

SHAPE OF THE QUARK GLUON PLASMA DROPLET REFLECTED IN THE HIGH p_{\perp} DATA

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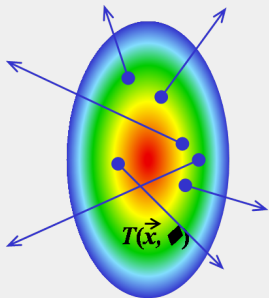
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- High energy particles:
 - ▶ Are produced only during the initial stage of QCD matter
 - ▶ Significantly interact with the QCD medium
 - ▶ Perturbative calculations are possible
- Theoretical predictions can be compared with a wide range of experimental data.
- Our state-of-the-art dynamical energy loss formalism is embedded in **DREENA framework: a versatile and fully optimized suppression calculation procedure** (previous talks by M. Djordjevic and D. Zigic).

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

QGP TOMOGRAPHY

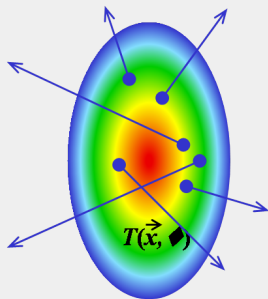
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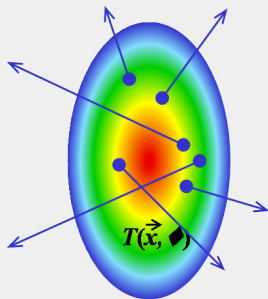


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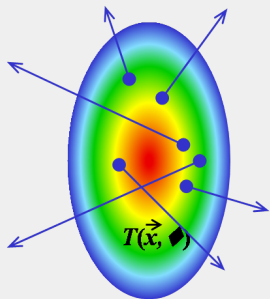
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- High- p_{\perp} probes are excellent tomography tools.
- We can use them to infer some of the bulk QGP properties.

HOW TO INFER THE SHAPE OF THE QGP DROPLET FROM THE DATA?

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- Alternative approaches for inferring anisotropy are necessary!
- Optimally, these should be complementary to existing predictions.
- Based on a method that is fundamentally different than models of early stages of QCD matter.

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- Use experimental data (rather than calculations which rely on early stages of QCD matter).
- Exploit information from interactions of rare high- p_{\perp} partons with QCD medium.
- Advances the applicability of high- p_{\perp} data.
- Up to now, this data was mainly used to study the jet-medium interactions, rather than inferring bulk QGP parameters, such as spatial anisotropy.

What is an appropriate observable?

The initial state anisotropy is quantified in terms of eccentricity parameter ϵ_2 :

$$\epsilon_2 = \frac{\langle y^2 - x^2 \rangle}{\langle y^2 + x^2 \rangle} = \frac{\int dx dy (y^2 - x^2) \rho(x, y)}{\int dx dy (y^2 + x^2) \rho(x, y)},$$

where $\rho(x, y)$ is the initial density distribution of the QGP droplet.

M. Djordjevic, S. Stojku, M. Djordjevic and P. Huovinen, Phys.Rev. C Rapid Commun. 100, 031901 (2019).

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- R_{AA} is sensitive only to the size of the system.

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- High- $p_{\perp} v_2$ is sensitive to both the anisotropy and the size of the system.
- R_{AA} is sensitive only to the size of the system.



Can we extract eccentricity from high- $p_{\perp} R_{AA}$ and v_2 ?

Use scaling arguments for high- p_{\perp}

$\Delta E/E \approx \langle T \rangle^a \langle L \rangle^b$, where within our model $a \approx 1.2$, $b \approx 1.4$

D. Zigic et al., JPG 46, 085101 (2019); M. Djordjevic and M. Djordjevic, PRC 92, 024918 (2015)

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$$R_{AA} \approx 1 - \xi \langle T \rangle^a \langle L \rangle^b$$

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$$v_2 \approx \frac{1}{2} \frac{R_{AA}^{in} - R_{AA}^{out}}{R_{AA}^{in} + R_{AA}^{out}} \implies$$

$$v_2 \approx \xi \langle T \rangle^a \langle L \rangle^b \left(\frac{b}{2} \frac{\Delta L}{\langle L \rangle} - \frac{a}{2} \frac{\Delta T}{\langle T \rangle} \right)$$

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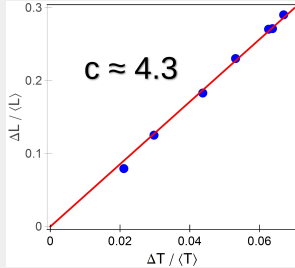
$$\frac{v_2}{1 - R_{AA}} \approx \left(\frac{b}{2} \frac{\Delta L}{\langle L \rangle} - \frac{a}{2} \frac{\Delta T}{\langle T \rangle} \right)$$

This ratio carries information on the asymmetry of the system,
but through both spatial and temperature variables.

M. Djordjevic, S. Stojku, M. Djordjevic and P. Huovinen, Phys.Rev. C Rapid Commun. 100, 031901 (2019).

ANISOTROPY PARAMETER ζ

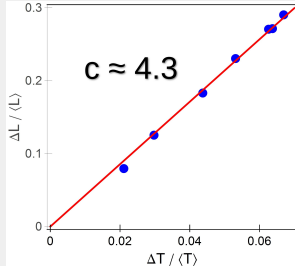
Temperature vs. spatial asymmetry:



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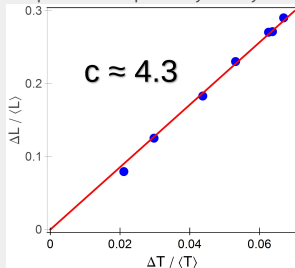
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$$\frac{v_2}{1 - R_{AA}} \approx \frac{1}{2} \left(b - \frac{a}{c} \right) \frac{\langle L_{out} \rangle - \langle L_{in} \rangle}{\langle L_{out} \rangle + \langle L_{in} \rangle} \approx 0.57\zeta$$

$$\zeta = \frac{\Delta L}{\langle L \rangle} = \frac{\langle L_{out} \rangle - \langle L_{in} \rangle}{\langle L_{out} \rangle + \langle L_{in} \rangle}$$

ANISOTROPY PARAMETER ς

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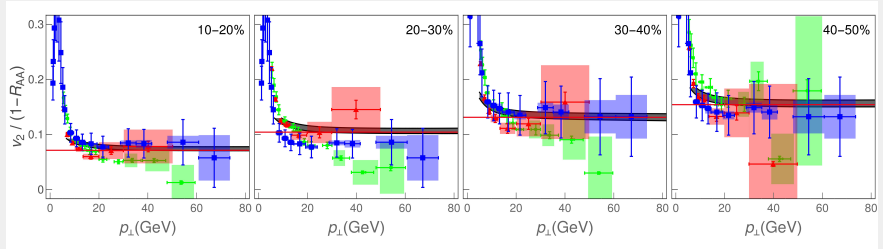
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$$\varsigma = \frac{\Delta L}{\langle L \rangle} = \frac{\langle L_{out} \rangle - \langle L_{in} \rangle}{\langle L_{out} \rangle + \langle L_{in} \rangle}$$

- At high p_{\perp} , v_2 over $1 - R_{AA}$ ratio is dictated **solely** by the geometry of the initial fireball!
- Anisotropy parameter ς follows **directly** from high p_{\perp} **experimental data!**

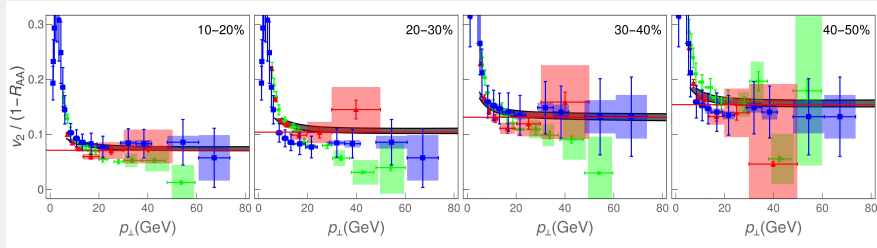
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COMPARISON WITH EXPERIMENTAL DATA



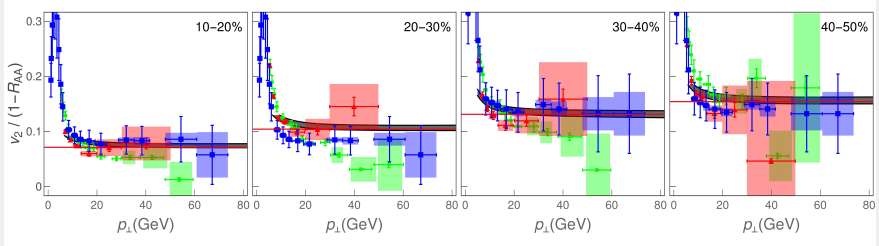
■ **Solid red line:** analytically derived asymptote.

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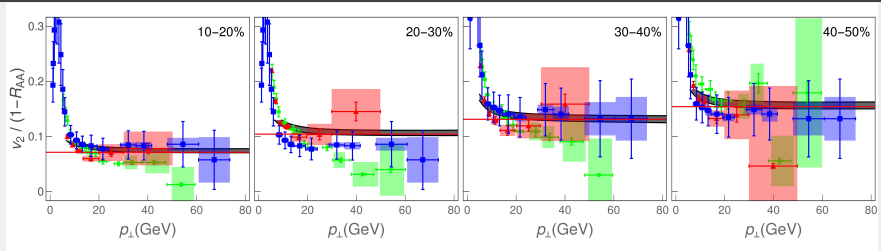
- **Solid red line:** analytically derived asymptote.
- For each centrality and from $p_{\perp} \approx 20 \text{ GeV}$, $v_2 / (1 - R_{AA})$ does not depend on p_{\perp} , but is determined by the geometry of the system.

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- **Solid red line:** analytically derived asymptote.
- For each centrality and from $p_{\perp} \approx 20\text{GeV}$, $v_2/(1 - R_{AA})$ does not depend on p_{\perp} , but is determined by the geometry of the system.
- The experimental data from **ALICE**, **CMS** and **ATLAS** show the same tendency, though the error bars are still large.
- In the LHC Run 3 the error bars should be significantly reduced.

COMPARISON WITH EXPERIMENTAL DATA



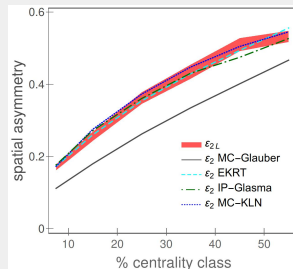
- $v_2/(1 - R_{AA})$ indeed carries the information about the system's anisotropy.
- It can be simply (from the straight line high- p_{\perp} limit) and robustly (in the same way for each centrality) inferred from experimental data.

ECCENTRICITY

Anisotropy parameter ς is not the commonly used anisotropy parameter ϵ_2 . To facilitate comparison with ϵ_2 values in the literature, we define:

$$\epsilon_{2L} = \frac{\langle L_{out} \rangle^2 - \langle L_{in} \rangle^2}{\langle L_{out} \rangle^2 + \langle L_{in} \rangle^2} = \frac{2\varsigma}{1 + \varsigma^2} \Rightarrow$$

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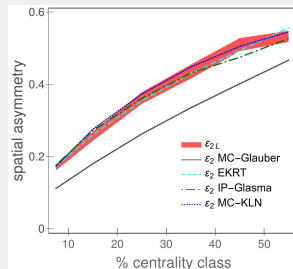


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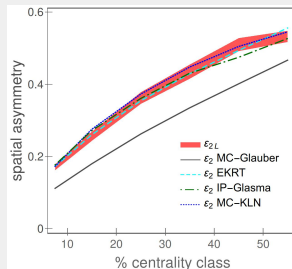
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The width of our ϵ_{2L} band is smaller than the difference in ϵ_2 values obtained by using different models.



Resolving power to distinguish between different initial state models, although it may not be possible to separate the finer details of more sophisticated models.

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- By using our dynamical energy loss formalism, we showed that a (modified) ratio of R_{AA} and v_2 presents a reliable and robust observable for straightforward extraction of initial state 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. This demonstrates the synergy of more common approaches for inferring QGP properties with high- p_{\perp} theory and data.

ACKNOWLEDGEMENTS



European Research Council

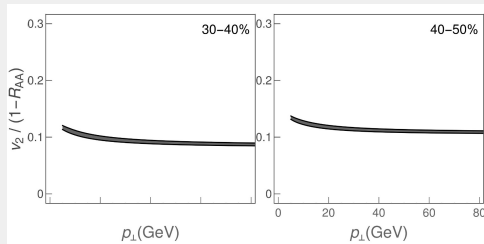
Established by the European Commission



**МИНИСТАРСТВО ПРОСВЕТЕ,
НАУКЕ И ТЕХНОЛОШКОГ РАЗВОЈА**

Thank you for your attention!

$v_2/(1 - R_{AA})$ with full 3+1D hydro DREENA



Flatness still observed. Further research is ongoing.