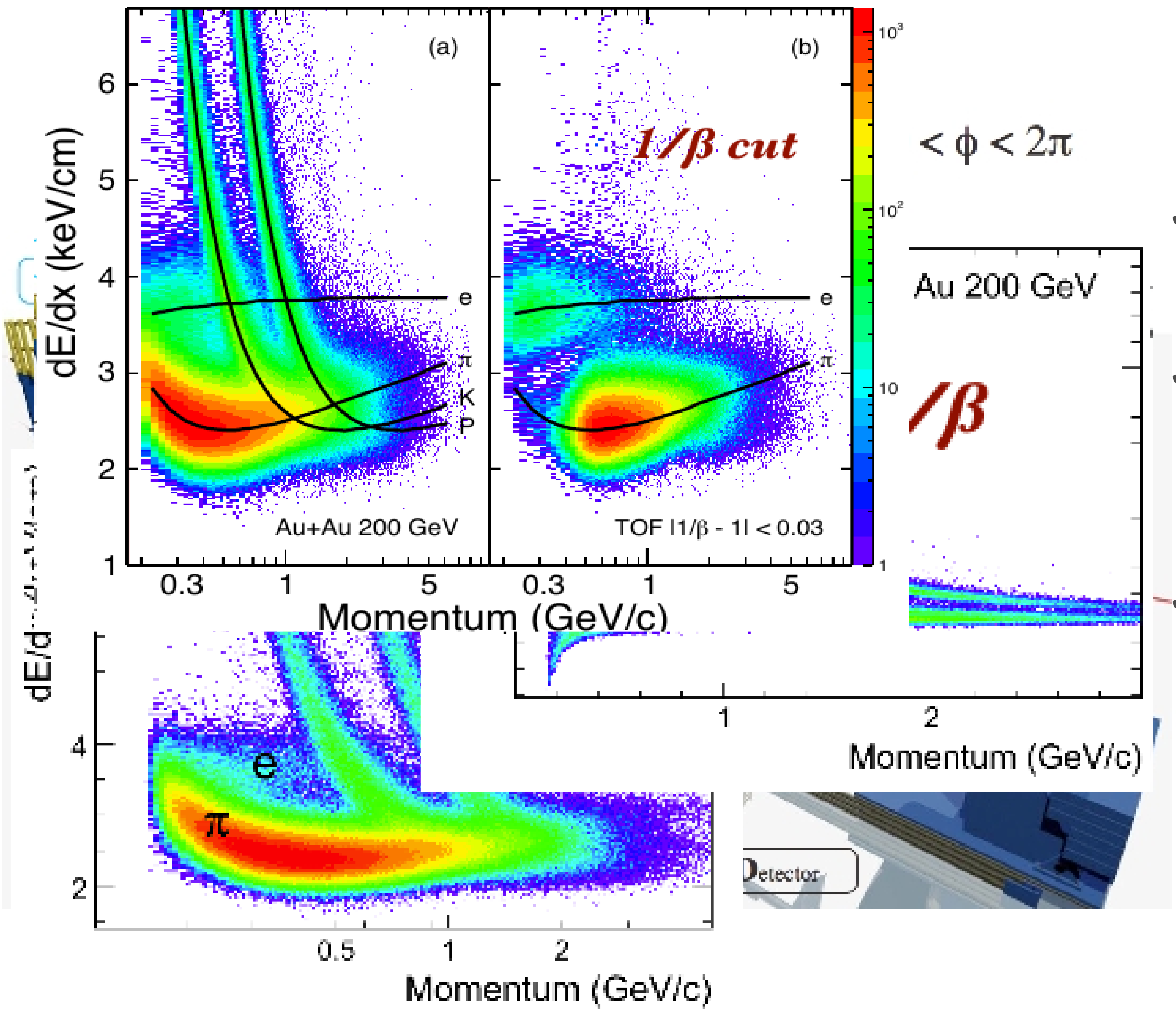

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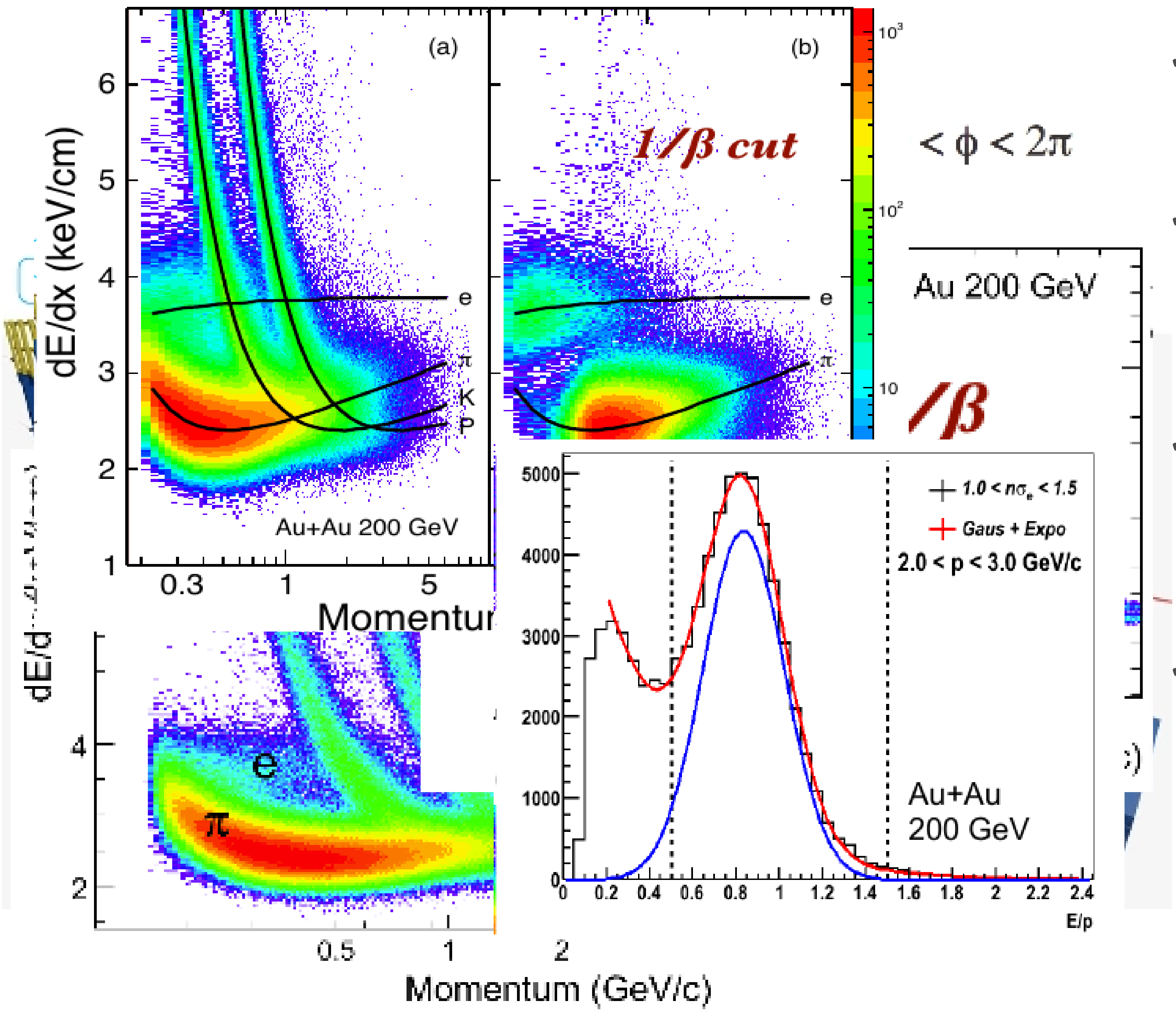
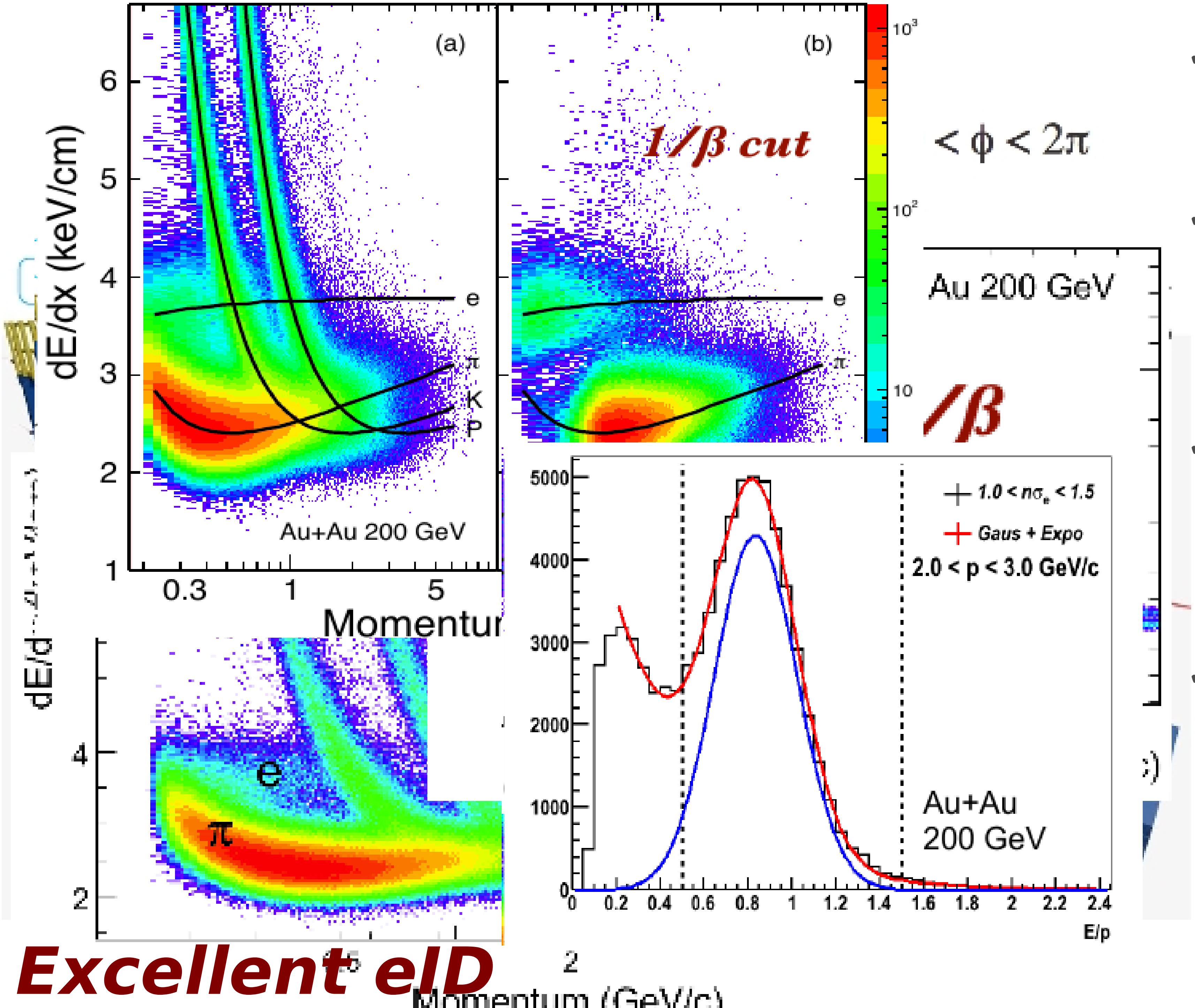


- ✓ Large acceptance:
  - $|\eta| < 1$, $0 < \varphi < 2\pi$
- ✓ ***TPC***
  - Tracking: p_T, η, φ
  - dE/dx: **PID**
- ✓ ***TOF***
  - Timing resolution < 100 ps
  - $1/\beta$: **PID**
- ✓ ***BEMC***
  - Tower $\Delta\eta \times \Delta\varphi = 0.05 \times 0.05$
  - Energy: $E/p \sim 1$ (for electrons)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

STAR EXPERIMENT, PID

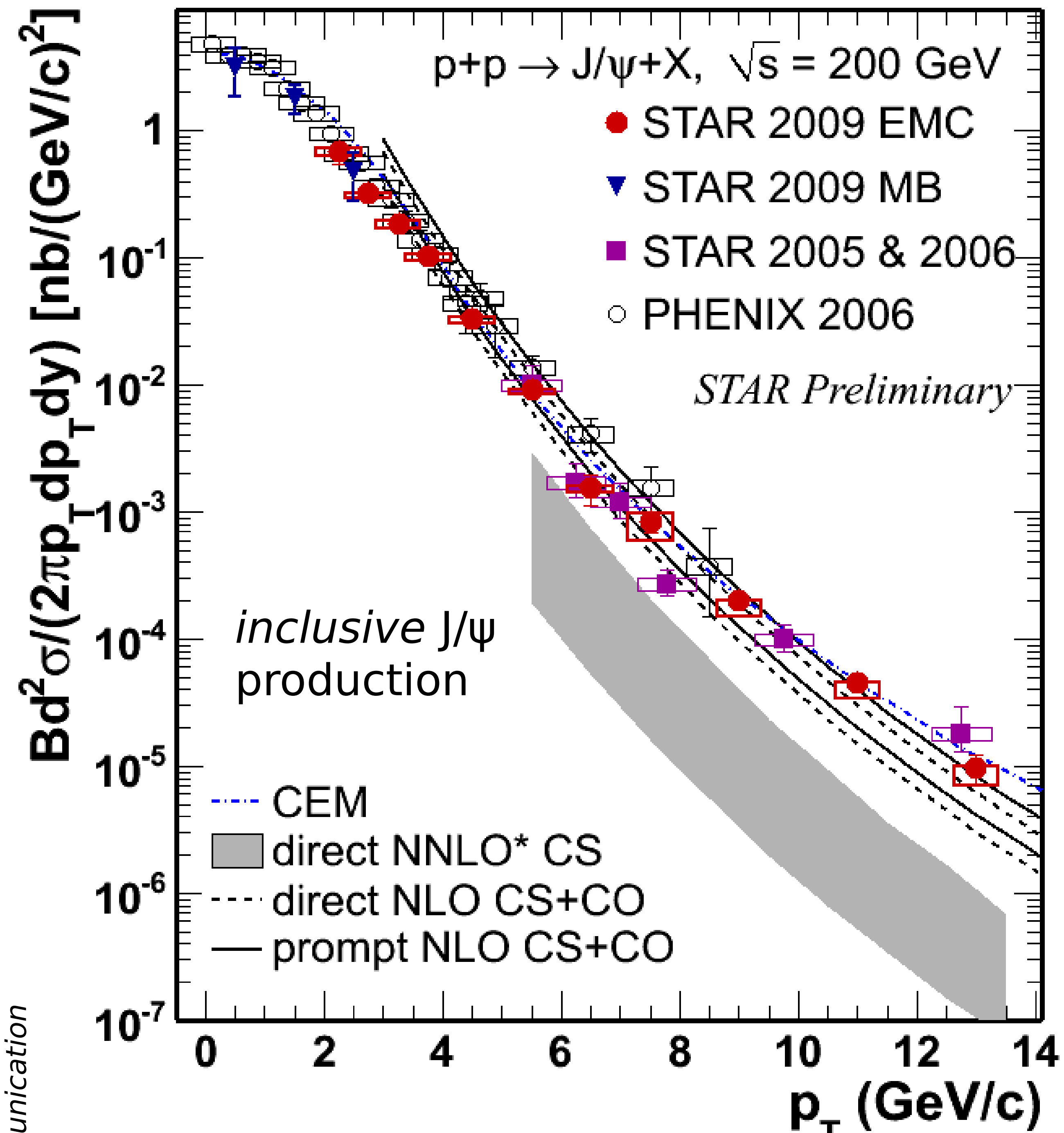
$J/\psi \rightarrow e^+e^-$ (BR 5.9%)



Excellent eID

- ✓ Large acceptance:
  - |η| < 1, 0 < φ < 2π
- ✓ ***TPC***
  - Tracking: p_T, η, φ
  - dE/dx: **PID**
- ✓ ***TOF***
  - Timing resolution < 100 ps
  - 1/β: **PID**
- ✓ ***BEMC***
  - Tower Δη x Δφ = 0.05 x 0.05
  - Energy: E/p ~ 1 (for electrons) **PID**
  - **Trigger**

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



STAR 2005&2006: Phys. Rev. C80, 041902(R) (2009)
PHENIX: Phys. Rev. D 85, 092004 (2012)
direct NNLO CS: 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. D 84, 51 114001 (2011) and private communication
CEM: A.D. Frawley, T Ullrich, R. Vogt, Pys. Rept. 462 (2008) 125, and R.Vogt private communication

STAR EMC : Phys. Lett. B 722 (2013) 55
STAR MB: Acta Phys. Polonica B Vol.5, No 2 (2012), 543

- ✓ *prompt* NLO CS+CO model describes the data for p_T > 4 GeV/c
- ✓ *prompt* CEM model can reasonably well describe the p_T spectra (overpredicts the data at p_T ~ 3 GeV/c)
- ✓ *direct* NNLO* CS model misses high-p_T part

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

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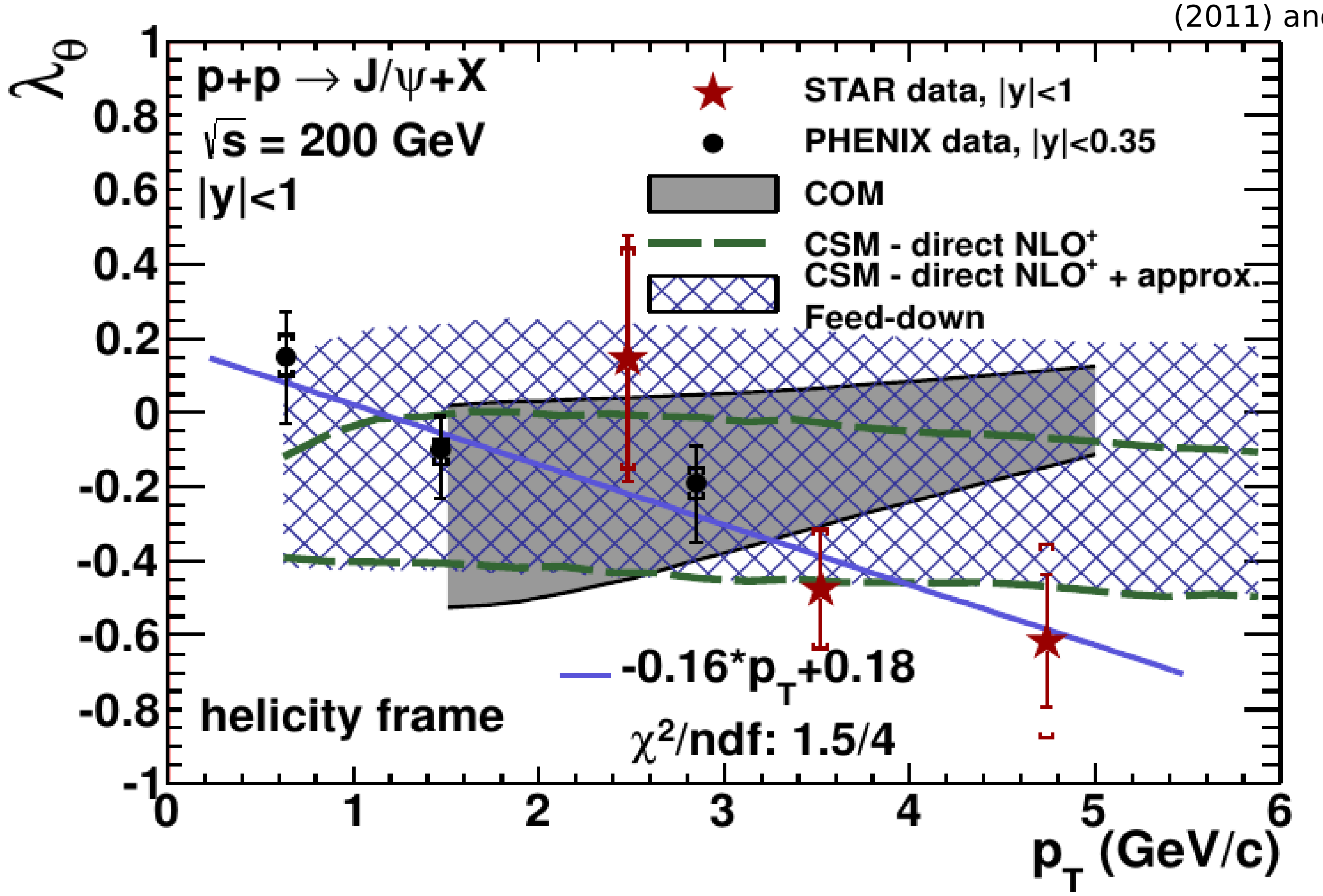
J/ψ polarization in p+p collisions at 200 GeV

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

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



STAR:
arxiv: 1311.1621

Polarization parameter λ_θ is measured in helicity frame at $|y| < 1$ and $2 < p_T < 6$ GeV/c

- ✓ RHIC data indicate trend towards longitudinal polarization with increasing p_T
- ✓ The result is consistent with NLO$^+$ CSM

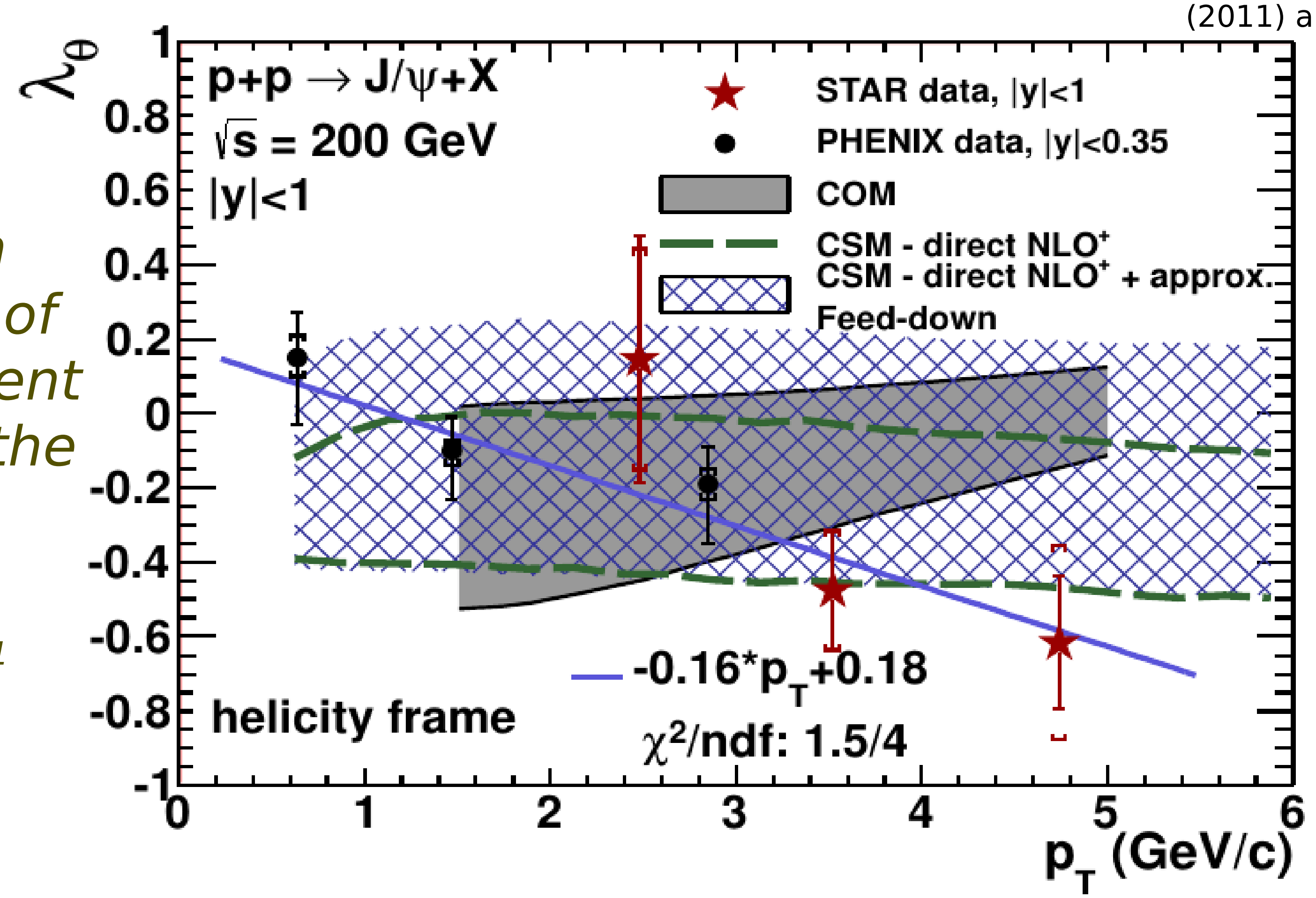
J/ψ polarization in p+p collisions at 200 GeV

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

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

2011 500 GeV data can help improve precision of polarization measurement and permit analysis of the full angular distribution

~1.8 pb^{-1} vs ~22 pb^{-1}



STAR: arxiv: 1311.1621

Polarization parameter λ_θ is measured in helicity frame at $|y| < 1$ and $2 < p_T < 6$ GeV/c

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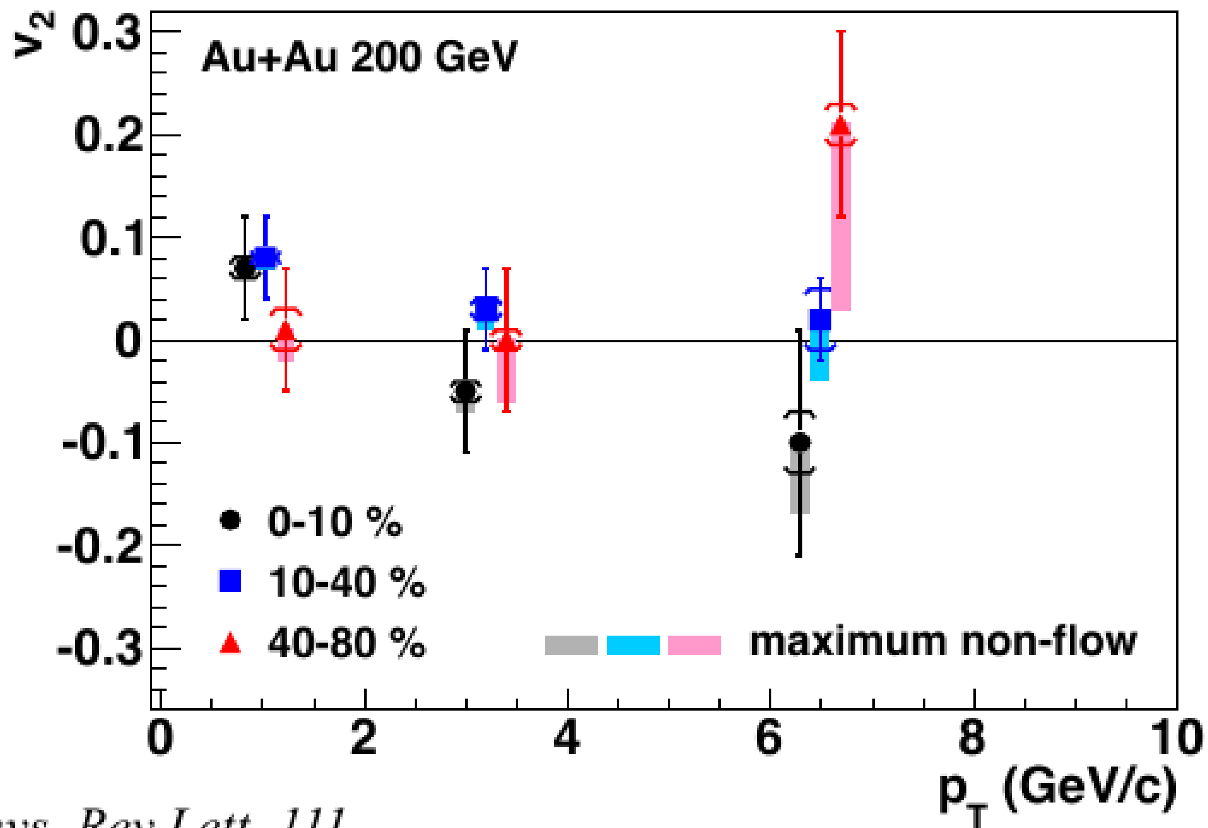
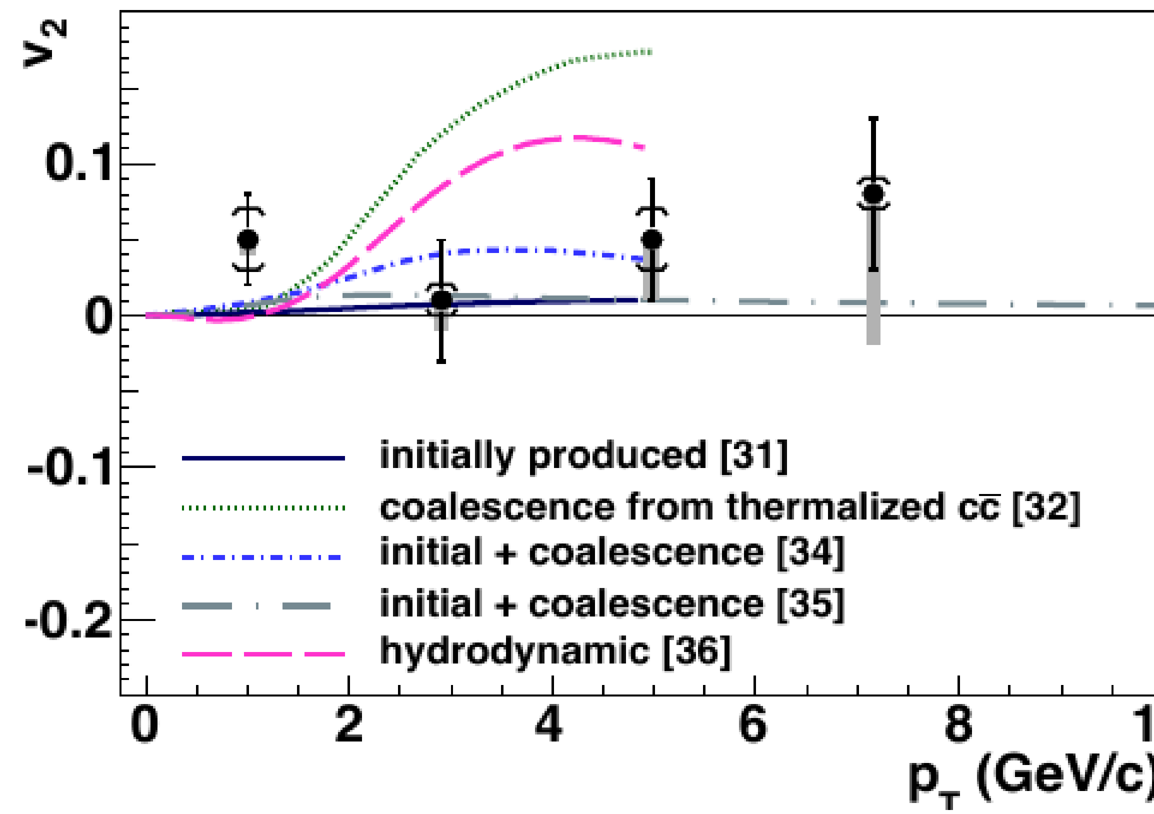
J/ψ v_2 in semi-central Au+Au collisions at 200 GeV



Phys. Rev Lett. 111 (2013) 52301



[31] L. Yan, P. Zhuang, and N. Xu, Phys. Rev. Lett. 97 (2006) 232301
[32] V. Greco, C.M. Ko, and R. Rapp, Phys. Lett. B 595 (2004) 202
[34] X. Zhao and R. Rapp, Phys. Lett. B 655 (2007) 126
[35] Y. Liu, N. Xu, and P. Zhuang, Nucl. Phys. A 834 (2010) 317c
[36] U. W. Heinz and C. Chen, private communication (2012)

✓ J/ψ v_2 is consistent with zero at $p_T > 2$ GeV/c

- disfavors the case that J/ψ with $p_T > 2$ GeV/c are produced dominantly by coalescence from thermalized (anti-)charm quarks

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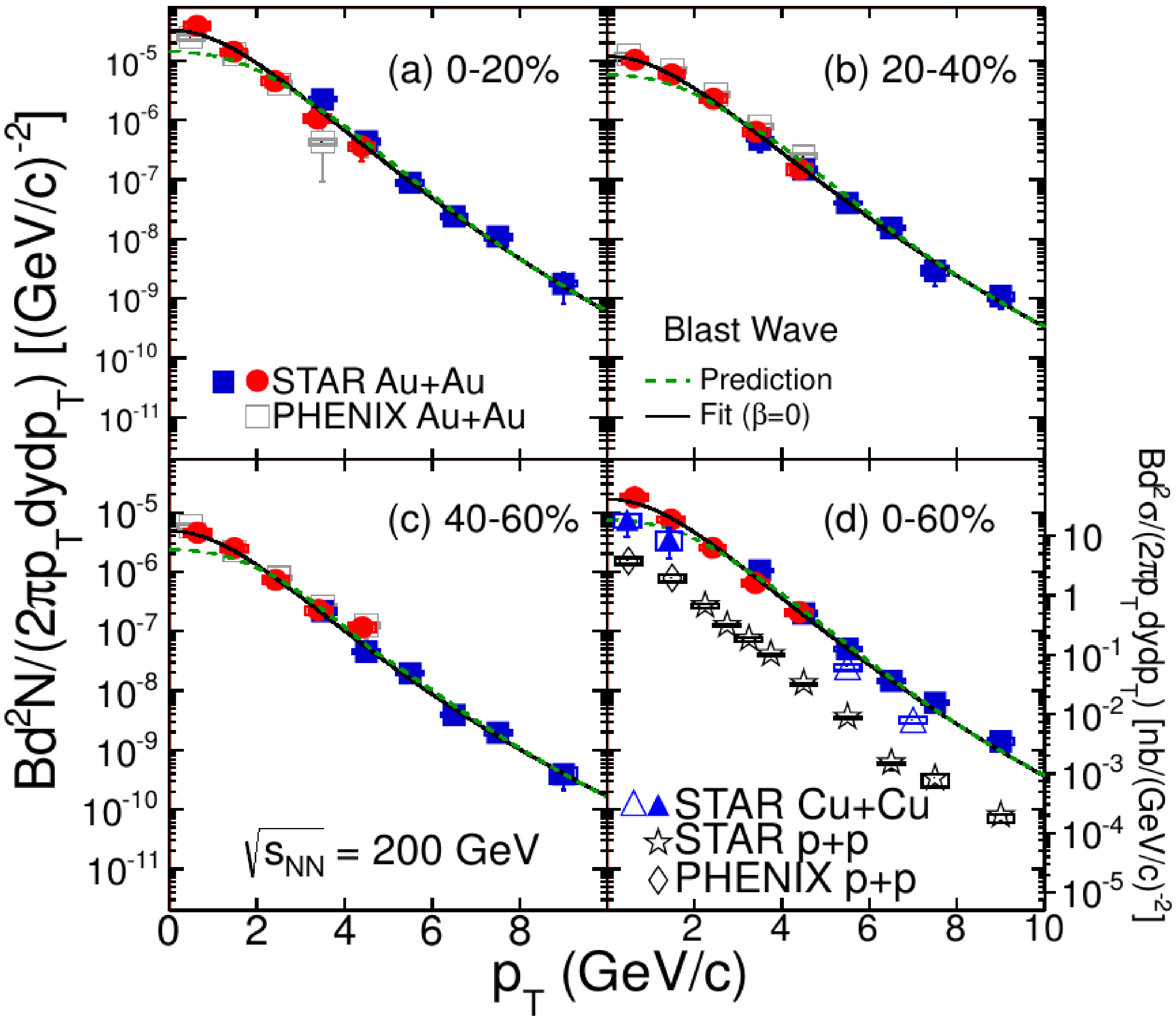
J/ψ p_T spectra in Au+Au collisions at 200 GeV



- ✓ At low p_T J/ψ spectra softer than the TBW prediction from light hadron

small radial flow ?

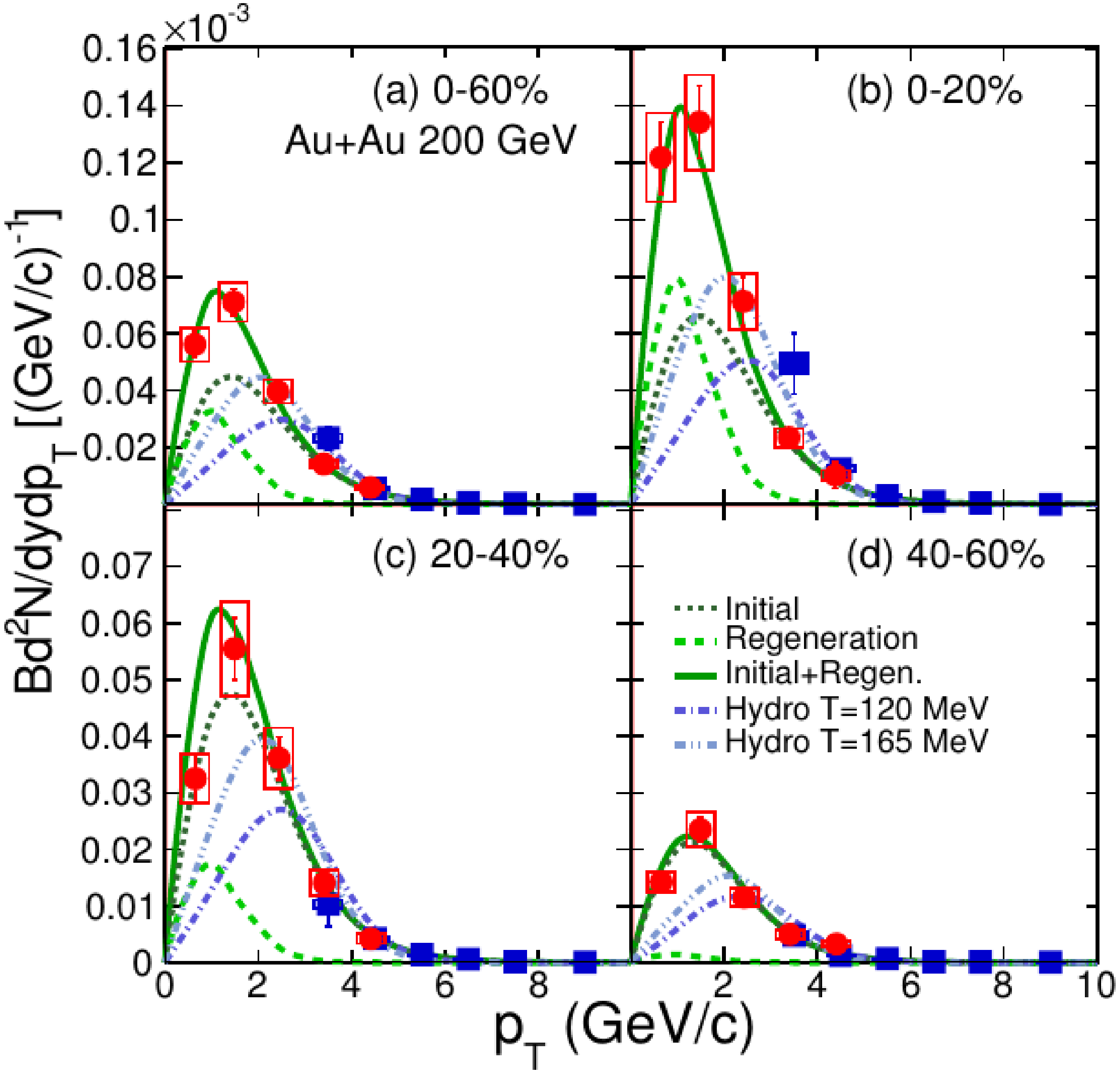
recombination at low p_T ?

J/ψ p_T range extended to 0-10 GeV/c

Tsallis Blast-Wave model:
Z.Tang et al., Phys. Rev. C 79 (2009) 051901
Z. Tang, L. Yi, L. Ruan, M. Shao, H. Chen, et al,,
Chin. Phys. Lett. 30 (2013) 031201
PHENIX: Phys. Rev. Lett. 98 (2007) 232301

STAR high-p_T : Phys. Lett. B 722 (2013) 55
STAR low-p_T : arxiv:1310.3563
STAR high-p_T Cu+Cu : Phys. Rev. C 80 (2009) 041902

J/ψ yield in Au+Au collisions at 200 GeV - comparison to models



✓ ***Viscous hydrodynamics***

- prediction for two J/ψ decoupling temperatures: T = 120 MeV and T = 165 MeV

Fails to describe the low-p_T J/ψ yield (< 2 GeV/c) and J/ψ elliptic flow at p_T > 2 GeV/c

✓ ***Liu et. al.***

- J/ψ suppression due to color screening + statistical regeneration + B-meson feed-down + formation-time effects

Describes the p_T spectrum

Hydro: U. W. Heinz and C. Shen (2011), private communication
Liu et. all: Y. Liu,Z. Qu, N. Xu, and P. Zhuang, Phys. Lett. B 678 (2009) 72

STAR high-p_T : Phys. Lett. B 722 (2013) 55
STAR low-p_T : arxiv:1310.3563

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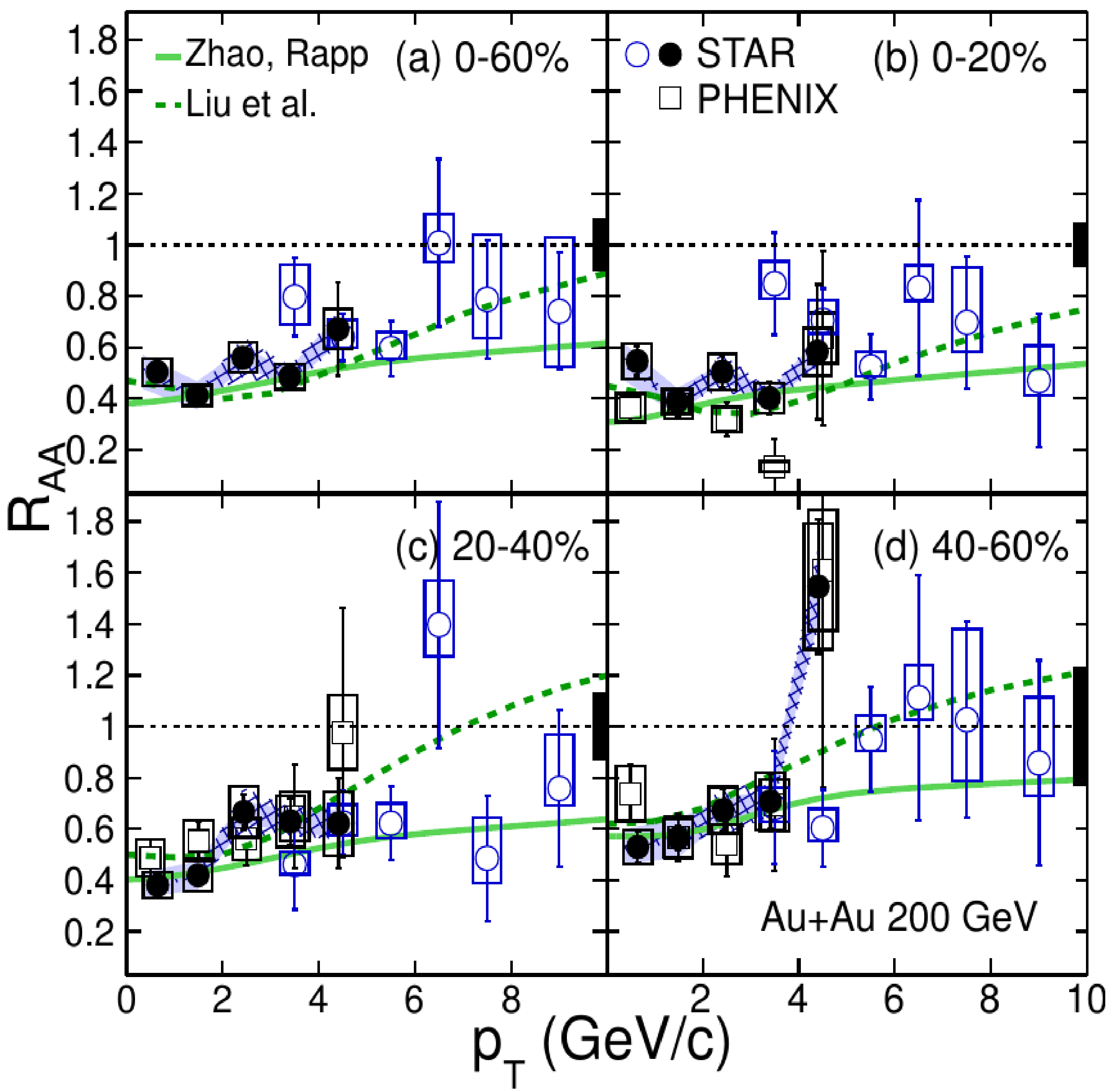
J/ψ R_{AA} vs p_T in Au+Au collisions at 200 GeV

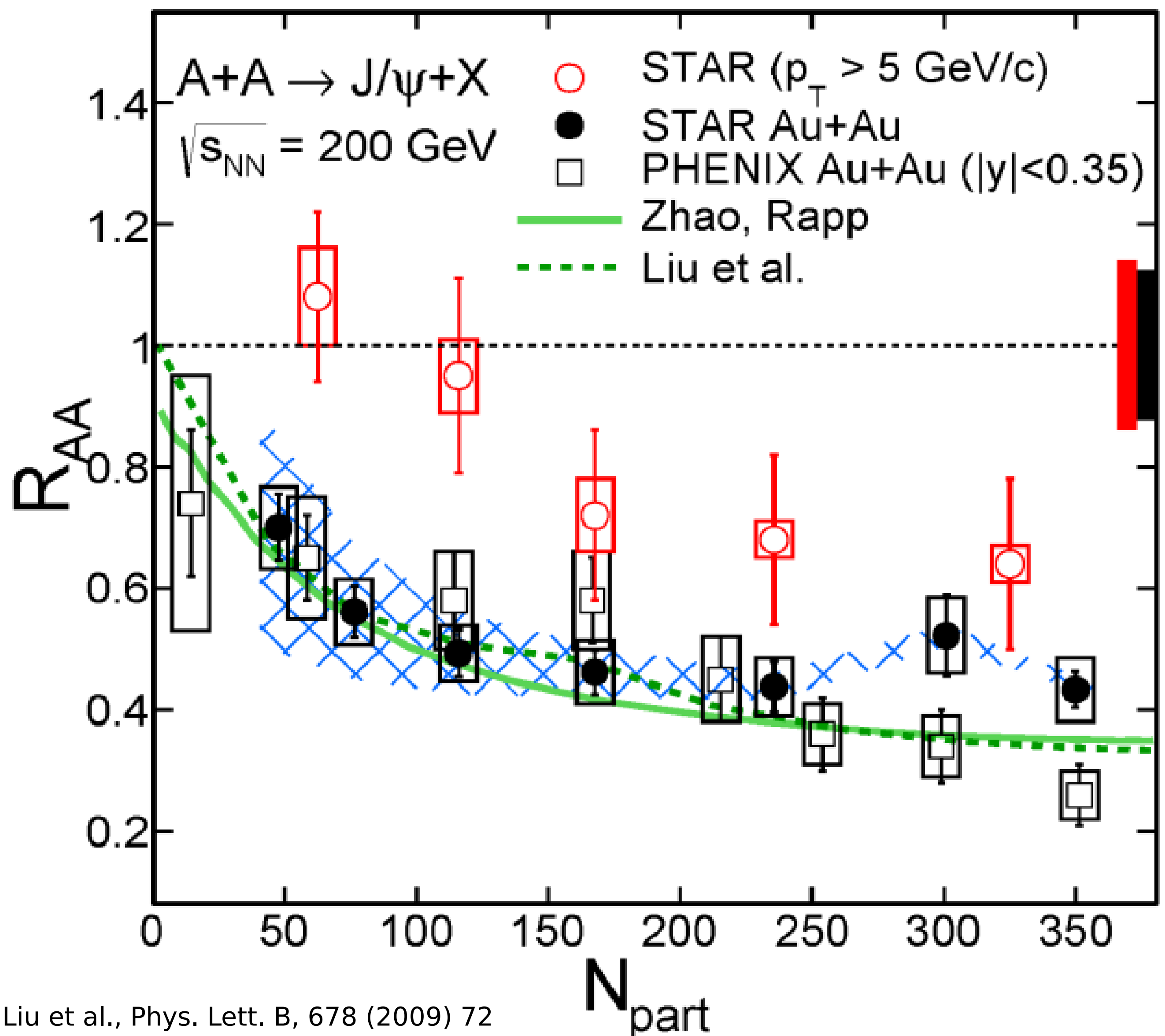


- ✓ J/ψ suppression decreases with increasing p_T across the centrality range
- ✓ Strong suppression at low p_T (< 3 GeV/c) for all centralities
- ✓ At high-p_T:
  - suppression for central collisions
  - R_{AA} consistent with unity in (semi-)peripheral collisions
- ✓ Data agrees with theoretical calculations
  - color screening + statistical regeneration
    - Zhao et. al: + formation-time effect and B-hadron feed-down

Y.Liu et al., Phys. Lett. B, 678 (2009) 72
Zhao, Rapp, Phys. Rev. C 82 (2010) 064905
PHENIX: Phys. Rev. Lett. 98 (2007) 232301

STAR high-p_T : Phys. Lett. B 722 (2013) 55
STAR low-p_T : arxiv:1310.3563

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



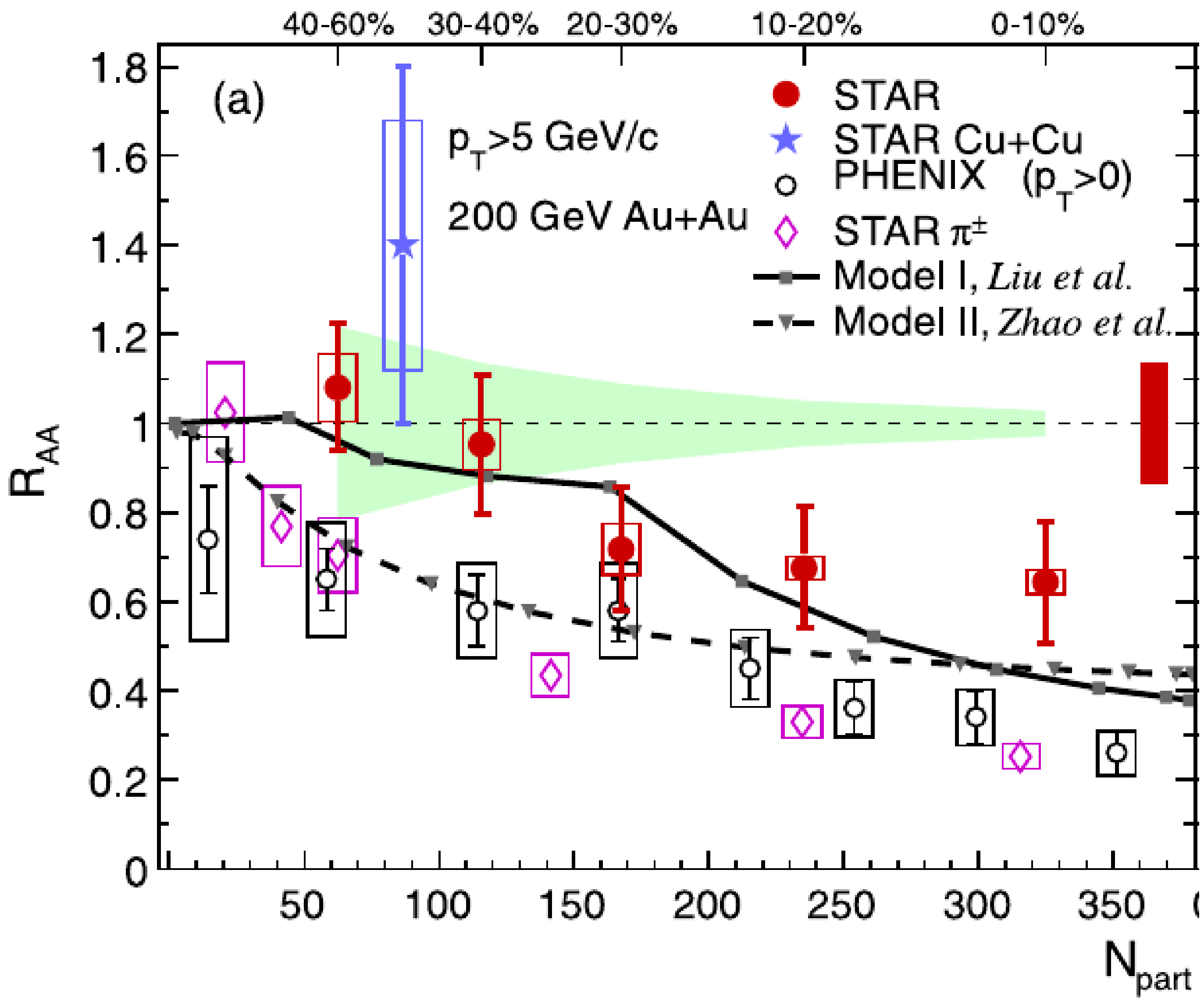
Y.Liu et al., Phys. Lett. B, 678 (2009) 72
Zhao, Rapp, Phys. Rev. C 82 (2010) 064905
PHENIX: Phys. Rev. Lett. 98 (2007) 232301

STAR high-p_T : Phys. Lett. B 722 (2013) 55
STAR low-p_T : arxiv:1310.3563

- ✓ Suppression increases with collision centrality
- ✓ High-p_T R_{AA} is systematically higher
- ✓ High-p_T J/ψ suppressed in central collisions
  - QGP effects ?

- ✓ Both models describe the data well at low p_T

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



Y.Liu et al., Nucl. Phys A 834 (2010) 317c
Zhao, Rapp, Phys. Rev. C 82 (2010) 064905
PHENIX: Phys. Rev. Lett. 98 (2007) 232301

STAR high-p_T : Phys. Lett. B 722 (2013) 55
STAR low-p_T : arxiv:1310.3563

- ✓ Suppression increases with collision centrality
- ✓ High-p_T R_{AA} is systematically higher
- ✓ High-p_T J/ψ suppressed in central collisions
  - QGP effects ?
- ✓ Both models describe the data well at low p_T
- ✓ At high p_T Liu et al. model describes the data well, while Zhao et. al model underpredicts the R_{AA}

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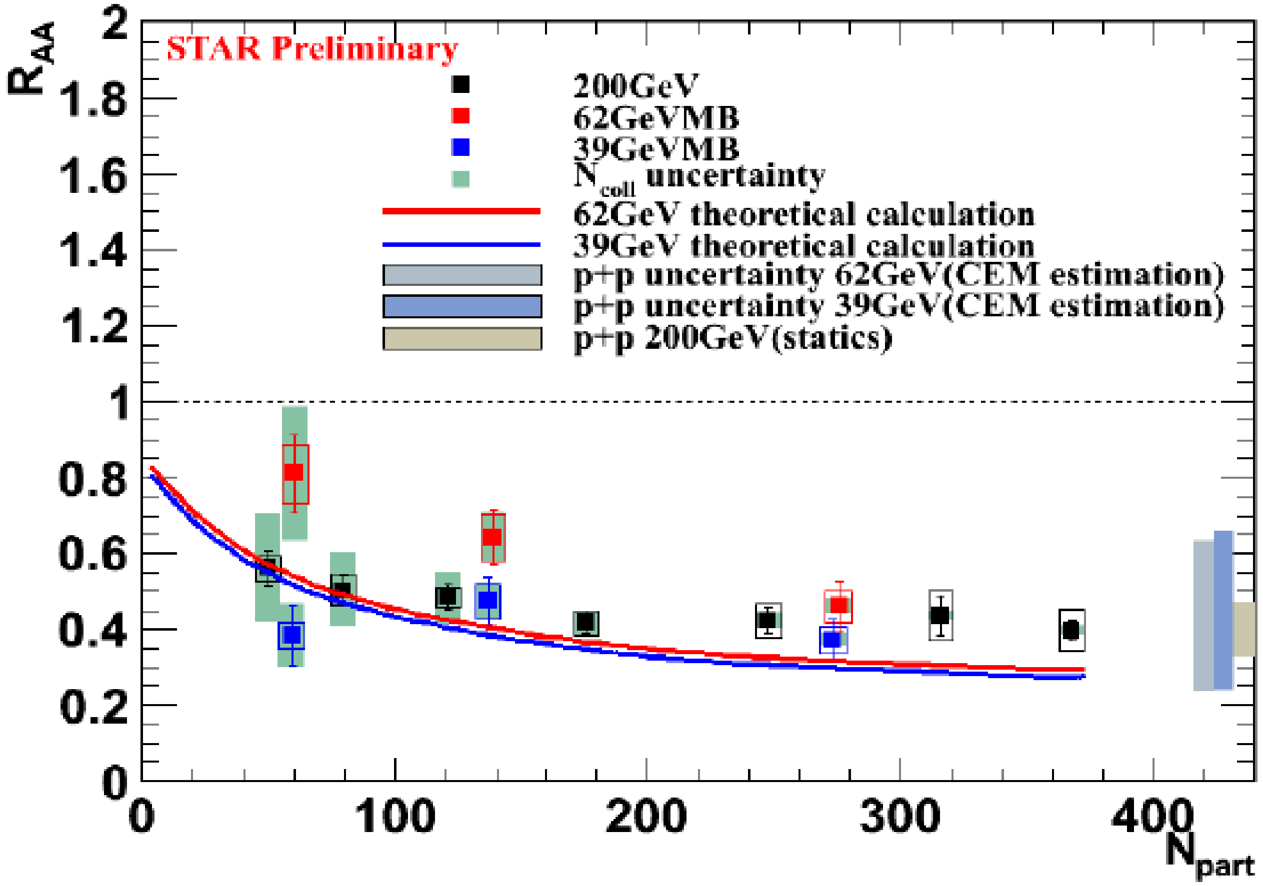
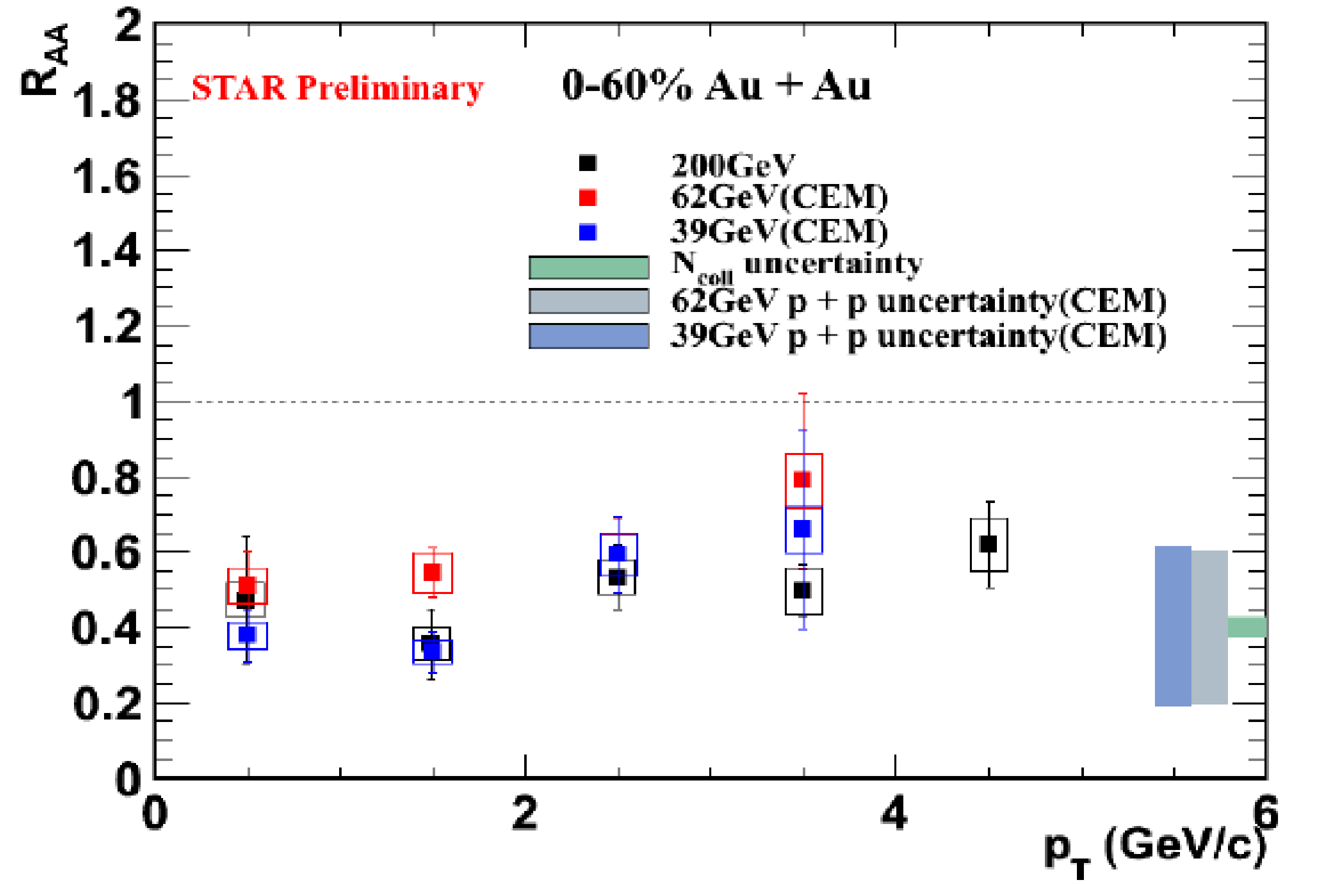
Energy dependence of J/ψ R_{AA}

theoretical calculation: X. Zhao, R. Rapp, Phys. Rev. C 82 (2010) 064905
CEM: R. E. Nelson, R. Vogt and A. D. Frawley, Phys. Rev. C 87, 014908 (2013).

New measurements at 62.4 and 39 GeV





- ✓ Suppression of J/ψ at 62.4 and 39 GeV - no strong energy dependence of J/ψ R_{AA}
- ✓ Data agrees with the prediction of the two-component model
  - p+p reference for 62.4 and 39 GeV data from Color Evaporation Model (CEM) - large theoretical uncertainties

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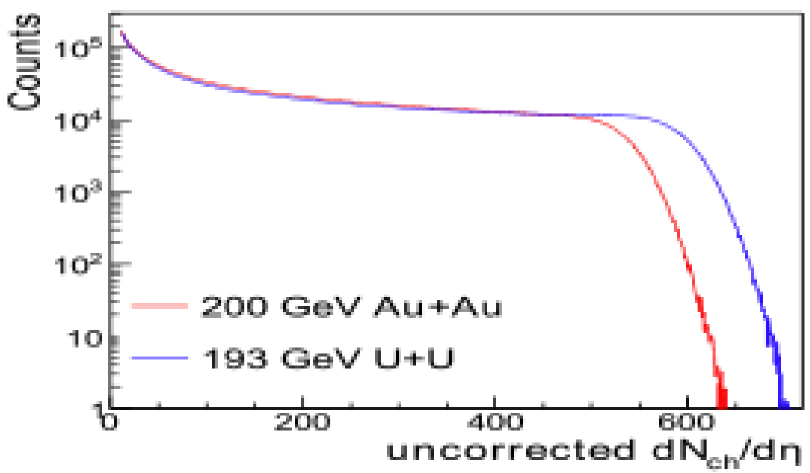
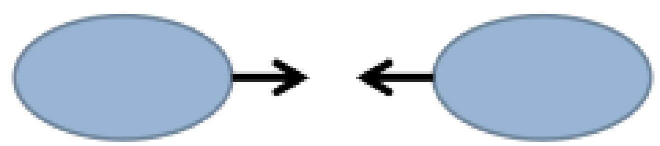
J/ψ in U+U collisions at 193 GeV

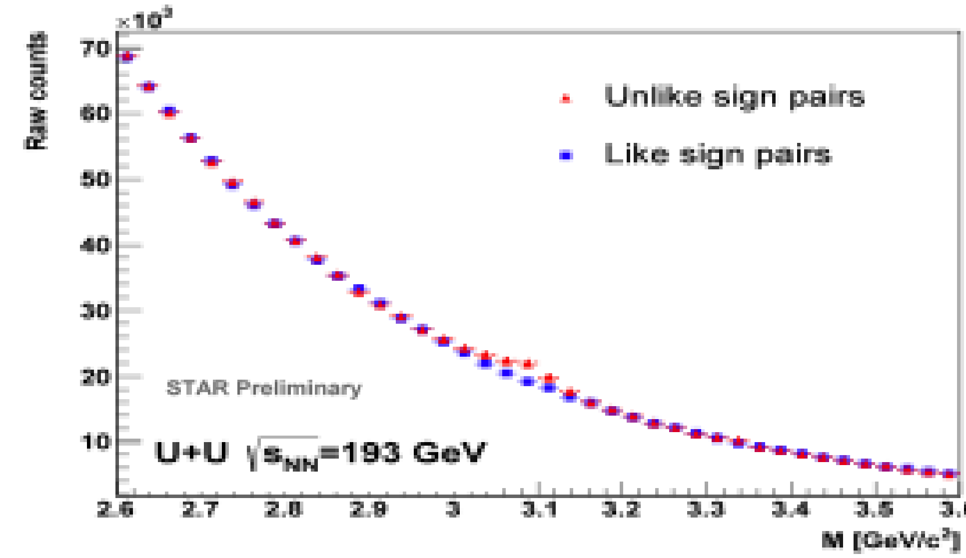
✓ Non- spherical nucleus - higher initial energy density





Tip-to-tip collision

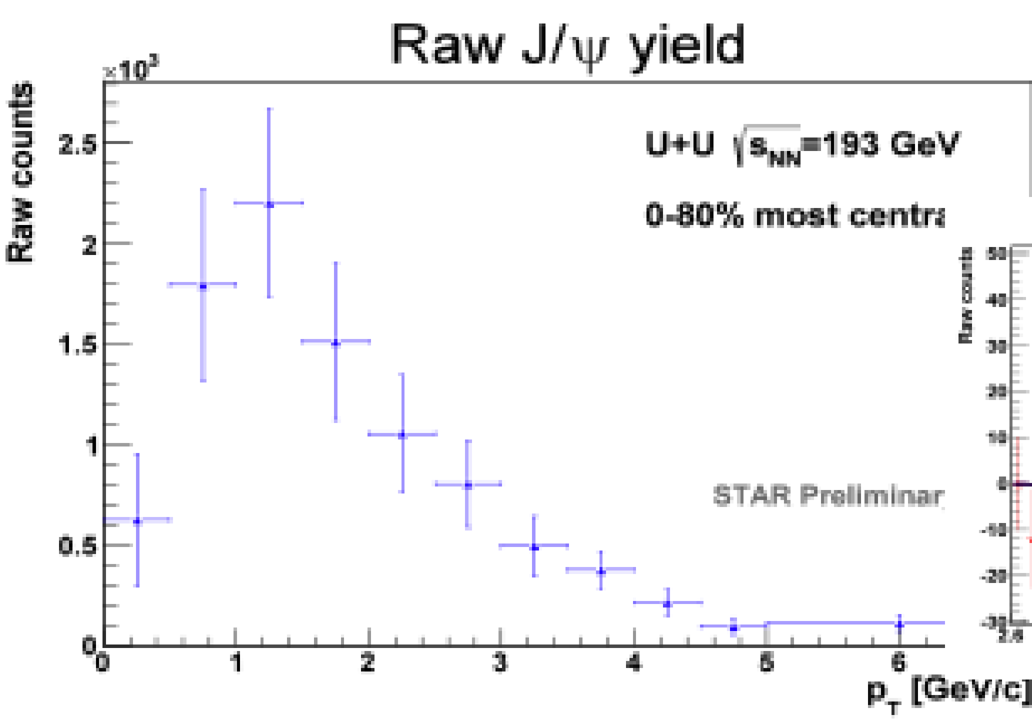
377M minimum bias events

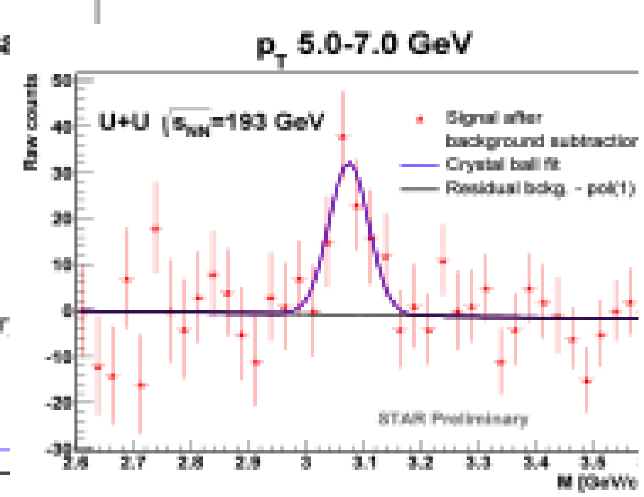


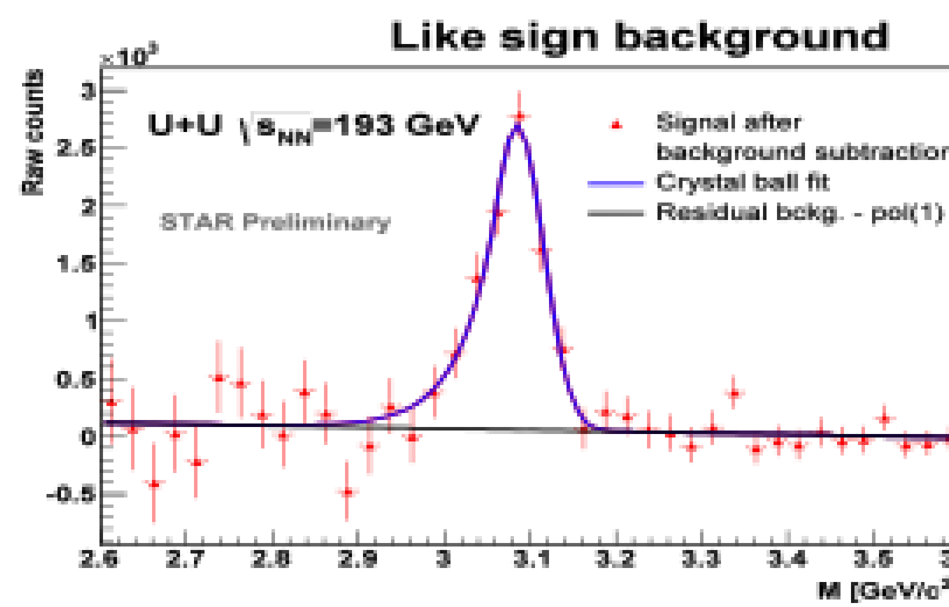
Can divide signal into 11 p_T bins up to 6 GeV/c

S = 9440 ± 640 in (2.9-3.2) GeV/c^2

significance ~ 13







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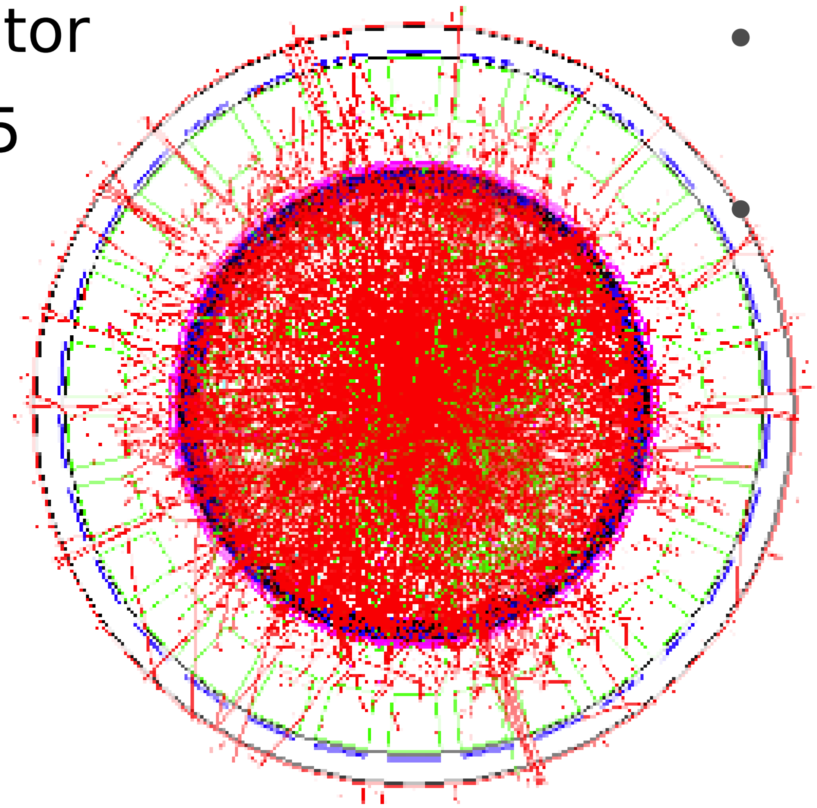
Muon Telescope Detector (MTD)

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

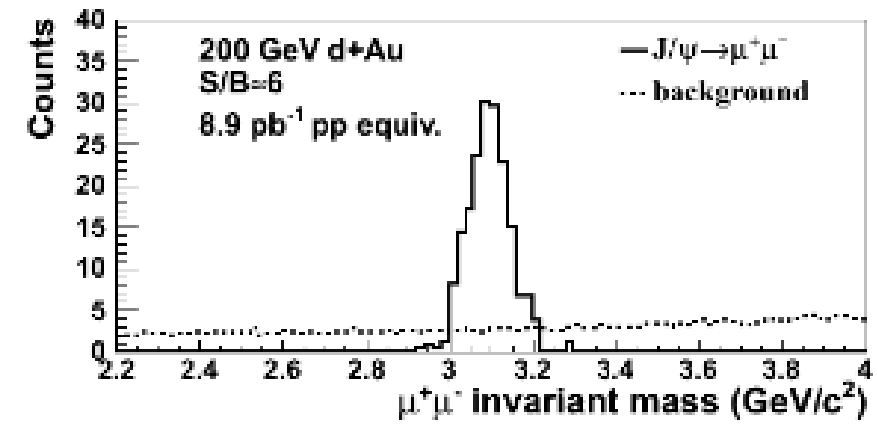
Acceptance: 45% at |η| < 0.5

Long-MRPCs

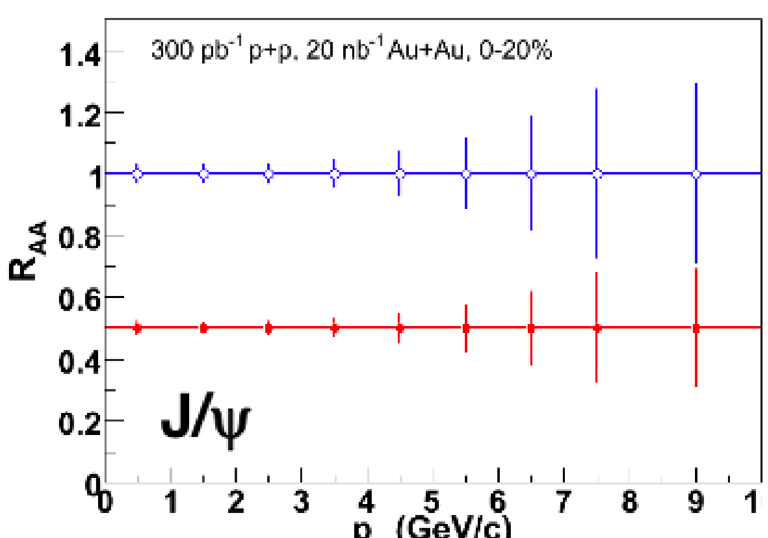
Electronics same as in STAR TOF

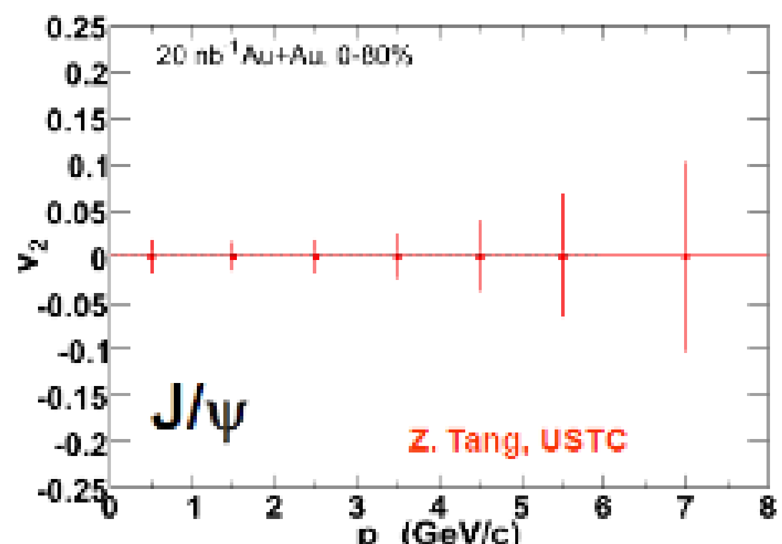


- No γ conversion
- Much less Dalitz decay contribution
- Less affected by radiative looses in the materials



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





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

Full system in 2014

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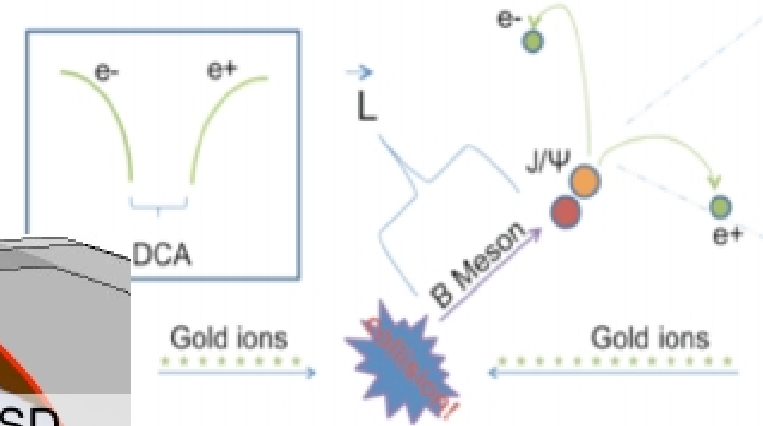
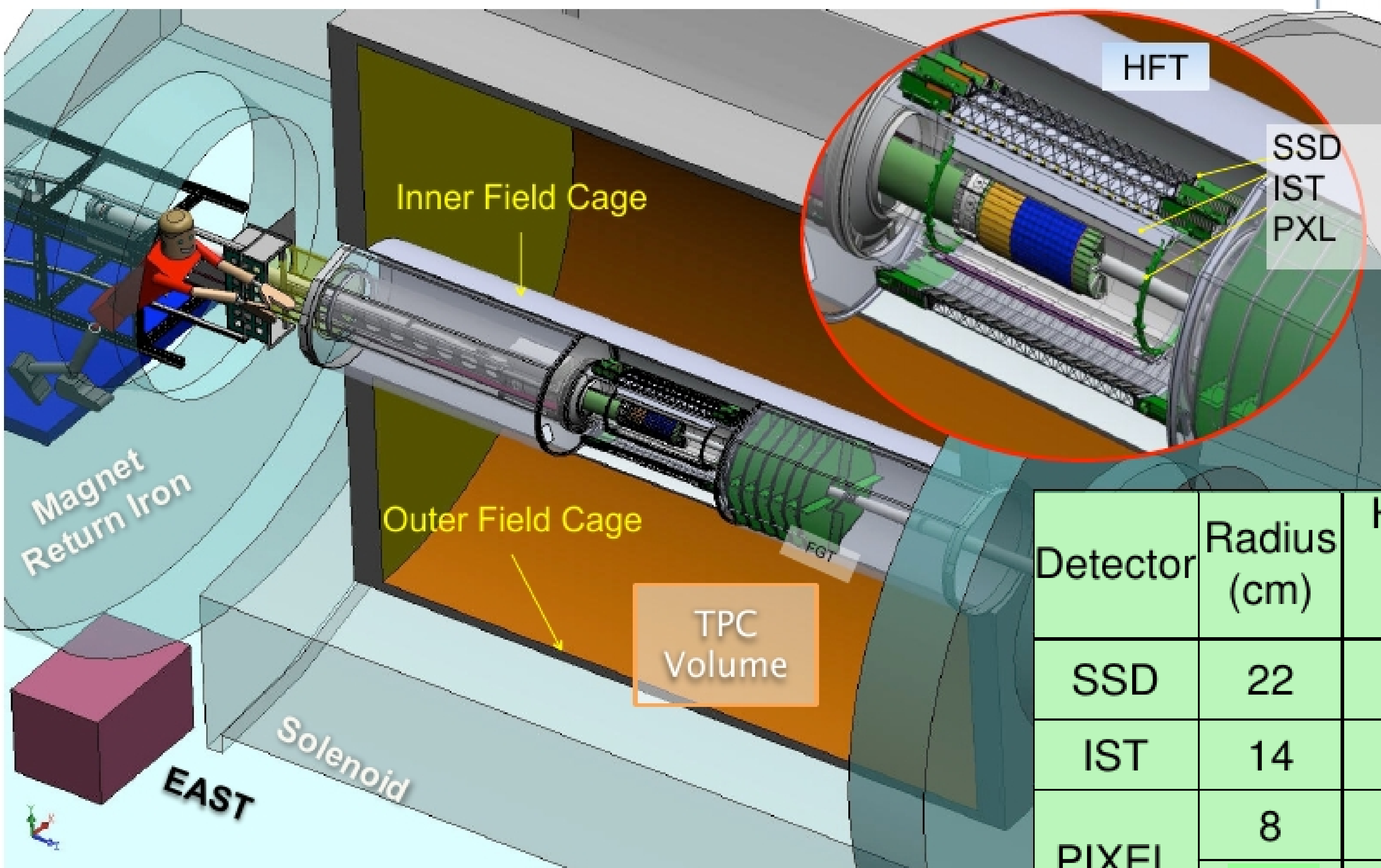
Heavy Flavor Tracker (HFT)

Non-prompt J/ψ: $\boldsymbol{B \rightarrow J/\psi + X}$





Detector	Radius (cm)	Hit Resolution R/φ - Z (μm - μm)	Radiation length
SSD	22	20 / 740	1% X_0
IST	14	170 / 1800	<1.5 %X_0
PIXEL	8	12/ 12	~0.4 %X_0
	2.7	12 / 12	~0.4% X_0

Full system in 2014

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Summary

- NLO CS+CO and CEM models describe J/ψ p_T spectrum in p+p, polarization consistent with NLO^+ CSM
- 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
- J/ψ suppression in Au+Au increases with centrality and decreases with p_T - at high p_T suppression for central collisions
- Similar J/ψ suppression at 200, 62.4 and 39 GeV

Czech Technical University in Prague
Faculty of Nuclear Science and Physical Engineering
Project „ Support of inter-sectoral mobility and quality enhancement of research teams at Czech Technical University in Prague "
CZ.1.07/2.3.00/30.0034

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Thank you !

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Backup

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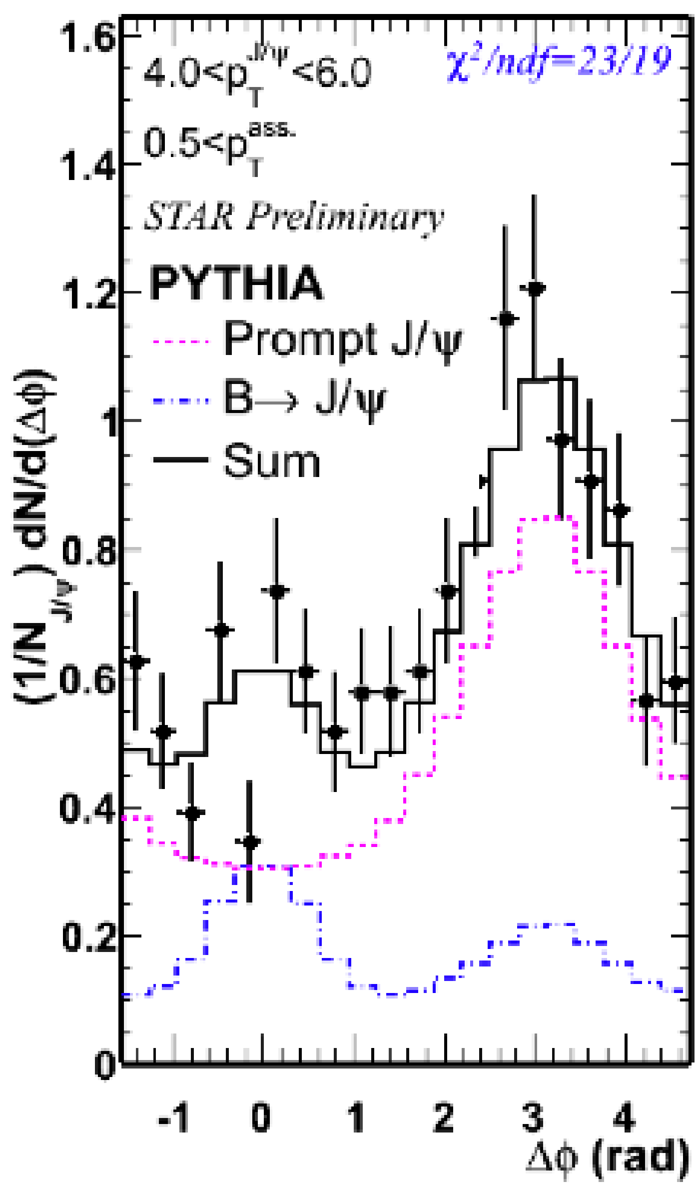
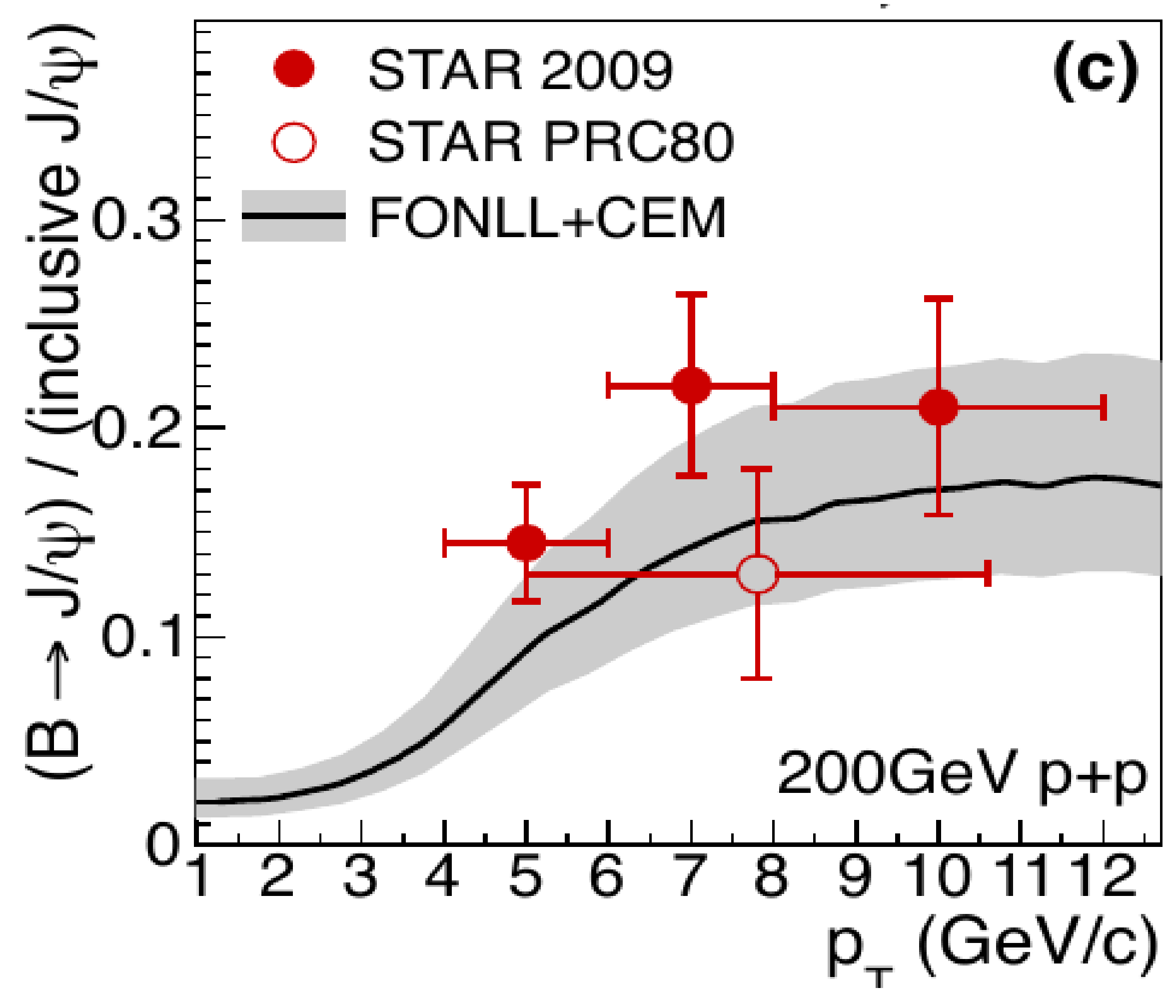
J/ψ-hadron correlations in p+p collisions at 200 GeV

Phys. Lett. B 722 (2013) 55

B → J/ψ feed-down

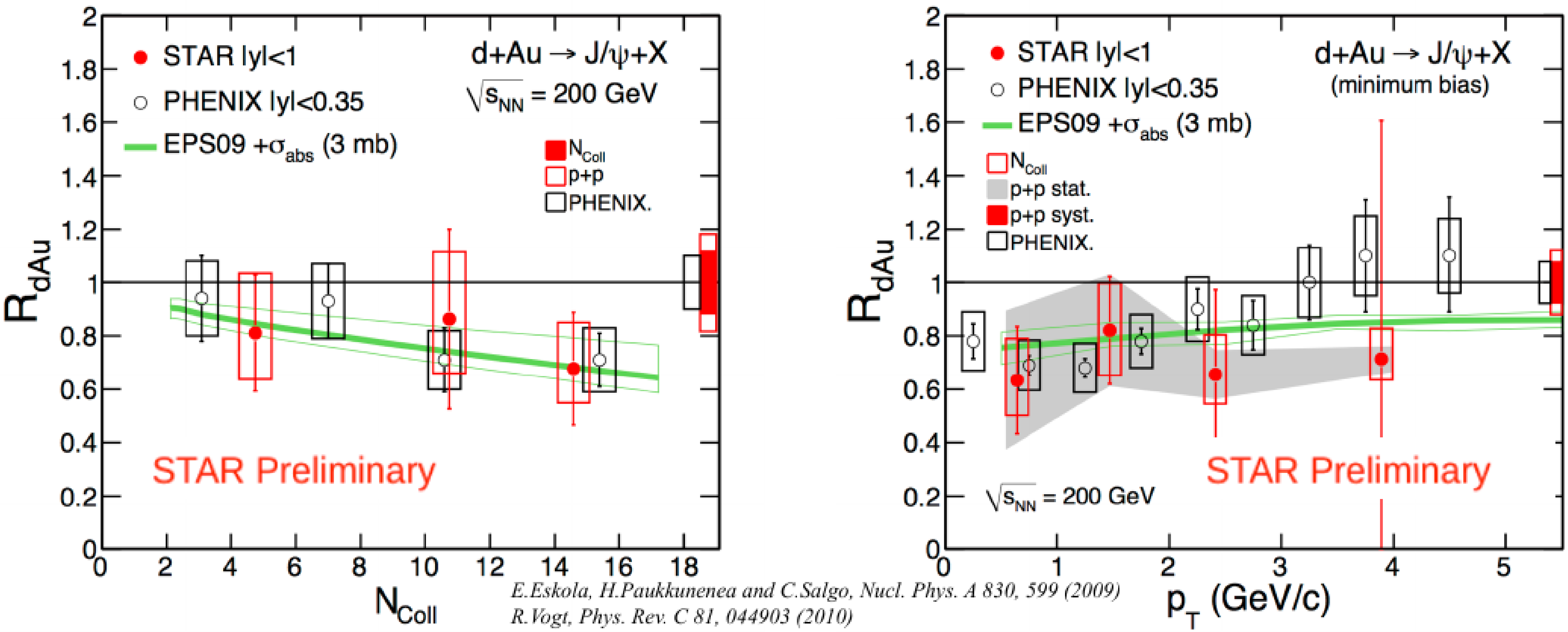
Model based extraction using PYTHIA





- ✓ 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

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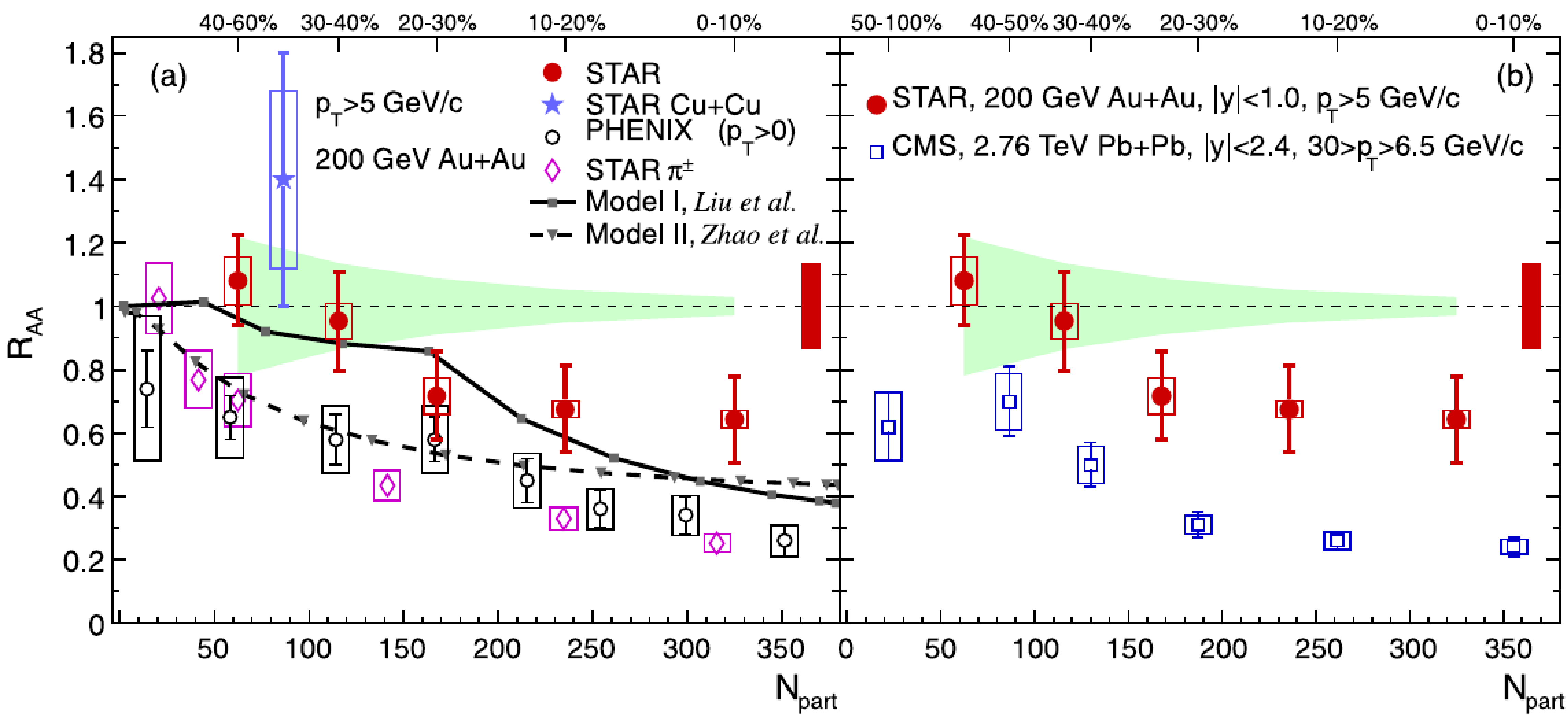
J/ψ R_{AA} vs N_{part} in Au+Au collisions at 200 GeV



- ✓ Higher R_{AA} for STAR than CMS for all centralities

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