Quarkonia measurements at STAR

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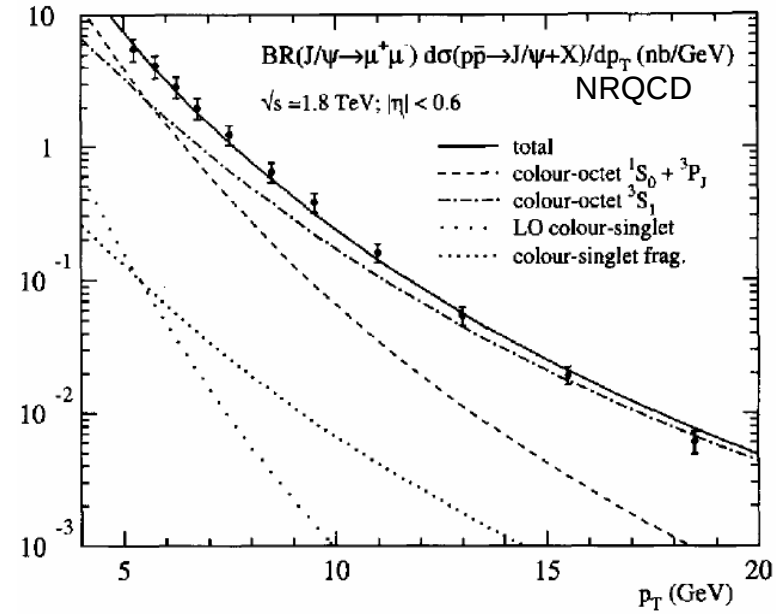
Outline:

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

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

sQGP effect

- Color screen effect [1)]
- Regeneration [2)]
- Gluon energy loss [3)]
- Heavy quark energy loss [3)]
- Decay feed-down

How the quarkonium produced 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)

The STAR Detector

Large acceptance: 2π coverage at mid-rapidity

Magnet

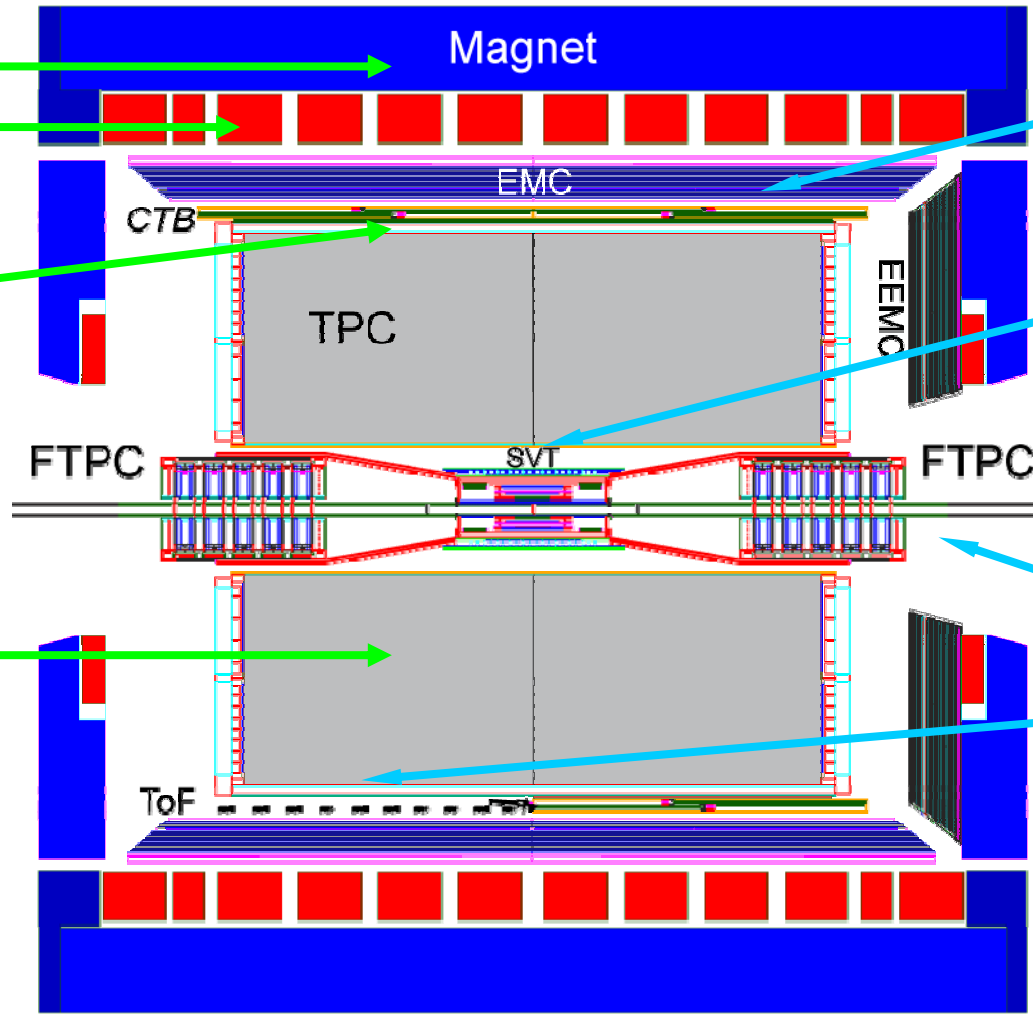
Coils

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

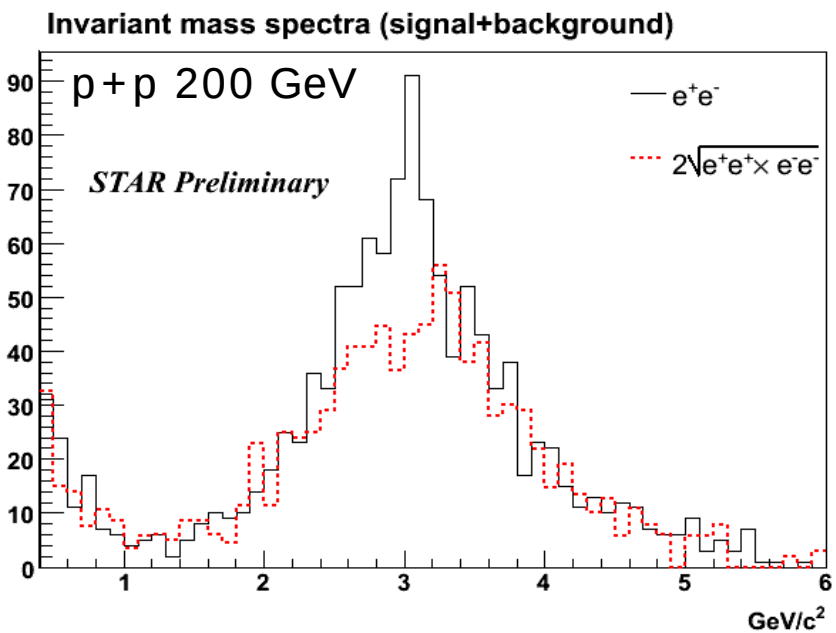
PMD

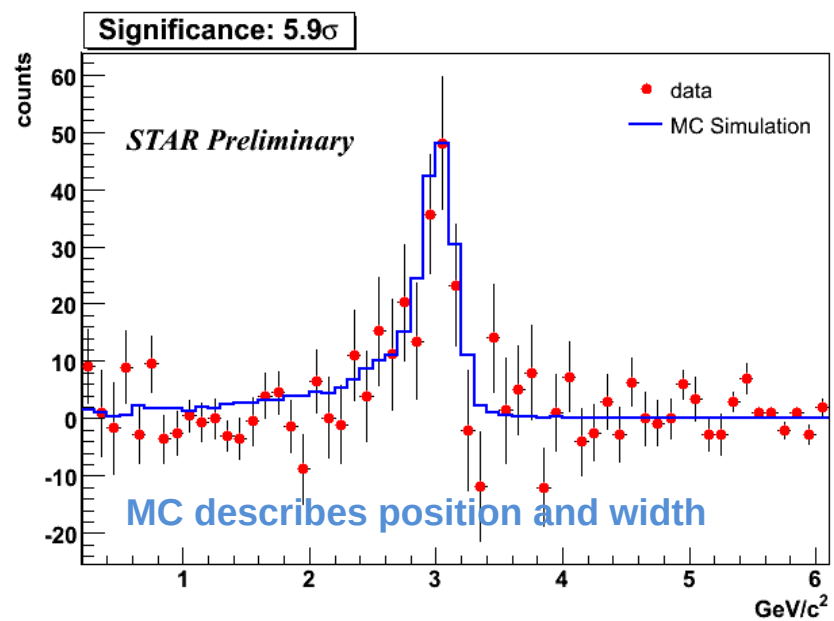
Year 2001+

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



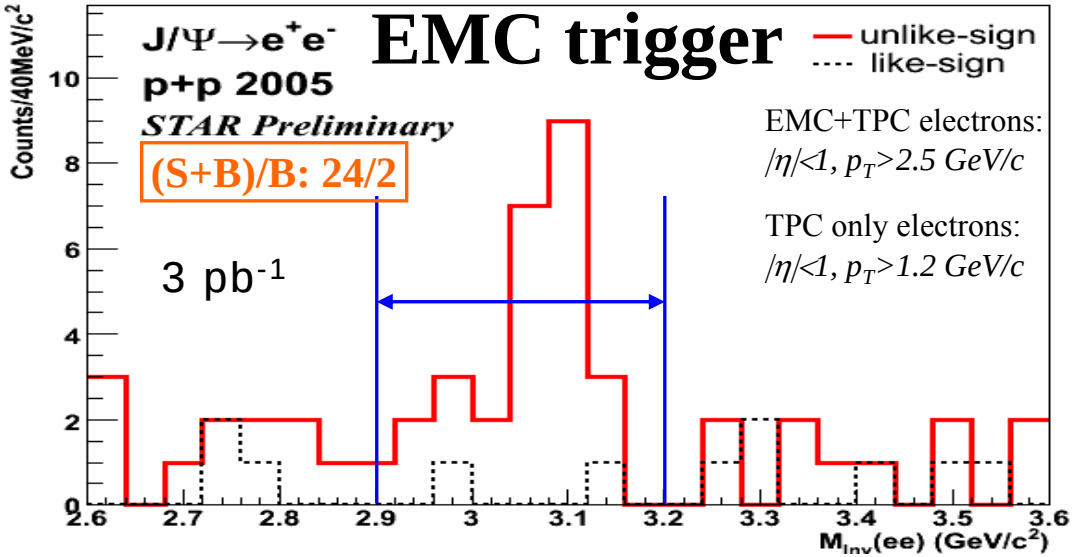


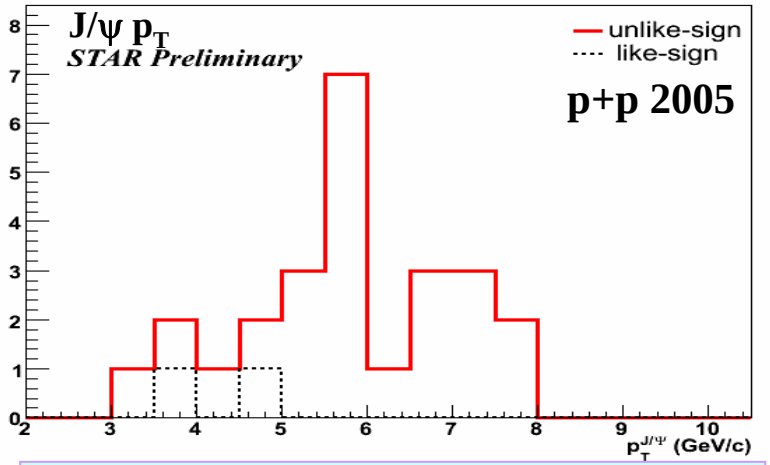
STAR has J/ψ capabilities at low p_T

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

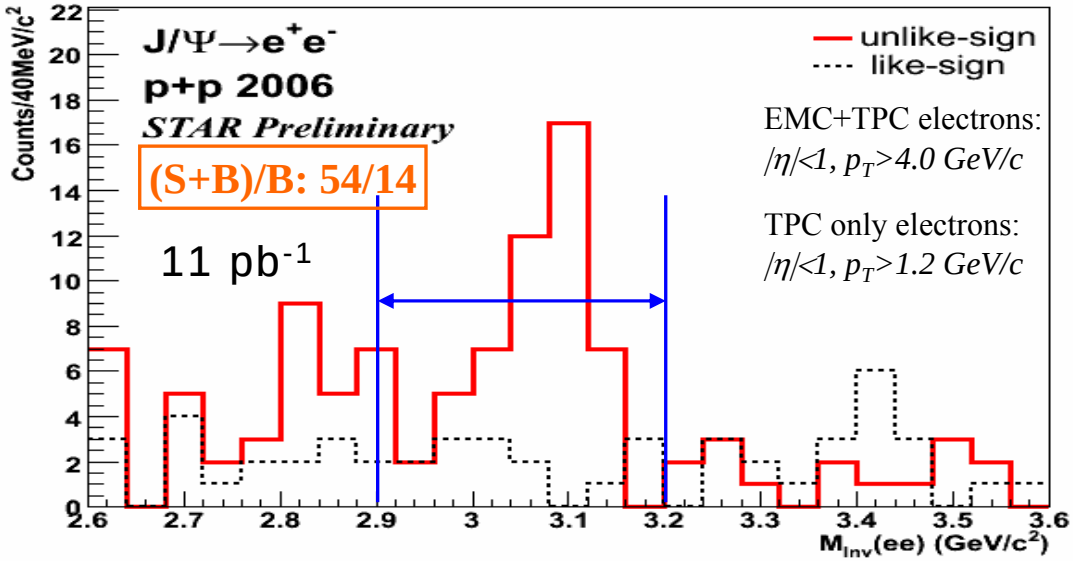
Integrated p+p luminosity at 200 GeV: 0.4 $(pb)^{-1}$

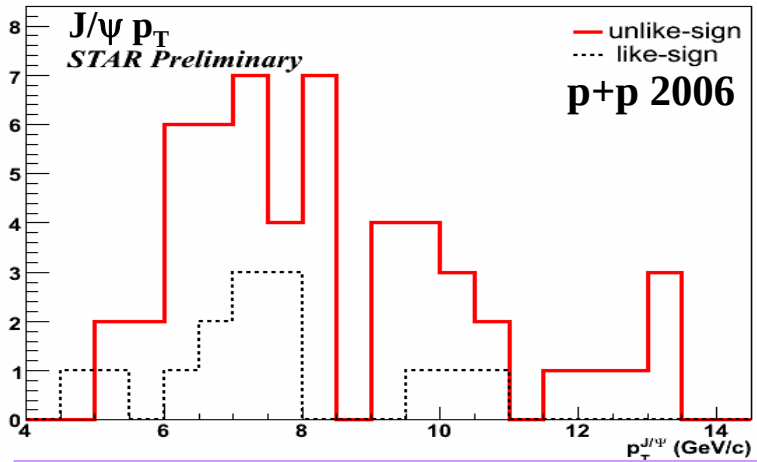
High p_T J/ψ in p+p at 200 GeV





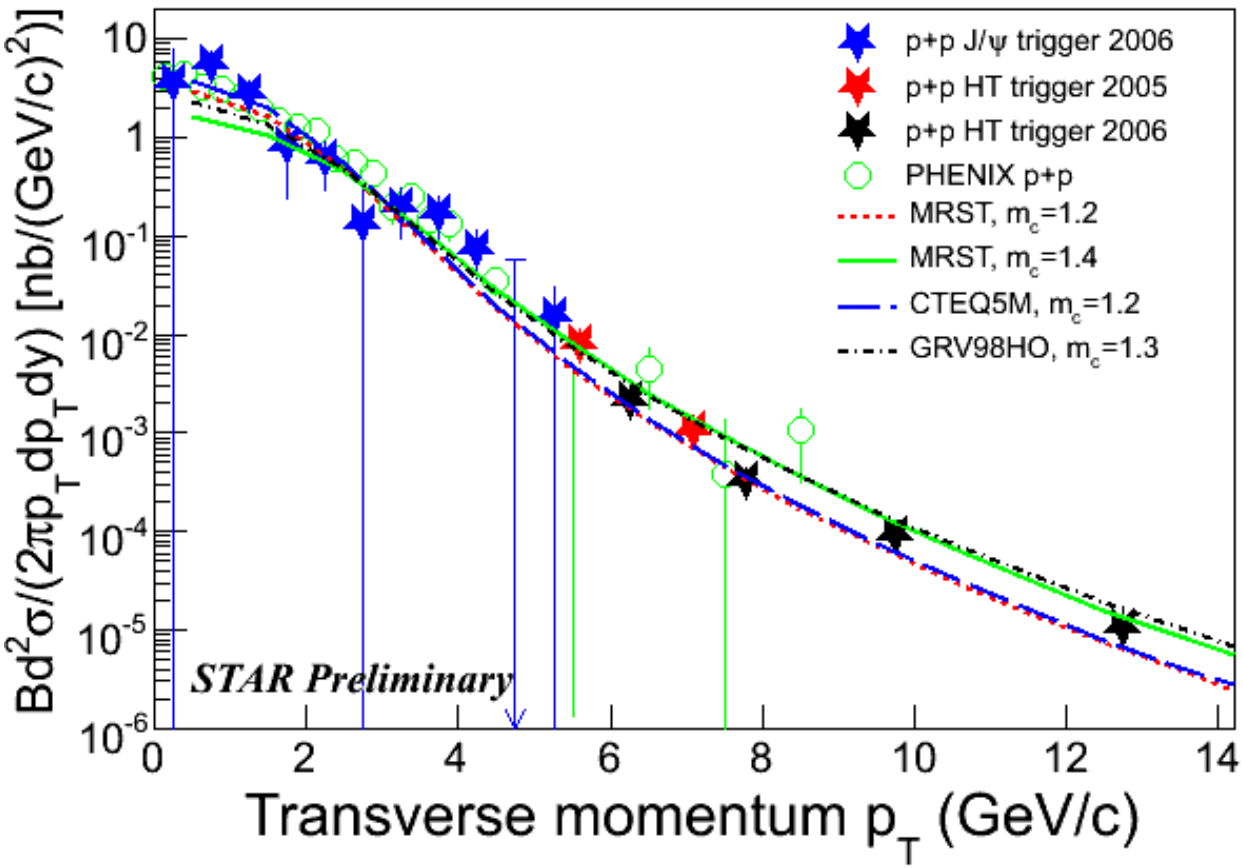
No background at p_T>5GeV/c





Reach higher p_T (~14GeV/c)

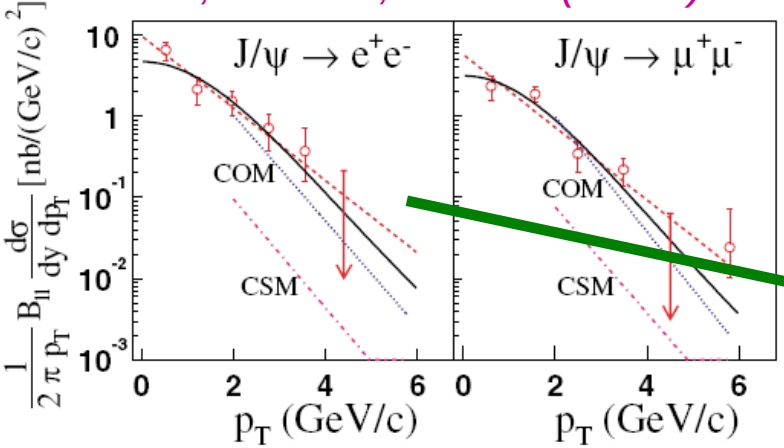
J/ψ spectra in p+p at 200 GeV



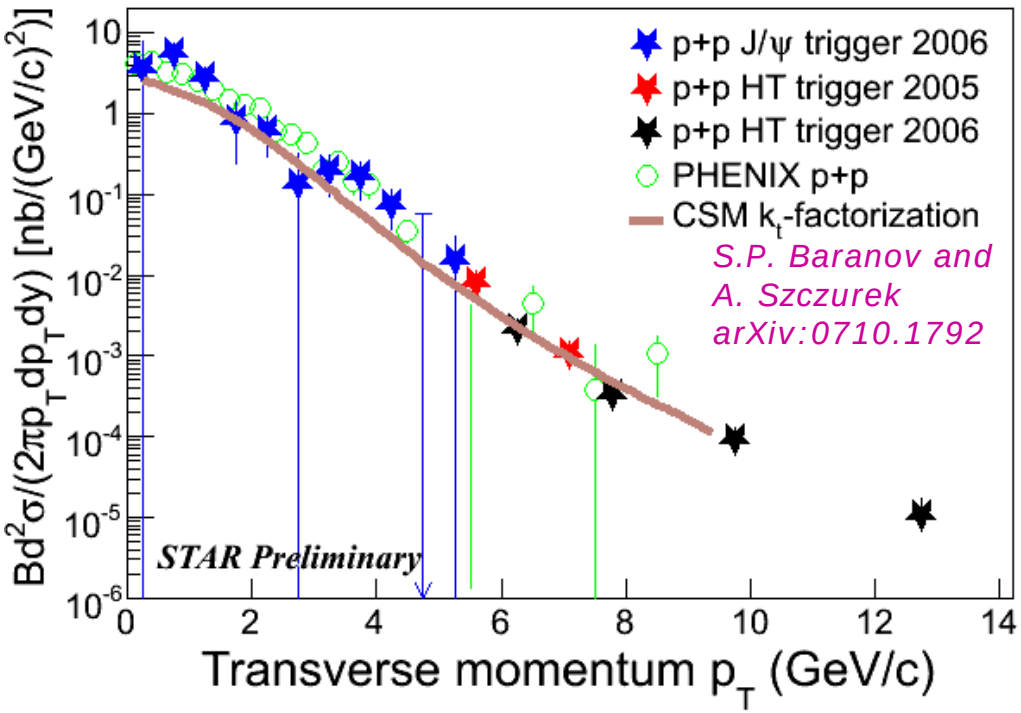
- Significantly extend p_T range of previous measurements in p+p at RHIC to 14 GeV/c
- Agreement of charm measurements between STAR and PHENIX
- Consistent with Color Evaporation calculations (R. Vogt, Private communication)

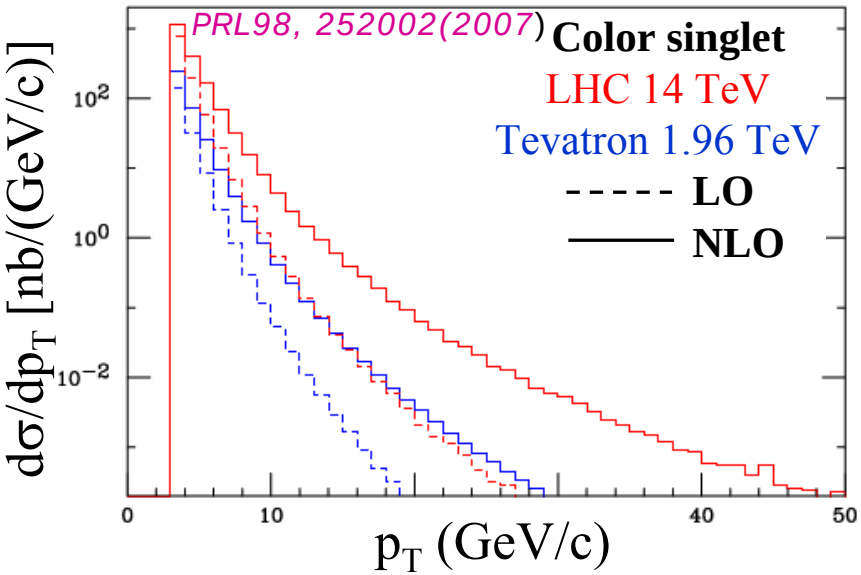
CSM with k_t-factorization

PHENIX, PRL 92, 05180 (2004)



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

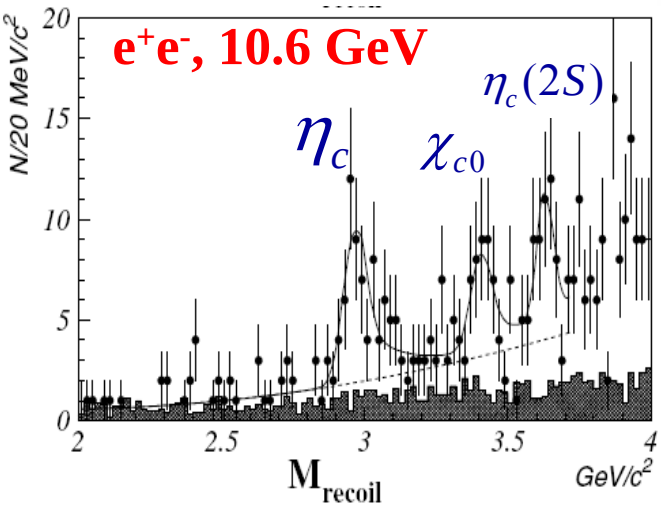




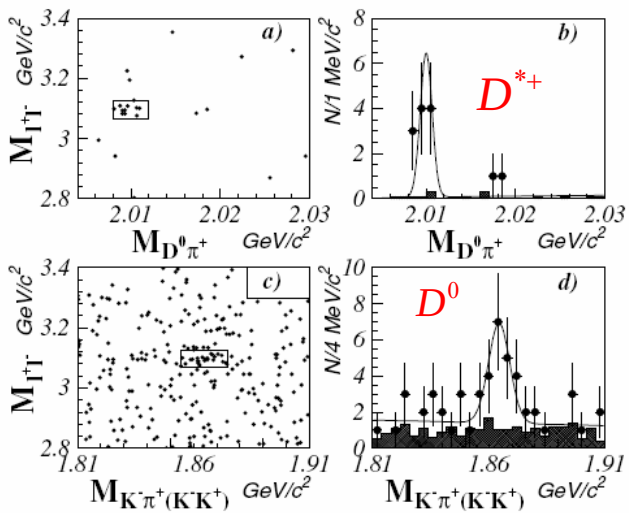
CSM NLO correction is huge

Are we done?

J/ψ+cc̄ production puzzle



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



Belle, PRL 89, 142001(2002)

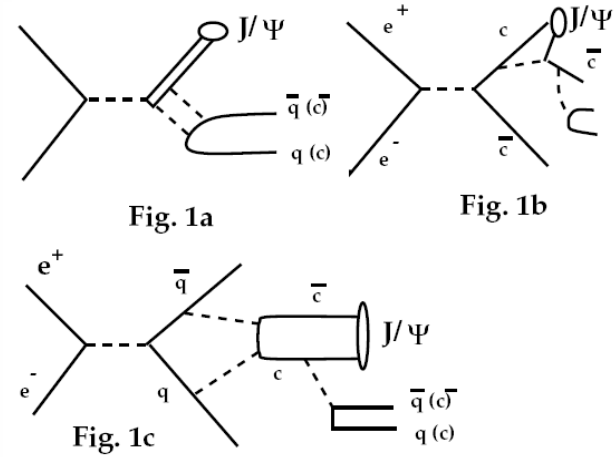


FIG. 1. The production of J/ψ in e^+e^- annihilation.

B.L. Loffe and D.E. Kharzeev PRD 69, 014016 (2004)

$(e^+e^- \rightarrow J/\psi + c\bar{c})/(e^+e^- \rightarrow J/\psi + X) = 0.59^{+0.15}_{-0.13} \pm 0.12$

0.82 ±0.15 ± 0.14 from new analysis. *T. Uglov, EPS 2003*

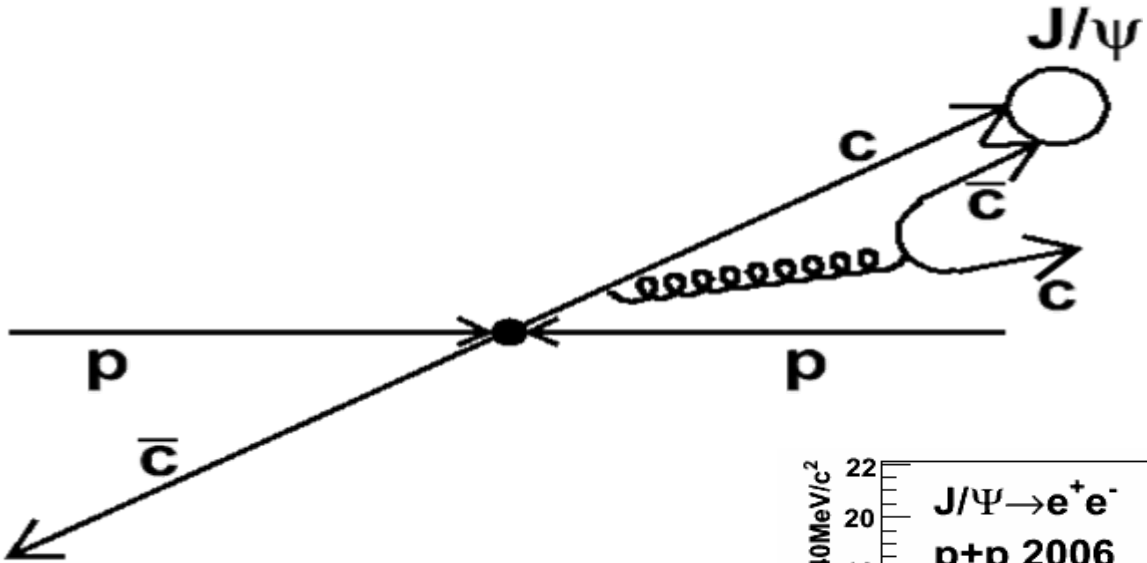
While CEM predict 0.049 *D. Kang, et al., PRD 71, 094019 and hep-ph/0412381*

NRQCD predict ~0.1 *K. Liu and Z. He, PRD 68, 031501 (2003)*

What will happen?: In p+p collisions;

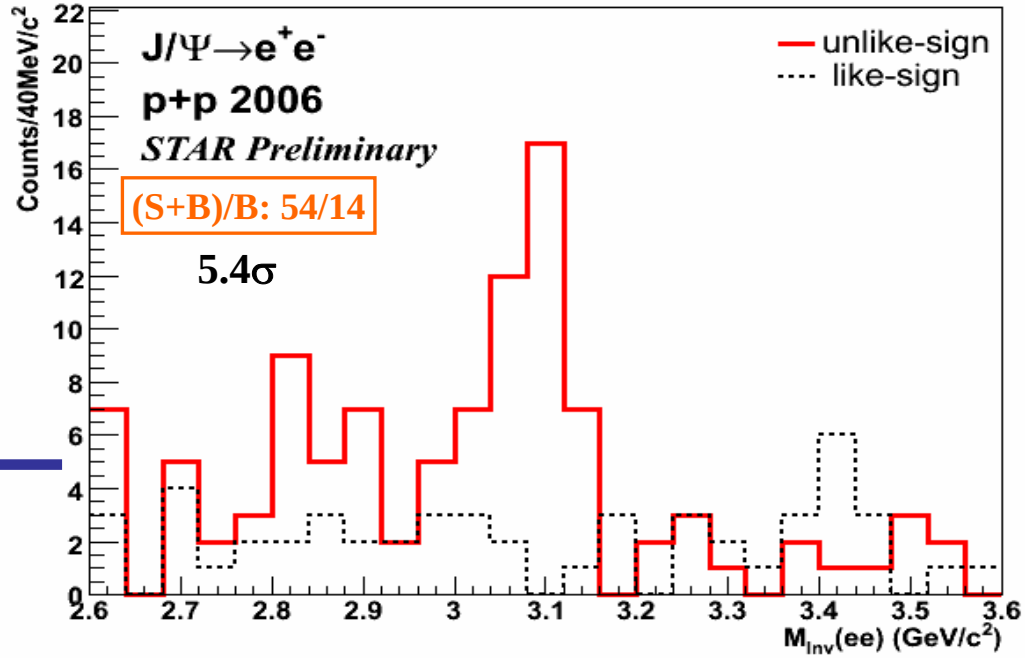
At higher energy (200 GeV)

J/ψ-hadron correlation



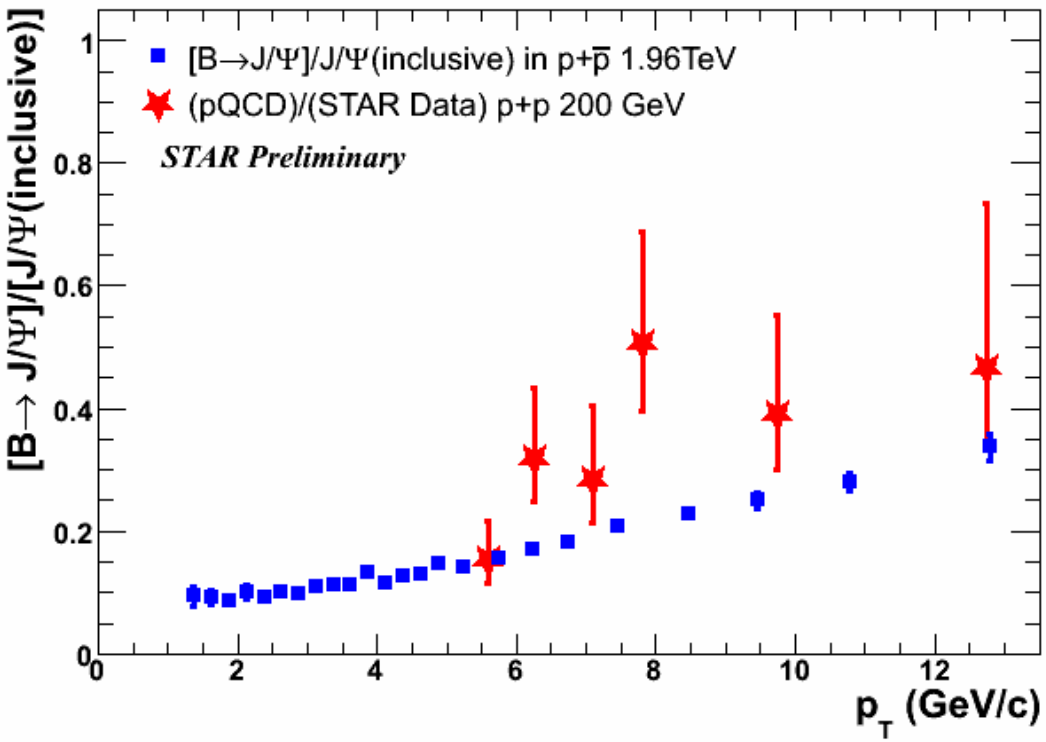
Near side correlation

Heavy quark fragmentation



Good S/B ratio makes this measurement possible

(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

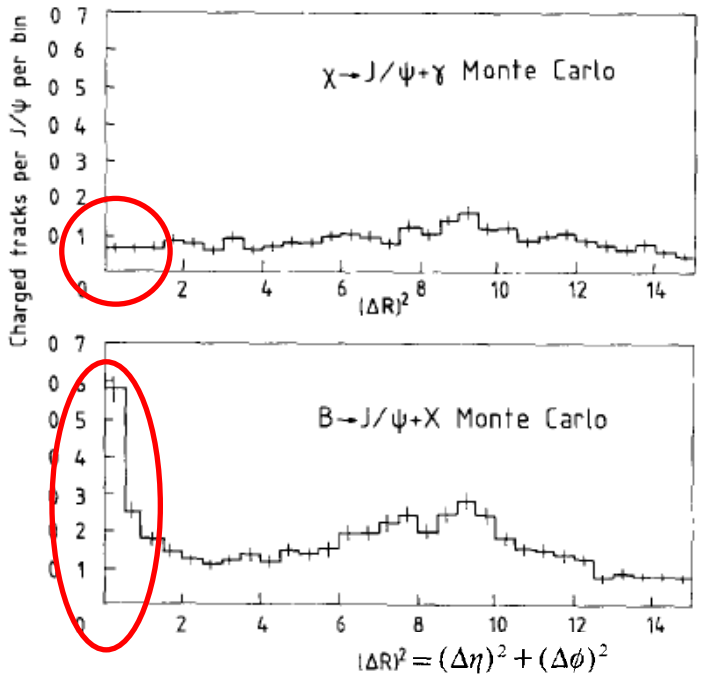
CLEO collaboration

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
- Need to be disentangled

Disentangle contributions via Correlations



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

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

$\rightarrow J/\psi + \gamma$

no near side correlation

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

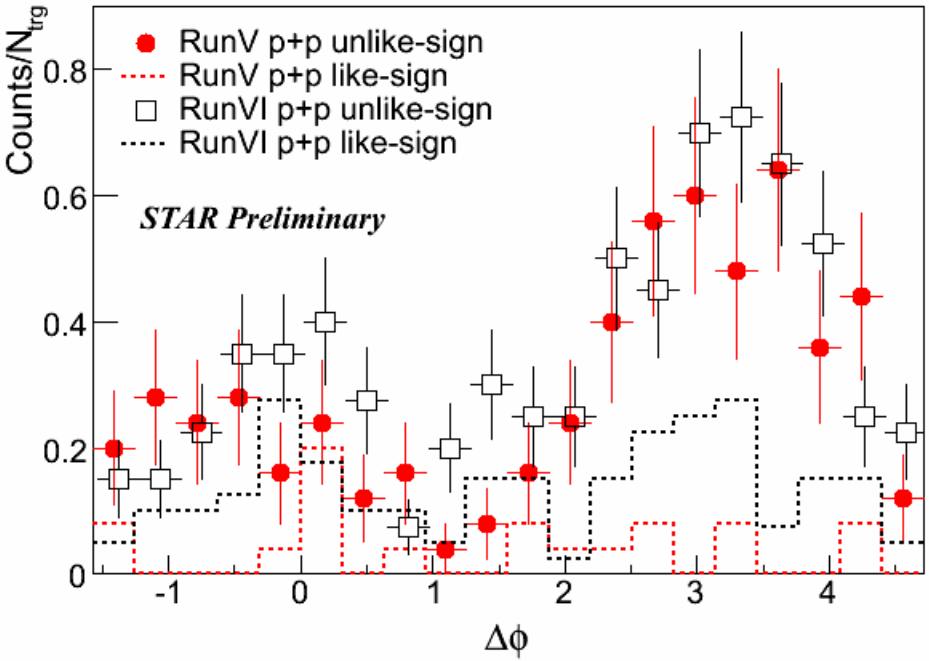
$\rightarrow B_{hadron} + X$

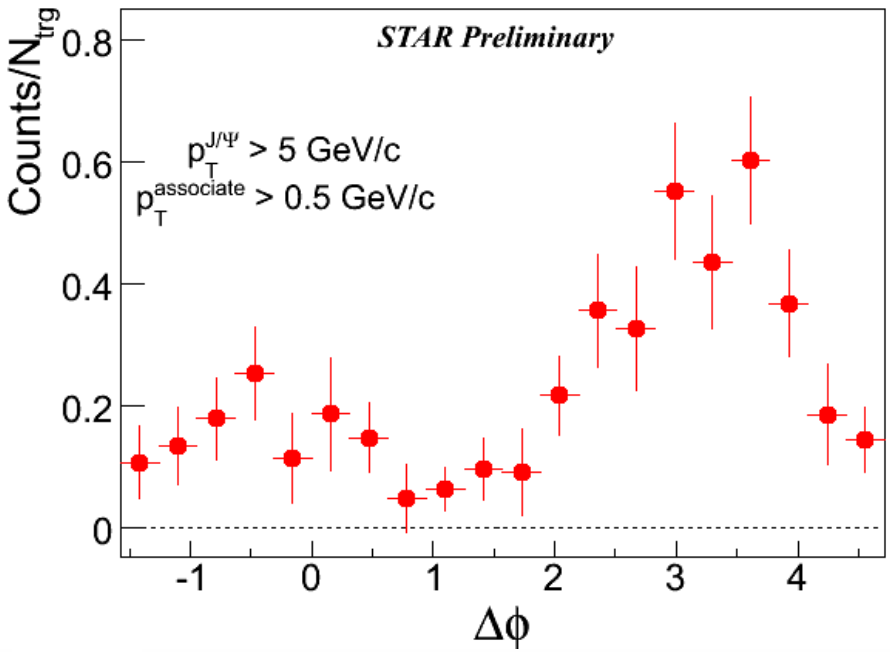
$\rightarrow J/\psi + X$

strong near side correlation

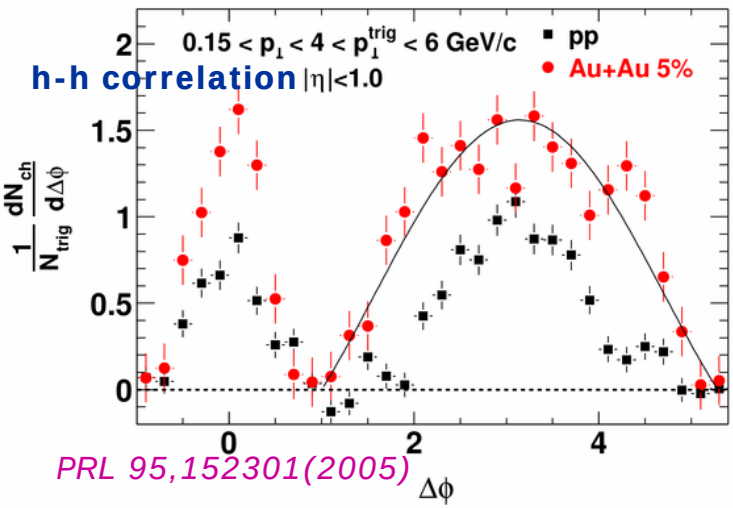
- **J/ψ-hadron correlation can also shed light on different source contribution to J/ψ production**
- **May be used to distinct CSM and COM**

J/ψ–hadron correlation in p+p



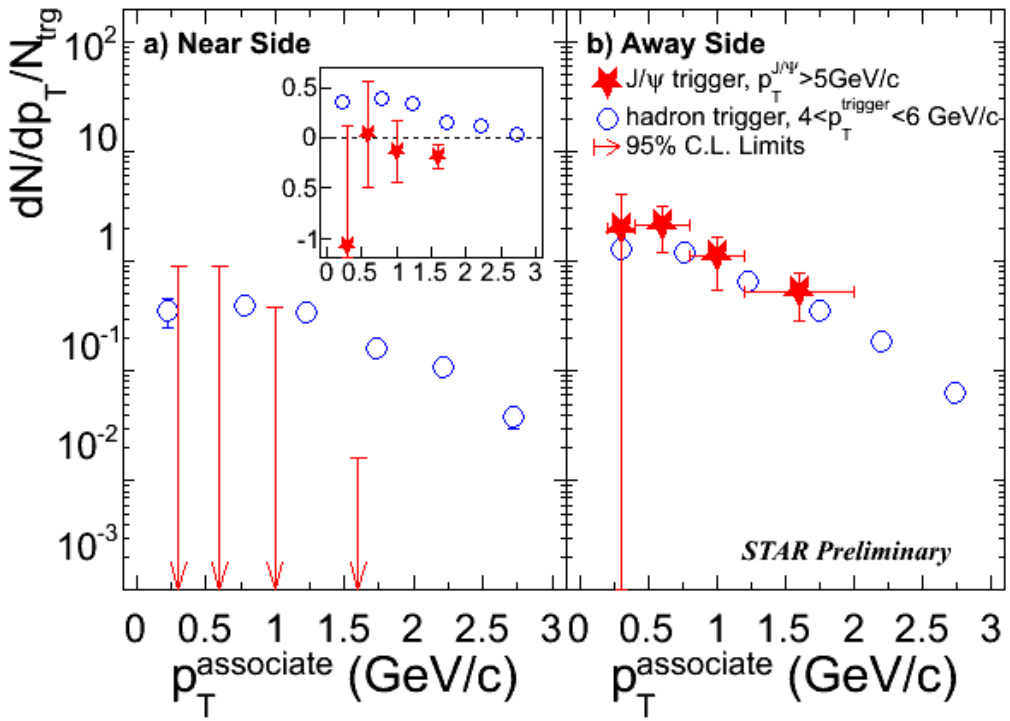


- No significant near side J/ψ-hadron azimuthal angle correlation
- Constrain B meson's contribution to J/ψ yield
- Hints of CSM?



PRL 95,152301(2005)

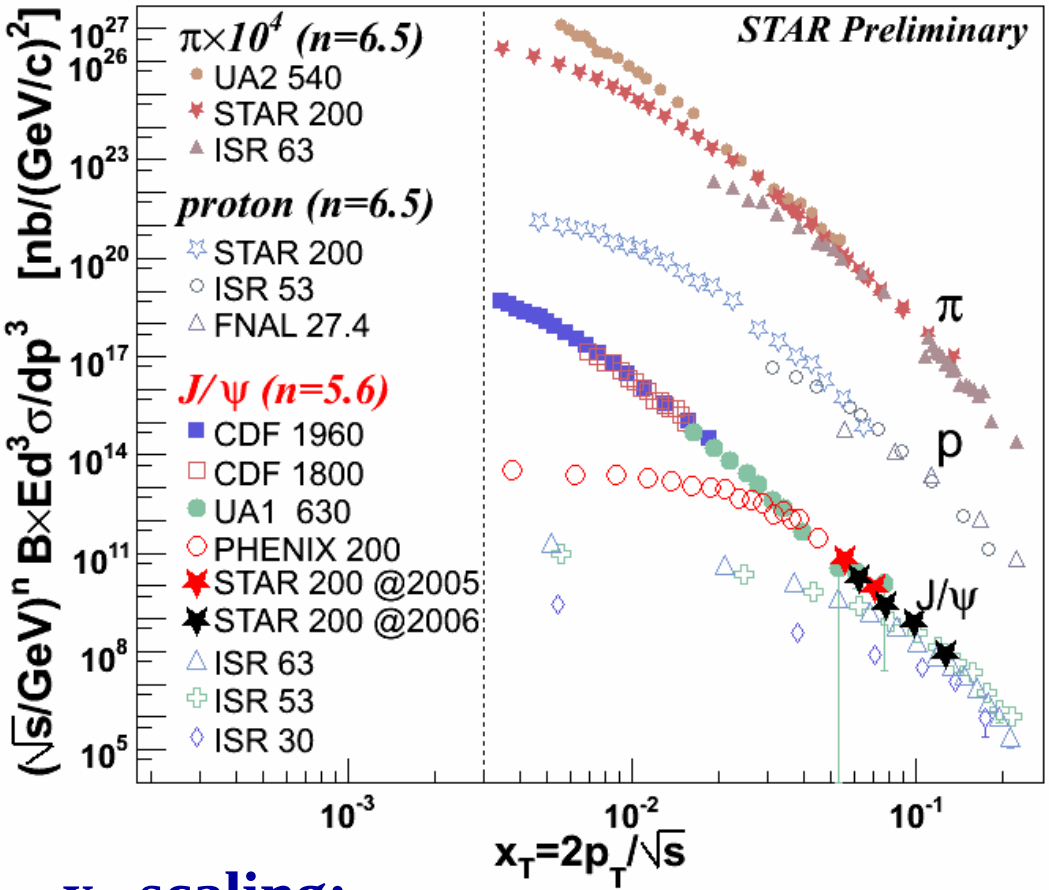
Yields in near/away side



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

x_T scaling



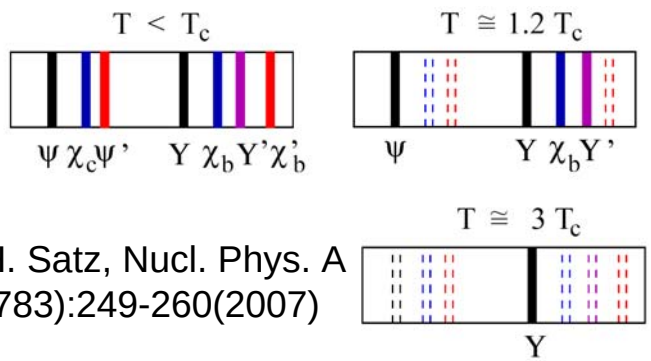
n is related to the number of point-like constituents taking an active role in the interaction

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

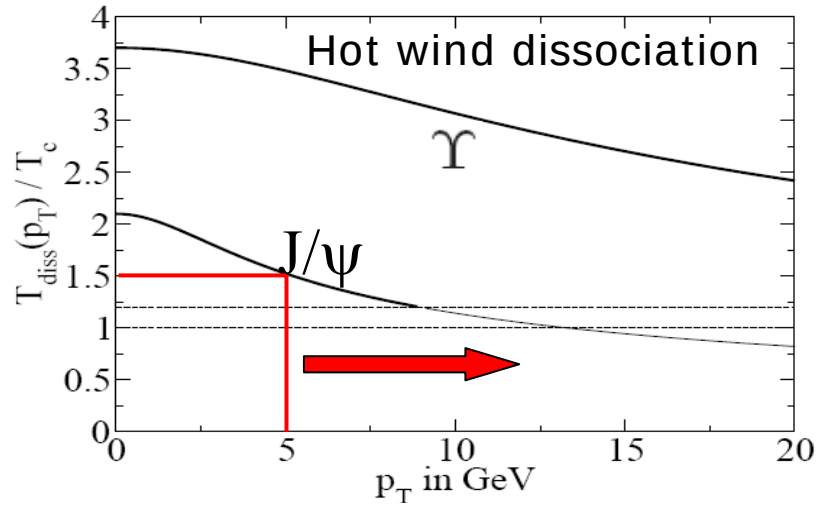
x_T scaling:

- ✓ **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**

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 maybe from excited stats (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 J/ψ suppression maybe more from the original J/ψ suppression

2-component approach

Predicted decrease R_{AA} X. Zhao and R. Rapp, hep-ph/07122407

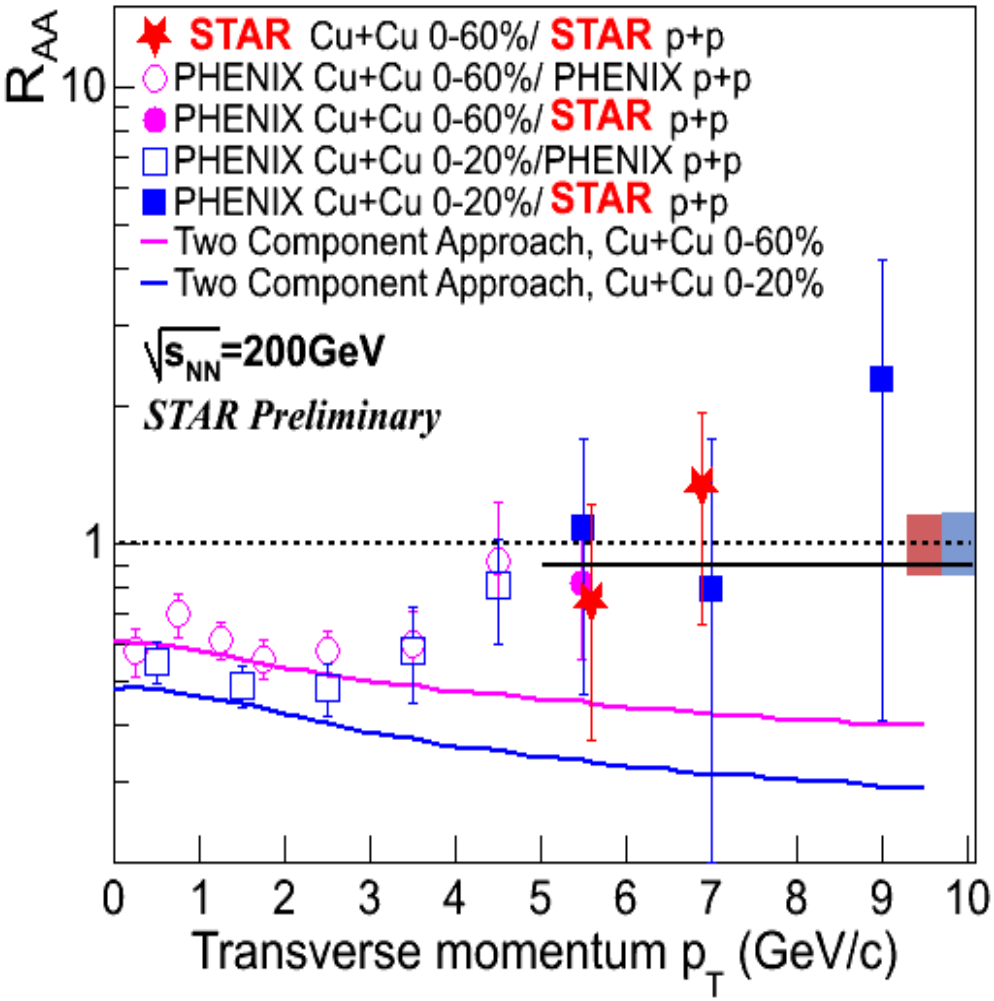
Predicted slightly increase R_{AA} after more consideration X. Zhao, WWND2008

Color singlet model predicted a increase R_{AA} (formed out of medium)

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

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

Nuclear modification factor R_{AA}



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

  $R_{AA}(p_T>5\ GeV/c) = 0.9 \pm 0.2$
- Indicates R_{AA} increase from low p_T to high p_T

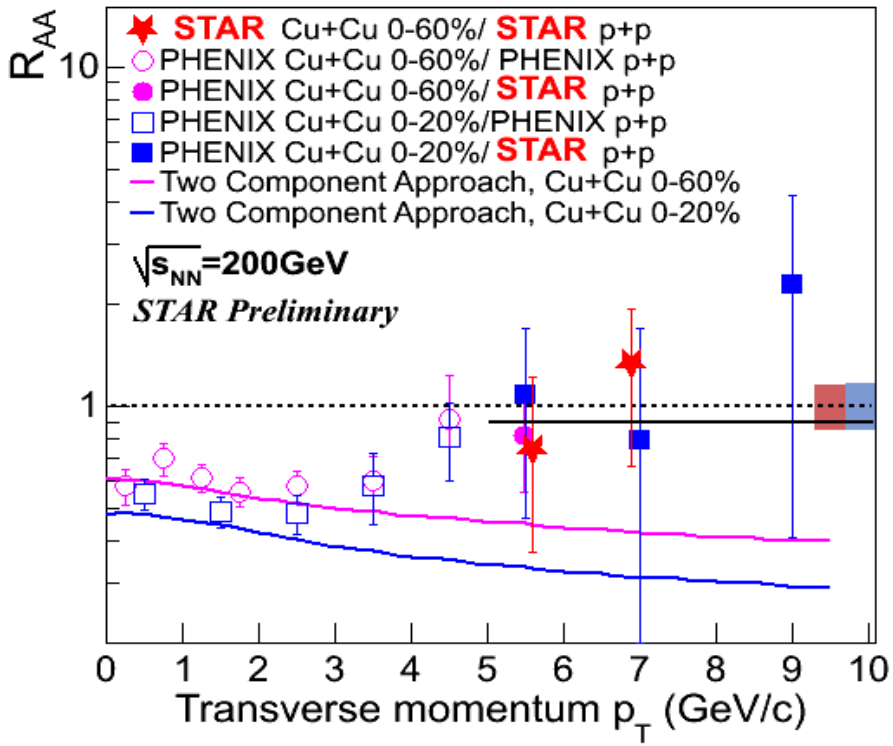
- Don't support AdS/CFT prediction
- Formed out of medium?

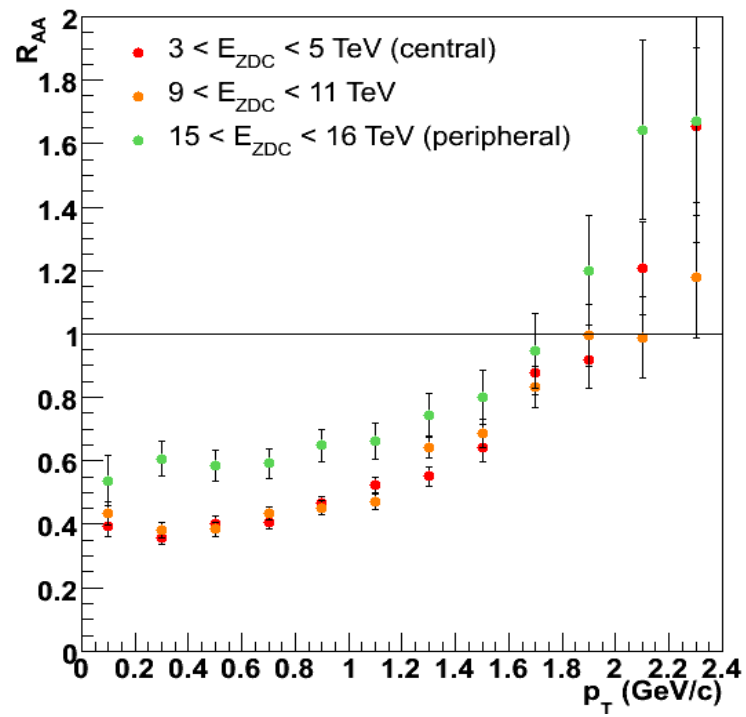
Affect by heavy quark/gluon energy loss

- Produced from virtual photon?

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

Compare to NA60

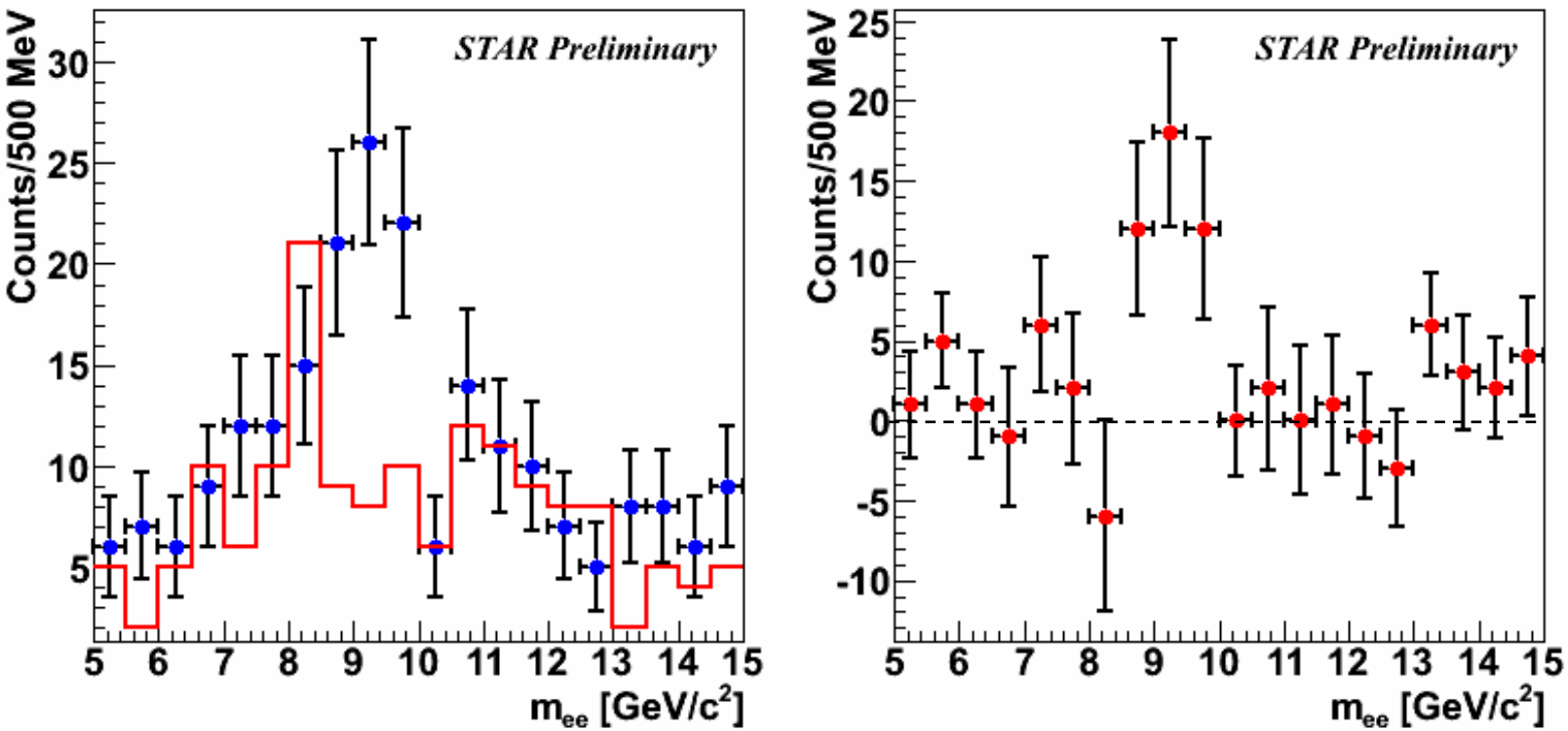




RHIC: Cu+Cu, $\sqrt{s_{NN}} = 200GeV$, consistent with no suppression at $p_T > 5$ GeV/c

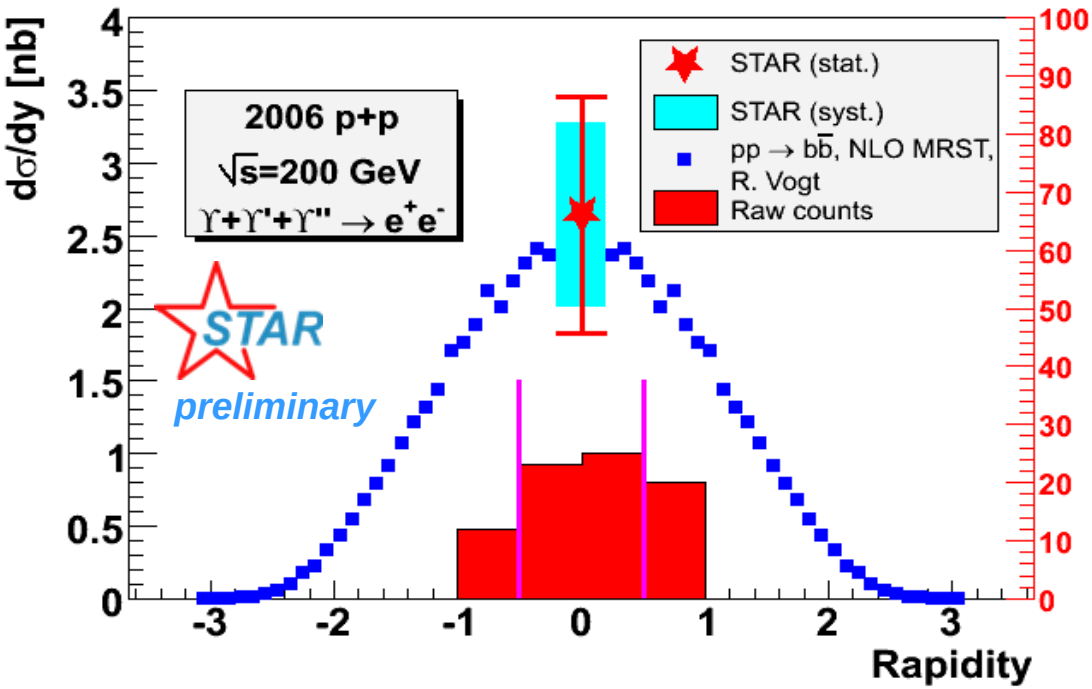
SPS: In+In, $\sqrt{s_{NN}} = 17.3GeV$, consistent with no suppression at $p_T > 1.8$ GeV/c

ϒ results: p+p

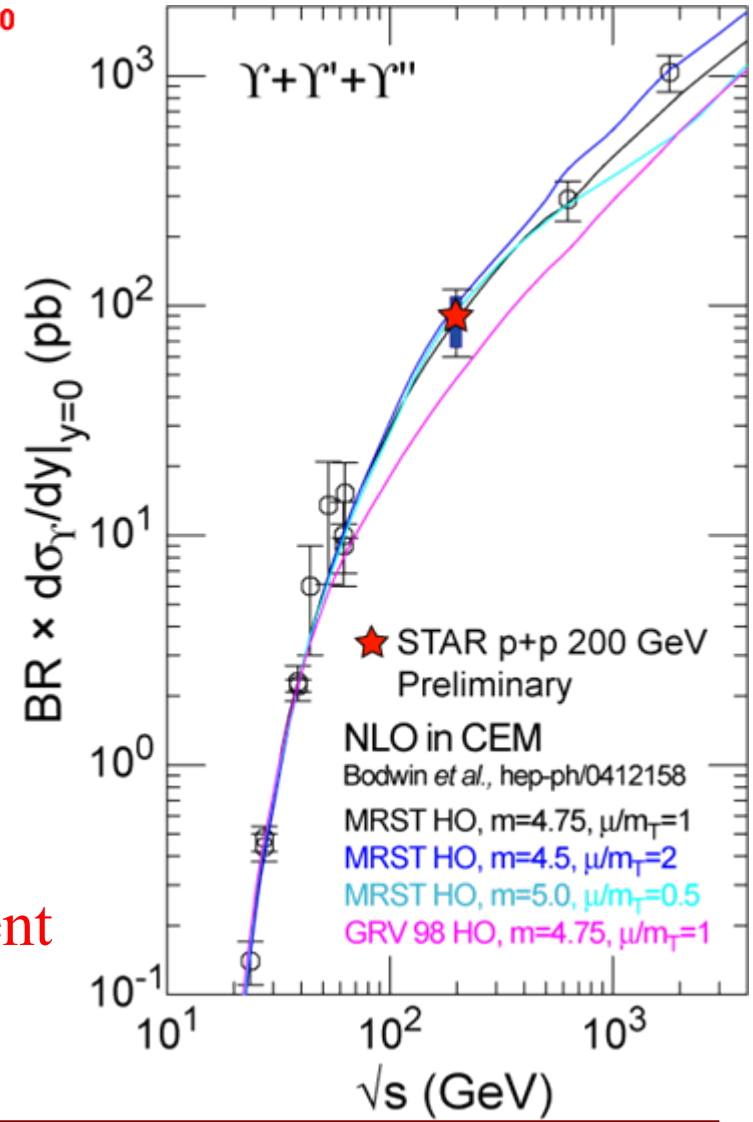


- ϒ(1S+2S+3S) total yield: integrated from 7 to 11 GeV from background-subtracted m_{ee} distribution
- Peak width consistent with expected mass resolution
- Significance of signal is 3σ
- Note: Contribution from Drell-Yan (~9%) ignored

ϒ results: p+p

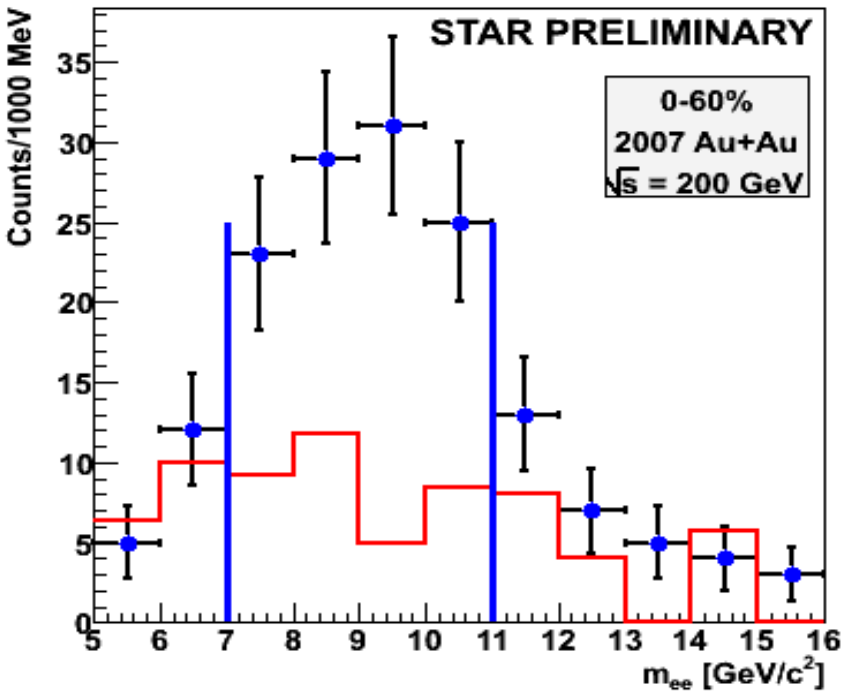


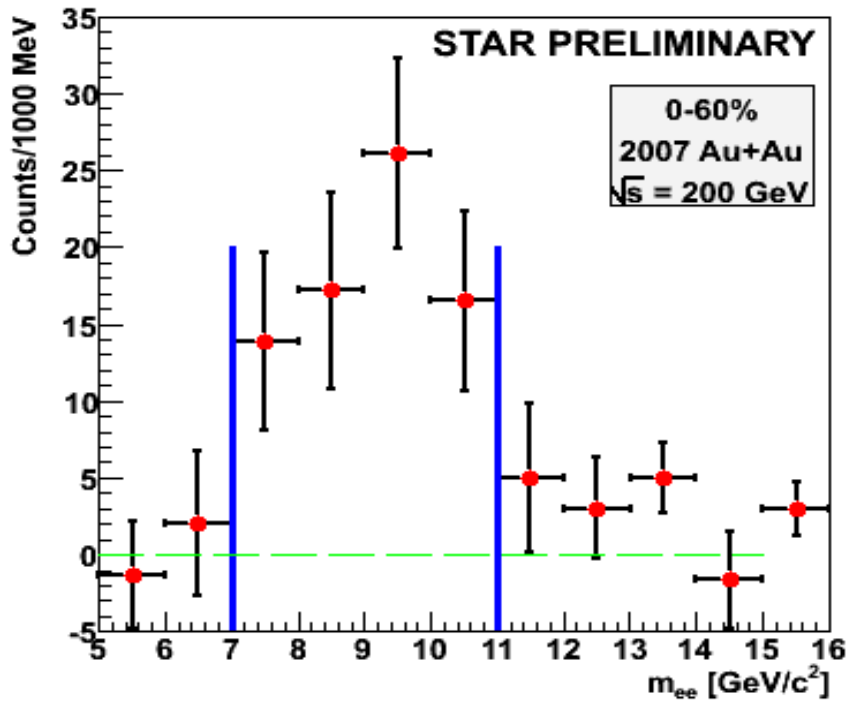
$B_{ee}\times(d\sigma/dy)_{y=0}$=91±28(stat.)±22(syst.) pb



STAR 2006 √s=200 GeV p+p ϒ+ϒ′+ϒ″→e^+e^- cross section consistent with pQCD and world data

ϒ results: Au+Au





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

Summary (J/ψ)

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

- **J/ψ–hadron azimuthal correlation in p+p**
  - ✓no significant near side correlation
    Expect strong near-side correlation from B→J/ψ+X
    Can be used to constrain J/ψ production mechanism
  - ✓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**
  - ✓Extend R_{AA} from p_T = 5 GeV/c to 10 GeV/c
  - ✓Indication of R_{AA} increasing at high p_T

Summary (Υ)

- **p+p measurement is consistent with pQCD and world data**

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

- **First measurement in heavy ion collisions (200GeV Au+Au)**

- **R_{AA} is in progress**

Coming soon

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

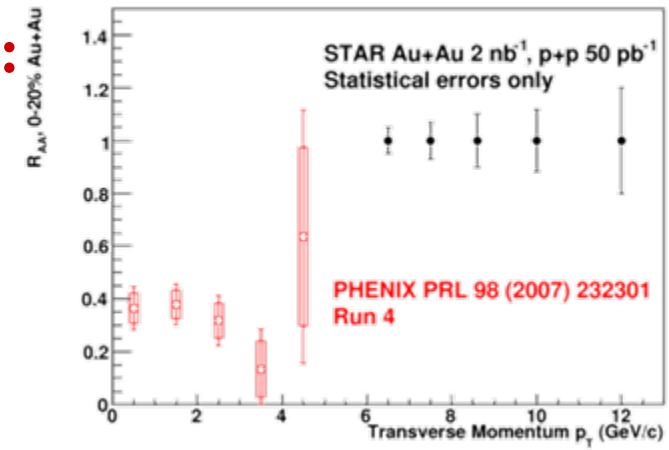
Upsilon R_{AA}

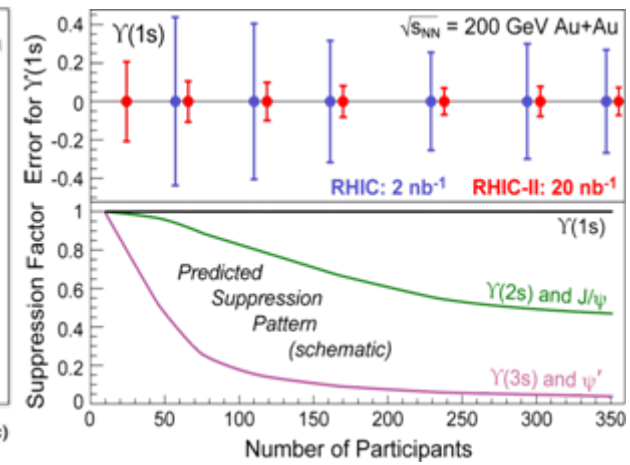
Run 8 (d+Au) just finished, Cold Nuclear Matter effect

Coming in the near future

RHIC II + DAQ1000:

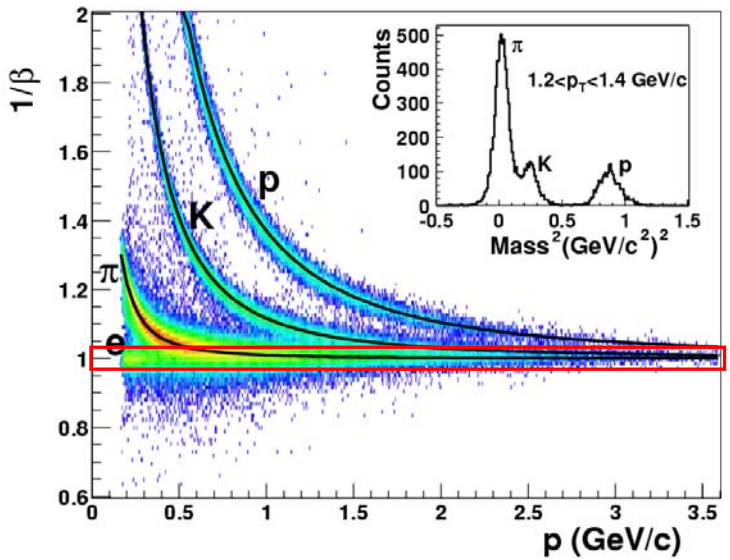
Enhance statistics

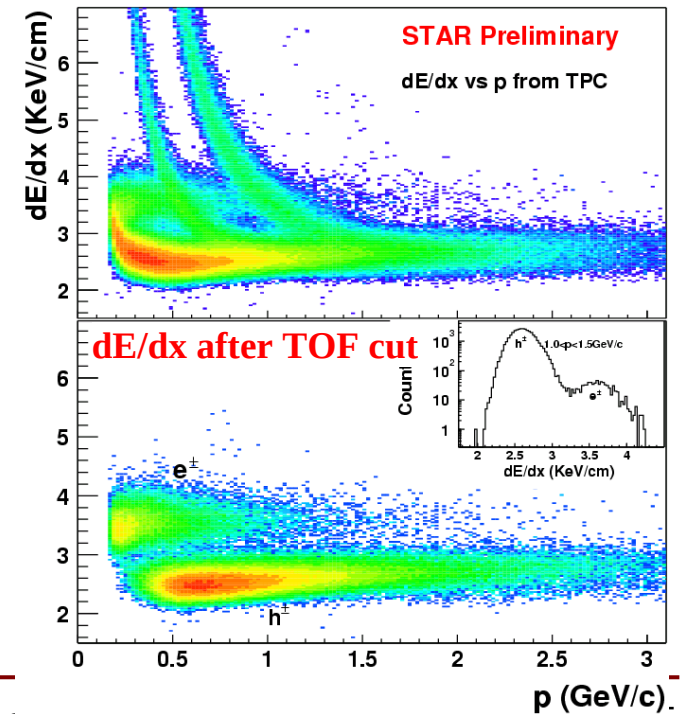




Time-Of-Flight:

Electron identification



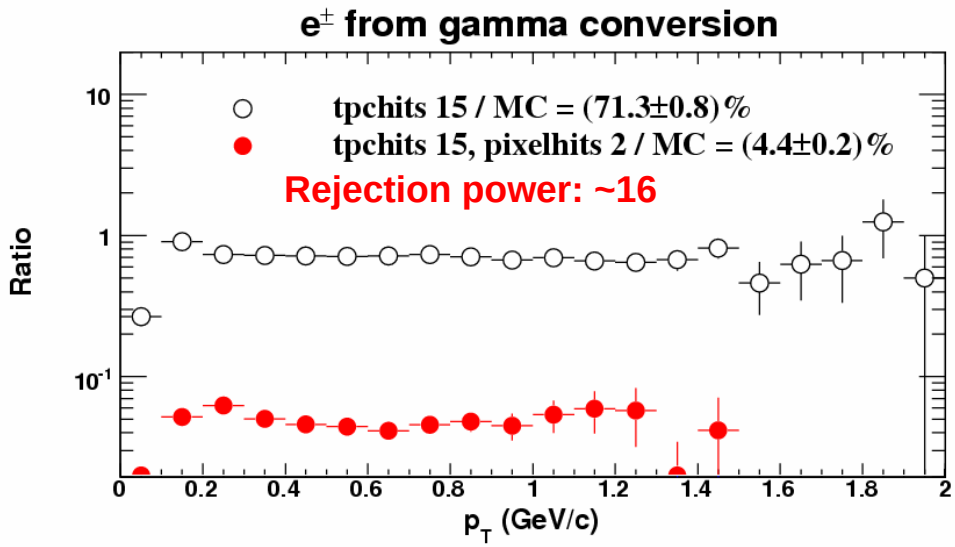


Coming in the near future

Heavy Flavor Tracker:

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

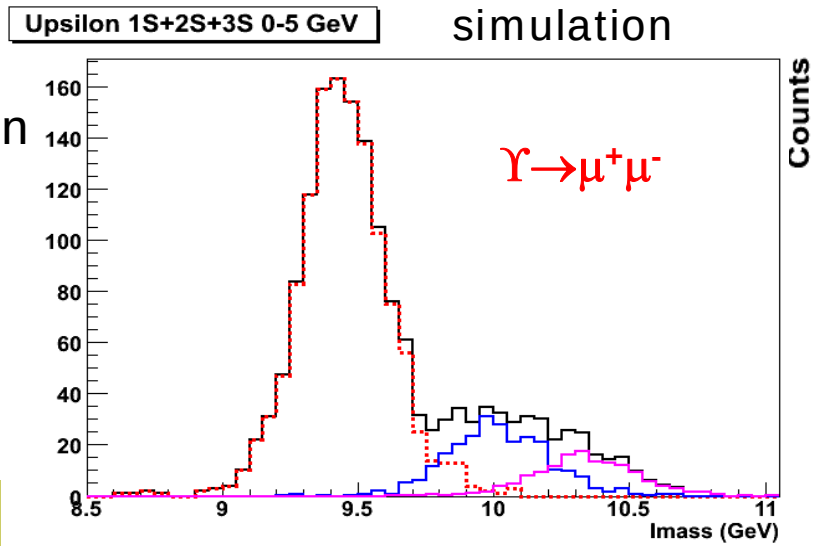
Topologically reconstruct J/ψ from B decay



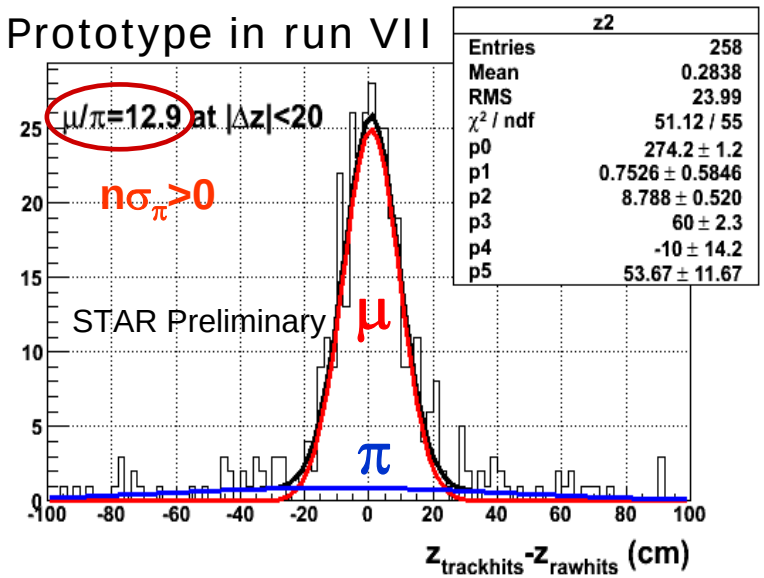
Muon Telescope Detector:

Muon identification

simulation



Prototype in run VII



Thanks!

Backup slides

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:

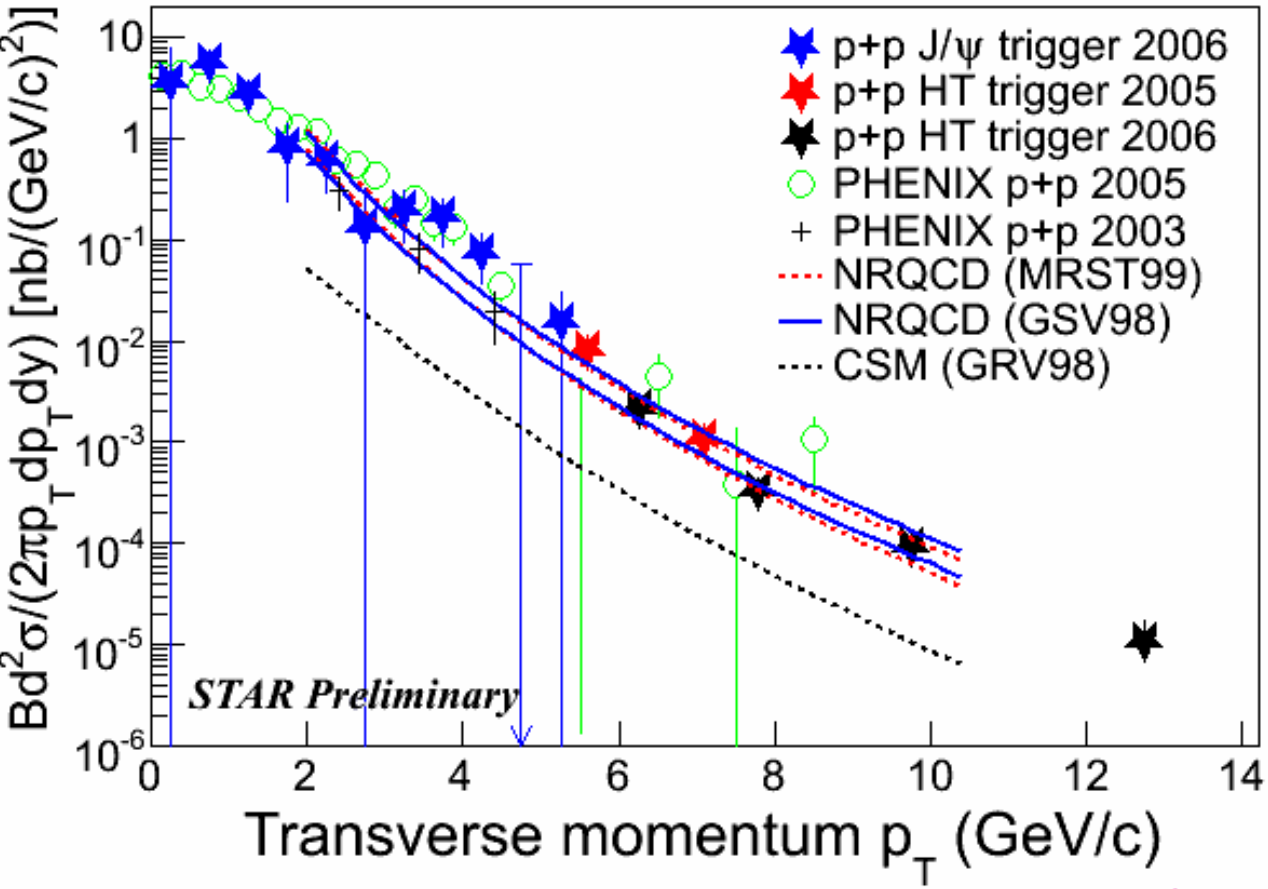
- 1. EMC triggered events in year 2005

  E_T>3.75 GeV

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

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

Spectra compared to NRQCD



F. Cooper, M. X. Liu and G. Nayak, PRL 93:171801, 2004