Photon suppression and dilepton enhancement in semi-QGP

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Collaborators:

- Photon/dilepton rate: Hidaka, SL, Satow, Skokov, Pisarski
- Collinear photon rate: SL, Satow, Pisarski
- Hydrodynamic simulation: Gales, Jeon, Paquet, Vujanovic

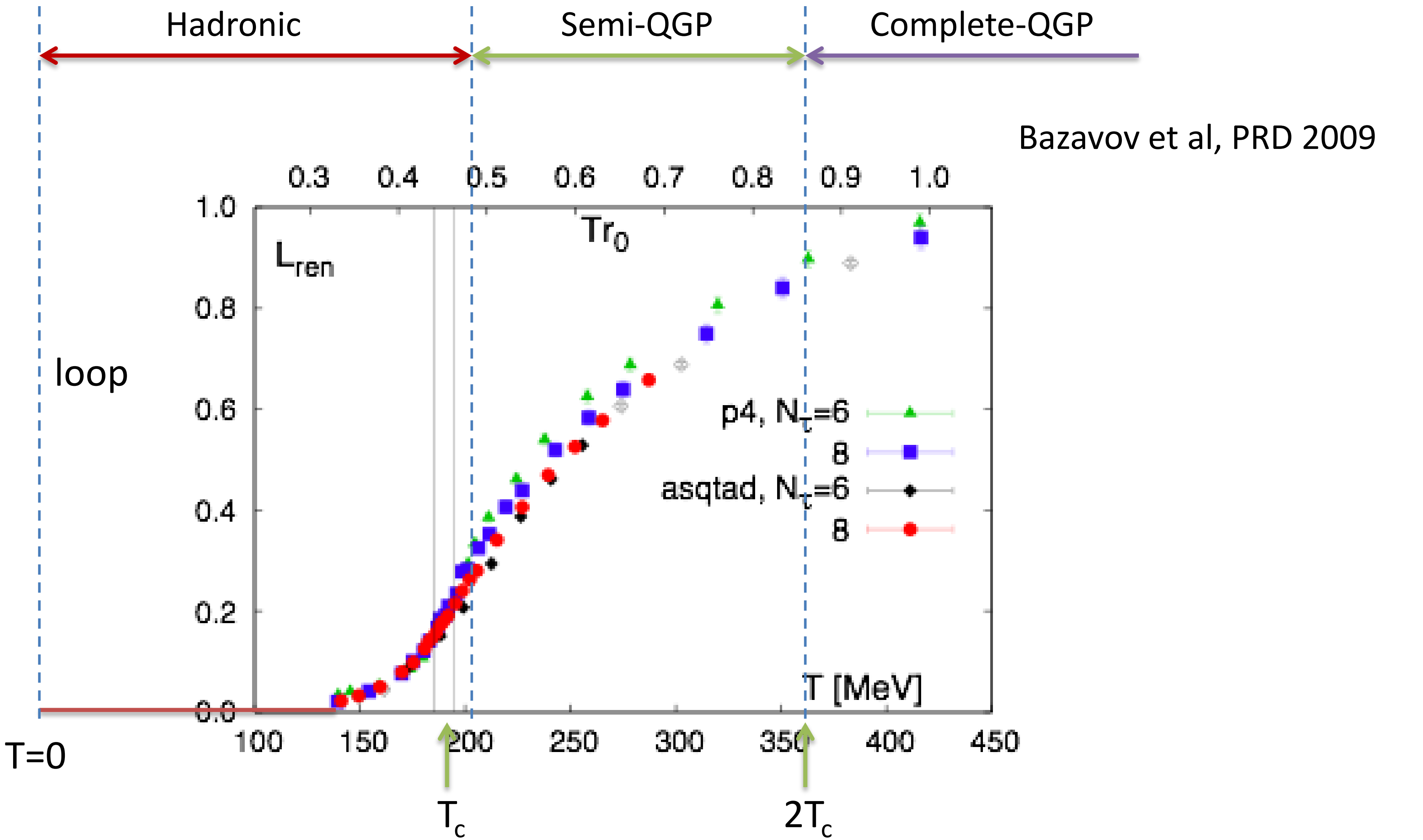
Darmstadt, May 19, 2014

Outline

- A brief introduction to semi-QGP
- Reduction of quark/gluon number densities
- Puzzle of photon v2
- Photon/dilepton rate in semi-QGP
- Comparison of semi-QGP and QGP
- Results of photon/dilepton with hydrodynamics

Polyakov loop in QCD

Semi-QGP in QCD, smooth rise of the loop



Effective matrix model

Polyakov loop $\ell(\vec{x}) = \frac{1}{N_c}\,\mathrm{tr}\,\mathcal{P}\exp\left(\int_0^{1/T} d\tau\ A_0(\vec{x},\tau)\right)$

Non-perturbative

can be modeled by classical background field $A_0 \;=\; (Q,-Q,0)/g$ ~ 1/g

$$\ell = \frac{1}{3}\left(1+2\cos\left(\frac{Q}{T}\right)\right)$$

high T limit $Q = 0$

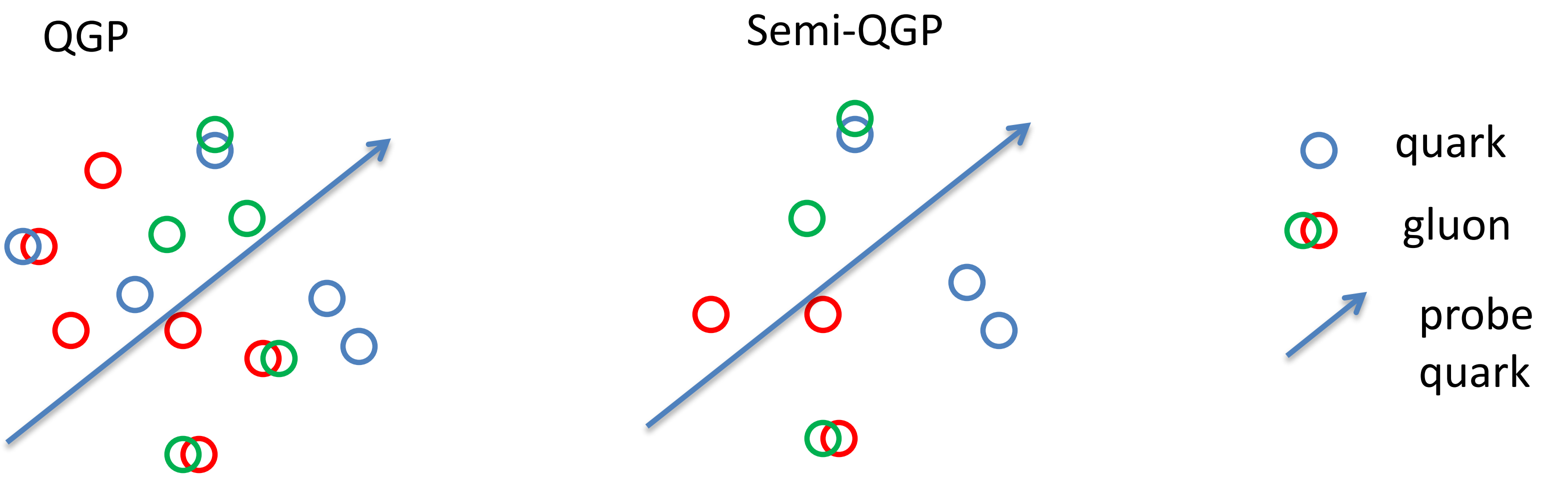
Dumitru, Guo, Hidaka, Korthals Altes, Pisakrski, PRD 2011, 2012

Q as imaginary chemical potential, reduces quark number density by the loop

$$\frac{1}{N}\sum_{a=1}^{N}\frac{1}{e^{(E-iQ_a)/T}+1} \sim \ell\,\frac{1}{e^{E/T}+1} \qquad \ell \leq 1$$

Similar reduction for gluon number density

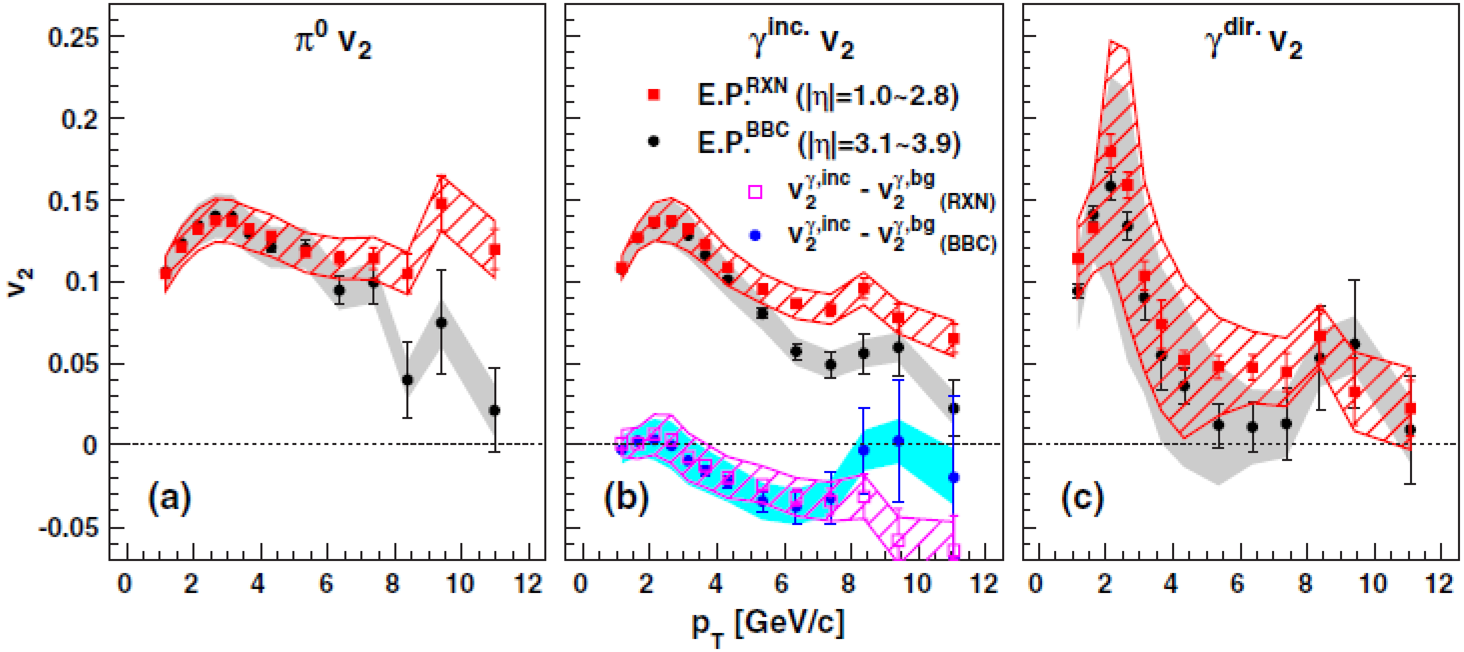
Reduction of d.o.f. & transports



less d.o.f. to scatter with $\Longrightarrow$ Suppression of energy loss & viscosity

Hidaka,Pisarski, PRD, 2008
SL, Pisarski, Skokov, PLB 2014

Puzzle of photon v2



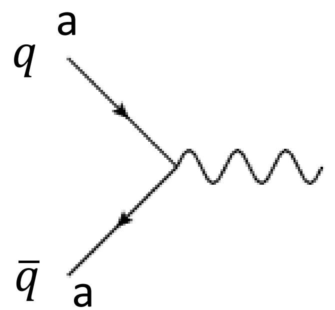
PHENIX, PRL 2012

v2 of photons comparable with v2 of pions at p_T < 4GeV

Many photons produced at early stage, high T QGP phase, expect less v2

Can semi-QGP help us understand the puzzle?

Enhanced dilepton production



Suppression of dilepton rate due to reduced of quark number density? NO!

Boltzmann approximation

Dilepton rate ~ $$e^2 \sum_{a=1}^{N} e^{-(E/2-iQ^a)/T} e^{-(E/2+iQ^a)/T} \left|\mathcal{M}_{l\bar{l}}\right|^2$$

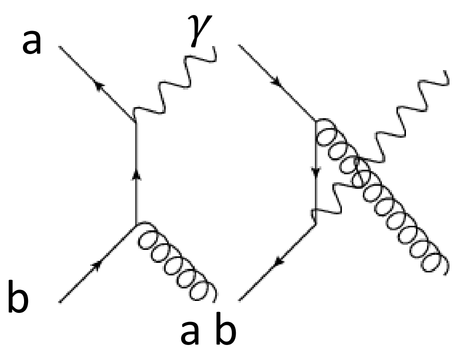
Effect of Q cancel out!

The effect of imaginary chemical potential cancels for a color singlet initial state.

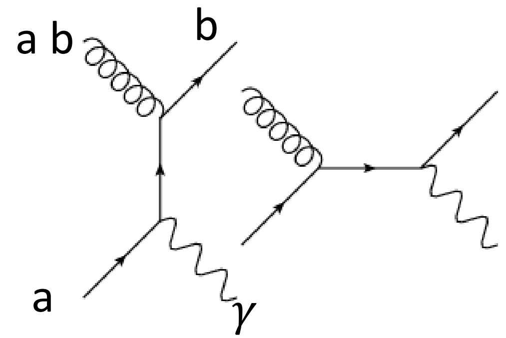
Moreover, the rate is even enhanced beyond Boltzmann approximation!

Suppressed photon production: 2→2 processes

Pair annihilation



Compton scattering



$$e^2 g^2 \sum_{a,b} e^{-(E_1 - iQ^a)/T} e^{-(E_2 + iQ^b)/T} |\mathcal{M}_\gamma^{ab}|^2$$

No cancellation!

$$e^2 g^2 \sum_{a,b} e^{-(E_1 - iQ^a)/T} e^{-(E_2 + iQ^a - iQ^b)/T} |\mathcal{M}_\gamma^{ab}|^2$$

Partial cancellation

Effect of imaginary chemical potential does not cancel out completely in the initial states.

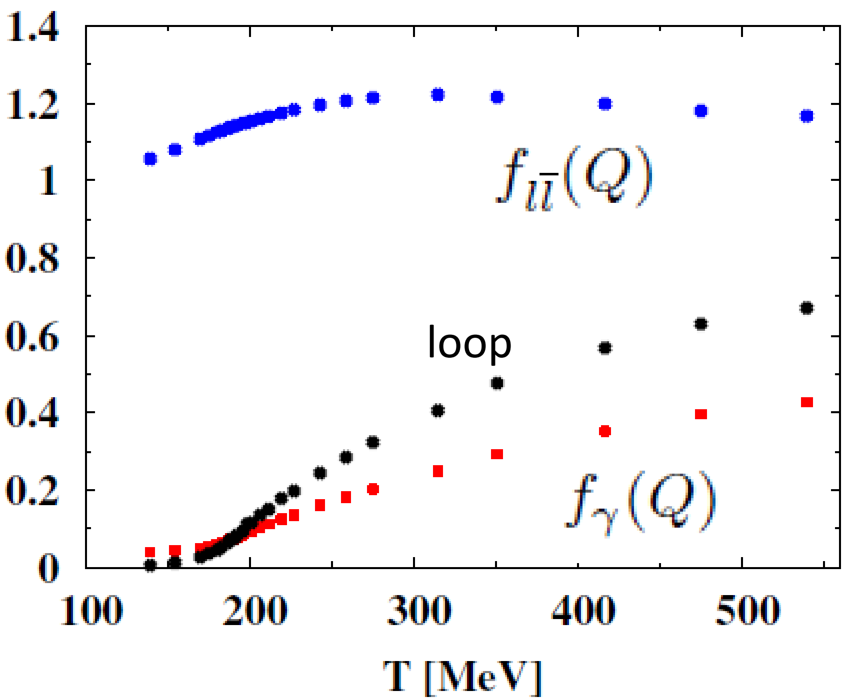
Suppression of photon rate from 2 → 2 processes.

Modification factors of dilepton & photon rate

Dilepton rate $$\left.\frac{d\Gamma}{d^4P}\right|_{Q\neq 0} = f_{l\bar{l}}(Q)\,\left.\frac{d\Gamma}{d^4P}\right|_{Q=0}$$

Photon rate $$\left.E\frac{d\Gamma}{d^3p}\right|_{Q\neq 0} = f_{\gamma}(Q)\,\left.E\frac{d\Gamma}{d^3p}\right|_{Q=0}$$

$f_{\gamma}(Q)$ for leading log 2 →2 rate



$f_{l\bar{l}}(Q)$ above 1, non-monotonous in T

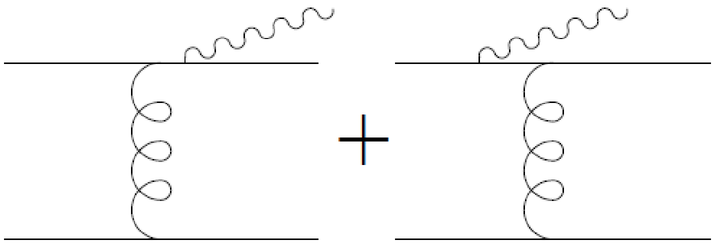
Dilepton in semi-QGP larger than QGP

$f_{\gamma}(Q)$ significantly below 1

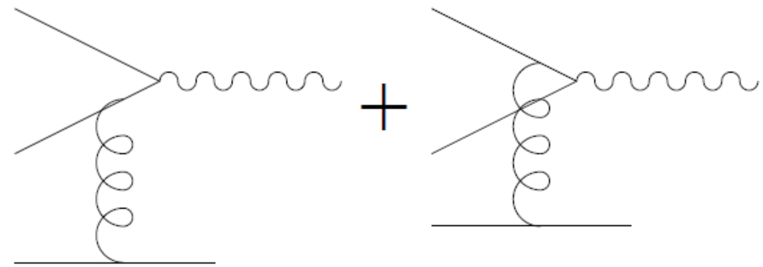
Photon in semi-QGP much smaller than QGP

Suppression of collinear photon rate

bremsstrahlung



pair annihilation



Aurenche, Gelis, Zaraket, PRD 2000
Arnold, Moore, Yaffe, JHEP 2001/2002

Scattering with arbitrary number of soft gluons contributes at the same order

Soft gluons in QGP give additional Bose-Einstein enhancement

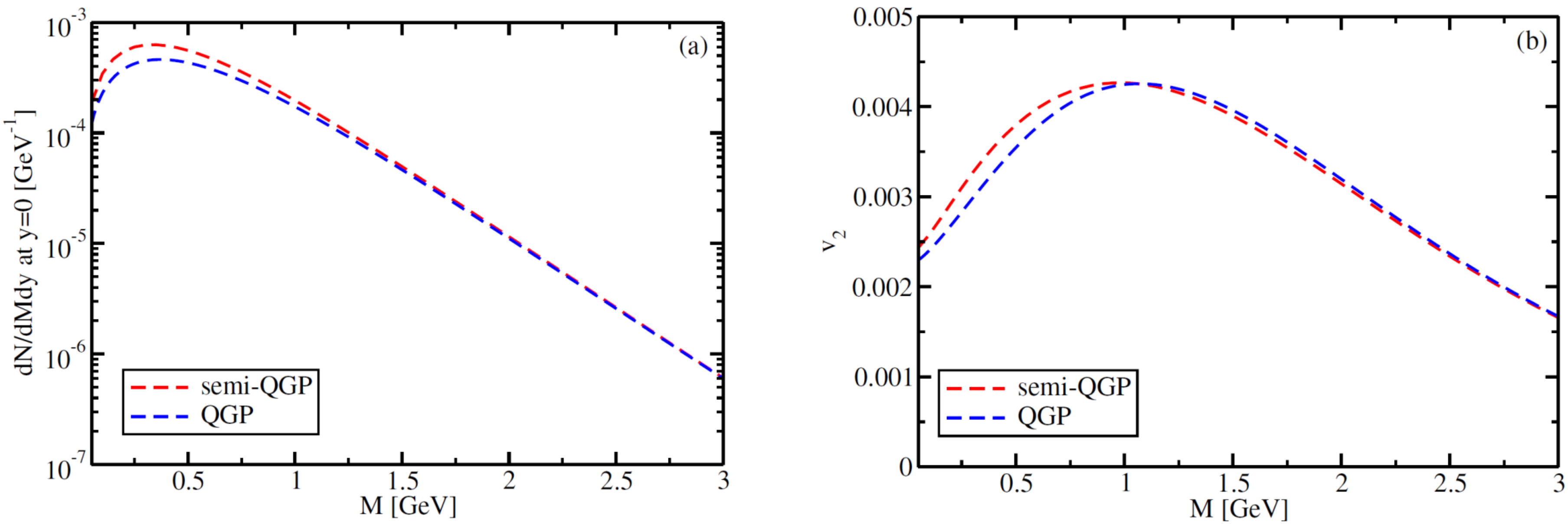
$$E \sim gT, \qquad \frac{1}{e^{E/T}-1} \sim \frac{1}{g}$$

In semi-QGP $E \to E - i(Q_a - Q_b)$, $\qquad \dfrac{1}{e^{(E-iQ_a+iQ_b)/T-1}} \sim O(1)$

Q ~ T hard, gluons soft only when a=b. Soft gluon density suppressed by 1/N

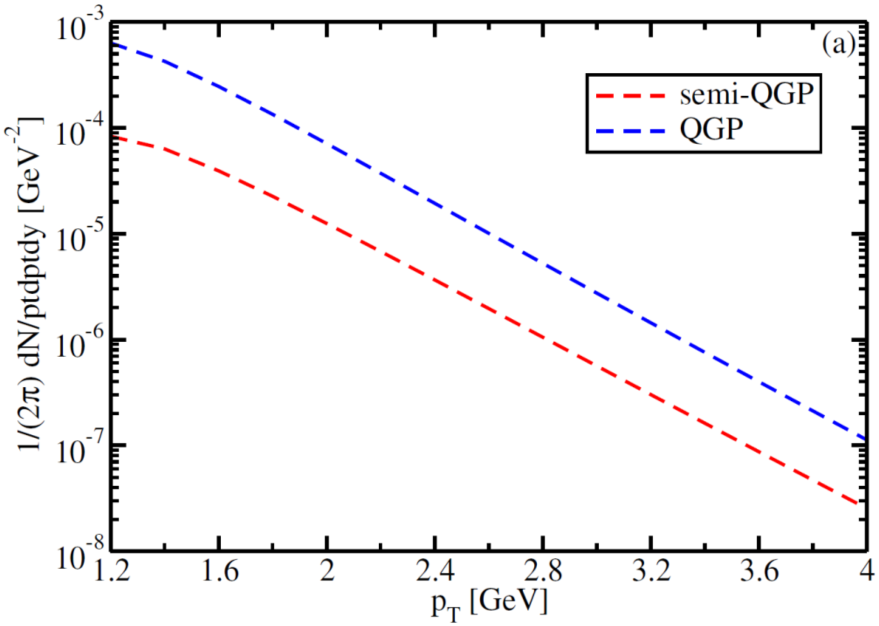
⇒ Collinear photon rate has additional 1/N suppression!

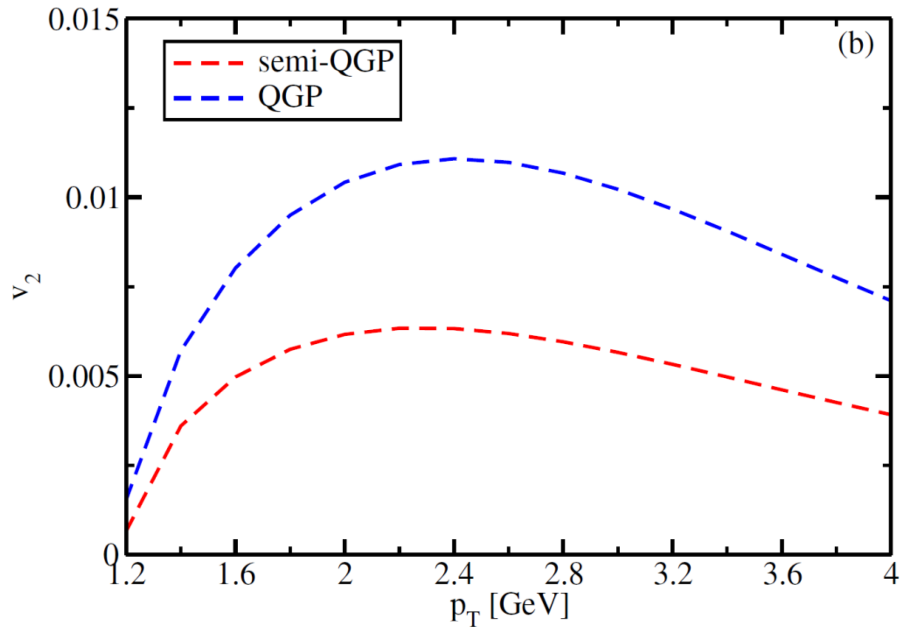
Dilepton (RHIC): no significant change



Modest enhancement in semi-QGP, no significant change to v2

Photon (RHIC): strong suppression

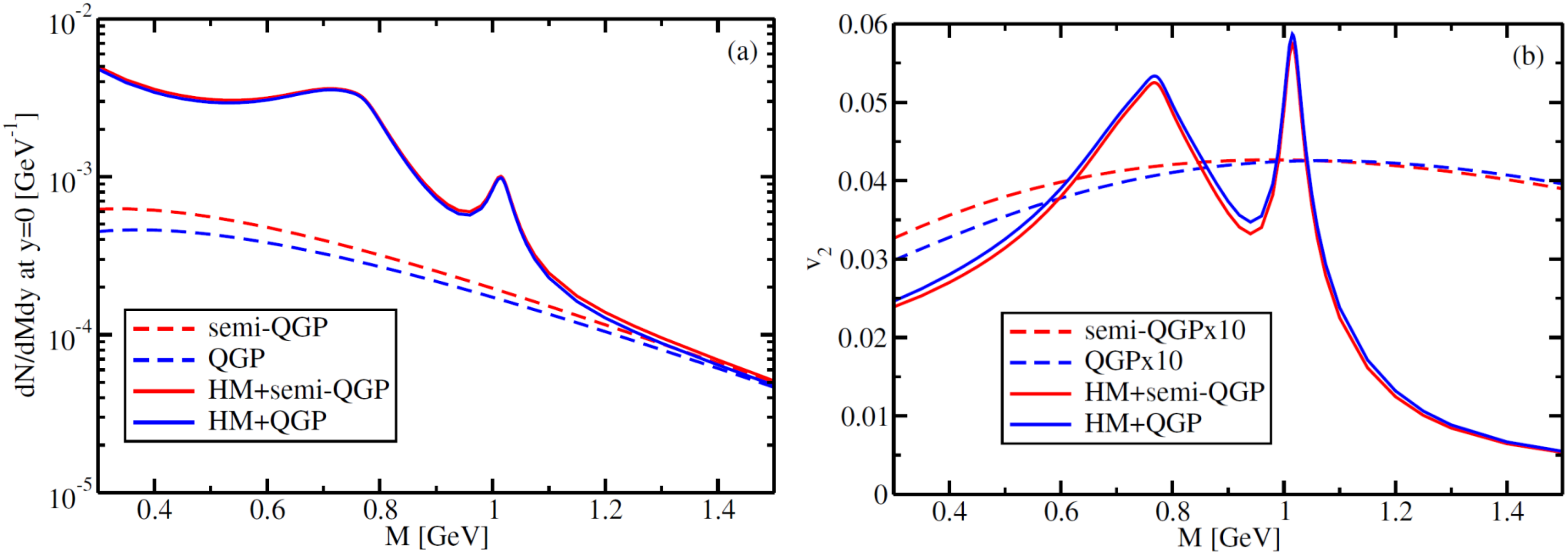




Strong suppression in semi-QGP.

semi-QGP increases the weight of photons at high T (less suppression).
Photon produced at high T experience less v2.

Dilepton (RHIC): QGP + hadronic matter

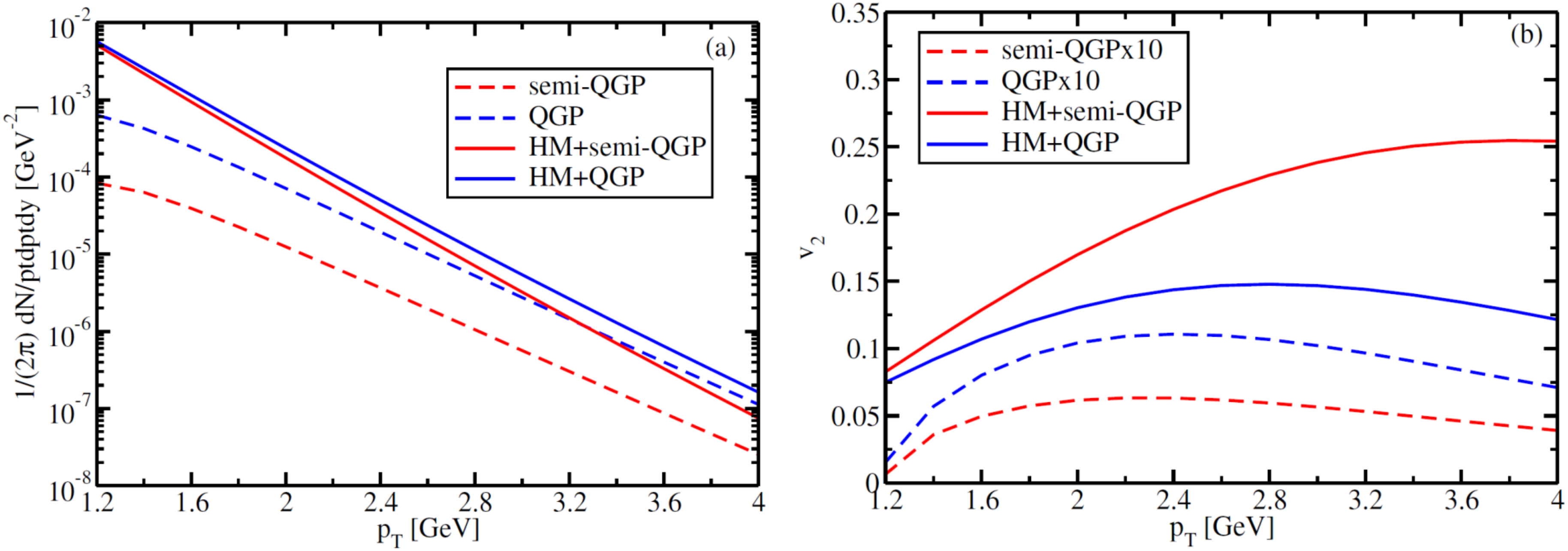


Semi-QGP enhances N_{QGP}, lowering the overall v2

$$v2_{QGP} < v2_{HM}$$

$$v2 = \frac{v2_{QGP} * N_{QGP} + v2_{HM} * N_{HM}}{N_{QGP} + N_{HM}}$$

Photon (RHIC): QGP + hadronic matter



Semi-QGP suppresses significantly N_{QGP}, enhancing the overall v2 $v2_{QGP} < v2_{HM}$

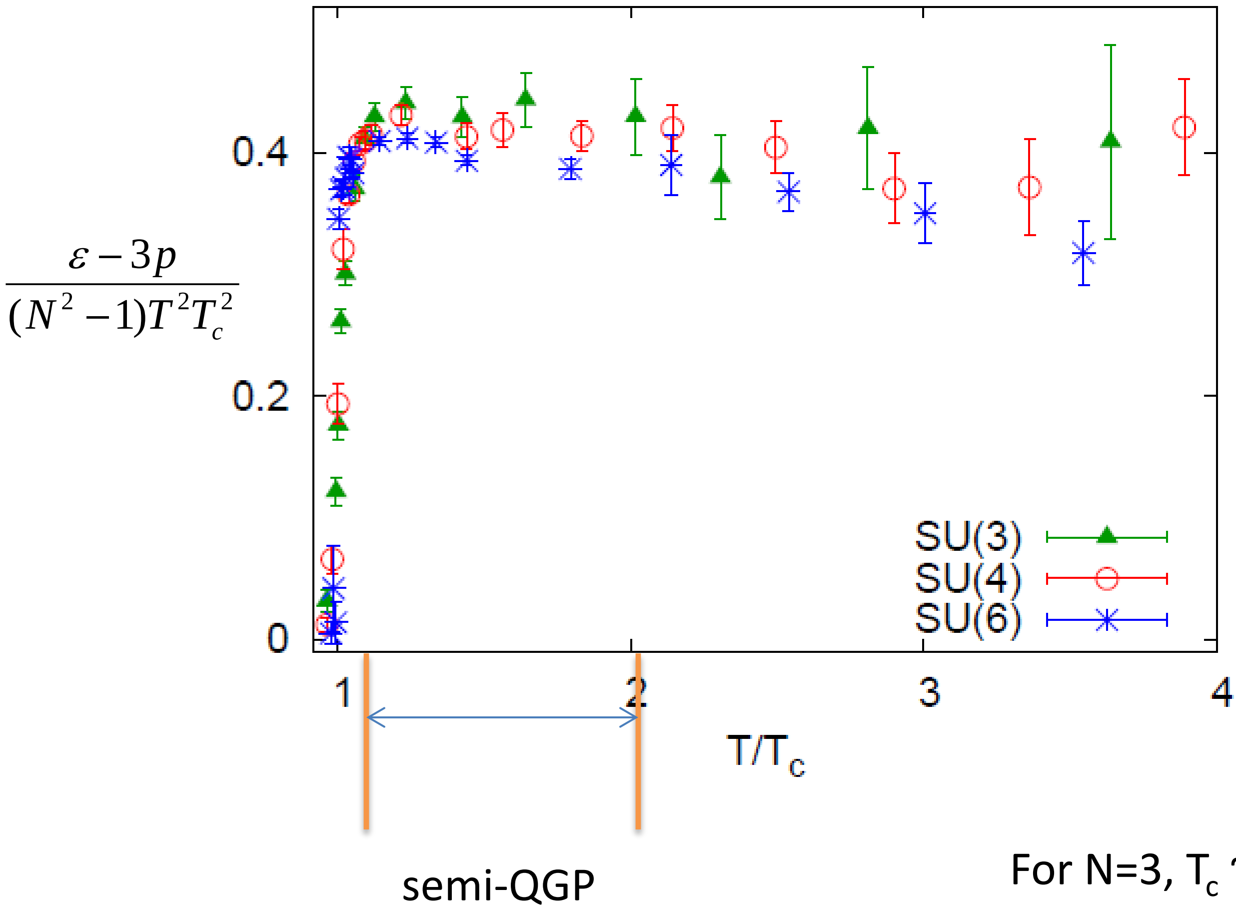
$$v2 = \frac{v2_{QGP} * N_{QGP} + v2_{HM} * N_{HM}}{N_{QGP} + N_{HM}}$$

Model of semi-QGP suggests different behavior in photon and dilepton v2

A more complete study will need constant under the log plus collinear rate

Thank you!

Scaling of thermodynamics in pure glue



trace anomaly normalized by number of d.o.f.

Datta, Gupta, PRD, 2010

For N=3, T_c ~ 180 MeV
QGP at RHIC: 350 MeV ↘ 180 MeV
LHC: 450 MeV ↘ 180 MeV