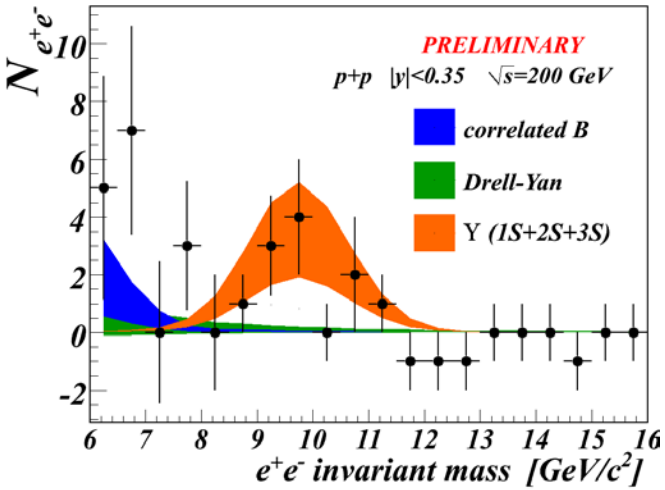
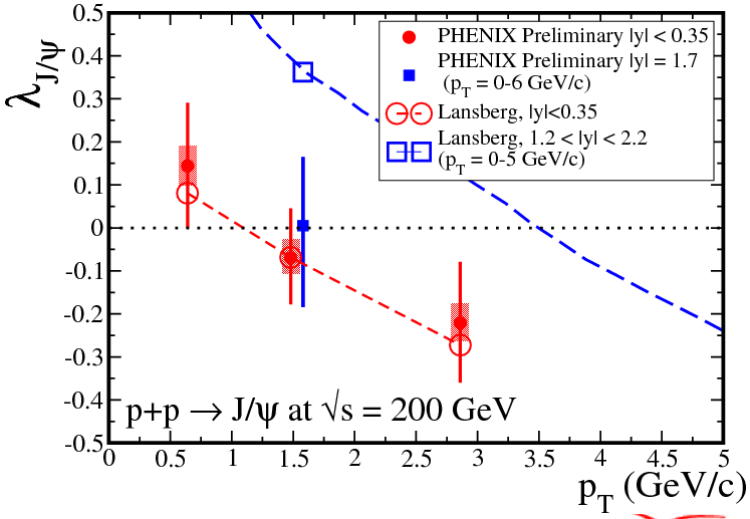
Highlights from PHENIX-I
Initial State and Early Times

Mike Leitch - LANL (for the PHENIX collaboration)

QM09, March 30, 2009 Knoxville

- Cold nuclear matter (CNM)
- Heavy quark production
- Quarkonia
- Photons





after lunch - Highlights from PHENIX-II: Exploring the QCD Medium – Carla Vale

Preview of Highlights:

- Suppression of rapidity-separated hadron pairs in d+Au
- Heavy-quark decay electrons:
  - Quarkonia contribute substantially
  - Beauty fraction ~50% for higher p_T
- High-p_T Cu+Cu J/Ψ suppression
- Upsilon suppressed in Au+Au
- Initial temperature from low-p_T photons

Cold Nuclear Matter (CNM) & Gluon Saturation

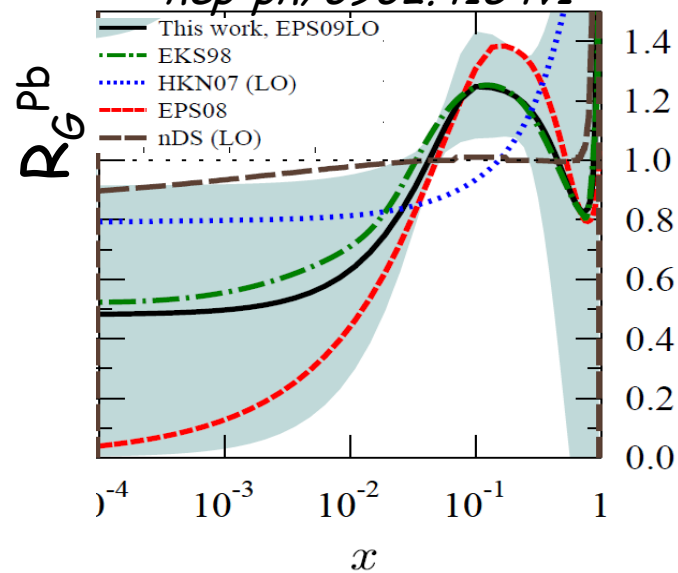
Cold Nuclear Matter (CNM) & Gluon Saturation

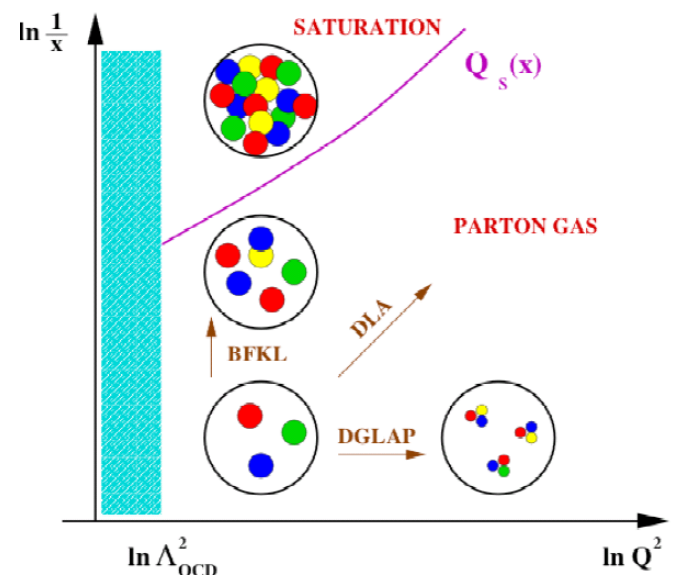
Traditional shadowing or coherence models

Gluon saturation at small x; amplified in a nucleus

Initial state energy loss & multiple scattering

hep-ph/0902.4154v1

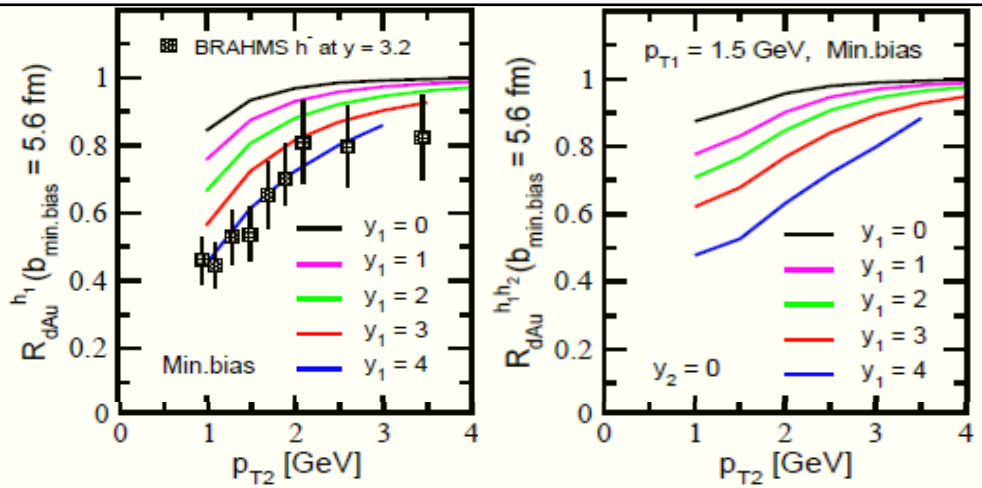




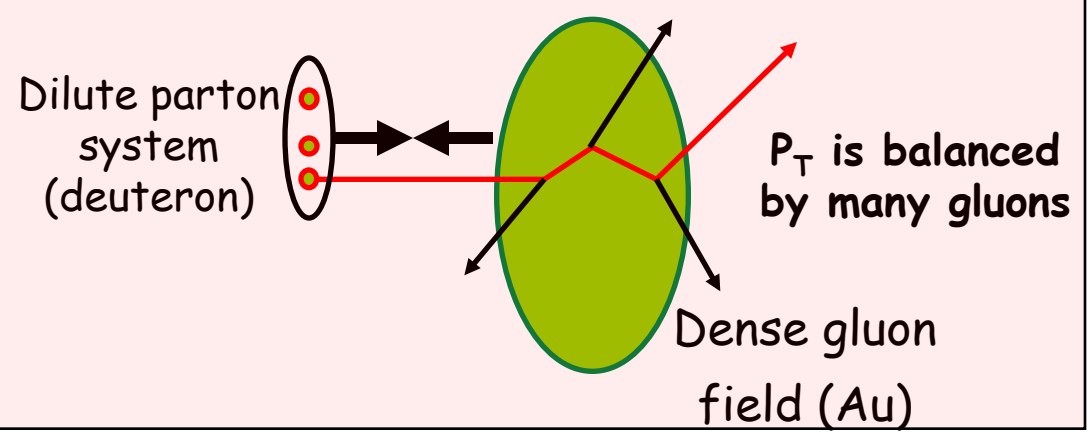
Rapidity-separated hadron correlations in d+Au

Two kinds of effects may give suppression in pairs that include a forward rapidity wrt mid-rapidity trigger hadron

shadowing (non-LT) gives suppression of pairs wrt to singles
Vitev, hep-ph/0405068v2

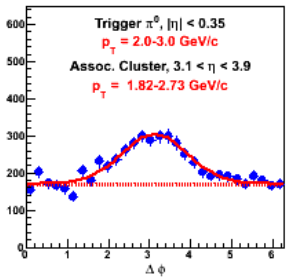


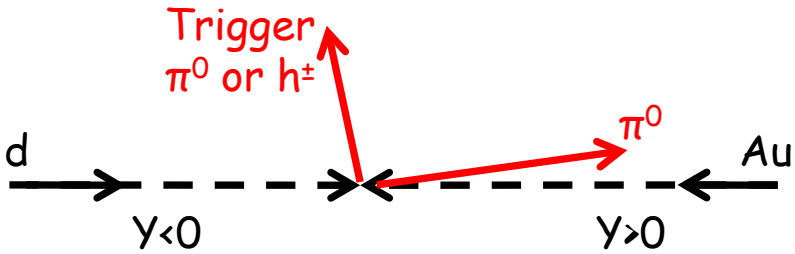
Mono-jets in the gluon saturation (CGC) picture give suppression of pairs per trigger and some broadening of correlation
Kharzeev, NPA 748, 727 (2005)



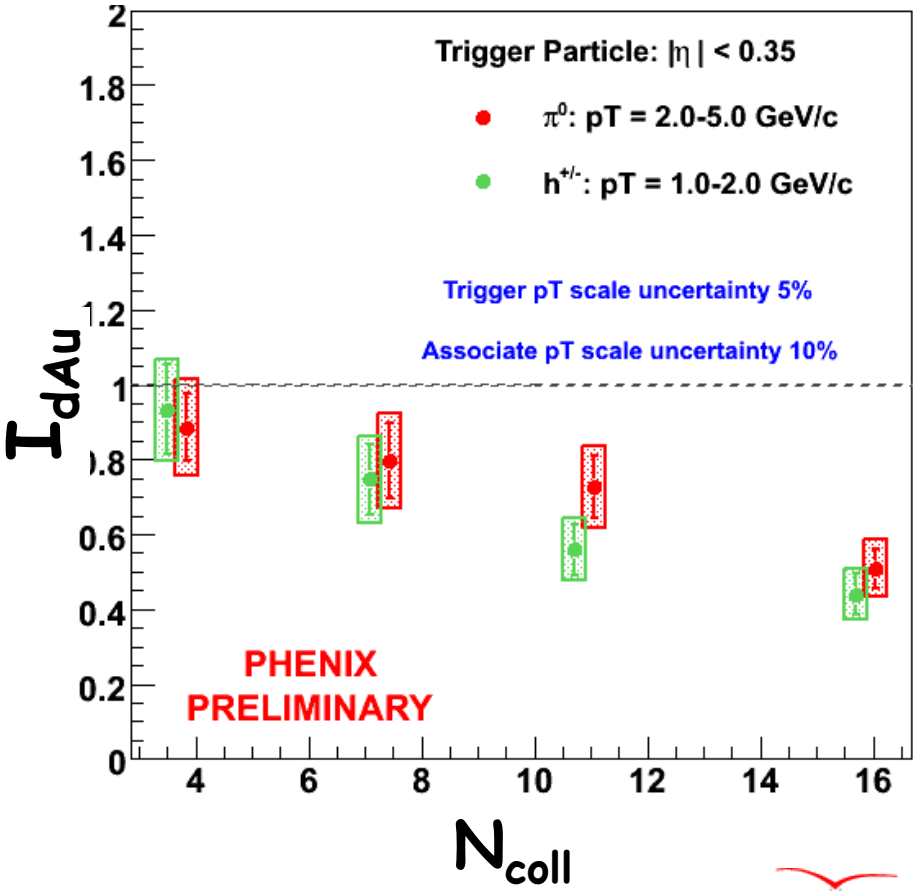
Rapidity-separated hadron correlations in d+Au

$$I_{dAu} = \frac{N^{pair}_{d+Au}\left[(\eta=3.5)+(\eta=0)\right] / N^{trig}_{d+Au}(\eta=0)}{N^{pair}_{p+p}\left[(\eta=3.5)+(\eta=0)\right] / N^{trig}_{p+p}(\eta=0)}$$





Associate π^0: 3.1<η<3.9 p_T = 0.45-1.59 GeV

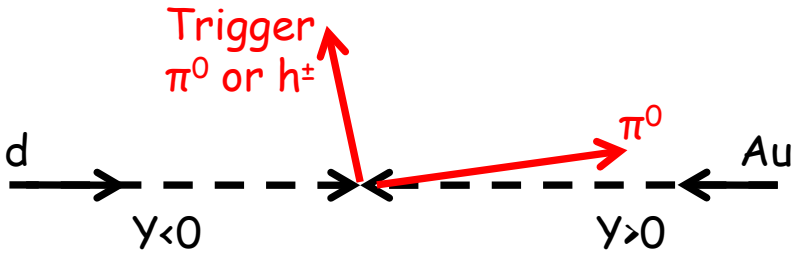


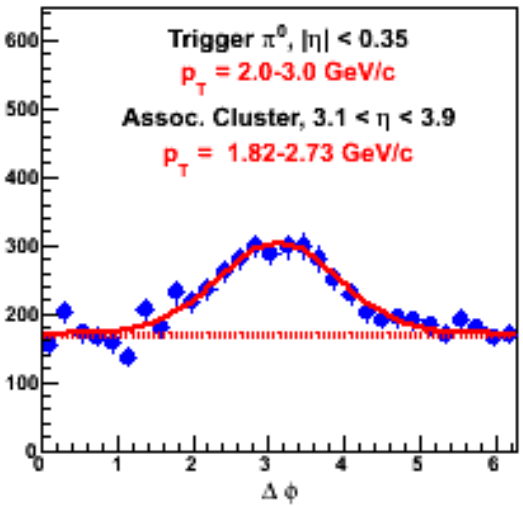
I_{dAu} suppressed at forward rapidity for more central collisions

Talk: B. Meredith (4D, Thu)

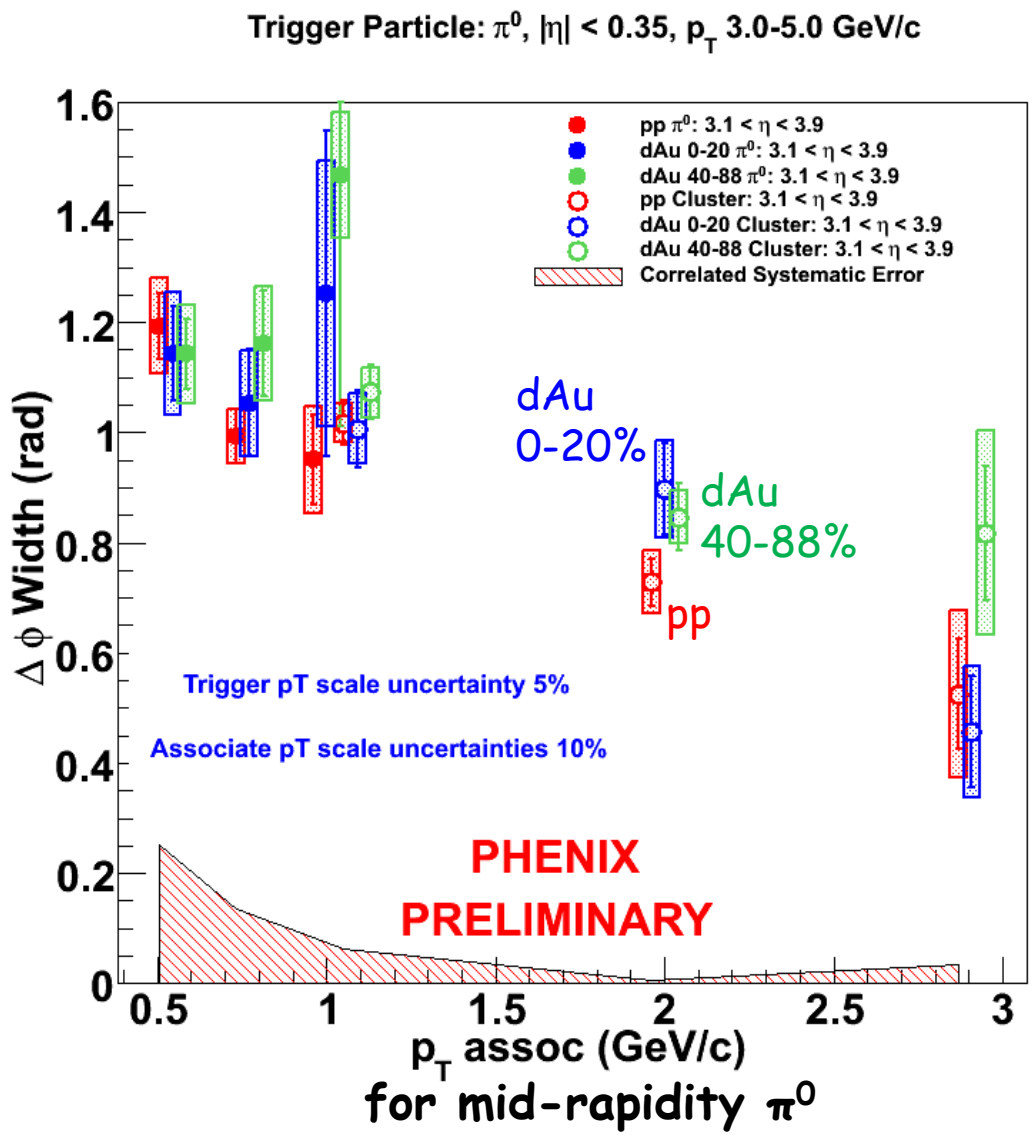
Talk: Z. Citron (4D, Thu)

Rapidity-separated hadron correlations in d+Au



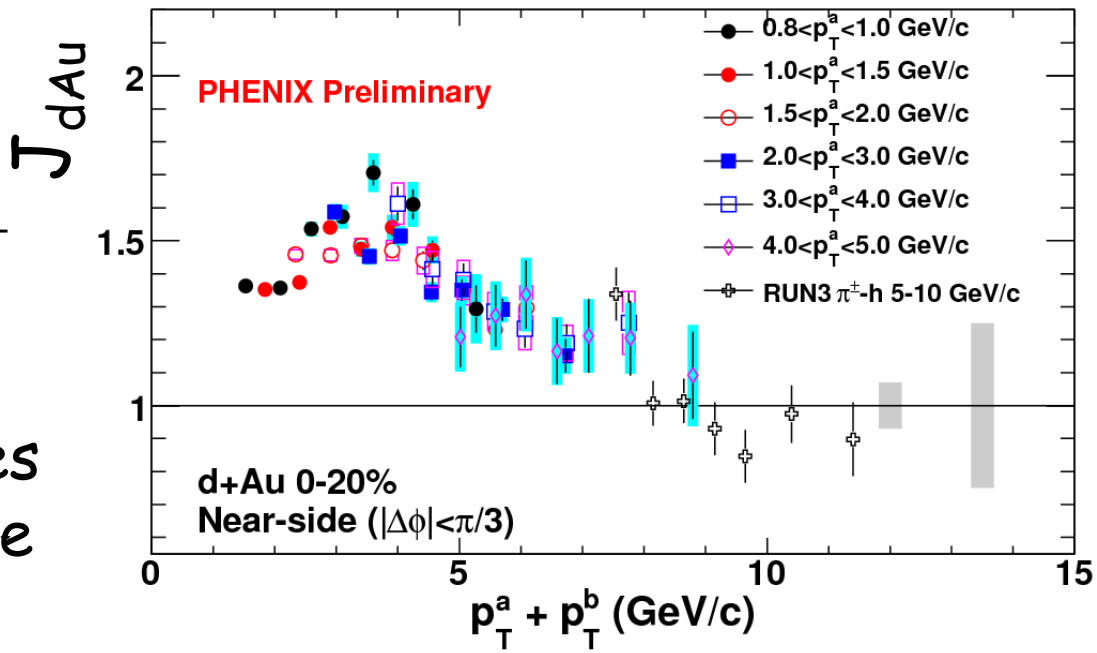


We observe no large broadening with centrality of the correlation peak within uncertainties



What about Mid-rapidity jet pairs in d+Au?

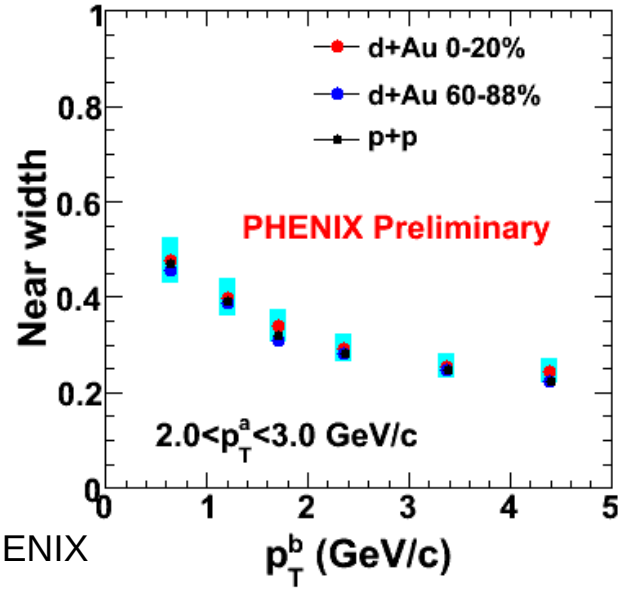
$$J_{dAu} = \frac{(PairYield)_{dAu}}{N_{coll} \times (PairYield)_{pp}}$$



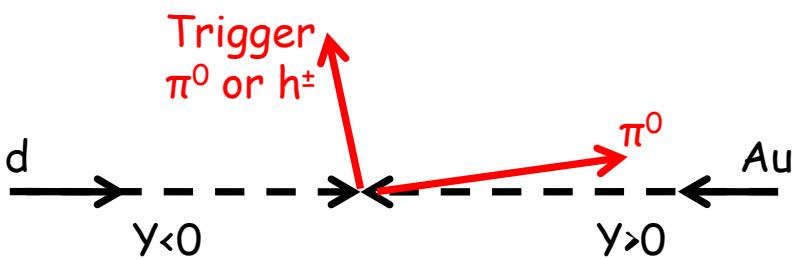
Number of jet pairs scales faster than N_{coll} (near side shown, far side similar)

- jet shapes show no centrality dependence

- a rather large Cronin-like enhancement



Cold Nuclear Matter (CNM) & Gluon Saturation



- I_{dAu} suppressed at forward rapidity for more central collisions

- No large broadening of correlation peak, within uncertainties

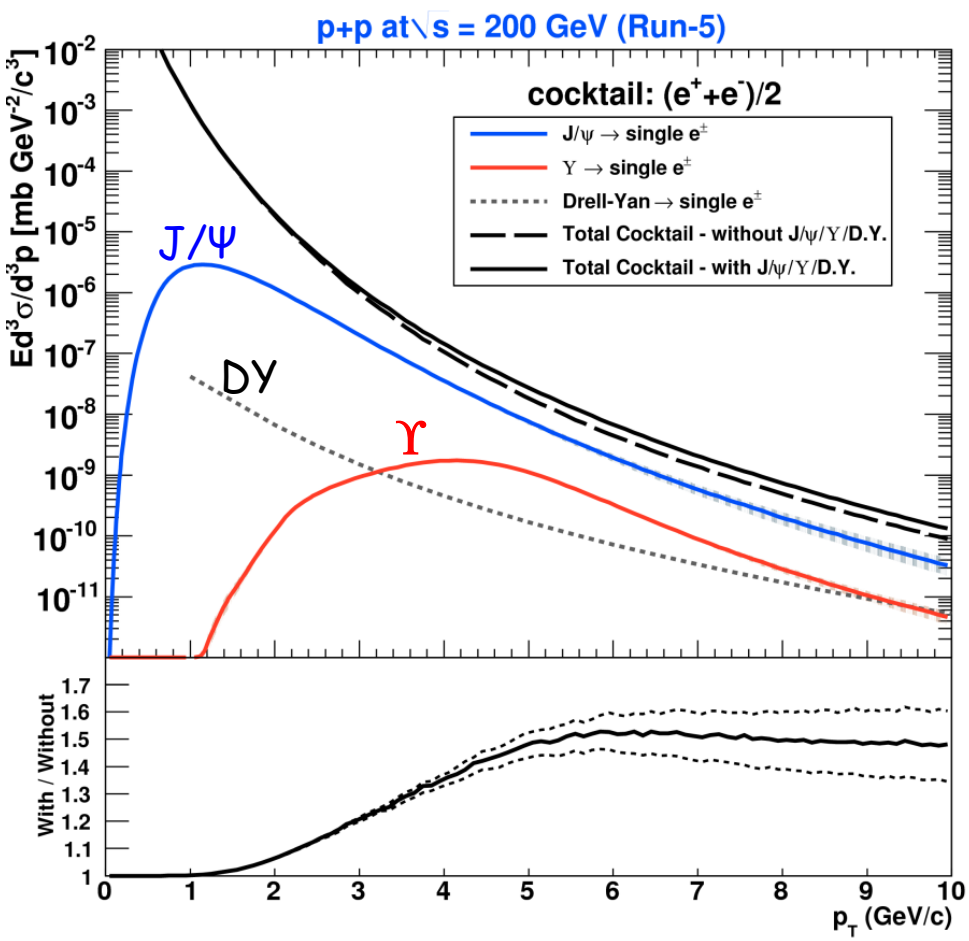
Two theoretical pictures may be relevant:
1. Traditional CNM effects, e.g. shadowing, init. state dE/dx
2. Gluon saturation, mono-jets

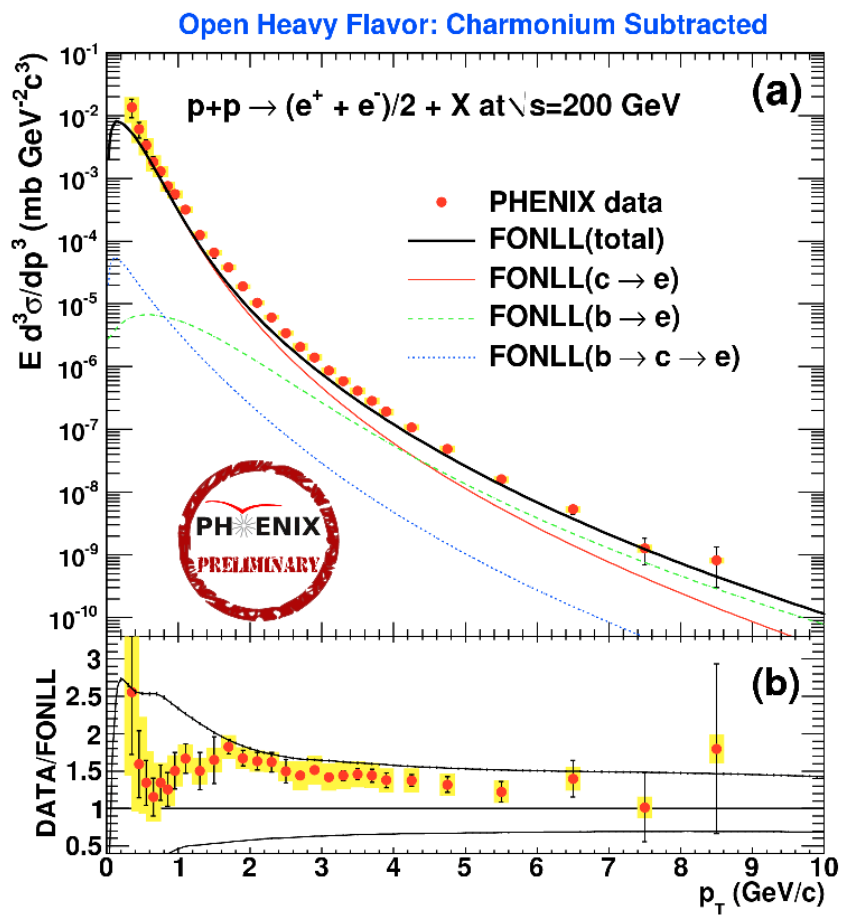
Open Heavy Quarks

Quarkonia Contributions to high-p_T heavy-quark electrons in p+p!

p+p collisions:

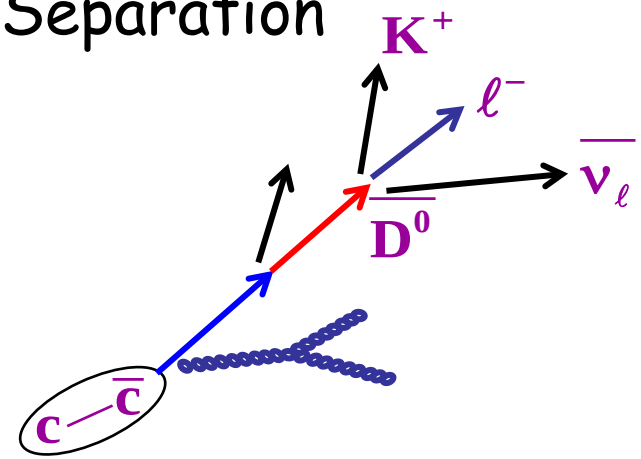
- up to 16% decrease in open heavy for $p_T > 5$ GeV/c
- similar story for Au+Au & R_{AuAu} not significantly changed





Talk: A. Dion (5D, Fri)

Open Heavy Quarks – b vs c Separation



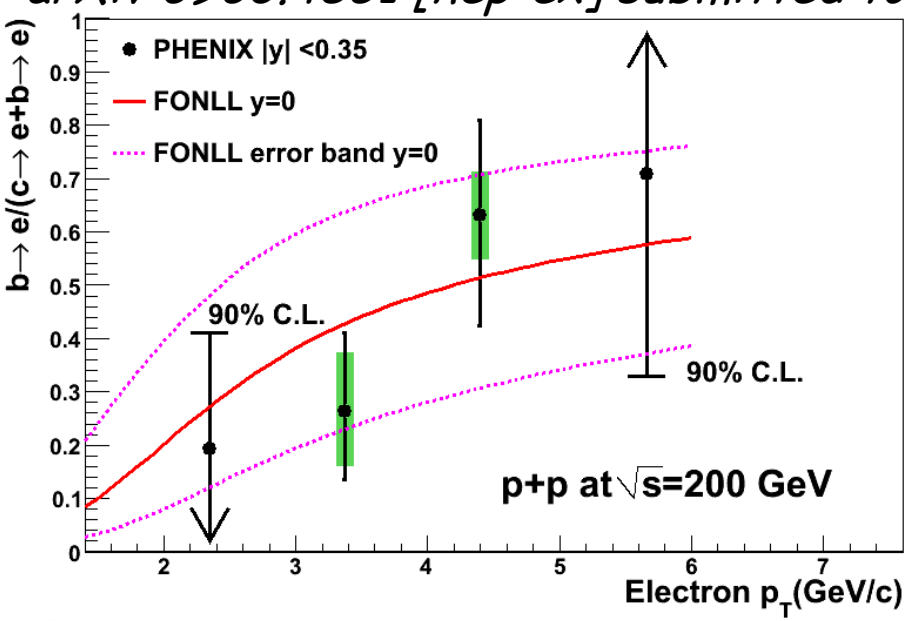
Understanding energy loss of heavy quarks in hot-dense matter:

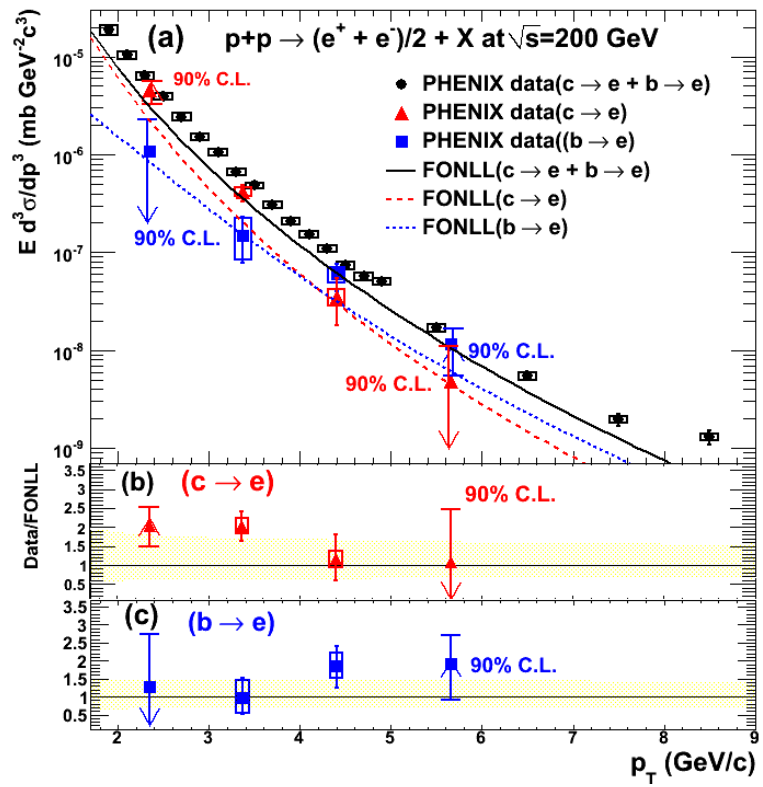
- Need to know fraction of b vs c vs p_T

b vs c from e-h decay correlations

- substantial fraction of b -> e for large p_T
- b cross section consistent with FONLL

arXiv:0903.4851 [hep-ex] submitted to PRL





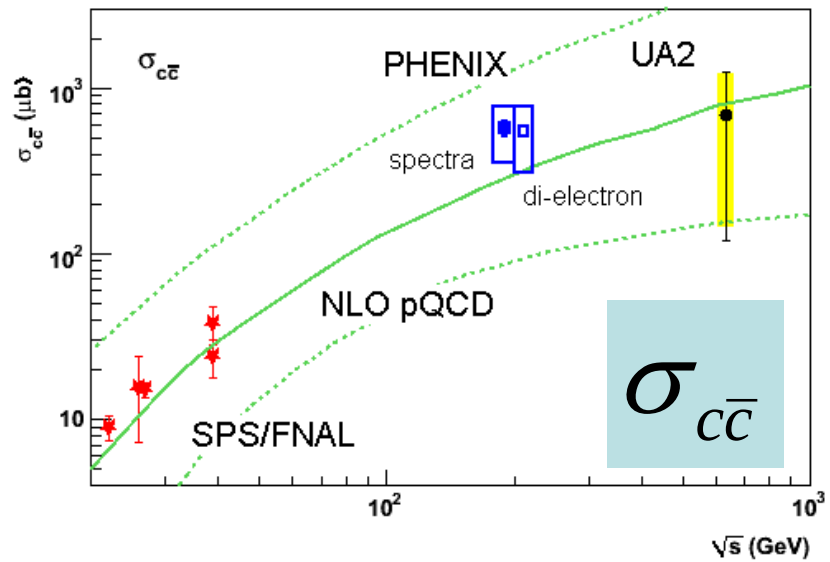
Open Heavy Quarks

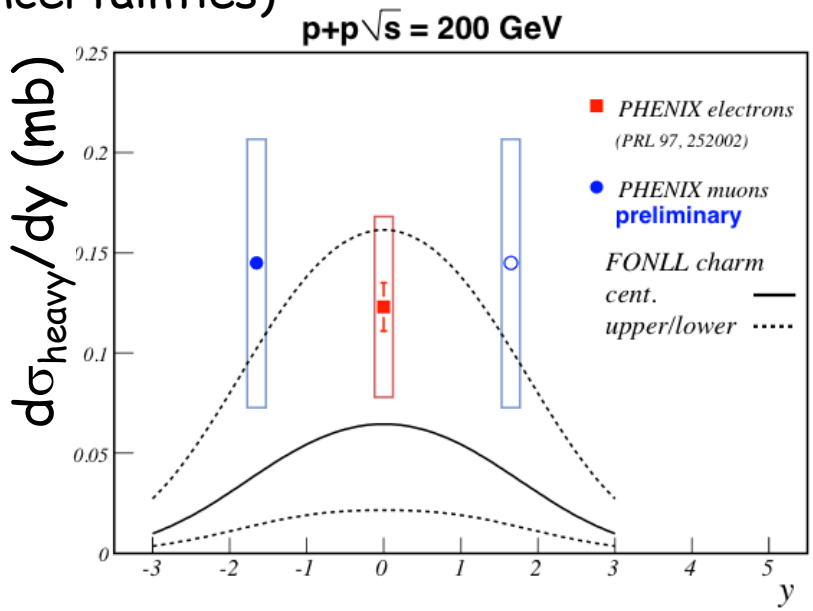
Cross sections determined three different ways in agreement:

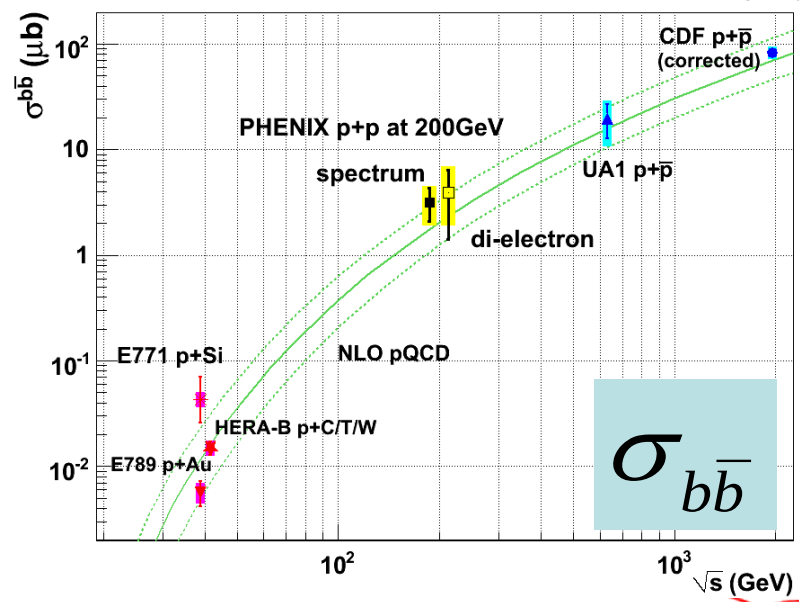
- single electron spectra methods:
  - cocktail subtraction
  - converter
- di-electrons

Talk: Y. Akiba (4C, Thu)

Muon measurement at forward rapidity also consistent (but with large uncertainties)



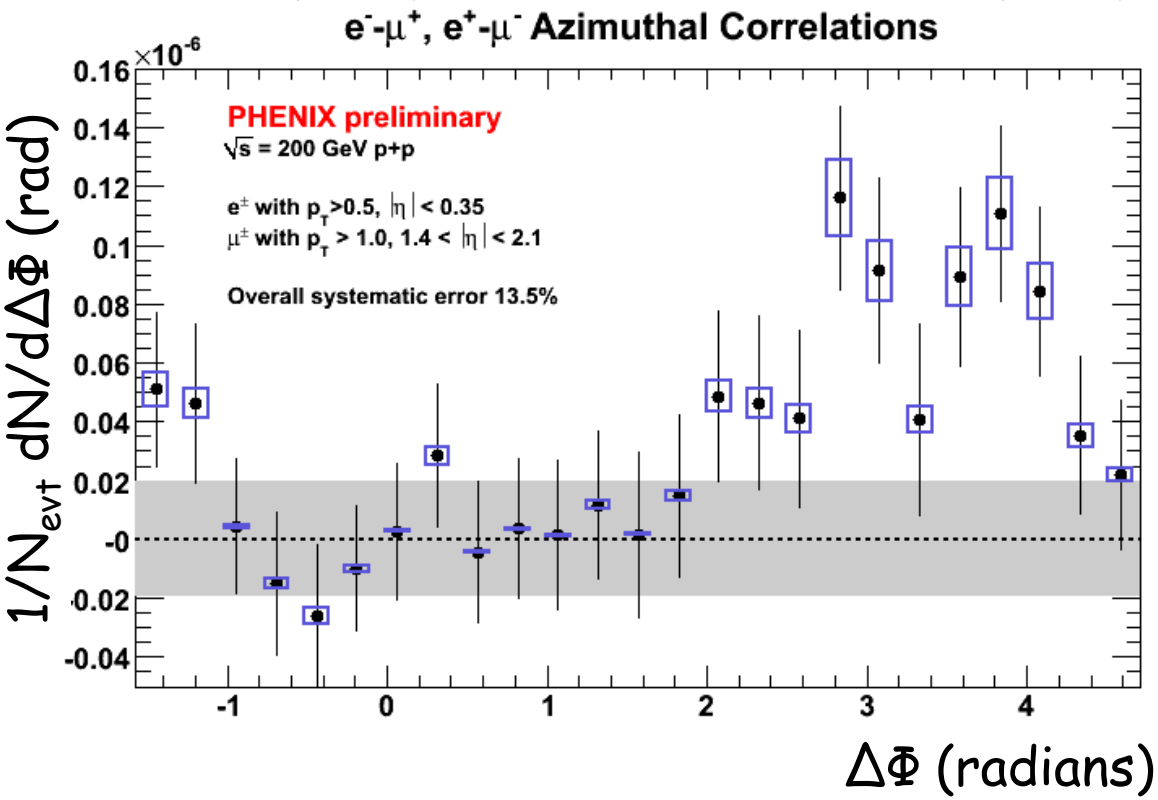




Open Heavy Quarks - e-μ Correlations

- e-μ: the long touted Golden channel for open heavy flavor at RHIC
- 1st proof of principle measurement in p+p

Mid-rapidity electron + Forward-rapidity muon



- future new method to get charm cross section
- study correlations of charm pairs - k_T
- baseline for future measurements in heavy-ion collisions (or d+Au)

Talk: T. Engelmore (6D, Fri)

Open Heavy Quarks

- Quarkonia contributions important to understand high p_T electrons from heavy quarks in p+p & Au+Au

- Beauty contributes at ~50% level or more above p_T = 4 GeV/c

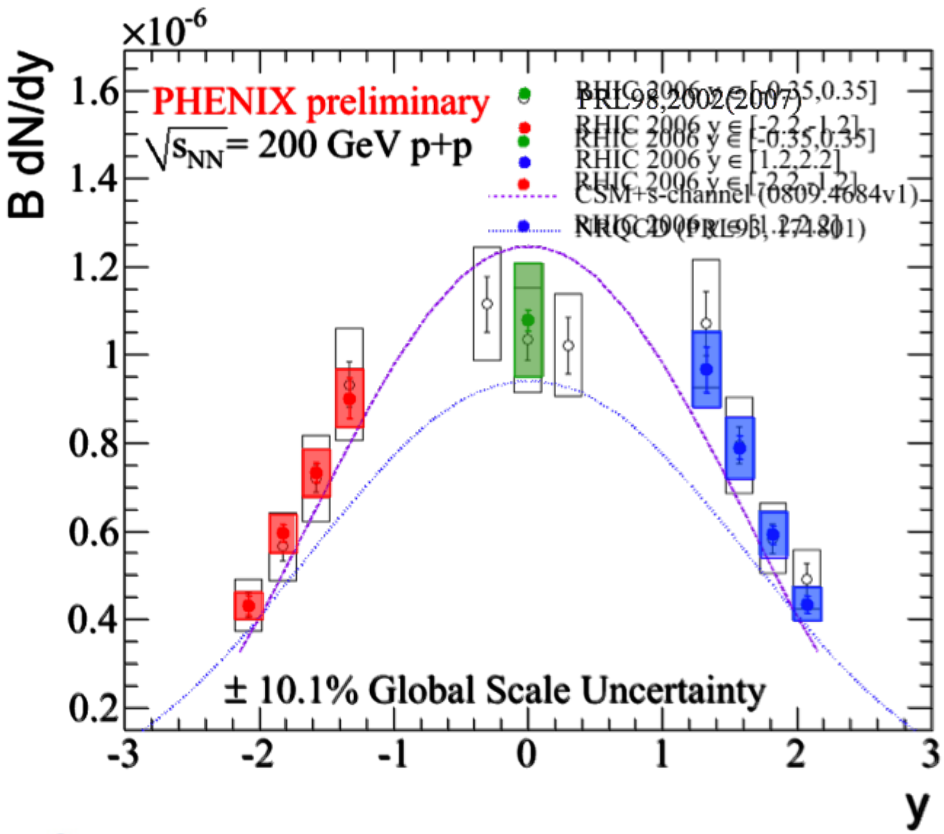
Quarkonia Production & Suppression

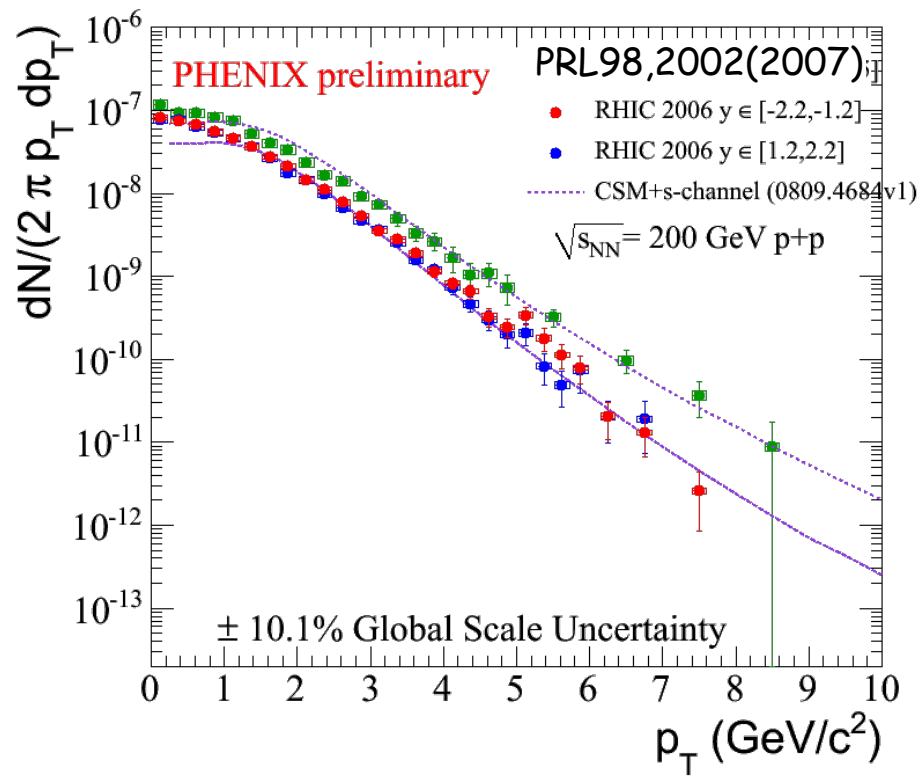
Quarkonia Production & Suppression – p+p

One of the main deficiencies in A+A J/Ψ studies is the p+p baseline

- 2006 p+p data with ~3 times previous (2005) luminosity!
- Much improved baseline, especially for high-p_T
- Lansberg (CSM) model and NRQCD model compare well vs rapidity & p_T

Talk: C. da Silva (1D, Tue)





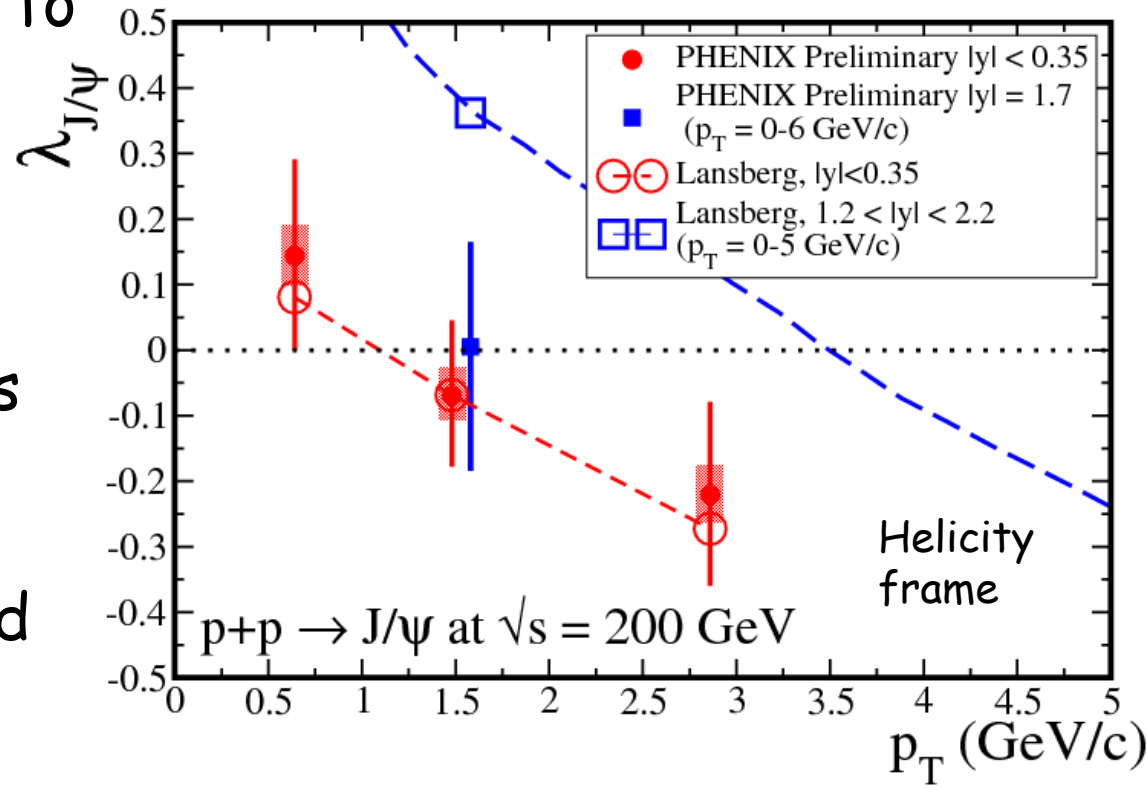
Quarkonia Production & Suppression – J/Ψ Polarization

New "s-channel cut" color singlet model (CSM) fit to CDF data:

- agrees with PHENIX:
- cross sections
- y=0 polarization results

- but disagrees (at 2-3 sigma level) with forward rapidity PHENIX result

Haberzettl, Lansberg PRL 100, 032006 (2008)

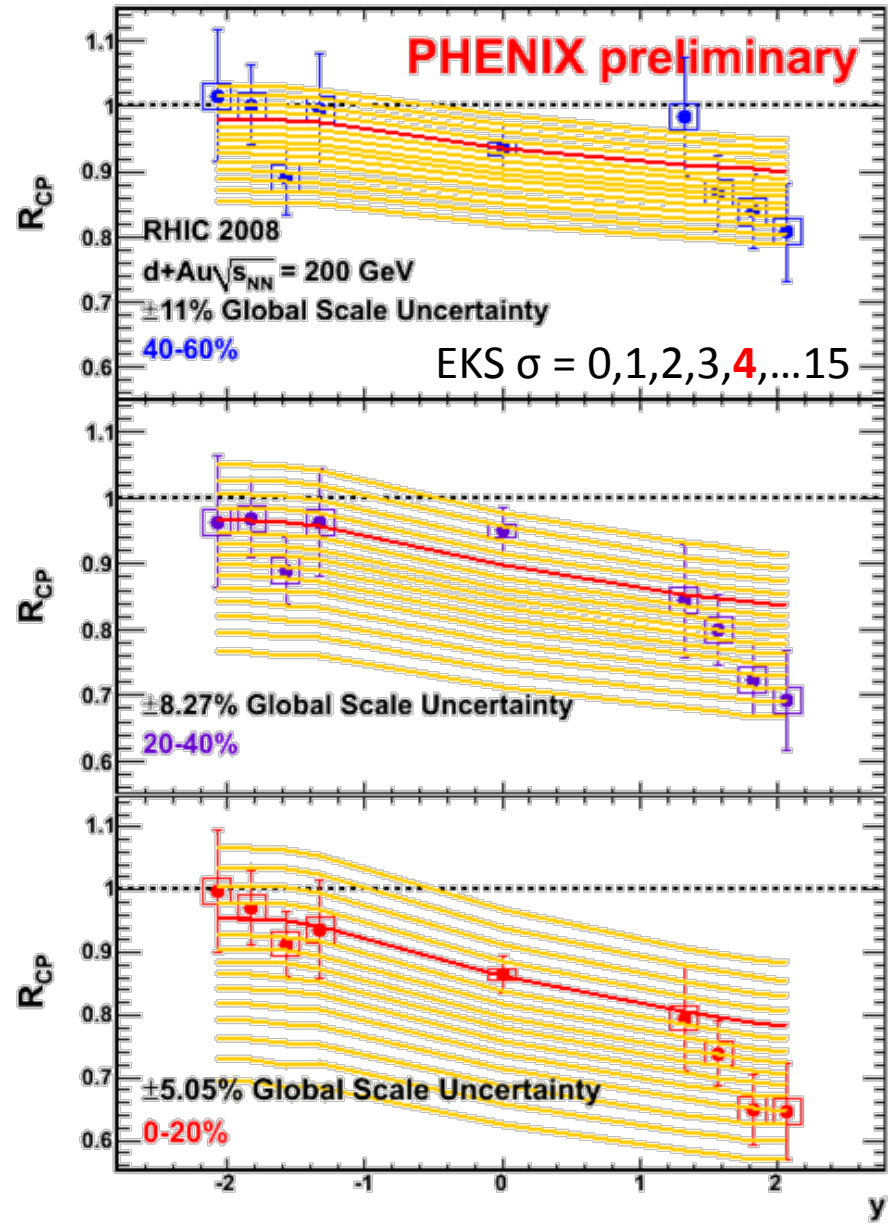


Quarkonia Production & Suppression – J/Ψ in d+Au

Initial d+Au J/Ψ update from new 2008 data (~30x 2003)

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

- R_{CP} pretty flat vs centrality at backward rapidity; but falls at forward rapidity (small-x)
- more soon – precision statistics requires precision systematics & careful analysis
- starting to study constraints on CNM models (thanks R. Vogt)



Higher p_T for J/ψ in Cu+Cu - probing for the "hot wind"?

New PHENIX R_{CuCu} out to p_T = 9 GeV/c !

- shows suppression that looks roughly constant up to high p_T

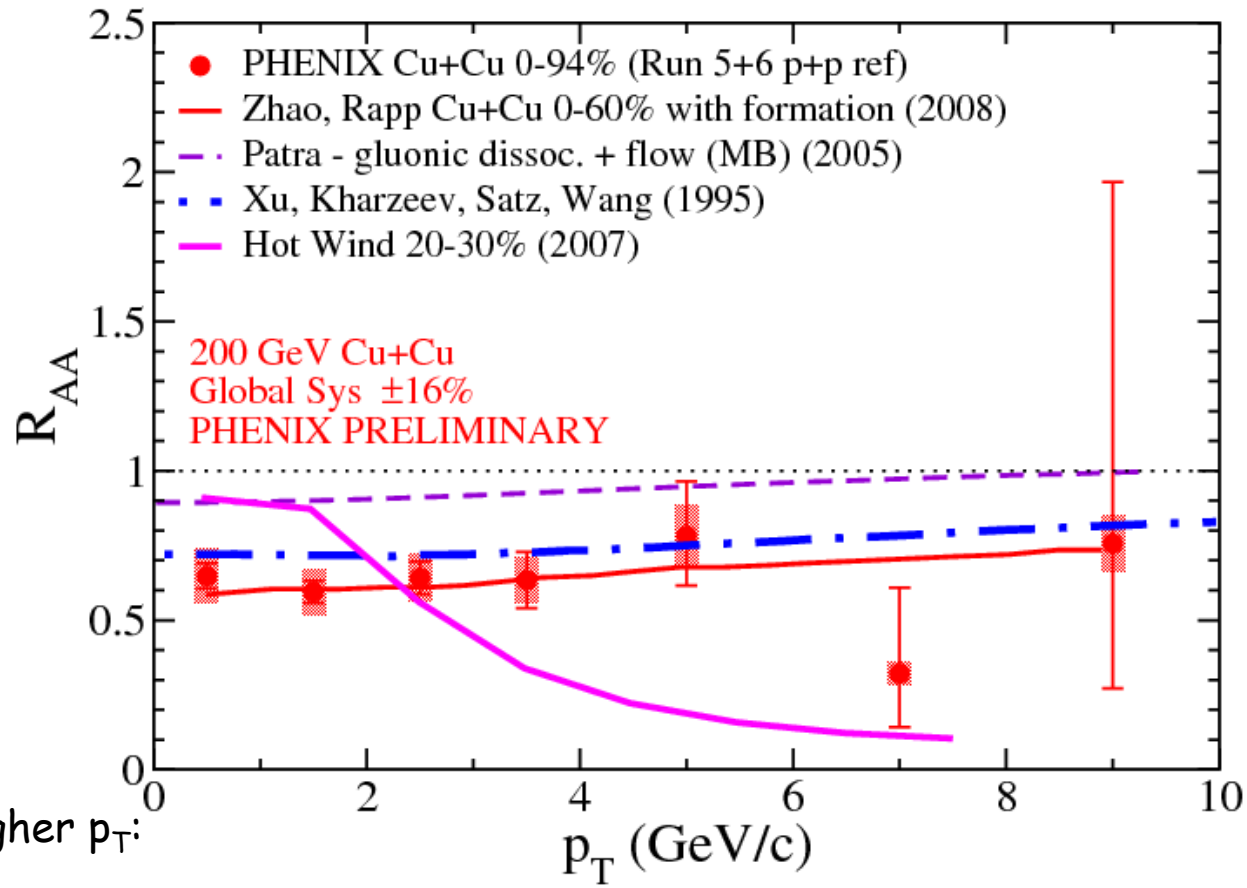
AdS/CFT ("hot wind") - more suppression at high p_T:
Liu, Rajagopal, Wiedemann
PRL 98, 182301(2007)

Regeneration (2-compenent):
Zhao, Rapp
hep-ph/07122407
& private communication

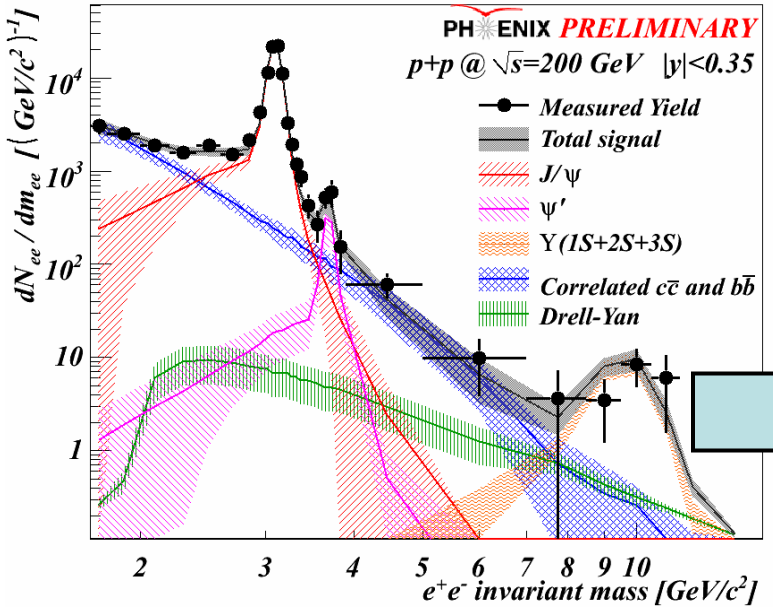
Equilibrating Parton Plasma:
Xu, Kharzeev, Satz, Wang,
hep-ph/9511331

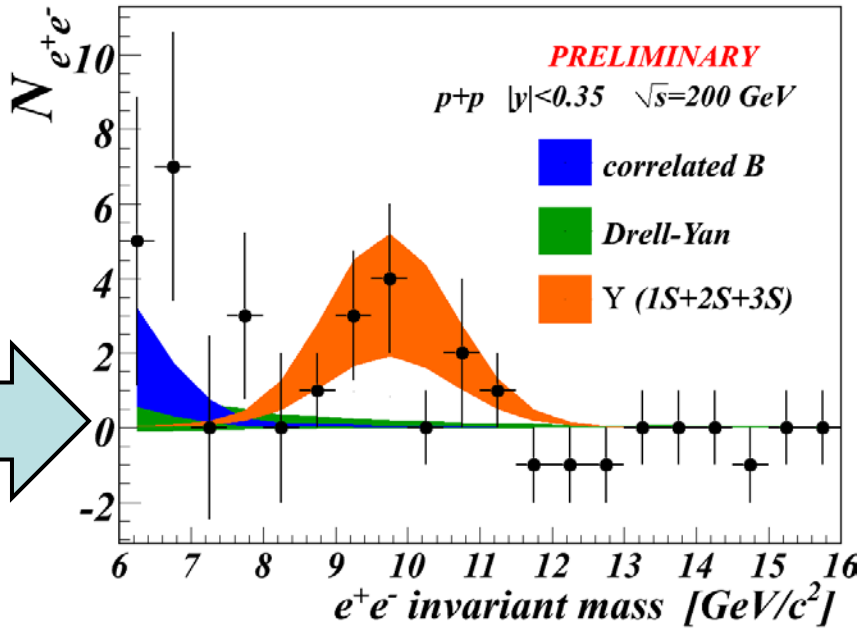
Gluonic dissoc. & flow:
Patra, Menon, *nucl-th/0503034*

Cronin – less suppression at higher p_T:
use d+Au data as a guide



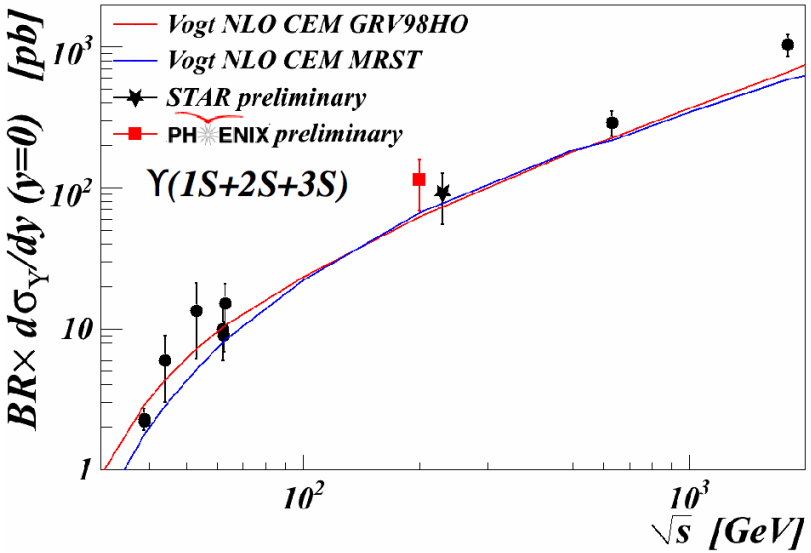
Quarkonia Production & Suppression – Upsilons in p+p



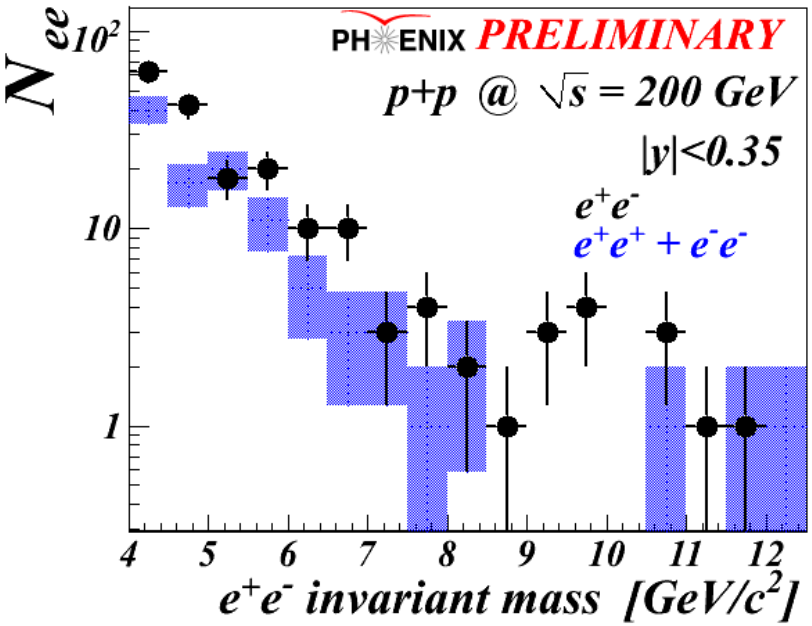


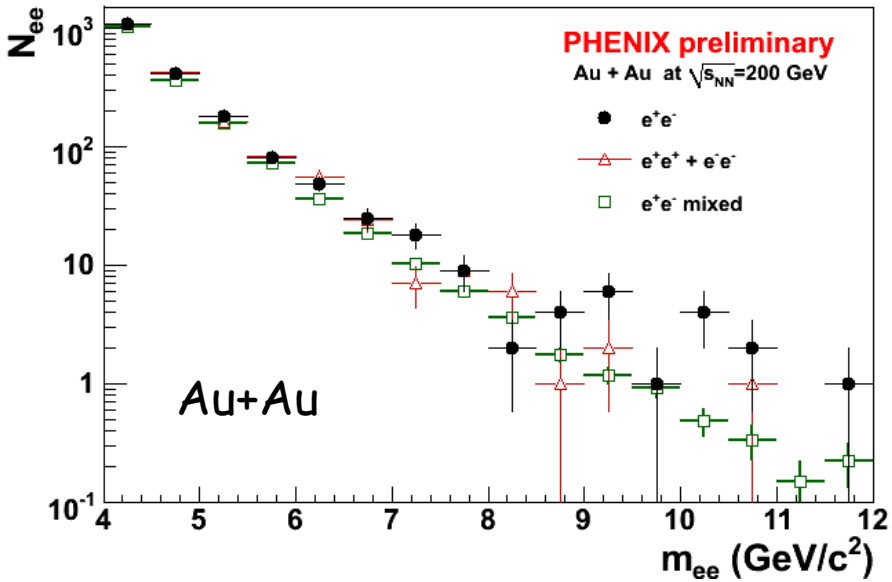
- Cross section follows world trend
- Baseline for Au+Au

$$BR * \frac{d\sigma}{dy}\Big|_{|y|<0.35} = 114^{+46}_{-45}\ pb$$

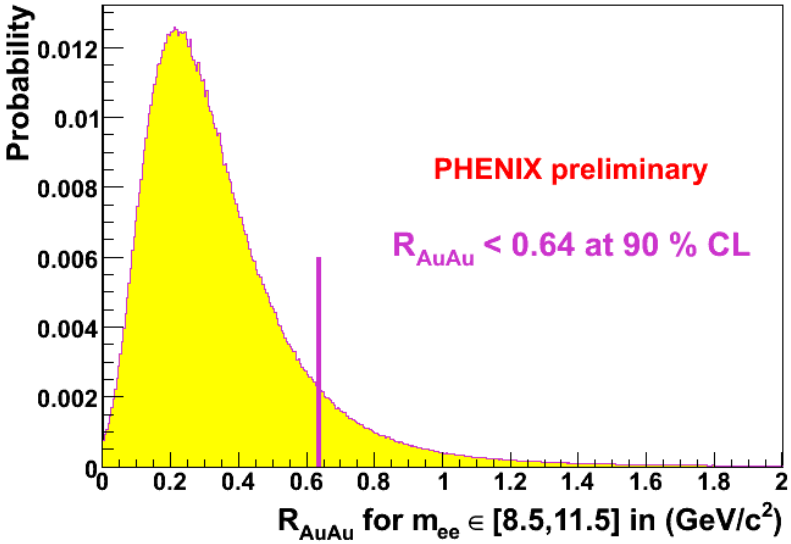


Quarkonia – Upsilons Suppressed in Au+Au





	p+p	Au+Au
N[8.5,11.5]	10.5(+3.7/-3.6)	11.7(+4.7/-4.6)
$N_{J/\psi}$	2653 ±70±345	4166 ±442(+187/-304)
$R_{AA}(J/\Psi)$	---	0.425 ±0.025±0.072



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

Talk: E. Atomssa (2D, Tue)

Should Υ's be Suppressed?

Υ's long touted as a standard candle for quarkonia melting
- but what should we really expect?

	$R_{AuAu}(y=0)$
J/Ψ	0.425 ± 0.025 ± 0.072
M_{e+e-}= [8.5,11.5 GeV]	< 0.64 at 90% C.L.

- σ_{abs} of Υ probably ~1/2 of that for J/Ψ – E772 (*PRL 64, 2479 (1990)*)
  - E772 Υ nuclear dependence corresponds to R_{AuAu} = 0.81

- Lattice expectations in Au+Au - Υ_{2S+3S} suppressed: R_{AuAu} = 0.73

- **absorption x lattice ~ 0.73 x 0.81 ~ 0.60 ??? – but need serious theory estimate instead of this naïve speculation!**
  - e.g. Grandchamp et al. hep-ph/0507314

Other considerations:
- Υ in anti-shadowing region (for mid-rapidity)

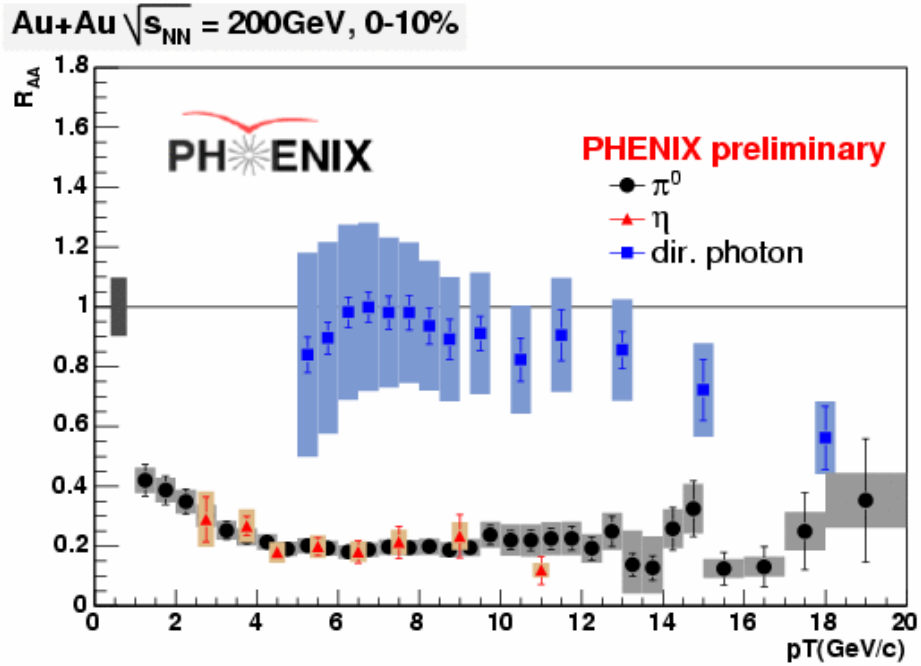
- CDF: 50% of Υ from χ_b for p_T>8 GeV/c - but less (25%?) at our p_T
  - *PRL84 (2000) 2094, hep-ex/9910025*

Quarkonia Production & Suppression

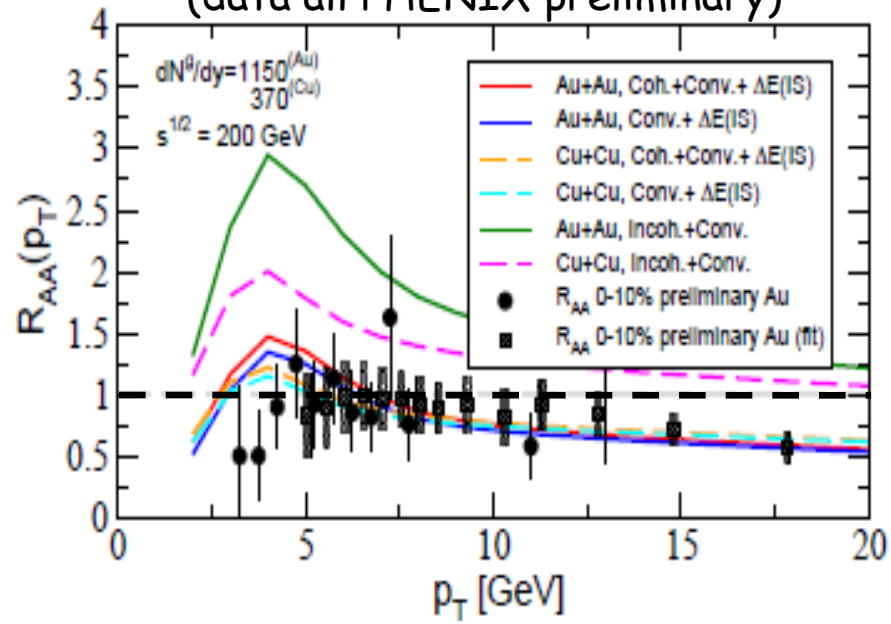
- J/Ψ polarization & Lansberg CSM prediction
  - consistent at mid rapidity
  - may be inconsistent at forward rapidity
- J/Ψ in Cu+Cu suppressed at R_{CuCu}~0.6 up to p_T = 8 GeV/c
- R_{AuAu} [8.5,11.5] < 0.64 at 90% C.L.
  - Upsilons suppressed
  - but shouldn't be a surprise – expect R_{AuAu}~60% from just CNM + sequential melting

Initial State & Temperature - Photons

Initial State & Temperature - Photons

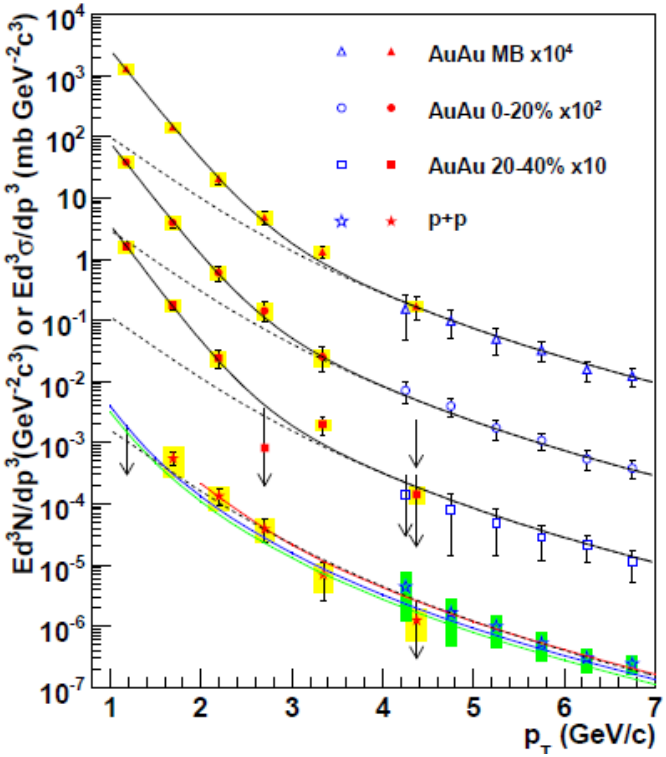


Isospin, Cronin, shadowing, dE/dx
Vitev, nucl-th/0810.3194v1
(data all PHENIX preliminary)



Au+Au photons have some modification at higher p_T, but may be just CNM effects – i.e. Cronin & neutron vs proton (isospin/charge) effects

Initial State & Temperature - Photons

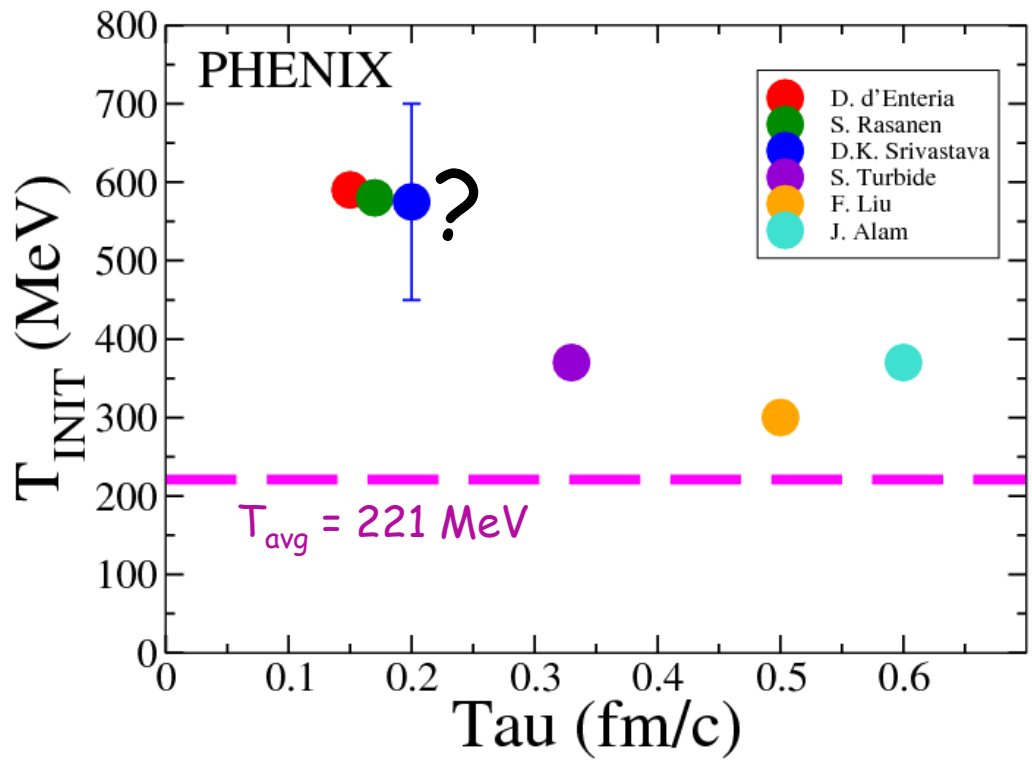


arXiv:0804.4168v1 [nucl-ex]

Nearly real photons extracted from shape of low-mass e^+e^- spectrum

Shows large enhancement above scaled p+p in low-p_T "thermal" region

Talk: Y. Yamaguchi (4C, Thu)



- Fit to the p_T slope in central collisions yields

  T_{avg} = 221 ±23 ±18 MeV
- Using models for the expansion

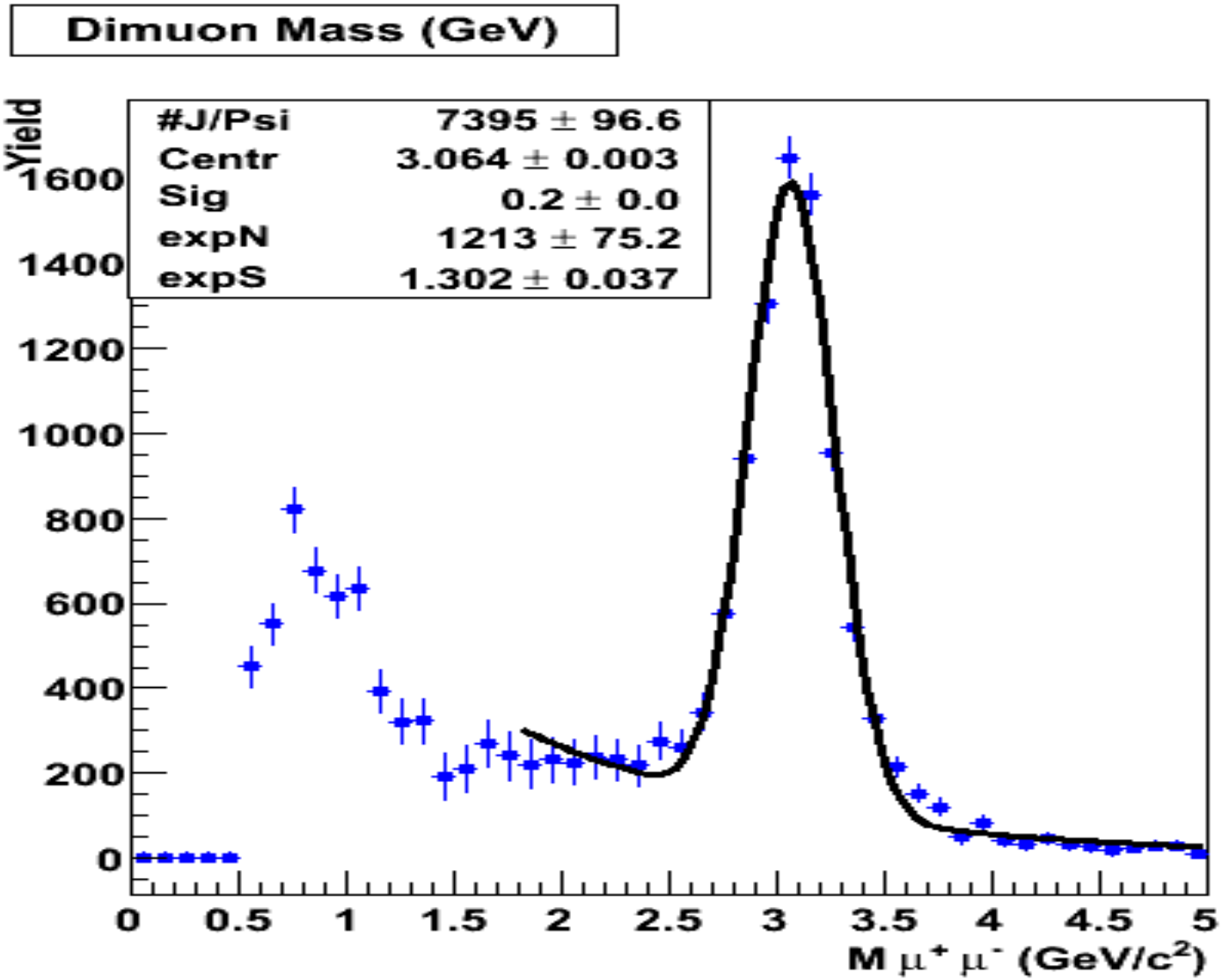
  T_{avg} = 221 → T_{init} > 300 MeV

Initial State & Temperature - Photons

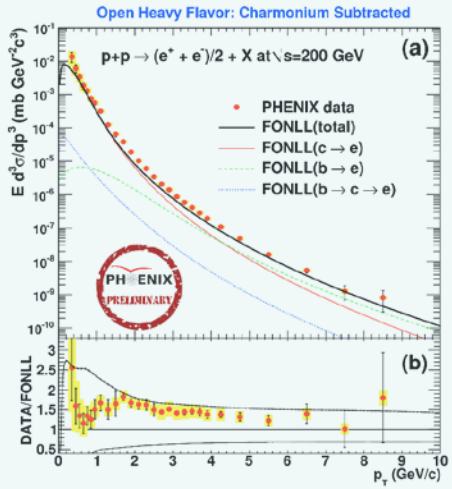
- high-p_T direct photon suppression consistent with calculations of CNM effects

- low-p_T thermal photons indicate initial temperatures of > 300 MeV

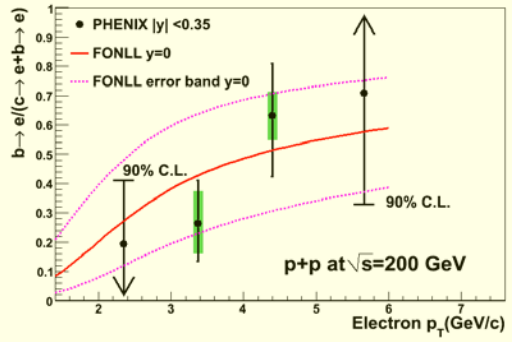
Hot of the Press - 28 March 2009
First J/Ψ → μμ from 500 GeV p+p collisions at PHENIX



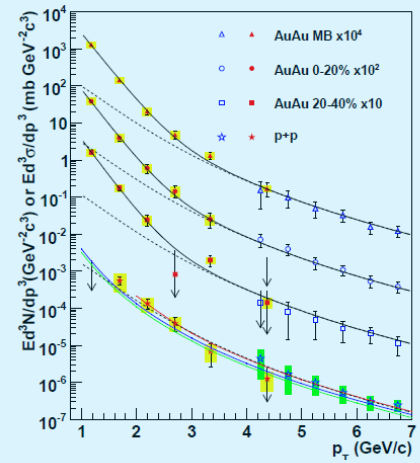
Summary – Initial State & Early Times



Quarkonia - contribute substantially to heavy-flavor electrons for p_T>5 GeV/c

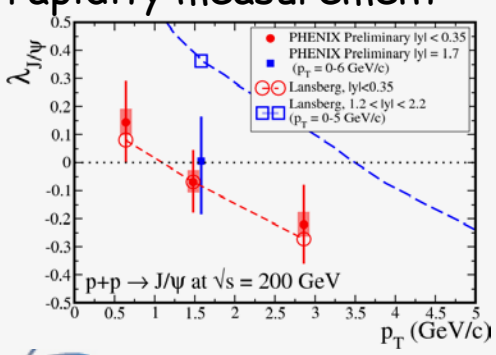


Beauty - ~50% or more in heavy-flavor electrons for p_T>4 GeV/c

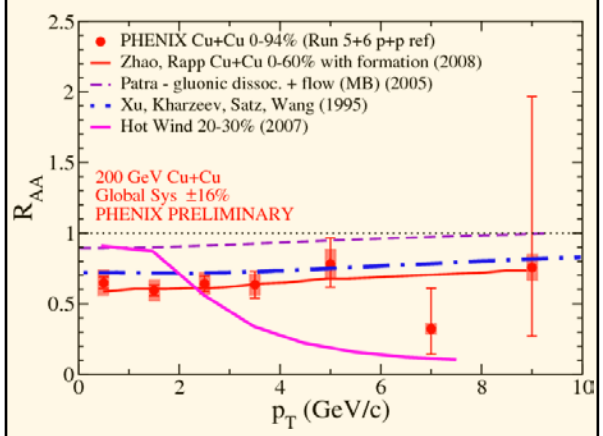


T_{init} > 300 MeV from low-p_T thermal photons

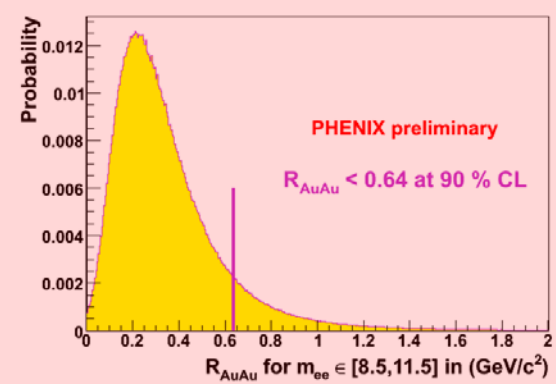
J/Ψ polarization -Lansberg CSM model misses forward rapidity measurement



J/Ψ in Cu+Cu suppressed up to p_T=8 GeV/c



R_{AuAu} [8.5,11.5] < 0.64 at 90% C.L.
ϒ 's suppressed in Au+Au
40% expected from CNM & Υ_{2S+3S}



BACKUP SLIDES

Talk: C. da Silva (1D-1, Mon)

Talk: E. Atomssa (2D-4, Mon)

Talk: Y. Tsuchimoto (3C-2, Thu)

Talk: M. Naglis (3D-2, Thu)

Talk: A. Dion (3D-4, Thu)

Talk: Y. Akiba (4C-1, Thu)

Talk: Y. Yamaguchi (4C-3, Thu)

Talk: T. Engelmore (4D-2, Thu)

Talk: B. Meredith (5D-1, Fri)

Talk: Z. Citron (5D-5, Fri)

Talk: Z. Conessa del Valle (6D-2, Fri)

Posters:

- Z. Conesa del Valle (AuAu Υ)
- K. Lee (pp Υ)
- M. Wysocki (AuAu J/Ψ)
- M. Donadelli ($\Psi'(p_T)$)
- D. McGlinchey (dAu J/Ψ)
- B. Kim (J/Ψ forward v_2)
- K. Kijima (pp low-mass vector mesons)
- L. Guo (pp phi->mumu)
- S. Campbell (CuCu e^+e^-)
- J. Kamin (pp e+e-)
- I. Garishvili (CuCu single-muons)
- H. Themann (c vs b)
- K. Sedgwick (RdAu(p_T) π^0 forward)
- A. Milov (m_T scaling)
- T. Sakaguchi (h, EM contraints)
- M. Durham (HBD)
- N. Apadula (VTX FNAL test)
- R. Petti (VTX c vs b)
- M. Kurosawa (VTX)
- A. Lebedev (VTX simulations)
- S. Rolnick (Focal)

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Brief PHENIX Status & Future

Recent detector improvements:

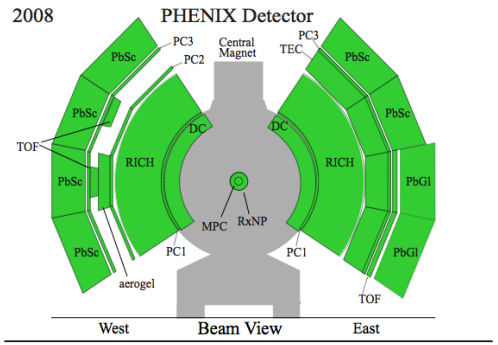
- large, more accurate reaction plane detector
- higher-p_T PID (TOF-West)
- forward (MPC) calorimeters
- Hadron blind detector (HBD)

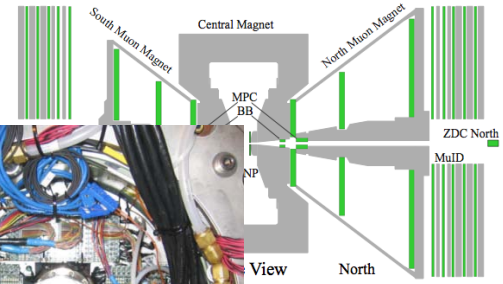
Operations improvements:

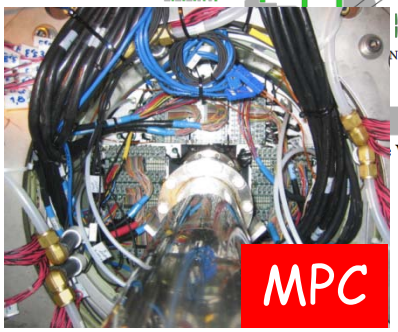
- integrated luminosity: Au+Au (x3); d+Au (x30)
- data taking efficiency: 52% (2007) -> 68% (2008)

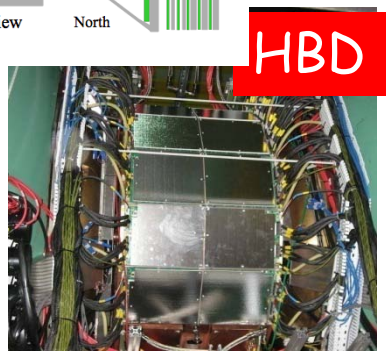
Future:

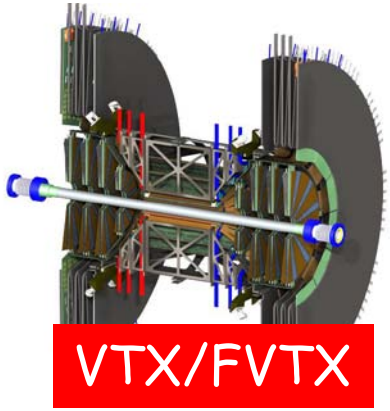
- HBD for clean low-mass dielectron measurements (next AuAu run)
- muon Trigger system for high-p_T muon triggering (W's)
- silicon detectors for new level of robustness in heavy-quark measurements
- continuing DAQ upgrades to maintain high speed and efficiency



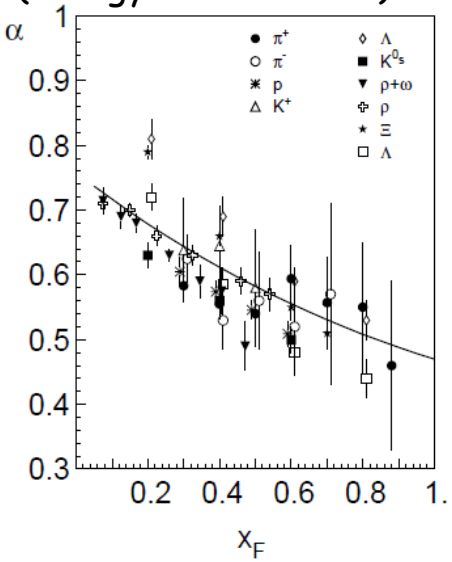




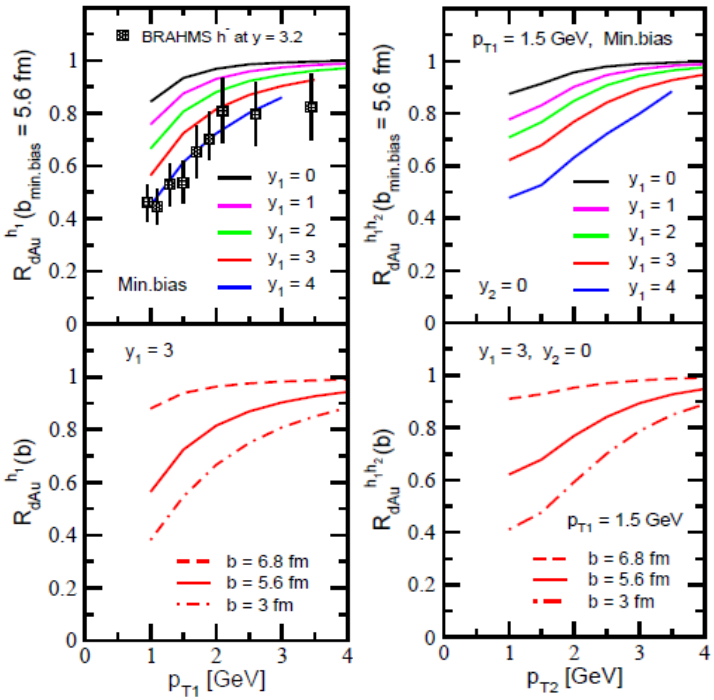




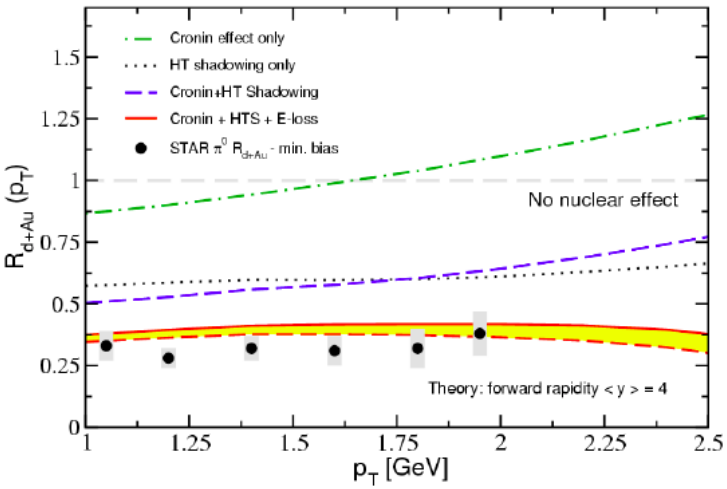
Kopeliovich, hep-ph/0501260v3
Universal Sudakov suppression (energy conservation)



Vitev, hep-ph/0405068v2
Dynamical shadowing

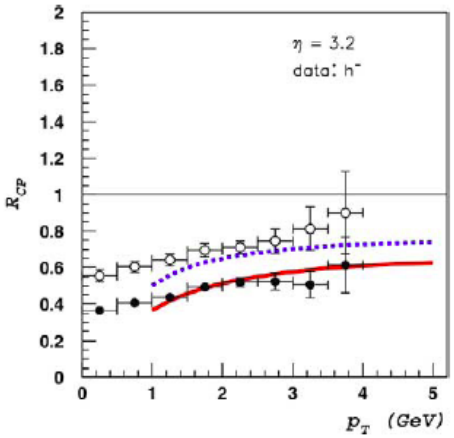


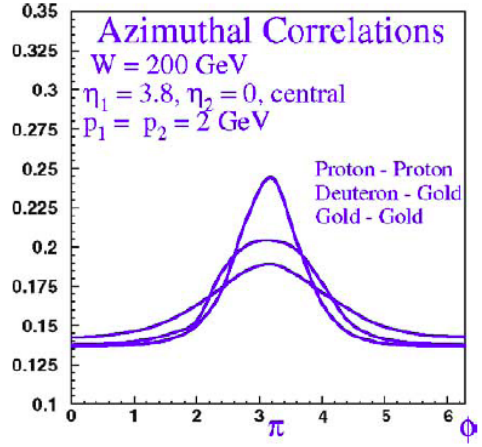
Vitev, hep-ph/0605200v1
CNM effects: dynamical shadowing, dE/dx, Cronin

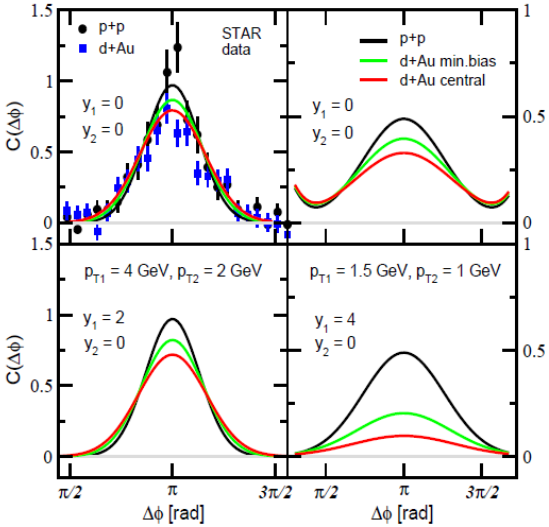


I.V., T.Goldman, M.B.Johnson, J.W.Qiu, Phys.Rev.D74 (2006)
I.V., in preparation

Kharzeev, NPA 748, 727 (2005)



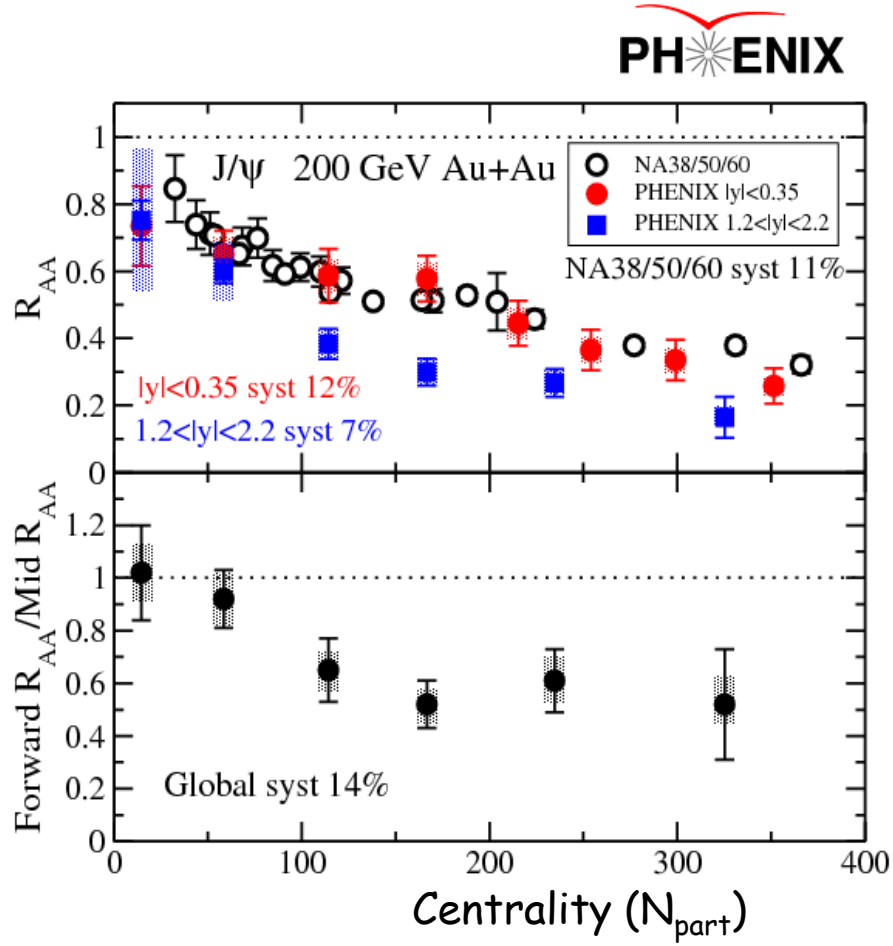




PHENIX A+A Data and Features

PHENIX Au+Au data shows suppression at mid-rapidity about the same as seen at the SPS at lower energy

- but stronger suppression at forward rapidity.
- Forward/Mid R_{AA} ratio looks flat above a centrality with N_{part} = 100

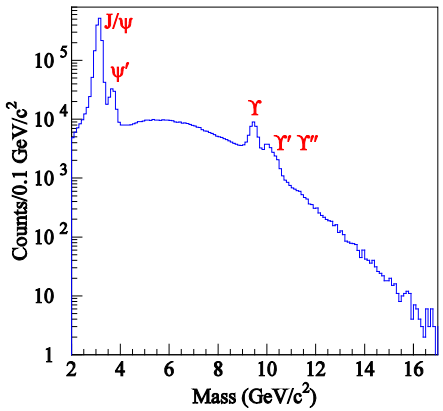


Several scenarios may contribute:

- Cold nuclear matter (CNM) effects
  - in any case are always present
- Sequential suppression
  - QGP screening only of χ_c & ψ'- removing their feed-down contribution to J/ψ at both SPS & RHIC
- Regeneration models
  - give enhancement that compensates for screening

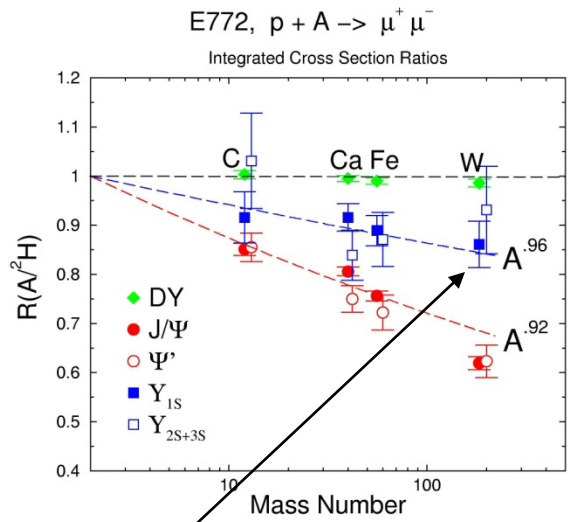
Mike Leitch -

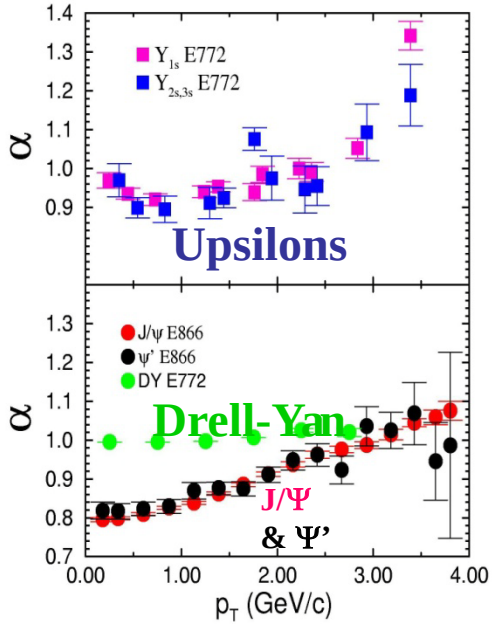
Contrasting ϒ's with J/ψ's



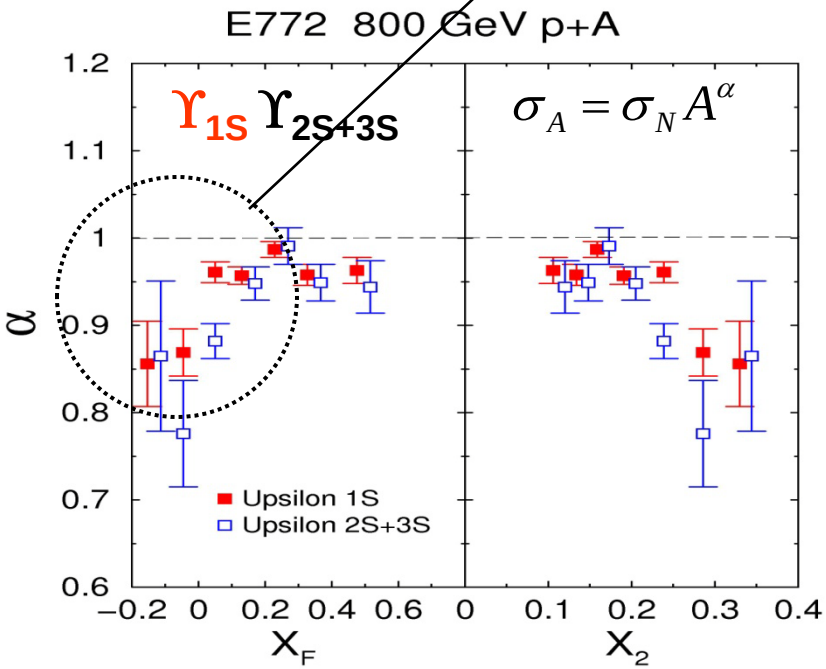
√S =39 GeV (E772 & E866)

- less absorption
- not in shadowing region (large x_2)
- similar p_T broadening
- Υ_{2S+3S} have large transverse polarization - unlike Υ_{1S} or J/ψ (as was shown earlier)





But careful: ϒ suppression is from data for x_2 > 0.1



Los Alamos NATIONAL LABORATORY

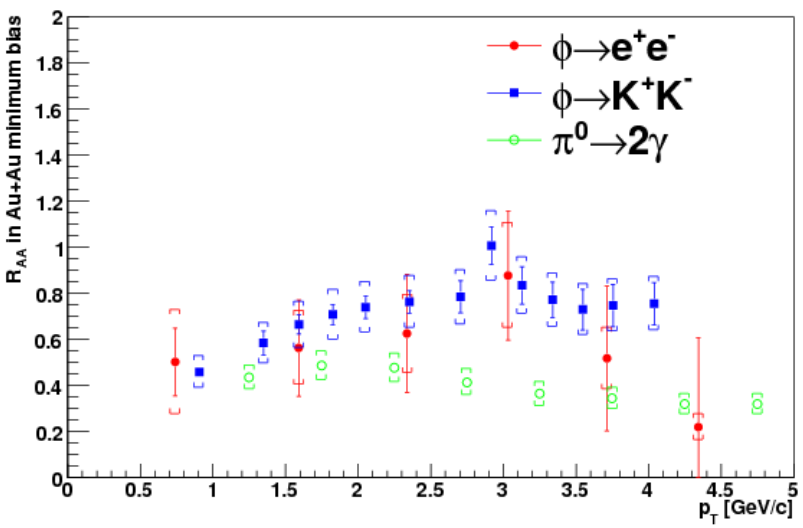
PHENIX

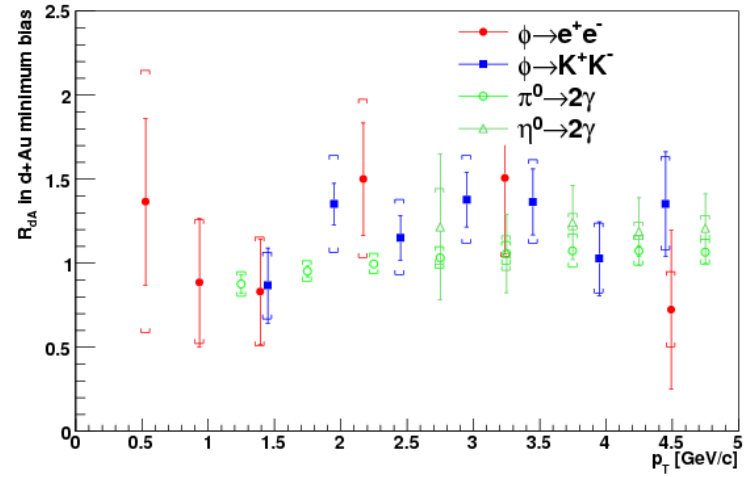
Low-mass Vector Mesons

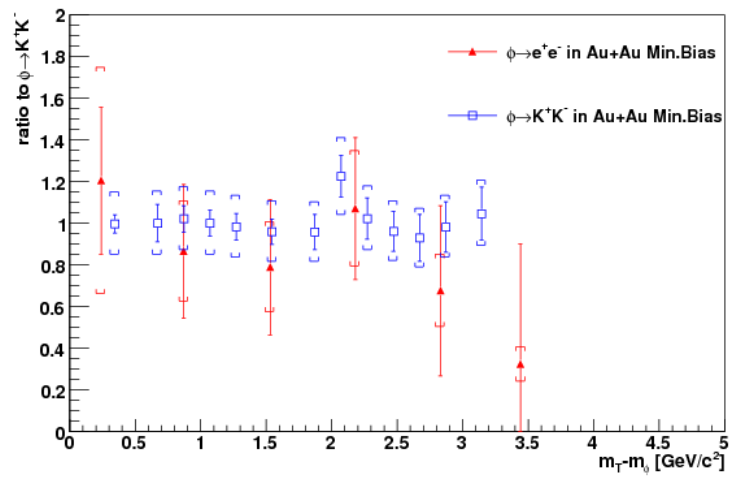
- mass & BR modification (rho, w, phi)
* nuclear effects on phi, ppg096 (Maxim)
  - hint of Cronin, less AA suppr than pions in central collisions
* phi in dAu, ppg053 (Yuji Tsuchimoto)
  - phi->ee falls wrt other decays with pT, change in BR in AuAu?
  - RdAu=1.5, Cronin
* phi->e+e- in dAu (Deepali poster)

Talk: Y. Tsuchimoto (3C-2, Thu)

Plots from ppg053 – which is NOT released – so can't use these

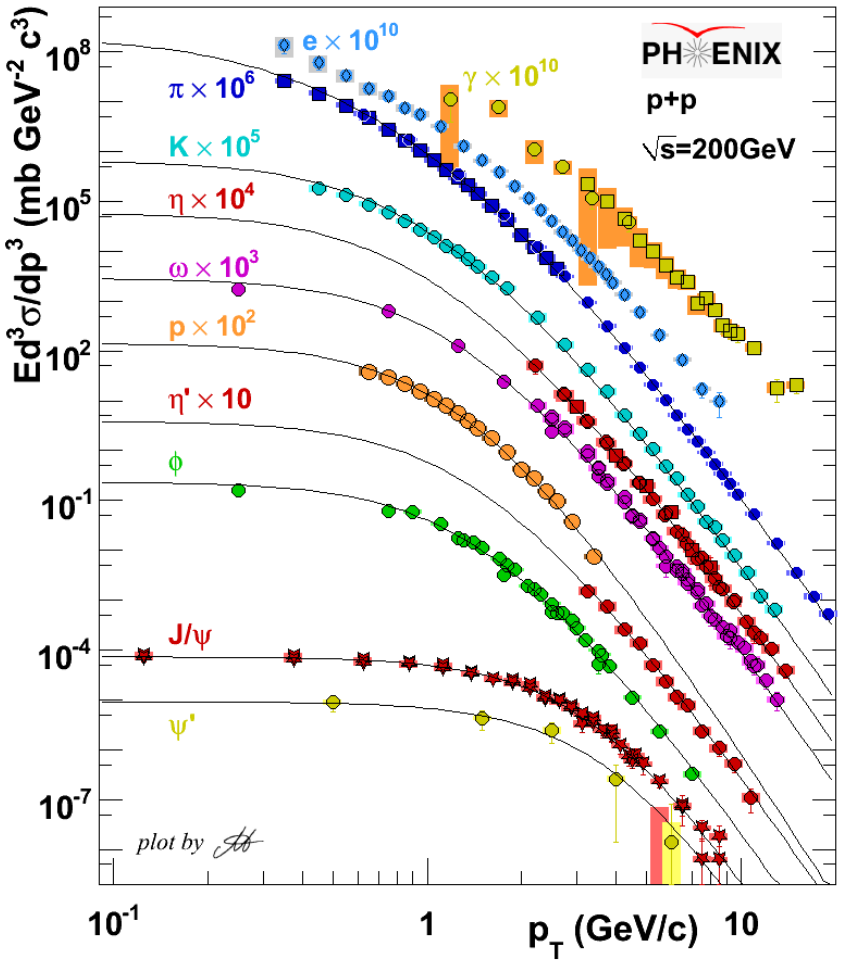


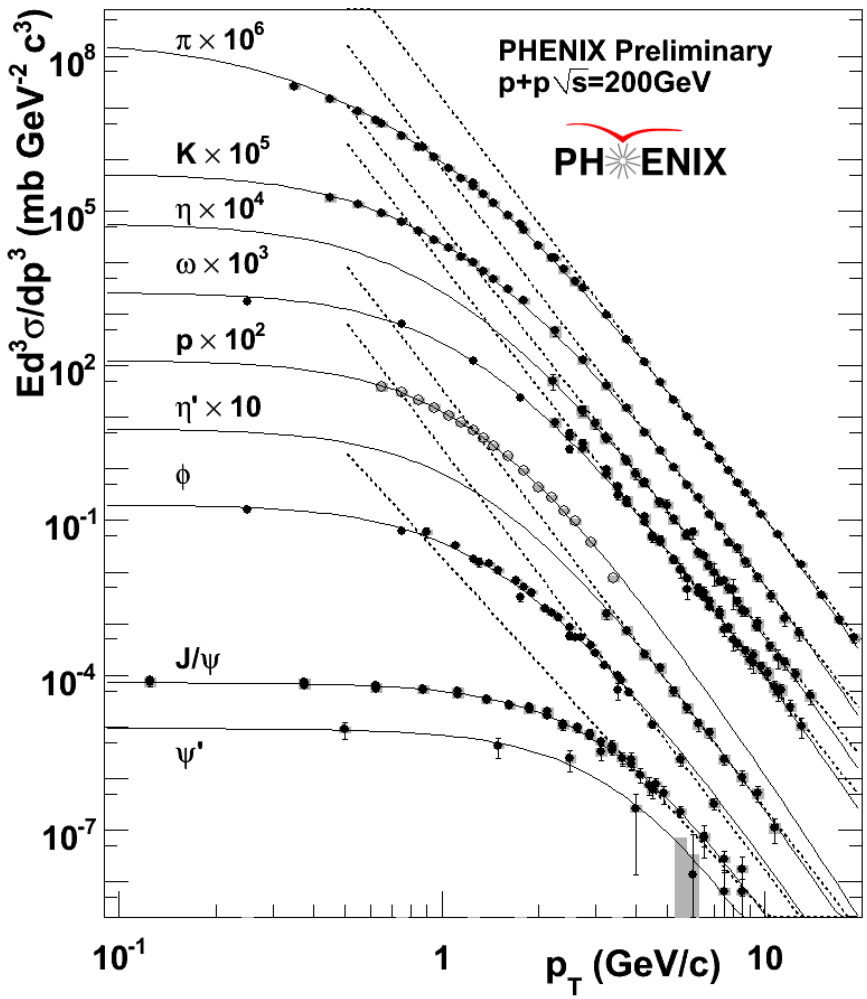




m_T Scaling

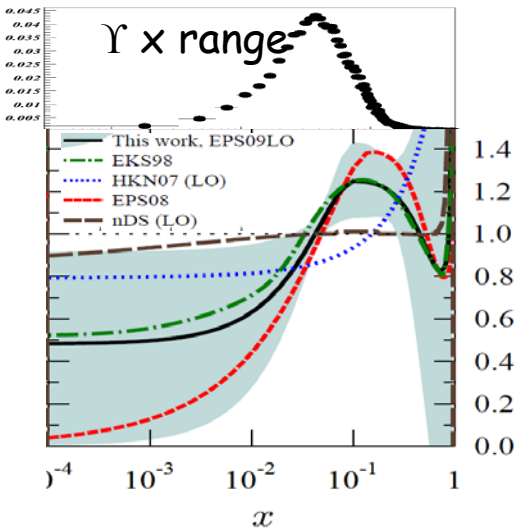
* ppg099 (Milov)
  - is there a physics msg here, what is physics basis of mT scaling? (equal velocity (flow-like) scaling?)



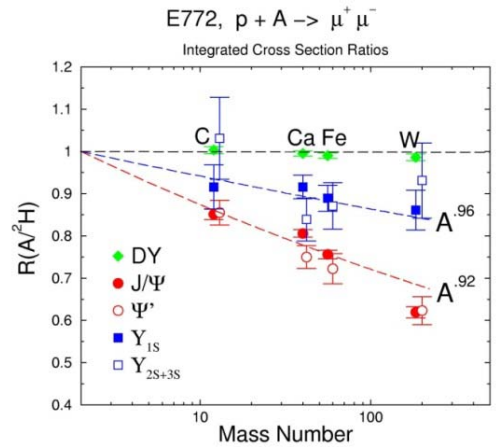


Should ϒ's be Suppressed?

	$R_{AuAu}(y=0)$
J/Ψ	0.425 ± 0.025 ± 0.072
M_{e+e-}= [8.5,11.5 GeV]	< 0.64 at 90% C.L.



- ϒ in anti-shadowing region (for mid-rapidity)
- σ_{abs} of ϒ probably ~1/2 of that for J/Ψ – see E772 at right
  - E772 ϒ nuclear dependence corresponds to R_{AuAu} = 0.81
- CDF: ½ of ϒ from χ_b for p_T>8 GeV/c - but less (25%?) at our p_T
  - see CDF *(PRL84 (2000) 2094, hep-ex/9910025)*
- Lattice expectations in Au+Au - Υ_{1S} unsuppressed; Υ_{2S+3S} suppressed: R_{AuAu} = (0.73)/(0.73+0.17+0.10) = 0.73
- absorption x lattice ~ 0.73x0.81 = 0.59??? – but need serious theory estimate instead of this naïve speculation!



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