Recent Heavy Flavor Results from PHENIX. A personal review …

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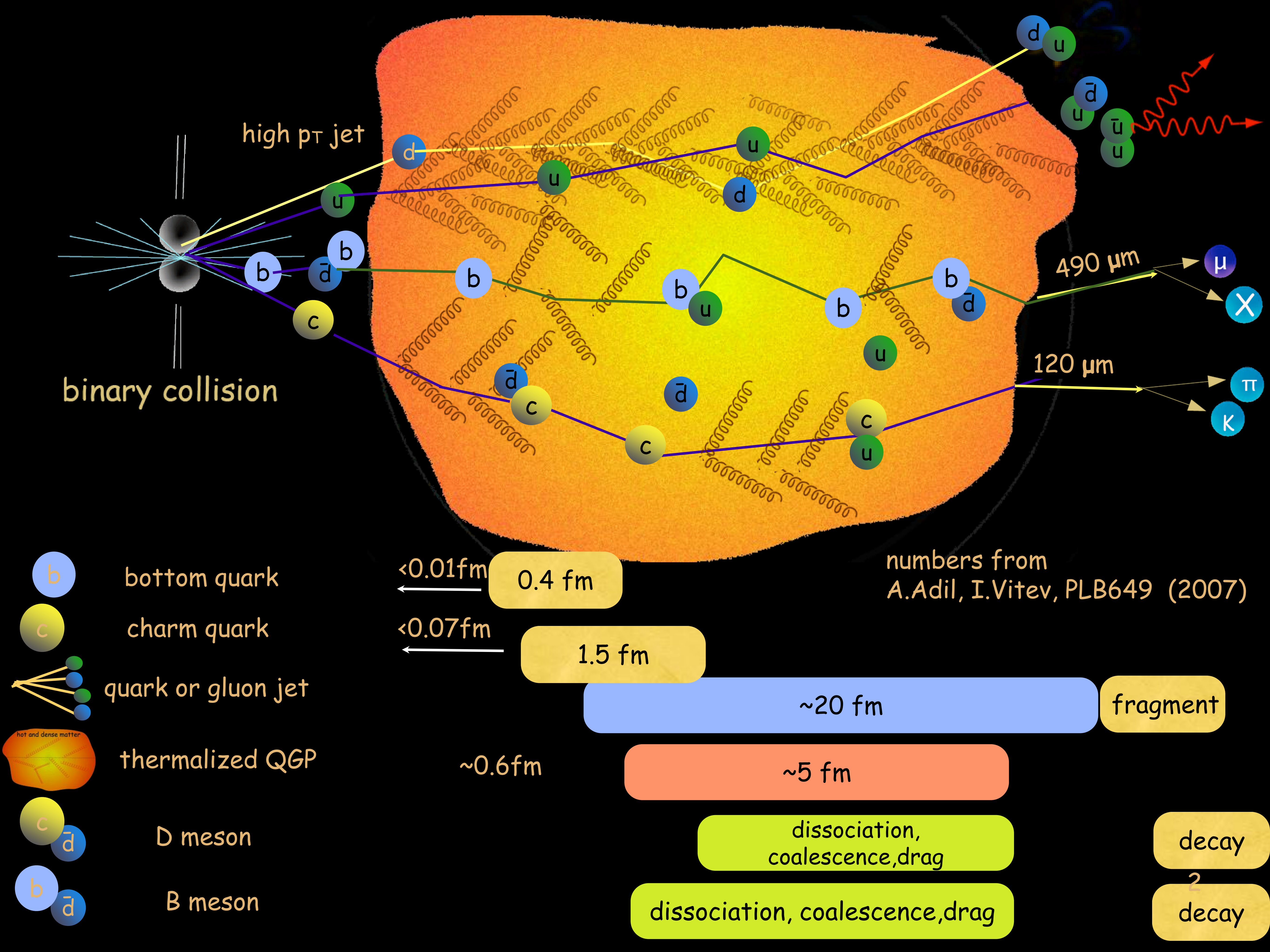
EST. 1943

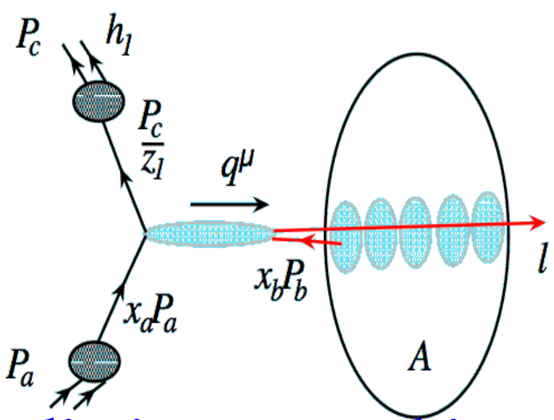
INT – Heavy Flavor and Electromagnetic Probes in Heavy Ion Collisions.
Seattle, Sep-19-2014


high pT jet
binary collision
490 μm
120 μm
μ
X
π
K
numbers from
A.Adil, I.Vitev, PLB649 (2007)
bottom quark
charm quark
quark or gluon jet
hot and dense matter
thermalized QGP
D meson
B meson
<0.01fm
0.4 fm
<0.07fm
1.5 fm
~20 fm
fragment
~0.6fm
~5 fm
dissociation,
coalescence,drag
decay
dissociation, coalescence,drag
2
decay

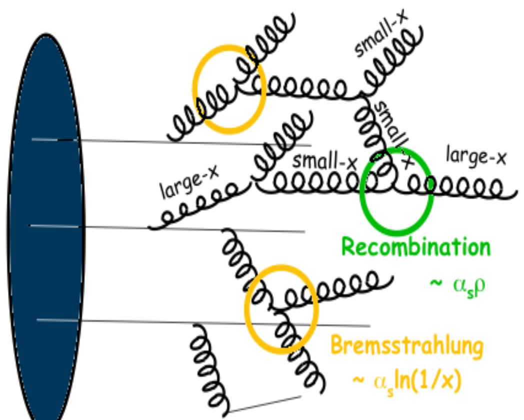
Competing effects on Quarkonia R_{AA}

arXiv:1404.2246

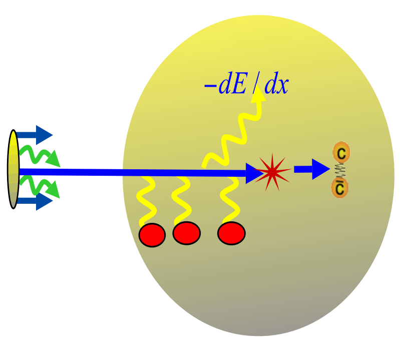
Multiple interactions



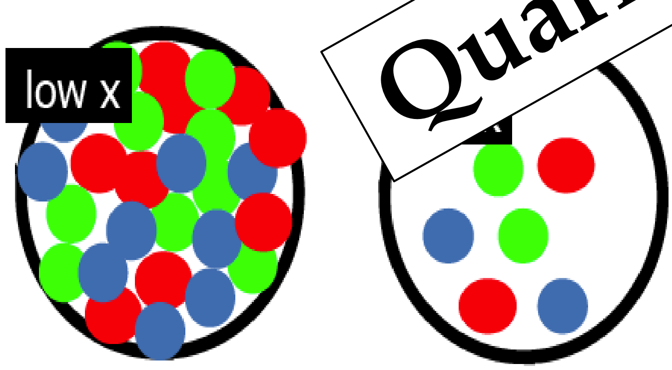
Radiation, recombinations

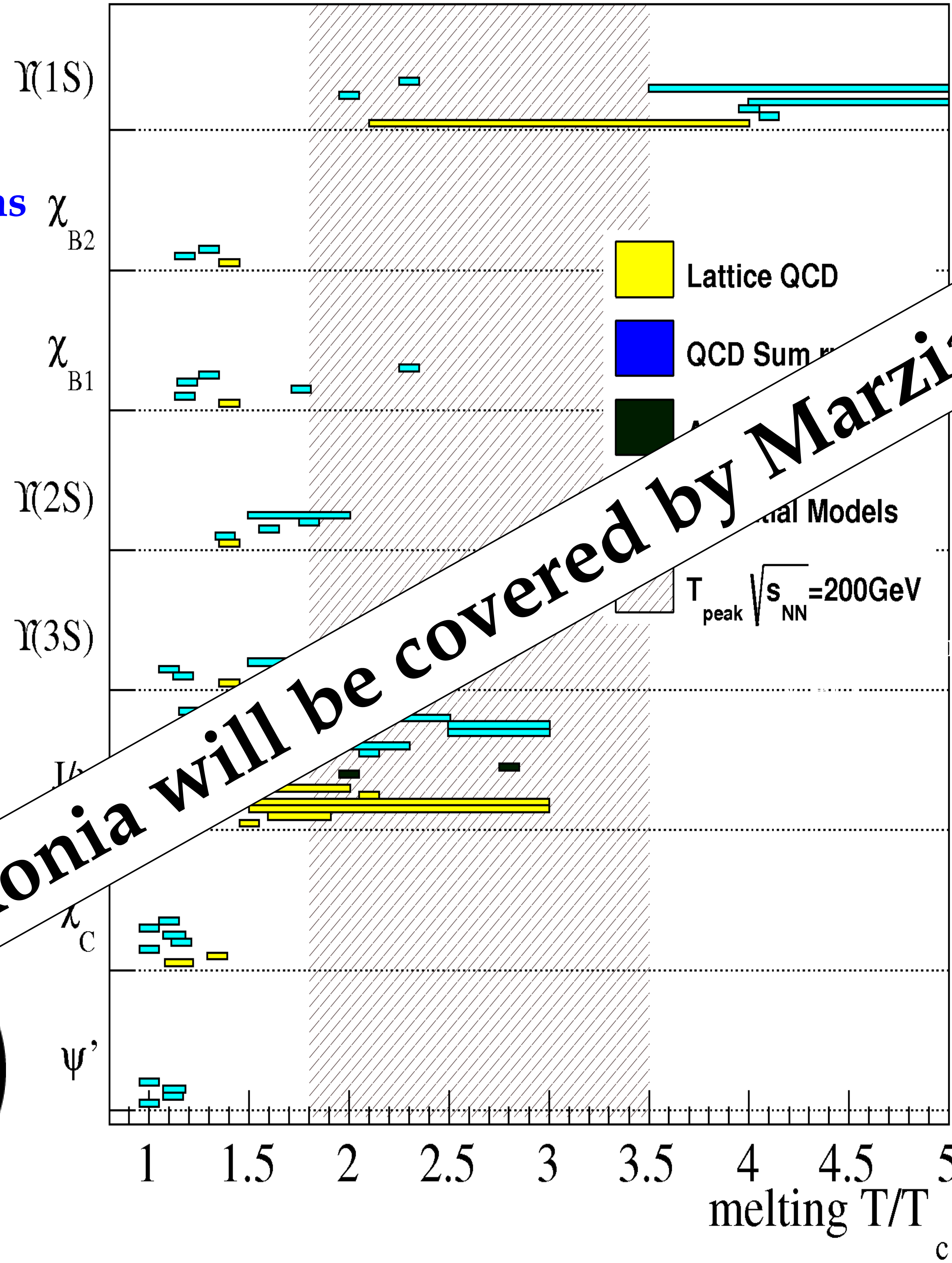


Parton energy loss



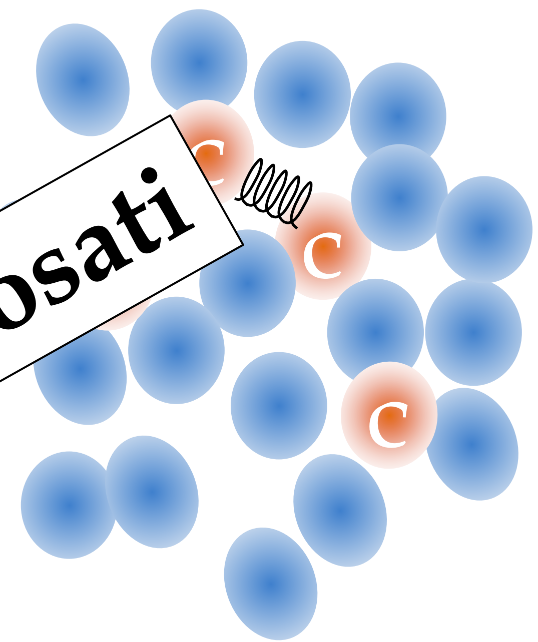
Gluon saturation

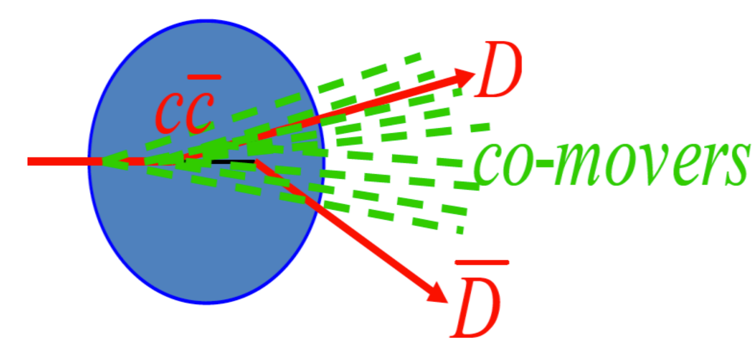




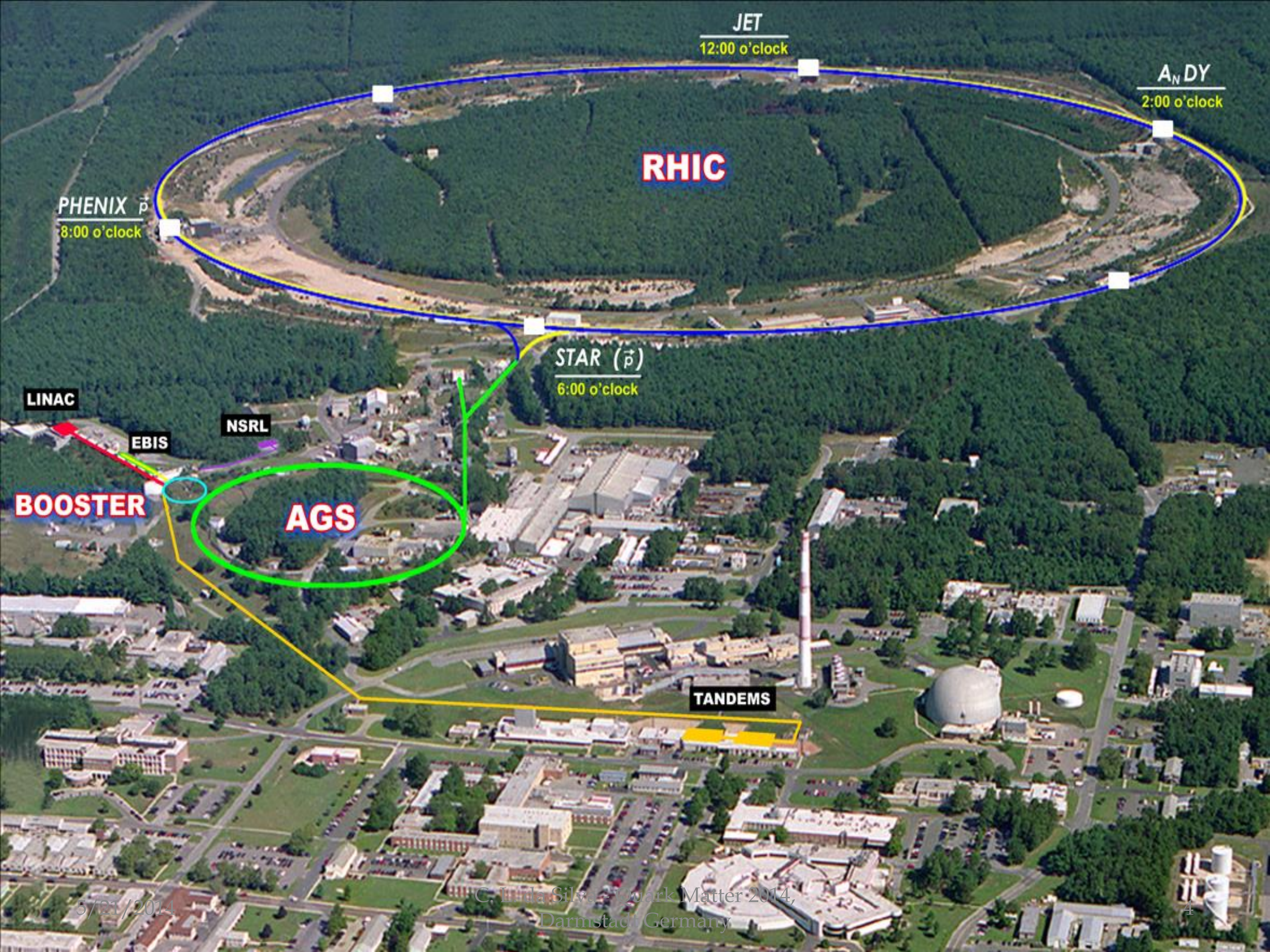
Quarkonia will be covered by Marzia Rosati

Coalescence, Regeneration





Need several measurements to isolate different effects.


JET
12:00 o'clock
A_NDY
2:00 o'clock
RHIC
PHENIX $\vec{p}$
8:00 o'clock
STAR ($\vec{p}$)
6:00 o'clock
LINAC
EBIS
NSRL
BOOSTER
AGS
TANDEMS

RHIC Ions – 6 species and 15 energies to date

$^{197}Au^{79} + ^{197}Au^{79}$

7, 9, 11, 15, 20, 27, **39, 62,** 130, **200.0** GeV/nucleon

$d + ^{197}Au^{79}$

200 GeV/nucleon

$^{63}Cu^{29} + ^{63}Cu^{29}$

22, 62, **200** GeV/nucleon

$p^{\uparrow} + p^{\uparrow}$

62, **200, 500, 510** GeV/nucleon

$^{63}Cu^{29} + ^{197}Au^{79}$

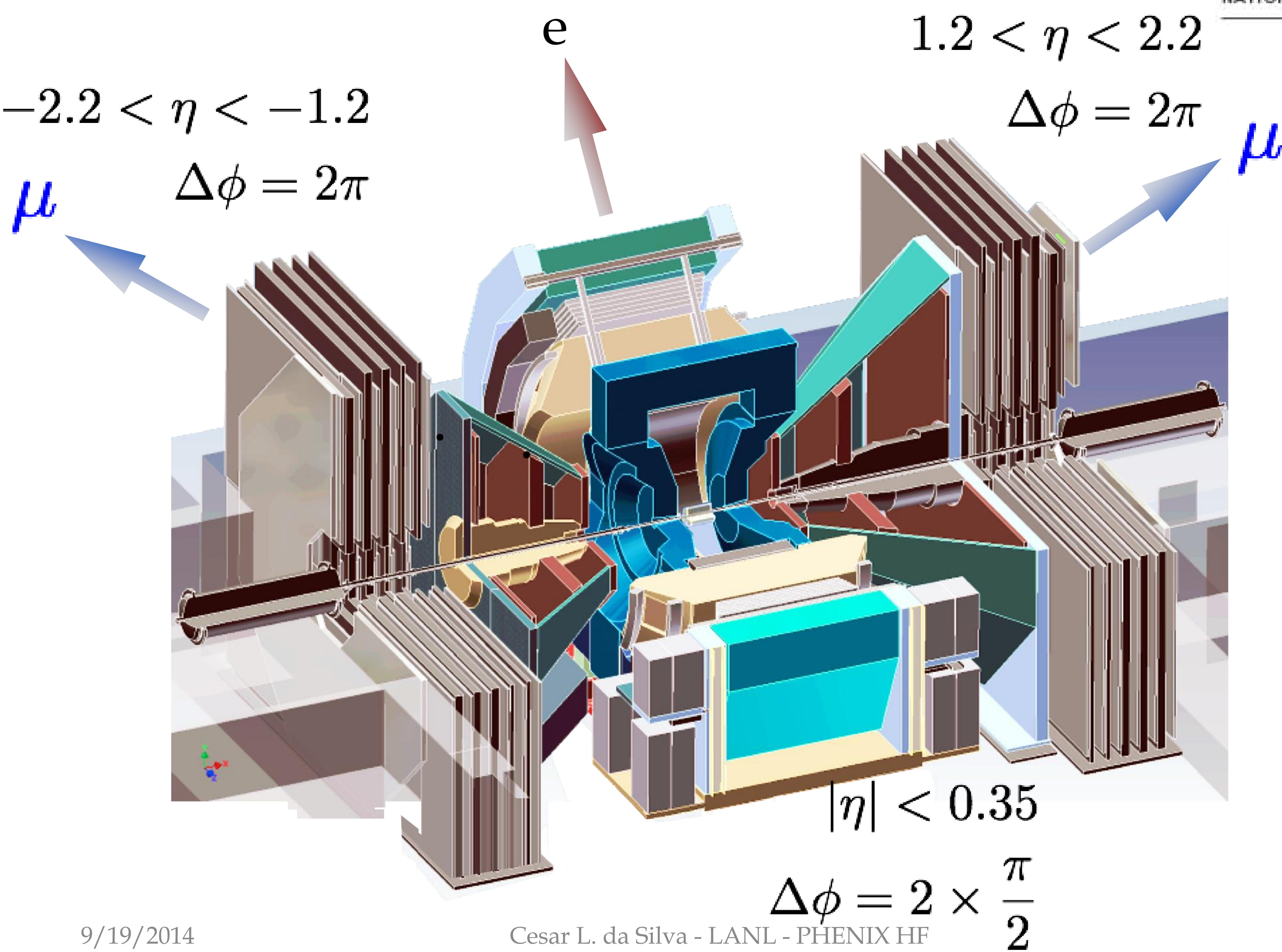
200 GeV/nucleon

$^{238}U^{92} + ^{238}U^{92}$

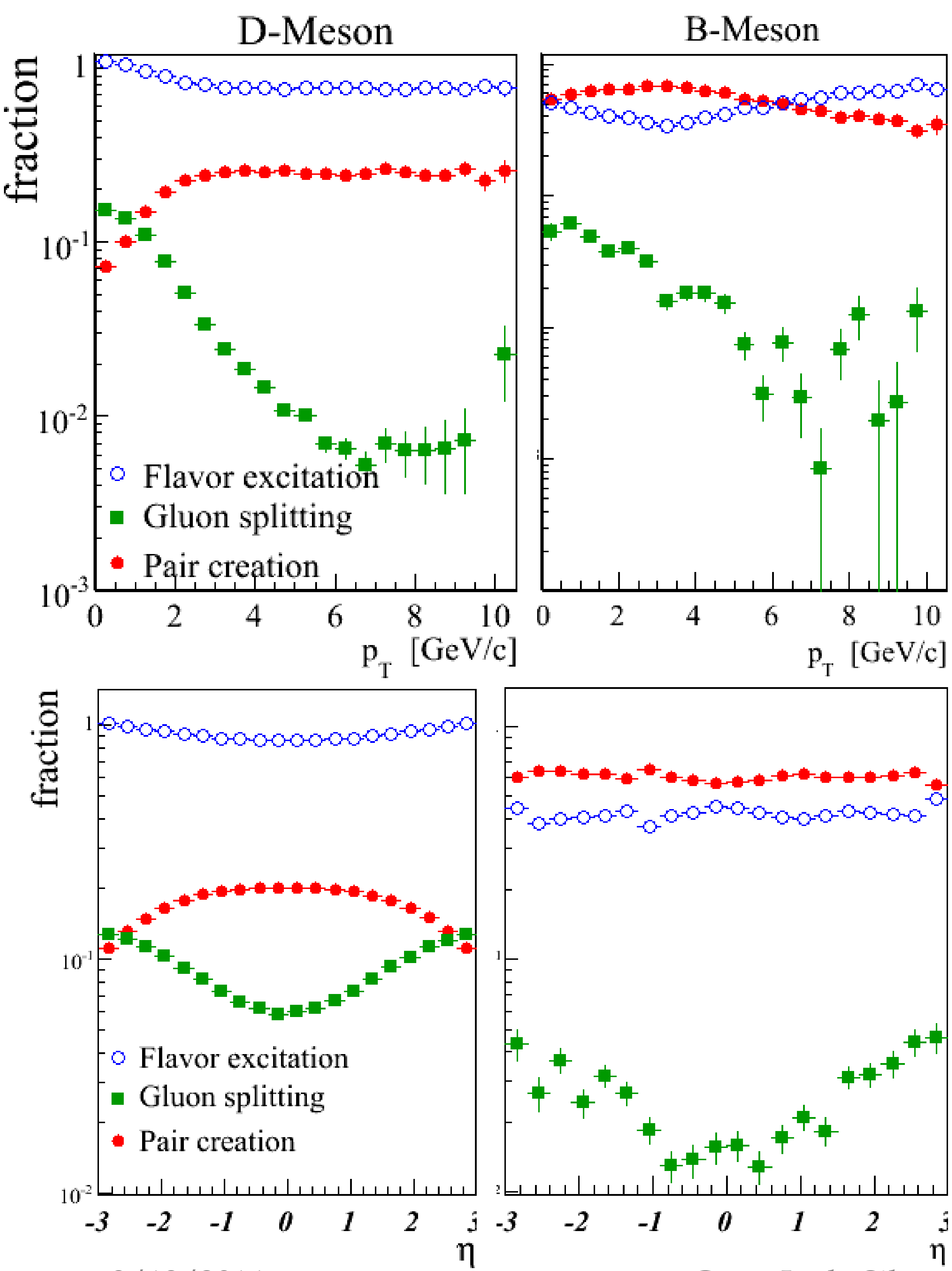
193 GeV/nucleon

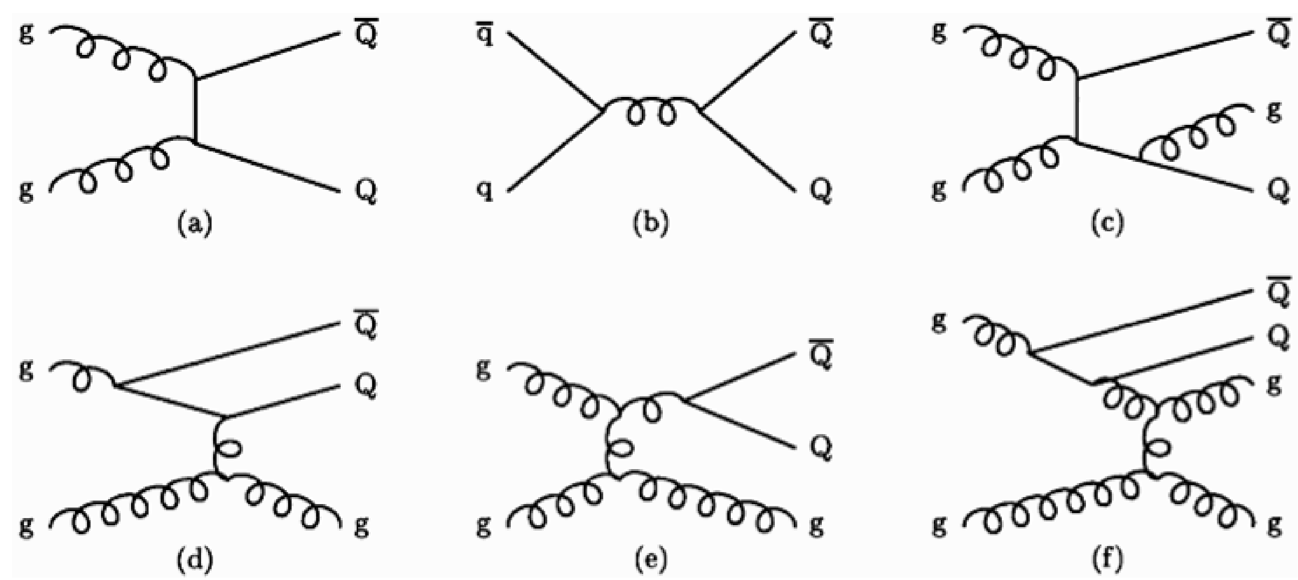
Can collide any species combination from proton(polarized) to uranium.

LEPTONS iN PHENIX DETECTOR



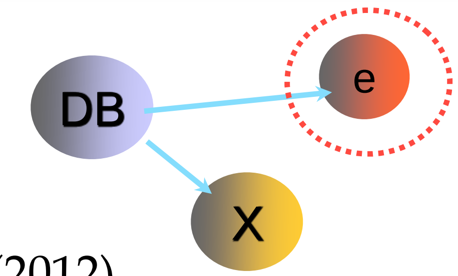
Sources of HF at RHIC





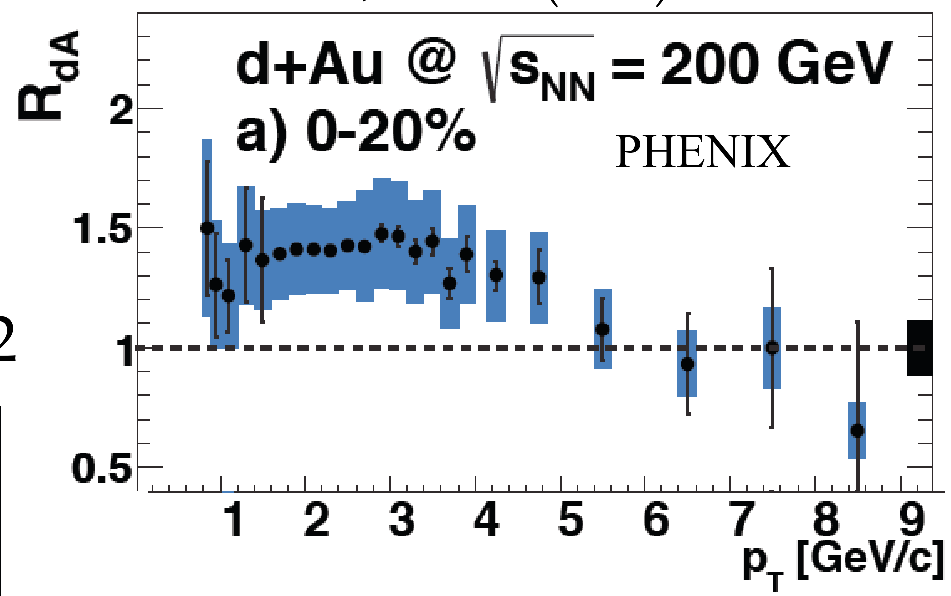
From PYTHIA

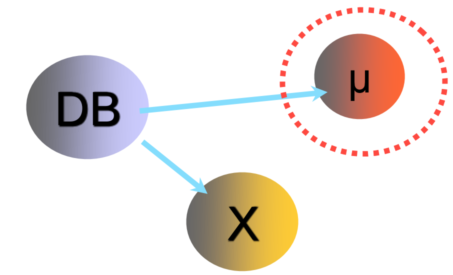
Heavy Flavor Results in d+Au Collisions



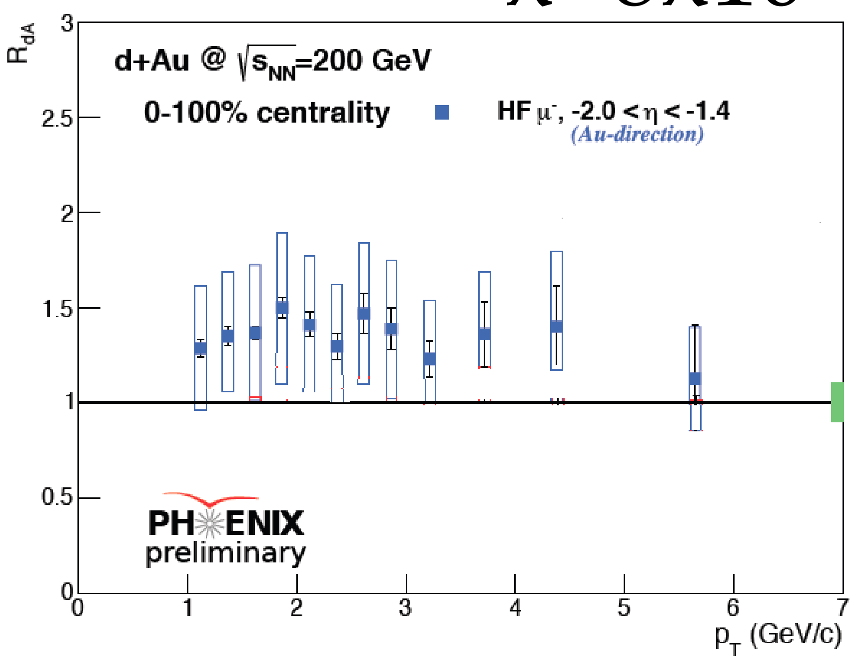
$x{\sim}10^{-2}$

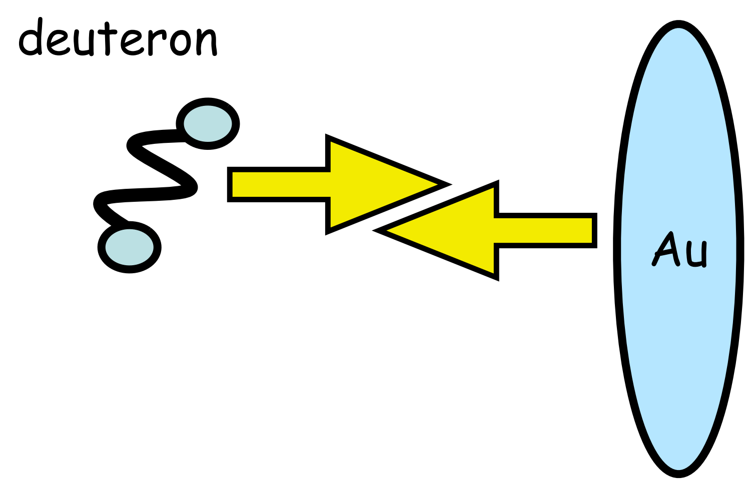
PRL109, 242301 (2012)



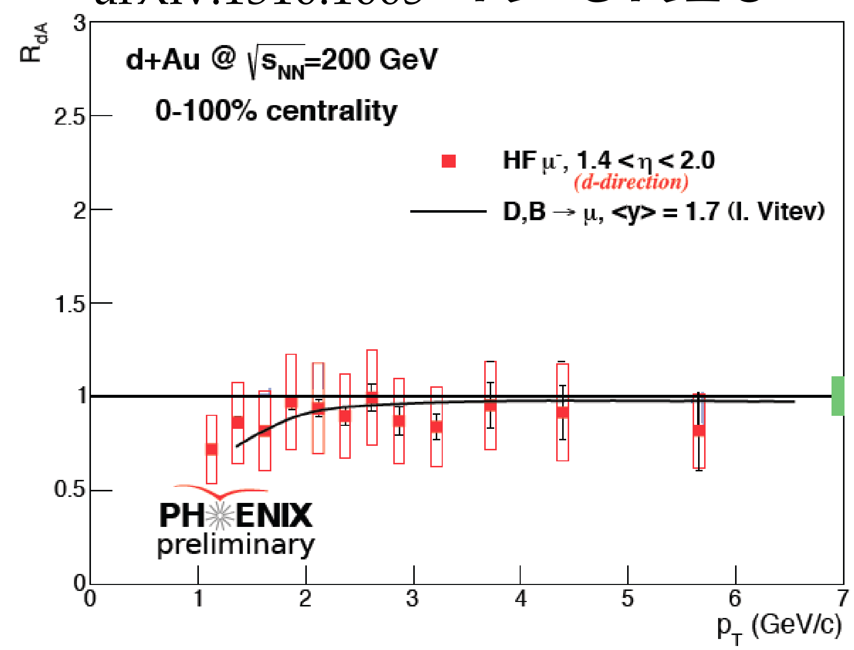


arXiv:1310.1005 $x{\sim}8x10^{-2}$

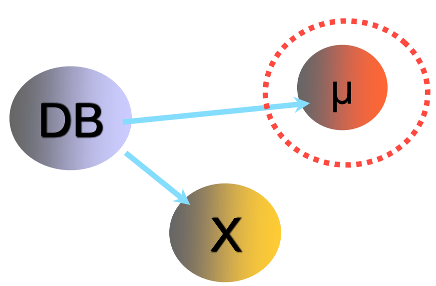




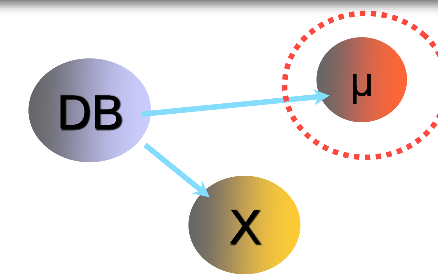
arXiv:1310.1005 $x{\sim}5x10^{-3}$

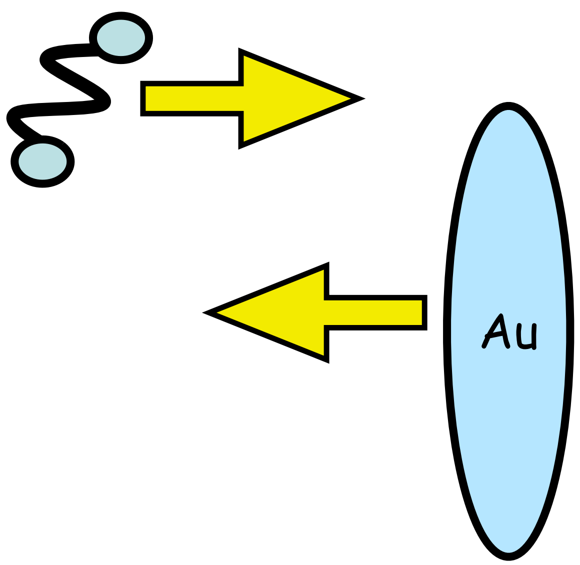


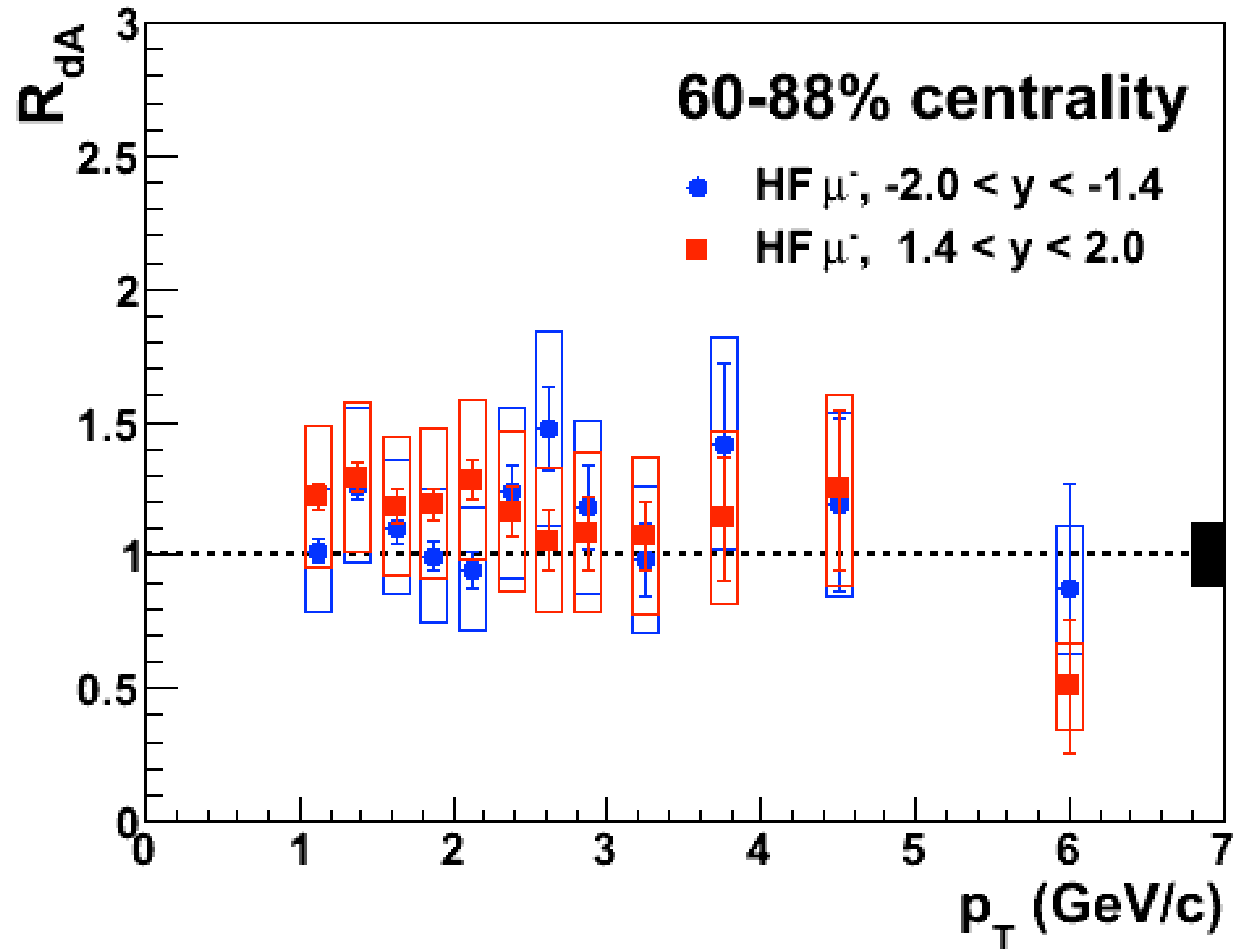
Vitev: coherent effect+Croning



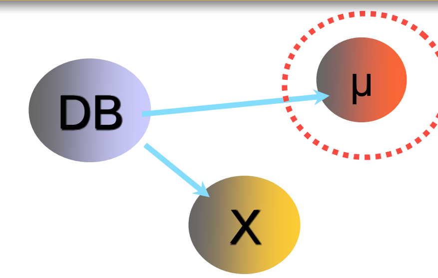
Heavy Flavor Results in d+Au Collisions

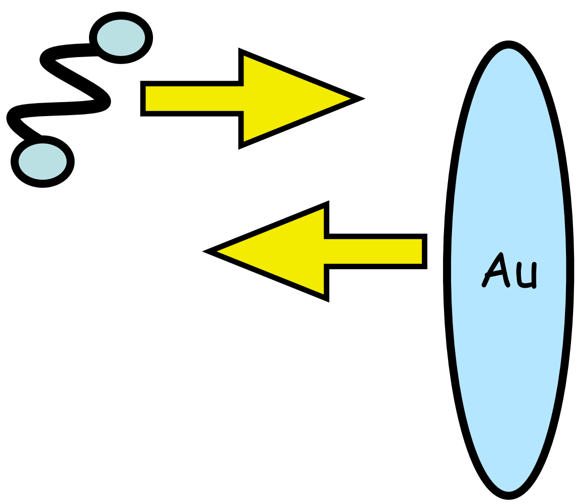


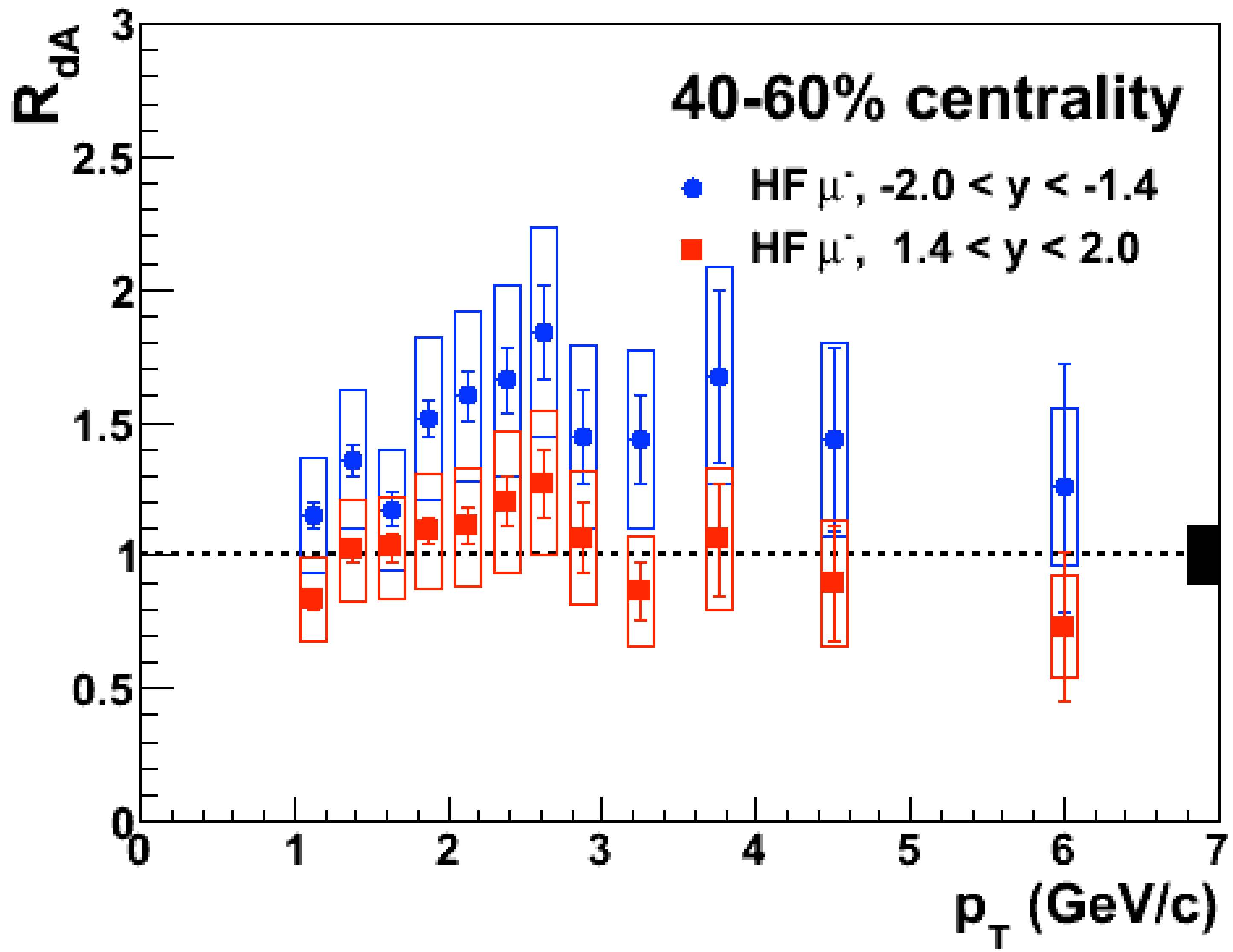




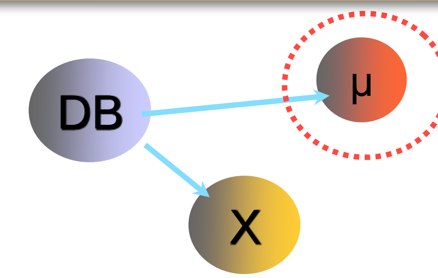
Heavy Flavor Results in d+Au Collisions

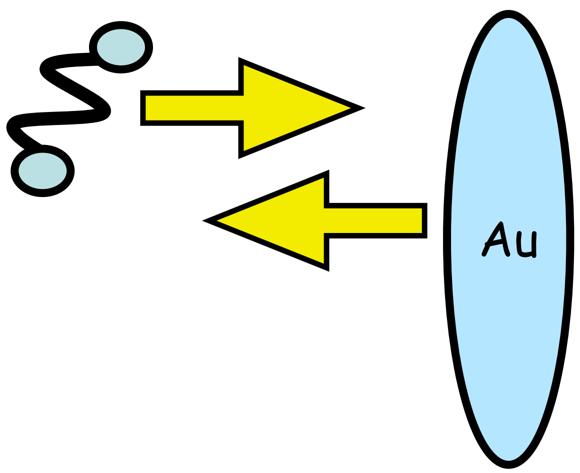


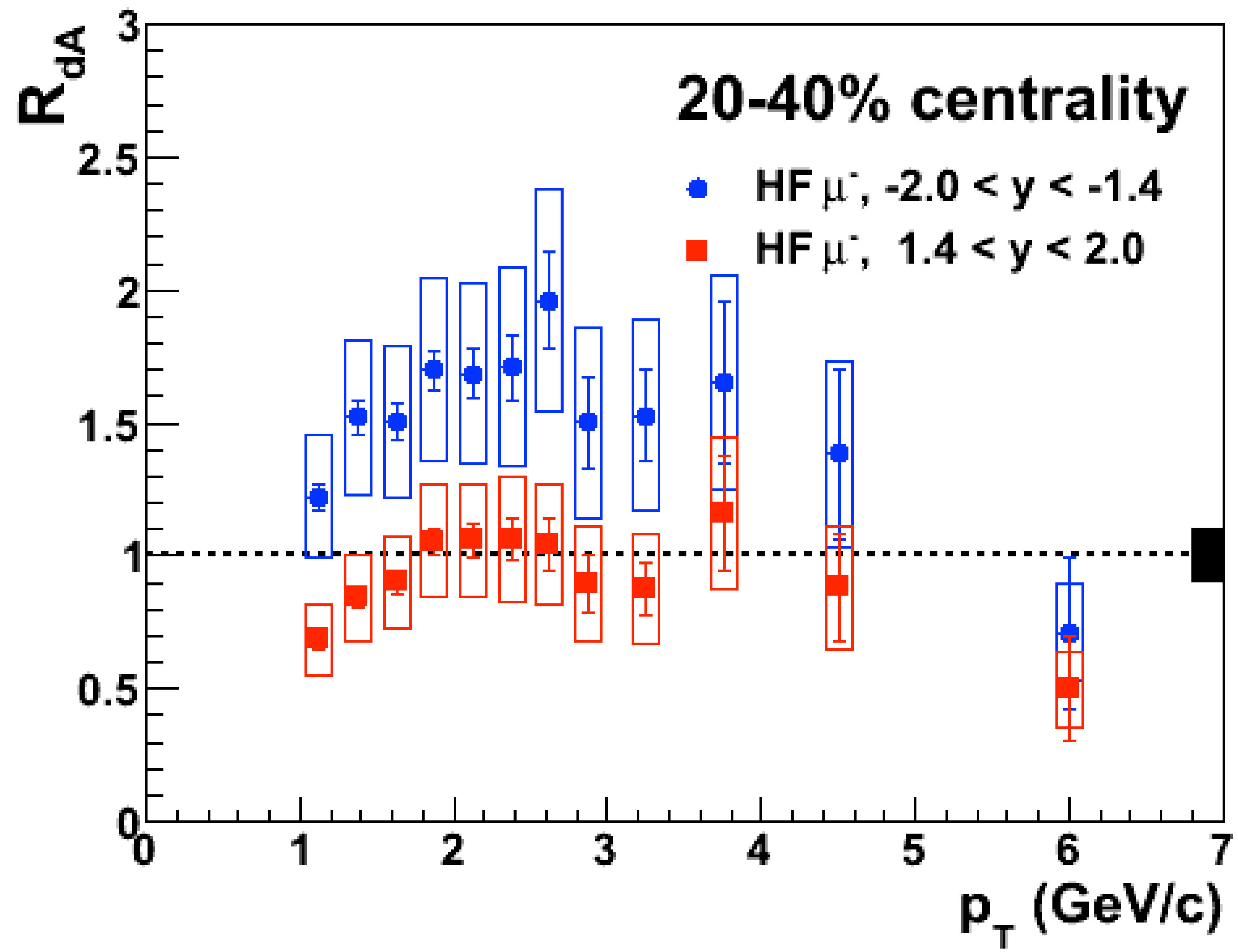




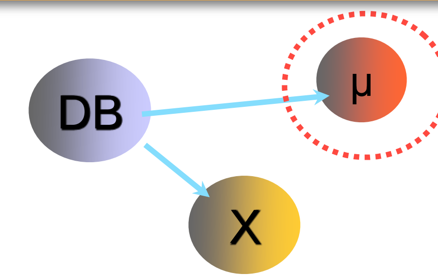
Heavy Flavor Results in d+Au Collisions

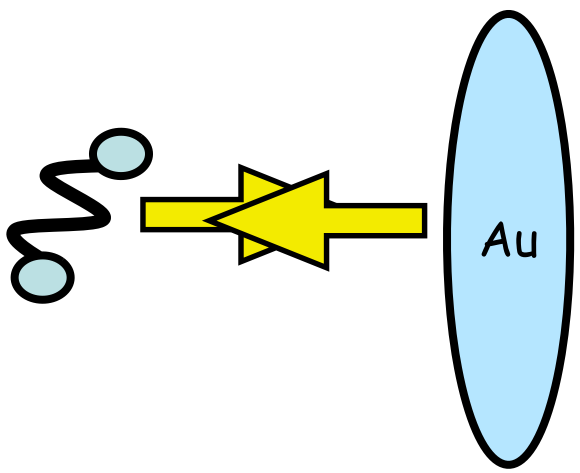


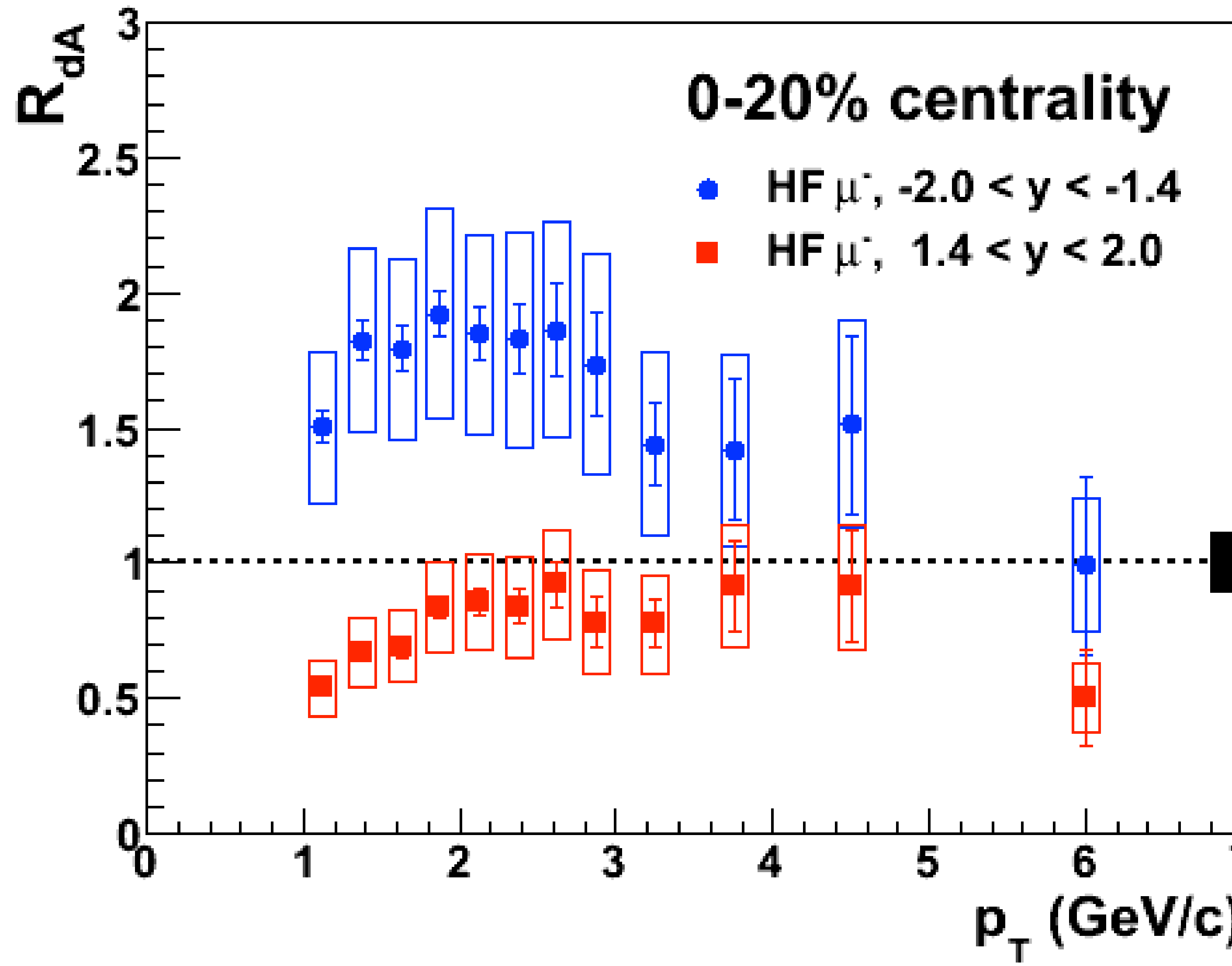




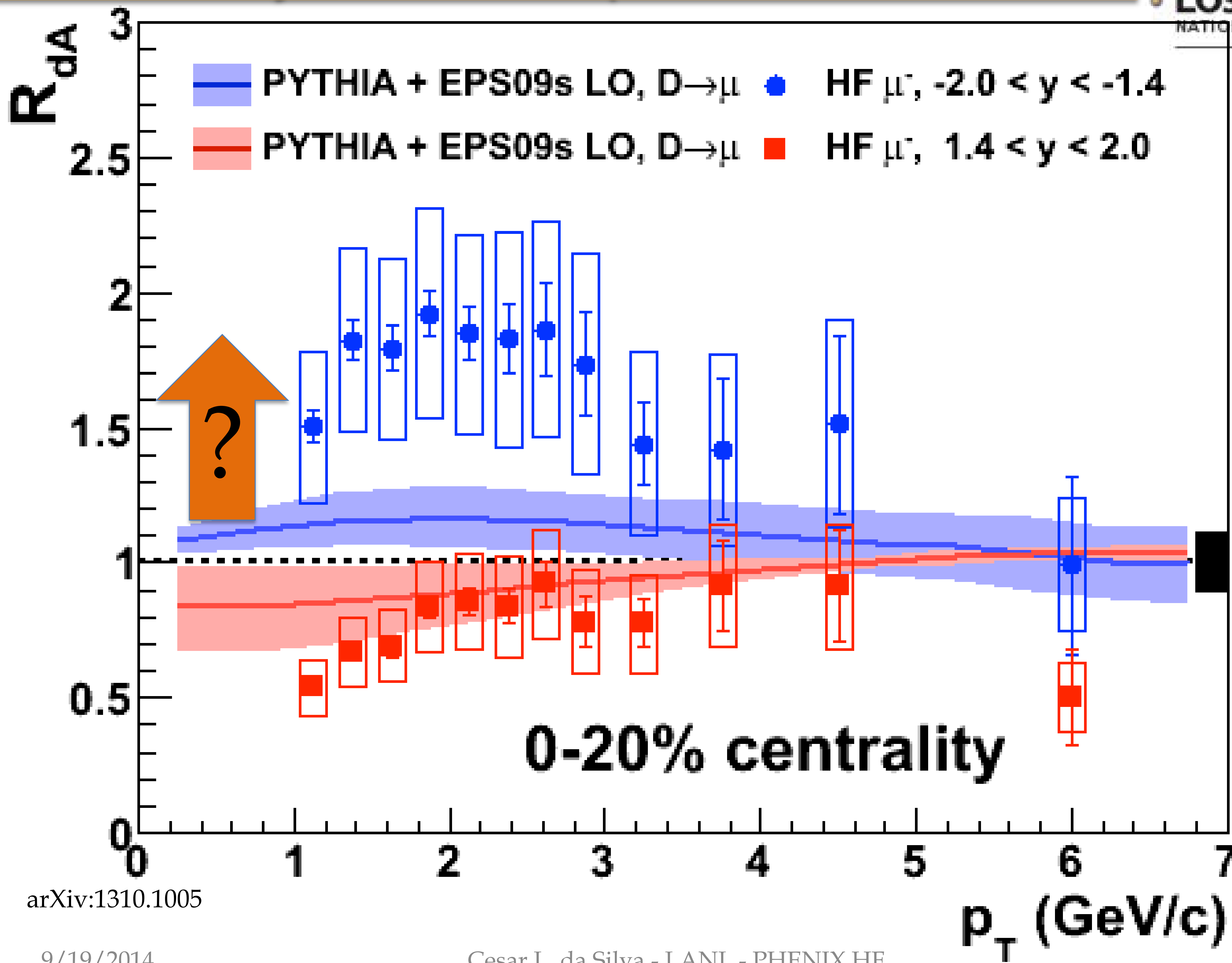
Heavy Flavor Results in d+Au Collisions





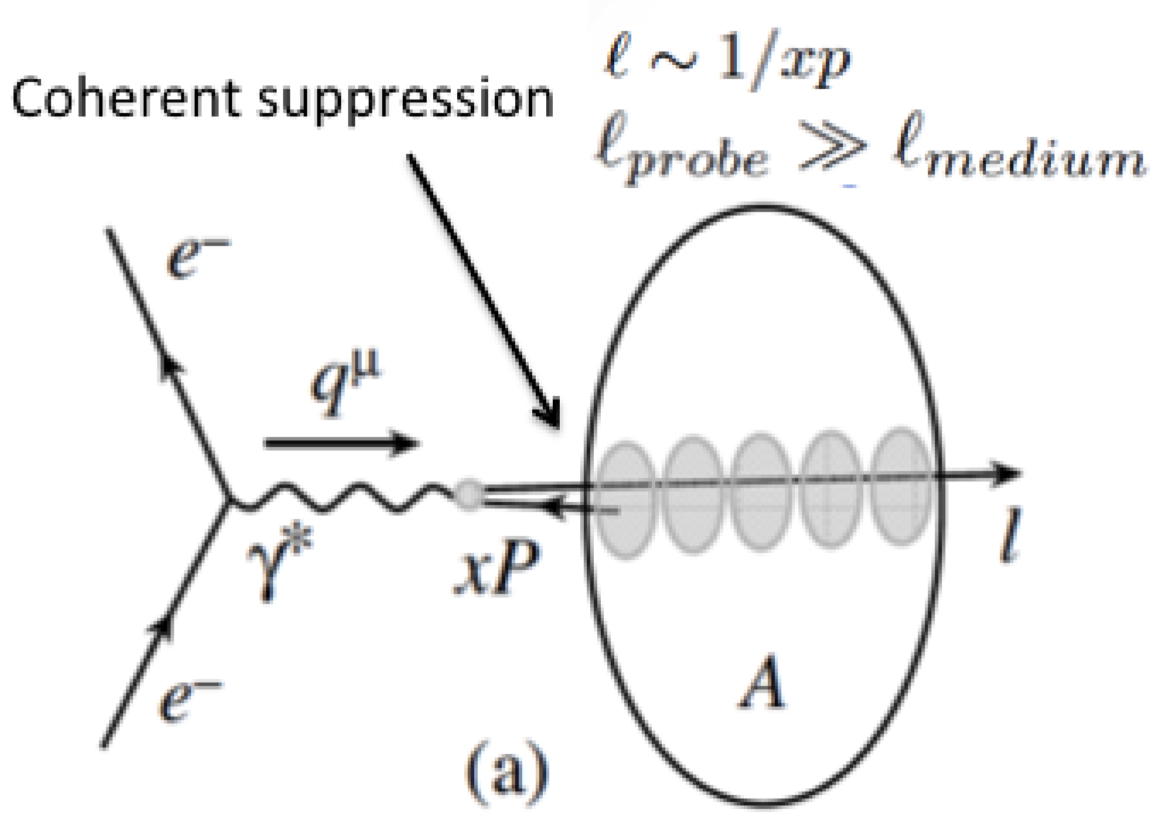


d+Au Heavy Flavor Comparison with EPS09s



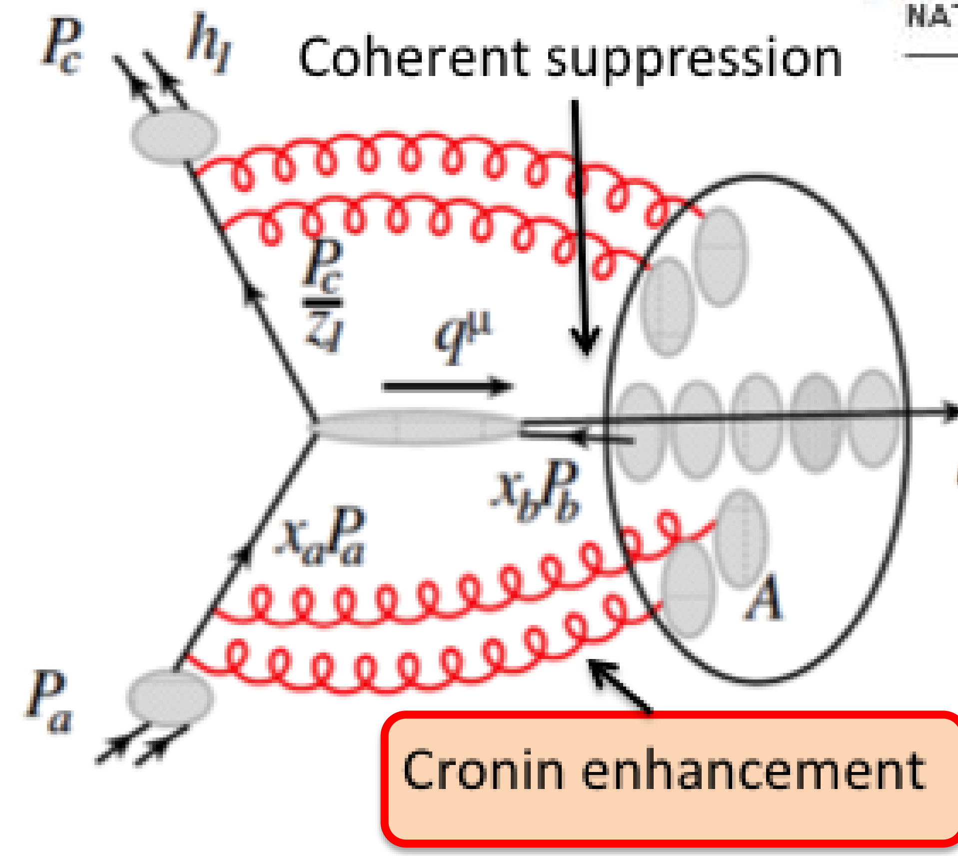
arXiv:1310.1005

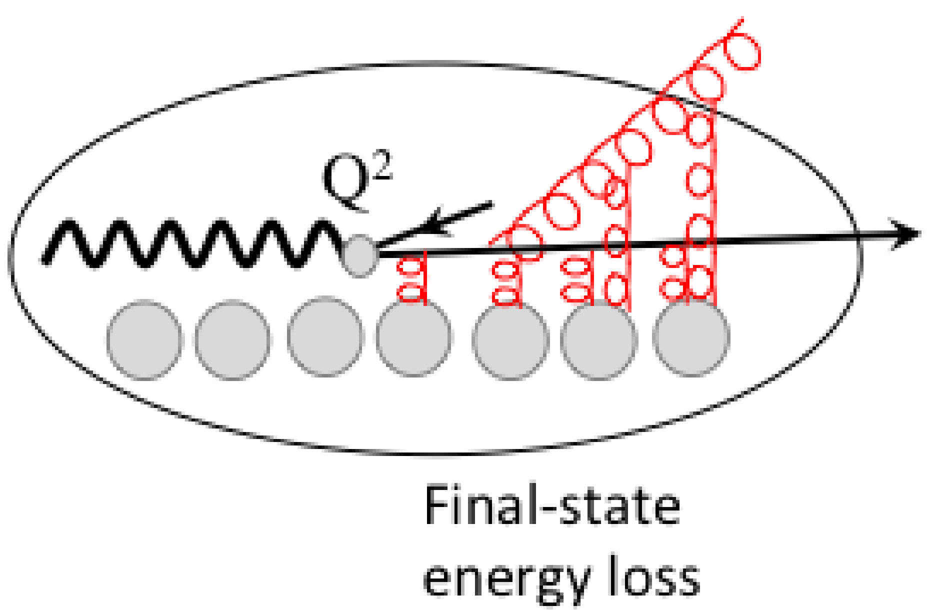
DIS

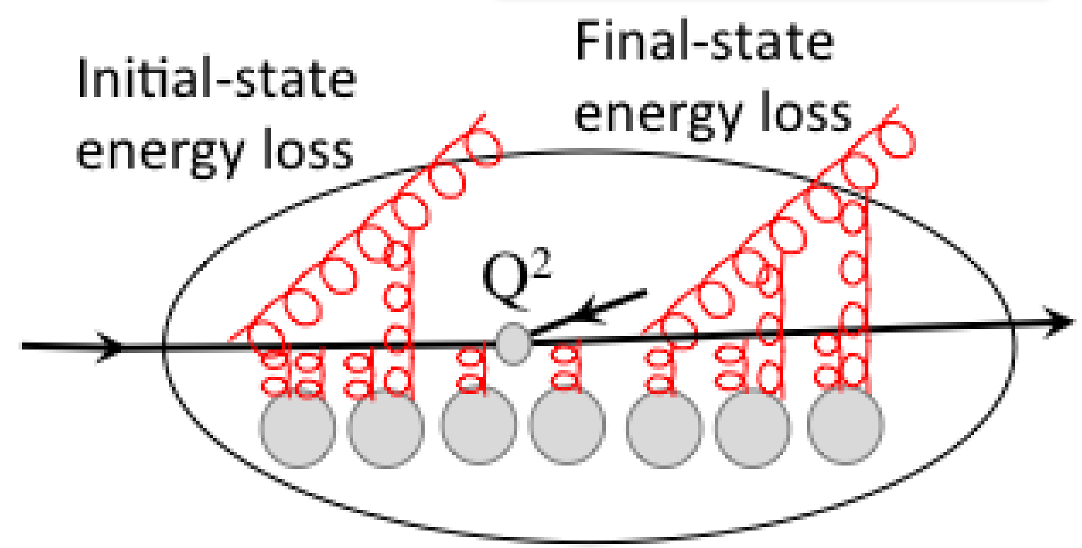


For x<0.01, l_{probe} > nuclear thickness

p+A



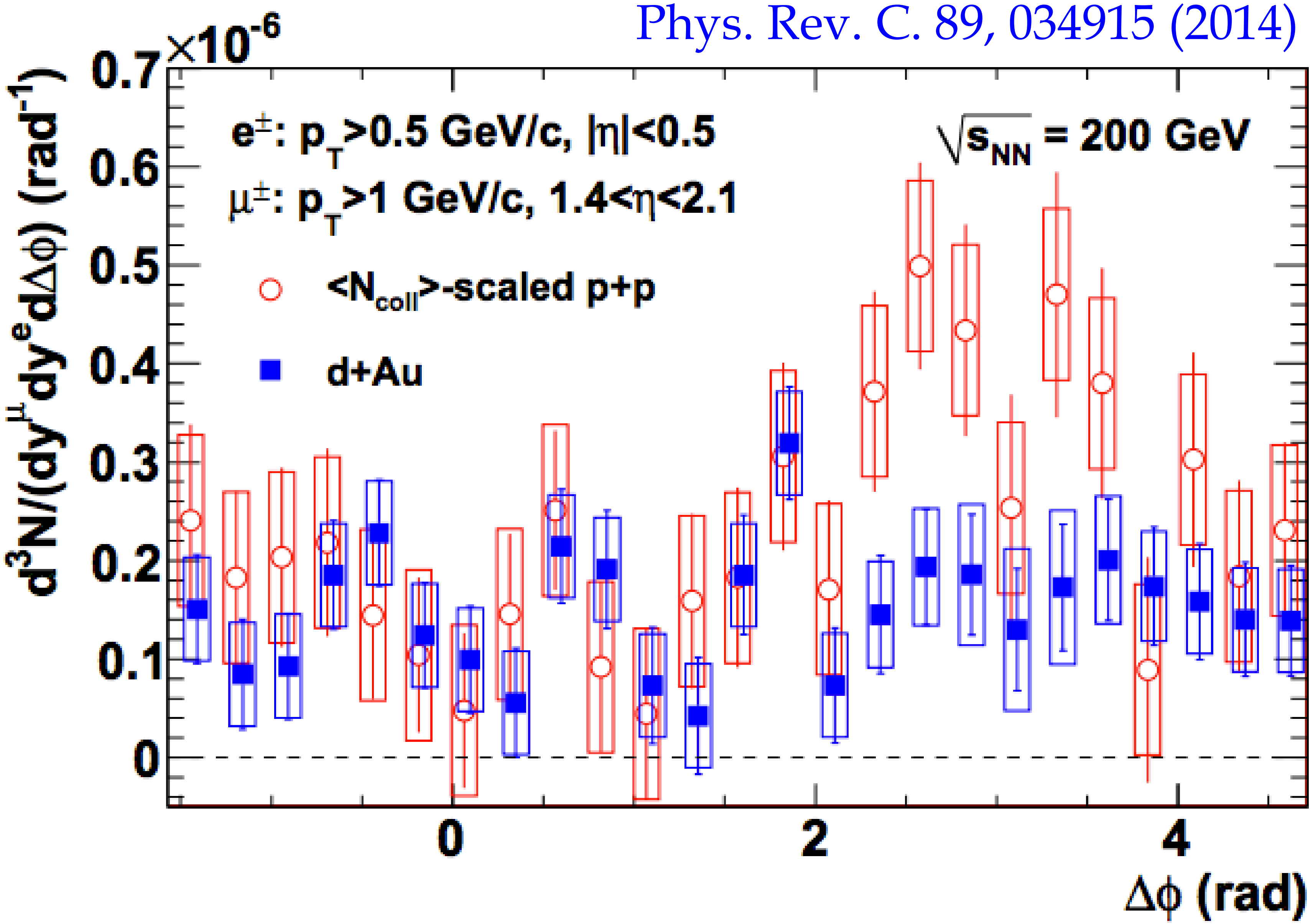




Not a surprise given the limited CNM coverage of DIS in EPS09.

Forward-mid rapidity HF correlation

Phys. Rev. C. 89, 034915 (2014)



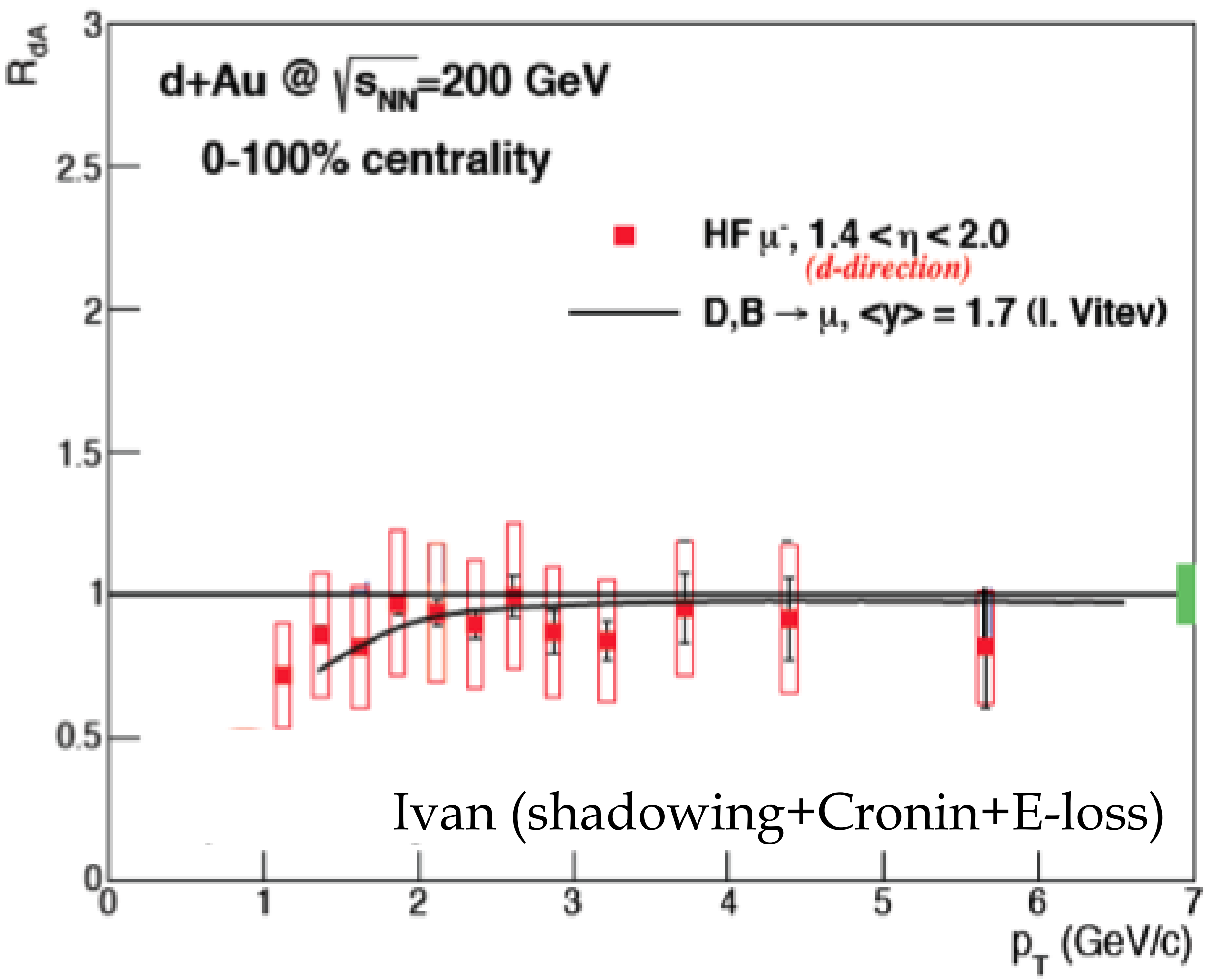
x~10^{-2}

JdA(2.7<Δϕ<3.2) = 0.433 ± 0.087 (stat) ± 0.135 (syst)

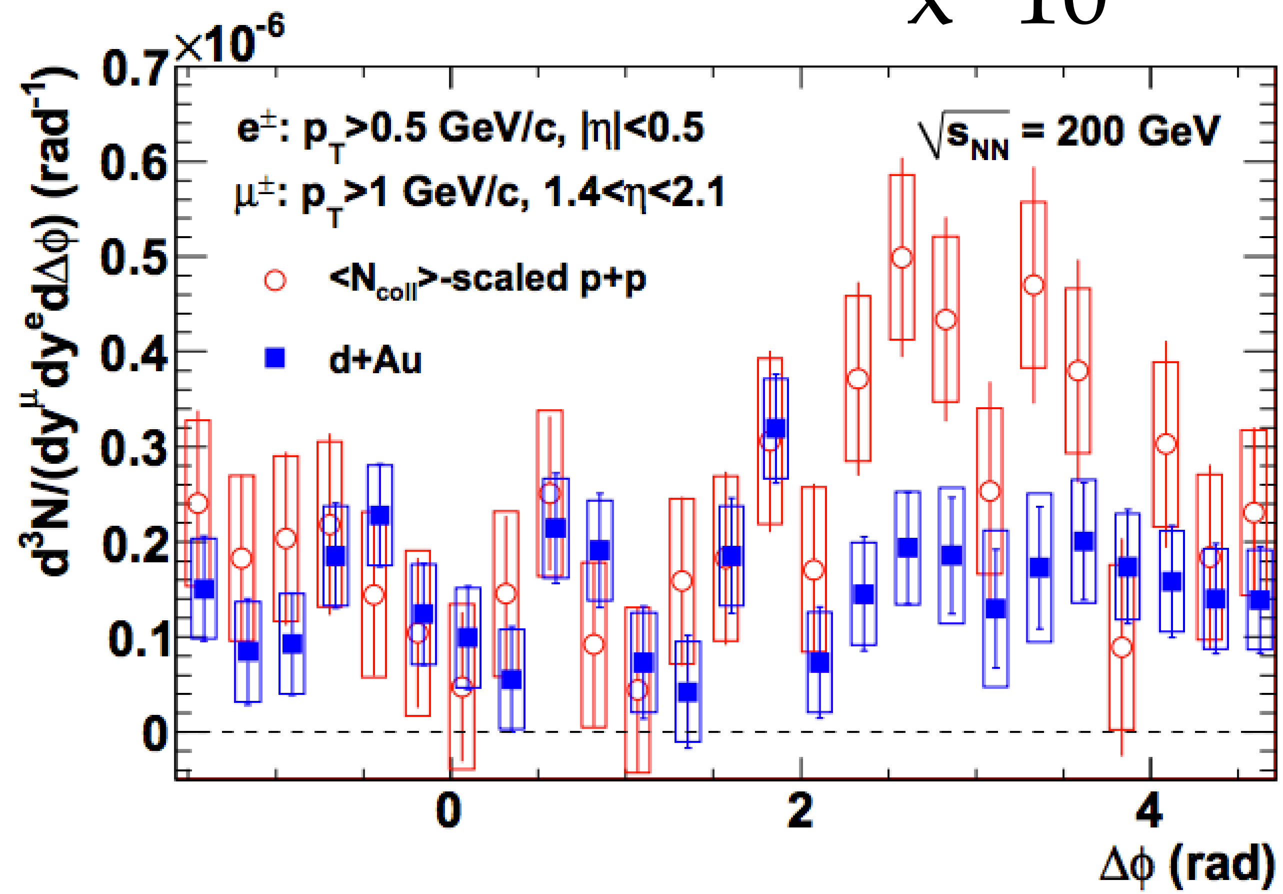
Back-to-back dominated by gluon fusion.
Continuum dominated by flavor excitation, gluon splitting.

Forward-mid rapidity HF correlation

x~5x10^{-3}



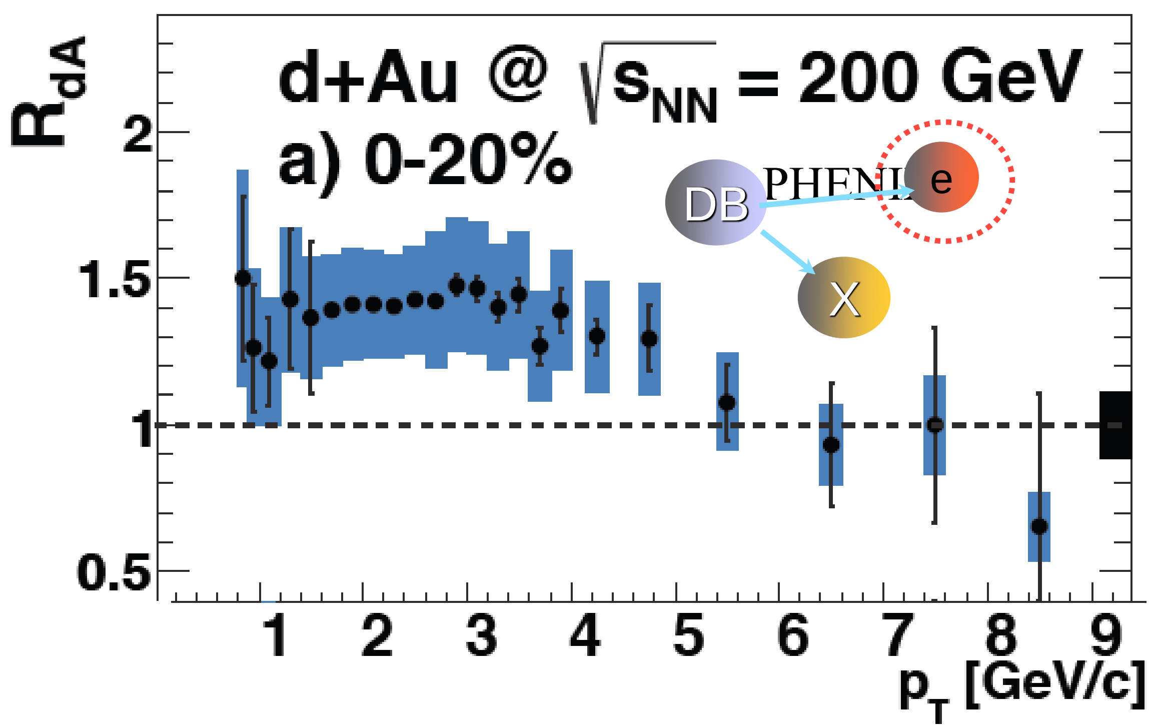
x~10^{-2}

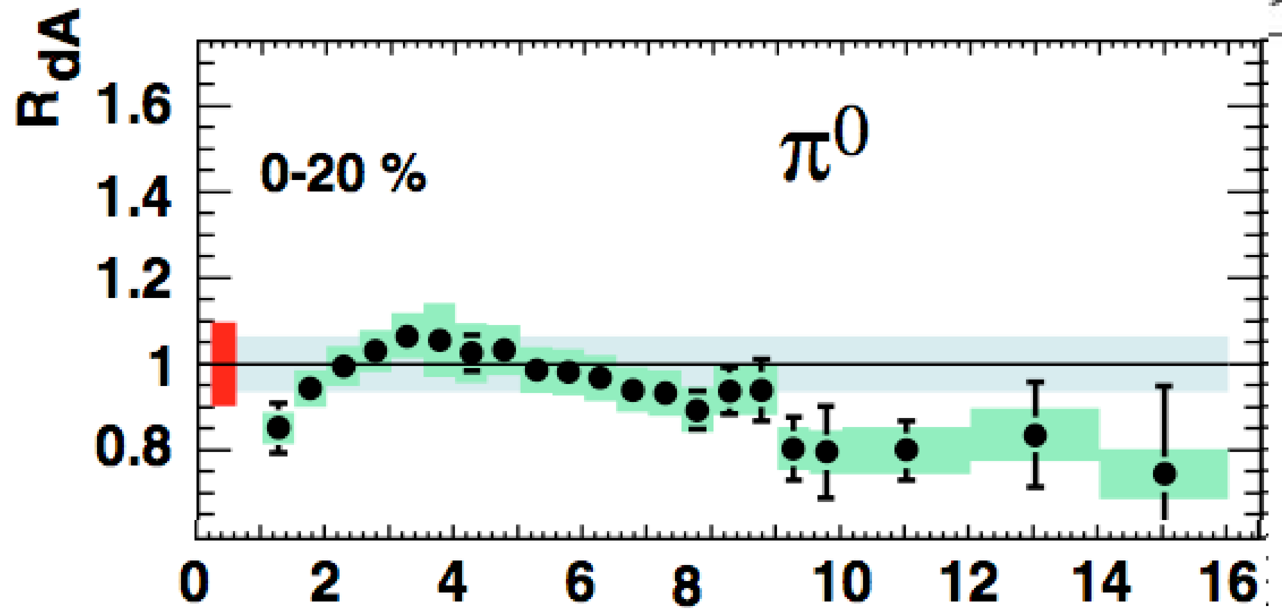


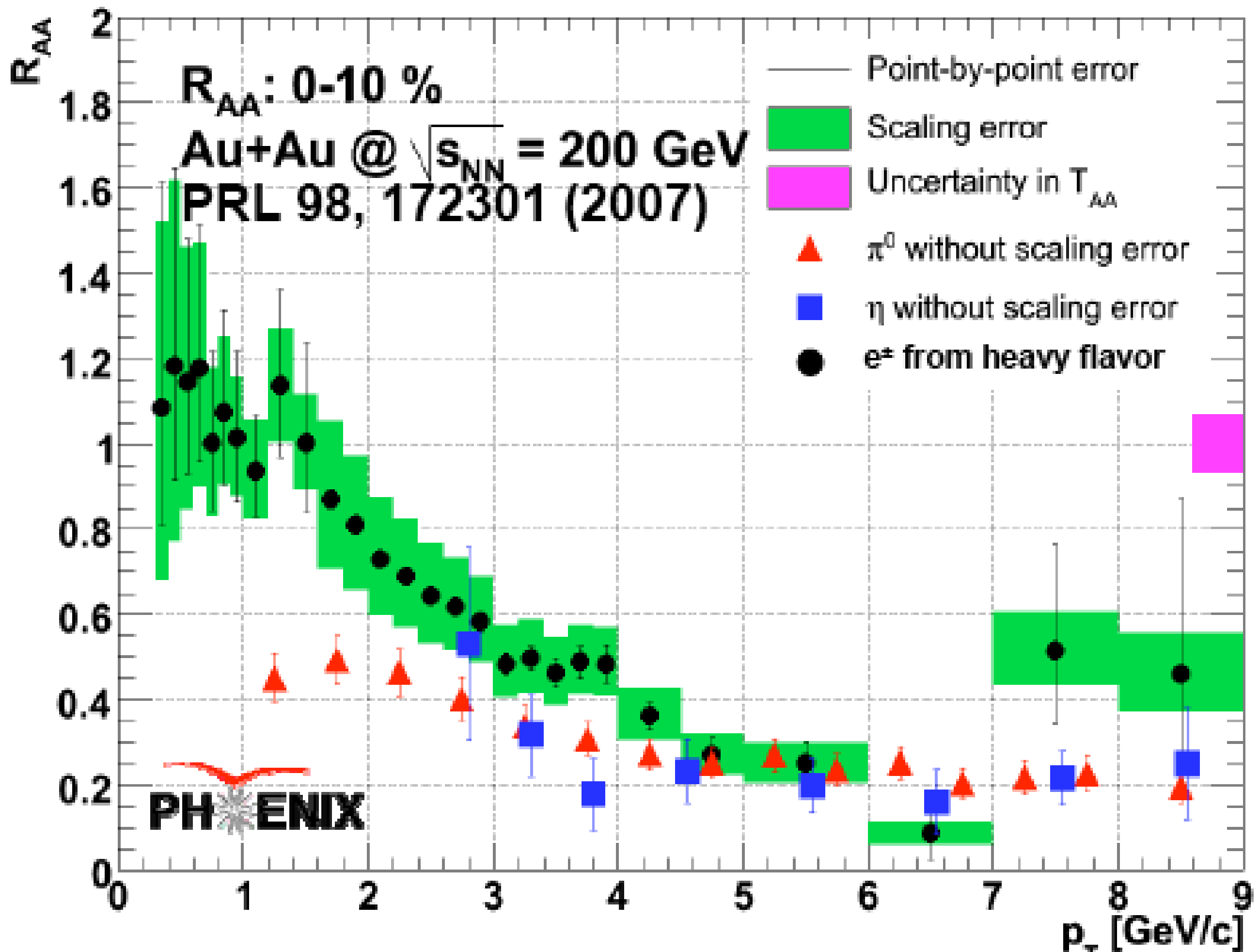
JdA(2.7<Δφ<3.2) = 0.433 ± 0.087 (stat) ± 0.135 (syst)

Suppression in JdA stronger than in smaller x single muons.
HF from gluon fusion has a stronger suppression.

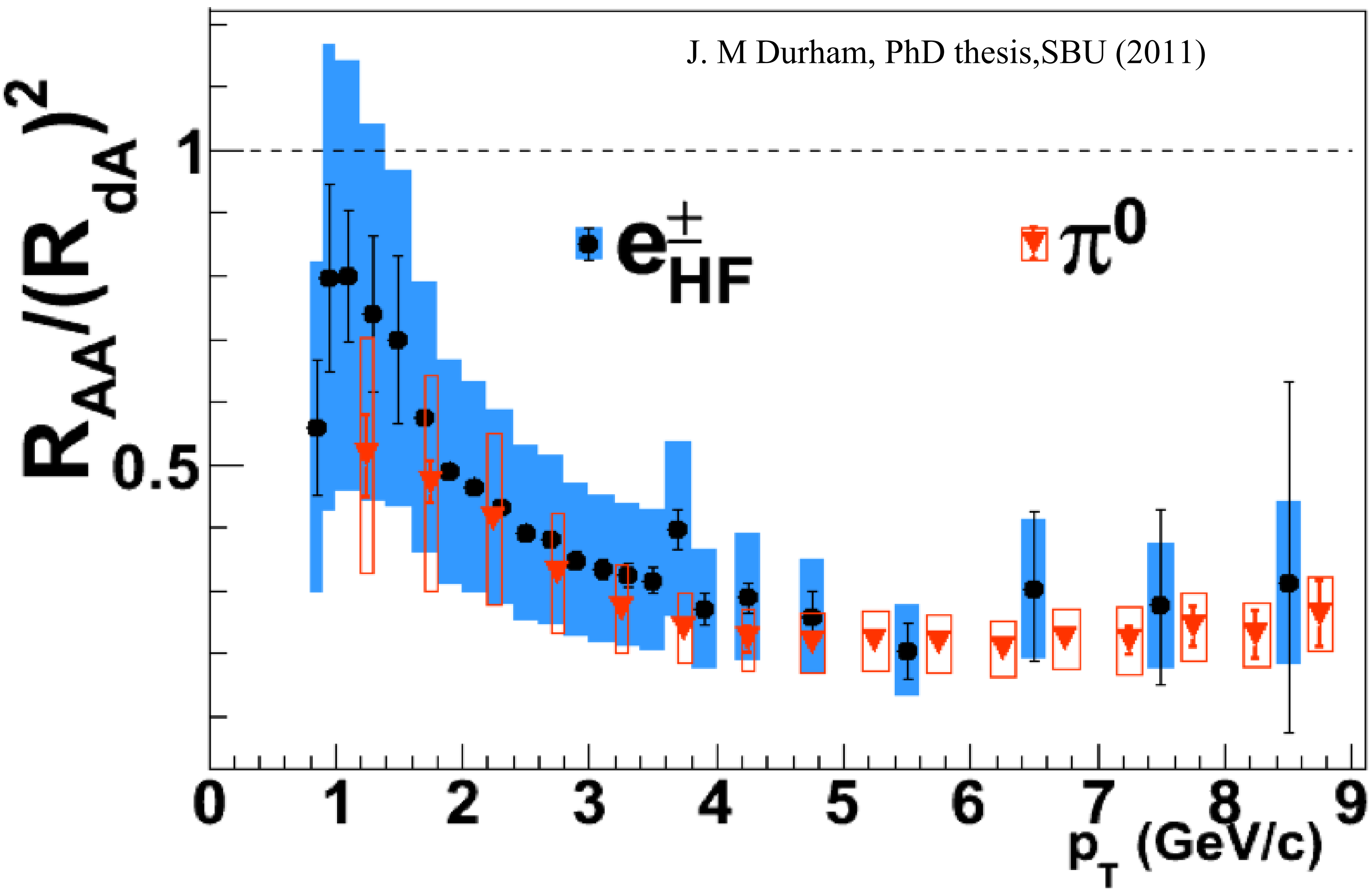
Light/Heavy quark comparison







Light/Heavy quark comparison

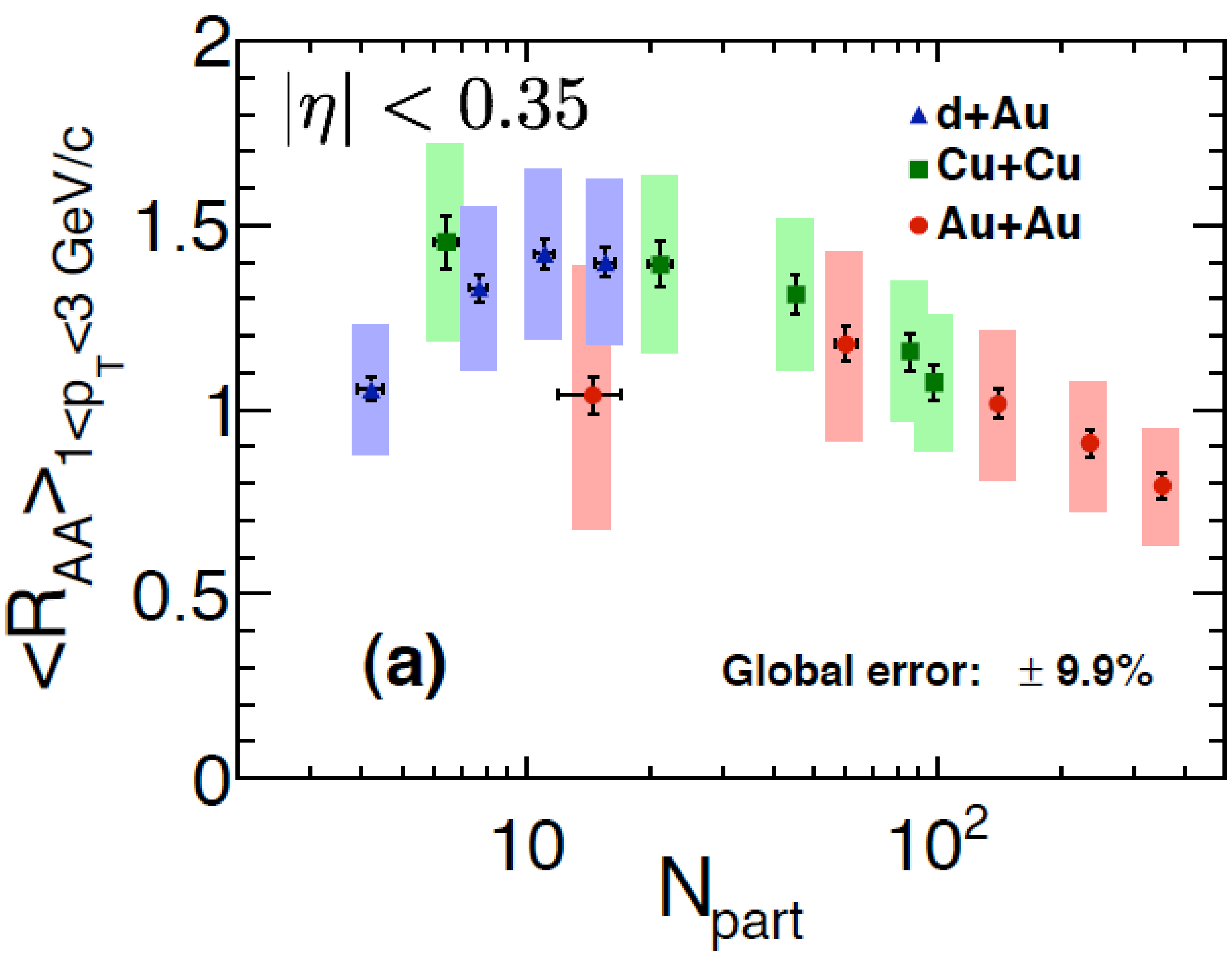


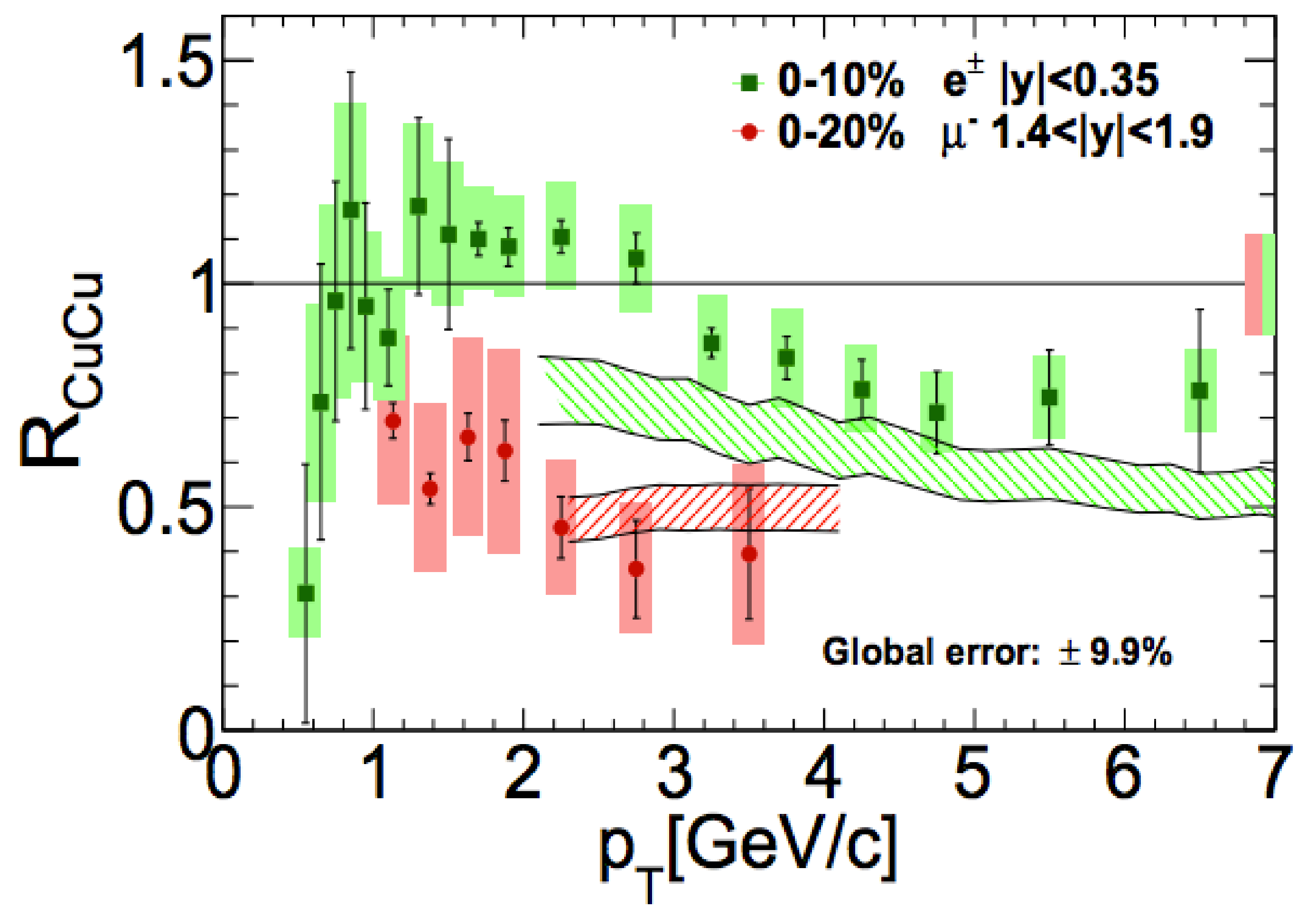
Final state modification of **light** and **heavy** quarks are consistent within uncertainties.

Is $(RdA)^2$ a valid representation of CNM effects in A+A ?

R_{AA} vs. p_T vs. N_{part} vs. system size

Phys. Rev. C 90, 034903 (2014)



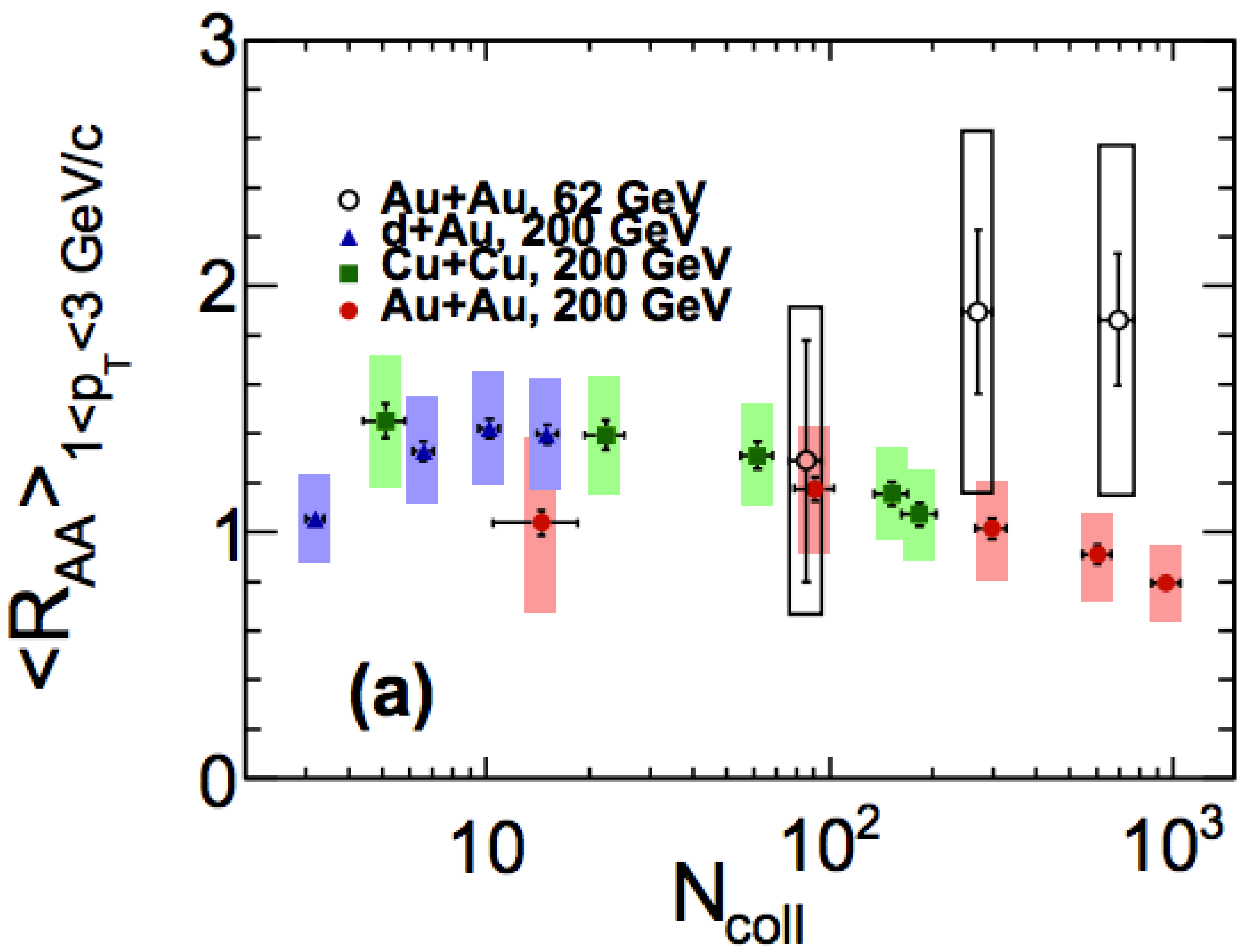


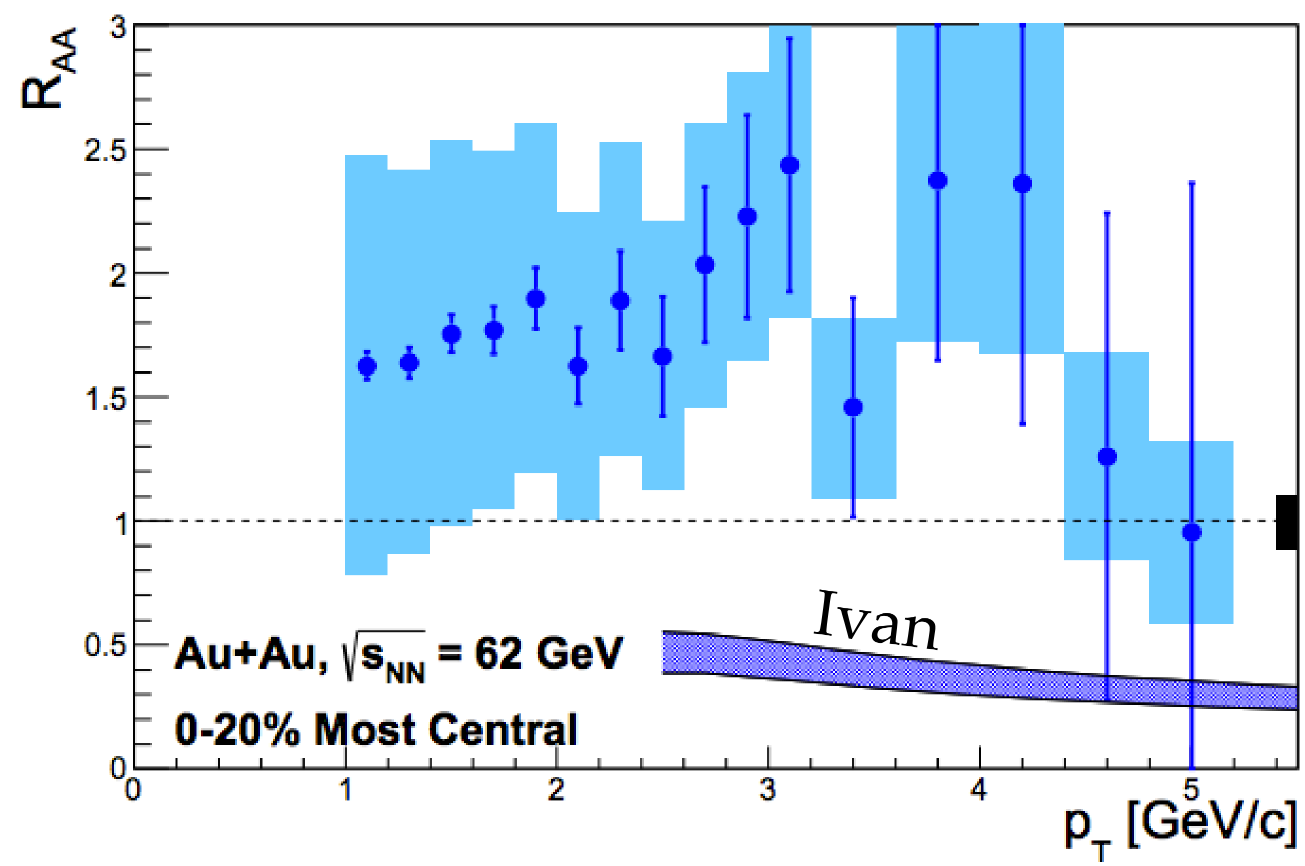
Modification in Cu+Cu is an interplay between d+Au and Au+Au mid-rapidity results.

$R_{AA}(p_T)$ indicates a strong contribution from CNM effects.

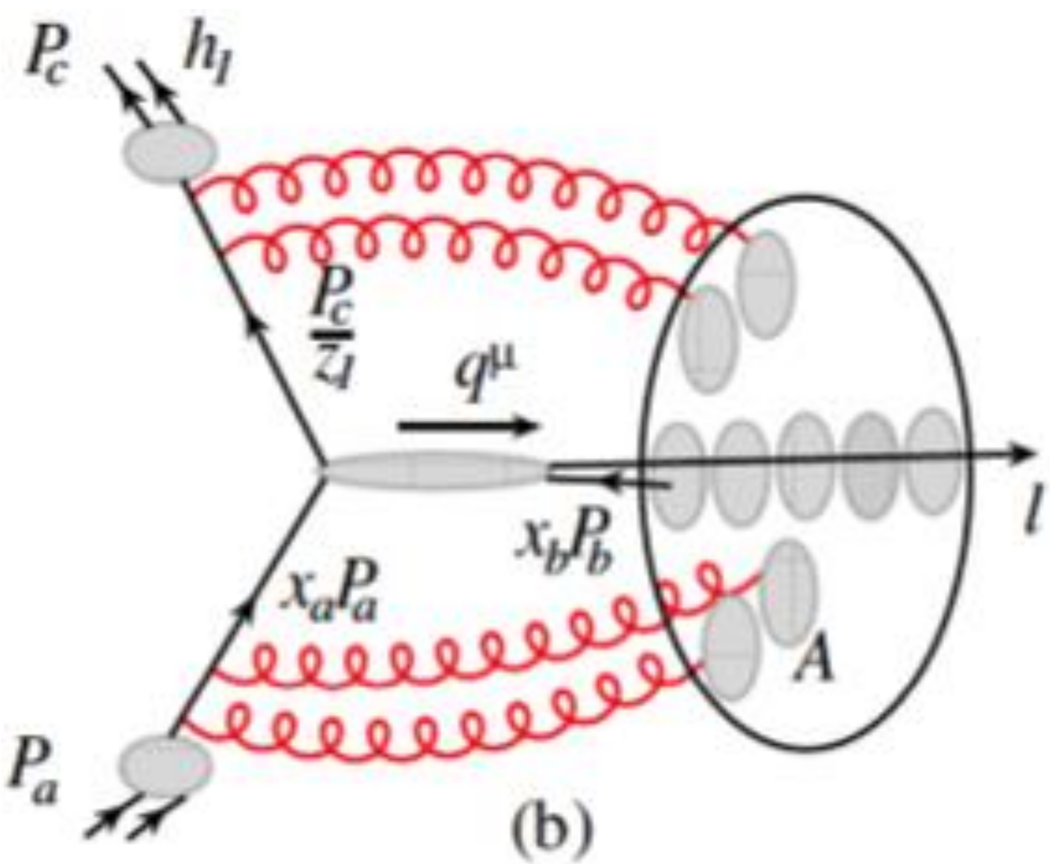
Model including partonic fracgmentation and dissociation E-loss, shadowing and Cronin underestimates low-p_T R_{AA} by at least 20%.

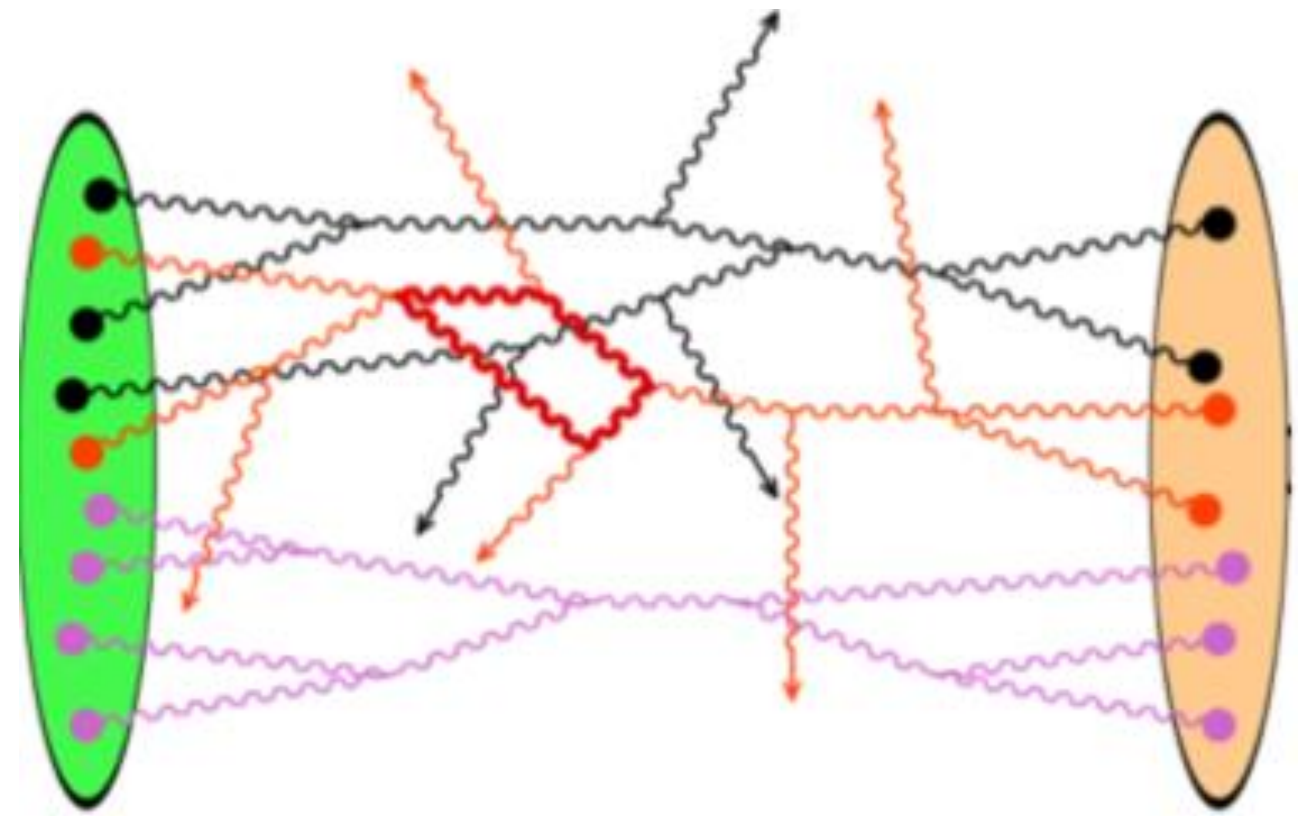
R_{AA} vs. p_T vs. N_{part} vs. Energy





Large HF enhancement when going to lower energies.
Largely underestimated by E-loss+shadowing+Cronin based models.



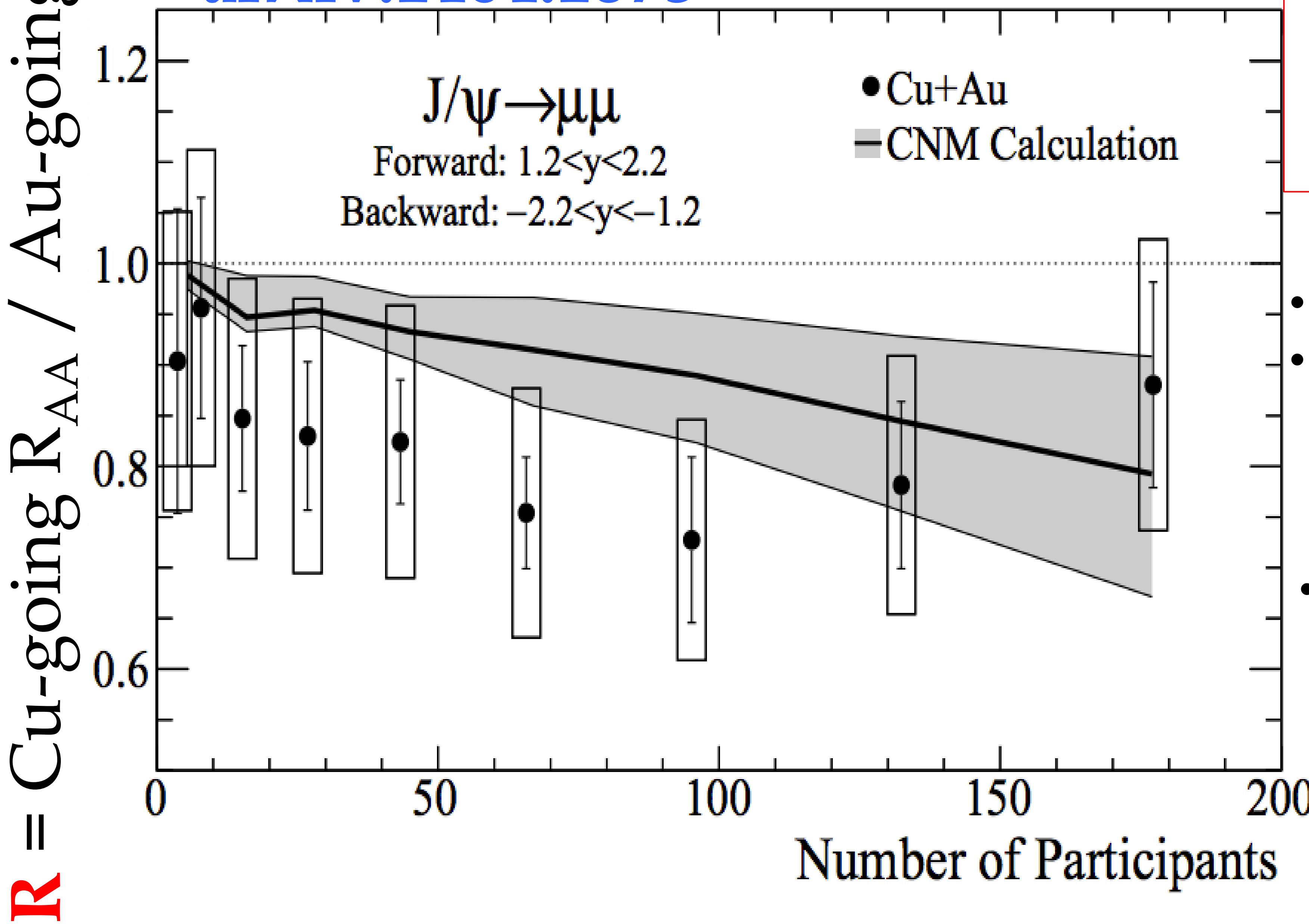


How CNM effects factorize in A+A collisions ?

A big challenge when estimating and interpreting RAA..

Disentangling CNM effects in HI collisions

arXiv:1404.1873



CNM = EPS09 + 4mb breakup

- Cu-going probes small-x in Au
- Au-going probes small-x in Cu
  → initial state effects cause **R** to decrease with centrality

- Final state effects causes more suppression in Au-going side
  → Final state effects should increase **R** with centrality

Rapidity dependence of CNM and QGP effects is not symmetric.

PHENIX is analyzing HF in Cu+Au (no breakup, formation time easier to understand). First FVTX data.

PERSPECTIVES

- HF analysis using run11 Au+Au and run12 Cu+Au going on. Will be the first R_{AA} and flow results from separated charm and bottom quarks by PHENIX.

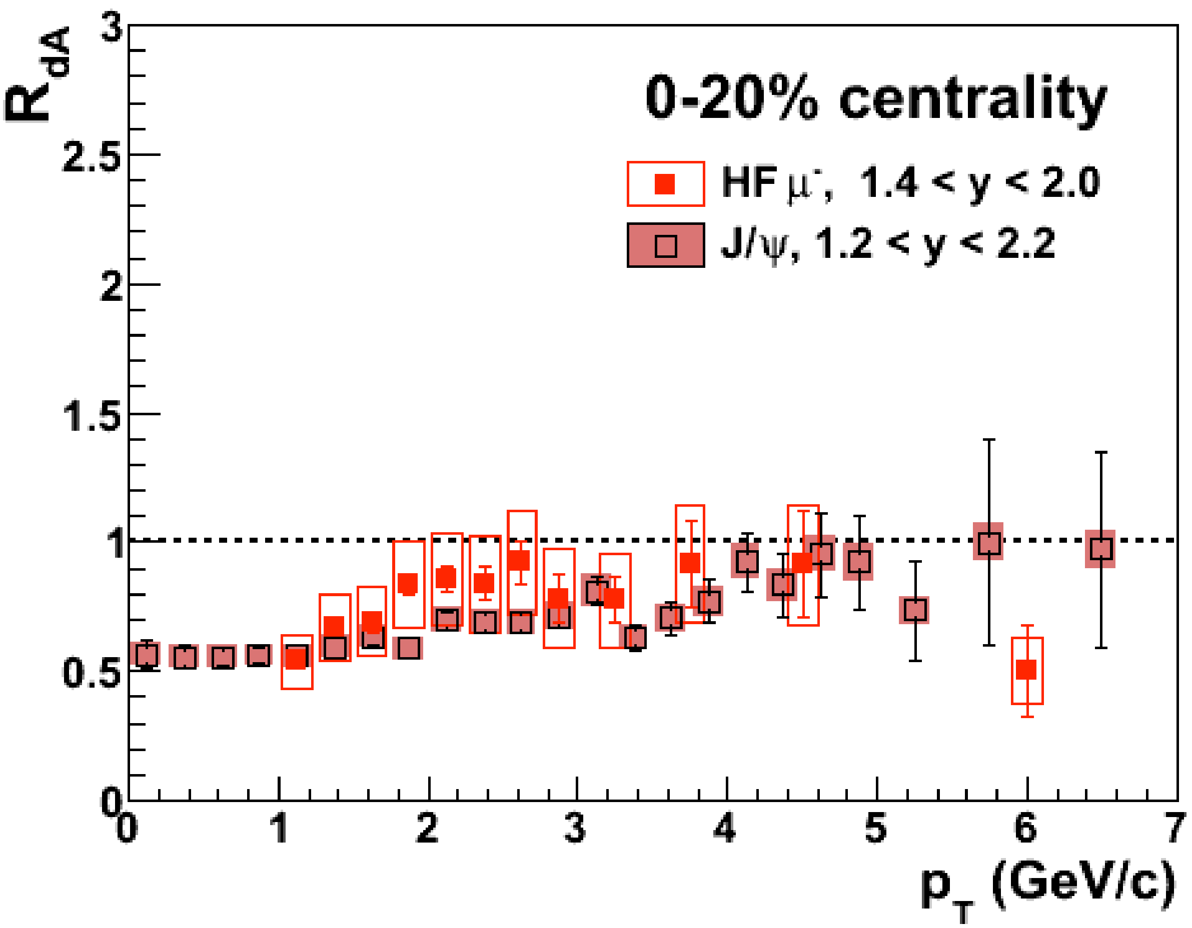
- Run14 Au+Au results are very promising
- More data than all previous runs combined
- Vertex detectors (VTX and FVTX) fully operational.

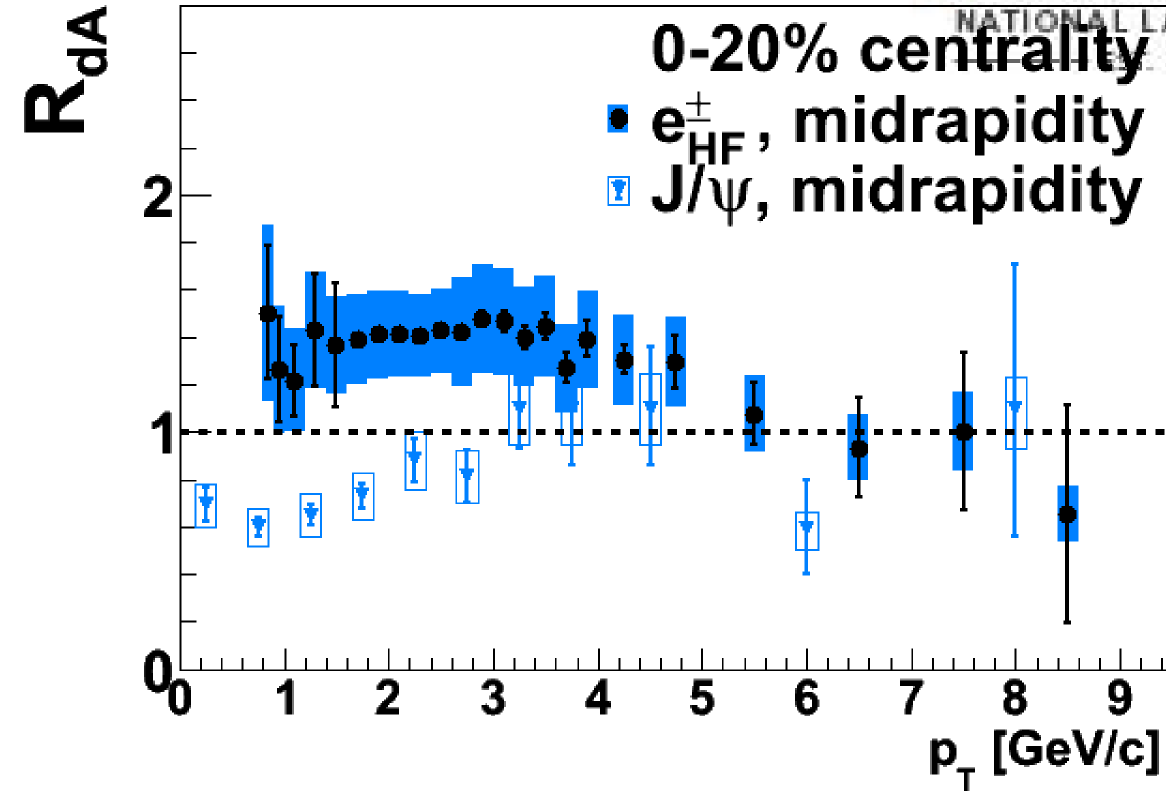
- Run15 p+A (Al,Cu,Au) can be the basis CNM measurement for high energy hadron collisions
- A-dependence can help distinguish the role of saturation, coherent effects(shadowing) and energy loss
- It will be a better reference for Cronin effect

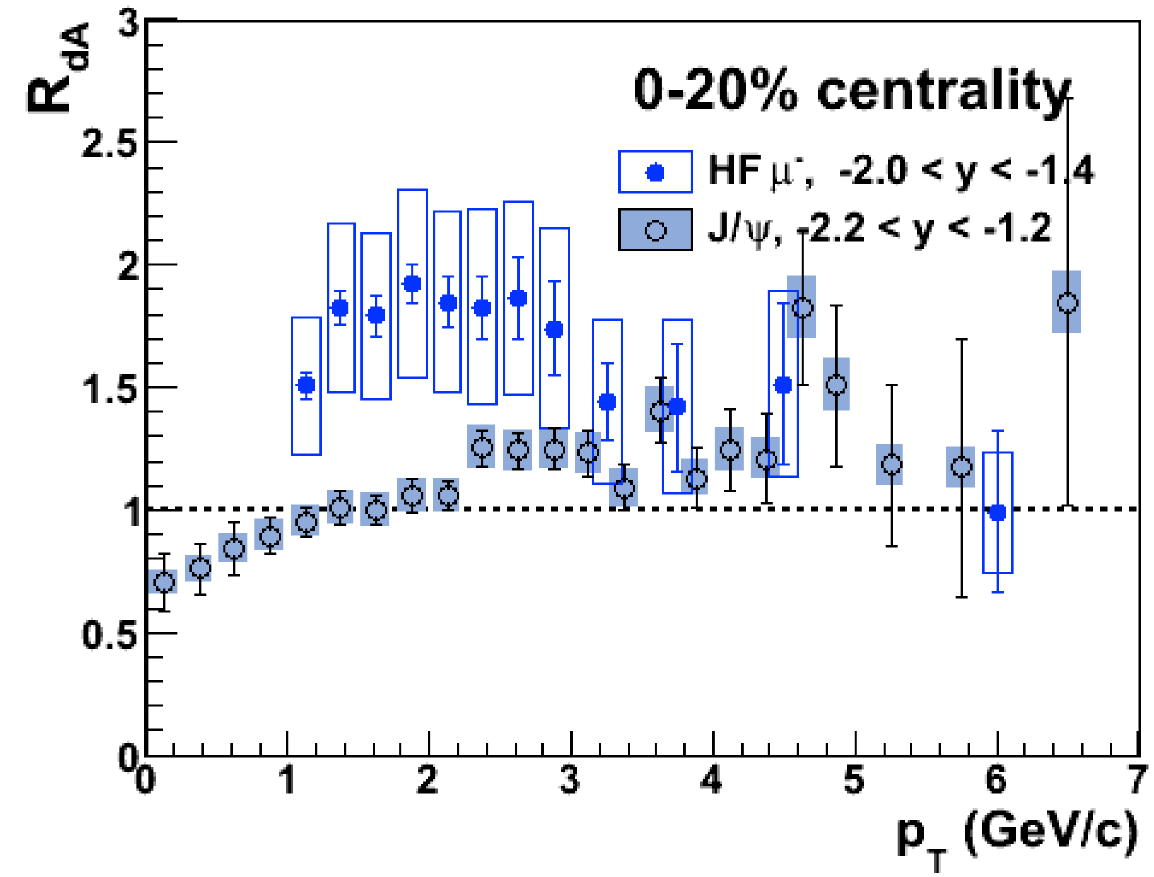
- Future detectors need to emphasize large coverage and precision in order to disentangle CNM and QGP effects

BACKUP SLIDES

Open and bound $c\bar{c}$ modifications

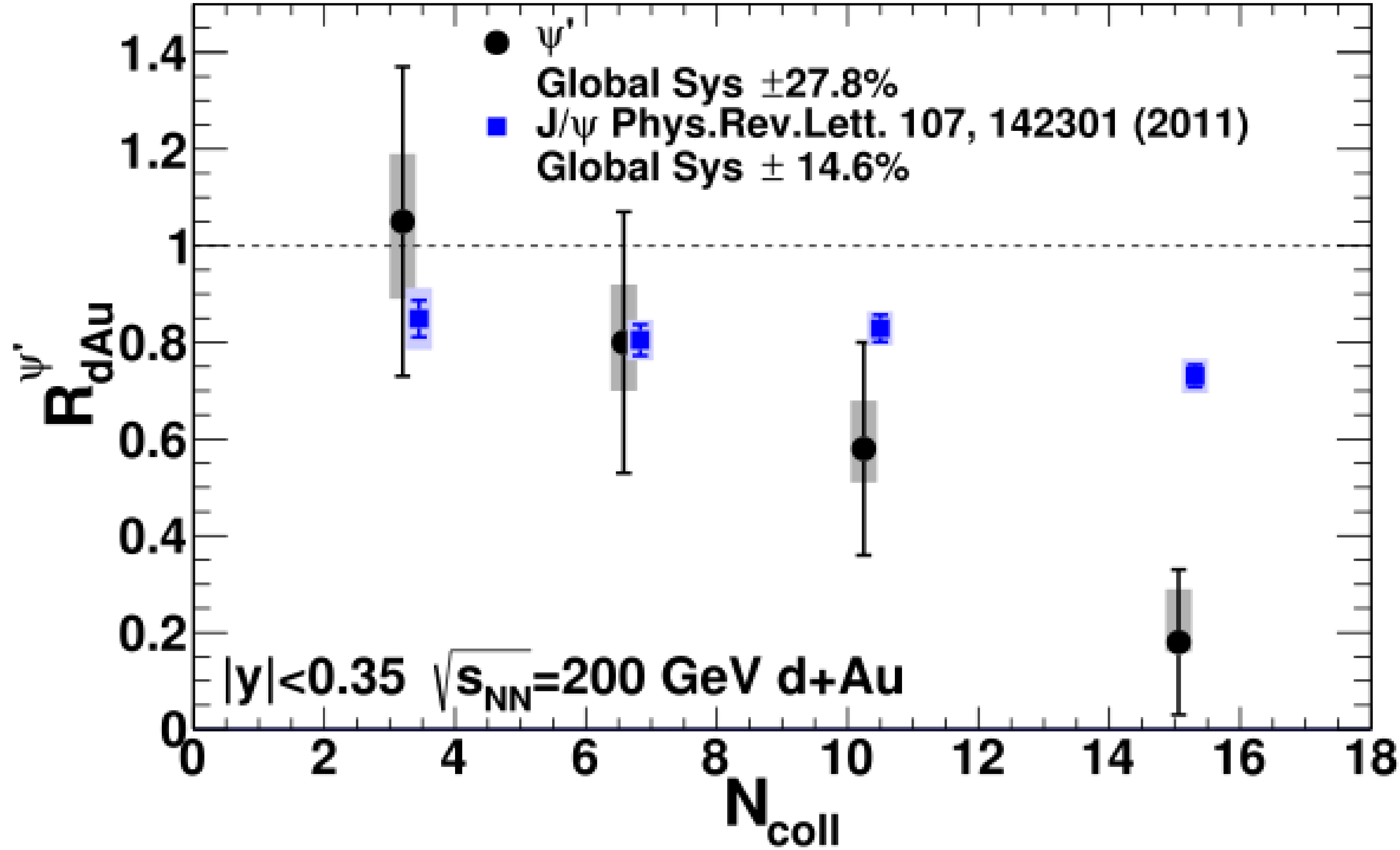






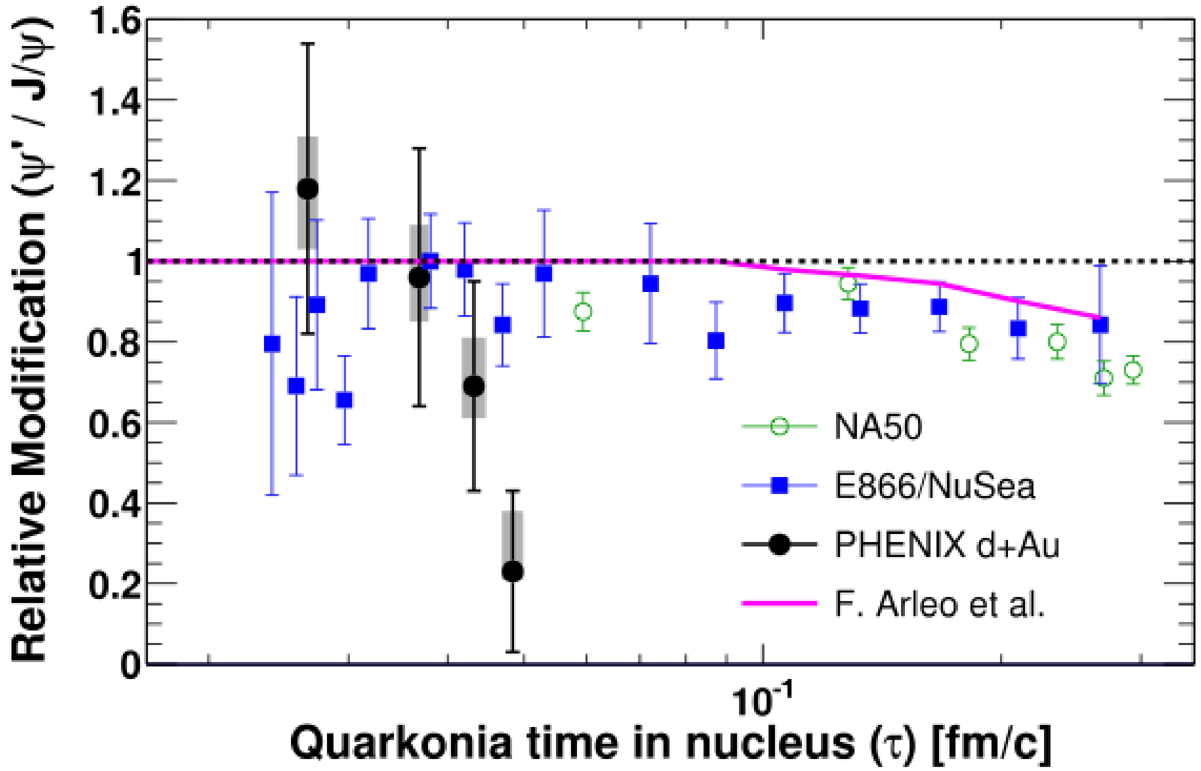
- J/ψ and open charm have same p_T dependence at forward direction
- Small final state effects.
- significant breakup of J/ψ at low p_T mid- and backward rapidities

PRL111, 202301 (2013)



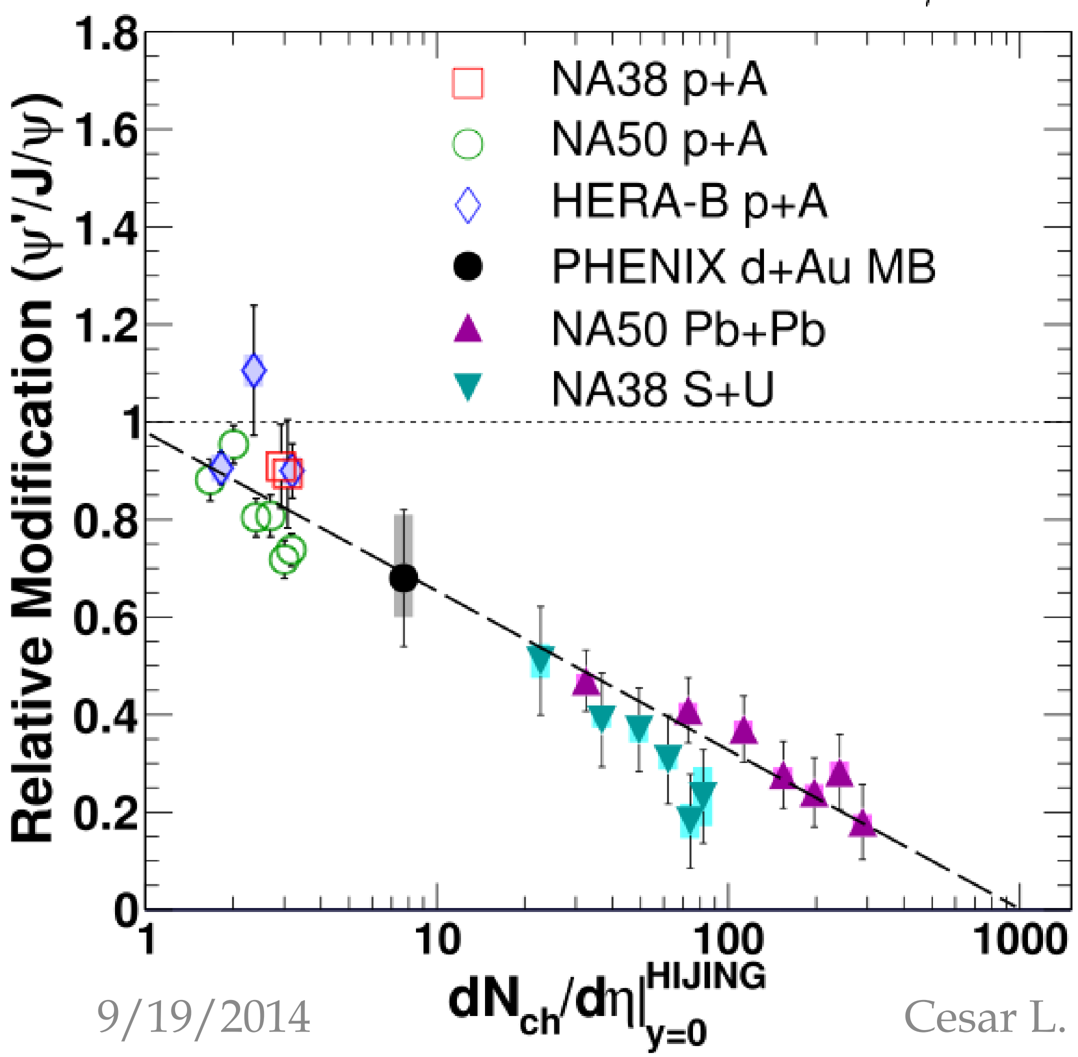
- ψ' has a binding energy $12\times$ smaller than J/ψ
- data suggests ψ' is more sensitive to final state effects
- excellent tool to study charmonium nuclear absorption

PRL111, 202301 (2013)



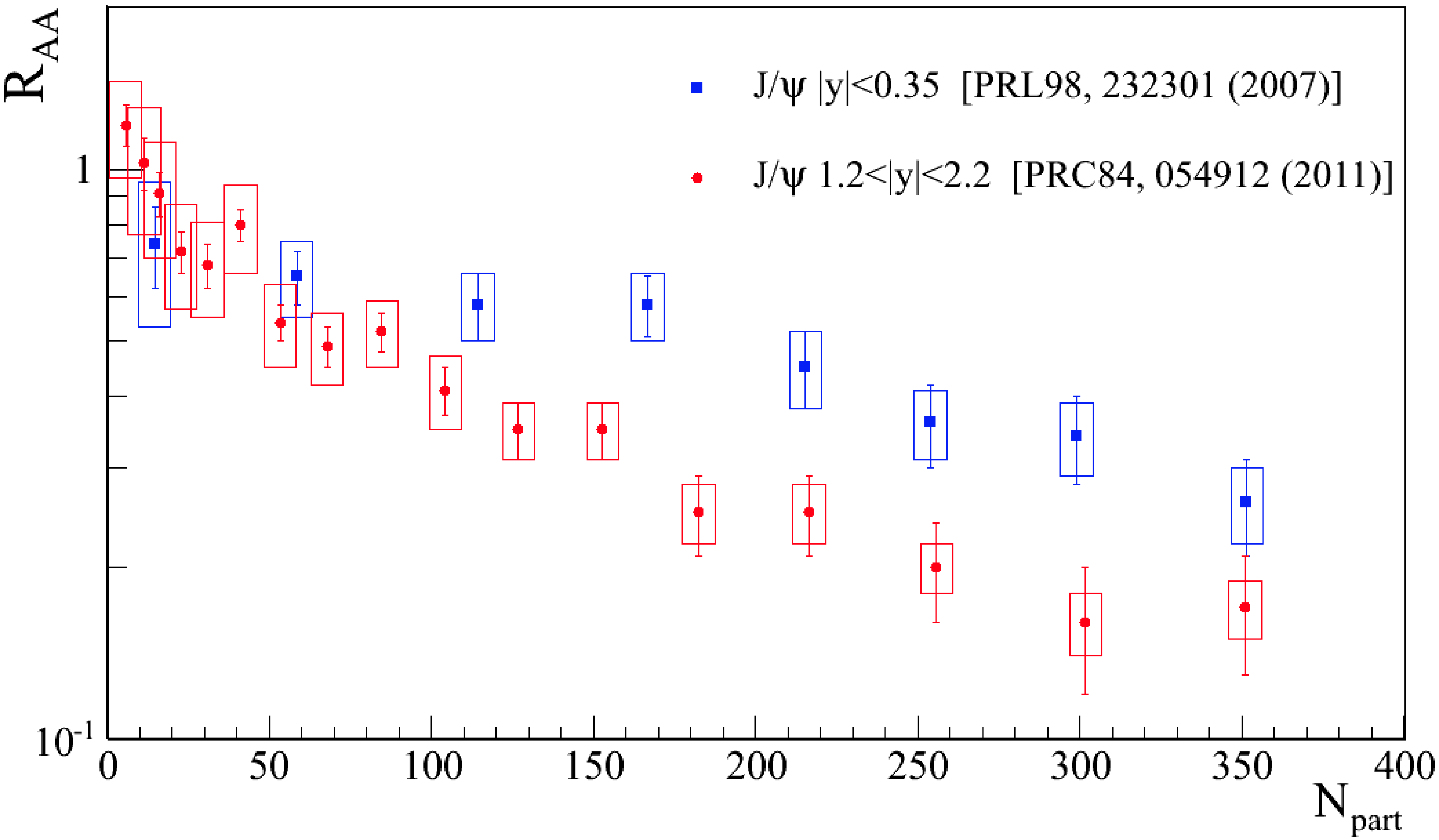
$\tau = \beta < L >$

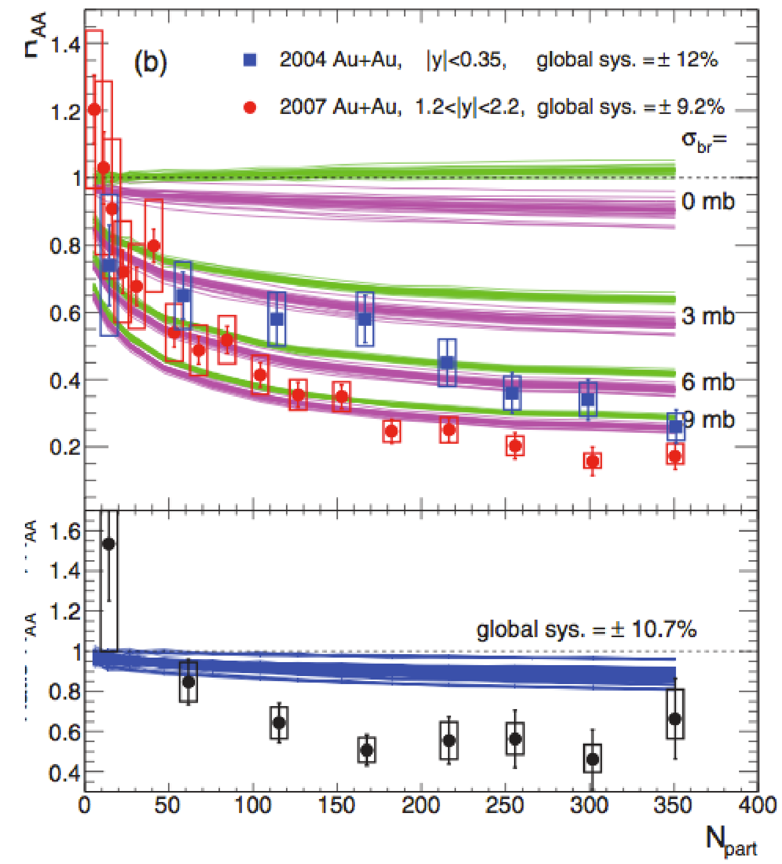
- bound $c\bar{c}$ may cross the nucleus as a pre-resonant state
- J/ψ and ψ' should have the same suppression
- data indicates something different



- particle activity can change the relative suppression of ψ'
- CMS sees the same behavior for Υ states
- comovers ?

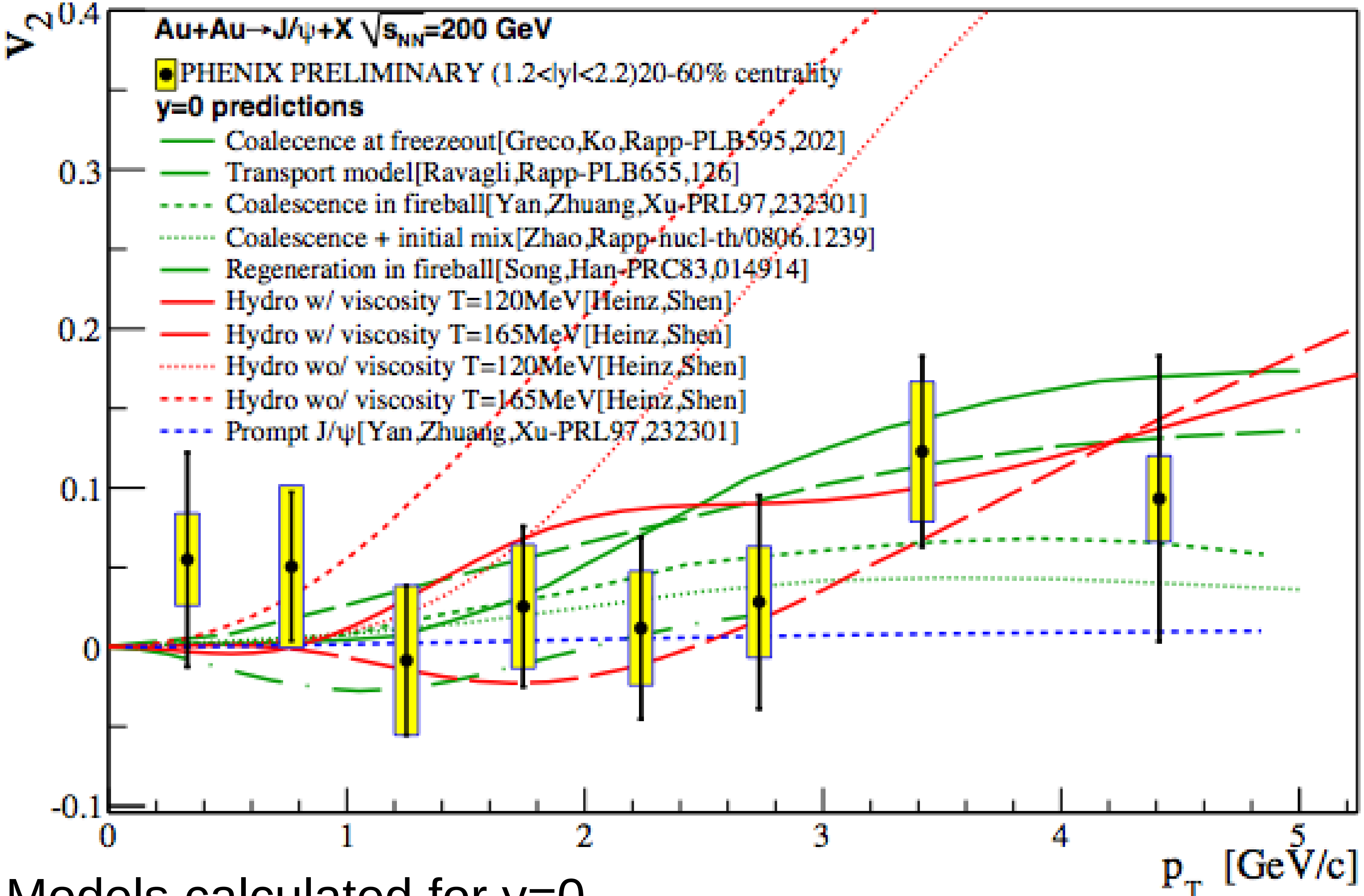
Mid- and large rapidity J/Psi R_{AA}





- EPS09 cannot describe the difference
- larger R_{AA} may indicates another source of J/ψ (regeneration ?)

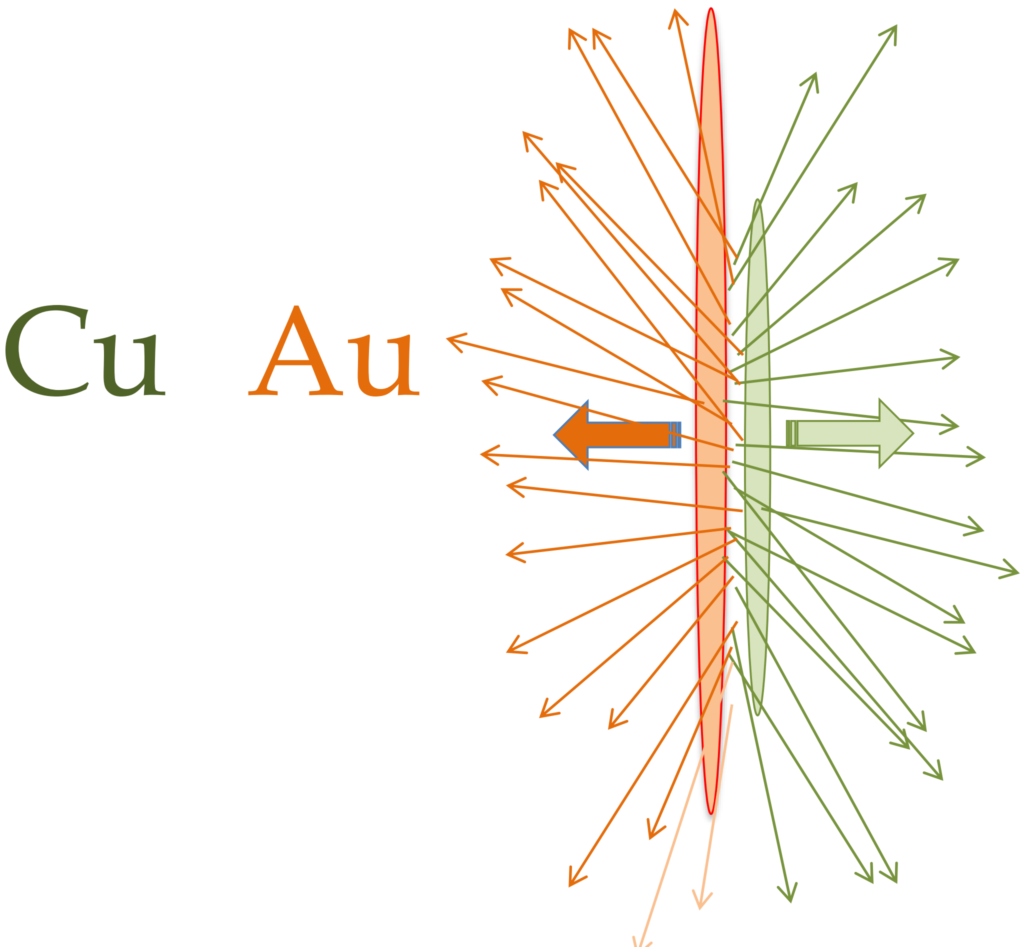
Los Alamos NATIONAL LABORATORY EST. 1943

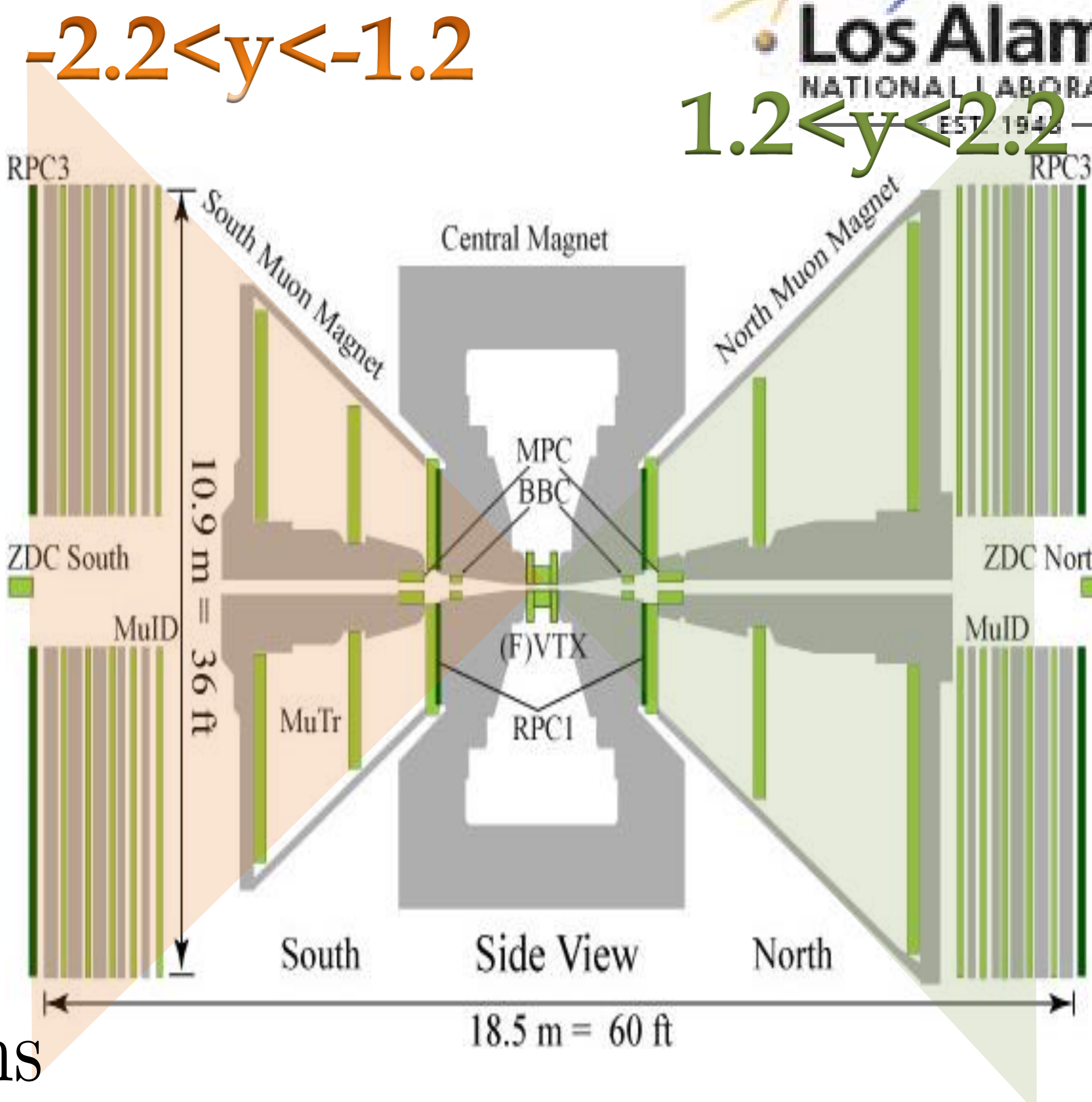


Models calculated for y=0

Data don't rule out most of coalescence/regeneration models.

Trend for increasing v_2 at high p_T ?

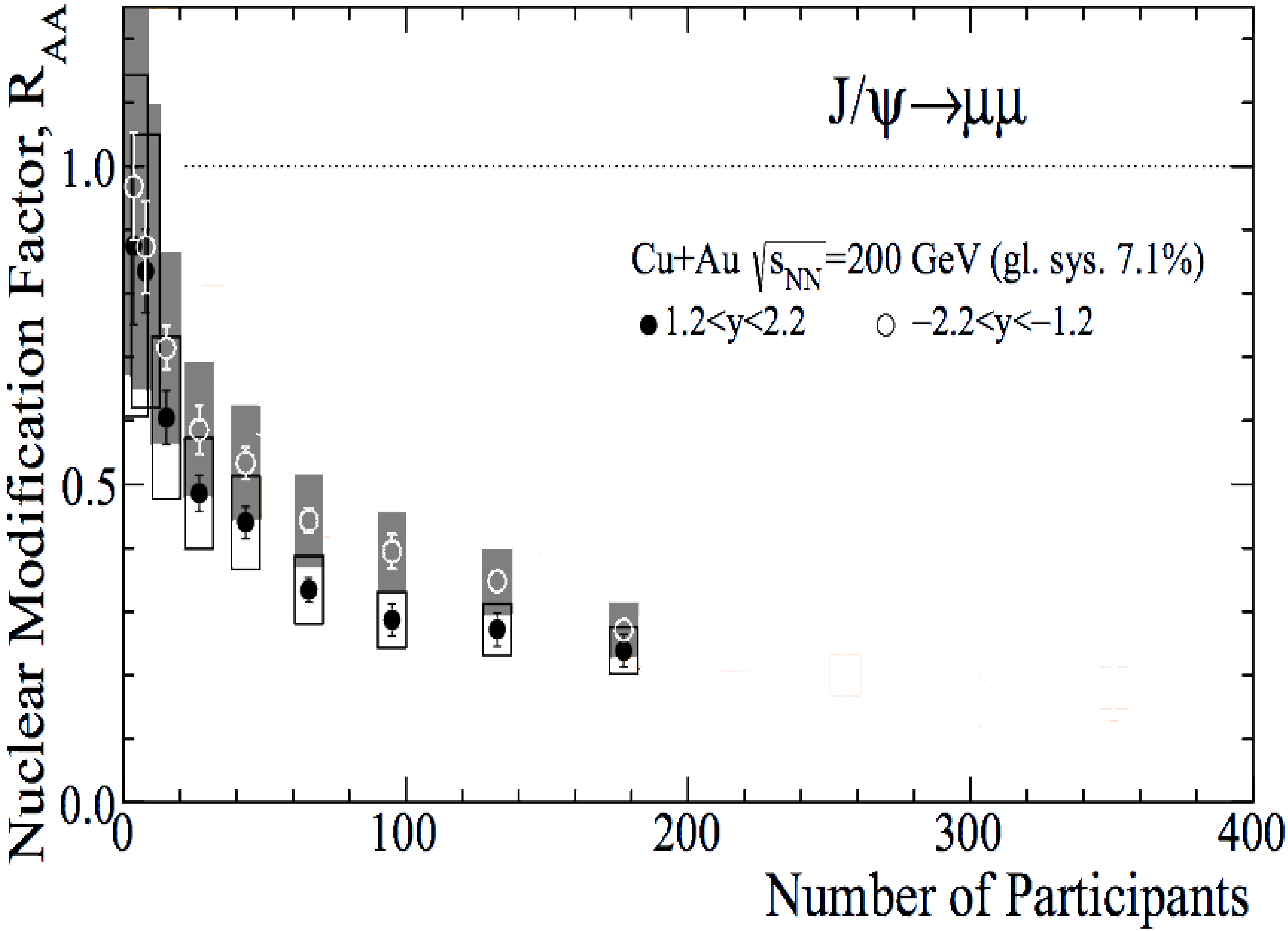




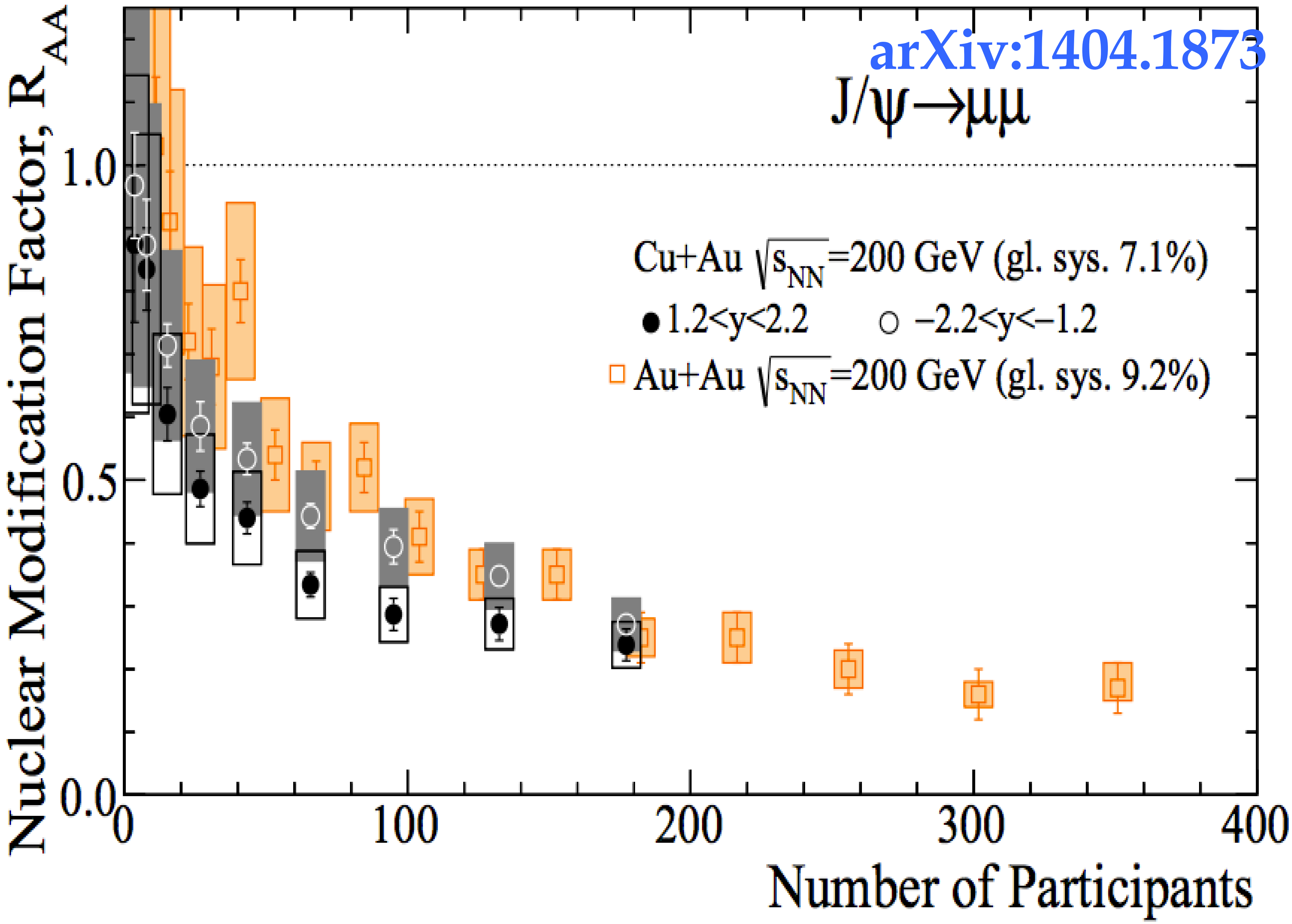
- break of the rapidity symmetry in
  - parton distribution modifications
  - nucleus crossing time of the $c - \bar{c}$ precursor
  - initial state energy loss
  - breakup in the hadronic phase
- comparisons with $p(d)$+A results will test CNM+QGP factorization

Is R_{AA} also Asymmetric ?

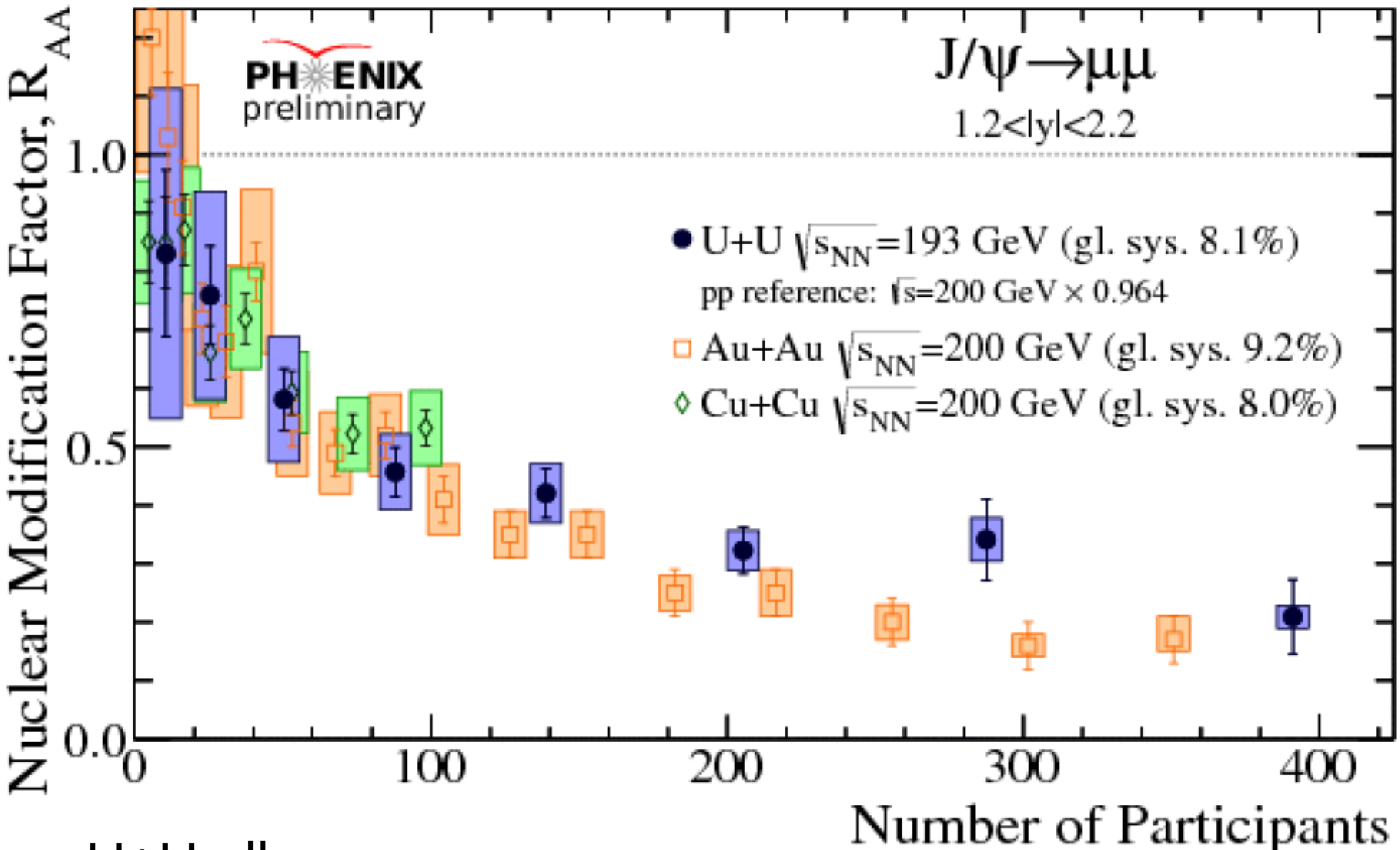
arXiv:1404.1873



Is R_{AA} also Asymmetric ?

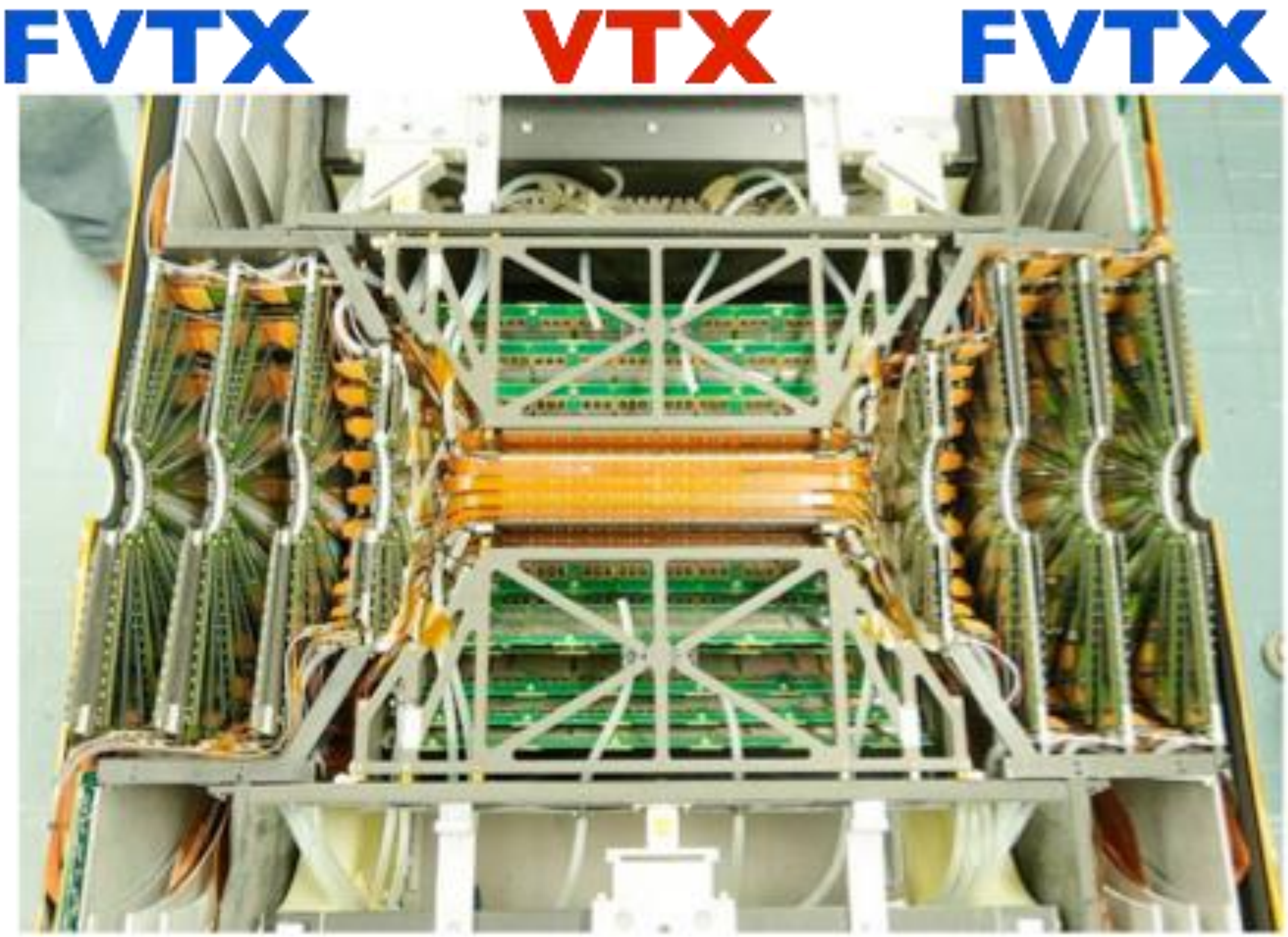


J/Psi R_{AA} in U+U collisions



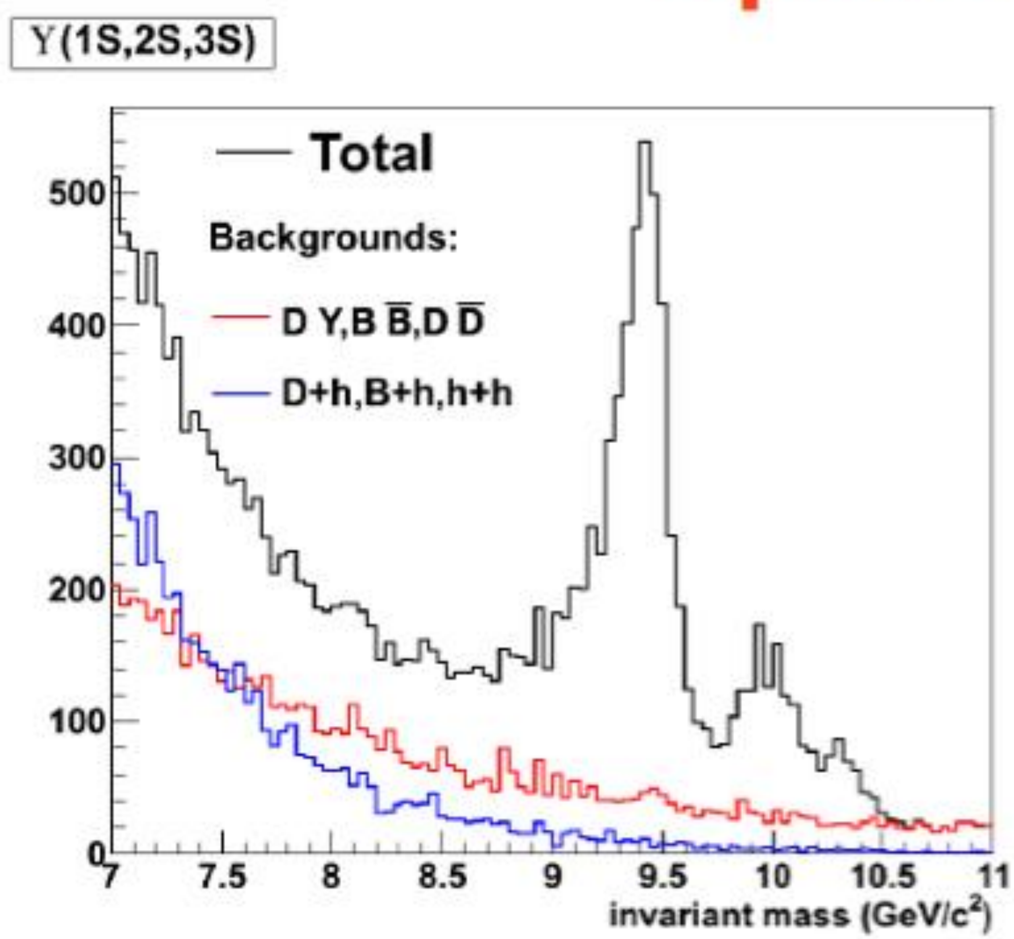
U+U allows:

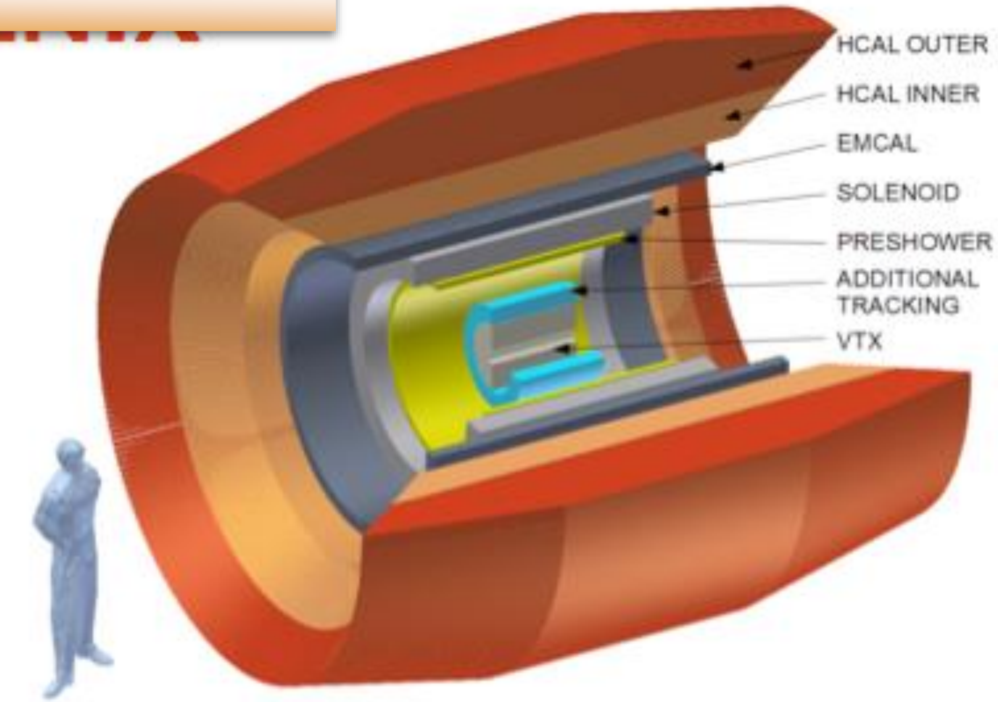
- higher energy density
- more room for recombination
- different geometry



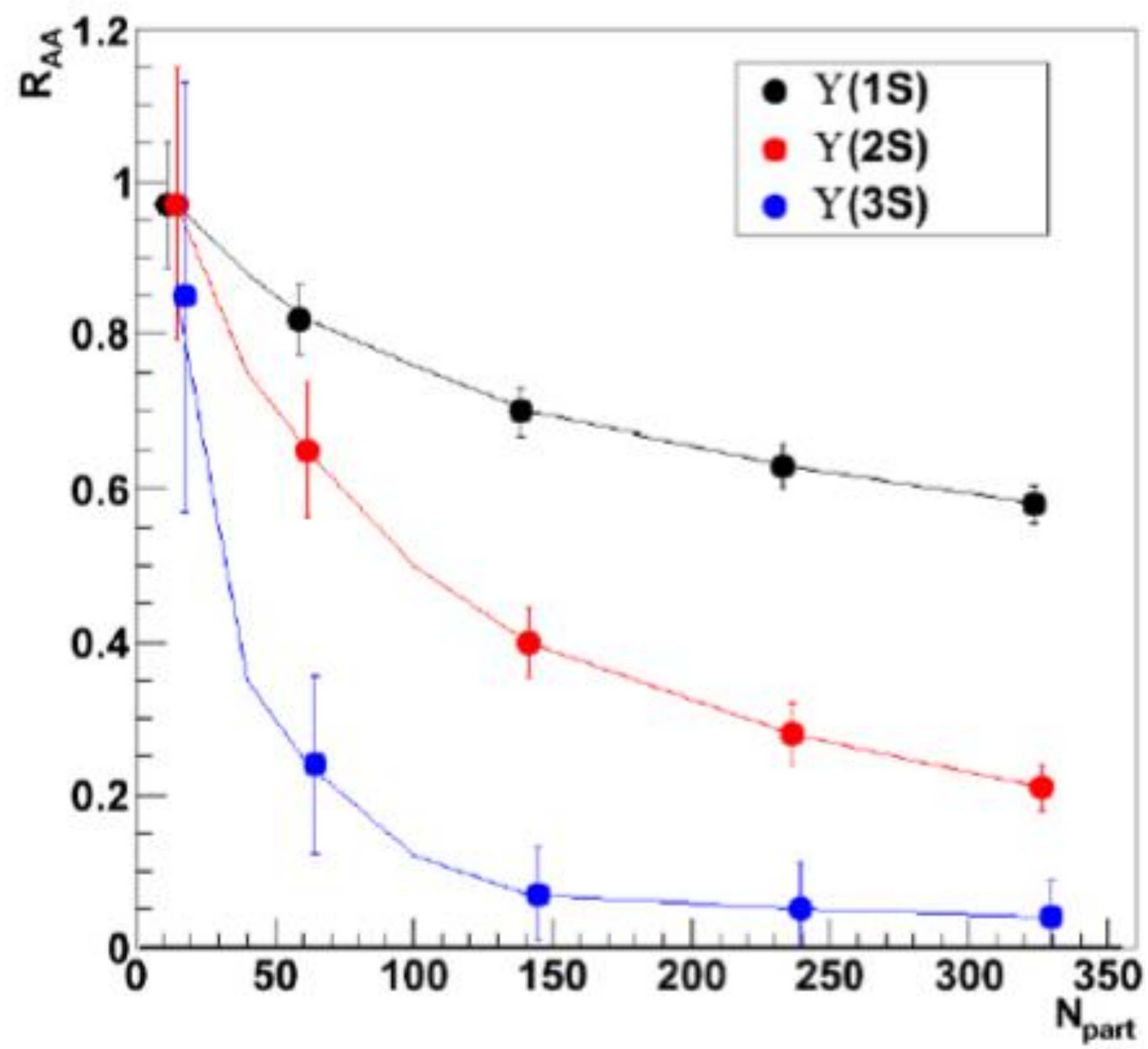
- charm and bottom nuclear modification factors at mid and forward rapidity
- ψ' measurement at forward rapididy
- heavy flavor v_2
- and much more ...

Upsilons in sPHENIX





Species	$\int L\,dt$	Events	$\langle N_{coll}\rangle$	Υ(1S)	Υ(2S)	Υ(3S)
$p+p$	$18\ pb^{-1}$	756 B	1	805	202	106
Au+Au (MB)		50 B	240.4	12794	3217	1687
Au+Au (0–10%)		5 B	962	5121	1288	675

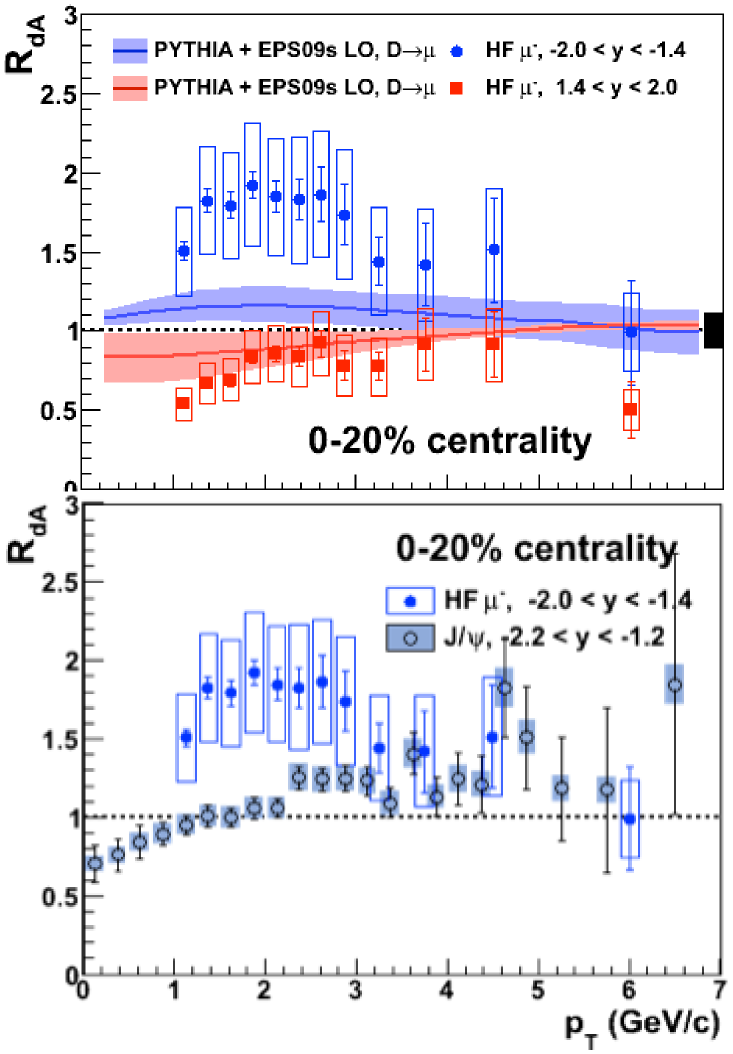


Clear separation of the three states
Large acceptance
Similar statistics to LHC

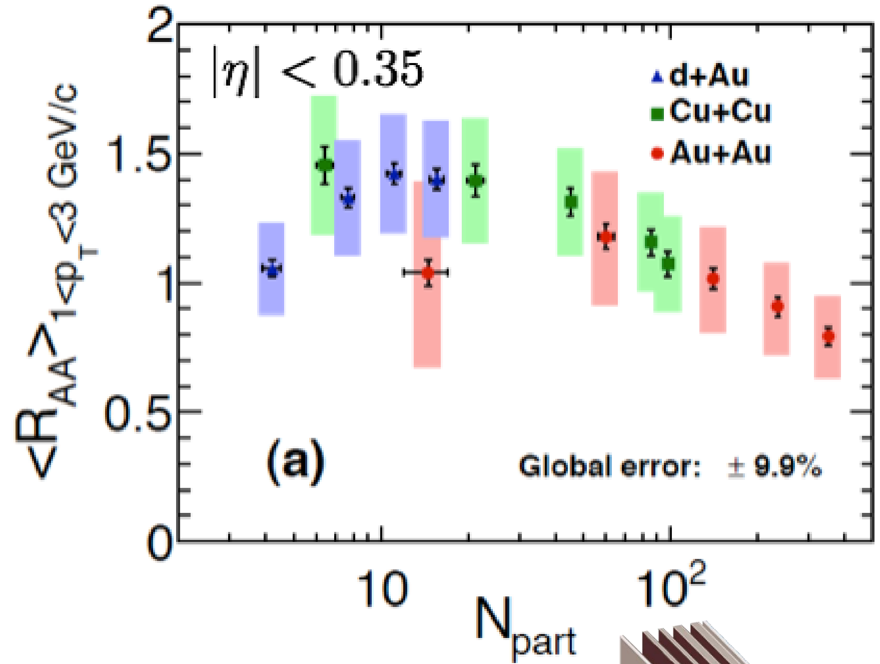
Scale of the HF R_{AA} with N_{part}.

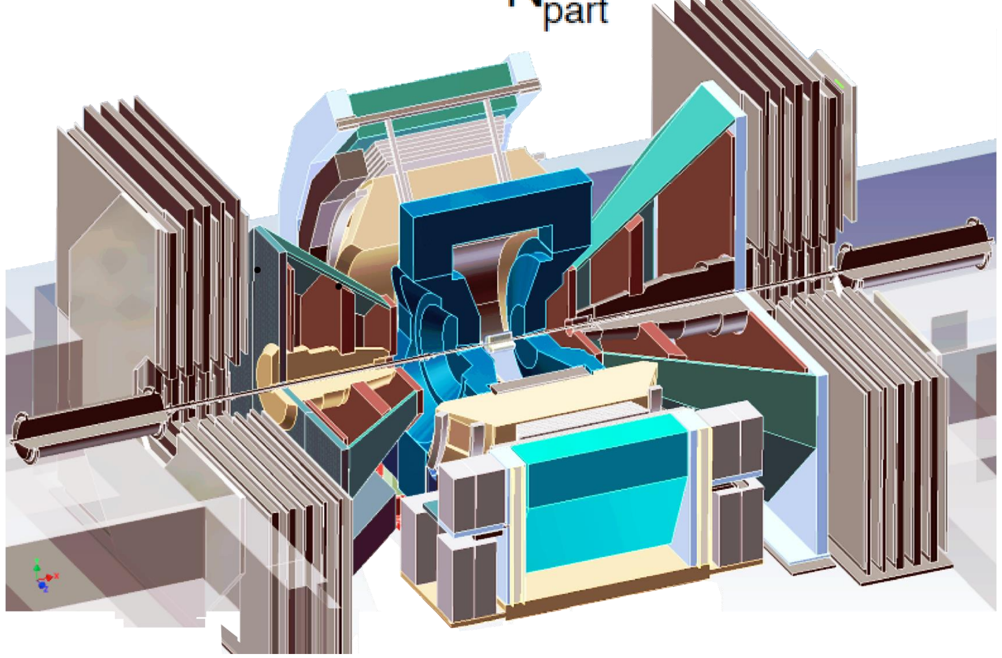
Los Alamos NATIONAL LABORATORY EST. 1943

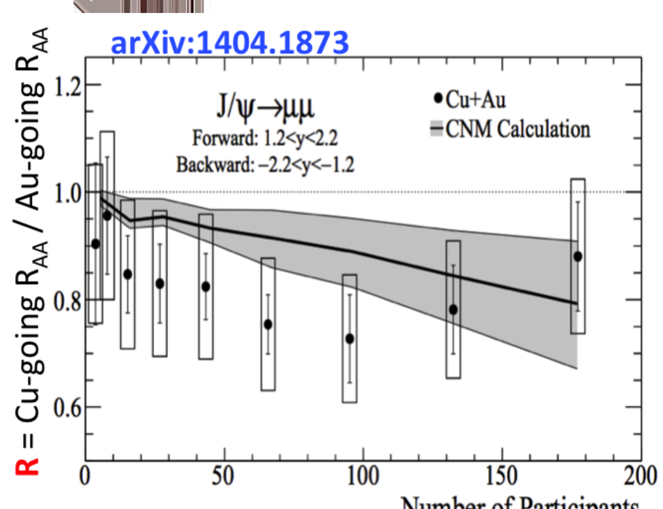
HF larger than EPS09 at backward direction



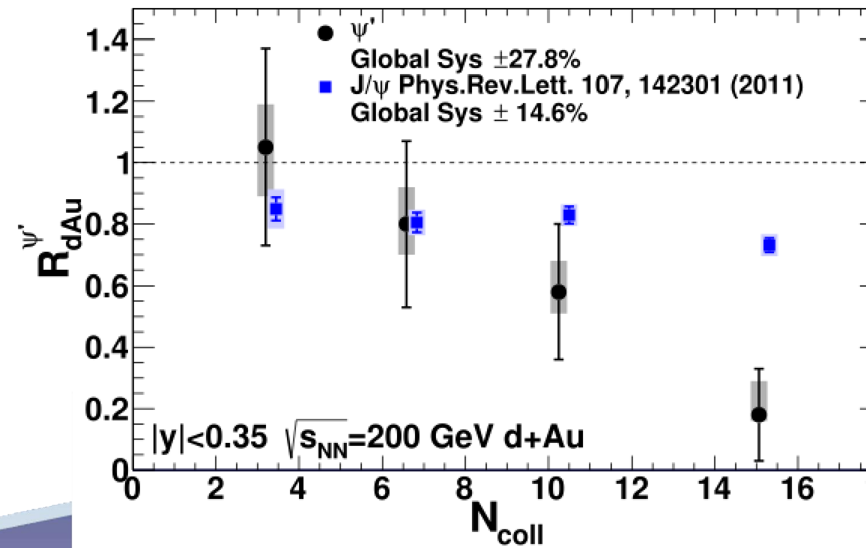
J/ψ more suppressed than HF at mid- and backward.
Hint for final state effect.

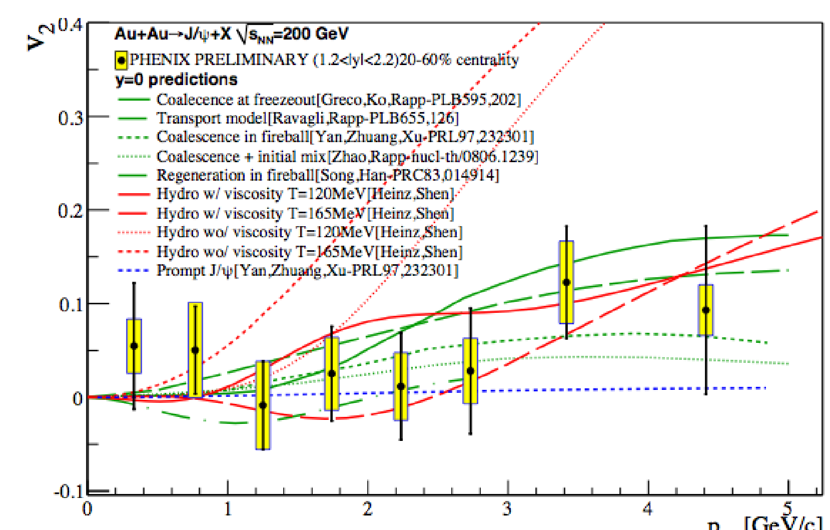




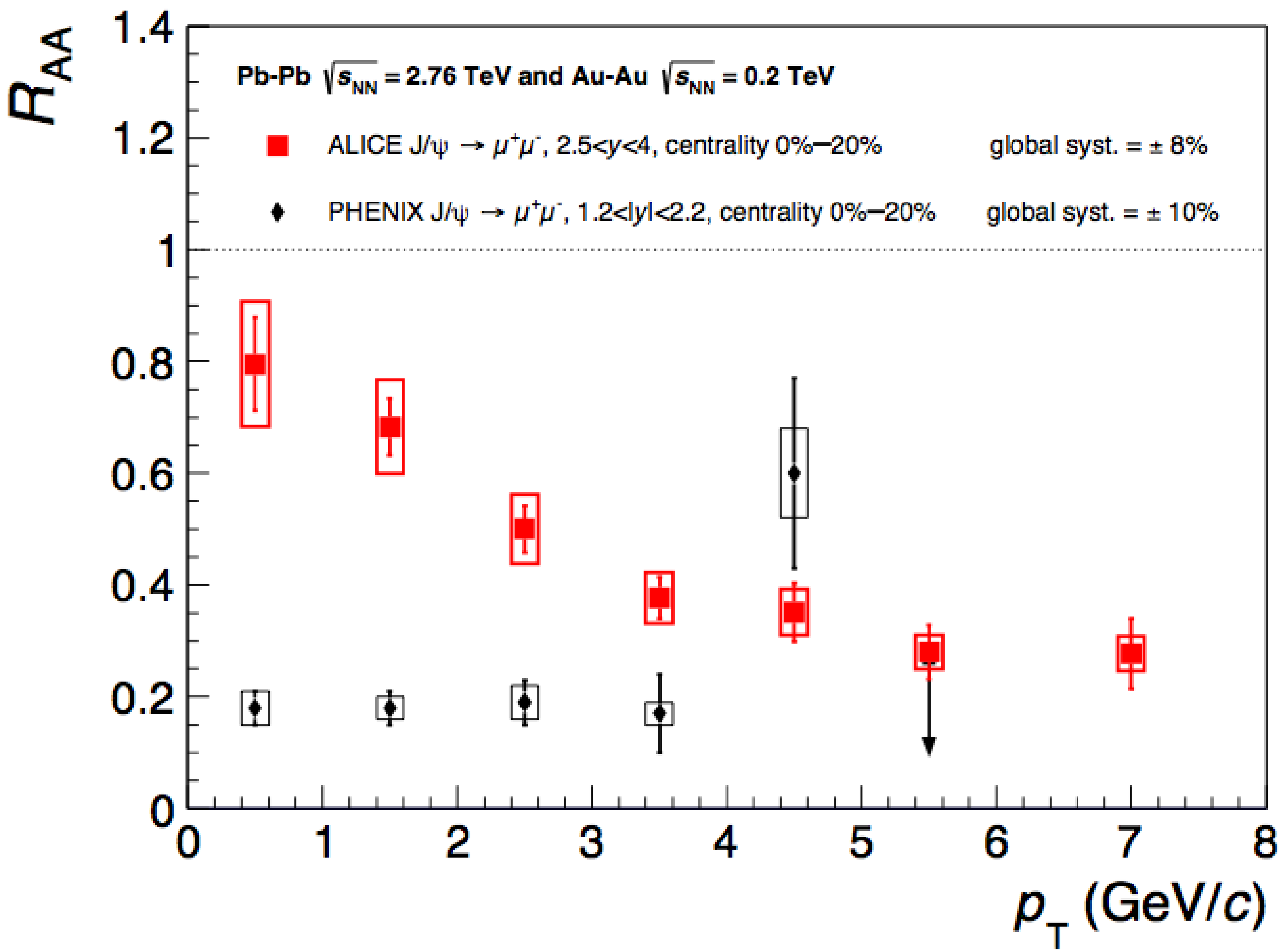


ψ' relative suppression suggests nuclear absorption from comover.





J/ψ v_2 still consistent with many charm coalescence scenarios.



R_{AA}
Pb-Pb $\sqrt{s_{NN}}$ = 2.76 TeV and Au-Au $\sqrt{s_{NN}}$ = 0.2 TeV
ALICE J/ψ → $\mu^+\mu^-$, 2.5<y<4, centrality 0%–20%
global syst. = ± 8%
PHENIX J/ψ → $\mu^+\mu^-$, 1.2<|y|<2.2, centrality 0%–20%
global syst. = ± 10%
p_T (GeV/c)