Collective Flow from QGP Hydro + Hadronic Cascade

Tetsufumi Hirano
Dept. of Physics
The Univ. of Tokyo

TH, U.Heinz, D.Kharzeev, R.Lacey, and Y.Nara (in preparation)

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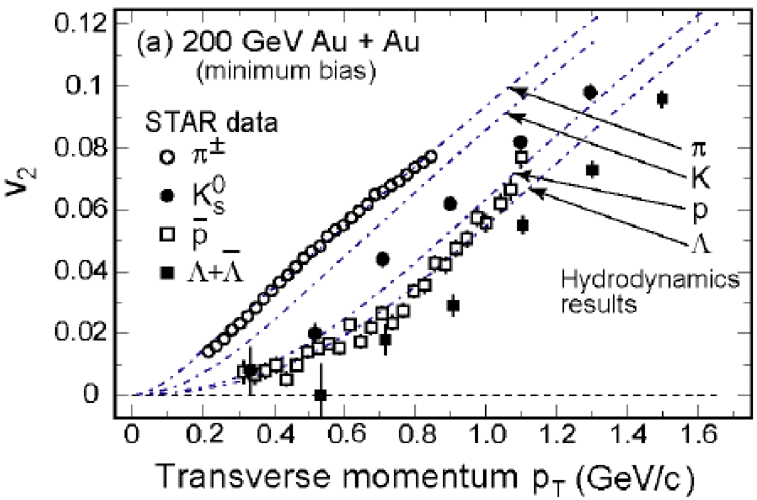
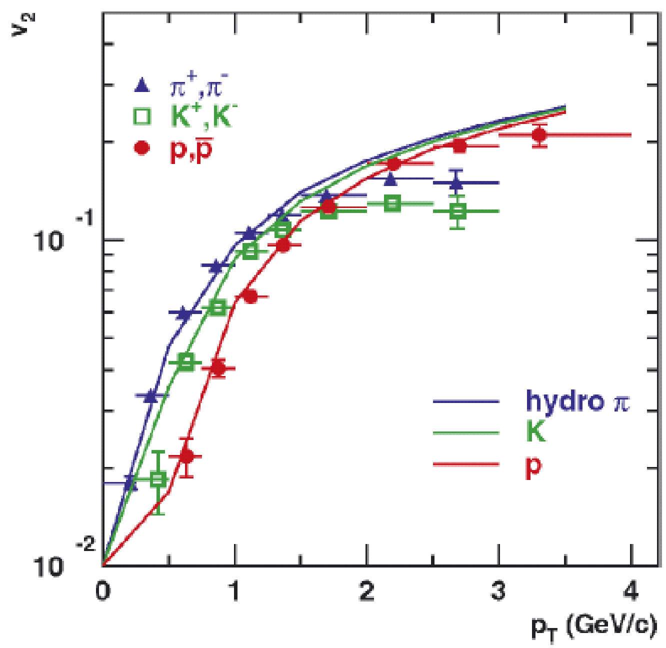
Outline

- Introduction & Motivation
- Mass ordering of $v_2(p_T)$ revisited
- Violation of mass ordering for ϕ mesons
- Summary

Is Mass Ordering of $v_2(p_T)$ a Direct Signal of Perfect Fluidity?



STAR white paper ('05)



PHENIX white paper ('05)

Lines: Results from **Ideal** hydro

Consequences of perfect fluid QGP?

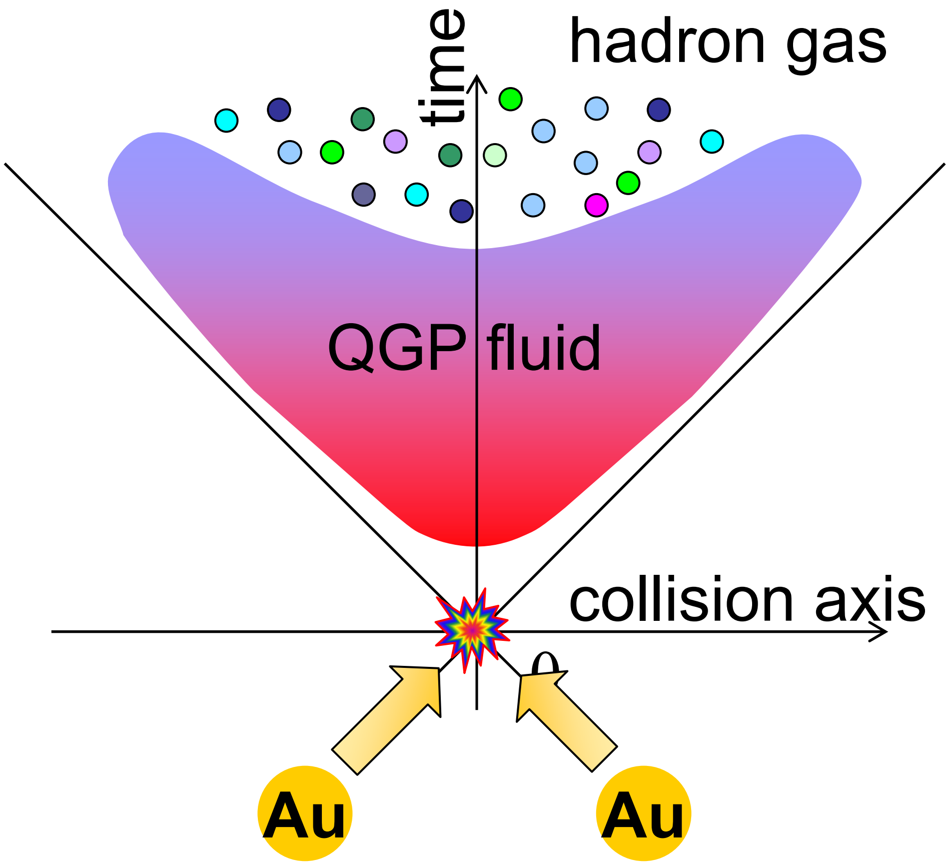
Motivation

To understand the QGP in H.I.C., need to understand the hadronic stage since

$$\begin{aligned} & \text{Observables} \\ \approx\ & (\text{Initial}) \otimes (\text{Pre-equilibrium}) \\ \otimes\ & (\text{QGP}) \otimes (\text{Phase transition}) \\ \otimes\ & (\text{Hadron}) \otimes (\cdots) \end{aligned}$$

Indispensable to disentangle these effects for understanding of unknowns.

A Hybrid Approach: QGP hydro + hadronic cascade



TH et al.('06)

Initial condition:

•Transverse → Glauber

•Longitudinal → "BGK triangle"

QGP fluid:

•3D ideal hydrodynamics (Hirano)

•massless free u,d,s+g gas + bag const.

•T_c = 170 MeV

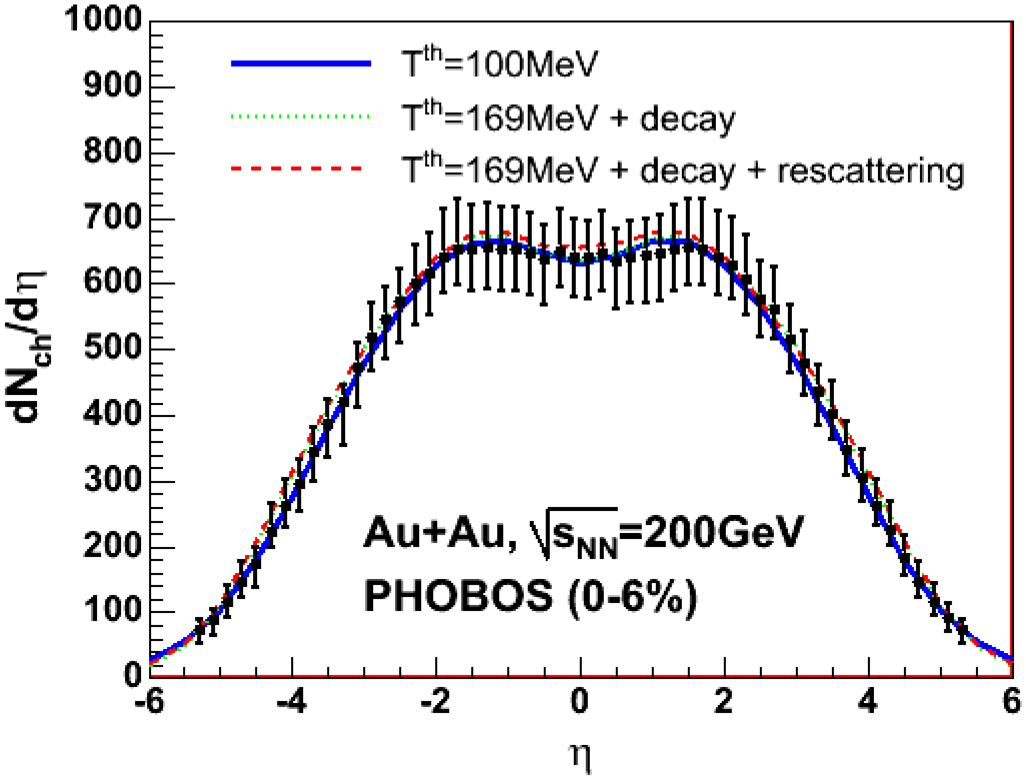
Hadron gas:

•Hadronic cascade, JAM1.09 (Nara)

•T_{sw} = 169 MeV

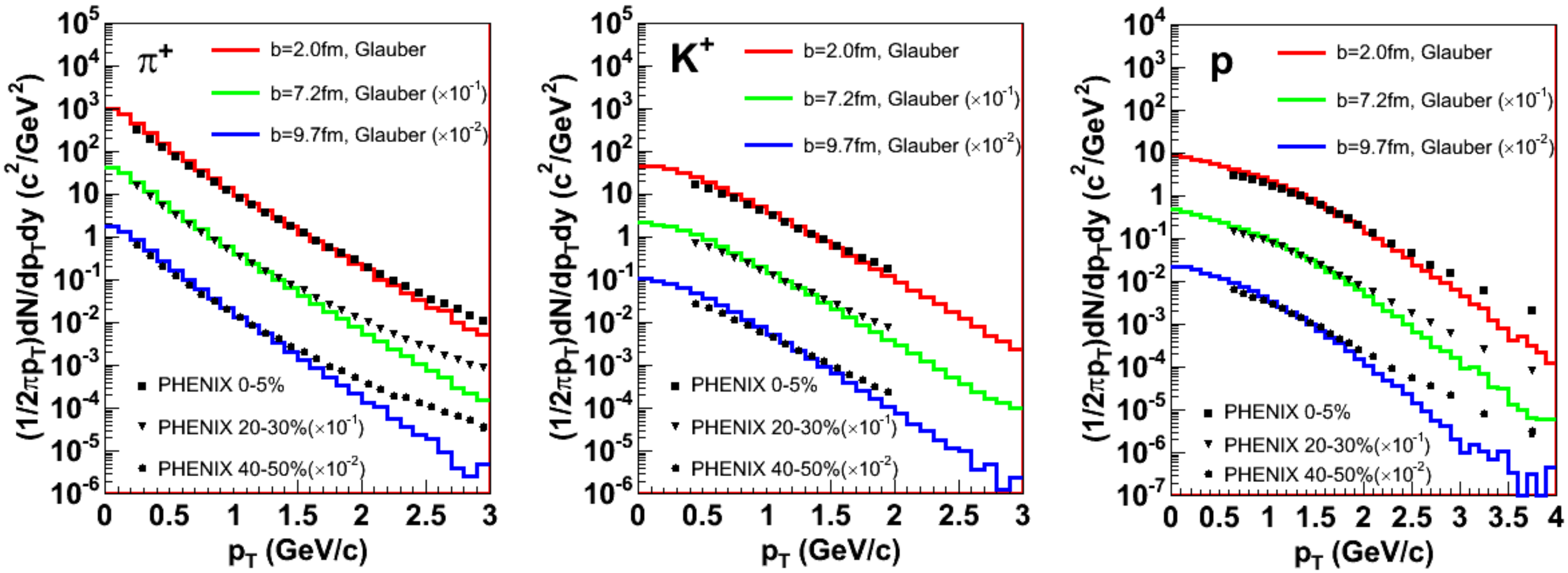
(1D) Bass, Dumitru (2D) Teaney, Lauret, Shuryak, (3D) Nonaka, Bass, Hirano et al.

Pseudorapidity Distribution



Tune initial parameters with T^{th} = 100MeV to reproduce dN/deta. Then, switch to hadronic cascade below $T=T^{sw}$. Caveat: Rejecting in-coming particles at T^{sw}

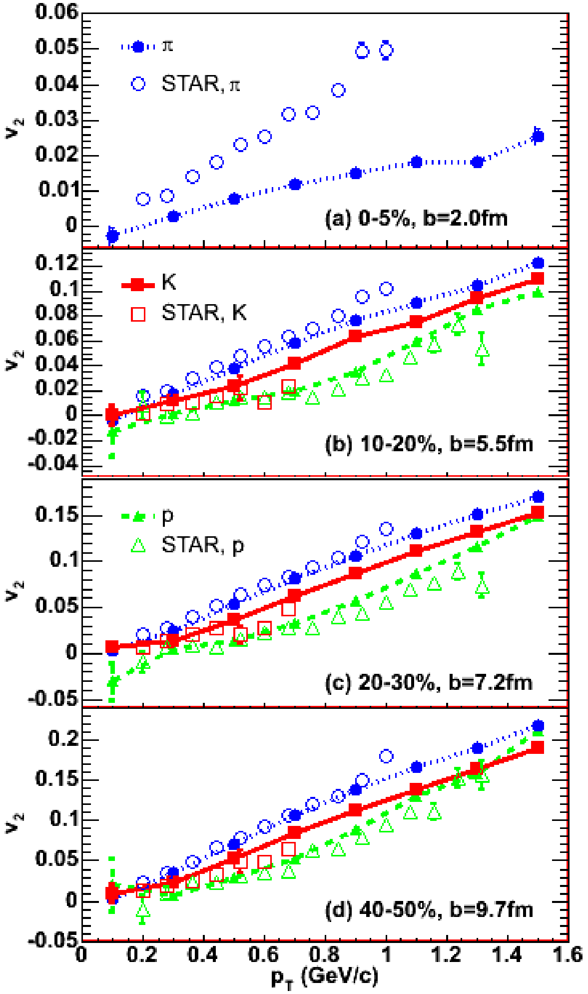
p_T spectra for pi, K, and p



Reasonable reproduction of yields and spectra in low p_T region (p_T<~1.5 GeV/c)

TH et al. (in preparation).

$v_2(p_T)$ for pi, K, and p



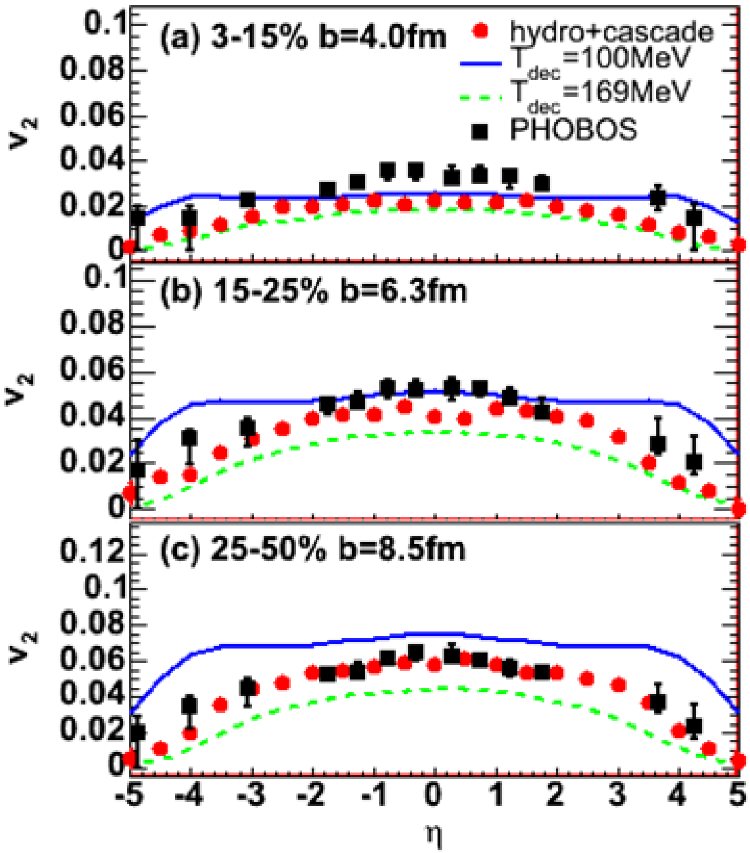
Fail to reproduce data due to (absence of) fluctuation of geometry

Miller&Snelling ('03), Bhalerao&Ollitrault('06)
Andrade et al ('06),Drescher&Nara ('07)
Browniowski et al('07)

OK!

TH et al. (in preparation).

Pseudorapidity Dependence of Elliptic Flow



Fail to reproduce data due to (absence of) fluctuation of geometry

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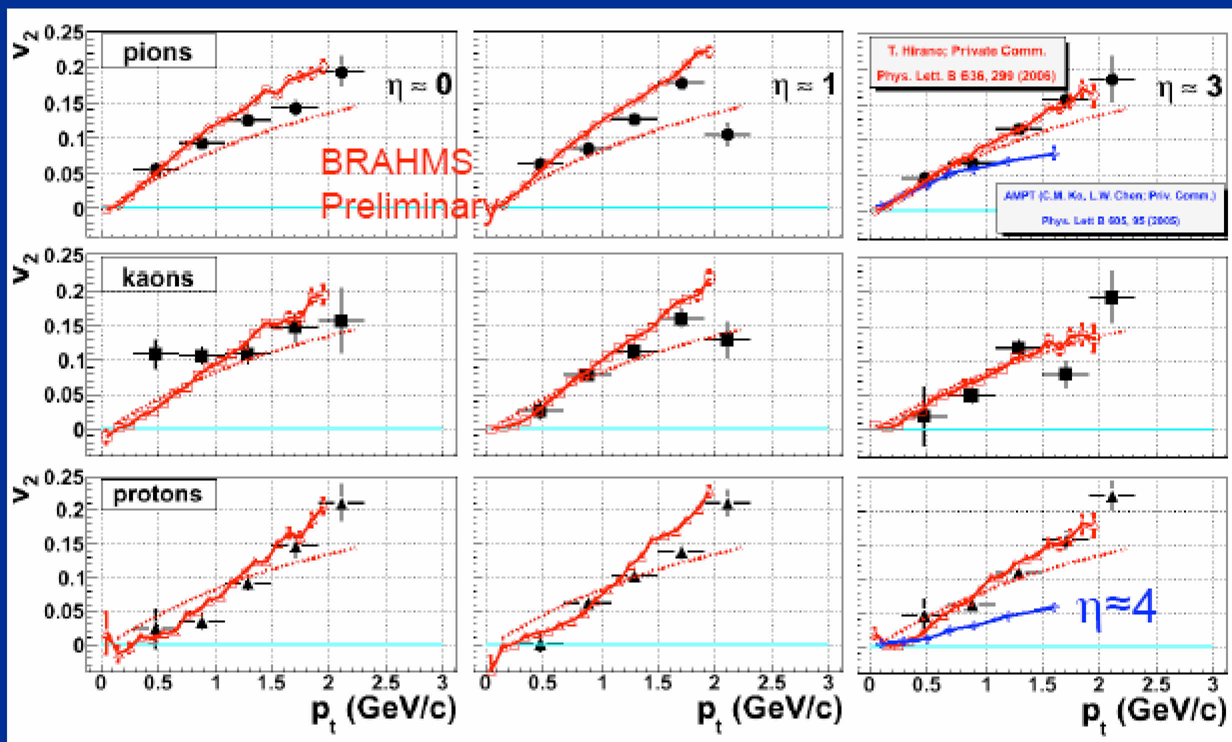
Andrade et al ('06),Drescher&Nara ('07)
Browniowski et al('07)

v2 is largely suppressed in forward region due to hadronic dissipation. Hydro + cascade generates a right amount of elliptic flow.

Hydro + Cascade at Work in Forward Rapidity Regions

Adapted from S.J.Sanders (BRAHMS) @ QM2006

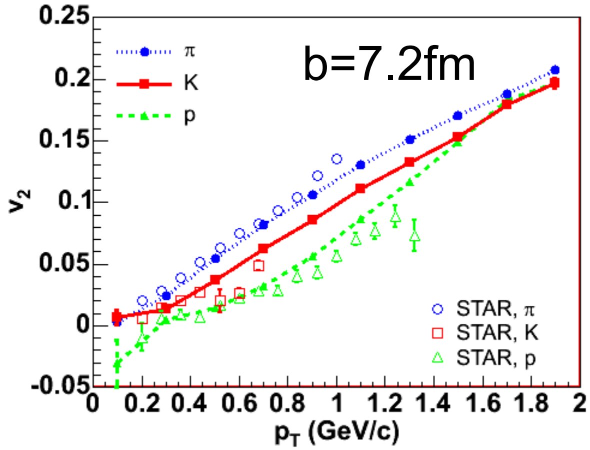
Comparison to models…

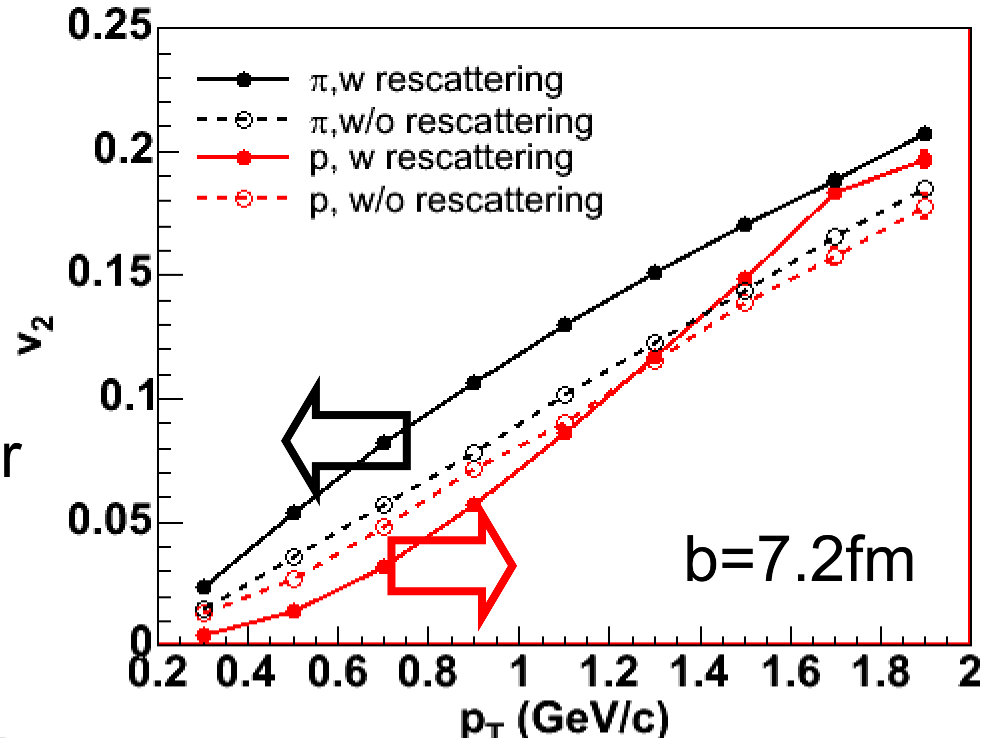


AMPT provides reasonable description with "string melting" near mid rapidity (|η|<3).
Lie-Wen Chen, Vincenzo Greco, Che Ming Ko, Peter F. Kolb Phys. Lett. B, 605(2005)95; private communication.

Hirano et al. start with Glauber initial conditions and follow through hadronic dissipation stage. Tetsufumi Hirano, Ulrich Heinz, Dmitri Kharzeev, Roy Lacey, Yasushi Nara Phys. Lett. 636 (2006) 299.

Origin of Mass Ordering





Mass ordering behavior results from **hadronic rescatterings**.
→Subtle interplay btw. "perfect fluid QGP" and "hadronic corona".

TH et al. (in preparation).

What happens to strangeness sector?

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ϕ-Meson Production as a Probe of the Quark-Gluon Plasma

Asher Shor[(a)]

Lawrence Berkeley Laboratory, University of California, Berkeley, California 94720, and Department of Physics, University of California, Los Angeles, California 90024

(Received 24 August 1984)

The formation of the quark-gluon plasma in relativistic nuclear collisions may be determined by enhanced production of ϕ mesons. This enhancement would result from the absence of the Okubo-Zweig-Iizuka suppression which inhibits ϕ production in ordinary p-p and π-p collisions, and from a large abundance of strange quarks in the plasma. The ϕ will not rescatter significantly in the subsequent expanding hadronic phase and would thereby retain information on the conditions of the hot plasma.

PACS numbers: 25.70.Np, 12.35.Ht, 21.65.+f

In recent years it has become evident that quarks and gluons are the basic constituents of matter and that QCD describes their interactions.[1] These constituents are very strongly bound and apparently cannot be liberated from the perturbative vacuum in which they exist.[2] At sufficiently large energy densities, nuclear matter would dissolve into quarks and gluons in a phase in which the perturbative vacuum would exist over the nuclear volume.[3] In this phase, the quarks

factors ranging from 10 (in the case of ϕ decay) to 1000 (in the case of J/ψ decay).[10] As an example, the exclusive reaction involving the production of a vector meson and charged pions in pp collisions at 24 GeV/c, while of almost equal magnitude for production of a ρ_0 or ω meson, is suppressed by a factor of 50 for ϕ production.[11] For inclusive ϕ production in pp and πp collisions, the OZI rule maintains that production of the ϕ should be suppressed unless accompanied by

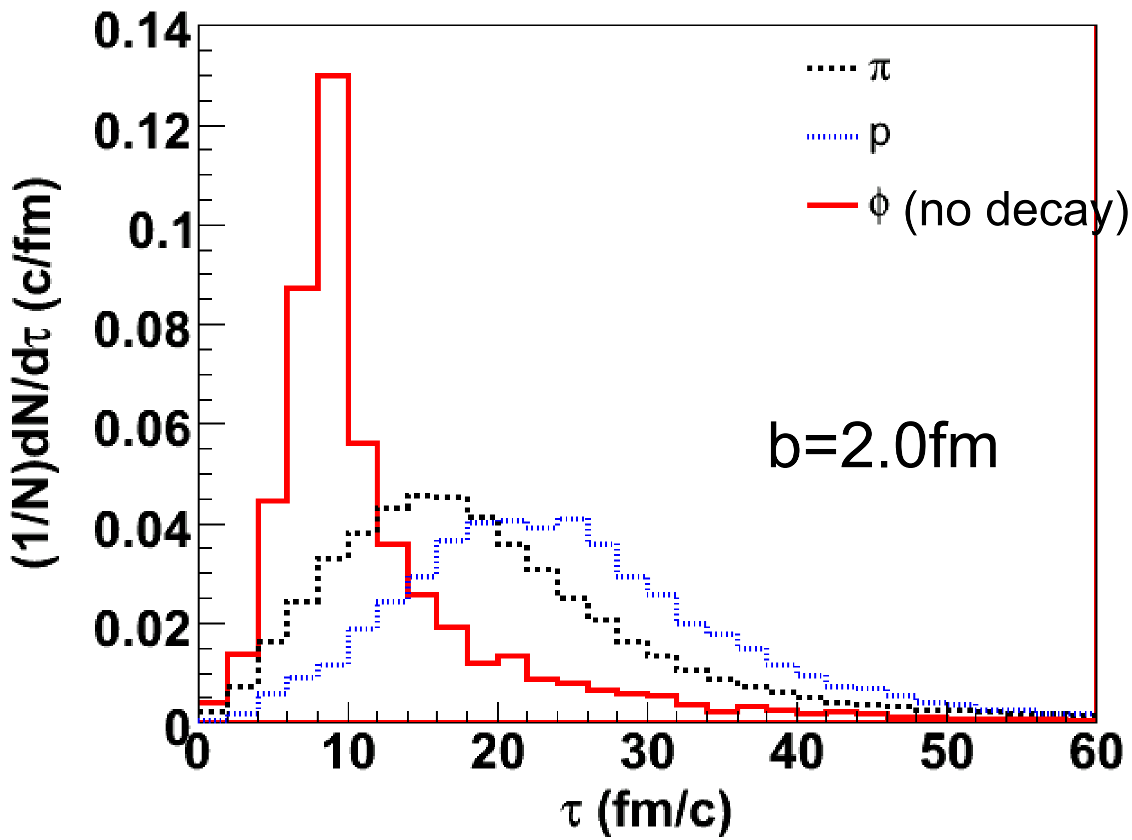
Additive Quark Model in Transport Codes (JAM/RQMD/UrQMD)

For cross sections without exp. data,

$$\sigma_{tot} = \sigma_{NN}\frac{n_1}{3}\frac{n_2}{3} \times \left(1 - 0.4\frac{n_{s1}}{n_1}\right)\left(1 - 0.4\frac{n_{s2}}{n_2}\right)$$

Expected to be very small for phi, Omega, etc.

Distribution of Freeze-Out Time

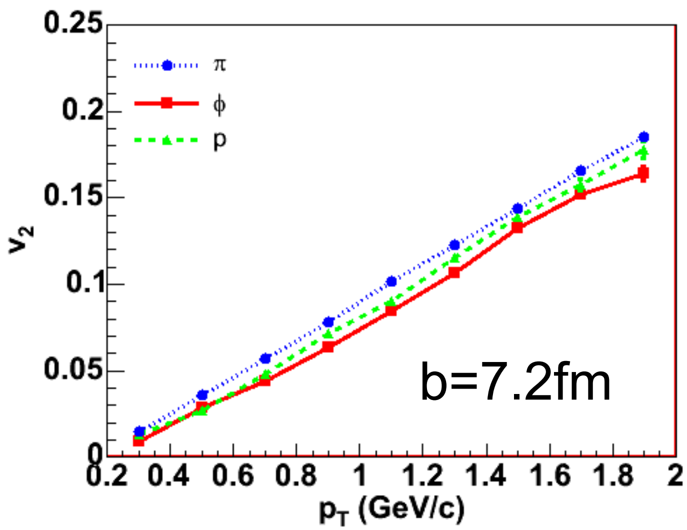


Early kinetic freezeout for multistrange hadrons: van Hecke, Sorge, Xu('98)
Phi can serve a direct information at the hadronization.

TH et al. (in preparation).

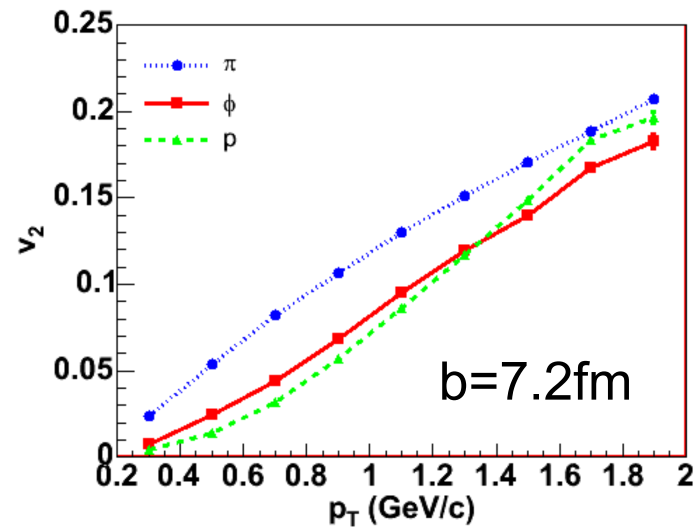
ϕ-meson case

Just after hadronization



$T = T_{sw}$ = 169 MeV

Final results



$$v_{2,\phi} > v_{2,p}$$

in p_T < 1 GeV/c

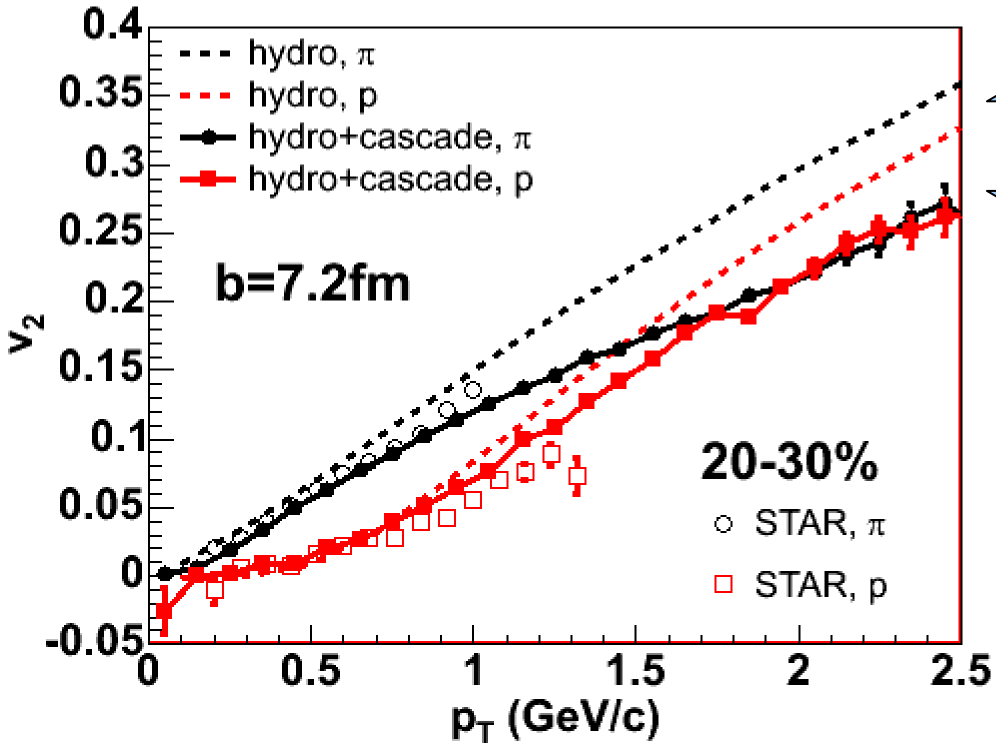
Caveat: Published PHENIX data obtained in p_T>~1GeV/c for ϕ mesons
This is NOT obtained within ideal hydrodynamics.

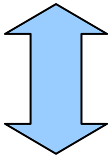
TH et al. (in preparation).

Summary

- A QGP fluid + hadronic rescattering
  - Reproduction of both p_T dist. and $v_2(p_T,m)$
  - Reproduction of integrated and differential v_2 in forward rapidity regions
  - Origin of mass ordering of $v_2(p_T)$
    - ➔Radial flow effect, not "mass effect".
    - ➔Need QGP to get large integrated v_2, Need hadronic rescattering to get correct mass ordering.
- Violation of mass ordering for phi mesons
  - ➔Clear signal to see this scenario
  - ➔Can serve a direct information of the QGP

Hadronic Dissipation Suppresses Differential Elliptic Flow



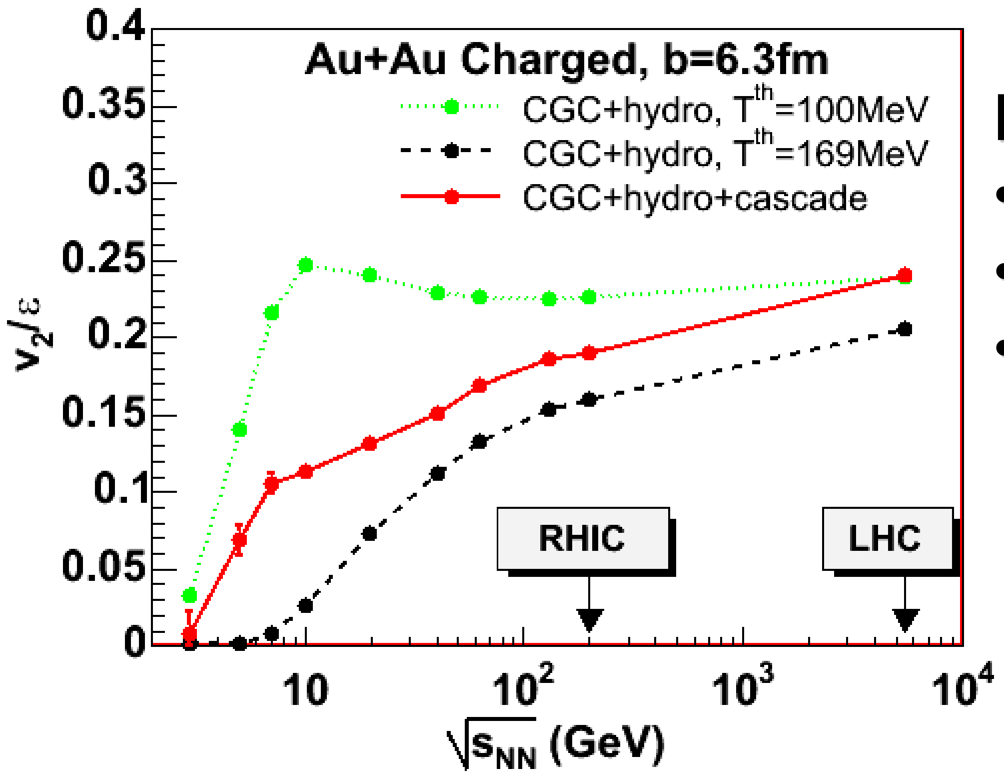


Difference comes from dissipation only in the hadron phase

- Relevant parameter: Γ_s/τ Teaney('03)
- Dissipative effect is not so large due to small expansion rate (1/tau ~ 0.05-0.1 fm^{-1})

Caveat: Chemically frozen hadronic fluid is essential in differential elliptic flow. (TH and M.Gyulassy ('06))

Excitation Function of v2



Hadronic Dissipation
- is huge at SPS.
- still affects v_2 at RHIC.
- is almost negligible at LHC.