# Gauge invariant non-perturbative production rate of photons and dileptons above $T_c$

Taekwang Kim, Masayuki Asakawa, Masakiyo Kitazawa (Osaka Univ.)
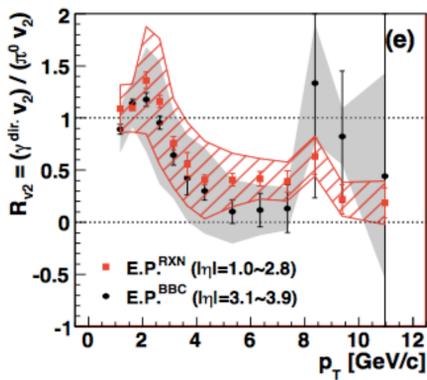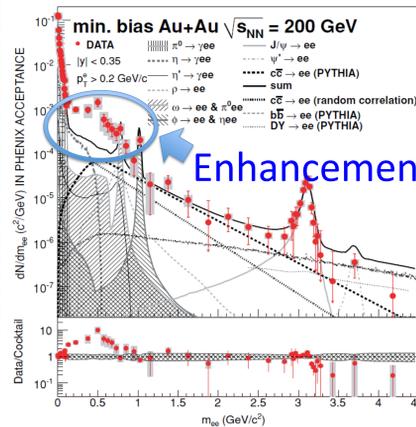
## Motivation

Hot media emit electromagnetic signals & $\gamma$, $l^+l^-$ can be direct signals from the media.

colorless nature

*"Curious puzzle"*

Large photon $v_2$ is observed.

To research deconfined medium contribution seems important.

One needs "*rate*" & hydro model.

$R_{v_2} = (\gamma^{dir}, v_2) / (\pi^0 v_2)$

(e)

E.P.$^{RXN}$ ($|\eta|$=1.0~2.8)
E.P.$^{BBC}$ ($|\eta|$=3.1~3.9)

$P_T$ [GeV/c]

PHENIX Collaboration, A. Adare, *et al.*(2012)

min. bias Au+Au $\sqrt{s_{NN}}$ = 200 GeV

Enhancement!

Dilepton production at RHIC shows an enhancement at low energy.

**QGP contribution?**

PHENIX Collaboration, A. Adare, *et al.*(2010)
Also see STAR Collaboration, L. Adamczyk, *et al.*(2013)

· We use lQCD data based on "quasi-particle" picture.

## Self energy

Propagator determines vertexes by Ward-Takahashi identity and isotropy

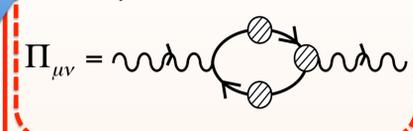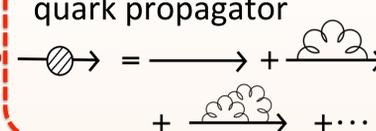\* Photon rate is estimated with "bare" vertex.

WTI is not satisfied

but

Quasi-particle kinematics can be understood.

## Strategy

1-loop with bare vertex

$\Pi_{\mu\nu} = $

Lattice quark propagator

$l^+l^-$ rate

$$\left.\frac{d^4\Gamma}{d\omega d^3q}\right|_{\vec{q}=\vec{0}} = \frac{\alpha}{12\pi^4}\frac{1}{q^2}\frac{1}{e^{\beta\omega}-1}\mathrm{Im}\,\Pi_\mu^{R,\mu}(\omega,\vec{0})$$
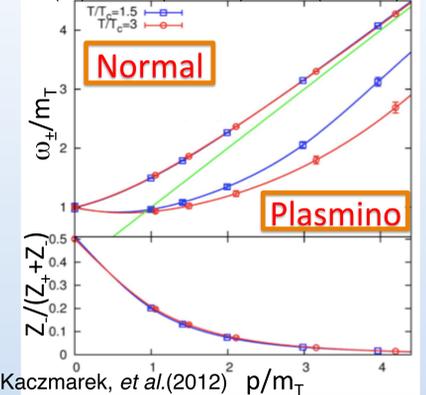
$\gamma$ rate

$$\omega\frac{d^3\Gamma}{d^3q} = -\frac{2}{(2\pi)^3}\frac{1}{e^{\beta\omega}-1}\mathrm{Im}\,\Pi_\mu^{R,\mu}(\omega,\vec{q})$$

L. D. McLerran, T. Toimela (1985); H. A. Weldon(1990); C. Gale, J. I. Kapusta (1991)

## Lattice/quasi-particle

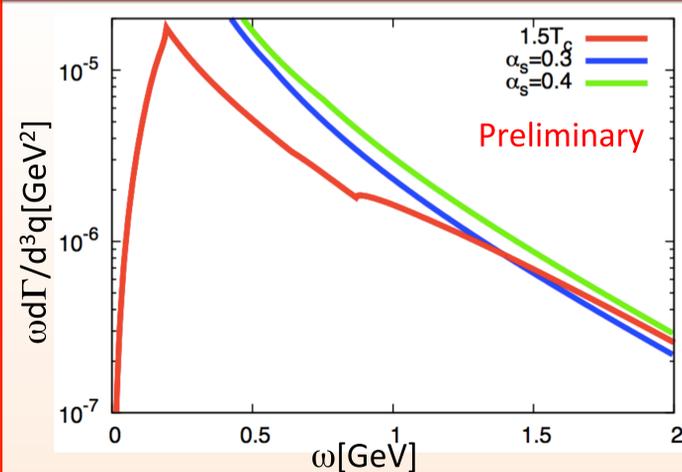2-pole quark spectral function obtained by quenched lQCD.

$$\rho_+(\omega) = Z_+\delta(\omega-\omega_+) + Z_-\delta(\omega+\omega_-)$$

$T/T_c$=1.5
$T/T_c$=3

Normal

Plasmino

$Z_-/(Z_++Z_-)$

O. Kaczmarek, *et al.*(2012)   $p/m_T$

## Results

### Photon production rate

1.5$T_c$
$\alpha_s$=0.3
$\alpha_s$=0.4

Preliminary

$\omega d\Gamma/d^3q$[GeV$^2$]

$\omega$[GeV]
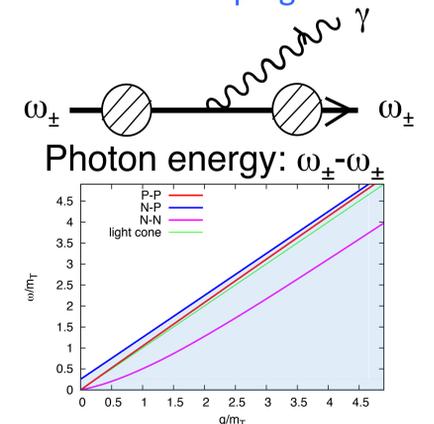
$T_c$=290MeV
$m_T \doteqdot 0.75T$
thermal mass
$\omega$, **q** : photon four momentum

perturbative analysis
Baier *et al.* (1992),
Kapusta *et al.* (1991),
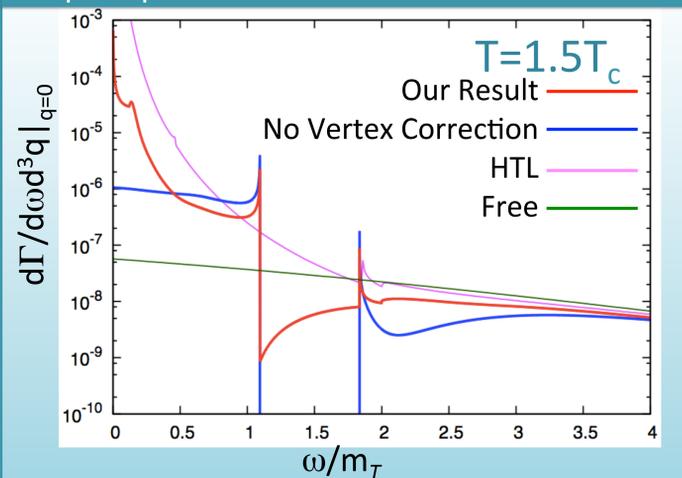Gale *et al.* (2014)

### Virtual photon dispersions

**quasi-particle pair annihilation**

$\omega_\pm$
$\omega_\pm$
$\gamma$

Photon energy: $\omega_\pm + \omega_\pm$

PP
NP
NN
light cone

$\omega/m_T$

$q/m_T$

**Landau damping**

$\gamma$
$\omega_\pm$
$\omega_\pm$

Photon energy: $\omega_\pm - \omega_\pm$

P-P
N-P
N-N
light cone

$\omega/m_T$

$q/m_T$

### Dilepton production rate

$T=1.5T_c$

Our Result
No Vertex Correction
HTL
Free

$d\Gamma/d\omega d^3q|_{q=0}$

$\omega/m_T$
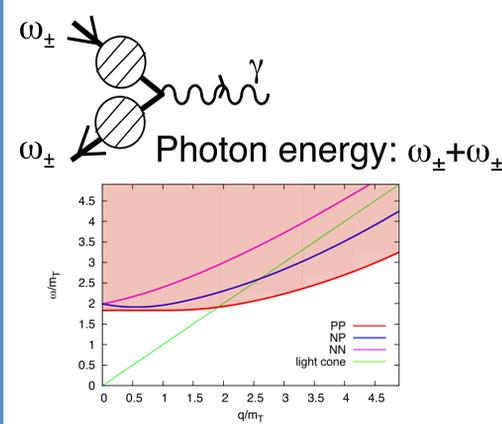
Comparable to perturbative analysis
· Sum of three production processes, plasmino-plasmino annihilation, normal-plasmino annihilation and normal-plasmino Landau damping.
· The structure reflects a simple result that plasmino exists in space-like region.
· Cherenkov radiation is small enough compared to annihilation rate.

· Enhancement around $1.1m_T$ is caused by Landau damping.
· 2 divergence comes from van Hove singularity.
· The vertex correction produces a production in which no corresponding annihilation process nor Landau damping of two quasi-particles exists.

## Summary

· We calculated photon & dilepton production rate from static deconfined medium using the quark propagator obtained in quenched lattice QCD.
· Photon production rate is comparable to perturbative result although production processes are different.
· Dilepton production rate enhanced owing to Landau damping.
· Future: a vertex correction & finite momentum analysis is need.