Cold Nuclear Matter, QGP Screening and Regeneration

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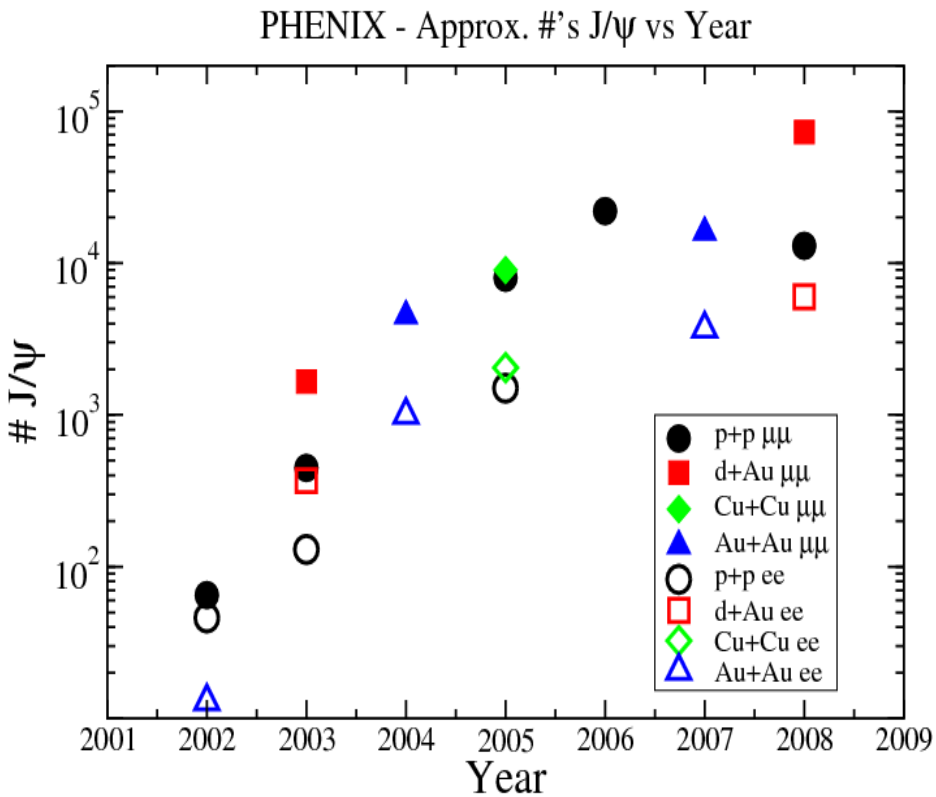
- Quarkonia & Deconfinement
- PHENIX A+A Results
- Cold Nuclear Matter (CNM)
- New 2008 d+Au data
- Sequential Screening
- Regeneration
- Future

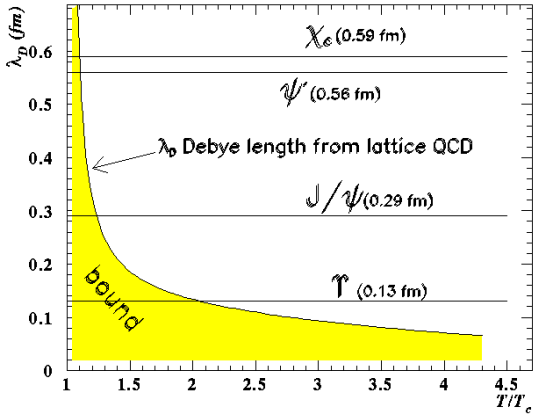


Deconfinement and Quarkonia

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

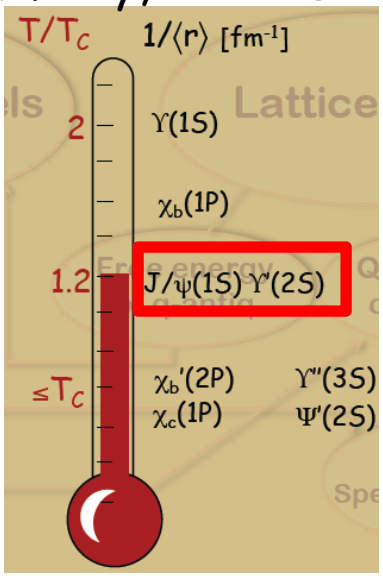
- Large quark energy loss in the medium implies high densities
- Flow scales with number of quarks
- Is there deconfinement? → quarkonia screening is the probe

(quarkonia = vector mesons = J/ψ, ψ', ϒ, ...)



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.

Mocsy, WWND08



RHIC: T/T_C ~ 1.9 or higher

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

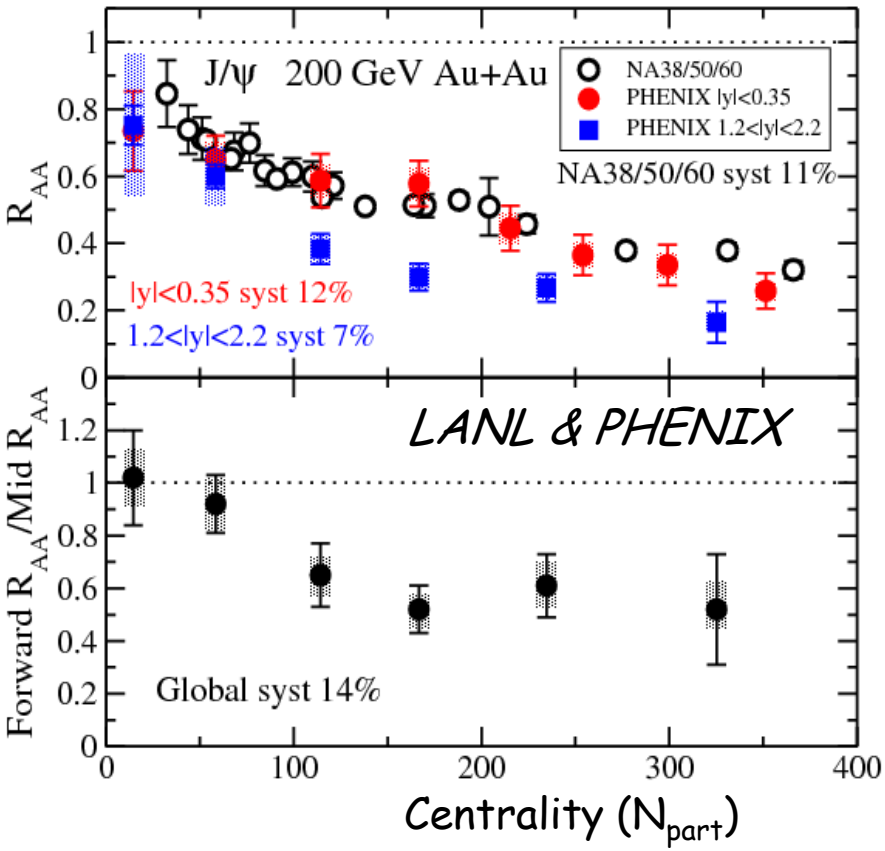
Satz, hep-ph/0512217

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.
- Forward/Mid R_{AA} ratio looks flat above a centrality with N_{part} = 100

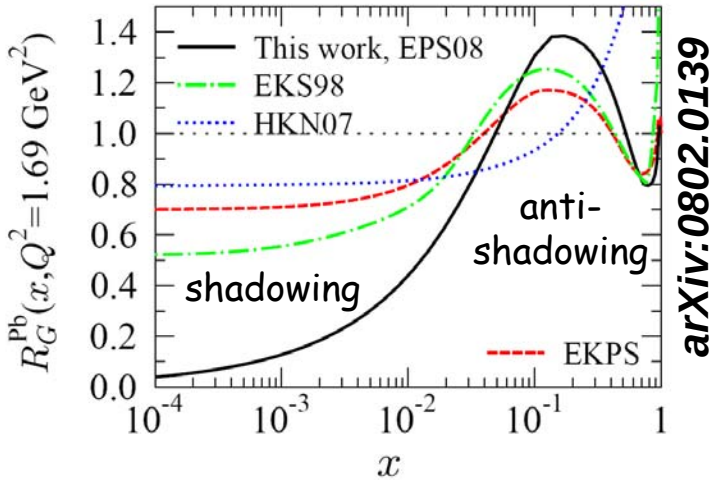


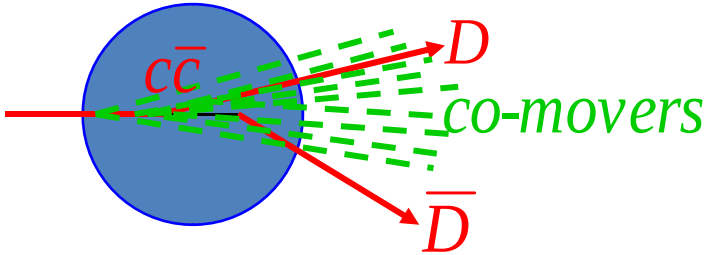
Several scenarios may contribute:

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

Cold Nuclear Matter (CNM) Physics

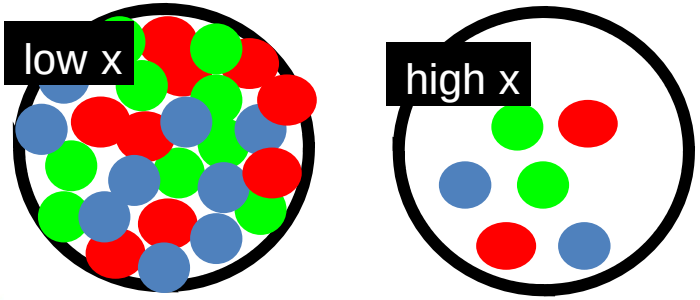
Traditional shadowing from fits to DIS or from coherence models



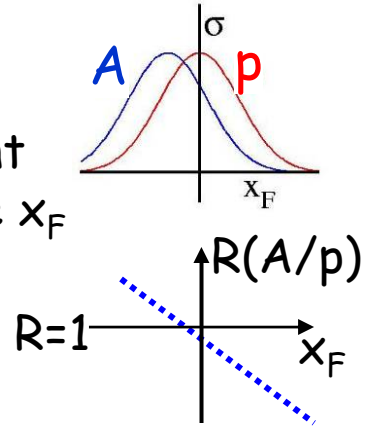


Absorption (or dissociation) of $c\bar{c}$ into two D mesons by nucleus or co-movers

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



CNM Physics – PHENIX, E866, NA3 Comparison

New Analysis of Run3 d+Au with new 2005 p+p baseline

PRC 77,024912(2008)

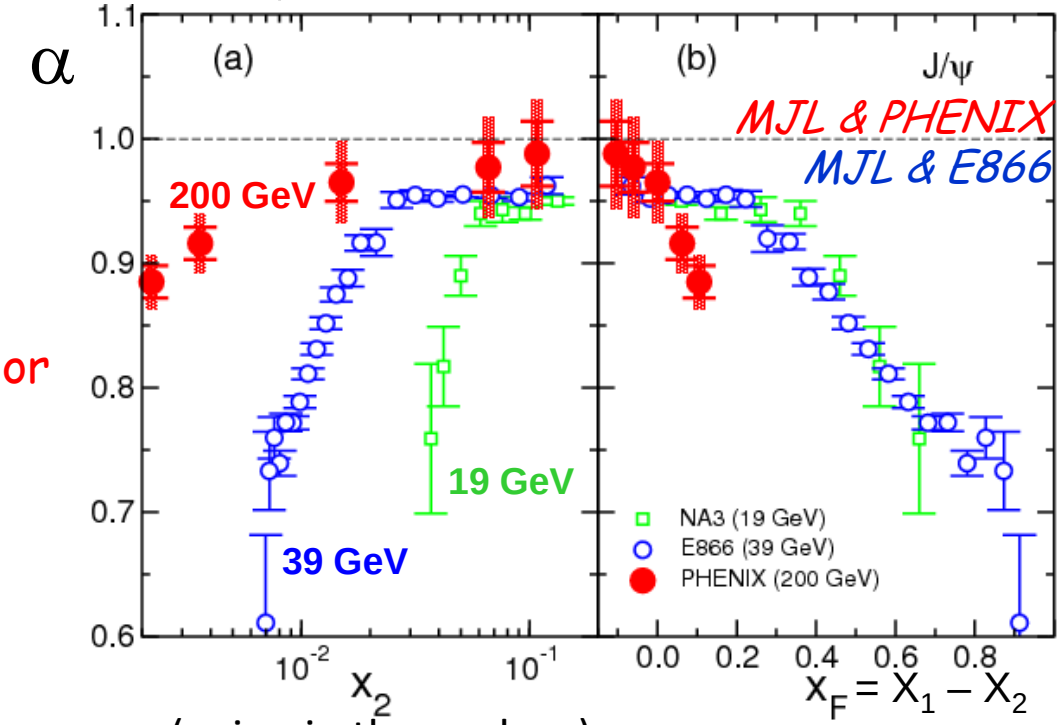
Compared to LANL-led E866/NuSea p+A results & lower-energy NA3 at CERN

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

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

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

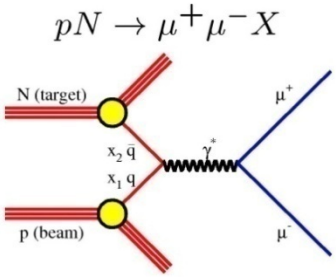
J/ψ α for different √s collisions



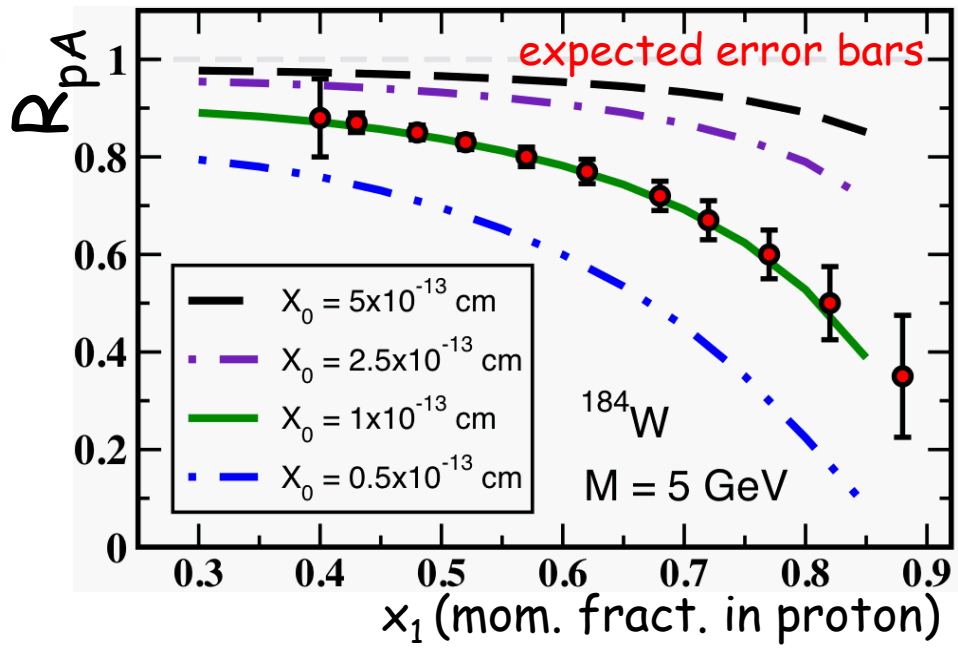
(x_2 is x in the nucleus)

FNAL E906 (120 GeV)
Quark Energy Loss in (Cold) Nuclei

Drell-Yan in p+A collisions – no final-state interactions



Vitev calculations with various levels of dE/dx compared to expected E906 error bars



In LANL-led E866 at 800 GeV, the nuclear dependence of Drell-Yan could not unambiguously separate dE/dx & small-x shadowing

With Drell-Yan for p+A at 120 GeV:

- $x > 0.1 \rightarrow$ NO shadowing
- only quark dE/dx remains

Important for understanding dE/dx at RHIC

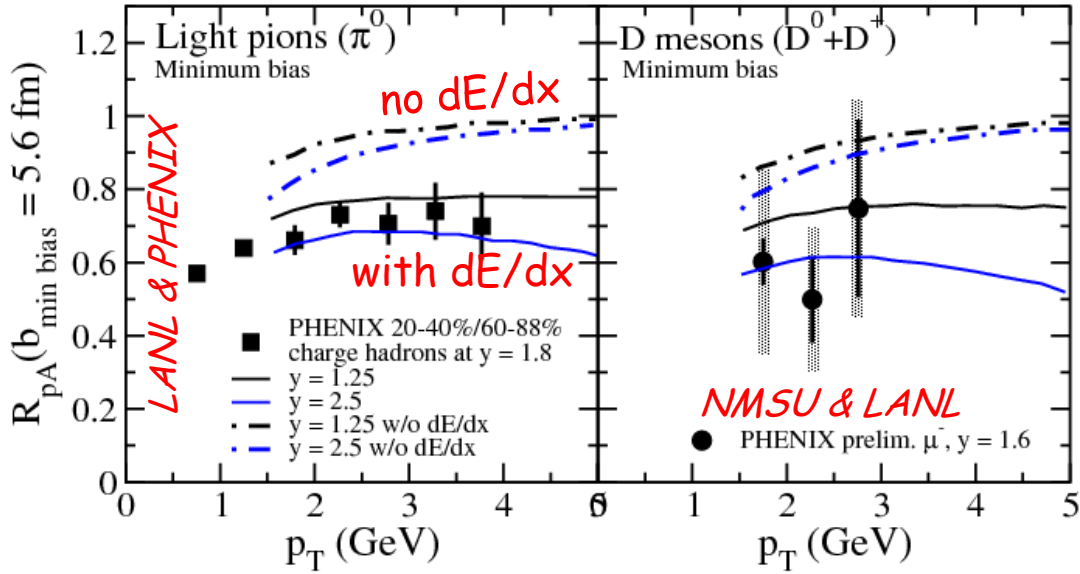
LANL LDRD for E906 led by Ming Liu

Vitev, Goldman, Johnson and, Qiu, Acta. Phys. Hung. **A27, 275 (2006).**

CNM Physics - Hadrons & Charm at Forward Rapidity

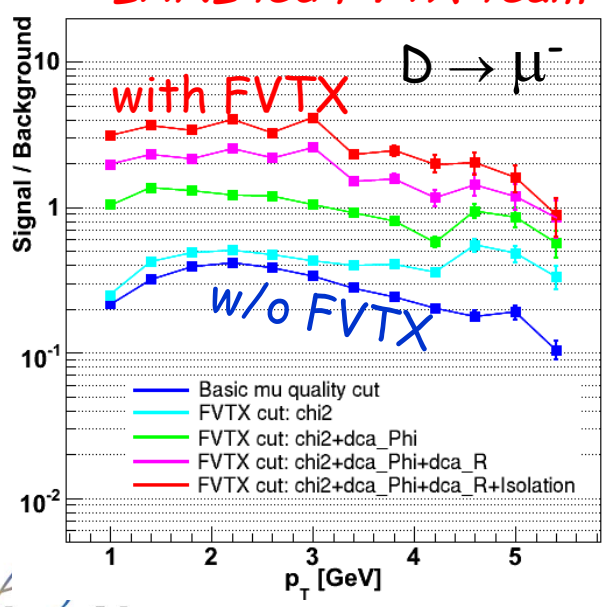
Vitev calculations with & w/o dE/dx compared to dAu data for π^0 & D

Vitev, Goldman, Johnson, Qiu, PR D74, 054010 (2006).



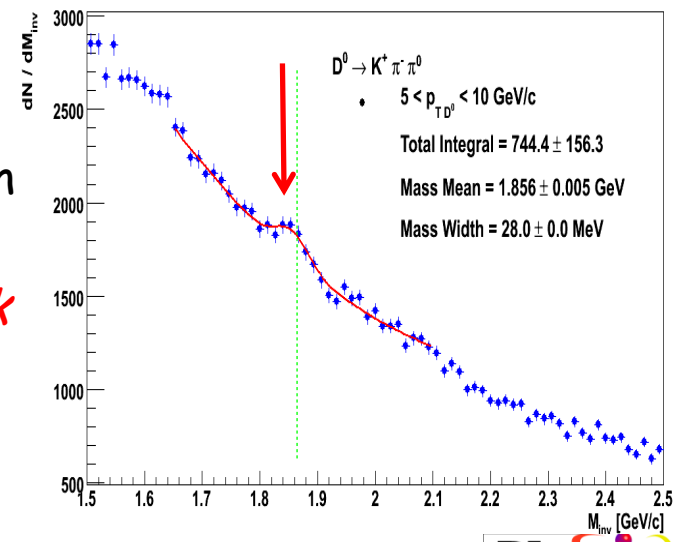
Precision measurements in future with FVTX

LANL led FVTX team



also exclusive $D^0 \rightarrow K^+ \pi^- \pi^0$ in p+p collisions

Sergey Butsyk



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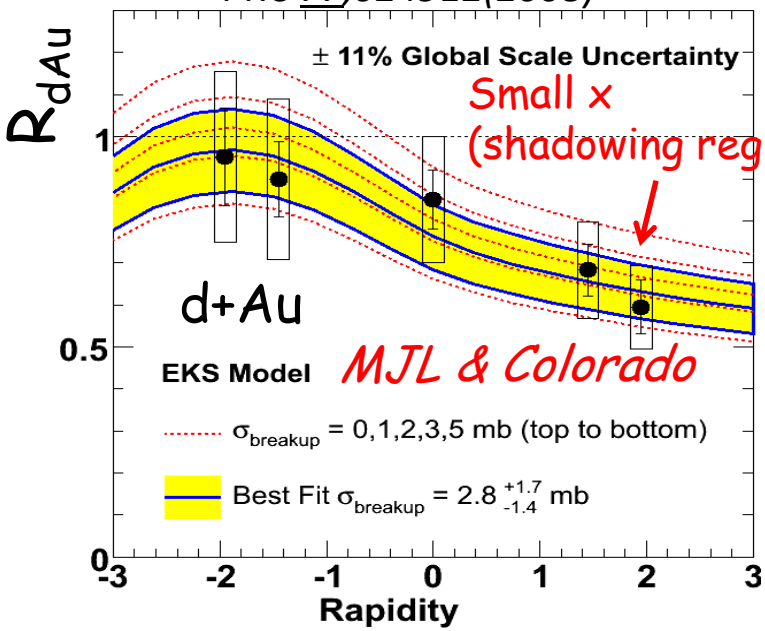
Physics

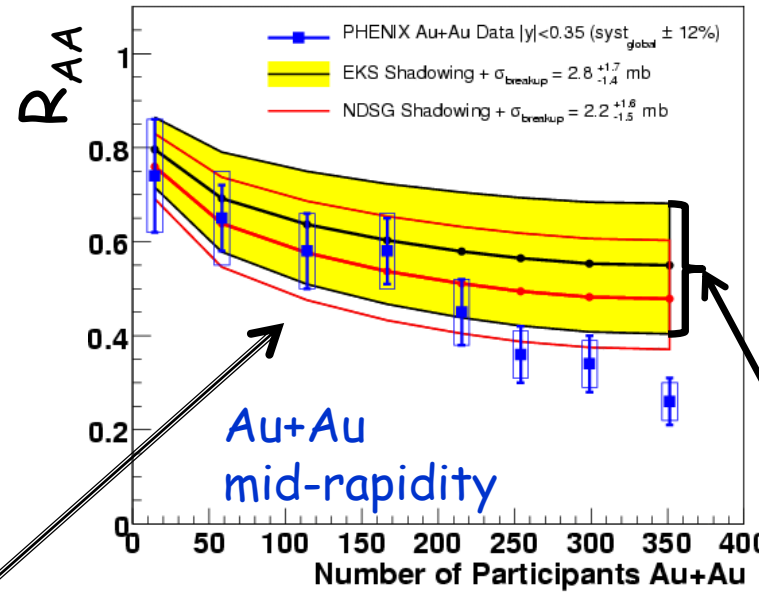
Present CNM Constraints on A+A data

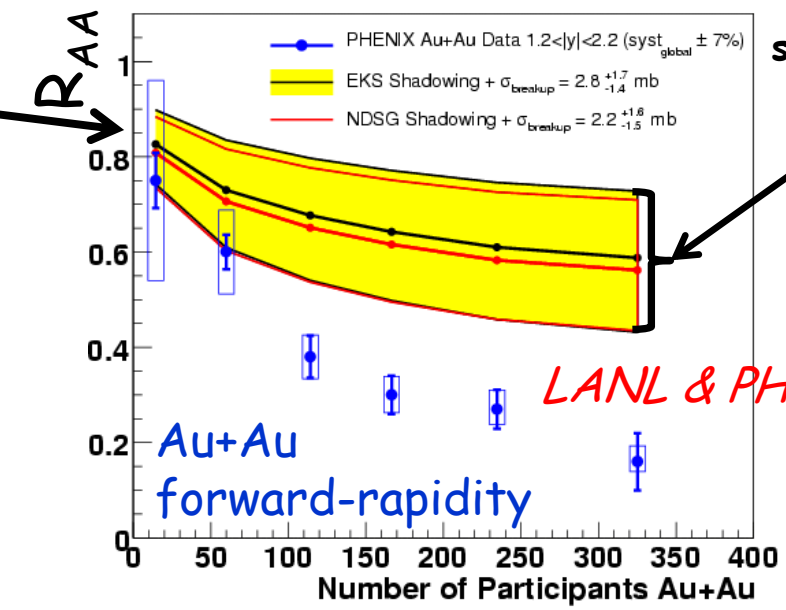
CNM effects (EKS shadowing + dissociation from fits to d+Au data, with R. Vogt calculations) give large fraction of observed Au+Au suppression, especially at mid-rapidity

PRC 77,024912(2008)



more accurate d+Au constraint badly needed





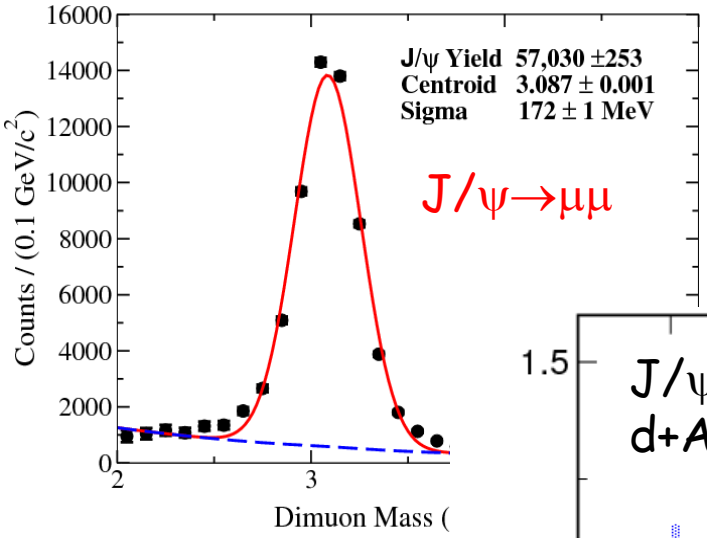
EKS shadowing band

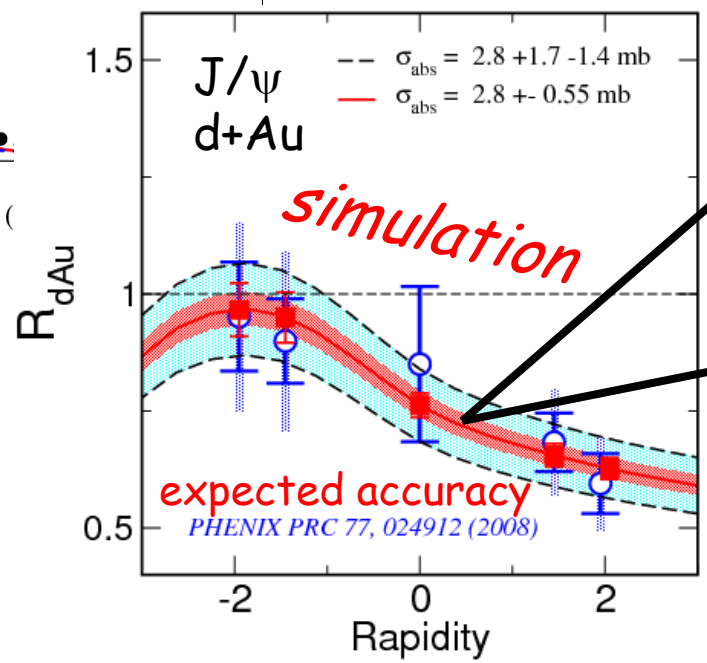
CNM Constraints from New Run8 d+Au J/ψ Data

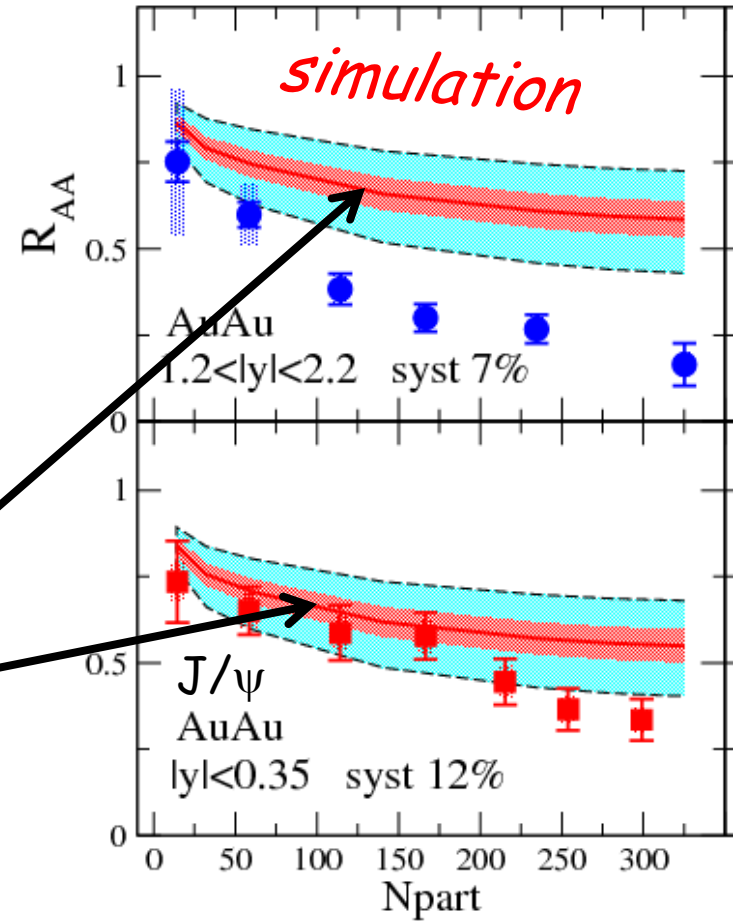
MJL PHENIX Run Coordinator service

- Run7 – Au+Au (833 μb^{-1}) – 3.4 x Run4
- Run8 – d+Au (80 nb^{-1}) – 30 x Run3

Expected improvement in CNM constraints (red) compared to Run3 (blue)







Mike Leitch, LANL

QGP Effects on Quarkonia
Sequential Screening and Gluon Saturation

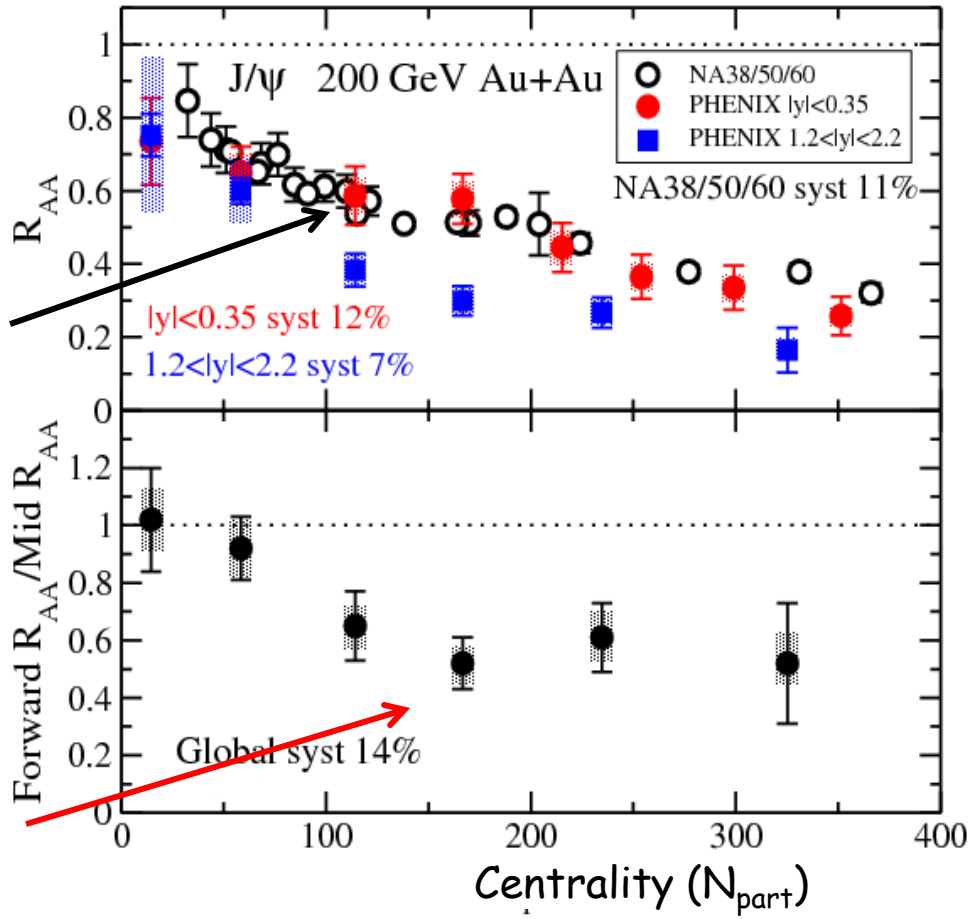
Some recent lattice calculations suggest J/ψ not screened at all

- suppression then comes only via feed-down from screened χ_C & ψ'

- then the situation would be the same at lower energies (NA38/50/60) as for RHIC mid-rapidity

- and the stronger suppression at forward rapidity at RHIC could come from gluon saturation

- *Can this picture explain flat forward/mid-rapidity R_{AA} super-ratio?*



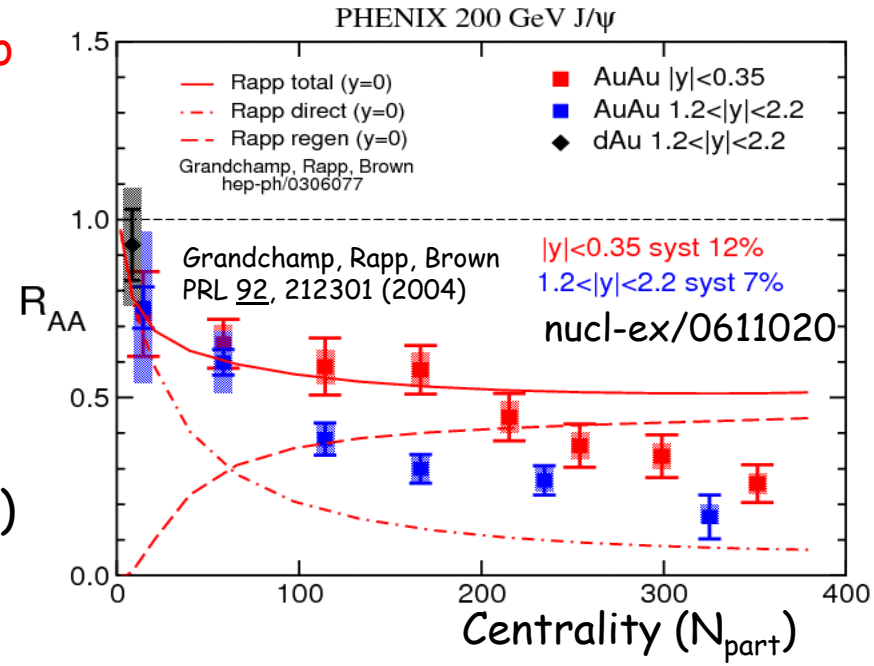
QGP effects on Quarkonia Regeneration – Compensating for Screening

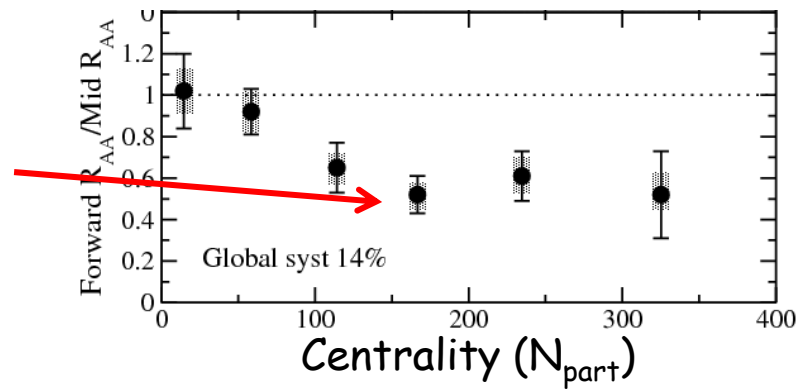
- larger gluon density at RHIC expected to give stronger suppression than SPS
- but larger charm production at RHIC gives larger regeneration

- forward rapidity lower than mid due to smaller open-charm density there
- very sensitive to poorly known open-charm cross sections (FVTX will help here)

- expect inherited flow from open charm
- regeneration would be HUGE at the LHC!

- *can the two compensating components (screening & regeneration) which may have diff. centrality dependences, give a flat forward/mid-rapidity R_{AA}?*

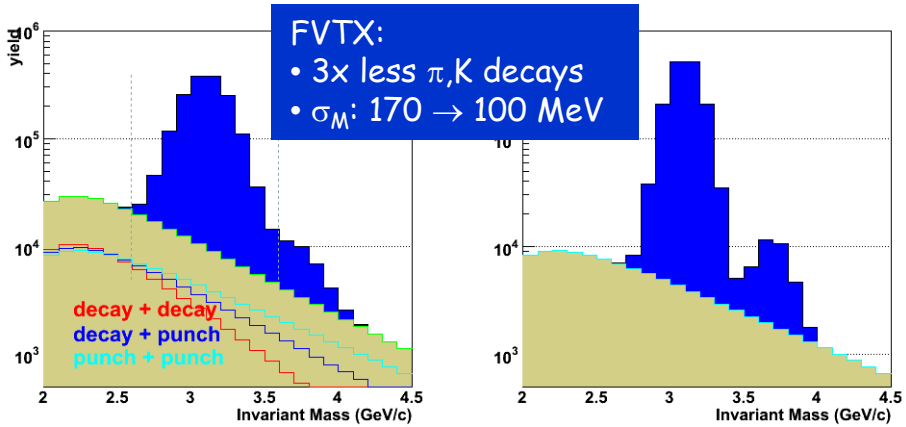


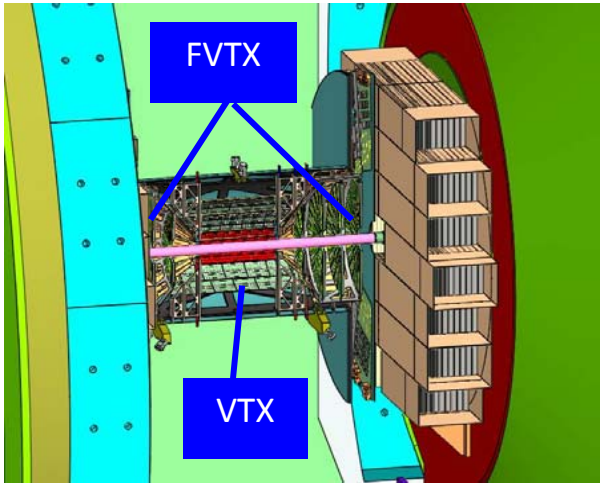


PHENIX Upgrades & RHIC Luminosity Advances

Vertex detectors (VTX,FVTX) + higher luminosity will give:

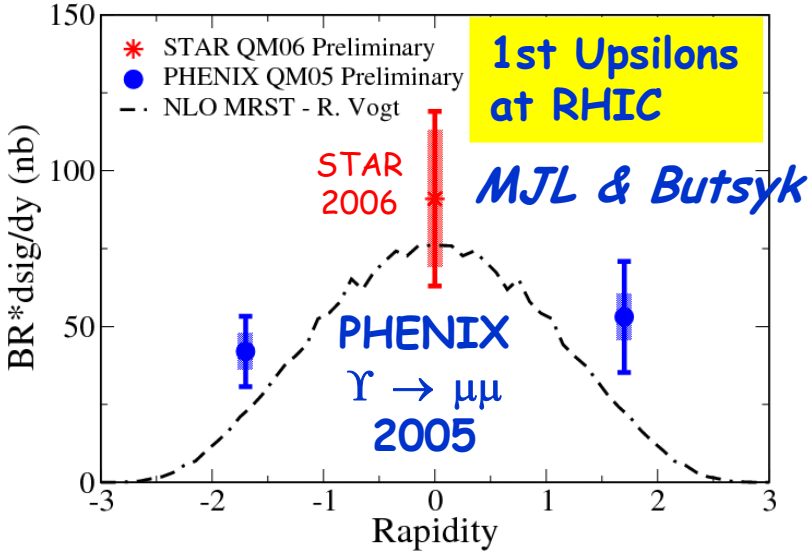
- ψ' measurement with reduced combinatoric background + sharper mass resolution
- precise open-heavy measurements to constrain regeneration picture
- hadrons at forward rapidity





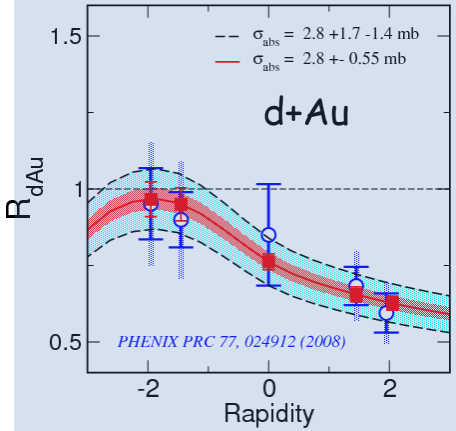
Rates for a 12-week Au+Au run at highest RHIC (stoch. cooled) luminosities (muon arms + FVTX)

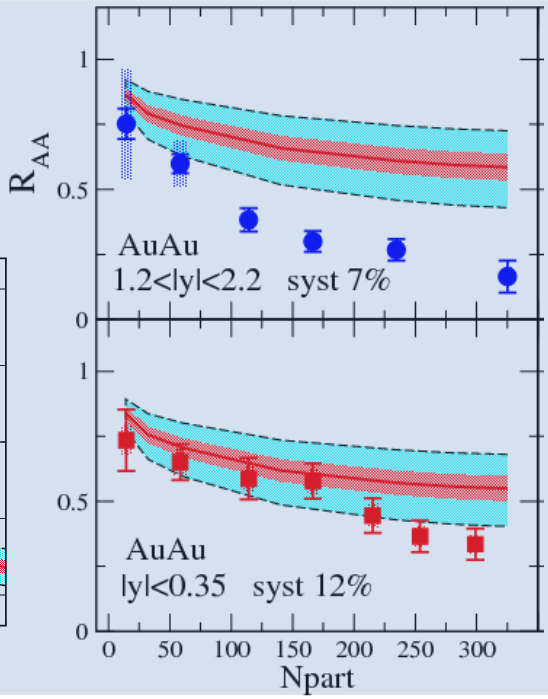
J/ψ	ψ'	ϒ	B → J/ψ X
121k	2.2k	600	3.4k



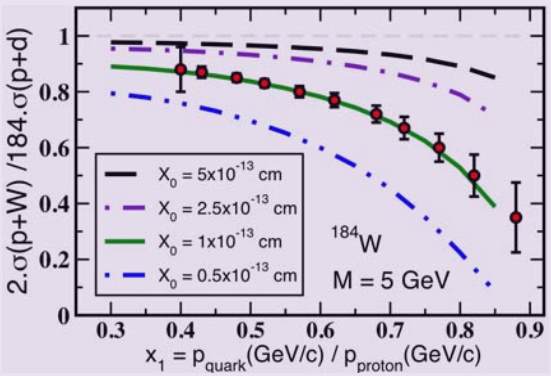
LANL Thrusts - CNM, Quarkonia Screening & Regeneration

Precise J/ψ CNM constraints from Run8 d+Au & A+A baseline

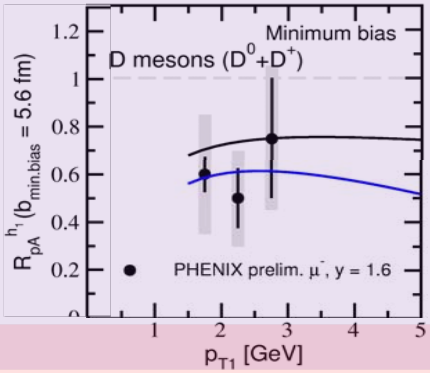




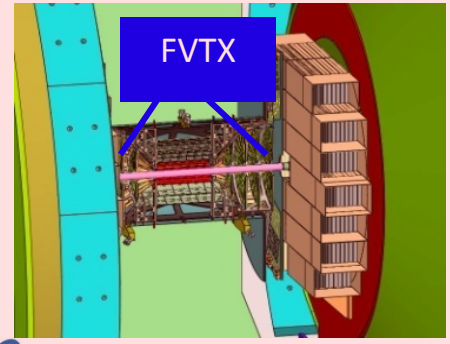
E906 Quark dE/dx in CNM

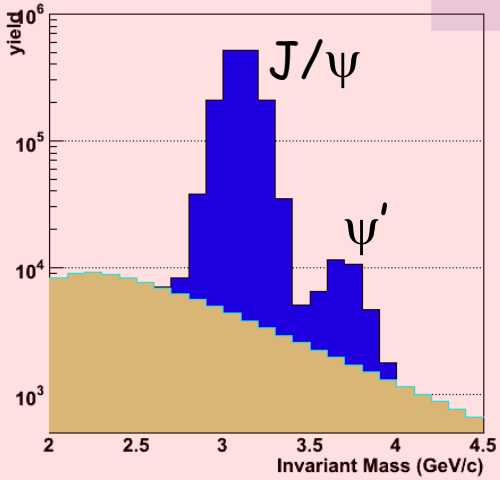


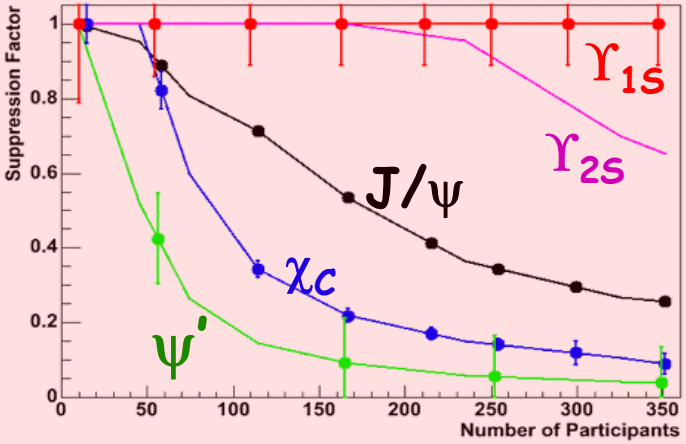
Forward hadrons & charm in d+Au & later with FVTX



ψ′ measurements & open-heavy with FVTX







Backup Slides

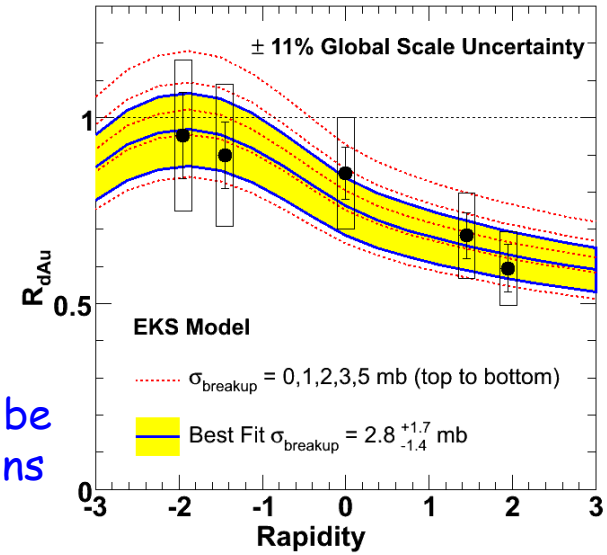
Nuclear Dependence Nomenclature – Ratio (R_{dAu}, R_{AA}) and Alpha (α)

$R_{dAu} = \alpha = 1$ if every N-N collision in a Nucleus contributes as if it were in a free nucleon

$$R_{dAu} = \frac{d\sigma^{dAu}/dy}{2\times 197\cdot(d\sigma^{pp}/dy)}$$

$$= \frac{dN^{dAu}/dy}{\langle n_{coll}^{dAu}\rangle dN^{pp}/dy}$$

$\langle n_{coll}\rangle$ from Glauber model calc. – can also be used for centrality bins

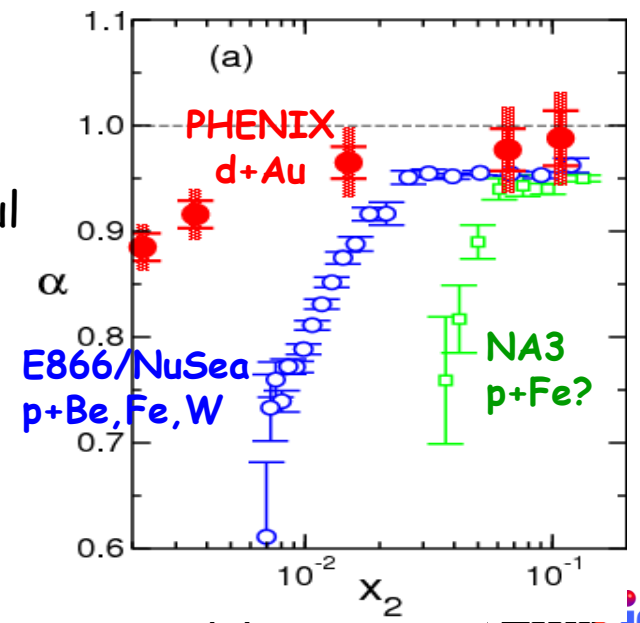


Where dN^{dAu}/dy is an invariant yield w/o absolute normalization factors that would be needed for a cross section (lower systematical uncertainties)

Alternatively, a power law with α – especially useful when comparing expts that used different nuclear targets

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

$$\alpha = 1 + \ln(R_{pA})/\ln(A)$$



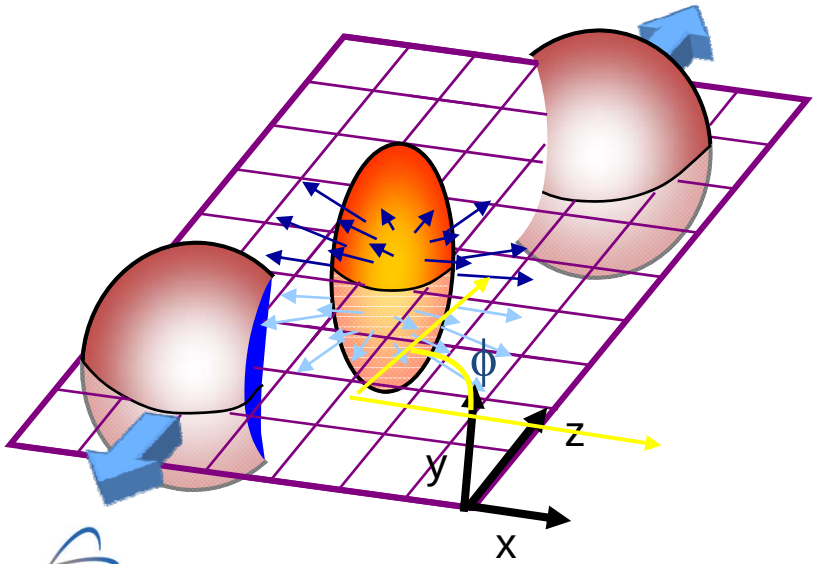
Flow: A Collective Effect

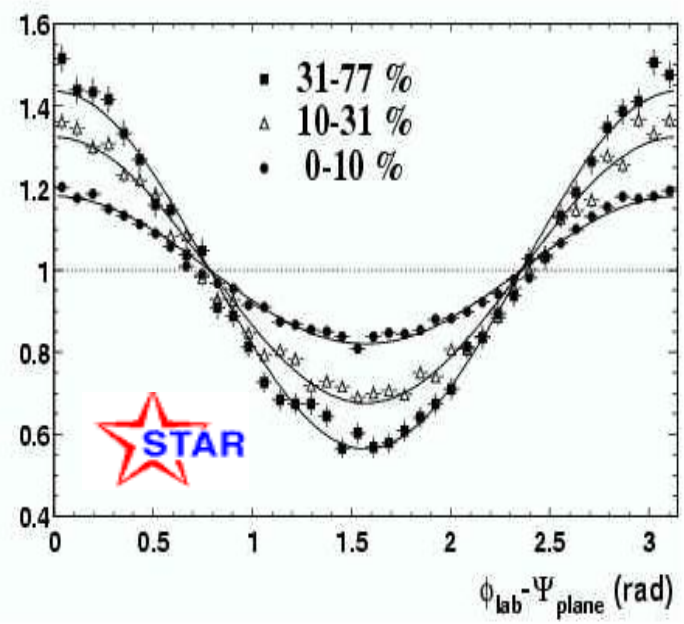
Initial spatial anisotropy converted into momentum anisotropy

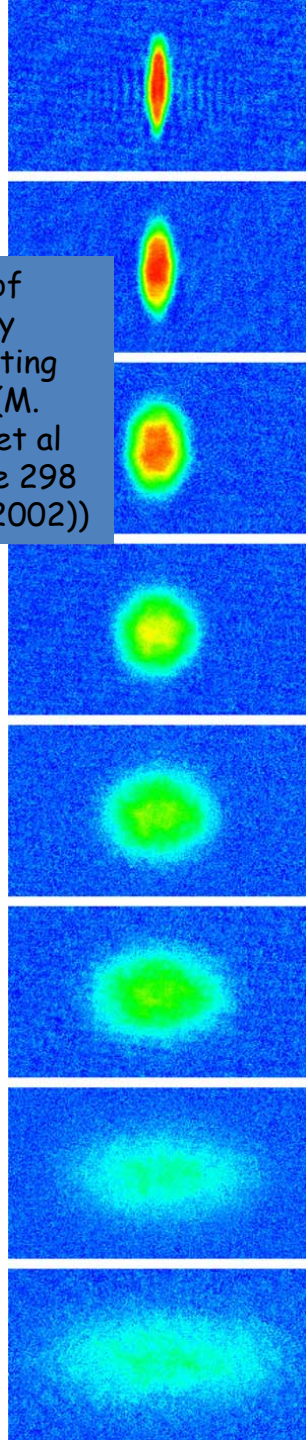
Efficiency of conversion depends on the properties of the medium

Elliptic flow = v_2 = 2nd fourier coefficient of momentum anisotropy

$$dn/d\phi \sim 1 + 2\, v_2(p_T) \cos(2\phi) + \ldots$$



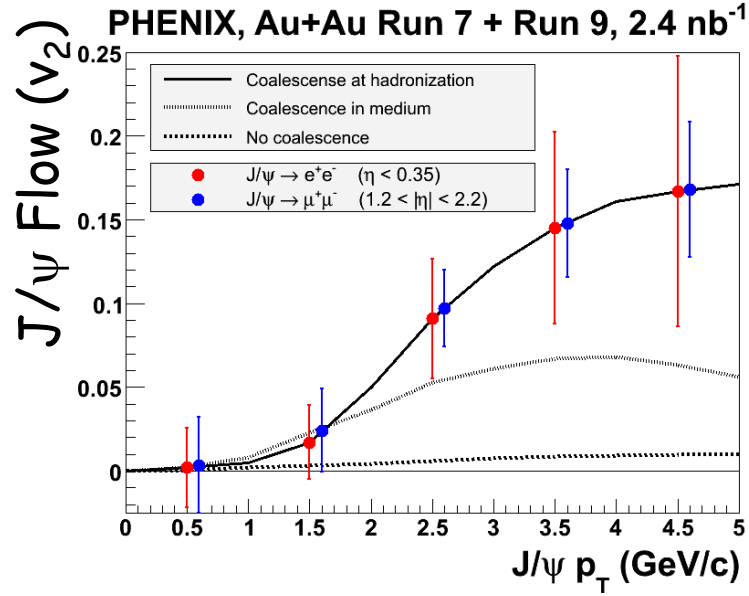




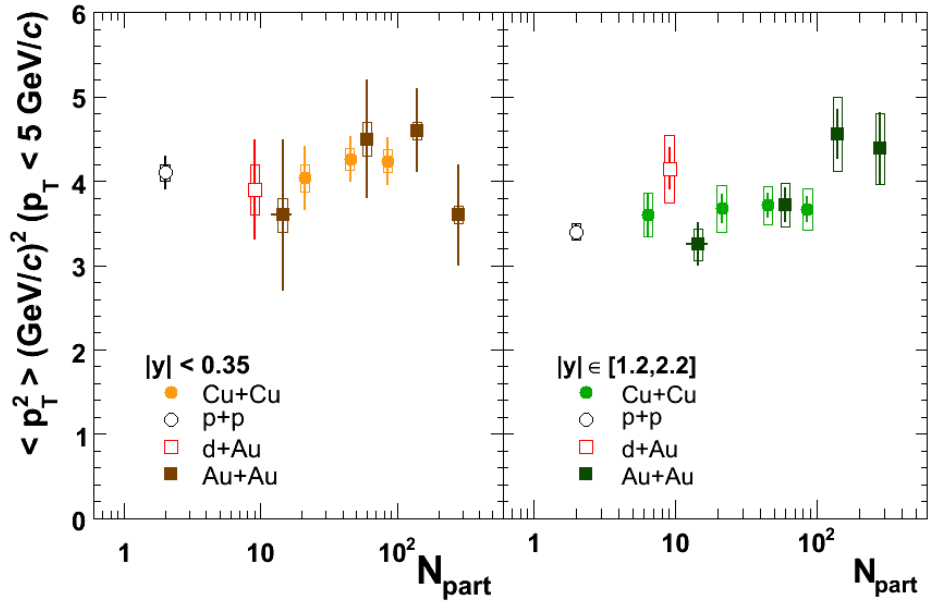
Gases of strongly interacting atoms (M. Gehm, et al Science 298 2179 (2002))

QGP effects on Quarkonia - J/ψ flow & p_T Broadening

- J/ψ's from regeneration should inherit the already observed large charm-quark elliptic flow
- First J/ψ flow measurement by PHENIX
- also need to measure open-charm flow at forward rapidity
- Projection for Run9+7 (2.4 nb^{-1}) with dimuons (blue) & dielectrons (red)



- CNM effects broaden p_T
  - initial-state mult. scatt. for both gluons
- but regeneration should narrow p_T
  - square of small-p_T peaked open-charm cross section
- AA data same as pp & relatively flat with centrality



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Physics