Temperature dependence of η/s in the sQGP

sQGP: transition region near T_d; *d=deconfinement*.

s = semi, not strong: Matrix model for the sQGP, *moderate* coupling.

Only glue (no quarks): transition region *narrow*, $T_d \rightarrow \sim 1.2\ T_d$.

With massless quarks: $T_\chi \neq T_d$: χ = *chiral*. Transition region *broad*.

Today: temperature dependence of η/s from matrix model.

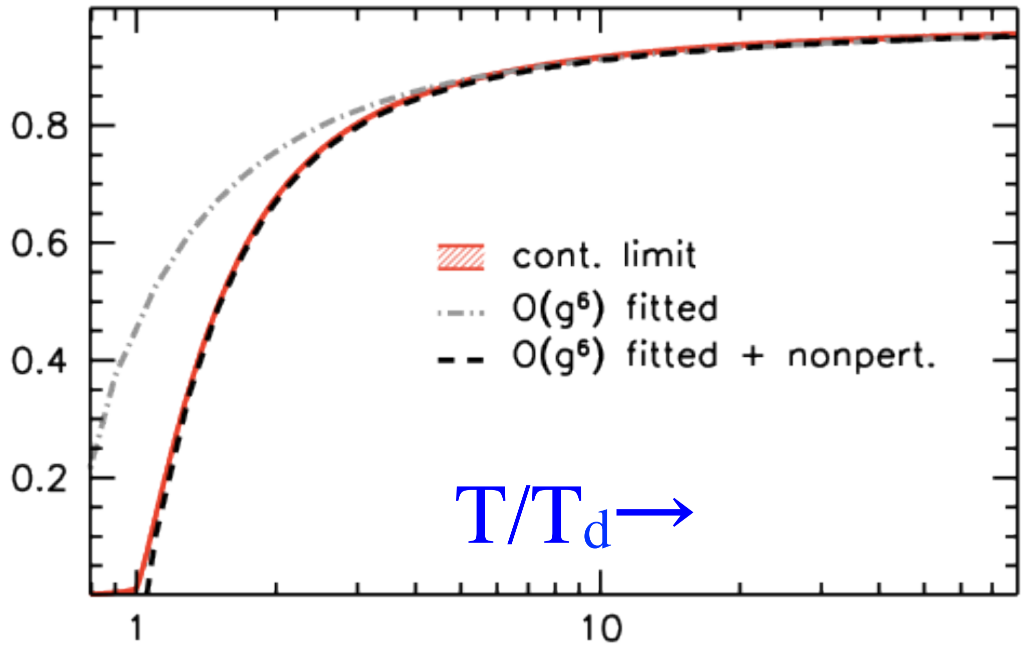
RDP & Skokov, 1206.1329. Kashiwa, RDP, & Skokov, 1205.0545.
Dumitru, Guo, Hidaka, Korthals-Altes, & RDP, 1205.0137 & 1011.3820

RDP & Hidaka, 0803.0453, 0906.1751, 0907.4609, 0912.0940; RDP, ph/0608242
Dumitru, Lenaghan, & RDP, ph/0410294
Dumitru, Hatta, Lenaghan, Orginos, & RDP, th/0311223
Meisinger, Miller, & Ogilvie, ph/0108009; RDP, arXiv:hep-ph/0006205

Massive quasi-particle models

“Pure” SU(3), no quarks. Pressure *very* small below T_d.

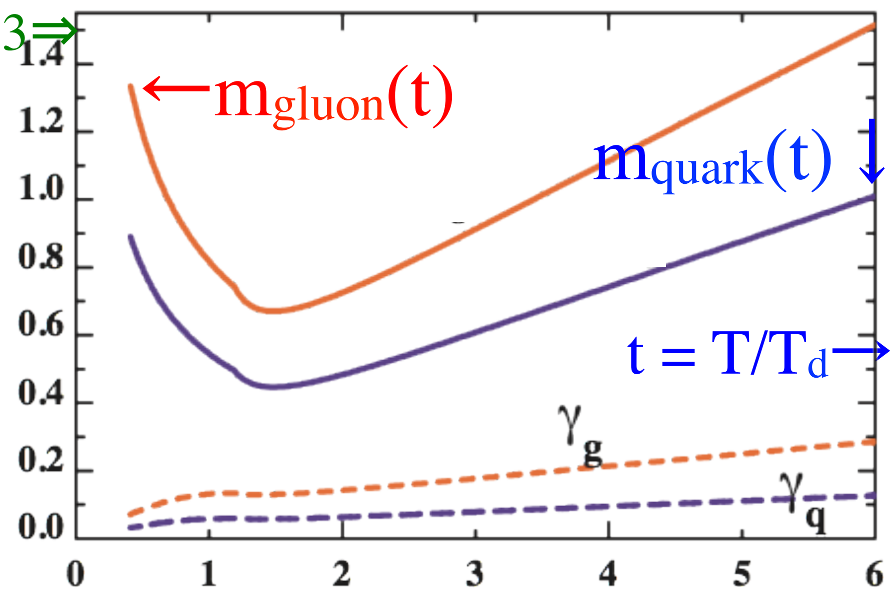
$\frac{p(T)}{p_{ideal}}$ ↑



⇐Borsanyi, Endrodi, Fodor, Katz, & Szabo, 1204.6184

Peshier, ph/0403225; Peshier & Cassing, ph/0502138

Bratkovskaya,Cassing,Konchakovski,Linnyk,1101.5793⇒



Parton Hadron String Dynamics:

Fit p(T) with massive quasi-particles

$T > 1.5\ T_d$: $m_{gluon} \sim m_{quark} \sim T$.

“Perturbative”, $m \sim gT$

$T < 1.5\ T_d$: to suppress the pressure,

large increase in m_{gluon} and m_{quark}.

Lattice: it's *not* a MIT bag constant

Lattice:

T: $T_d \rightarrow 1.2\, T_d$ - *complicated*

T: $1.2\, T_d \rightarrow 4\, T_d$: simplicity!

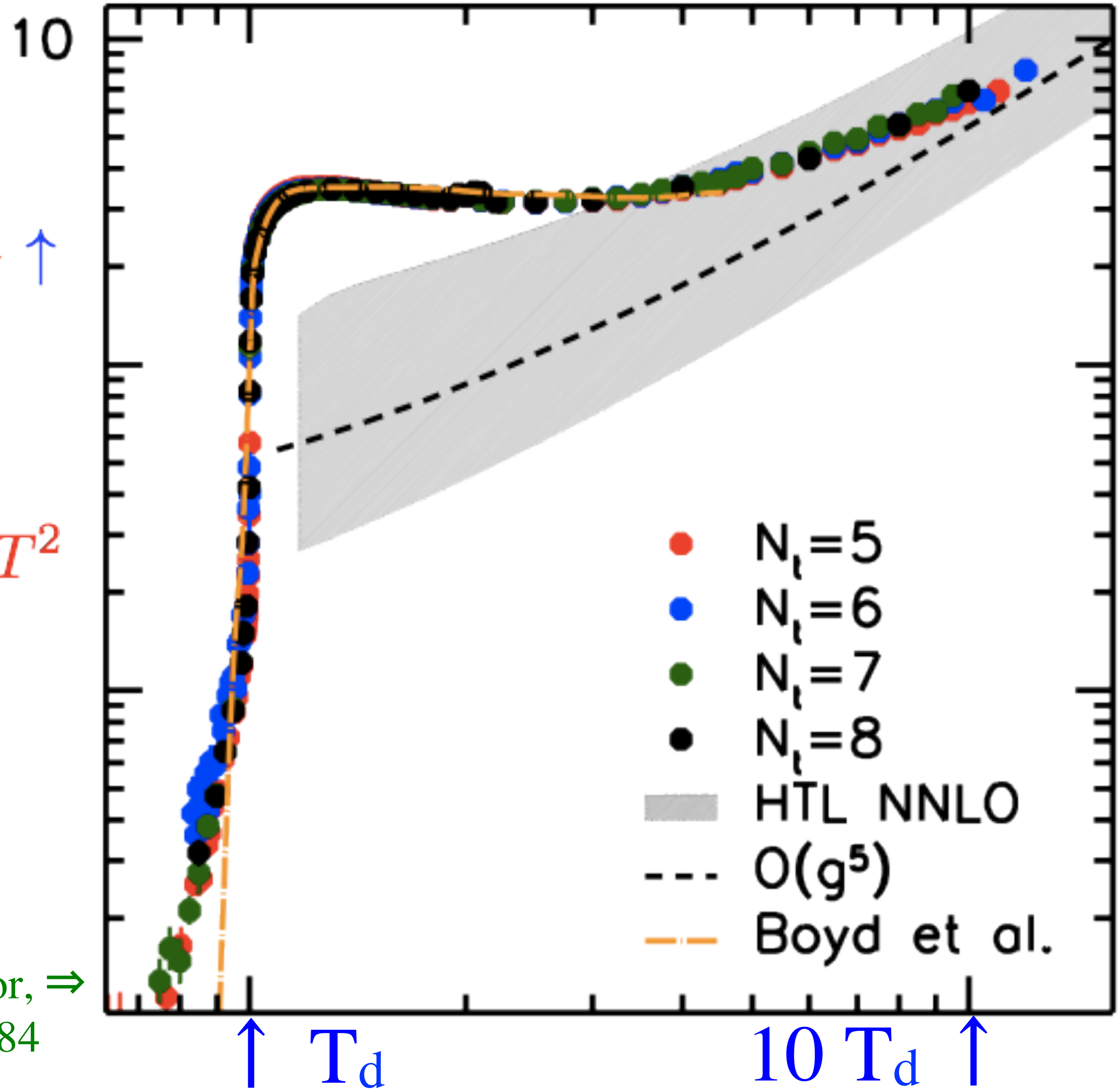
$$\frac{e-3p}{T^4}\;\frac{T^2}{T_d^2}\;\uparrow$$

For T: $1.2\, T_d \rightarrow 4\, T_d$:

$$p(T) \sim d_1\, T^4 - d_2\, T_d^2\, T^2$$

Above $1.2\, T_d$, the leading corrections to ideality are *not* a MIT bag constant, but $\sim T^2$

Borsanyi, Endrodi, Fodor, Katz, & Szabo, 1204.6184 ⇒



Order parameter for deconfinement

Thermal Wilson line: $$\mathbf{L} = \mathcal{P}\, \mathrm{e}^{ig\int_0^{1/T} A_0\, d\tau}$$

Trace = Polyakov loop, gauge *in*variant $$\ell = \frac{1}{3}\,\mathrm{tr}\,\mathbf{L}$$

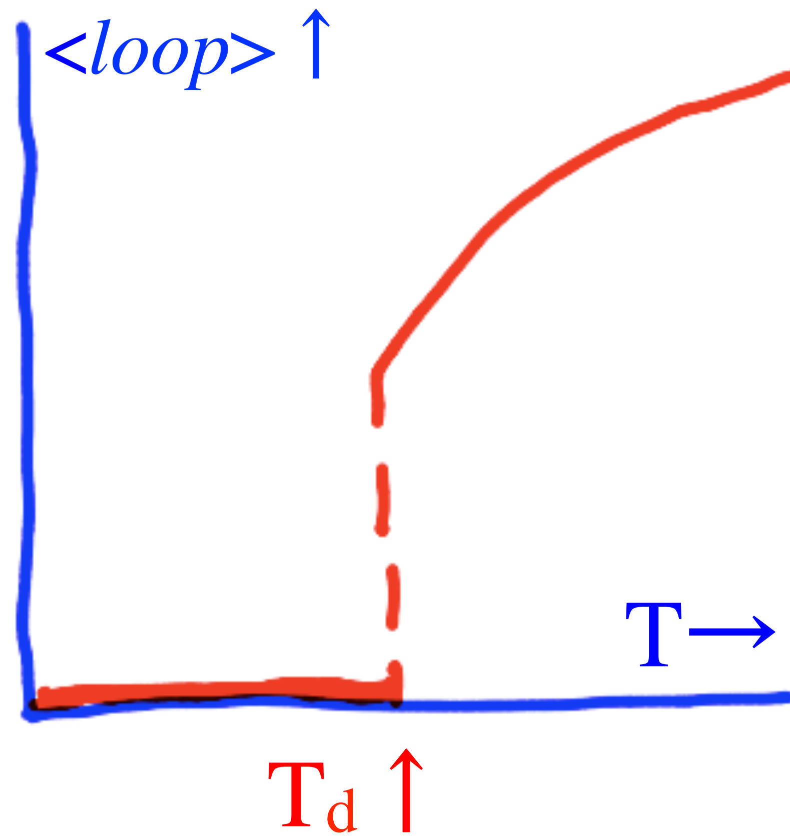
Matrix **L** gauge *de*pendent, eigenvalues gauge *in*variant:
basic variables of a matrix model

$\langle loop \rangle$ measures ionization of color:

$\langle loop \rangle = 1 \Rightarrow$ complete ionization;
perturbative regime

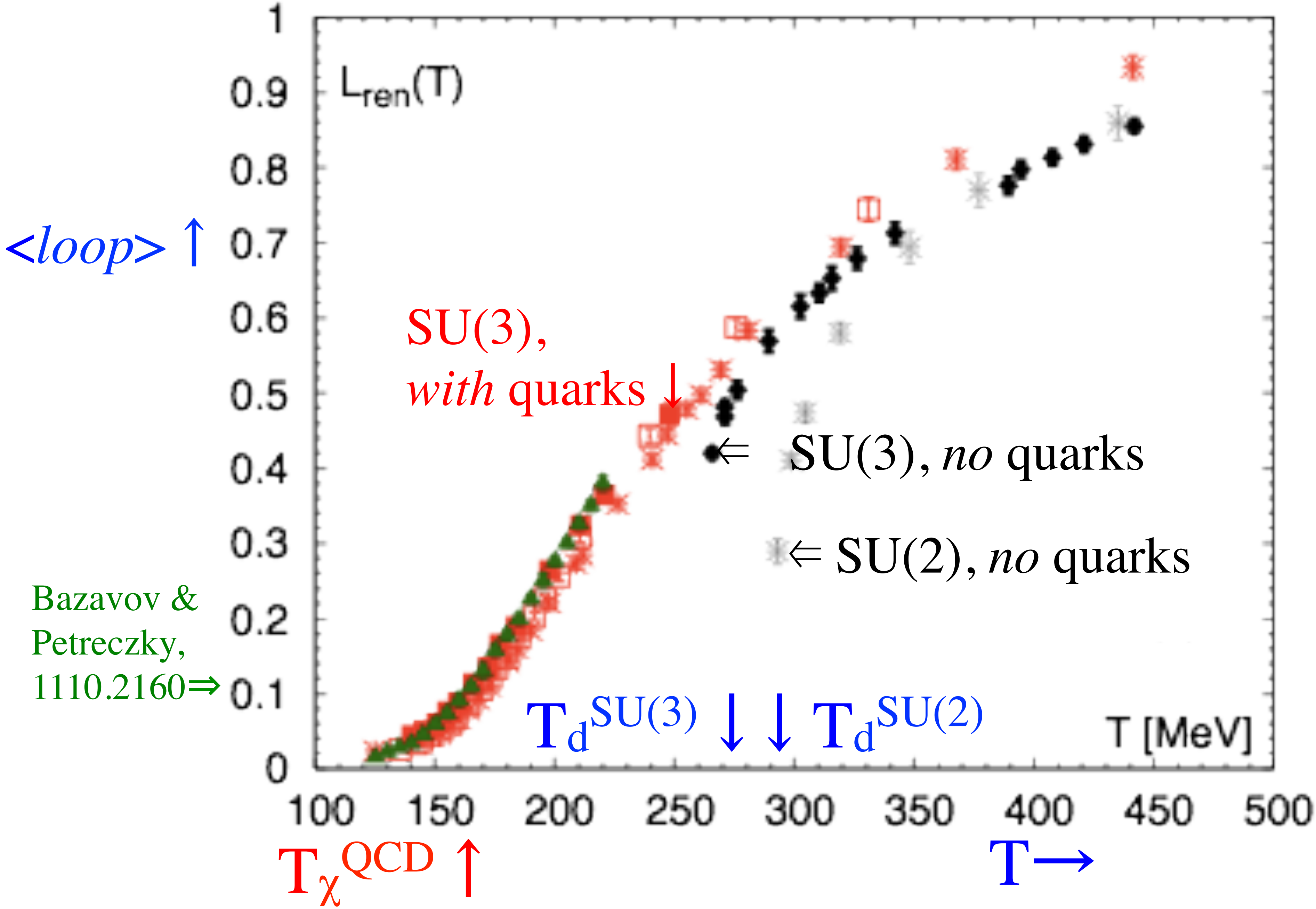
$\langle loop \rangle = 0 \Rightarrow$ no ionization; confined phase

$0 < \langle loop \rangle < 1$, *partial* ionization, semi-QGP



Loops from the lattice

At *same* T, dynamical quarks always generate partial ionization,
and so increase <*loop*>:



Only glue: matrix model for deconfinement

Simplest possible approximation: *constant* A_0
Necessary to model change in $\langle loop \rangle$

$$A_0^{cl} = \frac{\pi T}{g} \, q \, \lambda_3$$

Effective potential: perturbative term, $\sim T^4$,
+ non-perturbative term $\sim T_d^2 T^2$, added *by hand*

$$\lambda_3 = \begin{pmatrix} 1 & 0 & 0 \\ 0 & -1 & 0 \\ 0 & 0 & 0 \end{pmatrix}$$

$$V_{eff}(q) = T^4 \, V_{pert}(q) + T_d^2 \, T^2 \, V_{non}(q)$$

Typical mean field potential:

$$\left. \frac{d}{dq} V_{eff}(q) \right|_{\langle q \rangle} = 0 \; ; \; p(T) = -V_{eff}(\langle q \rangle)$$

For T: $T_d \rightarrow 1.2 \, T_d$: $\langle q \rangle \neq 0$, details of $V_{eff}(q)$ matter.

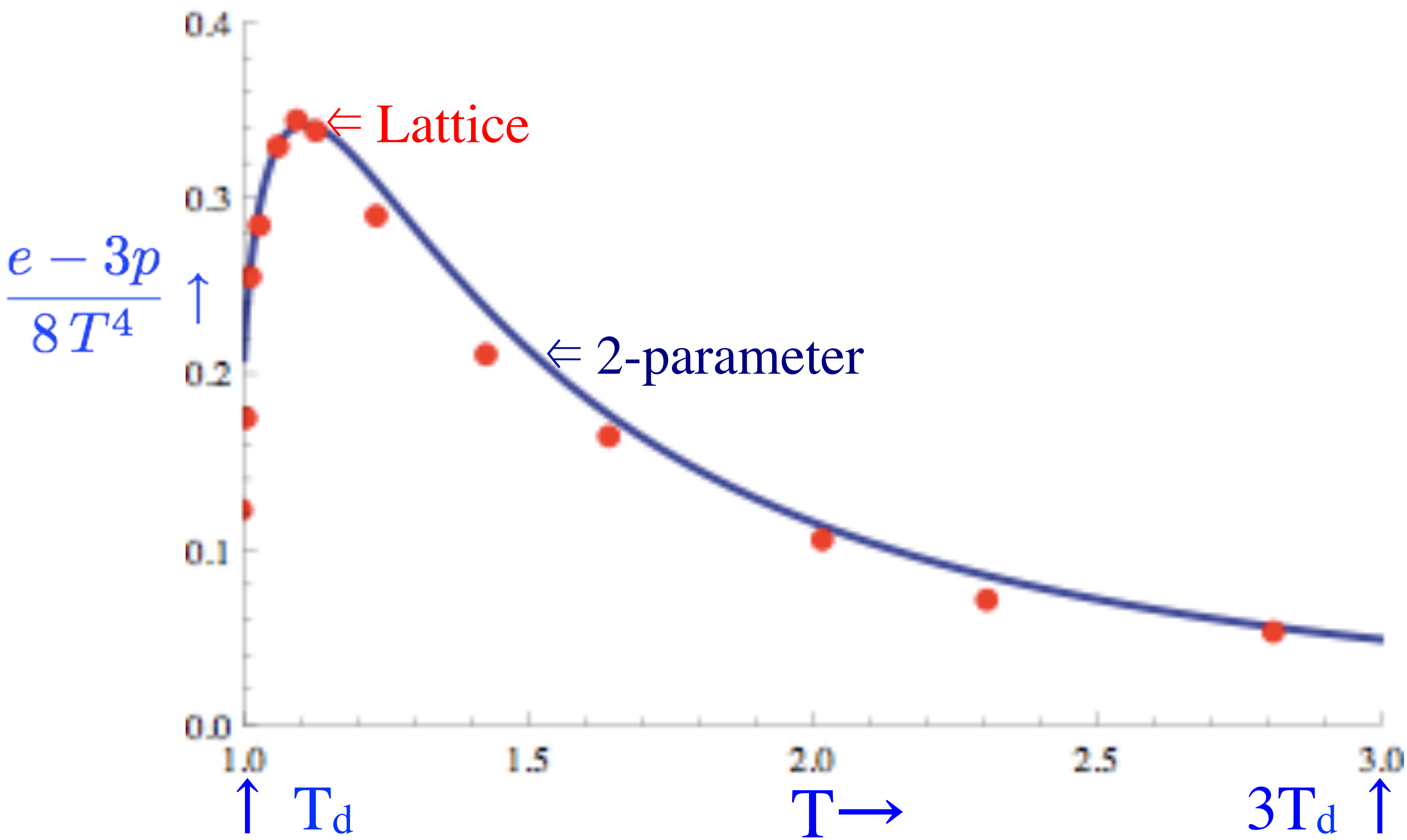
But for $T > 1.2 \, T_d$ - $\langle q \rangle \sim 0$,
$V_{non}(q) = \text{constant} \neq 0$, so:

$$p(T) \sim d_1 \, T^4 - d_2 \, T_d^2 \, T^2$$

Only glue: pressure

With two free parameters, fit to pressure(T):

Lattice: Beinlich, Peikert, & Karsch lat/9608141; Datta & Gupta 1006.0938

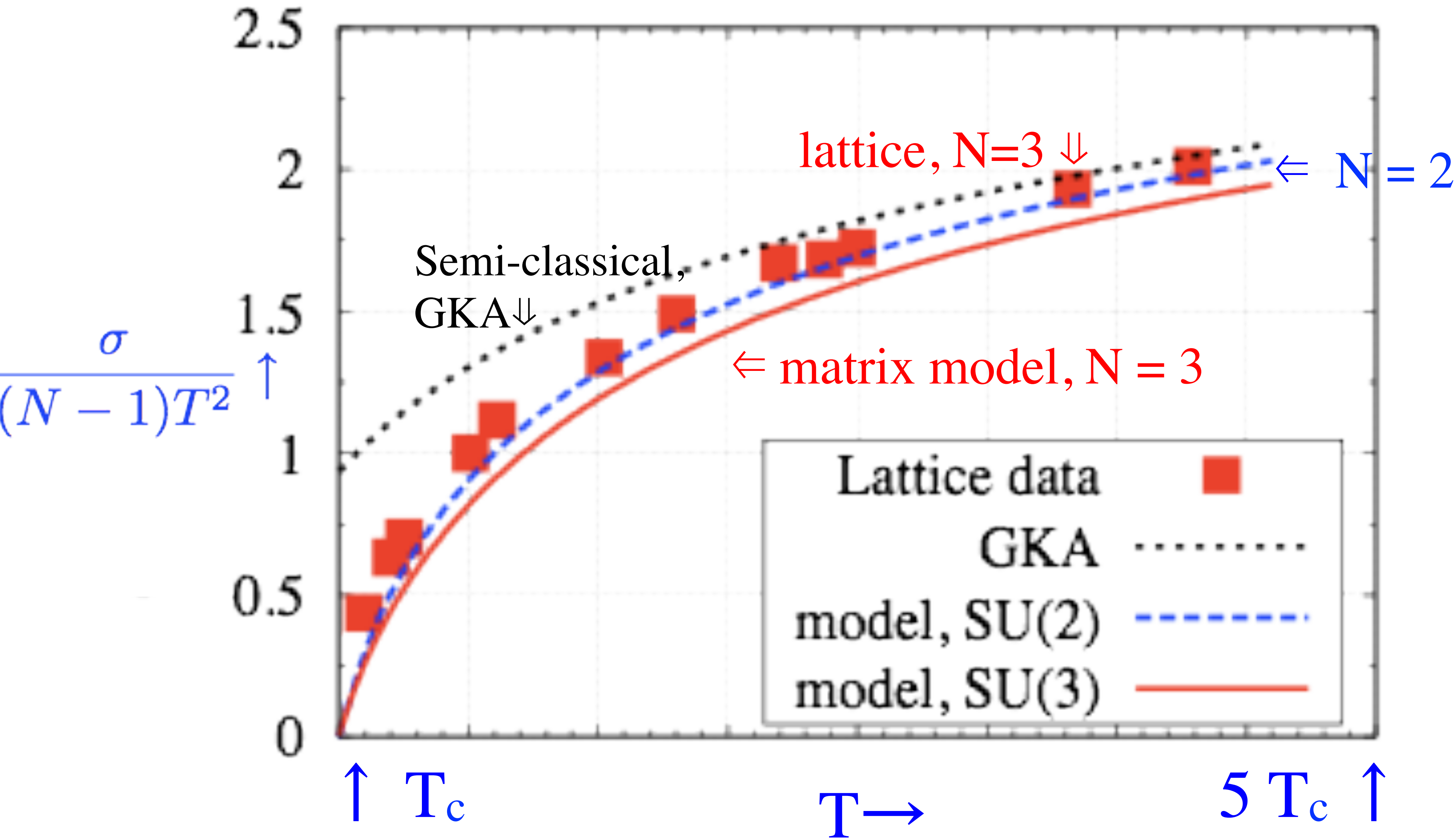


Only glue: ‘t Hooft loop

With no adjustment, fit to second function of T, ‘t Hooft loop

Semi-classical: Giovannangeli & Korthals-Altes, GKA: ph/0212298, ph/0412322

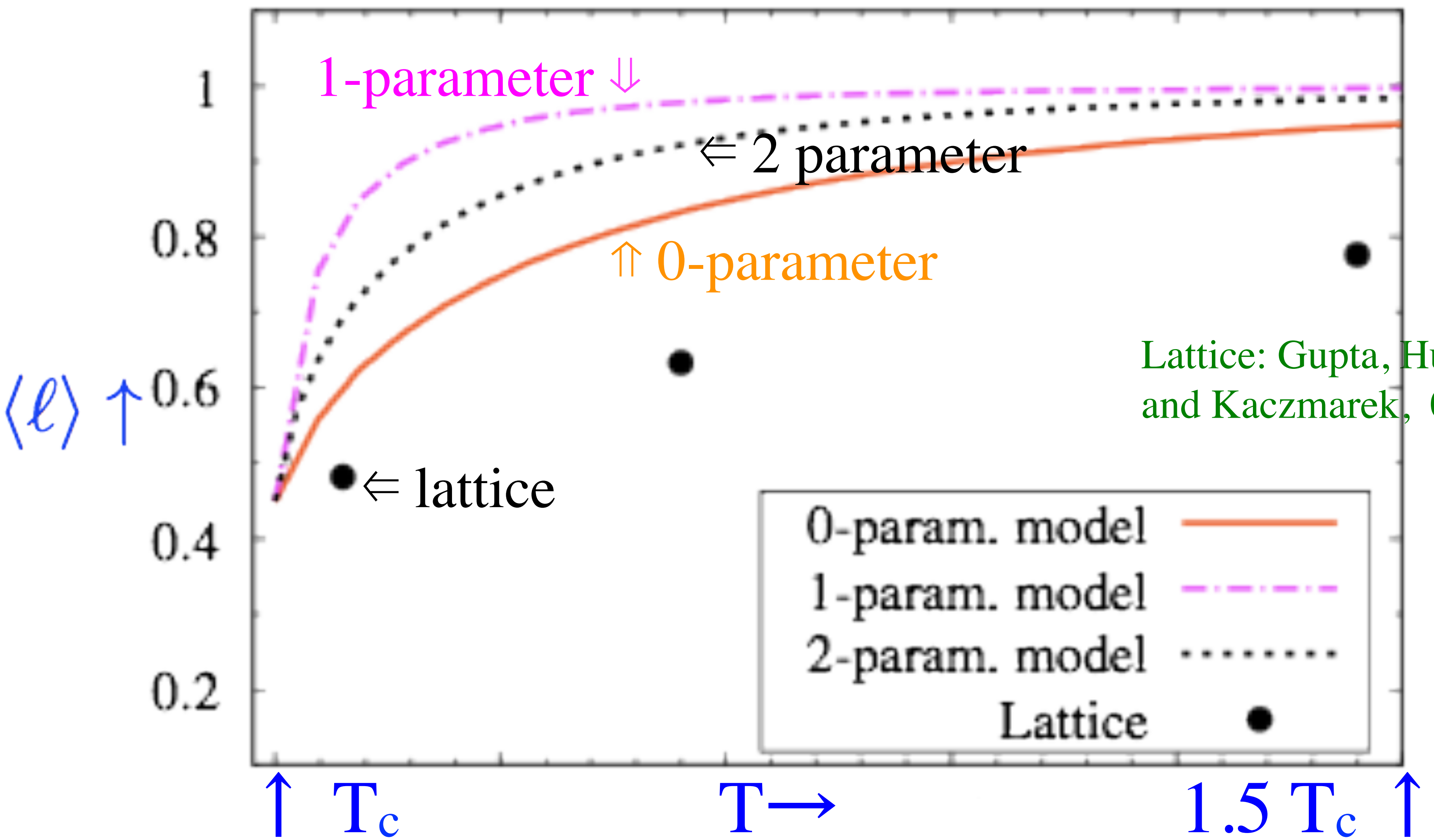
Lattice: de Forcrand, D’Elia, Pepe, lat/0007034; de Forcrand, Noth lat/0506005



Only glue: Polyakov loop?

Polyakov loop in matrix model ≠ (renormalized) loop from lattice

Does the renormalized Polyakov loop reflect the eigenvalues of **L**?



Lattice: Gupta, Hubner, and Kaczmarek, 0711.2251.

Matrix model with heavy quarks

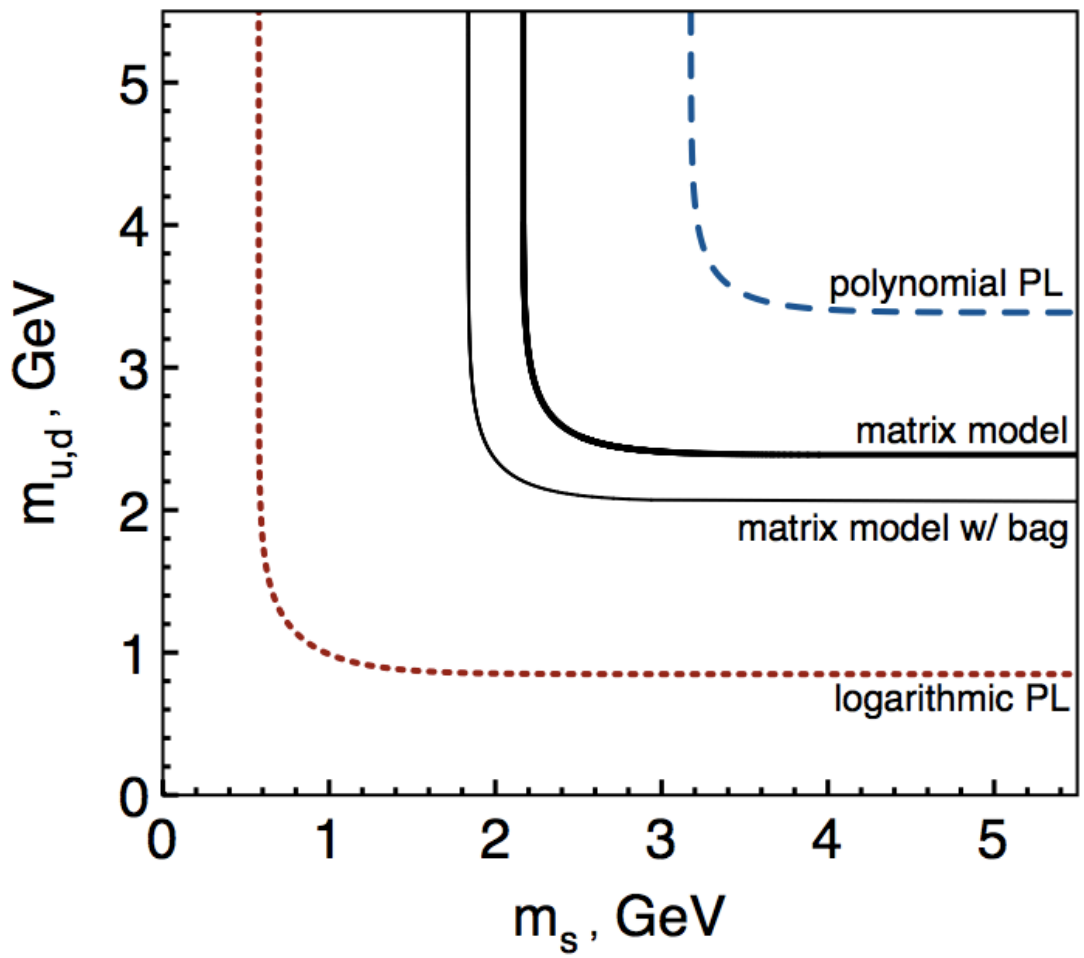
Add heavy quarks perturbatively, change *nothing* else.

Compute position of Deconfining Critical Endpoint, DCE.

Matrix model: $m_{DCE} \sim 2.40$ GeV, $T_{DCE} \sim 0.99\ T_d$

Lattice: Fromm, Langelage, Lottini, & Philipsen, 1111.4953 $m_{DCE} \sim 2.25$ GeV, $T_{DCE} \sim 0.98\ T_d$

Kashiwa, RDP, & Skokov, 1205.0545. ⇒



From here on:

Matrix model for $SU(N_c)$ gluons

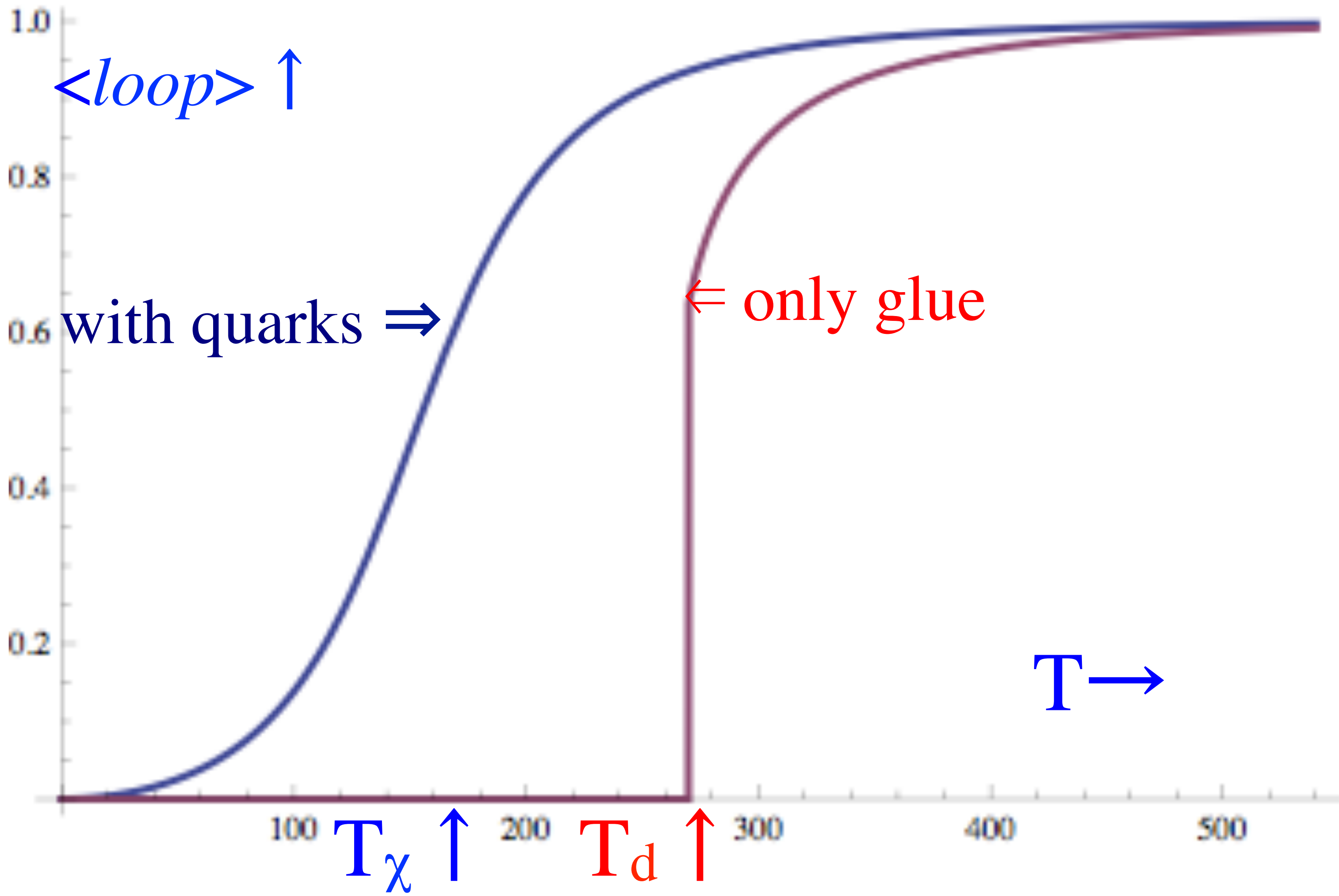
Two cases: only glue,

and with N_f flavors of massless quarks

$N_c = N_f = \infty$

Loops

In matrix model, when $N_f \sim N_c$, *no* definite relation between T_χ and T_d.

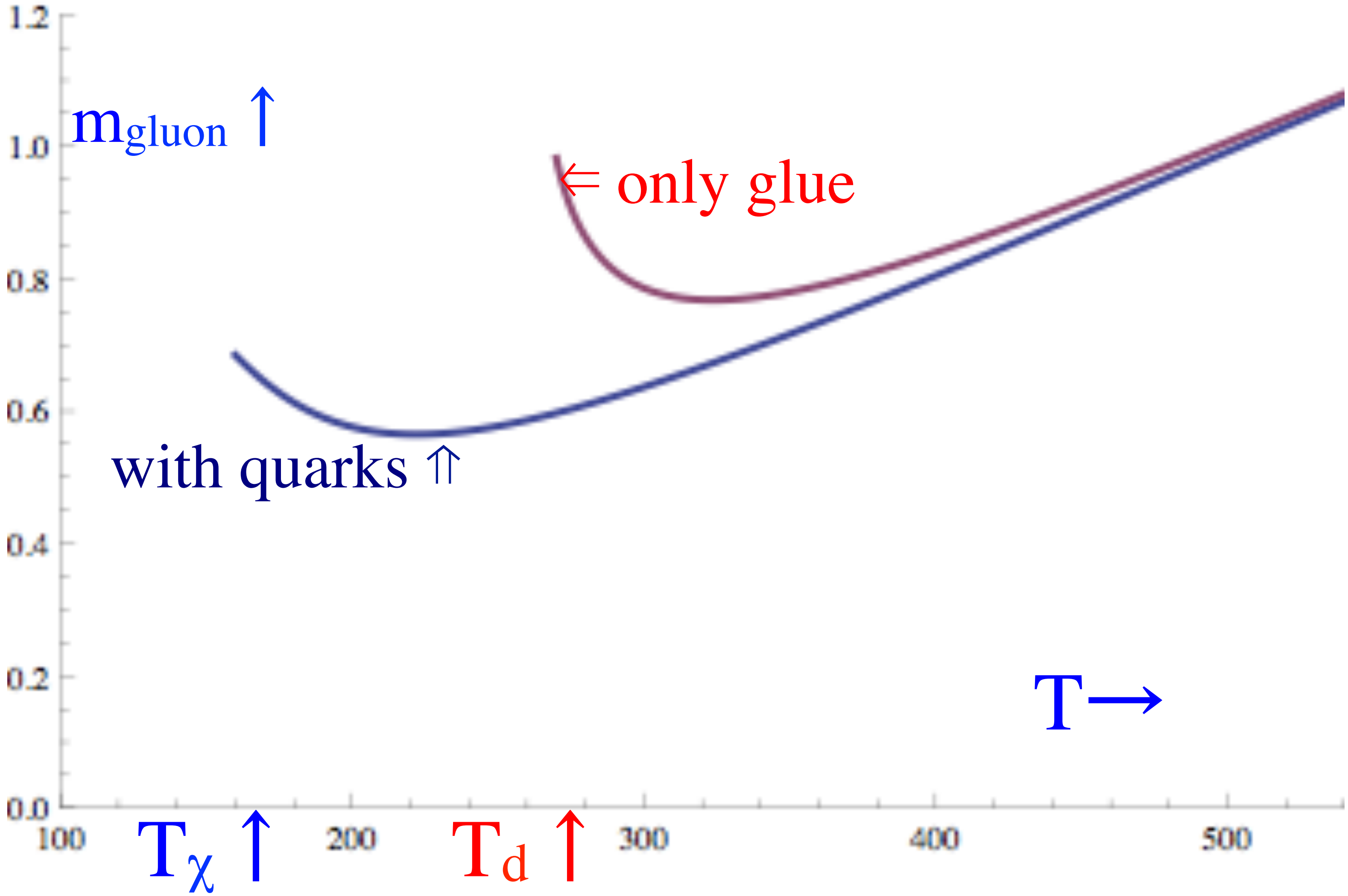


Effective gluon masses

Define effective gluon mass from loop:

$$< \ell > \equiv e^{-m_{gluon}/(1.7\,T)}$$

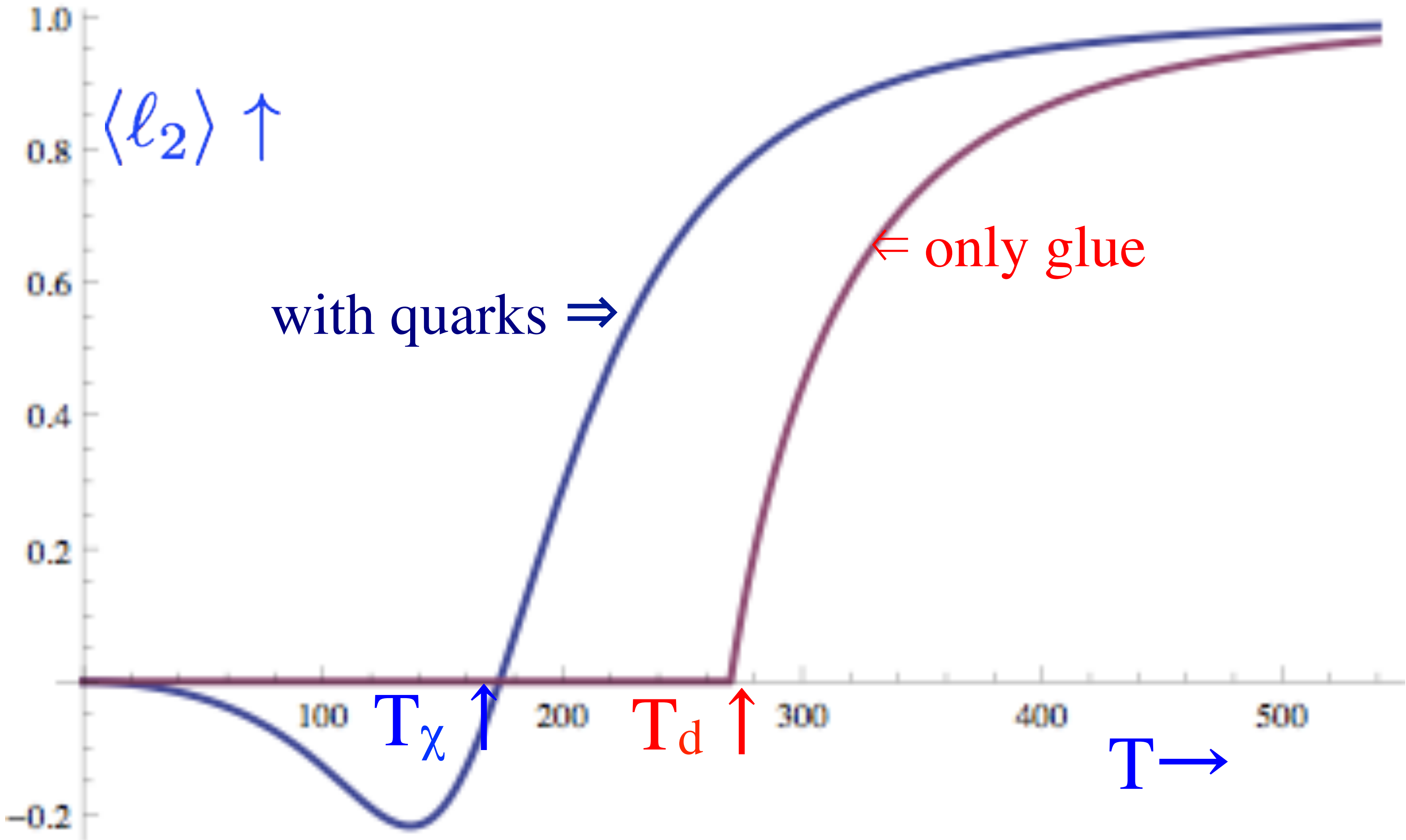
Like massive quasi-particle models!



Other loops

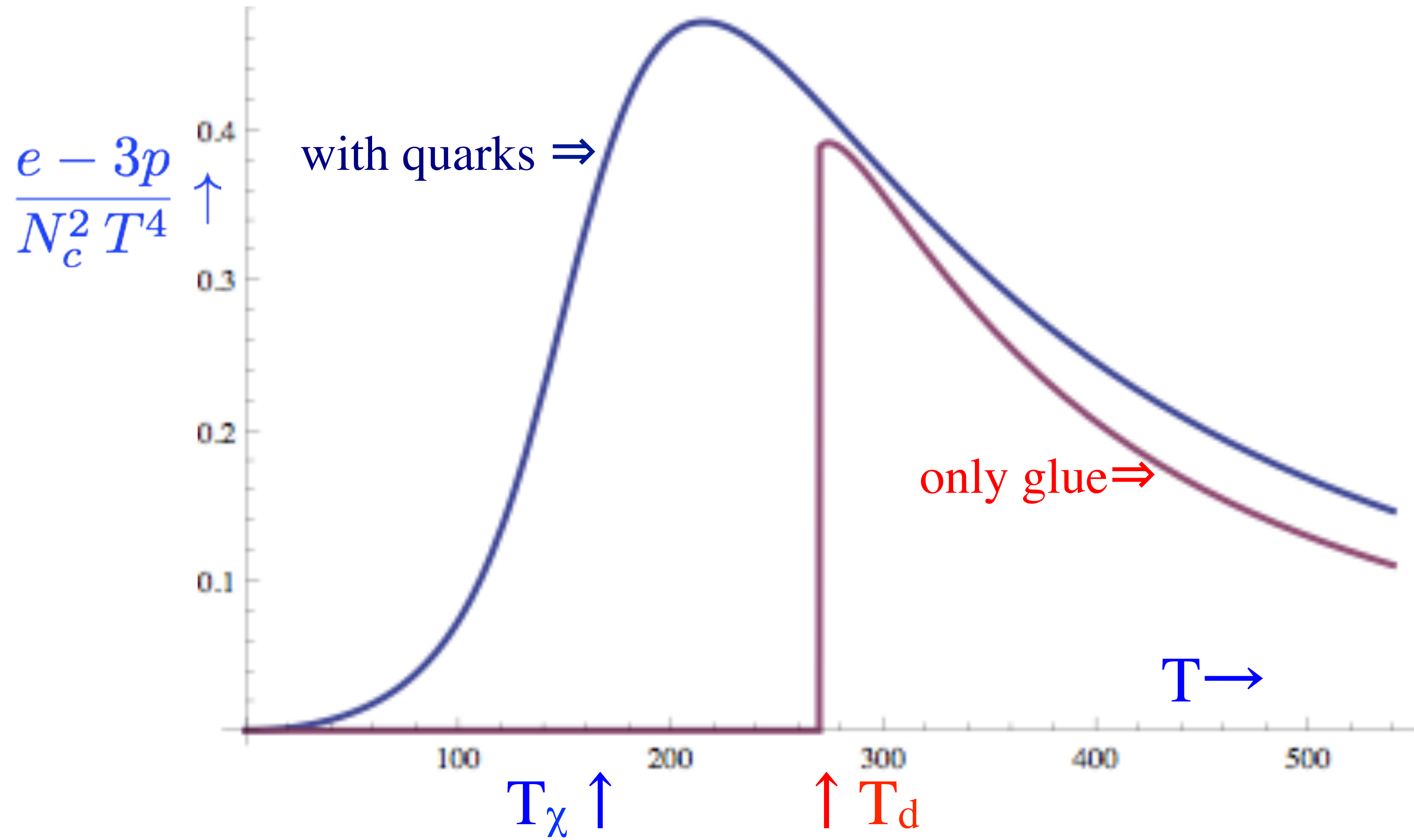
Many loops. E.g.:
Not necessarily positive, so no m_{eff}

$$\ell_2 = \frac{1}{N_c} \, \mathrm{tr} \, \mathbf{L}^2$$



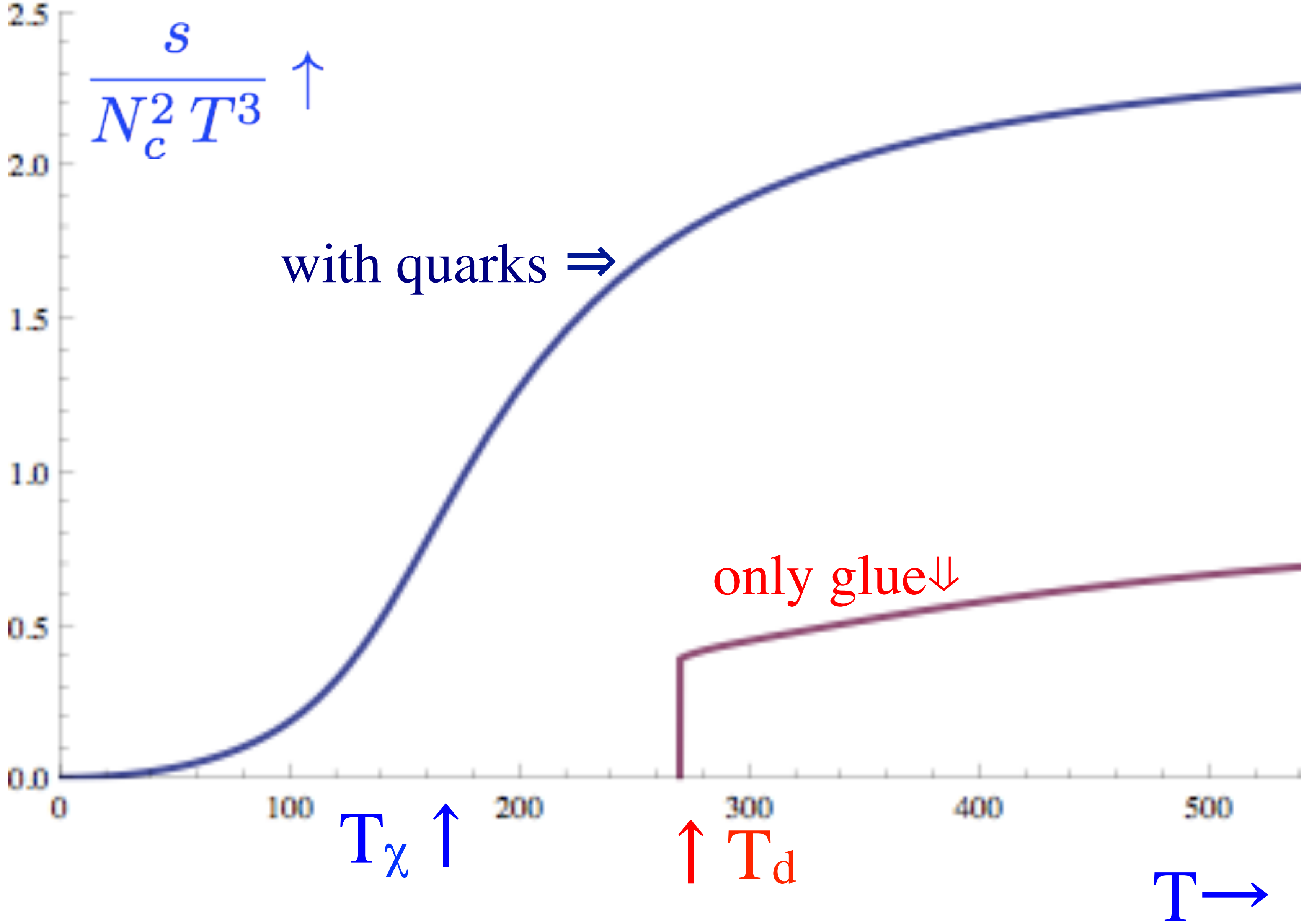
Interaction measure

e = energy density
p = pressure



Entropy

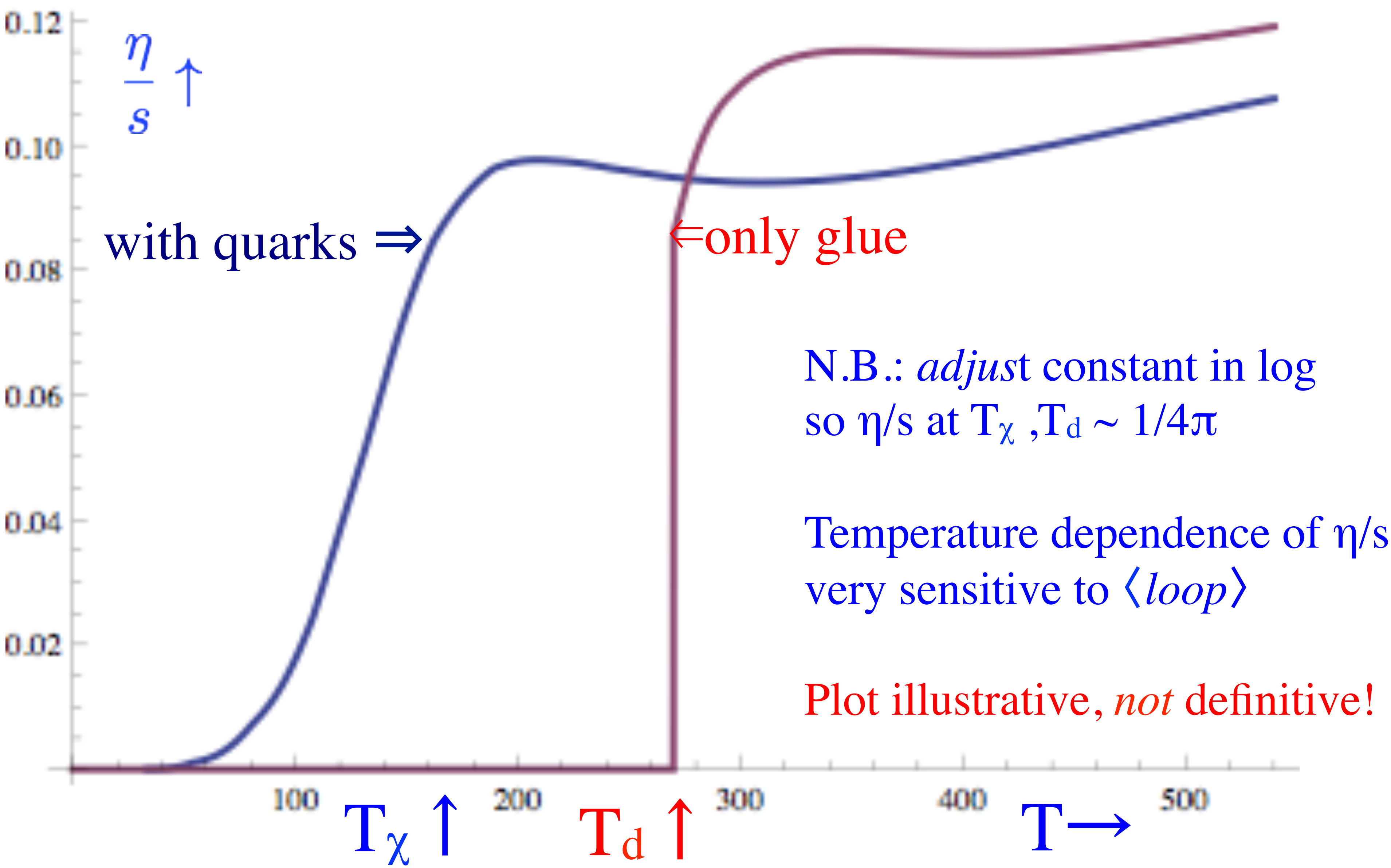
s = entropy density



Shear viscosity/entropy

Shear viscosity $\eta \sim \varrho^2/\sigma$, ϱ = density, σ = cross section.

sQGP: $\sigma \sim \langle loop \rangle^2$, but: $\varrho \sim \langle loop \rangle^2$, so $\eta \sim \langle loop \rangle^2$, *suppressed* for small $\langle loop \rangle$



Conclusions

Shear viscosity: $\eta \sim \varrho^2/\sigma$

ordinary kinetic theory: $\sigma \sim g^4$, $\varrho \sim 1$: at large g, η is small

semi-QGP: when $\langle \mathit{loop} \rangle << 1$, σ small, but ϱ^2 smaller, so η small

Density of color charges ϱ *must* be small in a weakly ionized phase

Energy loss: $dE/dx \sim g^2\, \varrho$

ordinary kinetic theory: at large g, dE/dx is *large*

semi-QGP: when $\langle \mathit{loop} \rangle << 1$, ϱ and so dE/dx is *small*

Matrix model: effective theory near T_d

"Phenomenology of the lattice"

Related work

Massive quasi-particle models: Peshier, Kampfer, Pavlenko, Soff '96,
Cassing, 0704.1410 & 0707.3033; Cassing & Bratkovskaya, 0907.5331;
Castorina, Miller, Satz 1101.1255; Castorina, Greco, Jaccarino, Zappala 1105.5902

Ours is a nonlinear matrix model, $\mathbf{L}^\dagger \mathbf{L} = \mathbf{1}$

Linear matrix models: Vuorinen & Yaffe, ph/0604100;
de Forcrand, Kurkela, & Vuorinen, 0801.1566; Zhang, Brauer, Kurkela, & Vuorinen, 1104.0572

Narrow transition region: Braun, Gies, Pawlowski, 0708.2413;
Marhauser & Pawlowski, 0812.1444; Braun, Eichhorn, Gies, & Pawlowski, 1007.2619

Deriving effective theory from QCD:

Monopoles: Liao & Shuryak, ph/0611131, 0706.4465, 0804.0255, 0804.4890, 0810.4116,
1206.3989; Shuryak & Sulejmanpasic, 1201.5624

Dyons: Diakonov & Petrov, th/0404042, 0704.3181, 0906.2456, 1011.5636

Bions: Unsal, 0709.3269; Simic & Unsal 1010.5515; Poppitz, Schaefer, & Unsal 1205.0290

Standard kinetic theory and η/s, dE/dx:
Majumder, Muller, & Wang, ph/0703082; Liao & Shuryak, 0810.4116
Asakawa, Bass, & Muller, ph/0603092, ph/0608270, 1208.2426