Two-particle correlation & HBT measurements in d+Au collisions at PHENIX

Takahito Todoroki
for the PHENIX Collaboration
University of Tsukuba

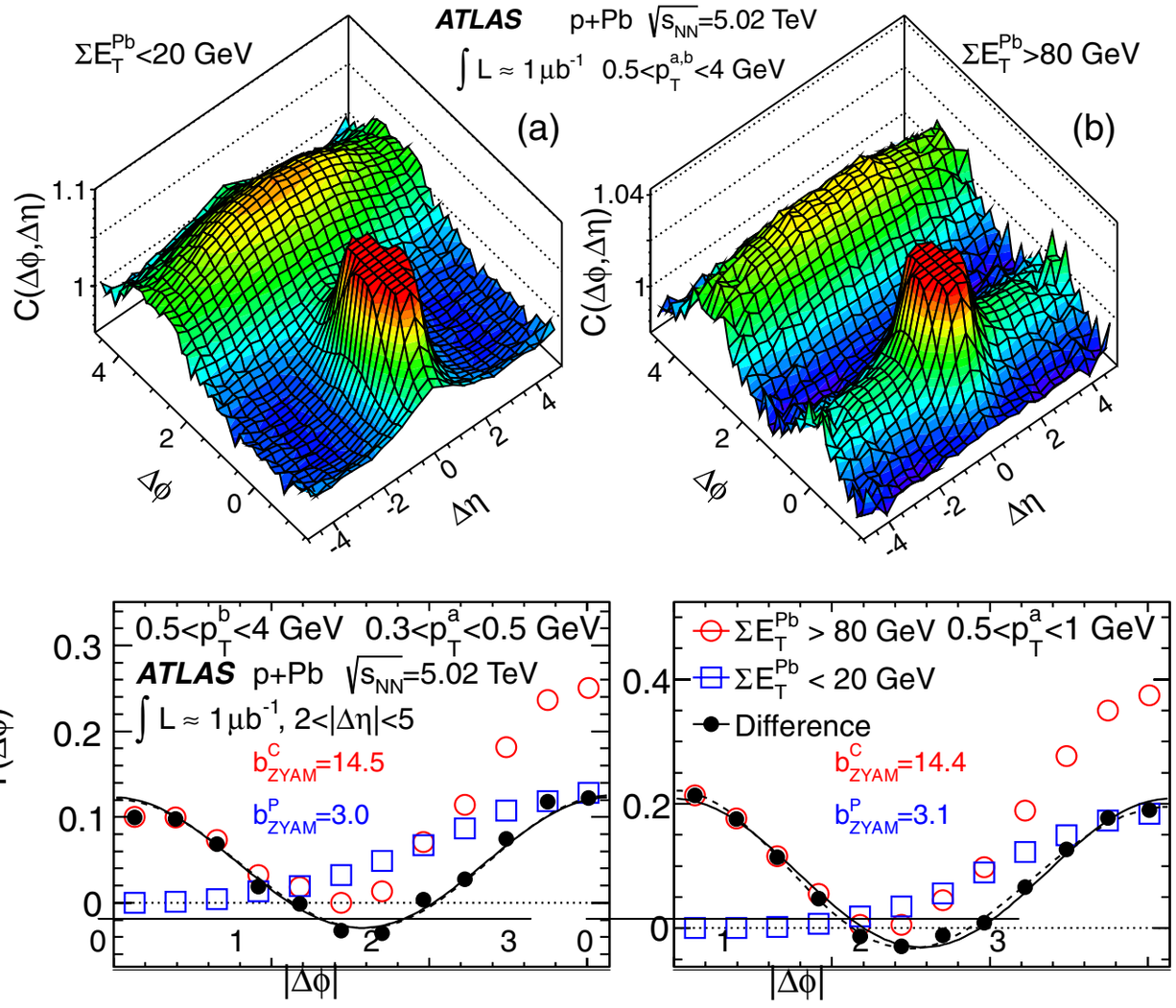
RHIC/AGS Users' Meeting 2014
"dA and Planning for pA, HE3-A"

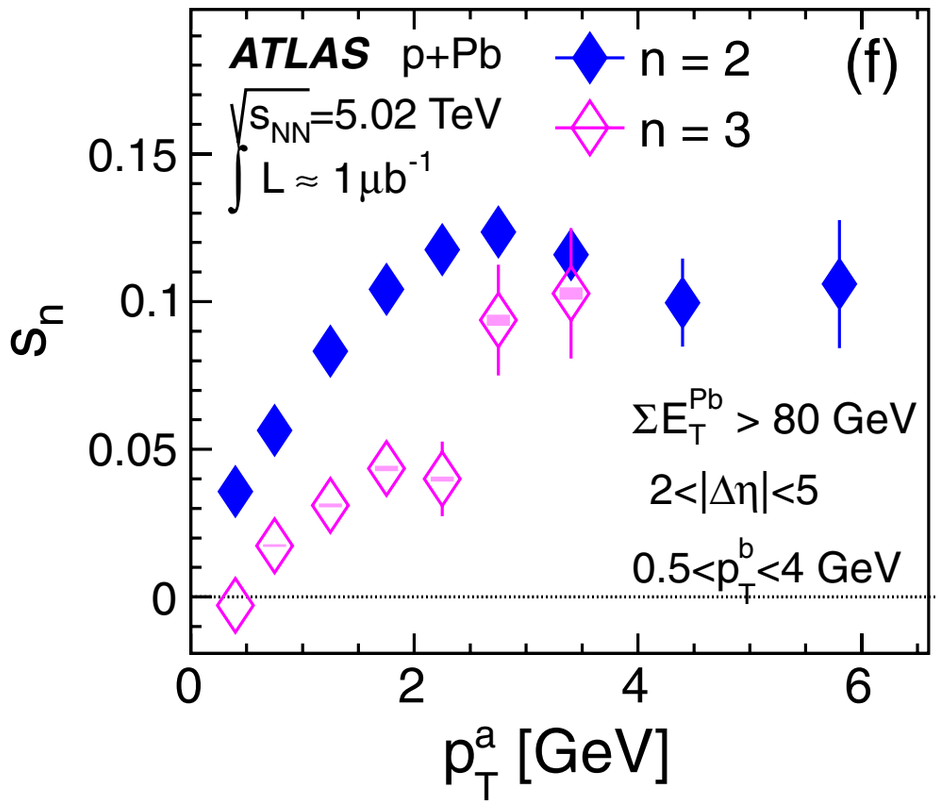
Many thanks for P.Stankus, S.Huang, J. Frantz, & B.Xia for their inputs

Outline

- Hadron-hadron (MPC tower) correlations at low-p_T
  - Ridge in d+Au collisions
- High p_T π^0-hadron correlations
  - Modification of correlations by possible cold or hot nuclear matter effects in d+Au collisions
- HBT interferometry
  - Evolution mechanism of d+Au collisions

Ridge and v_n in p+Pb collisions

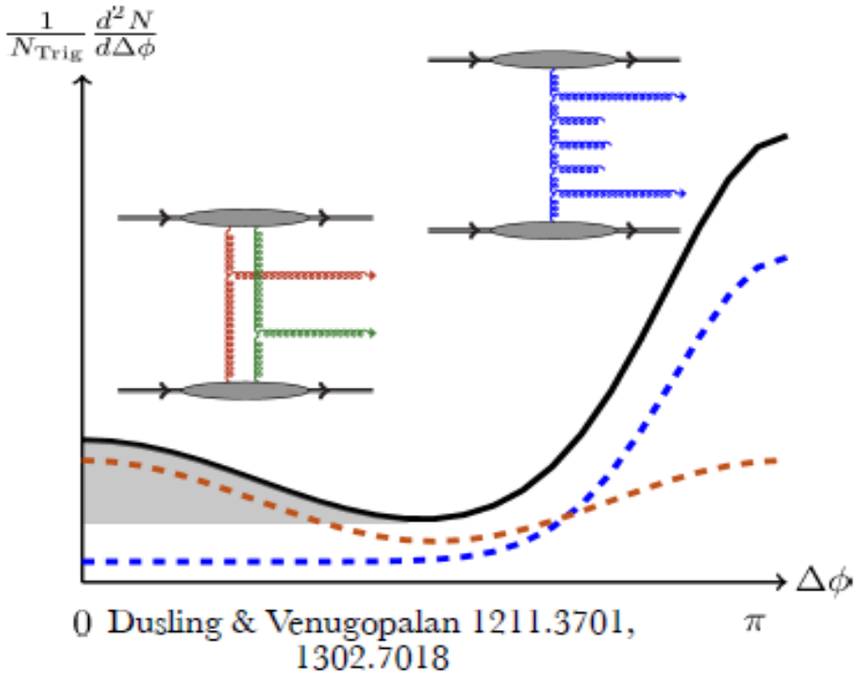




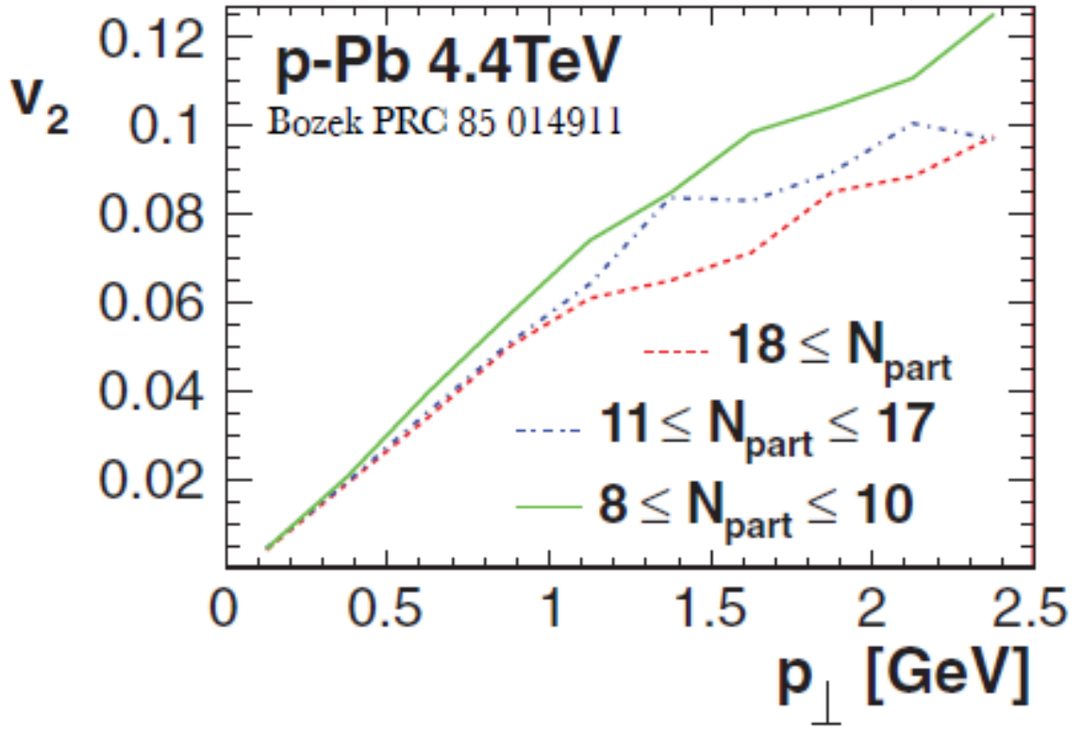
ALICE: Physics Letters B 726 (2013)
ATLAS: Phys. Rev. Lett. 110(2013)
CMS: Phys. Lett. B 7198(2013)

- Ridge is observed in most-central p+Pb collisions at 5.02 TeV
- Peripheral subtraction from central shows cos2Δφ term
- Non-zero v_n (n=2,3) is observed in p+Pb collisions !!

Initial or Final State Effect?



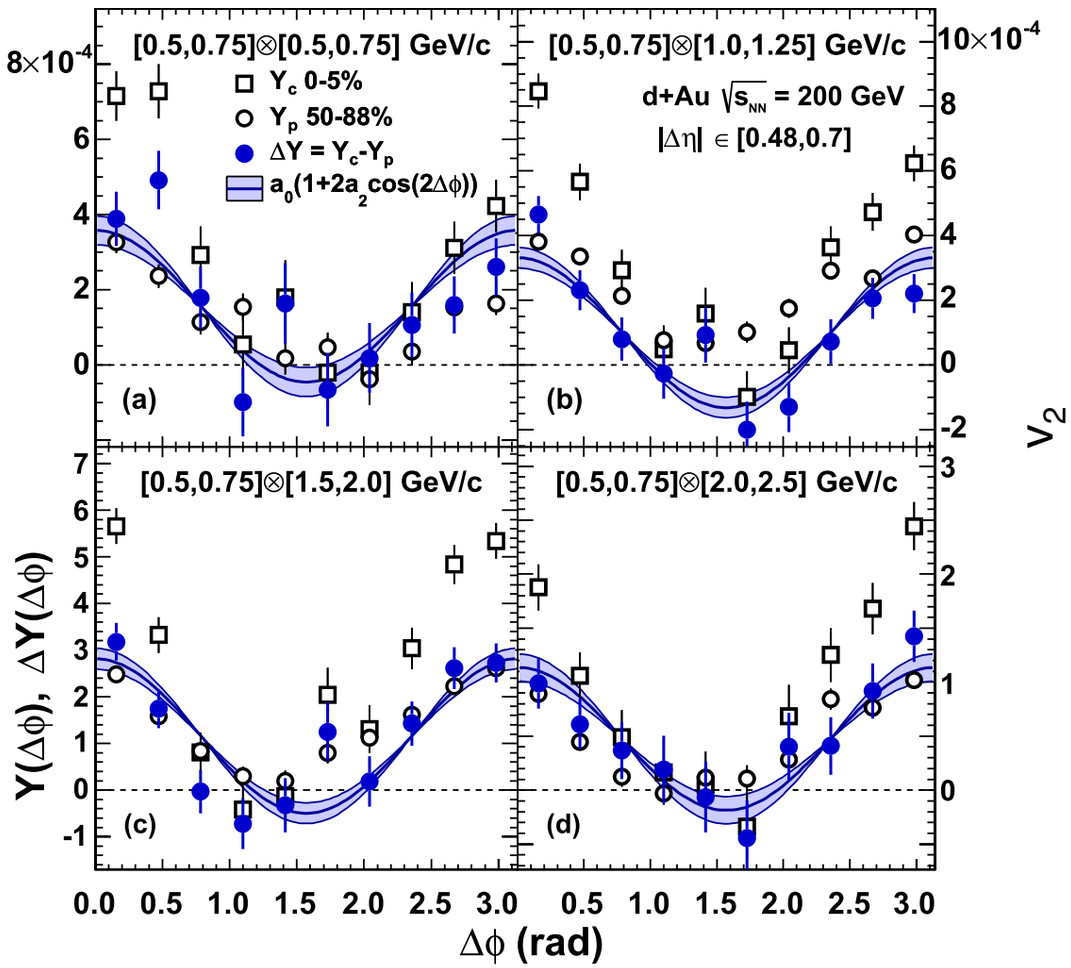
Dusling & Venugopalan 1211.3701, 1302.7018

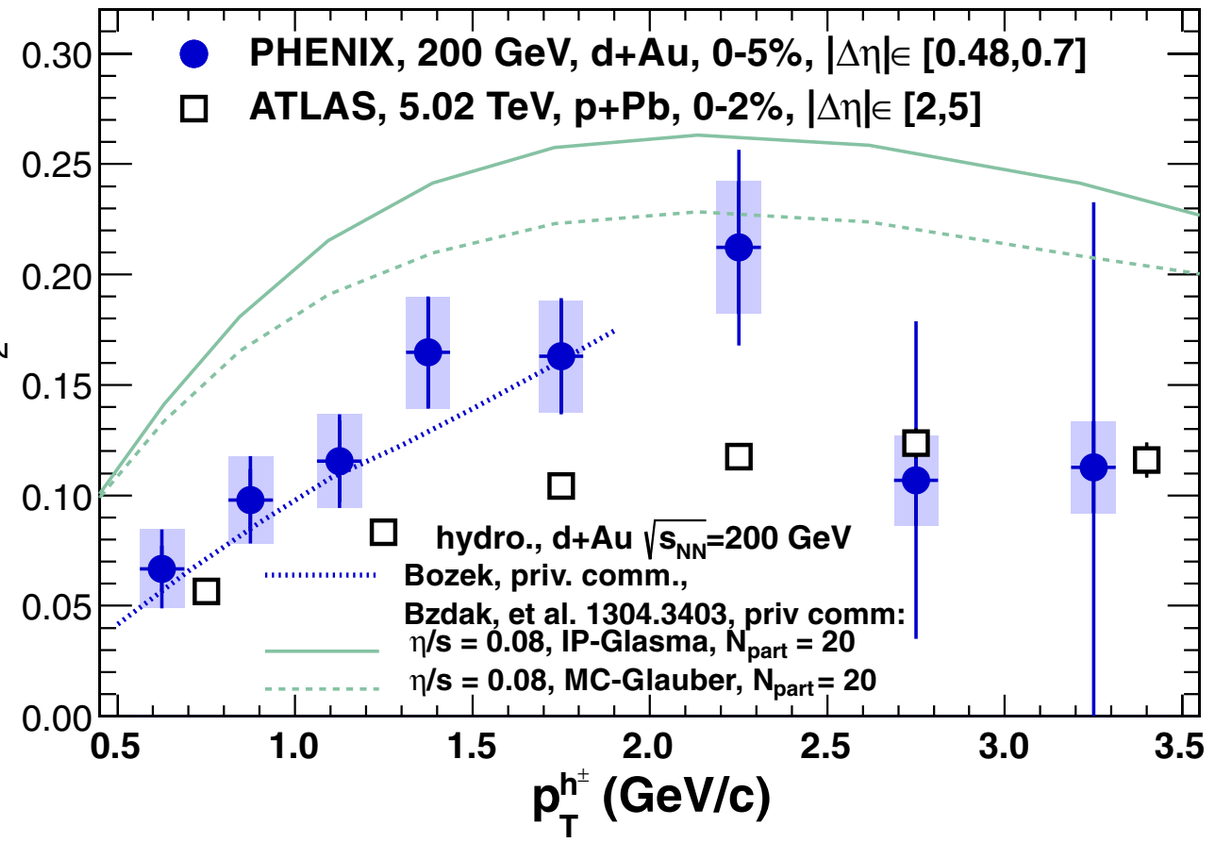


CGC **Hydrodynamics**

- Is the ridge observed in 200 GeV d+Au collisions?
- Amplitude of v_n (n=2,3)? (join v_n talk by Paul Stankus)
- HBT interferometry?

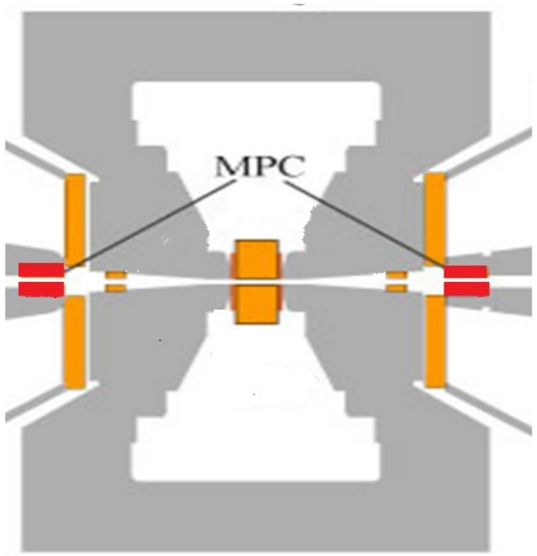
Ridge and v_2 in d+Au collisions

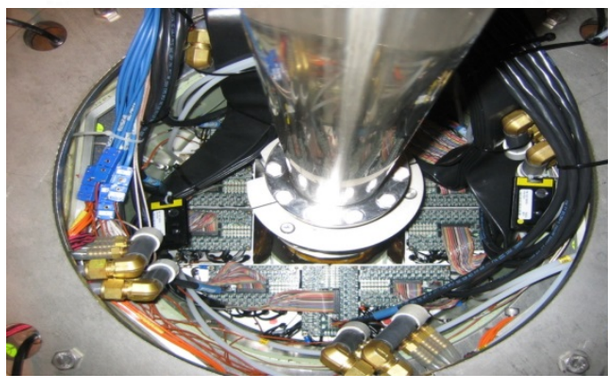


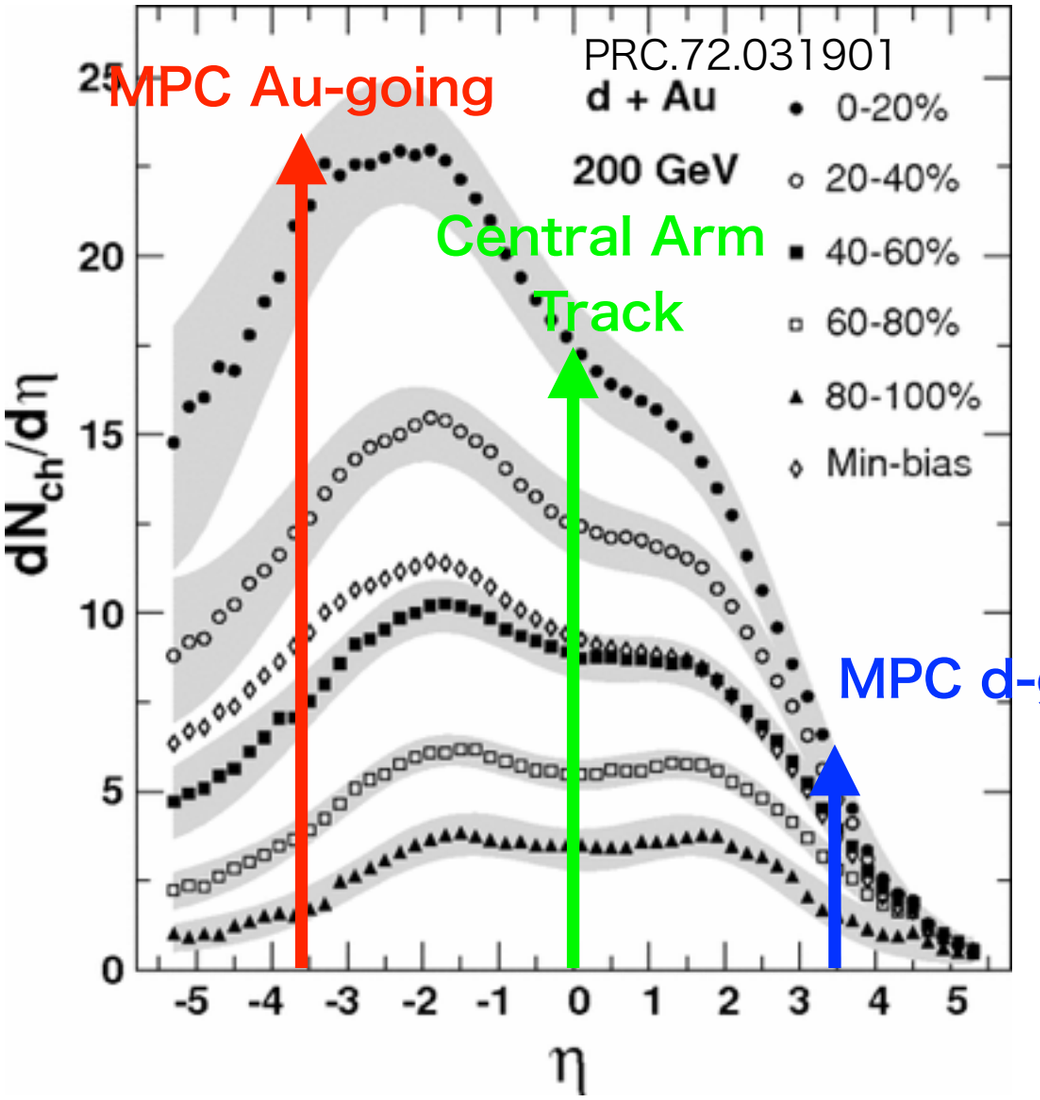


- cos2Δφ structure is observed after peripheral subtraction at $0.48<|\Delta\eta|<0.7$
- None zero v_2 is observed in 0-5% d+Au collisions, qualitatively similar p_T dependence of v_2 in 0-2% p+Pb collisions, which is consistent with hydrodynamics calculations
- Is there ridge in large $|\Delta\eta|$ correlations?

Long-range rapidity correlations







- Muon Piston Calorimeter (MPC) : at $3<|\eta|<4$
- Rapidity separation of $|\Delta\eta|>2.75$ is achieved by measuring correlations between tracks ($|\eta|<0.35$) and MPC towers

Track-tower angular correlations

$$s(\Delta\phi) = \frac{d(\omega_{tower} N_{same}^{track-tower})}{d(\Delta\phi)}$$

: Track-Tower correlations in same events

$$\Delta\phi = \phi_{tower} - \phi_{track}$$

ω_{tower} : Transverse Energy of each tower (Proportional to multiplicity)

$N_{same}^{track-tower}$: Number of Track-Tower Pairs in same events

$M(\Delta\phi)$: Track-Tower correlations in mixed events

$$C(\Delta\phi) = \frac{S(\Delta\phi) \int M(\Delta\phi)}{M(\Delta\phi) \int S(\Delta\phi)}$$

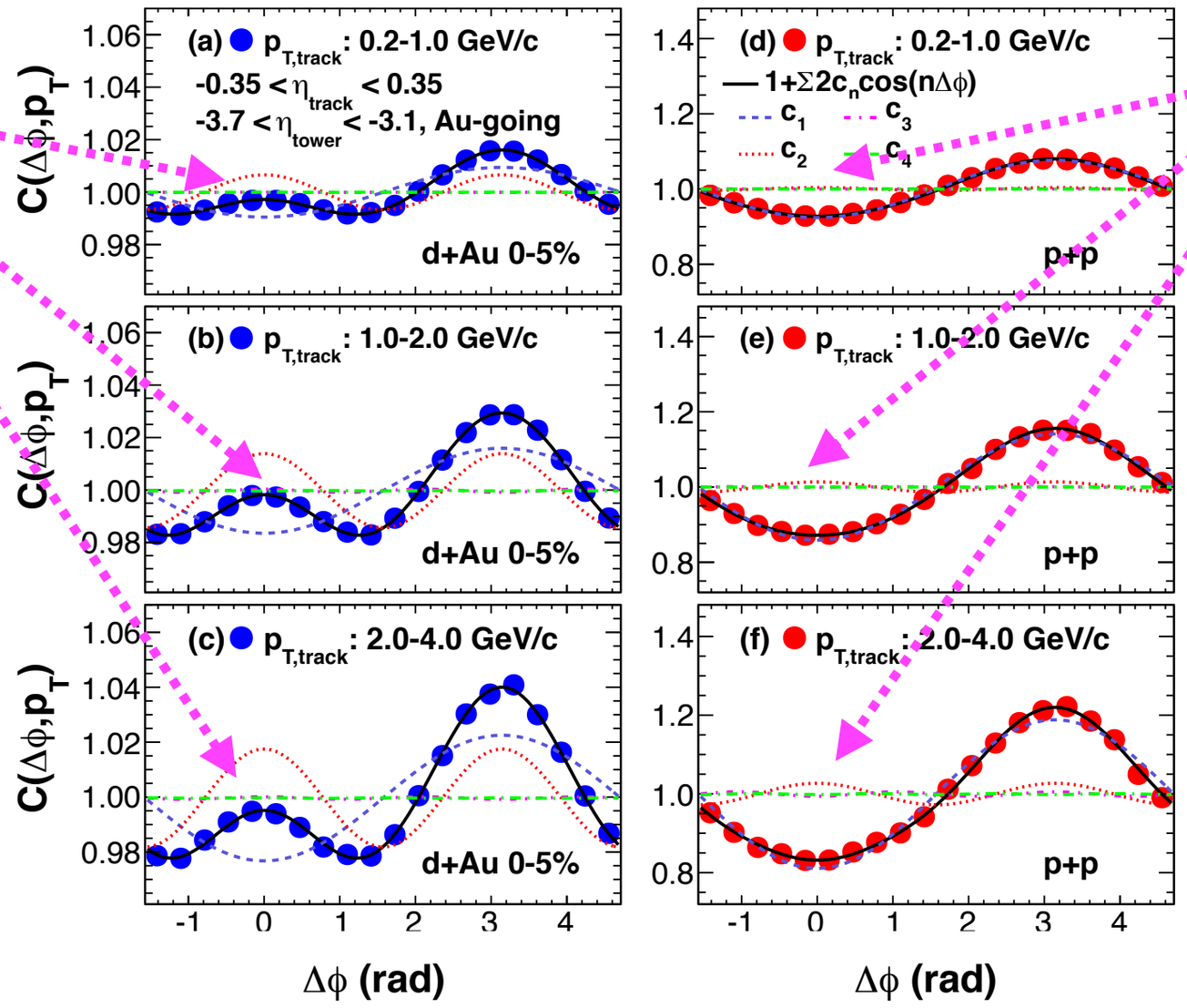
: Correlation Function by Event Mixing

Correlations in p+p and 0-5% d+Au collisions

arXiv:1404.7461

Ridge

No Ridge

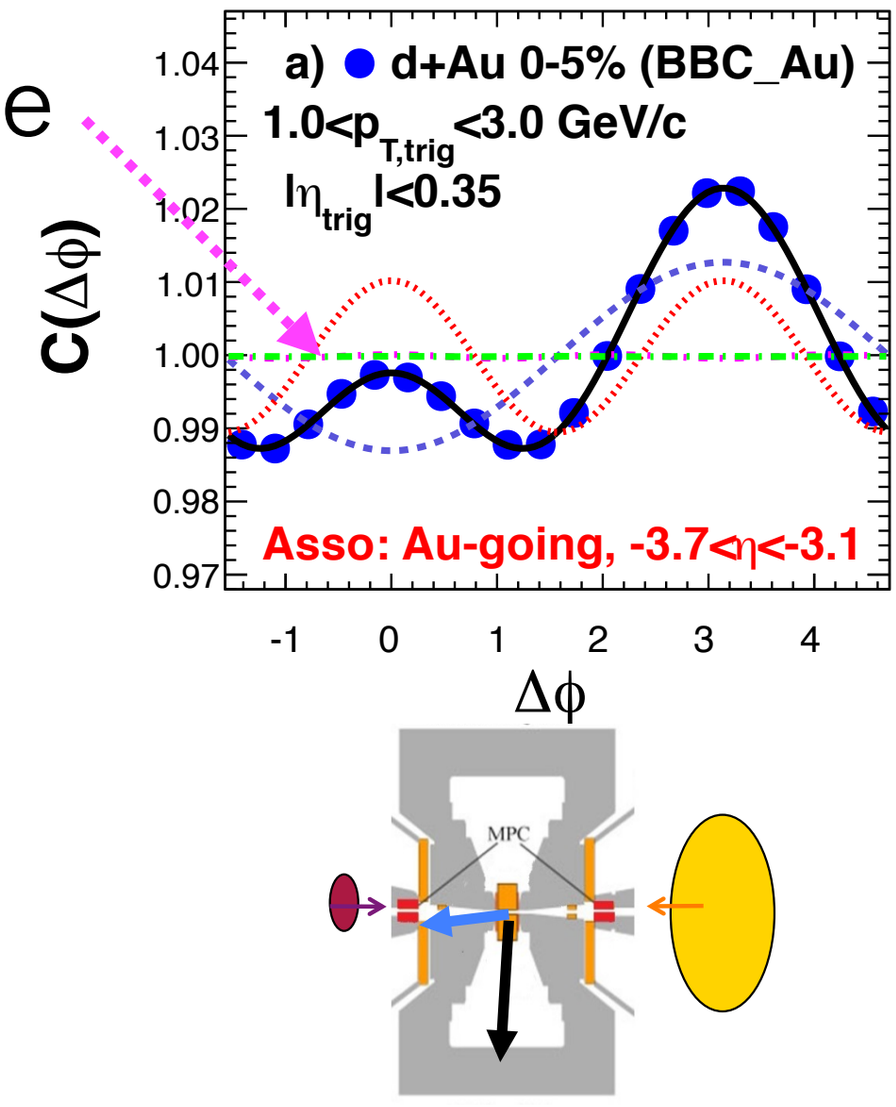


- Ridge is observed in 0-5% d+Au collisions, which is not observed in p+p collisions

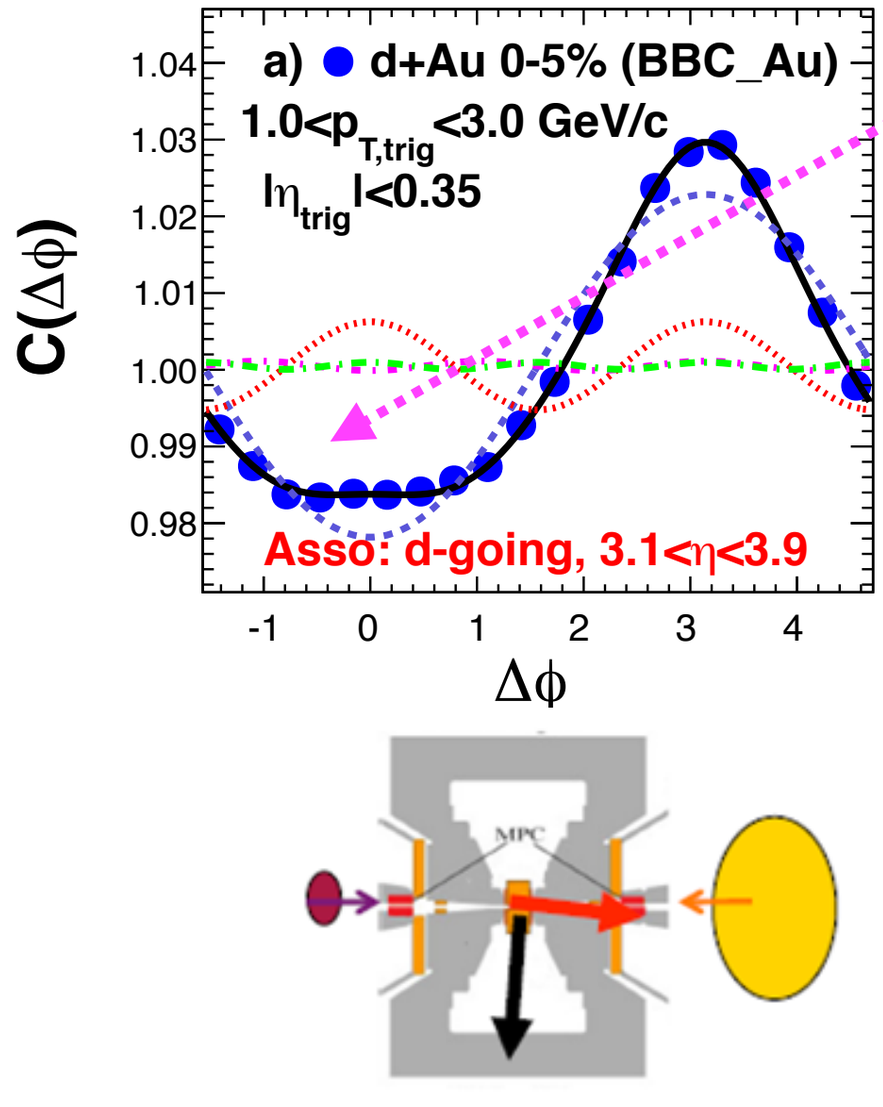
“Au-going” & “d-going”

arXiv:1404.7461

Ridge



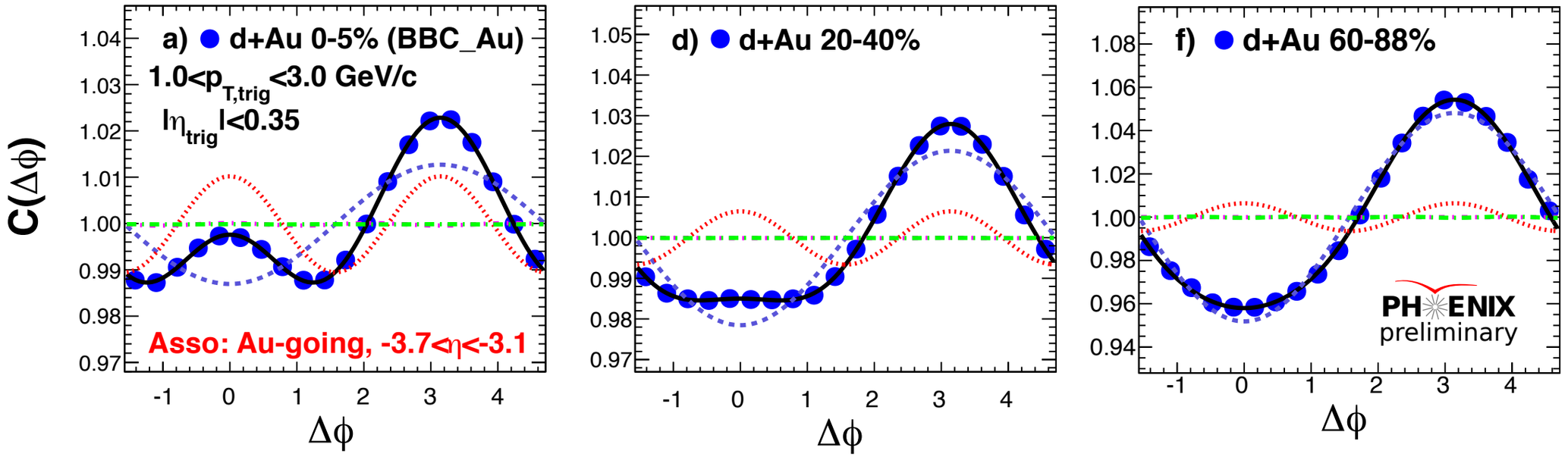
No Ridge



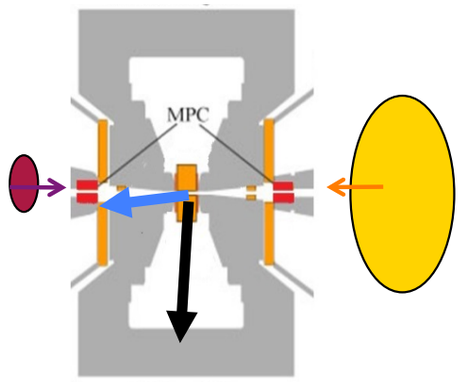
- Ridge is observed in “Au-going” direction
- No ridge is observed in “d-going” direction
- Non-zero cos2Δφ is observed in both directions

Centrality dependence in “Au-going” direction

arXiv:1404.7461

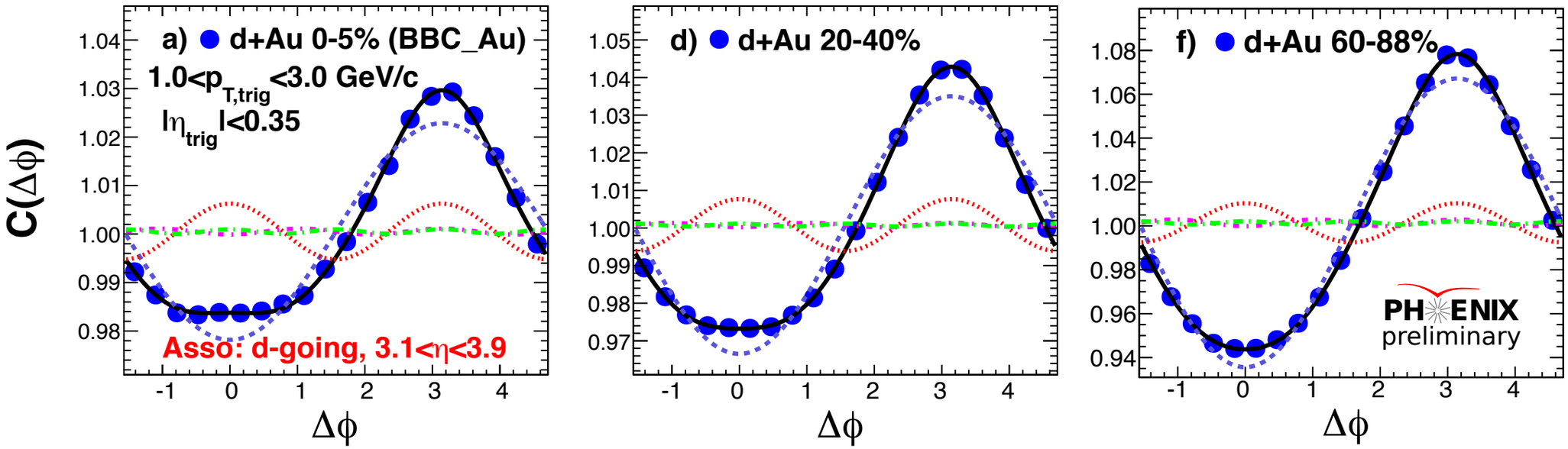


- Ridge is observed only in most-central d+Au collisions
- None-zero cos2Δφ is observed in all centralities

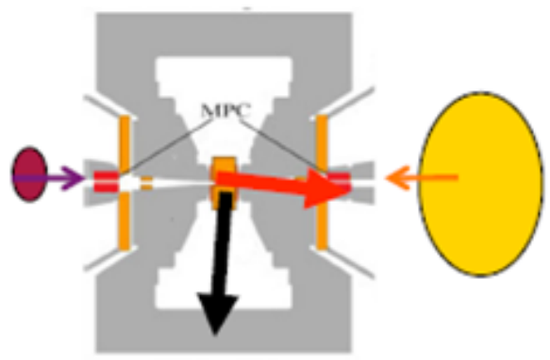


Centrality dependence in “d-going” direction

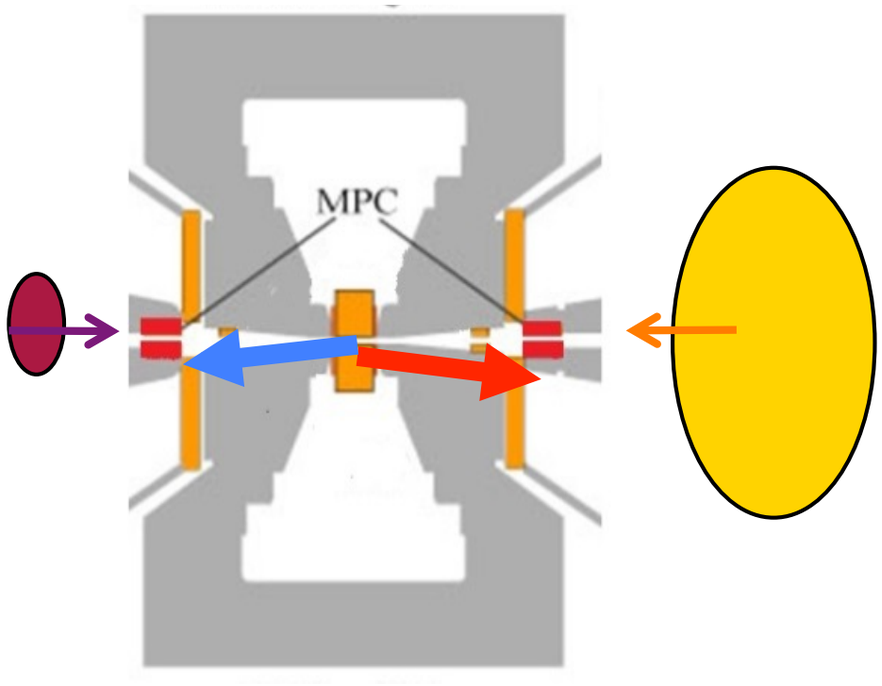
arXiv:1404.7461



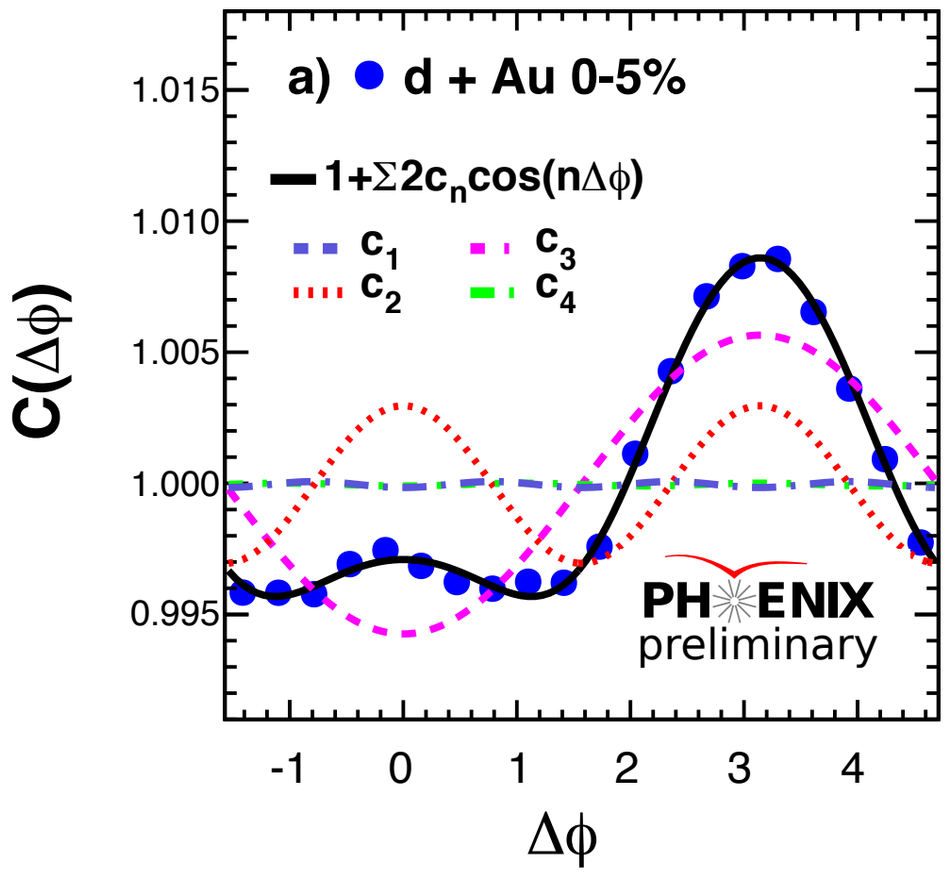
- No ridge is observed even in most-central
- None-zero cos2Δφ is observed in all centralities, cos2Δφ overwhelmed by cos1Δφ
- What if peripheral subtraction?
- Subtraction method appears to be important when discussing correlation shapes



Ridge at $|\Delta\eta|>6$

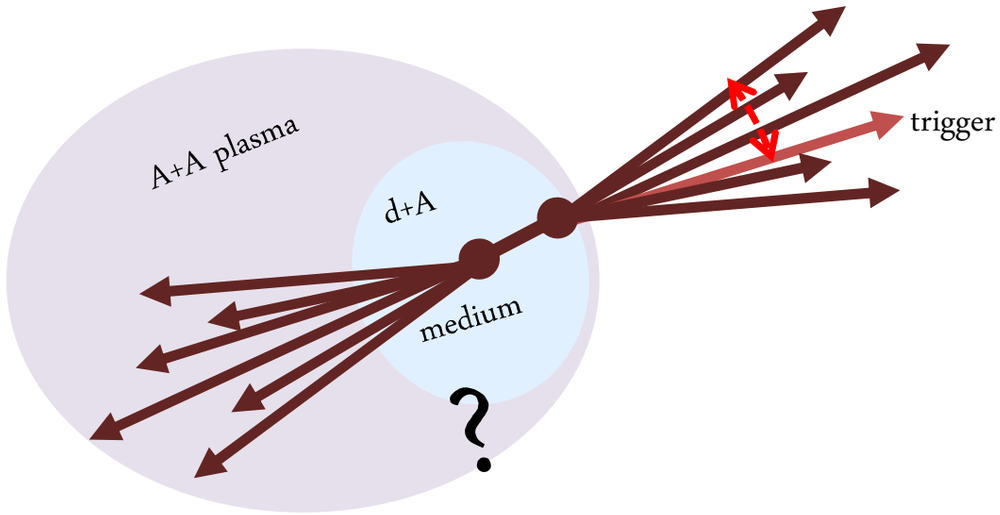


arXiv:1404.7461



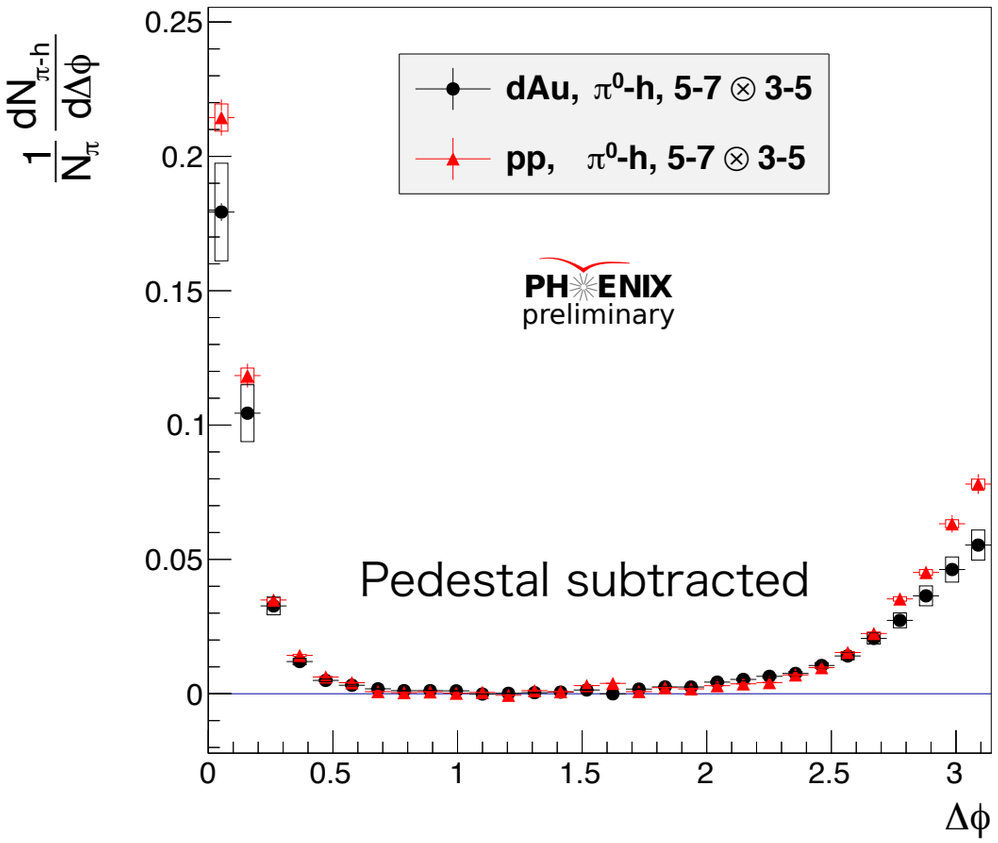
- E_T integrated tower-tower correlations
- Forward-Backward correlations show a ridge across $|\Delta\eta|>6$!!

High p_T π^0 - hadron correlations at $|\Delta\eta|<0.7$



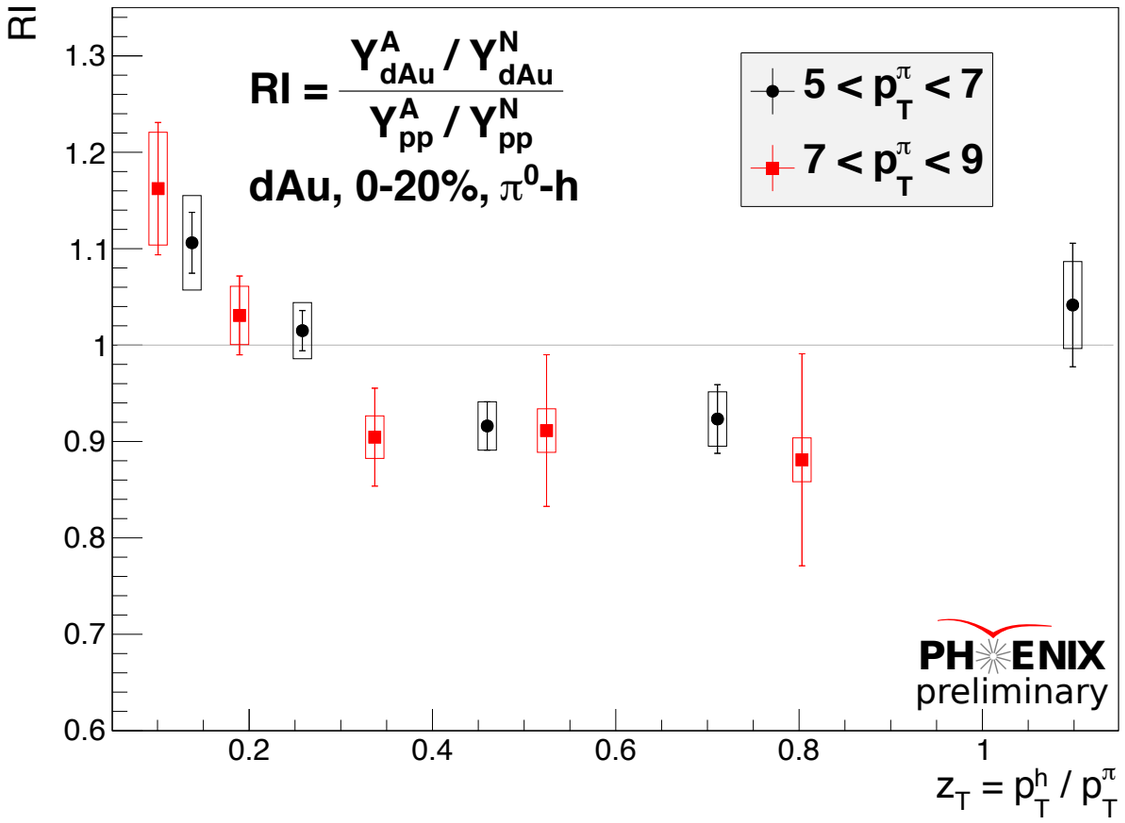
$$RI = \frac{Y^A_{dAu}/Y^N_{dAu}}{Y^A_{pp}/Y^N_{pp}}$$

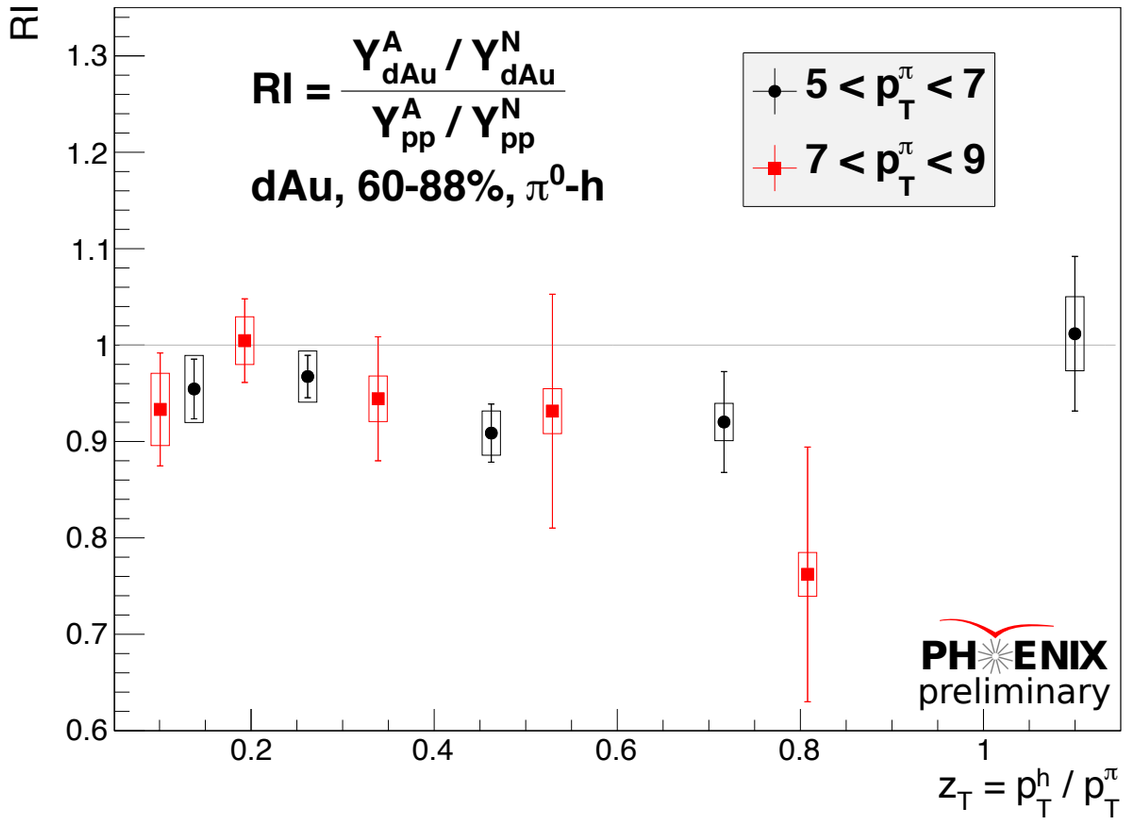
B. Xia & J. Frantz



- Search for modification of correlations by cold (hot) nuclear matter effects using surface biased i.e. un-modified clean near-side
- Systematics on Glauber N_{part}, Efficiencies, & even v_n harmonics are canceled out in RI
- RI should be sensitive to E_{loss} in medium and nuclear k_T but insensitive to nPDF effects such as shadowing etc.

Double ratio "RI" of Away/Near Yield





- Modification is observed!!
- ~10% suppression (1~2σ) at high-p_T in both central and peripheral collisions
- ~10% enhancement (~1σ) at low-p_T in only central collisions

PYTHIA Simulation of "RI"

k_T tuning of PYTHIA

Realistic case :

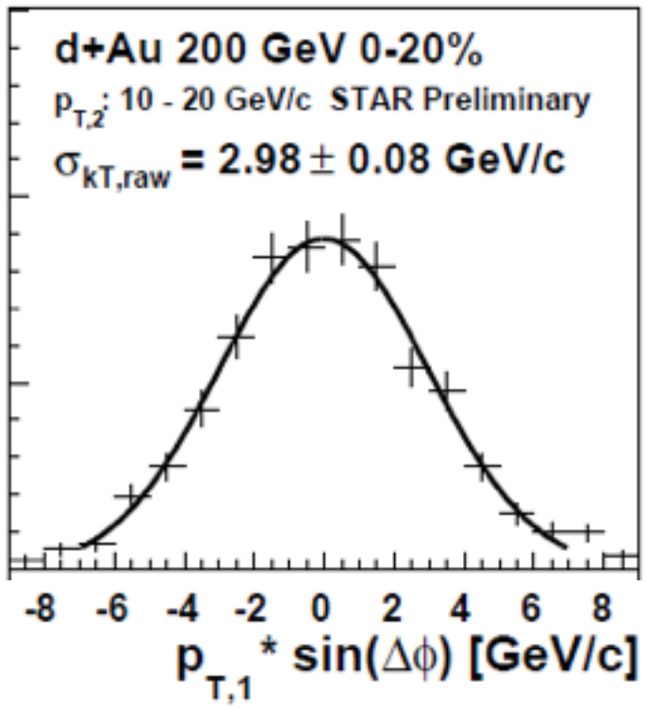
k_T^{dAu}=3.0,

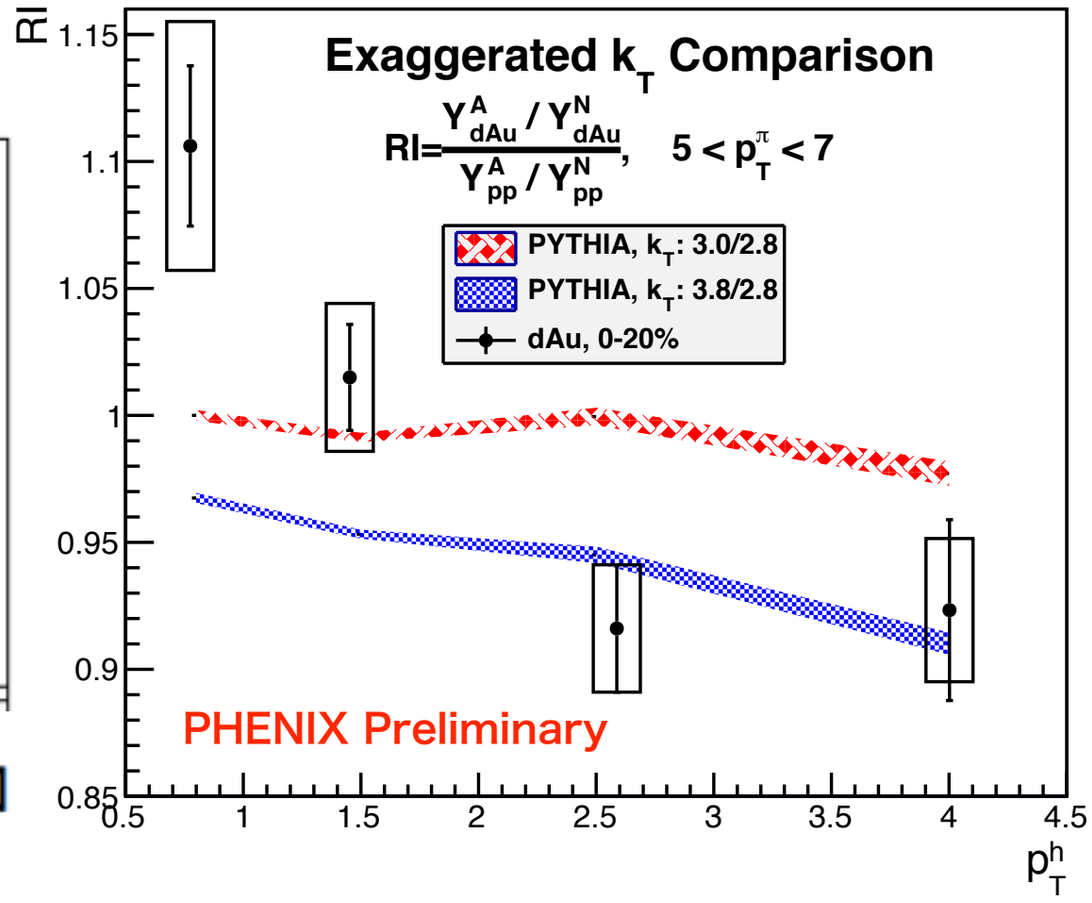
k_T^{pp}=2.8

Exaggerated case :

k_T^{dAu}=3.8,

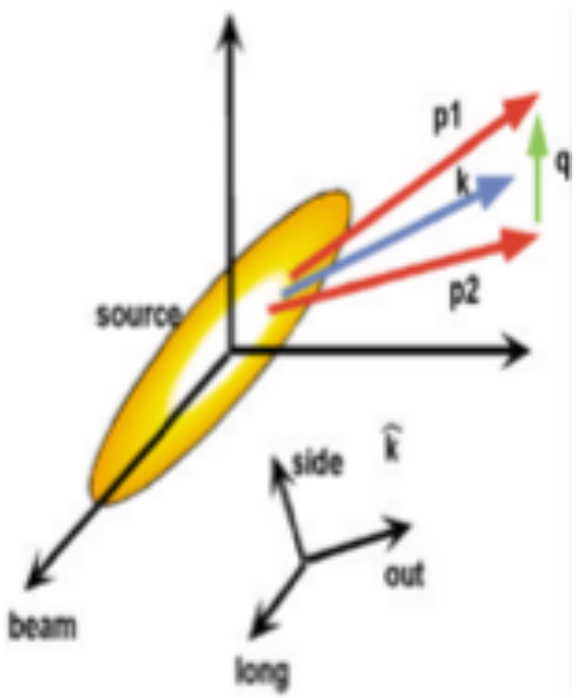
k_T^{pp}=2.8





- To check pure effect of k_T magnitude
- k_T effect does not seem to describe measurements
- More studies on possible "CNM" effects are needed to explain these measurements

HBT Methodology



LCMS Frame

Space momentum correlation

$$C_2 = P(p_1,p_2)/\{P(p_1)P(p_2)\} \sim 1 + |\rho(q)|^2$$
$$= C_2^{core} + C_2^{halo}$$
$$= [\lambda(1+G)F_{coul}] + [1-\lambda]$$

$$G = \exp\left(-R_s^2 q_s^2 - R_o^2 q_o^2 - R_L^2 q_L^2 - 2R_{os}^2 q_o q_s\right)$$

s : (sideward) geometrical size

o : (outward) geometry and time duration

L : (longitudinal) beam direction

os : outward-sideward cross term

F_{coul} : coulomb correction factor

λ : fraction of pairs in the core

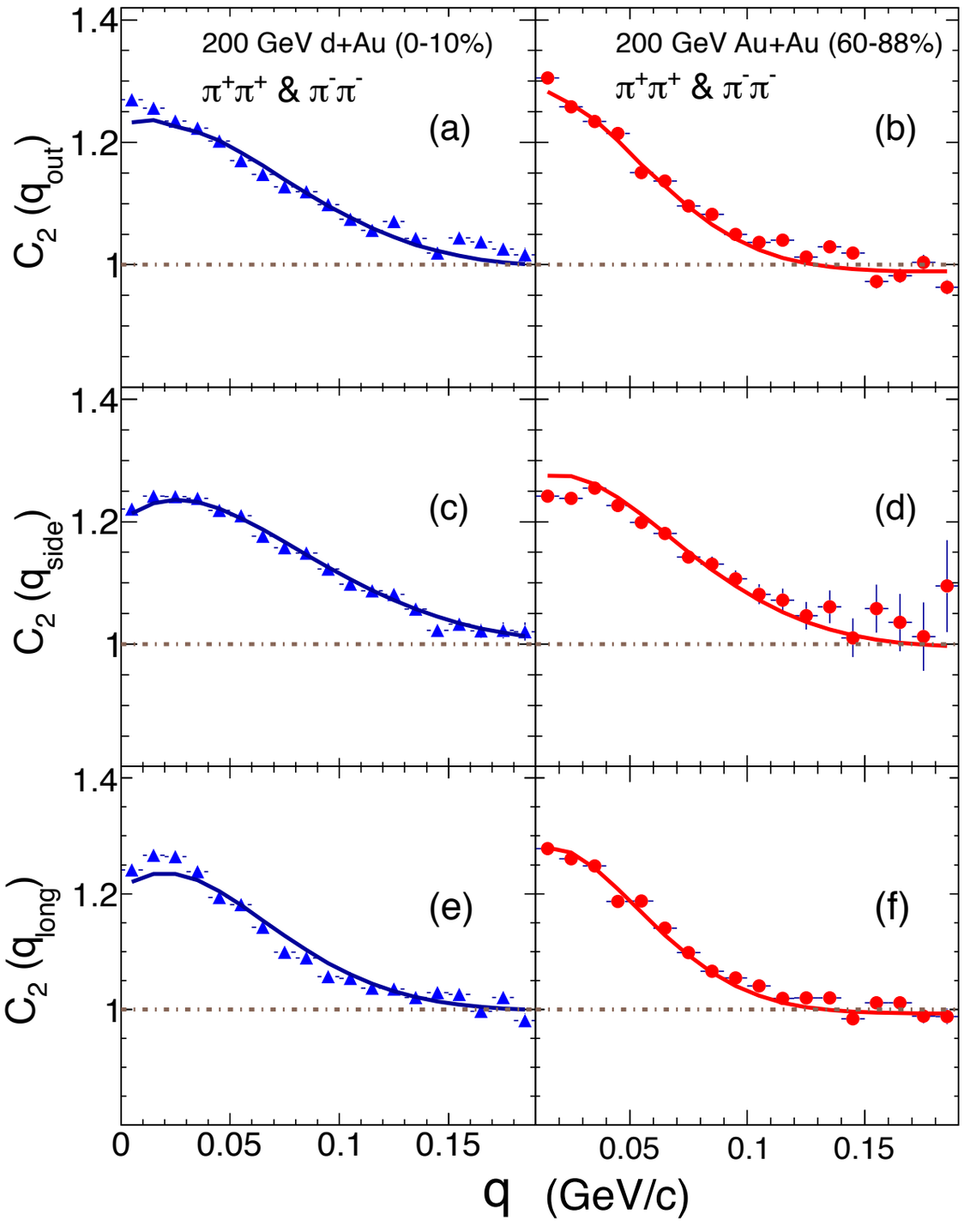
HBT correlation in d+Au & Au+Au

arXiv:1404.5291

- $\pi^{\pm}\pi^{\pm}$ HBT correlations measured at similar N_{part} & k_T

	N_{part}	$\langle k_T \rangle$
Au+Au	*16.7±1.1*	*0.39*
d+Au	*15.7±1.6*	*0.39*

- HBT correlations in d+Au larger than those in Au+Au imply smaller HBT radii



m_T dependence in d+Au & Au+Au

arXiv:1404.5291

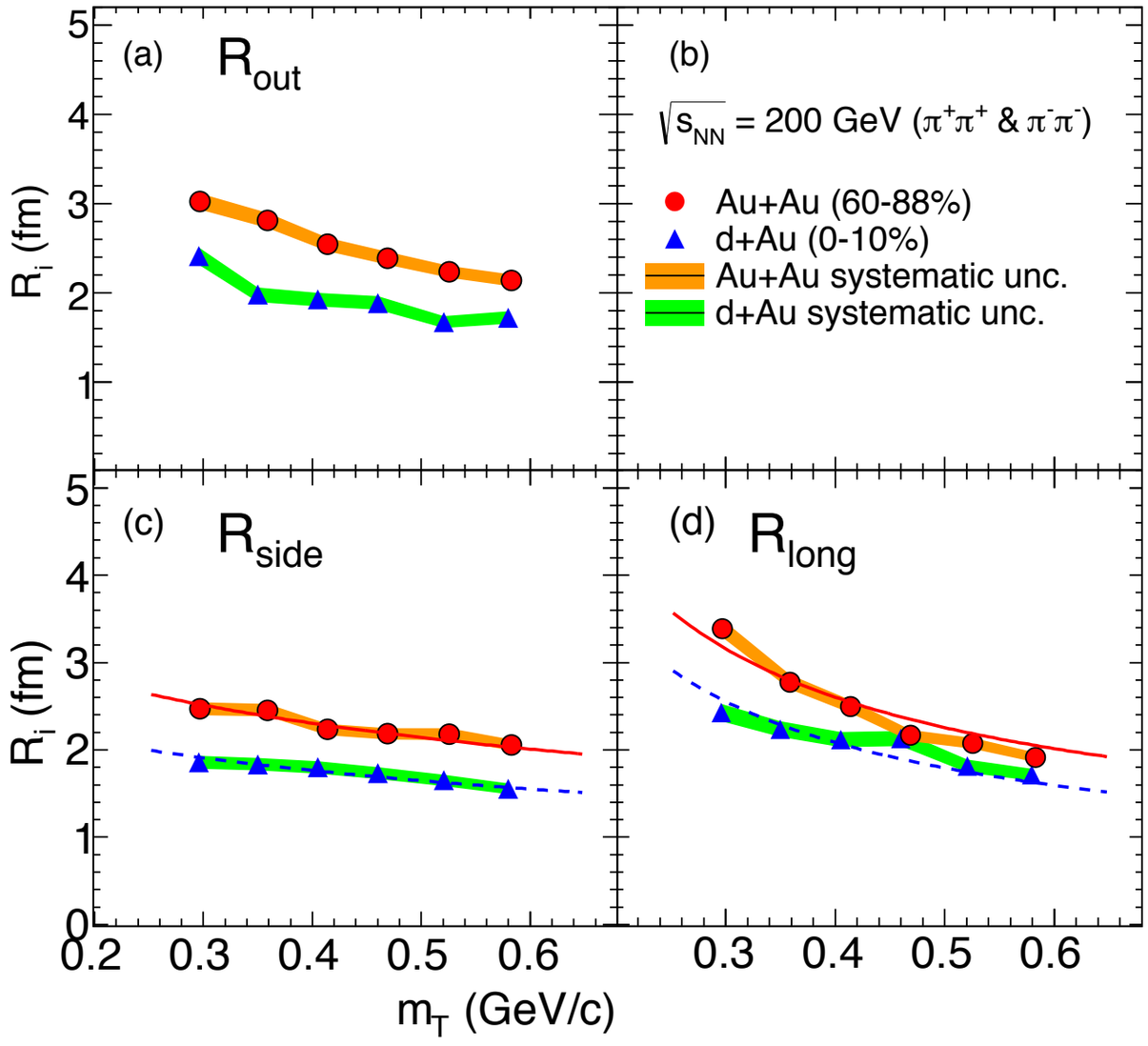
BW fit function

$$R_{\rm side} = R_{\rm geom}/\sqrt{(1+\beta^2(m_T/T))},$$

$$R_{\rm long} = \tau_0\sqrt{(T/m_T)[(K_2(m_T/T))/(K_1(m_T/T))]},$$

TABLE I. Fit parameters

	d+Au	Au+Au
τ_0 (fm/c)	$3.2 \pm 0.04 \pm 0.4$ (syst)	$3.8 \pm 0.04 \pm 0.3$ (syst)
χ^2/ndf	26/5	24/5
$R_{\rm geom}$ (fm)	$2.2 \pm 0.03 \pm 0.2$ (syst)	$2.8 \pm 0.03 \pm 0.2$ (syst)
χ^2/ndf	6/5	4/5



- Qualitatively similar m_T dependence in d+Au & Au+Au
  - Similar expansion dynamics?
- Blast-wave fitting defined by expansion velocity & freeze-out temperature works well for R_{side}

Emission duration & freeze-out volume

R_{out}/R_{side}~1

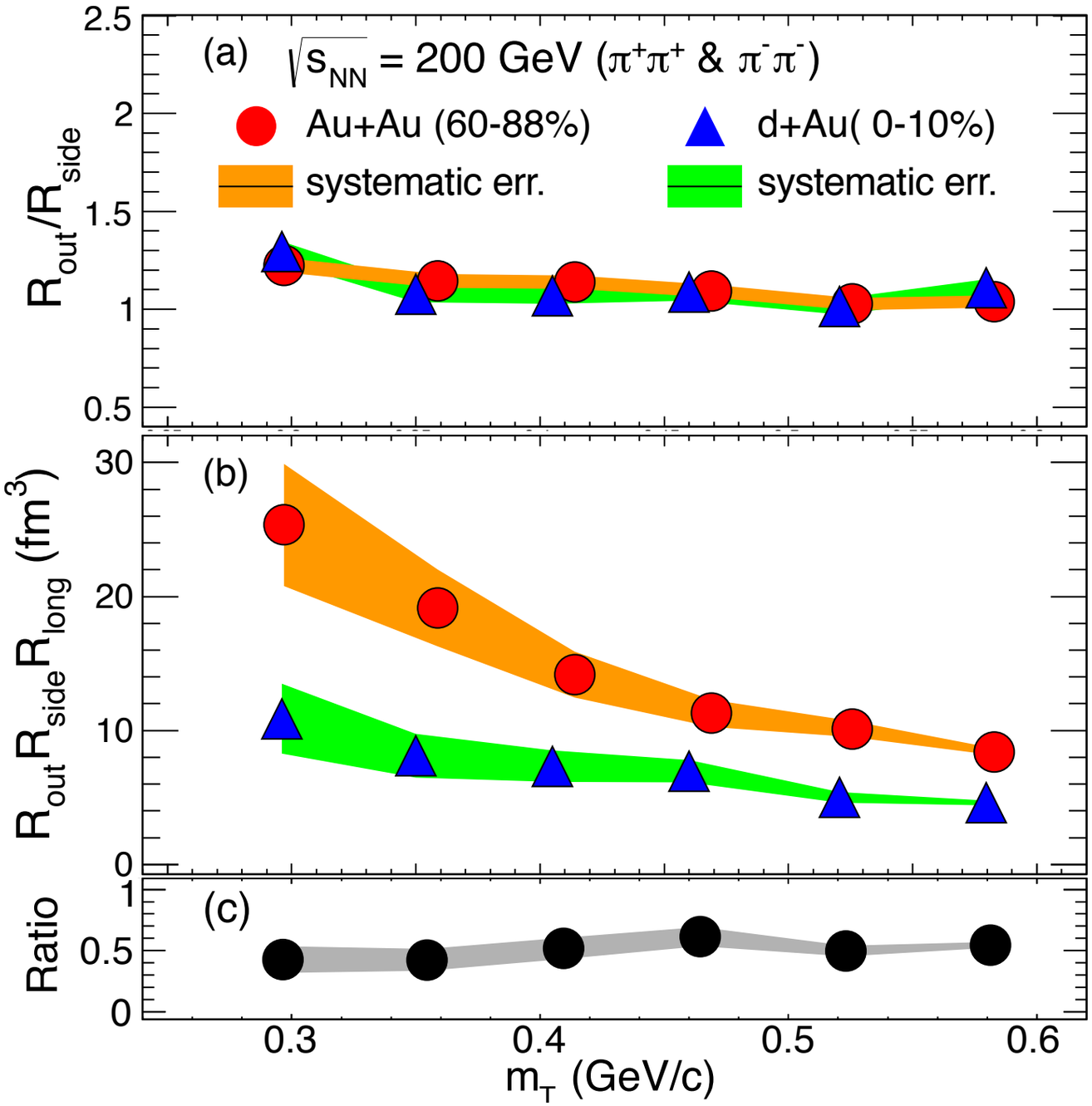
Short emission duration

Freeze-out Volume

v(dAu)<v(AuAu)

Similar m_T dependence

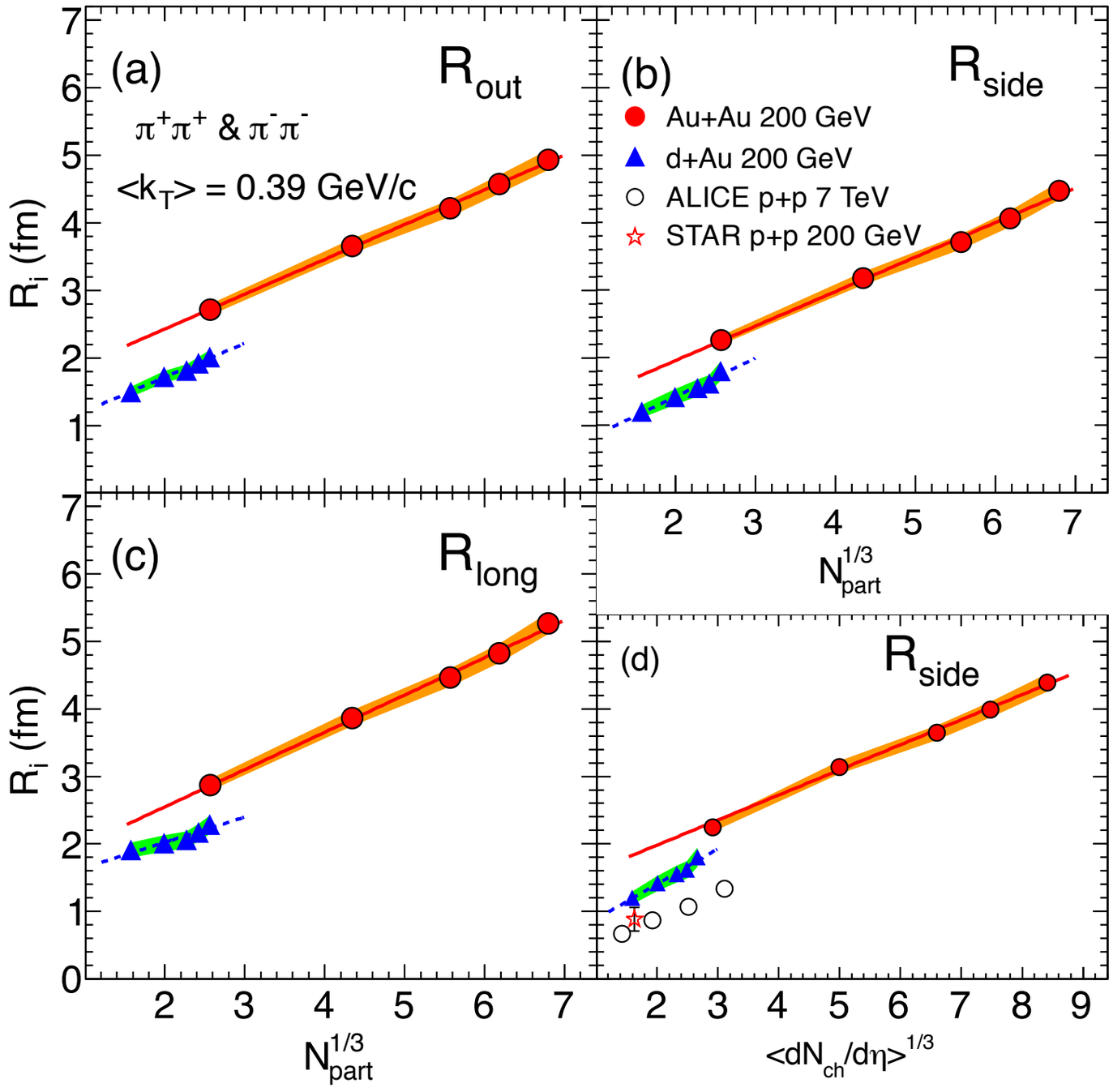
arXiv:1404.5291



HBT radii as a function of $N^{1/3}_{part}$

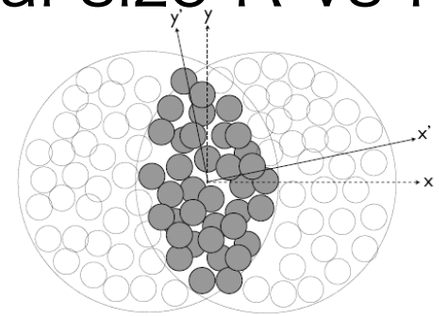
- d+Au & Au+Au HBT radii do not scale together but show a similar linearity
- p+p at 7 TeV also show a linearity with respect to $\langle dN_{ch}/\eta \rangle^{1/3}$

arXiv:1404.5291



Initial R dependence in p+A & A+A collisions

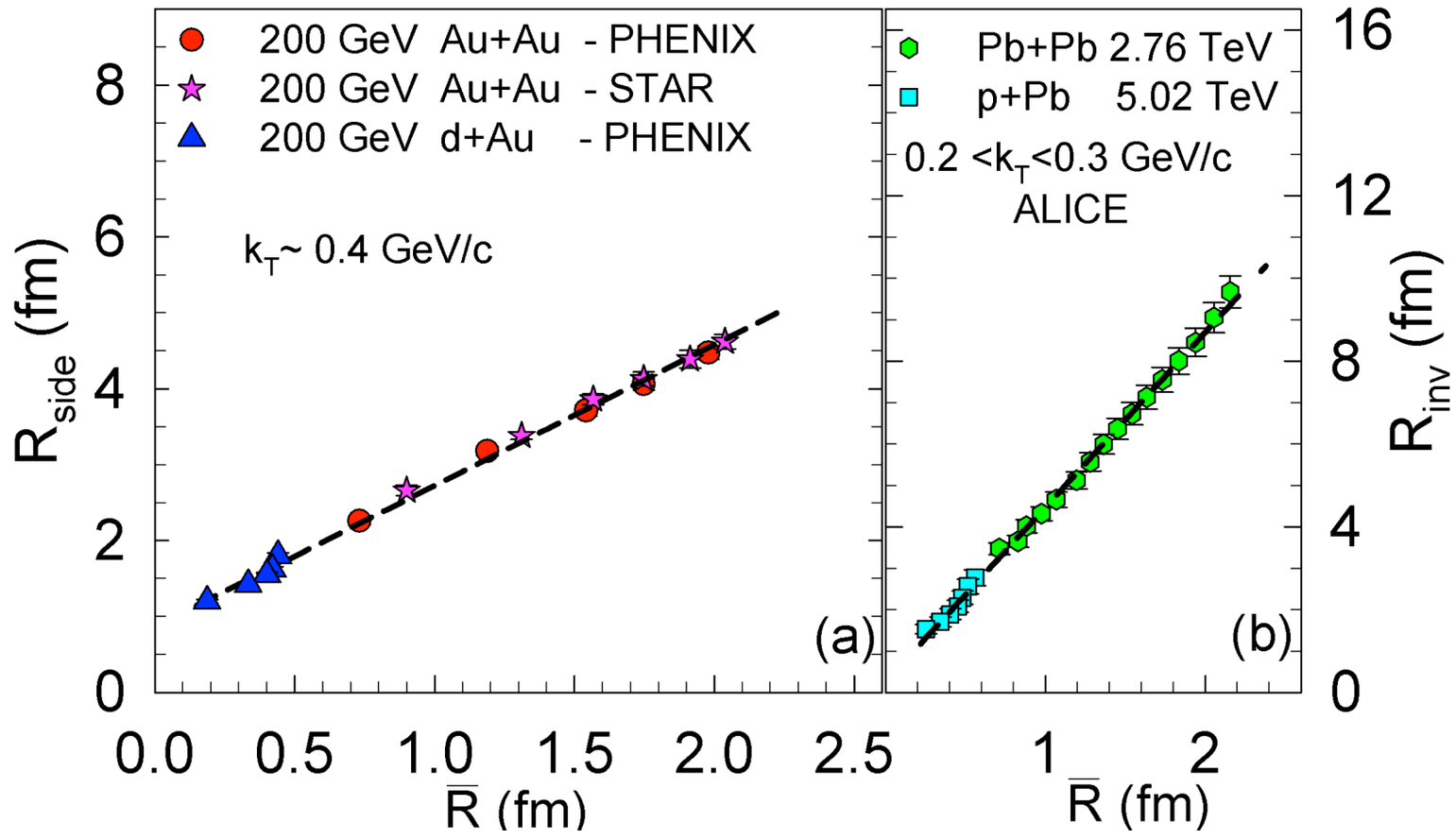
Glauber MC to obtain initial size R vs N_{part}



$$\frac{1}{\bar{R}} = \sqrt{\left(\frac{1}{\sigma_x^2} + \frac{1}{\sigma_y^2}\right)}$$

σ_x σ_y : RMS width of density distribution

arXiv:1404.5291

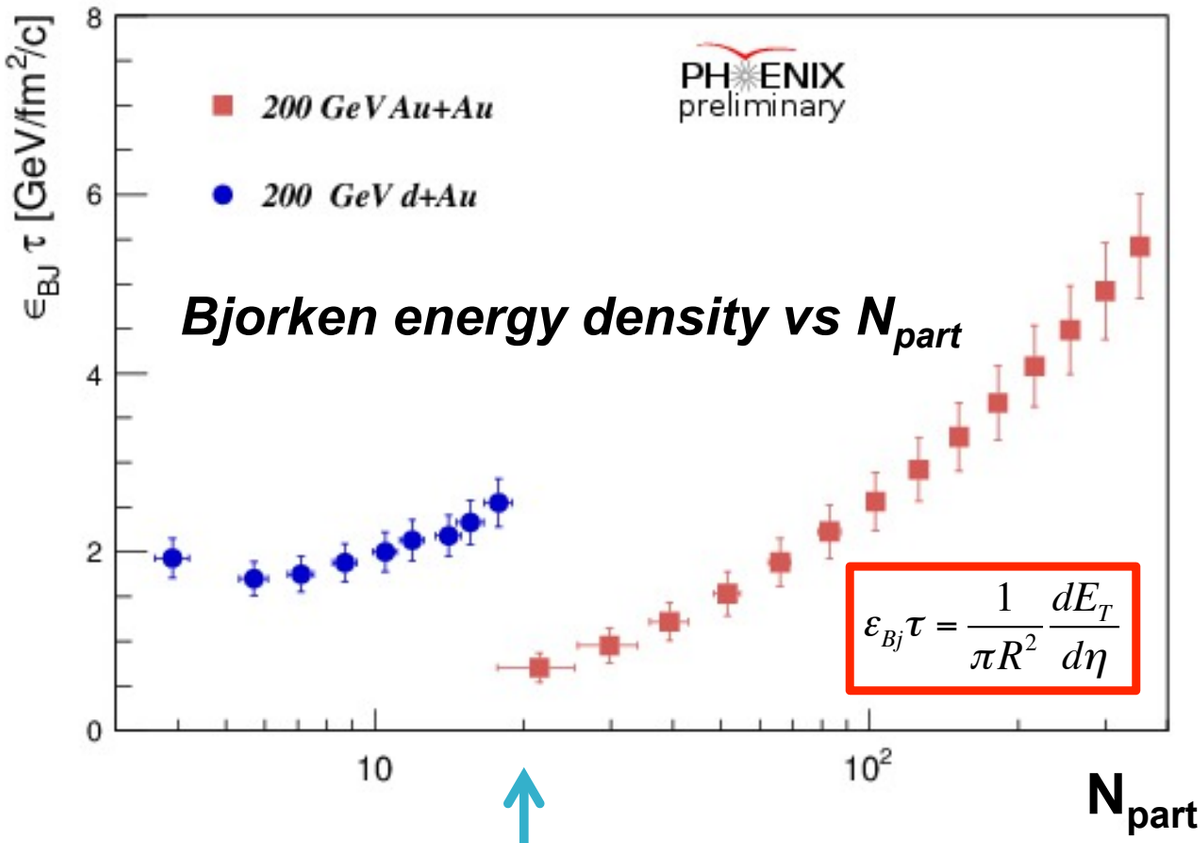


- Linearity and good scaling are seen in p+A and A+A collisions
- Implies possible radial expansion in p+A systems

Summary

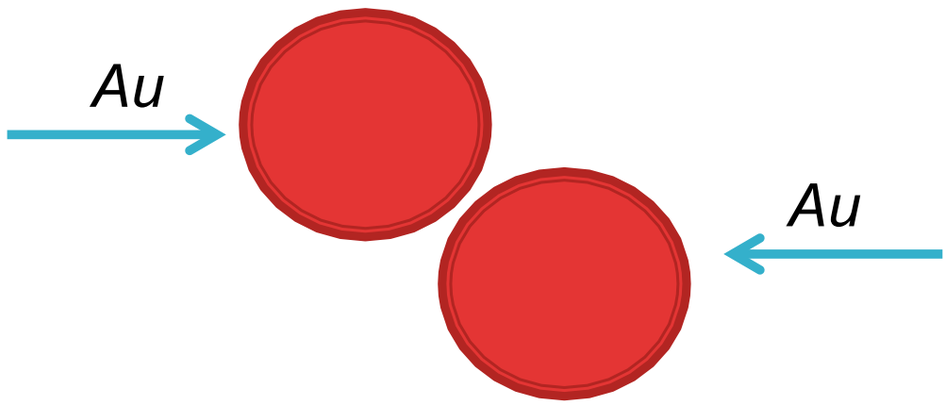
- Ridge is observed in most-central d+Au 200GeV collisions even across $|\Delta\eta|>6$, except “d-going” direction
- Modification of high p_T π^0- hadron correlations is observed. What kind of CNM(HNM) effects are needed to explain observation?
- Similar m_T dependence of HBT radii is observed in d +Au & Au+Au collisions, which implies similar expansion dynamics
- HBT radii of various collisions systems scale with initial participant size “R”. It suggest possible radial expansion in p+A collisions like A+A collisions?

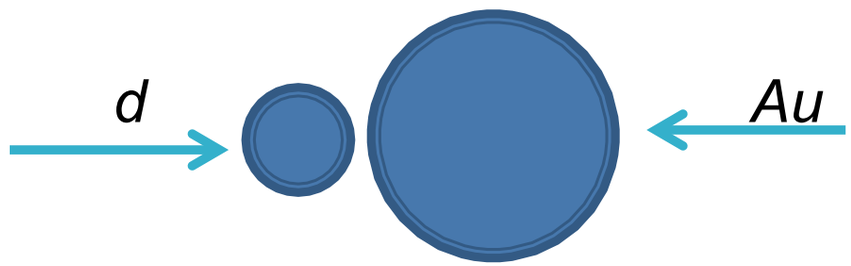
Auxiliary Slides



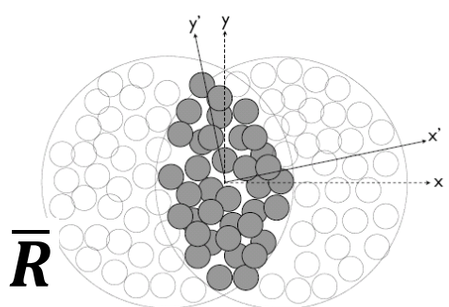
	N_{part}	$dE_T/d\eta$	$\bar{R}$	ε
Au+Au	16.7±1.1	19±.1.5	0.71	0.5
d+Au	15.7±1.6	22±1.5	0.44	2.5

Initial Parameters for peripheral Au+Au and central d+Au





Glauber Model initial size



$\bar{R}$

$$\frac{1}{\bar{R}} = \sqrt{\left(\frac{1}{\sigma_x^2} + \frac{1}{\sigma_y^2}\right)}$$

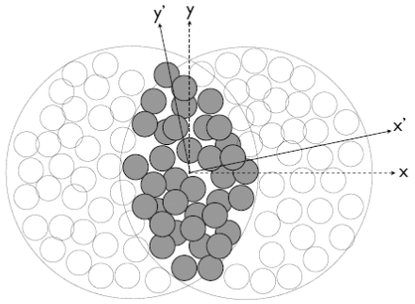
σ_x & σ_y → RMS widths of density distribution

Slide from N.Ajit QM'14

Hydro models associate a larger expansion time with a larger initial size $\bar{R}$ Does it make a good scaling parameter ?

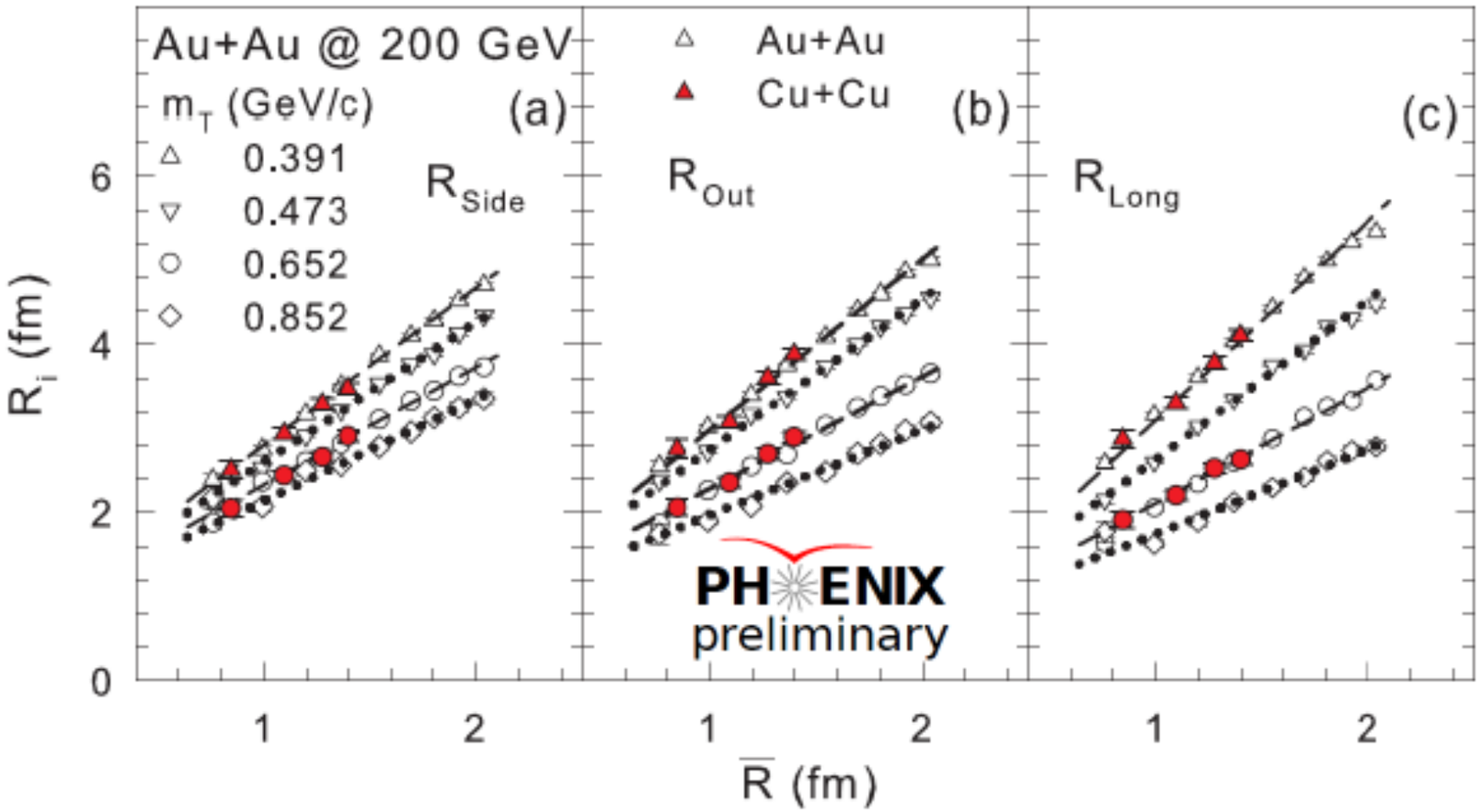
Use Glauber model to get

$N_{part}^{1/3}$ ***vs*** ***initial size*** $\bar{R}$



$$\frac{1}{\bar{R}} = \sqrt{\left(\frac{1}{\sigma_x^2} + \frac{1}{\sigma_y^2}\right)}$$

σ_x & σ_y → *RMS widths of density distribution*

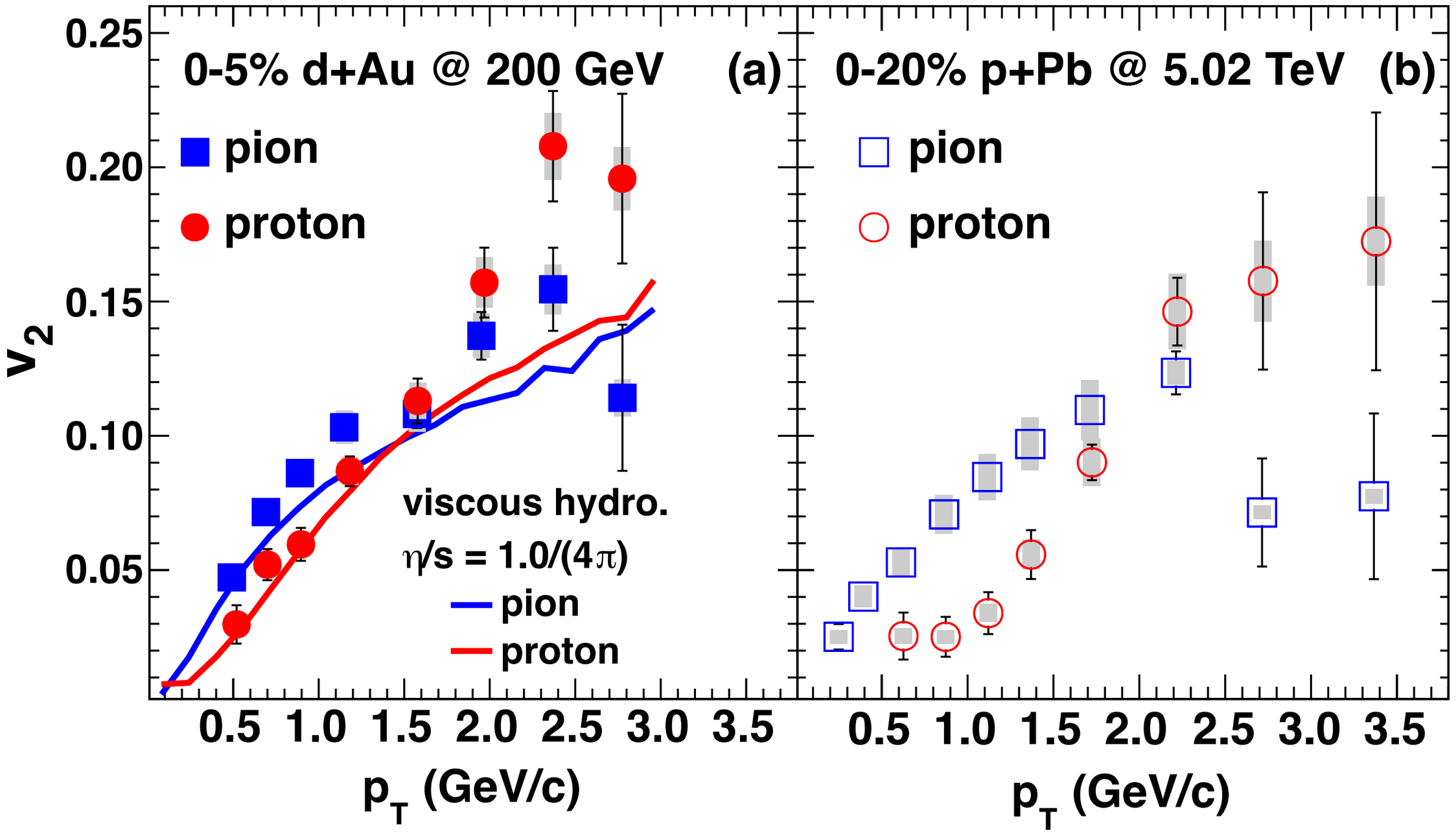


Pion HBT radii scale with $\bar{R}$

Linear dependence of transverse expansion on initial geometry

Slide from N.Ajit QM'14

Mass-ordering of v_2 in d+Au



- Mass-ordering at low-p_T is observed