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

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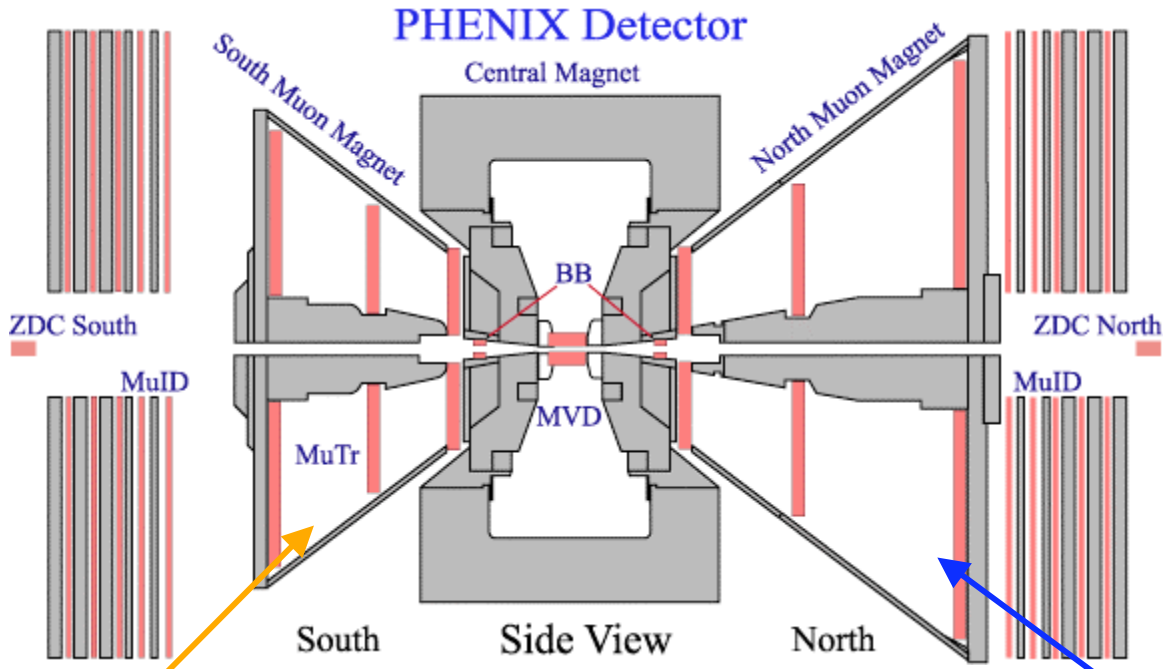
Los Alamos National Lab
(PHENIX Collaboration)

The PHENIX Detectors

deuteron → ✸ ← ***gold***



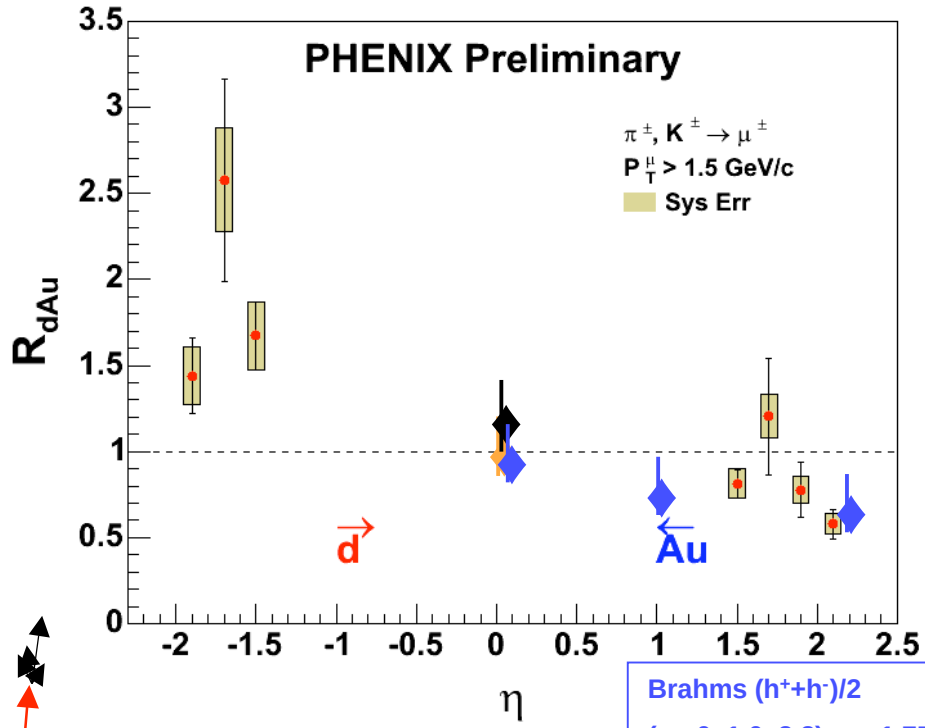
South Muon arm : $-1.2 > \eta > -2.0$

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

Physics Questions

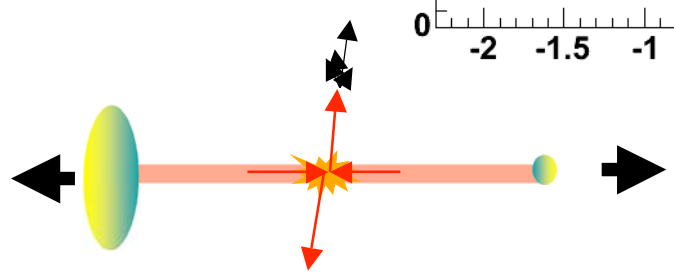
- Cold nuclear medium effects:
  - Parton distributions
    - gluon (anti)shadowing
    - CGC
  - Interactions with medium
    - Parton energy loss
    - QCD Power Correction
  - Recombination
- New probes:
  - Open Charm
  - J/Psi

High pT light hadrons



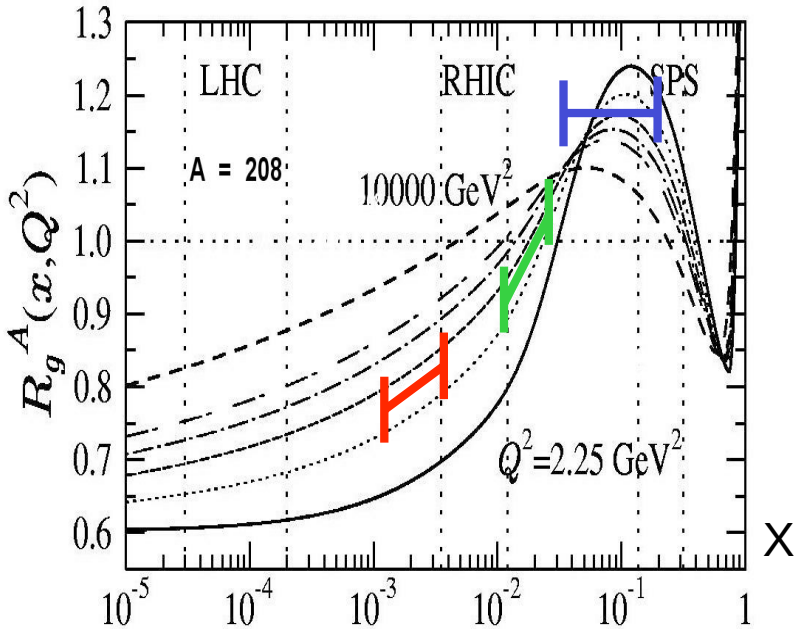
Brahms $(h^{+}+h^{-})/2$

$(\eta = 0, 1.0, 2.2)$ $p_T = 1.75$

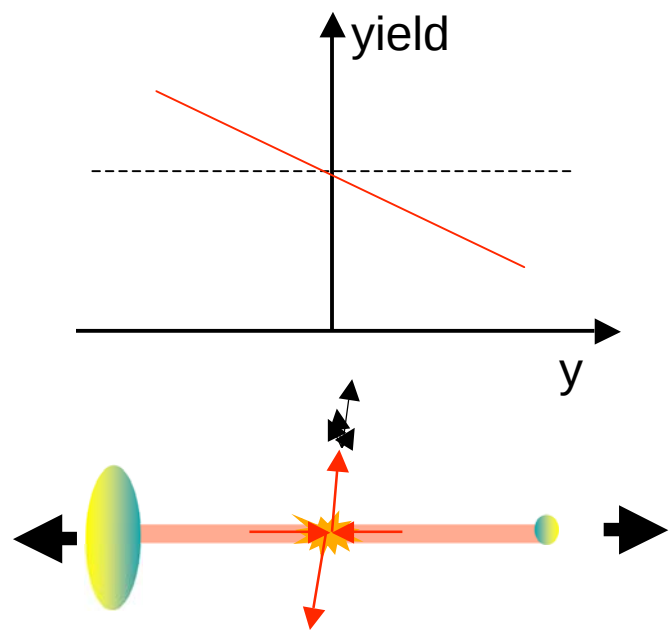


Gluon Shadowing in Heavy Nucleus

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



Universal

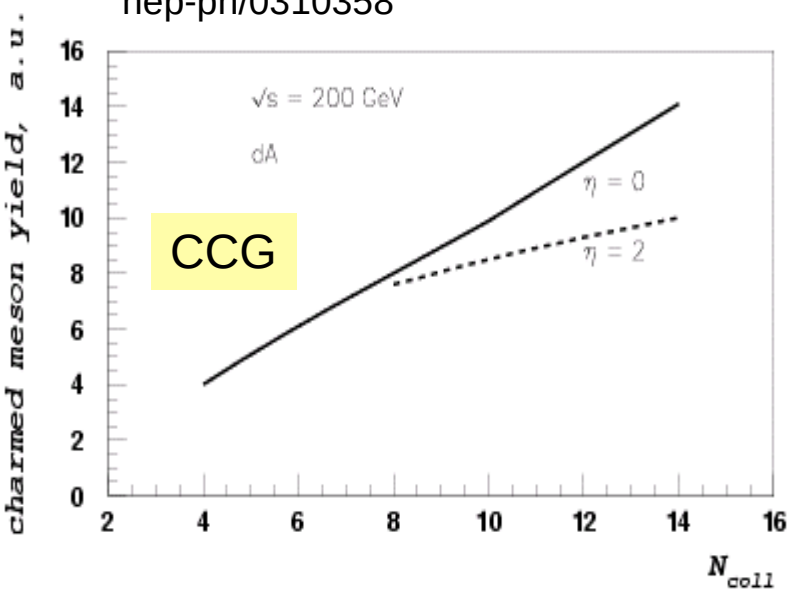


$$d\sigma^{p+p\to Q\bar{Q}} \propto F(x_1)\otimes F(x_2)\otimes d\hat{\sigma}^{x_1+x_2\to Q\bar{Q}}\otimes D(z)$$

Color Glass vs Dynamic Shadowing

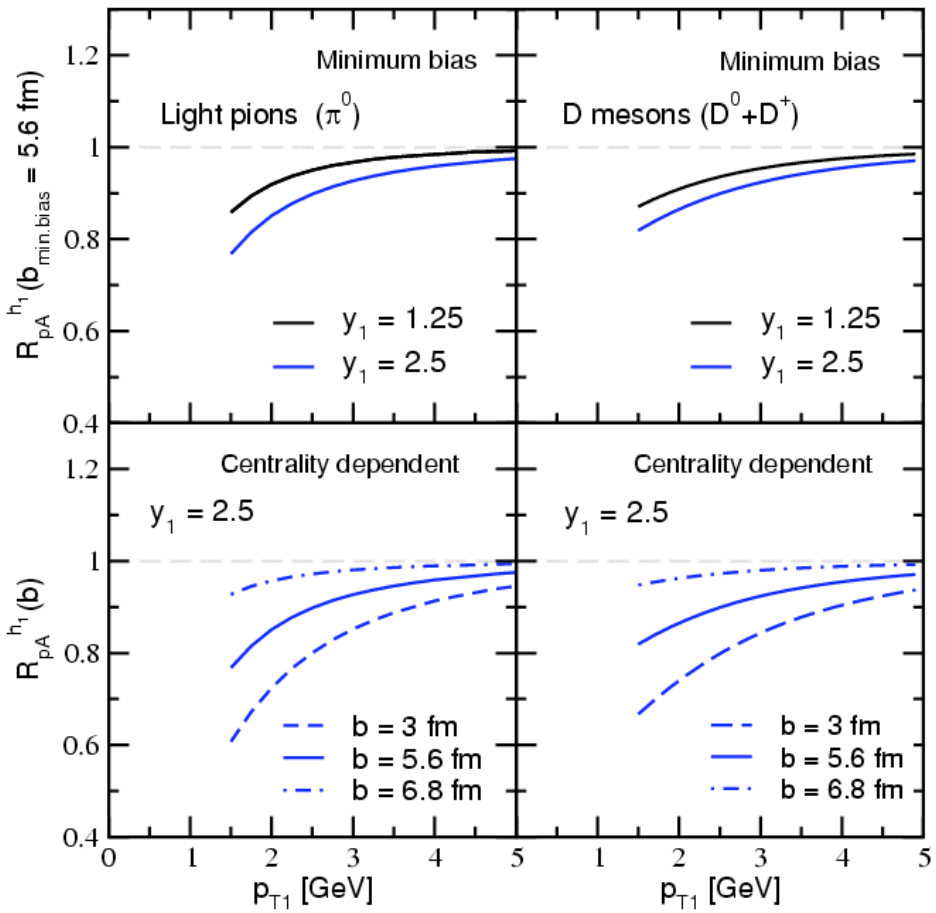
- A challenge!
  - Explore (x, Q) space
    - pT (Q^2) evolution
  - Collision energy scan
  - Different probes: light vs heavy!

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

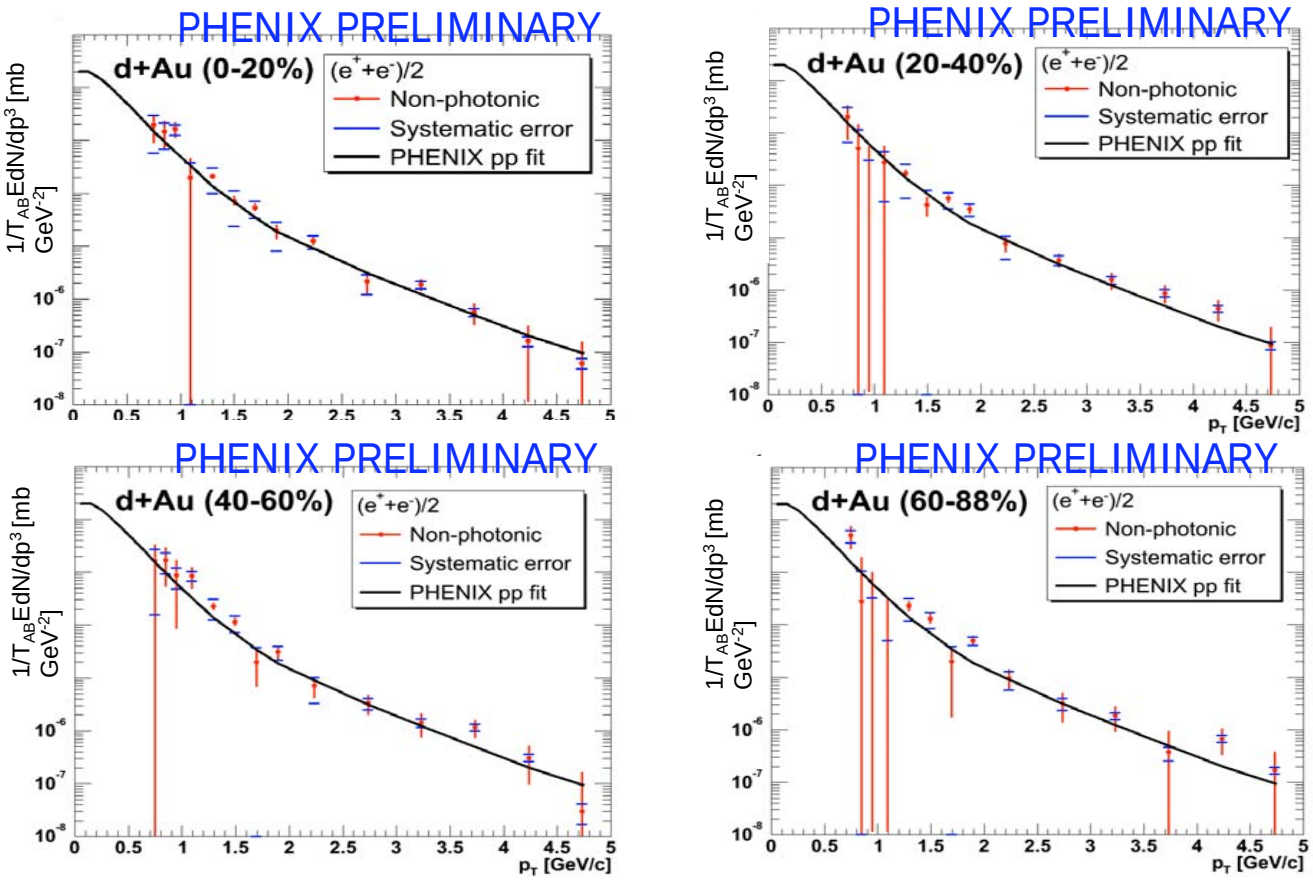


Power correction only

J. Qiu & I. Vitev



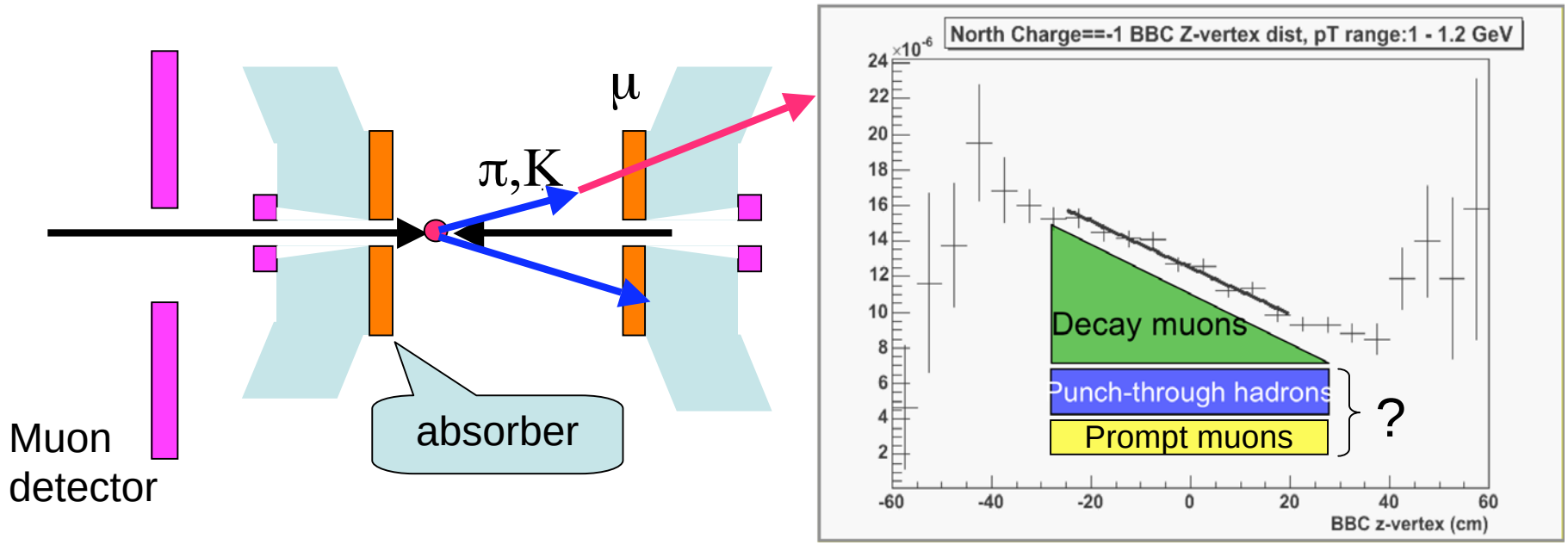
Open Charm in dAu ($e^{\pm}$ @ y =0)



"binary scaling" at mid-rapidity

Forward Muons from Charm Decays

The normalized muon event vertex distribution

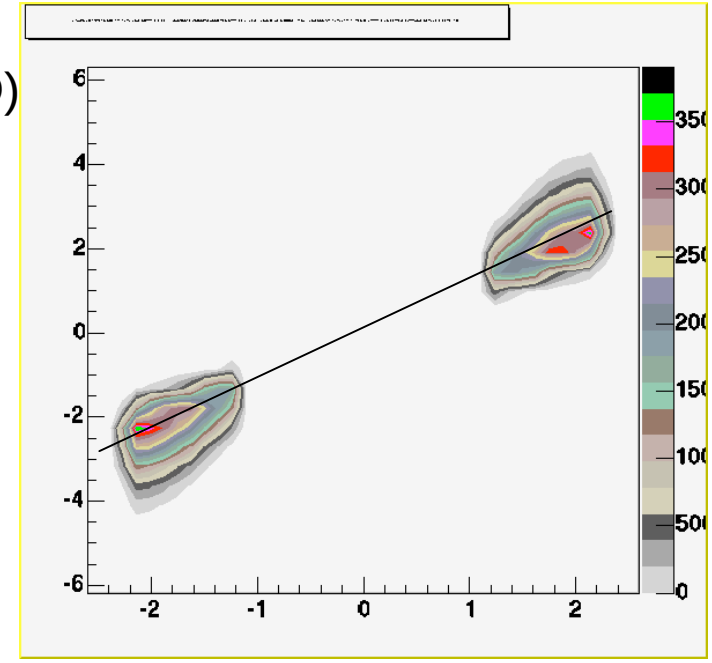


Open heavy flavor production can be measured through prompt muons

Prompt muon and D correlation

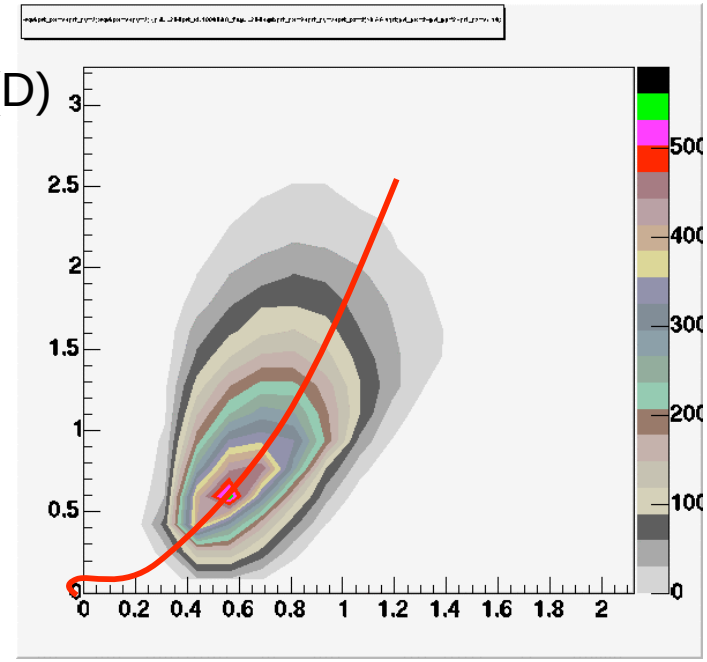
- Hard fragmentation
  - large <Z>
  - Strong correlations

η(D)



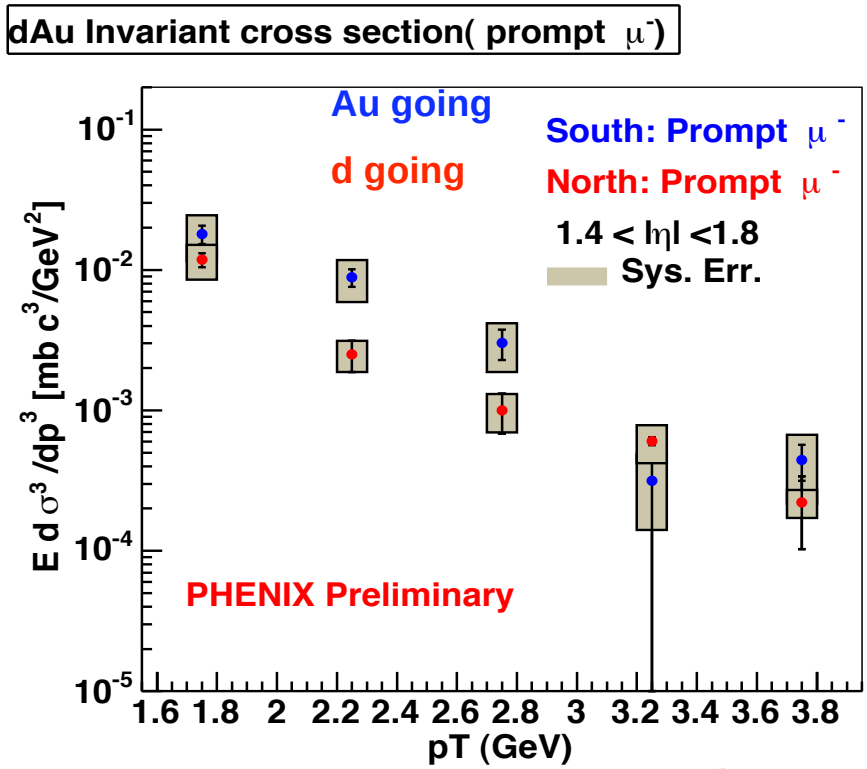
η (muon)

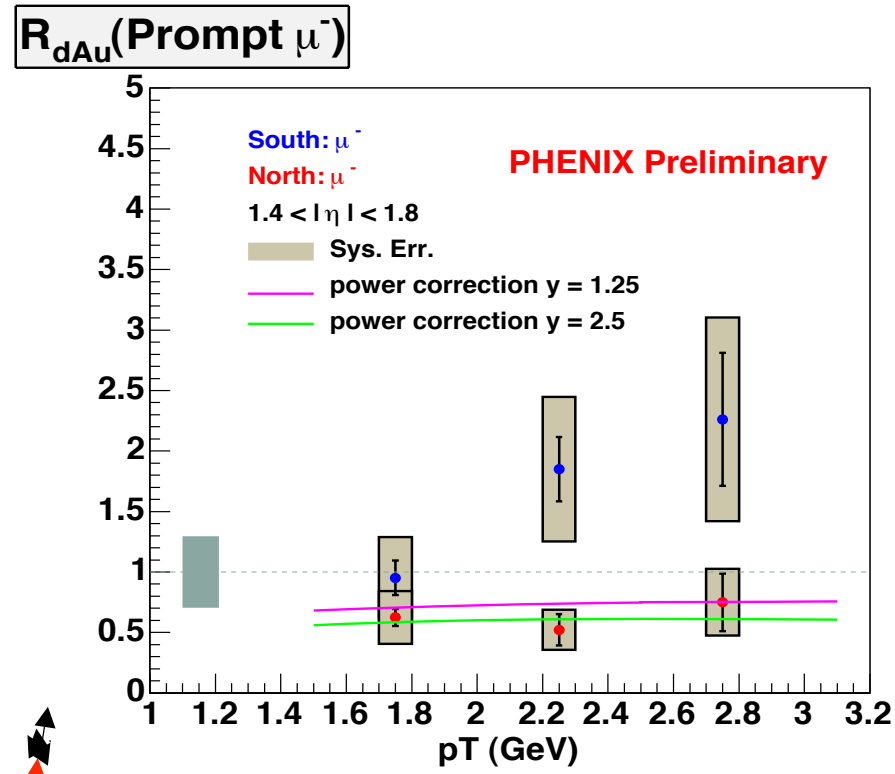
p_T(D)

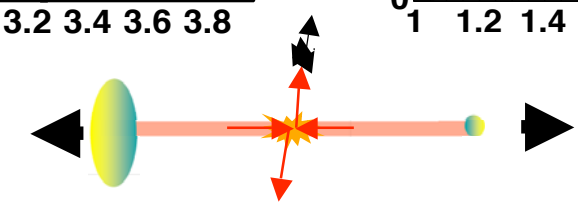


p_T (muons)

dAu: Prompt μ at Forward & Backward



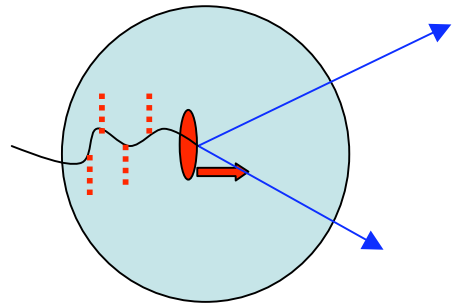


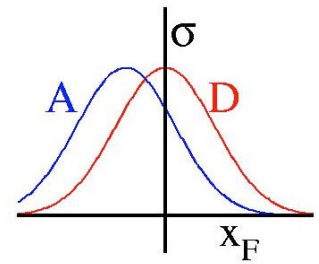


Suppression in forward rapidity; Enhancement in backward rapidity;
Different from central rapidity results !

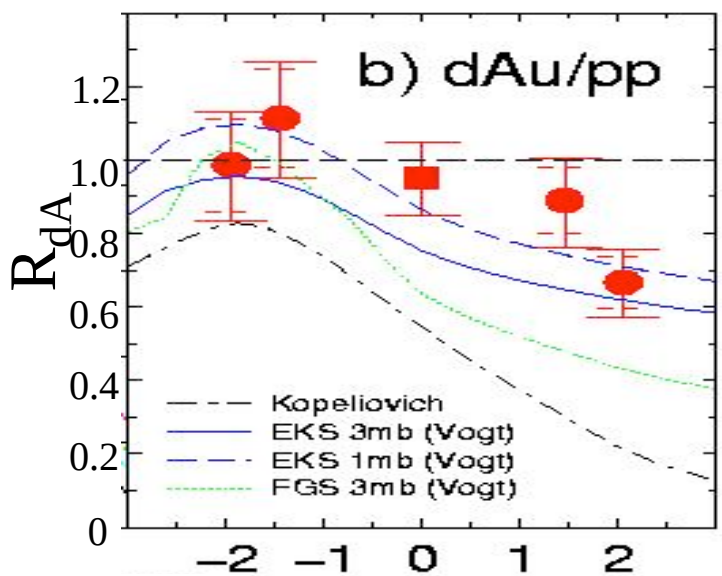
How about J/Psi?

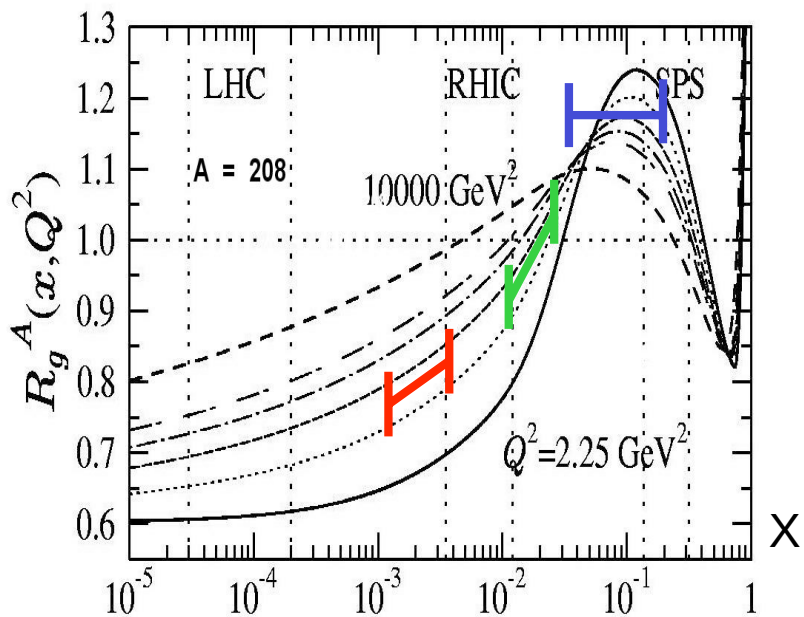
- _NO_ recombination!
- Gluon shadowing/saturation
- Initial state parton energy loss
- J/Psi final state nuclear absorption has minimal effects on the shape



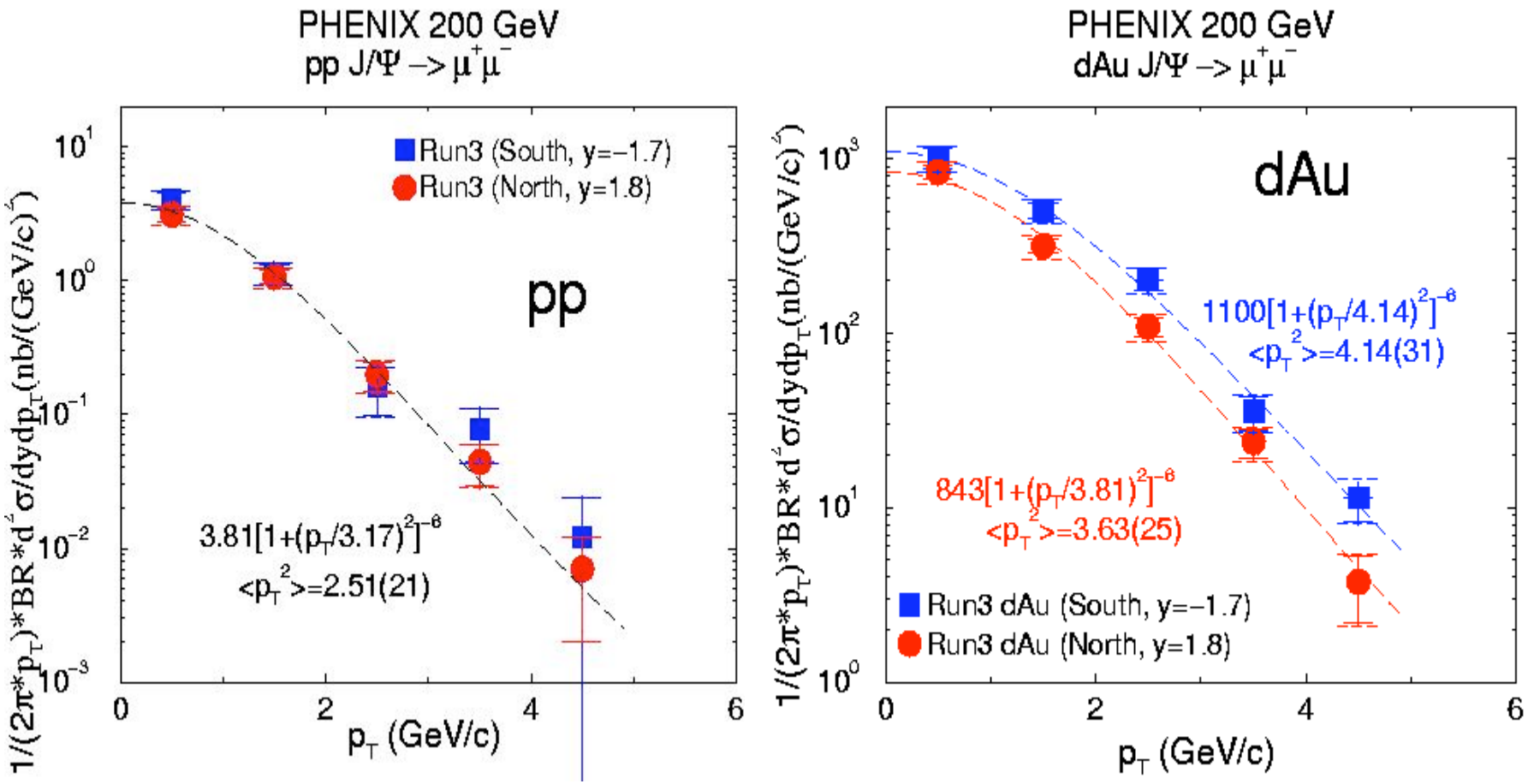


$$p \sim \gamma \cdot p_{lab} \sim 10^5 GeV$$





J/Psi p_T broadening in dAu collisions

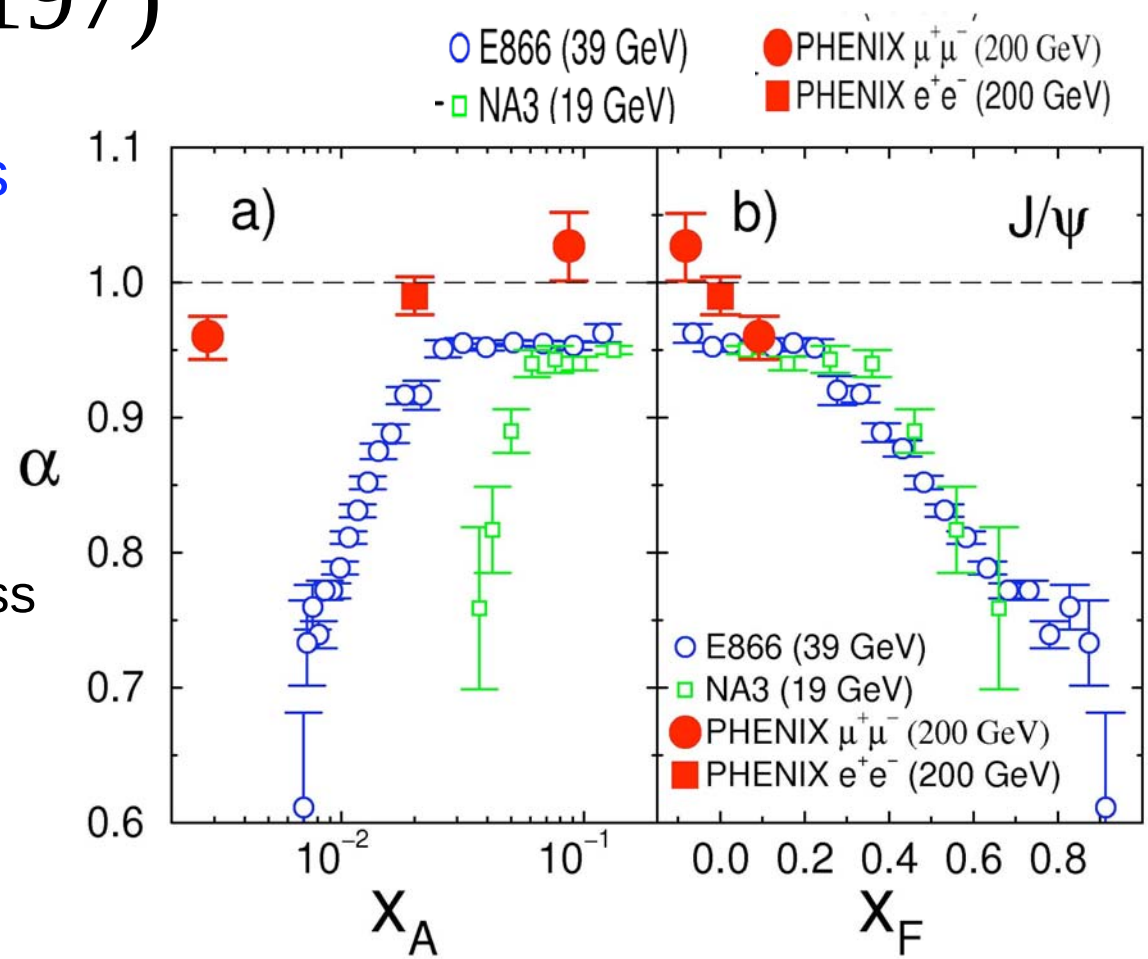


Broadening of J/ψ p_T distribution suggests initial scattering (maybe also energy loss) is important

Shadowing or Energy Loss ?

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

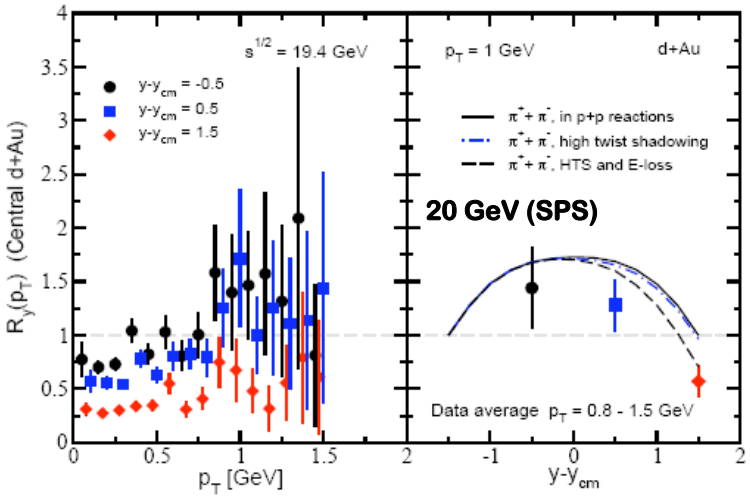
- Shadowing alone is not enough
- Initial state energy loss?
  - Incoming gluons loss a fraction of energy before the hard collisions
  - $X_1(\sim X_F)$ scaling



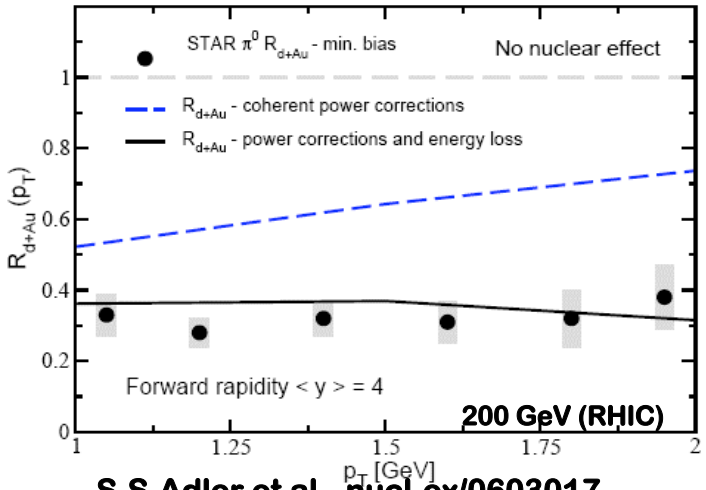
Cold Nuclear Matter Energy Loss

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)

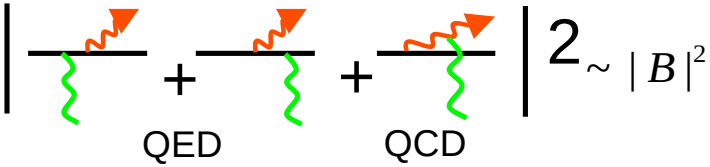
$$S_{LT} = S_{LT}(x, Q^2)$$

- 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



$$\left| \quad + \quad + \quad \right|^2 \sim |B|^2$$

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

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

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

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

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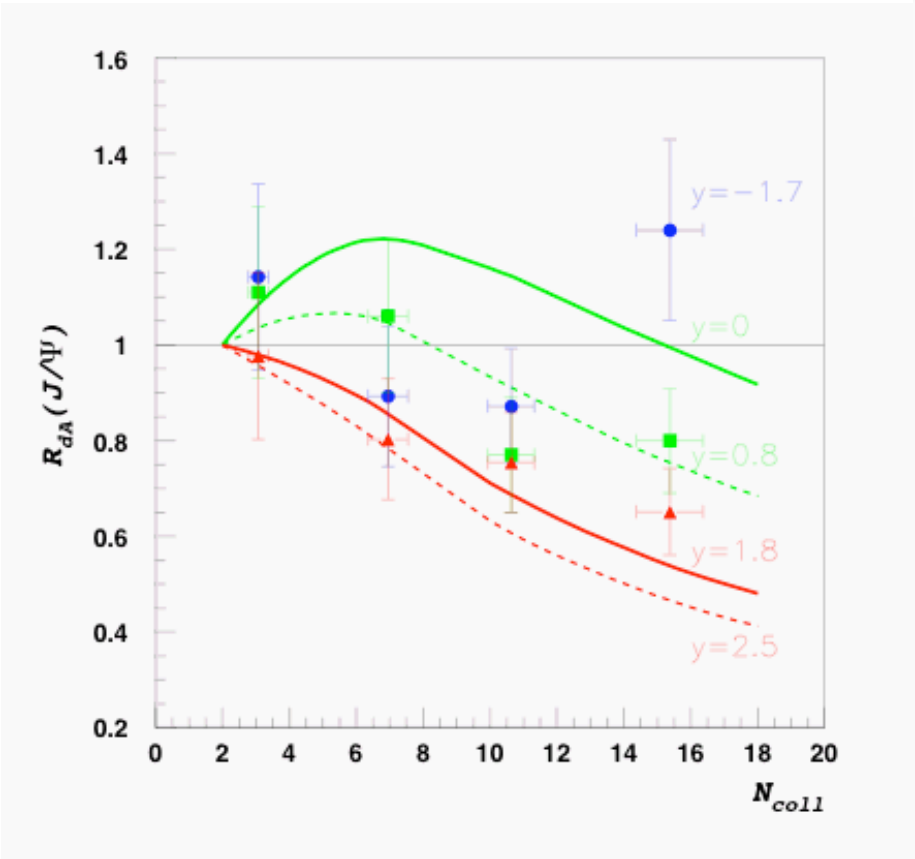
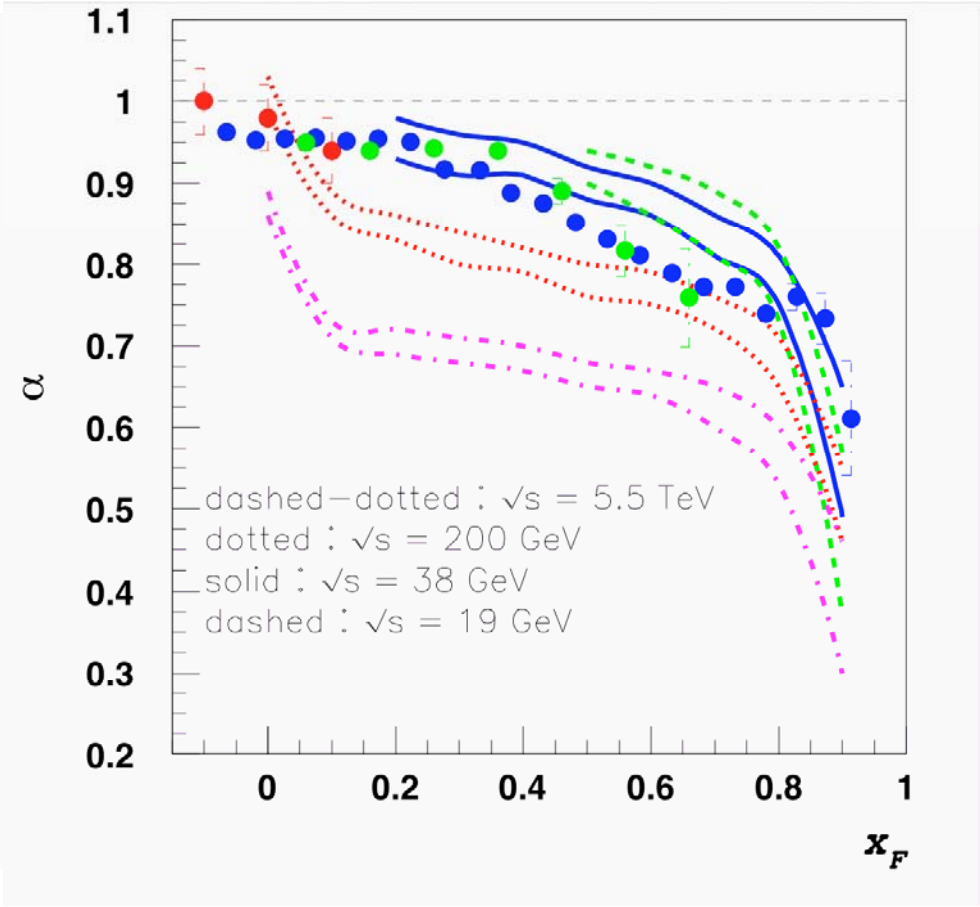
K. Tuchine

Signature of CGC ?

J/Psi in dAu @RHIC

Kharzeev & Tuchin hep-ph/0510358



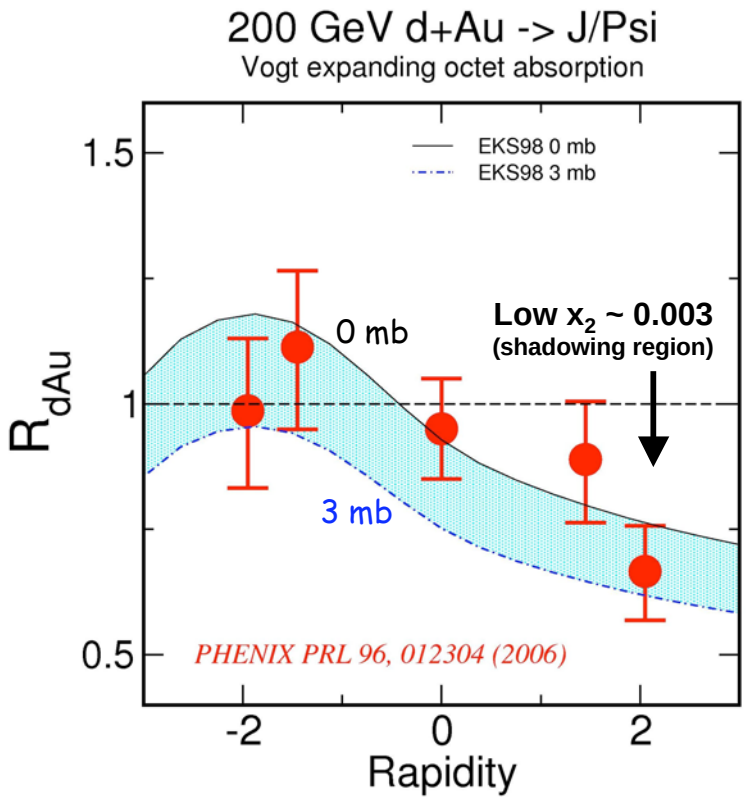


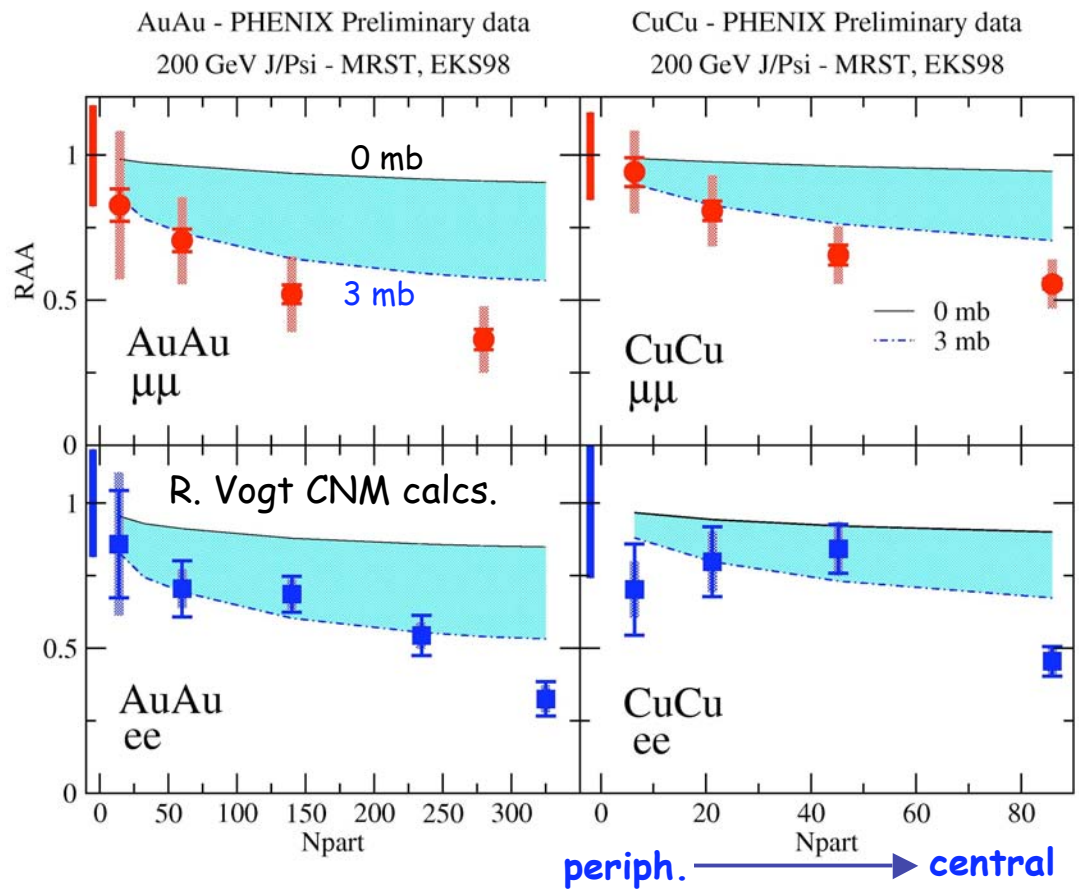
M. Liu Hard Probes 2006

Summary and Outlook

- Physics at Forward and Backward Rapidity:
  - open charm
  - J/psi
- Observed: heavy ~ ligh 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 -> (y, pT, sqrt(s)) experimentally
    - Parton energy loss vs shadowing
    - pT evolution – shadowing vs power correction
    - Shadowing vs recombination
  - Explore QCD dynamics in more details in coming years!

J/ψ Suppression (Cold or Hot)

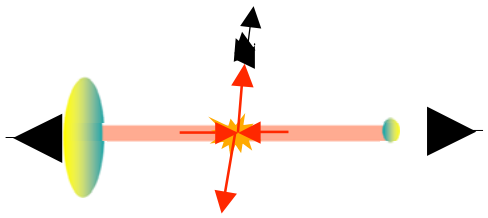


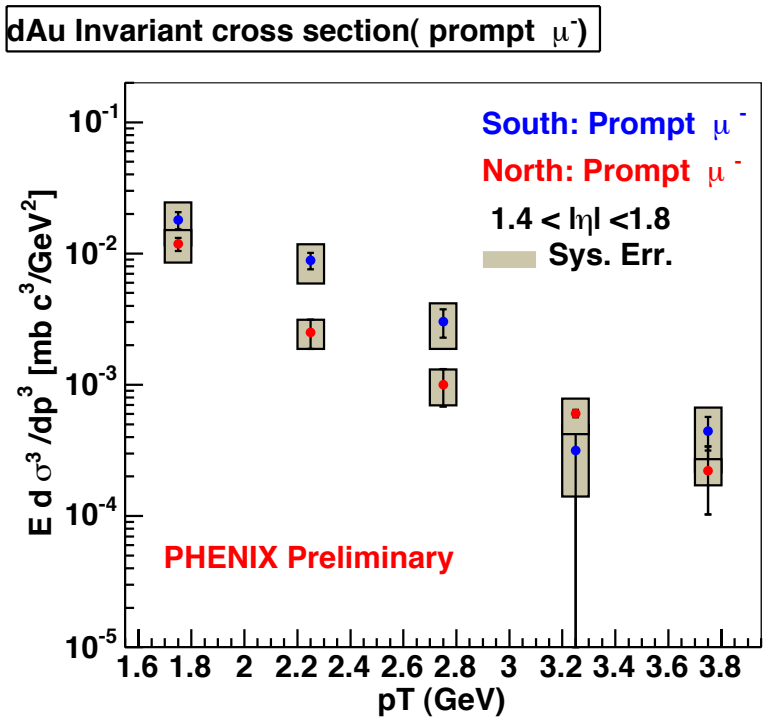


- Cold Nuclear Medium (CNM) calculations with shadowing & absorption
  - present dAu data probably only constrains absorption to: σ_{ABS} ~ 0-3 mb
- AA suppression is somewhat stronger than CNM calculations predict
  - but really need more precise dAu data!

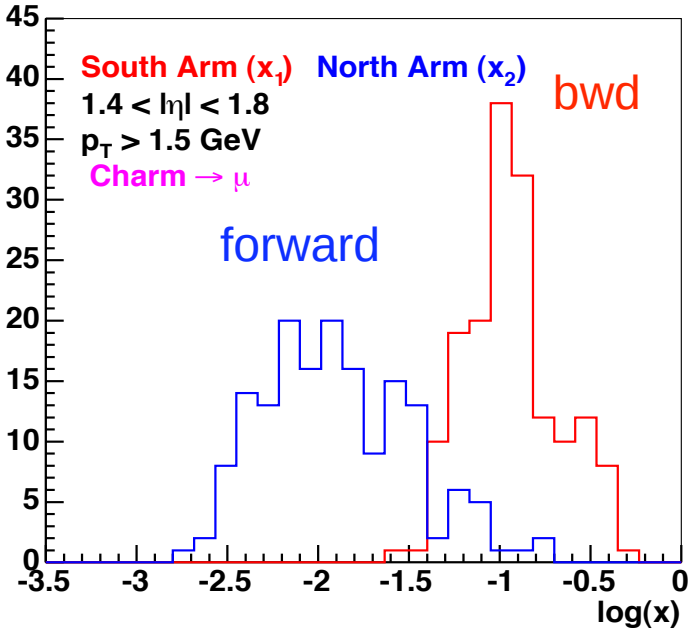
Prompt Muon Yields

- Forward and backward



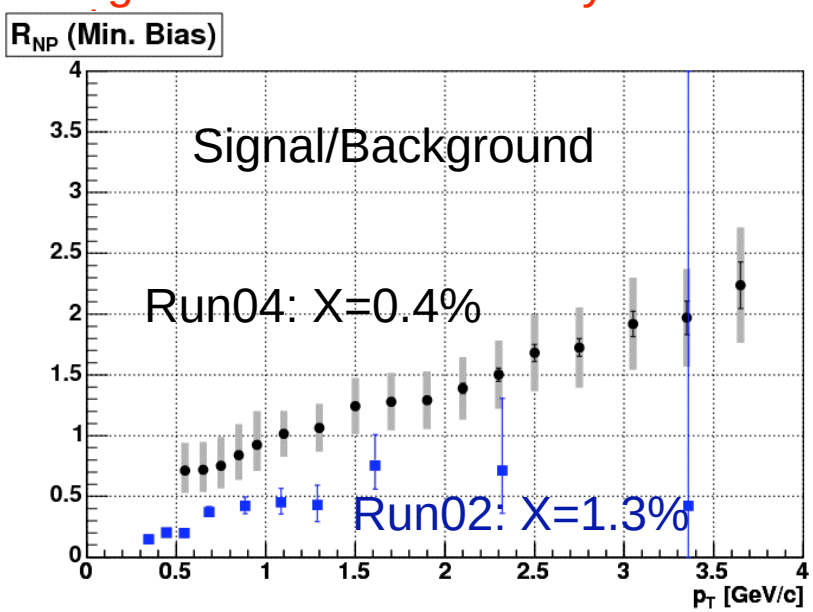


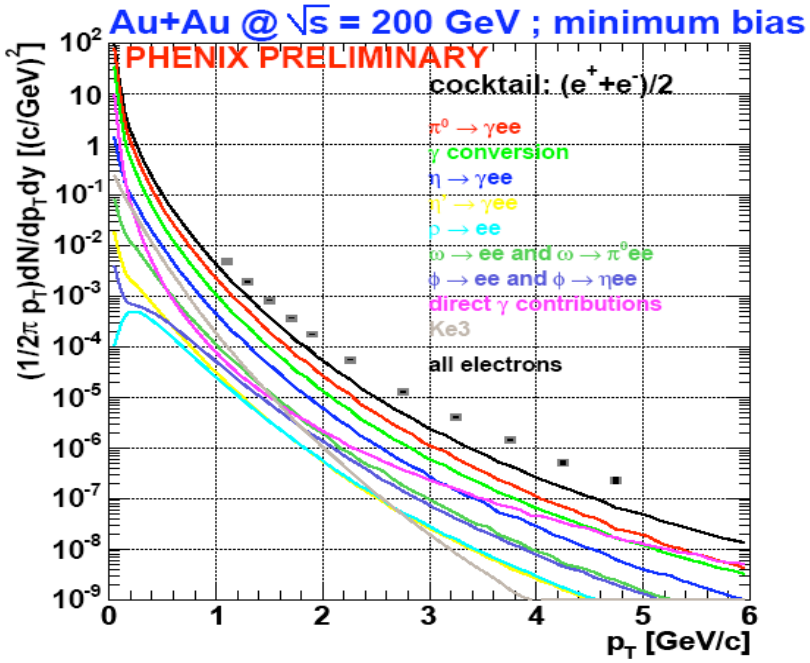
Probed X ranges in Au



Analysis Techniques: (non-photonic e)

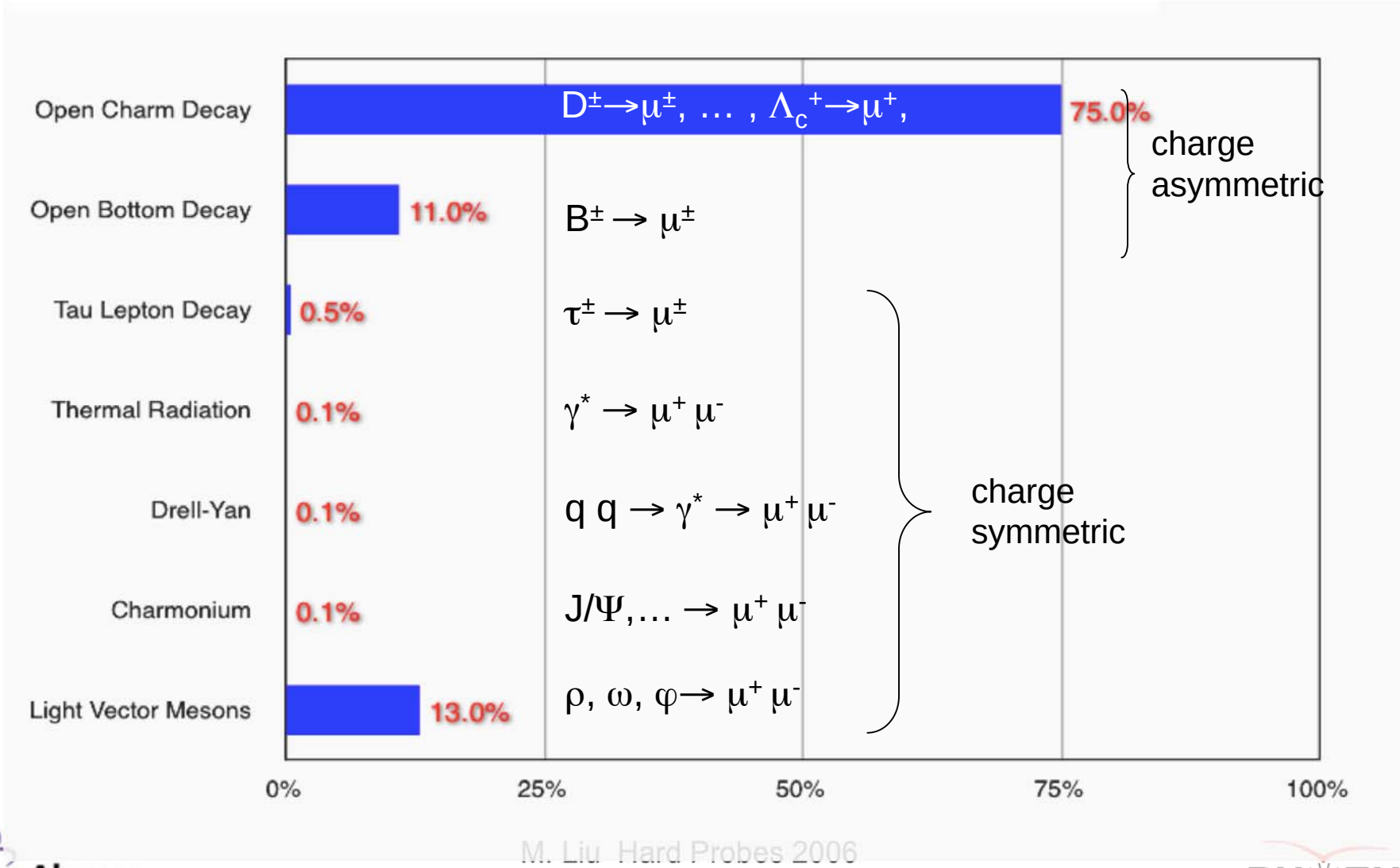
- Two complimentary analysis techniques for signal extraction
  - "Cocktail subtraction"
  - "Converter subtraction"
- Both analyses clearly show an excess "non-photonic" electron signal attributed to heavy flavor





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

Sources of prompt muons (p_T> 0.9GeV) (estimsted from Pythia)



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