

# Quarkonium production in p+p and A+A from STAR

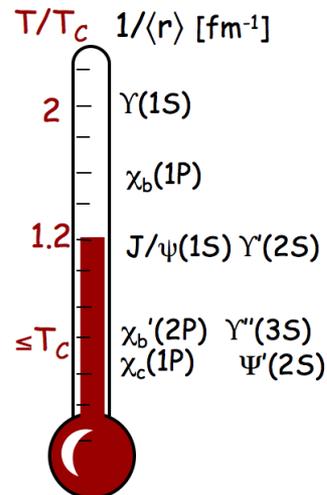
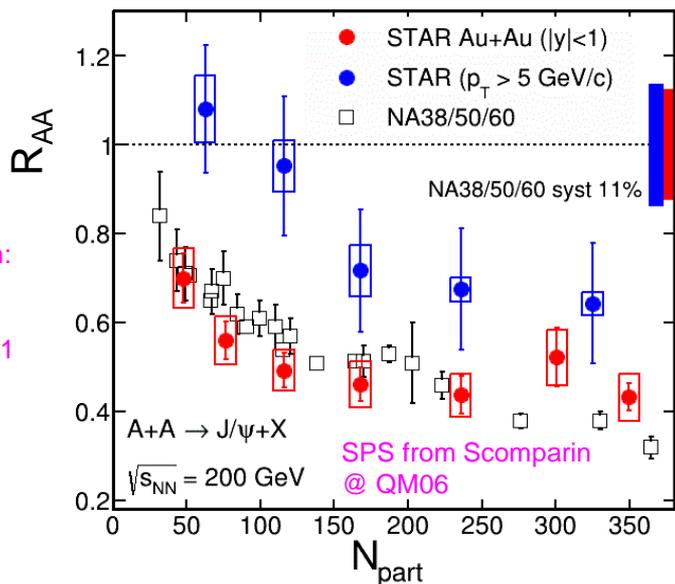
Wangmei Zha for the STAR Collaboration

University of Science and Technology of China  
Brookhaven National Laboratory

Quark Matter 2014 , May 19, 2014, Darmstadtium Schlossgraben  
164283, Darmstadt, Germany



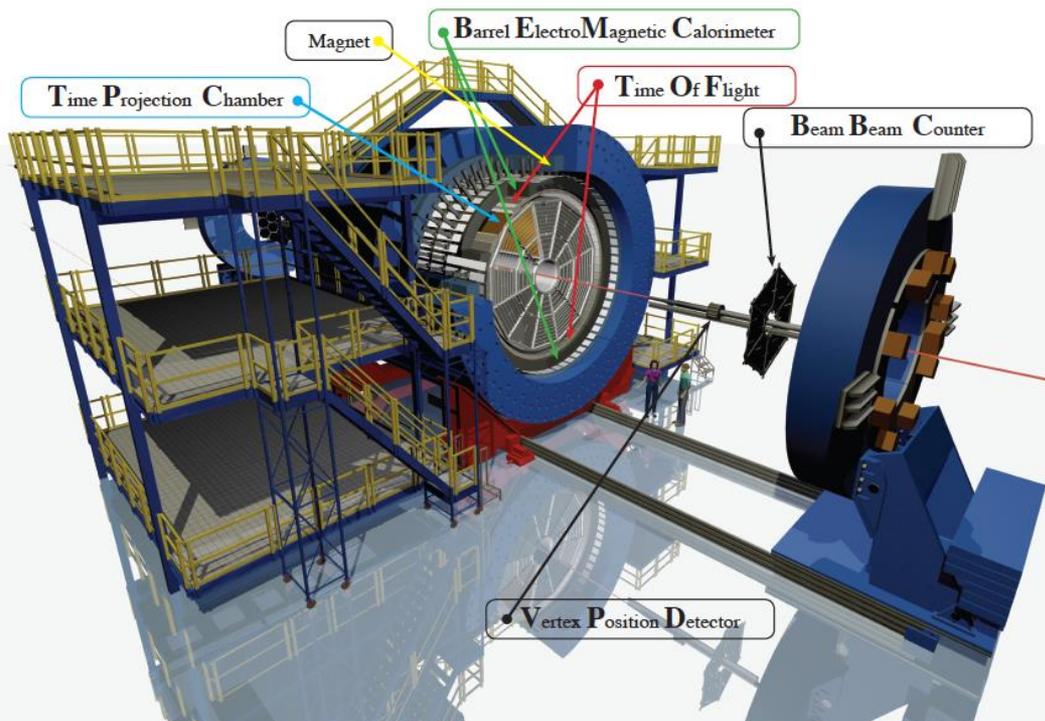
# Quarkonium suppression



Mocsy A., EPJC 61 (2009) 705

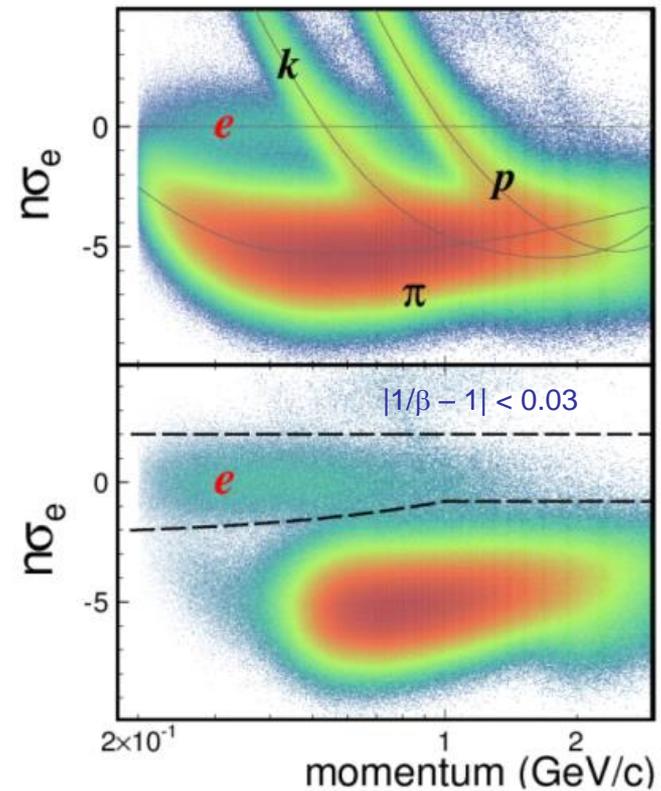
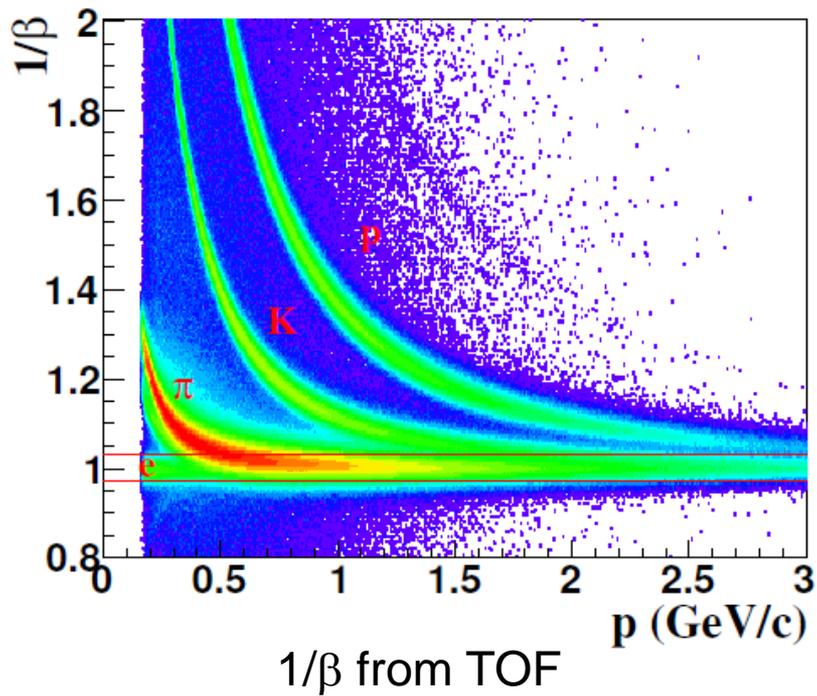
- Similar suppression at RHIC and SPS!
- RHIC BES program: provide a unique tool to study the interplay of CNM, screening, and regeneration effects.
- Sequential melting of quarkonia: a thermometer of QGP
- ✓ U+U : higher energy density
  - ✓ test the sequential melting of quarkonia
  - ✓ constrain models
- $\Upsilon$ : a cleaner probe
  - ✓ negligible regeneration at RHIC energy
  - ✓ less CNM effects

Solenoidal **T**racker **A**t **R**HIC :  $-1 < \eta < 1, 0 < \phi < 2\pi$

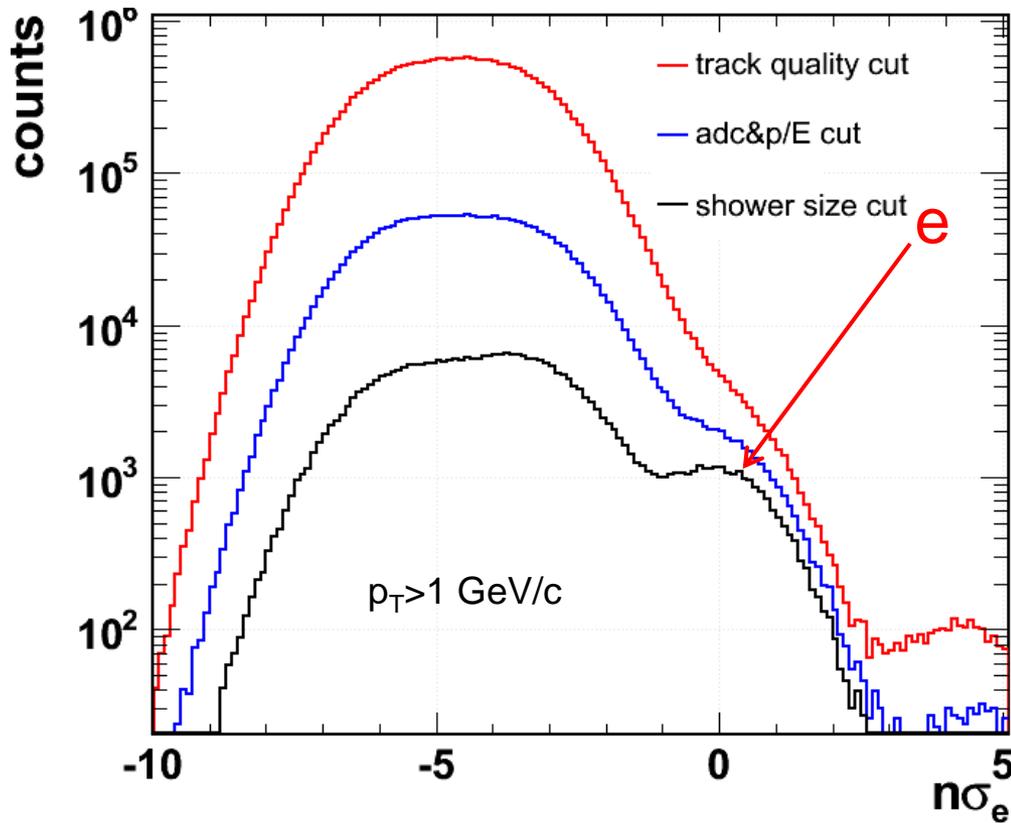


- Large acceptance:  
 $|\eta| < 1, 0 < \phi < 2\pi$
- Time Projection Chamber (TPC) – tracking, particle identification, momentum
- Time of Flight detector (TOF) – particle identification
- Barrel ElectroMagnetic Calorimeter (BEMC) – electron identification, triggering
- Barrel Shower Maximum Detector (BSMD) – electron identification  
 $\Delta\eta \times \Delta\phi = 0.007 \times 0.007$  at  $\sim 5X_0$   
Measure shower size and shower position

Low  $p_T$ : TPC + TOF



$n\sigma_e$ : Normalized  $dE/dx$

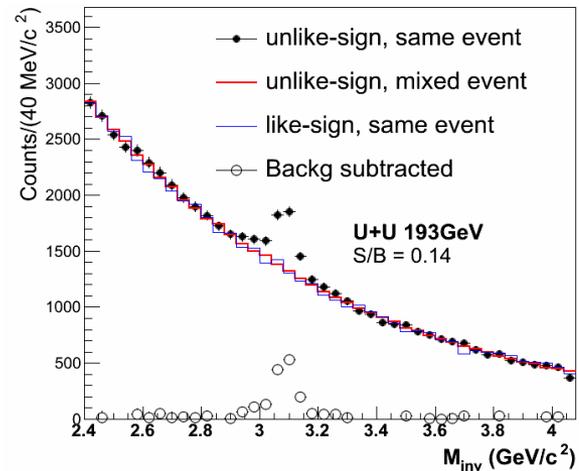
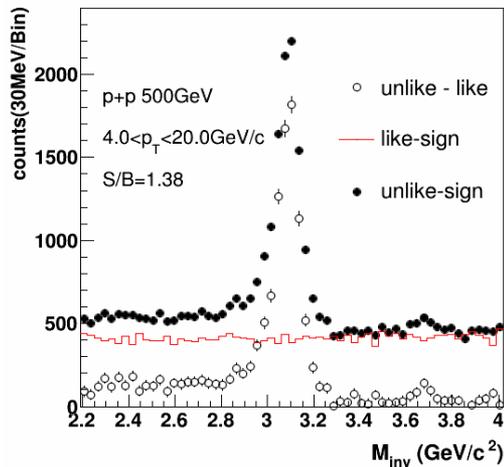
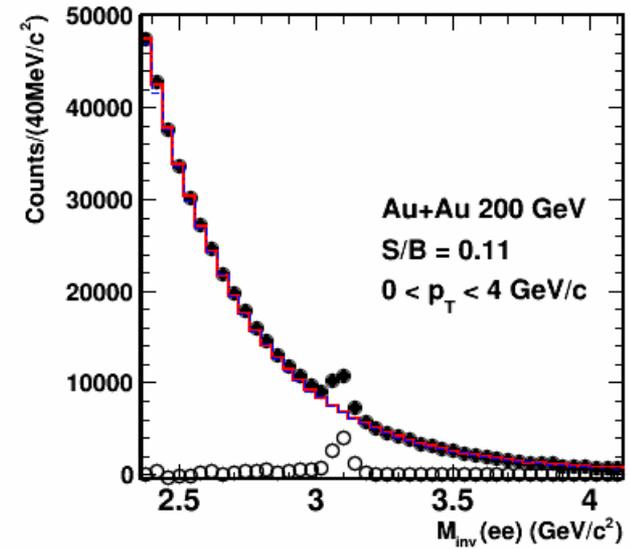
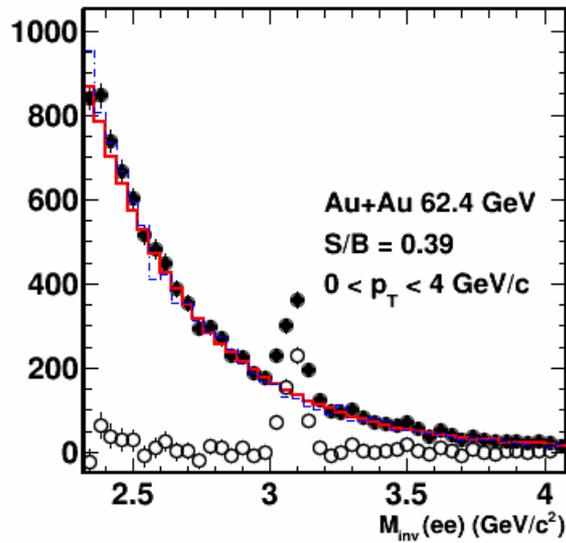
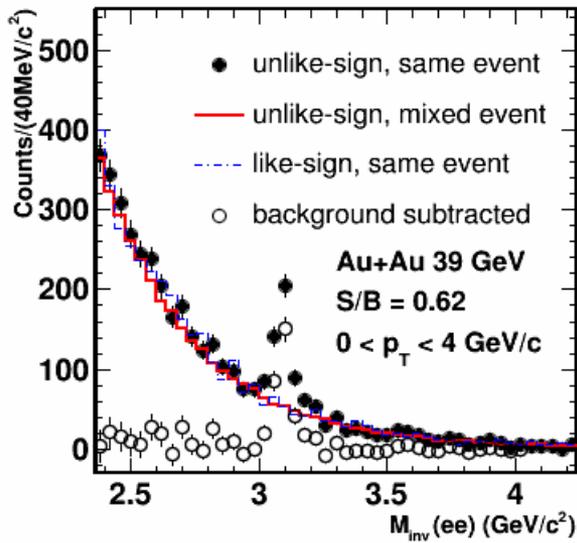


- **High  $p_T$ :**  
p/E to suppress hadrons  
further suppression from  
BSMD

p/E : 0.3 – 1.5  
 $n_\phi$  :  $\geq 1$   
 $n_\eta$  :  $\geq 1$

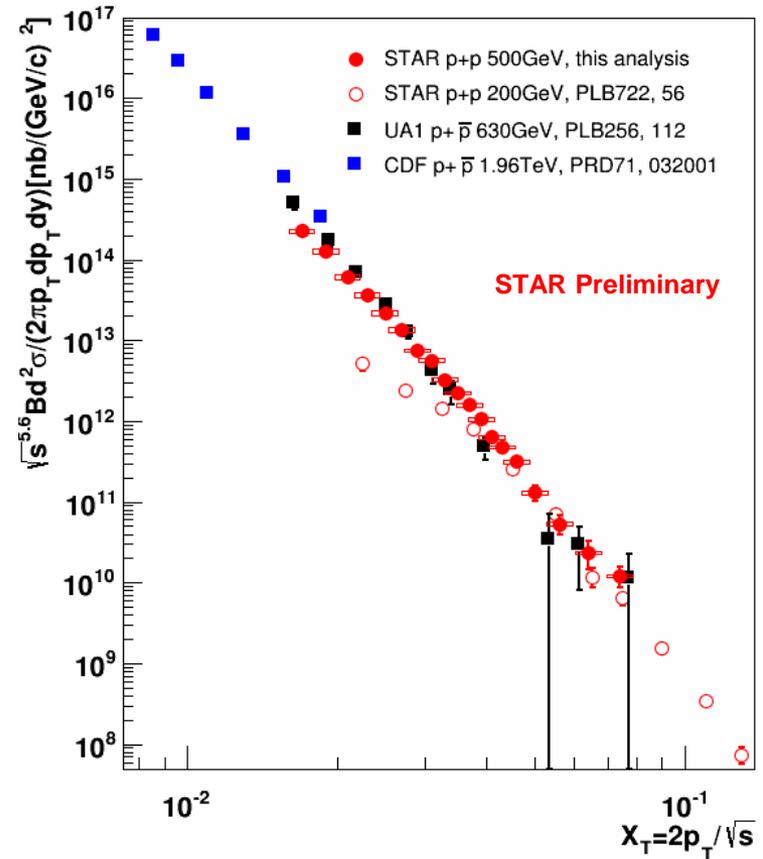
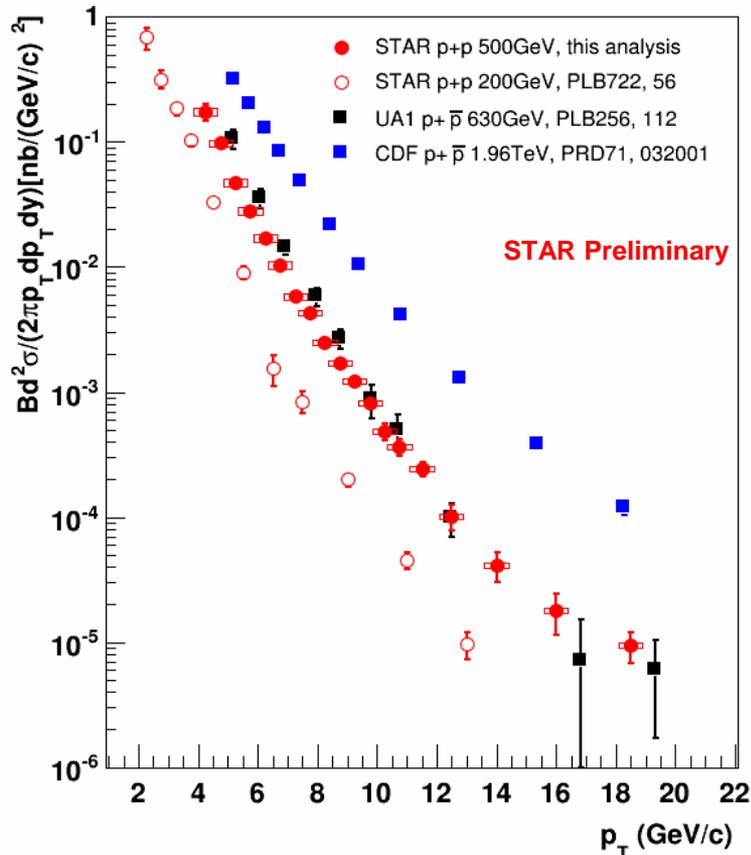
Distribution of normalized dE/dx  
after various cuts

# J/ψ signals





# J/ψ measurements in p+p 500 GeV

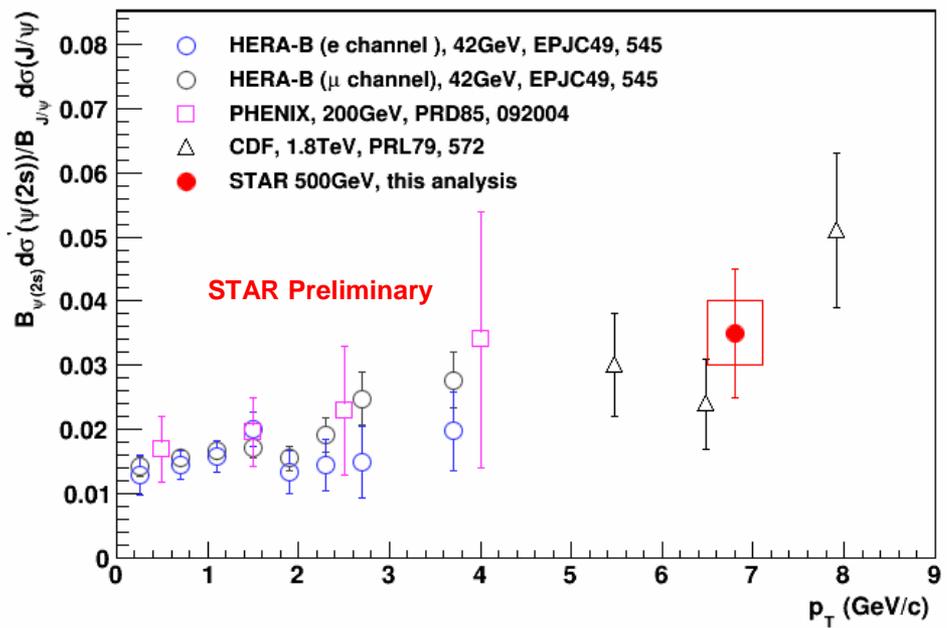
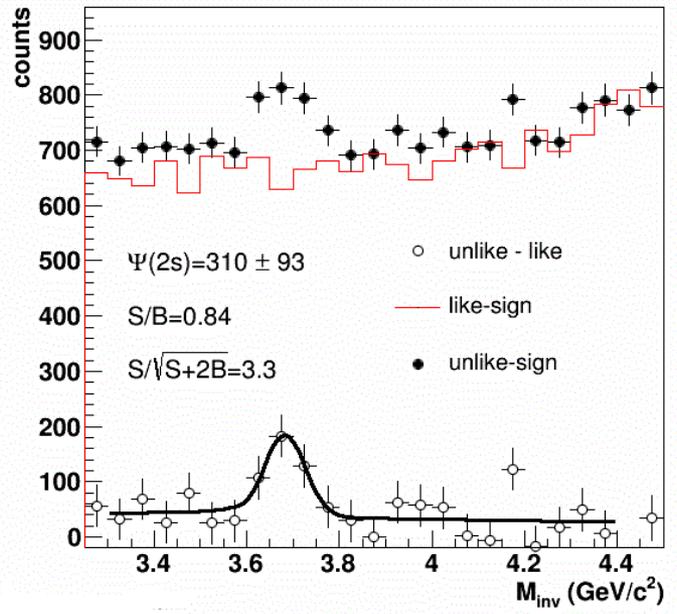


See poster contribution F-65 by Qian Yang

- J/ψ production measurements at a new beam energy.
- Precise measurements up to 20 GeV/c.
- Follow  $x_T$  scaling at  $p_T > 4$  GeV/c with  $n=5.6$ .
  - $n$  is obtained from ref: Phys. Rev. C **80**, 041902 (2009)



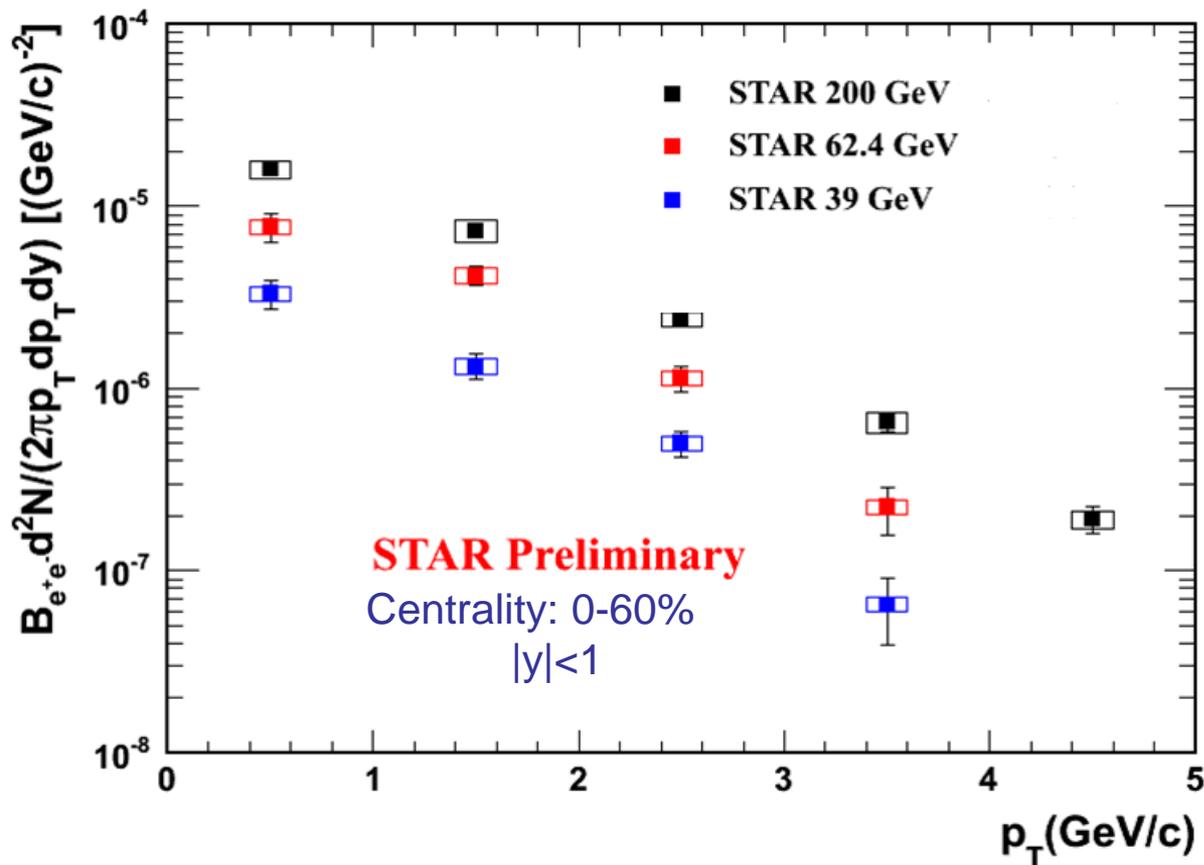
# Ratio of $\psi(2s)$ to $J/\psi$ in p+p 500 GeV



- ✓ First measurements at p+p 500 GeV!
- ✓ Consistent with previous measurements from other experiments.
- ✓ Constrain feed down contribution to  $J/\psi$  production.
- ✓ Additional test for production mechanisms of charmonium.



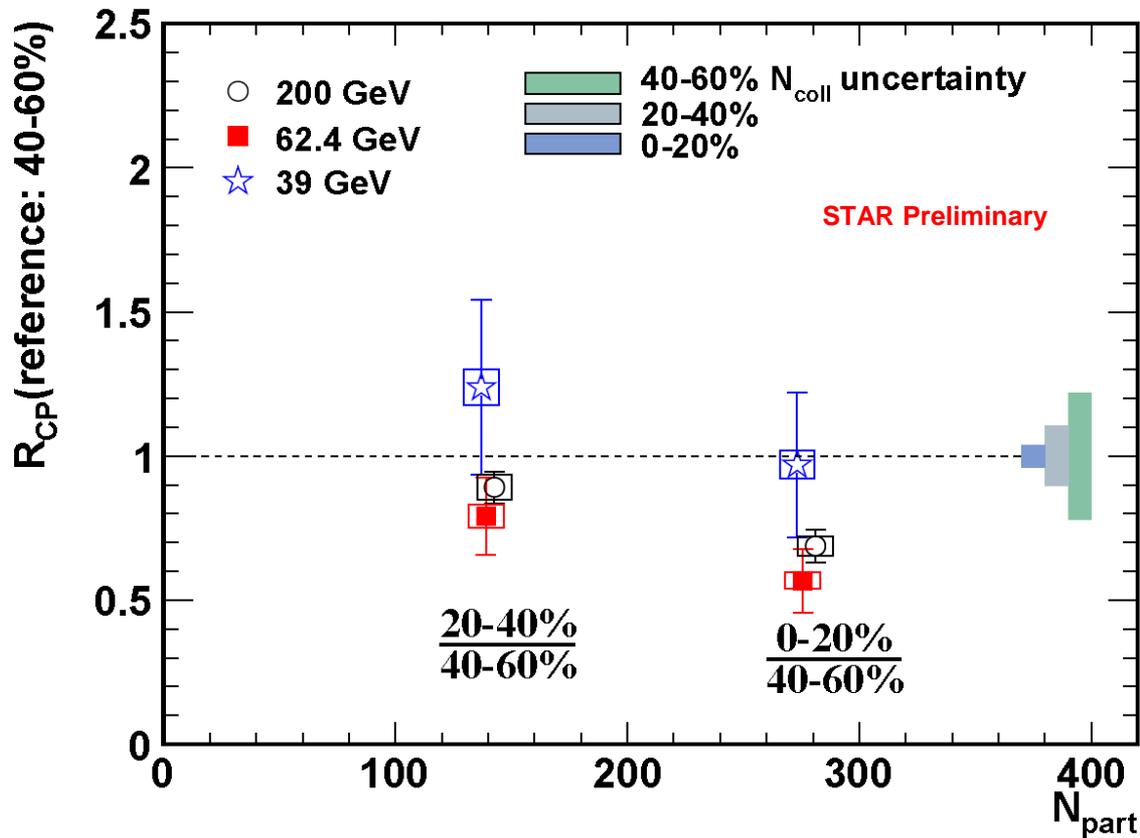
# J/ $\psi$ $p_T$ spectra in Au+Au from 39 - 200 GeV



✓ Measurements up to 4 GeV/c for Au+Au 39 and 62.4 GeV.



# Energy dependence of $J/\psi$ $R_{CP}$



$$R_{CP} = \frac{\frac{dN/dy}{\langle N_{coll} \rangle} (\text{central})}{\frac{dN/dy}{\langle N_{coll} \rangle} (\text{peripheral})}$$

➤ Nuclear modification factor  $R_{CP}$ : Shows significant suppression in central Au + Au collisions at 62.4 GeV, similar as at 200 GeV.



# Centrality dependence of $J/\psi R_{AA}$

Theoretical calculation from

Xingbo Zhao, Ralf Rapp

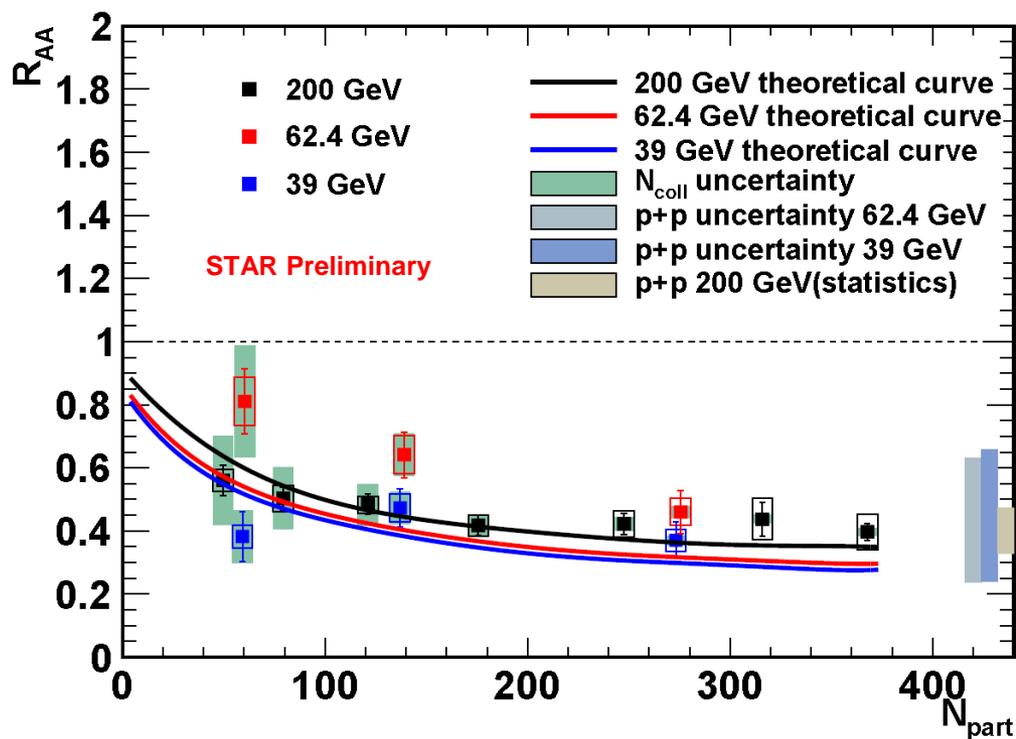
PhysRevC.82.064905

Contains two main components:  
direct suppression and  
regeneration

pp baseline for 39 and 62.4 GeV  
is estimated from CEM  
calculation

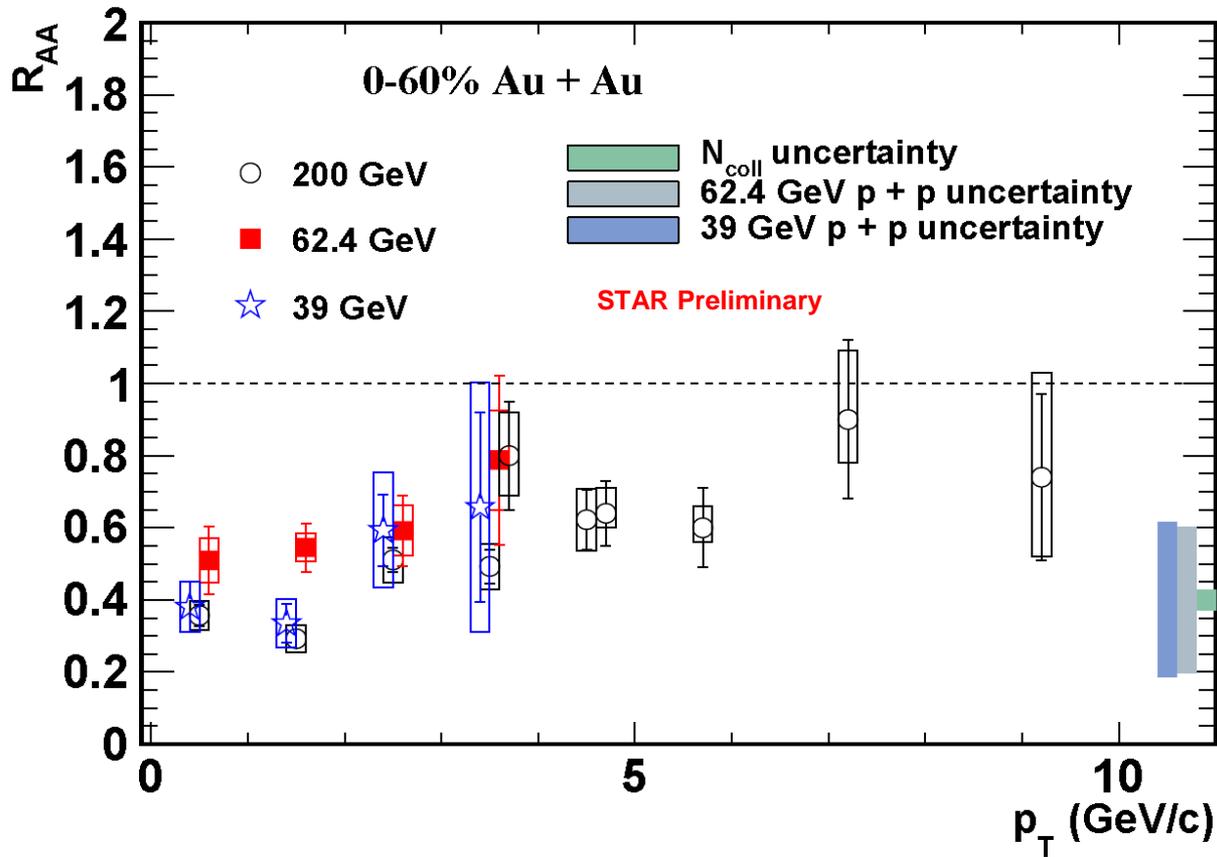
$$R_{AA} = \frac{1}{T_{AA}} \frac{d^2 N_{AA}/dprdy}{d^2 \sigma_{pp}/dprdy}$$

$$T_{AB} = \langle N_{coll} \rangle / \sigma_{inel}^{pp}$$



- Observed significant suppression of  $J/\psi$  production in Au+Au collisions from 39-200 GeV with respect to  $N_{coll}$  scaled p + p yields.
- No significant energy dependence observed for  $R_{AA}$ .
- Theoretical calculations are consistent with data.

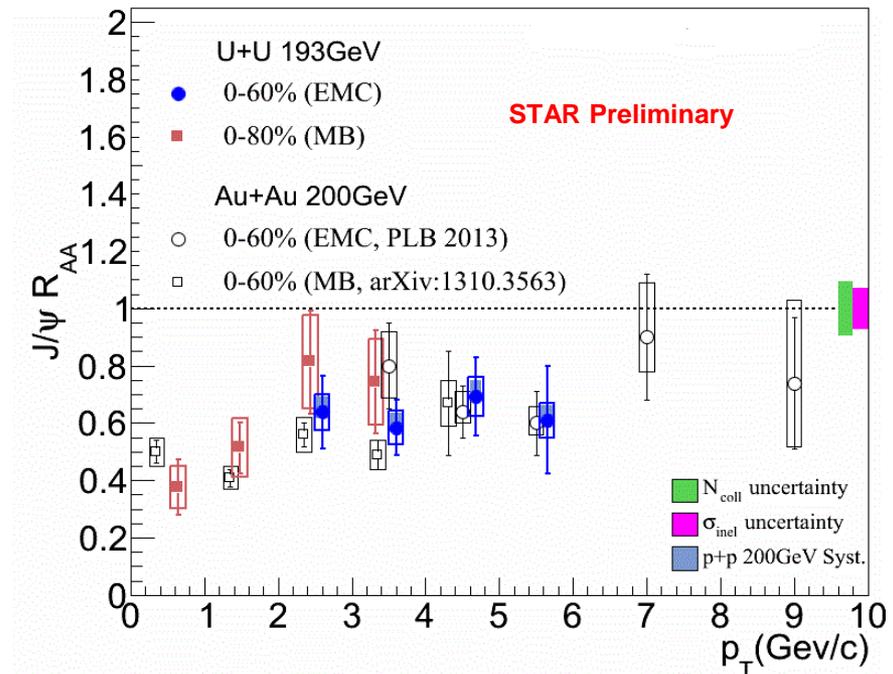
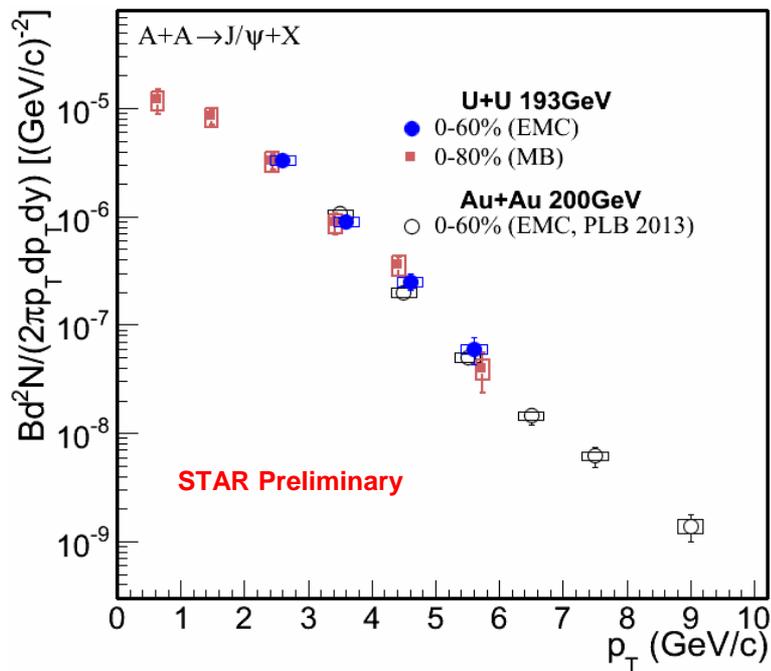
# J/ψ R<sub>AA</sub> versus p<sub>T</sub>



➤ Significant suppression at 39 and 62.4 GeV, similar as at 200 GeV.



# J/ψ measurements in U+U 193 GeV



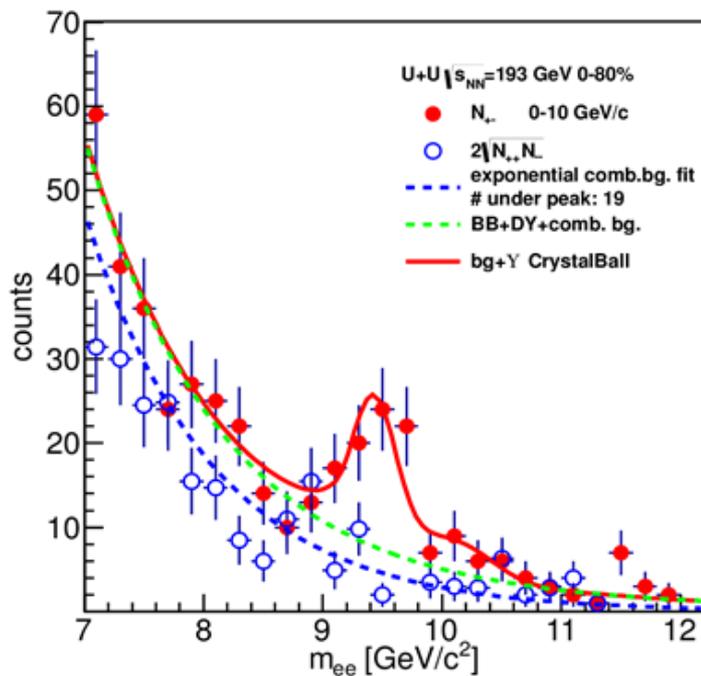
Baseline: J/ψ measurements in p+p 200 GeV.

See poster contribution F-23 by Ota Kukral and F-64 by Guannan Xie

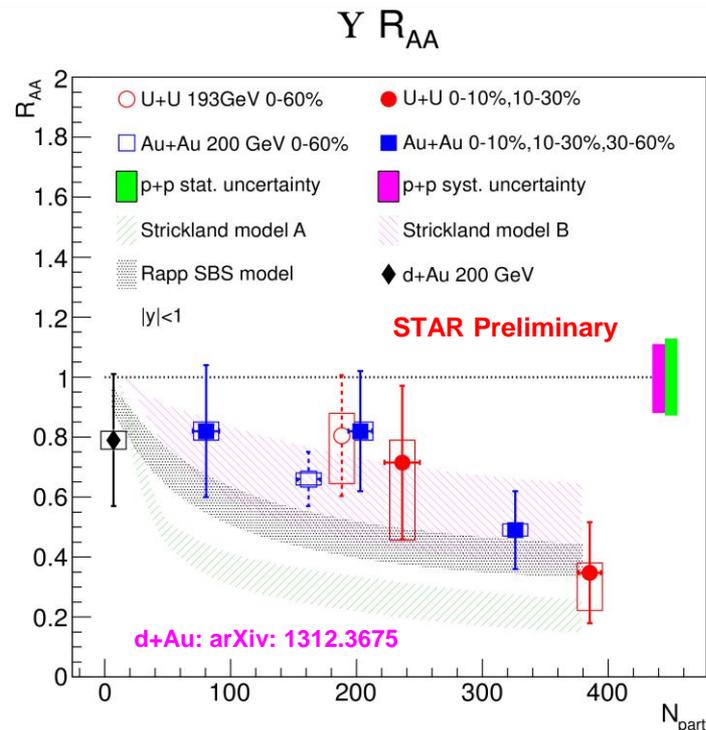
Similar suppression pattern as that in Au+Au 200 GeV!



# $\Upsilon(1S+2S+3S)$ measurements in U+U



See poster contribution F-58  
by Robert Vertesi



Baseline:  $\Upsilon$  measurements in p+p 200 GeV.

Model calculations are from:  
 M. Strickland, D. Bazow, Nucl. Phys. **A879**, 25 (2012)  
 A. Emerick, X. Zhao, R. Rapp, Eur. Phys. J **A48**, 72 (2012)

- Significant suppression at central collisions.
- Disfavor Strickland model A (potential model based on the heavy quark free energy).



# Summary

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- ✓  $J/\psi$  production in p+p 500 GeV follows  $x_T$  scaling at  $p_T > 4$  GeV/c and ratio of  $\psi(2s)$  to  $J/\psi$  is consistent with other experiments.
  
- ✓ Significant suppression of  $J/\psi$  production in Au + Au collisions from 39-200 GeV observed with respect to  $N_{\text{coll}}$  scaled p + p yields.
  - ✓ No significant energy dependence .
  - ✓ Model with two main components (direct suppression and regeneration) describes the centrality dependence of  $R_{AA}$  at 39-200 GeV.
  
- ✓ Significant  $\Upsilon$  and  $J/\psi$  suppression U+U, similar to that in Au+Au.

# Back up

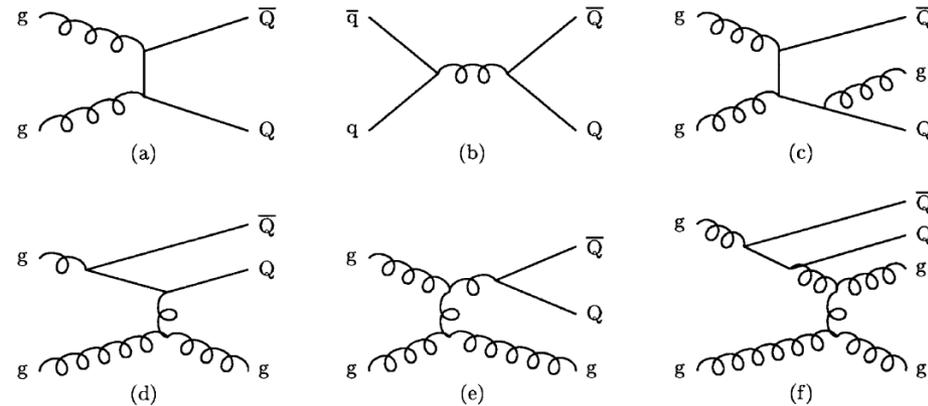
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# Quarkonium production mechanisms in p+p

- The hard processes to create heavy quarks can be calculated in pQCD.

- The soft processes to form quarkonium require modeling:

- Color Singlet Model
- Color Evaporation Model
- Non-Relativistic QCD



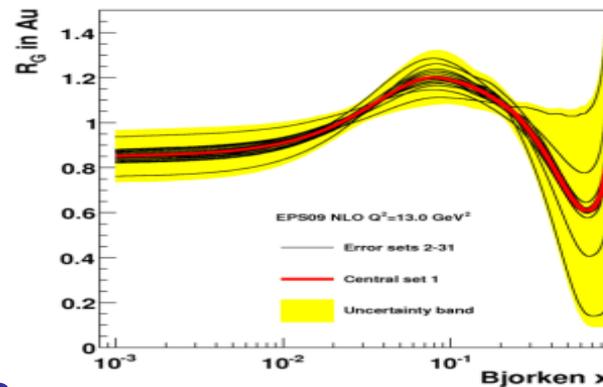
Berger E L, Jones D. Phys. Rev. D, 1981, 23(1521)

Fritzsch H. Phys. Lett. B, 1977, 67(217)

Bodwin G, Braaten E, Lepage G P. Phys. Rev. D, 1995, 51(1125)

# Cold Nuclear Matter (CNM) effects

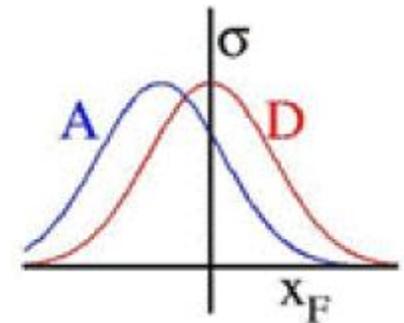
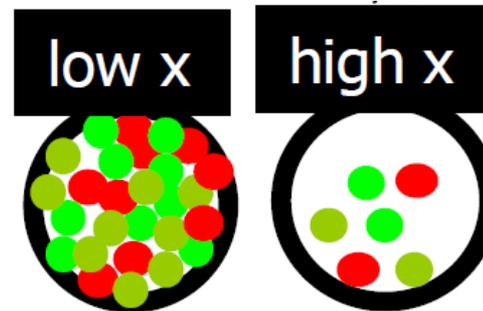
- ✓ PDF modification in nucleus
  - ✓ Gluon saturation, color glass condensate



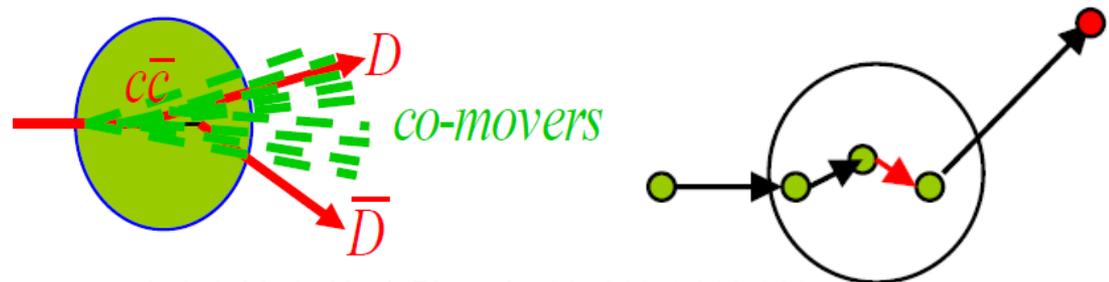
Eskola K. J., arXiv: 1209.1546, 2012

- ✓ Initial state energy loss

- ✓ Nuclear absorption



- ✓ Cronin effect



Leitch M. J., Nucl. Phys. A 782 (2007) 319-326

- ✓ ....

# Hot and Dense Medium effects

## ✓ Color-screening

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

## ✓ Gluon dissociation

Liu Y., Ko C. M., and Song T. Phys. Rev. C, 2013, 88(064902).

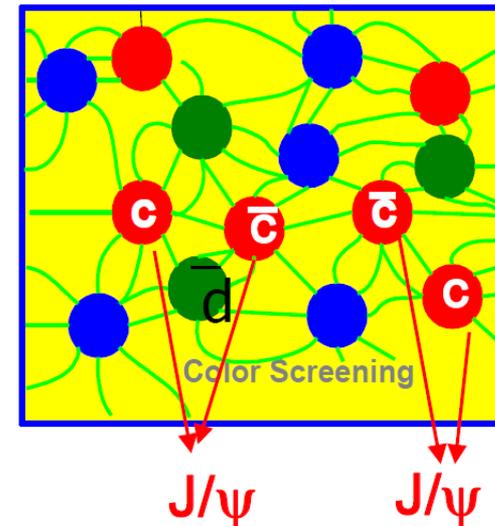
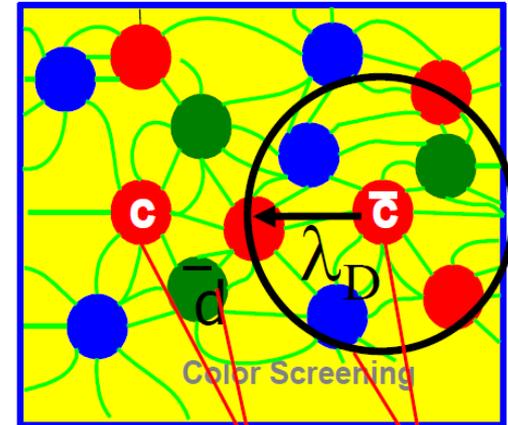
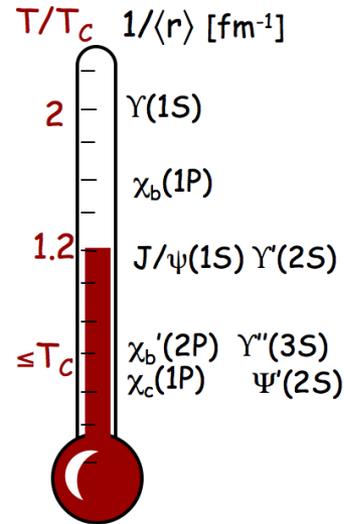
## ✓ Sequential melting

### ✓ QGP Thermometer

Mocsy A, Petreczky P. Phys. Rev. D, 2008, 77(014501)

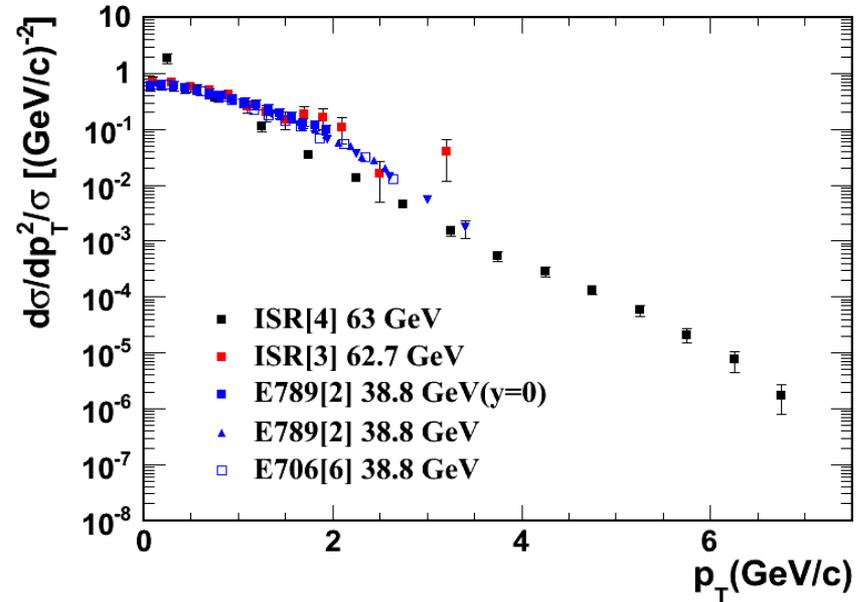
## ✓ Regeneration

Petreczky P. J., J. Phys. G, 2010, 37(094009)  
Grandchamp L. and Rapp R. Nucl. Phys. A, 2002, 709 (415)



# Measurements of $J/\psi$ cross section in 39 and 63 GeV $p + p$ collisions

Experiment	Reaction	Energy (GeV)	Cross section ( $y=0$ ) (nb/nucleon)
E771[1]	$p + \text{Si}$	38.8	$202 \pm 17$
E789 [2]	$p + \text{Au}$	38.8	$170 \pm 30$
ISR [3]	$p + p$	62.7	$172 \pm 15$
ISR [4]	$p + p$	63	$250 \pm 56$

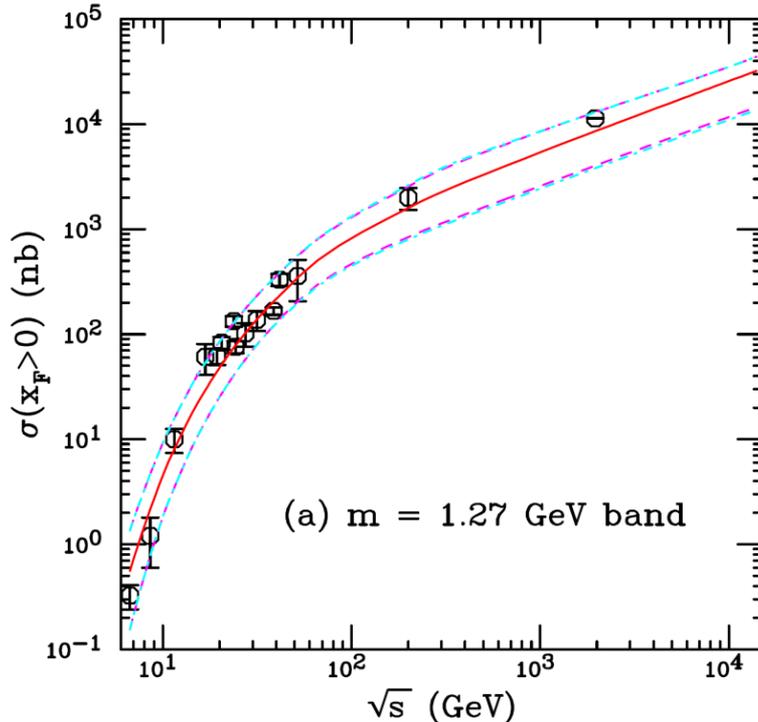


- [1] T. Alexopoulos et al, Phys. Rev. D55, 3927 (1997)
- [2] M.H. Schub et al., Phys. Rev. D 62, 1307 (1995)
- [3] A.G. Clark et al., Nucl. Phys. B 142, 29 (1978)
- [4] C. Kourkounelis et al., Phys. Lett. 91B, 481 (1980)
- [5] R. Nelson, R. Vogt et al, arXiv:1210.4610v1
- [6] A. Gribushin ( E706 ) et al., Phys. Rev. D 62, 012001 (2000).

Experimental results on cross section and  $p_T$  shape are inconsistent. We use Color Evaporation Model estimations as our  $p + p$  references for 39 and 62.4 GeV.

CEM describes the  $p_T$  and  $y$  distributions in 200 GeV  $p + p$  collisions<sup>[5]</sup>.

# p + p reference plot from CEM calculation



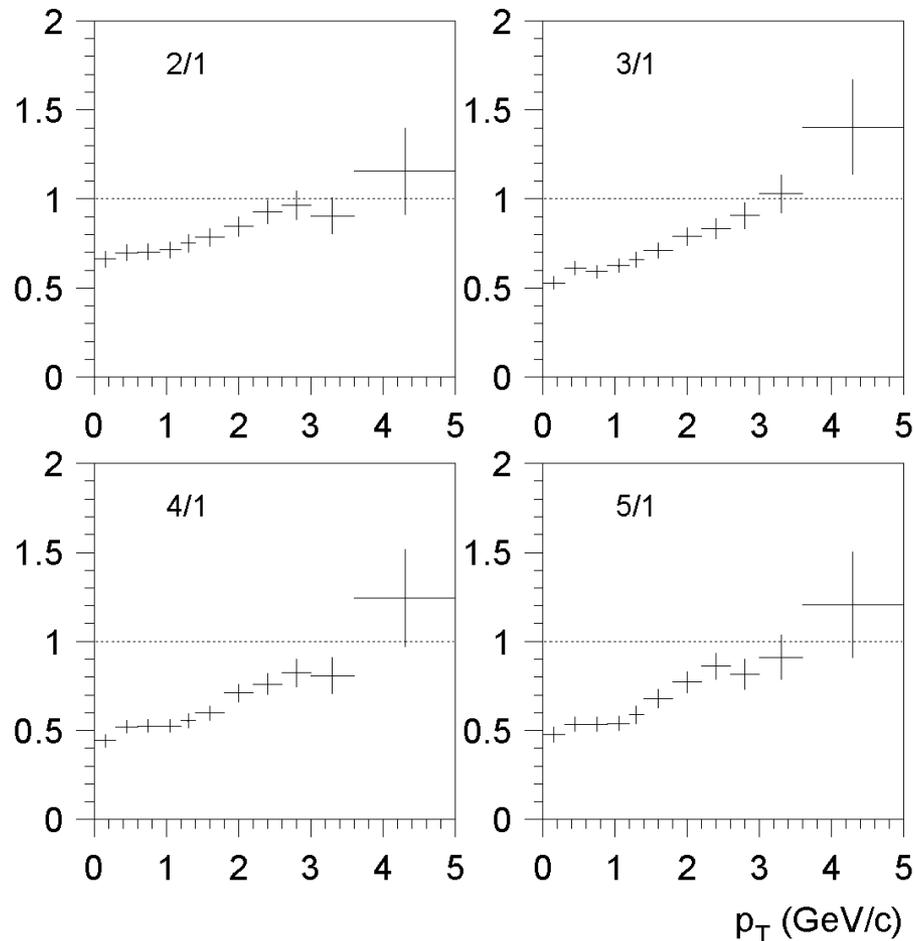
R. Nelson, R. Vogt et al,  
arXiv:1210.4610v1

39 GeV:  $Bd\sigma/dy = 8.7^{+5.6}_{-3.5}$  nb ( $|y| < 1.0$ )     $Bd\sigma/dy = 2.3^{+1.5}_{-1.0}$  nb ( $1.2 < |y| < 2.2$ )

62.4 GeV:  $Bd\sigma/dy = 17.1^{+9.9}_{-7.0}$  nb ( $|y| < 1.0$ )     $Bd\sigma/dy = 6.1^{+3.8}_{-2.6}$  nb ( $1.2 < |y| < 2.2$ )

- Utilize the world-wide open charm data to constrain the renormalization and factorization scale parameters in CEM.
- Match their calculations to the world-wide  $J/\psi$  data by a constant.

# $R_{CP}$ as a function of $p_T$ from NA50



[Phys. Lett. B 499 \(2001\) 85-96](#)

$R_i(p_T)$ : Ratios between the  $J/\psi$   $p_T$  distributions in the  $E_T$  bin  $i$  ( $i = 2; 3; 4; 5$ ) and in the first  $E_T$  bin