Elliptic Anisotropy v_2 May Be Dominated by Particle Escape instead of Hydrodynamic Flow

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Mostly based on *arXiv:1502.05572v3:*

Liang He, Terrence Edmonds, Zi-Wei Lin, Feng Liu, Denes Molnar, Fuqiang Wang:

Anisotropic parton escape is the dominant source of azimuthal anisotropy in transport models

Outline

Current paradigm of v_n development in heavy ion collisions

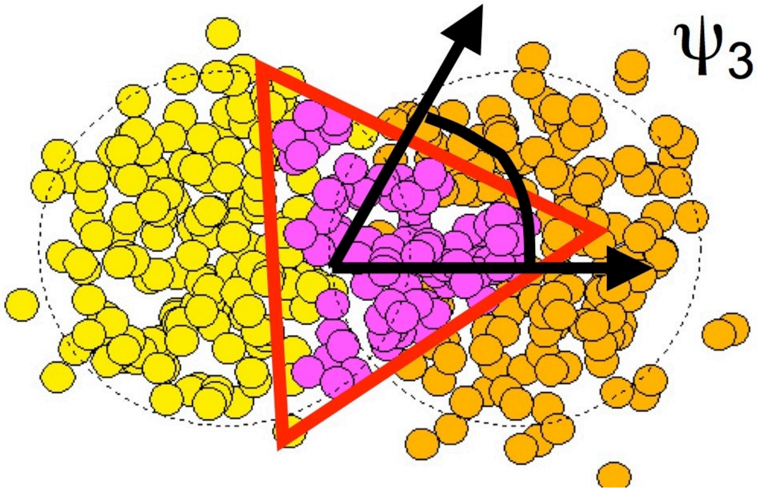
Our method: track all parton collisions

Estimate contribution of anisotropic particle escape to v_2
by destroying collective flow (through random-ϕ test)

Potential Consequences

Current Paradigm of v_n Development

Both hydrodynamics and transport models have been used to study v_n :



Alver and Roland, PRC 81 (2010)
discovered significant triangular flow
using A Multi-Phase Transport (AMPT);
➔ intense developments of
event-by-event hydrodynamics.

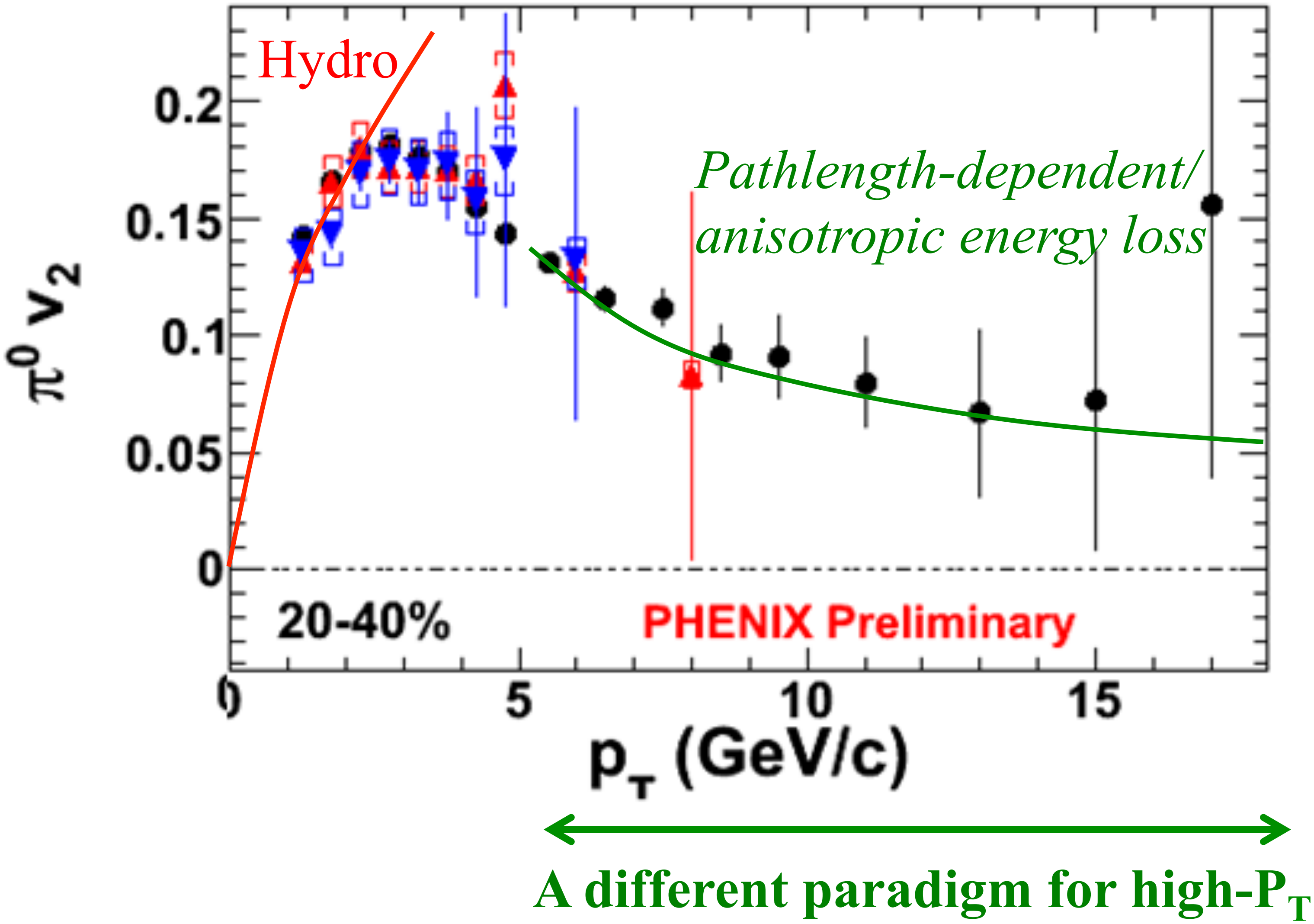
Current Paradigm

- Early hydro-type collective flow in sQGP
converts initial spatial anisotropy into final momentum-space v_n

- Transport models at large-enough cross section will approach hydrodynamics.

- Since both hydrodynamics and transport models can describe v_n data,
it is generally believed: for low-P_T in high-energy heavy ion collisions,
the mechanism of v_n development in transport models *(via particle interactions)*
is in principle the same as in hydrodynamics *(via pressure gradient)*.

Current Paradigm of v_n Development

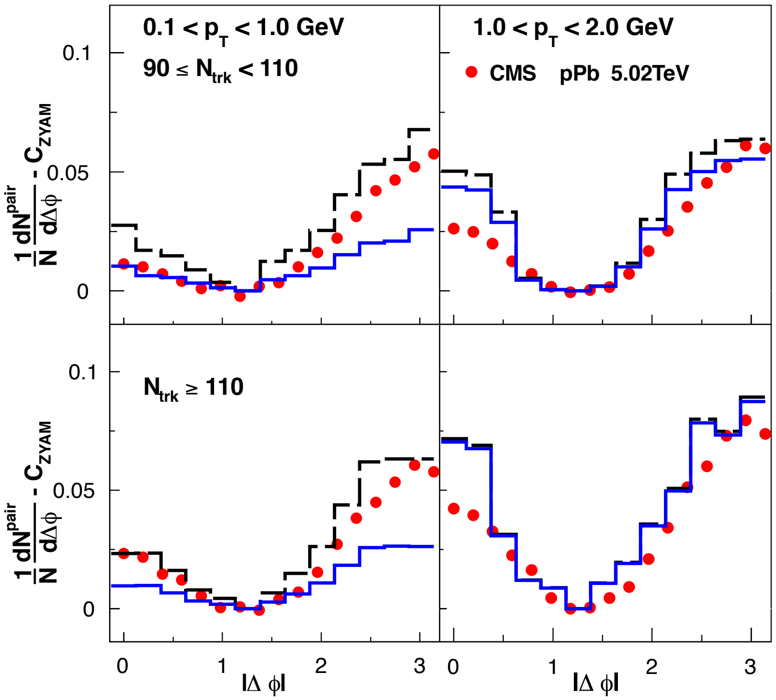


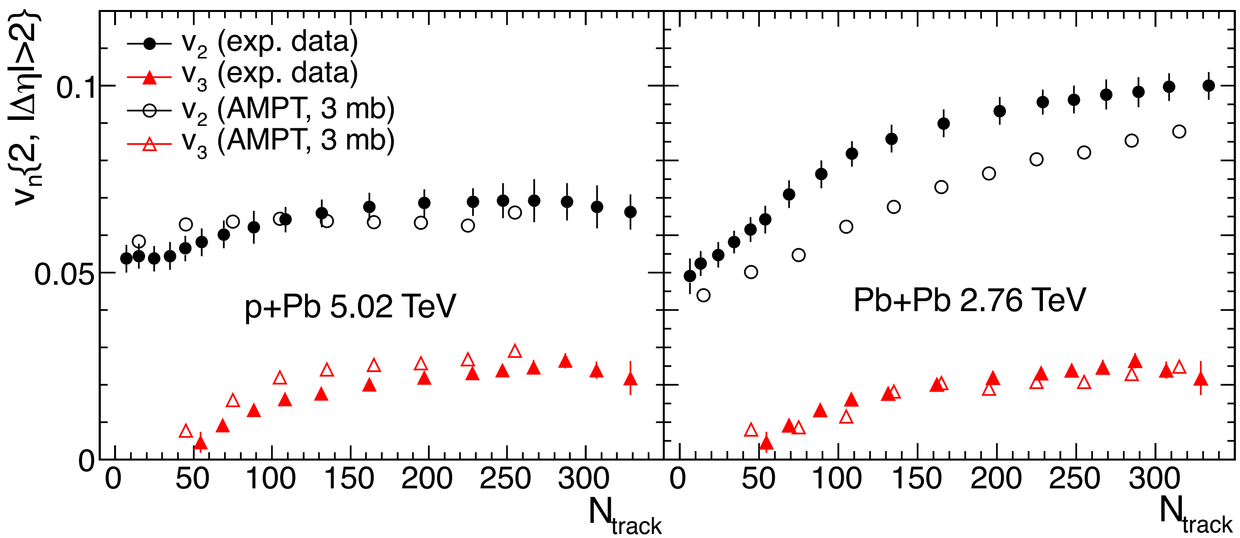
It is generally believed:

high-P_T observables cannot be described by hydrodynamics,
high-P_T v_2 is dominated by anisotropic energy loss before hadronization.

Current Paradigm of v_n Development

Small systems: both hydrodynamics and transport can describe flow





Bozek and Broniowski, PLB 718 (2013)
using e-by-e viscous hydrodynamics.

Bzdak and Ma, PRL 113 (2014)
using AMPT (String Melting version).

Puzzle for small systems such as p+Pb or d+Au:

mean free path may be comparable to the system size;

is hydrodynamics still applicable to such small systems?

Tracking Parton Collisions in Transport Models

Our method:

Study v_2 development

by tracking the complete collision history of each parton,

including

- separating partons into 3 populations:

  freezeout partons,

  active partons,

  all partons

- v_2 versus **Ncoll** (number of collisions suffered by a parton)

Most results shown here are obtained with AMPT (string melting version); some are obtained with MPC (elastic version of the parton cascade).

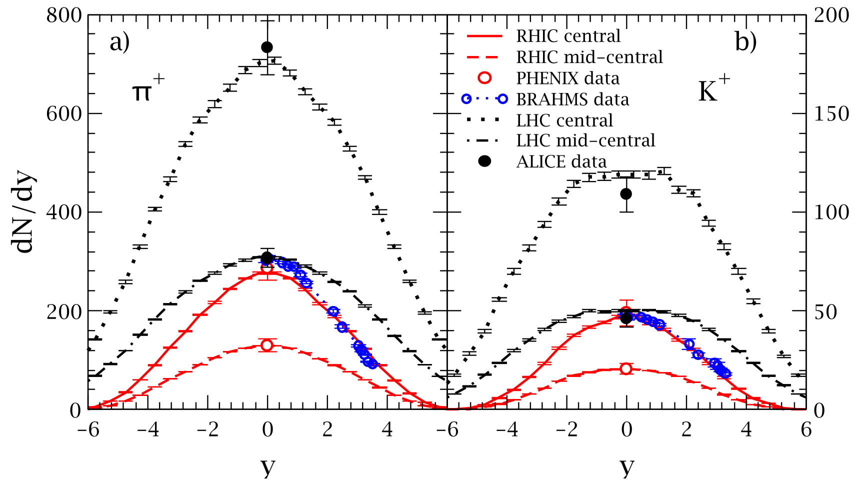
We only investigate the parton stage here.
v3 results are qualitative the same.

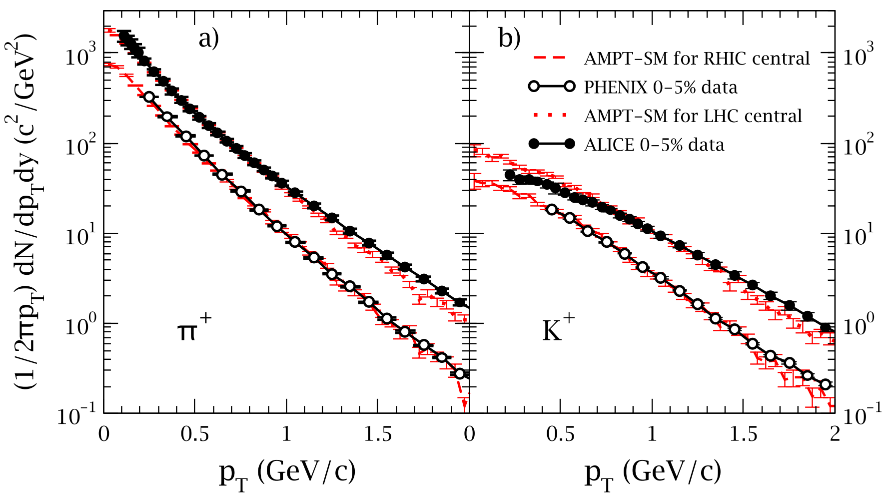
Constraining Parameters of the String Melting AMPT Model

Model has been tuned to reproduce low-pt π & K data on dN/dy, p_T spectra & v2 in central & mid-central 200AGeV Au+Au collisions: ZWL, PRC 90 (2014).

We use the same parameters for this study.

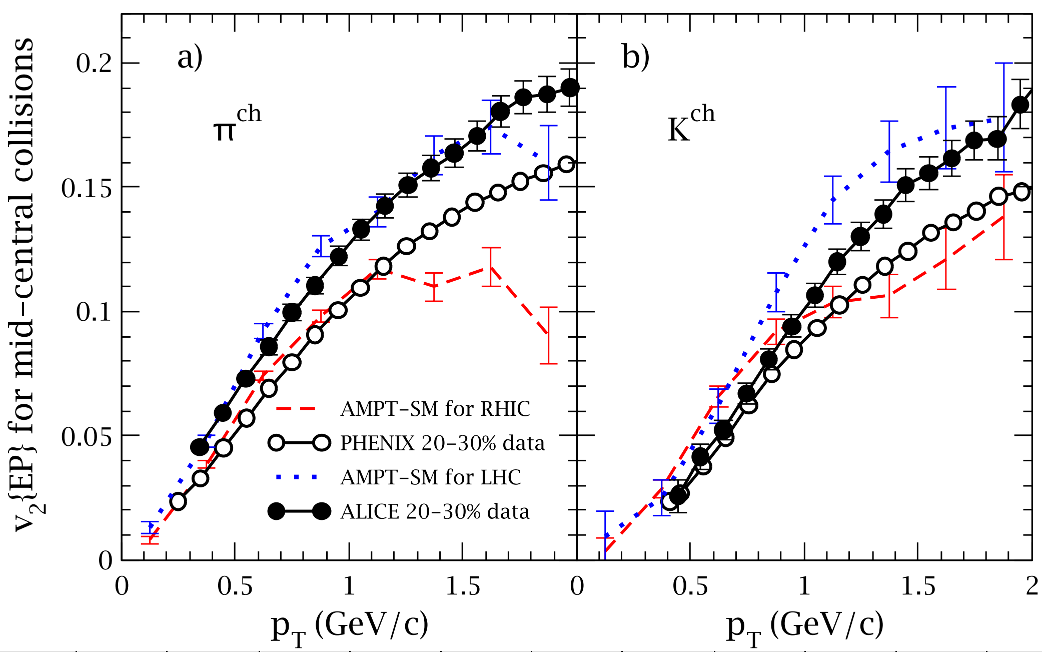
dN/dy of π & K





p_T spectra of π & K (in central collisions)

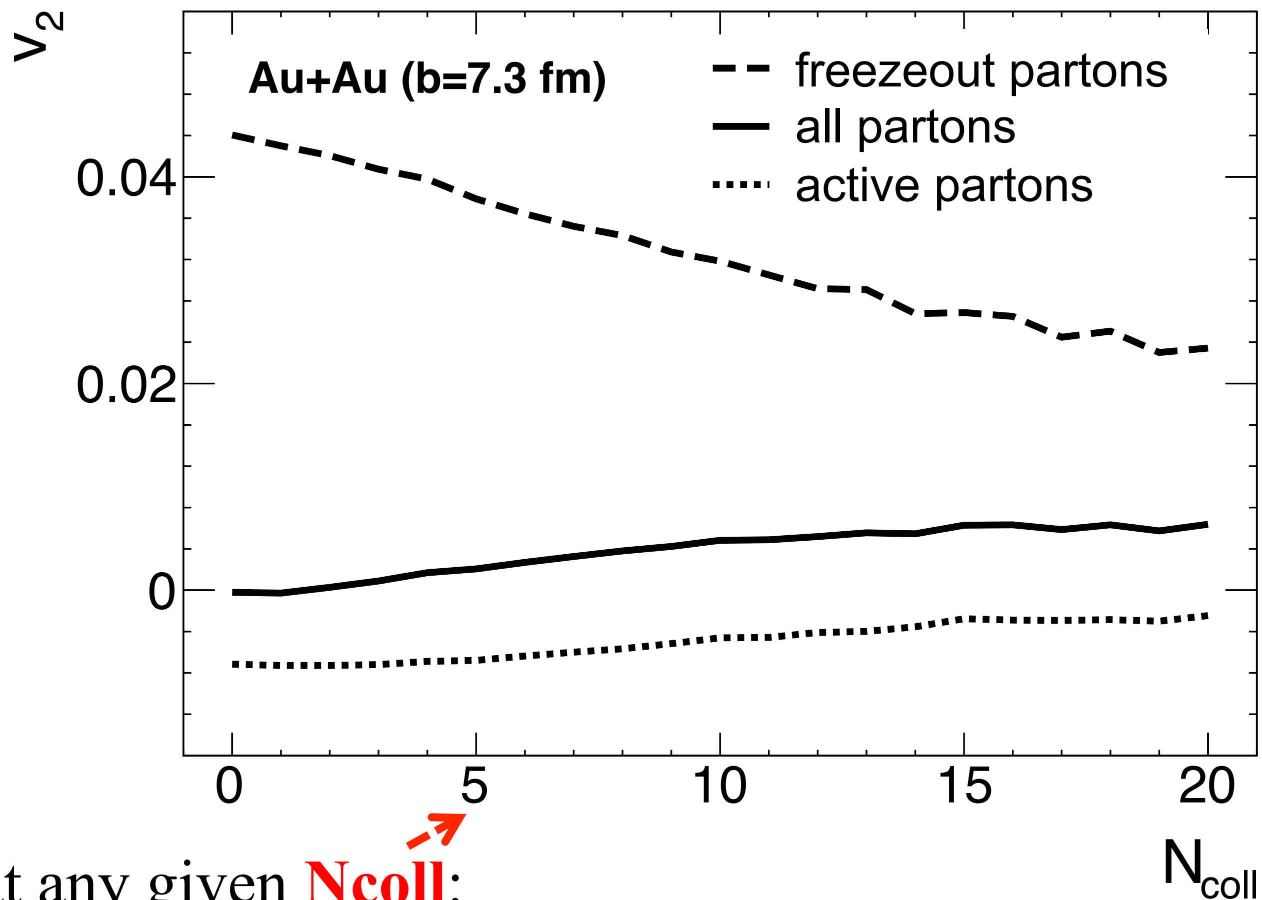
v2 of π & K (AuAu@200AGeV b=7.3fm)



Parton cross section σ =3mb

Results: v_2 versus collision # of each parton

Ncoll: *number of collisions suffered by a parton*



3 parton populations at any given **Ncoll**:

freezeout partons: *freeze out after exactly **Ncoll** collisions;*

active partons: *will collide further, freeze out after **>Ncoll** collisions;*

all partons: *sum of the above two populations*
*(i.e. all partons that have survived **Ncoll** collisions).*

Results: v_2 versus collision # of each parton

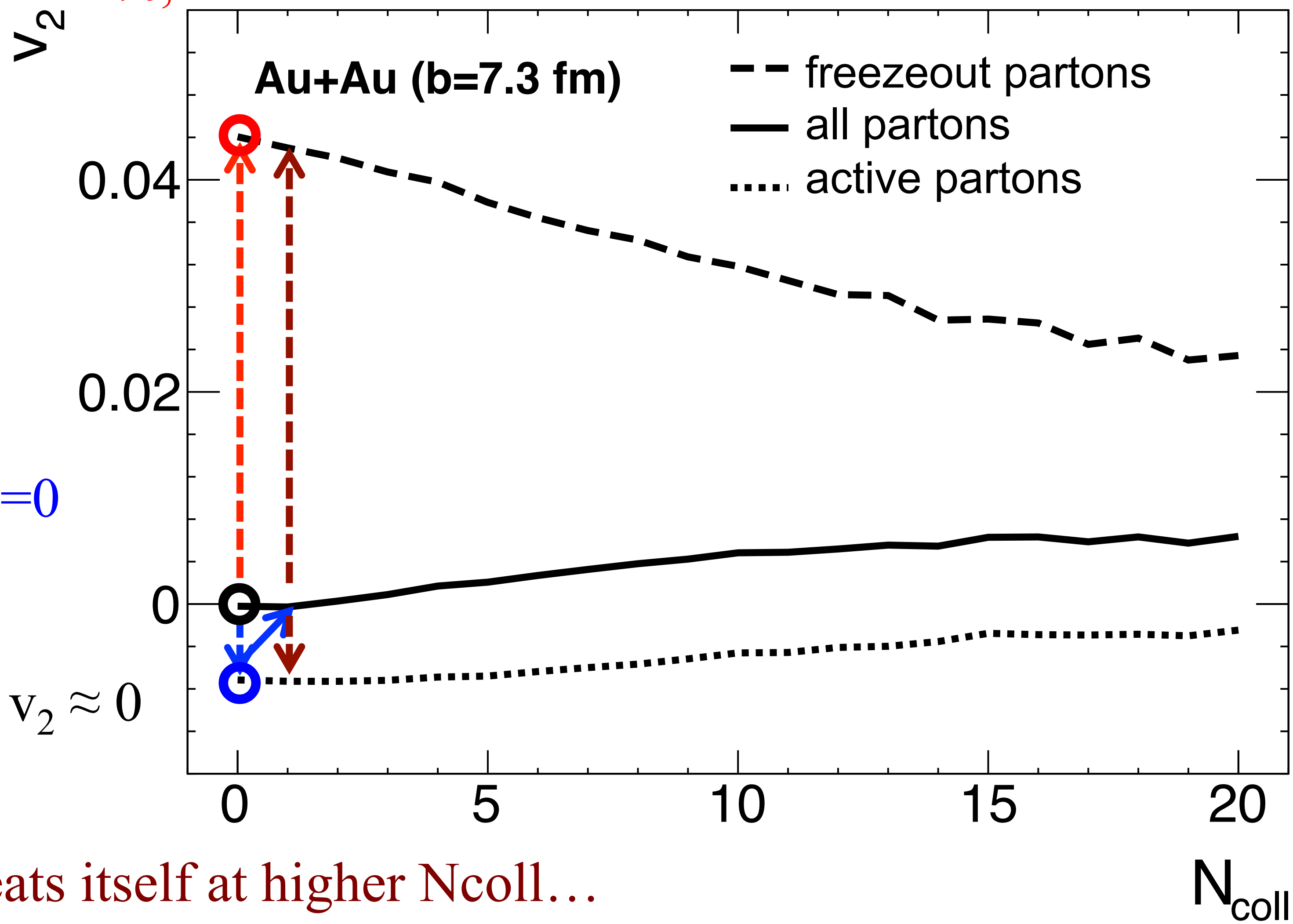
At Ncoll=0:

all partons: v_2=0 by symmetry;

they contain 2 parts:

escaped/freezeout: $v_2 \approx 4.5\%$,

active: $v_2 < 0$.



At Ncoll=1:

active partons at Ncoll=0

collide once each,

become

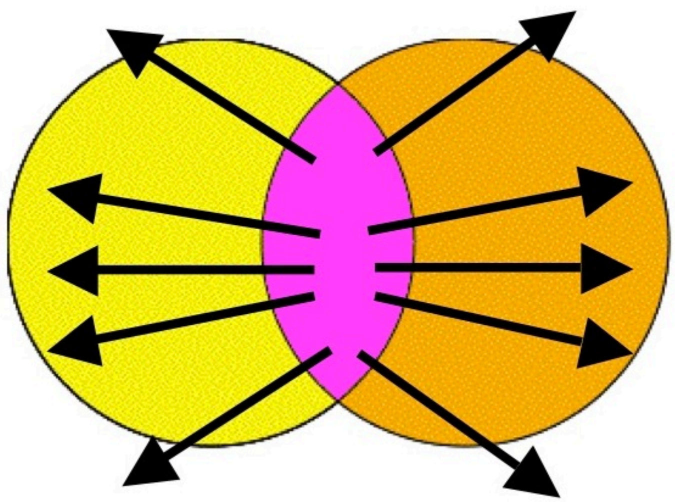
all partons at Ncoll=1: $v_2 \approx 0$

This process repeats itself at higher Ncoll…

Results: anisotropic particle escape

At Ncoll=0:
escaped partons: $v_2 \approx 4.5\%$,
purely due to
anisotropic escape probability
(response to geometrical shape only,
no contribution from collective flow)

In simplified picture of elliptic flow

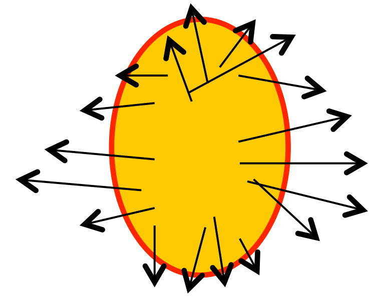


At Ncoll>=1:
escaped partons: $v_2 > 0$
due to
anisotropic escape probability
& (anisotropic) **collective flow**.

How to separate the two contributions?

Results: anisotropic particle escape

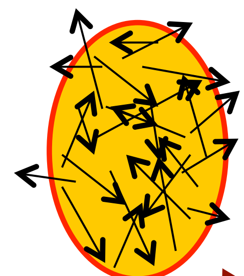
Final v_2 is generated by interactions in presence of spatial anisotropy, which also generate (anisotropic) collective flow.



f(**x**,**p**,t)

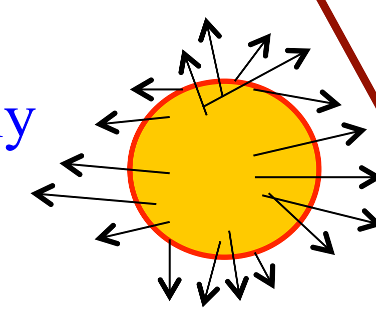
Let's view v_2 as coming from 2 separate but complimentary sources:

1) Pure escape ("the escape mechanism"):
v_2 from spatial anisotropy only
if there were 0 collective flow,
this is due to anisotropic escape probability.



f(**x**,iso **p**,t)

2) Pure flow: v_2 from anisotropic collective flow only
if there were no spatial anisotropy.



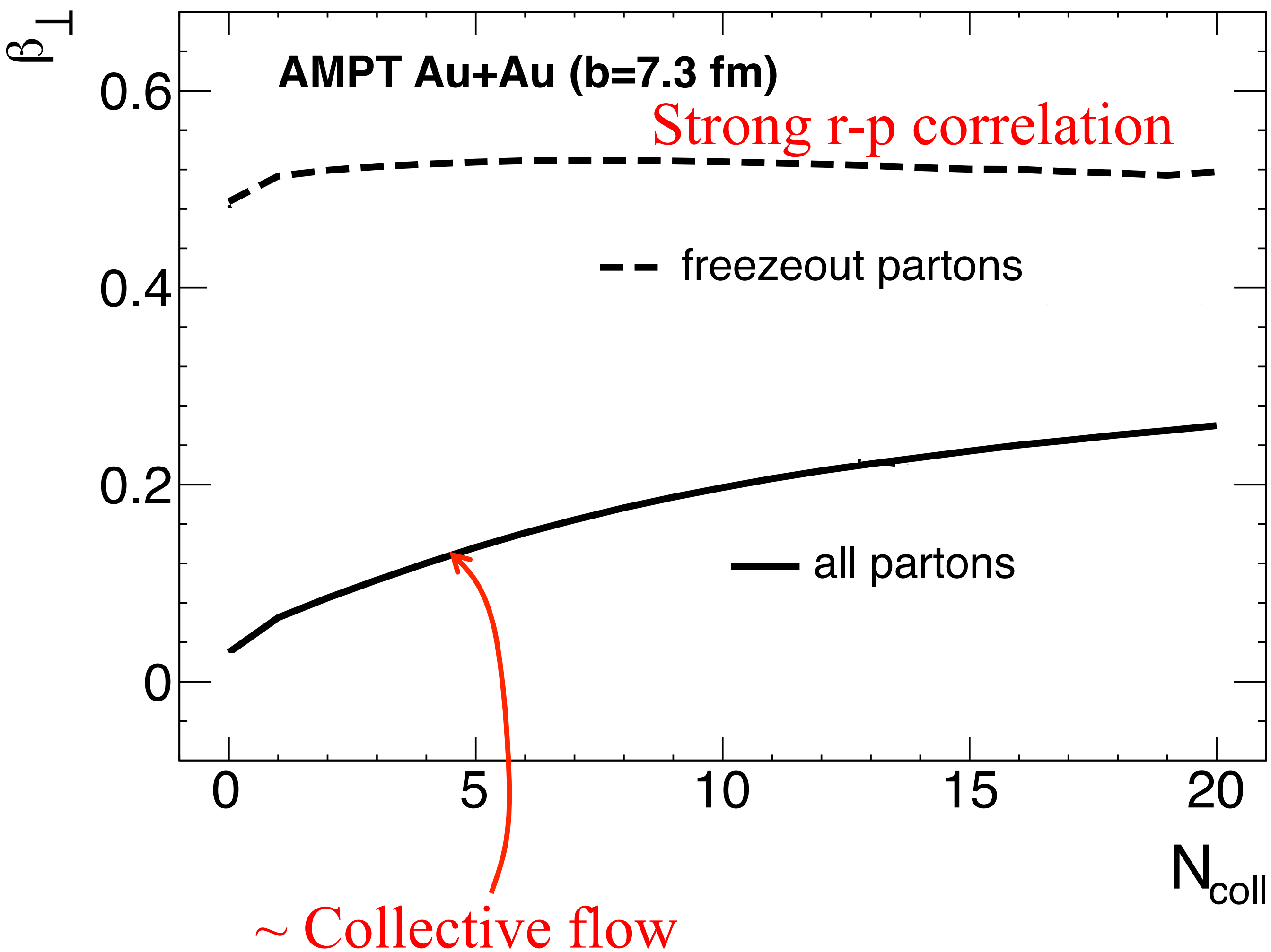
f(iso **x**,**p**,t)

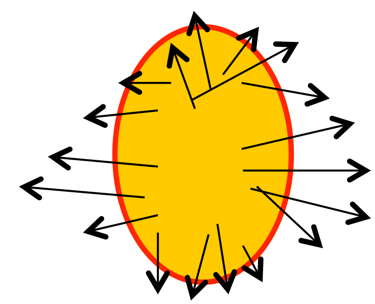
The two are coupled in the actual evolution,
so we design a Gedanken **random-ϕ test** to estimate contribution from **1)**:
we randomize ϕ after each parton scattering to destroy collective flow.

Results: space-momentum correlation vs collective flow

$$\beta_\perp = \left\langle \frac{\vec{r}_\perp \cdot \vec{p}}{r_\perp \; p} \right\rangle$$

reflects space-momentum correlation,
~ transverse flow velocity





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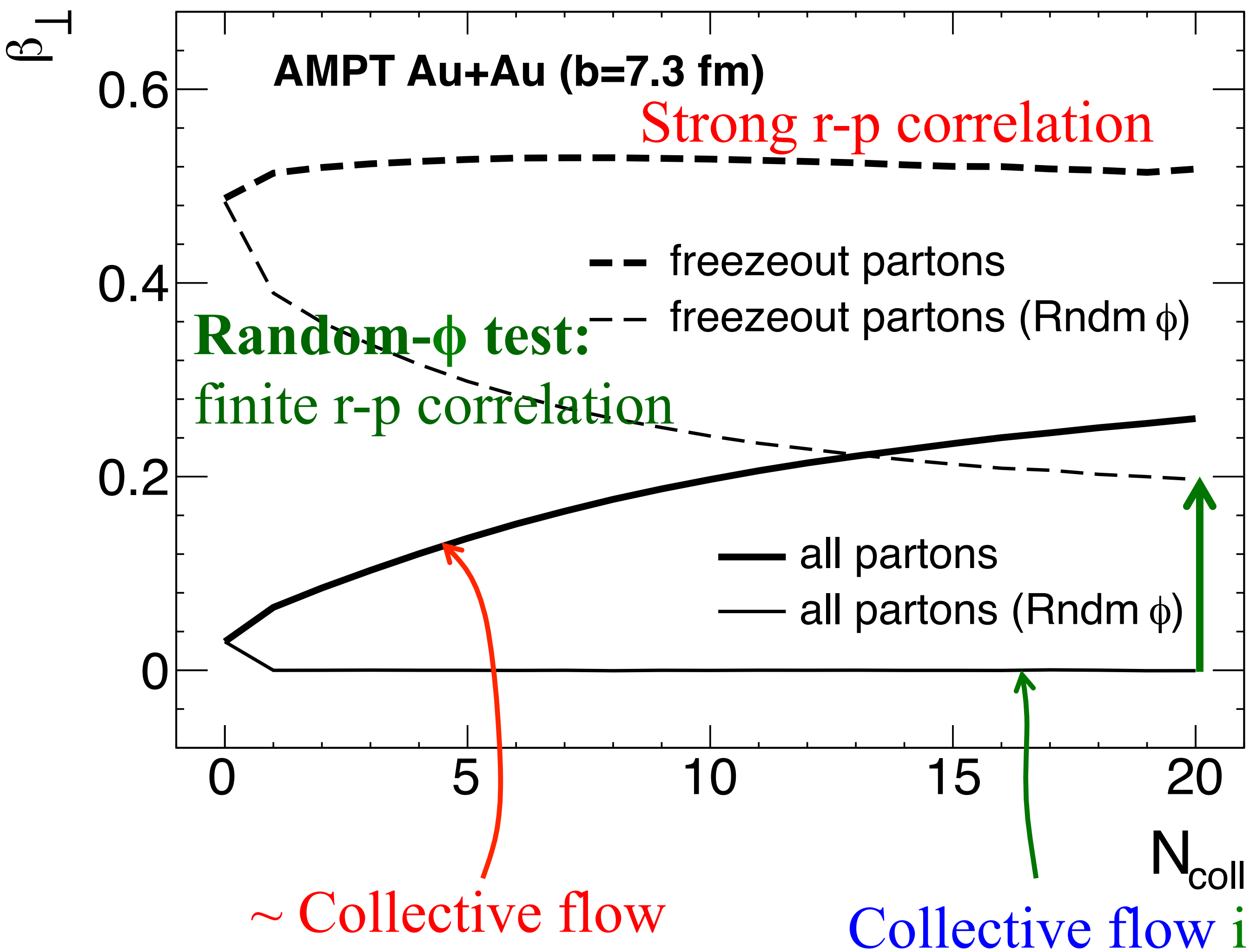
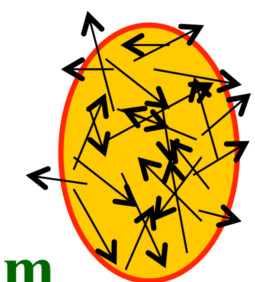
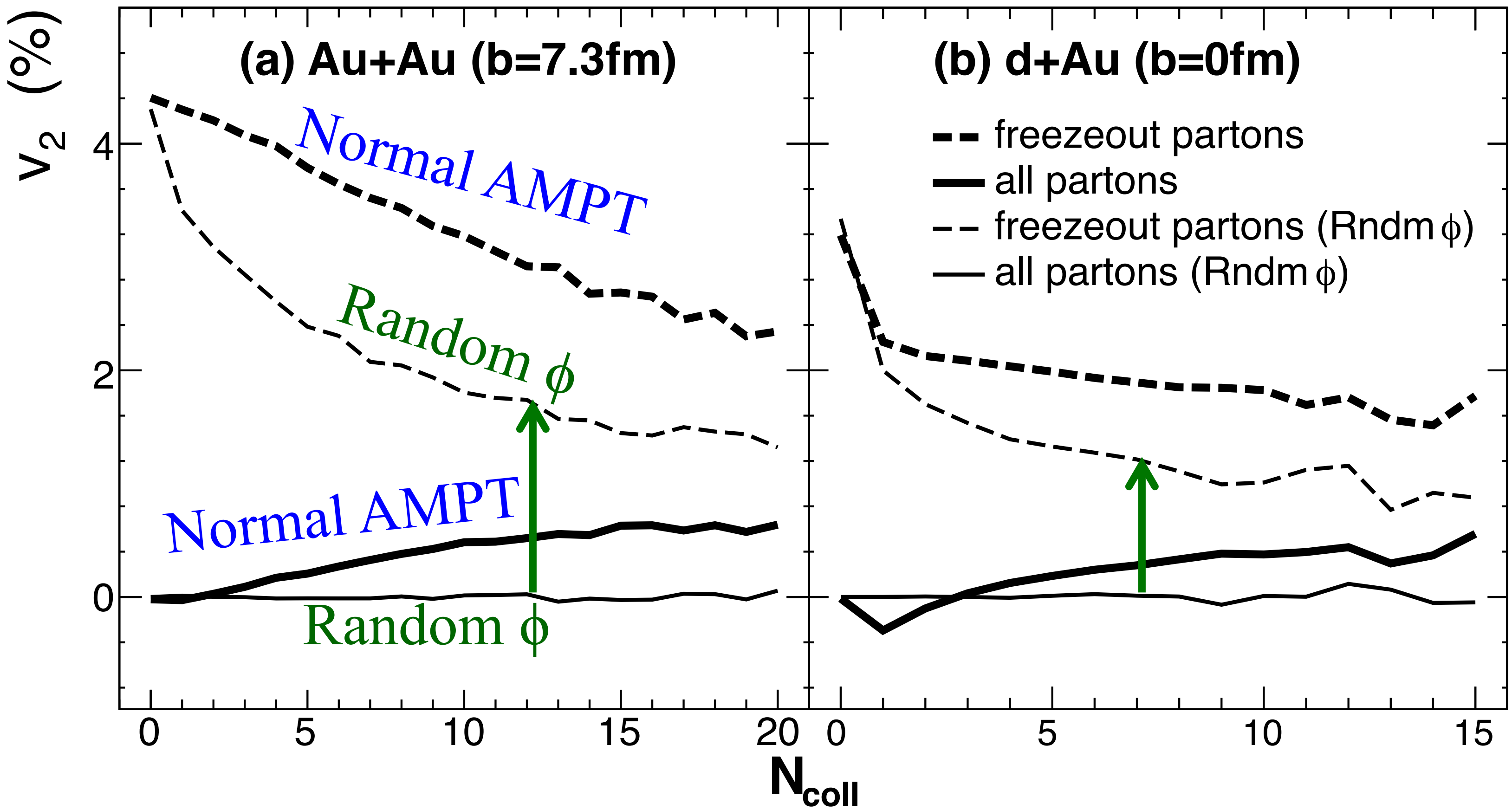


r-p correlation
purely from
escape mechanism,
not from collective flow



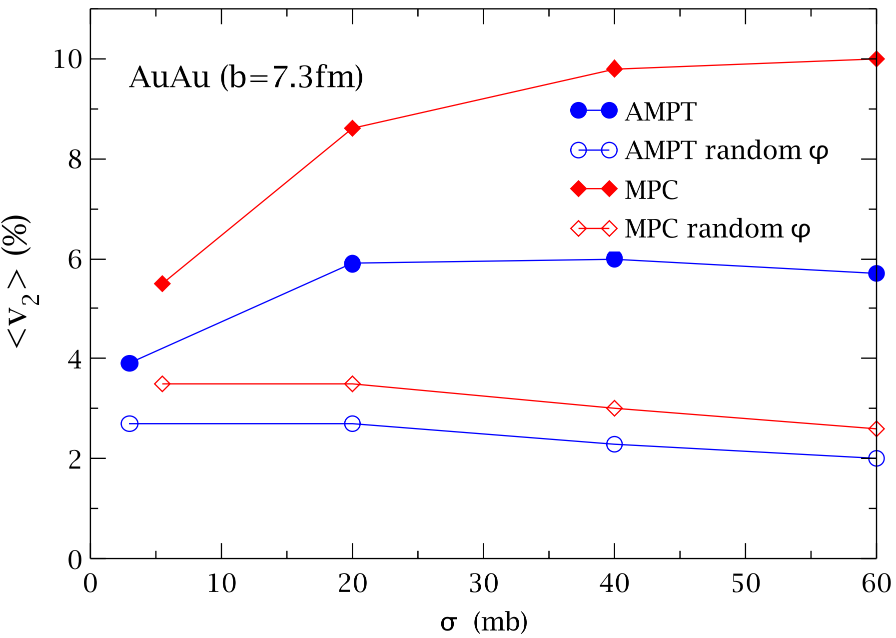
Results: contribution of escape mechanism to final v_2

v_2 from **Random Test:** purely from the escape mechanism

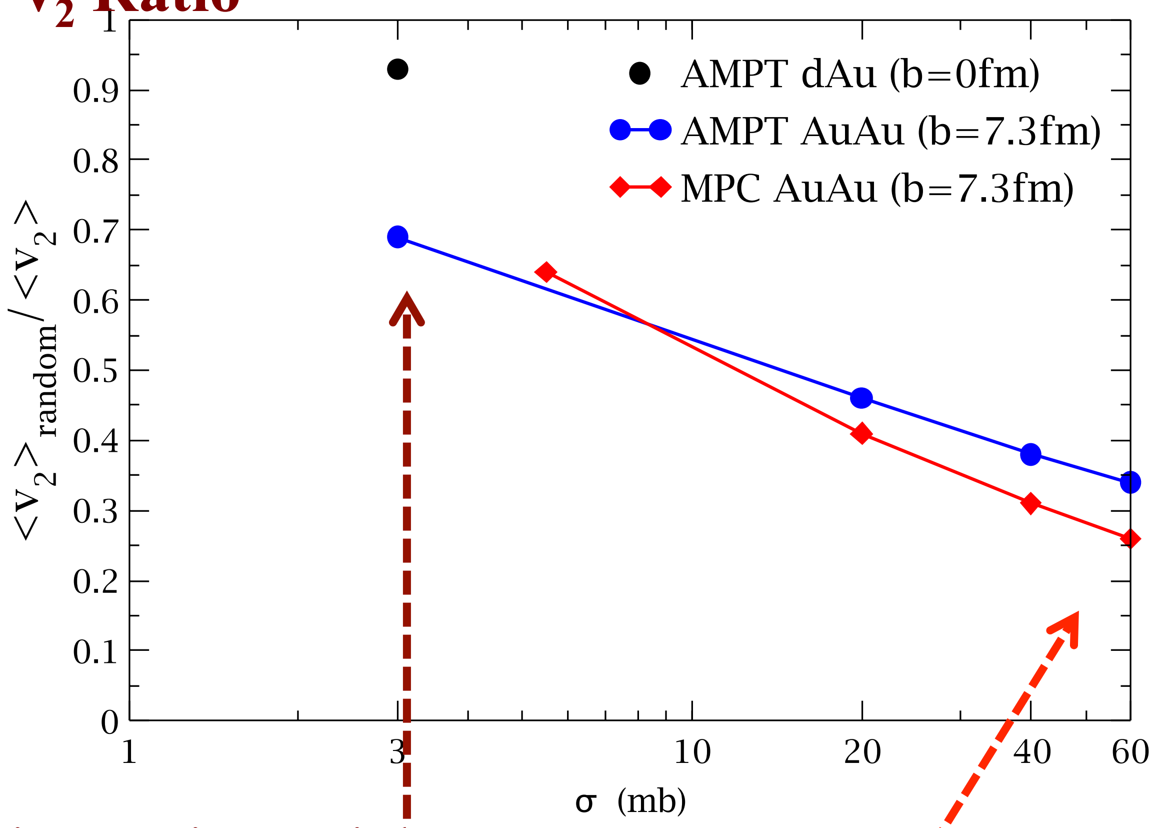


	Normal $\langle v_2 \rangle$	$\langle v_2 \rangle$ for random-ϕ	**Ratio** ~ contribution from pure escape	<Ncoll>
Au+Au	3.9%	2.7%	**69%**	4.6 (*modest*)
d+Au	2.7%	2.5%	**93%**	1.2 (*low*)

Results: contribution of escape mechanism to final v_2



v_2 Ratio



MPC: the same qualitative conclusion as AMPT
despite many differences
(*parton initial condition, cross section & dσ/dt, formation time, parton-subdivision*)

Anisotropic particle escape
is dominant contribution of v_2 for small systems & even for semi-central AuAu at RHIC

At very large σ or <Ncoll>,
hydrodynamic collective flow
will be the dominant contribution of v_2

New picture of v_n development:

One non-central Au+Au event from AMPT

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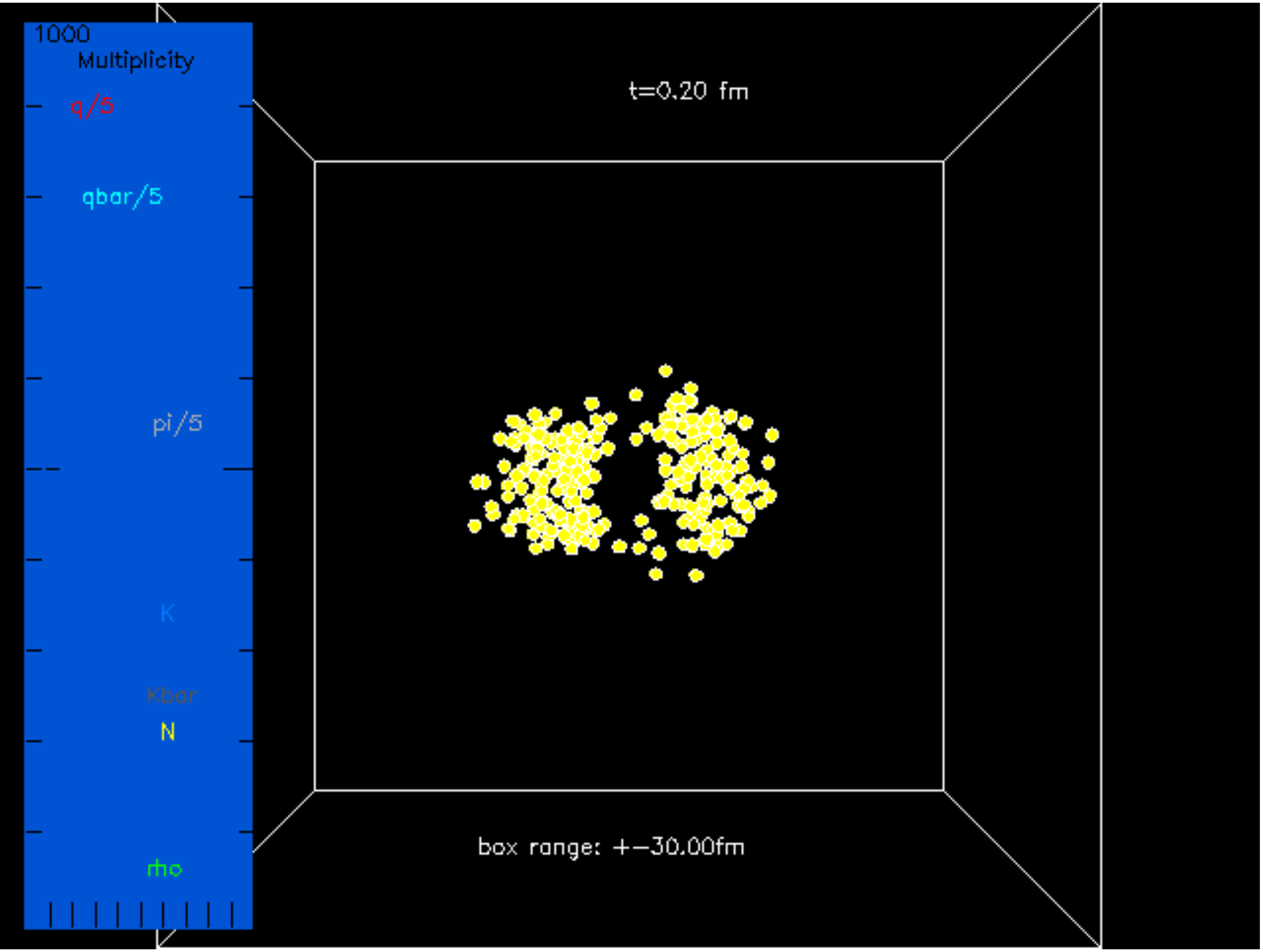
Beam axes



Particle # vs time

Particles freeze out with ϕ-dependent escape probability,

this dominates the final v_2 for systems at low to modest opacity/<Ncoll>.

Potential Consequences

- The escape mechanism helps to explain similar anisotropic flows observed in small and large systems:

since both are dominated by same mechanism (*anisotropic escape probability*)

- The driving force for v_2 at low & high P_T is qualitatively the same

since both are dominated by *anisotropic probability of interactions* before escape (scatterings for low P_T & energy loss for high P_T)

- At low to modest opacity/<Ncoll>: transport and hydrodynamics are different.

The escape mechanism dominates v_n at low to modest opacity/<Ncoll>;
hydro-type collective flow dominates v_n at very high opacity/<Ncoll>:
which is the case for AA collisions?
which is case for pp or pA collisions?