M. Gyulassy 3/13/15

# Consistency of Perfect Fluidity and Jet Quenching in semi-Quark-Gluon Monopole Plasmas

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(Dated: March 10, 2015)

We utilize a new framework, CUJET3.0, to deduce the energy and temperature dependence of jet transport parameter, $\hat{q}(E > 10\ GeV, T)$, from a combined analysis of available data on nuclear modification factor and azimuthal asymmetries from RHIC/BNL and LHC/CERN on high energy nuclear collisions. Extending a previous perturbative-QCD based jet energy loss model (known as CUJET2.0) with (2+1)D viscous hydrodynamic bulk evolution, this new framework includes three novel features of nonperturbative physics origin: (1) the Polyakov loop suppression of color-electric scattering (aka "semi-QGP" of Pisarski et al) and (2) the enhancement of jet scattering due to emergent magnetic monopoles near $T_c$ (aka "magnetic scenario" of Liao and Shuryak) and (3) thermodynamic properties constrained by lattice QCD data. CUJET3.0 reduces to v2.0 at high temperatures $T > 400$ MeV, but greatly enhances $\hat{q}$ near the QCD deconfinement transition temperature range. This enhancement accounts well for the observed elliptic harmonics of jets with $p_T > 10$ GeV. Extrapolating our data-constrained $\hat{q}$ down to thermal energy scales, $E \sim 2$ GeV, we find for the first time a remarkable consistency between high energy jet quenching and bulk perfect fluidity with $\eta/s \sim T^3/\hat{q} \sim 0.1$ near $T_c$.

CUJET3: Jiechen Xu, Jinfeng Liao, MG arXiv:1411.3673 [hep-ph]; version 2
CUJET2: Jiechen Xu, A. Buzzatti, MG, JHEP 1408 (2014) 063 , arXiv:1402.2956

# sQGP is a novel form of QCD matter discovered at RHIC in Au+Au @200 AGeV and probed at higher temp at LHC in Pb+Pb @2760 AGeV

**Theoretical interpretations of sQGP include**

**1) s̲trongly coupled – Q̲uark - G̲luon P̲lasmas (sQGP)**

**2) C̲olor G̲lass C̲ondensate (or Color Scintillator Arrays )**

**3) 10D *Black Holes* in $AdS_5 \times S_5$ with strings**

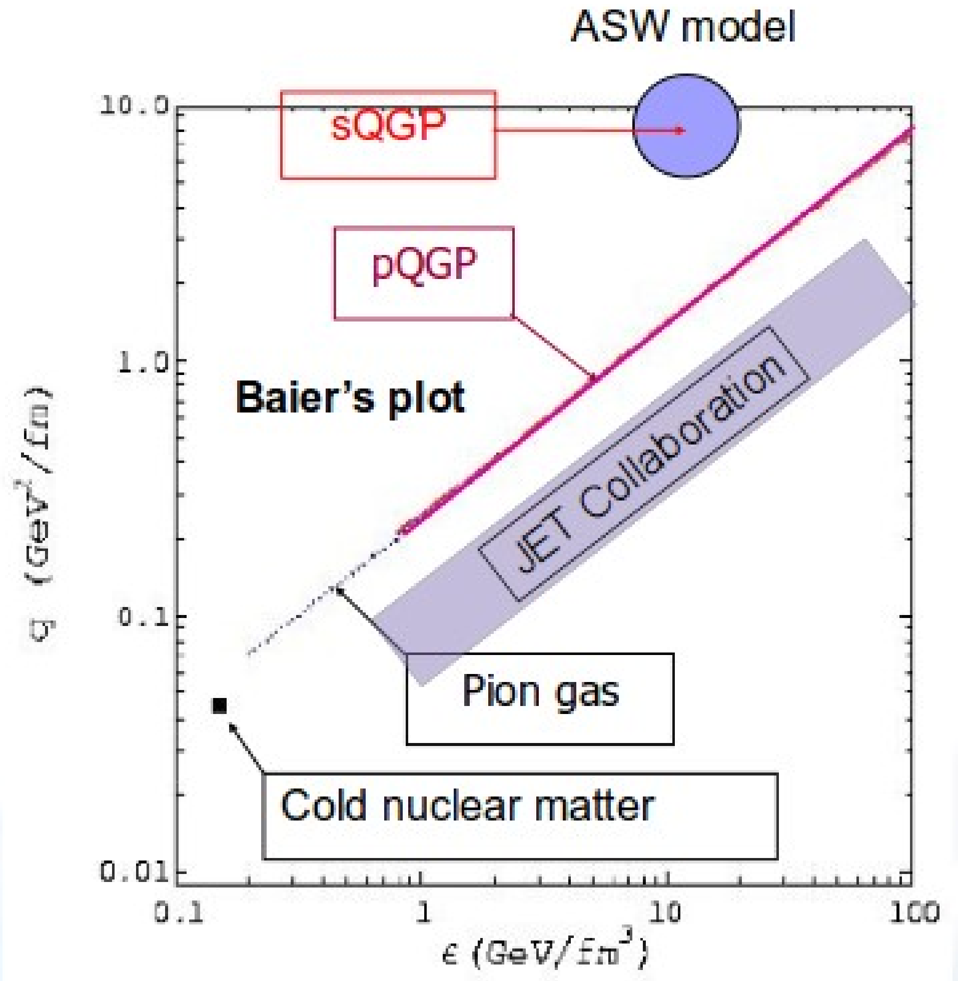
**4) Unruh Radiation *Fields* from Accelerating SU(N) sources**

**5) semi-Quark-Gluon-Monopole Plasmas (sQGMP)**

Ref 1: M.G, L. McLerran, NPA750:30,2005.
Ref 2: MG, L. Levai, , I.Vitev, T.S. Biró, PRD90 (2014) 5, 054025
Ref 4: T.S. Biró, Z. Szendi, Z. Schram, EPJ. A50 (2014) 6
Ref 5: Jiechen Xu, Jinfeng Liao, MG arXiv:1411.3673 [hep-ph]

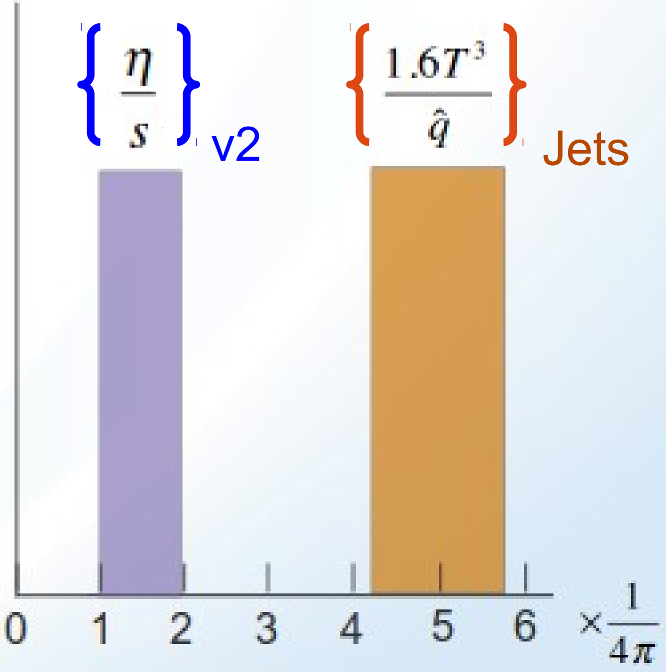
# Jet quenching vs. $\eta/s$

From B. Mueller's Theory Overview talk 12/2/13



Majumder, BM, Wang

$$\left.\begin{array}{l} \eta / s \approx \dfrac{0.065}{\alpha_s^2 \ln(q_{\max}^2 / m_D^2)} \\[2ex] T^3 / \hat{q} \approx \dfrac{0.04}{\alpha_s^2 \ln(q_{\max}^2 / m_D^2)} \end{array}\right\} \text{HTL Weakly Coupled}$$



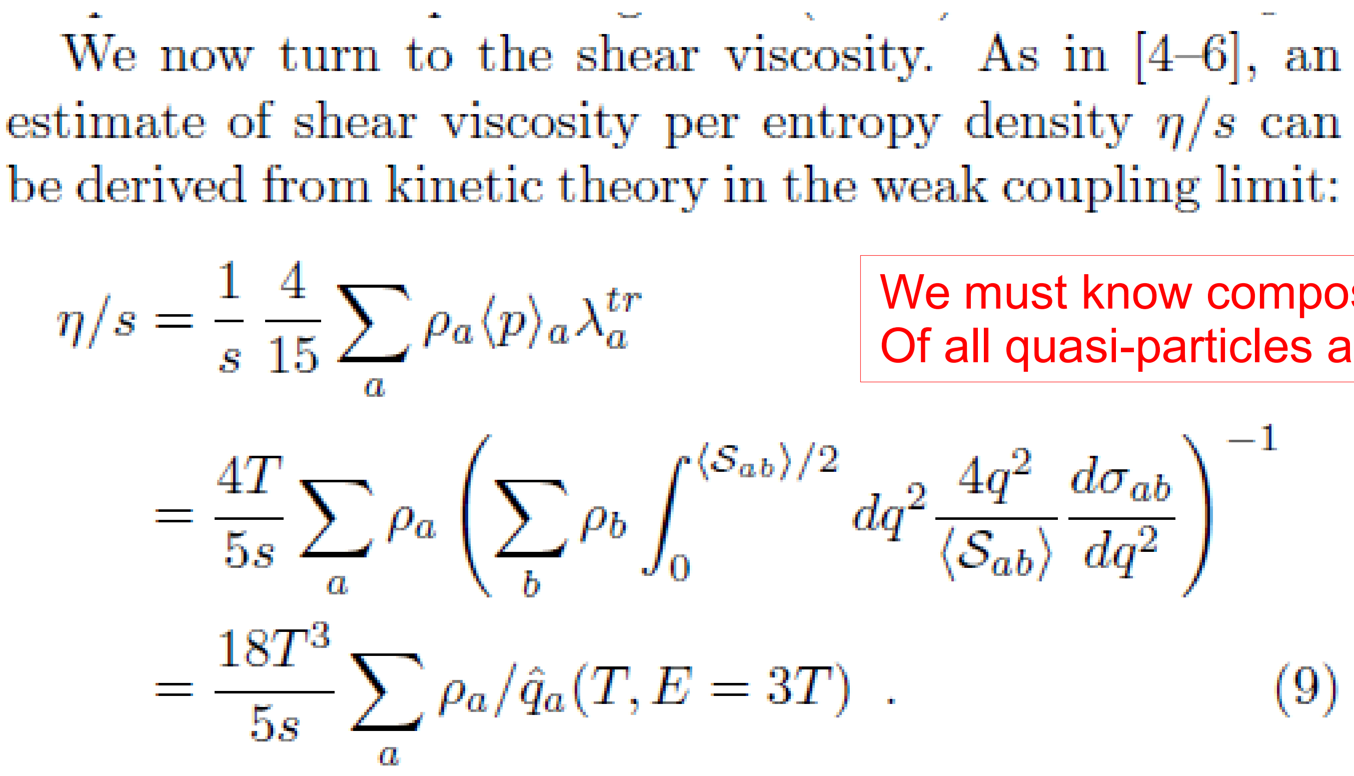
Bulk Flow suggests strongly coupled "perfect fluidity" for pT<2 GeV

But Hard Jet probes suggest weak jet medium interactions pT>10.

What is the missing physics that could resolve this Puzzle?

# Kinetic theory => inverse connection between eta/s and the jet transport qhat(T,E) field

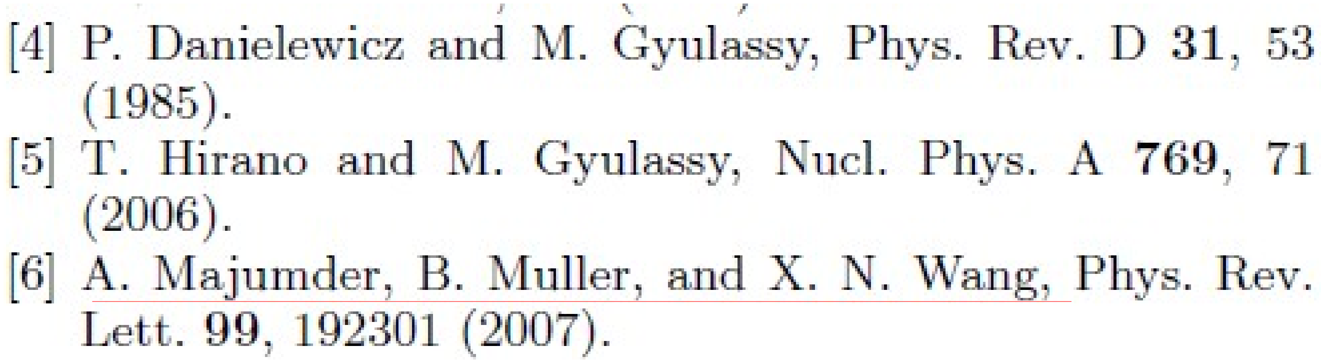
**Jiechen Xu, Jinfeng Liao, MG arXiv:1411.3673 [hep-ph]**



We now turn to the shear viscosity. As in [4–6], an estimate of shear viscosity per entropy density $\eta/s$ can be derived from kinetic theory in the weak coupling limit:

$$\begin{aligned}\eta/s &= \frac{1}{s}\frac{4}{15}\sum_a \rho_a \langle p\rangle_a \lambda_a^{tr} \\ &= \frac{4T}{5s}\sum_a \rho_a \left(\sum_b \rho_b \int_0^{\langle \mathcal{S}_{ab}\rangle/2} dq^2 \frac{4q^2}{\langle \mathcal{S}_{ab}\rangle}\frac{d\sigma_{ab}}{dq^2}\right)^{-1} \\ &= \frac{18T^3}{5s}\sum_a \rho_a/\hat{q}_a(T, E = 3T) \ . \end{aligned} \tag{9}$$

We must know composition and mfp
Of all quasi-particles a=1, …, n



[4] P. Danielewicz and M. Gyulassy, Phys. Rev. D **31**, 53 (1985).

[5] T. Hirano and M. Gyulassy, Nucl. Phys. A **769**, 71 (2006).

[6] A. Majumder, B. Muller, and X. N. Wang, Phys. Rev. Lett. **99**, 192301 (2007).

JET Collab 2013 pQCD Tomography summary
5 models extraction of qhat/T^3 jet transport coef

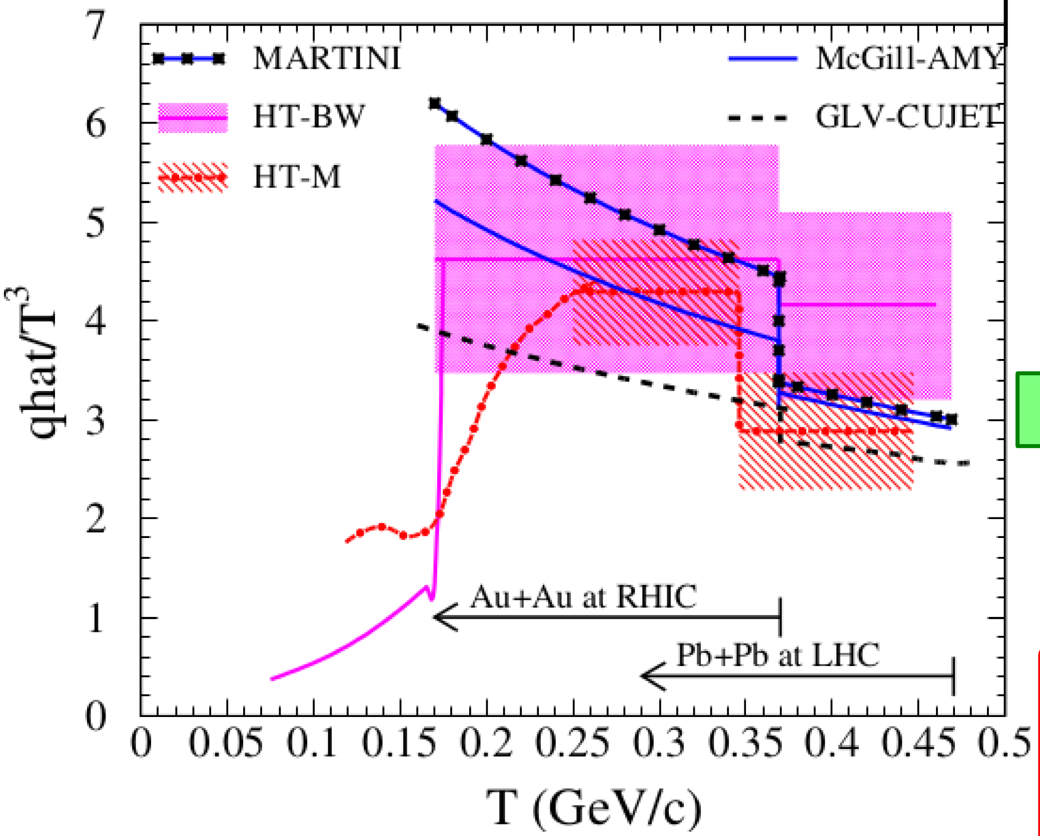


FIG. 10. (Color online) The assumed temperature dependence of the scaled jet transport parameter $\hat{q}/T^3$ in different jet quenching models for an initial quark jet with energy $E = 10$ GeV. Values of $\hat{q}$ at the center of the most central A+A collisions at an initial time $\tau_0 = 0.6$ fm/$c$ in HT-BW

Contrast to AdS Holography

LO=AdS+BH+NambuGoto $\lambda^{1/2}$

Over quenches jet RAA

$NLO_1$=LO+WS $\lambda^{1/2}+\lambda^0$

Only qualitatively consistent with RAA
vs very low Chi^2 pQCD tomography

In 2013:

Problem with pQCD HTL plasmas
and E>10 GeV constrained qhat

predicts way too large viscosity
eta/s ~ 1.6T3/qhat ~ 0.5 >> 0.1 from v2

***Jet quenching tomography is thus Inconsistent with Bulk hydro flow***

Could the unsolved JET v2 discrepancy
be related to above ??

Part 1: Open problems

1) QCD thermodynamics near Tc~ 150-250 MeV
Is not consistent with a wide range of popular models
Something is missing in sQGP picture.

2) Jet Quenching pT>10 GeV in AA can be well understood
In a perturbative QCD paradigm with only a modest
Qhat(pT>10,T)/T^3 ~ 4 but pQCD Qhat → 0 near Tc !
which is inconsistent with (3)

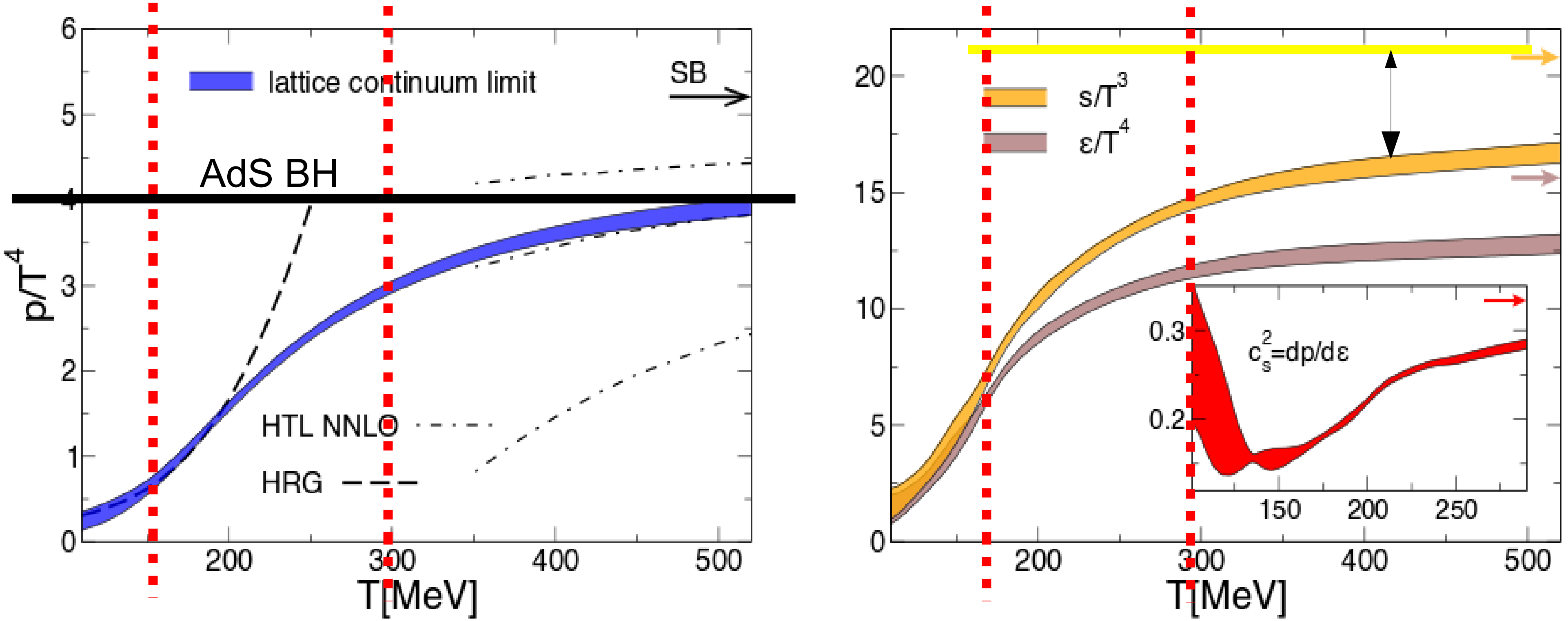
3) Bulk collective low pT< 2 GeV flow v2(pT) requires
Close to minimum eta/s ~ T^3/Qhat(pT~3T, T) ~ 0.1-0.2
That is Inconsistent with (2)

Part 2: Our proposed sQGMP solution to Part 1 puzzles

**Szabolcs Borsányi**[a], **Zoltán Fodor**[a,b,c], **Christian Hoelbling**[a], **Sándor D. Katz**[c,d],
**Stefan Krieg**[a,b*], **Kálmán K. Szabó**[a,e]

LATTICE2013 (2014) 155

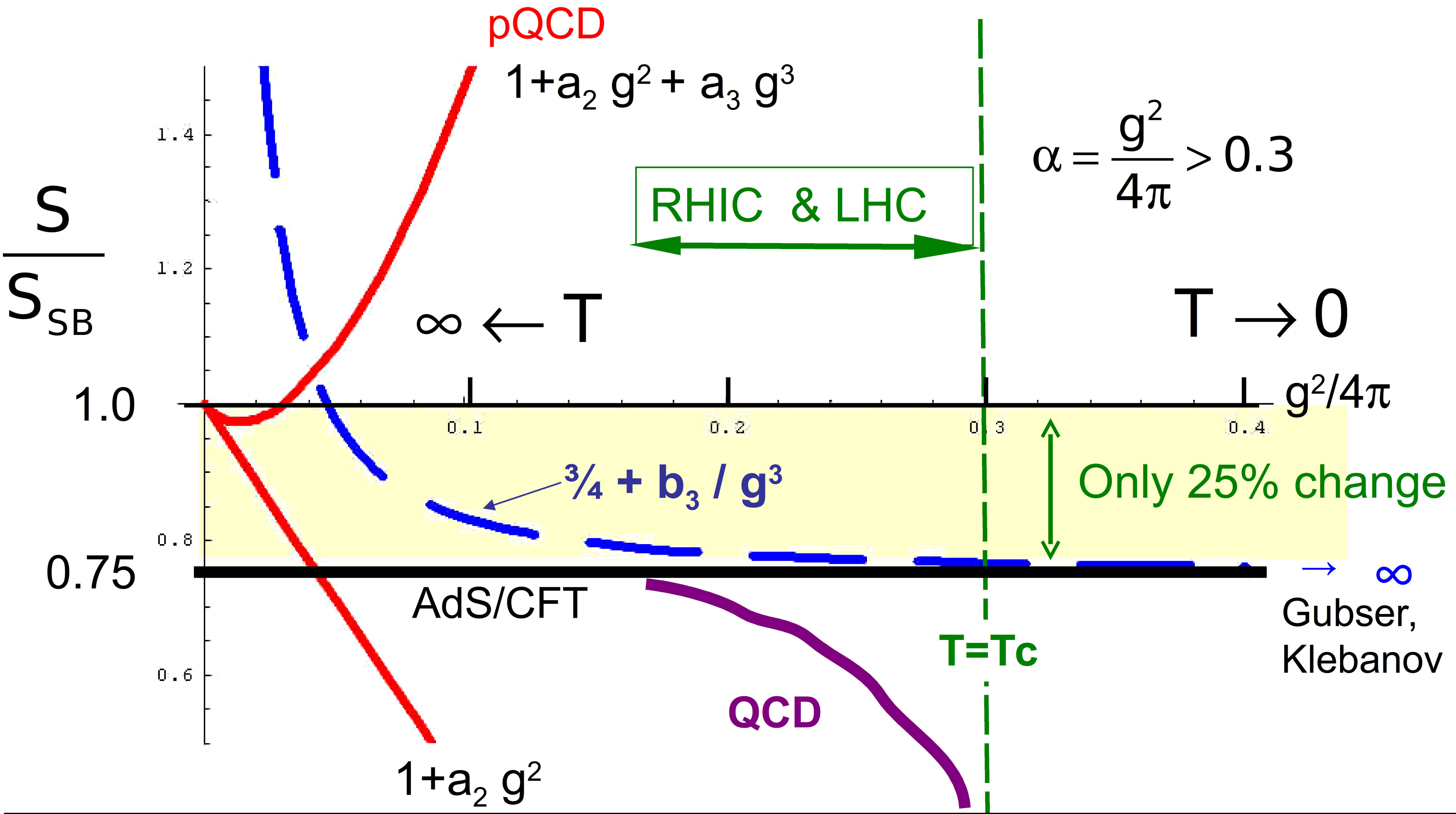
# . Continuum EoS for QCD with Nf=2+1 flavors



In the QCD transition temperature range 150 < T< 200 MeV the sQGP is
(1) *NOT* a Hadron Resonance Gas (HRG)
(2) *NOT* a perturbative Q+G plasma of quasi free quarks and gluons
(3) *NOT* a conformal AdS Black Hole
(4) possibly a semi-QGP + Mag monopole Plasma (sQGMP)

Weak vs Strong coupling expansion of QCD

# Physics Lessons from pQCD & string and lattice theory

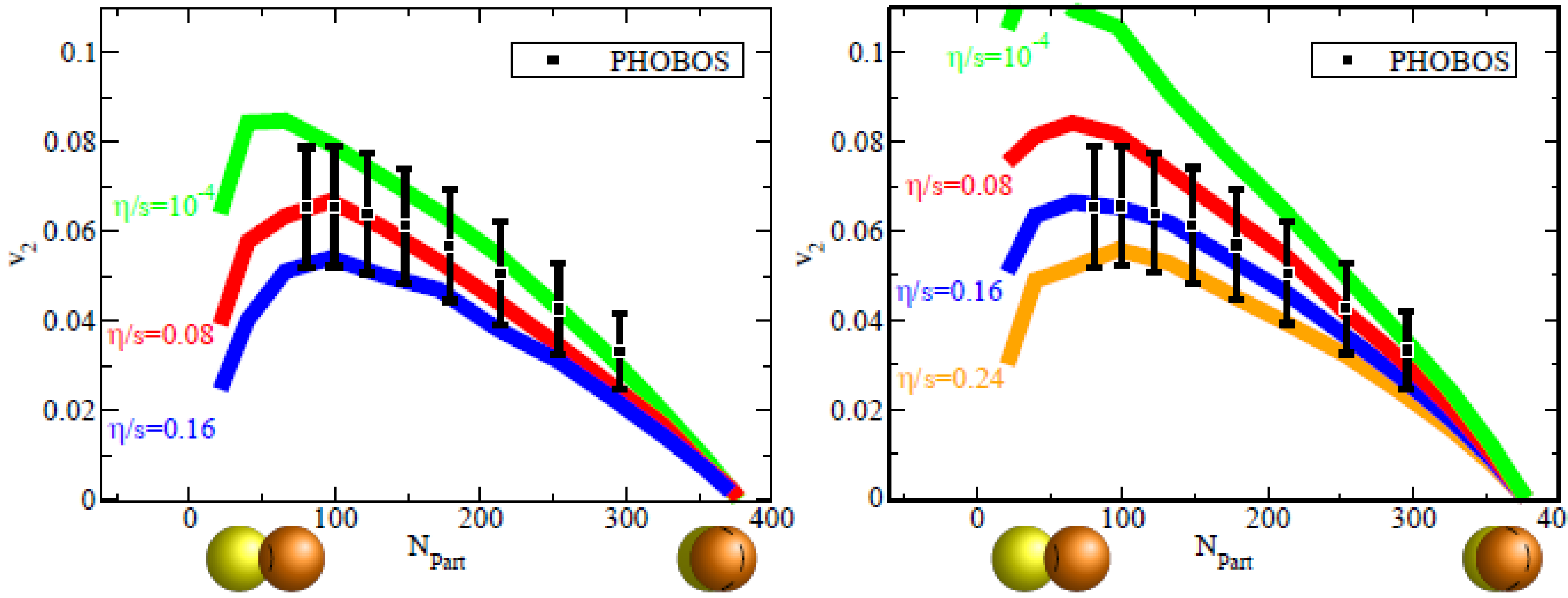


**AdS** BH Entropy $0.75 < S_{AdS} /S_{SB}$ for $0 < g^2 N_c < \infty$ !!

But lattice QCD near Tc $S_{QCD} /S_{SB} \sim 0.5$

From low pT<2 GeV elliptic flow exp, QGP appears to be a nearly perfect fluid

With viscosity to entropy ratio eta/s ~ 0.1 – 0.2 << perturbative QCD estimates ~ 0.5-1.0



"Glauber" initial conditions

"CGC" initial conditions

*(ML & Romatschke, Phys.Rev. C78 (2008) 034915)*

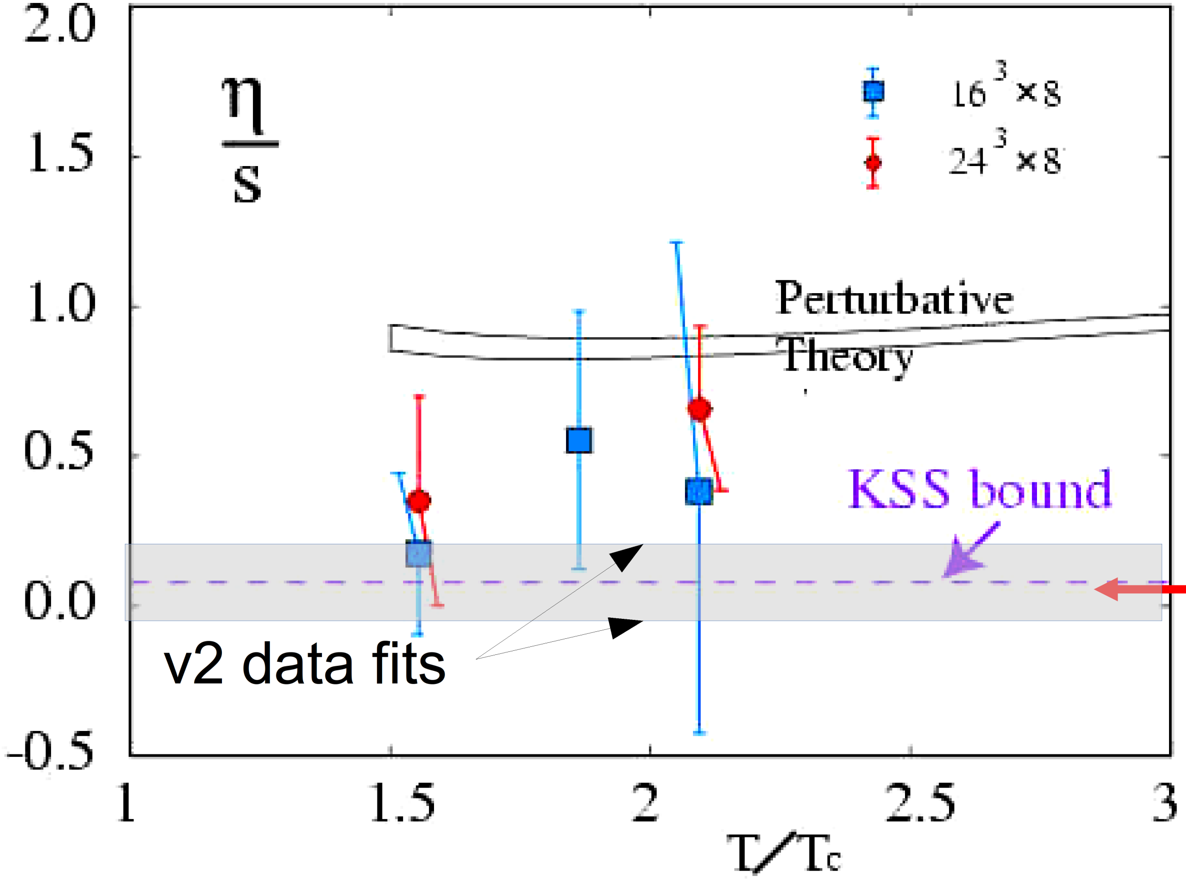
Elliptic Flow => near minimum quantum uncertainty bound
(P.Danielewic,MG 1985; Kovtun-Son-Starinets 2004)

MATT LUZUM (SACLAY) VISCOSITY OF THE QGP 8/14//2012 3 / 20

# Shear Viscosity Transport coefficient of a QGP: Lattice QCD *vs* pQCD *vs* AdS/CFT N=4 SYM

## vs RHIC v2 data constraints

Lattice QCD: A.Nakamura,S.Sakai, 2004



**N=4 SUSY: Policastro, Son, Starinets (2001)**

**Kovtun,Son,Starinets (2004)**

**Danielewicz, MG, (1985)** *

Perturbative QCD

$$\boxed{\frac{T\,\lambda_{pQCD}}{5} \approx \frac{(0.3)^2}{\alpha^2 \log 1/\alpha} \sim 1} \; *$$

$$\boxed{\left(\frac{\eta}{\sigma}\right)_{adS/CFT} = \frac{1}{4\pi}}$$

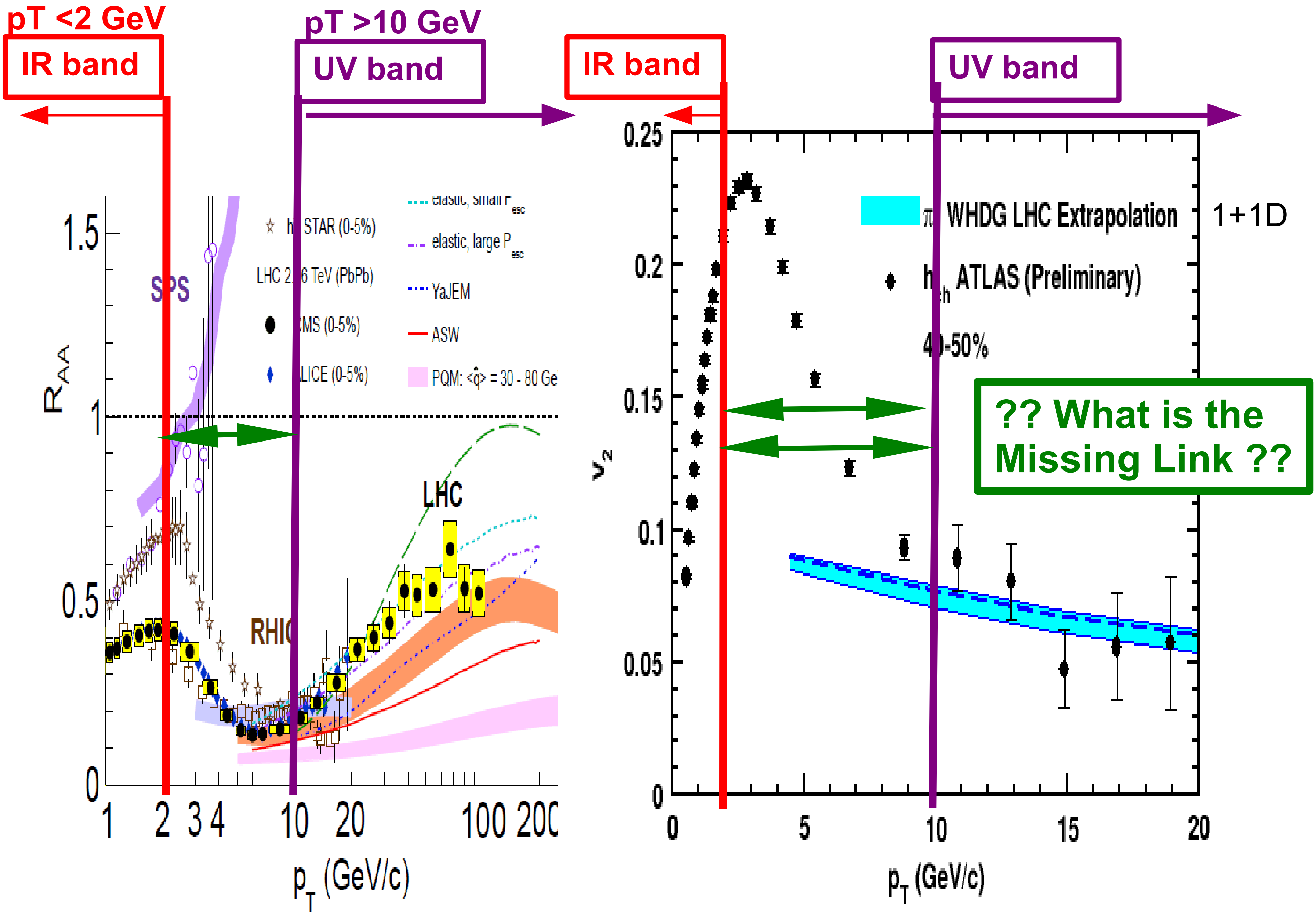
**N=4 SUSY**

**$g^2N_c \to \infty$**

$$\boxed{\frac{T\lambda_{min}}{5} \approx \frac{\hbar = 1}{15}} \; *$$

Minimum uncertainty estimate

# Bulk IR vs Jet Quenching UV Physics in A+A from SPS to LHC



pT <2 GeV

**IR band**

pT >10 GeV

**UV band**

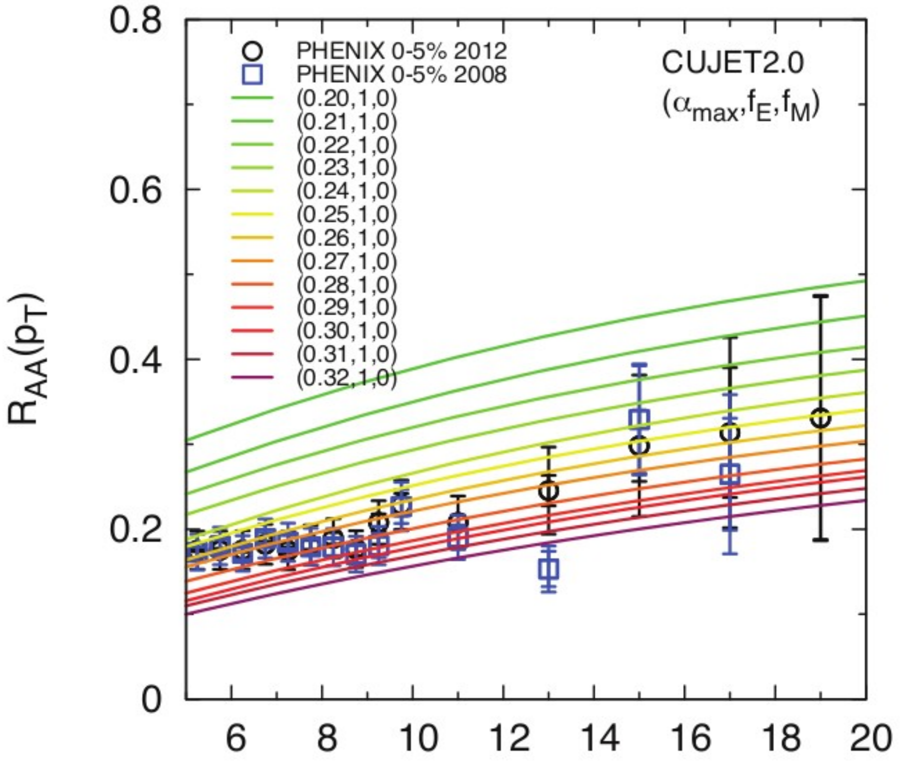
**IR band**

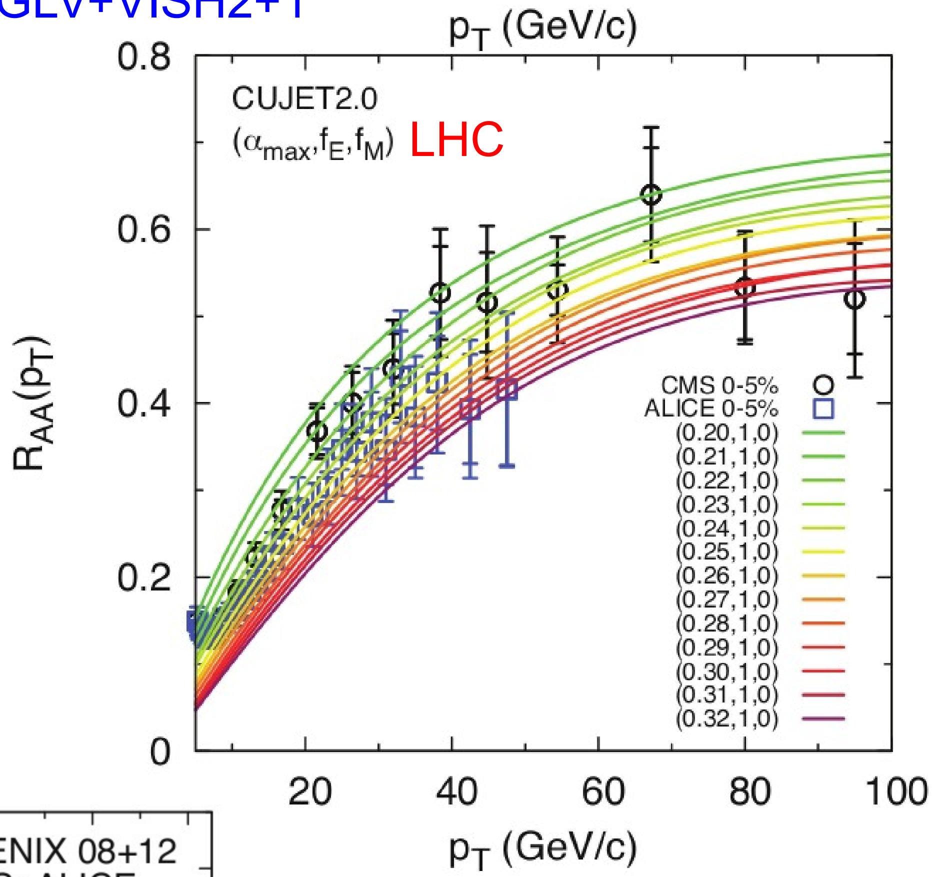
**UV band**

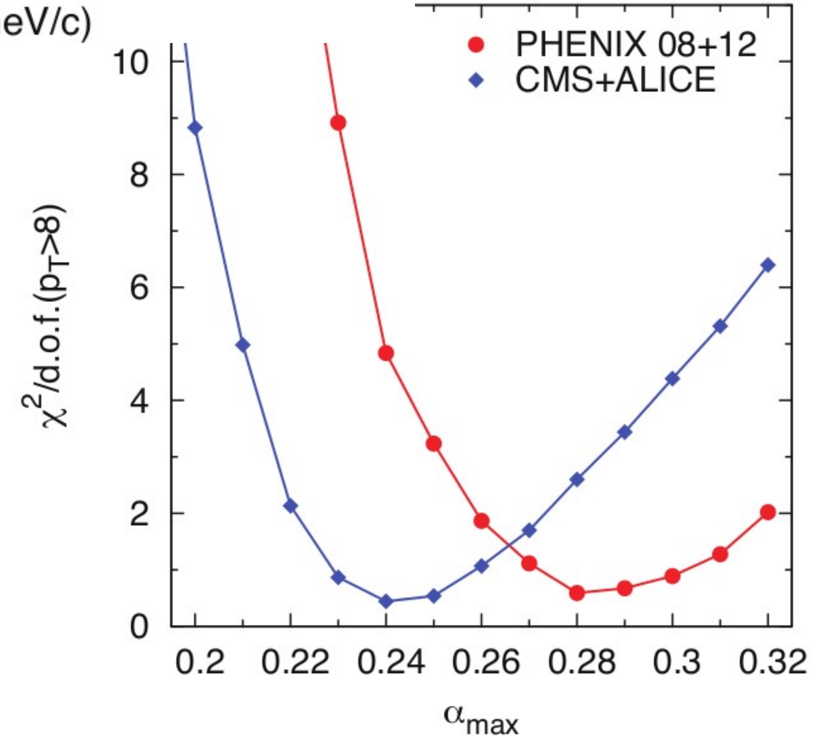
**?? What is the Missing Link ??**

**Is the physics in the bulk “IR” decoupled from jets in the “UV”**

Jiechen Xu, A. Buzzatti, MG: CUJET2.0=rcDGLV+VISH2+1







LHC RHIC

$$\alpha_{max} = 0.24 - 0.28$$

Consistent with both
RHIC and LHC at ~1.5 sigma

For HTL plasma with
FE=1, fM=0

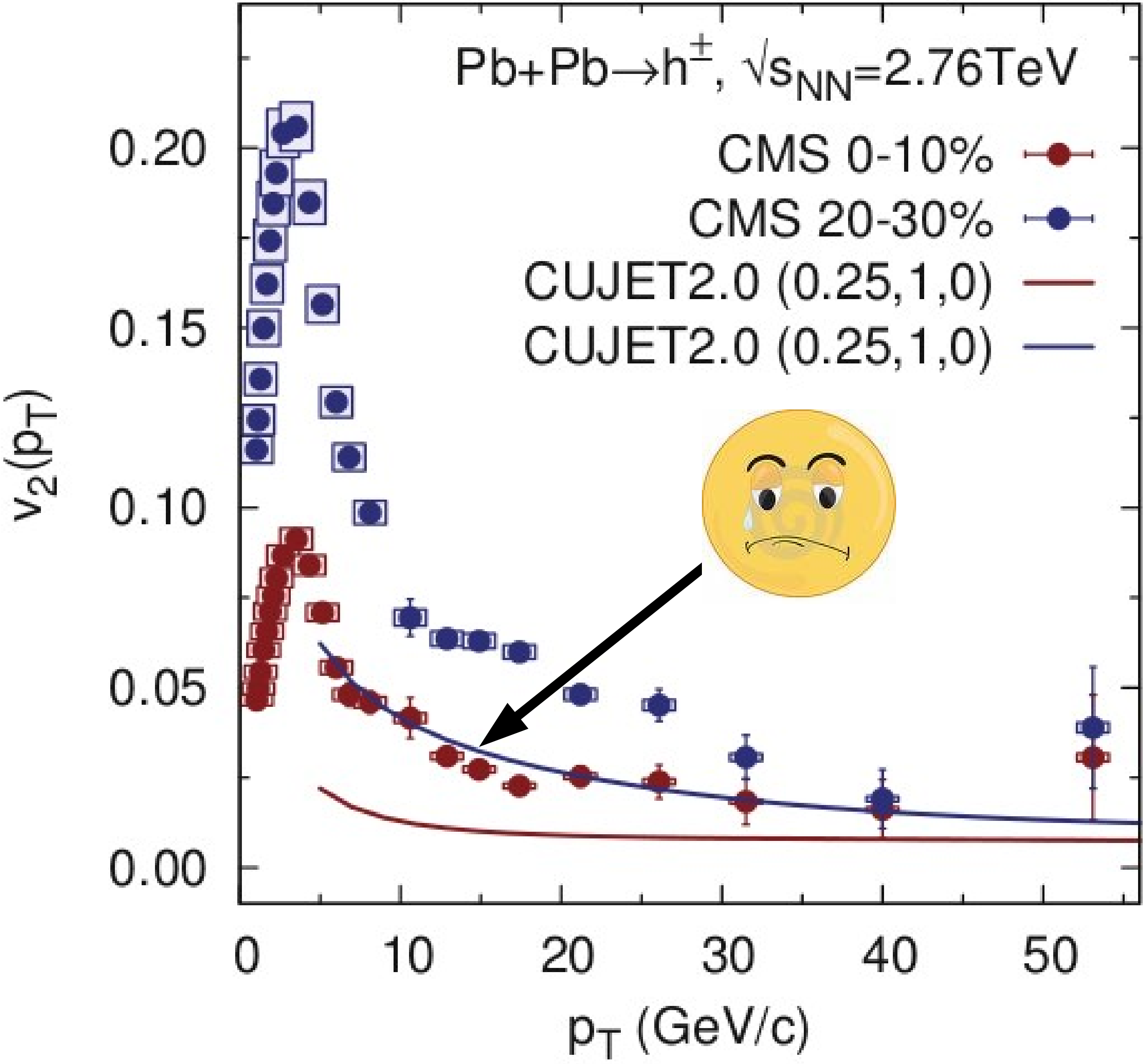
Jiechen Xu, A.Buzzatti, MG, JHEP 1408 (2014) 063

Our v2 Albatross
2

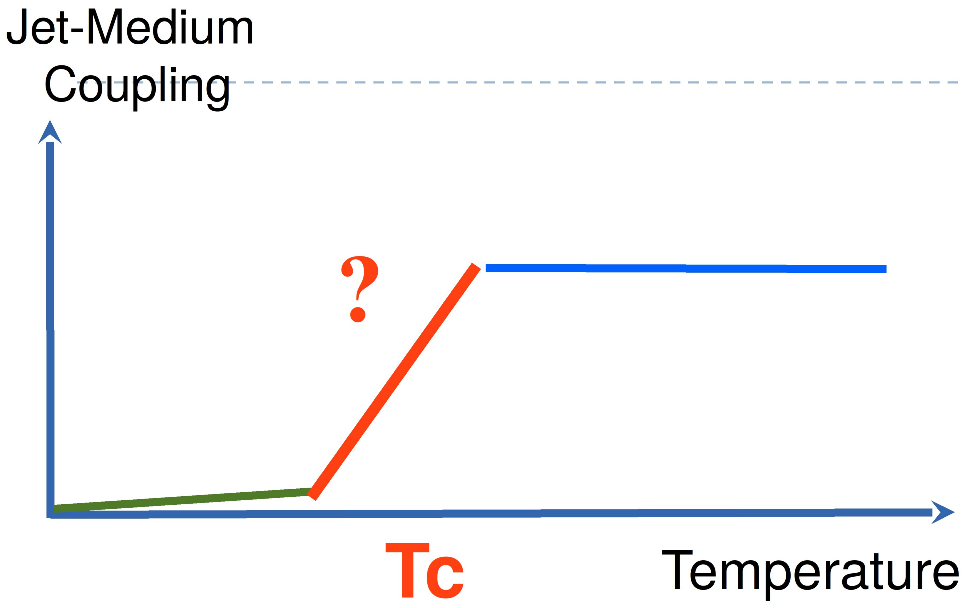
CUJET2.0
Under predicts
Jet v2 at LHC

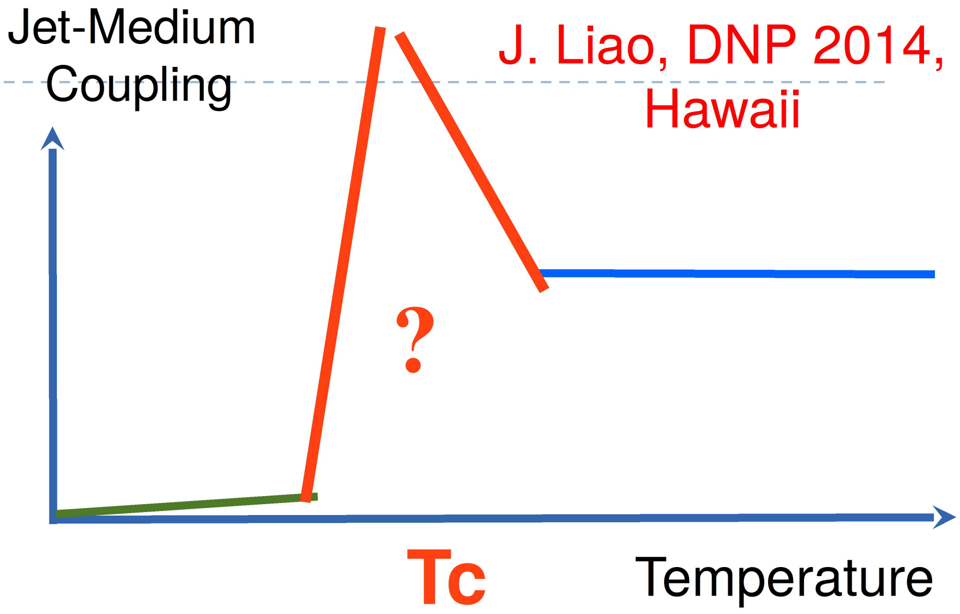
With alpha_max
Constrained by
RAA(RHIC+LHC)

The CUJET2.0 v2 Albatross



# How Does Jet-Medium Coupling Interpolate between T< Tc Transparency to T>Tc Opaqueness





J. Liao, DNP 2014, Hawaii

“Waterfall” scenario

“Volcano” scenario

- 
- How to reconcile jet transparency for T<<Tc be reconciled with color confinement below Tc and perfect fluidity near Tc?

The Theoretical Dilema:

At long wavelength pT<2 GeV QGP seems like almost infinitely coupled fluid

But at small wavelengths pT>10 GeV probes QGP appear perturbative

(This is commen unusual in superfluids and superconductors)

Can we reconcile these contradictory properties of QGP

In some unified calculable way??

We need a “missing link” ingredient like Cooper pairs

that can interpolate between near conformal perturbative QCD short wavelength

And far from conformal nonperturbative confinement physics near Tc ~ 200 MeV

# Part 2: Our proposed sQGMP solution to Part 1 puzzles

sQPMP = *semi*-chomoelectric(Q+G)+ *semi*-chromomagnetic Monolopes M

semi color elect quasiparticle Q+G are suppressed by Polyloop and Polyloop^2
(aka Pisarski et el)

semi color magnetic quasiparticle M that are emergent in vicinity of Tc
(aka Liao and Shuryak)

Semi also in sense that the competiting three Q+G+M Deg. Of Freedom
Evolve into perturbative Q+G HTL DOF for T > 3 Tc

**A key missing ingredient in both pQCD and AdS/CFT are Hadrons!!**

**Something must confine color electric q and g degrees of freedom below Tc**

The most natural candidate from analogy with condensed matter physics

is the magnetic dual of superconductivity (Nambu, Mandelstam, T'Hooft ~ 1974)

***IF*** QCD has *emergent chromo-magnetic monopole* degrees of freedom near Tc

And *IF* they condense below Tc (like Cooper pairs do in superconductors)

Then they can provide the missing sQGMP link physics between

the T >> Tc asymptotic pQCG wQGP world

and

the T<< Tc confined color neutral HRG world

Could critical scattering on elecmonopoles amd mag monopoles
explain perfect fluidity near Tc? (aka Liao and Suryak ?)

Slide from Jinfeng Liao on

# Dual Superconductivity

- Dual superconductivity is a promising mechanism for quark confinement. [Y.Nambu (1974). G.'t Hooft, (1975). S.Mandelstam, (1976) A.M. Polyakov (1975)]

**superconductor**

- Condensation of electric charges (Cooper pairs)
- Meissner effect: Abrikosov string (magnetic flux tube) connecting monopole and anti-monopole
- Linear potential between monopoles

**dual superconductor**

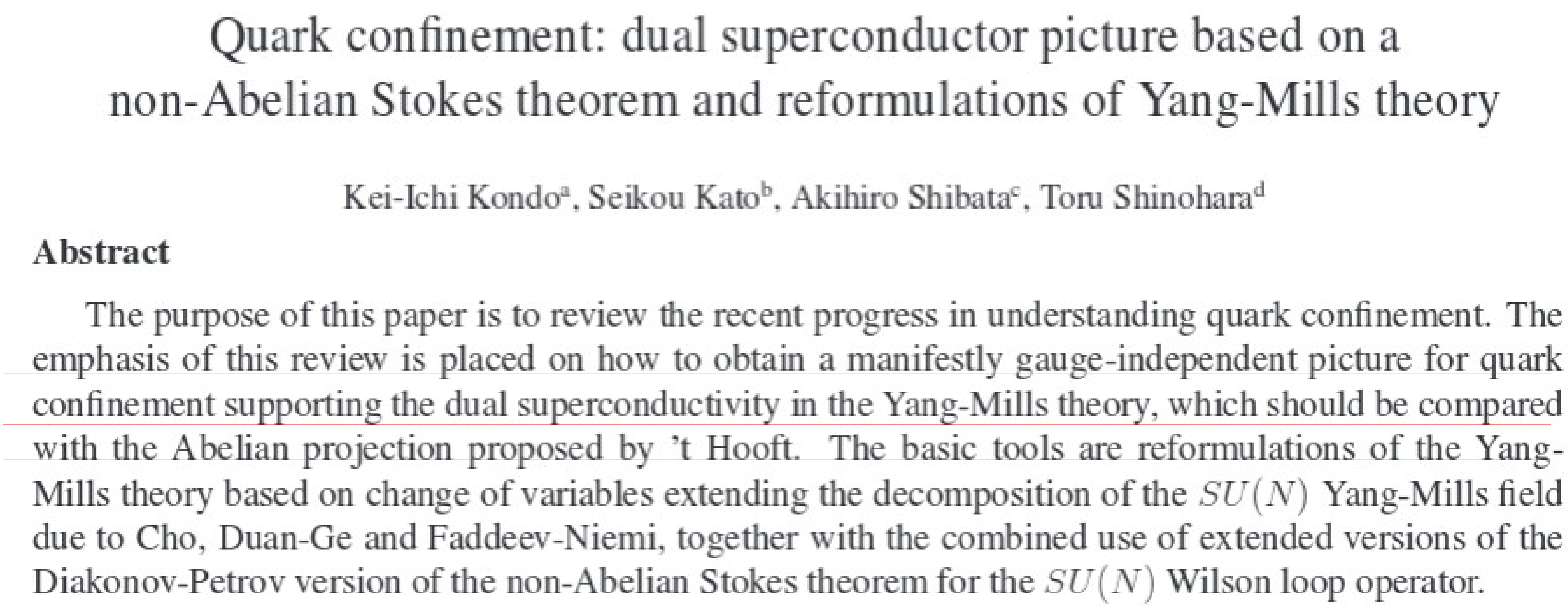
- Condensation of magnetic monopoles
- Dual Meissner effect: formation of a hadron string (chromo-electric flux tube) connecting quark and antiquark
- Linear potential between quarks

Akihiro, Shibata, Trento 2013

ArXiv:1409.1599 : **a 277 page review !**
Also arXiv:1412.8009 [hep-lat]

Status of QCD Monopoles Still Uncertain
And Hotly Debated After 40 !!

P-209
)14-23

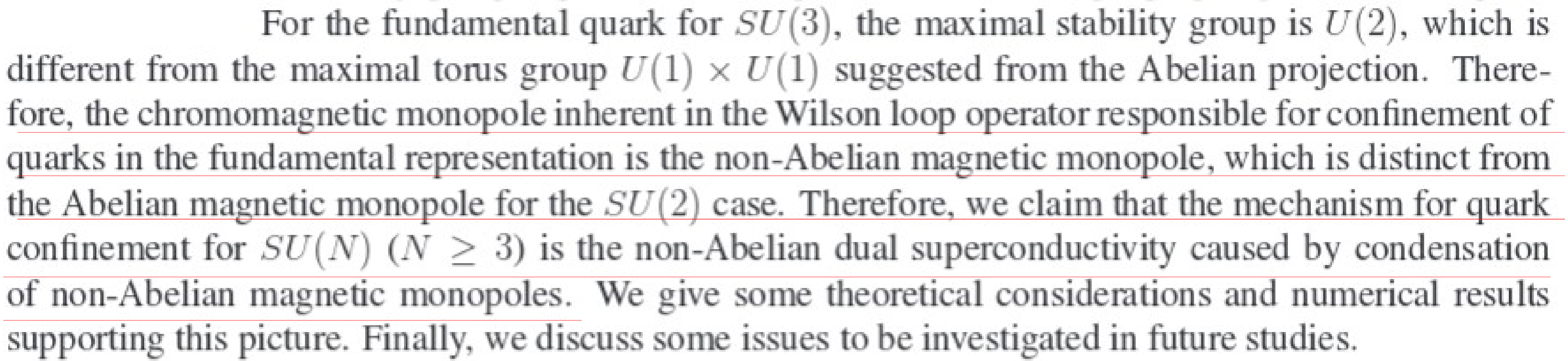


# Quark confinement: dual superconductor picture based on a non-Abelian Stokes theorem and reformulations of Yang-Mills theory

Kei-Ichi Kondo[a], Seikou Kato[b], Akihiro Shibata[c], Toru Shinohara[d]

**Abstract**

The purpose of this paper is to review the recent progress in understanding quark confinement. The emphasis of this review is placed on how to obtain a manifestly gauge-independent picture for quark confinement supporting the dual superconductivity in the Yang-Mills theory, which should be compared with the Abelian projection proposed by 't Hooft. The basic tools are reformulations of the Yang-Mills theory based on change of variables extending the decomposition of the $SU(N)$ Yang-Mills field due to Cho, Duan-Ge and Faddeev-Niemi, together with the combined use of extended versions of the Diakonov-Petrov version of the non-Abelian Stokes theorem for the $SU(N)$ Wilson loop operator.



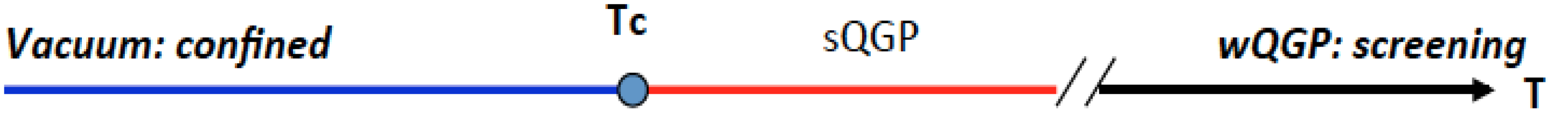
For the fundamental quark for $SU(3)$, the maximal stability group is $U(2)$, which is different from the maximal torus group $U(1) \times U(1)$ suggested from the Abelian projection. Therefore, the chromomagnetic monopole inherent in the Wilson loop operator responsible for confinement of quarks in the fundamental representation is the non-Abelian magnetic monopole, which is distinct from the Abelian magnetic monopole for the $SU(2)$ case. Therefore, we claim that the mechanism for quark confinement for $SU(N)$ $(N \geq 3)$ is the non-Abelian dual superconductivity caused by condensation of non-Abelian magnetic monopoles. We give some theoretical considerations and numerical results supporting this picture. Finally, we discuss some issues to be investigated in future studies.

# The Liao-Shuryak  sQGMP Scenario

T<< Lambda_QCD

T ~ Lambda_QCD

T>> Lambda_QCD



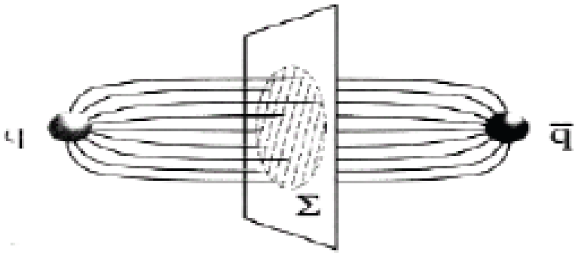
**Vacuum: confined**

**Tc**

sQGP

**wQGP: screening**

**T**



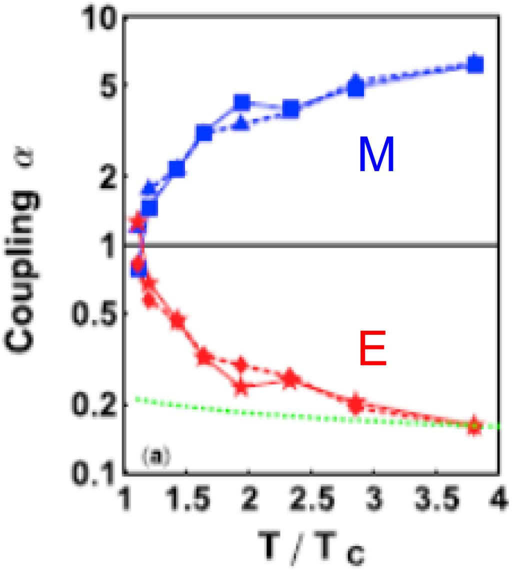
**Emergent plasma**
**with E & M charges:**
chromo-magnetic monopoles
are the "missing DoF"

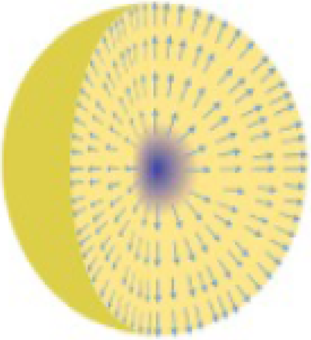
***Plasma of E-charges***
***E-screening: g T***
***M-screening: g^2 T***

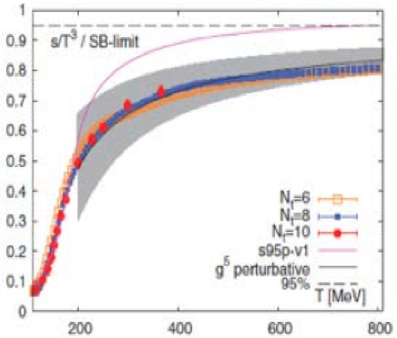
$$L(\mathbf{x}) = \frac{1}{N_c}\mathrm{tr}\mathcal{P}\exp\left[ig\int_0^{1/T} A_4(\tau,\mathbf{x})d\tau\right]$$

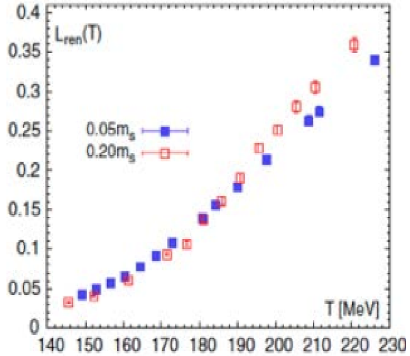
***Electric Flux Tube:***
***Magnetic Condensate***

$$\alpha_E * \alpha_M = 1.$$









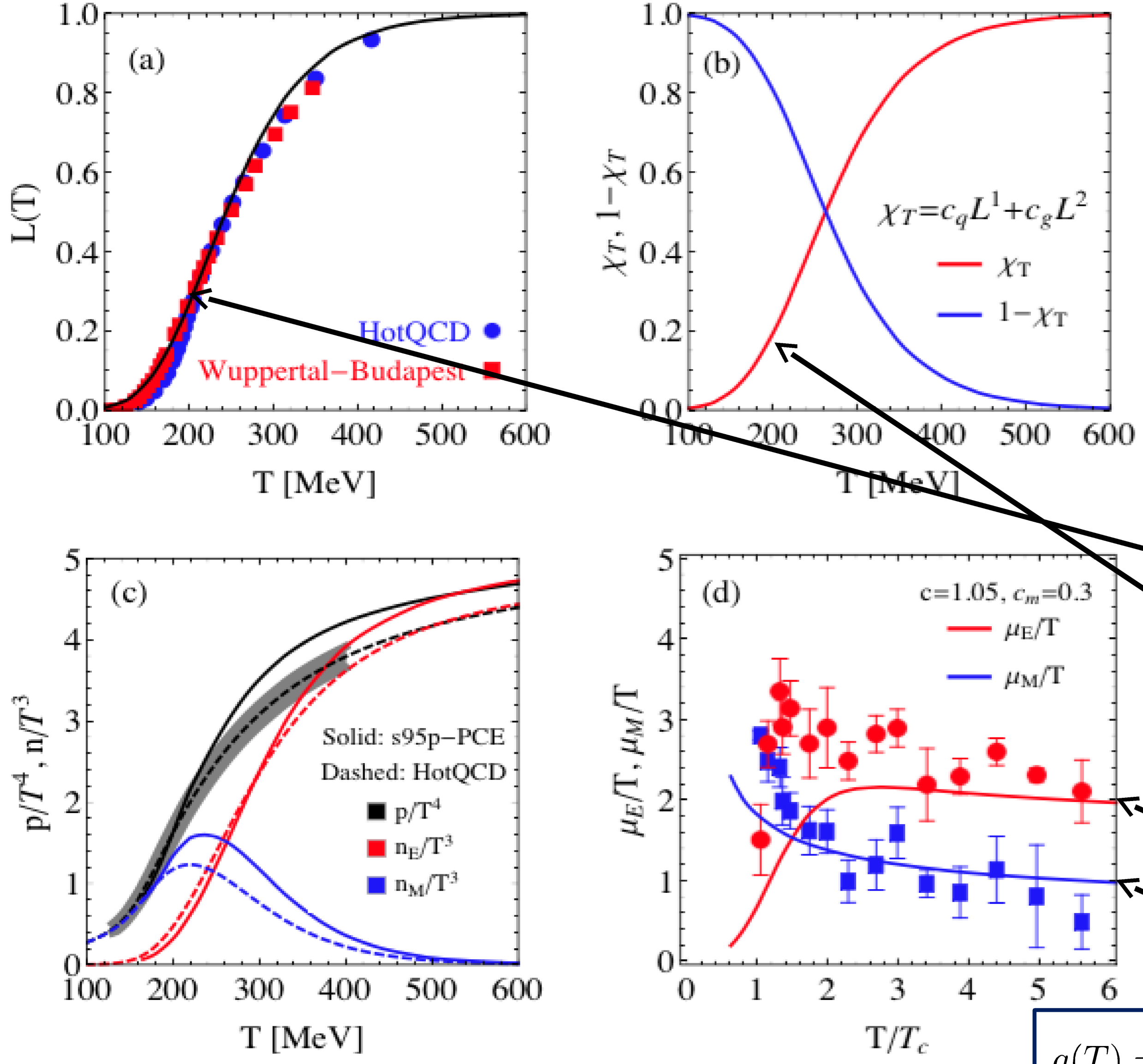
**A region around Tc with liberated degrees of freedom**
**but only partially liberated color-electric objects—missing D.o.F.:**
**semi-QGP + emergent magnetic component**

Jingeng Liao and Ed Shuryak

**Phys.Rev.C75:054907,2007; Phys.Rev.Lett.101:162302,2008;**
**Phys.Rev.C77:064905,2008; Phys.Rev.D82:094007,2010;**
**Phys.Rev.Lett.109:152001,2012.**

❖ Slide from Jinfeng Liao, APS DNP Hawaii 2014

# Lattice QCD: Polyakov Loop, EOS, Screening Masses



J.Xu, , J. Liao, MG, arXiv:1411.3673

$$L(\mathbf{x}) = \frac{1}{N_c}\mathrm{tr}\mathcal{P}\exp\left[ig\int_0^{1/T} A_4(\tau,\mathbf{x})d\tau\right]$$

FIG. 1: (Color online) (a) The Polyakov loop $L(T)$ parameterization of Eq.(8) compared with lattice data from the HotQCD [54] and Wuppertal-Budapest Collaboration [55]; (b) The relative ratios of electric (red, $\chi(T)$) and magnetic (blue, $1-\chi(T)$) quasi-particles in the QCD matter. (c) The EOS from HotQCD (gray band: lattice data, dashed black: parametrization, both in [56]) as well as the number density of E (red) and M (blue) components at various temperatures. (d) The temperature dependence of the screening mass $\mu_E/T$ (red, electric) and $\mu_M/T$ (blue, electric) in CUJET3.0 compared with lattice calculation [57].

$$L(T) = \left[\tfrac{1}{2} + \tfrac{1}{2}Tanh[0.00769(T-72.6)]\right]^{10}$$

$$\chi_T = c_q\, L + c_g\, L^2$$

$$\mu_E^2 \sim \alpha_E n_E / T$$

$$f_E = \mu_E/\mu = \sqrt{\chi_T}$$

$$f_M = \mu_M/\mu = c_m g$$

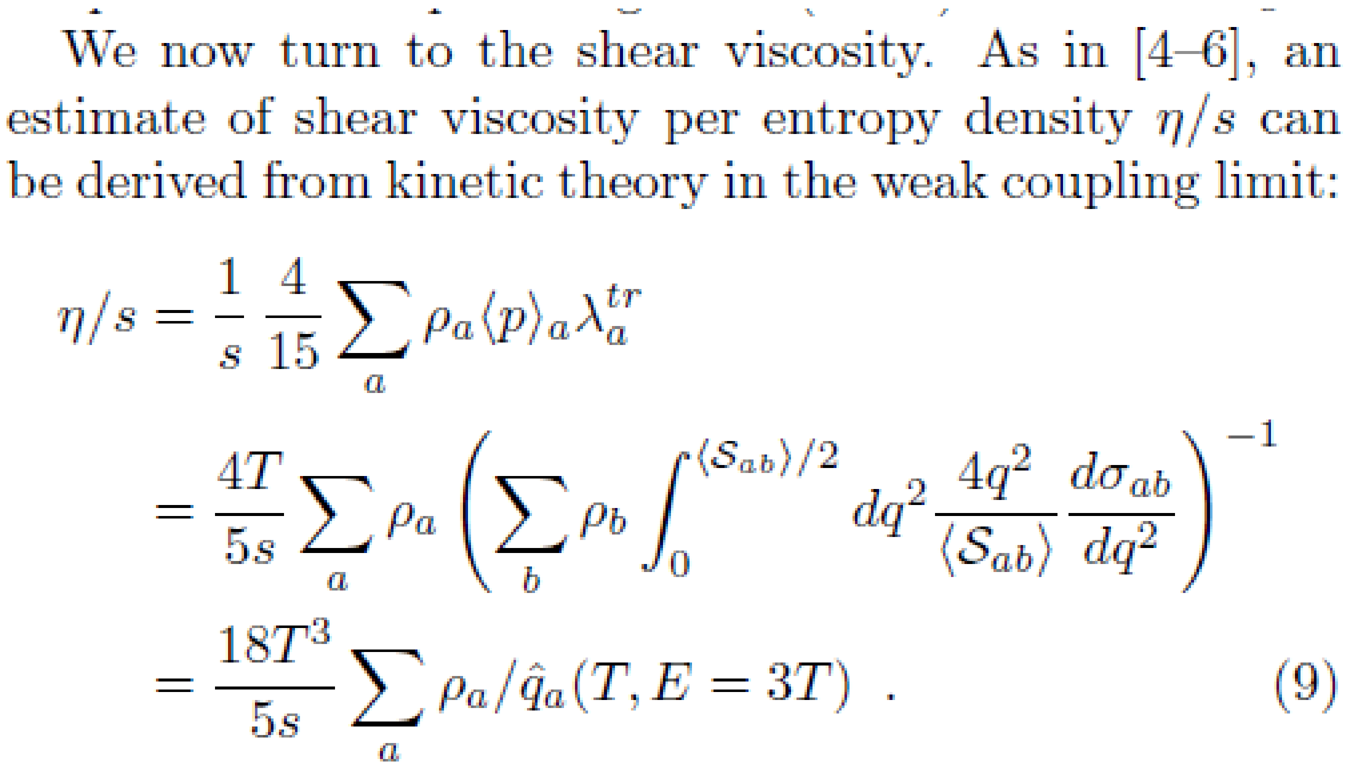
$$g(T) = \sqrt{4\pi\alpha_s(\mu^2(T))} = \mu(T)/(T\sqrt{N_c/3 + N_f/6})$$

Peshier, hep-ph/0601119

- The CUJET3.0 implementations of electric and magnetic components are constrained by available lattice data. No new free parameters introduced

# sQGP Kinetic theory => inverse connection between eta/s and the jet transport qhat(T,E) field

**Jiechen Xu, Jinfeng Liao, MG arXiv:1411.3673 [hep-ph]**



We now turn to the shear viscosity. As in [4–6], an estimate of shear viscosity per entropy density $\eta/s$ can be derived from kinetic theory in the weak coupling limit:

$$\begin{aligned}\eta/s &= \frac{1}{s}\frac{4}{15}\sum_a \rho_a \langle p\rangle_a \lambda_a^{tr} \\ &= \frac{4T}{5s}\sum_a \rho_a \left(\sum_b \rho_b \int_0^{\langle\mathcal{S}_{ab}\rangle/2} dq^2 \frac{4q^2}{\langle\mathcal{S}_{ab}\rangle}\frac{d\sigma_{ab}}{dq^2}\right)^{-1} \\ &= \frac{18T^3}{5s}\sum_a \rho_a/\hat{q}_a(T,E=3T)\ . \qquad (9)\end{aligned}$$

In sQGMP , a=1,2,3

(1) L suppresed quarks Q

(2) L^2 suppressed glue G

(3) emergent mag monopoles M

# Extracting jet transport coefficient from jet quenching at RHIC and LHC

: arXiv:1312.5003 Phys.Rev. C90 (2014) 1, 014909

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(The JET Collaboration) Posted 11/17/13

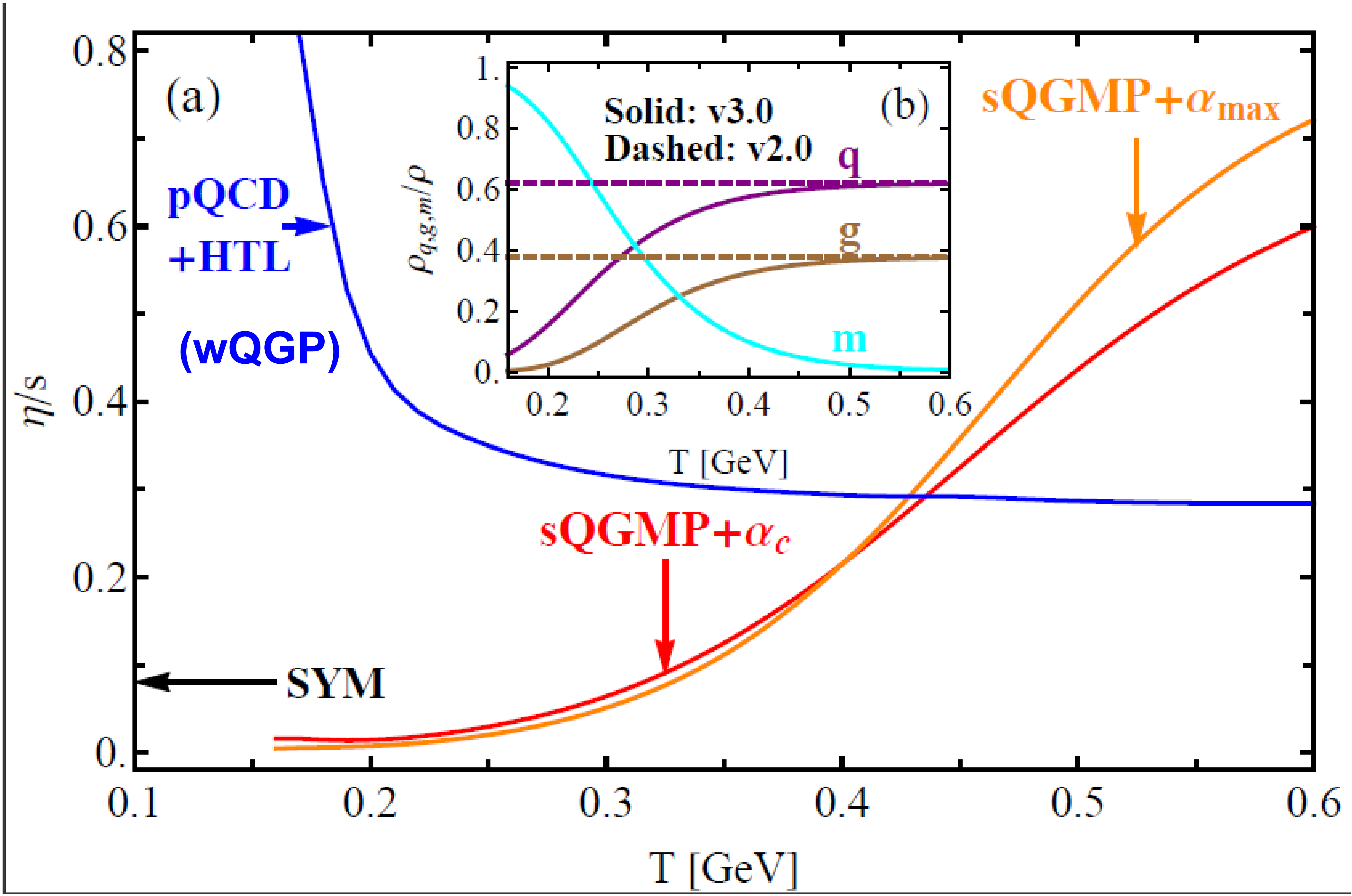
CUJET2.0 sQDP+DGLV+VISH2 $\alpha_s(Q^2) = \min[\alpha_{max}, 2\pi/9 \log(Q^2/\Lambda^2)]$

$$x\frac{dN_{Q\to Q+g}}{dx}(\mathbf{r},\phi) = \int d\tau \rho(\mathbf{r}+\hat{\mathbf{n}}(\phi)\tau,\tau) \int \frac{d^2\mathbf{q}_T}{\pi}\frac{d^2\sigma}{d^2\mathbf{q}_T} \int \frac{d^2\mathbf{k}_T}{\pi} \underline{\alpha_s(k_T^2/(x(1-x))}$$
$$\times \frac{12(\mathbf{k}_T{+}\mathbf{q}_T)}{(\mathbf{k}_T{+}\mathbf{q}_T)^2{+}\chi(\tau)} \cdot \left(\frac{(\mathbf{k}_T{+}\mathbf{q}_T)}{(\mathbf{k}_T{+}\mathbf{q}_T)^2{+}\chi(\tau)} - \frac{\mathbf{k}_T}{\mathbf{k}_T^2{+}\chi(\tau)}\right) \left(1-\cos\left[\frac{(\mathbf{k}_T{+}\mathbf{q}_T)^2+\chi(\tau)}{2x_+E}\,\tau\right]\right),$$

where the effective running differential cross section is

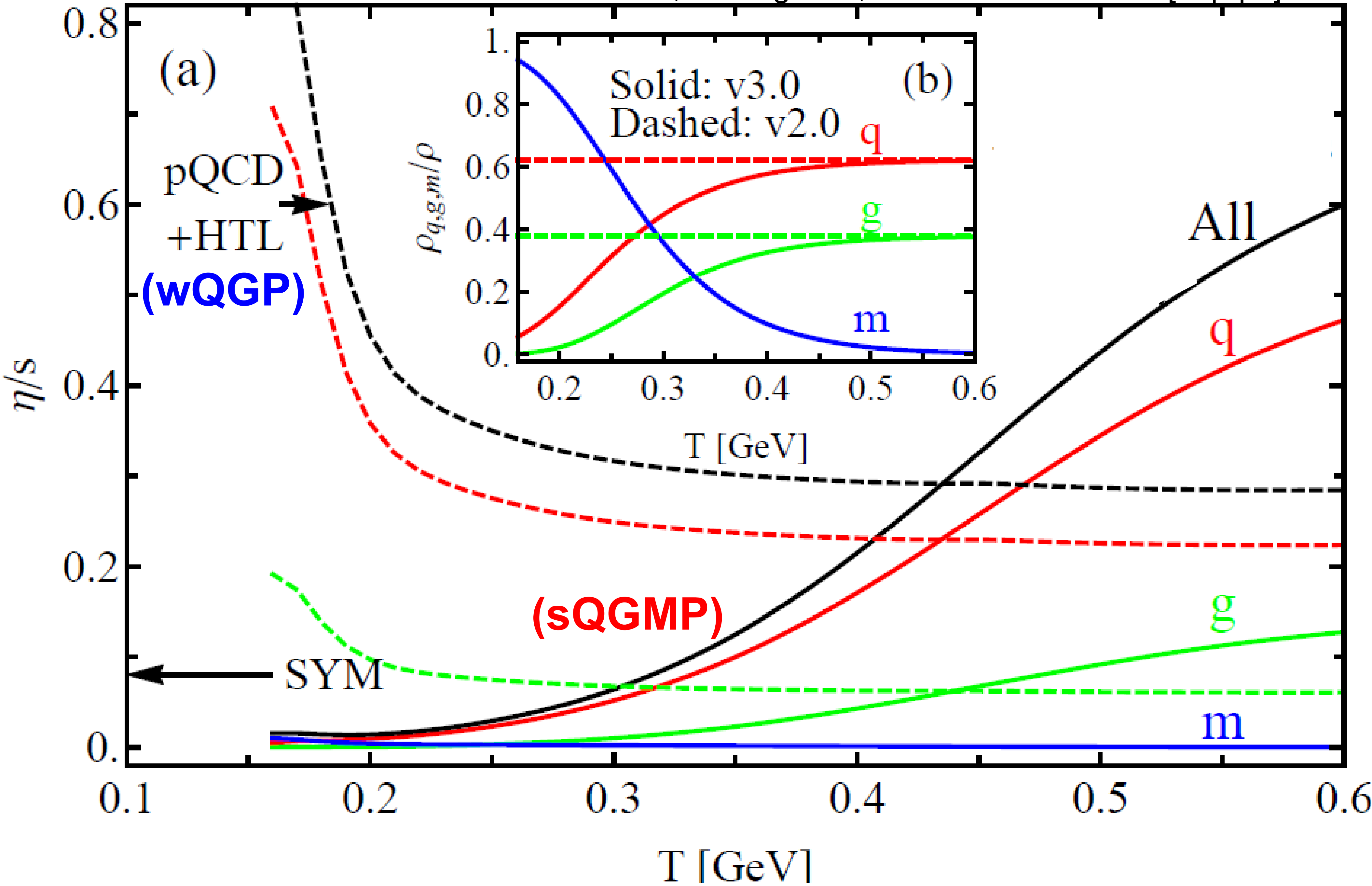
$$\frac{d^2\sigma}{d^2\mathbf{q}_T} = \frac{\underline{\alpha_s^2(\mathbf{q}_T^2)}}{(\mathbf{q}_T^2{+}f_E^2\mu^2(\tau))(\mathbf{q}_T^2{+}f_M^2\mu^2(\tau))}\,, \qquad (3)$$

that runs with both $q_T$ and the local temperature through $\mu^2(\tau) = 4\pi\underline{\alpha_s(4T^2)}T^2$ , the local HTL color electric Debye screening mass squared in a pure gluonic plasma with local temperature $T(\tau) \propto \rho^{1/3}(\mathbf{r},\tau)$ along the jet path $\mathbf{r}(\tau)$ through the plasma.


0.8
0.6
0.4
0.2
0.
$\eta/s$
(a)
pQCD
+HTL
(wQGP)
SYM
sQGMP+$\alpha_c$
sQGMP+$\alpha_{max}$
0.1
0.2
0.3
0.4
0.5
0.6
T [GeV]
1.
0.8
0.6
0.4
0.2
0.
$\rho_{q,g,m}/\rho$
Solid: v3.0
Dashed: v2.0
(b)
q
g
m
0.2
0.3
0.4
0.5
0.6
T [GeV]

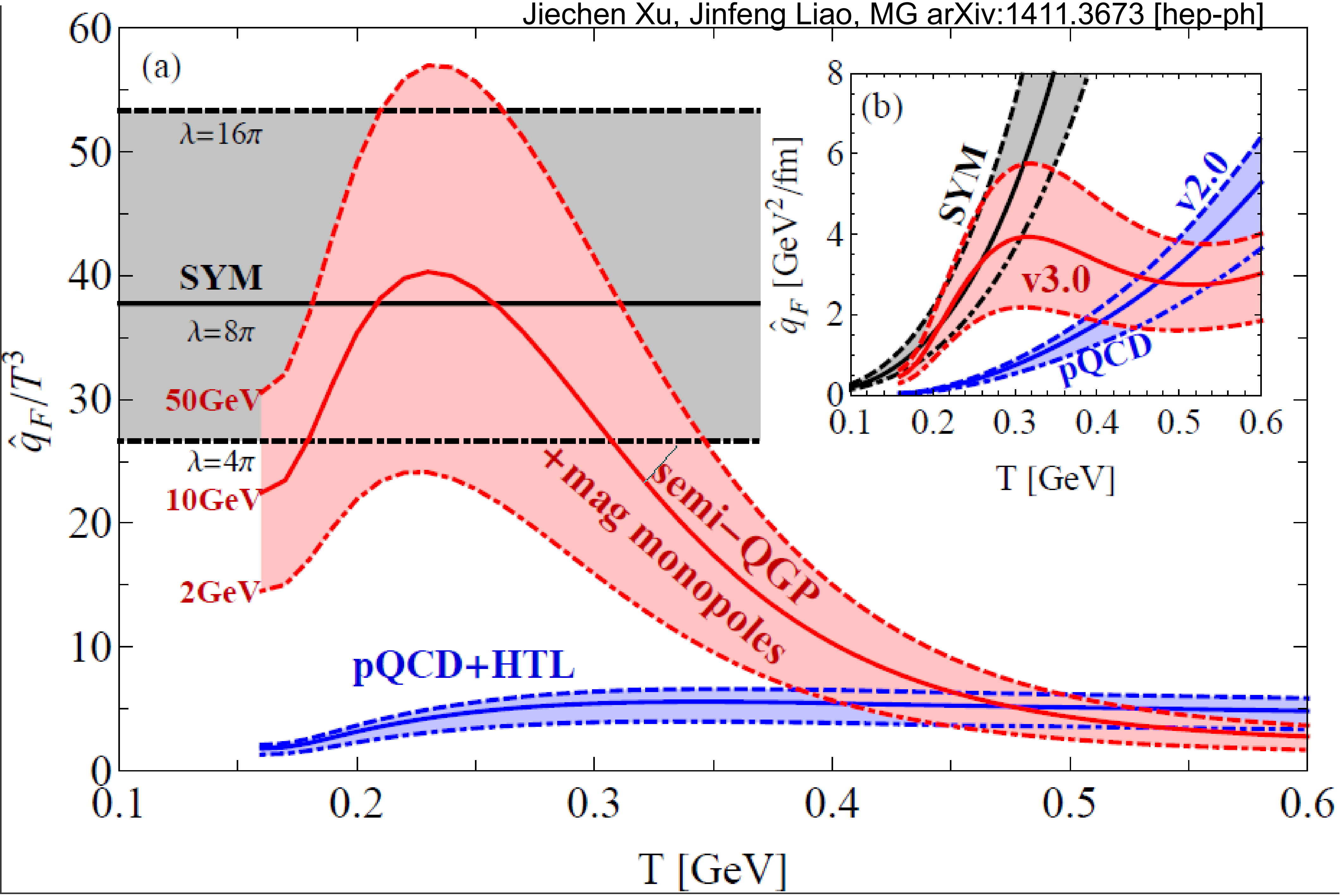
CUJET 2.0 vs 3.0 result fig 1: eta/s > 0.3 wQGP vs eta/s < 0.1 sQGMP for T< 300 MeV

Jiechen Xu, Jinfeng Liao, MG arXiv:1411.3673 [hep-ph]



# sQGMP interpolates between conformal pQCD and AdS limits Non-Conformally in T~ (1-2)Tc

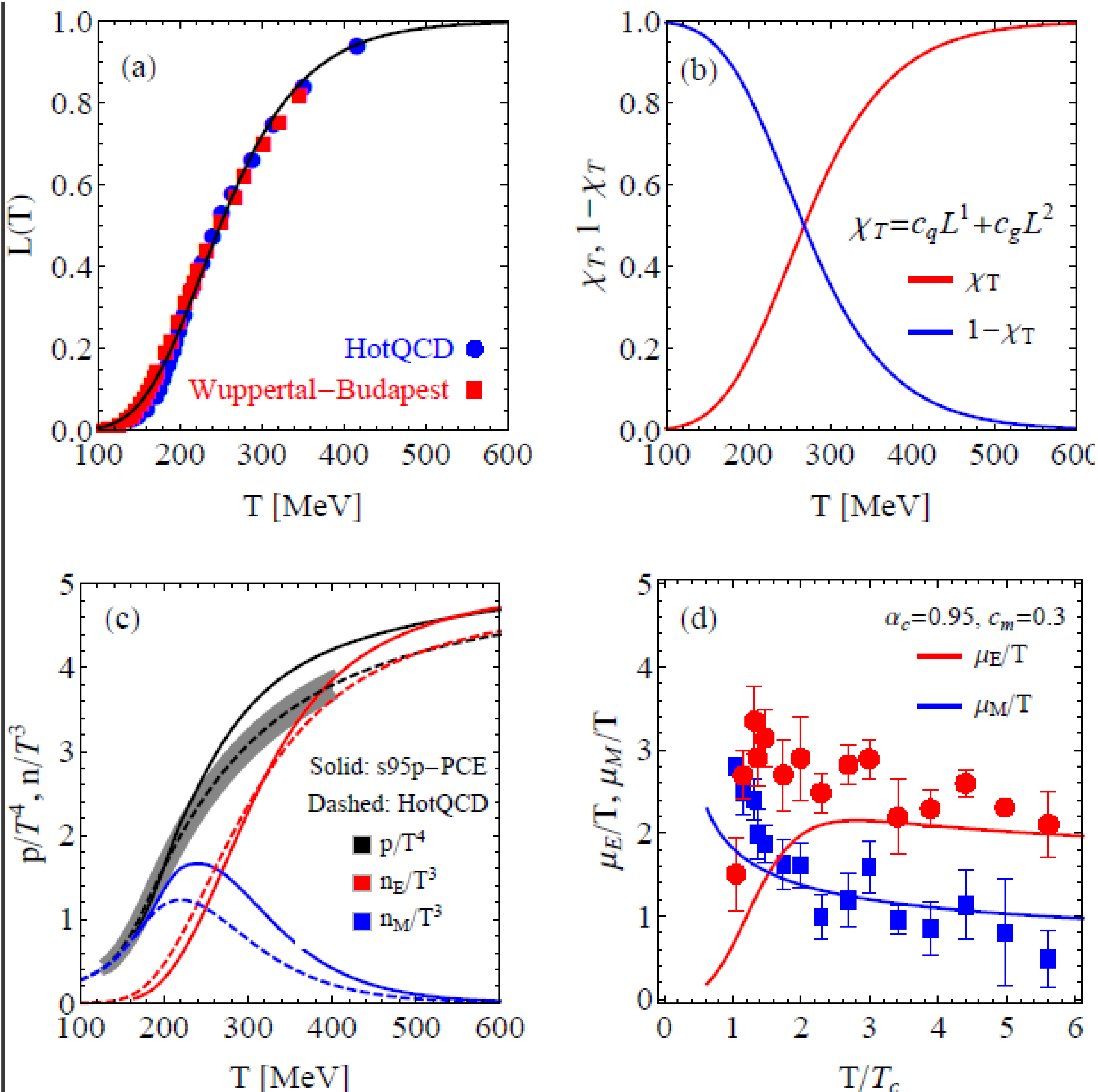
Jiechen Xu, Jinfeng Liao, MG arXiv:1411.3673 [hep-ph]



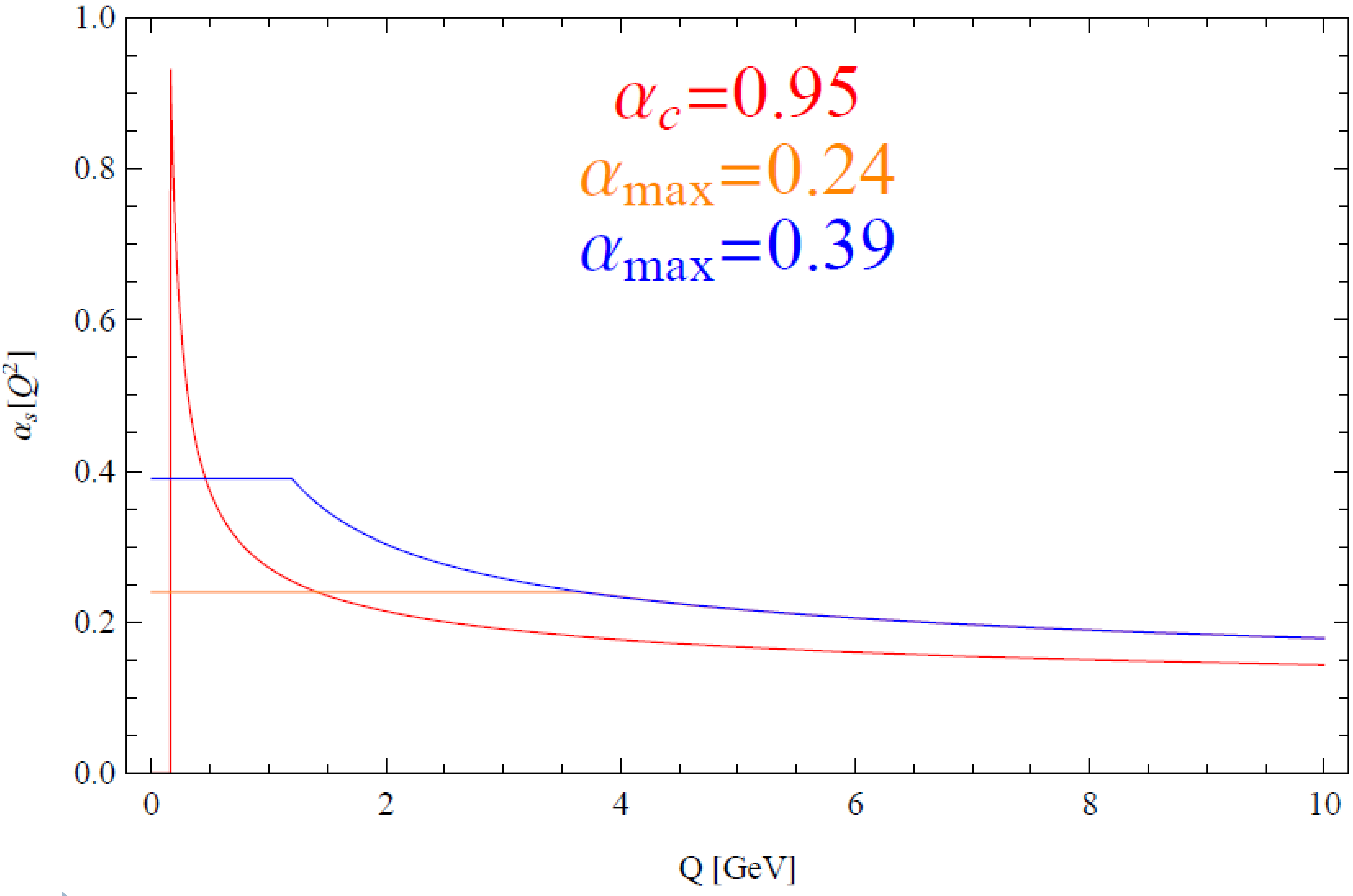
Lattice QCD
Input data to

CUJET3.0
XLG, **1411.3673v2**
**Result Fig.3**

Only parameter
Ro be fixed by
RAA(pt=10) LHC
Is
alpha_max



The running coupling model choices in CUJET3



# CUJET3.0 = CUJET2.0 + semi-QGP + Mag. Monopoles

We now include both color-electric and color-magnetic scattering centers.

Original DGLV has only quark/gluon scattering centers

$$\frac{dE}{dx} \propto \dots \int_{q^2} \left[ \frac{n_e \boxed{(\alpha_s(q^2)\alpha_s(q^2))}\, f_E^2}{q^2(q^2+f_E^2\mu^2)} + \frac{n_m \boxed{(\alpha_s^e(q^2)\alpha^m(q^2))}\, f_M^2}{q^2(q^2+f_M^2\mu^2)} \right] \dots$$

$$\frac{dE}{dx} \propto \dots \int_{q^2} \frac{n_e\, \alpha_s^2(q^2)\, f_E^2}{q^2(q^2+f_E^2\mu^2)} \dots$$

$$\frac{dE}{dx} \propto \dots \int_{q^2} \frac{n_T}{(q^2+f_E^2\mu^2)(q^2+f_M^2\mu^2)} \times \kappa(q^2,T)$$

=1, by Dirac Quantization

$$\kappa(q^2,T) \equiv \boxed{\alpha_s^2(q^2)}\,\chi_T \left(f_E^2 + \frac{f_E^2 f_M^2 \mu^2}{q^2}\right) + (1-\chi_T)\left(f_M^2 + \frac{f_E^2 f_M^2 \mu^2}{q^2}\right)$$

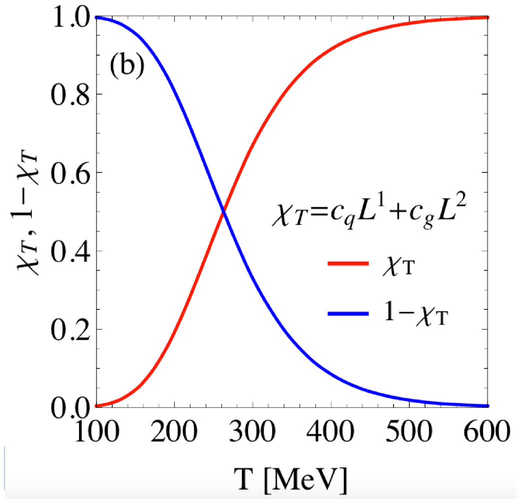
$$\chi_T = c_q\, L + c_g\, L^2$$

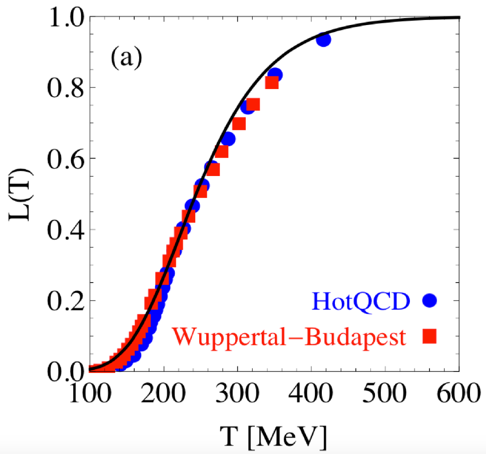
Polyakov Loop suppressed color electric component

$$f_E = \sqrt{\chi_T}$$

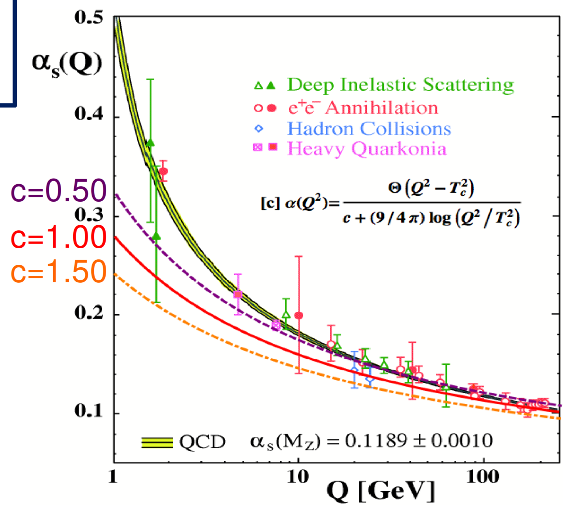
$$f_M = C_m\, g_T$$

$$L(\mathbf{x}) = \frac{1}{N_c} \mathrm{tr}\mathcal{P} \exp\left[ig \int_0^{1/T} A_4(\tau,\mathbf{x})d\tau\right]$$





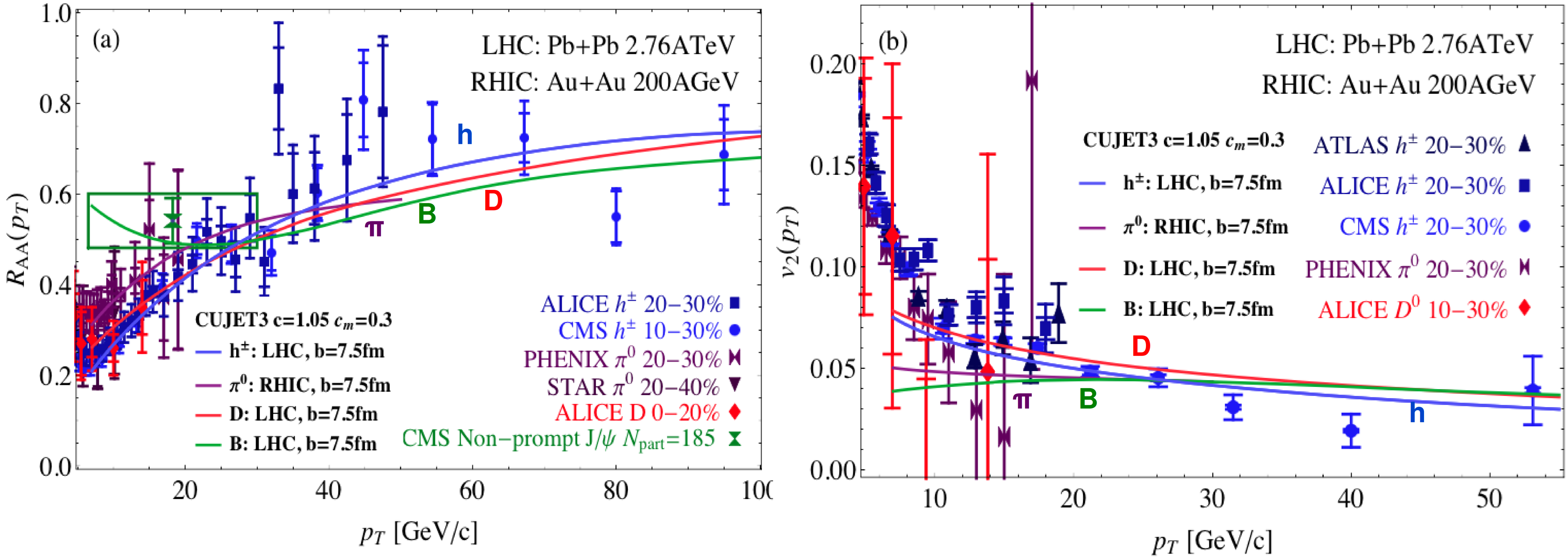
Bazavov et al., PRD 80 (2009)
Borsanyi et al., JHEP 09 (2010)



$$\alpha_s^2(q^2) \approx [1/[c + (9/2\pi)Log(q/\Lambda)]]^2$$

c = 1/alf_max is THE free param

# CUJET3.0 with sQGMP simultaneously describes (RHIC+LHC) * ($R_{AA}$+$v_2$) * (light + heavy)



JX, J. Liao, M. Gyulassy, arXiv:1411.3673

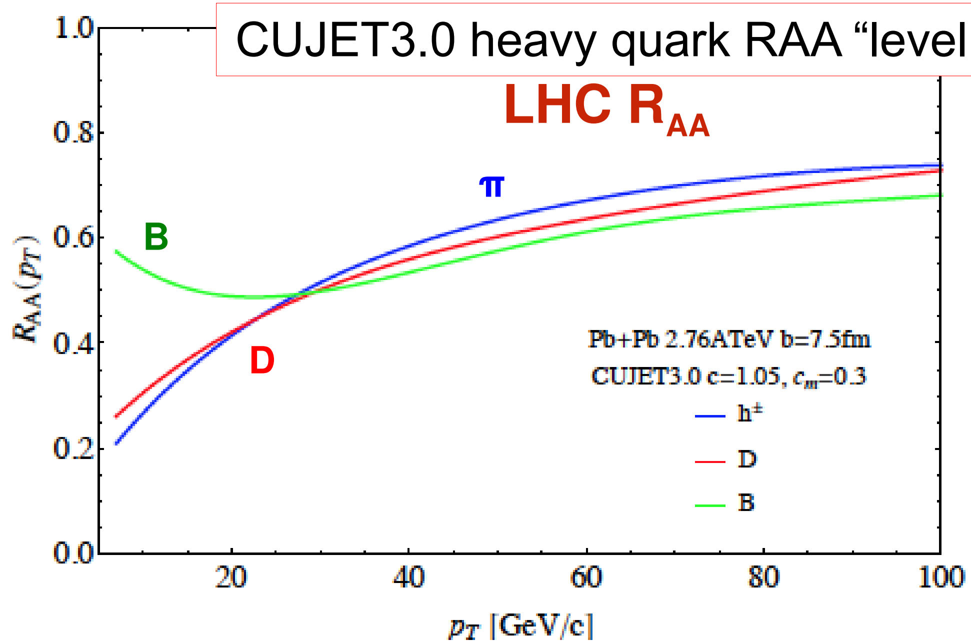
The combined set of observables

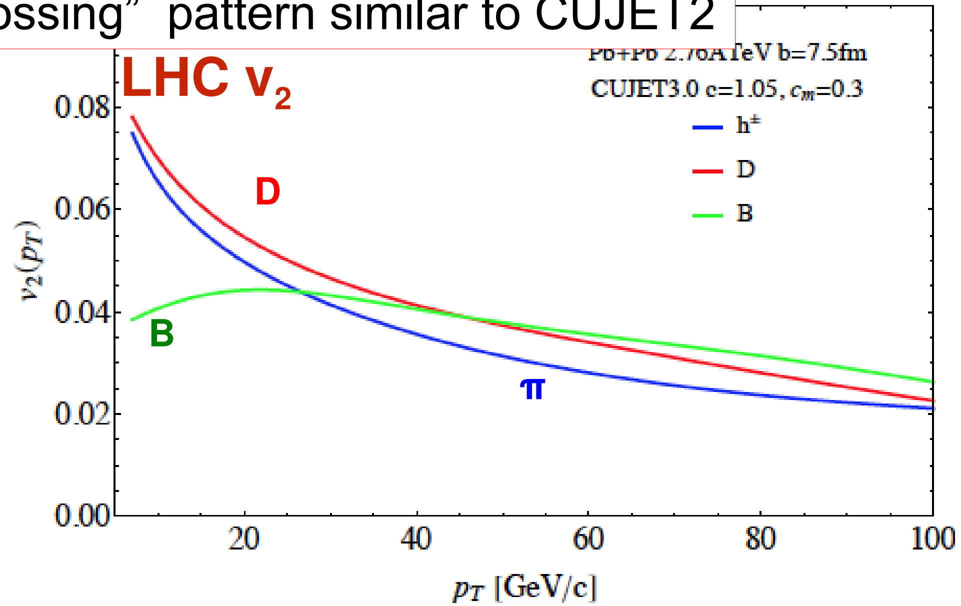
***(RHIC+LHC) * ($R_{AA}$+$V_2$) * (pion+D+B)***

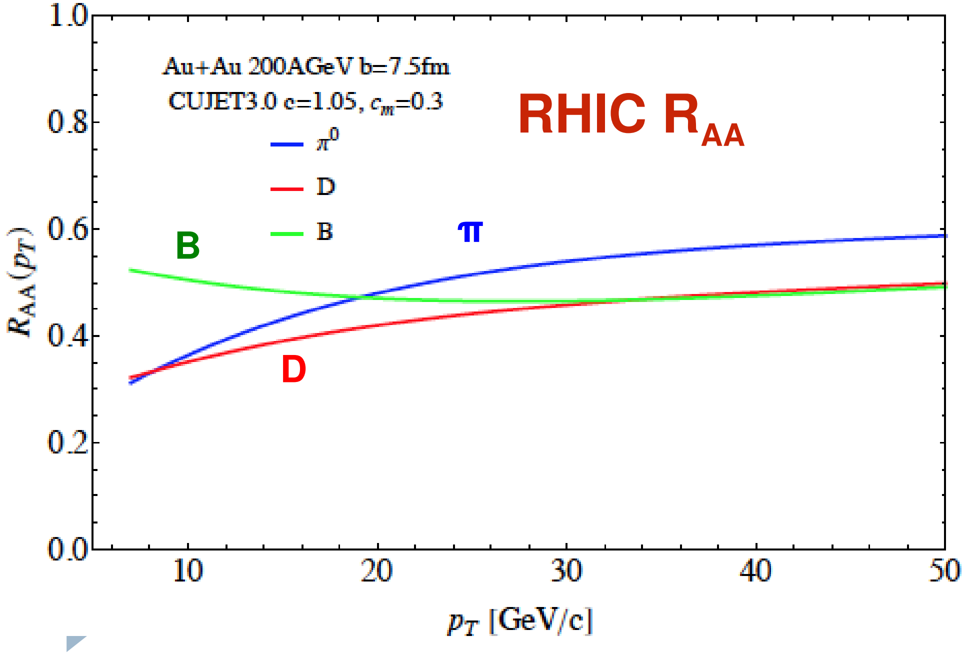
are consistently accounted for (within present experimental errors) in the CUJET3.0 sQGMP framework using lattice QCD constrained near-Tc enhanced jet-medium coupling and a VISH2+1 evolved semi-QGMP decomposition that reduces to HTL wQGP at high T>3Tc

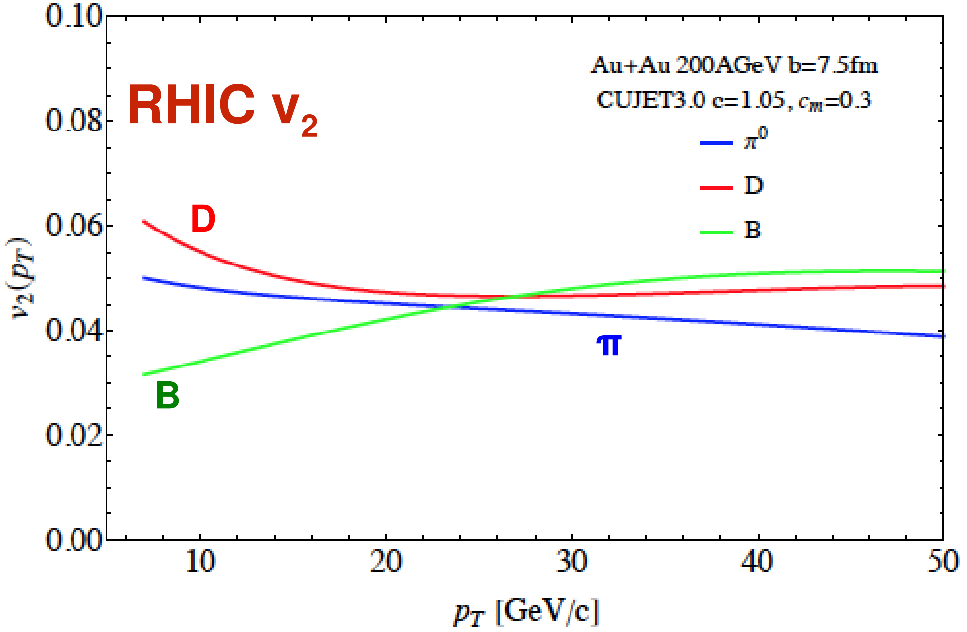
# Open charm and beauty at high $p_T$ $R_{AA}$ and $v_2$ at RHIC and LHC (20-30% centrality) from CUJET3.0

CUJET3.0 heavy quark RAA “level crossing”  pattern similar to CUJET2

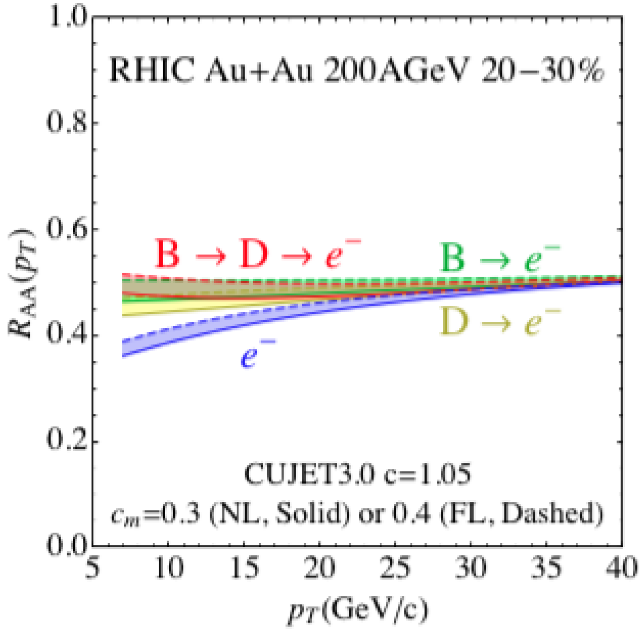


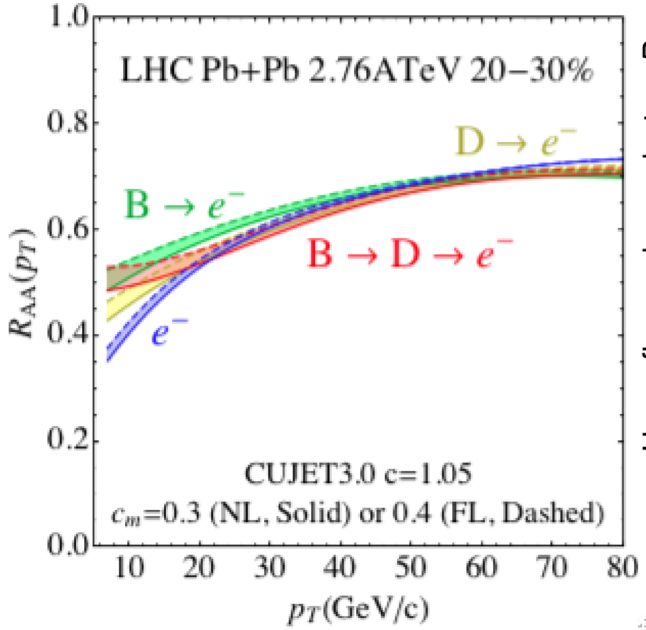


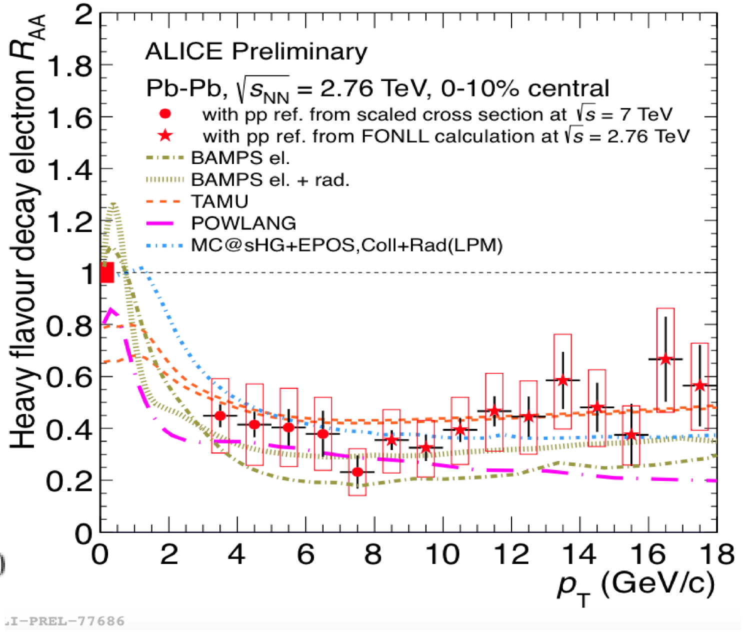


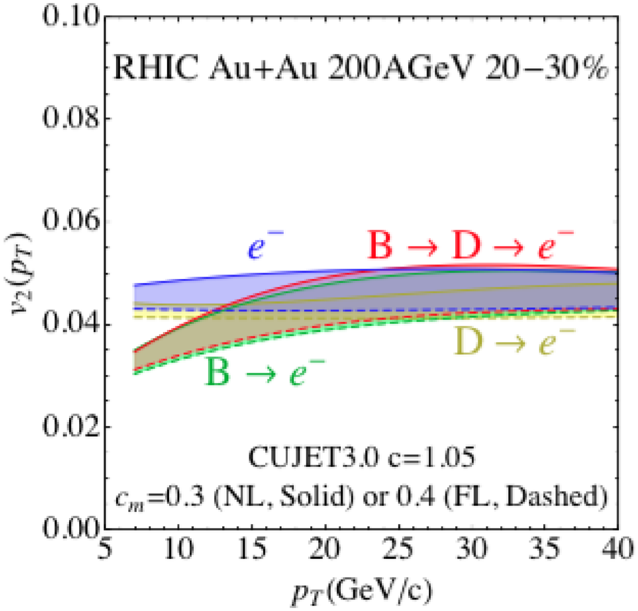


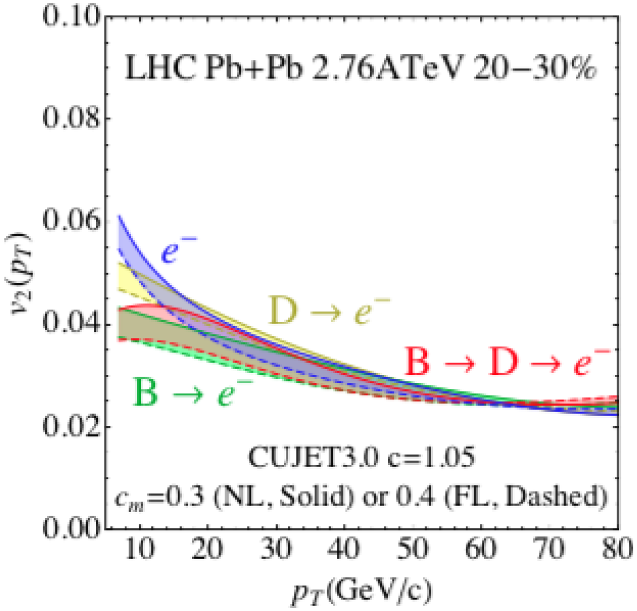
# CUJET3.0: HF Decay Electron RAA & v2

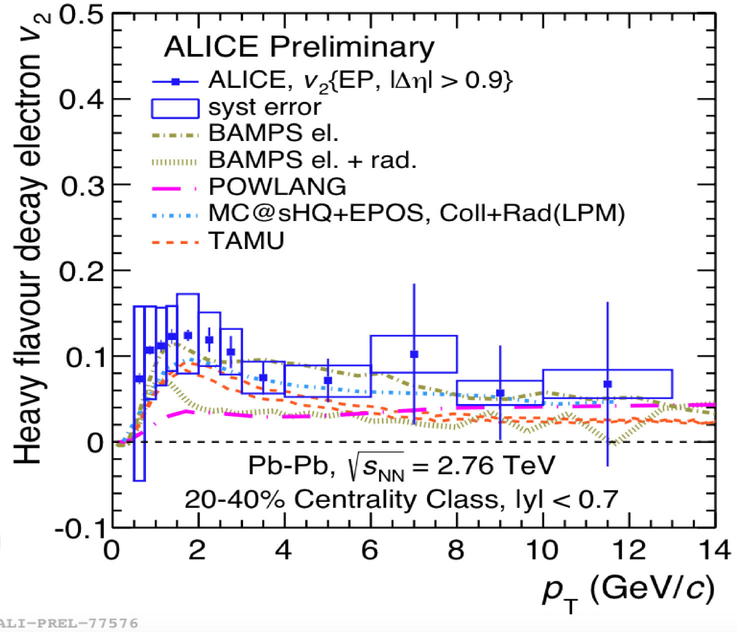












❖ To be compared with data

Summary :

(1) The combined 12 sets of observables,

(RHIC + LHC) * (RAA + V2) * (pion + D + B),

are consistently accounted in the CUJET3.0 sQGMP framework
using a lattice QCD constrained Q, G and M decomposition
of bulk constrained VISH2+1 hydrodynamic evolved fluids.

(2) Most remarkably, for the first time, the CUJET3.0 framework
Can solve the past apparent paradoxical inconsistency between previous
perturbative QCD based high E>10 jet transport field, qhat(E,T),
and the small kinetic theory eta/s (~ sum n_a/qhat_a(3T , T) )
needed to account for bulk "Perfect Fluidity".
In sQGMP is due to the 1/alf_s enhancement of color electric interactions
with emergent nonabelian color magnetic monopoles near Tc together
With the Polyakov line suppression of color electric components