Contribution of Anisotropic Particle Escape to Elliptic Flow from Transport Models

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Based on *arXiv:1502.05572:*

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 (v3, much expanded from v1)*
- *from A Multi-Phase Transport (v1)*

Outline

Current Picture of v_n Development in Heavy Ion Collisions

Method: Tracking Parton Collisions in Transport Models

Our Results

Potential Consequences

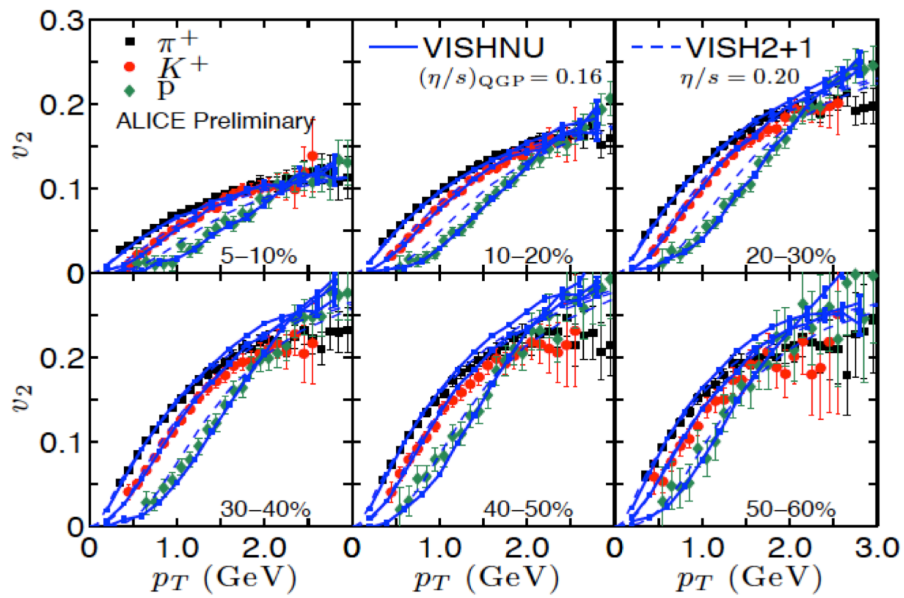
Current Picture of v_n Development

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

Hydrodynamics has been very successful
for global observables, especially flow v_n

$v_2(p_T)$ in PbPb@LHC: ALICE vs. VISHNU

Data: ALICE, preliminary (Snellings, Krzewicki, Quark Matter 2011)
Dashed lines: Shen et al., PRC84 (2011) 044903 (VISH2+1, MC-KLN, $(\eta/s)_{QGP}$=0.2)
Solid lines: Song, Shen, UH 2011 (VISHNU, MC-KLN, $(\eta/s)_{QGP}$=0.16)



VISHNU yields correct magnitude and centrality dependence of $v_2(p_T)$ for pions, kaons and protons!
Same $(\eta/s)_{QGP} = 0.16$ (for MC-KLN) at RHIC and LHC!

Heinz, BES Workshop at LBNL 2014
using viscous hydrodynamics.

Transport model can describe flow v_n :
degree of equilibration is controlled by cross section σ

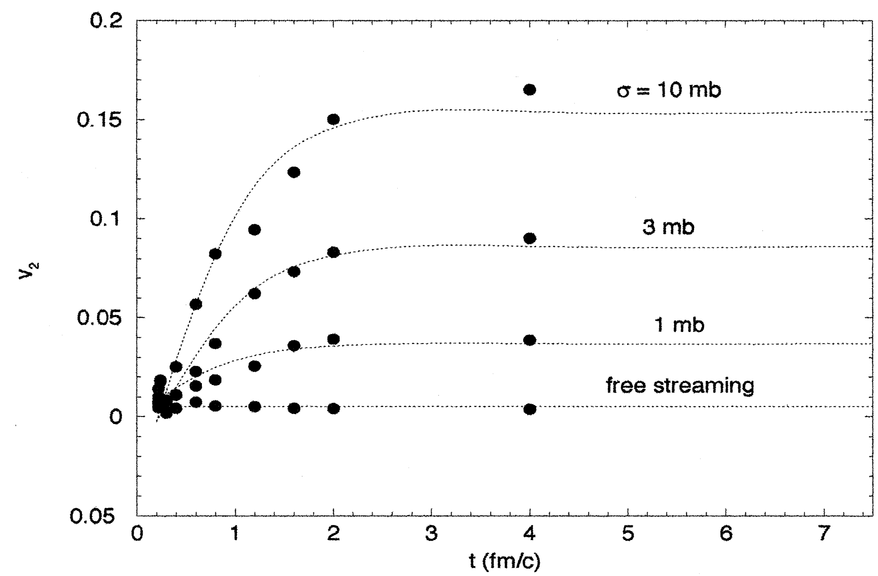
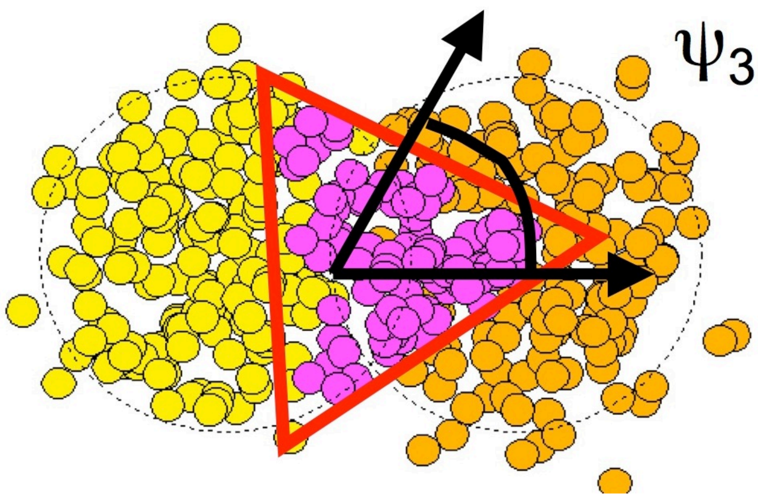


Fig. 1. Time evolution of v_2 coefficient for different effective parton scattering cross sections in Au-Au collisions at $\sqrt{s} = 200$ AGeV with impact parameter 7.5 fm. Filled circles are cascade data, and dotted lines are hyperbolic tangent fits to the data.

Zhang, Gyulassy and Ko, PLB (1999)
using elastic parton transport.

Current Picture of v_n Development

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

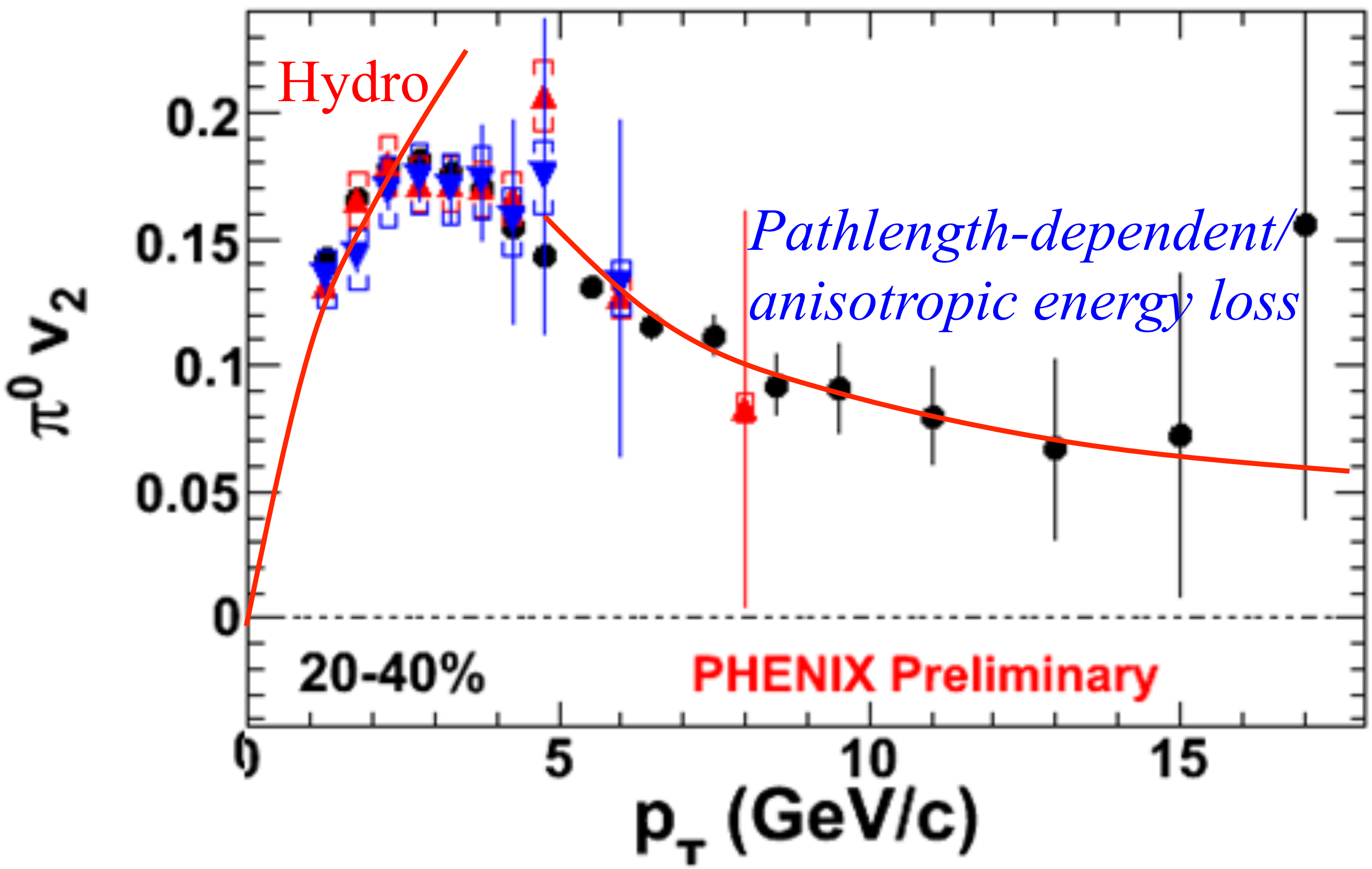


Alver and Roland, PRC (2010) discovered significant triangular flow using A Multi-Phase Transport (AMPT);
➔ intense developments of event-by-event hydrodynamics.

Transport at large-enough cross section will approach hydrodynamics.

It is generally believed: for low-P_T in high-energy heavy ion collisions, the mechanism of v_n development from transport model *(via particle interactions)* is in principle the same as viscous hydrodynamics *(via pressure gradient)*.

Current Picture of v_n Development



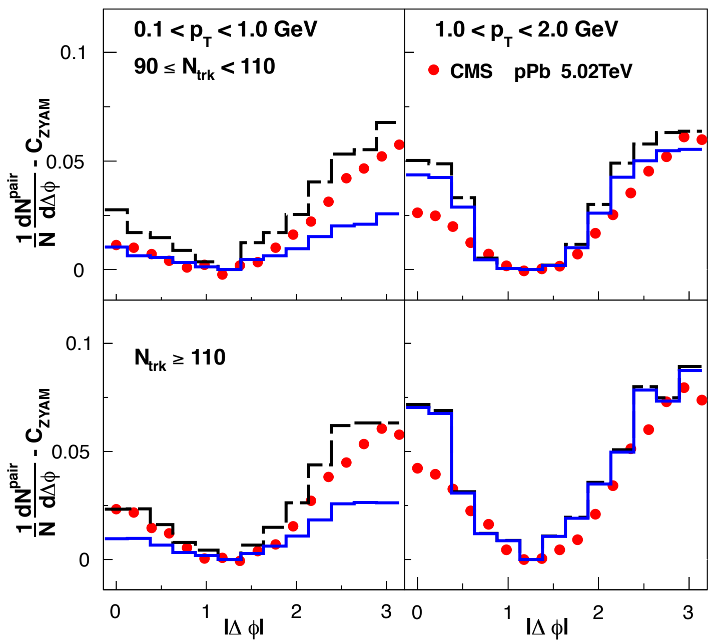
A different paradigm for high-P_T

It is generally believed:

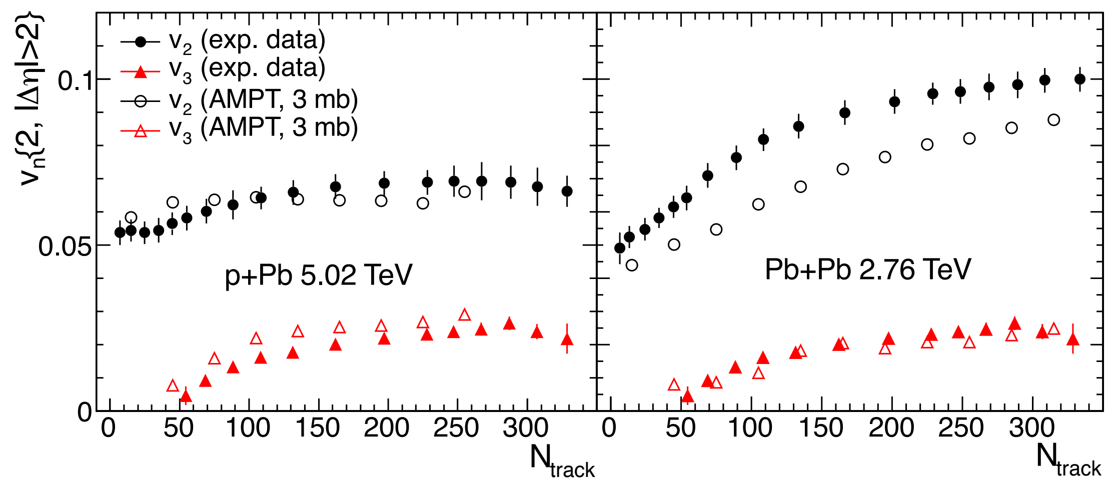
high-P_T observables cannot be described by hydrodynamics,
one needs particle transport *(plus energy loss, fragmentation, etc)*

Current Picture of v_n Development

Small systems: both hydrodynamics and transport can describe flow



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



Bzdak and Ma, PRL (2014)
using A Multi-Phase Transport (AMPT).

Puzzle for small systems such as p+Pb or d+Au:
Mean free path may comparable to the system size;
is hydrodynamics still applicable to such small systems?

Tracking Parton Collisions in Transport Models

Method:

Study v_n development

by tracking the complete collision history of each parton,

including

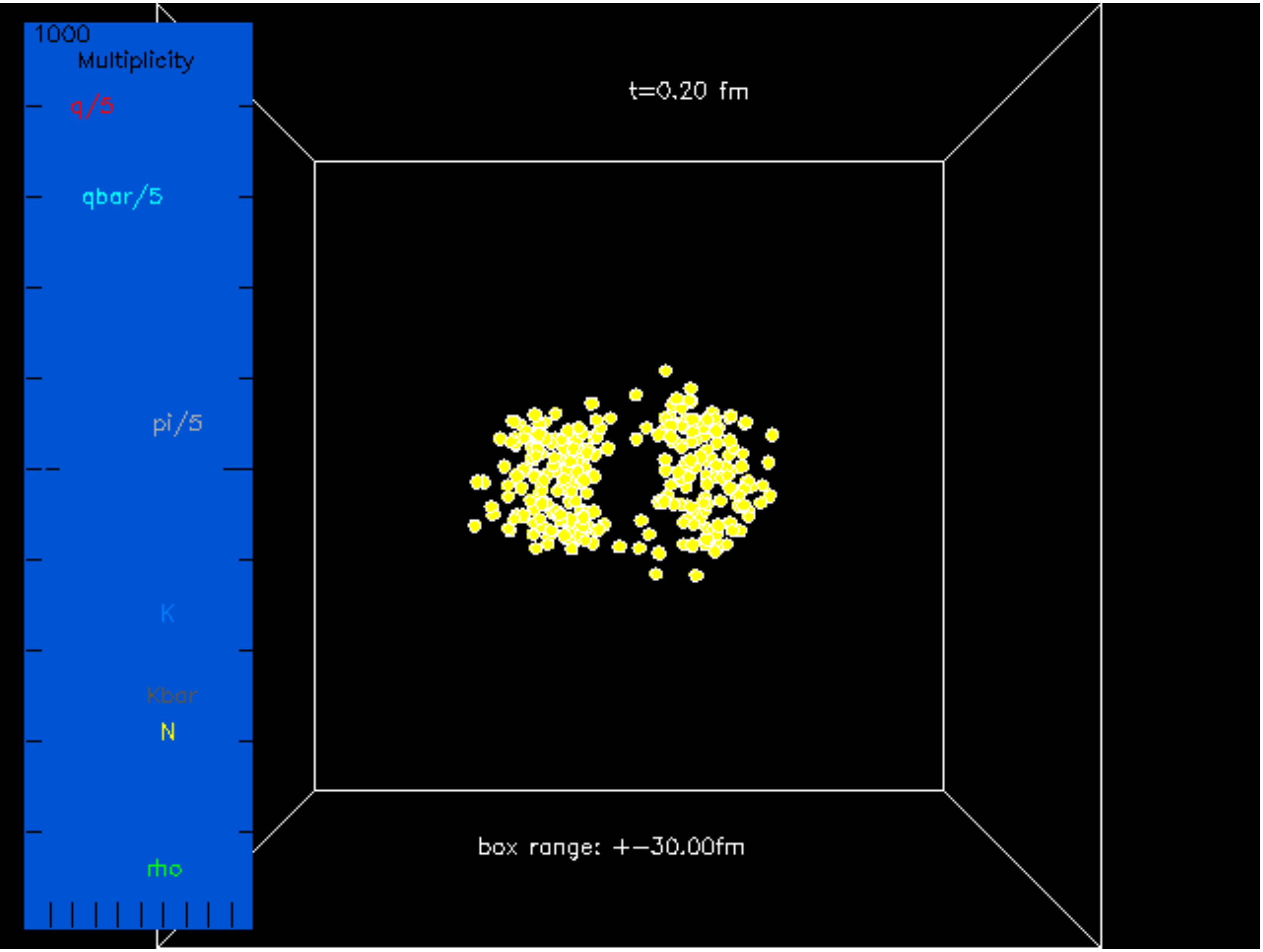
- 3 parton populations

  (e.g. freezeout partons, active partons & all partons)
- v_n versus **Ncoll** *(number of collisions suffered by a parton)*
- v_n versus time

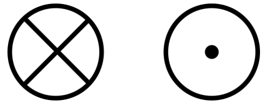
Most results shown here are obtained with AMPT (string melting version); some obtained with MPC (elastic version of the parton cascade).

We only study the parton stage here.

A b=10 fm Au+Au event at 200AGeV from String Melting AMPT



Particle # vs time



Beam axes

60fm-long box;

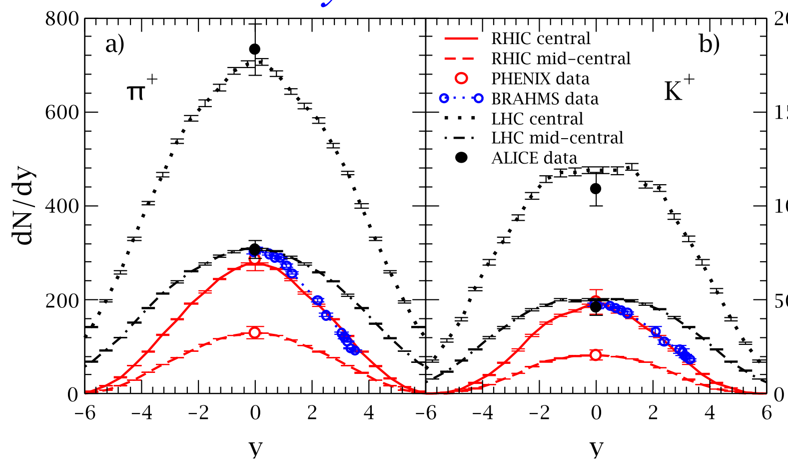
shows only formed particles.

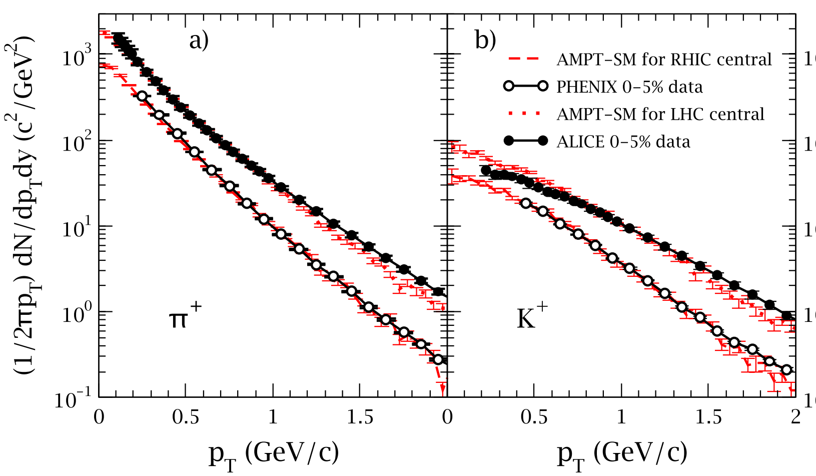
1st frame: right after the primary collision, only spectator nucleons are formed.

Constraining Parameters of the String Melting AMPT

Same parameters for Au+Au as in ZWL PRC (2014),
which described low-pt (<2GeV/c) π & K data on dN/dy, p_T spectra & v2
in central & mid-central events of 200AGeV Au+Au.

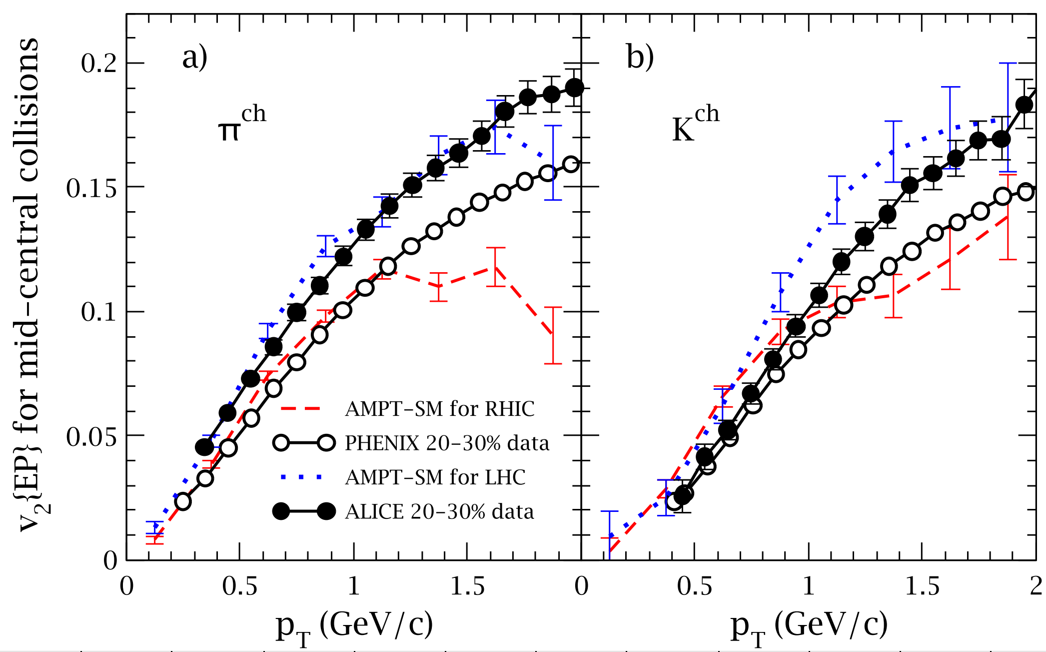
dN/dy of π & K





p_T spectra of π & K (in central collisions)

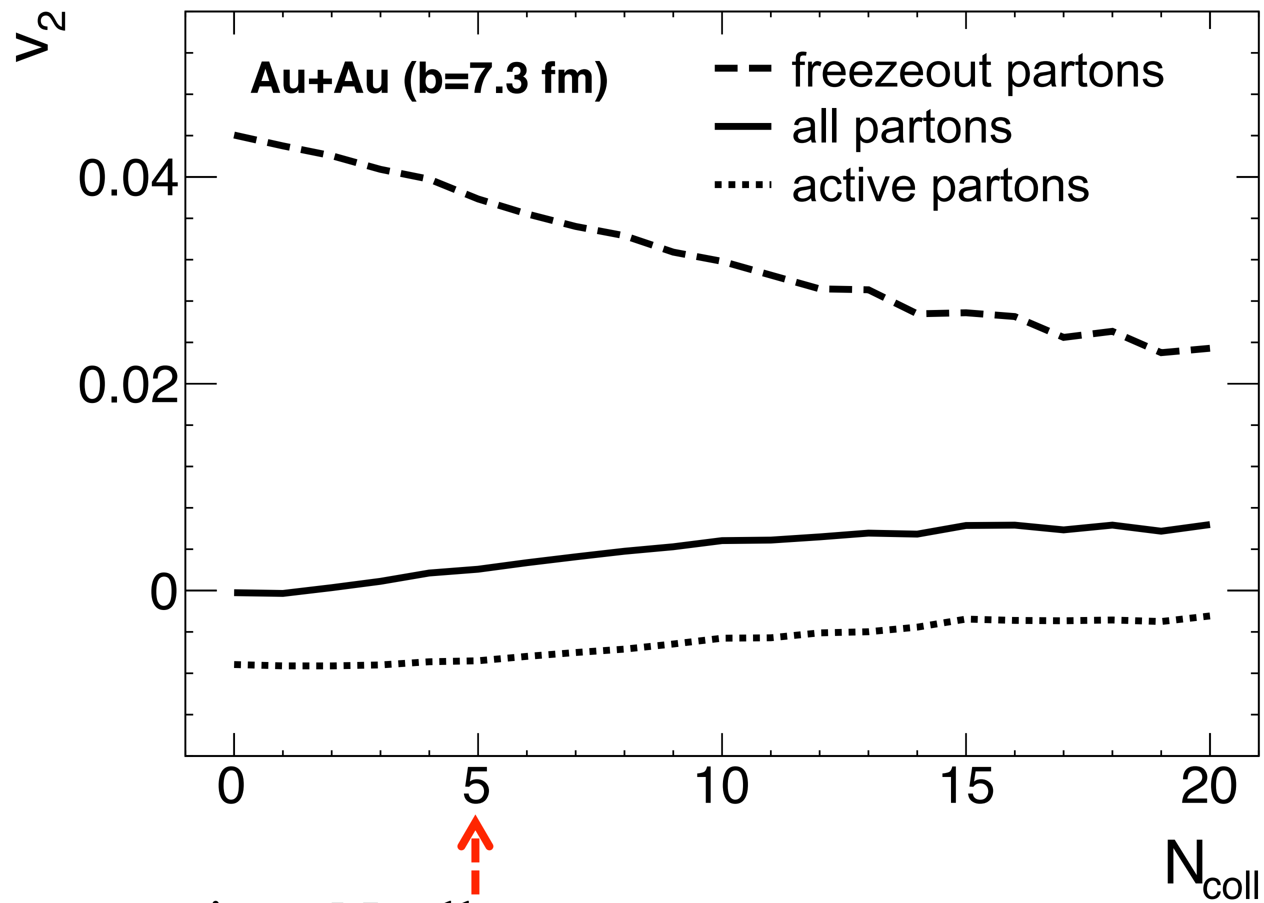
v2 of π & K (AuAu@200AGeV b=7.3fm)



Parton cross section σ =3mb

Results: v2 versus collision # of each parton

Ncoll: *number of collisions suffered by a parton*



3 parton populations at a given Ncoll:

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

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

all partons: *sum of the above two populations*

(i.e. all formed partons that have survived Ncoll collisions).

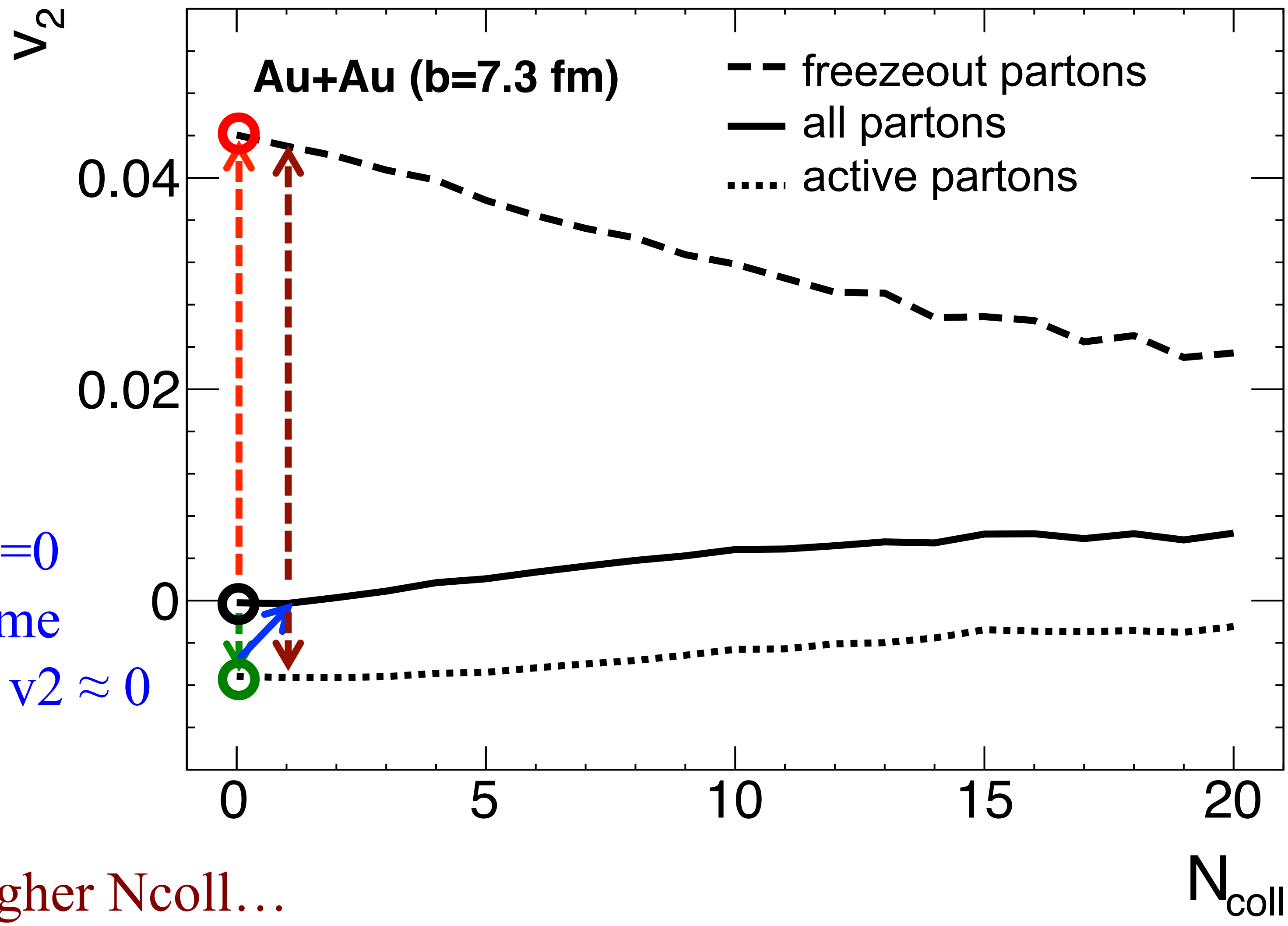
Results: v2 versus collision # of each parton

At Ncoll=0:

all partons: v2=0 by symmetry;

escaped/freezeout: v2 ≈ 4.5%;

Active: v2 <0.

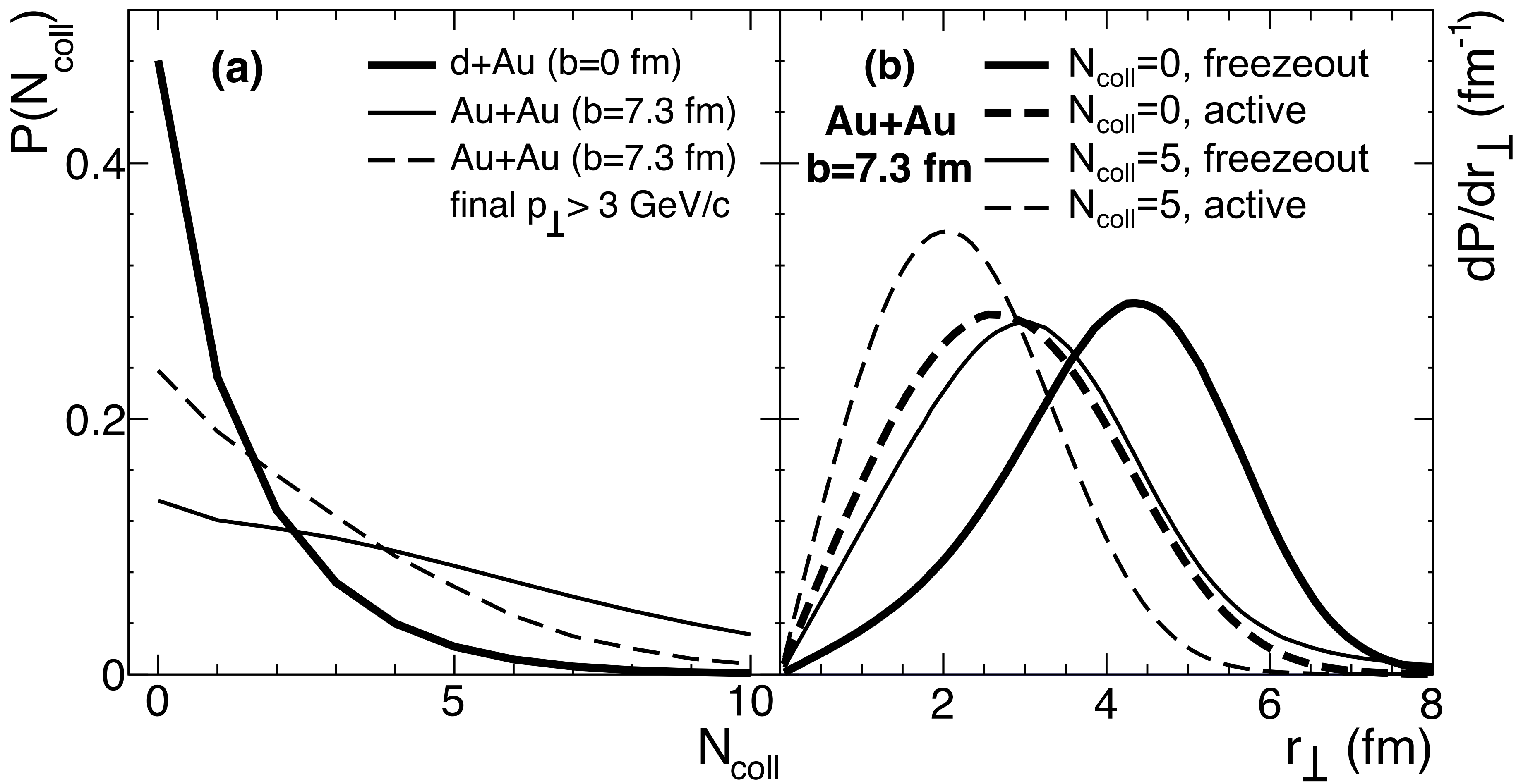


At Ncoll=1:

active partons at Ncoll=0 collide once each, become **all partons** at Ncoll=1: v2 ≈ 0

this repeats itself to higher Ncoll…

Results: freezeout vs collision # of a parton



<Ncoll>=4.6 for Au+Au
=1.2 for d+Au.

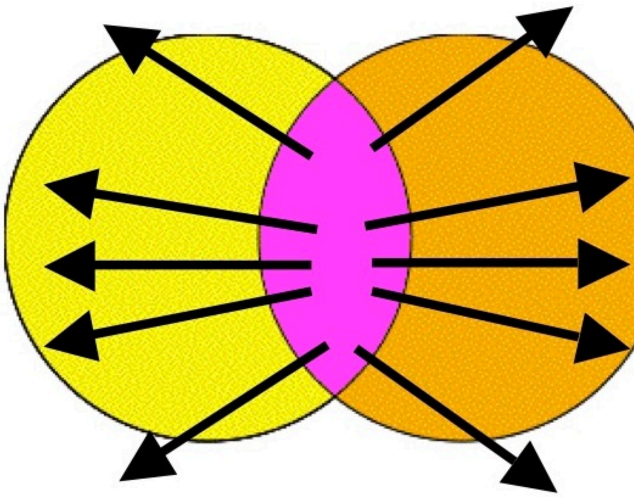
Freezeout in the outer region
(~surface emission, but not from a sharp surface);

freezeout region moves in with Ncoll.

Results: anisotropic particle escape

At Ncoll=0:
Escaped: v2 ≈ 4.5%,
purely due to
anisotropic escape probability
(response to geometrical shape only,
no effect from collective flow)

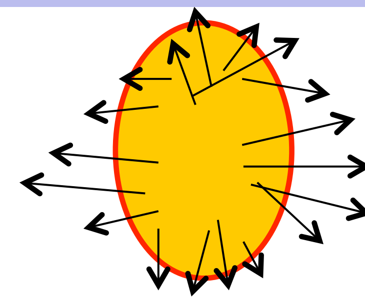
In simplified picture of elliptic flow



At Ncoll>=1:
Escaped: v2>0
due to
the above **anisotropic escape probability**
modified by collective flow of all active partons

Results: anisotropic particle escape

Final v2 is generated by interactions,
which generate anisotropic collective flow
and freezeout/escape from an anisotropic shape:

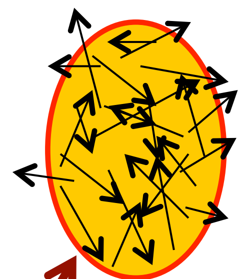


f(**x**,**p**,t)

Let's view v2 as coming from 2 separate but compounding sources:

1) anisotropic escape probability

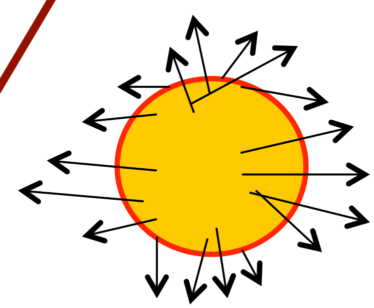
we define this term as:
effect due to spatial anisotropy only
if there were 0 collective flow



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

2) collective flow of all active partons

effect from anisotropic collective flow only
if there were no spatial anisotropy



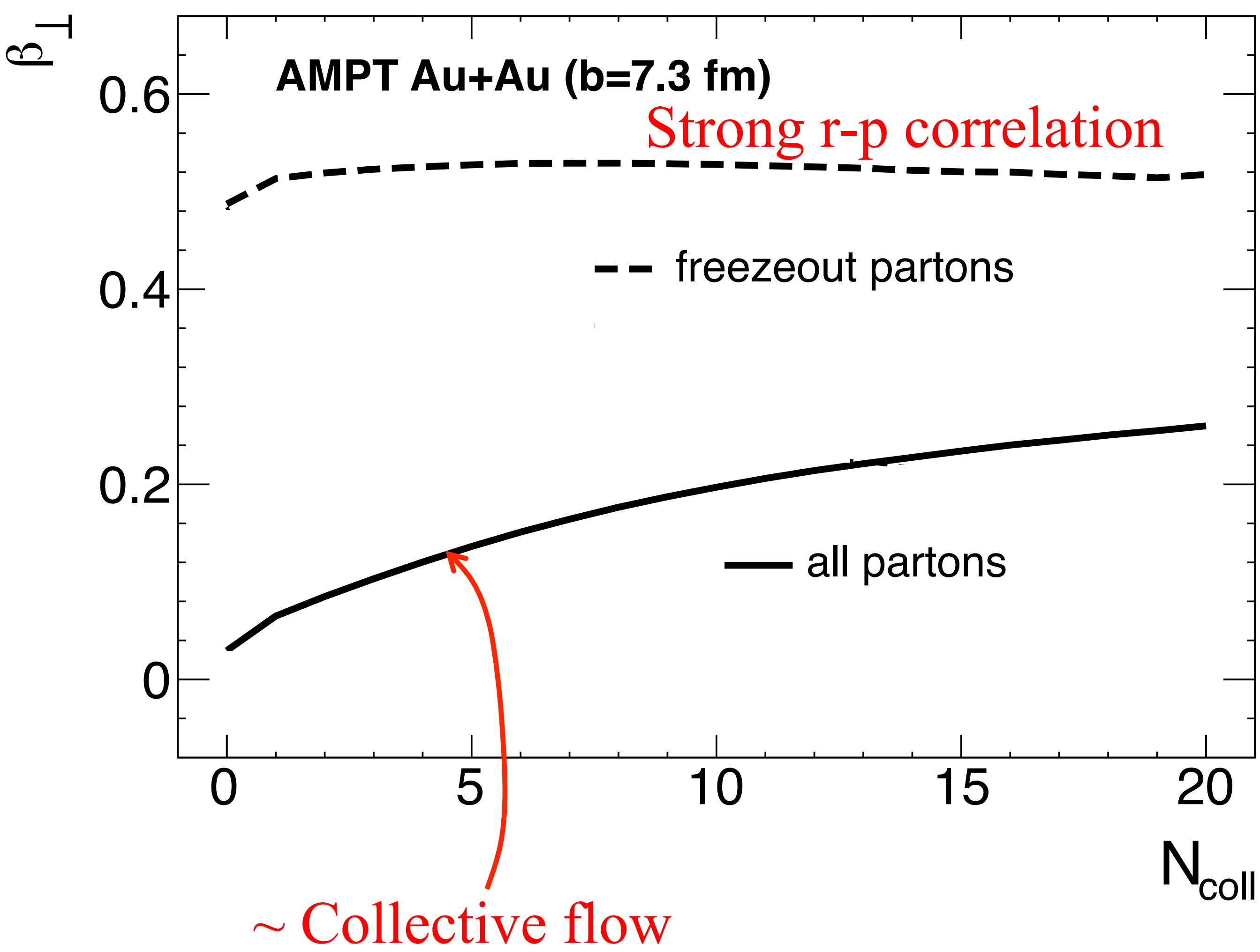
f(iso **x**,**p**,t)

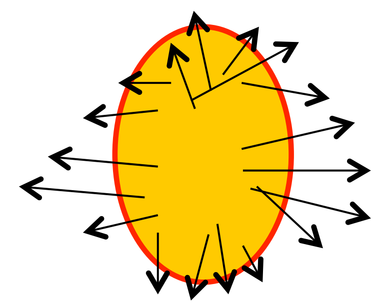
They are coupled in the actual evolution,
so we design a **Random Test** to estimate **1):**
ϕ is randomized (after each scattering) to destroy collective flow

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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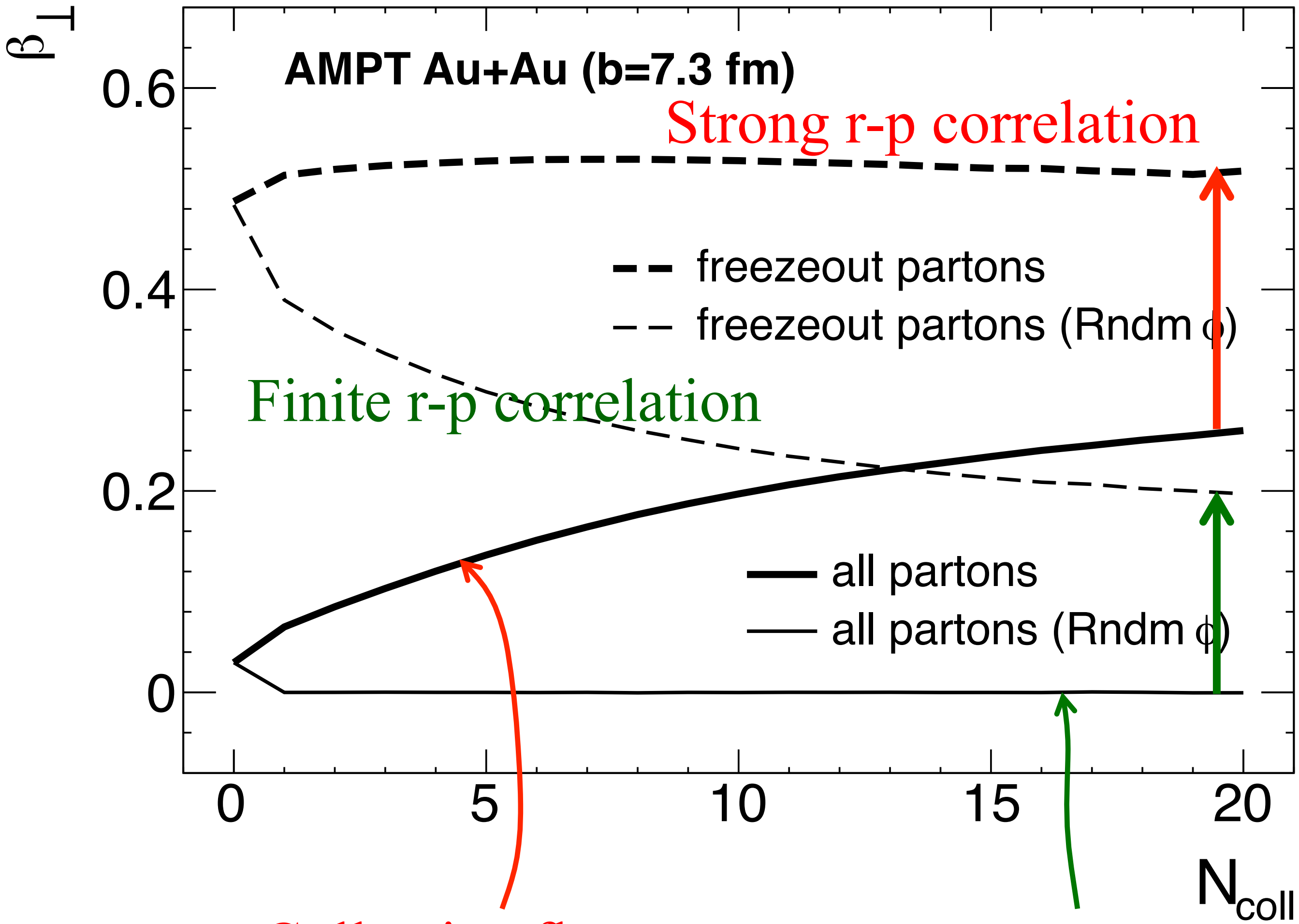
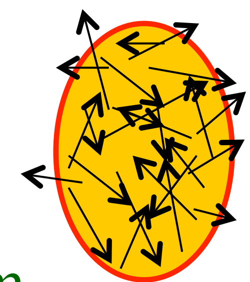


Addition increase
from escape mechanism

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

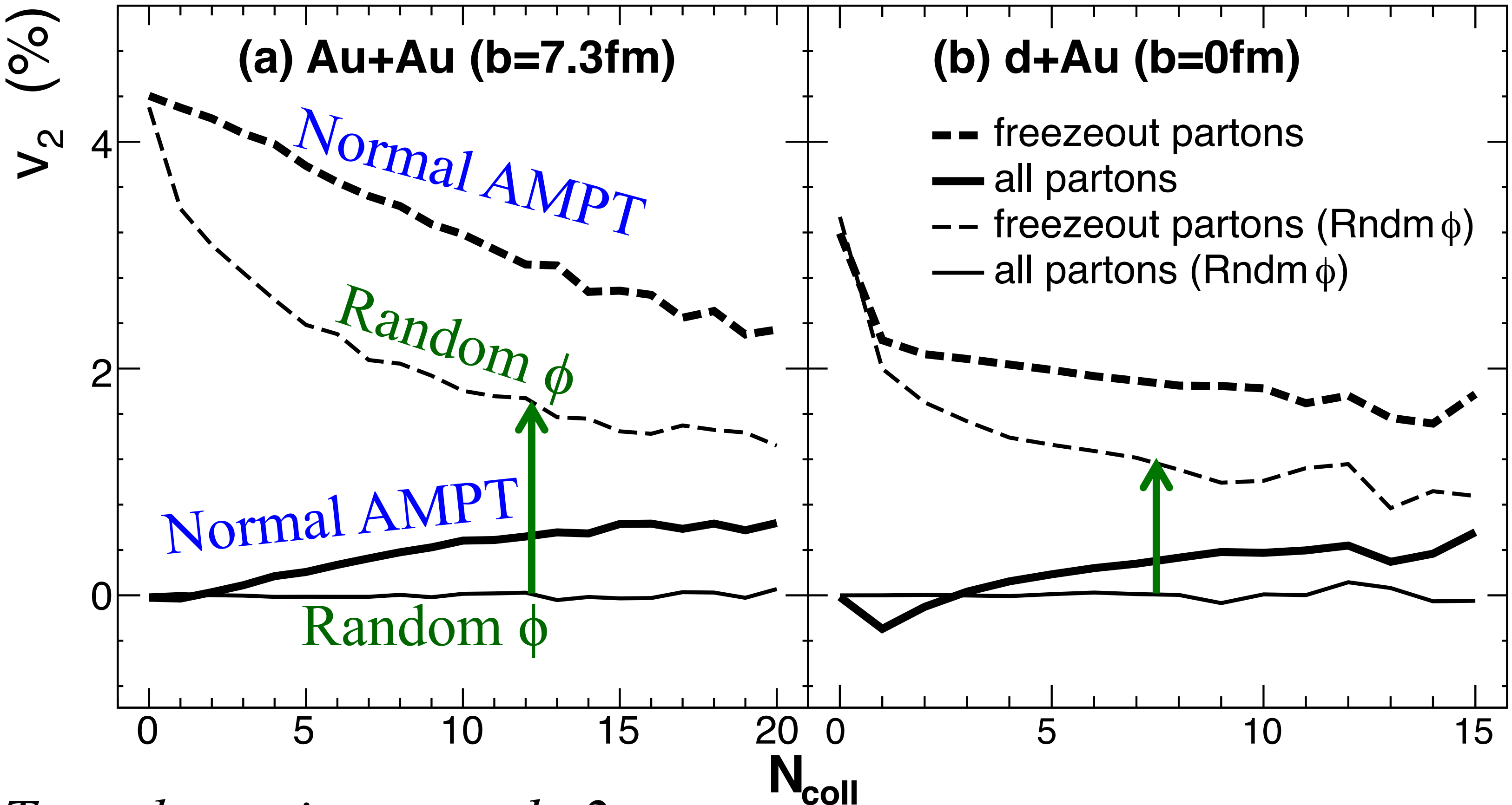


Collective flow

Random Test:
collective flow is destroyed

Results: contribution of escape mechanism to final v2

v2 from **Random Test:**
purely from escape mechanism, *at 0 collective flow*



AMPT results on integrated v2:

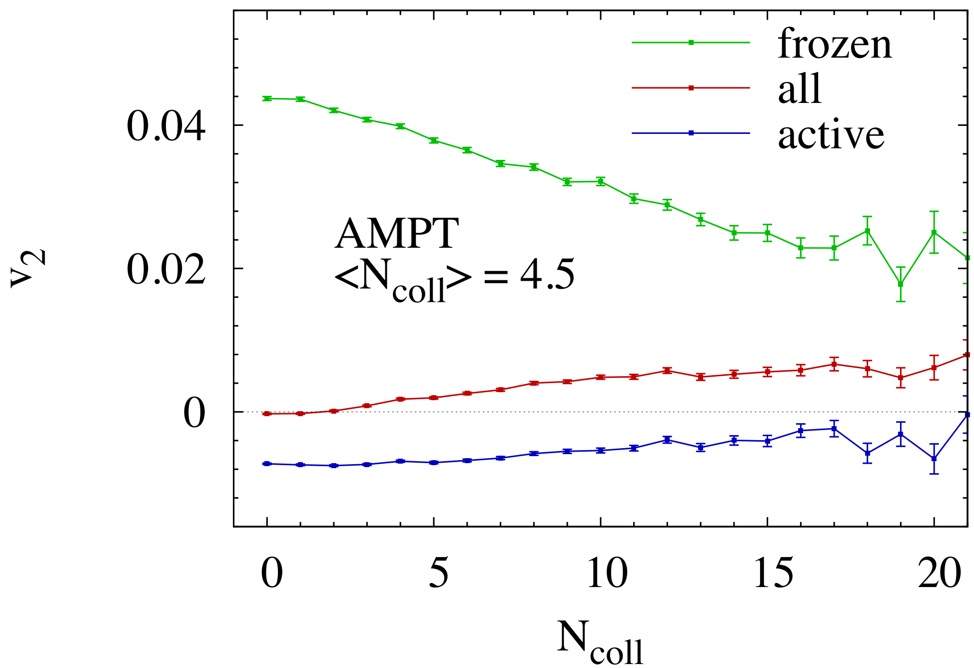
	Normal	Random ϕ	Ratio: ~contribution from pure escape
Au+Au	3.9%	2.7%	69%
d+Au	2.7%	2.5%	93%

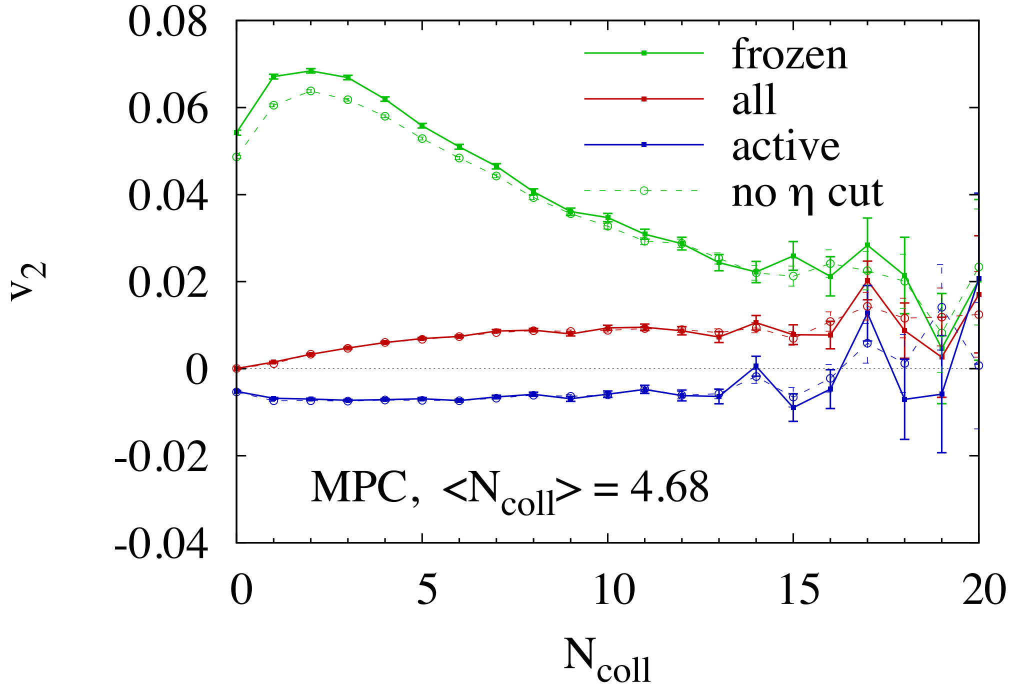
Results: this is a general feature of transport models

MPC gives essentially the same results as AMPT at similar <Ncoll>

despite differences in

parton initial condition (number, density profile, P_T spectrum), dσ/dt, formation time, parton-subdivision.

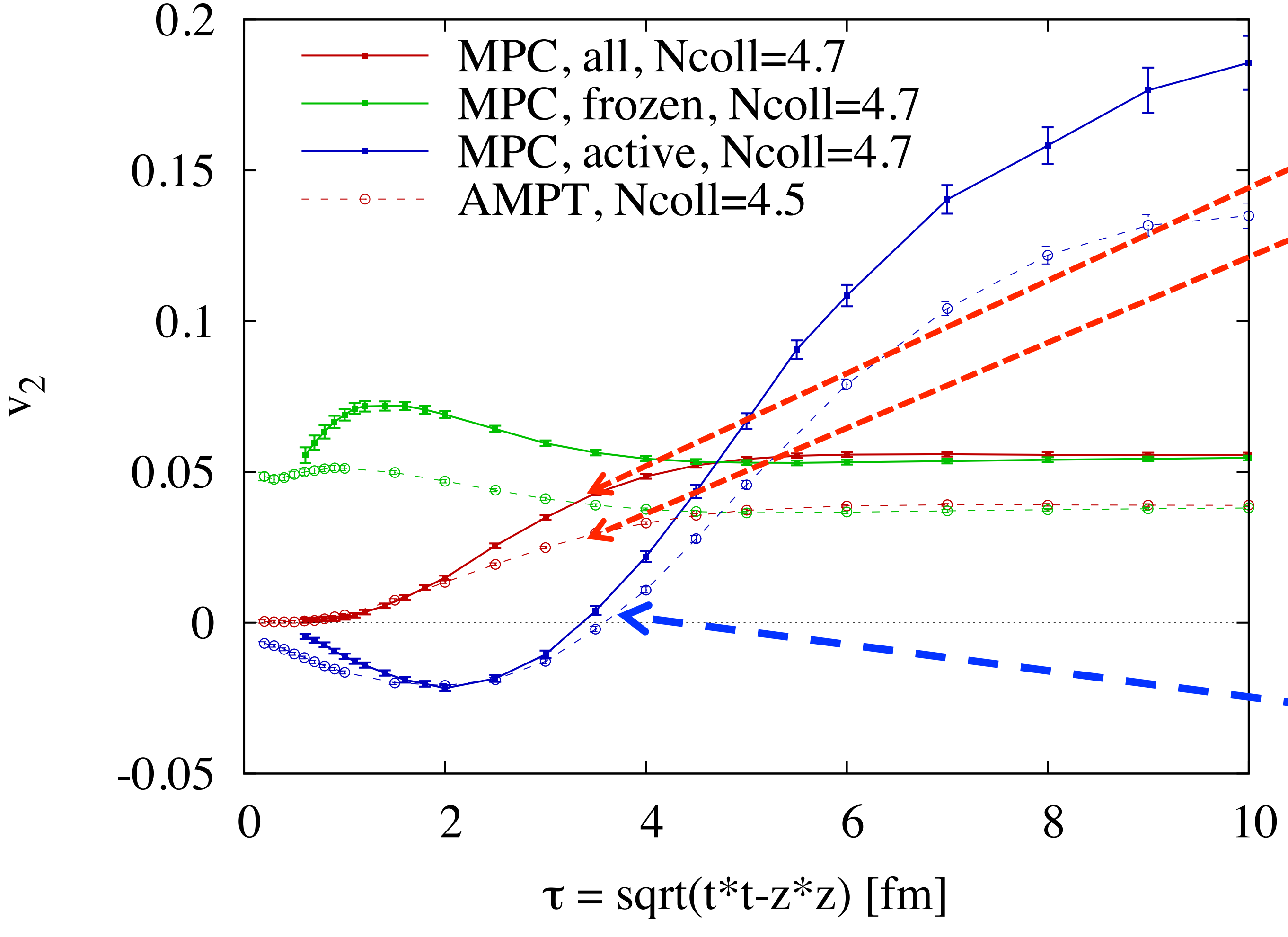




Results: this is a general feature of transport models

MPC gives essentially the same results as AMPT at similar <Ncoll>

Time-dependence of 3 parton populations:
frozen partons, active partons, & *all partons*

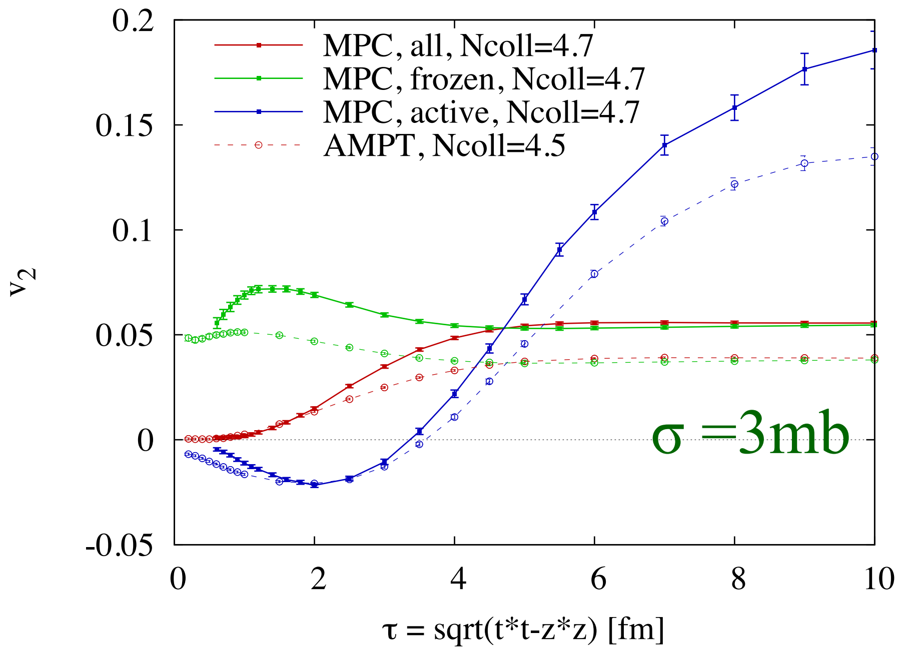


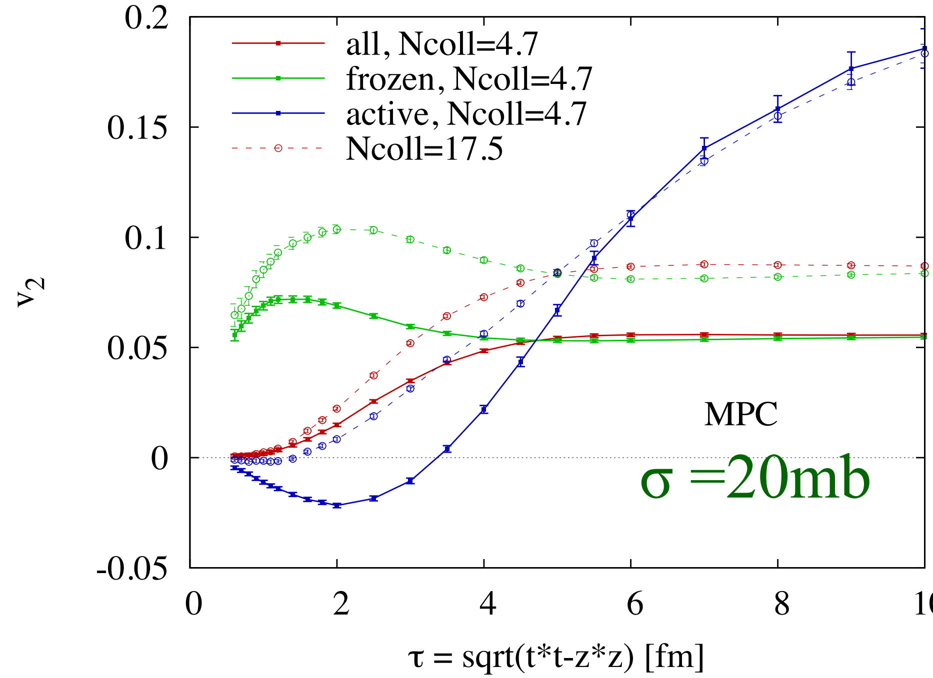
v2 of all partons gradually builds up within ~4 fm/c

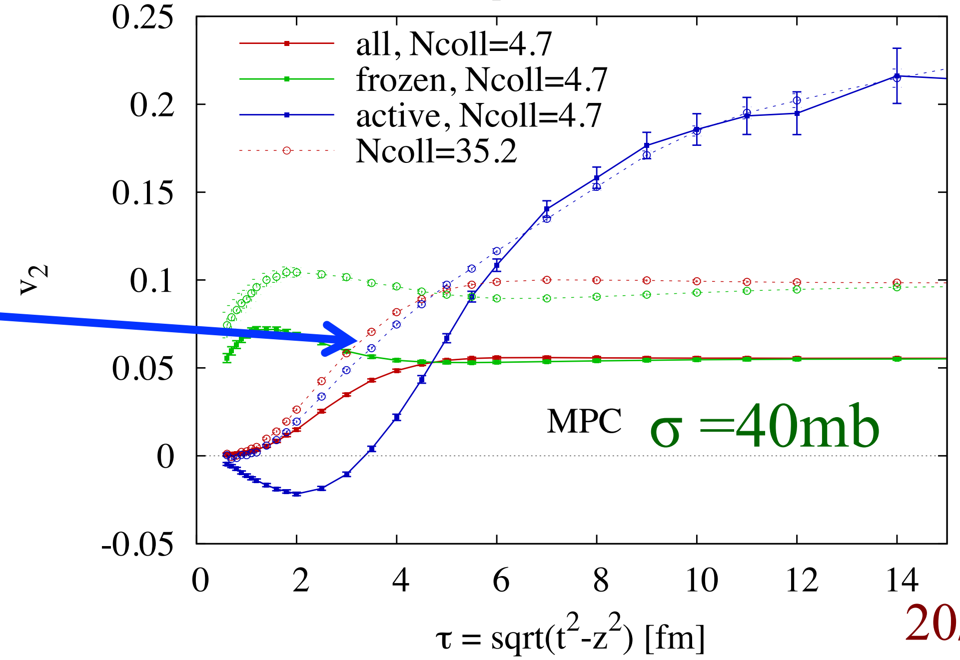
v2 of active partons is small or negative during most of v2 build-up

Results: Anisotropic Particle Escape versus Hydrodynamic Flow

When will hydrodynamic flow dominate?

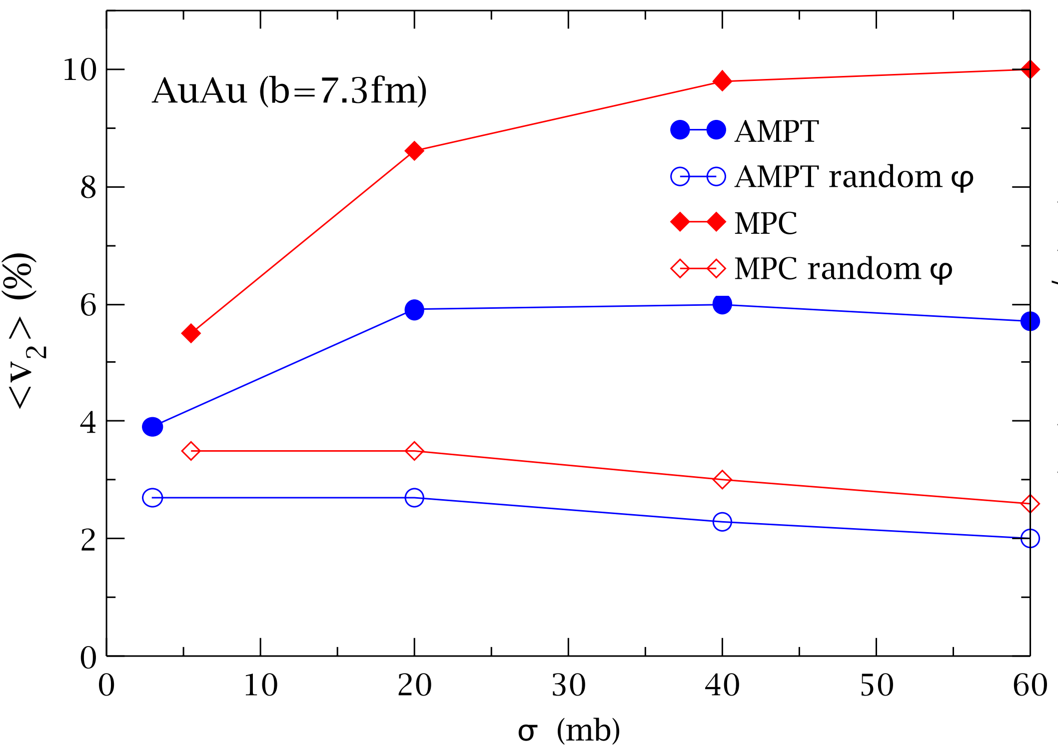


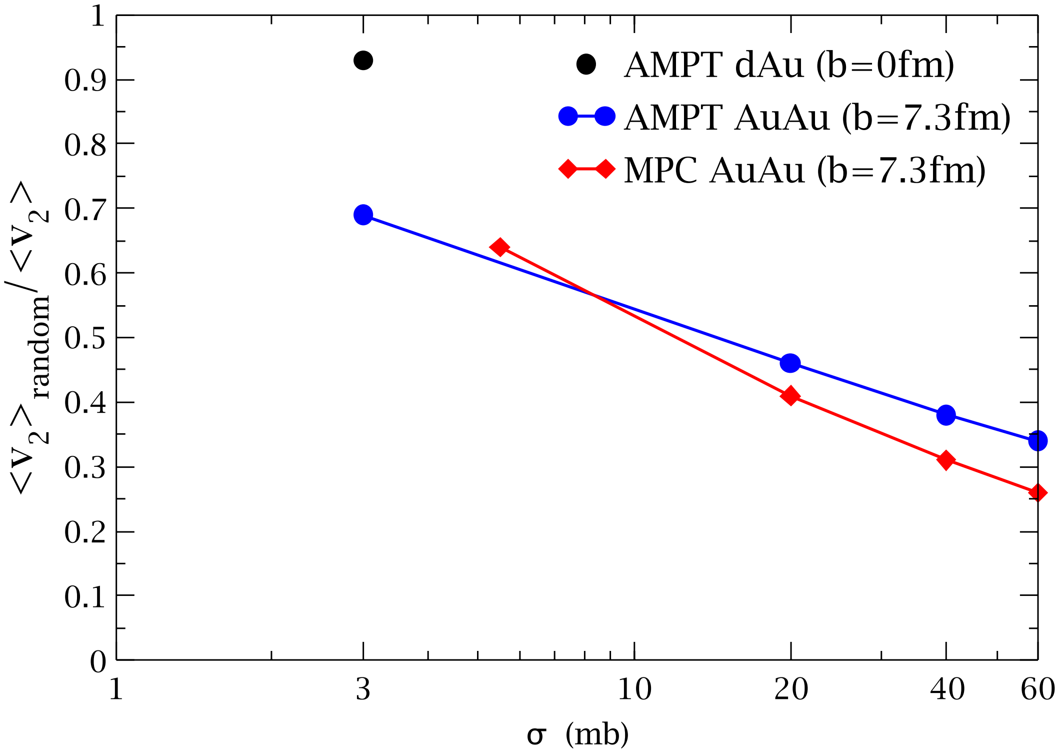




At very high <Ncoll> or σ :
v2 of active partons follows the total v2 closely during the early v2 build-up

Results: Anisotropic Particle Escape versus Hydrodynamic Flow

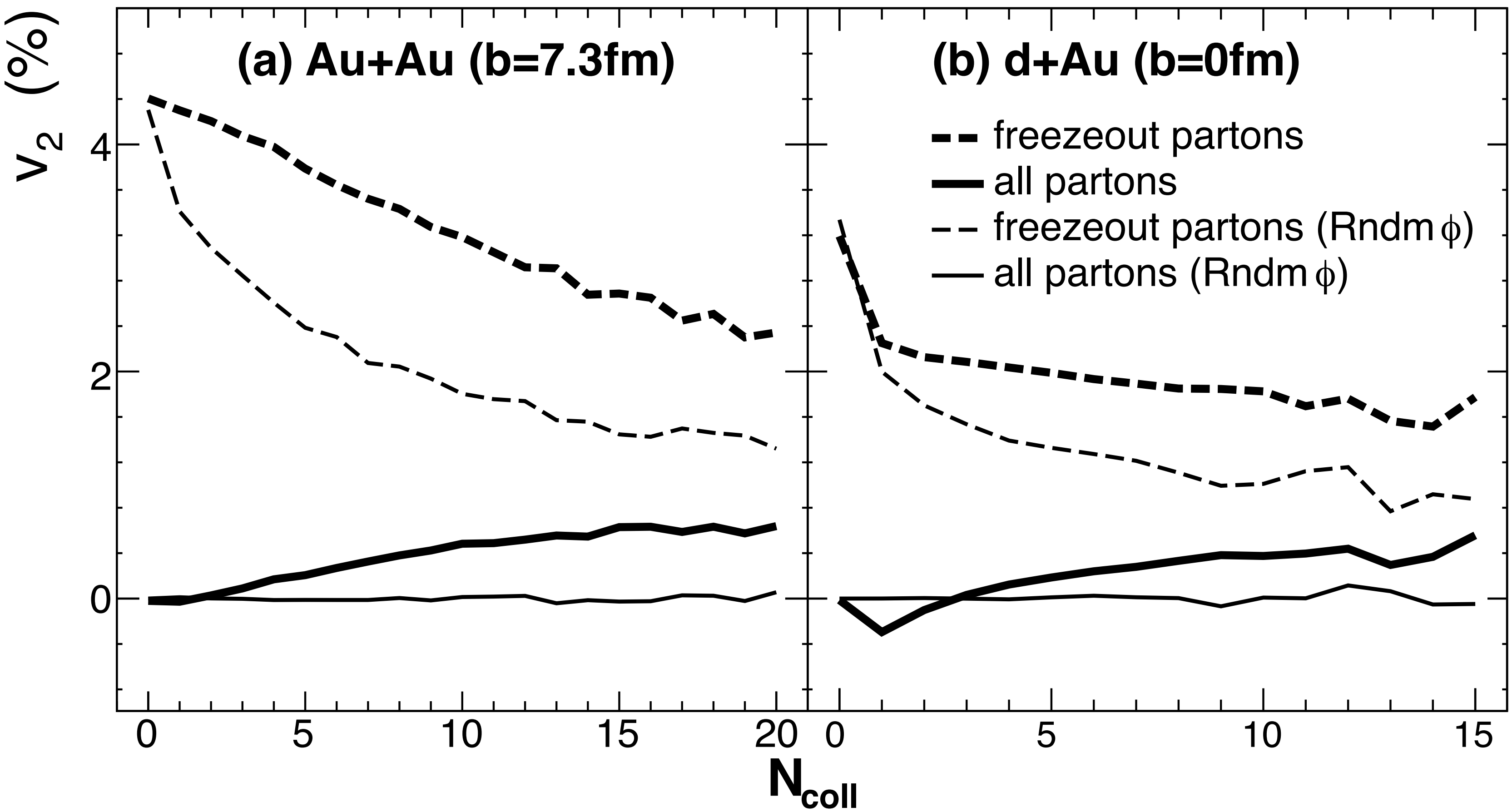




Escape mechanism is dominant
for small system v2
& maybe even for semi-central AuAu at RHIC

Hydrodynamic collective flow
will dominate at very high σ or <Ncoll>

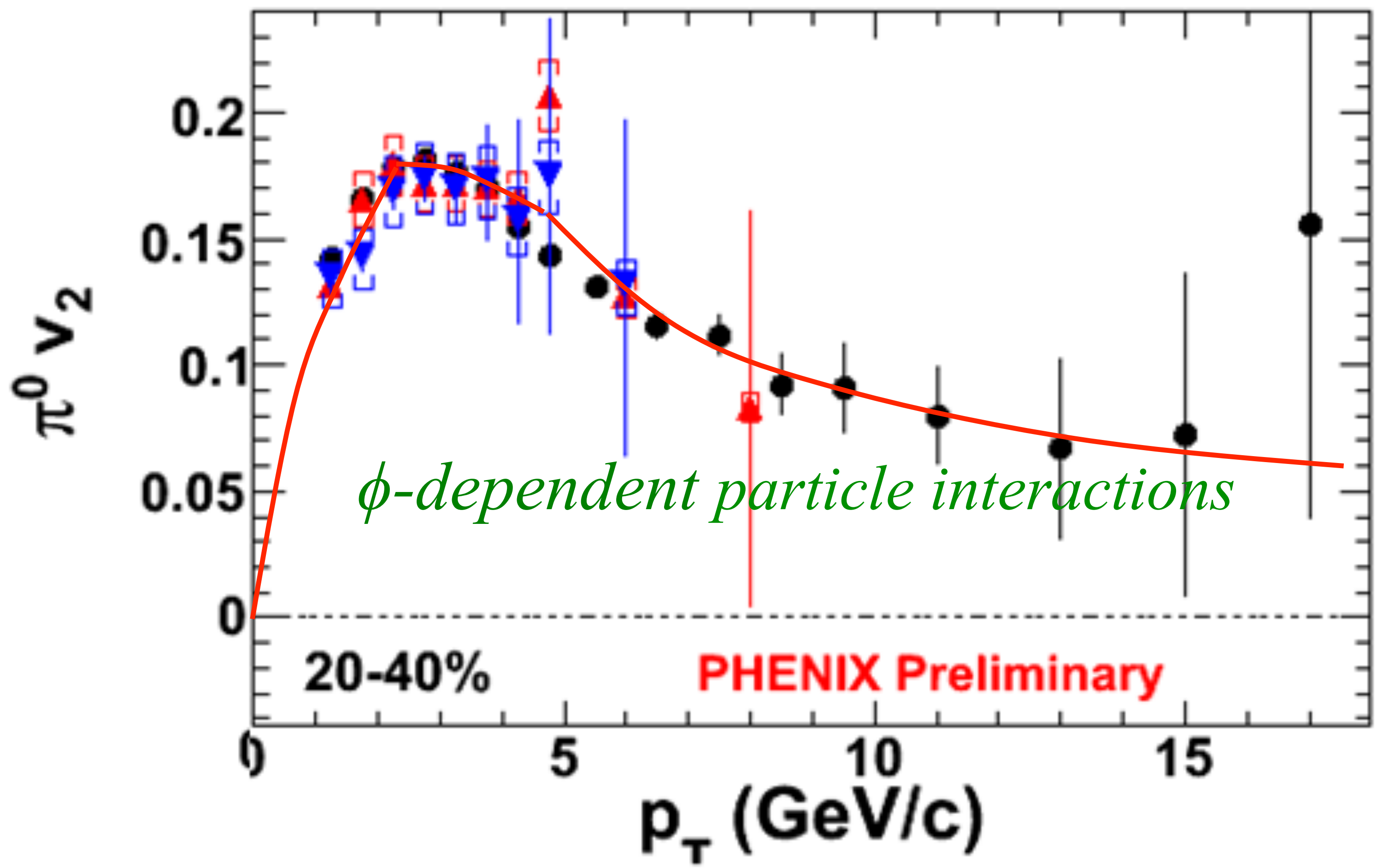
Potential Consequences



- **Explains similar anisotropic flows observed in small systems and in large systems:**

since both are dominated by the escape mechanism *(ϕ-dependent interactions & escape probability)*

Potential Consequences



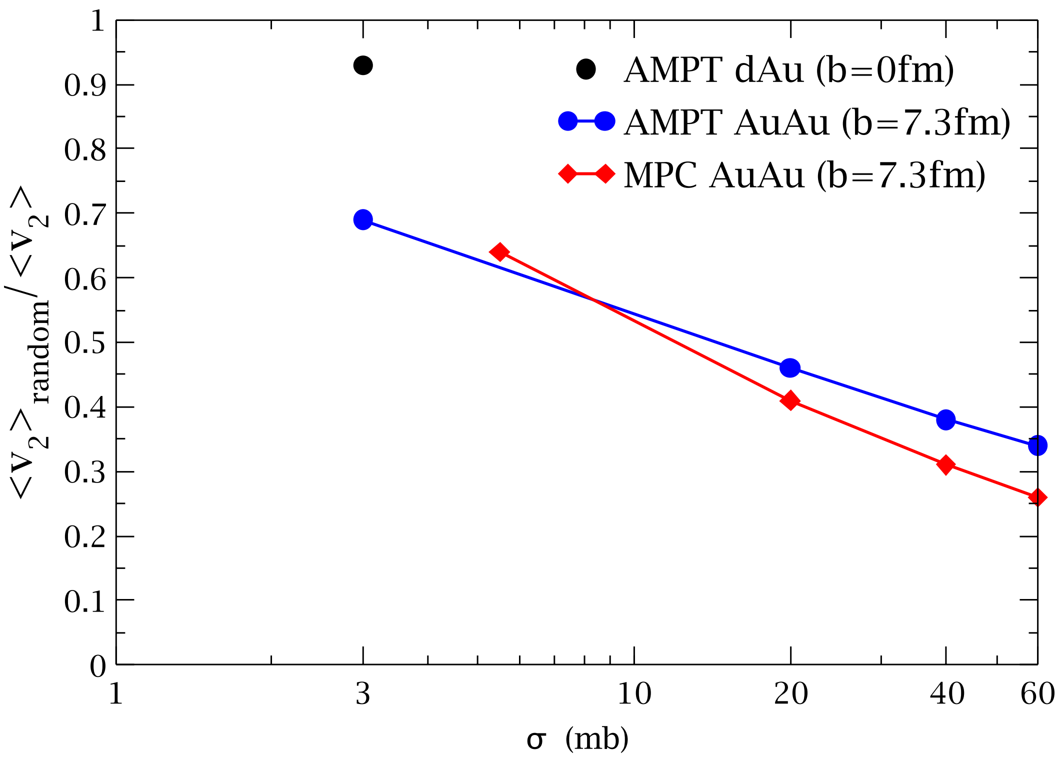
- **Main reason for v_n at low P_T and high P_T are qualitatively the same** since both are dominated by the escape mechanism *(ϕ-dependent particle interactions including energy-loss)*

Potential Consequences

Hydrodynamics
needs to include the escape mechanism
(negative part of Cooper-Frye?
continuous emission?)

will affect sQGP properties extracted
by comparing v_n with hydrodynamics

Hydrodynamics can dominate v_n
at very high interaction strength
or collision number <Ncoll>:
is it the case for heavy ion collisions?



Anisotropic Particle Escape versus Hydrodynamic Flow

Hydrodynamics describe vn data well.
AMPT/transport describes vn data well.

Are they essentially the same?

How can we differentiate them with experimental observables?

Can they be improved to converge toward each other?