Vector-meson production
in STAR and PHENIX

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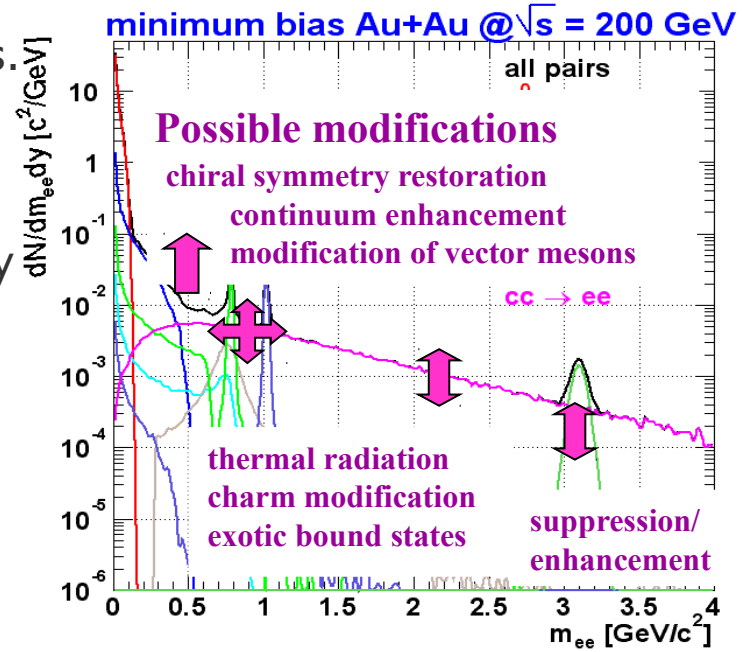
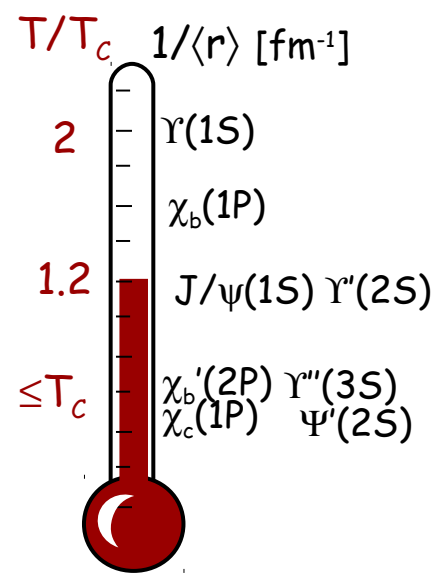
Motivation

- More than 10% of bulk meson production in HI collisions.
- Lifetime comparable to QGP.
- Vector mesons (ρ, ω, ϕ, J/ψ, ψ' and ϒ) have dilepton decay channels → bring information about medium properties directly to the detector .
- Light vector mesons and low-mass continuum: sensitive to chiral symmetry restoration that will appear as mass shifts, broadening or excess yield.
- J/ψ suppression due to the color screening of the binding potential → classic QGP formation signature.
  T. Matsui, H. Satz, Phys. Lett. B178, 416 (1986).
- Sequential disappearance of states → QGP temperature
  – T and binding energy determine suppression
  – model dependent

  A. Mocsy and P. Petreczky PRD 77 014501 (2008)





PHENIX: low mass dileptons in p+p

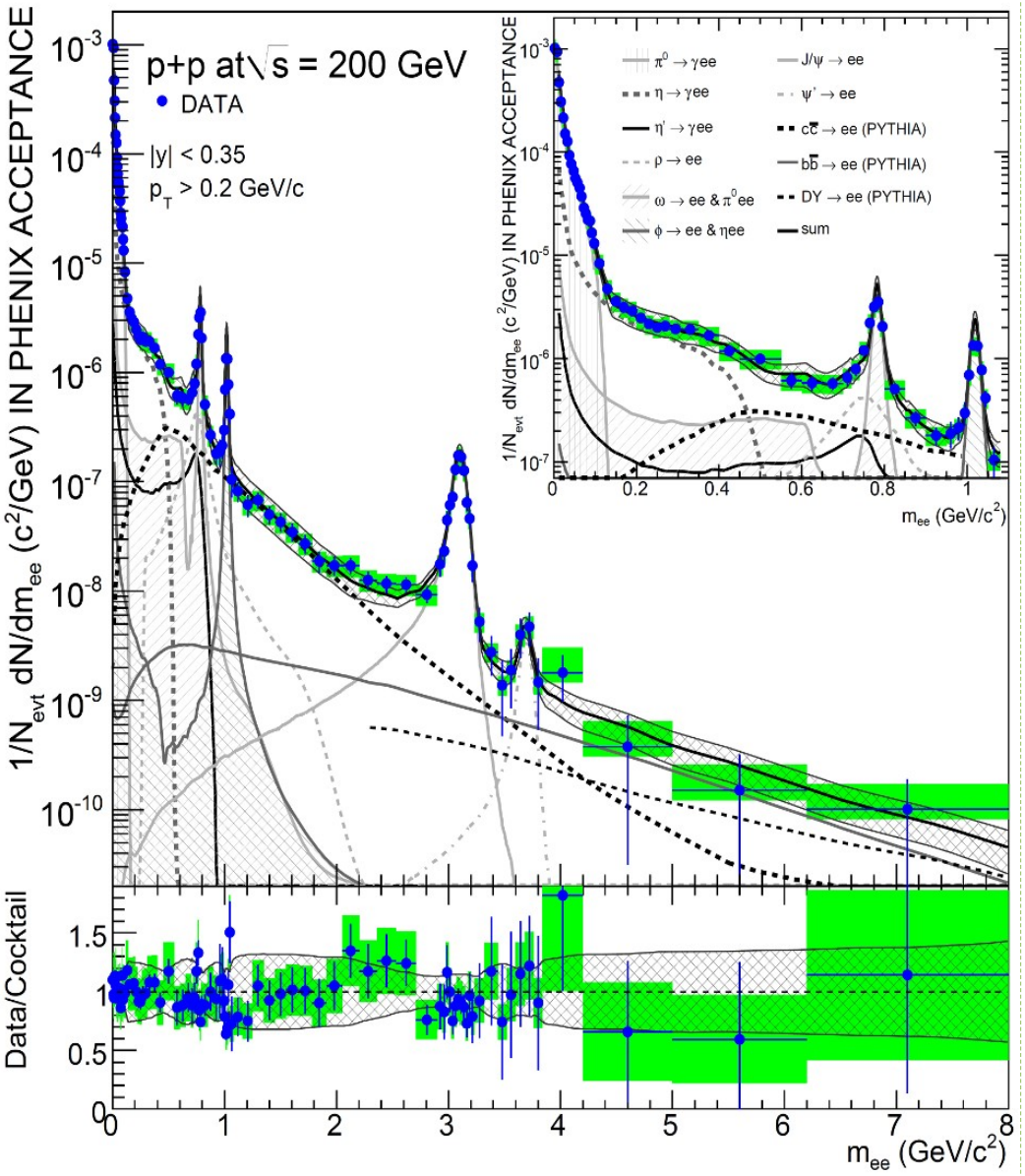
Analysis:

- Reconstruct mass and p_T of e^+e^- pairs
- Identify and reject conversion in the detector material
- Subtract combinatorial background
- Apply efficiency correction
- Subtract additional correlated background
- Compare with known hadronic sources

see for details : **PRC 79, 81 034911 (2010)**

- Inclusive mass spectrum of e+e- pairs measured in the mass range 0-8 GeV/c^2
- Understood well in terms of:
  - hadronic cocktail at low masses
  - heavy flavor + DY at high masses
- Measurements in p+p is a baseline for Au+Au

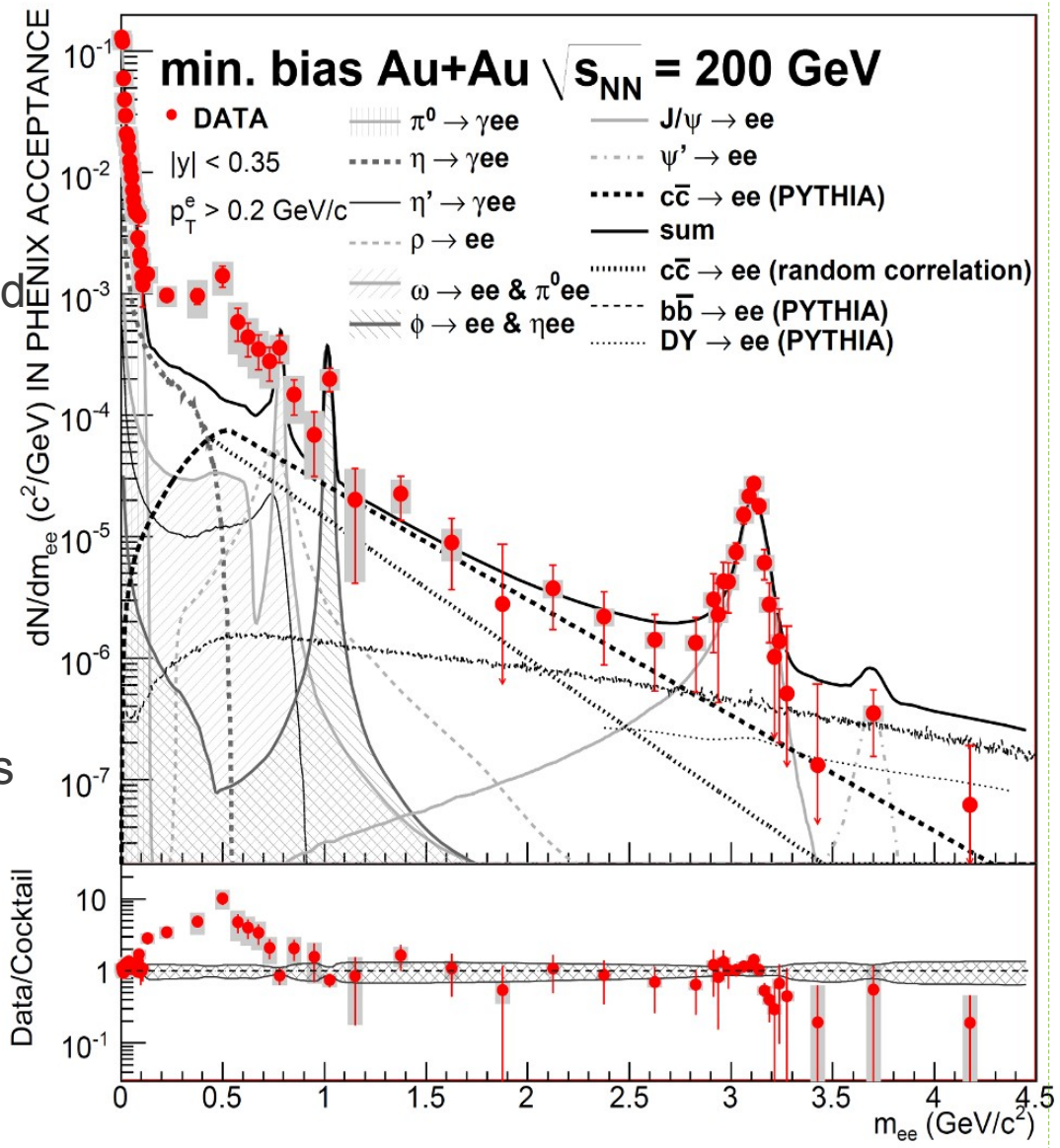
PLB 670, 313 (2009)



PHENIX: low mass dileptons in Au+Au

PRC 79, 81 034911(2010)

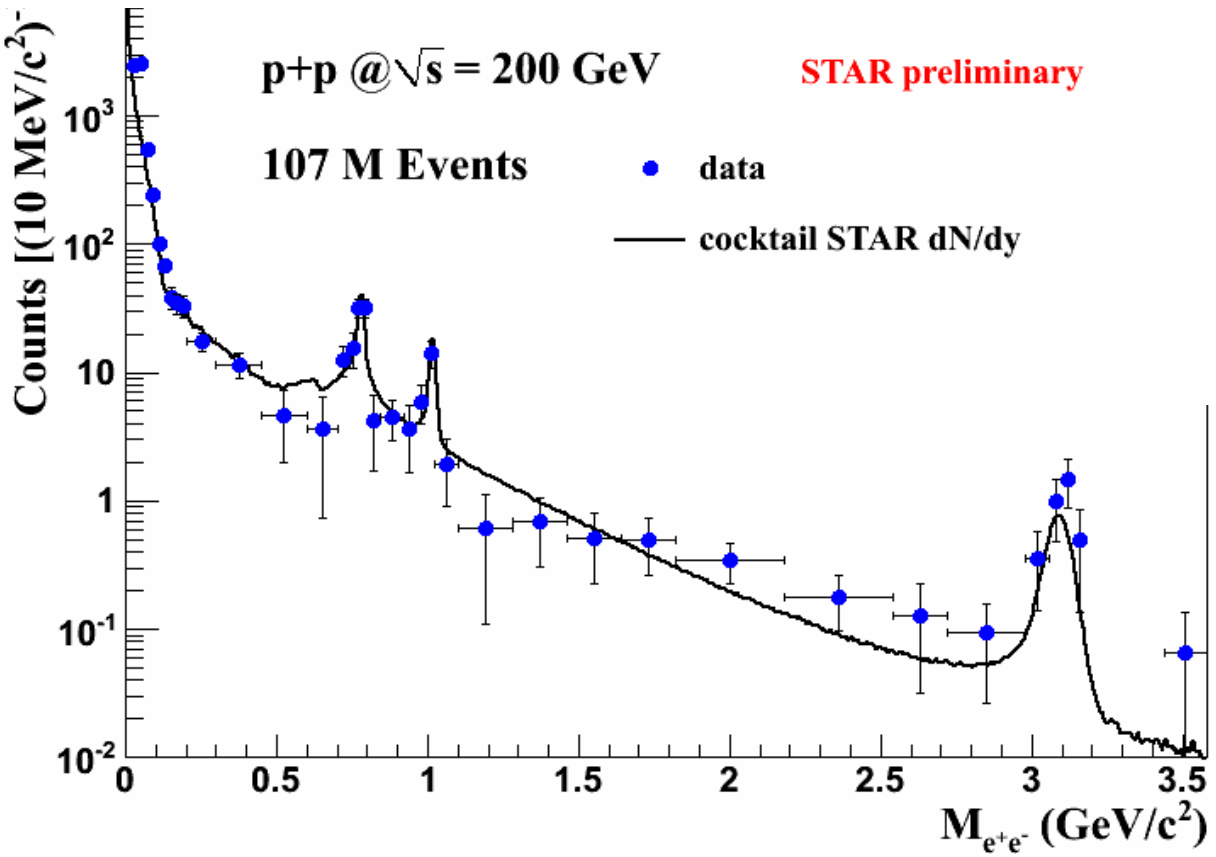
- Inclusive mass spectrum of e+e- pairs measured in the mass range 0-4.5 GeV/c^2.
- Compared with the various hadronic sources of e+e- pairs. Cocktail of the sources is based on π^0 / η spectra measured by PHENIX.
- Huge excess of the measured yield of e+e- pairs over the expected hadronic contributions by a factor:
  4.7+/- 0.4(stat.)+/-1.5(syst.)+/-0.9(model)
- Characteristic properties:
  - Enhancement down to very low masses
  - Enhancement concentrated in central collisions
  - Enhancement is mostly at low p_T
  - No enhancement in the intermediate mass region

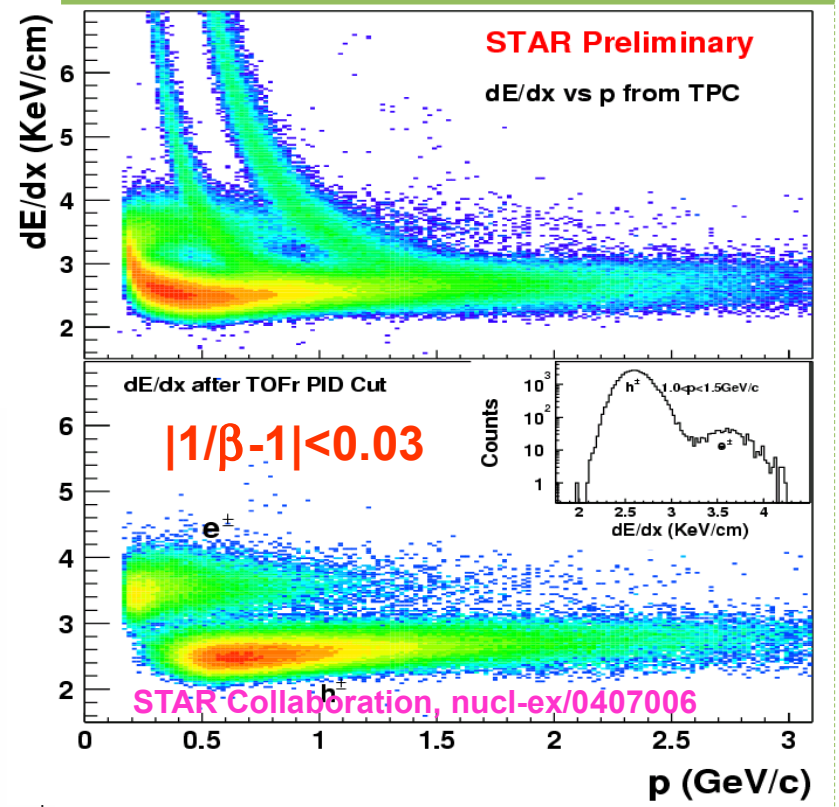


STAR: low mass dileptons in p+p

With installation of the ToF barrel (72% y2009, 100% y2010) STAR got an enormous asset to its dilepton program!

- TOF: e PID for pT < 3 GeV/c
- High electron purity: 99%
- Efficiency ≥ than 60% (std. cuts)

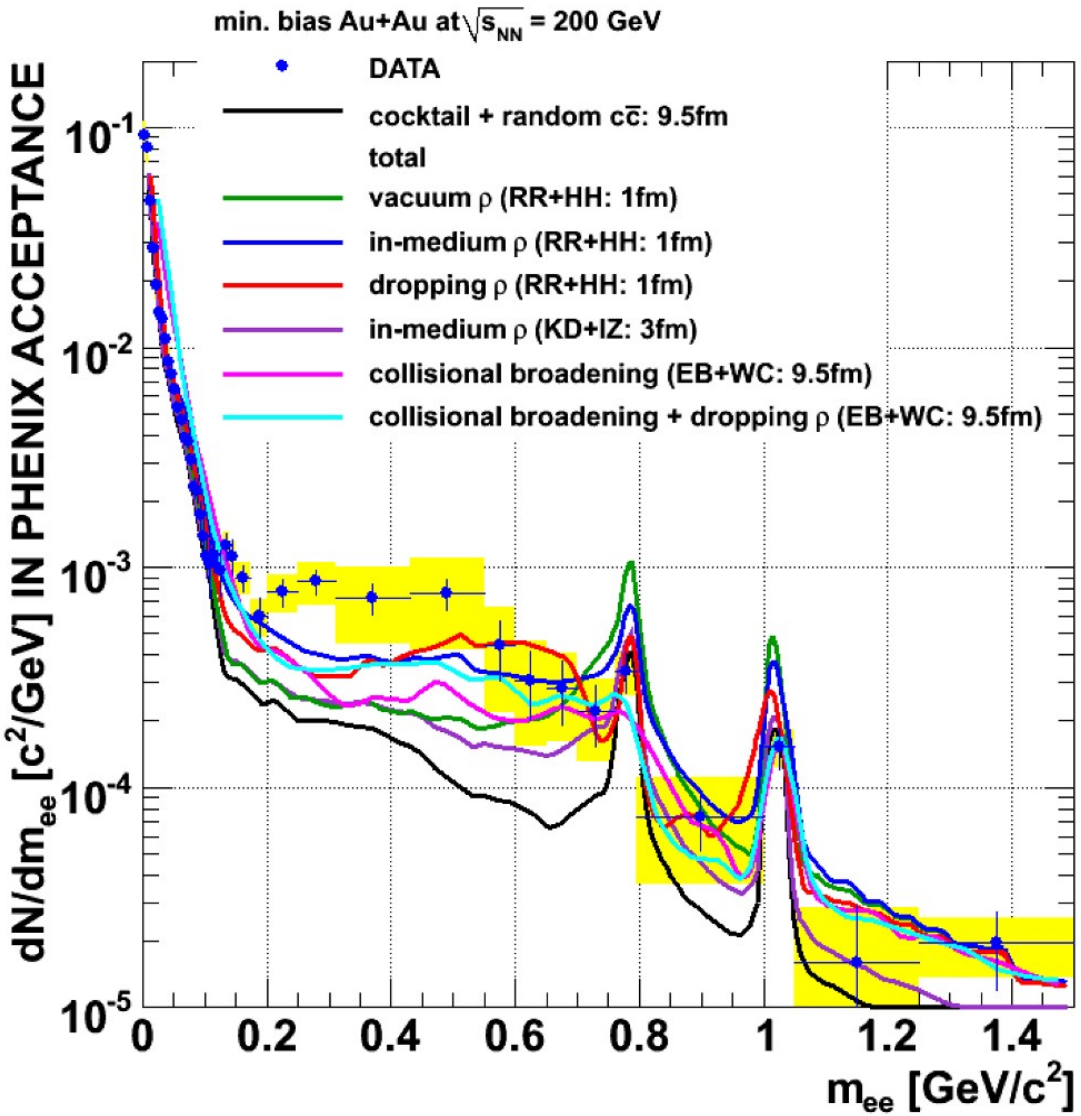




Analysis of Au+Au data is ongoing!

see Lijuan Ruan HP2010 talk

PHENIX: model comparison

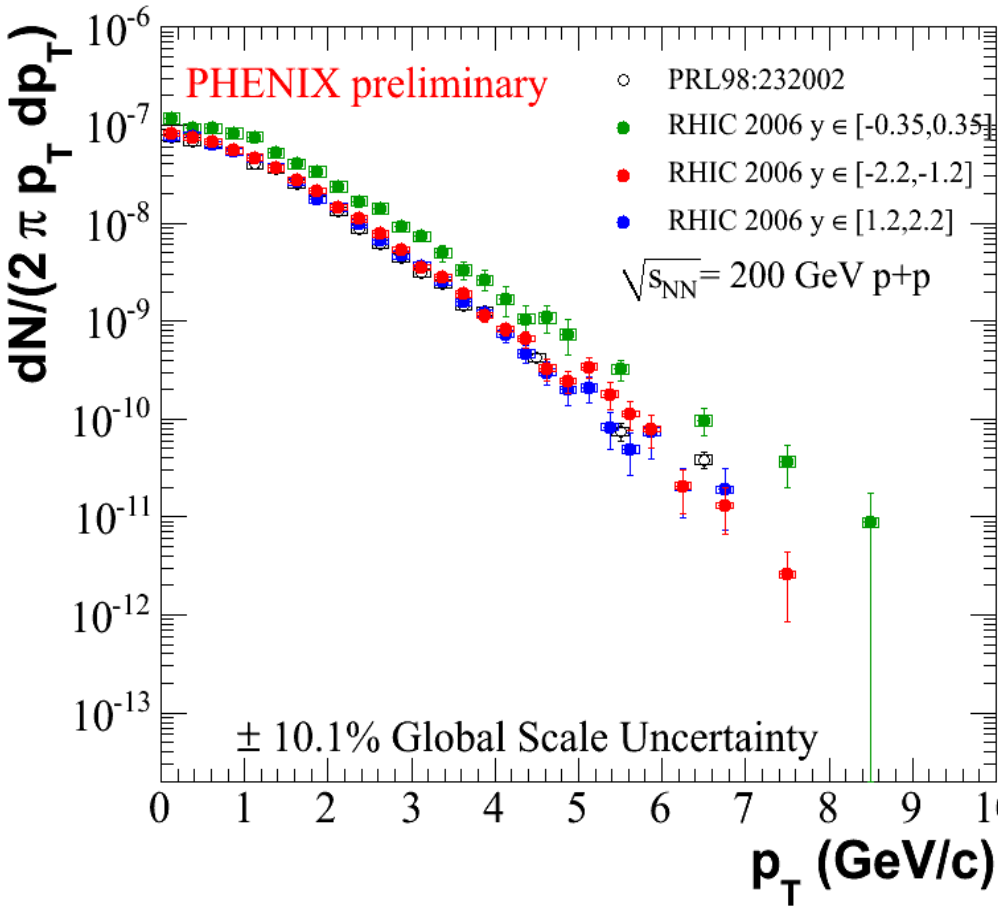


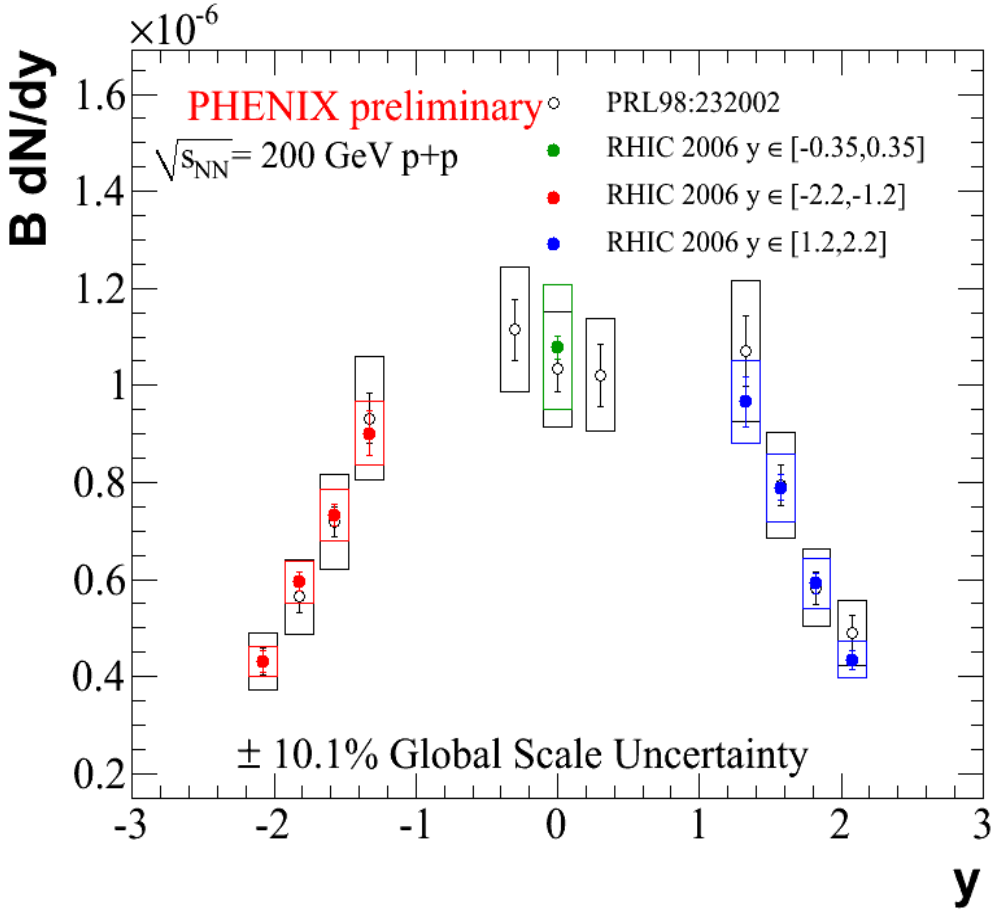
All models and groups that successfully described the SPS data fail in describing the PHENIX results

see for details : **PRC 79, 81 034911 (2010)**

PHENIX: J/Ψ production in p+p

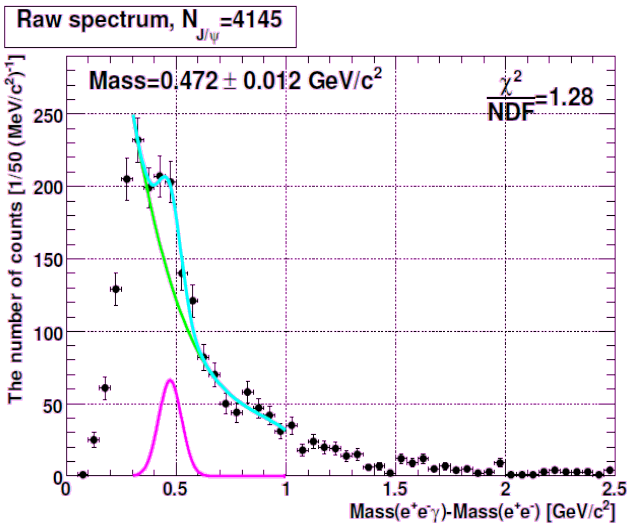
High luminosity measurements of J/Ψ yields over wide rapidity range from p+p collisions. Good agreement with previously published results. Baseline for HI data.

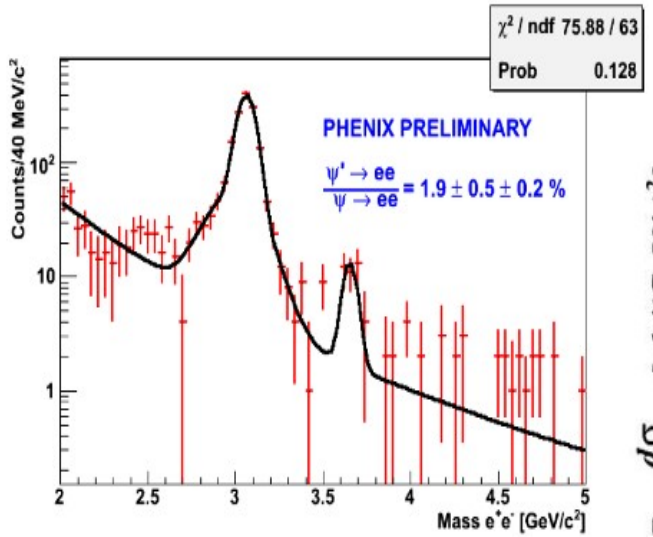


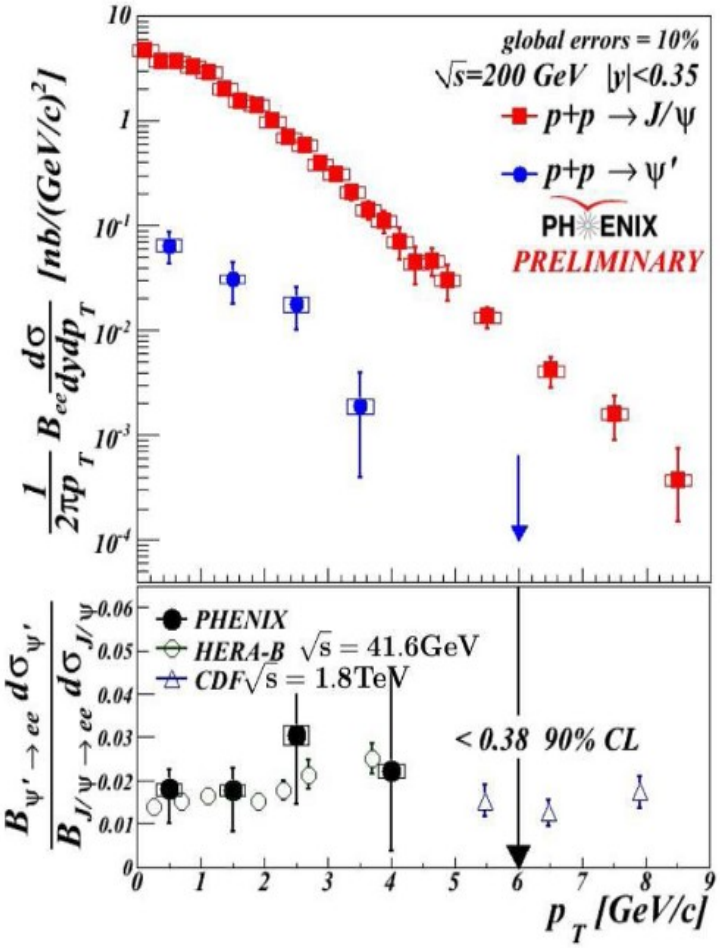


Final result coming that combines run-6 and run-8 are expected soon.

PHENIX: J/Ψ feed-down from χ_c and ψ' (p+p)







Feed-down $\chi_c \to J/\Psi$:

PHENIX	**World avg.***	**Lattice****
<42%(90% CL)	30+/-8.0%	25+/-5.0%

Feed-down $\Psi' \to J/\Psi$:

PHENIX	**World avg.***	**Lattice****
8.6+/-2.5%	8.1+/-0.3%	8.0+/-2.0%

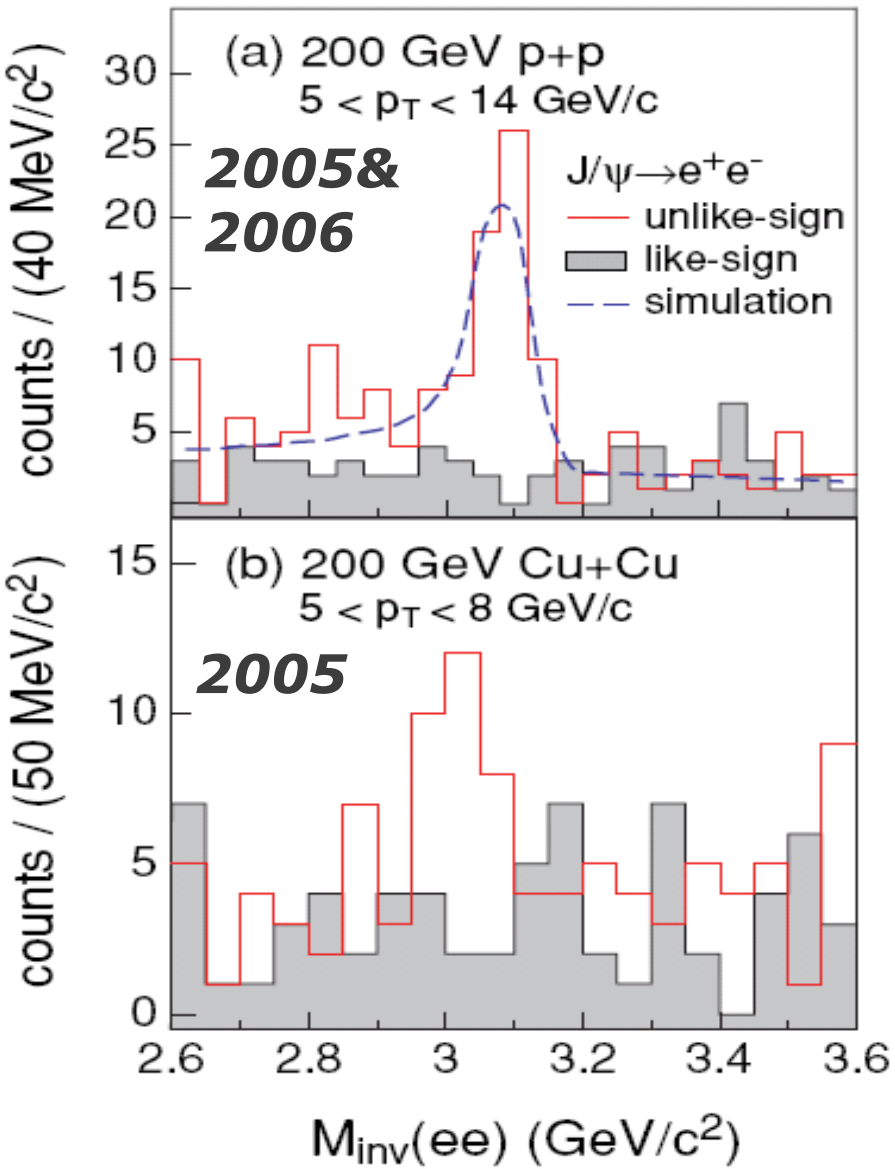
No significant energy or p_T dependence of the Ψ' / J/ψ ratio has been observed. Data is consistent with CDF and HERA-B

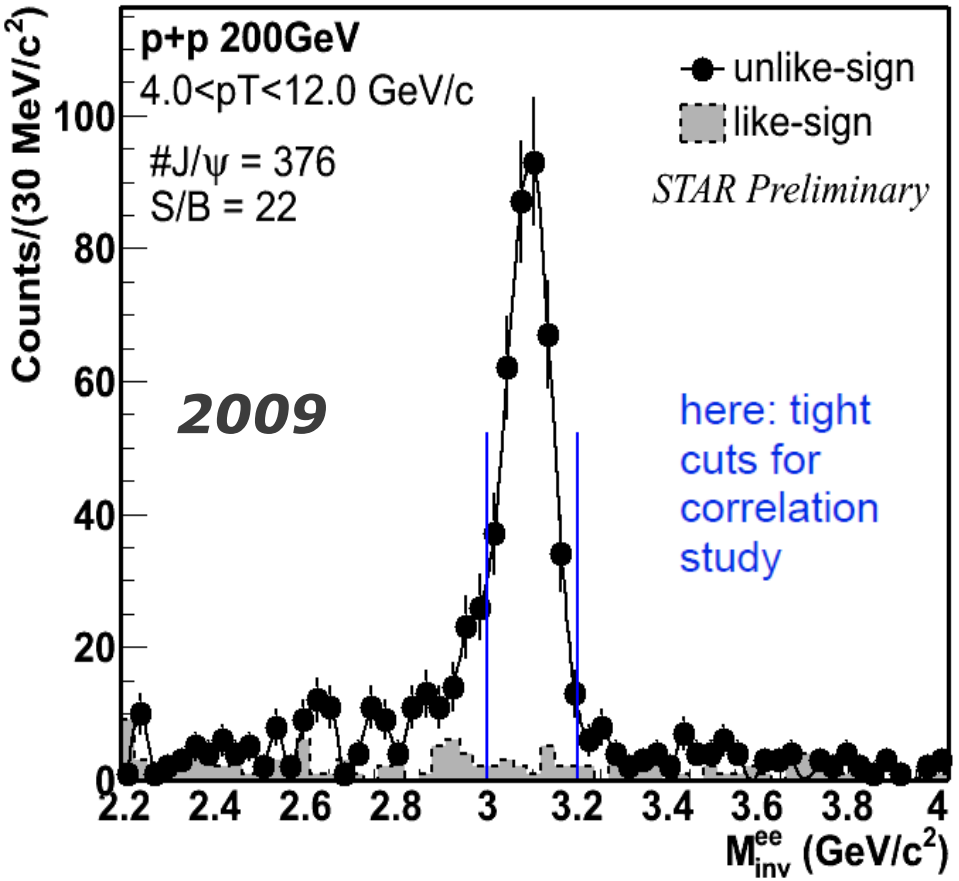
*Faccioli at all, JHEP 0810:004, 2008
** Phys.Rev.D64:094015

HERA-B: Eur. Phys. J. C49, 545 (2007)
CDF: PRL 79, 572 (1997)

STAR: J/Ψ production in p+p and Cu+Cu at high-p_T

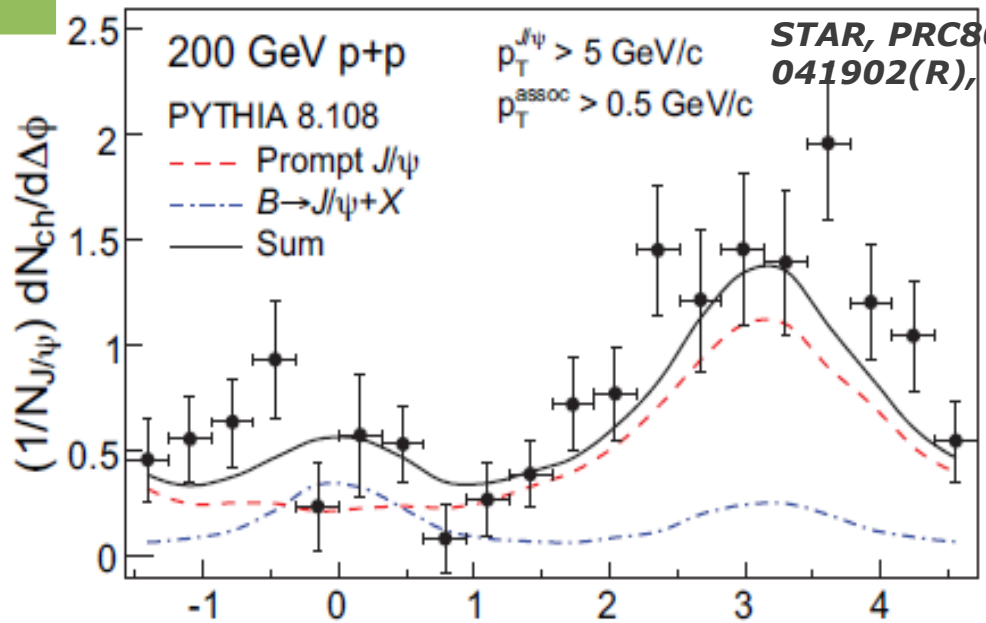
PRC80, 041902(R), 2009



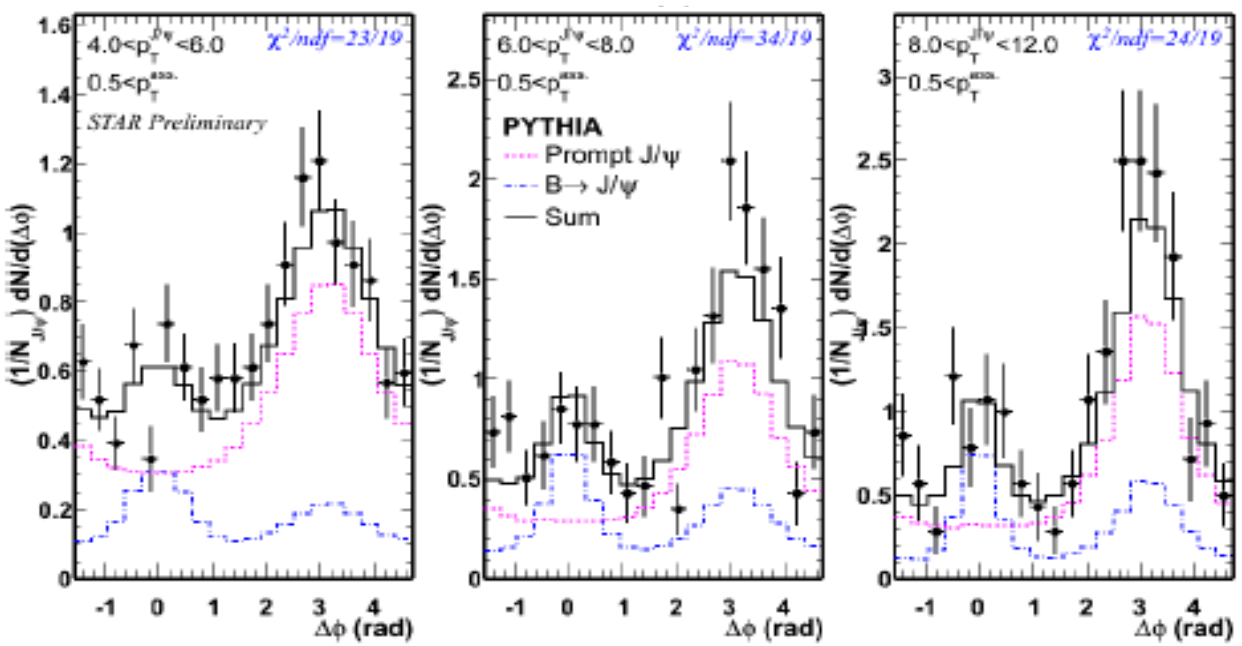


- Steady improvements due to higher L and improved trigger
- Low material budget run
- Expect spectra for 2009 data soon

STAR: constraining bottom contribution



STAR, PRC80, 041902(R), 2009



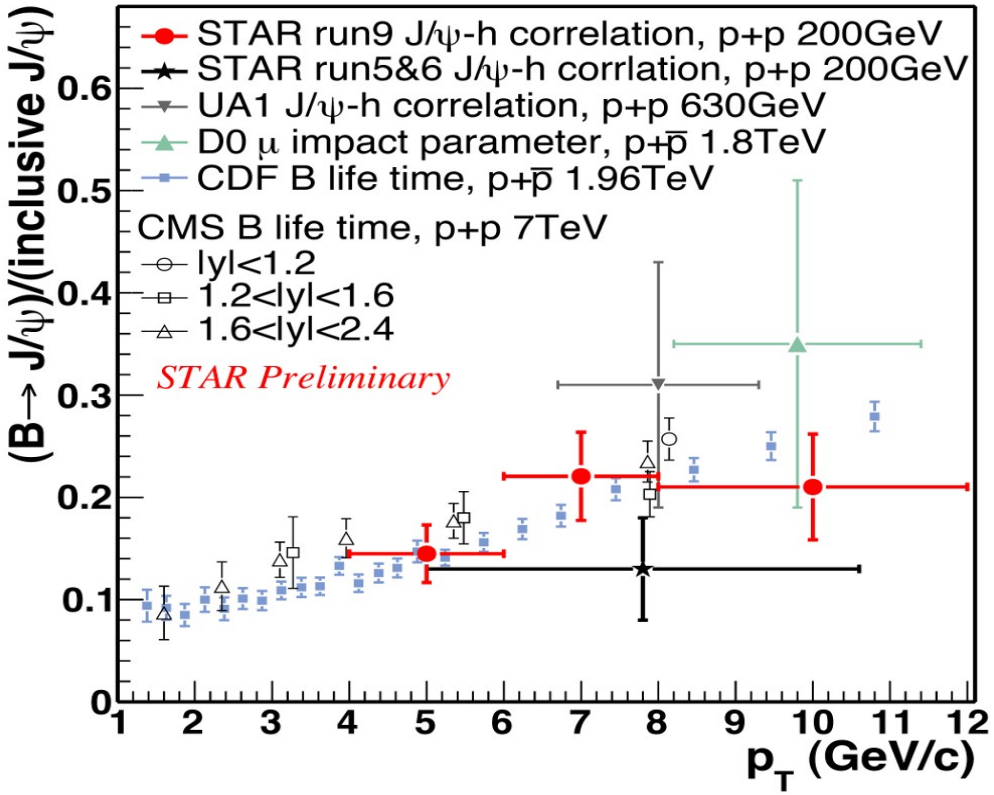
Previous result:

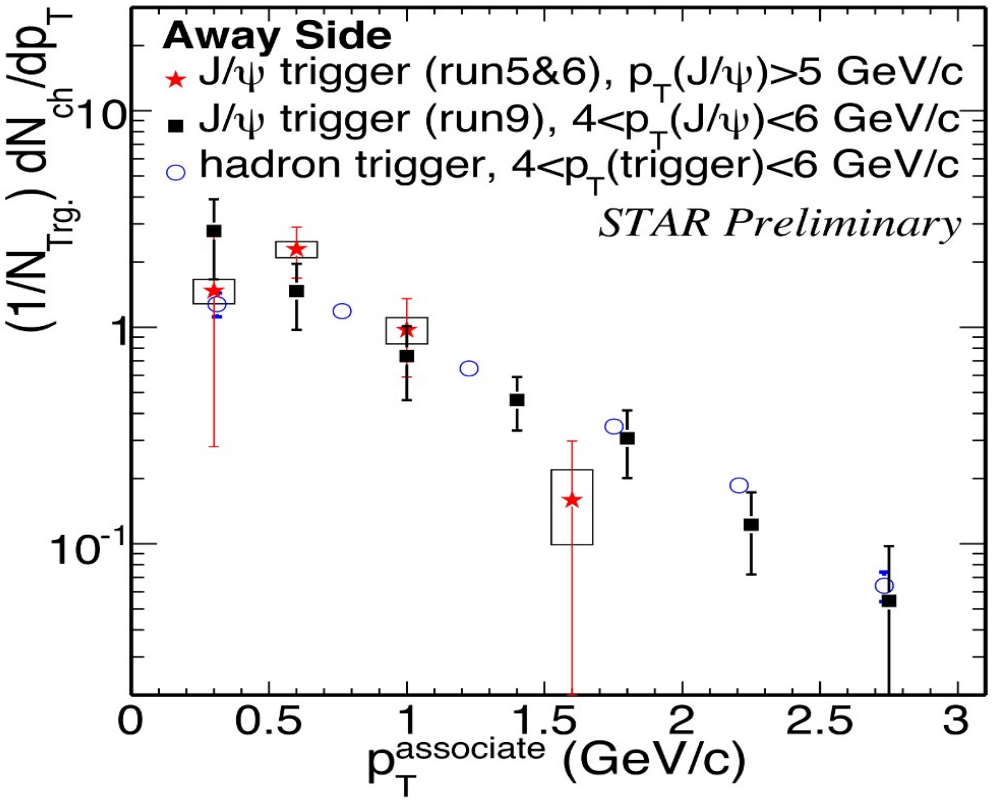
- No significant near side J/ψ-hadron azimuthal angle correlation
- Correlation show low B contribution (13 ± 5) %

Run 9:

- Higher statistics
- Divide into 3 p_T bins

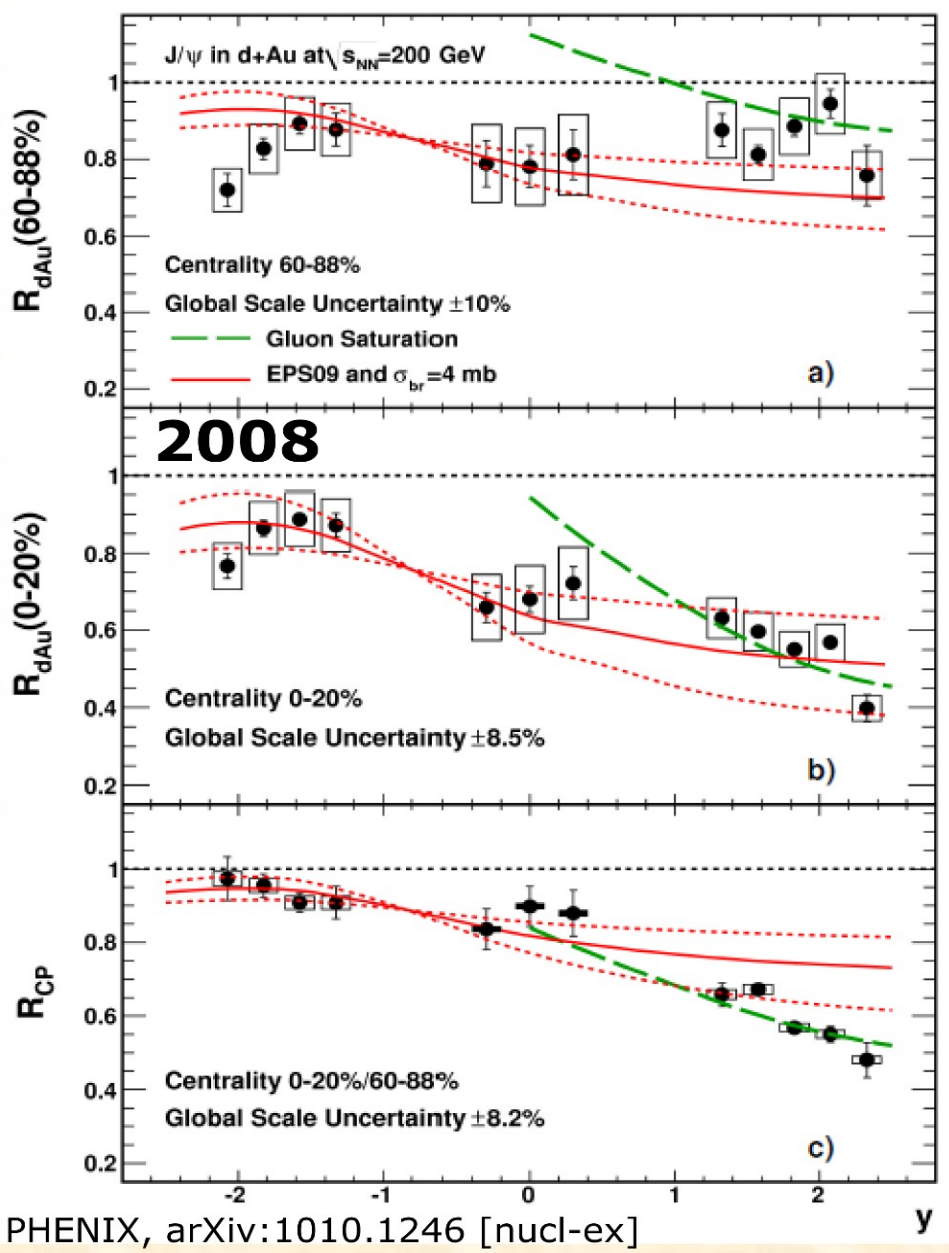
STAR: constraining bottom contribution





- Old and new results are in agreement
- No significant beam energy dependence
- Away side: Consistent with h-h correlation

PHENIX: J/Ψ production in d+Au



PHENIX, arXiv:1010.1246 [nucl-ex]

Factor of 30 increase in statistics in year 2008 (80 nb^{-1}) compared to year 2003 (2.74 nb^{-1})

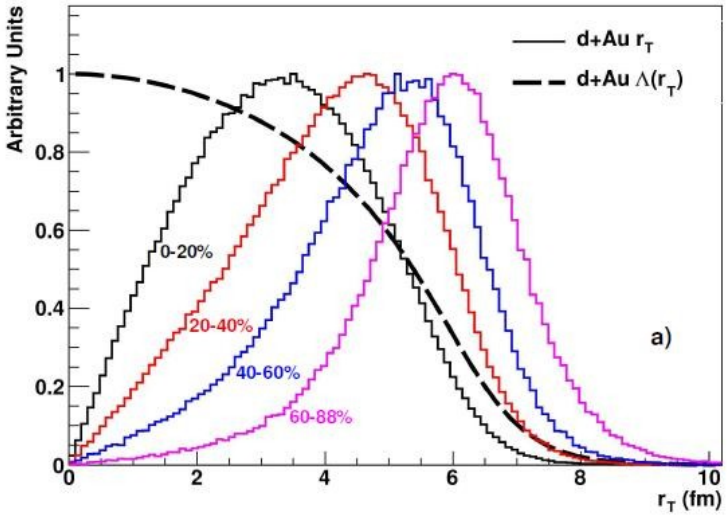
$$R_{dAu} = \frac{1}{<N_{coll}>} \frac{dN^{d+Au}_{J/\psi}/dy}{dN^{p+p}_{J/\psi}/dy}$$

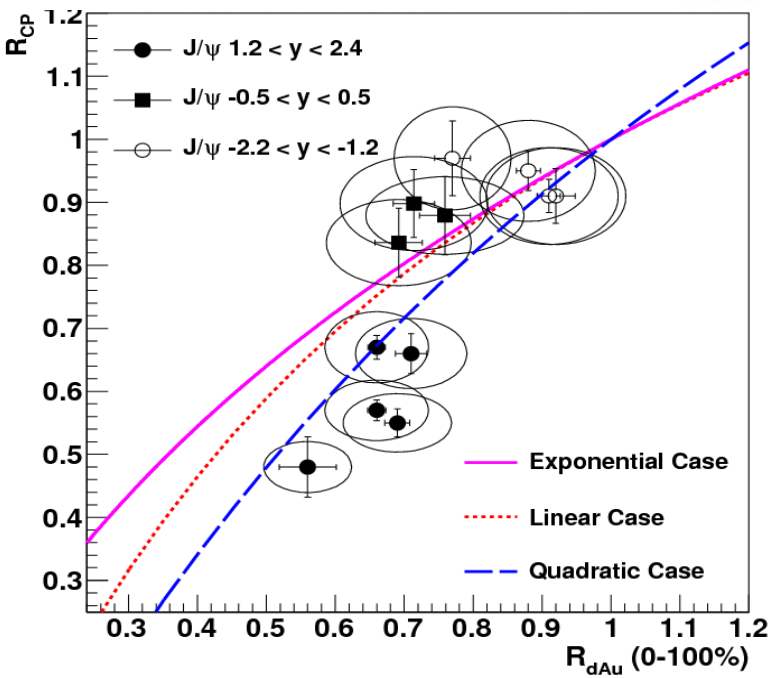
$$R_{CP}^{0-20\%} = \frac{N_{inv}^{0-20\%} / \langle N_{coll}^{0-20\%} \rangle}{N_{inv}^{60-88\%} / \langle N_{coll}^{60-88\%} \rangle}$$

- Rapidity dependence:
  Rcp ~ 1 at negative rapidity
  At positive rapidity, Rcp < 1 and decreases in most central collisions.
- EPS09 and $\sigma_{breakup}$ (red line) does not describe rapidity dependence
- Gluon saturation (green line) describes data only at forward rapidity.

PHENIX: J/Ψ production in d+Au

arXiv:1010.1246





Test dependence of nuclear effects on the density weighted longitudinal thickness through the gold nucleus.

$$\text{Exponential}: M(r_T) = e^{-a\Lambda(r_T)}$$

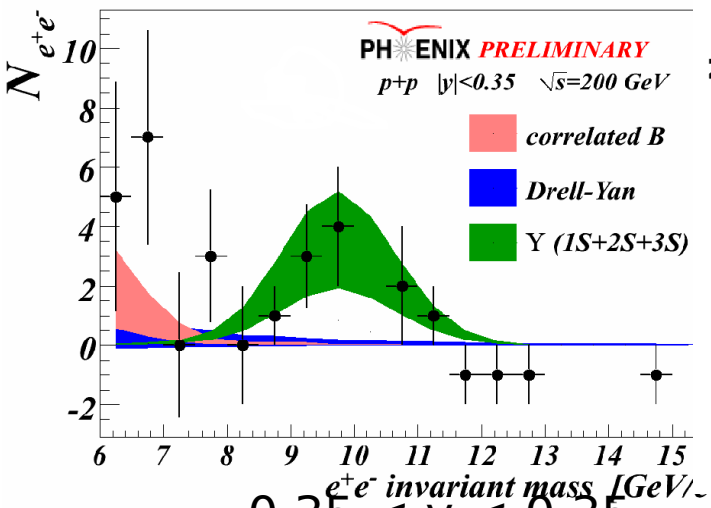
$$\text{Linear}: M(r_T) = 1.0 - a\Lambda(r_T)$$

$$\text{Quadratic}: M(r_T) = 1.0 - a\Lambda(r_T)^2$$

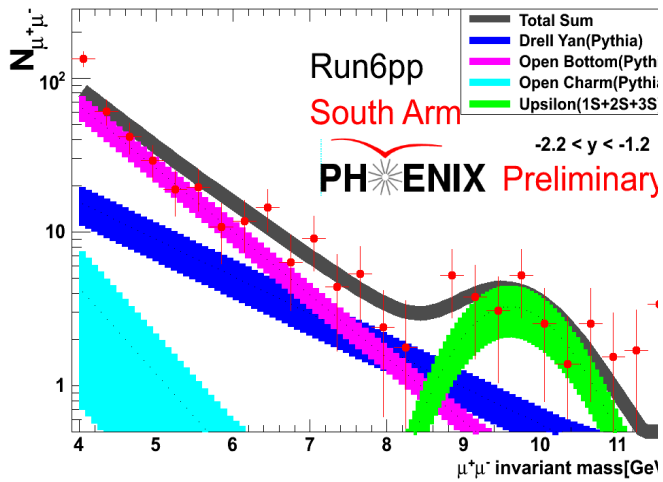
At forward rapidity data do not favor linear and exponential dependences

At mid and backward rapidities – not enough discriminating power

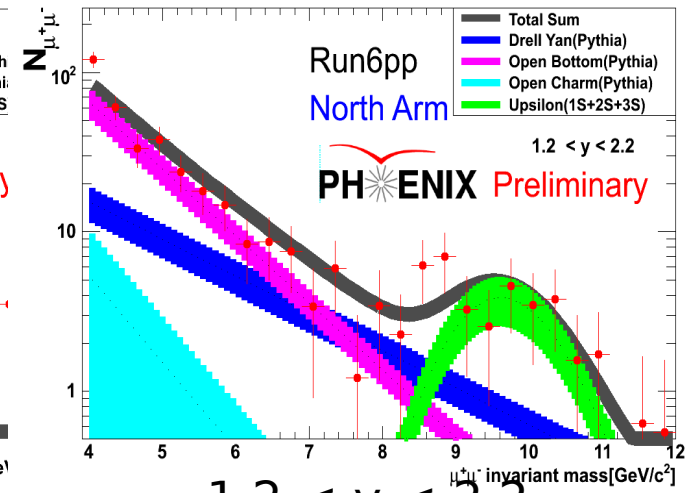
PHENIX: Υ(1S+2S+3S) production in p+p



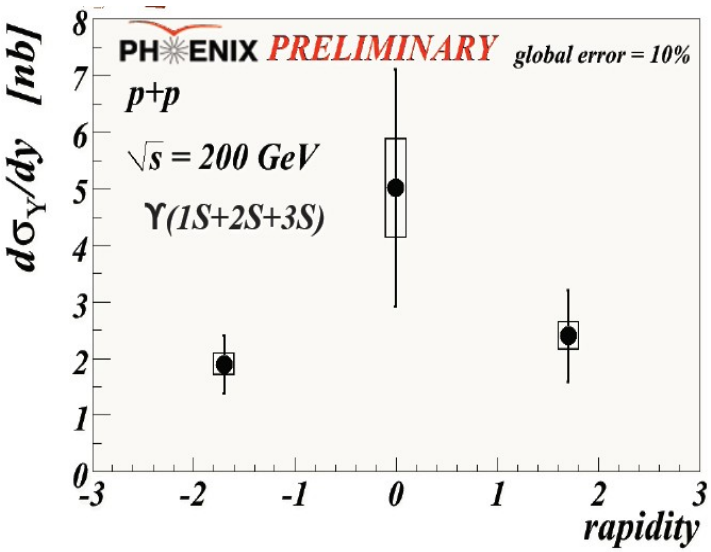
-0.35 < y < 0.35

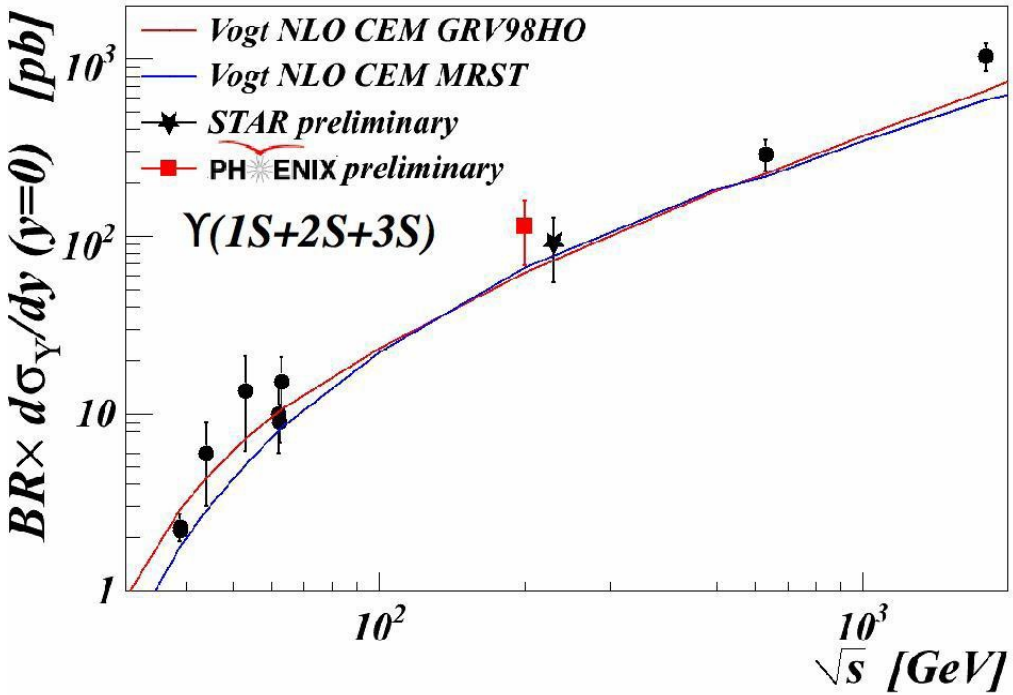


-2.2 < y < -1.2



1.2 < y < 2.2

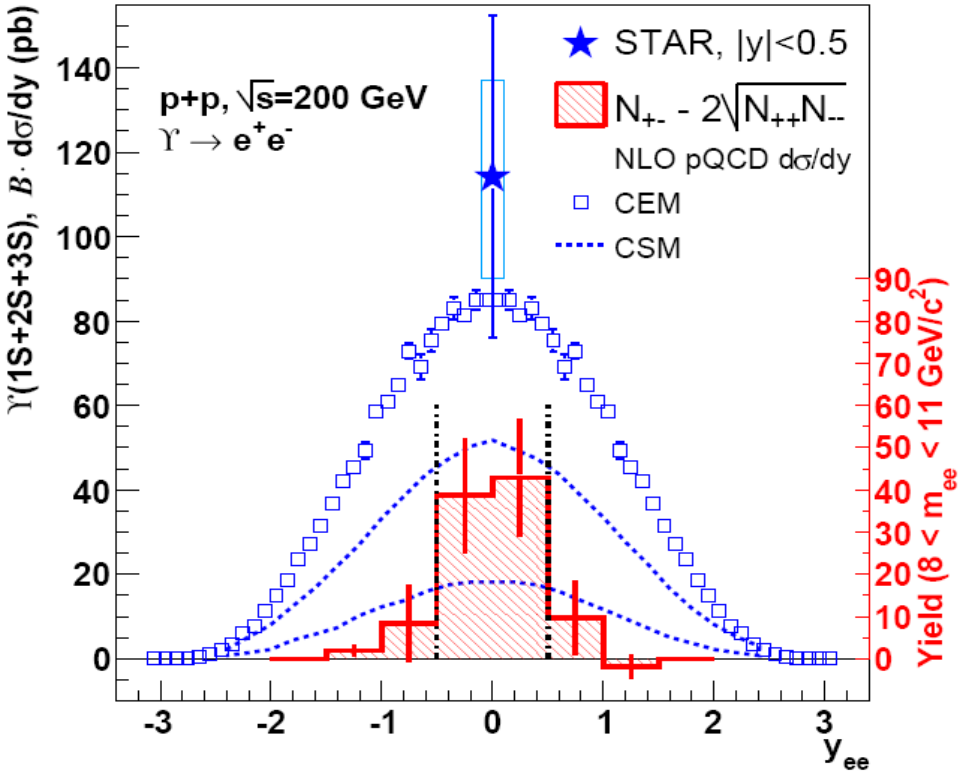


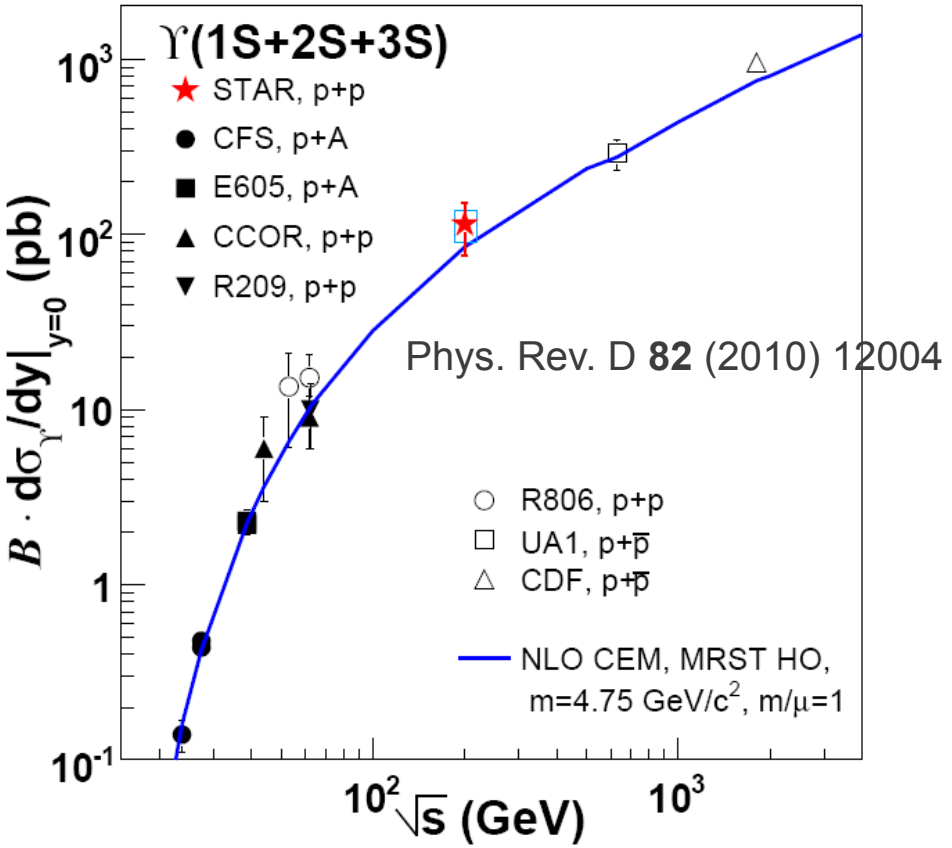


Total cross section: $B\frac{d\sigma_\Upsilon}{dy}\Big|_{|y|<0.35} = 114^{+46}_{-45} pb$

STAR: Υ(1S+2S+3S) production in p+p

Phys. Rev. D **82** (2010) 12004





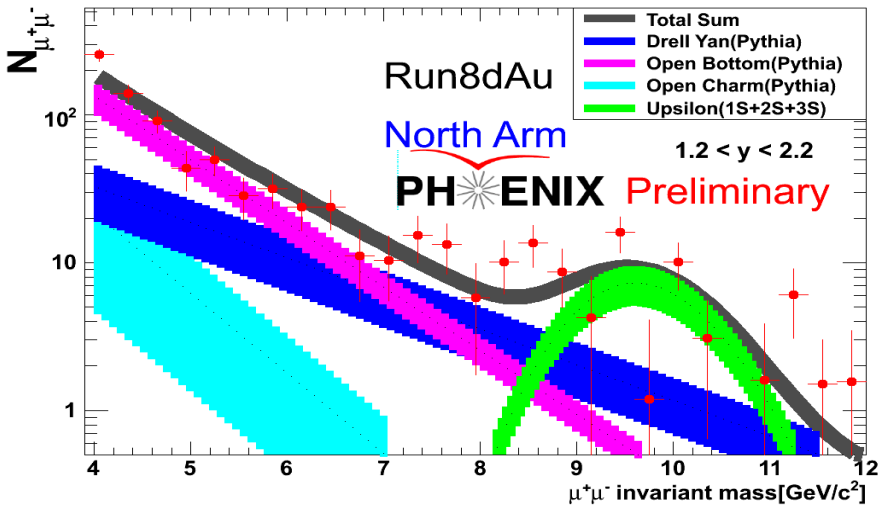
Phys. Rev. D **82** (2010) 12004

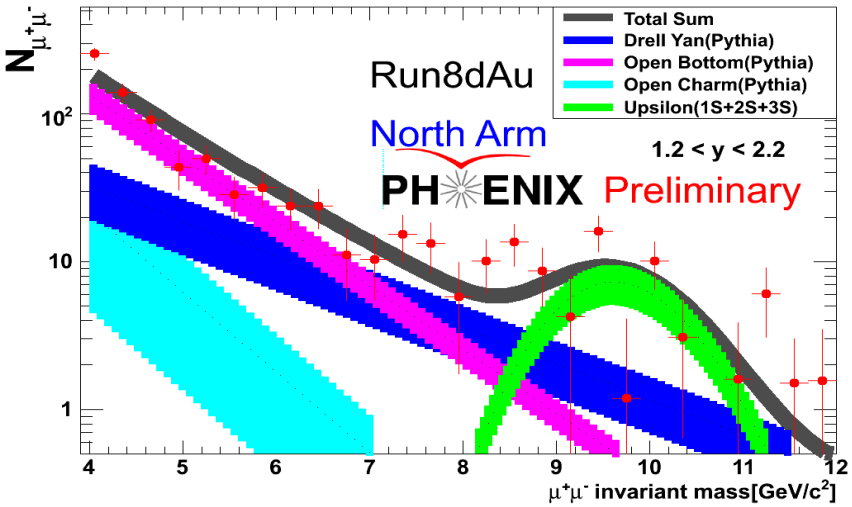
$$\sum_{n=1} \mathcal{B}(nS) \times \sigma(nS) = 114 \pm 38\ ^{+23}_{-24}\ \text{pb}$$

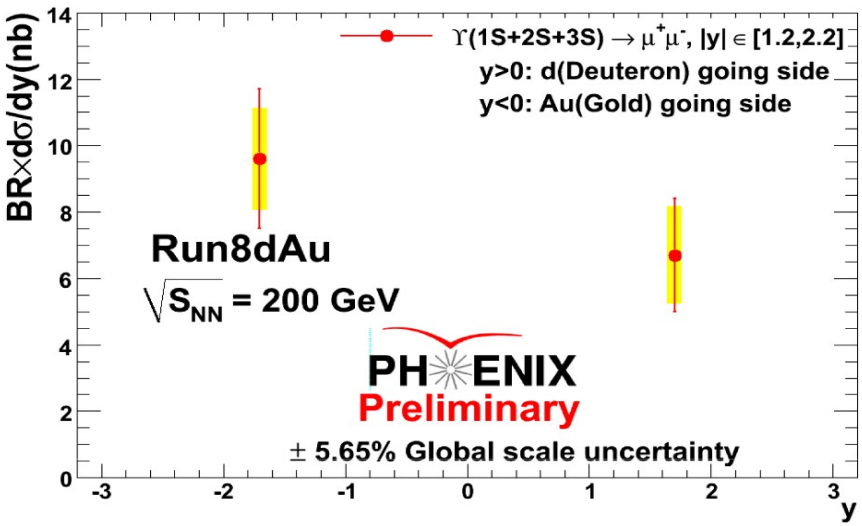
$$\left(\sigma_{DY} + \sigma_{b\bar{b}}\right)_{|y|<0.5,\ 8<m_{ee}<11\ \text{GeV/c}^2} = 38 \pm 24\ \text{pb}$$

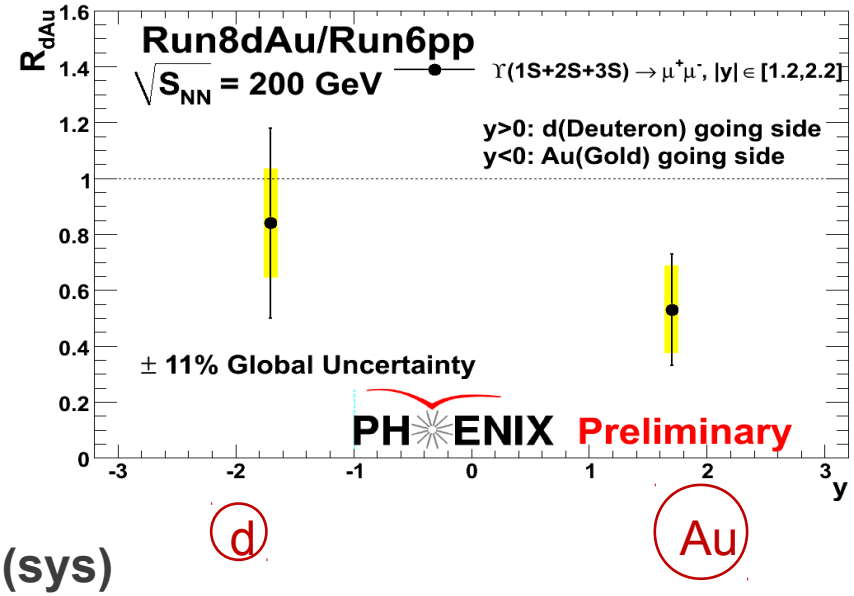
STAR 2006 √s=200 GeV p+p Υ(1S+2S+3S)→e^+e^- cross section consistent with pQCD and world data trend

PHENIX: Υ(1S+2S+3S) production in d+Au







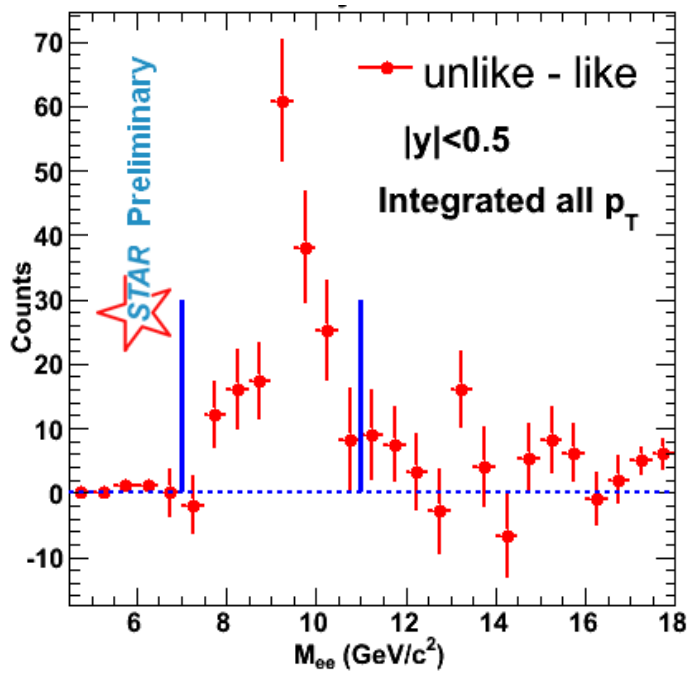


$R_{dA}[1.2,2.2] = 0.53+/-0.20(stat)+/-0.16(sys)$

$R_{dA}[-2.2,-1.2] = 0.84+/-0.34(stat)+/-0.20(sys)$

STAR: Υ(1S+2S+3S) production in d+Au

arXiv:0907.4538



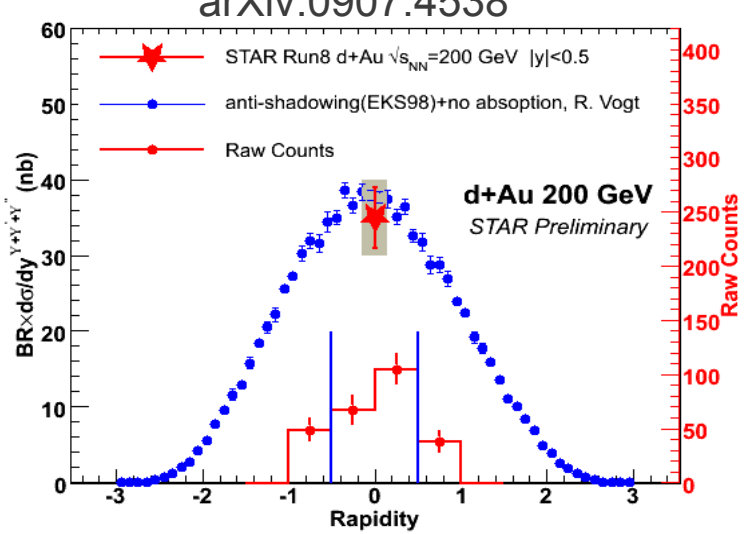
Υ(1S+2S+3S)+DY+$b\bar{b}$ raw yield
(7<m [GeV/c^2]<11) = 172 ± 20 (stat.)

Strong signal (8σ)

$$BR \times \left(\frac{d\sigma}{dy}\right)^{\Upsilon(1S+2S+3S)}_{y=0} = 35 \pm 4(stat.) \pm 5(sys.)\ \text{nb}$$

$$\left(\sigma_{DY} + \sigma_{b\bar{b}}\right)_{|y|<0.5,\ 7<m_{ee}<11\ \text{GeV/c}^2} \approx 10\%$$

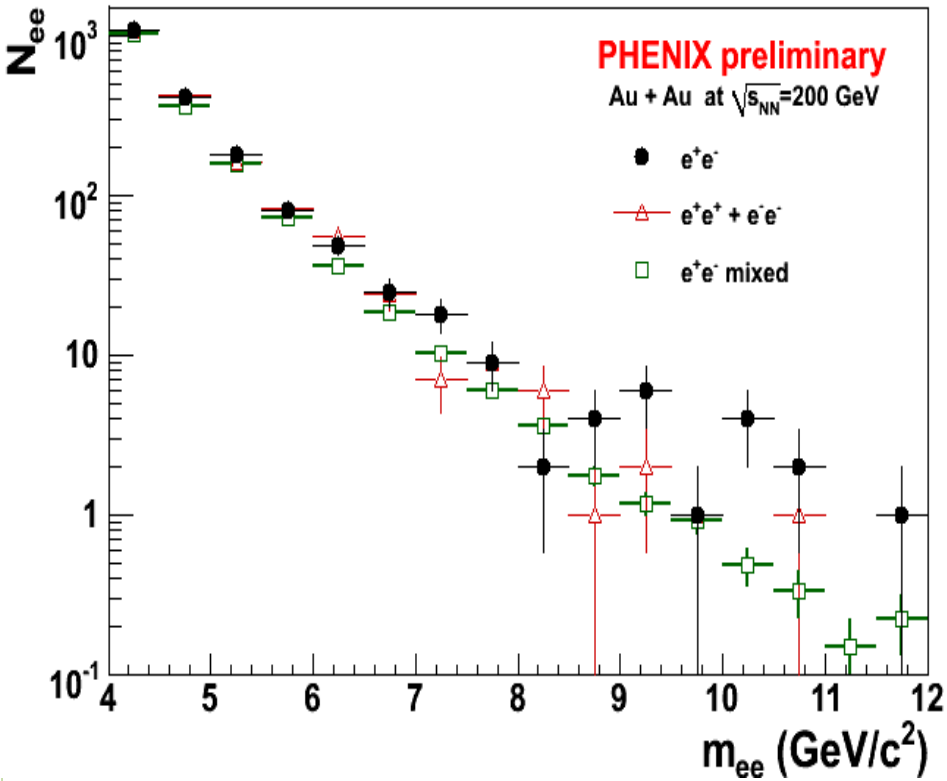
arXiv:0907.4538

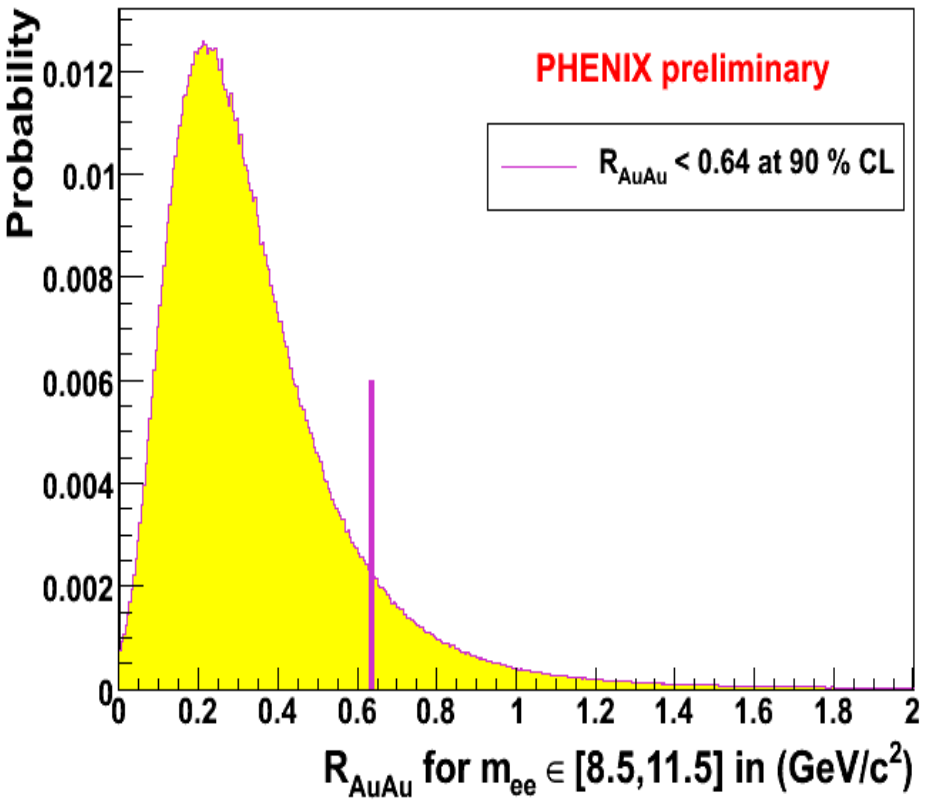


Nuclear modification factor at midrapidity:

$$R_{dA} = 0.78 \pm 0.28(stat) \pm 0.20(sys)$$

PHENIX: Υ(1S+2S+3S) production in Au+Au

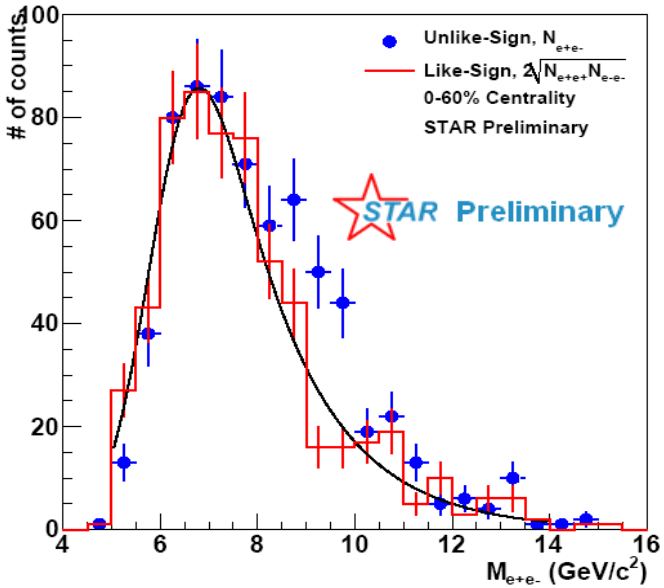


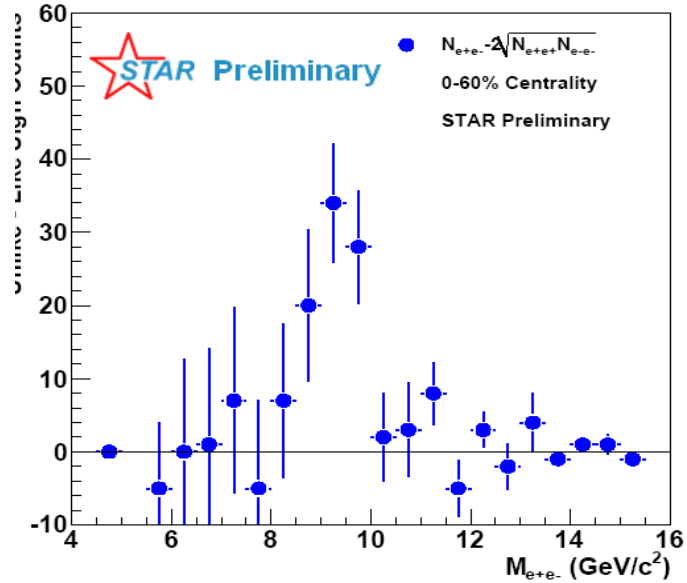


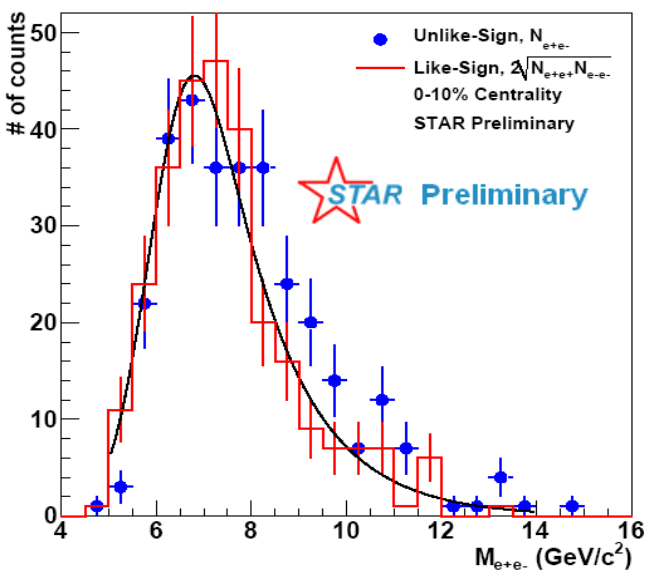
-0.35 < y < 0.35

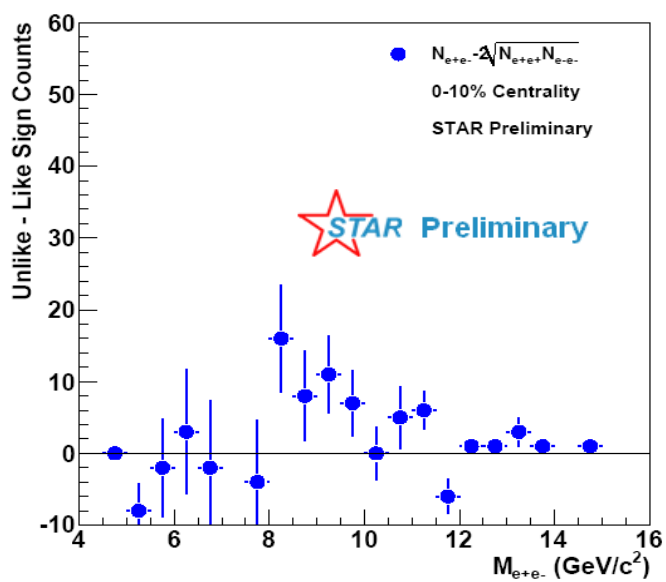
R_{AuAu} [8.5,11.5] < 0.64 at 90% C.L.

STAR: Υ(1S+2S+3S) production in Au+Au









Year 2007
$8<m<11$ GeV/c^2

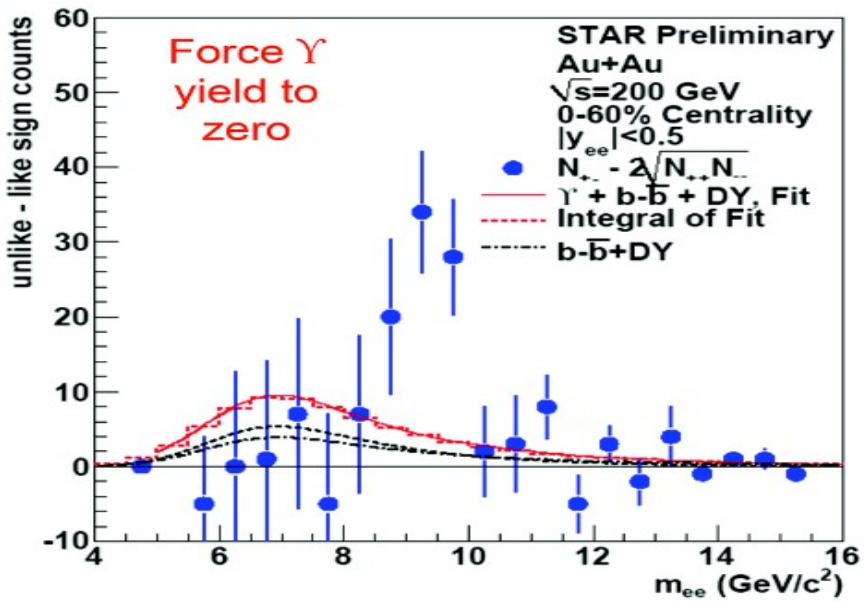
0-60%
4.6σ significance
95 Signal counts
1.11×10^9 events

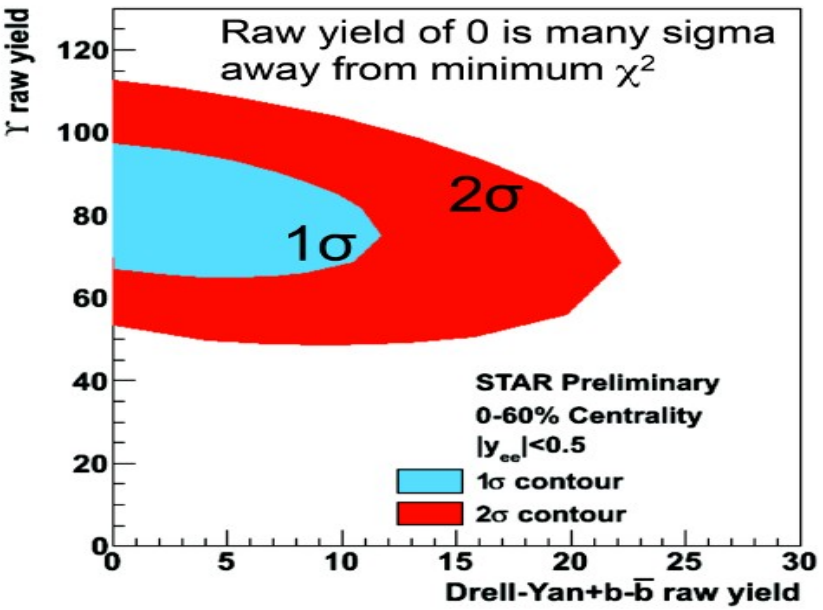
0-10%
3.5σ significance
47 Signal counts
1.78×10^8 events

Includes Υ, Drell-Yan + $b\bar{b}$

STAR: Y(1S+2S+3S) production in Au+Au

How solid is the Y(1S+2S+3S) signal in 0-60% centrality?





ϒ yield determined by:

ϒ(8.5<m<11 GeV/c2) = $N_{+-} - 2\sqrt{N_{++}N_{--}} - (\int DY + \square bb)$

assuming Nbin scaling

0-60%: 64±16(stat)±25(sys)

0-10%: 21±11(stat) ± 11(sys)

$$R_{AA}(0-60)=0.78\pm0.32(stat)\pm0.22(sys,Au+Au)\pm0.09(sys,p+p)$$

$$R_{AA}(0-10)=0.63\pm0.44(stat)\pm0.29(sys,Au+Au)\pm0.07(sys,p+p)$$

Summary

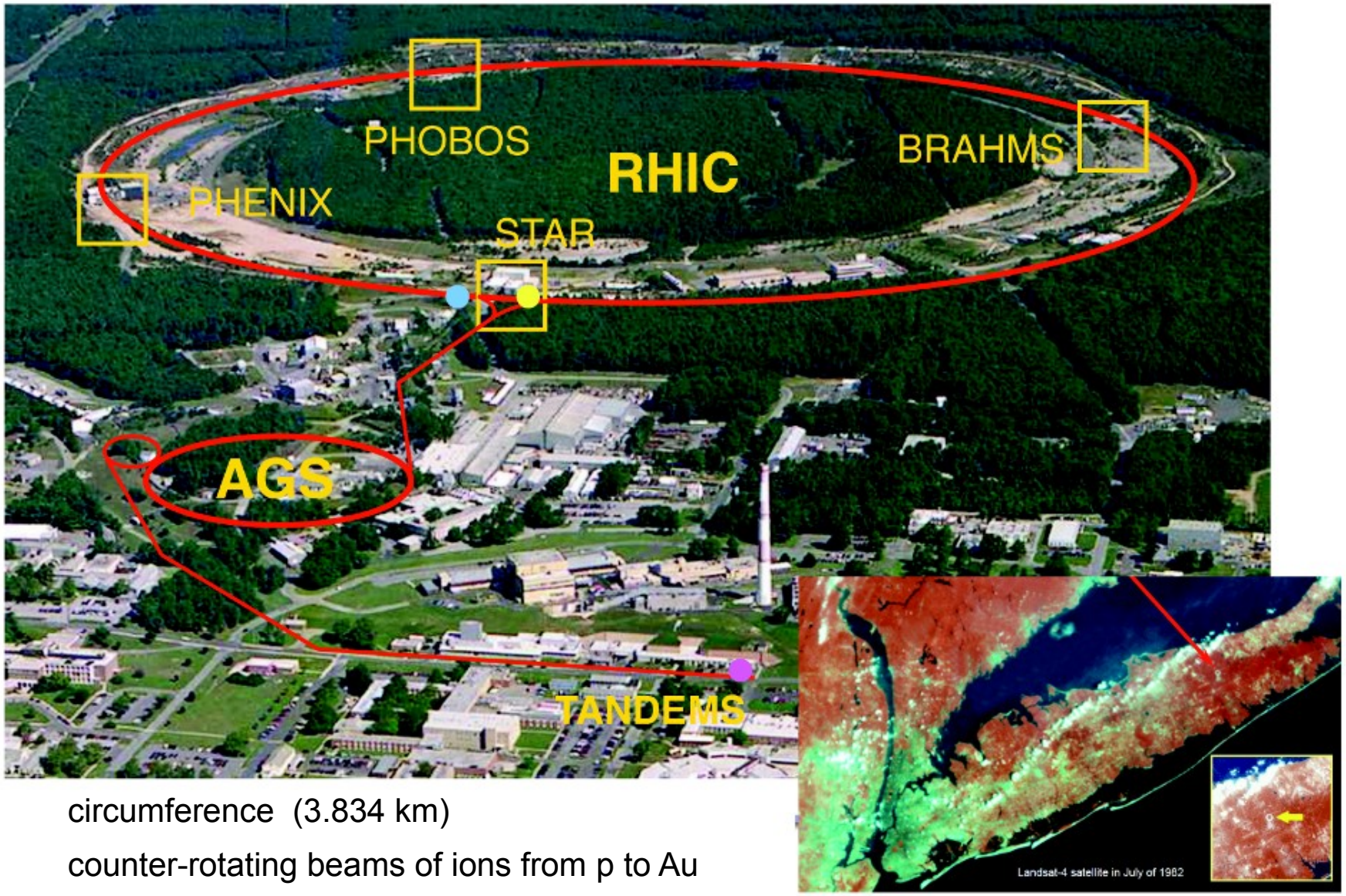
My apologies for not showing many other exiting results.

- Low mass vector mesons
  - PHENIX: Low mass e+e- pair enhancement in Au+Au
  - STAR: Similar analysis is ongoing. Stay tuned.
- J/ψ
  - PHENIX:
    - High statistic measurement in p+p: spectra.
    - Ψ' and χ_c feed-down on p+p
    - High statistic measurement in d+Au: R_{dAu}, Rcp
  - STAR:
    - High statistic p+p data-sample is being analyzed. Spectra soon.
    - B-meson feed-down in p+p through J/ψ-h correlations
- Υ
  - PHENIX, STAR:
    - cross-section measured in p+p, R_{dAu}, R_{AuAu}

Many analyses are ongoing and results being finalized

BACKUP

Relativistic Heavy Ion Collider (RHIC)



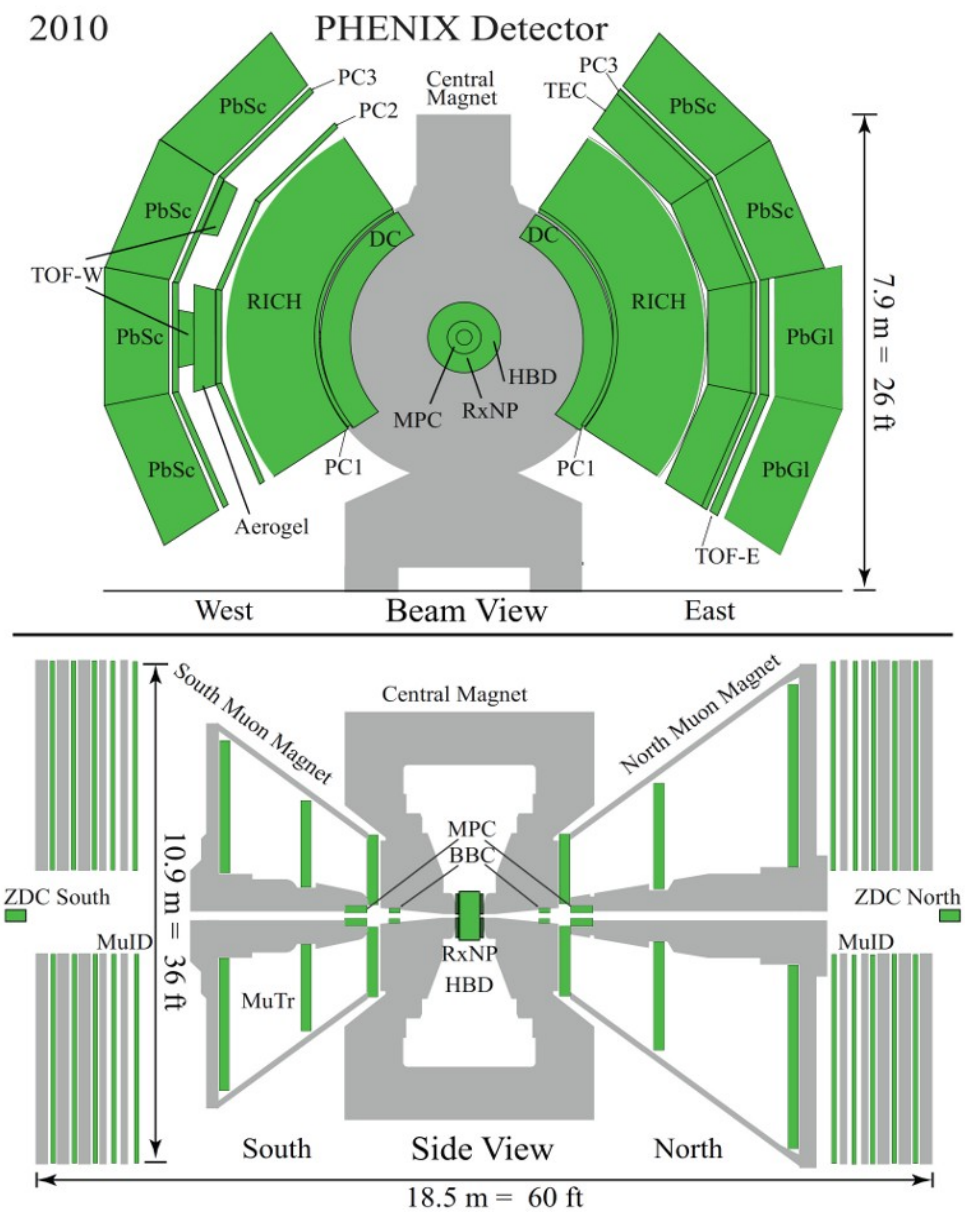
circumference (3.834 km)

counter-rotating beams of ions from p to Au

species (p+p, d+Au, Cu+Cu, Au+Au)

max center-of-mass energy (200, 500) GeV

PHENIX Detector



Central Arms: hadrons, photons, electrons;

- $-0.35 \leq \eta \leq 0.35$;
- $p_e > 0.2$ GeV/c;
- $\Delta\phi = \pi(2\ arms \times \pi/2)$;
- charged particle tracking analysis using DC and PC.

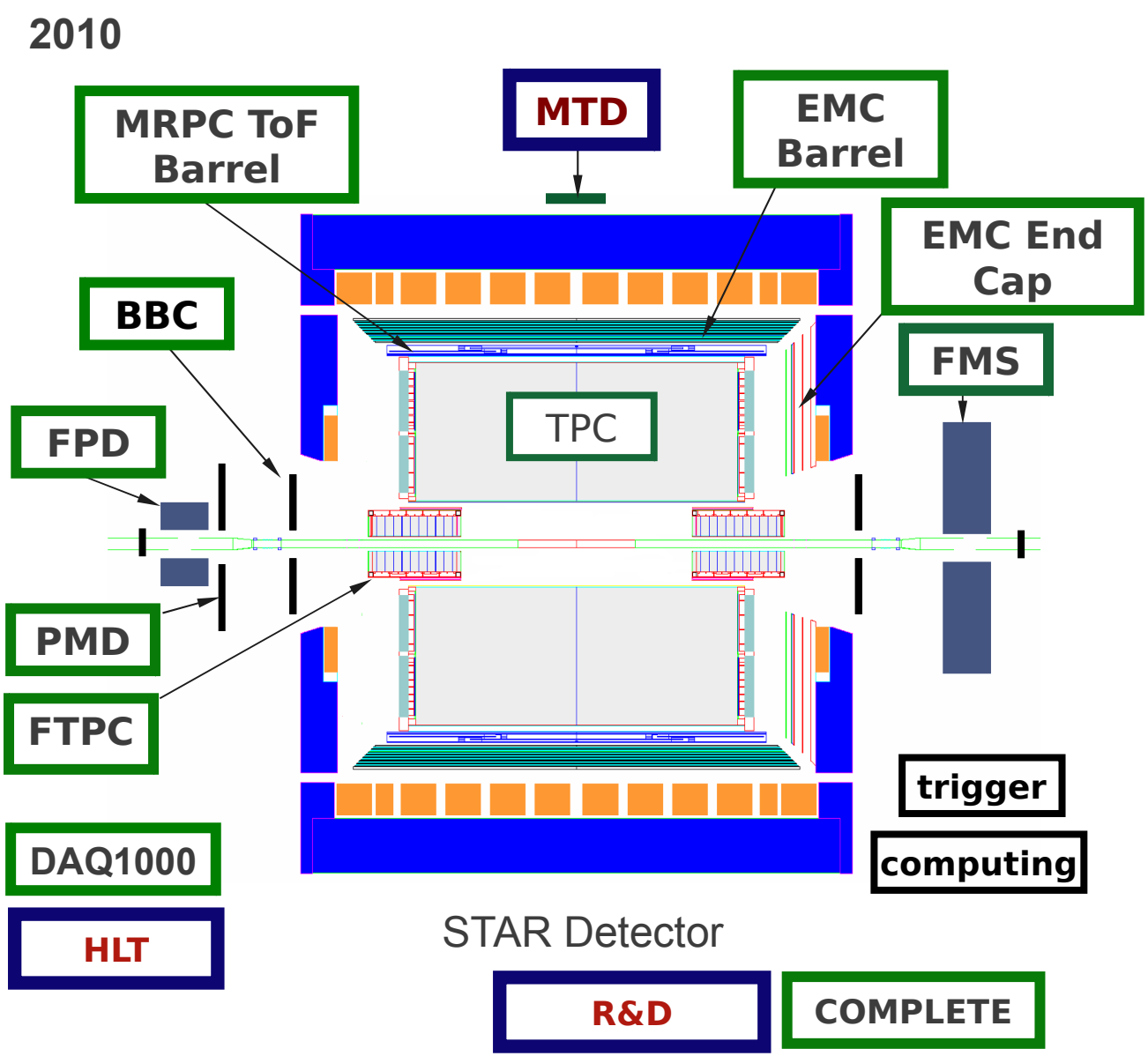
Electron identification based on:

- Ring Imaging Čerenkov detector (RICH);
- Electromagnetic Calorimeter (EMCal).

Forward rapidity arms: muons;

- $1.2 \leq |\eta| \leq 2.4$;
- $p_\mu > 1.0$ GeV/c
- $\Delta\phi = 2\pi$
- μ-Magnets and μ-Identifier steel absorb hadrons, π-rejection $\sim$ 250:1
- μ-Tracker reconstructs trajectories and determines momentum.

STAR Detector



TPC

-1.8<η<1.8, 2π in azimuth
Charged particle tracking.
PID via ionization energy loss measurements (dE/dx).

BEMC

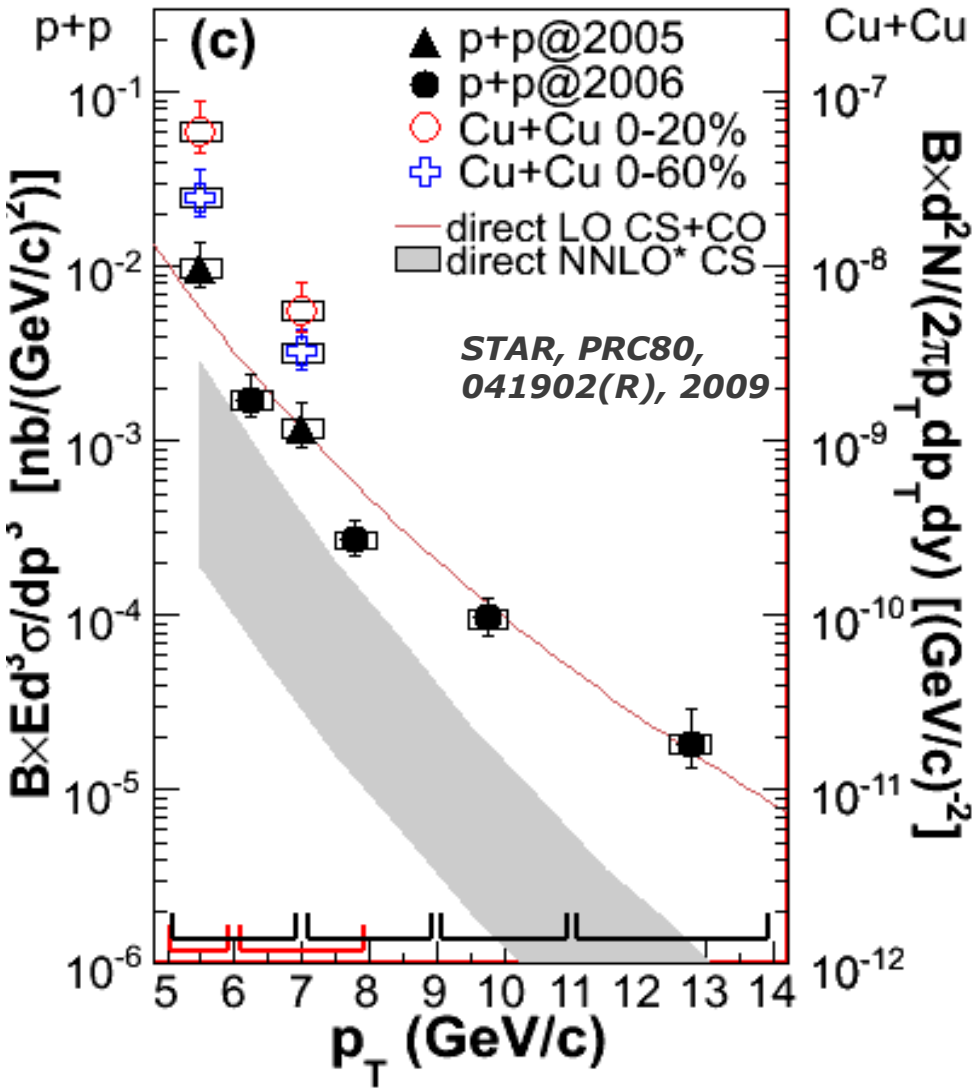
-1.0<η<1.0, 2π in azimuth
Electron PID via E/p measurement.

High-energy tower trigger.

ToF

-0.9<η<0.9, 2π in azimuth
(72% y2009, 100% y2010)
Timing resolution: ~100 ps
PID: π/K up to 1.6 GeV/c
(π+K)/proton up to 3 GeV/c

STAR: J/Ψ spectra in p+p



Color singlet model: direct NNLO* still miss the high p_T part.

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

LO CS+CO: better agreement with the measurements, leave little room for higher charmonium states and B feeddown.

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

Expect spectra for 2009 data soon