

# Medium formation in small systems?

Selected recent results from  
PHENIX in  $d+Au$  and  $^3He+Au$

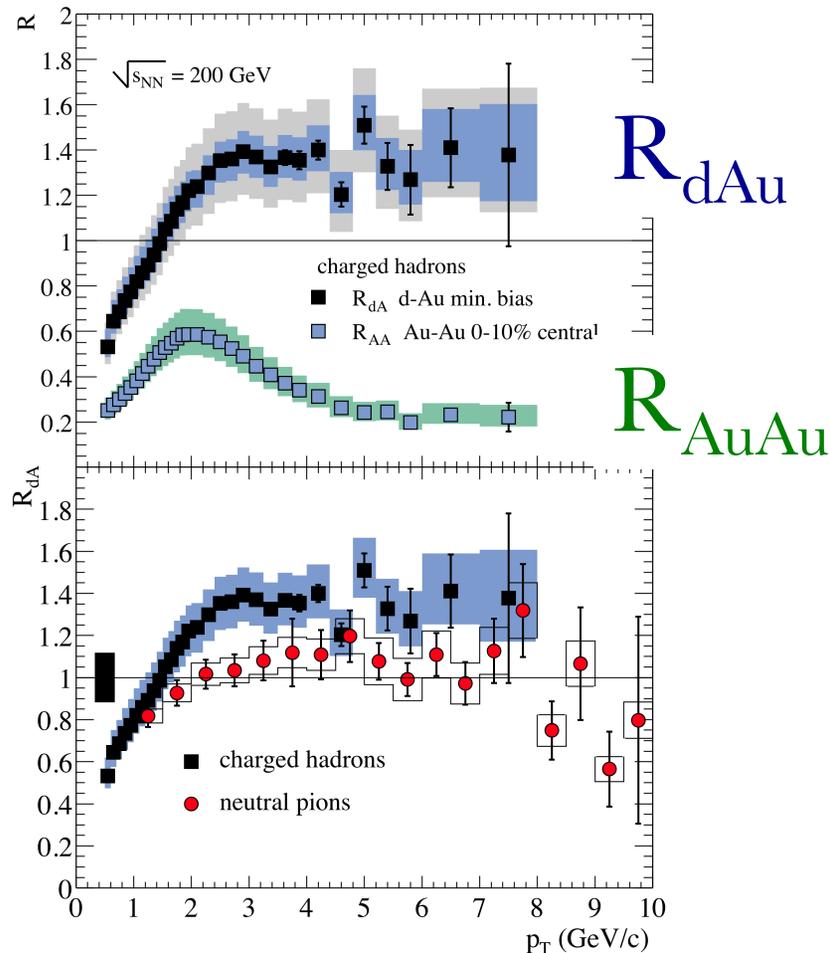
Paul Stankus

Oak Ridge National Lab

WWND 2015, Jan 26 Keystone CO

# A funny thing happened...

...on the way to the control example.



**Idea:** d+Au is just like N+N except for initial-state/CNM effects on partons.

**2003:** d+Au does not show jet quenching!  
There was much rejoicing!

**But:** That simple picture is breaking down...

“A search for possible evidence of a created medium being formed in small collision systems, e.g. H+A and He+A at RHIC and LHC energies”

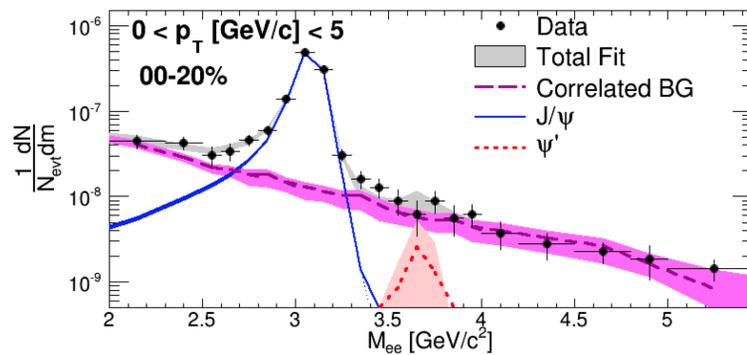
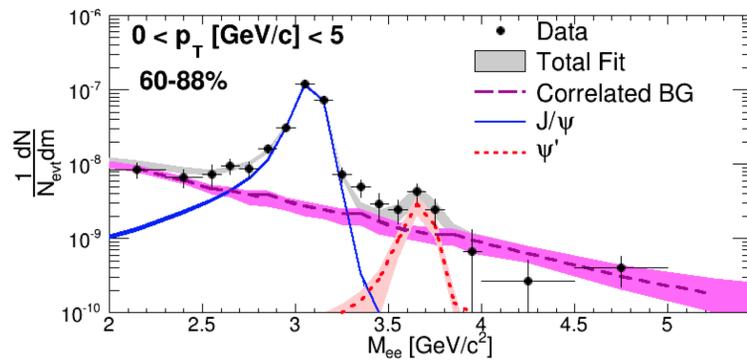
or

“A search for possible evidence of a created medium being formed in small collision systems, e.g. H+A and He+A at RHIC and LHC energies”

or

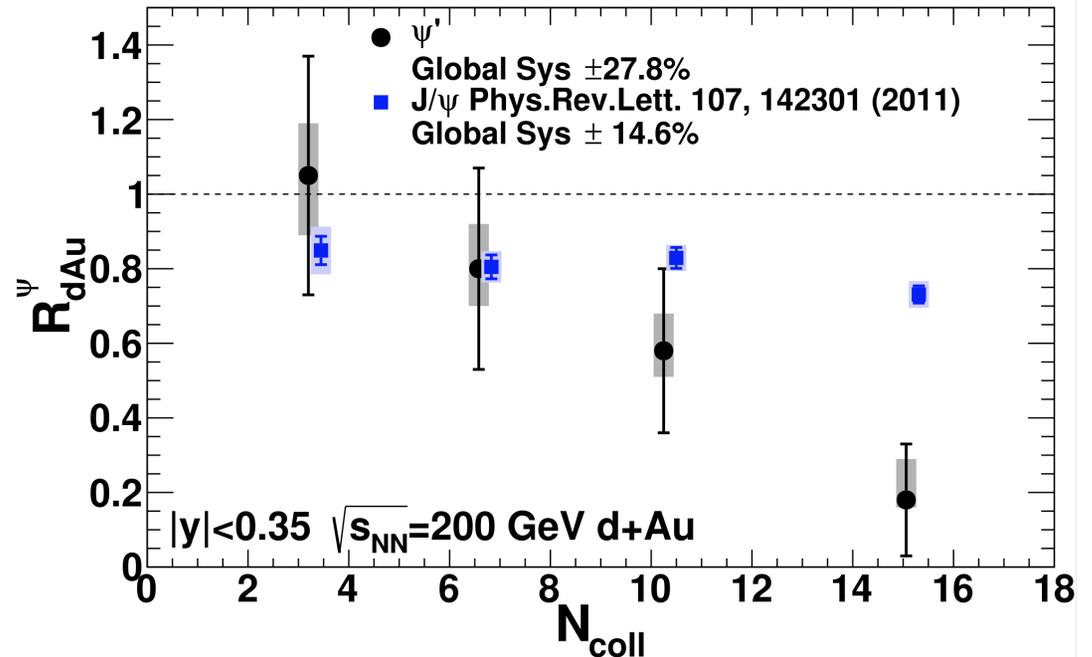
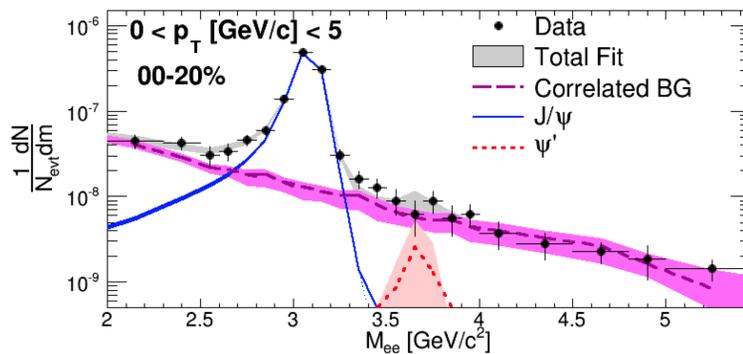
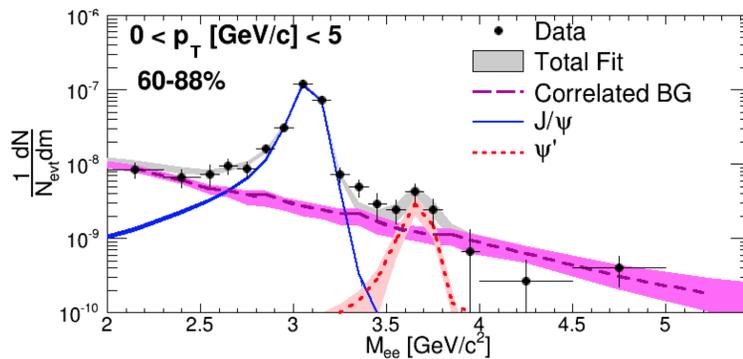
*“Small Medium At Large”*

# Psi' (over?) suppression in d+Au



PRL 111, 202301 (2013)

# Psi' (over?) suppression in d+Au



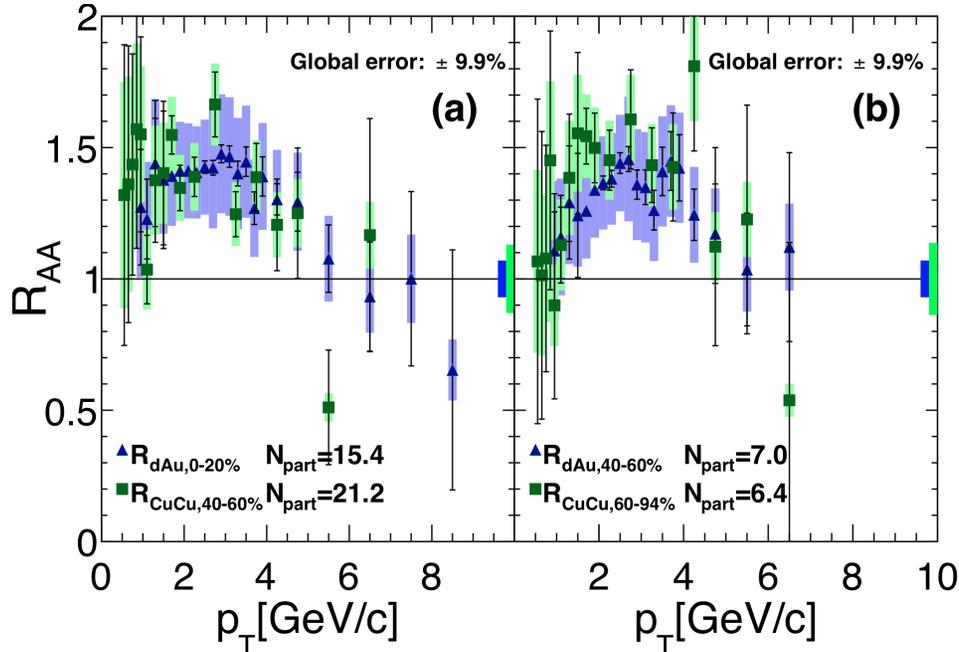
Relative suppression of Psi'  
compared to J/Psi – is it a  
created medium effect?  
(Also seen by ALICE in p+Pb)

PRL 111, 202301 (2013)

# Charm boost follows $N_{\text{Part}}$

Heavy-flavor electrons in three systems

d+Au meets Cu+Cu

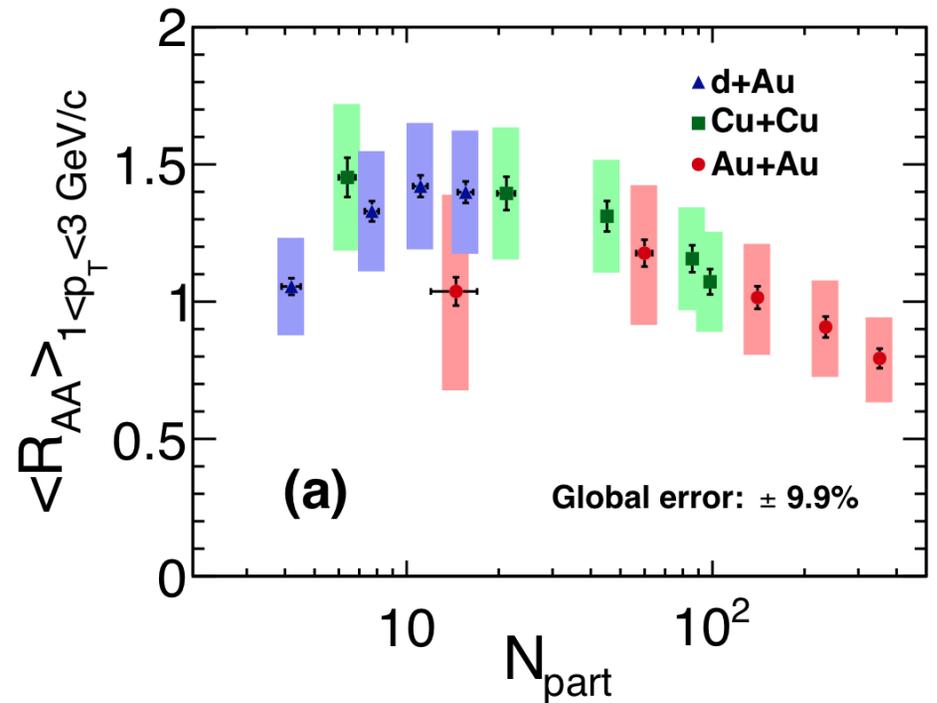
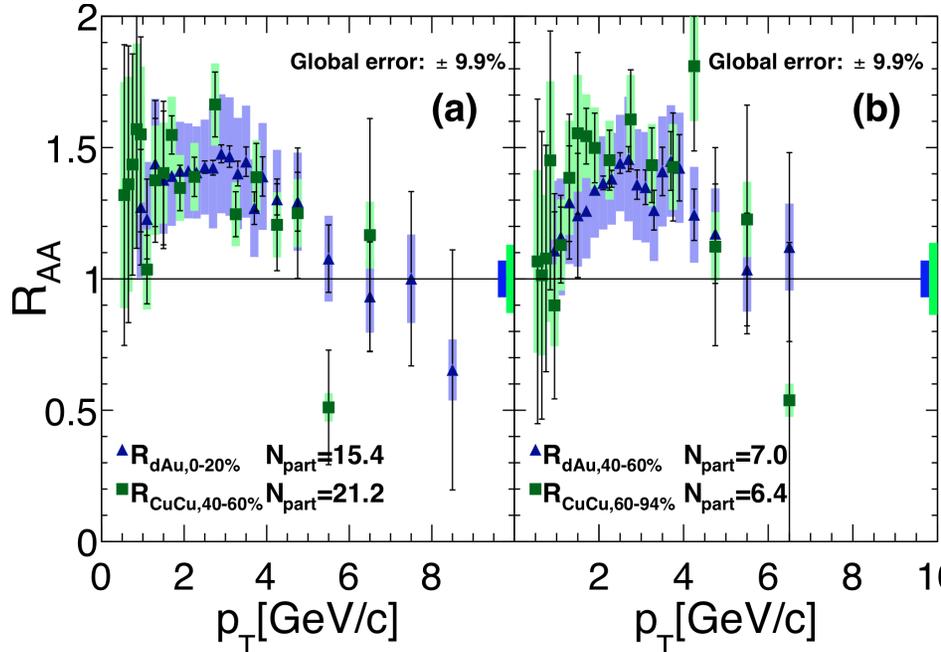


arXiv:1310.8286

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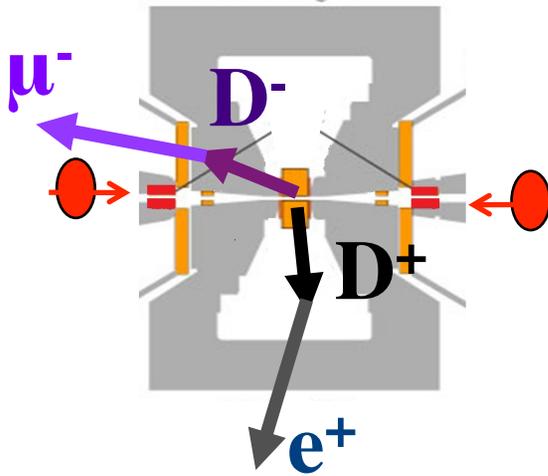


arXiv:1310.8286

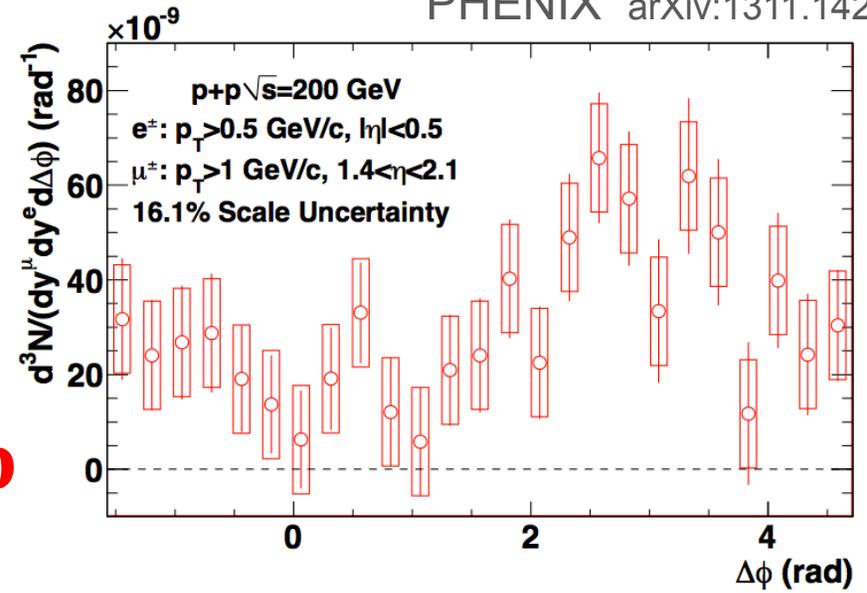
Single charm is pushed but never destroyed; is trend with  $N_{\text{part}}$  indicative of medium effect?

# Open charm de-correlation

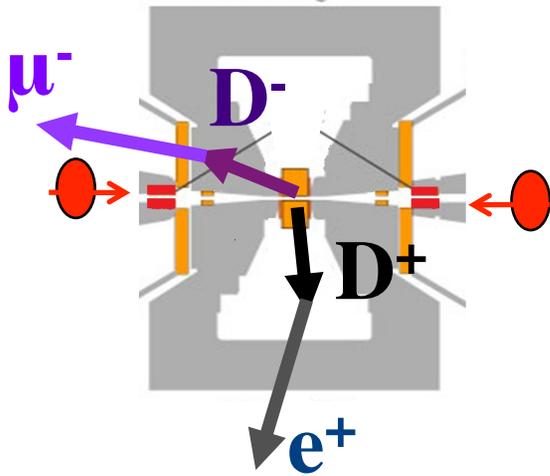
PHENIX arXiv:1311.1427



**p+p**

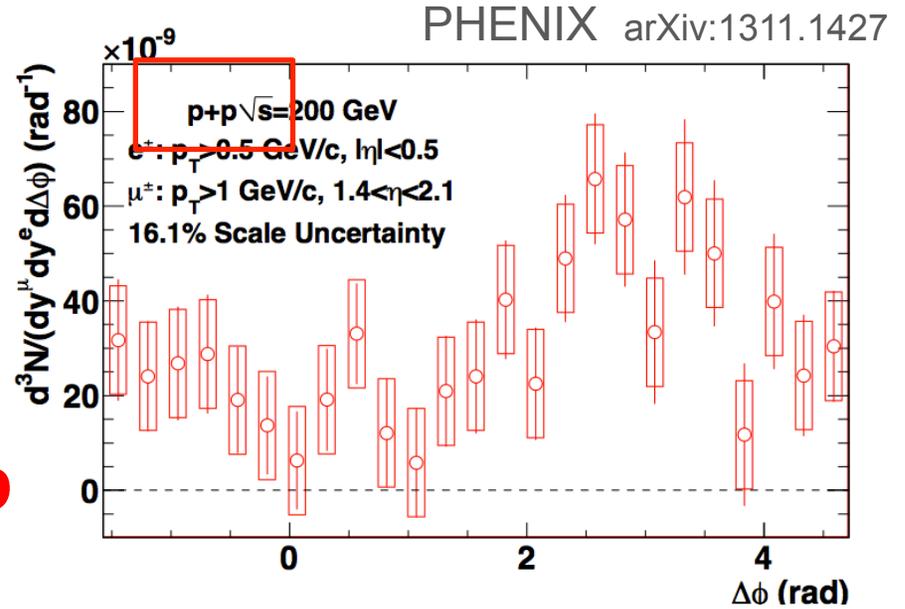


# Open charm de-correlation

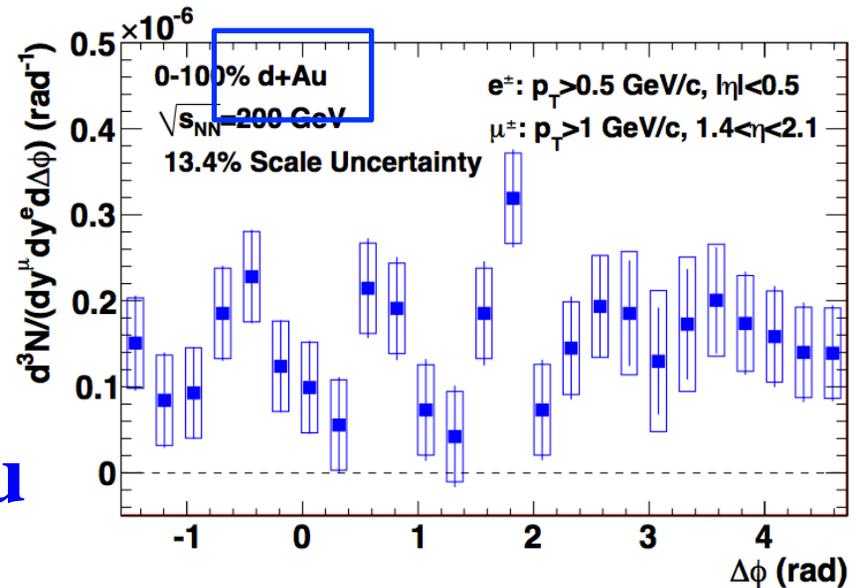


Back-to-back correlation of associated charm is decreased in d+Au; what is the site of any re-scattering?

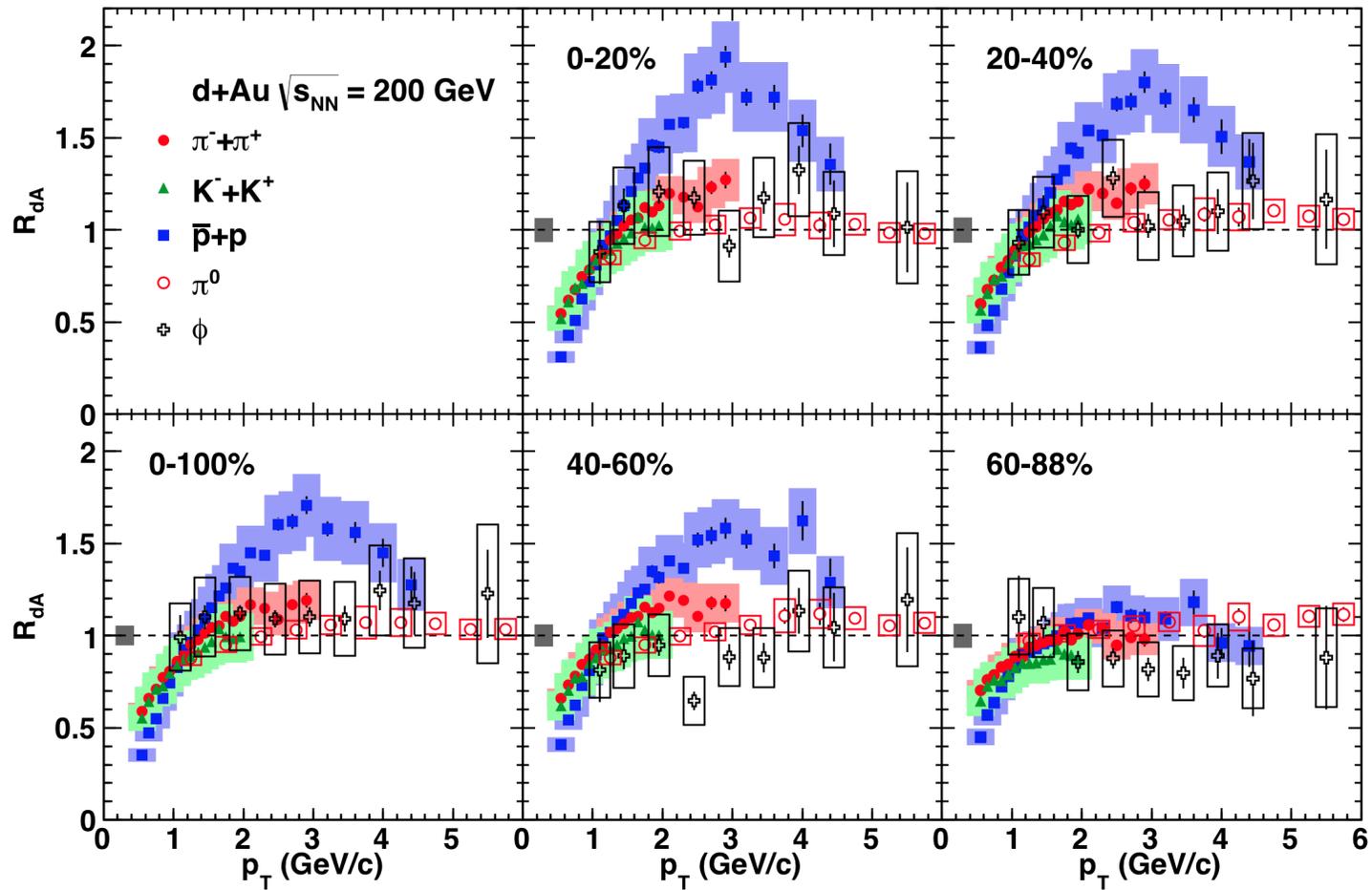
**p+p**



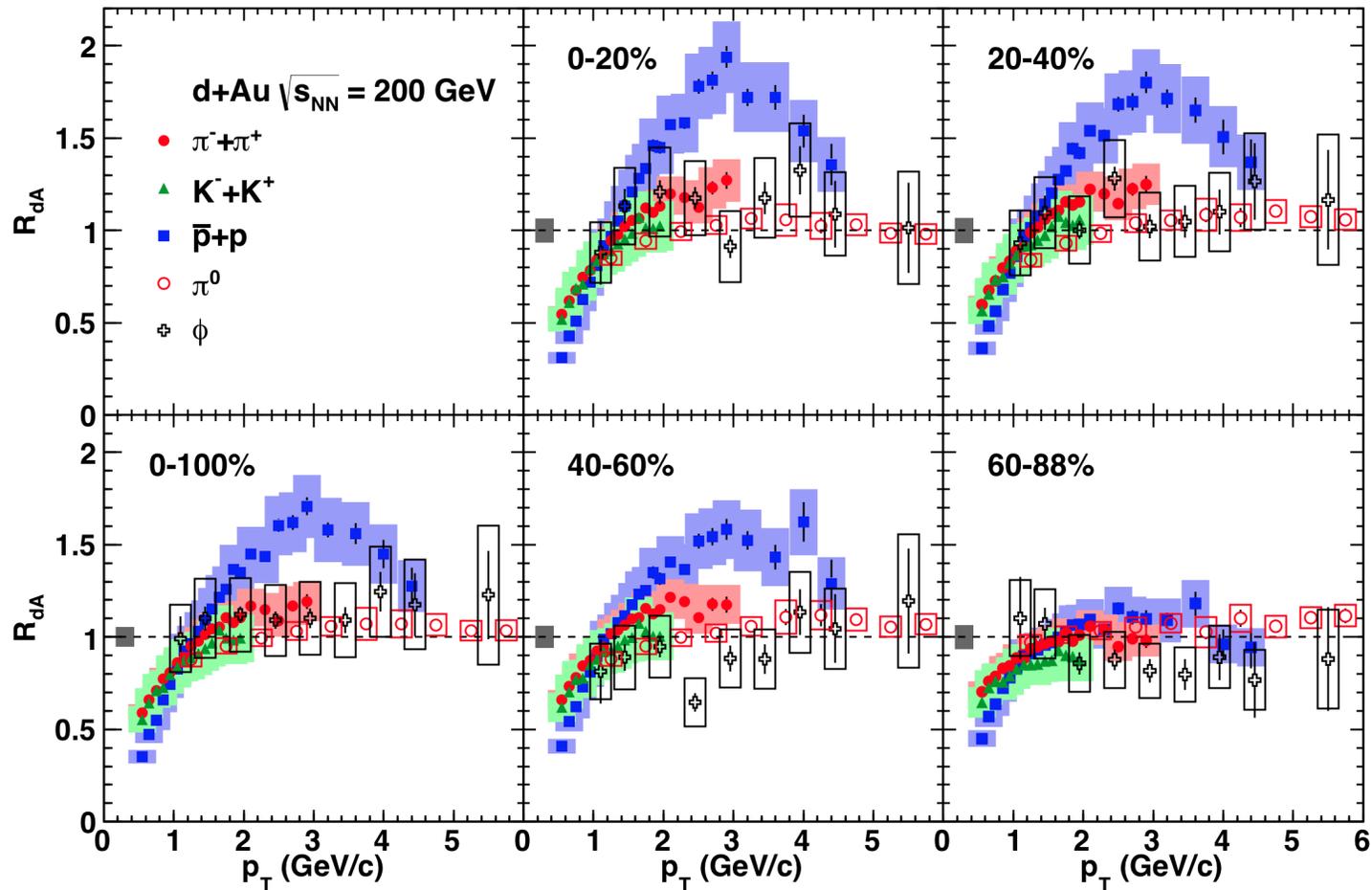
**d+Au**



# Light hadrons Cronin rides again?

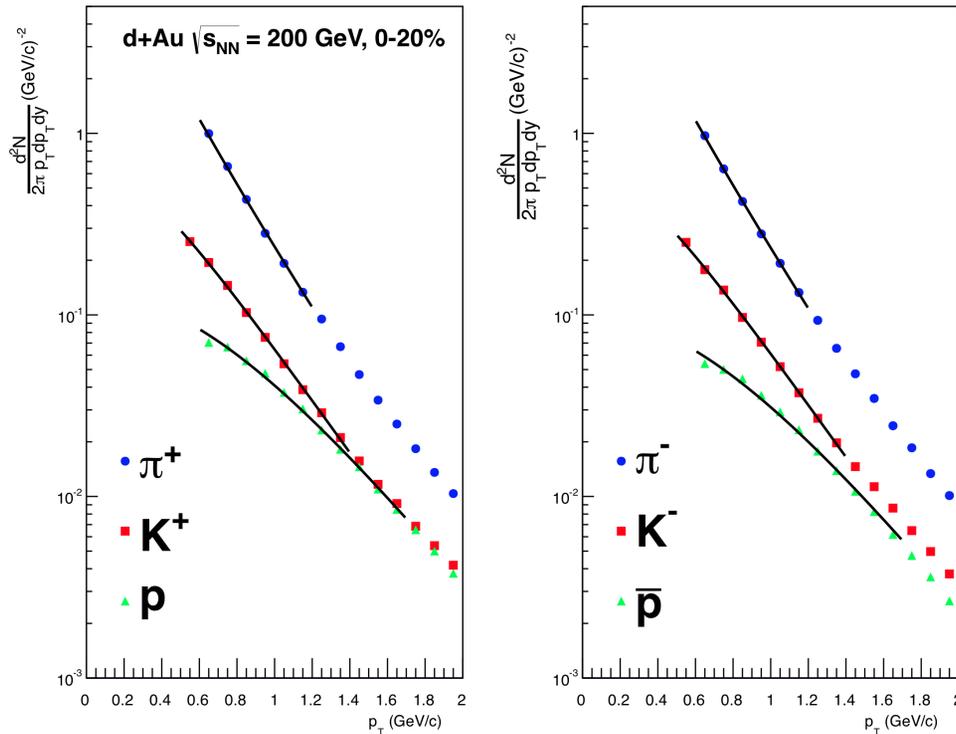


# Light hadrons Cronin rides again?



**Dramatic baryon enhancement: recombination from a medium?**

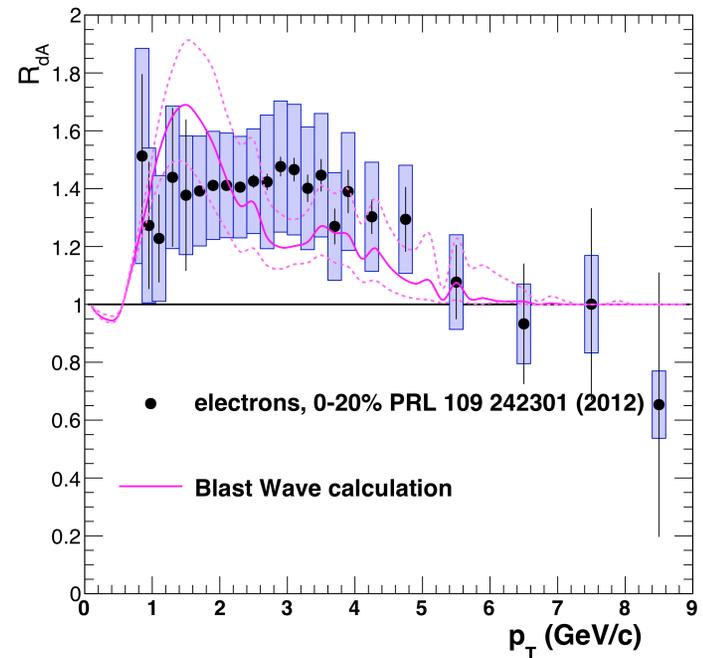
# Radial flow in d+Au?



**Blast-wave fits to identified light hadron spectra**

A. Sickles, Phys. Lett. B731 51-56 (2014),  
 “Possible Evidence for Radial Flow of Heavy Mesons in d+Au Collisions”

Was it the source of the Cronin effect?



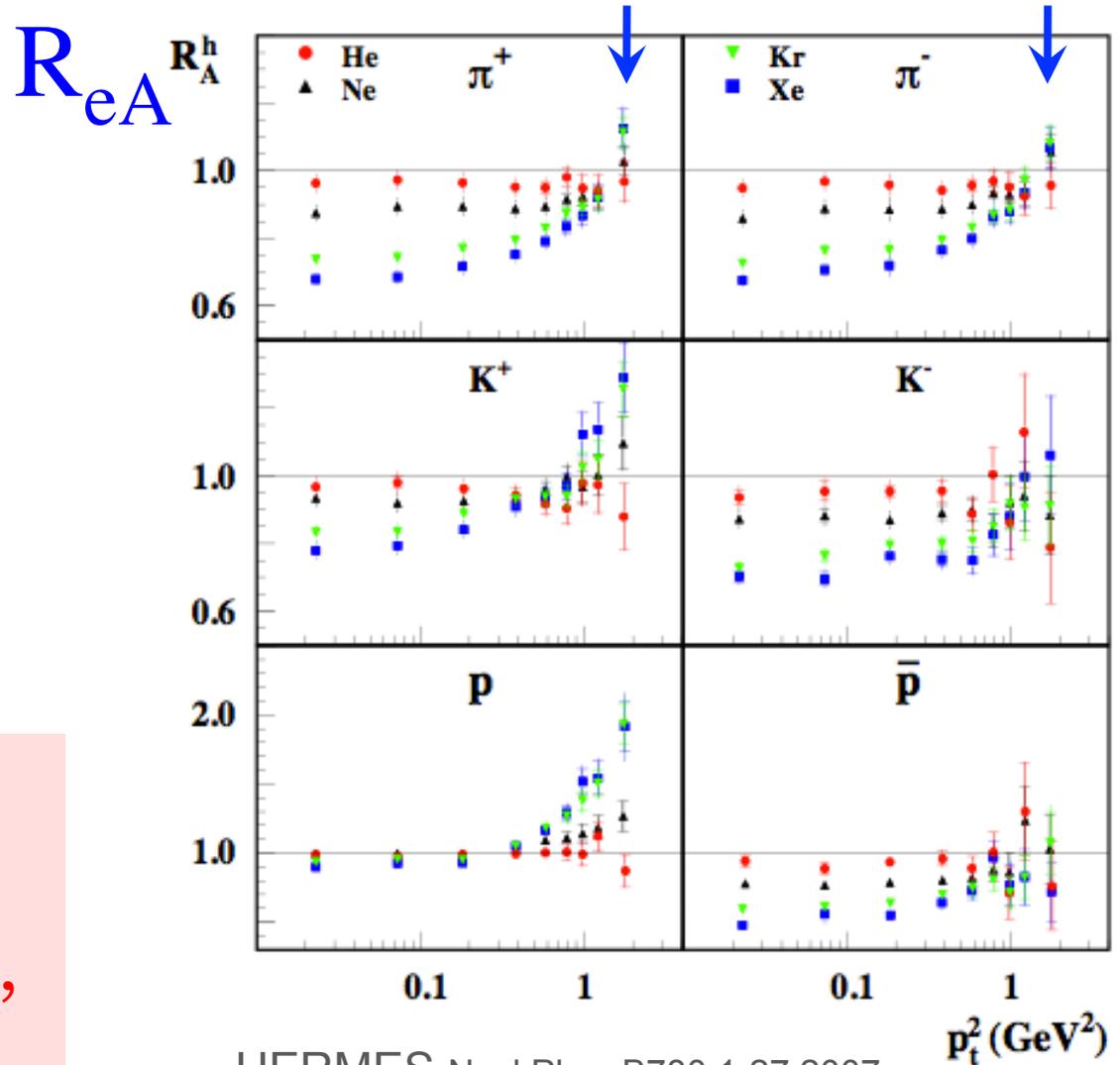
**Heavy-flavor (charm) electron  $R_{dAu}$**

# Caution: Cronin rides in $e+A$

Enhancement of  
(+) hadron yields at  
 $p_T \sim 1-1.5 \text{ GeV}/c$   
is seen with  
increasing  $A$  in  $e+A$ .

Pattern is *sort of* like  
radial flow?

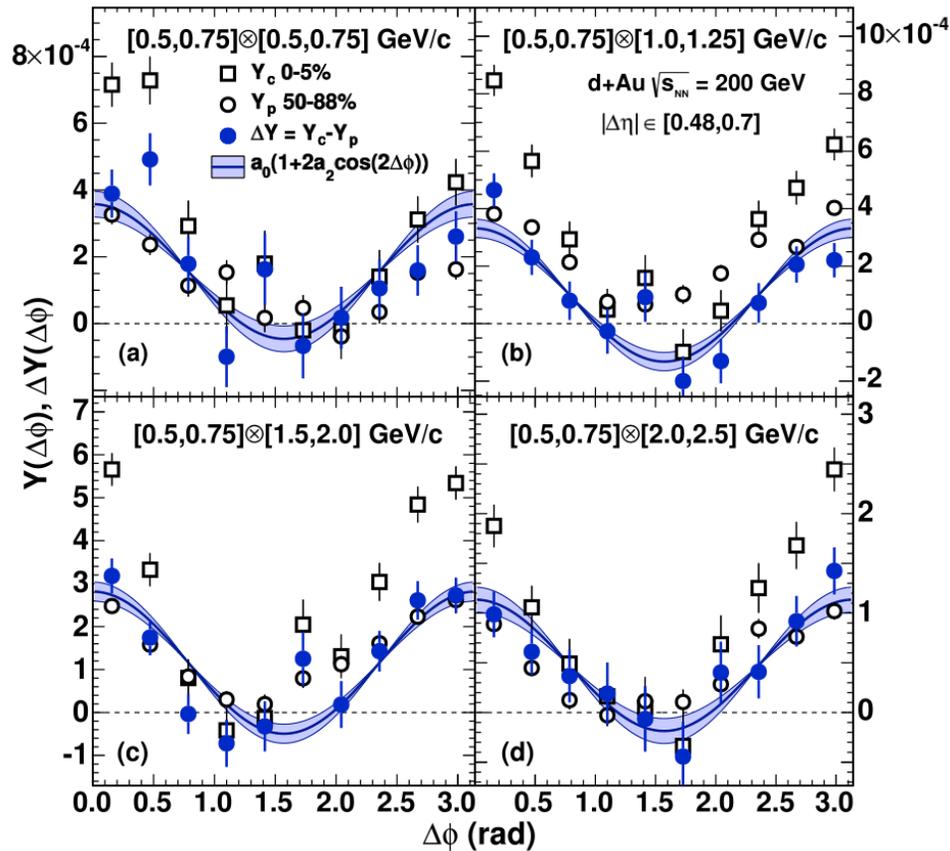
**Moral:** Need to  
look at small  
systems with full,  
proper models



HERMES Nucl.Phys.B780:1-27,2007

# Elliptic flow in d+Au?

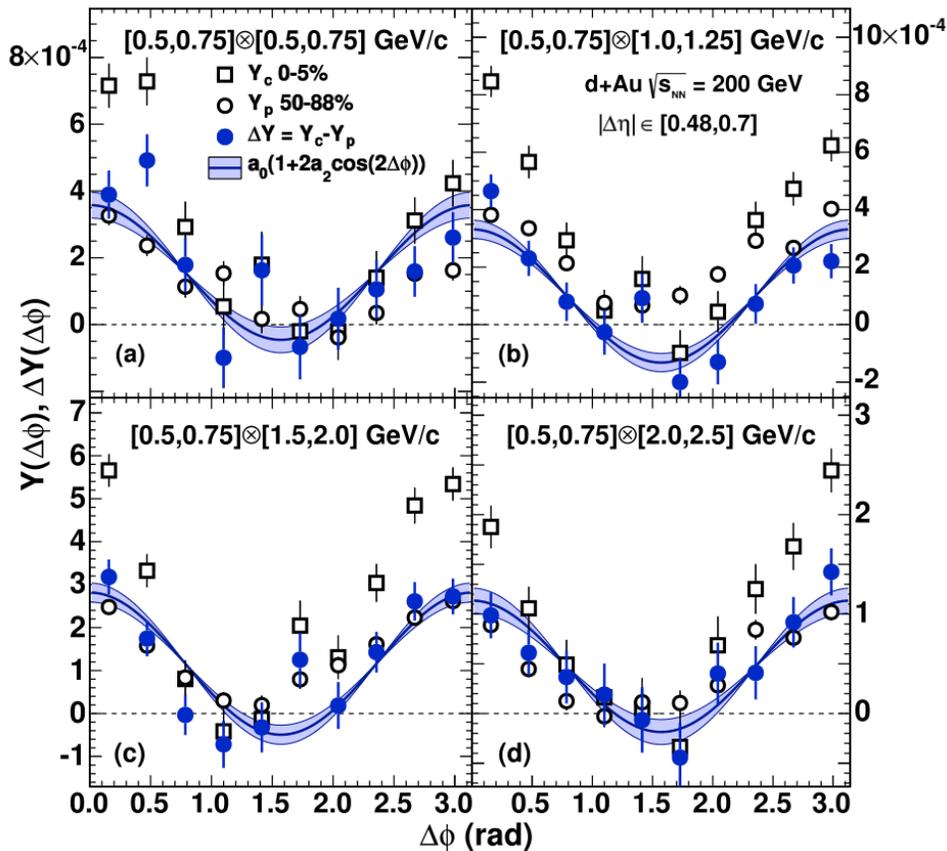
Charged pairs at mid-rapidity over  $\Delta\phi$ ;  
central, peripheral and difference



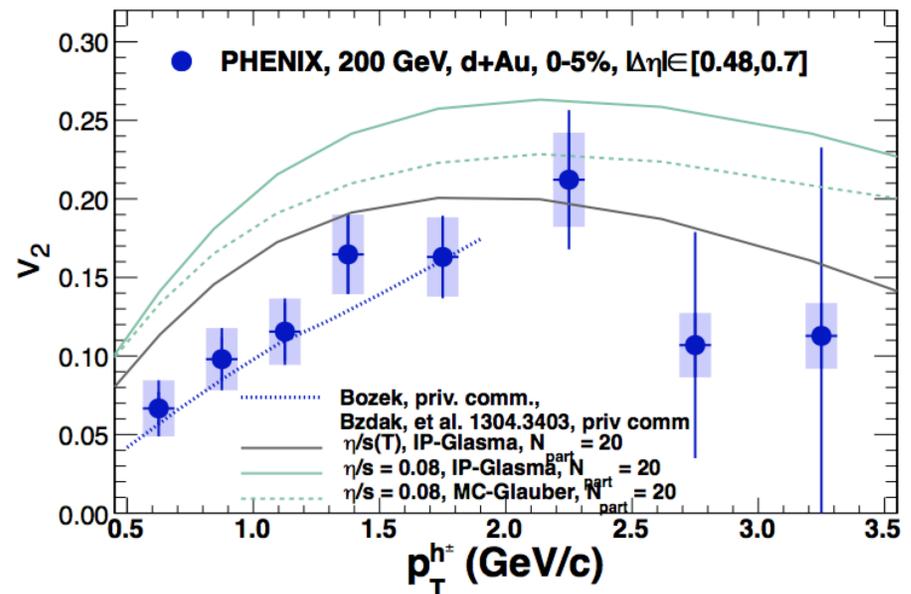
PRL 11, 212301 (2013)

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PRL 11, 212301 (2013)

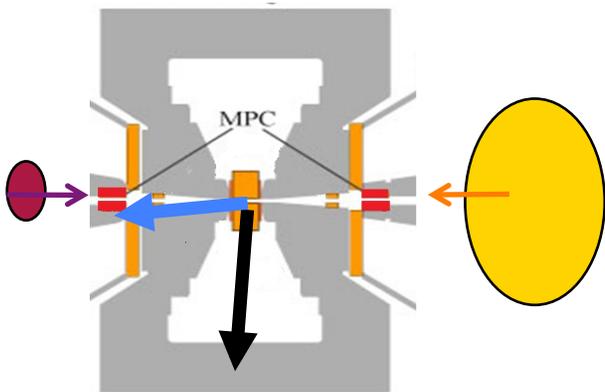


Quadrupole anisotropy allows  
extraction of singles  $v_2$

Caution: C-P subtraction may not  
play well with jet modifications

# Near-side “ridge” in d+Au?

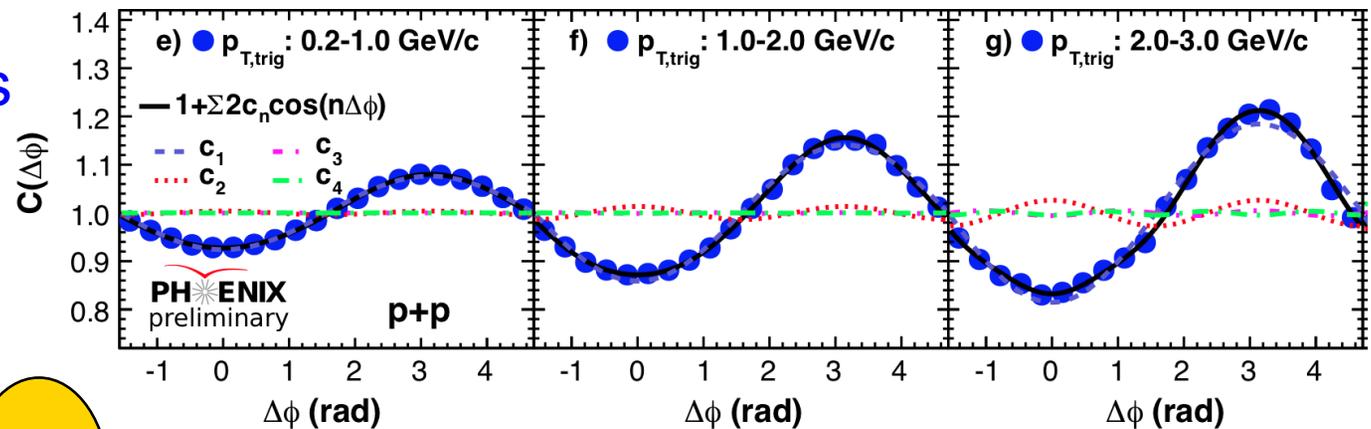
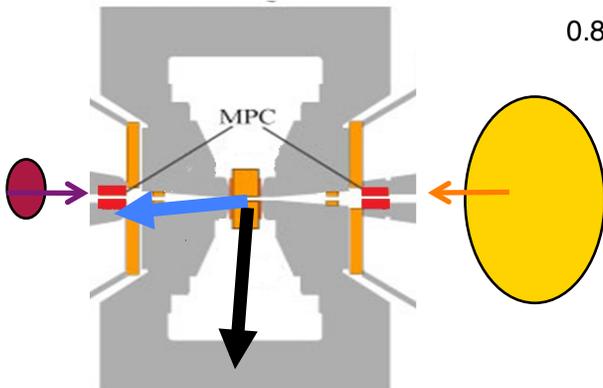
Pair central arm tracks with MPC-S,  $\Delta\eta \sim 3.4$



# Near-side “ridge” in d+Au?

Pair central arm tracks with MPC-S,  $\Delta\eta \sim 3.4$

p+p min-bias

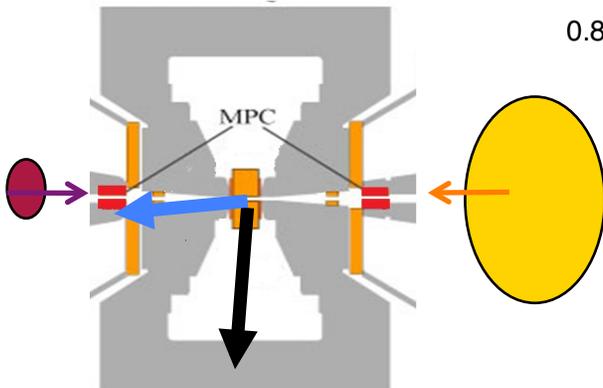
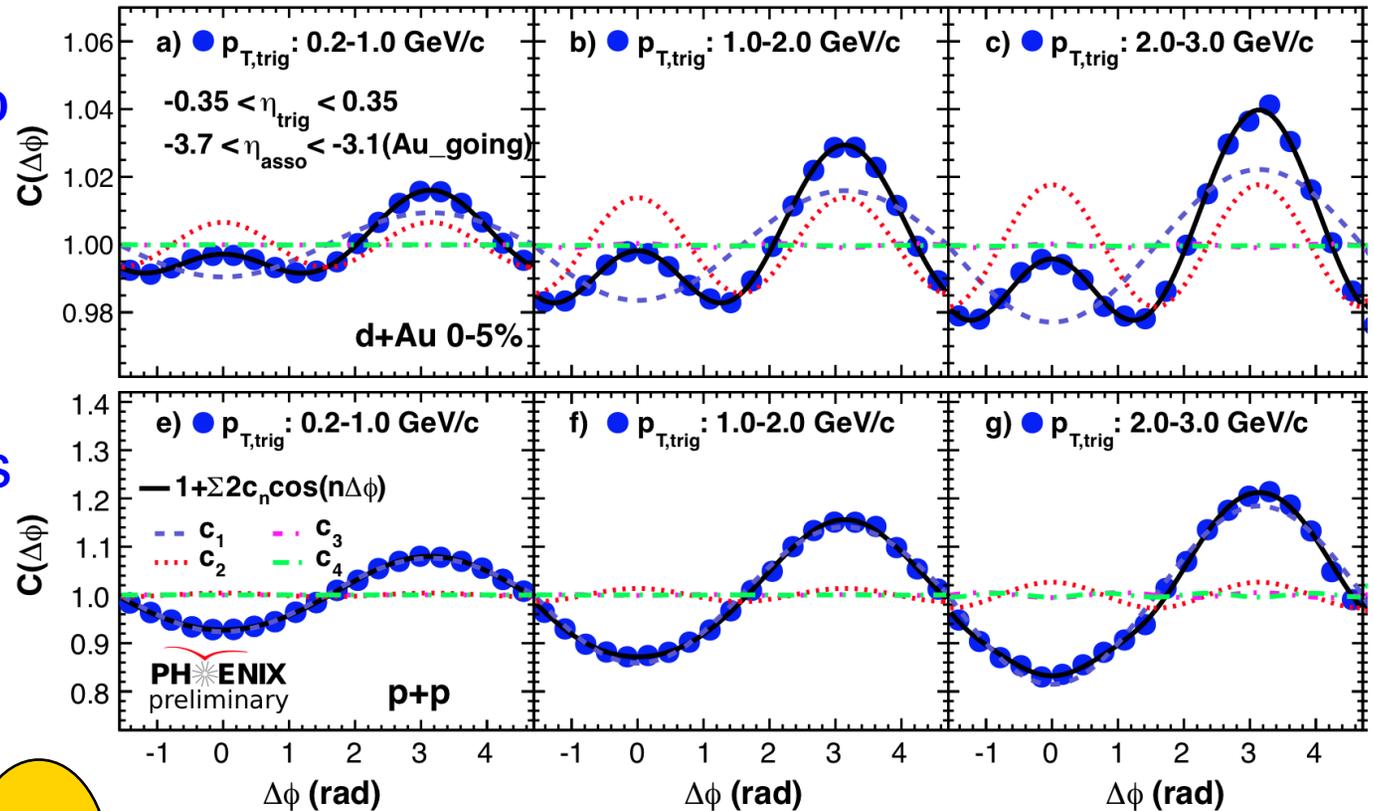


# Near-side “ridge” in d+Au?

Pair central arm tracks with MPC-S,  $\Delta\eta \sim 3.4$

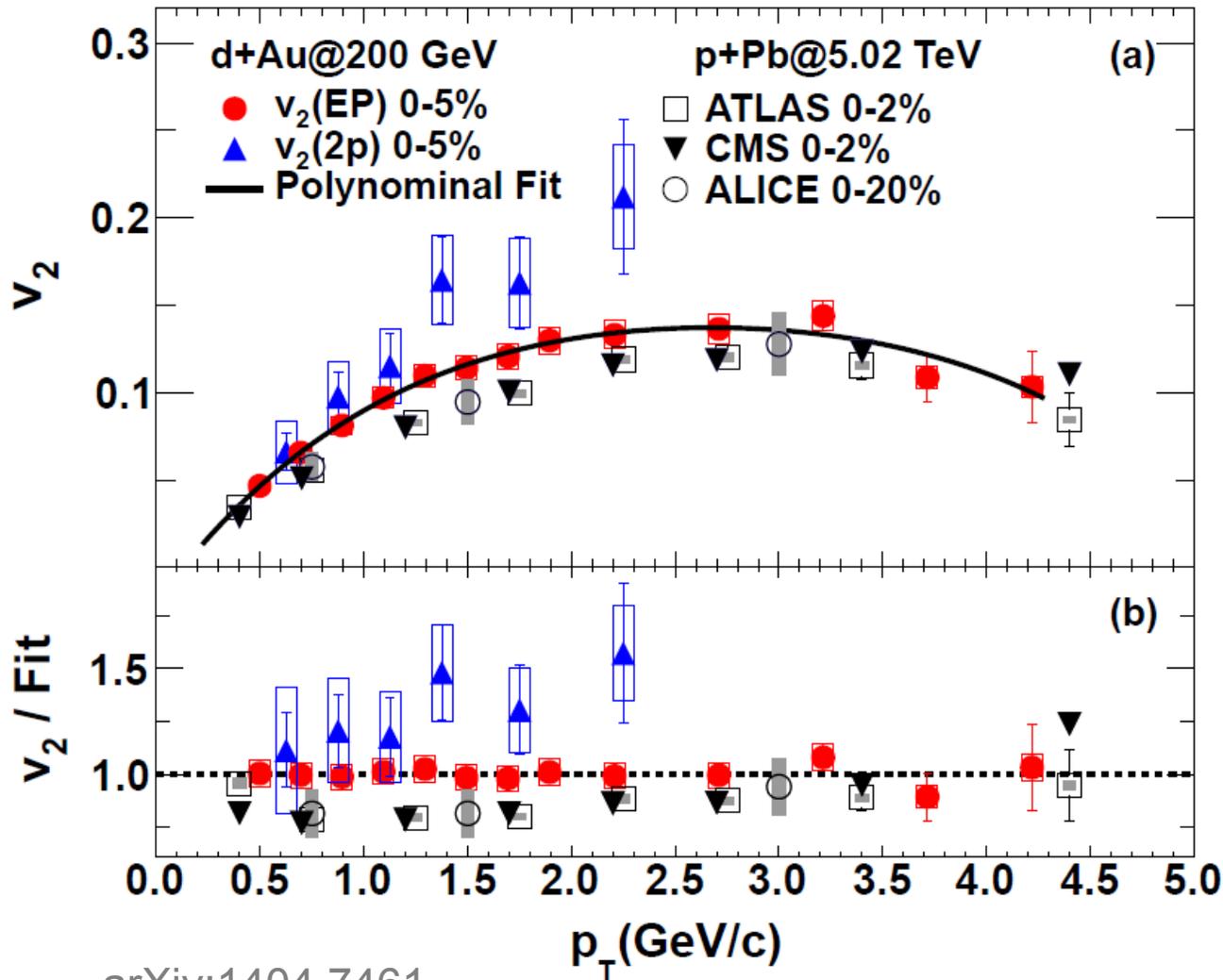
d+Au 0-5%

p+p min-bias



arXiv:1404.7461

# $v_2(\text{EP})$ of charged hadron in 0-5% d+Au

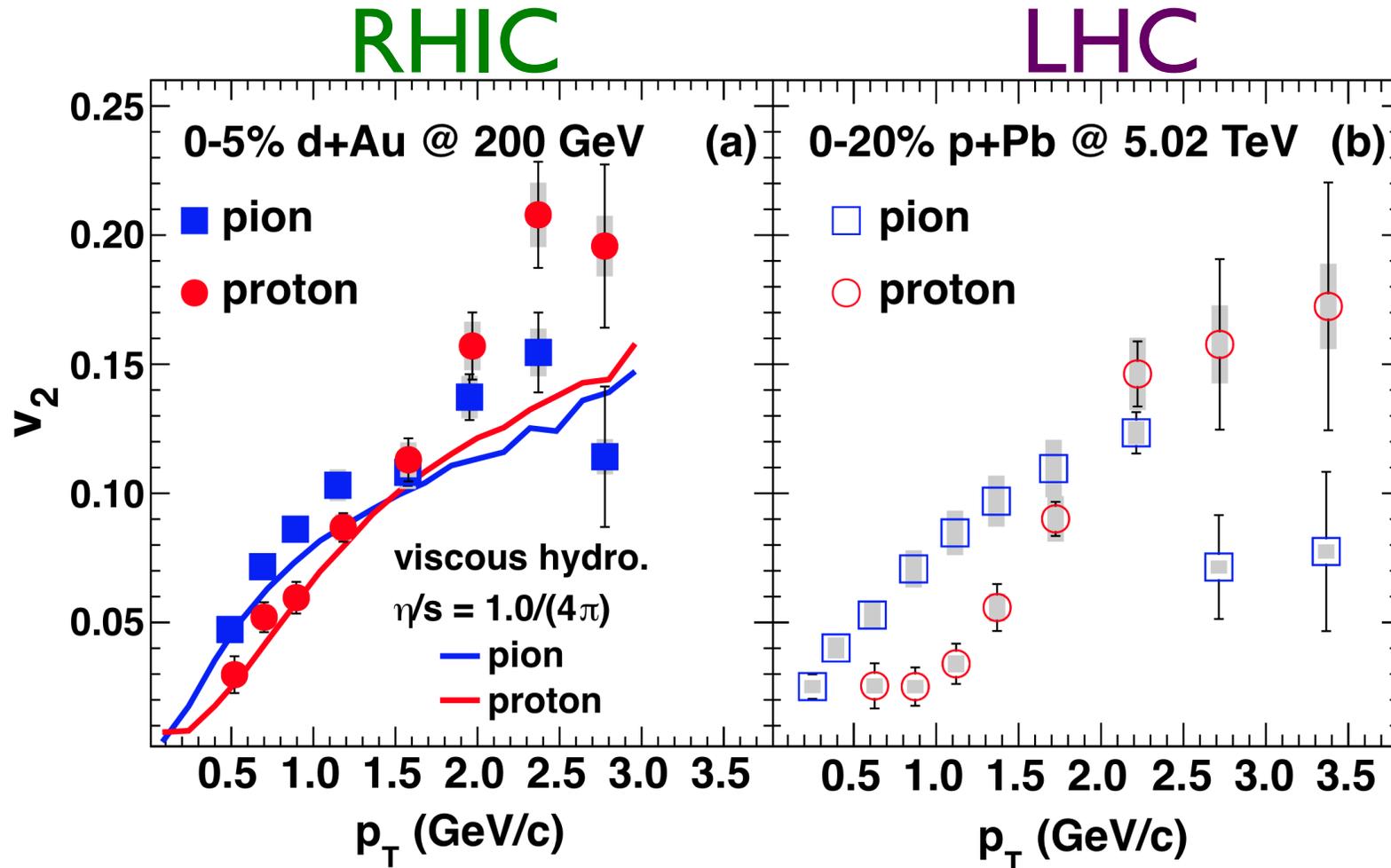


arXiv:1404.7461

Hydro-like  
shape in  
 $v_2(p_T)$ ?

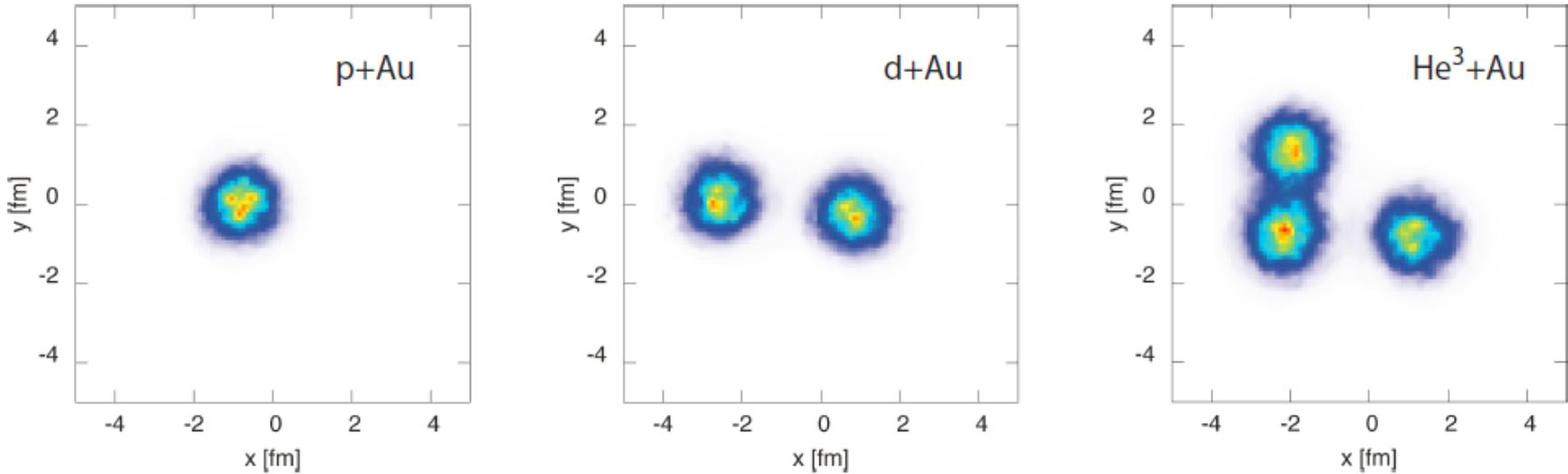
No observable  
 $v_3$  over long  
range, within  
statistics; but  
seen in p+Pb  
at LHC.

# Mass splitting of $v_2$ (EP)

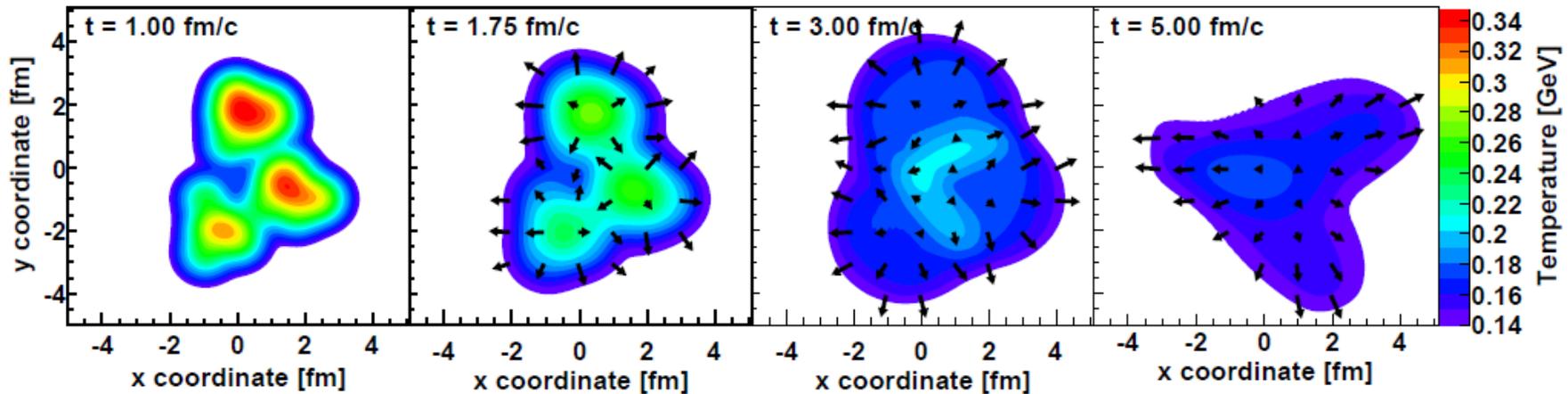


# Geometry in small systems

IP Glasma



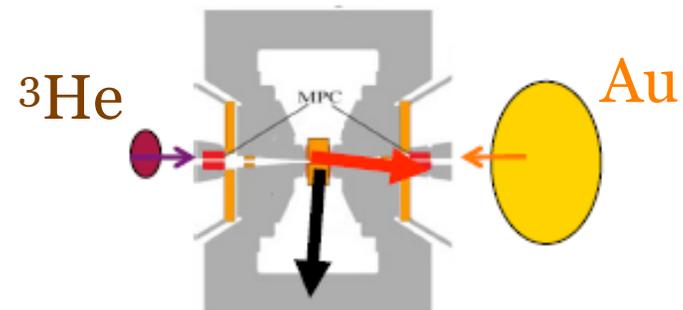
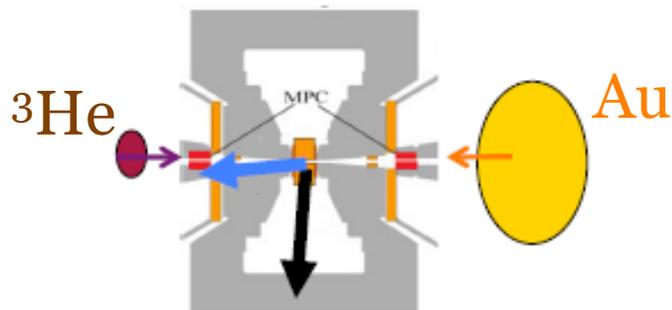
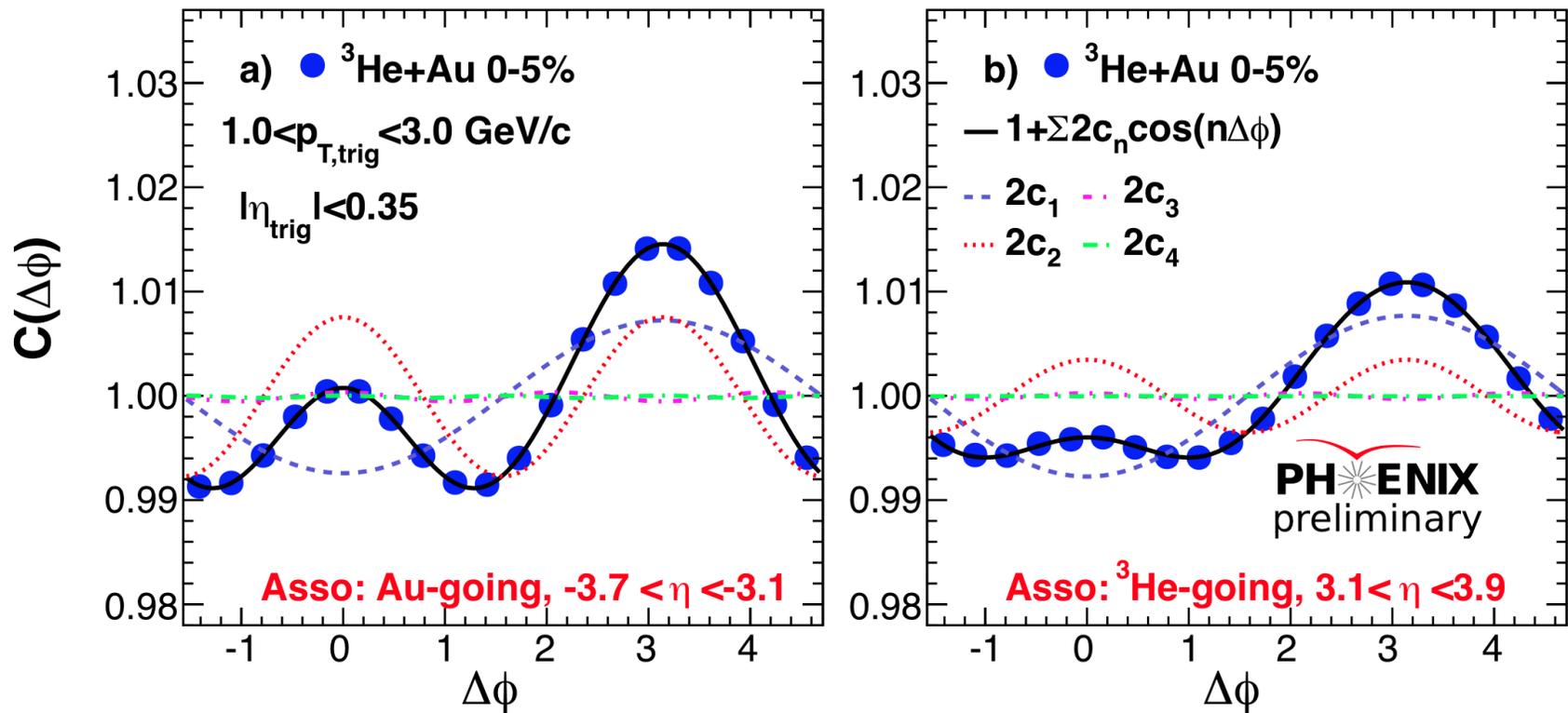
arXiv:1407.7557

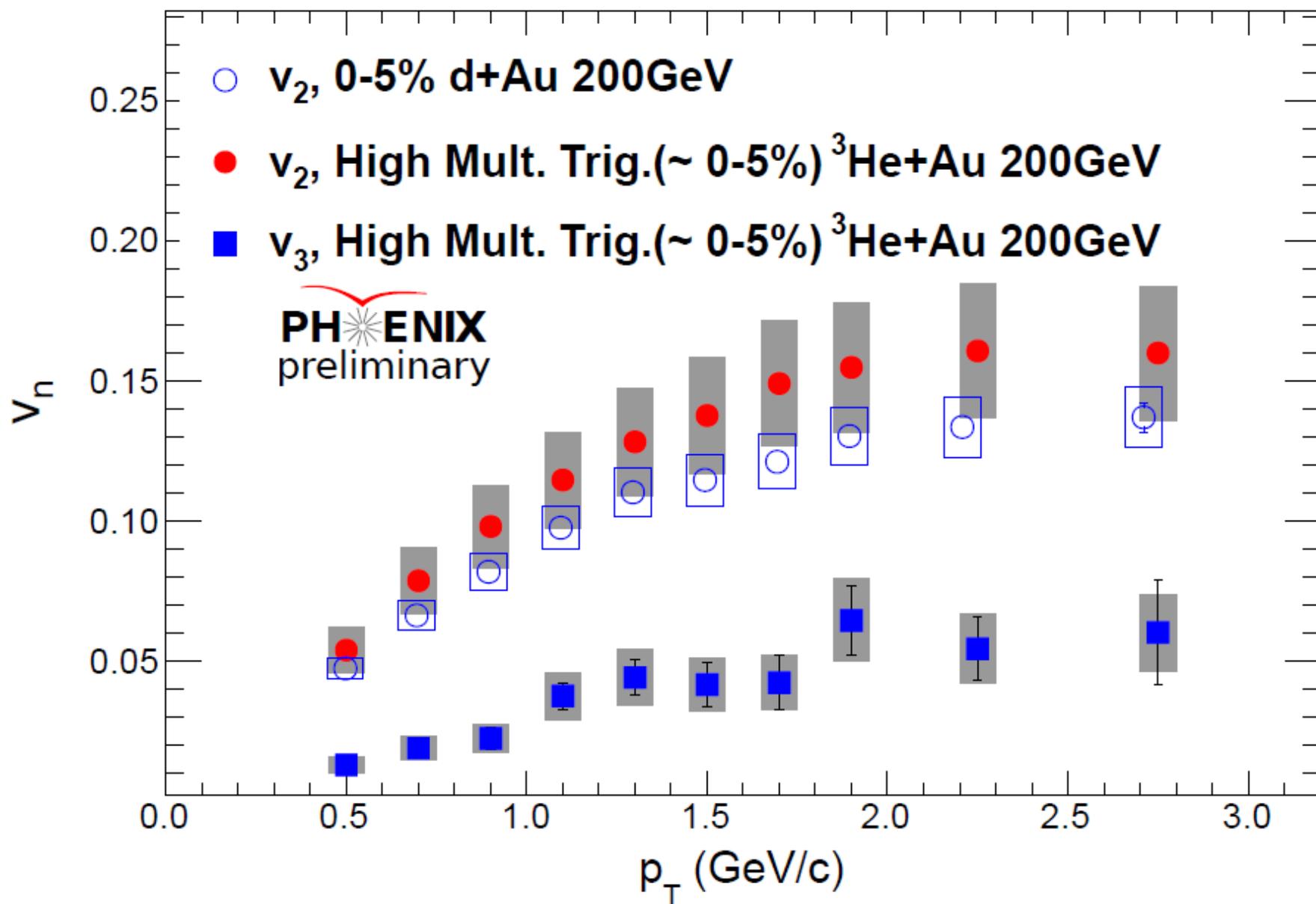


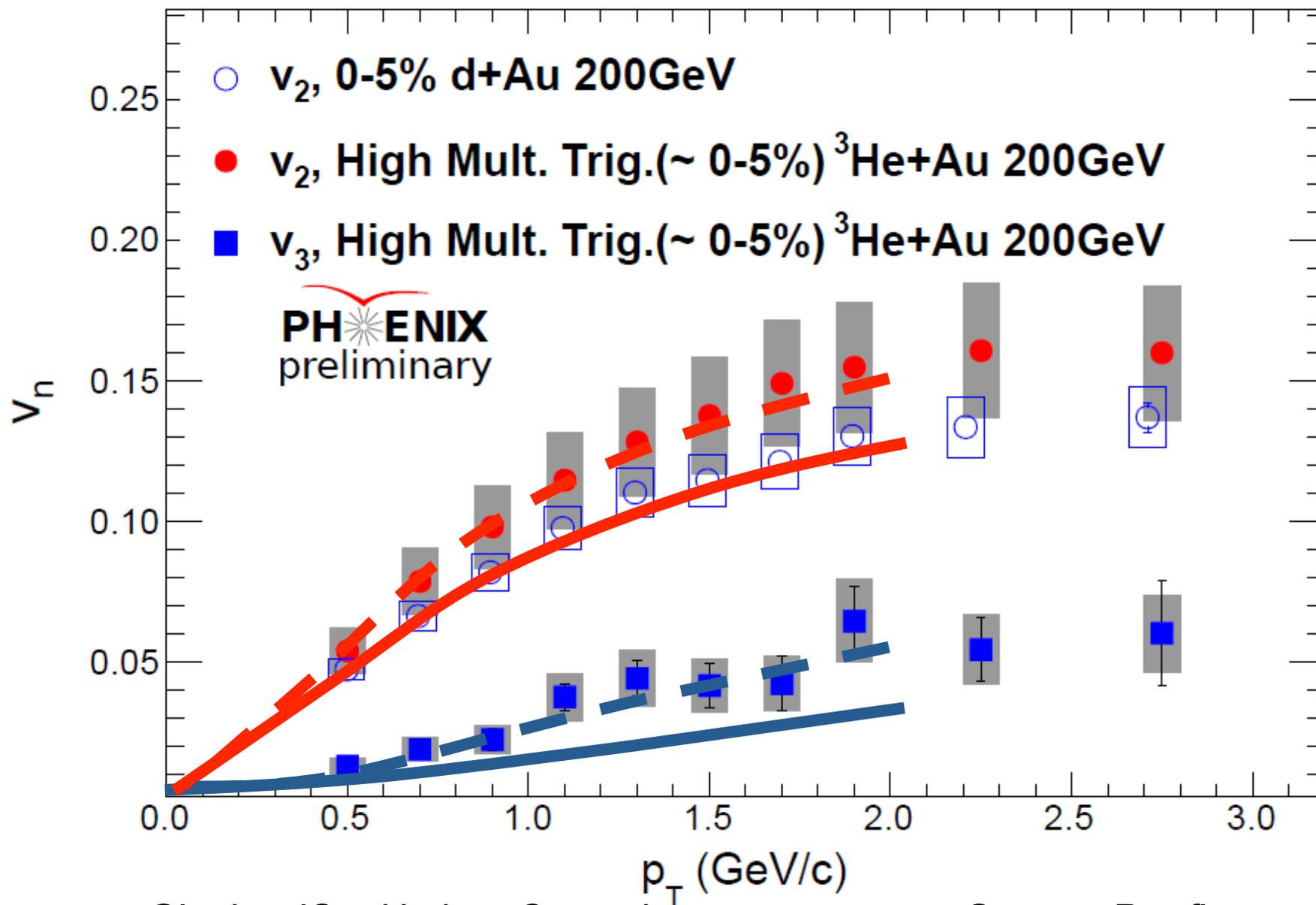
PRL 113, 112301 (2014)

Glauber nucleons

# Long-range correlation in $^3\text{He}+\text{Au}$







— Glauber IS + Hydro + Cascade  
 PRL 113, 112301 (2014)

- - - Same + Pre-flow  
 Romatschke, QM14

# Summary: Hints and Allegations

Small systems at RHIC and LHC have interesting physics beyond CNM effects – some observables are highly **suggestive of a created medium** being formed.

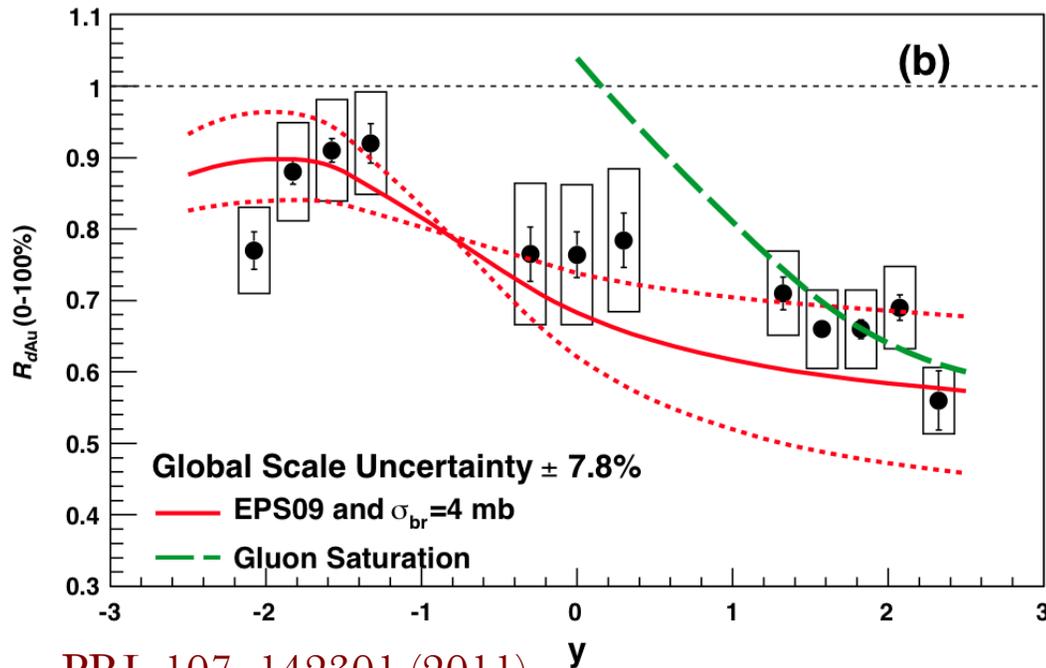
## Selected observations from PHENIX:

- $\Psi'$  relative suppression
- Single charm radial boost
- Associated charm de-correlation
- Ridge/flow-like correlations across  $\Delta\eta \sim 3.4$ , see  $v_2$  in d+Au and  $v_3$  in  $^3\text{He}+\text{Au}$
- **Not mentioned here:** HBT,  $\gamma^{\text{Dir}}$ , LVM, high- $p_T$

**Moral:** Need to address *all* observables within a complete “standard-ish” model (all effects, as much as possible)

# Backup material

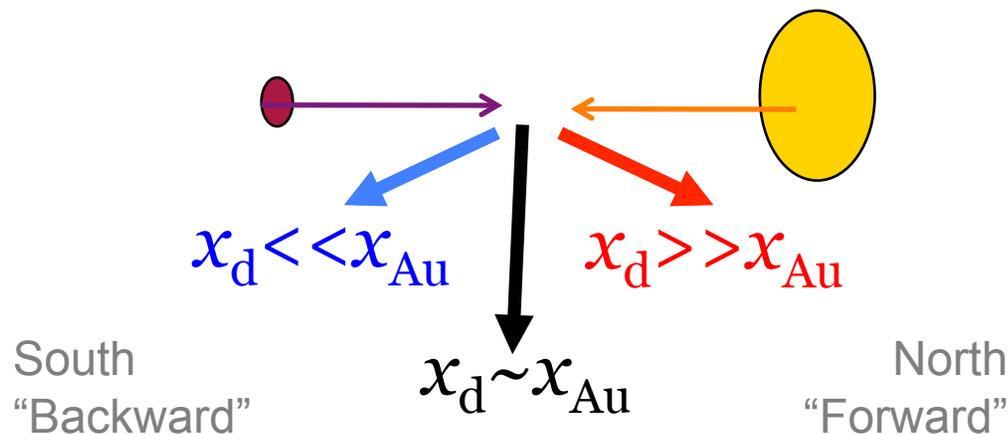
# d+Au to forward/backward J/Psi



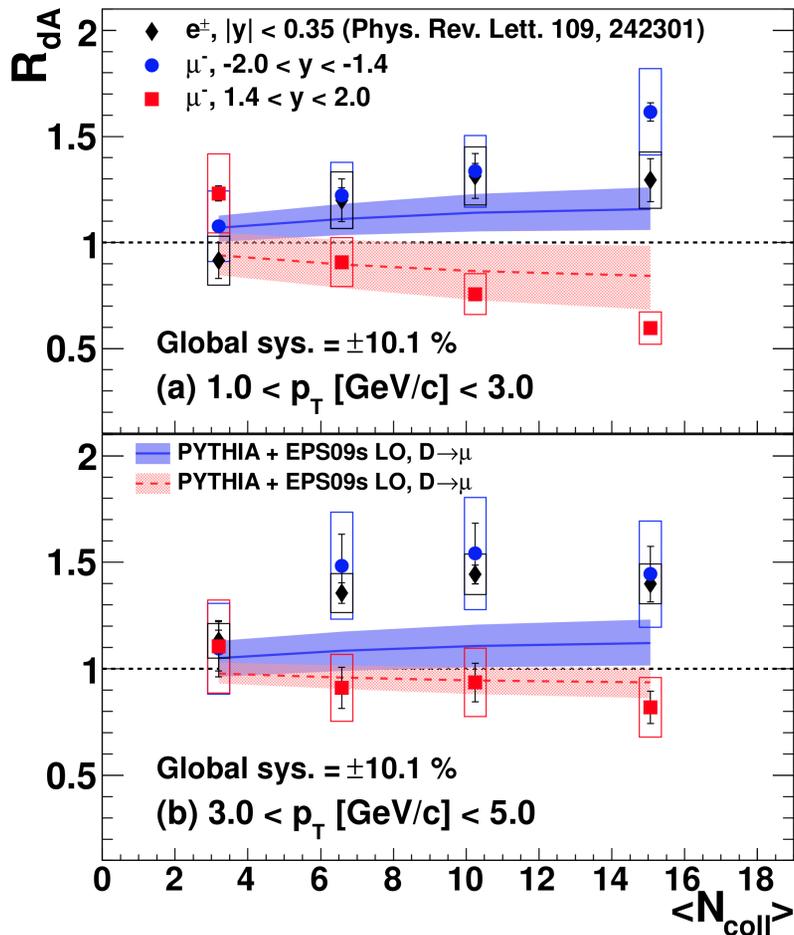
PRL 107, 142301 (2011)

$R_{dAu}$  for J/Psi in  
min-bias d+Au

For inclusive d+Au,  
CNM modifications  
capture forward/  
backward difference  
(but geometry  
dependence is harder).



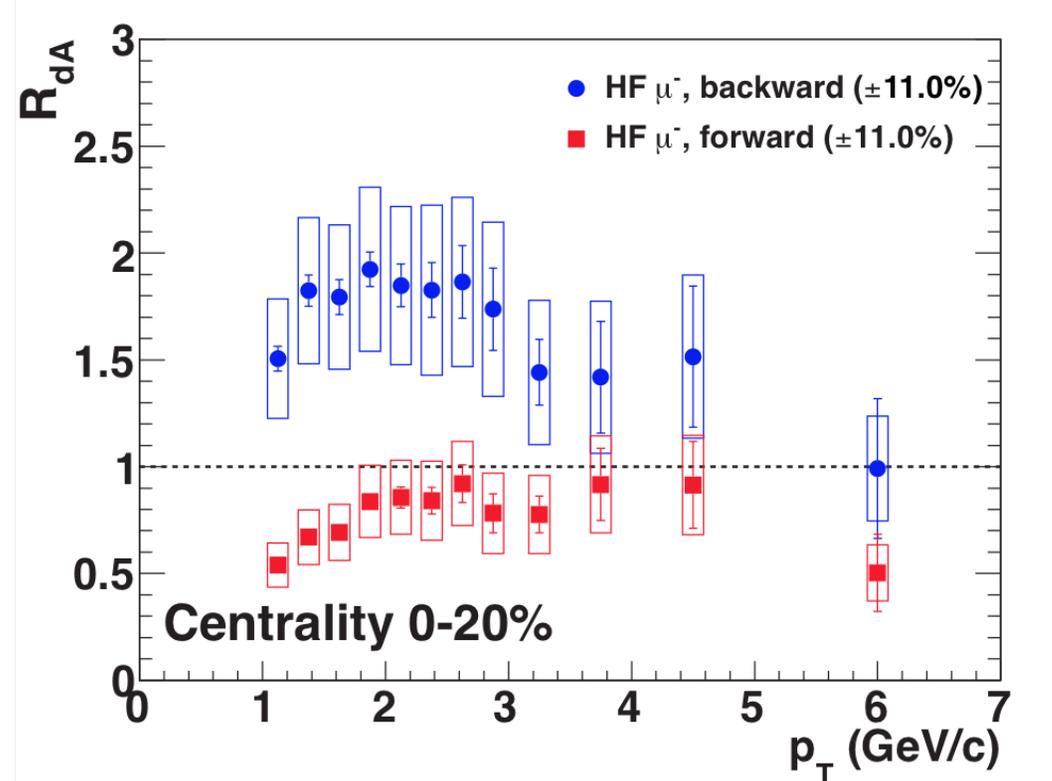
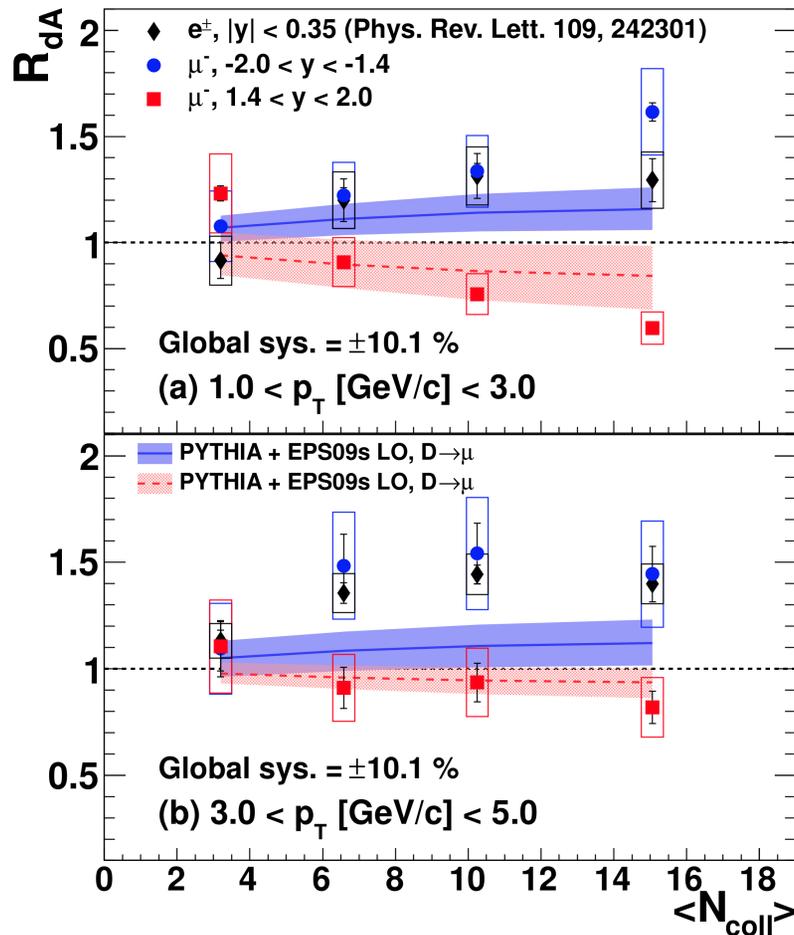
# Heavy flavor leptons, forward/back



Forward-backward difference  
seen, but larger than from EPS09

arXiv:1310.1005

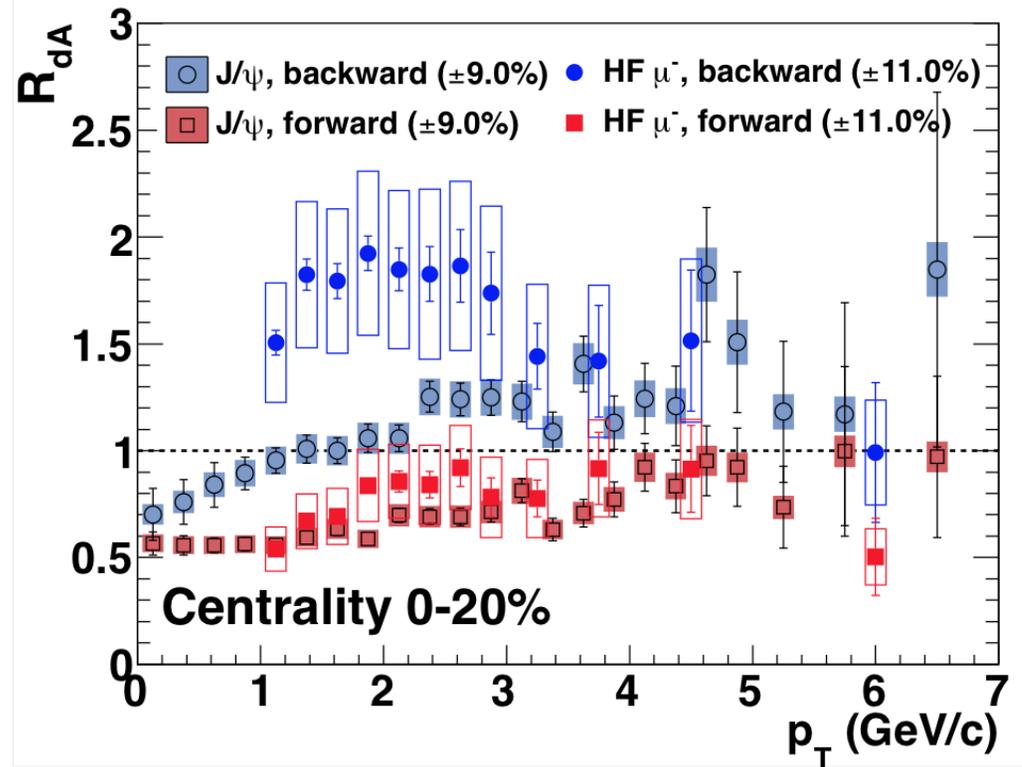
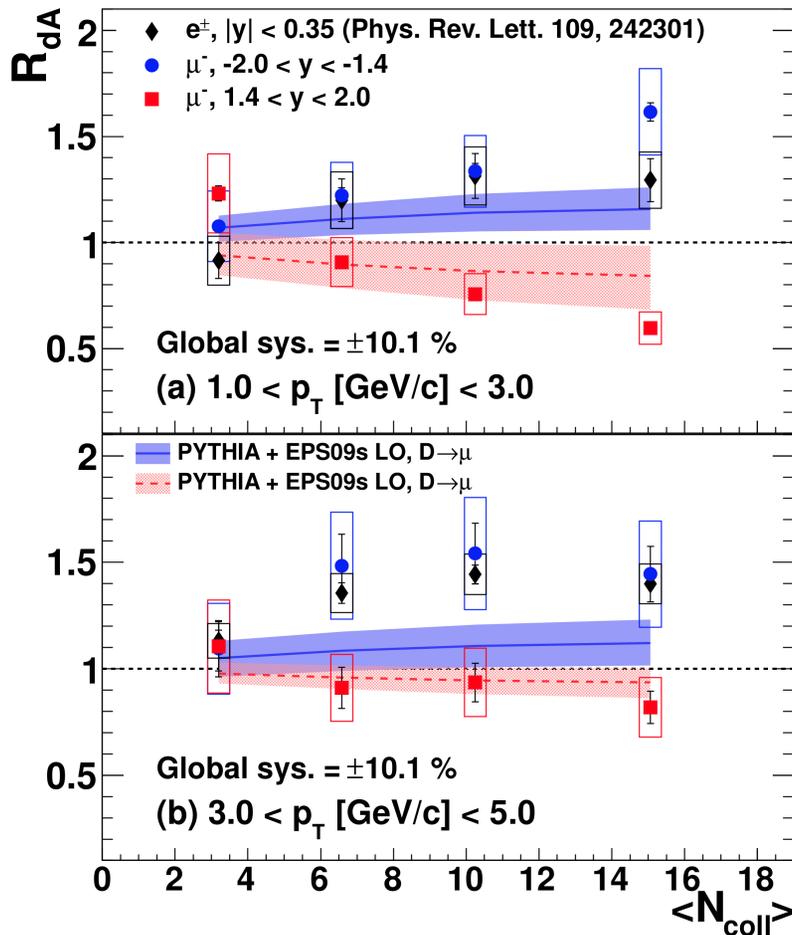
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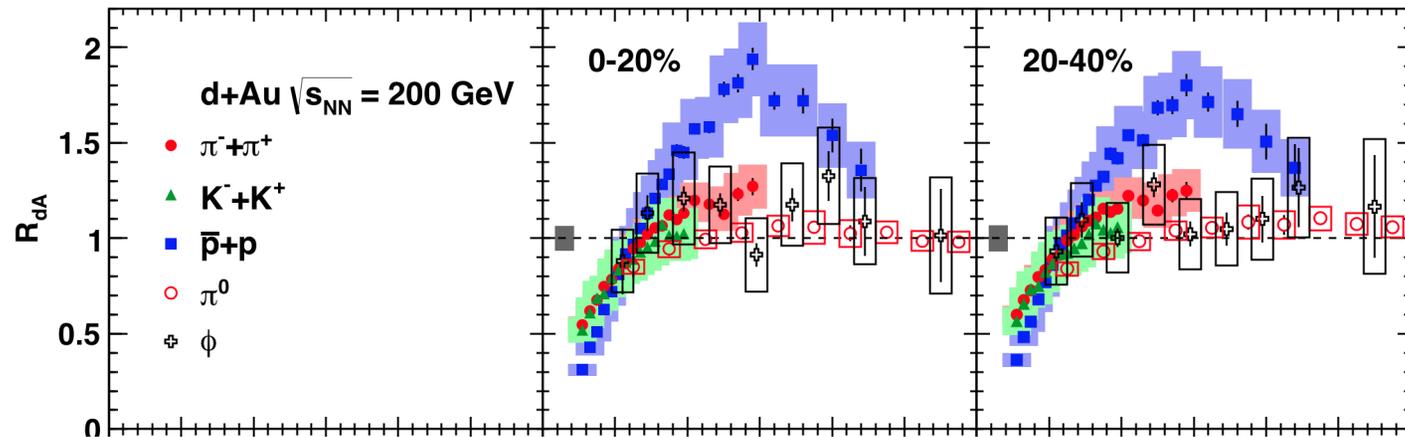


Backward, Au-going effect larger for HF than for J/Psi

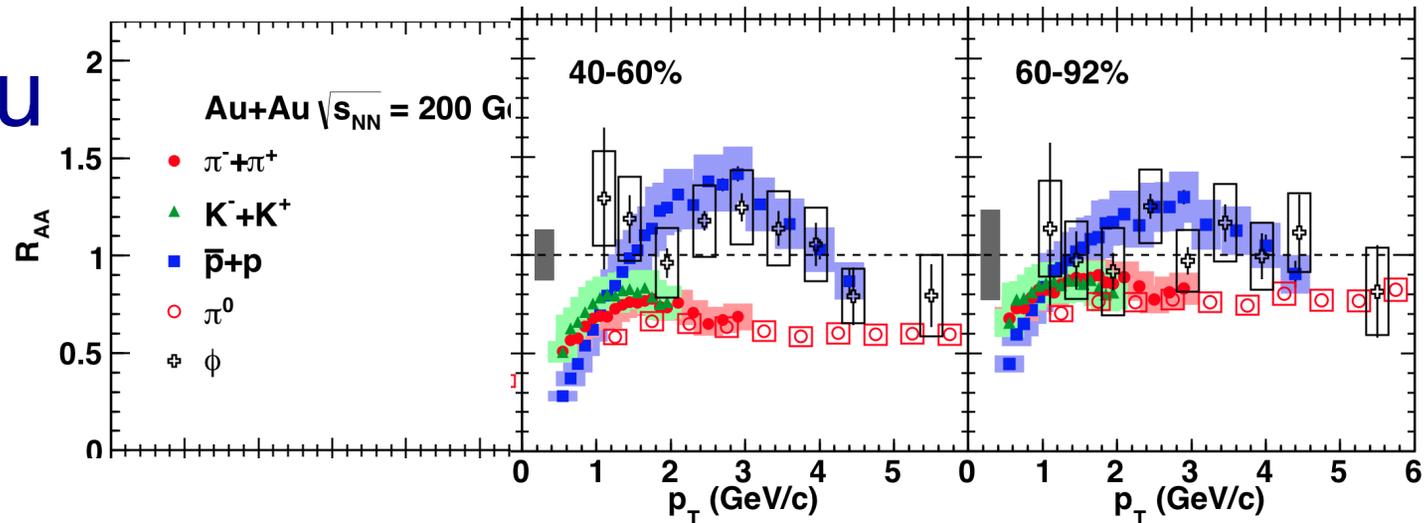
arXiv:1310.1005

# Central d+Au vs Periph Au+Au

d+Au

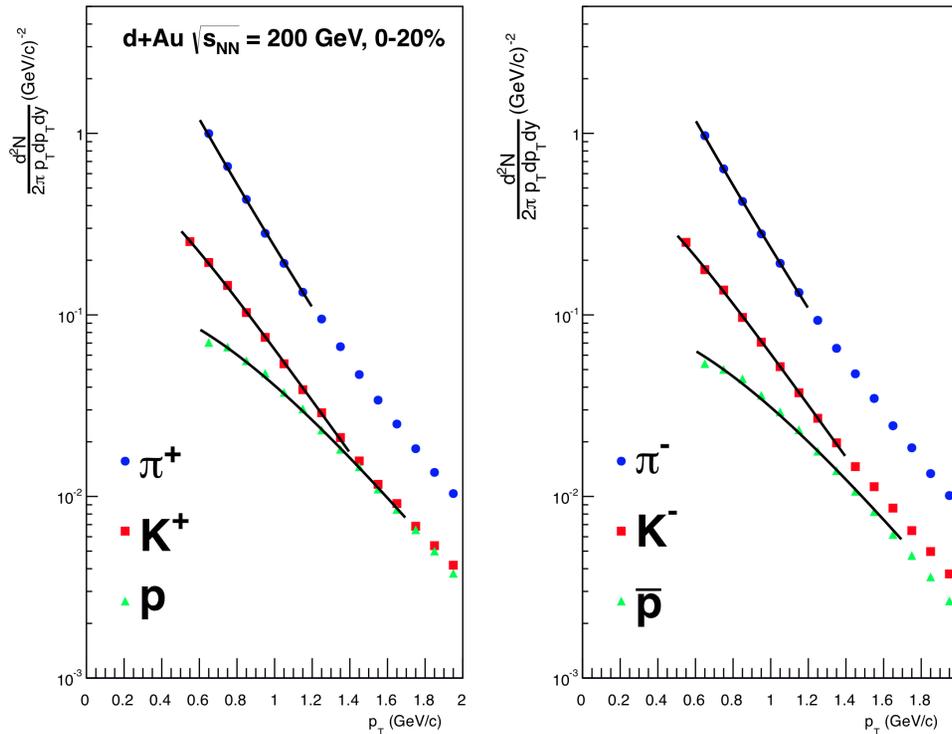


Au+Au



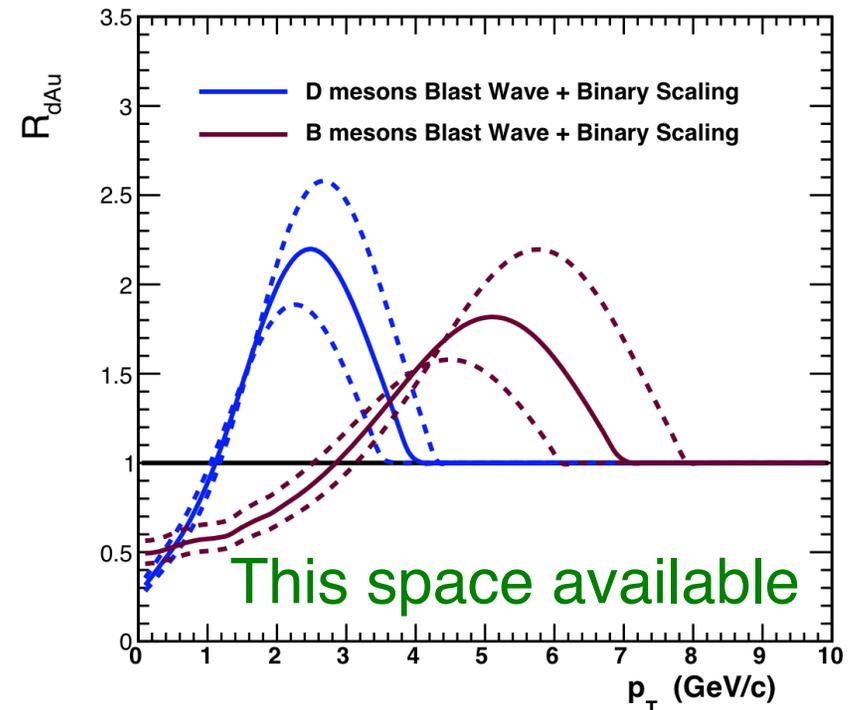
Phys. Rev. C 88, 024906 (2013)

# Radial flow in d+Au?



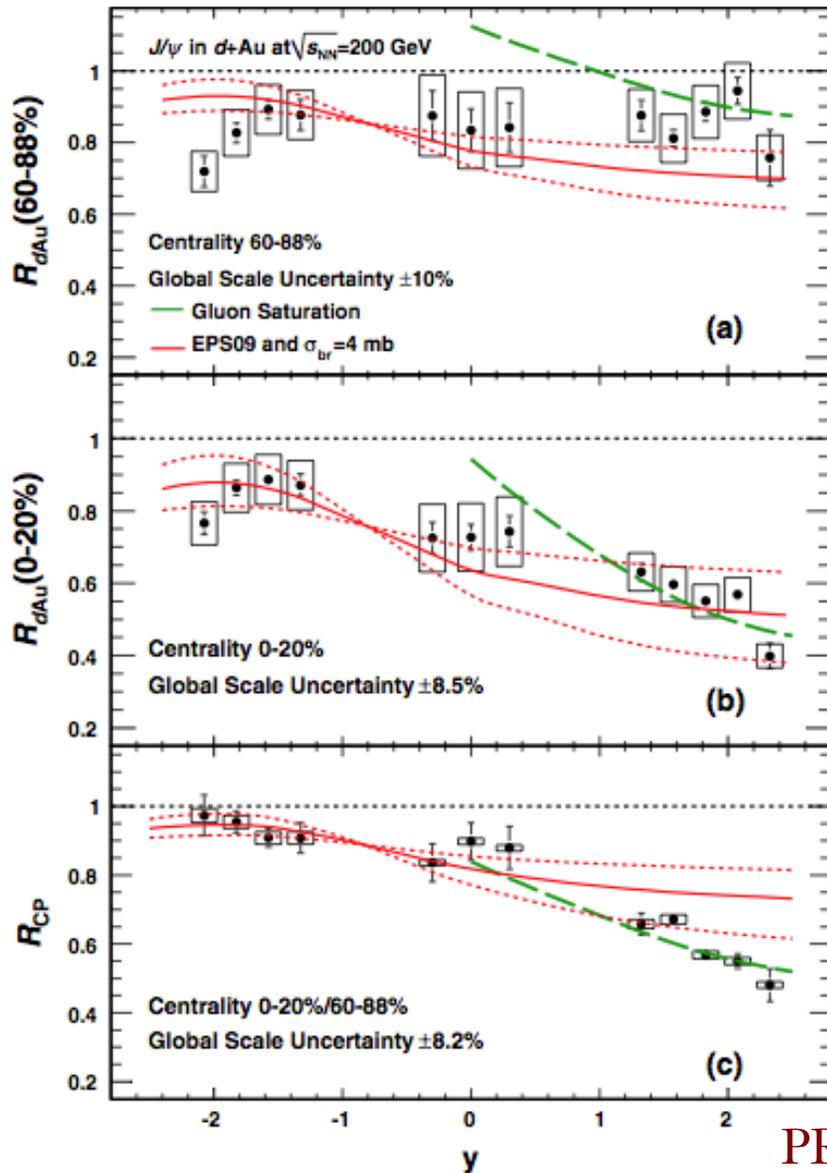
**Blast-wave fits to identified light hadron spectra**

A. Sickles, Phys. Lett. B731 51-56 (2014),  
 “Possible Evidence for Radial Flow of Heavy Mesons in d+Au Collisions”



**Heavy-flavor meson  
predicted  $R_{dAu}$**

# Geometry of CNM effects?



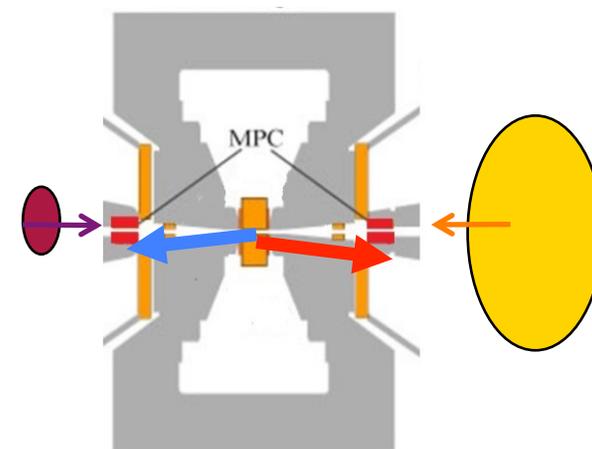
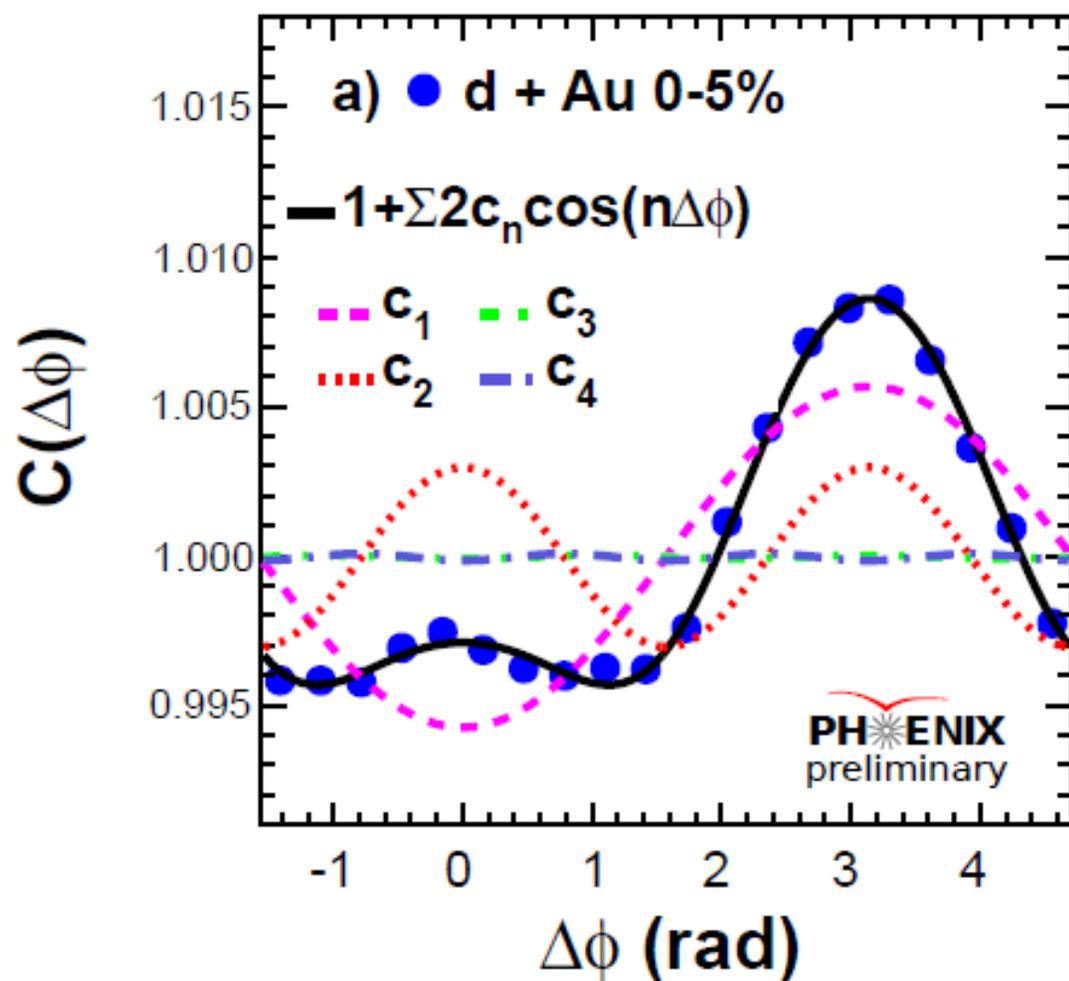
Peripheral

Central

$R_{CP}$

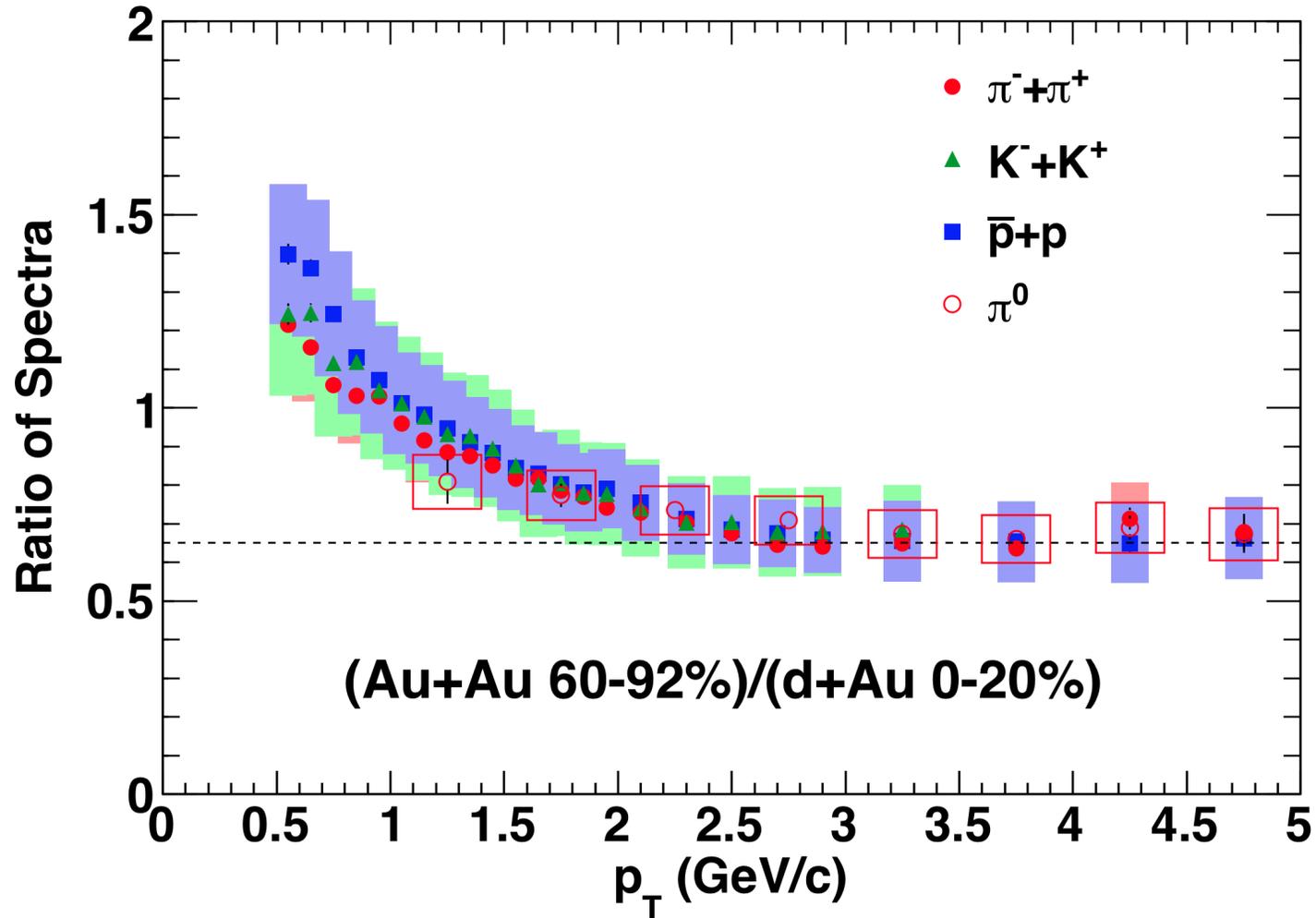
CNM modification does *not* reproduce centrality/geometry dependence.

# Near-side “ridge” over $\Delta\eta \sim 7$

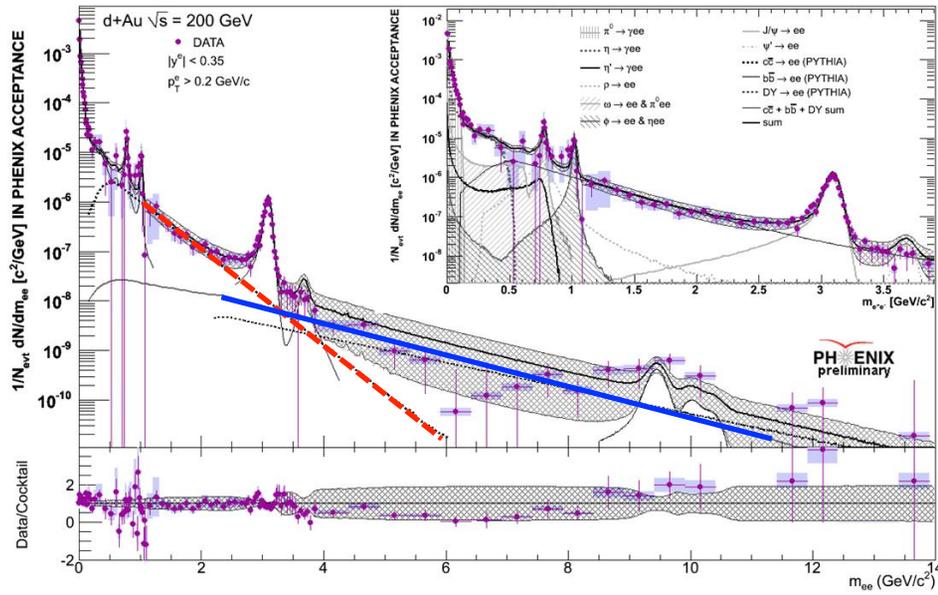


Correlation between  
Au-going and  
d-going MPC  
towers

# Periph Au+Au/Central d+Au



# More news...



**cc** vs **bb** separation via  
dielectrons in d+Au  
across mass and  $p_T$