Evidence for the Chromo-Magnetic Component of the Quark-Gluon Plasma

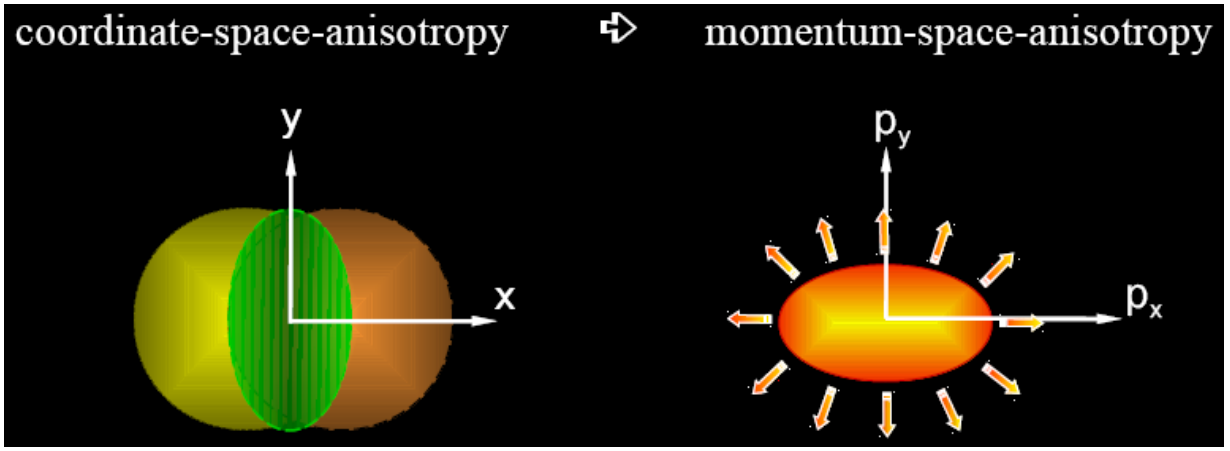


Jinfeng Liao

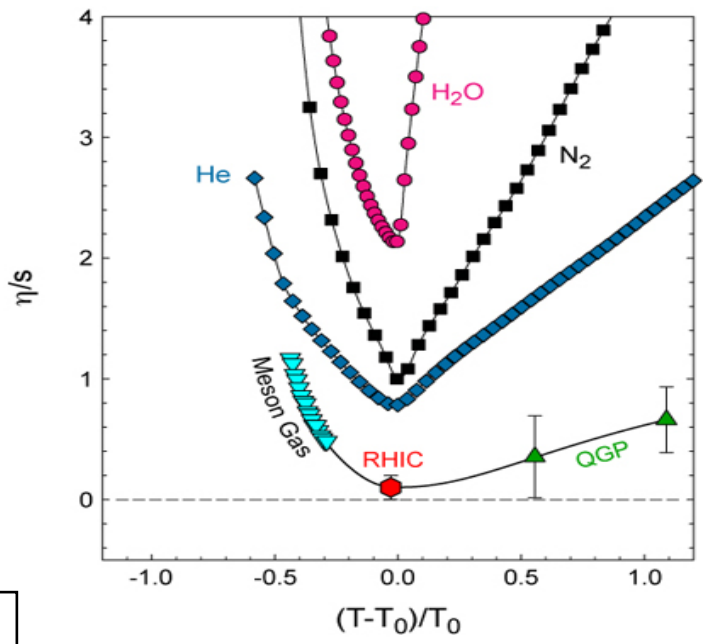
Indiana University

Magnetic Component

The Most Perfect Fluid



$$\frac{dN}{dP_t\, d\phi} = \frac{dN}{dP_t}\left[1 + 2\, v_2\,(P_t) \cos(2\phi) + \ldots\right]$$



This response is very sensitive to fluid dissipation

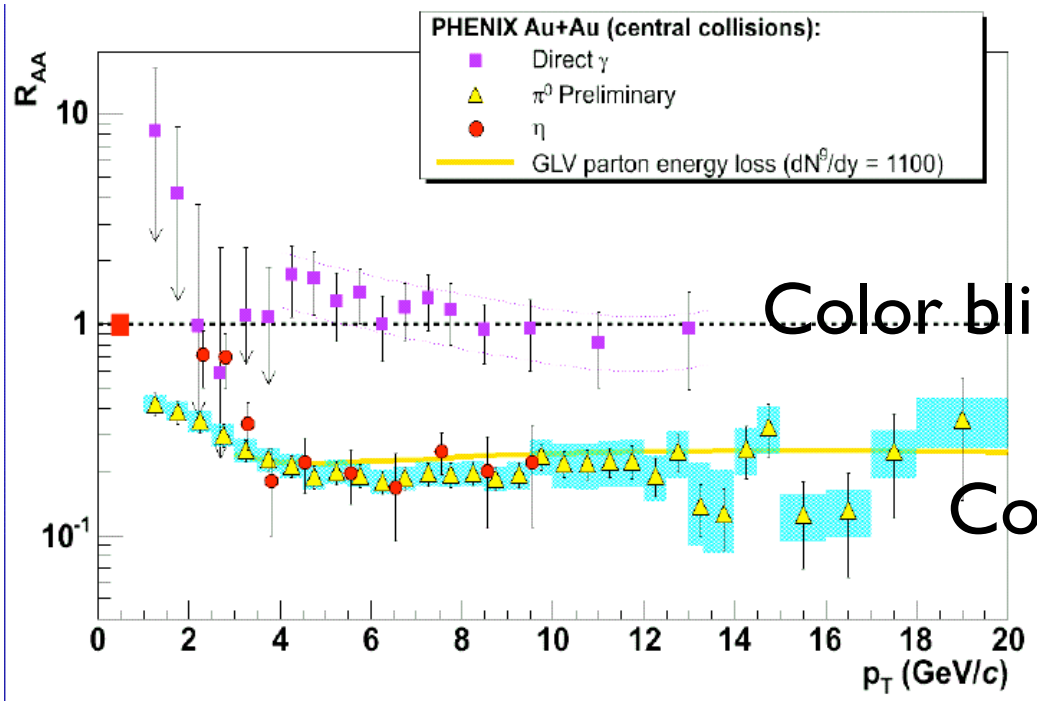
$$1 \leq 4\pi(\eta/s)_{QGP} \leq 2.5$$

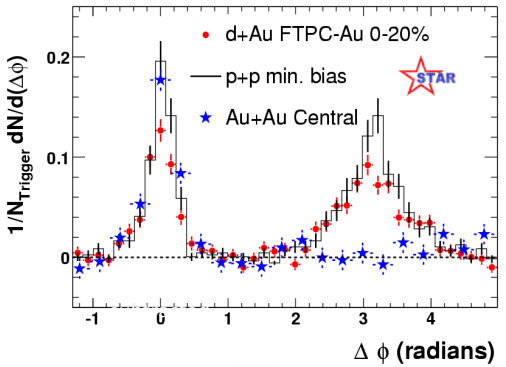
QGP is a quantum fluid:

$$\lambda_{M.F.P.} \sim \lambda_{de\ Broglie}$$

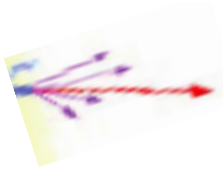
[Interesting connections to string theory and cold atomic gases]

A Color-Opaque Plasma





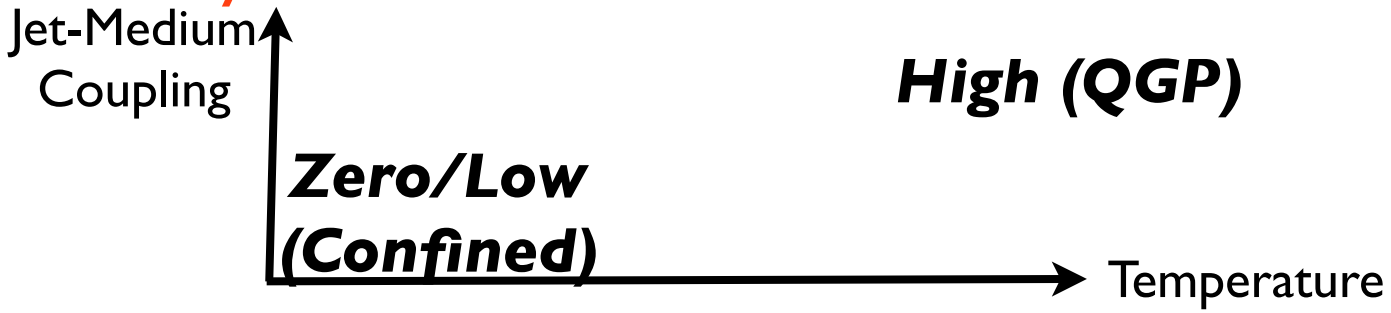
Color blind probe



Colorful probe



A qualitatively different medium

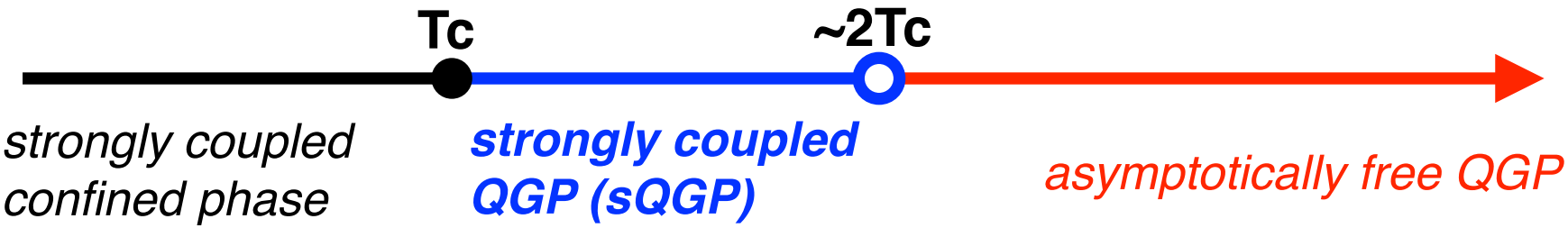


sQGP: The Matter Just About to Confine Color

The old belief



The new paradigm thanks to discoveries at RHIC and LHC:



The matter just above confinement, is more closely related to the confined world, rather than to the faraway place of asymptotic QGP!

This is to say, the confinement physics (whatever it is), must continue robustly into this region
—— We called it the "postconfinement" regime!

Continuation of Hadronic States

Rethinking the properties of the quark gluon plasma at T approximately T(c)

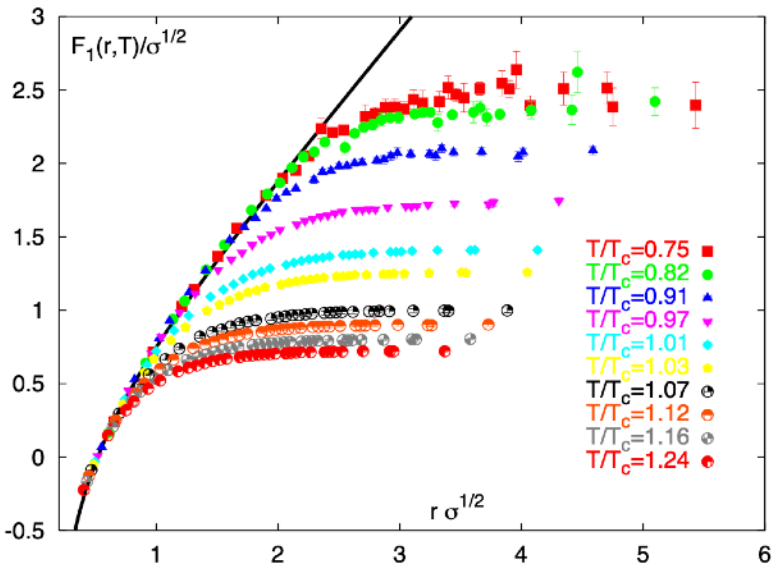
Edward V. Shuryak (SUNY, Stony Brook), Ismail Zahed (SUNY, Stony Brook) (Jul, 2003)

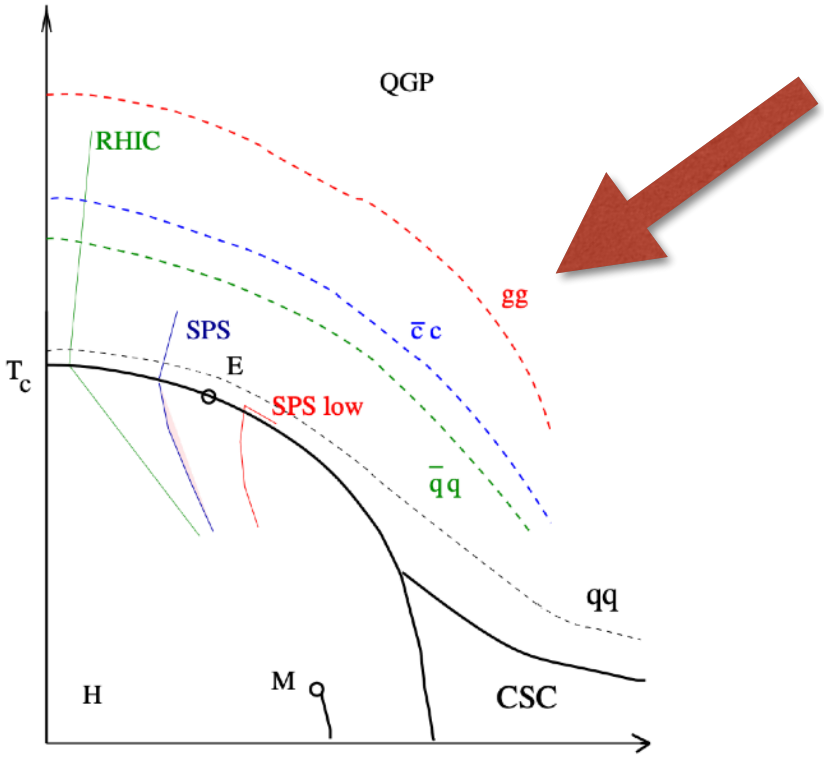
Published in: *Phys.Rev.C* 70 (2004) 021901 • e-Print: hep-ph/0307267 [hep-ph]

Towards a theory of binary bound states in the quark gluon plasma

Edward V. Shuryak (SUNY, Stony Brook), Ismail Zahed (SUNY, Stony Brook) (Mar, 2004)

Published in: *Phys.Rev.D* 70 (2004) 054507 • e-Print: hep-ph/0403127 [hep-ph]



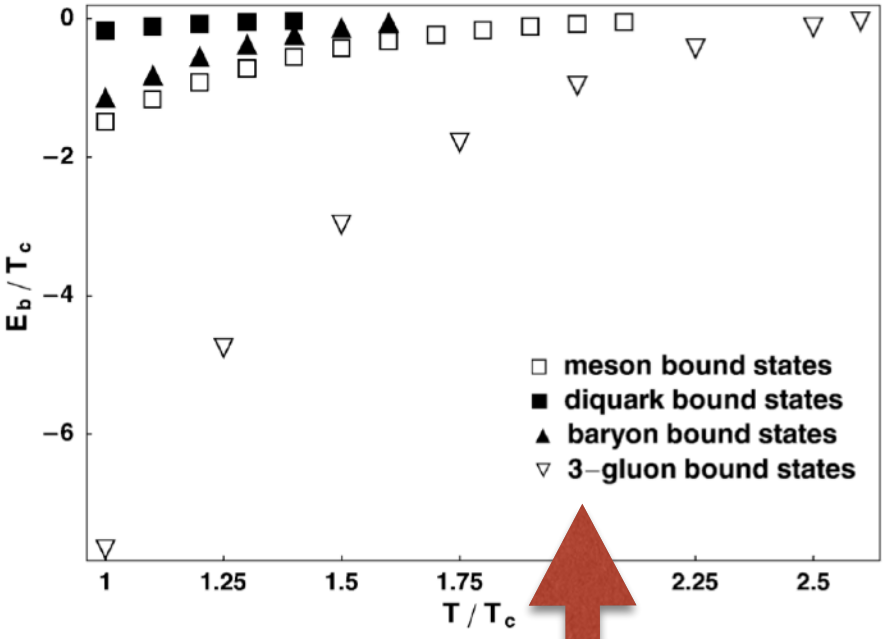


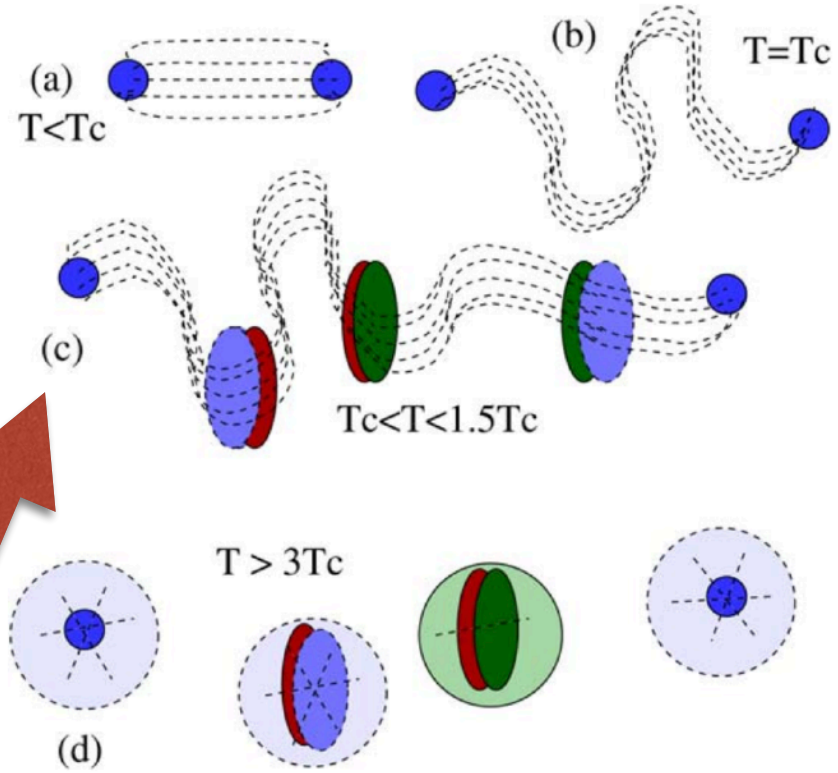
Continuation of Hadronic States

Polymer chains and baryons in a strongly coupled quark-gluon plasma

Jinfeng Liao (SUNY, Stony Brook), Edward V. Shuryak (SUNY, Stony Brook) (Aug, 2005)

Published in: *Nucl.Phys.A* 775 (2006) 224-234 • e-Print: hep-ph/0508035 [hep-ph]





Simplest glueballs

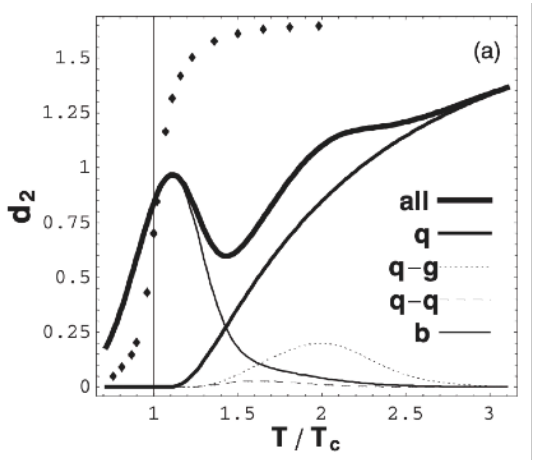
Stringy objects

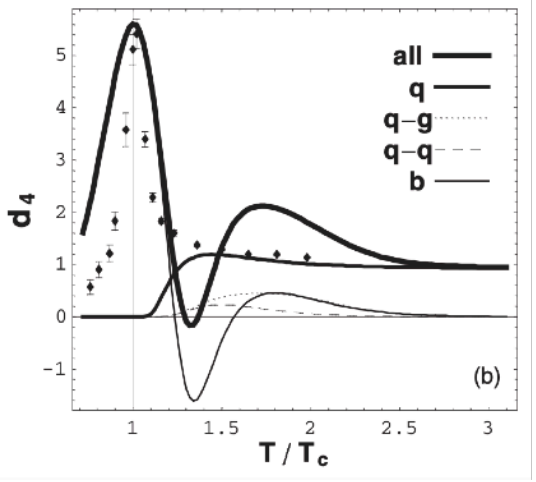
Conserved Charge Fluctuations above Tc

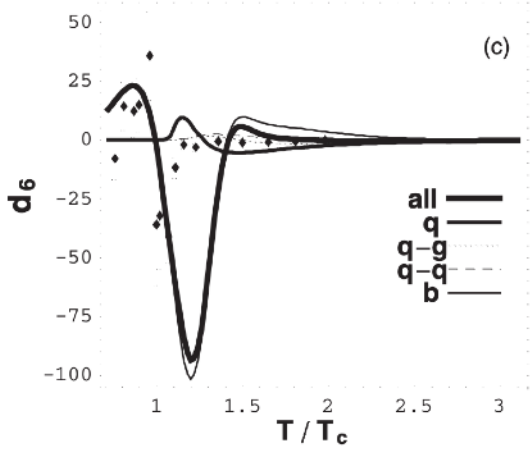
What do lattice baryonic susceptibilities tell us about quarks, diquarks and baryons at T > Tc?

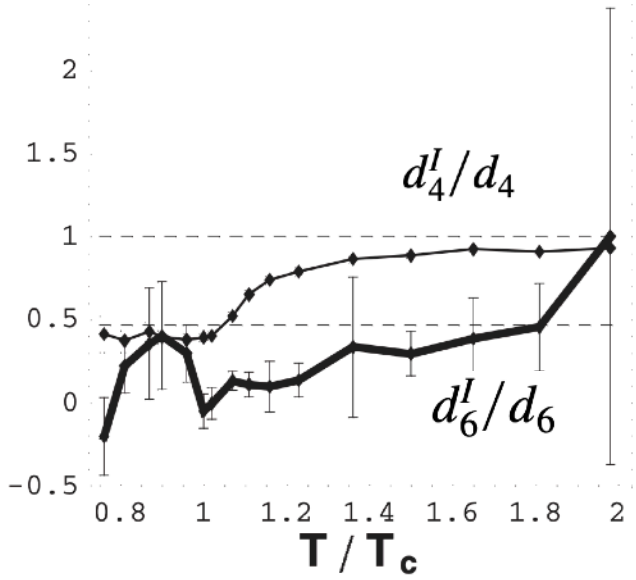
Jinfeng Liao (SUNY, Stony Brook), Edward V. Shuryak (SUNY, Stony Brook) (Oct, 2005)

Published in: *Phys.Rev.D* 73 (2006) 014509 • e-Print: hep-ph/0510110 [hep-ph]









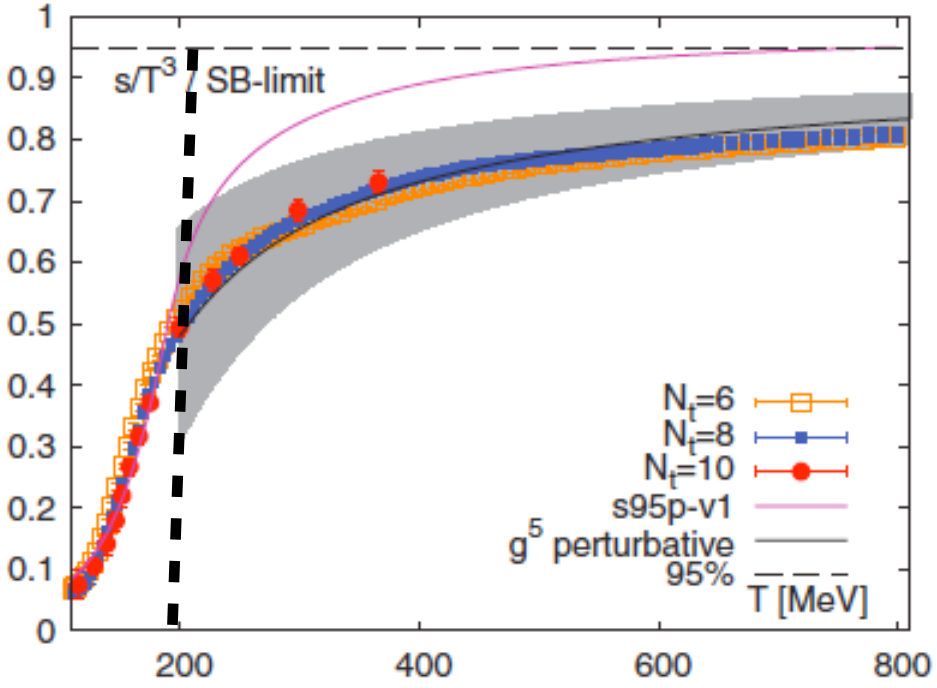
Higher order susceptibilities and off-diagonal ones are sensitive to hadronic states!

Pressing Issues at the Time

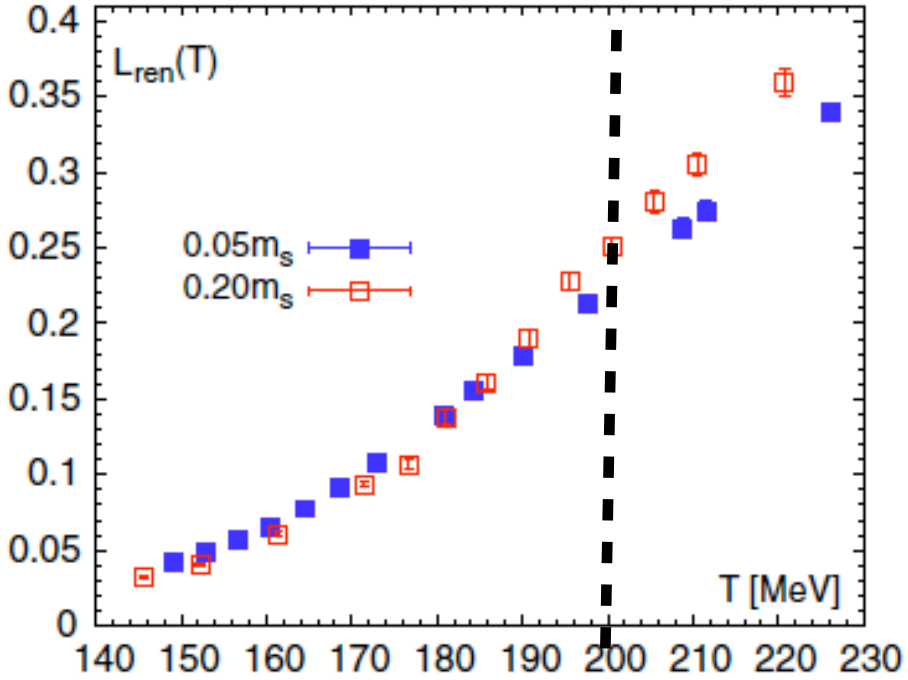
- ***What happens to confinement/deconfinement?***
- ***String / fluxtube above Tc: what protects them?***
- ***How to understand the static Q-bar-Q potential?***
- ***Dominant degrees of freedom?***
- ***Transport properties?***

Liberation of Color? Missing DoF?

Degrees of freedom



Degree of color liberation

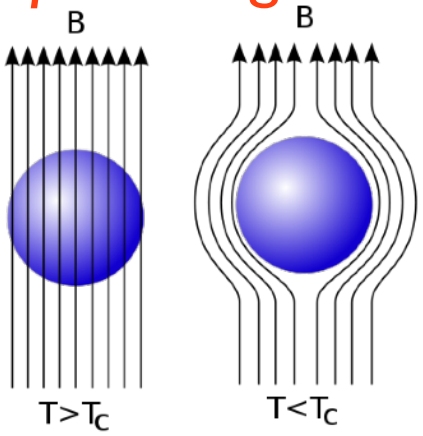


A region around Tc with liberated degrees of freedom
but only partially liberated color-electric objects.
(Hidaka & Pisarski: semi-QGP)

Then what are the "extra" dominant DoF here???
Chromo-magnetic monopoles from confining vacuum!

QCD Vacuum as "Superconductor" of Monopoles

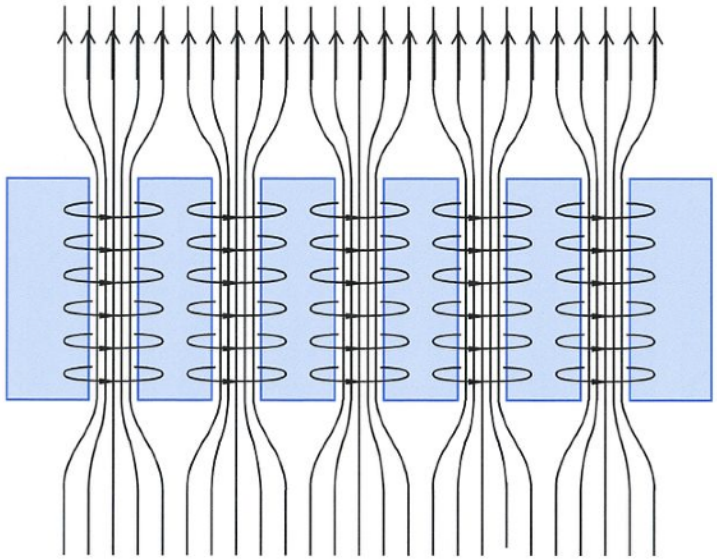
Meissner effect: electric (cooper-pair) condensate expels magnetic fields, and squeezes them into flux tube.

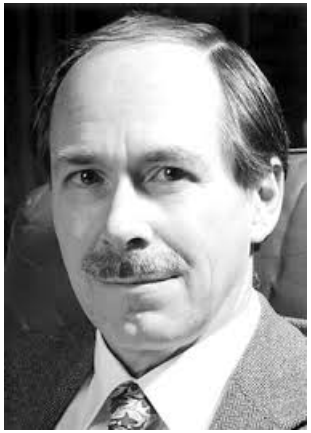


$$\mathbf{j}_s = -\frac{n_s e^2}{mc}\mathbf{A}. \qquad \textbf{(London equation)}$$

$$\nabla \times \mathbf{B} = \frac{4\pi \mathbf{j}}{c} \qquad \nabla^2 \mathbf{B} = \frac{1}{\lambda^2}\mathbf{B}, \qquad \lambda \equiv \sqrt{\frac{mc^2}{4\pi n_s e^2}}.$$

$$\Rightarrow \quad B_z(x) = B_0 e^{-x/\lambda}.$$







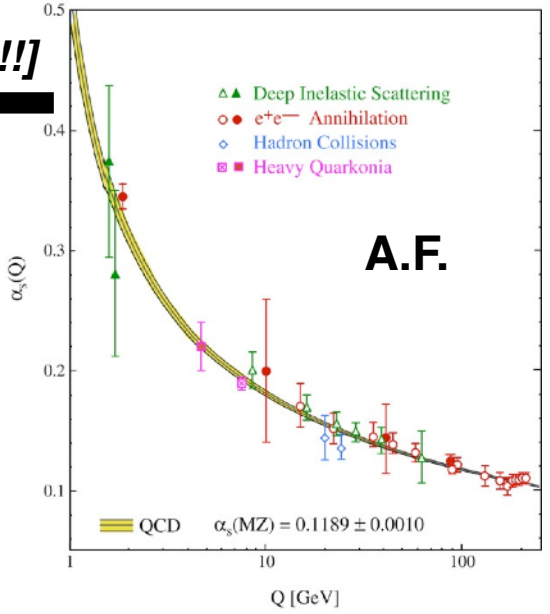


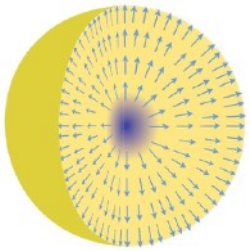
't Hooft, Mandelstamm, Nambu
—> transforming this insight into QCD

QCD Vacuum as "Superconductor" of Monopoles

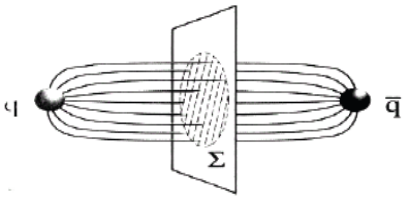
very strong coupling
at low energy
—> emergent magnetic monopoles
—> monopole condensate in vacuum

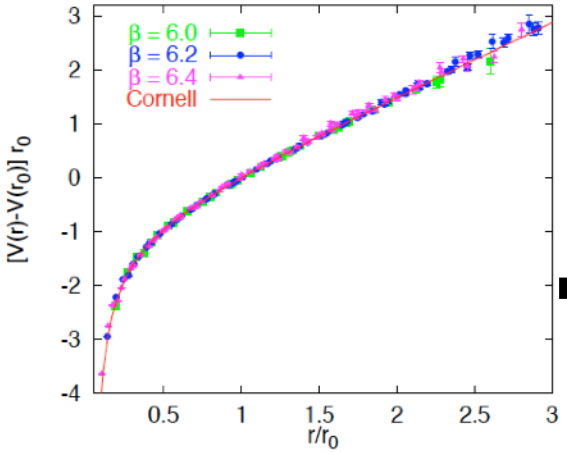
[hard to workout!!!]





Many evidences from lattice simulations



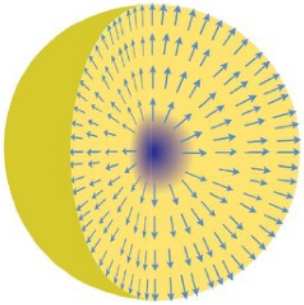


Regge phenomena;
Veneziano amplitudes;
Lund model,
string fragmentation;
…

flux tube, linear potential,
and stringy hadrons

Magnetic Monopoles & E-M Duality

't Hooft-Polyakov (1974):
monopoles naturally arise as topological solutions
to classical EoM in non-Abelian gauge theories;
Dirac Quantization obeyed, mass & size ~ 1/g



$$\mathbf{Dirac: e^{*} g = 1}$$

What happens if the gauge theory with monopoles is in strongly coupled regime?



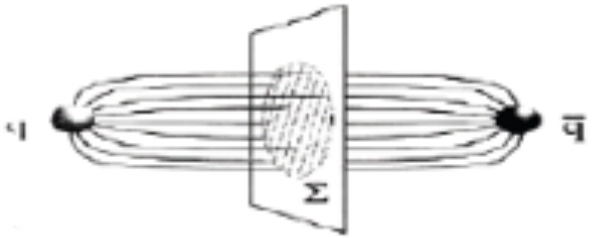
E-M Duality: (Motonen, Olive, 1977)
strong coupling → *change of D.o.F. toward emergent ones ;*
Dirac condition → E and M couplings inversely related
E weakly coupled → theory in terms of E language
E strongly coupled → theory better described by Magnetic.

The classical work by Seiberg-Witten (1994) for N=2 SYM:
All work in this way, including the confinement !

Confinement Physics above "Tc"

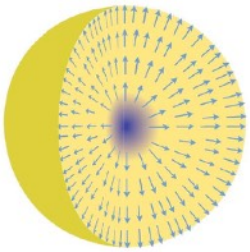
T<< Lambda_QCD | T ~ Lambda_QCD | T>> Lambda_QCD

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



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



Condensate monopoles —> dense thermal monopoles 1-2Tc: thermal monopoles play key role in this regime.

PHYSICAL REVIEW C 75, 054907 (2007)

Strongly coupled plasma with electric and magnetic charges

Jinfeng Liao and Edward Shuryak

JL & Shuryak, PRC2007;PRL2008

A New Phase Diagram (— Old By Now!!!)

JL & Shuryak, PRC2007 [hep-ph/0611131 [hep-ph]]

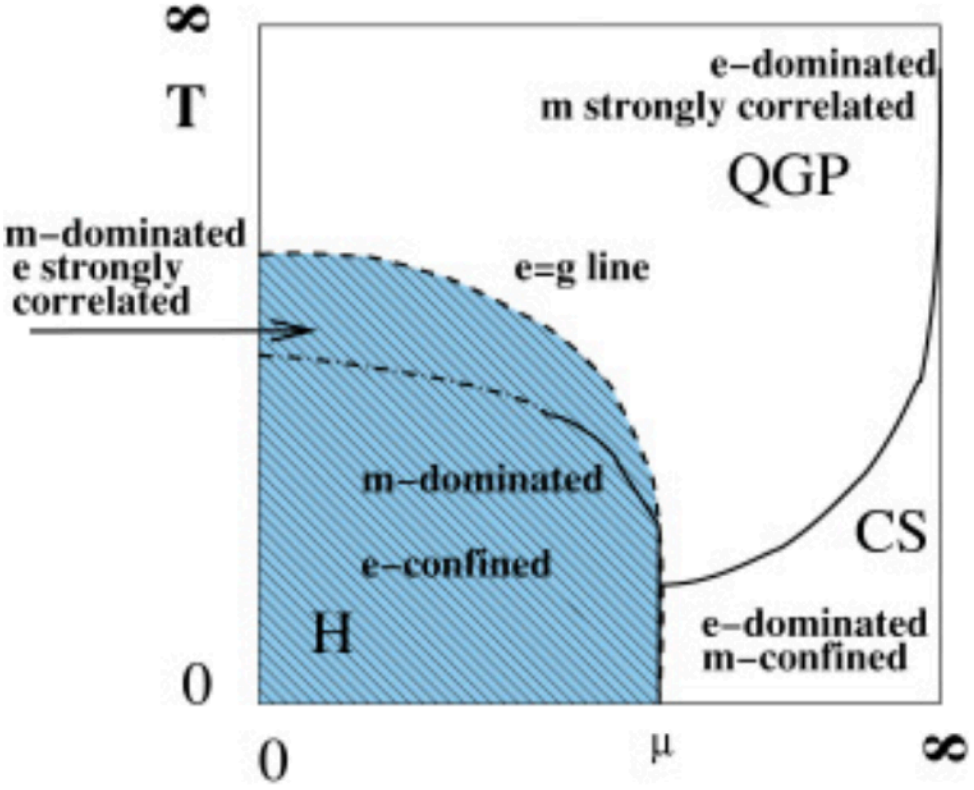
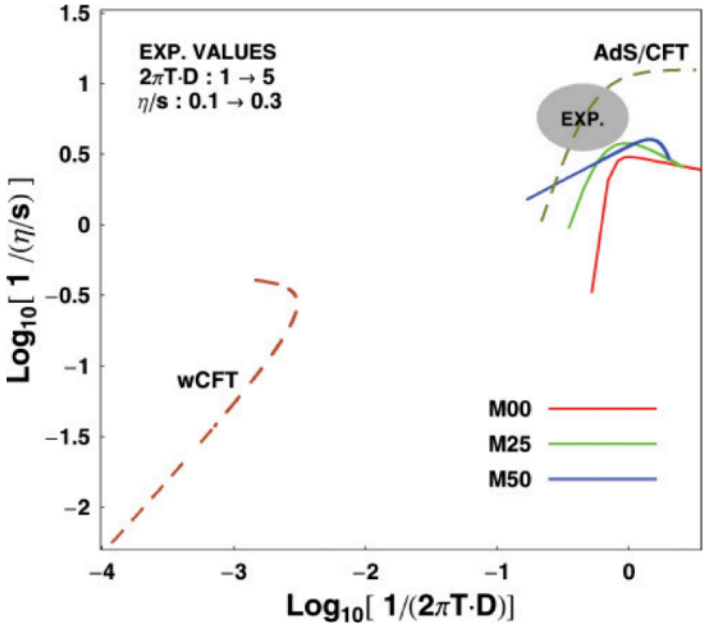


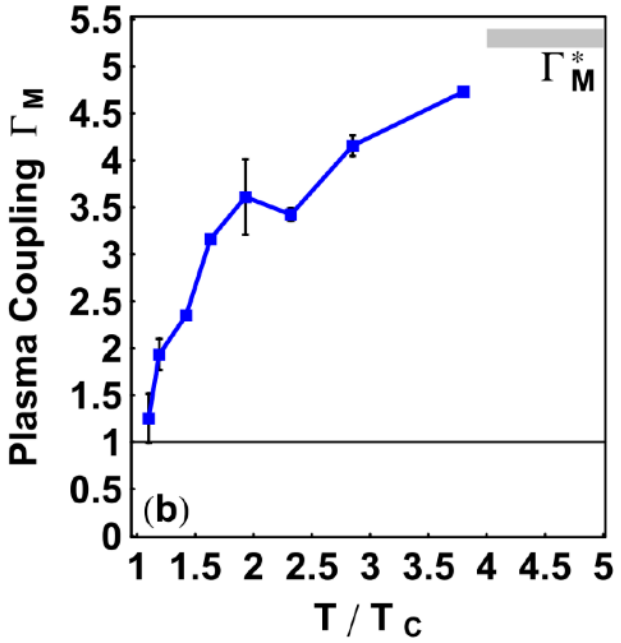
FIG. 1. (Color online) A schematic phase diagram on a ("compactified") plane of temperature and baryonic chemical potential $(T-\mu)$. The (blue) shaded region shows the "magnetically dominated" region $g < e$, which includes the e-confined hadronic phase as well as the "postconfined" part of the QGP domain. The light region includes the "electrically dominated" part of the QGP and also the color superconductivity (CS) region, which has e-charged diquark condensates and therefore is obviously m-confined. The dashed line called "e=g line" is the line of electric-magnetic equilibrium. The solid lines indicate true phase transitions; the dash-dotted line is a deconfinement cross-over line.

A new phase boundary based on E-M duality

Transport Properties



$$\Gamma \equiv \frac{\alpha_C/(\frac{3}{4\pi n})^{1/3}}{T}$$



PRL 101, 162302 (2008) PHYSICAL REVIEW LETTERS week ending 17 OCTOBER 2008

The Magnetic Component of Quark-Gluon Plasma is also a Liquid

Jinfeng Liao and Edward Shuryak
Department of Physics and Astronomy, State University of New York, Stony Brook, New York 11794, USA
(Received 17 April 2008; revised manuscript received 26 August 2008; published 15 October 2008)

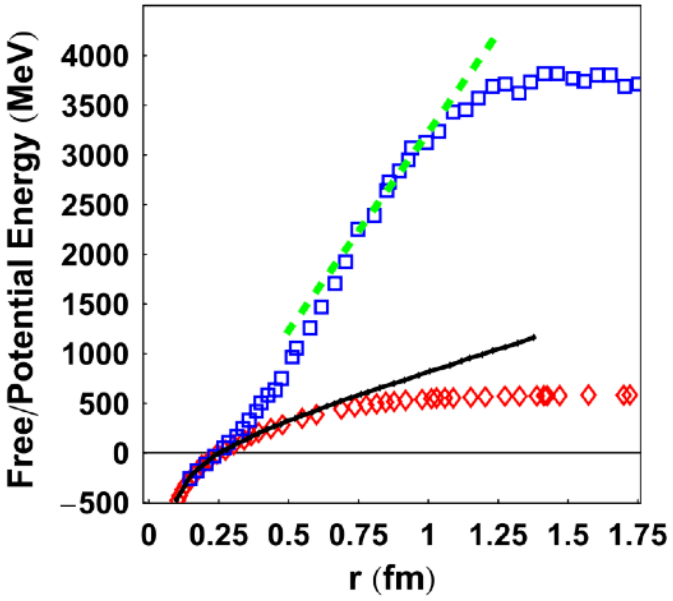
JL & Shuryak, PRC2007;PRL2008

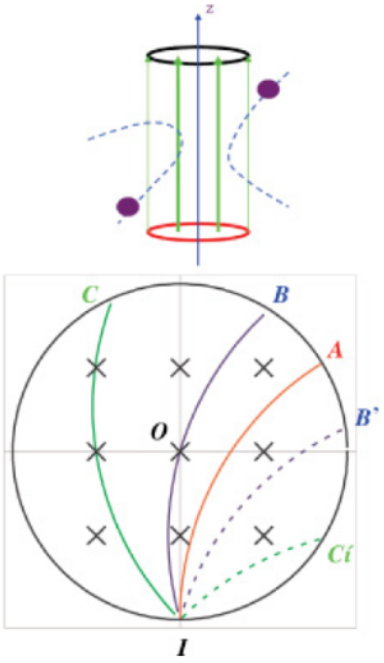
The Fluxtube/String above Tc

Electric Flux Tube in Magnetic Plasma

Jinfeng Liao (SUNY, Stony Brook), Edward Shuryak (SUNY, Stony Brook) (Jun, 2007)

Published in: *Phys.Rev.C* 77 (2008) 064905 • e-Print: 0706.4465 [hep-ph]





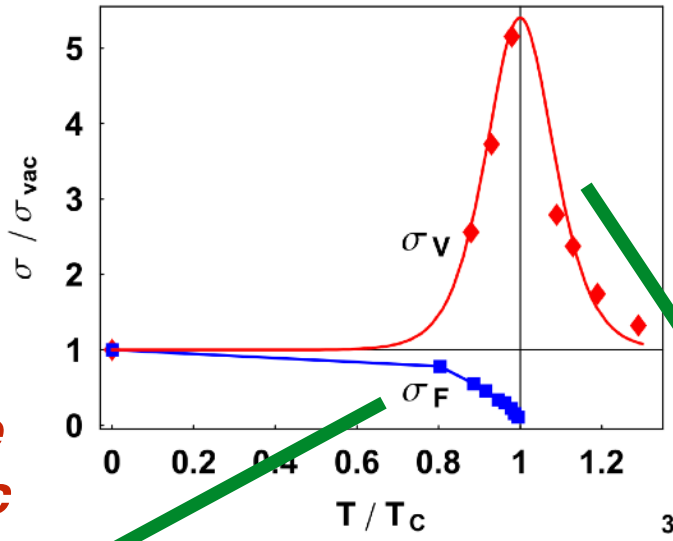
Magnetic currents from scattering of thermal monopoles can support electric fluxtube, when they are dense and "slow".

The Fluxtube/String above Tc

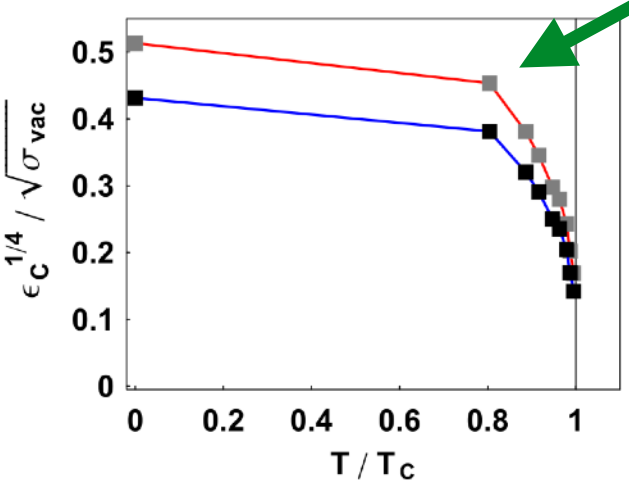
Static $\bar{Q}Q$ Potentials and the Magnetic Component of QCD Plasma near T_c

Jinfeng Liao (SUNY, Stony Brook), Edward Shuryak (SUNY, Stony Brook) (Apr, 2008)

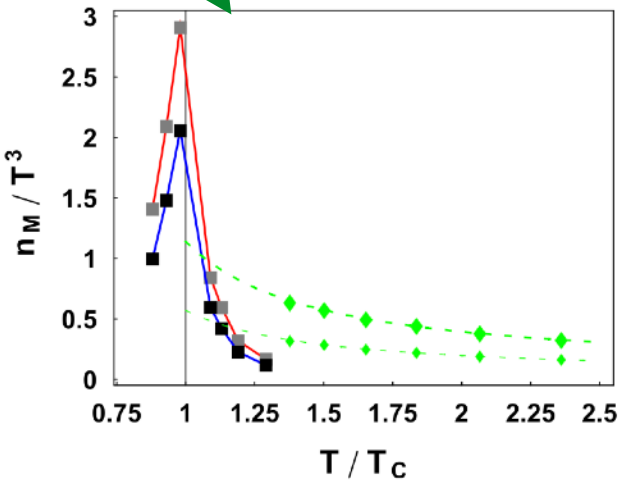
Published in: *Phys.Rev.D* 82 (2010) 094007 • e-Print: 0804.4890 [hep-ph]



Melting of monopole condensate below Tc



Emergence of thermal monopoles near Tc

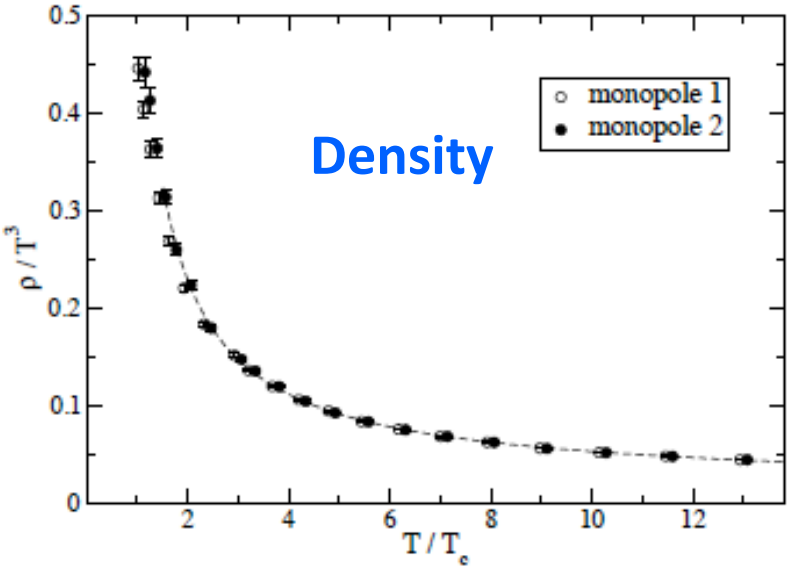


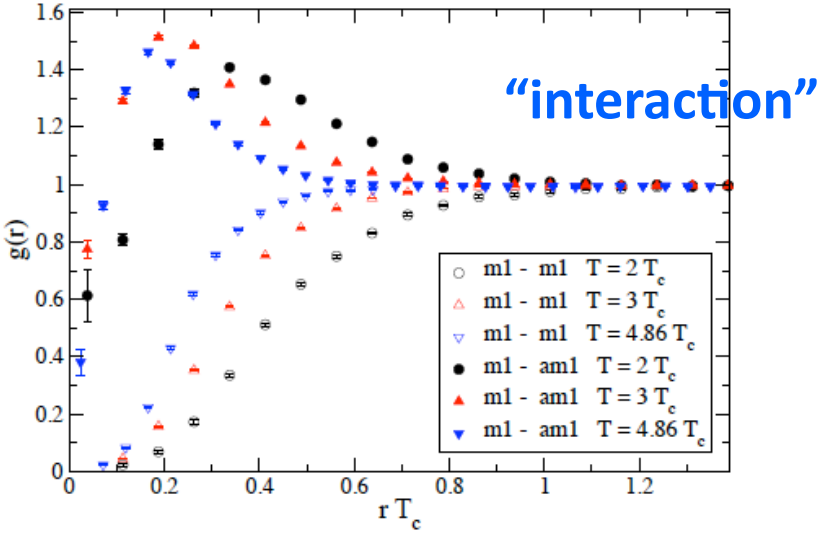
Lattice Insights

Chernodub & Zakharov, SU(2) pure gauge:
hep-ph/0611228 [hep-ph]

$$\rho(T) \approx T_c^3 \qquad (T_c < T < 2T_c)\,. \qquad\qquad \rho(T) \approx (0.25\,T)^3 \qquad (T > 2T_c)$$

for SU(3) pure gauge theory
Bonati & D'Elia, arXiv:1308.0302[hep-lat]



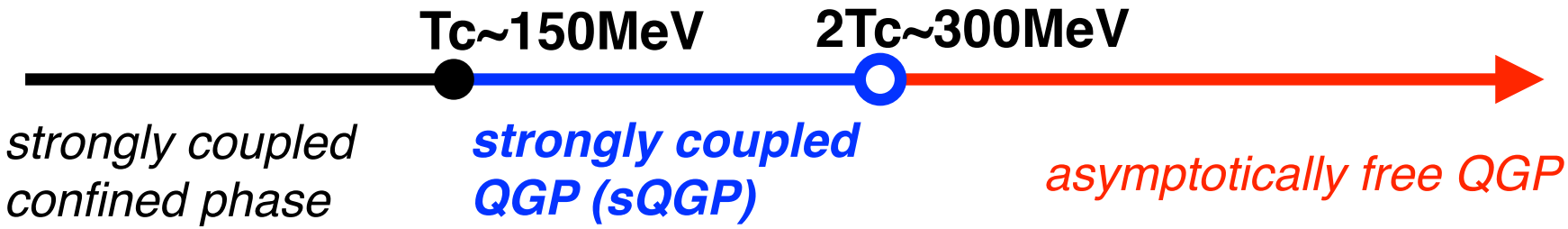


sQGP: Significant Magnetic Component

The old belief



The new paradigm



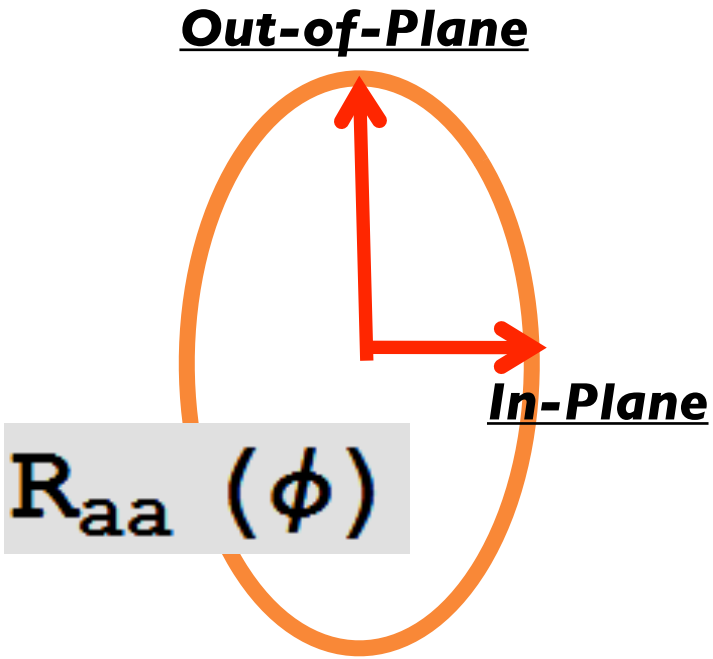
The sQGP is a new emergent phase of QCD matter, with suppressed quarks/gluons and a significant monopole component: It naturally bridges the confined phase and wQGP!

Can we find an experimental evidence for the magnetic component?

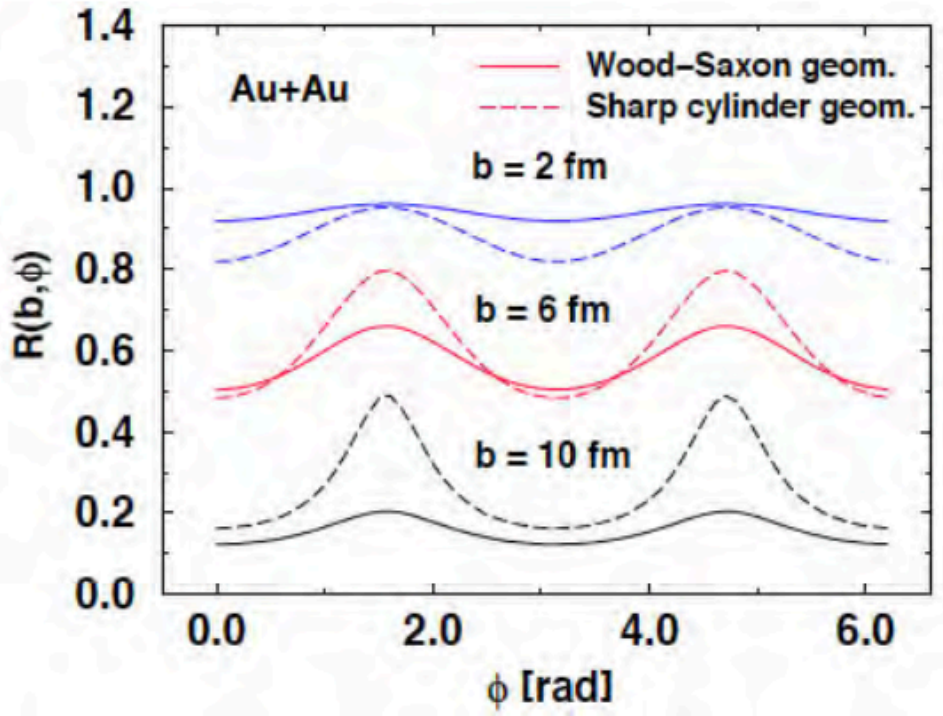
Experimental Evidence?!

Geometric Tomography

Geometric tomography(~2000)
[Gyulassy,Vitev,Wang, arXiv:nucl-th/0012092

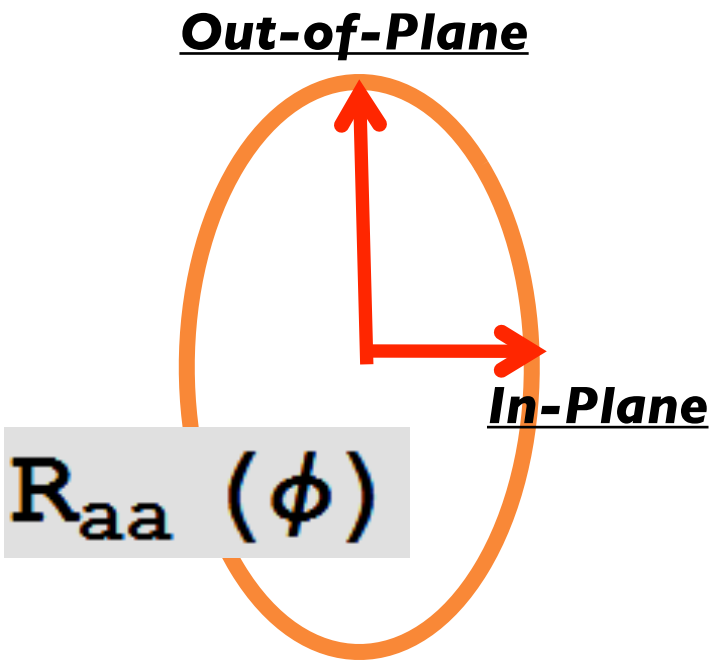


$I_{in} < I_{out} \Rightarrow (R_{aa})_{in} > (R_{aa})_{out}$

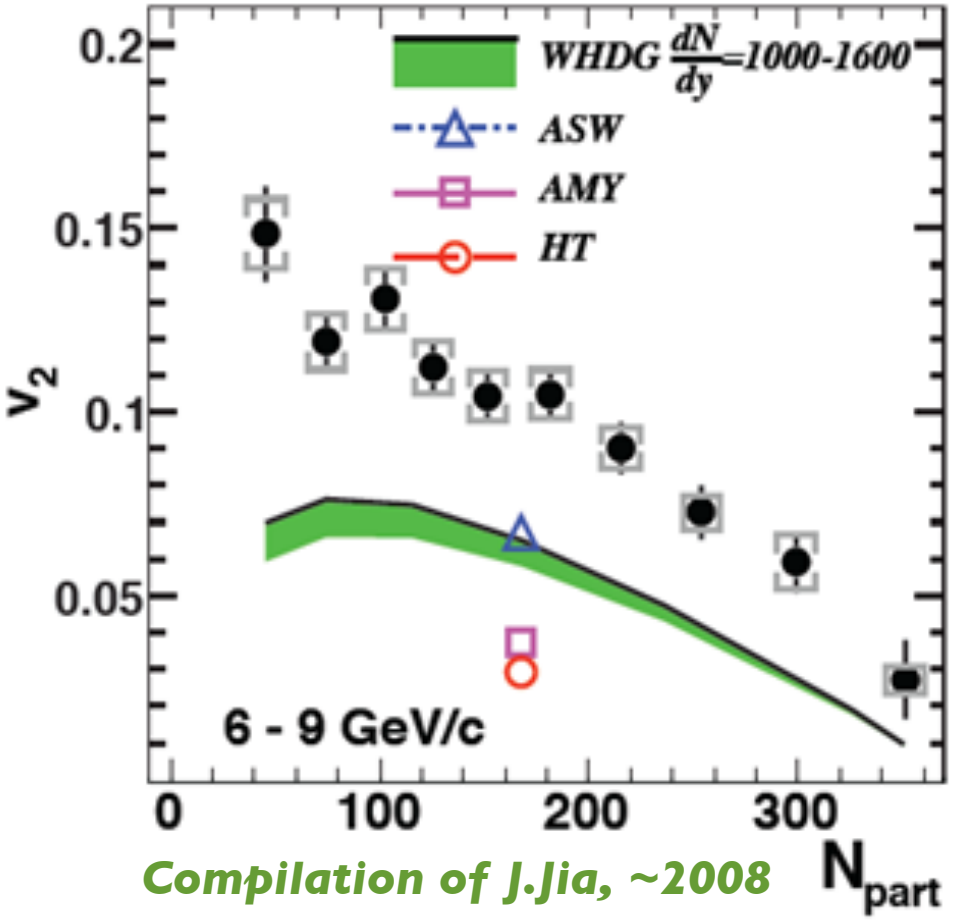


However: exp. data showed much larger anisotropy?!
Geometric model analysis: Shuryak; Drees-Feng-Jia;…

Geometric Tomography



$I_{in} < I_{out} \Rightarrow (R_{aa})_{in} > (R_{aa})_{out}$

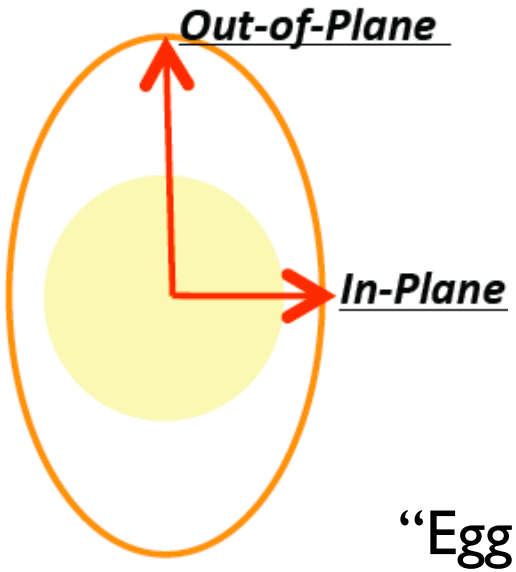


Compilation of J.Jia, ~2008

Till ~ 2008: clear discrepancy between accurate data and model predictions.

High Pt v2 became a long standing challenge

Where Are Jets Quenched (More Strongly)?



Taken for granted in all previous models: Jet-medium coupling is T-independent.

We realized the puzzle may concern more radical questions:

Where are jets quenched (more strongly)?

Geometry is a sensitive feature:
"Egg yolk" has one geometry,"Egg white" has another.

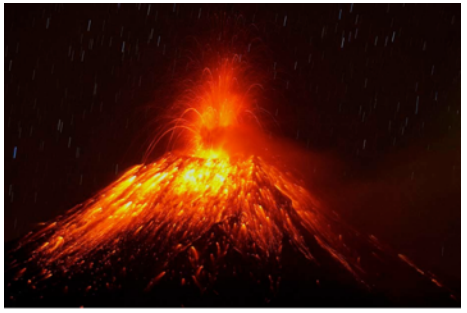
PRL 102, 202302 (2009) PHYSICAL REVIEW LETTERS week ending 22 MAY 2009

Angular Dependence of Jet Quenching Indicates Its Strong Enhancement near the QCD Phase Transition

Jinfeng Liao[1,2,*] and Edward Shuryak[1,†]

[1]*Department of Physics and Astronomy, State University of New York, Stony Brook, New York 11794, USA*
[2]*Nuclear Science Division, Lawrence Berkeley National Laboratory, Berkeley, California 94720, USA*
(Received 22 October 2008; revised manuscript received 19 February 2009; published 22 May 2009)

Near-Tc Enhancement of Jet-Medium Coupling



Three major findings:

(1) With fixed Raa, the jet v2 is VERY sensitive to the T-dependence of jet-medium coupling;

(2) Energy loss around Tc region enhances the jet v2;

(3) RHIC data suggests a very strong enhancement near Tc.

Over time, these points were confirmed by many later studies.

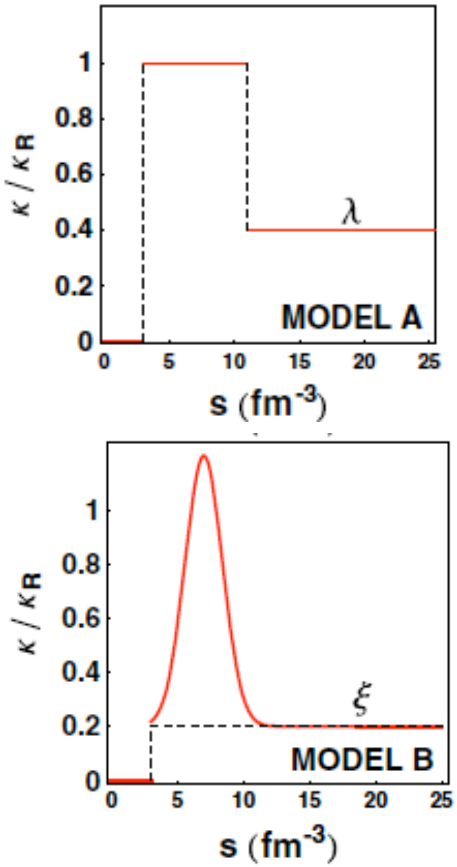
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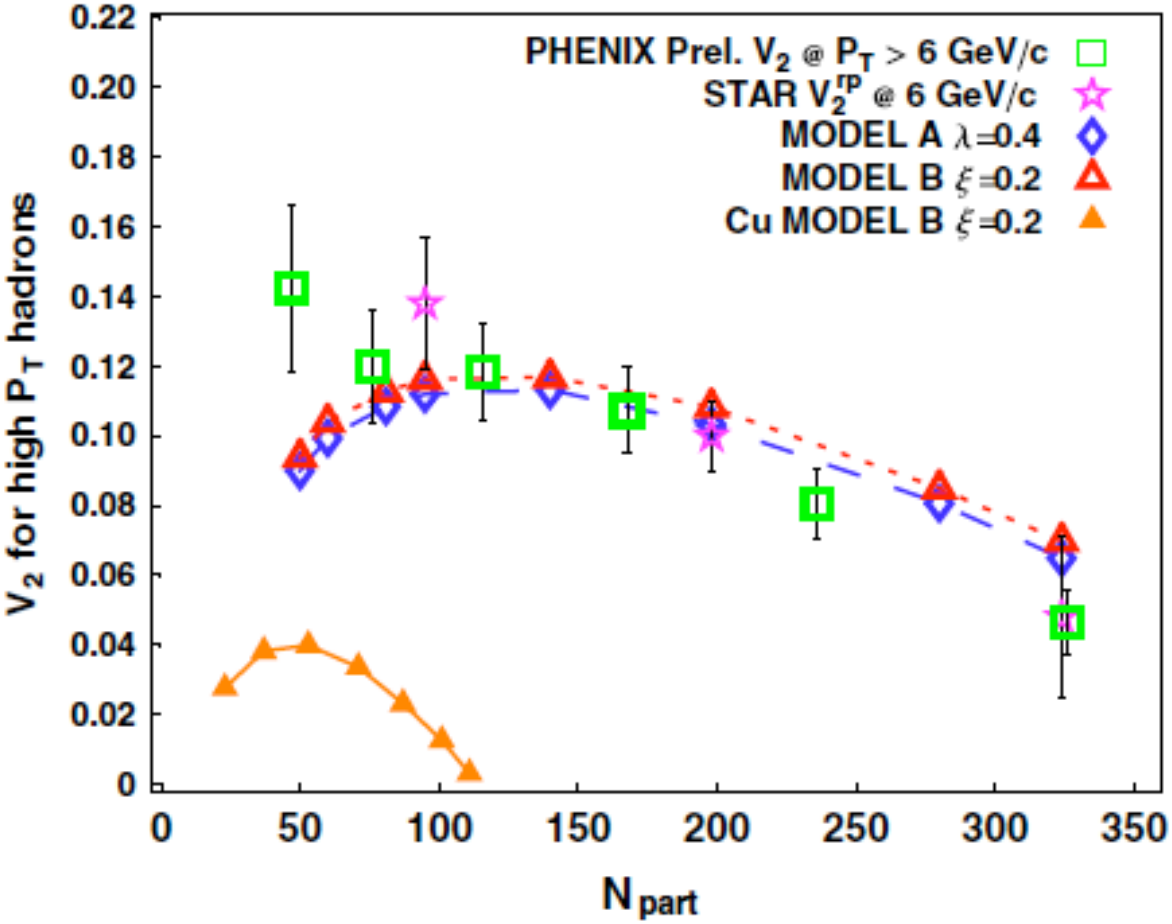
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Near-Tc Enhancement (NTcE)





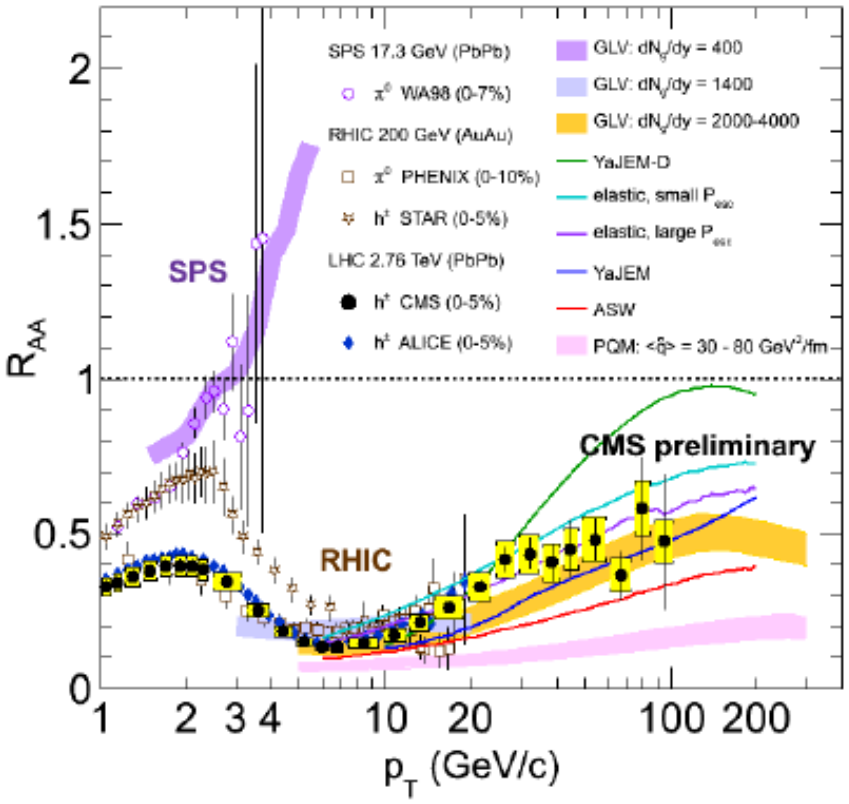


In the paper PRL(2009) we concluded:

"In relativistic heavy ion collisions the jets are quenched about **2--5 times stronger** in the near-Tc region than the higher-T QGP phase."

The RHIC+LHC Era

Raa(RHIC)~Raa(LHC)



(RHIC+LHC) & (Raa+V2): a highly constraining set of observables for jet energy loss models!

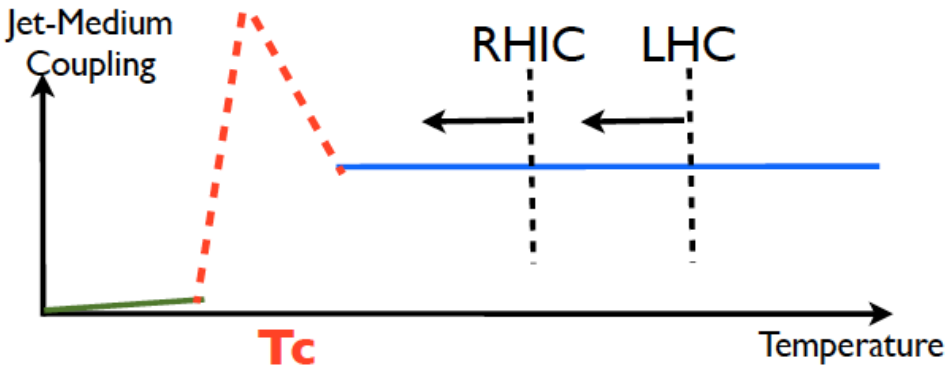
Already a clear hint of LESS OPACITY: similar R_aa, despite twice the density!

— "surprising transparency" (Horowitz & Gyulassy, QM11)

— naturally expected if the "volcano scenario" is indeed true (Liao PANIC11)

$$< \kappa >_{\rm RHIC} : < \kappa >_{\rm LHC} \approx 1 : 0.72$$

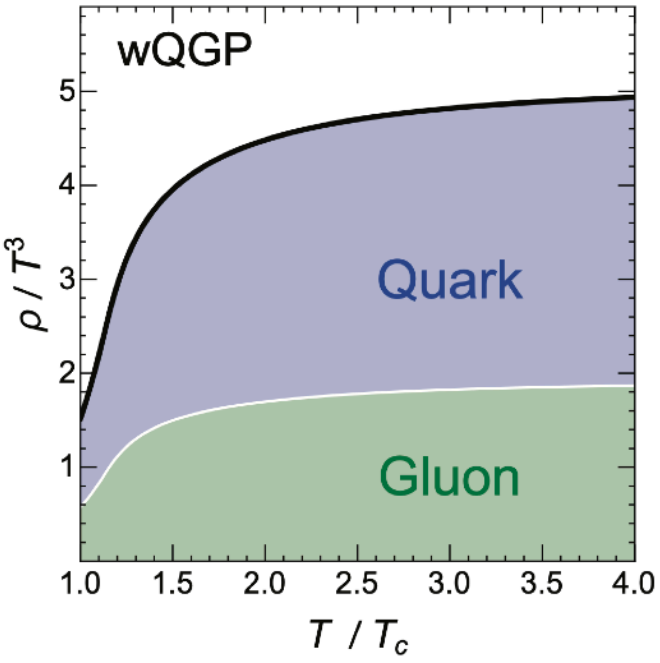
JL, arXiv:1109.0271; Zhang & JL, arXiv: 1208.6361; arXiv:1210.1245



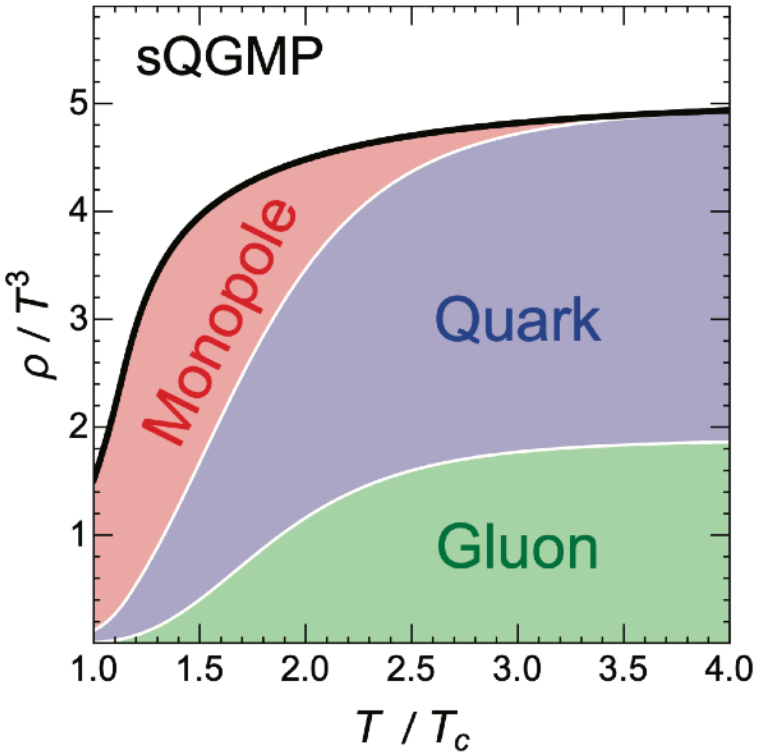
sQGMP: semi-Quark-Gluon-Monopole-Plasma

The thermal monopoles near Tc provides the natural mechanism of enhancing jet energy loss.

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



v.s.



To implement the magnetic scenario in a sophisticated jet energy loss model —> CUJET3
It allows quantitative test of the magnetic component.

CUJET3: semi-Quark-Gluon Monopole Plasma

CHIN. PHYS. LETT. Vol. 32, No. 9 (2015) 092501 Express Letter

Consistency of Perfect Fluidity and Jet Quenching in Semi-Quark-Gluon Monopole Plasmas *

Jiechen Xu(徐杰谌)[1], Jinfeng Liao(廖劲峰)[2,3]**, Miklos Gyulassy[1]**

[1]*Department of Physics, Columbia University, New York 10027, USA*
[2]*Physics Department and CEEM, Indiana University, Bloomington 47408, USA*
[3]*RIKEN BNL Research Center, Bldg. 510A, Brookhaven National Laboratory, New York 11973, USA*

(Received 31 July 2015)

We utilize a new framework, CUJET3.0, to deduce the energy and temperature dependence of the jet transport parameter, $\hat{q}(E > 10\ \mathrm{GeV}, T)$, from a combined analysis of available data on nuclear modification factor and azimuthal asymmetries from high energy nuclear collisions at RHIC/BNL and LHC/CERN. 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: (i) the Polyakov loop suppression of color-electric scattering (aka 'semi-QGP' of Pisarski et al.), (ii) the enhancement of jet scattering due to emergent magnetic monopoles near T_c (aka 'magnetic scenario' of Liao and Shuryak), and (iii) thermodynamic properties constrained by lattice QCD data. CUJET3.0 reduces to v2.0 at high temperatures $T > 400$ MeV, while 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.

PACS: 25.75.−q, 12.38.Mh, 24.85.+p, 13.87.−a DOI: 10.1088/0256-307X/32/9/092501





Bridging soft-hard transport properties of quark-gluon plasmas with CUJET3.0

Jiechen Xu,[a] Jinfeng Liao[b,c] and Miklos Gyulassy[a]

[a]*Department of Physics, Columbia University, 538 West 120th Street, New York, NY 10027, U.S.A.*
[b]*Physics Department and Center for Exploration of Energy and Matter, Indiana University, 2401 North Milo B. Sampson Lane, Bloomington, IN 47408, U.S.A.*
[c]*RIKEN BNL Research Center, Brookhaven National Laboratory, Building 510A, Upton, NY 11973, U.S.A.*

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JHEP02(2016)169

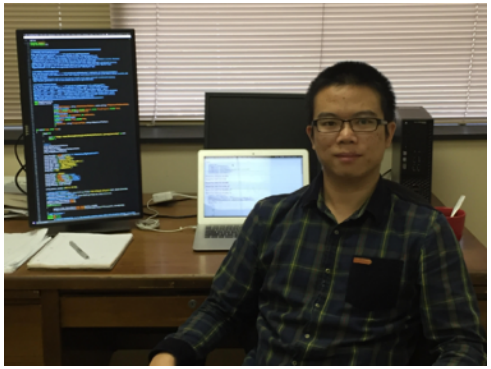
CUJET3: semi-Quark-Gluon Monopole Plasma

Chinese Physics C Vol. 42, No. 10 (2018) 104104

Probing the color structure of the perfect QCD fluids via soft-hard-event-by-event azimuthal correlations *

Shuzhe Shi[1)] Jinfeng Liao[1;1)] Miklos Gyulassy[2,3,4]

[1] Physics Department and Center for Exploration of Energy and Matter,
Indiana University, 2401 N Milo B. Sampson Lane, Bloomington, IN 47408, USA
[2] Nuclear Science Division, Lawrence Berkeley National Laboratory, Berkeley, CA 94720, USA
[3] Pupin Lab MS-5202, Department of Physics, Columbia University, New York, NY 10027, USA
[4] Institute of Particle Physics and Key Laboratory of Quark & Lepton Physics (MOE),
Central China Normal University, Wuhan 430079, China



Chinese Physics C Vol. 43, No. 4 (2019) 044101

Global constraints from RHIC and LHC on transport properties of QCD fluids in CUJET/CIBJET framework*

Shuzhe Shi(施舒哲)[1;1)] Jinfeng Liao(廖劲峰)[1;2)] Miklos Gyulassy[2,3,4;3)]

[1] Physics Department and Center for Exploration of Energy and Matter, Indiana University,
2401 N Milo B. Sampson Lane, Bloomington, IN 47408, USA
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Institute of Particle Physics and Key Laboratory of Quark &Lepton Physics (MOE), Central China Normal University, Wuhan, 430079, China

A Sophisticated Simulation Framework

DGLV-CUJET framework for describing multi-parton scattering:

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

Original DGLV formalism has only quark/gluon scattering centers

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

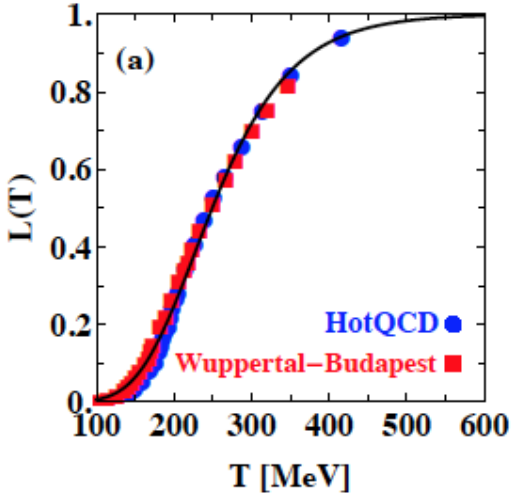
We now include both color-electric and color-magnetic scattering centers.

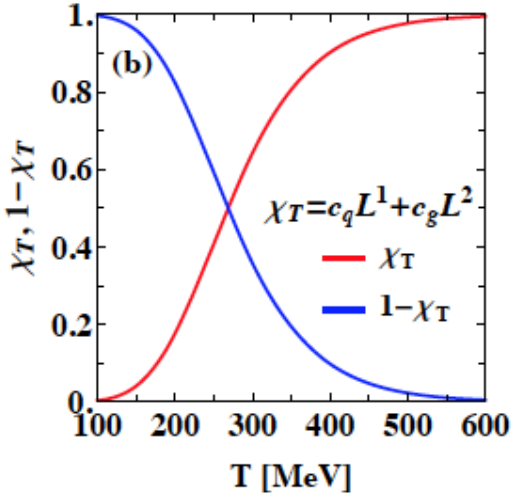
$$\left[\frac{n_e\left(\alpha_s(q^2)\alpha_s(q^2)\right)f_E^2}{q^2(q^2+f_E^2\mu^2)} + \frac{n_m\left(\alpha^e(q^2)\alpha^m(q^2)\right)f_M^2}{q^2(q^2+f_M^2\mu^2)}\right]$$

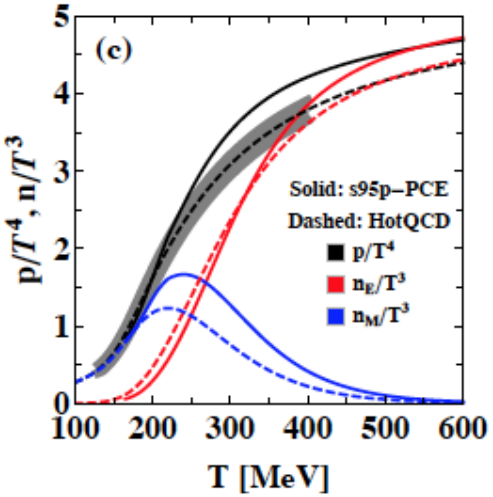
Bulk evolution: VISH2+1

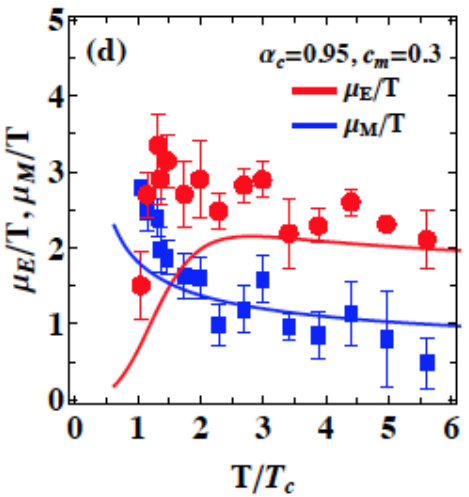
Xu, JL, Gyulassy, arXiv:1411.3673

The Making of sQGP in CUJET3.0









** Electric density:*
L-loop suppression

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

** Magnetic density:*
constrained by total pressure

$$(1-\chi_T)$$

** Running coupling:*

$$\alpha_s(Q^2) = \alpha_c / \left[1 + \frac{9\alpha_c}{4\pi}\mathrm{Log}(\frac{Q^2}{T_c^2})\right]$$

** Screening:*

$$f_E(T) = \sqrt{\chi_T} \quad , \quad f_M(T) = c_m\, g$$

The model implementations of electric and magnetic components are carefully **constrained by available lattice data.**

[Xu, JL, Gyulassy, arXiv:1411.3673(CPL);1508.00552(JHEP)]

Systematic Calibration of CUJET3

We constrain the two key parameters of sQGMP by a global chi-square analysis of ALL light hadron data.

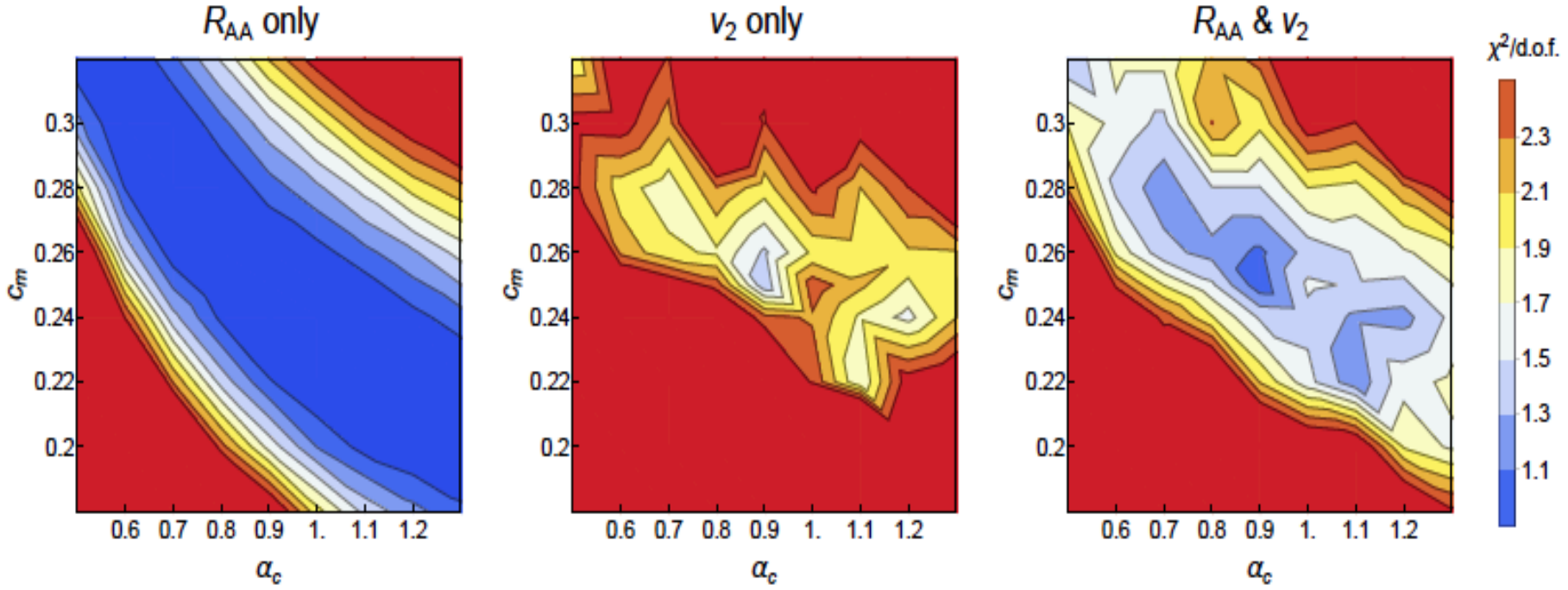
We compute χ^2/d.o.f. for each of the following 12 data sets:

- 200 GeV Au-Au Collisions, 0-10% Centrality Bin, $R_{AA}(\pi^0)$: PHENIX [33, 34];
- 200 GeV Au-Au Collisions, 0-10% Centrality Bin, $v_2(\pi^0)$: PHENIX [34];
- 200 GeV Au-Au Collisions, 20-30% Centrality Bin, $R_{AA}(\pi^0)$: PHENIX [33, 34];
- 200 GeV Au-Au Collisions, 20-30% Centrality Bin, $v_2(\pi^0)$: PHENIX [34];
- 2.76 TeV Pb-Pb Collisions, 0-10% Centrality Bin, $R_{AA}(h^{\pm})$: ALICE [35];
- 2.76 TeV Pb-Pb Collisions, 0-10% Centrality Bin, $v_2(h^{\pm})$: ATLAS [36], CMS [37];
- 2.76 TeV Pb-Pb Collisions, 20-30% Centrality Bin, $R_{AA}(h^{\pm})$: ALICE [35];
- 2.76 TeV Pb-Pb Collisions, 20-30% Centrality Bin, $v_2(h^{\pm})$: ALICE [38], ATLAS [36], CMS [37];
- 5.02 TeV Pb-Pb Collisions, 0-5% Centrality Bin, $R_{AA}(h^{\pm})$: ATLAS-preliminary [39], CMS [31];
- 5.02 TeV Pb-Pb Collisions, 0-5% Centrality Bin, $v_2(h^{\pm})$: CMS [32];
- 5.02 TeV Pb-Pb Collisions, 10-30% Centrality Bin, $R_{AA}(h^{\pm})$: CMS [31];
- 5.02 TeV Pb-Pb Collisions, 20-30% Centrality Bin, $v_2(h^{\pm})$: CMS [32];

[S. Shi, J. Liao, M. Gyulassy, CPC2018]

Systematic Calibration of CUJET3

We constrain the two key parameters of sQGMP by a global chi-square analysis of ALL light hadron data.

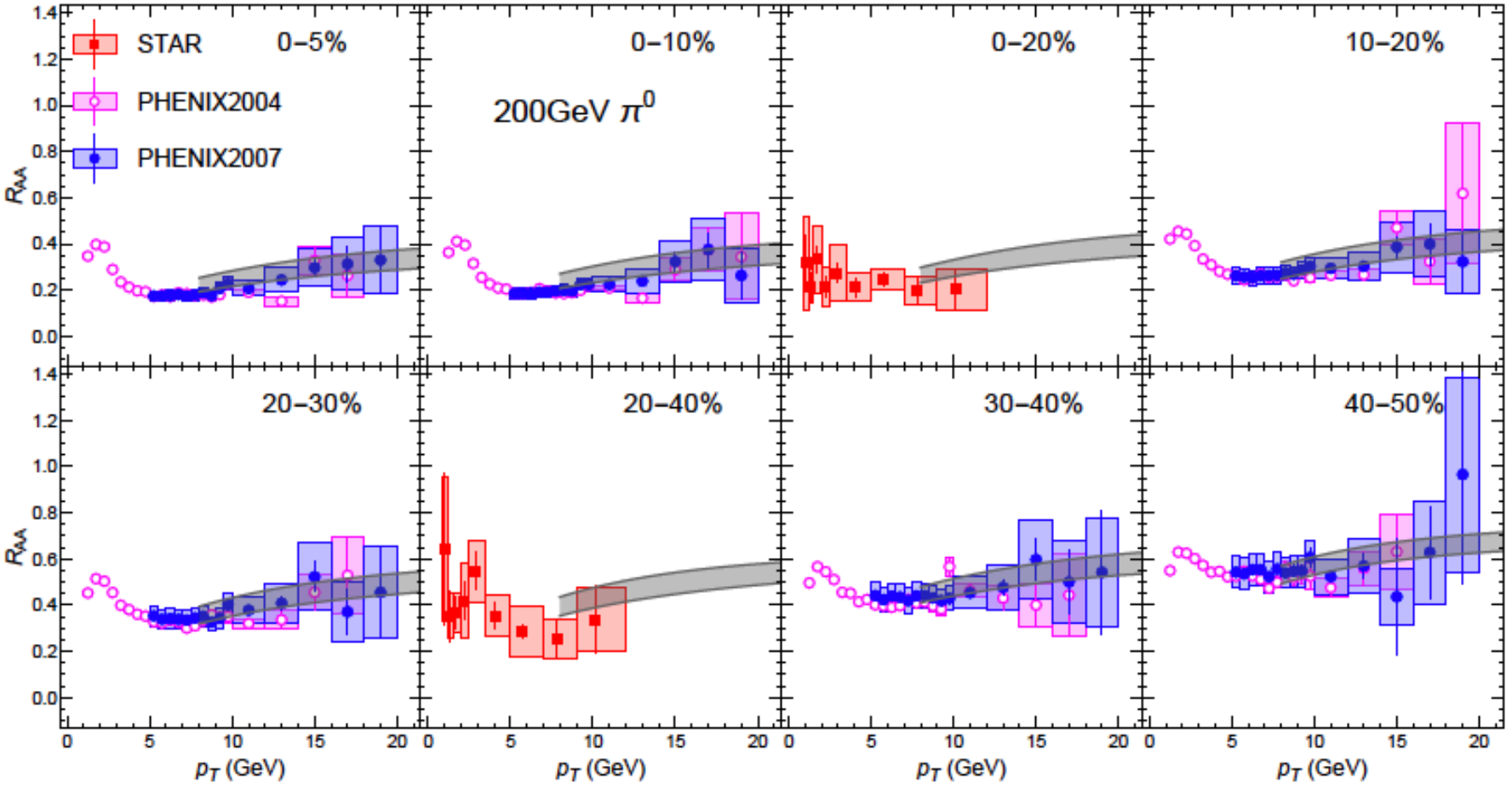


Optimal values: $\alpha_c = 0.9,\ c_m = 0.25$

[chi^2/dof =0.97]

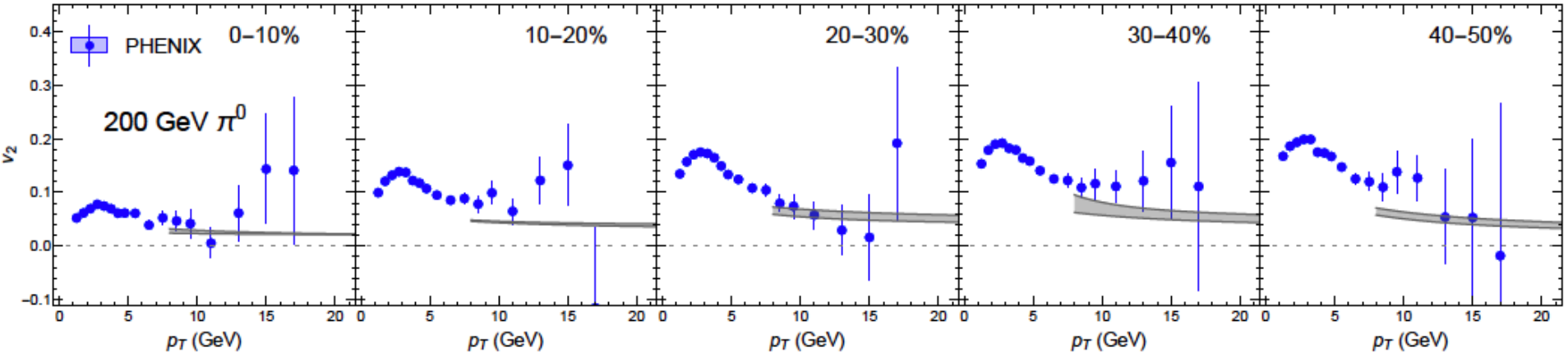
[S. Shi, J. Liao, M. Gyulassy, CPC2018]

Comparison with Light Hadron Data



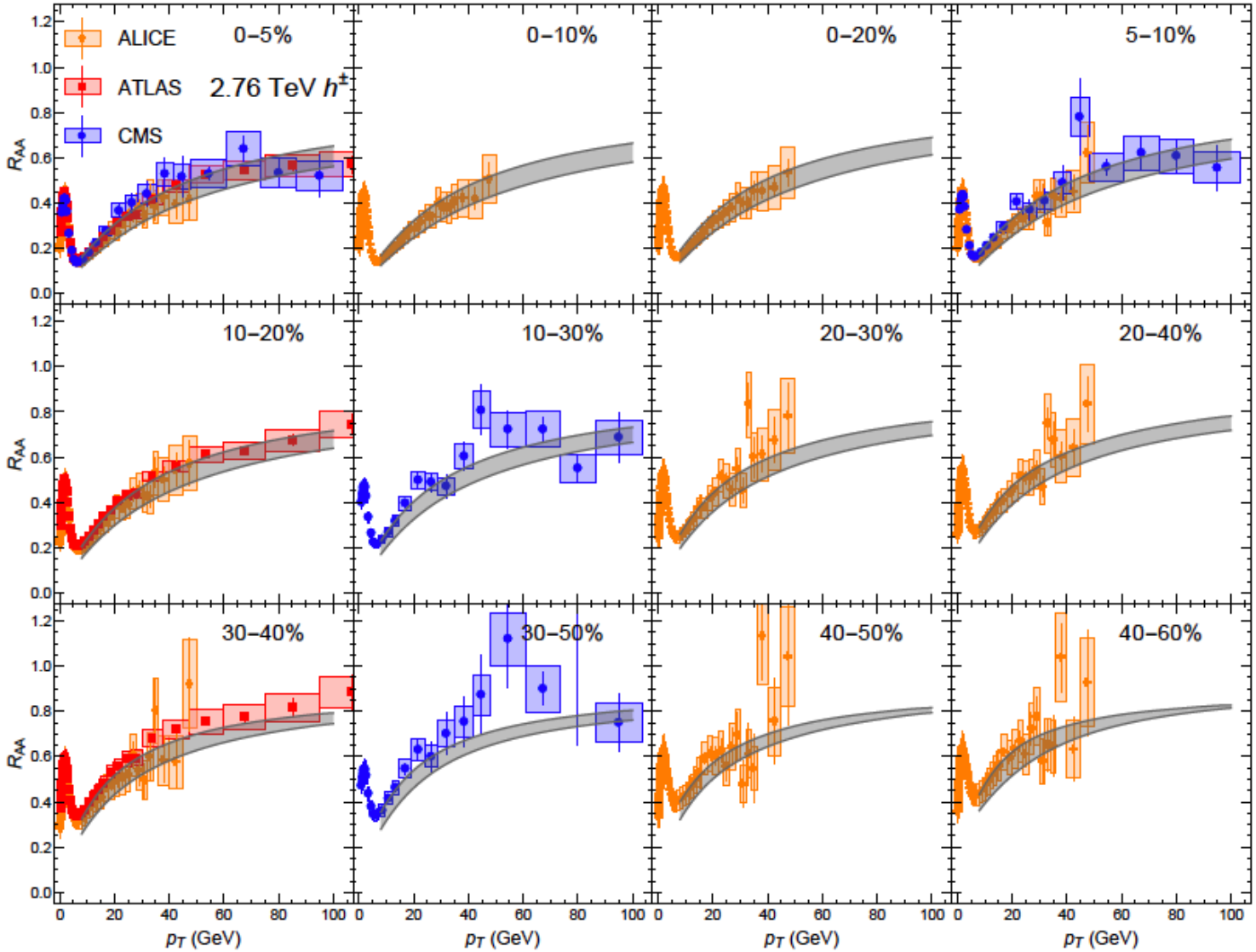
[S. Shi, J. Liao, M. Gyulassy, CPC2018]

Comparison with Light Hadron Data



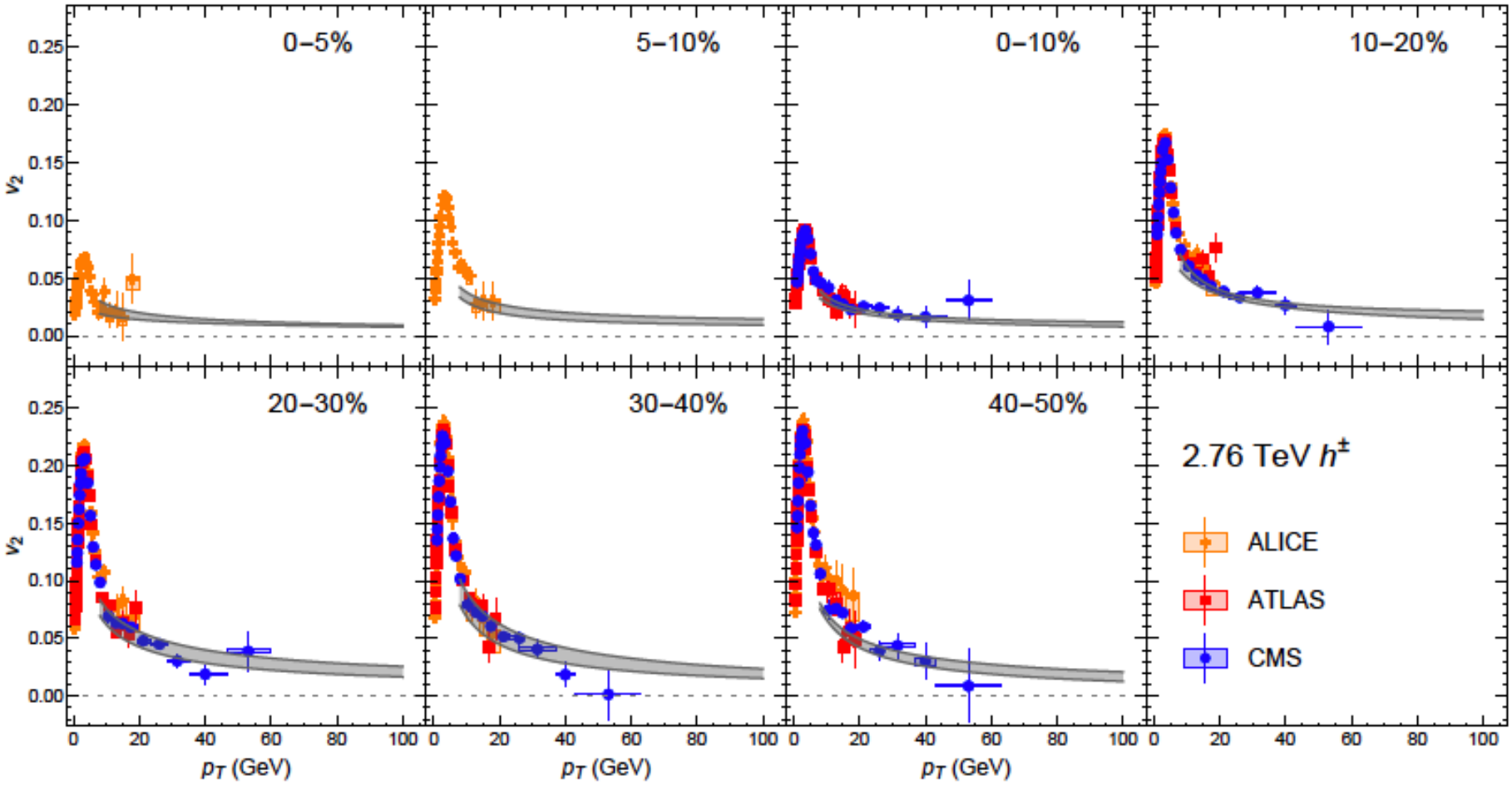
[S. Shi, J. Liao, M. Gyulassy, CPC2018]

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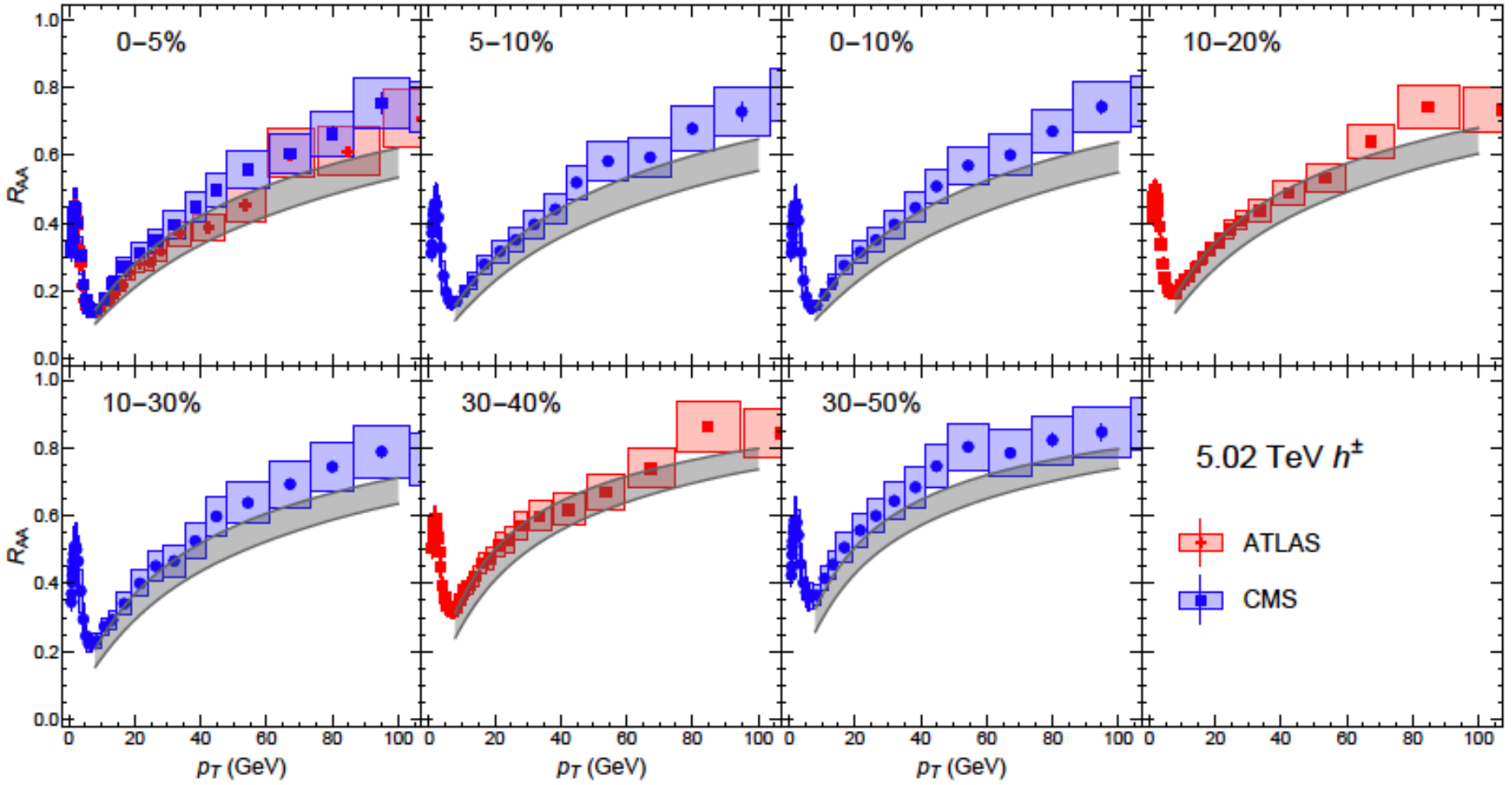
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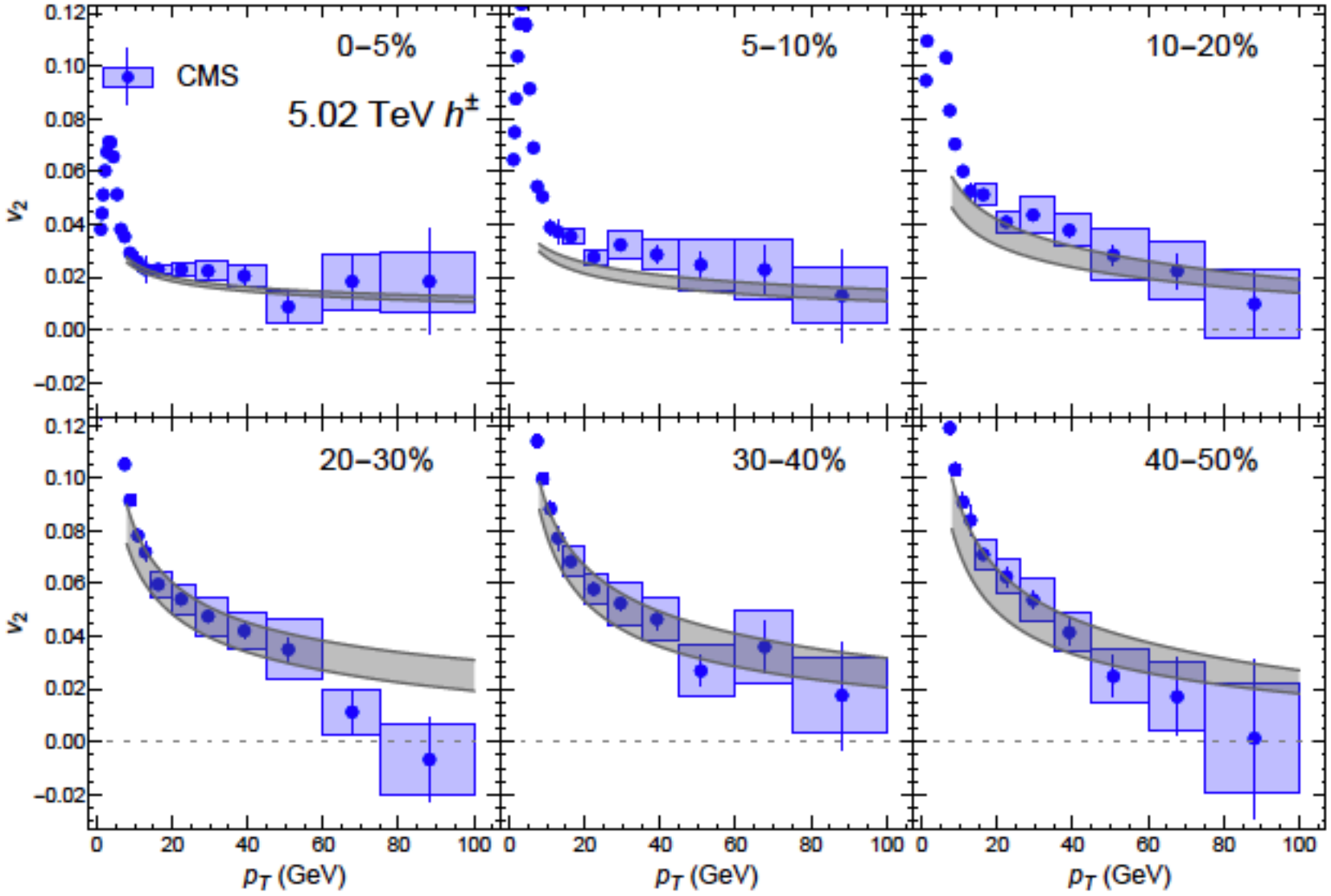
[S. Shi, J. Liao, M. Gyulassy, CPC2018]

Comparison with Light Hadron Data



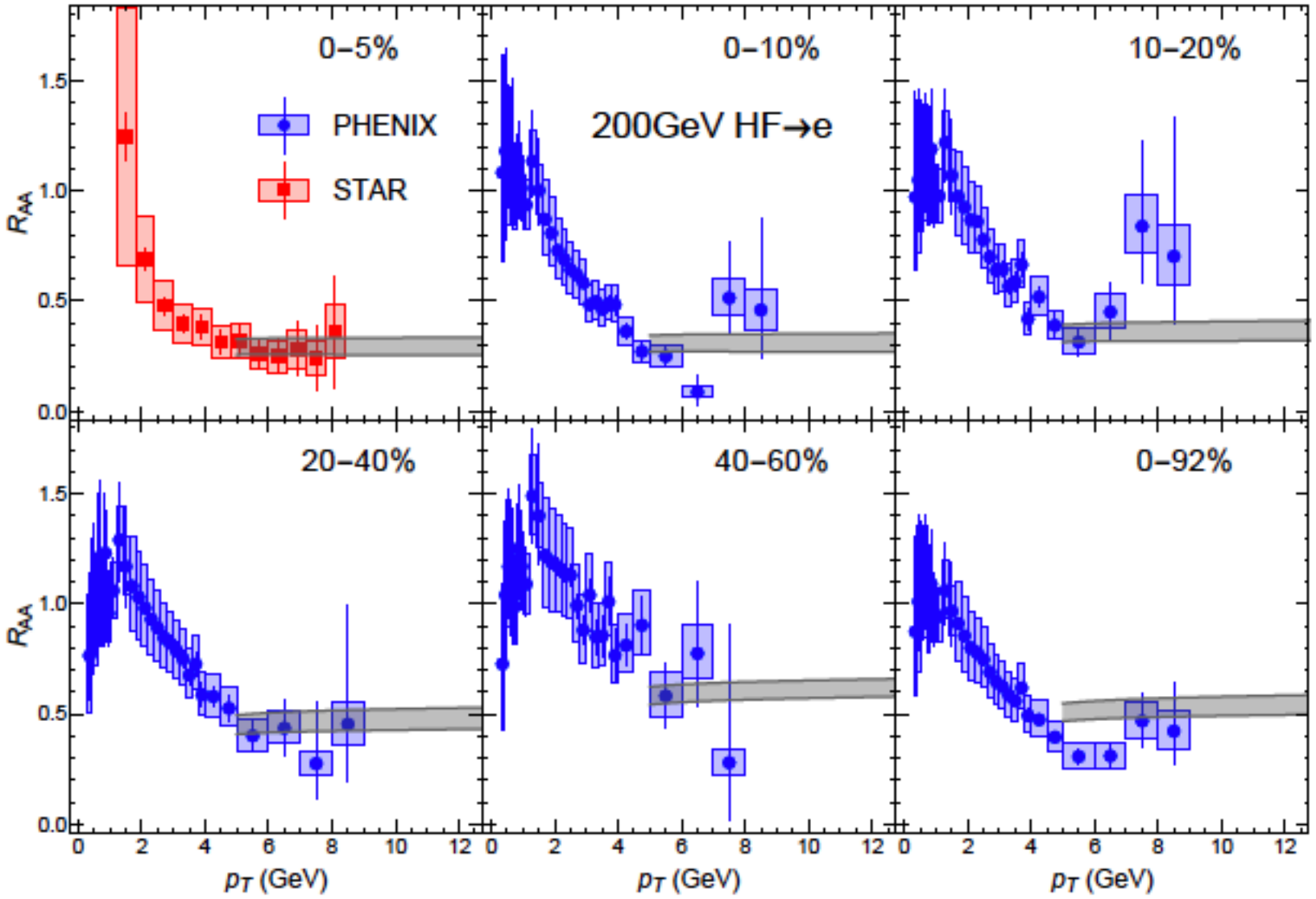
[S. Shi, J. Liao, M. Gyulassy, CPC2018]

Comparison with Light Hadron Data



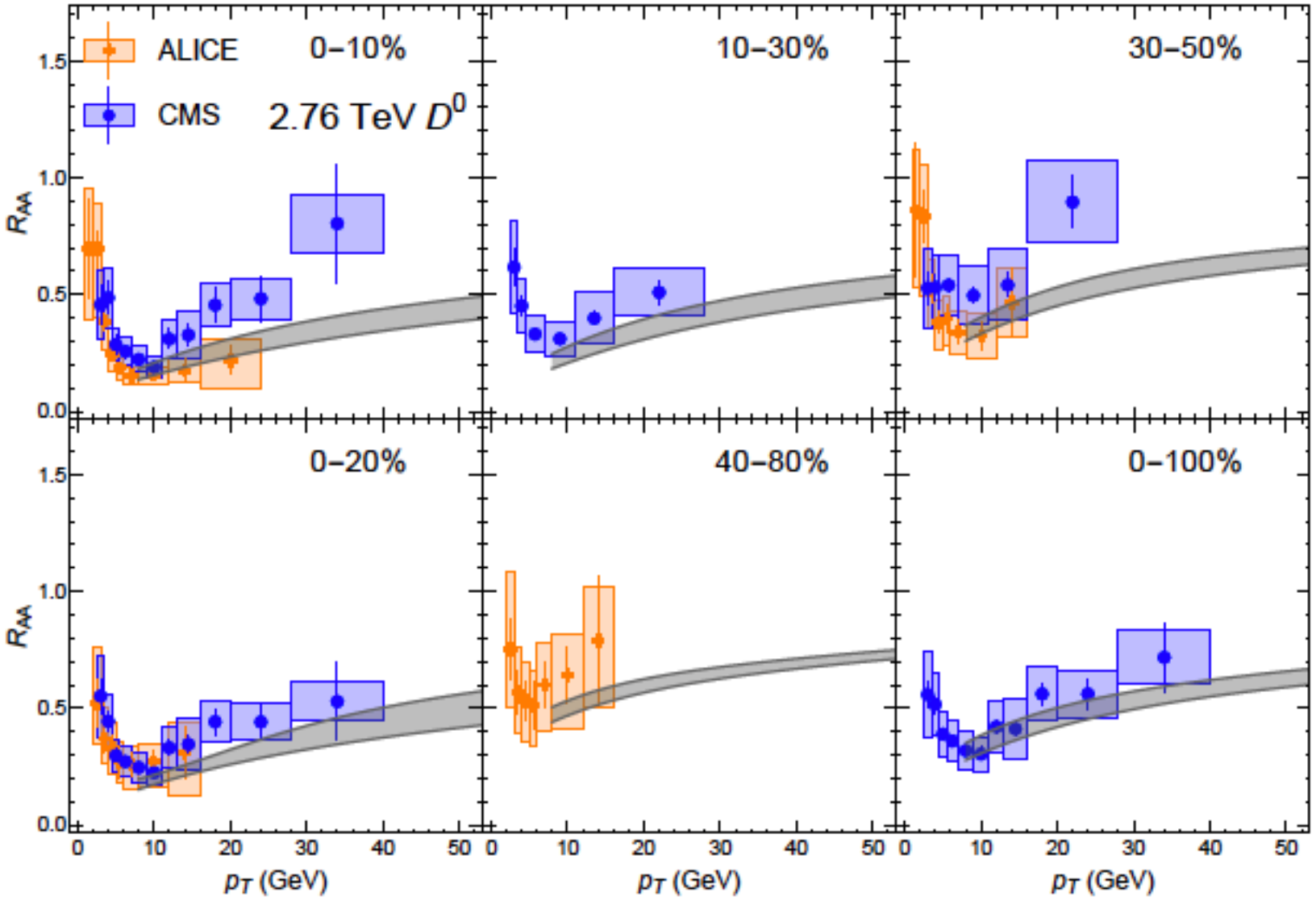
[S. Shi, J. Liao, M. Gyulassy, CPC2018]

Independent Test with Heavy Flavor Data



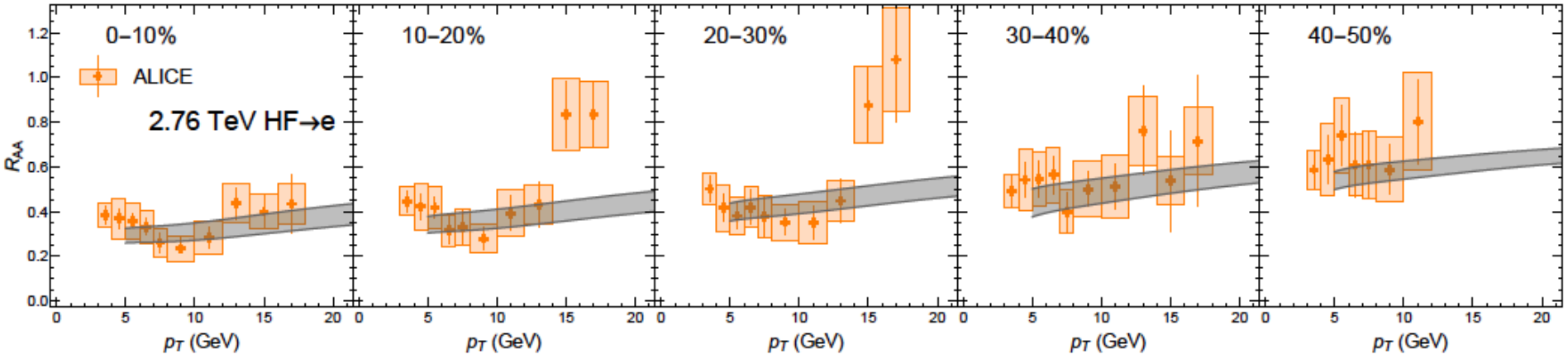
[S. Shi, J. Liao, M. Gyulassy, CPC2018]

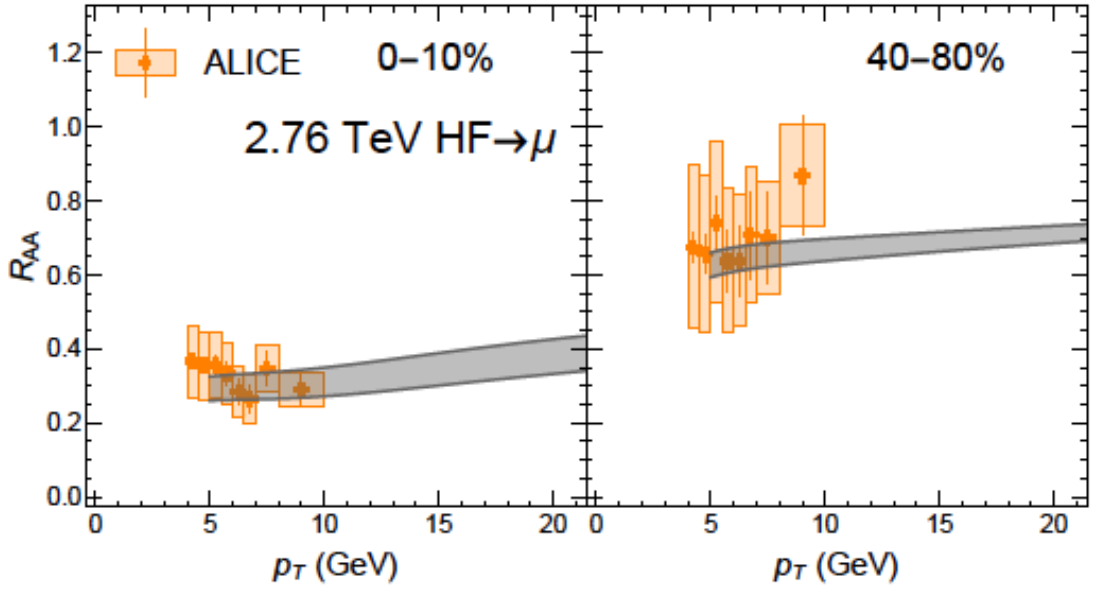
Independent Test with Heavy Flavor Data



[S. Shi, J. Liao, M. Gyulassy, CPC2018]

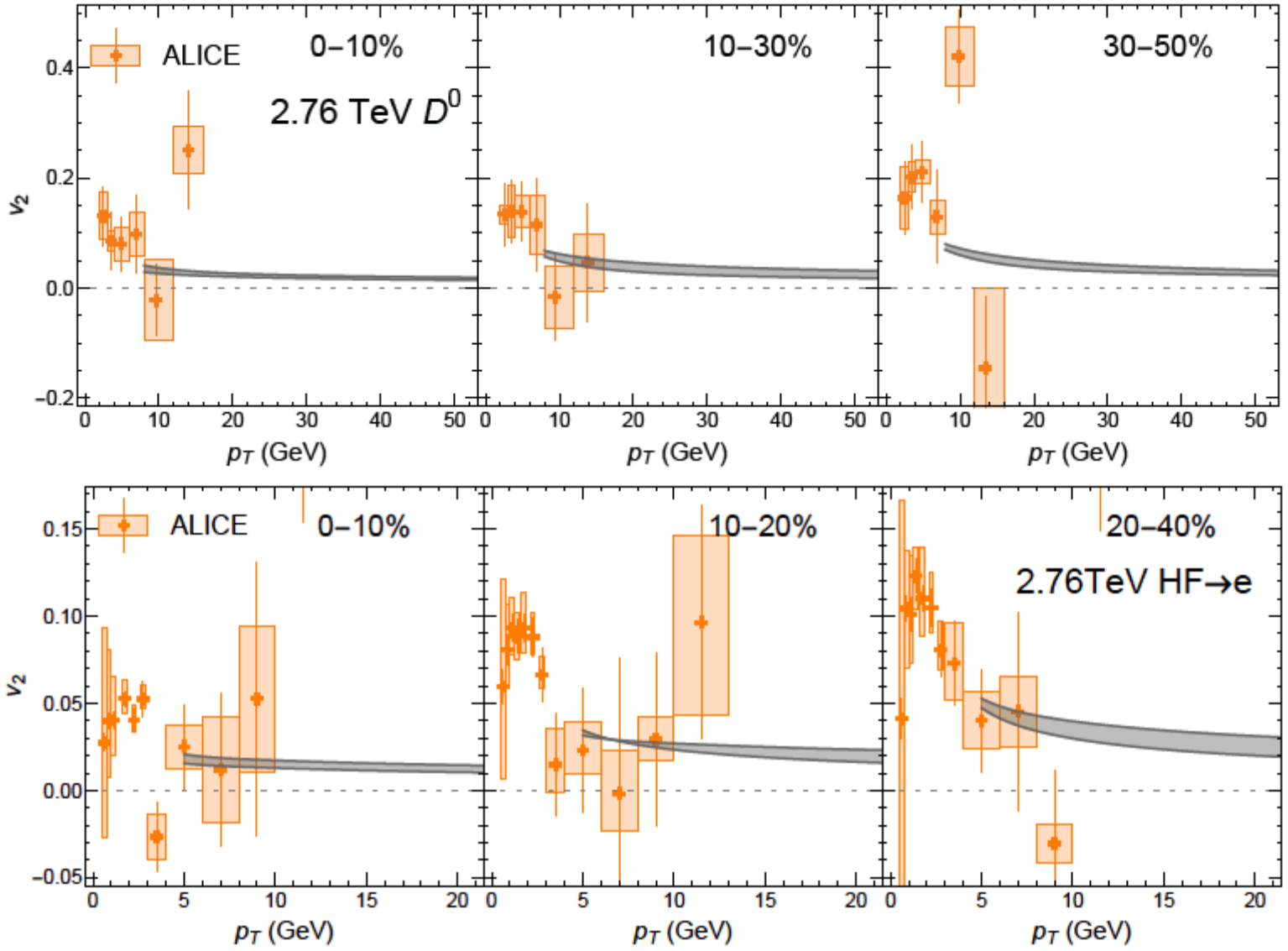
Independent Test with Heavy Flavor Data





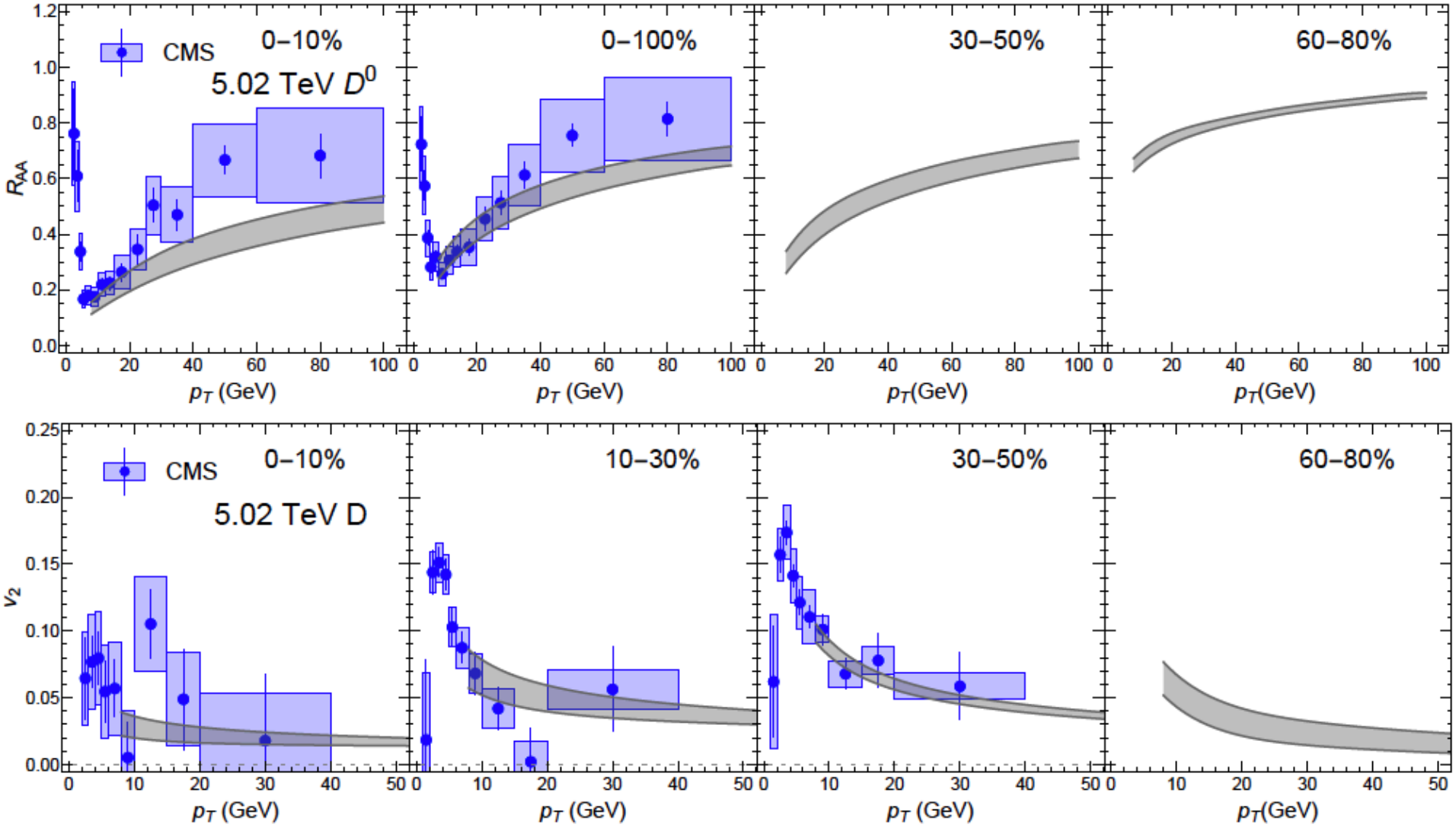
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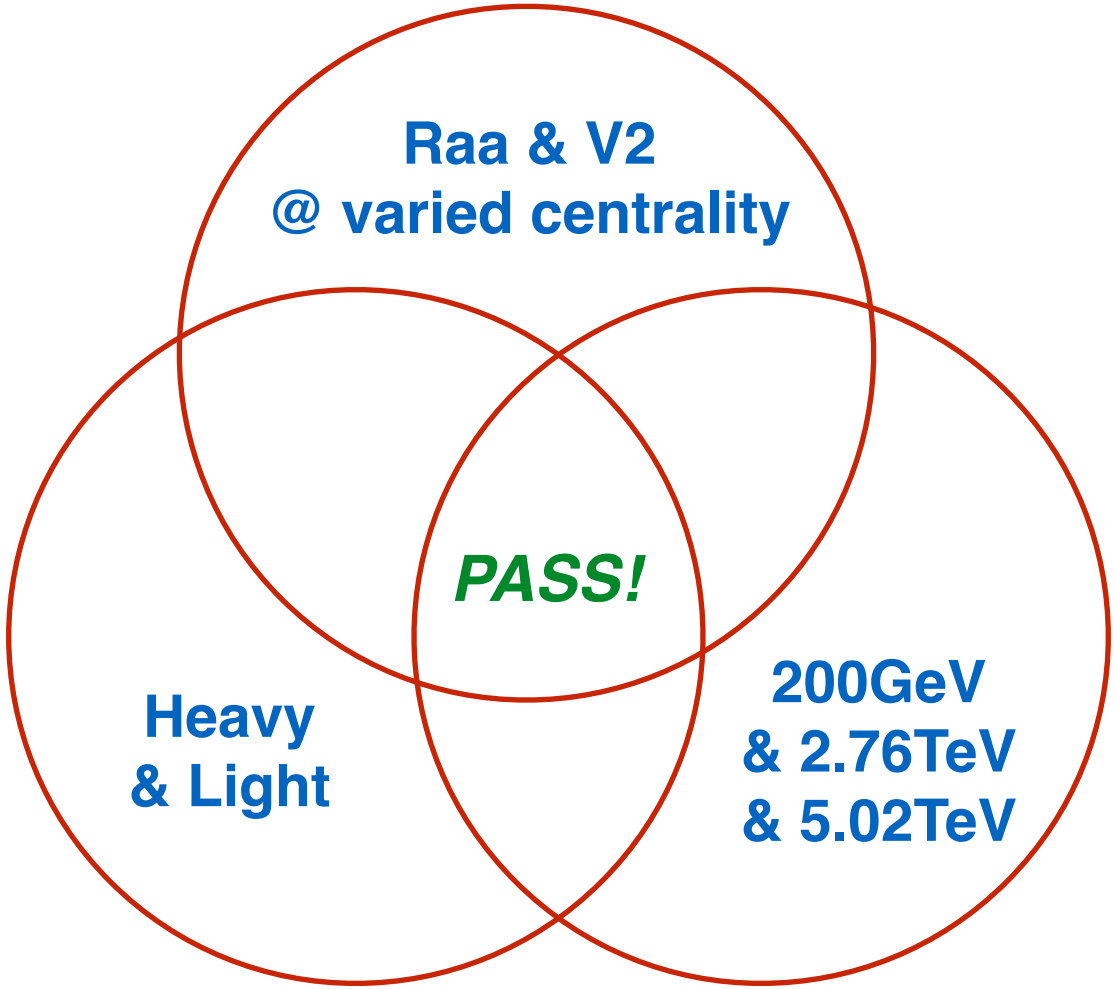
[S. Shi, J. Liao, M. Gyulassy, CPC2018]

Independent Test with Heavy Flavor Data



[S. Shi, J. Liao, M. Gyulassy, CPC2018]

Passing the Big Challenge



CUJET3 has passed this challenge.
Every model should take up this challenge.

A New Breakthrough

Bayesian inference of the magnetic component of quark-gluon plasma

Yu Guo,[1] Jinfeng Liao,[2,*] and Shuzhe Shi[1,3,†]

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[2] *Physics Department and Center for Exploration of Energy and Matter, Indiana University, 2401 N Milo B. Sampson Lane, Bloomington, IN 47408, USA.*
[3] *State Key Laboratory of Low-Dimensional Quantum Physics, Tsinghua University, Beijing 100084, China.*

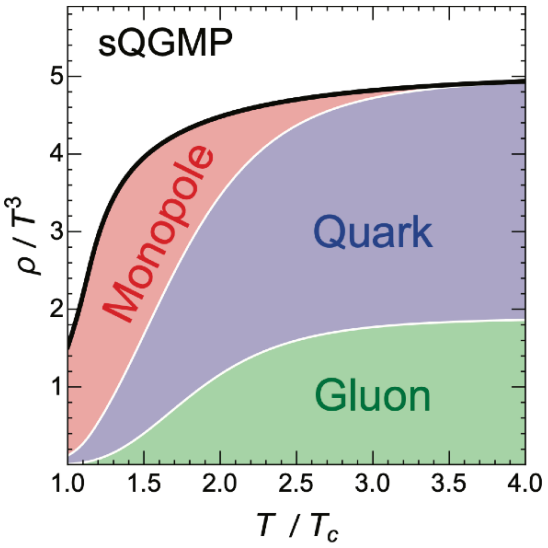
(Dated: October 21, 2025)

The chromo-magnetic monopoles (CMM), emergent topological excitations of non-Abelian gauge fields carrying chromo-magnetic charge, have long been postulated to play an important role in the vacuum confinement of quantum chromodynamics (QCD), the deconfinement transition at temperature $T_c \approx 160$MeV, as well as the strongly coupled nature of quark-gluon plasma (QGP). While such CMMs have been found to provide solutions for challenging puzzles from heavy-ion collision measurements, they were typically introduced as model assumptions in the past. Here we show how their very existence can be determined and their abundance extracted in a data-driven way for the first time. Using the CUJET3 framework for calculations of jet energy loss and analyzing a comprehensive experimental data set for nuclear modification factor ($R_{\rm AA}$) and elliptic flow (v_2) of high-transverse-momentum hadrons, the fraction of CMMs in the QGP is obtained by Bayesian inference and is found to be substantial in the $1 \sim 2T_c$ region. The posterior CMM fraction is further validated by excellent agreement with additional data and is also shown to predict QGP transport properties quantitatively consistent with the state-of-the-art knowledge.

Is there chromo-magnetic component?
Let data decide!

[Yu Guo, JL, Shuzhe Shi, arXiv:2510.16838]

Data-Driven Extraction



$$\rho_g \equiv \left(\frac{16}{16+9N_f}\right)\chi_T\rho$$

$$\rho_q \equiv \left(\frac{9N_f}{16+9N_f}\right)\chi_T\rho$$

$$\rho_m = (1-\chi_T)\rho$$

Leave chi(T) as free parameters and utilize Bayesian Inference (BI) to reach a data-driven determination!

[Yu Guo, JL, Shuzhe Shi, arXiv:2510.16838]

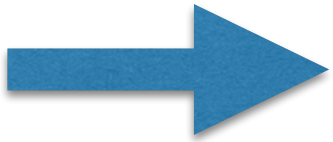
Parameters and Priors

$$\alpha_C \quad [0.3, 1.34] \qquad\qquad c_M \quad [0.19, 0.56]$$

$$\chi_T(T) \qquad\qquad \textit{10 uniform temperature points}$$

$$[0.0, 1.0] \qquad \{0.16, 0.20, \cdots, 0.52\} \ \text{GeV}$$

We consider two scenarios:
unconstrained or monotonic



Posterior

$$p(\theta|\mathcal{D}) = \mathcal{N}_{\text{norm}}\, p(\mathcal{D}|\theta)\, p(\theta)$$

[Yu Guo, JL, Shuzhe Shi, arXiv:2510.16838]

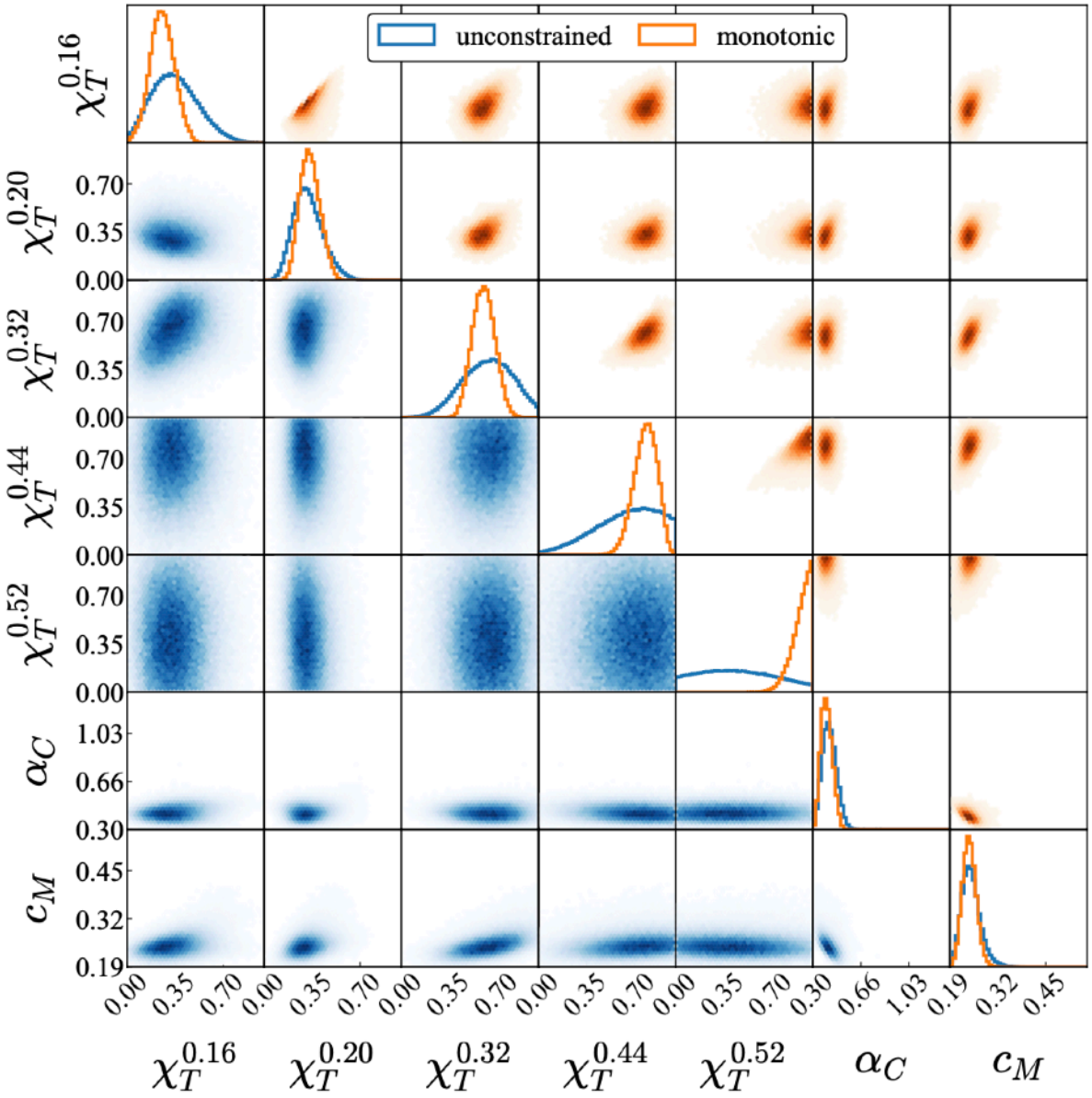
Experimental Dataset

Collab./Ref.	System	Centr. (%)	p_T (GeV/c)
PHENIX [56, 57]	Au-Au 200 GeV	0–10, 20–30	$R_{AA}^{\pi^0}$: [7, 19] $v_2^{\pi^0}$: [5, 16]
ATLAS [60, 61]	Pb-Pb 2760 GeV	0–10, 20–30	R_{AA}^{ch}: [6.68, 59.8] v_2^{ch}: [8, 18]
CMS [64, 65]	Pb-Pb 5020 GeV	0–5	R_{AA}^{ch}: [6.4, 54.4] v_2^{ch}: [12.9, 67.7]

A total of 100 individual data points are used for this analysis.

[Yu Guo, JL, Shuzhe Shi, arXiv:2510.16838]

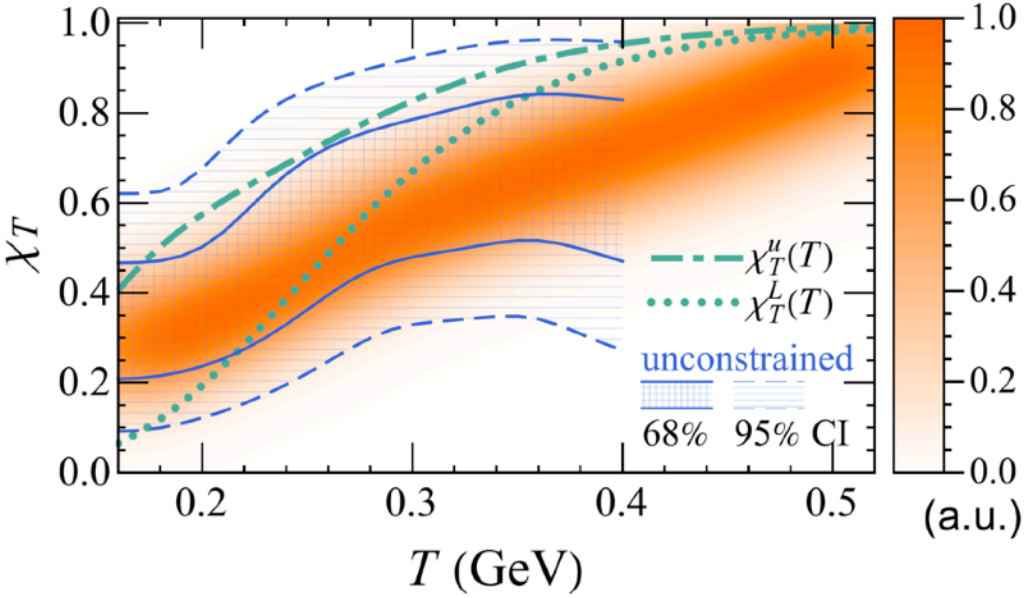
Posterior Distributions

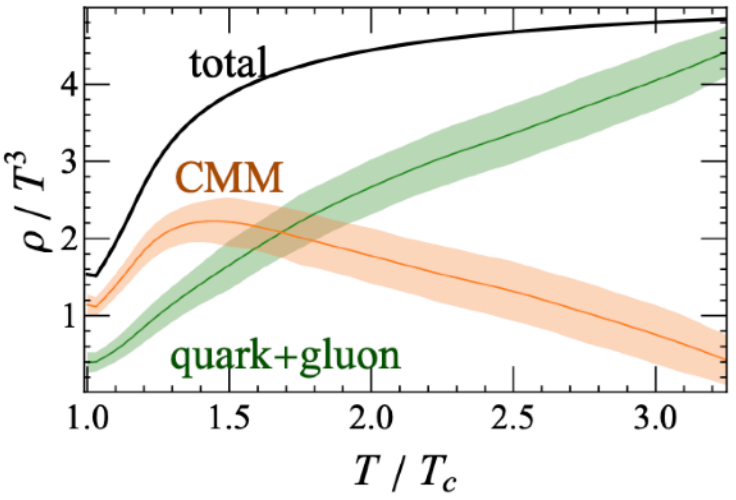


[Yu Guo, JL, Shuzhe Shi, arXiv:2510.16838]

Experimental Dataset

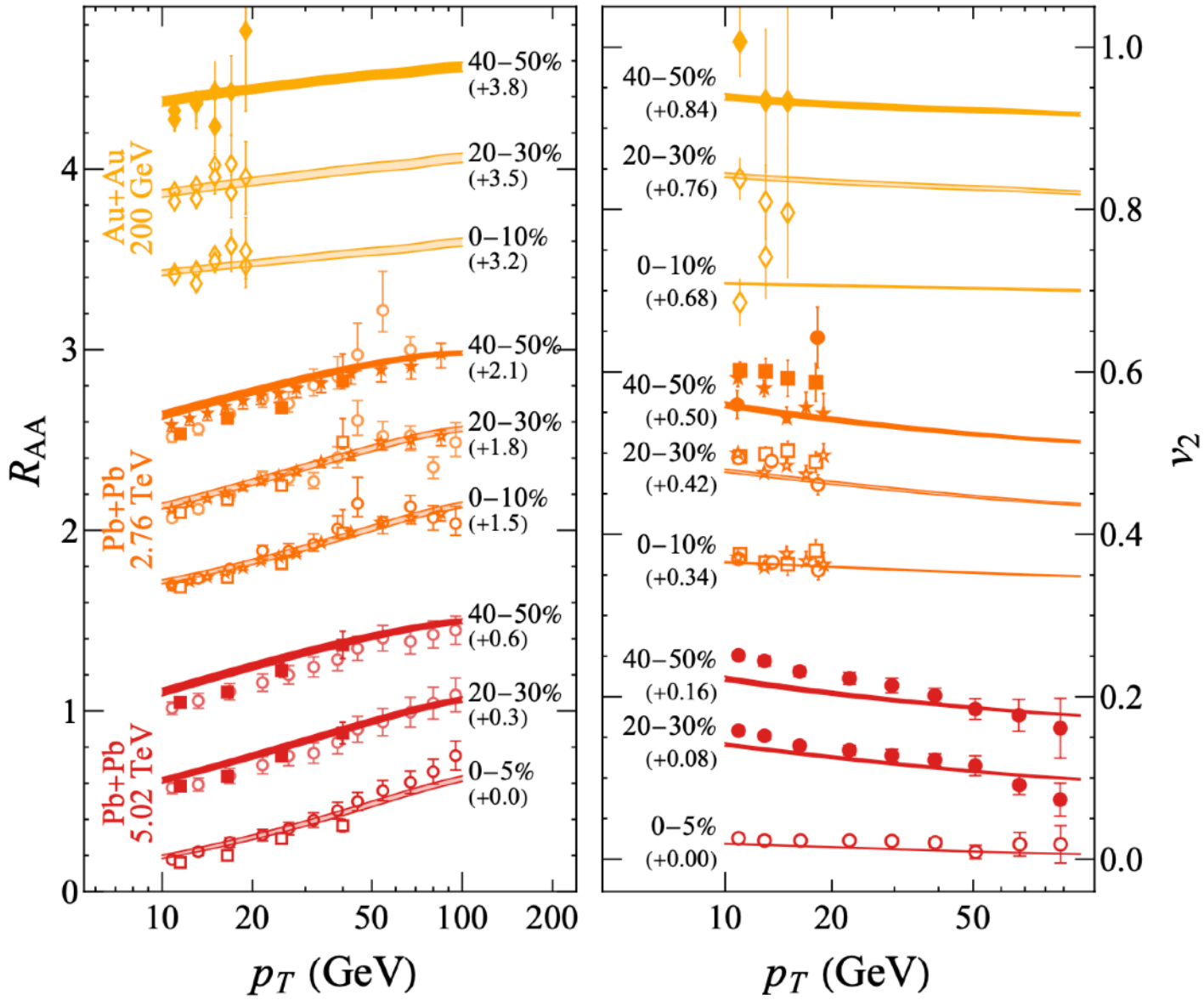
- *Consistent determination of alpha_c and c_M*
- *chi(T) is well constrained in the lower T region*
- *chi(T) is not well constrained in the higher T region*
- *The monotonic constraint naturally resolves high-T issue*





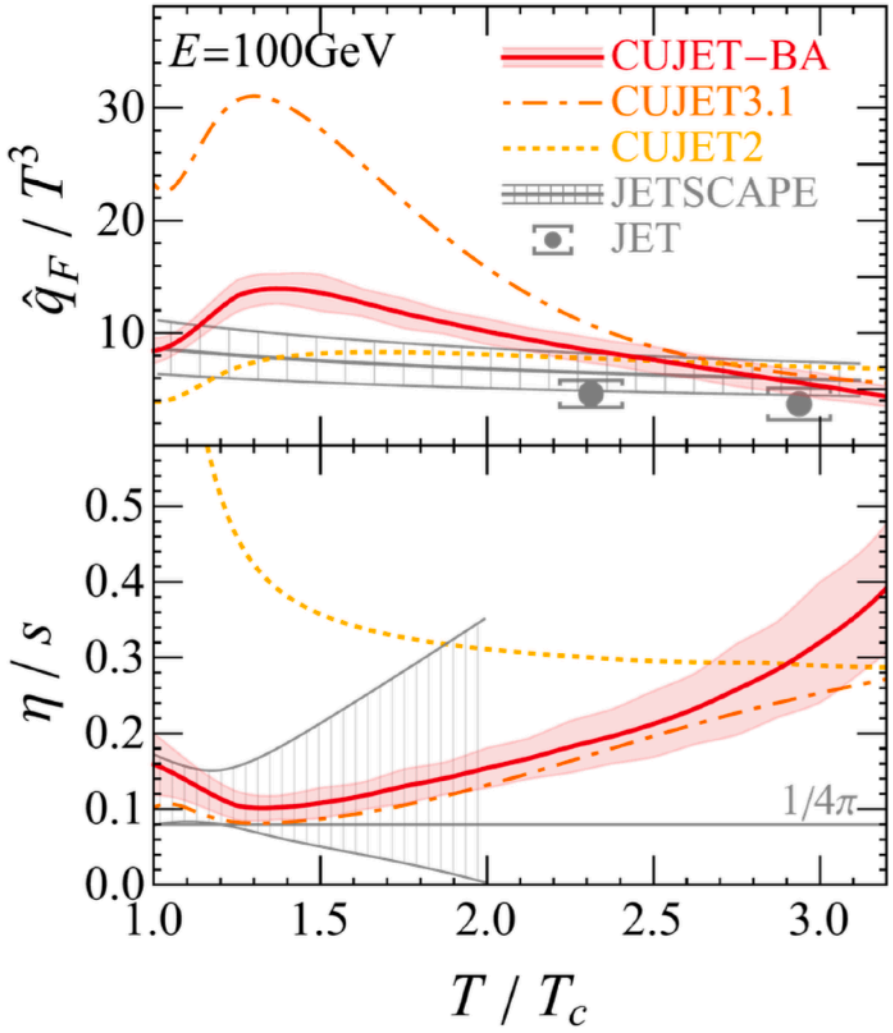
[Yu Guo, JL, Shuzhe Shi, arXiv:2510.16838]

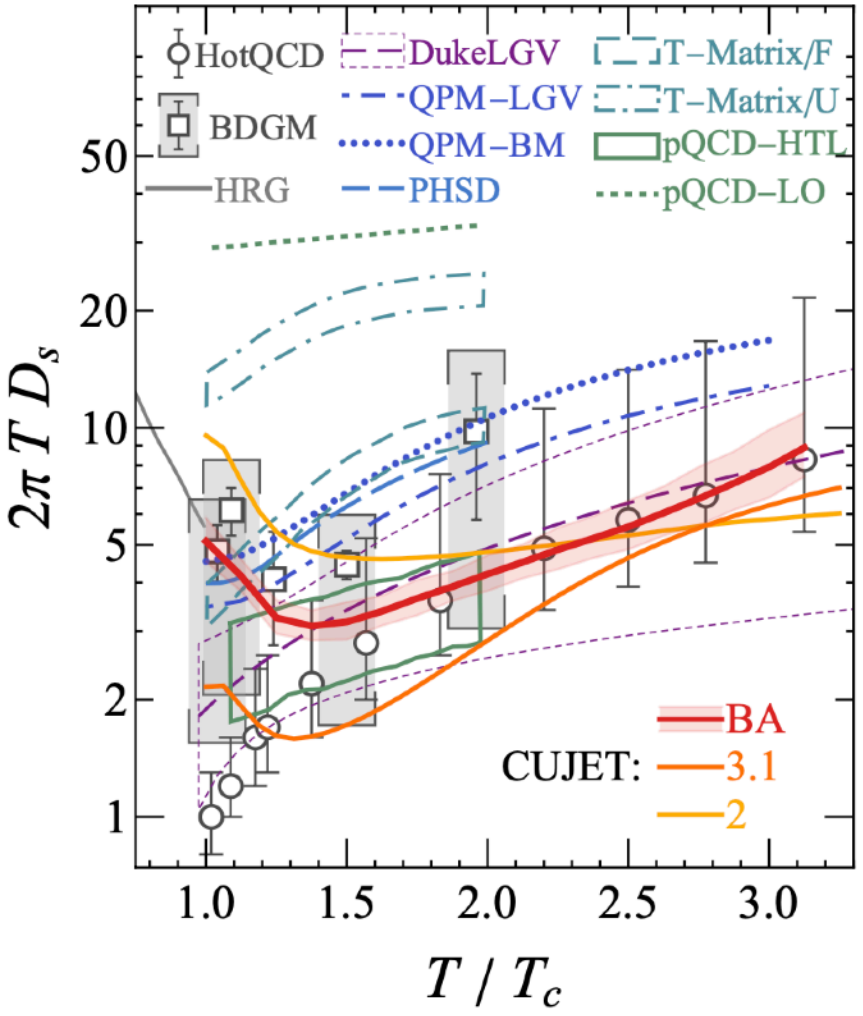
Posterior Validation



[Yu Guo, JL, Shuzhe Shi, arXiv:2510.16838]

Predictions for Transport Coefficients





[Yu Guo, JL, Shuzhe Shi, arXiv:2510.16838]

Summary

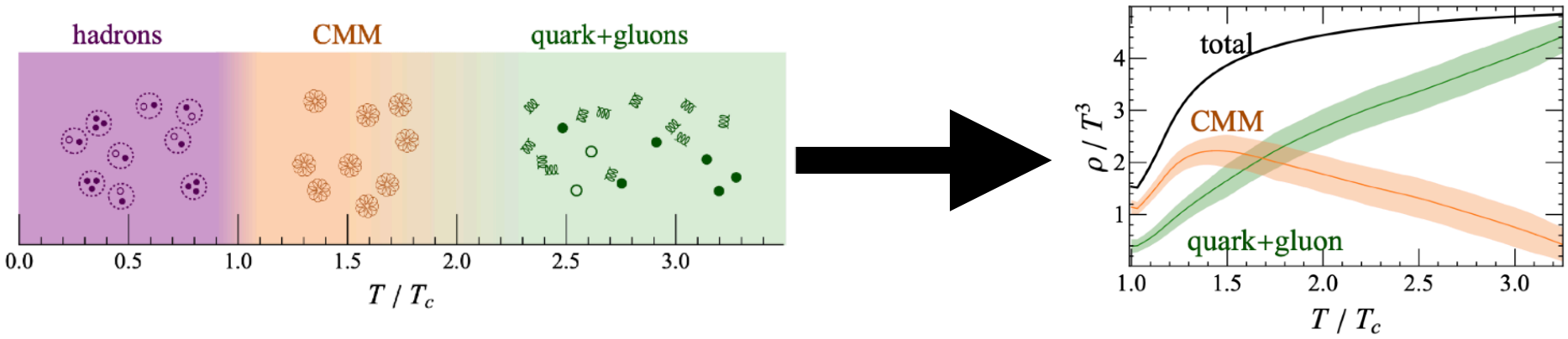
Summary

- ***Chromo-magnetic component plays an important role in understanding both vacuum confinement below Tc and the observed properties of sQGP in 1~2Tc.***

- ***Raa and v2 measurements of jet quenching can be used to quantitatively extract the magnetic component.***

- ***Posterior results from Bayesian inference provide evidence of such magnetic component and quantify their T-dependent density.***

- ***The predicted transport coefficients agree well with known results.***



Establishing a microscopic description of sQGMP !

Final Remarks

- *There emerges a broad consensus:*

  a different form of QCD matter @ temperatures 150 ~ 300 MeV

  in between simple hadrons and simple quarks/gluons

- *Its interpretation appears "messy" at the moment:*

  sQGMP with magnetic monopoles; sQGB with glueballs;

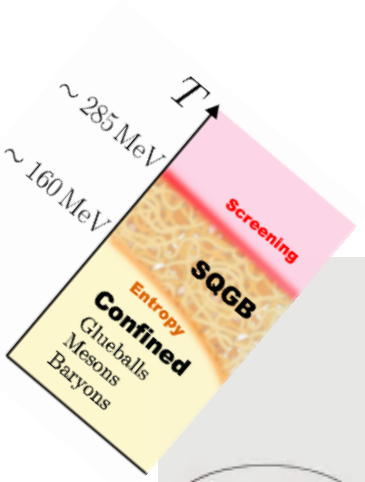
  Persistent Hagedorn states; stringy fluid;

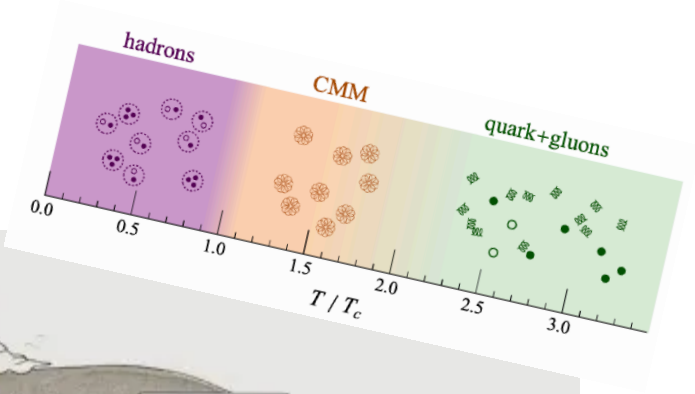
  nontrivial gluon propagator from functional methods; ……

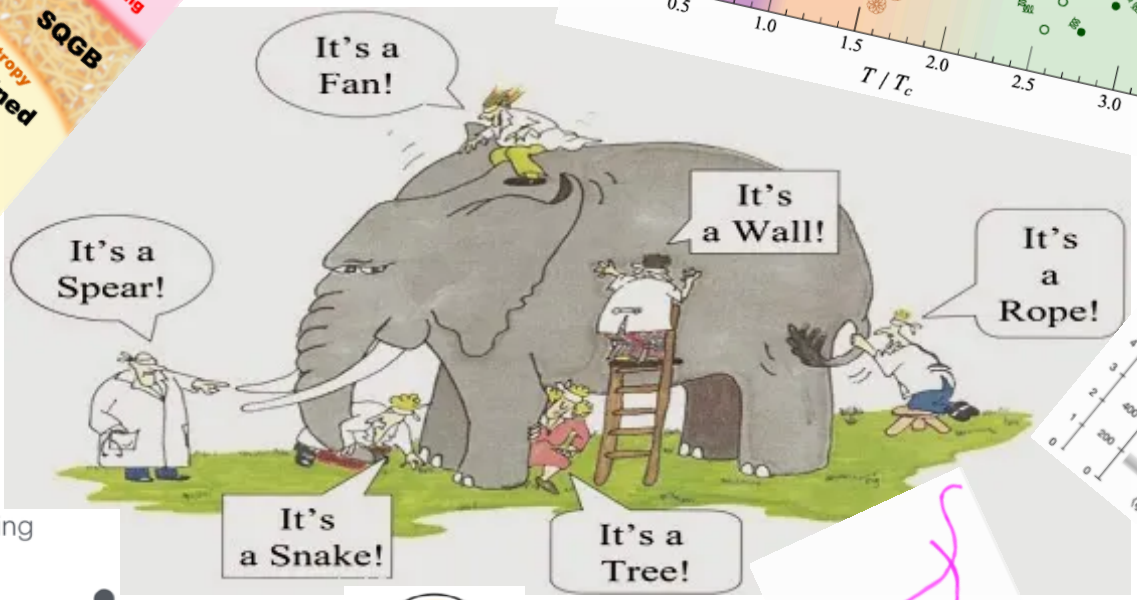
- *These "buenas ideas" are not necessarily mutually exclusive.*

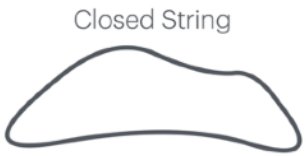
- *It is important to demonstrate how they can explain empirical properties observed in heavy-ion (and neutron star) experiments.*

Final Remarks





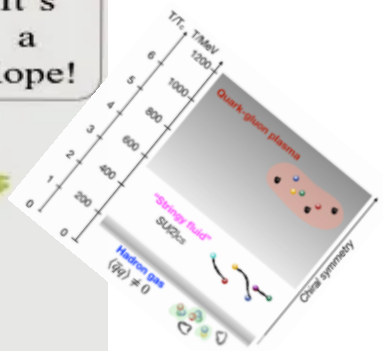








Glueball





"Go for the mess. That's where the action is."— Steven Weinberg