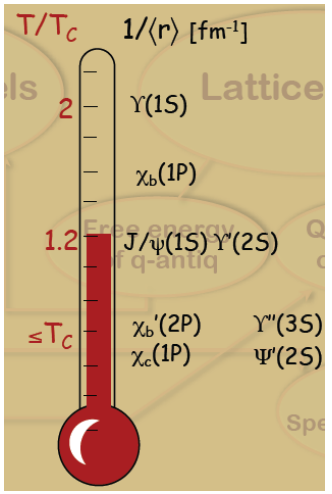
LANL Nuclear Physics at RHIC & E906
Mike Leitch (MJL) --- August 5, 2010

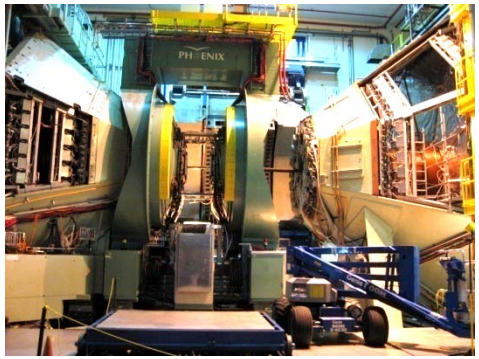
Quark-gluon Plasma (QGP) Physics:
- Quarkonia screening
- Muon arm performance improvements
- Heavy-quarks

Cold Nuclear Matter (CNM) Physics:
- gluon saturation & energy loss – solving the J/ψ puzzle

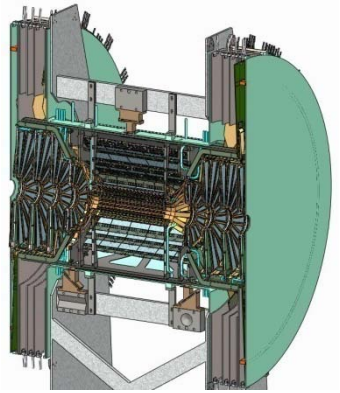
New physics reach with the FVTX

Quarkonia screening in QGP



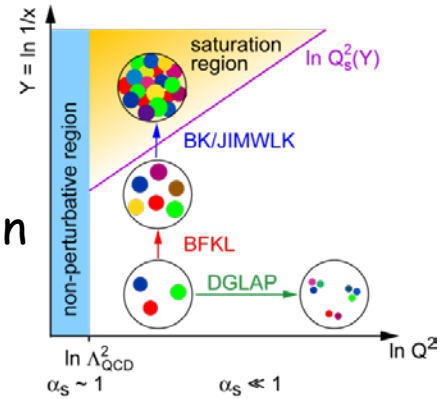


PHENIX Muon Tracker



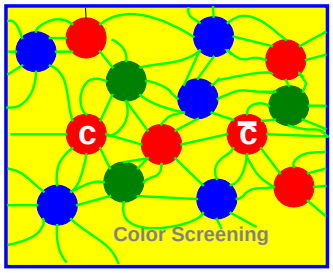
FVTX

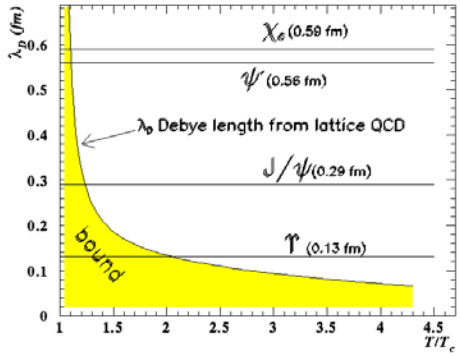
gluon saturation



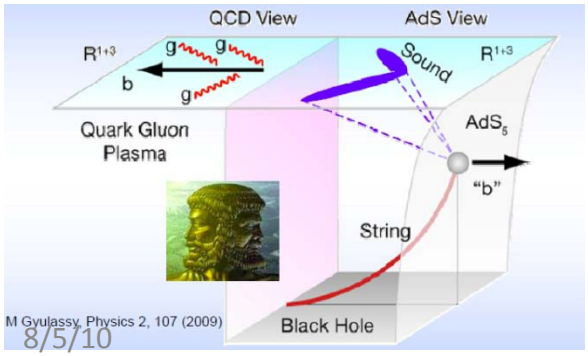
Fundamental QGP Physics Questions

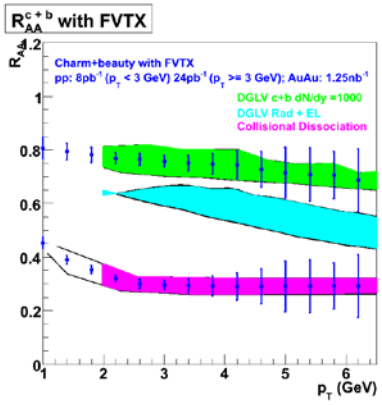
Screening in QGP: NSAC Milestone: DM5 – *"Measure the energy and system size dependence of J/Ψ production over the range of ions and energies available at RHIC."*





Heavy-quark dE/dx in QGP: NSAC Milestone: DM12 – *"Measure production rates, high p_T spectra, and correlations in heavy-ion collisions at $\sqrt{s_{NN}}$ = 200 GeV for identified hadrons with heavy flavor valence quarks to constrain the mechanism for parton energy loss in the quark-gluon plasma."*

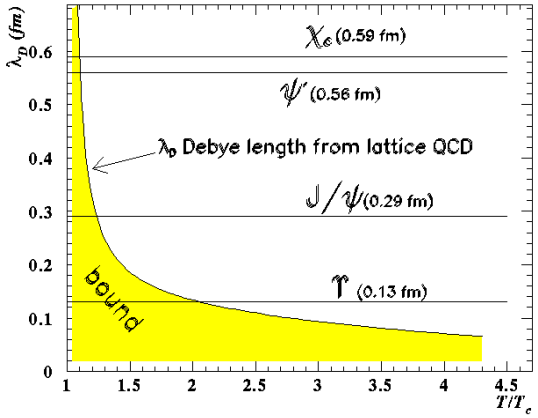




Quarkonia & Deconfinement

For the hot-dense medium (QGP) created in A+A collisions at RHIC:

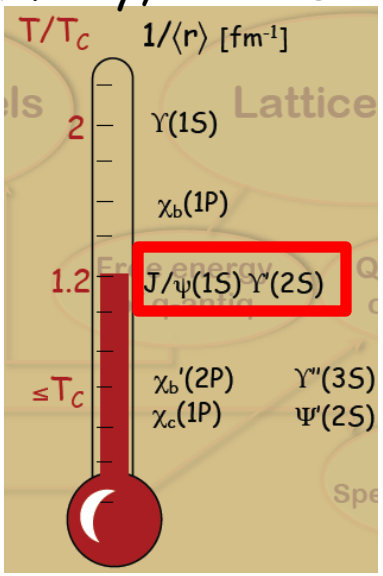
- Large quark energy loss in the medium implies high densities
- Flow scales with number of quarks
- Is there deconfinement? → look for Quarkonia screening



Debye screening predicted to destroy J/ψ's in a QGP with other states "melting" at different temperatures due to different sizes or binding energies.

RHIC: T/T_C ~ 1.9 or higher

Mocsy, WWND08



Different lattice calculations do not agree on whether the J/ψ is screened or not – measurements will have to tell!

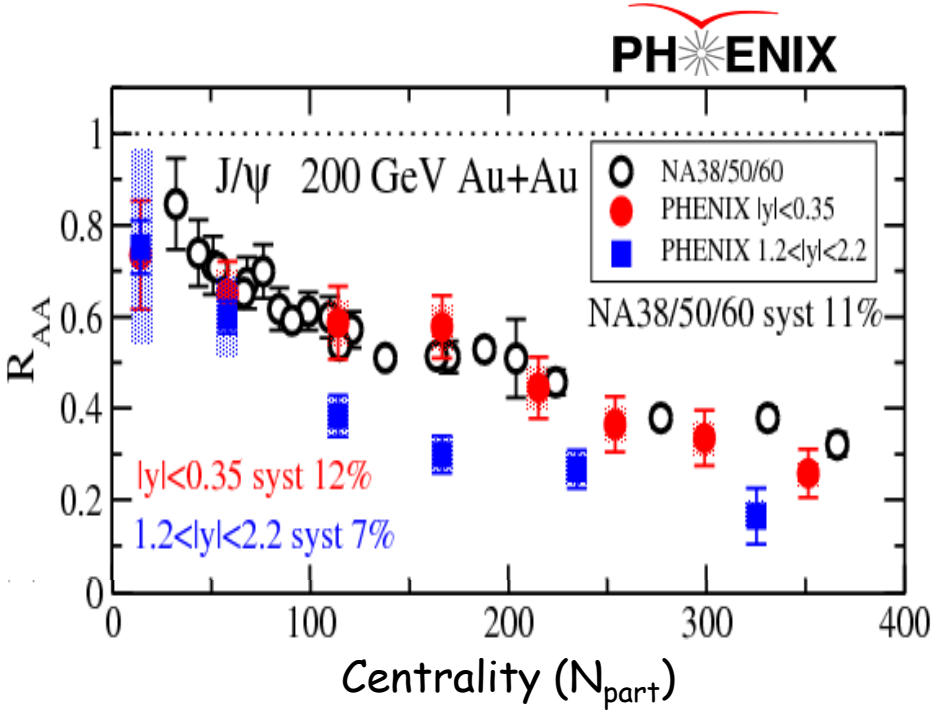
Satz, hep-ph/0512217

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

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

Several scenarios may contribute:
- Cold nuclear matter (CNM) effects
  - important, need better constraint
- 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

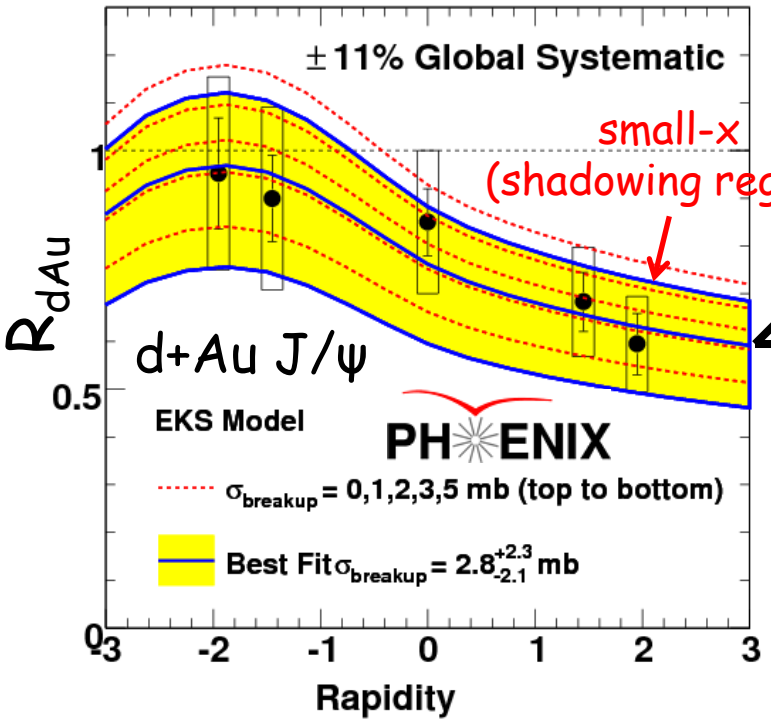


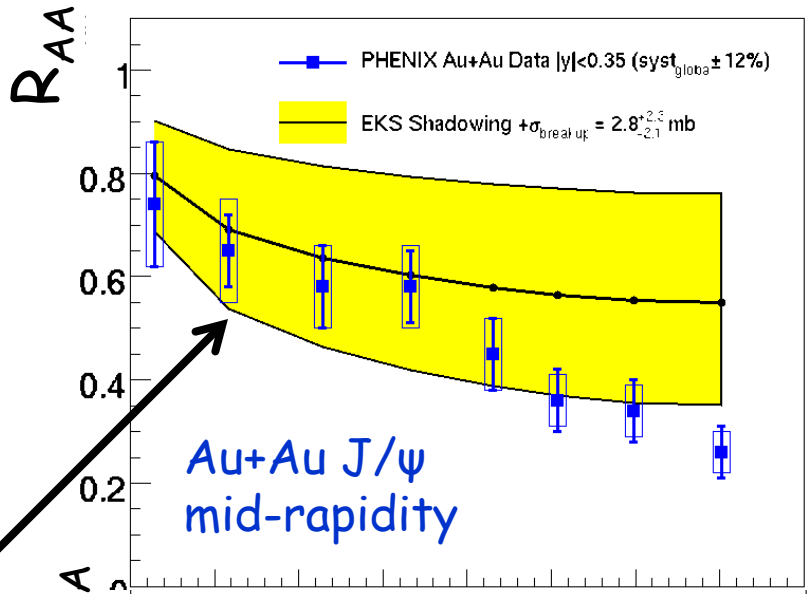
from QM06 J/ψ MJL Plenary talk

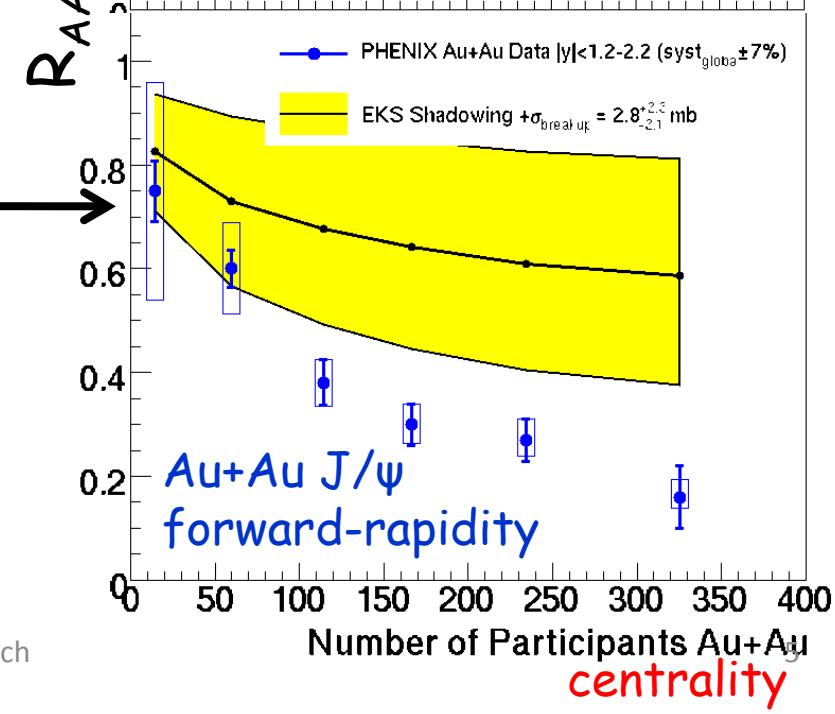
CNM J/ψ Constraints from d+Au on A+A data

EKS shadowing + dissociation from fits to d+Au data (using R. Vogt theoretical calcs.)

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



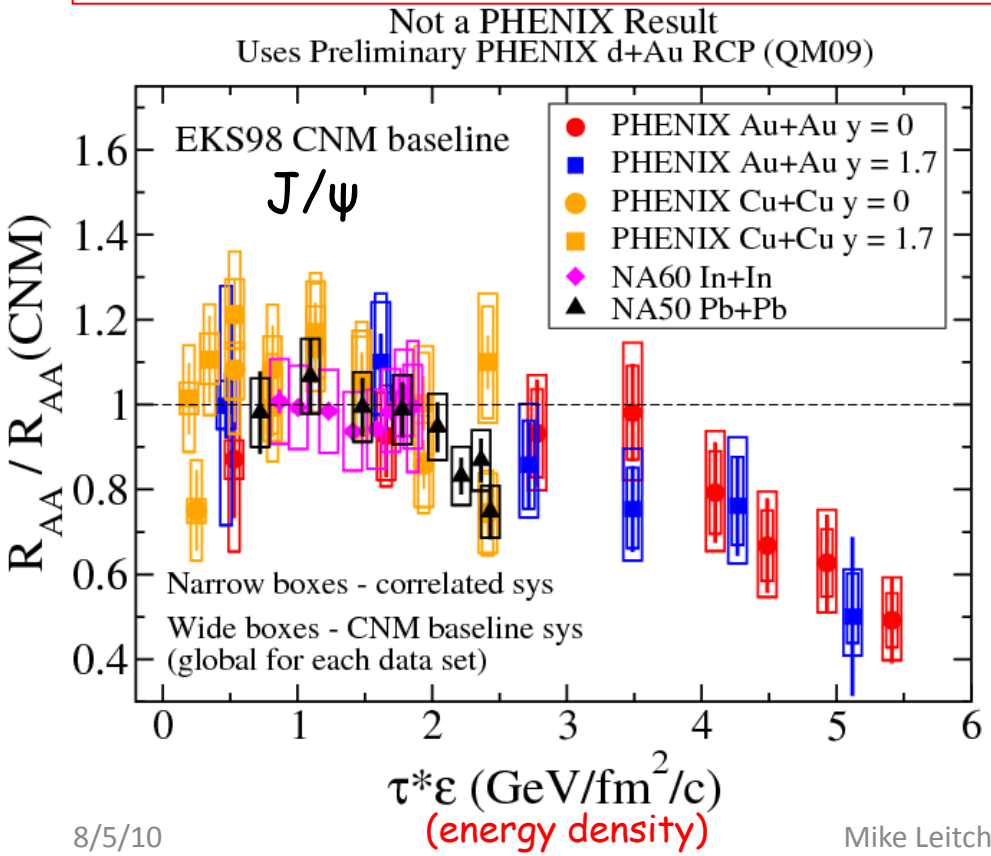




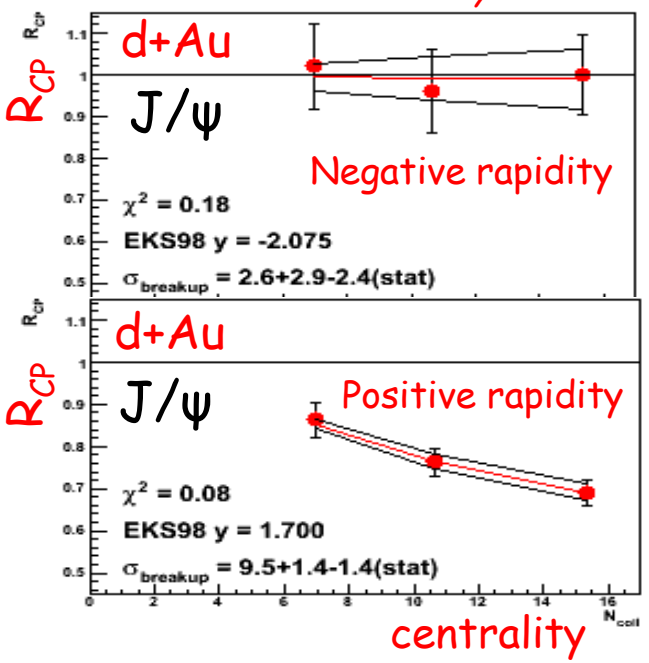
Anomalous Suppression (RHIC & SPS) of J/ψ in A+A Collisions after dividing out d(p)+A baselines

Fit d+Au to an *effective breakup cross-section* that varies with rapidity; predict and divide out CNM effects from Au+Au suppression

Plot by Leitch @ Seattle/INT Workshop – June 09



Frawley fits

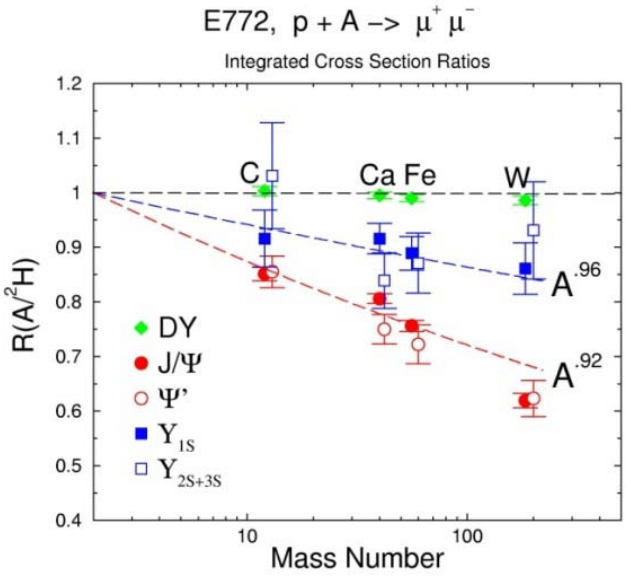


<u>Caution</u> - Many systematic uncertainties on relative (SPS vs RHIC) energy density scales

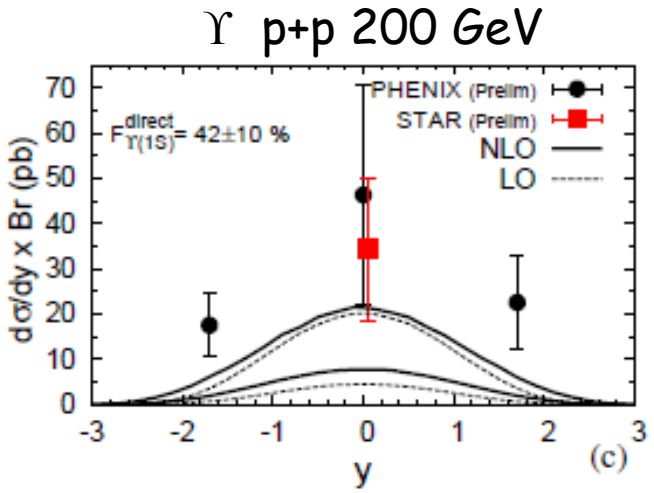
Adding Upsilons (1S+2S+3S)

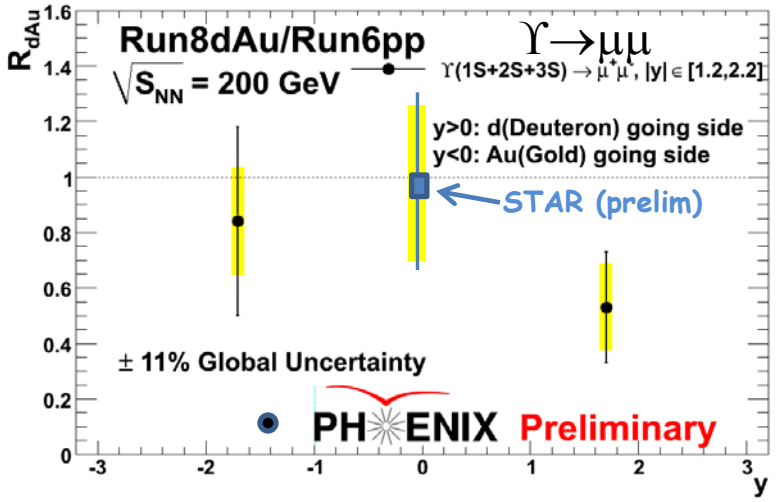
- Our FNAL/E772 saw substantial suppression of Upsilons in p+A

- Beginning to get 1st Upsilon measurements at PHENIX
- d+Au forward rapidity suppression observed



K. Lee (Korea U.), MJL, …

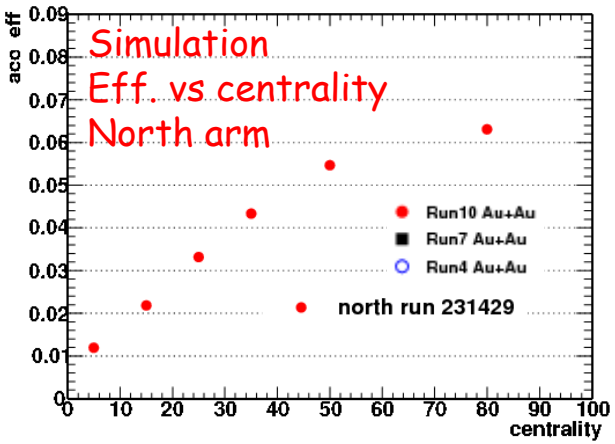


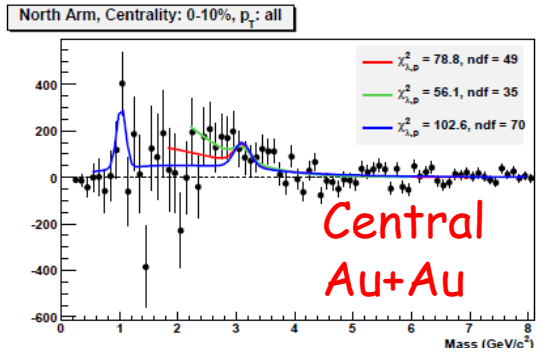


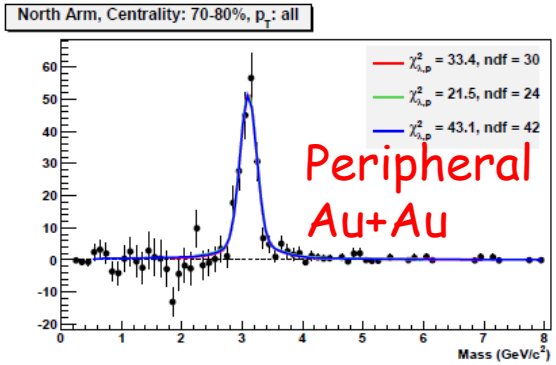
Improving Muon Arm Performance for Central Au+Au Collisions

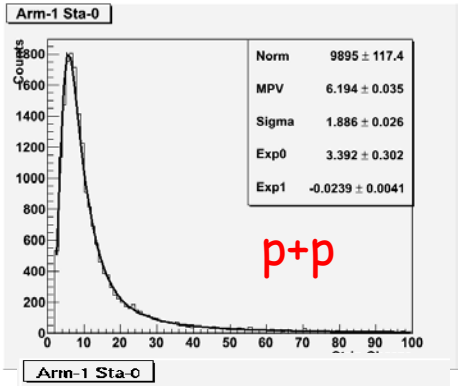
Central Au+Au collisions:

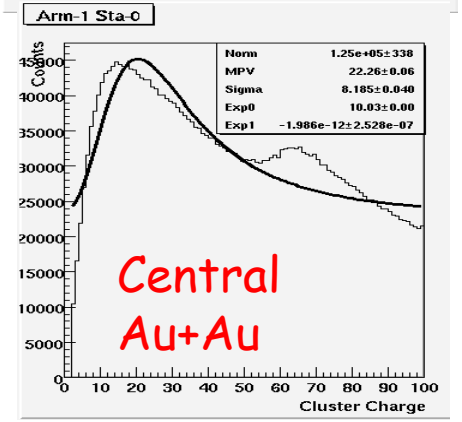
- efficiency low , occupancy high
- no J/ψ peak in North arm
- large pileup in cluster charge

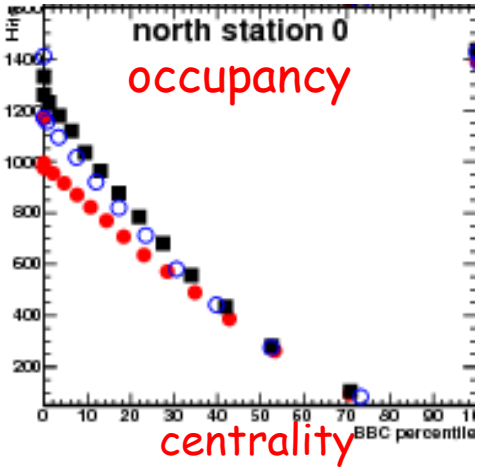








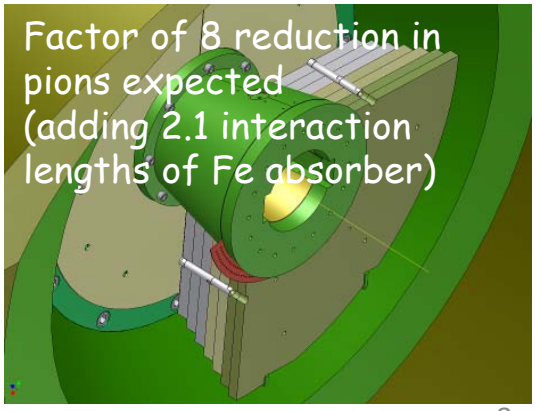




Improvements for Run11:

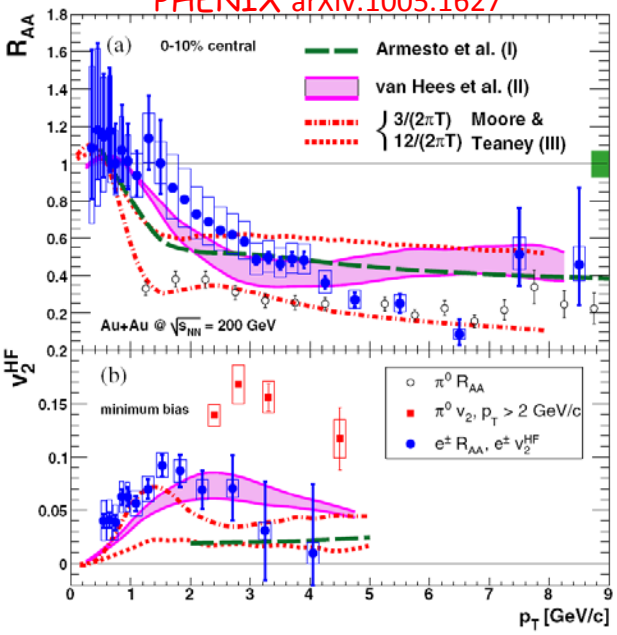
- addition of absorber
- low-level software improvements
- anode termination

Pereira, MJL, LANL, …



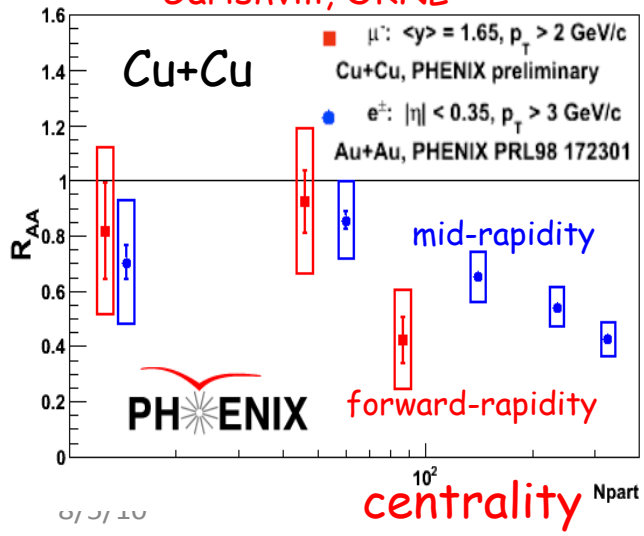
Energy loss & probing the properties of the QGP with heavy-quarks

PHENIX arXiv:1005.1627



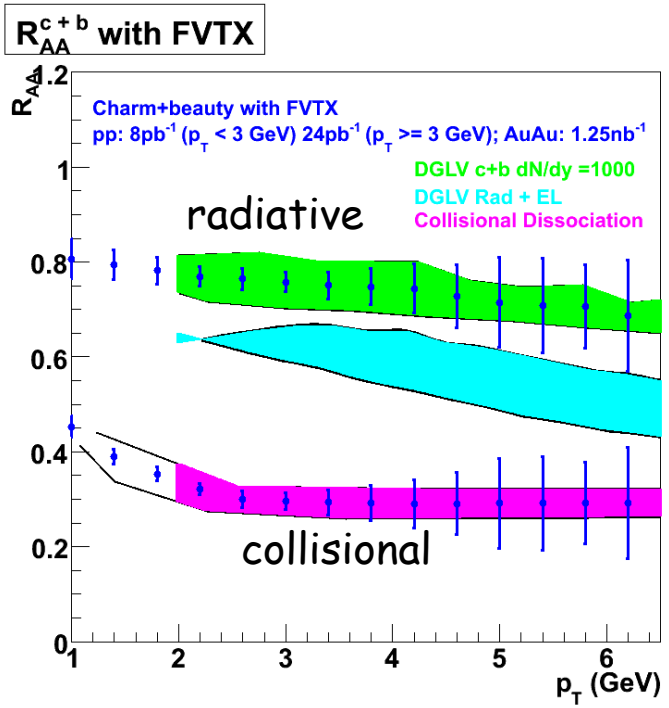
Mid-rapidity heavy-q's show suppression & flow – contrary to earlier expectations

Garishvili, ORNL



Forward rapidity heavy-q's show suppression in Cu+Cu

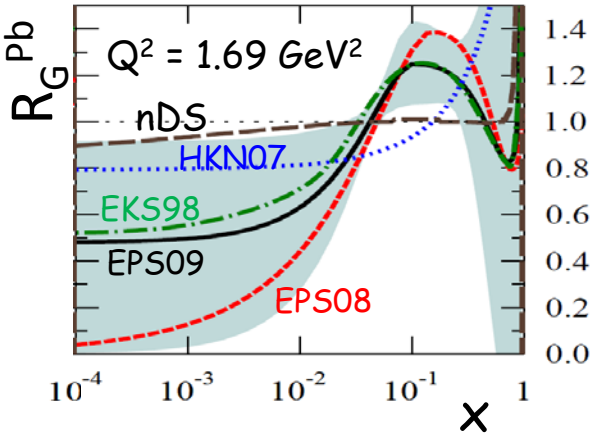
Distinguishing radiative and collisional energy loss & measurement of flow with FVTX at forward rapidity



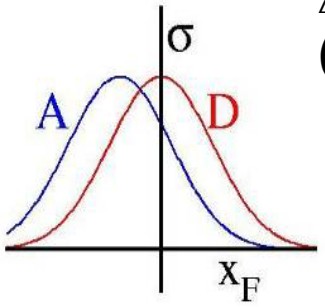
Fundamental Cold Nuclear Matter (CNM) Physics Questions

NSAC Milestone: DM8 – "Determine gluon densities at low x in cold nuclei via p + Au or d + Au collisions."

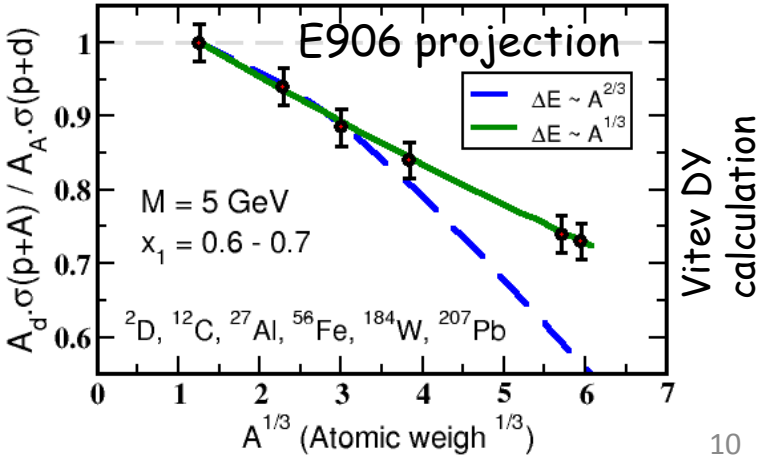
- Leading twist gluon shadowing
- Coherence models & higher-twist (HT) shadowing
- Gluon Saturation: at small-x, 2→ 1 diagrams become important and deplete the low-x region; amplified in a nucleus.



NSAC Milestone: DM12 – "…constrain the mechanism for parton energy loss in the quark-gluon plasma." And what about energy loss in cold nuclear matter?



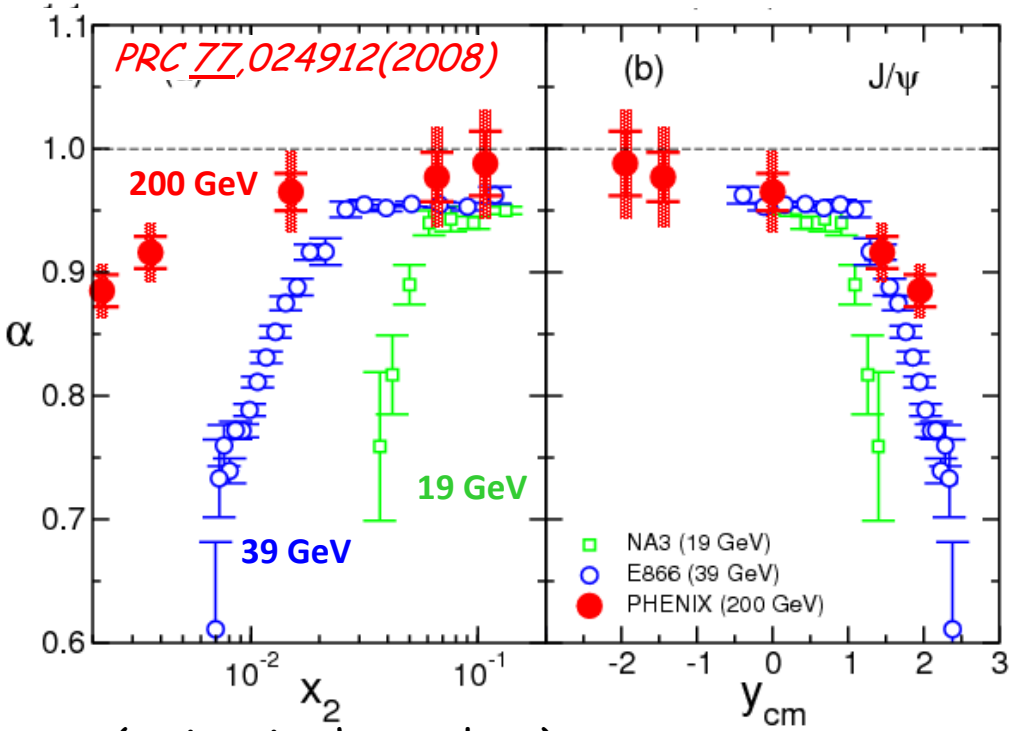
$\Delta E \sim L$ or L^2?
(collisional or radiative?)



CNM Physics – the J/ψ Puzzle

$$\sigma_{pA} = \sigma_{pp} A^{\alpha}$$

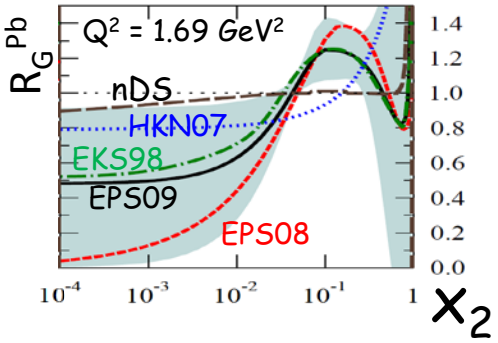
J/ψ α for different √s collisions
E866 p+A & lower-energy NA3 at CERN



(x_2 is x in the nucleus)

Scaling of E866 vs PHENIX better vs y_{cm}

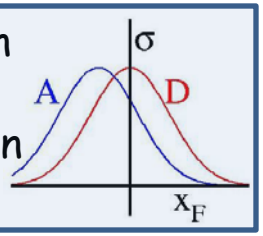
Suppression not universal vs x_2 as expected for shadowing



Closer to scaling with x_F or rapidity

- initial-state gluon energy loss?

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



- or gluon saturation?

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

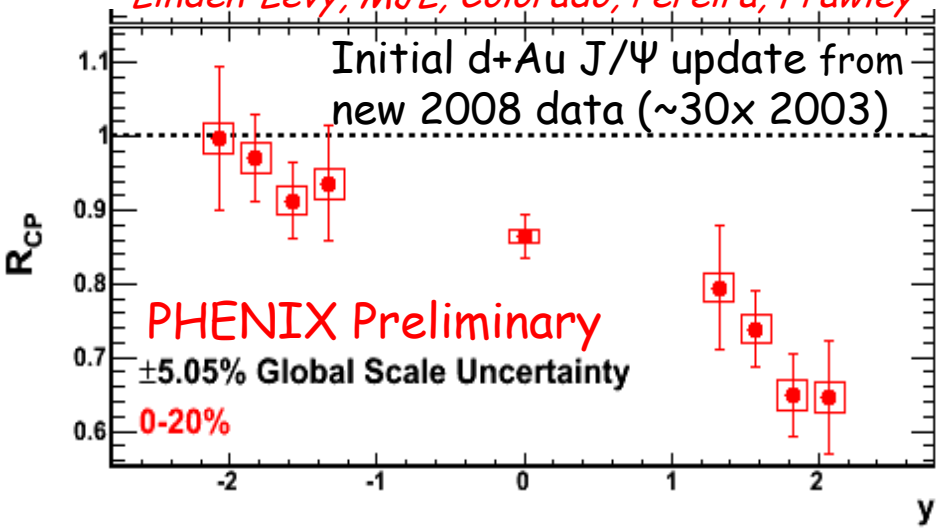
New CNM Constraints from d+Au on A+A data

New CNM fits using 2008 PHENIX d+Au Rcp - (Frawley, Vogt, MJL, others…)

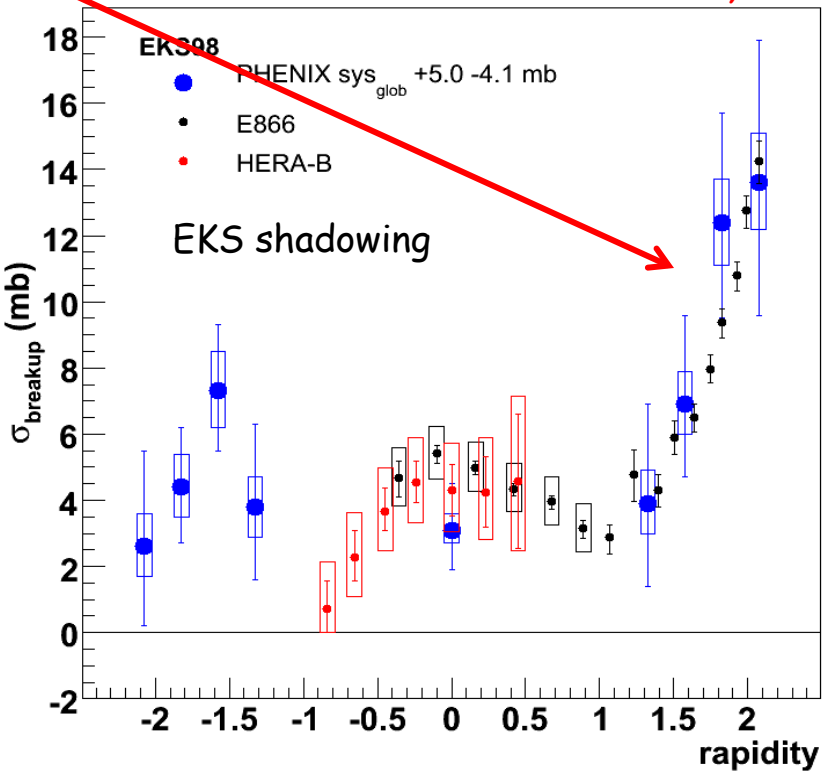
- similar to before, use models with shadowing & breakup
- but allow ***effective*** breakup cross section to vary with rapidity to obtain good description of data
- large effective breakup cross section at large positive rapidity – probably indication of need to add initial-state dE/dx?

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

Linden-Levy, MJL, Colorado, Pereira, Frawley



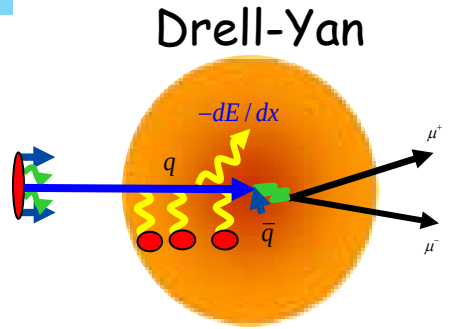
Frawley

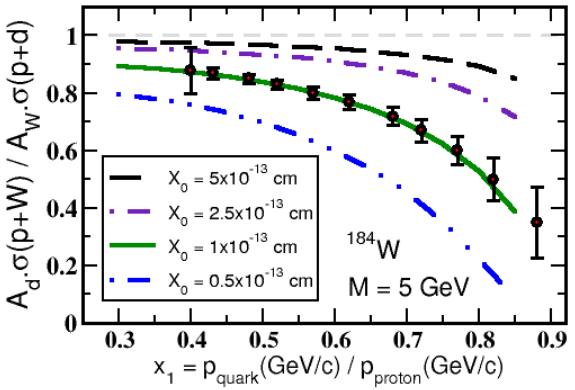


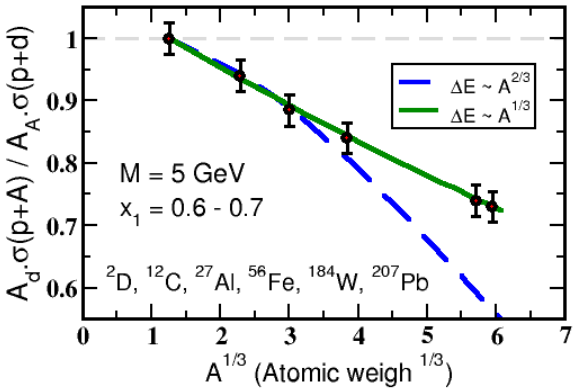
Constrain the Initial-state dE/dx
FNAL E906 – Drell Yan

In E906 at 120 GeV, nuclear suppression in Drell-Yan should only be from dE/dx ($x_2 > 0.1$)
(E866 at 800 GeV, could not unambiguously separate shadowing and dE/dx effects at low x)

E906 LANL LDRD – Liu, McGaughey,…



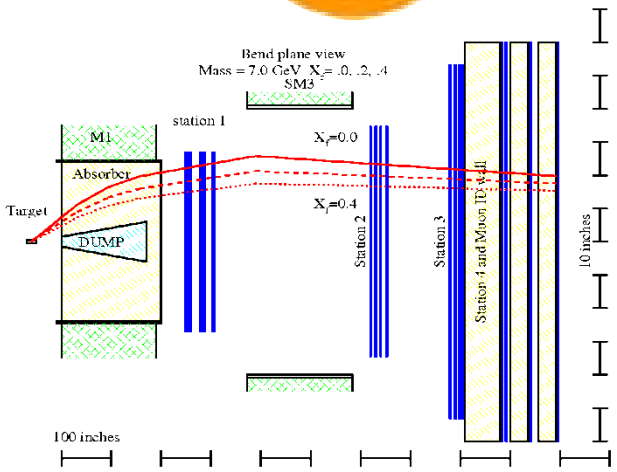




from Vitev

$$\frac{\Delta E}{E} \propto \frac{\mu^2 L^2}{\lambda_g} \frac{\ln E/Q_0}{E}$$

$$\frac{\Delta E}{E} \propto \frac{L}{\lambda_g} \ln \frac{E}{Q_0}$$



- Distinguish radiative from collisional (L^2 vs L) quark dE/dx
- then "extrapolate" with theory to energy loss of gluons for quarkonia production

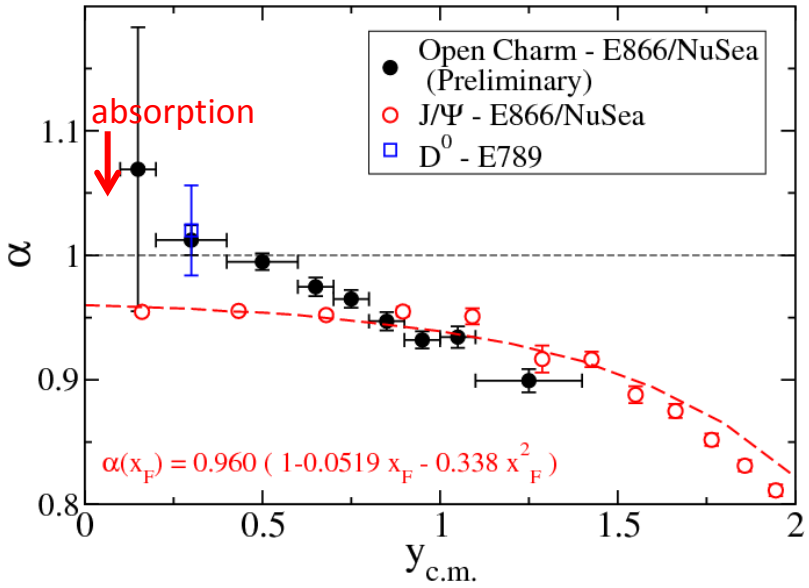
Isolate initial and final-state effects
Open-heavy flavor with Vertex Detectors

Forward open-charm p+A nuclear dependence (single-μ $p_T > 1$ GeV/c) – very similar to that of J/Ψ (E866/NuSea):

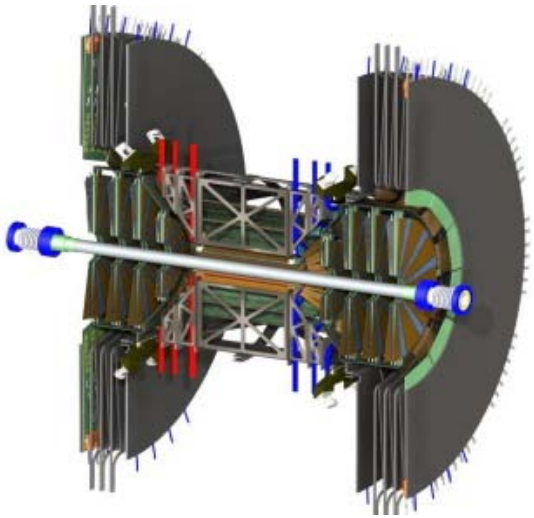
- implies that dominant effects are in the initial state
  - e.g. dE/dx, Cronin (since shadowing disfavored by lack of x_2 scaling)

Need to follow this example at RHIC in d+Au collisions

E866/NuSea (Klinksiek et al.)

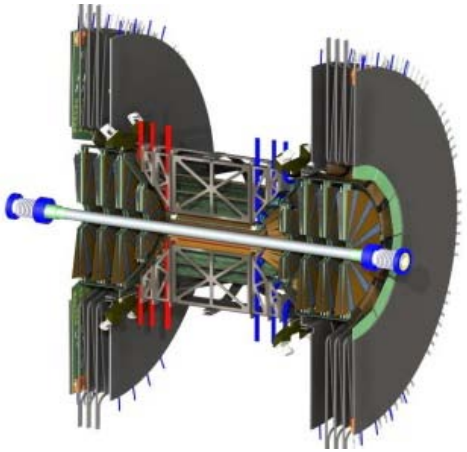


New c,b measurements with FVTX to isolate initial & final-state effects via comparisons with quarkonia

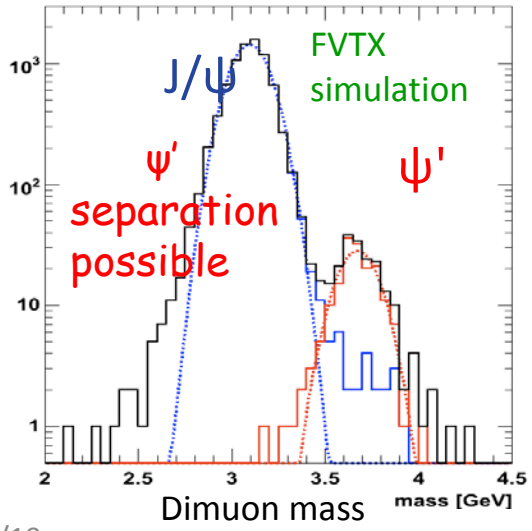


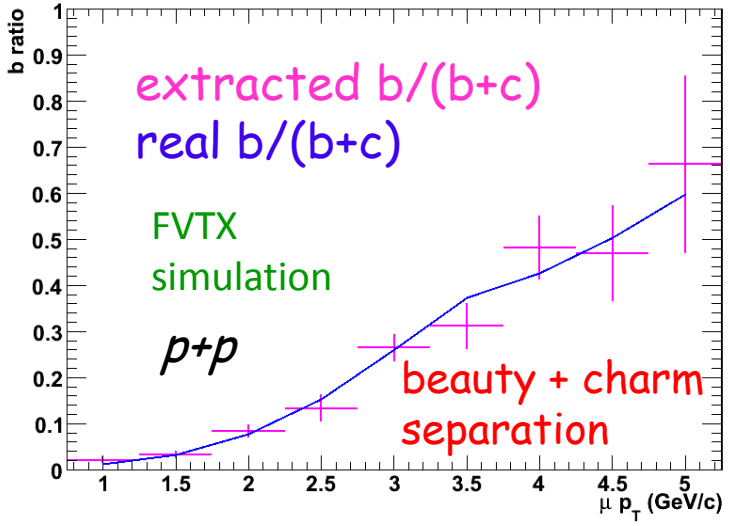
New Physics Reach with FVTX at PHENIX

- Direct identification of D, B → μ + X and B → J/Ψ → energy loss and shadowing for D,B mesons
- Improved J/ψ and ψ′ mass resolution → enable use of ψ′ as a probe
- Reduced backgrounds by rejection of π and K → enable Drell-Yan measurements
- Installation in summer of 2011



Simulations - Z. You, X. Wang, LANL, NMSU





Summary – LANL QGP and CNM Physics

QGP physics – quarkonia screening & heavy-quark energy loss

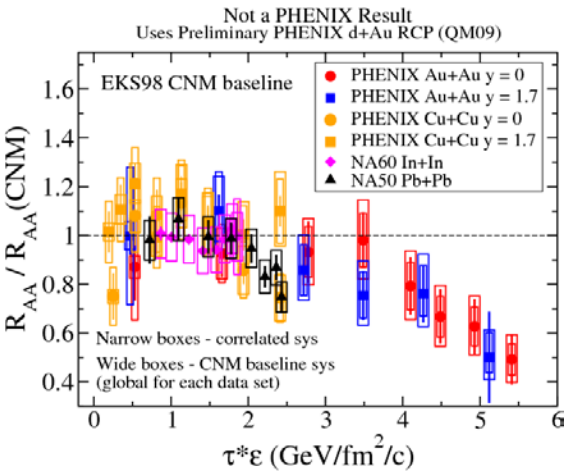
- need informed CNM baseline
- improve muon arm for central Au+Au
- add Upsilon and ψ′
- charm & beauty dE/dx in QGP with FVTX

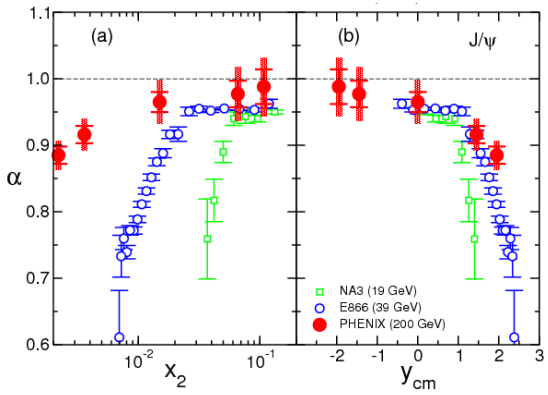
CNM physics – gluon saturation & parton energy loss in nuclei

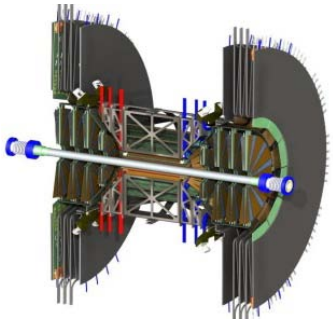
- solving the J/ψ puzzle with input from
  - gluon dE/dx – constrain with Drell-Yan (E906)
  - initial state – common with heavy-quark production

FVTX enables

- accurate open charm & beauty measurements
- isolation of ψ′
- pulling RHIC Drell-Yan out from beneath backgrounds

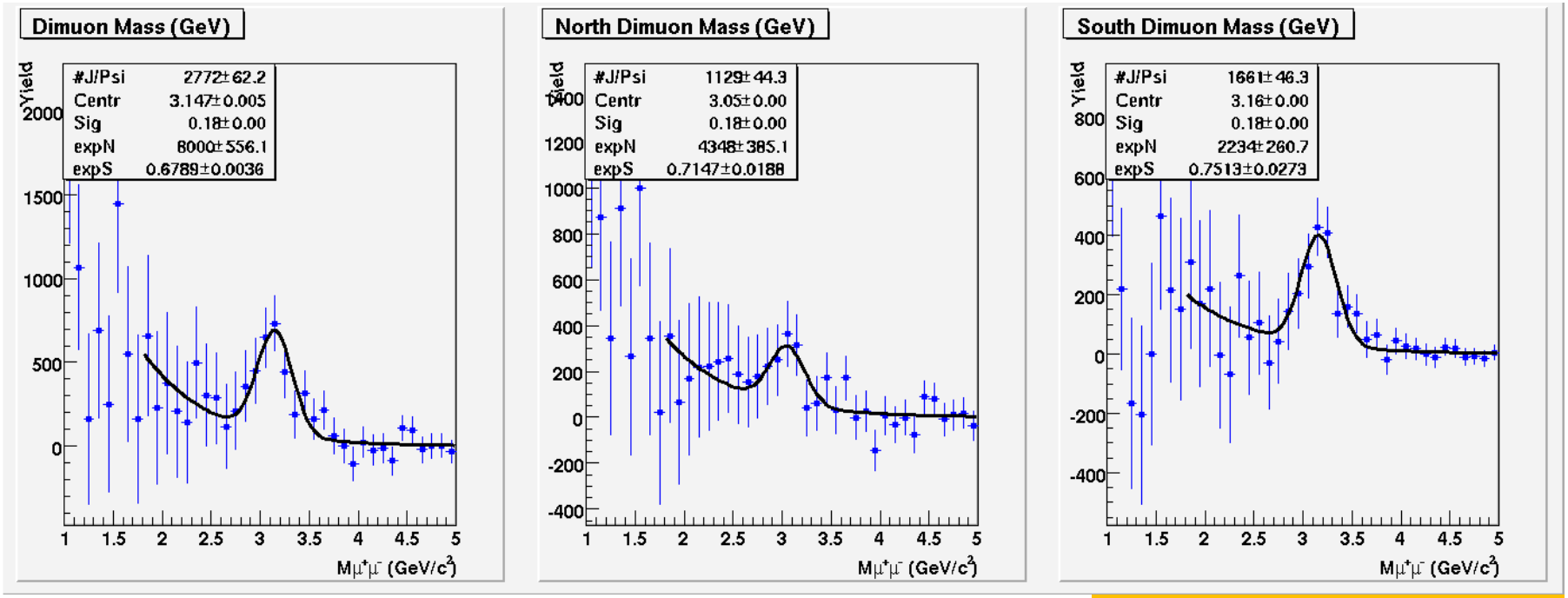






Backup Slides

J/ψ in Muon Arms in Run10 @ 200 GeV



J/ψ yield as expected

Analyzed Luminosity (for mass plots):
147.7 μb^{-1} gives 18.8 +- 0.4 (stat) J/Ψ per μb^{-1}
Compared to Run7 Au+Au which had about 18.2 J/Ψ per μb^{-1}

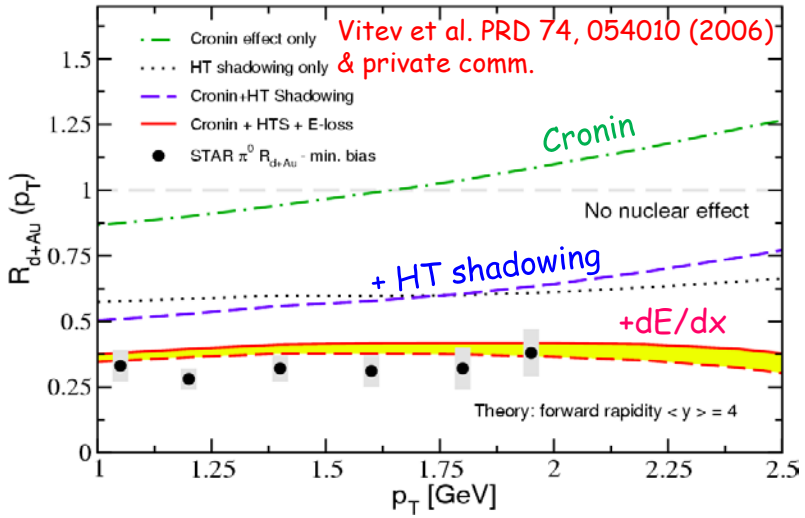
Comments - Shadowing and/or Gluon Saturation?

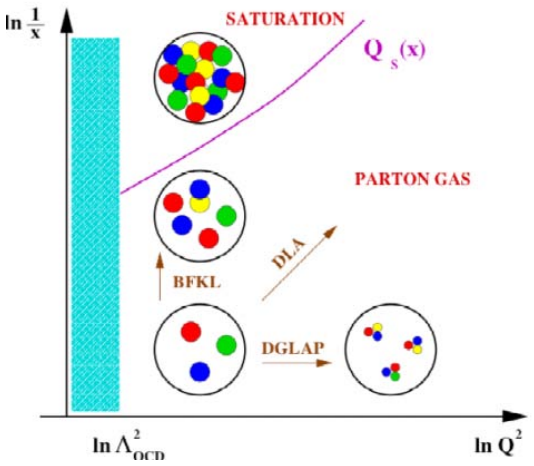
pQCD in high-density (small-x) gluon region involves complicated (NLO or higher-twist) processes, e.g. $g+g \rightarrow g$

- Larry McLerran says that a correct pQCD calculation should be equivalent to the CGC (color glass condensate) picture

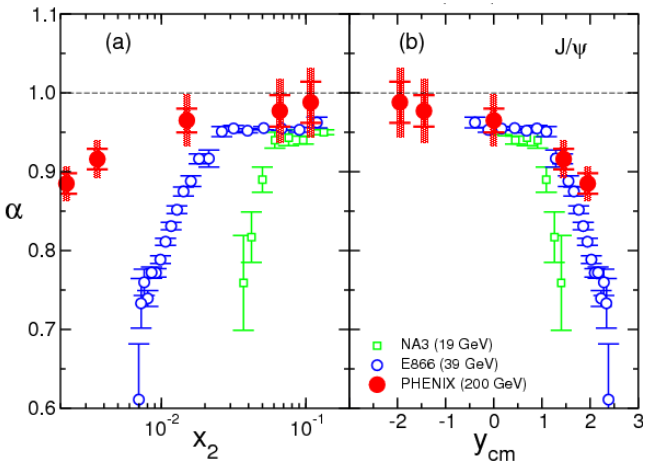
CGC is a "new" extreme state of cold QCD matter

- it can describe ONLY the high-density region
- no consistent description of A+A processes that involve gluons both in and out of this region
- not relevant for lower energy collisions (x not small) where large effects seen

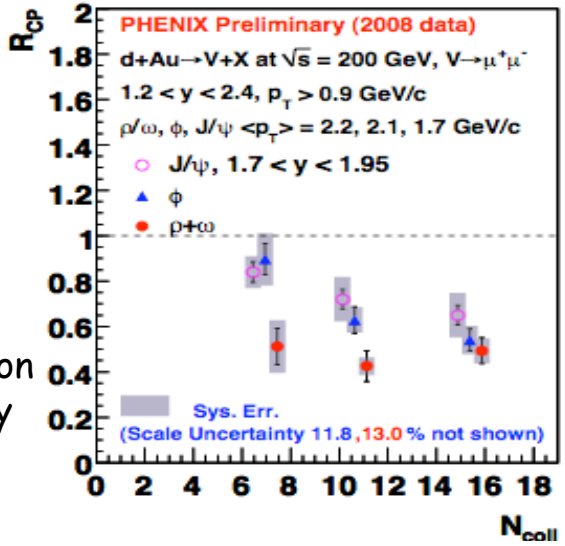




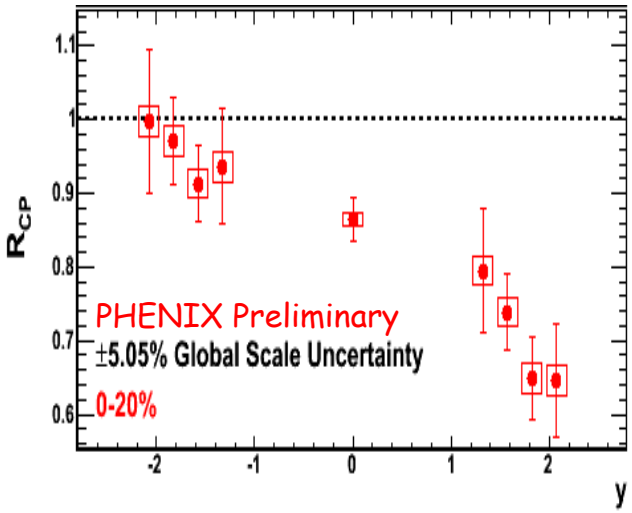
Recent CNM results from d+Au collisions



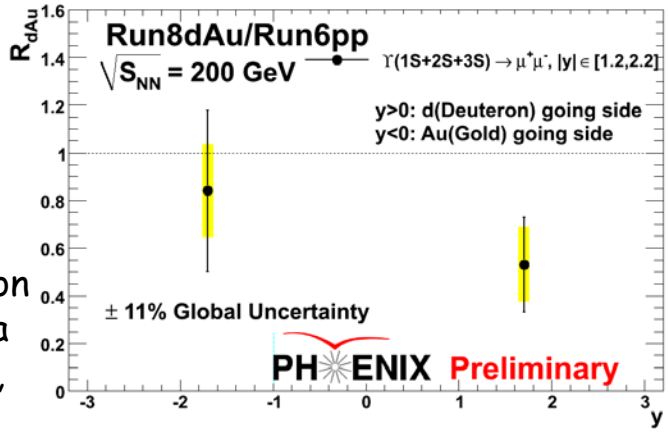
J/ψ suppression in CNM for RHIC d+Au compared to lower energy experiments (Colorado, Leitch, Pereira)



φ, ρ and ω suppression for forward-rapidity (Lei Guo, …)



New J/ψ suppression from 2008 d+Au data (Colorado, Leitch, Pereira)



Upsilon suppression in 2008 d+Au data (K. Lee (Korea U.), Leitch, …)

Isolating & quantifying gluon saturation & CNM dE/dx

A 6-year View for the LANL HI Physics Program

2010	2011	2012	2013	2014	2015
500 GeV p+p 200 GeV Au+Au	500 GeV p+p 200 GeV Au+Au	200 GeV p+p 200 GeV d+Au	500 GeV p+p 200 GeV Cu+Au, U+U	200 GeV Au+Au 62 GeV Au+Au p+He^3	???
FVTX construction →	Physics with FVTX for multiple species of collisions →				
				PHENIX Decadal Upgrades →	
R_{AA} J/ψ central	R_{AA} c,b R_{AA} ψ'	R_{dAu} c,b,J/ψ, ψ',ϒ, DY	R_{CuCu} c,b,J/ψ, ψ',ϒ	R_{AA} ϒ, DY 62 GeV c,J/ψ, ψ'	(yr. data taken; analysis ~1 yr later)
E906 startup →			E906 dE/dx		JPARC Pol. DY?
	1st LHC HI Run	2nd LHC HI Run		1st high-lumi HI Run	2nd high-lumi HI Run
	σ_{Z0} in p+p and Pb+Pb	Z_0, ϒ R_{AA} & jet shapes		Z_0-jet tagging	Z_0-jet A+A fragm. modif.
→			Pixel readout HI upgrade		
				LHC p+A?	