

ANISOTROPY OF THE QGP DROPLET EXPLORED THROUGH HIGH- p_{\perp} DATA

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INTRODUCTION

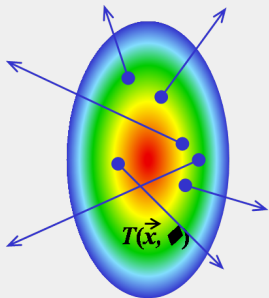
- **Quark-gluon plasma** is a new form of matter, which consists of interacting quarks, antiquarks and gluons
- Energy loss of **high energy particles** traversing QCD medium is an excellent probe of QGP properties.
- High energy particles:
 - ▶ Are produced only during the initial stage of QCD matter
 - ▶ Significantly interact with the QCD medium
 - ▶ Perturbative calculations are possible
- Theoretical predictions vs. experimental data.

INTRODUCTION

- Dynamical Radiative and Elastic ENergy Loss Approach: a versatile and fully optimized suppression calculation procedure.
- Capable of generating high- p_{\perp} predictions for:
 - ▶ different collision systems
 - ▶ collision energies
 - ▶ centralities
 - ▶ observables...
- Versions: DREENA-C, DREENA-B, DREENA-A

QGP TOMOGRAPHY

- **Our main goal:** use high- p_{\perp} data to infer bulk properties of QGP.



- High energy particles lose energy when they traverse QGP.
- This energy loss is sensitive to QGP properties.
- **We can realistically predict this energy loss.**



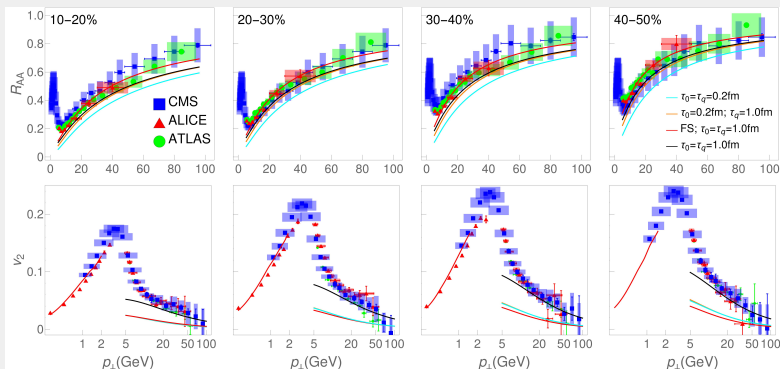
- High- p_{\perp} probes are excellent tomography tools.
- We can use them to infer some of the bulk QGP properties.

QGP TOMOGRAPHY

- We have demonstrated this by constraining the early evolution with high- p_{\perp} data

Stefan Stojku, Jussi Auvinen, Marko Djordjevic, Pasi Huovinen, Magdalena Djordjevic, Phys. Rev. C 105, L021901

(2022)



ANISOTROPY

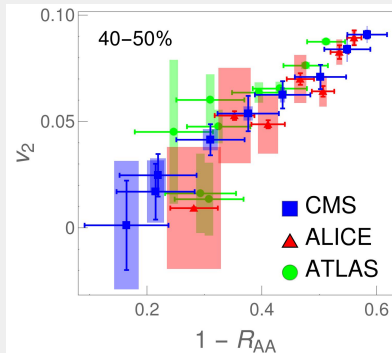
- Initial spatial anisotropy: one of the main properties of QGP. One of the major limiting factors for QGP tomography.
 - Still not possible to infer anisotropy from experimental data.
 - Alternative approaches are necessary.
 - We propose a novel approach, based on inference from already available high- p_{\perp} R_{AA} and v_2 measurements.

 - We previously argued that $v_2/(1 - R_{AA})$ saturates at high- p_{\perp}
 - Saturation value reflects the geometry of the system
- M. Djordjevic, S. Stojku, M. Djordjevic and P. Huovinen, Phys.Rev. C Rapid Commun. 100, 031901 (2019).
- This argument: analytic considerations and a simple 1+1D medium expansion

ANISOTROPY

- We here study the behavior of $v_2/(1 - R_{AA})$ in a system that expands in both longitudinal and transversal directions.

Stefan Stojku, Jussi Auvinen, Lidija Zivkovic, Pasi Huovinen, Magdalena Djordjevic, arXiv:2110.02029[nucl-th]



- v_2 and $1 - R_{AA}$ are directly proportional at high p_{\perp} .
- This is equivalent to a p_{\perp} -independent ratio of v_2 and $1 - R_{AA}$.
- Can fluid dynamical calculations reproduce such proportionality?
Can we relate this observation to the anisotropy of the system?

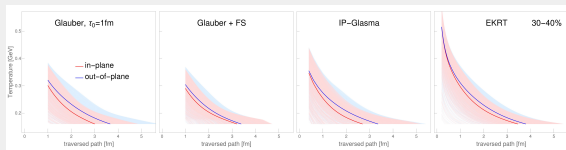
ANISOTROPY

- **DREENA-A: can accommodate any temperature profile and generate high- p_{\perp} R_{AA} and v_2 predictions.**

D. Zigic, I. Salom, J. Auvinen, P. Huovinen and M. Djordjevic, arXiv:2110.01544 [nucl-th].

- We visualize the temperatures partons experience in the **in-plane** and **out-of-plane** directions for different initializations and evolutions.

Stefan Stojku, Jussi Auvinen, Lidija Zivkovic, Pasi Huovinen, Magdalena Djordjevic, arXiv:2110.02029[nucl-th]



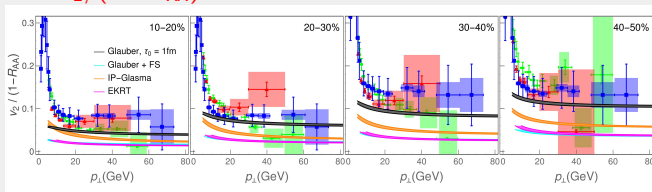
$$\langle T_x(t) \rangle = \frac{1}{N} \sum_{i=1}^N T(x_i + t, y_i, t)$$

$$\langle T_y(t) \rangle = \frac{1}{N} \sum_{i=1}^N T(x_i, y_i + t, t)$$

$v_2/(1 - R_{AA})$ RESULTS

- Does $v_2/(1 - R_{AA})$ saturate?
- Does this saturation carry information on the anisotropy of the system?
- What kind of anisotropy measure is revealed through high- p_{\perp} data?

We calculate $v_2/(1 - R_{AA})$ within DREENA-A framework:



Stefan Stojku, Jussi Auvinen, Lidija Zivkovic, Pasi Huovinen, Magdalena Djordjevic, arXiv:2110.02029[nucl-th]

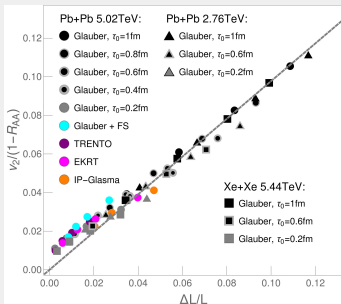
The phenomenon of $v_2/(1 - R_{AA})$ saturation is robust!

How to explore if it contains information on the system anisotropy?

CONNECTION TO ANISOTROPY

■ Next: Plot charged hadrons' $v_2/(1 - R_{AA})[100\text{GeV}]$ vs. $\Delta L/\langle L \rangle$

Stefan Stojku, Jussi Auvinen, Lidija Zivkovic, Pasi Huovinen, Magdalena Djordjevic, arXiv:2110.02029[nucl-th]



- Centrality classes: 10-20%, 20-30%, 30-40%, 40-50%
- Surprisingly simple relation between $v_2/(1 - R_{AA})$ and $\Delta L/\langle L \rangle$.
- Slope ≈ 1 .
- $v_2/(1 - R_{AA})$ carries information on the system anisotropy, through $\Delta L/\langle L \rangle$.

JET-TEMPERATURE ANISOTROPY

- Define a more direct measure of anisotropy? Explicit dependence on time evolution?
- We define jT :

$$jT(\tau, \phi) \equiv \frac{\int dx dy T^3(x + \tau \cos \phi, y + \tau \sin \phi, \tau) n_o(x, y)}{\int dx dy n_o(x, y)}$$

- jT is not azimuthally symmetric. We define its 2nd Fourier coefficient jT_2 :

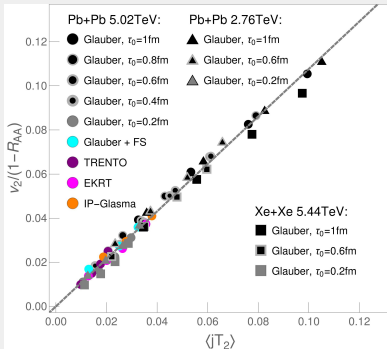
$$jT_2(\tau) = \frac{\int dx dy n_o(x, y) \int \phi \cos 2\phi T^3(x + \tau \cos \phi, y + \tau \sin \phi, \tau)}{\int dx dy n_o(x, y) \int \phi T^3(x + \tau \cos \phi, y + \tau \sin \phi, \tau)}$$

JET-TEMPERATURE ANISOTROPY

■ A simple time-average of jT_2 : jet-temperature anisotropy:

Stefan Stojku, Jussi Auvinen, Lidija Zivkovic, Pasi Huovinen, Magdalena Djordjevic, arXiv:2110.02029[nucl-th]

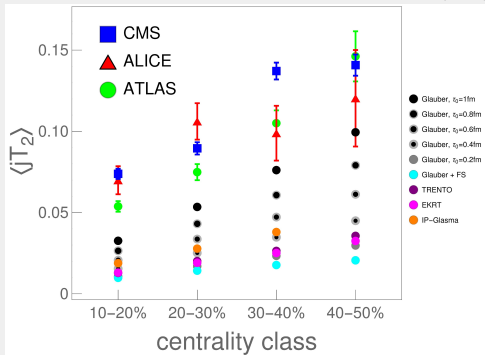
$$\langle jT_2 \rangle = \frac{\int_{\tau_0}^{\tau_{cut}} d\tau jT_2(\tau)}{\tau_{cut} - \tau_0}$$



- τ_{cut} : the time when the center of the fireball has cooled to critical temperature T_C .
- $v_2/(1 - R_{AA})$ shows a linear dependence on $\langle jT_2 \rangle$, with a slope close to 1.
- $v_2/(1 - R_{AA})$ carries information on this property of the medium.

JET-TEMPERATURE ANISOTROPY

- We evaluated $\langle jT_2 \rangle$ from experimentally measured $R_{AA}(p_\perp)$ and $v_2(p_\perp)$: the fitted ratio was converted to $\langle jT_2 \rangle$.



- All three experiments lead to similar values of $\langle jT_2 \rangle$.
- Jet-temperature anisotropy provides an important constraint on bulk-medium simulations - they should be tuned to reproduce it.

CONCLUSIONS AND ACKNOWLEDGEMENTS

- High- p_{\perp} theory and data - traditionally used to explore high- p_{\perp} parton interactions with QGP.
- High- p_{\perp} probes can become powerful tomography tools, as they are sensitive to global QGP properties (e.g. spatial anisotropy).
- A (modified) ratio of R_{AA} and v_2 - a reliable and robust observable for straightforward extraction of spatial anisotropy.
- The saturation is directly proportional to jet-temperature anisotropy.
- It will be possible to infer anisotropy directly from LHC Run 3 data: an important constraint to models describing the early stages of QGP formation.
- Synergy of more common approaches for inferring QGP properties with high- p_{\perp} theory and data.

ACKNOWLEDGEMENTS



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НАУКЕ И ТЕХНОЛОШКОГ РАЗВОЈА**