Recent results on collective effects in small systems from PHENIX at RHIC

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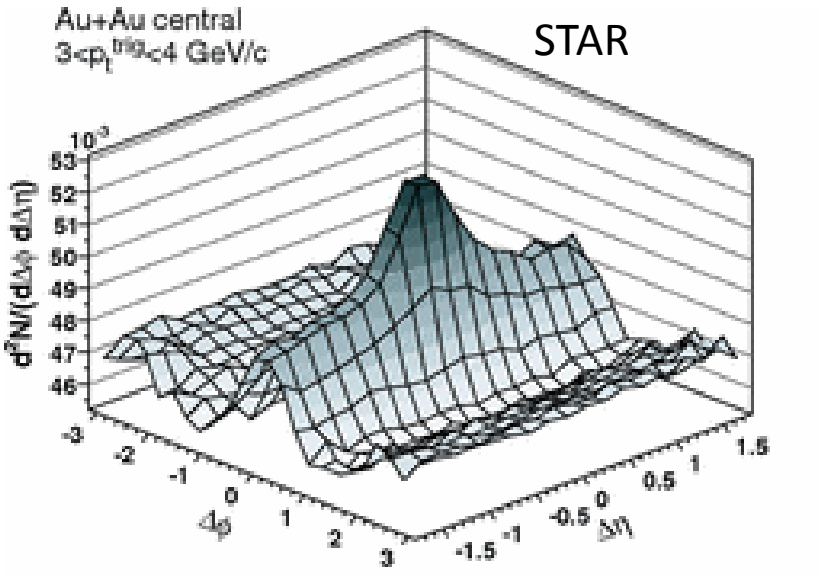
Columbia University

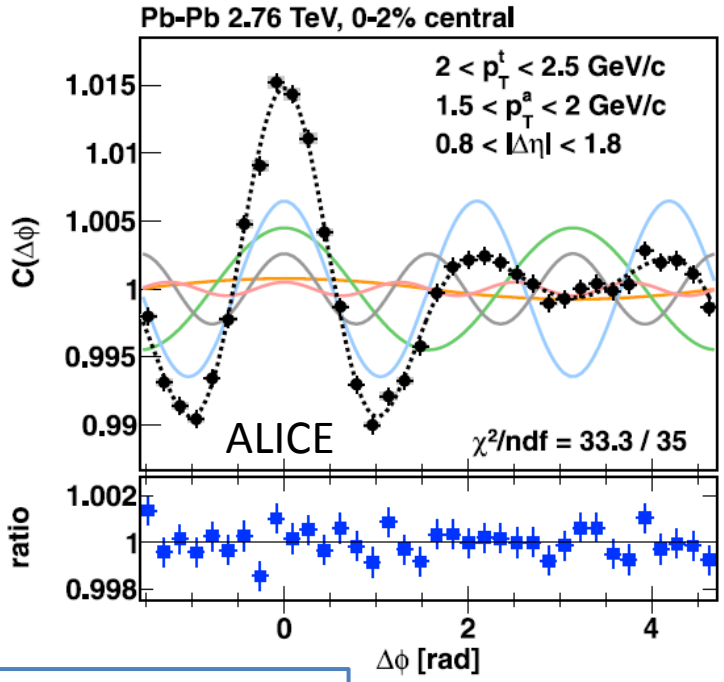
ICHEP -- Aug 4, 2016 -- Chicago, IL

Collectivity in Heavy Ion Collisions

STAR & PHOBOS found a ridge in h-h in Au+Au

Decompose C($\Delta\phi$) into Fourier components, c_n





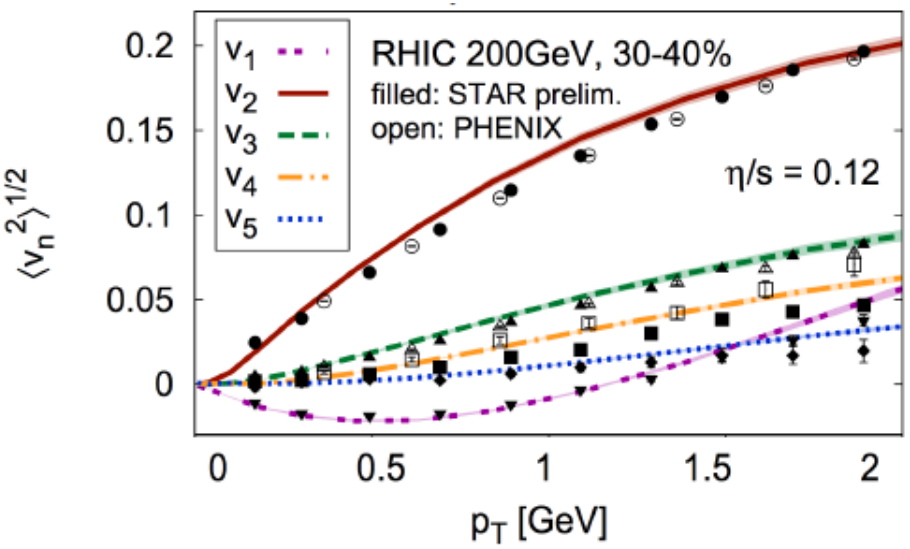
$$c_n(p_{T1}, p_{T2}) = v_n(p_{T1})v_n(p_{T2})$$

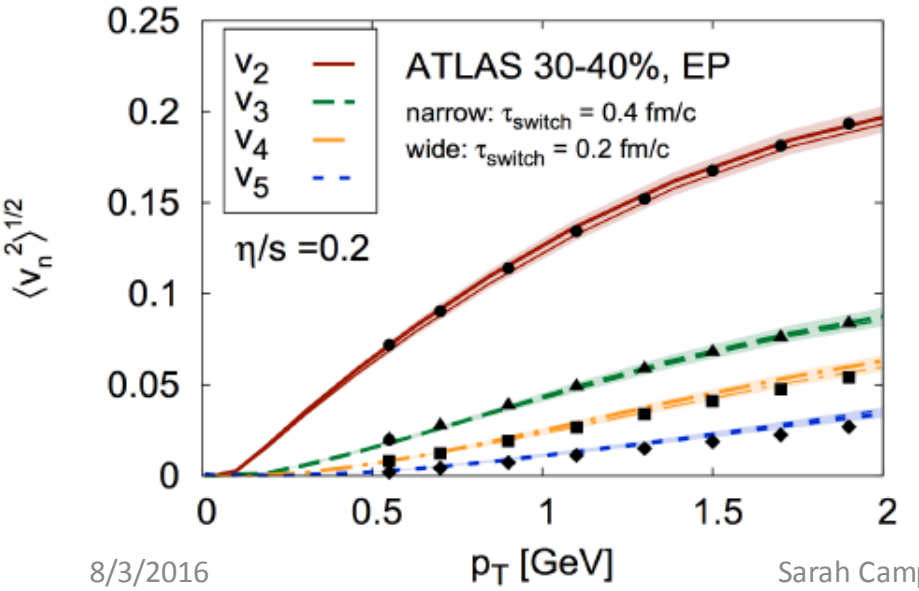
STAR PRC 80 (2009) 064912
PHOBOS PRL 104 (2010) 062301

Luzum PLB 696 (2011) 499
ALICE PLB 708 (2012) 249

A+A v_n at LHC and RHIC

Gale et al. PRL 110 (2013) 012302

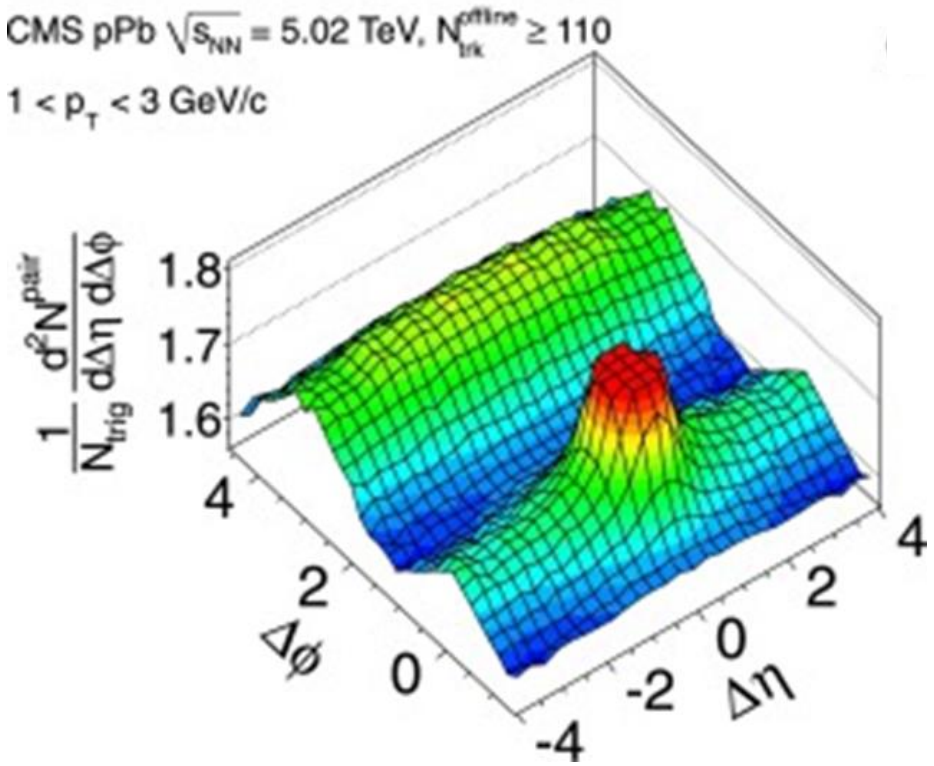


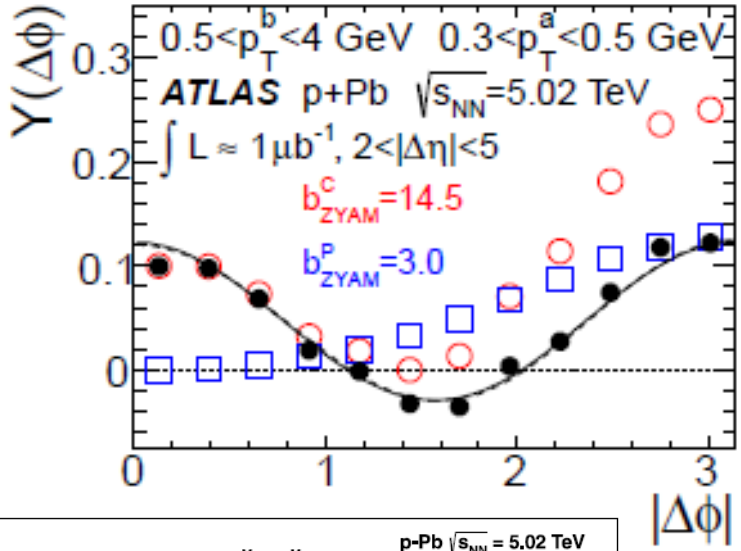


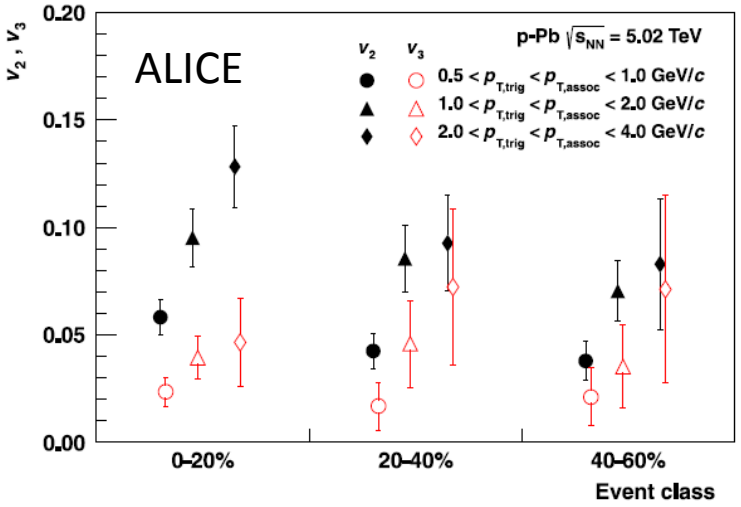
- Similar anisotropies at LHC and RHIC
- v_n well described by the same hydrodynamic model
- Similar underlying physics processes

Collectivity in p+Pb at LHC

CMS, ATLAS and ALICE see a ridge in 5 TeV p+Pb

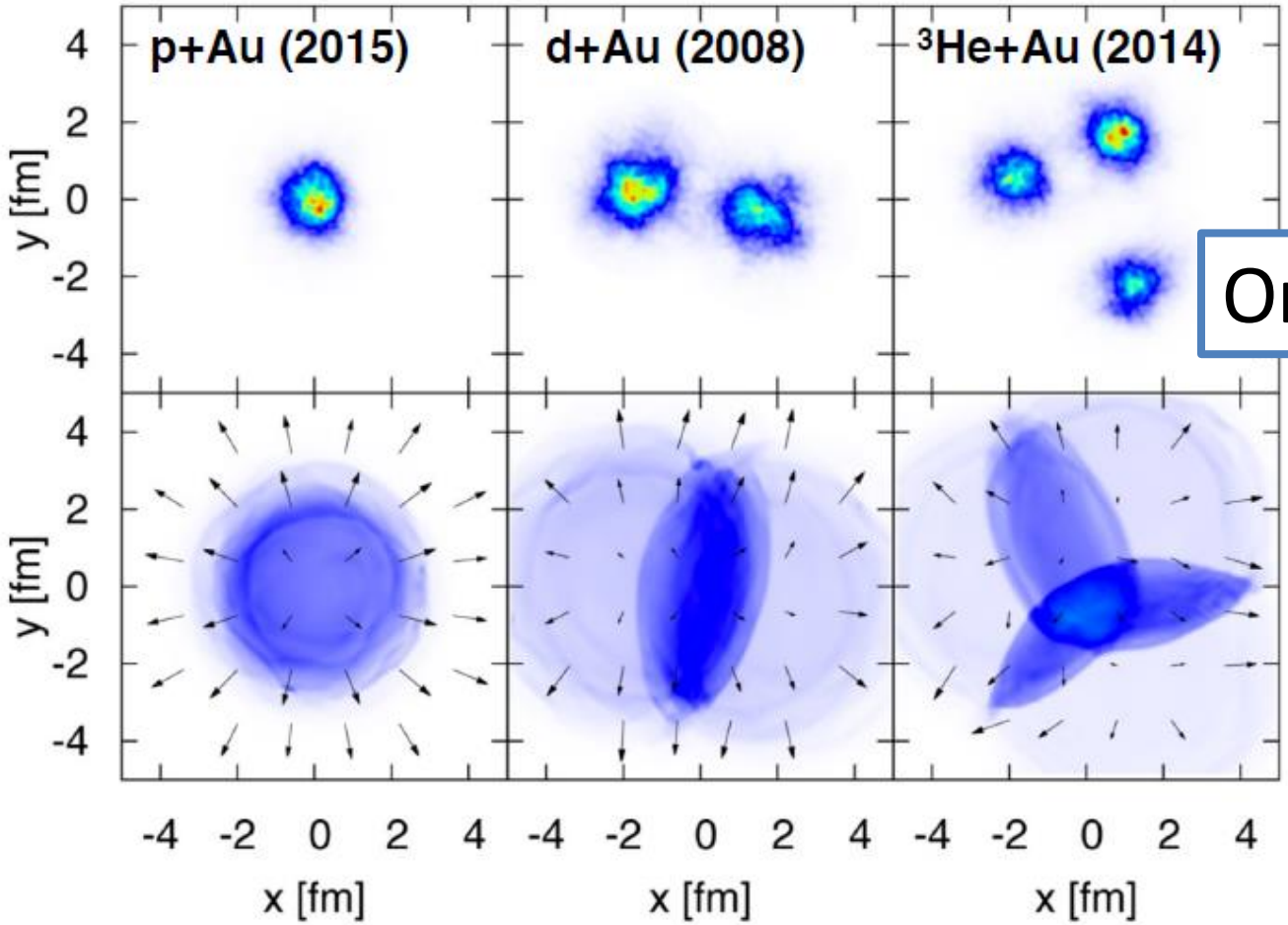






CMS PLB 718 (2013) 795
ATLAS PRL 110 (2013) 182302
ALICE PLB 719 (2013) 29

Small Systems → Initial State Geometry



Only at RHIC!

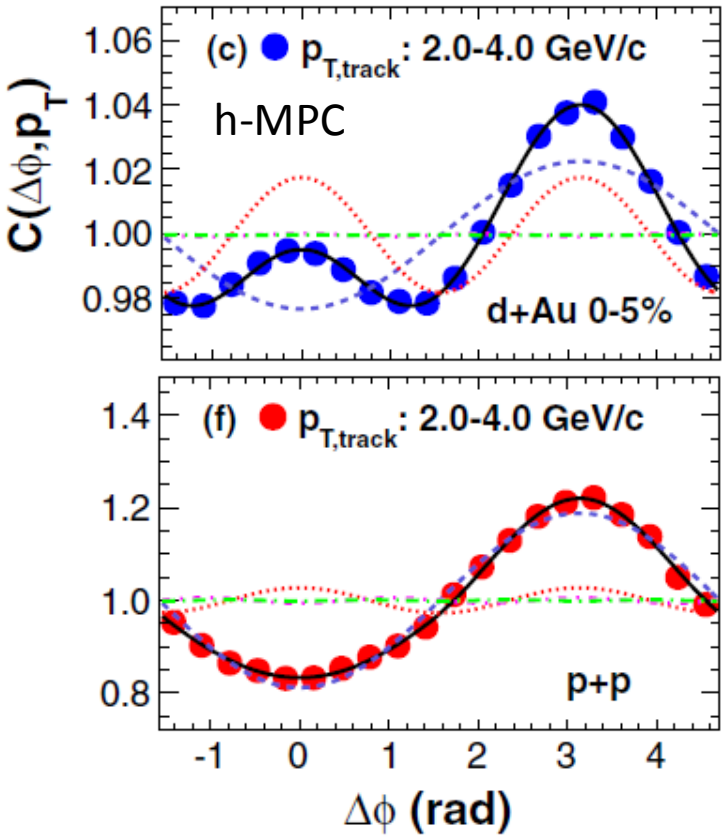
This talk: 200 GeV d+Au, ^{3}He+Au and p+Au at PHENIX

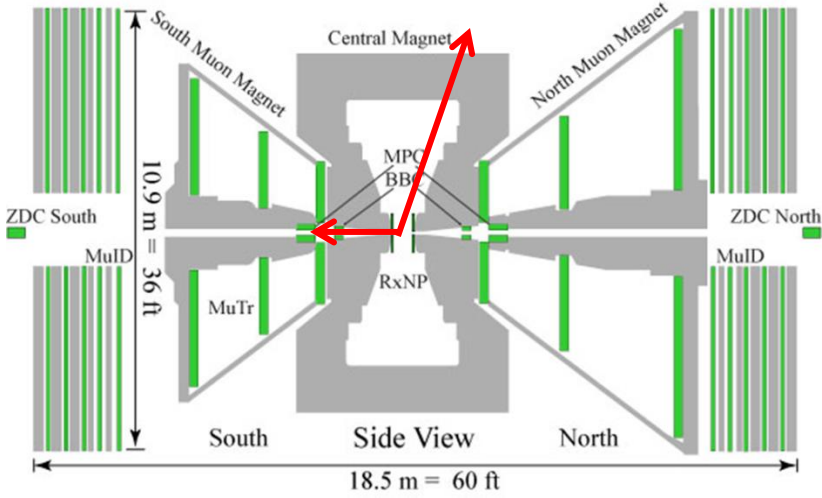
Image from B. Schenke

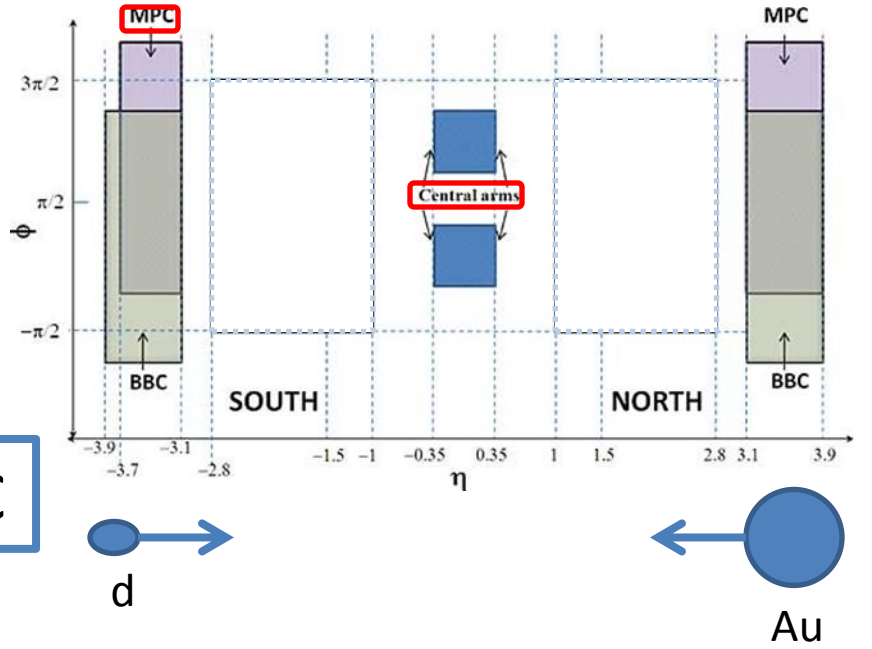
d+Au

d+Au: Long-range Correlation Measurement

$|\Delta\eta| \in [2.75, 4.05]$



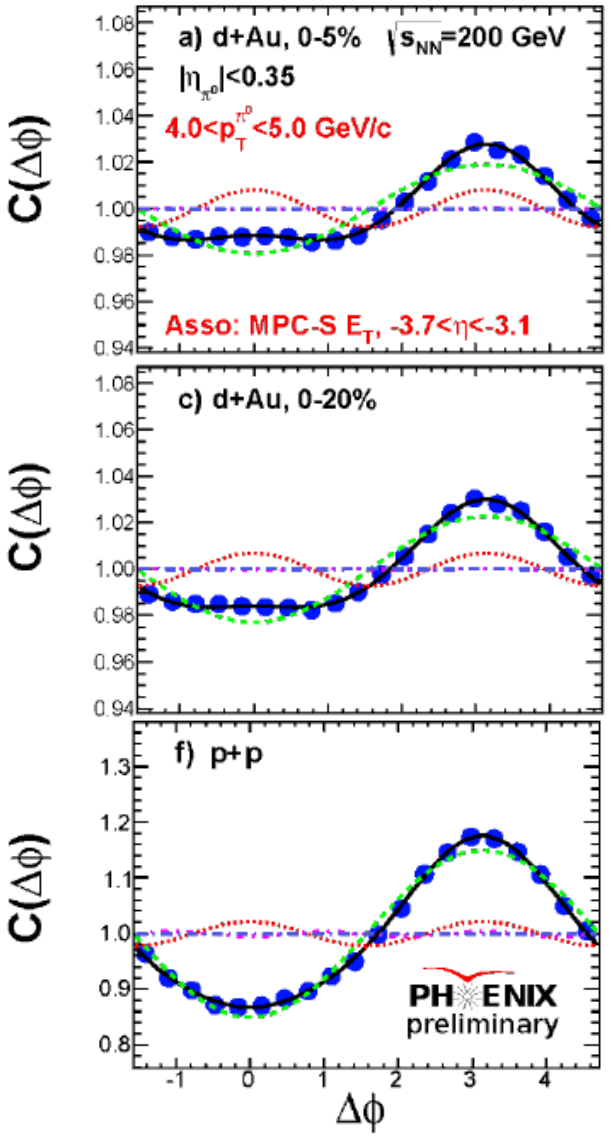


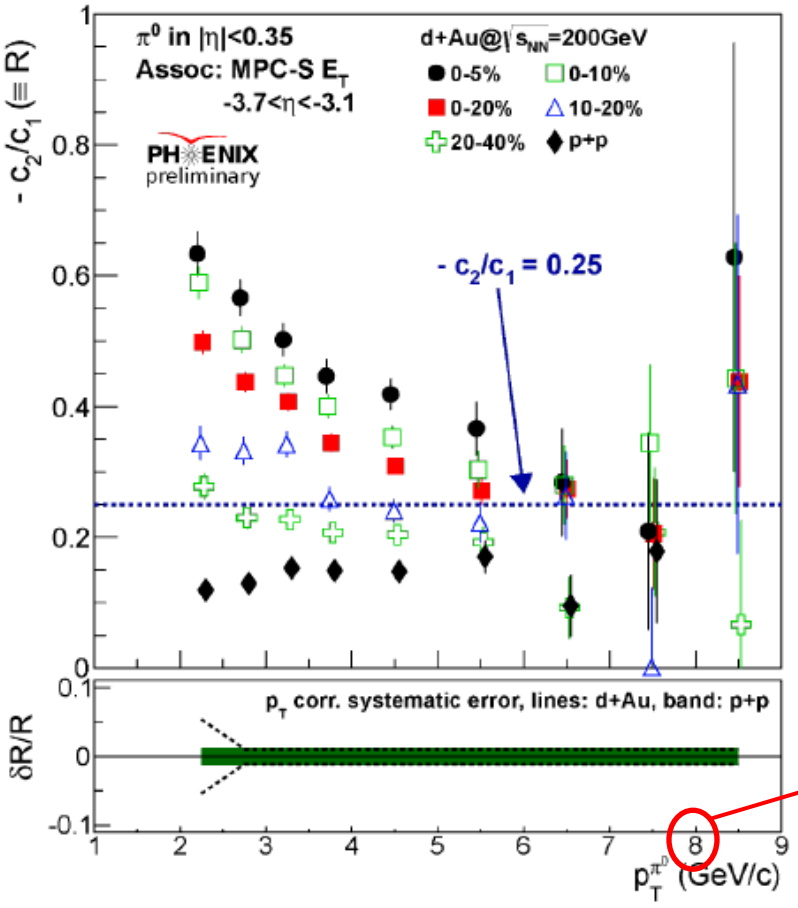


Ridge in d+Au confirmed at RHIC

PRL 114 192301 (2015)

Reach higher p_T with π^0-MPC

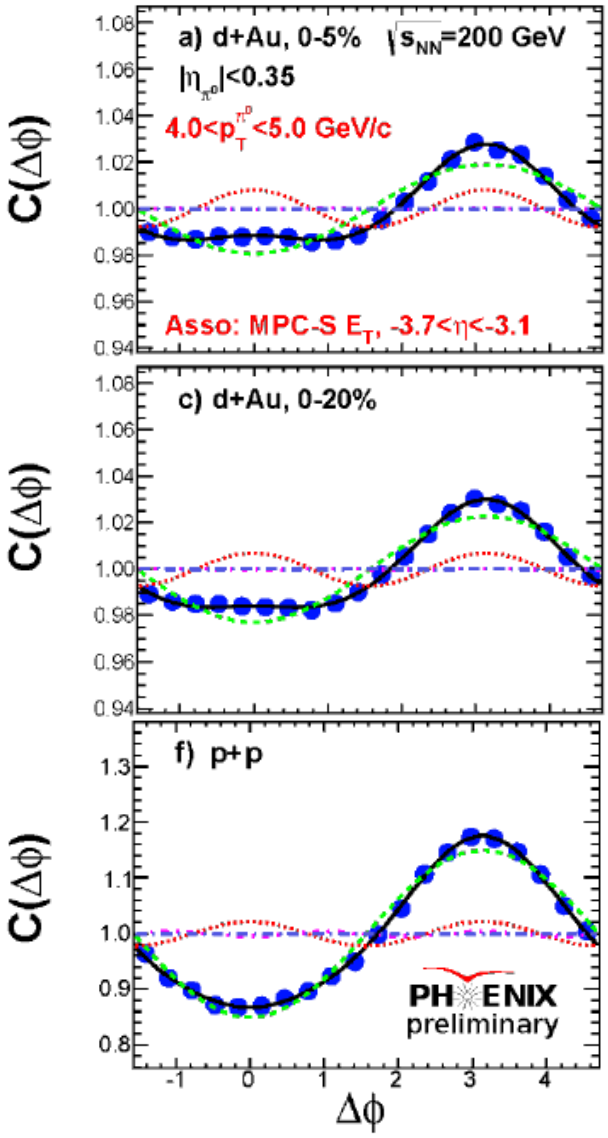


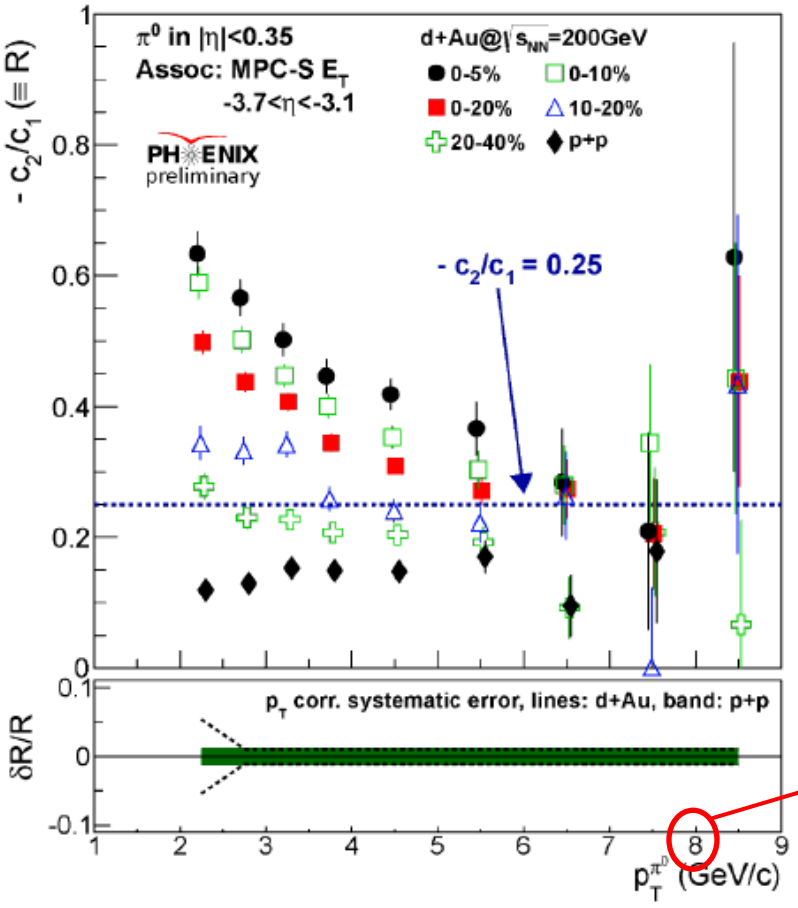


Measurement out to 8 GeV/c

Ridge stronger in central d+Au
→ similar behavior to low p_T h-MPC

Reach higher p_T with π^0-MPC



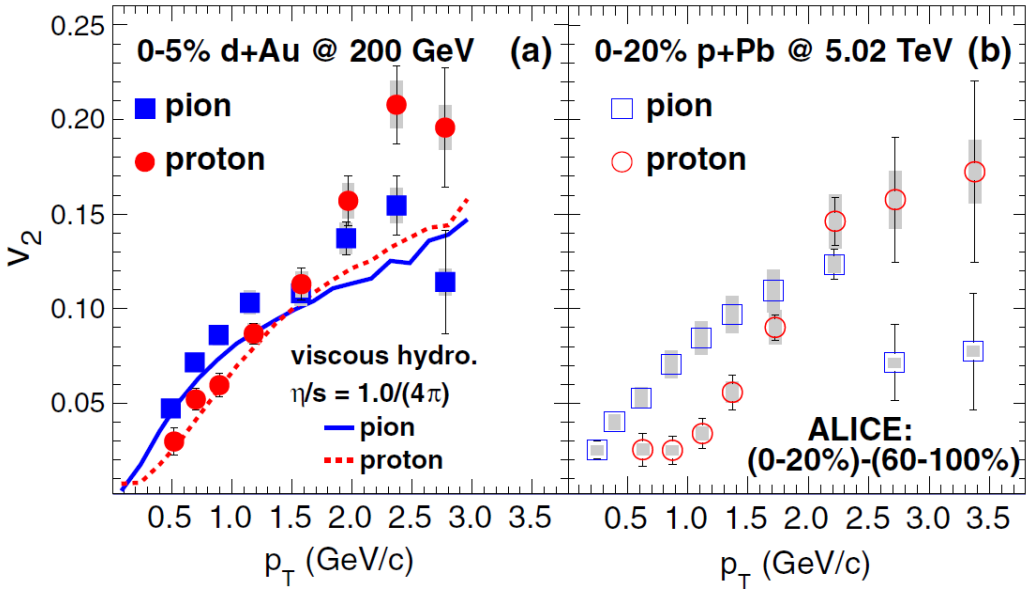


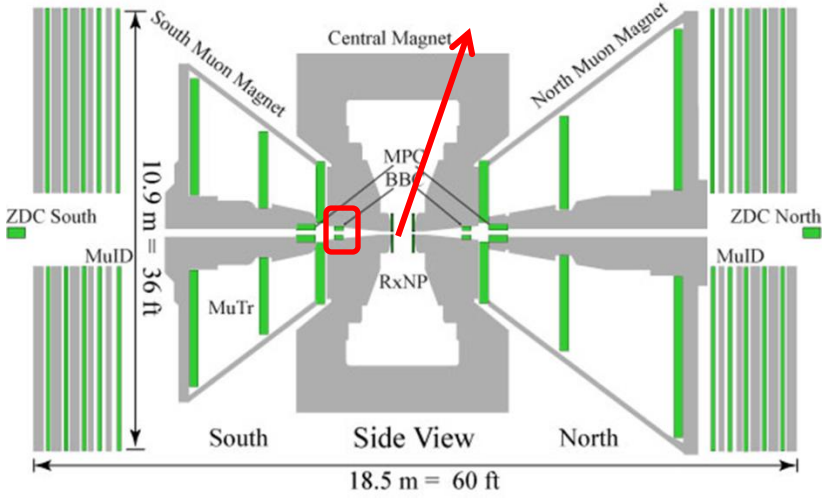
Measurement out to 8 GeV/c

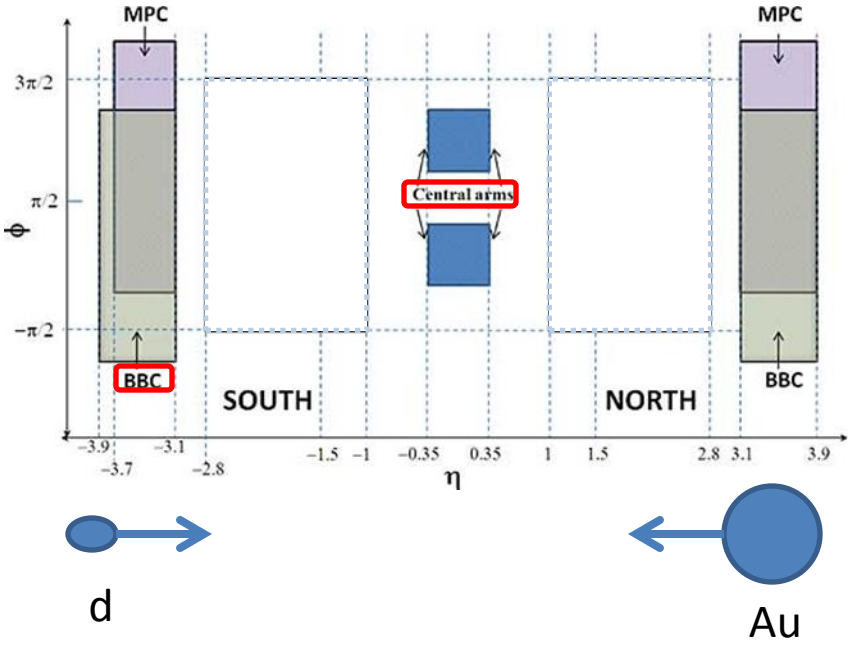
Study energy loss in d+A?

d+Au: Event-plane Measurement

$$v_2 = \frac{\langle \cos 2(\phi - \Psi_{EP}) \rangle}{Res(\Psi_{EP})}$$





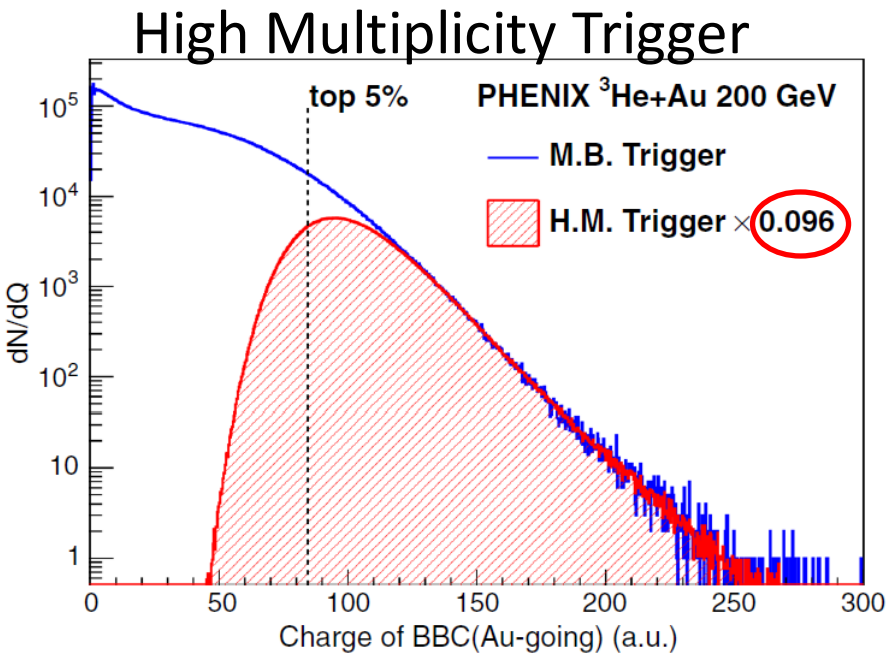


Mass ordering, similar to what is seen in A+A

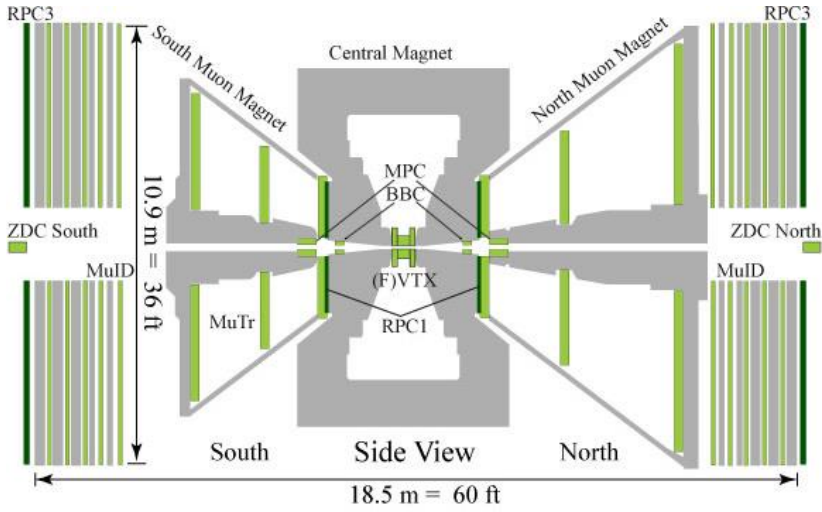
PRL 114 192301 (2015)

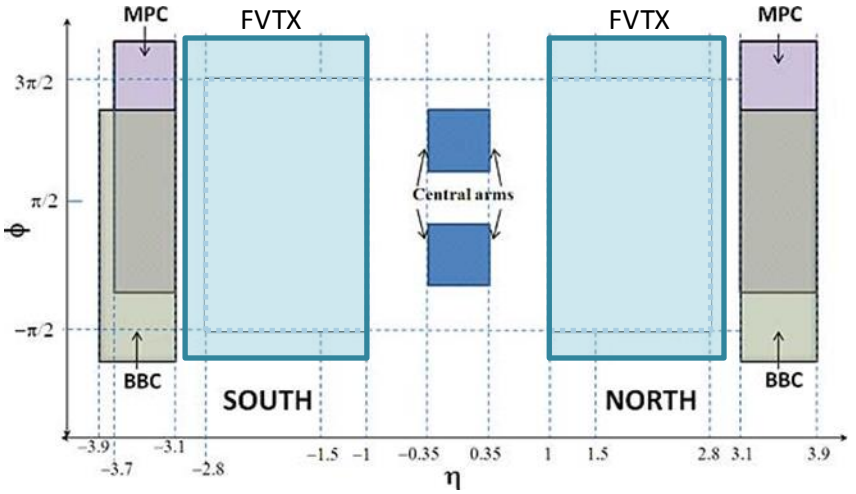
^{3}He+Au and p+Au

Detector Upgrades

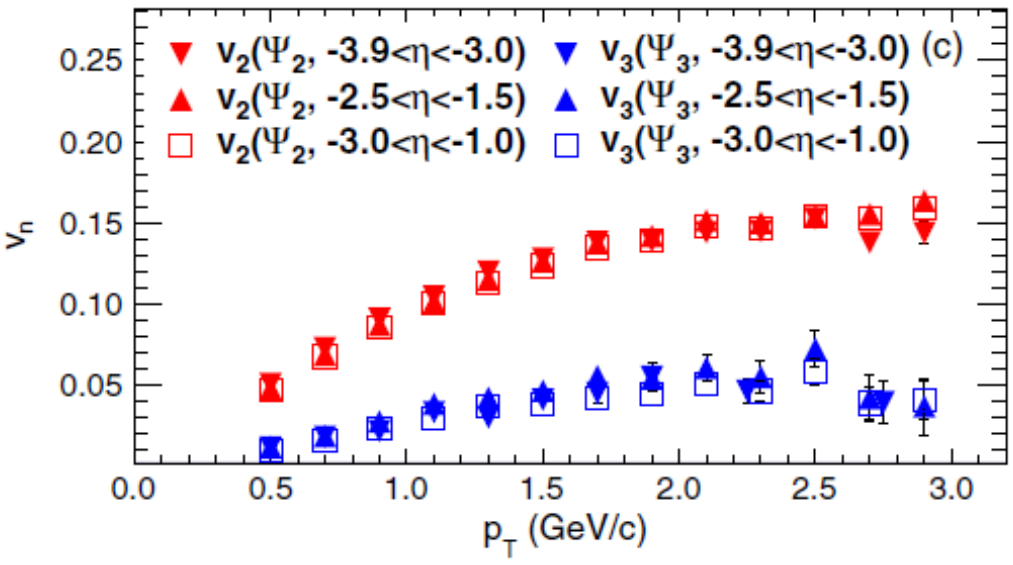


Almost all central events are recorded

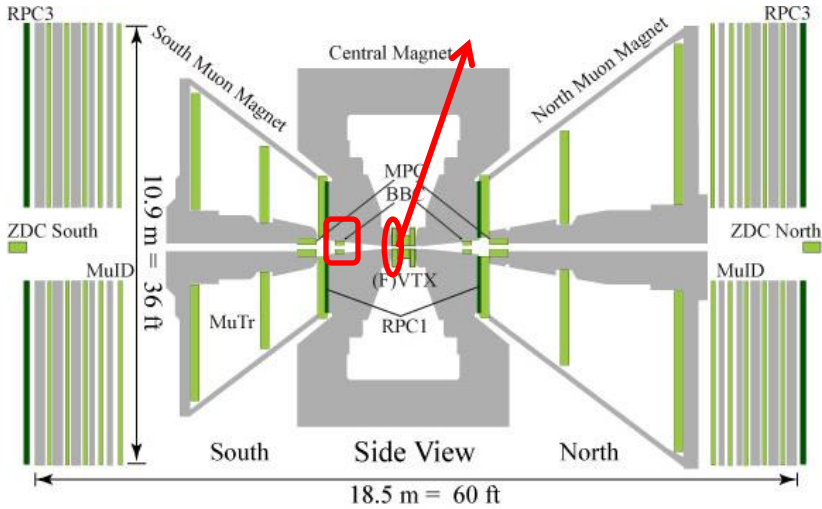


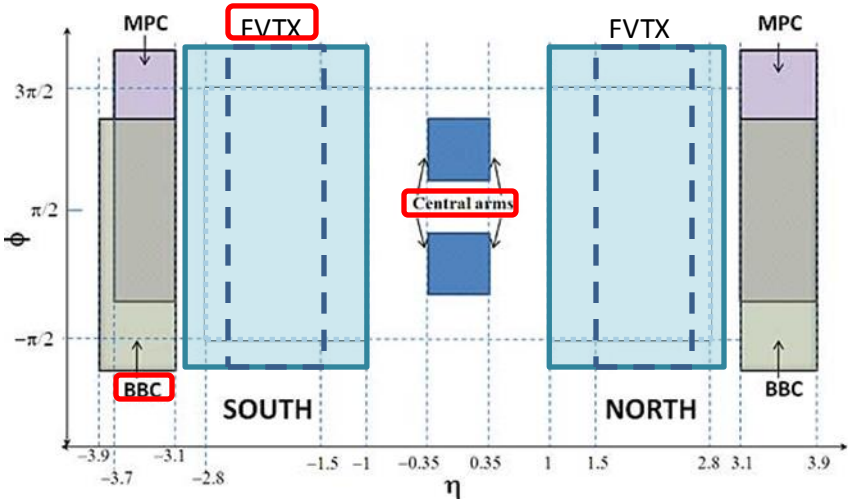


^{3}He+Au: Event-plane Measurement



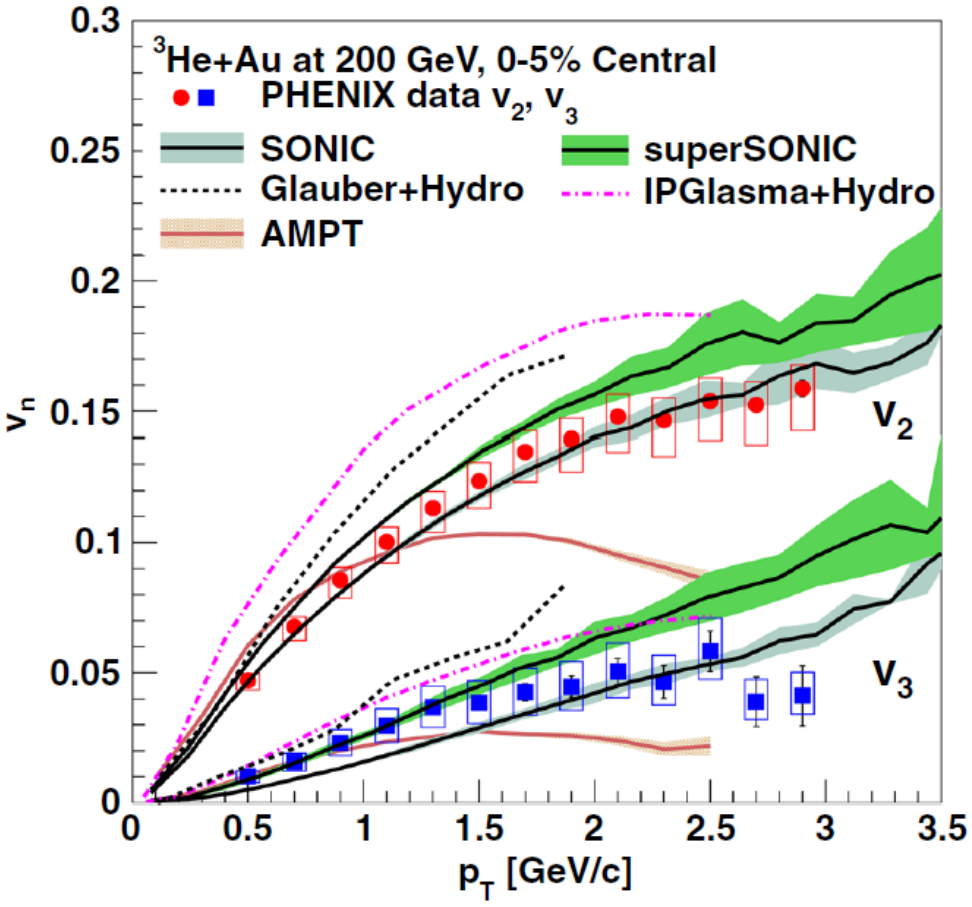
$v_3 > 0$ seen in ^{3}He+Au, as expected from initial collision geometry

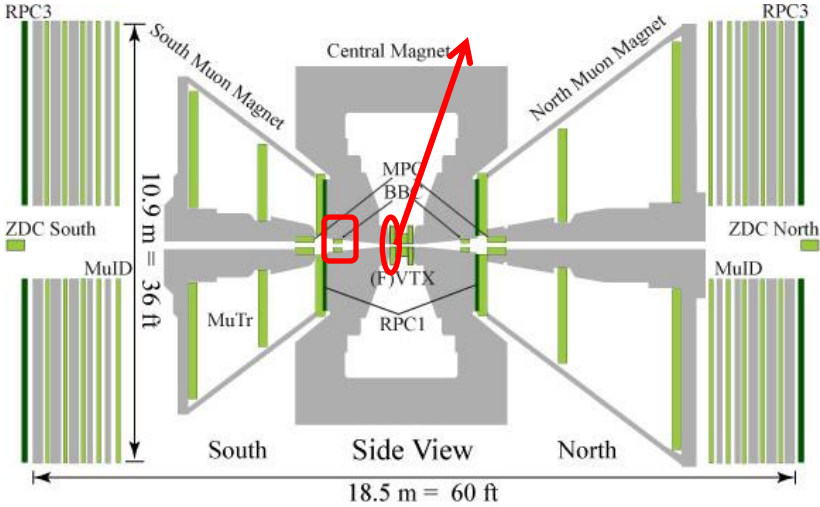


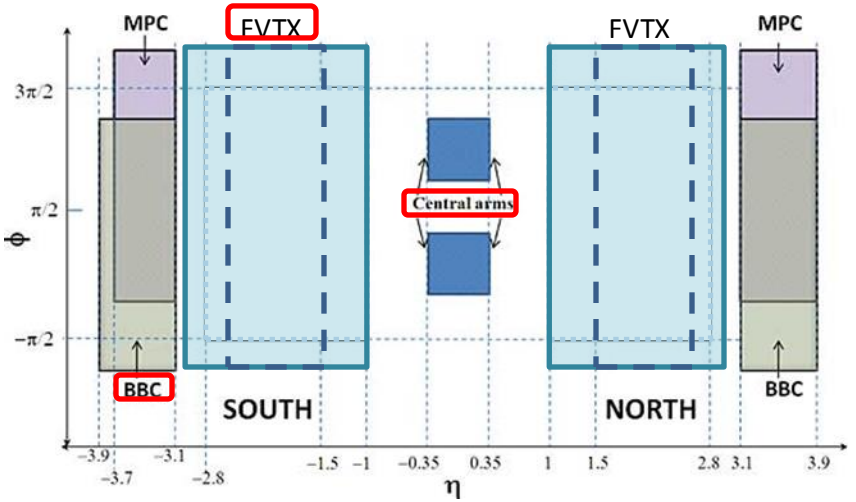


PRL 115 (2015) 142301

^{3}He+Au: Event-plane Measurement







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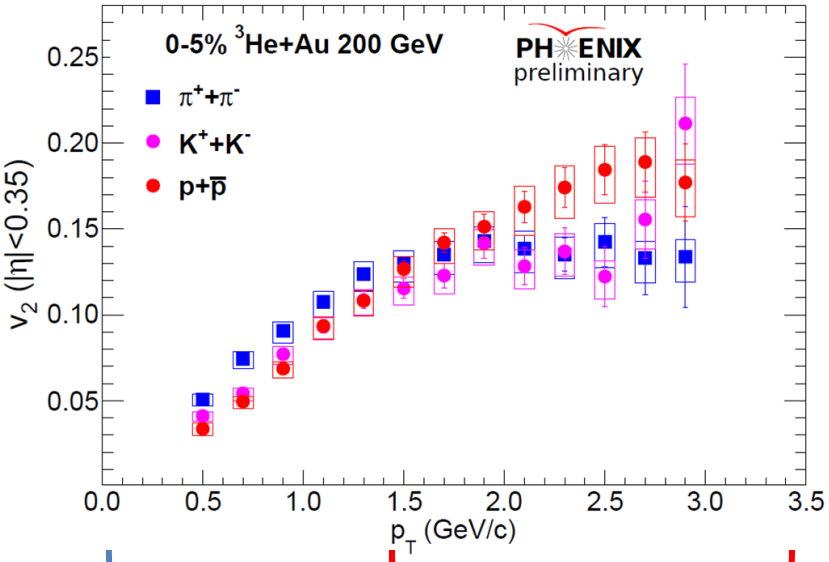
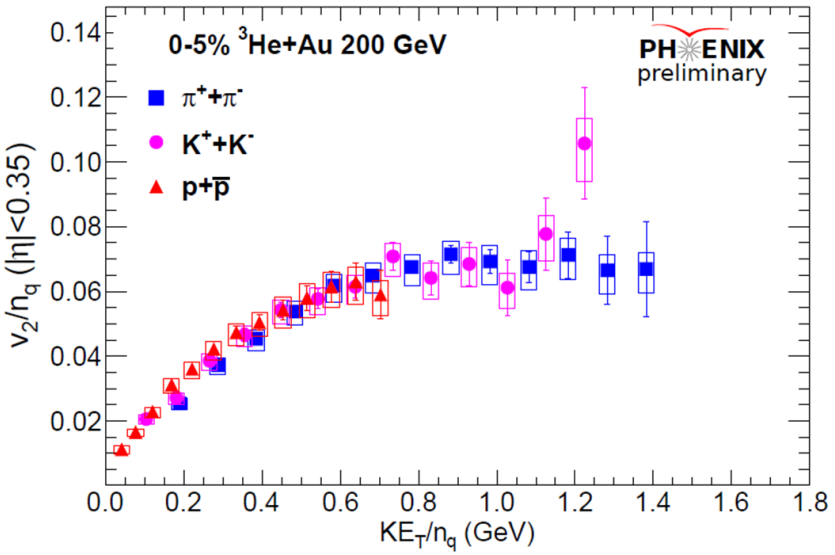
Identified particle v_2 in ^{3}He+Au



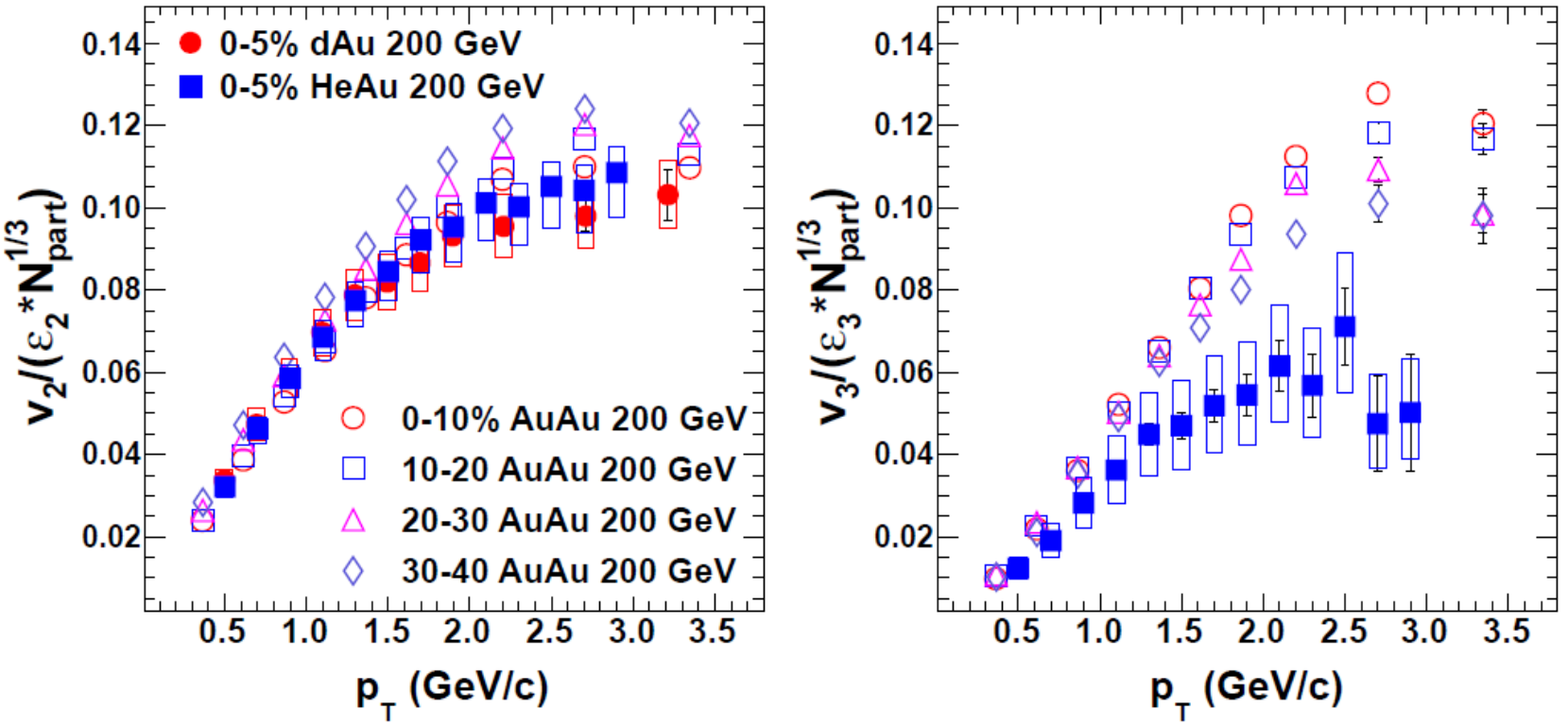


Mass-ordering

Meson-baryon splitting

Follows n_q-scaling, much like A+A

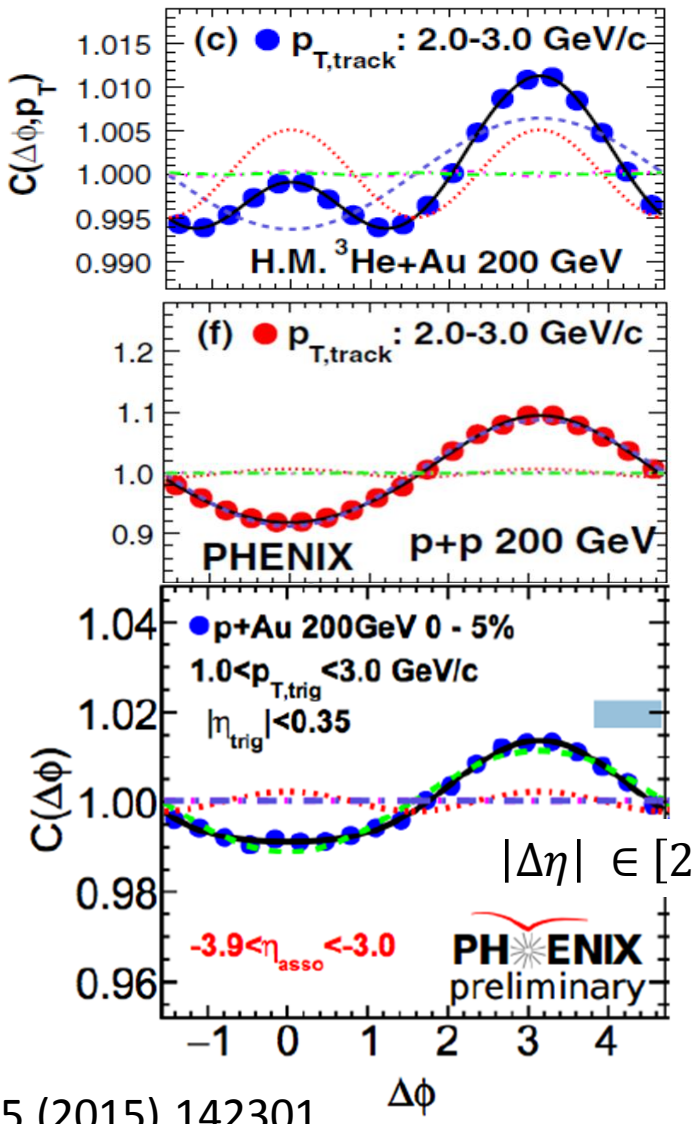
$v_n/\left(\epsilon_n \sqrt[3]{N_{Part}}\right)$ scaling



Does not work as well in small collision systems, especially v_3

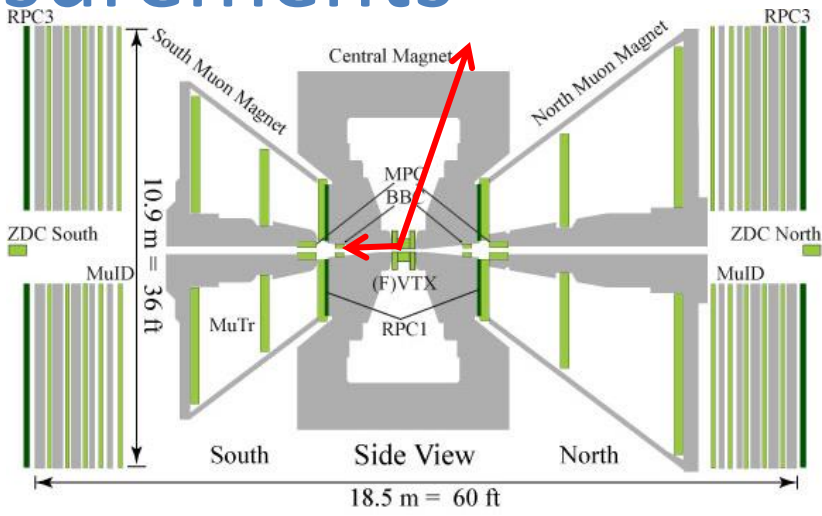
Higher-order anisotropy damps quickly in small collision systems

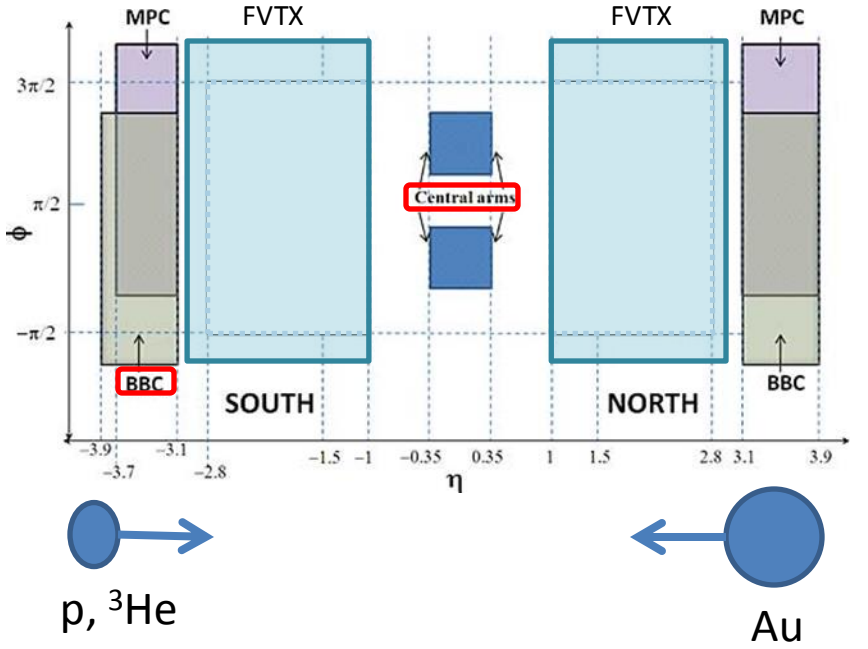
^{3}He+Au, p+Au: Long-range Correlation Measurements



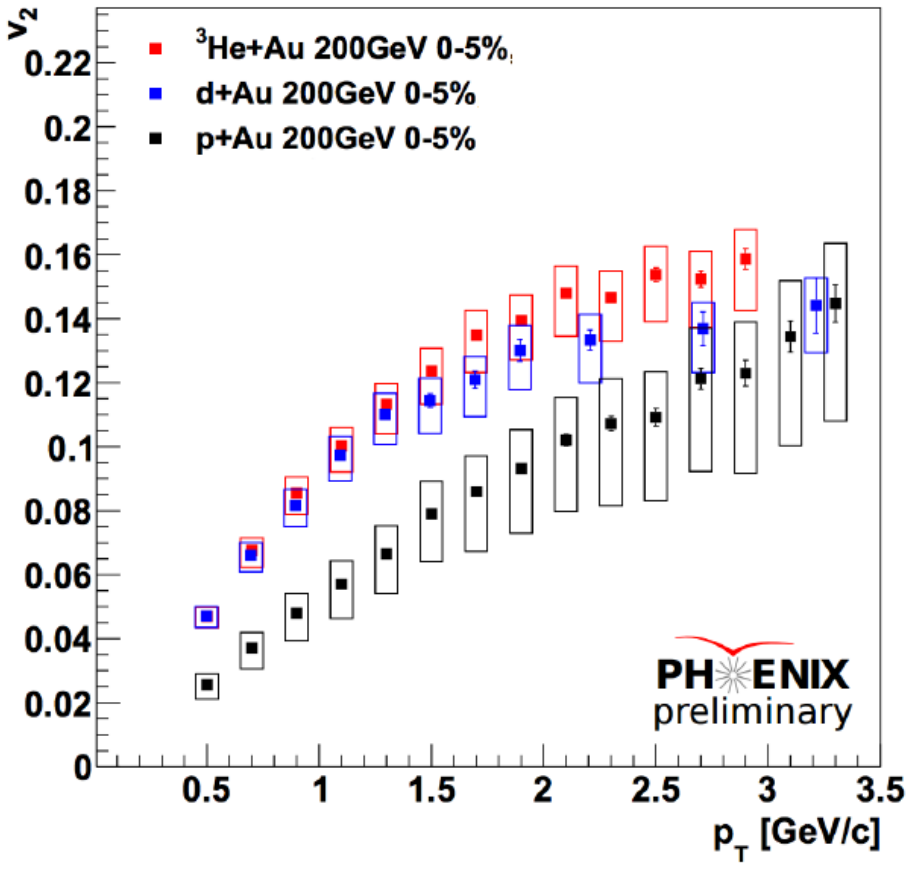
$|\Delta\eta| \in [2.75, 4.05]$

PRL 115 (2015) 142301





v_2 in p+Au, d+Au, ^{3}He+Au

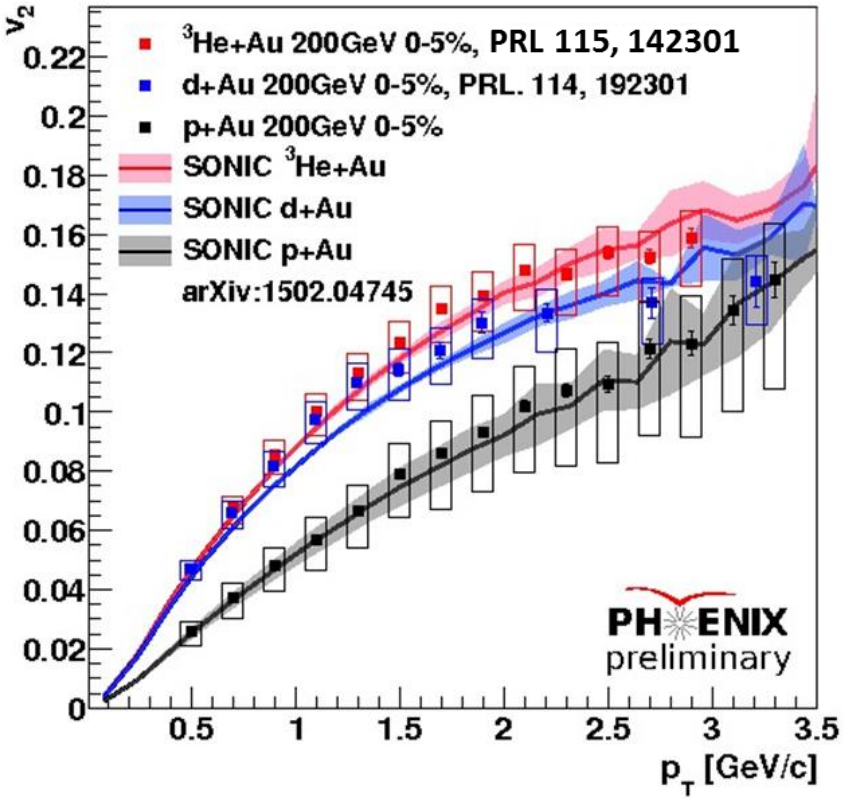


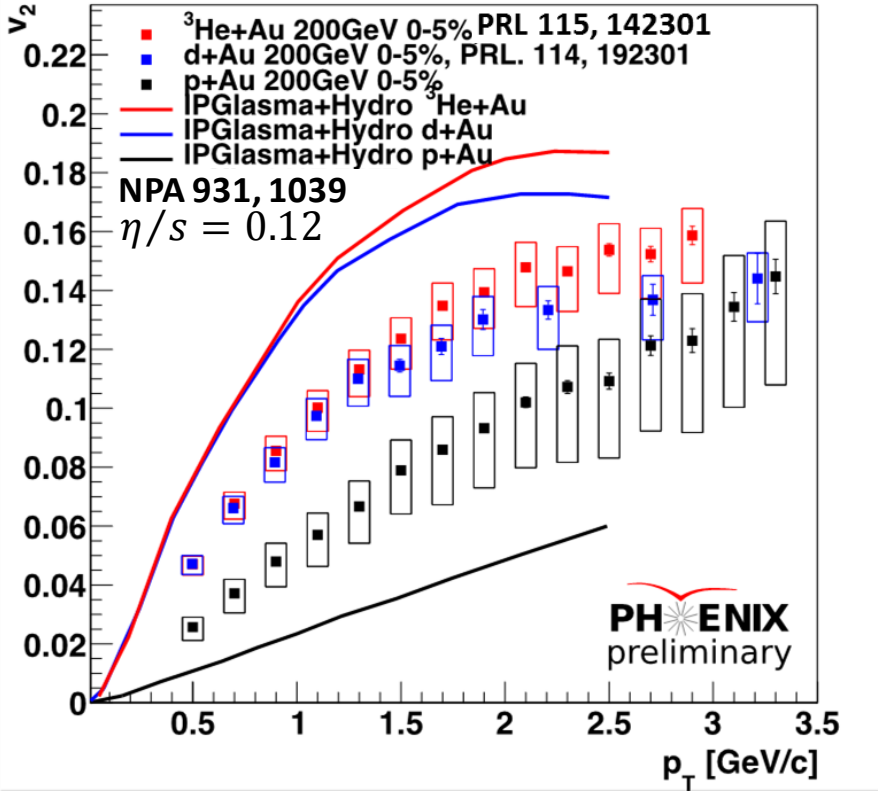
$$\epsilon_2^{d+Au} \sim \epsilon_2^{^3He+Au}$$

$$\epsilon_2^{d+Au} > \epsilon_2^{p+Au}$$

v_2 follows ϵ_2 ordering

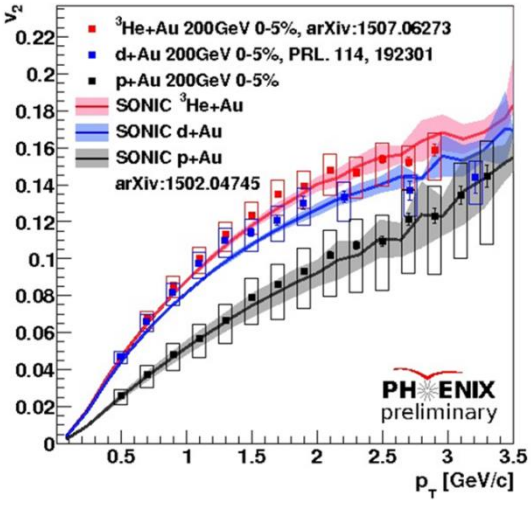
Theory comparisons

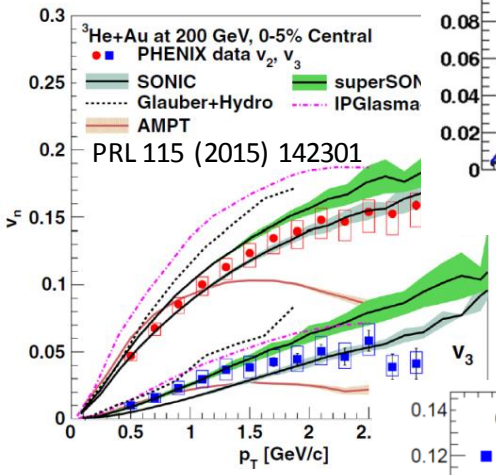


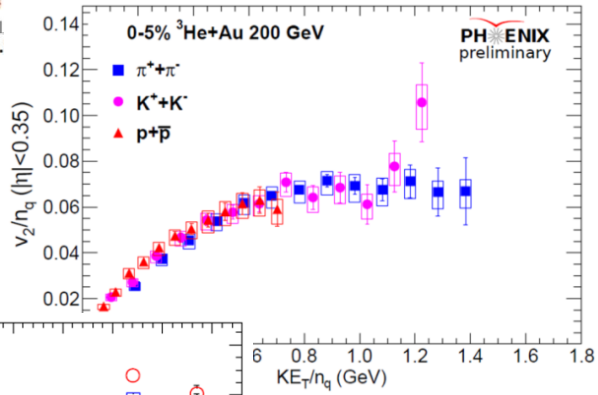


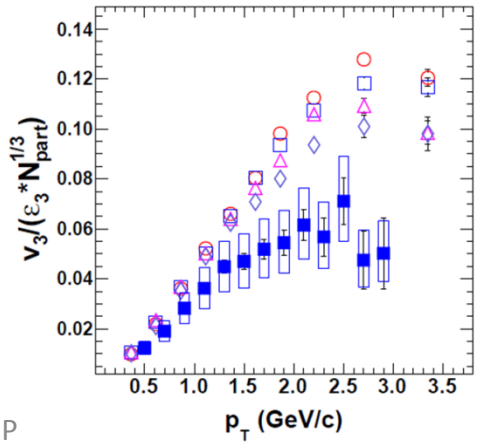
Conclusions

- Initial state geometric effects
  - ϵ_2 ordering of v_2 in p+Au, d+Au, ^{3}He+Au
  - v_3 in ^{3}He+Au
- Hydrodynamic modeling
- Mass ordering of v_2 in d+Au, ^{3}He+Au at low p_T
  - n_q-scaling of v_2 in ^{3}He+Au
- Faster damping v_3 in ^{3}He+Au
- Extend p_T out to 8GeV/c in d+Au using π^0-MPC



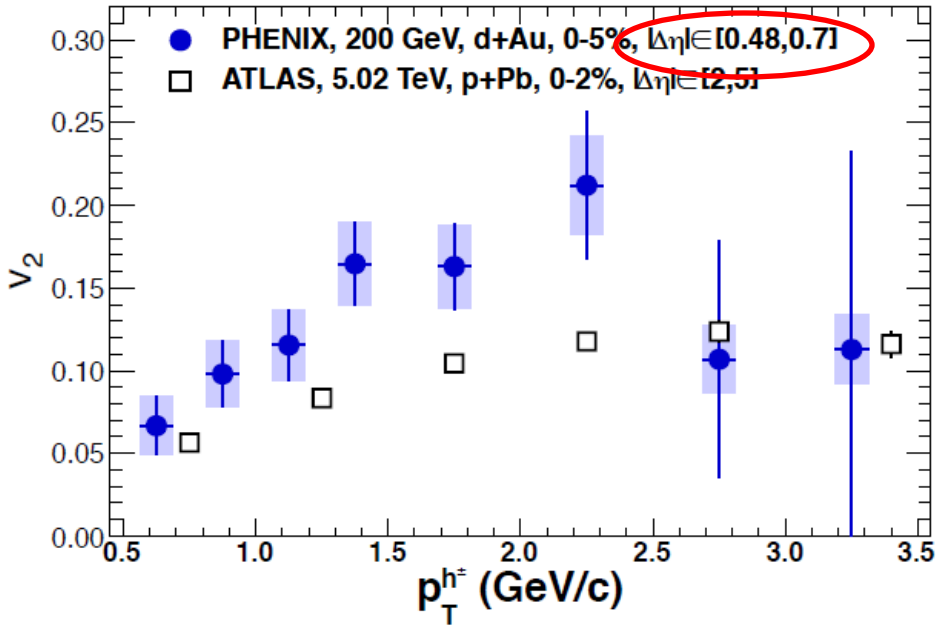




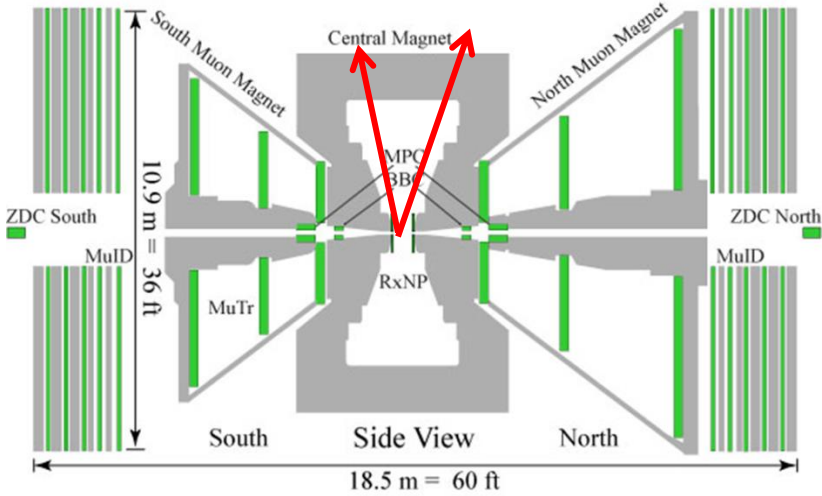


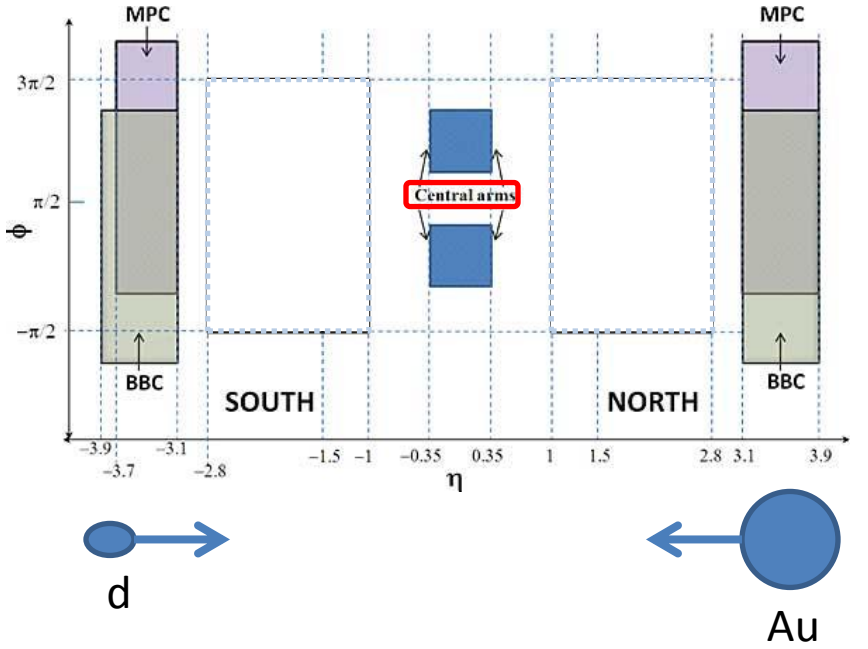
Backup

d+Au: Central Arm Correlation Measurement



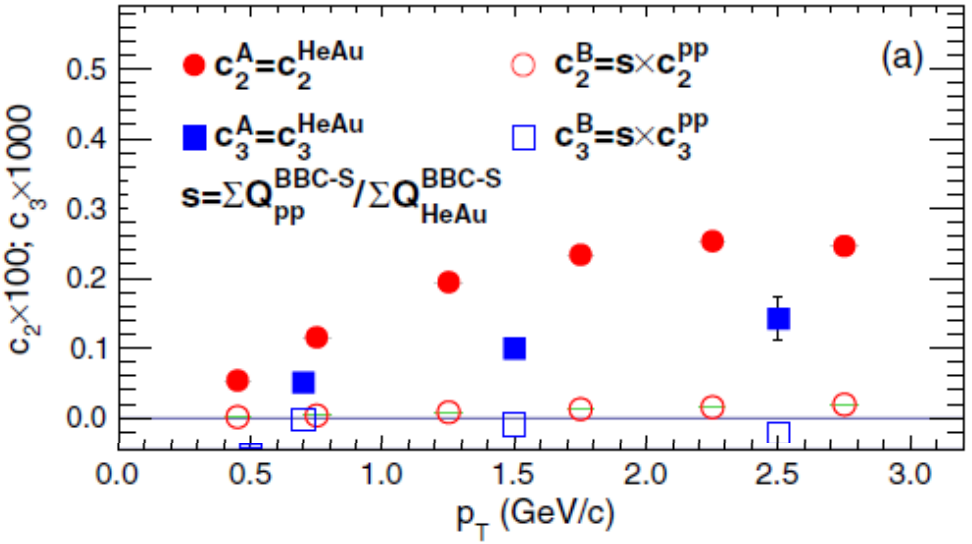
Suggests ridge-like behavior in d+Au at RHIC





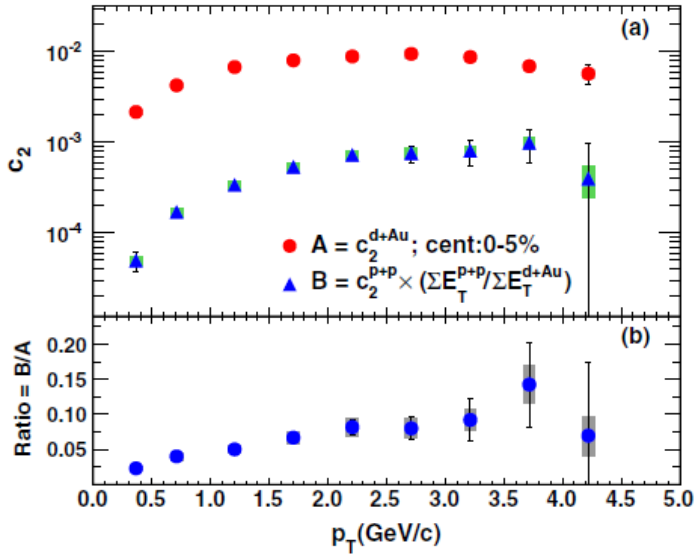
PHENIX PRL 111 212301 (2013)
ATLAS PRL 110 182302 (2012)

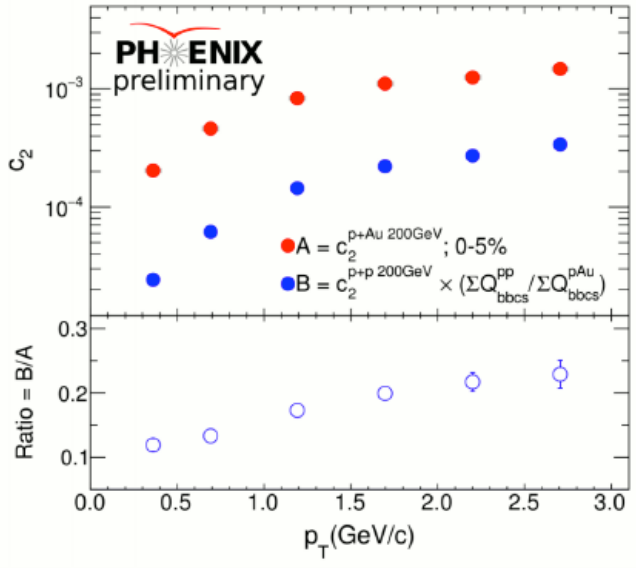
Estimating non-flow



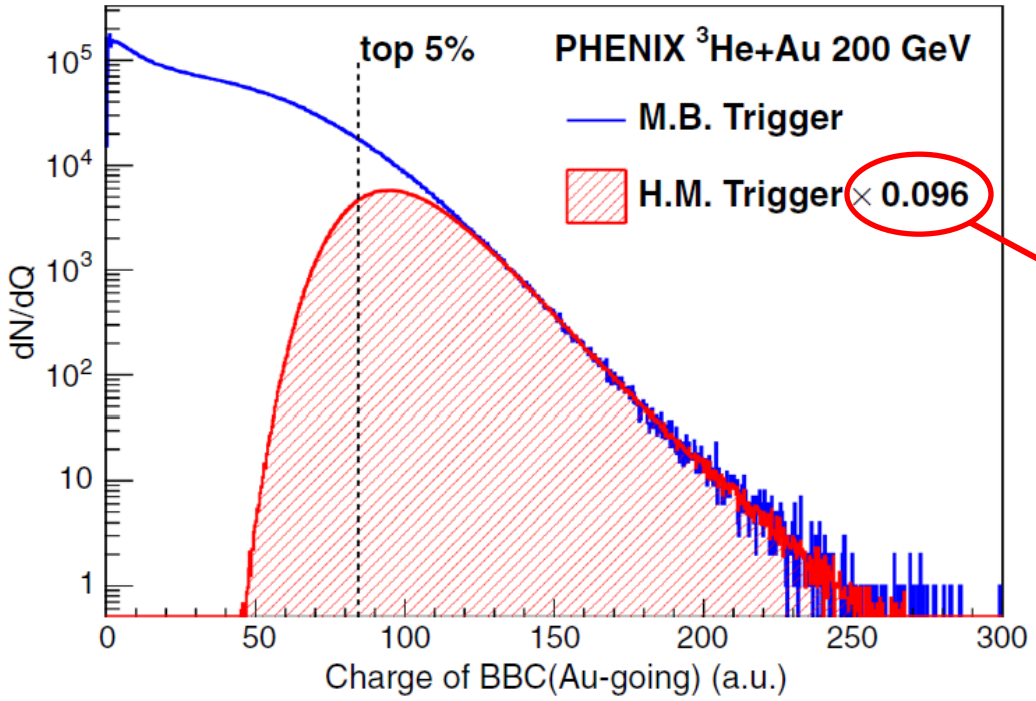
$$c_n{}^{d+Au} = c_n{}^{Non-Elem.} + c_n{}^{Elem.}$$

$$c_n{}^{Elem.} \approx c_n{}^{p+p} \frac{\sum E_T{}^{p+p}}{\sum E_T{}^{d+Au}}$$





High multiplicity trigger in ^{3}He+Au

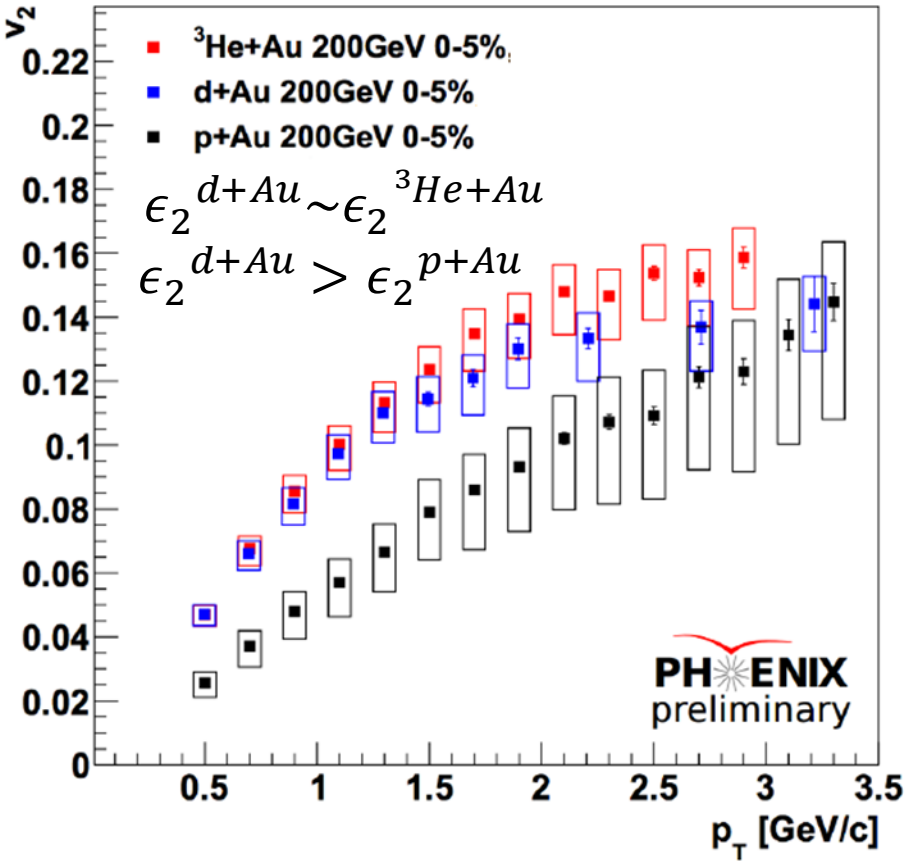


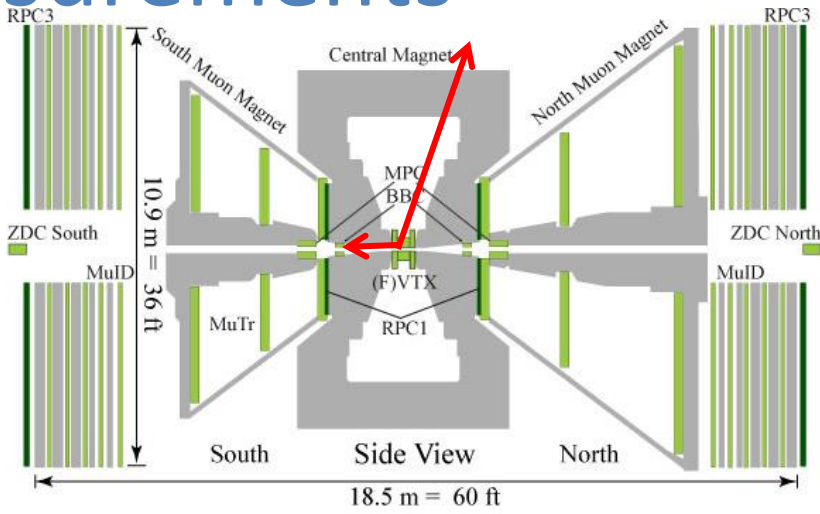
10 × enhancement of high multiplicity events

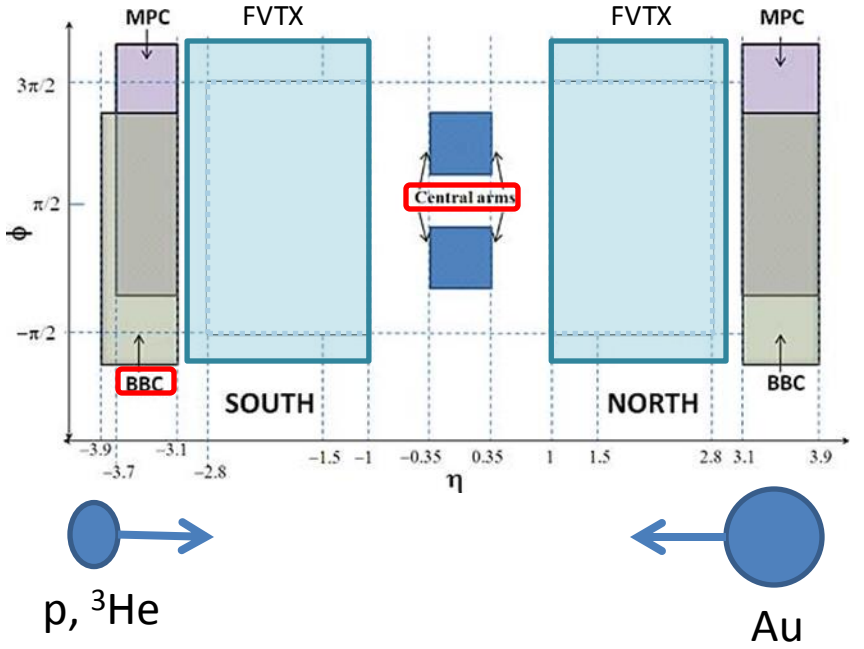
Almost all central events are recorded

PRL 115 (2015) 142301

^{3}He+Au, p+Au: Long-range Correlation Measurements



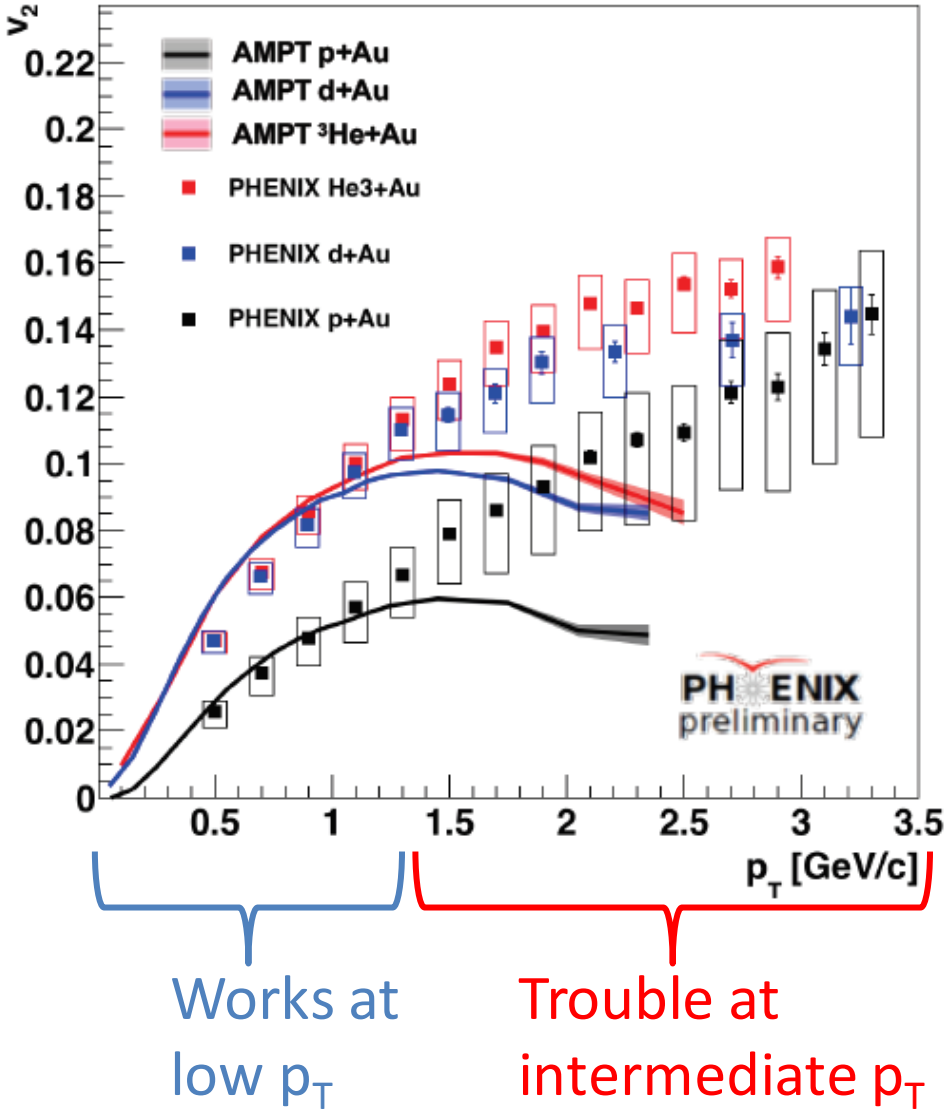




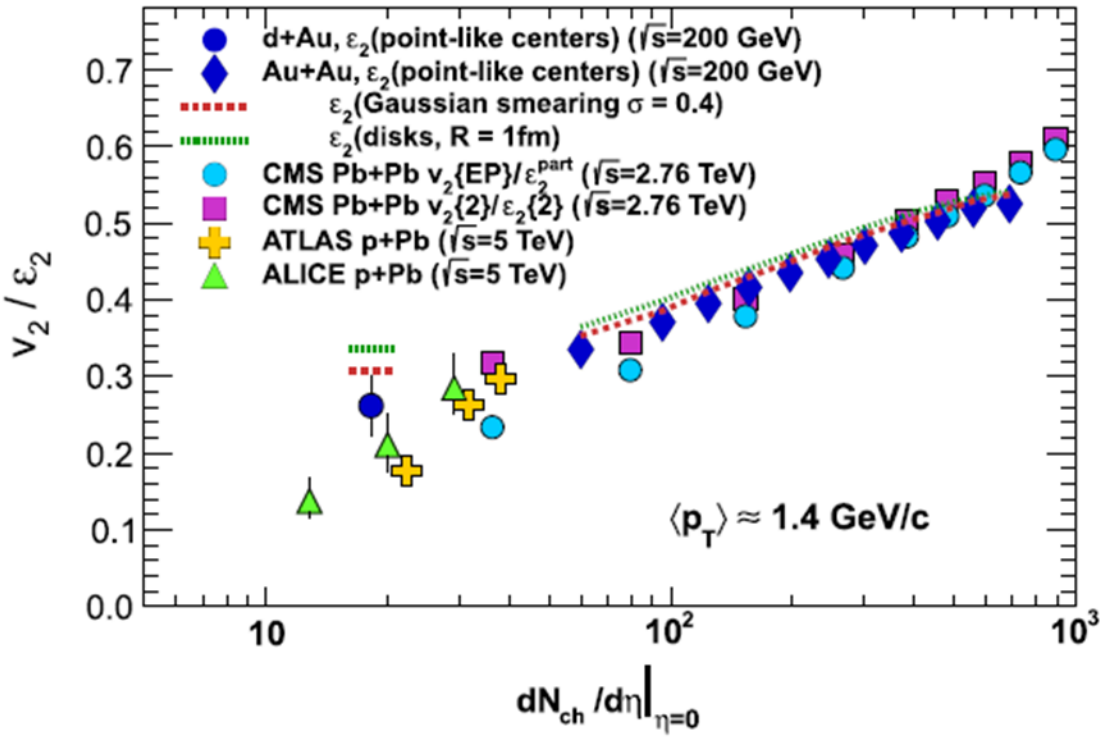
v_2 follows ϵ_2 ordering

PRL 115 (2015) 142301

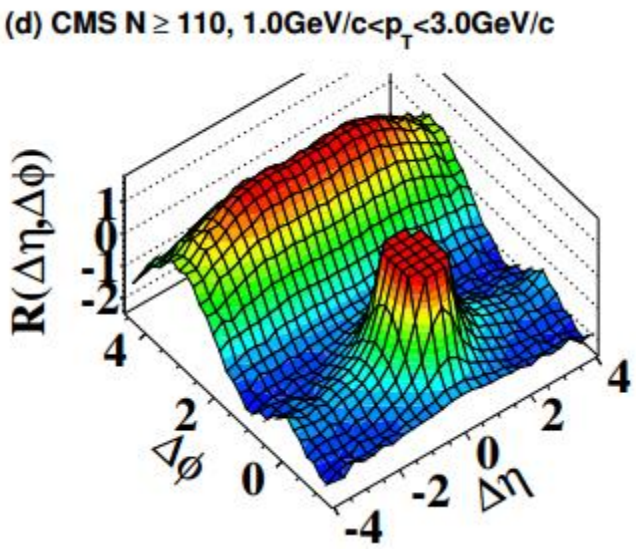
AMPT Comparison



Orjuela-Koop et. al. PRC 92 (2015) 054903


d+Au, ε_2(point-like centers) ($\sqrt{s}$=200 GeV)
Au+Au, ε_2(point-like centers) ($\sqrt{s}$=200 GeV)
ε_2(Gaussian smearing σ = 0.4)
ε_2(disks, R = 1fm)
CMS Pb+Pb $v_2\{EP\}/\varepsilon_2^{part}$ ($\sqrt{s}$=2.76 TeV)
CMS Pb+Pb $v_2\{2\}/\varepsilon_2\{2\}$ ($\sqrt{s}$=2.76 TeV)
ATLAS p+Pb ($\sqrt{s}$=5 TeV)
ALICE p+Pb ($\sqrt{s}$=5 TeV)
$\langle p_T \rangle \approx$ 1.4 GeV/c
v_2 / ε_2
$dN_{ch}/d\eta|_{\eta=0}$
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
10
10^2
10^3

Collectivity in p+p



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Abstract

- Collisions of simple systems, such as p+p, or p+Nucleus have been used as benchmarks for our understanding of Heavy Ion Collisions, since it was assumed they would be free of the effects from hot nuclear matter.

  Recently long range correlations and anisotropies of momentum spectra have been seen in such collisions, challenging this assumption. Such phenomena have been understood to be the result of the collective motion, which can best be described by hydrodynamics, whose initial conditions are set by the geometry of the colliding systems, together with their fluctuations. This talk will discuss the recent results from the PHENIX experiment at RHIC using a variety of colliding species (p+Au, d+Au, He3+Au) which give a better understanding of the origin of the observed correlations and anisotropies, thus providing insight as to whether a Quark Gluon Plasma is formed in these simple system