Dilepton production as probe to dense matter EOS

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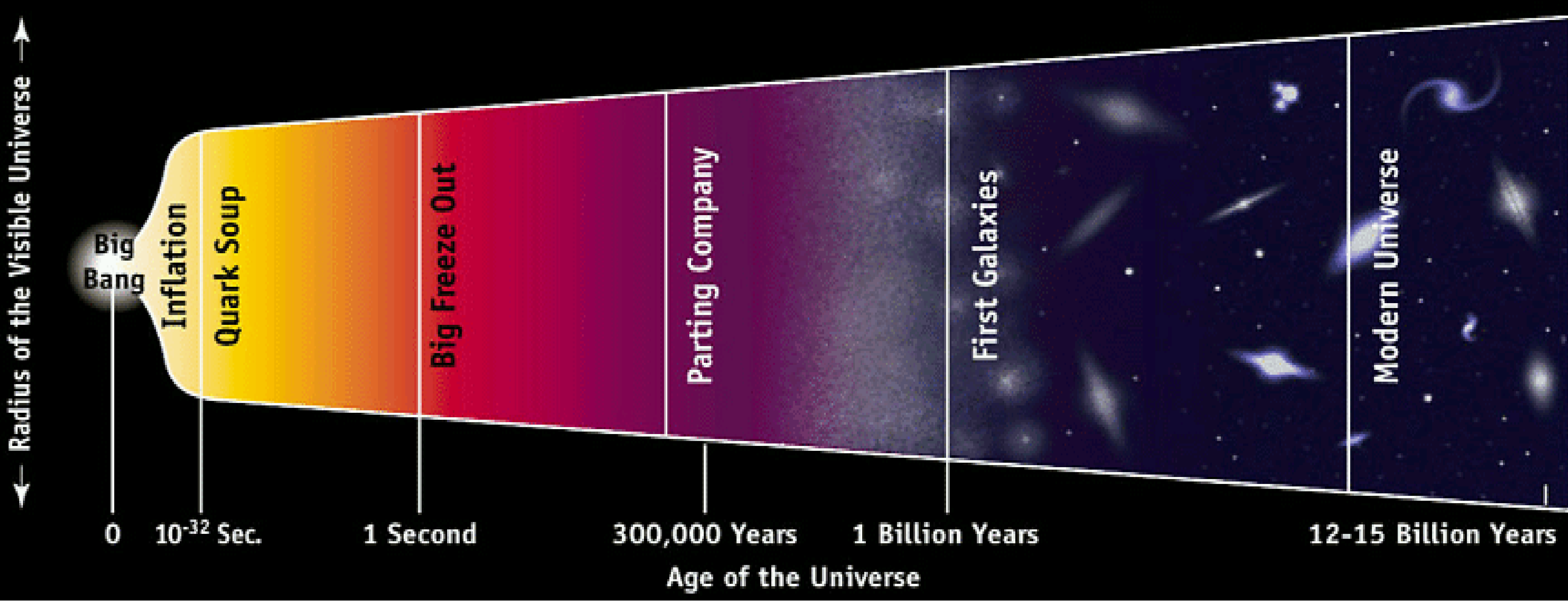
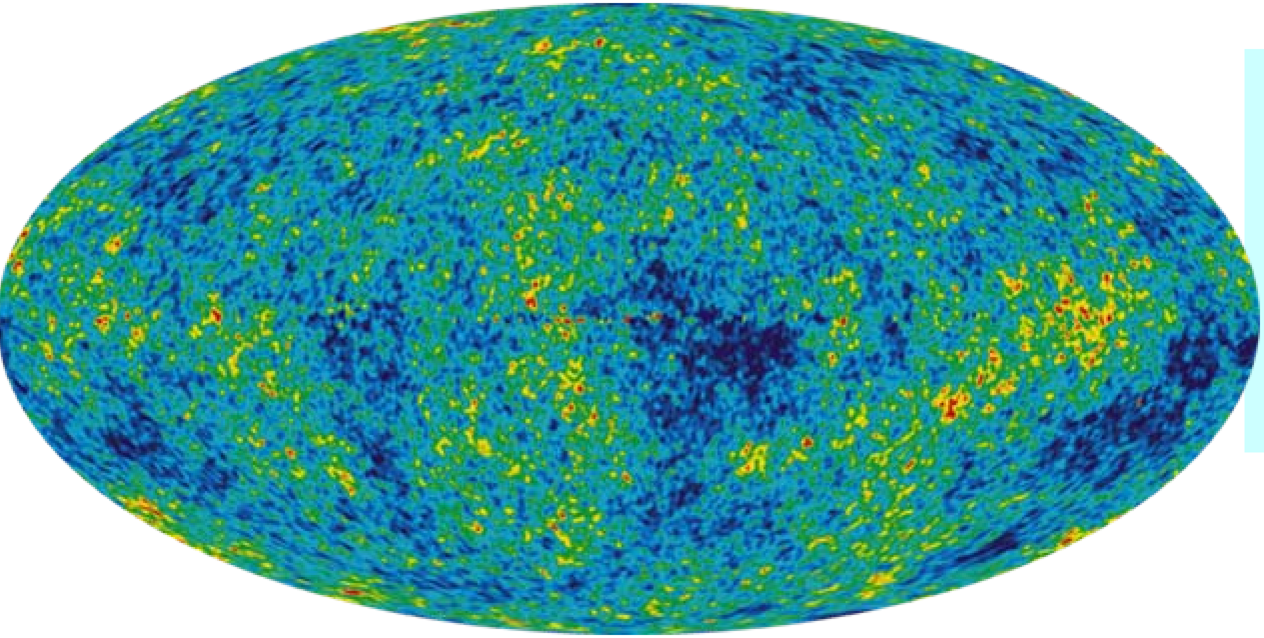
Hirschegg workshop 2010
Strongly Interacting Matter under Extreme Conditions

Outline

1. **Motivation**
2. **Dilepton production: background information (previous talks: Hemmick, Van Hees, Usai)**
3. **Hydrodynamics simulation for space-time information of fireball**
4. **Dilepton spectra as probe to EOS for dense matter**
5. **Summary and conclusion**

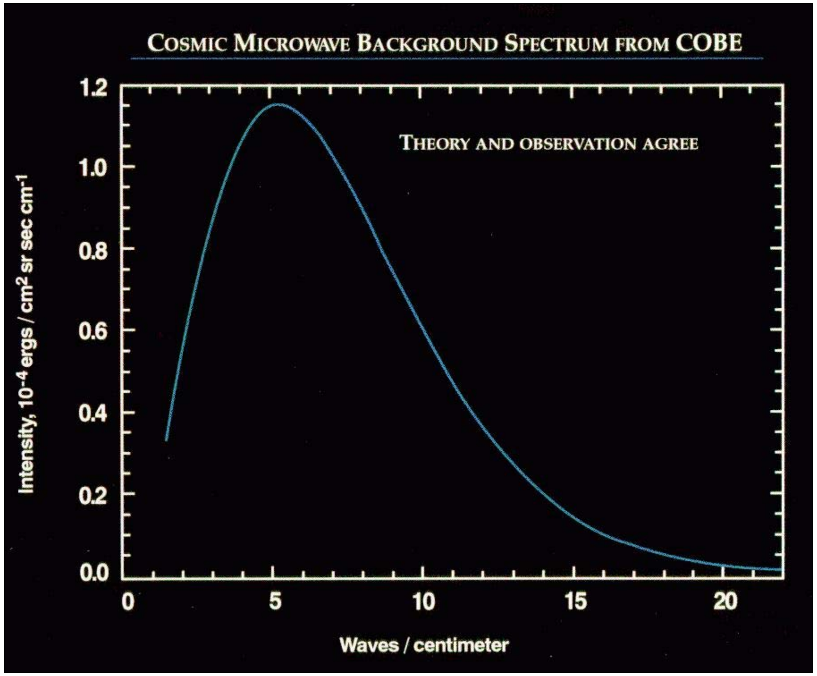


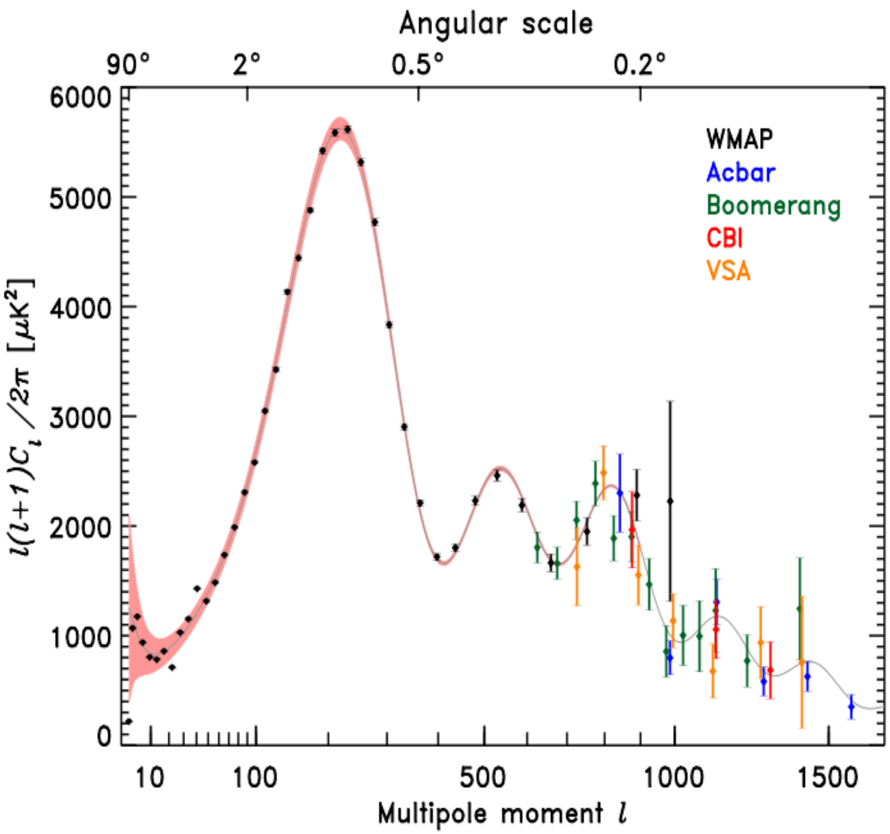


Cosmic microwave background radiation

Electromagnetic probe to the early universe

Spectra of CMBR





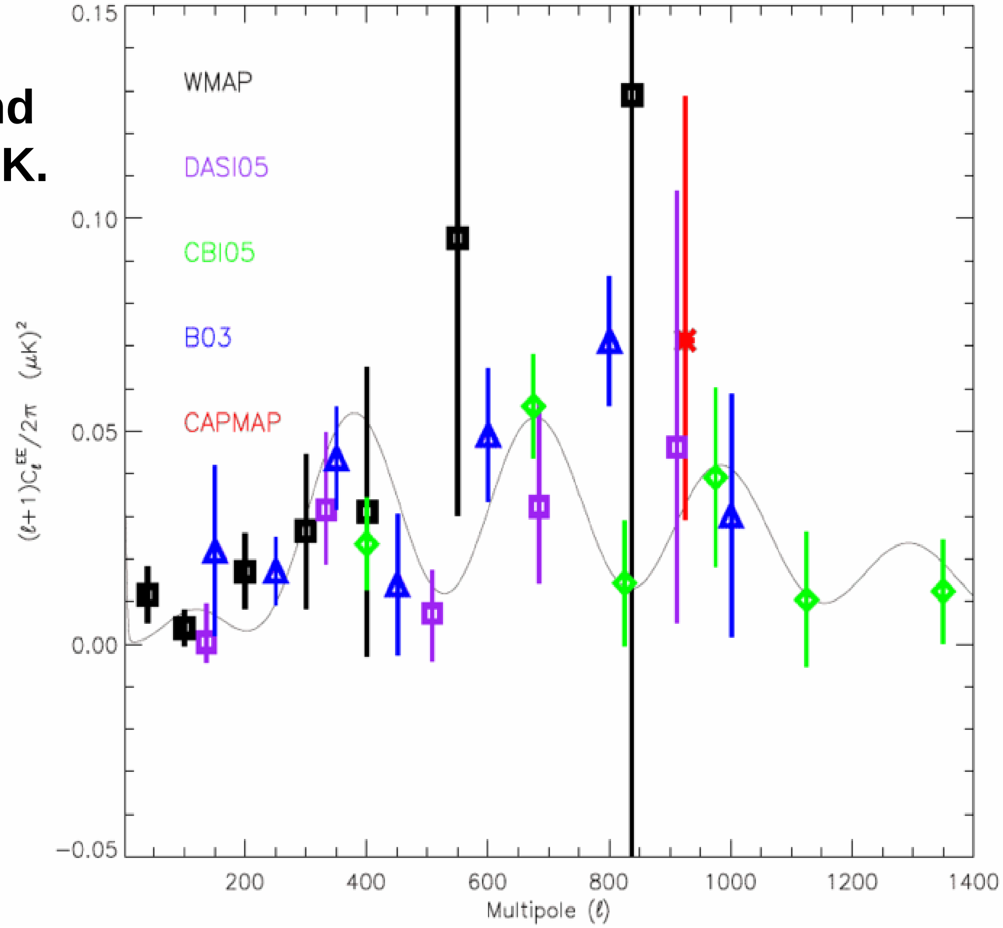
The CMBR spectrum measured on COBE satellite is the most-precisely measured black body spectrum in nature. The power spectrum of the CMBR temperature anisotropy in terms of the angular scale (or multipole moment).

Polarization of CMBR

The cosmic microwave background is polarized at the level of a few μ K.

E-modes are from Thomson scattering in an inhomogeneous plasma.

B-modes are not produced from the plasma physics alone, may be from cosmic inflation and determined by the density of primordial gravitational wave.



E polarization measurements as of March 2006 in terms of angular scale

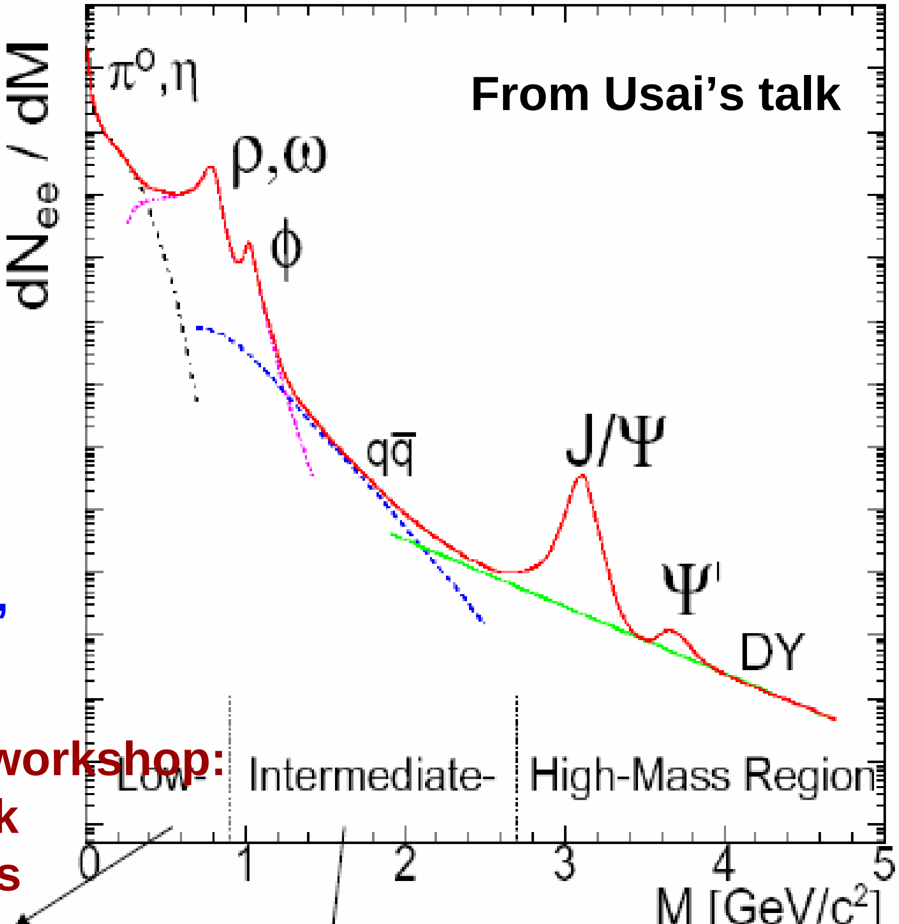
Dilepton invariant mass spectra

1. Electromagnetic probe to hot/dense medium

2. Chiral symmetry restoration

3. Space-time evolution of fireball

4. Drell-Yan,Charmonium, open charm,q-qbar in QGP, Pion-pion in HG via vector mesons, Dalitz decays, 4-pion, ……



McLerran & Toimela, '85
Rapp & Wambach, 00'
Van Hees & Rapp, 06', 08'
Ruppert et al, 08'
……

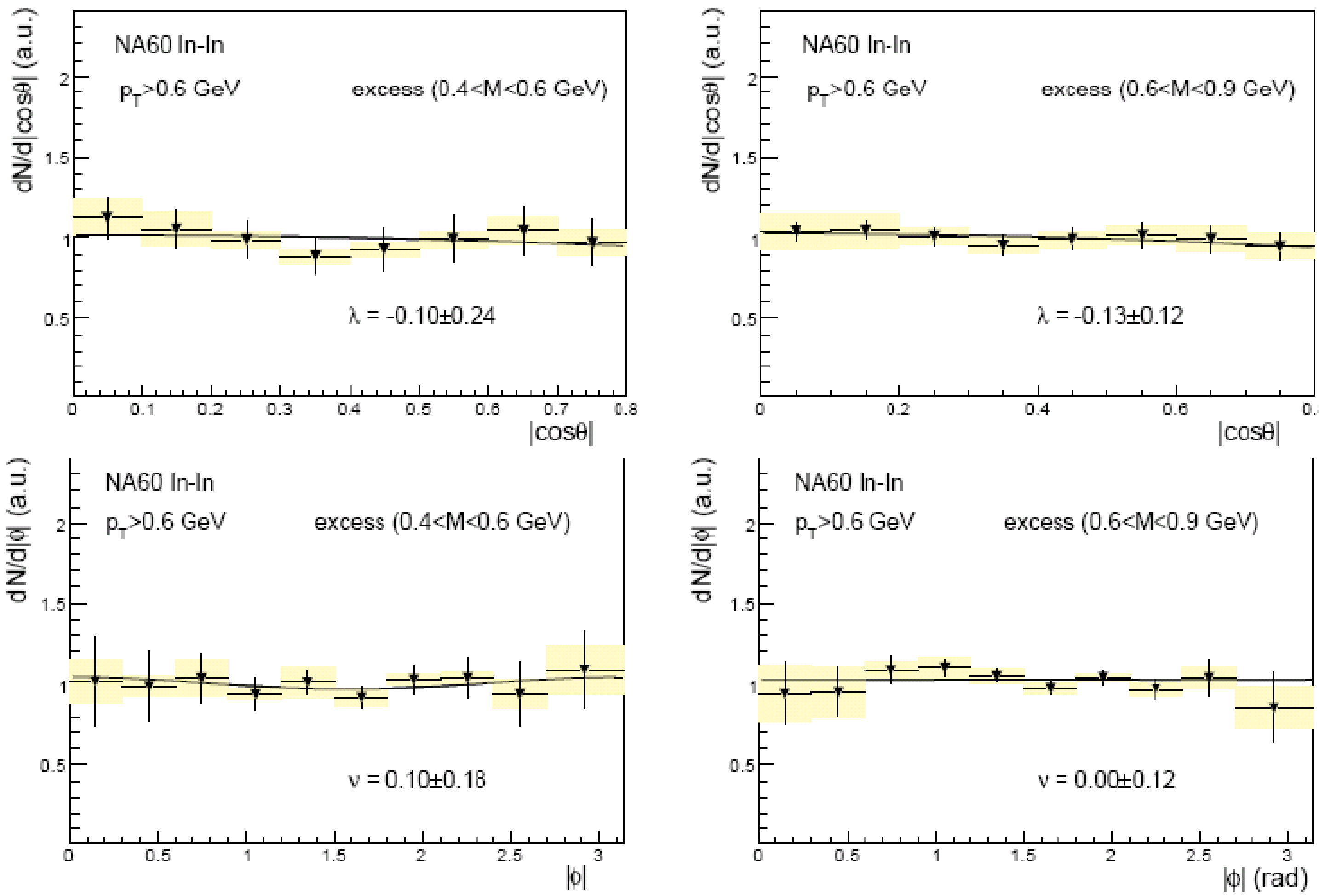
On this workshop:
Hemmick
Van Hees
Usai

Hadron gas
(dominated by ππ)

QGP and/or hadron gas
(multipion)

Polarization of excess dileptons

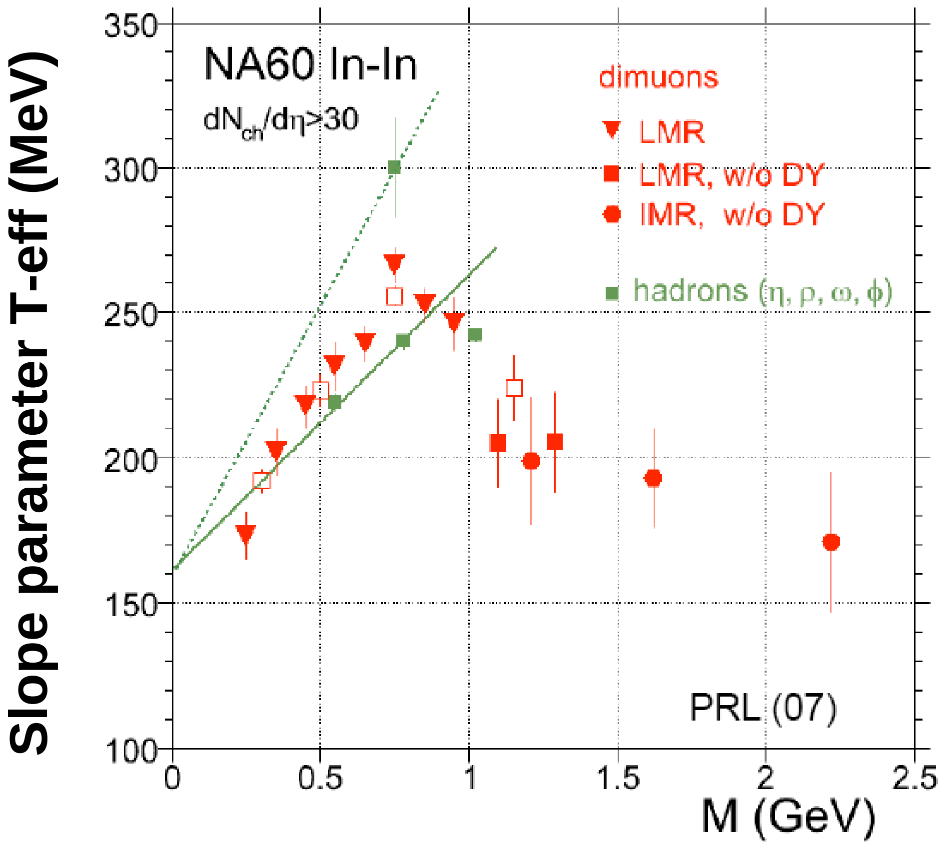
PRL 102 (2009) 222301



Lack of any polarization in excess (and in hadrons) supports emission from a thermalized source

From Usai's talk

Effective temperature



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

$$T_{\rm eff} = T_0 + M v_T^2$$

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

NA60, PRL100, 022302(2008)

Motivation and strategy

• Dilepton production in Au+Au collisions at 200 AGeV, with M in [1,2.5] GeV, pion-pion (through rho-meson) and q-qbar annihilation

• Space-time evolution of medium is described by a 2+1 ideal hydro model, different EOS are used for hydro

• Slope parameters and elliptic flows show distinct features from two phases, such features may provide a probe to phase transition and the equations of state for dense and hot matter

Dilepton emission rate

u: fluid velocity

$$\frac{dN}{d^4x} = \int \frac{d^3p_1}{(2\pi)^3}\frac{d^3p_2}{(2\pi)^3} f(p_1, u, T) f(p_2, u, T) \sigma(a^+a^- \to l^+l^-; p_1, p_2) v_{rel}$$

Space-time history encoded

$$\sigma_q(M) = (N_c N_s^2 \sum_f e_f^2)\tilde{\sigma}(M)$$

$$\sigma_\pi(M) = \frac{m_\varrho^4}{(M^2 - m_\rho^2)^2 + (m_\rho \Gamma_\rho)^2}\sqrt{1 - \frac{4m_\pi^2}{M^2}}\tilde{\sigma}(M)$$

$$\tilde{\sigma}(M) = \frac{4\pi}{3}\frac{\alpha^2}{M^2}\left(1 + \frac{2m_l^2}{M^2}\right)\sqrt{1 - \frac{4m_l^2}{M^2}}$$

azimuthal angle of fluid velocity and dilepton

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

$$\frac{d^2N}{P_T dP_T M dM} = \frac{1}{16\pi^4}\int d^4x \sigma_a(M)(M^2 - 4m_a^2) I_0\left[\frac{1}{T}\gamma_T v_T P_T\right] K_0\left[\frac{1}{T}\gamma_T M_T\right]$$

Dilepton emission rate

Spectra in transverse momentum and invariant mass

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

Slope parameter

M* depends on M monotonously

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

Hydrodynamics for HIC

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

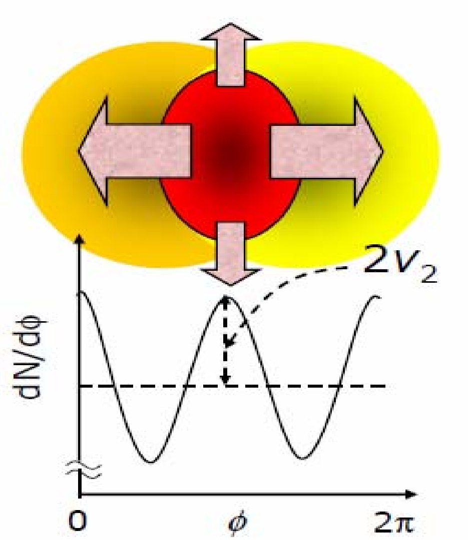
Early works:

Baym, Friman, Blaizot et al 86', Rischke 98', Kolb & Heinz, 00', ...

On this workshop:

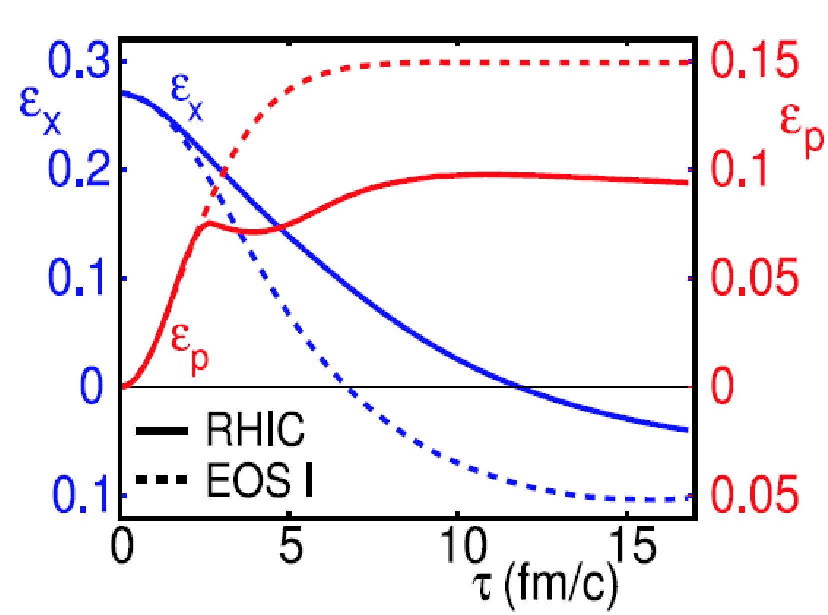
Florkowski, Kisiel, Ollitrault, Snellings, Werner, …

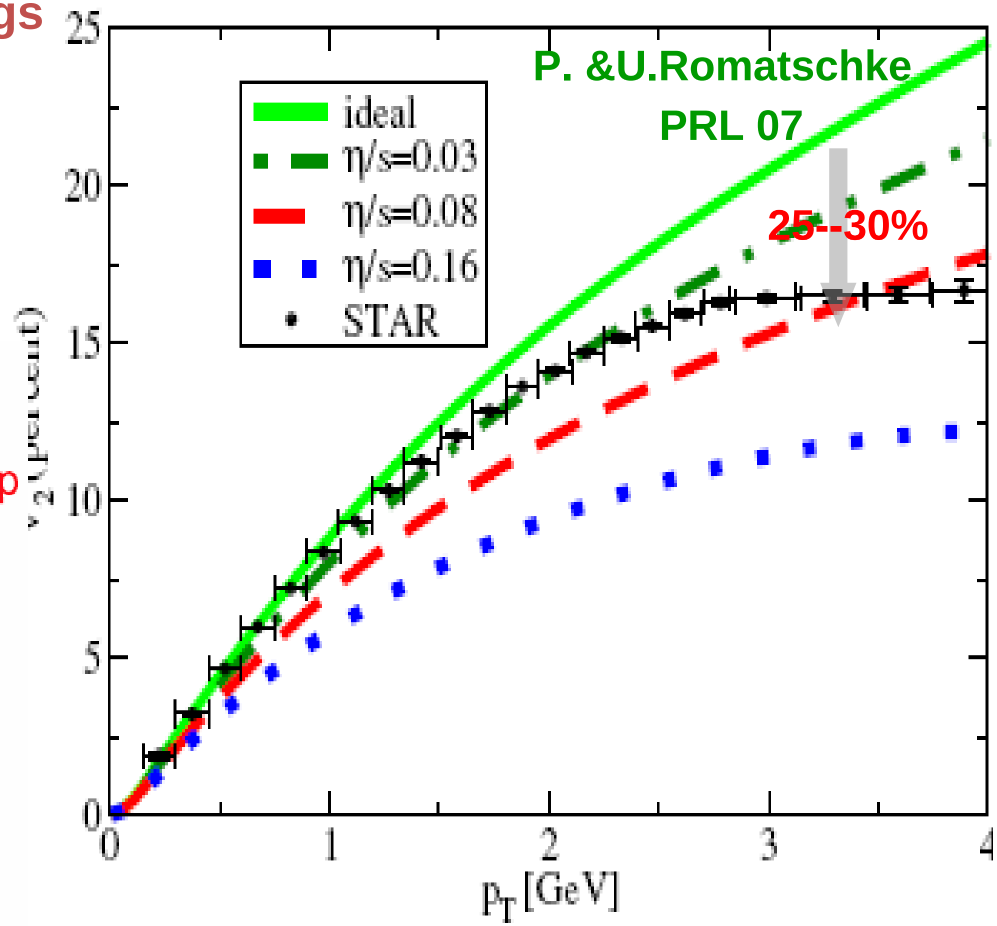
Hydro: Elliptic flow



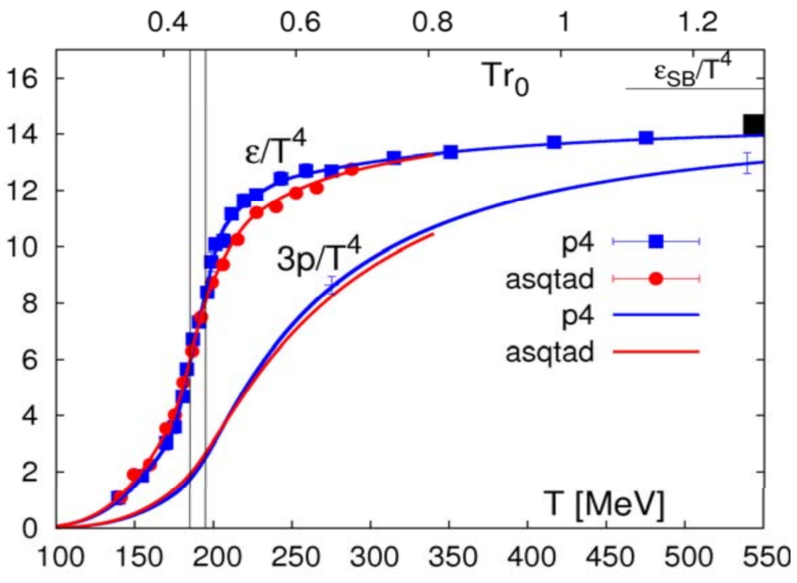
Talks:
Ollitrault
Snellings

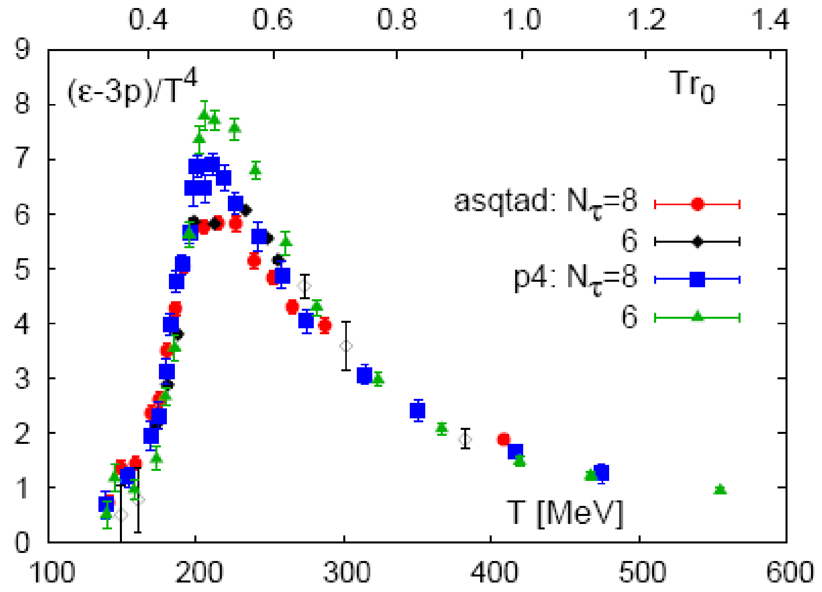
Ideal vs Viscous hydro





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), Phys.Rev.D80:014504,2009

On this workshop:
Laermann, Petreczky

Four equations of state (EOS)

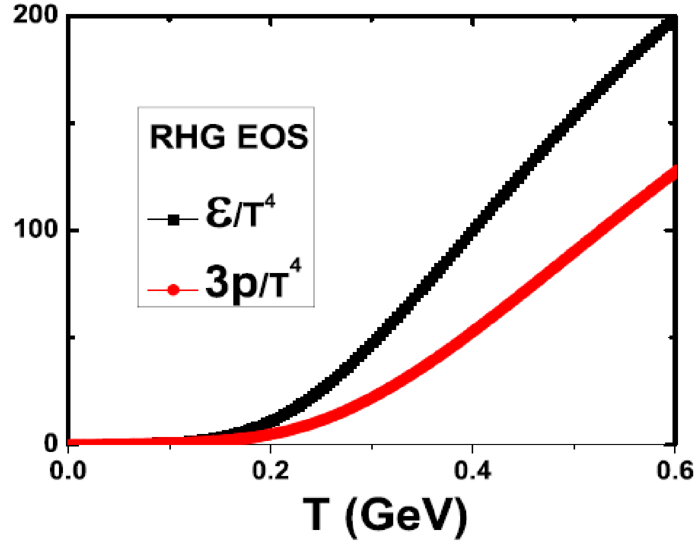
Massless ideal QGP

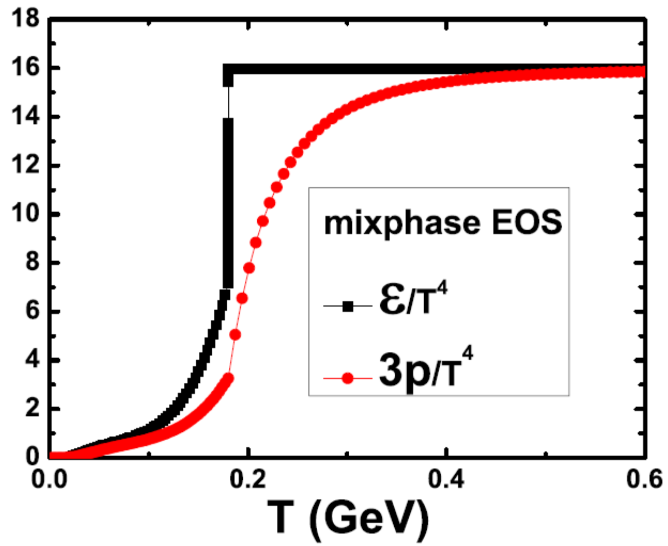
$$\epsilon = 3p = 16T^4$$

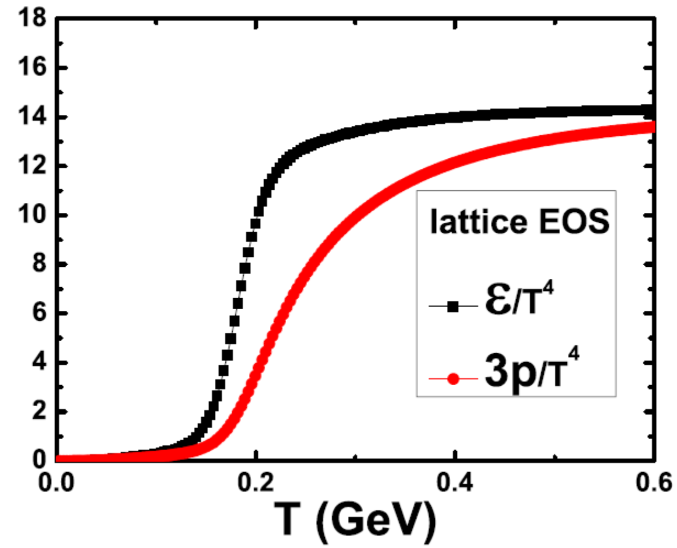
Hadron gas [Braun-Munzinger, Redlich, Stachel, nucl-th/0304013]

$$P = \sum_{m_i < m_{max}} \frac{g_i T^2}{2\pi^2} \sum_{k=1}^{\infty} \frac{(\pm 1)^{k+1}}{k^2} \lambda_i^k m_i^2 K_2\left(\frac{k m_i}{T}\right)$$

$$\frac{\epsilon - 3P}{T^4} = \sum_{m_i < m_{max}} \frac{g_i}{2\pi^2} \sum_{k=1}^{\infty} (\pm 1)^{k+1} \frac{1}{k} \lambda_i^k \left(\frac{m_i}{T}\right)^3 K_1\left(\frac{k m_i}{T}\right)$$

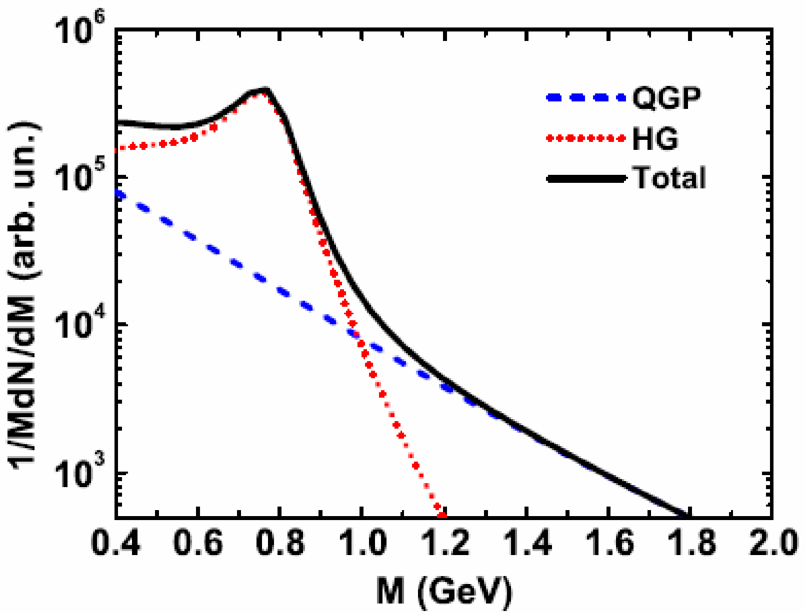


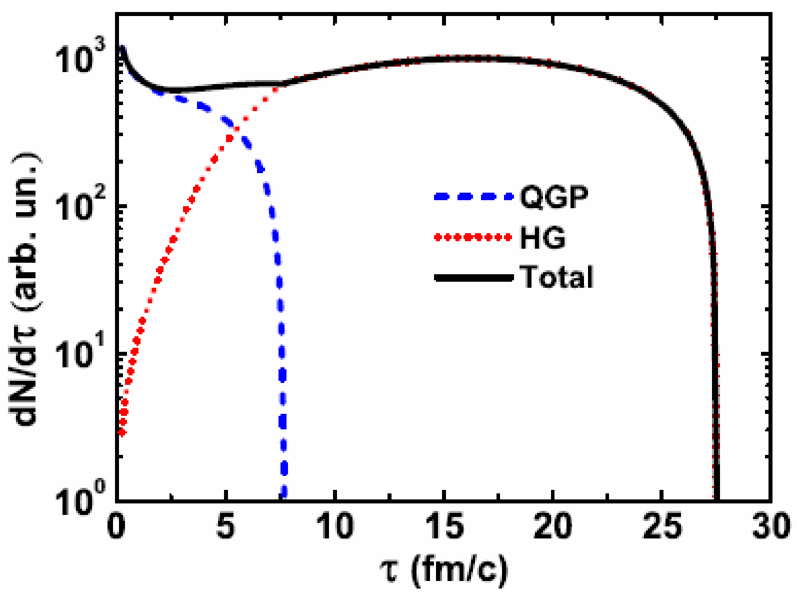




Time evolution of the rate

Lattice EOS

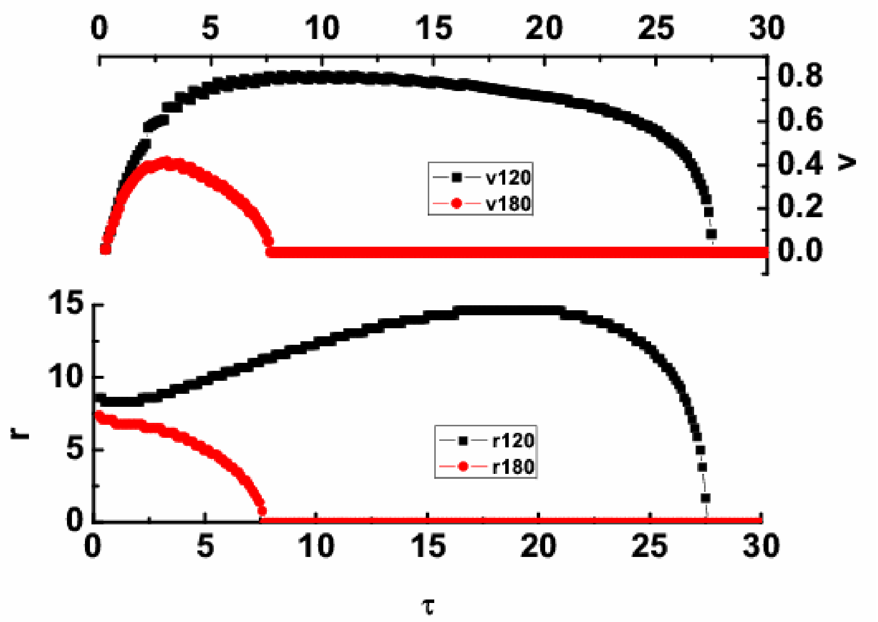




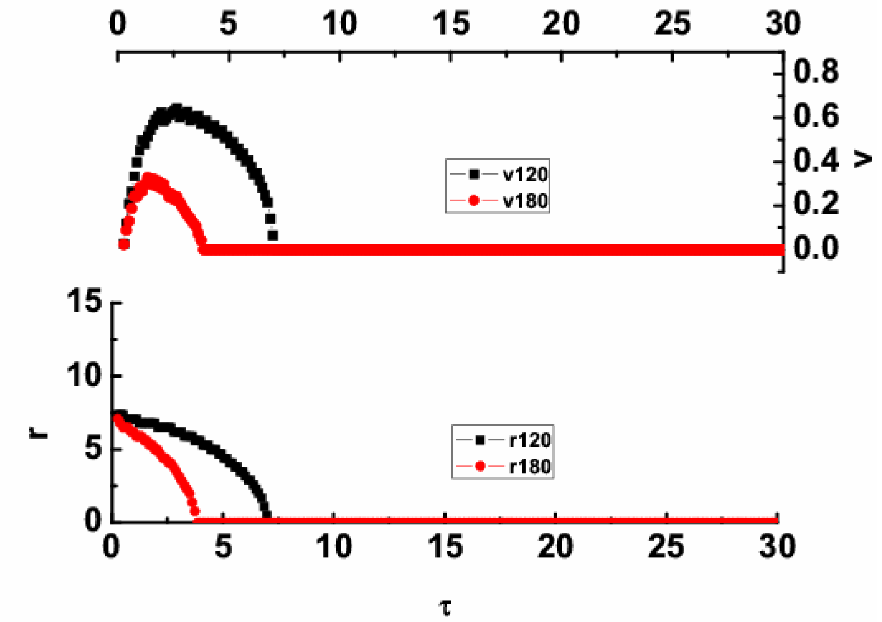
Differential multiplicity as functions of the dilepton invariant mass and proper time. The Lattice EOS is used. The unit is arbitrary.
The contributions from QGP and HG are shown in dashed and dotted lines.

Evolution of radial flow: isothermal contour

Hadron Gas EOS



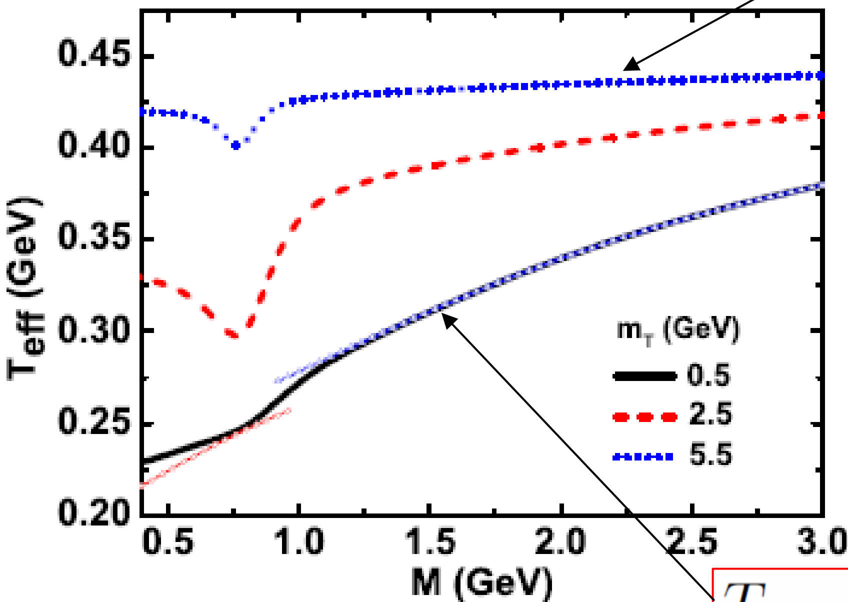
Free QGP EOS

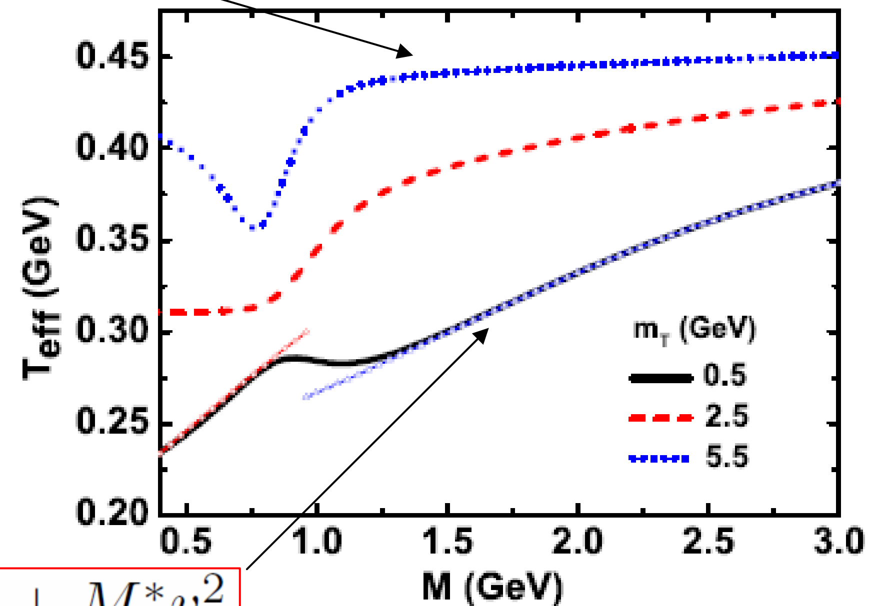


Slope parameter: pt and EOS dependence

Mixed phase EOS | **Lattice EOS**

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

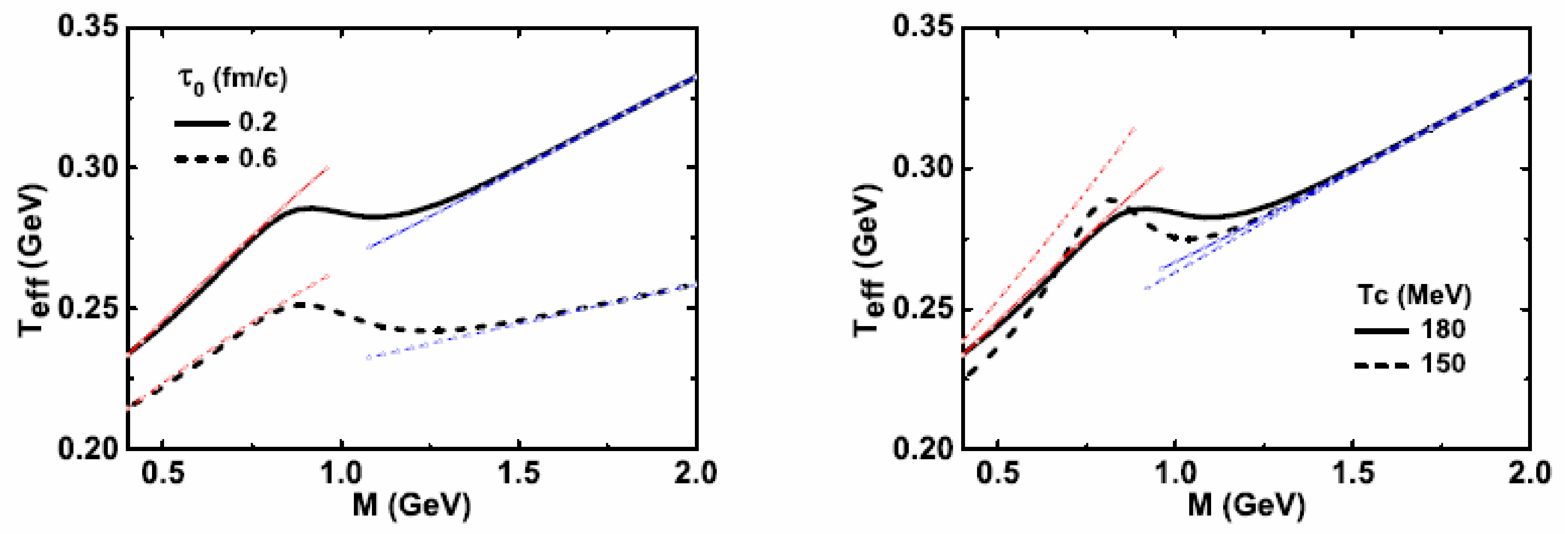




$$T_{eff} \sim T + M^* v_T^2$$

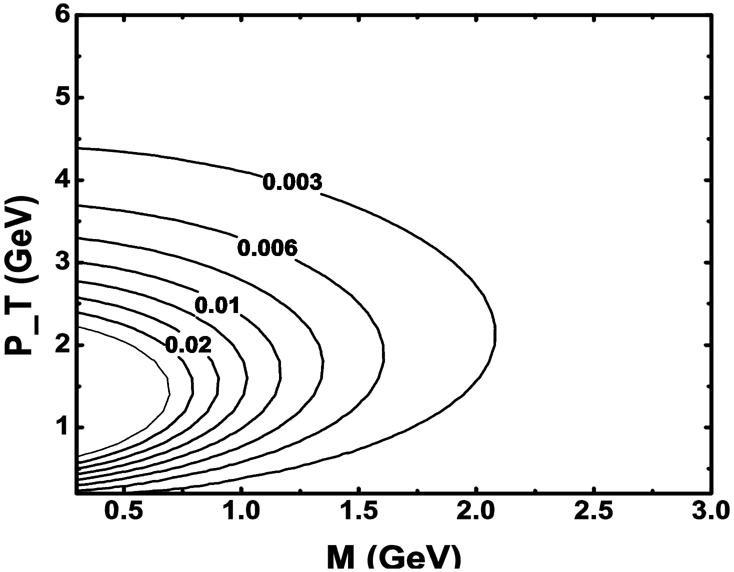
Slope parameter as functions of *M* for the mixed phase (left panel) and the lattice (right panel) EOS. The results for different values of *mT* are shown in the solid, dashed and dotted lines. The lines with hollowed circles/triangles are extracted from the HG/QGP components.

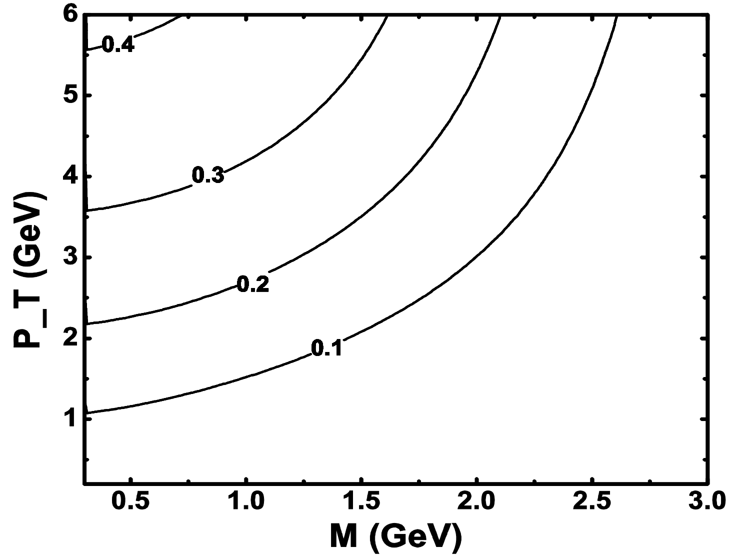
Slope parameter: parameter dependence

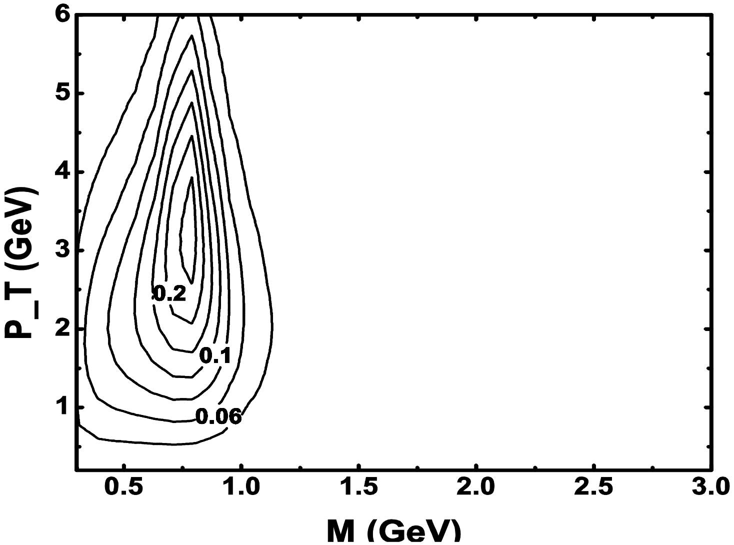


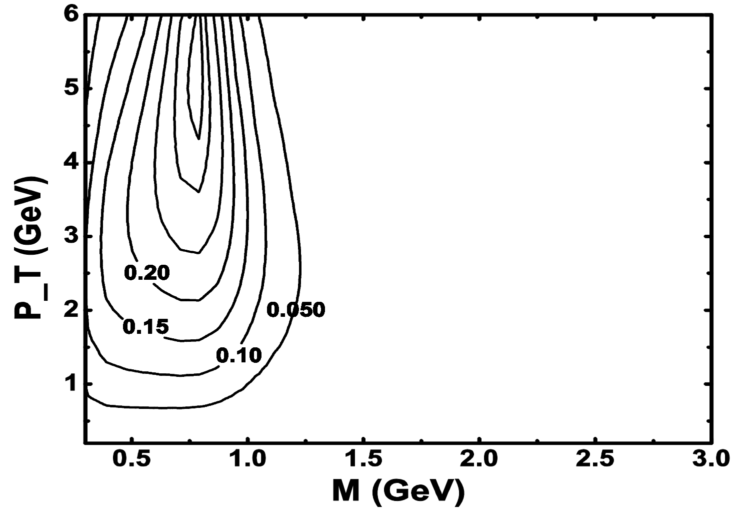
Parameter dependences of the slope parameter with the lattice EOS. Left panel: the initial time for the hydrodynamic evolution τ 0= 0.2*;* 0.6 fm/c. Right panel: the phase transition temperature *Tc* = 180, 150 MeV.

v2-contour in (P_T,M) for dilepton

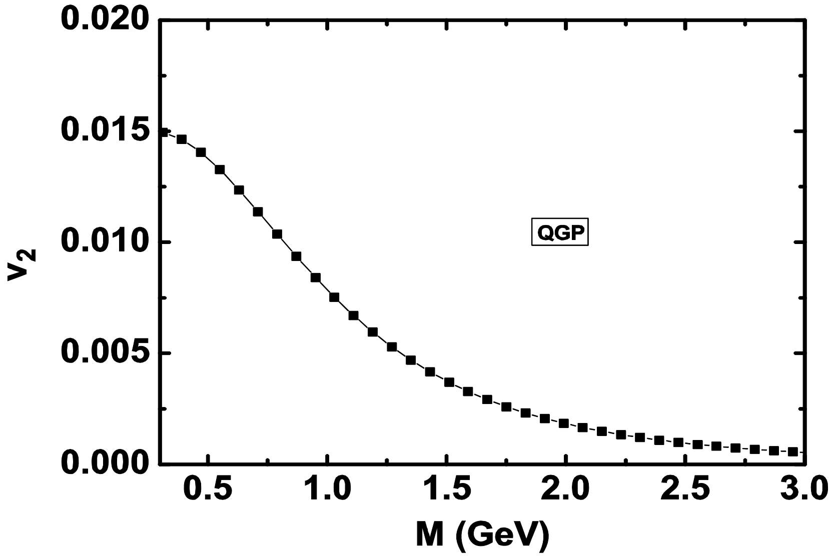


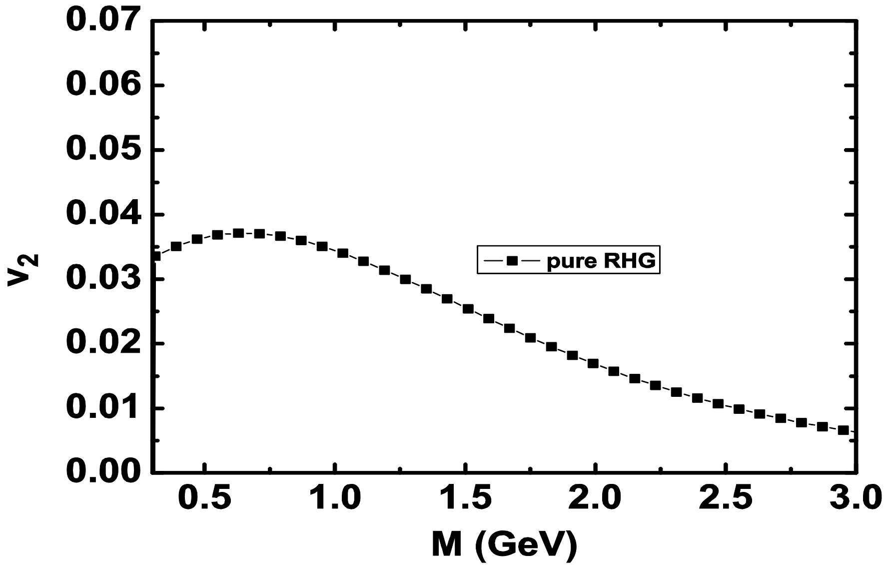


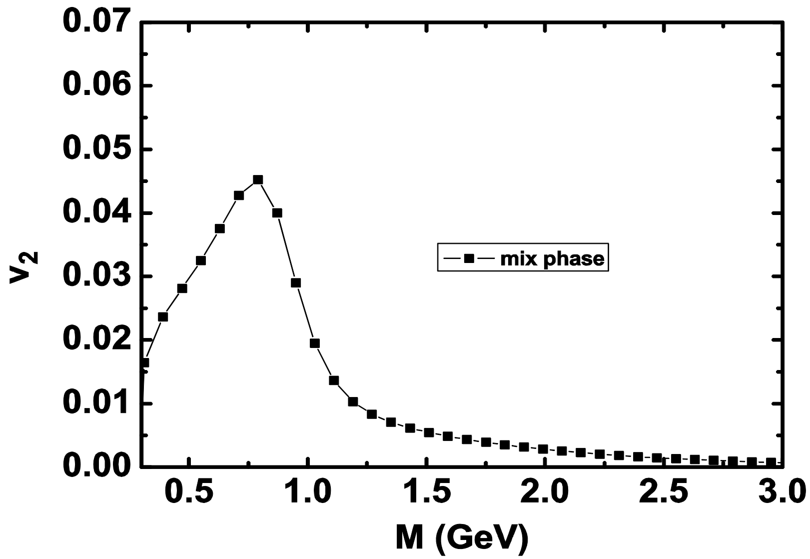


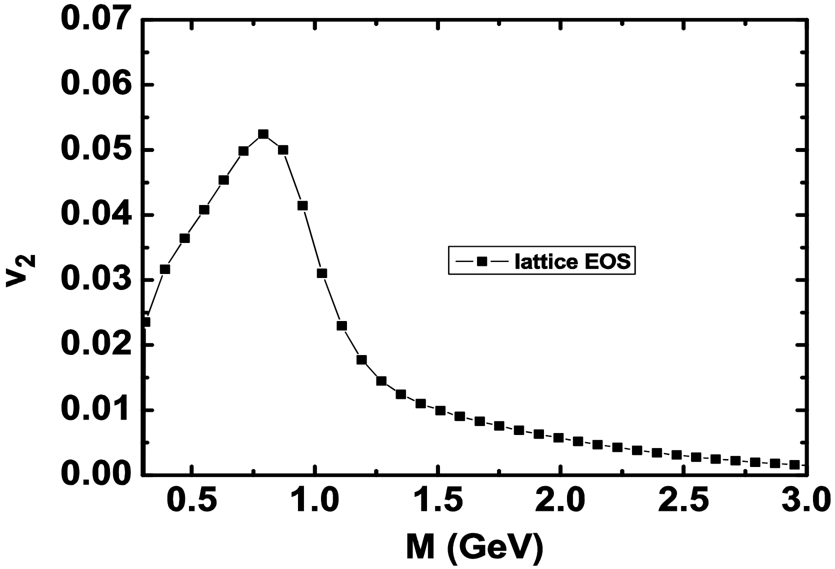


Elliptic flow







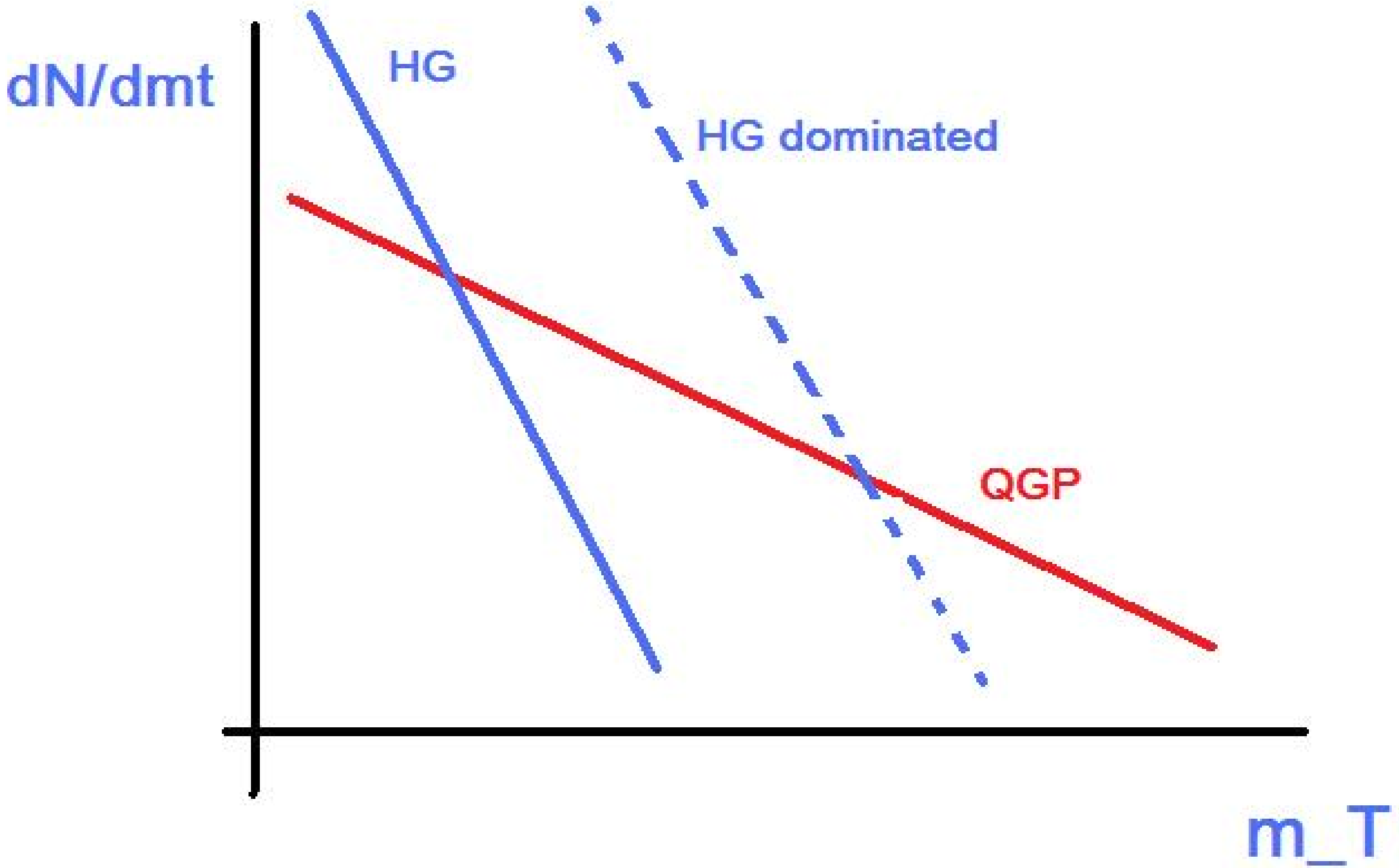


Summary and Conclusion

- Slope parameters and elliptic flows show distinct features from two phases, such features may provide a probe to phase transition and the equations of state for dense and hot matter
- The space-time evolution of dilepton rate is descibed by hydro
- The same calculation will be extended by including (a) pion-pion annihilation via other vector meson channel like omega and phi meson, (b) 4-pion scattering, and (c) Charmonium and Drell-Yan

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