XXIV QUARK MATTER DARMSTADT 2014

Probe the QCD Media Using ϕ-meson Event Anisotropy v_2

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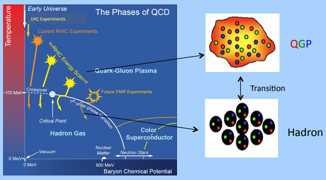
Abstract: In order to study the QCD phase structure, Relativistic Heavy Ion Collider (RHIC) has conducted the beam energy scan program since 2010. In this presentation, we report our analysis on the energy dependence of ϕ−meson and proton v_2 from minimum bias (MB) Au+Au collisions at $\sqrt{s_{NN}}$ =7.7 GeV - 200 GeV. The p_T integrated v_2 ($\langle v_2\rangle$) values for both ϕ meson and proton are found to be proportional to the collision energy and at $\sqrt{s_{NN}}$ < 19.6 GeV, the ϕ meson $\langle v_2\rangle$ values become less than that of protons. Since ϕ-mesons do not participate in the hadronic re-scatterings, this observation indicates that the hadronic interactions become dominant at the lower energy collisions. In addition, comparing the p_T dependent of v_2 for ϕ meson and proton, from MB 200GeV Au+Au collisions, we have shown the effect of the later stage hadronic re-scatterings on protons $v_2(p_T)$ distribution. Transport model such as AMPT provides consistent predictions.

Introduction

The Quantum Chromodynamcis (QCD) predicts:

- At low temperature and low density, quarks and gluons are confined within the hadrons.
- However at very high temperature and/or at very high energy density the quarks and gluons will be no longer confined within the hadrons.

Such de-confined states is known as Quark-Gluon-Plasma (QGP)



Ref: STAR Collaboration: arXive:1007.2613 ; R. V. Gavai and S. Gupta, Phys. Rev. D 71, 114014 (2005);

Au+Au @ $\sqrt{s_{NN}}$=200 GeV:

- Clear signature for de-confinement and partonic collectivity was observed.

Ref. STAR Collaboration ,Nucl. Phys. A 757 (2005) 101

Motivation:

- What will happen if we decrease the centre-of-mass energy ?

Method

Integrated $\langle v_2\rangle$ is defined as

$$\langle v_2\rangle = \frac{\int v_2(p_T)\frac{dN}{dp_T}dp_T}{\int \frac{dN}{dp_T}dp_T}$$

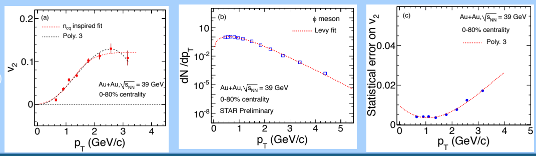
, i.e it folds the measured $v_2(p_T)$ with the p_T distribution.

Step 1: Fit the v_2 vs p_T with function: $f_{v_2}(p_T) = \frac{an}{1+\exp[-(p_T/n-b)/c]} - dn$ and/or 3rd order polynomial

Step 2: Fit dN/dp_T vs p_T with Levy function: $f_{Levy}(p_T) = \frac{dN}{dy}\times\frac{(n-1)(n-2)}{2\pi nT[nT+m(n-2)]}\times\left(1+\frac{\sqrt{p_T^2+m^2}-m}{nT}\right)^{-n}$

Step 3: Fit the error on $v_2(p_T)$ with polynomial function

Ref: Phys. Rev. C 89, 034909 (2014) Md. Nasim; Md. Nasim (for STAR Collaboration) Pos (CPOD 2013) 49 & STAR Collaboration : PRL 110, 142301 (2013)



Probe for QGP

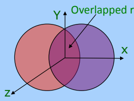
Elliptic Flow (v_2):

A measure of momentum anisotropy in particle production and is defined as

$$v_2 = \langle\cos(2(\phi-\psi_{EP}))\rangle$$

- Sensitive to early times in the evolution of the system
- Sensitive to the equation of state

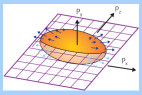
Ref: Nucl. Phys. A715 (2003) 653c, P. klob et al,



$$\phi = \tan^{-1}\left(\frac{py}{px}\right),\quad \psi_{EP} = \frac{1}{n}\tan^{-1}\left(\frac{\sum\sin(2\phi)}{\sum\cos(2\phi)}\right)$$

Interactions → Pressure (P)

$$y > x \rightarrow \frac{\partial P}{\partial x} > \frac{\partial P}{\partial y}$$



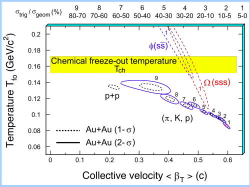
ϕ meson: A clean probe for early dynamics

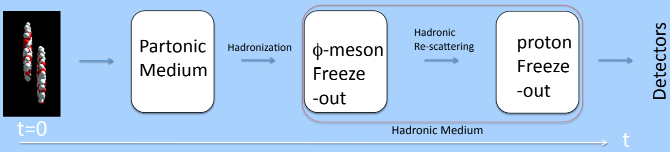
- Low hadronic interaction cross-section
- Early freeze-out compared to other hadrons (π,K,p)
- T_{fo}~T_{ch}~T_c (Lattice QCD)

Ref: PRL 54, 1985 (1985), A. Shor & Eur. Phys. J. A 29, 209 (2006) A. Sibirtsev et. al

Ref: STAR Collaboration , Nucl. Phys. A 757 (2005) 101

Hence less affected by late-stage hadronic interactions.





Models Used

AMPT:

- ✓ A multi phase transport model which use the same initial conditions as in HIJING.
- ✓ AMPT with string melting (AMPT-SM) scenario (ver.1.21) which includes partonic effects and quark coalescence as a mechanism of hadronization.
- ✓ AMPT with default settings (ver.1.11) is a model based on HIJING with initial and final state rescattering effects. Hadronization is via string fragmentation.

Ref: Phys. Rev. C 72, 064901(2005) Z. Lin et al.

UrQMD:

- ✓ A transport model which includes hadronic interactions only. version: 2.3

Ref: J. Phys. G. Nucl. Part. Phys. 25 (1999) M. Bleicher et al.

Effect of Hadronic Re-scattering

STAR preliminary data: $v_2(\phi)/v_2(p)$ > 1.0 at low p_T

Hydro Model

- Hydro + Cascade model qualitatively explain the data.

Ref: Phys. Rev. C 77,044909 (2008), T. Hirano et al.

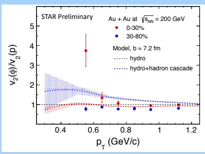
Transport Model

- $v_2(\phi)/v_2(p)$ increases with increases in hadron cascade time in AMPT model.

Ref: Phys. Rev. C 87, 014903 (2013), Md. Nasim , et al.

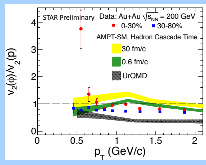
Proton v_2: Affected by hadronic re-scattering.

ϕ-meson v_2: Not affected by hadronic re-scattering due to small hadronic interaction cross section.



Violation of mass odering between ϕ and proton v_2 in data, could be the effect of hadronic re-scatterings on proton v_2

Md. Nasim (for STAR Collaboration) Nucl. Phys. A 904 , 413c (2013)

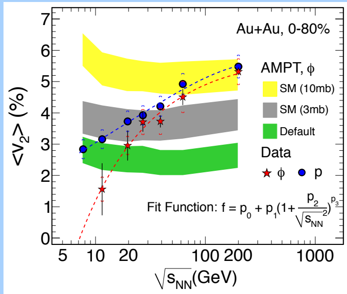


Energy dependence of p_T Integrated $\langle v_2\rangle$

- $\langle v_2\rangle$ (ϕ) for $\sqrt{s_{NN}}$ ≥ 19.6 GeV can be described by AMPT-SM by varying parton-parton cross section from 3 mb to 10 mb.
- AMPT default (hadronic model) over-predict data at $\sqrt{s_{NN}}$ = 11.5 GeV
- $\sqrt{s_{NN}}$ > 19.6 GeV : $\langle v_2(\phi)\rangle$ ~ $\langle v_2(p)\rangle$
- $\sqrt{s_{NN}}$ ≤ 19.6 GeV : $\langle v_2(\phi)\rangle$ << $\langle v_2(p)\rangle$
- Difference between $\langle v_2(\phi)\rangle$ and $\langle v_2(p)\rangle$ is ~1.5σ at 11.5 GeV
- In addition, difference in v_2 between particle and anti-particle was observed at low beam energy.

Ref: STAR Collaboration , PRL 110, 142301 (2013)

Contribution to the collectivity from partonic phase decreases with decreasing beam energy.



Ref: Phys. Rev. C 89, 034909 (2014) ,Md. Nasim

Summary

Partonic Collectivity:

✧ At high collision energy ($\sqrt{s_{NN}}$ ≥ 27 GeV), we observed similar magnitude of $\langle v_2\rangle$ for both ϕ meson and proton.

✧ At lower energy ($\sqrt{s_{NN}}$ ≤ 19.6 GeV), the magnitude of ϕ-meson $\langle v_2\rangle$ is much smaller than proton, indicating that the hadronic interaction become dominant in the low energy region.

✧ AMPT model with string melting scenario quantitively explains the data at $\sqrt{s_{NN}}$ ≥ 19.6 GeV by varying the parton-parton interaction cross-section from 3mb to 10 mb. For lower beam energies data is below calculations from AMPT-default model. Indicates collectivity for ϕ is difficult to generate without partonic interactions.

Hadronic Re-scattering :

✧ STAR preliminary data shows $v_2(\phi)/v_2(p)$ > 1.0 at low p_T . Both Hydro+Cascade and AMPT model qualitatively explains the data by considering effect late stage hadronic interaction on proton v_2.

Partonic interactions dominant for $\sqrt{s_{NN}}$ ≥ 19.6 GeV (μ_B ≤210 MeV)

Hadronic interactions dominant for $\sqrt{s_{NN}}$ ≤ 11.5 GeV (μ_B ≥315 MeV)

Acknowledgement:
Financial support from XXIV Quark Matter organizer committee and Department of Physics and Astronomy, UCLA are gratefully acknowledged. This work is supported by DST SwarnaJayanti fellowship of Govt. of India.