Quark Matter 2011
Annecy, France
2011/05/27

Can transport peak explain the low-mass enhancement of dileptons at RHIC?

Yukinao Akamatsu (Nagoya)
Hideki Hamagaki (Tokyo)
Tetsuo Hatsuda (Tokyo/RIKEN)
Tetsufumi Hirano (Sophia/Tokyo)

Ref: Akamatsu, Hamagaki, Hatsuda, Hirano, in preparation

Quark Matter 2011
Annecy, France
2011/05/27

Can transport peak explain the low-mass enhancement of dileptons at ~~RHIC~~ PHENIX?

Yukinao Akamatsu (Nagoya)
Hideki Hamagaki (Tokyo)
Tetsuo Hatsuda (Tokyo/RIKEN)
Tetsufumi Hirano (Sophia/Tokyo)

Ref: Akamatsu, Hamagaki, Hatsuda, Hirano, in preparation

Transport peak?

What is it?

When is it important?

Why is it appealing?

Dilepton production at PHENIX

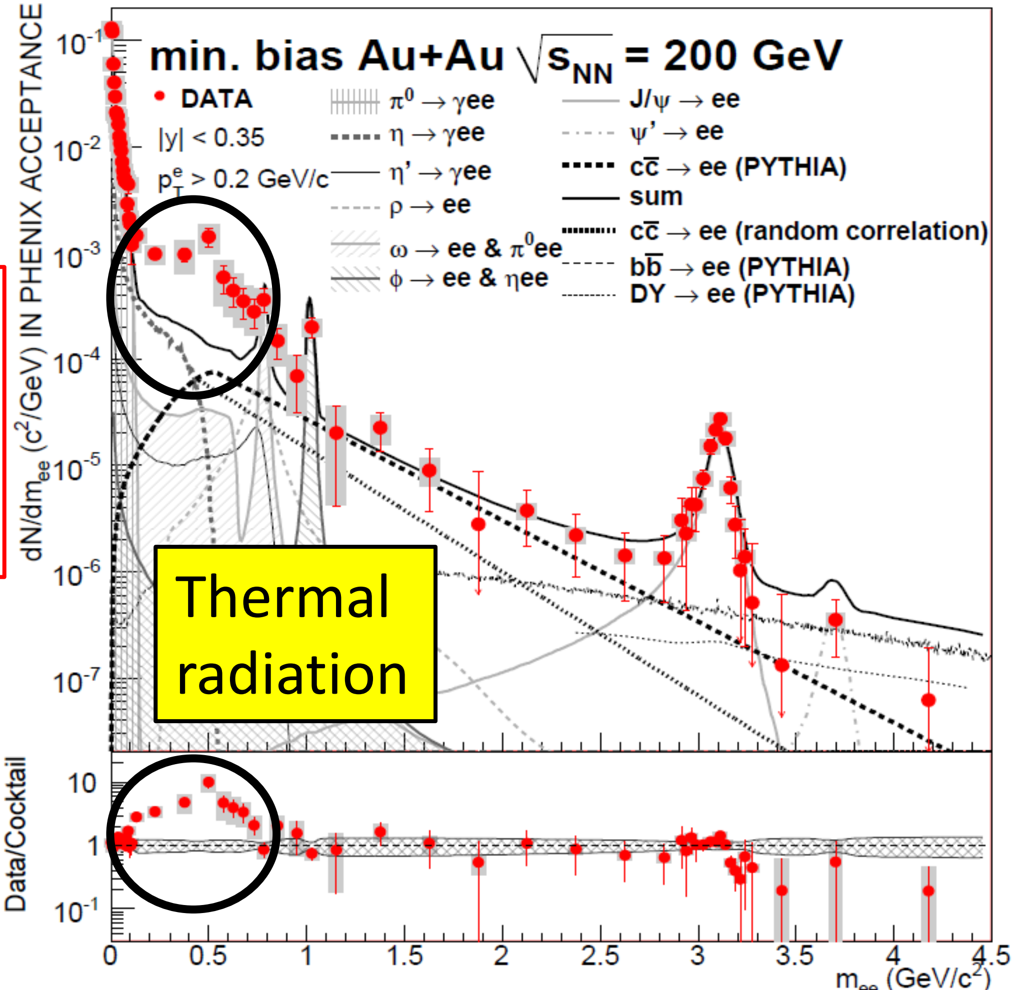
Low-mass (m_{ee}<0.6GeV) enhancement has been a challenge to theorists:

Rapp ('01,'10)
Dusling, Zahed ('07,'09)
Bratkovaskaya, Cassing, Linnyk ('09,'10)
Ghosh, Sarkar, Alam ('10)
…

Hadron interaction, chiral symmetry (Hadronic phase) / pQCD(QGP phase)

⬇ Successful at SPS but not at RHIC

Non-perturbative process in QGP phase is important.



AuAu collision @ PHENIX

Formula for thermal radiation

Retarded correlator (or spectral function) of QCD-EM current

$$\frac{E_1 E_2 dN_{\mathrm{ee}}}{d^3 p_1 d^3 p_2 d^4 x} = \frac{2e^4 L_{\mu\nu}(p_1, p_2)}{(2\pi)^6 q^4} \mathrm{Im}\, G_{\mathrm{R}}^{\mu\nu}(q;T) f_{\mathrm{BE}}(q^0;T), \;\; q^\mu \equiv p_1^\mu + p_2^\mu .$$

$$G_R^{\mu\nu}(\omega, k) \equiv \int d^4 x e^{iqx} i\theta(t) \left\langle \left[J^\mu(x), J^\nu(0) \right] \right\rangle_T$$

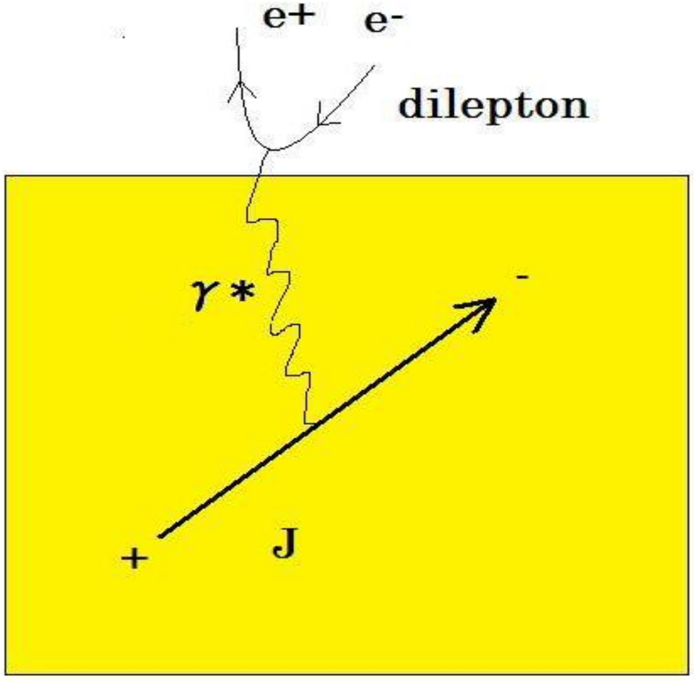
What's in the spectral function?

- Large ω : Towers of higher resonances/Quark pair annihilation
- Intermediate ω : Vector correlation (vector meson/qqbar)
- Small ω : Transport phenomena

Charge transport and dilepton

In each fluid element:

1. charge fluctuation → current
2. current → dileptons



*Remark:

net charge = 0 at RHIC/LHC

→ only induced current flows

Spectral function at small ω & k

Linear response theory:

$$\delta H(t) = \int d^3x J^\mu(x) \delta A_\mu(x)$$

$$\rightarrow \left\langle \delta J^\mu(q) \right\rangle_T = -G_R^{\mu\nu}(q;T)\delta A_\nu(q)$$

2nd order relativistic dissipative hydrodynamics in external electromagnetic field:

Israel ('76)
Israel, Stewart ('79)

$$J^\mu(x) = \left(\delta\rho(x), \vec{v}(x)\right),\ \partial_\mu J^\mu = 0,$$

$$\vec{v}(x) = \sigma\vec{E}(x) - D\nabla\delta\rho(x) - \tau_J \frac{\partial \vec{v}}{\partial t},$$

$$\sigma \equiv \chi D,\ \ \chi \equiv \frac{\partial\rho}{\partial\mu}.$$

Ohm's law, **Fick's law**
Memory effect

Linear response theory

$$\mathrm{Im}\, G_R^{(L)}(q;T) = -\frac{\chi D \omega q^2}{\omega^2 + (\tau_J \omega^2 - Dk^2)^2},$$

$$\mathrm{Im}\, G_R^{(T)}(q;T) = -\frac{\chi D \omega}{\tau_J{}^2 \omega^2 + 1}.$$

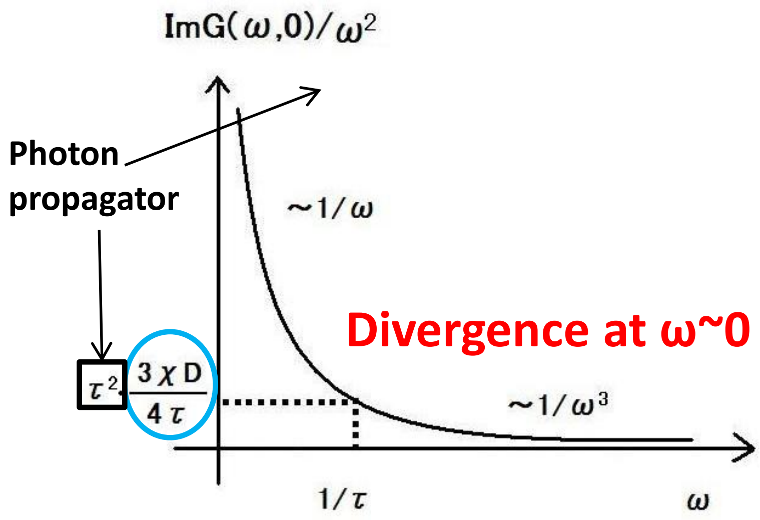
Spectral shape & strength

Spectral shape:

$$\mathrm{Im}\,G_{\mathrm{R}}^{(\mathrm{L})}(q;T) = -\frac{\chi D \omega q^2}{\omega^2 + (\tau_{\mathrm{J}}\omega^2 - Dk^2)^2},$$

$$\mathrm{Im}\,G_{\mathrm{R}}^{(\mathrm{T})}(q;T) = -\frac{\chi D \omega}{\tau_{\mathrm{J}}{}^2\omega^2 + 1},$$

$$\mathrm{Im}\,G_{\mathrm{R}}^{\mu\mu} = 2\,\mathrm{Im}\,G_{\mathrm{R}}^{(\mathrm{T})} + \mathrm{Im}\,G_{\mathrm{R}}^{(\mathrm{L})}$$



Stronger at larger χ, D and smaller τ:

- Susceptibility χ : how large the charge fluctuation is.
- Diffusion constant D : how effectively current is induced.
- Relaxation time τ_{J} : how swiftly current is induced.

$$\text{induced current}: \vec{v}(x) = \sigma\vec{E}(x) - D\vec{\nabla}\delta\rho(x) - \tau_{\mathrm{J}}\frac{\partial\vec{v}}{\partial t}$$

Parameterization

$$D \propto 1/T, \tau_{\mathrm{J}} \propto 1/T.$$

	D	τJ
pQCD	4/T	15/T
AdS/CFT	1/2πT	ln2/2πT

Arnold et al. ('00,'03), Hong, Teaney ('10)

Natsuume, Okamura ('08)

$$\chi(T) = 0.28T^2\left[1 + \tanh\left(\frac{T - 0.155\mathrm{GeV}}{0.023\mathrm{GeV}}\right)\right].$$

χ(T) : Using lattice result for quark number susceptibility

Allton et al. ('05)

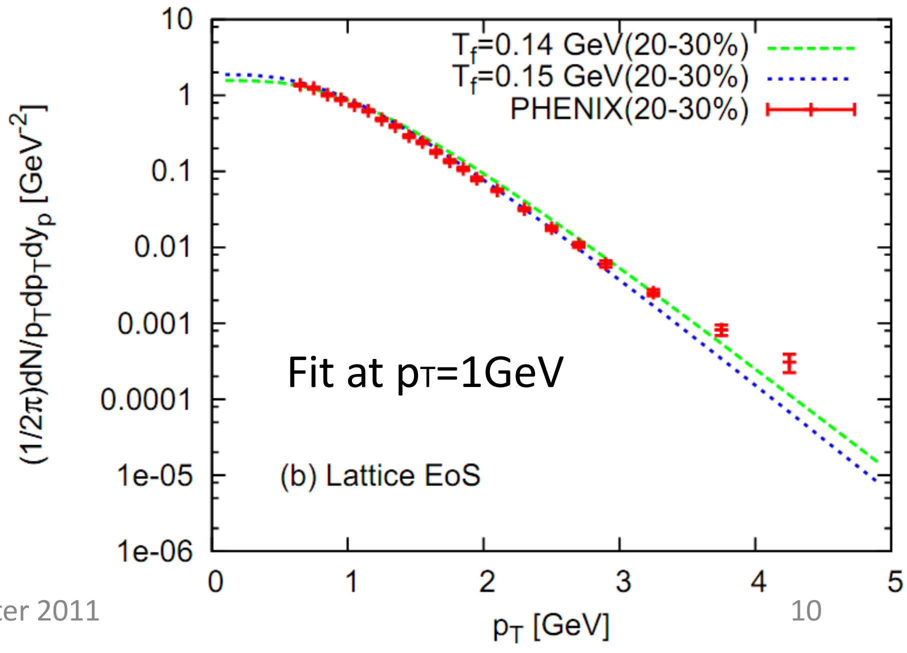
Hydro model setting

Viscosity	EoS	Initial	Hadronic phase
Perfect fluid	**Lattice**	**Modified BGK**	**Chemical equilibrium**

How far the matter
evolves under hydrodynamics

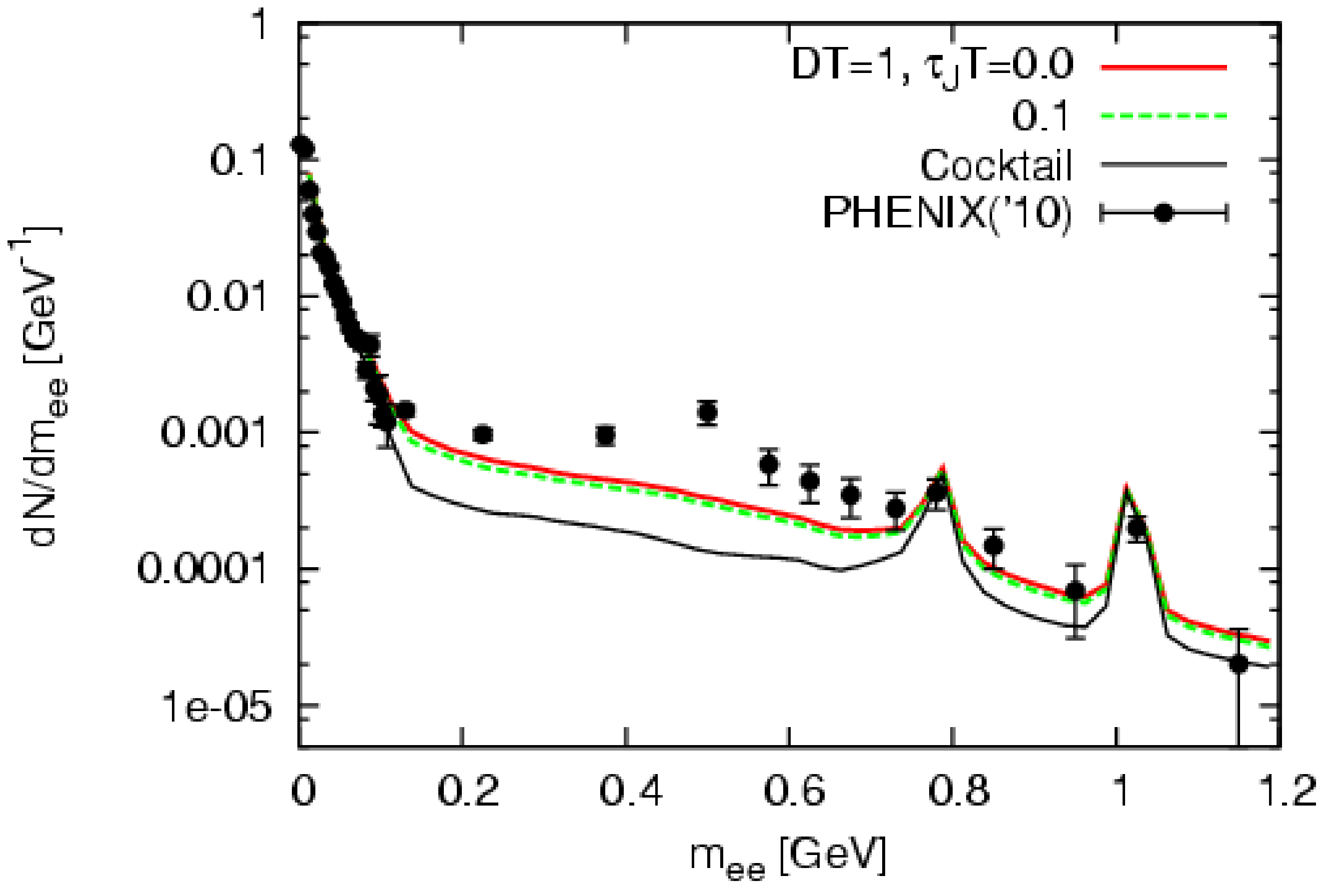
Until $T_f = 0.15$ GeV

Proton spectra:
theory vs. experiment



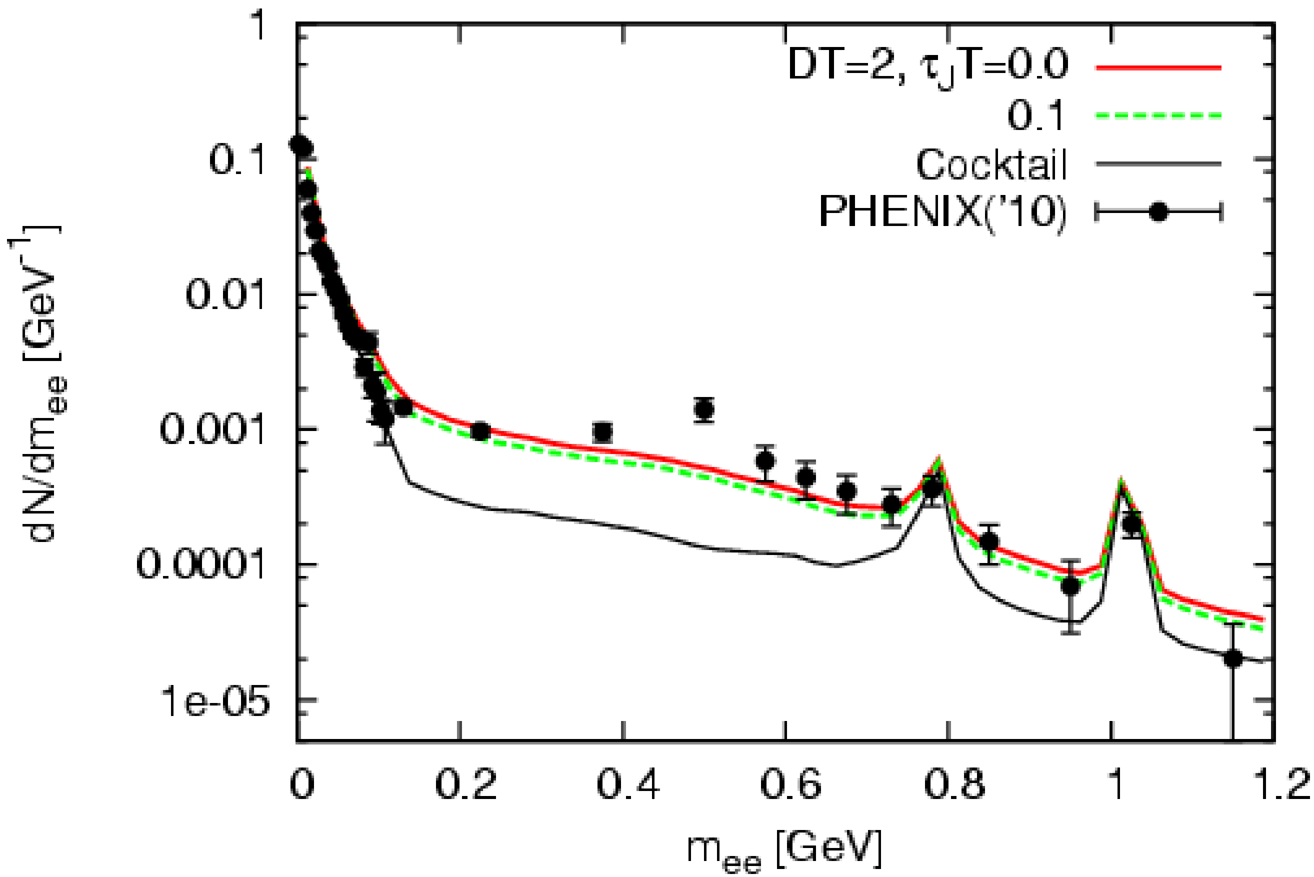
Invariant mass spectra

DT=1 : no solution



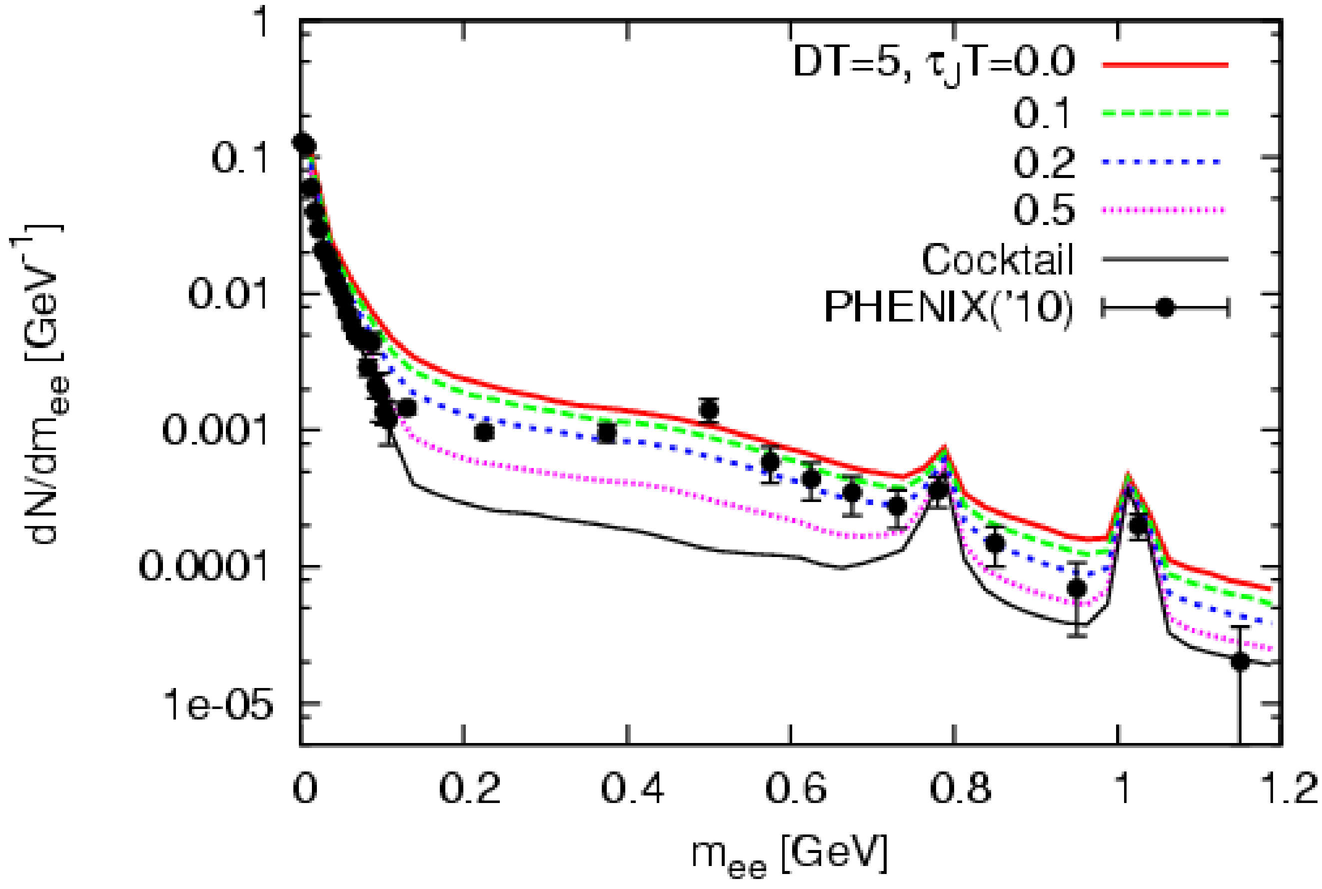
Invariant mass spectra

(DT, τJT)=(2, 0-0.1) : good agreement



Invariant mass spectra

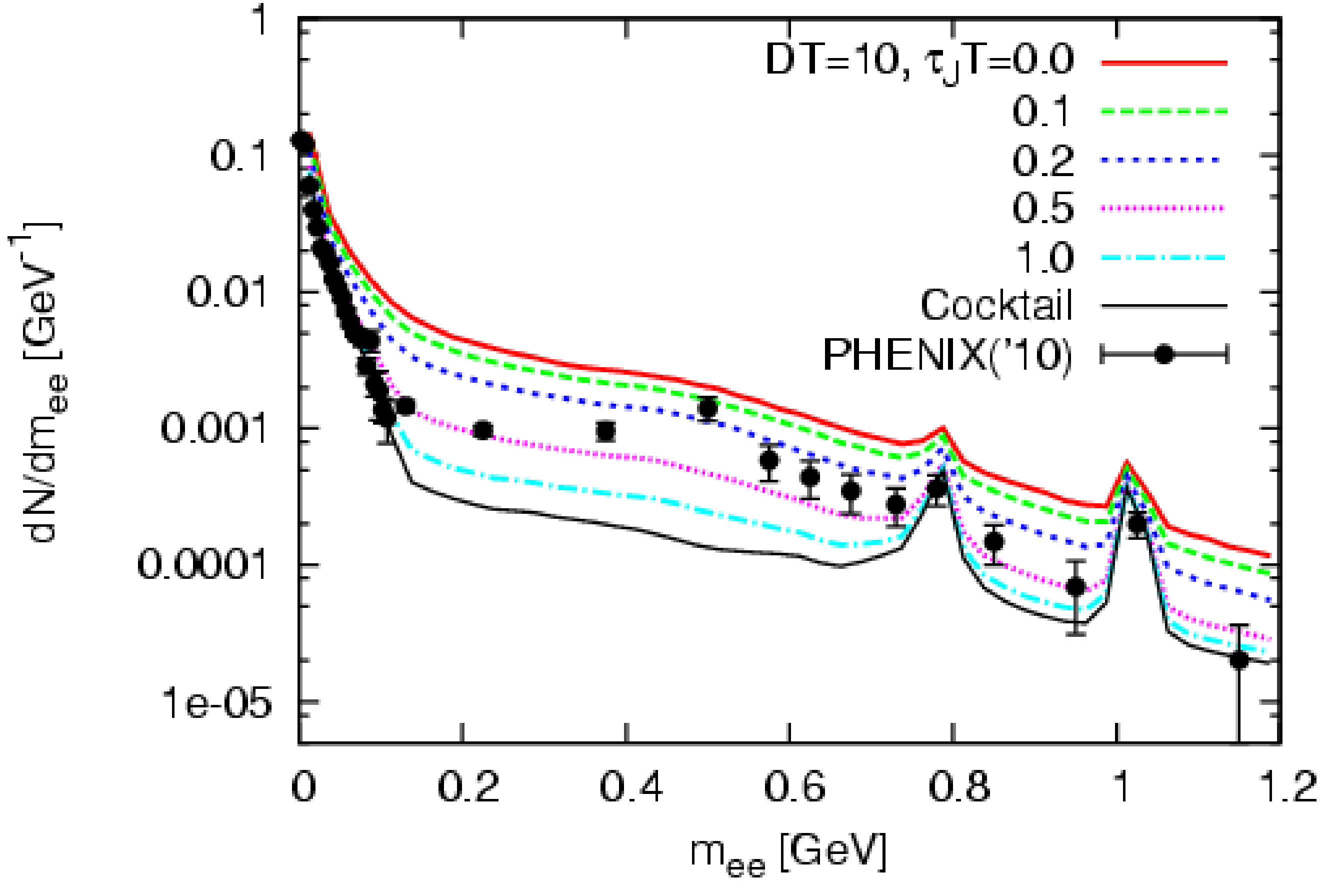
(DT, τJT)=(5, 0.2), (2, 0-0.1) : good agreement



Invariant mass spectra

(DT, τJT)=(10, 0.5), (5, 0.2), (2, 0-0.1) : good agreement

DT=1 : no solution → lower bound D≧2/T

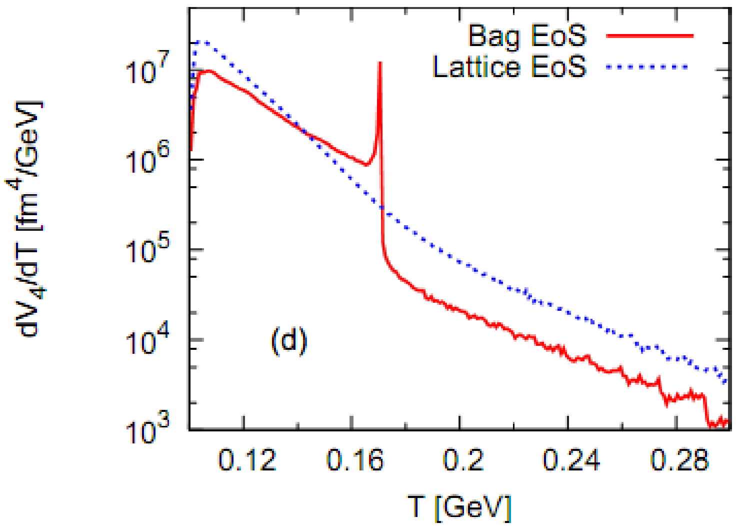


Main source: fluctuation or volume?

- Large charge fluctuation at high-T

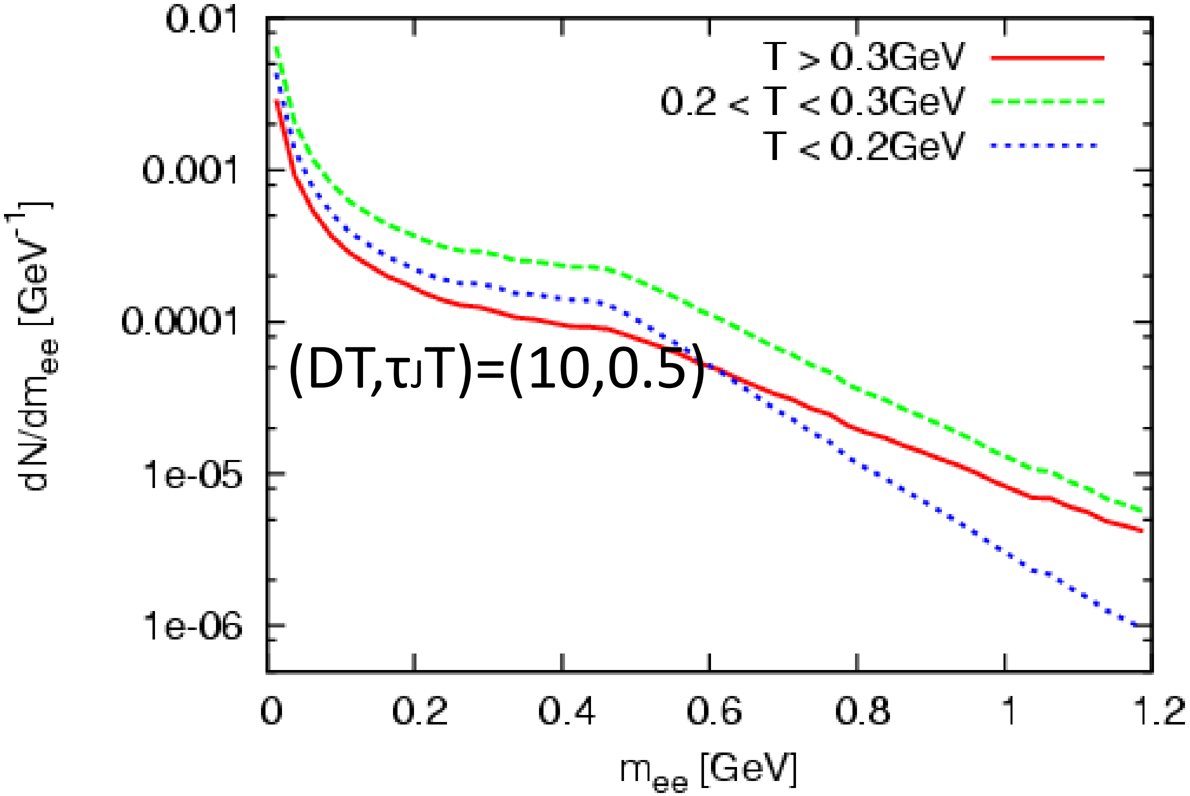
$$\text{Spectral strength} \propto \chi(T)$$
$$= 0.28T^2\left[1+\tanh\left(\frac{T-0.155\text{GeV}}{0.023\text{GeV}}\right)\right]$$

- Large spacetime volume at low-T



Main source: volume or fluctuation?

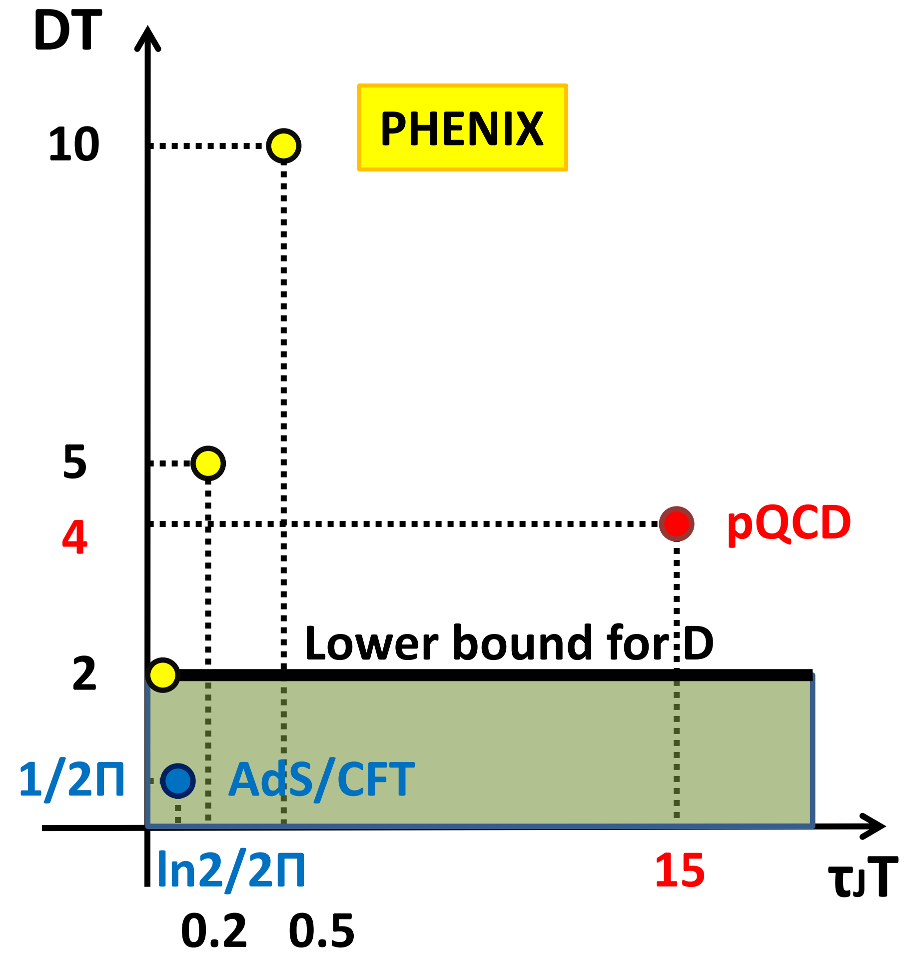
Large production rate due to thermal fluctuation of charge in hot region strongly compensates smallness of volume !



Transport coefficients

Assumptions made:

- Validity of transport-SPF
- Hydro with chem.eq.
- No radiation from pre-eq. stage



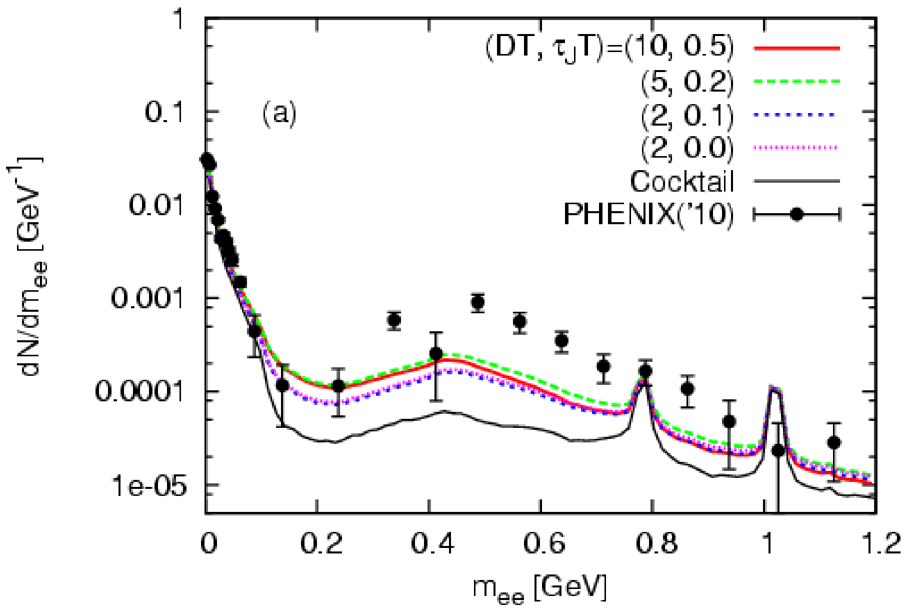
Summary

- **Dilepton production via transport phenomena is studied. Transport spectral function is parameterized with diffusion constant D, relaxation time τ_J, and susceptibility χ.**
- **PHENIX Data set lower bound for D $\geqq$ 2/T. Solution (D, τ_J) is not uniquely obtained, but all the solutions are far from both pQCD and AdS/CFT results.**
- **Main source of thermal dilepton radiation is high-T QGP phase due to the large fluctuation.**
- **Application to photon radiation at RHIC and to dilepton/photon radiation at LHC.**

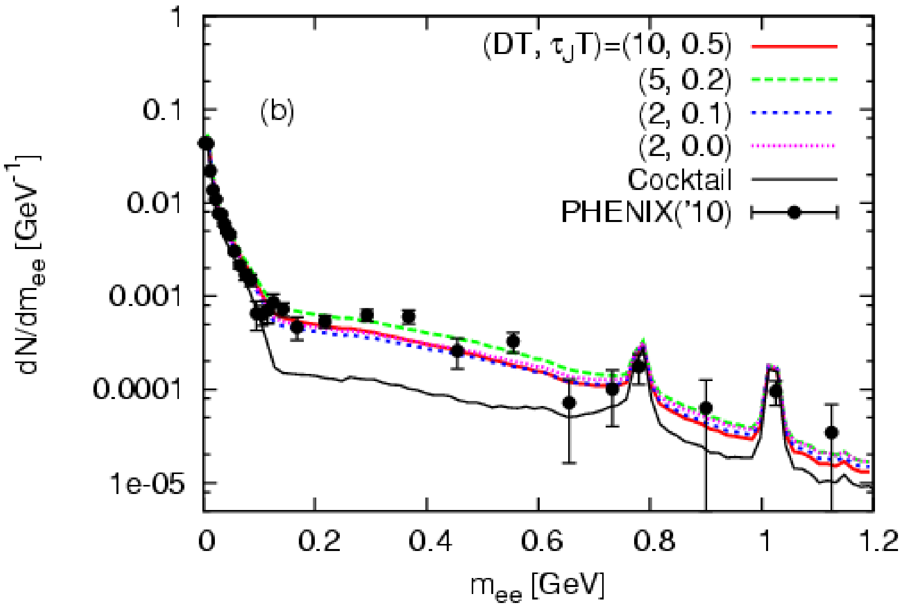
Thank you for your attention
& patience before the banquet!

Backup

Invariant mass spectra (p_T-window)

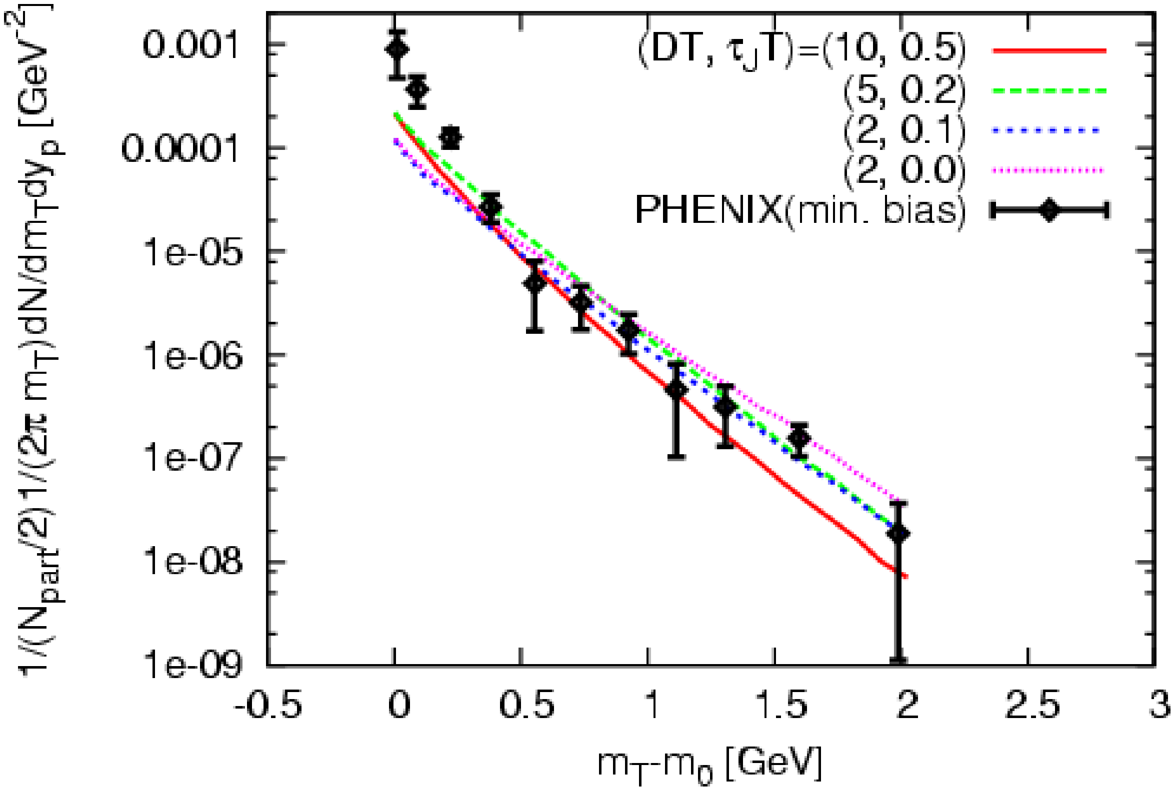


$0<p_T<0.5$GeV



$0.5<p_T<1.0$GeV

Mт-slope



(DT, τ_JT)=(10, 0.5)
(5, 0.2)
(2, 0.1)
(2, 0.0)
PHENIX(min. bias)
0.001
0.0001
1e-05
1e-06
1e-07
1e-08
1e-09
-0.5
0
0.5
1
1.5
2
2.5
3
m_T-m_0 [GeV]
$1/(N_{part}/2)\,1/(2\pi\, m_T)\,dN/dm_T dy_p$ [GeV^{-2}]

Transport-SPF

Transport-SPF(DT=10,τJT=0.5)