The physics mechanism of light and heavy flavor v_n and mass ordering in AMPT

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Mostly based on:

L. He, T. Edmonds, Z.-W. Lin, F. Liu, D. Molnar, F.Q. Wang, **Phys. Lett. B 735,506(2016)**
Z.-W. Lin, T. Edmonds, L. He, F. Liu, D. Molnar, F.Q. Wang, **QM'15, arXiv:1512.06465**
H.L. Li, L. He, Z.-W. Lin, D. Molnar, F.Q. Wang, W. Xie, **Phys. Rev. C 93,051901(R)(2016)**
H.L. Li, L. He, Z.-W. Lin, D. Molnar, F.Q. Wang, W. Xie, **arXiv:1604.07387v2**

SQM， UC Berkeley 27 June- 1July 2016

Outline

Introduction

Results and discussion

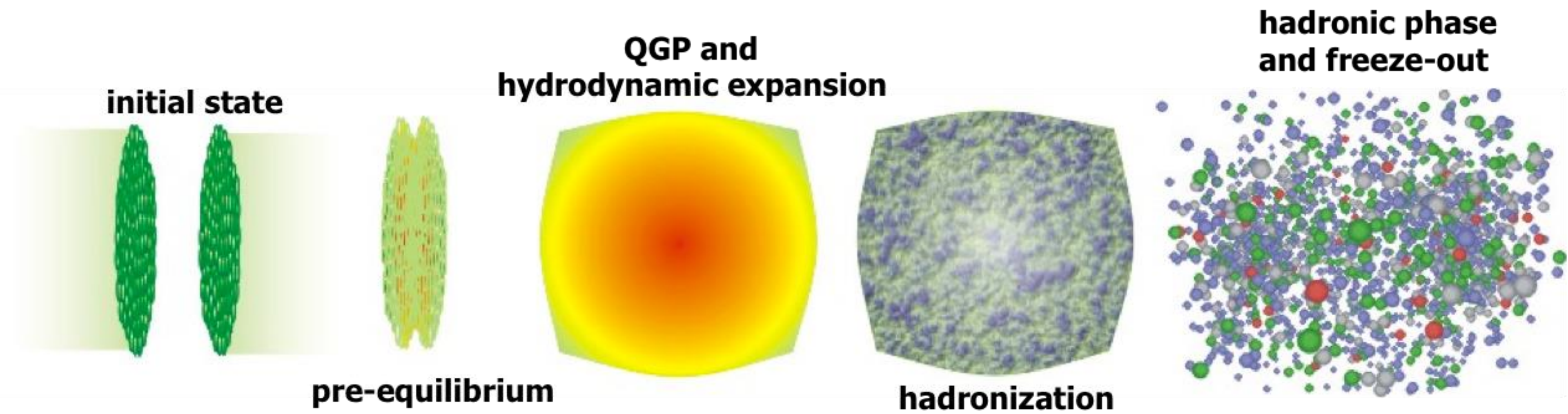
★ V_n development in AMPT

★ Origin of the mass splitting of V_n

★ Charm quark's V_n

Summary

Heavy ion collisions



Hard probes (p_T,M>>Λ_{QCD}=200 MeV)

Jet queching

Heavy quarks (tagged b-jets) ....

Soft probes (p_T~Λ_{QCD}=200 MeV)

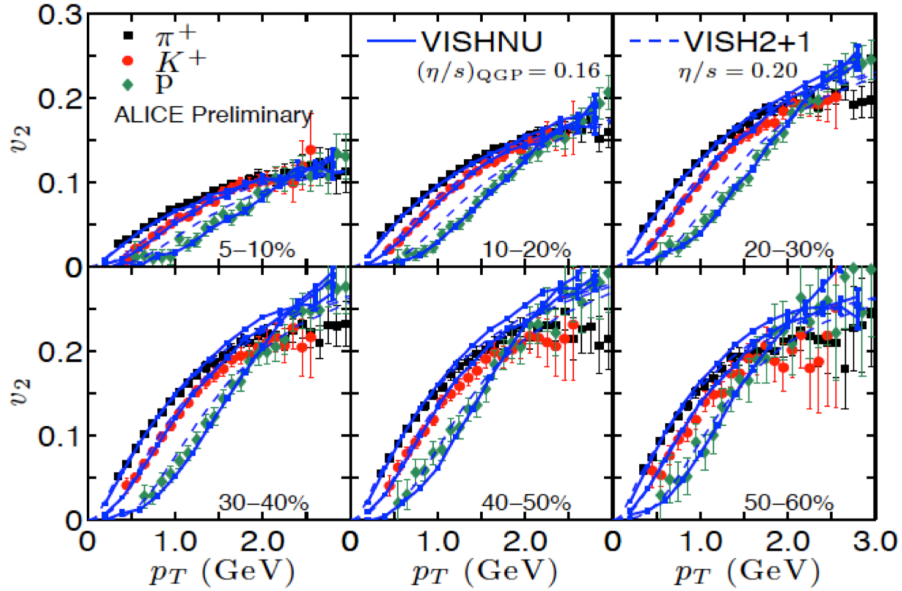
Collective flow……

Hydrodynamic vs transport

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 also describe flow v_n :
degree of equilibration is controlled by cross section σ

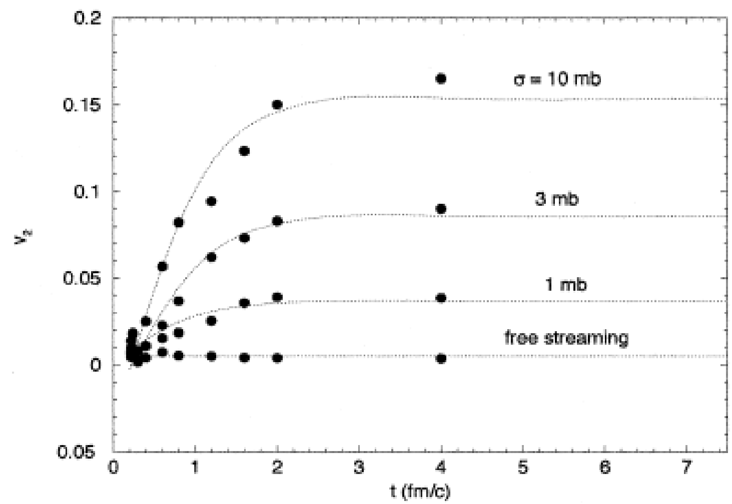
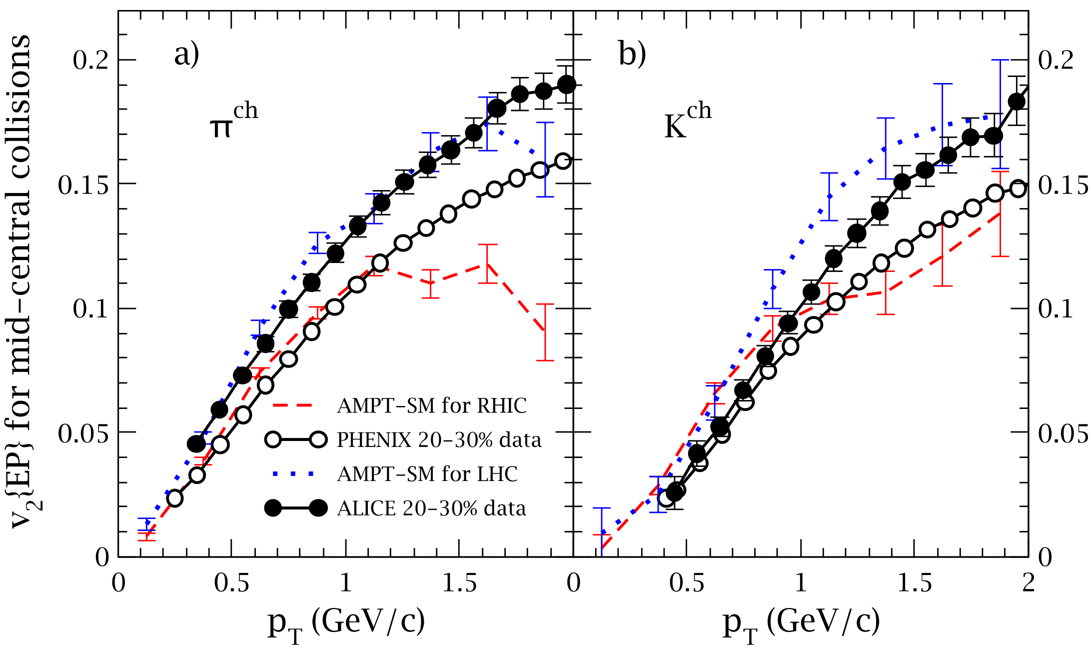


Fig. 1. Time evolution of v_2 coefficient for different effective parton scattering cross sections in Au-Au collisions at $\sqrt{s} = 200$ AGeV with impact parameter 7.5 fm. Filled circles are cascade data, and dotted lines are hyperbolic tangent fits to the data.

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

A Multi-Phase Transport (AMPT) model describes data

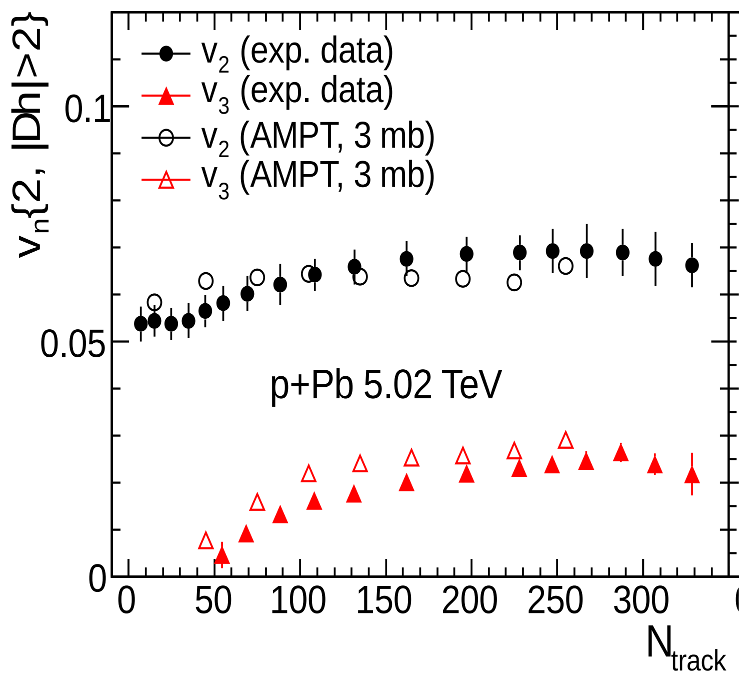
AMPT describes low-pt (<2GeV/c) π & K data on dN/dy, p_T spectra & v2 in central & mid-central events of 200AGeV Au+Au & 2760AGeV Pb+Pb.



v2 of π & K (AuAu@200AGeV b=7.3fm)

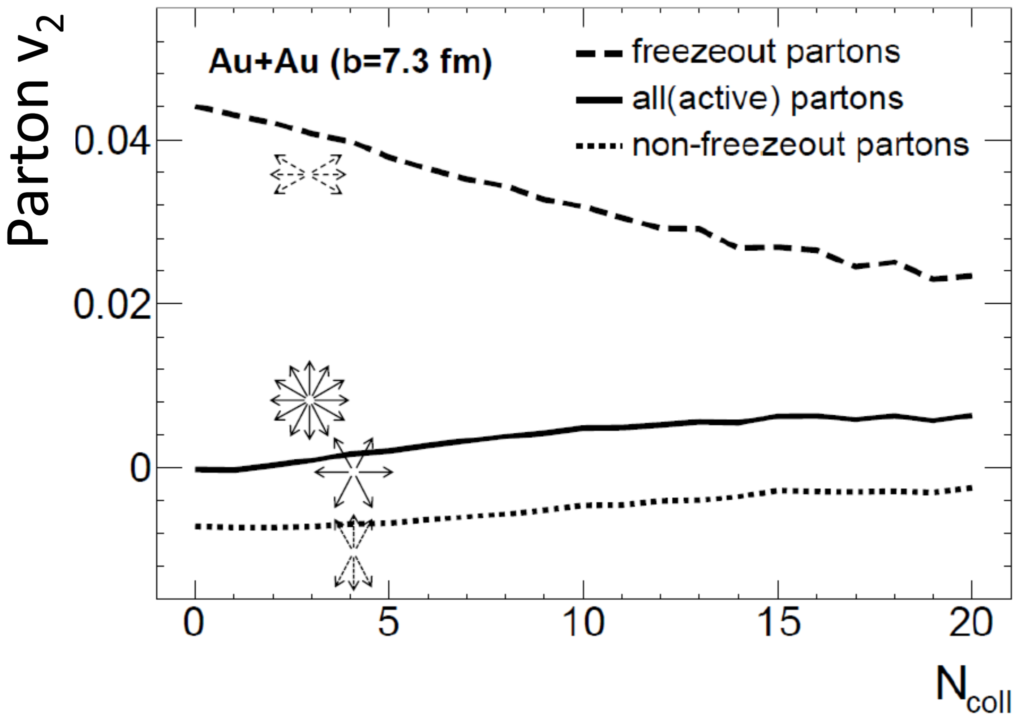
Z.-W.Lin,PRC90 (2014) 1, 014904

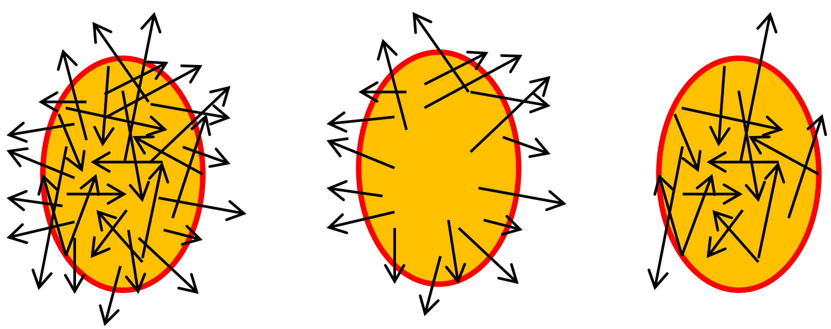
Collectivity in small colliding systems



Bzdak and Ma,
Phys.Rev.Lett. 113 (2014) 25, 252301

Parton azimuthal anisotropy developed in AMPT



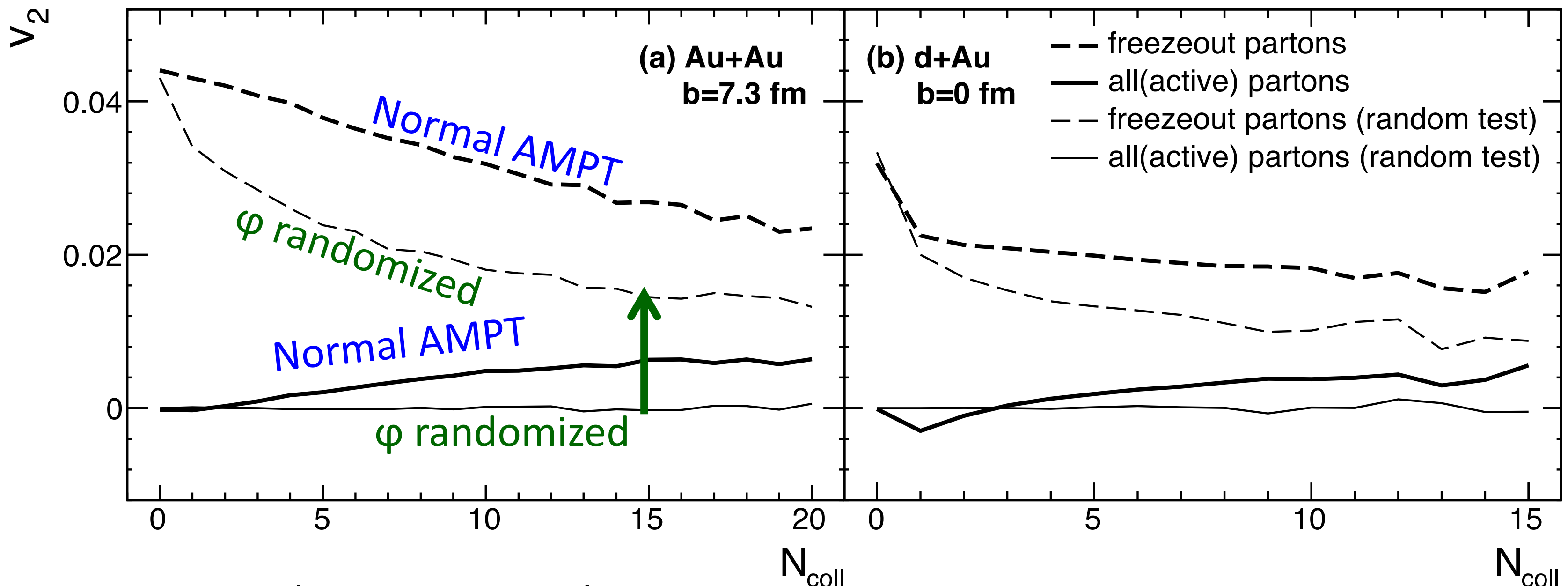


- Partons freeze out with large positive v_2, even when they do not interact at all.
- This is due to larger escape probability along x than y.
- Remaining partons start off with negative v_2, and become ~isotropic (v_2~0) after one more collision.
- Process repeats itself.
- Similar for v_3.
- Similar for d+Au collisions.

L. He, T. Edmonds, Z.-W. Lin, F. Liu, D. Molnar, F.Q. Wang, Phys. Lett. B 735,506(2016)

Majority anisotropy from escape

v2 from Random Test:
purely from escape mechanism, *not from collective flow*



AMPT results on integrated v2:

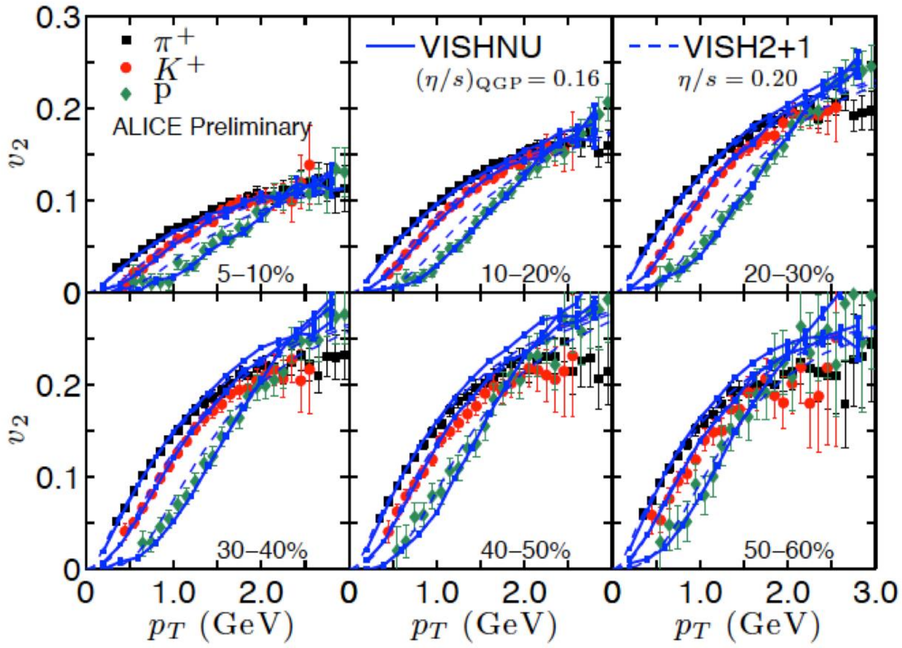
	Normal	φ randomized	% from escape
Au+Au	3.9%	2.7%	69%
d+Au	2.7%	2.5%	93%

L. He, T. Edmonds, Z.-W. Lin, F. Liu, D. Molnar, F.Q. Wang, Phys. Lett. B 735,506(2016)

Majority of anisotropy comes from the “escape mechanism”

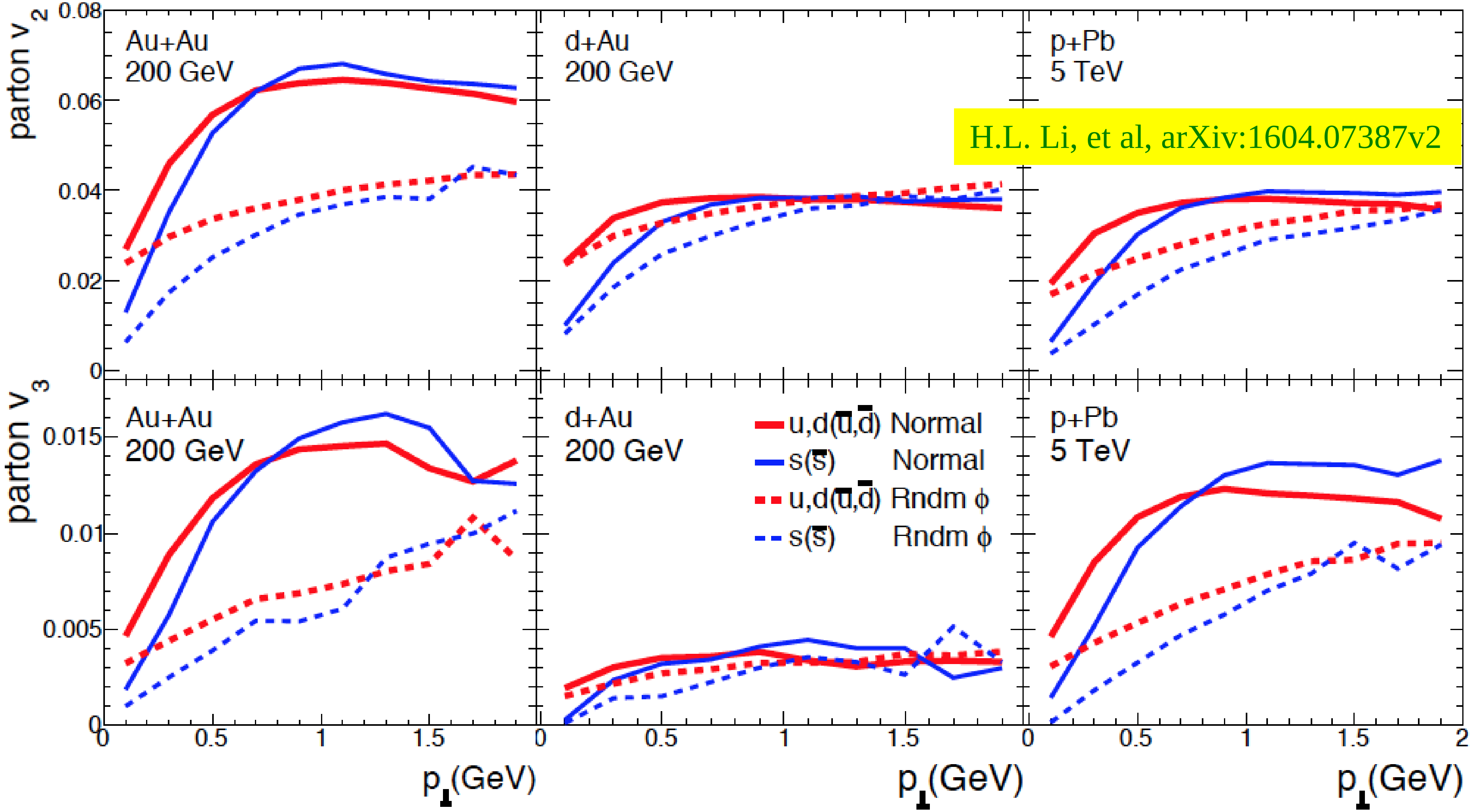
The contribution to anisotropy from hydrodynamic-type collective flow is found to be small.

The mass splitting of v_n



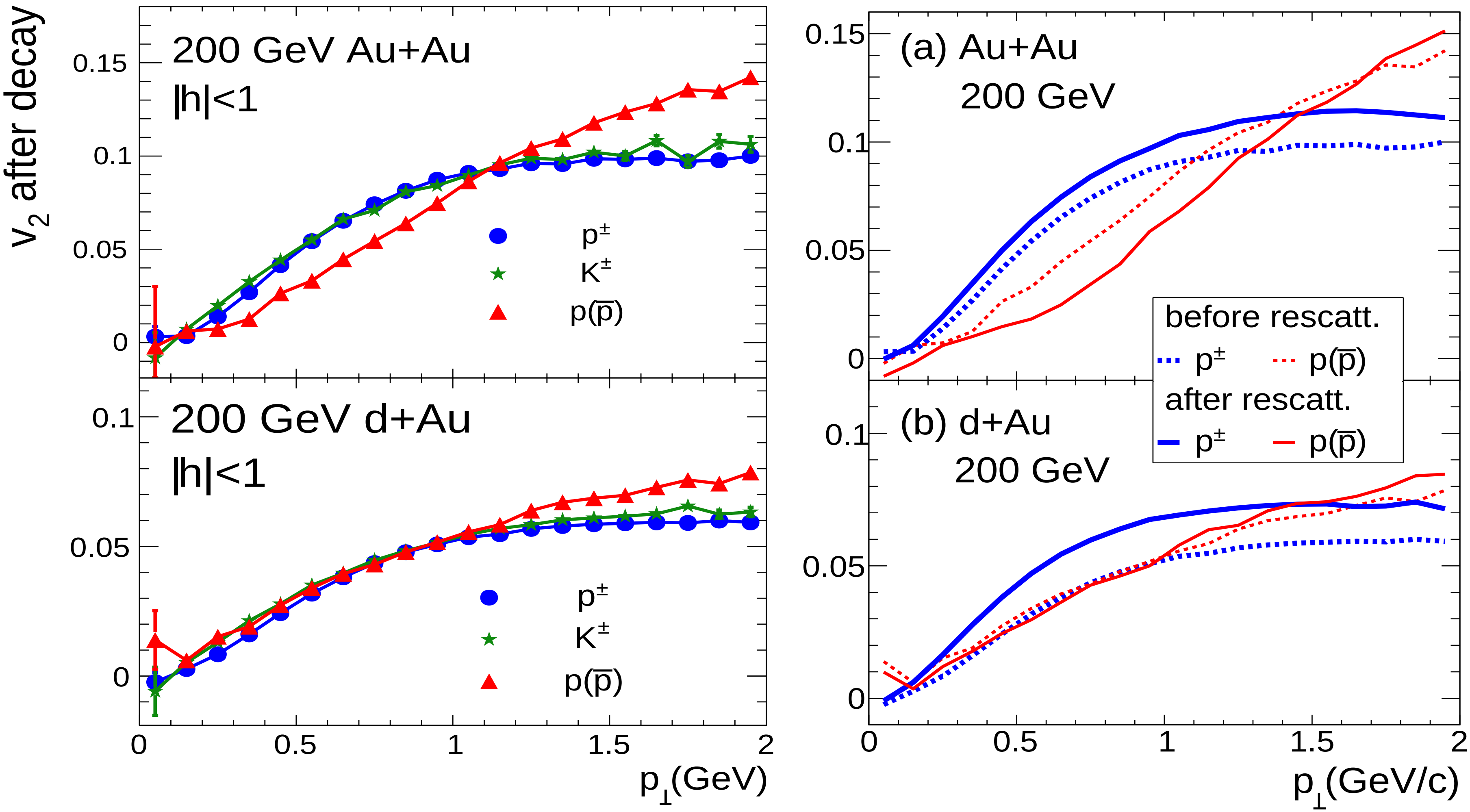
What's origin of the mass splitting?

Partonic v_n



The mass splitting of partonic anisotropy may be caused by mass difference rather than collective flow.

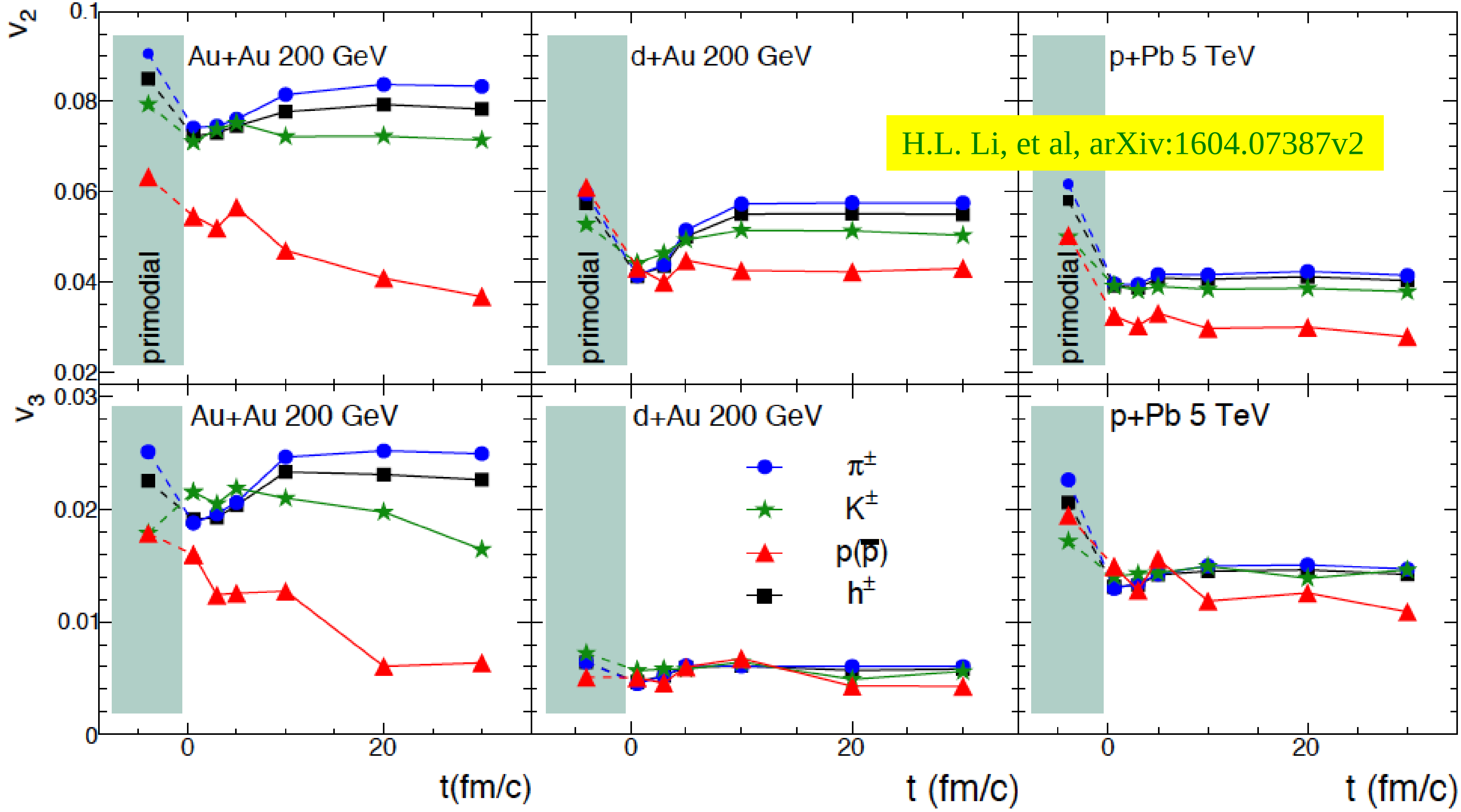
Mass splitting from coalescense and hadronic rescattering



H.L. Li et al, Phys. Rev. C 93,051901(R)(2016)

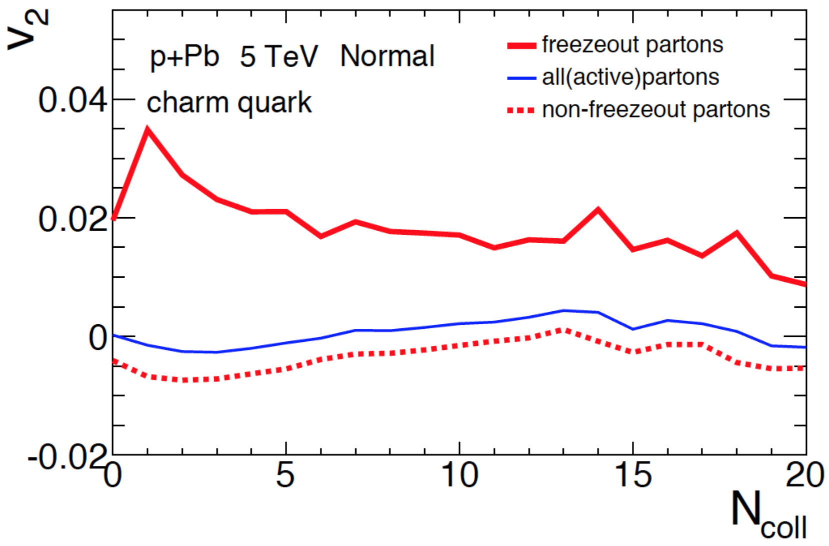
The mass splitting is reduced by decays but significantly increased by hadronic scatterings.

Origins of v_n mass splitting

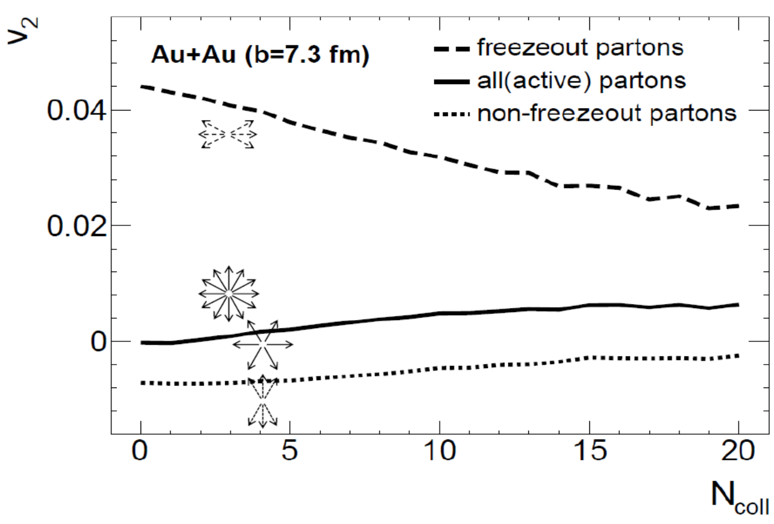


The mass splitting is due to coalescence and, more importantly, hadronic rescatterings.

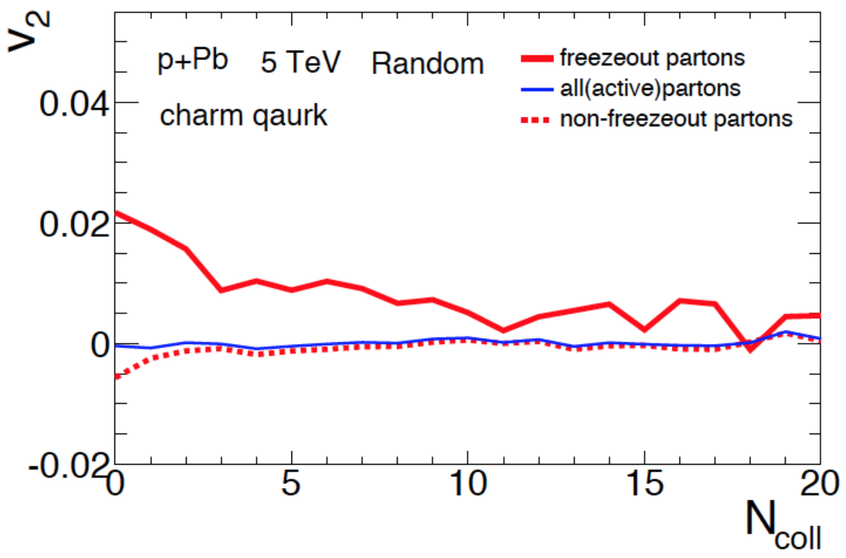
Charm quark



v_2
p+Pb 5 TeV Normal
charm quark
freezeout partons
all(active)partons
non-freezeout partons
0.04
0.02
0
-0.02
0
5
10
15
20
N_{coll}

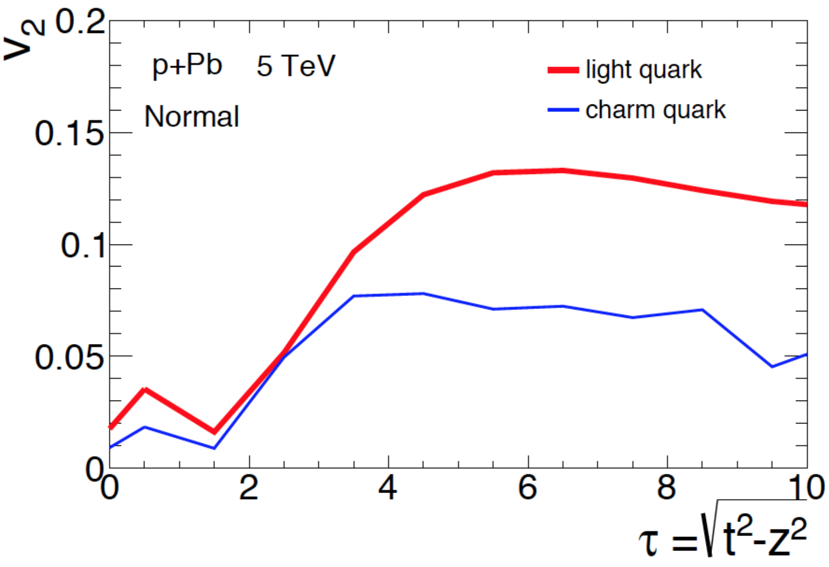


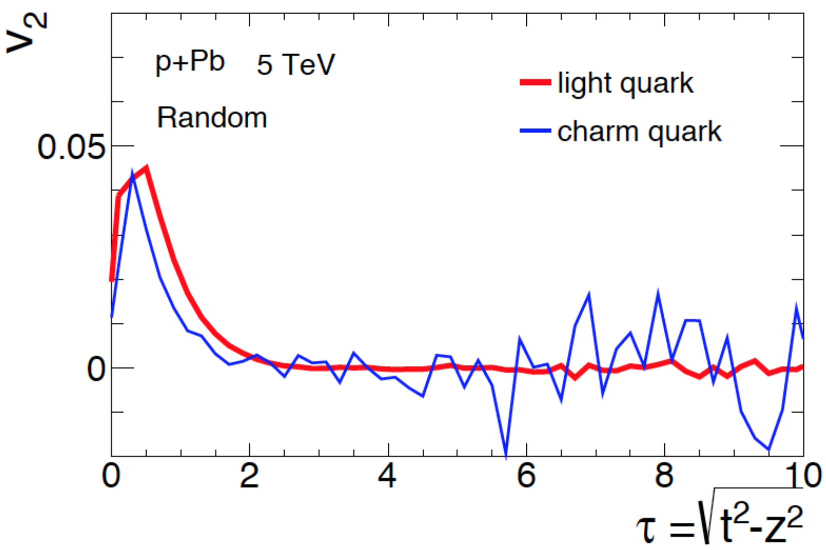
v_2
Au+Au (b=7.3 fm)
freezeout partons
all(active) partons
non-freezeout partons
0.04
0.02
0
0
5
10
15
20
N_{coll}



v_2
p+Pb 5 TeV Random
charm qaurk
freezeout partons
all(active)partons
non-freezeout partons
0.04
0.02
0
-0.02
0
5
10
15
20
N_{coll}

Charm quark





Look at light and charm quark freeze out v2 at the same proper time (same geometry).
v2 vs. proper time is same for light and charm quark, suggesting common escape mechanism.

Summary

I. The anisotropic parton escape is the dominant source of azimuthal anisotropy of light quark in transport model.

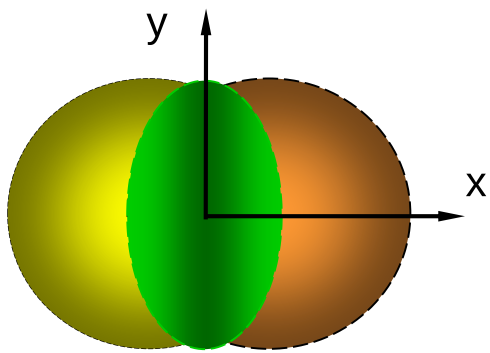
II. The mass splitting of v_n is due to coalescence, and more importantly, hadronic rescatterings.

III. Charm and light quark v2 mechanisms appear to be the same in pPb.

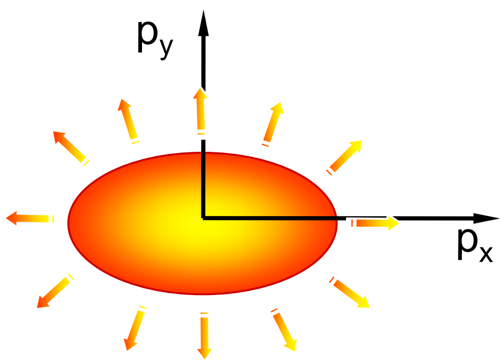
Back up

Azimuthal anisotropies

coordinate space



Momentum space



- Coordinate space configuration anisotropic (almond shape) however, initial momentum distribution isotropic (spherically symmetric)

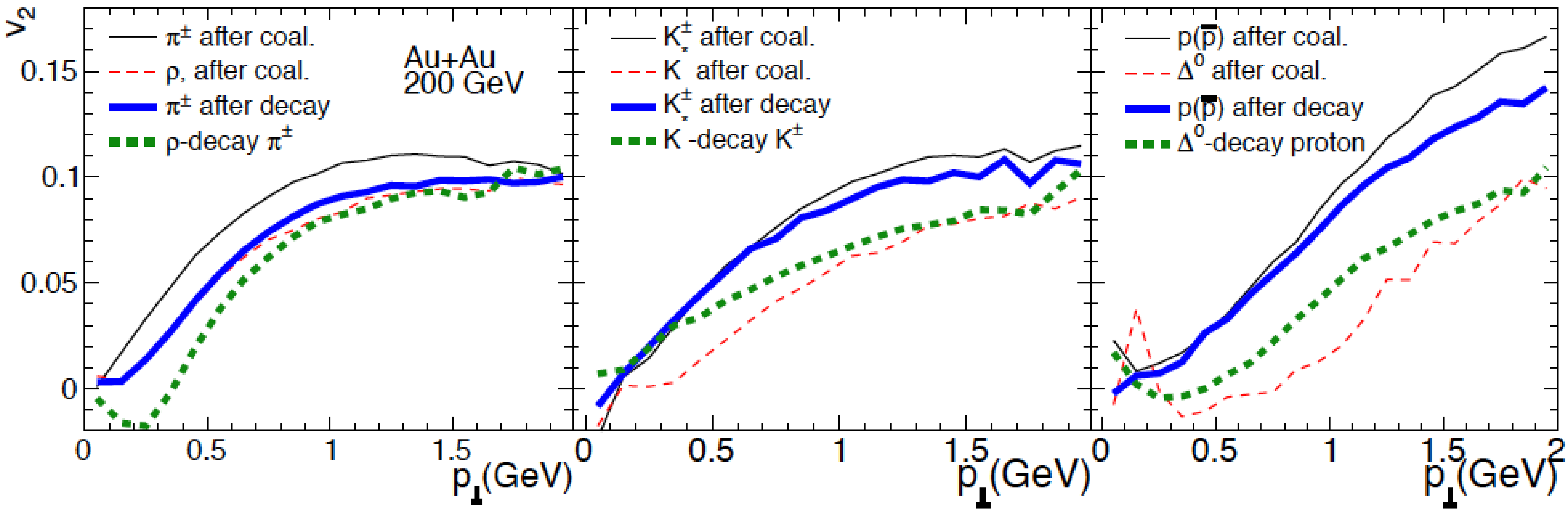
- Only interactions among constituents generate a pressure gradient, which transforms the initial coordinate space anisotropy into a momentum space anisotropy (no analogy in pp)

- Multiple interactions lead to thermalization -> limiting behavior ideal hydrodynamic flow

$$E\frac{d^3N}{d^3p} = \frac{1}{2\pi}\frac{d^2N}{p_t dp_t dy}\left(1+\sum_{n=1}^{\infty}2v_n\cos\left(n\left(\phi-\Psi_r\right)\right)\right)$$

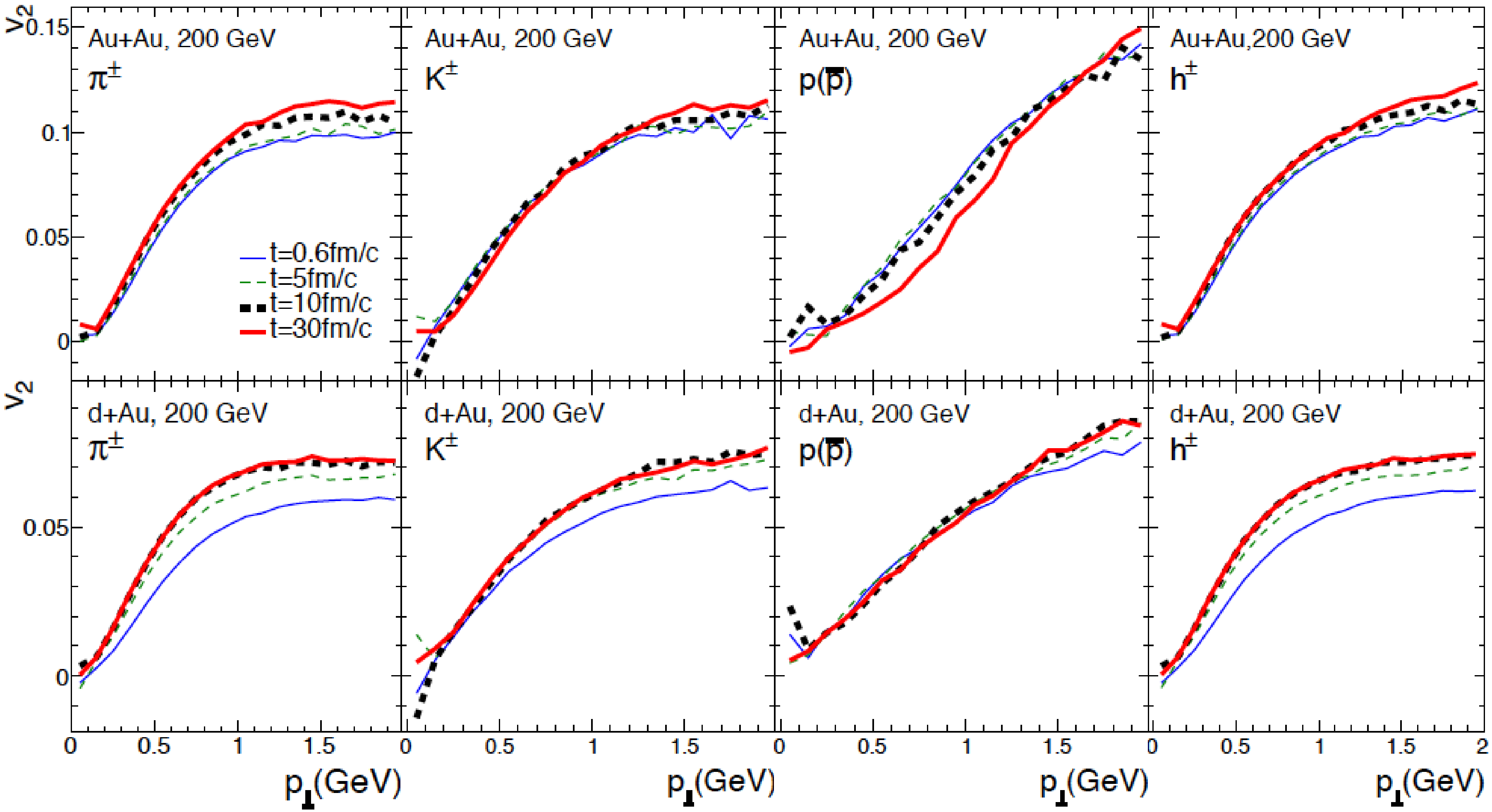
$$v_n = \cos\left(n\left(\phi-\Psi_r\right)\right), \qquad \phi = \tan^{-1}\left(\frac{p_y}{p_x}\right)$$

Decays



v_2
π± after coal.
ρ, after coal.
π± after decay
ρ-decay π±
Au+Au
200 GeV
K± after coal.
K* after coal.
K± after decay
K*-decay K±
p(p̄) after coal.
Δ0 after coal.
p(p̄) after decay
Δ0-decay proton
0.15
0.1
0.05
0
0
0.5
1
1.5
2
$p_\perp$(GeV)

Hadronic rescatterings



Hadronic eccentricity