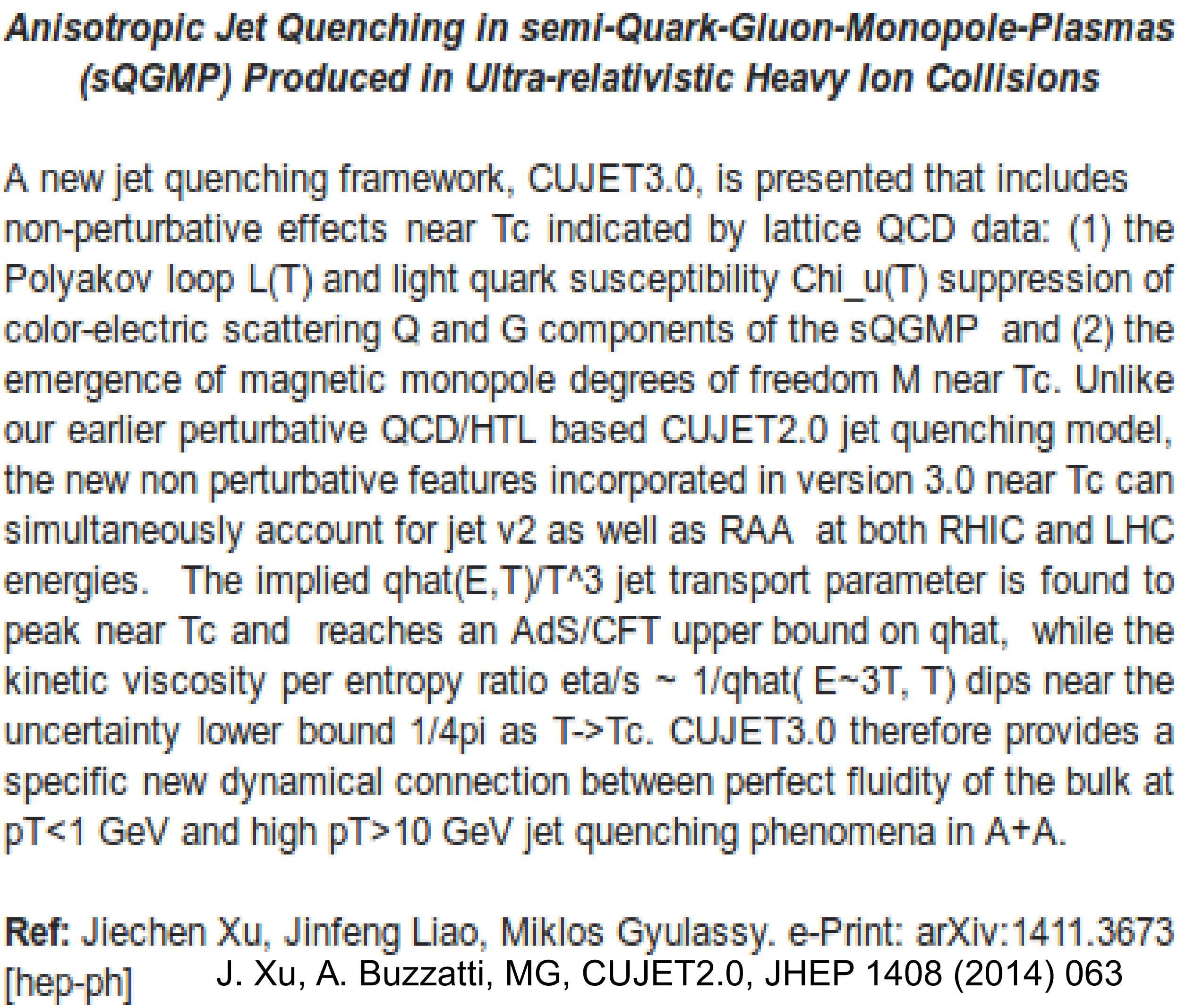
The Strongly Coupled Quark-Gluon-Monopole Plasma (sQGMP) as viewed through jet v2 at RHIC and LHC



Anisotropic Jet Quenching in semi-Quark-Gluon-Monopole-Plasmas (sQGMP) Produced in Ultra-relativistic Heavy Ion Collisions

A new jet quenching framework, CUJET3.0, is presented that includes non-perturbative effects near Tc indicated by lattice QCD data: (1) the Polyakov loop L(T) and light quark susceptibility Chi_u(T) suppression of color-electric scattering Q and G components of the sQGMP and (2) the emergence of magnetic monopole degrees of freedom M near Tc. Unlike our earlier perturbative QCD/HTL based CUJET2.0 jet quenching model, the new non perturbative features incorporated in version 3.0 near Tc can simultaneously account for jet v2 as well as RAA at both RHIC and LHC energies. The implied qhat(E,T)/T^3 jet transport parameter is found to peak near Tc and reaches an AdS/CFT upper bound on qhat, while the kinetic viscosity per entropy ratio eta/s ~ 1/qhat(E~3T, T) dips near the uncertainty lower bound 1/4pi as T->Tc. CUJET3.0 therefore provides a specific new dynamical connection between perfect fluidity of the bulk at pT<1 GeV and high pT>10 GeV jet quenching phenomena in A+A.

Ref: Jiechen Xu, Jinfeng Liao, Miklos Gyulassy. e-Print: arXiv:1411.3673 [hep-ph]

J. Xu, A. Buzzatti, MG, CUJET2.0, JHEP 1408 (2014) 063

Miklos Gyulassy
(Columbia University)

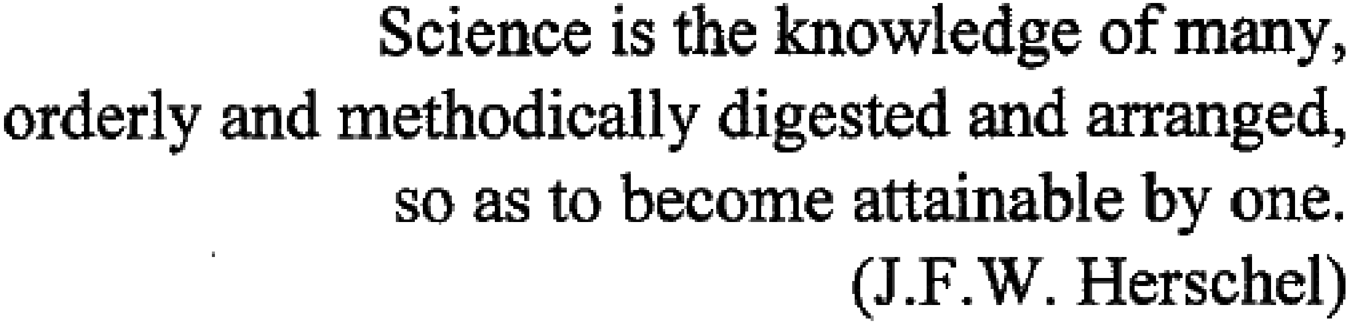
In collaboration with

Jiechen Xu

Jinfeng Liao
(Indiana U
& RBRC)

Magnetic Component of Quark-Gluon Plasma is also a Liquid!
Jinfeng Liao, Edward Shuryak, Phys.Rev.Lett. 101 (2008) 162302

Part 1: Acknowlegments:



> Science is the knowledge of many,
> orderly and methodically digested and arranged,
> so as to become attainable by one.
> (J.F.W. Herschel)

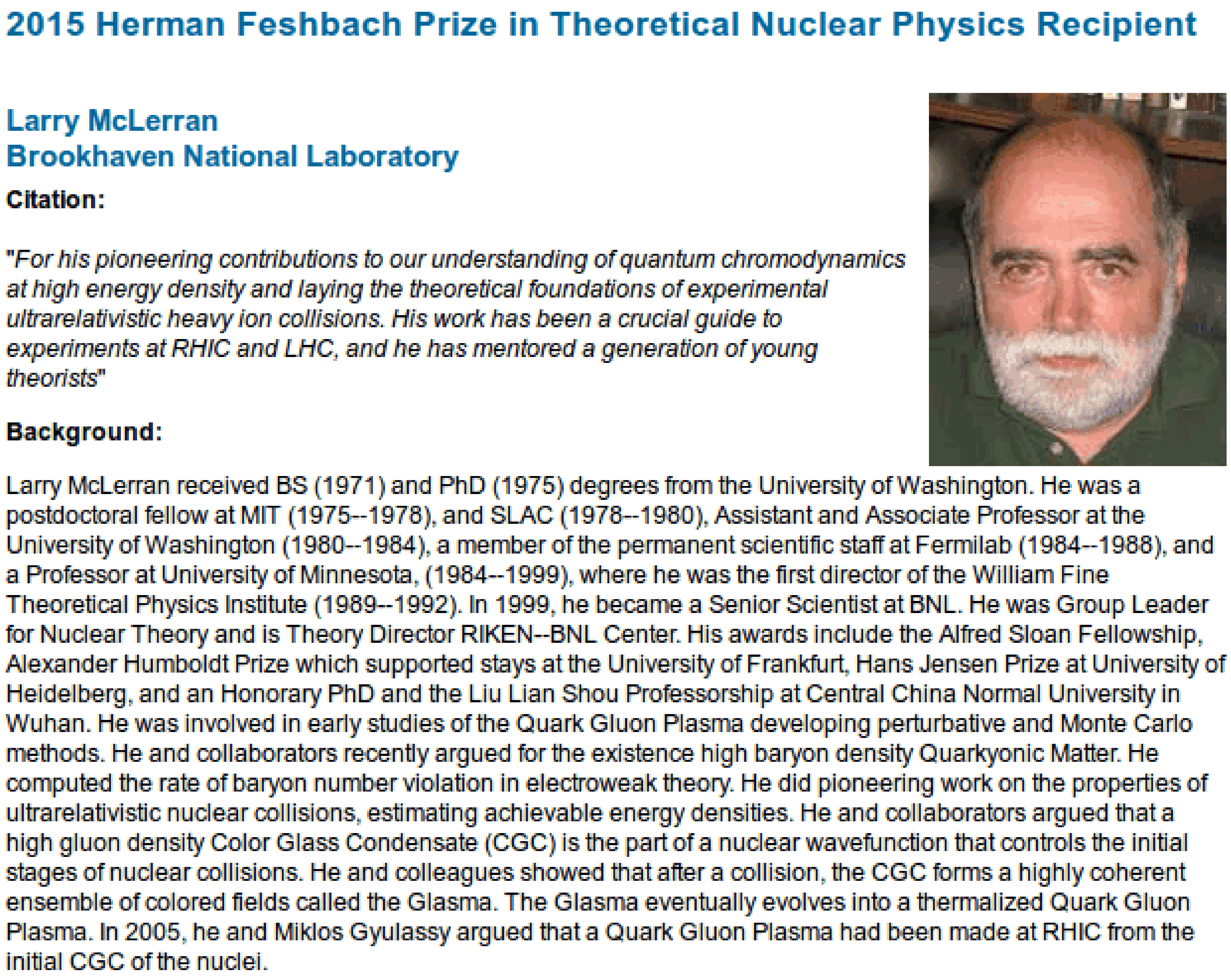
Celebrating T. W. Bonner Prizes in the field of the High Energy AA Field

and the appointment Professor B. Jacak at UCB and as NSD/LBL division head

2008 2015 UCB&NSD 2015 2014

"For developing foundational experimental and theoretical tools to enable and guide generations of experiments in relativistic heavy ion physics. The combination of experiment and theory led to the initial discoveries at RHIC, ongoing precision studies of the properties of hot nuclear matter, and to exploration of the nuclear matter phase diagram."

Another cause for celebration in 2015 for the High Energy AA Field of Nuclear Science



2015 Herman Feshbach Prize in Theoretical Nuclear Physics Recipient

Larry McLerran
Brookhaven National Laboratory

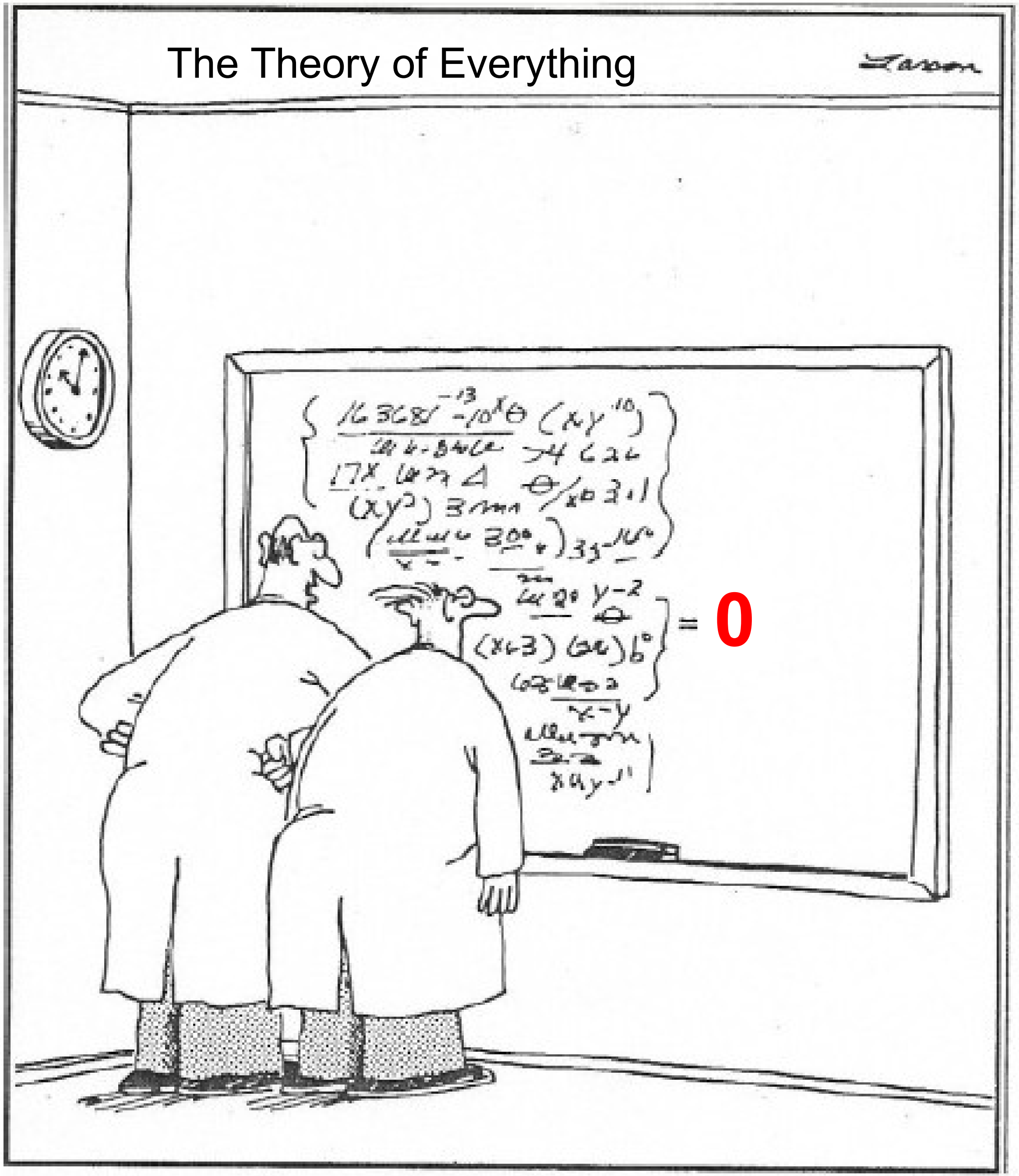
Citation:

"For his pioneering contributions to our understanding of quantum chromodynamics at high energy density and laying the theoretical foundations of experimental ultrarelativistic heavy ion collisions. His work has been a crucial guide to experiments at RHIC and LHC, and he has mentored a generation of young theorists"

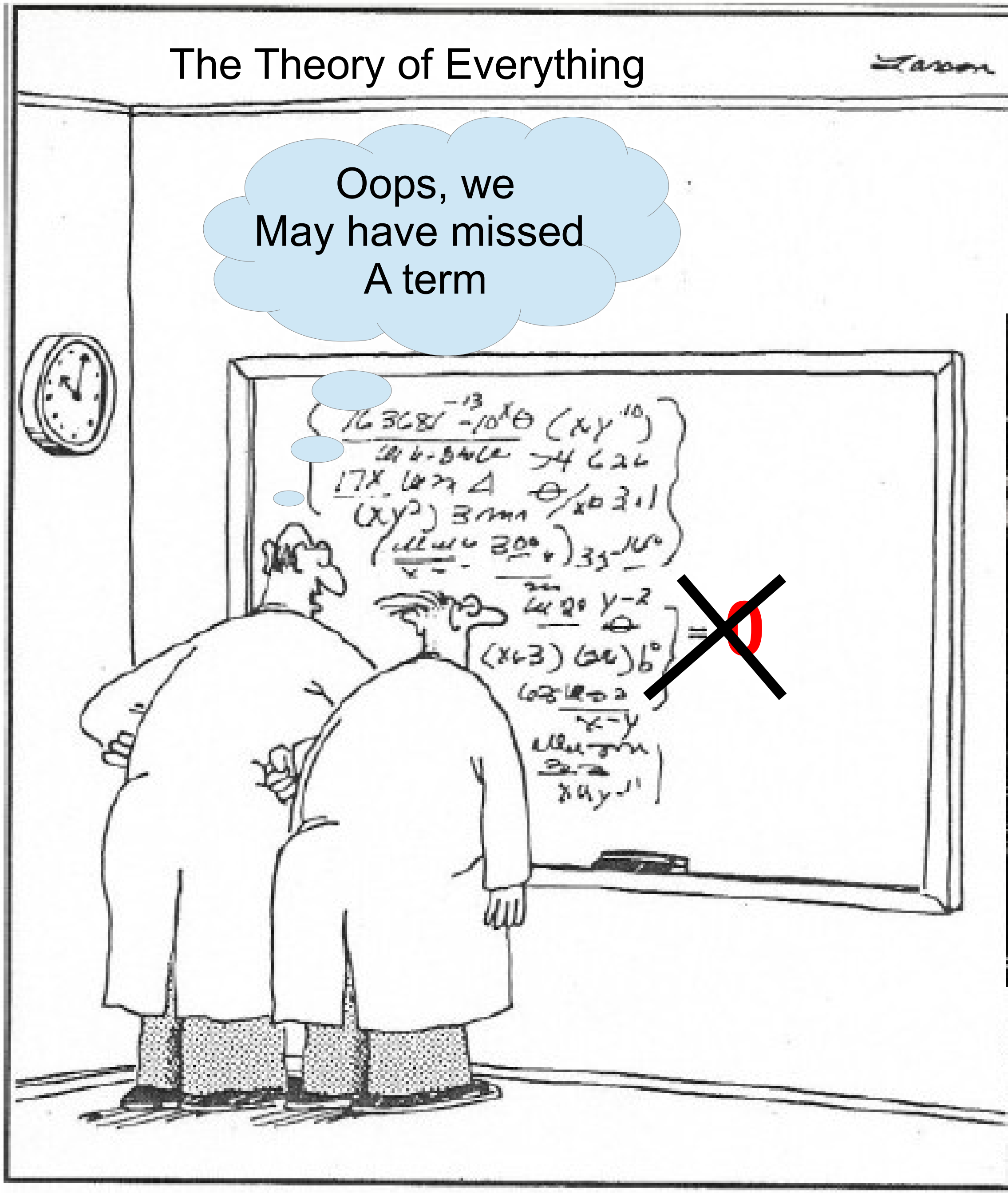
Background:

Larry McLerran received BS (1971) and PhD (1975) degrees from the University of Washington. He was a postdoctoral fellow at MIT (1975--1978), and SLAC (1978--1980), Assistant and Associate Professor at the University of Washington (1980--1984), a member of the permanent scientific staff at Fermilab (1984--1988), and a Professor at University of Minnesota, (1984--1999), where he was the first director of the William Fine Theoretical Physics Institute (1989--1992). In 1999, he became a Senior Scientist at BNL. He was Group Leader for Nuclear Theory and is Theory Director RIKEN--BNL Center. His awards include the Alfred Sloan Fellowship, Alexander Humboldt Prize which supported stays at the University of Frankfurt, Hans Jensen Prize at University of Heidelberg, and an Honorary PhD and the Liu Lian Shou Professorship at Central China Normal University in Wuhan. He was involved in early studies of the Quark Gluon Plasma developing perturbative and Monte Carlo methods. He and collaborators recently argued for the existence high baryon density Quarkyonic Matter. He computed the rate of baryon number violation in electroweak theory. He did pioneering work on the properties of ultrarelativistic nuclear collisions, estimating achievable energy densities. He and collaborators argued that a high gluon density Color Glass Condensate (CGC) is the part of a nuclear wavefunction that controls the initial stages of nuclear collisions. He and colleagues showed that after a collision, the CGC forms a highly coherent ensemble of colored fields called the Glasma. The Glasma eventually evolves into a thermalized Quark Gluon Plasma. In 2005, he and Miklos Gyulassy argued that a Quark Gluon Plasma had been made at RHIC from the initial CGC of the nuclei.

The Theory of Everything

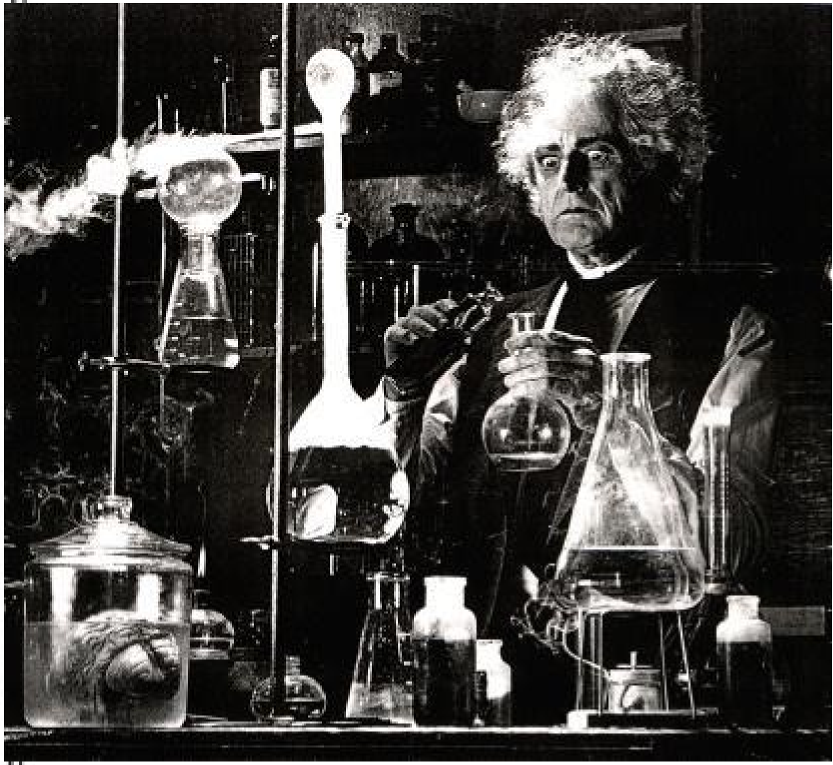


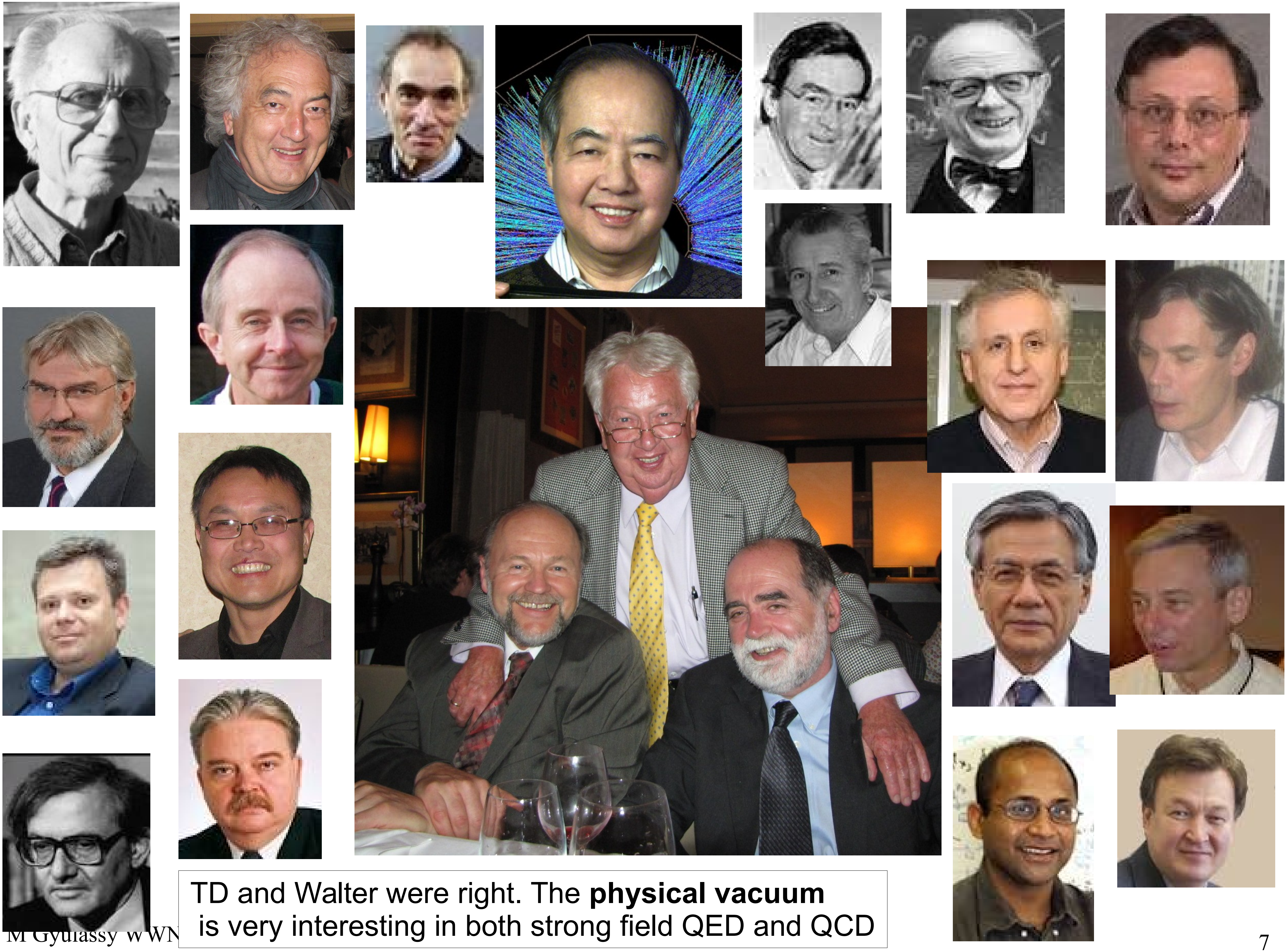
"No doubt about it, Ellington—we've mathematically expressed the purpose of the universe. Gad, how I love the thrill of scientific discovery!"



"No doubt about it, Ellington—we've mathematically expressed the purpose of the universe. Gad, how I love the thrill of scientific discovery!"

<u>But</u> Experimentalists
Always have the Last Word
In Physics





TD and Walter were right. The **physical vacuum** is very interesting in both strong field QED and QCD

> Science is the knowledge of many,
> orderly and methodically digested and arranged,
> so as to become attainable by one.
> (J.F.W. Herschel)

Xin-Nian and I joined forces during 1990 BNL Workshop on RHIC
and somehow we got to be coauthors on
John Harris' and **38** experimentalists including **Howard Weiman** , and
Tim Hallman, P. Jacobs, Art Poszkanzer, Reinhard Stock, James Symons, ….

1990 LBL-29488 a TPC exp proposal (later STAR)
“Concept for an experiment on particle and jet production at mid-rapidity “

“aimed to study correlations between global observables on an event by event basis and the use of hard scattering of partons as a probes of the properties of high density nuclear matter”

Xin-Nian and I wrote the first of 33 papers so far on “Jets in relativistic heavy ion collisions”
Sep 1990. 23 pp. LBL-29390 (BNL RHIC Workshop 1990:0079-102)

Over 100 theorists and 1000 experimetalists work in the AA field fo ther past 40 years

It was my luck to work at LBL , Columbia, ITP Frankfurt, RBRC/BNL, CERN, INS Tokyo, and KFKI Budapest with many

	MG's coauthors	papers	cites with
1	X.N.Wang	33	5089
2	I.Vitev	24	3303
3	P.Levai	24	1753
4	M.Djordjevic	13	1265
5	L.D.McLerran	3	1052
6	S.Wicks	9	1005
7	W.A.Horowitz	8	964
8	D.Molnar	10	959
9	D.H.Rischke	11	938
10	M.Plumer	9	936
11	Bin Zhang	12	801
12	Ben Wei Zhang	3	738
13	G.Torrieri	20	668
14	W.Greiner	11	637
15	R.Vogt	5	595
16	B.Betz	18	593
17	S.K.Kauffmann	7	593
18	Z.W.Lin	6	583
19	V.Topor.Pop	22	566
20	J.Barrette	16	531
21	K.J.Eskola	6	525
22	A.Dumitru	5	499
23	C.Gale	14	468
24	G.Papp	10	465
25	G.G.Barnafoldi	9	465
26	C.M.Ko	3	430
27	S.E.Vance	9	425
28	G.I.Fai	9	413
29	R.Venugopalan	3	389
30	P.Danielewicz	3	379
31	S.Gavin	5	372
32	H.Stoecker	16	362
33	J.Noronha	19	351
34	En.Ke.Wang	2	336
35	L.P.Csernai	5	323
36	S.Jeon	6	322
37	M.H.Thoma	3	307
38	D.Vasak	9	301
39	H.T.Elze	9	301
40	T.Hirano	3	247
41	S.Padula	12	246
42	K.A.Frankel	10	204
43	J.Zimanyi	2	141
44	A.V.Selikhov	6	131
45	A.Adil	8	123
46	A.Buzzatti	8	117
47	C.Y.Pang	4	90
48	N.Xu	3	89
49	A.Accardi	3	88
50	A.Iwazaki	3	83
51	E.A.Remler	3	59

Larry’s Physics Dynasty extends far and wide

Postdocs

Raju Venugopalan
Francois Gelis
Yoshimasa Hidaka
Kazu Itakura
Kenji Fukushima
Yoshi Hatta
Harmen Warringa
Tuomas Lappi
Anna Stasto
Takeshi Ikeda
Yuri Kovchegov
Derek Teaney
Juergen Scahffner Bielich
Adrian Dumitru
Alex Kovner
Andre Peshier
Kirill Tuchin
Sangyong Jeon

Hua Bin Tang
Heribert Weigert
Dietrich Bodeker
Axel Vischer
Rong Tai Wang
X. Q. Qang
Larry Carson
Tuomo Toimela
Peter Arnold
Ben Svetitsky
J. Van der Bij
Hiroshi Itoyama
Ashoke Sen

PhD Students

Sai Ping Li (Seattle)
Bao Hua Liu (MN)
Xu Li (MN)
Jamal Jalilian Marian (Baruch)
Alejandro Ayala Mercado (UNAM MX)
H. von Gersdorff (U.Oregon)

Jet Probes of sQGMP @ RHIC *and* LHC with RAA *and* v2

Recent attempts to establish a ***quantitative*** link between Jets and Perfect Fluidity

1) in 2013 **QCD Tomography** with CUJET2.0 = rc-DGLV + VISH2+1 results for RAA at RHIC and LHC were compared with 5 pQCD models

* JET collab PRC90(2014)014909

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

Success with RAA@RHIC&LHC, but the jet v2 “Albatross” Remained

2) 2014 CUJET3.0 = rc-DGLV + VISH2+1 + semi-QGP+ mag-Monopole = CUJET2.0+sQGMP (semi-Quark-Gluon-Monopole-Plasma)**

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

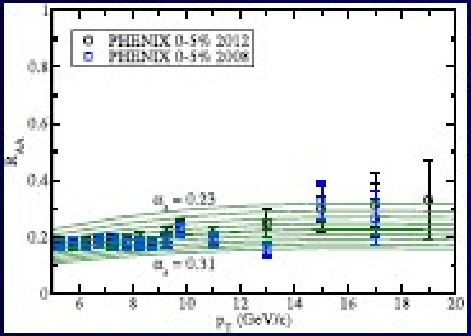
** J.Liao and E.Shuryak, PRL102(2009),PRL101(2008),PRC75(2007)

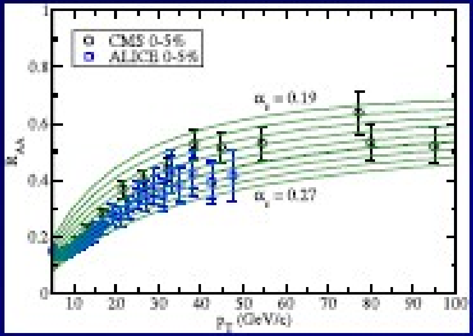
Solves v2 Problem *AND* provides a quantitative new connection between a Tc enhanced jet transport qhat(E>10GeV, T) field and minimal viscosity eta/s ~ T^3/qhat(E → 3T, T)

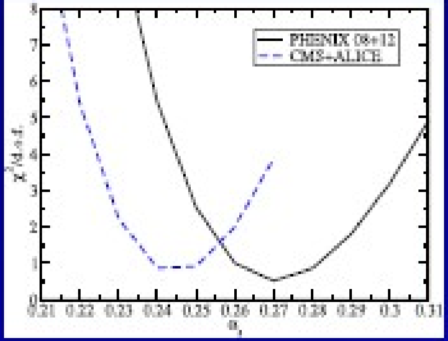
Jet quenching phenomenology

RAA @ RHIC and LHC are now quantitatively accounted for

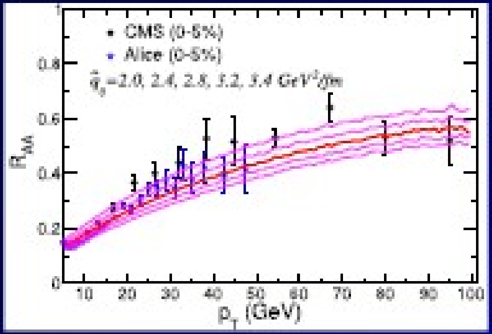
McGill-AMY

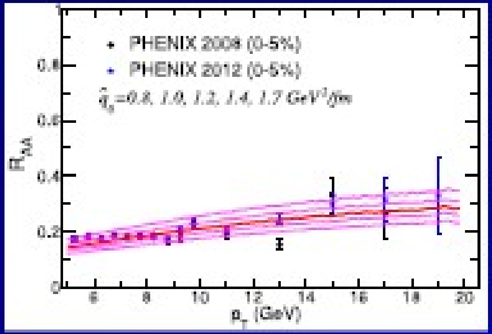


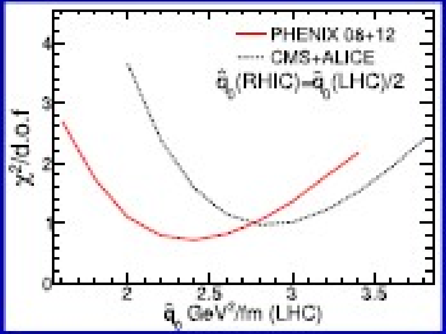




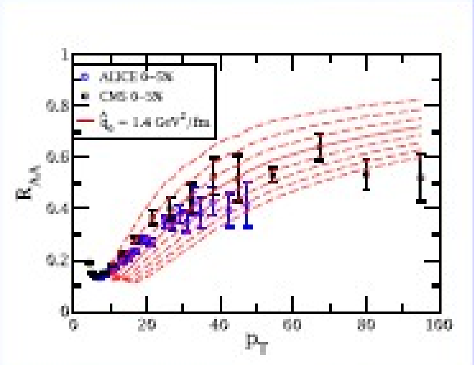
HT-BW

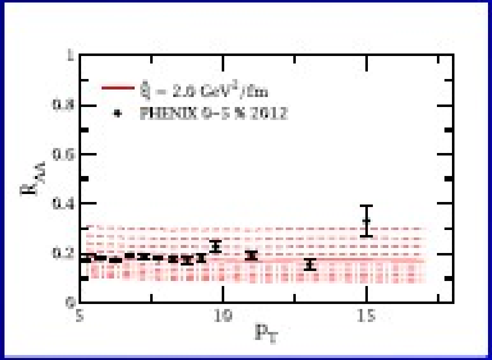


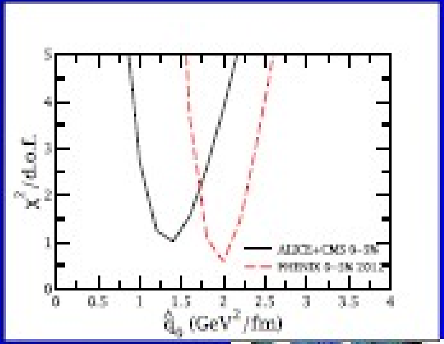




HT-M



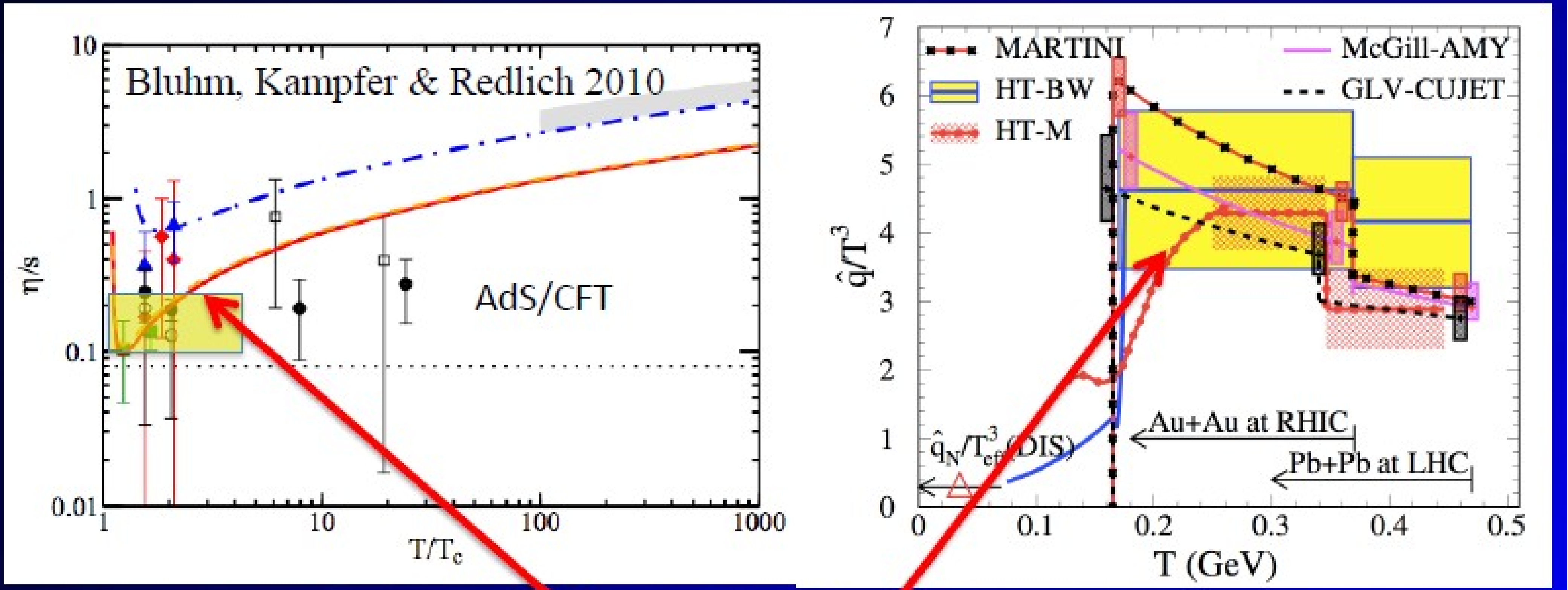




Summary

First step towards quantitative extraction of qhat from combined jet quenching at RHIC and LHC

Future: mapping out energy and T-dependence at RHIC & LHC



$$\frac{\eta}{s} \geq \frac{3T^3}{2\hat{q}}$$

Majumder, Muller & XNW (2007)

Liu et al.PRL 2006

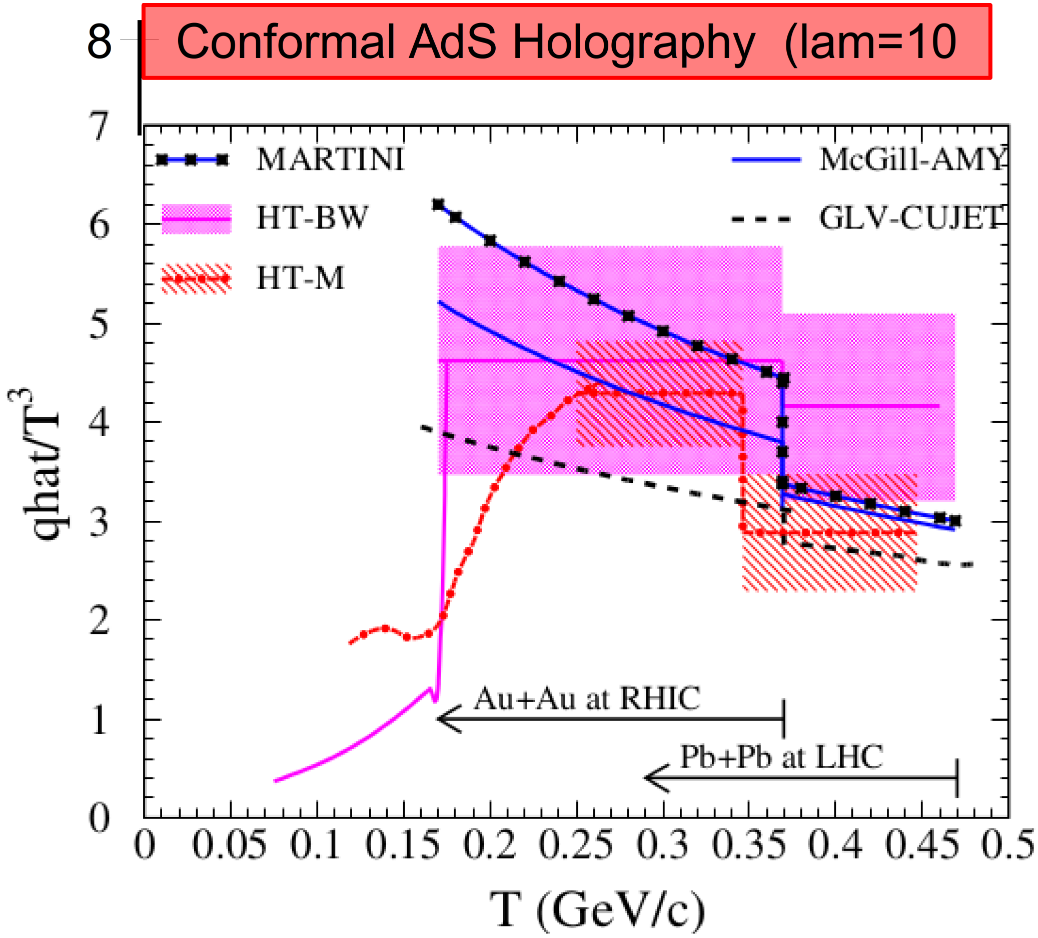


FIG. 10. (Color online) The assumed temperature dependence of the scaled jet transport parameter $\hat{q}/T^3$ in different jet quenching models for an initial quark jet with energy $E = 10$ GeV. Values of $\hat{q}$ at the center of the most central A+A collisions at an initial time $\tau_0 = 0.6$ fm/c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

AdS hybrid qhat is
Incompatible with RHIC+LHC
RAA data for pT>10 GeV

Nevertheless Conformal AdS
Minimal viscosity/entropy 1/4pi
Is consistent with pT< 2GeV
Perfect Fluidity observed at
RHIC and LHC

What is the missing link physics
Between 2-10 GeV?

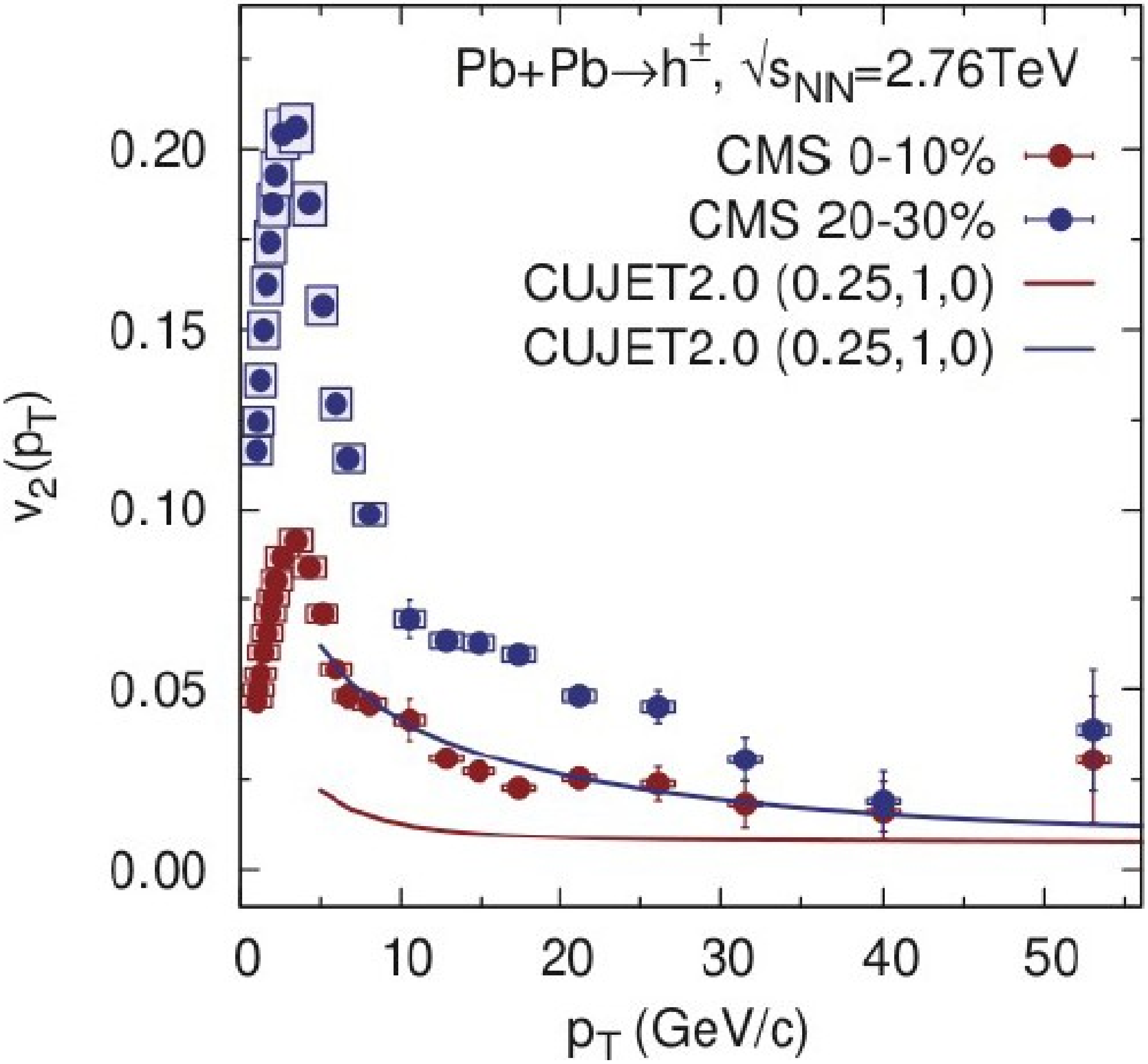
Does that physics also solve the
Jet v2 Albatross problem?

The JET collab's v2 Albatross

Is this relate to the apparent incompatibility of Perfect Fluidity with Jet Tomography?

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

CUJET2.0 's v2 Albatross

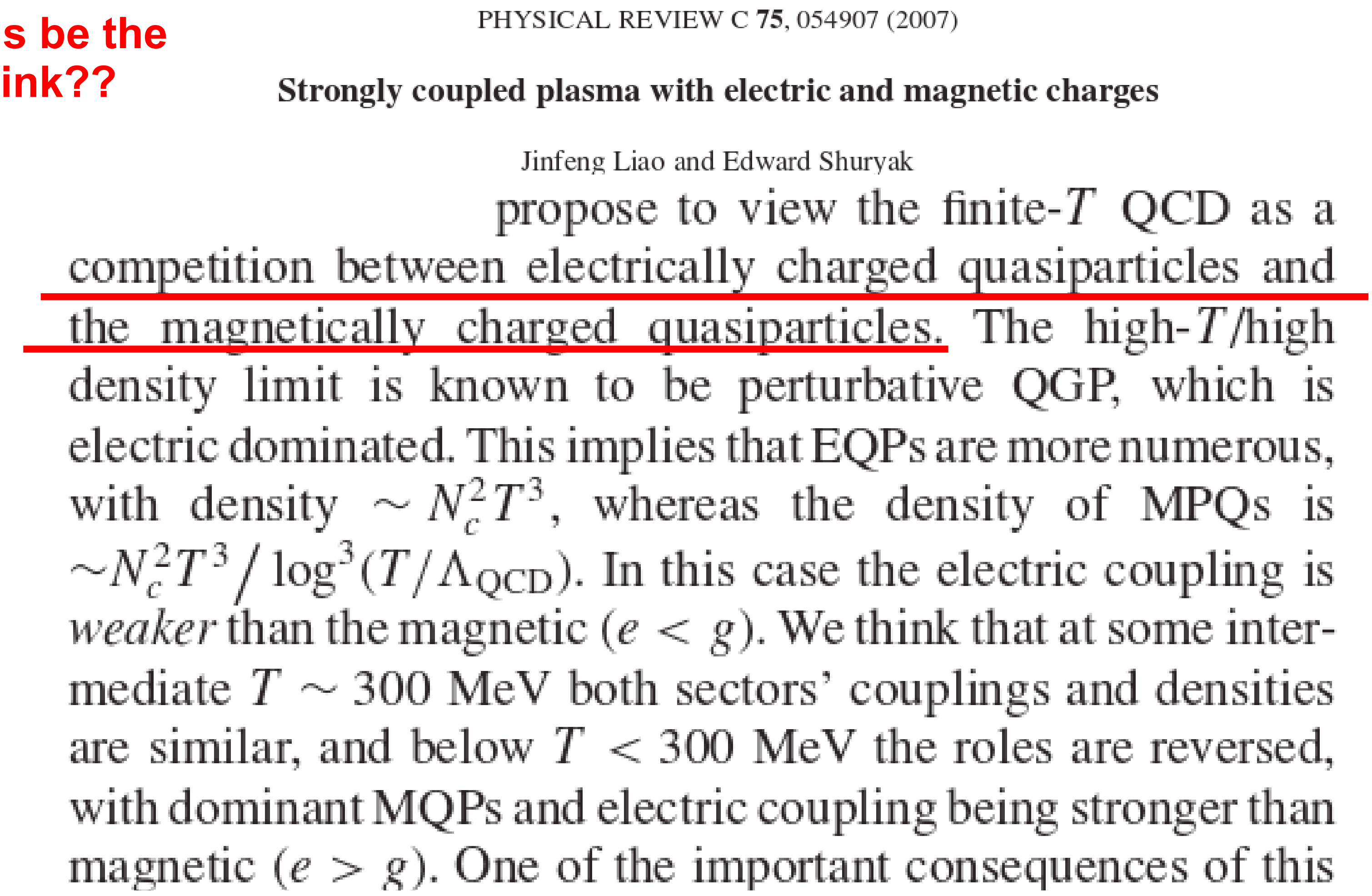


2

CUJET2.0
Significantly
Under predicts
Jet v2 at LHC

With alpha_max
Constrained by
RAA(RHIC+LHC)

Could this be the Missing link??

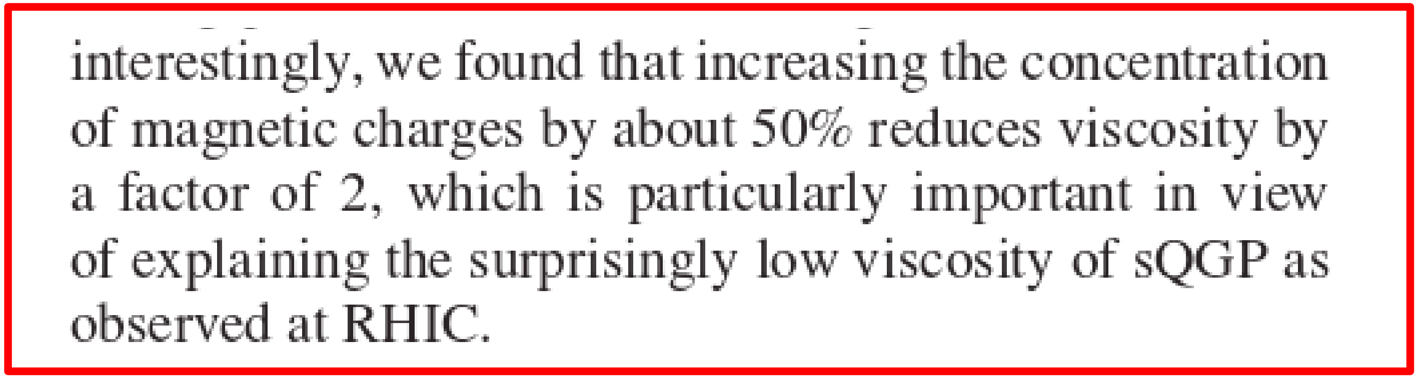


PHYSICAL REVIEW C **75**, 054907 (2007)

Strongly coupled plasma with electric and magnetic charges

Jinfeng Liao and Edward Shuryak

propose to view the finite-T QCD as a competition between electrically charged quasiparticles and the magnetically charged quasiparticles. The high-T/high density limit is known to be perturbative QGP, which is electric dominated. This implies that EQPs are more numerous, with density $\sim N_c^2 T^3$, whereas the density of MPQs is $\sim N_c^2 T^3 / \log^3(T/\Lambda_{\mathrm{QCD}})$. In this case the electric coupling is *weaker* than the magnetic ($e < g$). We think that at some intermediate $T \sim 300$ MeV both sectors' couplings and densities are similar, and below $T < 300$ MeV the roles are reversed, with dominant MQPs and electric coupling being stronger than magnetic ($e > g$). One of the important consequences of this

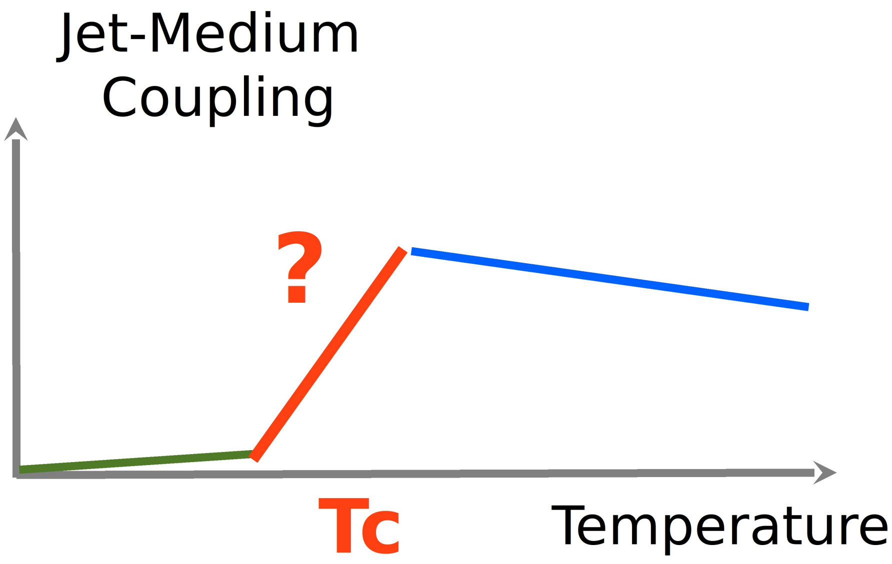


interestingly, we found that increasing the concentration of magnetic charges by about 50% reduces viscosity by a factor of 2, which is particularly important in view of explaining the surprisingly low viscosity of sQGP as observed at RHIC.

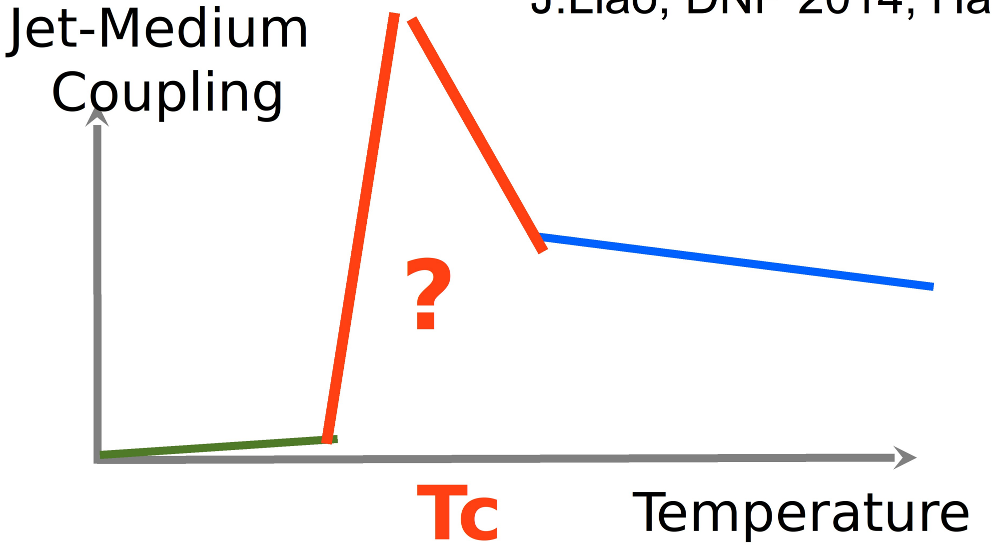
CUJET3.0 was designed to test quantitatively this proposal

Coupling from Transparency to Opaqueness

J.Liao, DNP 2014, Hawaii



“Waterfall” scenario



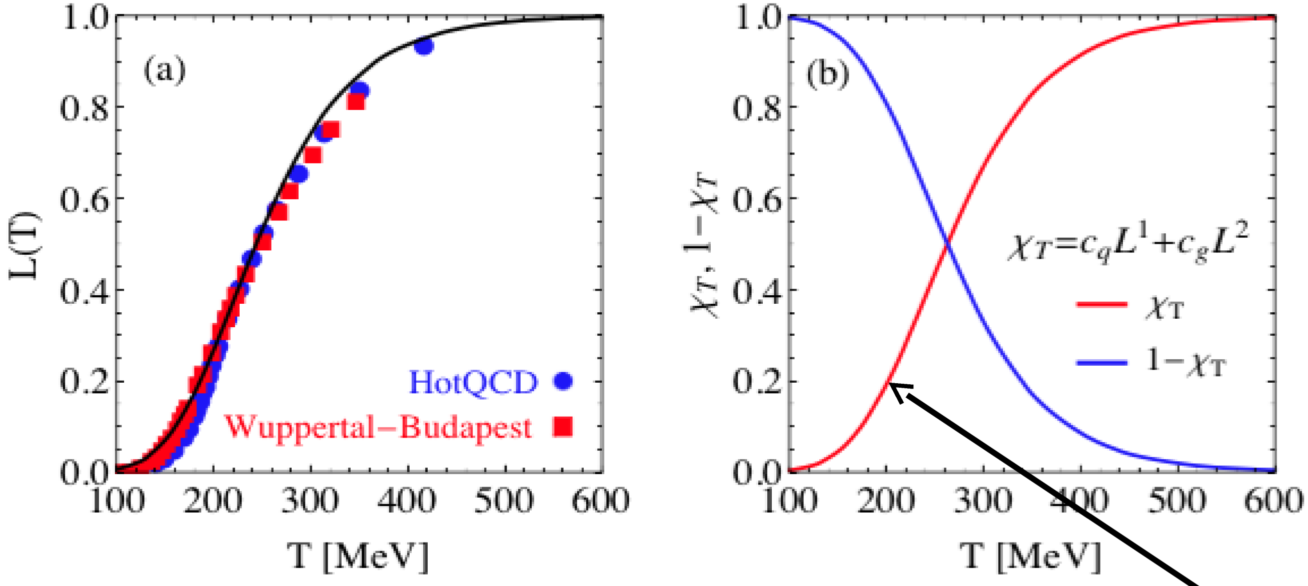
“Volcano” scenario

How does jet opacity for pT>10 GeV for T>>Tc
Connect to jet transparency for T<< Tc?
Can jet transparency for T<< Tc be reconciled with
color confinement below Tc and perfect fluidity near Tc??

Lattice QCD data: Polyakov Loop, EOS, and Screening Masses

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

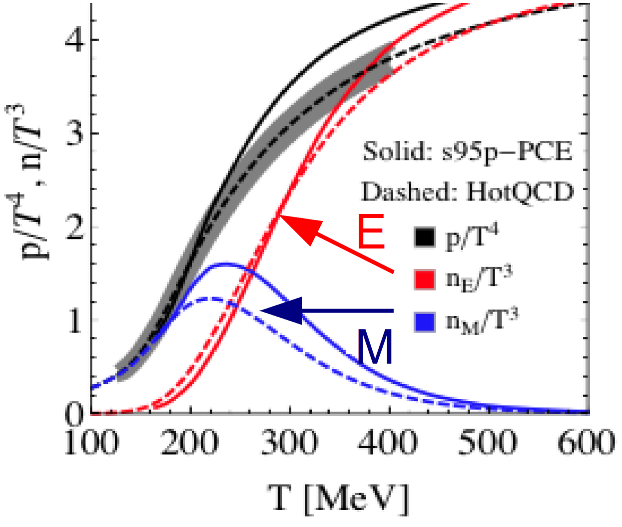
$$L(T) = \left[\tfrac{1}{2} + \tfrac{1}{2}Tanh[0.00769(T-72.6)]\right]^{10}$$

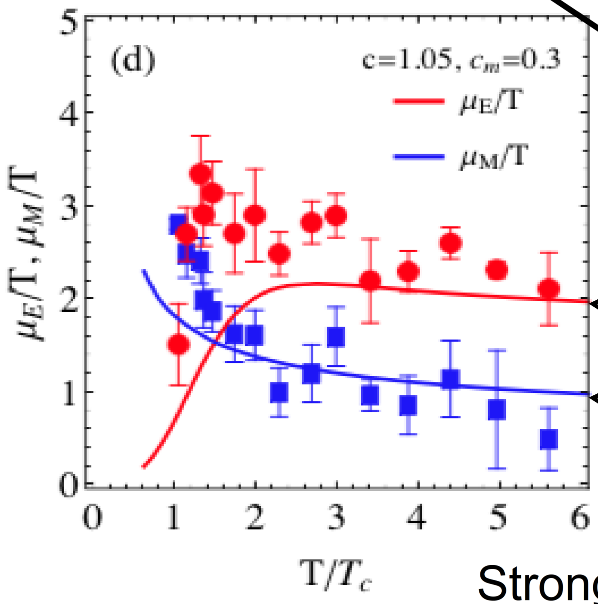


(R. Pisarski et al)

Semi-QGP:
Strong suppression of
Color electric d.o.f.
Near Tc

Density of Color Electric and
Color Magnetic monolpoles





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

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

$$f_M = C_m\,g_T$$

Strong deviations T<2Tc
From HTL Debye screening

Part II: CUJET3.0

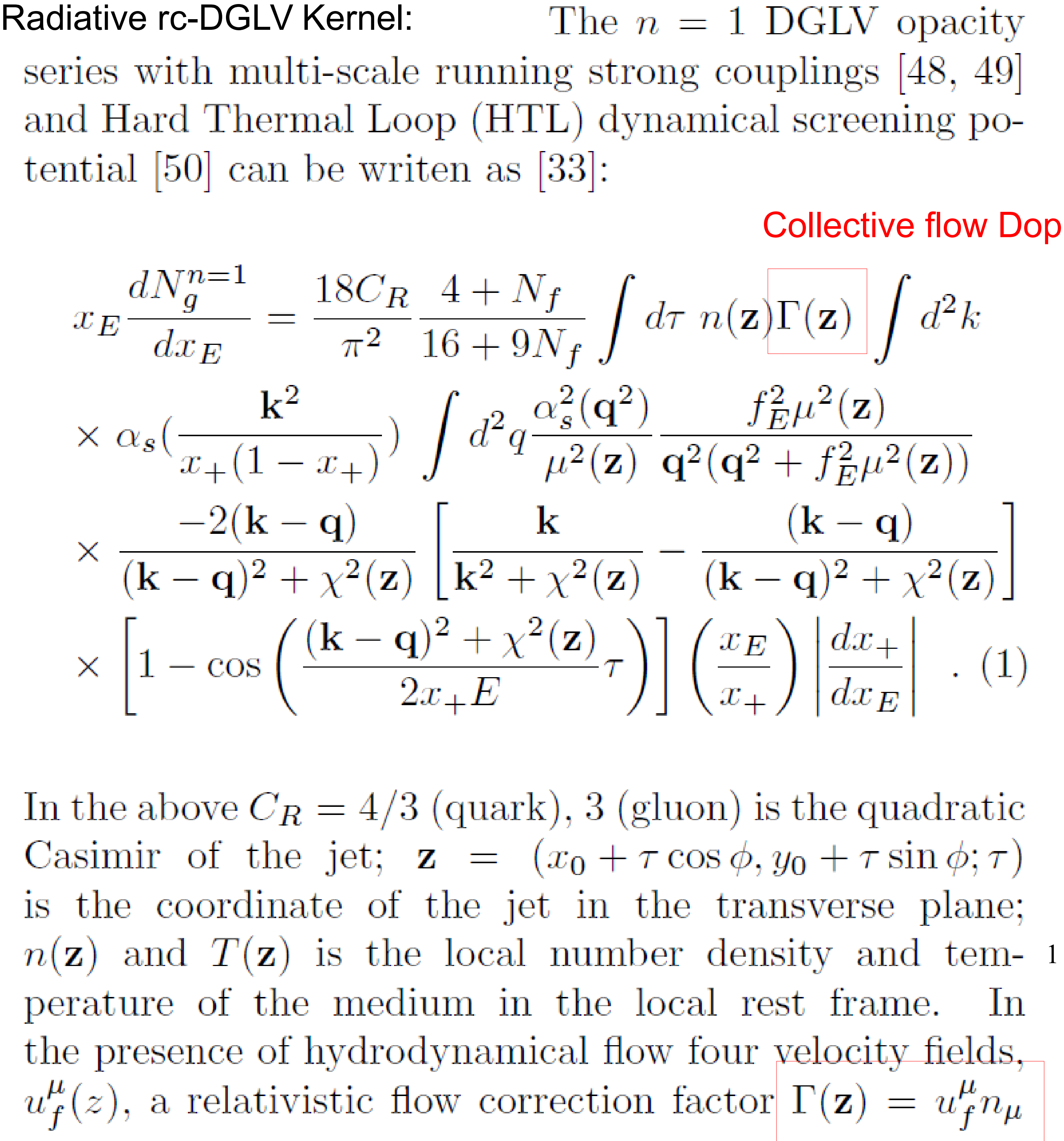
CUJET3.0 = (rc-DGLV + VISH2+1)* + Mag-Mono**+ semi-QGP***

= CUJET2.0+ sQGMP (semi-Quark-Gluon-Monopole-Plasma)**

* Jiechen Xu, Jinfeng Liao, MG, arXiv:1411.3673 [hep-ph]
** J.Liao and E.Shuryak, PRL102(2009),PRL101(2008),PRC75(2007)
*** Y. Hidaka and R. D. Pisarski, PRD 78(2008), 81(2010)

Solves v2 Problem retaining RAA consistency
AND provides a quantitative new connection between
a Tc enhanced jet transport qhat(E>10GeV, T) field and
minimal viscosity eta/s ~ T^3/qhat(E → 3T, T) → 0.1 near T -> Tc

CUJET2.0 Radiative rc-DGLV Kernel:

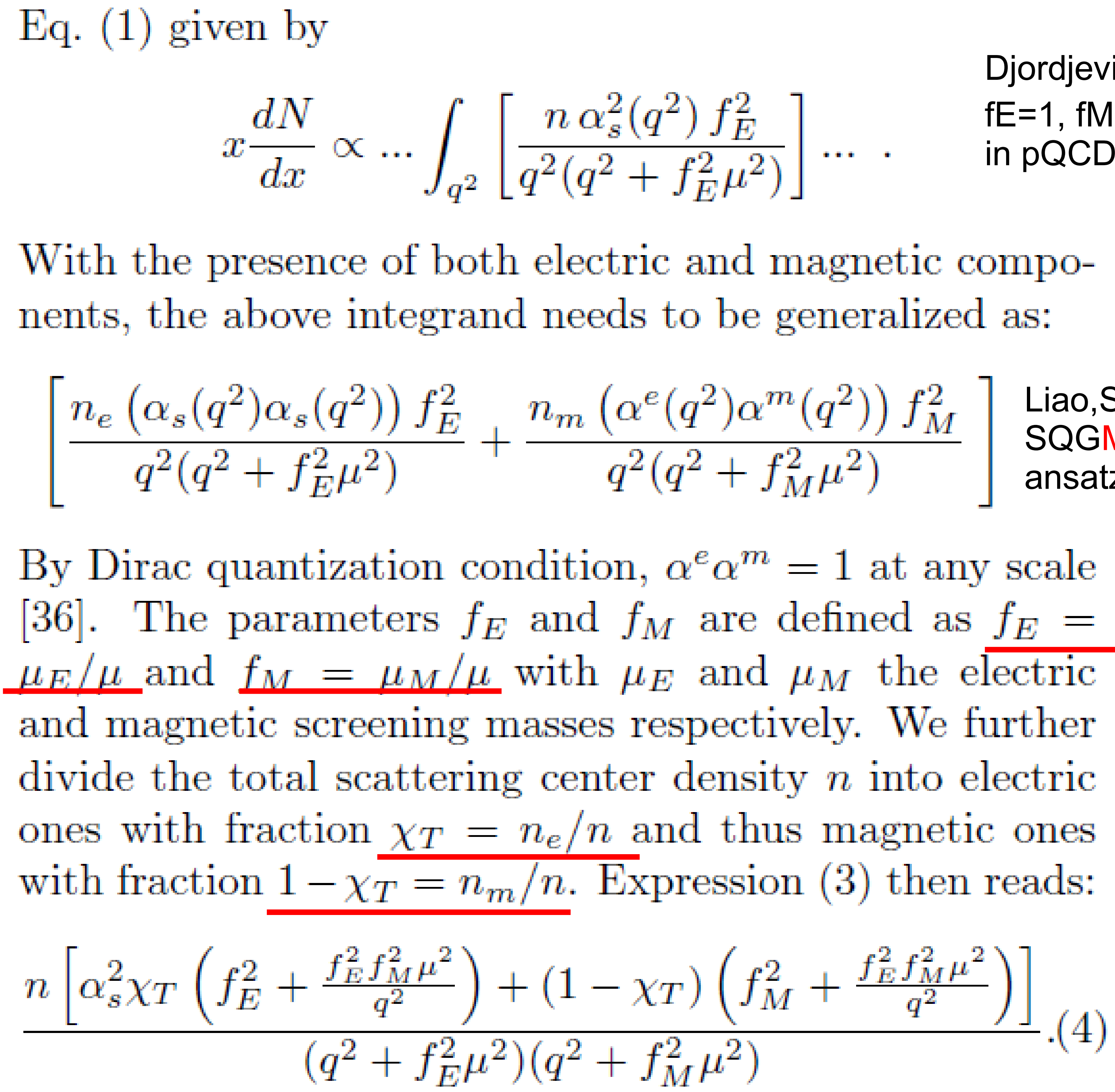


The $n = 1$ DGLV opacity series with multi-scale running strong couplings [48, 49] and Hard Thermal Loop (HTL) dynamical screening potential [50] can be writen as [33]:

Collective flow Doppler factor

$$
\begin{aligned}
x_E \frac{dN_g^{n=1}}{dx_E} &= \frac{18C_R}{\pi^2}\frac{4+N_f}{16+9N_f}\int d\tau\; n(\mathbf{z})\boxed{\Gamma(\mathbf{z})}\int d^2k \\
&\times \alpha_s\left(\frac{\mathbf{k}^2}{x_+(1-x_+)}\right)\int d^2q\,\frac{\alpha_s^2(\mathbf{q}^2)}{\mu^2(\mathbf{z})}\,\frac{f_E^2\mu^2(\mathbf{z})}{\mathbf{q}^2(\mathbf{q}^2+f_E^2\mu^2(\mathbf{z}))} \\
&\times \frac{-2(\mathbf{k}-\mathbf{q})}{(\mathbf{k}-\mathbf{q})^2+\chi^2(\mathbf{z})}\left[\frac{\mathbf{k}}{\mathbf{k}^2+\chi^2(\mathbf{z})}-\frac{(\mathbf{k}-\mathbf{q})}{(\mathbf{k}-\mathbf{q})^2+\chi^2(\mathbf{z})}\right] \\
&\times \left[1-\cos\left(\frac{(\mathbf{k}-\mathbf{q})^2+\chi^2(\mathbf{z})}{2x_+E}\tau\right)\right]\left(\frac{x_E}{x_+}\right)\left|\frac{dx_+}{dx_E}\right| \;. \quad (1)
\end{aligned}
$$

In the above $C_R = 4/3$ (quark), 3 (gluon) is the quadratic Casimir of the jet; $\mathbf{z} = (x_0+\tau\cos\phi, y_0+\tau\sin\phi;\tau)$ is the coordinate of the jet in the transverse plane; $n(\mathbf{z})$ and $T(\mathbf{z})$ is the local number density and temperature of the medium in the local rest frame. In the presence of hydrodynamical flow four velocity fields, $u_f^\mu(z)$, a relativistic flow correction factor $\boxed{\Gamma(\mathbf{z}) = u_f^\mu n_\mu}$



Eq. (1) given by

$$x\frac{dN}{dx} \propto \ldots \int_{q^2} \left[\frac{n\,\alpha_s^2(q^2)\,f_E^2}{q^2(q^2 + f_E^2\mu^2)} \right] \cdots \ .$$

Djordjevic et al
fE=1, fM=0
in pQCD/HTL QGP

With the presence of both electric and magnetic components, the above integrand needs to be generalized as:

$$\left[\frac{n_e\left(\alpha_s(q^2)\alpha_s(q^2)\right)f_E^2}{q^2(q^2 + f_E^2\mu^2)} + \frac{n_m\left(\alpha^e(q^2)\alpha^m(q^2)\right)f_M^2}{q^2(q^2 + f_M^2\mu^2)} \right]$$

Liao,Shuryak
SQGMP
ansatz

By Dirac quantization condition, $\alpha^e\alpha^m = 1$ at any scale [36]. The parameters f_E and f_M are defined as $f_E = \mu_E/\mu$ and $f_M = \mu_M/\mu$ with μ_E and μ_M the electric and magnetic screening masses respectively. We further divide the total scattering center density n into electric ones with fraction $\chi_T = n_e/n$ and thus magnetic ones with fraction $1-\chi_T = n_m/n$. Expression (3) then reads:

$$\frac{n\left[\alpha_s^2\chi_T\left(f_E^2 + \frac{f_E^2 f_M^2\mu^2}{q^2}\right) + (1-\chi_T)\left(f_M^2 + \frac{f_E^2 f_M^2\mu^2}{q^2}\right)\right]}{(q^2 + f_E^2\mu^2)(q^2 + f_M^2\mu^2)} . \quad (4)$$

M Gyulassy

CUJET3.0 = CUJET2.0 + semi-QGP + mag. monopoles

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

HTL

sQGMP

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

$$\boxed{\alpha^e\alpha^m = 1}$$

1

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

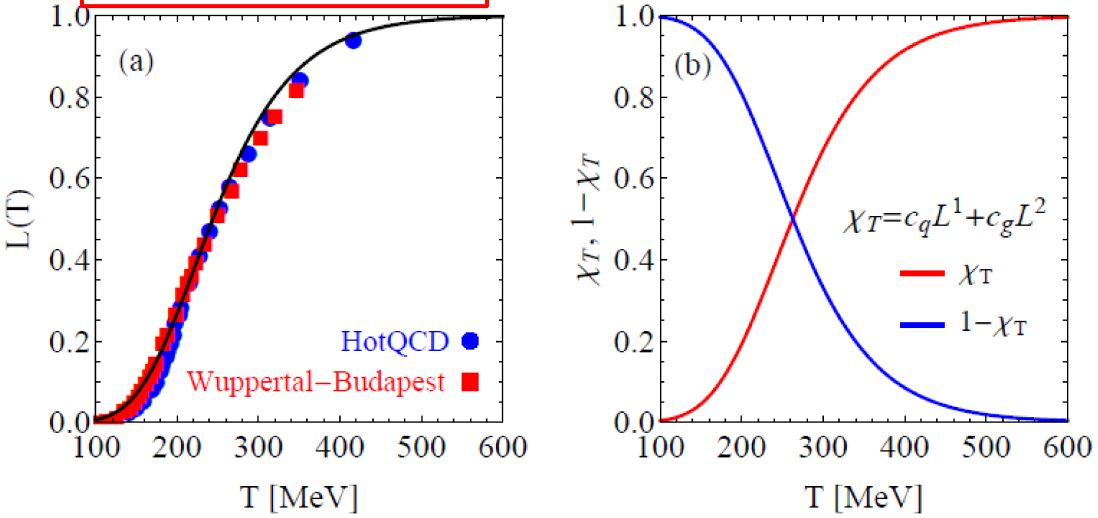
$$\chi_T = c_q\, L + c_g\, L^2$$

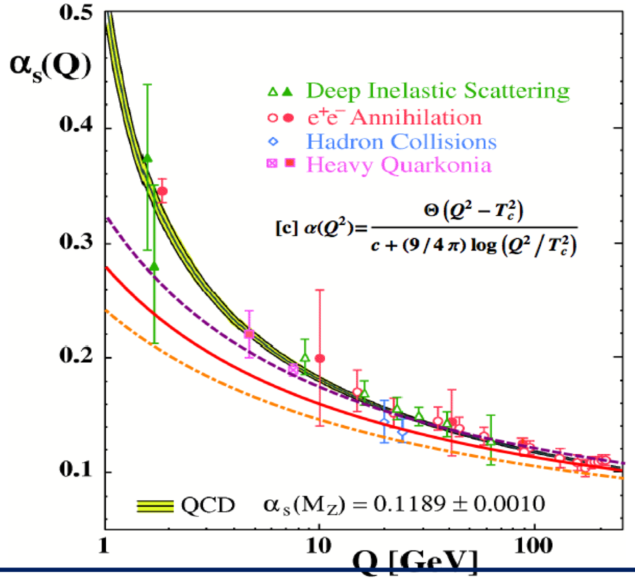
Polyakov suppressed color electric component

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

$$f_M = C_m\, g_T$$

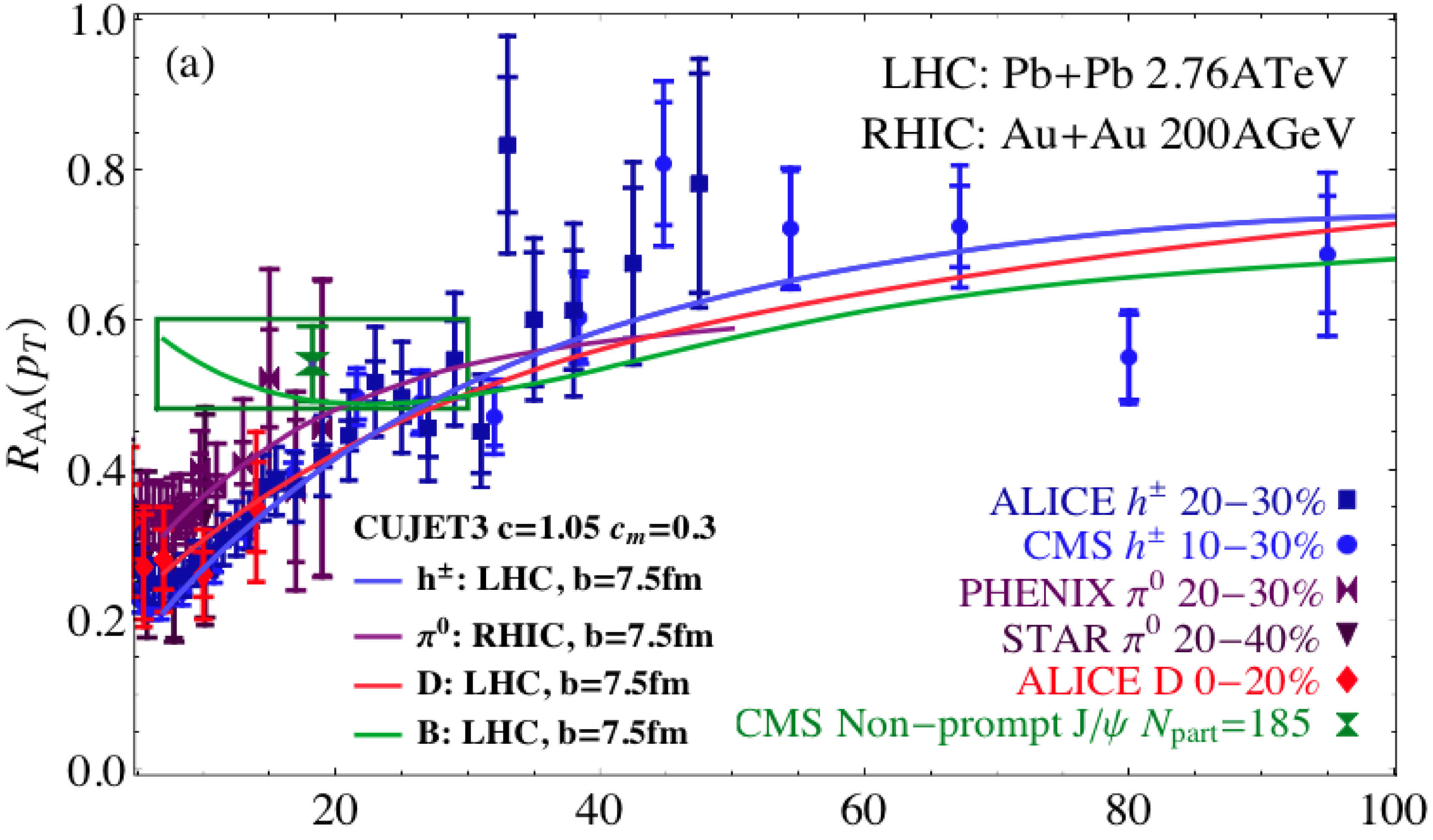
$$L(\mathbf{x}) = \frac{1}{N_c} \mathrm{tr}\mathcal{P} \exp\left[ig \int_0^{1/T} A_4(\tau,\mathbf{x})d\tau \right]$$





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

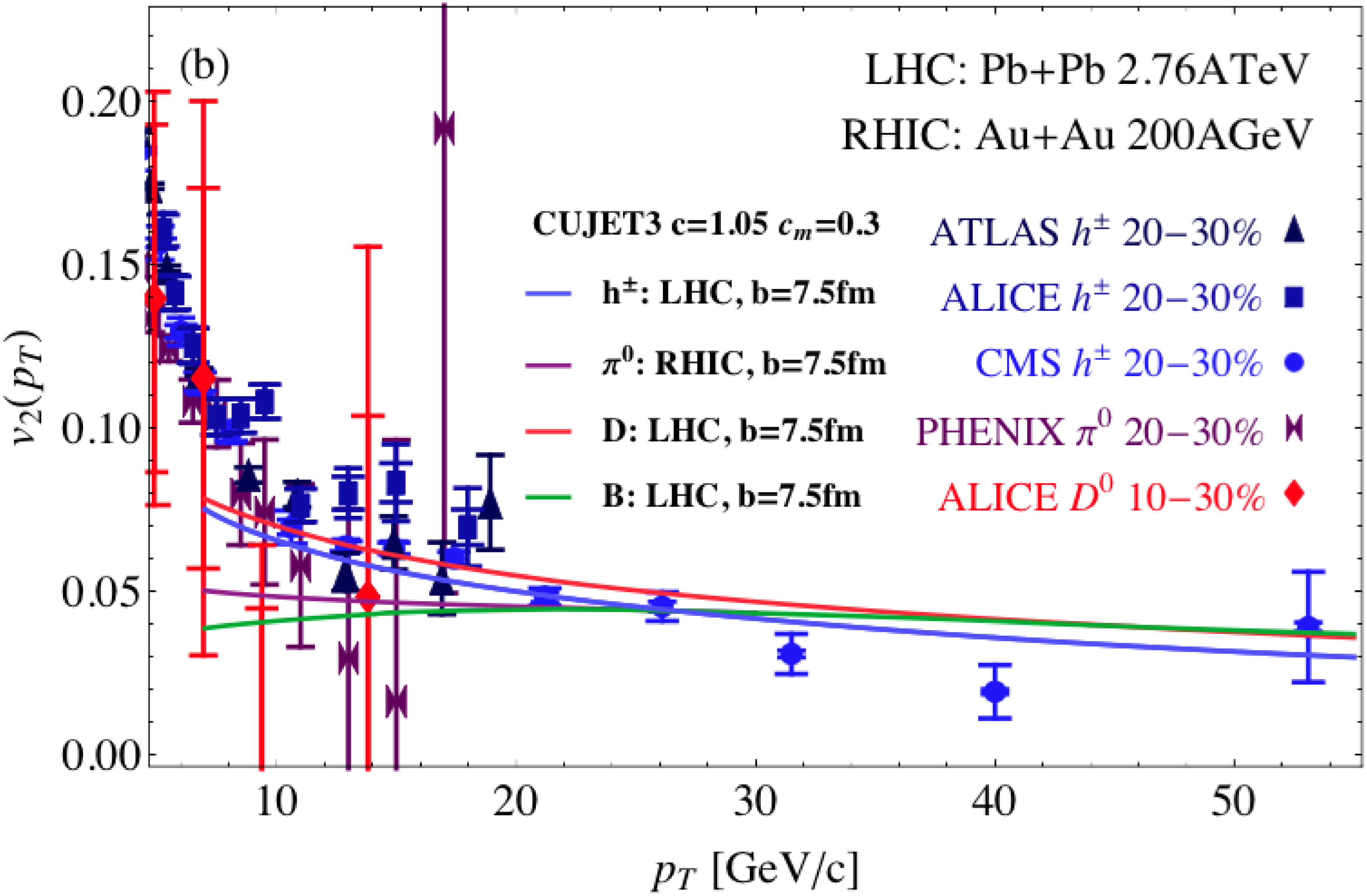
CUJET3.0: RAA at RHIC & LHC



$$R^h_{AA}(p_T, y; \sqrt{s}, b) = \frac{dN^h_{AA}/dydp_T}{N_{\rm bin}\, dN^h_{pp}/dydp_T}.$$

- CUJET3.0 with $(c, c_m)=(1.05, 0.3)$ fits R_{AA} at both RHIC and LHC

CUJET3.0: Jet v2 at RHIC & LHC

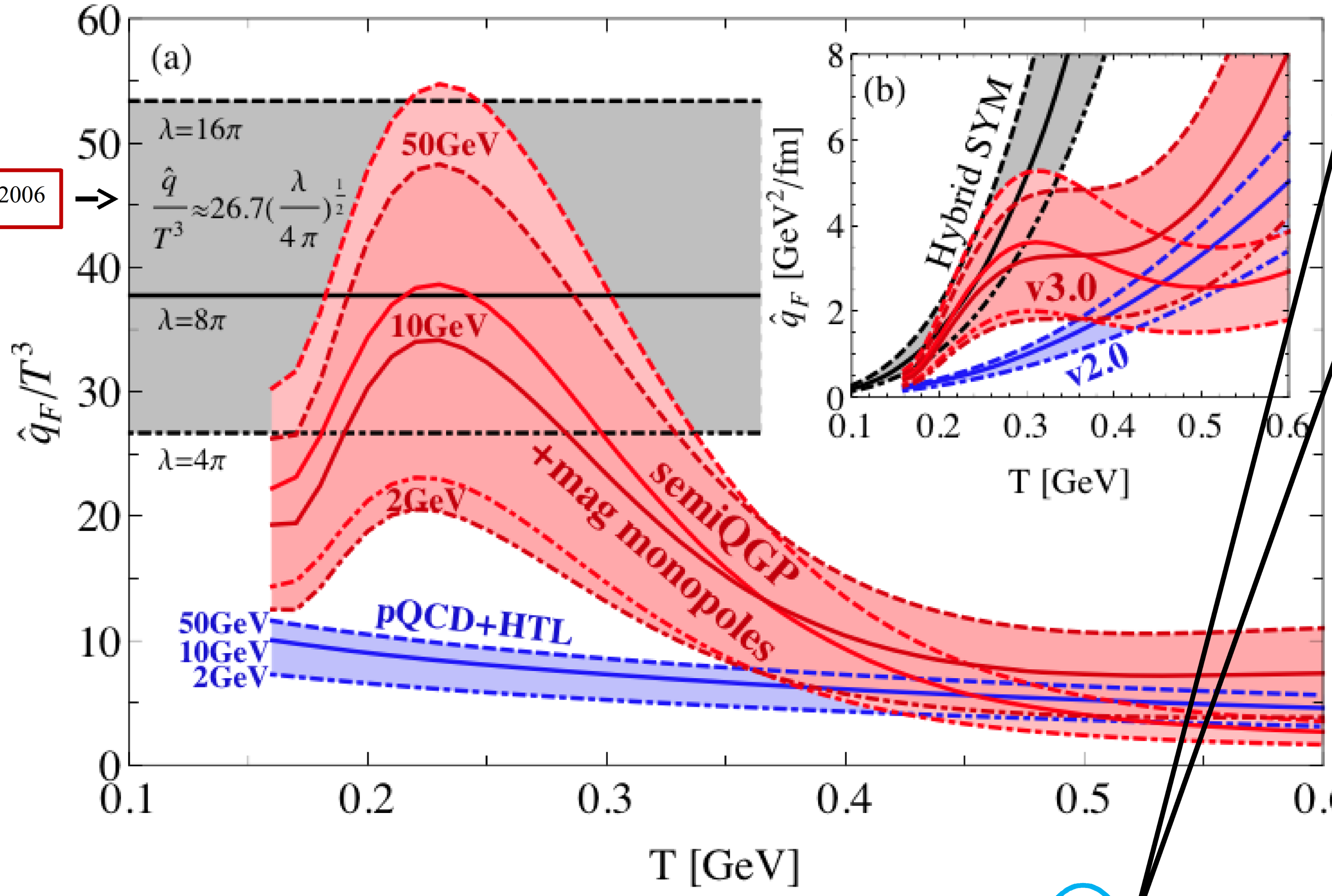


sQGMP solves the jet v2 consistency problem with RAA. What about the eta/s connection?

❖CUJET3.0 with $(c,c_m)=(1.05,0.3)$ accounts ok jet v_2 ~0.05 at both RHIC and LHC

CUJET3.0: qhat(E,T) for quark jet in a sQGPM

Liu et al.PRL 2006 →



SR

PR

$$\hat{q}_F = \int_0^{6ET} dq^2 \frac{2\pi q^2}{(q^2+f_E^2\mu^2)(q^2+f_M^2\mu^2)}\rho(T) \times \left[(C_{qq}f_q + C_{qg}f_g)\alpha_s^2(q^2) + C_{qm}(1-f_q-f_g)\right]$$

$$\rho(T) = \frac{p(T)}{T}\frac{90\zeta(3)(16+9N_f)}{\pi^4(16+10.5N_f)}$$

$$\rho_s(T) = \frac{s(T)}{4}\frac{90\zeta(3)(16+9N_f)}{\pi^4(16+10.5N_f)}$$

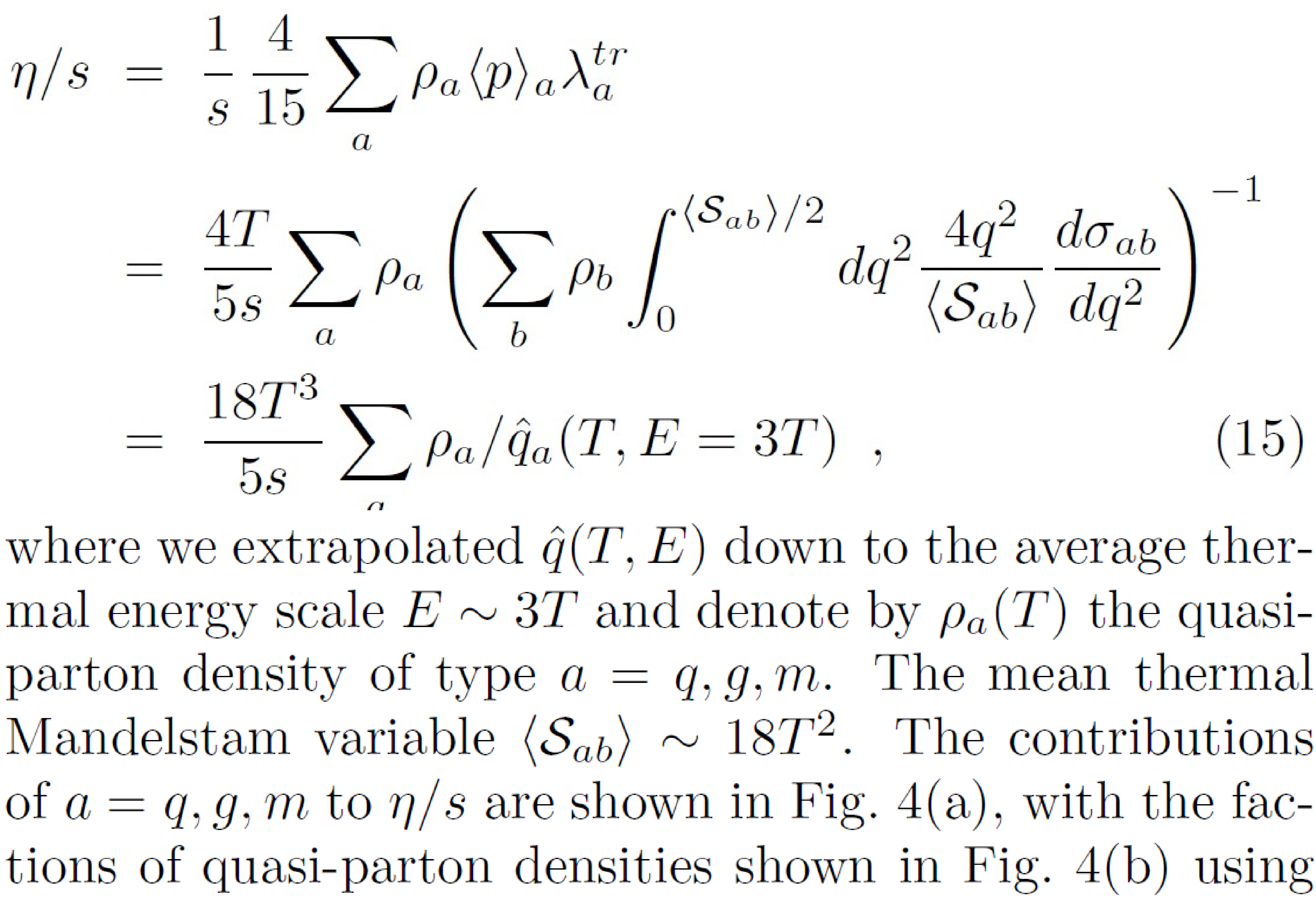
$PR: \; f_q = \frac{10.5N_fL(T)}{16+10.5N_f}, \; f_g = \frac{16L(T)^2}{16+10.5N_f}$,

$SR: \; f_q = \frac{10.5N_fL(T)}{90\rho_s(T)/\pi^2T^3}, \; f_g = \frac{16L(T)^2}{90\rho_s(T)/\pi^2T^3}$

- ❖ CUJET3.0 solution exhibits a “volcano” interpolation of qhat/T^3 between strong “AdS-like” sQGP at 200<T<350 MeV range to a more transparent “HTL-like” CUJET2.0 for T>400MeV

J.Xu, Columbia, 12/03/2014 sld 28

Kinetic Theory estimate of viscosity of semi-QGMP:

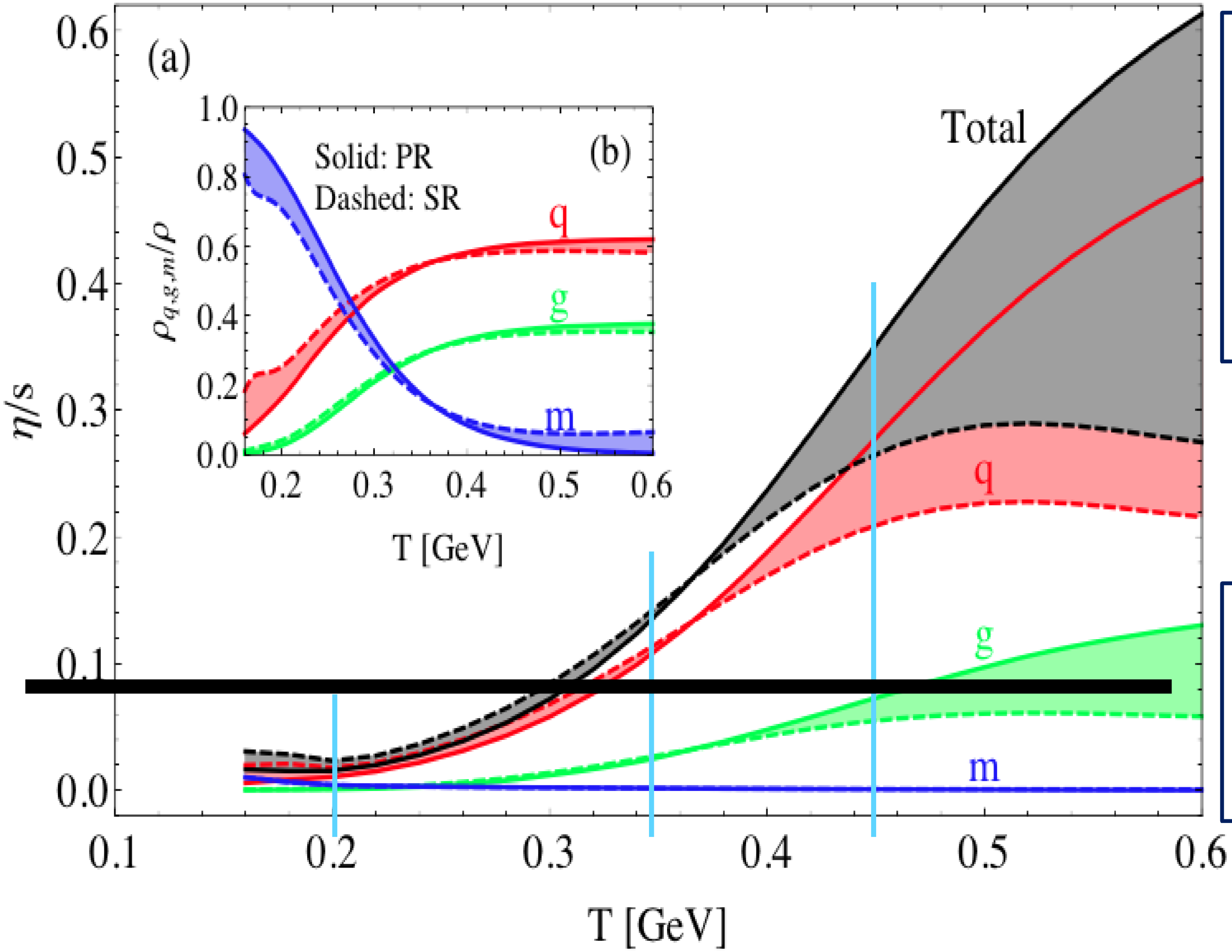


$$\begin{aligned}\eta/s &= \frac{1}{s}\frac{4}{15}\sum_a \rho_a \langle p\rangle_a \lambda_a^{tr} \\ &= \frac{4T}{5s}\sum_a \rho_a \left(\sum_b \rho_b \int_0^{\langle\mathcal{S}_{ab}\rangle/2} dq^2 \frac{4q^2}{\langle\mathcal{S}_{ab}\rangle}\frac{d\sigma_{ab}}{dq^2}\right)^{-1} \\ &= \frac{18T^3}{5s}\sum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

where we extrapolated $\hat{q}(T,E)$ down to the average thermal energy scale $E \sim 3T$ and denote by $\rho_a(T)$ the quasi-parton density of type $a = q, g, m$. The mean thermal Mandelstam variable $\langle\mathcal{S}_{ab}\rangle \sim 18T^2$. The contributions of $a = q, g, m$ to η/s are shown in Fig. 4(a), with the factions of quasi-parton densities shown in Fig. 4(b) using

CUJET3.0: eta/s vs T

Fig.4



$$\begin{aligned}\eta/s &= \frac{4}{15}\frac{1}{4\rho}\sum_a \rho_a \langle p\rangle_a \lambda_a^{tr} \\ &= \frac{T}{5}\sum_a f_a \left(\sum_b \rho_b \int_0^{9T^2} dq^2 \frac{4q^2}{18T^2}\frac{d\sigma_{ab}}{dq^2}\right)^{-1} \\ &= \frac{18T^3}{20}\sum_a f_a/\hat{q}_a(T, E=3T) \ ,\end{aligned}$$

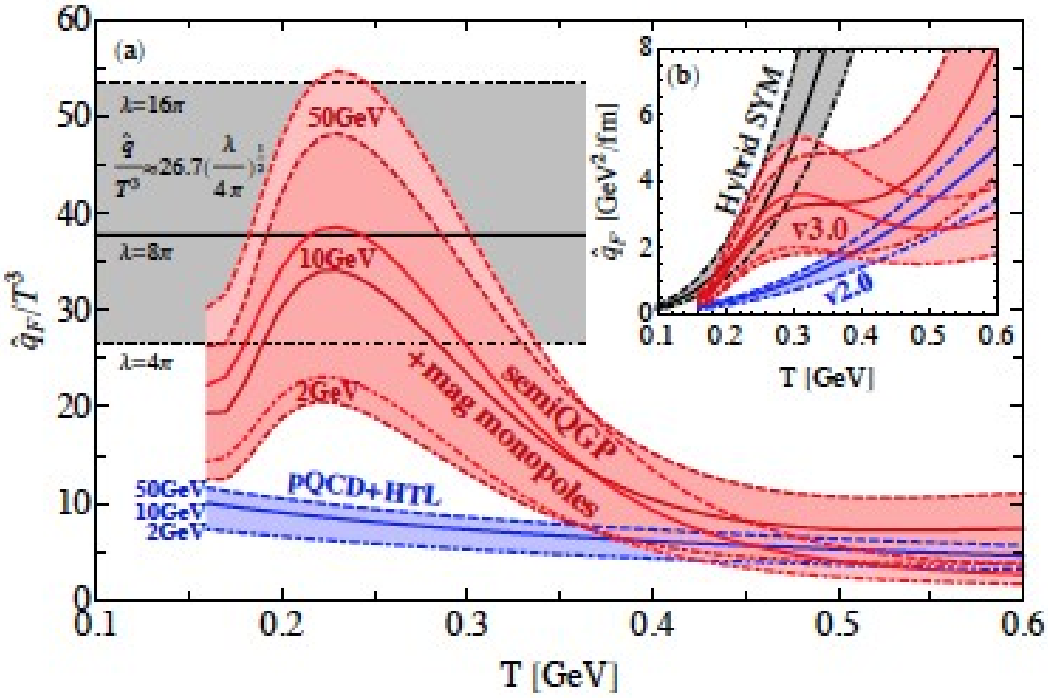
c.f.
Danielewicz, Gyulassy PRD 1985;
Hirano,Gyulassy NPA 2006;
Majumder, Muller, Wang PRL 2007

$$PR \ : \ f_q = \frac{10.5 N_f L(T)}{16+10.5N_f}, \ f_g = \frac{16L(T)^2}{16+10.5N_f} \ ,$$

$$SR \ : \ f_q = \frac{10.5 N_f L(T)}{90\rho_s(T)/\pi^2 T^3}, \ f_g = \frac{16L(T)^2}{90\rho_s(T)/\pi^2 T^3}$$

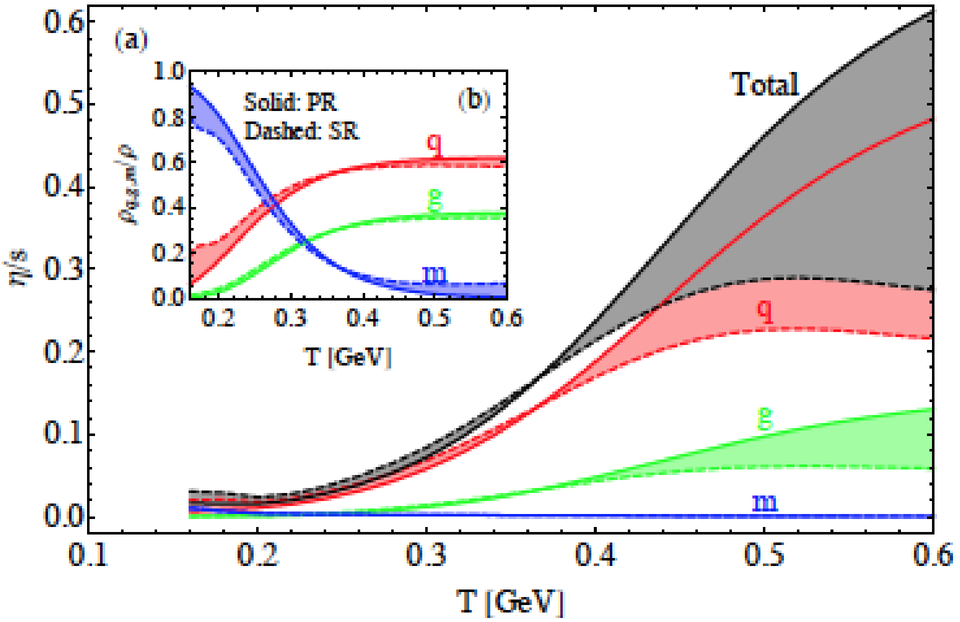
- ❖ Near eta/s ~ 1/4pi in 160< T<300 dominated by jet+monopole scattering
- ❖ Grows to eta/s~0.24-0.32 @ 450MeV,
- ❖ Below Tc Mag Monopoles condense and sQGMP → high eta/s Hadron Resonance (HRG not implemented in v3.0)

Near-Tc Matter Properties of sQGMP are special!



Jet transport coefficient q-hat/T^3 computed from CUJET3.0 shows a strong peak near Tc!

Shear viscosity, eta/s, computed from CUJET3.0 shows a clear minimum near Tc and rapid rise at high T!



BES@RHIC and LHC are both essential to constrain and map out the strongly non-conformal QCD confinement transition physics in and out of perfect fluidity jet opacity!

J.Xu, JLiao, MG, arXiv:1411.3673

Summary

- CUJET2.0 solved both the “heavy quark puzzle” and the “surprising transparency” of QGP @LHC
  - Dynamical QCD medium + Elastic energy loss + Realistic path length fluctuations + pQCD pp spectra
  - Multi-scale running strong coupling
- But v2 50% underpredicted high pT >10 with CUJET2.0 !
- And eta/s way over predicted with extrapolated down to pT-> 2GeV

- With pQCD + semi-QGP + magnetic monopoles, CUJET3.0 explains high pT (RAA & v2) at (RHIC & LHC) simultaneously
  - ** qhat from CUJET3.0 smoothly bridges the hybrid AdS/SYM holography and the pQCD tomography limit
  - ** eta/s from CUJET3.0 approaches perfect fluidity near Tc

Future test with heavy quark tomography at RHIC and LHC will be important
To further test consistency of the sQGMP non-perturbative features constrained
By lattice QCD