Quarkonia in the STAR experiment

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esf evropský sociální fond v ČR
EVROPSKÁ UNIE
MINISTERSTVO ŠKOLSTVÍ, MLÁDEŽE A TĚLOVÝCHOVY
OP Vzdělávání pro konkurenceschopnost
INVESTICE DO ROZVOJE VZDĚLÁVÁNÍ

Quarkonia at RHIC - Motivation

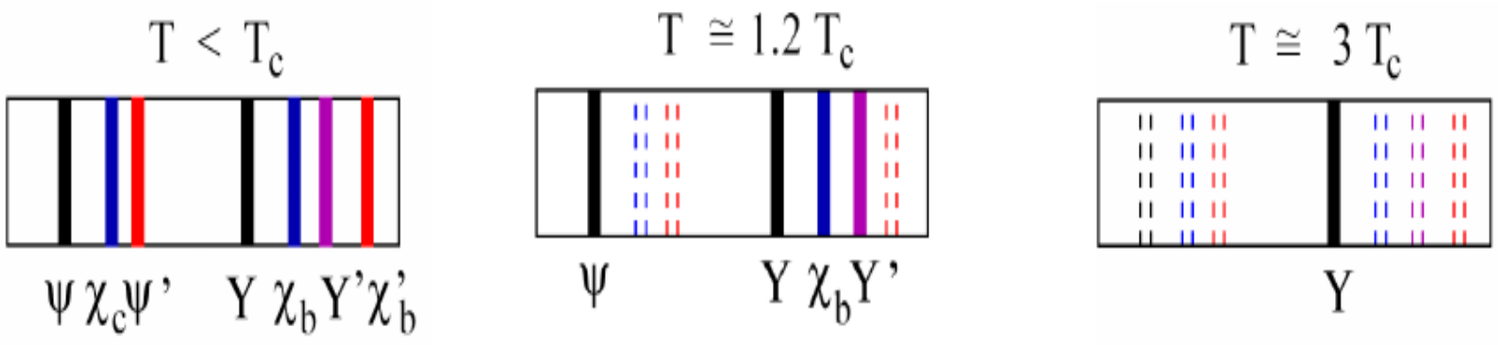
Charmonia: J/ψ, ψ', χ_c $\quad J/\psi \rightarrow e^+e^-$ (BR 5.9%)

Bottomonia: $\Upsilon(1S)$, $\Upsilon(2S)$, $\Upsilon(3S)$, χ_b $\quad \Upsilon \rightarrow e^+e^-$ (BR 2.4%)

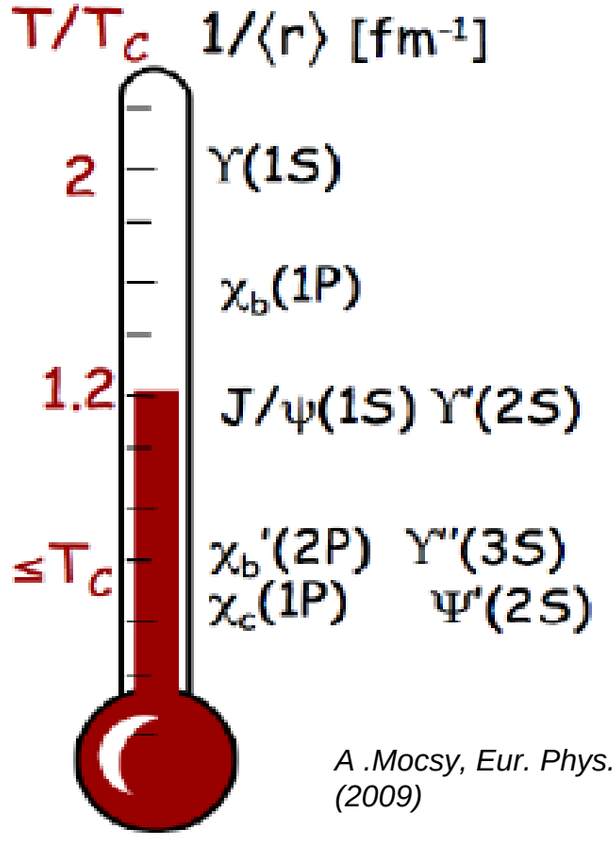
- ✓ ***color screening*** - quarkonium suppression in QGP in heavy-ion collisions
- ✓ ***QGP thermometer*** - suppression of different states is determinated by T_C and their binding energies

Screening radius:

$r_D(T) \propto 1/T$



Quarkonium spectral lines as the thermometer



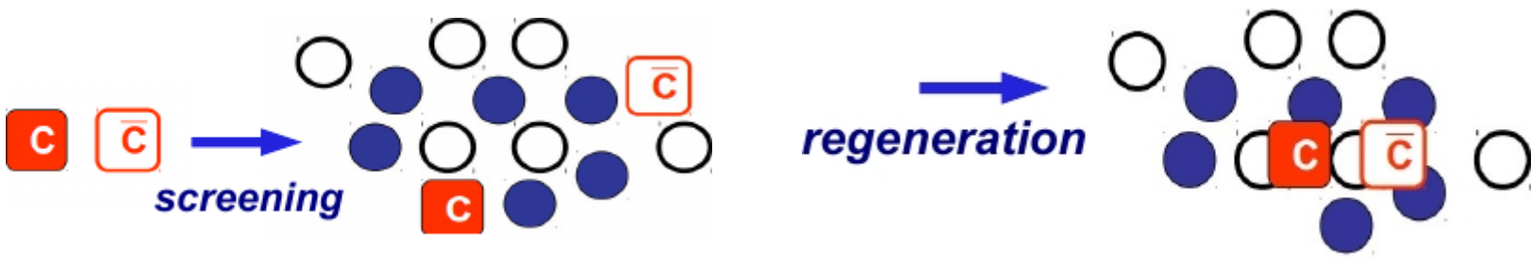
H.Satz, Nucl. Phys. A 783, 249 (2007)

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

Quarkonia – other effects

But there are additional complications:

- Still unclear ***production mechanism*** in elementary collisions
- ***Feed-down:*** ***direct J/ψ*** (~60%), feed down from **ψ'** and χ_c (~40%); **B-mesons** feed-down (up to 25% at 12 GeV/c, Phys. Lett. B722 (2013) 55)
- ***Cold Nuclear Matter (CNM) effects*** - nuclear (anti-)shadowing, Cronin effect, nuclear absorption, …
- Other ***Hot Nuclear Matter effects*** - regeneration, …

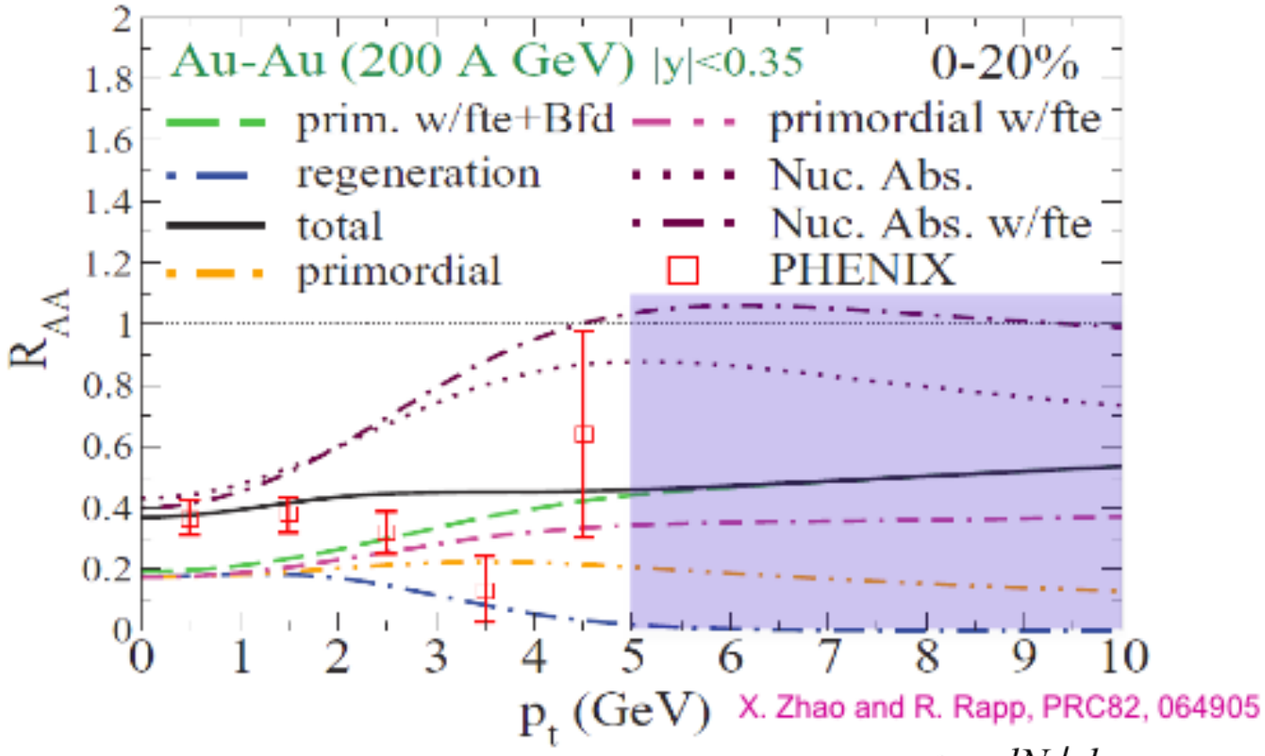


Strategy

- ***High-p_T J/Ψ and ϒ – cleaner probes***

- ✔ High-p_T J/ψ - almost not affected by CNM effects and recombination
- ✔ ϒ - negligible co-mover absorption and recombination

  at RHIC: σ_{cc} ~800μb >> σ_{bb} ~(1-2)μb



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

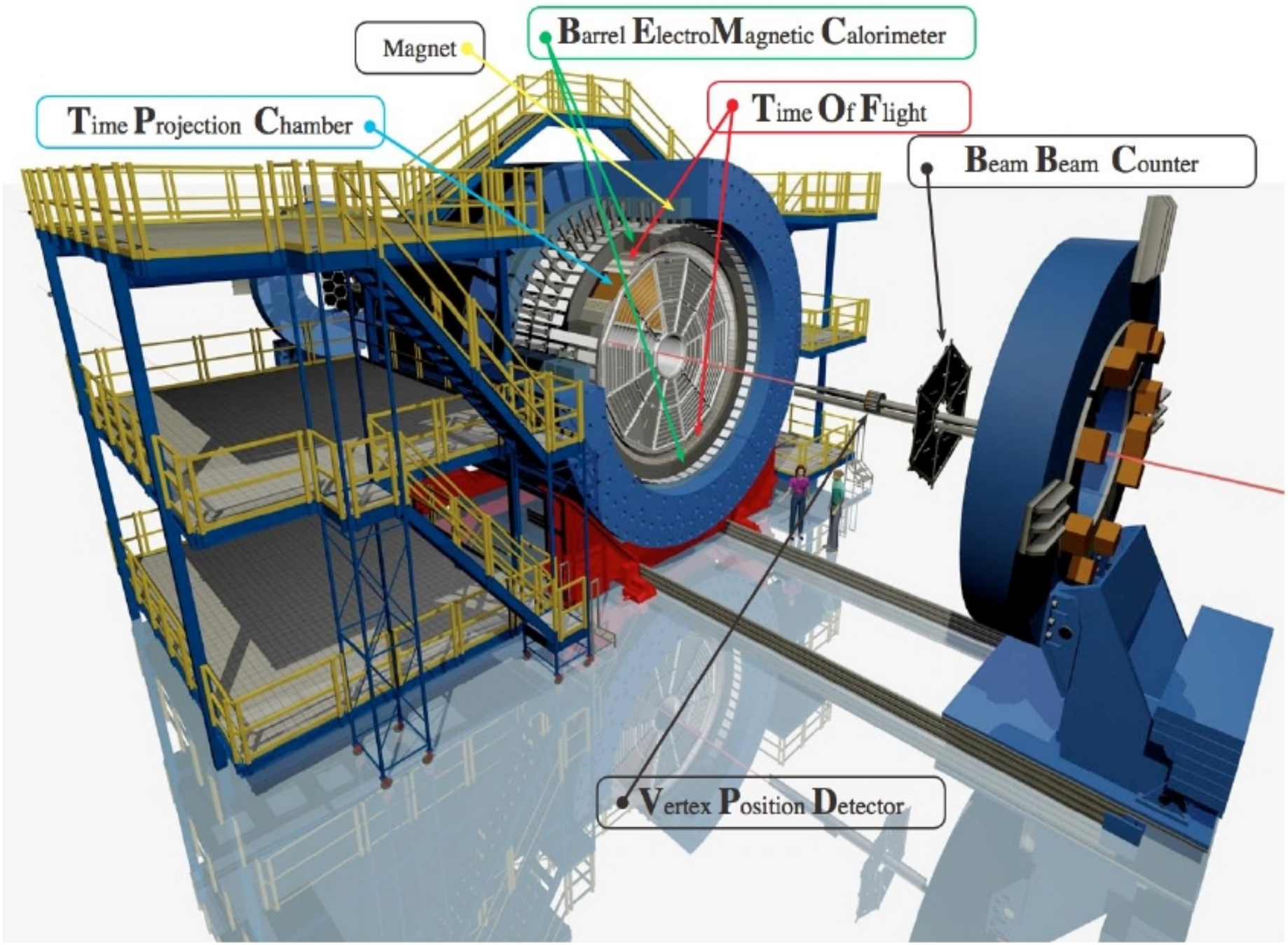
- ✔ Energy dependence of quarkonium production - varying relative contributions

- ***Measure quarkonia at different colliding systems and energies***

STAR Experiment

J/ψ / $\Upsilon \rightarrow e^+ e^-$

Large acceptance: $|\eta| < 1$, $0 < \varphi < 2\pi$



- VPD - minimum bias trigger
- TPC
- TOF
- BEMC

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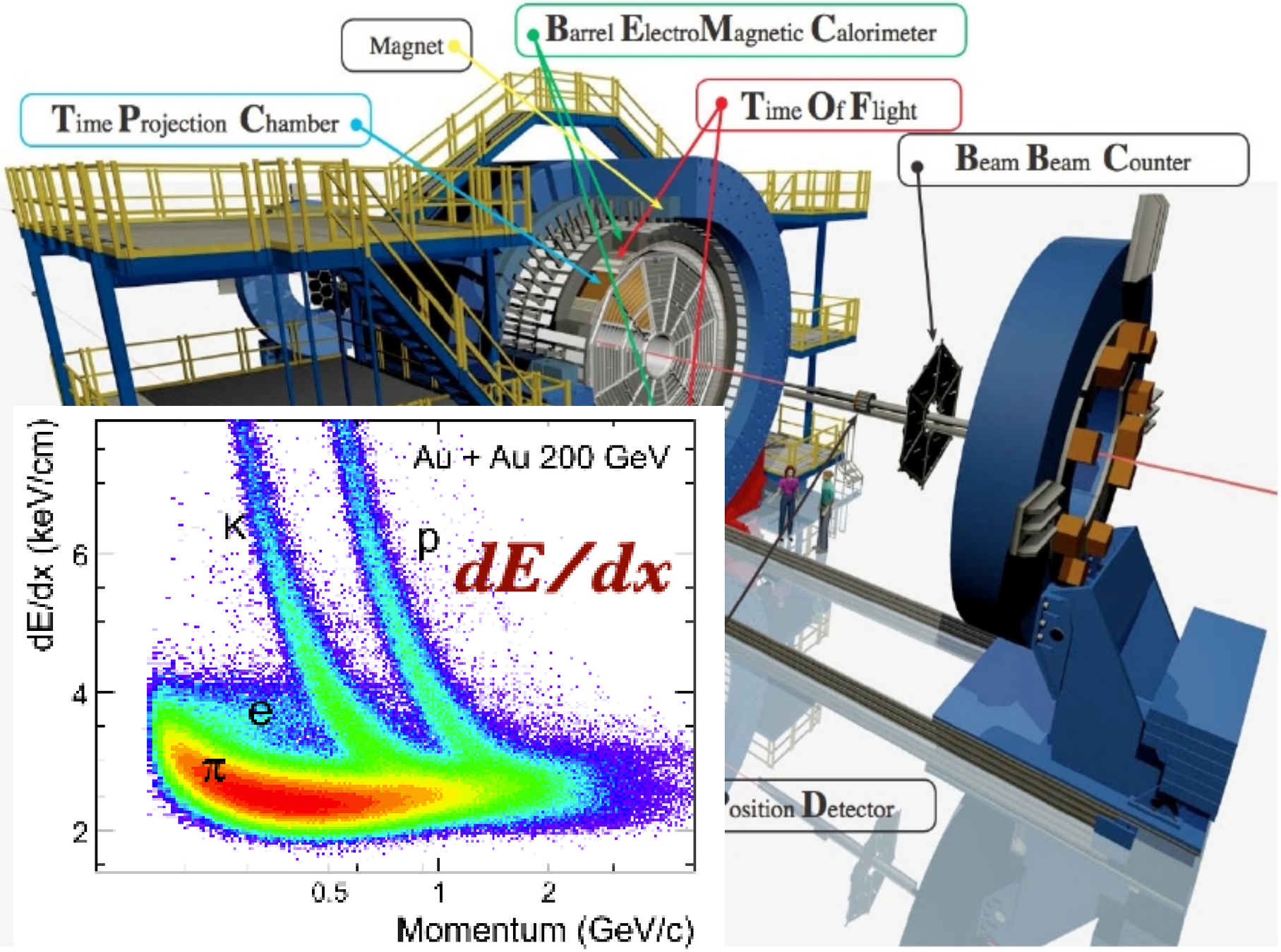

- ✔ VPD - minimum bias trigger
- ✔ TPC – tracking, **PID**: dE/dx
- ✔ TOF
- ✔ BEMC

STAR Experiment

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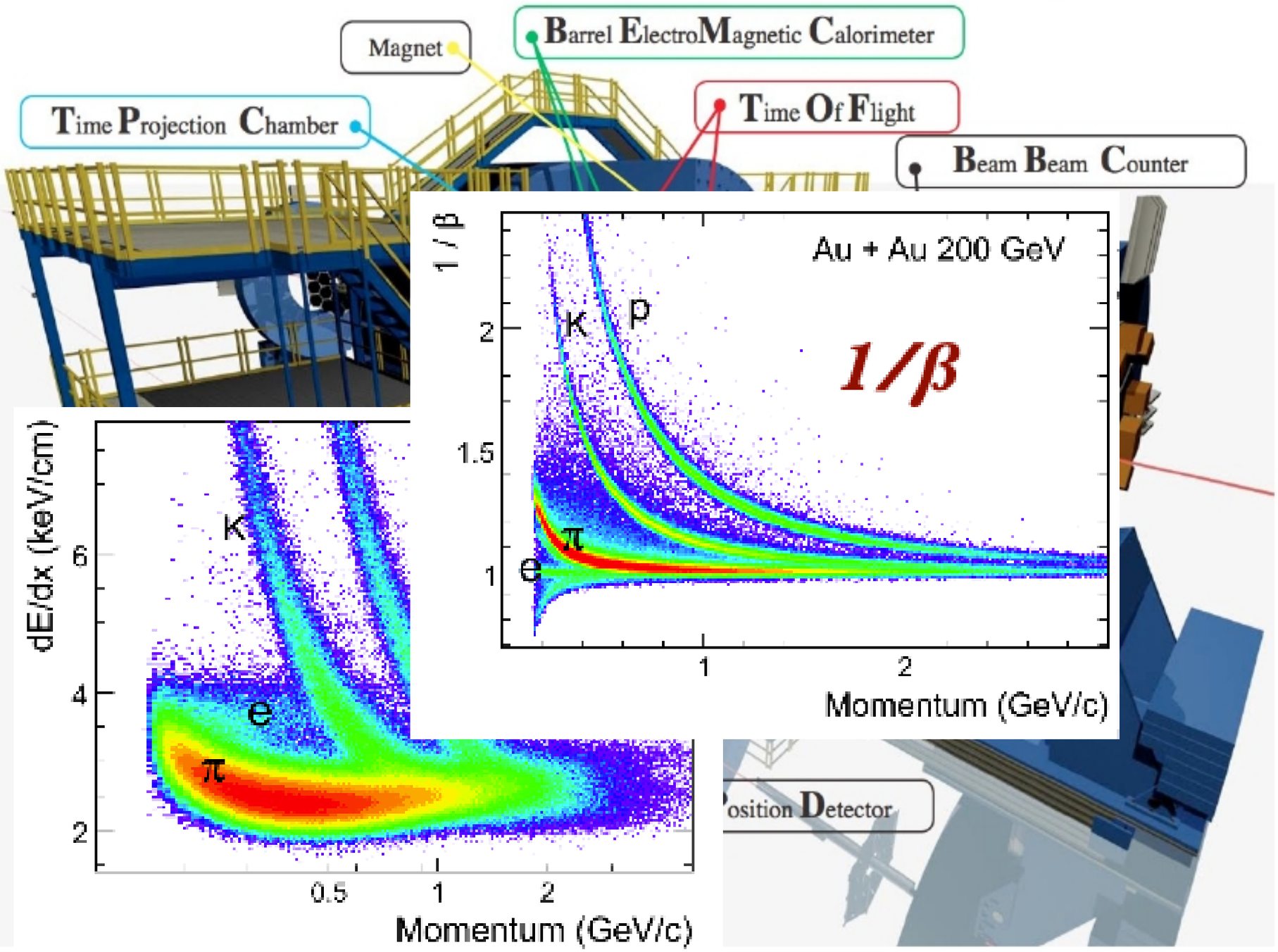

- VPD - minimum bias trigger
- TPC – tracking, **PID**: dE/dx
- TOF – time resolution < 100 ps **PID**: 1/β
- BEMC

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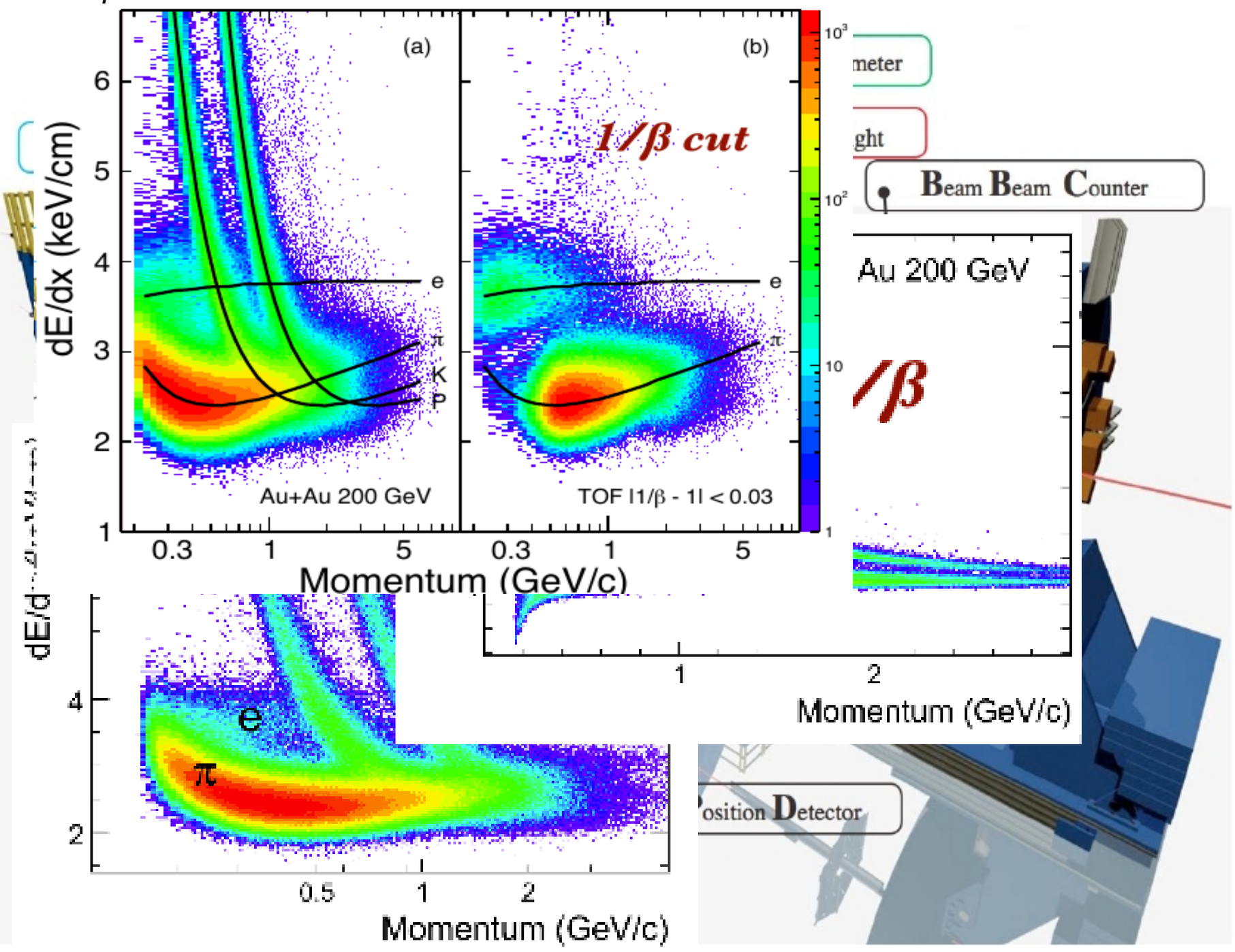

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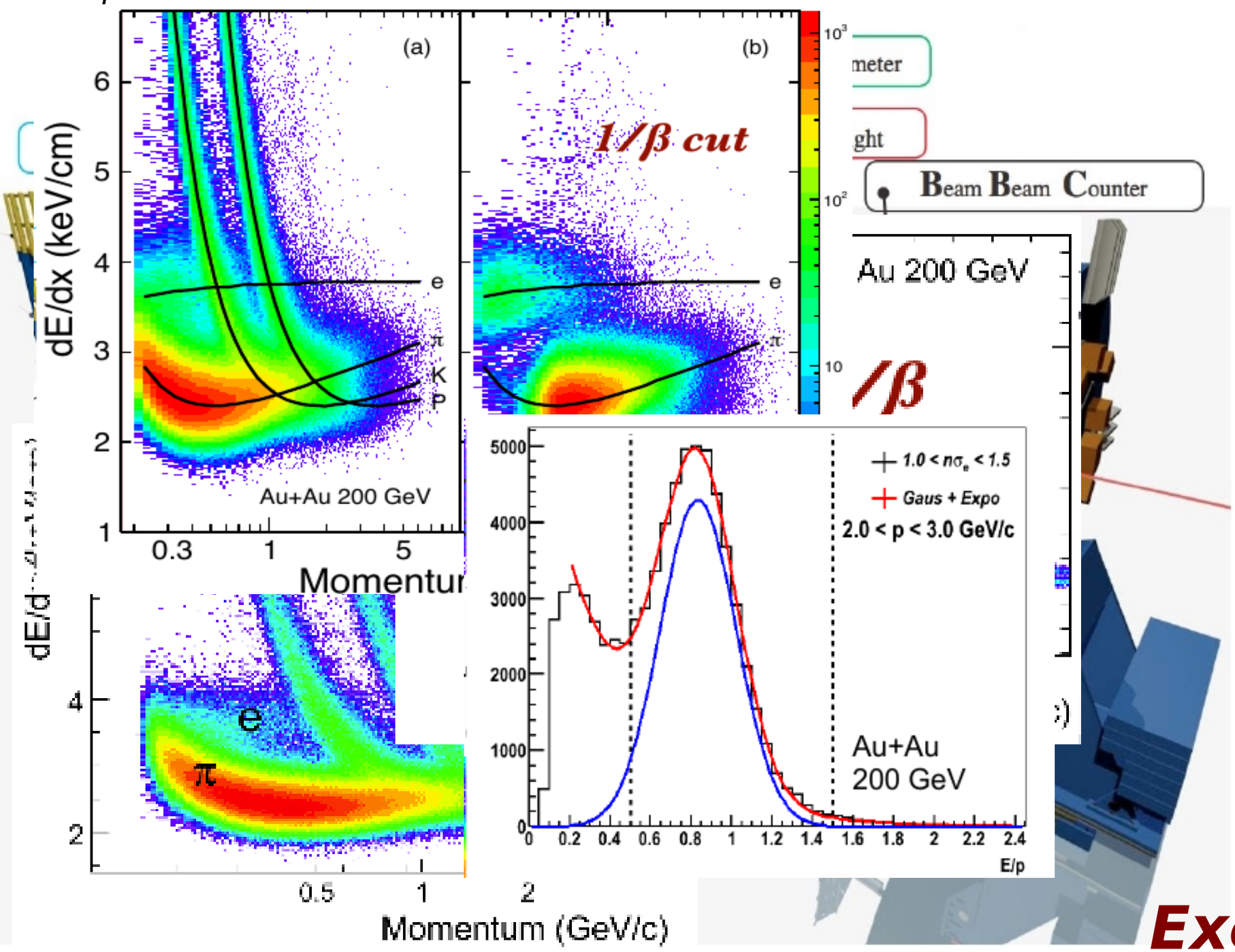


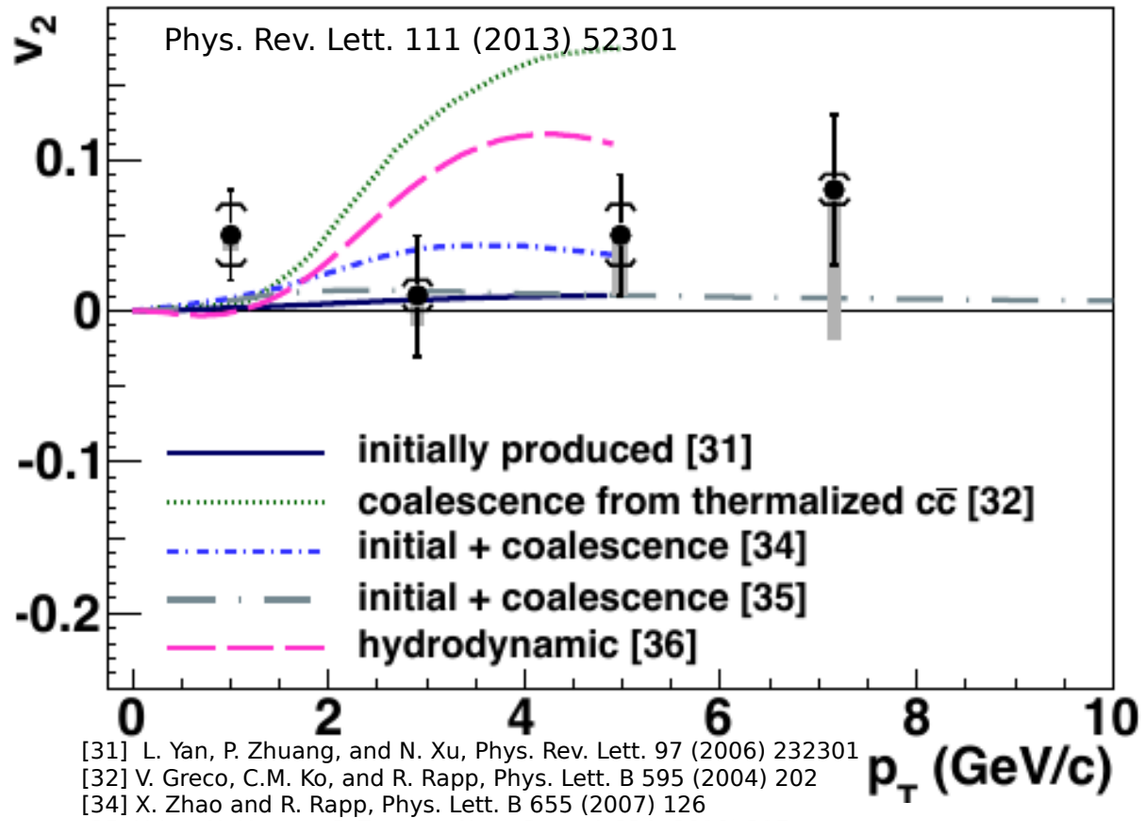
- VPD - minimum bias trigger
- TPC – tracking, **PID**: dE/dx
- TOF – time resolution < 100 ps
  PID: 1/β
- BEMC – trigger
  PID: E/p (~1 for electron)

Excellent eID

J/Ψ v_2 in Au+Au 200 GeV

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

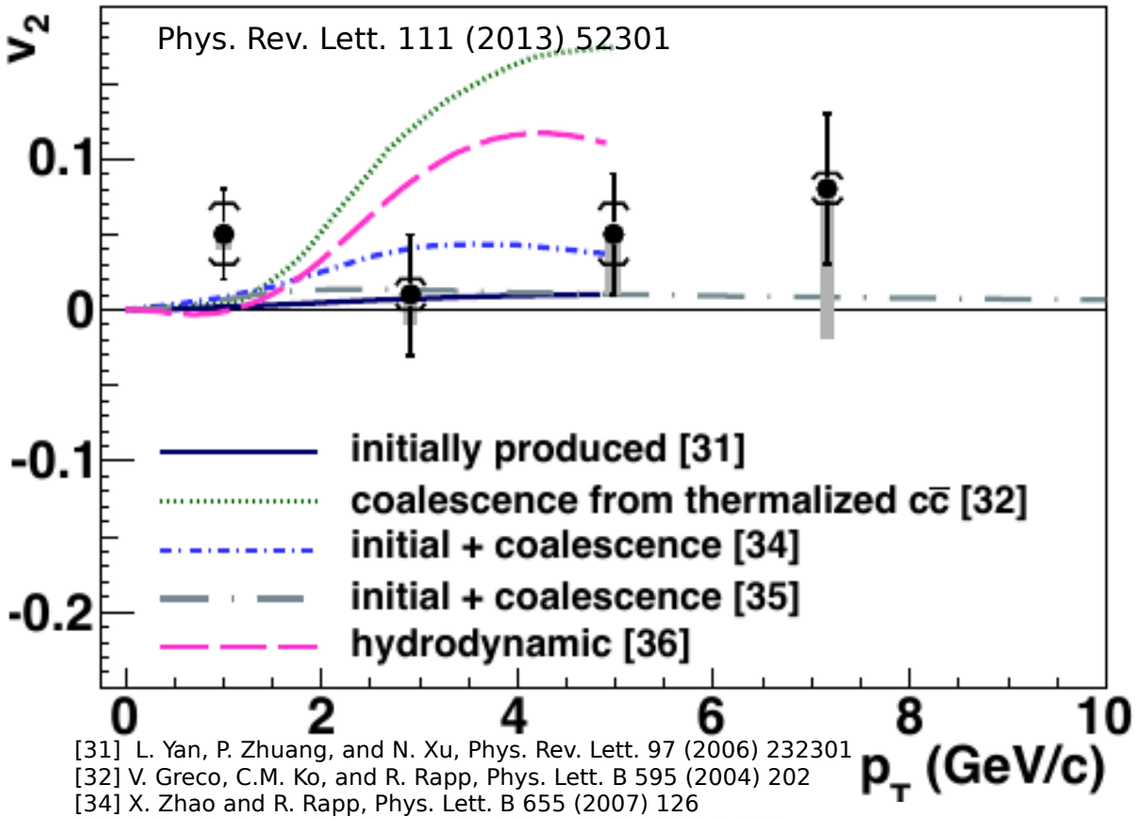
  → Disfavors the model with J/ψ production via thermalized (anti-)charm coalescence



[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 and p_T spectra in Au+Au 200 GeV

- ✓ J/ψ v_2 is consistent with zero at $p_T > 2$ GeV/c
  - ➔ Disfavors the model with J/ψ production via thermalized (anti-)charm coalescence



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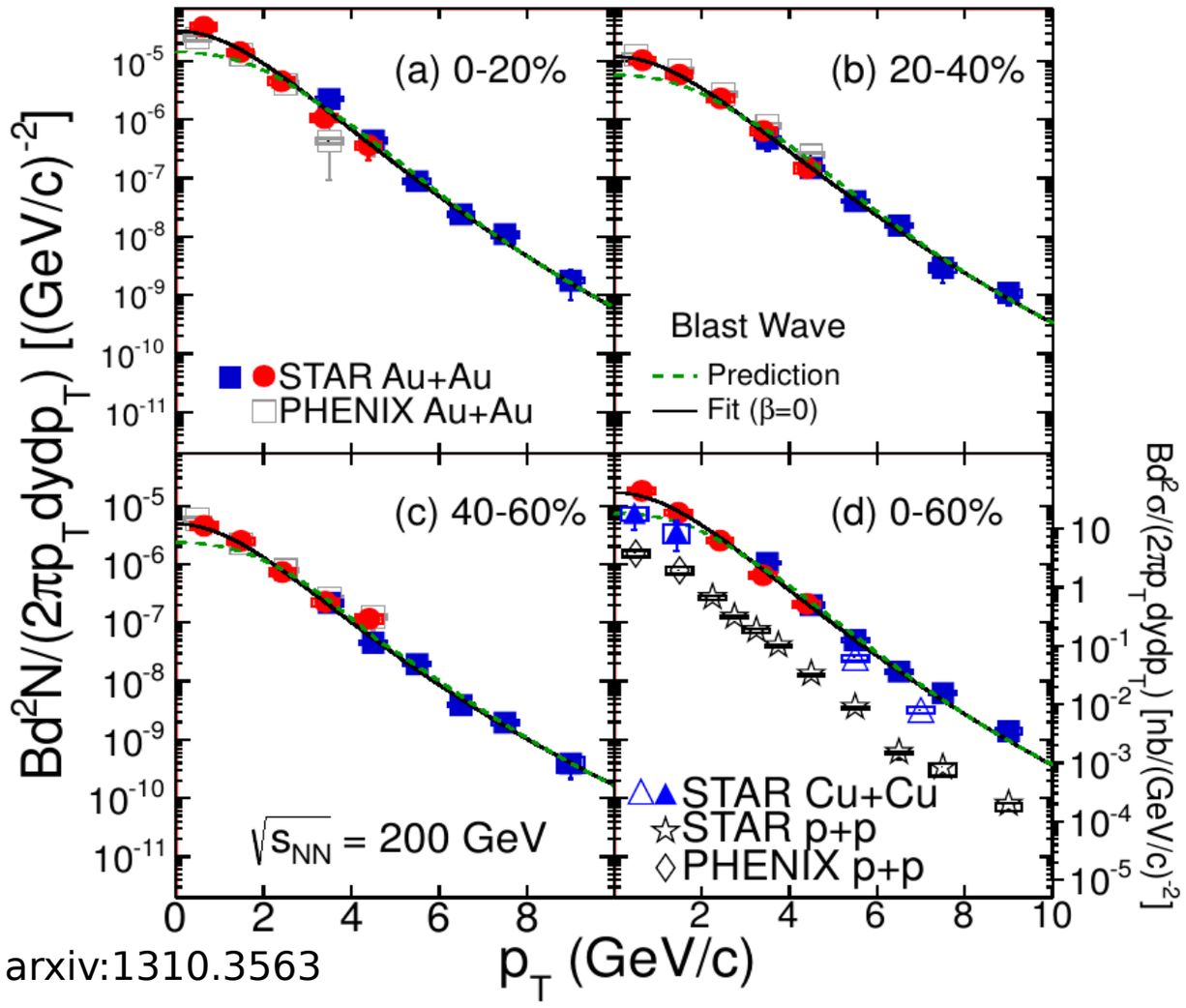
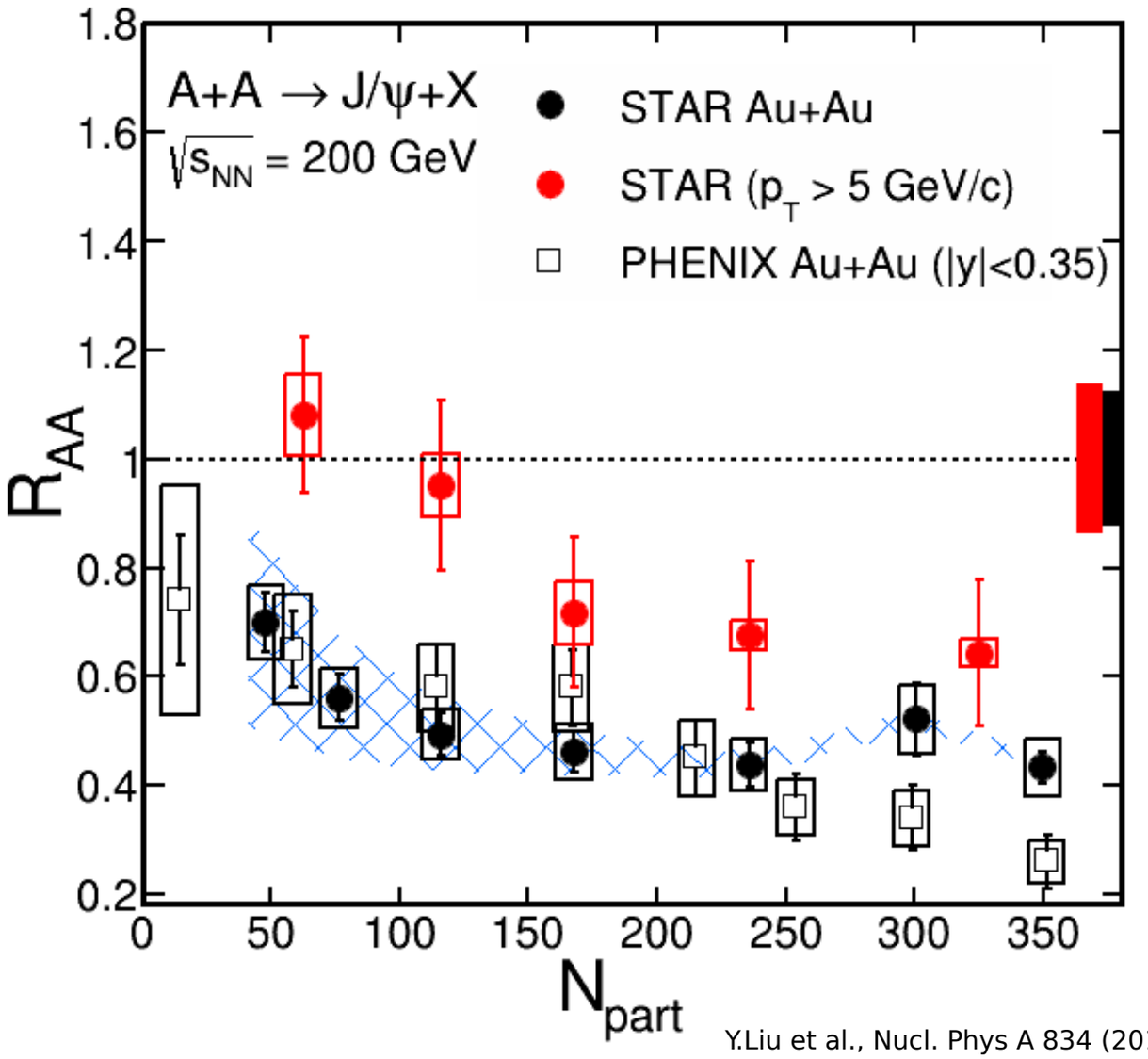


arxiv:1310.3563

- ✓ At low p_T J/ψ spectra softer than the TBW prediction from light hadron
  - ➔ small radial flow ?
  - ➔ regeneration at low p_T ?

J/Ψ R_{AA} in Au+Au 200 GeV

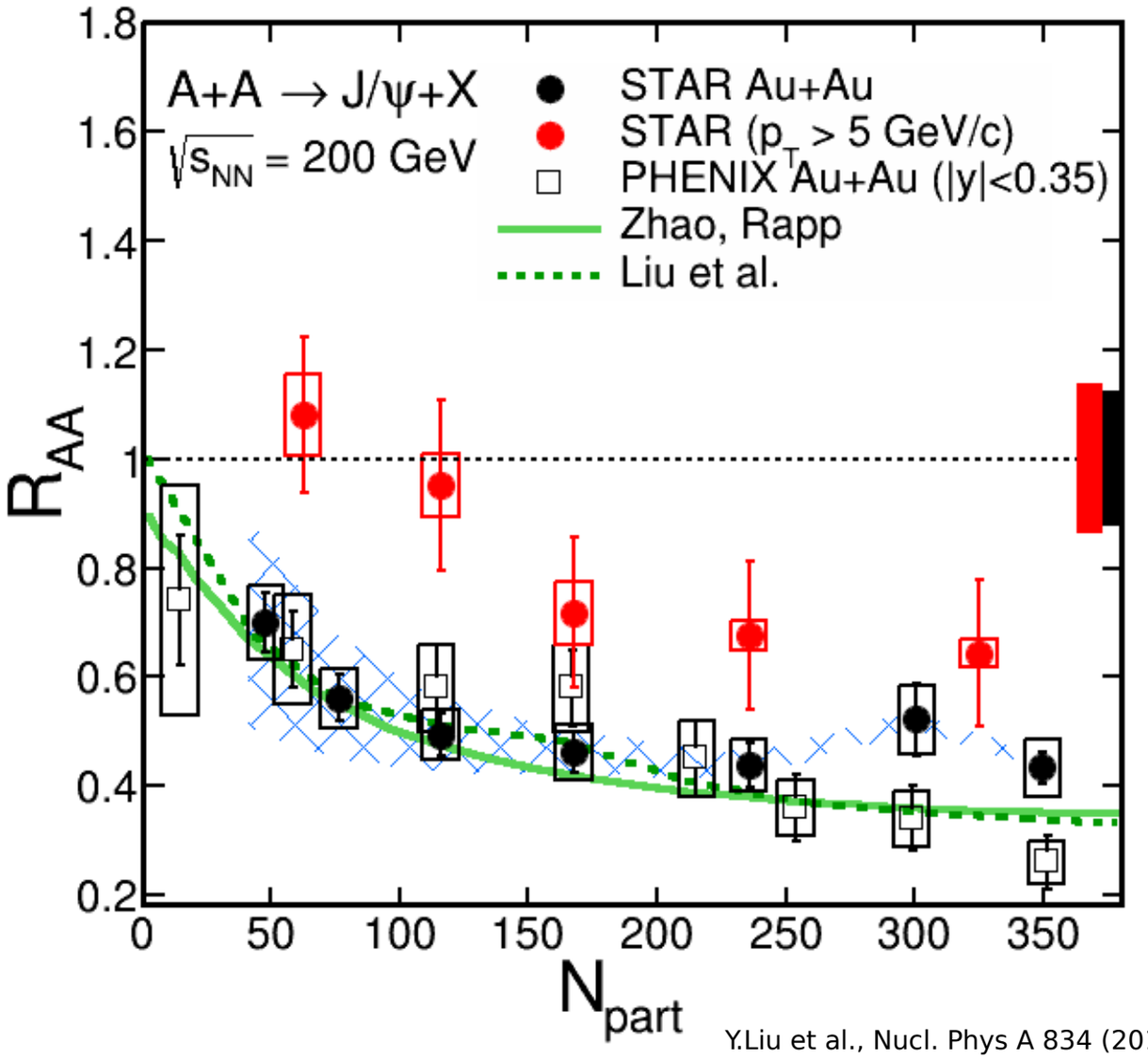


- ✓ Suppression increases with collision centrality
- ✓ High-p_T R_{AA} is systematically higher
  - ➢ J/ψ at high-p_T almost not affected by CNM effects and recombination
- ✔ High-p_T J/ψ suppressed in central collisions
  - ➔ May indicate QGP effects

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

Y.Liu et al., Nucl. Phys A 834 (2010) 317c
Zhao, Rapp, Phys. Rev. C 82 (2010) 064905

J/Ψ R_{AA} in Au+Au 200 GeV



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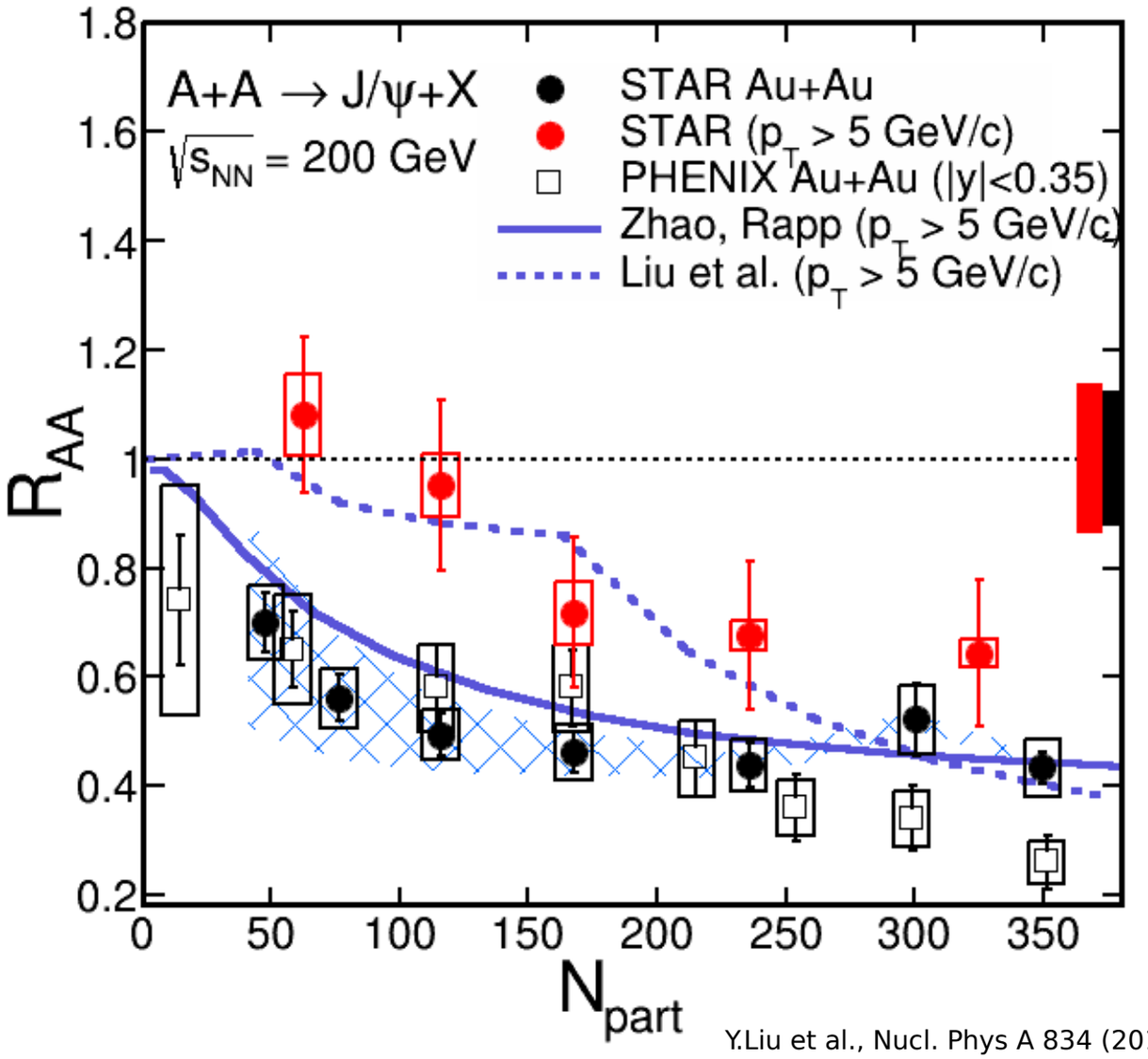
- ➔ Both models – *color screening* + *statistical regeneration* - describe the data well at low p_T

J/Ψ R_{AA} in Au+Au 200 GeV



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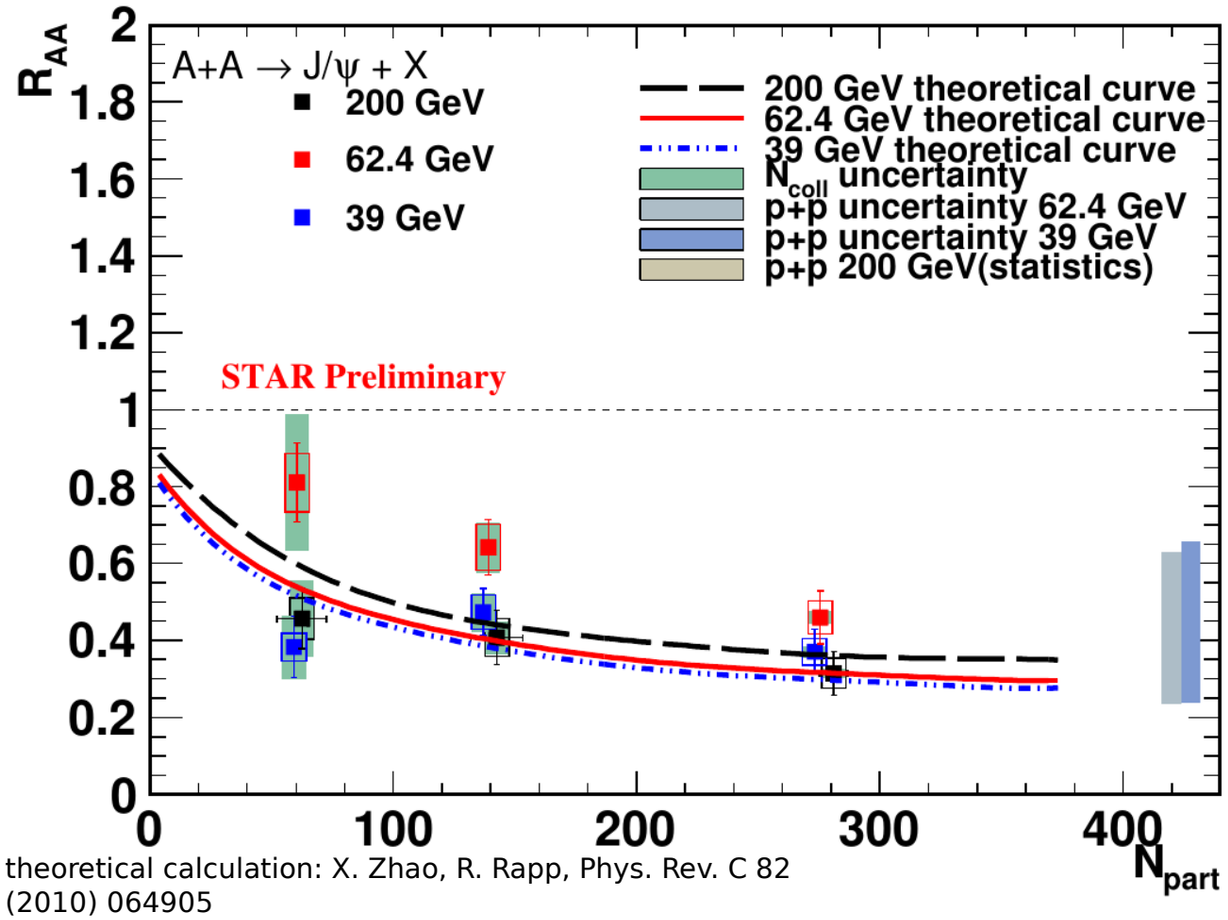
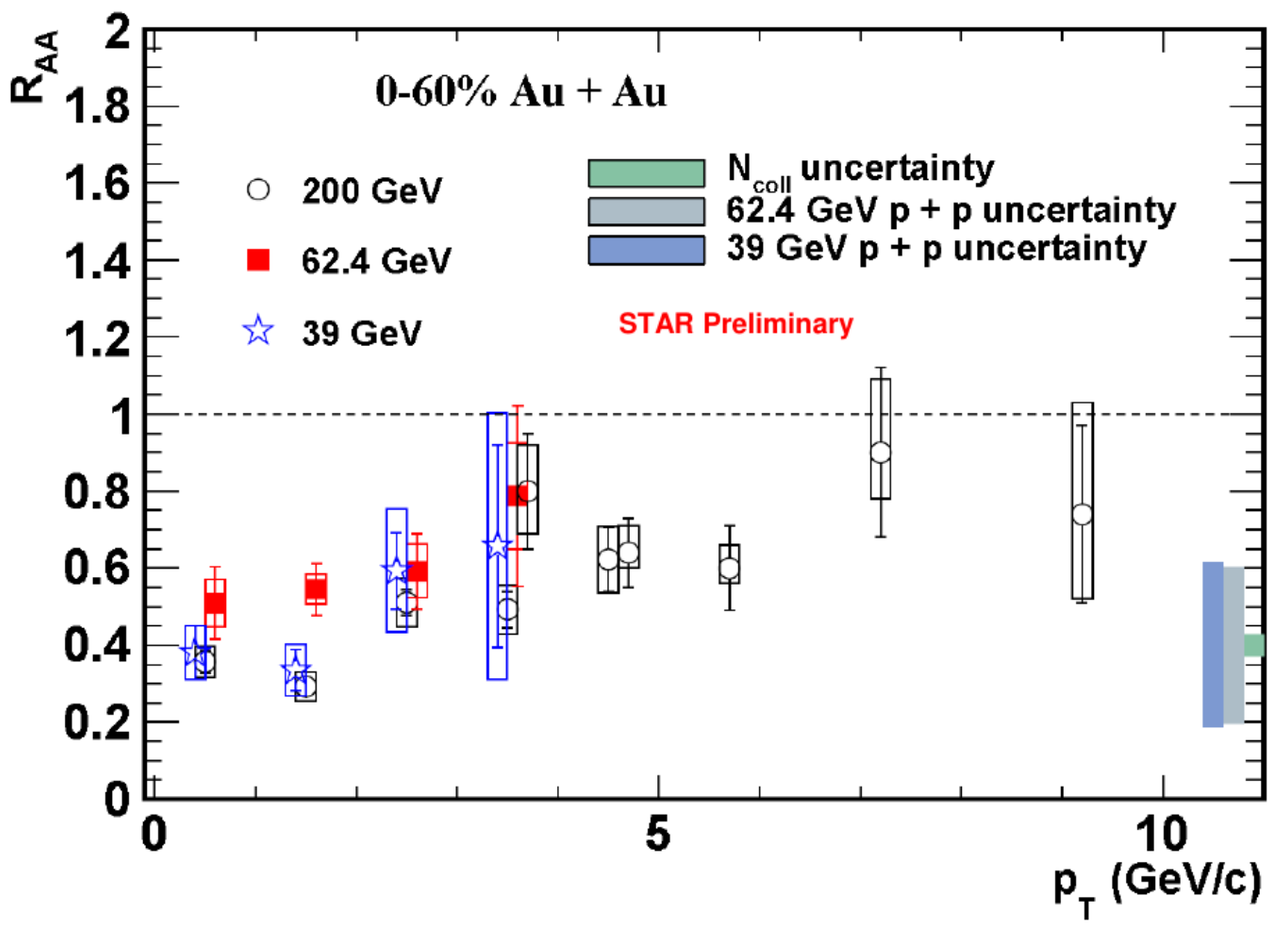
Y.Liu et al., Nucl. Phys A 834 (2010) 317c
Zhao, Rapp, Phys. Rev. C 82 (2010) 064905

- ➔ At high p_T Liu et al. model describes the data well, while Zhao et. al model underpredicts the R_{AA}

Energy dependence of J/Ψ R_{AA}



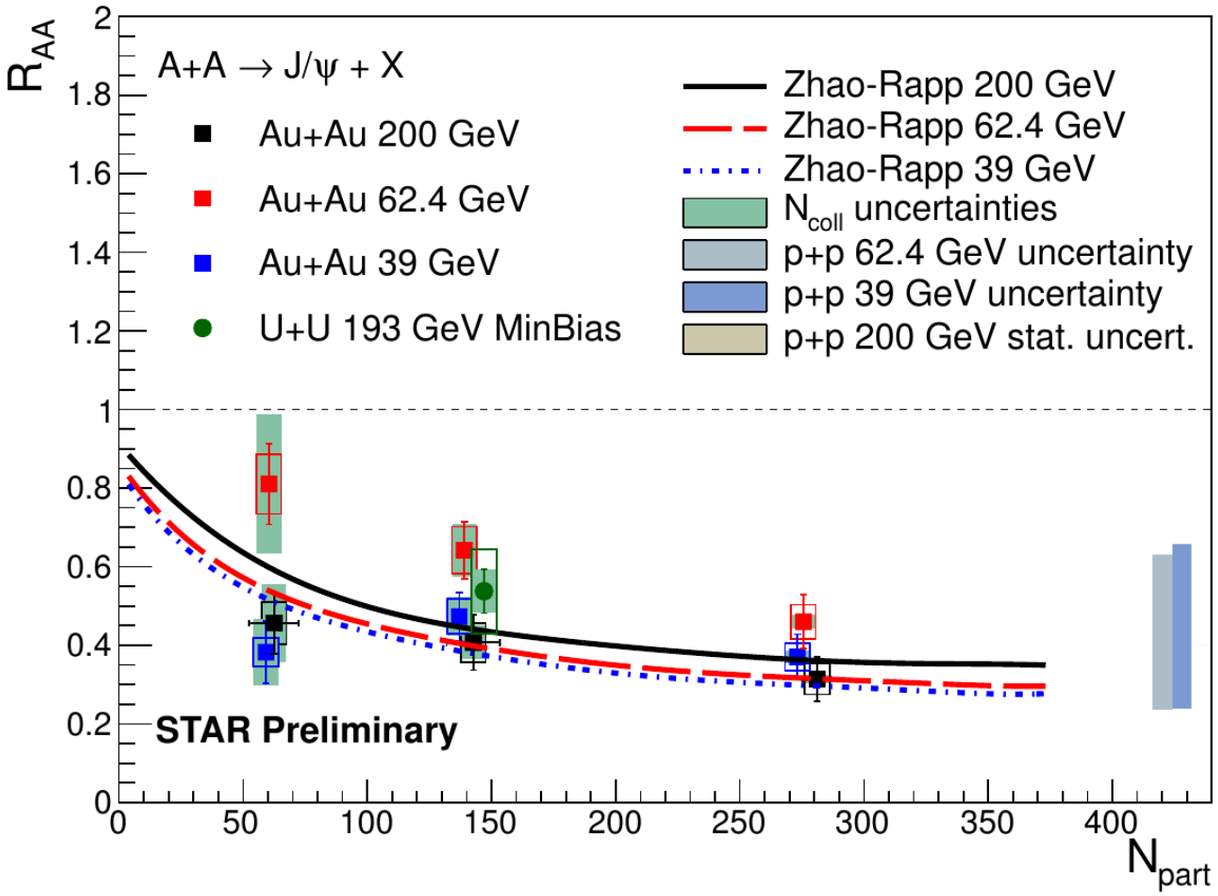
theoretical calculation: X. Zhao, R. Rapp, Phys. Rev. C 82 (2010) 064905
CEM: R. E. Nelson, R. Vogt and A. D. Frawley, Phys. Rev. C 87, 014908 (2013).

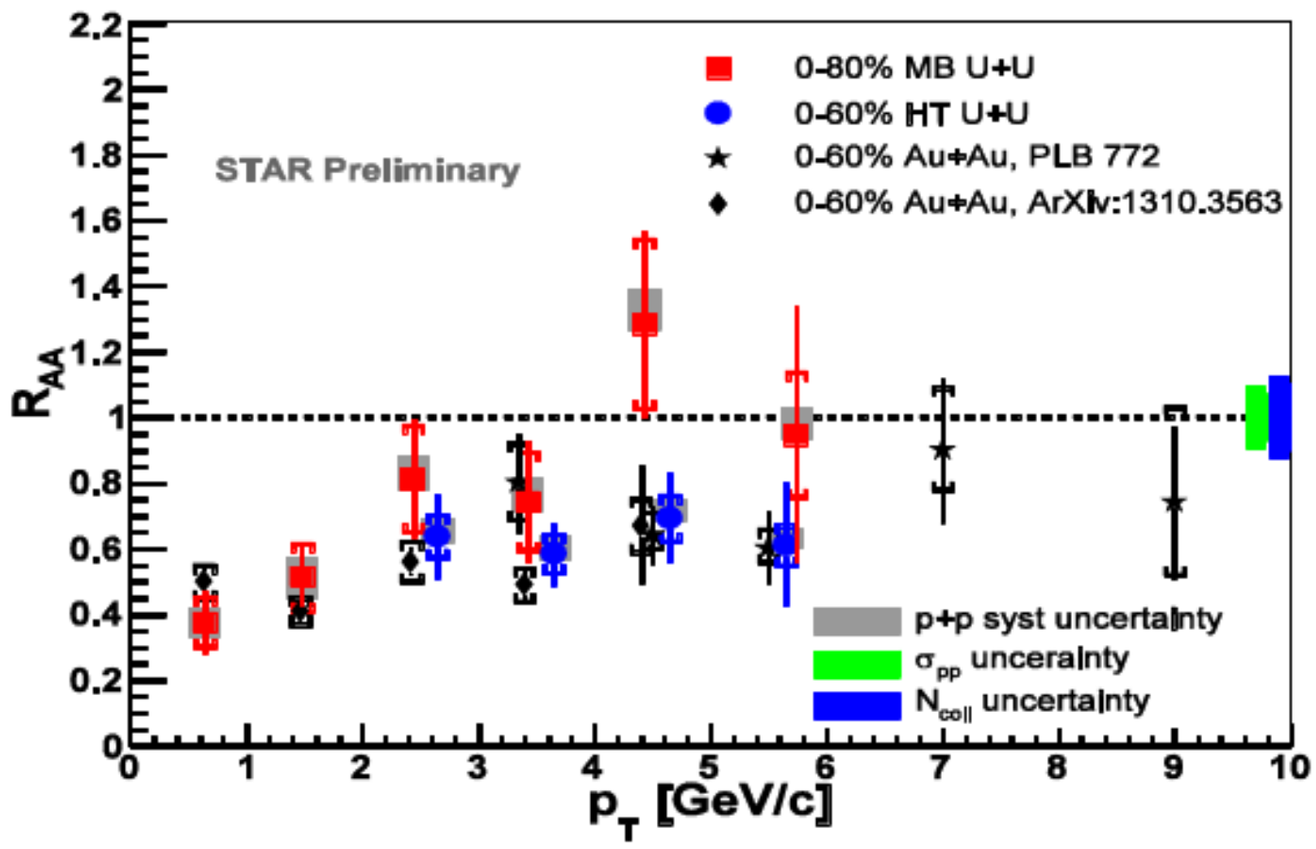


- ✓ Significant suppression at 62.4 and 39 GeV, similar to 200 GeV - no strong energy dependence of J/ψ R_{AA} within uncertainties
- ➔ Data agrees with the prediction of the two-component model
  - *p+p reference for 62.4 and 39 GeV data from Color Evaporation Model (CEM) - large theoretical uncertainties*

J/Ψ R_{AA} in U+U 193 GeV

- Higher energy density can be reached in U+U collisions

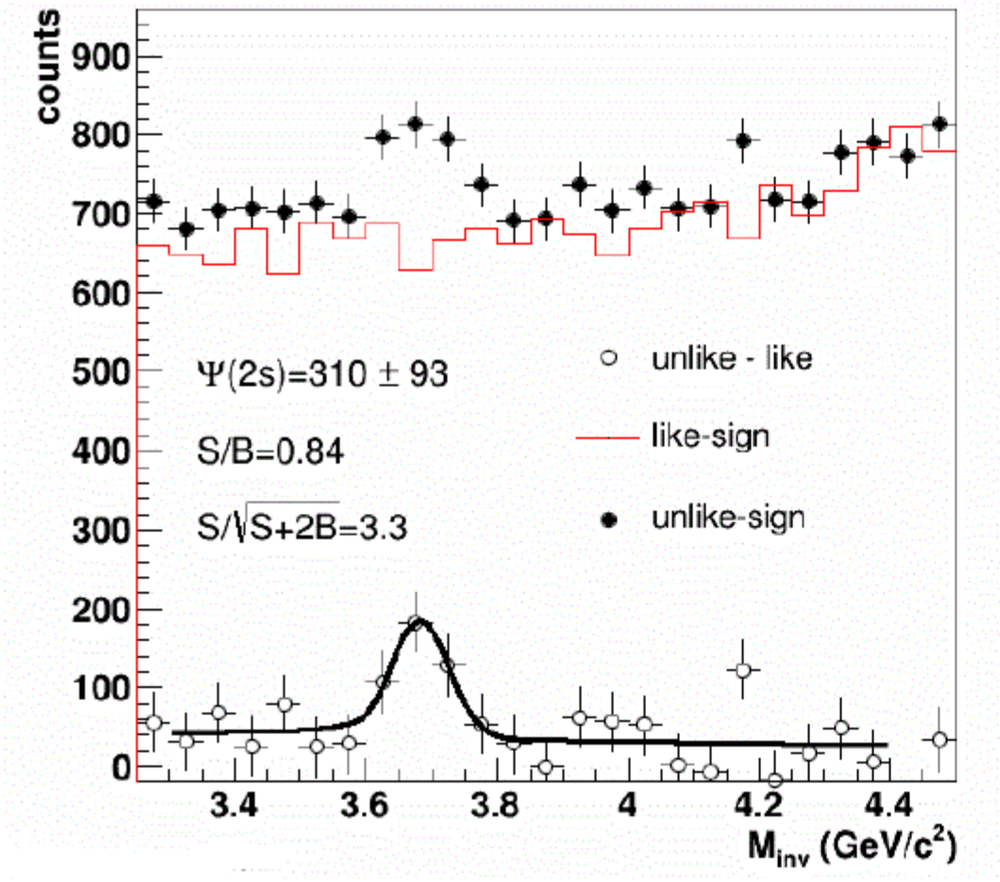


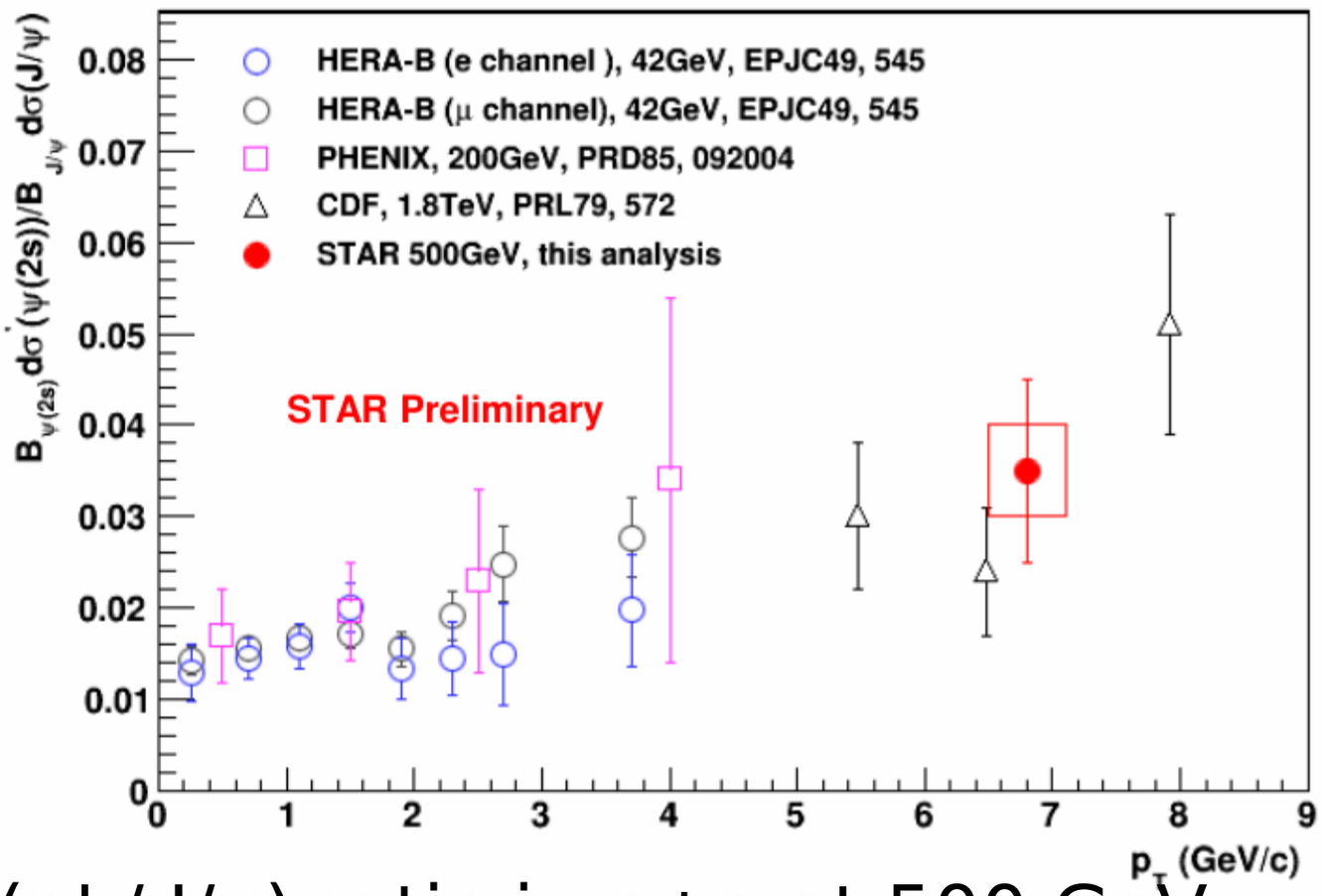


- ✔ Similar suppression pattern in U+U and Au+Au collisions
  - *p+p reference from 200 GeV*

Ψ' in p+p 500 GeV

- Constrain ψ' feed-down contribution to J/ψ
- Test of charmonium production models – charmonium production mechanisms in p+p are still unclear





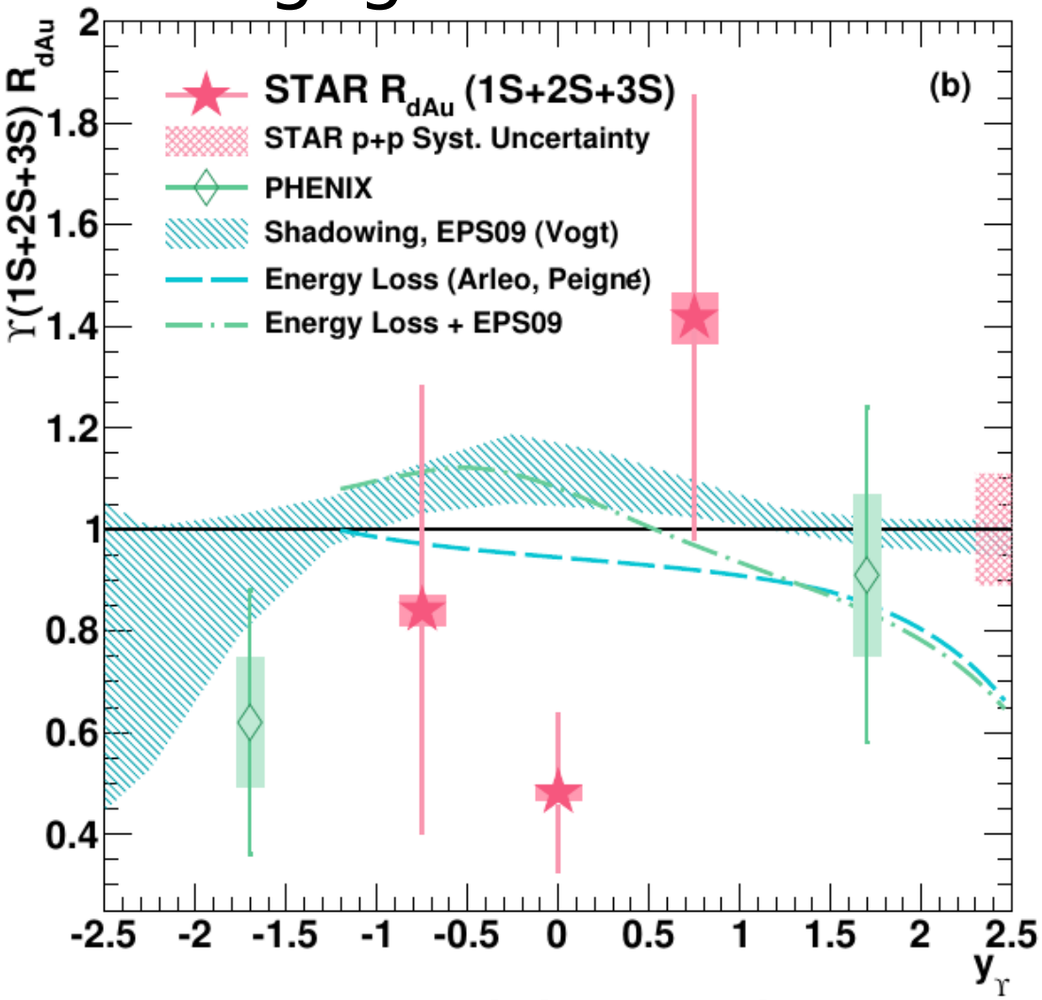
✓ First measurement of (ψ' / J/ψ) ratio in p+p at 500 GeV

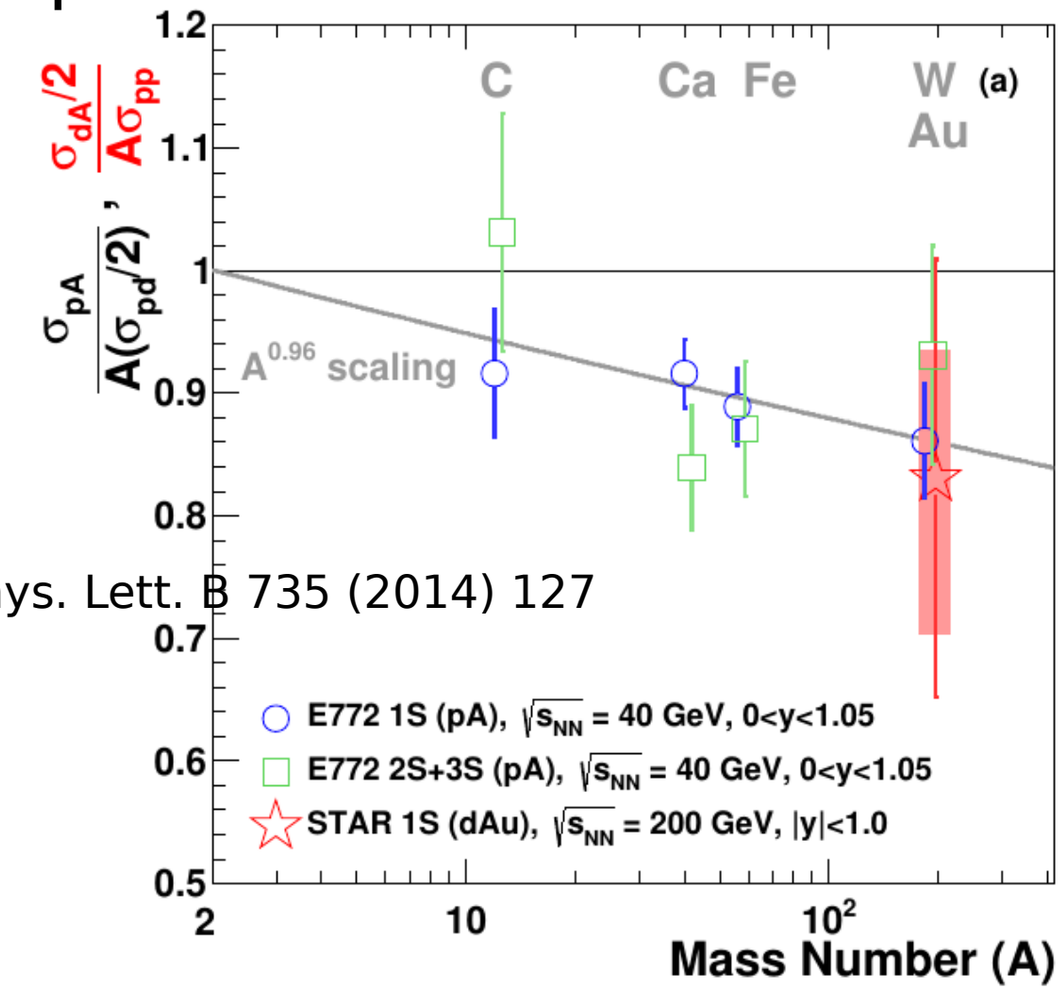
➔ Consistent with other experiments

➔ No collision energy dependence observed

Upsilon in du+Au 200 GeV, CNM effects

- Υ - negligible co-mover absorption and recombination



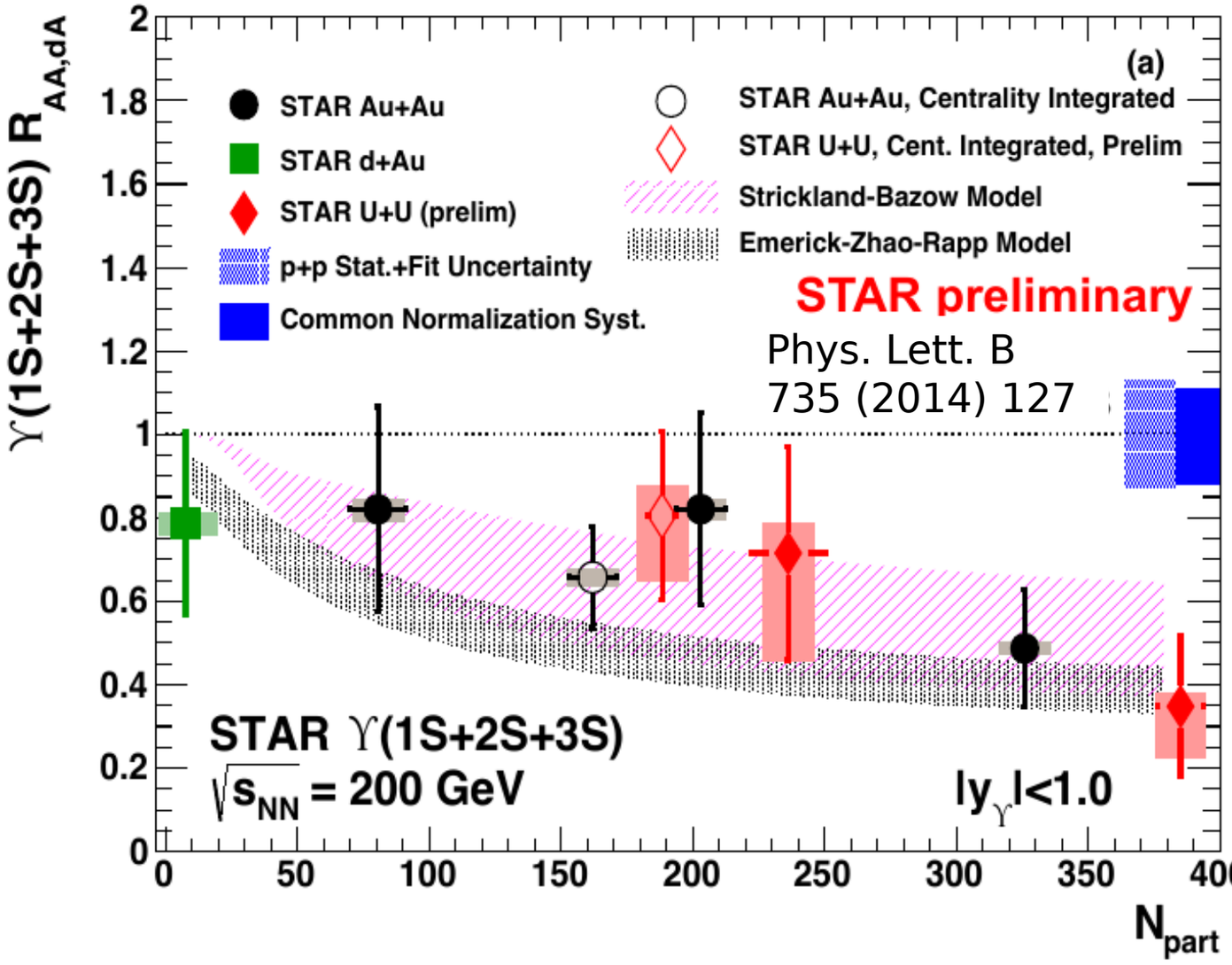


Phys. Lett. B 735 (2014) 127

- Agreement with models except y~0
- Suppression at y~0, in addition to shadowing and initial state parton energy loss
- Similar suppression seen at E772

- *Better understanding of the suppression needed*

Upsilon in d+Au, Au+Au and U+U



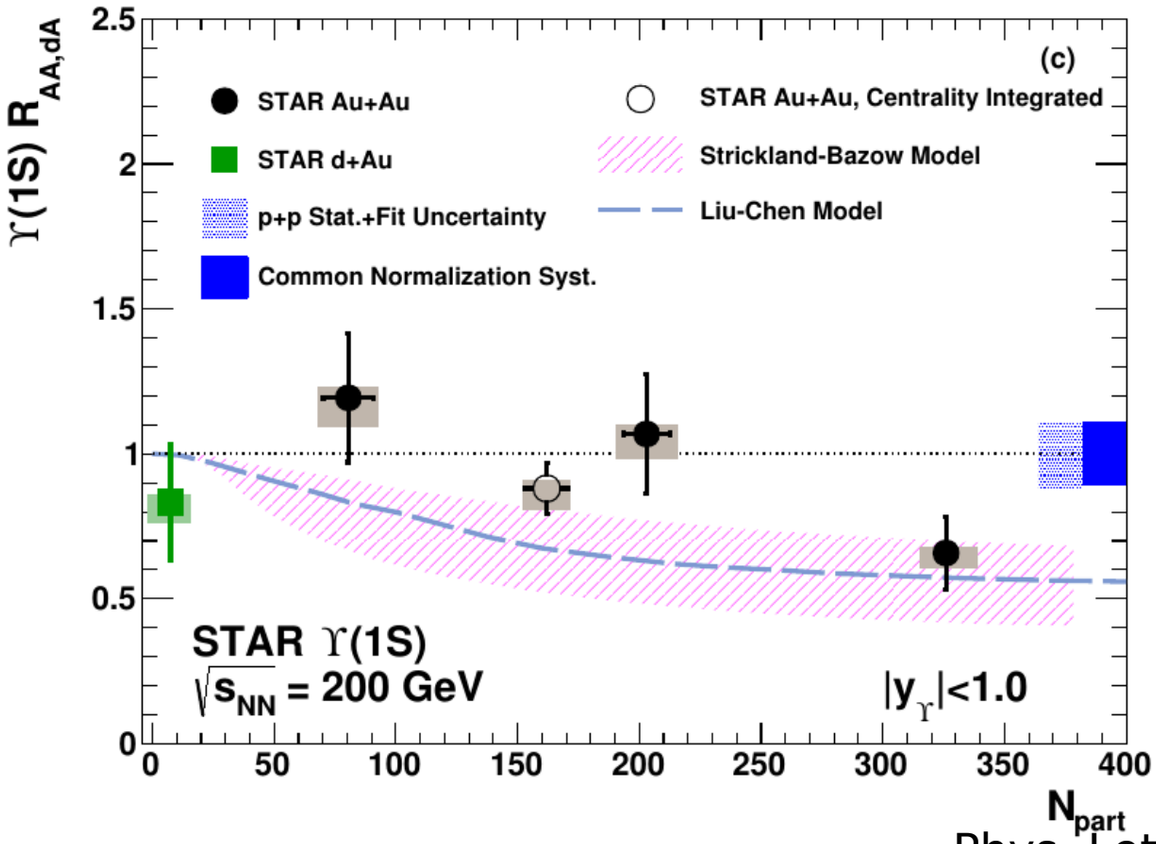
- *Strickland-Bazow Model (arXiv:1112.2761):*
  428 < T < 442 MeV, internal energy potential
- *Emerick-Zhao-Rapp Model (Eur. Phys. J A48, 72 (2012)):*
  CNM effects included, strong binding scenario

✓ Suppression increases with collision centrality

✓ The same trend in Au+Au and U+U collisions

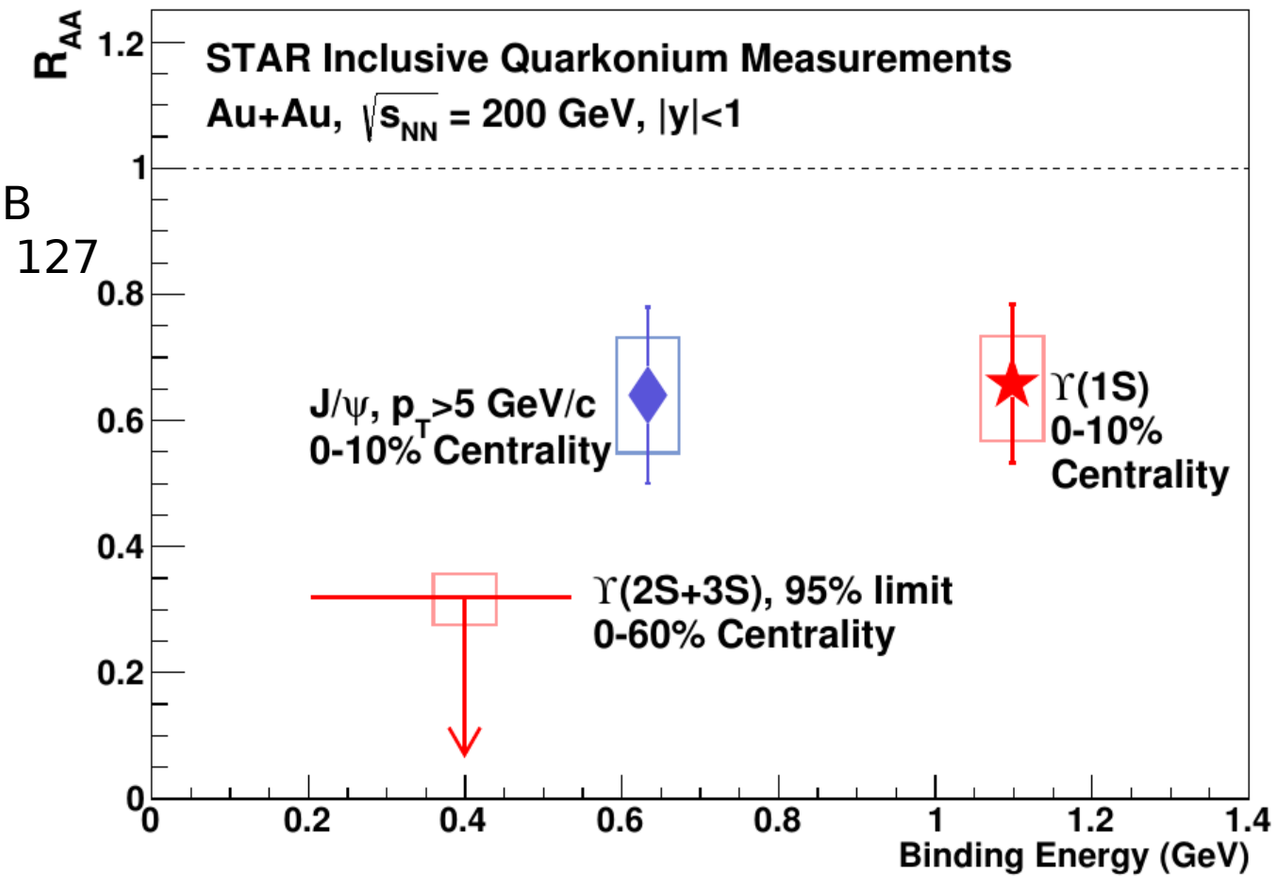
✓ Agreement with models that include presence of QGP

Upsilon states suppression in Au+Au



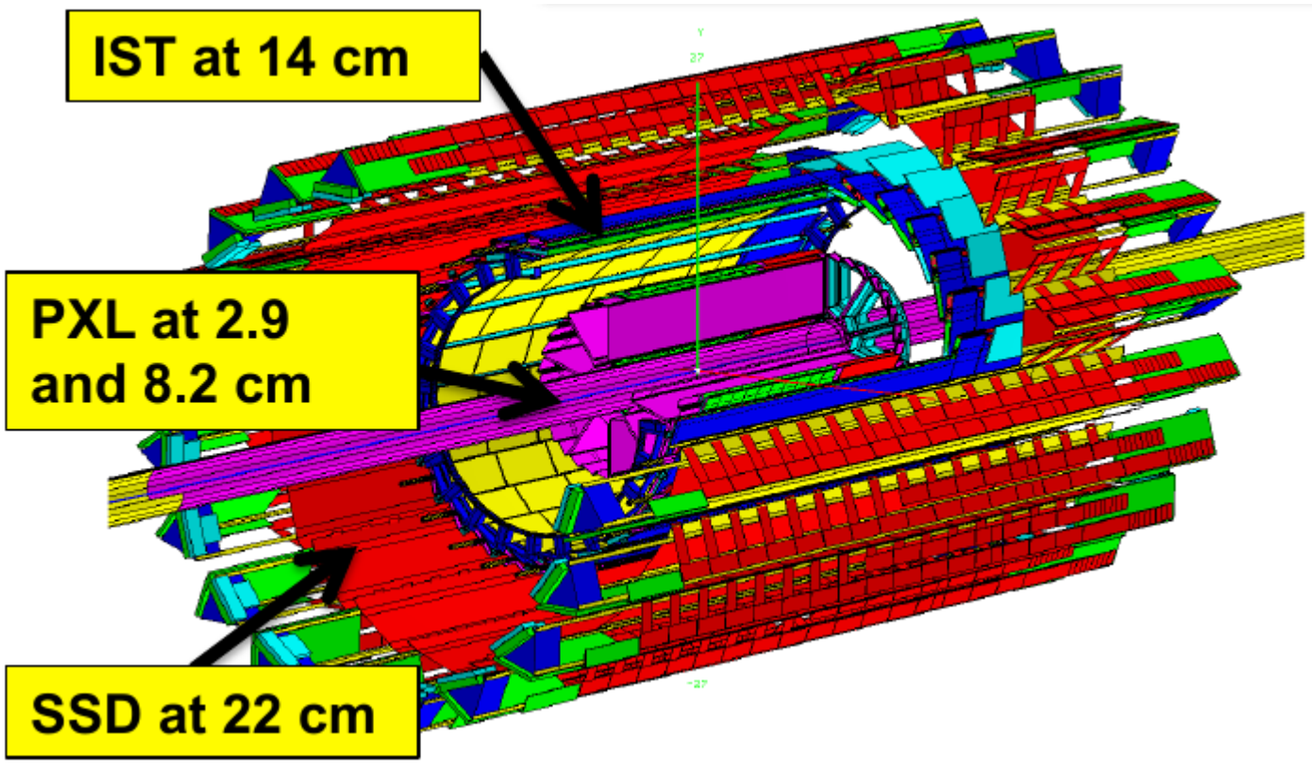
Phys. Lett. B 735 (2014) 127

- ✓ Suppression of Υ(1S) in central collisions consistent with model predictions
- *Liu et al. Model (arXiv:1009.2585)* – suppression mostly due to dissociation of the excited states

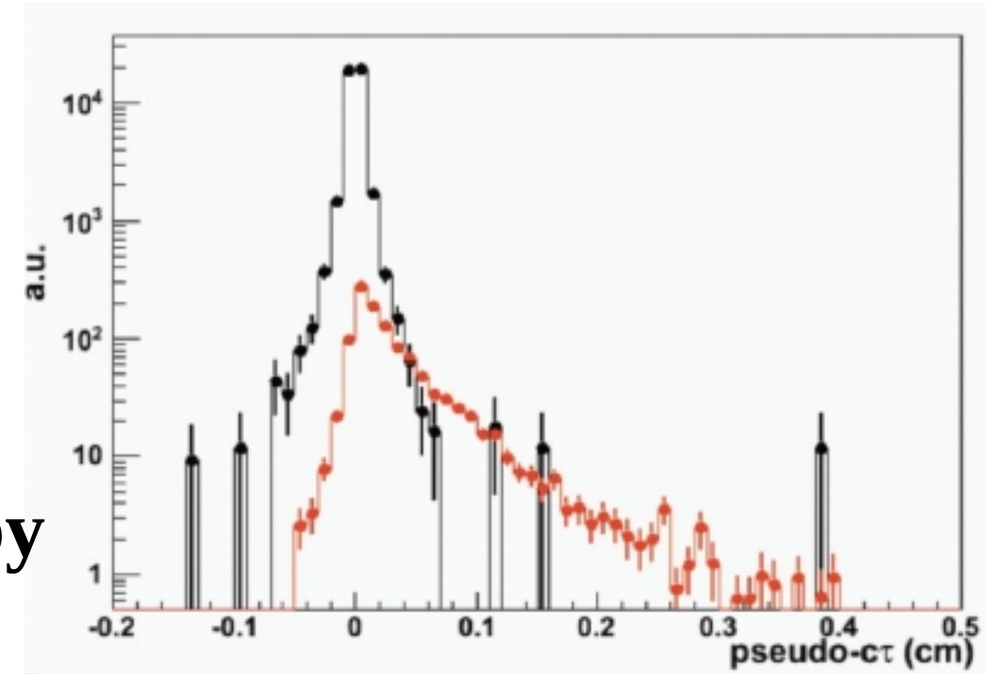


- ✔ Indication of complete Υ(2S+3S) suppression

Heavy Flavor Tracker (HFT)



- Inner tracking system with 3 sub-systems
- Direct topological reconstruction of a decay vertex



Precise pointing resolution

$$B \rightarrow J/\psi + X$$

<u>Prompt J/ψ</u> production measurements by subtracting the contribution from B decays

Fully installed and takes data since 2014

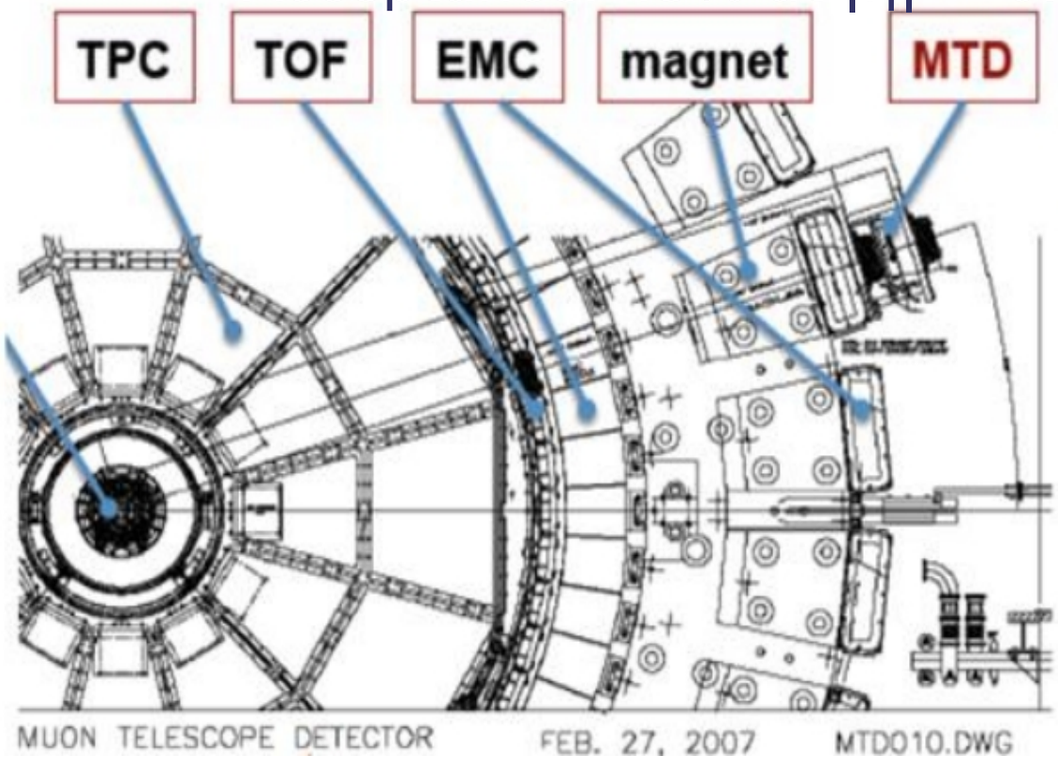
Muon Telescope Detector (MTD)

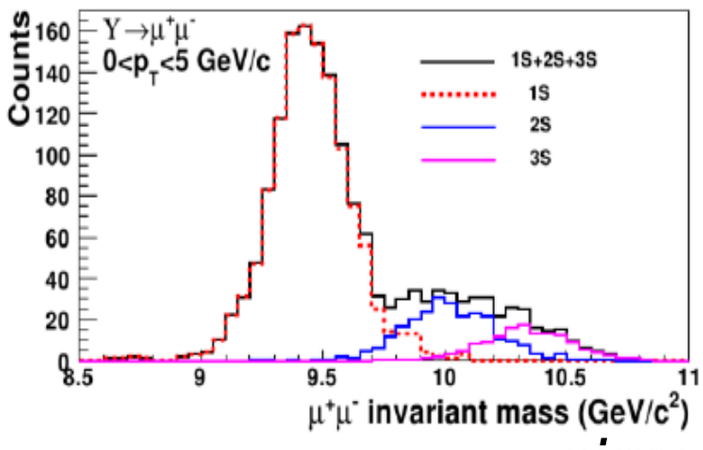
Precision quarkonium measurements via di-μ channel

μ advantages over e:

- No γ conversion
- Much less Dalitz decay contribution
- Less affected by radiative loses in the detector material

Acceptance: 45% at |η| < 0.5

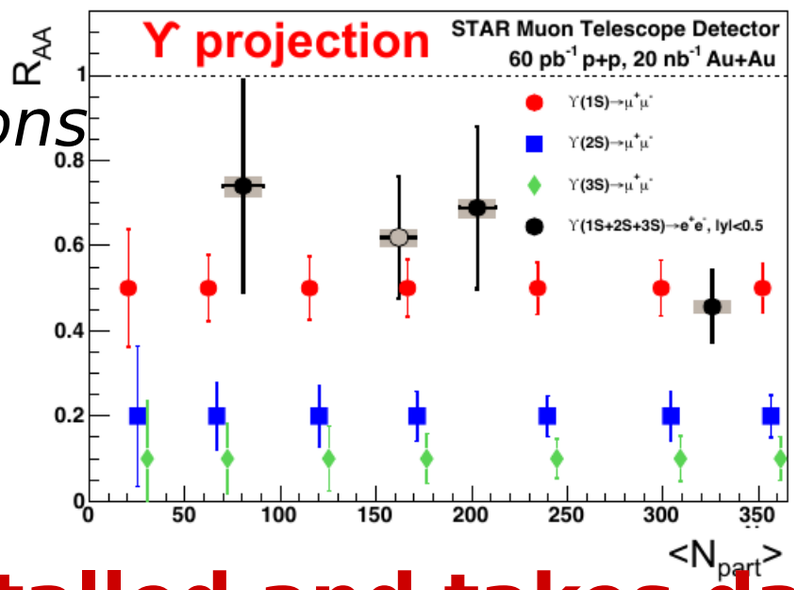


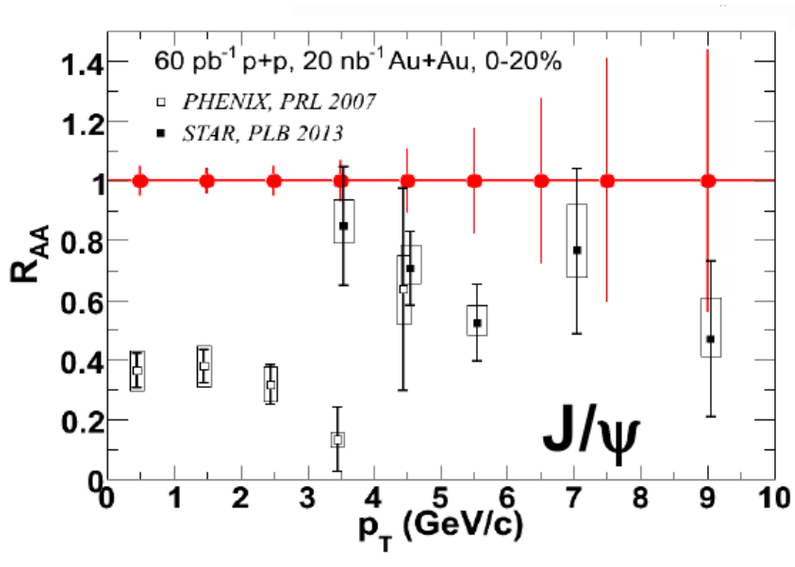


simulations

- ✗ Multi-gap Resistive Plate Chamber (MRPC) - gas detector
- ✗ Long-MRPCs

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





Fully installed and takes data since 2014

Summary

- No strong energy dependence of J/ψ suppression in Au+Au 200, 62.4, 39 GeV
- Similar J/ψ and ϒ suppression in Au+Au and U+U
- High p_T J/ψ and ϒ suppressed in central Au+Au 200 GeV
- Indication for complete ϒ(2S) and ϒ(3S) suppression

→ Signals of the QGP presence

- First ψ' measurement in p+p at 500 GeV

→ No collision energy dependence of (ψ' / J/ψ) ratio seen

- *HFT and MTD since 2014 – significant improvement of quarkonium measurements*

Thank you !