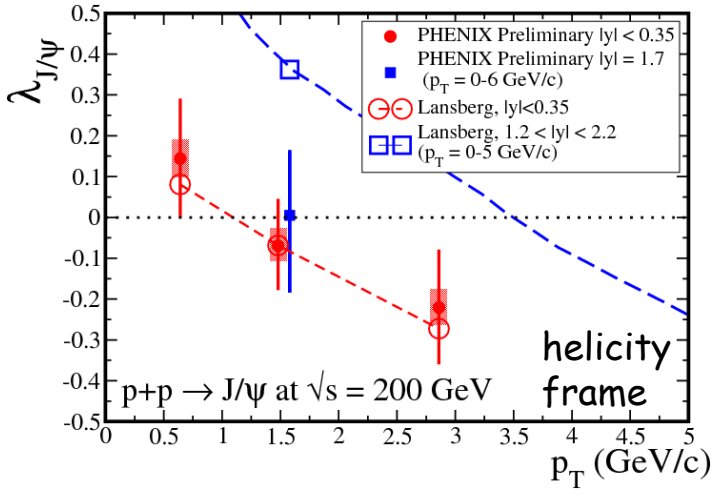
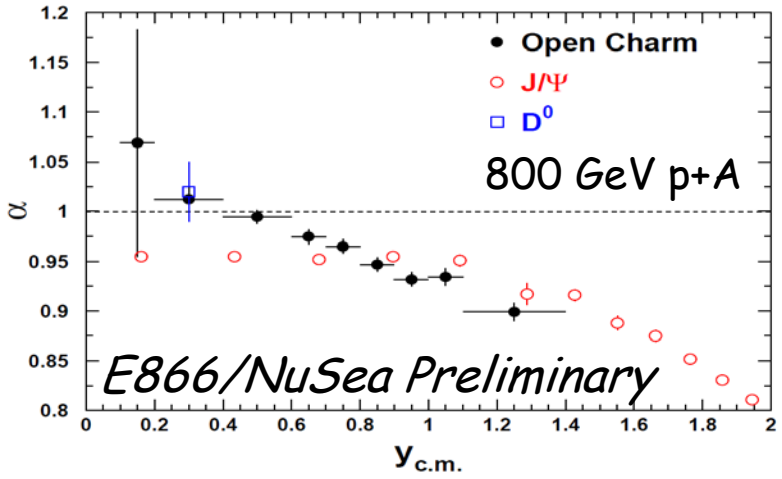
Charmonia Production in p(d)+A and A+A Collisions

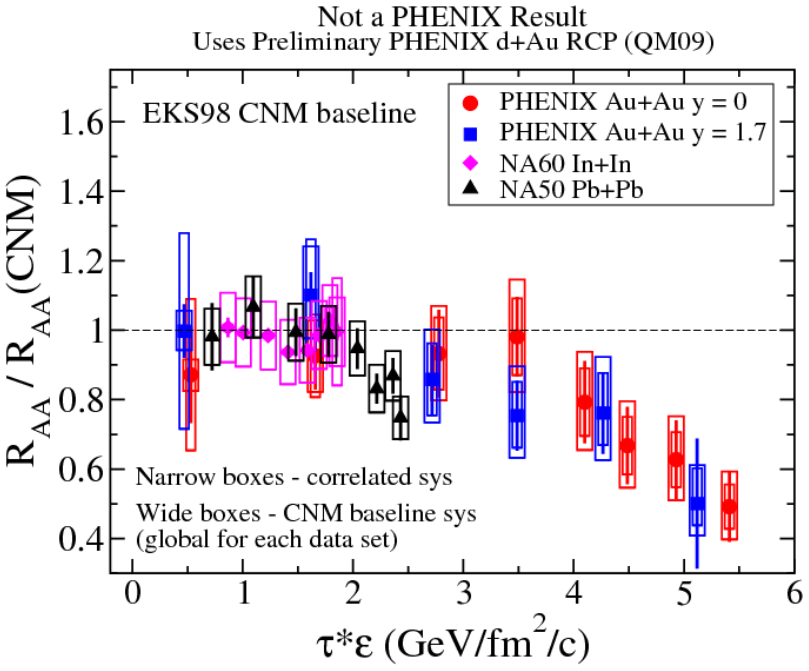
Mike Leitch – LANL– leitch@bnl.gov

INT, Seattle - 16-26 June 2009





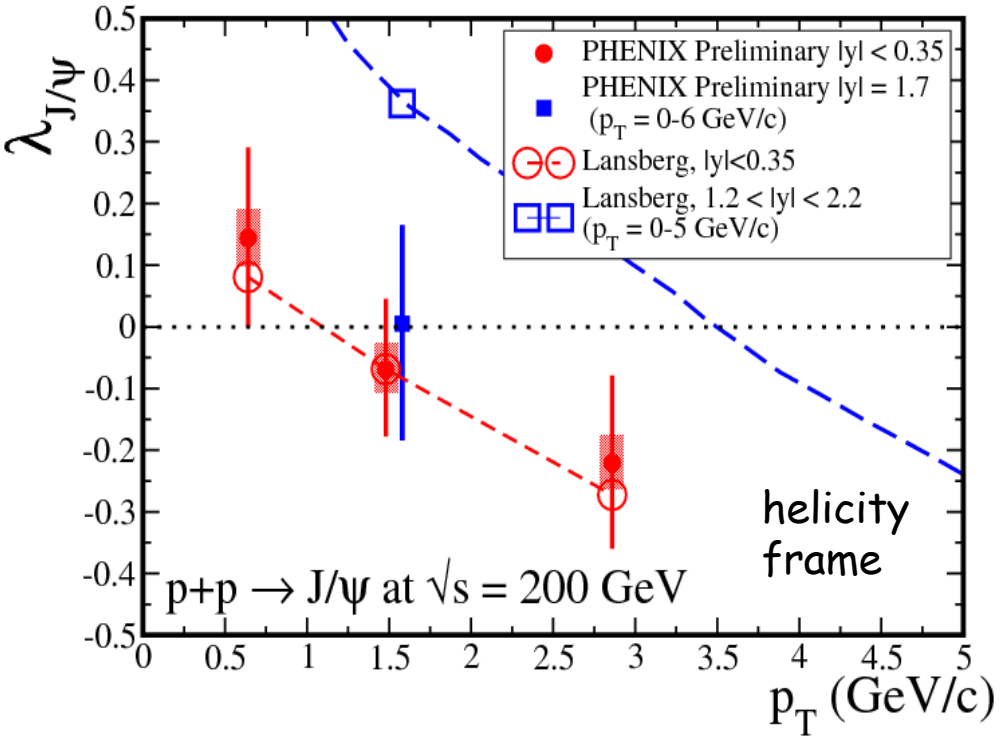
- p+p – one comment
- p+A and d+A
- CNM in A+A & PHENIX compared to SPS



Quarkonia Polarization
p+p Collisions
- One comment -

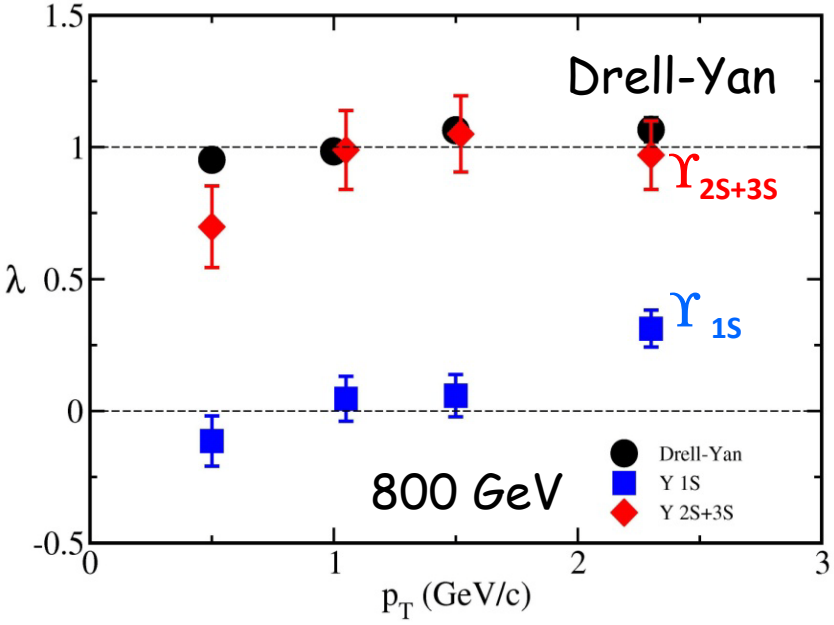
Quarkonia Production – Polarization

Haberzettl, Lansberg PRL 100, 032006 (2008)



(does not include effect of feeddown from χ_c & ψ')

E866/NuSea – PRL 86, 2529 (2001)



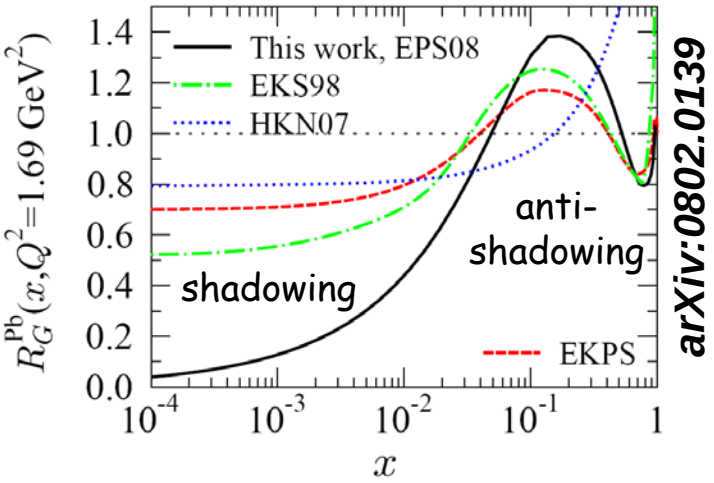
Υ maximally polarized for (2S+3S), but NOT for (1S)

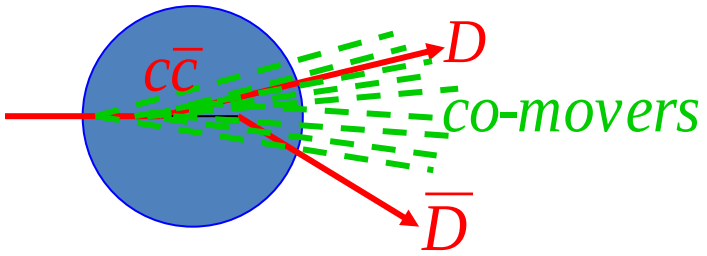
* Is feed-down washing out polarization? (~40% of 1S from feed-down)

CNM effects on Quarkonia
p+A (FNAL) and d+A (RHIC)

What CNM effects are important? (CNM = Cold Nuclear Matter)

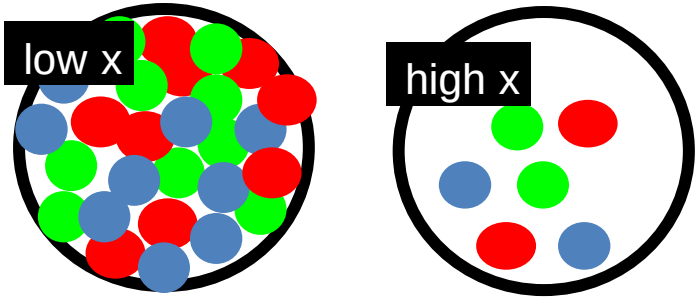
Traditional shadowing from fits to DIS or from coherence models



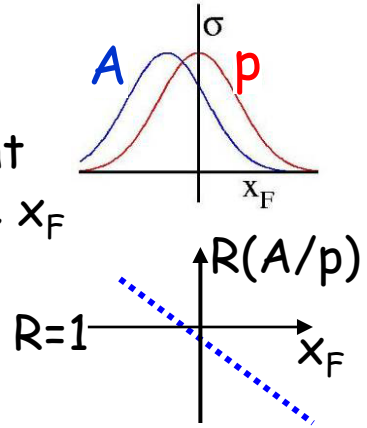


Absorption (or dissociation) of $c\bar{c}$ into two D mesons by nucleus or co-movers

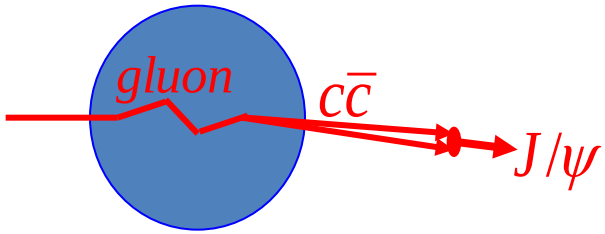
Gluon saturation from non-linear gluon interactions for the high density at small x; amplified in a nucleus.



Energy loss of incident gluon shifts effective x_F and produces nuclear suppression which increases with x_F



Transverse Momentum Broadening
Another Cold Nuclear Matter Effect

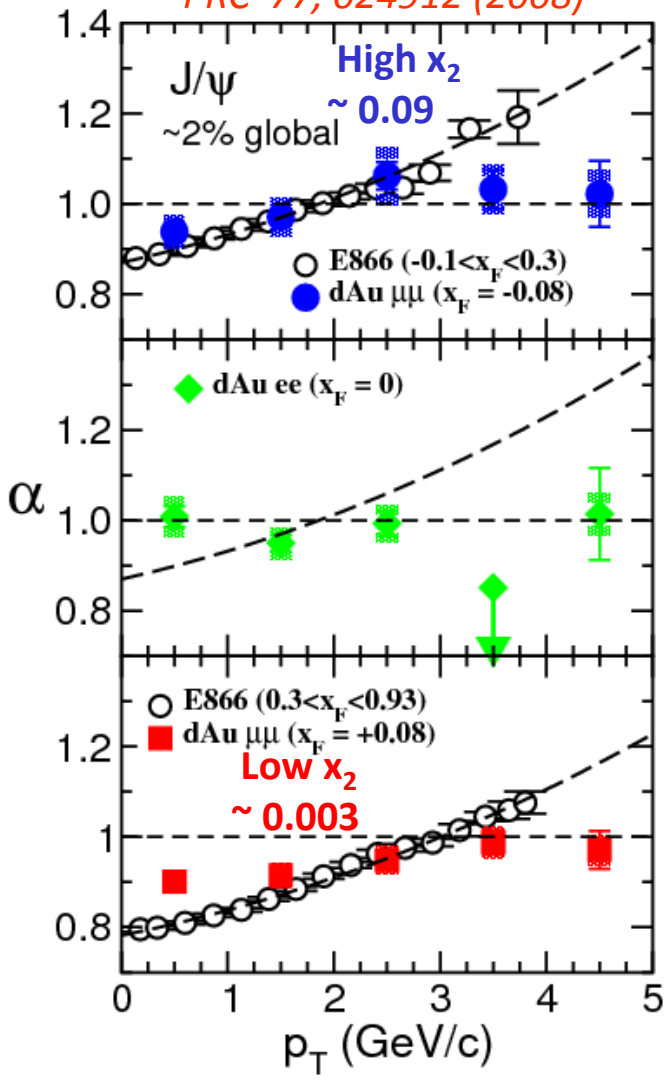


Initial-state gluon multiple scattering causes p_T broadening (or Cronin effect)

$$\sigma_A = \sigma_N A^{\alpha}$$

PHENIX 200 GeV dAu shows some p_T broadening, but may be flatter than at lower energy ($\sqrt{s}$=39 GeV in E866/NuSea)

PRC 77, 024912 (2008)

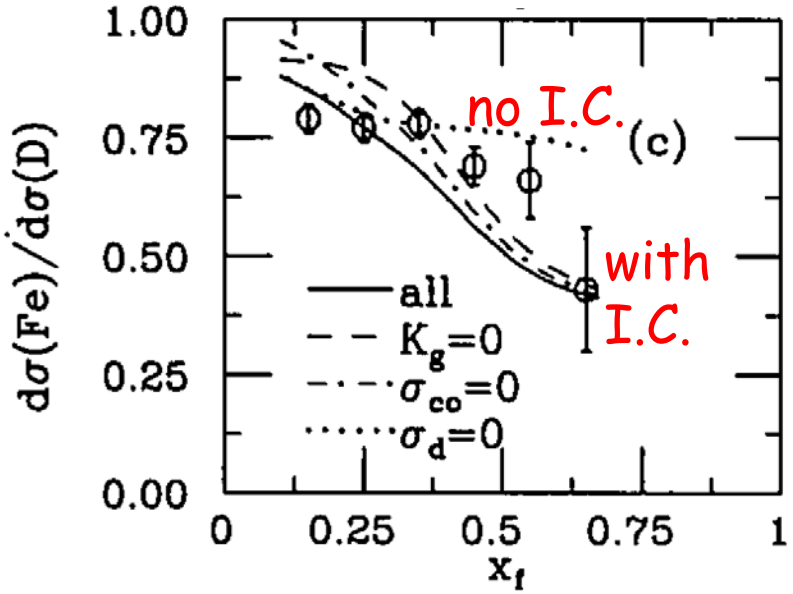


Intrinsic charm contribution to Quarkonia

At large x_F (≥ 0.5) intrinsic $c\bar{c}$ components of the projectile proton can dominate the production of charm pairs

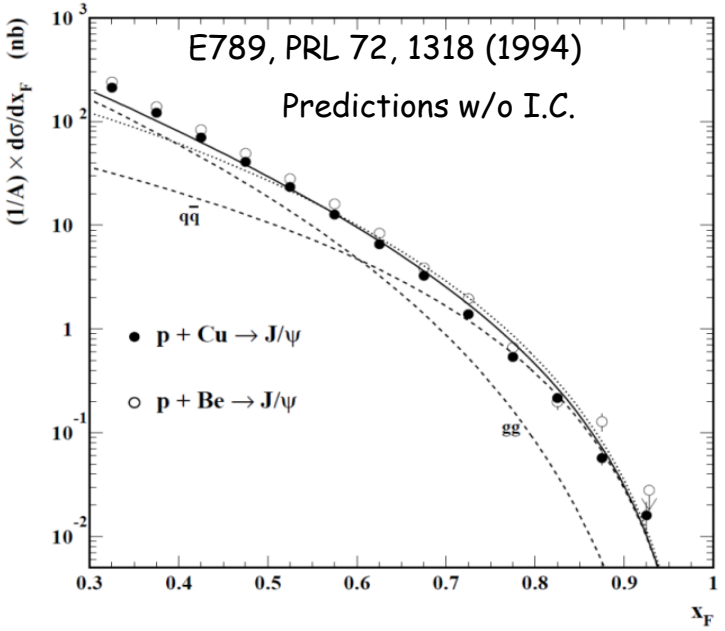
- $A^{2/3}$ dependence via surface stripping of light quarks to free charm pair component

Vogt, Brodsky, Hoyer, NP B360, 67 (1991)
(also includes absorption and shadowing)



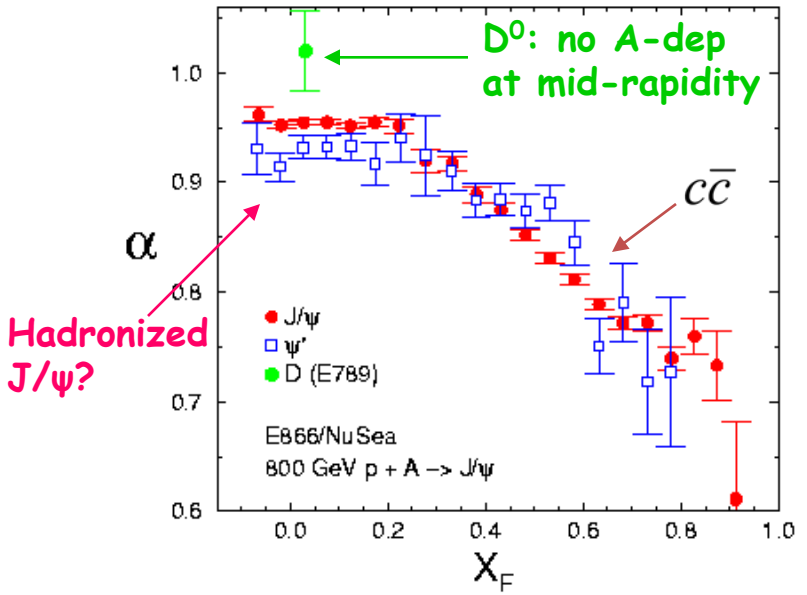
But E789 set limit on I.C. contribution via shape of cross section vs x_F

- $< 2.3 \times 10^{-3}$ nb/nucleon (1.8 nb/nucleon predicted)

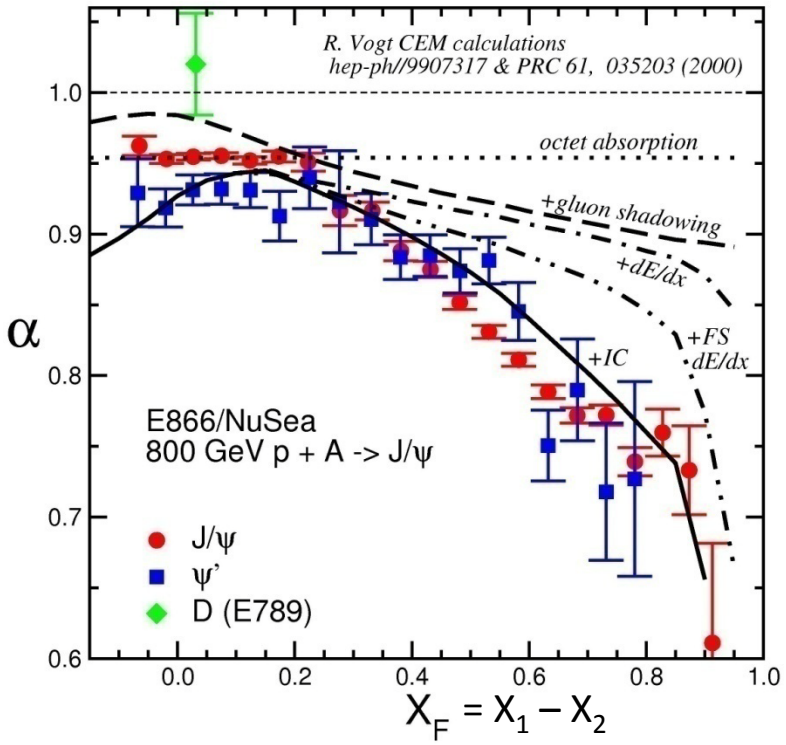


J/ψ suppression in p+A fixed-target

800 GeV p+A (FNAL)
PRL 84, 3256 (2000); PRL 72, 2542 (1994)



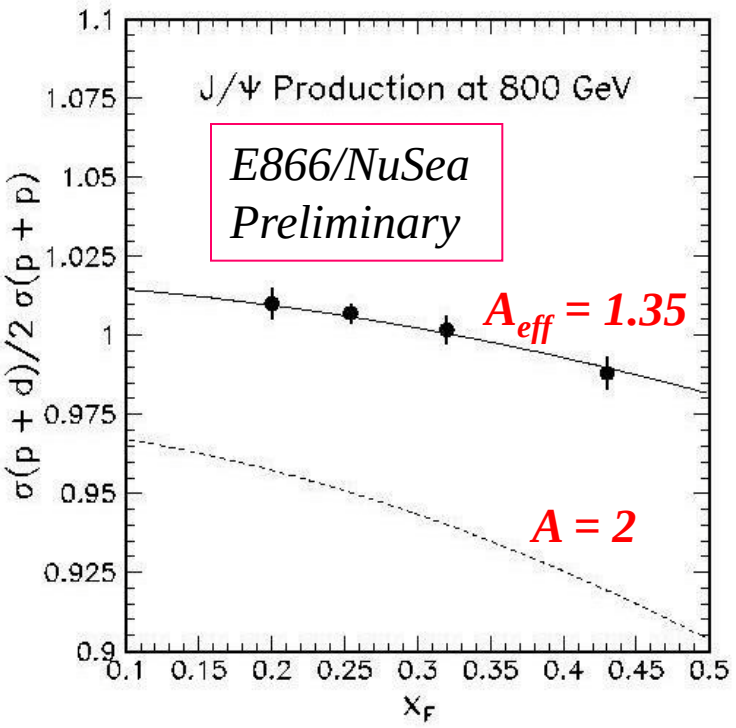
E866/NuSea, $\sigma = \sigma_N * A^{\alpha}$

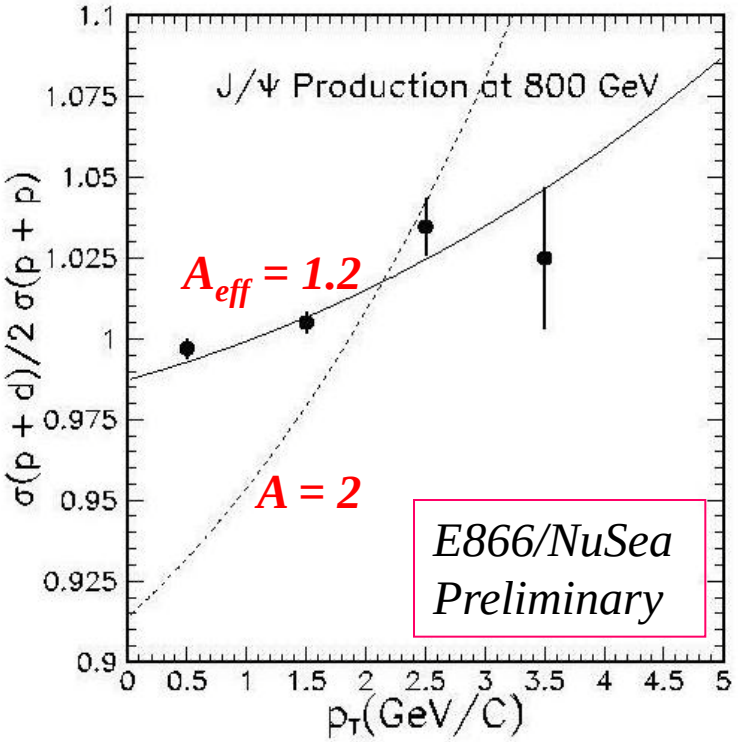


- J/Ψ and Ψ' similar at large x_F where they both correspond to a $c\bar{c}$ traversing the nucleus
- Near x_F = 0 -- D^0 not suppressed, J/Ψ and Ψ' suppressed due to absorption, Ψ ' slightly stronger since both starting to become hadronized states in nucleus
- what about open charm at higher x_F?

Many ingredients to explain the J/ψ nuclear dependence – R. Vogt (2000)

(Small) J/ψ Nuclear Dependence Even for Deuterium/Hydrogen!





Nuclear dependence in deuterium seems to follow the systematics of larger nuclei, but with $A_{eff,}$ smaller than two.

From fits to E866/NuSea
p + Be, Fe, W data: $\sigma_{pA} \sim \sigma_{pp} A^{\alpha}$

$$\alpha(x_F) \propto 1 - 0.052 x_F - 0.034 x_F^2$$
$$\alpha(p_T) \propto 0.06 p_T + 0.011 p_T^2$$

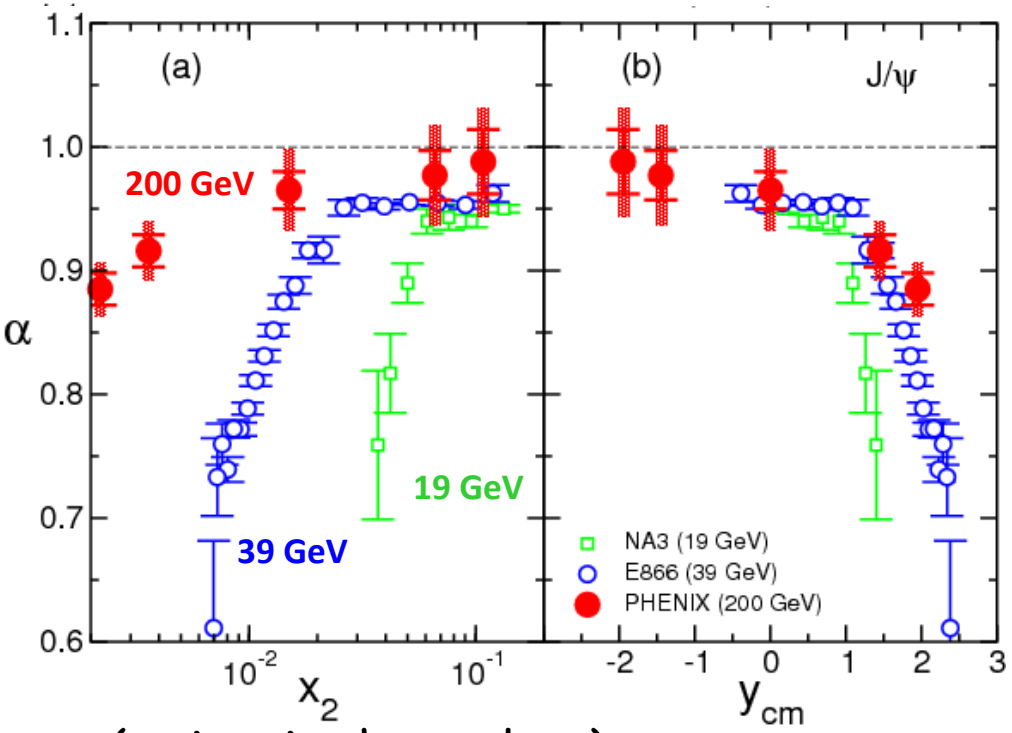
CNM Physics – PHENIX, E866, NA3 Comparison

New Analysis of Run3 d+Au with new 2005 p+p baseline
PRC 77,024912(2008)

Compared to E866/NuSea p+A results & lower-energy NA3 at CERN

$$\sigma_A = \sigma_N A^{\alpha}$$

J/ψ α for different √s collisions



(x_2 is x in the nucleus)

Suppression not universal vs x_2 as expected for shadowing, but closer to scaling with x_F, why?

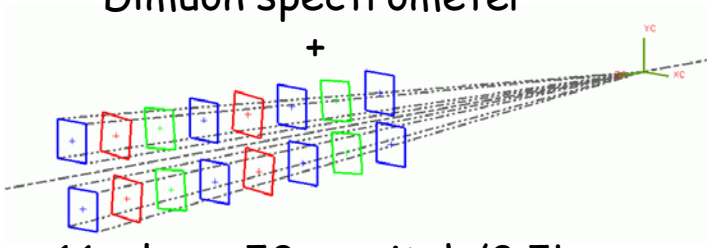
- initial-state gluon energy loss?
- gluon saturation?

Scaling of E886 vs PHENIX better vs y_{cm}

Fermilab E789: D^0 & $B \rightarrow J/\psi\ X$ (charm & beauty using silicon)

Dimuon spectrometer

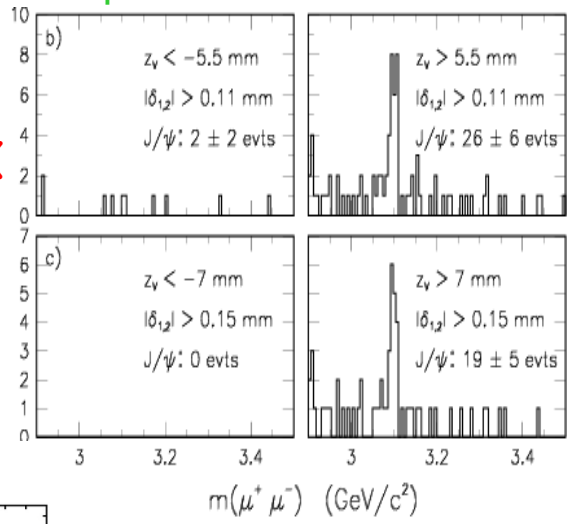
+

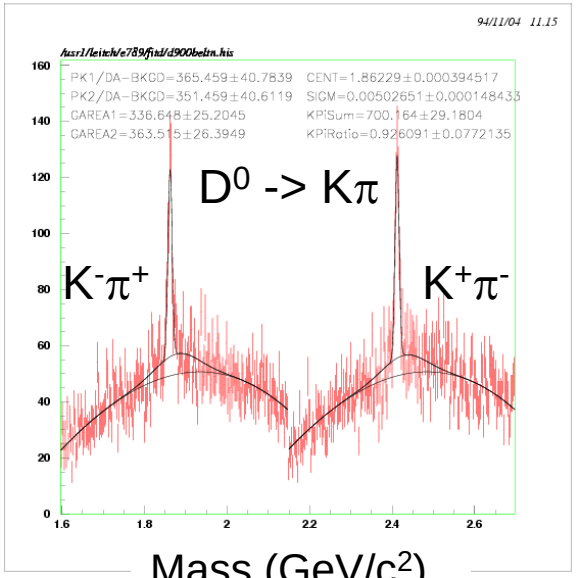


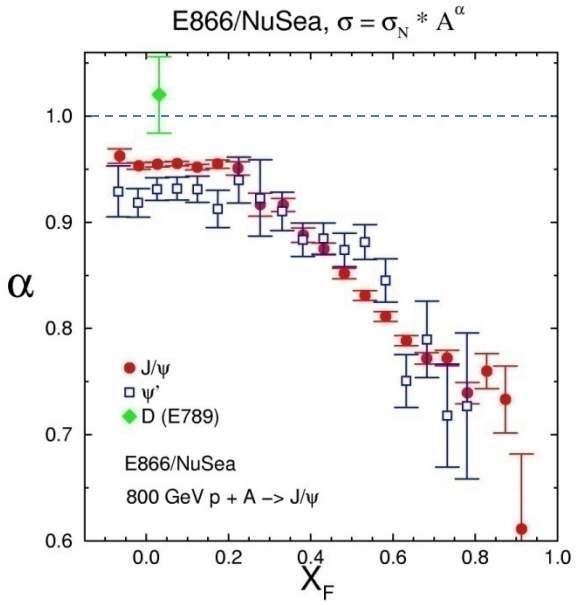
16-plane, 50μm pitch/8.5k strip silicon vertex detector

upstream downstream

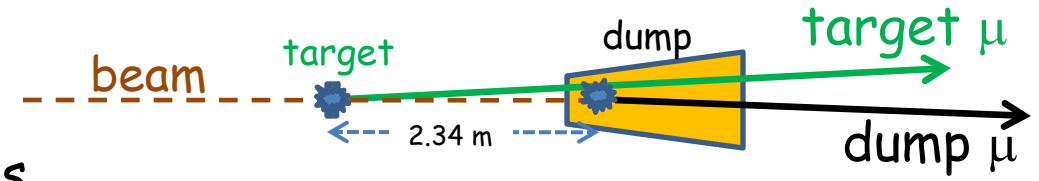
$B \rightarrow J/\psi + X$



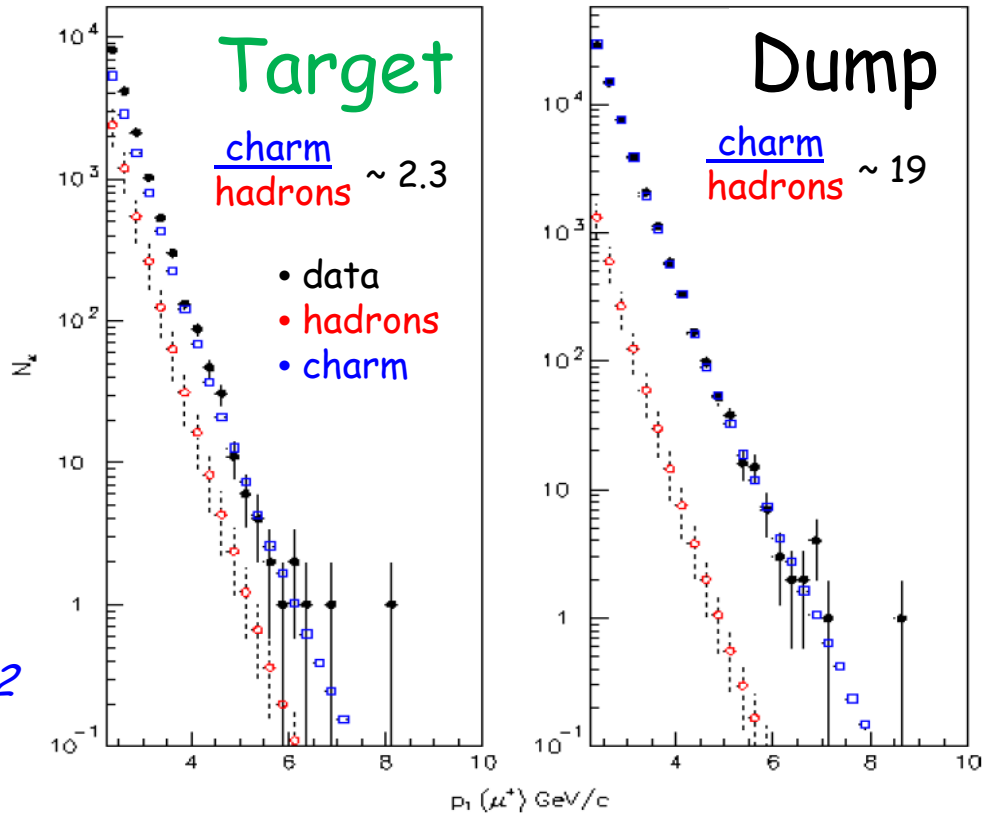




E866/NuSea Open Charm Measurement



- hadronic cocktail explains ~30% of target & <5% of dump μ's
  - as expected since dump absorbs light hadrons before they can decay
- charm decays consistent between Cu target and Cu dump
- use same method for Be to get nuclear dependence



E866/NuSea 800 GeV p+A

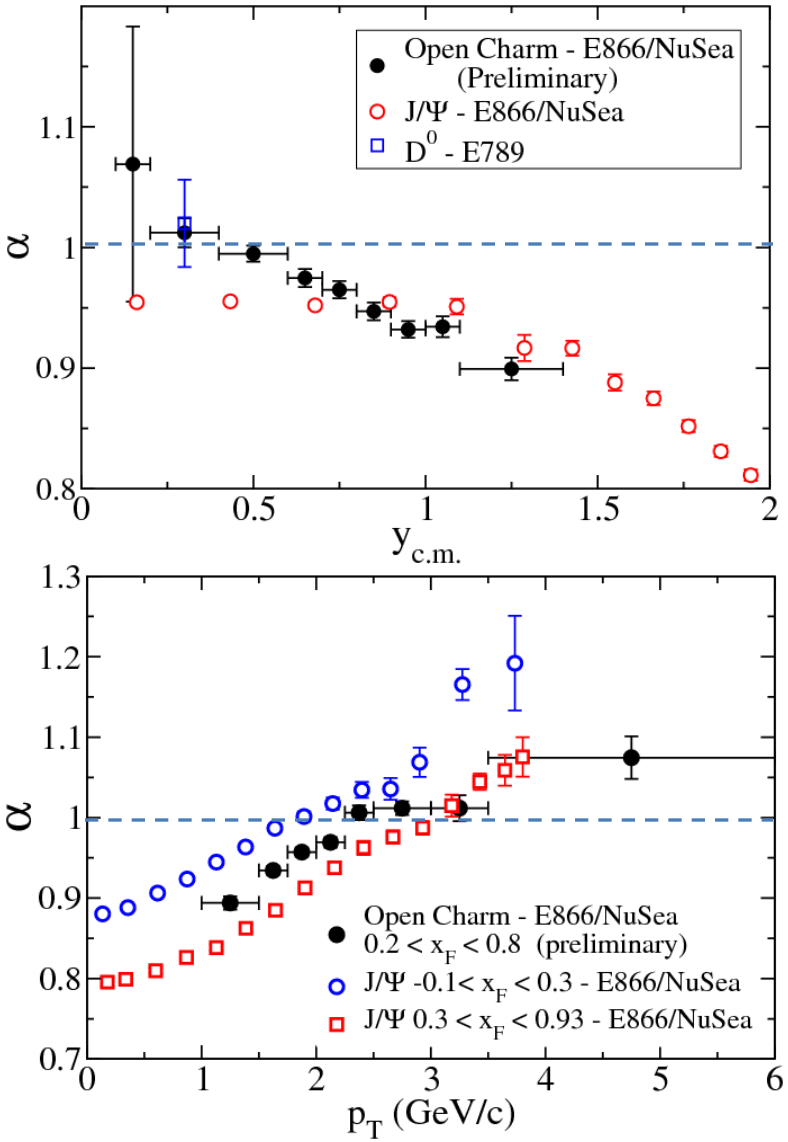
- *S. Klinksiek thesis - hep-ex_0609002*
- *paper in preparation*

Comparing Open & Closed charm Nuclear Dependences

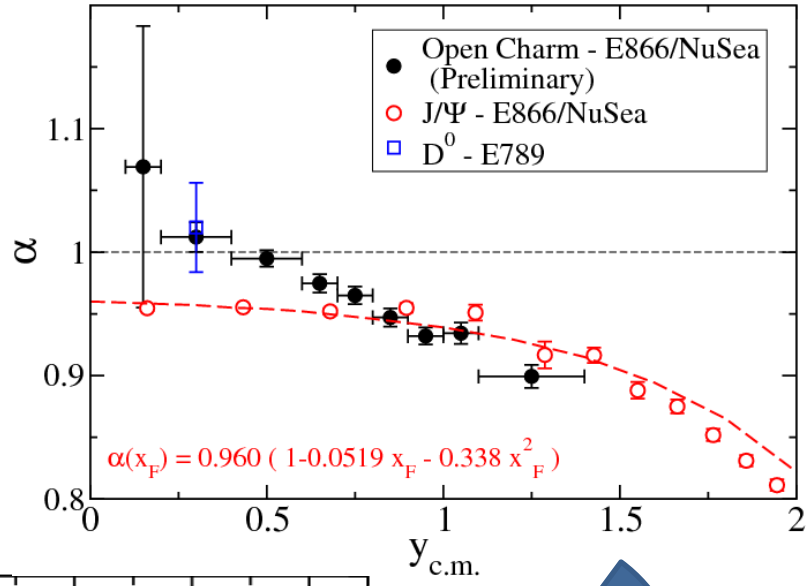
Open-charm p+A nuclear dependence (single-μ $p_T > 1$ GeV/c) – very similar to that of J/Ψ

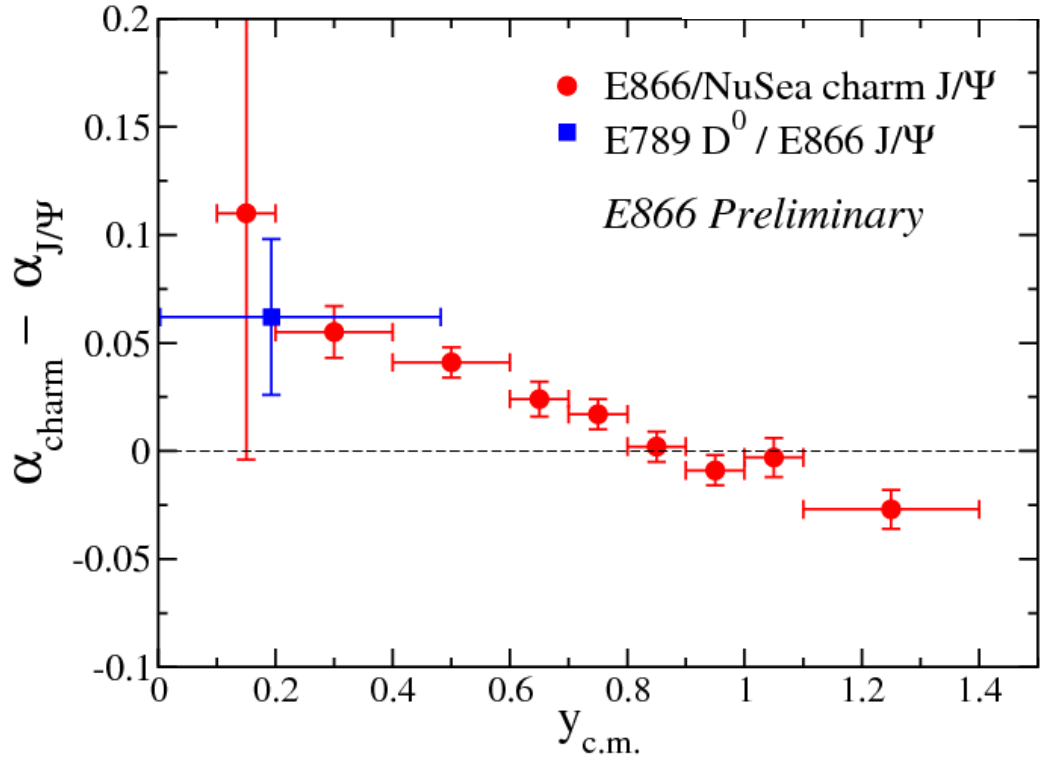
- dominant effects are in the initial state
  - e.g. shadowing, dE/dx, Cronin
- weaker open-charm suppression at y=0 attributed to lack of absorption for open charm

E866/NuSea 800 GeV p+A



Difference in Suppression (alpha) between Open & Closed charm



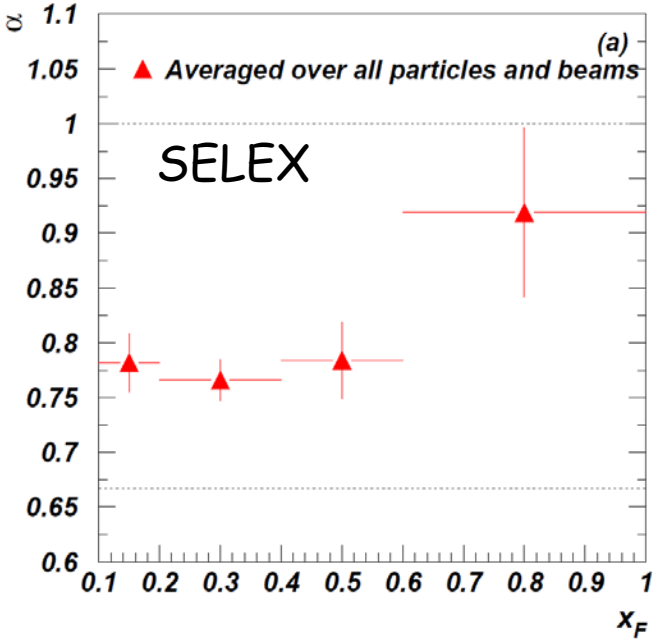


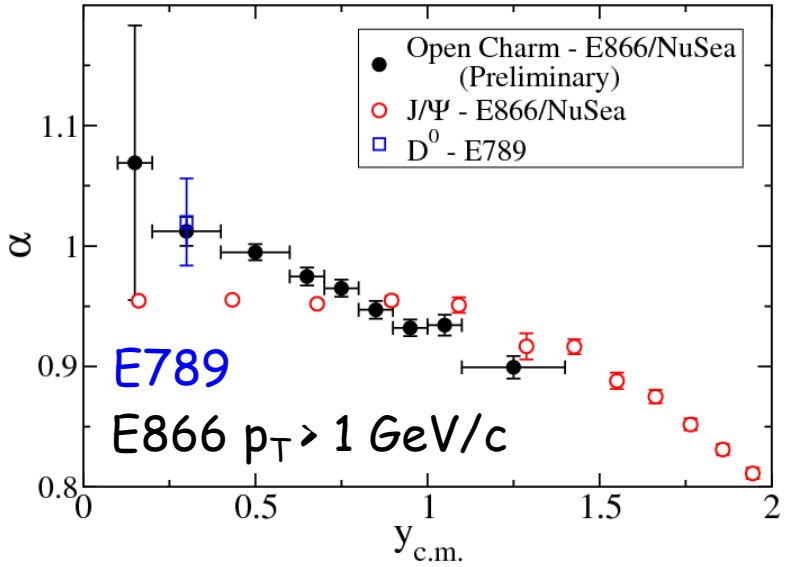
SELEX – hep-ex_0902.0355??

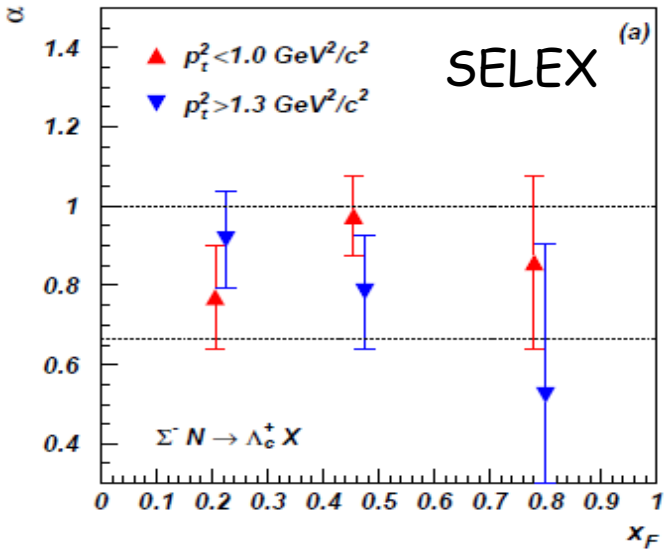
SELEX – a zoo of beams & charm particles:

• $(\pi^{\pm}, p, \Sigma^{-}) + A \rightarrow (D^0, D^*, D^{\pm}, D_s, \Lambda_c)$

Appears to be inconsistent with both E789 D^0 & E866/NuSea open charm single muon msmts





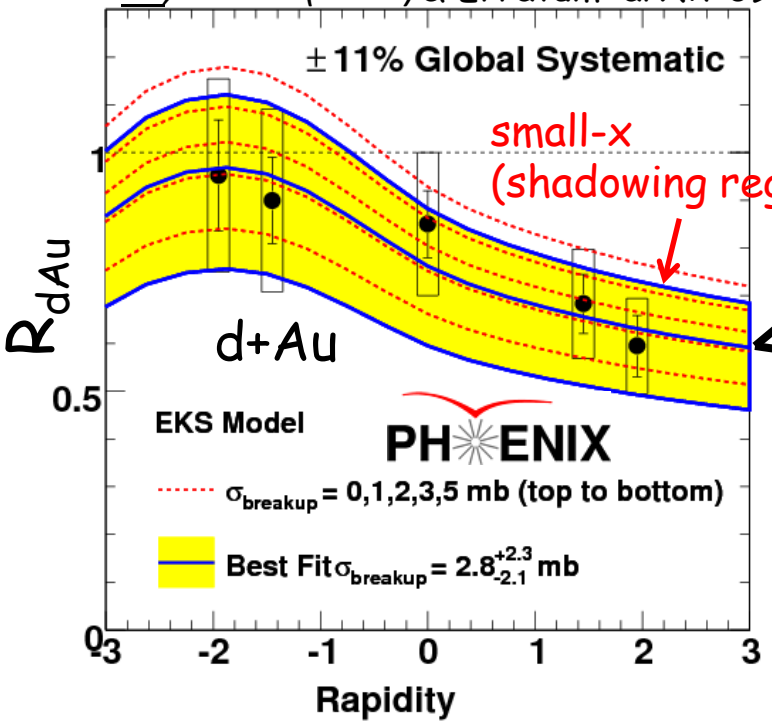


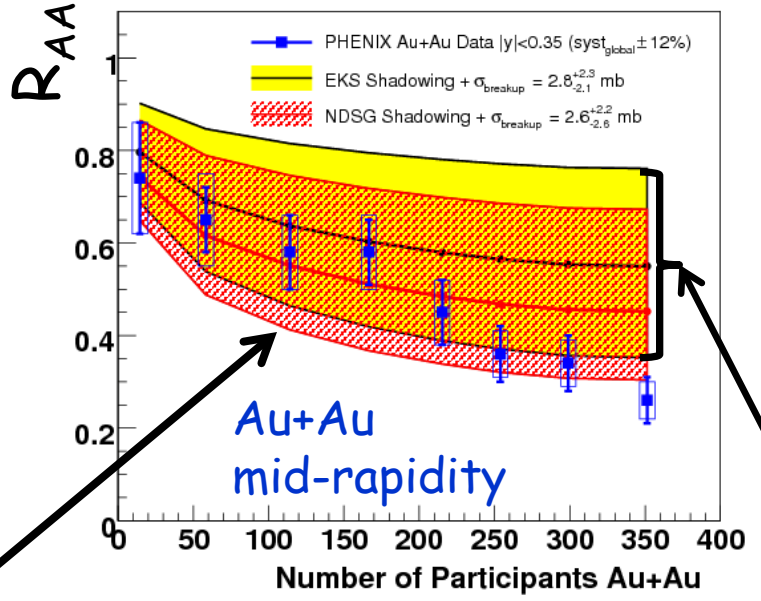
Hint of more similar result for $p_T^2 > 1.3$ GeV/c in one SELEX channel?

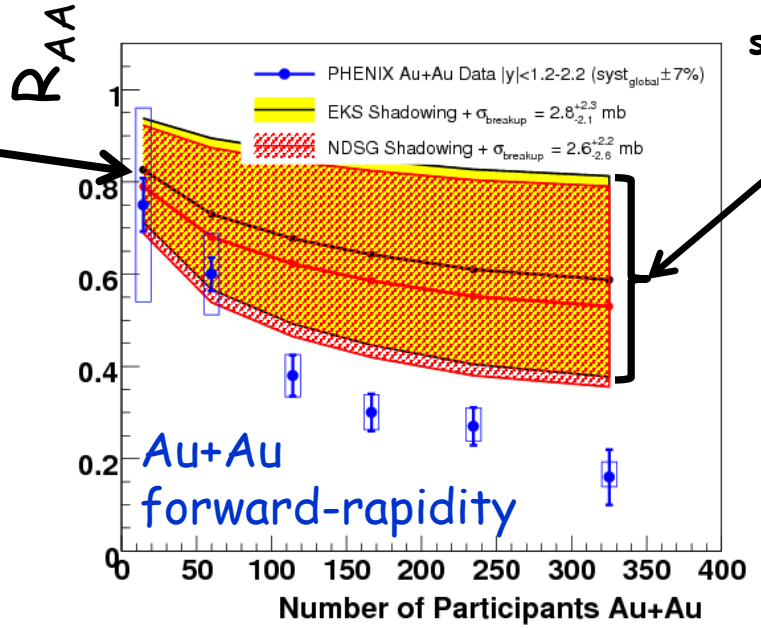
Present CNM Constraints on A+A data

CNM effects (EKS shadowing + dissociation from fits to d+Au data, with R. Vogt calculations) give large fraction of observed Au+Au suppression, especially at mid-rapidity

PRC 77,024912(2008) & Erratum: arXiv:0903.4845







EKS shadowing band

more accurate d+Au constraint from new 2008 data

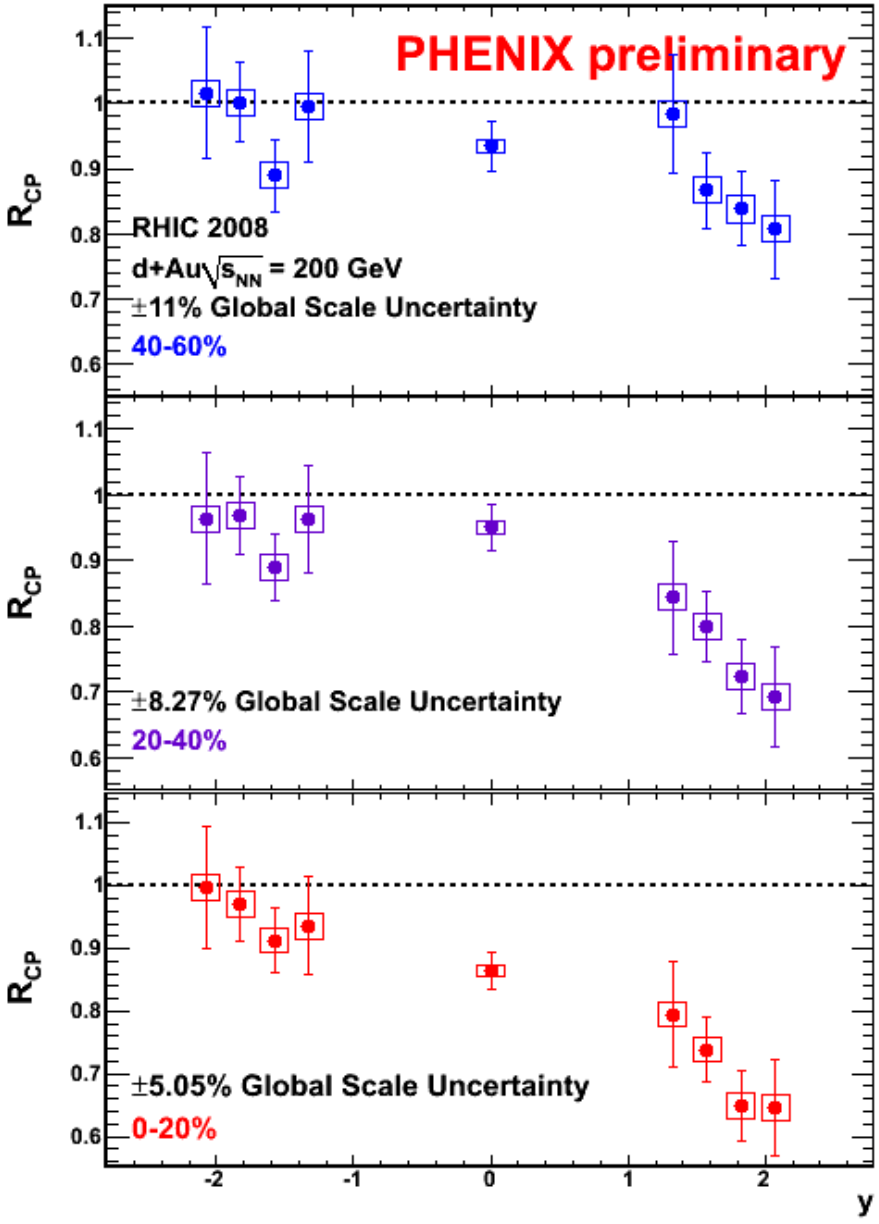
Quarkonia Production & Suppression – J/Ψ in d+Au

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

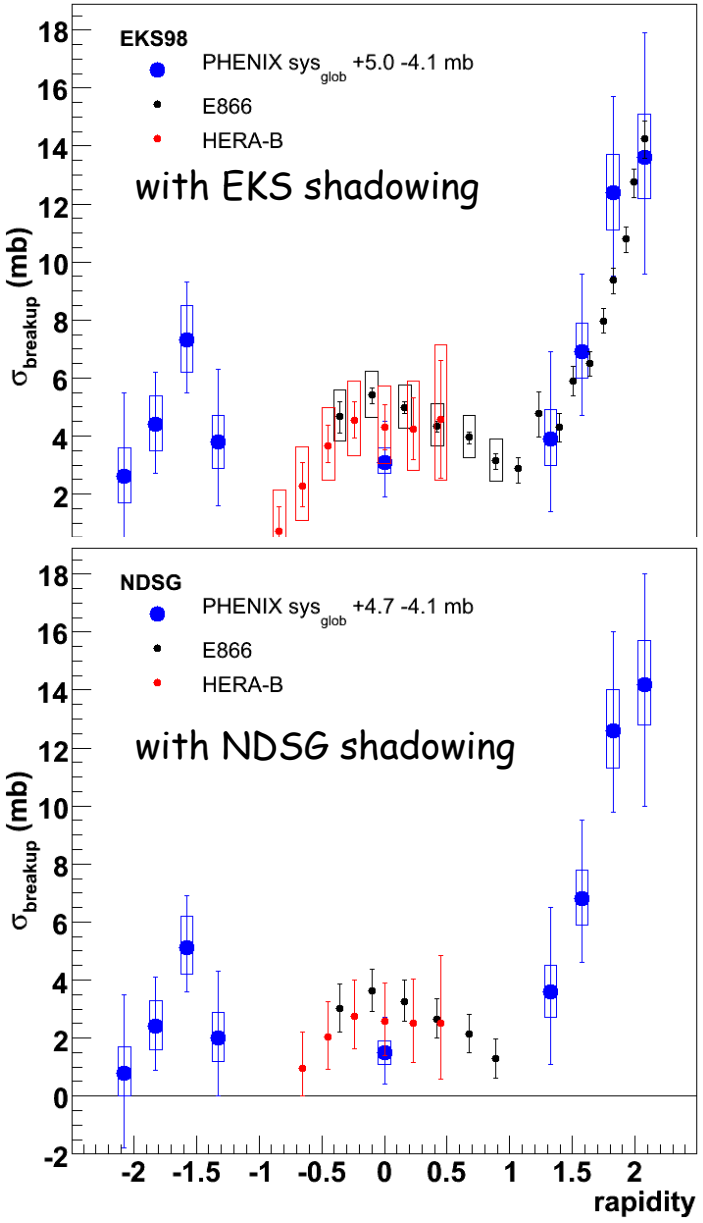


New CNM fits using 2008 PHENIX d+Au Rcp (Tony Frawley, Ramona Vogt, …)

- similar to before, use models with shadowing & absorption/breakup
- but allow effective breakup cross section to vary with rapidity
  - to obtain good description of data for projections to A+A

- get "$\sigma_{breakup}(y)$"; compare to E866/NuSea & HERA-B
- Lourenco, Vogt, Woehri - arXiv:0901.3054

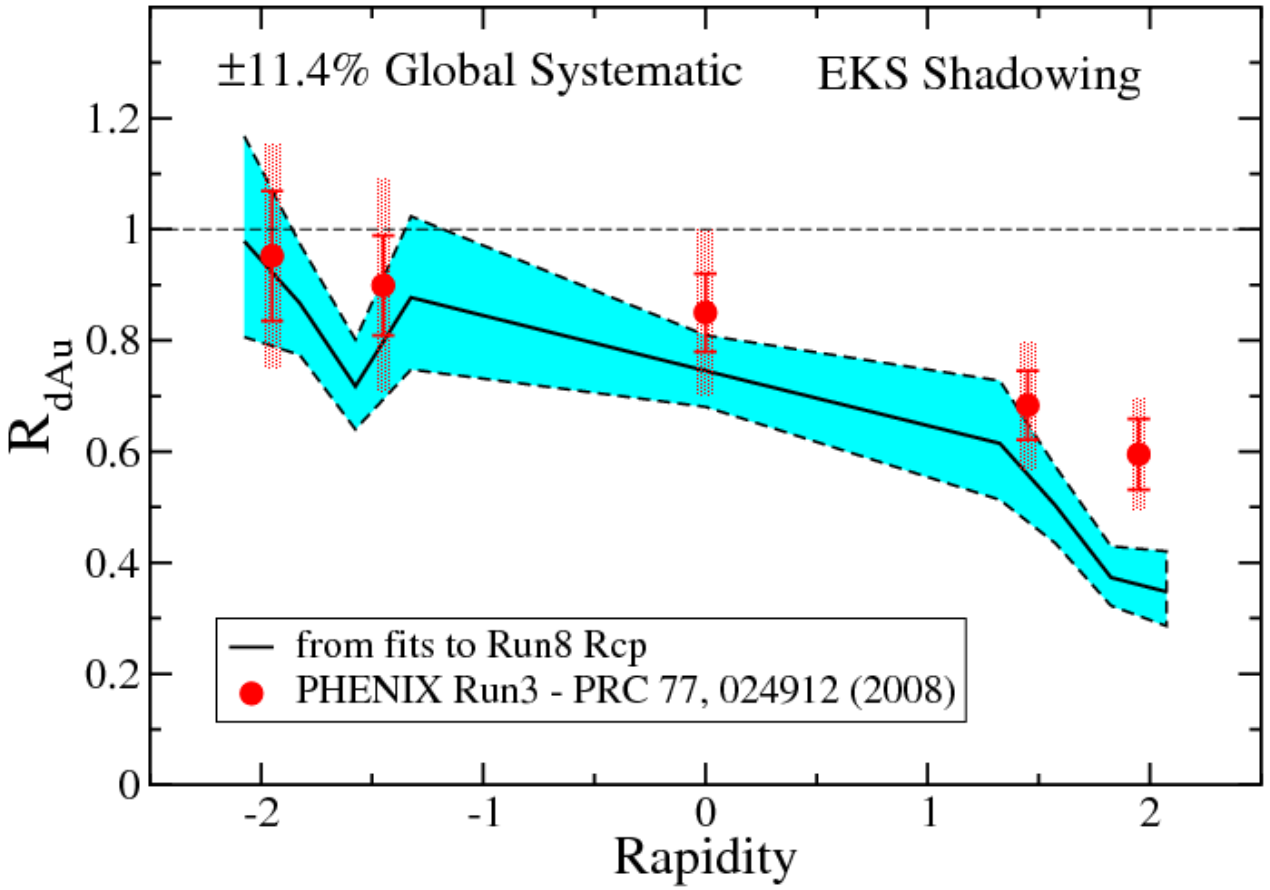
- common trend: large increasing effective breakup cross section at large positive rapidity
- need additional physics in CNM model – e.g. initial-state dE/dx



Comparision of New Effective Breakup Cross Section fits to published 2003 d+Au R_{dAu} Results (cross check)

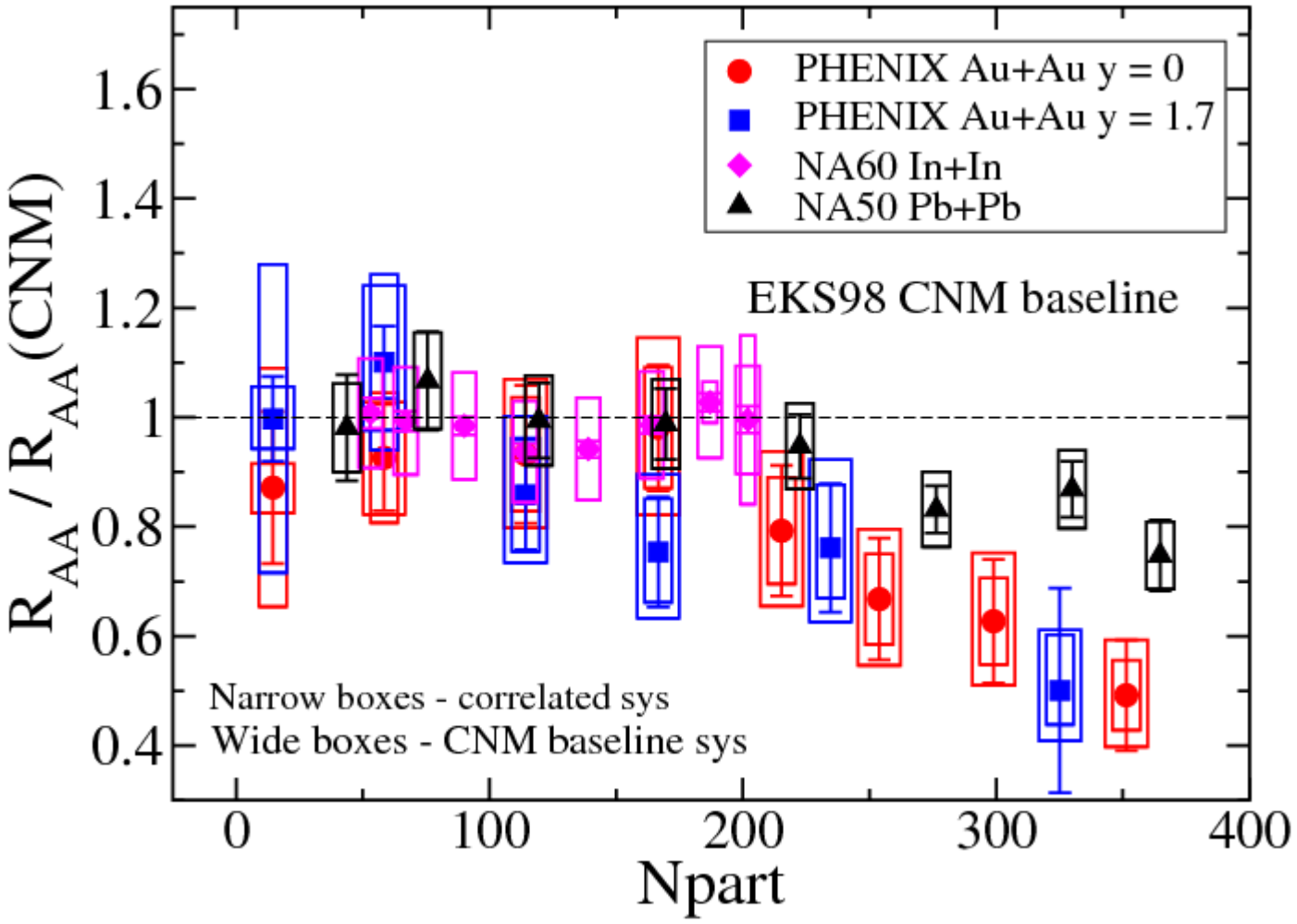
CNM derived from new Rcp is consistent with RdAu from old 2003 data

- *PRC 77,024912(2008)*



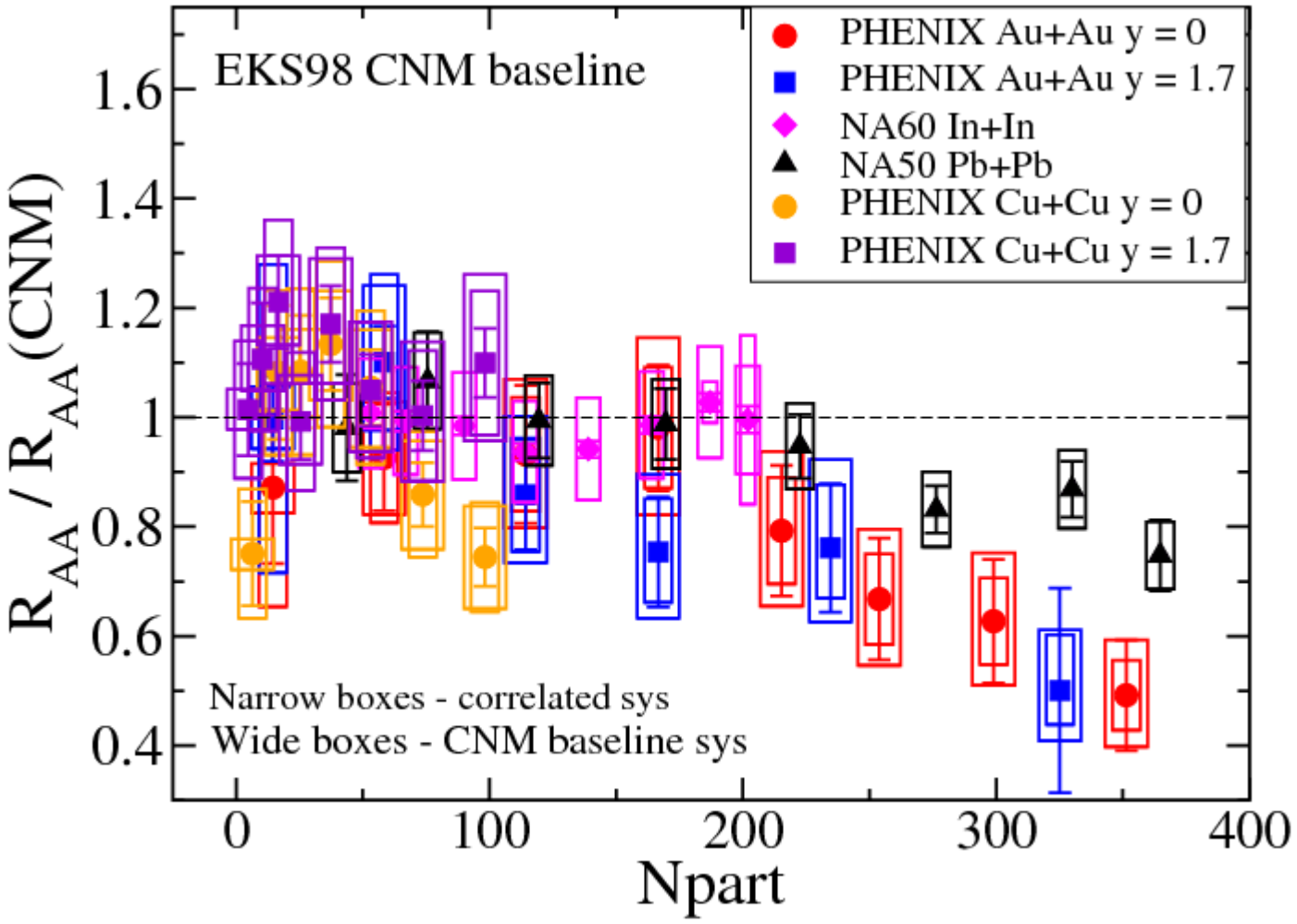
Anomalous Suppression vs Npart

SPS & PHENIX separate at large Npart



Anomalous Suppression vs Npart

With PHENIX CuCu added

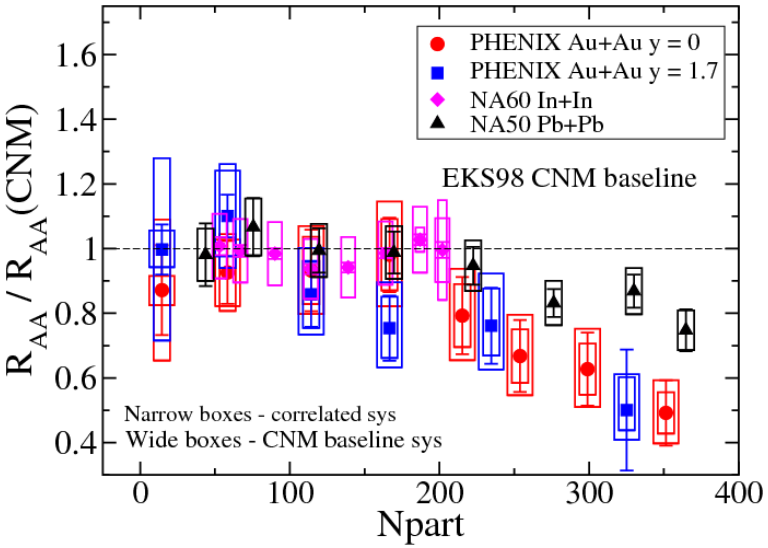


Comparing Anomalous Suppression at RHIC & SPS vs Energy Density

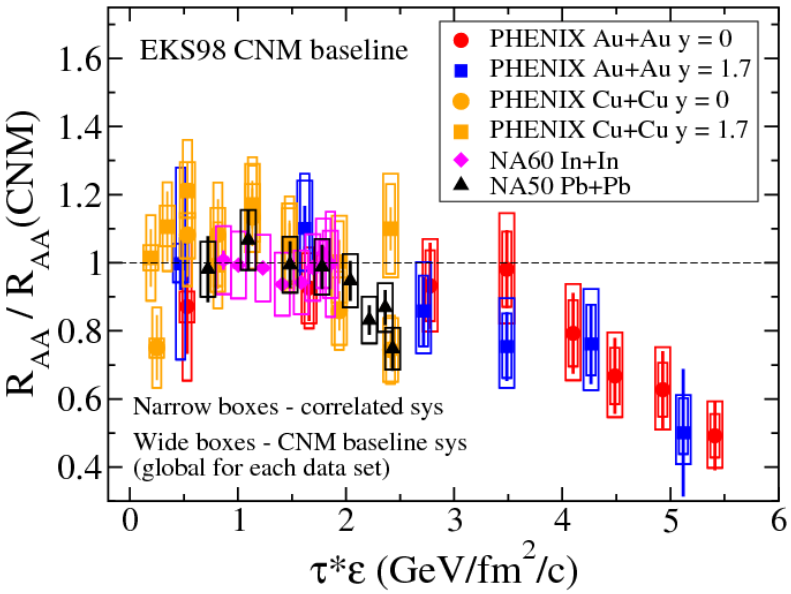
Caution - Many systematic uncertainties on relative (SPS vs RHIC) energy density scales:

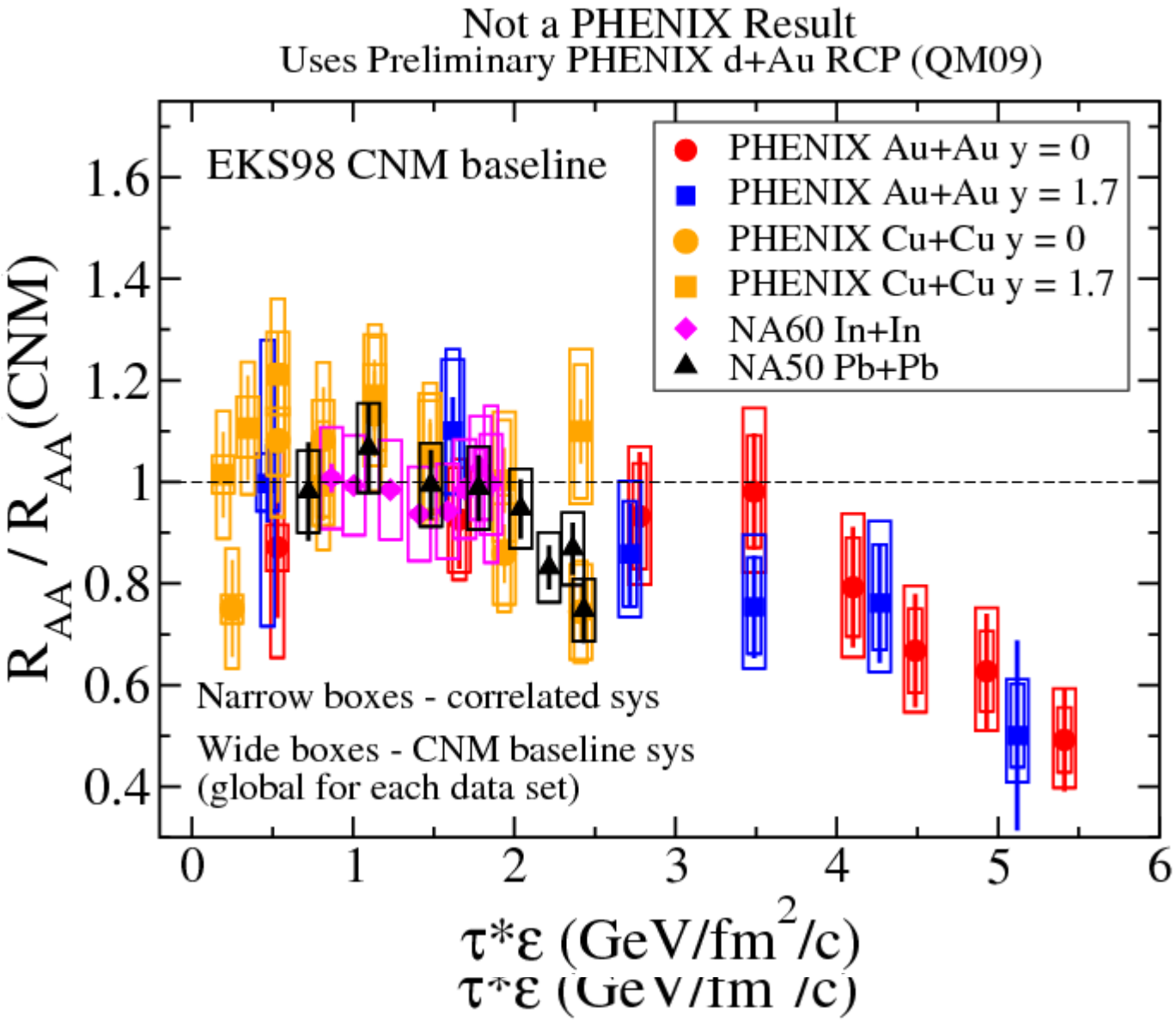
- Using WA98 for dE_T/dy at NA50/60 (matches best with dN/dy from Roberta Analdi)
  - substantially different from NA49 values (~25%)?

  see PRC 71, 034908 (2005)
- use Glauber MC for NA50/60 areas
- Use tau*energy density scale; but is tau same or different between SPS & RHIC energy?
- No Cu+Cu dN/dy or dE_T/dy at RHIC, so using Au+Au values at same N_{part}

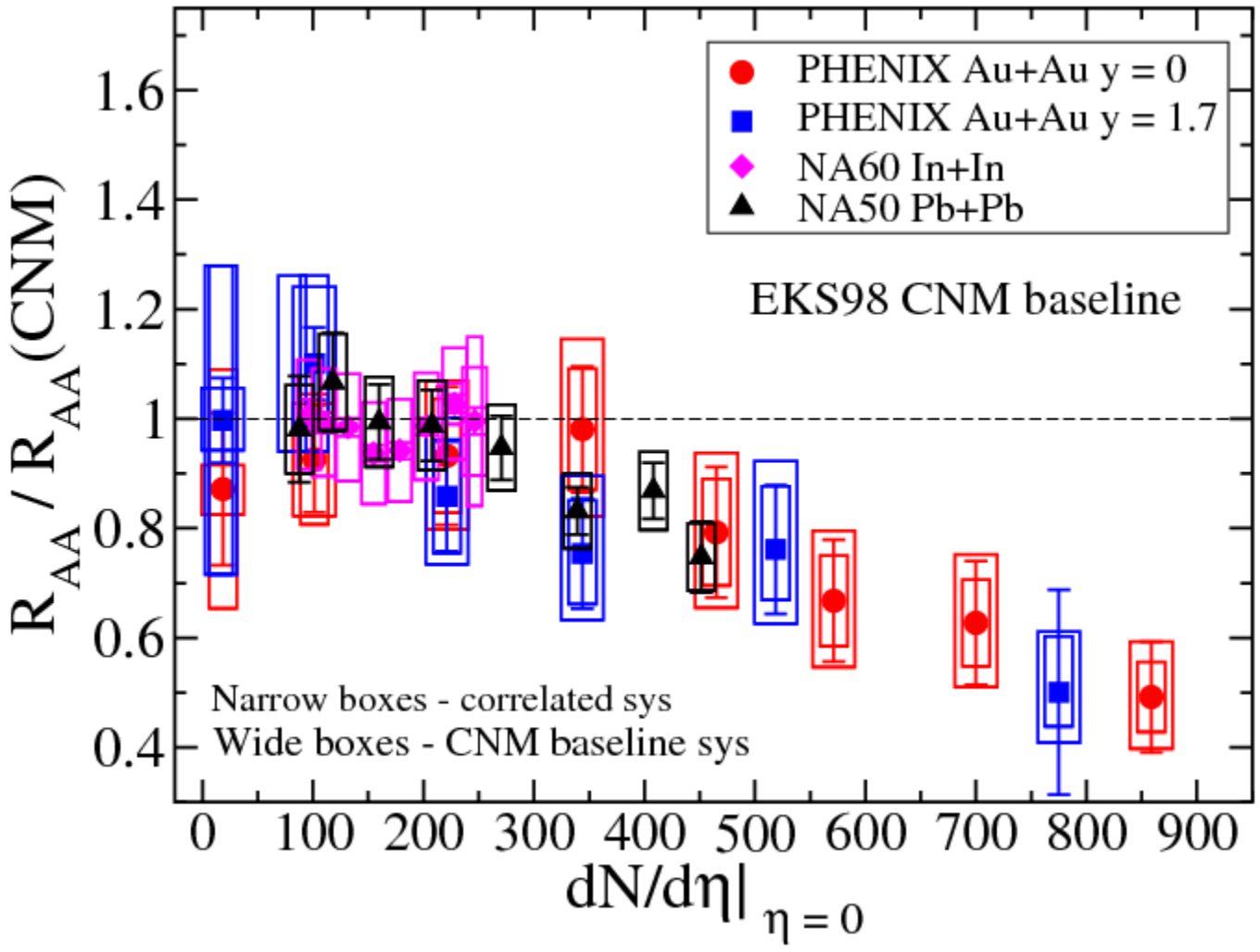


Not a PHENIX Result
Uses Preliminary PHENIX d+Au RCP (QM09)

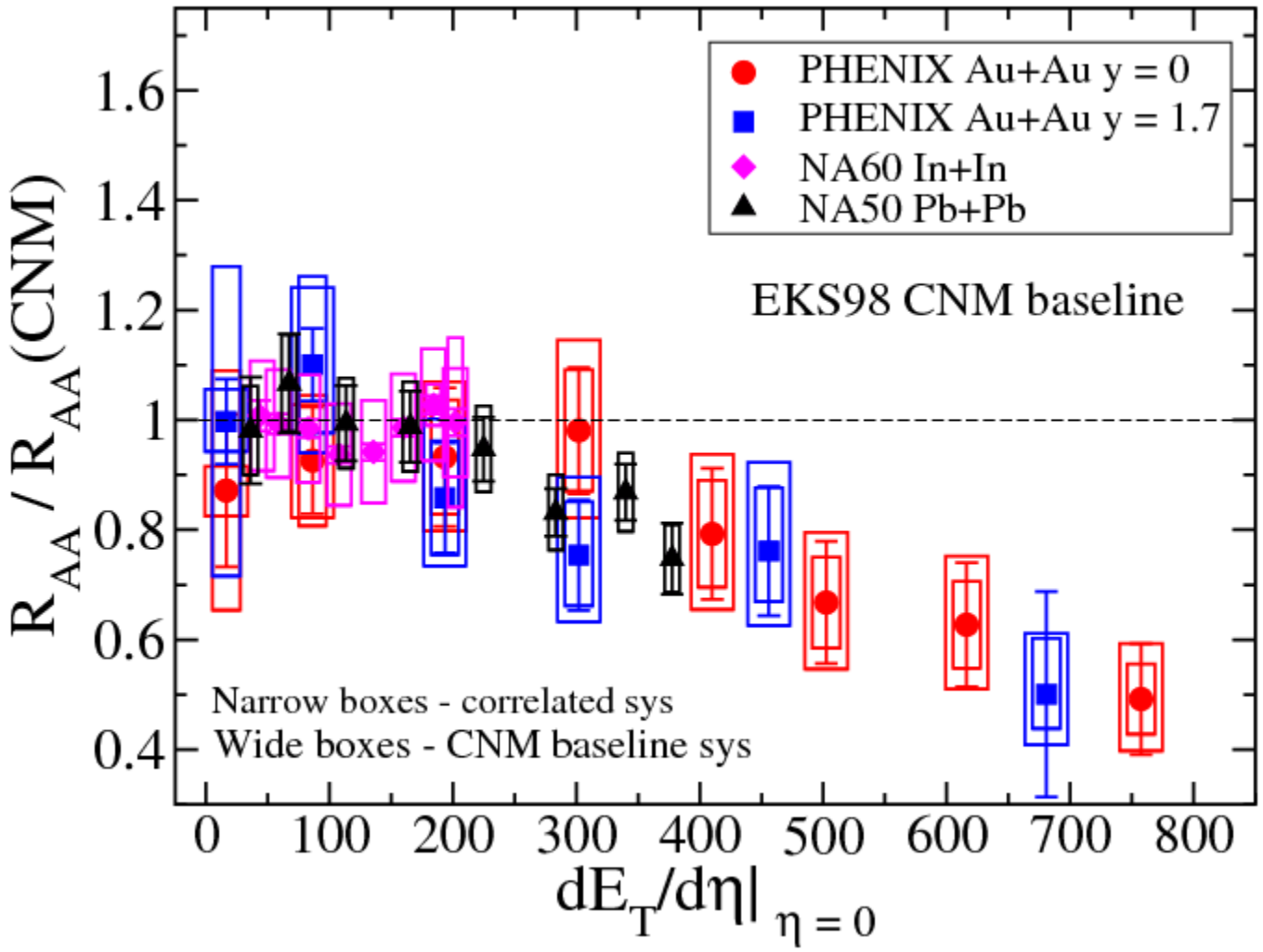



Not a PHENIX Result
Uses Preliminary PHENIX d+Au RCP (QM09)
EKS98 CNM baseline
PHENIX Au+Au y = 0
PHENIX Au+Au y = 1.7
PHENIX Cu+Cu y = 0
PHENIX Cu+Cu y = 1.7
NA60 In+In
NA50 Pb+Pb
Narrow boxes - correlated sys
Wide boxes - CNM baseline sys
(global for each data set)
R_AA / R_AA(CNM)
τ*ε (GeV/fm²/c)

Anomalous Suppression vs $dN_{ch}/d\eta$



Anomalous Suppression vs $dE_T/d\eta$

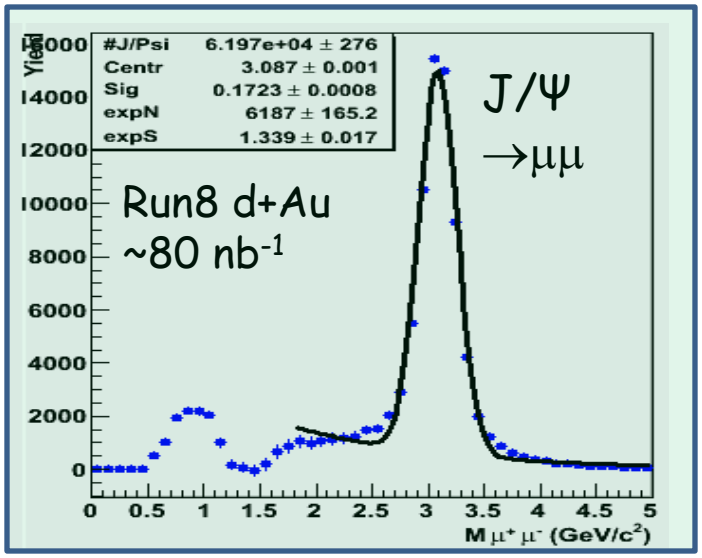


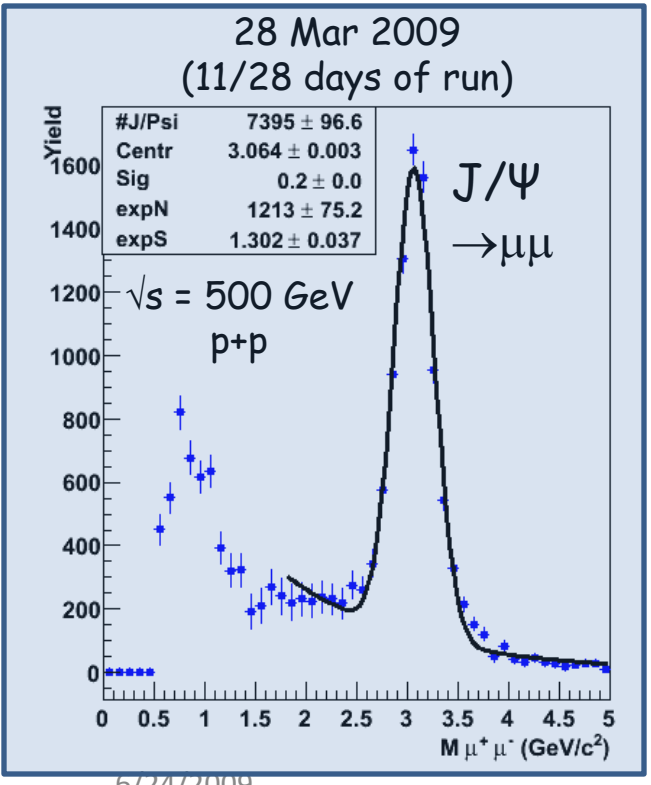
Future

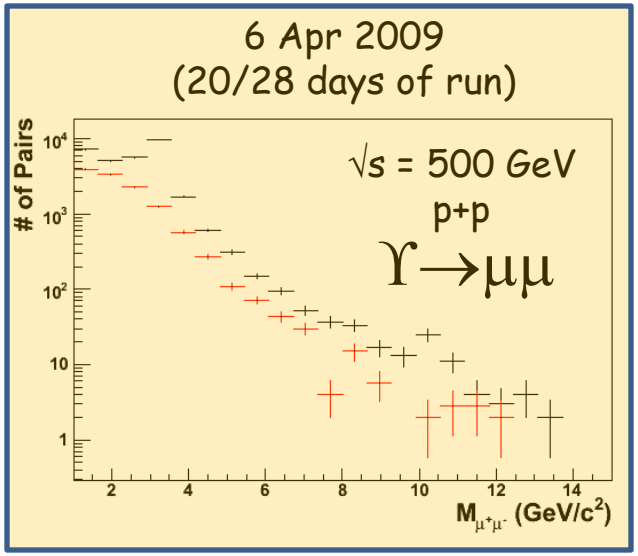
Recent PHENIX J/Ψ→μμ data sets

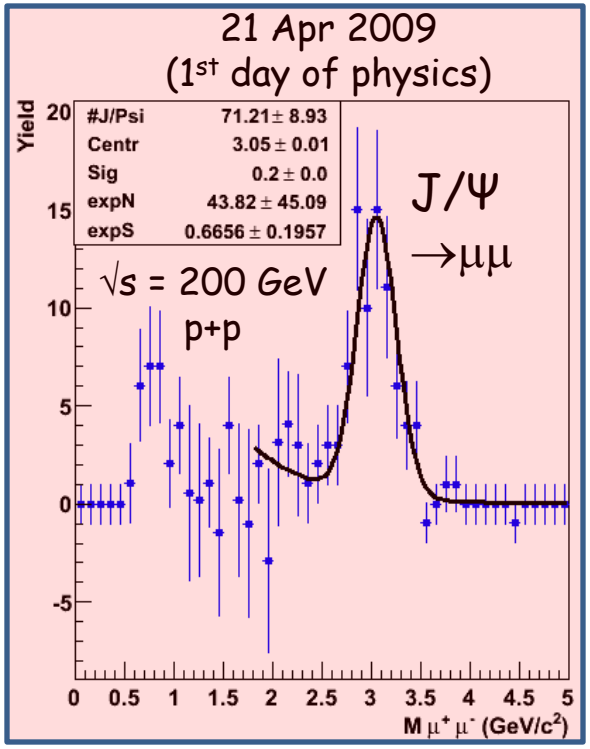
Run9 p+p now ongoing, with longitudinal polarization:

- 28 days of 500 GeV
- ~64 days of 200 GeV









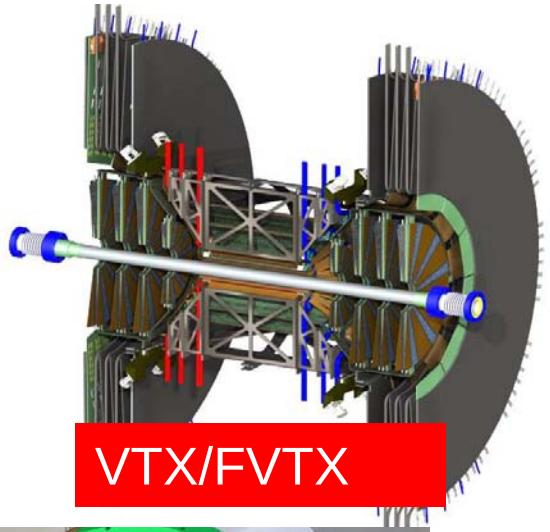
Upgrades & Quarkonia at PHENIX

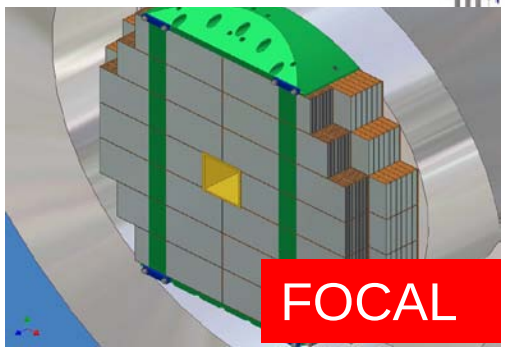
Vertex Detectors (VTX & FVTX)
- better $\Upsilon \rightarrow e^+e^-$ mass resolution & background at mid-rapidity
- separation of Ψ' from J/Ψ & reduction of backgrounds at forward-rapidity ($\mu^+\mu^-$)
- $B \rightarrow J/\Psi\ X$

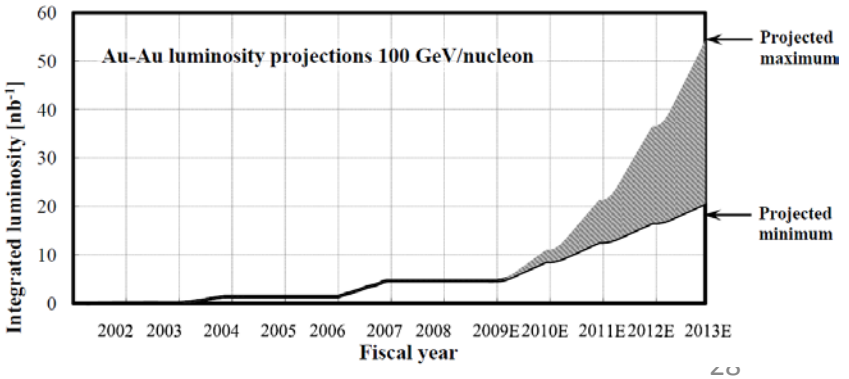
Forward Calorimetry (FOCAL)
- $\chi_c \rightarrow J/\Psi + \gamma$ in p+p & d+Au

Removing Hadron Blind Det. (HBD)
- when vertex detectors go in, HBD comes out (smaller photon conversion backgrounds)

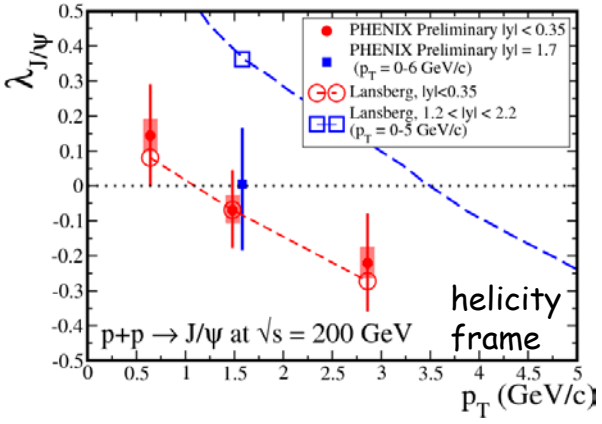
And increased machine Luminosity benefits these rare processes



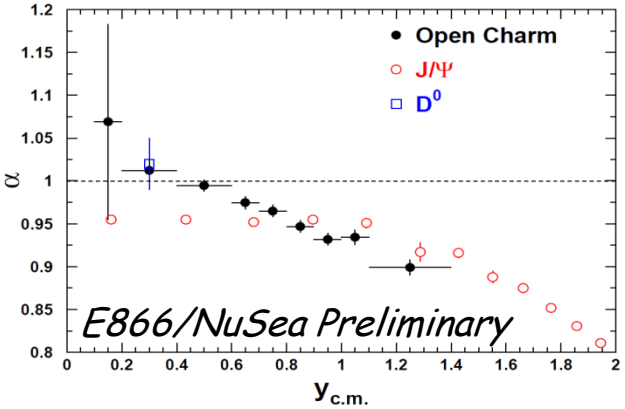




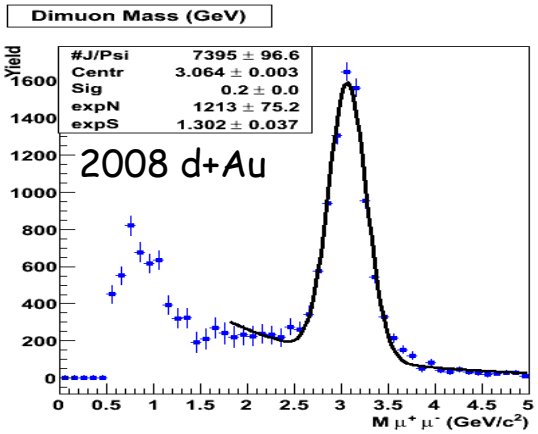
Summary



New CSM good except for forward J/Ψ polarization

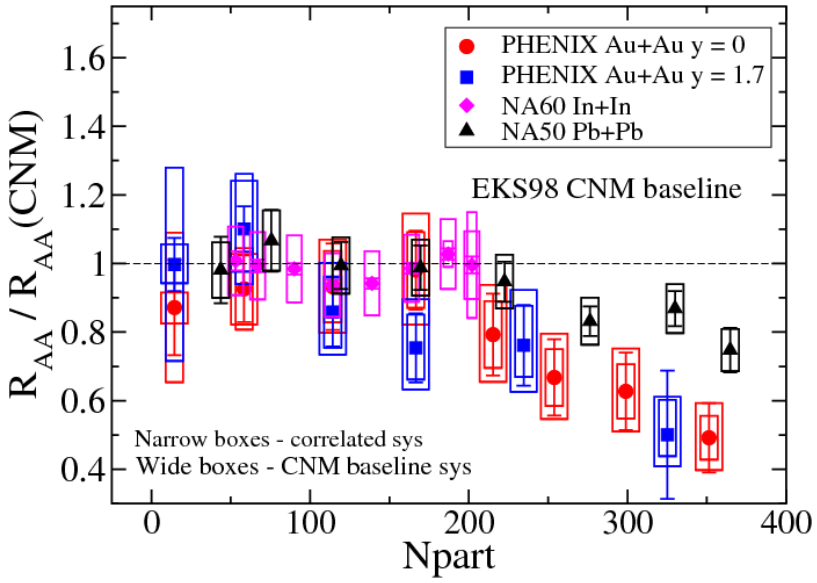


Many CNM effects possible:
- similarity of open charm → initial state
- lack of x2 scaling → not shadowing

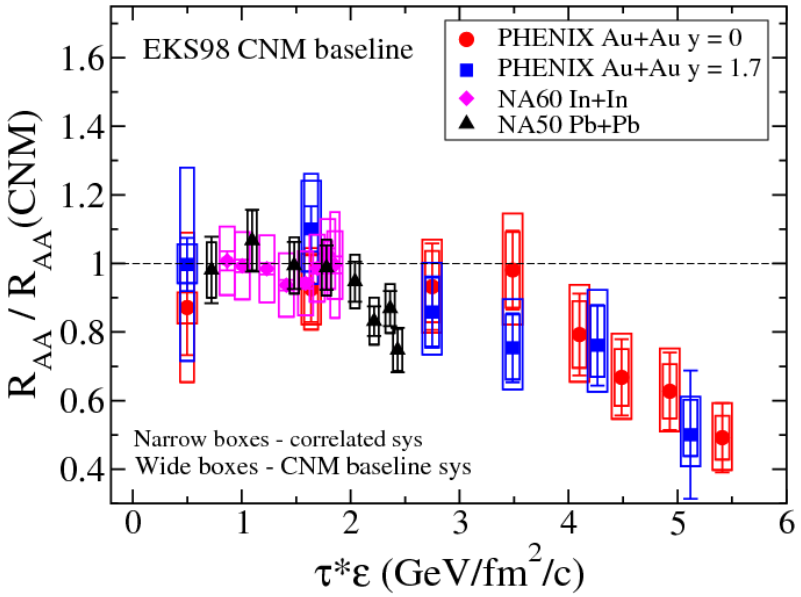


New d+Au data coming soon

Anomalous Suppression @ RHIC & SPS



Scales with Energy Density?



Mike Leitch