Dilepton production as probe to phase transition

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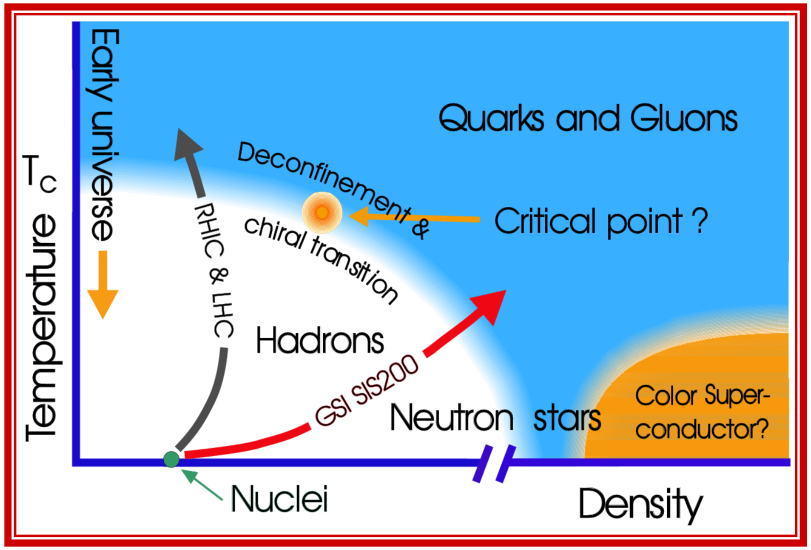
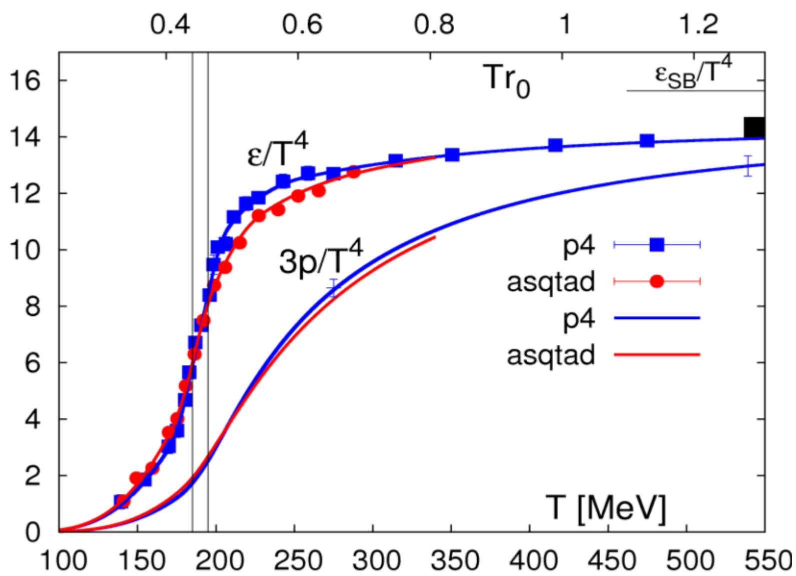
Outline

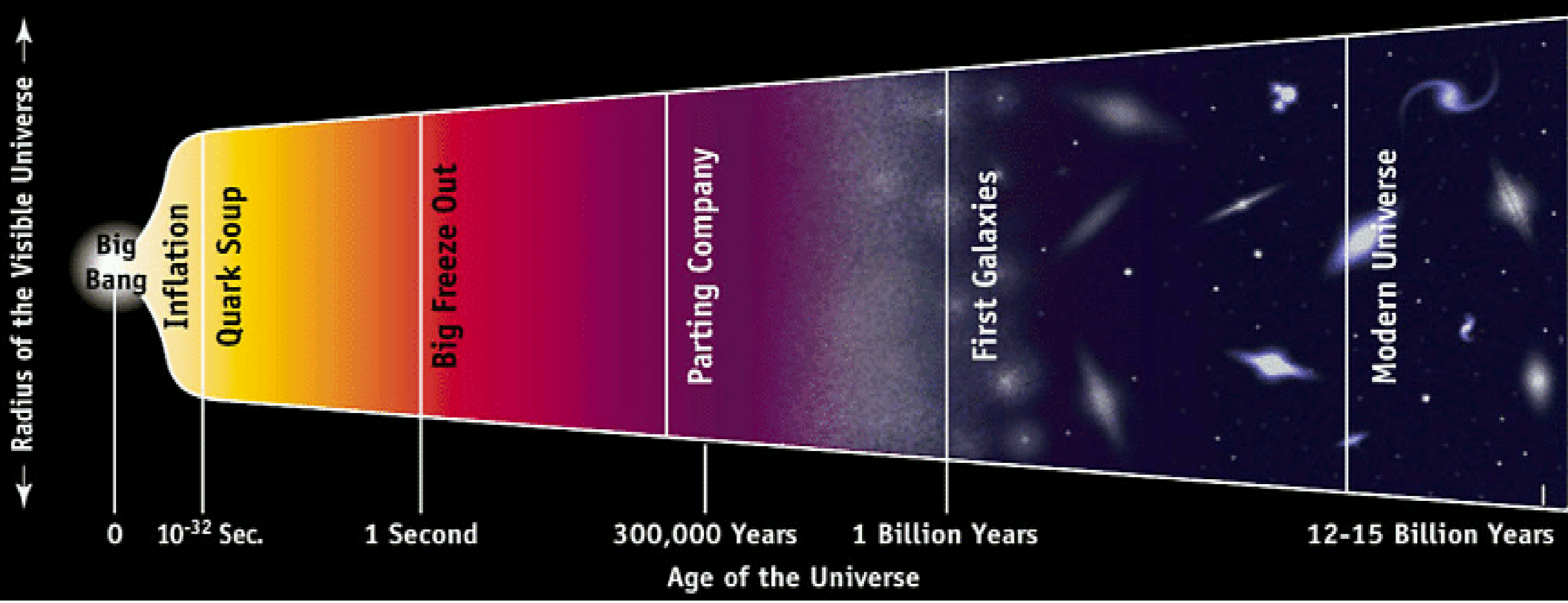
1. Dilepton production: Background information
2. Hydrodynamics for HIC in a nutshell
3. Dilepton as probe to phase transition of dense matter
4. Summary

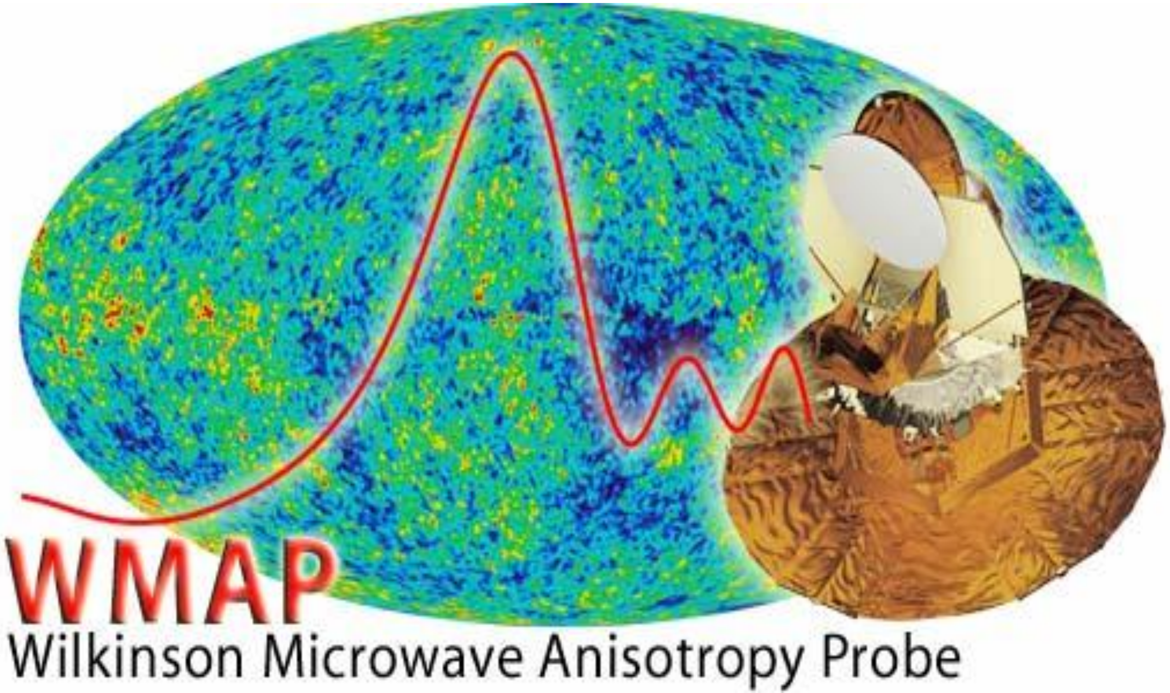
Dense or hot QCD matter EOS





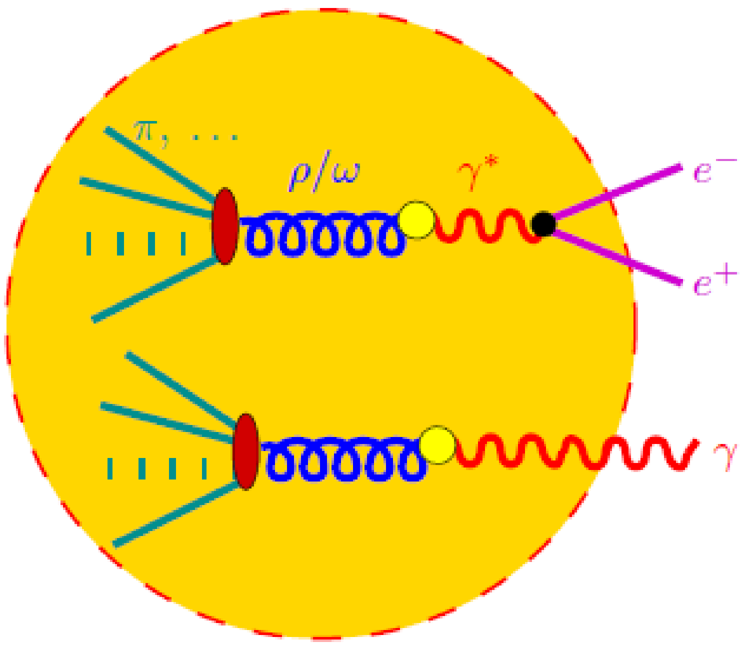
Bernard et al, (MILC) PRD 75 (07) 094505,
Cheng et al, (RBC-Bielefeld) PRD 77 (08) 014511
Bazavov et al, (HotQCD), arXiv:0903.4379

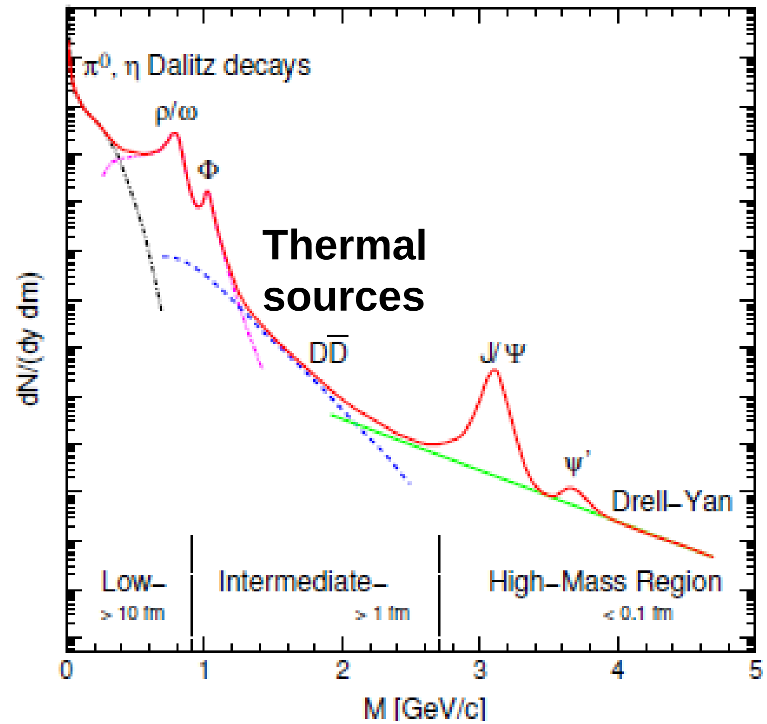




Electromagnetic probe to early universe

Dilepton as probe to state of fireball in small bang





- Early in collision (hard probes):
  Heavy flavor production
  DrellYan, direct radiation

- Later in collisions:
  π0, η, ω Dalitz decays
  ρ, ω, φ decays

Dilepton as probe to state of fireball in small bang

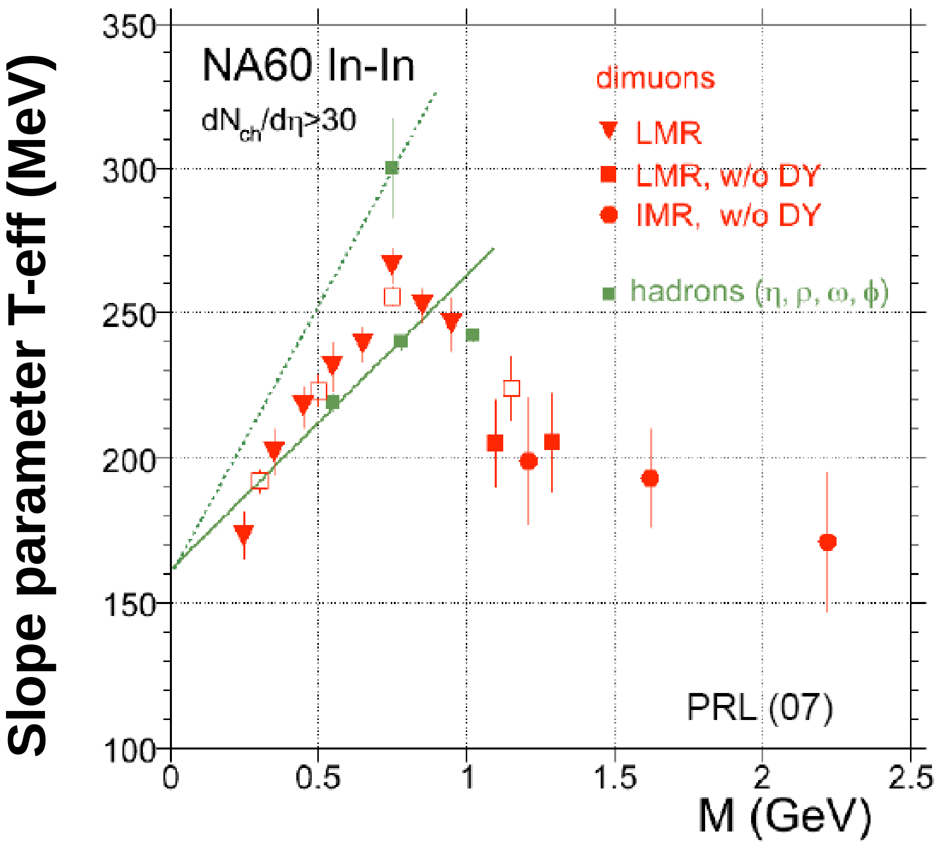
Thermal sources:

1. Space-time evolution of the fireball, hydrodynamics needed

2. Chiral symmetry (partial) restoration:
medium modifications for
$\pi\pi$ or q q-bar$\rightarrow\rho\rightarrow$ lepton pair

3. Medium effects on hard probes: heavy flavor energy loss

Effective temperature



$$\frac{dN}{m_T dm_T} \sim \exp\left(-\frac{m_T}{T_{\mathrm{eff}}}\right)$$

$$T_{\mathrm{eff}} = T_0 + Mv^2$$

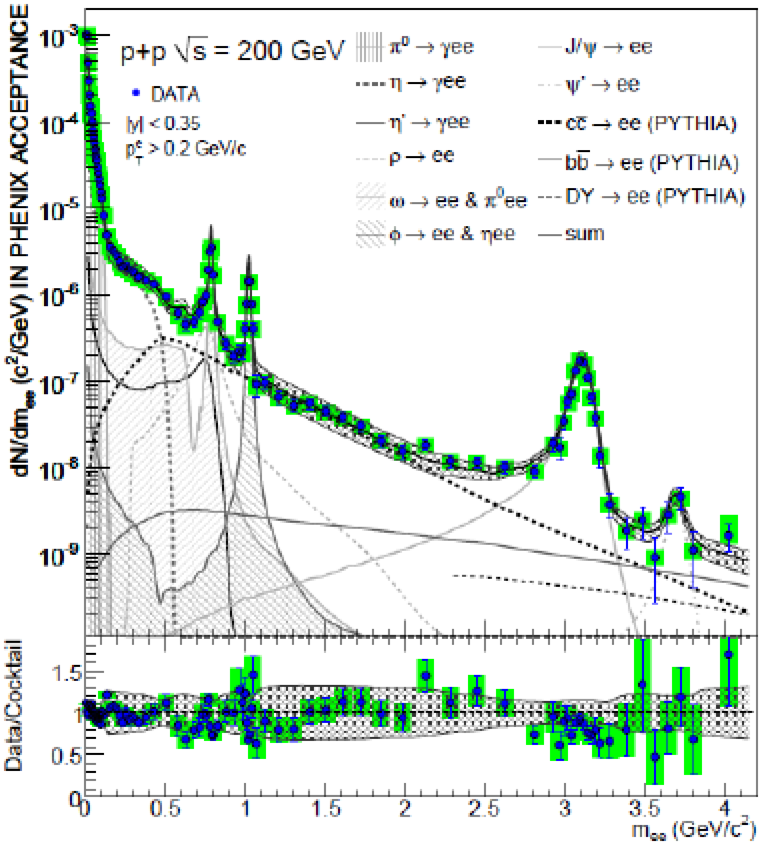
The transition to a low-flow region may signal a transition from a hadronic source to a partonic source

NA60, PRL100, 022302(2008)

Continuum pp and AuAu

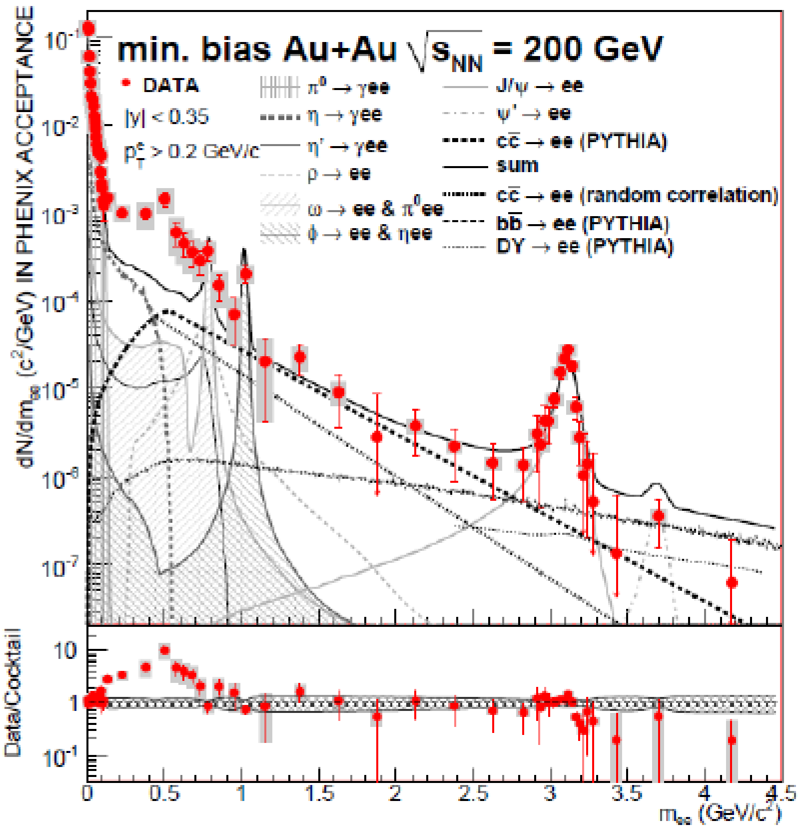
PHENIX

Phys. Lett. B 670, 313 (2009)



PHENIX, Phys.Rev.C81:034911,2010

arXiv:0912.0244



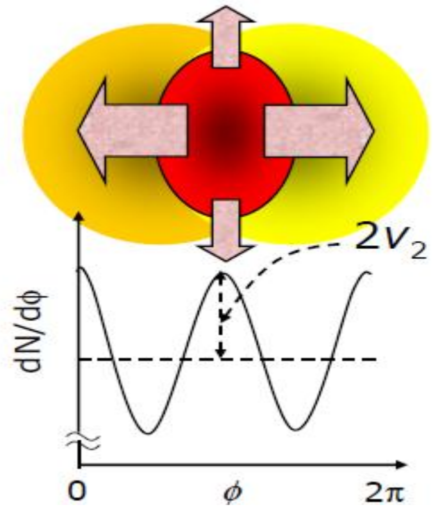
Hydrodynamics for HIC

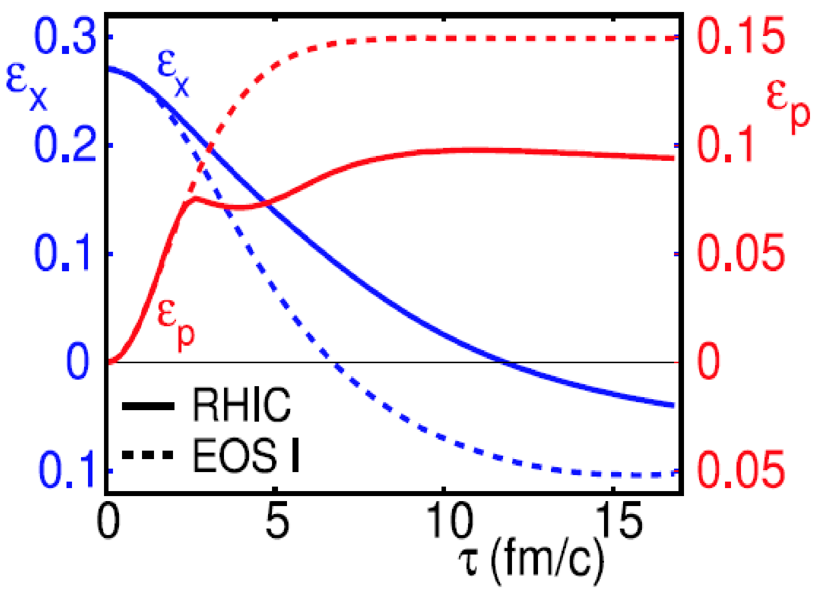
- **Assumption:** thermalization, Ideal or Viscous
- **Inputs:** EOS, initial conditions, freeze-out conditions
- **Outputs:** space-time evolution
- **Comparison with data:** T_f, v2, pt-spectra, …
- **Further application:** fluctuation & correlation, non-equilbrium statistics, ...

References:

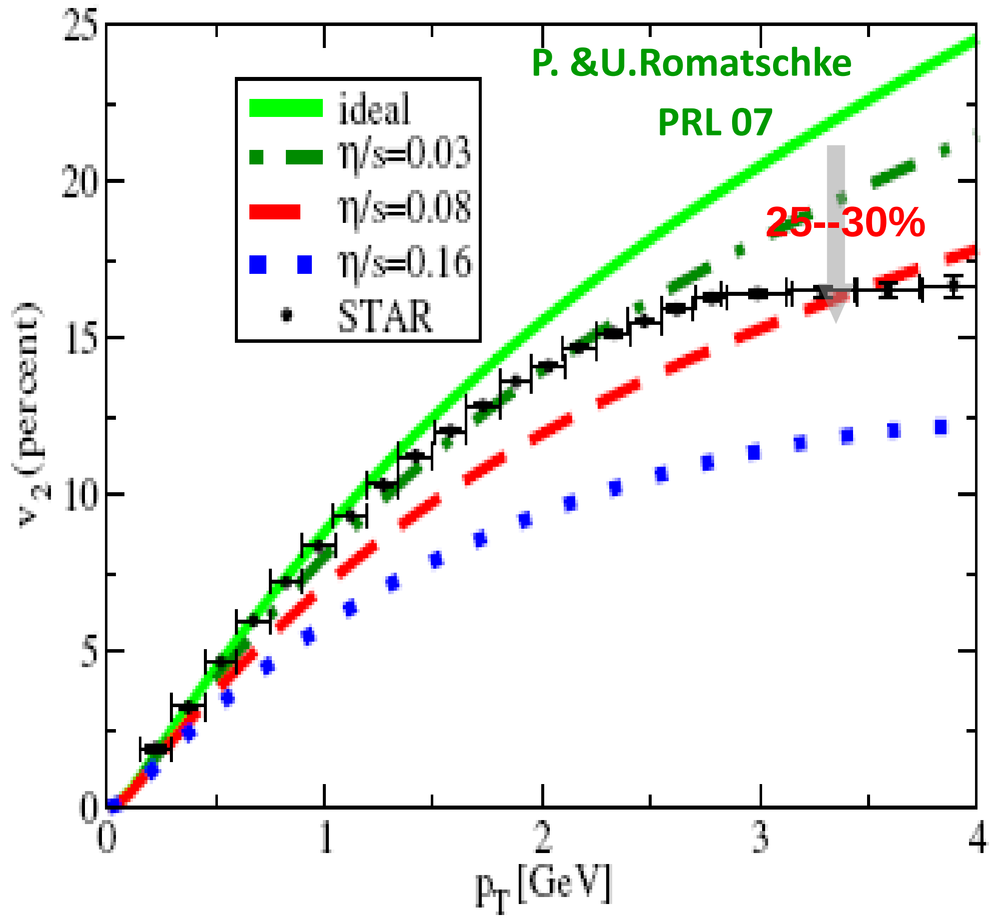
Baym 86', Rischke 98', Kolb & Heinz, 00', many others ...

Hydro: Elliptic flow





Ideal vs Viscous hydro



Dilepton emission rate

$$\frac{\partial n}{\partial t d^4Q} = 2e^2 \frac{1}{Q^4} n_B(q_0) F^{\mu\nu}(Q) \mathrm{Im}\Pi^R_{\mu\nu}(Q)$$

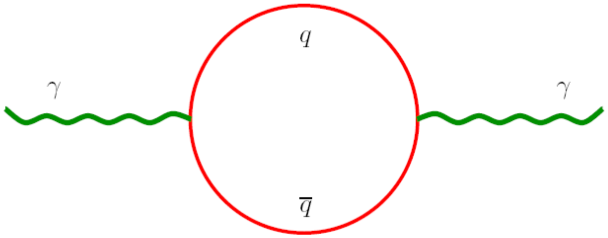
$$= \frac{\alpha}{12\pi^4} \frac{1}{Q^2} n_B(q_0) \left(1 + \frac{2m^2}{Q^2}\right) \sqrt{1 - \frac{4m^2}{Q^2}} \left(Q^\mu Q^\nu / Q^2 - g^{\mu\nu}\right) \mathrm{Im}\Pi^R_{\mu\nu}(Q)$$

$$= -\frac{\alpha}{12\pi^4} \frac{1}{Q^2} n_B(q_0) \left(1 + \frac{2m^2}{Q^2}\right) \sqrt{1 - \frac{4m^2}{Q^2}} \mathrm{Im}\Pi^{R\mu}_{\mu}(Q)$$

← **photon polarization tensor**

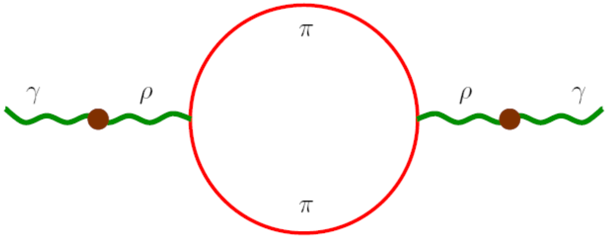
$$J^h_\mu = \sum_V \frac{e}{g_V} m_V^2 V_\mu$$

VMD model for π-π



$$\mathrm{Im}\Pi^R = -\frac{e^2}{g_V^2} m_V^4 \mathrm{Im}D^R_\rho$$

$$D^R_\rho = \frac{\mathrm{Im}\Pi^R_\rho}{(q^2 - m_\rho^2 + \mathrm{Re}\Pi^R_\rho)^2 + [\mathrm{Im}\Pi^R_\rho]^2}$$



Dilepton emission rate

$$\frac{d^3N}{P_T dP_T M dM d\phi_P} = \frac{1}{32\pi^5}\int d^4x \sigma_a(M)(M^2 - 4m_a^2)\exp\left[\frac{1}{T}\gamma_T v_T P_T \cos(\phi_v - \phi_P)\right] K_0\left[\frac{1}{T}\gamma_T M_T\right]$$

$$\begin{aligned} M_T &= \sqrt{M^2 + P_T^2} \\ m_T &= M_T - M \end{aligned}$$

$$\begin{aligned} \sigma_q(M) &= (N_c N_s^2 \sum_f e_f^2)\widetilde{\sigma}(M) \\ \sigma_\pi(M) &= \frac{m_\varrho^4}{(M^2 - m_\rho^2)^2 + (m_\rho \Gamma_\rho)^2}\sqrt{1 - \frac{4m_\pi^2}{M^2}}\widetilde{\sigma}(M) \\ \widetilde{\sigma}(M) &= \frac{4\pi}{3}\frac{\alpha^2}{M^2}\left(1 + \frac{2m_l^2}{M^2}\right)\sqrt{1 - \frac{4m_l^2}{M^2}} \end{aligned}$$

$$\frac{d^2N}{m_T dm_T M dM} \sim \sqrt{\frac{\overline{T}}{\overline{\gamma}_T}}\frac{\sqrt{m_T + M}}{m_T}\exp\left(-\frac{m_T + M}{T_{eff}}\right)$$

$$\overline{\gamma}_T = 1/\sqrt{1 - \overline{v}_T^2}$$

$$T_{eff} \sim \begin{cases} \overline{T} + M^* \overline{v}_T^2, & \text{for } P_T \ll M \\ \overline{T}\sqrt{\frac{1+\overline{v}_T}{1-\overline{v}_T}}, & \text{for } P_T \gg M \end{cases}$$

m_T scaling as signature for phase transition

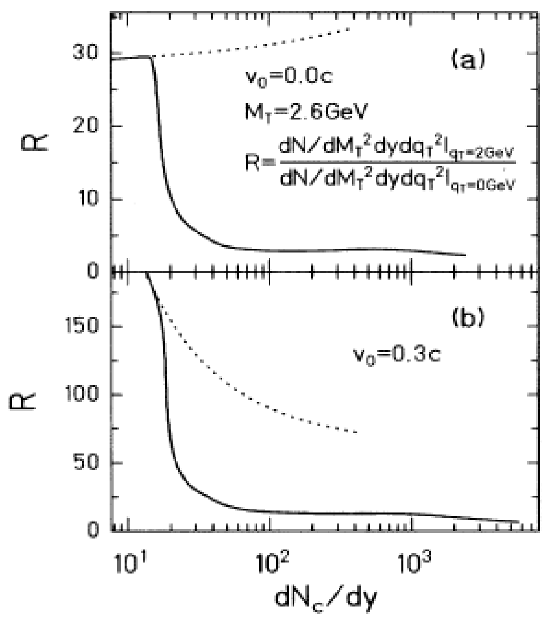


FIG. 1. (a) The ratio of the differential dilepton yield $dN/dM_T^2\,dy\,dq_T^2$ at $q_T = 2$ GeV to that at $q_T = 0$ in a central $^{197}\mathrm{Au}+^{197}\mathrm{Au}$ collision. Parameters are given in the text. The solid curve is the result with the initial state in the quark-gluon phase if the temperature is above the critical temperature while the dotted curve is obtained by assuming that the initial state is always in the hadronic phase. (b) Same as (a) except that v_0 is $0.3c$.

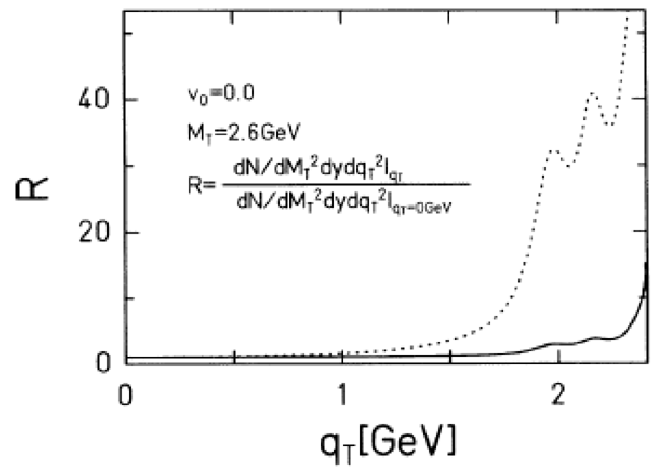
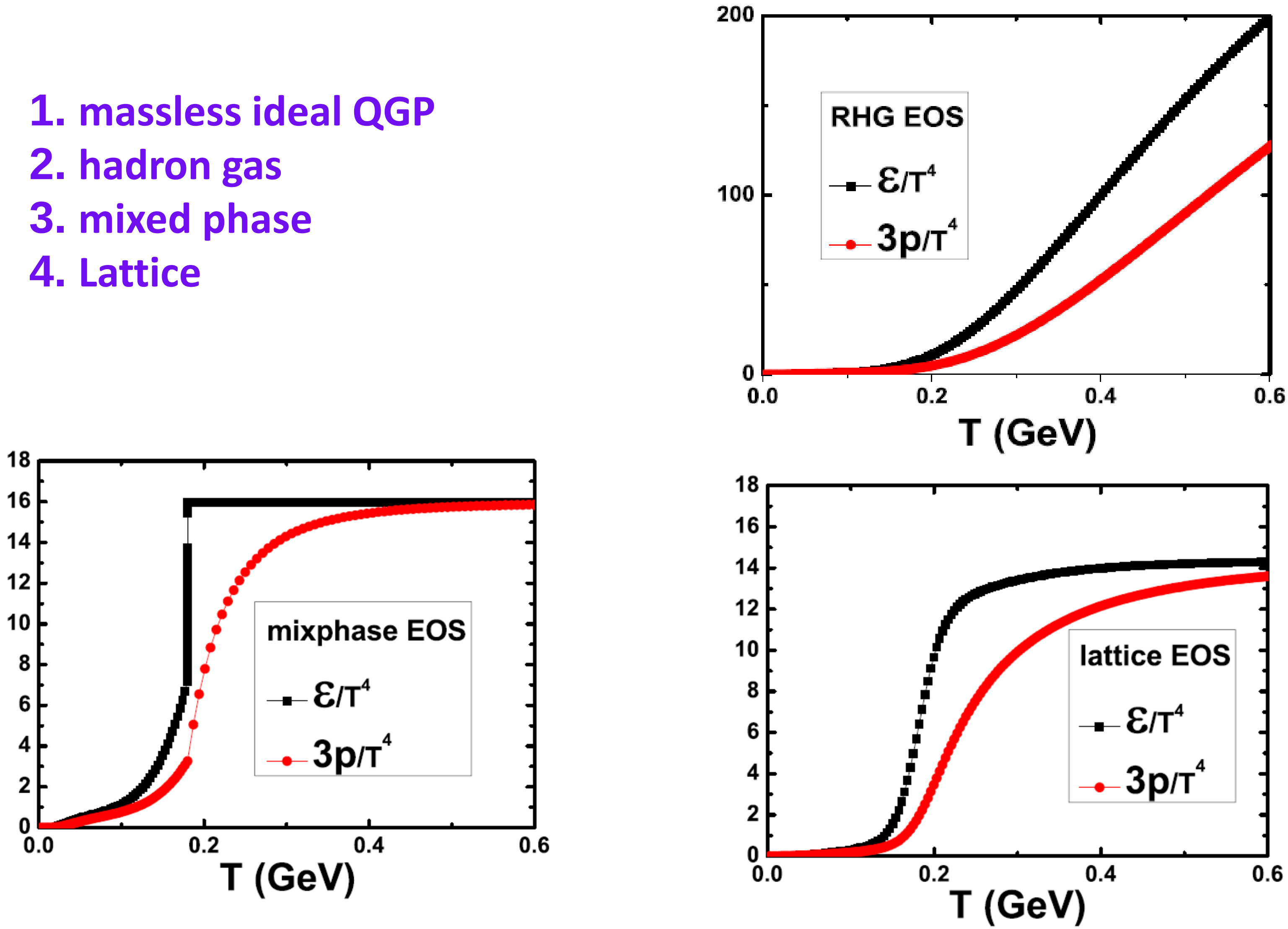


FIG. 2. The ratio of $dN/dM_T^2\,dy\,dq_T^2$ at $q_T \in [0,\ 2.4\ \mathrm{GeV}]$ to that at $q_T = 0$. M_T and dN_c/dy are fixed at 2.6 GeV and 150, respectively. The definition of the solid and dotted curves is the same as in Fig. 1.

Asakawa, Ko, Levai, PRL 1993

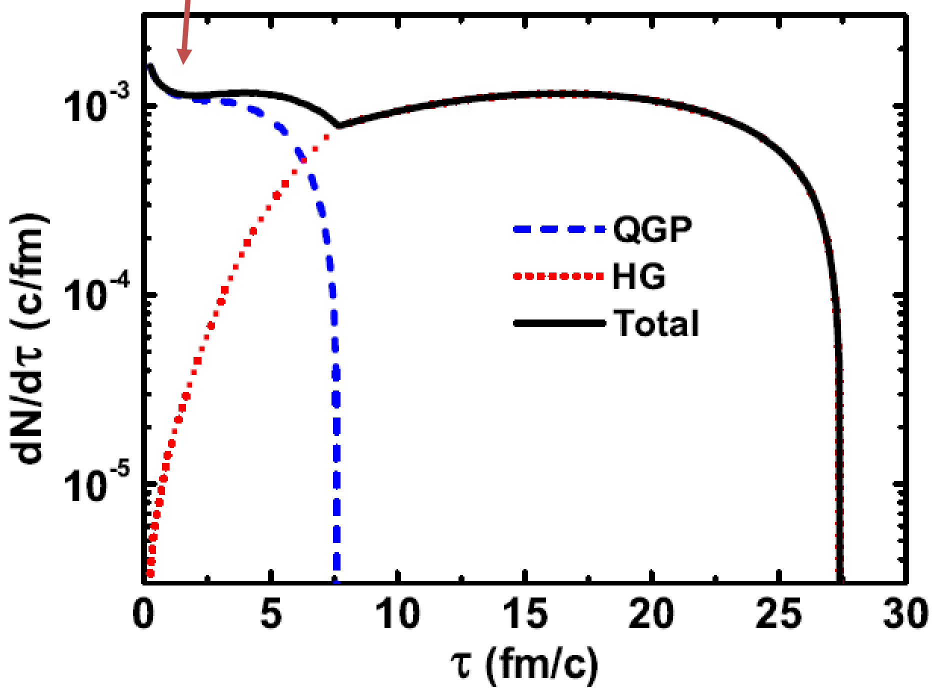
Equation of state (EOS)

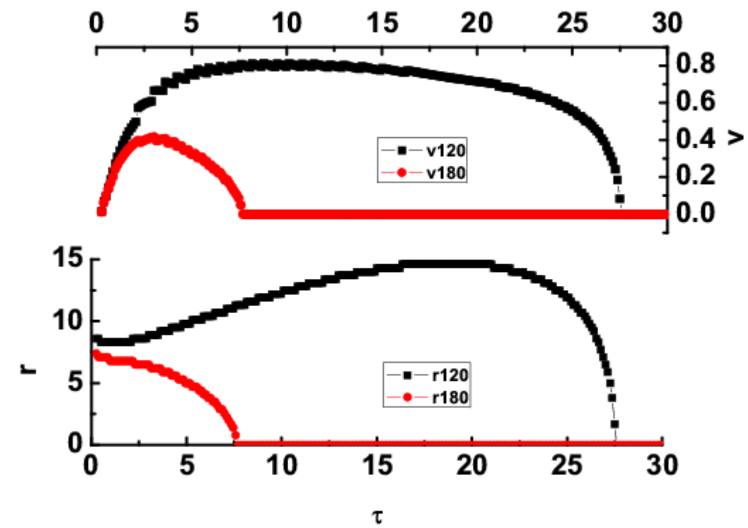
1. massless ideal QGP
2. hadron gas
3. mixed phase
4. Lattice

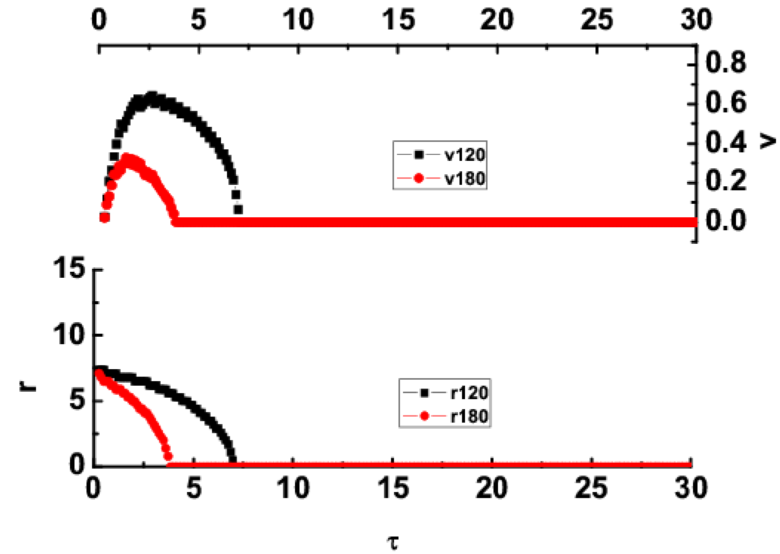


Time evolution of the rate: lattice EOS

$$\dot{\epsilon} = -(\epsilon + P)/\tau$$

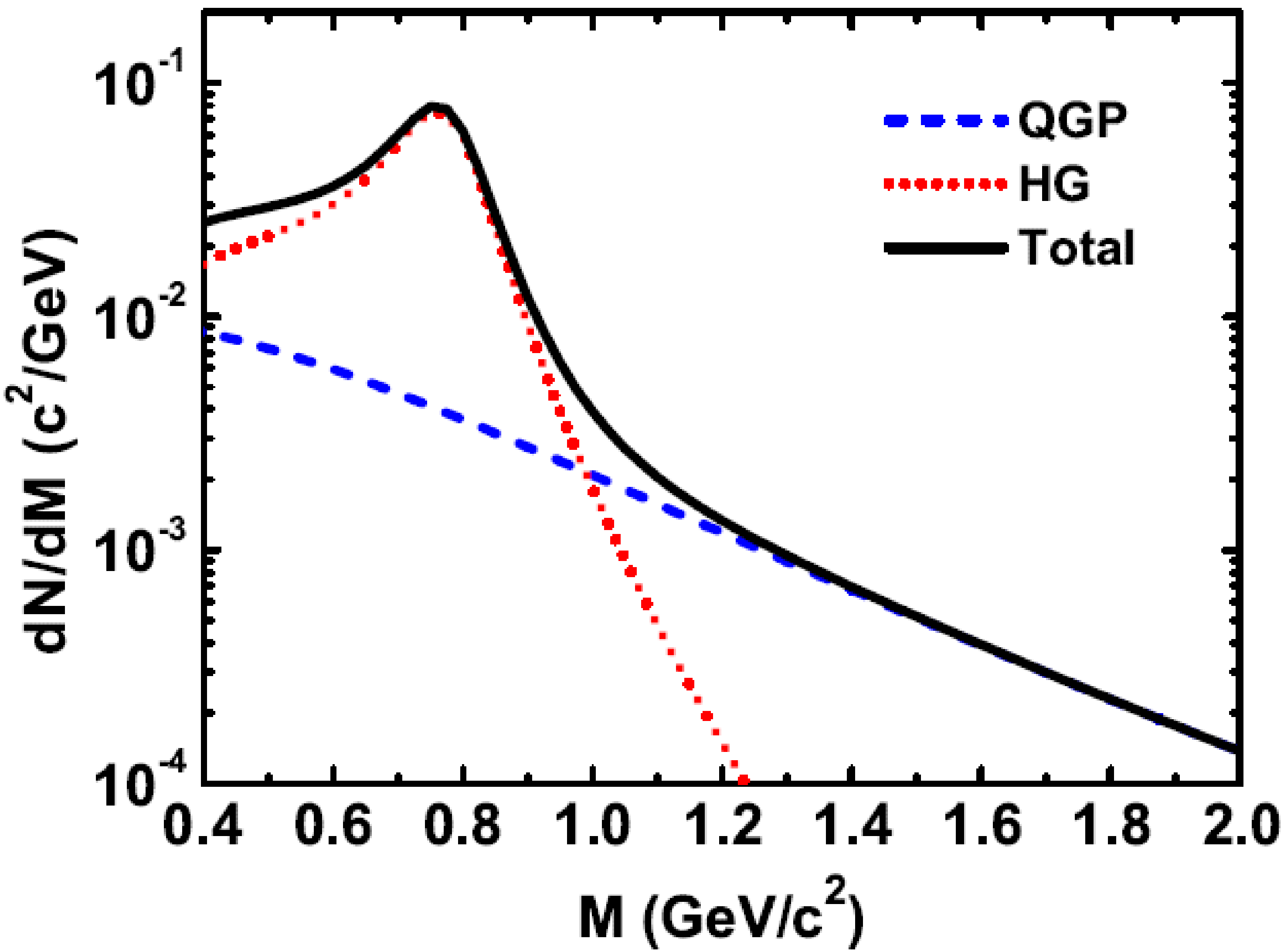




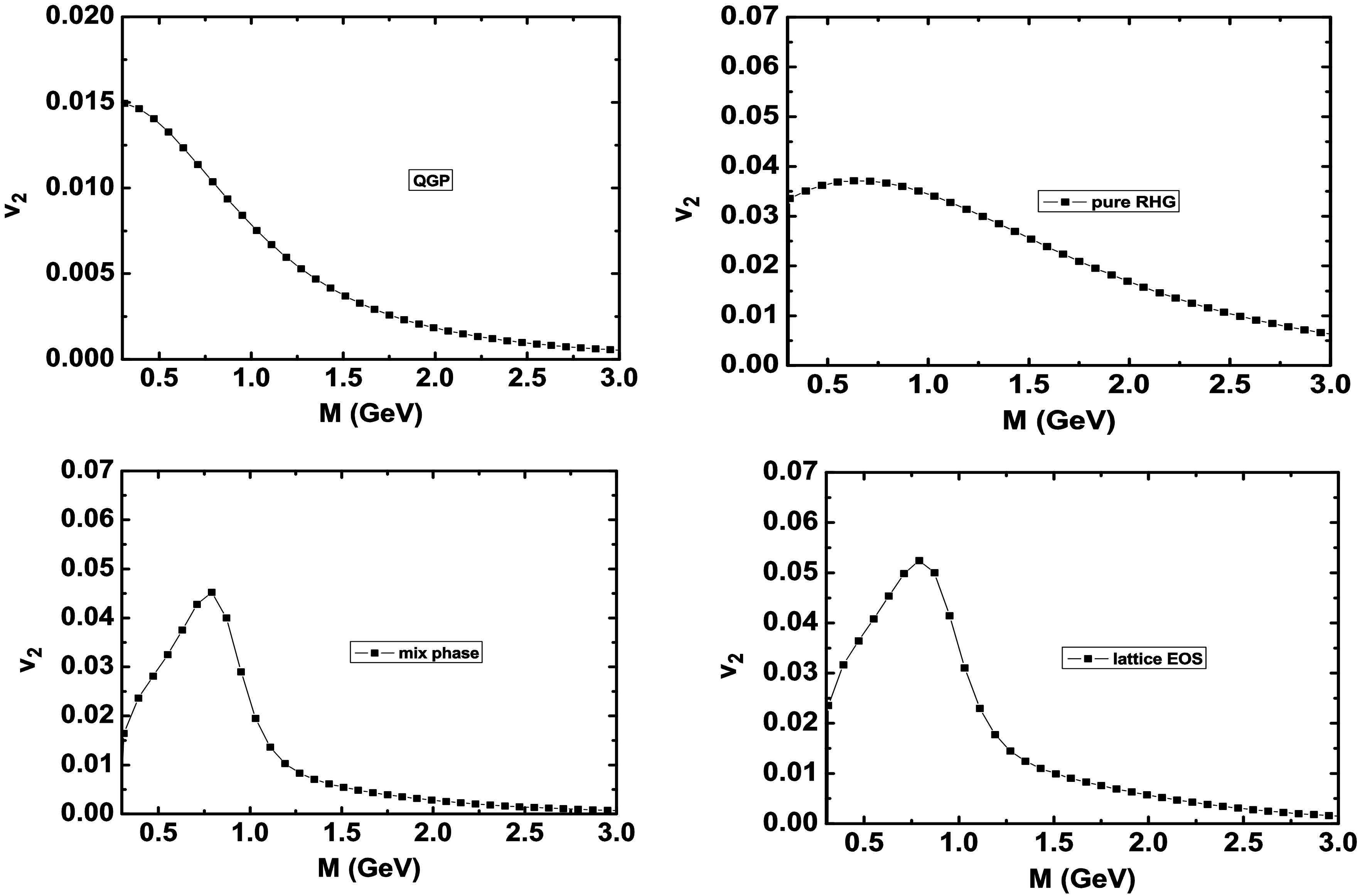


Lattice EOS, Tc≈180 MeV

Invariant mass spectra

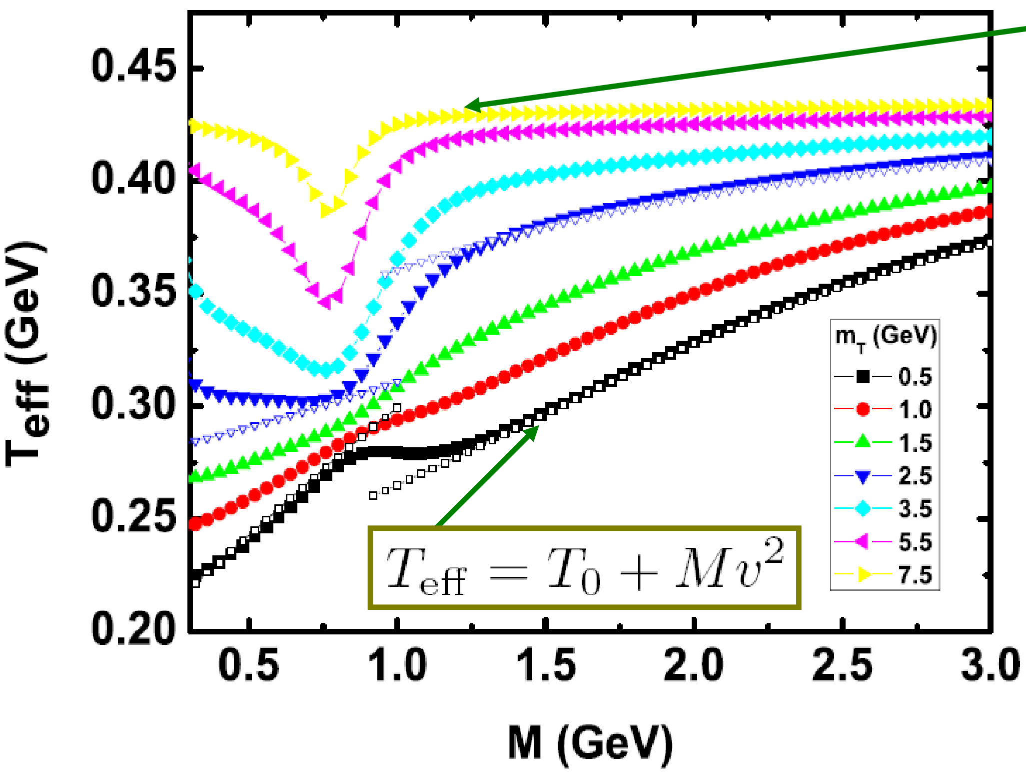


Elliptic flow



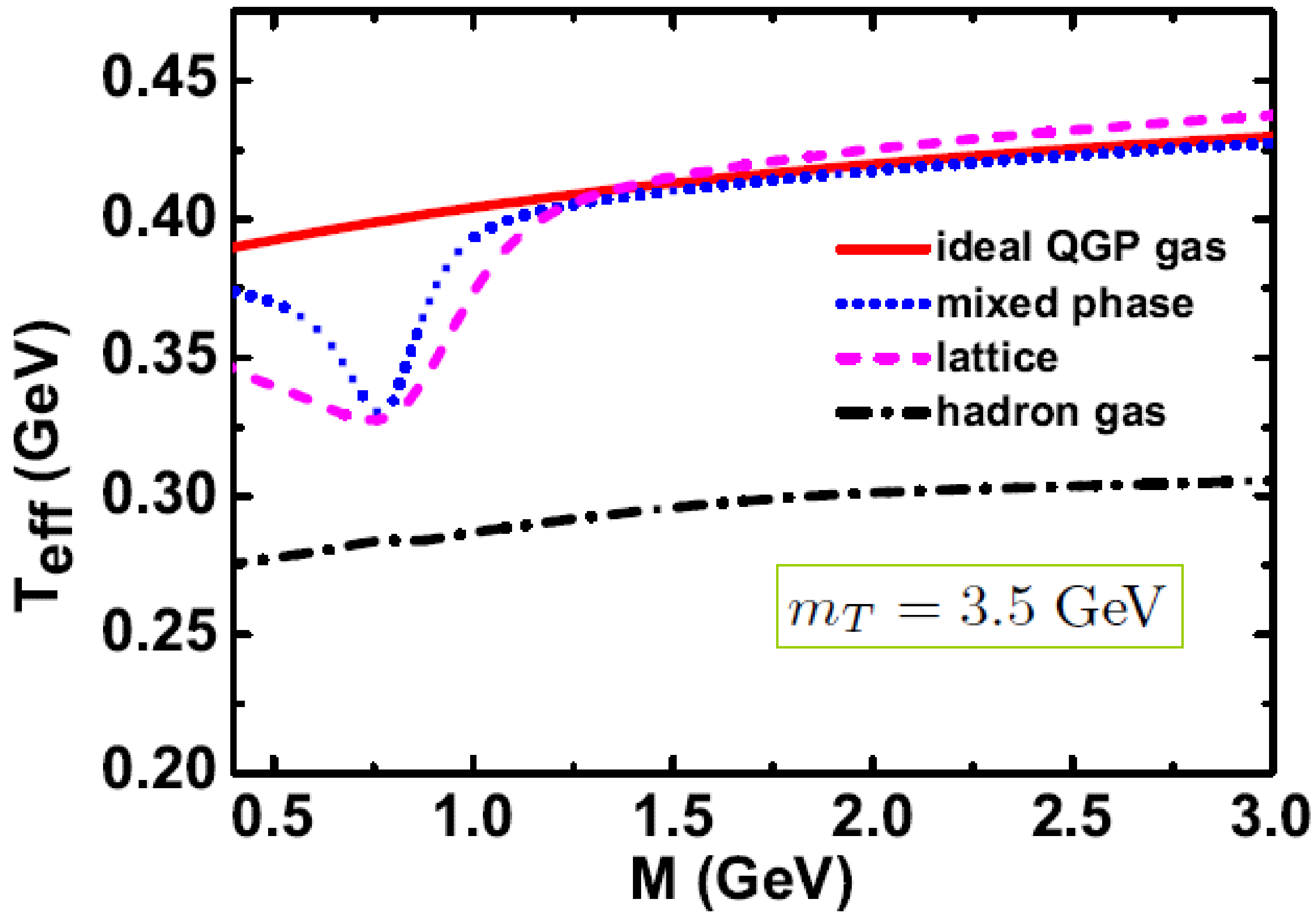
Effective Temperature: lattice EOS

$$T_{eff} \sim T\sqrt{\frac{1+v_T}{1-v_T}}$$

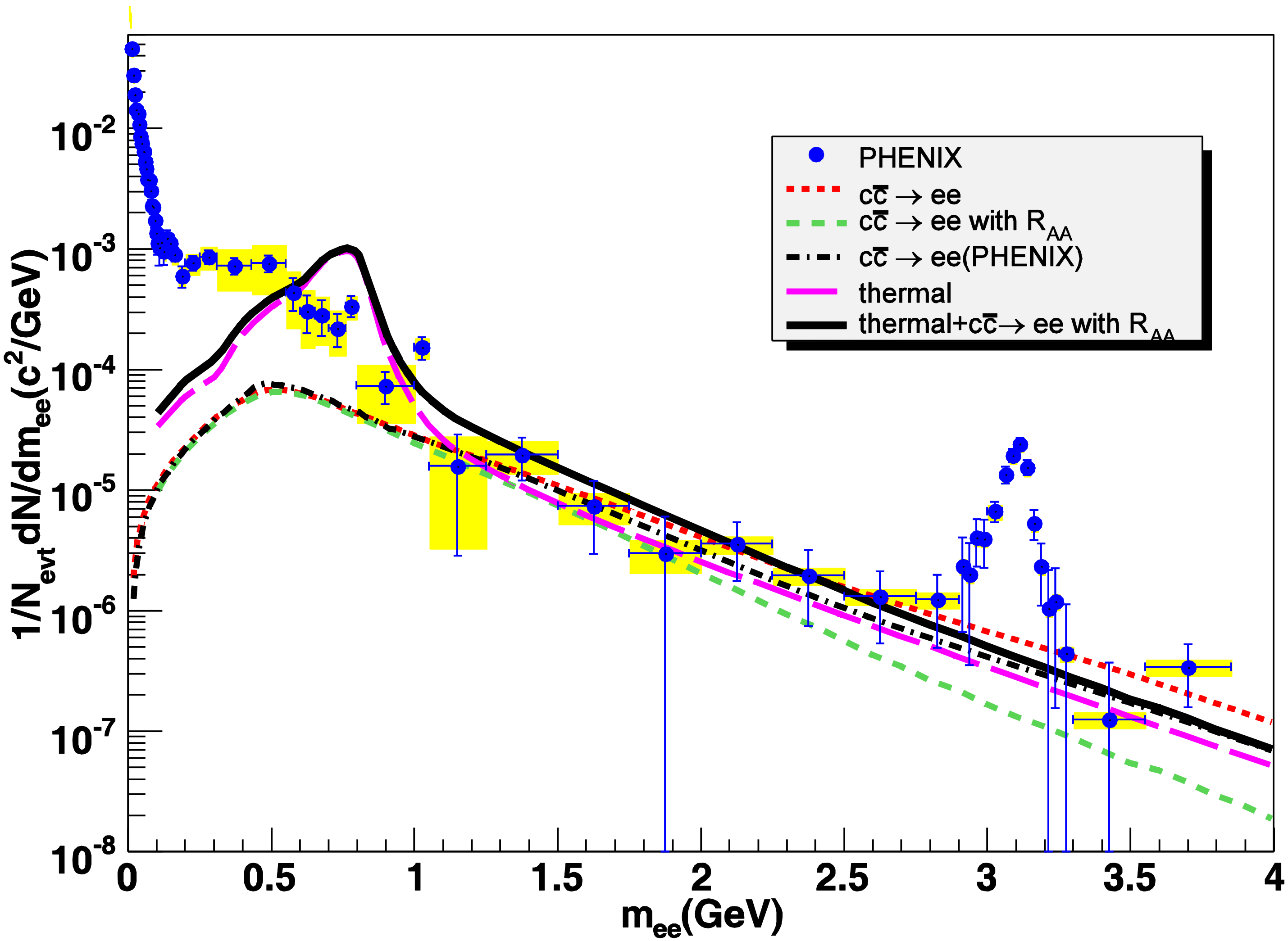


- Two stages of evolution
- M<1 GeV: HG dominates
- M>1GeV: QGP dominats
- gives structure

Slope parameter as probe to phase transition



Continuum vs thermal contribution In intermediate M

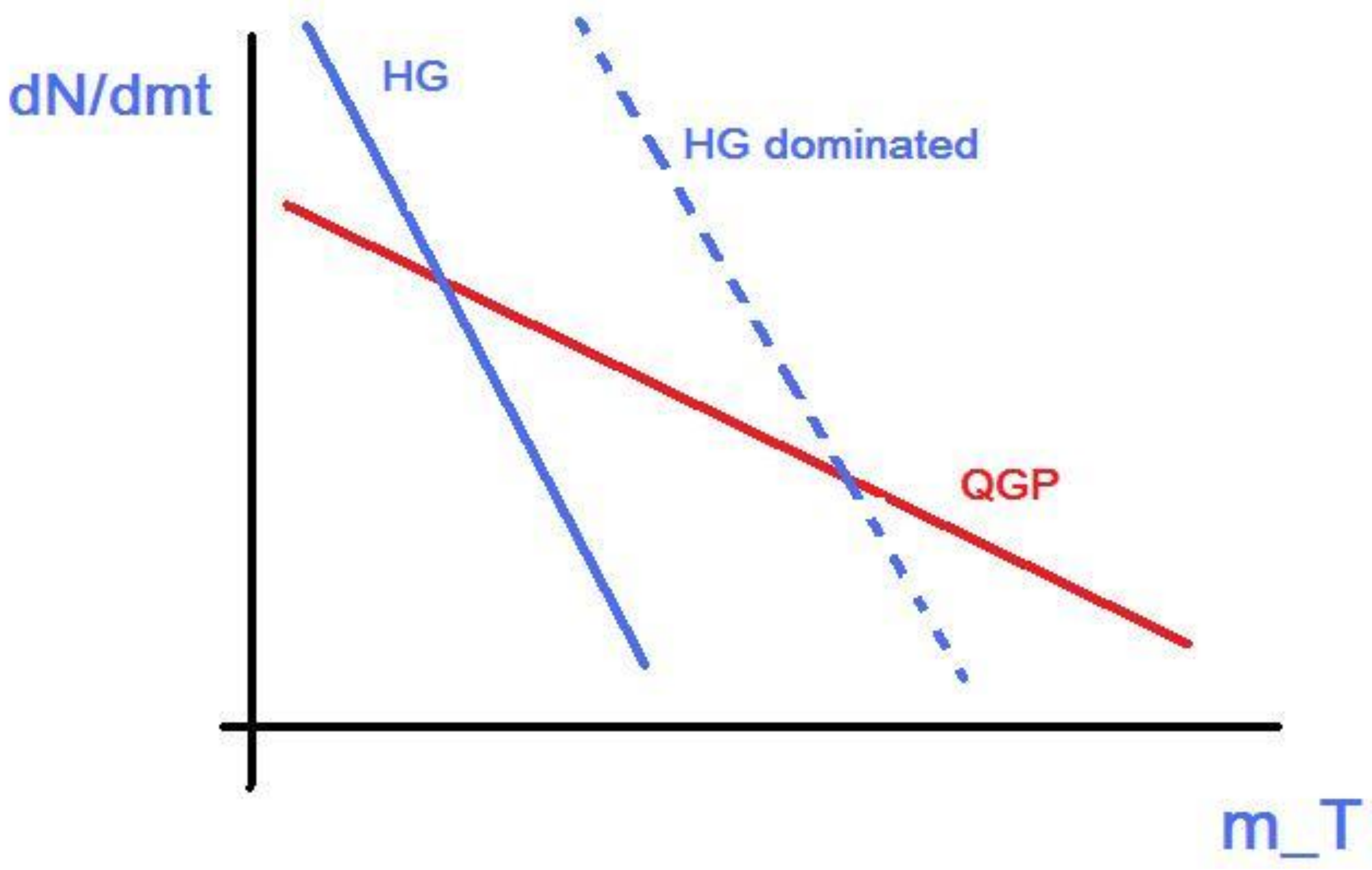


Summary and Conclusion

- The space-time evolution of dilepton rate can be descibed by hydro
- Different EOS are used for comparison
- medium modifications have been included
- We found that thermal contribution is more important than D-meson decays
- Observables of di-lepton can serve as a probe to phase transition in HIC

Thanks!

Backup



In LRF(Local Rest Frame), $u_\mu = (1,0,0,0)$, boost in transverse plane with velocity $(v_\parallel, v_\perp = 0) = (v_x, v_y)$,

$$u'_0 = \frac{u_0 + v_\parallel u_\parallel}{\sqrt{1-v_\parallel^2}} = \frac{1}{\sqrt{1-v_\parallel^2}}$$

$$u'_\parallel = \frac{u_\parallel + v_\parallel u_0}{\sqrt{1-v_\parallel^2}} = \frac{v_\parallel}{\sqrt{1-v_\parallel^2}}$$

So in the $(\tau,\ \parallel,\ \perp,\ z)$ coordinate, $(v_x,\ v_y) \Rightarrow (v_\parallel, v_\perp = 0)$

$$u_\mu = (1, u_\parallel = 0, u_\perp = 0, 0) \Rightarrow u'_\mu = \frac{1}{\sqrt{1-v_\parallel^2}}(1, v_\parallel, v_\perp = 0, 0)$$

go back to the $(\tau,\ x,\ y,\ z)$ frame, $u'_\mu = \frac{1}{\sqrt{1-v_x^2-v_y^2}}(1, v_x, v_y, 0)$

Boost in longitudinal direction $v_z = \tanh\eta$

$$u''_0 = \frac{u'_0 + v_z u'_z}{\sqrt{1-v_z^2}} = \cosh\eta u'_0$$

$$u''_z = \frac{u'_z + v_z u'_0}{\sqrt{1-v_z^2}} = \sinh\eta u'_0$$

so $u''_\mu = \frac{1}{\sqrt{1-v_x^2-v_y^2}}(\cosh\eta, v_x,\ v_y, \sinh\eta)$