Quarkonia measurements at STAR

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Outline:

- Introduction
- J/ψ results
- ϒ results
- Outlook

BROOKHAVEN NATIONAL LABORATORY
a passion for discovery

Office of Science
U.S. DEPARTMENT OF ENERGY

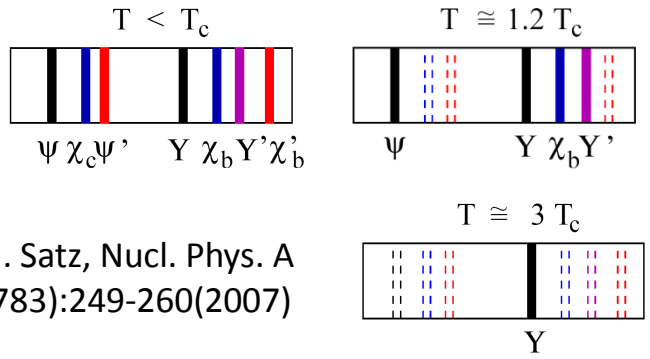
Quarkonia in sQGP

- Color screening effect [1)]
- Recombination [2)]
- Gluon energy loss [3)]
- Heavy quark energy loss [3)]
- Decay feed-down
- (comover, cold matter effect) at (hadronic phase, initial stage)

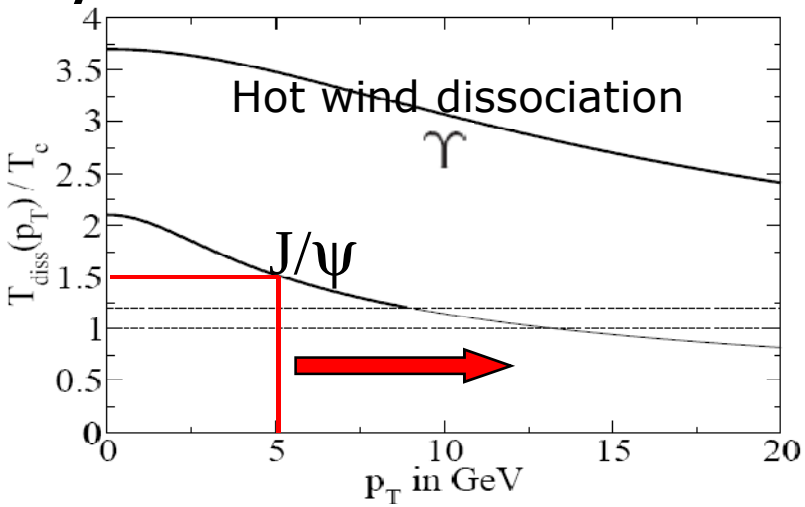
How do the quarkonium behave in the presence of sQGP?

1) *T. Matsui and H. Satz, Phys. Lett. B178, 416 (1986)*
2) *R. L. Thews and M. L. Mangano, Phys. Rev. C73, 014904 (2006)*
3) *M. B. Johnson et al., Phys. Rev. Lett. 86, 4483 (2001) and R. Baier et al., Ann. Rev. Nucl. Part. Sci. 50, 37 (2000)*

High p_T J/ψ in heavy ion collisions



H. Satz, Nucl. Phys. A (783):249-260(2007)



J/ψ suppression at low p_T could be from suppressed excited states (ψ', χ_c)

F. Karsch, D. Kharzeev and H. Satz, PLB 637, 75 (2006)

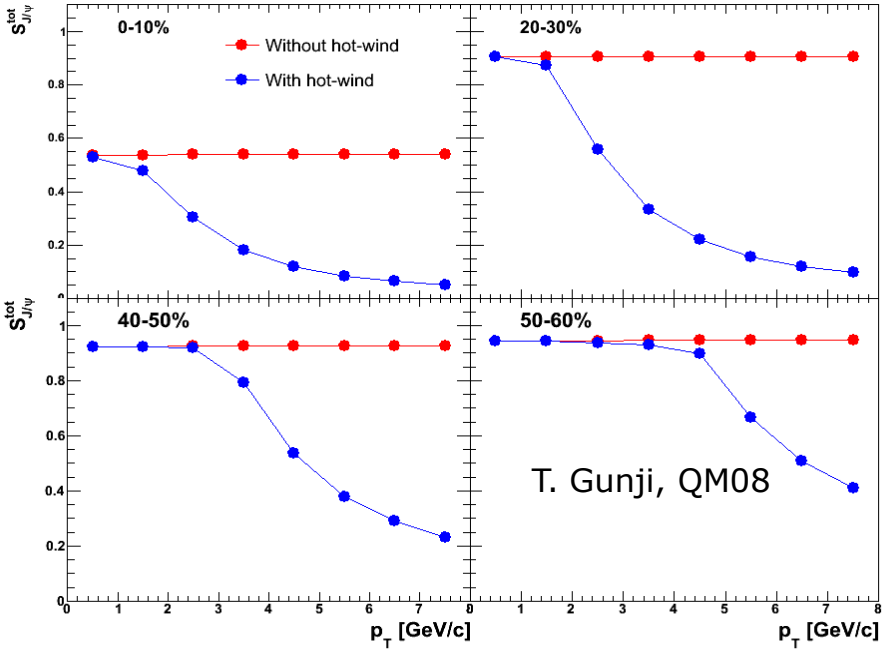
H. Liu, K. Rajagopal and U.A. Wiedemann PRL 98, 182301(2007) and hep-ph/0607062

High p_T direct J/ψ suppression ➔ related to hot wind dissociation?

2-component approach

Predicted decrease R_{AA}

X. Zhao and R. Rapp, hep-ph/07122407



Color singlet model predicted an increase R_{AA}

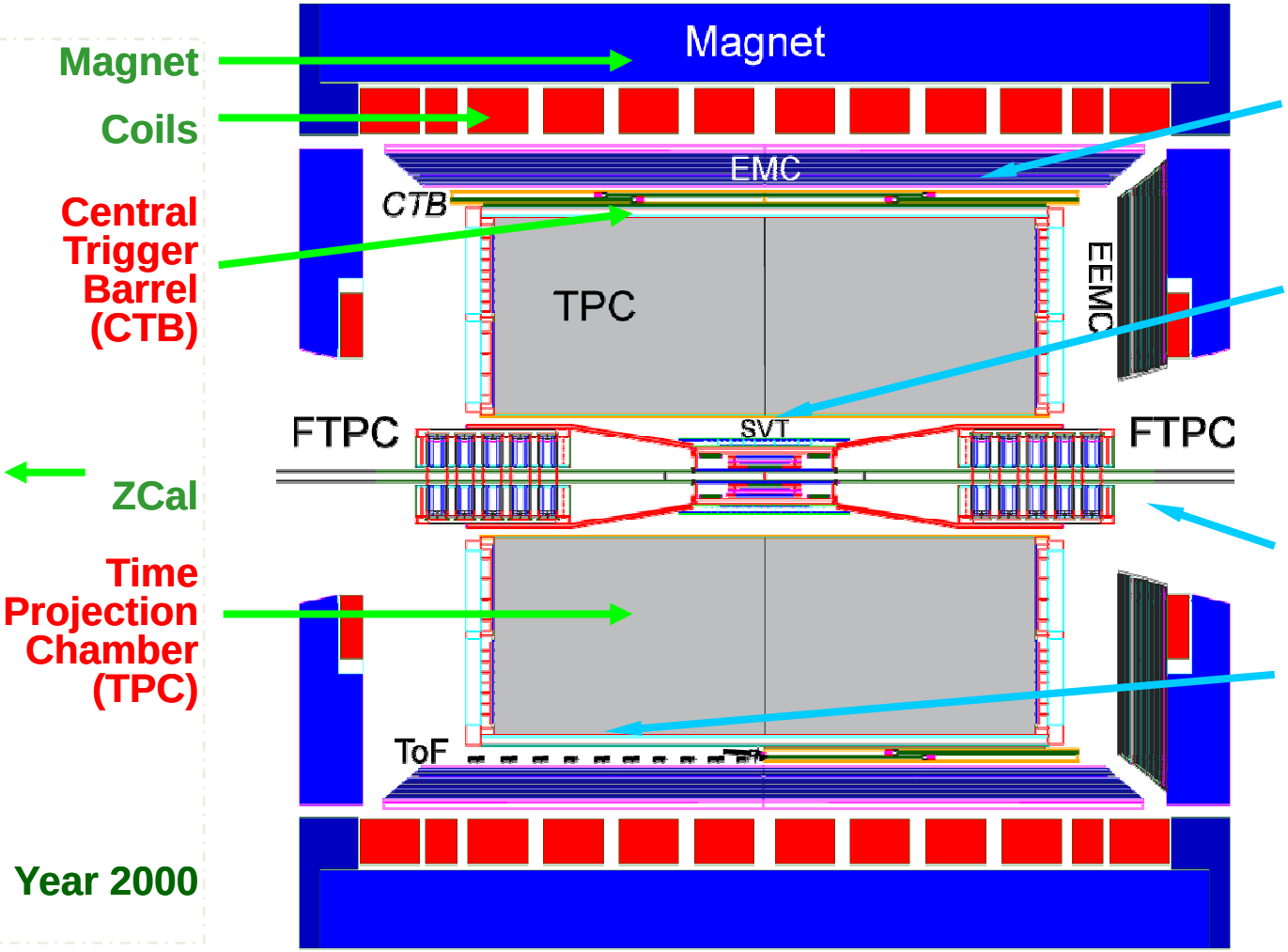
(formed outside of medium)

K. Farsch and R. Petronzio, PLB 193(1987), 105

J.P. Blaizot and J.Y. Ollitrault, PLB 199(1987),499

The STAR Detector

Large acceptance: 2π coverage at mid-rapidity



Magnet

Coils

Central Trigger Barrel (CTB)

ZCal

Time Projection Chamber (TPC)

Year 2000

Barrel EM Cal (BEMC)

Silicon Vertex Tracker (SVT)
Silicon Strip Detector (SSD)

FTPC
Endcap EM Cal
FPD

TOFp, TOFr

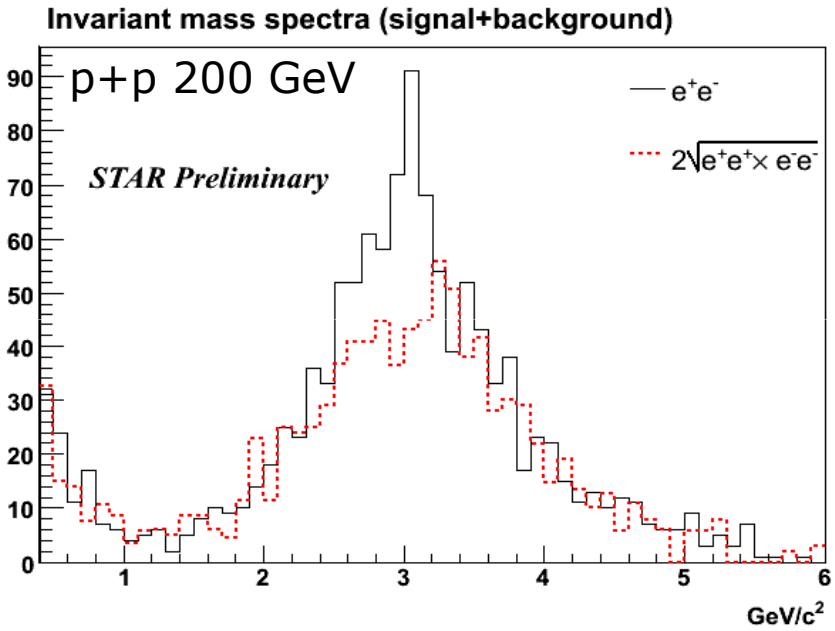
PMD

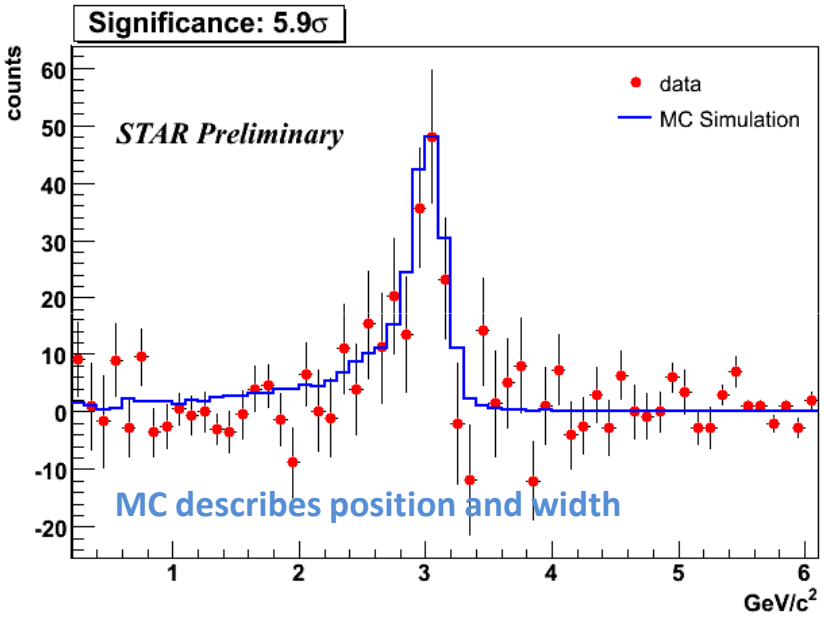
Year 2001+

Future upgrade: Time of Flight, DAQ1000, Heavy Flavor Tracker, Muon Telescope Detector

Low p_T J/ψ in p+p at 200 GeV

J/ψ trigger $0 < p_T < 5.5$ GeV/c



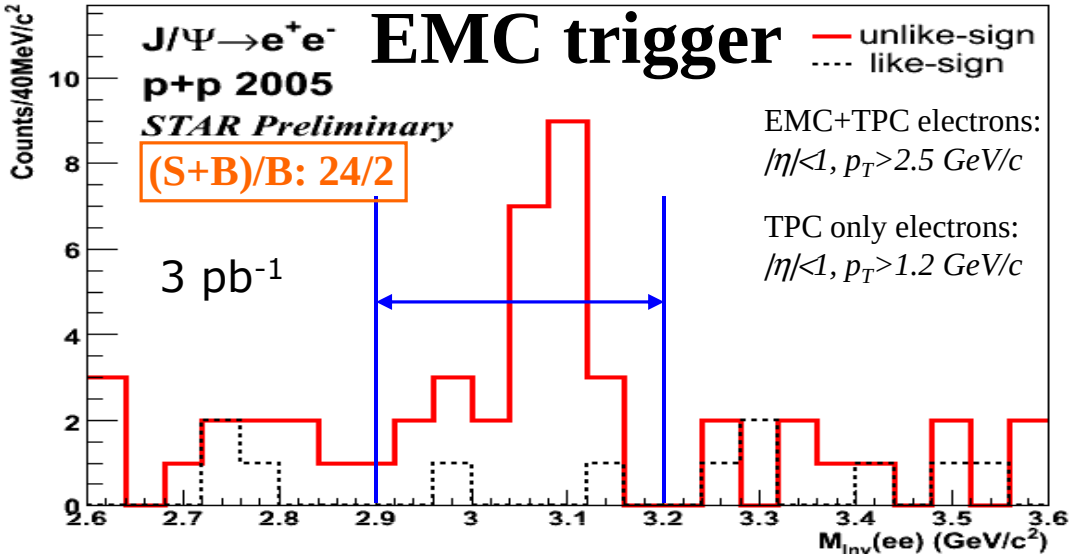


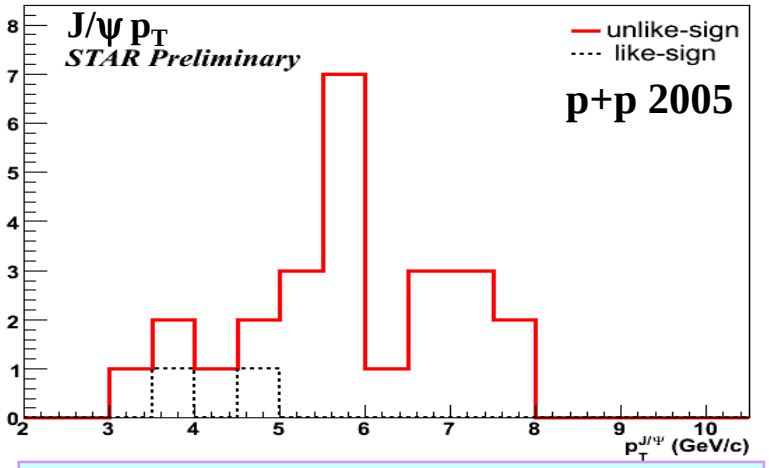
STAR has J/ψ capabilities at low p_T

Mass and width consistent with MC simulation, low mass tail from electron bremsstrahlung

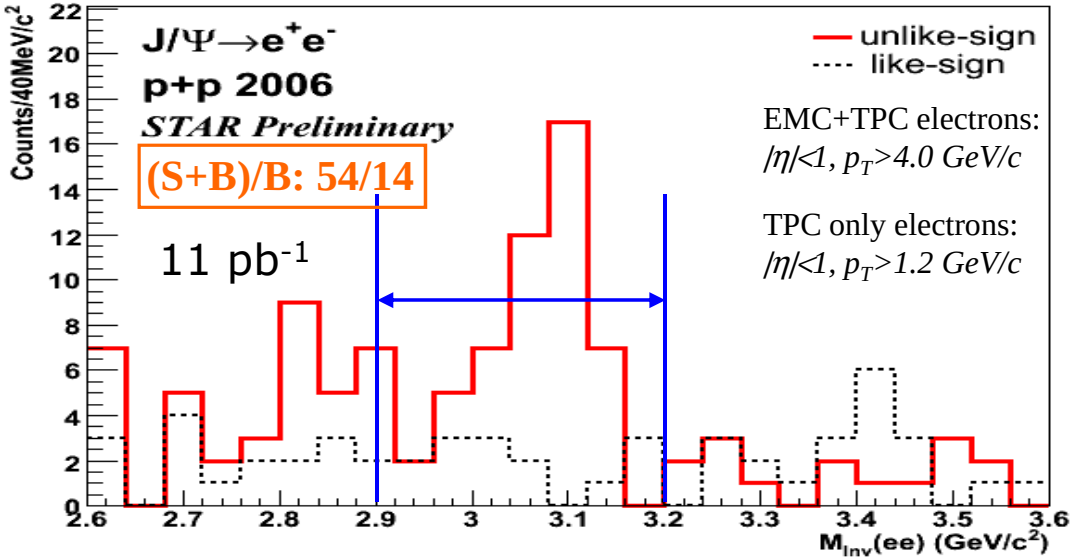
Integrated p+p luminosity at 200 GeV: 0.4 $(pb)^{-1}$

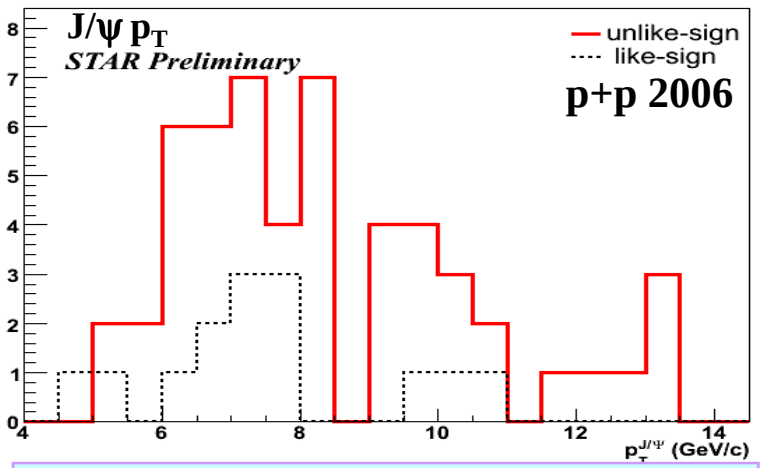
High p_T J/ψ in p+p at 200 GeV





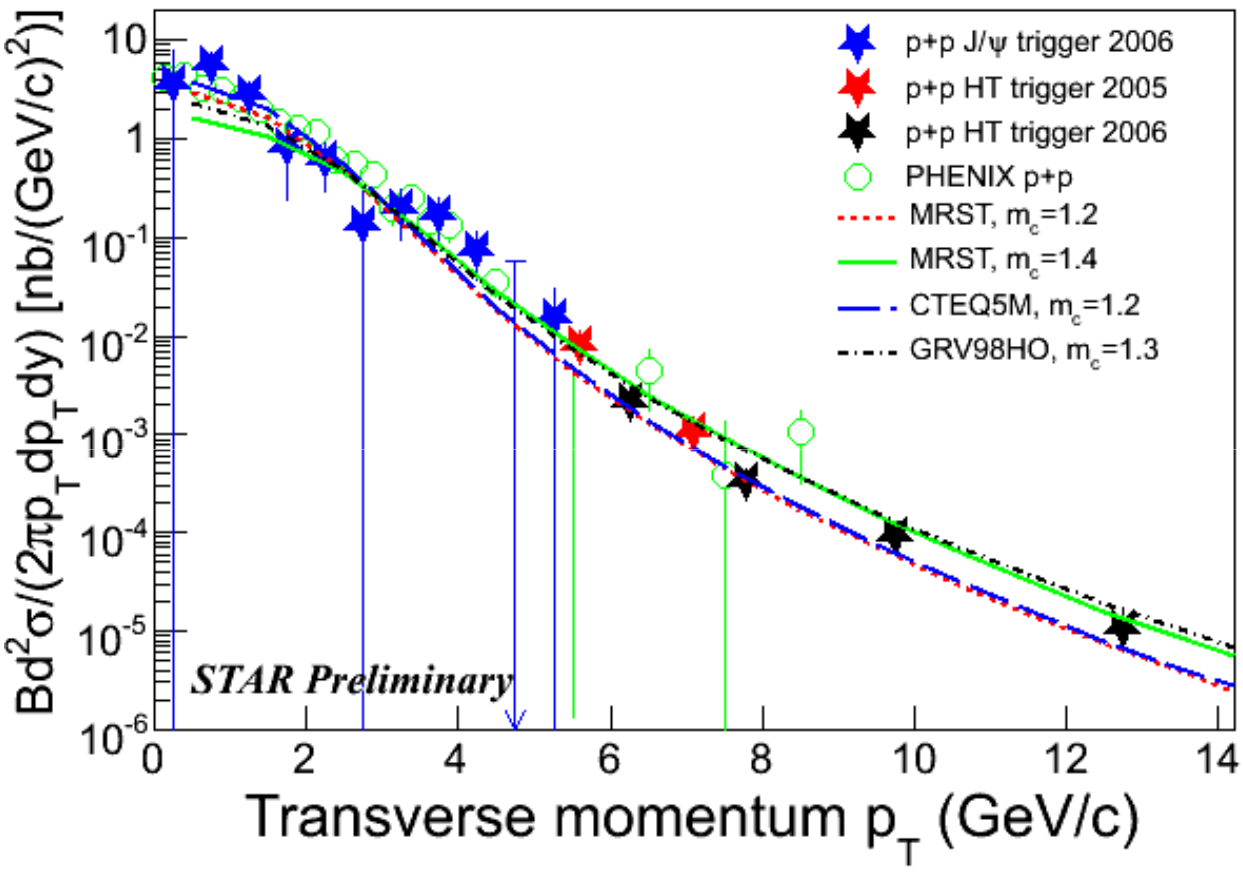
No background at p_T>5GeV/c





Reach higher p_T (~14GeV/c)

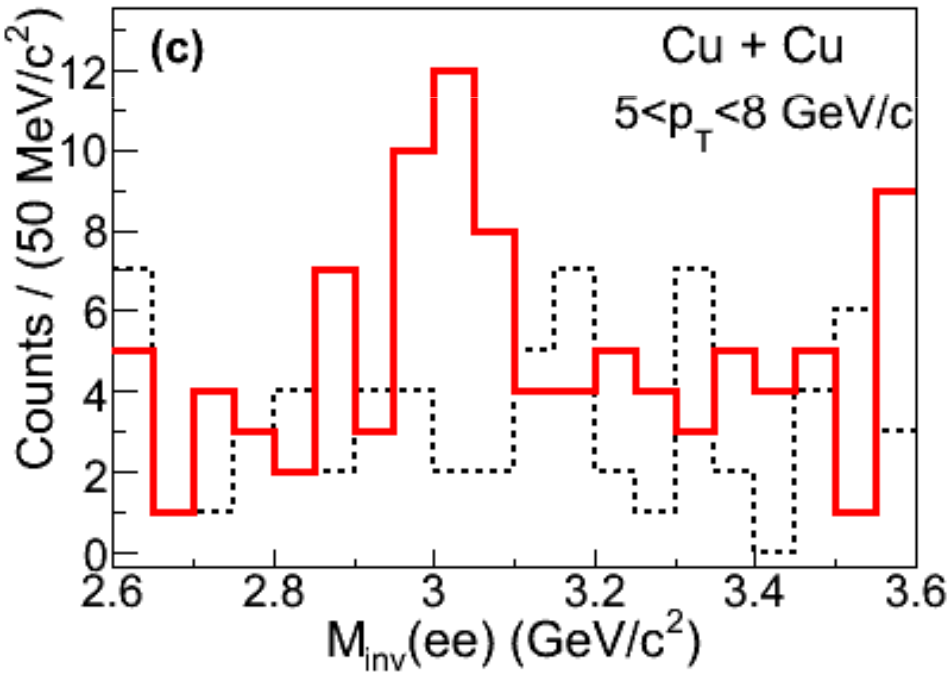
J/ψ spectra in p+p at 200 GeV

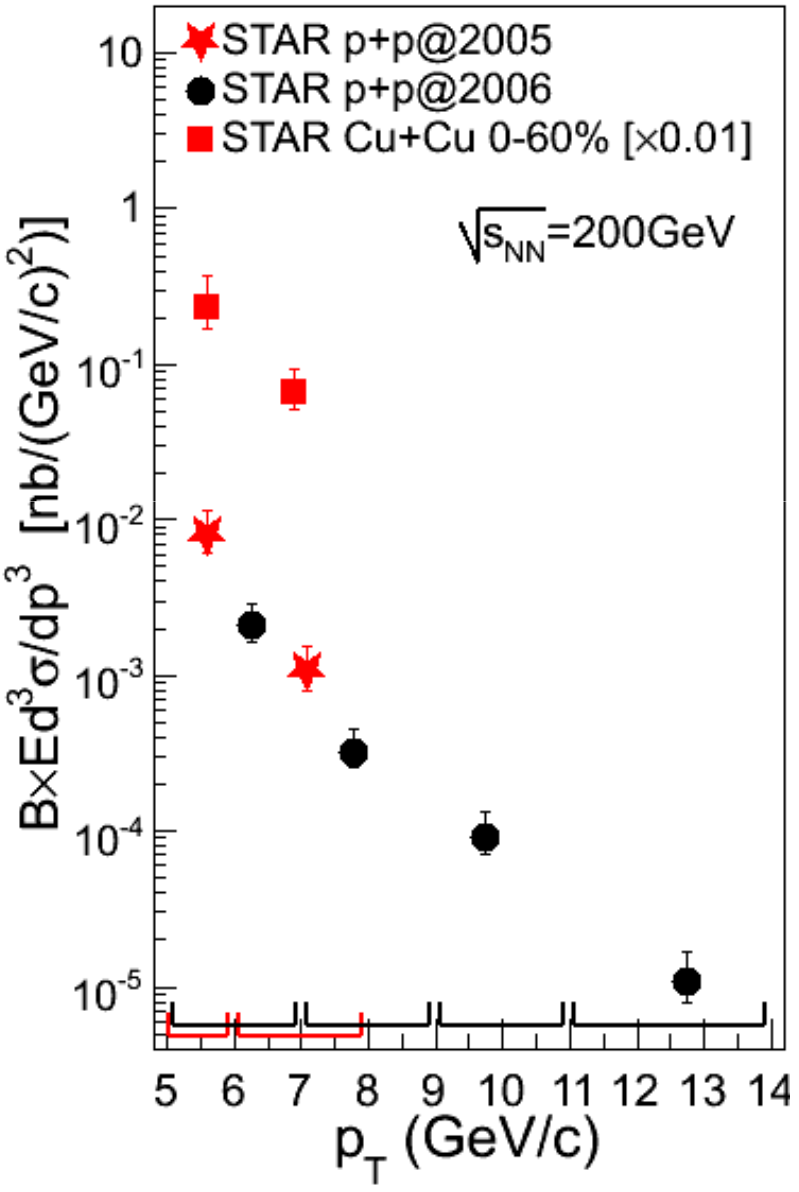


- Significantly extend p_T range of previous measurements in p+p at RHIC to 14 GeV/c
- Agreement of charm measurements between STAR and PHENIX
- Consistent with Color Evaporation calculations (R. Vogt, Private communication)

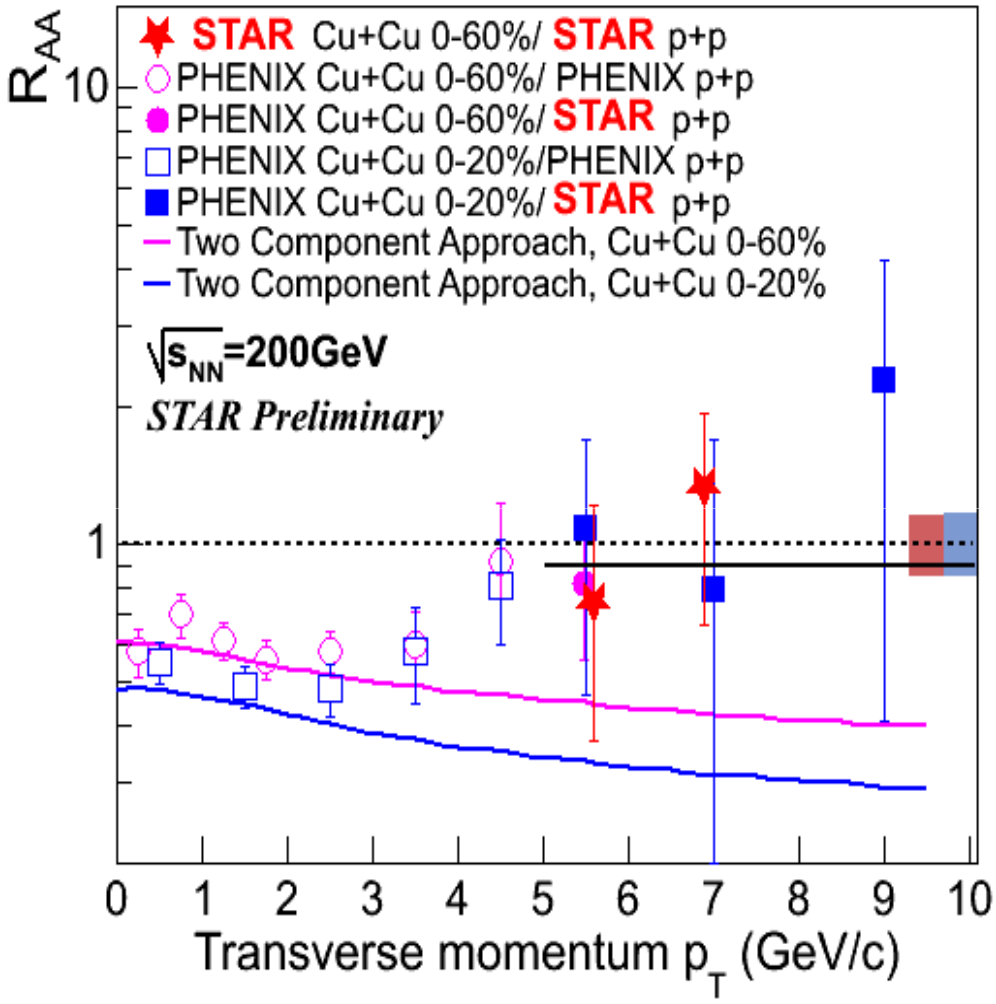
J/Ψ in Cu+Cu

- Signal with good S/B ratio
- p_T range overlaps with p+p data
- Luminosity: 0.9 nb^{-1}





Nuclear modification factor R_{AA}



- Double the p_T range to 10GeV/c
- Consistent with no suppression at high p_T:

  $R_{AA}(p_T>5$ GeV/c) = 0.9±0.2

  2σ above low-p_T data
- Indicates R_{AA} increase from low p_T to high p_T

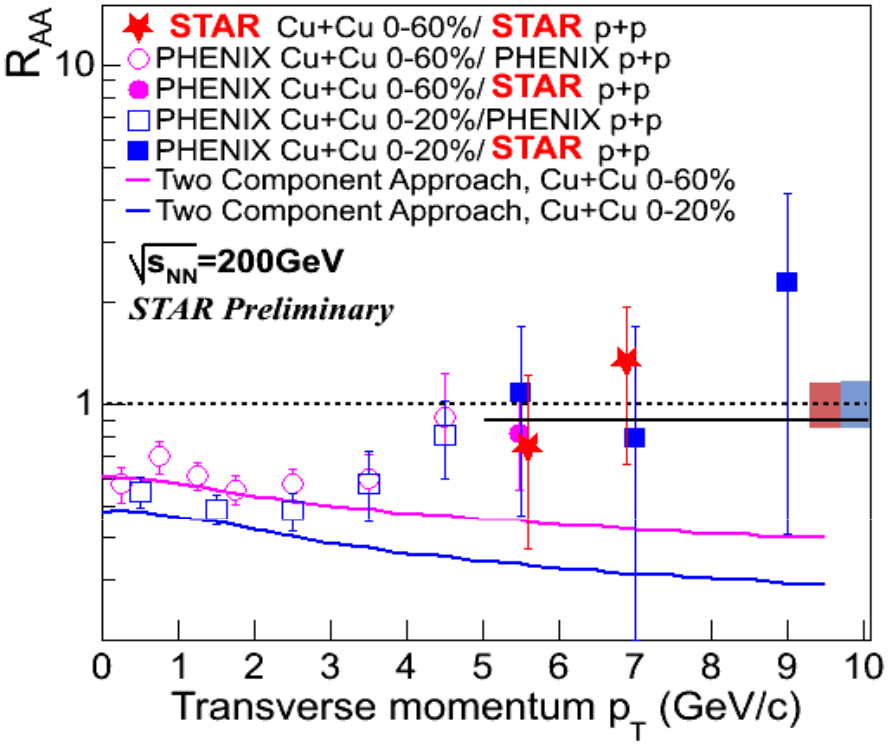
- Doesn't agree with AdS/CFT prediction
- Formed out of medium?

Affect by heavy quark/gluon energy loss

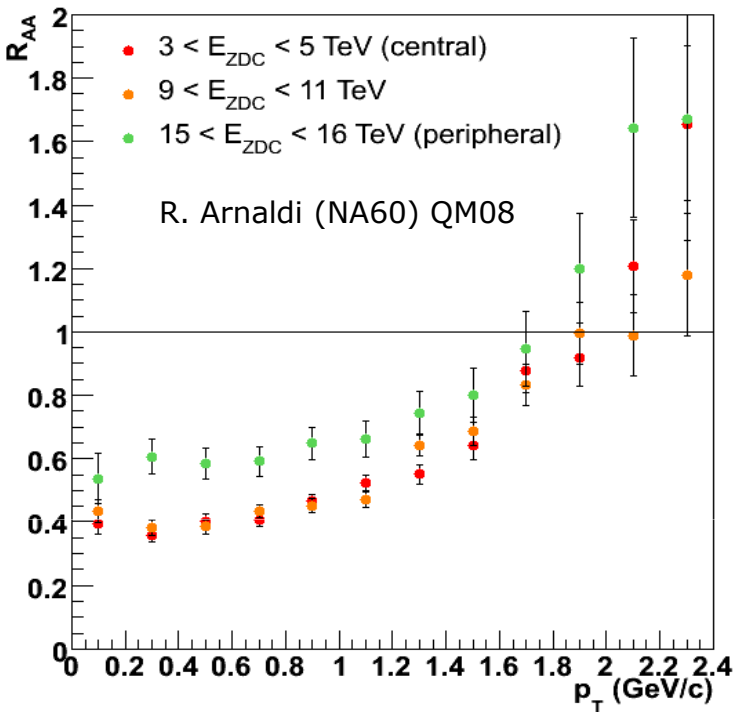
- Decay from other particles?

2-component Approach predicted slightly increase R_{AA} after more consideration *X. Zhao, WWND2008*

R_{AA} Comparison to NA60



RHIC: Cu+Cu, $\sqrt{s_{NN}} = 200GeV$
consistent with no suppression at $p_T > 5$ GeV



SPS: In+In, $\sqrt{s_{NN}} = 17.3GeV$,
consistent with no suppression at $p_T > 1.8$ GeV

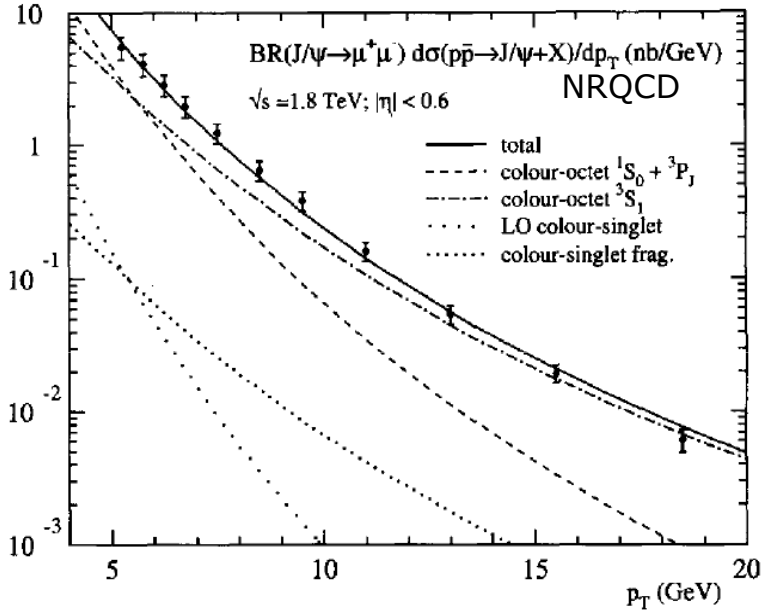
Cronin
pA➔pp
Thermal fit

Important to understand production mechanism ➔

Quarkonium production mechanism

- ✓ Color singlet model (CSM) [1] → pQCD
- ✓ Color octet model (COM) [2] → NRQCD
- ✓ Color evaporation model (CEM) [3]
- ✓ …

- Gluon fusion
- Heavy quark fragmentation [4]
- Gluon fragmentation [5]
- Decay feed-down
- …

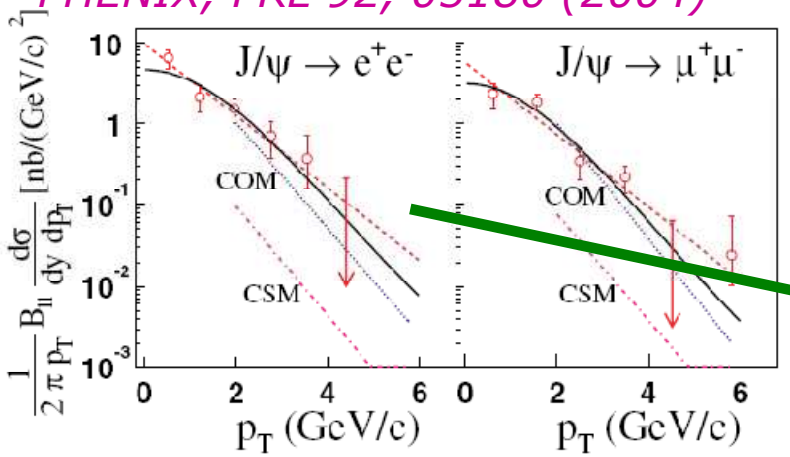


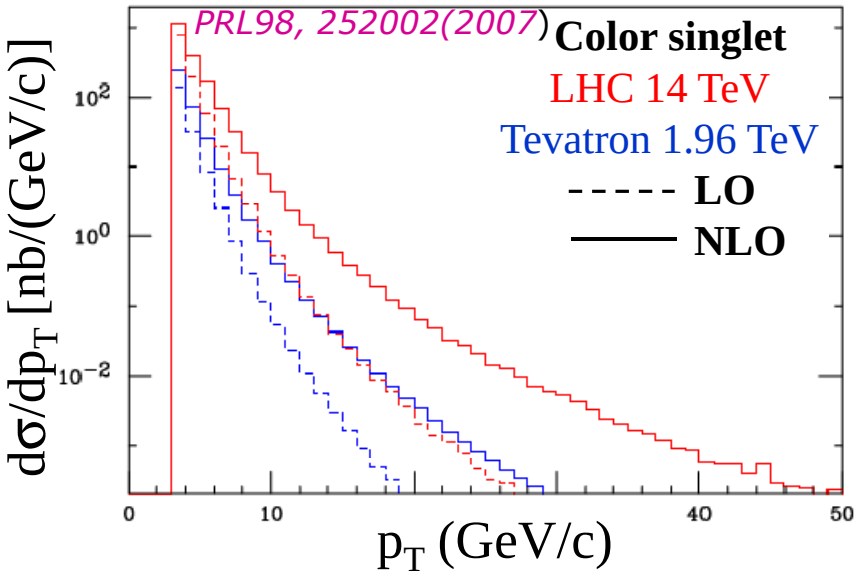
What's the production mechanism at RHIC energy?

1) R. Baier et al., PLB 102, 364 (1981)
2) M. Kramer, Progress in Particle and Nuclear Physics 47, 141 (2001)
3) H. Fritzsch, PLB 67, 217 (1977)
4) Cong-Feng Qiao, hep-ph/0202227
5) K. Hagiwara et al., hep-ph/0705.0803

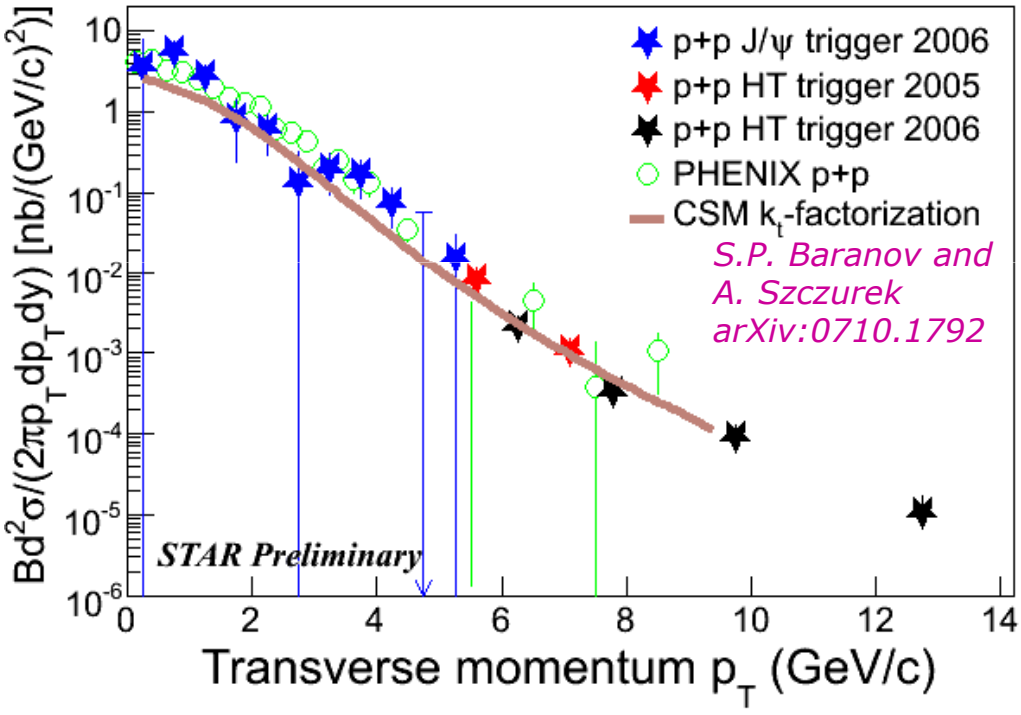
CSM with k_t-factorization

PHENIX, PRL 92, 05180 (2004)

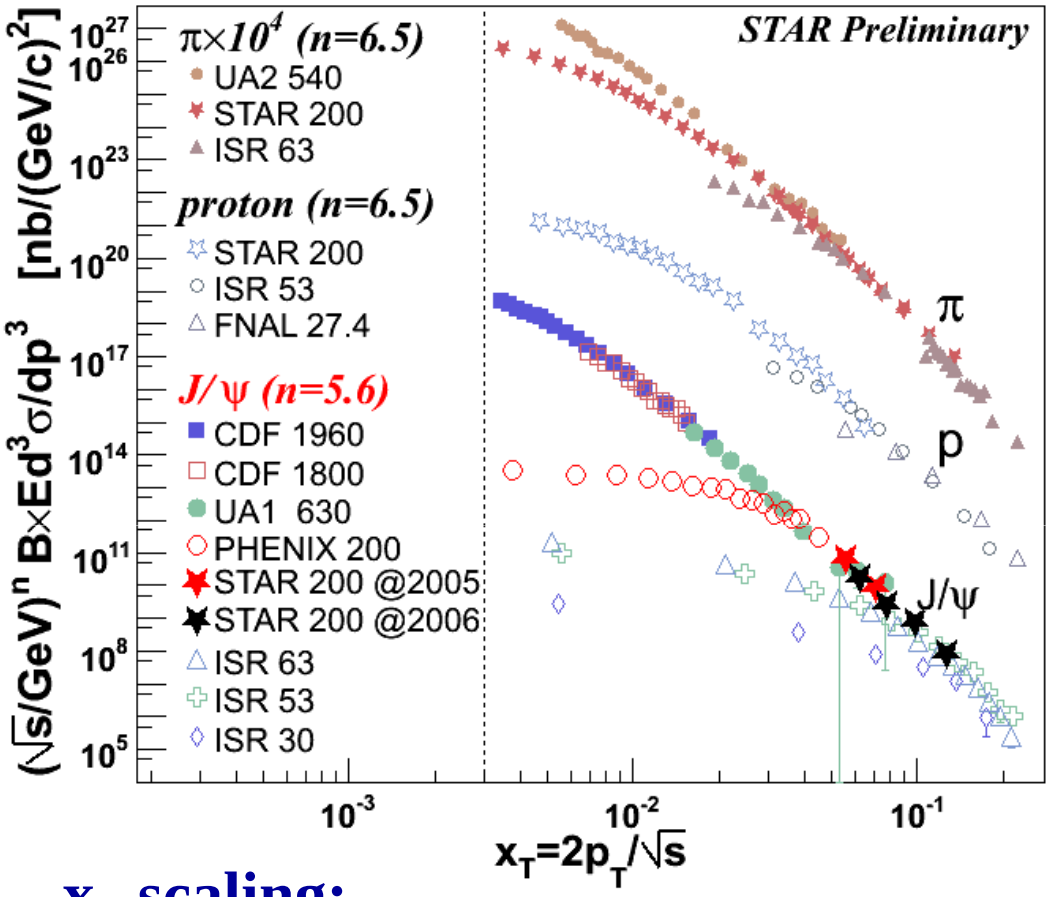




CSM can also describe the data with some improvement like the k_t-factorization approach



x_T scaling



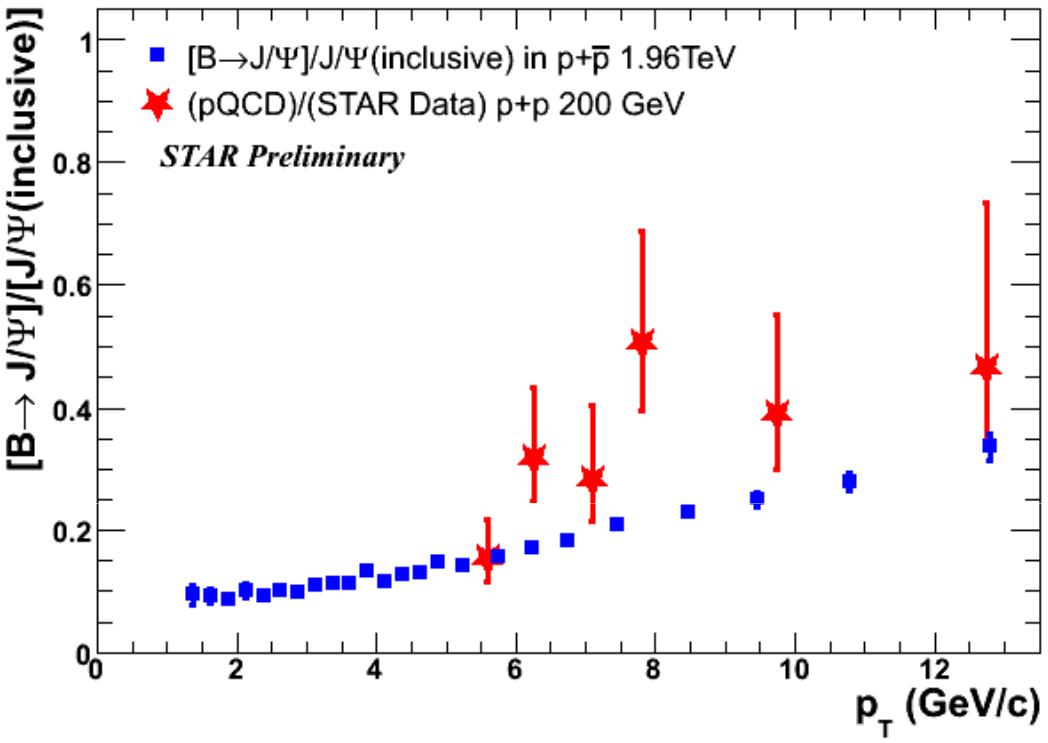
n is related to the number of point-like constituents taking an active role in the interaction

n=8: diquark scattering
n=4: QED-like scattering

x_T scaling:

- ✓ **π and proton: n=6.5±0.8** ***PLB 637, 161(2006)***
- ✓ **J/ψ: n=5.6±0.2**
- ✓ **J/ψ production: closer to 2→2 scattering**

(B→ J/ψ)/(inclusive J/ψ)



1) Generated B spectrum is from pQCD

M. Cacciari, P. Nason and R. Vogt

PRL 95(2005),122001

2) Decay B→J/ψ, kinematics and branch ratio are from CLEO measurements

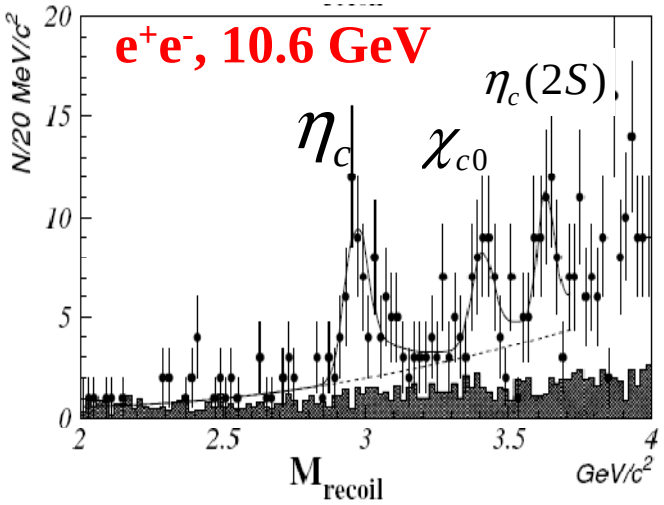
CLEO collaboration

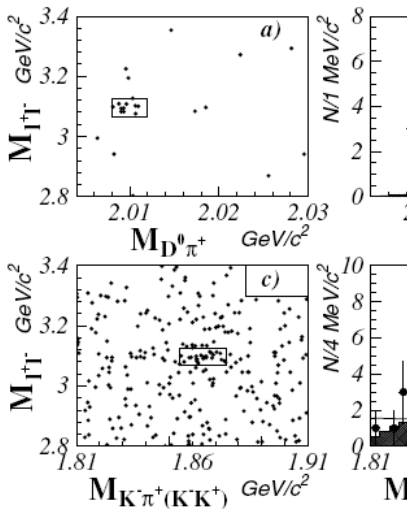
PRL 89(2002),282001

- B→J/ψ contributes significantly to the inclusive J/ψ yields at high p_T (>5 GeV/c)

  Assuming B production from pQCD (no experimental B spectra at RHIC yet)
- Can be used to constrain B production

More J/ψ production puzzles

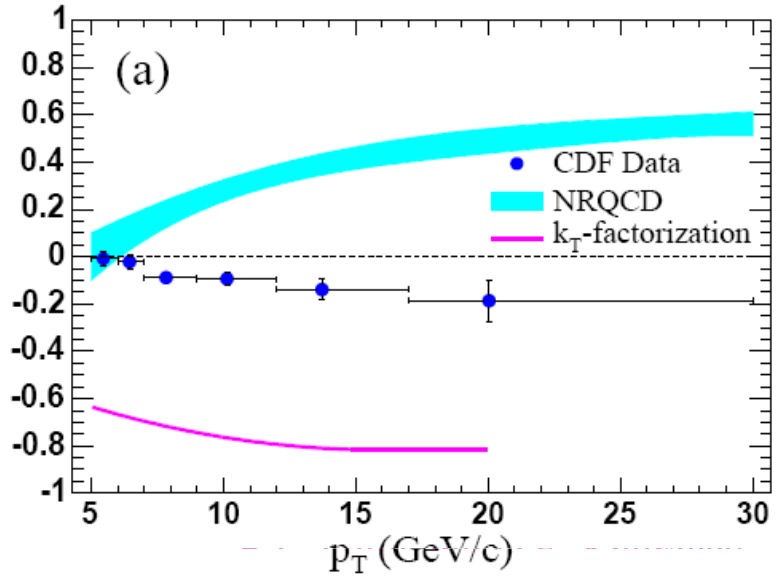


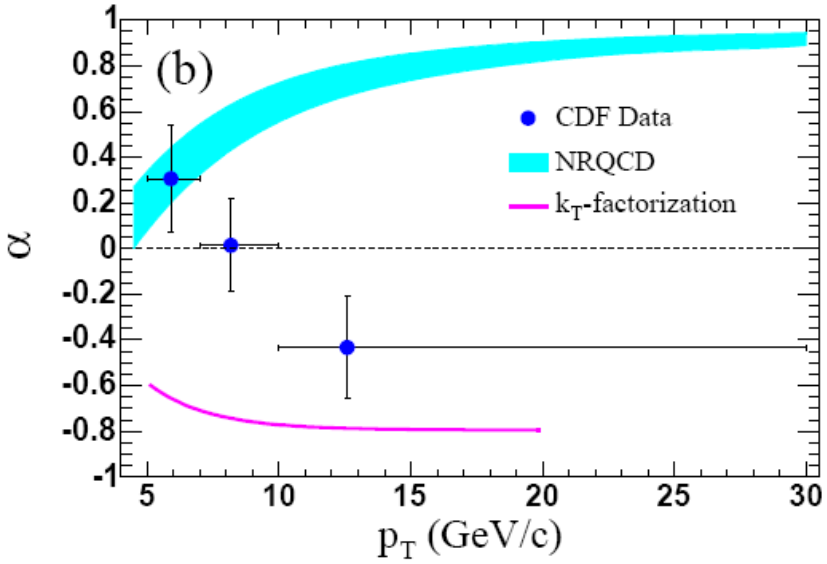


$$M_{recoil} = \sqrt{(\sqrt{s} - E^*_{J/\psi})^2 - p^{*2}_{J/\psi}}$$

η_c

Belle, PRL 89, 1420



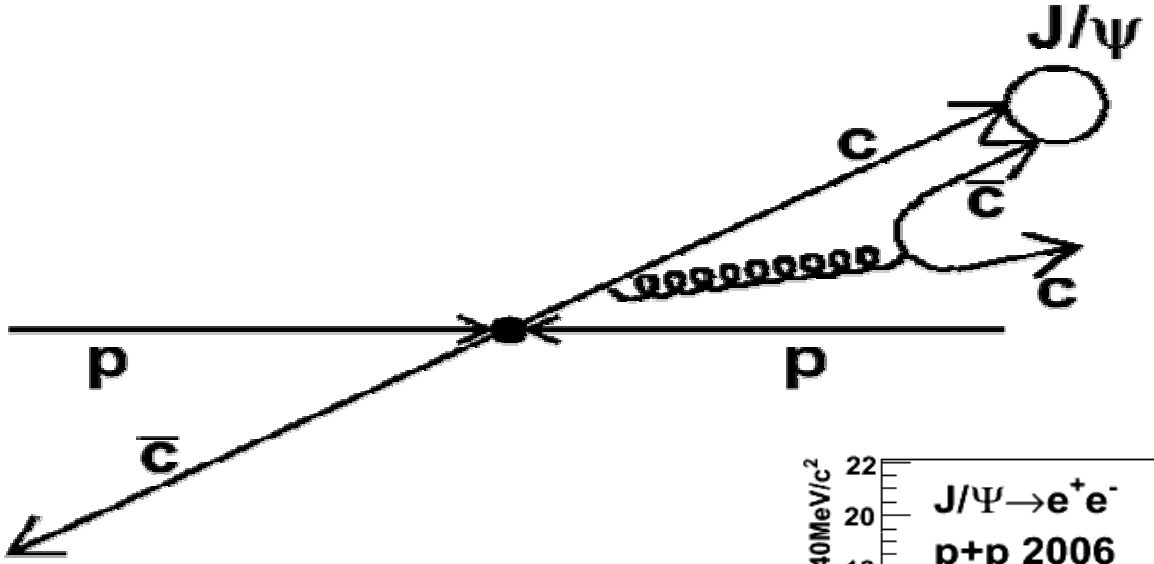


$(e^+e^- \rightarrow J/\psi + c\bar{c})/(e^+e^- \rightarrow J/\psi + X) = 0.59^{+0.15}_{-0.13} \pm$
0.82 ±0.15 ± 0.14 from new analysis. *T.*

While CEM predict 0.049 *D. Kang, et al., PRD 71, (*
NRQCD predict ~0.1 *K. Liu and Z. He, PRD 68*

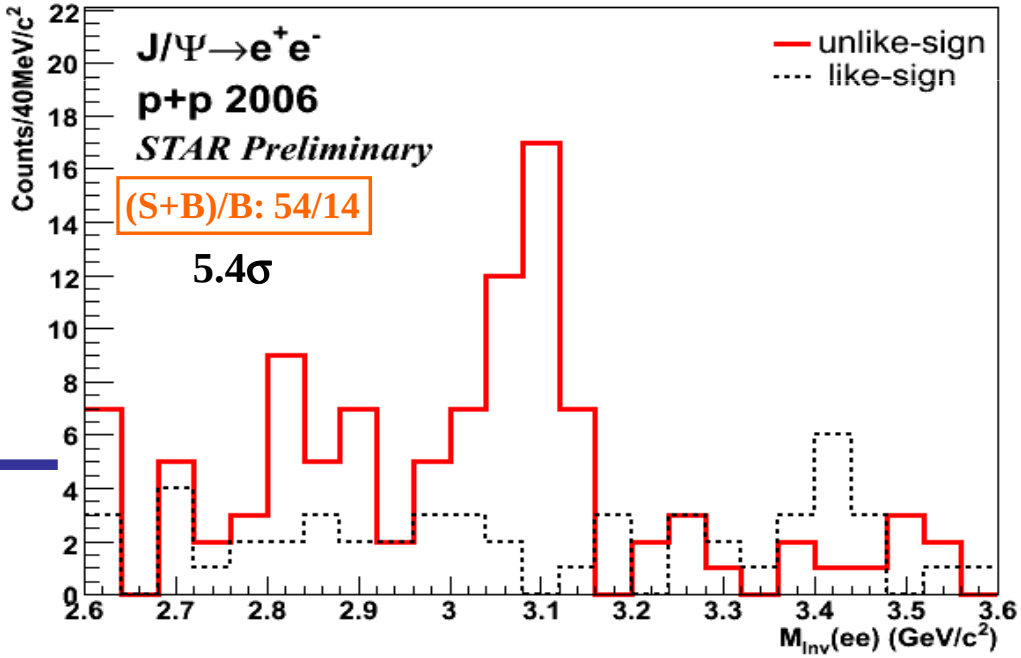
What happens?: In p+p collisions;
At higher energy (200 GeV)

J/ψ-hadron correlation



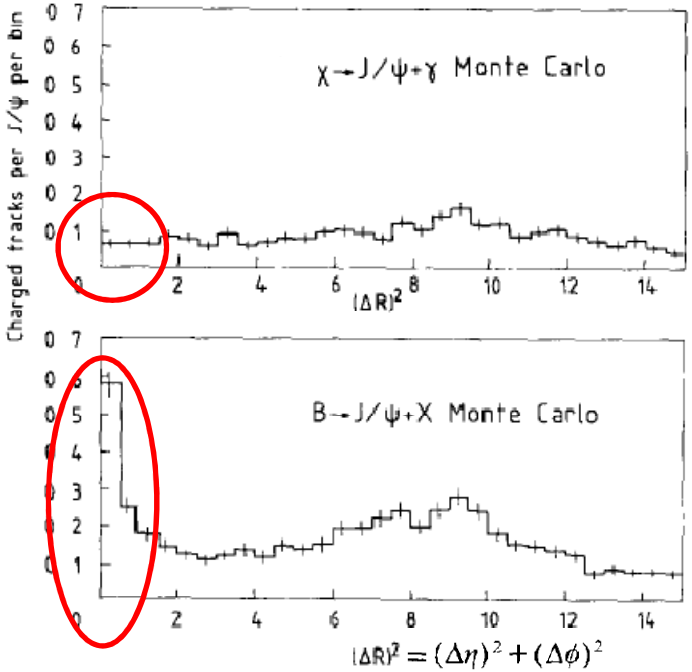
Near side correlation

Heavy quark fragmentation



Good S/B ratio makes this measurement possible

Disentangle contributions via Correlations



$\Leftrightarrow$

1) $g + g \rightarrow \chi + g$

$\rightarrow J/\psi + \gamma$

no near side correlation

$\Leftrightarrow$

2) $g + g \rightarrow b + \bar{b}$

$\rightarrow B_{hadron} + X$

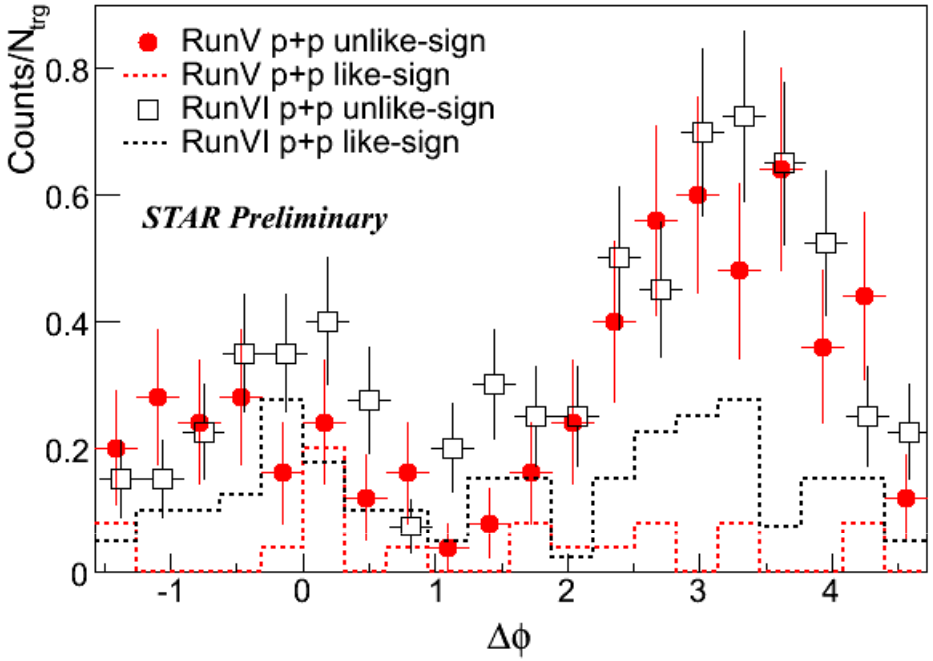
$\rightarrow J/\psi + X$

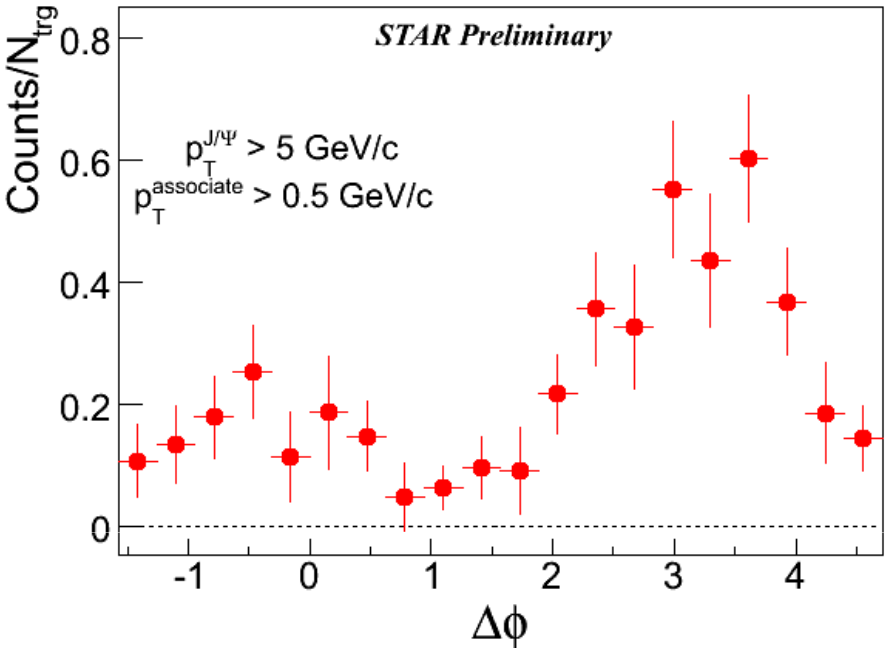
strong near side correlation

PLB 200, 380(1988) and PLB 256,112(1991)

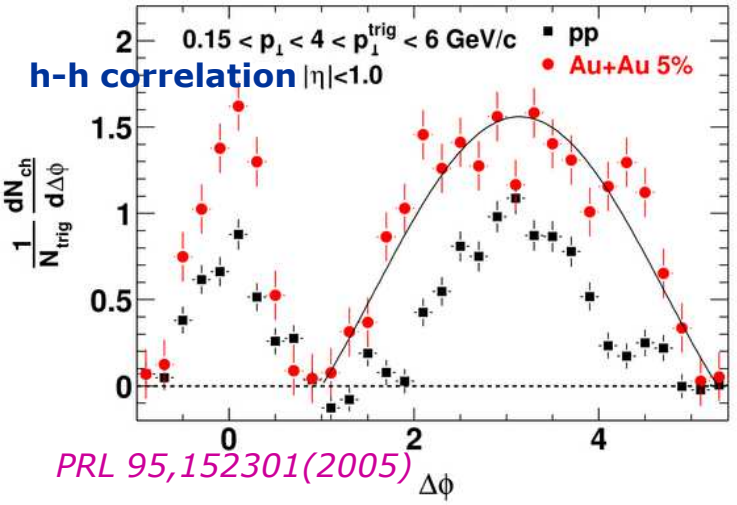
- **J/ψ-hadron correlation can also shed light on different source contribution to J/ψ production**
- **May be used to distinct CSM and COM**

J/ψ–hadron correlation in p+p



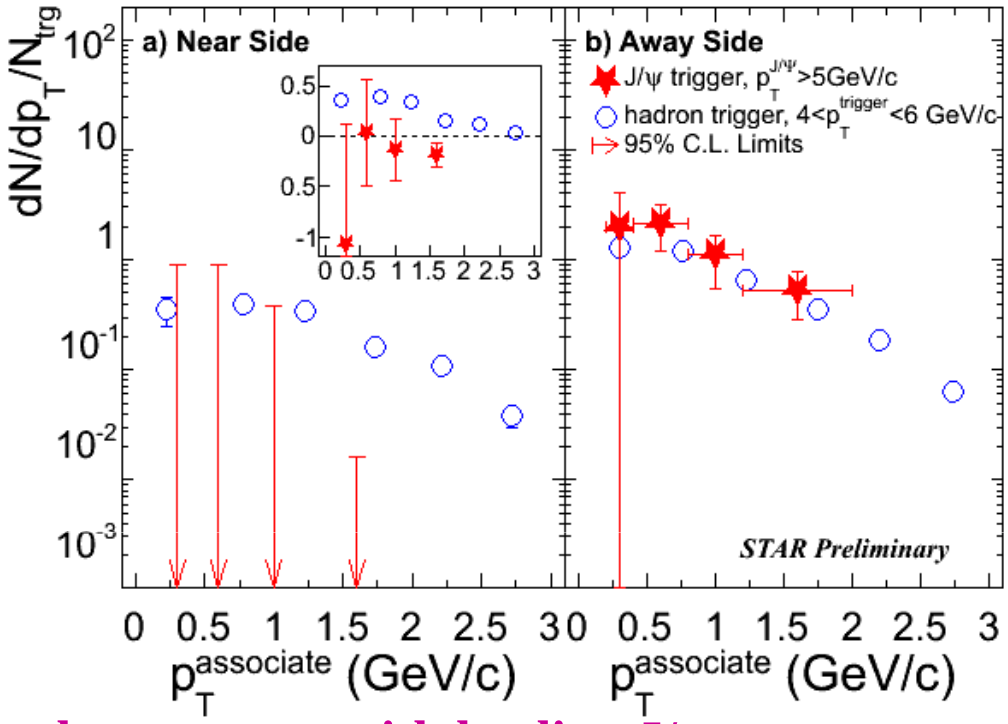


- No significant near side J/ψ-hadron azimuthal angle correlation
- Constrain B meson's contribution to J/ψ yield
- Hints of CSM?



PRL 95,152301(2005)

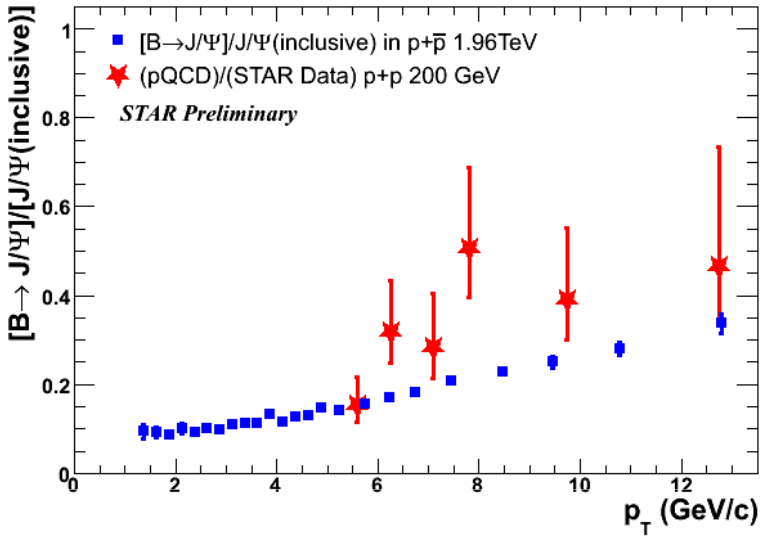
Yields in near/away side

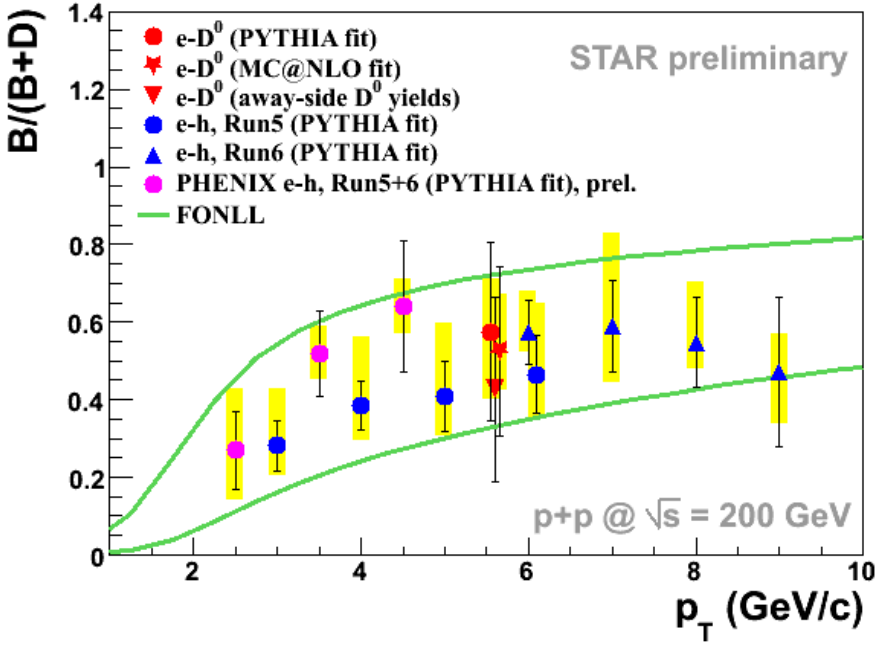


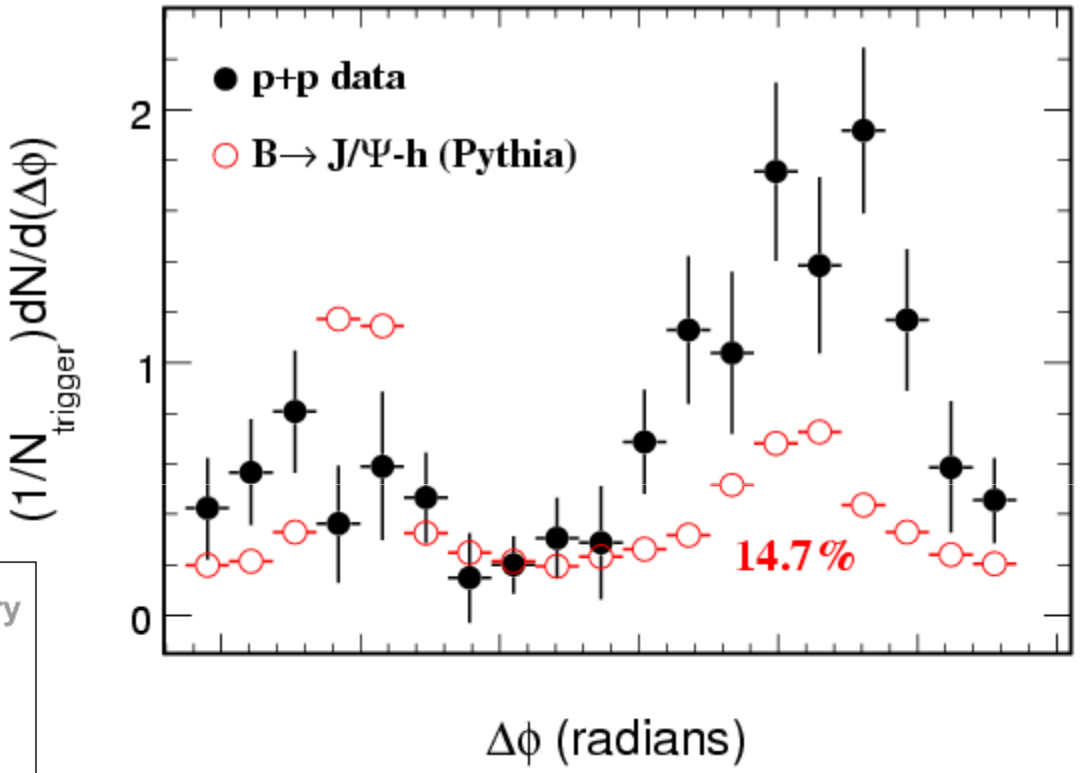
Associated hadron spectra with leading J/ψ:

- Away side: Consistent with leading charged hadron correlation measurement (h-h)
  ➔away-side from gluon or light quark fragmentation
- Near side: Consistent with no associated hadron production
  B➔J/ψ not a dominant contributor to inclusive J/ψ
  constrain J/ψ production mechanism

Constrain Bottom yields



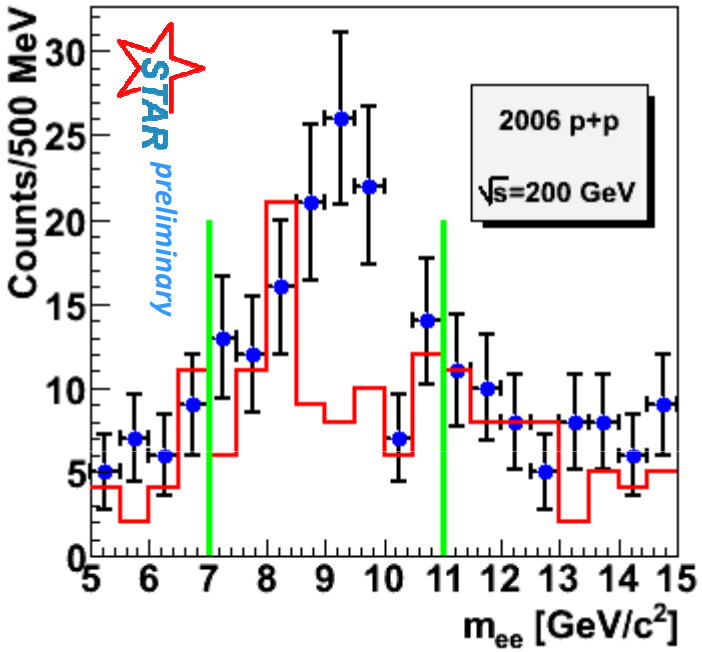


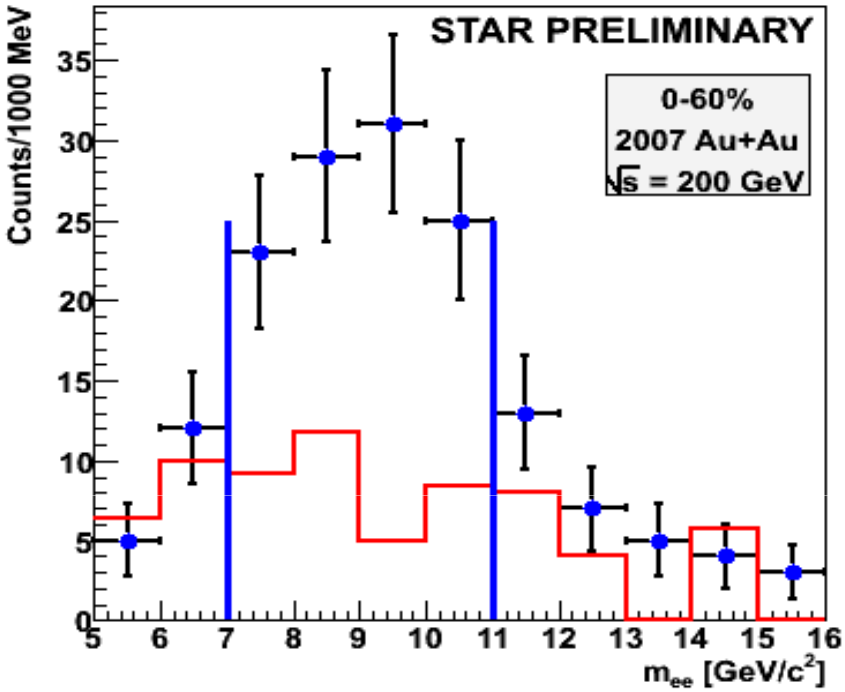


- pQCD predicts significant B➔J/Ψ
- Correlations shows low B contribution
- can used to further constrain B yields
- PYTHIA productions all show strong near-side correlation ➔

higher order production mechanism?

ϒ Signal in p+p and Au+Au

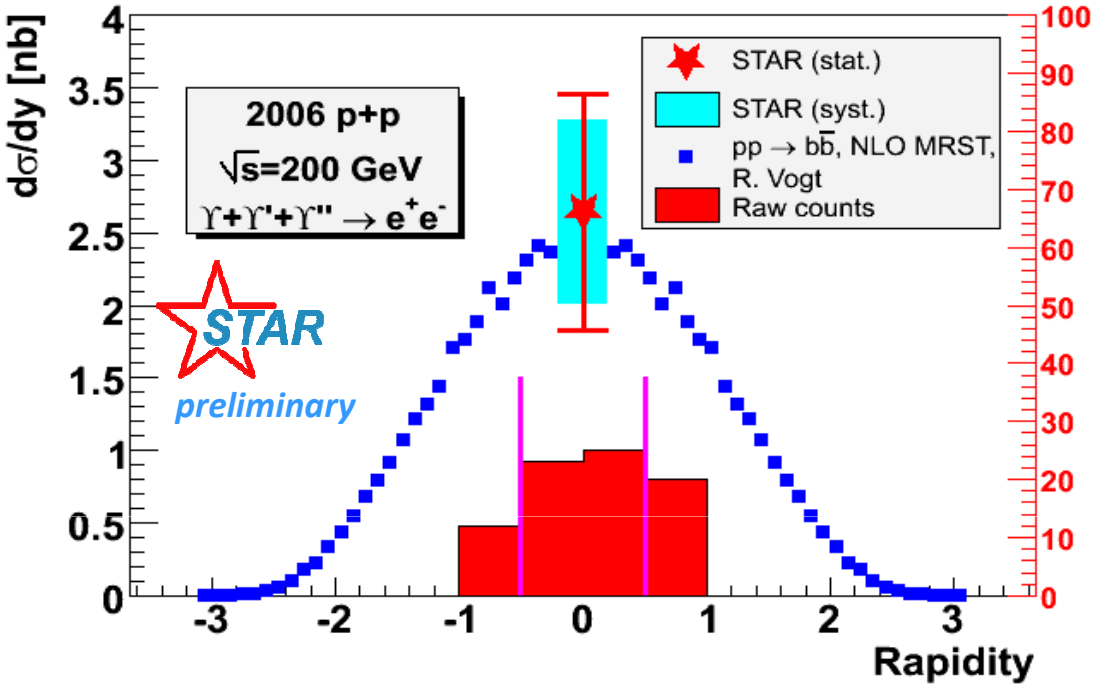




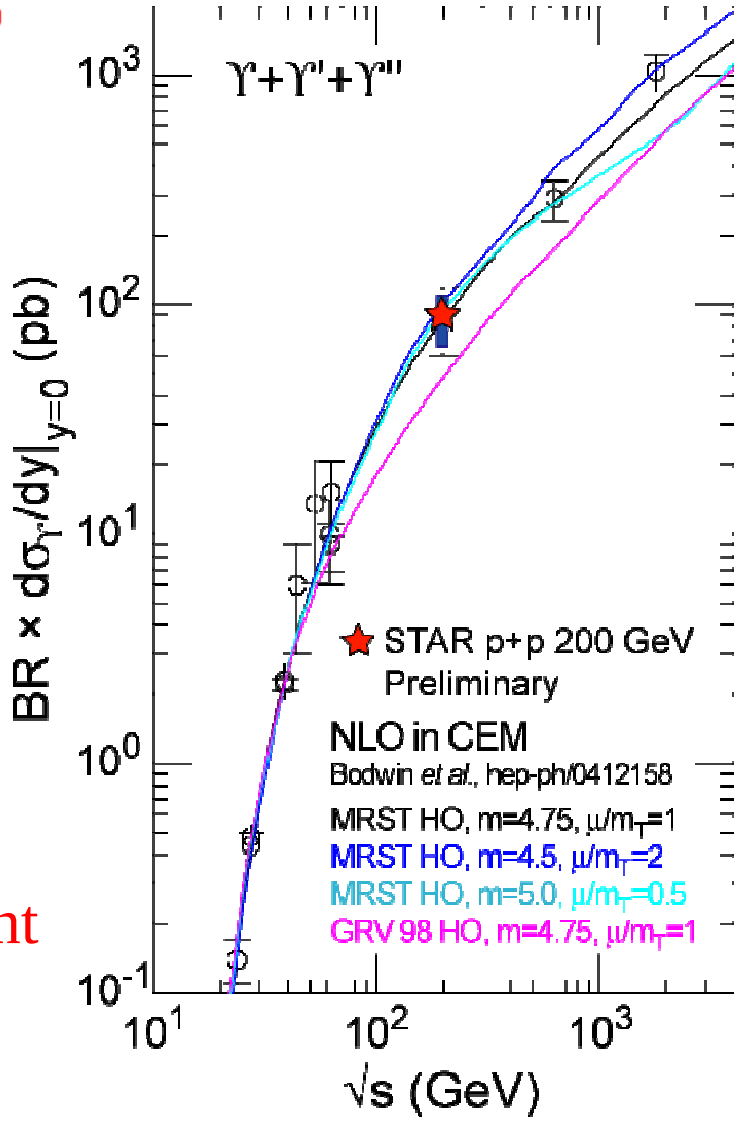
- ϒ(1S+2S+3S) total yield: integrated from 7 to 11 GeV from background-subtracted m_{ee} distribution
- Significance of signal is 3σ
- Note: Contribution from Drell-Yan (~9%) ignored

- 4σ signal
- First measurement of ϒ in nucleus-nucleus collisions ever
- R_{AA} in progress

ϒ cross-section in p+p



$B_{ee} \times (d\sigma/dy)_{y=0} = 91 \pm 28(stat.) \pm 22(syst.)$ pb

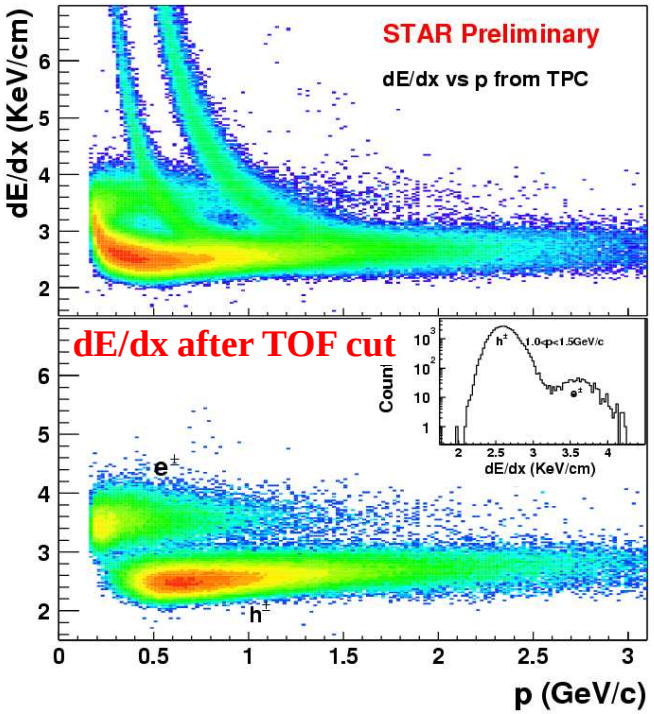


STAR 2006 √s=200 GeV p+p
$\Upsilon+\Upsilon'+\Upsilon'' \rightarrow e^+e^-$ cross section consistent with pQCD and world data

Future dramatic improvement of J /Ψ at low p_T

EMC+TOF (large acceptance):

- J /Ψ production
- Different states predicted to melt at different T in color medium
- Charmonia(J/Ψ), bottonia (ϒ)



Quarkonium dissociation temperatures – Digal, Karsch, Satz

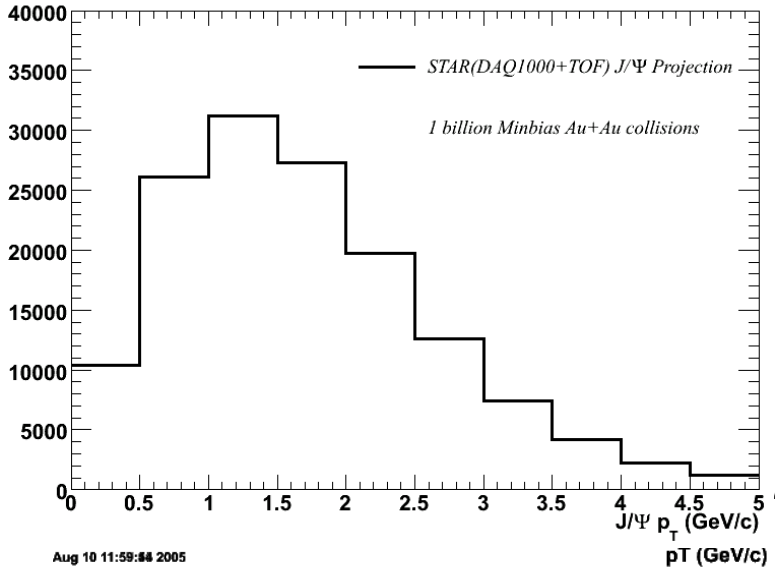
state	$J/\psi(1S)$	$\chi_c(1P)$	$\psi(2S)$	$\Upsilon(1S)$	$\chi_b(1P)$	$\Upsilon(2S)$	$\chi_b(2P)$	$\Upsilon(3S)$
T_d/T_c	2.10	1.16	1.12	> 4.0	1.76	1.60	1.19	1.17

PHENIX Acceptance: $|\eta|<0.35, \phi=2*\pi/2$

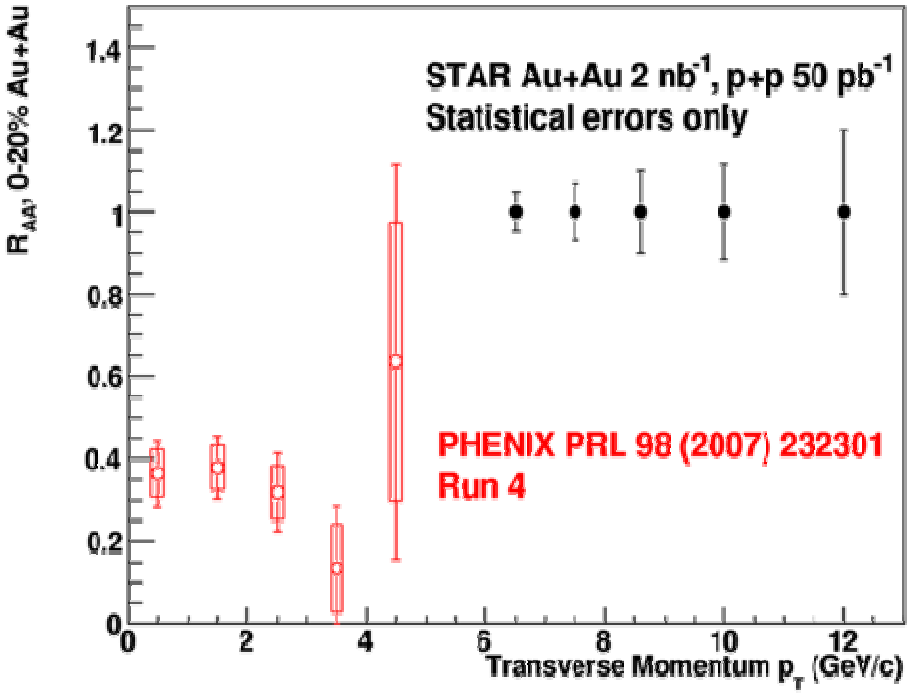
STAR TOF Upgrade Acceptance: $|\eta|<0.9, \phi=2*\pi$

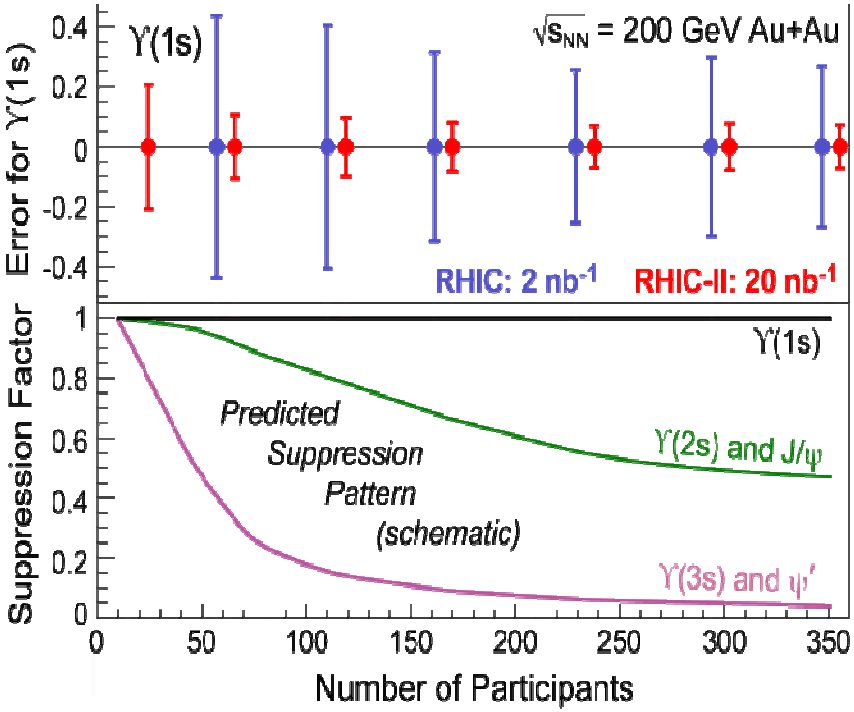
J/ψ yields from 10^9 minbias Au+Au events:
$43.8\times10^{-9}/0.040\times10^{9}*292*0.5*1.8*0.5=$
144,000➔0.3% v_2 error

$\sigma_{J/\psi}$ σ_{pp} N N_{bin} ε y R_{AA}



High luminosity for Υ & high-p_T J/Ψ





Time-Of-Flight:

Electron identification

RHIC II + DAQ1000:

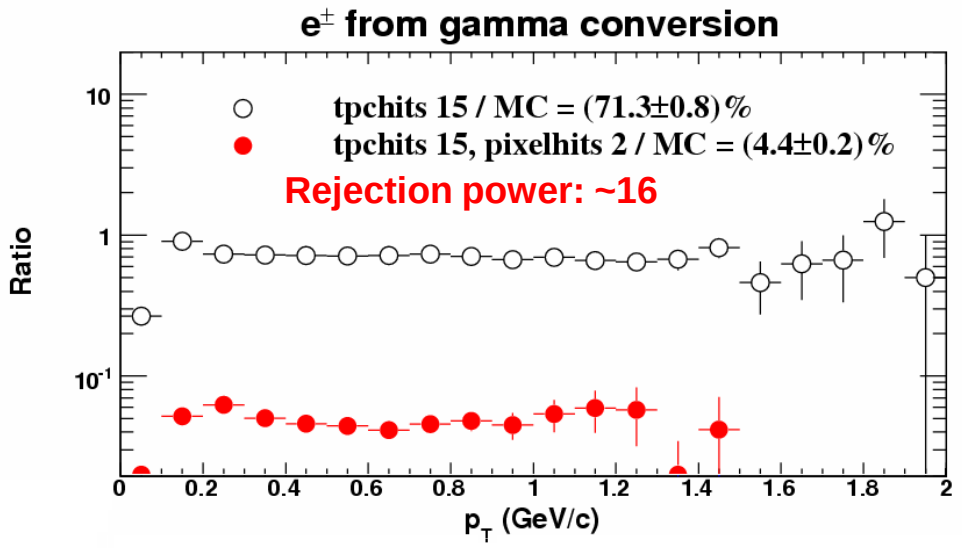
Enhance statistics

Longer term: Quarkonia in STAR

Heavy Flavor Tracker:

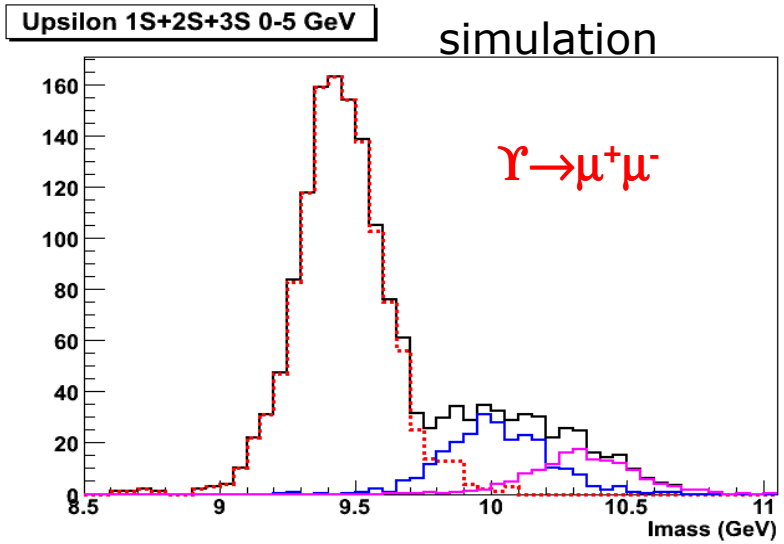
$\gamma \rightarrow e^+e^-$ rejection

Topologically reconstruct J/ψ from B decay



Muon Telescope Detector:

Muon identification



Summary (J/ψ)

- **J/ψ spectra in 200 GeV p+p collisions at STAR**
  1. Extend the p_T range up to ~14 GeV/c
  2. Spectra can be described by CEM and CSM.
  3. High p_T J/ψ follows x_T scaling with n=5.6
  4. Spectra at high p_T can be used to constrain B production

- **J/ψ–hadron azimuthal correlation in p+p**
  1. no significant near side correlation
     Expect strong near-side correlation from B→J/ψ+X
     Can be used to constrain J/ψ production mechanism
  2. Away-side spectra consistent with h-h correlation
     indicates gluon or light quark fragmentation

- **J/ψ R_{AA} from 200 GeV Cu+Cu collisions at STAR**
  1. Extend R_{AA} from p_T = 5 GeV/c to 10 GeV/c
  2. Indication of R_{AA} increasing at high p_T

Future

J/ψ results from Run 7 Au+Au, data is still under production

Upsilon R_{AA}

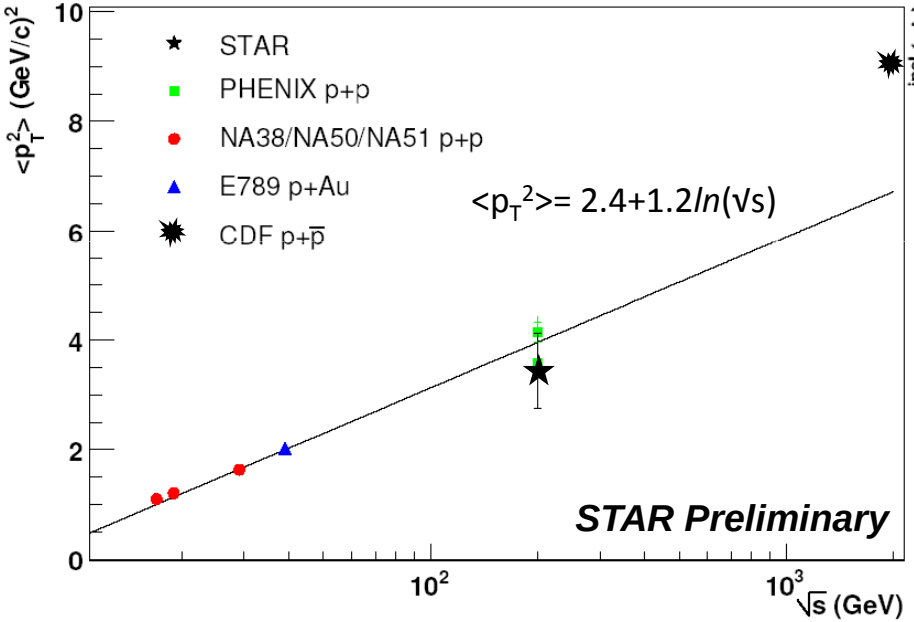
Run 8 (d+Au) just finished, Cold Nuclear Modification

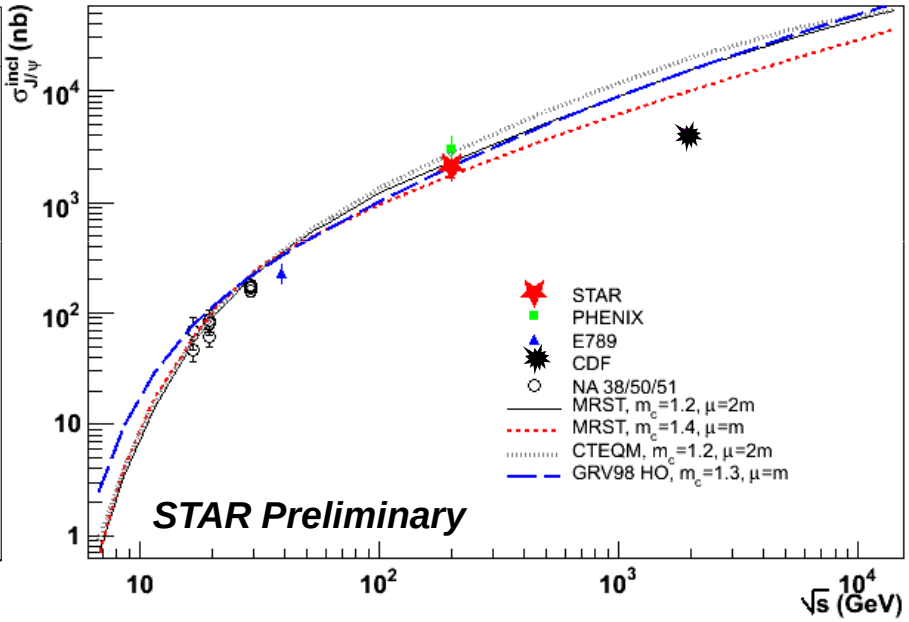
Run9—10, Au+Au and p+p runs with TOF and DAQ1000

Backup slides

mean p_T^2 and cross section

STAR Measurement & world data





$<p_T^2>$= 3.43±0.68 (GeV/c)^2

CEM calculation

M. Bejidian et al., hep-ph/0311048

CEM can also describe the total cross section

Datasets

Triggered data

p+p data sample:

- 1. J/ψ triggered events in year 2006
- Integrated luminosity: 377 $(nb)^{-1}$
- 2. ϒ triggered events in year 2006
- Integrated luminosity: 9$(pb)^{-1}$

Au+Au data sample:

- 1. ϒ triggered events in year 2007

  Integrated luminosity: 300$(\mu b)^{-1}$

  pp-equivalent: 12$(pb)^{-1}$

High-p_T J/ψ

p+p data sample:

- 1. EMC triggered events in year 2005

  E_T>3.5 GeV

  Integrated luminosity: 3 $(pb)^{-1}$
- 2. EMC triggered events in year 2006

  E_T>5.4 GeV

  Integrated luminosity: 11 $(pb)^{-1}$

Cu+Cu data sample:

- 1. EMC triggered events in year 2005

  E_T>3.75 GeV

  Integrated luminosity: 0.9 $(nb)^{-1}$

  pp-equivalent: 3 $(pb)^{-1}$