Latest results on Υ production in heavy ion collisions from the STAR experiment

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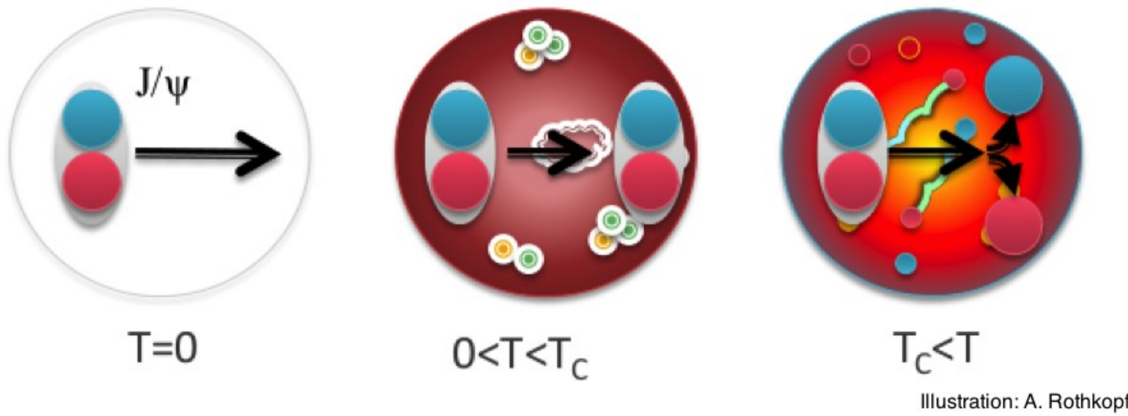
Quarkonia in the sQGP

- Debye screening of heavy quark potential
  → Quarkonia are expected to dissociate

T. Matsui, H. Satz, Phys.Lett. B178, 416 (1986)



Charmonia ($c\bar{c}$):
J/Ψ, Ψ', χ_c

Bottomonia ($b\bar{b}$):
ϒ(1S), ϒ(2S), ϒ(3S), χ_B

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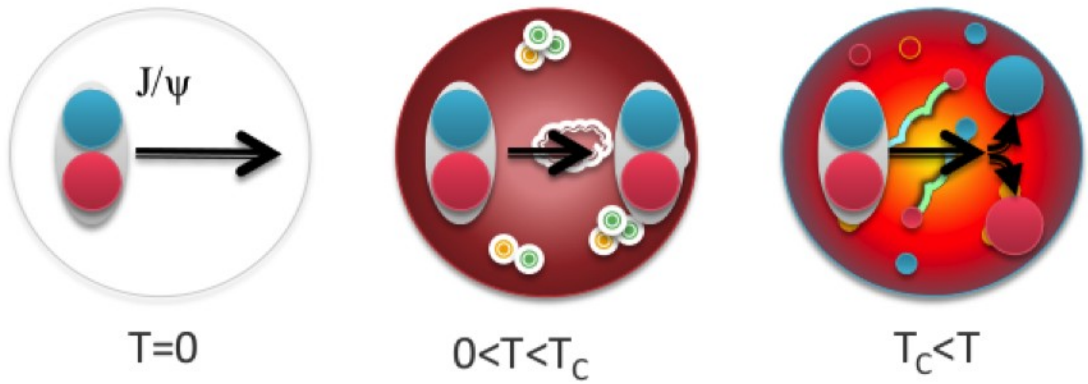

Illustration: A. Rothkopf

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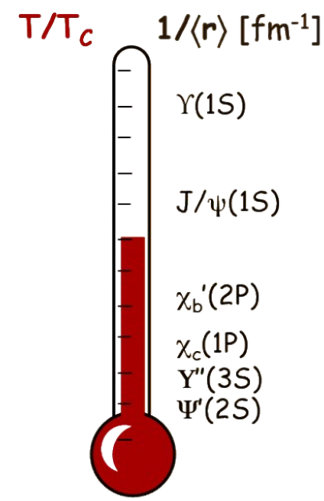


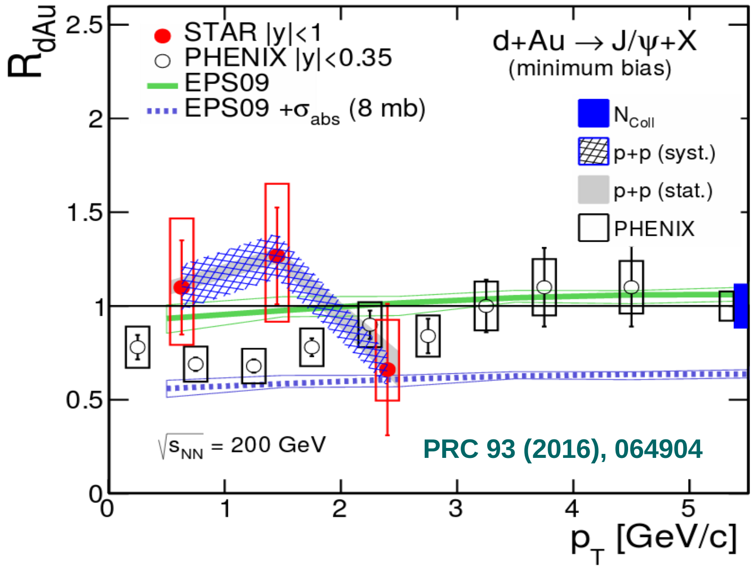
- Sequential melting: Different states dissociate at different temperatures

  Á. Mócsy, P. Petreczky, Phys. Rev. D77, 014501 (2008)

Quarkonia may serve as sQGP thermometer

Lessons from J/ψ

- Cold nuclear matter effects
  - Nuclear shadowing
    (PDF modification in the nucleus)
  - Initial state energy loss
  - Co-mover absorption



PHENIX: PRC 87, 034904 (2013)
EPS09: NPA 830, 599 (2009)
+σ_{abs}: PRC 81, 044903 (2010)

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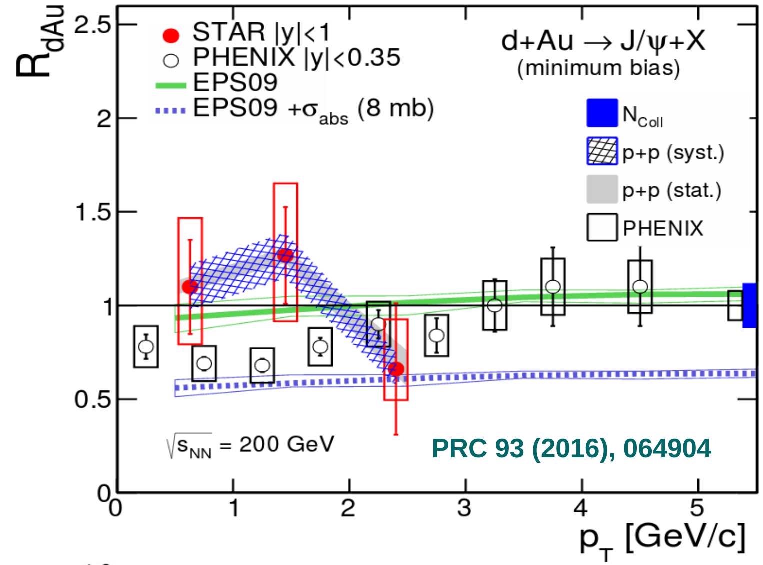
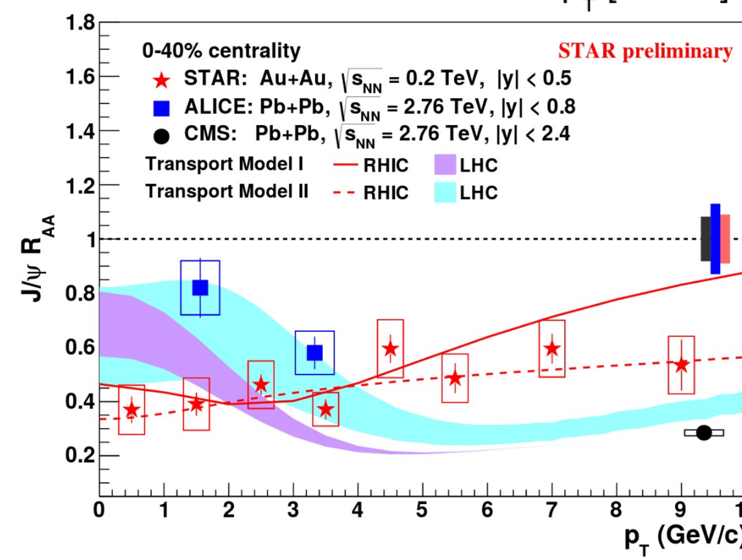
  - Coalescence of uncorrelated charm and bottom pairs





ALICE : PLB 734 (2014) 314
CMS: JHEP 05 (2012) 063
PHENIX: PRL 98 (2007) 232301

Transport models at RHIC
I: PLB 678 (2009) 72
II. PRC 82 (2010) 064905

Transport models at LHC
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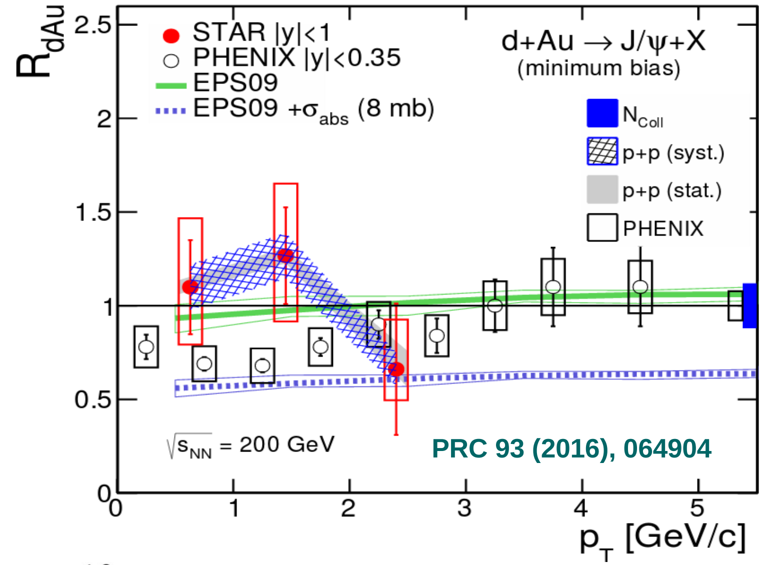
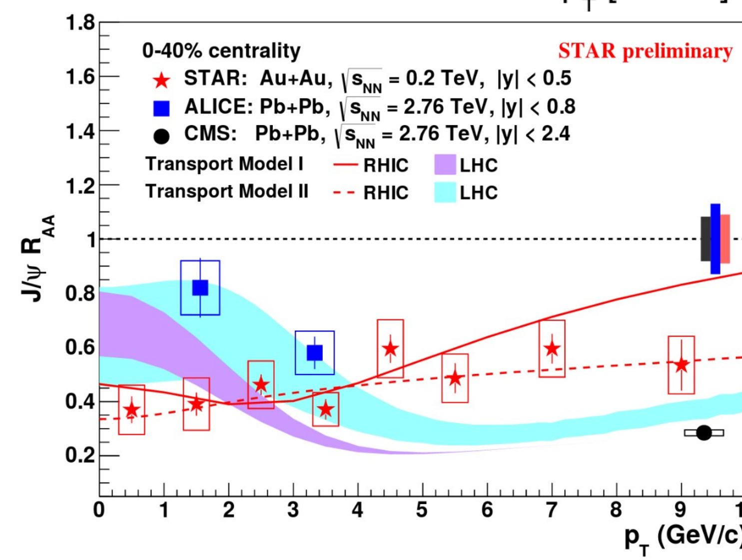
- Feed-down
  - χ_c, ψ’, B-meson decay to J/ψ





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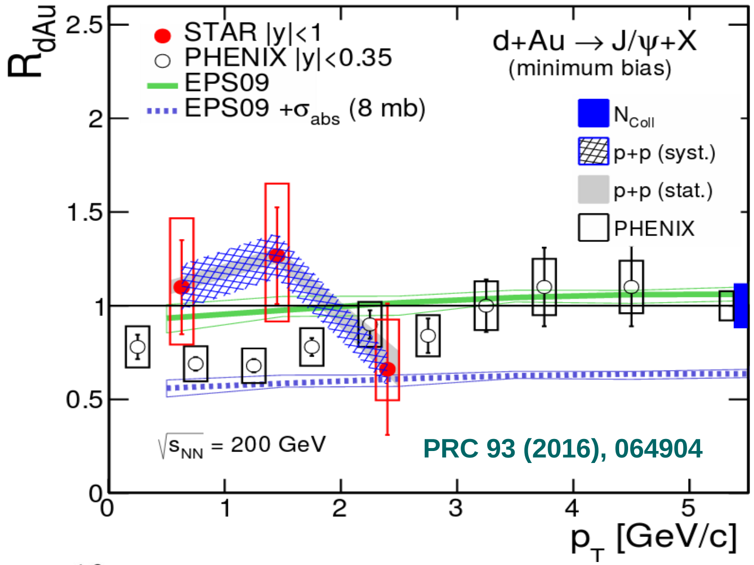

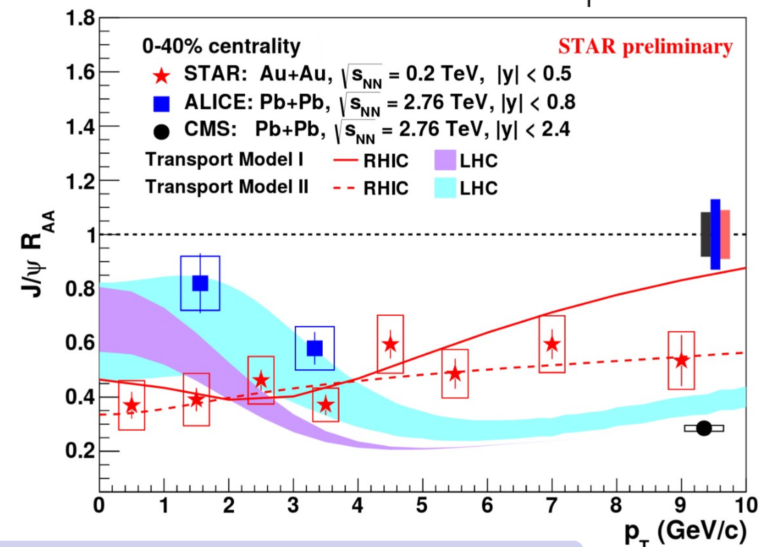

Only qualitative understanding of these effects

Υ production at RHIC

- Υ co-mover absorption is negligible at RHIC energies
  - Υ (1S) is tightly bound, larger kinematic threshold.
  - x-section is 5-10 times smaller than for J/ψ (σ~0.2 mb)
    Lin & Ko, PLB 503 (2001) 104
- Υ recombination → negligible at RHIC:
  - σ_{cc} ~800 μb >> σ_{bb} ~ (1-2) μb

    Andronic, Braun-Munzinger, Redlich & Stachel, NPA 789 (2007) 334.
- Υ excited states: test sequential suppression

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Υ states provide a cleaner probe at RHIC

- Υ measurements : a challenge
  - Low production rate
  - Large acceptance, specific trigger needed
  - Feed-down still present: χ_b, Υ(2S), Υ(3S) to Υ(1S) …

Measurements by collision system

- **p+p – pQCD benchmark and reference for nuclear effects**
  $\sqrt{s}$ = 200 GeV (preliminary 500 GeV)
- **d+Au (p+Au) – cold nuclear matter effects**
  $\sqrt{s_{NN}}$ = 200 GeV
- **A+A – hot nuclear matter effects**
  - **Au+Au** $\sqrt{s_{NN}}$=200 GeV
  - **U + U** $\sqrt{s_{NN}}$=193 GeV

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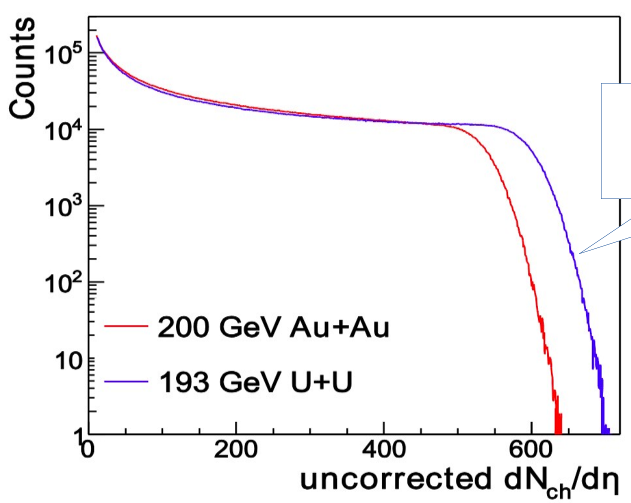
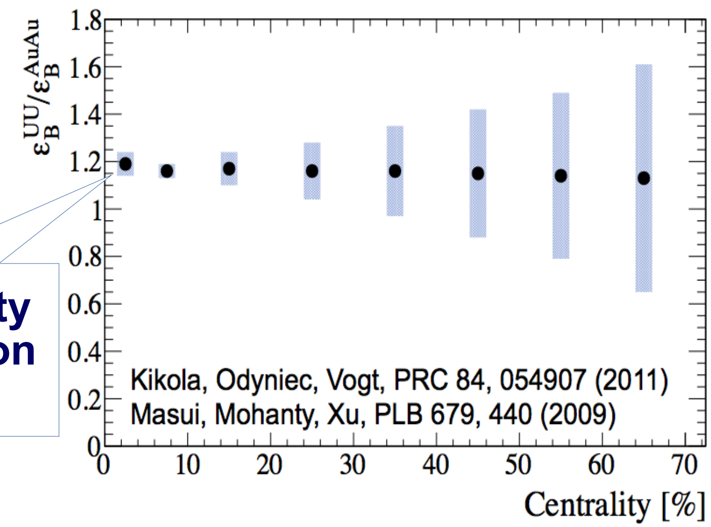


Highest N_{part} reach at RHIC

Energy density ~20% higher on the average



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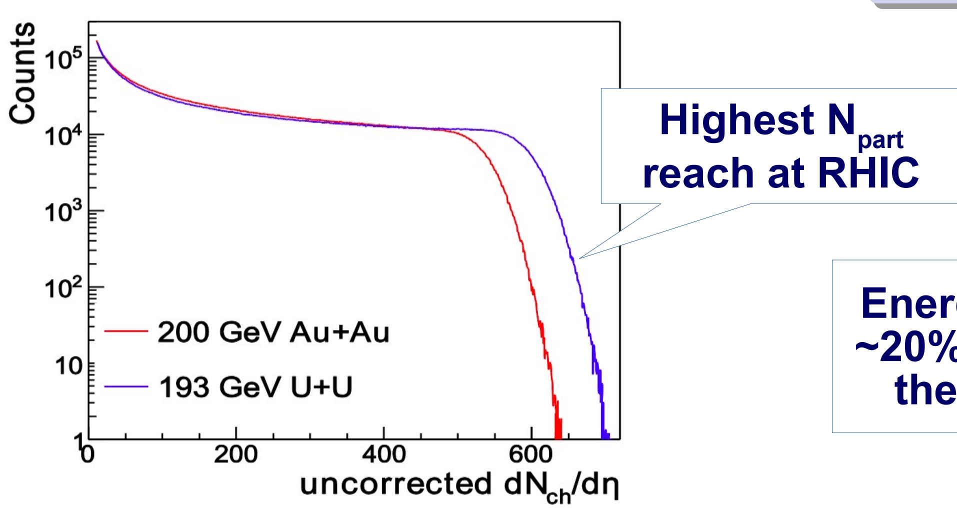
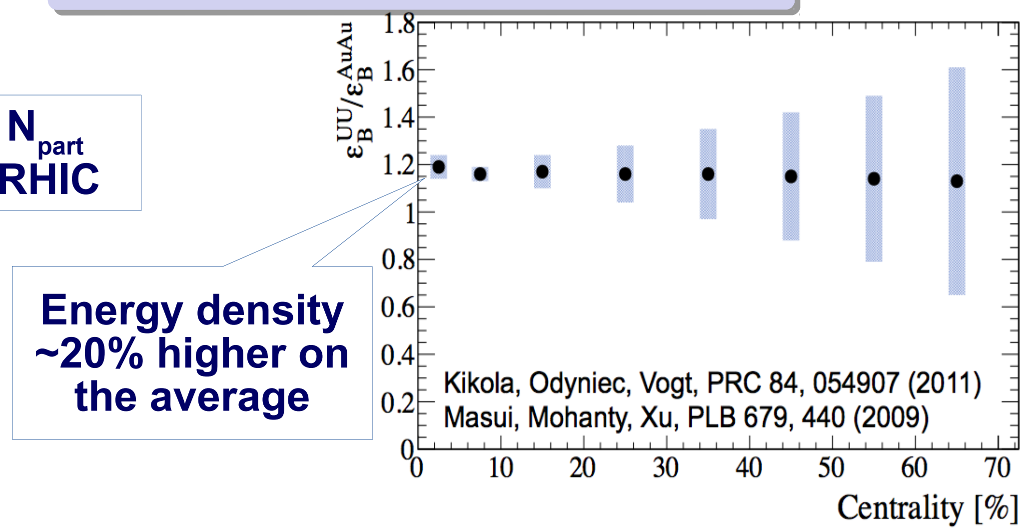
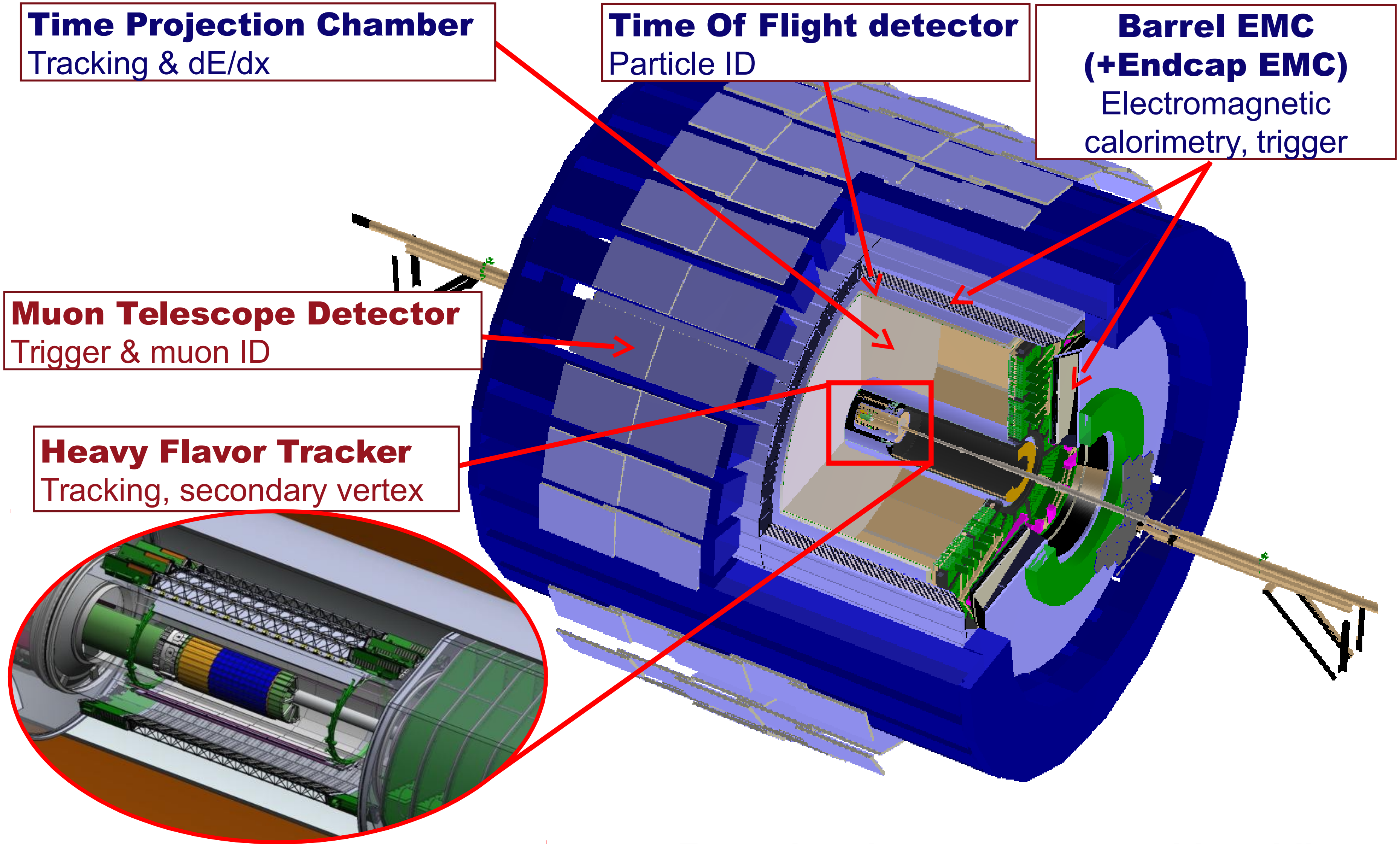
New preliminary results in the $\Upsilon \to \mu\mu$ channel

New final results





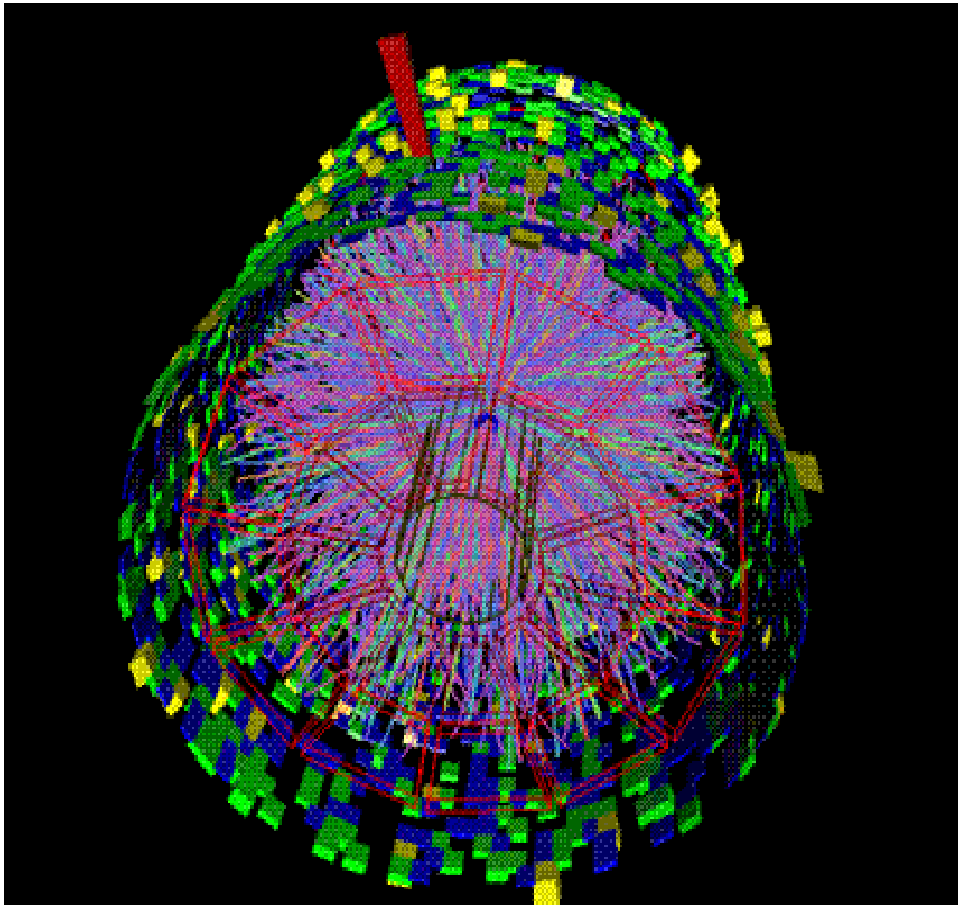
The STAR experiment



Full azimuthal coverage at mid-rapidity

Reconstruction in the $\Upsilon \rightarrow e^+e^-$ channel

A central A+A collision event in STAR



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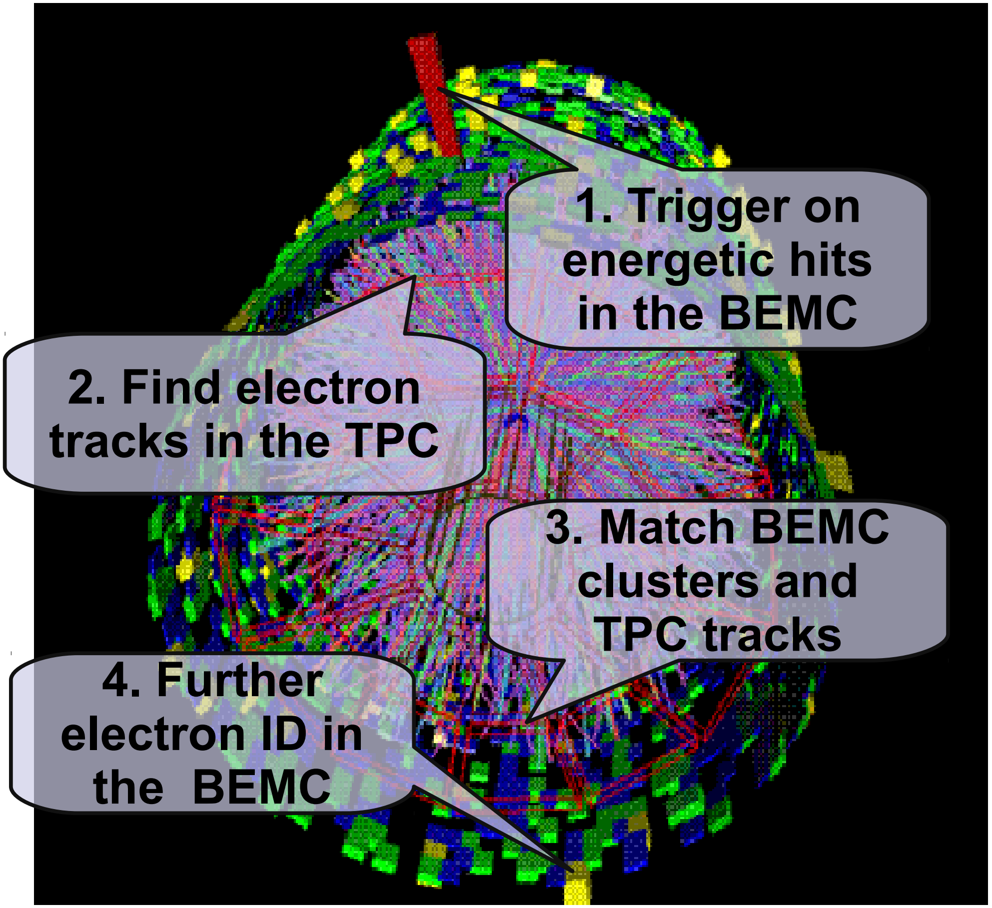

$\Upsilon \rightarrow e^+e^-$ (BR ~ 2%)

- Large invariant mass (m_{ee}~10 GeV/c^2)
- Back-to-back electron-positron pair
- Rather energetic electrons (typically >3 GeV)

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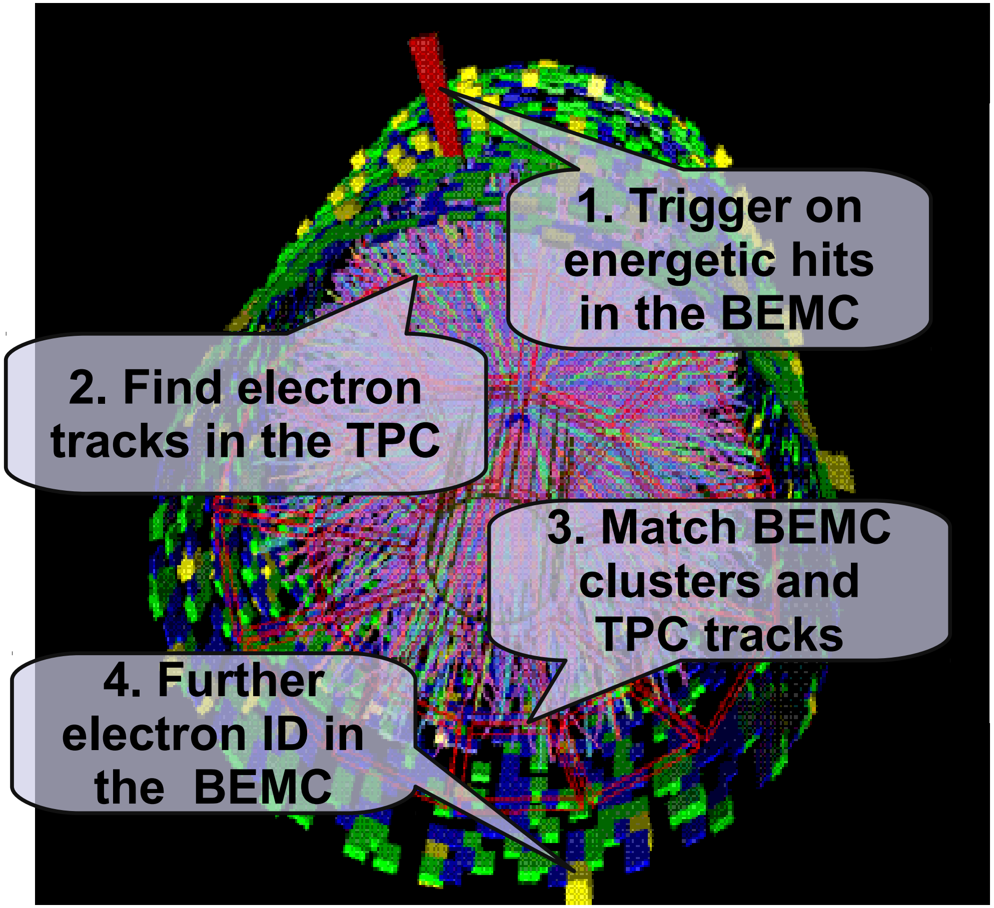

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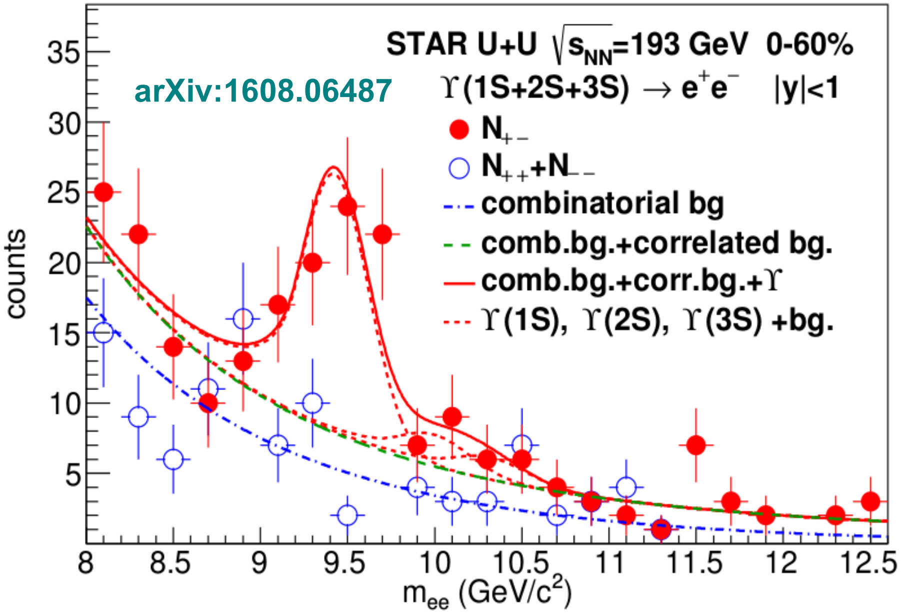
Reconstructed invariant mass (U+U 193 GeV)



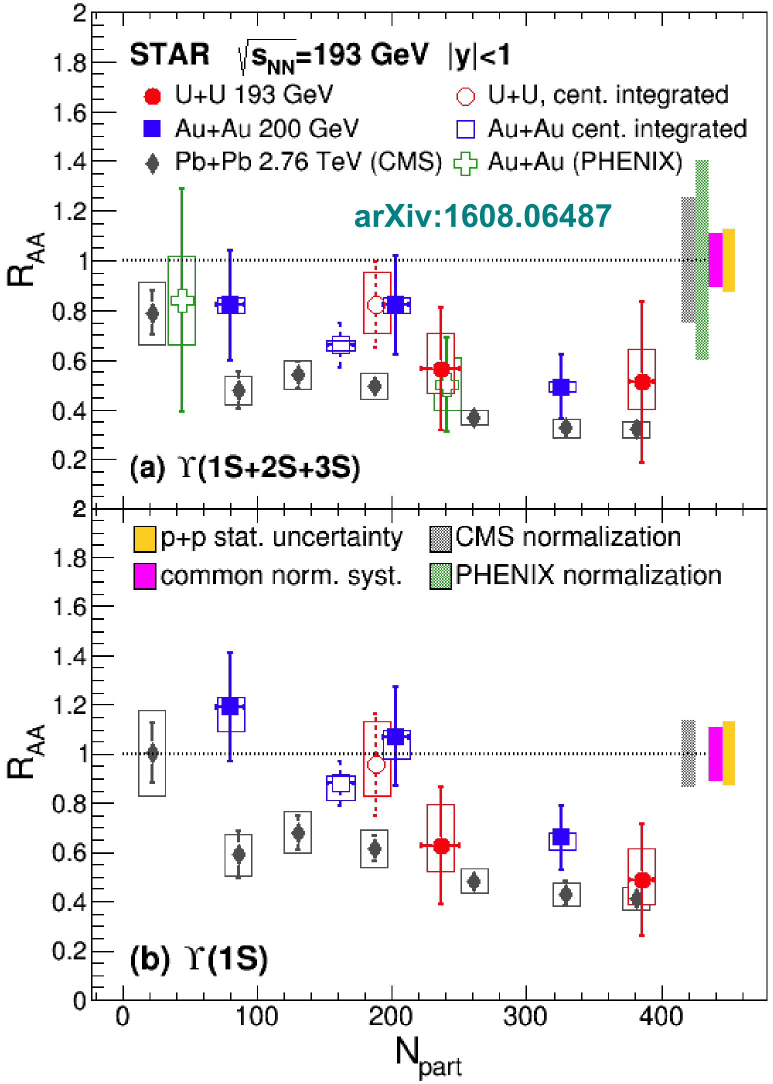
Yield determined using a simultaneous signal+background fit

- Signal: Υ(1S)+Υ(2S)+Υ(3S) Crystal ball functions including Bremsstrahlung tail
- Background: $b\bar{b} \to e^+e^-X$ and Drell-Yan processes, random correlation

R_{AA}^{Υ} in Au+Au and U+U

ϒ(1S+2S+3S)

ϒ(1S)



PHENIX, PRC 87 (2013)
CMS, PRL 109 (2012) 222301

R_{AA}^{Υ} in Au+Au and U+U

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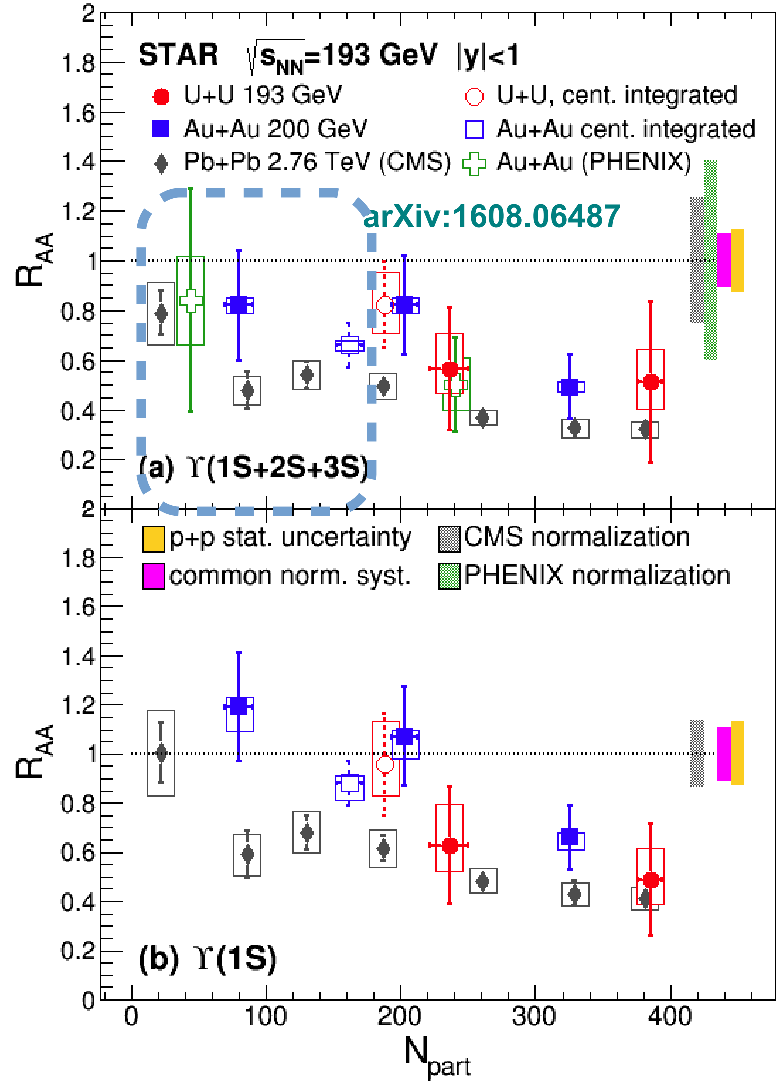
Peripheral collisions:

- no significant suppression observed

ϒ(1S)



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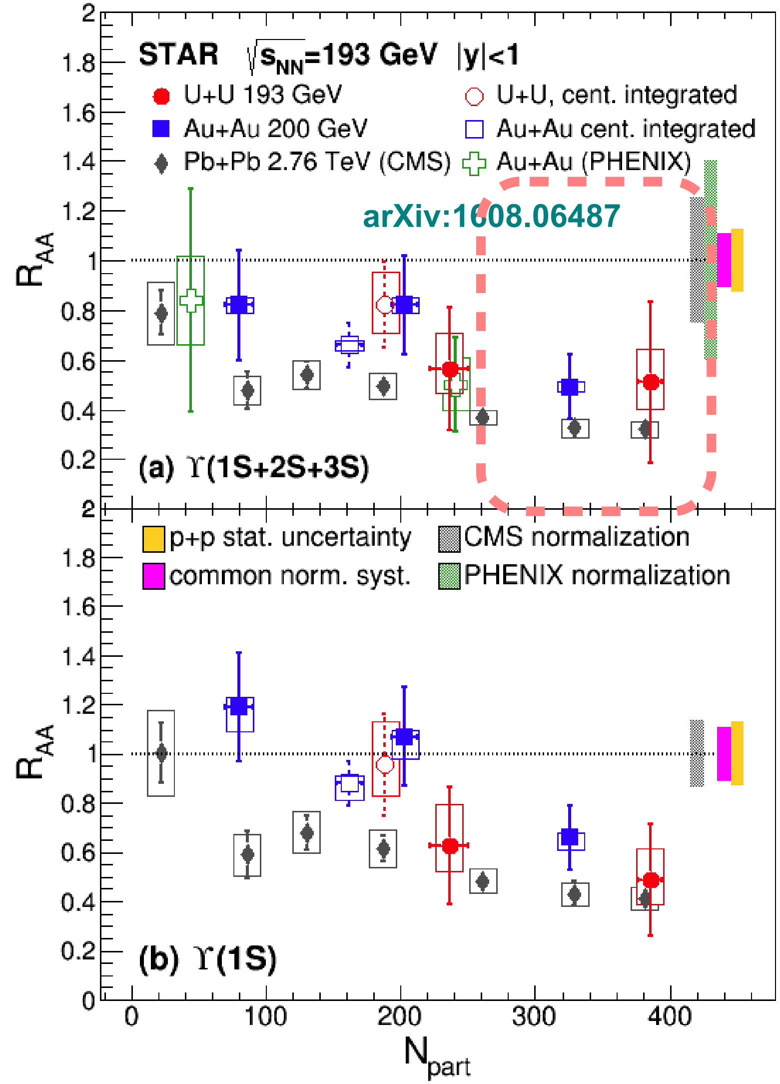

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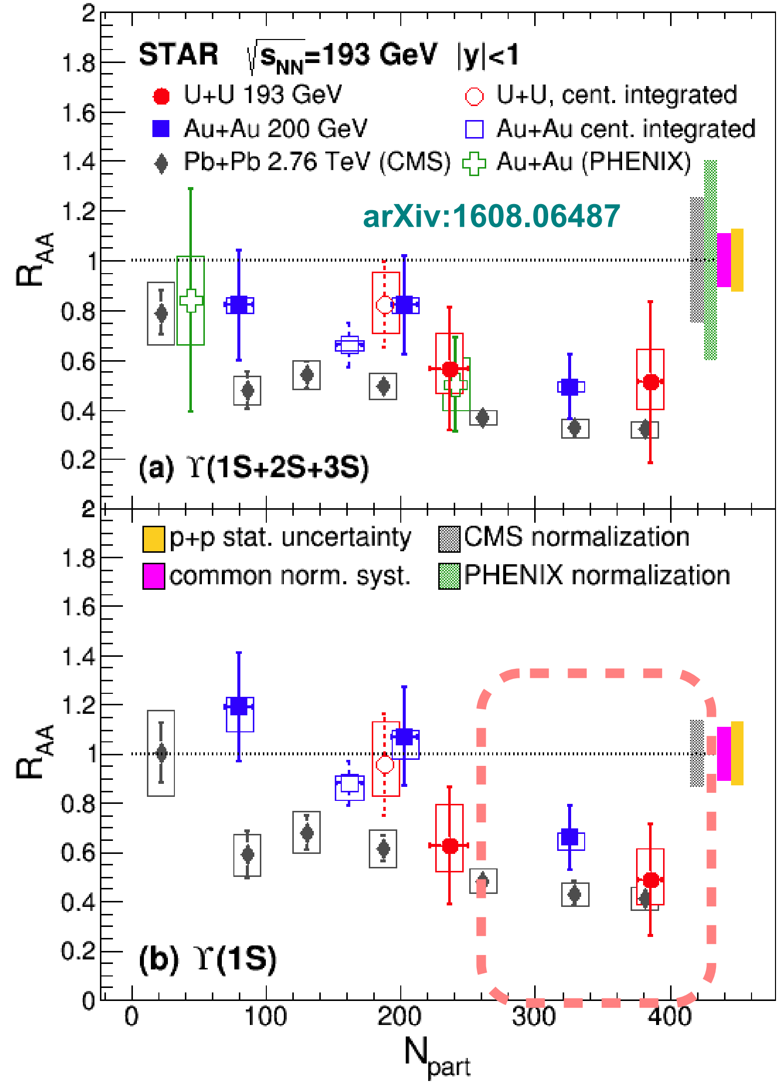
ϒ(1S) – Central collisions:

- Combined Au+Au and U+U data:

$$R_{AA}^{\Upsilon(1S)} = 0.63 \pm 0.16 \pm 0.09$$

Suppression significant, but not complete



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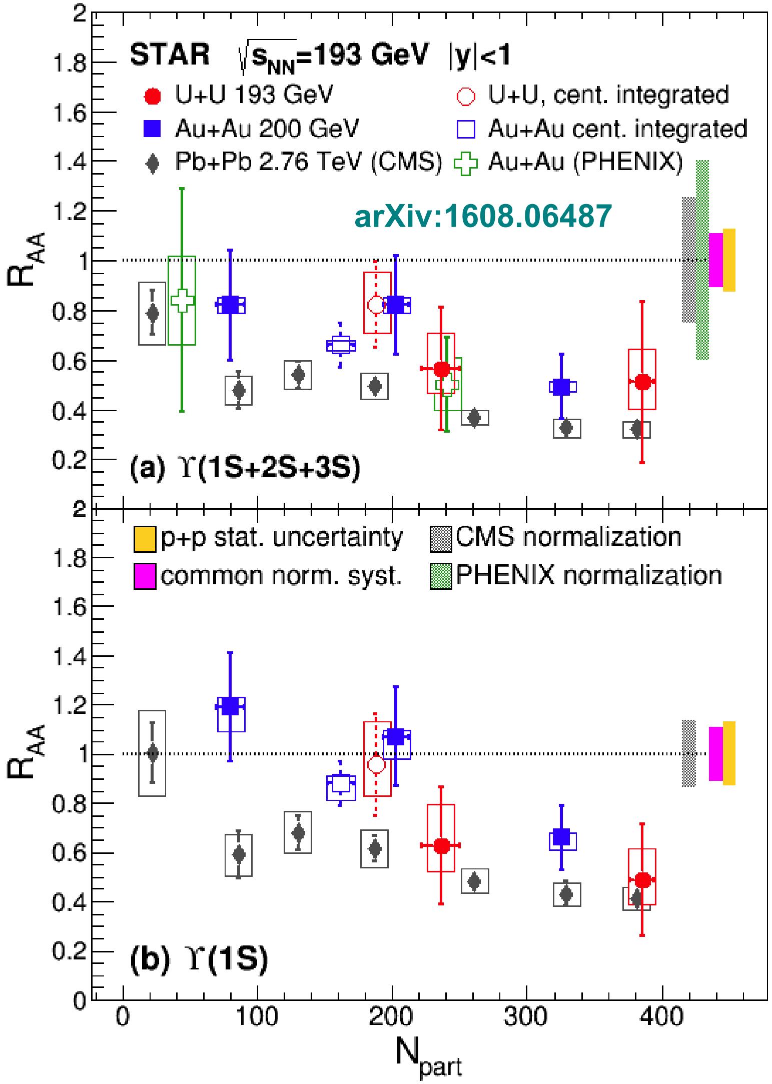

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New U+U data confirms and extends Au+Au trend

R_{AA}^{Υ} : model comparison

Strickland, Bazov,

Nucl.Phys.A 879, 25 (2012)

- No CNM effects, 428<T<443 MeV
- Potential model 'B' based on **heavy quark internal energy**
- Potential model 'A' based on heavy quark free energy (disfavored)

Liu, Chen, Xu, Zhuang,

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- Potential model, no CNM effects
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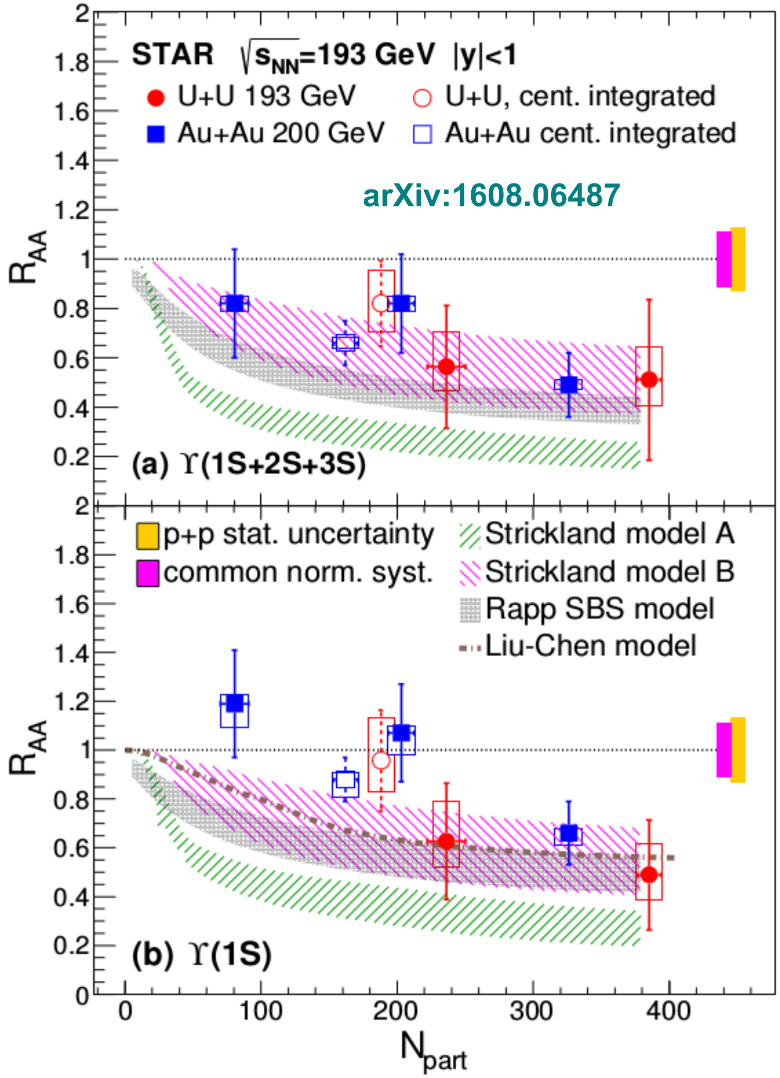
- Strong binding scenario



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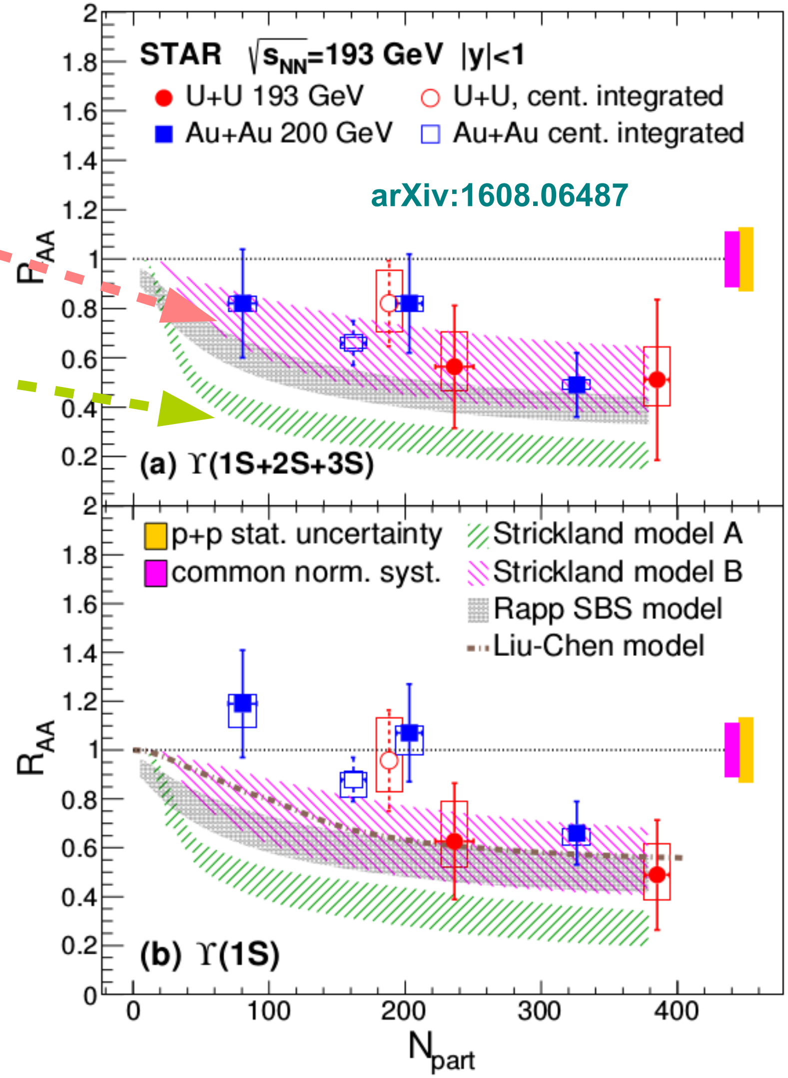

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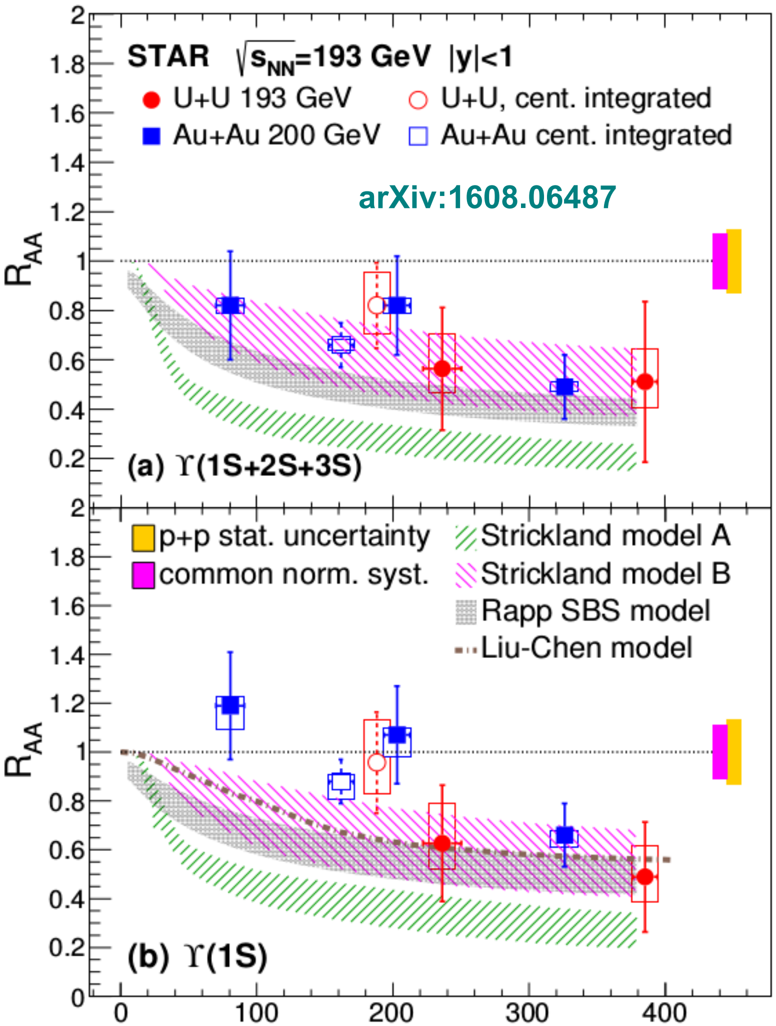
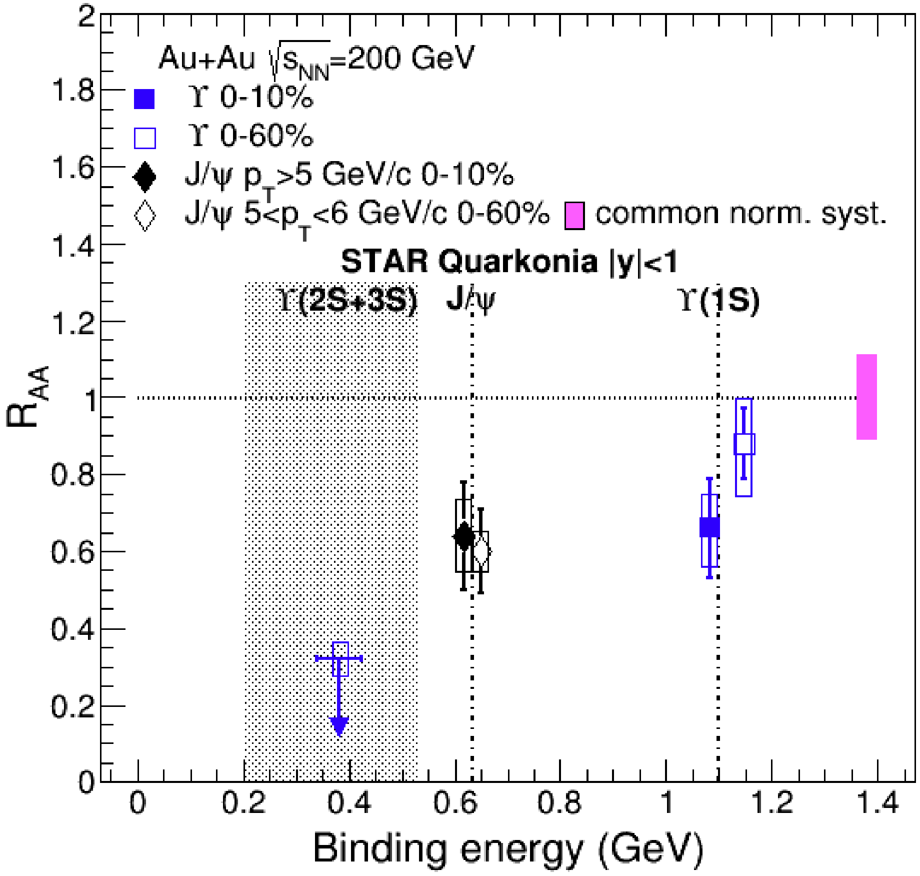


Suppression indicates Υ melting in a deconfined medium

<u>However</u>: CNM effects have to be understood! ***=> 2015 p+Au data***

Excited ϒ states in Au+Au and U+U

PLB 735 (2014) 127



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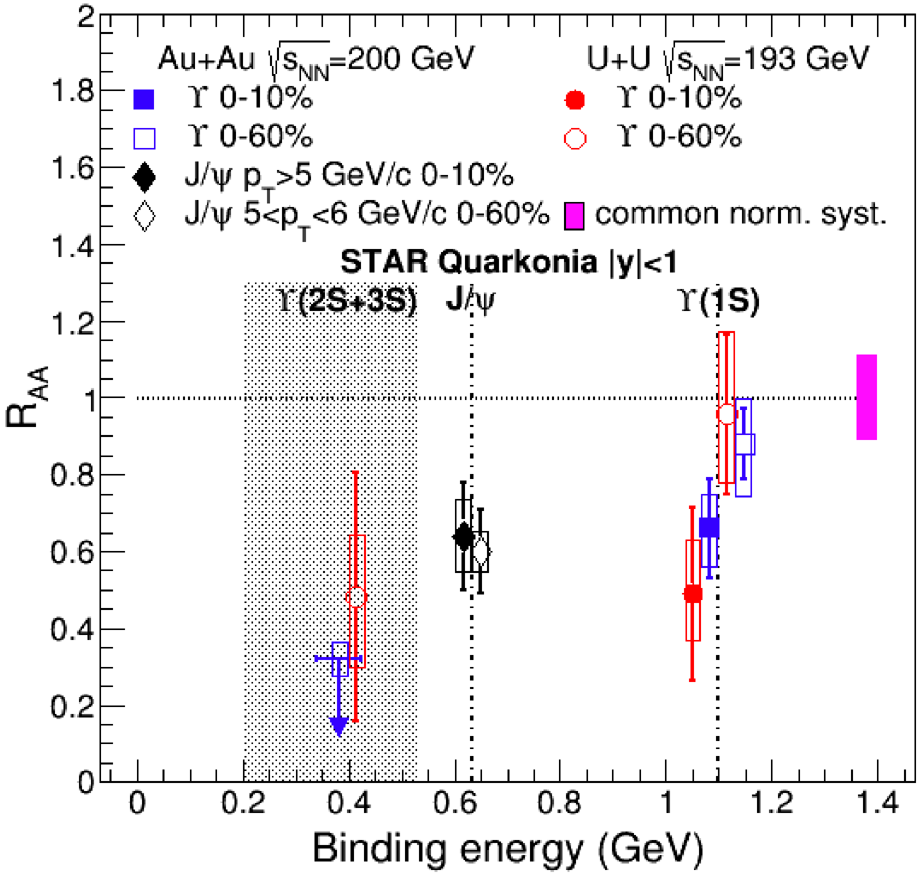
arXiv:1608.06487



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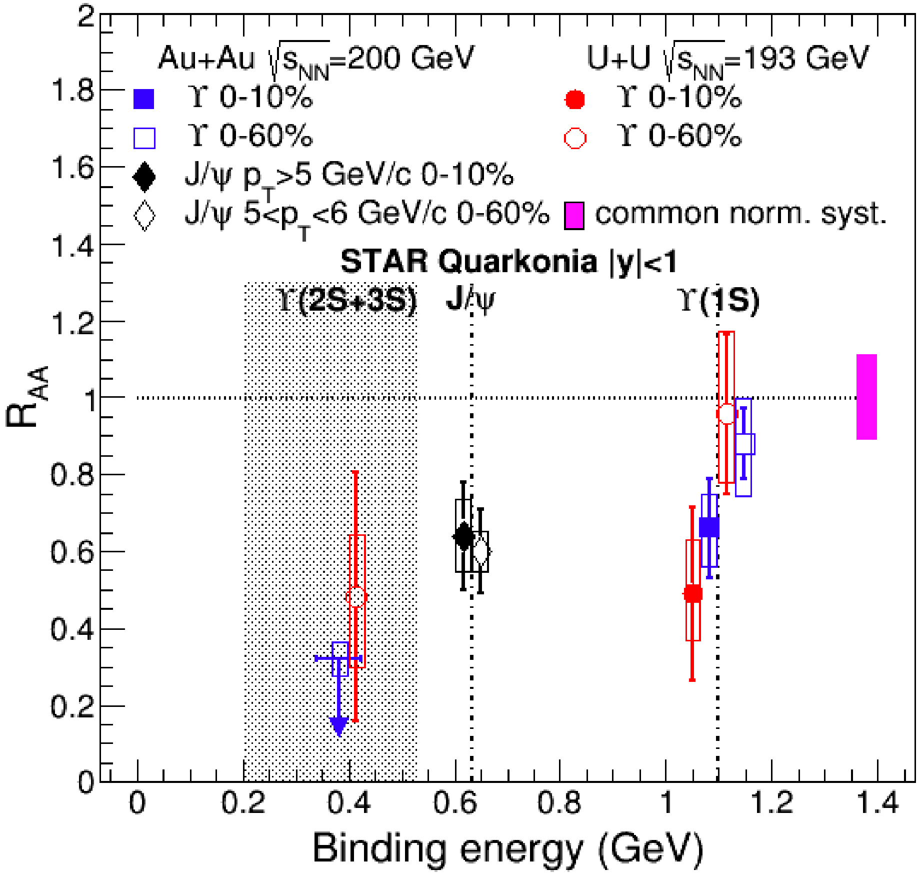

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ϒ suppression pattern supports sequential melting

RHIC vs. LHC: Sequential melting

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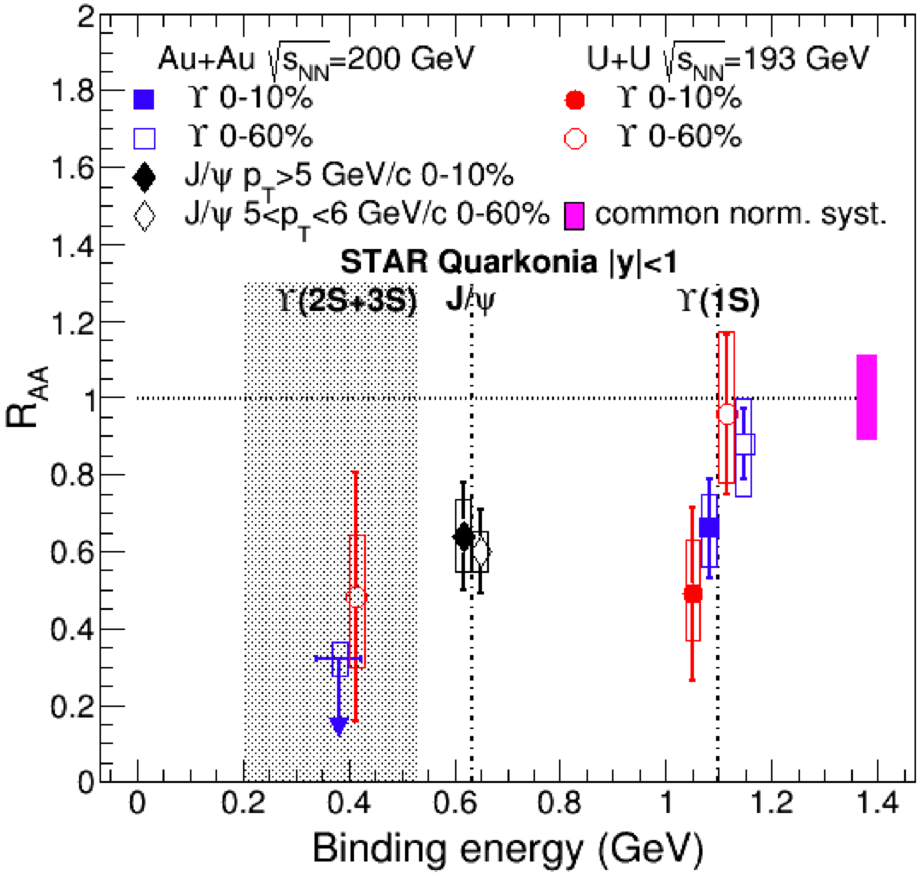
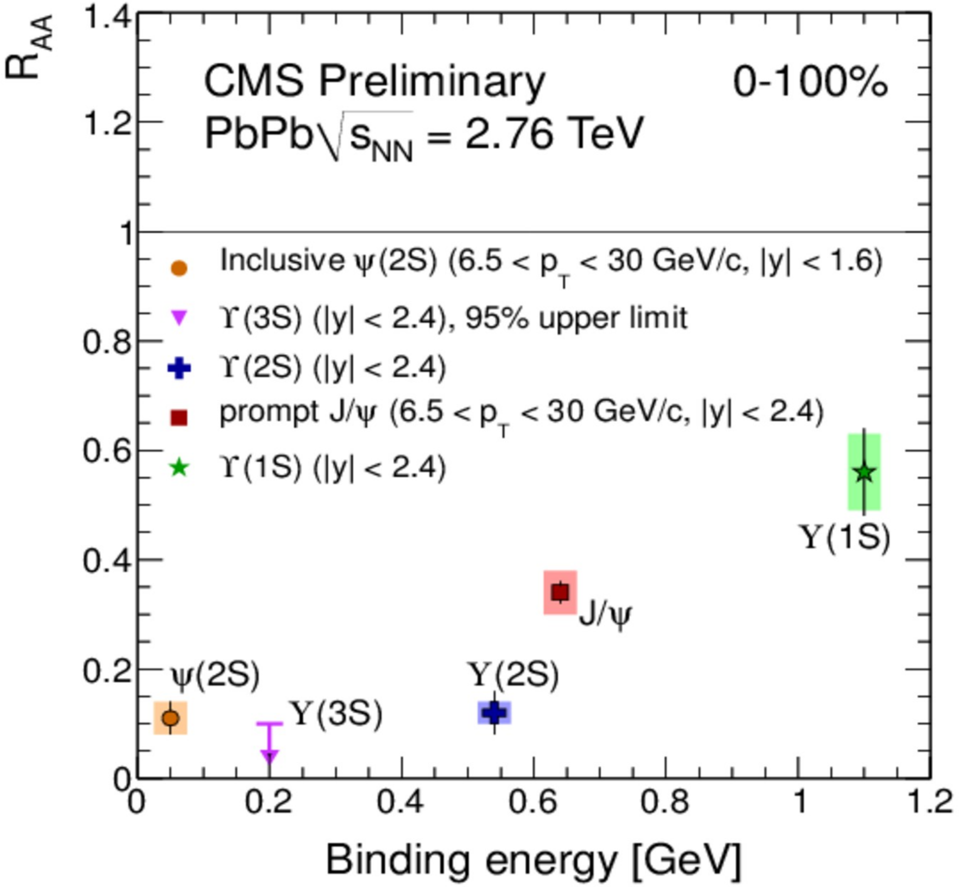
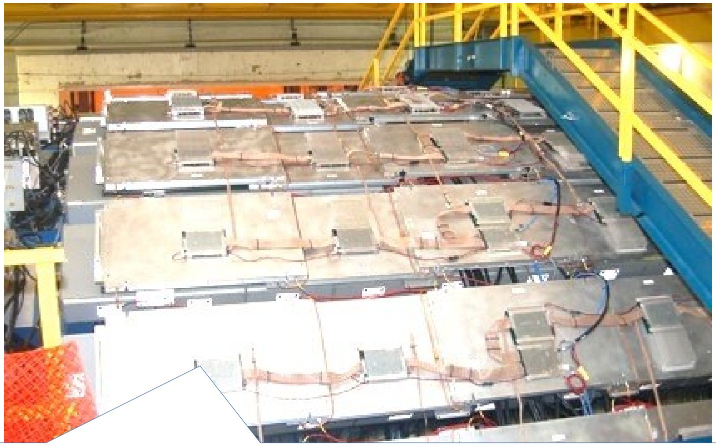


CMS HIN-12-014

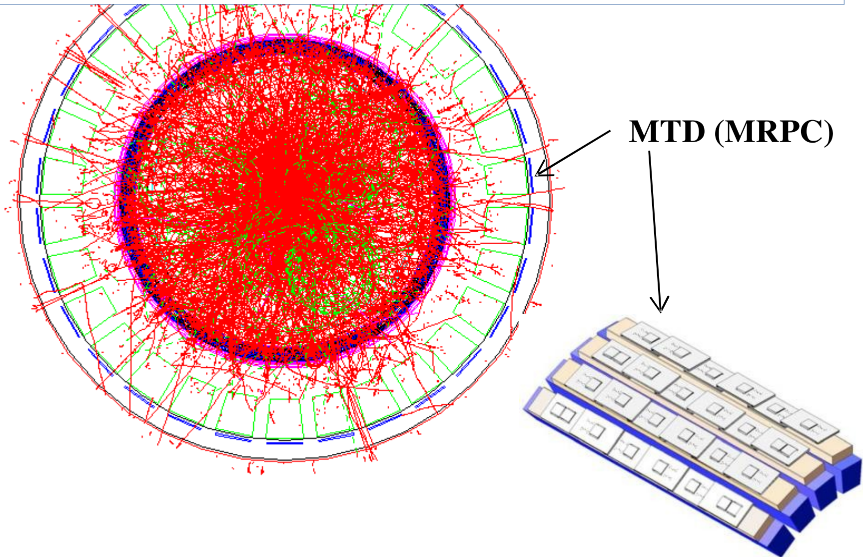


- Similar suppression of $\Upsilon(1S)$ at central events at RHIC $\sqrt{s_{NN}}$=200 GeV Au+Au and LHC $\sqrt{s_{NN}}$=2.76 TeV Pb+Pb collisions

$\Upsilon \rightarrow \mu^+\mu^-$ analysis with the MTD



MTD (from 2014): Outermost, gas detector
- Physics goal: **Precision measurement of heavy quarkonia through the muon channel**
- Acceptance: 45% in azimuth, |y|<0.5



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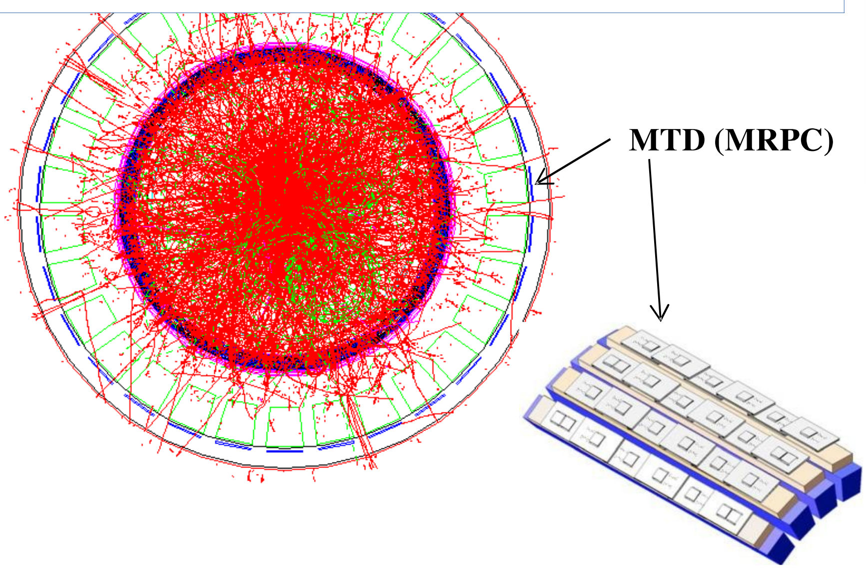
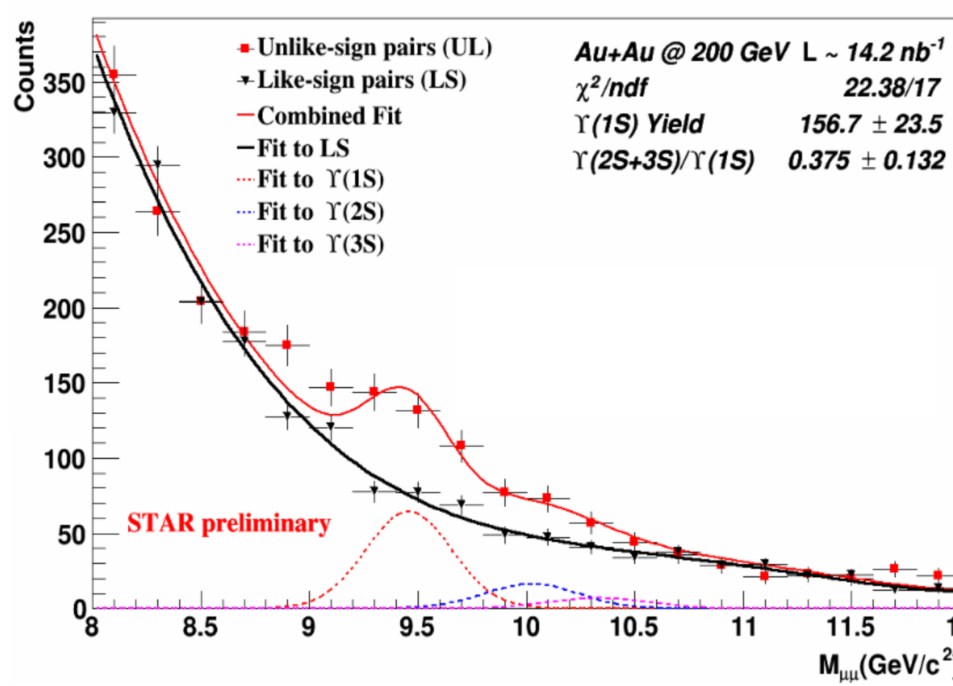
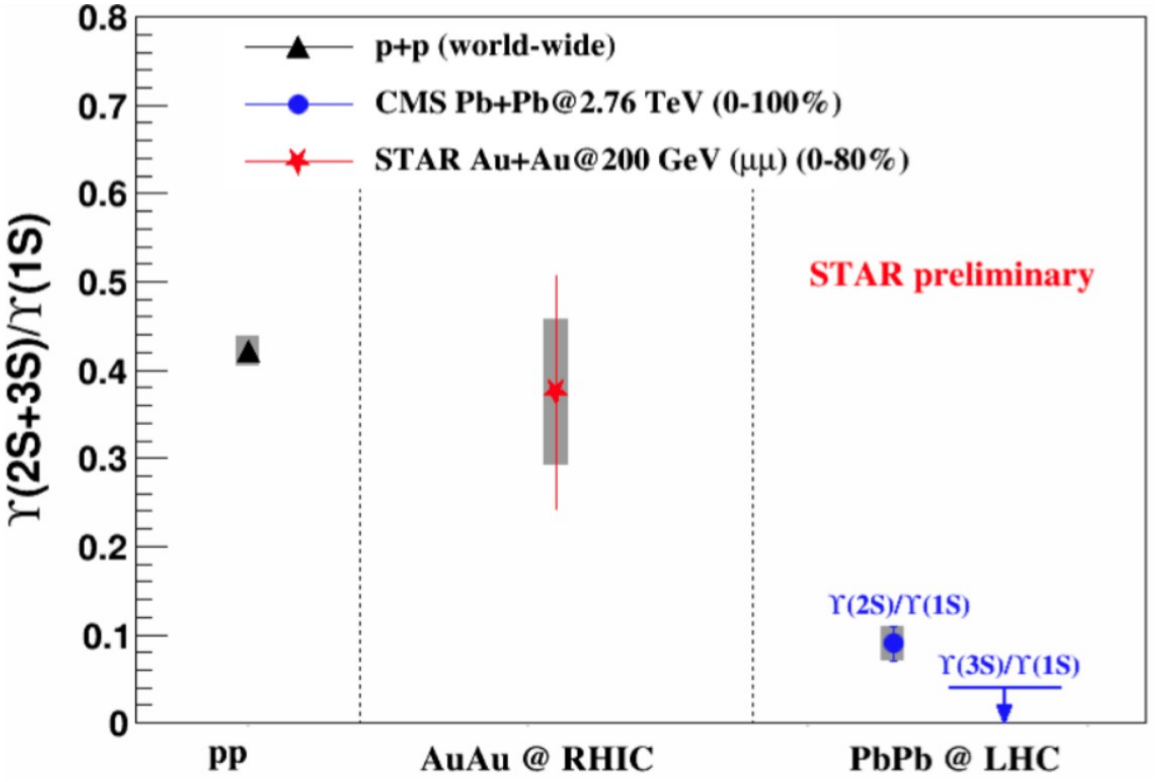


Reconstructed invariant mass (Au+Au 200 GeV)



- Separation of Υ(2S+3S) and Υ(1S)
  - Challenging in dielectron channel due to Bremsstrahlung
- Indication of an Υ(2S+3S) signal

Excited to ground state ratio



- 2014 Au+Au data from the dimuon channel
  - Compared to p+p (PDG) and LHC Pb+Pb

CMS: PRL 109 (2012) 222301, JHEP 04 (2014) 103

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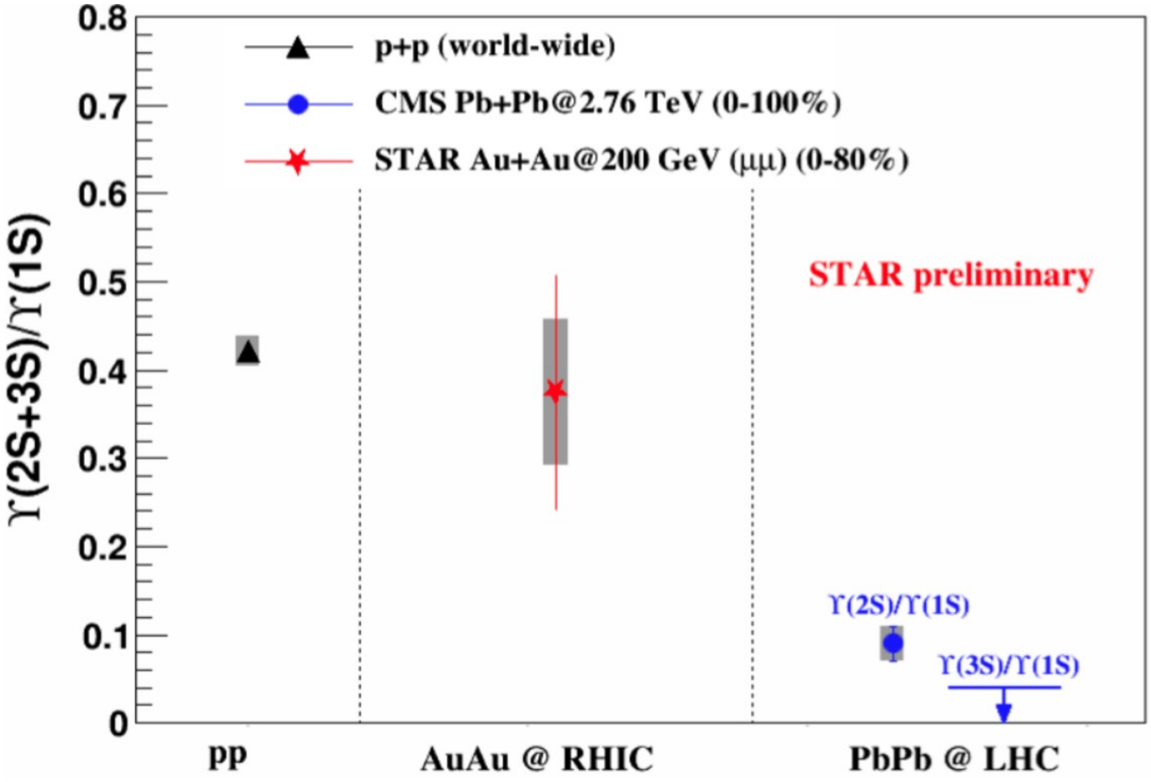

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Hint of less ϒ(2S+3S) dissociation at RHIC than at LHC

Summary

Significant suppression of Υ states in central A+A collisions

- Υ(1S) at RHIC is similarly suppressed as high-p_T J/ψ
- Υ(2S) and Υ(3S) suppression is stronger than Υ(1S)
  → *clear signal of melting in a deconfined medium*
- Υ suppression in most central collisions similar to LHC

U+U measurements: extend the Au+Au observations

- Similar patterns in Υ(1S) and Υ(1S+2S+3S)
- Suppression of central Υ(1S) confirmed

Au+Au measurements with MTD (preliminary)

- Indication of excited states in 0-80% centrality data
- Hint of less Υ(2S+3S) dissociation at RHIC than at LHC

Thank You!

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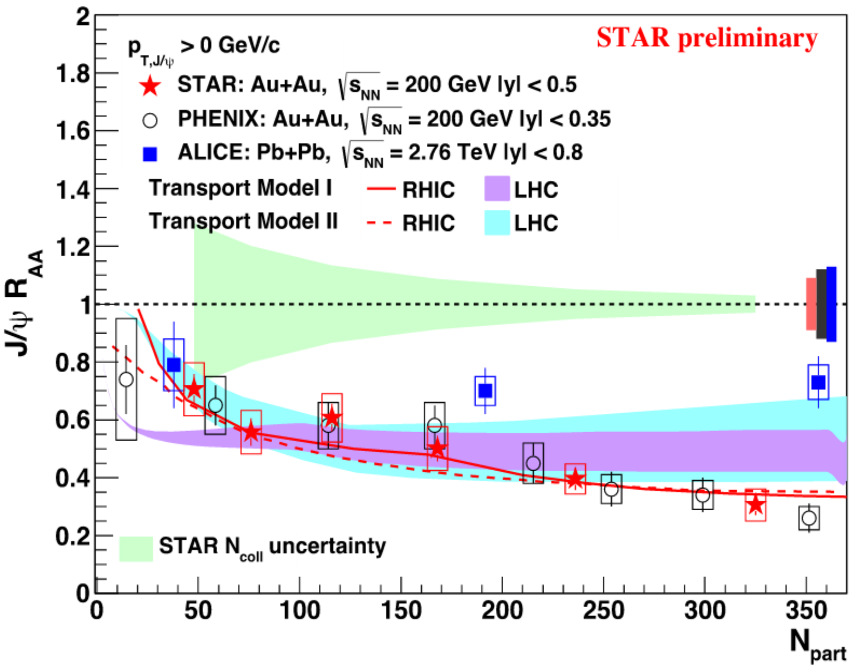
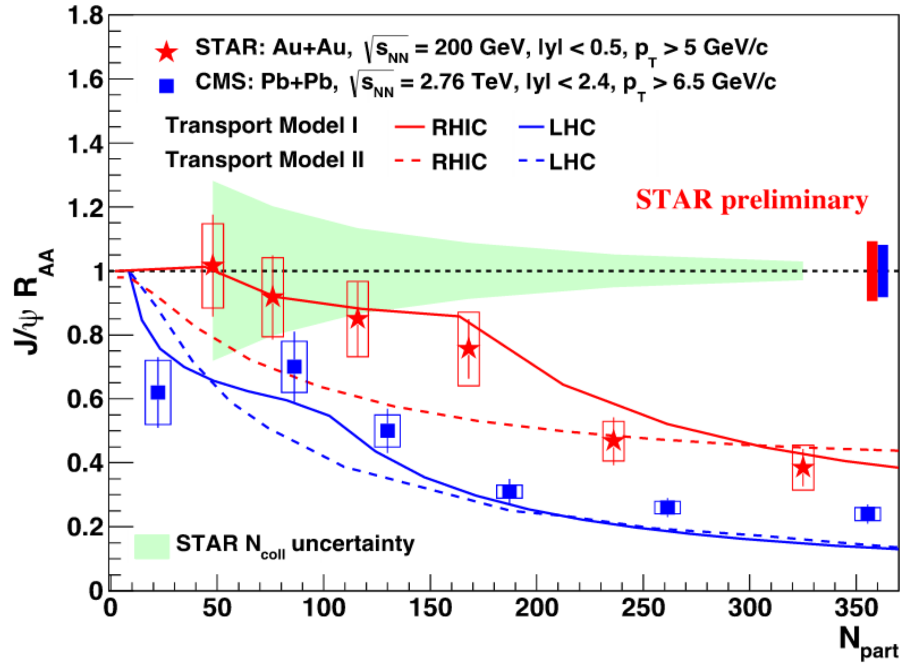
STAR Collaboration

J/ψ R_{AA} – data vs. models in details





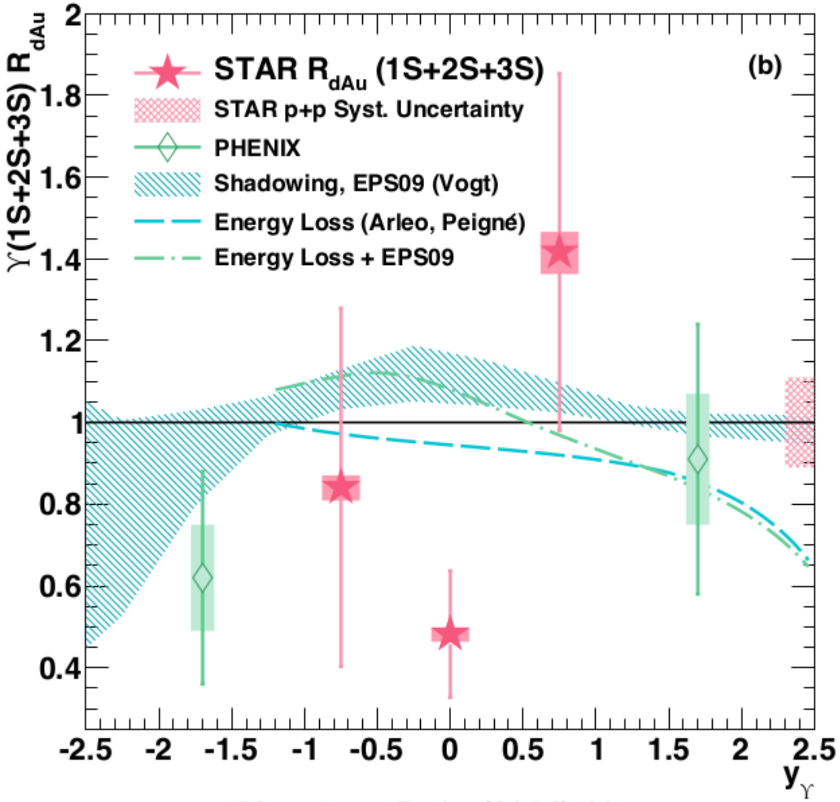
- J/ψ RAA for pT>0 GeV/c: RHIC is smaller than LHC
  -> more recombination at LHC
- J/ψ RAA for pT>5 GeV/c : LHC is smaller than RHIC
  -> stronger dissociation at LHC
- Transport models with dissociation and recombination qualitatively describe data

Data:
ALICE : PLB 734 (2014) 314
CMS: JHEP 05 (2012) 063
PHENIX: PRL 98 (2007) 232301

Transport models at RHIC
I: PLB 678 (2009) 72
II. PRC 82 (2010) 064905

Transport models at LHC
I: PRC 89 (2014) 054911
II. NPA 859 (2011) 114

Υ R_{dAu} – CNM effects



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R_{dAu} =0.48 ±0.14(stat) ±0.07(syst) ±0.02(pp stat) ±0.06(pp syst)
|y|<0.5

- Models include
  - Gluon nPDF (Anti)shadowing
  - Initial parton energy loss
- Indication of suppression at mid-rapidity beyond models

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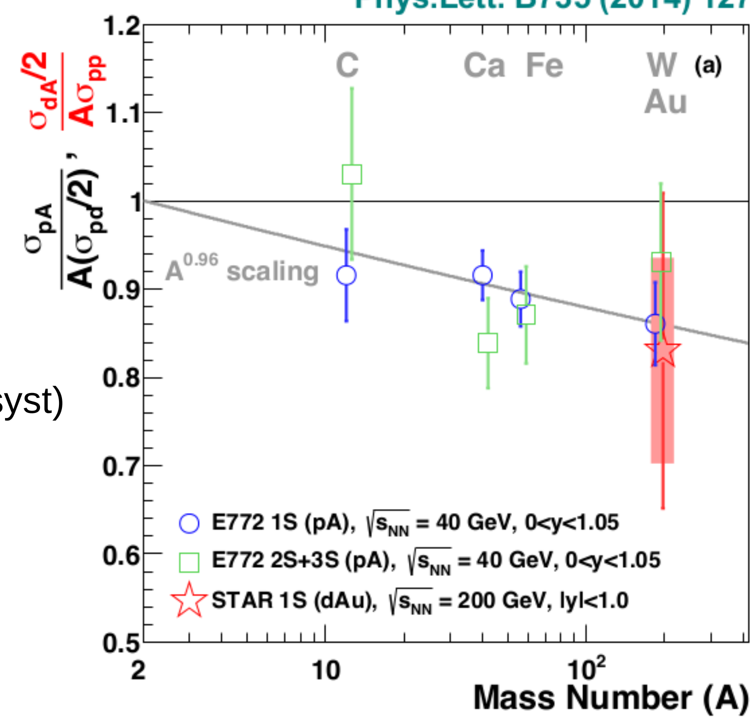
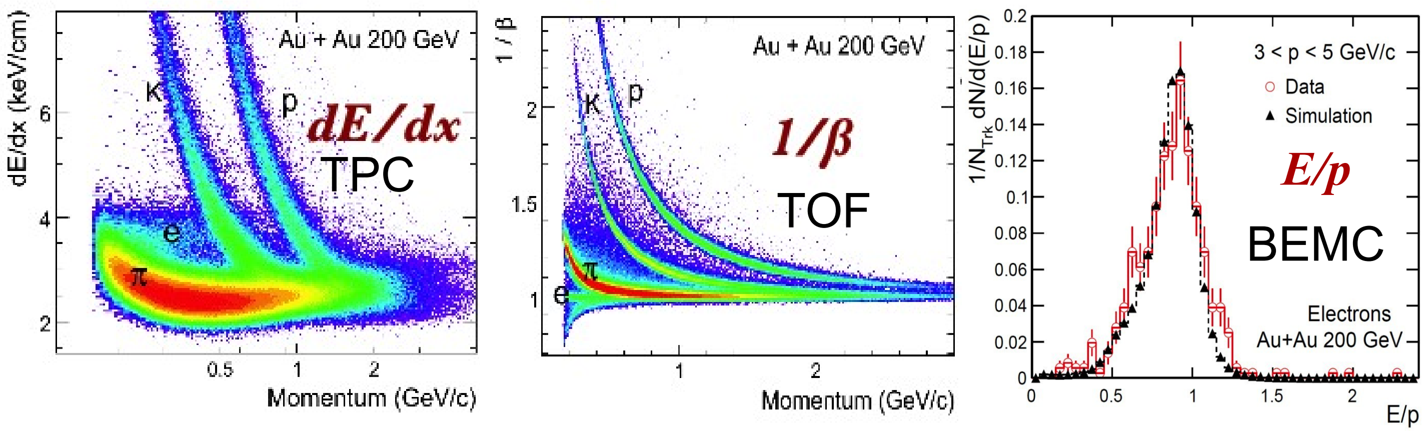


- STAR data consistent with E772

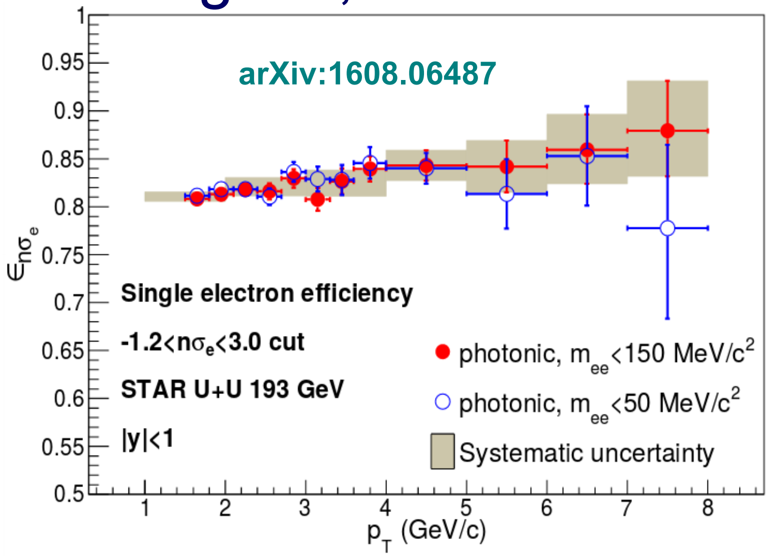
Analysis (BEMC)



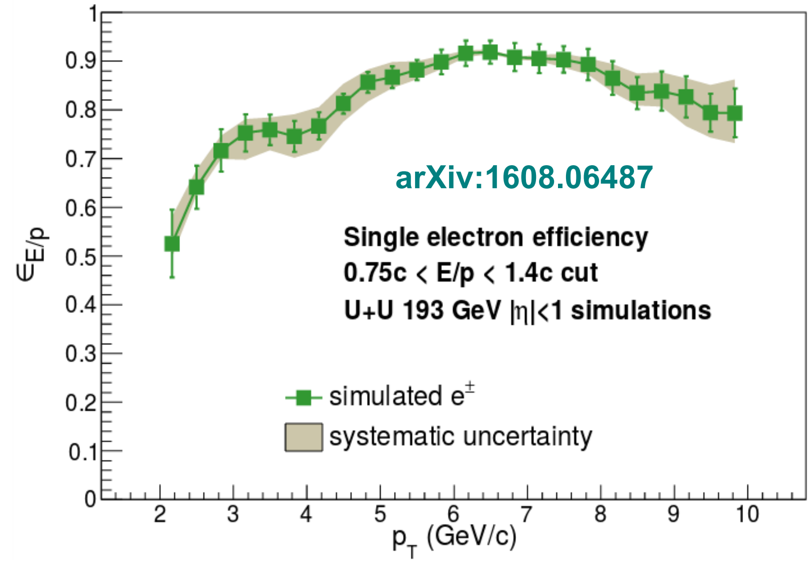
- **Trigger**
  - **L0**: ‘High tower trigger’ saves events with high energy hit in the Barrel Electromagnetic Calorimeter **(**BEMC) tower
- **Electron tracks**
  - Fractional energy loss dE/dx , $-1.2<n\sigma_e<3$
- **Matching and calorimeter ID**
  - Clusterize energy in the BEMC *(3 adjacent towers with most of the energy deposit)*
  - Project TPC tracks onto clusters to match them: $\Delta R_{match} = \sqrt{(\Delta\eta^2+\Delta\varphi^2)} < 0.04$
  - Cluster energy matches track momentum: $0.75<E/p<1.4$ *(U+U)*
  - Energy deposit is compact, mostly in a single tower:
    triggered $e^{\pm}$: $E_{tower}/E>0.7$, associated $e^{\pm}$: $E_{tower}/E>0.5$ *(U+U)*

Acceptance and efficiency, U+U

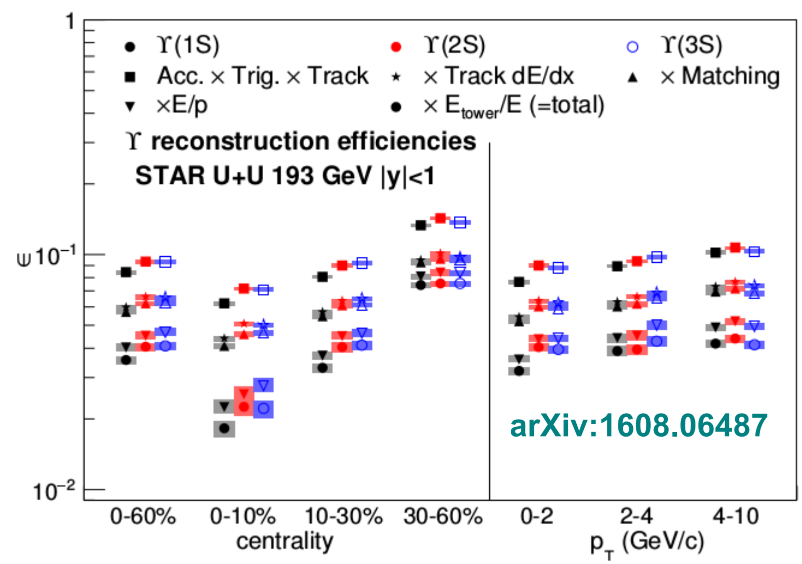
Single e, TPC selection



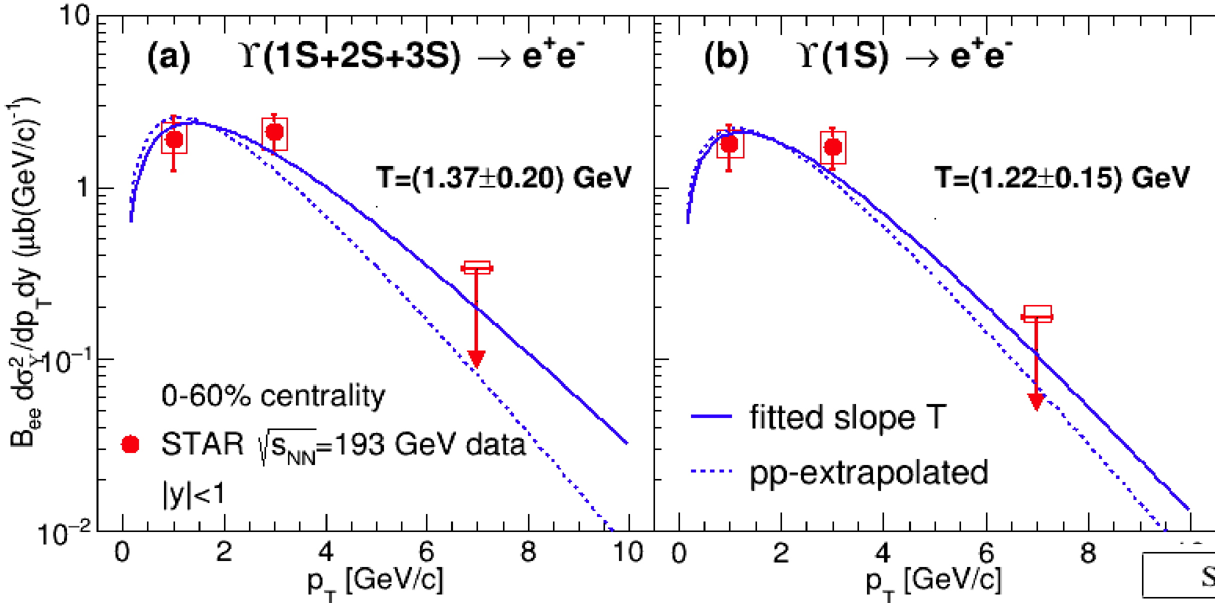
Single e, BEMC selection



- 15M high-tower-triggered U+U 193 GeV events (263 μb^{-1})
- Divided into 3 centrality bins
  0–10 %, 10–30 %, 30–60 %
- or… 3 bins in p_T^{Υ}:
  0–2 GeV/c, 2–4 GeV/c, 4–10 GeV/c
- Total acceptance & efficiency for $\Upsilon \to e^+e^-$ reconstruction: ~ 2-3%



Υ x-section and p_T-spectrum in U+U



Υ cross section

U+U 193 GeV, 0-60%

$$B_{ee} \times (d\sigma^{\Upsilon}_{AA}/dy) = 4.27 \pm 0.90^{+0.90}_{-0.82}$$

stat. syst

arXiv:1608.06487

Source of systematic uncertainty		value (%)
Number of binary collisions (R_{AA}-only)		2.2
Geometrical acceptance (yield-only)		$^{+1.7}_{-3.0}$
p_T and y distributions		2.1
Trigger efficiency		$^{+1.1}_{-3.6}$
Tracking efficiency		11.8
TPC dE/dx		$^{+4.0}_{-6.4}$
TPC–BEMC matching		5.4
BEMC $E_{cluster}/p$		$^{+8.8}_{-13.2}$
BEMC $E_{tower}/E_{cluster}$		2.0
Signal extraction	Υ(1S+2S+3S)	$^{+8.4}_{-7.0}$
	Υ(1S)	$^{+11.9}_{-5.7}$
	Υ(2S+3S)	$^{+5.3}_{-19.7}$

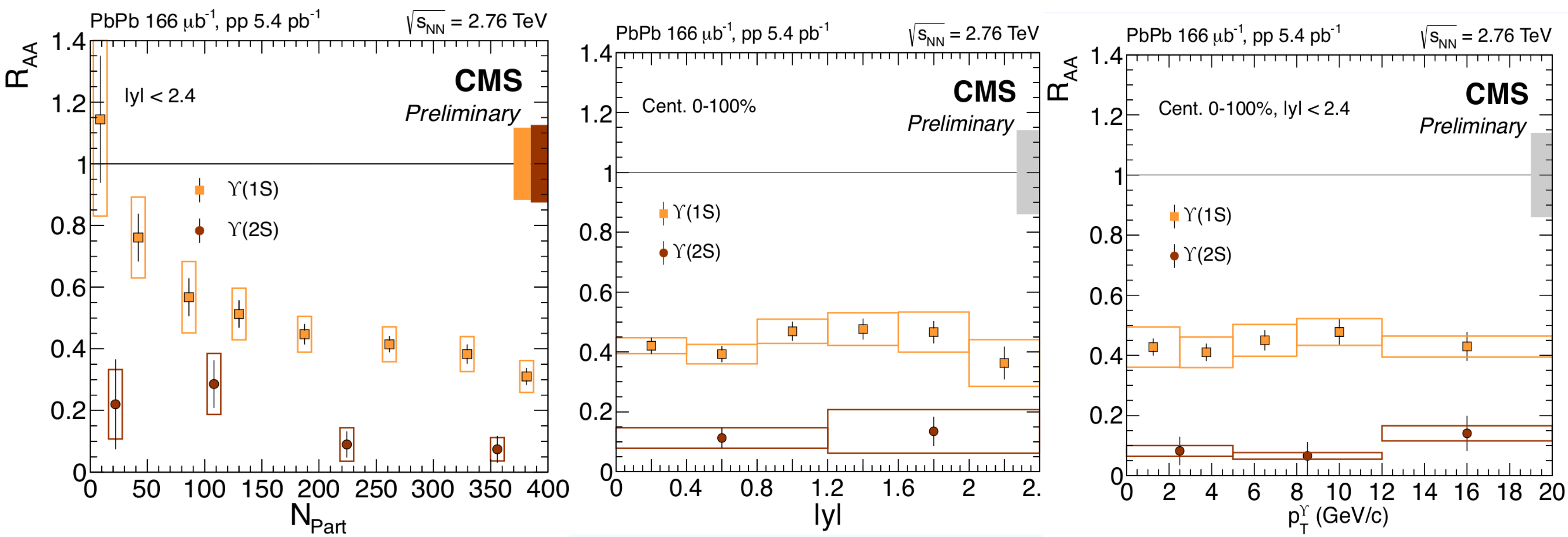
$$f(p_T) = \frac{p_T}{\exp(p_T/T+1)}$$

Expected T is extrapolated from ISR, CDF and CMS pp ($p\bar{p}$) results

PLB91, 481 (1980).
PRL88, 161802 (2002).
PRD83, 112004 (2011).

In addition: p+p reference syst.

CMS Υ R_{AA} (Run2 preliminary)



- Improvements since Run1
  - pp reference x 20
  - Bigger, more precise PbPb sample
  - Reduced stat. uncertainties
- **$R_{AA}(y)$ and $R_{AA}(p_T)$: The suppression is constant** over the analysis range

Rapp WBS & SBS

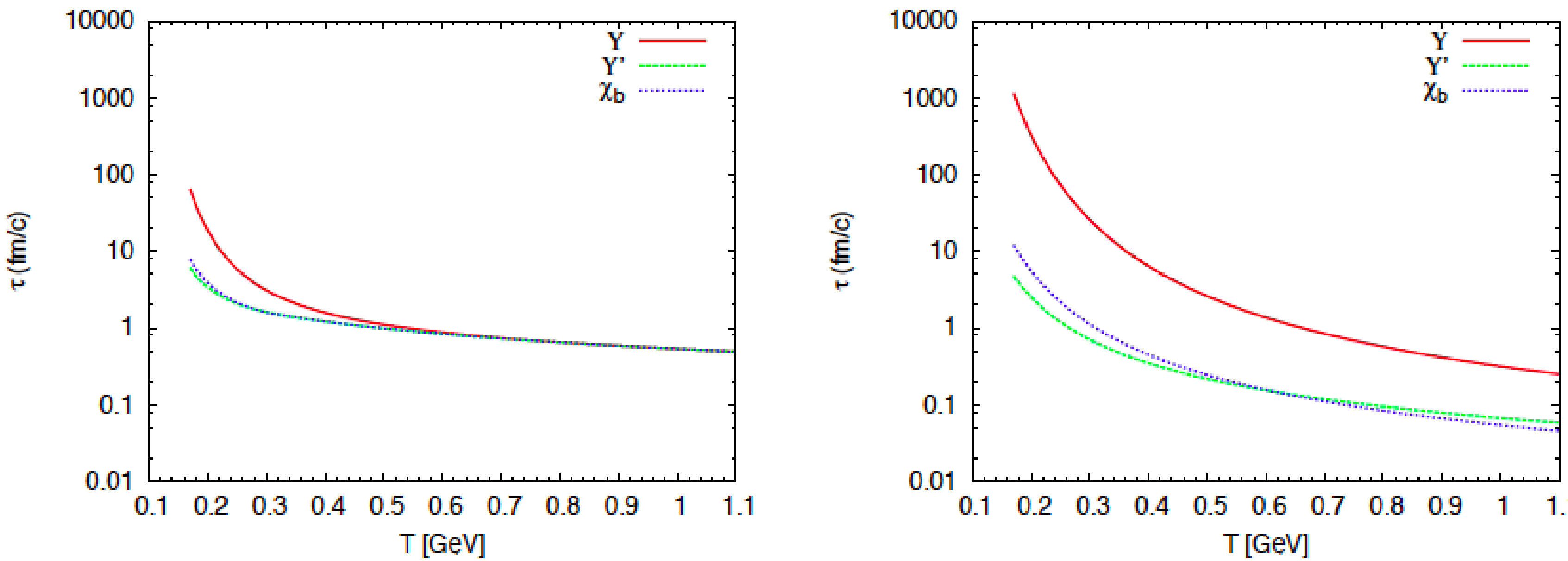


FIG. 2: Bottomonium lifetimes in the QGP for the two binding scenarios defined in the text; left panel: WBS with quasifree dissociation; right: SBS with gluo-dissociation; solid lines: Υ, dashed lines: Υ', dotted lines: χ_b.

Emerick, Zhao, Rapp, Eur. Phys. J A48, 72 (2012)