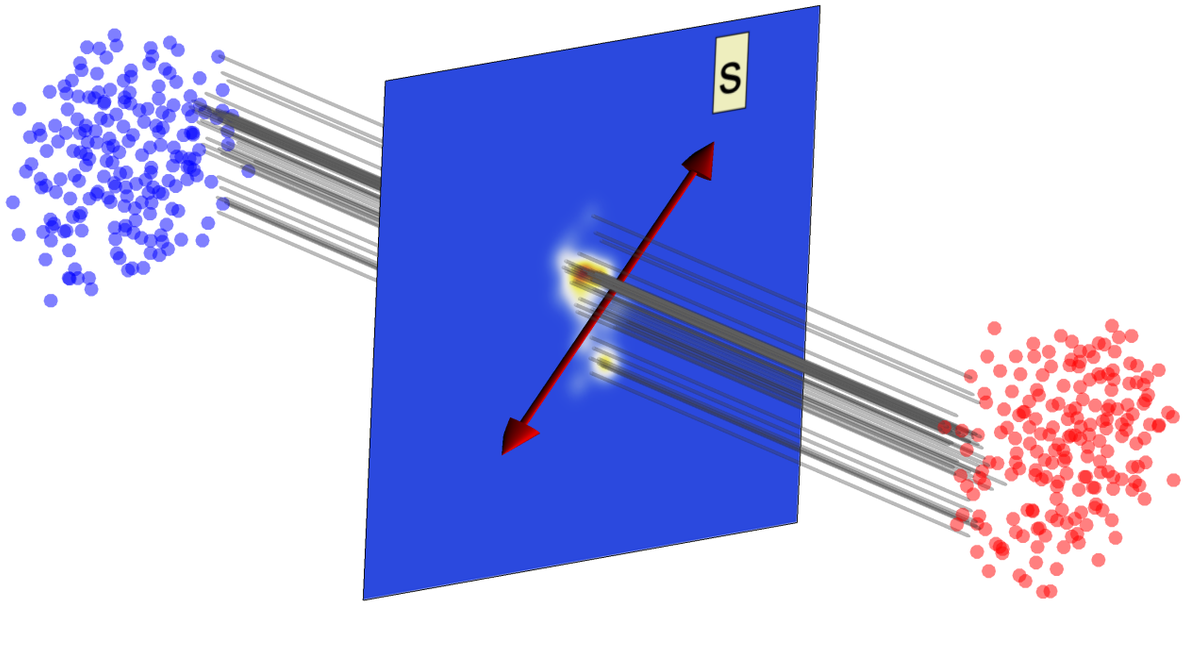
# PROBING THE CONSTITUENT OF THE QCD PLASMA VIA CUJET3.1/CIBJET FRAMEWORK

Shuzhe Shi

Dept. Physics, McGill University

in collab. with: Miklos Gyulassy, Jinfeng Liao & Jiechen Xu

# Jets — “Tomography” Of The QCD Plasma





*What can we learn from the “tomography” of the hot medium?*

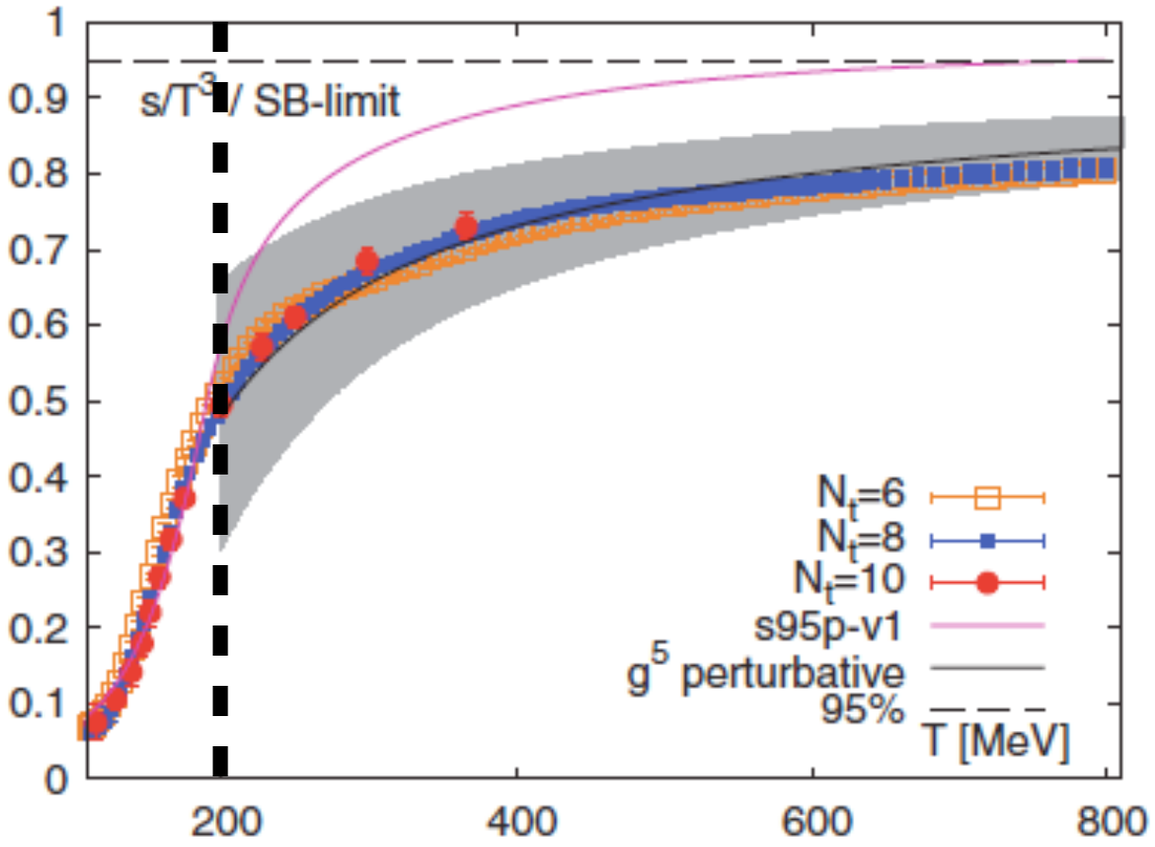
- interaction between jet & medium
- constituent of the hot medium

  ==> chromo magnetic monopoles?

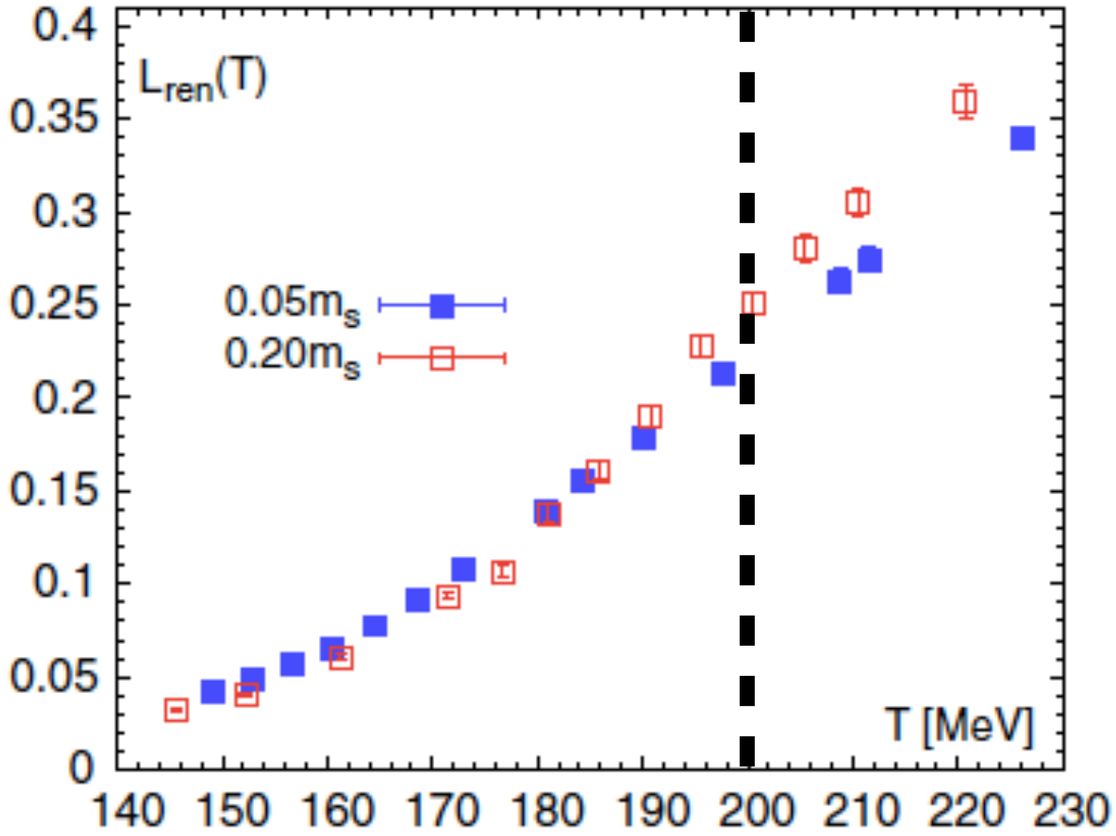
# semi Quark-Gluon Plasma

slide from J. Liao

## Degree of freedom




## Degree of color liberation

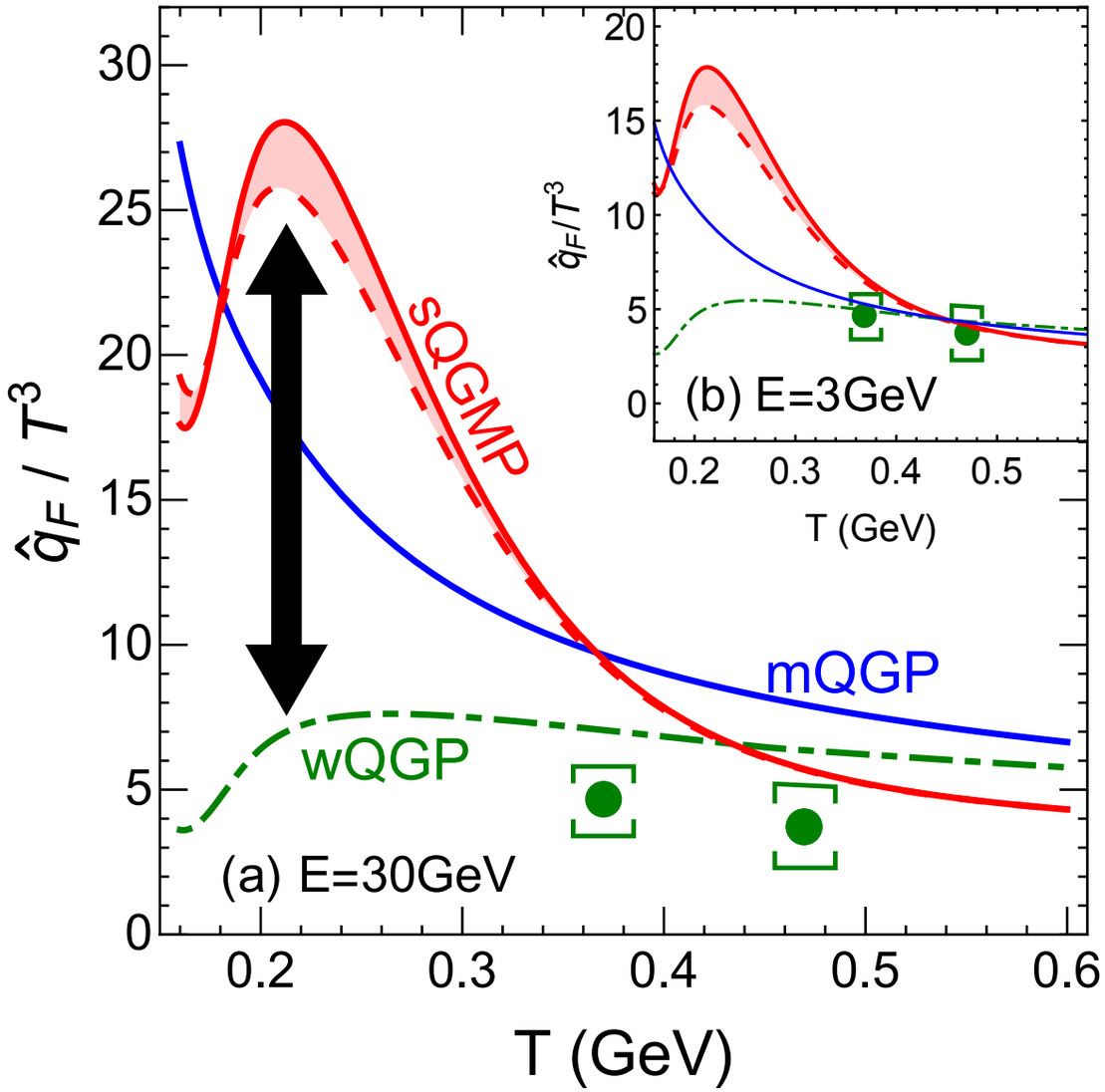


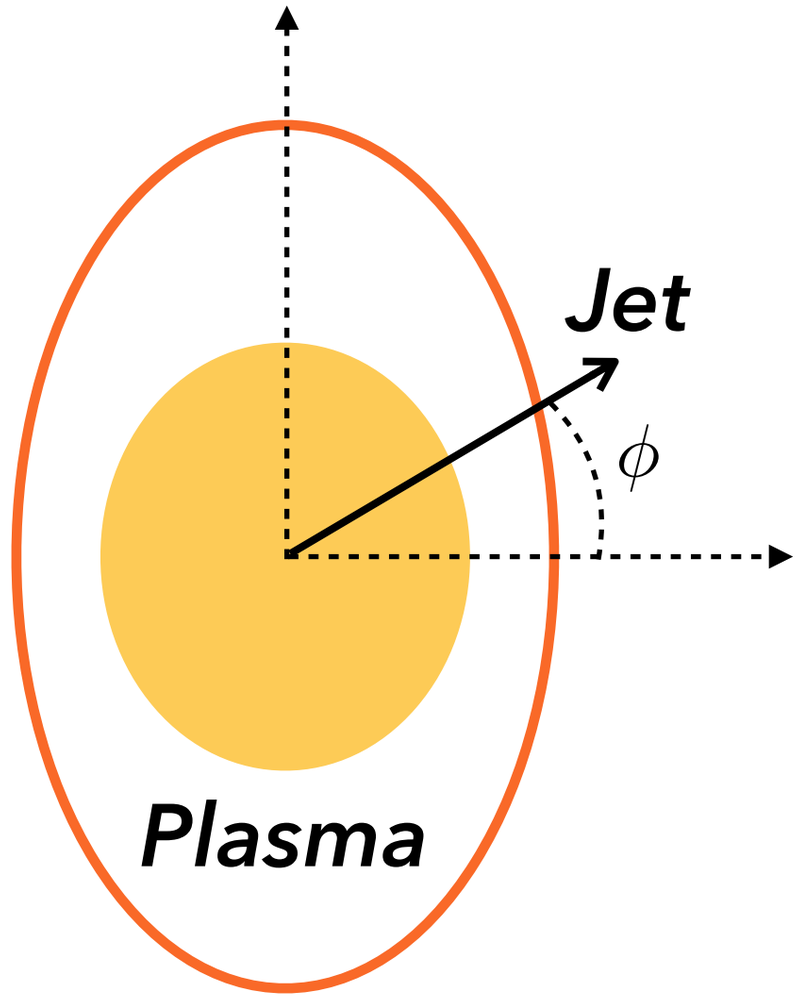

Pisarski & collaborators:

A region around $T_c$ with liberated degrees of freedom but only partially liberated color-electric objects

Missing d.o.f ?? ==> chromo-magnetic monopoles ?

# Jet Quenching In The sQGMP Scenario



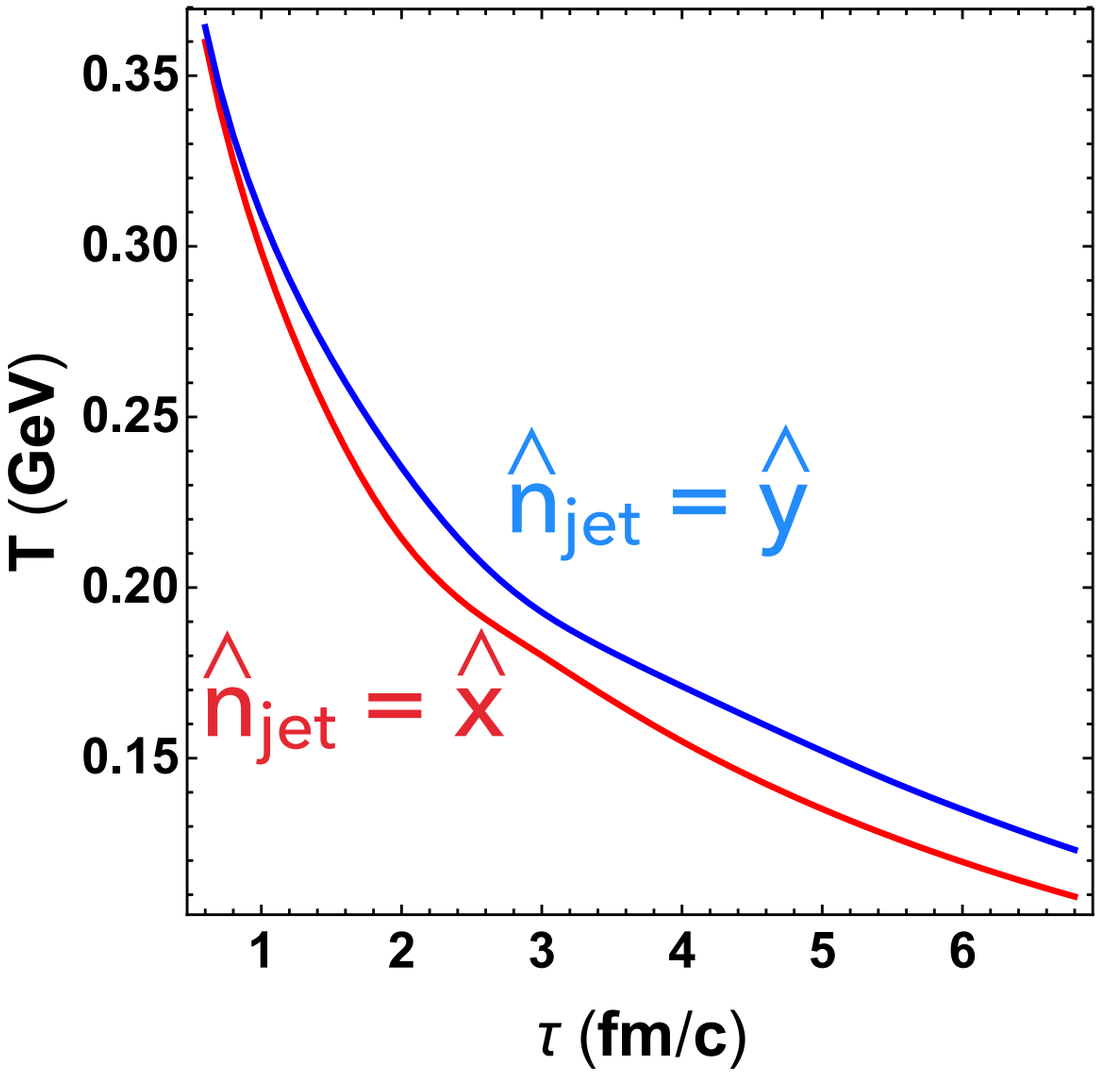



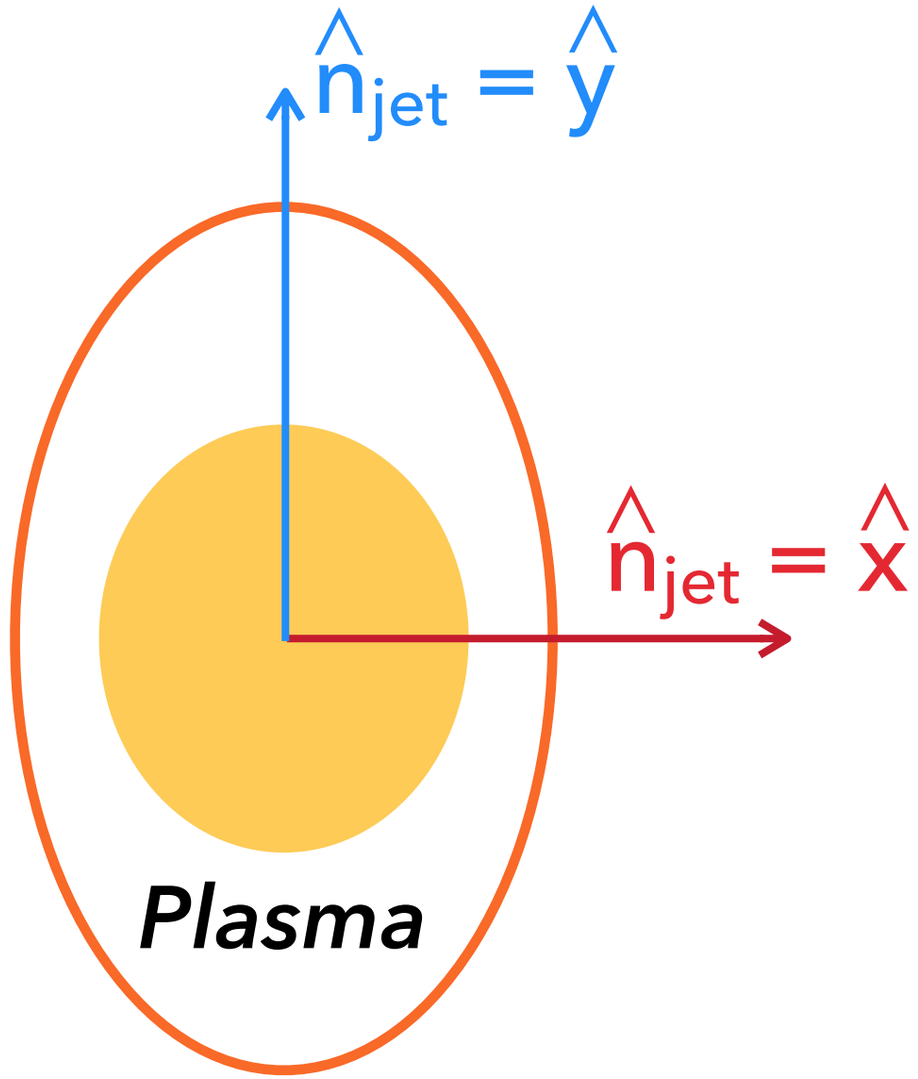

slide from J. Liao

Geometry is a sensitive feature:
“Egg yolk” has one geometry,
“Egg white” has another

# Jet Quenching In The sQGMP Scenario

Temperature @ (x[$\tau$],y[$\tau$]) = (0,0) + c $\tau$ $\hat{n}_{jet}$

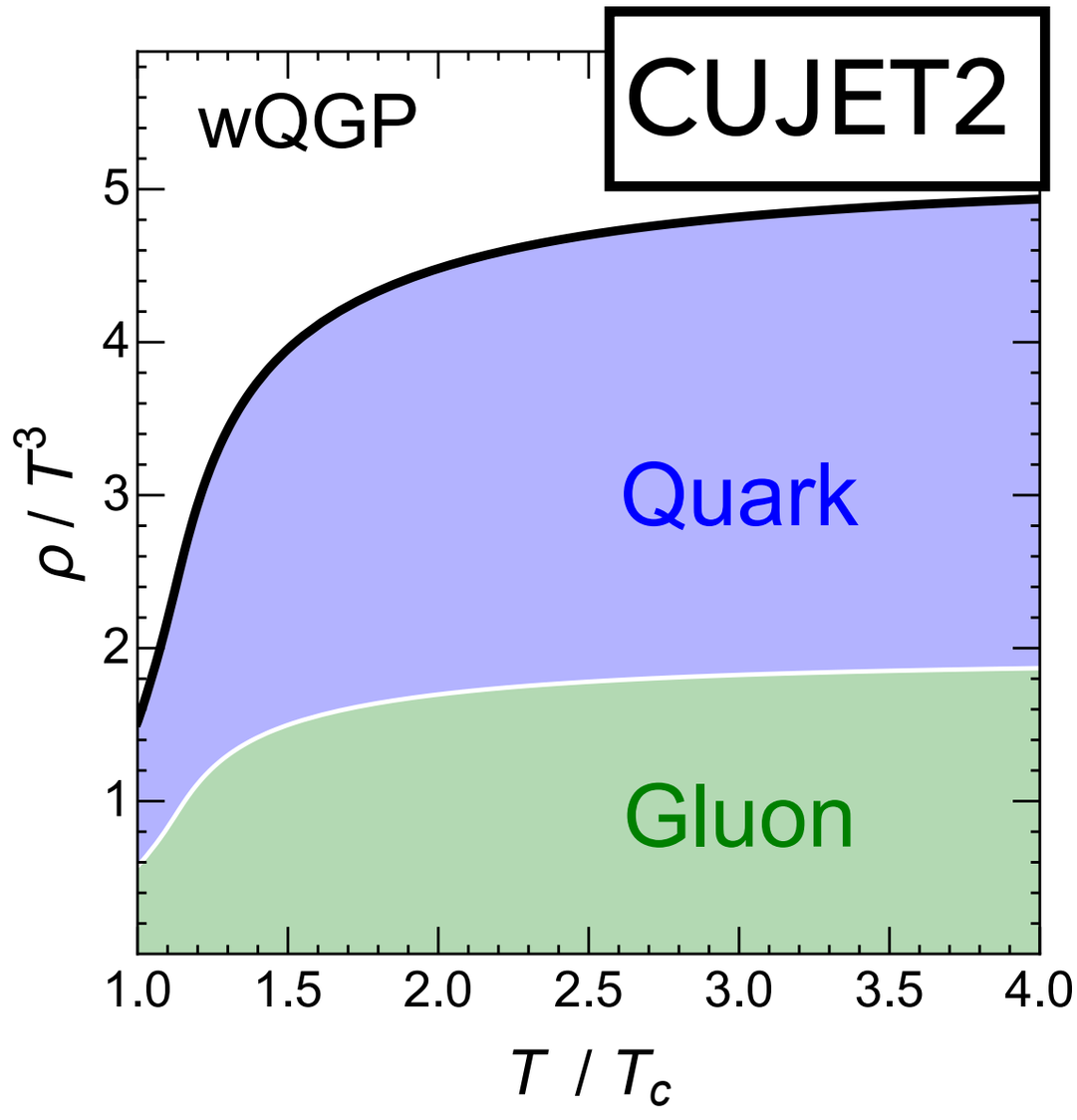



[2.76 TeV, 40-50%]

# wQGP v.s. sQGMP

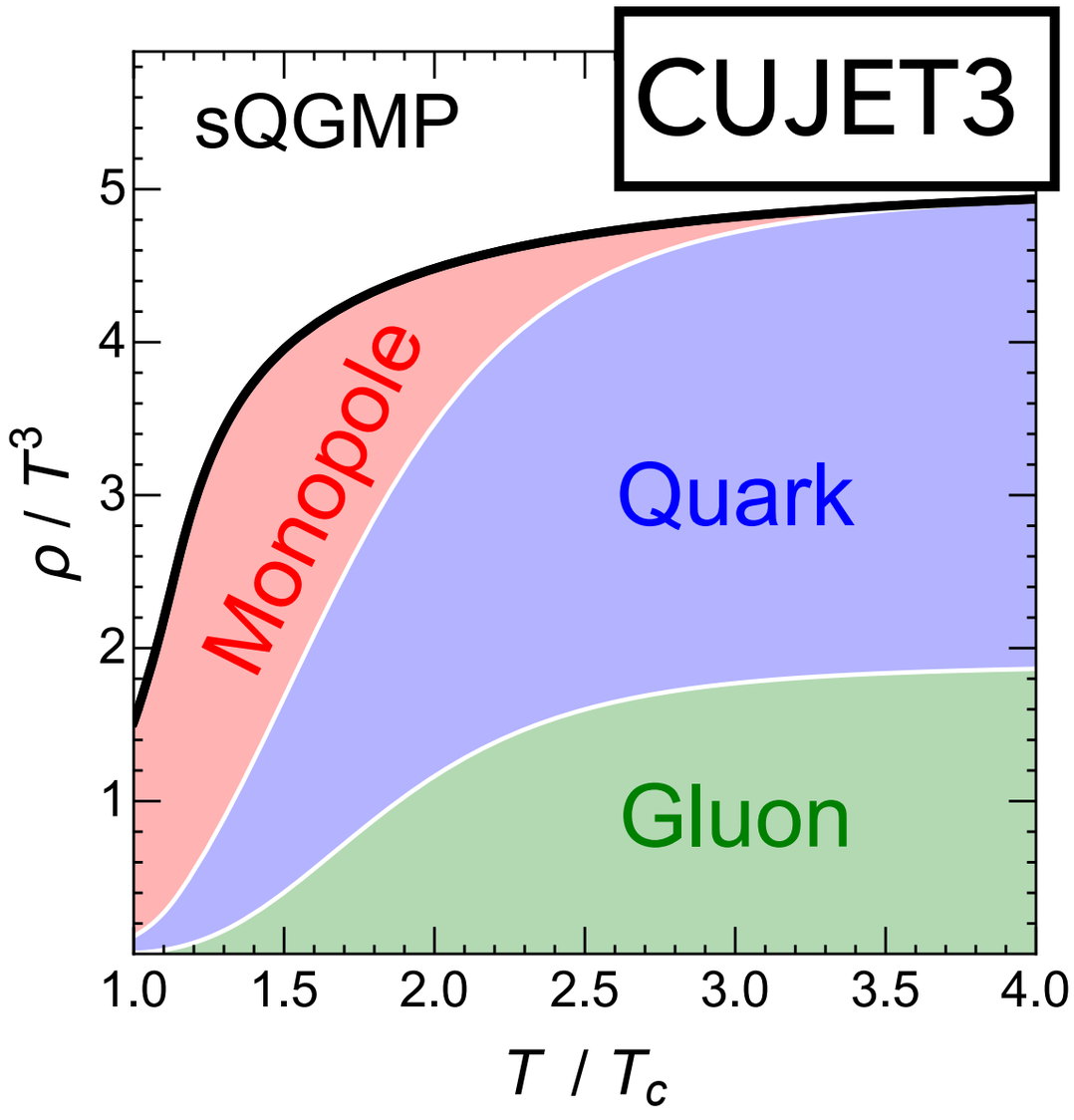
## wQGP




A. Buzzatti and M. Gyulassy, PRL(2012)
J. Xu, A. Buzzatti and M. Gyulassy, JHEP(2014)

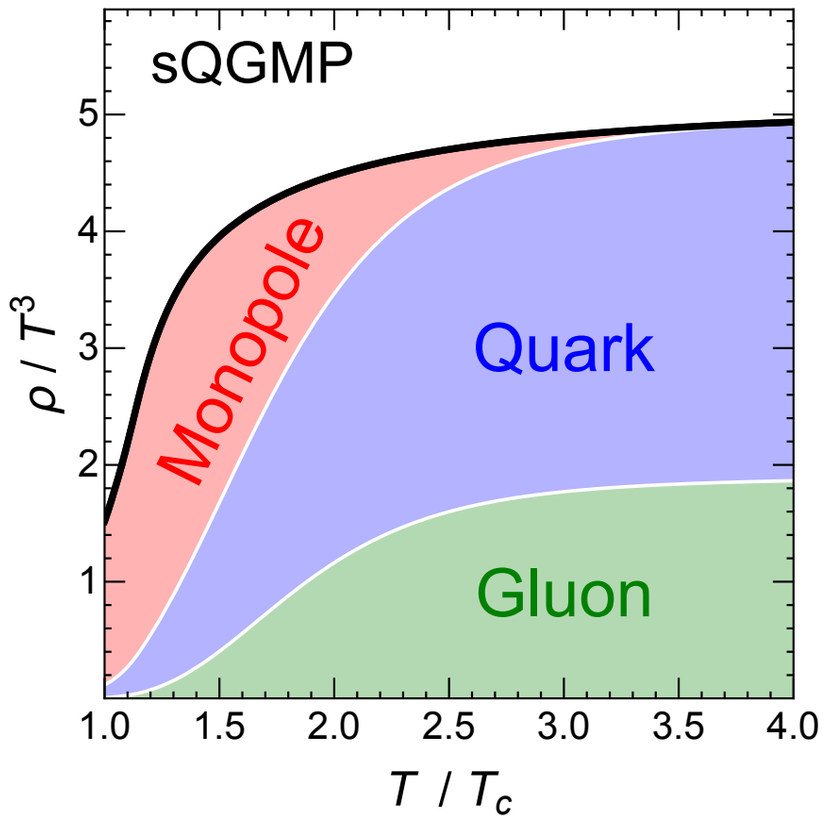
**v.s.**

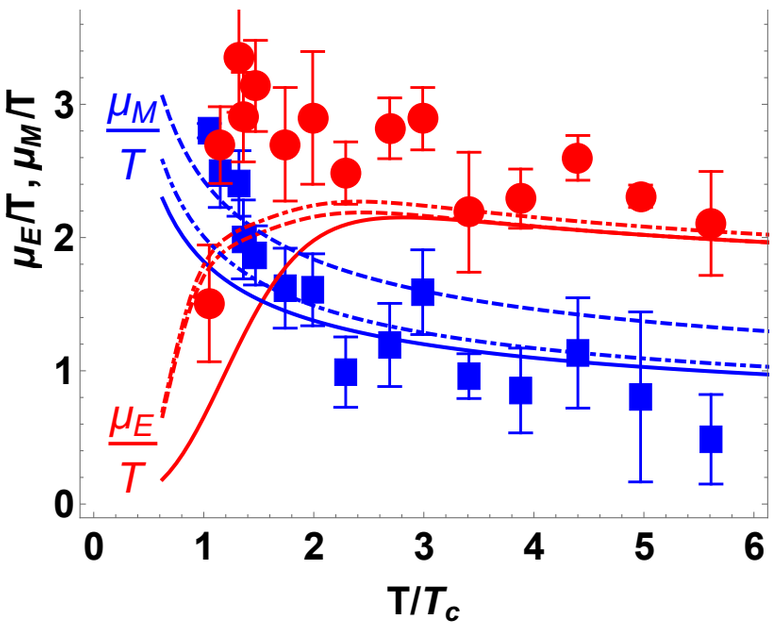
## sQGMP




J. Xu, J. Liao and M. Gyulassy, CPL (2015)
J. Xu, J. Liao and M. Gyulassy, JHEP (2016)
SS, J. Xu, J. Liao and M. Gyulassy, NPA (2017)
SS, J. Liao and M. Gyulassy, CPC (2018)
SS, J. Liao and M. Gyulassy, arXiv:1808.05461

# CUJET3 Framework




- E-den.: Polyakov-loop suppression

$$\rho_E/\rho = \chi_T = c_q L + c_g L^2$$

- M-den.: constrained by total entropy

$$\rho_M/\rho = 1 - \chi_T$$

- Running coupling:

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

- Screening:

$$f_E = \sqrt{\chi_T}\,, \qquad f_M = \boxed{c_m} g$$

- on top of VISHNU2+1 hydro bkg.

J. Xu, J. Liao and M. Gyulassy, CPL (2015)
J. Xu, J. Liao and M. Gyulassy, JHEP (2016)

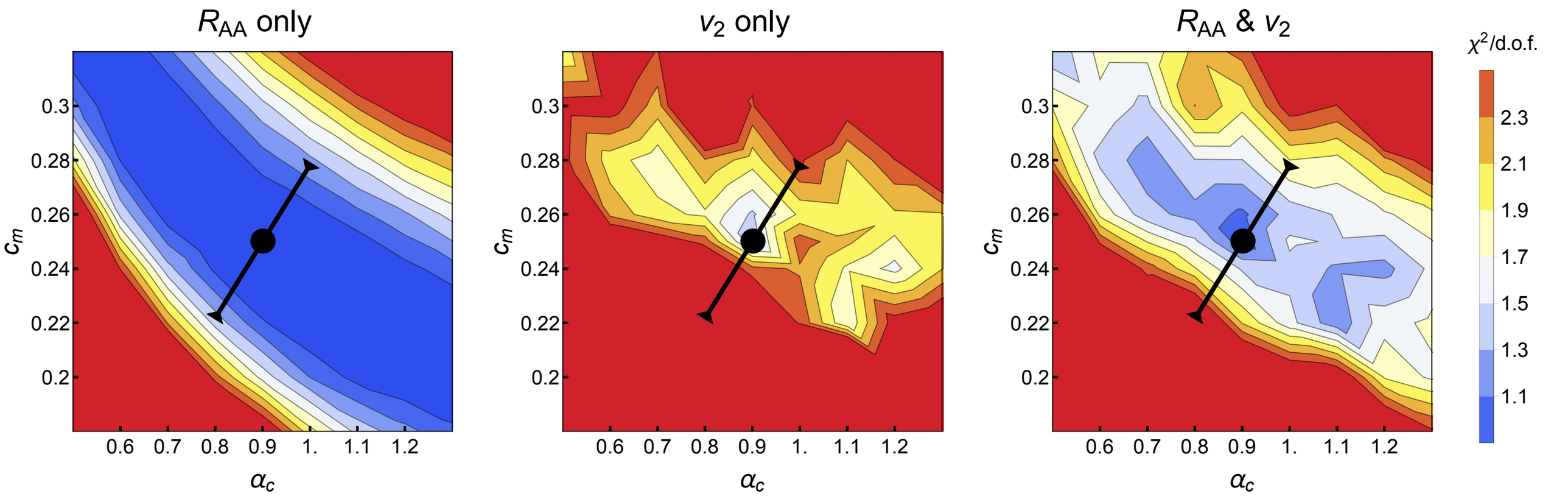
# Parameter Calibration

Two key parameters in the CUJET3 model:

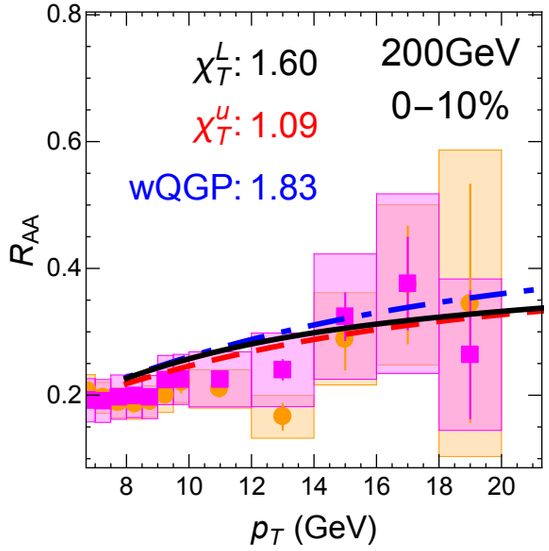
- $\alpha_c$ : running coupling $\alpha_s(q^2)$ @ $q = T_c$
- $c_m$ : parameter characterizing monopole screening mass

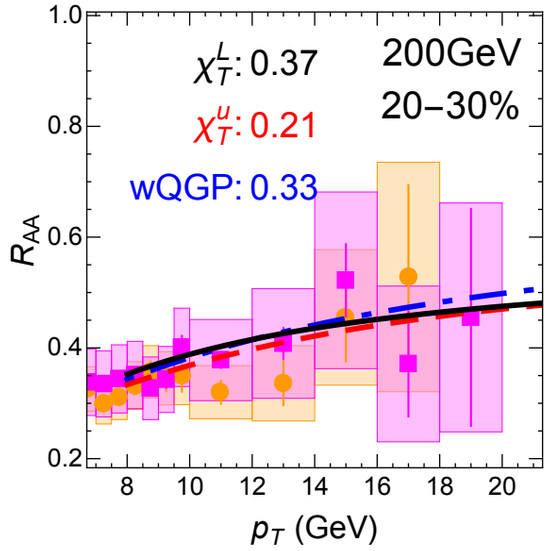
Calibrated with 12 (light hadron) data sets:

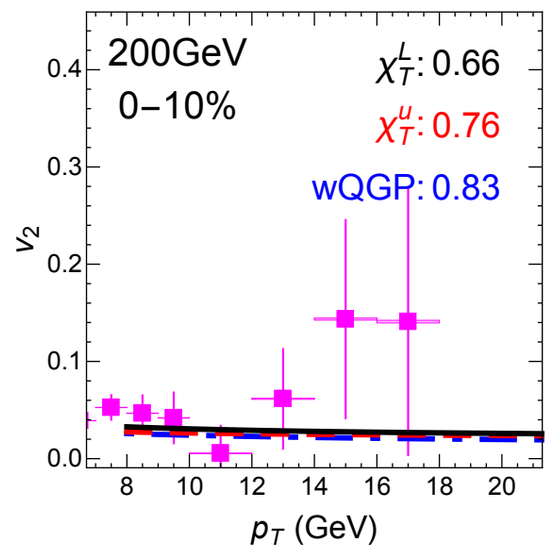
(200 GeV, 2.76 TeV, 5.02 TeV) ⊗ (0-5%, 20-30%) ⊗ ($R_{AA}$, $v_2$)

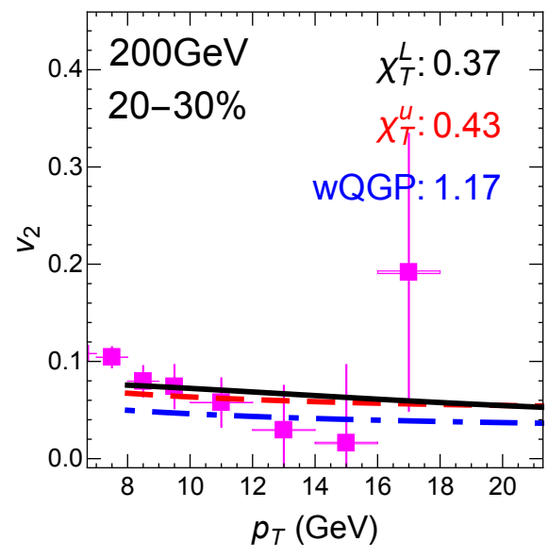


# sQGMP(Black&Red) v.s. QGP(Blue)

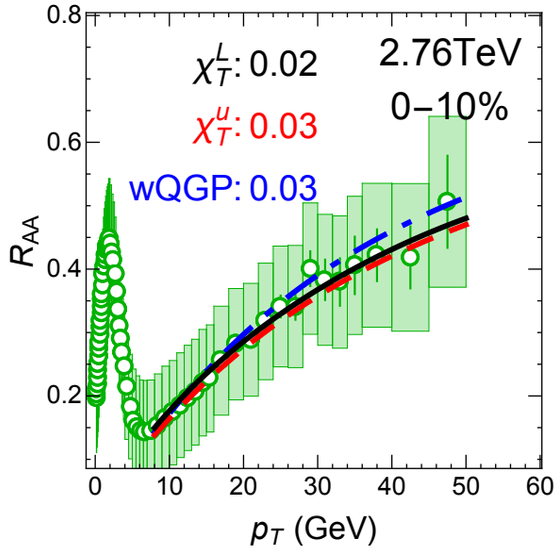


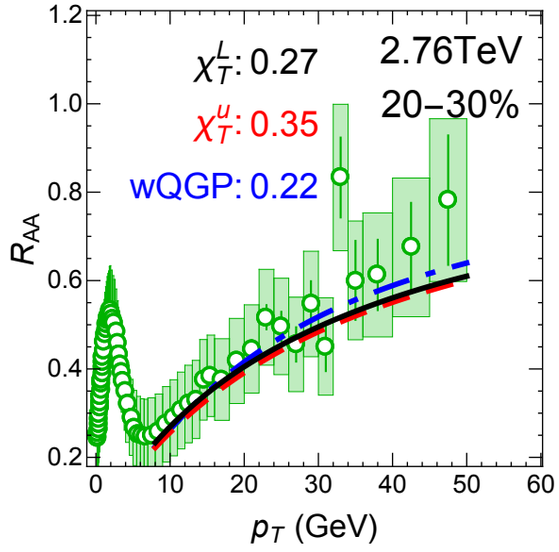



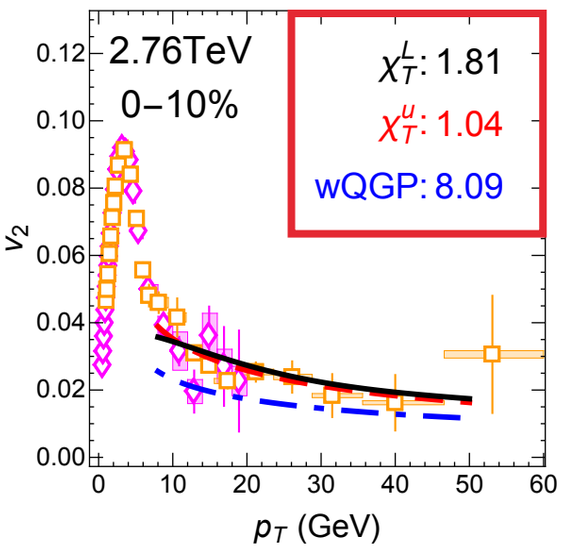



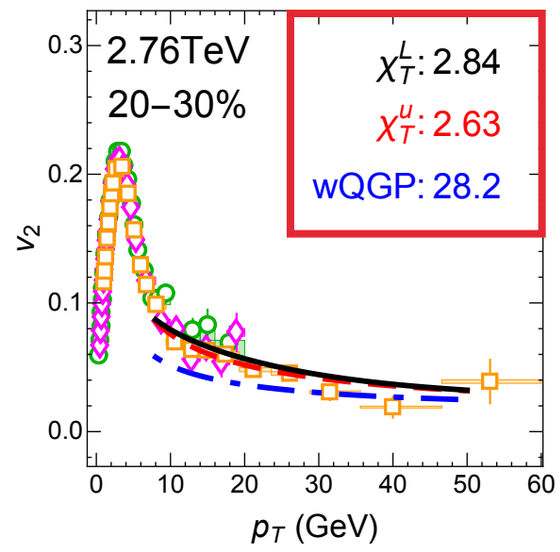



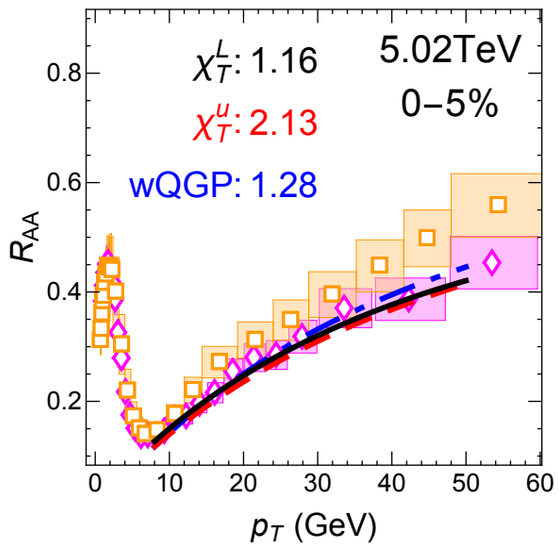

$\chi^2$/d.o.f.

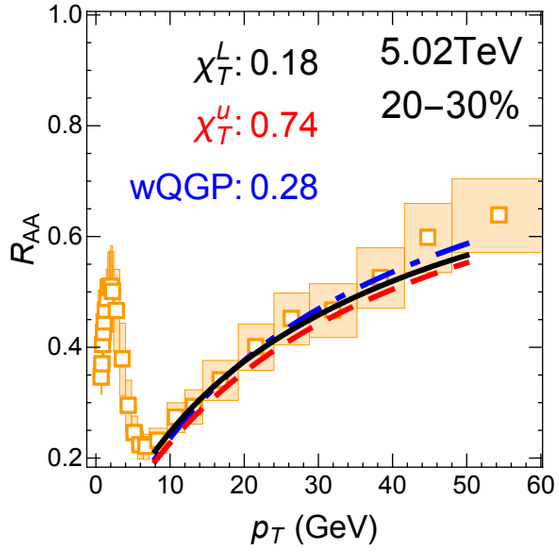


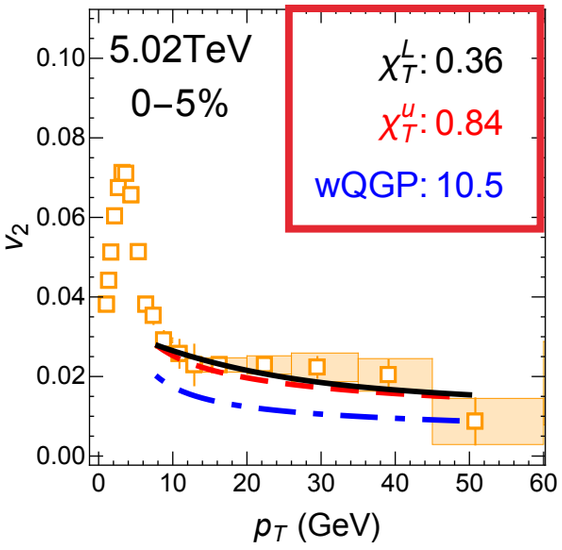



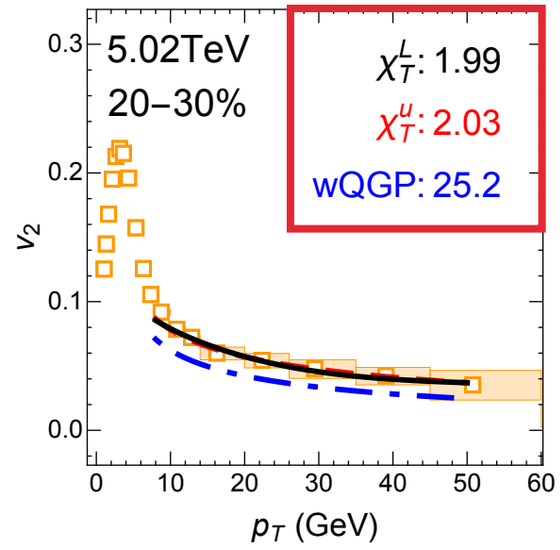



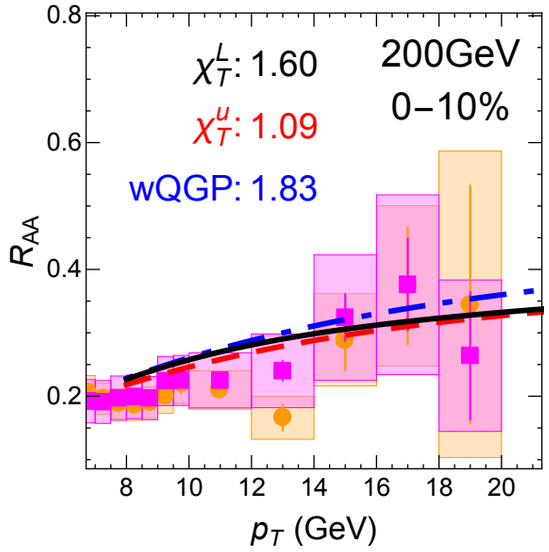



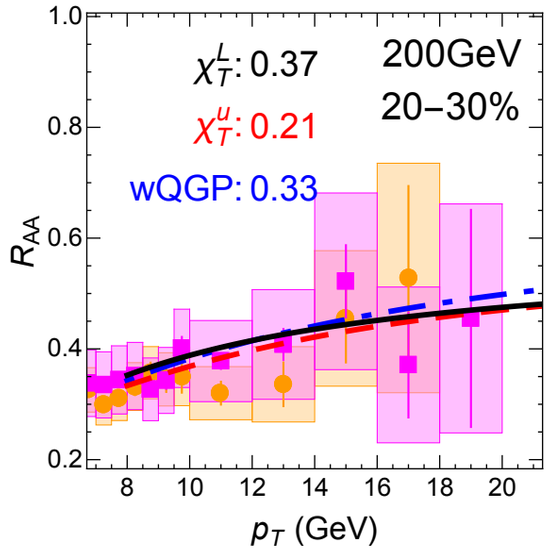



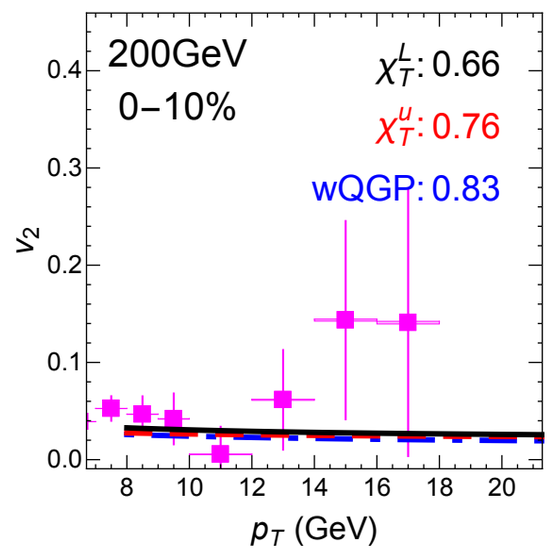



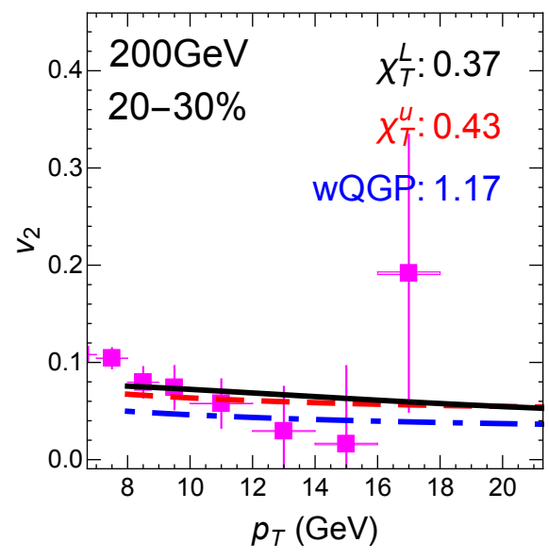



# sQGMP(Black&Red) v.s. QGP(Blue)

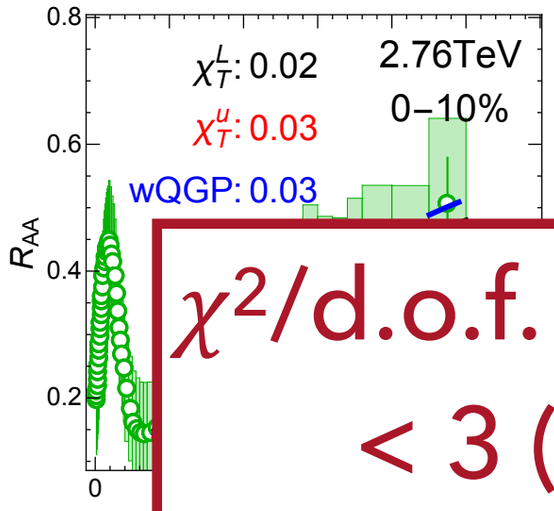


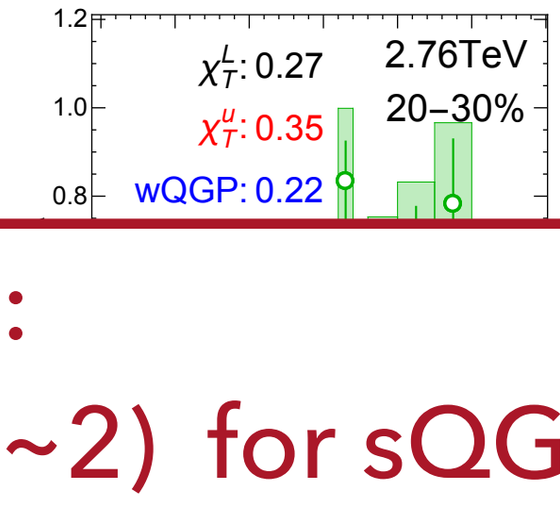



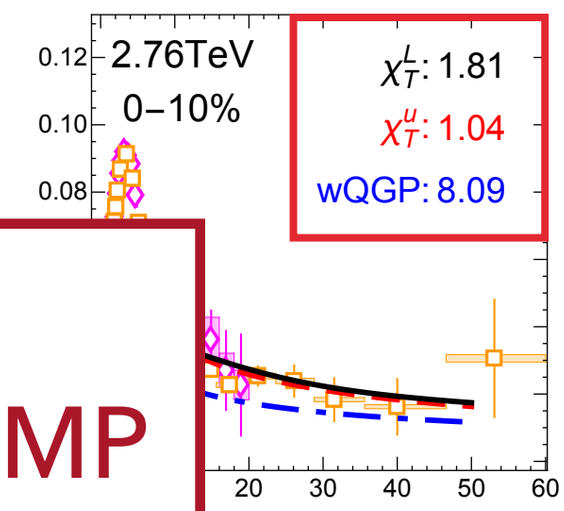



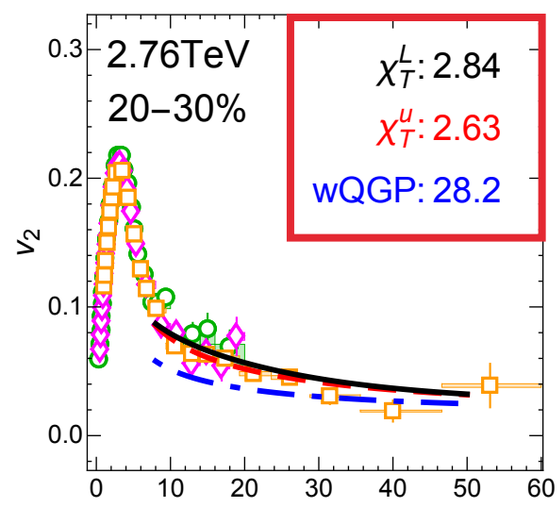




$\chi^2$/d.o.f.



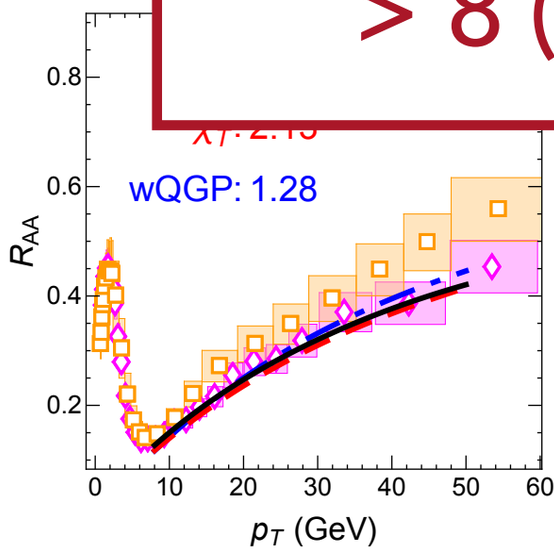



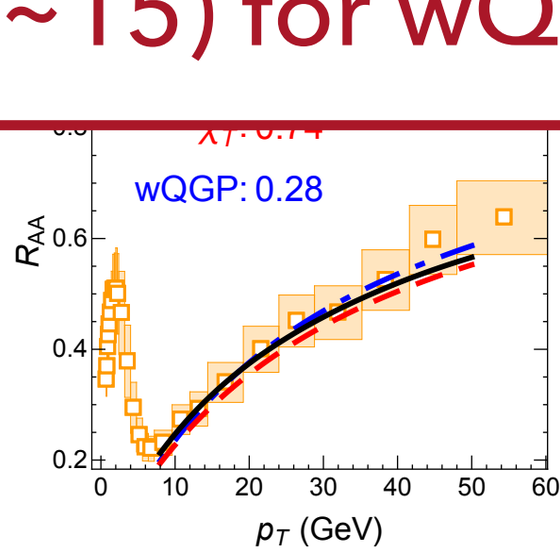



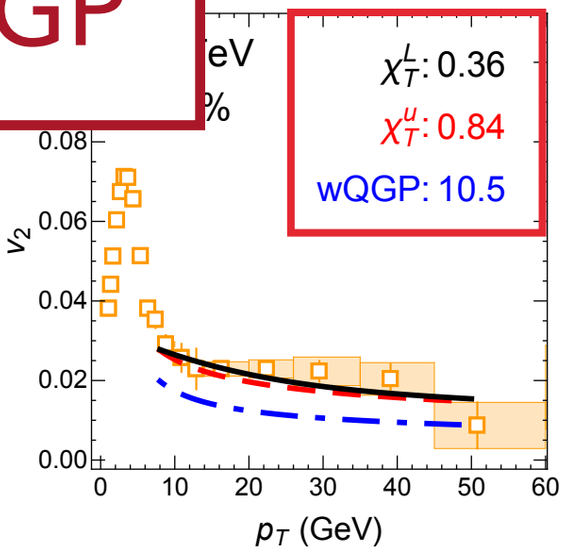

$\chi^2$/d.o.f. :

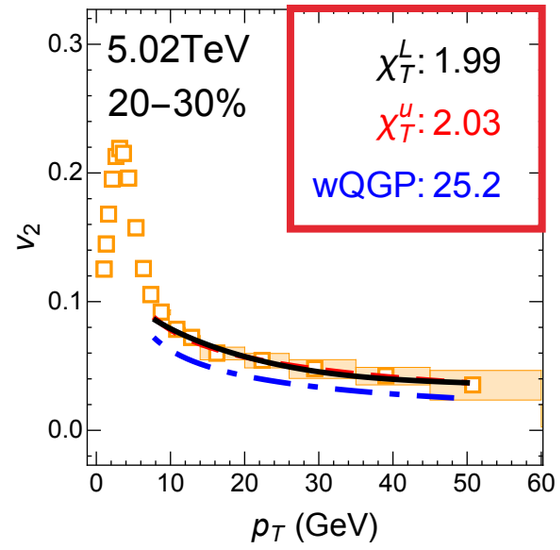
< 3 (~2) for sQGMP

> 8 (~15) for wQGP

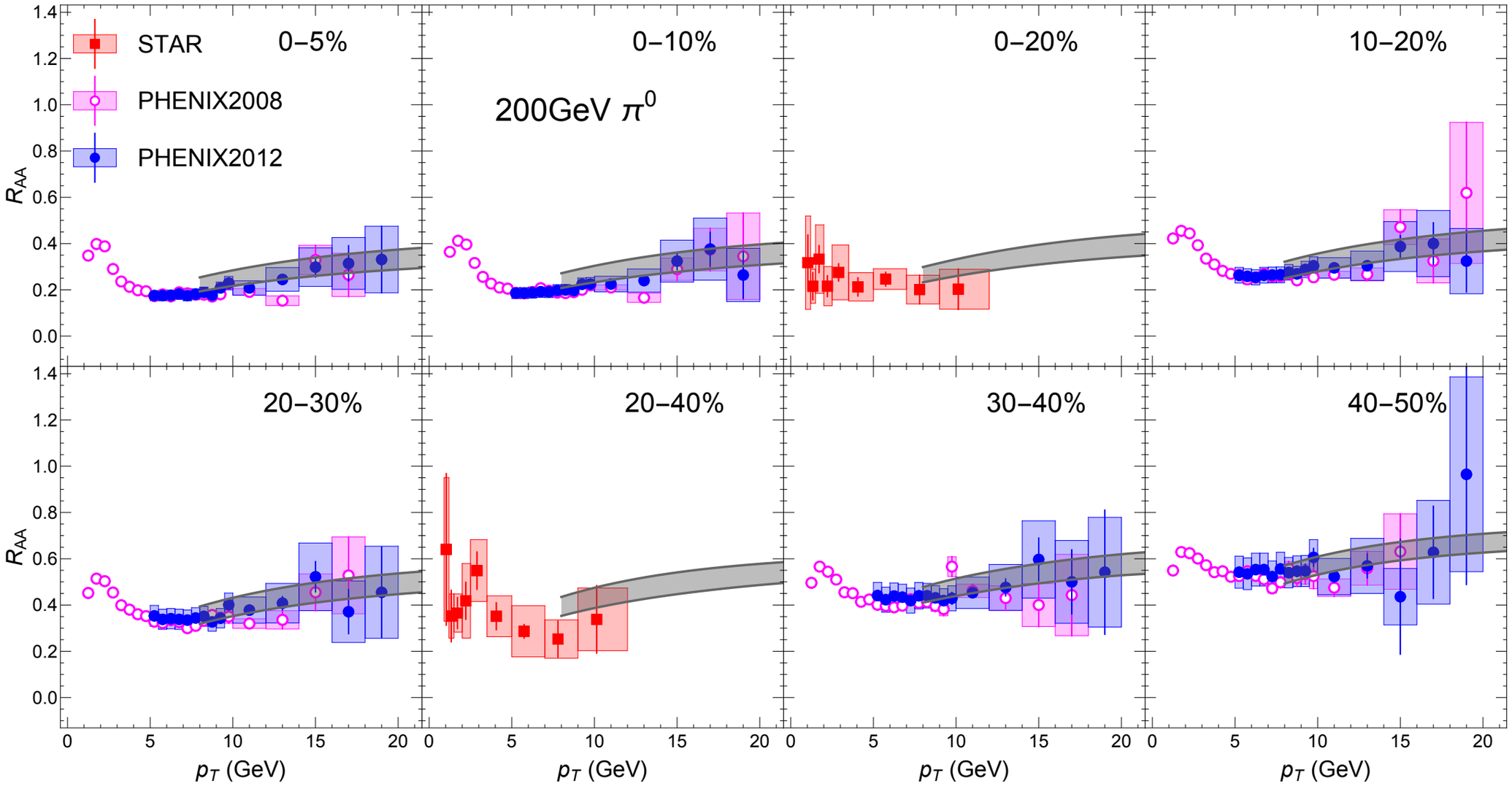


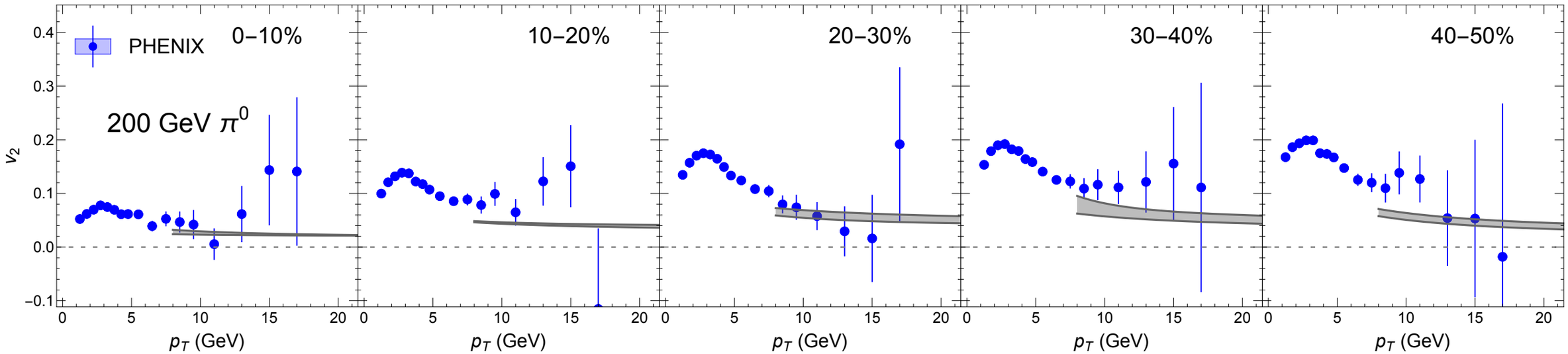



# Au - Au @ 0.2 ATeV, (light) hadron $R_{AA}$



# Au - Au @ 0.2 ATeV, (light) hadron $R_{AA}$

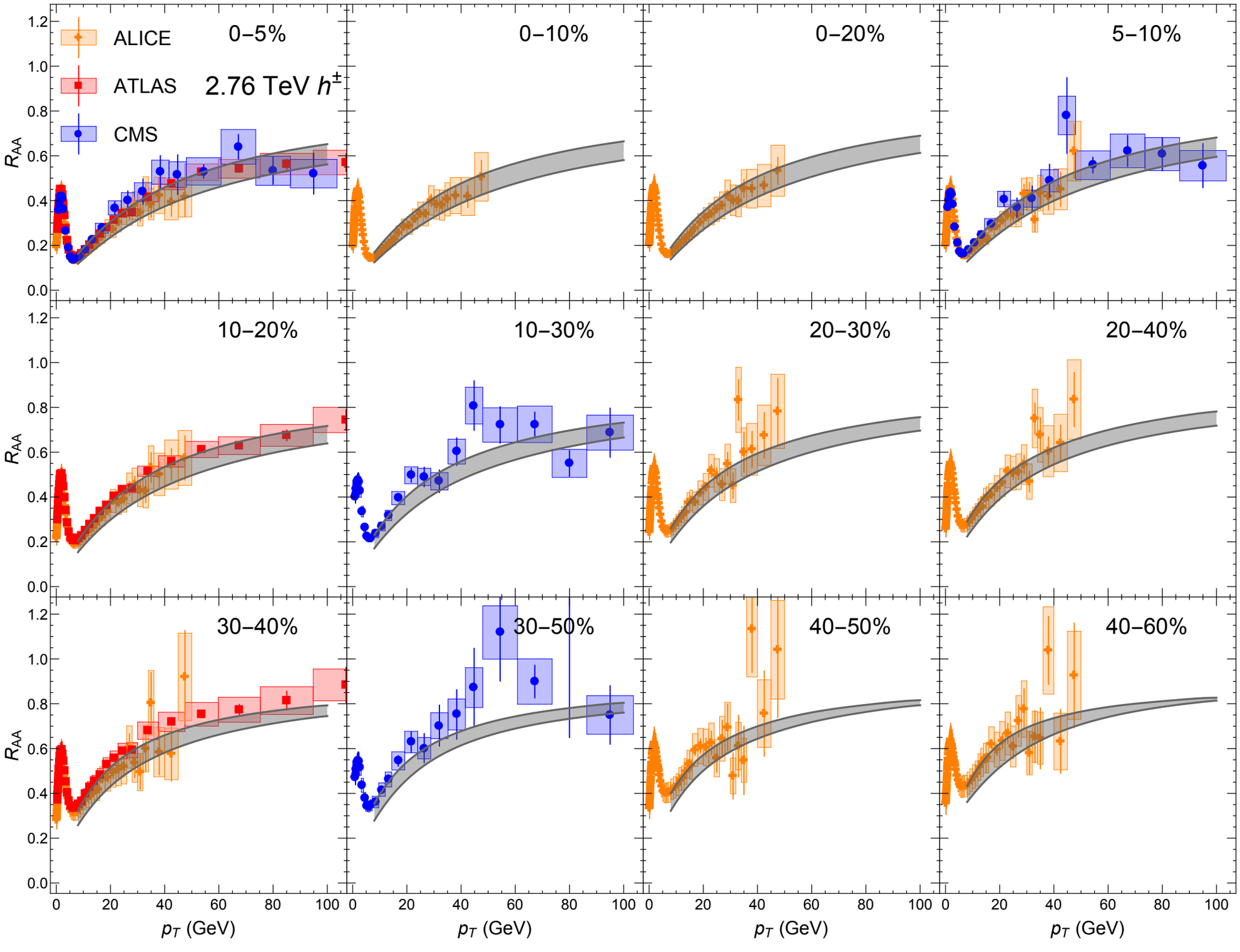
# Au - Au @ 0.2 ATeV, (light) hadron $v_2$



# Au - Au @ 0.2 ATeV, (light) hadron $R_{AA}$

## Au - Au @ 0.2 ATeV, (light) hadron $v_2$

## Pb - Pb @ 2.76 ATeV, (light) hadron $R_{AA}$

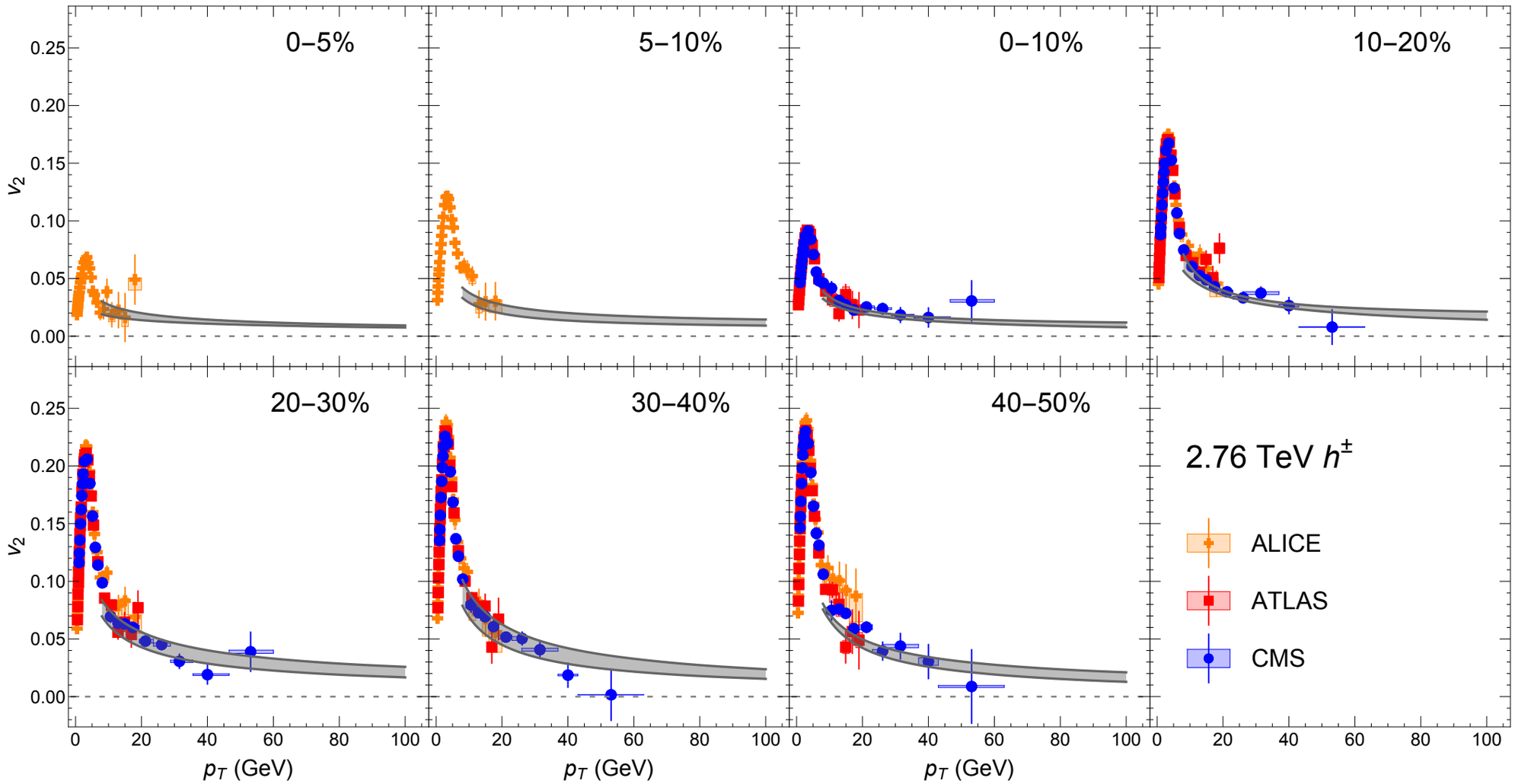


Au - Au @ 0.2 ATeV, (light) hadron $R_{AA}$

Au - Au @ 0.2 ATeV, (light) hadron $v_2$

Pb - Pb @ 2.76 ATeV, (light) hadron $R_{AA}$

Pb - Pb @ 2.76 ATeV, (light) hadron $v_2$



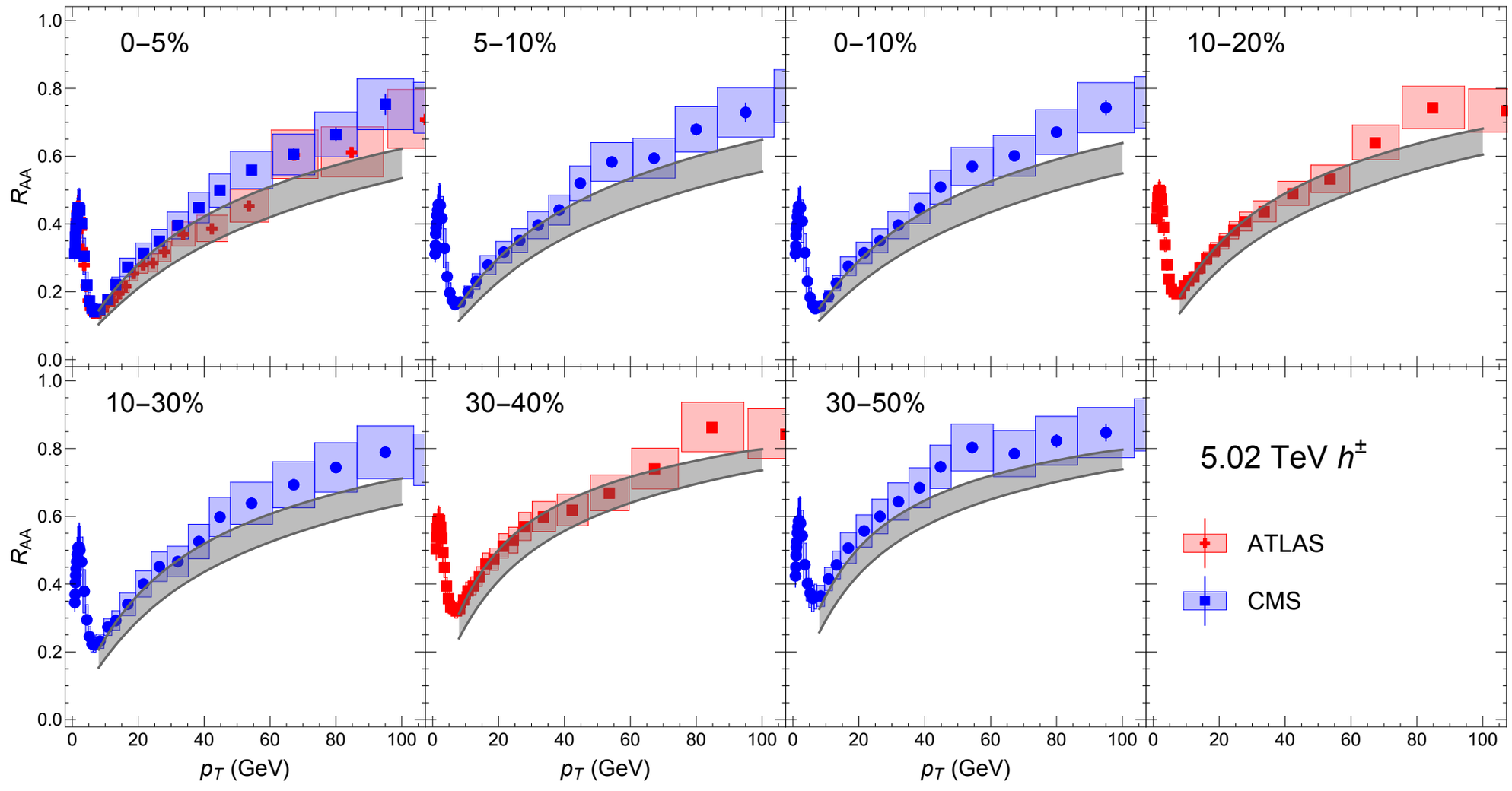
Au - Au @ 0.2 ATeV, (light) hadron $R_{AA}$

Au - Au @ 0.2 ATeV, (light) hadron $v_2$

Pb - Pb @ 2.76 ATeV, (light) hadron $R_{AA}$

Pb - Pb @ 2.76 ATeV, (light) hadron $v_2$

Pb - Pb @ 5.02 ATeV, (light) hadron $R_{AA}$



Au - Au @ 0.2 ATeV, (light) hadron $R_{AA}$

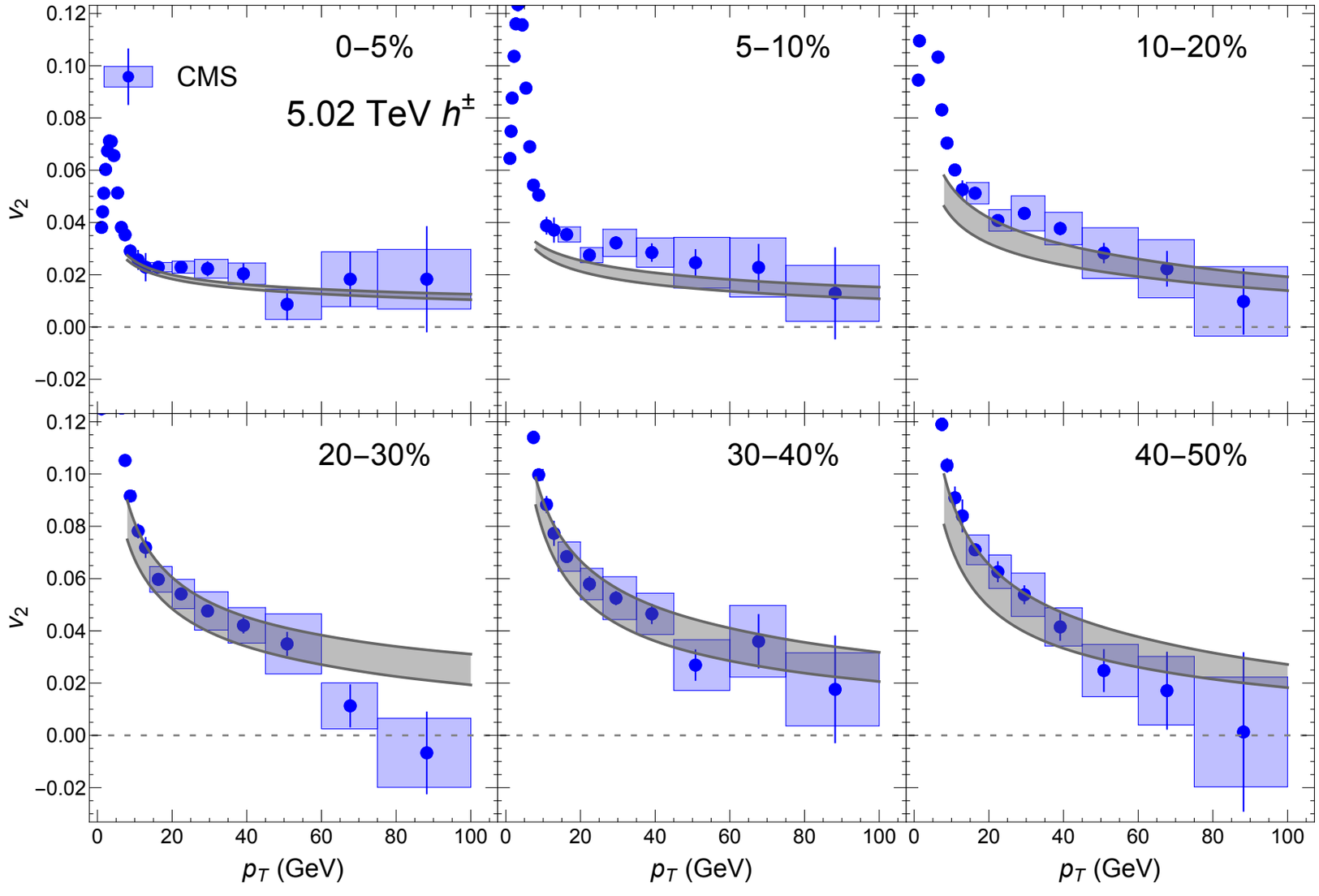
Au - Au @ 0.2 ATeV, (light) hadron $v_2$

Pb - Pb @ 2.76 ATeV, (light) hadron $R_{AA}$

Pb - Pb @ 2.76 ATeV, (light) hadron $v_2$

Pb - Pb @ 5.02 ATeV, (light) hadron $R_{AA}$

Pb - Pb @ 5.02 ATeV, (light) hadron $v_2$



Au - Au @ 0.2 ATeV, (light) hadron $R_{AA}$

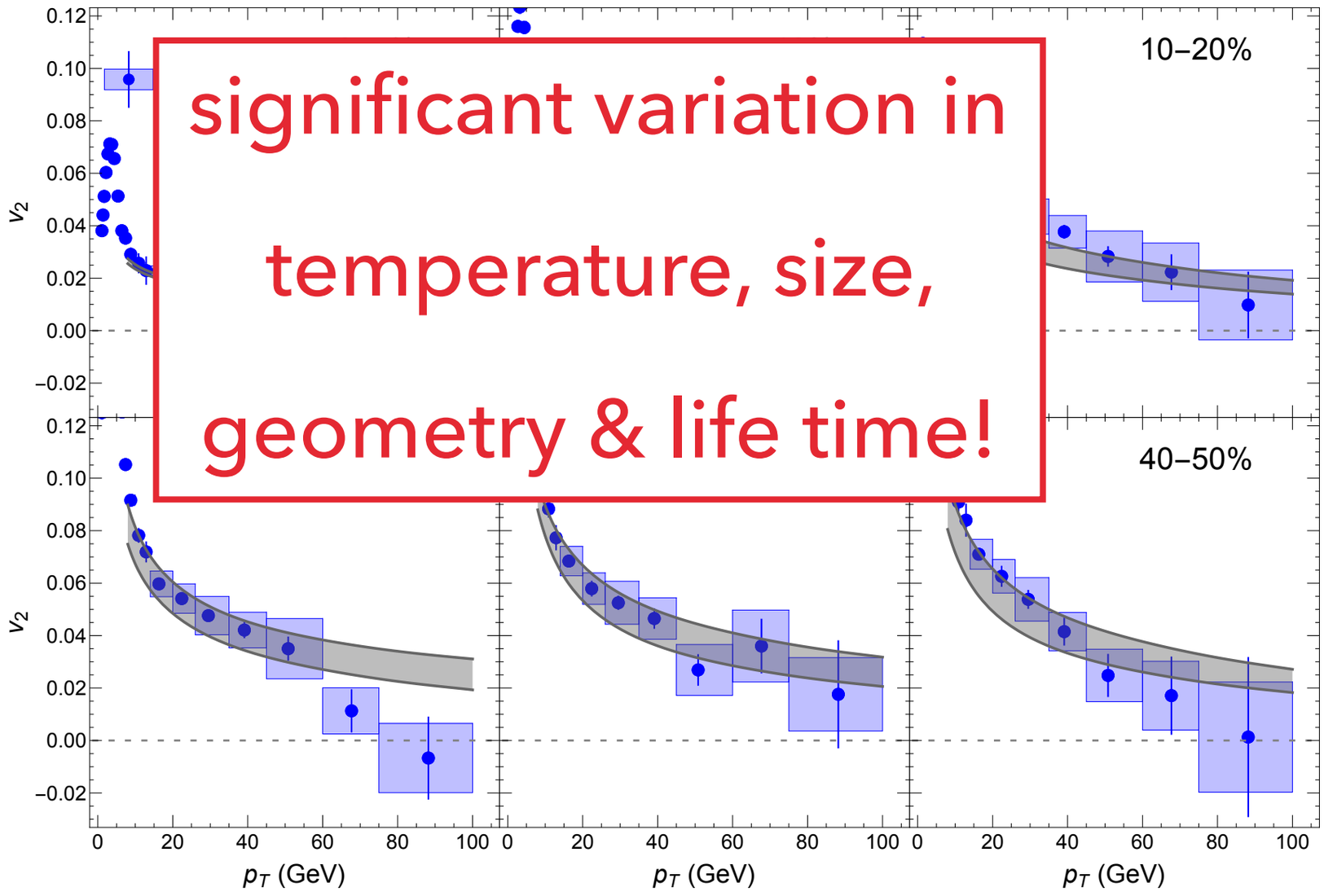
Au - Au @ 0.2 ATeV, (light) hadron $v_2$

Pb - Pb @ 2.76 ATeV, (light) hadron $R_{AA}$

Pb - Pb @ 2.76 ATeV, (light) hadron $v_2$

Pb - Pb @ 5.02 ATeV, (light) hadron $R_{AA}$

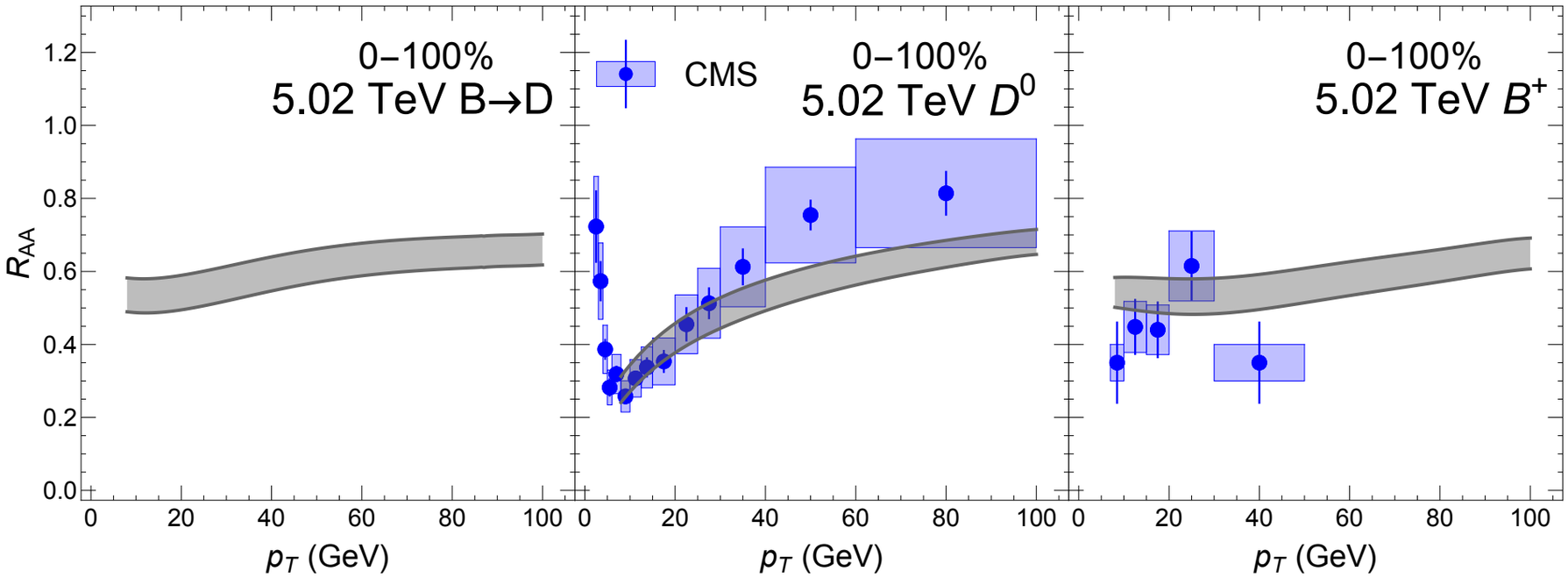
Pb - Pb @ 5.02 ATeV, (light) hadron $v_2$



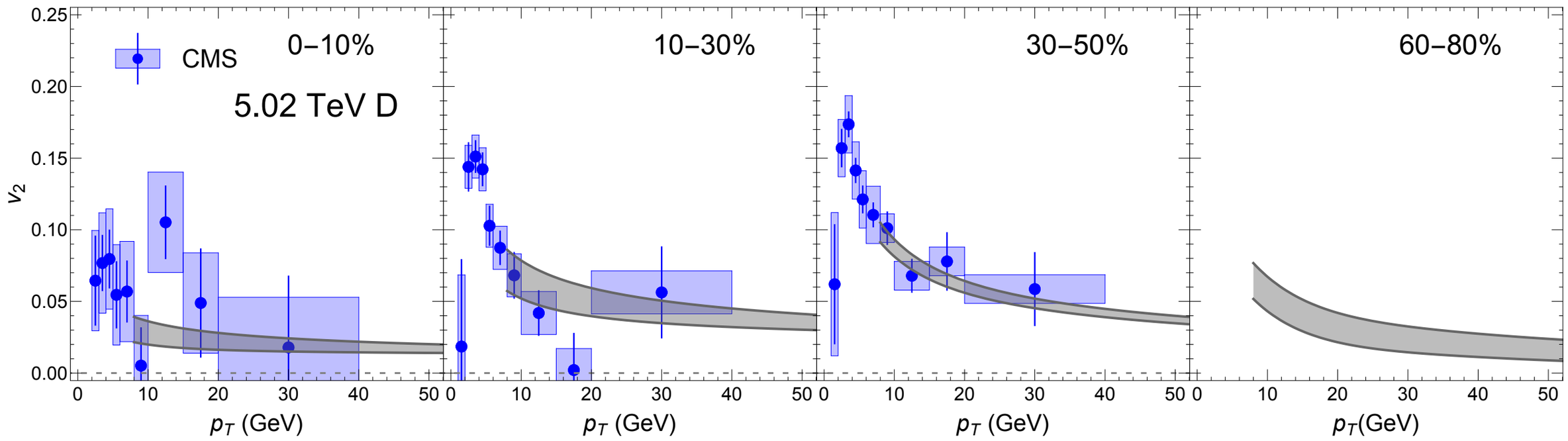

significant variation in temperature, size, geometry & life time!

# Independent Test: Heavy-Flavor Observables

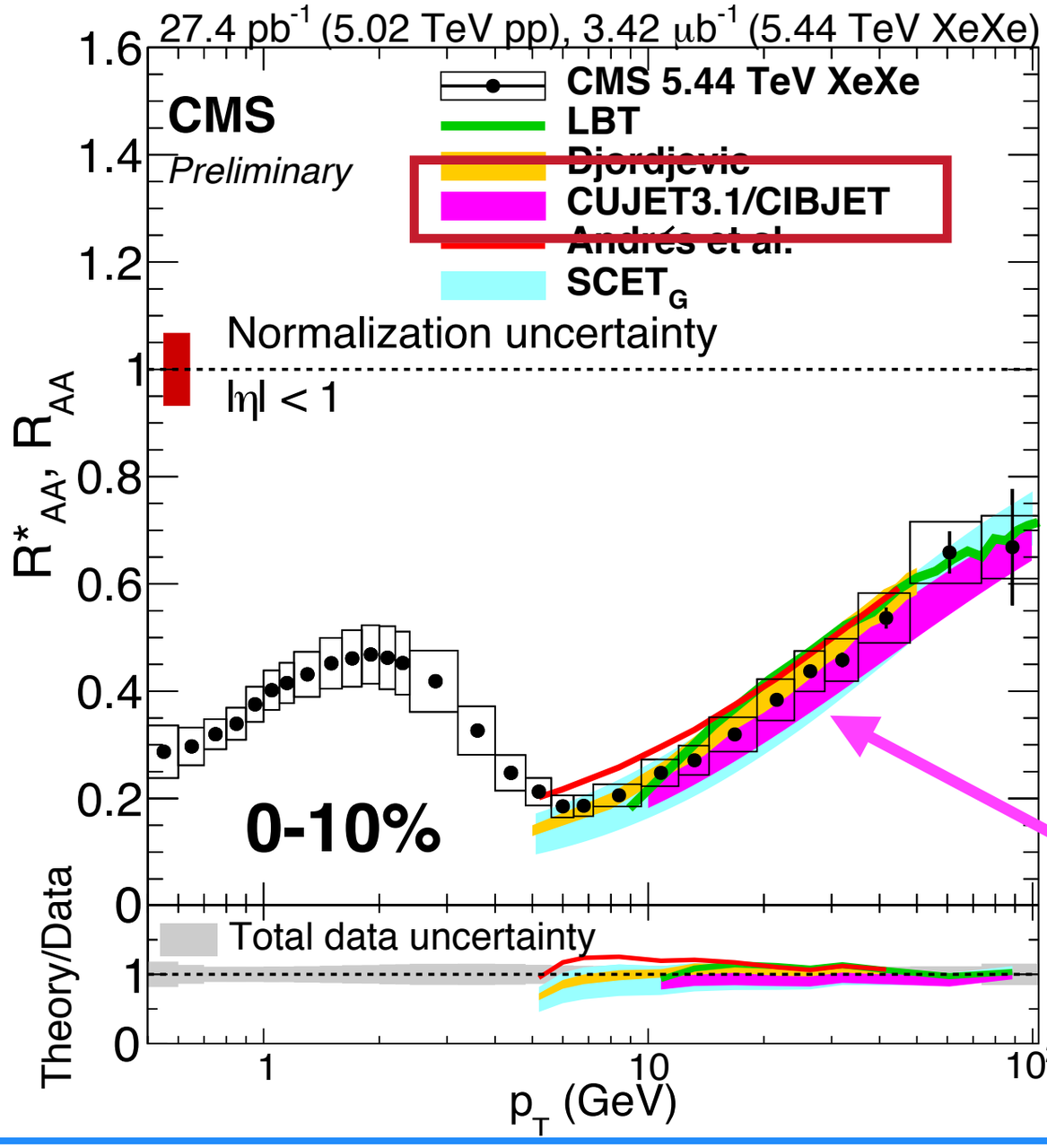
## Pb - Pb @ 5.02 ATeV, HF meson $R_{AA}$

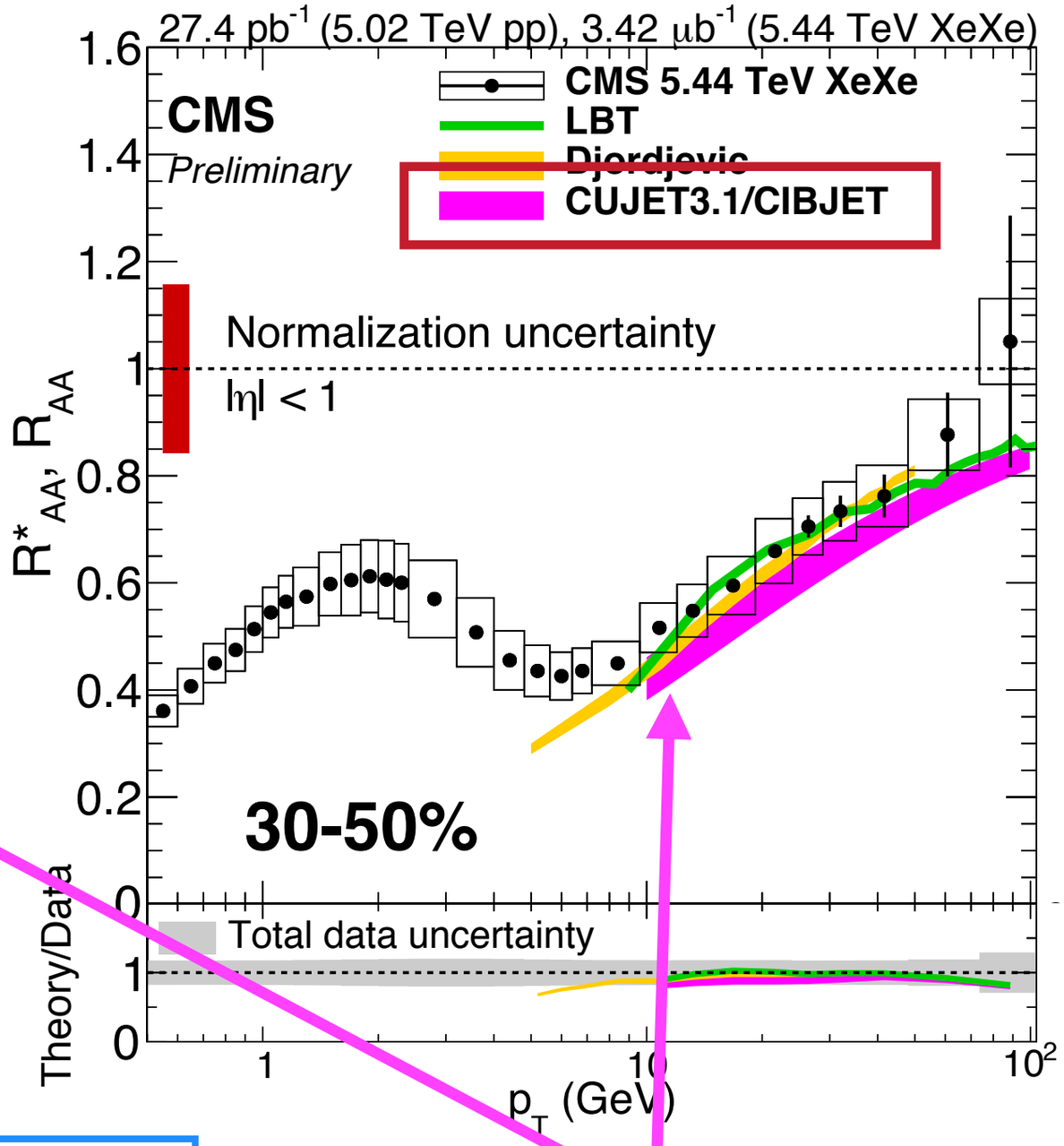



## Pb - Pb @ 5.02 ATeV, HF meson $v_2$



# Independent Test: Xe-Xe @ 5.44 TeV




figs from CMS note: CMS-PAS-HIN-18-004

**CUJET3 predictions**

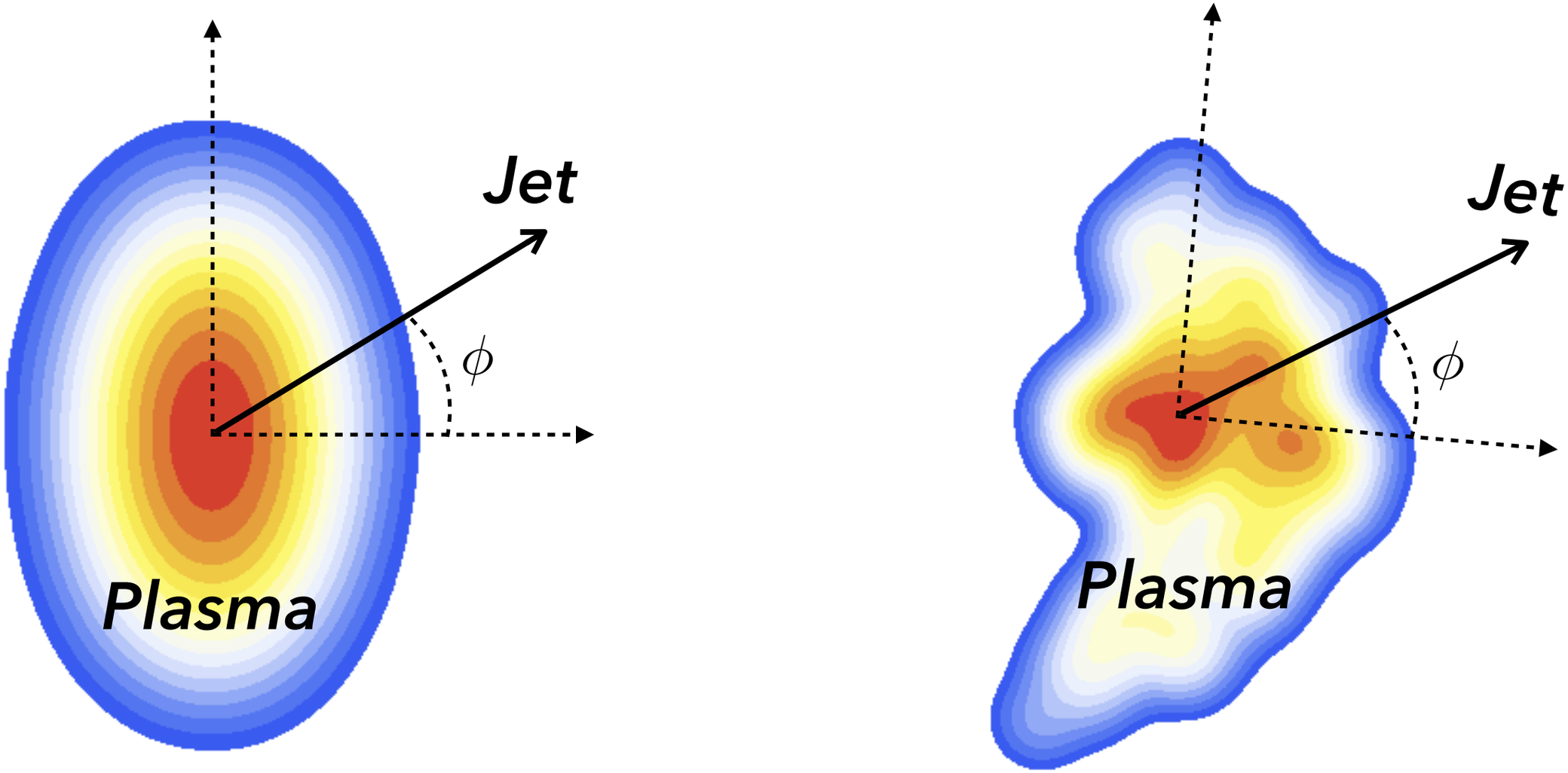
**Radius [$^{208}$Pb] ~ 6.6 fm**

**Radius [$^{129}$Xe] ~ 5.7 fm**

SS, J.Liao & M.Gyulassy, **arXiv:1808.05461**

# Influence Of Event-By-Event Bulk Background

$$R_{AA}(p_T, \varphi) = R_{AA}(p_T) \times [1 + 2\, v_2(p_T) \cos(2\varphi - 2\Psi_2) + 2\, v_3(p_T) \cos(3\varphi - 3\Psi_3) + \dots ]$$




CIBJET = E-by-E VISHNU + CUJET3.1

(hot medium bkg.) (jet Energy-Loss)

# Influence Of Event-By-Event Bulk Background

in experiments:

$$v_n^{\rm hard}\{2\} = \frac{\left\langle\left\langle \exp[in\phi_1^{\rm soft} - in\phi_2^{\rm hard}]\right\rangle\right\rangle}{\left\langle\left\langle \exp[in\phi_1^{\rm soft} - in\phi_2^{\rm soft}]\right\rangle\right\rangle^{1/2}}$$

$$= \frac{\left\langle v_n^{\rm soft} v_n^{\rm hard}\right\rangle}{\left\langle (v_n^{\rm soft})^2\right\rangle^{1/2}}$$

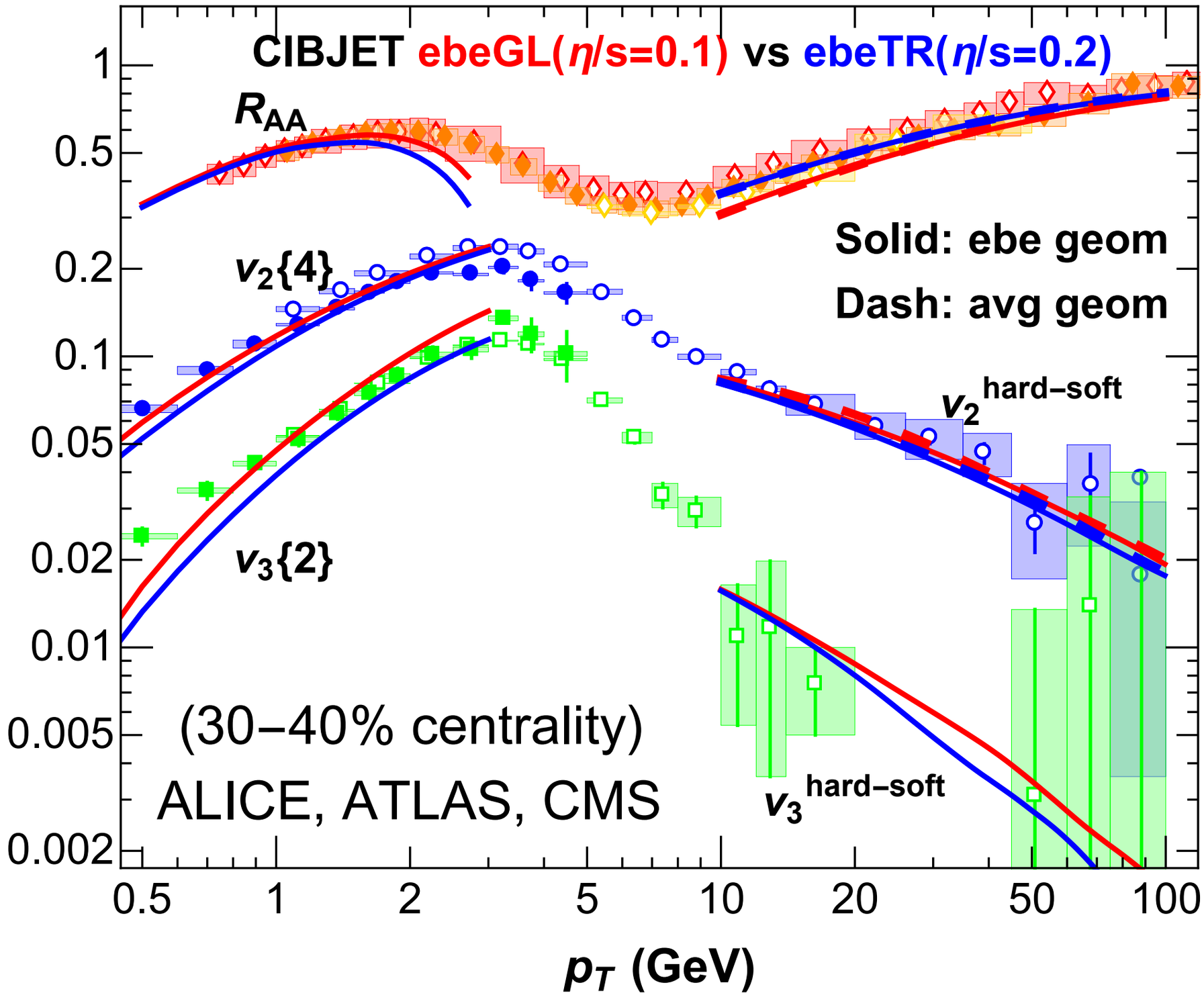
larger $v_n^{soft} \Longrightarrow$ greater weight

in CIBJET:

$$v_n \equiv \left\langle \frac{v_n^{\rm soft}}{\langle (v_n^{\rm soft})^2\rangle^{1/2}} \frac{\int_0^{2\pi} d\phi\, R_{AA}(p_T,\phi)\cos[n\phi - n\psi_n^{\rm soft}]}{\int_0^{2\pi} d\phi\, R_{AA}(p_T,\phi)} \right\rangle$$

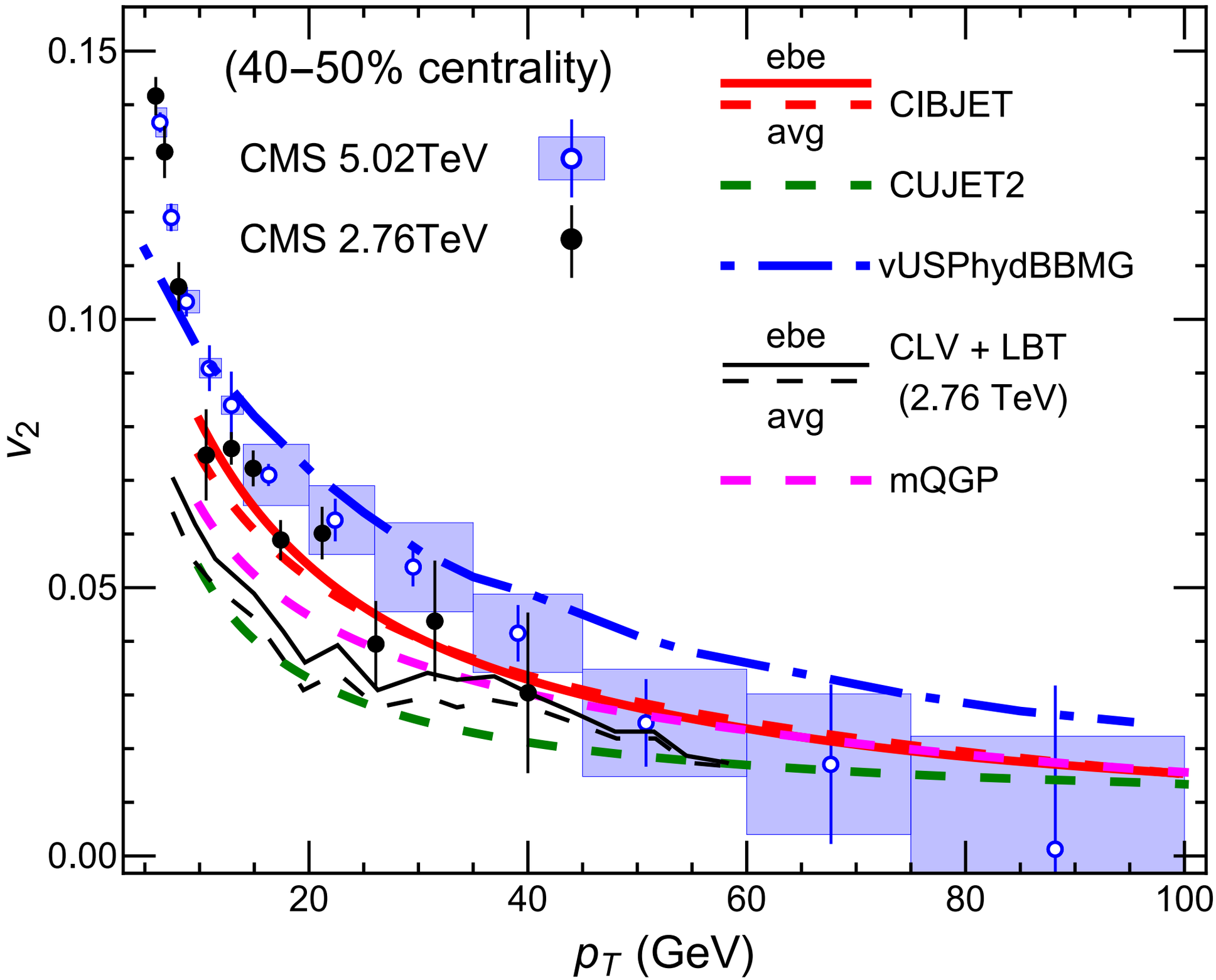
# Influence Of Event-By-Event Bulk Background

**Pb+Pb 5.02ATeV SHEE ($R_{AA}$, $v_2$, $v_3$) vs $p_T$**



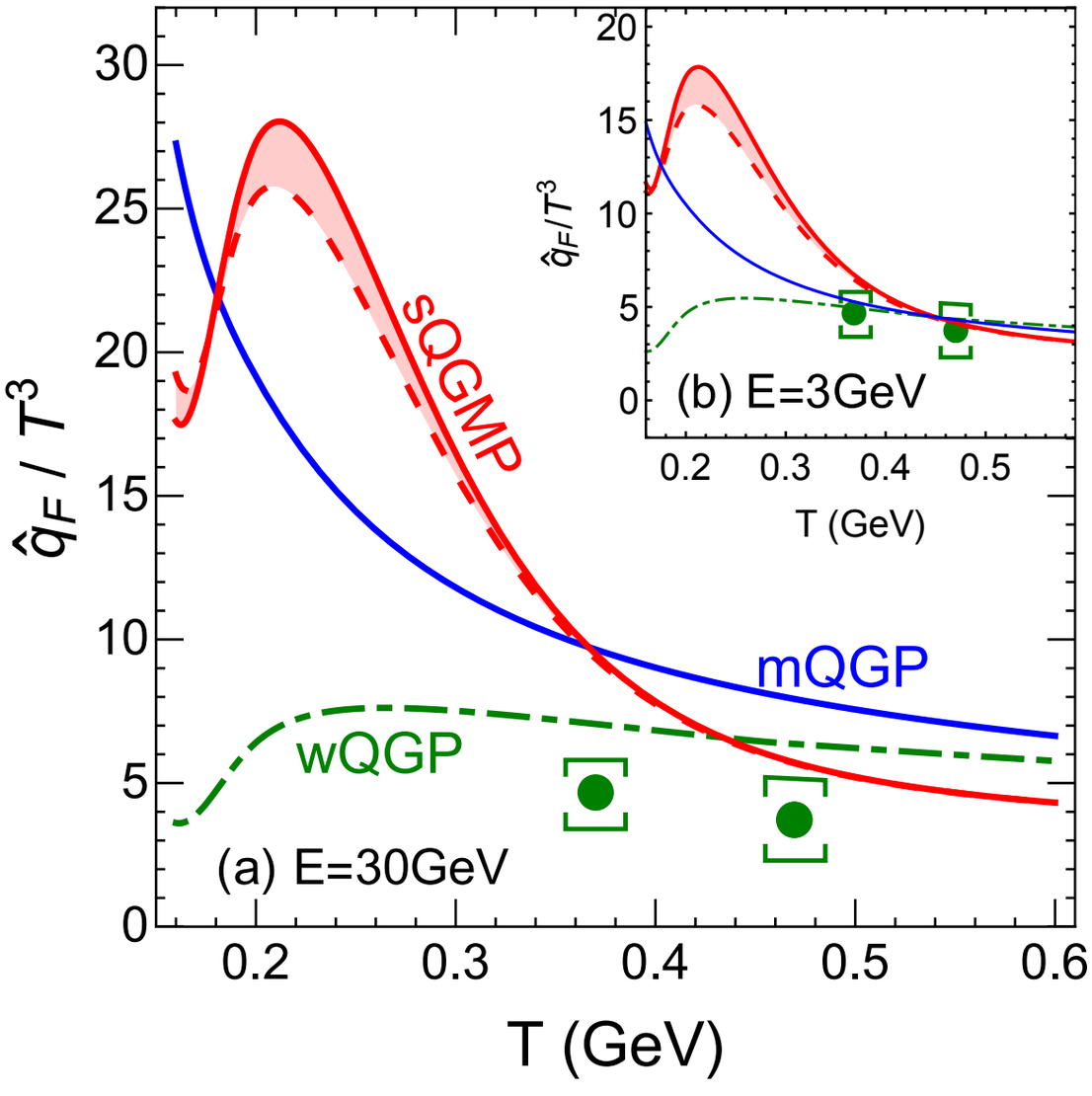

SS, J.Liao & M.Gyulassy, **Chin. Phys. C**(2018)

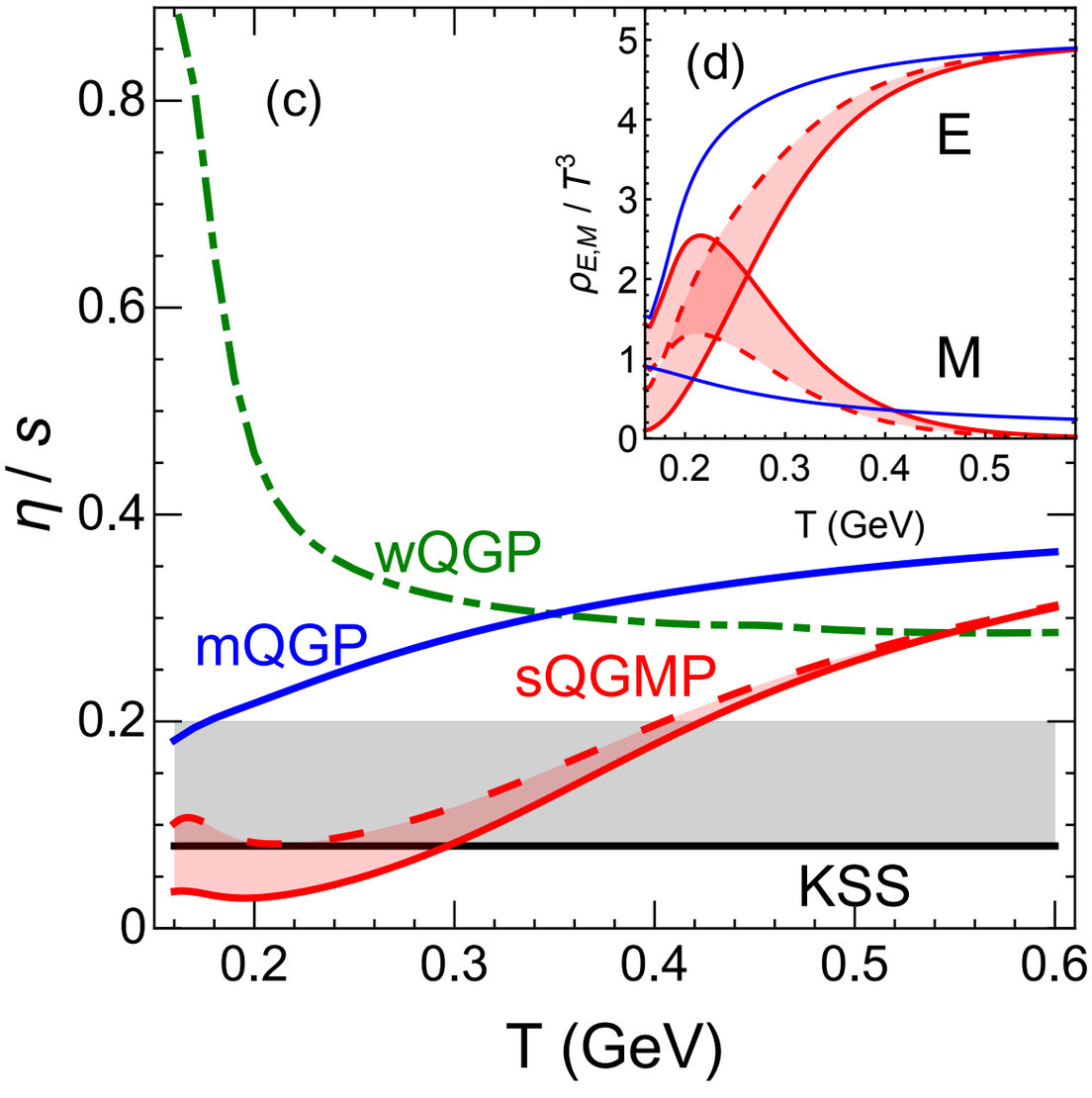
# Influence Of Event-By-Event Bulk Background



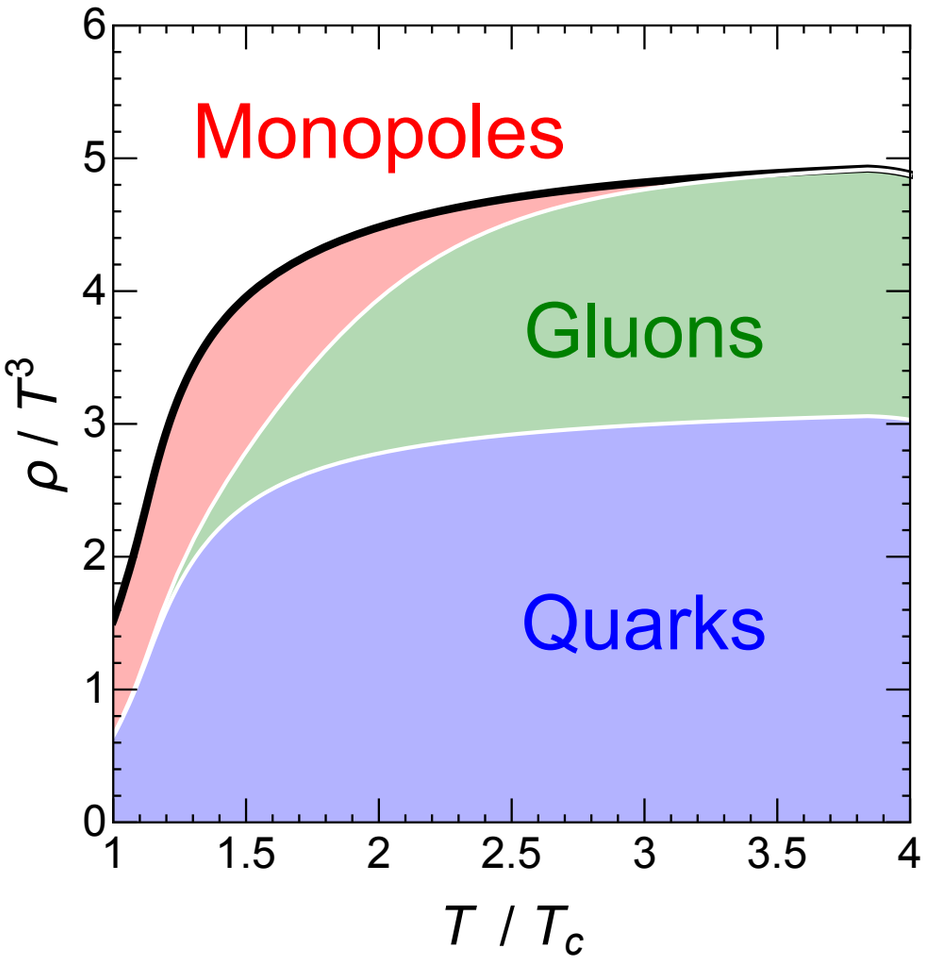

SS, J.Liao & M.Gyulassy, **Chin. Phys. C(2018)**

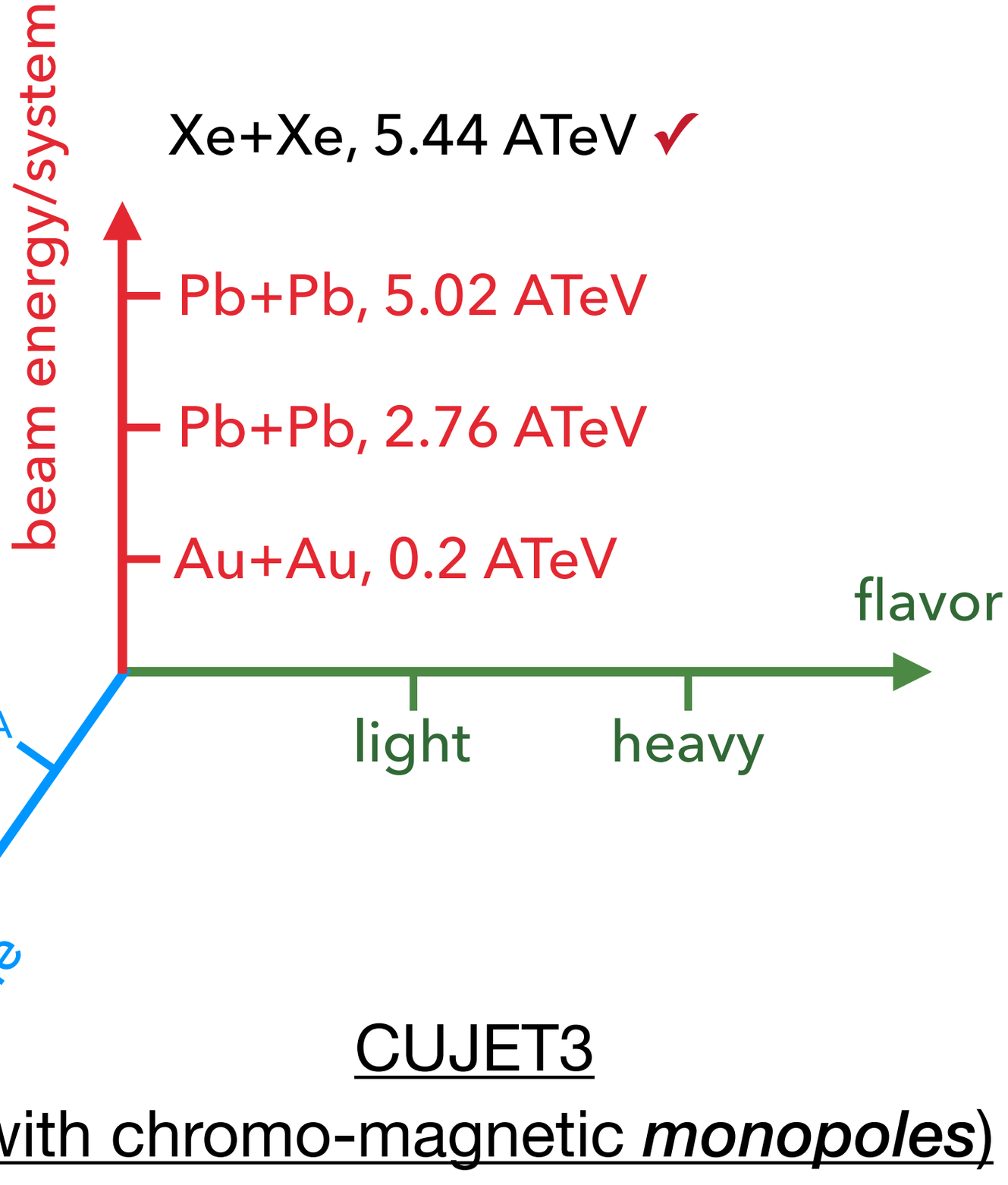
# Transport Coefficients



# Summary



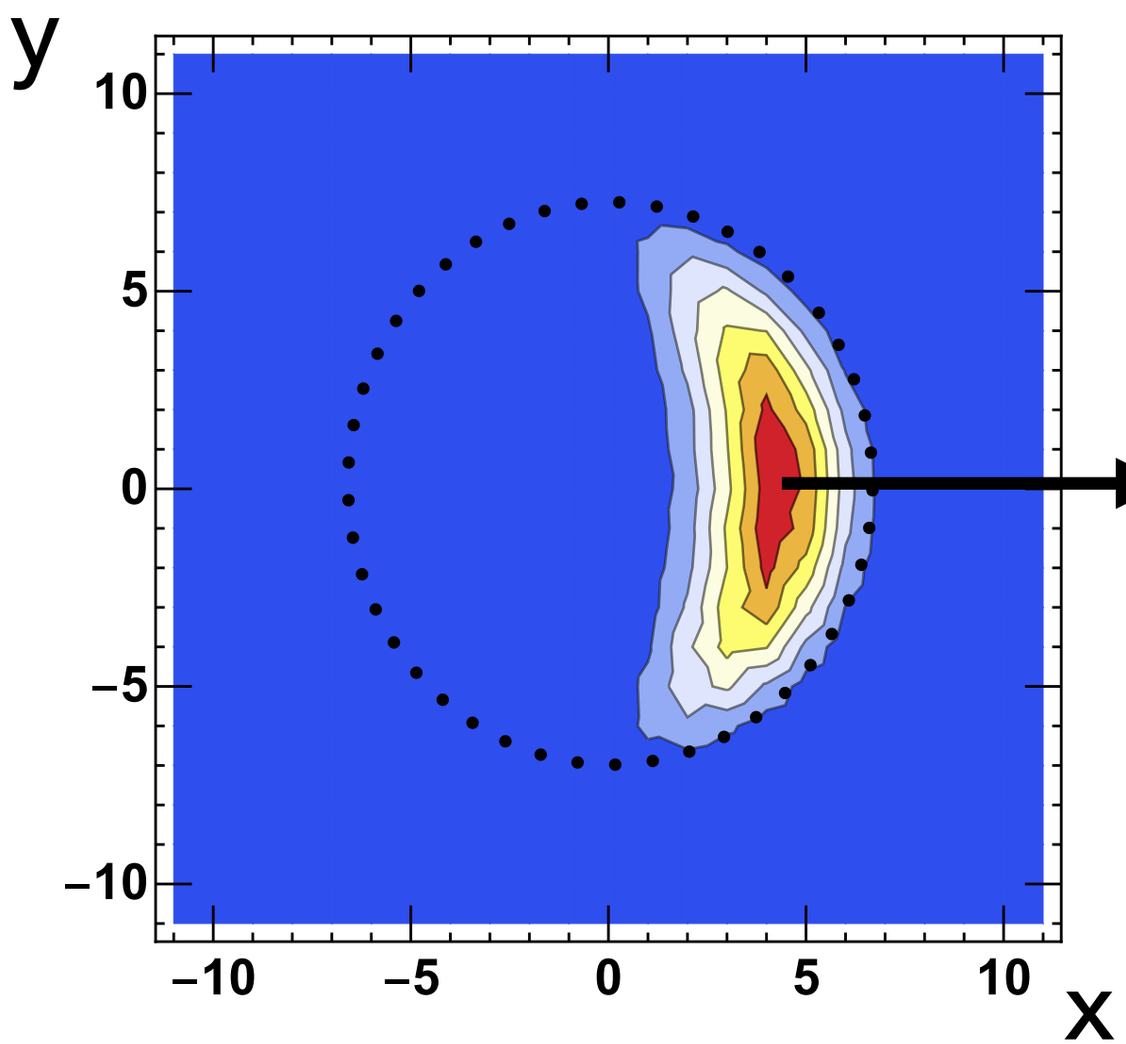




E-by-E
(CIBJET)

CUJET3
(with chromo-magnetic ***monopoles***)
phenomenologically favored in ***"3D"***

# Outlook

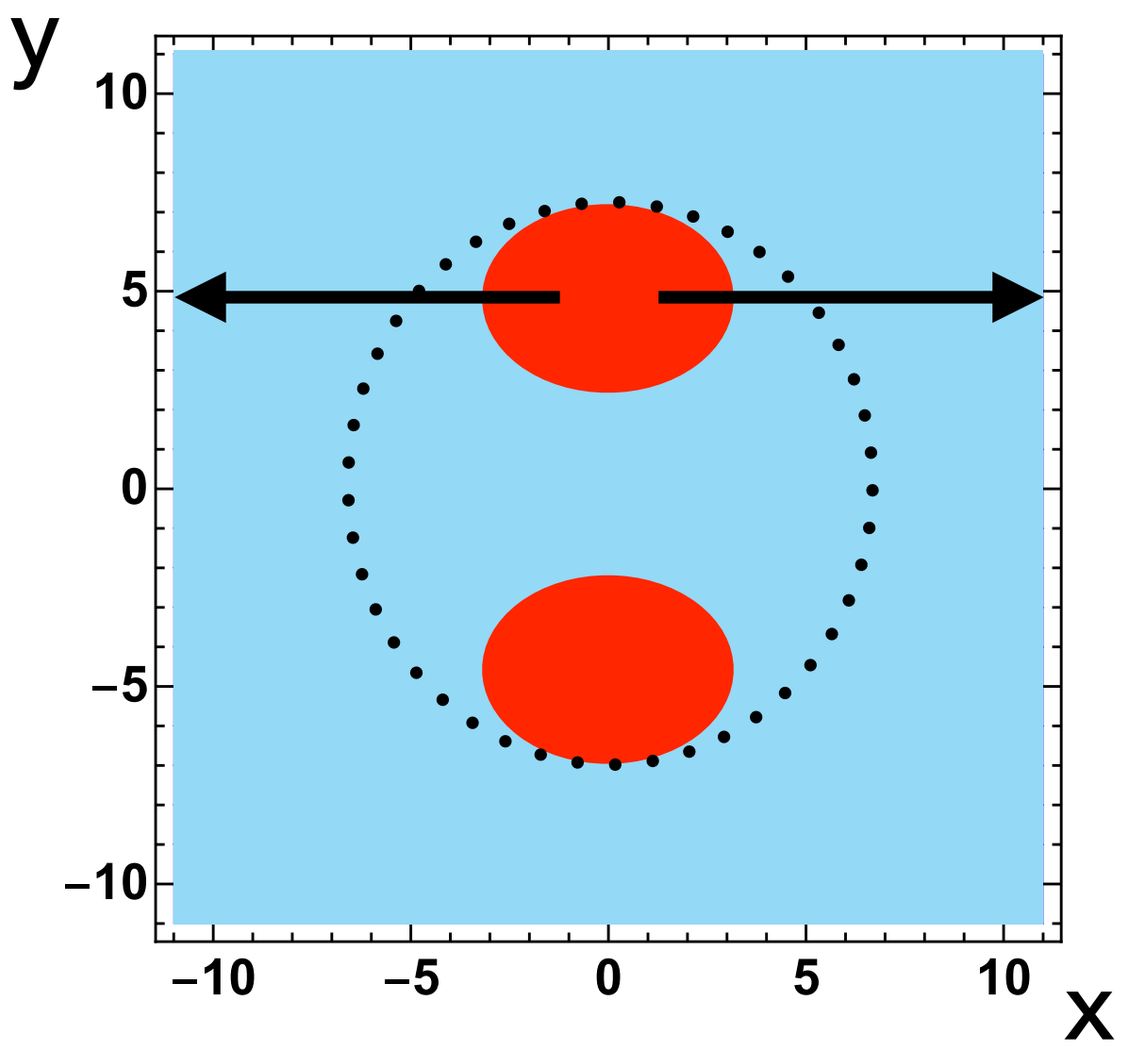
## Dijet Observables –– what is different?




probability distribution of
creation spot for (single) gluon jet

# Outlook

## Dijet Observables —– what is different?




probability distribution of
creation spot for di-gluon jet?

# THANK YOU !

# Back-Up

soft - hard $v_n$ correlation