High-p_T asymmetries as a probe of initial stages in heavy-ion collisions

Carlota Andrés

Jefferson Lab

High-p_T Workshop

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arXiv:1902.03231

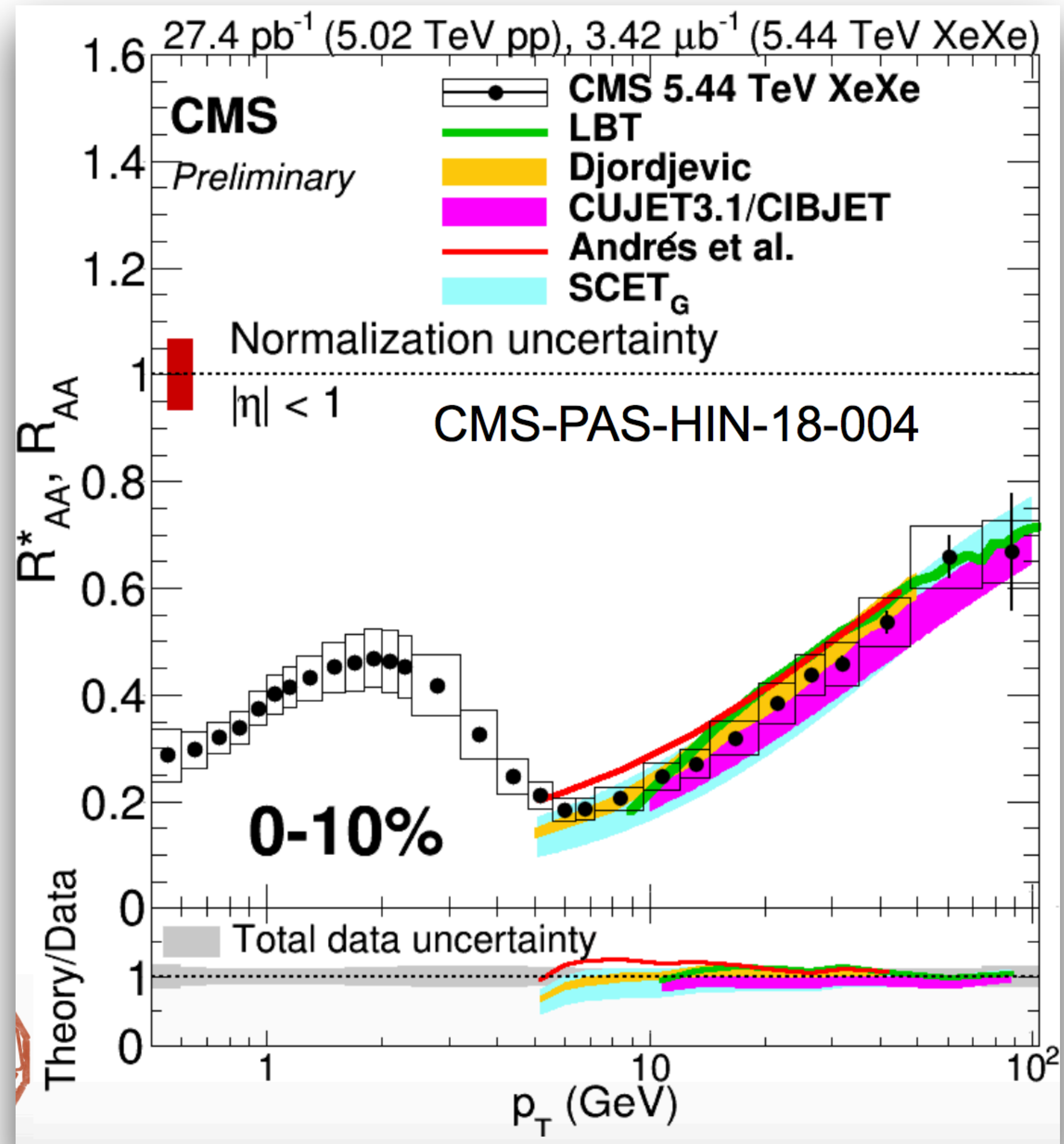
Jefferson Lab EXPLORING THE NATURE OF MATTER

In collaboration with:

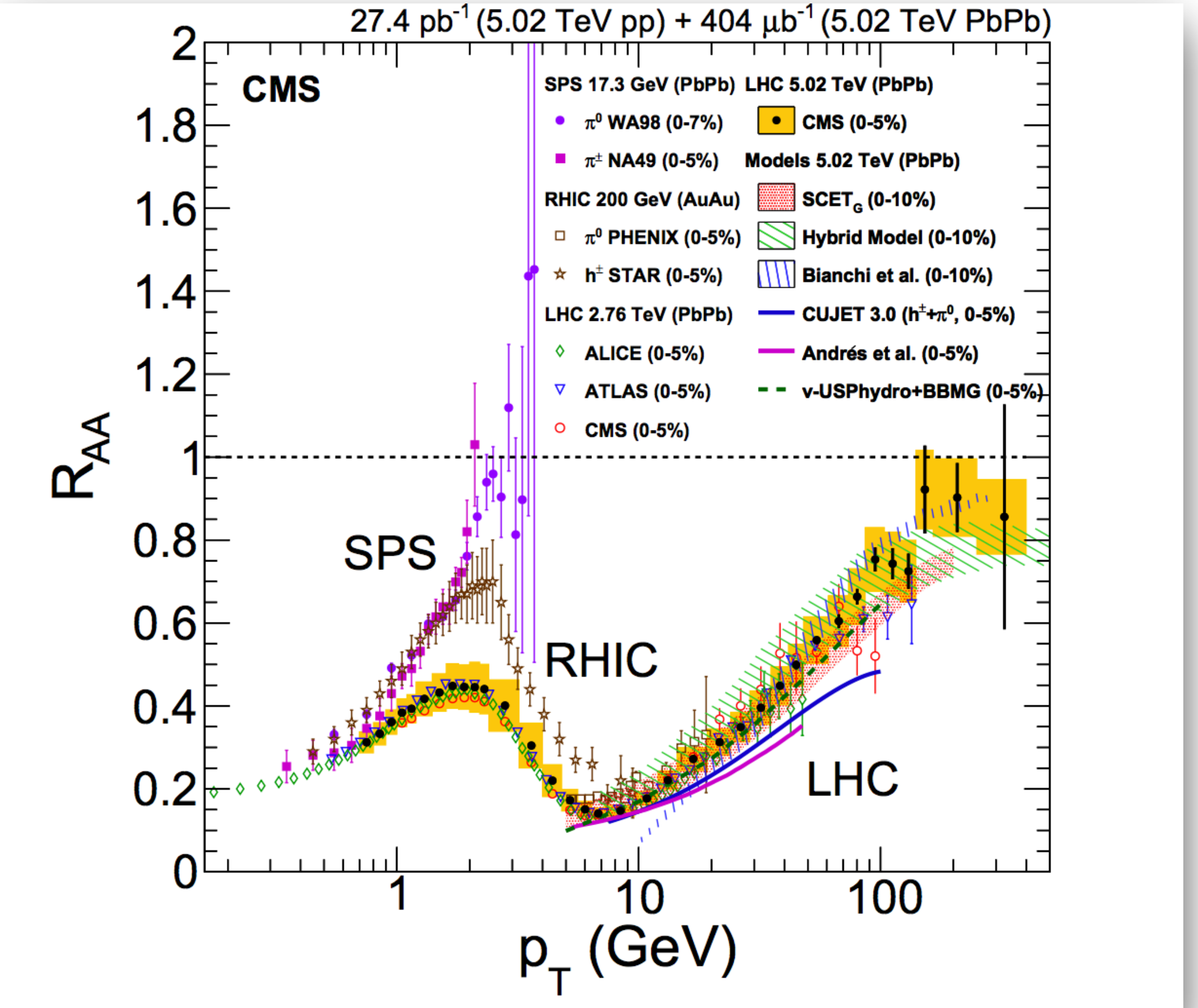
N. Armesto, H. Niemi, R.Paatelainen, Carlos Salgado

Motivation

R_{AA}

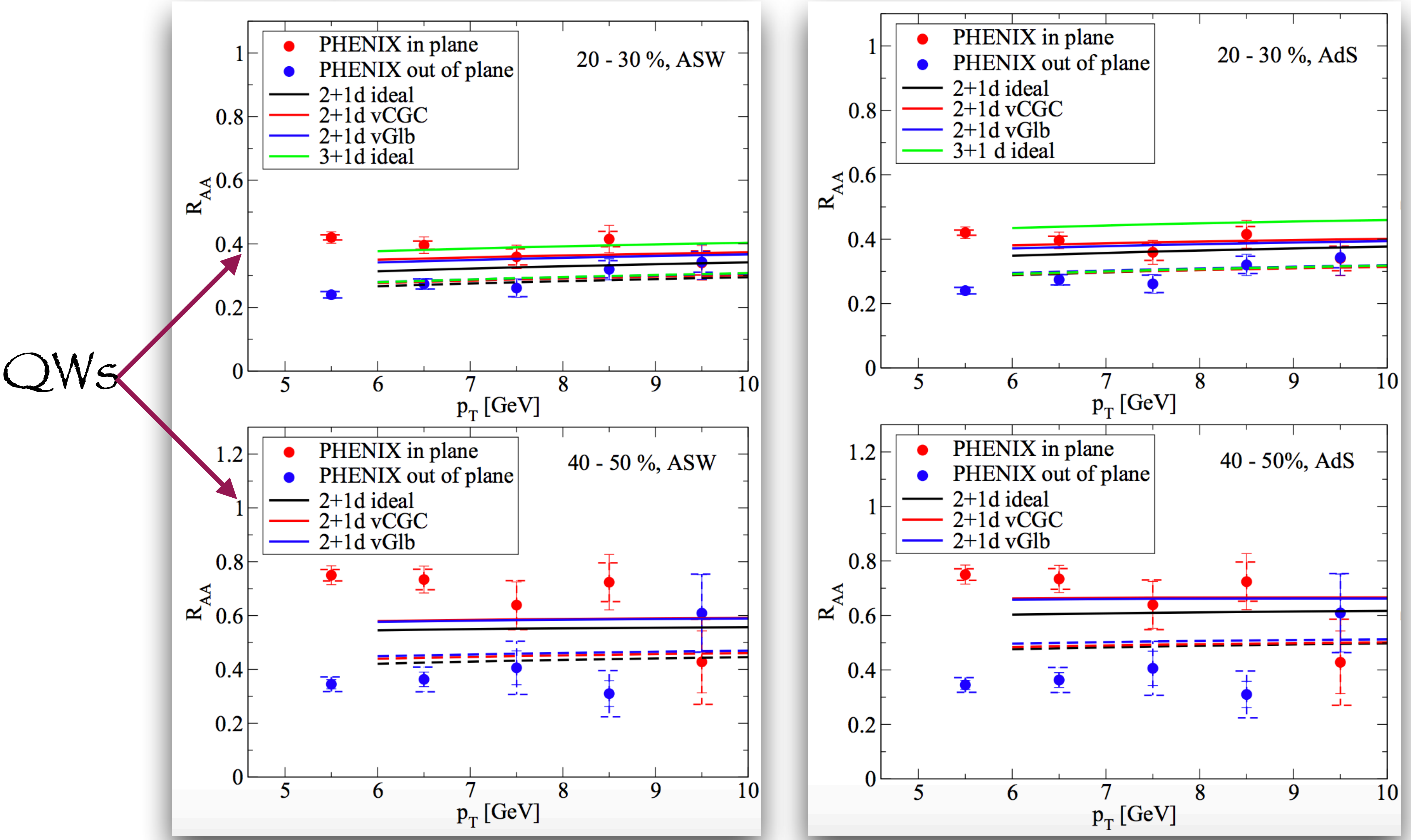


Austin Baty, QM2018



CMS Collaboration, JHEP 04 039 (2017)

High-p_T v_2

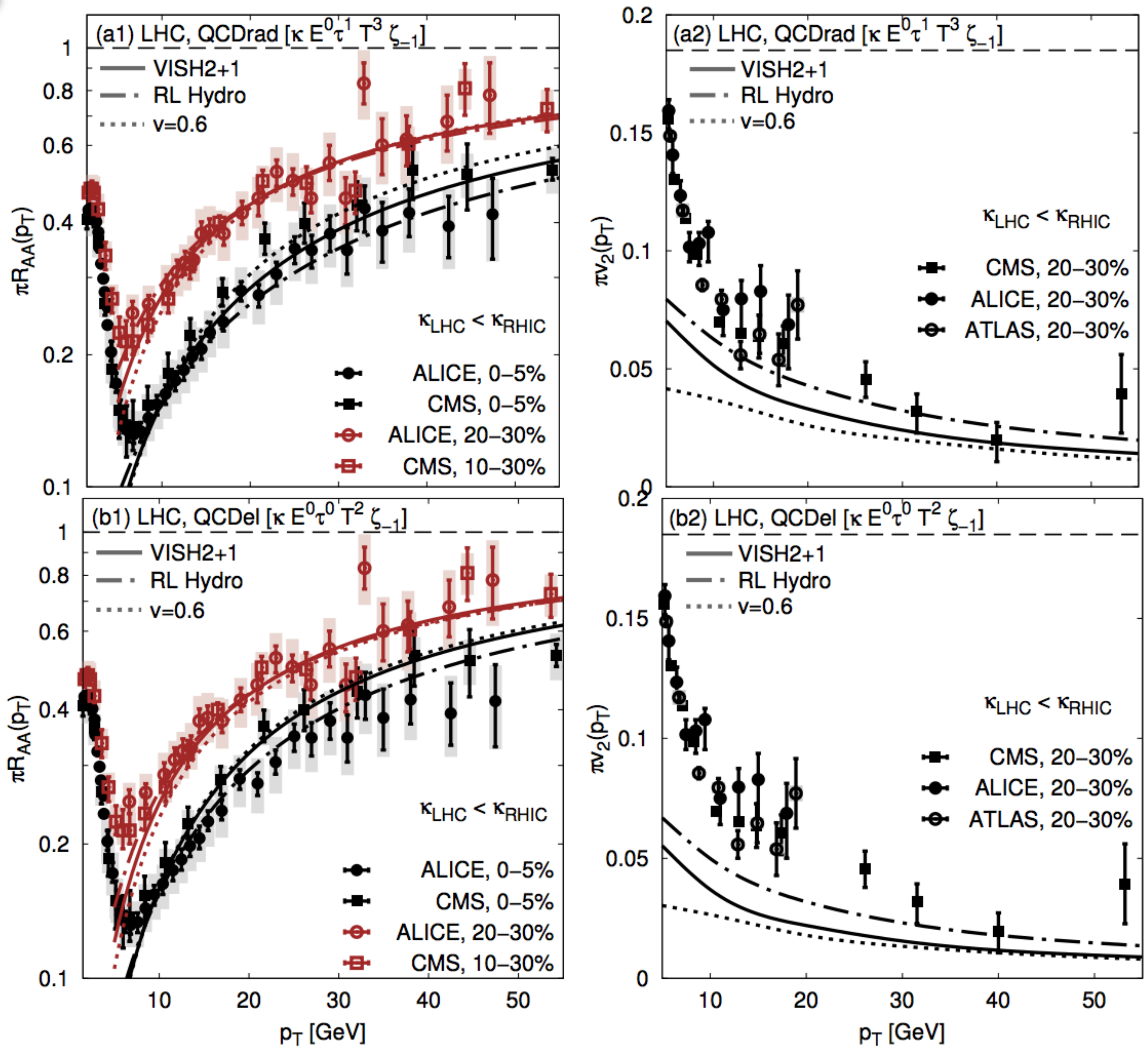


T. Renk et al. Phys. Rev. C 83 (2011) 014910

High-p_T v_2

$$\frac{dE}{dL} \sim LT^3$$

$$\frac{dE}{dL} \sim T^2$$



B. Betz and M. Gyulassy, JHEP 08, 090 (2014)

The scalar product

Average over all the events

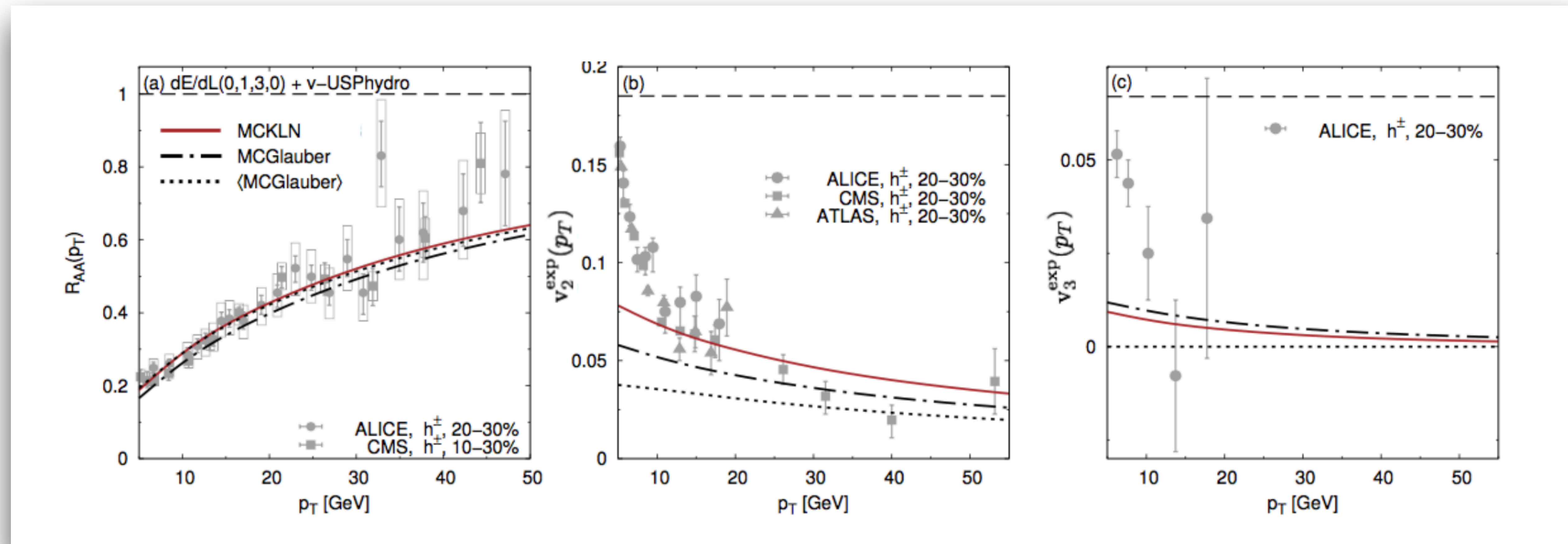
$$\frac{R_{AA}(p_T,\phi)}{R_{AA}(p_T)} = 1 + 2\sum_{n=1}^{\infty} v_n^{hard}(p_T)\cos\left[n\phi - n\psi_n^{hard}(p_T)\right]$$

$$v_n^{exp}(p_T) = \frac{\left\langle v_n^{soft}\, v_n^{hard}(p_T)\cos\left[n\left(\psi_n^{soft} - \psi_n^{hard}(p_T)\right)\right]\right\rangle}{\sqrt{\left\langle\left(v_n^{soft}\right)^2\right\rangle}}$$

PbPb 2.76 TeV

Matthew Luzum and Jean-Yves Ollitrault, Phys. Rev. C87 (2013) 044907

J. Noronha-Hostler et al. Phys. Rev. Lett. 116, 252301 (2016)



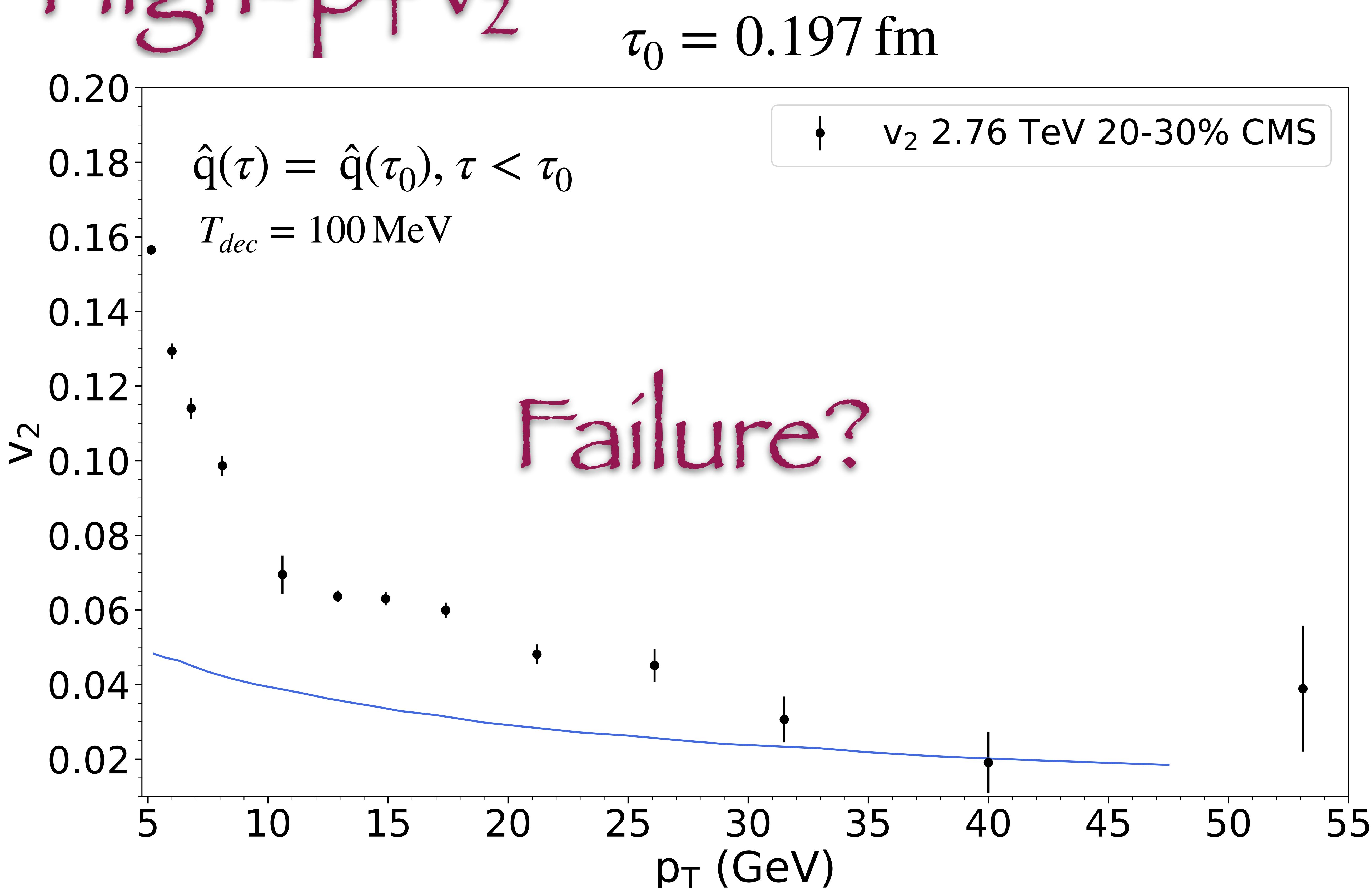
Energy loss $\frac{dE}{dL} \sim LT^3$

Hydro: v-USPhydro

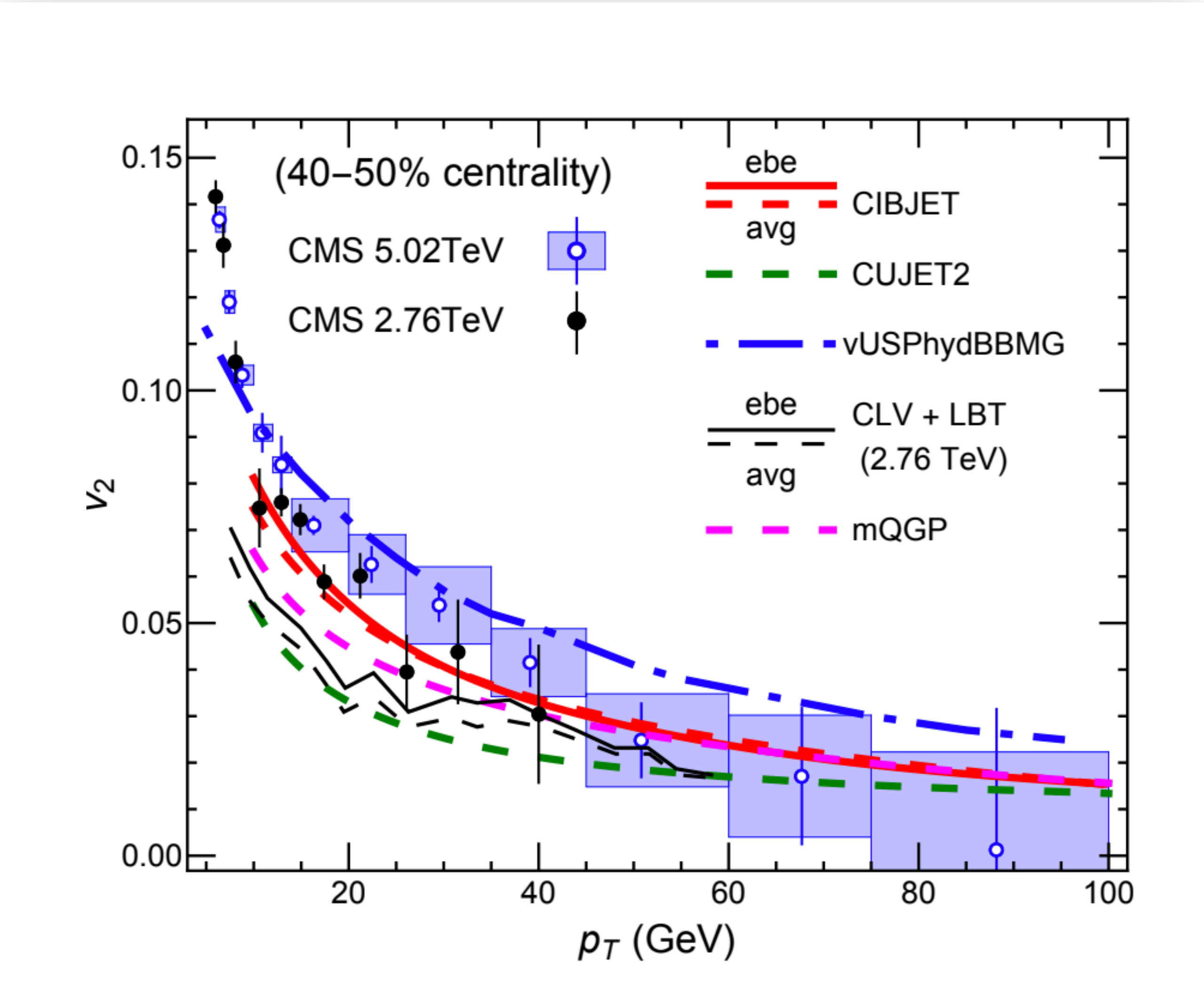
$\tau_0 = 0.6\ \mathrm{fm}$

High-p_T v_2

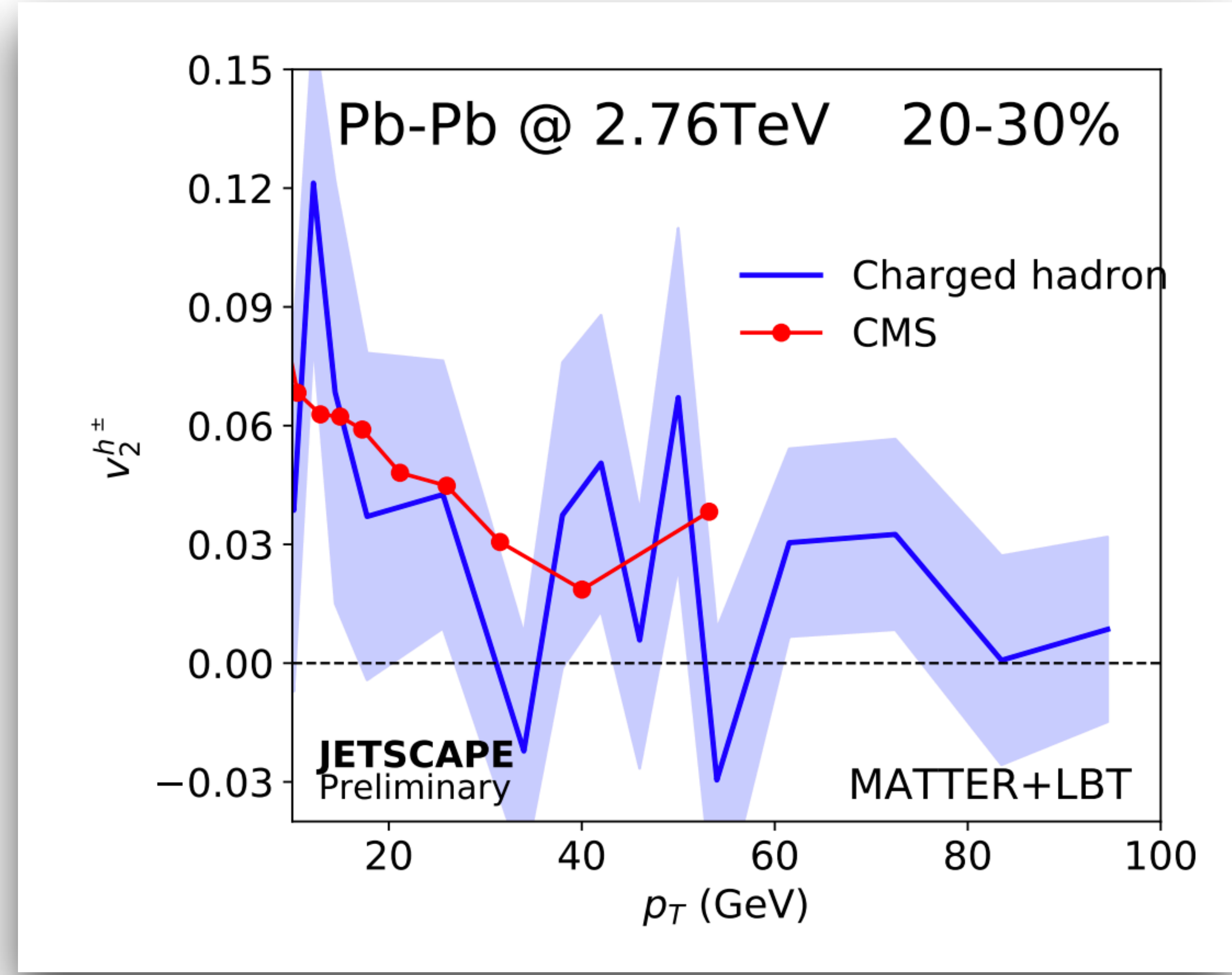
EKRT + QWs



High p_T-v_2



CIBJET
Chin. Phys. C42 (2018) 10 104104
VISHNU viscous hydrodynamics



JETSCAPE
arXiv: 1902.05934

Formalism

Formalism

- Single-inclusive cross section:

$$\frac{d\sigma^{AA\to h+X}}{dp_T dy} = \int \frac{dx_1}{x_1}\frac{dx_2}{x_2}\frac{dz}{z}\sum_{i,j,k} x_1 f_{i/A}(x_1,Q^2) x_2 f_{j/A}(x_2,Q^2)\frac{d\hat{\sigma}^{ij\to k}}{d\hat{t}} D_{k\to h}(z,\mu_F^2)$$

CTEQ6.6 + EPS09

- Fragmentation functions:

$$D_{k\to h}^{(med)}(z,\mu_F^2) = \int_0^1 d\epsilon P_E(\epsilon)\frac{1}{1-\epsilon} D_{k\to h}^{(vac)}\left(\frac{z}{1-\epsilon},\mu_F^2\right)$$

DSS

ENERGY LOSS: ASW Quenching Weights (QWs)

Probability distribution of a fractional energy loss, $\epsilon = \Delta E/E$, of the hard parton in the medium

Quenching Weights

- Computed in the Multiple Soft Scattering approximation

$$\sigma(\mathbf{r})n(\xi) \simeq \frac{1}{2}\hat{q}(\xi)\mathbf{r}^2$$

Perturbative tails neglected

- Relation between $\hat{q}$ and the hydrodynamic properties of the medium

$$\hat{q}(\xi) = K \cdot 2\epsilon^{3/4}(\xi)$$

K → Fitting parameter

$\epsilon^{3/4}(\xi)$ → EKRT hydro

EKRT hydrodynamics

- EKRT event by event hydrodynamics

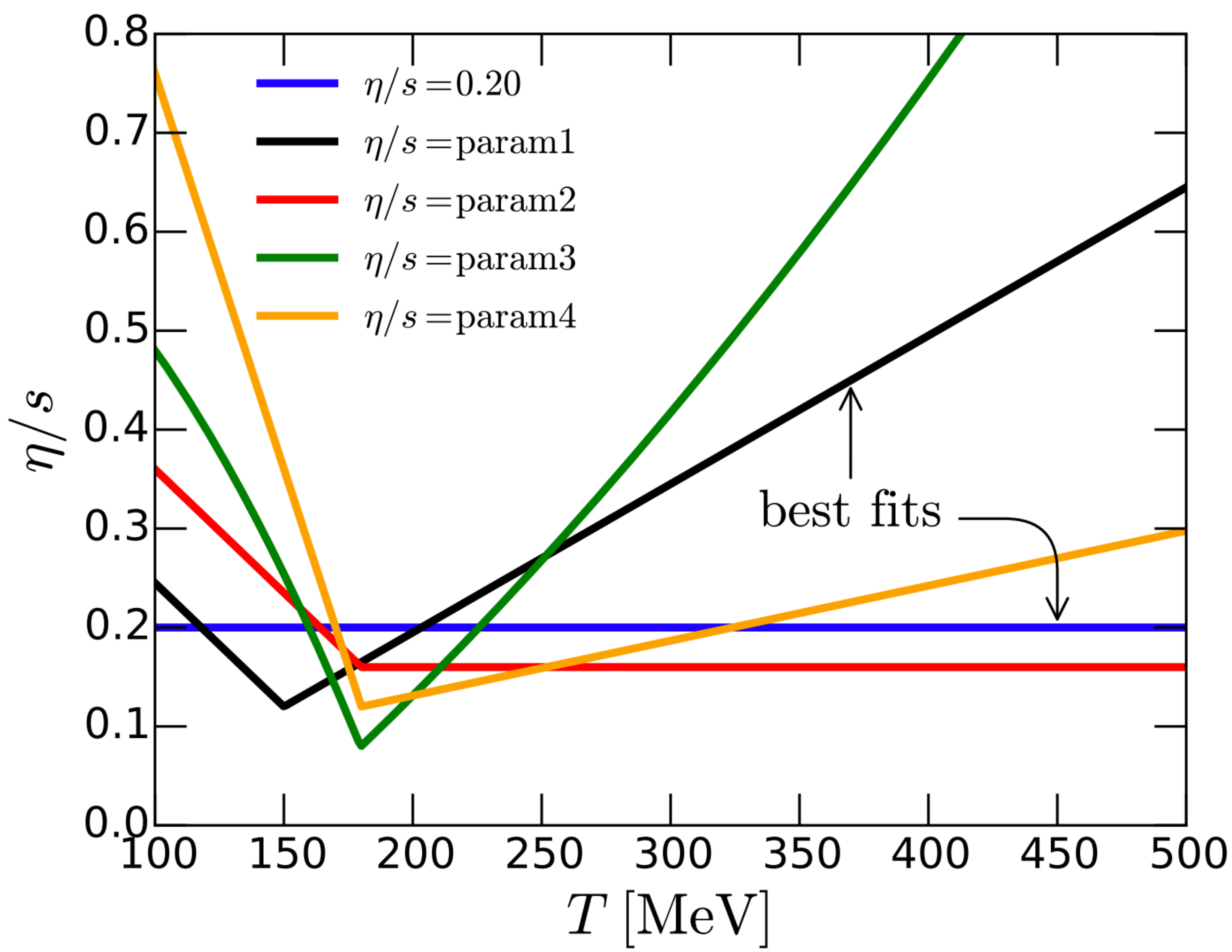
Initial conditions: minijets + saturation model

$\tau_f = 0.197$ fm

$\eta/s = param1$

$T_{ch} = 175$ MeV

$T_{dec} = 100$ MeV



Phys. Rev. C 93, 024907 (2016)

Open questions

- When do we STOP the energy loss?

$$T_q = T_{ch} = 175\,\text{MeV}$$

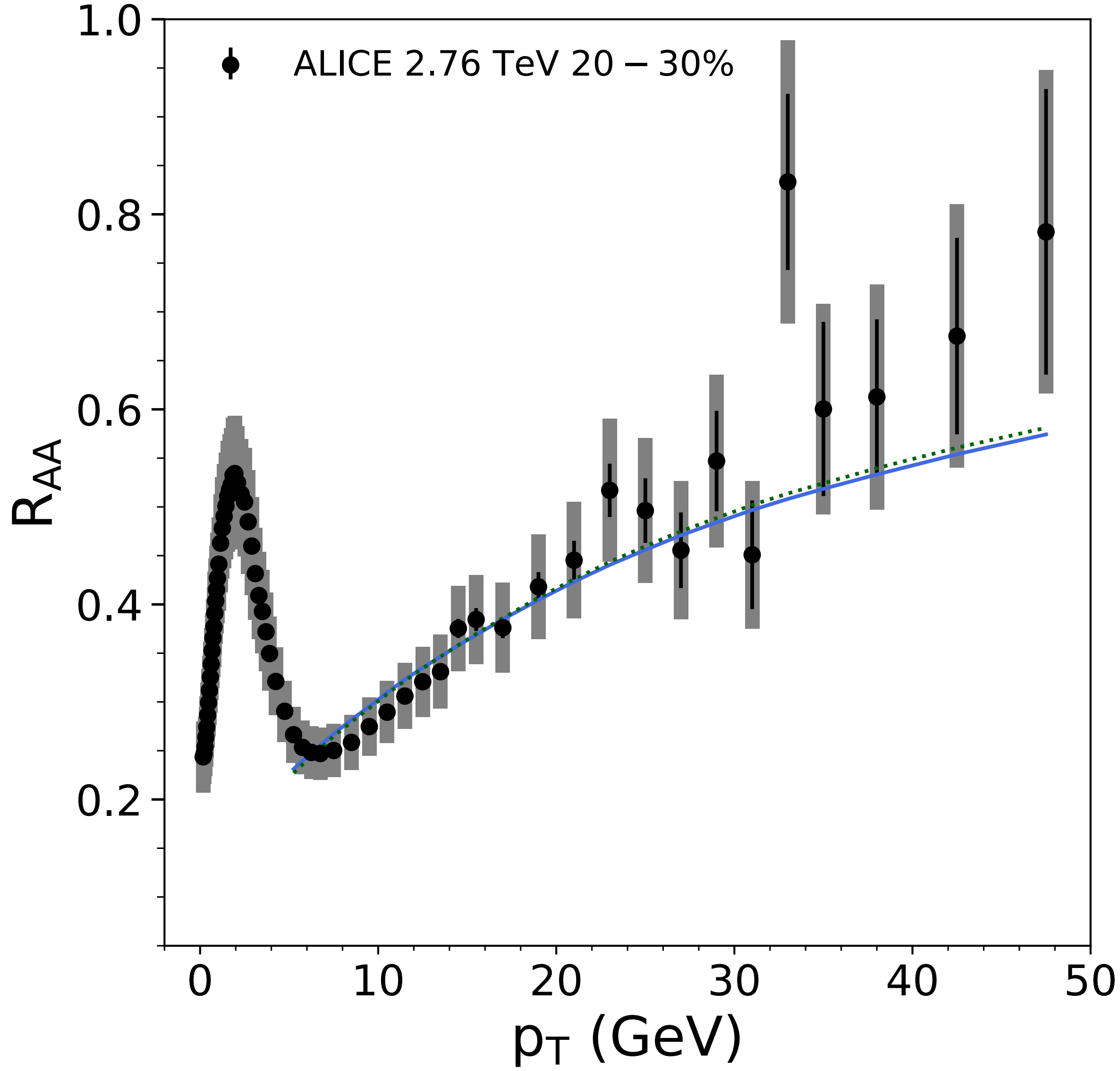
$$T_q = T_{kin} = 100\,\text{MeV}$$

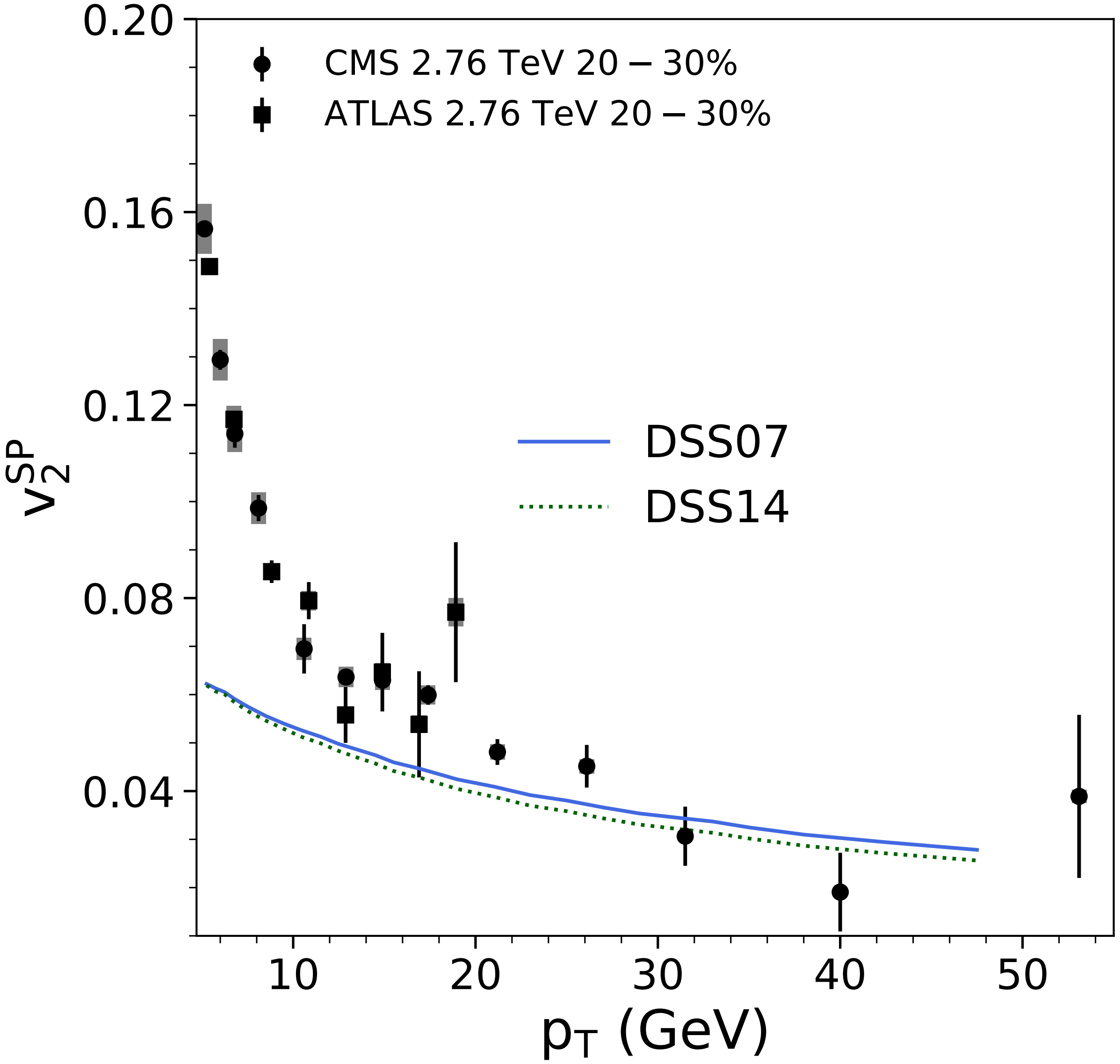
- When do we START the energy loss?
    - Case i) $\tau_q = 0 \qquad \left(\hat{q}(\xi) = \hat{q}(\tau_f) \quad \text{for} \quad \xi < \tau_f = 0.197\,\text{fm}\right)$
    - Case ii) $\tau_q = 0.197\,\text{fm}$
    - Case iii) $\tau_q = 0.572\,\text{fm}$ → Energy loss delayed ~0.6 fm

Dependence on FFs

High-p_T v_2 underestimated

High-p_T v_2 almost insensitive to the FFs



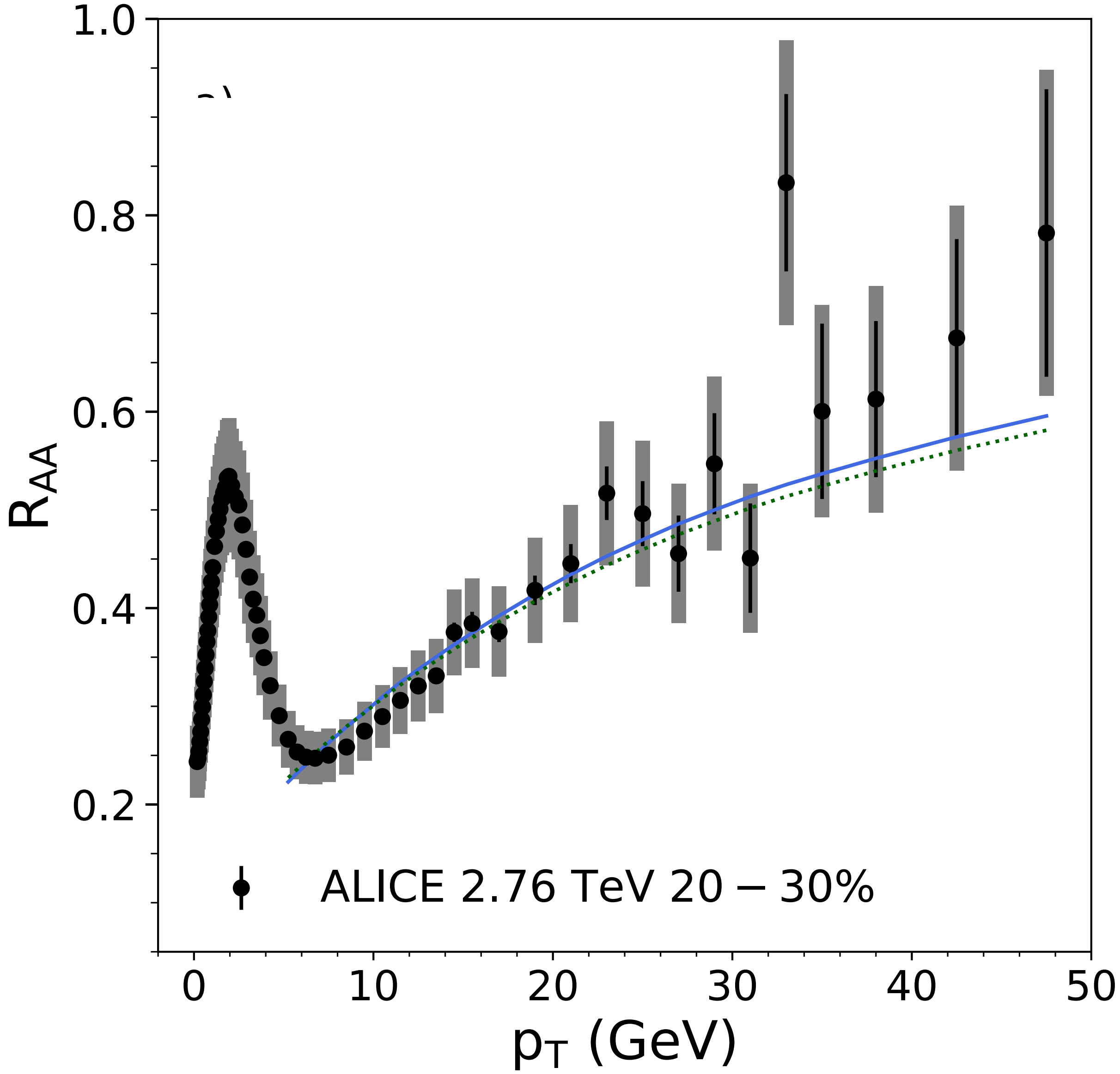


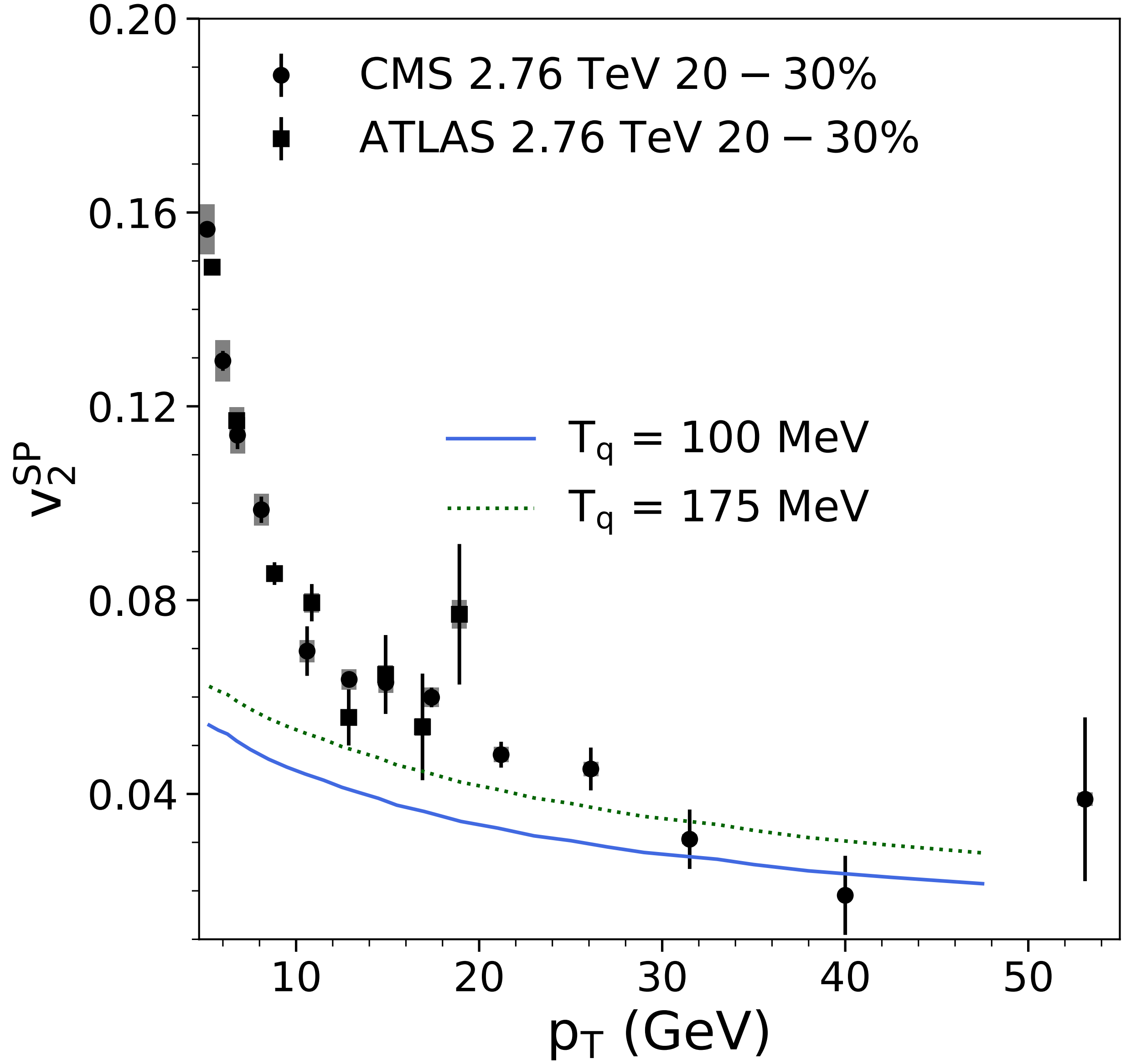
$$T_q = T_{ch} = 175\,\text{MeV}$$

Case ii) $\tau_q = 0.197\,\text{fm}$

Dependence on T_q

High-pT v_2 still not well described. Better with NO energy loss in the hadronic phase



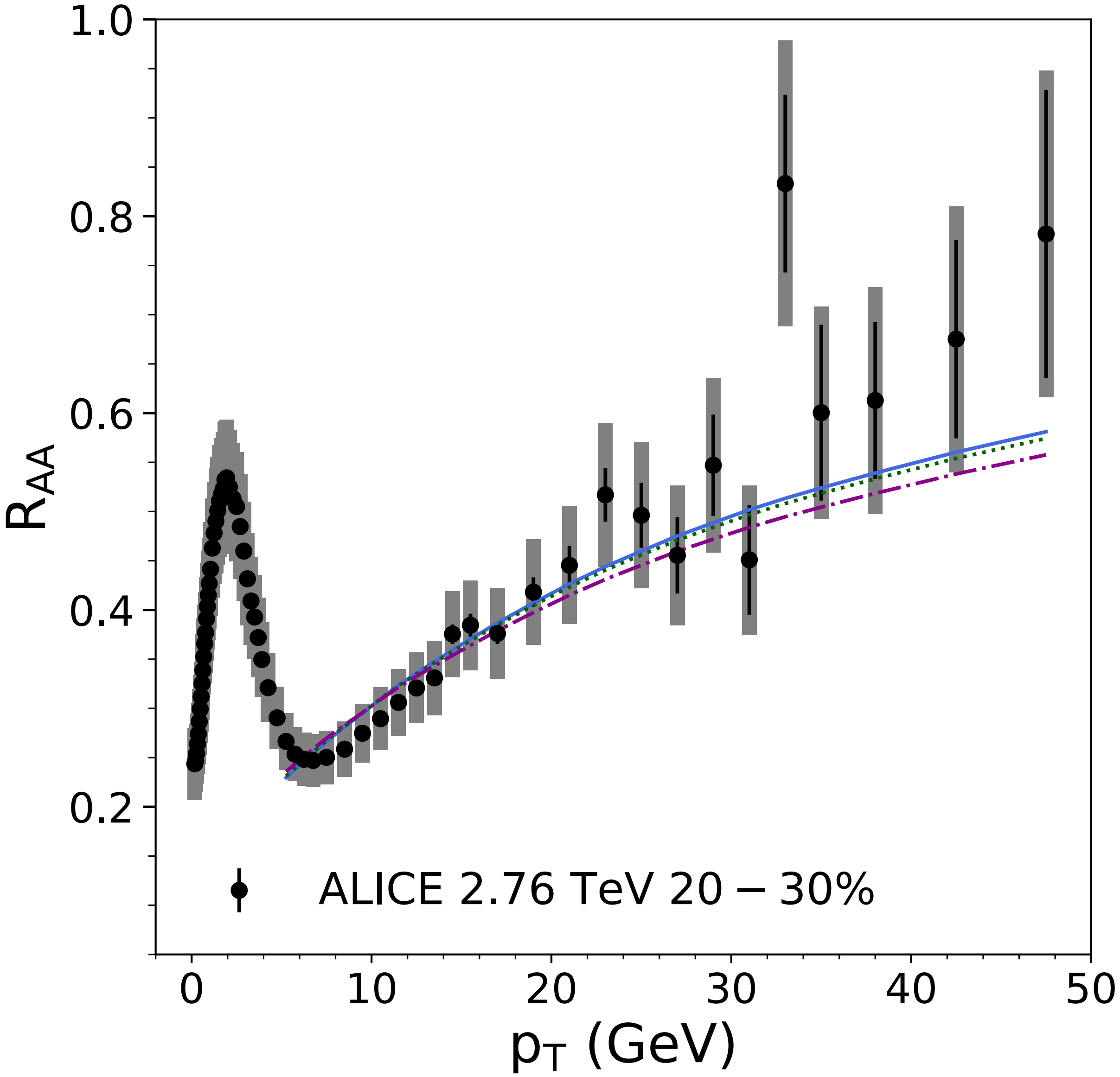


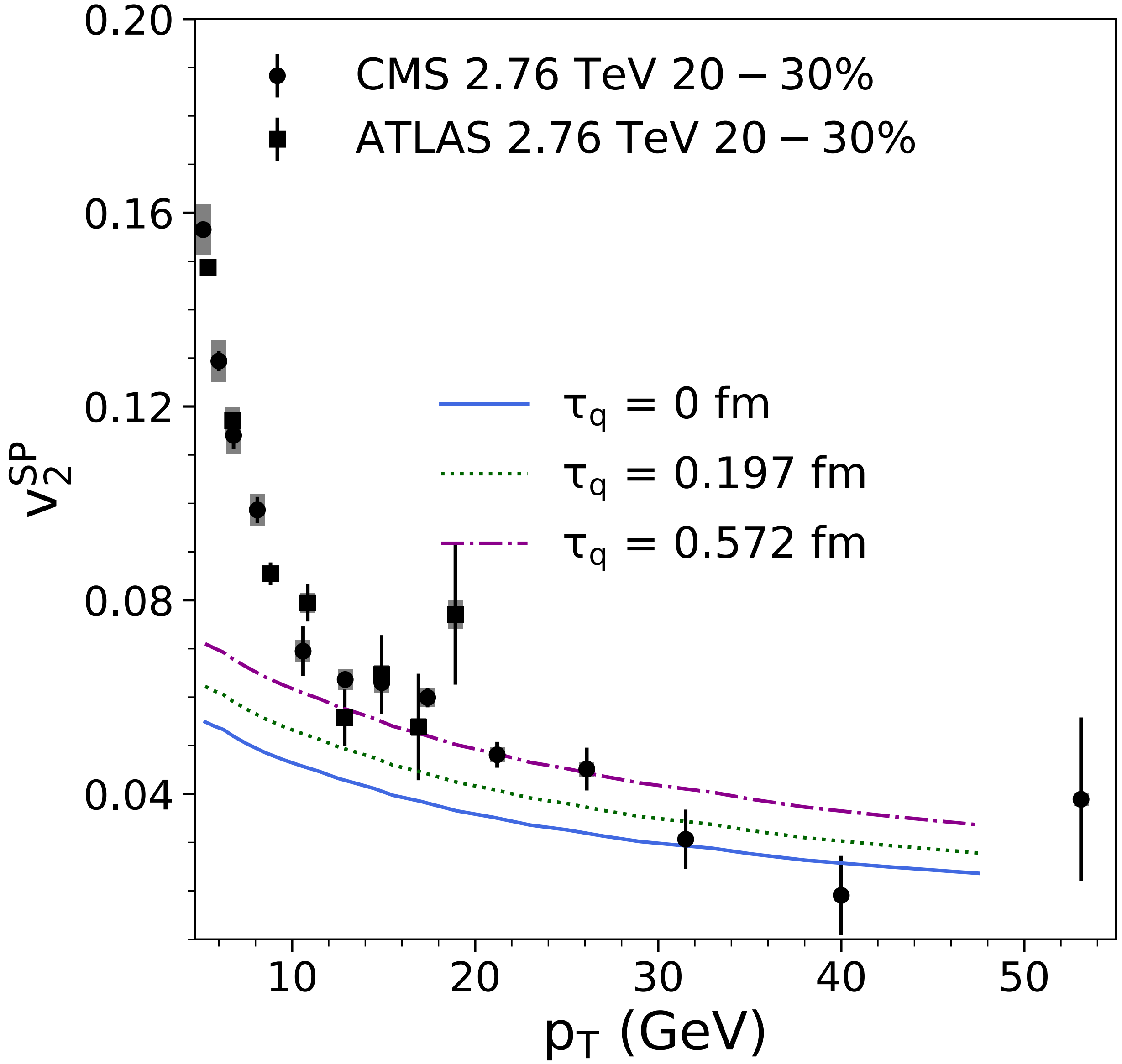
DSS07

Case ii) $\tau_q = 0.197$ fm

Dependence on τ_q

High-p_T harmonics are very sensitive to initial stages!





DSS07

$$T_q = T_{ch} = 175\,\text{MeV}$$

Conclusions

- The high-p_T v_2 puzzle is not as simple as one could think
- We have analyzed the sensitivity of the high-p_T v_2 to:
  - FFs
  - T_{dec}
  - τ_q
- The high-p_T azimuthal asymmetries are very sensitive to the early times
- The high-p_T v_2 data indicate the need of switching off the energy loss for the first ~0.6 fm

We can fit the high-p_T harmonics, but can we really understand why?

Backup slides

- Quenching Weights

$$P(\Delta E) = \sum_{n=0}^{\infty} \frac{1}{n!} \left[\prod_{i=1}^{n} \int d\omega_i \frac{dI^{(med)}(\omega_i)}{d\omega} \right] \delta\left(\Delta E - \sum_{i=1}^{n} \omega_i \right) \exp\left[- \int_0^{\infty} d\omega \frac{dI^{(med)}}{d\omega} \right]$$

$$\omega \frac{dI^{(med)}}{d\omega} = \frac{\alpha_s C_R}{(2\pi)^2 \omega^2} 2Re \int_{\xi_0}^{\infty} dy_l \int_{y_l}^{\infty} d\bar{y}_l \int d\mathbf{u} \int_0^{\chi\omega} d\mathbf{k}_\perp e^{-i\mathbf{k}_\perp \cdot \mathbf{u}} e^{-\frac{1}{2} \int_{\bar{y}_l}^{\infty} d\xi n(\xi)\sigma(\mathbf{u})} \frac{\partial}{\partial \mathbf{y}} \cdot \frac{\partial}{\partial \mathbf{u}}$$

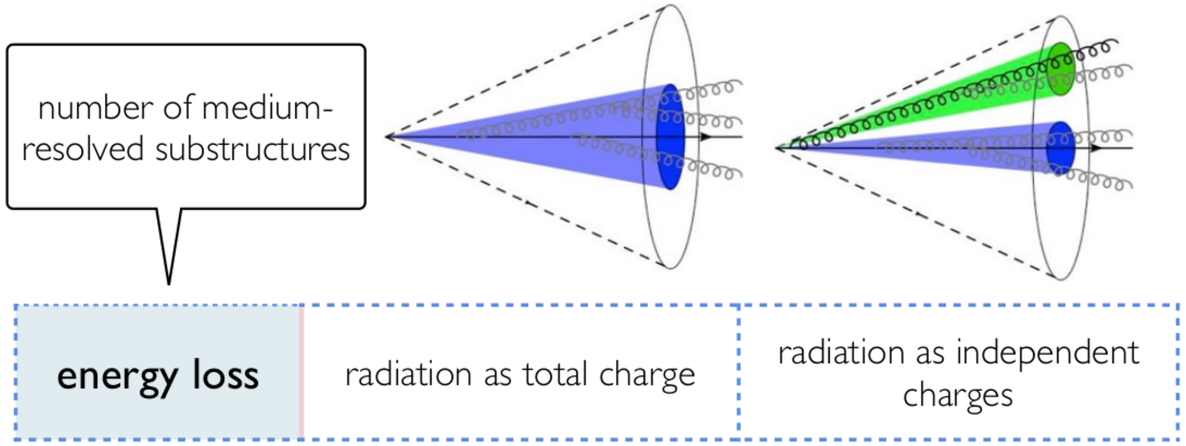
$$\times \int_{y=0}^{\mathbf{u}=\mathbf{r}(\bar{y}_l)} \mathcal{D}\mathbf{r} \exp\left[i \int_{y_l}^{\bar{y}_l} d\xi \frac{\omega}{2} \left(\dot{\mathbf{r}}^2 - \frac{n(\xi)\sigma(\mathbf{r})}{i\omega} \right) \right]$$

Quenching Weights

- Based on two assumptions:
  - Fragmentation functions are NOT medium-modified

    Total coherence case:

    - Jets lose energy as a single parton
    - FFs vacuum-like



KT, HP 2016

Casalderrey-Solana, Mehtar-Tani, Salgado, Tywoniuk, PLB 725 357 (2013)

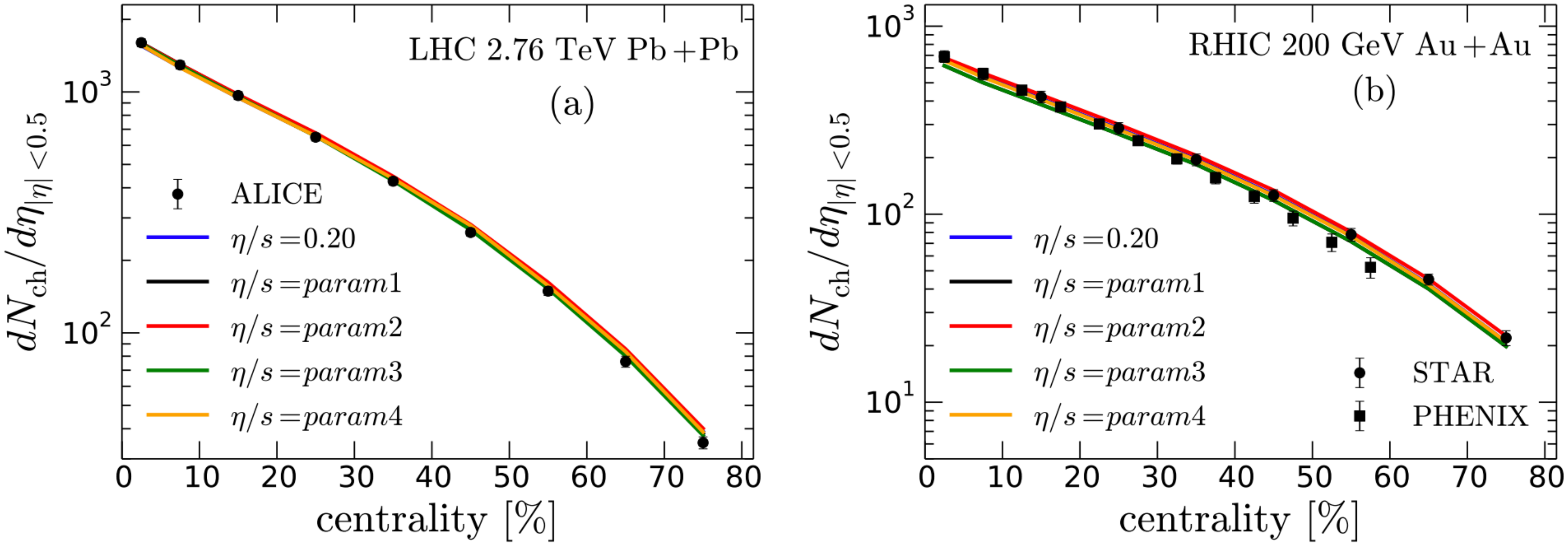
  - Gluon emissions are independent

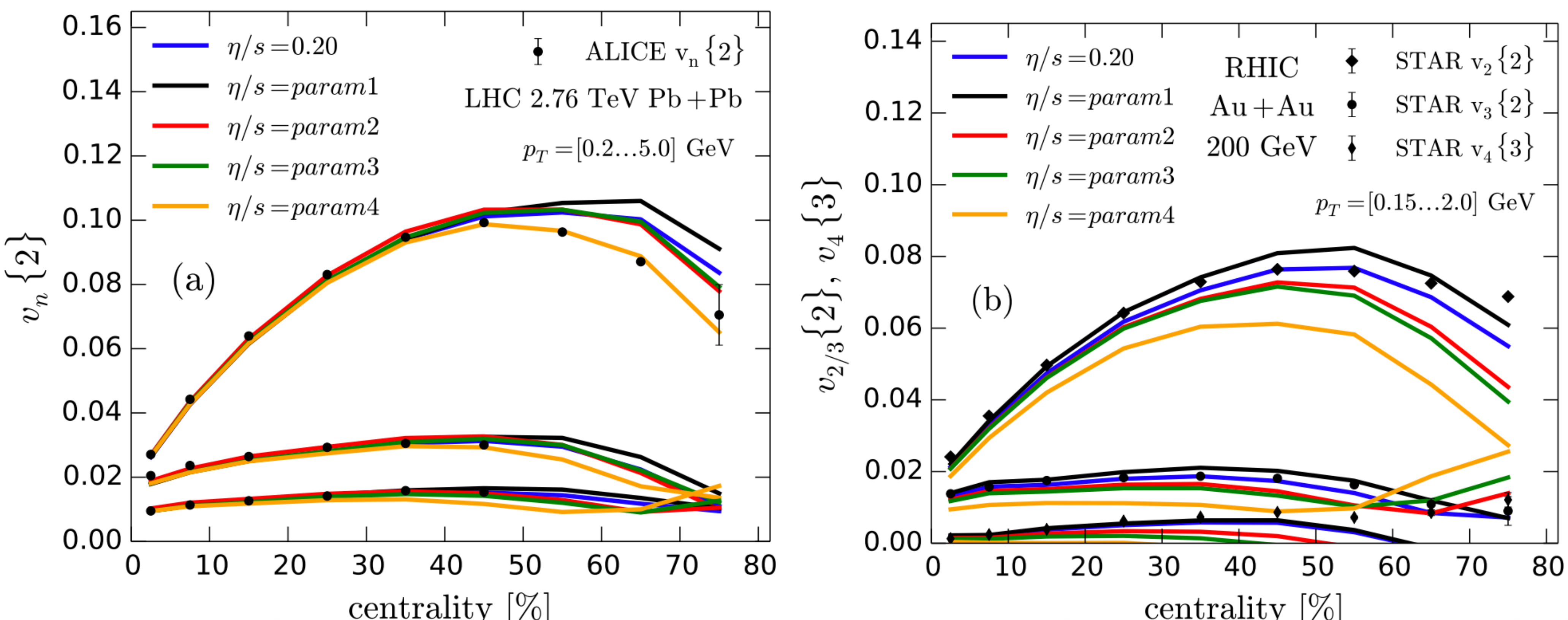
    Good approximation for soft radiation

    J. P. Blaizot, F. Dominguez, E. Iancu and Y. Mehtar-Tani, JHEP 1301 143 (2013)

EKRT Hydro

Phys. Rev. C 93, 024907 (2016)





arXiv:hep-ph/0209038, R. Baier.

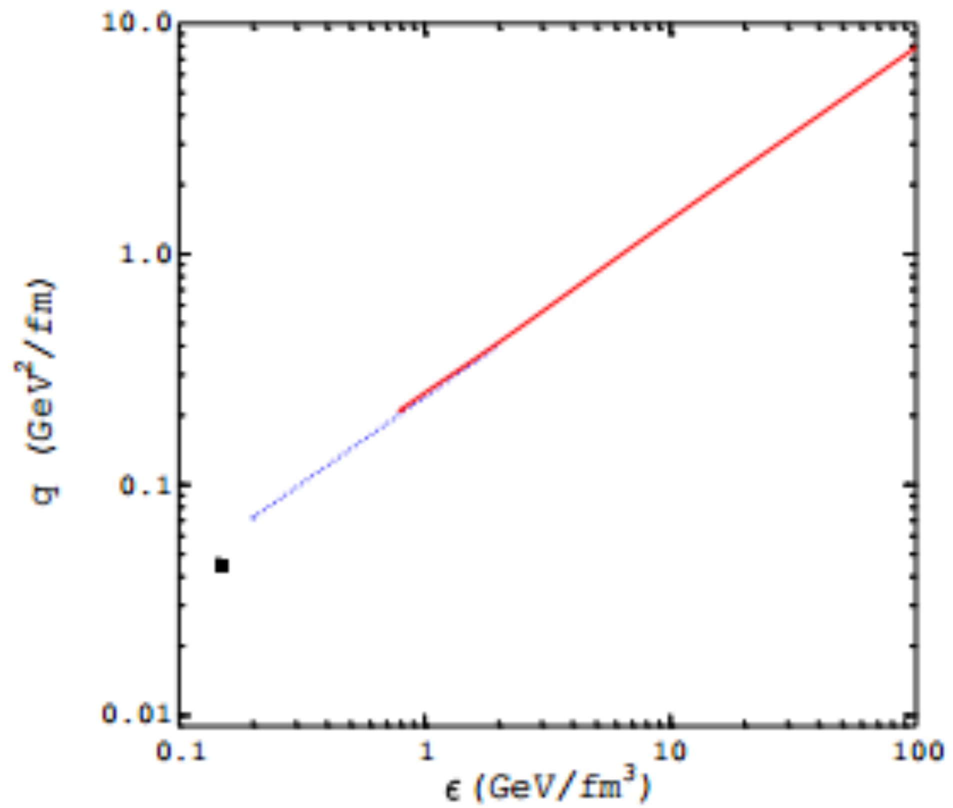


Figure 3. Transport coefficient as a function of energy density for different media: cold, massless hot pion gas (dotted) and (ideal) QGP (solid curve)