# Recent Results from PHENIX experiment at RHIC

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**for PHENIX collaboration**

# RHIC Run History

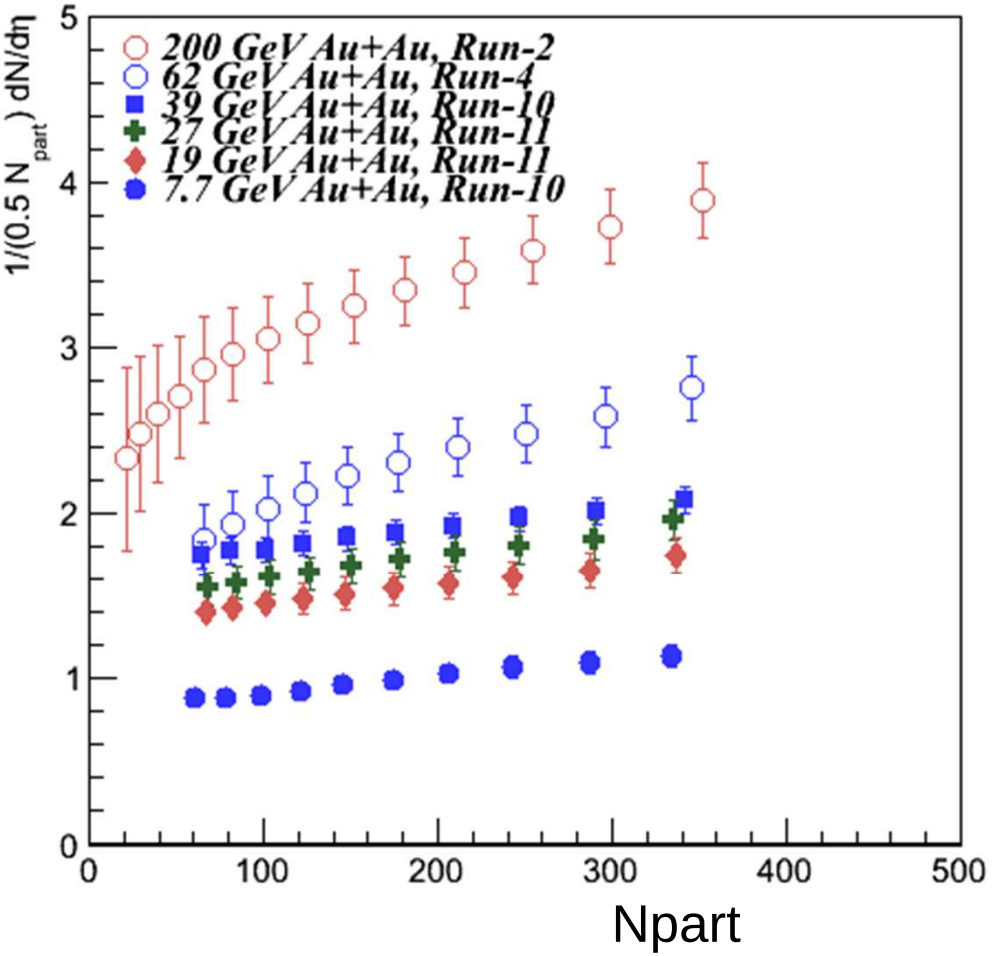
"12 years circle"

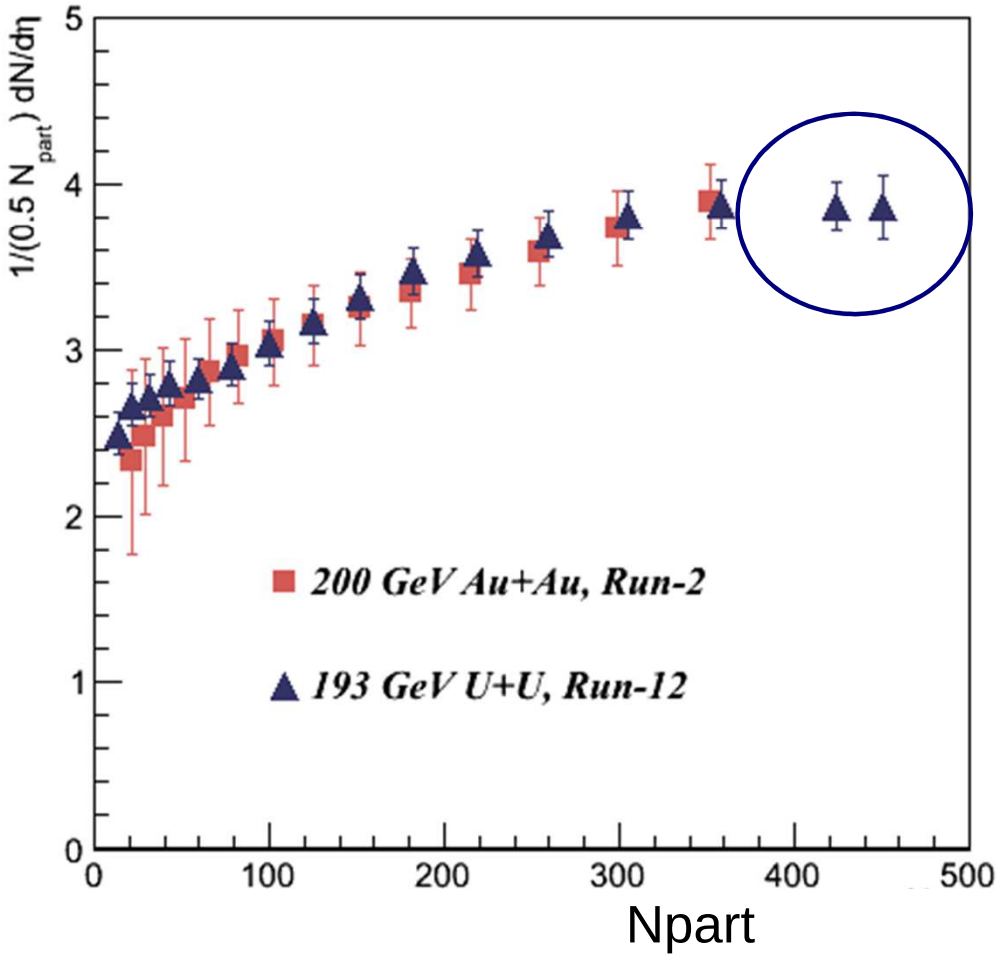
*Beam energy scan*

*New colliding species*

| RHIC Run | Year | Species | Energy | Ldt |
|---|---|---|---|---|
| Run-1 | 2000 | Au+Au | 130 GeV | 1 μb-1 |
| Run-2 | 2001-2 | Au+Au | 200 GeV | 24 μb-1 |
| | | Au+Au | 19 GeV | |
| | | p+p | 200 Gev | 150 nb-1 |
| Run-3 | 2002/3 | d+Au | 200 GeV | 2.74 nb-1 |
| | | p+p | 200 GeV | 0.35 nb-1 |
| Run-4 | 2003/4 | Au+Au | 200 GeV | 241 μb-1 |
| | | Au+Au | 62.4 GeV | 9 μb-1 |
| Run-5 | 2005 | Cu+Cu | 200 GeV | 3 nb-1 |
| | | Cu+Cu | 62.4 GeV | 0.19 nb-1 |
| | | Cu+Cu | 22.4 GeV | 2.7 μb-1 |
| Run-6 | 2006 | p+p | 200 GeV | 10.7 pb-1 |
| | | p+p | 62.4 GeV | 100 nb-1 |
| Run-7 | 2007 | Au+Au | 200 GeV | 813 μb-1 |
| Run-8 | 2007/2008 | d+Au | 200 GeV | 80 nb-1 |
| | | p+p | 200 GeV | 5.2 pb-1 |
| | | Au+Au | 9.2 GeV | |
| Run-9 | 2009 | p+p | 200 GeV | 16 pb-1 |
| | | p+p | 500 GeV | 14 pb-1 |
| Run-10 | 2010 | Au+Au | 200 GeV | 1.3 nb-1 |
| | | Au+Au | 62.4 GeV | 100 μb-1 |
| | | Au+Au | 39 GeV | 40 μb-1 |
| | | Au+Au | 7.7 GeV | 260 mb-1 |
| Run-11 | 2011 | p+p | 500 GeV | 27 pb-1 |
| | | Au+Au | 200 GeV | 915 μb-1 |
| | | Au+Au | 27 GeV | 5.2 μb-1 |
| | | Au+Au | 19.6 GeV | 13.7 M events |
| Run-12 | 2012 | p+p | 200 GeV | 9.2 pb-1 |
| | | p+p | 510 GeV | 30 pb-1 |
| | | U+U | 193 GeV | 171 μb-1 |
| | | Cu+Au | 200 GeV | 4.96 nb-1 |

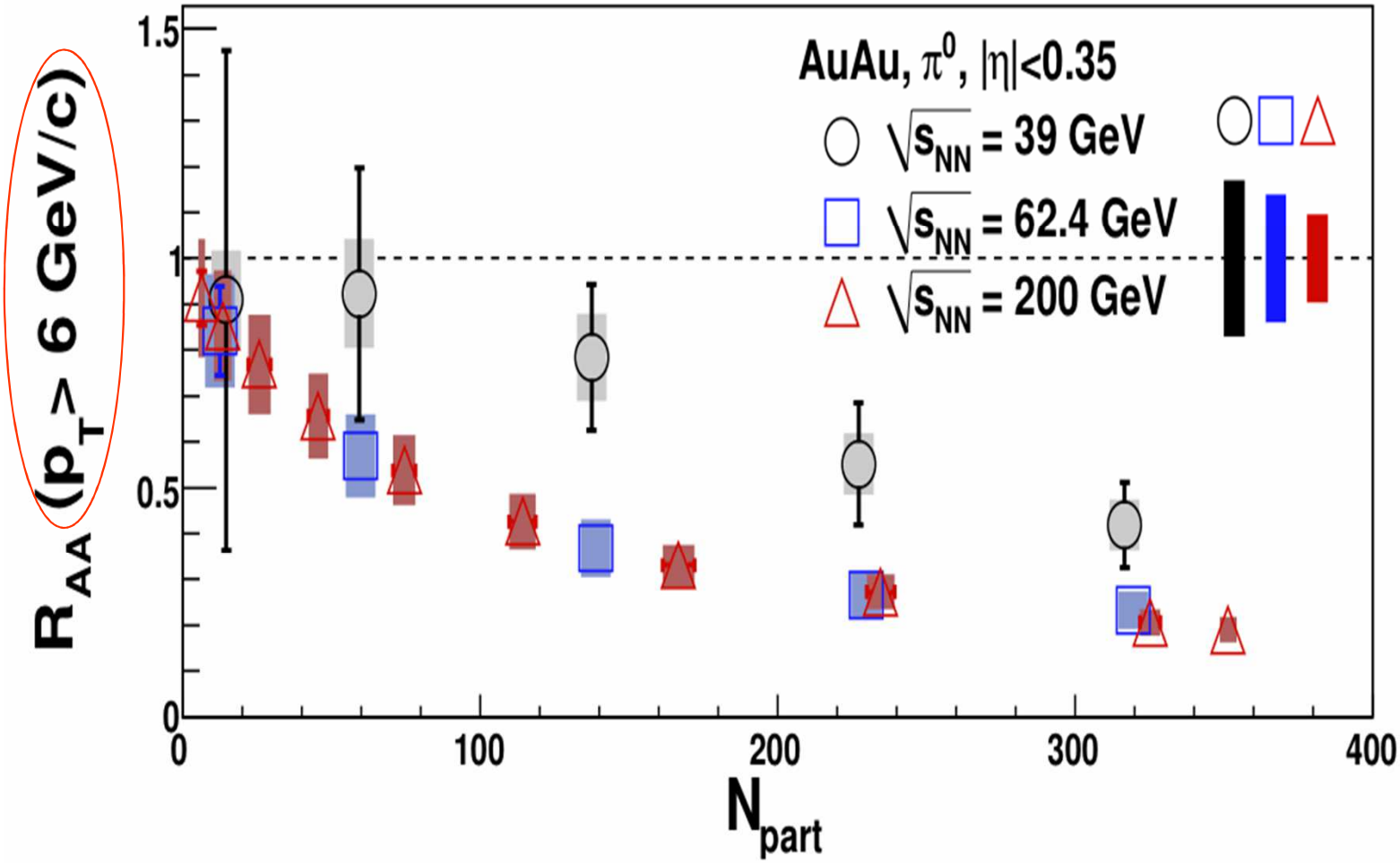
# Energy scan. Global variables. **dN/dη**




*Very smooth behavior*

# Energy scan. $\mathbf{R_{AA}}$

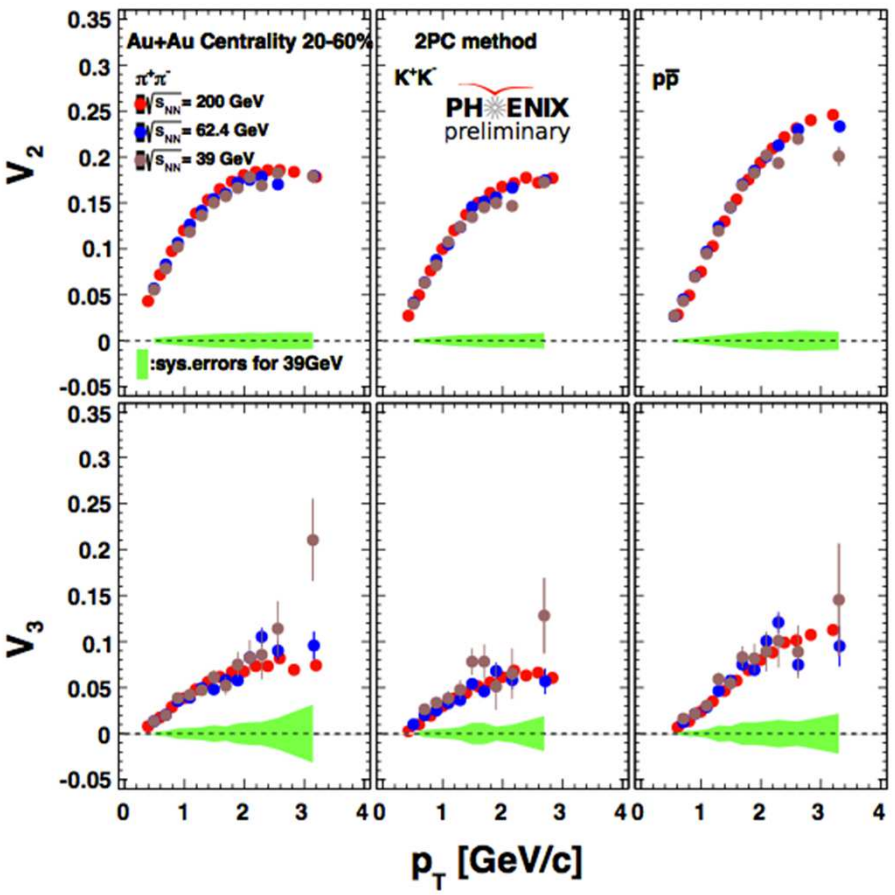


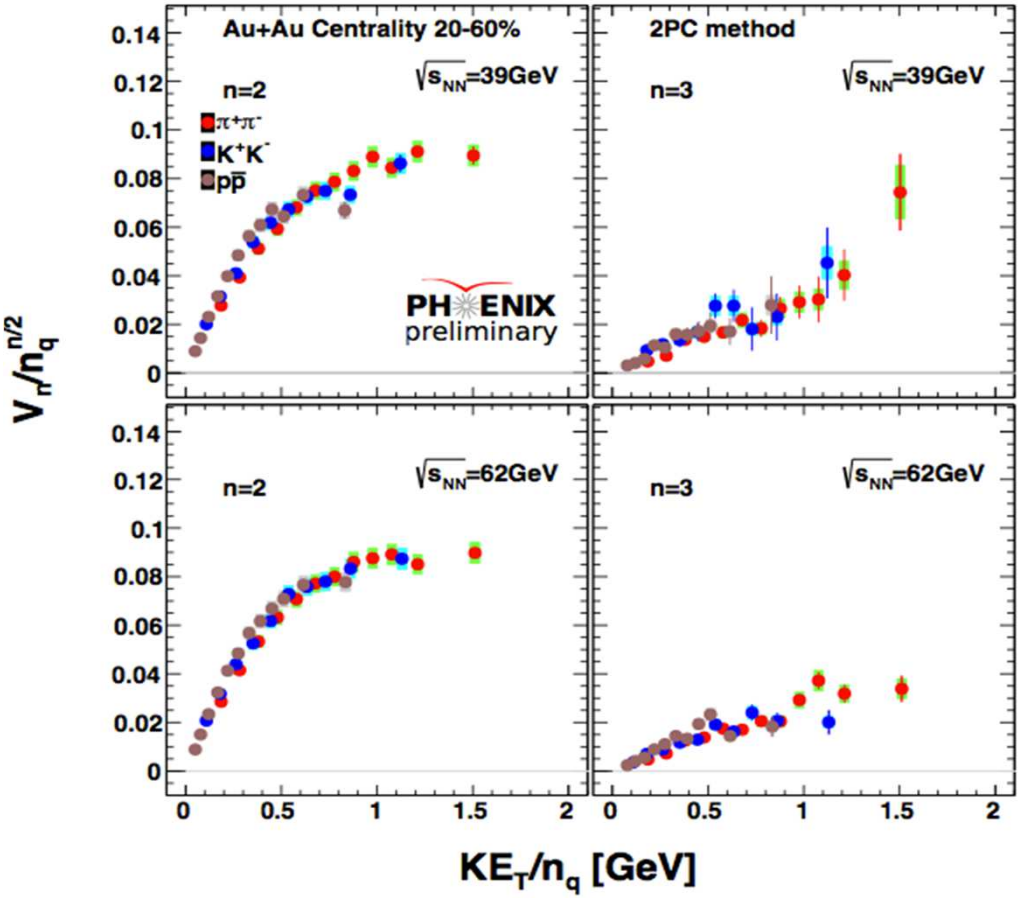

*Behavior changes between 39 and 64 GeV*

**arXiv:1204.1526**

**27 GeV analysis is underway**

# Energy scan. Flow, $v_2$ and $v_3$



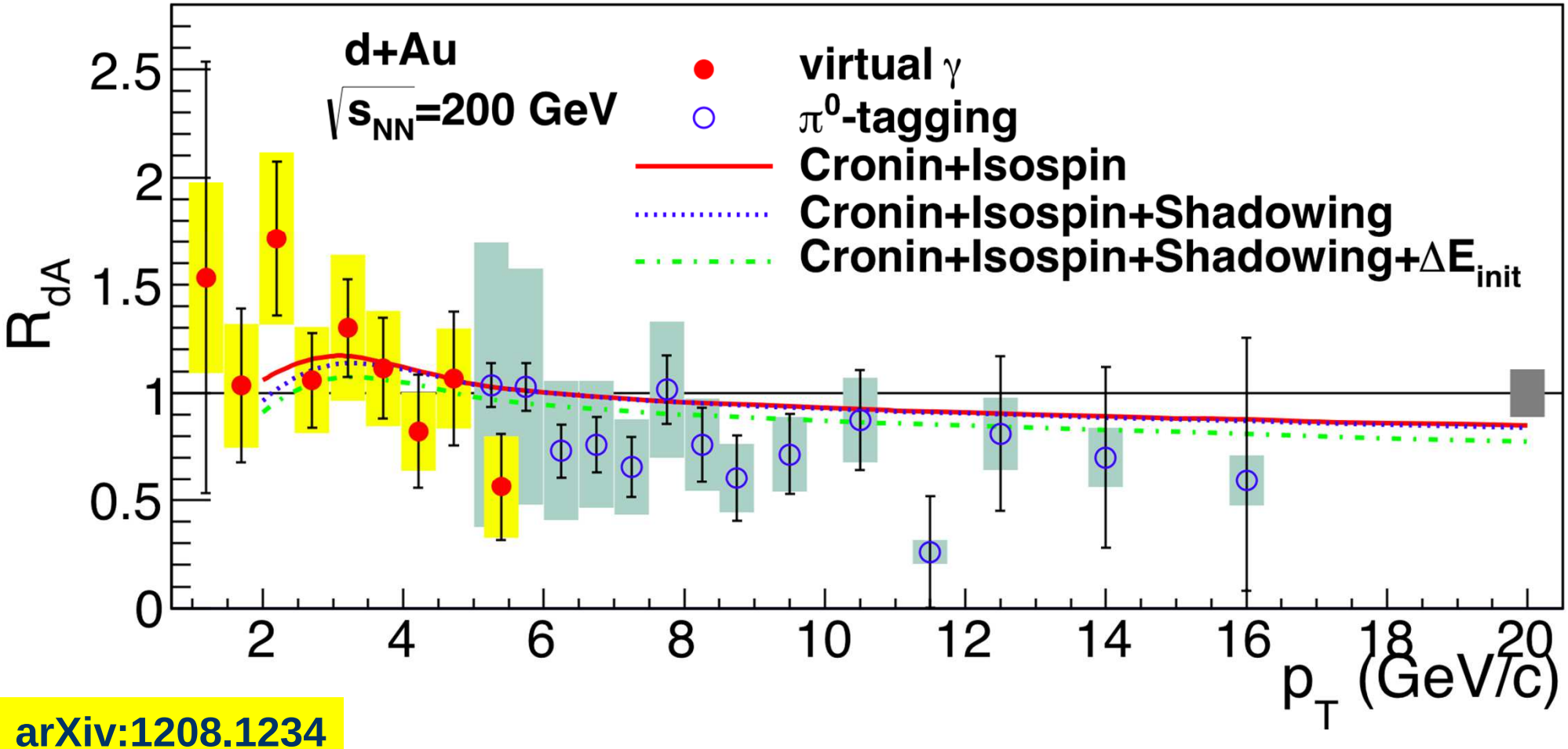




*200, 62.4 and 39 GeV PID data shows the same v2, v3 values. Observed flow is saturated in this energy range*

*Number-Constituen-Qarks scaling of vn for identified charged hadrons observed for the beam energy range of 39–200 GeV confirms partonic flow down to 39 GeV*

# d+Au data: **probing initial state**

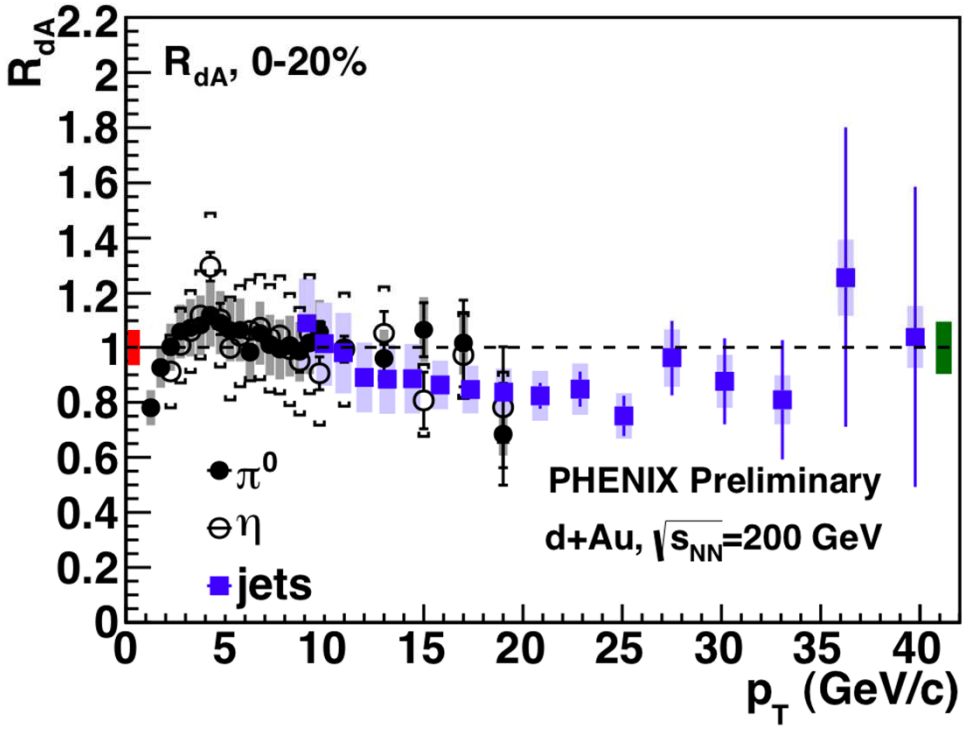
Direct photons. *No modification in initial hard scattering and PDF compared to p+p*

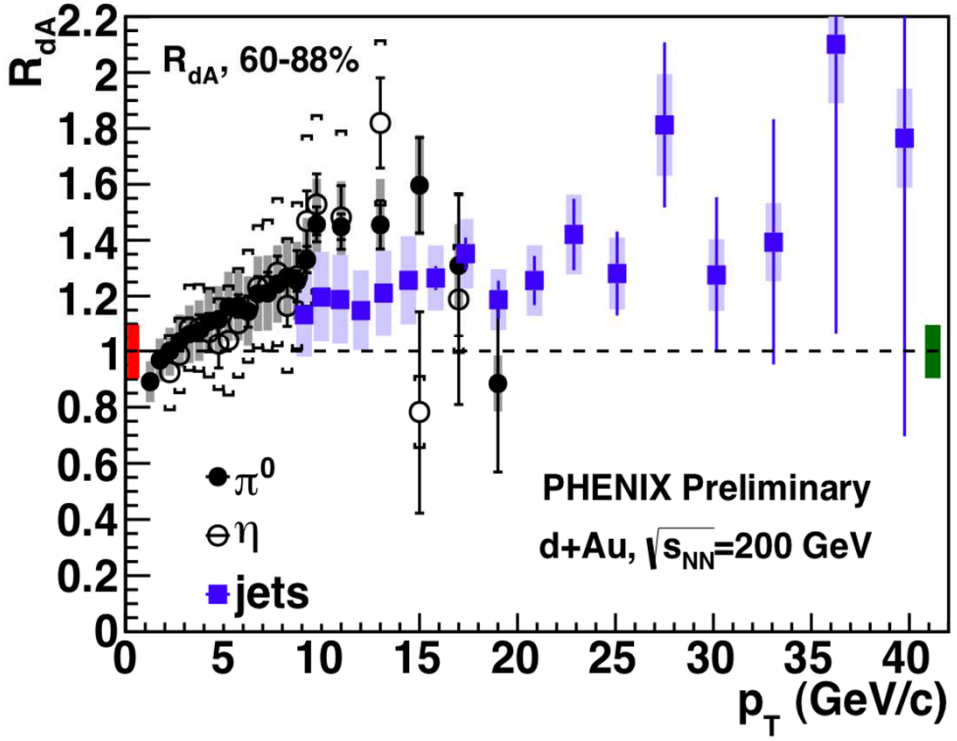



arXiv:1208.1234

# d+Au data: Jet probes.

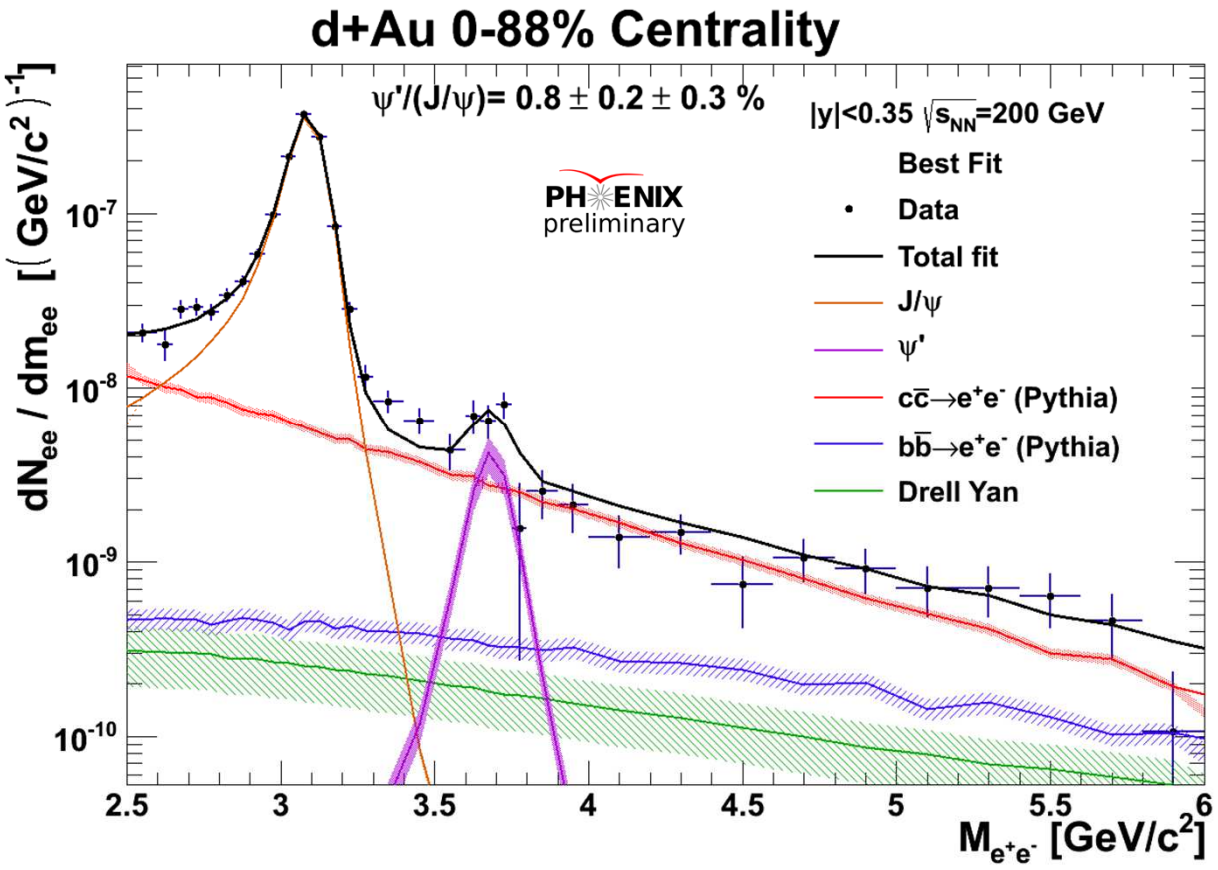
*Jets are reconstructed at mid-rapidity in d+Au up to 40 GeV/c.*
*RdA increases for more peripheral collisions at high pT?*



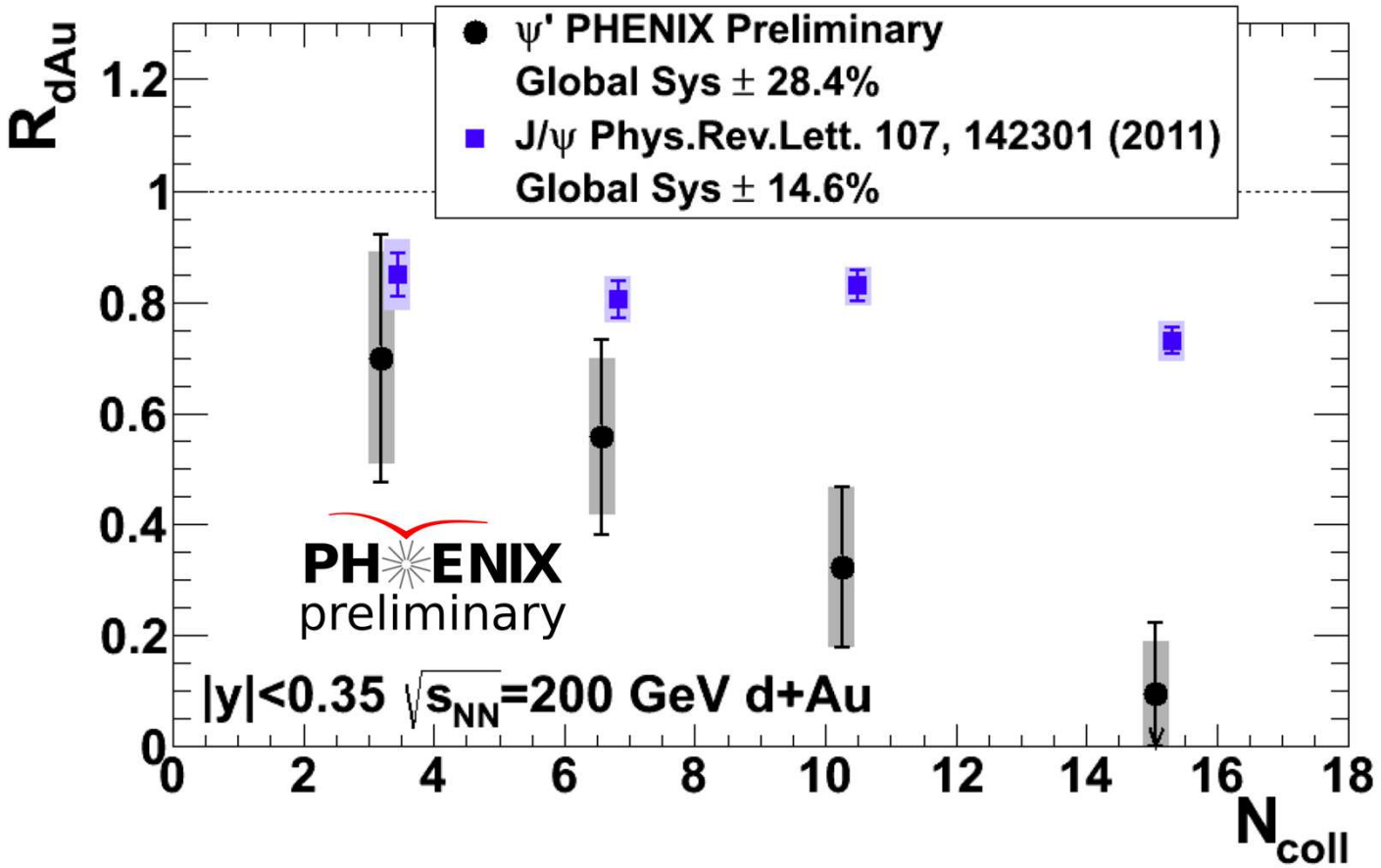

*Some trigger bias here?*

# d+Au data: First measurement of ψ'




*ψ'/(J/ψ) = 2% in p+p, 0.8% in d+Au*

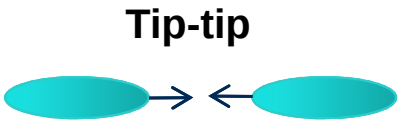
# ψ' is strongly suppressed in dAu




***Factor of >5!***

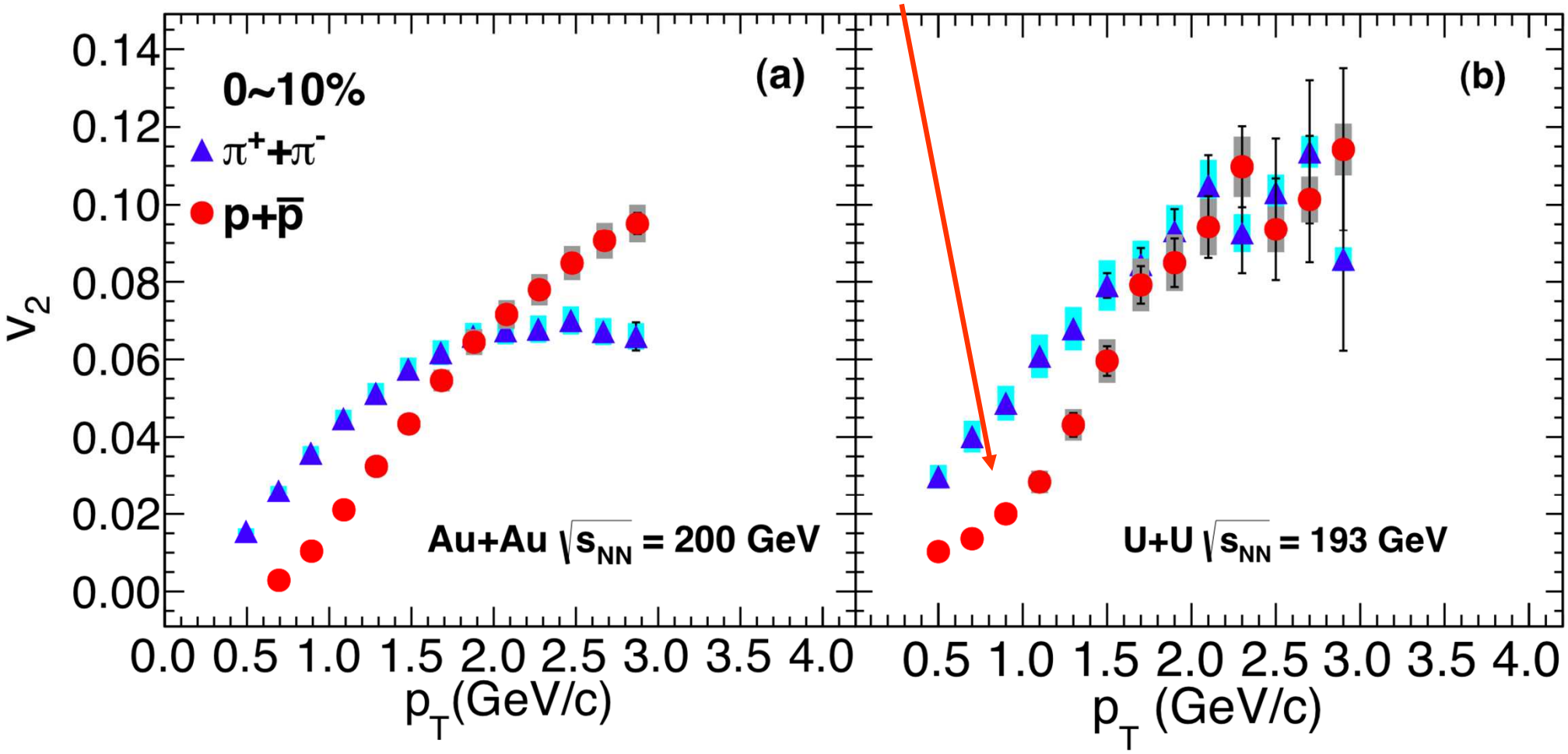
*Very challenging for models!*

# U+U collisions. Large eccentricity

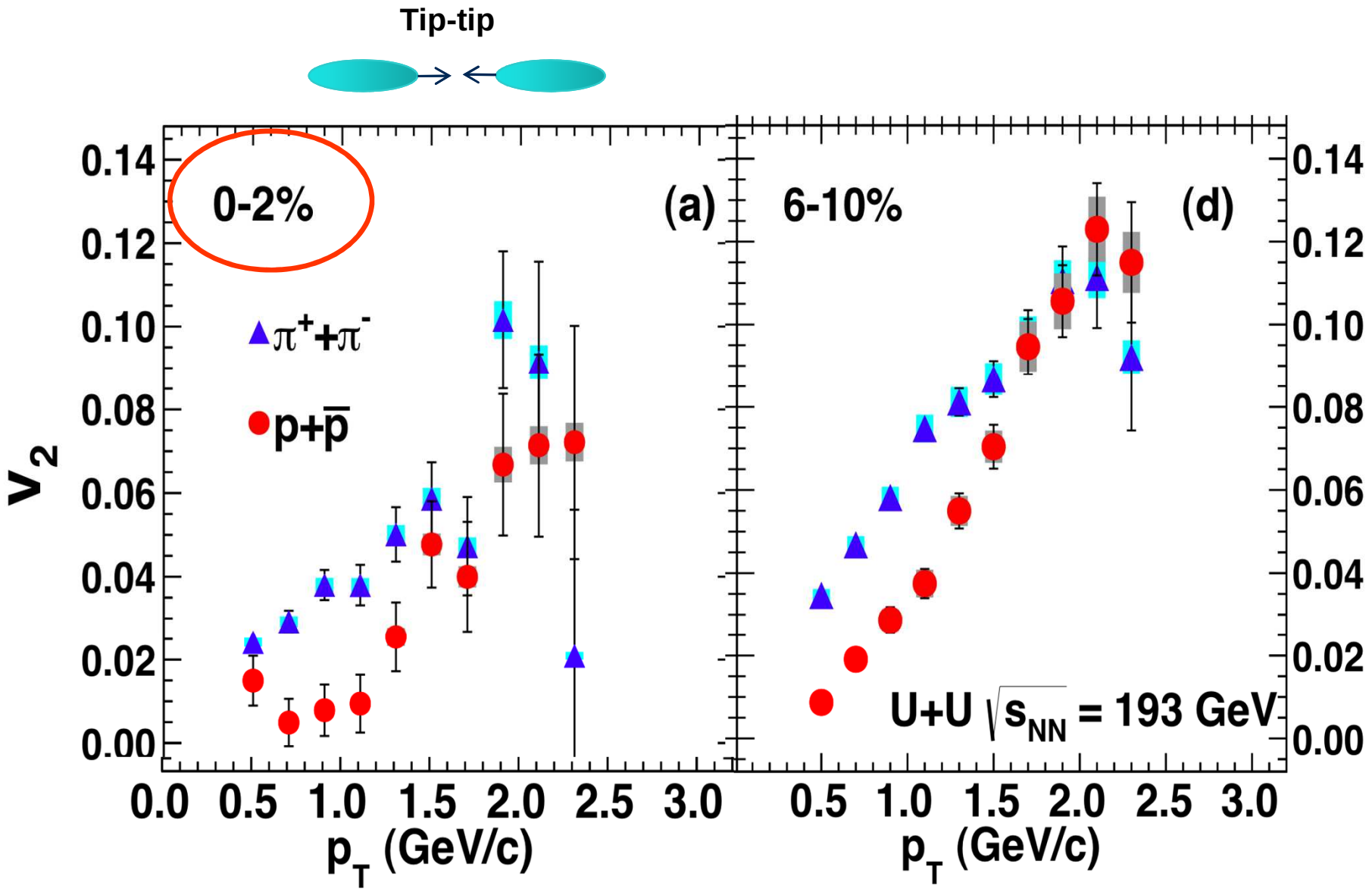



## Identified particles flow v2 in Au+Au and U+U

Flattening of v2 at low pT for (anti) protons in UU

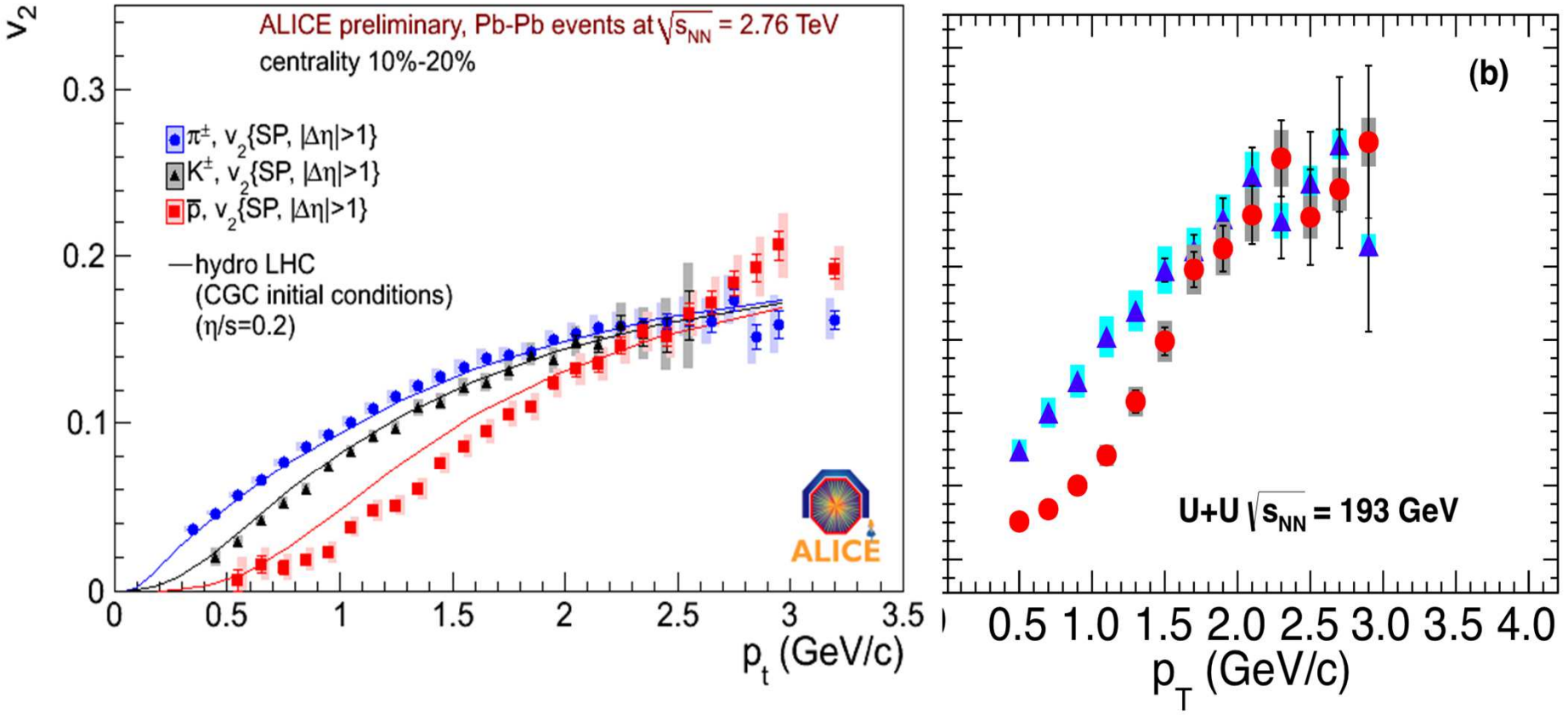


# Strong radial flow in Tip-Tip enriched events...



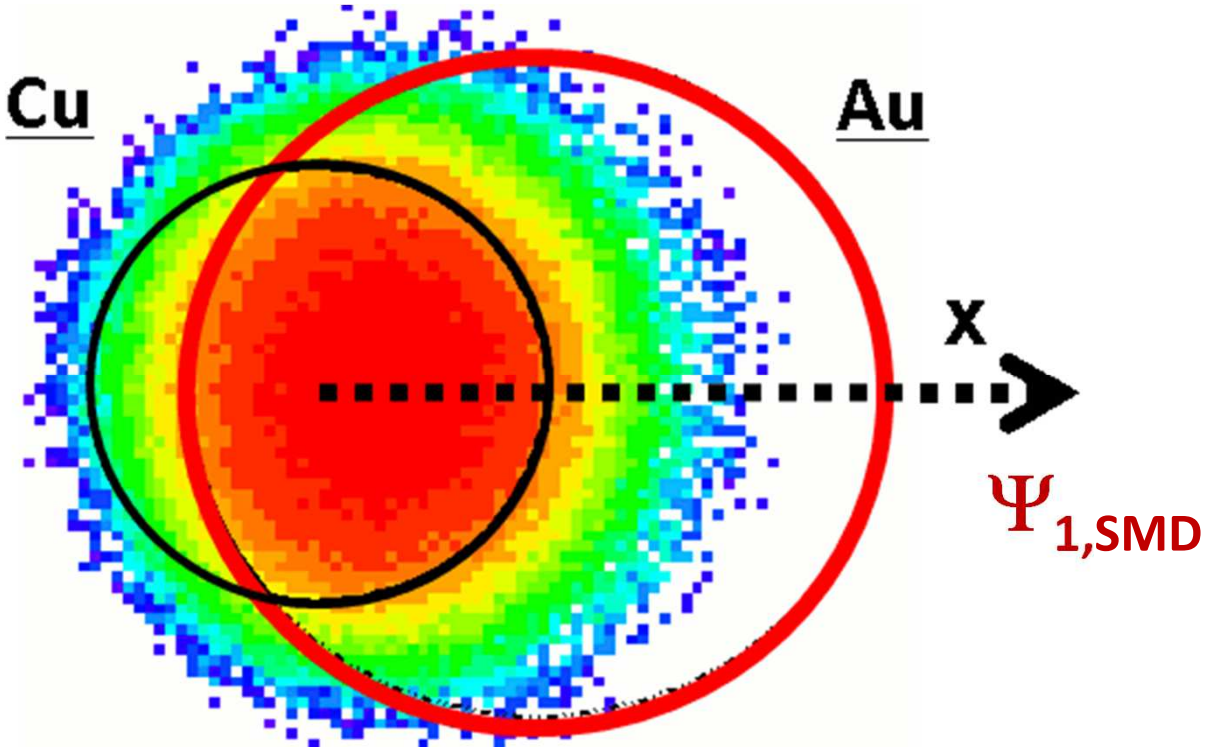

... due to geometry or higher energy density?

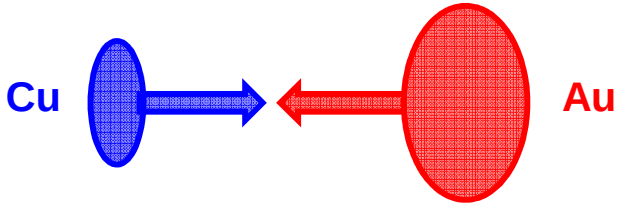
# Similar radial flow at RHIC and LHC

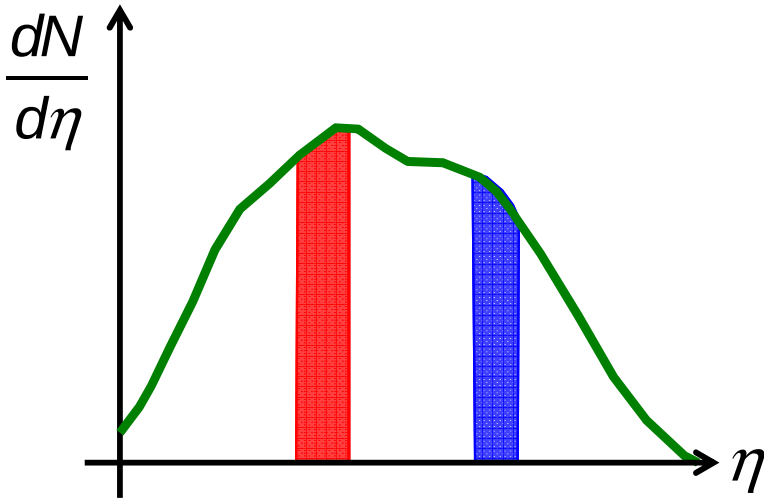


# Asymmetric Cu+Au collisions

- Asymmetric coordinate space leads to asymmetric density profile and pressure gradient
- Shower Max Detector (SMD) sees Au-spectator and defines $\Psi_1$

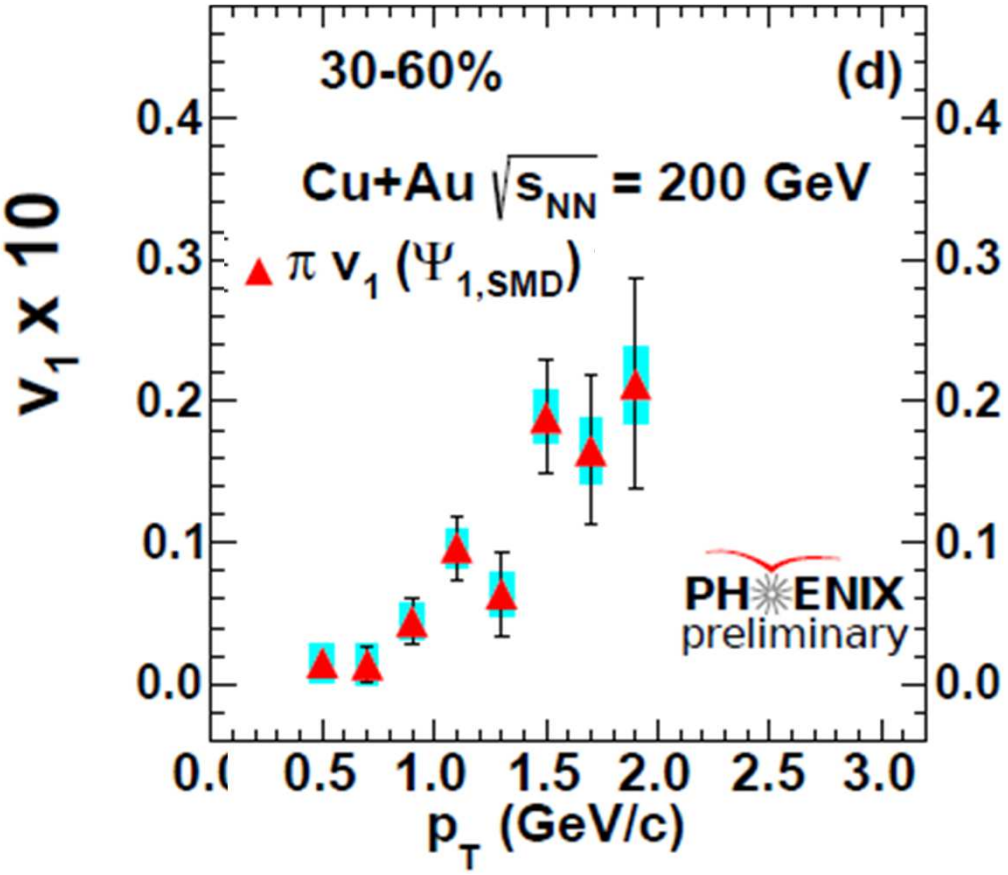


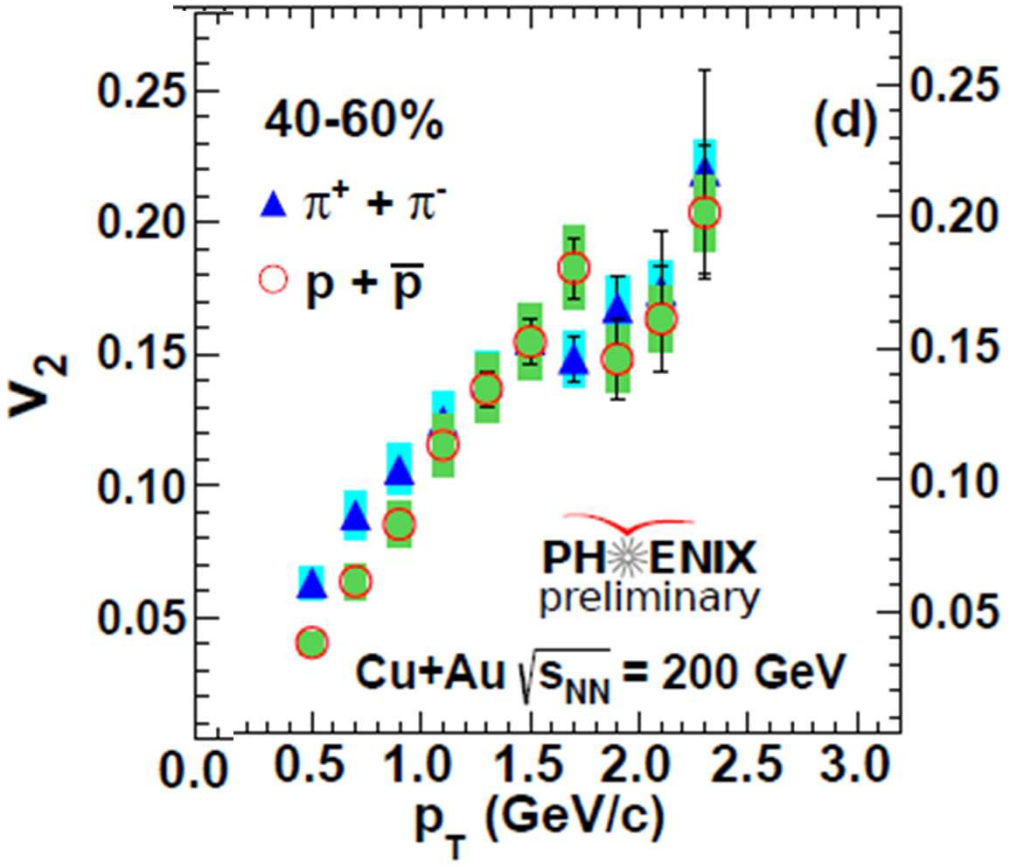



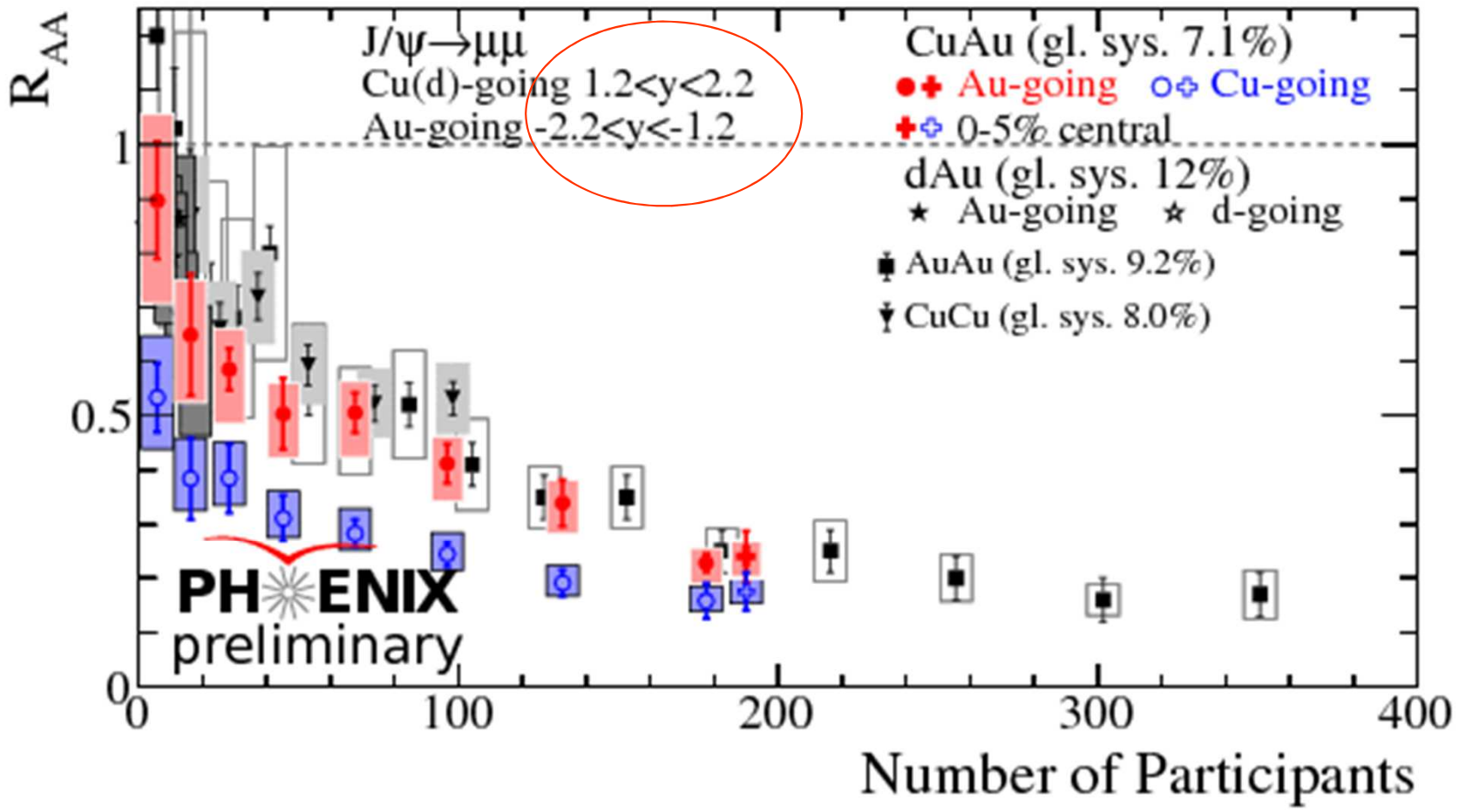
# Flow in Cu+Au collisions, $v_1$ and $v_2$

- SMD sees Au-spectators and defines $\Psi_1$
- Sizable $v_1$ is seen (direction opposite to AMPT)



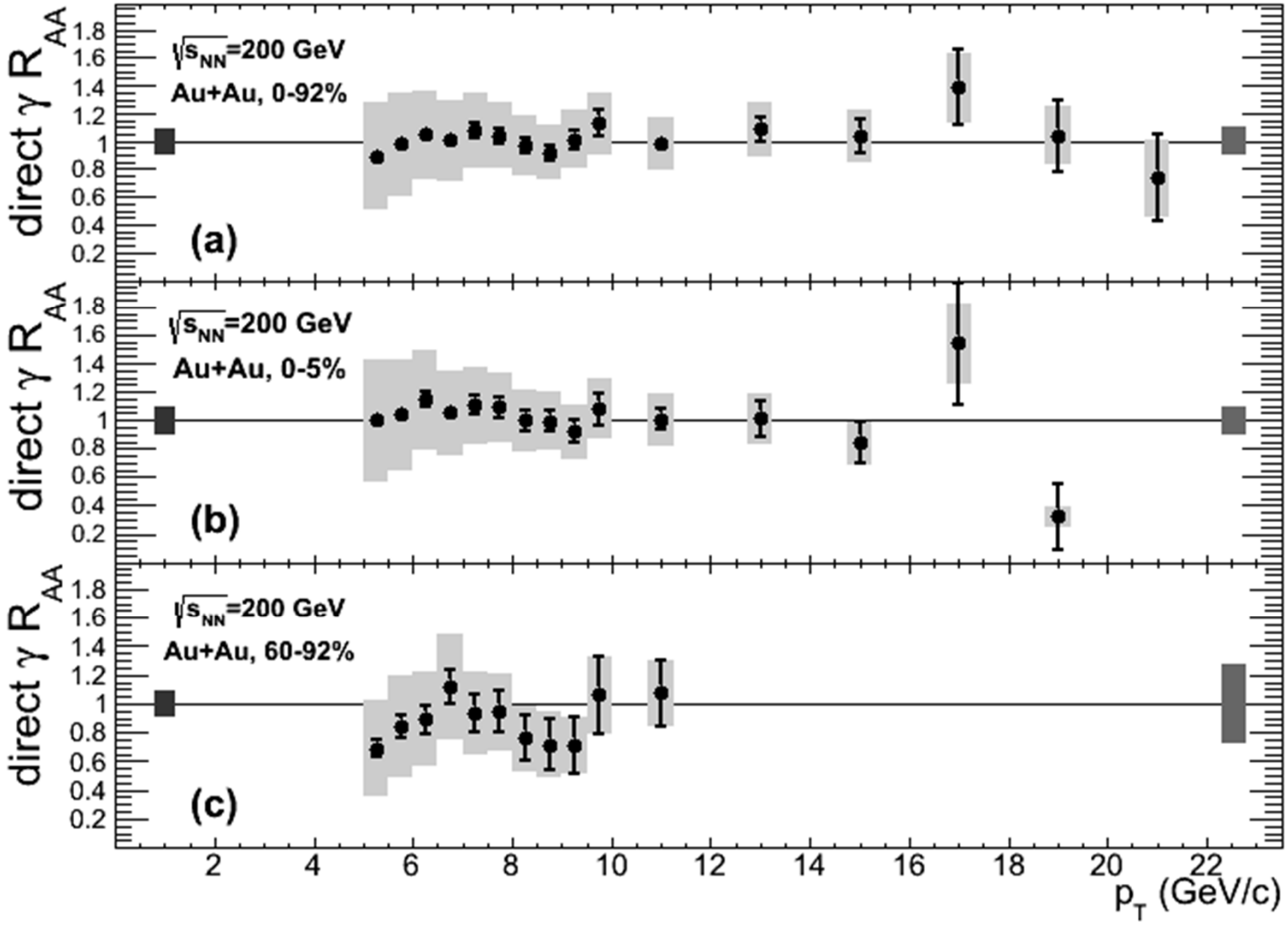



# J/ψ in Cu+Au and Au+Au




- *J/ψ suppression in Au-going direction is the same as Au+Au*
- *Cu-going direction stronger suppression than in Au+Au*

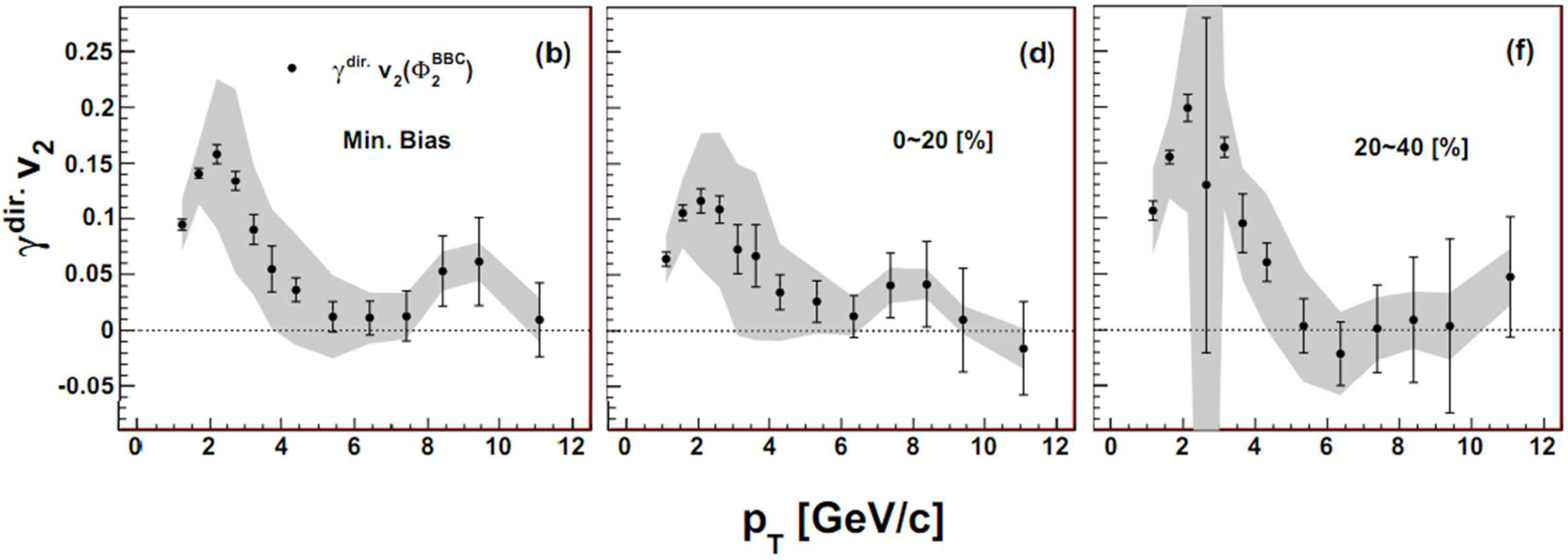
# Au+Au. Direct photon RAA with much better statistics




*Number-of-collision scaling is valid over the whole range*

# Direct/thermal photon azimuthal asymmetry.

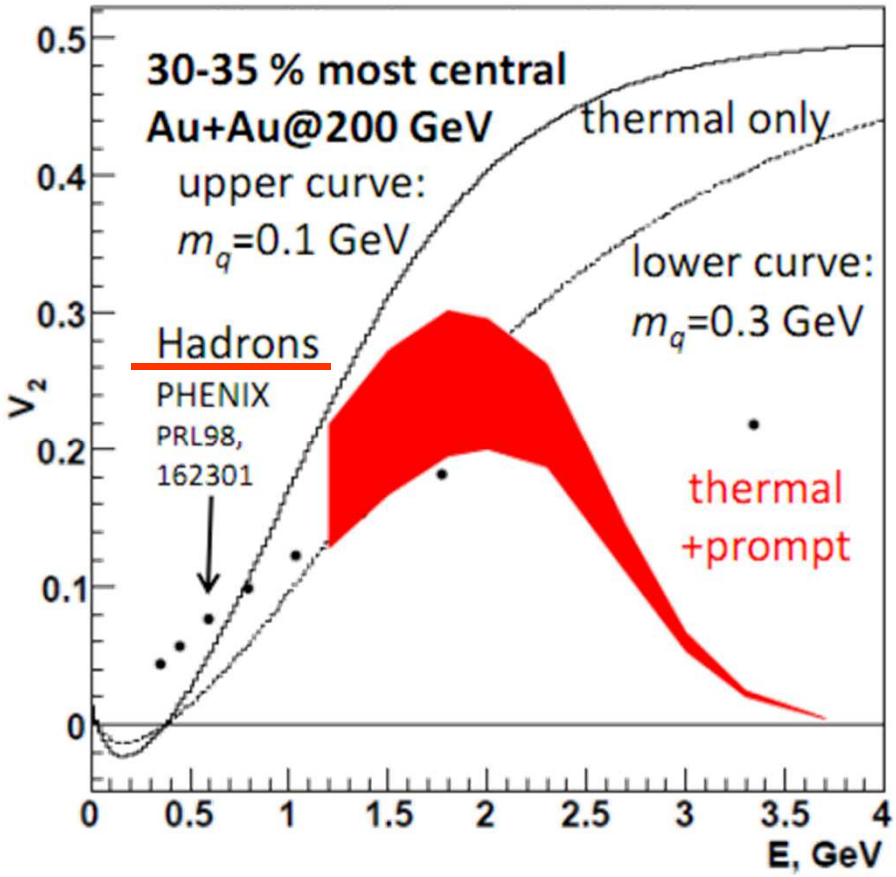
## Au+Au, 200 GeV




***Photons flow!*** *$V_2$ is very similar to hadrons! Very challenging for theory.*

*Does it mean that most of "thermal photons" are produced at later time when flow is already developed?*

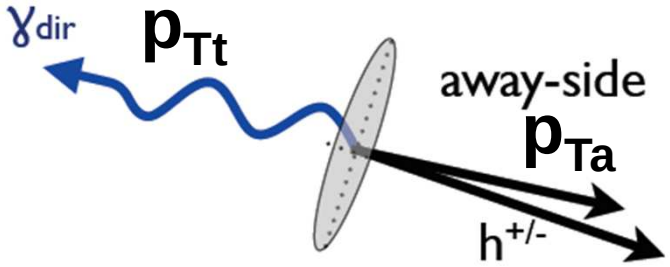
# Indeed, thermal photons can flow as much as hadrons if are produced at the stage when flow is already developed




*The reason – blu and red photon energy shift*

***V. Pantuev, arXiv:1105.4033***

# γ-h correlation in Au+Au



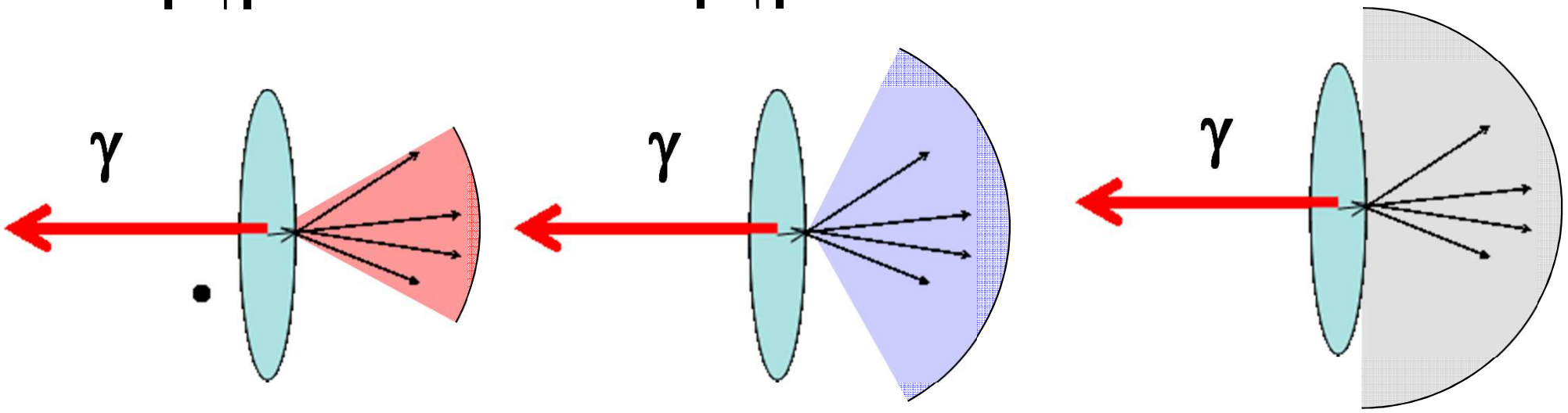

$z_T = p_{Ta}/p_{Tt}$

$\xi = \ln(1/z_T)$

$$I_{AA} \equiv \frac{(1/N_{trig}dN/d\xi)_{AA}}{(1/N_{trig}dN/d\xi)_{pp}}$$

- Associated particles in three angle ranges are integrated

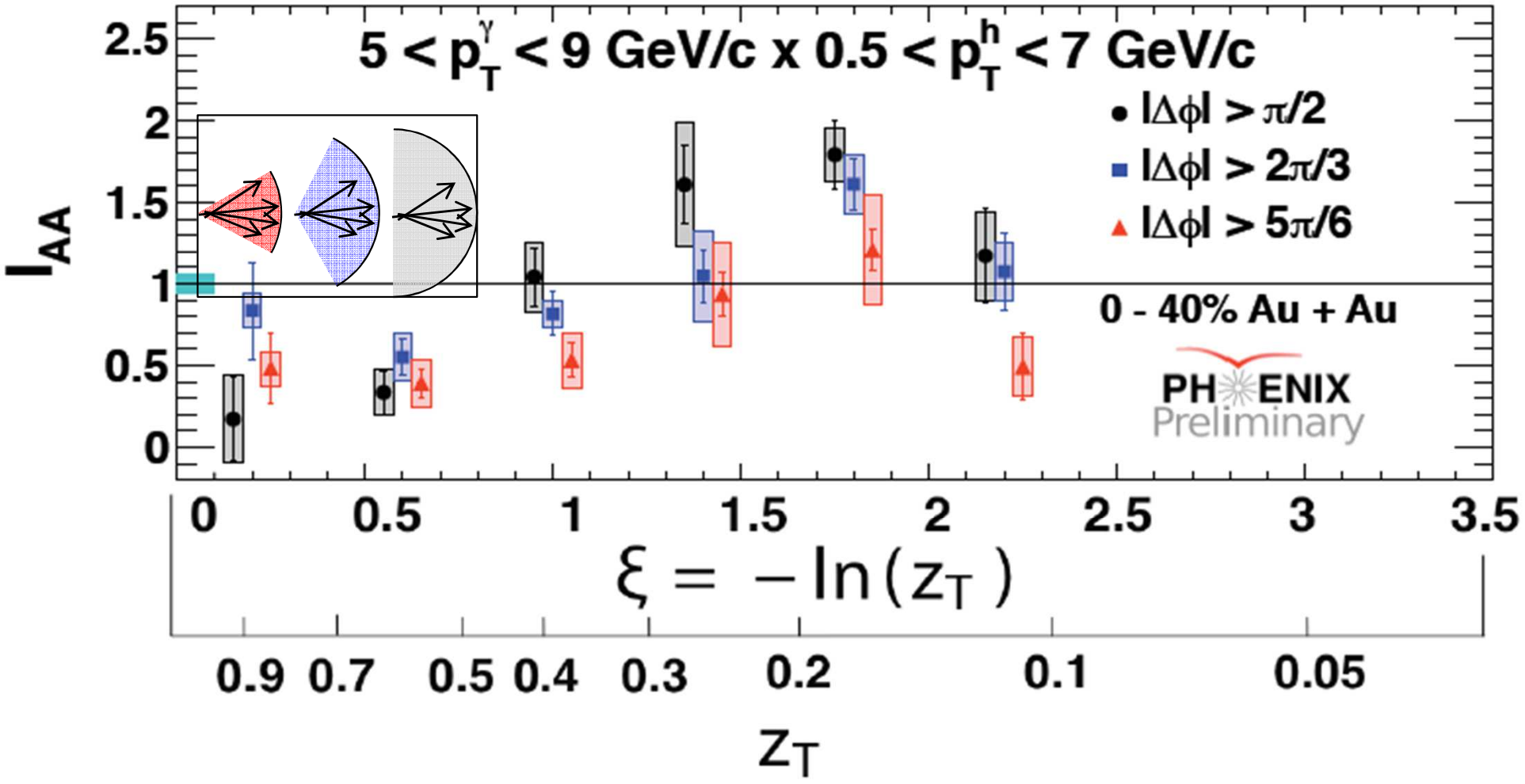
$|\Delta\phi|>5\pi/6$ $|\Delta\phi|>2\pi/3$ $|\Delta\phi|>\pi/2$



# γ-h correlation in Au+Au

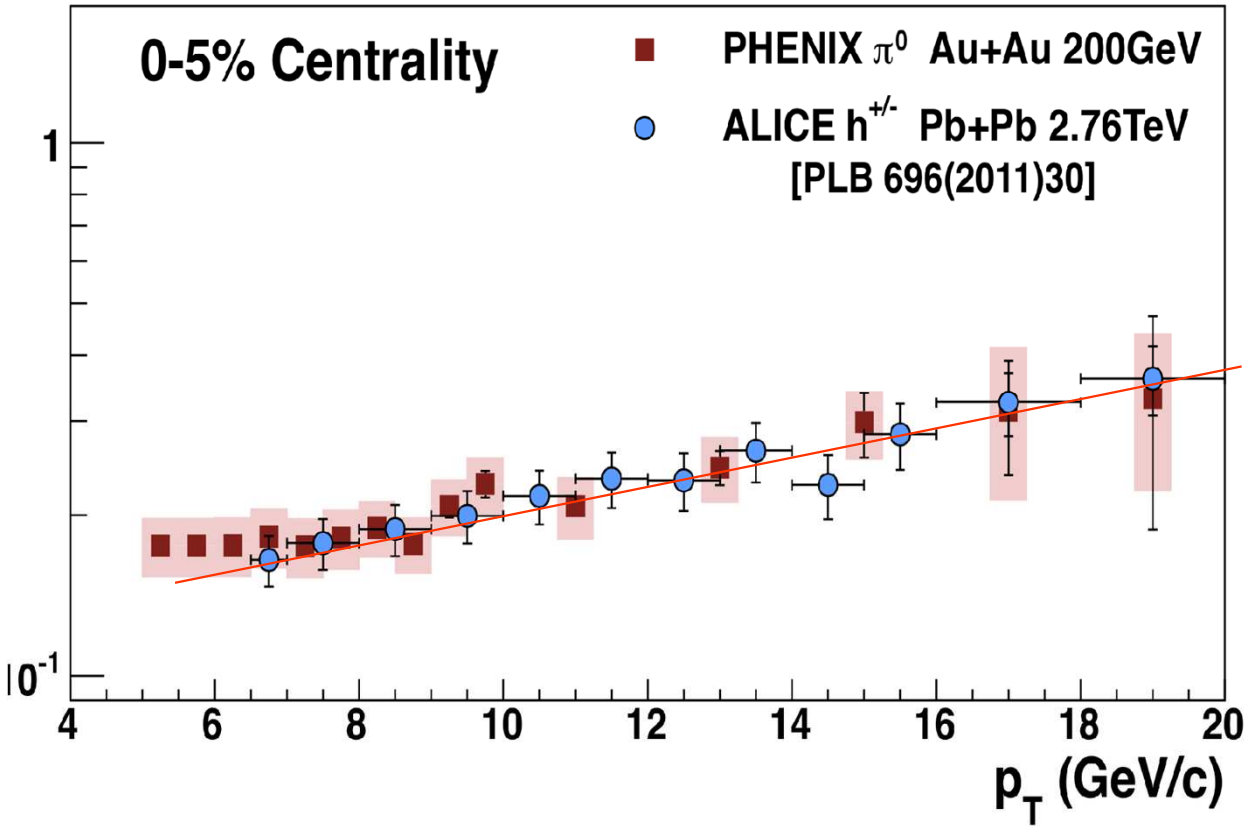
$$I_{AA} \equiv \frac{(1/N_{trig}dN/d\xi)_{AA}}{(1/N_{trig}dN/d\xi)_{pp}}$$

Low $z_T$ away side particles distributed over wider angle



# $R_{AA}$ RHIC energy vs. LHC

- $\pi^0$ in Au+Au 200GeV 0-5%, up to 20 GeV/c
- Rising slope in $R_{AA}$: $(1.06 +0.34 -0.29) \times 10^{-2}(GeV/c)^{-1}$

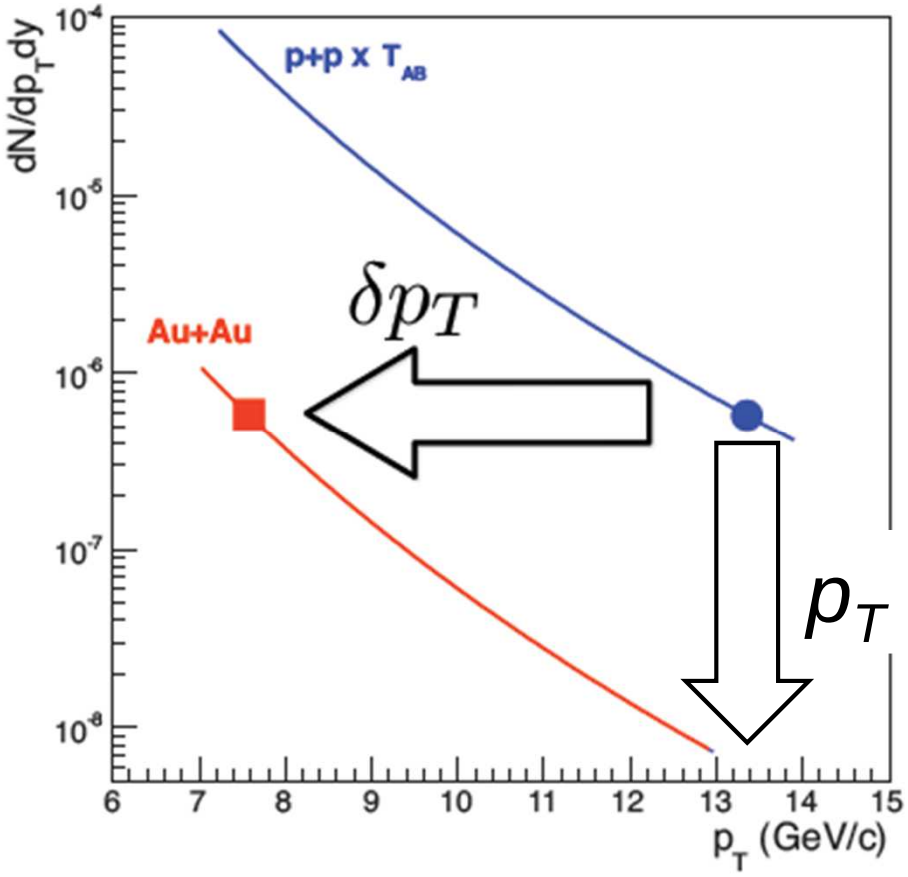


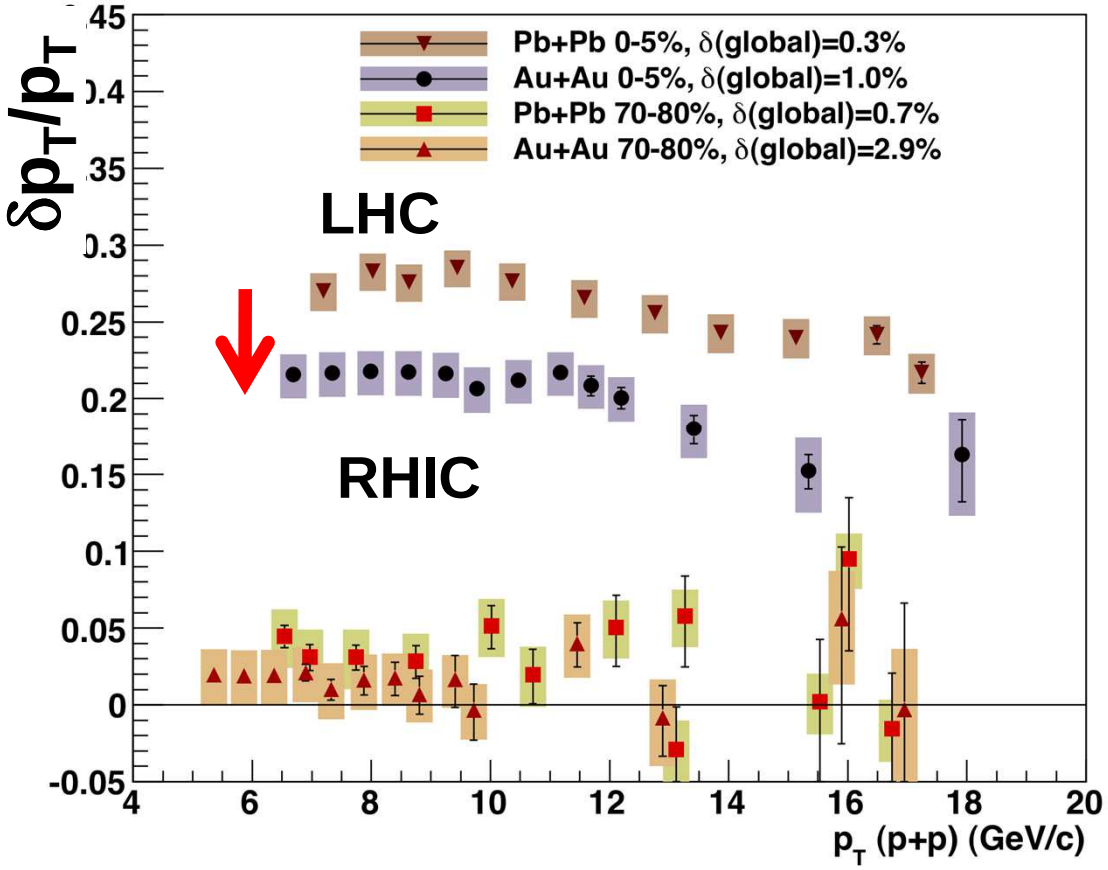

Charged hadrons in Pb+Pb 2.76TeV 0-5%

*RAA for both systems look very similar*

# Parton Fractional momentum loss

- Measure fractional momentum loss ($\delta p_T/p_T$) instead of $R_{AA}$
- Different $\delta p_T/p_T$ for same $R_{AA}$

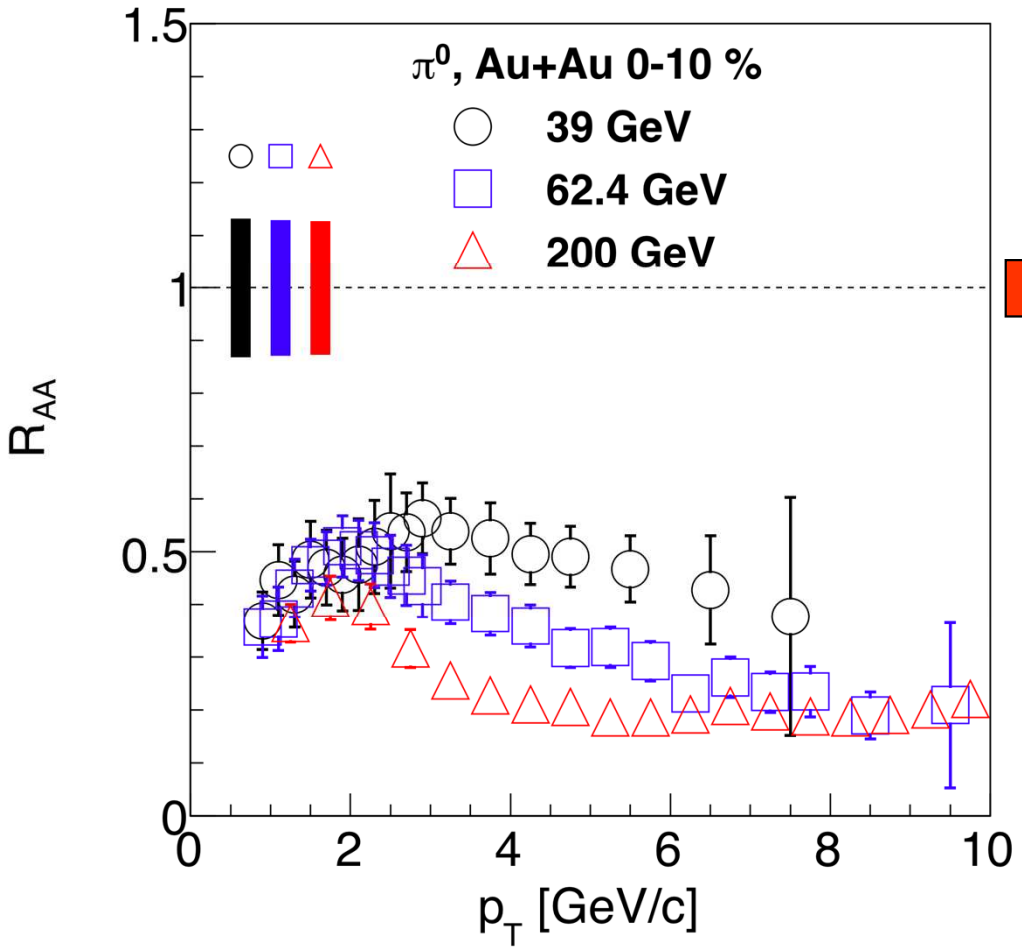


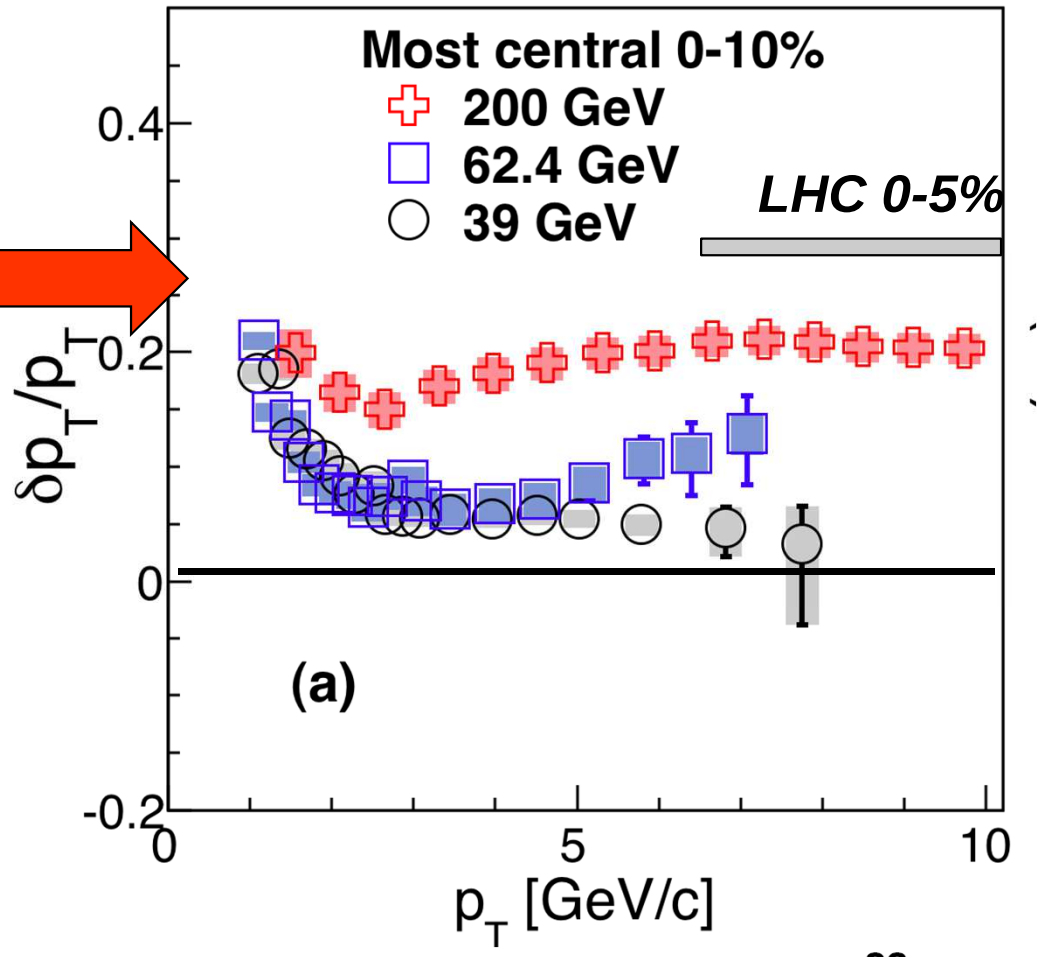




arXiv:1208.2254

# Energy dependence of $\delta p_T/p_T$

- $\delta p_T/p_T$ decreases significantly going from 200GeV to 62, 39GeV

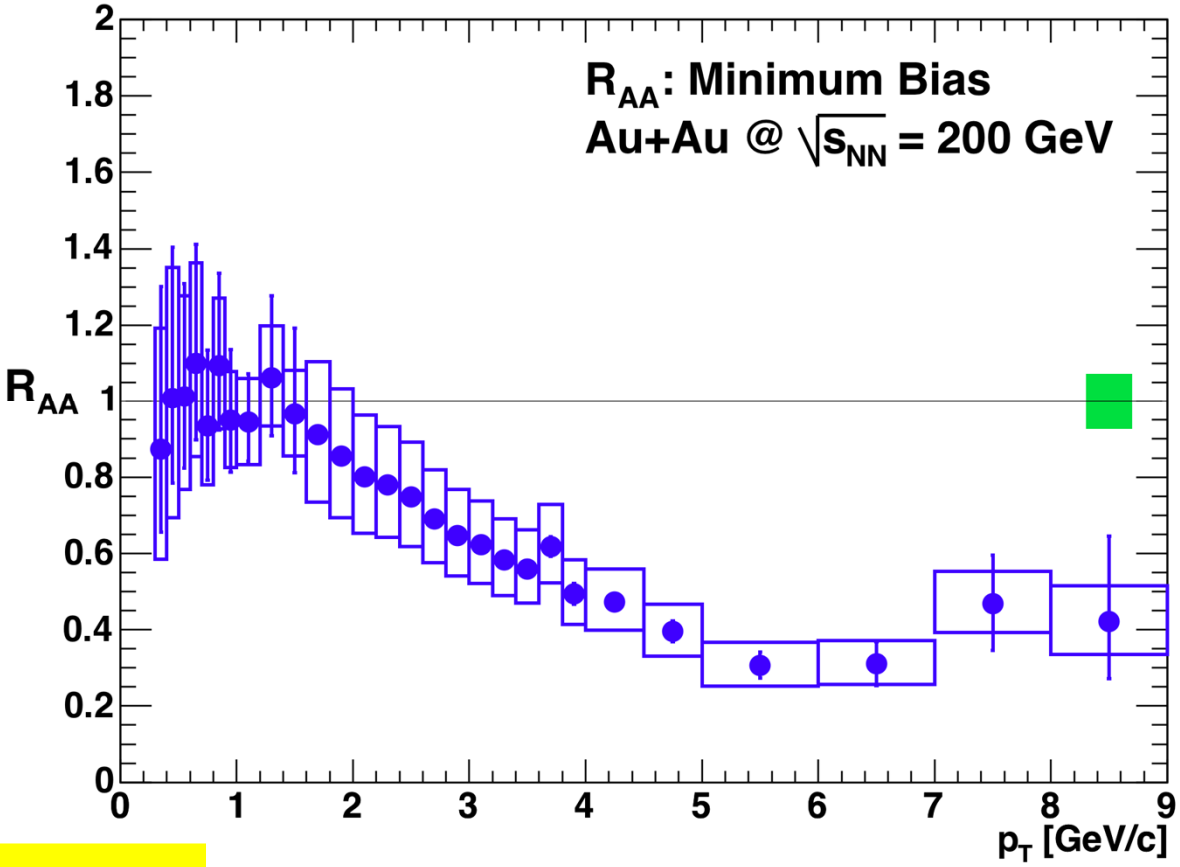



arXiv:1204.1526

# Non-photonic single electrons

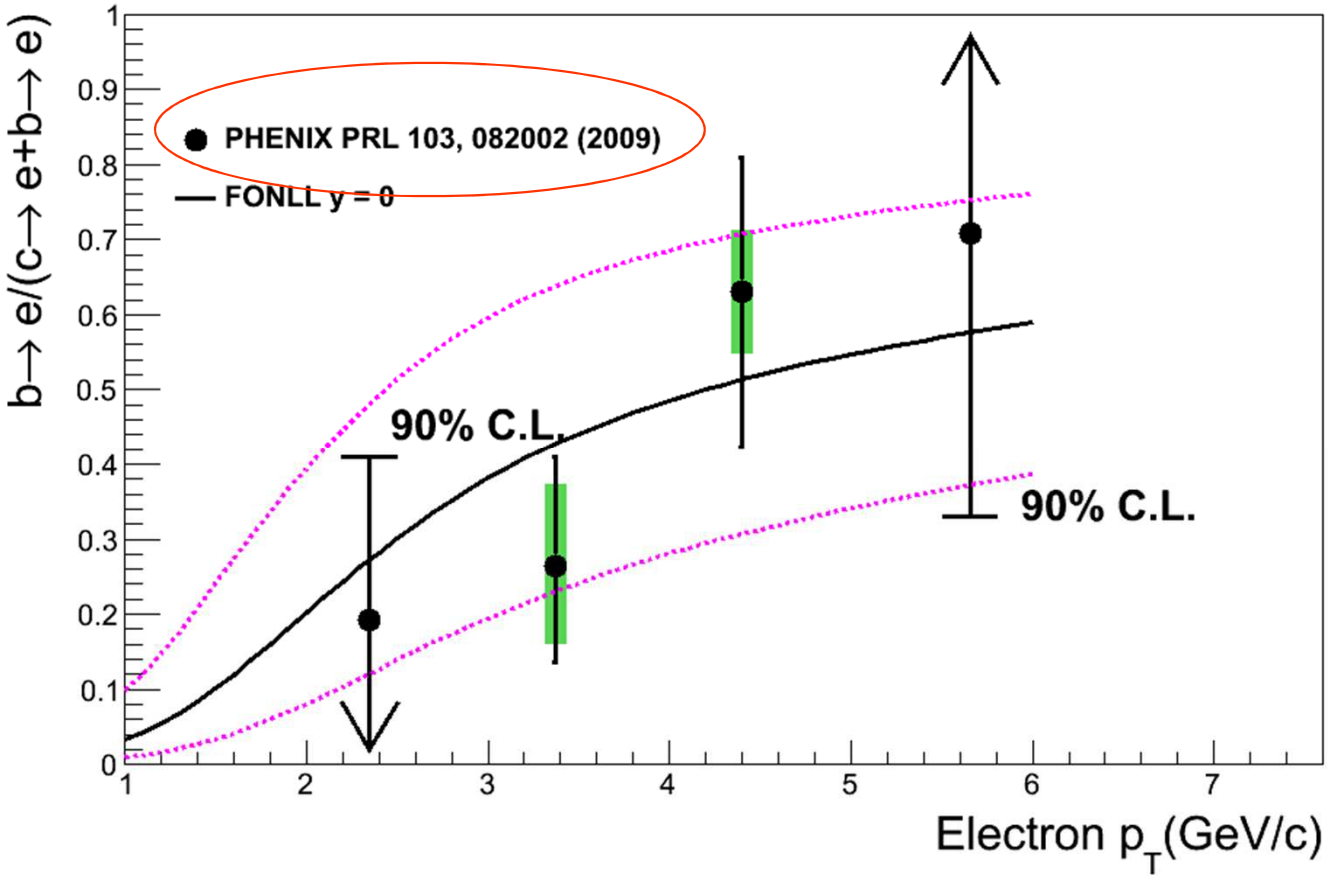
- **Heavy flavor** electron $R_{AA}$ is a mixture of charm and bottom contributions
- We really want $R_{AA}$ for **charm** and **bottom** separately




PRC. 84, 044905 (2007)

# Charm and bottom decomposition

- For p+p collisions (b->e)/(b->e + c->e) ratio from partial reconstruction of $D \rightarrow e^{+/-} K^{-/+} X$

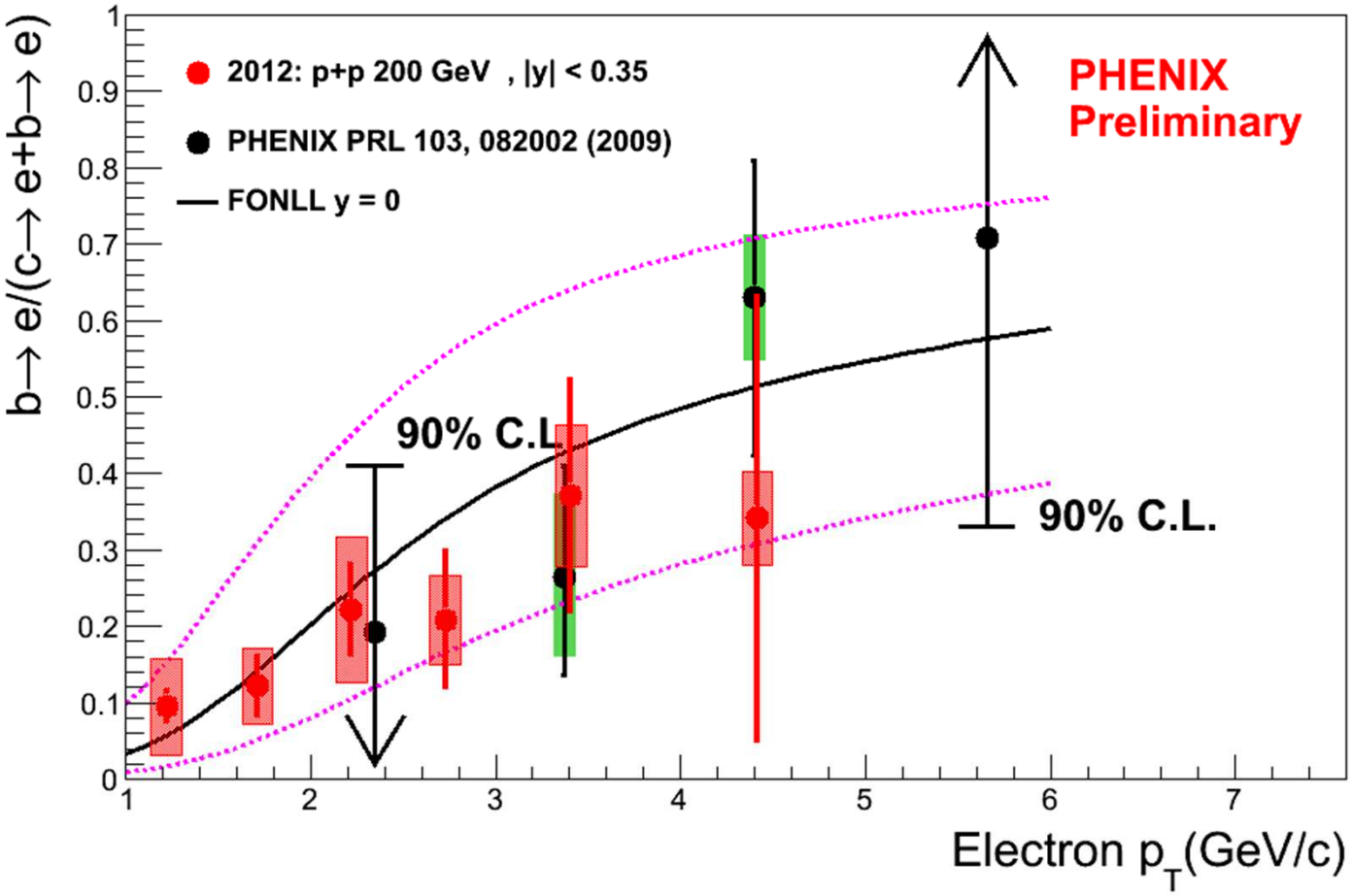



*Bottom contribution becomes dominant above 4 GeV/c*

# First direct c/b decomposition

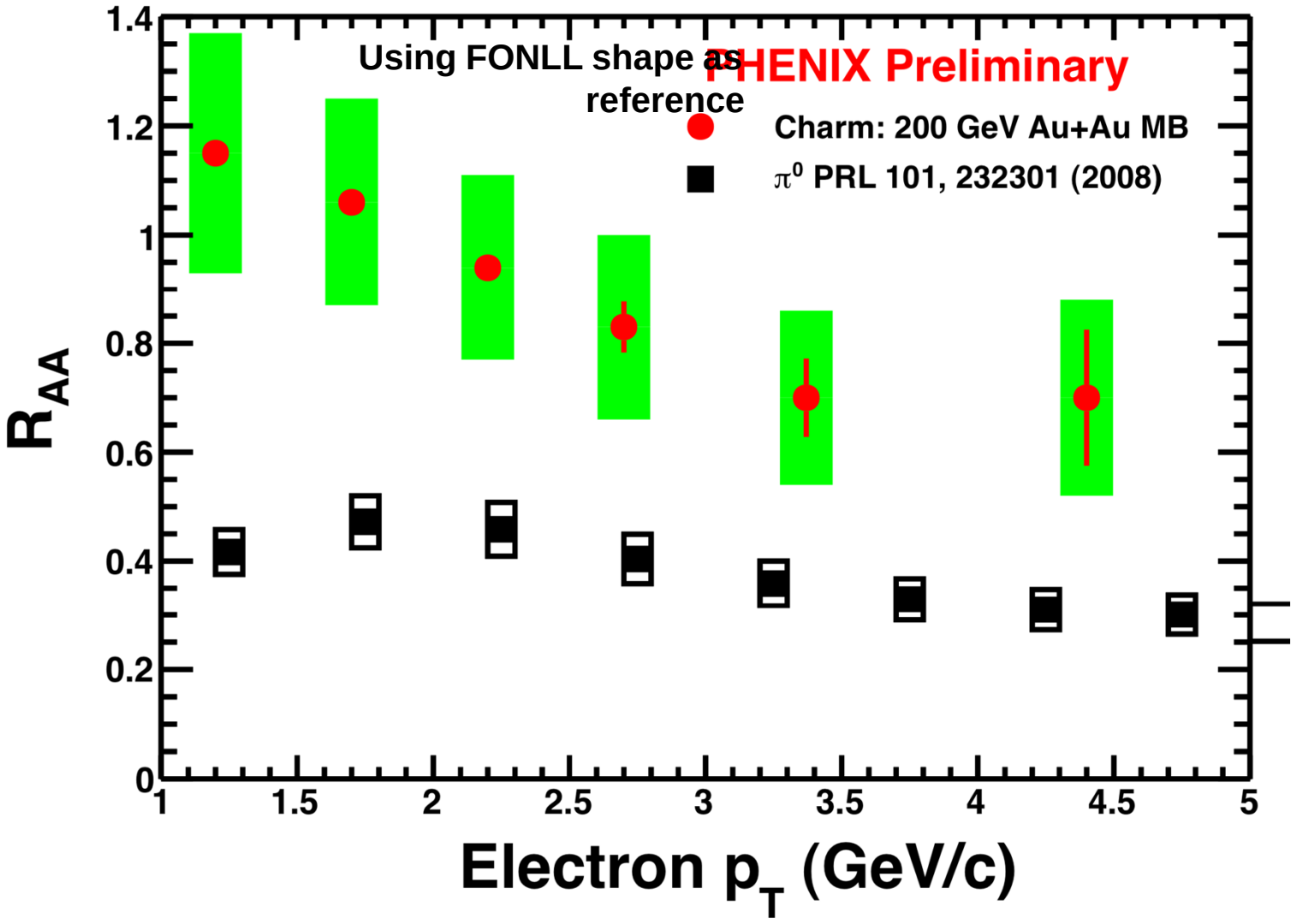
## with new Si-VTX detector

- New direct measurement of bottom fraction agrees with FONLL



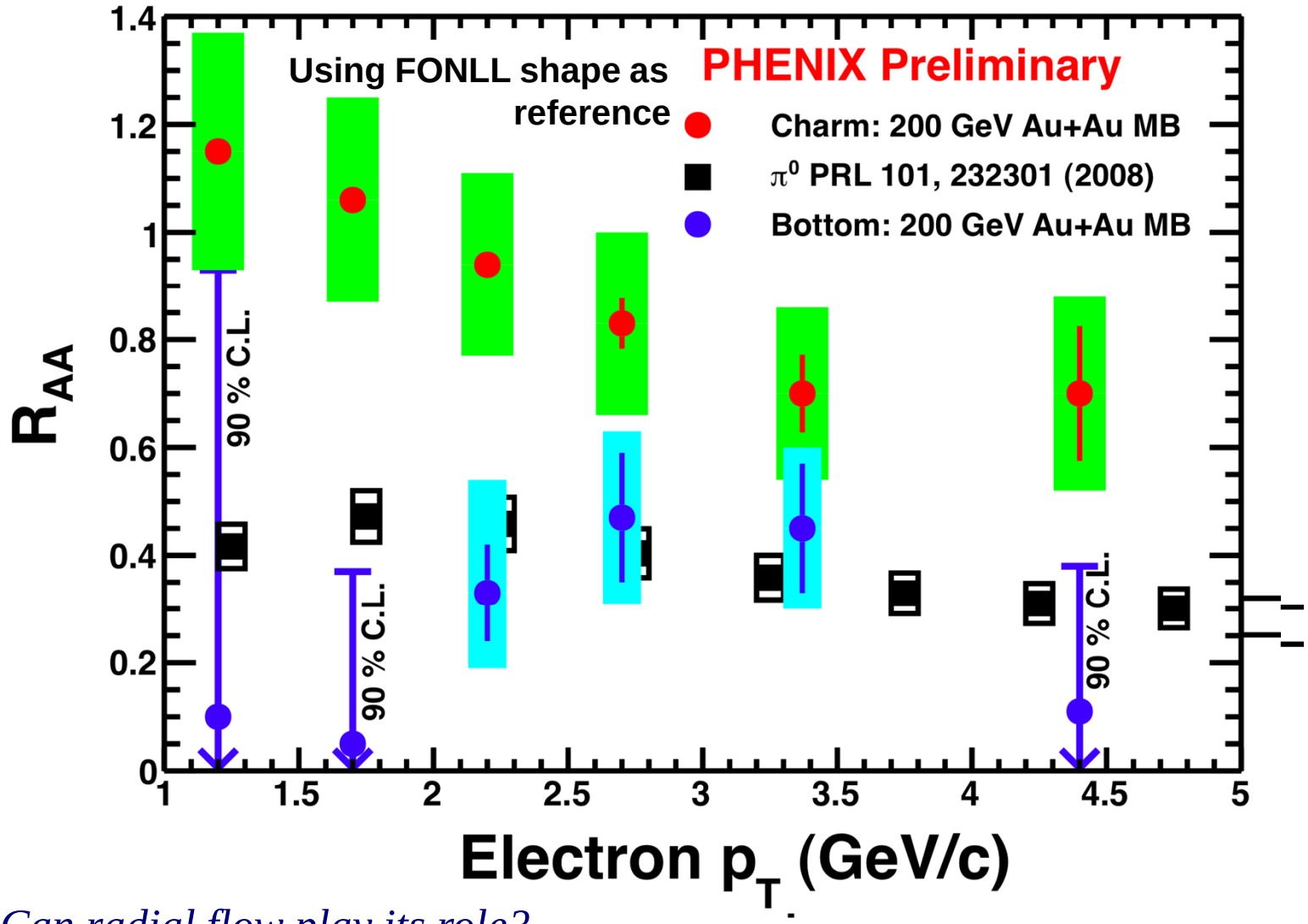
# $R_{AA}$ for c→e and $\pi^0$

- Charm contribution is less suppressed



# $R_{AA}$ for c→e, b→e and $\pi^0$

- Bottom contribution is heavily suppressed!




*Can radial flow play its role?*

# Summary

- 39 – 200 GeV energy scan confirms general features: smooth change of global variables, jet suppression, flow
- **High statistics d+Au data give good reference for cold nuclear effects. Big surprise that ψ' are strongly suppressed**
- Tip-to-tip U+U collisions demonstrate strong radial flow
- **Direct photons with much better statistics confirm N-collision scaling for hard process. Thermal photons flow!**
- Parton fractional momentum loss increases with beam energy from 39 to 200 GeV – more dense matter is formed
- **Non-photonic electrons. With new Si-vertex detector can distinguish Charm and Bottom quarks. For a big surprise, electrons from Bottom are suppressed much stronger**

# Circle of life