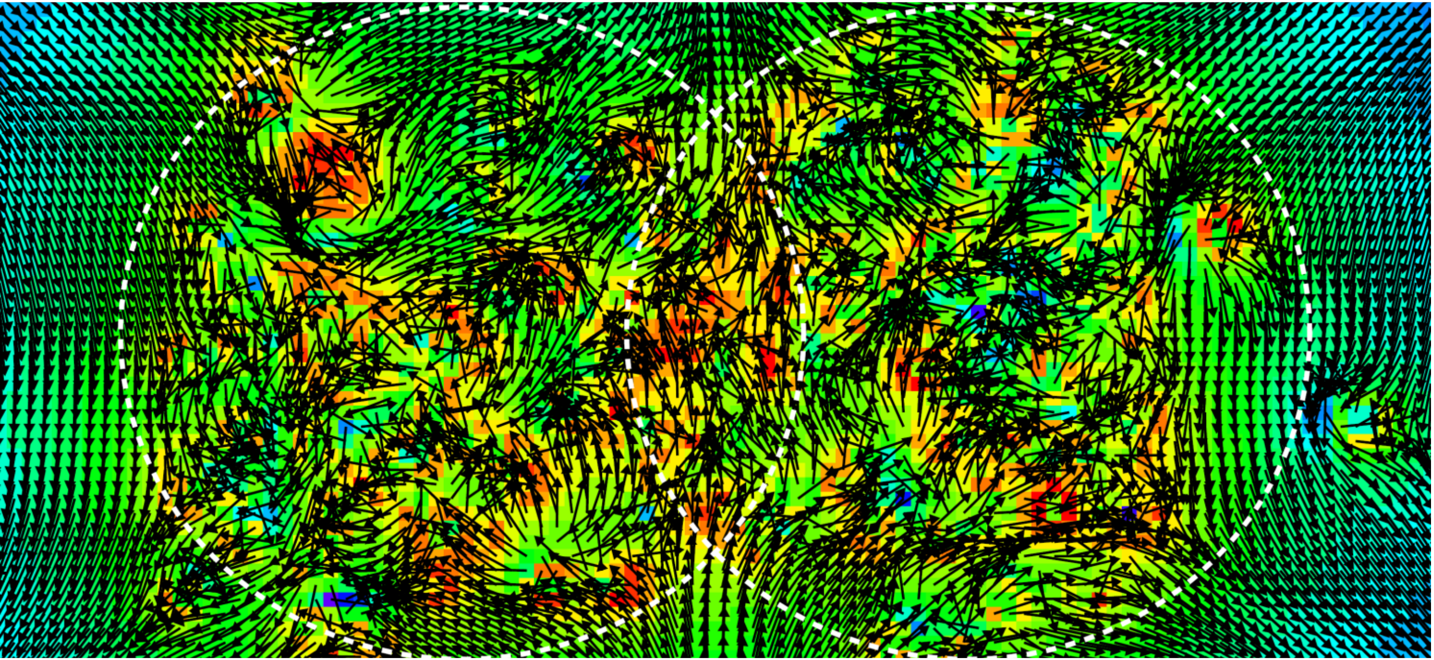
(Non) Random Thoughts I Think…

Jamie Nagle (University of Colorado Boulder)



5/22/2017

What are small system results telling us?

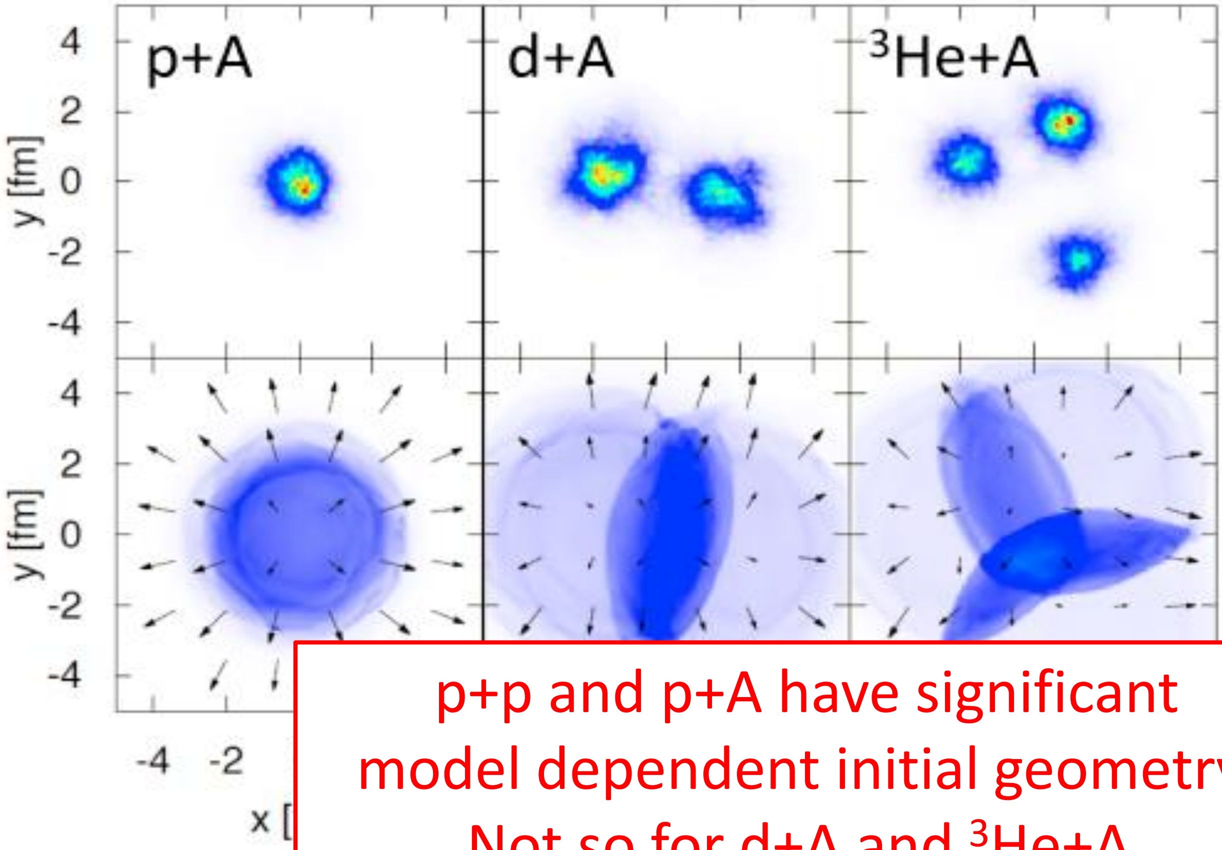
Small system results need to be viewed together as a whole…

So many things appear the same…
the idea that the physics is completely different at RHIC and the LHC, completely different in p+p and p+Pb, completely different in p+Au and d+Au seems vanishingly small…

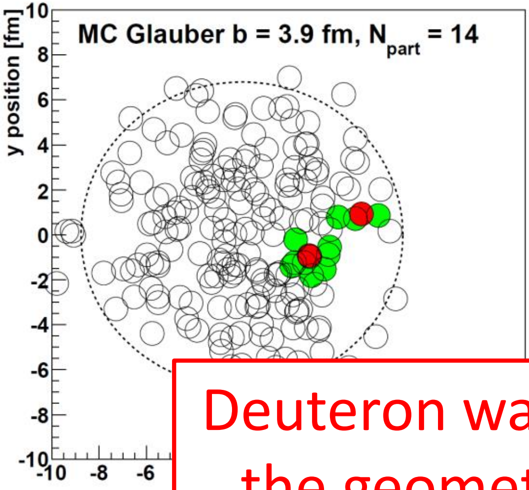
What can we find consensus on?

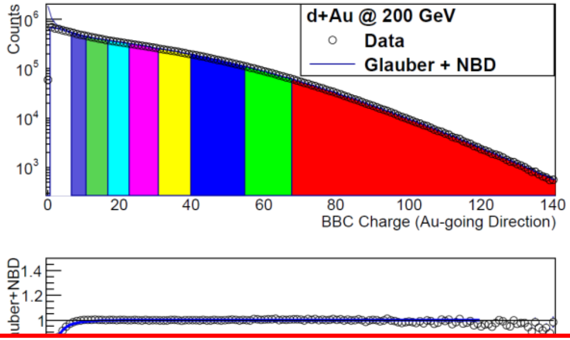
$\varepsilon_2^{IPGlasma} = 0.099$ $\varepsilon_2^{IPGlasma} = 0.595$ $\varepsilon_2^{IPGlasma} = 0.555$

$\varepsilon_2^{Glauber} = 0.231$ $\varepsilon_2^{Glauber} = 0.540$ $\varepsilon_2^{Glauber} = 0.504$



p+p and p+A have significant model dependent initial geometry. Not so for d+A and ^{3}He+A.

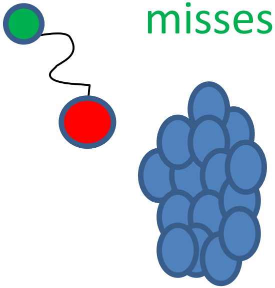


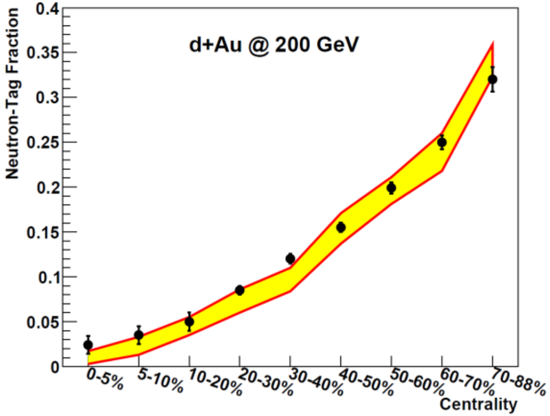


Deuteron wavefunction is well known and the geometry validated by experiment.

d+Au

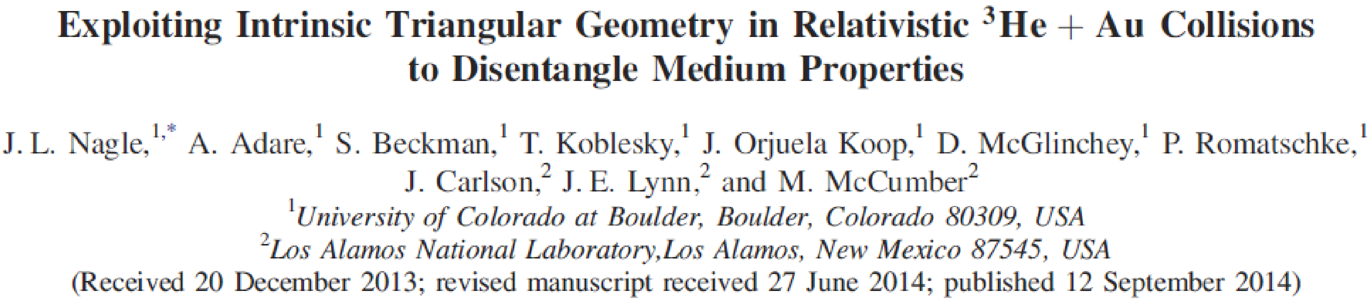
Sometimes the neutron misses





http://journals.aps.org/prc/abstract/10.1103/PhysRevC.90.034902

Geometry Tests at RHIC



Exploiting Intrinsic Triangular Geometry in Relativistic ^{3}He + Au Collisions to Disentangle Medium Properties

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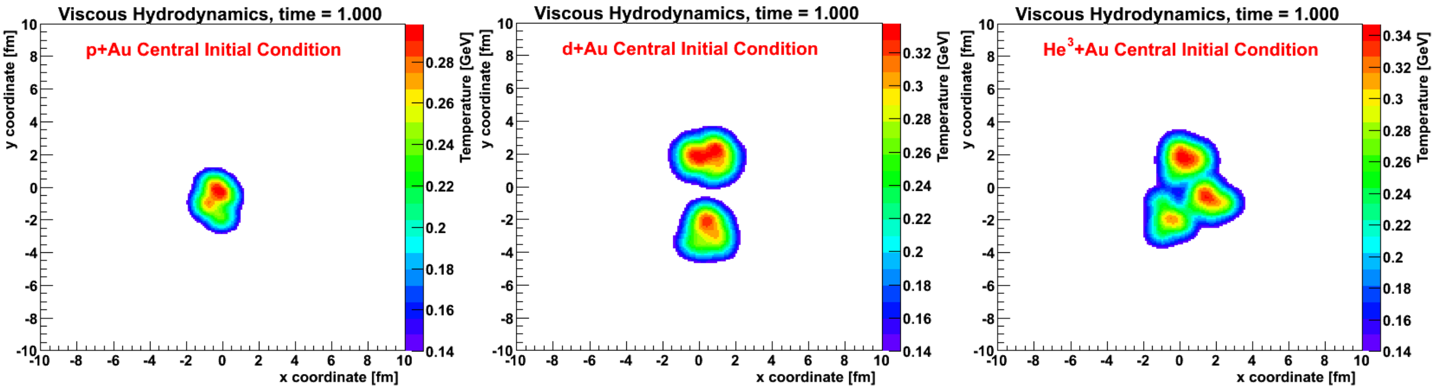
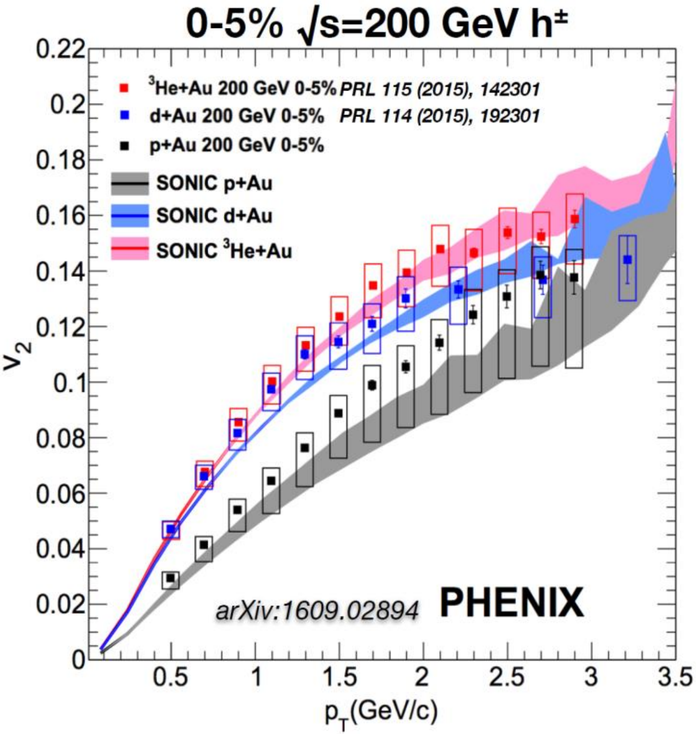
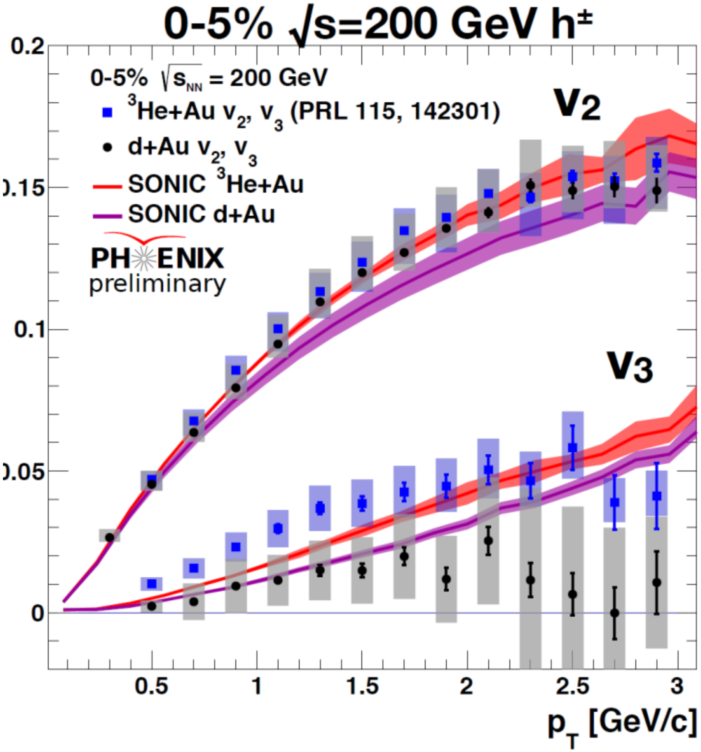
(Received 20 December 2013; revised manuscript received 27 June 2014; published 12 September 2014)

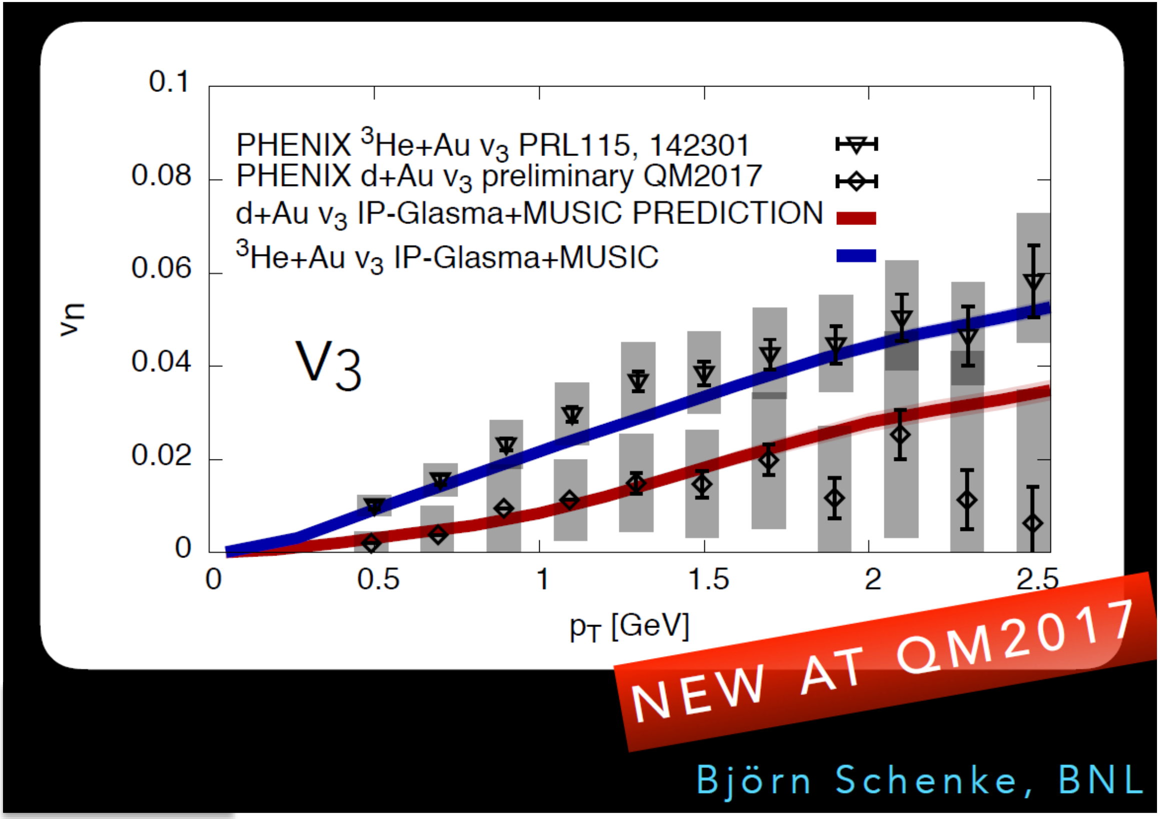


Experimental results and hydrodynamic predictions



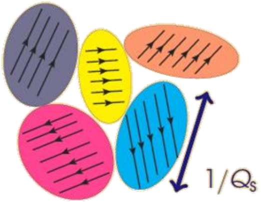


Experimental results and hydrodynamic predictions



Key Point on “Momentum Domains” Explanation

Non-Geometry correlations in momentum space

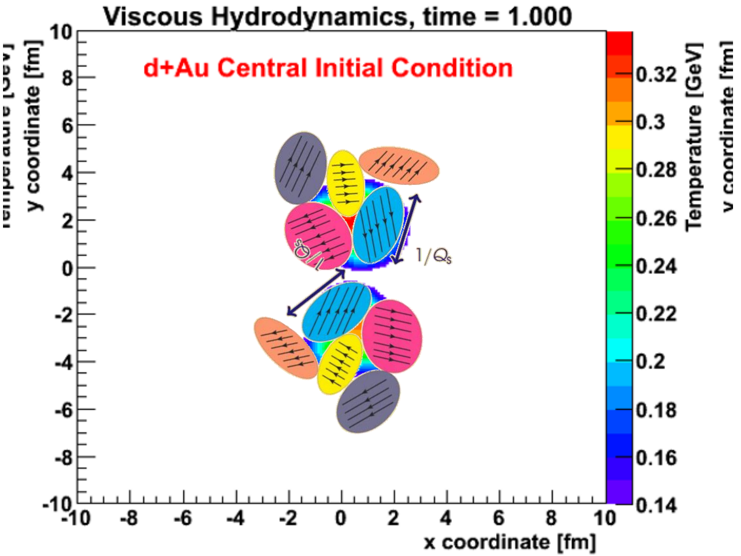


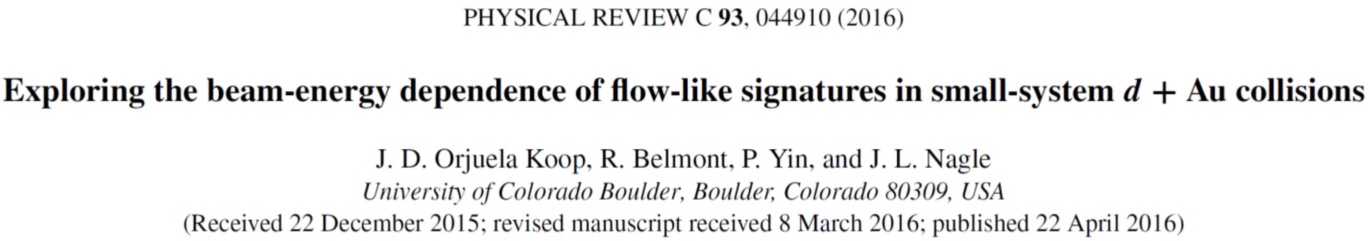
In a d+Au system, domains from two hot spots are uncorrelated.

Thus, v_2 has a dilution effect.

v_2 (d+Au) < v_2 (p+Au)

Needs a full calculation. Then falsifiable theory.





PHYSICAL REVIEW C **93**, 044910 (2016)

Exploring the beam-energy dependence of flow-like signatures in small-system *d* + Au collisions

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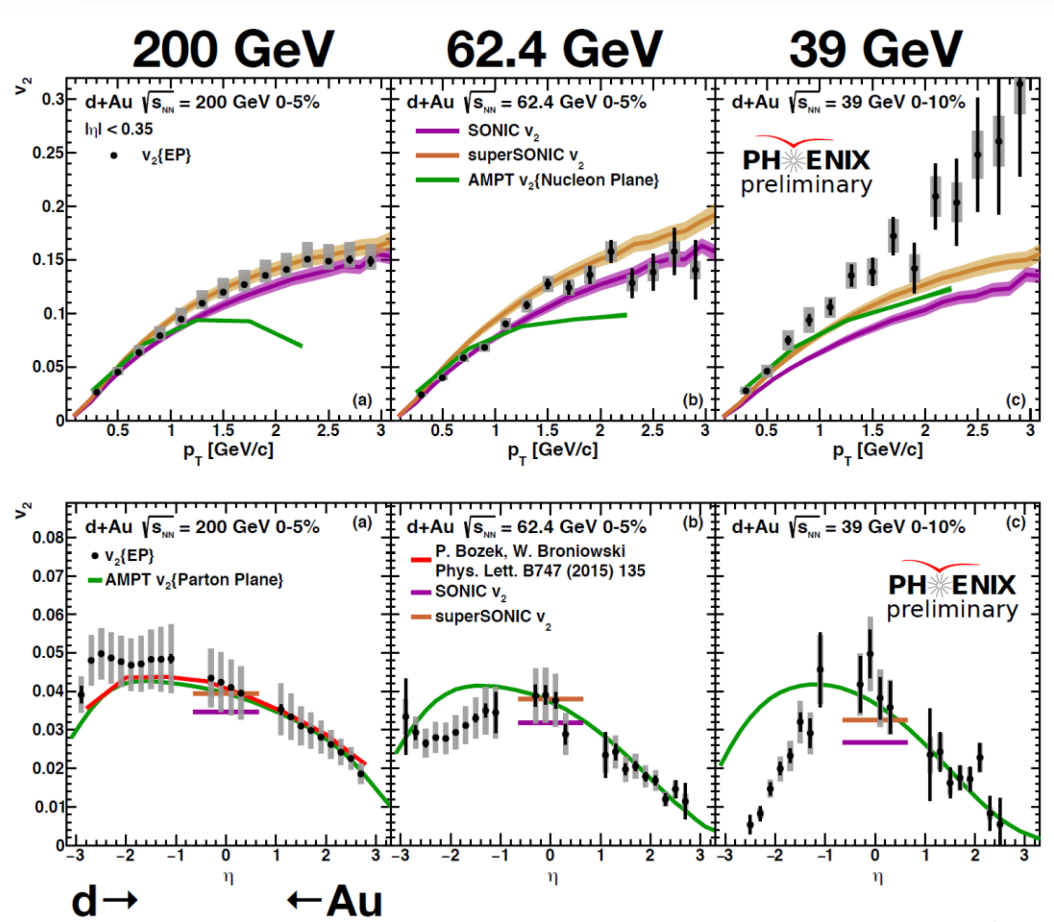
University of Colorado Boulder, Boulder, Colorado 80309, USA

(Received 22 December 2015; revised manuscript received 8 March 2016; published 22 April 2016)

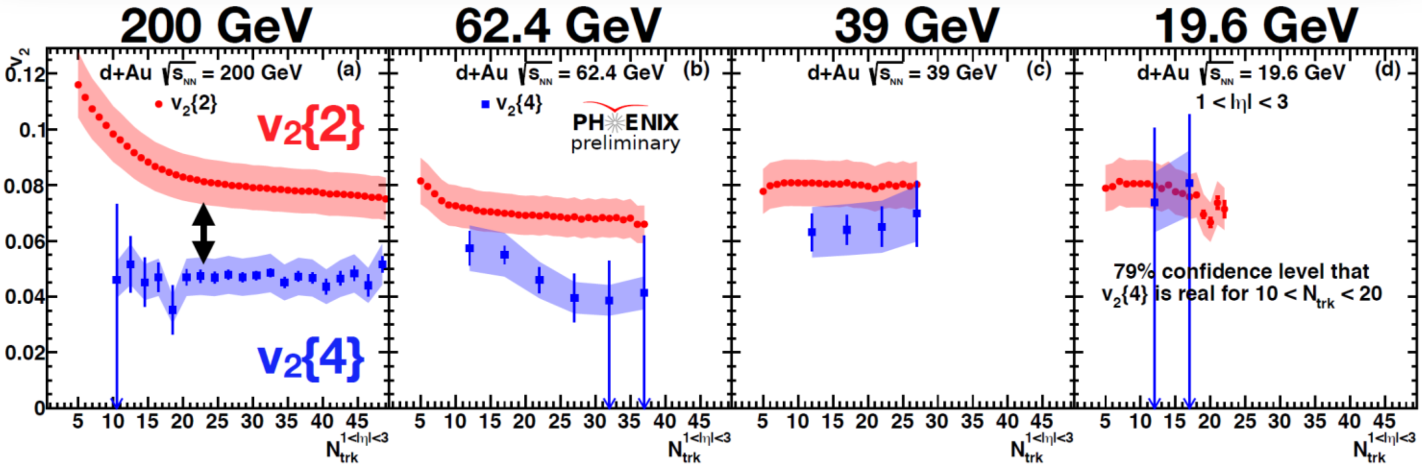
Extend small system data from
19.6 GeV → 200 GeV → 5.02 TeV

PHENIX d+Au Beam Energy Scan



See Darren McGlinchey's QM17 Talk

Two- and Four- Particle Cumulants

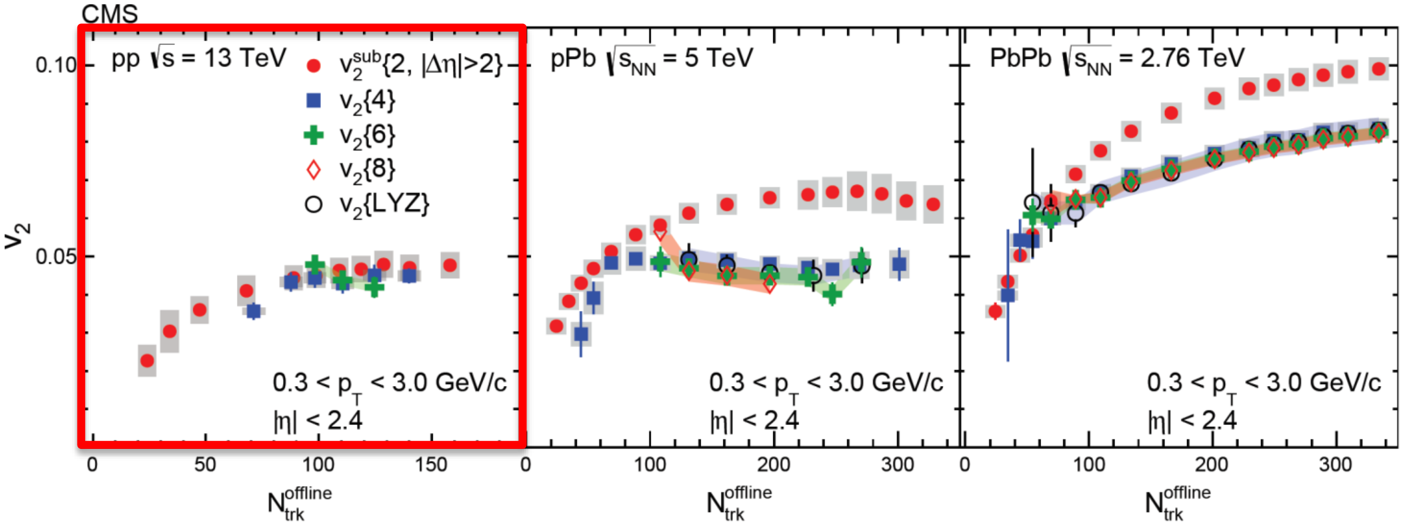


Higher cumulants themselves are not unique to hydrodynamics or collectivity.

However, they are a powerful constraint on model calculations.

See Ron Belmont’s QM17 Talk

Multi-Particle Cumulants at the LHC



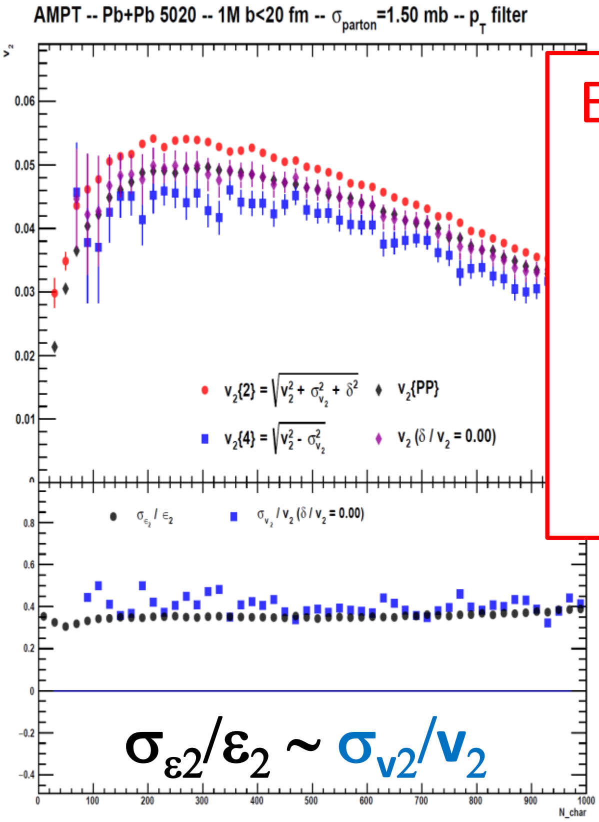
$$v\{2\}^2 = \langle v\rangle^2 + \sigma^2 + \delta^2$$

$$v\{4\}^2 = \langle v\rangle^2 - \sigma^2$$

Detailed relation of cumulants with geometry fluctuations…

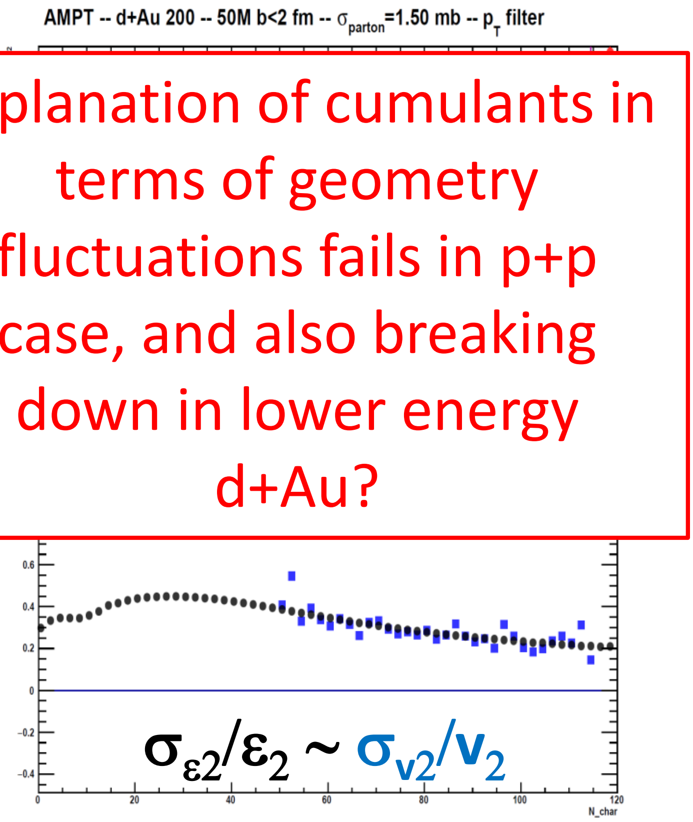
Why is p+p different?

AMPT Shows $v_2\{2\}$ and $v_2\{4\}$ splitting dominated by geometry fluctuations… and mean agrees with "true geometry" result.



$\sigma_{\varepsilon 2}/\varepsilon_2 \sim \sigma_{v2}/v_2$

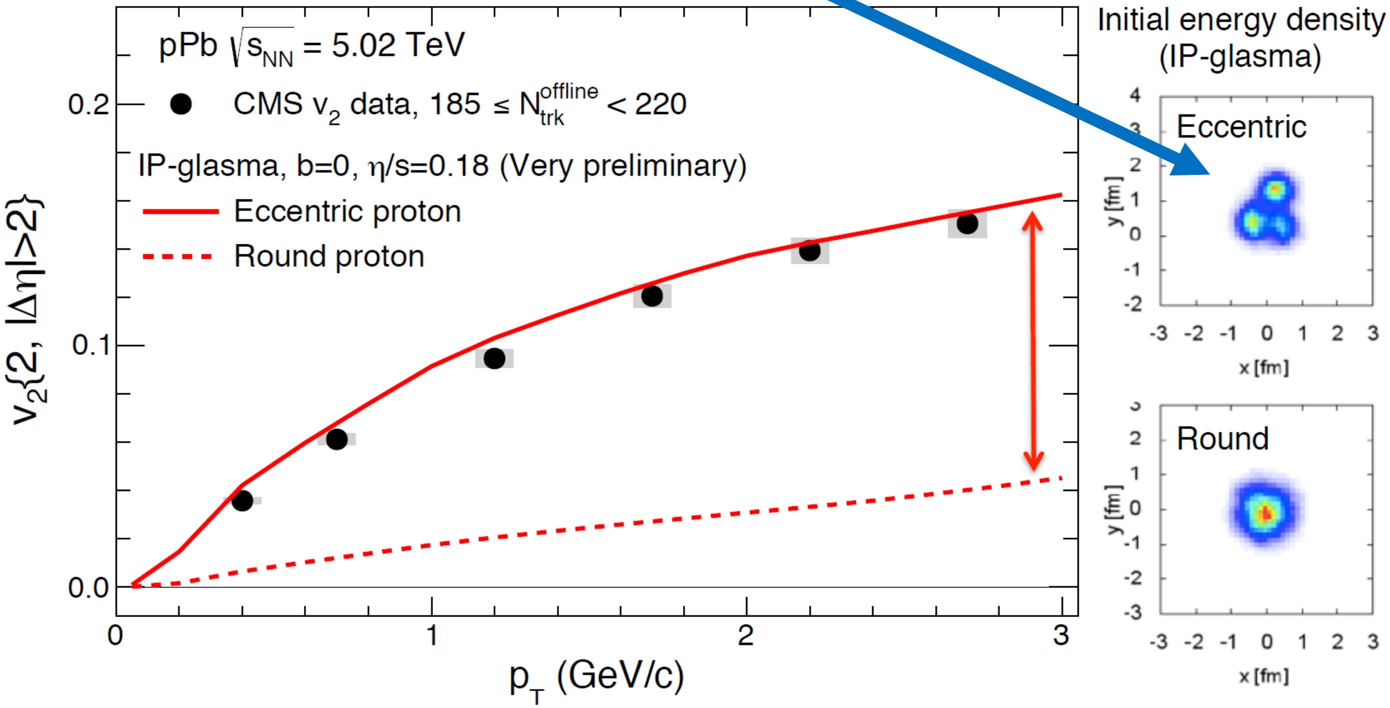
Explanation of cumulants in terms of geometry fluctuations fails in p+p case, and also breaking down in lower energy d+Au?



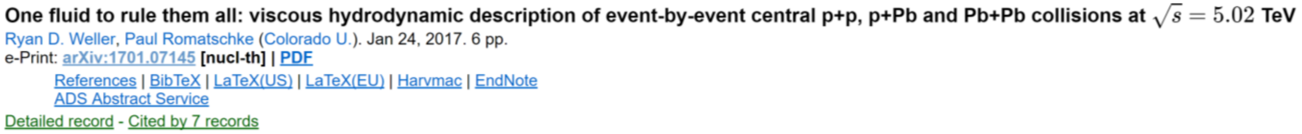
$\sigma_{\varepsilon 2}/\varepsilon_2 \sim \sigma_{v2}/v_2$

In p+A, proton substructure matters

Not ^{3}He but rather 3 constituent quarks


Initial energy density (IP-glasma)

Simplest extension to proton substructure…



One fluid to rule them all: viscous hydrodynamic description of event-by-event central p+p, p+Pb and Pb+Pb collisions at $\sqrt{s} = 5.02$ TeV
Ryan D. Weller, Paul Romatschke (Colorado U.). Jan 24, 2017. 6 pp.
e-Print: arXiv:1701.07145 **[nucl-th]** | **PDF**
References | BibTeX | LaTeX(US) | LaTeX(EU) | Harvmac | EndNote
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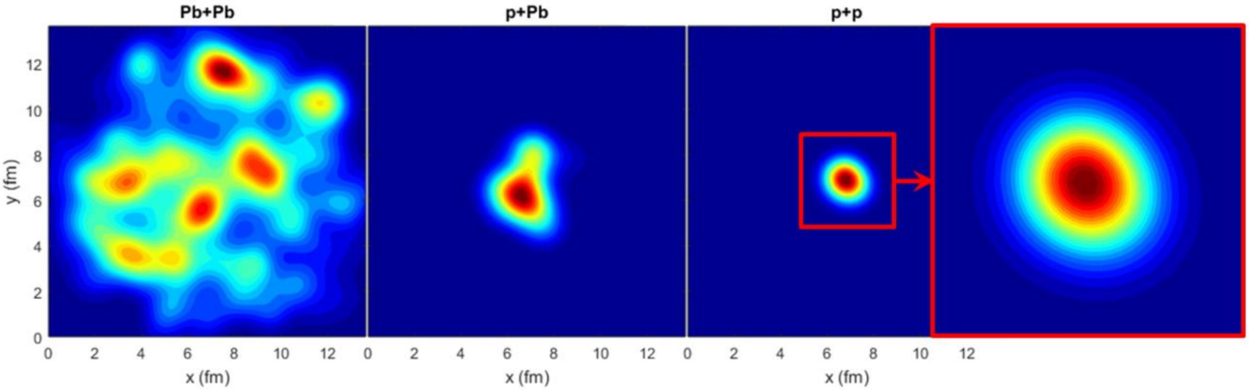
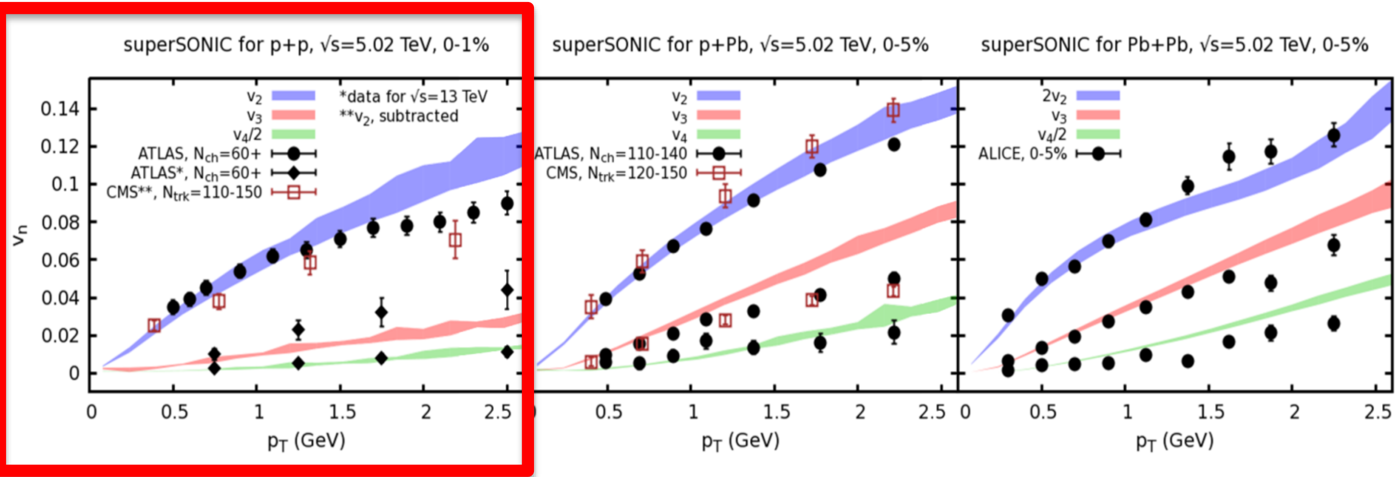
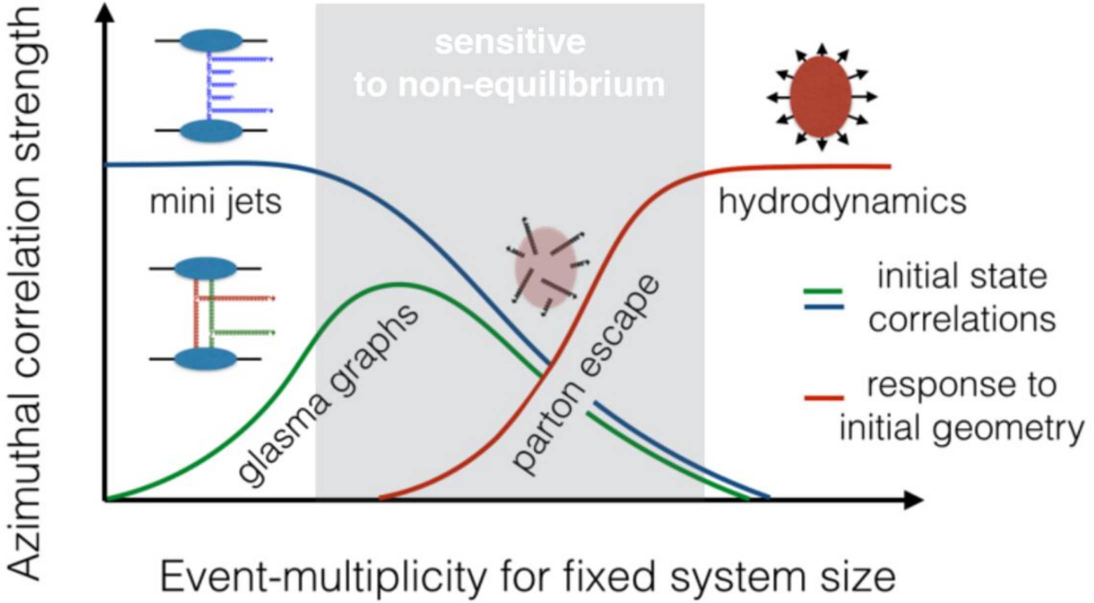






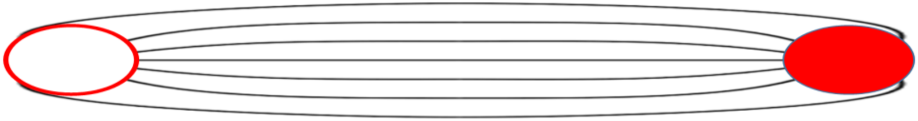
-> Small systems provide a unique laboratory to

Really? Where does low-multiplicity d+Au @ 39 GeV fit (mini-jets?)

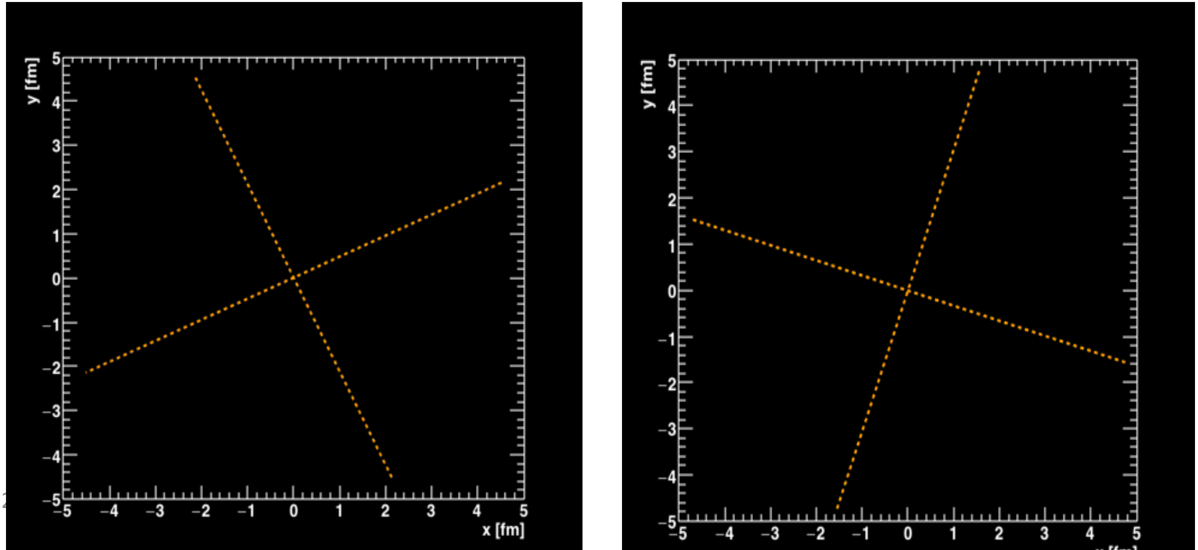
This paradigm does not address the data as a whole (RHIC & LHC, pp-pA-dA-HeA, …)

What about in e^+e^- collisions?

Study with modified AMPT underway. Geometry only from fluctuations in parton generation from a single string.



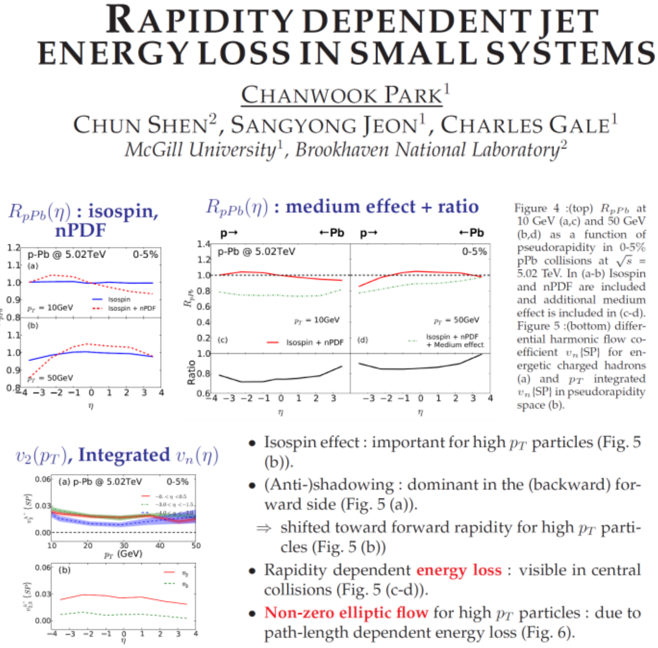
Quark + Antiquark make a single color string. CM Energy = Z0 mass.



What are small system results telling us?

What are predictions or consequences of hydrodynamics or final state parton scattering in small systems?

Jet Quenching Effects?



RAPIDITY DEPENDENT JET ENERGY LOSS IN SMALL SYSTEMS

CHANWOOK PARK[1]
CHUN SHEN[2], SANGYONG JEON[1], CHARLES GALE[1]
McGill University[1], Brookhaven National Laboratory[2]

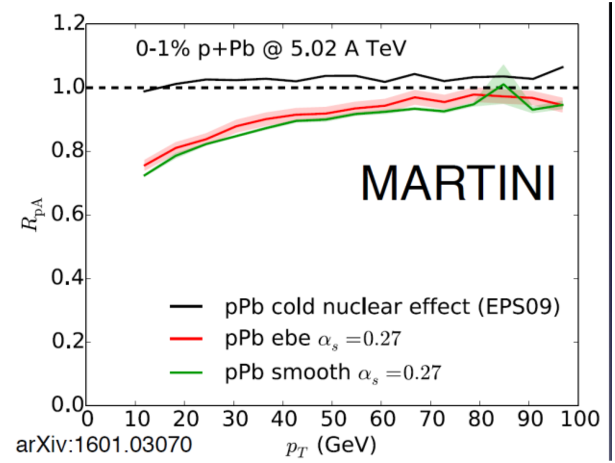
$R_{pPb}(\eta)$: isospin, nPDF

$R_{pPb}(\eta)$: medium effect + ratio

Figure 4 :(top) R_{pPb} at 10 GeV (a,c) and 50 GeV (b,d) as a function of pseudorapidity in 0-5% pPb collisions at $\sqrt{s}$ = 5.02 TeV. In (a-b) Isospin and nPDF are included and additional medium effect is included in (c-d). Figure 5 :(bottom) differential harmonic flow coefficient $v_n\{SP\}$ for energetic charged hadrons (a) and p_T integrated $v_n\{SP\}$ in pseudorapidity space (b).

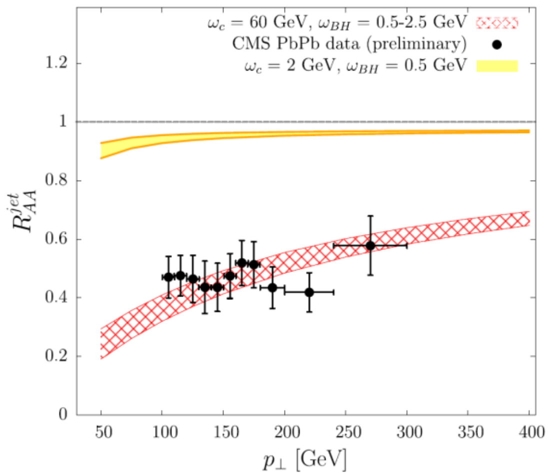
$v_2(p_T)$, Integrated $v_n(\eta)$

- Isospin effect : important for high p_T particles (Fig. 5 (b)).
- (Anti-)shadowing : dominant in the (backward) forward side (Fig. 5 (a)).
  ⇒ shifted toward forward rapidity for high p_T particles (Fig. 5 (b))
- Rapidity dependent **energy loss** : visible in central collisions (Fig. 5 (c-d)).
- **Non-zero elliptic flow** for high p_T particles : due to path-length dependent energy loss (Fig. 6).

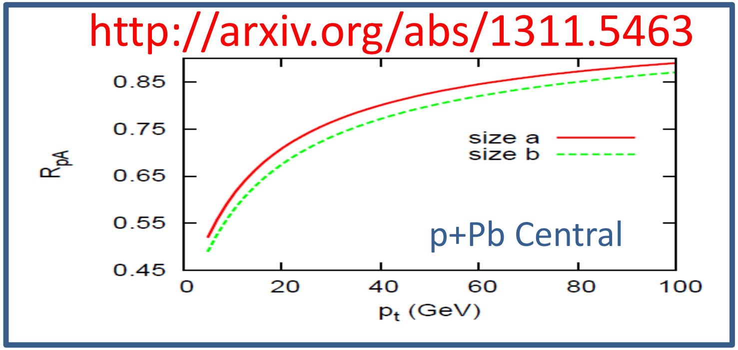


arXiv:1601.03070

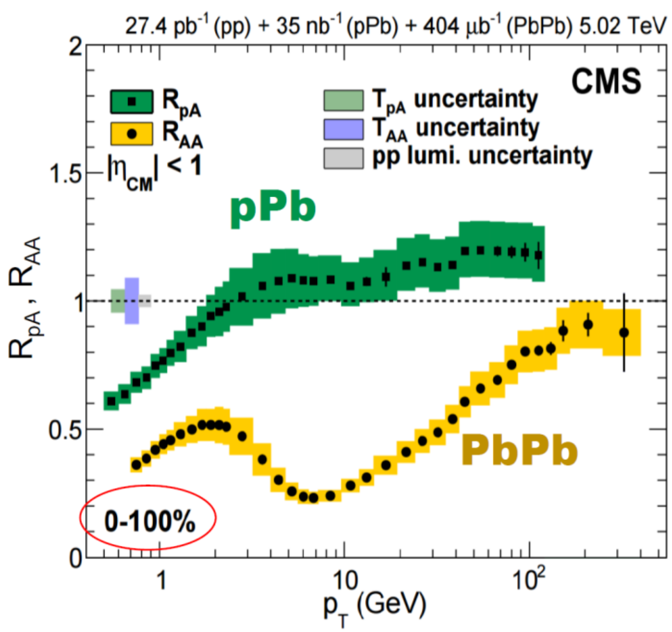
K. Tywoniuk / Nuclear Physics A 926 (2014) 85–91

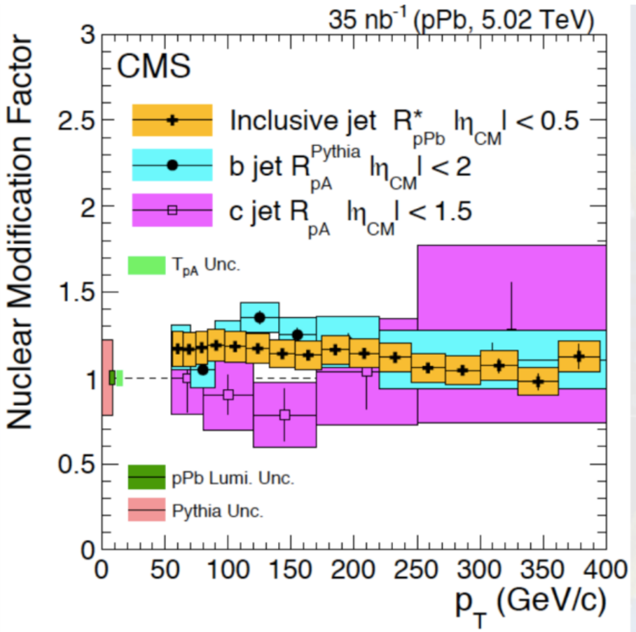


http://arxiv.org/abs/1311.5463



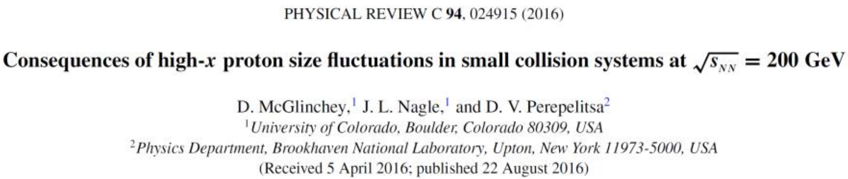
p+Pb Experimental Results (Minimum Bias)





Hard to find min. bias modifications at high p_T, though non-negligible systematic uncertainties.

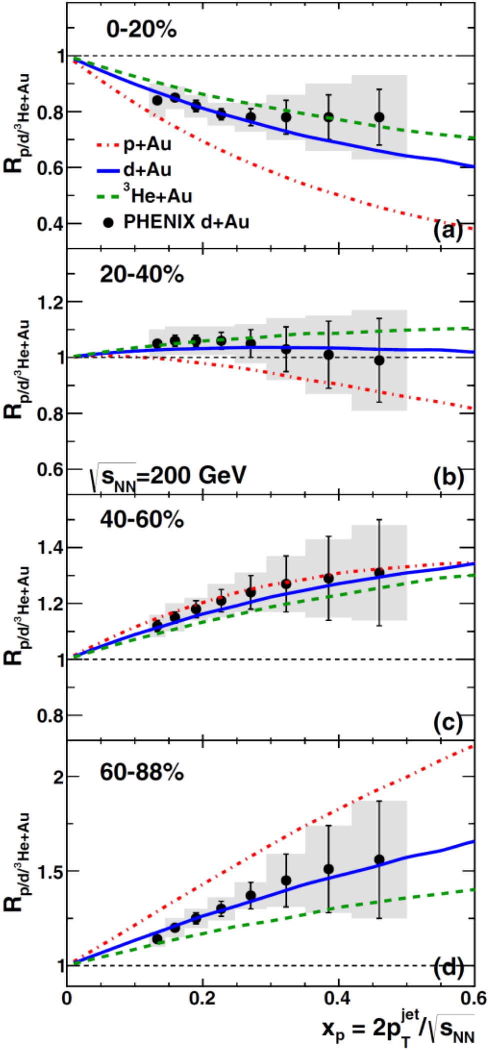
Multiplicity ("centrality") selection is still an open issue…



PHYSICAL REVIEW C **94**, 024915 (2016)

Consequences of high-x proton size fluctuations in small collision systems at $\sqrt{s_{NN}} = 200$ GeV

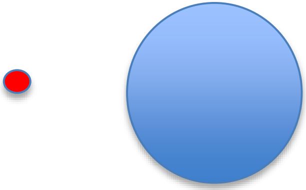
D. McGlinchey,[1] J. L. Nagle,[1] and D. V. Perepelitsa[2]
[1] *University of Colorado, Boulder, Colorado 80309, USA*
[2] *Physics Department, Brookhaven National Laboratory, Upton, New York 11973-5000, USA*
(Received 5 April 2016; published 22 August 2016)



How to resolve?

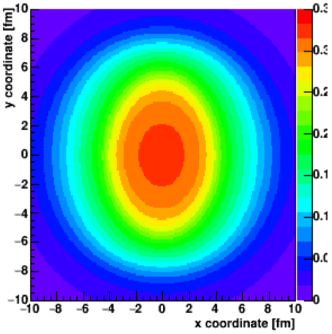
Is the auto-correlation with any centrality measure too big to overcome?

Exact physics model? Is that enough?



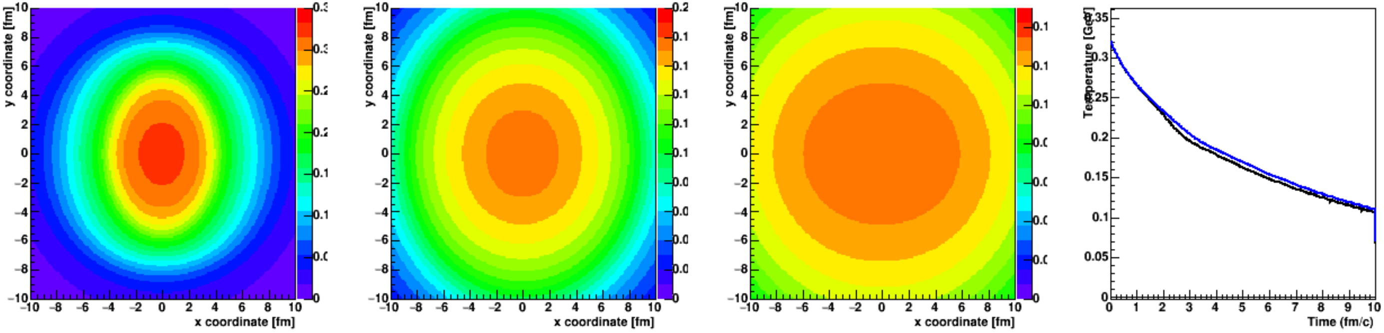
ALICE method with Pb-spectator neutrons might help, but a very broad central bin (nothing like 0-1%)...

Jet quenching and high p_T v_2



Looks like a big path dependence (up vs. down)

However, hydrodynamic evolution washes most of this out. Only very modest temperature difference at late time between paths.



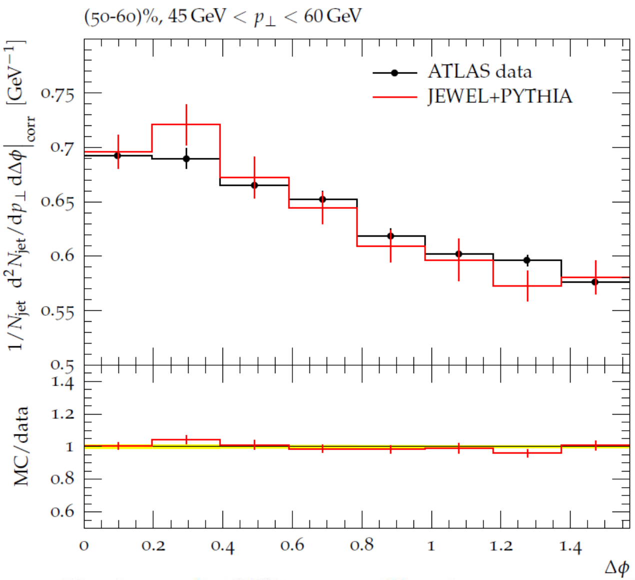
This is why quenching models invoke “near Tc enhancement”. Trying to amplify this late time small difference.

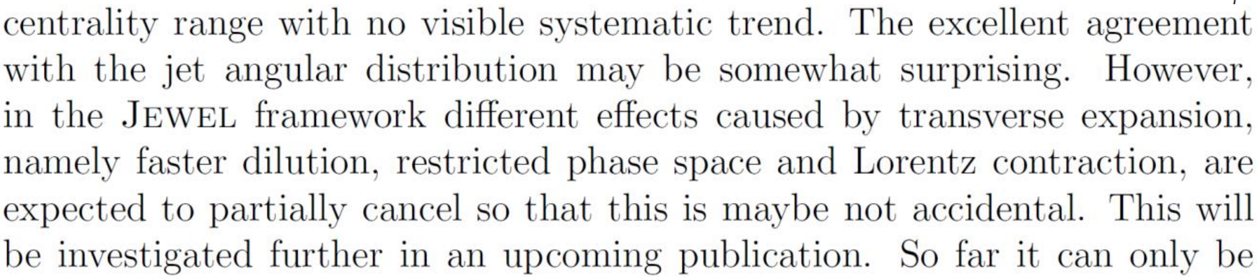
JEWEL – question of path dependence versus jet shape…

The default JEWEL medium does not expand in the transverse plane…

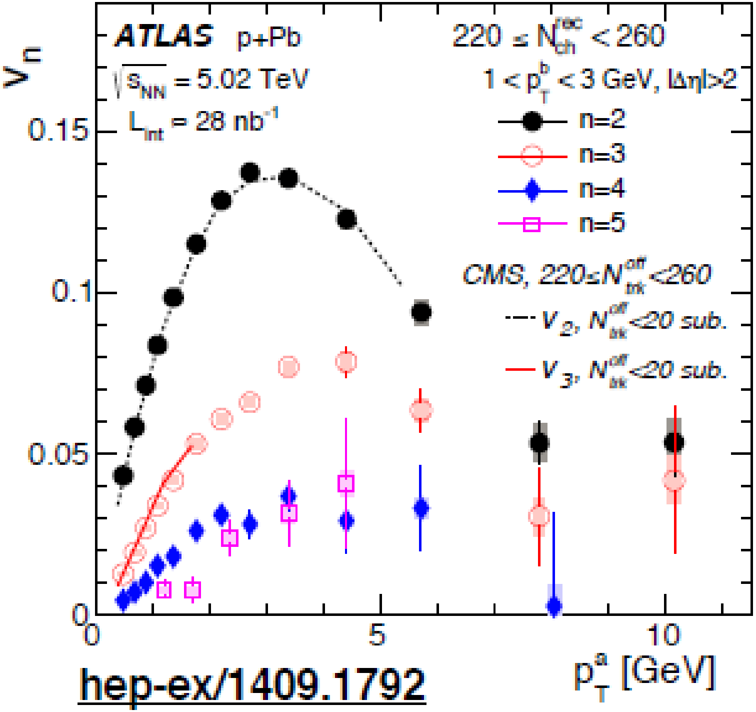
Pb+Pb agreement with high pT jet v2.

However….

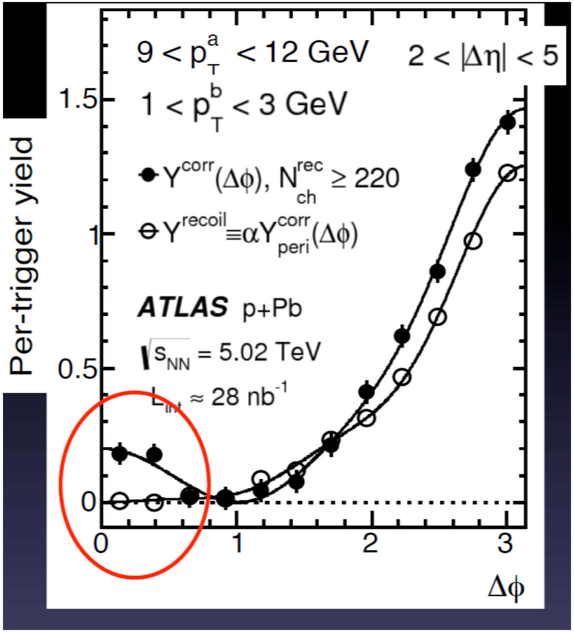



centrality range with no visible systematic trend. The excellent agreement with the jet angular distribution may be somewhat surprising. However, in the JEWEL framework different effects caused by transverse expansion, namely faster dilution, restricted phase space and Lorentz contraction, are expected to partially cancel so that this is maybe not accidental. This will be investigated further in an upcoming publication. So far it can only be

More than a hint in p+Pb at high p_T...

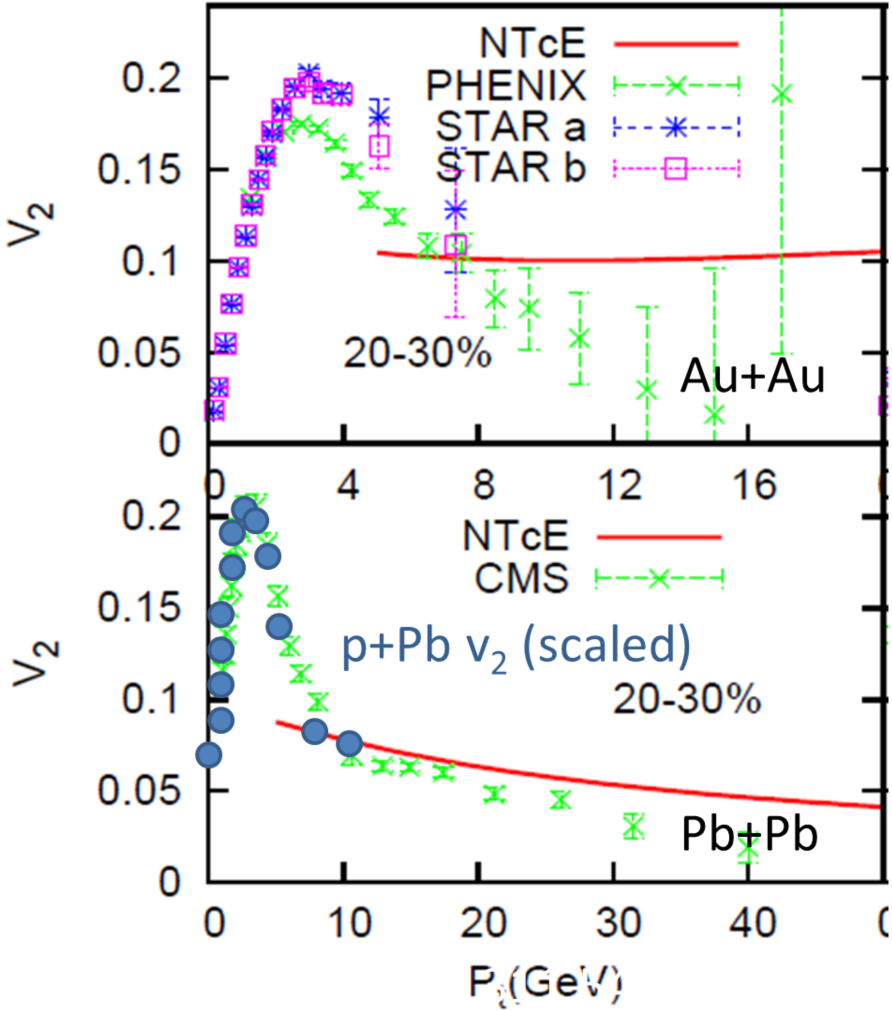


hep-ex/1409.1792



Would love to have more statistics extending up in pT…

Also with measurements at RHIC in p/d+Au…



NTcE – Near T_c Enhancement of medium coupling boosts the v2 at high p_T.

3 Regions

(1) Low pT → Hydro
(2) High pT → E-loss
(3) Mid pT → ???

Scaled p+Pb points match the Pb+Pb pattern

What does that tell us about the 3 regions?

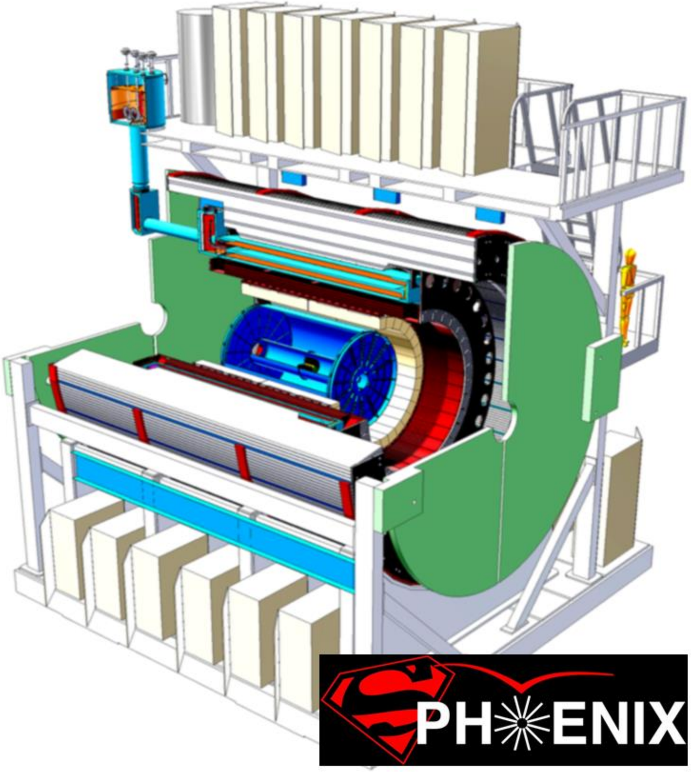
BaBar Magnet 1.5 T

Coverage $|\eta| < 1.1$

Inner MAPS tracker
Outer Fast TPC

Electromagnetic
Calorimeter

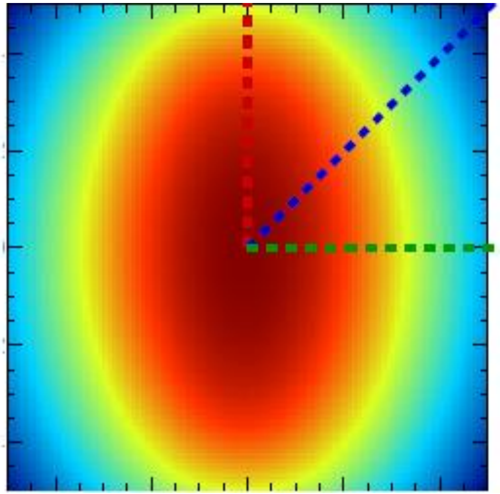
Hadronic
Calorimeter

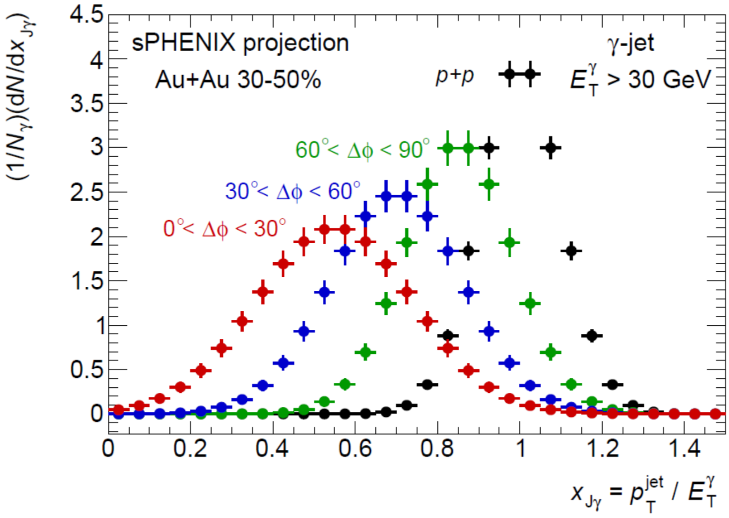


CD-0 Approval , September 27, 2016 !

Precision measurements at RHIC and the LHC

Golden channel where photon calibrates quark energy



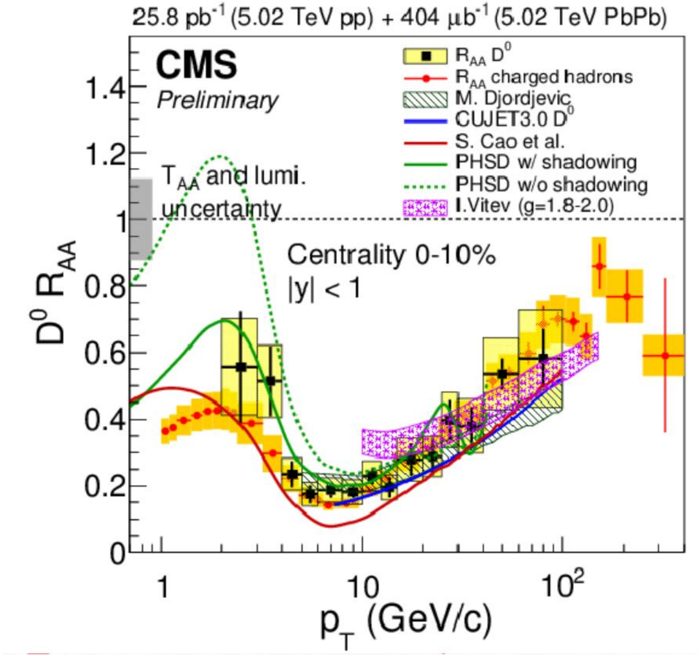


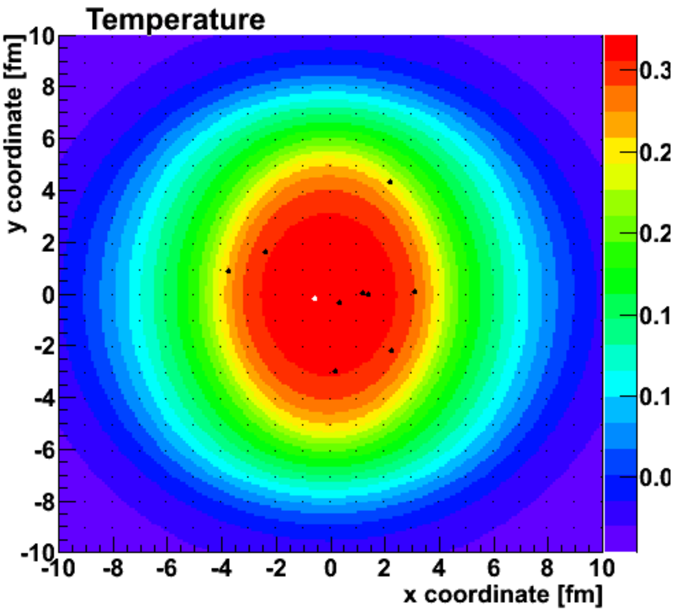
What are small system results telling us?

What are predictions or consequences of hydrodynamics or final state parton scattering in small systems?

Heavy Quark Effects?

Geometry and Shadowing Question

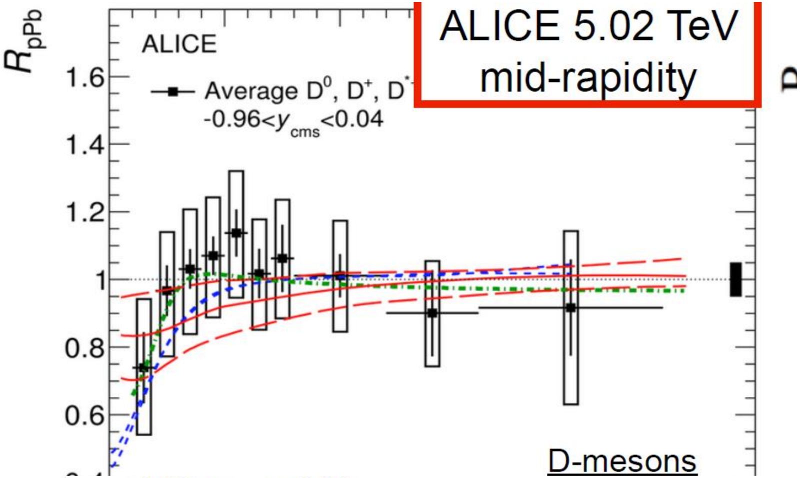




Shadowing suppressed charm x2 for pT < 3 GeV.

Key for description. What about the spatial correlation?

Heavy quarks in small systems…



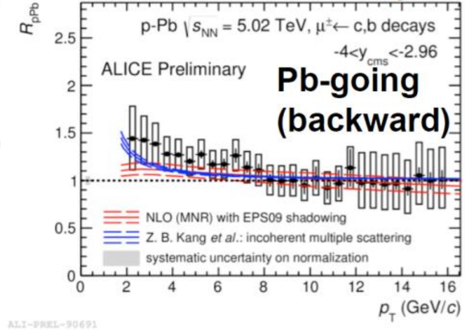
ALICE 5.02 TeV
mid-rapidity

D-mesons

$-4.46<y_{CMS}<-2.96$

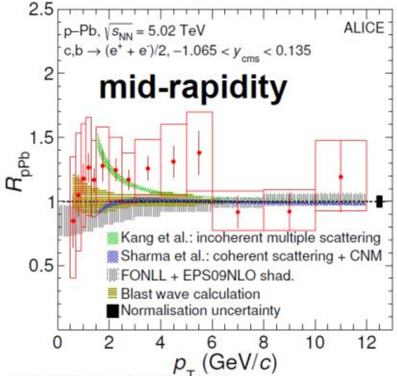
$10^{-2}<x<5\cdot10^{-2}$

c,b→μ



Pb-going (backward)

c,b→e

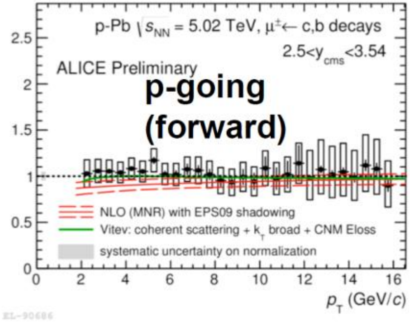


mid-rapidity

$2.03<y_{CMS}<3.53$

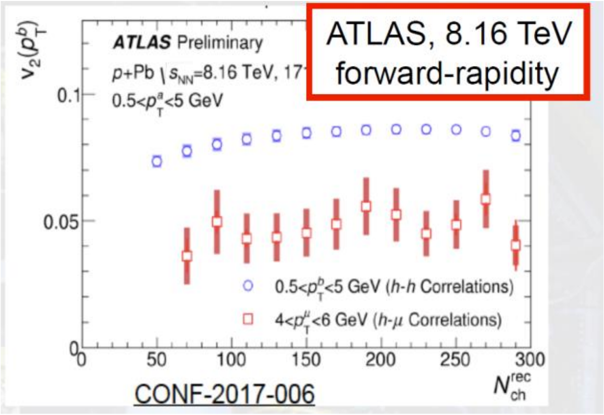
$10^{-5}<x<8\cdot10^{-5}$

c,b→μ



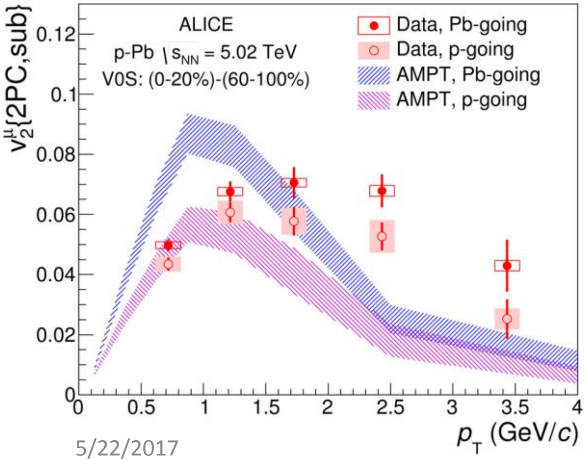
p-going (forward)

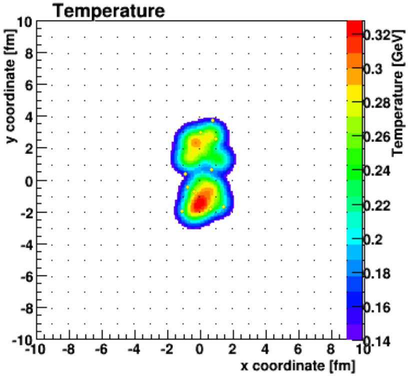
Charm in Small Systems

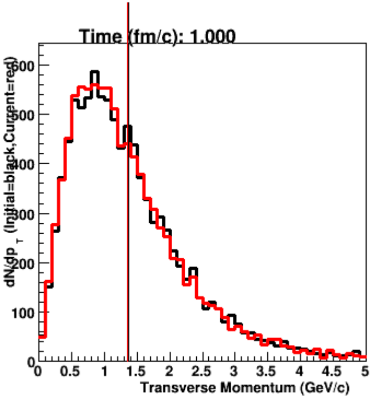


Field needs tests of medium in small systems.

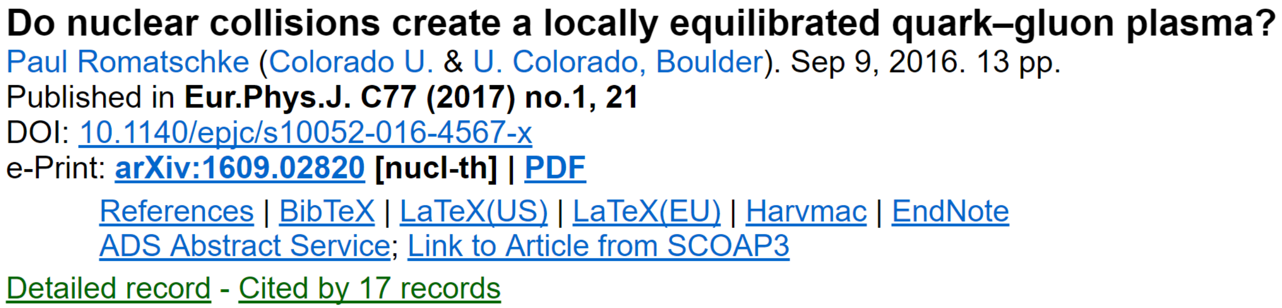
Heavy flavor shows signals already. Need calculations for full understanding and more data.



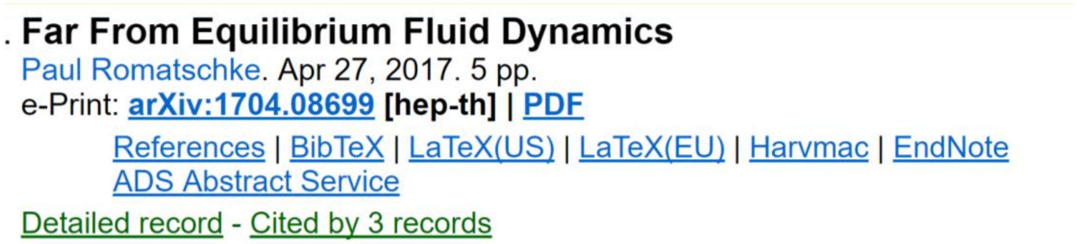




Small Systems
and
Big Questions



Do nuclear collisions create a locally equilibrated quark–gluon plasma?
Paul Romatschke (Colorado U. & U. Colorado, Boulder). Sep 9, 2016. 13 pp.
Published in **Eur.Phys.J. C77 (2017) no.1, 21**
DOI: 10.1140/epjc/s10052-016-4567-x
e-Print: **arXiv:1609.02820 [nucl-th] | PDF**
References | BibTeX | LaTeX(US) | LaTeX(EU) | Harvmac | EndNote
ADS Abstract Service; Link to Article from SCOAP3
Detailed record - Cited by 17 records



. **Far From Equilibrium Fluid Dynamics**
Paul Romatschke. Apr 27, 2017. 5 pp.
e-Print: **arXiv:1704.08699 [hep-th] | PDF**
References | BibTeX | LaTeX(US) | LaTeX(EU) | Harvmac | EndNote
ADS Abstract Service
Detailed record - Cited by 3 records

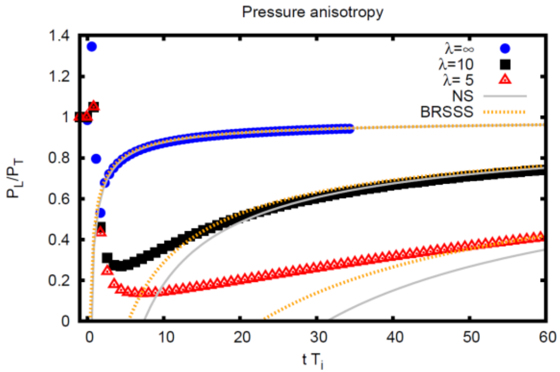
Papers I am trying to understand…

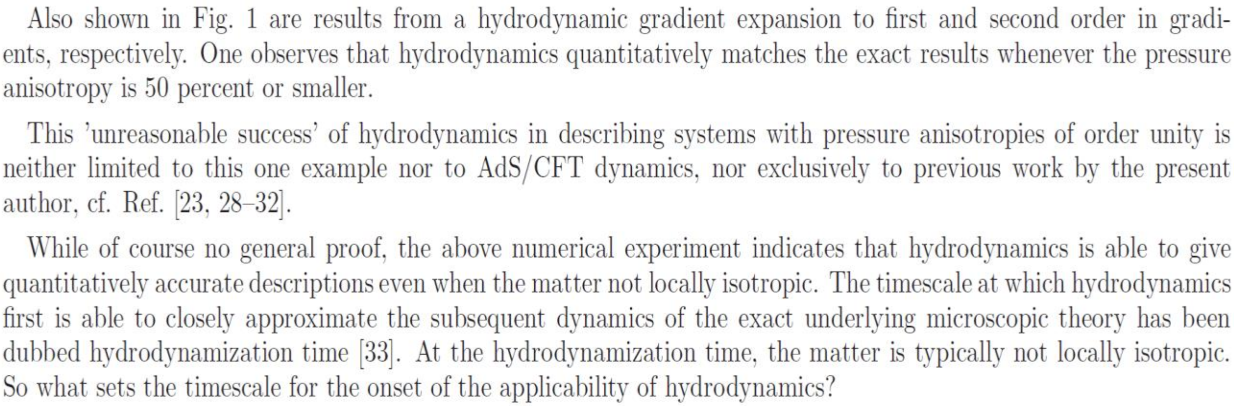
- What if the conjectures are correct – always far from equilibrium?
- How to test if the conjectures are correct?

Equilibration – is this required to call system a Quark-Gluon Plasma?

Isotropization – thought to be a required condition….

Hydrodynamization – just means the hydrodynamic description works

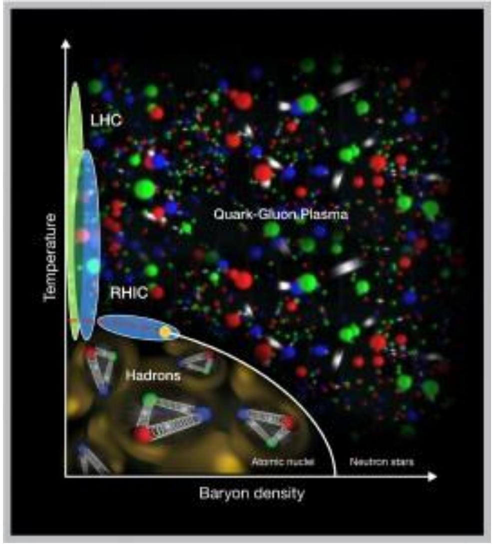




Also shown in Fig. 1 are results from a hydrodynamic gradient expansion to first and second order in gradients, respectively. One observes that hydrodynamics quantitatively matches the exact results whenever the pressure anisotropy is 50 percent or smaller.

This 'unreasonable success' of hydrodynamics in describing systems with pressure anisotropies of order unity is neither limited to this one example nor to AdS/CFT dynamics, nor exclusively to previous work by the present author, cf. Ref. [23, 28–32].

While of course no general proof, the above numerical experiment indicates that hydrodynamics is able to give quantitatively accurate descriptions even when the matter not locally isotropic. The timescale at which hydrodynamics first is able to closely approximate the subsequent dynamics of the exact underlying microscopic theory has been dubbed hydrodynamization time [33]. At the hydrodynamization time, the matter is typically not locally isotropic. So what sets the timescale for the onset of the applicability of hydrodynamics?



If heavy ion collisions create matter that is never very close to local equilibrium (big if), in what sense do we call it a quark-gluon plasma?

What does it then mean to say “heavy quarks are thermalized”, “energy lost by the jet is equilibrated”?

Maybe it is just a chocolate chip cookie.