Probing the shape of QGP using high-$p_\perp$ tomography

Bithika Karmakar
Incubator of Scientific Excellence - Centre for Simulations of Superdense Fluids
University of Wrocław, Poland

60th Karpacz Winter School on Theoretical Physics

Collaborators: Dusan Zigic, Jussi Auvinen, Pasi Huovinen, Marko Djordjevic and Magdalena Djordjevic

19 May 2024

Contents

- Introduction
- High-$p_\perp$ energy loss: DREENA
- Probing the initial profiles
- Study of the early evolution
- Summary

Introduction

- Quark Gluon Plasma (QGP) is created in ultrarelativistic heavy-ion collisions.
- Consists of interacting quarks, antiquarks and gluons.
- Low-$p_\perp (p_\perp \leq 5GeV)$ observables are generally used to study the medium properties.
- High-$p_\perp$ partons propagate through the medium. Jet looses energy by interacting with the medium.
- The rare high-$p_\perp$ particles can also become excellent probe of the QCD matter.

Initial condition model

- Initial condition models (e.g., Glauber, MC-KLN, IP Glasma etc) aim to determine the initial energy or entropy deposition.
- Bayesian analysis has been used to constrain the initial conditions using T$_{\text{R}}$ENTo model. Nature Phys. 15, no. 11, 1113-1117 (2019)
- For a pair of projectiles A and B colling along z axis, the participant thickness is $T_{A,B}(x, y) = \int dz\, \rho^{part}_{A,B}(x, y, z)$.
- The initial entropy density is $s(x, y) \propto T_R(p; T_A, T_B) = \left(\frac{T_A^p + T_B^p}{2} \right)^{1/p}$.
- $p = 0$ is found to be preferred in Bayesian analysis when initial free streaming is considered.

Probing the shape of QGP droplet

- Initial free streaming not favored by high-$p_\perp$ data.
  S. Stojku, J. Auvinen, M. Djordjevic, P. Huovinen and M. Djordjevic, Phys. Rev. C **105** (2022) 2, L021901
- Can lead to different results without free streaming.
- DREENA can be used to constrain the initial profiles with no free streaming.
- We use $p \in \{1/3, 0, -1/3, -2/3, -1\}$ to see which value the high-$p_\perp$ data prefers.
- Other parameters of the bulk evolution are tuned to agree with the low-$p_\perp$ data.
- We use constant η/s in each case.

DREENA

- **D**ynamical **R**adiative and **E**lastic **EN**ergy loss **A**pproach
    - Based on finite temperature field theory and generalized HTL approach

  M. Djordjevic, PRC **74**, 064907, (2006) ; PRC **80**, 064909 (2009), M. Djordjevic and U. Heinz, PRL **101**, 022302

    - Finite size dynamical medium is considered
    - Takes into account both radiative and collisional energy losses
    - Generalized to the case of magnetic mass and running coupling
- $$\frac{E_f d^3\sigma_q(H_Q)}{dp_f^3} = \frac{E_i d^3\sigma(Q)}{dp_i^3} \otimes P(E_i \to E_f) \otimes D(Q \to H_Q),$$
- $$\frac{E_f d^3\sigma_u(H_Q)}{dp_f^3} = \frac{E_i d^3\sigma(Q)}{dp_i^3} \otimes D(Q \to H_Q).$$
- No fitting parameter used

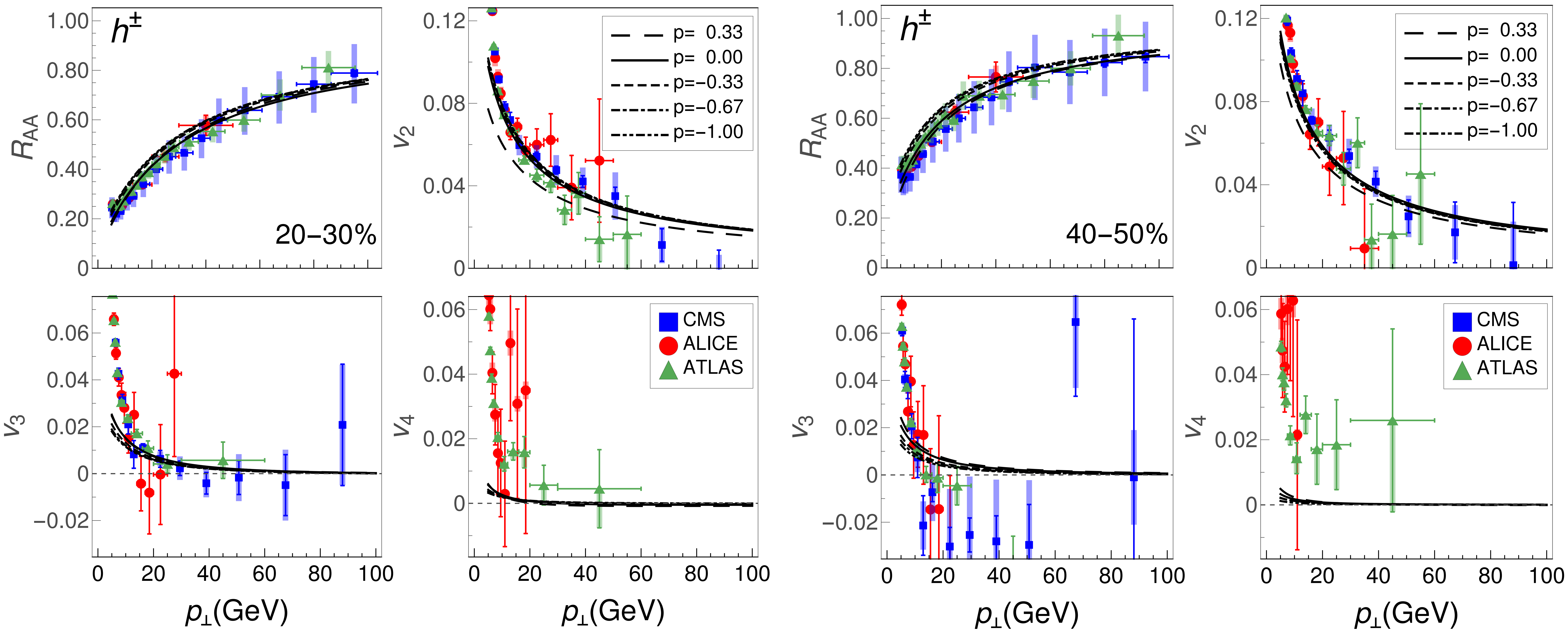
Generalized DREENA-A (Adaptive)

D. Zigic, J. Auvinen, I. Salom, M. Djordjevic and P. Huovinen Phys. Rev. C **106** (2022) 4, 044909

- Generalized DREENA-A includes event-by-event fluctuating arbitrary temperature profiles.
- The medium temperature depends on the position of the parton.
- Agrees with R_{AA}, high-$p_\perp$ v_2, v_3. Predictions vastly underestimates high-$p_\perp$ v_4 (High-$p_\perp$ v_4 puzzle)
- Allows to extract bulk medium properties.

Charged hadron R_{AA} and high-$p_\perp$ v_n in Pb+Pb $\sqrt{s} = 5.02$ TeV

BK, D. Zigic, P. Huovinen, M. Djordjevic, M.Djordjevic and J. Auvinen arXiv:2403.17817

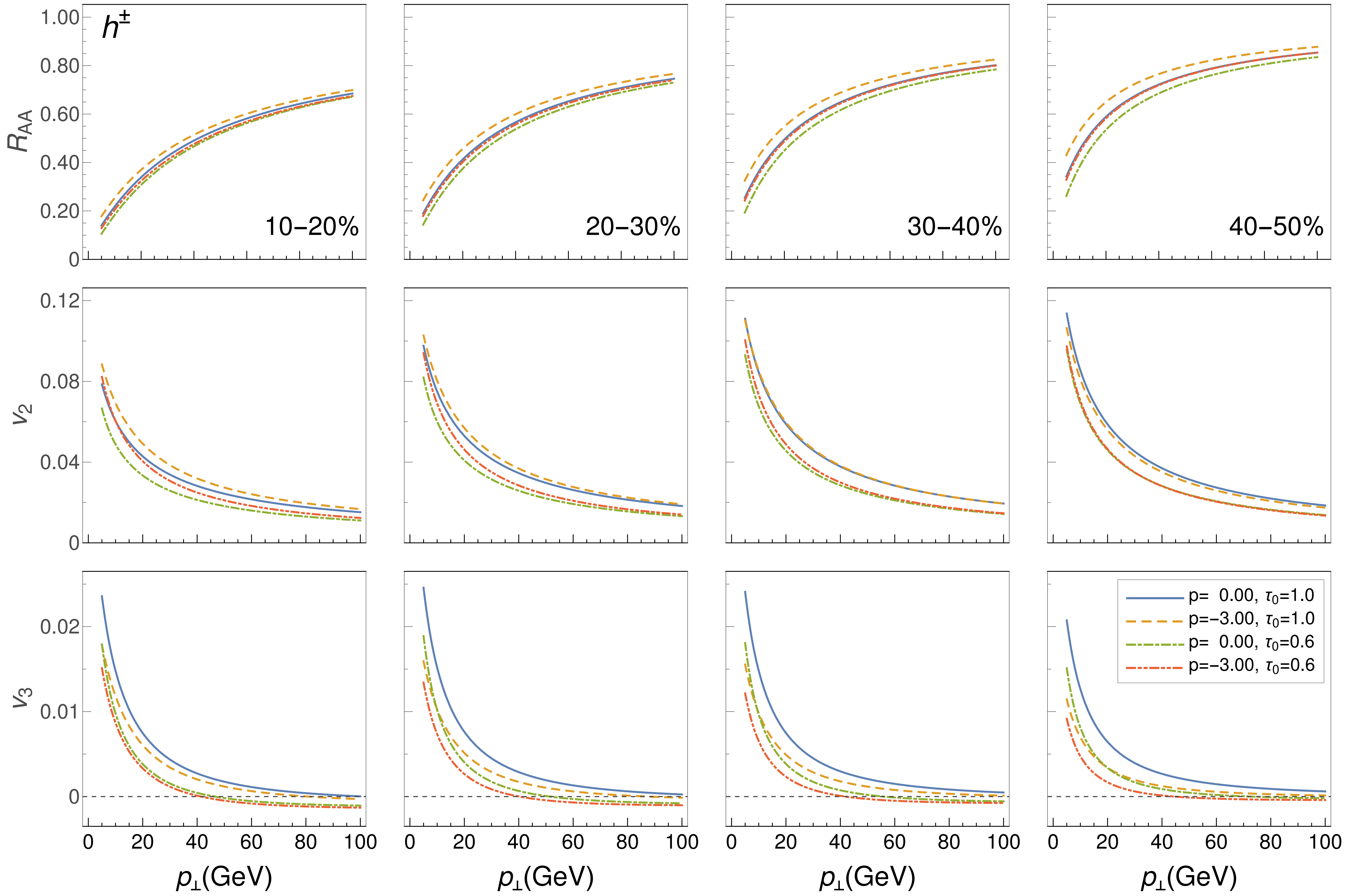


Study of early evolution of heavy-ion collision

- Although high-$p_\perp$ data prefer no initial free streaming and delayed onset of hydrodynamics, it may appear unrealistic.
- We try to accommodate earlier onset of hydrodynamic evolution by considering the highly anisotropic initial profiles (T$_\mathrm{R}$ENTo $p < 0$).
- We consider $\tau_0 = 1\,fm$, $0.6\,fm$ and $0.2\,fm$.
- Readjusted η/s and T$_\mathrm{R}$ENTo normalization to reproduce the low-$p_\perp$ data.

Charged hadron R_{AA} and high-$p_\perp$ v_n in Pb+Pb $\sqrt{s} = 5.02$ TeV

BK, D. Zigic, P. Huovinen, M. Djordjevic, M.Djordjevic and J. Auvinen arXiv:2403.17817



Summary

- The shape of the initial state has been modulated by varying the parameter p of T$_{\mathrm{R}}$ENTo model.
- It is found that $p \approx 0$ gives the best overall fit which is consistent with the Bayesian analysis of low-$p_\perp$ data.
- We tested if larger anisotropy of the initial profiles ($p \ll 0$) would allow an earlier onset of fluid dynamical evolution.
- Lower values of p enhance R_{AA} and high-$p_\perp$ v_2, the enhancement is insufficient for facilitating an earlier onset of transverse expansion.

Thank you for your attention

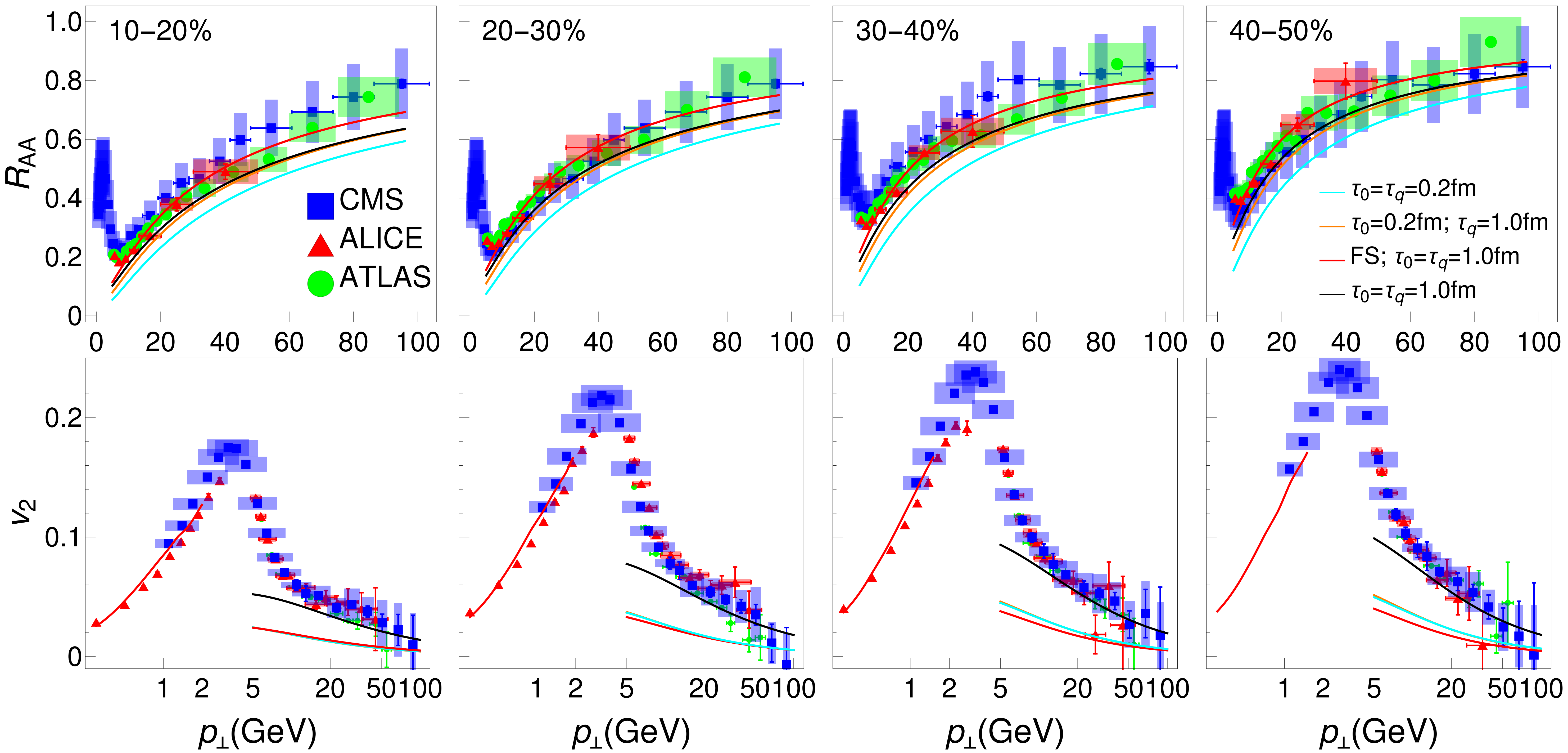
CSSF
INCUBATOR OF SCIENTIFIC EXCELLENCE

erc
European Research Council
Established by the European Commission

Early evolution using DREENA-A

S. Stojku, J. Auvinen, M. Djordjevic, P. Huovinen and M. Djordjevic, Phys. Rev. C **105** (2022) 2, L021901

1. Cyan $\rightarrow \tau_q = \tau_0 = 0.2fm$
2. Orange $\rightarrow \tau_0 = 0.2fm; \tau_q = 1fm$
3. Red $\rightarrow$ FS; $\tau_0 = \tau_q = 1fm$
4. Black $\rightarrow \tau_0 = \tau_q = 1fm$



- Fits low-$p_\perp$ data well
- Divergent is disfavored by R_{AA} data
- Delaying τ_q hardly changes v_2
- Early FS does not fit data as well

$\text{Pb} + \text{Pb} \sqrt{s} = 5.02$ TeV

- v_2 predictions approach data when $\tau_0 = \tau_q = 1fm$ (No early free steaming)

Anisotropy parameters

BK, D. Zigic, P. Huovinen, M. Djordjevic, M.Djordjevic and J. Auvinen arXiv:2403.17817