Charm V_2 is more hydrodynamic than light quark V_2

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Mostly based on:

H.L. Li, Z.-W. Lin, , F.Q. Wang **, in preparation;**
H.L. Li, Z.-W. Lin, , F.Q. Wang , **Journal of Physics (SQM'2016) 779,012063 (2017)**
Z.-W. Lin, **H.L. Li**,, F.Q. Wang , **Presentation at SQM'2017**

Outline

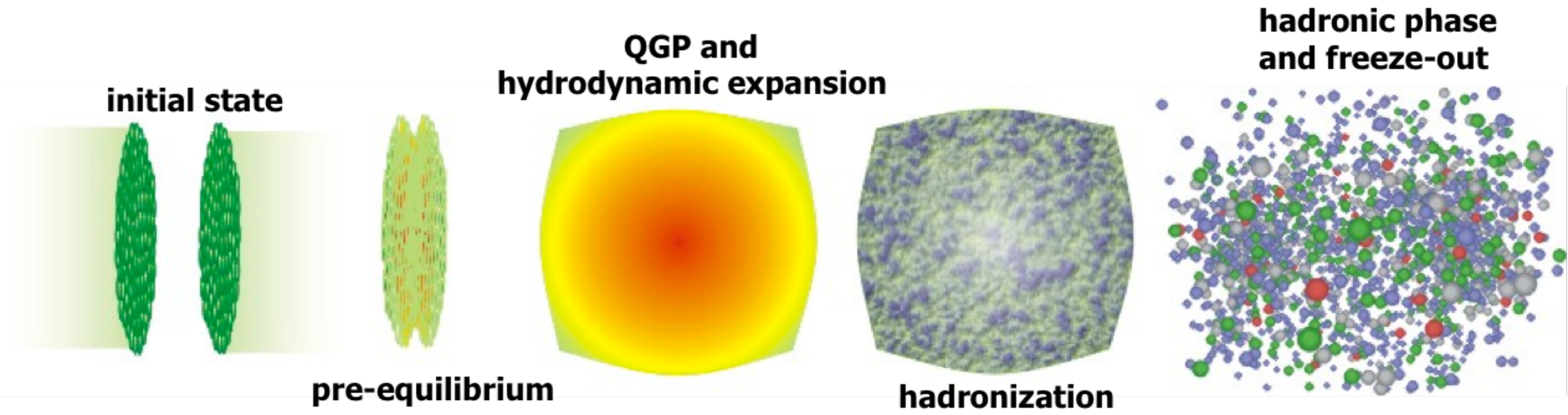
Introduction

Results and discussion

- ★ V_2 development in AMPT
- ★ Charm quark's V_2

Summary

Heavy ion collisions



Hard probes (p_T,M>>Λ_{QCD}=200 MeV)
Jet queching
Heavy quarks (tagged b-jets) ....

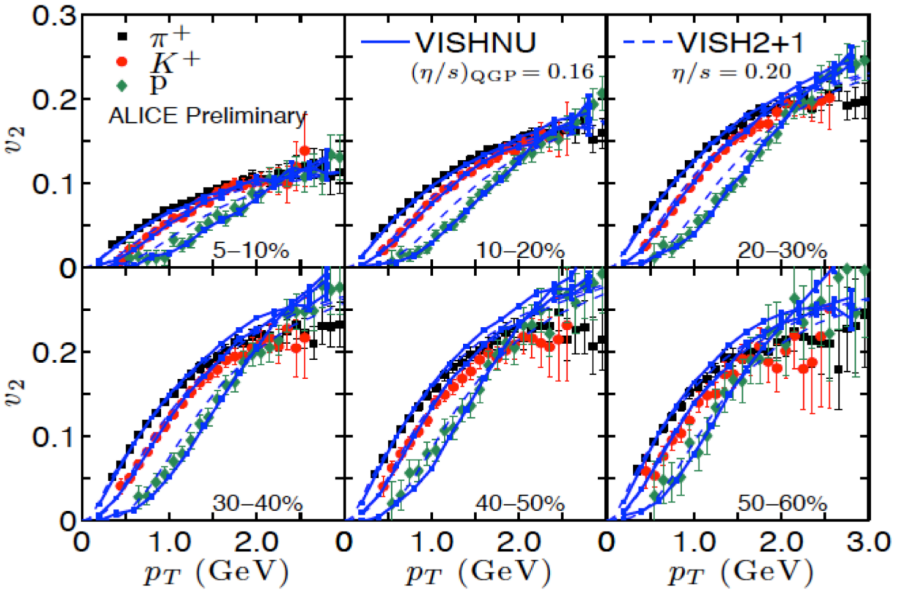
Soft probes (p_T~Λ_{QCD}=200 MeV)
Collective flow……

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

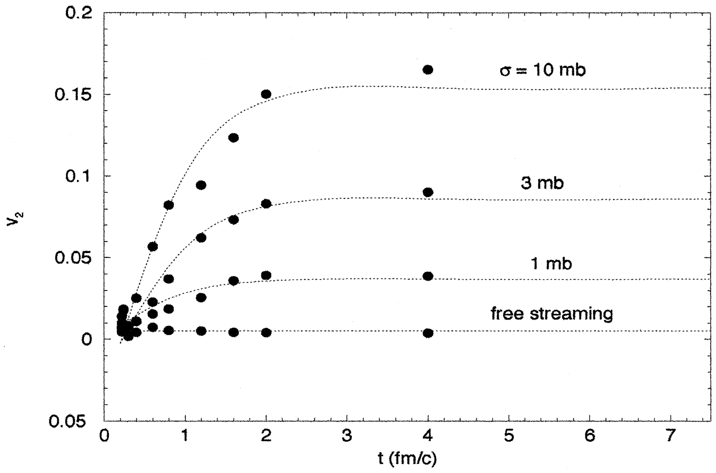
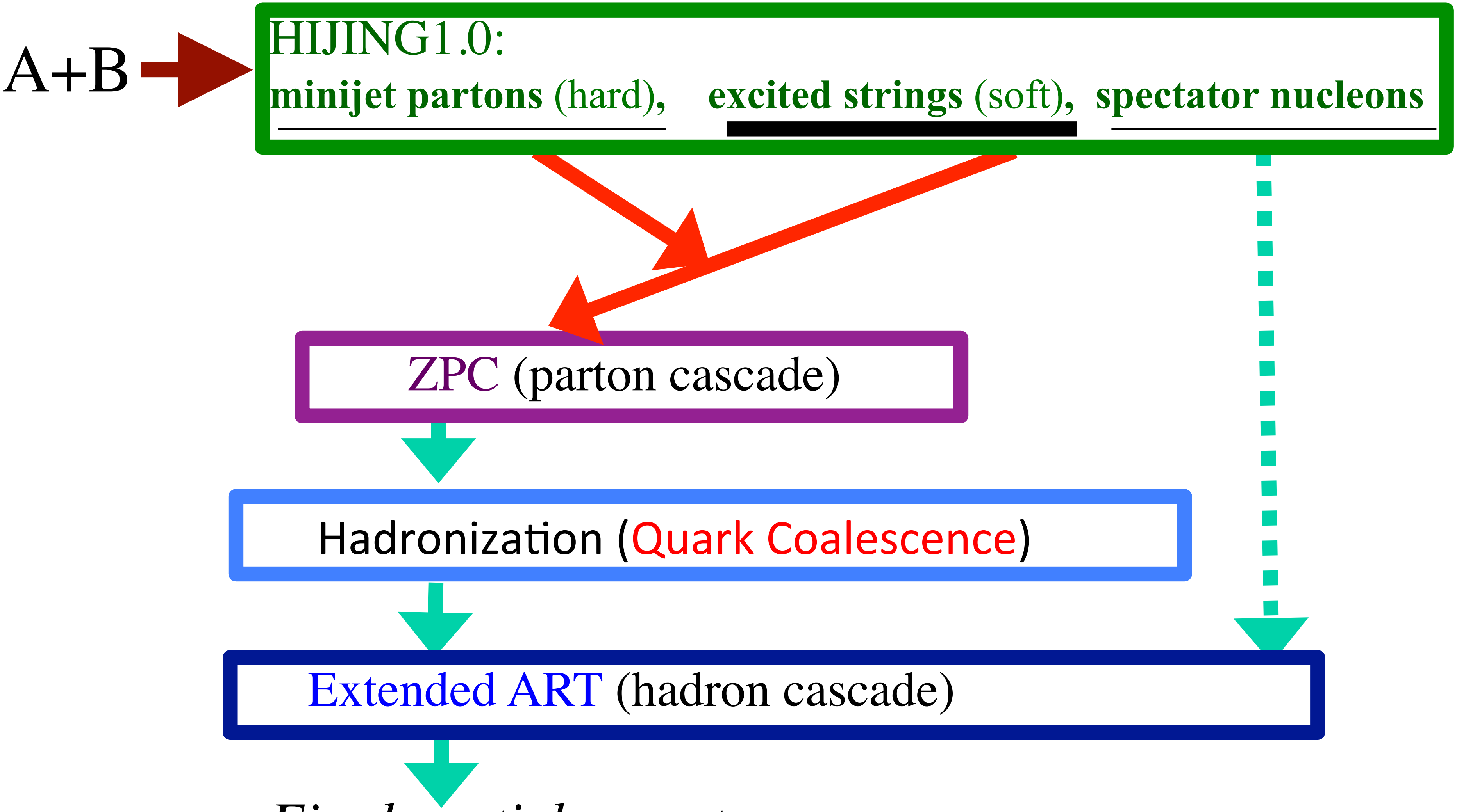


Fig. 1. Time evolution of v_2 coefficient for different effective parton scattering cross sections in Au-Au collisions at $\sqrt{s}=200$ AGeV with impact parameter 7.5 fm. Filled circles are cascade data, and dotted lines are hyperbolic tangent fits to the data.

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

Structure of AMPT (String Melting version)



A+B

HIJING1.0:

minijet partons (hard), **excited strings** (soft), **spectator nucleons**

ZPC (parton cascade)

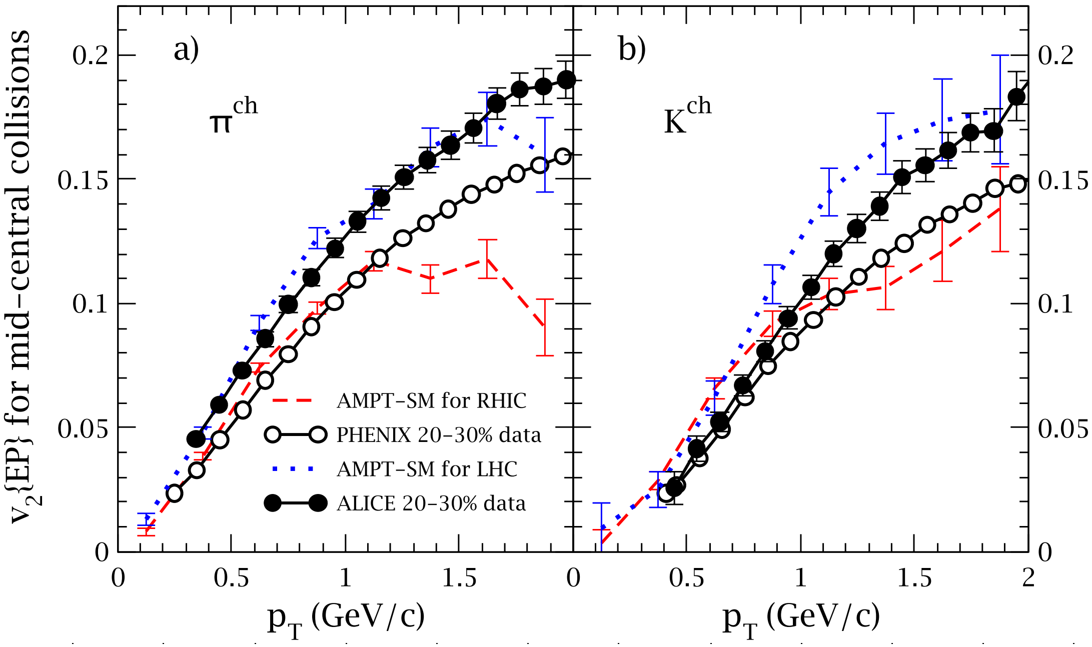
Hadronization (Quark Coalescence)

Extended ART (hadron cascade)

Final particle spectra

A Multi-Phase Transport (AMPT) model describes data

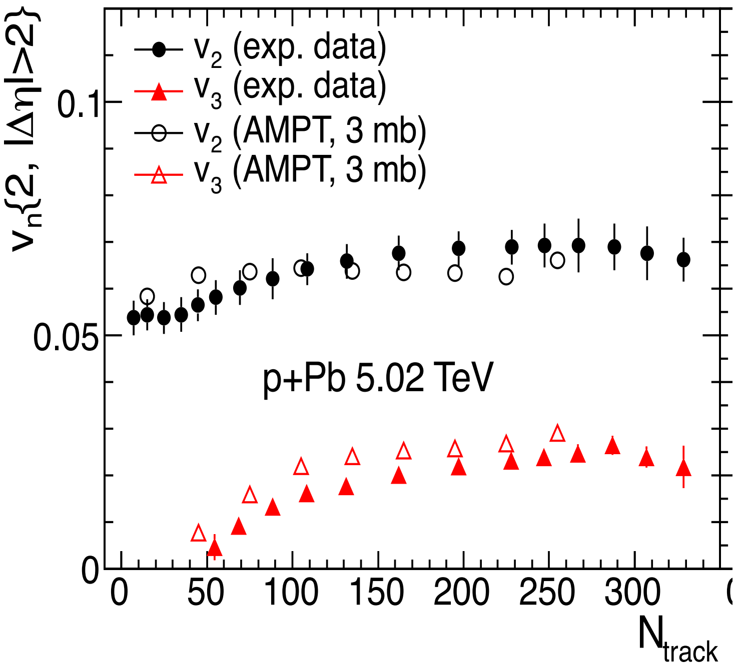
AMPT describes low-pt (<2GeV/c) π & K data on dN/dy, p_T spectra & v2 in central & mid-central events of 200AGeV Au+Au & 2760AGeV Pb+Pb.



v2 of π & K (AuAu@200AGeV b=7.3fm)

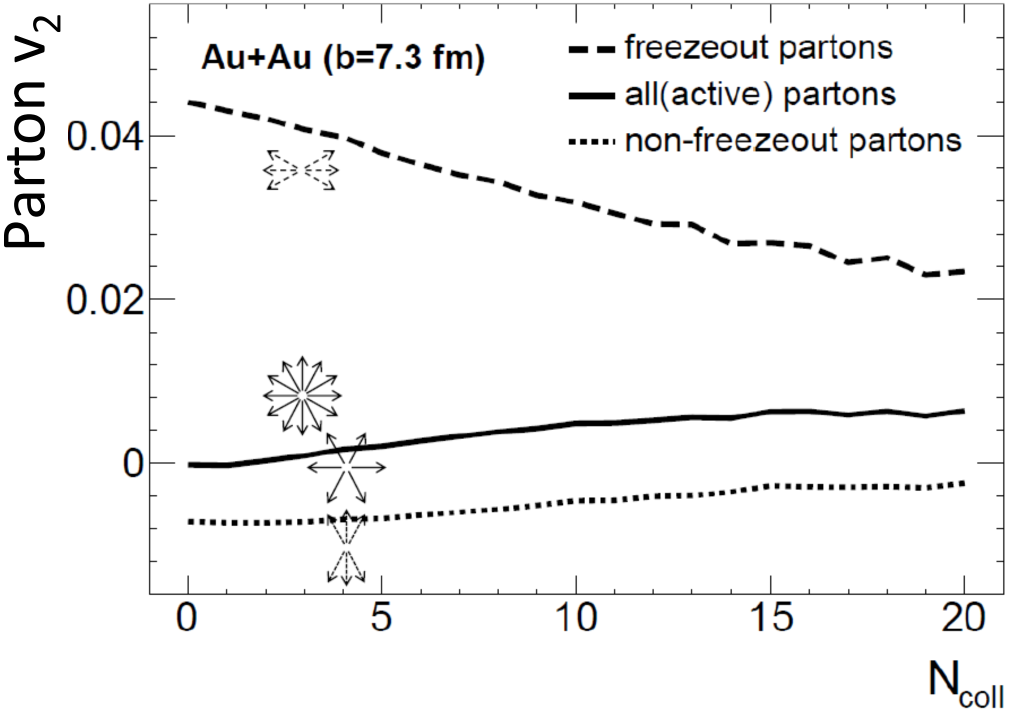
Z.-W.Lin,PRC90 (2014) 1, 014904

Collectivity in small colliding systems

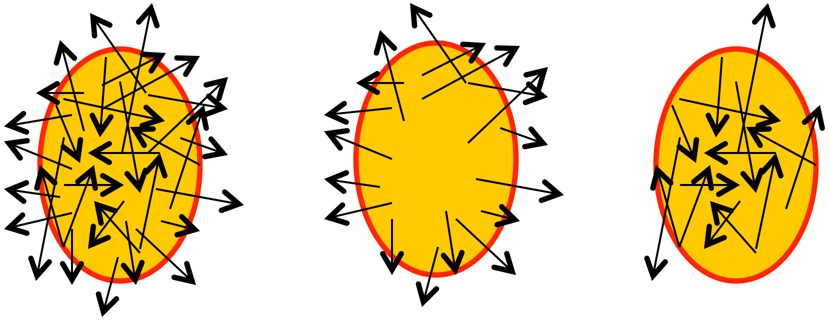


Bzdak and Ma,
Phys.Rev.Lett. 113 (2014) 25, 252301

Parton azimuthal anisotropies developed in AMPT



Ncoll: *number of collisions suffered by a parton.*



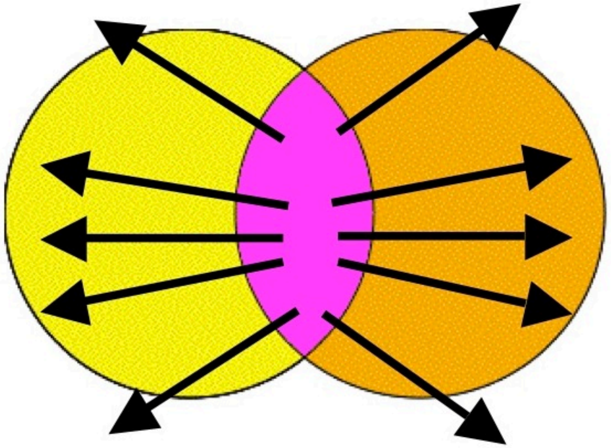
- Partons freeze out with large positive v_2, even for partons that do not interact at all.
- This is due to larger escape probability along x than y induced by parton scatterings.
- Remaining partons start off with negative v_2, and become ~isotropic (v_2~0) after one more collision.
- Process repeats 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)

Anisotropic particle escape

At Ncoll=0:
Escaped: v2 ≈ 4.5%,
purely due to
anisotropic escape probability
(interaction-induced response
to geometrical shape)

Simplified picture of elliptic flow

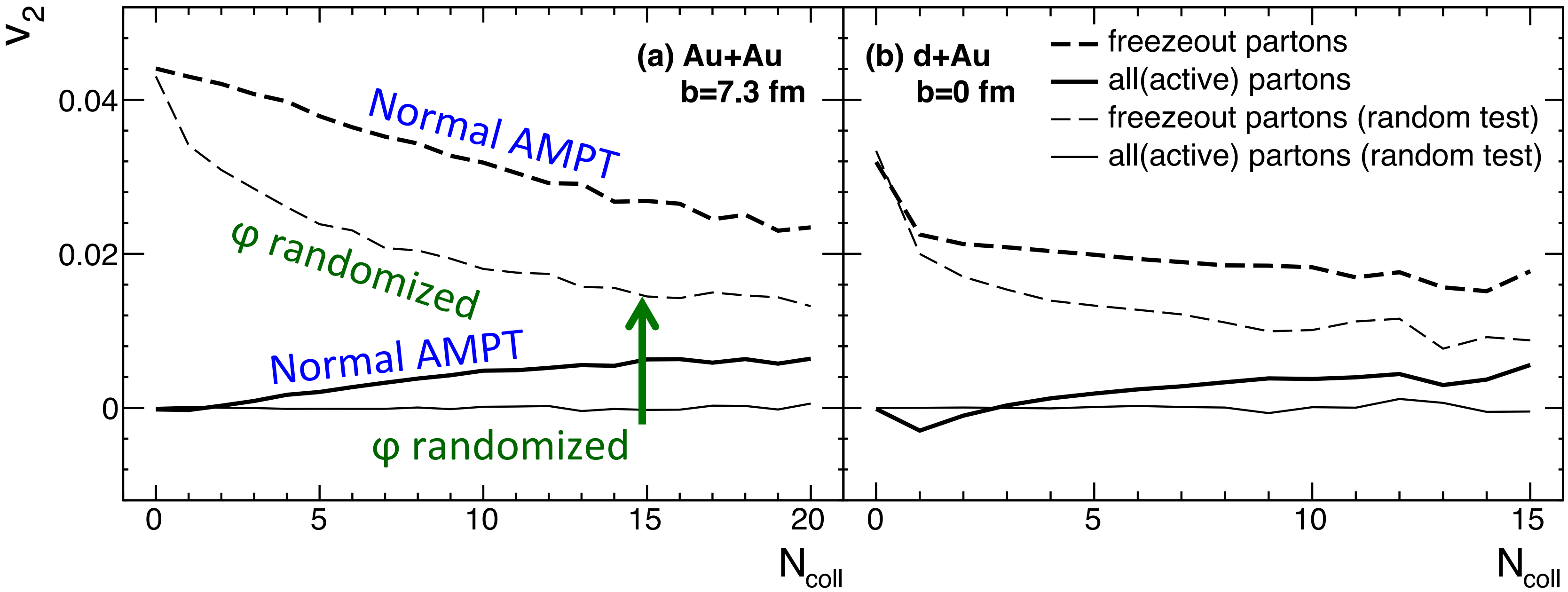


At Ncoll>=1:
Escaped: v2>0
due to
anisotropic escape probability
& from hydrodynamic flow of all
active partons

← Which part
is more important?

Majority anisotropy from escape at RHIC

v2 from Random Test(destroy hydrodynamic flow but keep the anisotropic shape):
purely from escape mechanism, not from hydrodynamic flow



AMPT results on integrated v2:

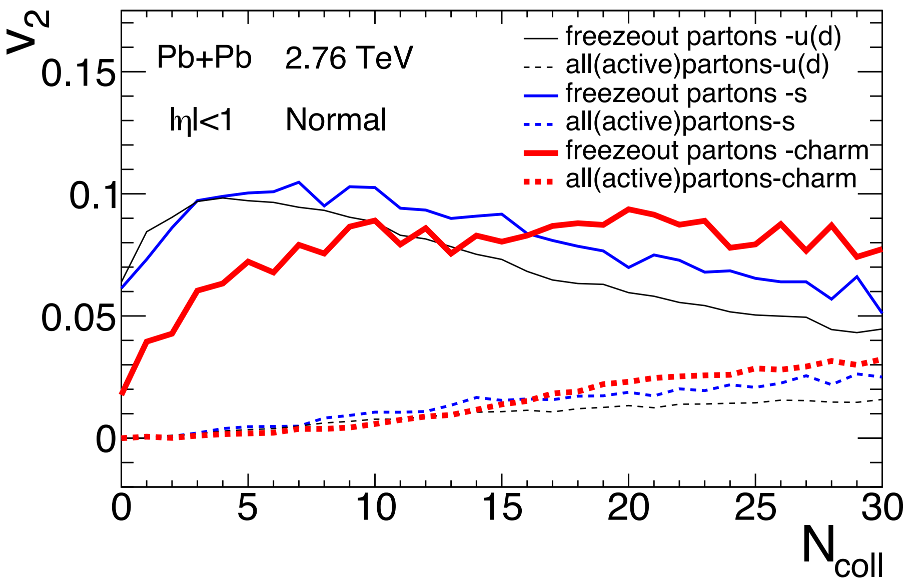
	Normal	φ randomized	% from escape
Au+Au	3.9%	2.7%	69%
d+Au	2.7%	2.5%	93%

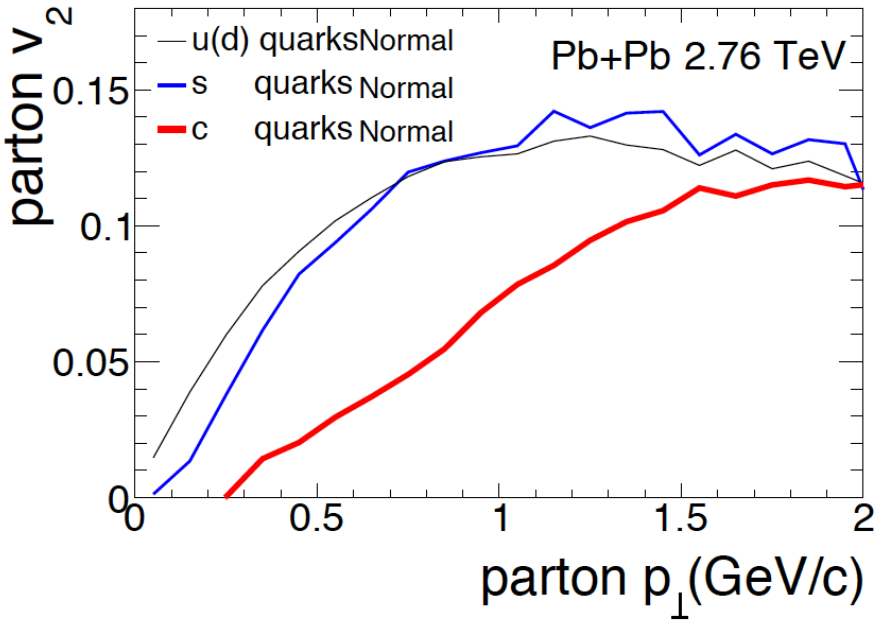
L. He, T. Edmonds, Z.-W. Lin,
F. Liu, D. Molnar, F.Q. Wang,
Phys. Lett. B 735,506(2016)

Majority of anisotropy comes from the "escape mechanism". The contribution to anisotropy from hydrodynamic flow is found to be small

Azimuthal anisotropies of different flavours

We now use string melting AMPT to analyze light (u/d), strange, charm quarks in p+Pb@5TeV, Au+Au@200GeV, Pb+Pb@2.76TeV. Hanlin Li, ZWL, Fuqiang Wang, in preparation.





Mass ordering in v2(Ncoll):

v2c < v2s < v2ud at small Ncoll;

v2c > v2s > v2ud at large Ncoll.

Mass ordering in v2(P_T):

- mass ordering at low P_T:
  v2c < v2s < v2ud.

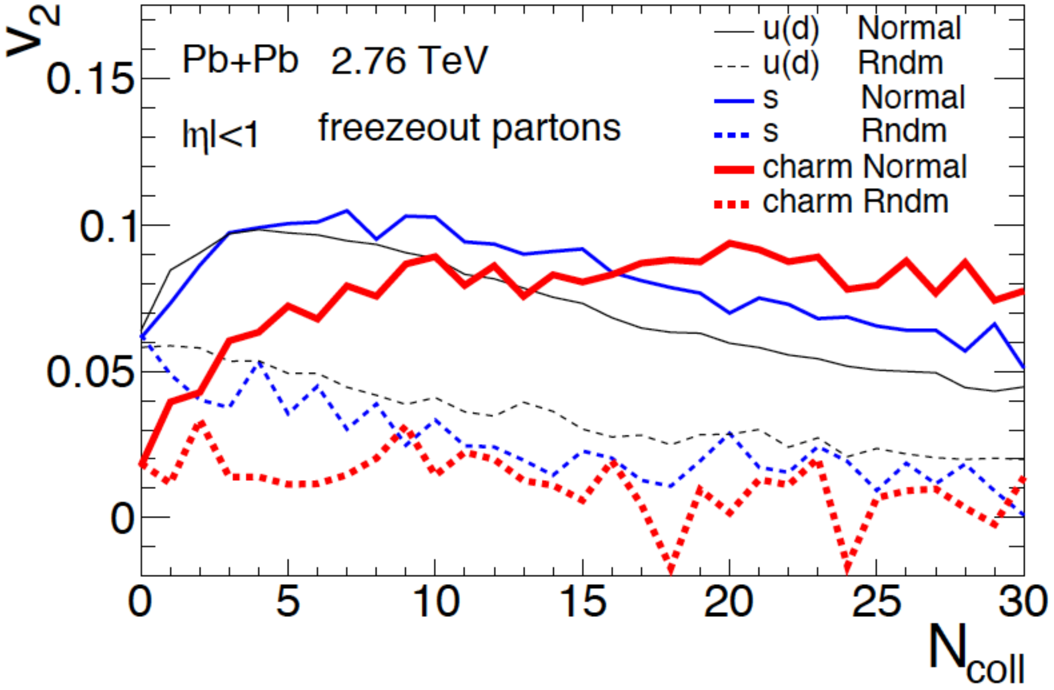
Hanlin Li et al. PRC 93 (2016); PRC 96 (2017).

Question:

Does the escape mechanism work differently for v2 of different flavours?

The escape mechanism: flavour dependence

Pb+Pb
2.76TeV
8fm



1 , Escape mechanism at work for charm v2 as well as (u,d,s) quark.
2, Hydro-dynamics type flow seems to have more contribution to charm v2 than light quarks.

Esha, Md. Nasim & Huang, JPG44 (2017);
Greco's talk at QM2017.

The escape mechanism: flavour dependence

u/d

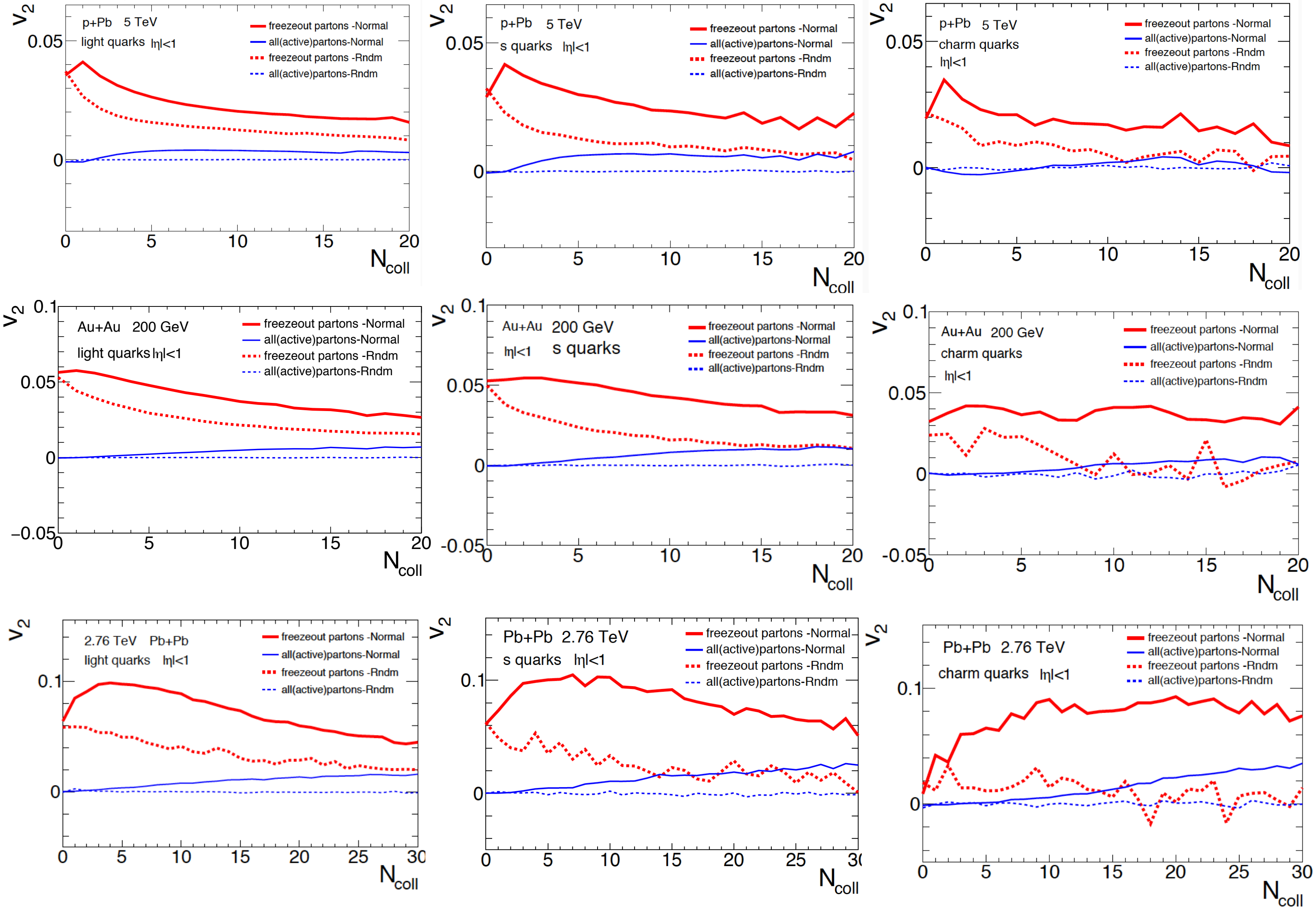
s

c

p+Pb
5TeV
b=0fm

Au+Au
200GeV
6.6-8.1fm

Pb+Pb
2.76TeV
8fm



Quarks v2 as function of Ncoll and significantly depends on mass and collisions system.

The escape mechanism: flavour dependence

	pPb b=0fm	**AuAu** b=6.6-8.1fm	**PbPb** b=8fm
light	<Ncoll>= 2.02 <v2>Rndm= 2.392% <v2>Norm= 3.279% <v2>Rndm/<v2>Norm **=72.9%**	<Ncoll>= 4.5 <v2>Rndm= 2.931% <v2>Norm= 4.468% <v2>Rndm/<v2>Norm **=65.6%**	<Ncoll>= 9.82 <v2>Rndm= 3.214% <v2>Norm=7.562% <v2>Rndm/<v2>Norm **=42.5%**
s-quark	<Ncoll>= 2.54 <v2>Rndm=1.894% <v2>Norm=3.203% <v2>Rndm/<v2>Norm **=59.1%**	<Ncoll>= 5.45 <v2>Rndm= 2.266% <v2>Norm= 4.784% <v2>Rndm/<v2>Norm **=47.4%**	<Ncoll>= 11.14 <v2>Rndm= 2.23% <v2>Norm= 8.424% <v2>Rndm/<v2>Norm **=26.5%**
c-quark	<Ncoll>= 4.23 <v2>Rndm=1.214% <v2>Norm=2.139% <v2>Rndm/<v2>Norm **=56.8%**	<Ncoll>= 8.6 <v2>Rndm=0.8455% <v2>Norm=3.885% <v2>Rndm/<v2>Norm **=22%**	<Ncoll>= 15.48 <v2>Rndm=0.6724% <v2>Norm=7.923% <v2>Rndm/<v2>Norm **=8.5%**

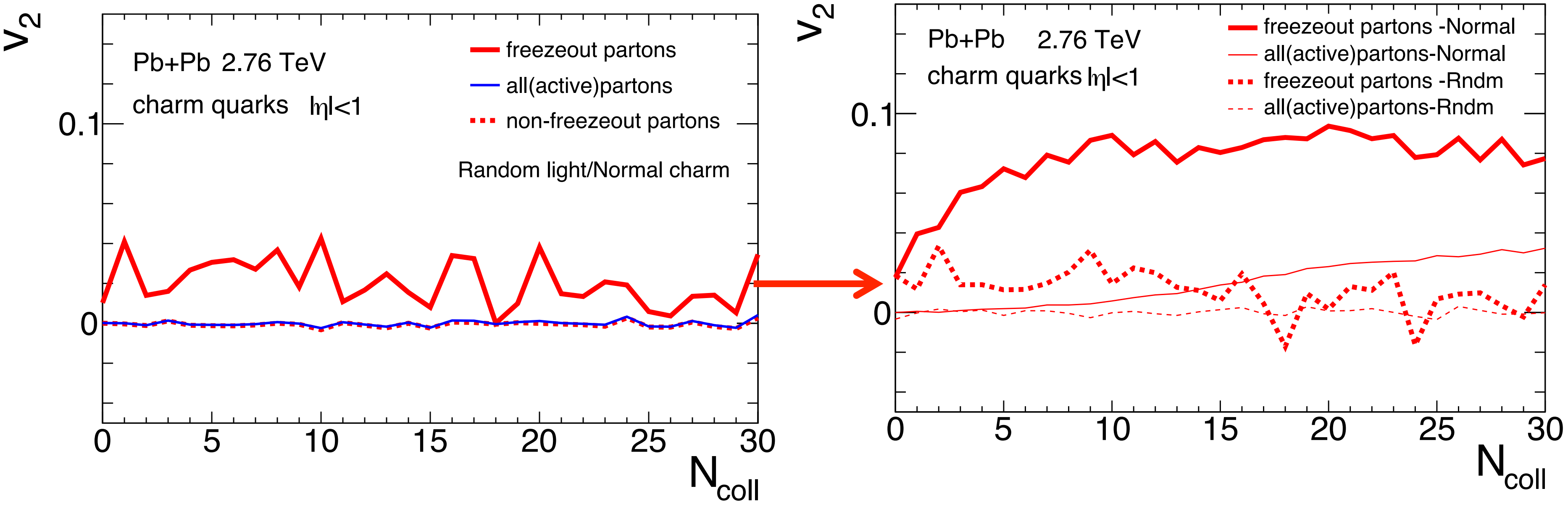
q → Q

System size/energy → Less from escape mechanism/ more from hydrodynamics type flow.

Questions:

1. Where does charm hydro-dynamics type v_2 come from ?
2. Why charm v_2 is more hydro-dynamics ?

The escape mechanism: flavour dependence



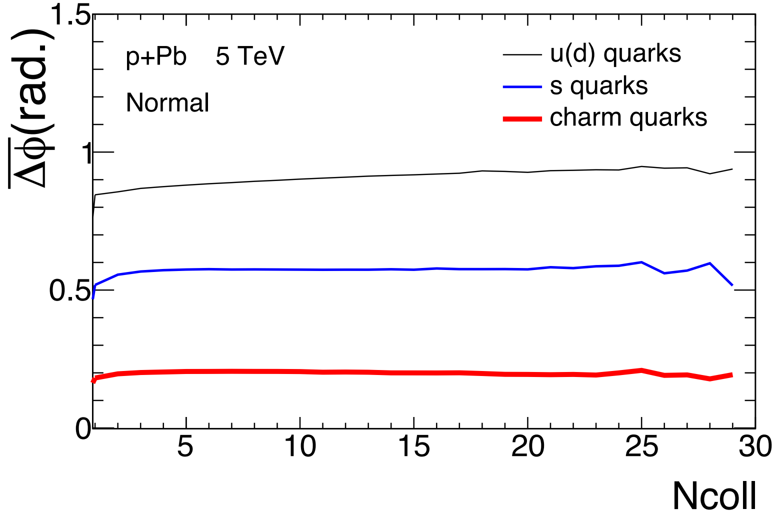
Random light /Normal charm:

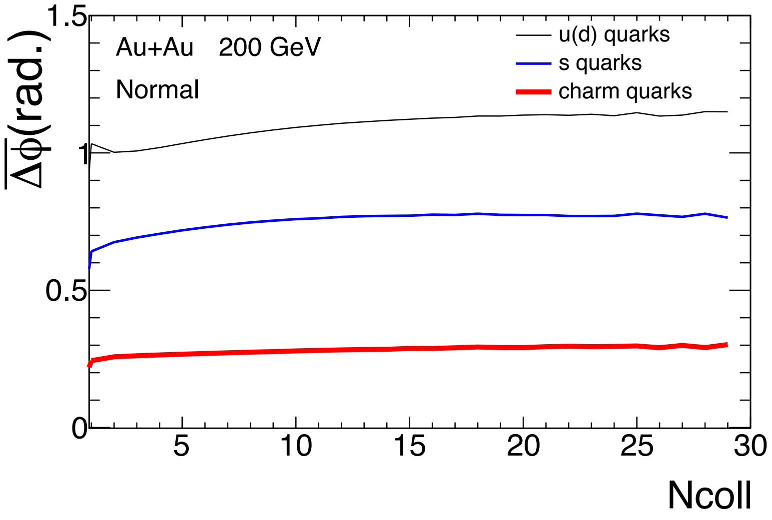
Random-φ for u/d/s quarks only
(Normal charm: charm quarks keep their hydrodyanmic flow)

large reduction of charm v2 (like all-flavour random-φ test)
light quark hydrodynamic flow is essential for charm v2.

The deflection angle

$\Delta\phi$: change of azimuth due to one collision (*the Ncoll-th collision*):





Mass ordering on
the mean parton deflection angle:

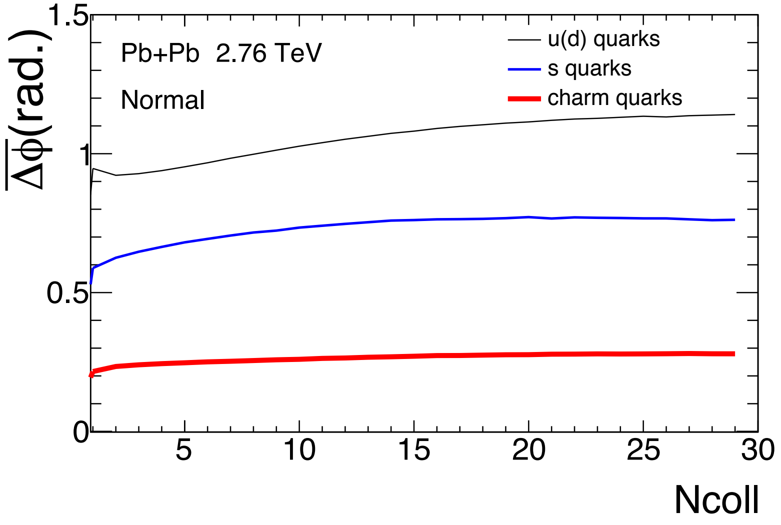
$$\Delta\phi\_c < \Delta\phi\_s < \Delta\phi\_u(d)$$

it is more difficult to deflect a heavier quark,

so light quark flow

& strong light-charm interactions

are essential to generate significant charm v2.



Toy Model studies

Simple MC toy model:

v_2 vs. $<N_{coll}>$:
Sampling partons starting at (x=0,y=0) and traversing same shape medium of different sizes.

The initial $v_2 = 0$

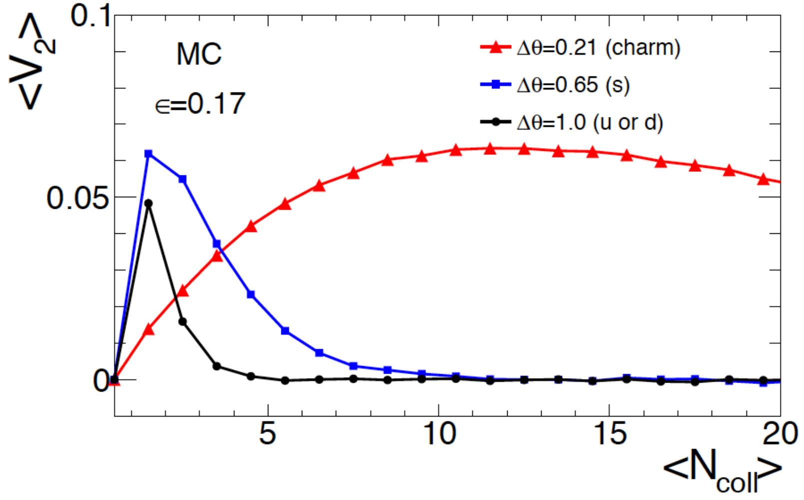
The parton's azimuth ϕ_f after <Ncoll> collisions.

$$\phi_f = \phi_i + Gaus(\sqrt{N_{coll}(\phi_i)} \cdot \Delta\theta)$$

$$N_{coll}(\phi_i) = <N_{coll}> \cdot (1 - 2\varepsilon_2 \cdot \cos(2\phi_i))$$

$\Delta\theta$ is the parton's average azimuthal deflection after each collision.

The final $v_{2\_final} = <\cos(2\phi_f)>$



With small N_{coll}, light quark v_2 is larger than charm v_2. With large N_{coll}, it is the opposite. This is because the light quarks are more randomized after many collisions due to the large angle change per collision.

Summary

1.The common escape mechanism at work for both charm and light quark v_2.

2. Light quark flow and strong charm-light interactions are essential for large charm v2.

3. The charm v2 is found be much more sensitive to hydrodynamic flow than light quark v2.

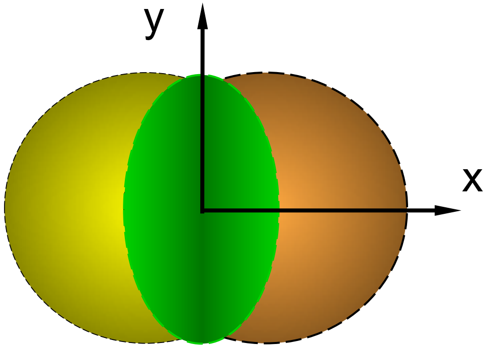
4. Comparative study of light and heavy quark anisotropies is important to investigate the medium properties in heavy ion collisions.

Thank you!

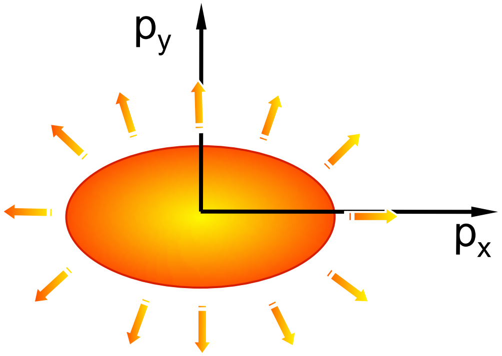
Back up

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

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

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