Quarkonia in STAR

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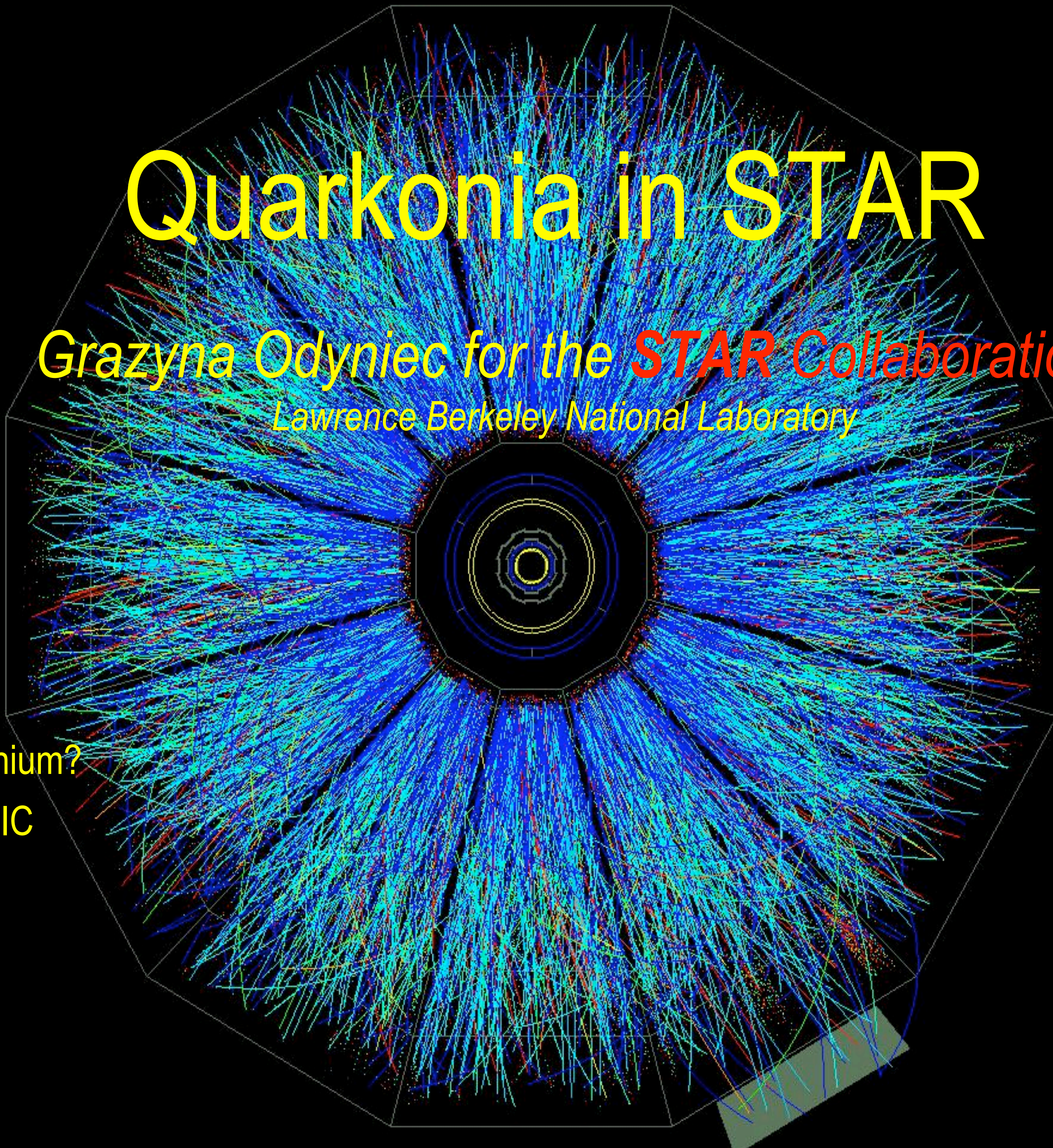


Outline :

Why quarkonium?

STAR @ RHIC

J/ψ results

ϒ results

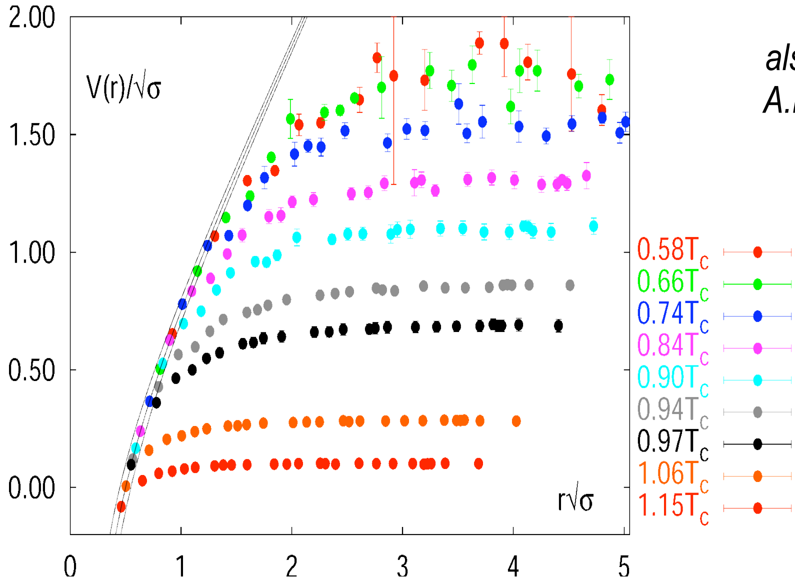
outlook

Why quarkonia ?

Classic signature of quark-gluon plasma formation:
charm & bottom quarks produced in the initial hard parton-parton scattering (large mass) at RHIC
➔ present through evolution of collision ➔ excellent tool to study properties of QGP

signature of deconfinement : suppression of J/ψ due to the screening of the binding potential between c and c-bar quarks in QGP

T.Matsui, H.Satz, Phys.Lett. B 178, 416 (1986)

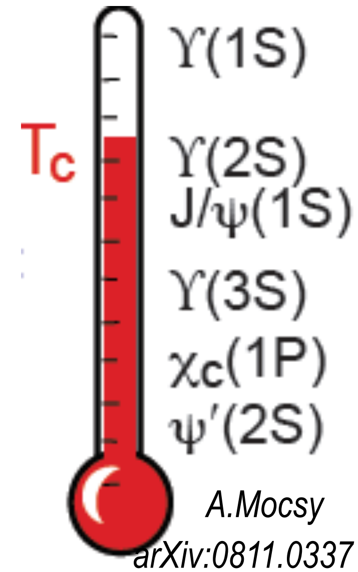


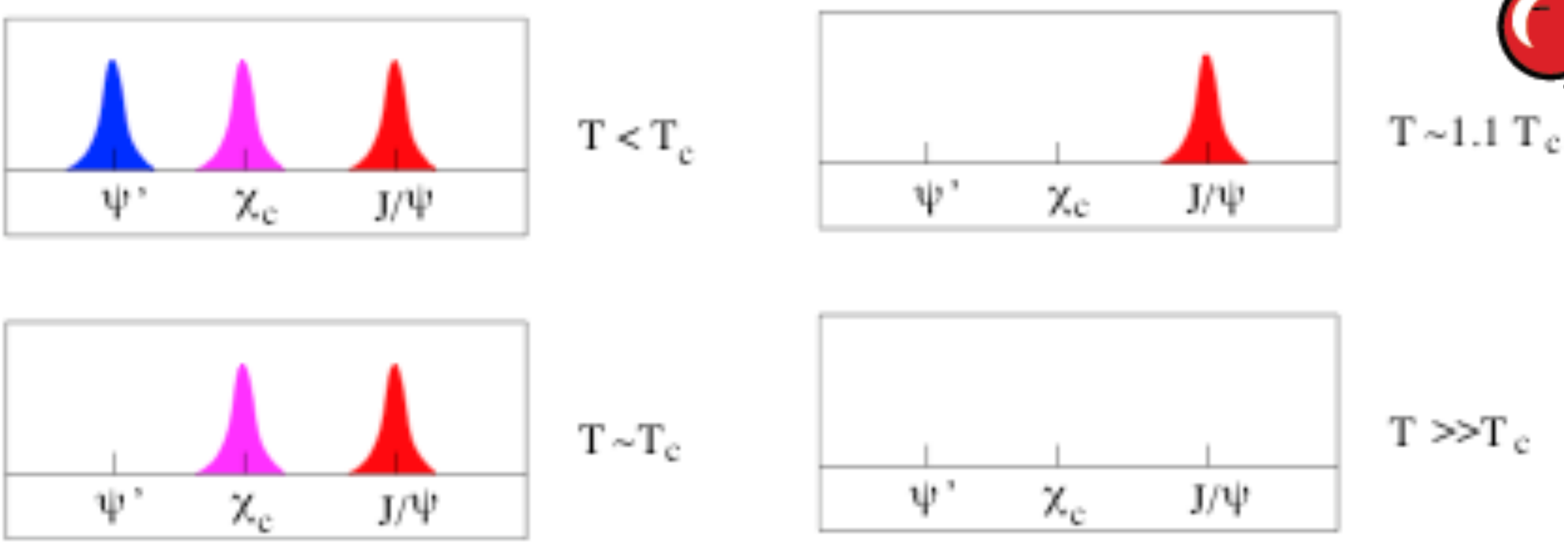
also recent lattice calculations:
A.Mocsy and P.Petreczky, Phys.Rev.Lett.99, 211602 (2007), arXiv:0706.2183,
Phys.Rev.D 77,014501 (2008), arXiv:0705.2559

Quarkonia: - QGP Thermometer

With increasing temperature the different quarkonium states "melt" sequentially as a function of their binding strength: the most loosely bound state disappears first, the ground state last

Suppression of states is determined by T_c and their binding energy





Dissociation points of the different quarkonium states provide a way to measure the temperature of the medium

J/ψ suppression at SPS ~ J/ψ suppression at RHIC

a new mechanism at RHIC ?

suppression vs. regeneration *P. Braun-Munzinger and J. Stachel, Phys. Lett. B490,196 (2000); L. Grandchamp and R. Rapp, Phys. Lett. B523, 60 (2001); M. I. Gorenstein et al., Phys. Lett. B524, 265 (2002); R. L. Thews, M. Schroedter, and J. Rafelski, Phys. Rev. C63, 054905 (2001); Yan, Zhang and Xu, Phys.Rev.Lett.97, 232301 (2006);*

sequential melting of charmonia states *F. Karsch, D. Kharzeev and H. Satz, PLB 637, 75 (2006); B. Alessandro et al. (NA50), Eur. Phys. J. C 39 (2005) 335; H. Satz, Nucl. Phys. A (783):249-260(2007)*

Need to understand: fraction of direct production

decay feed-down from B and χ_c states

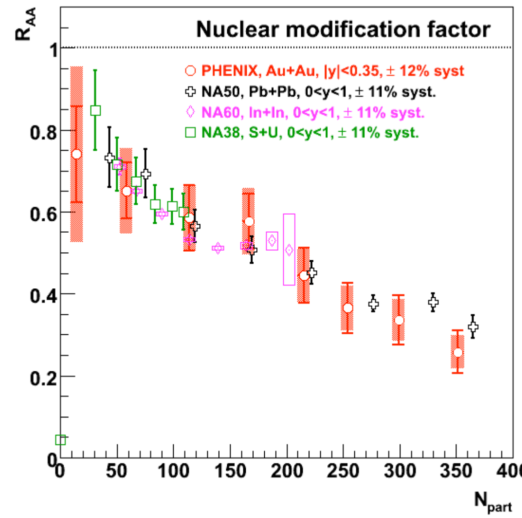
gluon and heavy quark fragmentation

color screening

recombination

comover and cold matter effects

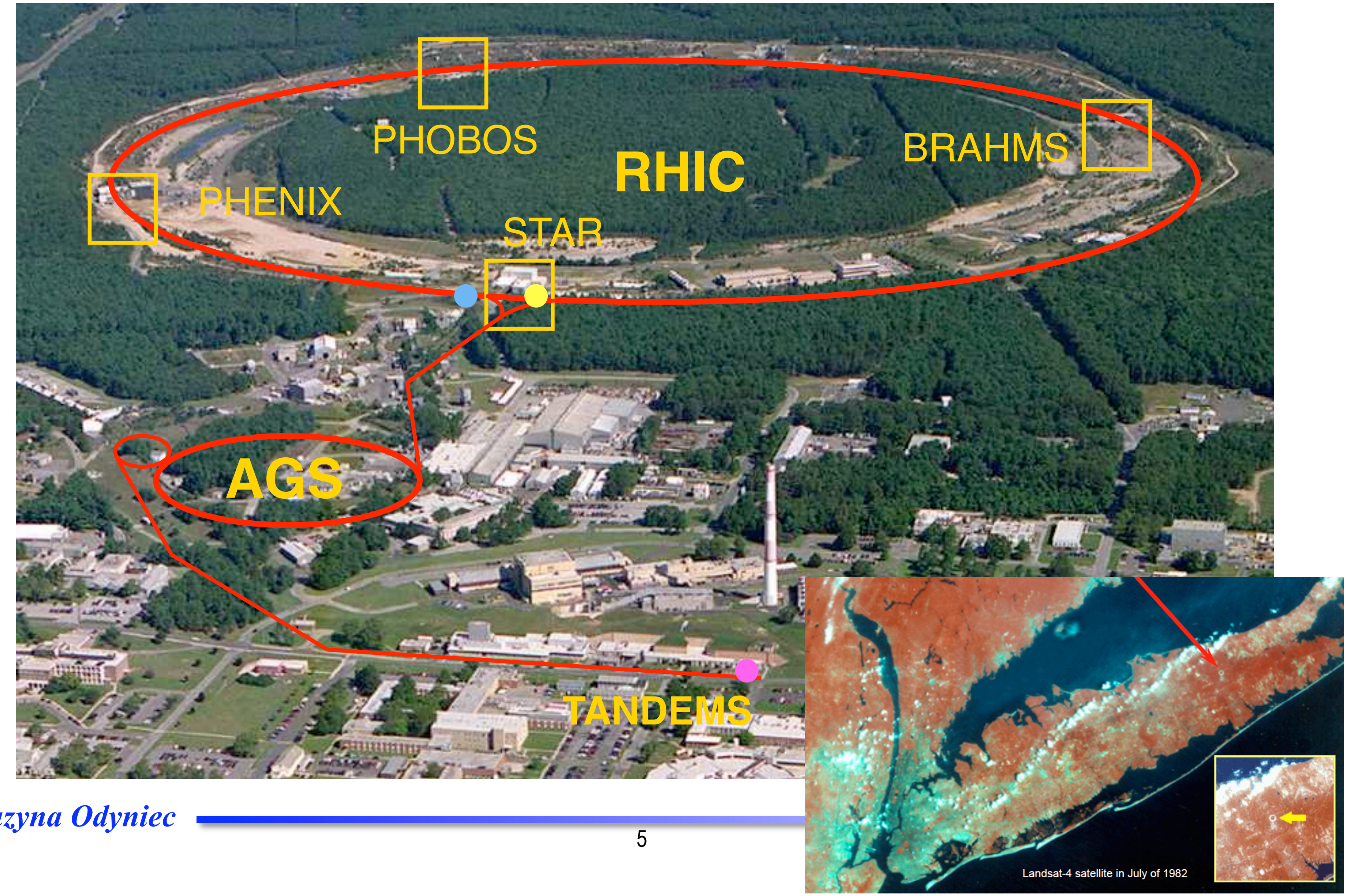
energy loss …



Production of quarkonia is complex and there is no convincing model, so far, even for p+p ➔ need detailed study (p+p, p+A, A+A)

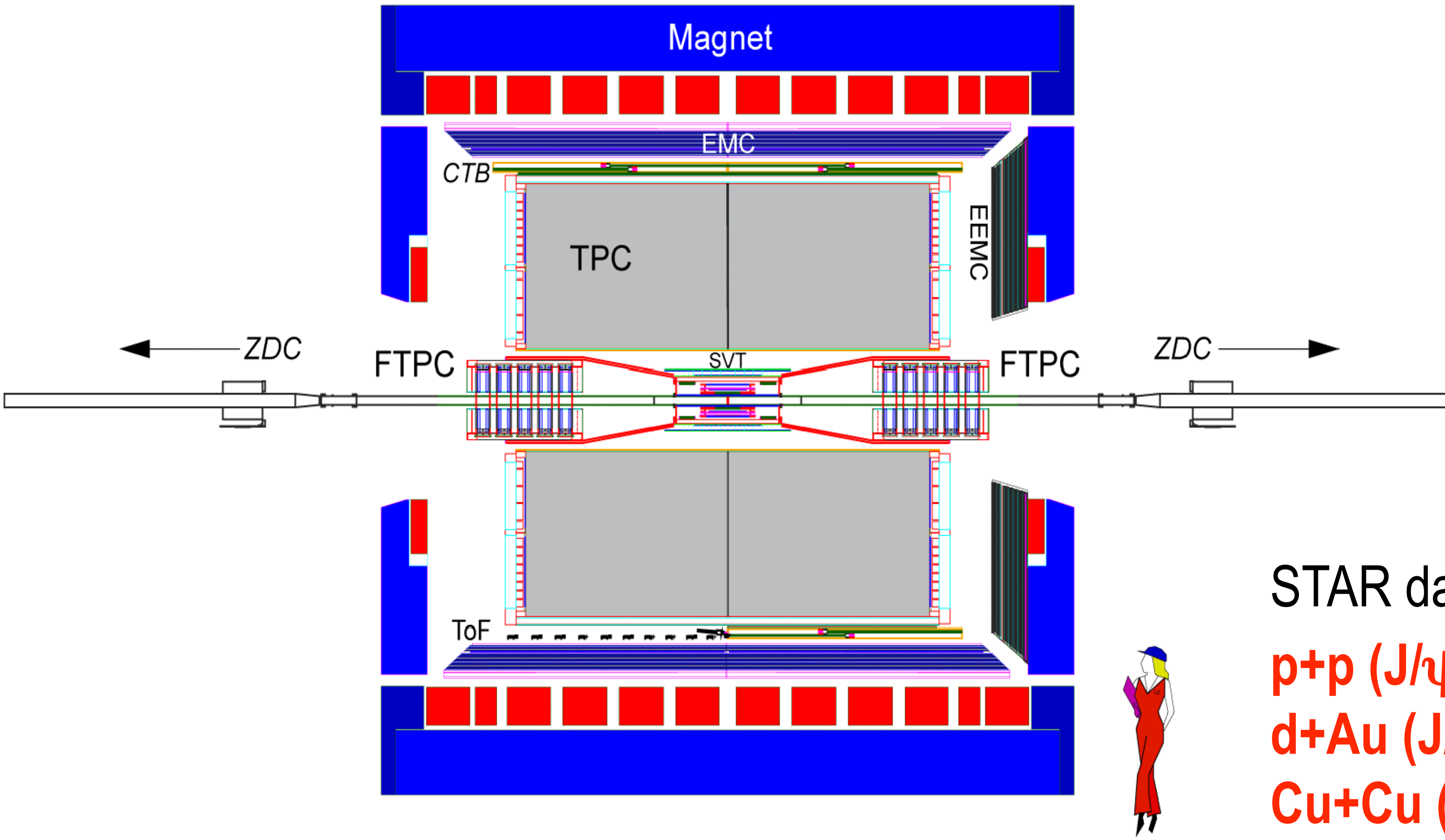
Relativistic Heavy Ion Collider (RHIC)

Brookhaven National Laboratory (BNL), Upton, NY



STAR Detector

Large acceptance: full 2π coverage at mid-rapidity



STAR data :

p+p (J/ψ, Υ)

d+Au (J/ψ, Υ)

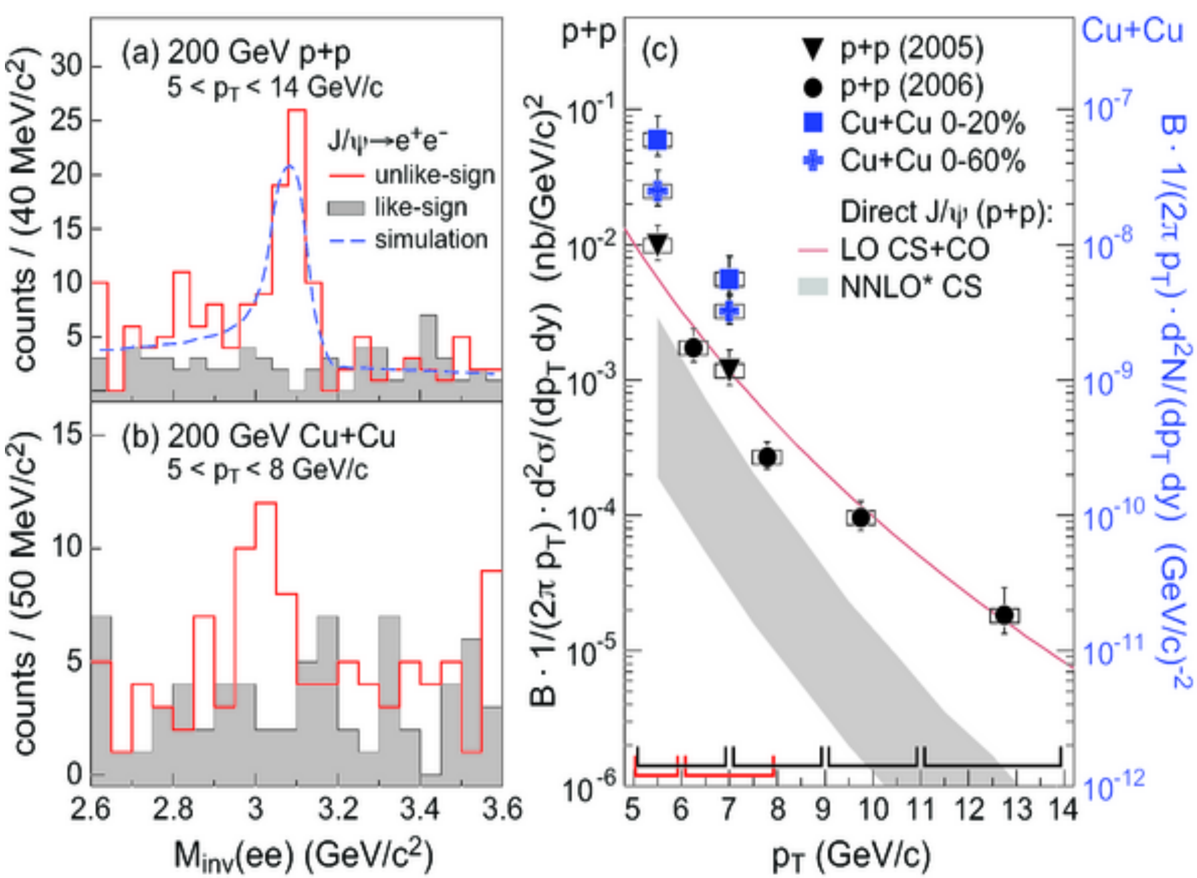
Cu+Cu (J/ψ)

Au+Au (J/ψ, Υ)

J/ψ (p_t>5 GeV) in p+p and Cu+Cu at 200 GeV

Phys.Rev.C80:041902,2009 (STAR)

J/ψ -> e+e- (5.9 %)



NRQCD (LO CO+CS) – describes data well, but no room for feed down from ψ', χ_c, B

G. C. Nayak, M. X. Liu, and F. Cooper, Phys. Rev. D68, 034003 (2003), and private communication

NNLO CS predicts a steeper p_t dependence

P. Artoisenet et al., Phys. Rev. Lett. 101, 152001 (2008), and J.P. Lansberg private communication

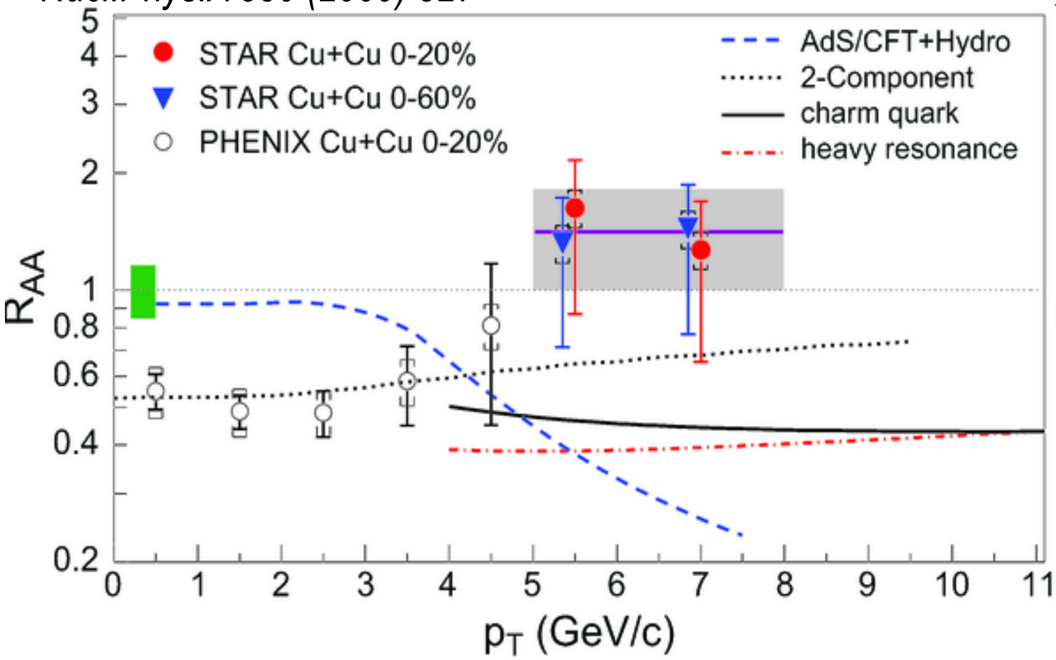
No feed down included in models (estimated to be a factor of ~1.5)

Can we constraint the B feed-down though other observables ?

$$R_{AA}(p_T) = \frac{d^2N^{AA}/dp_T d\eta}{T_{AA} d^2\sigma^{NN}/dp_T d\eta}$$

Nuclear modification factor R_{AA}^{Cu+Cu} at high-$p_\perp$

Nucl.Phys.A 830 (2009) 327



R_{AA}^{Cu+Cu} is rising towards unity for > 5 GeV (but uncertainty !)

- no suppression at high $p_\perp$

$R_{AA}(p_\perp > 5\ GeV/c) = 1.4 \pm 0.4 \pm 0.2$

J/ψ is the only hadron measured in RHIC HI collisions that does not exhibit significant $p_\perp$ suppression

In contrast to strong suppression of open charm *B.Abedev et al.,Phys.Rev.Lett. 98 (2007), 192301, S.Adler et al., Phys.Rev.Lett. 96(2006) 032301.*

Two Component Model (including: color screening, stat.coalescence, B feed-down,formation time) describes data *X. Zhao and R. Rapp (2007), arXiv:0712.2407; Y.P. Liu, et al., Phys.Lett.B678:72-76,2009*

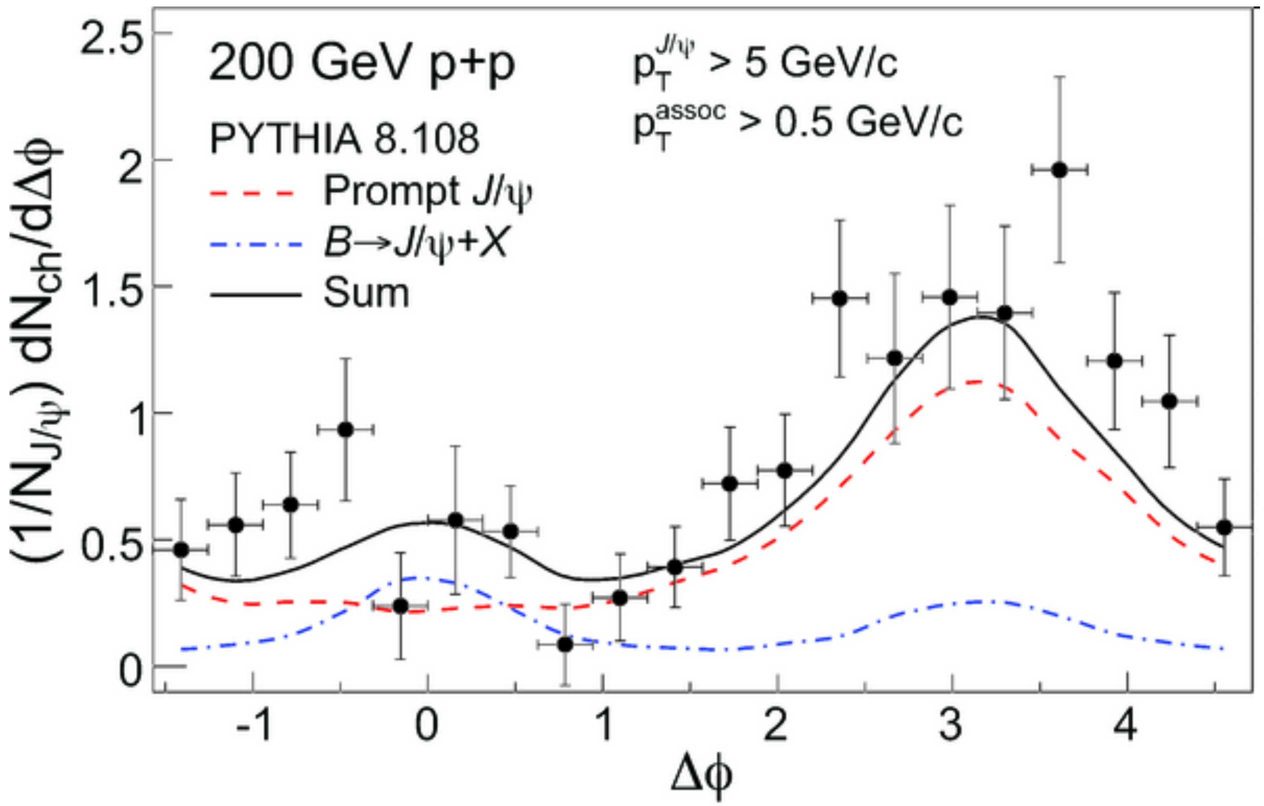
Contradicts AdS/CFT+ Hydro prediction (99% C.L.)

H. Liu, K. Rajagopal and U.A. Wiedemann PRL 98, 182301(2007); T. Gunji, J. Phys.G 35, 104137 (2008)

Constraining bottom yields

J/ψ-h azimuthal correlation

Phys.Rev.C80:041902,2009 (STAR), arXiv:0904.0439 (STAR)



pQCD predicts significant B -> J/ψ

correlation shows a <u>low B contribution </u>(13 +/- 5)% at p_t > 5 GeV

can be used to further constrain B yields

Understanding J/ψ production mechanism

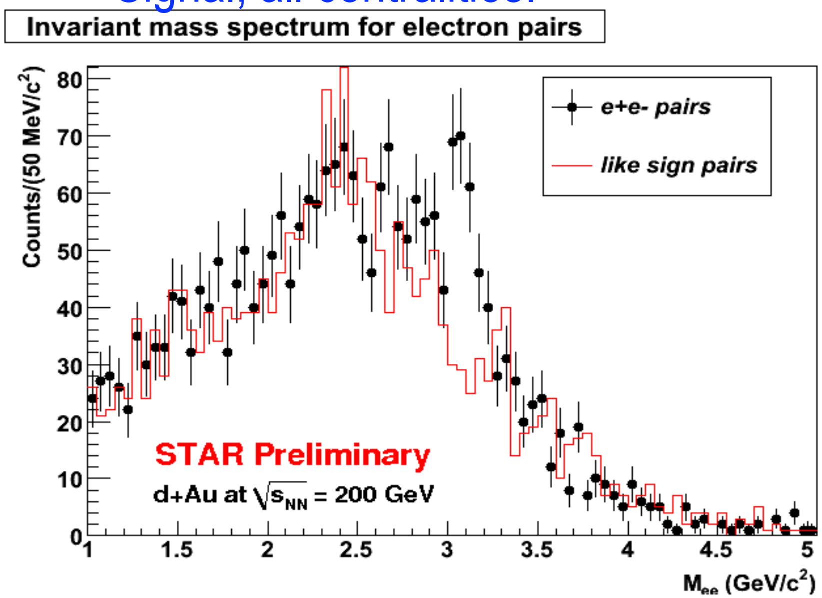
- p+p baseline

  currently all models have difficulty simultaneously reproducing quarkonia cross section, pt and polarization

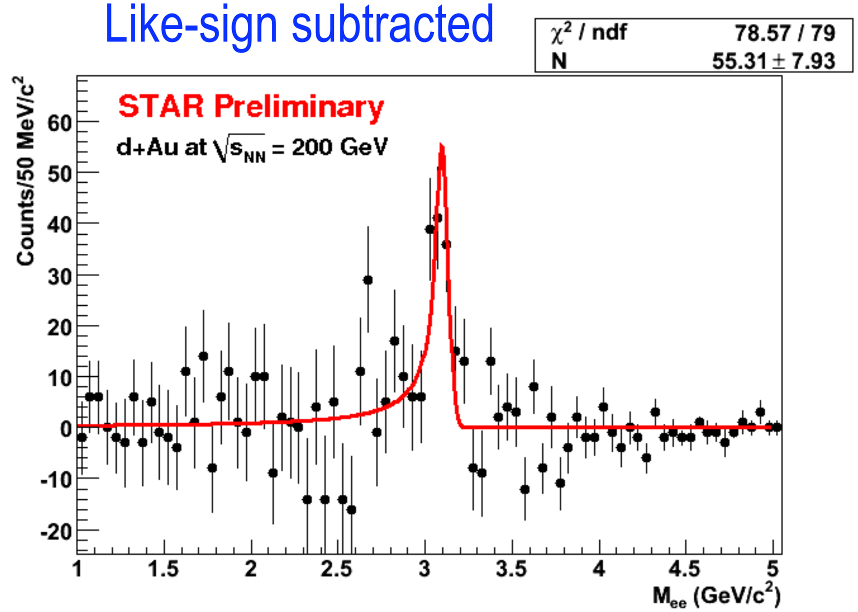
- d+Au important (cold nuclear matter effects)
  - initial state energy loss
  - gluon shadowing
  - Cronin effect
  - nuclear absorption

Low-p_t J/ψ in d+Au, Run 8 (no inner silicon detector)

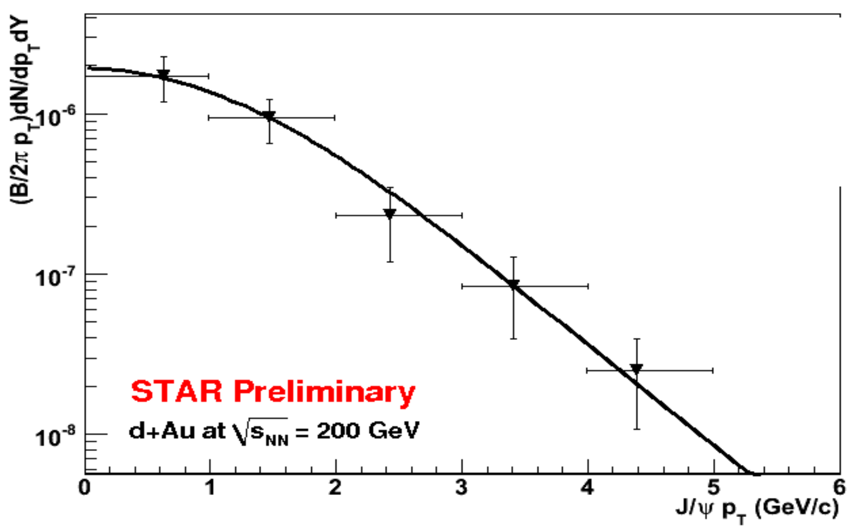
Signal, all centralities.



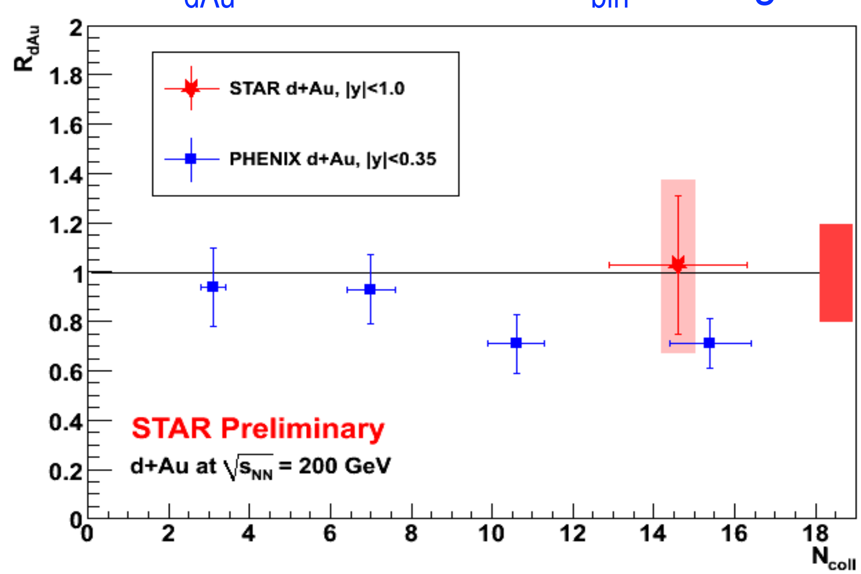
Like-sign subtracted



Corrected, 0-20% most central



R_{dAu}: consistent with N_{bin} scaling



Bottomonia

More of the same ?

NO !

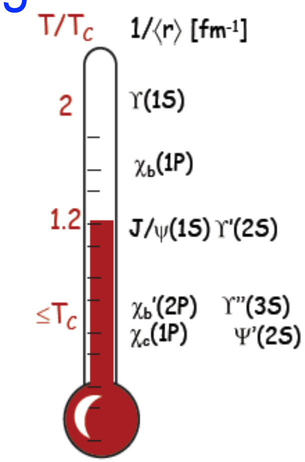
Υ is a much <u>cleaner</u> probe of high-temperature color screening

⟶ sequential disappearance of states (QCD thermometer):

at 200 GeV : Υ(1S) does not melt

Υ(2S) is likely to melt

Υ(3S) will melt *A.Mocsy, P.Petraczky PRD 77 014501 (2008)*



Co-mover absorption is very small *Phys.Lett.B 503, 104 (2001)*

Less problems with feed-down (compare to J/ψ)

Recombination negligible at RHIC *Phys.Rev.Lett. 95, 122001 (2005)*

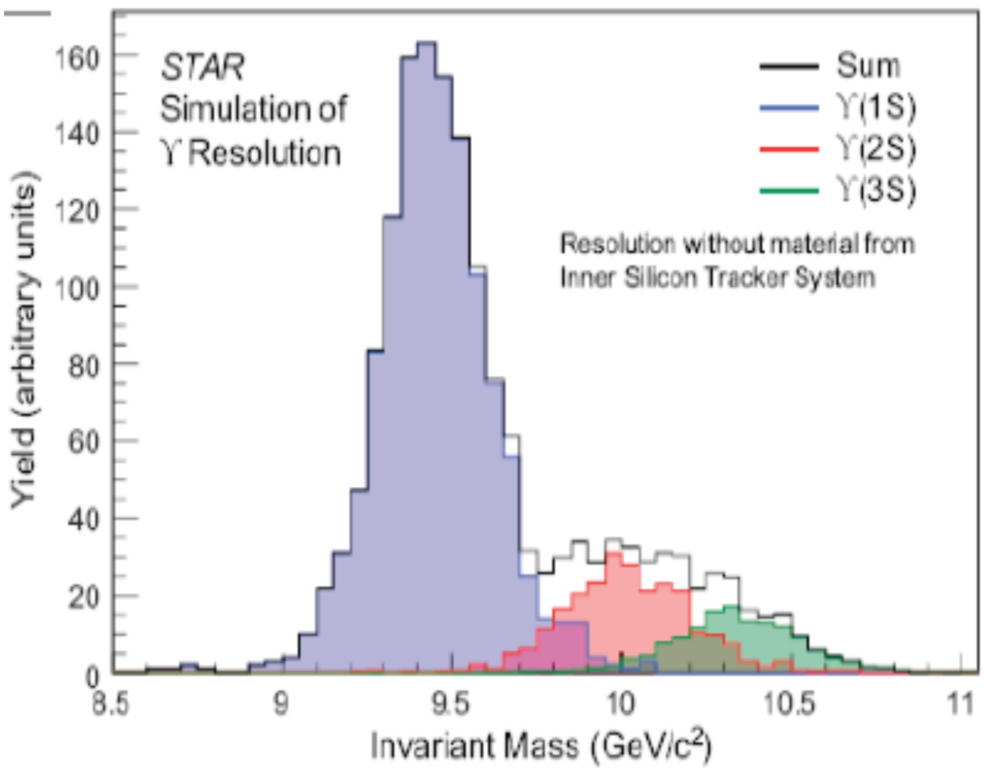
(… and it will complicate the picture at LHC)

ϒ (1S+2S+3S)

Branching fractions for $\Upsilon(nS) \rightarrow e^+e^-$ Phys. Lett. B 667, 1 (2008)

ϒ state	$\mathcal{B}$ (%)	σ (nb)
ϒ(1S)	2.38±0.11	6.60
ϒ(2S)	1.91±0.16	2.18
ϒ(3S)	2.18±0.21	1.32

Phys.Rep. 462, 125 (2008)



extremely low rate:

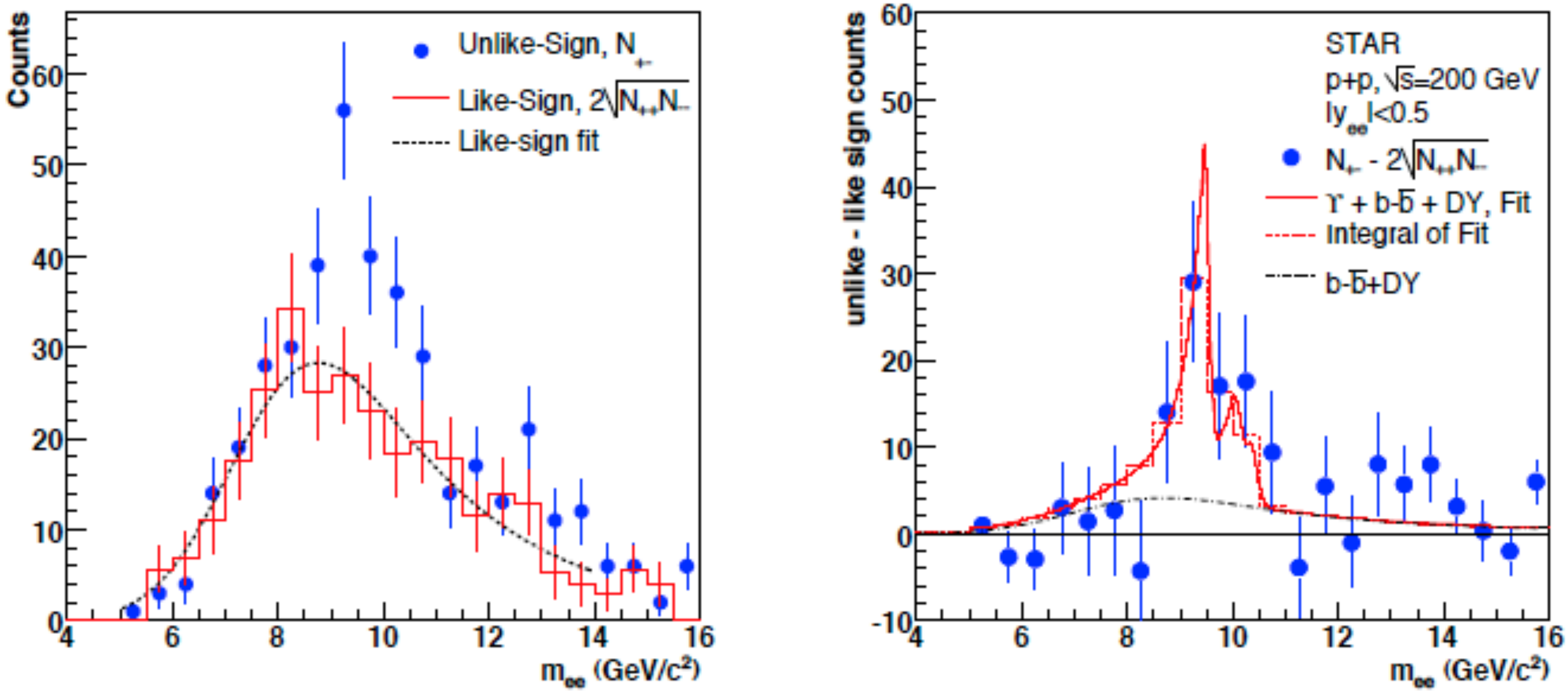
10^{-9}/min.bias pp collision (3 orders of magnitude smaller than $\sigma_{J/\psi}$)

ϒ (1S+2S+3S) separation ?

requires a high resolution :
Run 2006 (pp), 2007(AuAu) – large material budget
Run 2008 (dAu), 2009 (pp), 2010 (AuAu) - small material budget – <u>separation possible</u>

First Υ(nS) from p+p @ 200 GeV

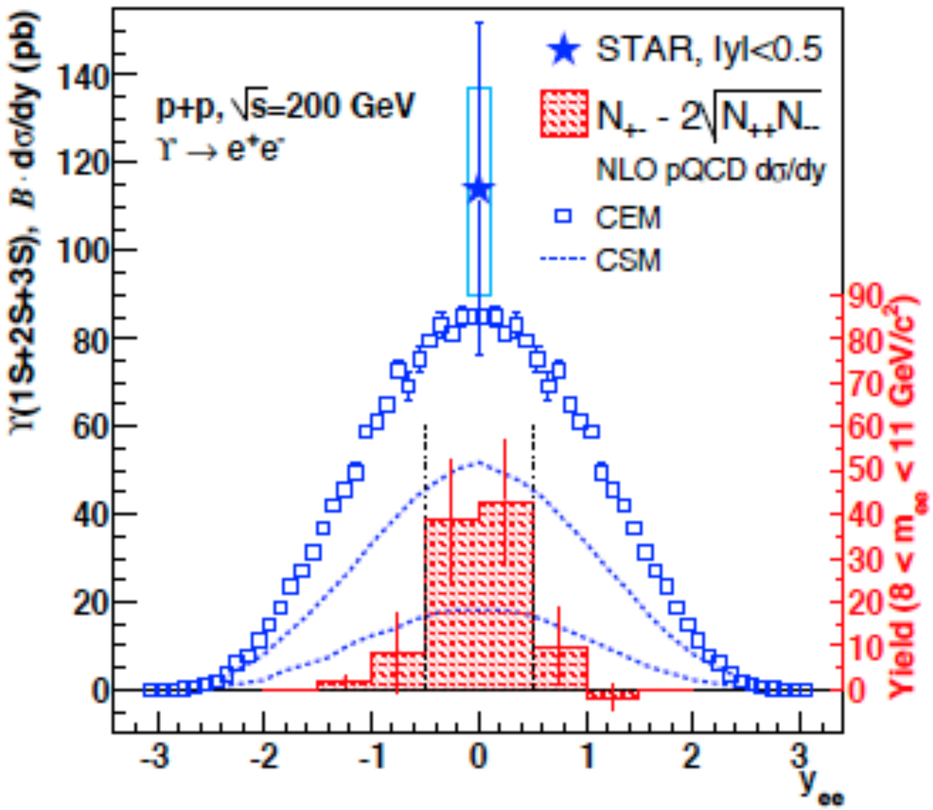
e-preprint: nucl-ex 1001.2745

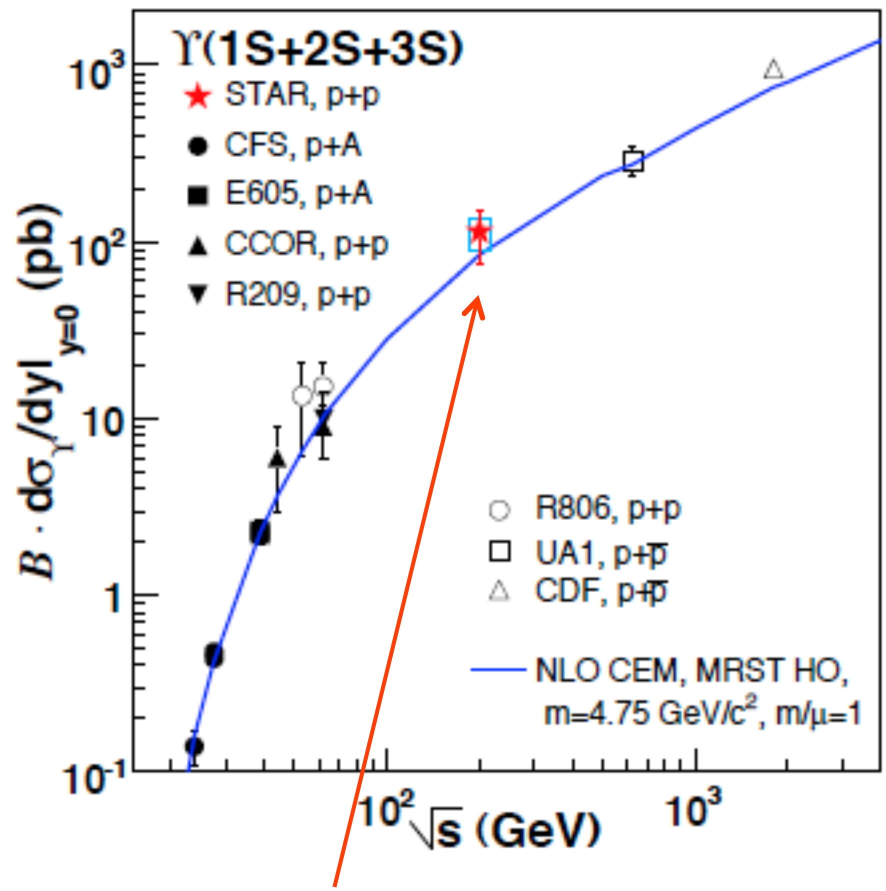


$$\sum_{n=1}^{3} B(nS) \times \sigma(nS) = 114 \pm 38 + 23 / - 24\text{pb}$$

STAR ϒ (nS) in pp vs theory and world data

arXiv:1001.27451



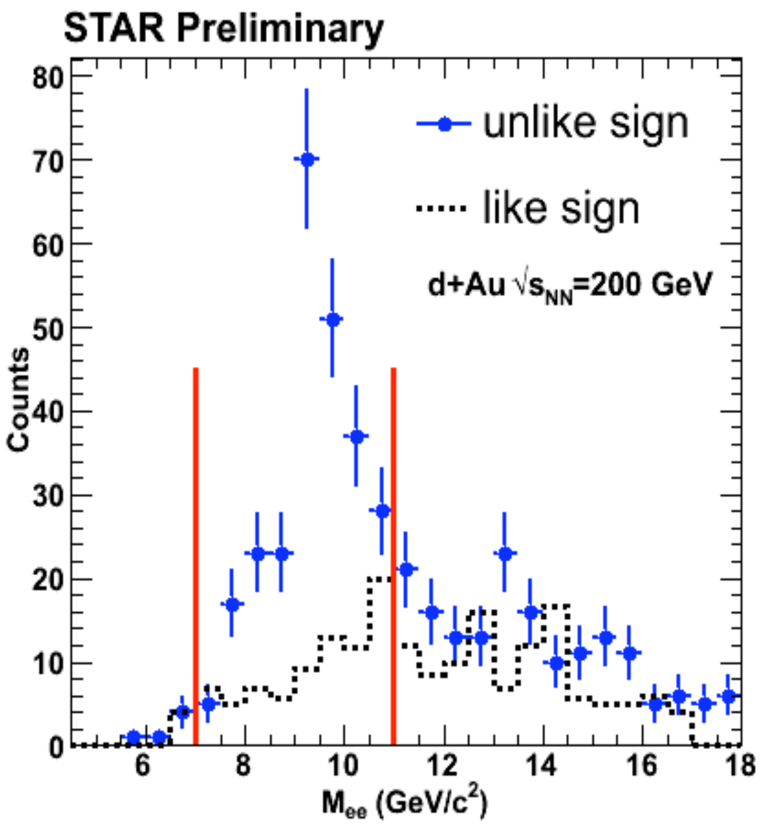


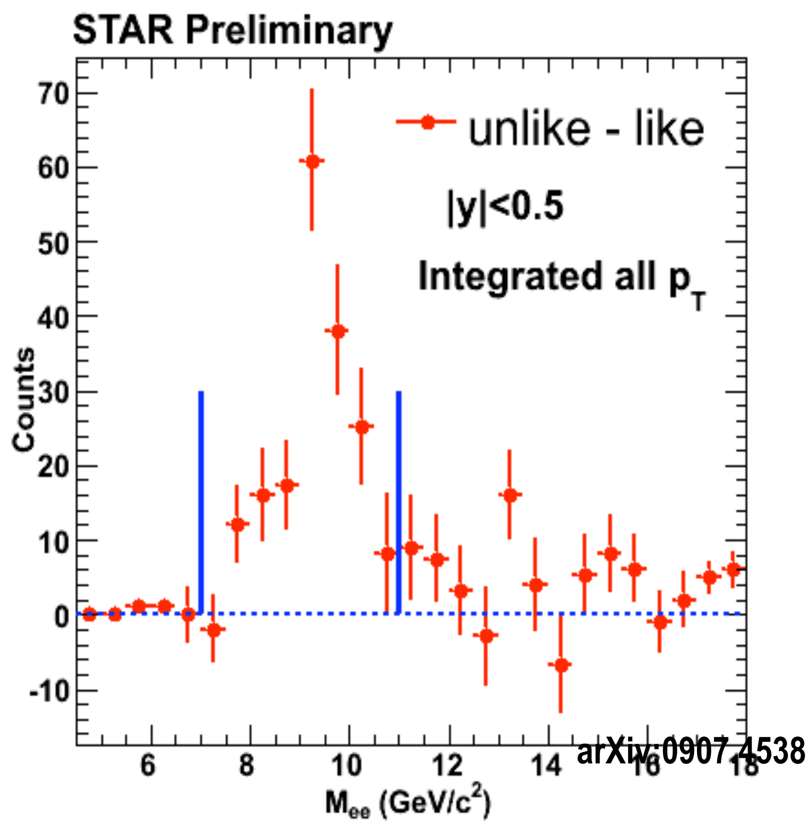
STAR ϒ in p+p at 200 GeV at mid-rapidity is consistent with CEM at NLO (inconsistent with CSM: ~ 2σ)

Consistent with world data trend

Υ in d+Au

Nucl.Phys. A830 (2009) 235, , nucl-ex 0907.4538





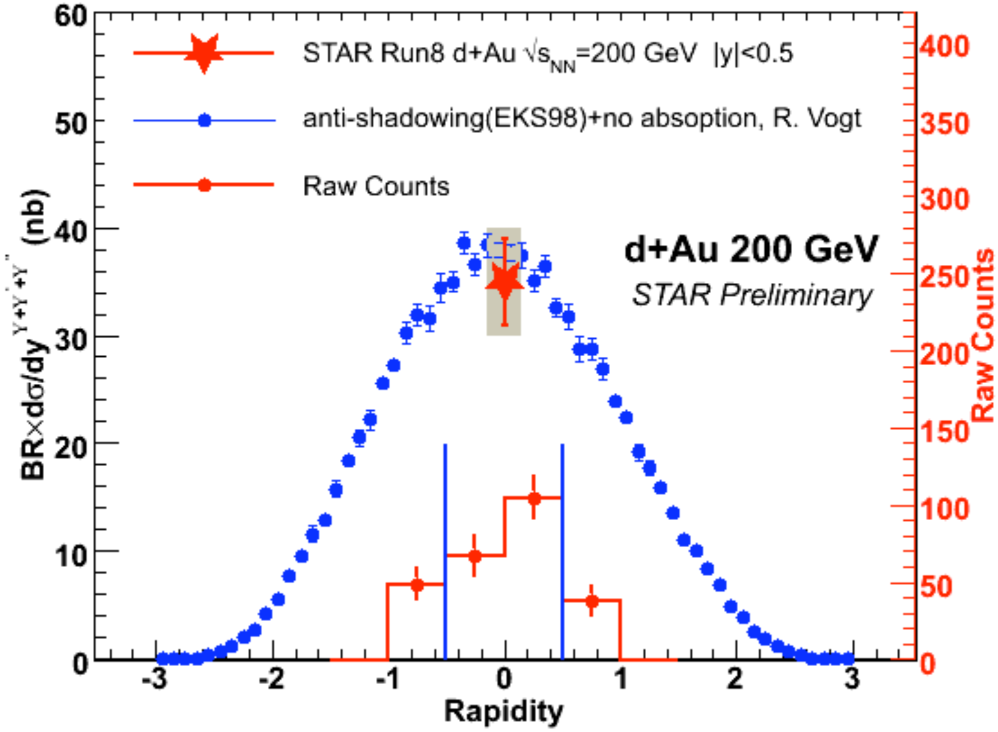
Υ(1S+2S+3S) total yield: integrated from 7 to 11 GeV from background-subtracted m_{ee} distribution

raw yield: 172 +/- 20 (stat.)

strong signal, 8σ significance (no SVT, "low mass run")

STAR ϒ (nS) in dAu vs theory

arXiv:0907.4538



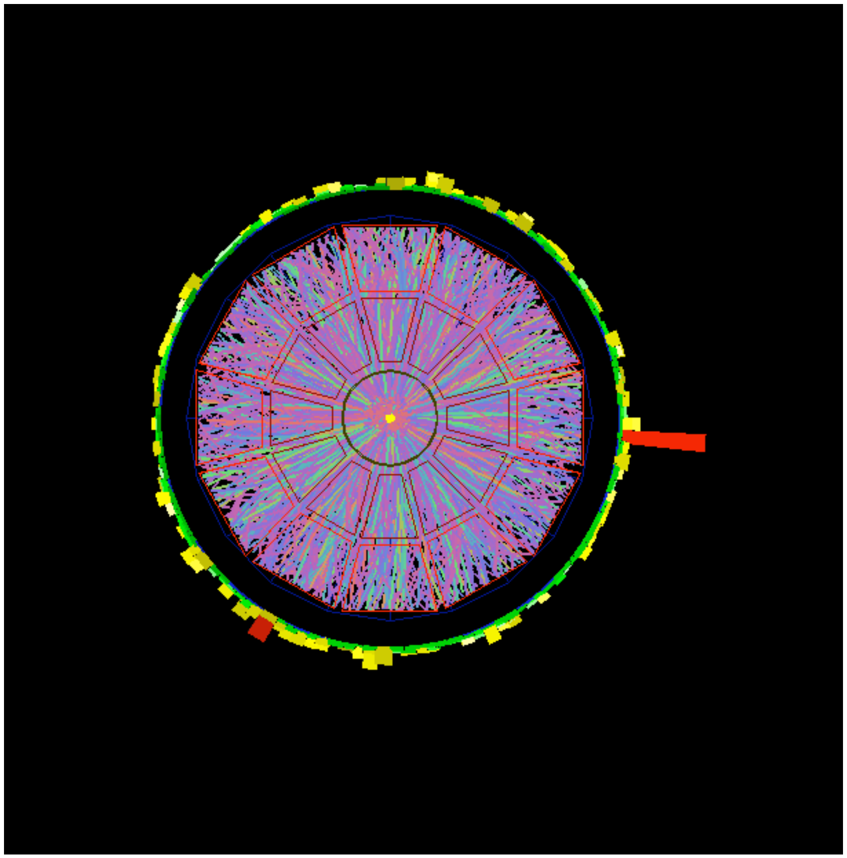
$$\sum_{n=1}^{3} B(nS) \times \sigma(nS) = 34 \pm 4 \pm 5\text{nb}$$

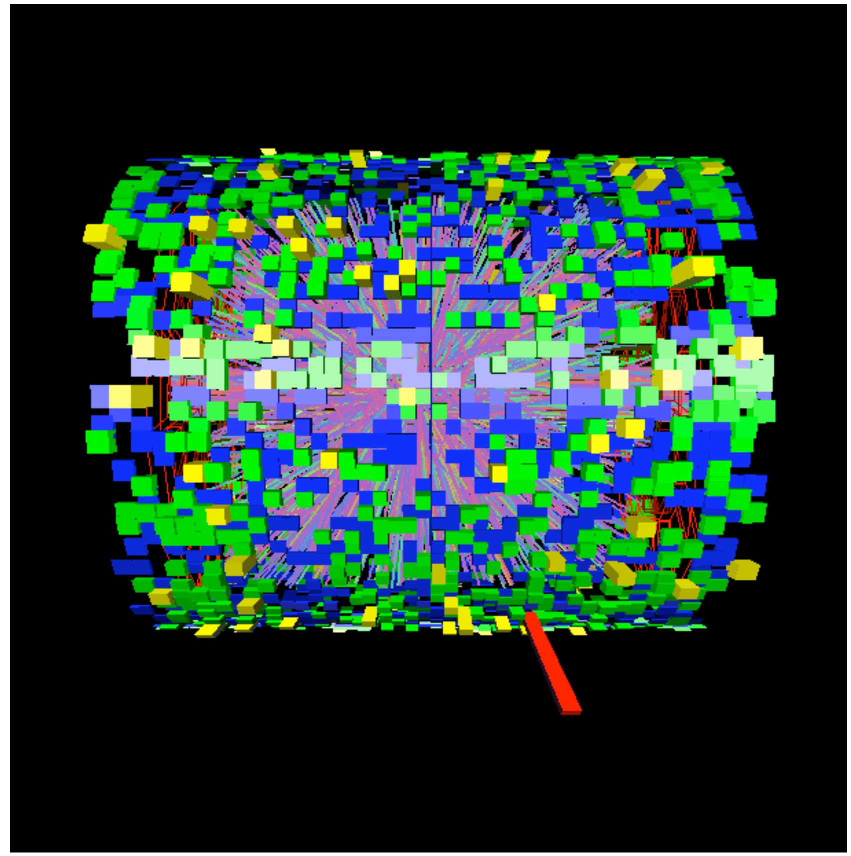
$R_{dAu} = 0.98 \pm 0.32(\text{stat.}) \pm 0.28(\text{sys.})$

CNM effects (shadowing) are small, need more pp statistics to quantify the effect (~ consistent with N_{bin} scaling)

Υ (nS) in Au+Au

Animation: Manuel Calderón de la Barca Sánchez





Au+Au, 200 GeV STAR upsilon event - analysis in progress !!!

Summary and Future

J/ψ spectra in 200 GeV p+p collisions in STAR:

- extended pt range up to ~14 GeV/c
- spectra can be described by CEM and CSM
- azimuthal correlations constrain B contribution

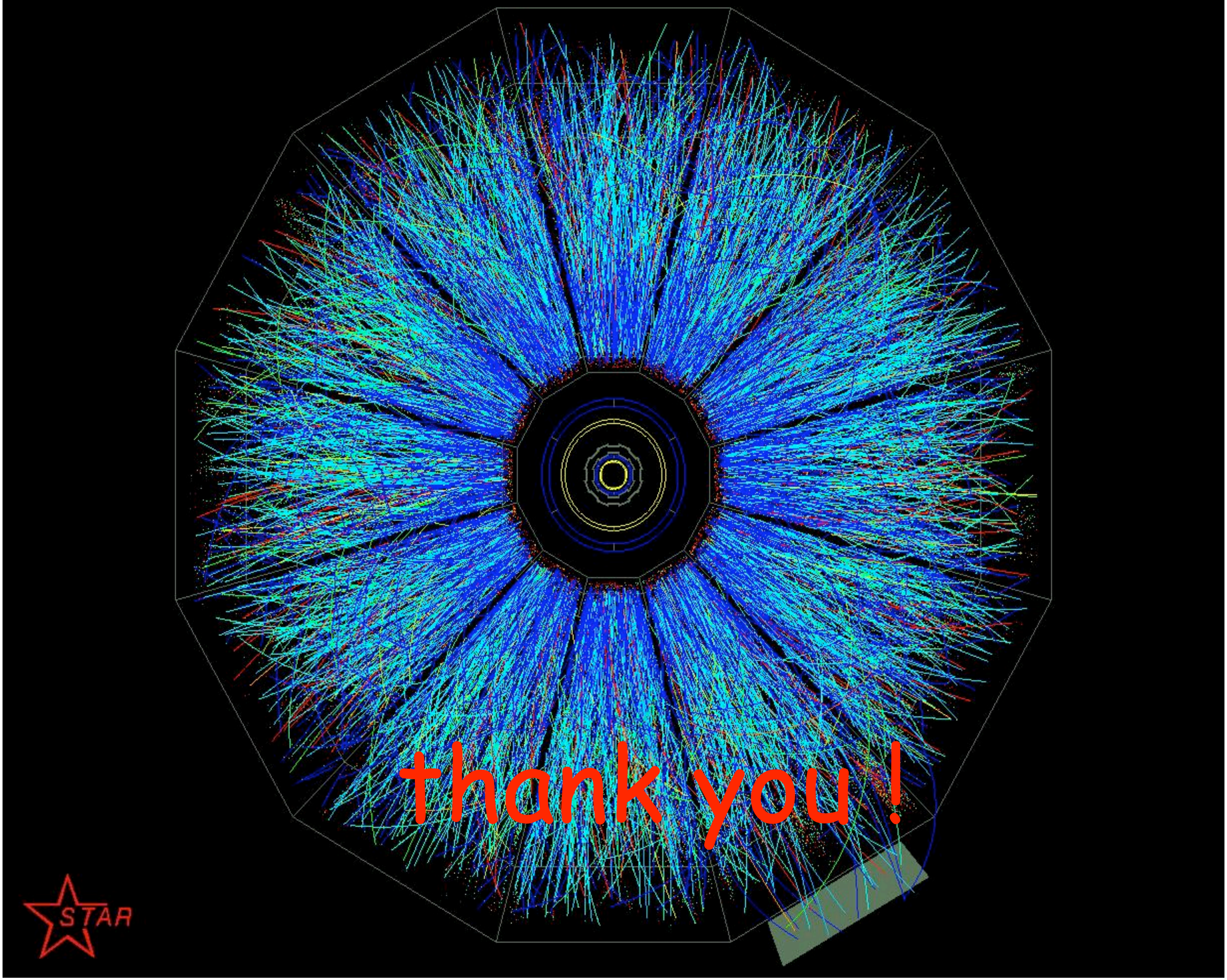
J/ψ in Cu+Cu high p_t:

- R_{AA} increases at high p_t (p_t >5 GeV)

$\Upsilon+\Upsilon'+\Upsilon'' \rightarrow e^+e^-$ cross-section at $\sqrt{s}$=200 GeV:

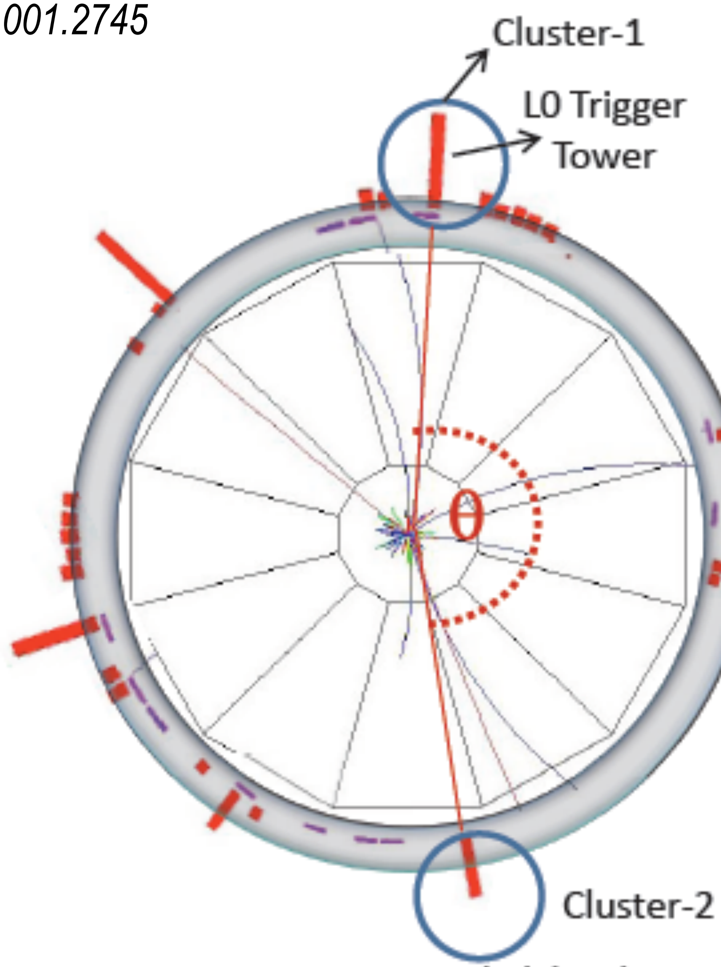
- p+p : B×(dσ/dy)= 114±38(stat)±23/24(sys) pb
- d+Au : B×(dσ/dy)= 35±4(stat)±5(sys) nb
  - R_{dAu} =0.98±0.32(stat)±0.28(sys)
    - consistent with binary scaling
    - good reference for QGP effects
- Au+Au (central 0-60%) – analysis in progress

Analysis of low material run are in progress (pp, 200 GeV - run 9, AuAu, 200 GeV - run 10).
May allow separation 1S,2S,3S states.


thank you !
STAR

ϒ Trigger in STAR

arXiv:1001.2745



L0 – fast hardware trigger:

$E_T > E_t^{threshold}$

L2 – software trigger:

$E_T^{(cl.1)} > E_T^{thershold1}$, $E_T^{(cl.2)} > E_T^{thershold2}$,

Calculate: $\cos\theta$

$$m^{(cl1-cl2)} = 2\sqrt{E^{cl1}E^{cl2}(1-\cos\theta)}$$

$$m^{(cl1-cl2)} > m^{threshold} \ ?$$

Decision in ~5 ms for slow detectors to keep / abort data

Modification Factor R_{AA}

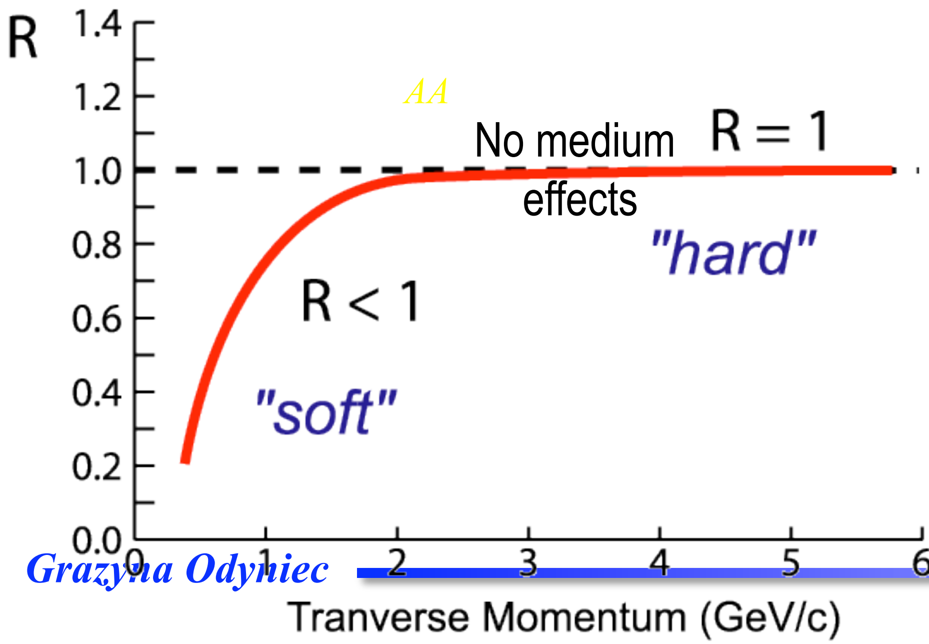
1. Compare Au+Au to nucleon-nucleon cross sections
2. Compare Au+Au central/peripheral

Nuclear Modification Factor:

$$R_{AA}(p_T) = \frac{d^2N^{AA}/dp_T d\eta}{T_{AA} d^2\sigma^{NN}/dp_T d\eta}$$

nucleon-nucleon cross section

$\langle N_{binary} \rangle / \sigma_{inel}^{p+p}$



If no "effects":

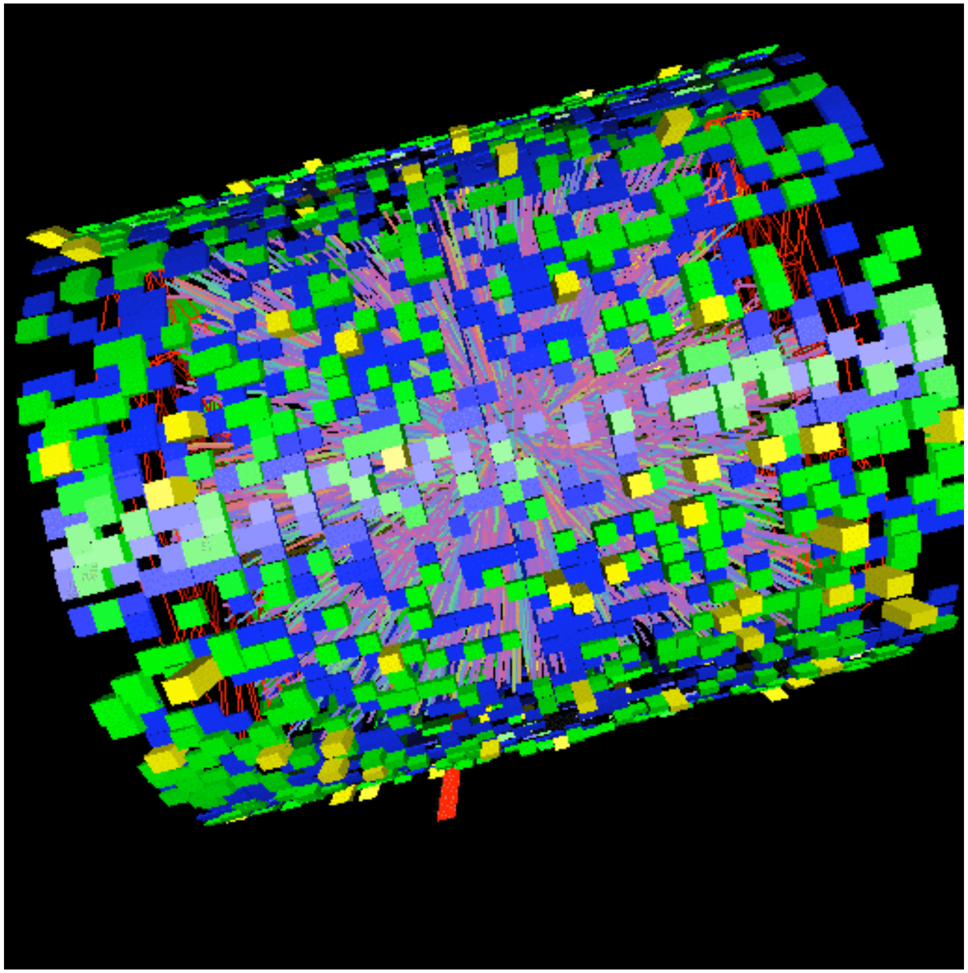
R_{AA} < 1 in regime of soft physics

R_{AA} = 1 at high-p_T where hard scattering dominates

Suppression:

R_{AA} < 1 at high-p_T

ϒ (nS) in Au+Au



some info
about upsilon
trigger ?

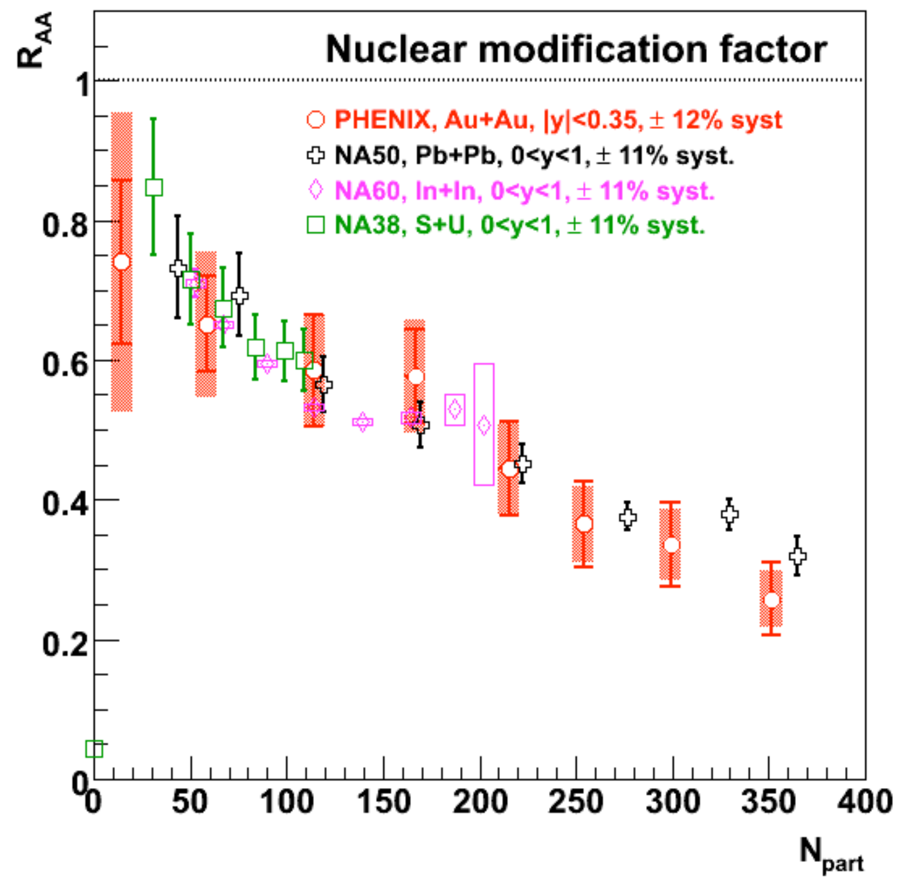
Au+Au, 200 GeV
STAR upsilon event

analysis in
progress !!

1: R_{AuAu} (y≈0 @RHIC) ≈ R_{PbPb} (@ SPS)

- At mid-y R_{AA} looks similar, while there are obvious differences:
  - at a given N_{part}, at RHIC much higher energy densities…
  - cold nuclear matter effects should be drastically different ($x_{Bjorken}$, σ_{abs}…)
  - …

RHIC: PRL98 (2007) 232301, SPS: from Scomparin @ QM06



The STAR Detector