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RHIC highlights and prospects for Heavy-flavour studies

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Czech Technical University in Prague

Probing the Strong Interaction at A Fixed Target ExpeRiment with the LHC beams

Ecole de Physique des Houches

15.1.2014

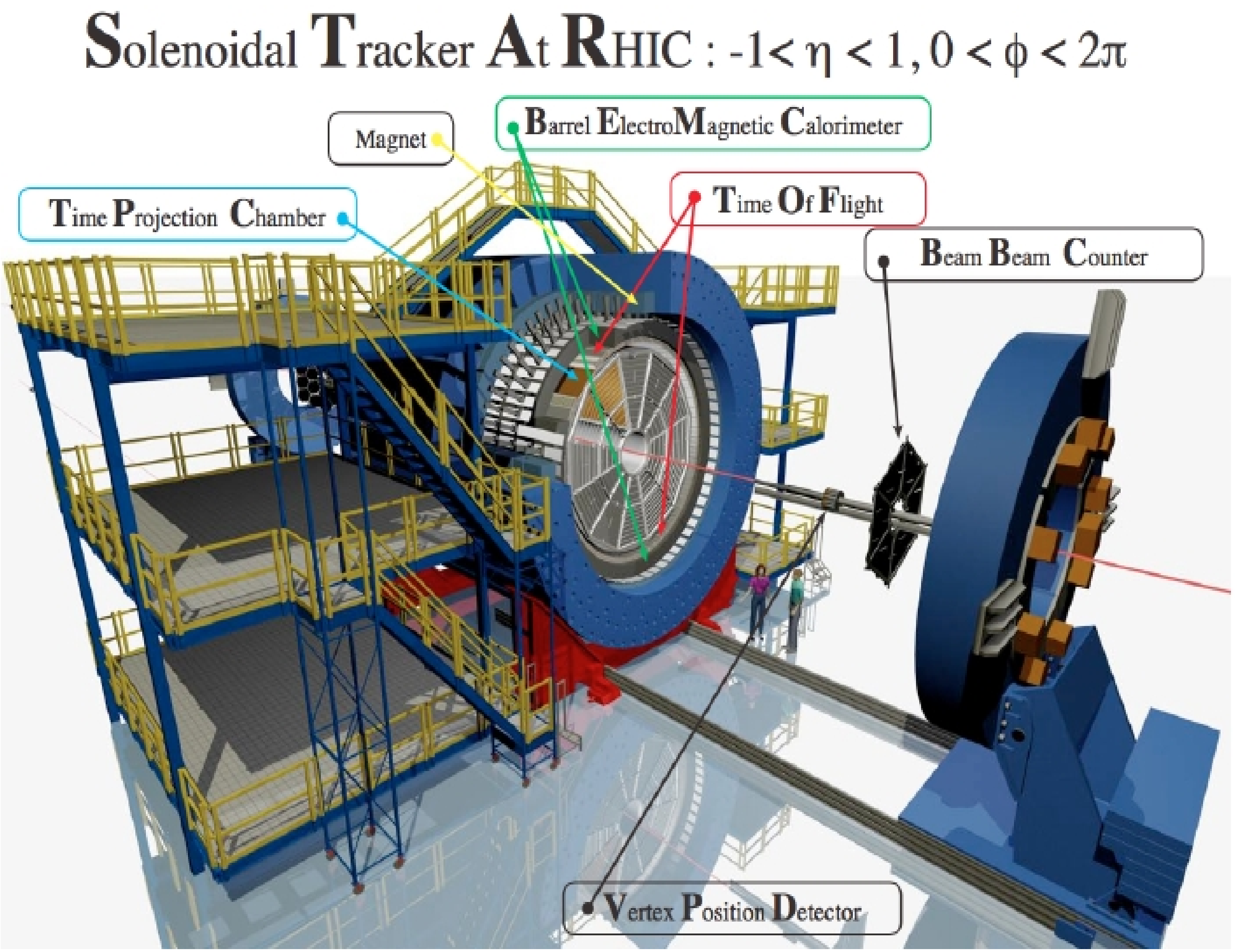
AFTER @ LHC

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

Outline

- Quarkonia and heavy flavor measurements in d+Au and A+A collisions and different energies
- Prospects

STAR EXPERIMENT

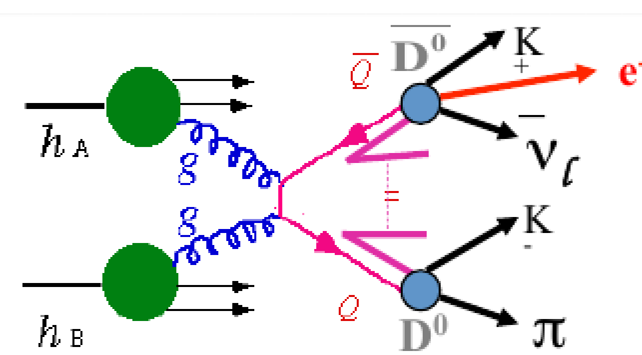


✓ Large acceptance:

- |η| < 1, 0 < φ < 2π

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

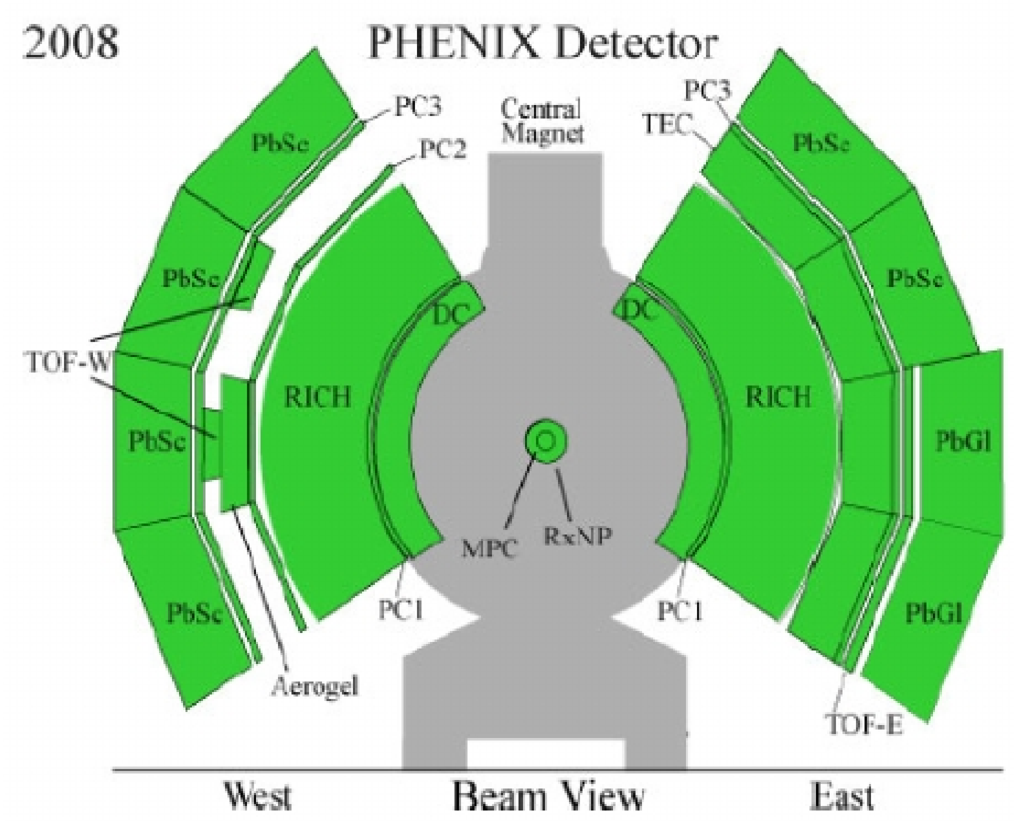
$$\Upsilon \rightarrow e^{+}e^{-} \;(BR\ 2.4\%)$$

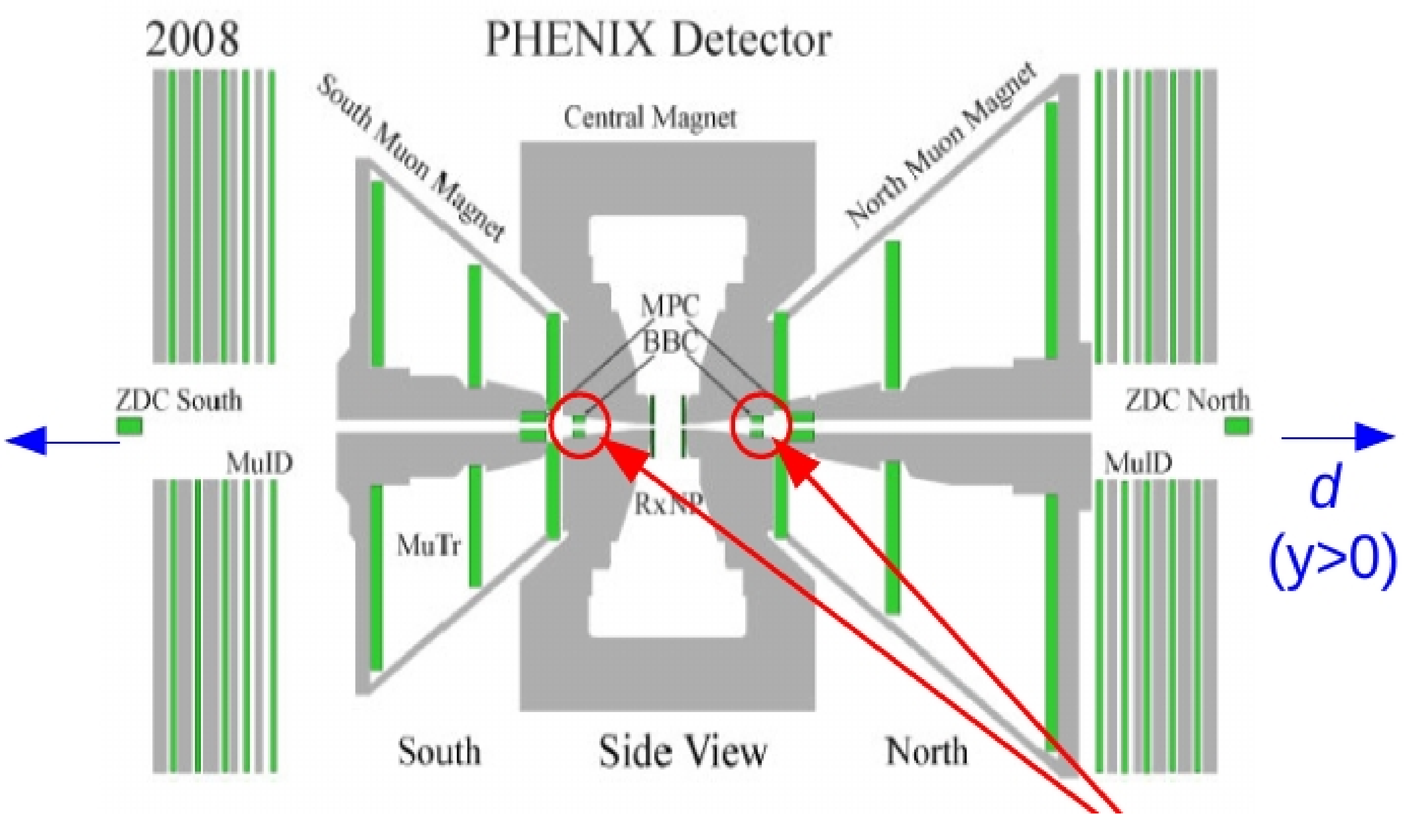


PHENIX EXPERIMENT

D, B → $e^{\pm}$
J/ψ → $e^{+}e^{-}$
$-0.35 < y < 0.35$
$\Delta\Phi = \pi$

D, B → $\mu^{\pm}$
J/ψ → $\mu^{+}\mu^{-}$
$-2.2 < y < -1.2$
$1.2 < y < 2.4$
$\Delta\Phi = 2\pi$





Central Arms

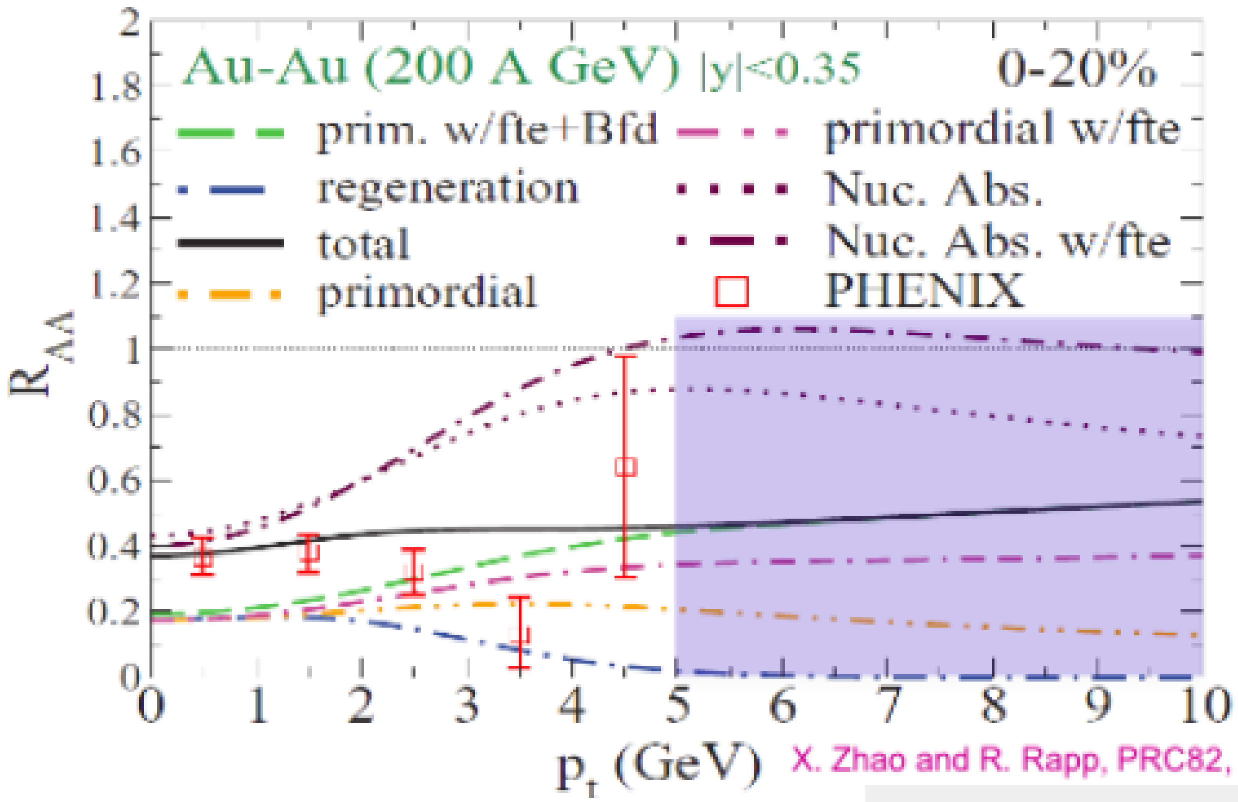
Muon Arms

Quarkonia at RHIC

- ✓ Quarkonia 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
- ✓ ***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 (anti-)shadowing, Cronin effect, nuclear absorption, initial-state parton energy loss, ...
- ✗ Other ***Hot Nuclear Matter effects*** – statistical coalescence, ...

How to disentangle color screening vs CNM effects vs recombination

- <u>J/ψ production vs energy</u> - *varying relative contributions*
- <u>High-p_T J/ψ</u> - *almost not affected by Nucl. Abs. and recombination*
- <u>Υ</u> rare but clearer probe compare to J/ψ – *negligible co-mover absorption and recombination*



X. Zhao and R. Rapp, PRC82, 064905

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

σ_{cc} @ RHIC: 797 ± 210 $^{+208}_{-295}$ μb. (PRD 86, 072013(2012))

σ_{bb} @ RHIC: ~ 1.34 – 1.84 μb (PRD 83 (2011) 052006)

- <u>Quarkonia in d+Au</u> – *investigate CNM effects*

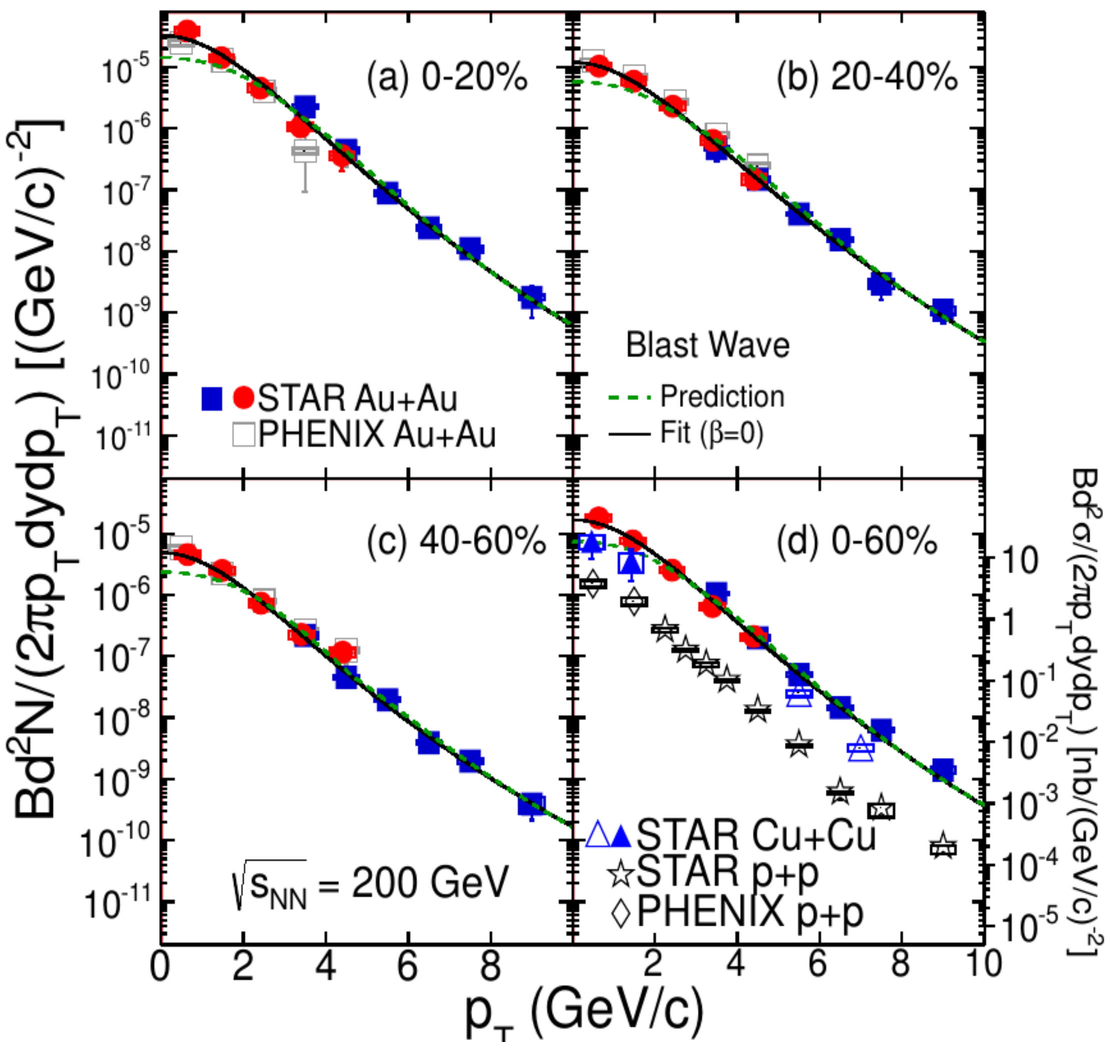
✓ *Measure quarkonia production for different colliding systems, centralities and collision energies*

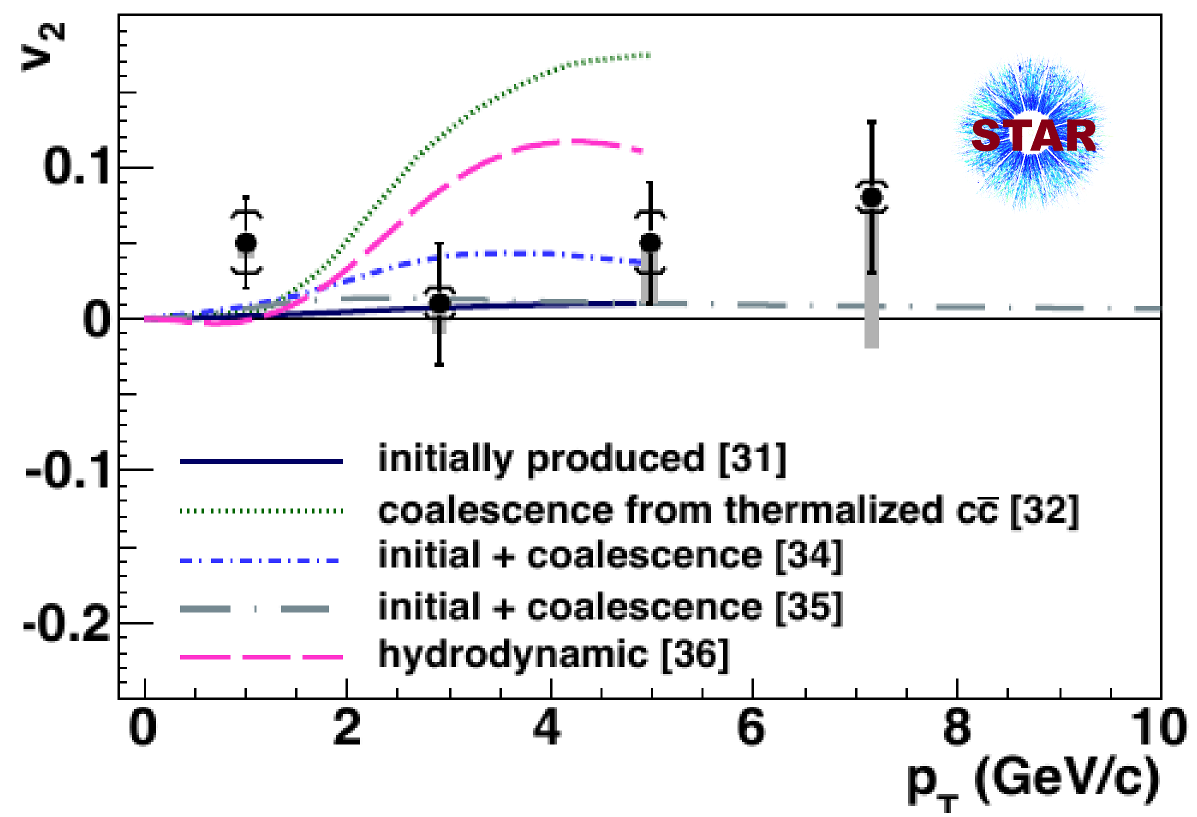
➡ p_T spectra, R_{AA}, polarization, elliptic flow ...

J/ψ

A+A

J/ψ in Au+Au at 200 GeV at mid-rapidity





[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*

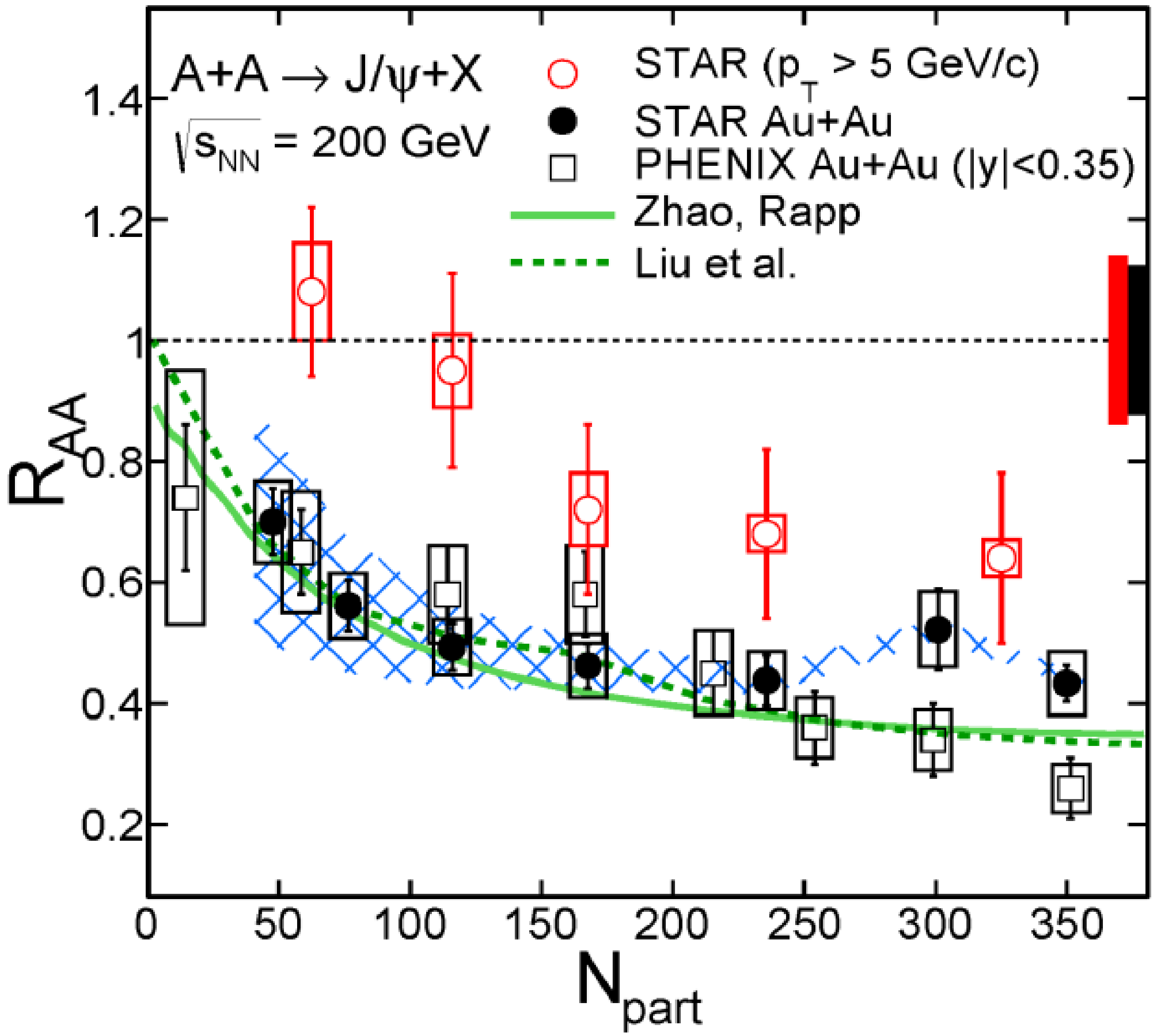
- disfavors the case that J/ψ with $p_T > 2$ GeV/c are produced dominantly by coalescence from thermalized (anti-)charm quarks

✓ *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 R_{AA} vs N_{part} in Au+Au at 200 GeV at mid-rapidity



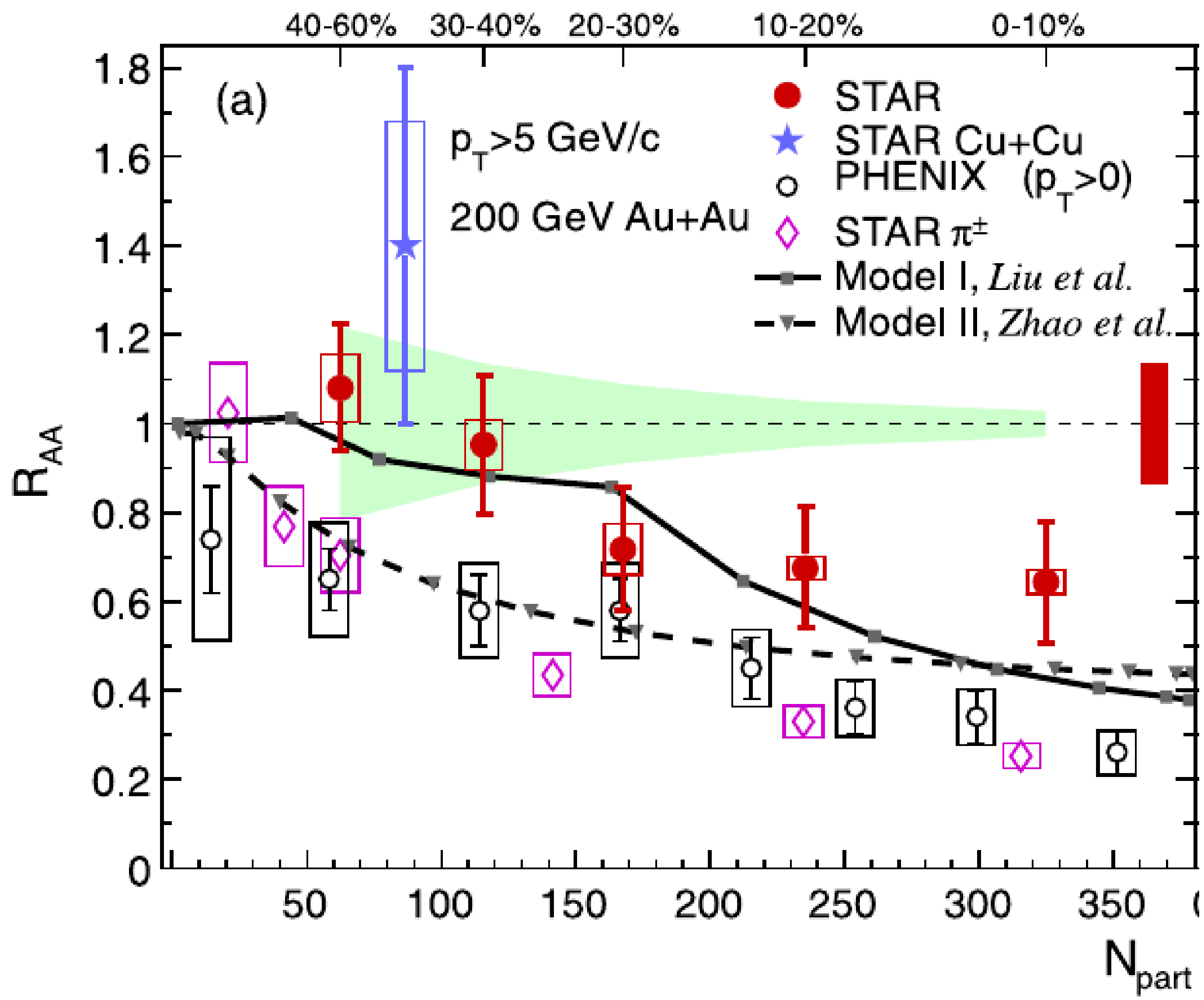
- ✓ *Suppression increases with collision centrality and decreases with p_T*
- ✓ High-p_T R_{AA} is systematically higher
- ✓ High-p_T J/ψ suppressed in central collisions
  - QGP effects ?
- Both models describe the data at low p_T

- ✓ Theoretical calculations
  - color screening + statistical regeneration + CNM
    - 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 at 200 GeV at mid-rapidity



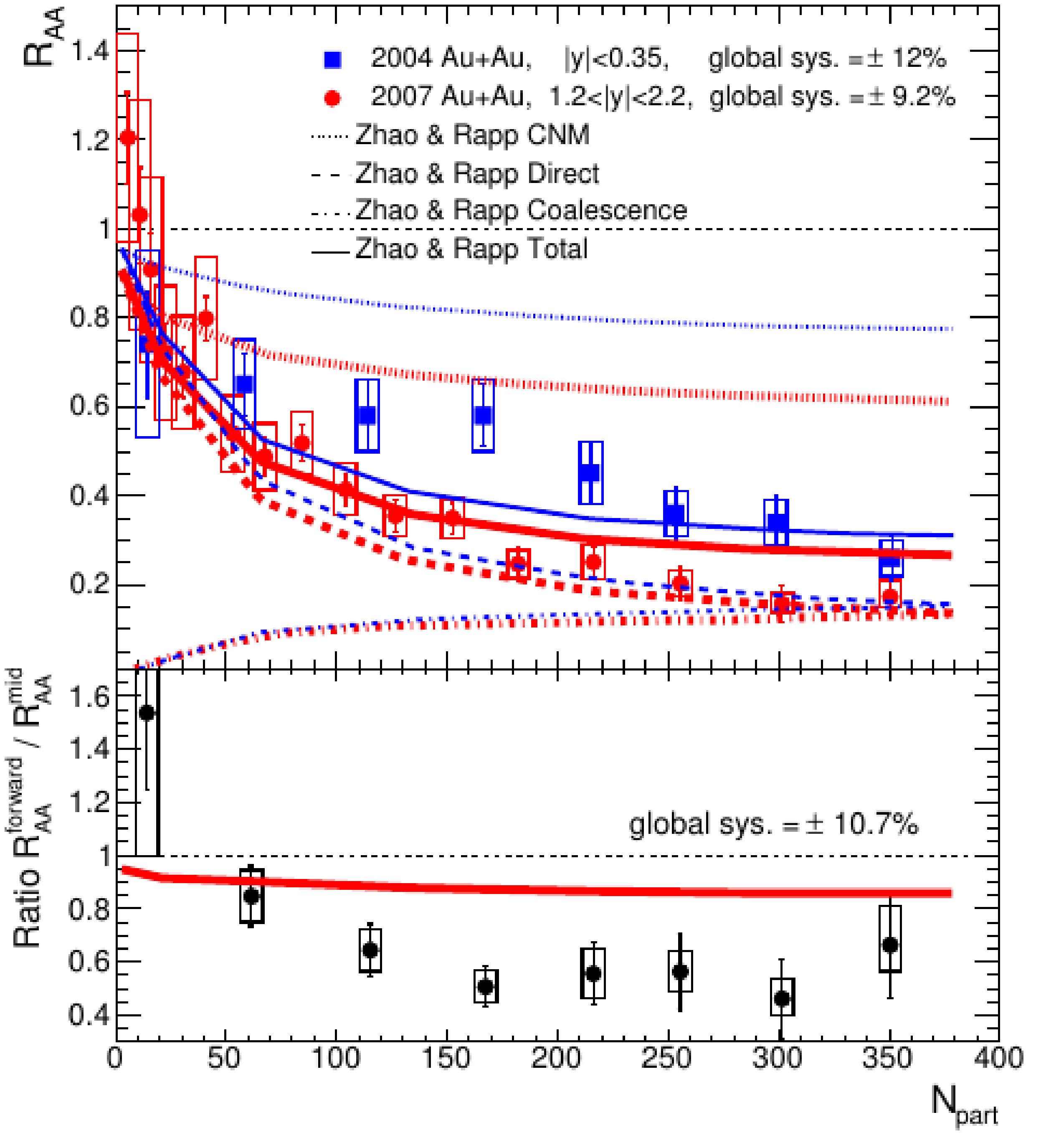
- ✓ *Suppression increases with collision centrality and decreases with p_T*
- ✓ High-p_T R_{AA} is systematically higher
- ✓ High-p_T J/ψ suppressed in central collisions
  - QGP effects ?
- Both models describe the data at low p_T
- At high p_T Liu et al. model describes the data well, while Zhao et.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

- ✓ *No suppression at high-p_T Cu+Cu*

PHENIX: Phys. Rev. Lett. 98 (2007) 232301
STAR high-p_T : Phys. Lett. B 722 (2013) 55
STAR low-p_T : arxiv:1310.3563

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

J/ψ R_{AA} in Au+Au at 200 GeV, mid vs. forward y



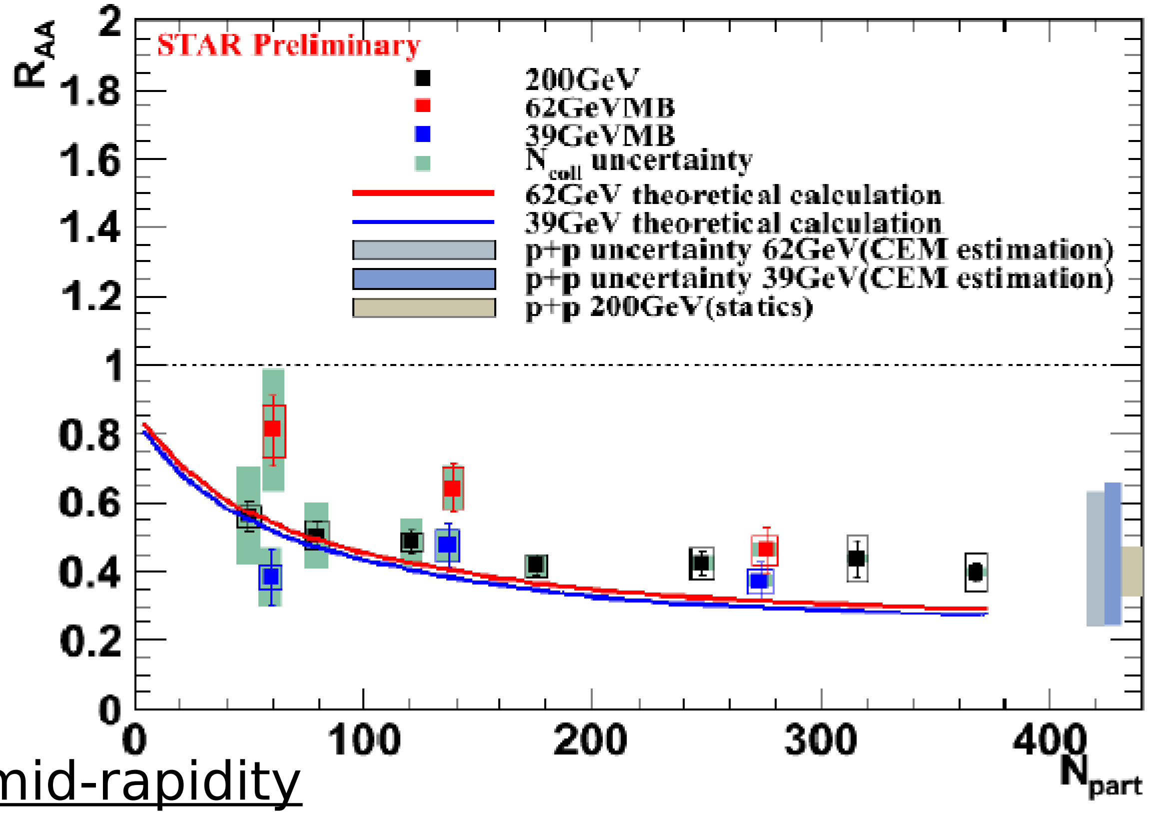
PHENIX: Phys. Rev. Lett. 98 (2007) 232301

✓ *More suppression for forward rapidity at low p_T*

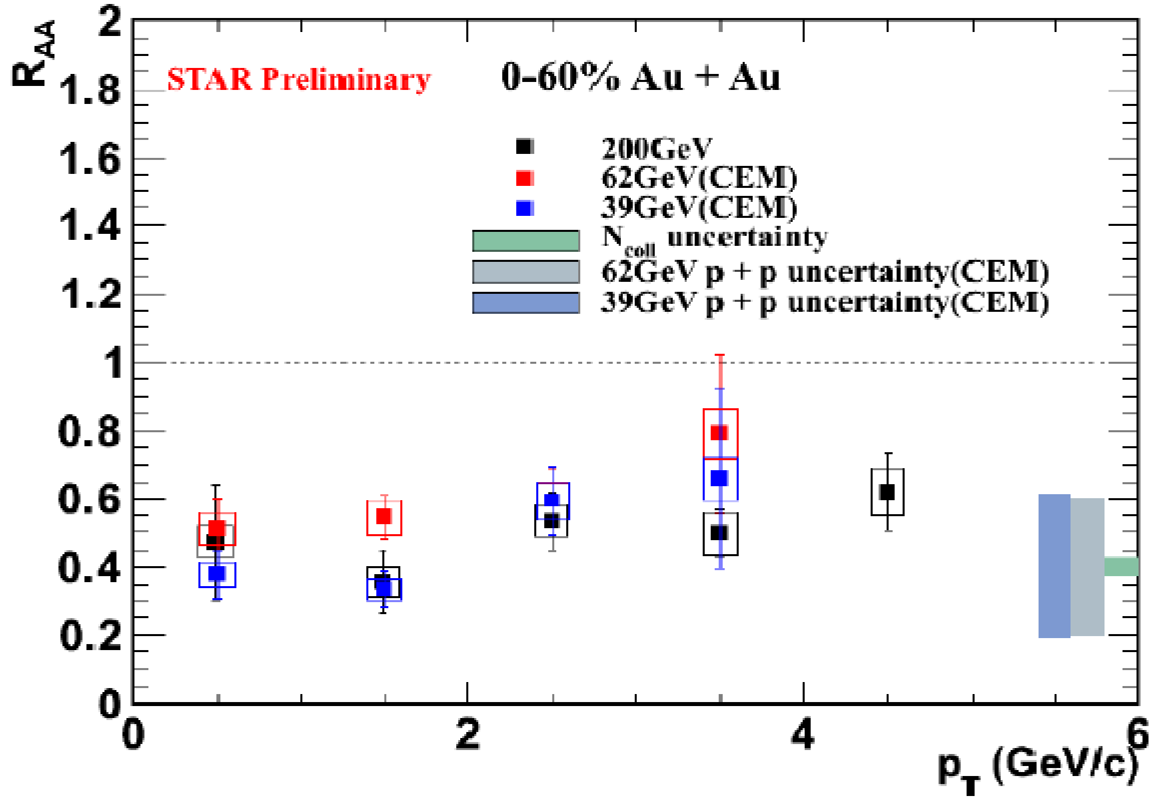
- Qualitative agreement between data and model trends
- Similar model predictions (coalescence) for forward and mid-rapidity - disagreement with data

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

Energy dependence of J/ψ R_{AA}



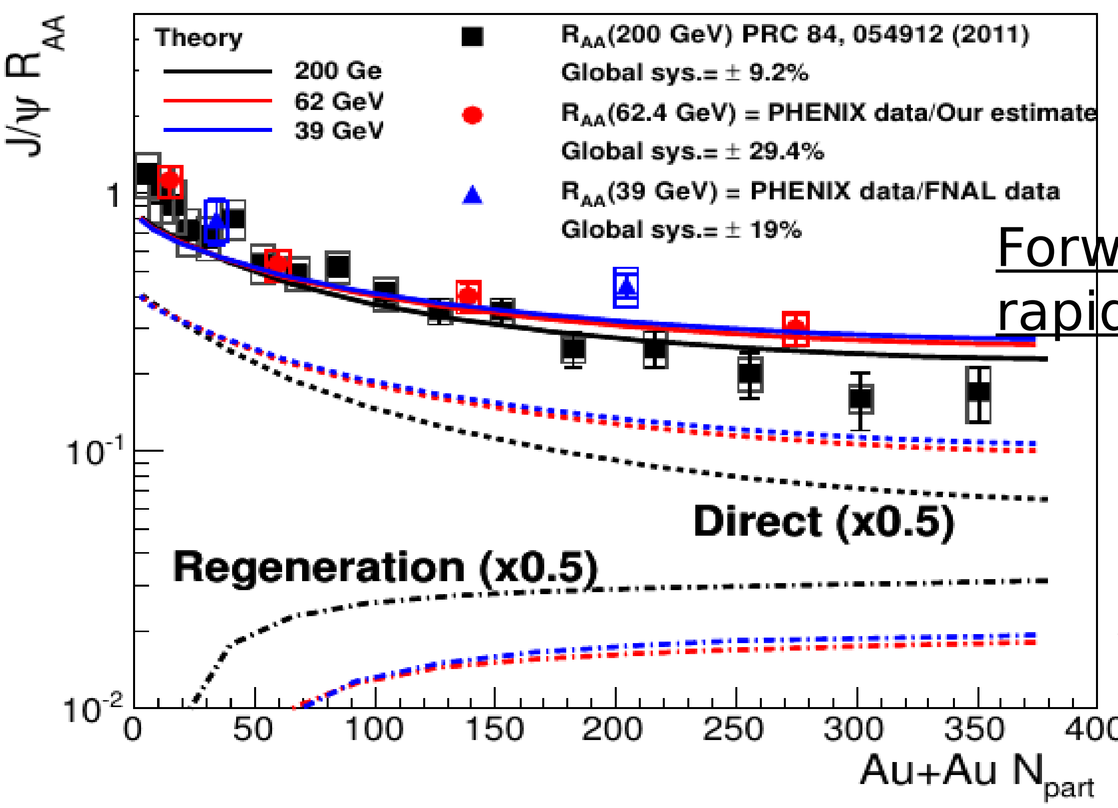
mid-rapidity



- The collision energy dependence of the various competing effects influencing the final J/ψ yields are all quite different

✓ *Suppression of J/ψ at 62.4 and 39 GeV - no strong energy dependence of J/ψ R_{AA}*

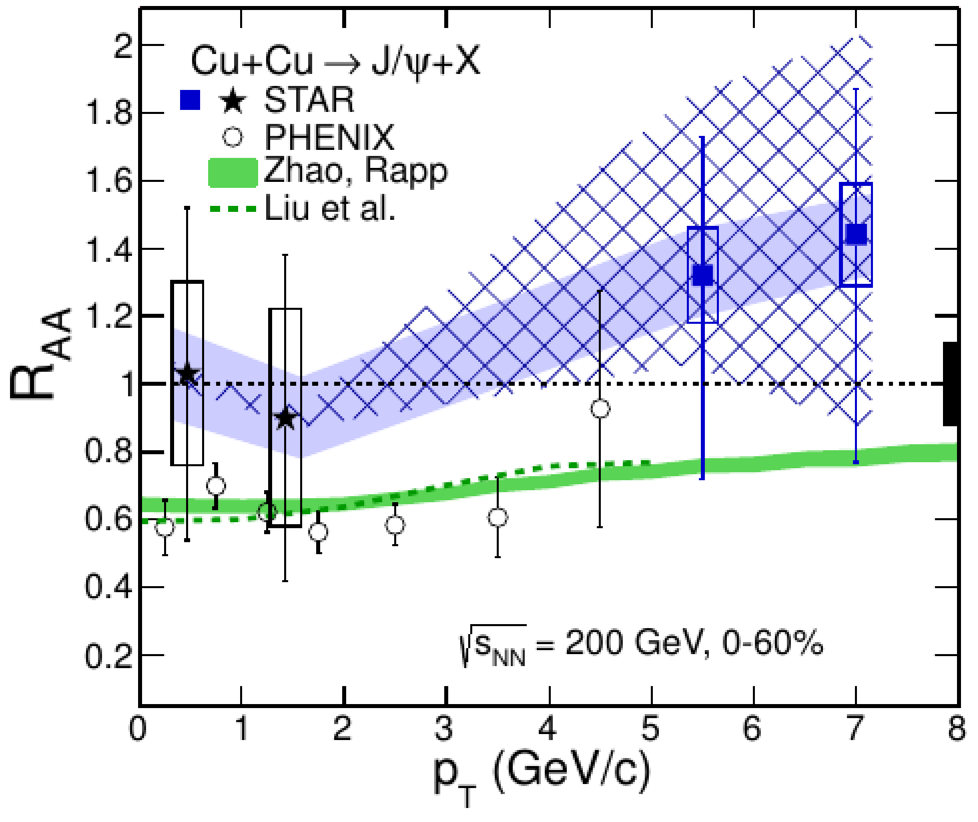
- Data agrees with the prediction of the theoretical calculations



Forward rapidity

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).

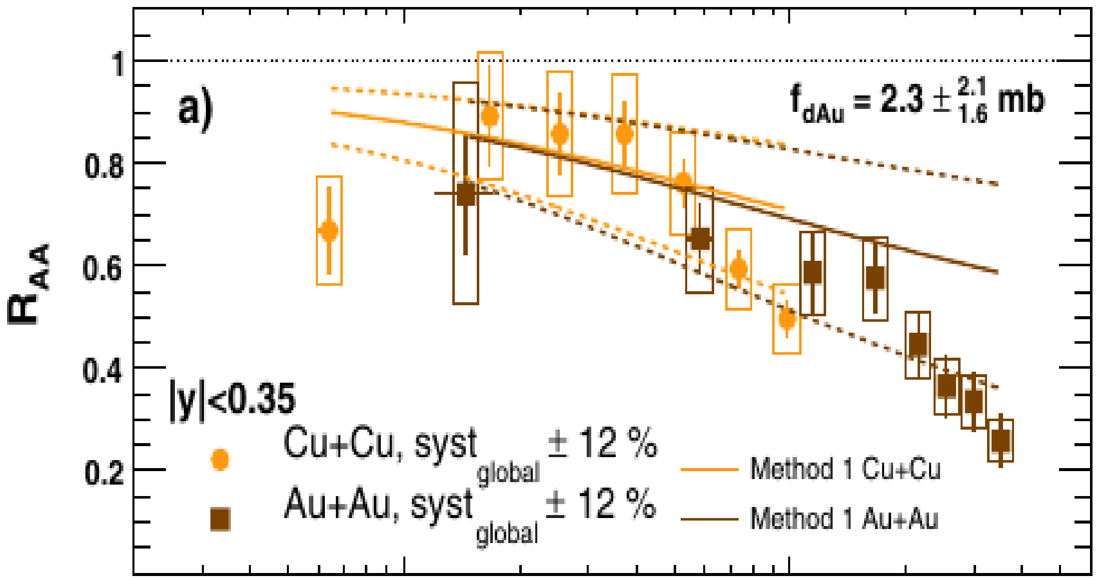
J/ψ production in various systems



<u>mid-rapidity</u>

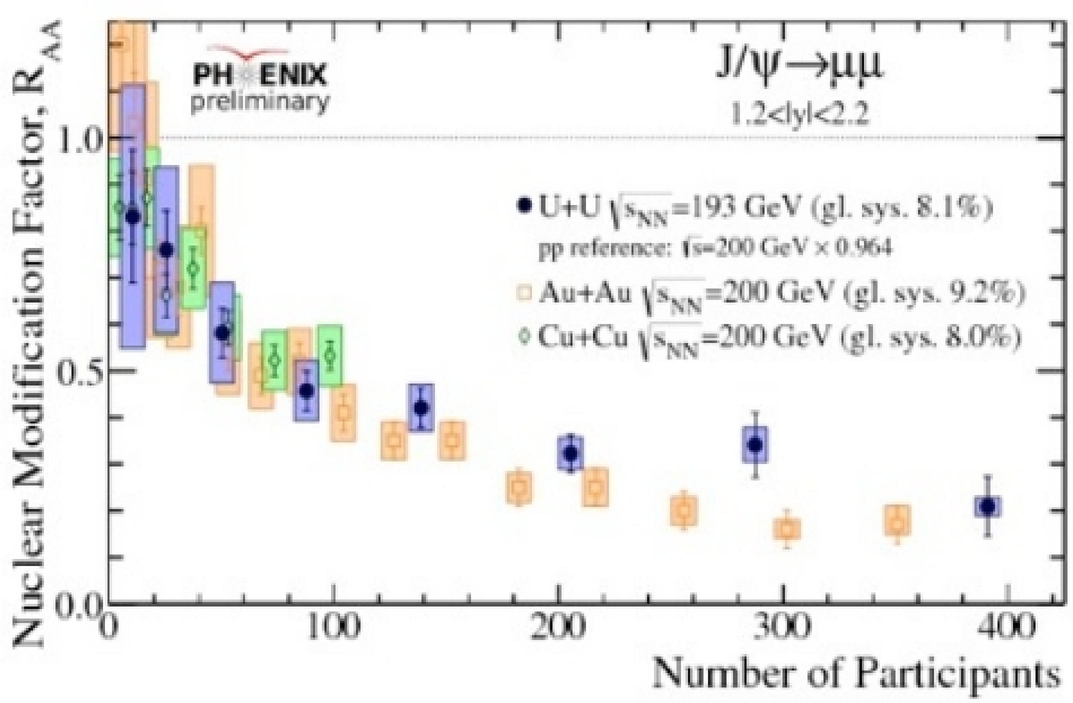
- ✓ *No suppression in Cu+Cu at high p_T*
- ✓ *Suppression at low p_T*

J/ψ production in various systems



mid-rapidity

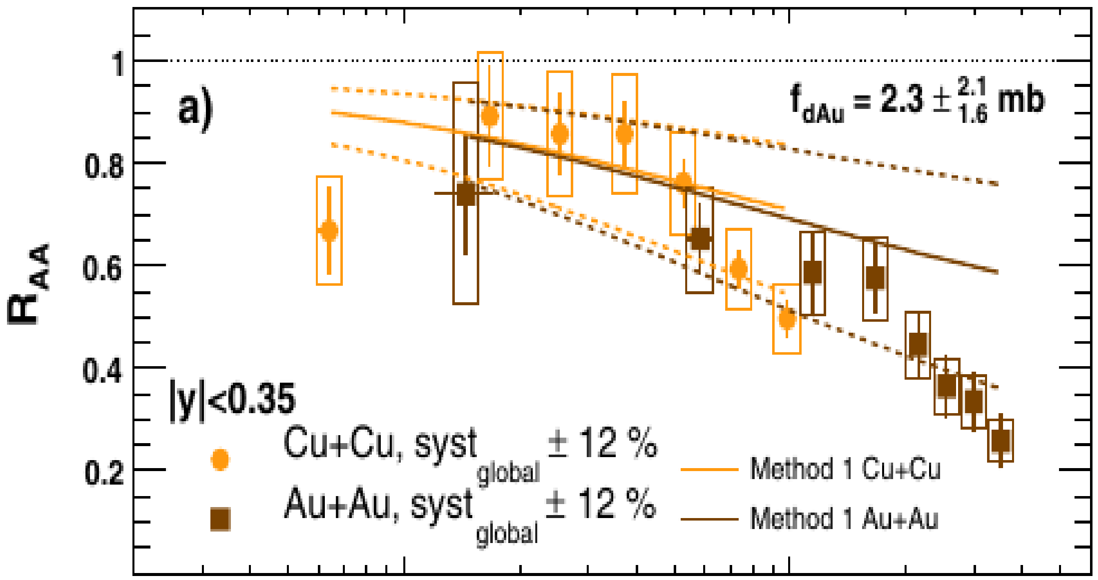
- ✓ *No suppression in Cu+Cu at high p_T*
- ✓ *Suppression at low p_T, similar to Au+Au*



Forward rapidity

- ✓ *Similar suppression in Au+Au, Cu+Cu and U+U at low p_T*

J/ψ production in various systems



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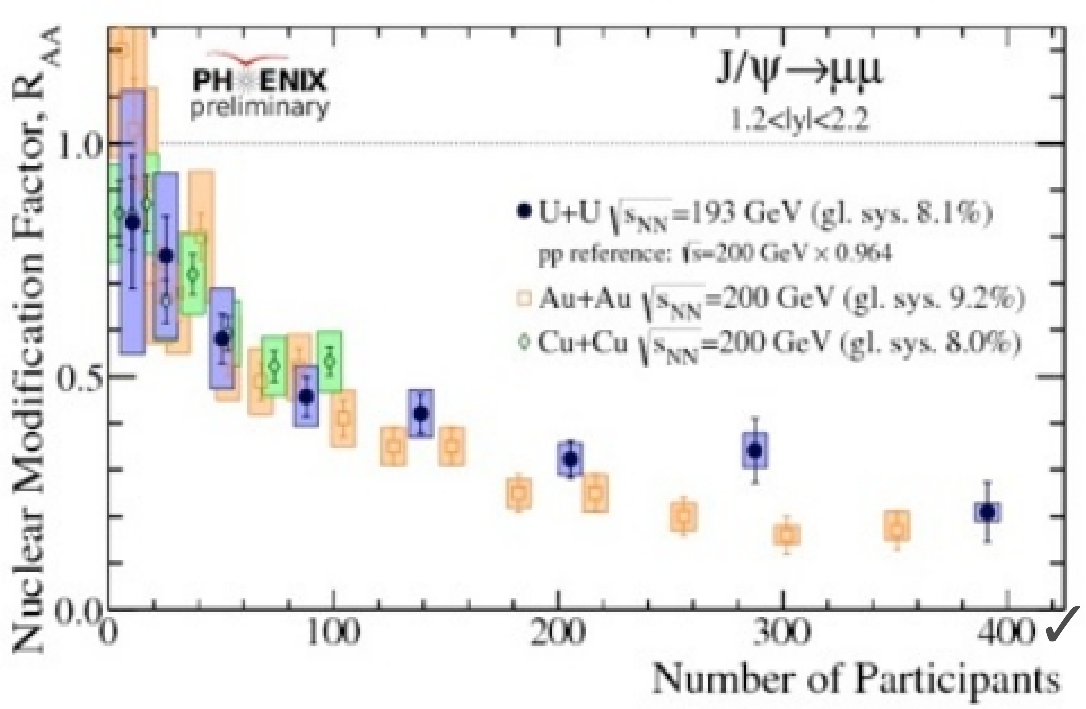

Forward rapidity

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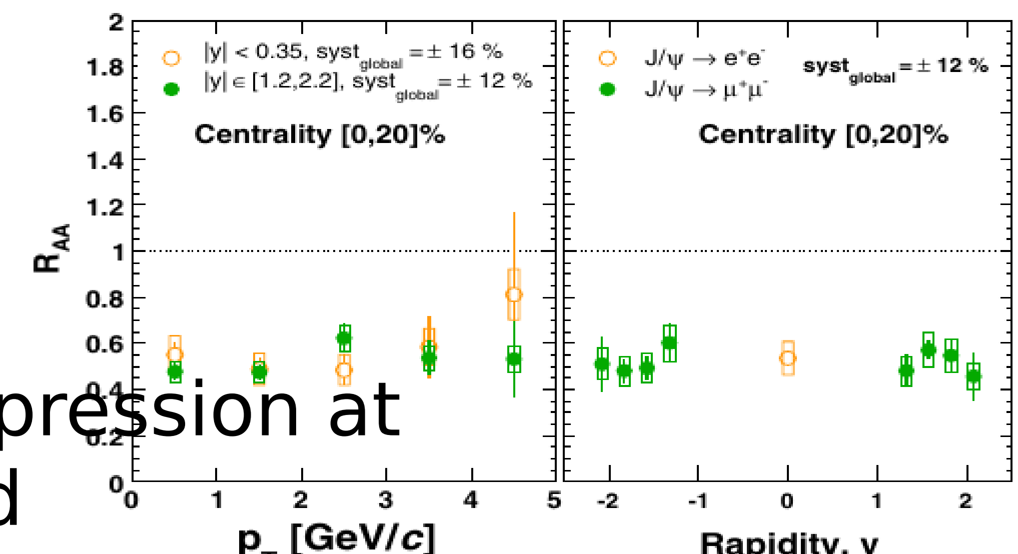


✓ Similar suppression at forward and mid-rapidity at low p_T

- Indication of QGP effects at central Au+Au collisions for hight p_T J/ψ

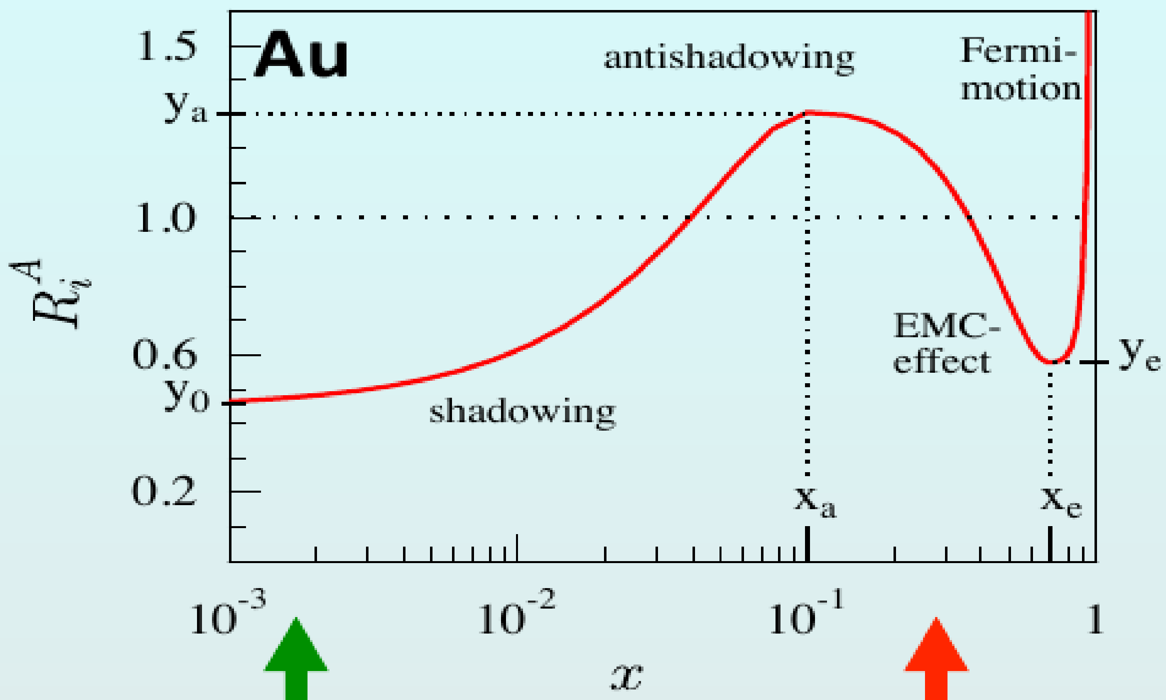
Need to understand CNM effects

d+Au

J/ψ in d+Au collisions at 200 GeV

PRC87, 034911 (2013)

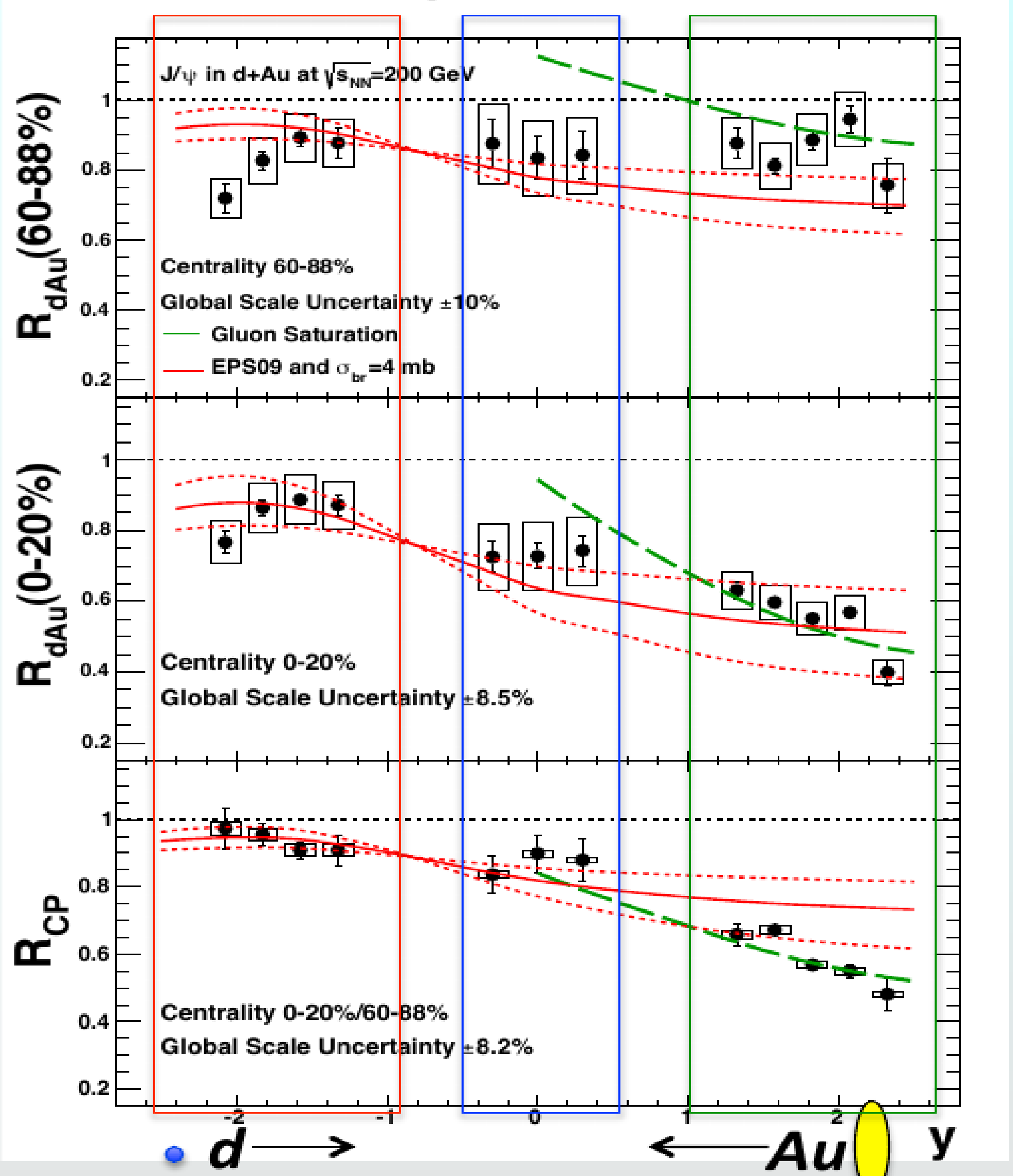
Initial State: what's where?



Forward
+ y
d-going

Backward
- y
Au-going

d+Au -> J/ψ from PHENIX

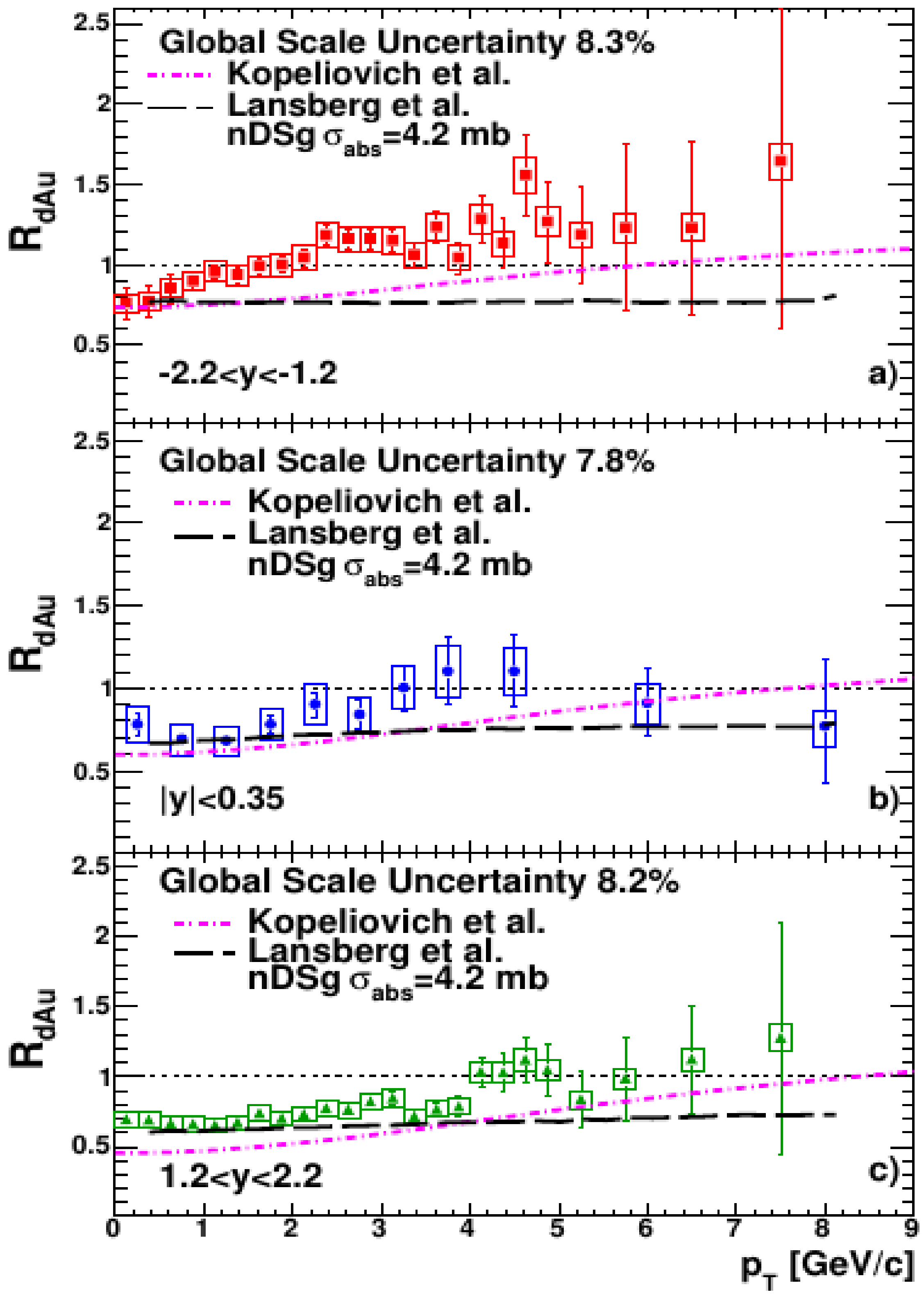


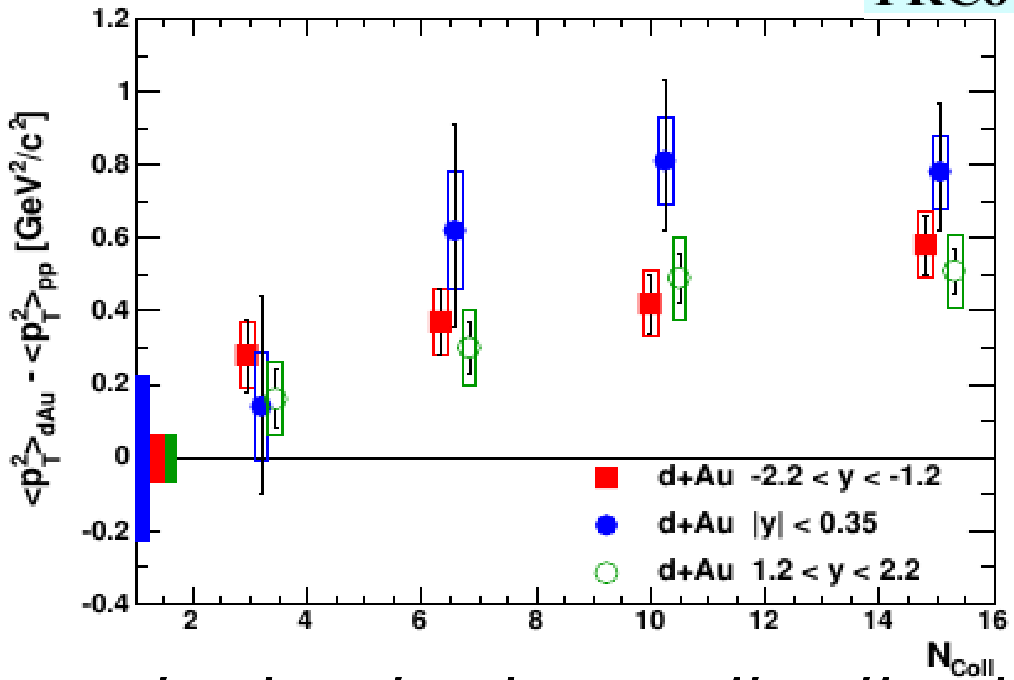
B.Jacak - HEP2013

PHENIX

J/ψ in d+Au collisions at 200 GeV

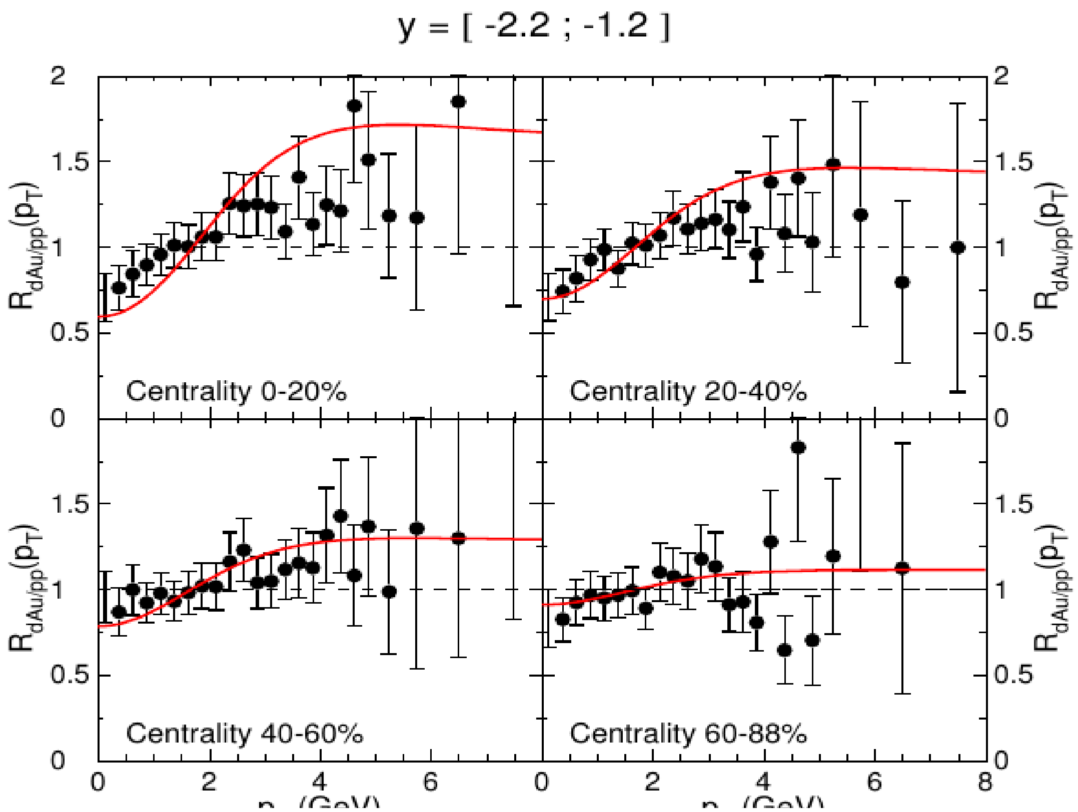
PRC87, 034911 (2013)

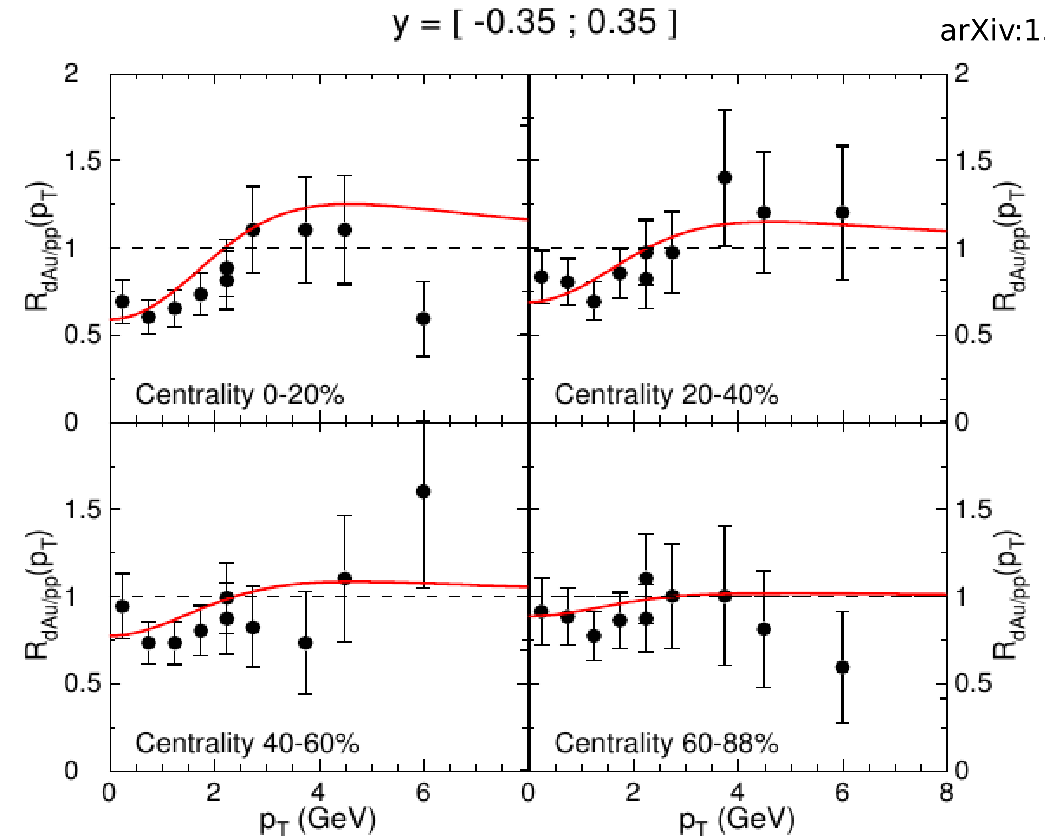




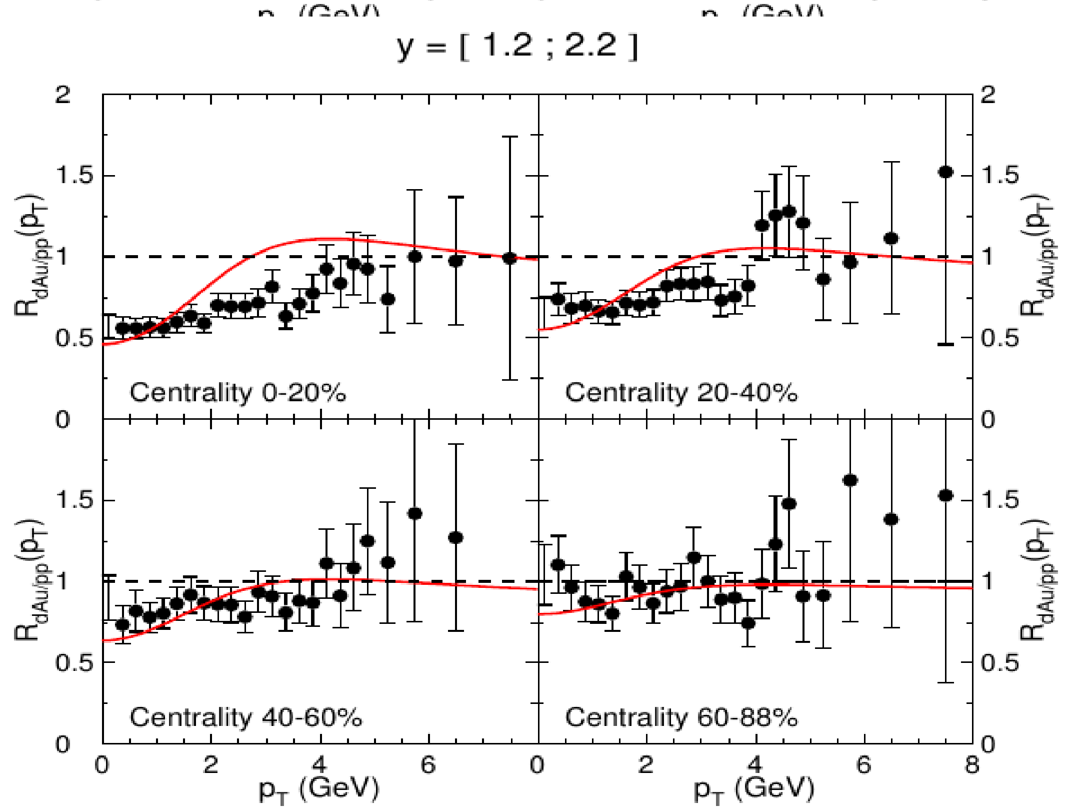
- ✓ *Broadening in the p_T distribution –* multiple scattering
- ✓ *At backward rapidity suppression only at the lowest p_T, high p_T* - Cronin effect
- ✓ *More suppression at forward and mid y (lower x)*
- Kopeliovich et al. (dipole model) - greater level of suppression than seen in the data
- Lansberg et al. - flat in p_T
  - doesn't describe the backward rapidity data

J/ψ in d+Au collisions at 200 GeV



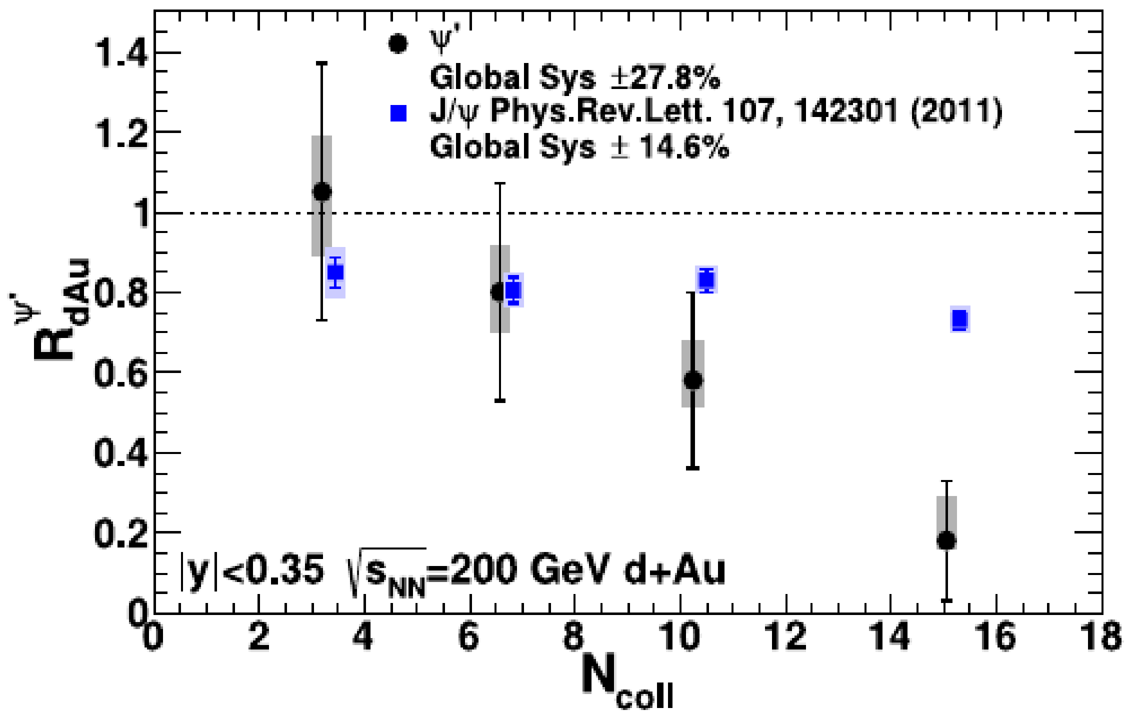


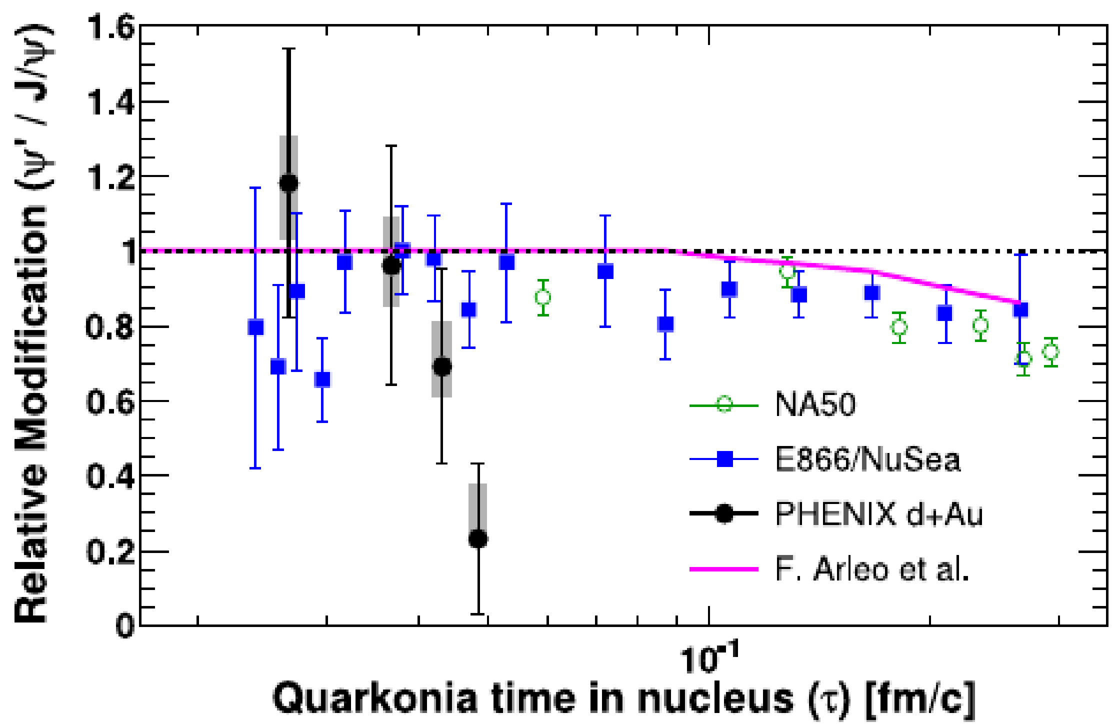
arXiv:1304.0901



- ✓ Model: parton energy loss and p_T broadening $\hat{q}_0 = 0.075\ \mathrm{GeV}^2/\mathrm{fm}$
- ✓ Describes the data well

Ψ' in d+Au collisions at 200 GeV

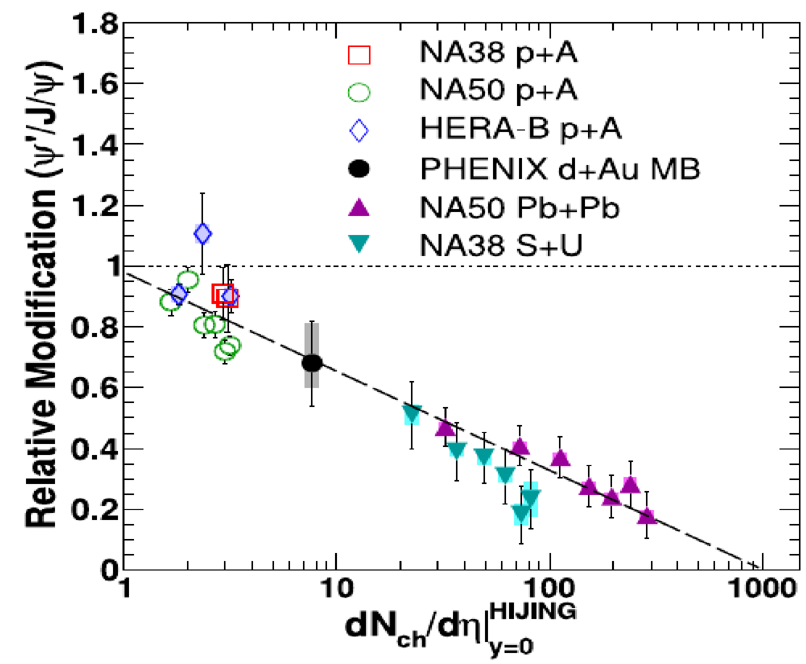




- Very short nuclear crossing time

✓ *Stronger Ψ' than J/Ψ suppression in central collisions*

- Ψ' suppression not due to breakup alone

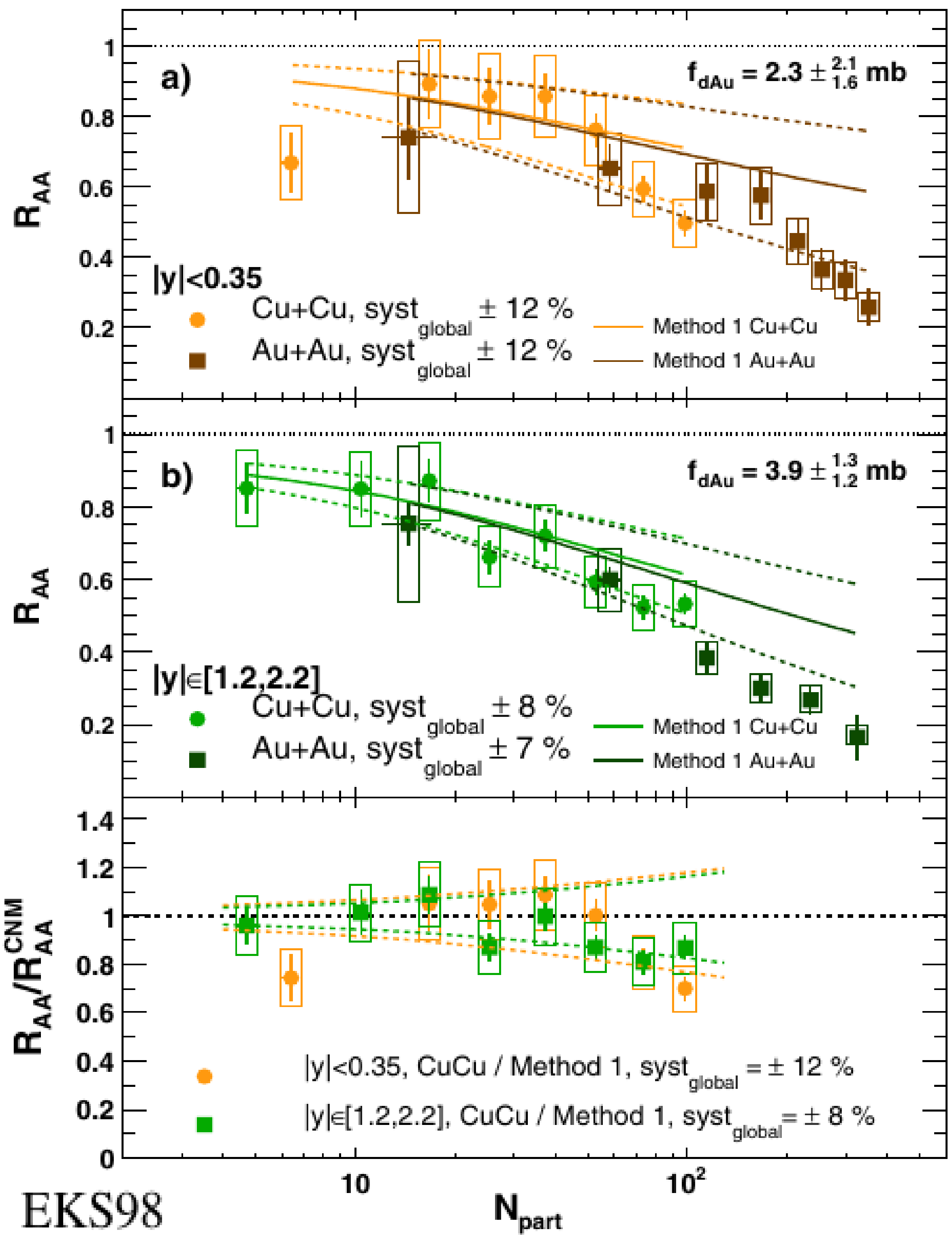


✓ *Common trend in modification of Ψ'/J/Ψ vs Nch/dη*

- Interactions with final-state hadrons may play a role; Ψ' easier to break up

arXiv:1305.5516

J/ψ in Cu+Cu collisions at 200 GeV

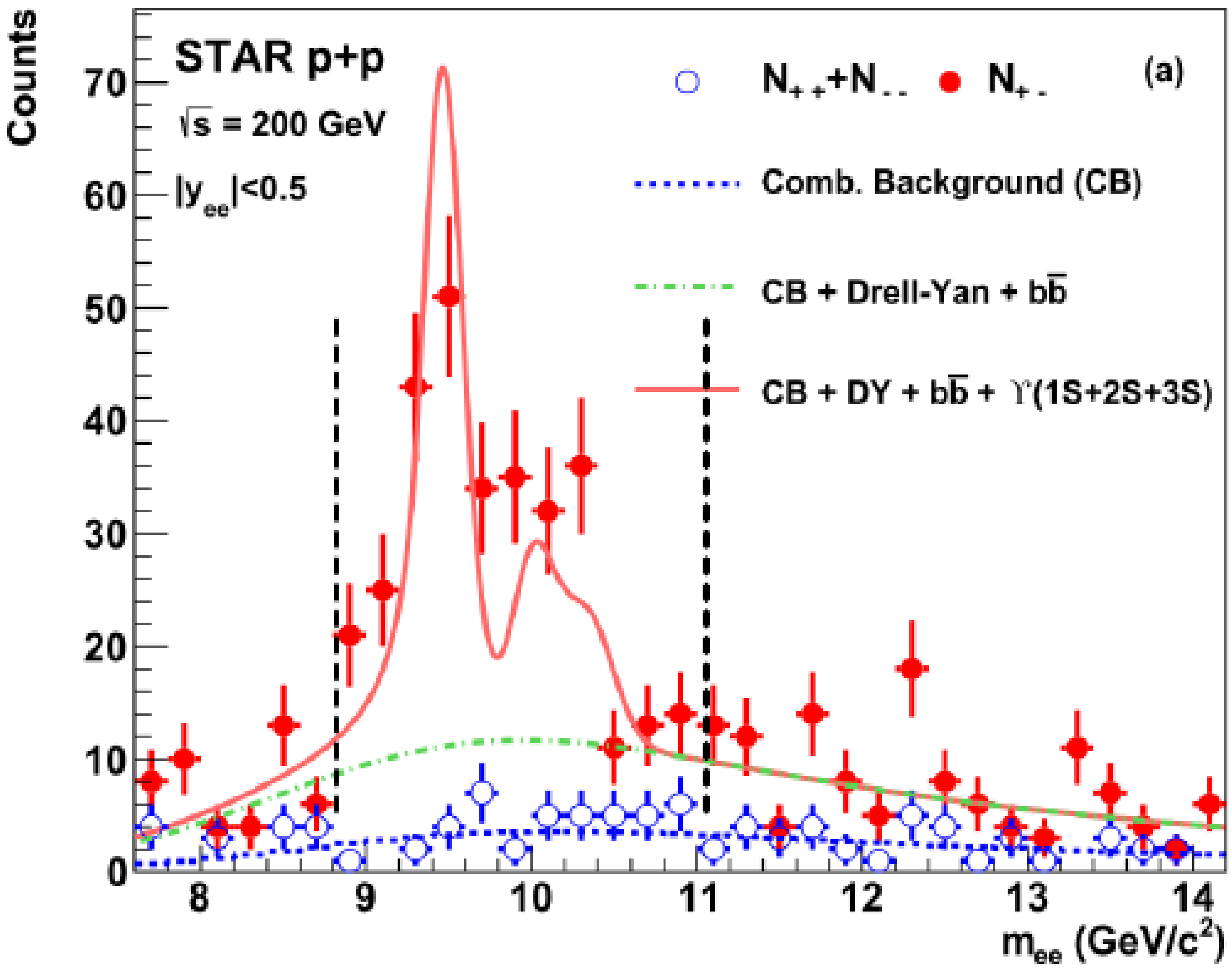


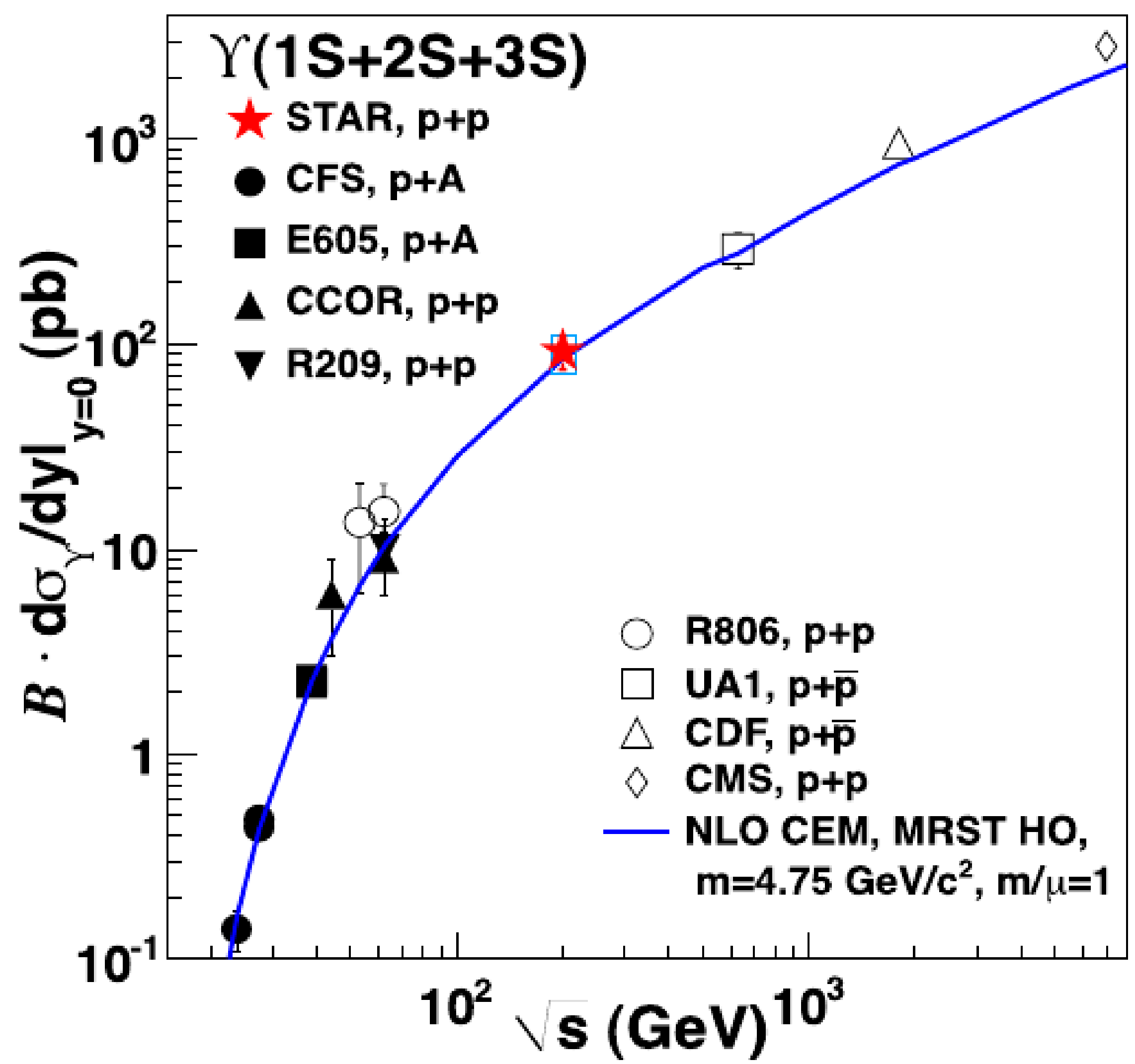
- ✓ f – breakup cross-section – optimized separately for y=0 and |y| = 1.7 in d+Au (2003)
- ✓ Cu+Cu suppression consistent with CNM effects (up to Npart ~ 50)

Y

Υ signal in p+p collisions

arXiv:1312.3675

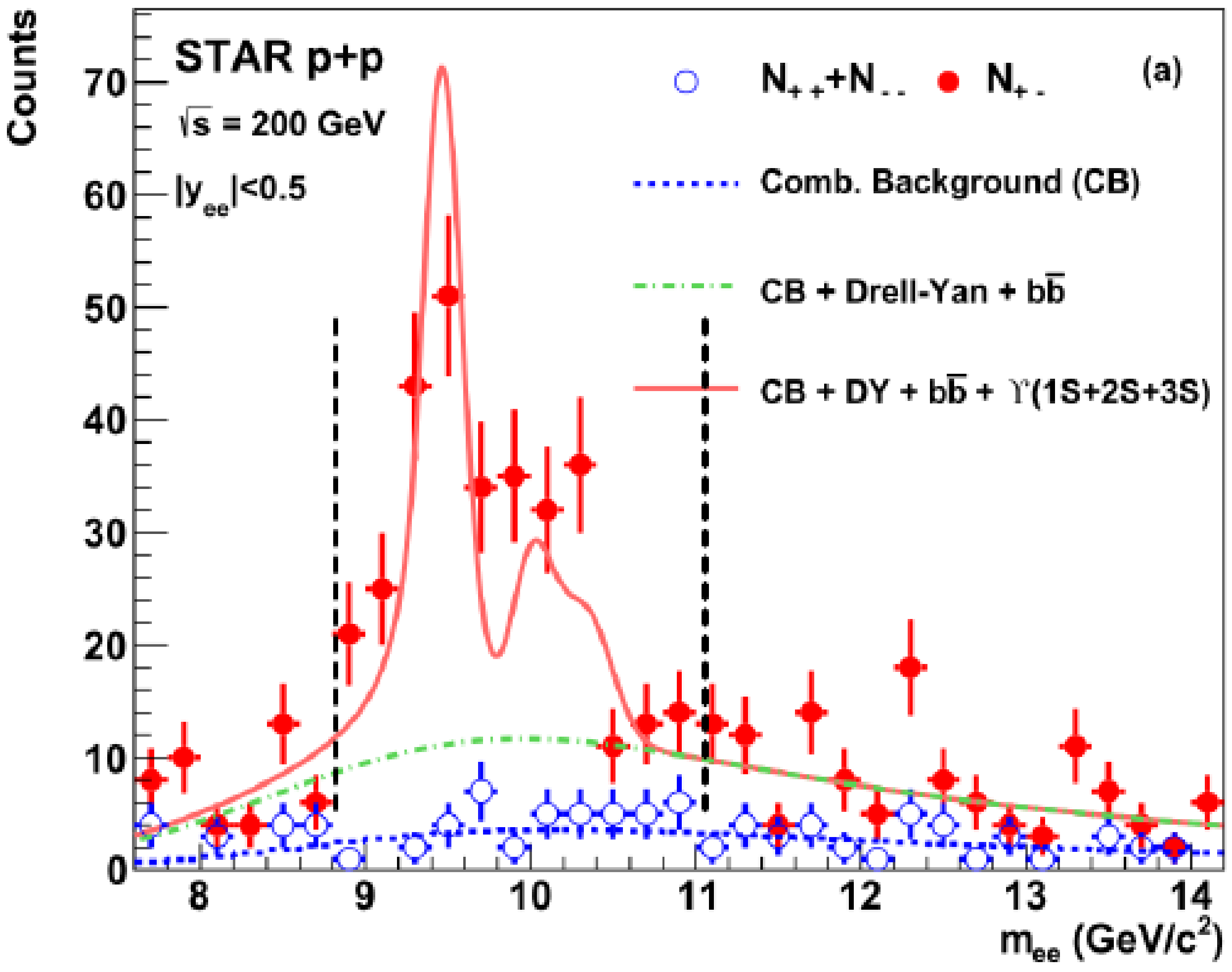


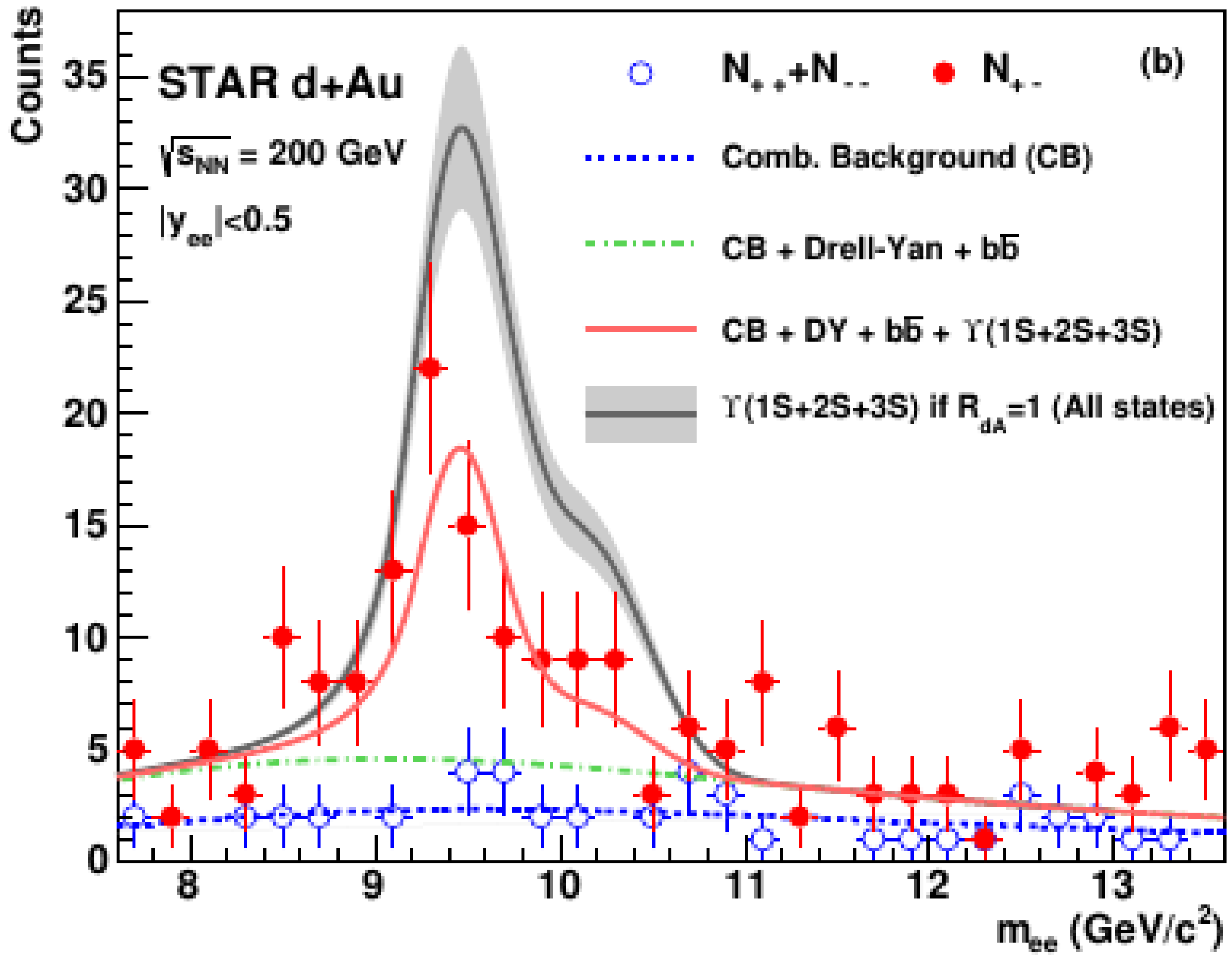


- ✓ Agreement with world data trend

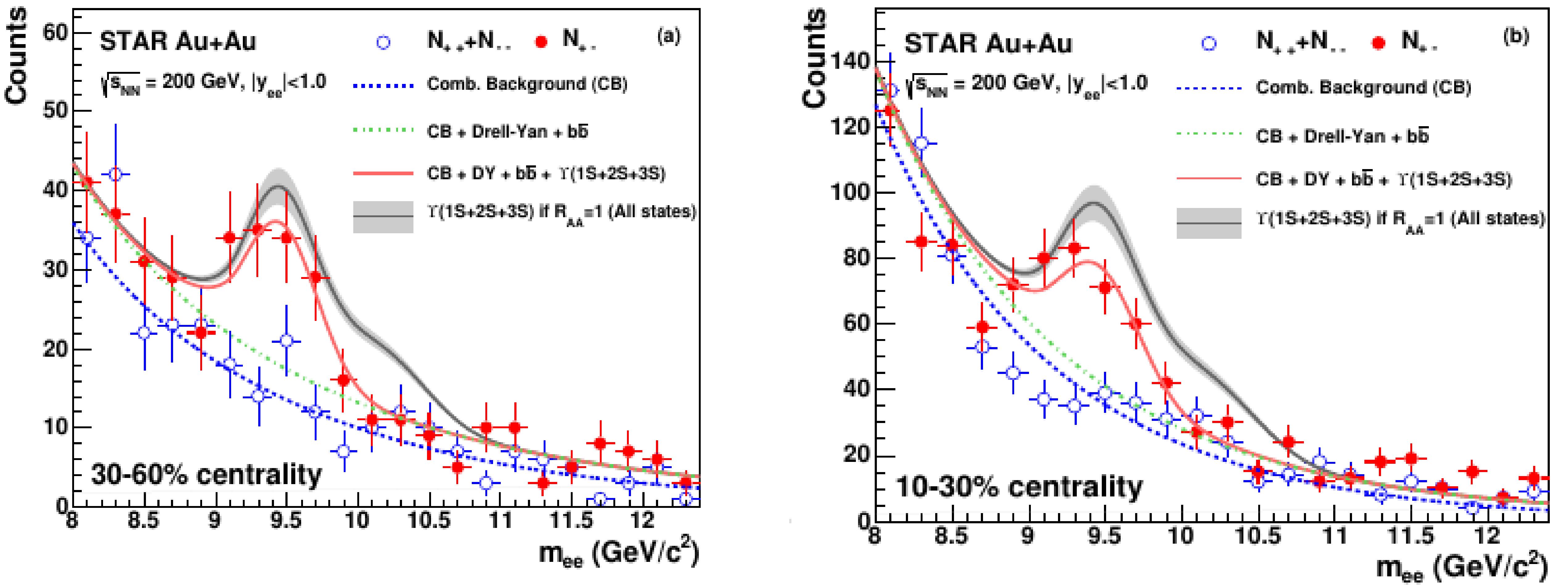
Υ signal in p+p and d+Au collisions

arXiv:1312.3675



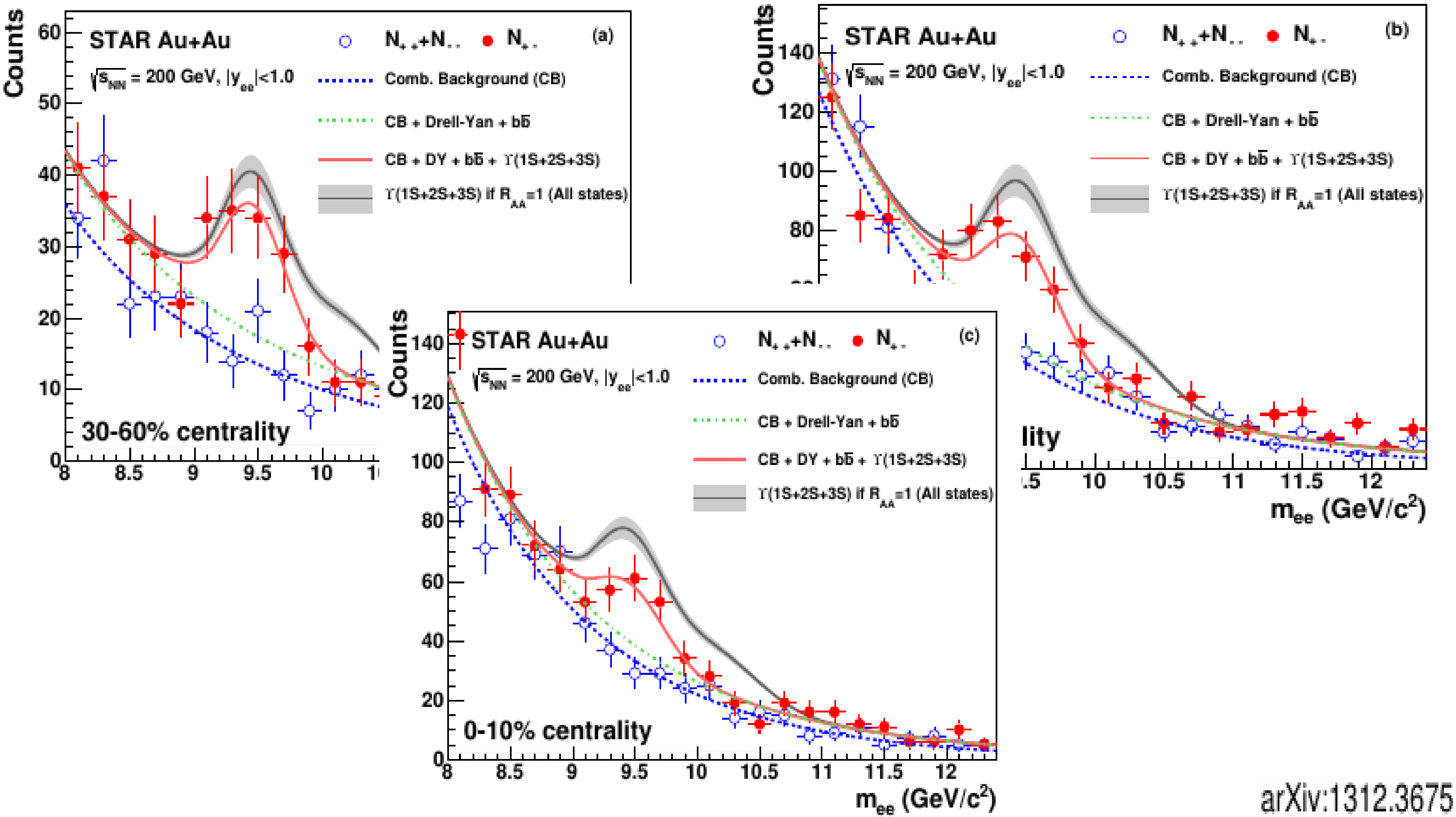


Υ signal – Au+Au collisions



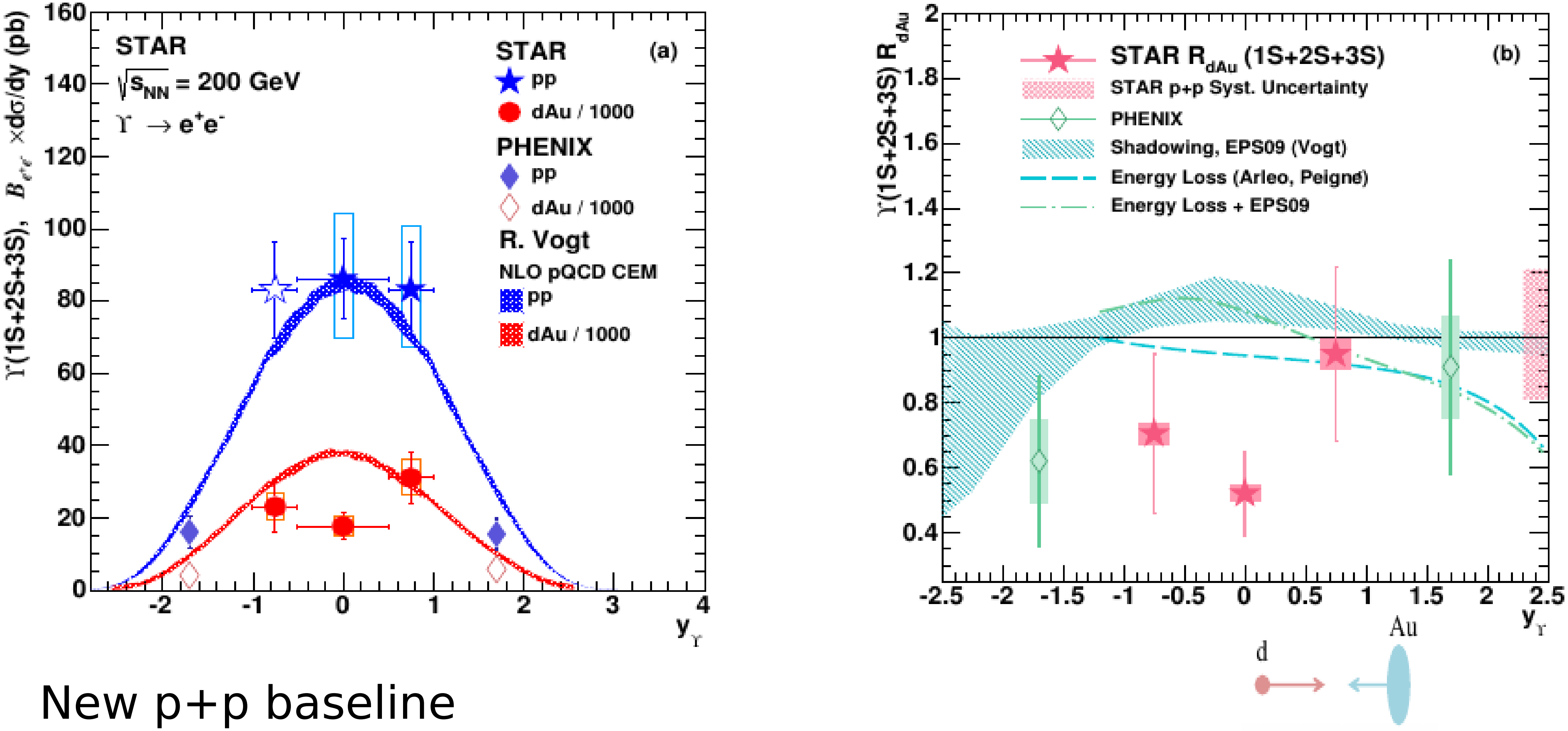
arXiv:1312.3675

Υ signal – Au+Au collisions



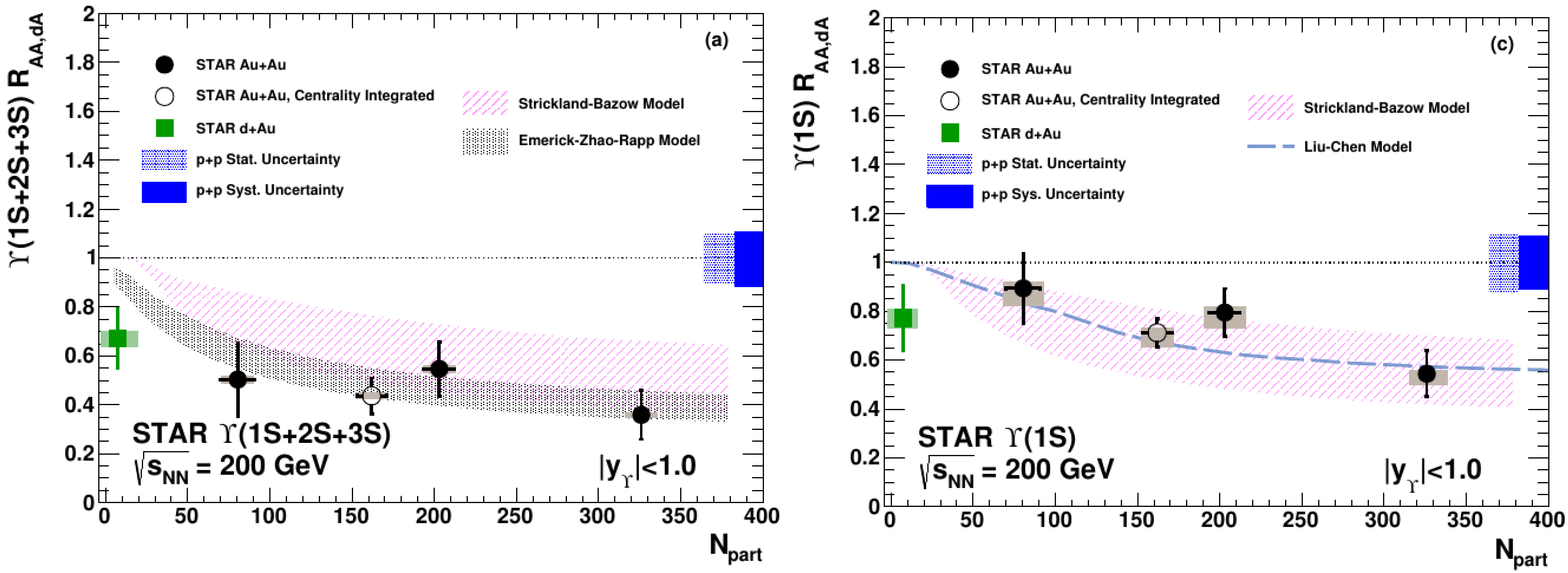
arXiv:1312.3675

Υ in p+p and d+Au collisions at 200 GeV



- ✓ New p+p baseline
- ✓ Agreement with pQCD Color Evaporation Model prediction – except mid-rapidity d+Au
- ✓ *Data indicates more suppression at mid-rapidity than model predictions for CNM effects*

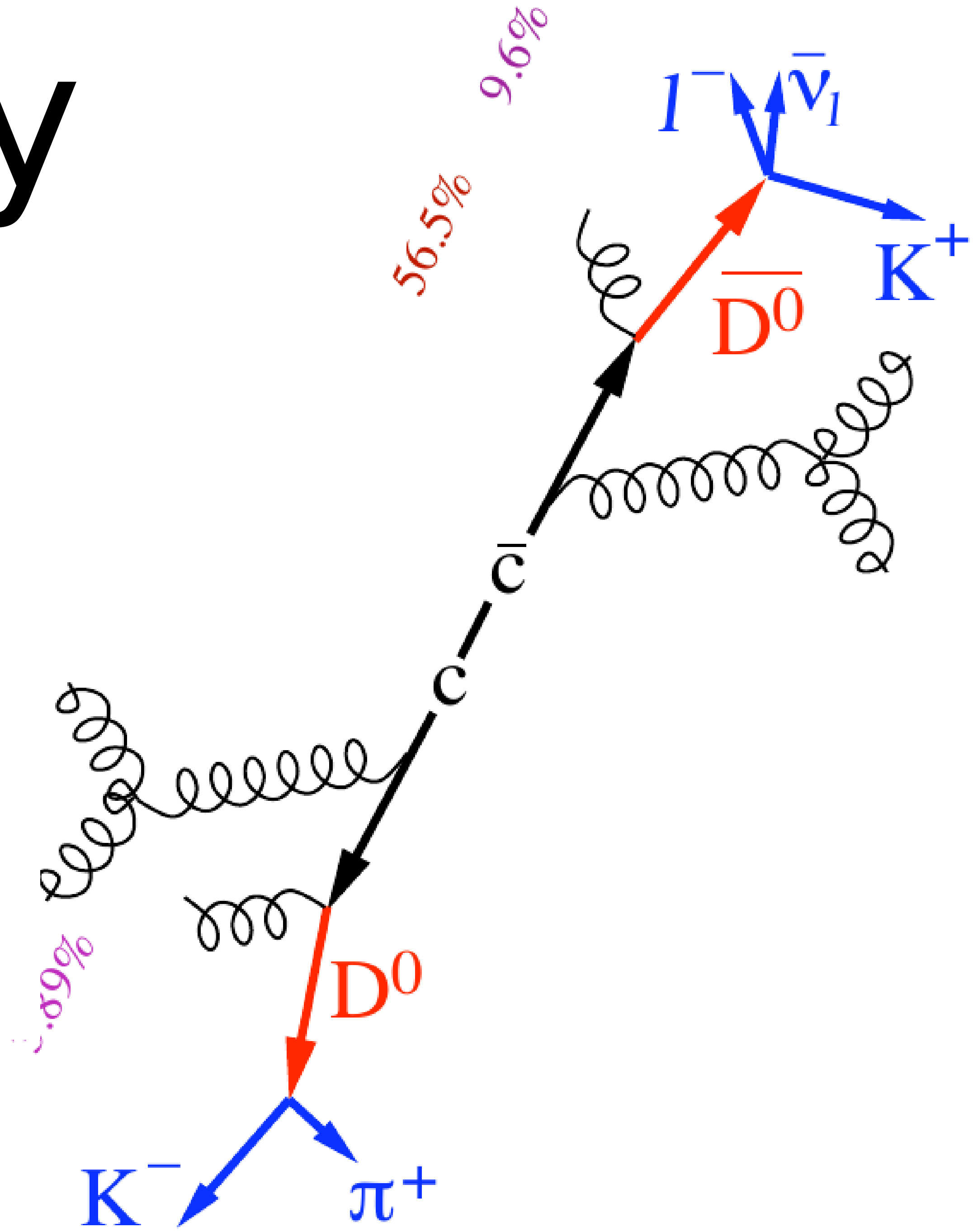
Υ R_{AA} in Au+Au collisions at 200 GeV



- ✓ Suppression in central Au+Au collisions
- ✓ Comparison to dynamical model with feed-down (CNM effects only in Rapp et. al. Model)
- ✓ Result is consistent with complete melting of 2S and 3S states

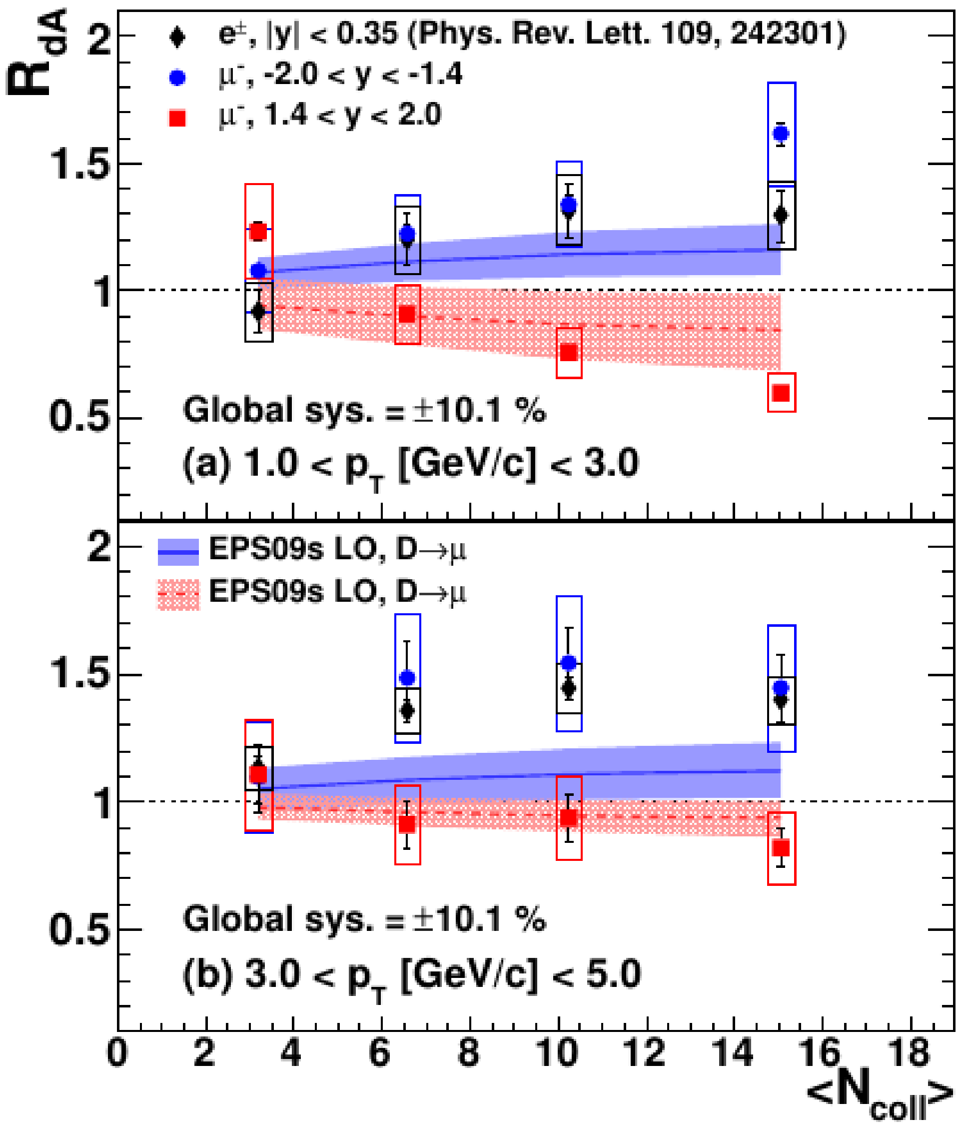
Open heavy flavor

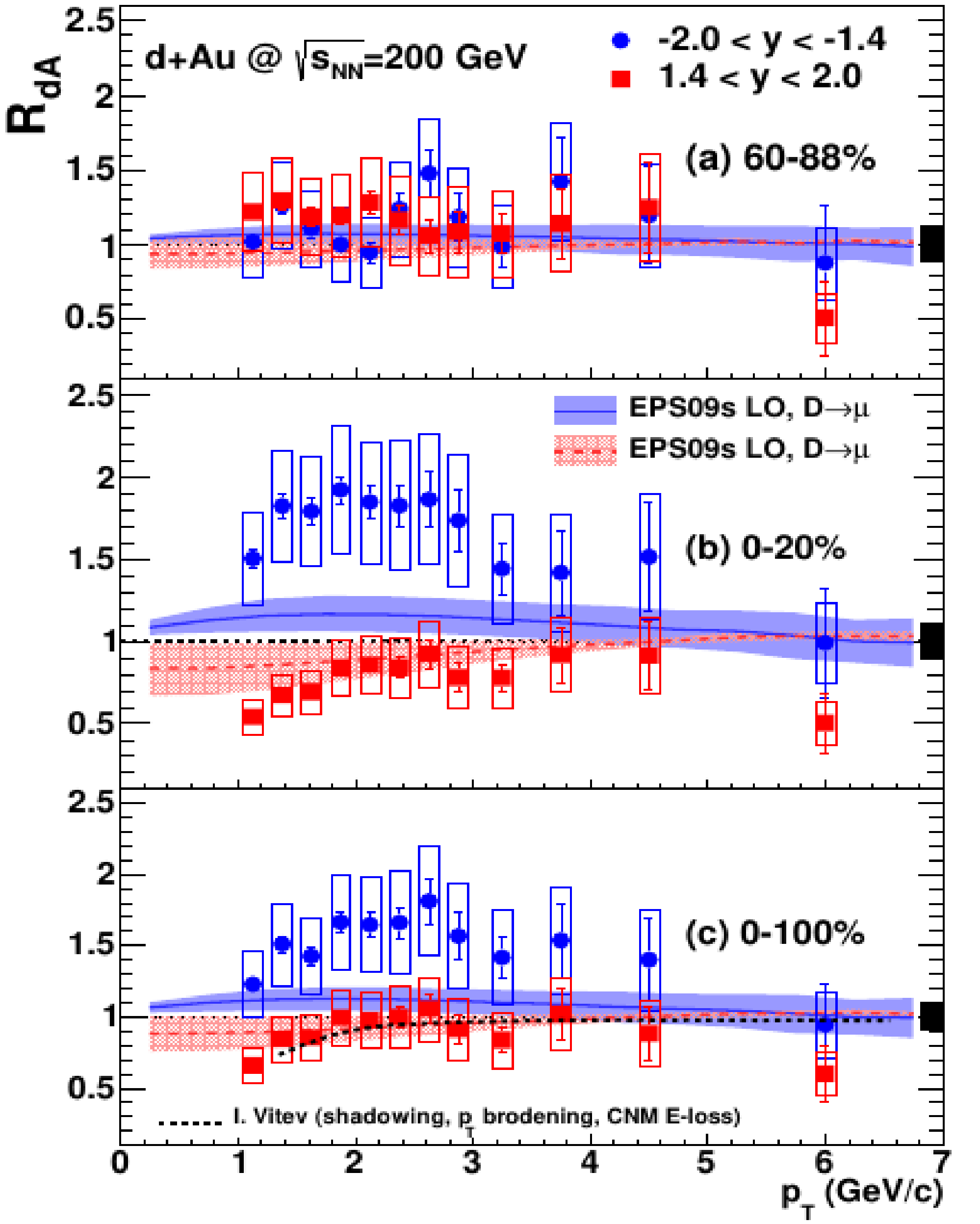
- ★ Indirect measurements through semi-leptonic decay
  - ★ can be triggered easily (high p_T)
  - ★ higher B.R.
  - ★ indirect access to the heavy quark kinematics
  - ★ contribution from both charm and bottom hadron decays
- ★ Direct reconstruction
  - ★ direct access to heavy quark kinematics
  - ★ difficult to trigger (high energy trigger only for correlation measurements)
  - ★ smaller Branching Ratio (B.R.)
  - ★ large combinatorial background (need handle on decay vertex)



- **Au+Au, Cu+Cu, U+U, …**
  - How does a parton lose its energy in the QGP? $\Delta E_g > \Delta E_q > \Delta E_c > \Delta E_b$?
  - Using the HF as a probe to study properties of the QGP and their dependence on system size, energy, …

Heavy flavor leptons in d+Au

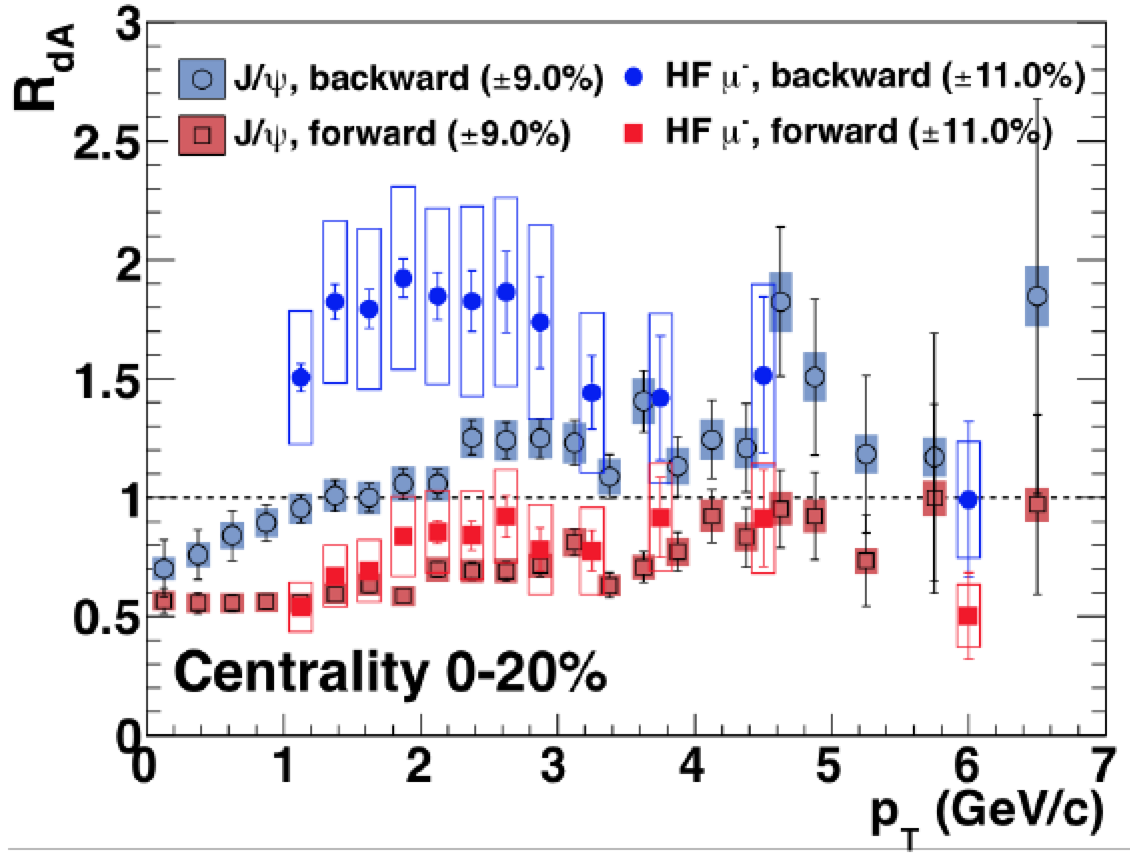


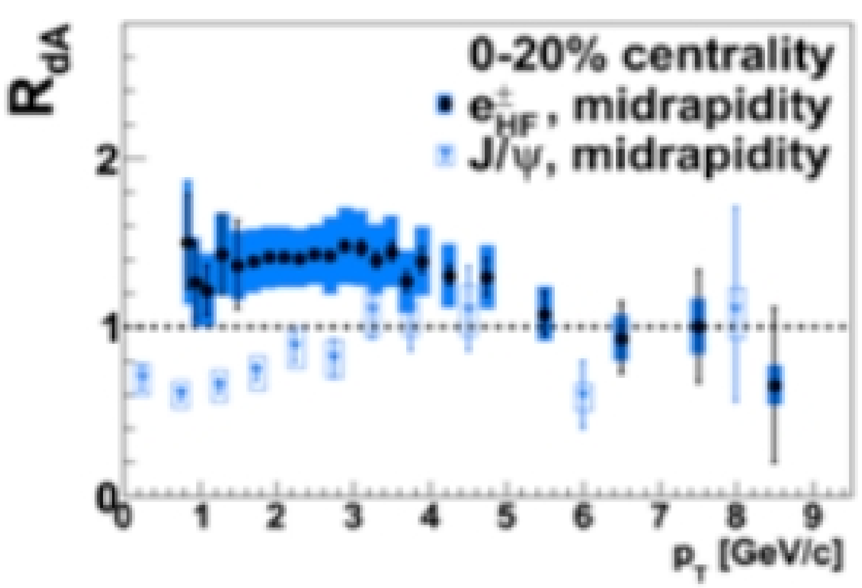


- ✓ Enhancement in backward rapidity (Au-going) sensitive to high-x in Au and at mid-rapidity
- ✓ Suppression in forward rapidity (d-going) sensitive to low-x

HF leptons vs J/ψ in d+Au

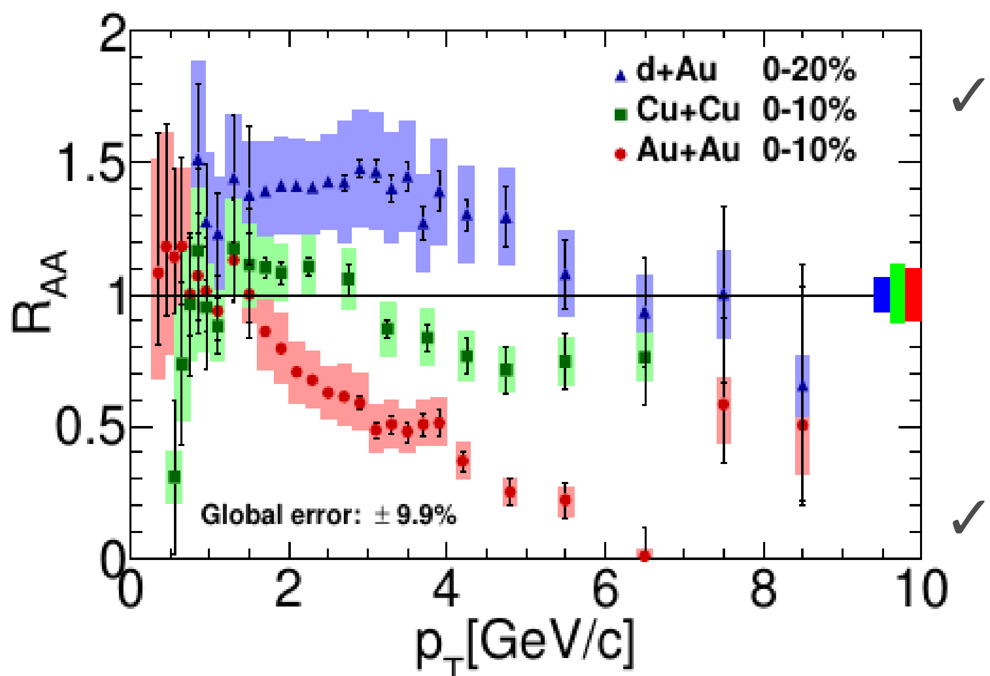
Caveat: Different kinematics



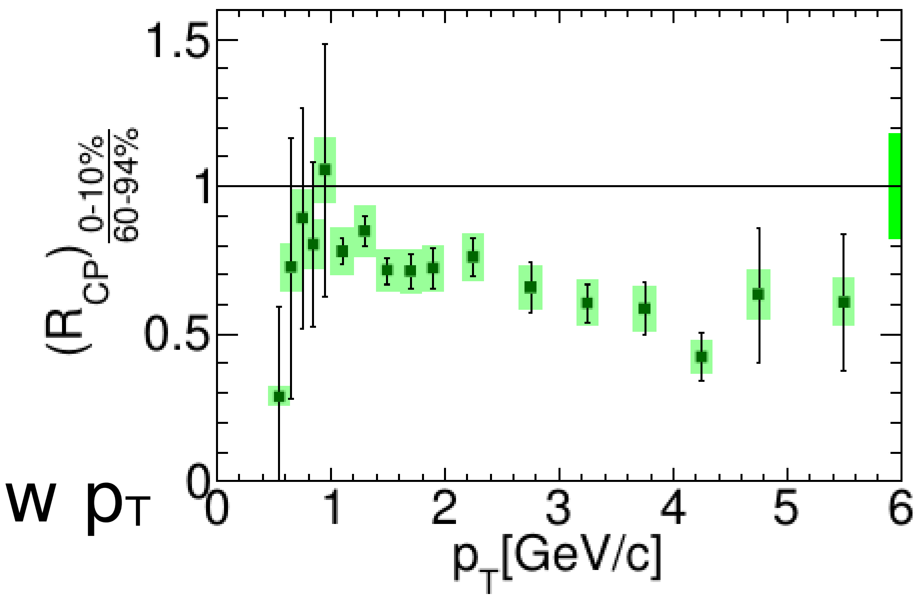


- ✓ Stronger J/ψ *suppression at backward and mid-rapidity*
  - nuclear breakup affects J/ψ production
- ✓ *Similar suppression at forward rapidity*
  - shorter time in nucleus, low co-mover density

HF electrons in different systems



✓ Suppression in the central relative to peripheral Cu+Cu collisions



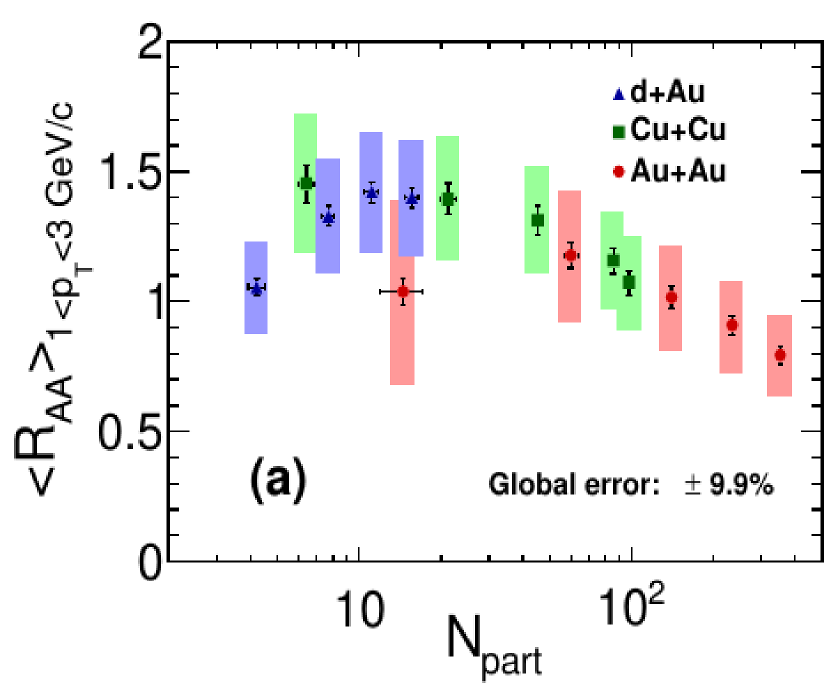
✓ Enhancement at low p_T Cu+Cu peripheral collisions

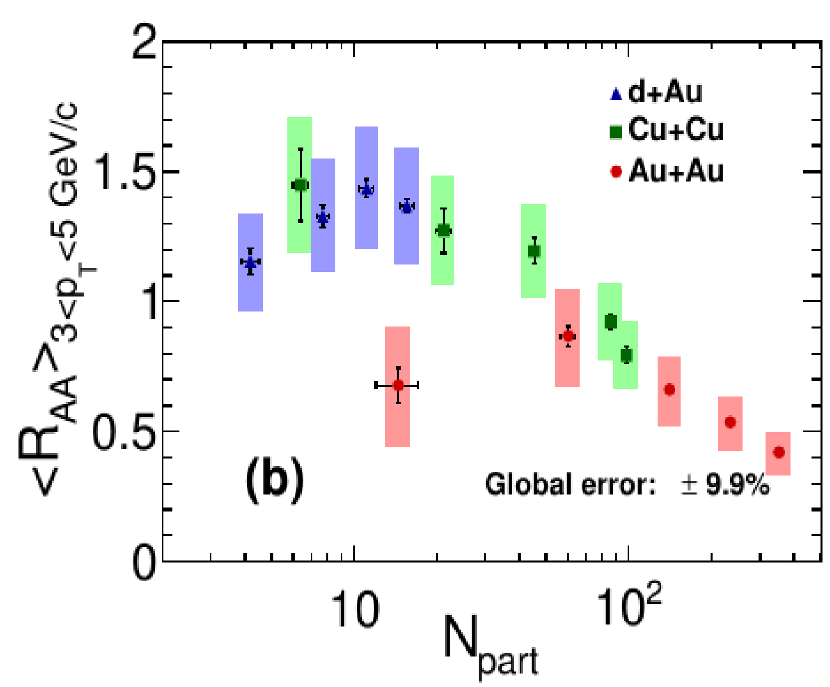
arXiv:1310.8286

✓ Different suppression in central collisions – hierarchy between 3 systems

Different system sizes

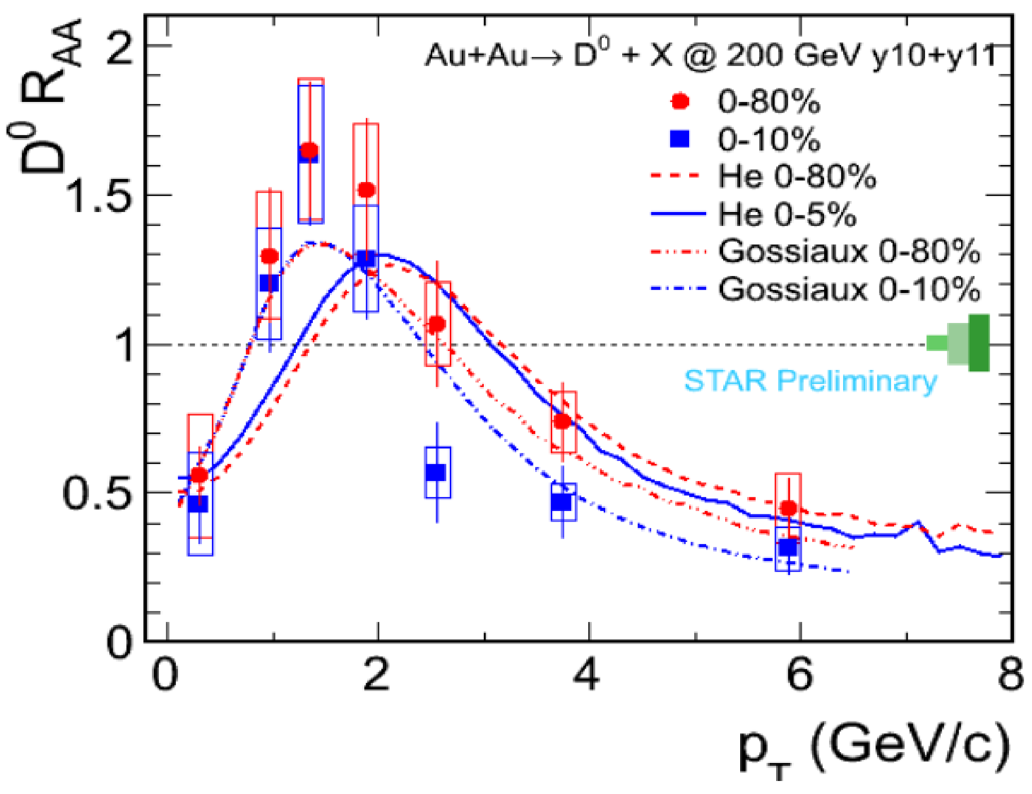
- *Central d+Au ≈ peripheral Cu+Cu*
- *Central Cu+Cu ≈ peripheral Au+Au*



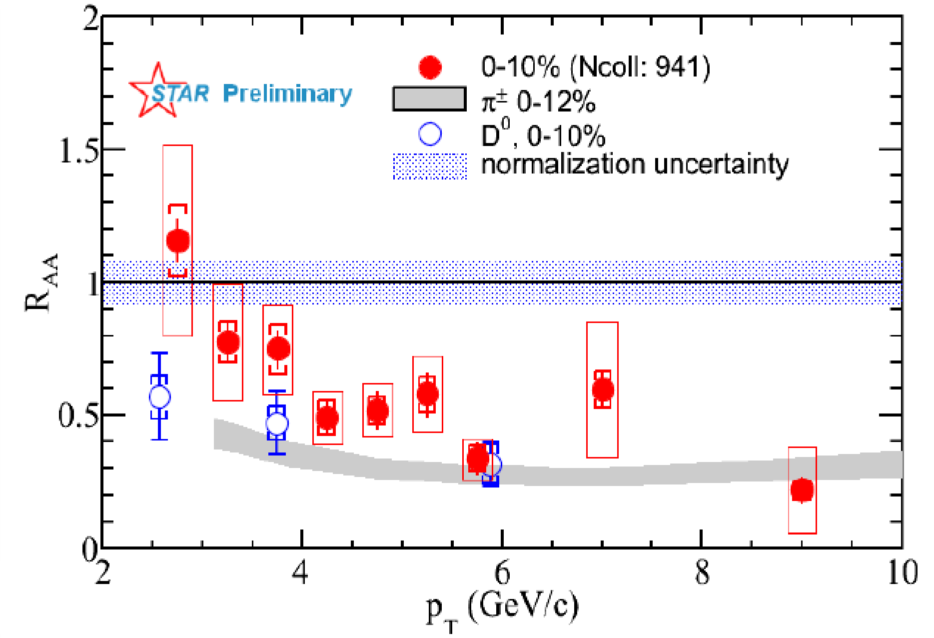


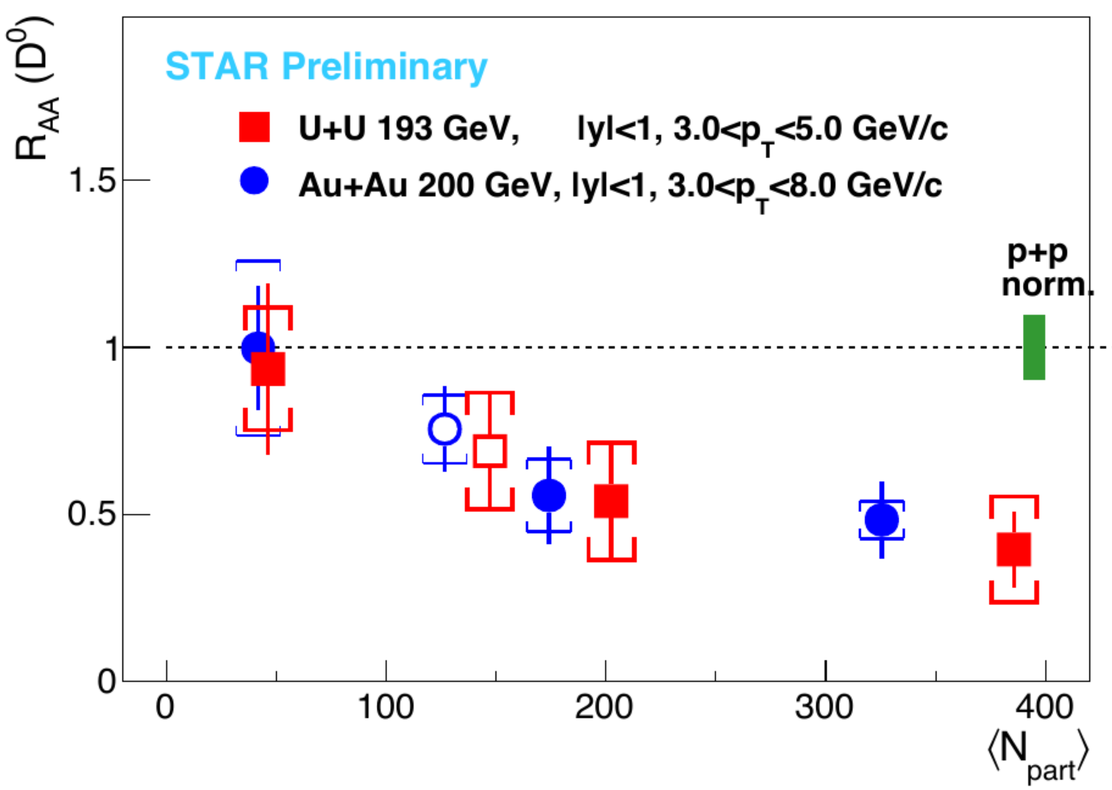
✓ Similar trend

Open charm hadronic channel



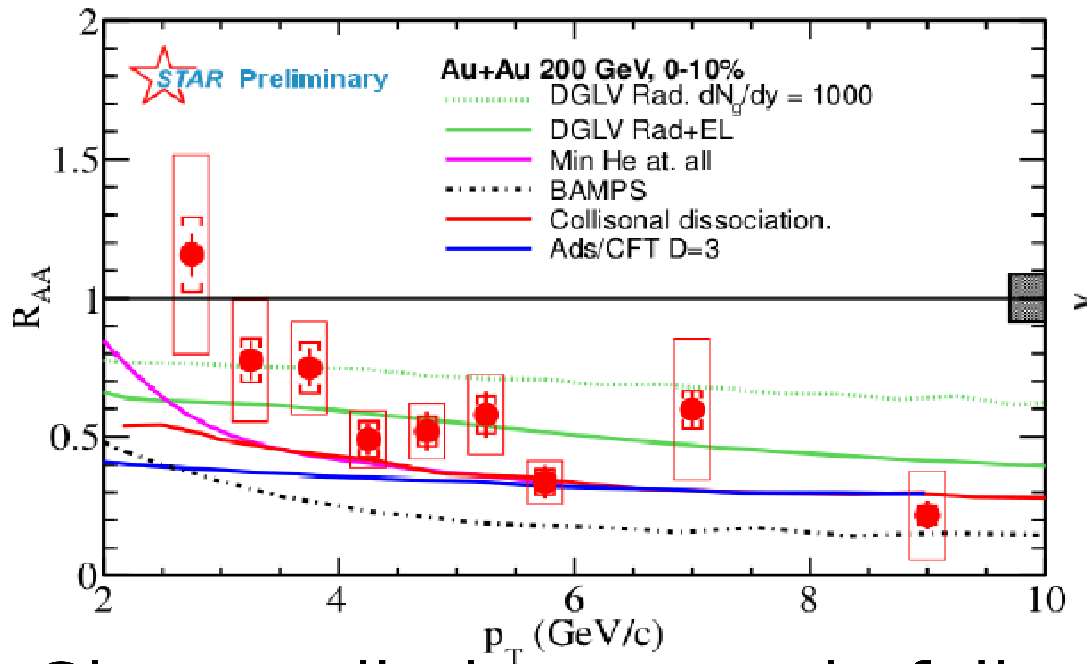
- ✓ Low-p_T enhancement described by models with light quark coalescence with charm
- ✓ Hight-p_T suppression is similar to pions (also in d+Au)
- ✓ D0 and NPE suppressions are similar

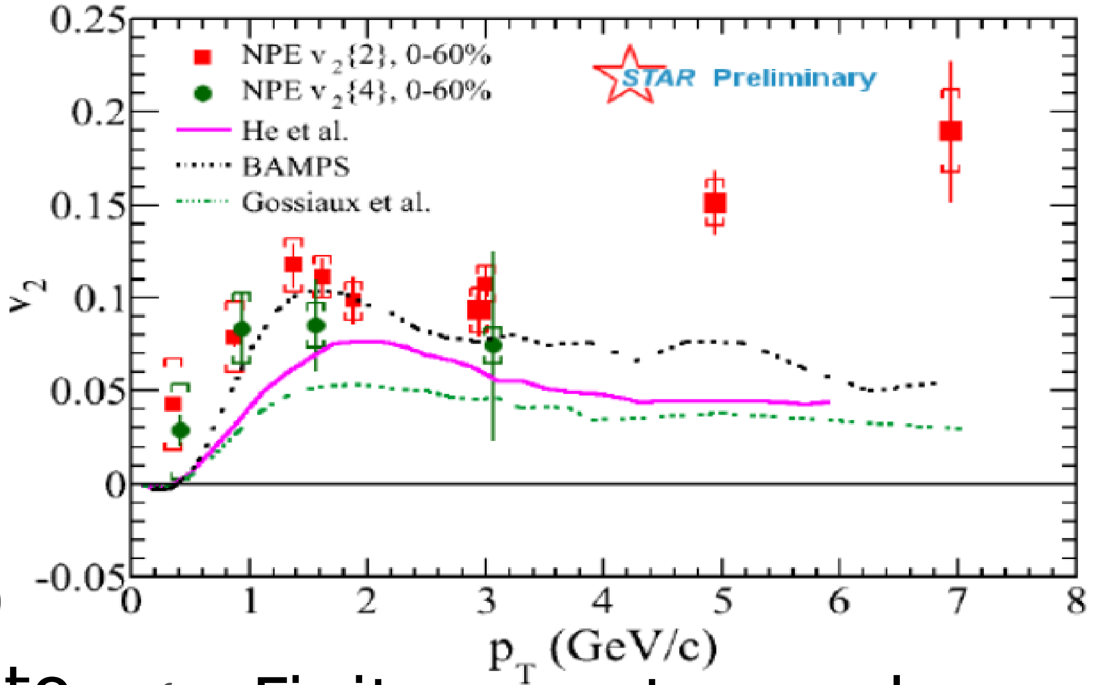




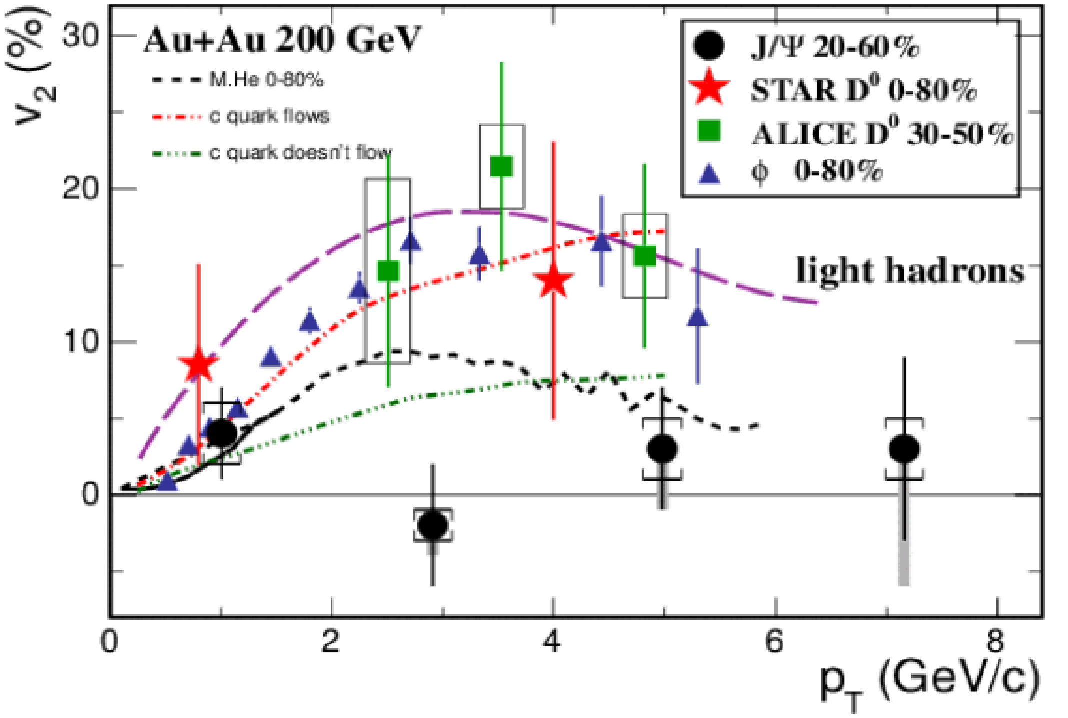
- ✓ Similar behavior in U+U collisions as in Au+Au collisions

Open heavy flavor flow





- ✓ Gluon radiation scenario fails to explain large NPE suppression at high-p_T
- ✓ Finite v_2 – strong charm-medium interaction



It's challenging to describe the suppression and v2 simultaneously.

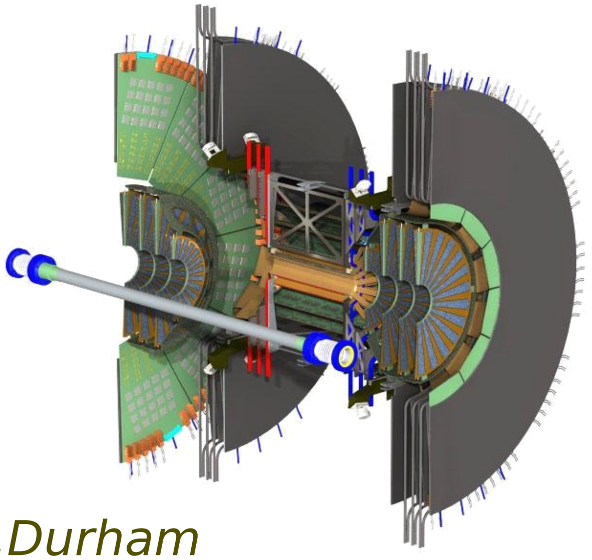
Summary of what was measured so far

- Quarkonia and Open Heavy Flavor measurements for different colliding systems (Au+Au, Cu+Cu, *U+U*, d+Au, *Cu+Au)*
- And also different energies (39, 62.4 and 200 GeV)
  - Crucial to understand the CNM effects – p(d)+A collisions at different energies
  - Separate charm and bottom

Prospects

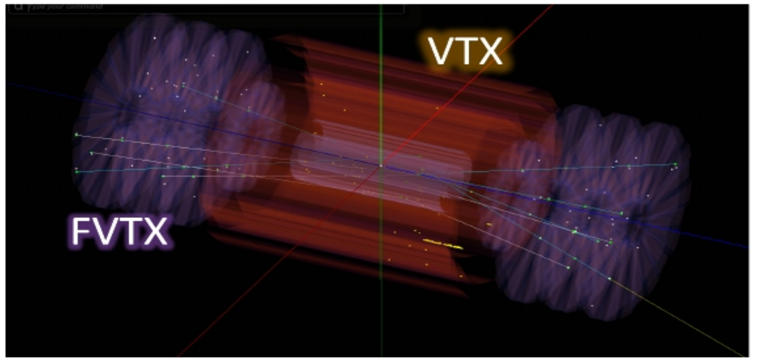
PHENIX upgrade

Installed and taking data: FVTX

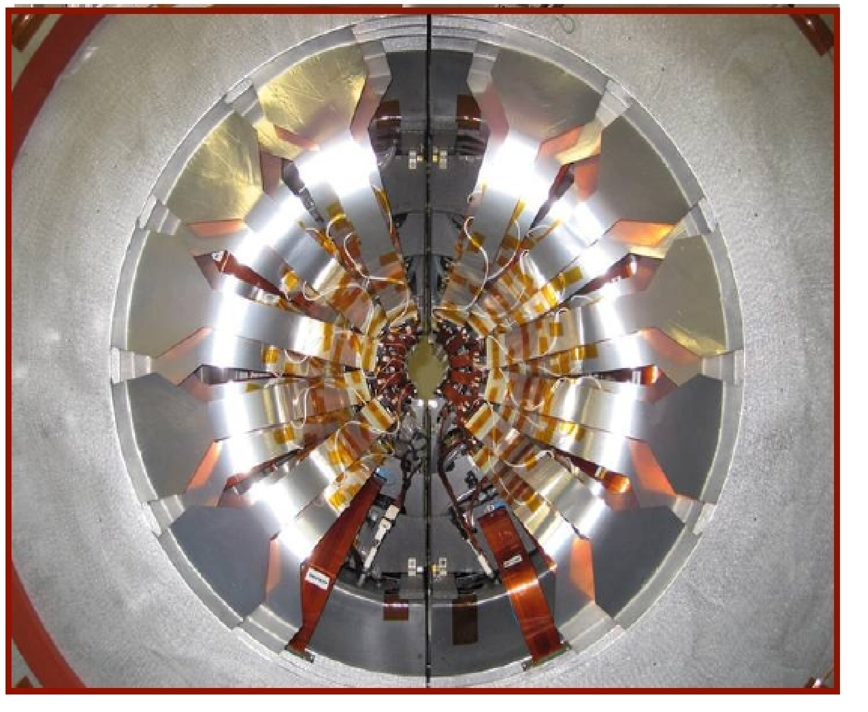


M.Durham - HP2013

Silicon detector for precision tracking at forward rapidity, covering PHENIX muon arms
-b/c muon separation
-ψ(2s) at forward rapidity
-Drell Yan dimuon production



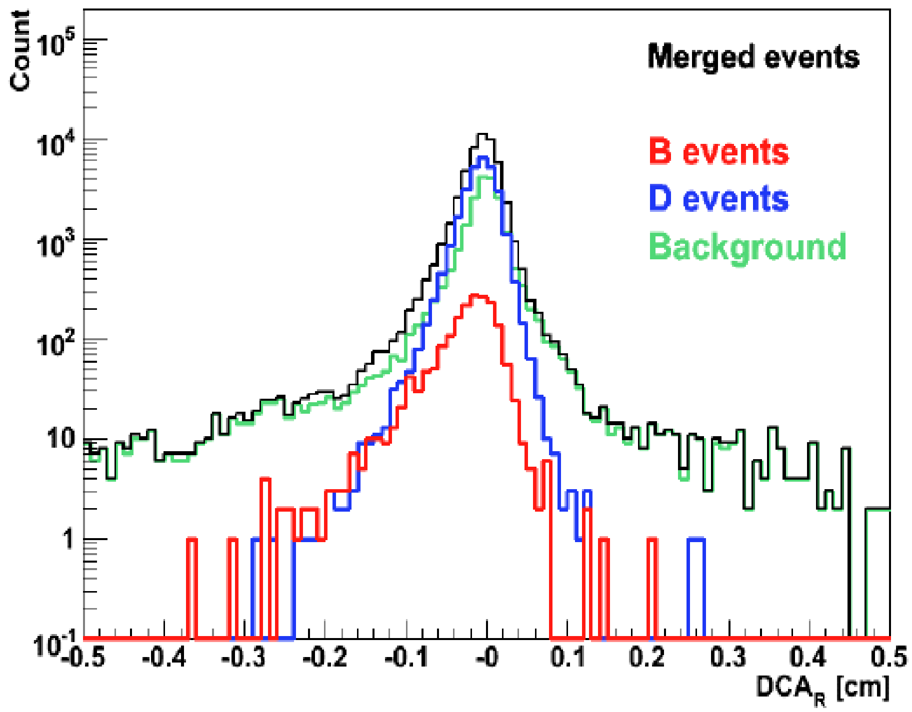
Front view of VTX



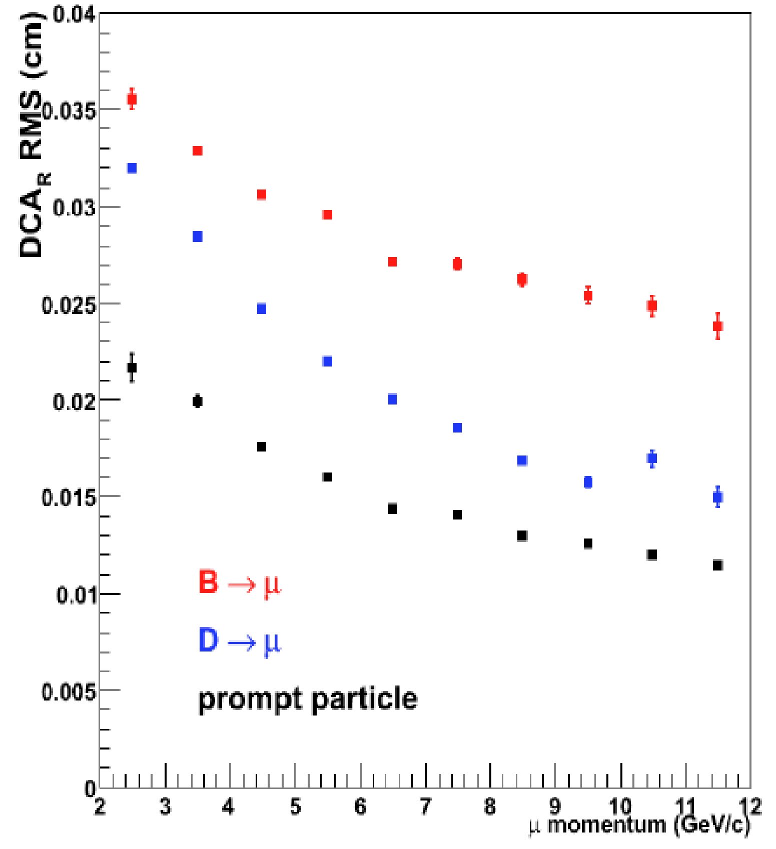
- VTX provides two new capabilities:
  1) Tag and reject conversion providing an independent measurement of photonic background
  2) Measure distance of closest approach to separate charm and bottom components of heavy flavor spectra

PHENIX request for 2015 RHIC beam includes p+C, p+Cu, p+Au

DCA_R for c/b separation



Simulated DCA_R for each process



DCA_R vs momentum

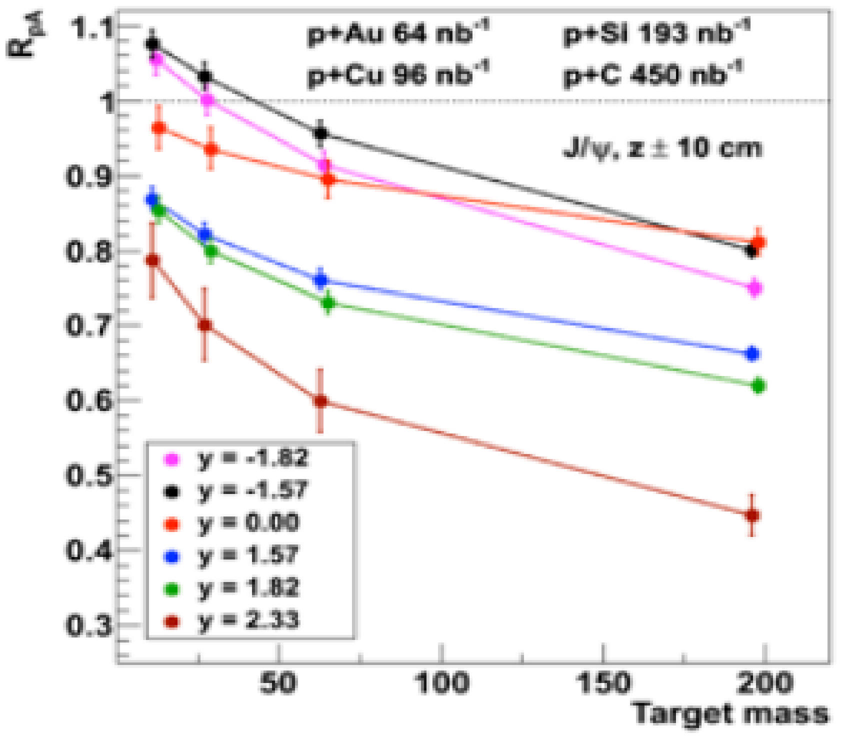
Decay μs from D, B and hadrons have different DCA_R shapes in a given μ p_T bin.

-> Fit the shapes to data or cut out to reduce background keeping a specific window.

Upcoming p+A with PHENIX

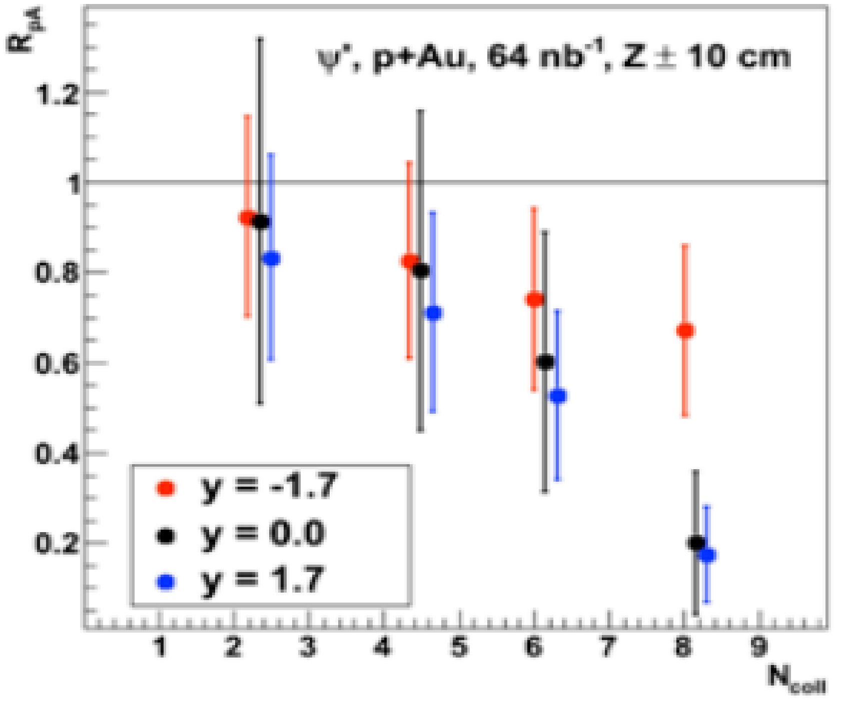
J/ψ in p+(Au, Cu, Si) at 12 rapidities

- Measure J/ψ R_{AA} vs centrality for p+(Au, Cu, Si).
- Study CNM effects vs mass at 200 GeV.
- Compare varying centrality with varying mass.



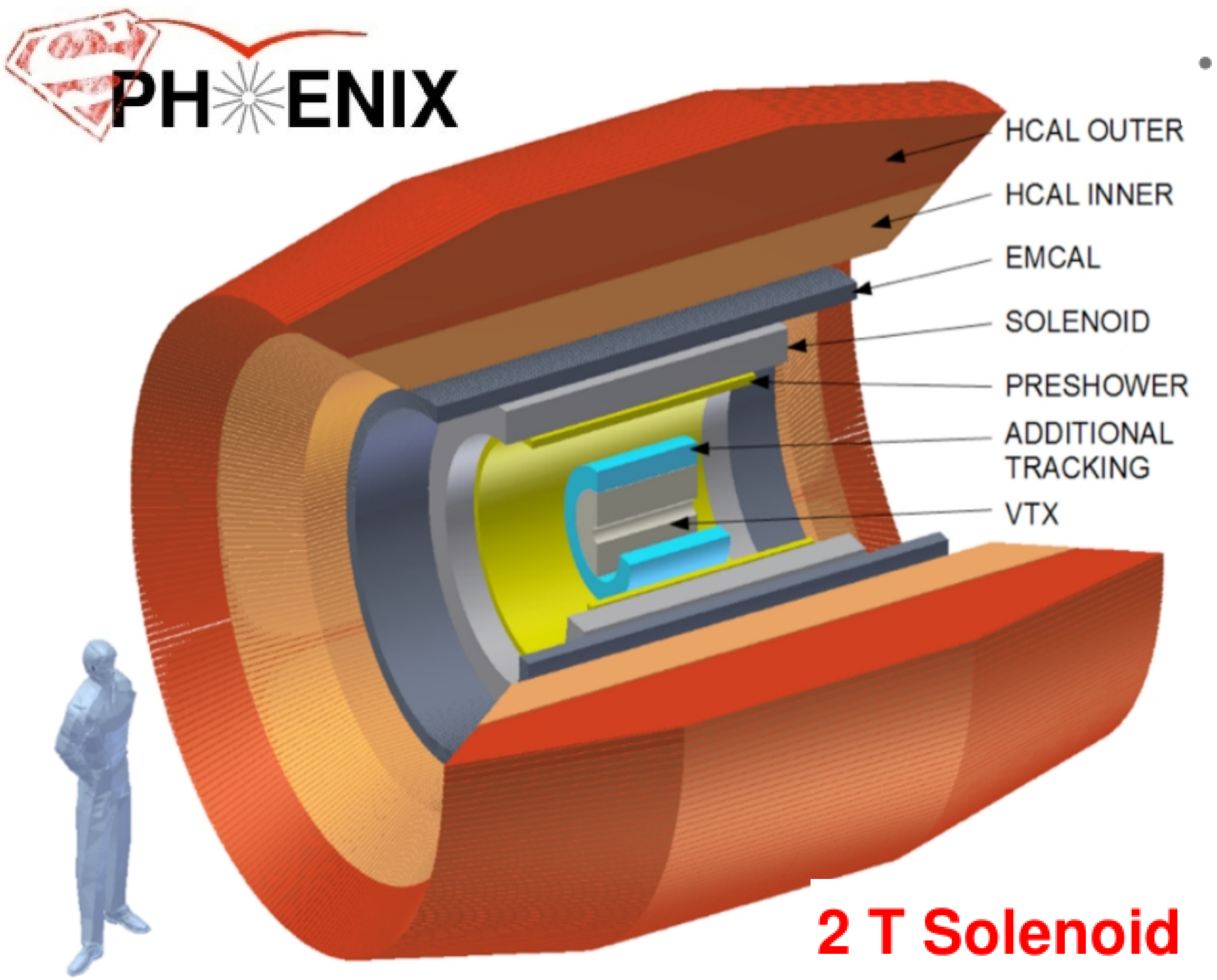
ψ' in p+Au at forward, mid, backward y

- Vary mix of CNM effects on ψ' production.
- Feasible only in p+Au case due to statistical precision.



A.Frawley - HP2013

sPHENIX Barrel upgrade

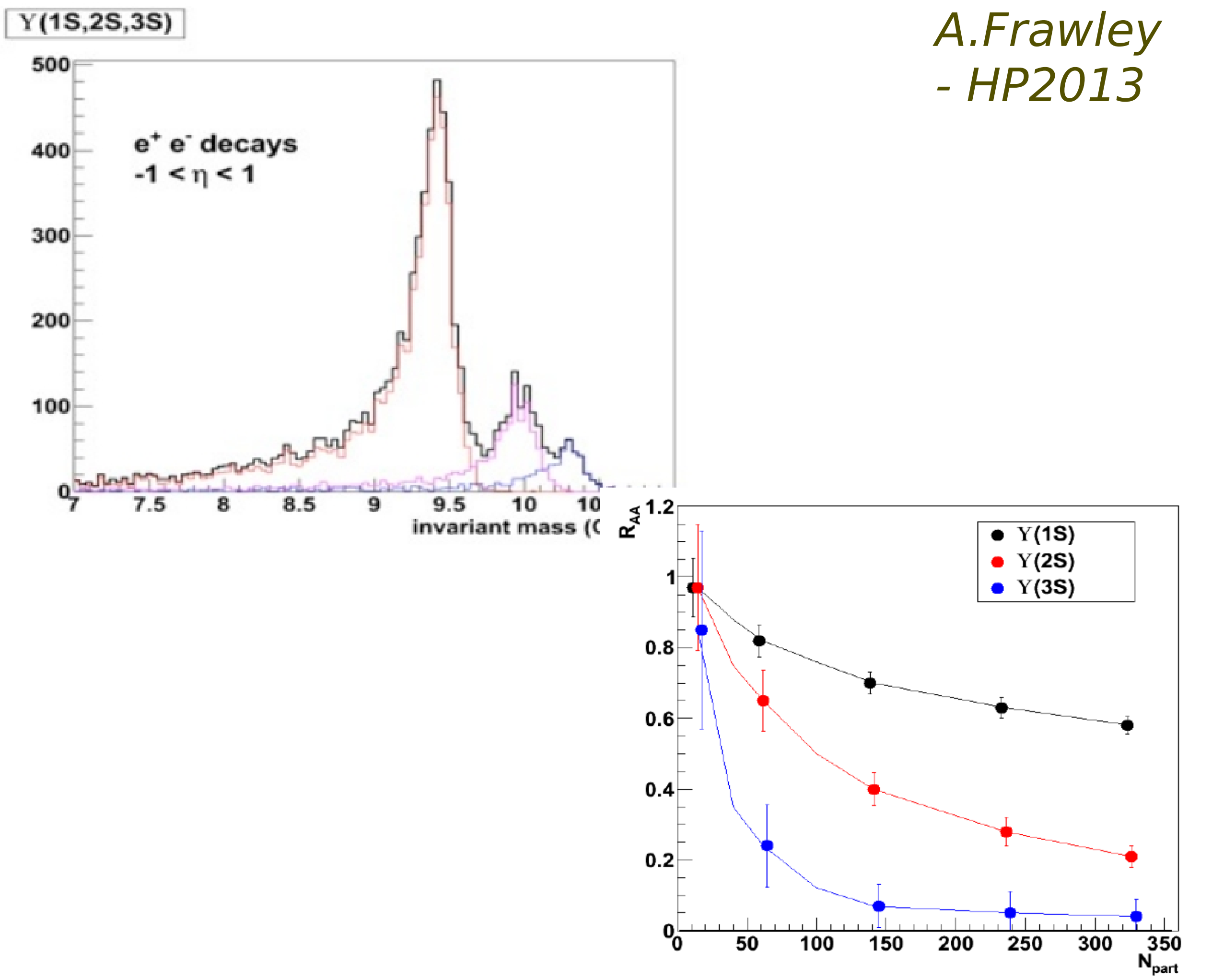


arXiv:1207.6378

- sPHENIX is a significant reworking of PHENIX

- The proposed large acceptance sPHENIX detector, which is designed as a jet detector, will also – with added tracking and electron ID, make good separated Upsilon measurements.

A.Frawley - HP2013



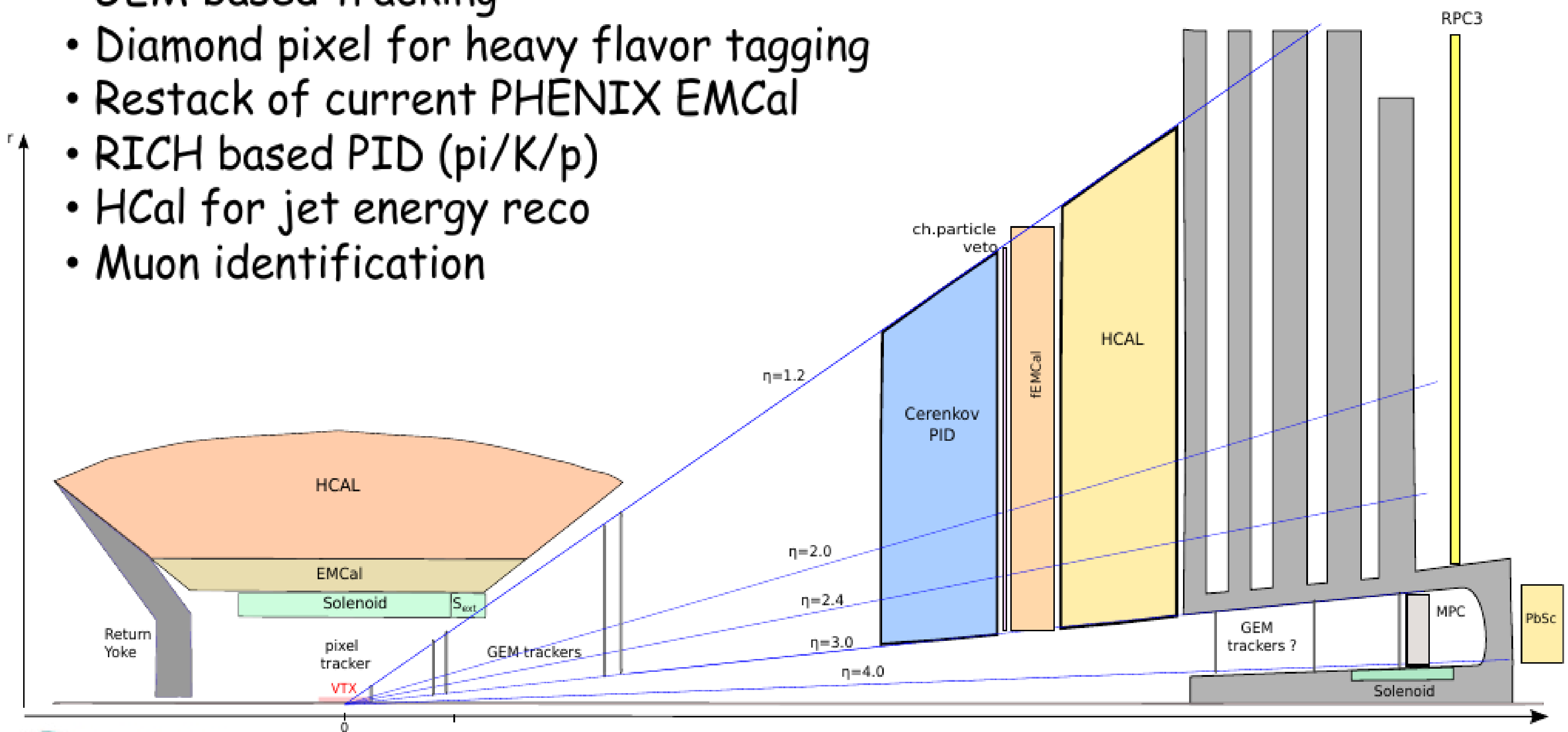
- interesting because of medium properties near T_C and because of complementarity with jet and quarkonia measurements from LHC

- additional tracking layers and EMCal pre-shower provide mass resolution and pion rejection to enable quarkonia program to augment STAR's and complement LHC

Forward sPHENIX

Optimized for jets and photons/DY over a large range in rapidity (η~4)

- Extension/modification of the central solenoid for B field
- GEM based tracking
- Diamond pixel for heavy flavor tagging
- Restack of current PHENIX EMCal
- RICH based PID (pi/K/p)
- HCal for jet energy reco
- Muon identification



RIKEN BNL Research Center

- Forward sPHENIX is being designed with ePHENIX in mind
- A forward EMCal + tracker on the opposite side will need to be added for ePHENIX

J.Seele - QM2012

Muon Telescope Detector (MTD)

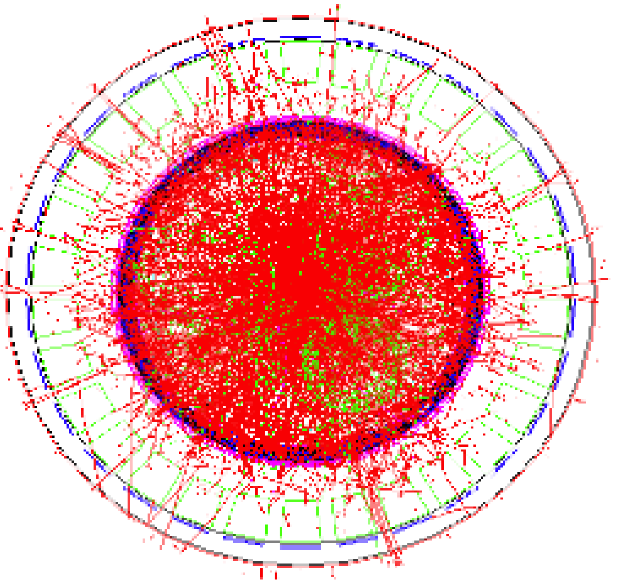
Accessing muons at mid-rapidity

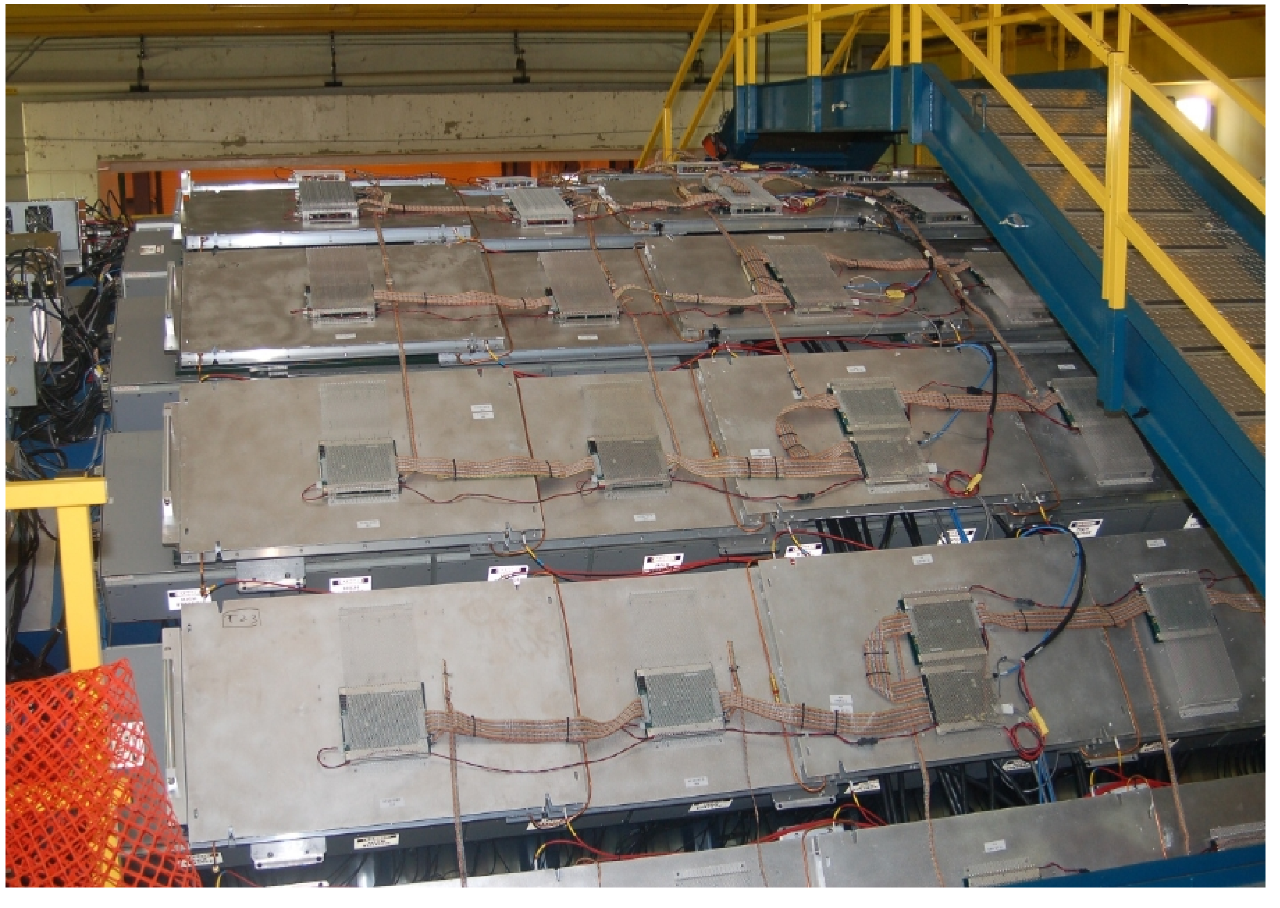
Multi-gap Resistive Plate Chamber (MRPC) - gas detector

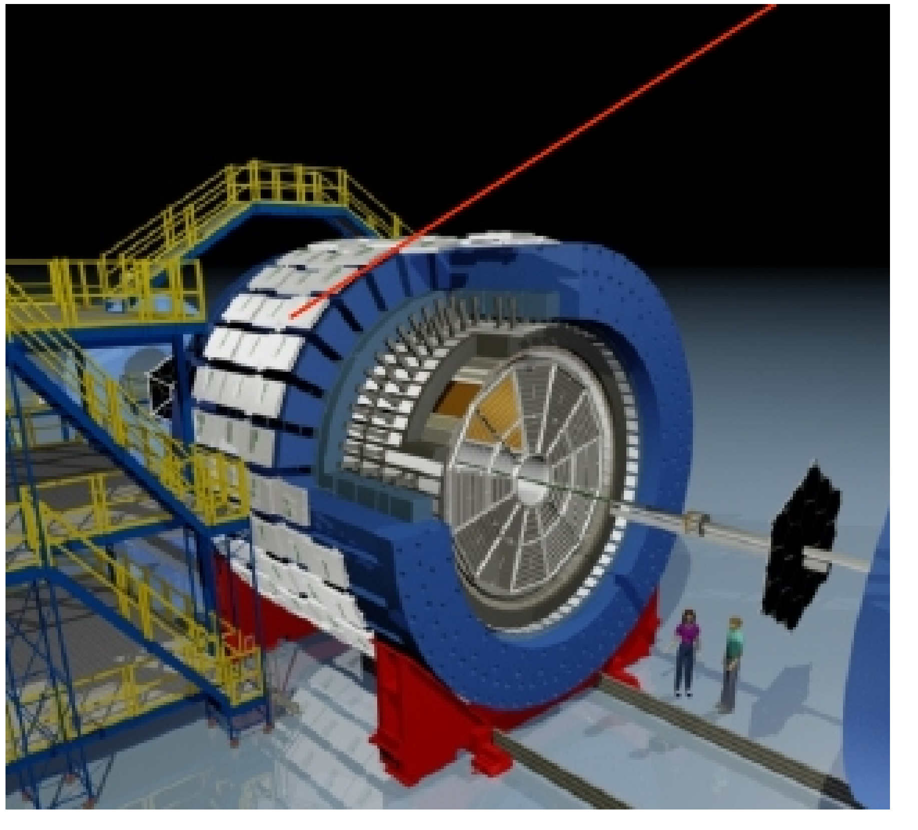
Acceptance: 45% at $|\eta| < 0.5$

Long-MRPCs

Electronics same as in STAR TOF







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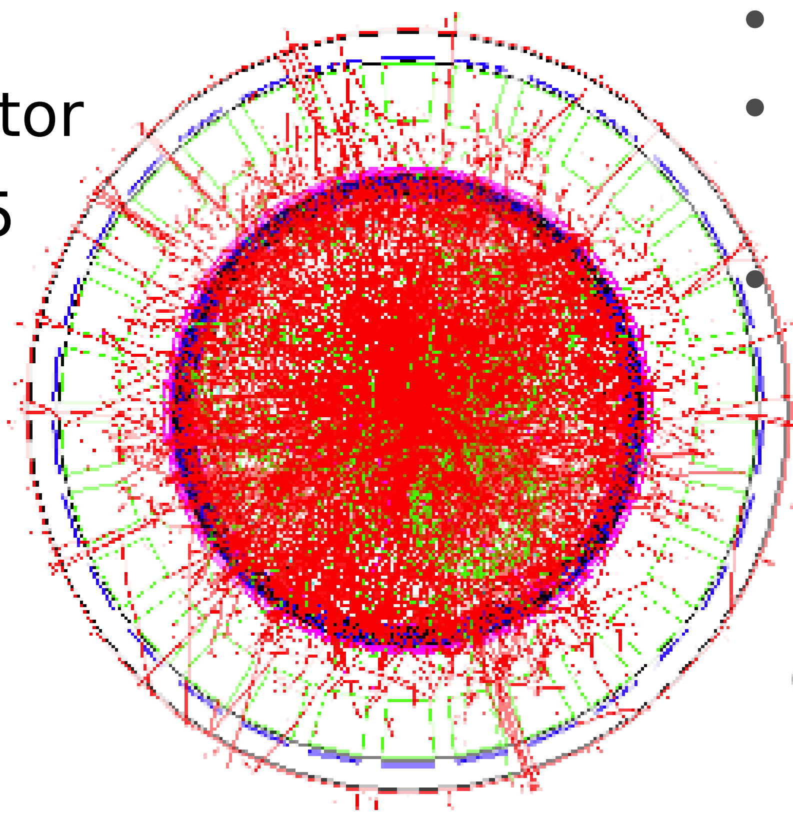
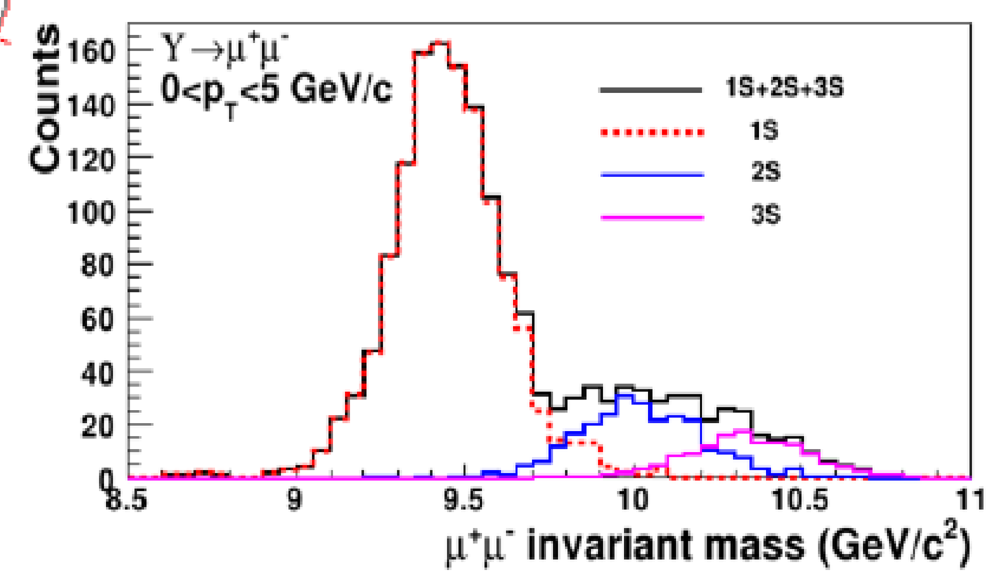
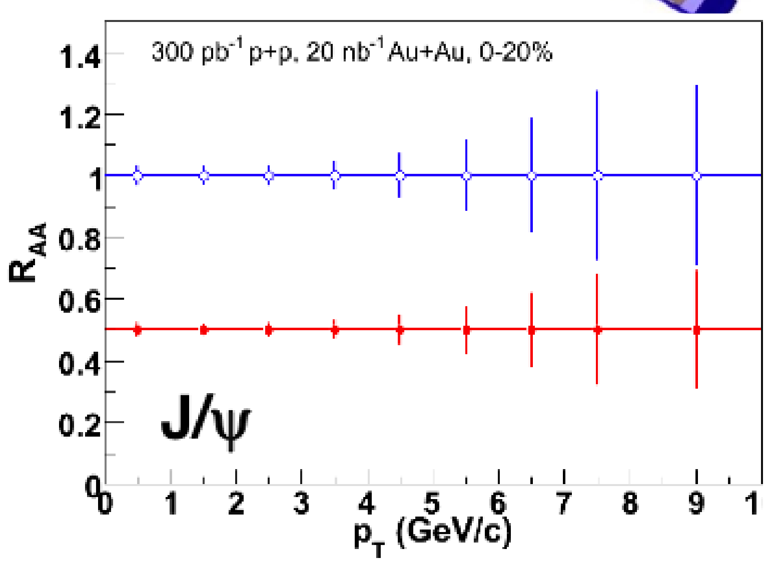
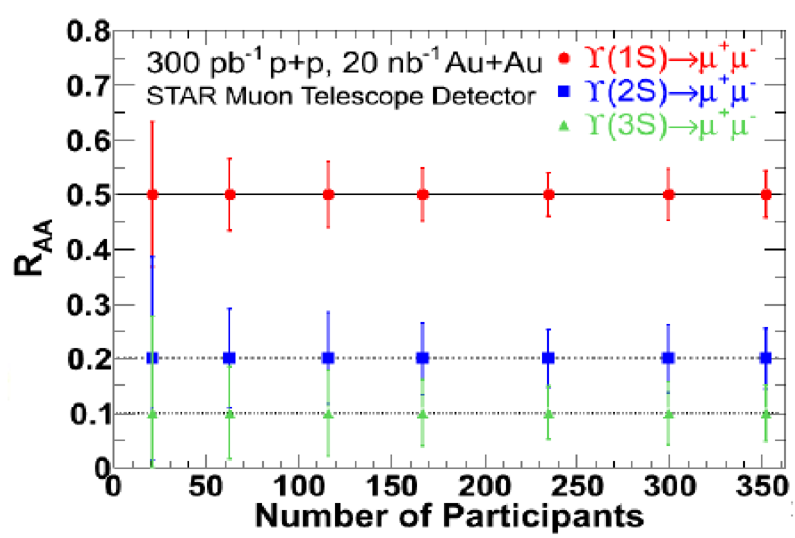


- No γ conversion
- Much less Dalitz decay contribution
- Less affected by radiative looses in the materials







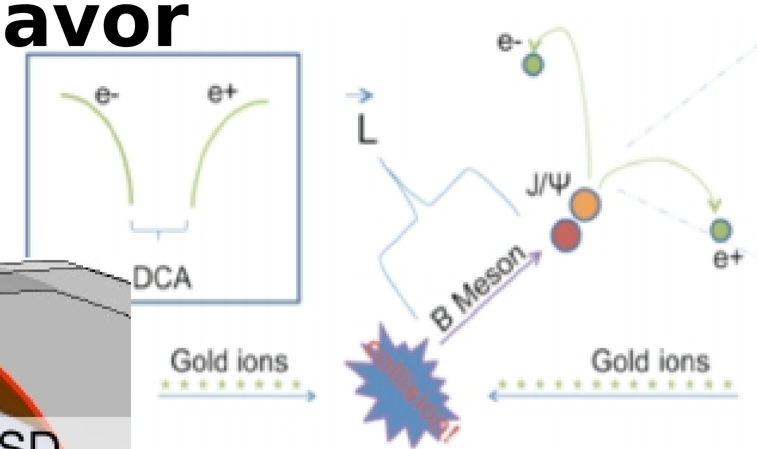
- Excellent mass resolution
- Trigger capability – e-muon, di-muon

Full system in 2014

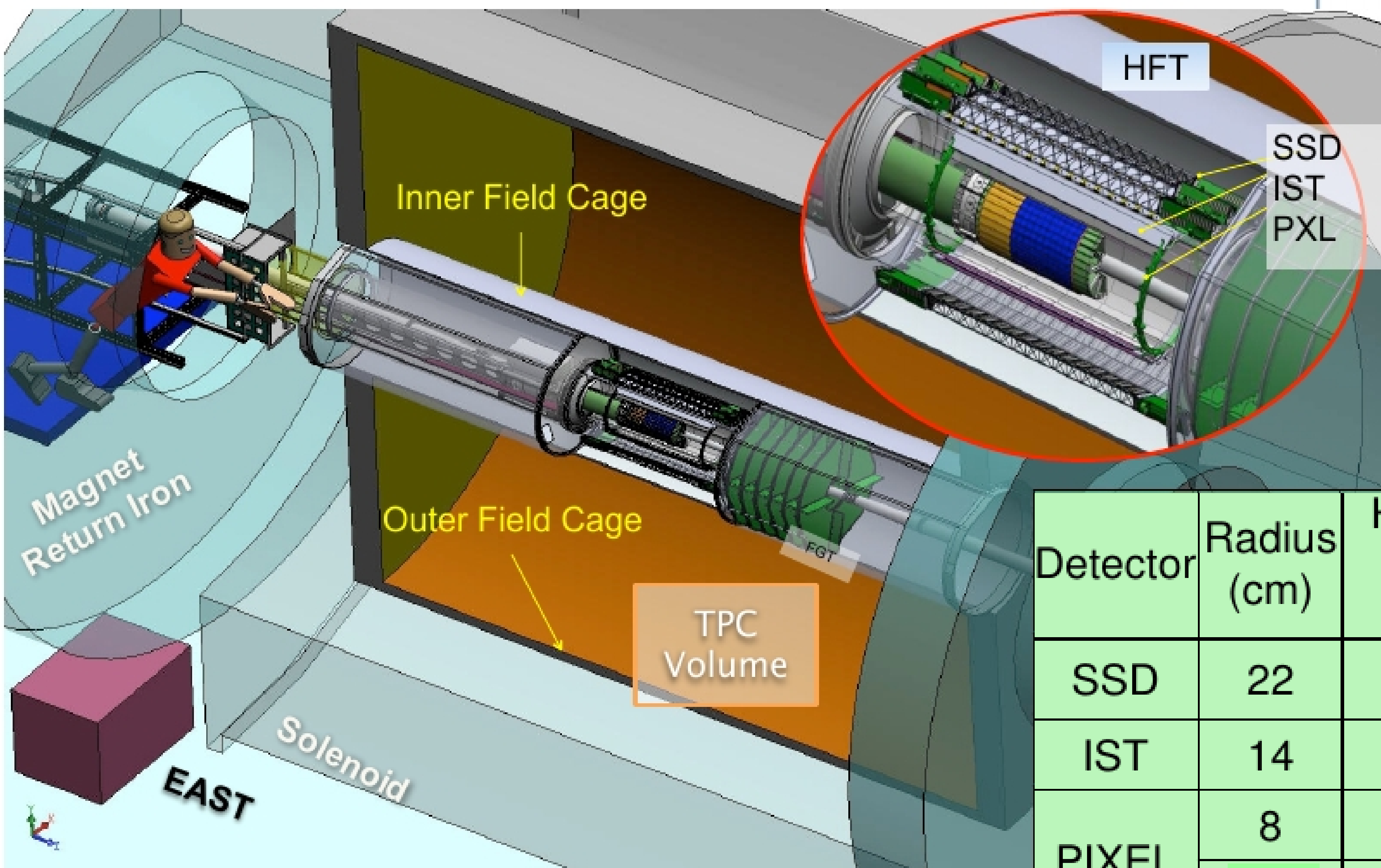
Heavy Flavor Tracker (HFT)

Precision vertex detector: **Open heavy flavor**

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



Direct topological reconstruction of decay vertex

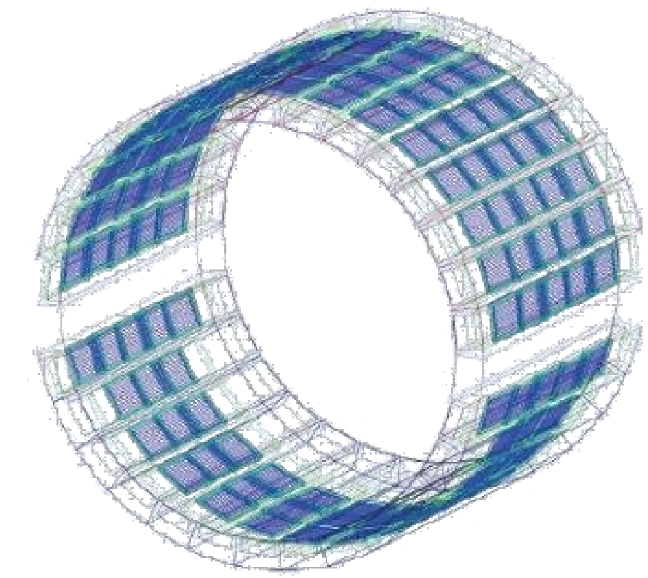


Detector	Radius (cm)	Hit Resolution R/φ - Z (μm - μm)	Radiation length
SSD	22	20 / 740	1% X_0
IST	14	170 / 1800	<1.5 %X_0
PIXEL	8	12/ 12	~0.4 %X_0
	2.7	12 / 12	~0.4% X_0

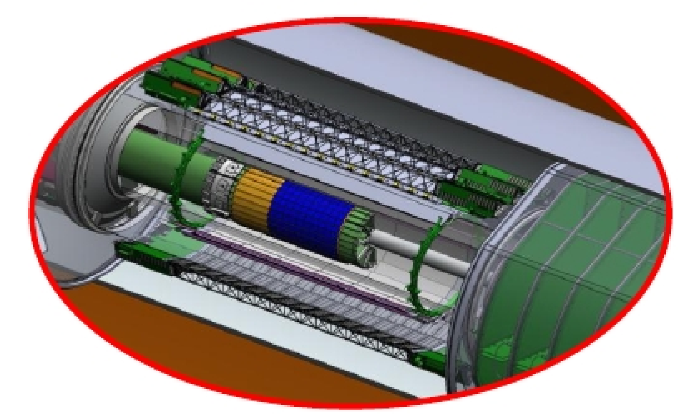
Full system in 2014

MTD + HFT

- Heavy Flavor Tracker + Muon Telescope Detector on track for RHIC Run 14
  - major focus: heavy-flavor & dilepton measurements
  - revisit Au+Au, p+p, and p+Au at $\sqrt{s_{NN}}$=200 GeV
- Separate charm and bottom, study open heavy flavor (HFT), quarkonia (MTD), thermal dileptons (MTD)
  - combine HFT+MTD: separate secondary J/Ψ from prompt
  - combine MTD+BEMC: trigger on e-μ pairs to disentangle charm contributions to the dilepton IMR



Muon Telescope Detector



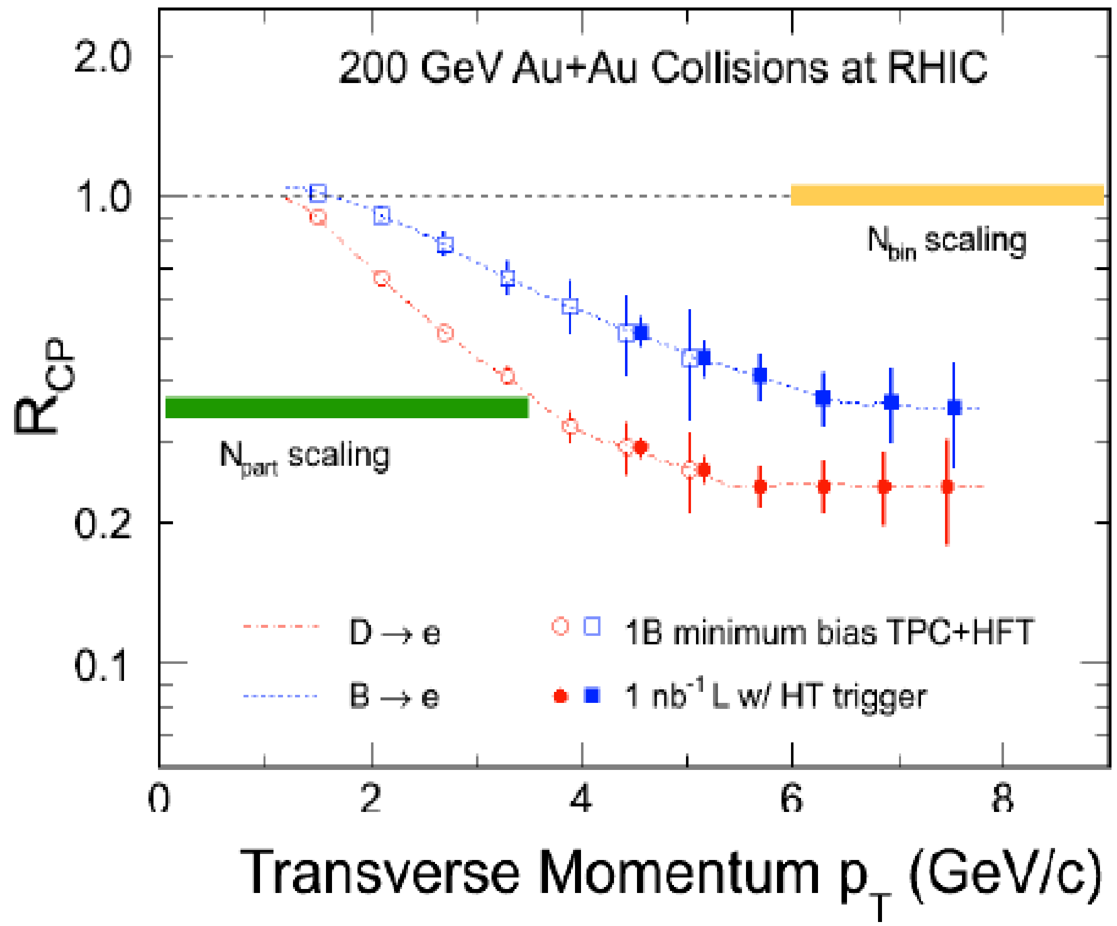
Heavy Flavor Tracker

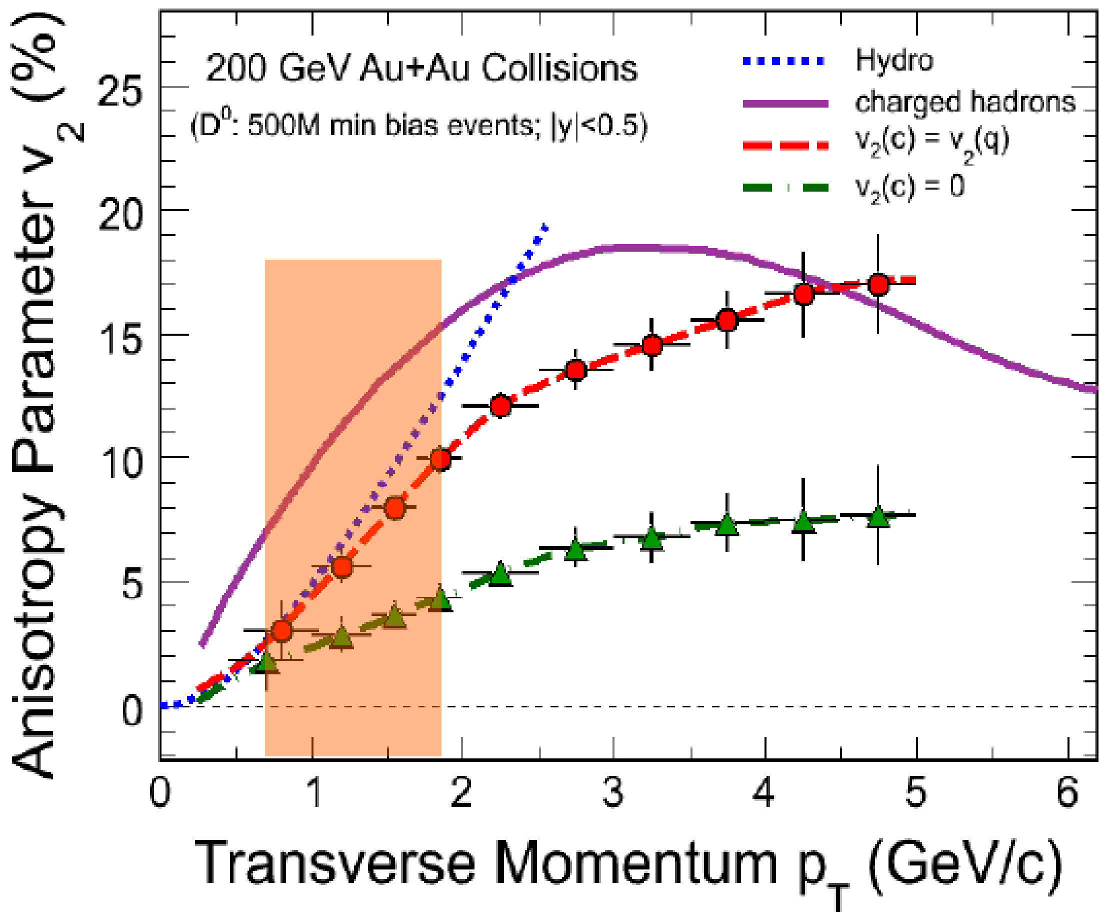
B.Christie - HEP2013

european social fund in the czech republic EUROPEAN UNION MINISTRY OF EDUCATION, YOUTH AND SPORTS OP Education for Competitiveness
INVESTMENTS IN EDUCATION DEVELOPMENT

STAR projections for Run 14,15

unique high precision at low p_T -> medium thermalization, total charm production





Assuming D^0 R_{cp} distribution as charged hadron.

500M Au+Au m.b. events at 200 GeV.

- Charm R_{AA} □

Energy loss mechanism!
Color charge effect!
Interaction with QCD matter!

Assuming D^0 v_2 distribution from quark coalescence.

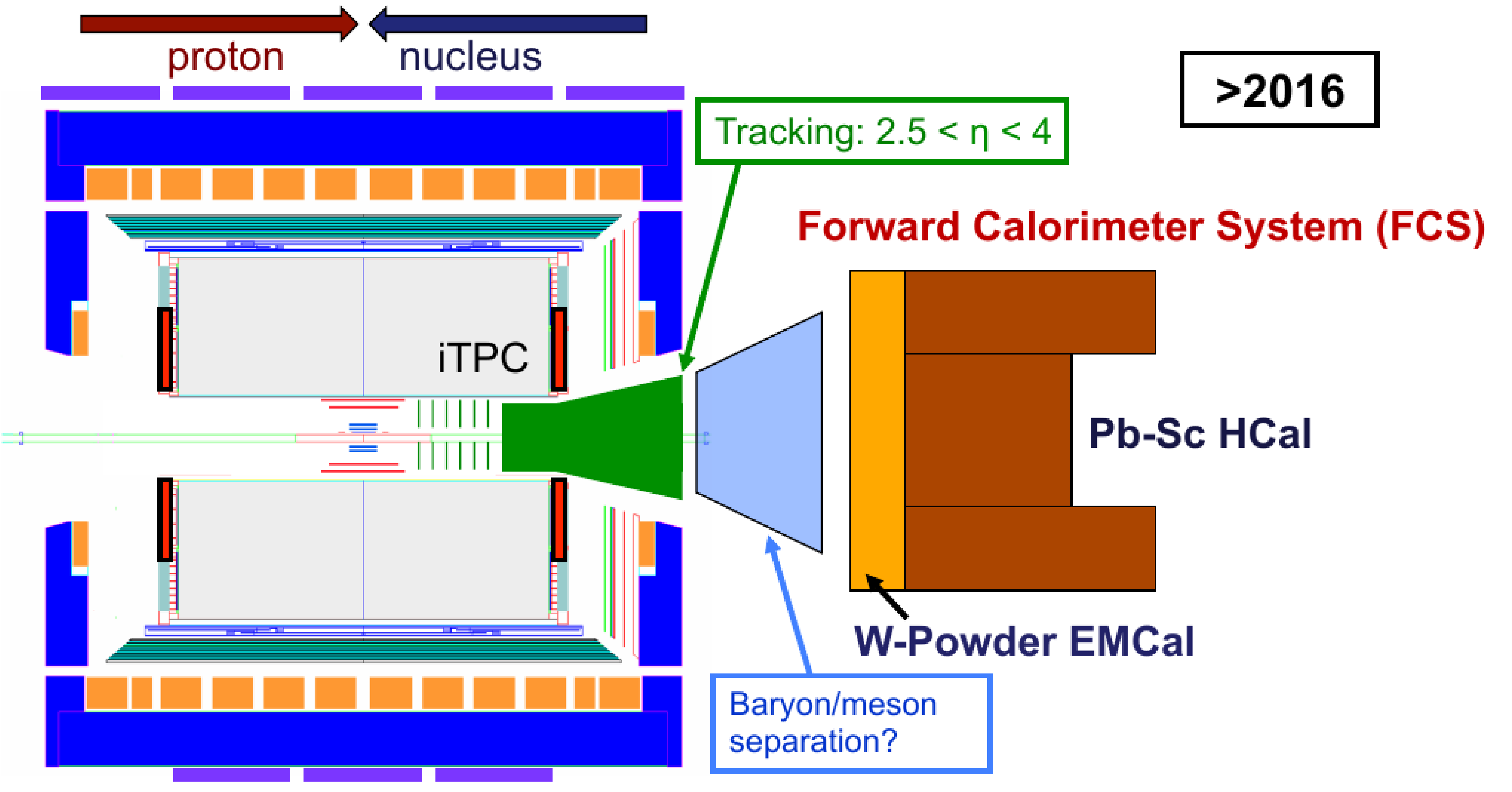
500M Au+Au m.b. events at 200 GeV.

- Charm v_2 □

Medium thermalization degree
Drag coefficients!

B.Christie - HEP2013

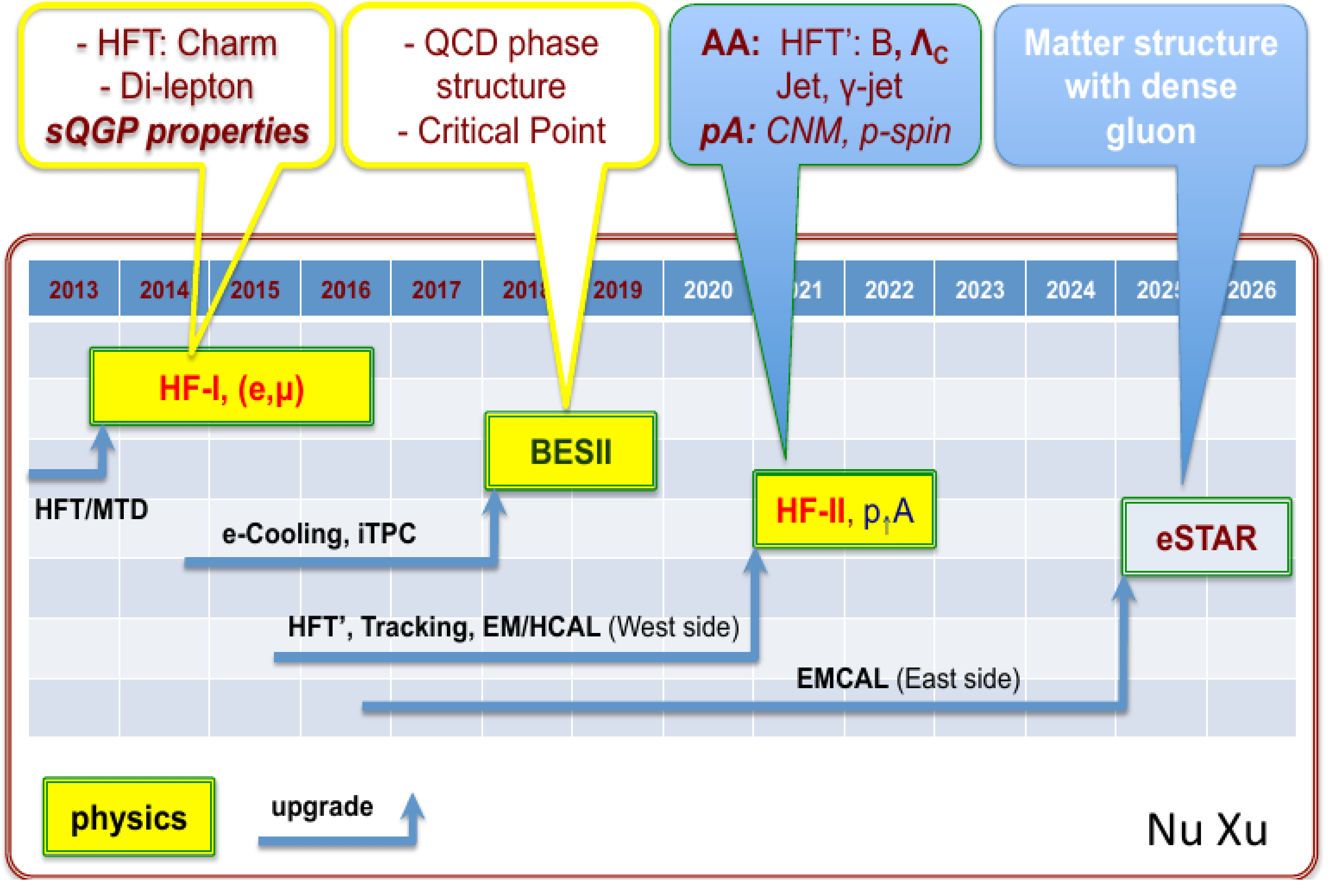
STAR forward upgrade



- **Forward instrumentation optimized for p+A and transverse spin physics**
  - **Charged-particle tracking**
  - ***e*/*h* and γ/π^0 discrimination**
  - **Baryon/meson separation**

STAR future

- HF-I (2014-2016)
  - Au+Au, p+p, p+Au
  - HFT and MTD upgrade significantly improve STAR's hard-probes potential
- HF-II/pA (2021/2022)
  - A+A and p+A
  - further upgrades to improve B, Λ_C, and jet physics in A+A
  - CNM



Thank you !

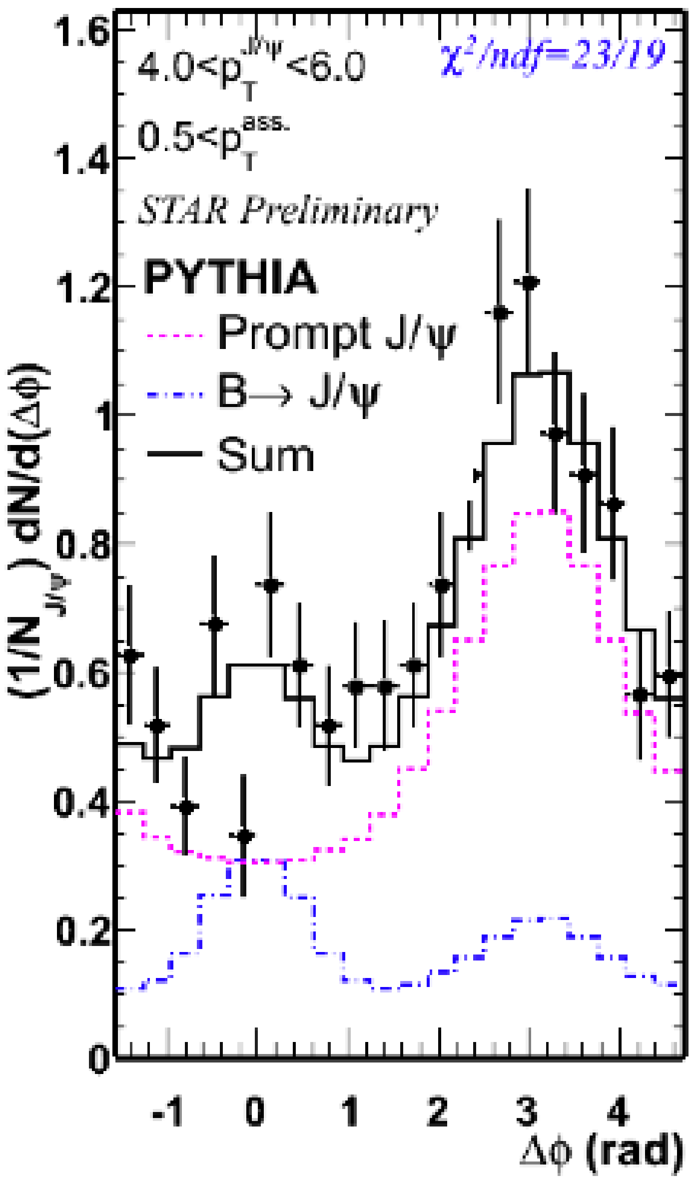
Backup

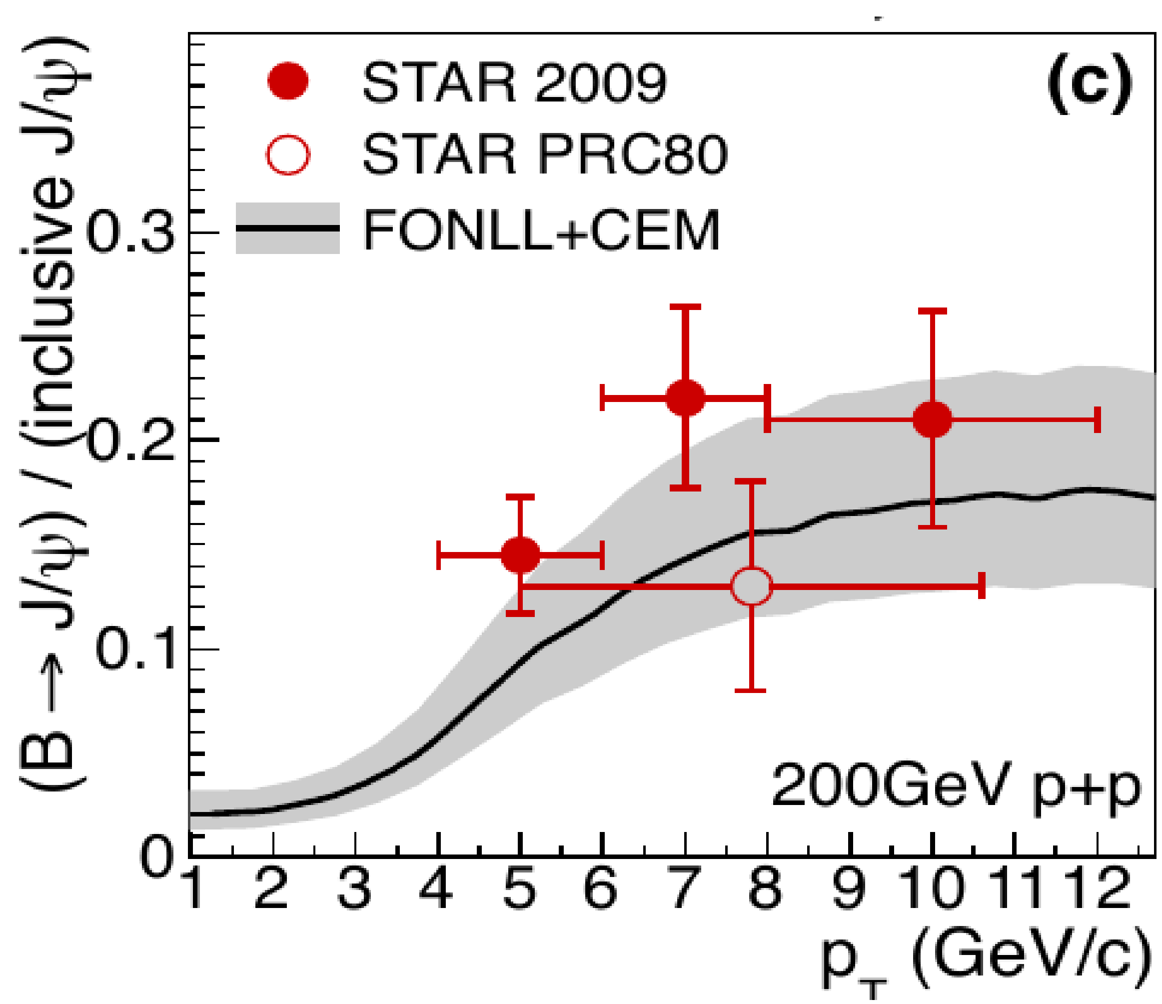
J/ψ-hadron correlations in p+p collisions at 200 GeV

Phys. Lett. B 722 (2013) 55

B → J/ψ feed-down

Model based extraction using PYTHIA

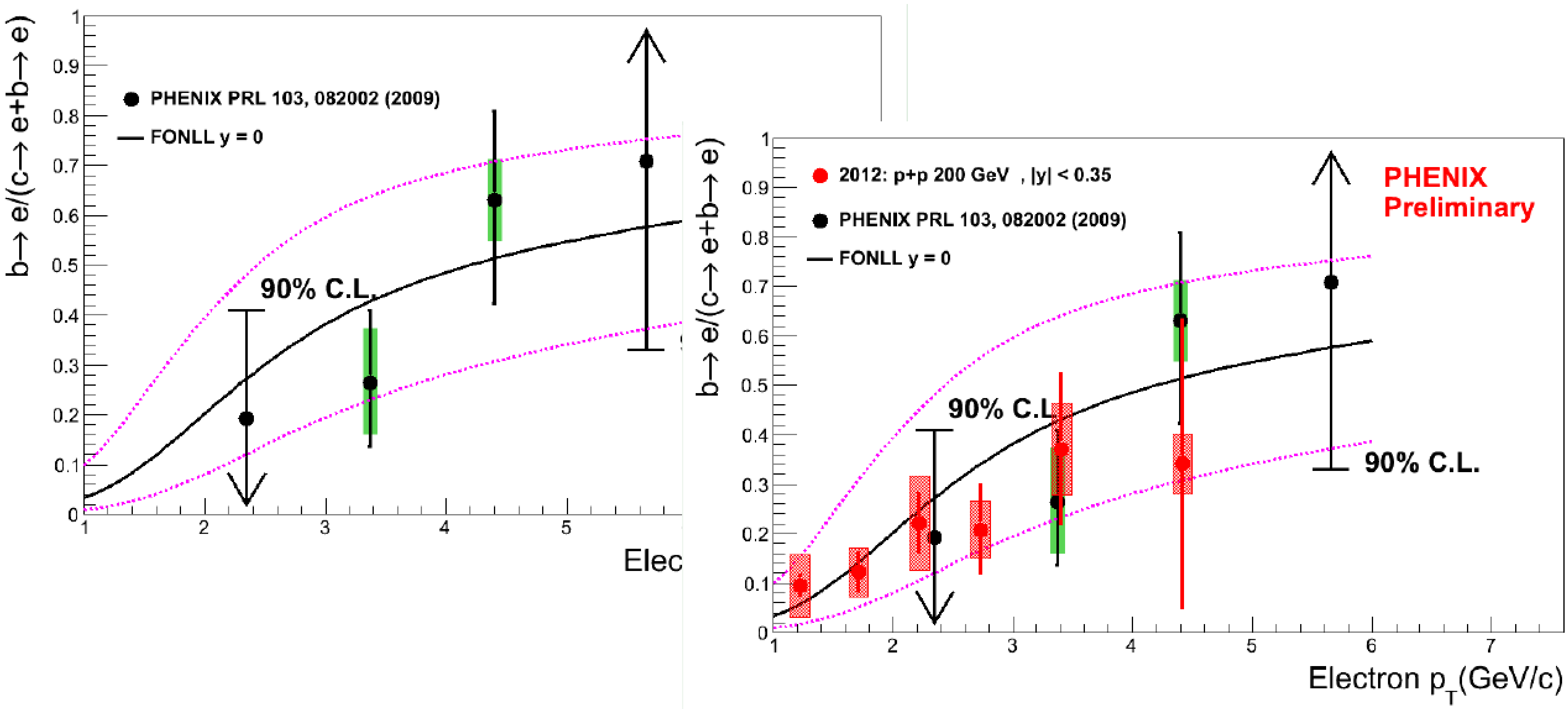




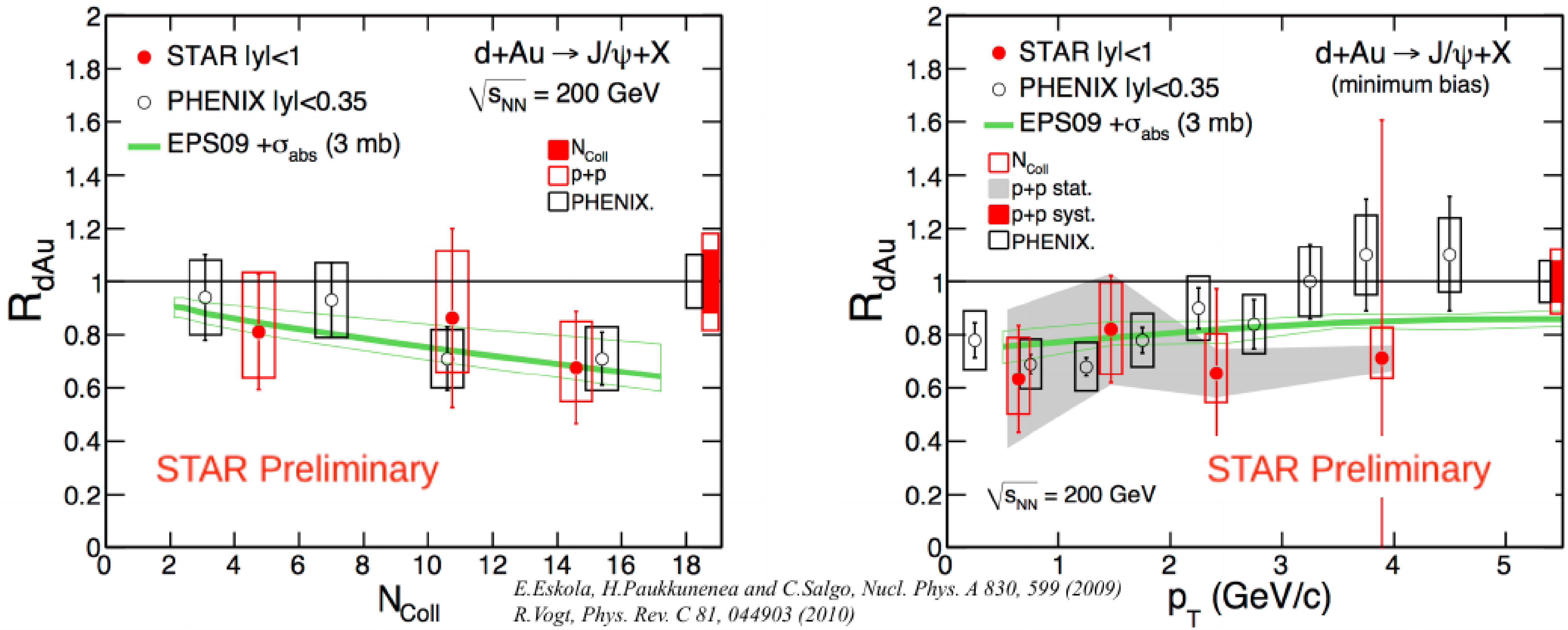
- ✓ Extracted from near side J/ψ-h correlation
- ✓ B-hadron feed-down contribution of 10-25% at 4-12 GeV/c
- ✓ Result consistent with FONLL+CEM calculation

Charm and bottom decomposition

- (b->e)/(b->e + c->e) ratio for p+p collisions from partial reconstruction of D→$e^{+/-}K^{-/+}X$



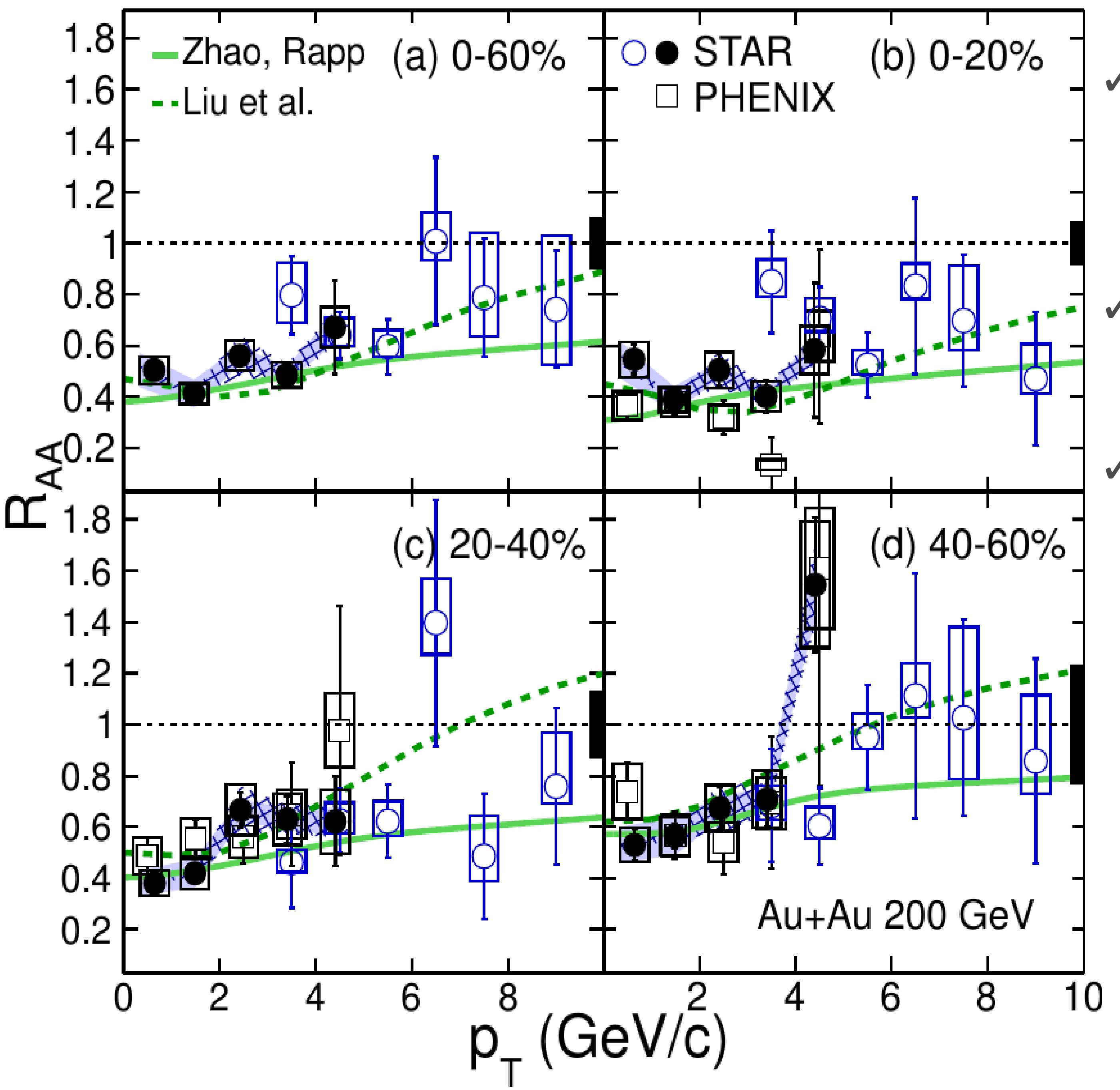
J/ψ R_{AA} in d+Au collisions at 200 GeV



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 R_{AA} vs p_T in Au+Au at 200 GeV at mid-rapidity

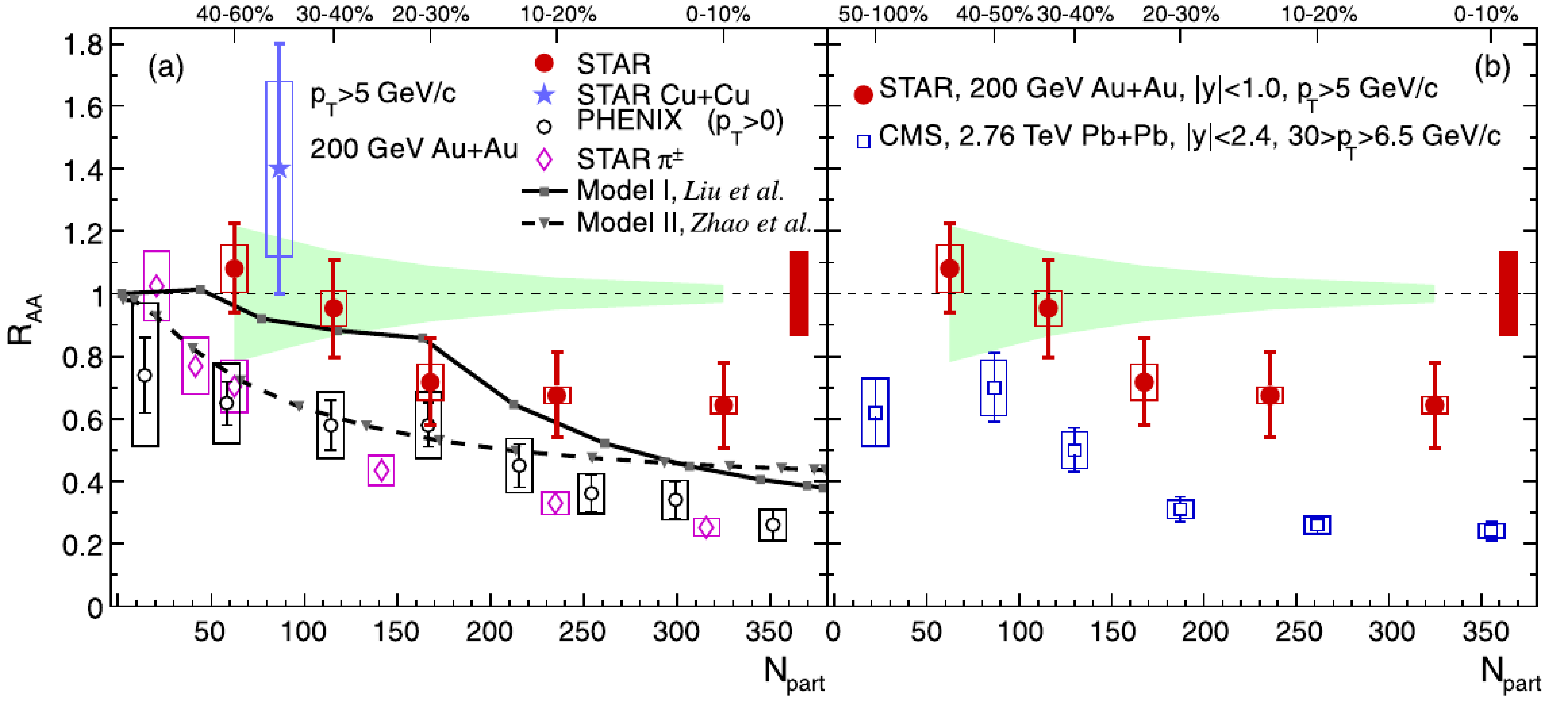


- ✓ J/ψ suppression decreases with increasing p_T across the centrality range
- ✓ Strong suppression at low p_T (< 3 GeV/c) for all centralities
- ✓ At high-p_T:
  - suppression for central collisions
  - R_{AA} consistent with unity in (semi-)peripheral collisions
- ✓ Data agrees with theoretical calculations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

PHENIX: Phys. Rev. Lett. 98 (2007) 232301
STAR high-p_T : Phys. Lett. B 722 (2013) 55
STAR low-p_T : arxiv:1310.3563

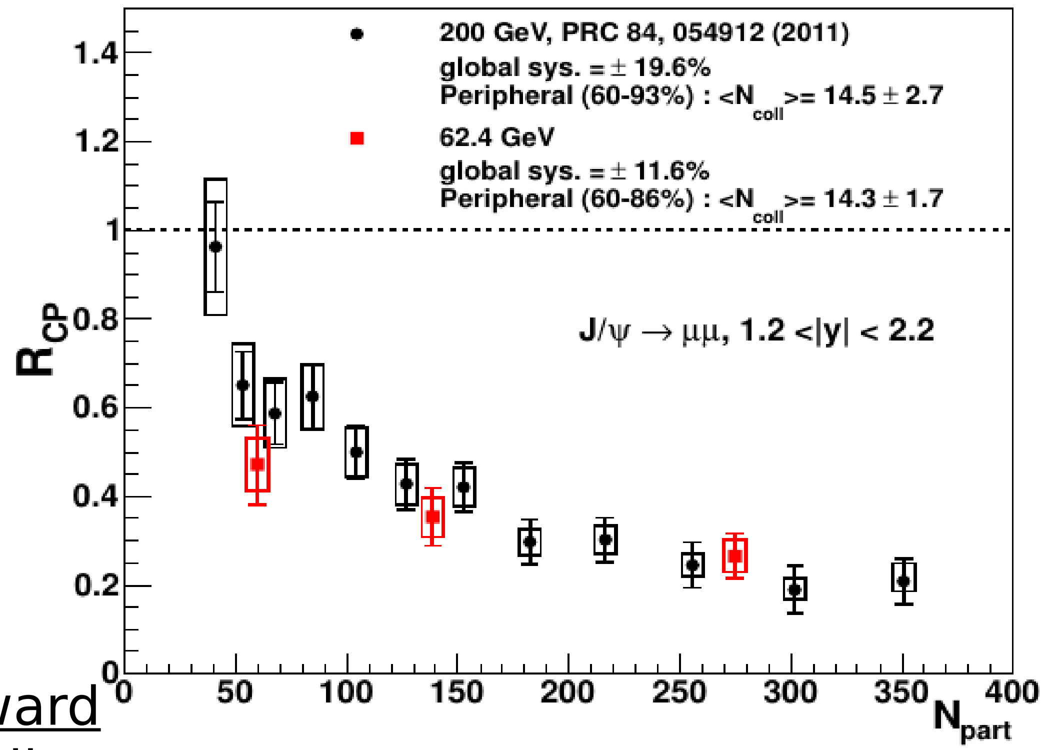
Y.Liu et al., Phys. Lett. B, 678 (2009) 72
Zhao, Rapp, Phys. Rev. C 82 (2010) 064905

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

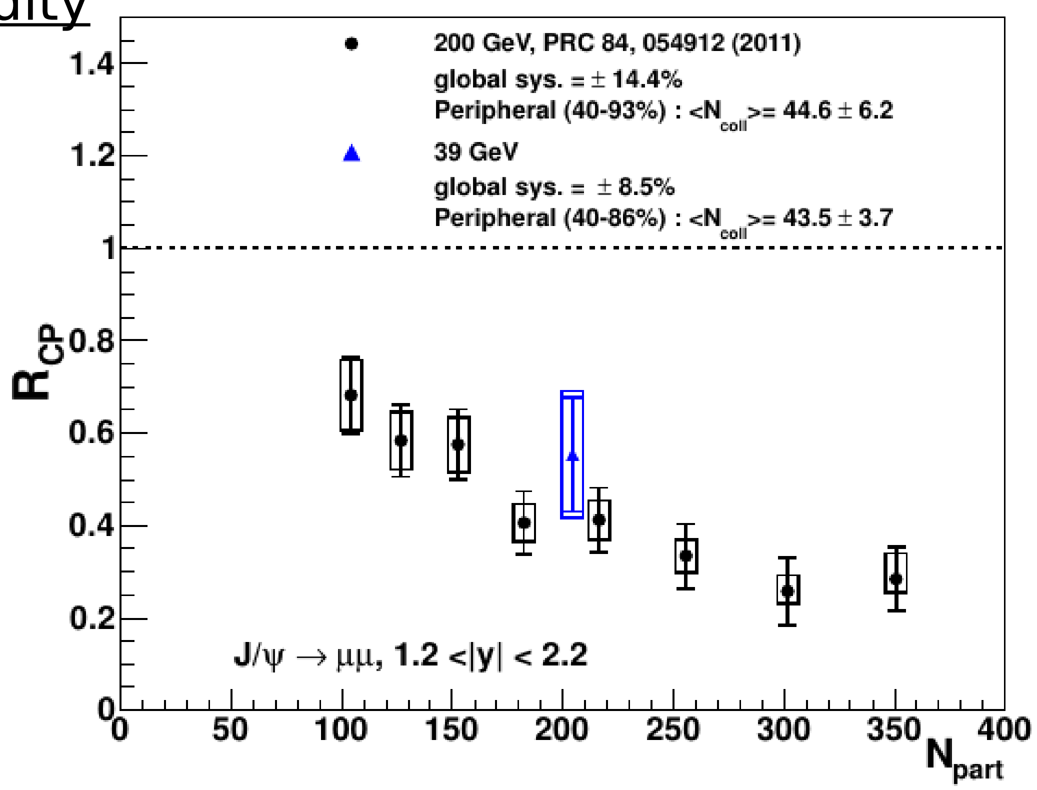


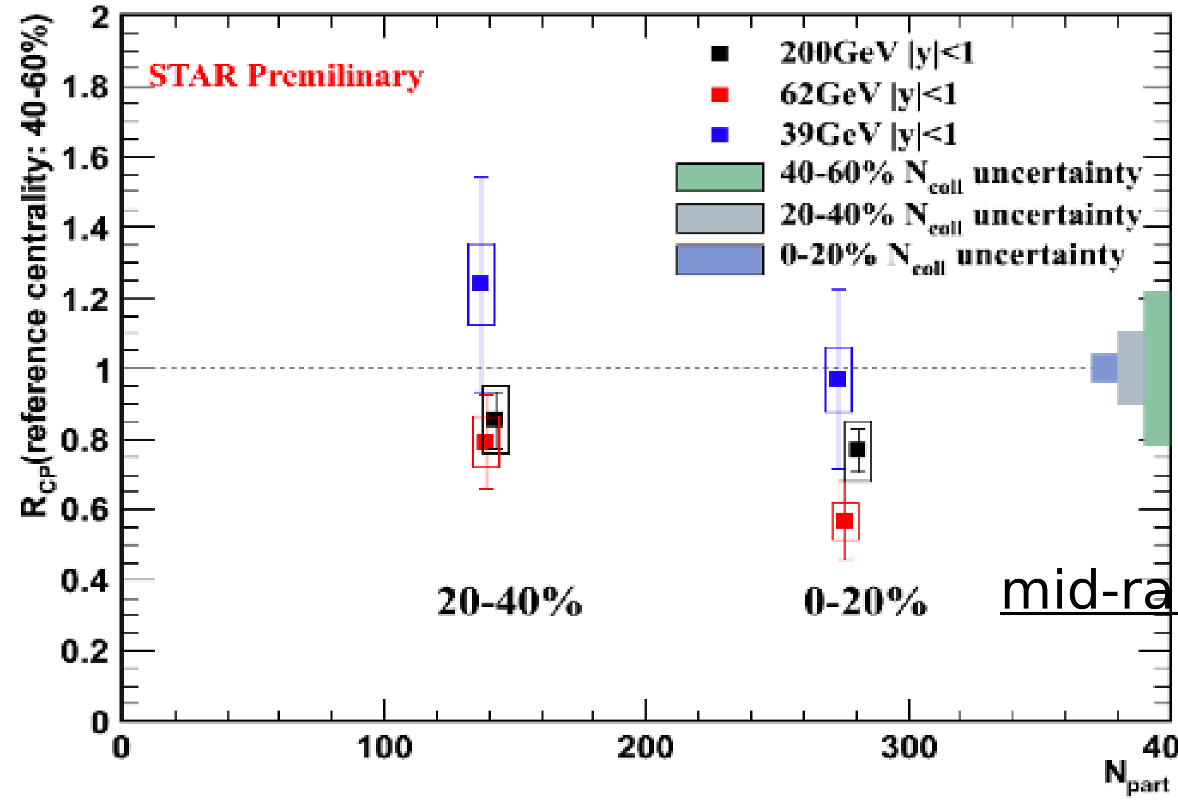
- ✓ Higher R_{AA} for STAR than CMS for all centralities

Energy dependence of J/ψ R_{CP}, Au+Au



Forward rapidity



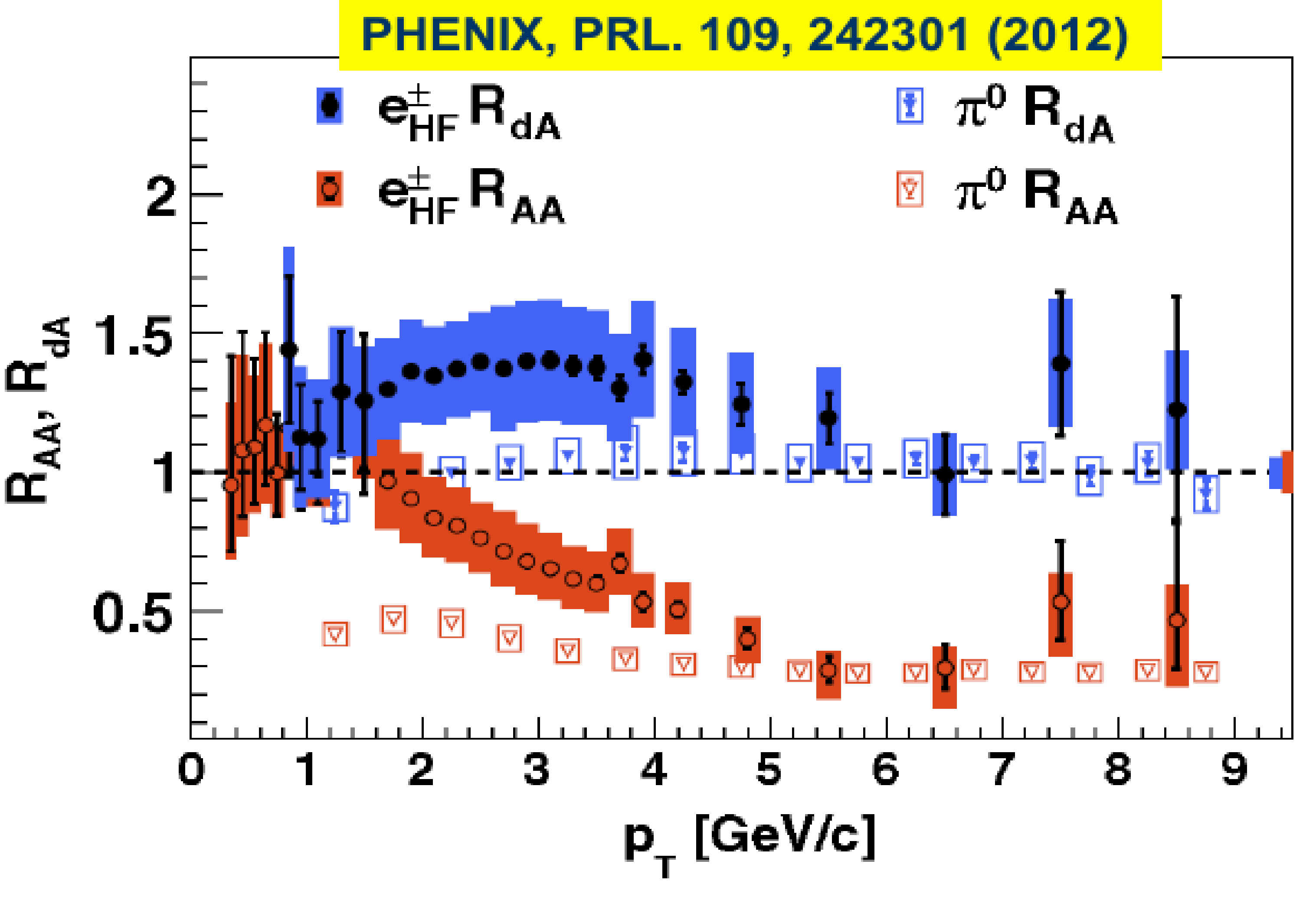


mid-rapidity

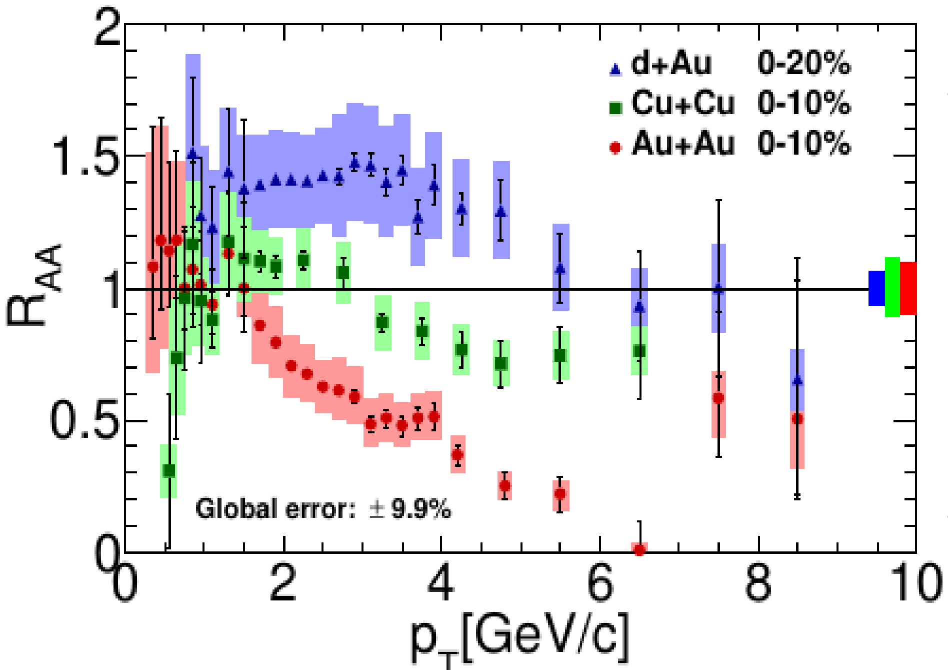
- ✓ Similar suppression for all energies

Flavor similarity

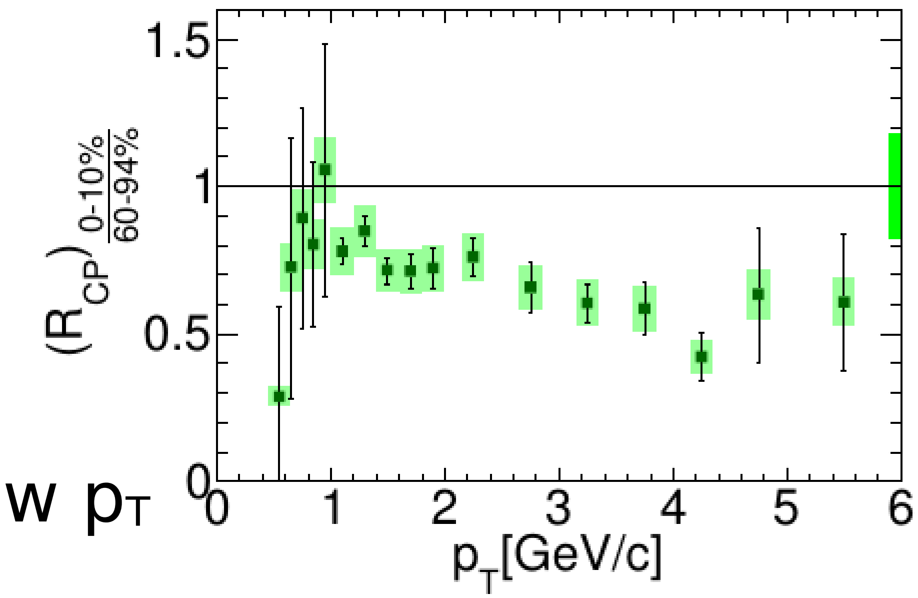
- Different quark flavor may give different interaction.
  - Mass ordering (dead-cone effect, etc.)
- At high p_T (p_T>5GeV/c), electrons from heavy quark (c,b) show similar R_{AA} and R_{dA} as π^0's from light quark (u,d) or gluons.



HF electrons in different systems



✓ Suppression in the central relative to peripheral Cu+Cu collisions

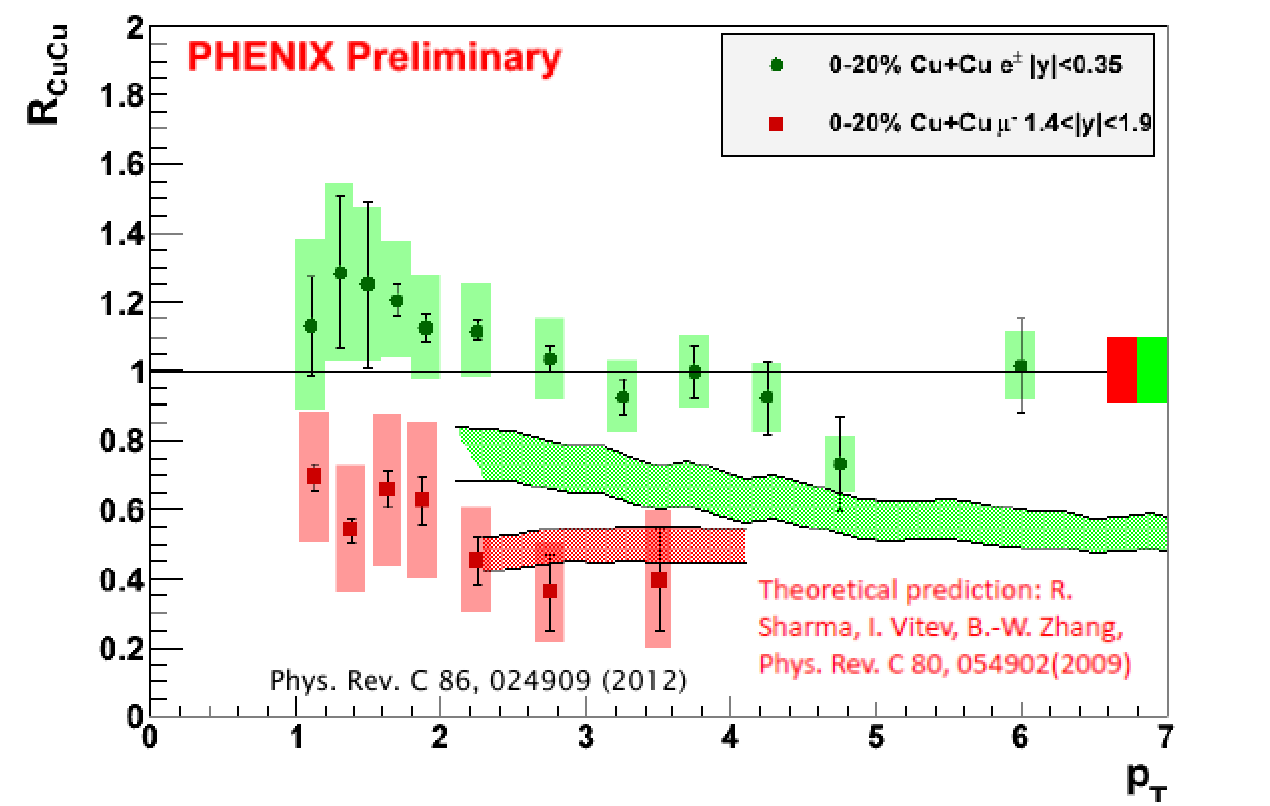


✓ Enhancement at low p_T Cu+Cu peripheral collisions

✓ Different suppression in central collisions – hierarchy between 3 systems

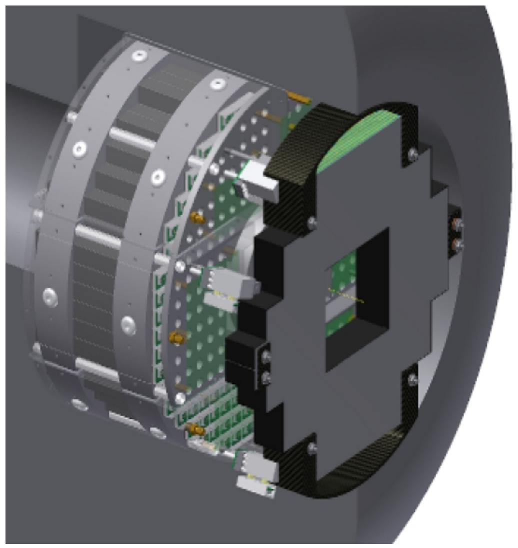
Different system sizes

- *Central d+Au ≈ peripheral Cu+Cu*
- *Central Cu+Cu ≈ peripheral Au+Au*



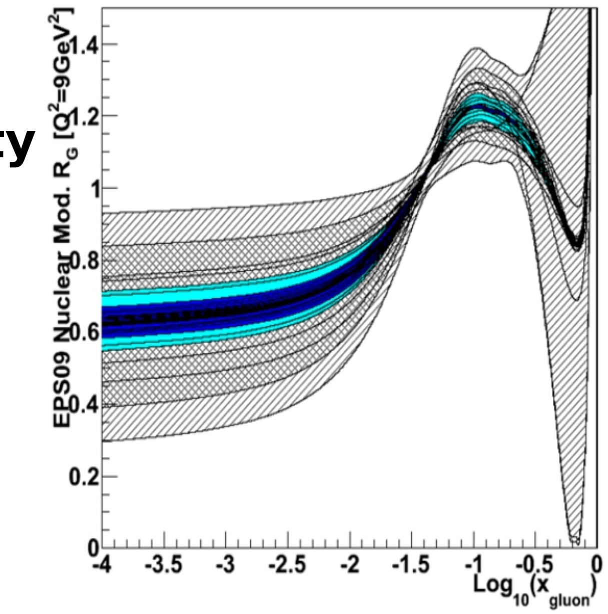
PHENIX upgrade

Soon to come: MPC-EX



Preshower for enhanced capability of forward calorimeter

Far forward direct photon measurement to constrain low-x PDFs



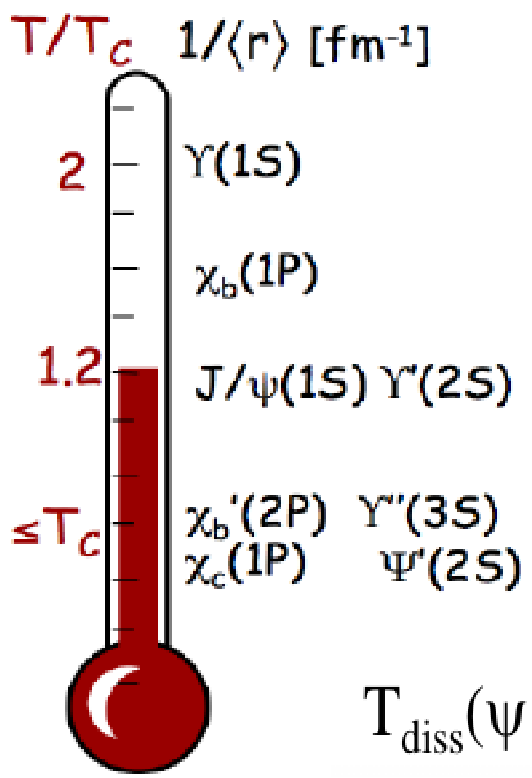
M.Durham - HP2013

Quarkonia at RHIC - Motivation

Charmonia: J/ψ, ψ', χ_c *Bottomonia:* $\Upsilon(1S)$, $\Upsilon(2S)$, $\Upsilon(3S)$, χ_b

- ✓ Quarkonia 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 Thermomete

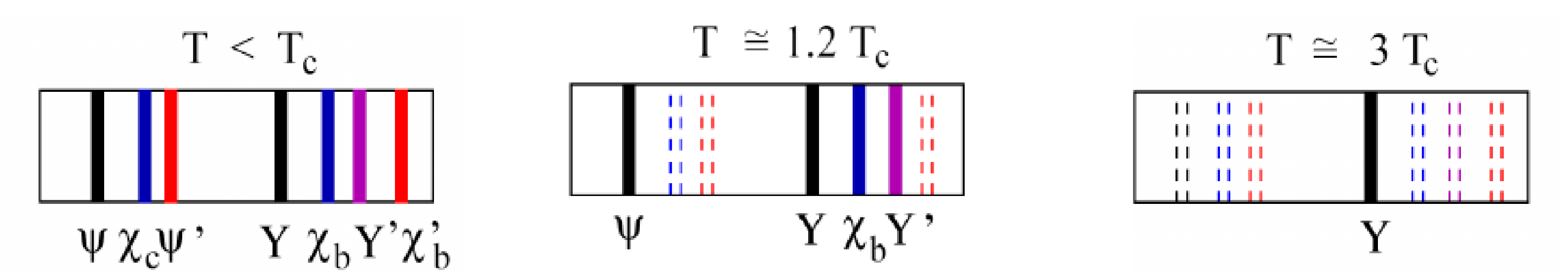


A.Mocsy, Eur. Phys. J. C61, 705-710 (2009)

Screening radius:

$r_D(T) \propto 1/T$

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



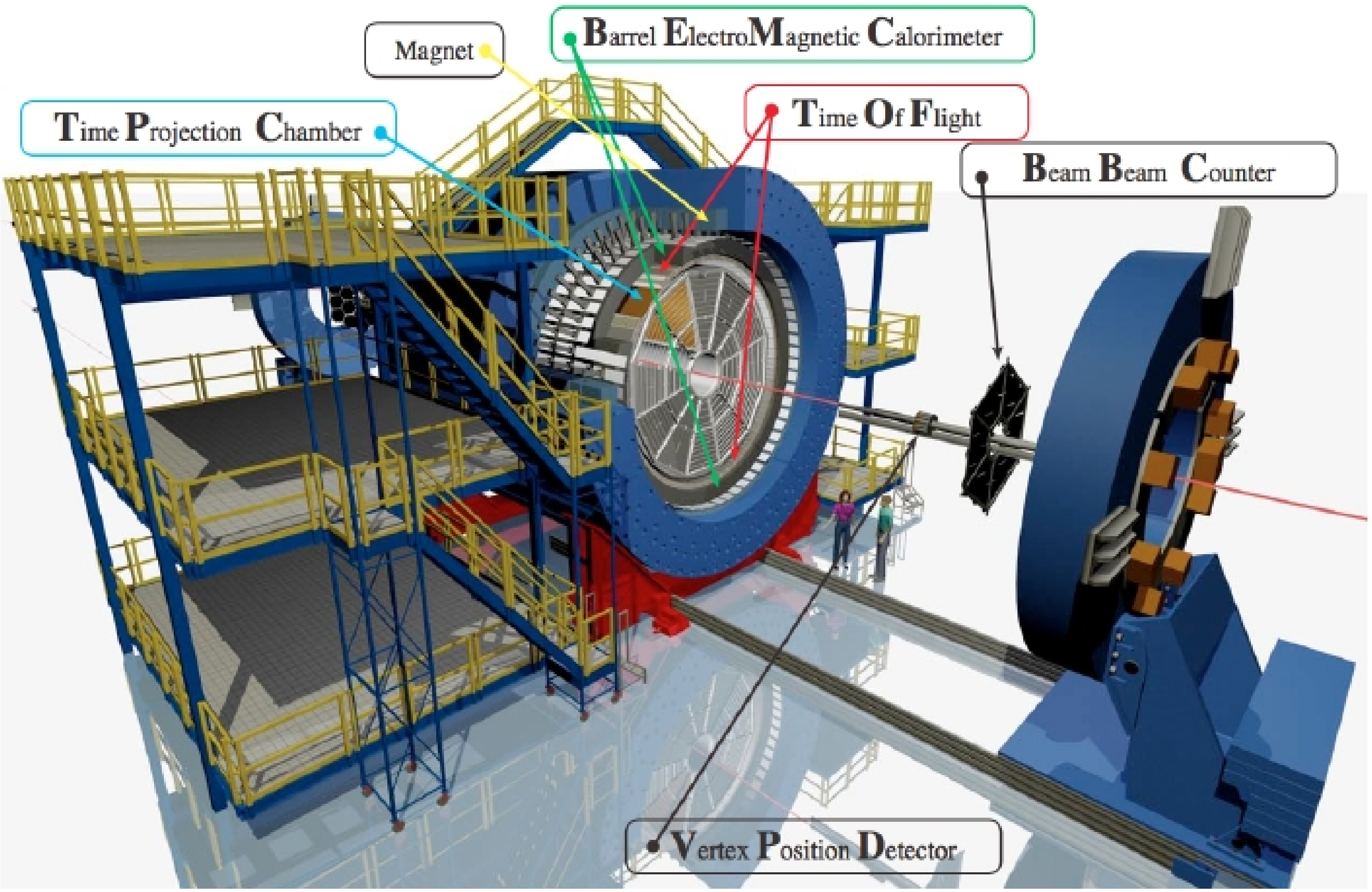
Quarkonia spectral lines as thermometer

$$T_{diss}(\psi') \approx T_{diss}(\chi_c) < T_{diss}(\Upsilon(3S)) < T_{diss}(J/\psi) \approx T_{diss}(\Upsilon(2S)) < T_{diss}(\Upsilon(1S))$$

STAR EXPERIMENT, PID

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

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

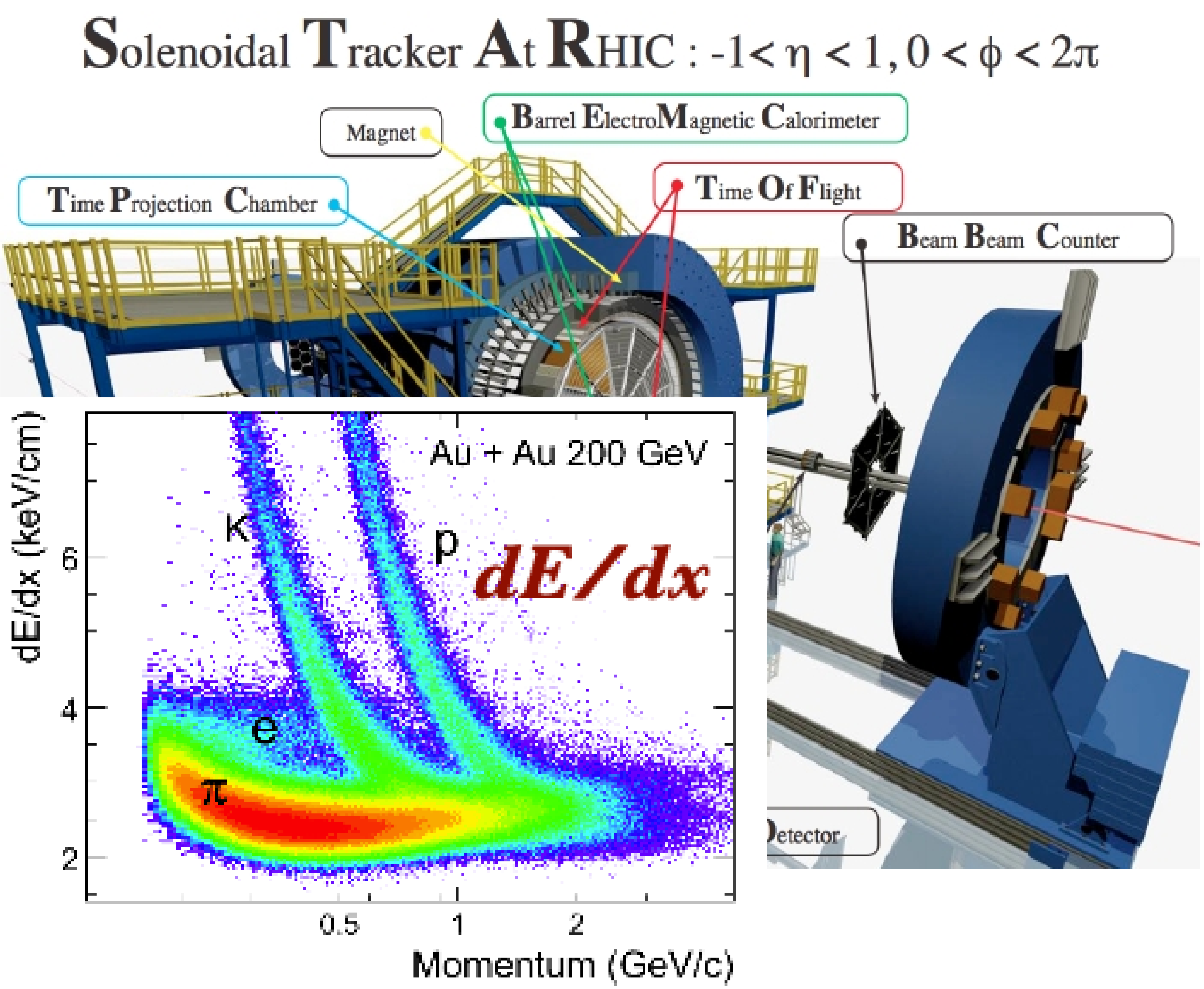


✓ Large acceptance:

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

STAR EXPERIMENT, PID

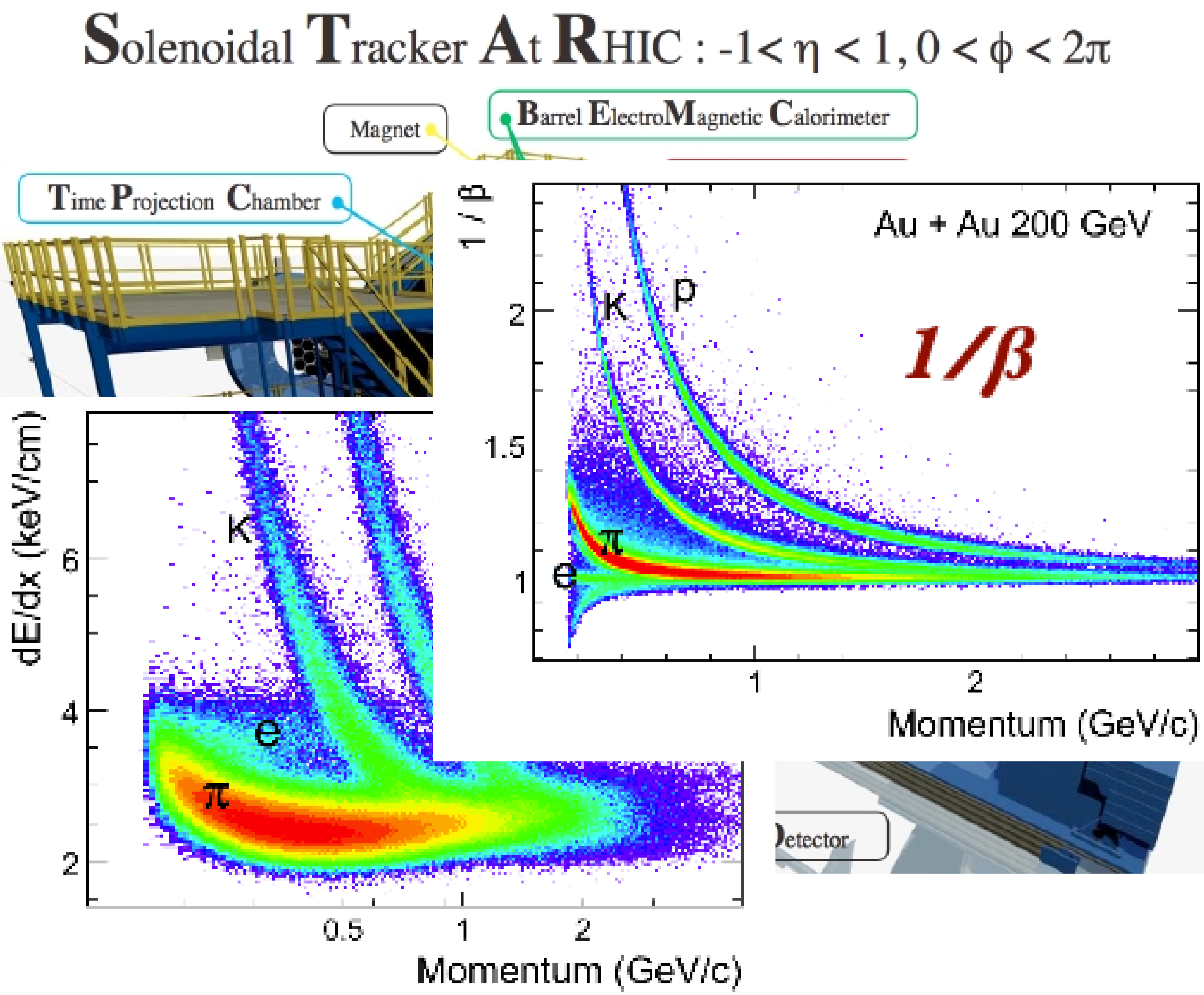
$J/\psi \rightarrow e^{+} e^{-}$ (BR 5.9%)



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

STAR EXPERIMENT, PID

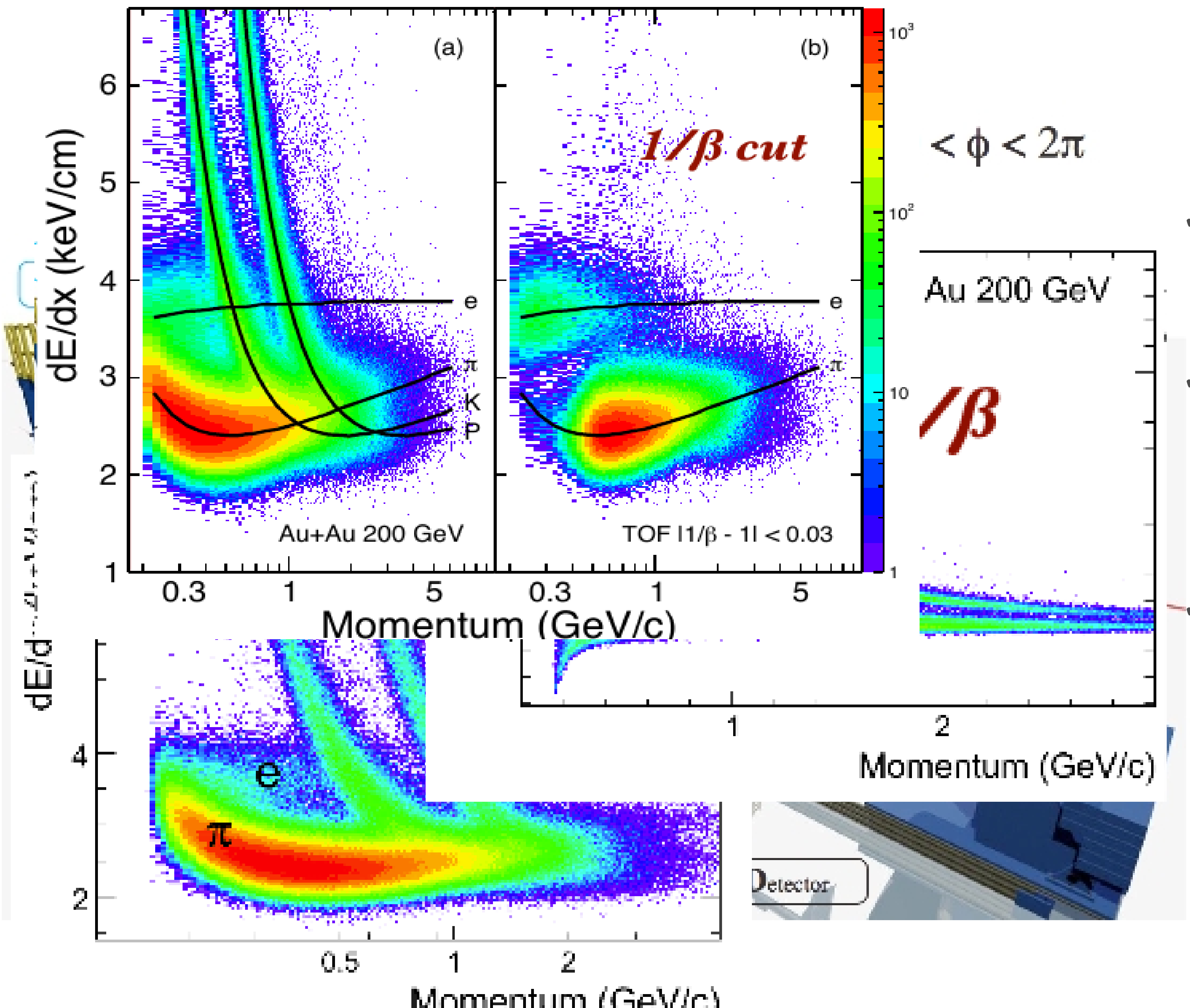
$J/\psi \rightarrow e^+e^-$ (BR 5.9%)



- ✓ 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

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



- ✓ Large acceptance:
  - |η| < 1, 0 < φ < 2π
- ✓ ***TPC***
  - Tracking: p_T, η, φ
  - dE/dx: **PID**
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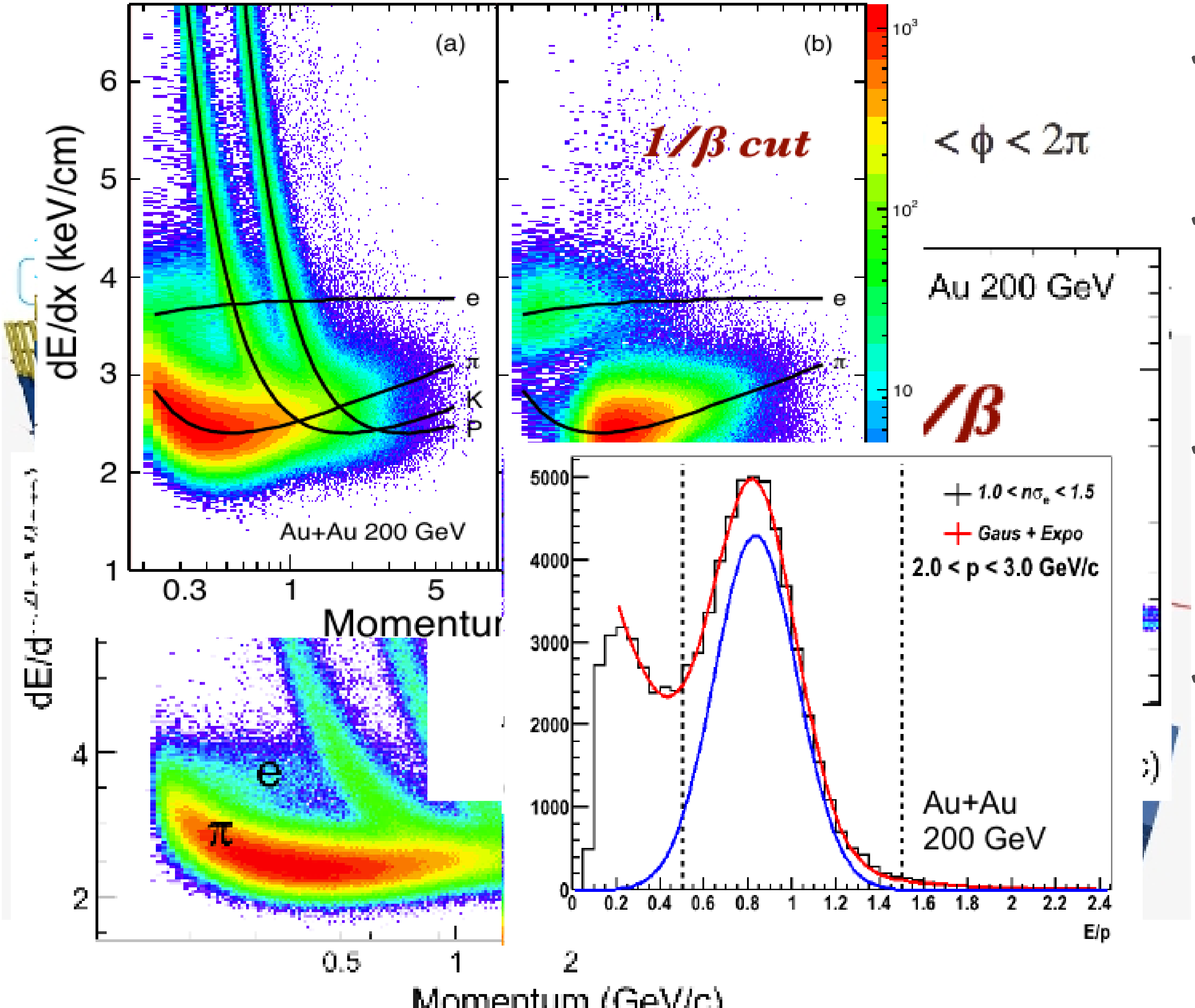
STAR EXPERIMENT, PID

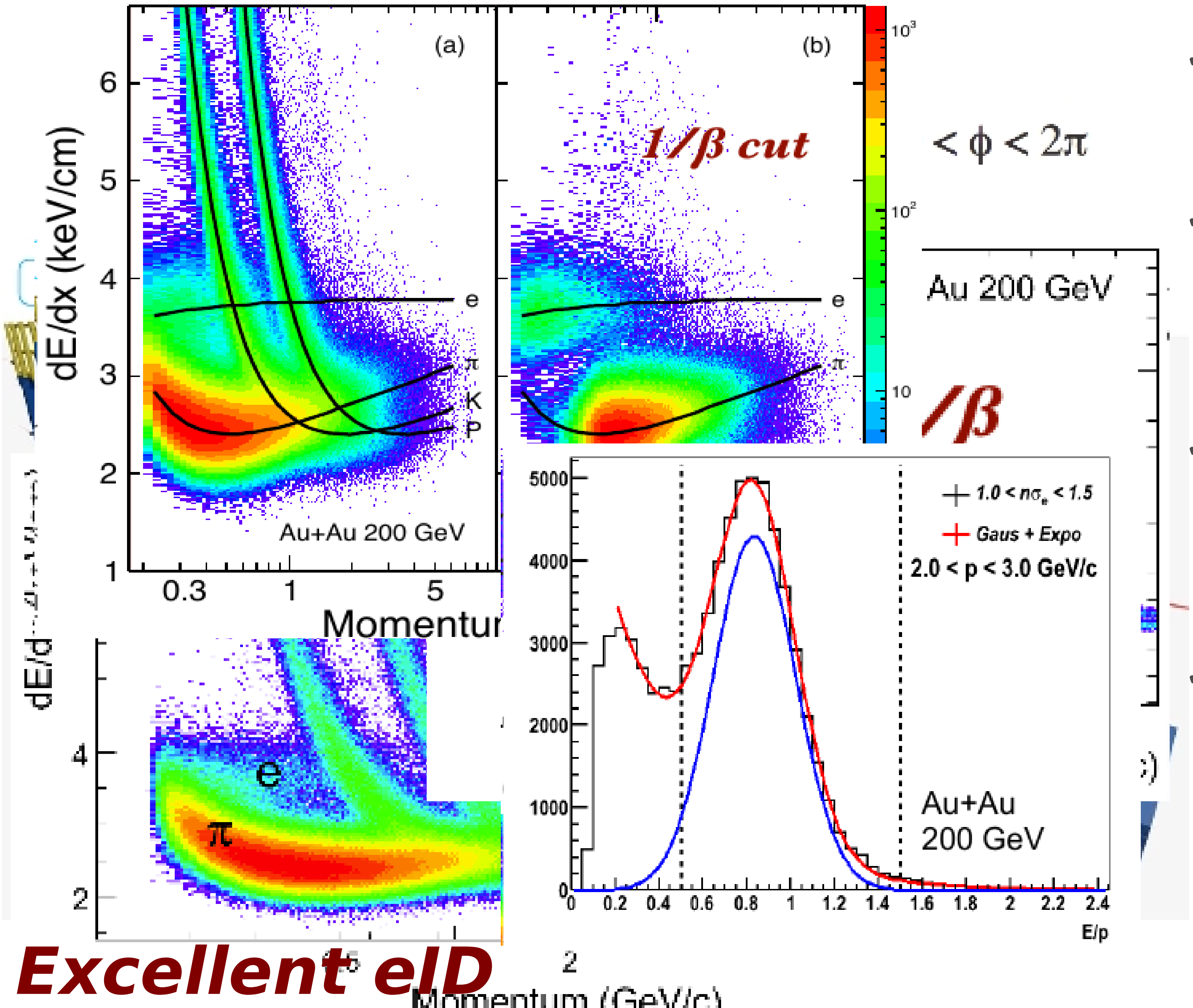
$J/\psi \rightarrow e^{+}e^{-}$ (BR 5.9%)



- ✓ 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%)

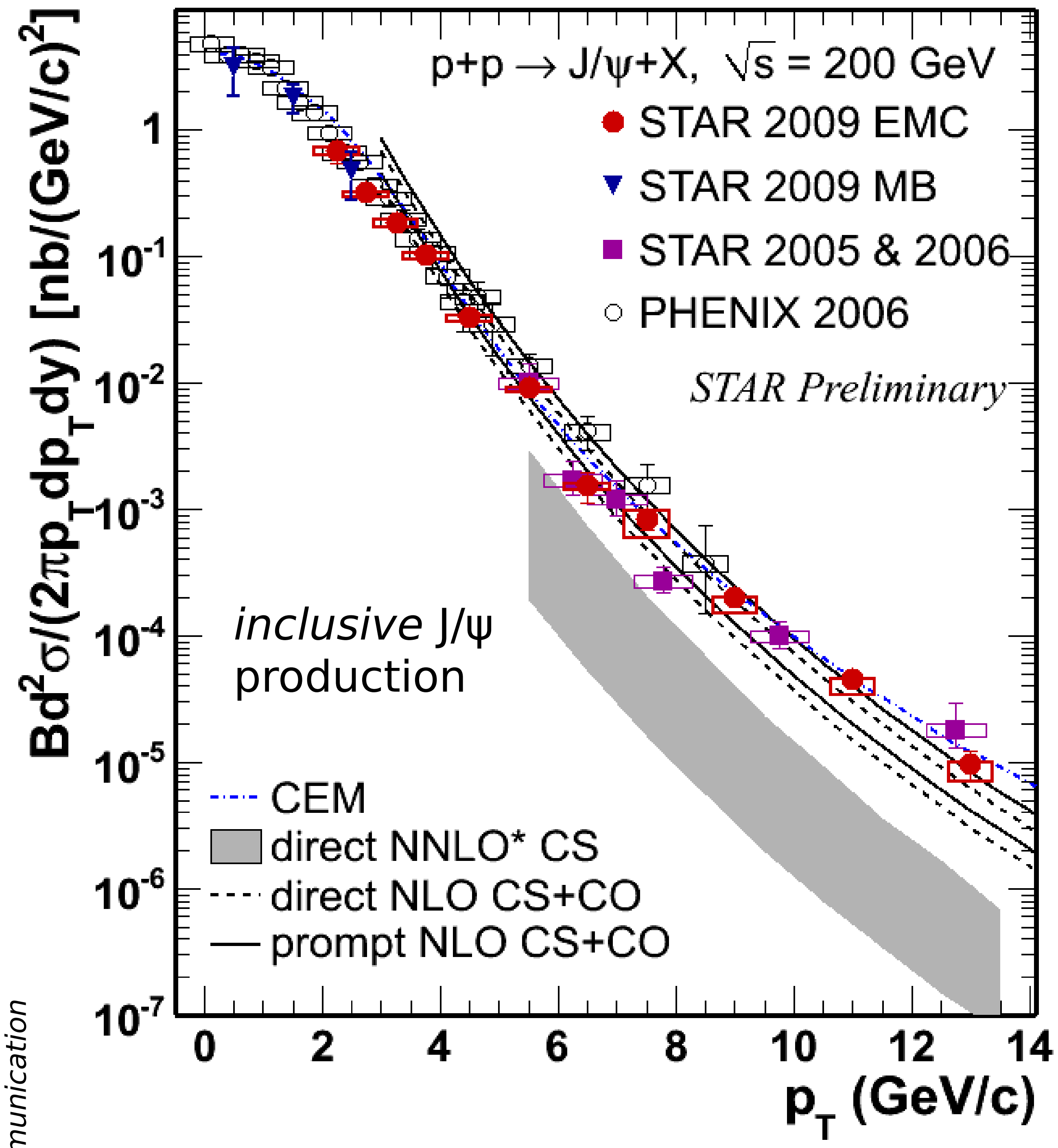


Excellent eID

- ✓ 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, Phys. Rept. 462 (2008) 125, and R.Vogt private communication

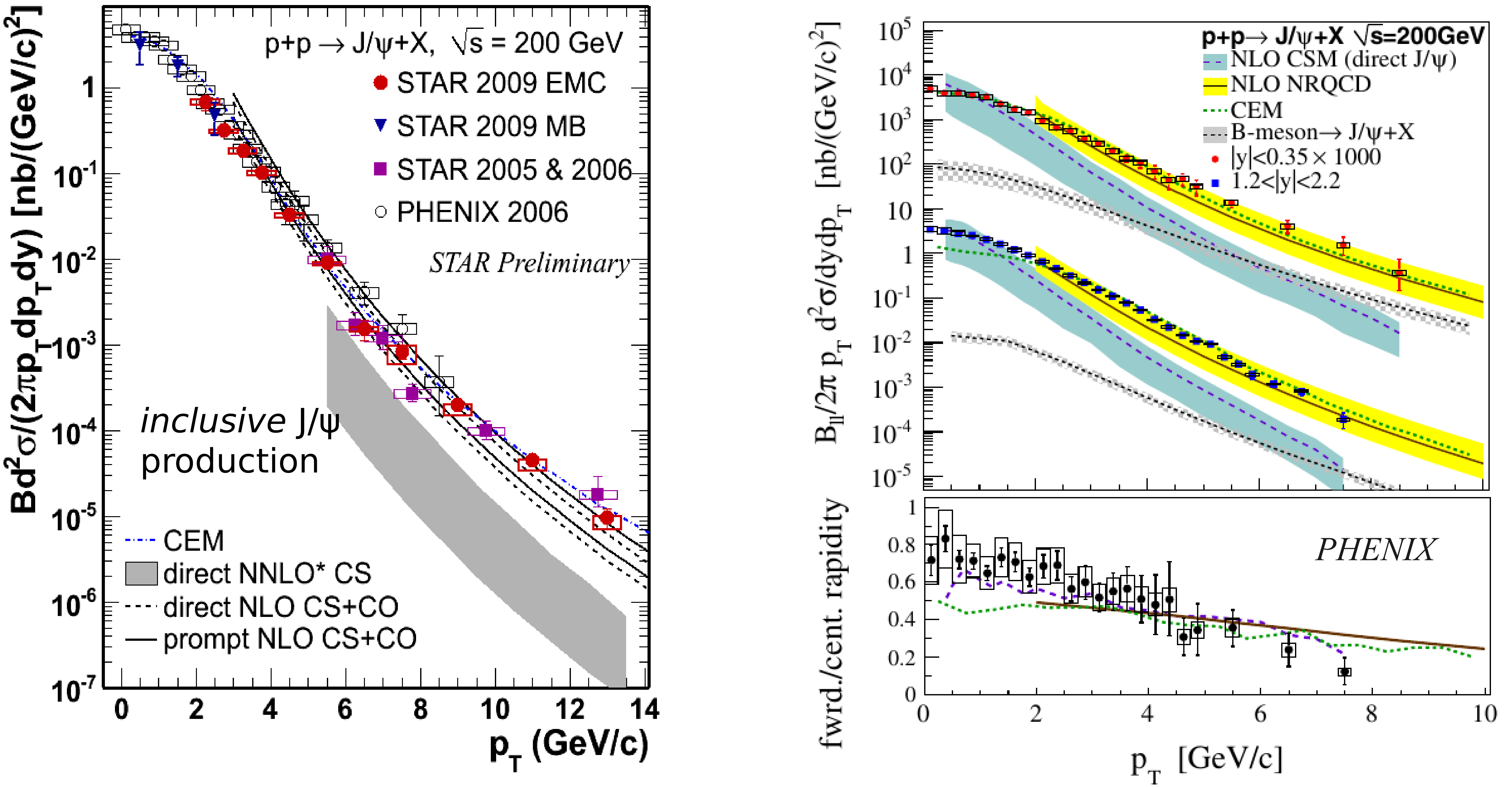


STAR EMC : Phys. Lett. B 722 (2013) 55
STAR MB: Acta Phys. Polonica B Vol.5, No 2 (2012), 543

- ✓ *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

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



STAR EMC : Phys. Lett. B 722 (2013) 55

STAR MB: Acta Phys. Polonica B Vol.5, No 2 (2012), 543

PHENIX: Phys. Rev. D 85, 092004 (2012)

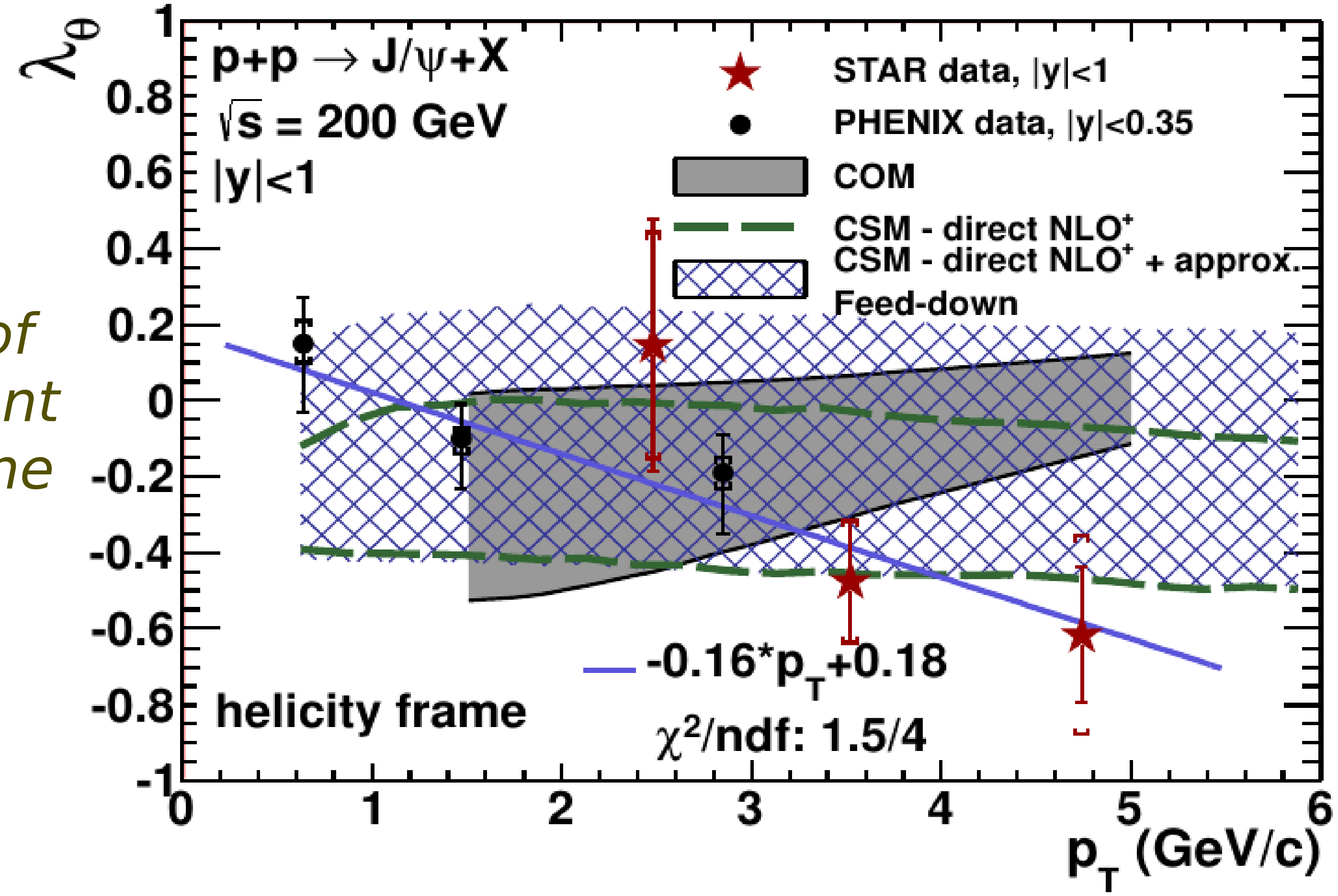
J/ψ polarization in p+p collisions at 200 GeV

STAR: arxiv: 1311.1621
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

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

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}



Polarization parameter λ_θ is measured in helicity frame at |y| < 1 up to p_T = 6 GeV/c

- ✓ RHIC data indicate trend towards longitudinal polarization with increasing p_T
- ✓ Different trend seen in the COM prediction

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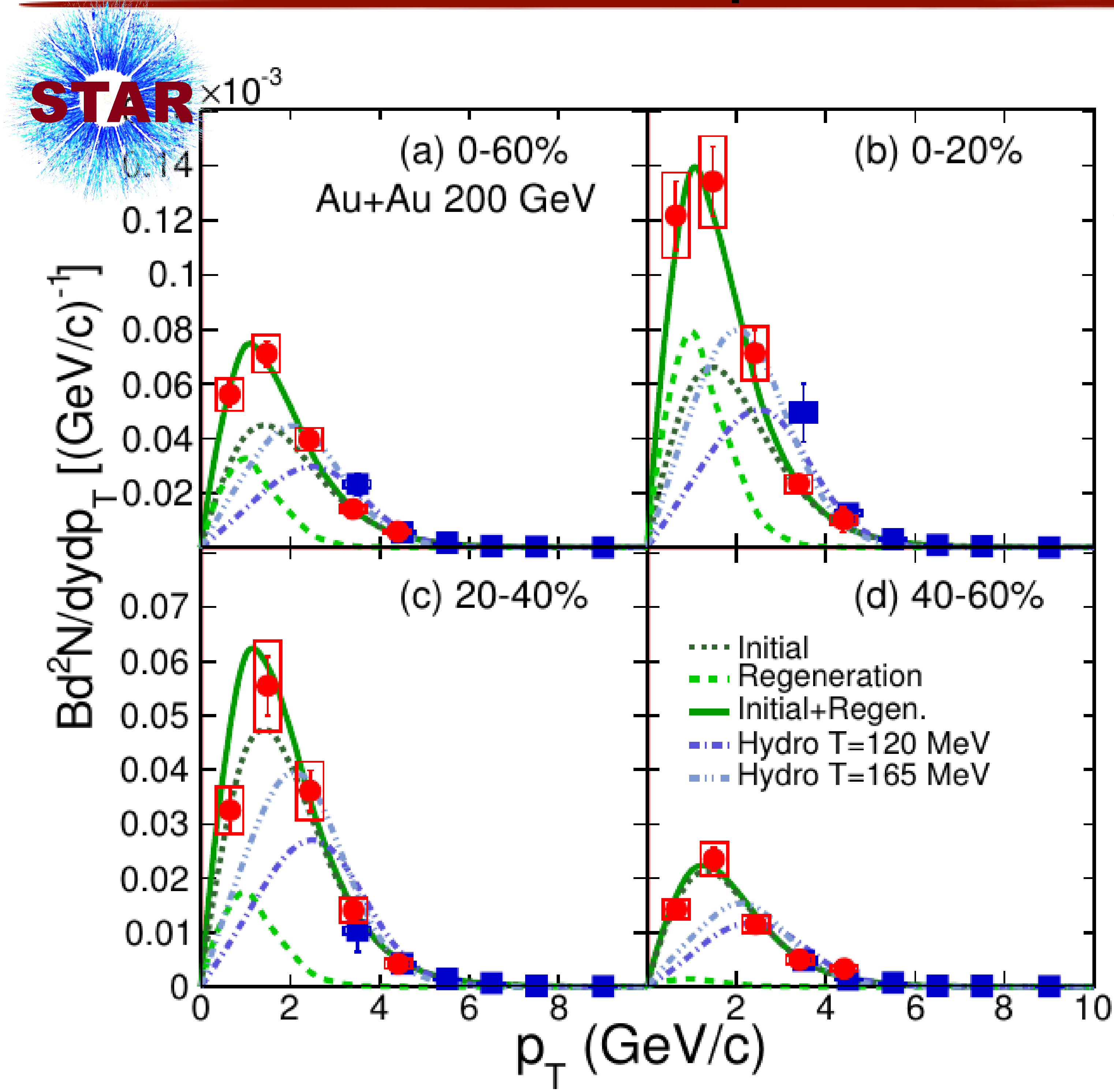
J/ψ yield in Au+Au collisions at 200 GeV - comparison to models



- ✓ ***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

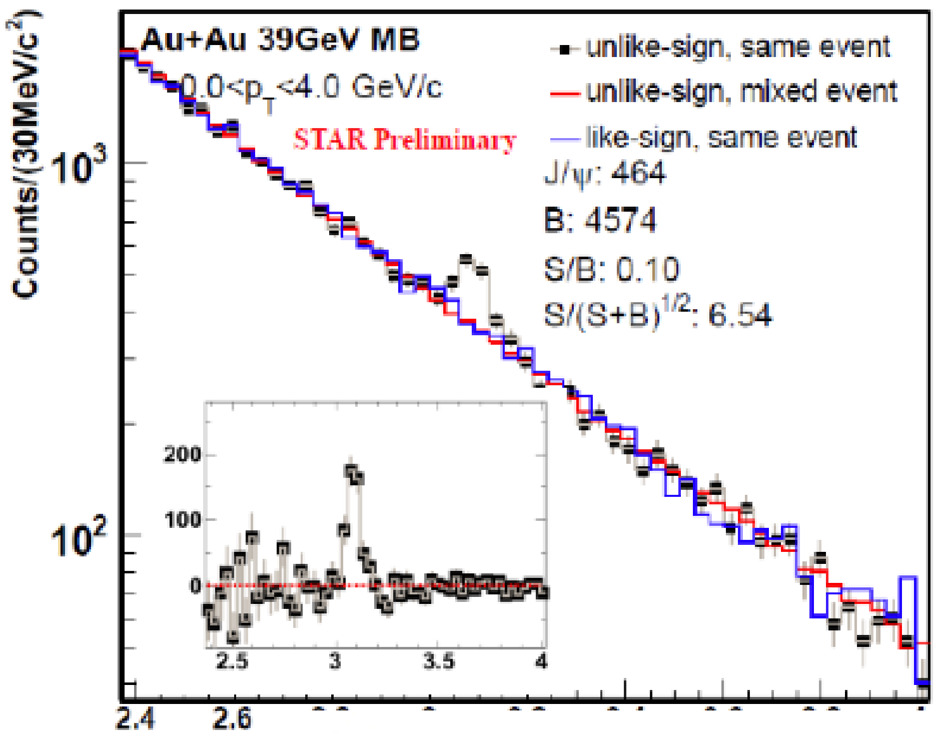
Describes the p_T spectrum

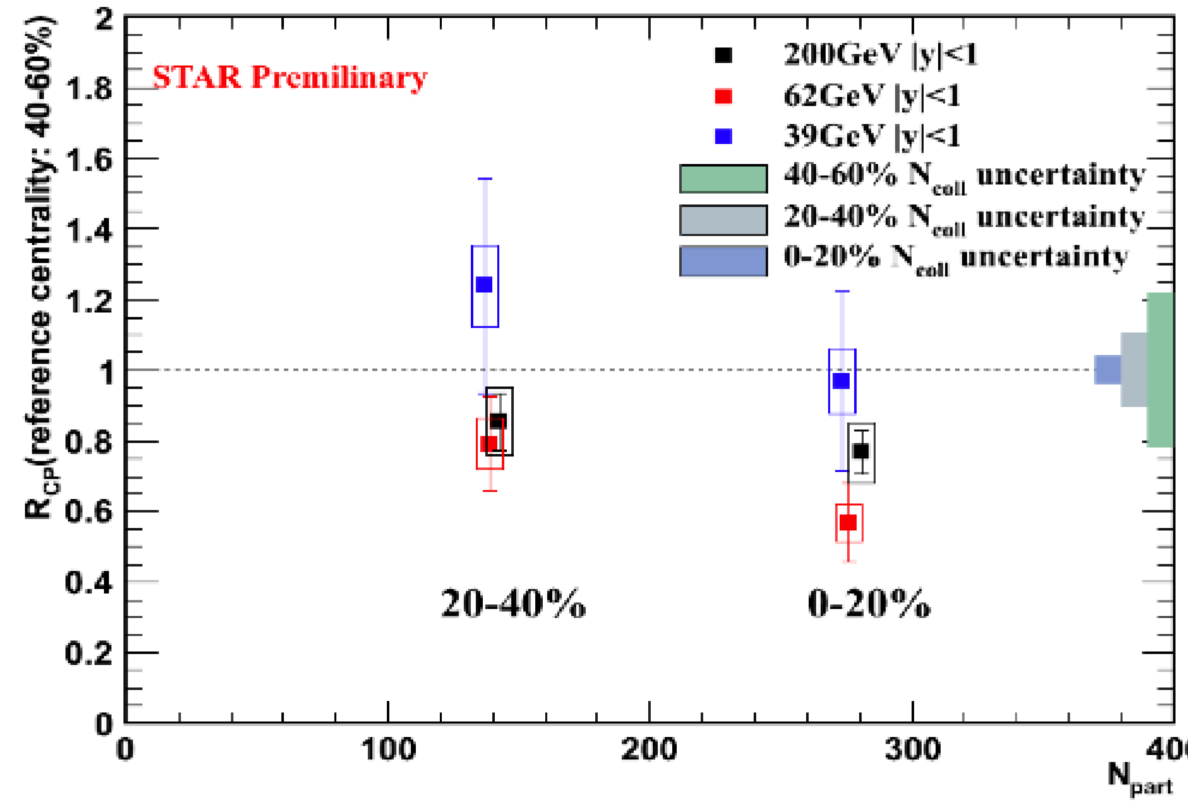
Hydro: U. W. Heinz and C. Shen (2011), private communication
Liu et. all: Y. Liu,Z. Qu, N. Xu, and P. Zhuang, Phys. Lett. B 678 (2009) 72

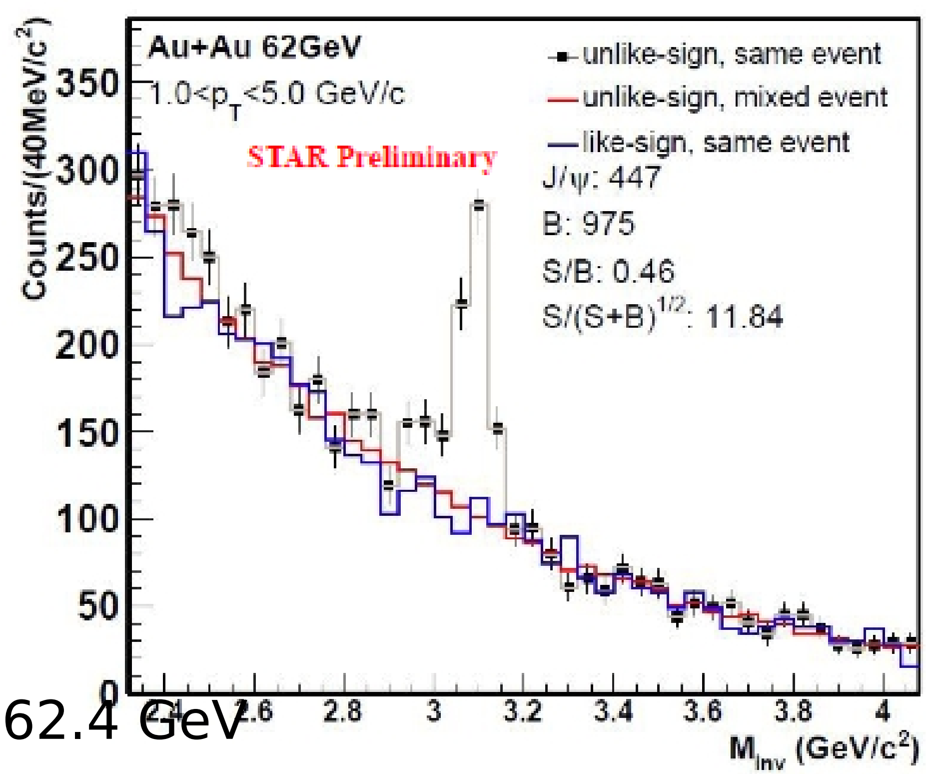
STAR high-p_T : Phys. Lett. B 722 (2013) 55
STAR low-p_T : arxiv:1310.3563

Energy dependence of J/ψ R_{CP}

New measurements at 62.4 and 39 GeV



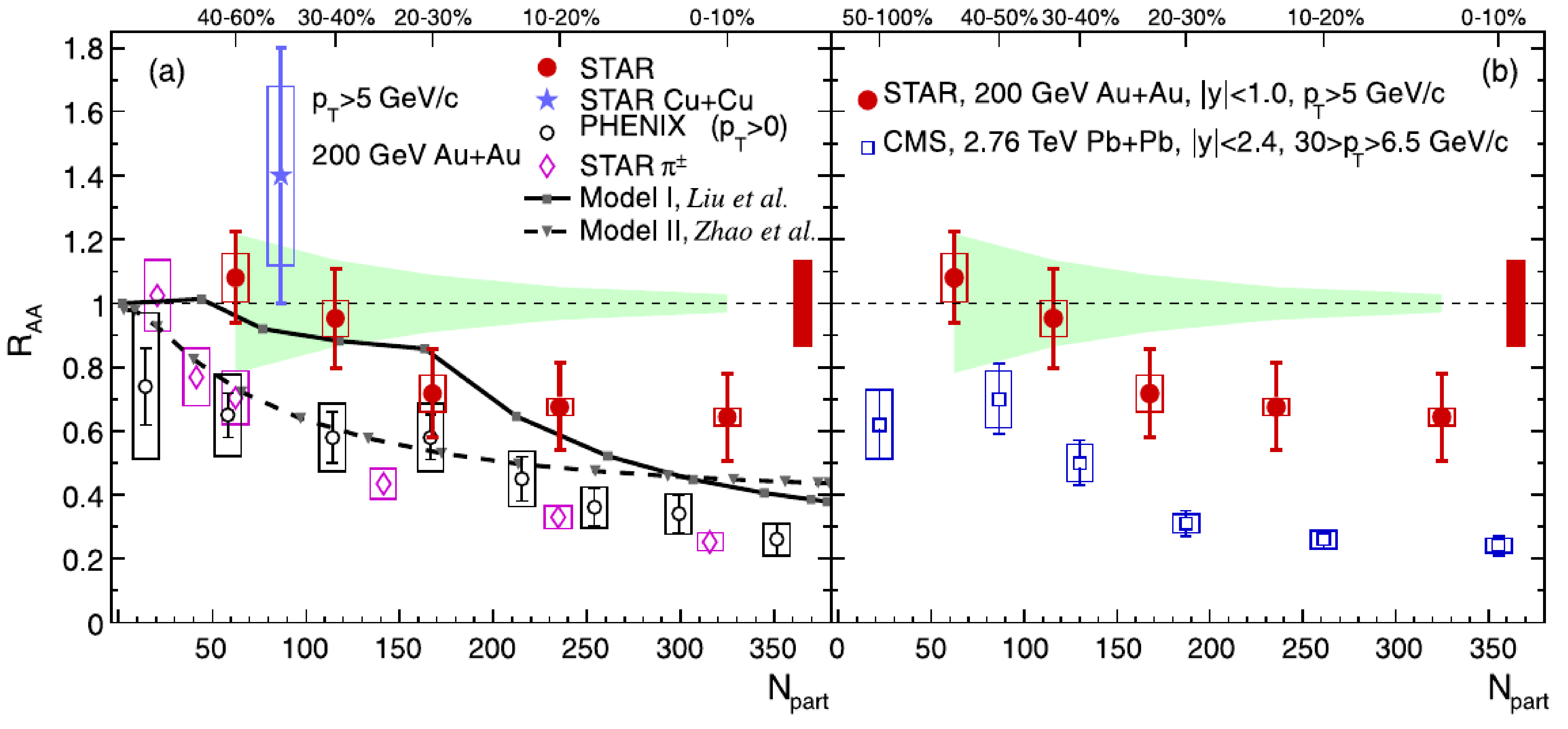




62.4 GeV

✓ Significant suppression at 200 and 62.4 GeV in central collisions

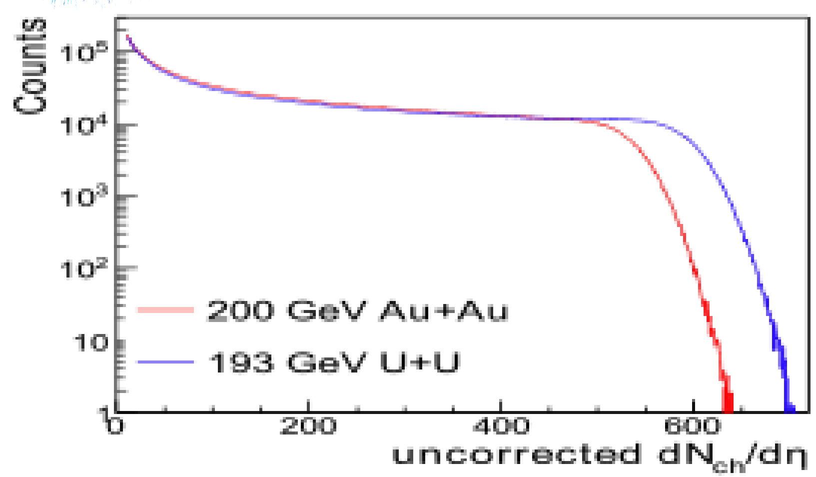
J/ψ R_{AA} vs N_{part} in Au+Au collisions at 200 GeV

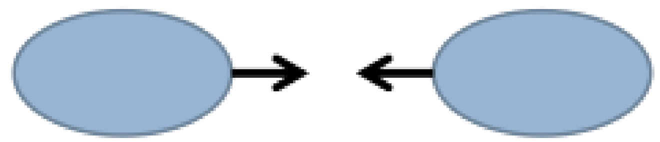


✓ Higher R_{AA} for STAR than CMS for all centralities at high p_T

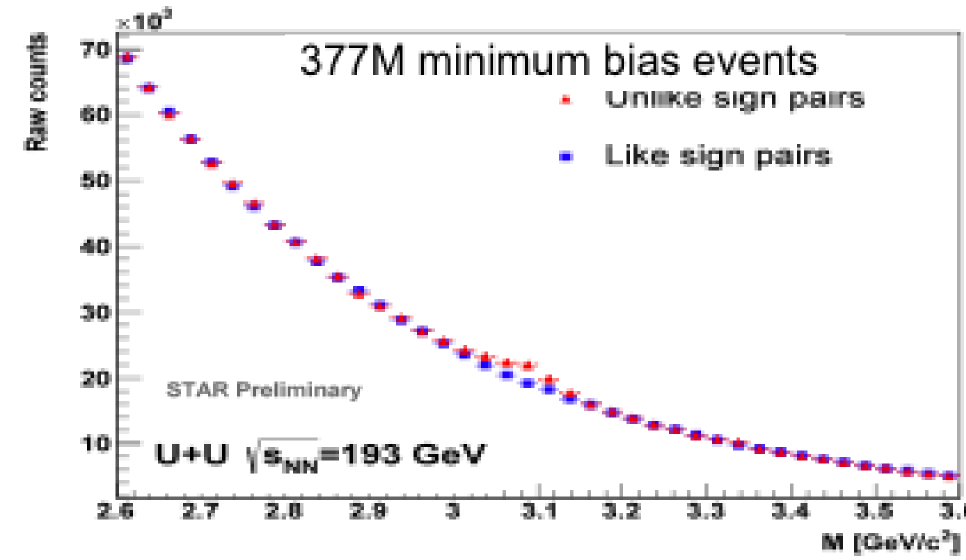
J/ψ in U+U collisions at 193 GeV

- ✓ Non- spherical nucleus - higher initial energy density





Tip-to-tip collision



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