

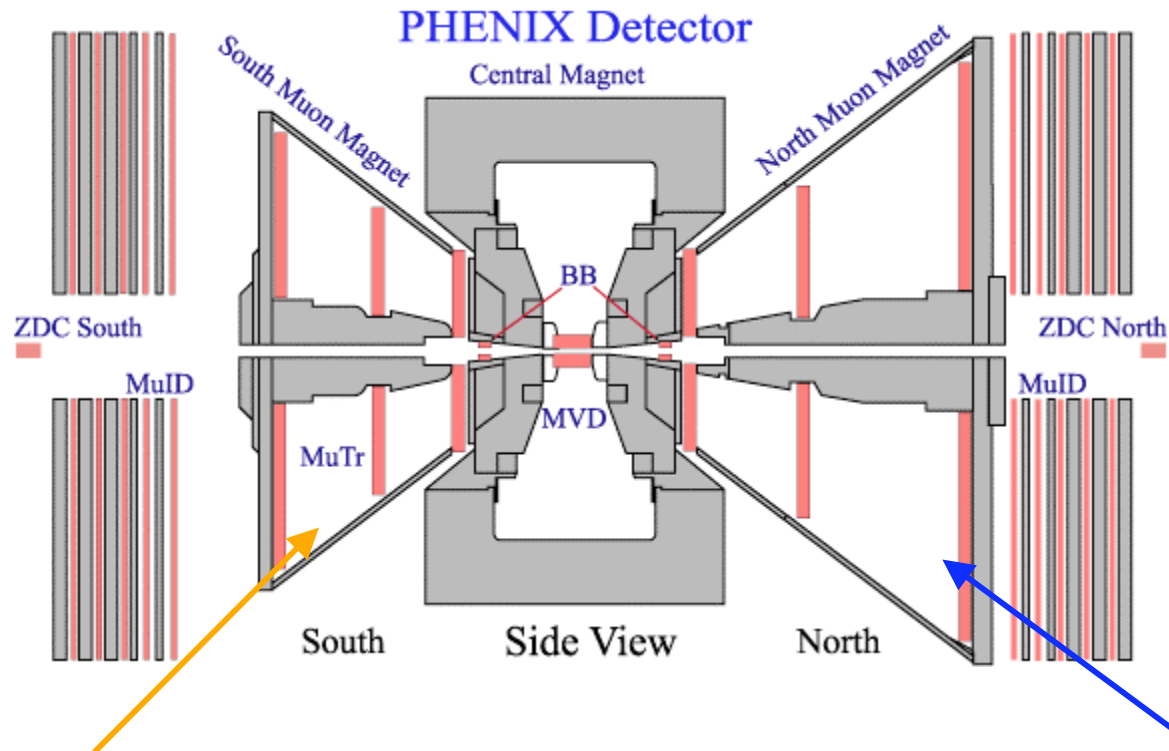
Open Charm and Charmonium Production at Large Rapidity in d+Au Collisions at RHIC

Ming X. Liu

Los Alamos National Lab
(PHENIX Collaboration)

The PHENIX Detectors

deuteron →  ← *gold*



South Muon arm : $-1.2 > \eta > -2.0$

North Muon arm : $2.4 > \eta > 1.2$

Physics Questions

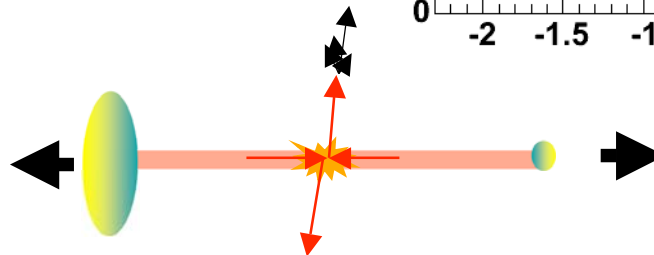
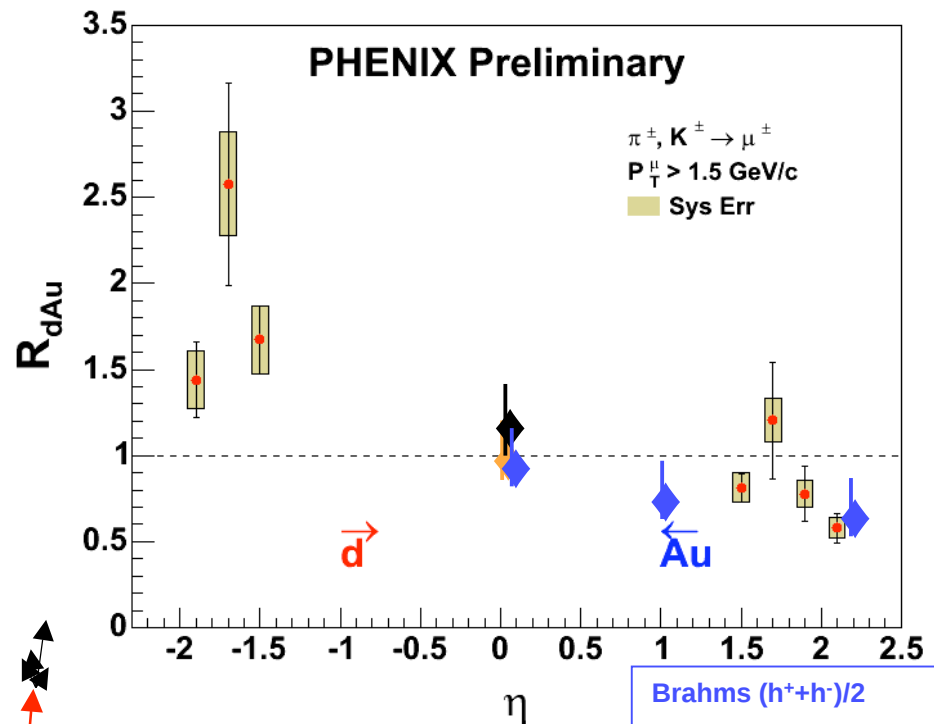
- Cold nuclear medium effects:

- Parton distributions
 - gluon (anti)shadowing
 - CGC
- Interactions with medium
 - Parton energy loss
 - QCD Power Correction
- Recombination

- New probes:

- Open Charm
- J/Psi

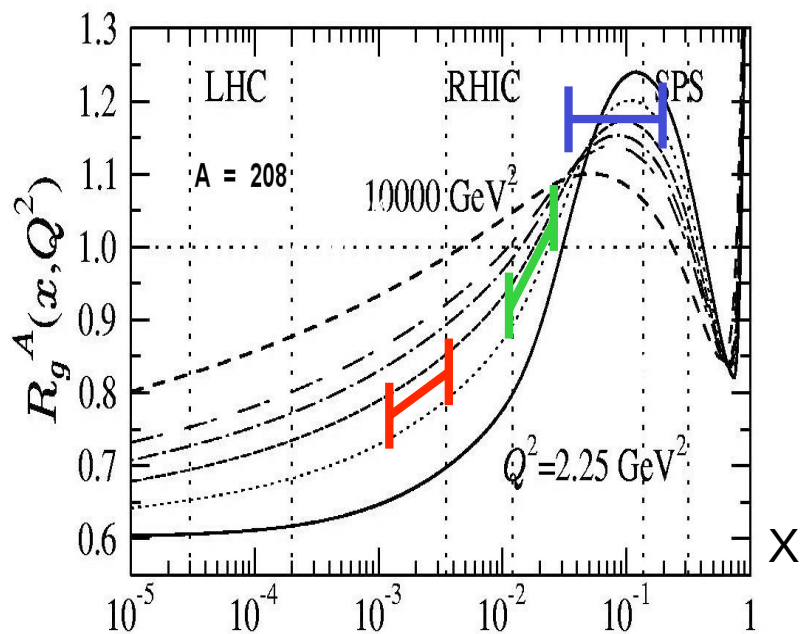
High pT light hadrons



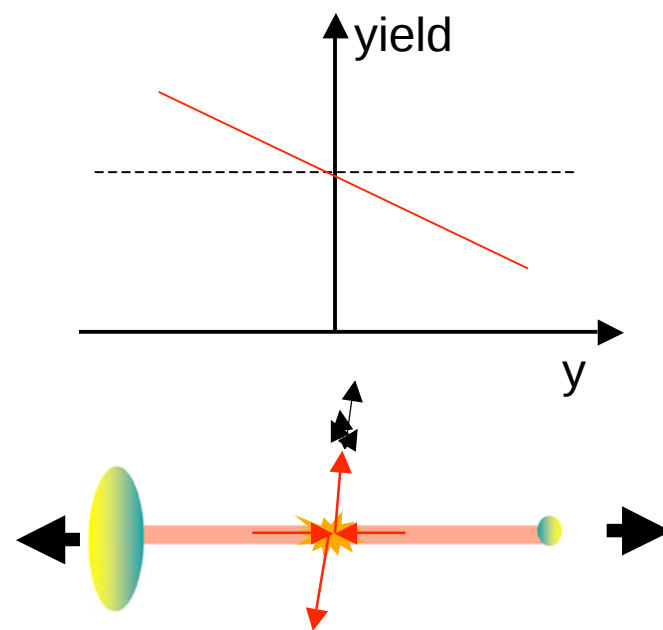
M. Liu Hard Probes 2006

Gluon Shadowing in Heavy Nucleus

From Eskola, Kolhinen, Vogt
Nucl. Phys. A696 (2001) 729-746.



Universal



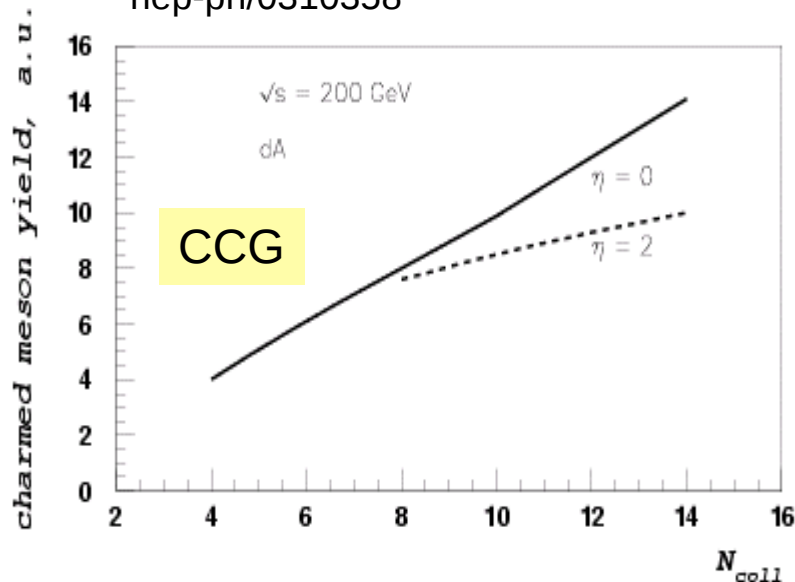
$$d\sigma^{p+p \rightarrow Q\bar{Q}} \propto \underline{F(x_1) \otimes F(x_2)} \otimes d\hat{\sigma}^{x_1+x_2 \rightarrow Q\bar{Q}} \otimes D(z)$$

Color Glass and Dynamic Shadowing

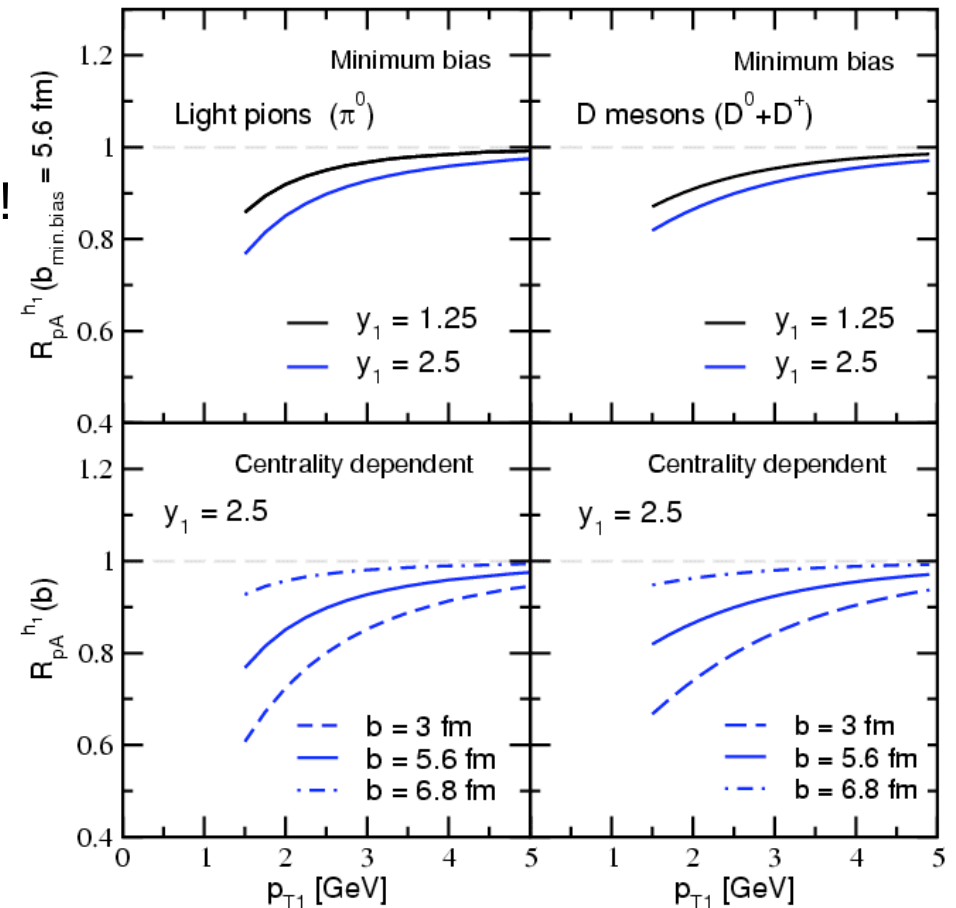
- A challenge!

- Explore (x, Q) space
 - pT (Q²) evolution
- Collision energy scan
- Different probes: light vs heavy!

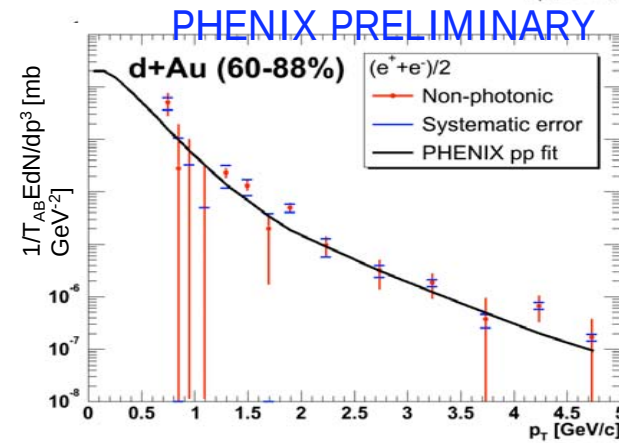
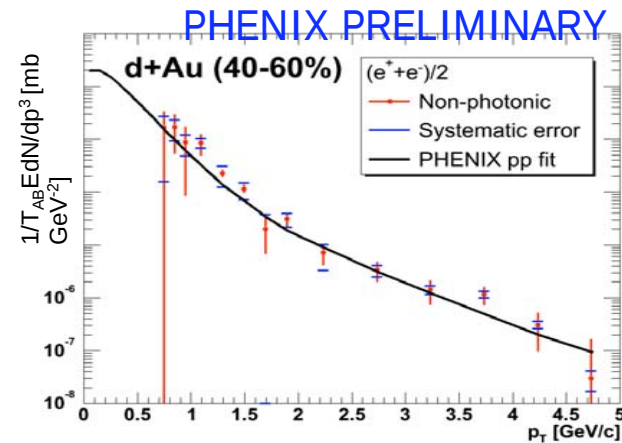
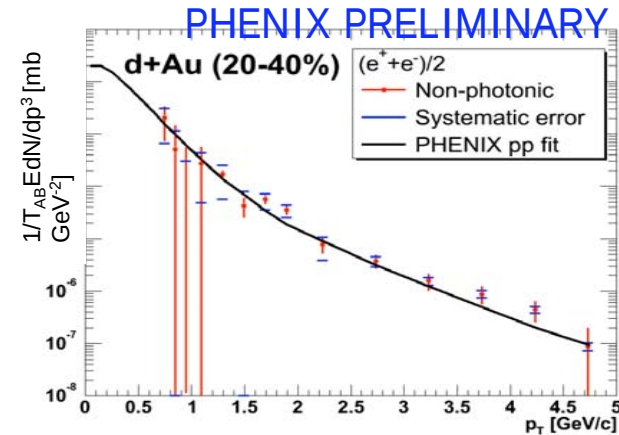
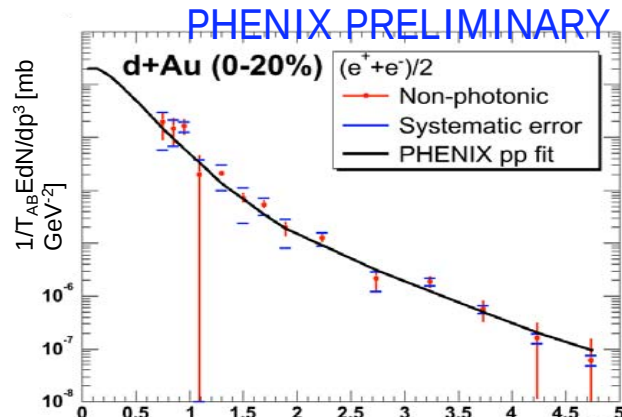
D. Kharzeev & K. Tuchin
hep-ph/0310358



Power correction only J. Qiu & I. Vitev



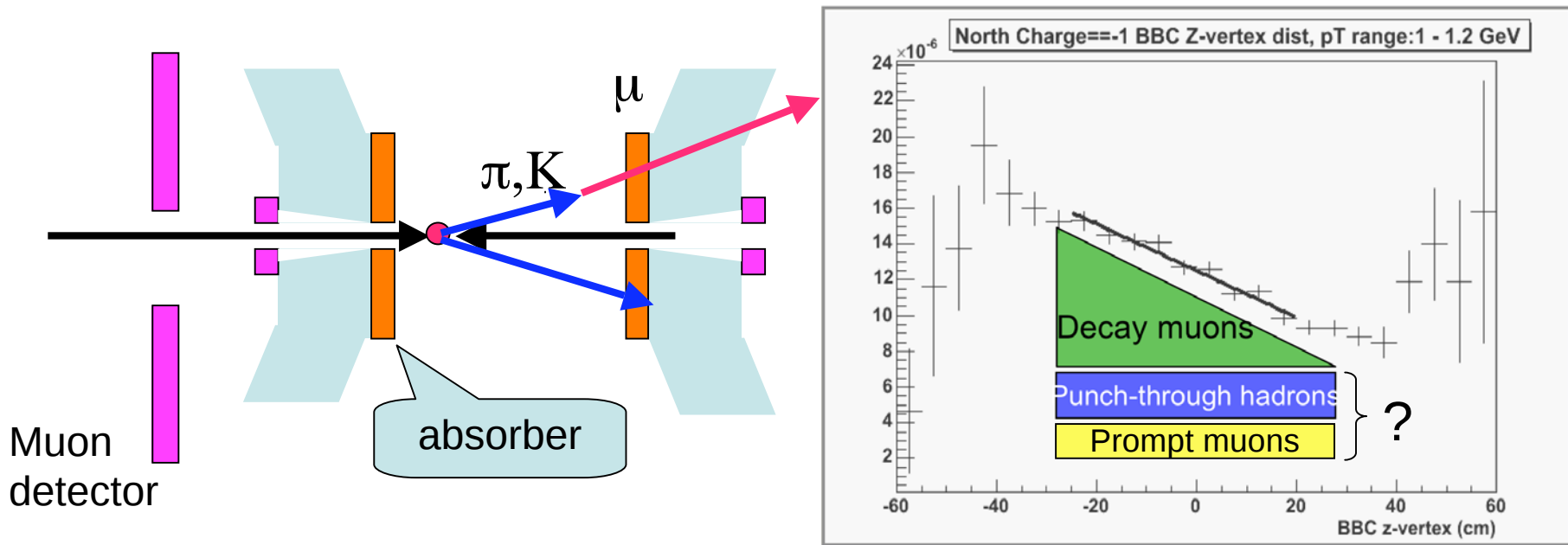
Open Charm in dAu ($e^\pm$ @ $y=0$)



“binary scaling” at mid-rapidity

Forward Muons from Charm Decays

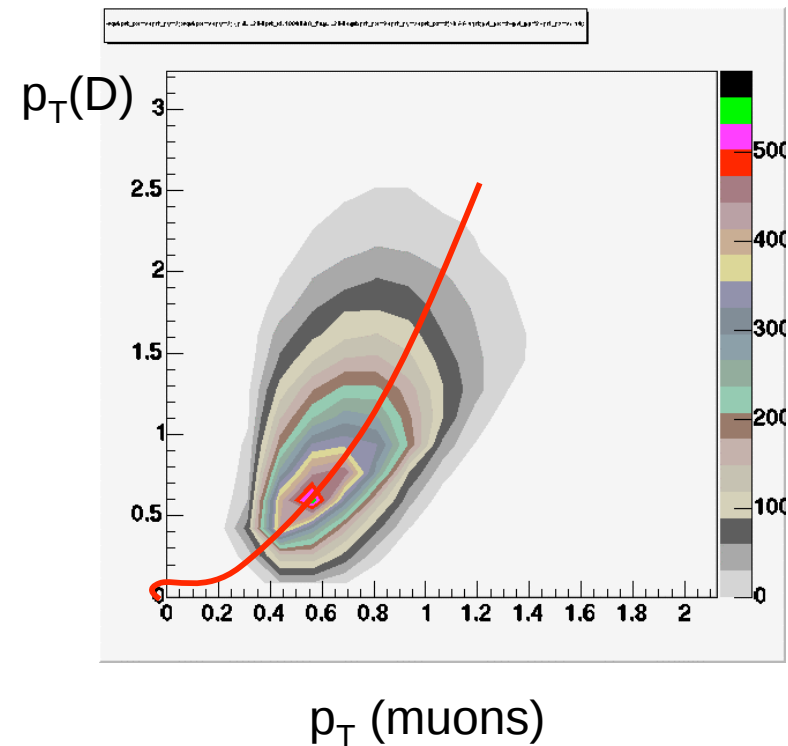
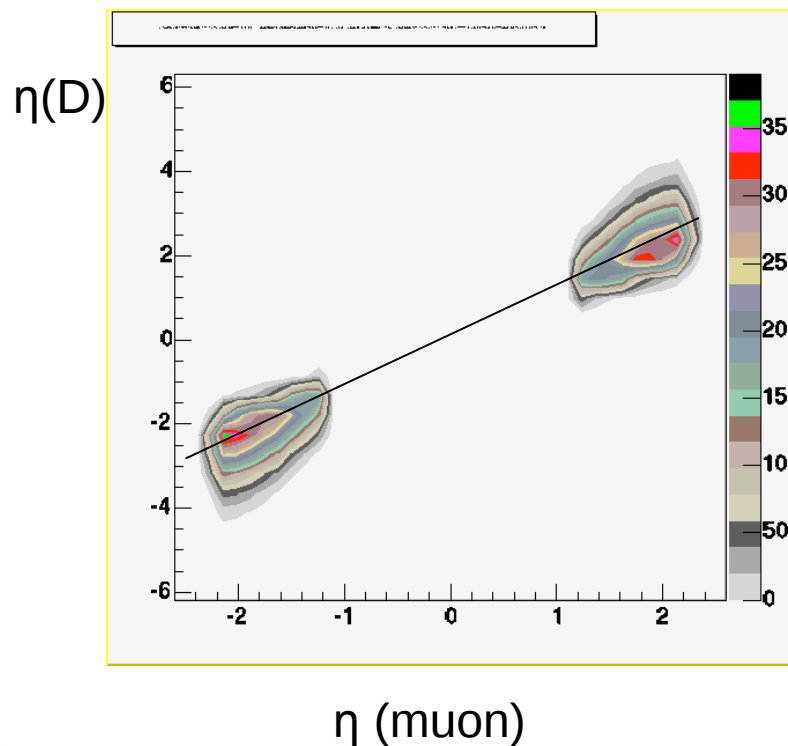
The normalized muon event vertex distribution



Open heavy flavor production can be measured through prompt muons

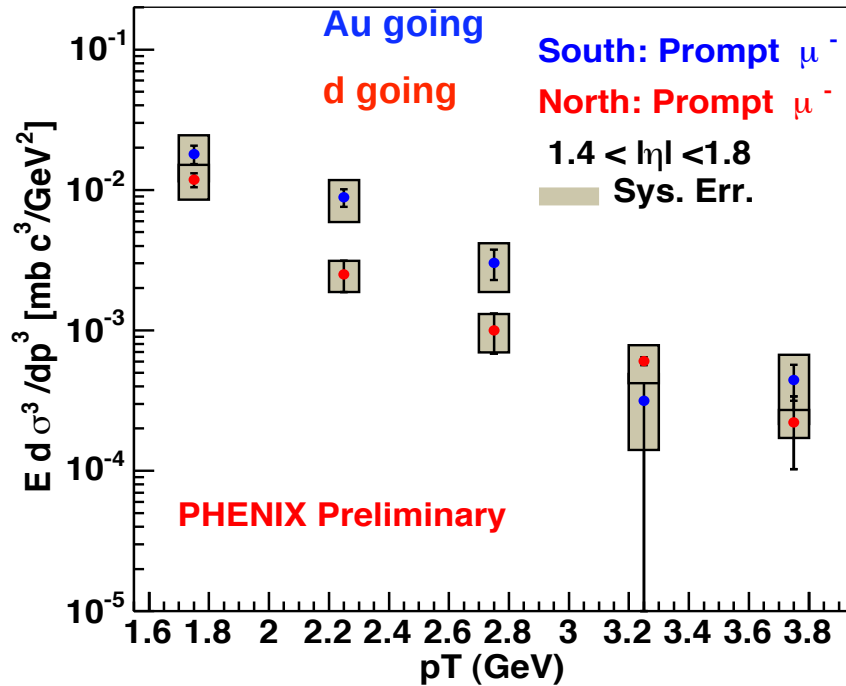
Prompt muon and D correlation

- Hard fragmentation
 - large $\langle Z \rangle$
 - Strong correlations

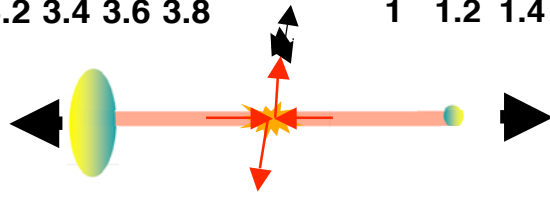
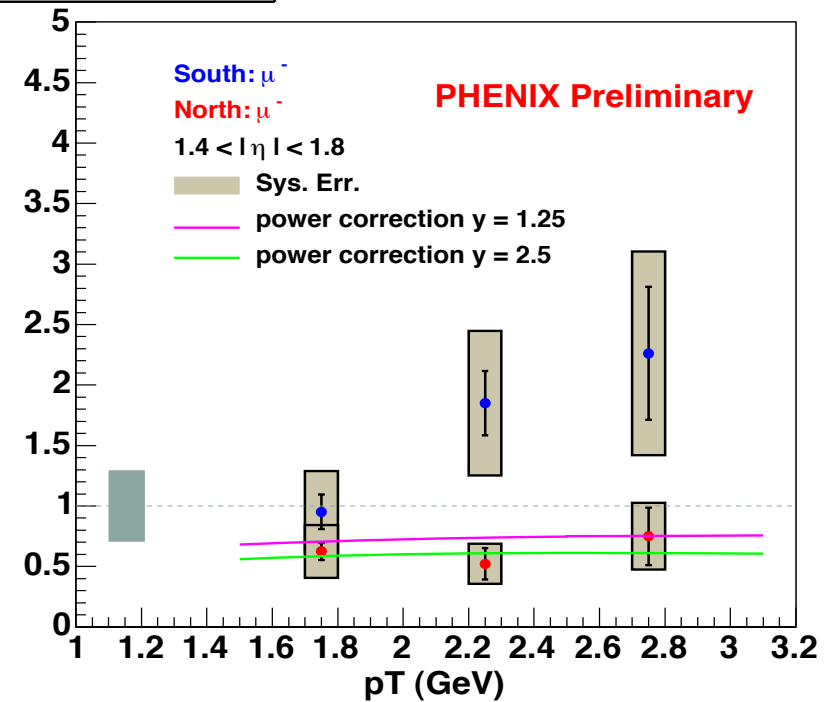


dAu: Prompt μ at Forward & Backward

dAu Invariant cross section(prompt μ^-)



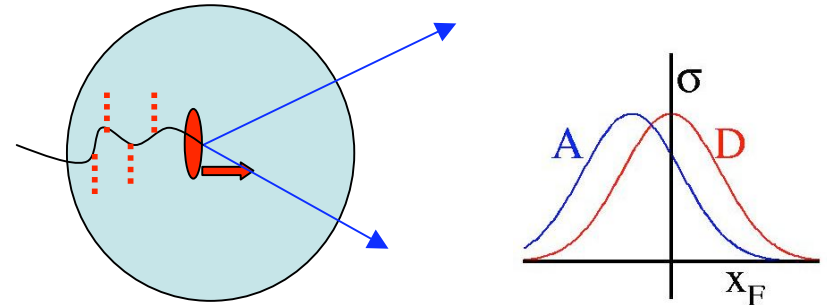
$R_{dAu}(\text{Prompt } \mu^-)$



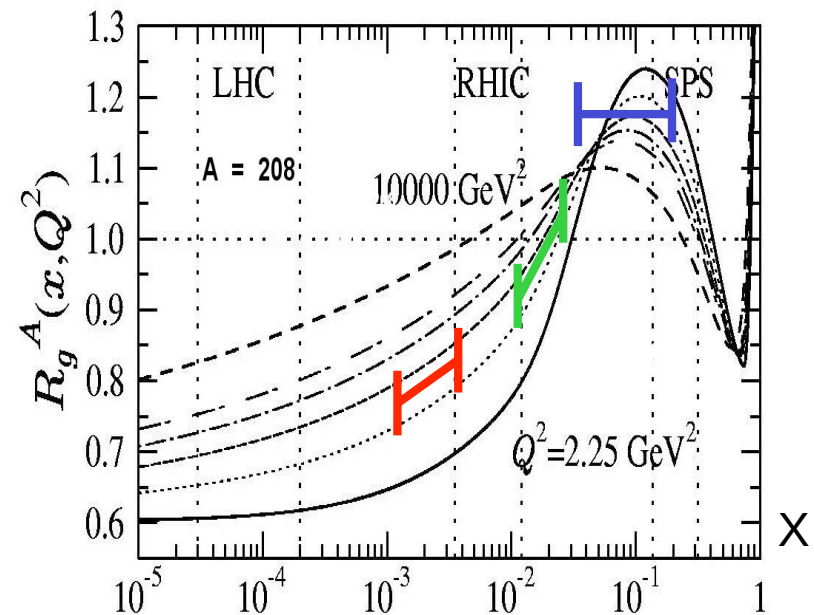
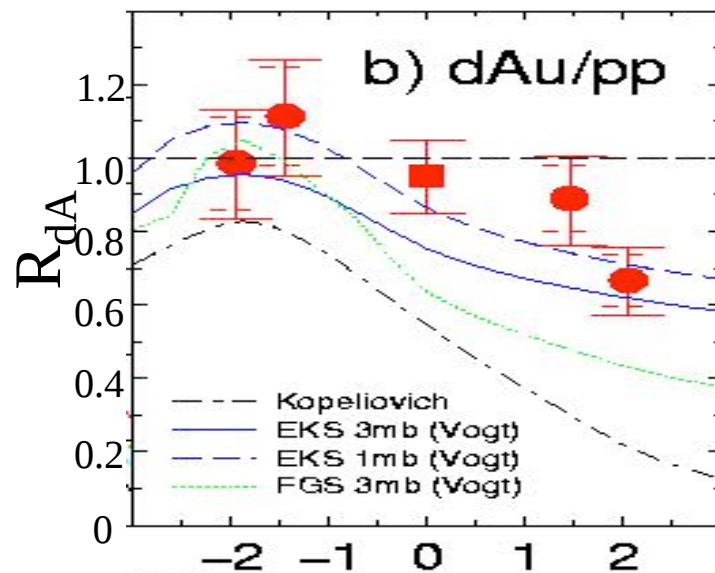
Suppression in forward rapidity; Enhancement in backward rapidity;
Different from central rapidity results !

How about J/Psi?

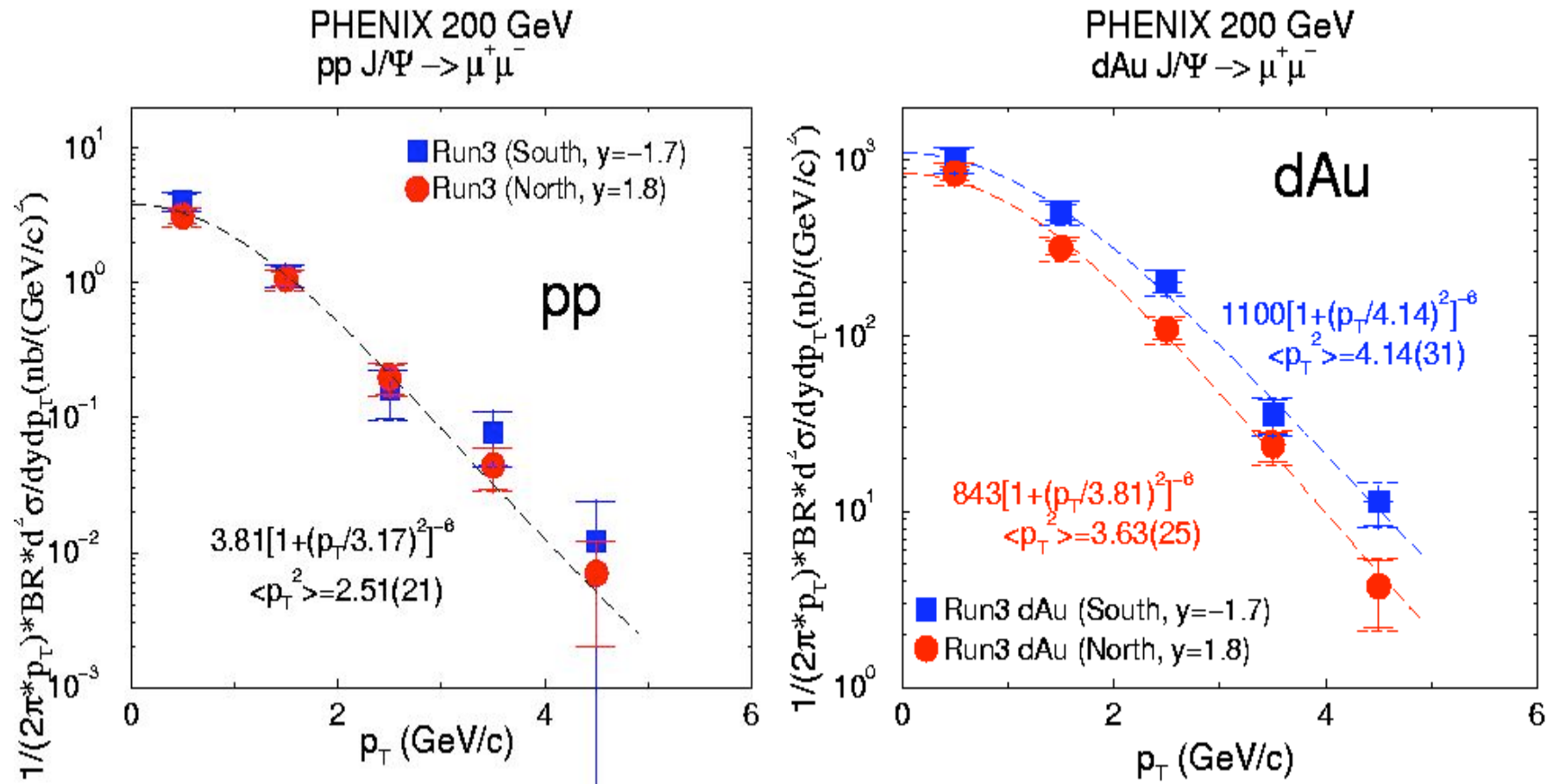
- **_NO_ recombination!**
- Gluon shadowing/saturation
- Initial state parton energy loss
- J/Psi final state nuclear absorption has minimal effects on the shape



$$p \sim \gamma \cdot p_{lab} \sim 10^5 \text{ GeV}$$



J/Psi p_T broadening in dAu collisions

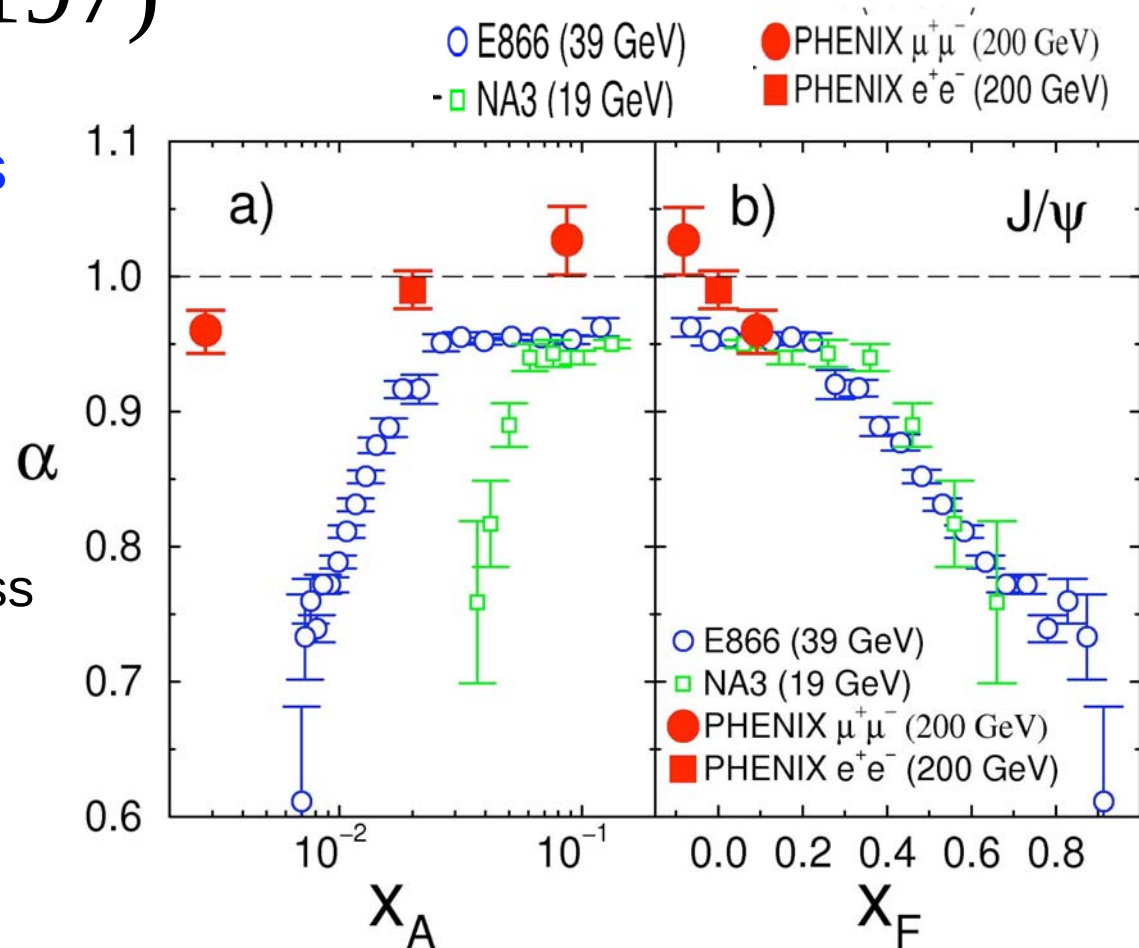


Broadening of J/ ψ p_T distribution suggests initial scattering (maybe also energy loss) is important

Shadowing or Energy Loss ?

$$\sigma_{dA} = \sigma_{pp} (2 \times 197)^\alpha$$

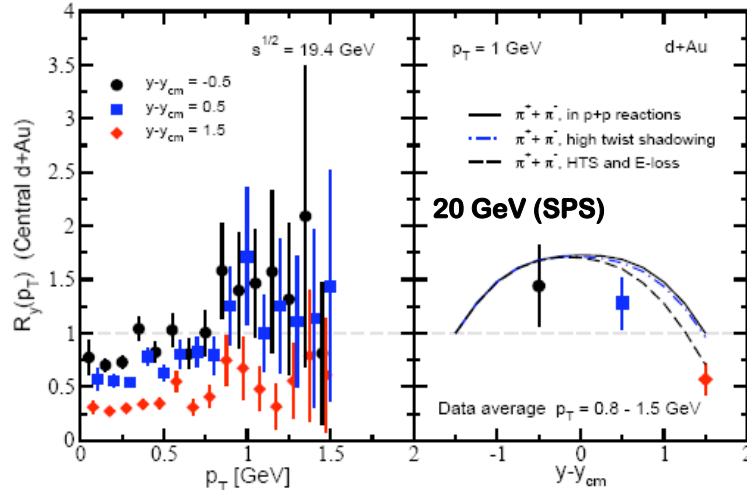
- Shadowing alone is not enough
- Initial state energy loss?
 - Incoming gluons loss a fraction of energy before the hard collisions
 - $X_1(\sim X_F)$ scaling



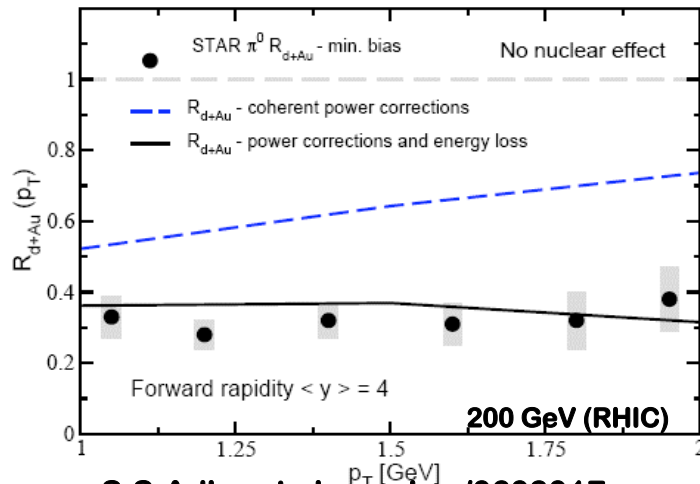
Cold Nuclear Matter Energy Loss

I. Vitev

b) Initial state inelastic scattering



T.Alber et al., E.Phys.J.C 2 (1998)



S.S.Adler et al., nucl-ex/0603017

I.V., T.Goldman, M.B.Johnson, J.W.Qiu, hep-ph/0605200

B.Kopeliovich, et al., Phys.Rev.C72 (2005)

- Shadowing parameterizations: **(not)**

$$S_{LT} = S_{LT}(x, Q^2)$$

- Dynamical calculations of high twist shadowing: **(not)**

$$S_{HT} = S_{HT}(q(g); \hat{t}(z_1, (z_2)))$$

- Energy loss: in combination with HTS **(yes)**

Initial state E-loss

$$\left| \frac{\text{QED}}{\text{QCD}} + \frac{\text{QED}}{\text{QCD}} + \frac{\text{QED}}{\text{QCD}} \right|^2 \sim |B|^2$$

J.Gunion and G.Bertsch, Phys.Rev.D25 (1982)

$$\frac{dN_g^{(BG)}}{dy d^2k_\perp} \propto \frac{\alpha_s}{\pi^2} \frac{q_\perp^2}{k_\perp^2 (k_\perp - q_\perp)^2} \phi(x, Q^2) \rightarrow \phi\left(\frac{x}{1-\varepsilon}, Q^2\right)$$

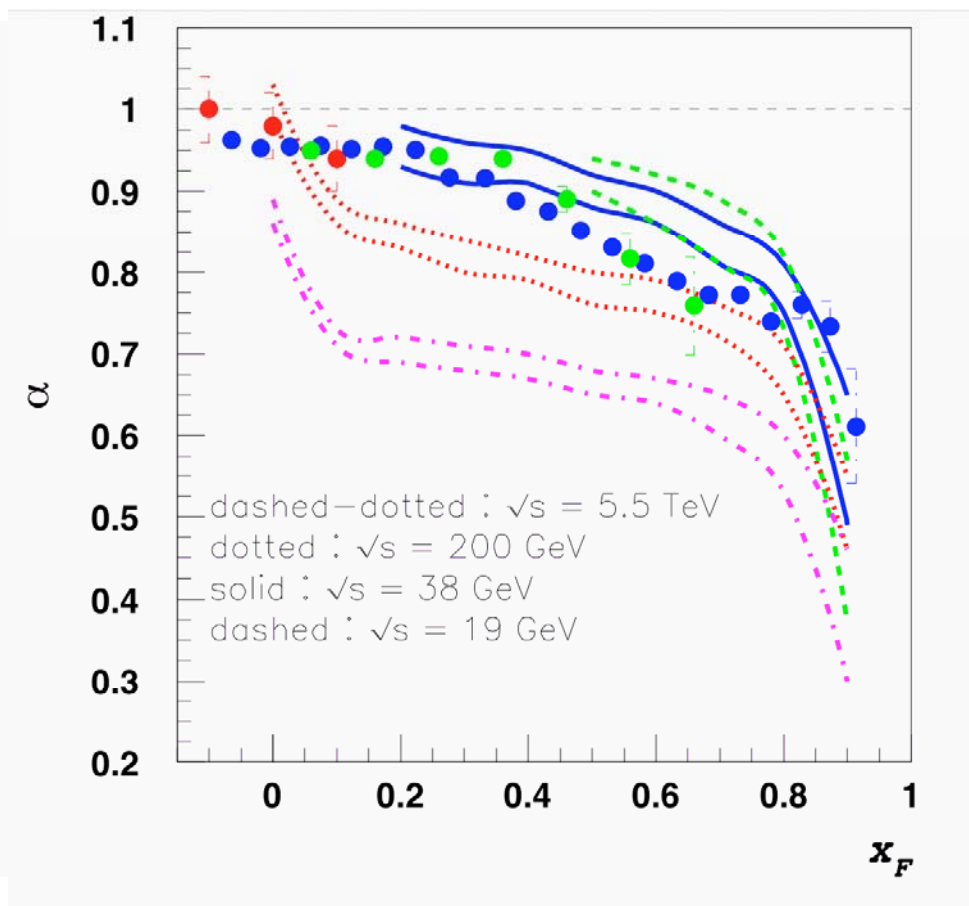
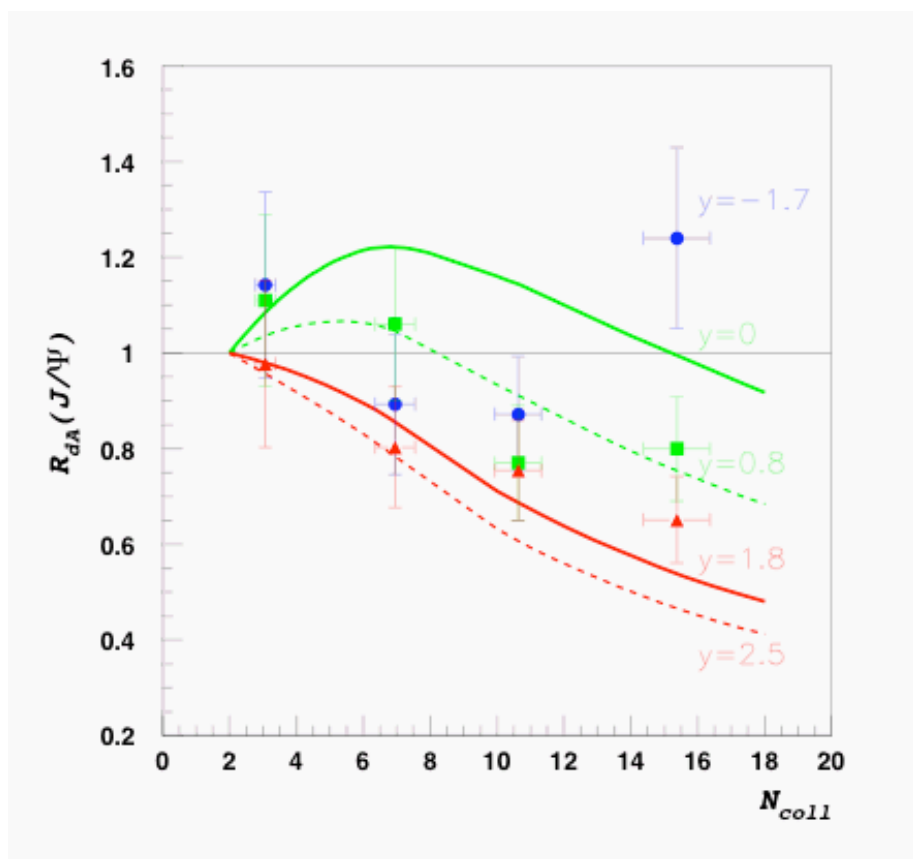
$$\varepsilon = \Delta E / E = k A^{1/3}, \quad k_{\text{min bias}} = 0.0175$$

M. Liu Hard Probes 2006

To investigate: $k = k(\mu, \lambda_{jet}, E, m)$ PHENIX

CGC and J/Psi in dAu @RHIC

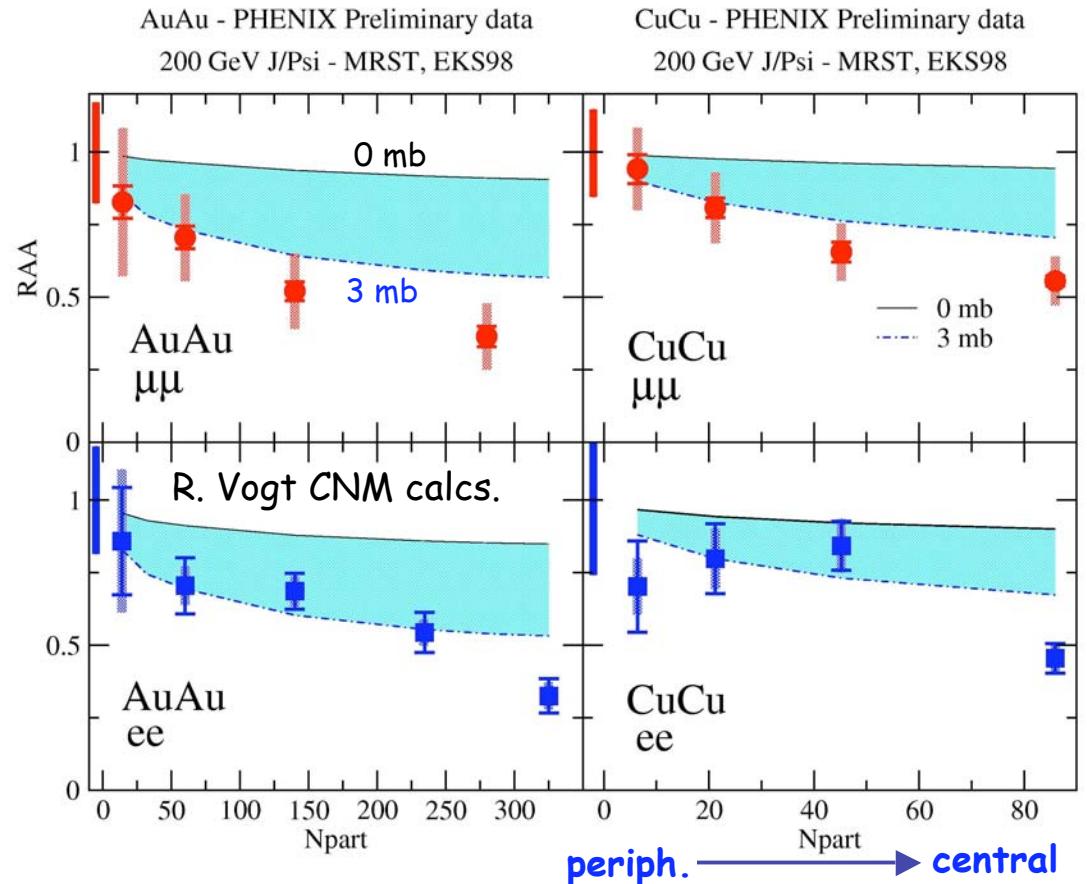
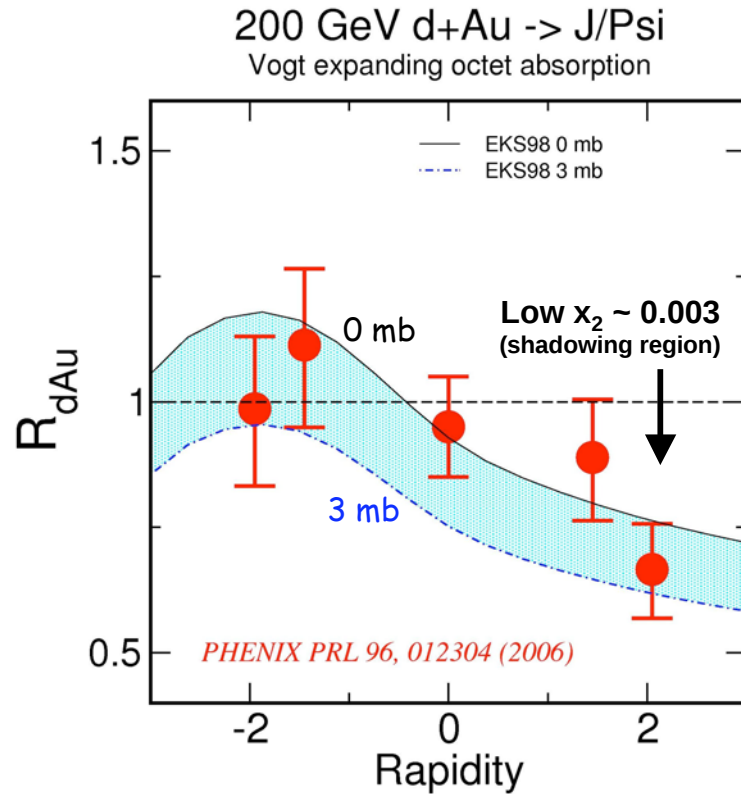
Kharzeev & Tuchin hep-ph/0510358



Summary and Outlook

- Physics at Forward and Backward Rapidity:
 - open charm
 - J/ψ
- Observed: heavy $\sim$ light hadrons
 - suppression in the forward
 - enhancement in the backward
- Causes for such effects are not very clear
 - Shadowing: CGC, Power correction
 - Initial state energy loss
 - Need more theoretical work and better data
- Future:
 - Lower energy dAu collisions: stay away from shadowing regions
 - Explore $\{x, Q, \sqrt{s}\}$ space $\rightarrow$ $(y, p_T, \sqrt{s})$ experimentally
 - Parton energy loss vs shadowing
 - p_T evolution – shadowing vs power correction
 - Shadowing vs recombination
 - Explore QCD dynamics in more details in coming years!

J/ψ Suppression (Cold or Hot)

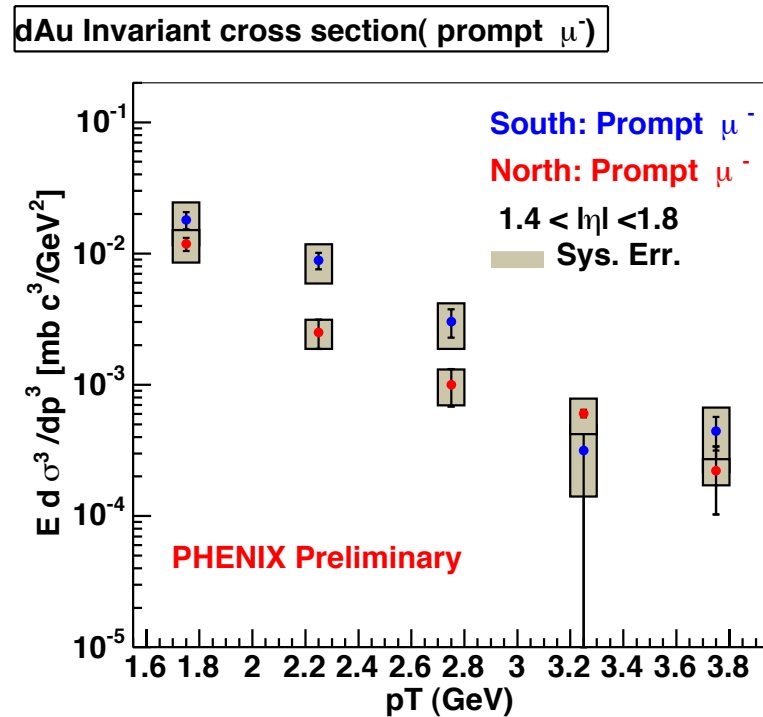
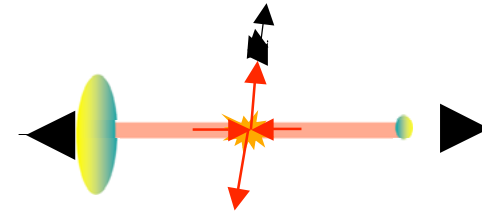


- Cold Nuclear Medium (CNM) calculations with shadowing & absorption
- present dAu data probably only constrains absorption to: $\sigma_{\text{ABS}} \sim 0\text{-}3 \text{ mb}$

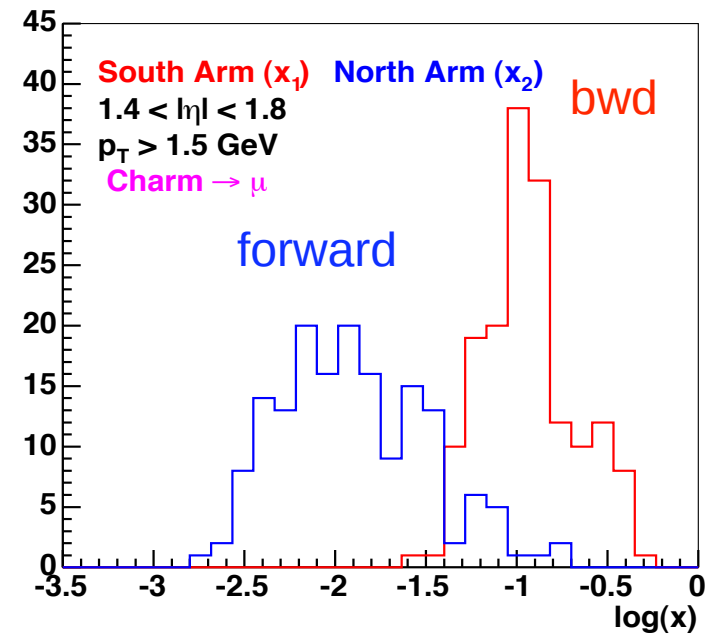
- AA suppression is somewhat stronger than CNM calculations predict
- but really need more precise dAu data!

Prompt Muon Yields

- Forward and backward

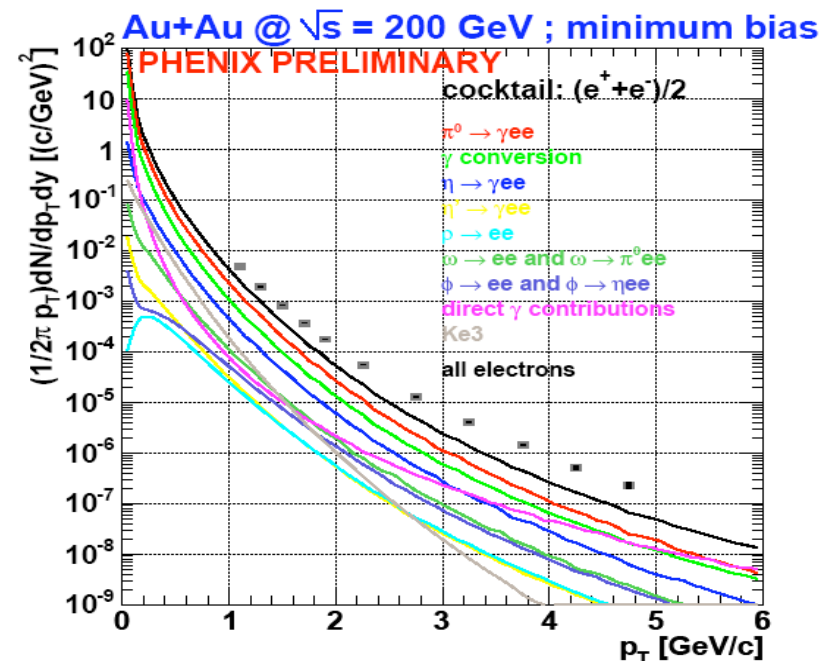
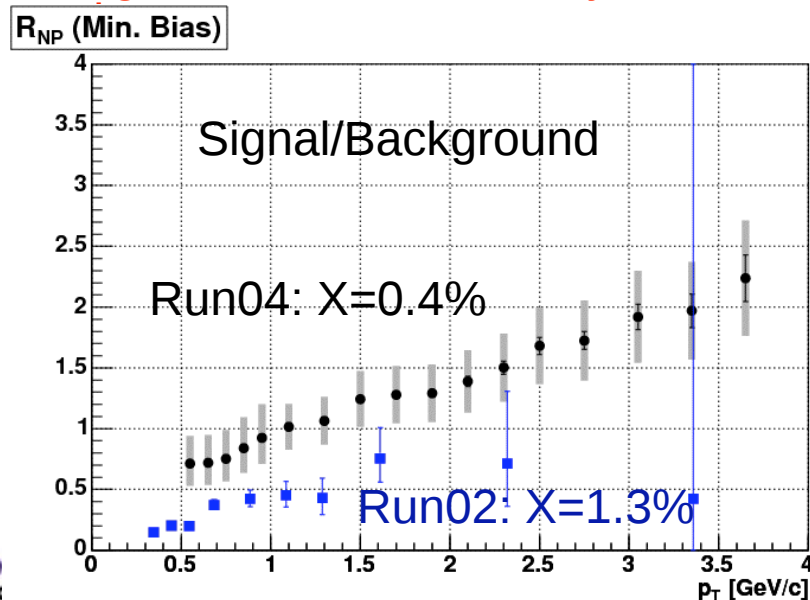


Probed X ranges in Au



Analysis Techniques: (non-photonic e)

- Two complimentary analysis techniques for signal extraction
 - “Cocktail subtraction”
 - “Converter subtraction”
- Both analyses clearly show an excess “non-photonic” electron signal attributed to heavy flavor



$S/B > 1$ for $p_T > 1$ GeV/c

bes 2006

Sources of prompt muons ($p_T > 0.9\text{GeV}$) (estimated from Pythia)

