Suppression of high p_T single hadrons and dihadrons in heavy-ion collisions at $\sqrt{s_{NN}}$ = 0.2, 2.76, 5.02 and 5.44 TeV

Central China Normal University

Xie Man

Collaborated with Shu-yi Wei, Guangyou Qin, Hanzhong Zhang

2018/6/22

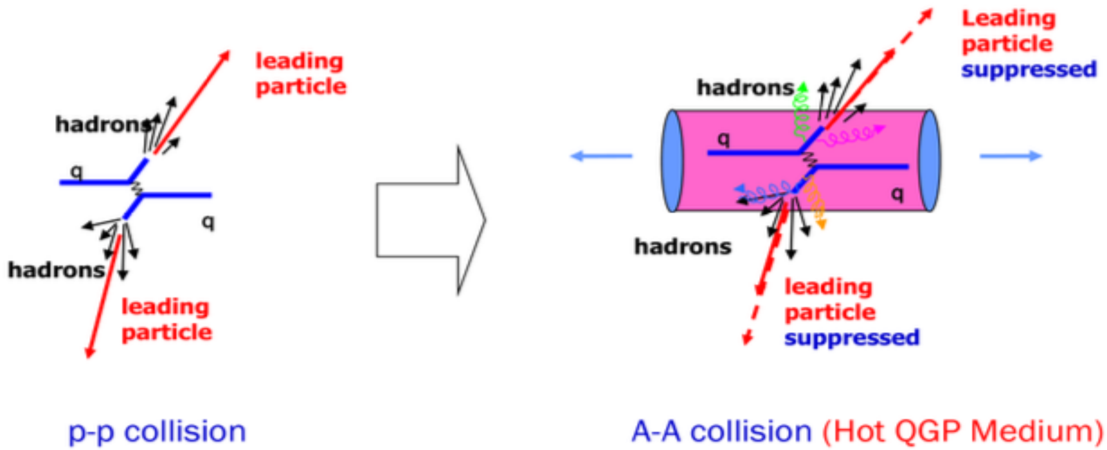
Outline

- Introduction
- NLO pQCD, JQ mFFs, and Hydro models
- Extracted $\hat{q}_0$ via single and dihadron suppression in HIC
- Prediction for dihadron suppression factor at 5.02 and 5.44TeV
- Summary and outlook

Introduction

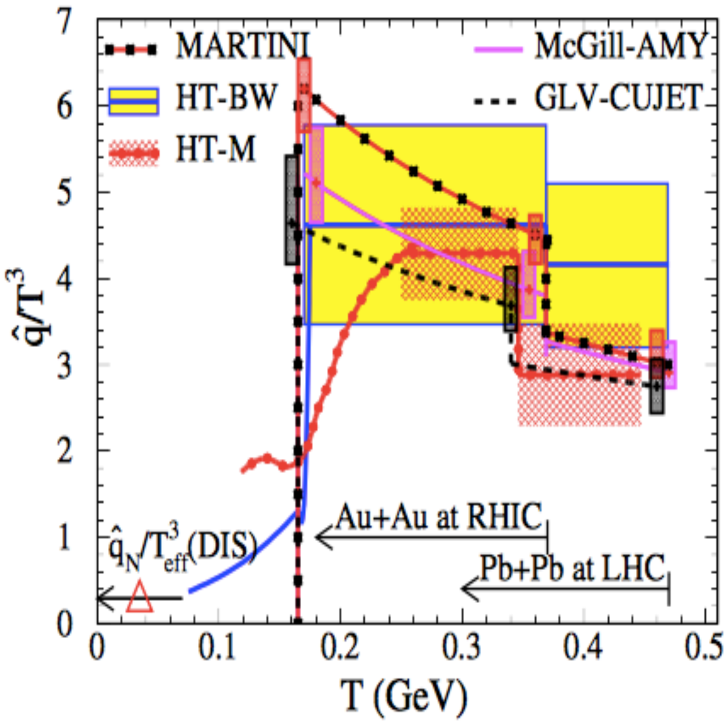
- **Jet quenching:** [X.-N. Wang and M. Gyulassy, Phys. Rev. Lett. 68, 1480(1992)]

  The hard jet losses a large amount of its energy via radiating gluon induced by multiple scattering.



- Jet energy loss in the QGP medium: $\Delta E \propto \hat{q}$---jet transport coefficient.
- $\hat{q} \equiv \frac{d<q_T^2>}{dL}$:transverse momentum broadening squared per unit length. [BDMPS, NPB482(1997)291]

Motivation



In the initial time and in the center of the fireball

$$\hat{q} \approx \begin{cases} 1.2 \pm 0.3 \\ 1.9 \pm 0.7 \end{cases} \mathrm{GeV}^2/\mathrm{fm} \ \ \mathrm{at} \ \ \begin{matrix} \mathrm{T{=}370\ MeV}, \\ \mathrm{T{=}470\ MeV}, \end{matrix}$$

[The JET collaboration.arXiv:1312.5003,Dec 2013]

- Extracting $\hat{q}_0$ via single hadron and dihadron suppression in HIC.
- Whether the dihadron $\hat{q}_0$ is consistent with the single hadron?
- Predicting the dihadron suppression factor I_{AA} in central and non-central Pb+Pb collisions at $\sqrt{s_{NN}}$=5.02TeV and Xe+Xe collisions at $\sqrt{s_{NN}}$=5.44TeV.

NLO pQCD parton model

- In A+A collisions, dihadron spectra can be given by:

$$\frac{d\sigma}{dy_1 d^2p_T^{h1} dy_2 d^2p_T^{h2}} = \sum_{abcd} \int d^2b d^2r t_A(\vec{r}) t_B(|\vec{r}-\vec{b}|) dx_a dx_b dz_c dz_d$$
$$\times f_{a/A}(x_a, \mu^2, \vec{r}) f_{b/B}(x_b, \mu^2, (|\vec{r}-\vec{b}|)) \frac{\hat{s}}{2\pi z_c^2 z_d^2} \times \frac{d\sigma}{d\hat{t}}(ab \to cd)$$
$$\times D_{h/c}(z_c, \mu^2, \Delta E_c) D_{h/d}(z_d, \mu^2, \Delta E_d) \delta^4(p_a + p_b - p_c - p_d) + O(\alpha_s^3)$$

- $t_A(\vec{r})$ →thickness function: Woods-Saxon
- $f_{a/A}$ →PDF: CTEQ6.6M, EPS09 [Eur. Phys. J. C 12, 375(2000)], [JHEP 0904, 065 (2009)]
- $\frac{d\sigma}{d\vec{t}}$ →hard scattering cross section
- $D_{h/c}^{0}$ →FFs: Kretzer [PHYSICAL REVIEW D, VOLUME 62, 054001]

Modified fragmentation functions--mFFs

- Modified fragmentation functions in QGP medium:

$$D_{h/c}(z_c,\mu^2,\Delta E_c) = (1-e^{-\langle N_g\rangle})\left[\frac{z_c{}'}{z_c}D^0_{h/c}(z_c{}',\mu^2) + \langle N_g\rangle\frac{z_g{}'}{z_c}D^0_{h/g}(z_g{}',\mu^2)\right]$$

$$+e^{-\langle N_g\rangle}D^0_{h/c}(z_c,\mu^2)$$

where $z_c{}' = p_T/(p_{Tc}-\Delta E_c)$, $z_g{}' = \langle N_g\rangle p_T/\Delta E_c$.
[X.-N. Wang, PRC70 (2004) 031901], [H. Z. Zhang, J.F. Owens, Phys. Rev. Lett. 98.212301 (2007)], and [H. Z. Zhang, J.F. Owens, Phys. Rev. Lett. 103, 032302 (2009)]

- Total energy loss of jet in high-twist method:

$$\frac{\Delta E}{E} = C_A\frac{\alpha_s}{2\pi}\int d\tau\int_0^{Q^2}\frac{dl_T^2}{l_T^4}\int_\epsilon^{1-\epsilon}dz\left[1+(1-z)^2\right]\times\hat{q}_F(y)4sin^2\left(\frac{l_T^2\tau}{4z(1-z)E}\right)$$

[W.T. Deng and X.-N. Wang, Phys. Rev. C81,024902(2010], [E. Wang and X.-N. Wang, Phys. Rev. Lett. 87, 142301 (2001); 89, 162301 (2002)]

2+1 D hydrodynamics medium model

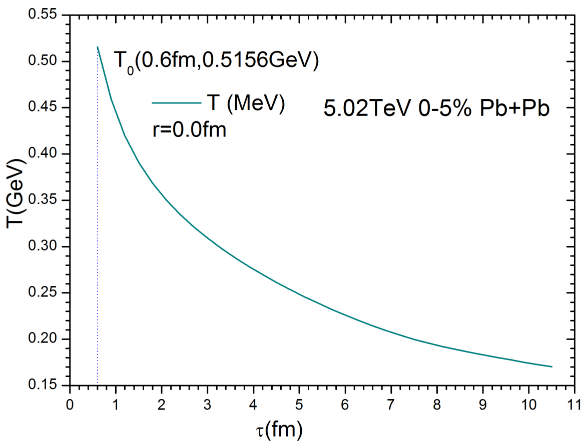
- $\hat{q}$ depends on the local T in the jet trajectory:

$$\hat{q}(\tau,r)=\left[\hat{q}_0\frac{\rho_g(\tau,r)}{\rho_g(\tau_0,0)}(1-f)\right]\frac{p^\mu u_\mu}{p_0} \quad \rho_g\propto T^3 \rightarrow \boxed{\frac{\hat{q}}{T^3}=\frac{\hat{q}_0}{T_0^3}=C}$$

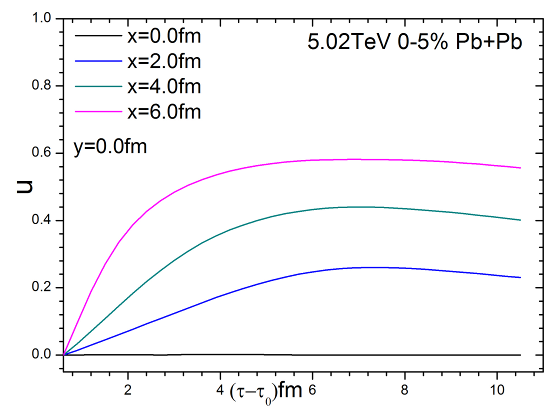
- hadron phase fraction: $f(\tau,r)=\begin{cases}0 & \text{when } T\geq 170\text{ MeV}\\ 1 & \text{when } T\leq 170\text{ MeV}\end{cases}$

[X. Chen, T. Hirano, E. Wang, X.-N. Wang, H. Z. Zhang, Phys. Rev. C84 (2011) 034902]

- T, u are given by 2+1 D hydro to describe the medium evolution. [Z. Qiu, C. Shen and U. Heinz, Phys. Lett. B 707, 151 (2012)]



Medium Temperature



Medium Velocity

Nuclear modification factor

- Single hadron nuclear modification factor:

$$R_{AA} = \frac{dN_{AA}/dyd^2p_T}{T_{AA}(b)d\sigma_{pp}/dyd^2p_T}$$

- Dihadron nuclear modification factor:

$$I_{AA}(z_T) = \frac{D_{AA}(z_T)}{D_{pp}(z_T)} = \frac{D_{AA}(p_T^{assoc})}{D_{pp}(p_T^{assoc})}$$

where $z_T = \frac{p_T^{assoc}}{p_T^{trig}}$.

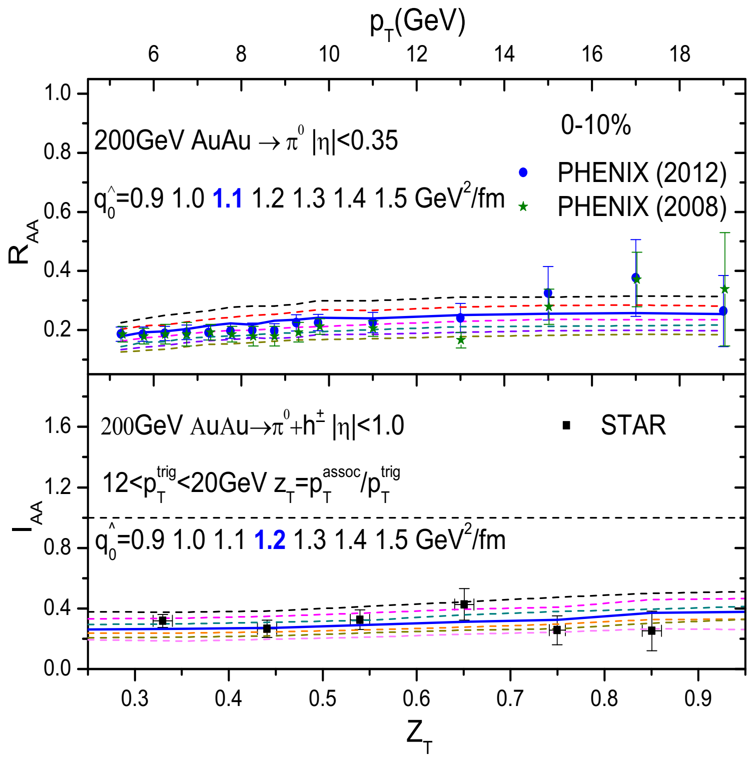
$$D_{AA}(z_T) \equiv \frac{1}{N_{AA}^{trig}} \frac{dN_{AA}^{h_1 h_2}}{dz_T} = \frac{\int dp_T^{trig} dy^{trig} \int dy^{assoc} d\Delta\phi \frac{p_T^{trig} d^5\sigma_{AA}{}^{h_1 h_2}}{dp_T^{trig} dy^{trig} dp_T^{assoc} dy^{assoc} d\Delta\phi}}{\int dp_T^{trig} dy^{trig} \frac{d^2\sigma_{AA}{}^{h_1}}{dp_T^{trig} dy^{trig}}}$$

or

$$D_{AA}(p_T^{assoc}) \equiv \frac{1}{N_{AA}^{trig}} \frac{dN_{AA}^{h_1 h_2}}{dp_T^{assoc}} = \frac{\int dp_T^{trig} dy^{trig} \int dy^{assoc} d\Delta\phi \frac{d^5\sigma_{AA}{}^{h_1 h_2}}{dp_T^{trig} dy^{trig} dp_T^{assoc} dy^{assoc} d\Delta\phi}}{\int dp_T^{trig} dy^{trig} \frac{d^2\sigma_{AA}{}^{h_1}}{dp_T^{trig} dy^{trig}}}$$

Extracting $\hat{q}_0$ via dihadron suppression in HIC

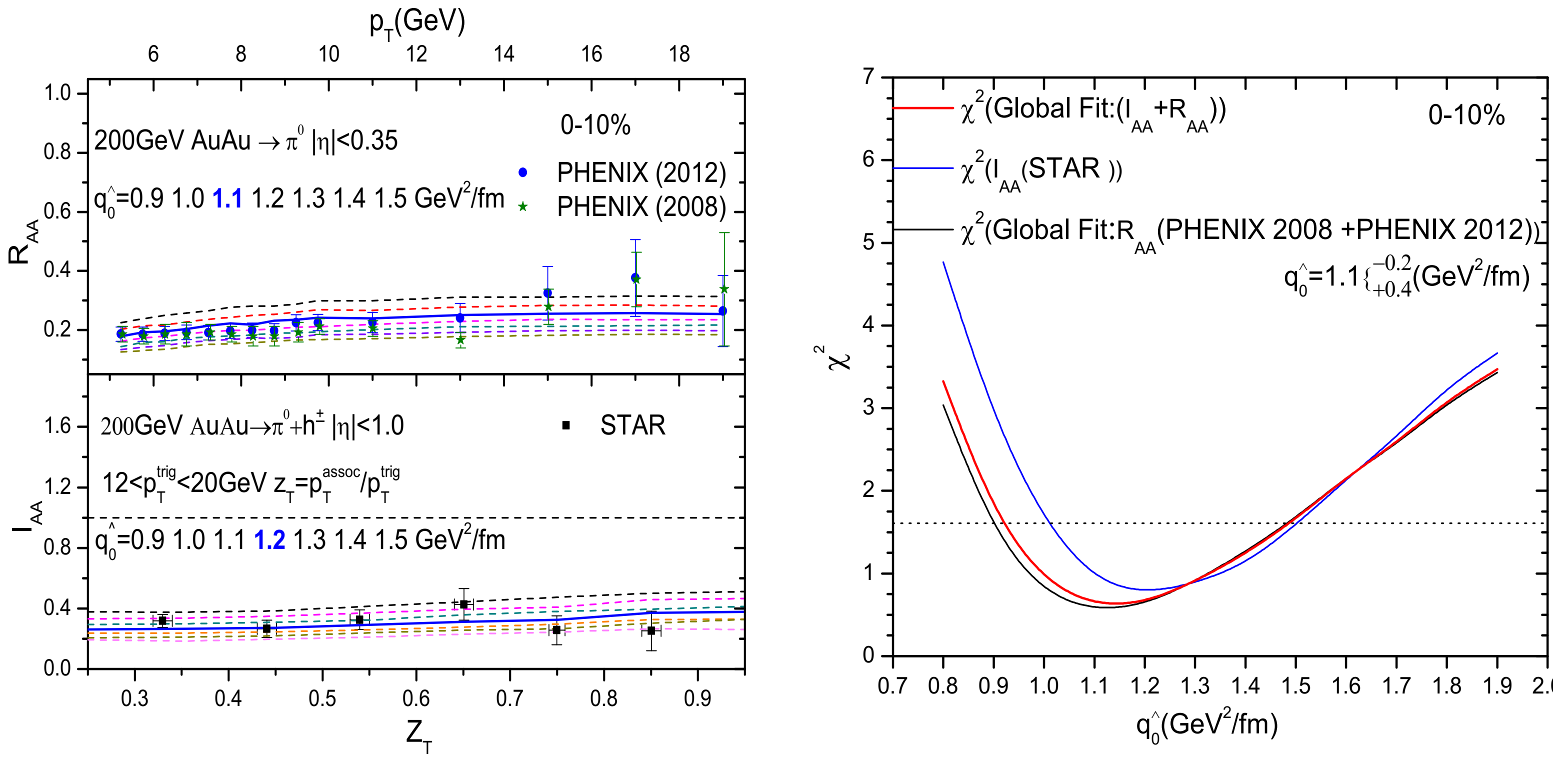
- Extracting parameters $\hat{q}_0$ in central Au+Au collisions at $\sqrt{s_{NN}}$=200 GeV.



Data from [[PHENIX Collaboration], Phys. Rev. C 87, no. 3,034911(2013), Phys. Rev. Lett. 101, 232301(2008)], and [[STAR], arXiv: 1604. 01117v2 [nucl-ex] 7 Apr 2016]

Extracting $\hat{q}_0$ via dihadron suppression in HIC

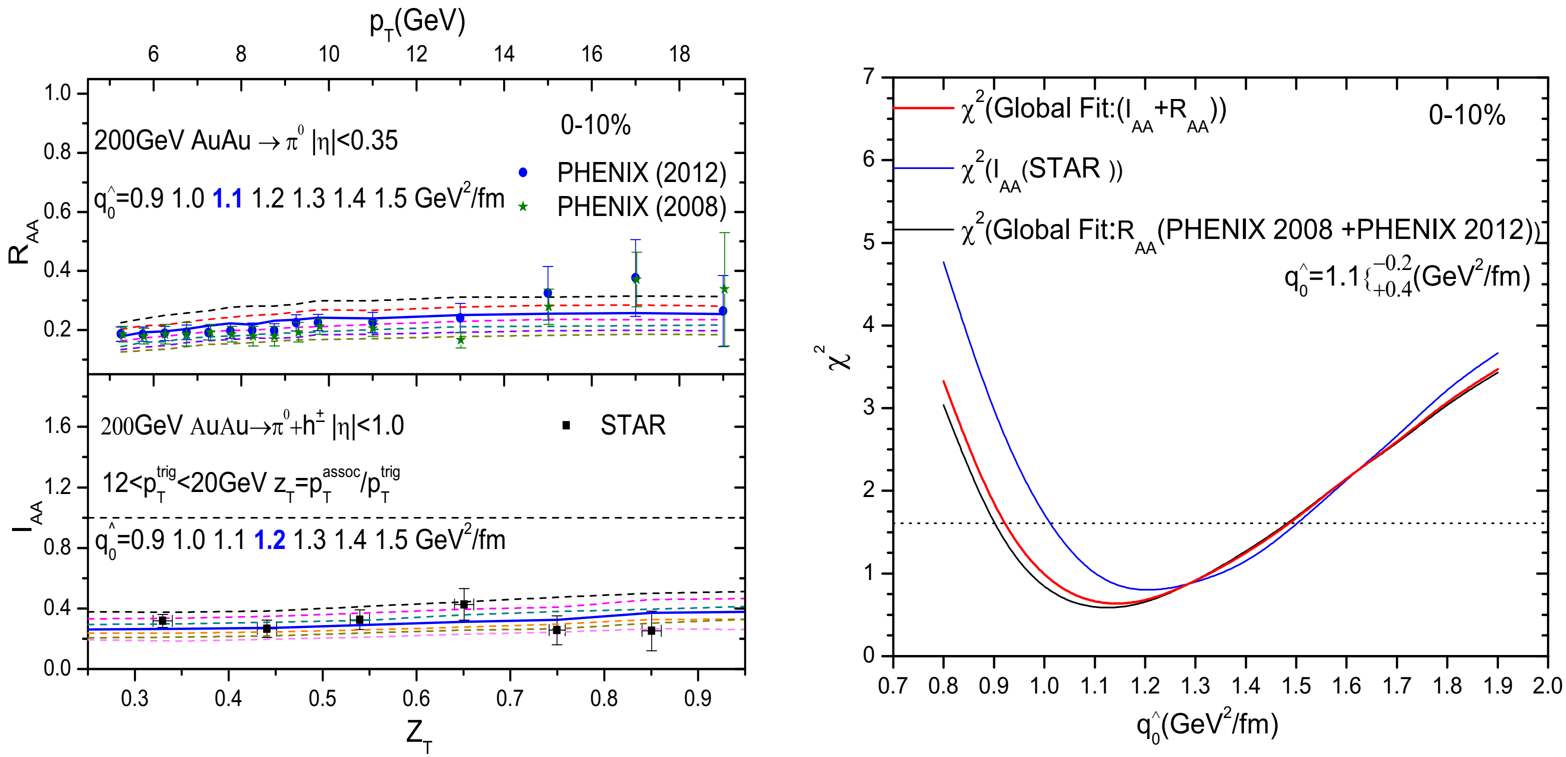
- Extracting parameters $\hat{q}_0$ in central Au+Au collisions at $\sqrt{s_{NN}}$=200 GeV.



Data from [[PHENIX Collaboration], Phys. Rev. C 87, no. 3,034911(2013), Phys. Rev. Lett. 101, 232301(2008)], and [[STAR], arXiv: 1604. 01117v2 [nucl-ex] 7 Apr 2016]

Extracting $\hat{q}_0$ via dihadron suppression in HIC

- Extracting parameters $\hat{q}_0$ in central Au+Au collisions at $\sqrt{s_{NN}}$=200 GeV.

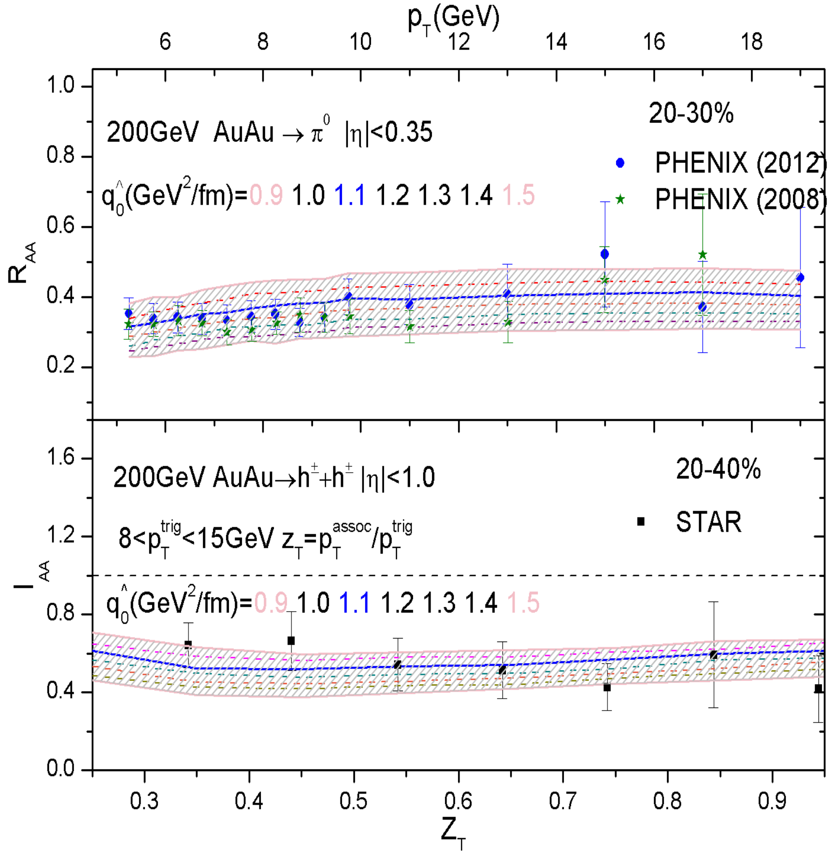


$$\hat{q}_0=1.1\{^{-0.2}_{+0.4}(GeV^2/fm)$$

Data from [[PHENIX Collaboration], Phys. Rev. C 87, no. 3,034911(2013), Phys. Rev. Lett. 101, 232301(2008)], and [[STAR], arXiv: 1604. 01117v2 [nucl-ex] 7 Apr 2016]

Extracting $\hat{q}_0$ at RHIC in the 20– 40% centrality

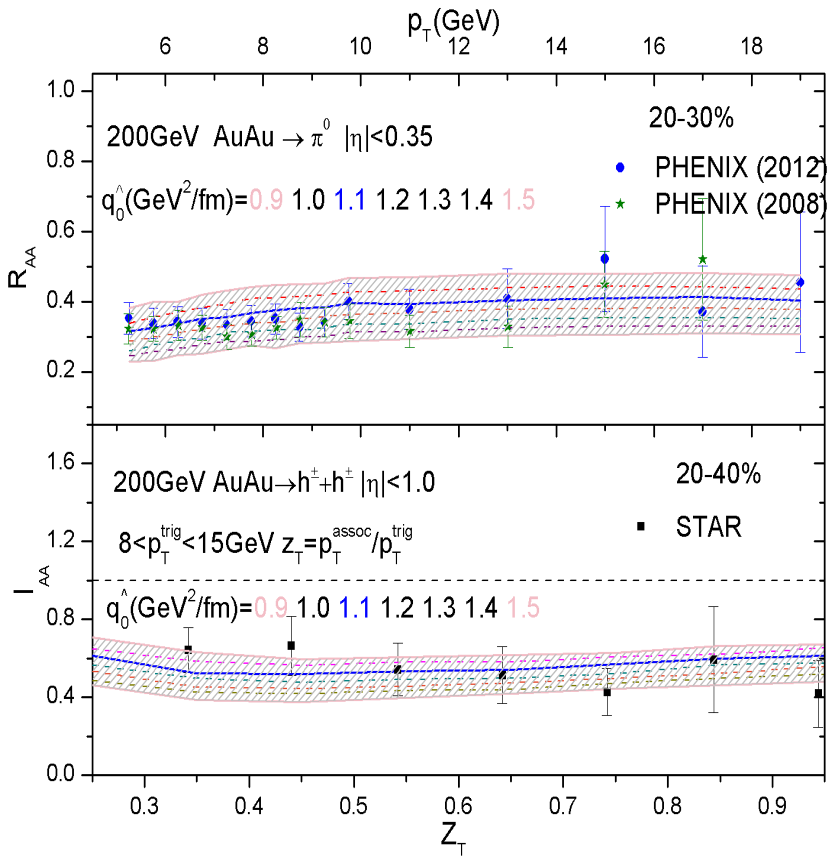
- $\mathrm{R_{AA}}$ and $\mathrm{I_{AA}}$ in the 20 - 40 % centrality with the $\hat{q}_0$ values extracted from central Au+Au collisions as compared to experimental data.



Data from [[PHENIX Collaboration], Phys. Rev. C 87, no. 3,034911(2013), Phys. Rev. Lett. 101, 232301(2008)], and [[STAR], Phys. Rev. Lett. 97, 162301(2006)]

Extracting $\hat{q}_0$ at RHIC in the 20– 40% centrality

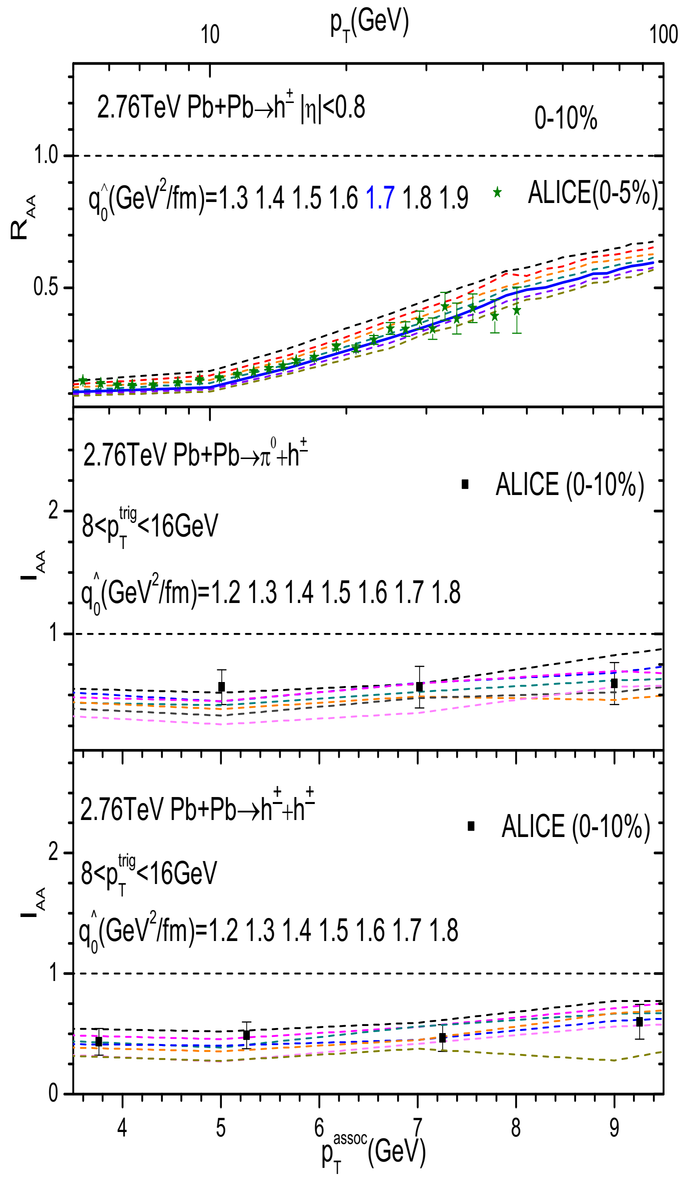
- R_{AA} and I_{AA} in the 20 - 40 % centrality with the $\hat{q}_0$ values extracted from central Au+Au collisions as compared to experimental data.

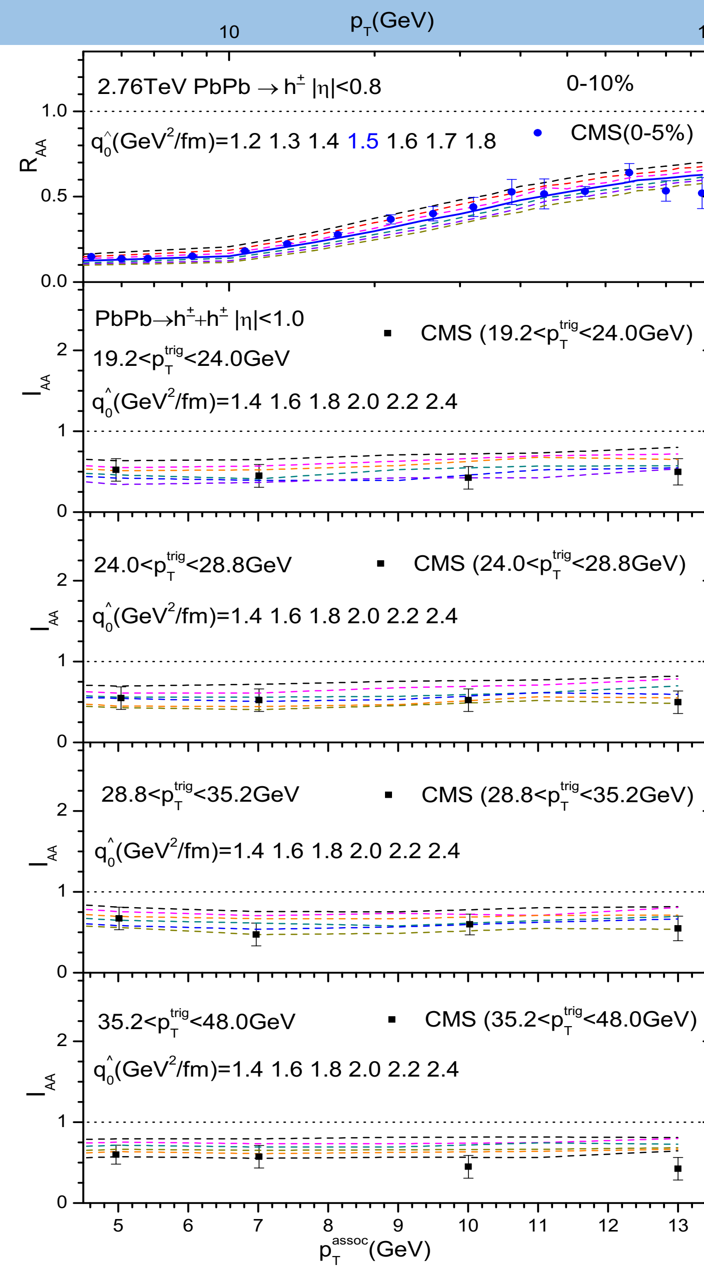


- ➢ Dihadron $\hat{q}_0$ is consistent with single hadron.
- ➢ Non central collisions results is consistent with central collisions.

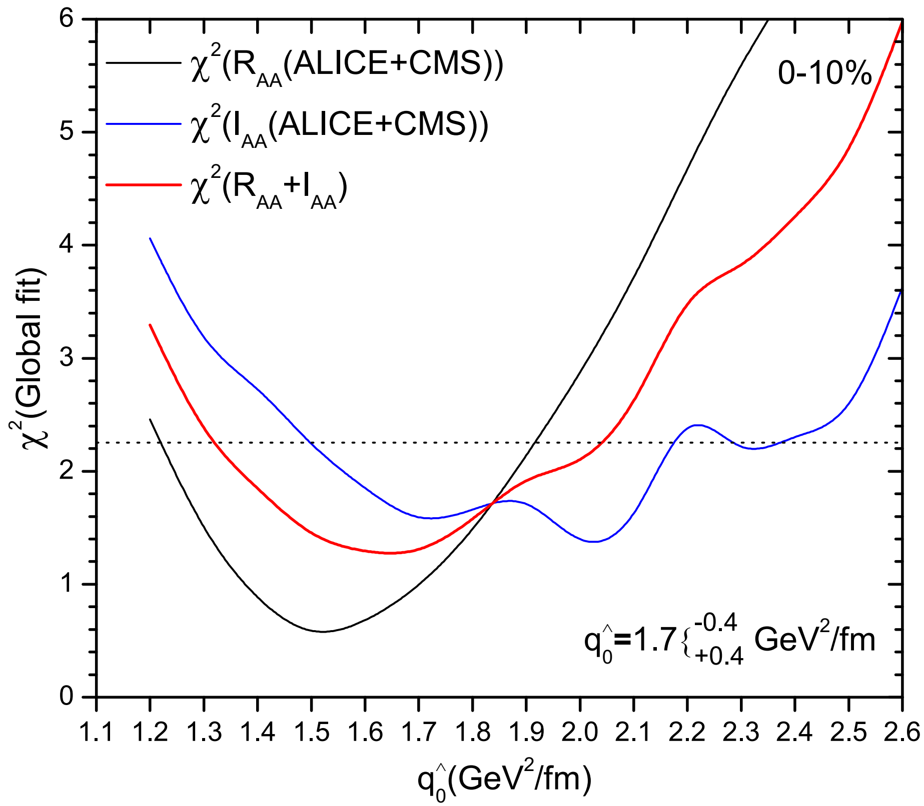
Data from [[PHENIX Collaboration], Phys. Rev. C 87, no. 3,034911(2013), Phys. Rev. Lett. 101, 232301(2008)], and [[STAR], Phys. Rev. Lett. 97, 162301(2006)]

Extracting $\hat{q}_0$ in central Pb+Pb collisions at $\sqrt{s_{NN}}$=2.76 TeV





Extracting $\hat{q}_0$ in central Pb+Pb collisions at $\sqrt{s_{NN}}$=2.76 TeV

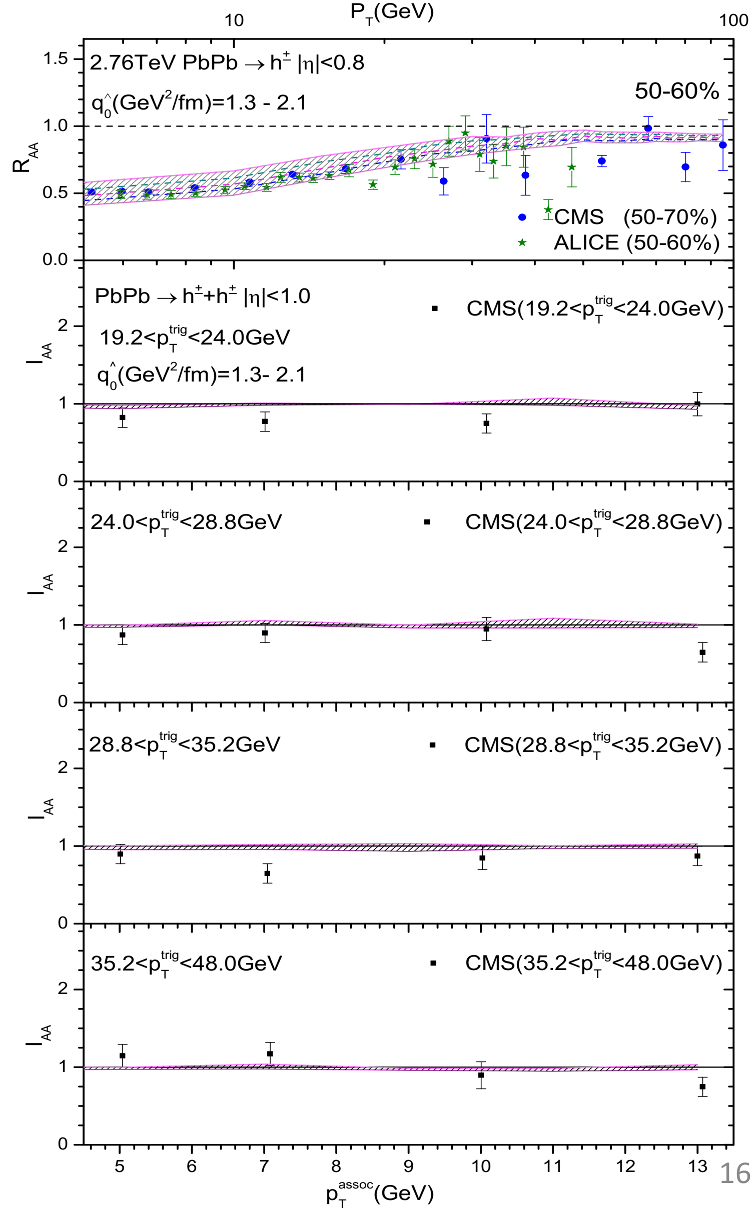


$\hat{q}_0=1.7\{^{-0.4}_{+0.4}(GeV^2/fm)$

Data from [[ALICE Collaboration], Phys. Lett. B 720 52-62(2013), Phys. Lett. B 763 238-250(2016)], [CMS Collaboration], Nuclear. Phys. A 904-905 451c-454c(2013), and [Eur. Rhys. J. C 72, 1945(2012)]

Extracting $\hat{q}_0$ in non-central collisions at $\sqrt{s_{NN}}$=2.76 TeV

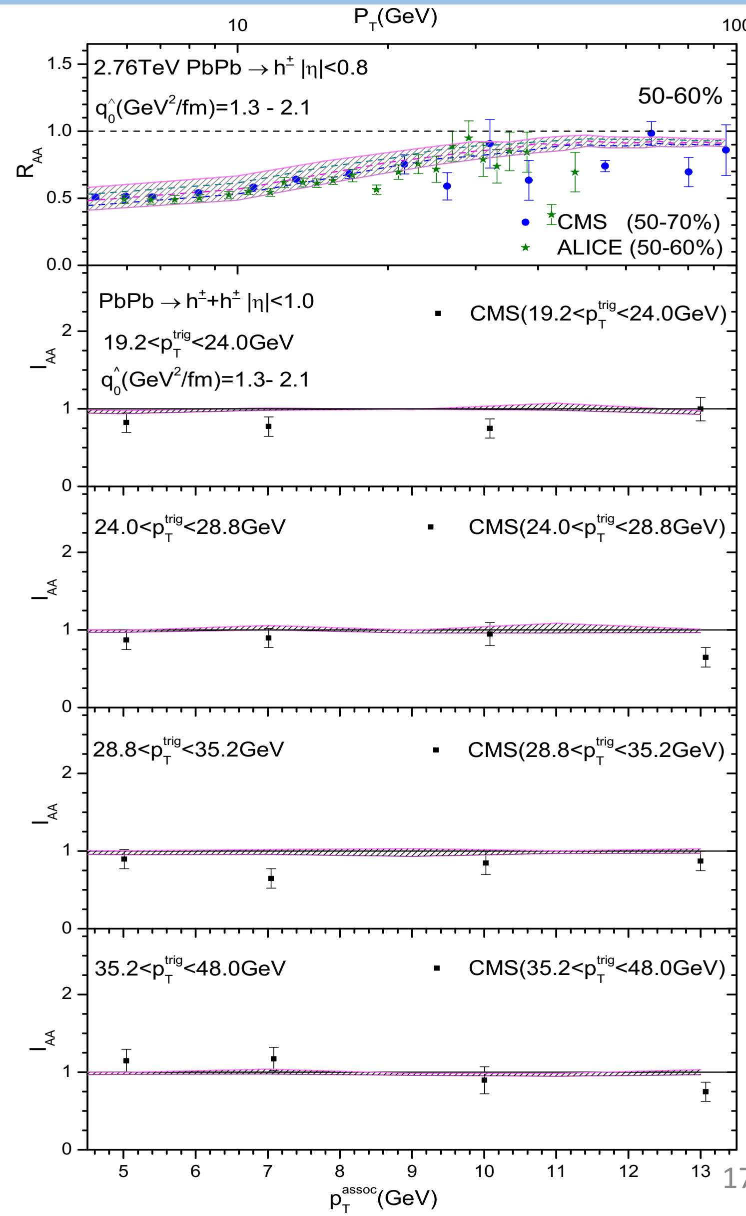
- $\mathrm{R_{AA}}$ and $\mathrm{I_{AA}}$ in the 50 - 60 % centrality with the $\hat{q}_0$ values extracted from central Pb+Pb collisions as compared to experimental data.



Extracting $\hat{q}_0$ in non-central collisions at $\sqrt{s_{NN}}$=2.76 TeV

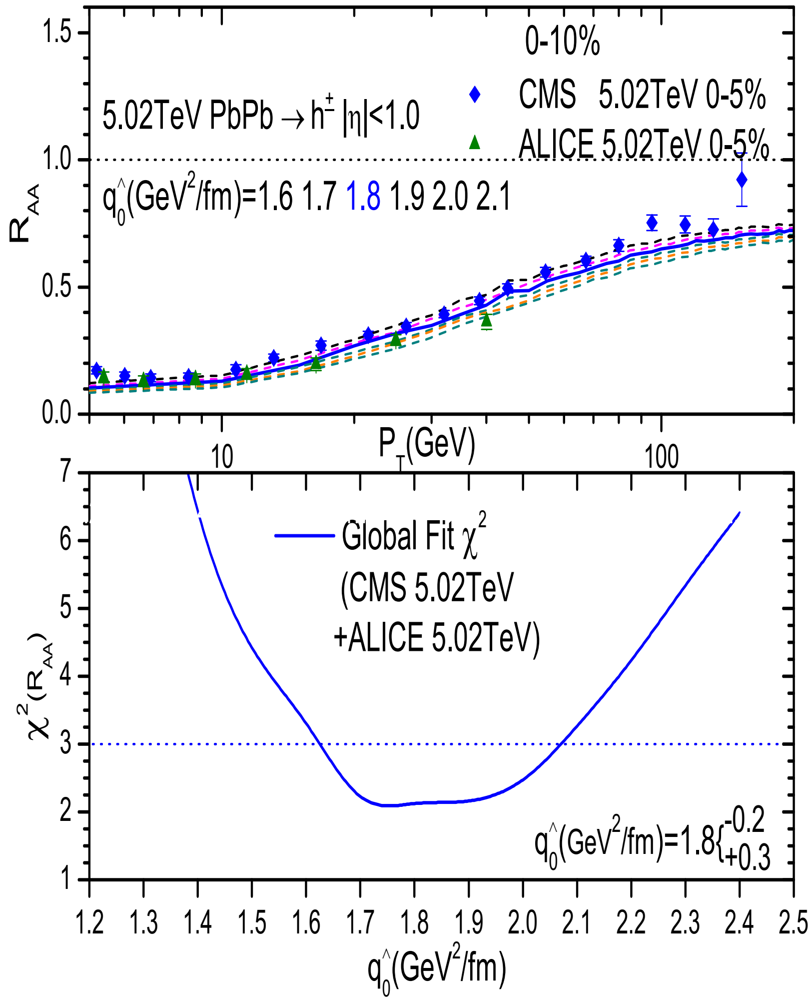
- $\mathrm{R_{AA}}$ and $\mathrm{I_{AA}}$ in the 50 - 60 % centrality with the $\hat{q}_0$ values extracted from central Pb+Pb collisions as compared to experimental data.

> ➢ $\hat{q}_0$ extracted from di-hadron suppression is consistent with single hadron.
>
> ➢ The single hadron $\mathrm{R_{AA}}$ and dihadron $\mathrm{I_{AA}}$ with the $\hat{q}_0$ extracted from central A+A collisions can give a good description of experimental data for the non-central collisions.



Extracting $\hat{q}_0$ via single hadron R_{AA} at $\sqrt{s_{NN}}$=5.02 TeV

- Extracting parameters $\hat{q}_0$ via single hadron suppression in central Pb+Pb collisions at $\sqrt{s_{NN}}$=5.02 TeV.

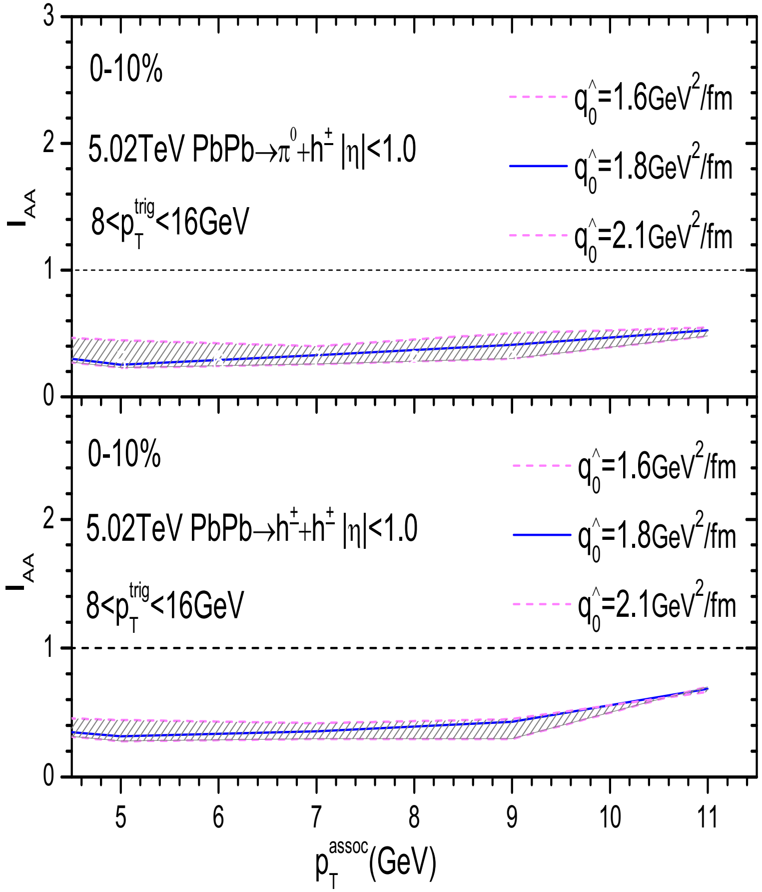


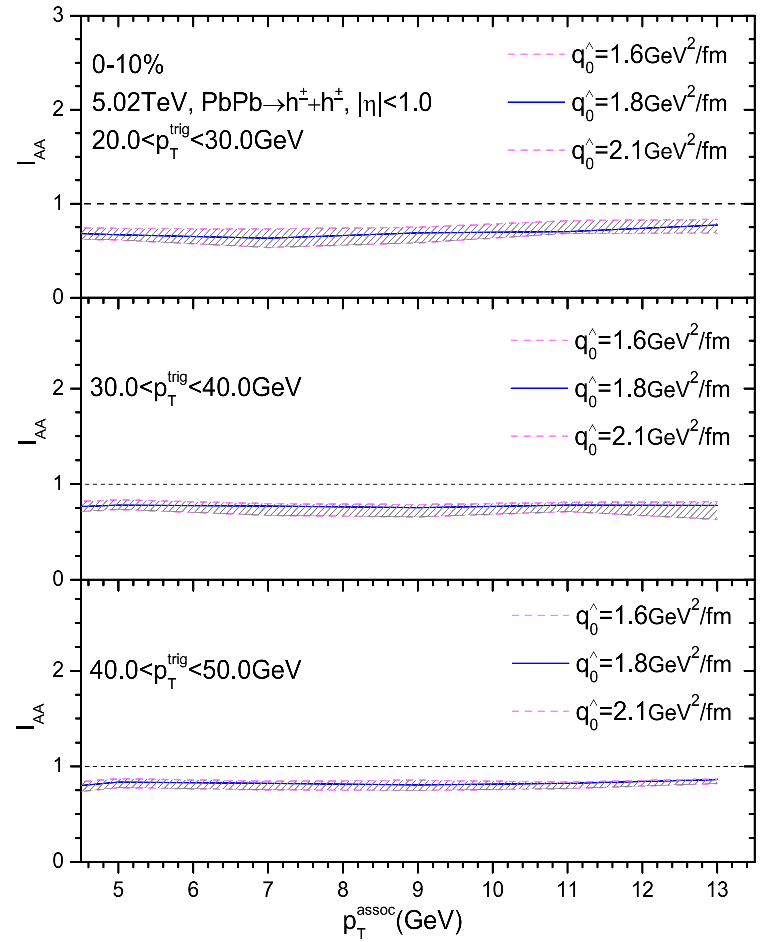
$\hat{q}_0=1.8\{^{-0.2}_{+0.3}(GeV^2/fm)$

[Data from [CMS collaboration], JHEP 1704 039 (2017), [ALICE collaboration], CERN EP 025 (2018), [arXiv:1802.09145v1[nucl-ex]](2018)]

Prediction $\mathrm{I_{AA}}$ for central collisions at $\sqrt{s_{NN}}$=5.02 TeV

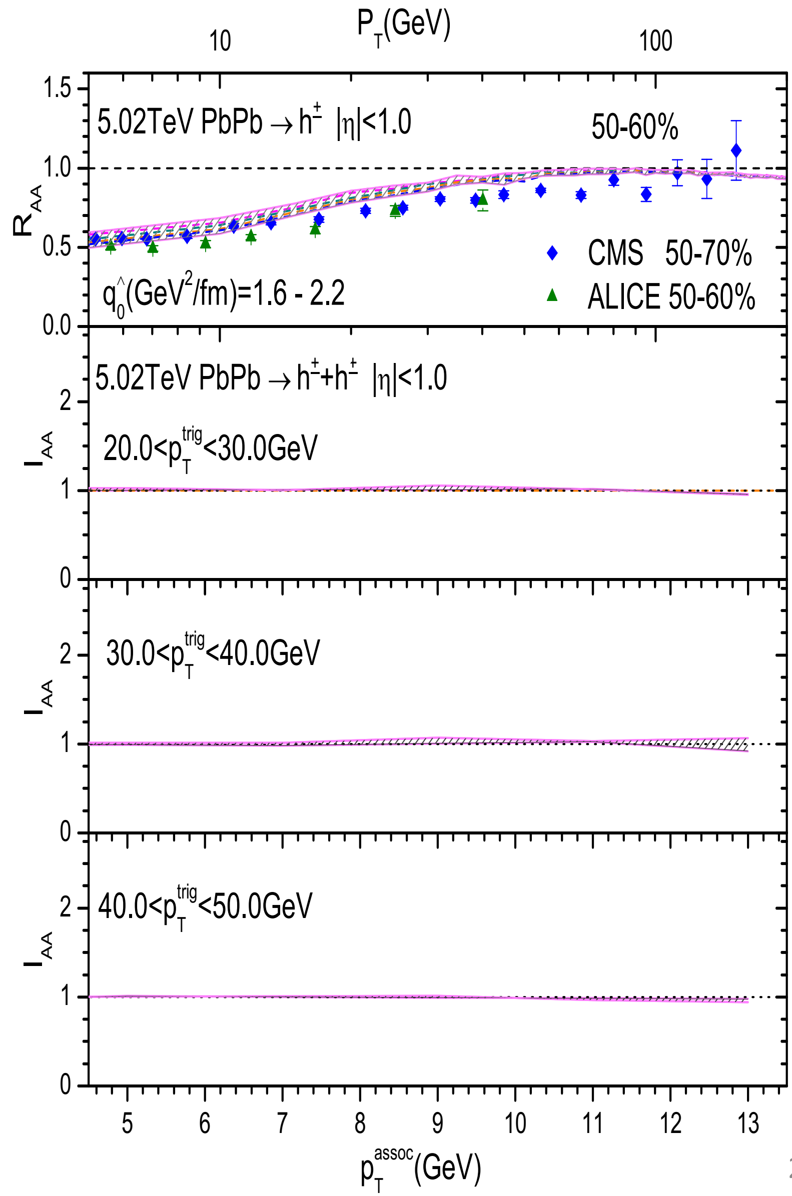
- The prediction of dihadron $\mathrm{I_{AA}}$ for central Pb+Pb collisions at $\sqrt{s_{NN}}$=5.02 TeV with the $\hat{q}_0$ values extracted from central Pb+Pb collisions.





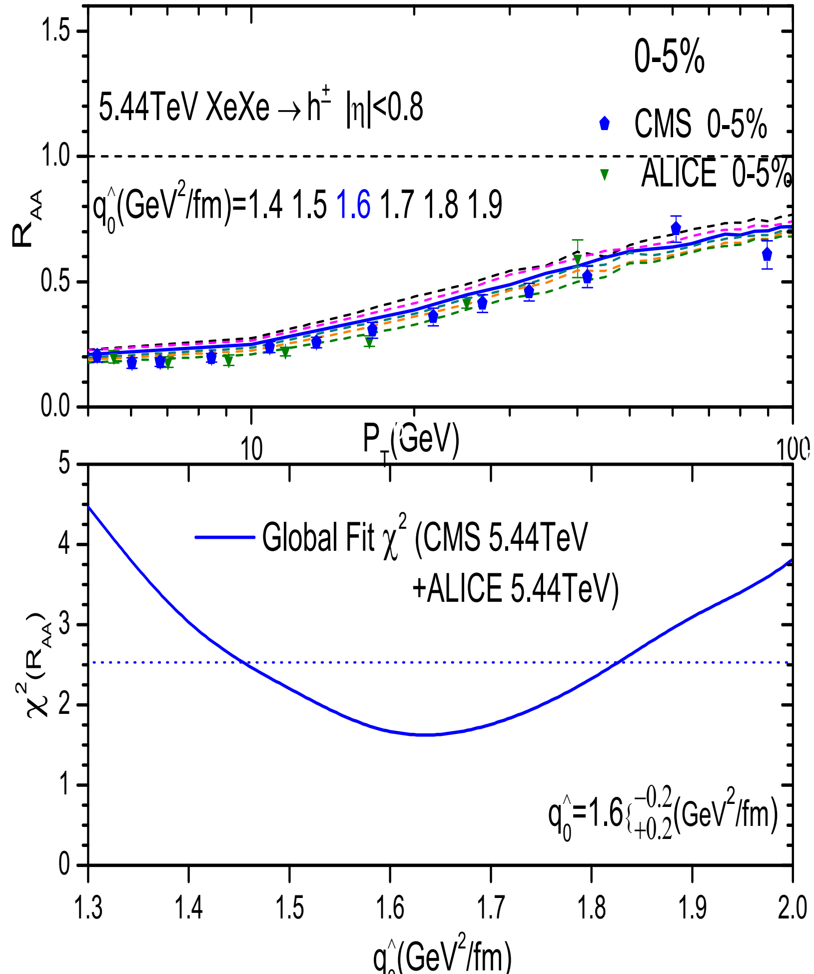
Prediction I_{AA} for non-central collisions at $\sqrt{s_{NN}}$=5.02 TeV

- The prediction of dihadron I_{AA} for Pb+Pb collisions in 50-60% centrality at $\sqrt{s_{NN}}$=5.02 TeV with the $\hat{q}_0$ values extracted from central Pb+Pb collisions.



Extracting $\hat{q}_0$ via single hadron $\mathrm{R_{AA}}$ at $\sqrt{s_{NN}}$=5.44 TeV

- Extracting parameters $\hat{q}_0$ via single hadron suppression in central Xe+Xe collisions at $\sqrt{s_{NN}}$=5.44 TeV.

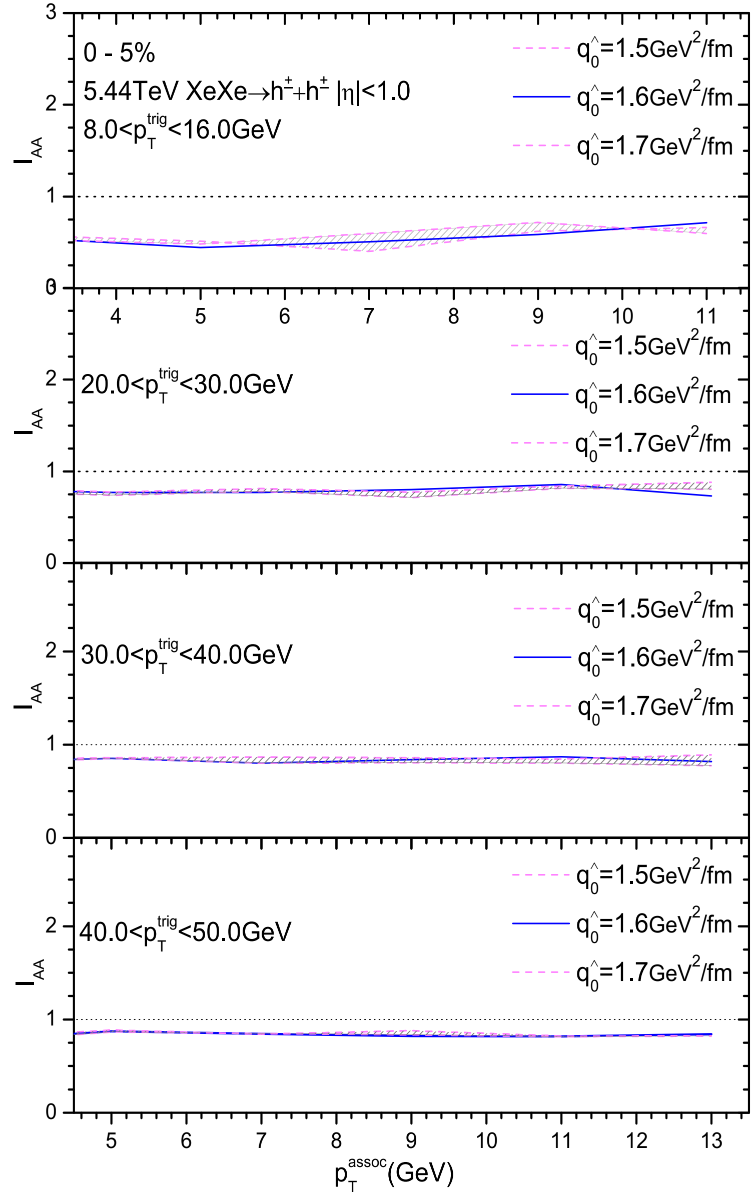


$\hat{q}_0$=1.6$\{^{-0.2}_{+0.2}(GeV^2/fm)$

[Data from [ALICE collaboration], CERN EP 112 (2018), [arXiv:1805.04399v1[nucl-ex]](2018)]

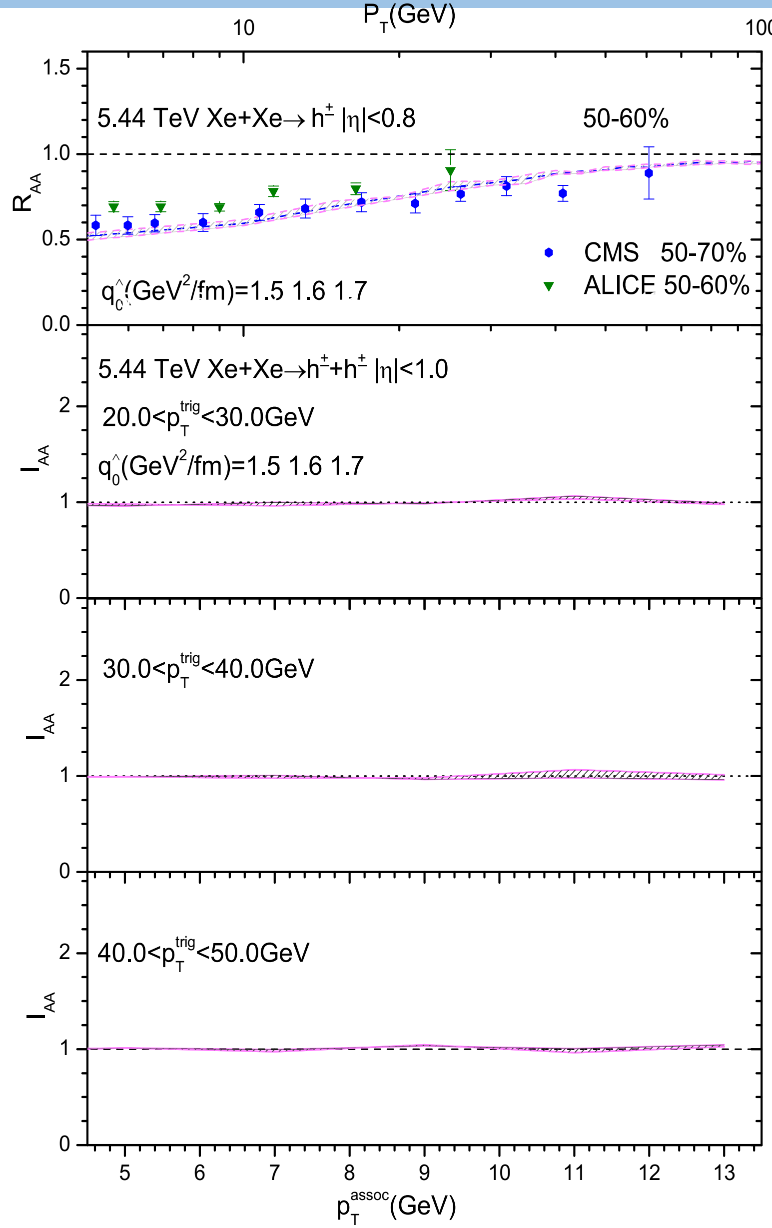
Prediction $\mathrm{I_{AA}}$ for central Xe+Xe collisions at $\sqrt{s_{NN}}$=5.44 TeV

- The prediction of dihadron $\mathrm{I_{AA}}$ for central Xe+Xe collisions at $\sqrt{s_{NN}}$=5.44 TeV with the $\hat{q}_0$ values extracted from central Xe+Xe collisions.



Prediction $\mathrm{I_{AA}}$ for non-central Xe+Xe collisions

- The prediction of dihadron $\mathrm{I_{AA}}$ for Xe+Xe collisions in 50 60% centrality at $\sqrt{s_{NN}}$=5.44 TeV with the $\hat{q}_0$ values extracted from central Xe+Xe collisions.



Summary and Outlook

- Large p_T hadrons are studied in a NLO pQCD parton model in heavy-ion collisions with mFFs due to jet quenching.
- We obtain $\hat{q}_0 \approx 1.1\{^{-0.2}_{+0.4}\ GeV^2/fm$ for central Au+Au collisions at 200GeV, and $\hat{q}_0 \approx 1.7\{^{-0.4}_{+0.4}\ GeV^2/fm$ for central Pb+Pb collisions at 2.76 TeV.
- We predicted the dihadron suppression factors for central and non-central Pb+Pb collisions at 5.02TeV with the $\hat{q}_0$ extracted via single hadron suppression.
- We also used the latest data of Xe+Xe collisions to extract $\hat{q}_0$, and predicted dihadron suppression factors for central and non-central Xe+Xe collisions.
- In the future, to study jet quenching we want to do jet-hadron photon-hadron correlations to extract $\hat{q}_0$.

THANK YOU!