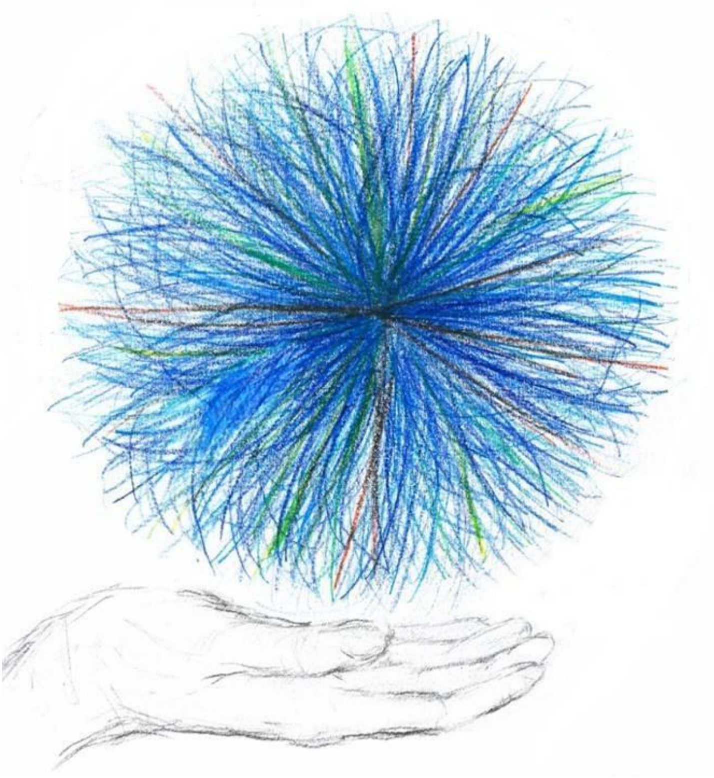


Past, present and future of high-pt observables

Magdalena Djordjevic,

Important lessons that I learned from Miklos:

- **Always spend your time efficiently**
- **Always look things at the bright side**
- **Finishing the work on time is a priority**


Thank you, Miklos!

How to infer the shape of the QGP droplet from the data?

In collaboration with: **Stefan Stojku, Marko Djordjevic, Pasi Huovinen**

European Research Council

МИНИСТАРСТВО ПРОСВЕТЕ,
НАУКЕ И ТЕХНОЛОШКОГ РАЗВОЈА

Initial spatial anisotropy

Initial spatial anisotropy is one of the main properties of QGP.

A major limiting factor for precision QGP tomography.

Still not possible to directly infer the initial anisotropy from experimental measurements.

Several theoretical studies (MC-Glauber, EKRT, IP-Glasma, MC- KLN) infer the initial anisotropy; lead to notably different predictions, effecting predictions of both low and high pt observables.

Alternative approaches for inferring anisotropy are necessary!

Optimally, these approaches should be complementary to existing predictions.

Based on a method that is fundamentally different to models of early stages of QCD matter.

A novel approach to extract the initial state anisotropy

- **Inference from already available high pt R_{AA} and v_2 measurements (also to be measured with much higher precision in the future).**
- **Use experimental data (rather than on calculations of early stages of QCD matter).**
- **Exploit information from interactions of rare high-pt partons with QCD medium .**
- **Advances the applicability of high pt data.**
- **Up to now, these data mainly used to study the jet-medium interactions, rather then inferring bulk QGP parameters, such as spatial asymmetry.**

What is appropriate observable?

M.D., S. Stojku, M. Djordjevic and P. Huovinen, arXiv:1903.06829

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

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

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

High pt v_2 is sensitive to both the anisotropy of the system and its size.

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

Can we extract eccentricity from high pt v_2 and R_{AA} data?

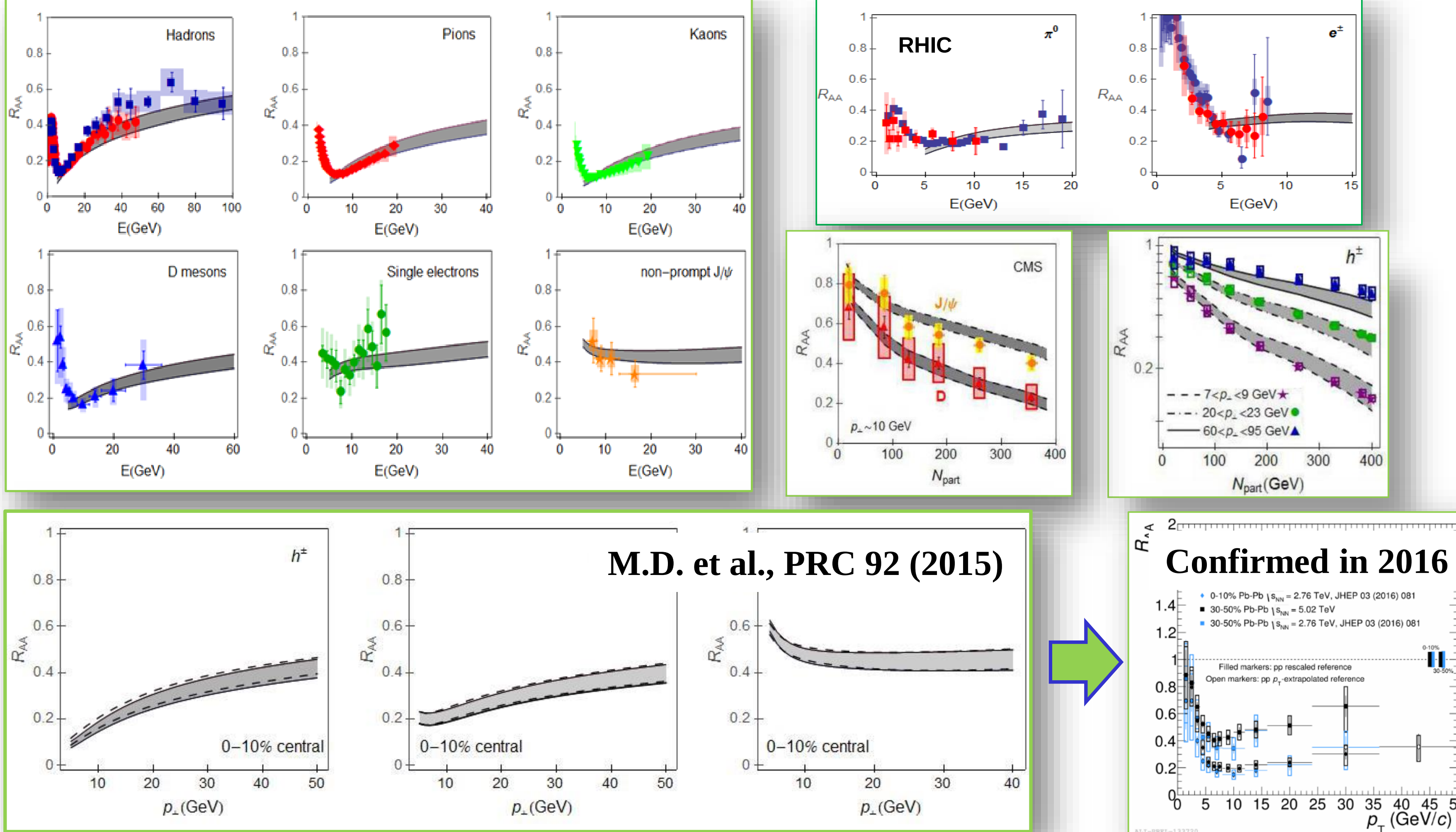
The dynamical energy loss formalism

Use our DREENA-B numerical framework, which is based on the dynamical energy loss formalism:

Includes:

- ***Finite size finite temperature*** **QCD medium of** ***dynamical*** **(moving) partons**
- **Based on finite T field theory and generalized HTL approach**
  M. D., PRC74 (2006), PRC 80 (2009), M. D. and U. Heinz, PRL 101 (2008).
- **Same theoretical framework for both radiative and collisional energy loss**
- **Finite magnetic mass effects** **(M. D. and M. Djordjevic, PLB 709:229 (2012))**
- **Running coupling** **(M. D. and M. Djordjevic, PLB 734, 286 (2014)).**
- **Relaxed soft-gluon approximation** **(B. Blagojevic, M. D. and M. Djordjevic, PRC 99, 024901, (2019)).**

Integrated in a numerical procedure including parton production, fragmentation functions, path-length and multi-gluon fluctuations.



- Explains high pt for different probes, collision energies, and centralities.
- Resolved the longstanding “heavy flavour puzzles at RHIC and LHC”.
- Good agreement with subsequent measurements.
- Clear predictions for future experiments.
- Agreement obtained by the same model and parameter set, no fitting parameters introduced.

Anisotropy observable

Use a simple scaling arguments for high pt (M.D., *et al.*, arXiv:1805.04030; M. D. and M. Djordjevic, PRC 92, 024918 (2015))

$$\Delta E/E \sim \langle T\rangle^a \langle L\rangle^b$$

where within our model $a \approx 1.2$, $b \approx 1.4$, consistent with the data.

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

$$\begin{aligned} v_2 &\approx \frac{1}{2}\frac{R_{AA}^{in} - R_{AA}^{out}}{R_{AA}^{in} + R_{AA}^{out}} \\ &\approx \xi \langle T\rangle^a \langle L\rangle^b \left(\frac{b}{2}\frac{\Delta L}{\langle L\rangle} - \frac{a}{2}\frac{\Delta T}{\langle T\rangle}\right) \end{aligned}$$

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

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

M.D., S. Stojku, M. Djordjevic and P. Huovinen, arXiv:1903.06829

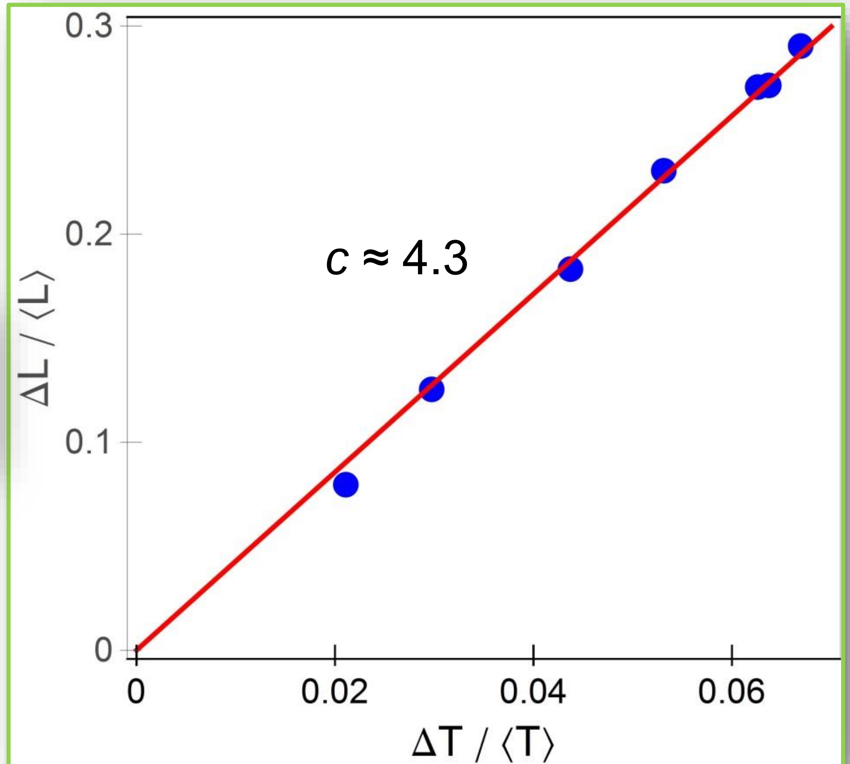
Anisotropy parameter ς

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

$$\frac{v_2}{1-R_{AA}} \approx \frac{1}{2}(b-\frac{a}{c})\frac{\Delta L}{\langle L\rangle} \approx 0.57\varsigma$$

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

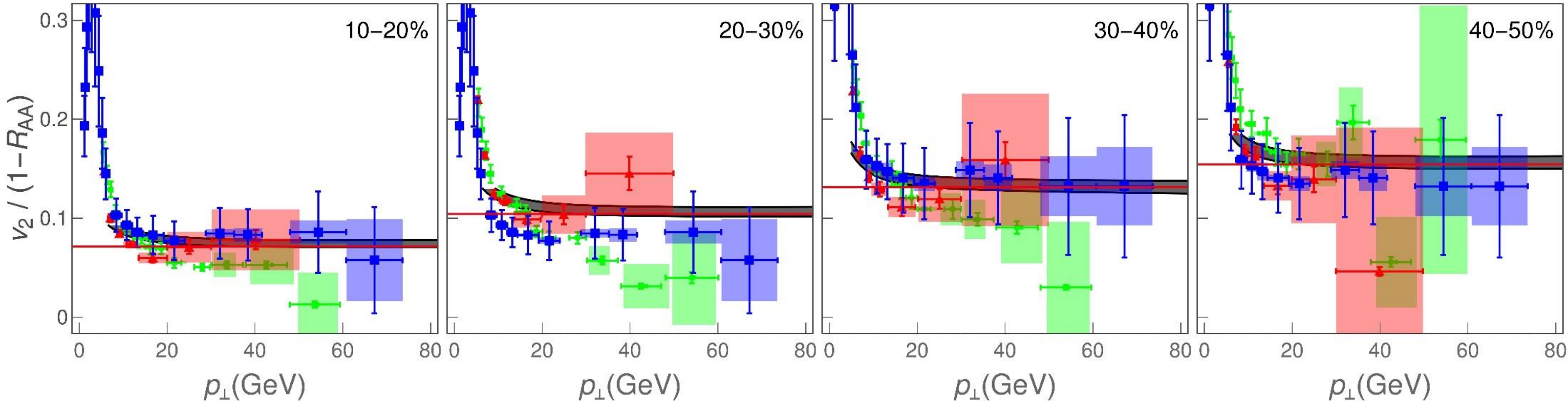
Temperature and spatial assymetry:



At high pt v_2 over 1-R_{AA} ratio is dictated *solely* by the geometry of the initial fireball.

Anisotropy parameter ς can be *directly* extracted from the high-pt experimental data.

Predictions *vs.* data



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

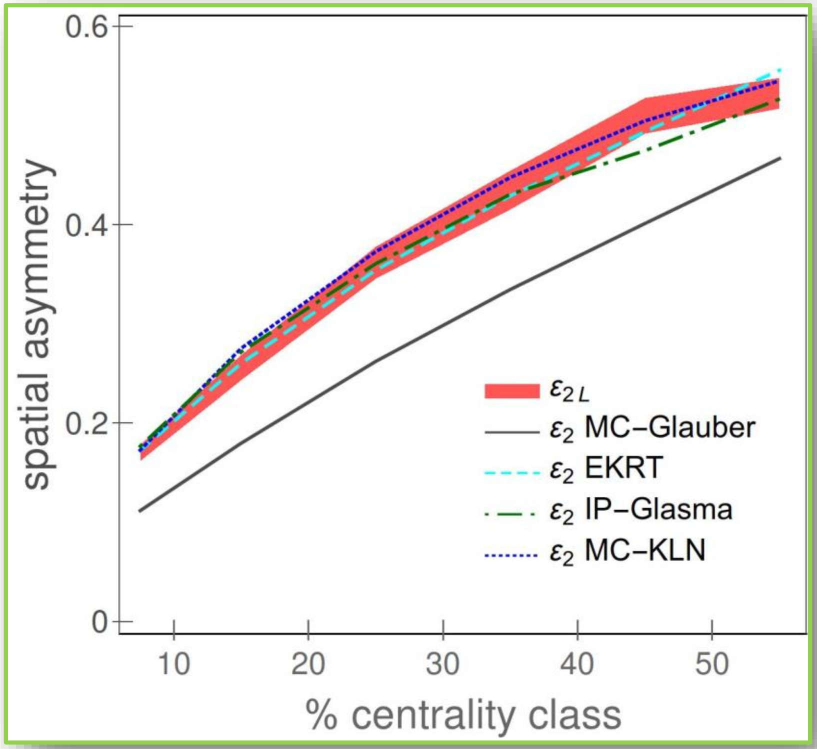
$v_2/(1\text{-}R_{AA})$ indeed carries the information about the system's anisotropy, which can be simply (from the straight line high-pt limit) and robustly (in the same way for each centrality) inferred from experimental data.

Eccentricity

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

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

and compare with results in the literature.



ε_{2L} is in an excellent agreement with ε_2 from which we stared from.

$v_2/(1-R_{AA})$ – reliable/robust procedure to recover initial state anisotropy.

The width of our ε_{2L} band is smaller than the difference in the ε_2 values obtained by using different models (e.g. MC-Glauber vs. MC-KLN).

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

M.D., S. Stojku, M. Djordjevic and P. Huovinen, arXiv:1903.06829

Summary

High-pt theory and data are traditionally used to explore high-pt parton interactions with QGP, while QGP bulk properties are explored through low-pt data and corresponding models.

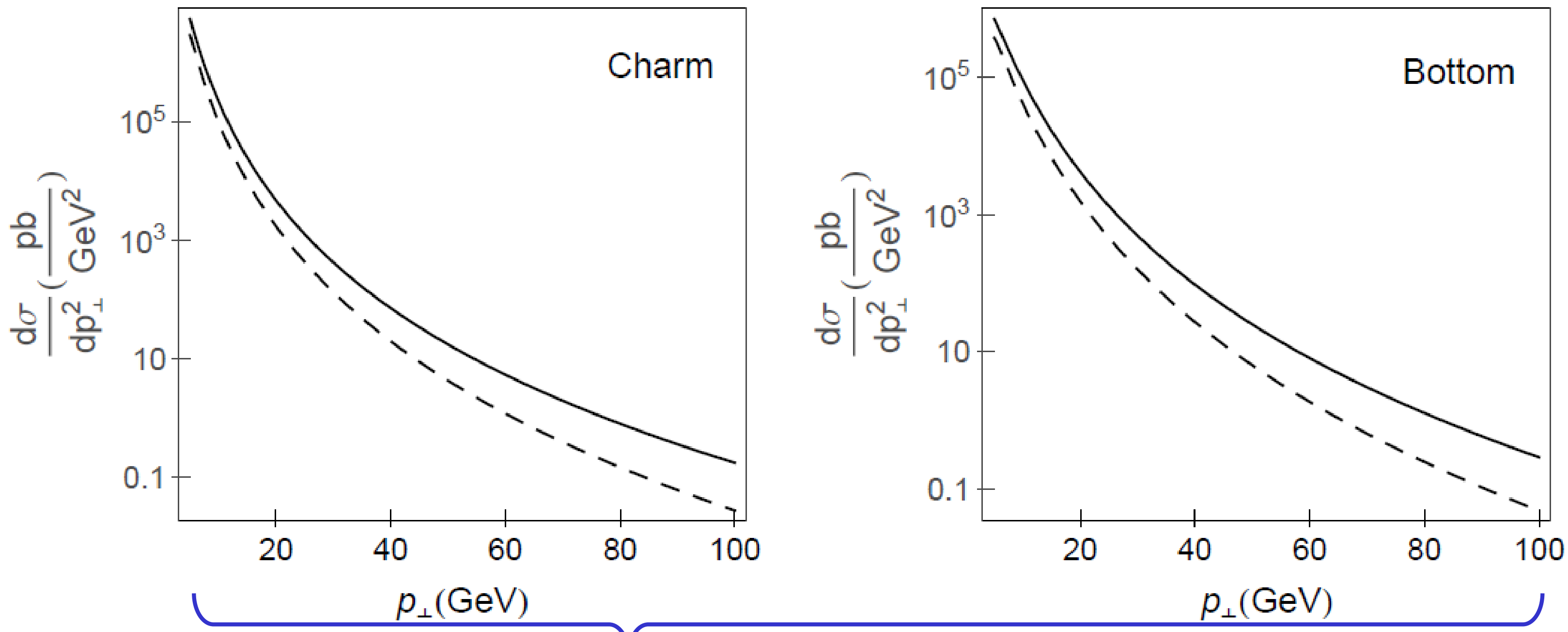
We here showed that, in the case of spatial anisotropy of the QCD matter, high-pt probes are also powerful tomography tools, as they are sensitive to global QGP properties.

With 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 a initial state anisotropy.

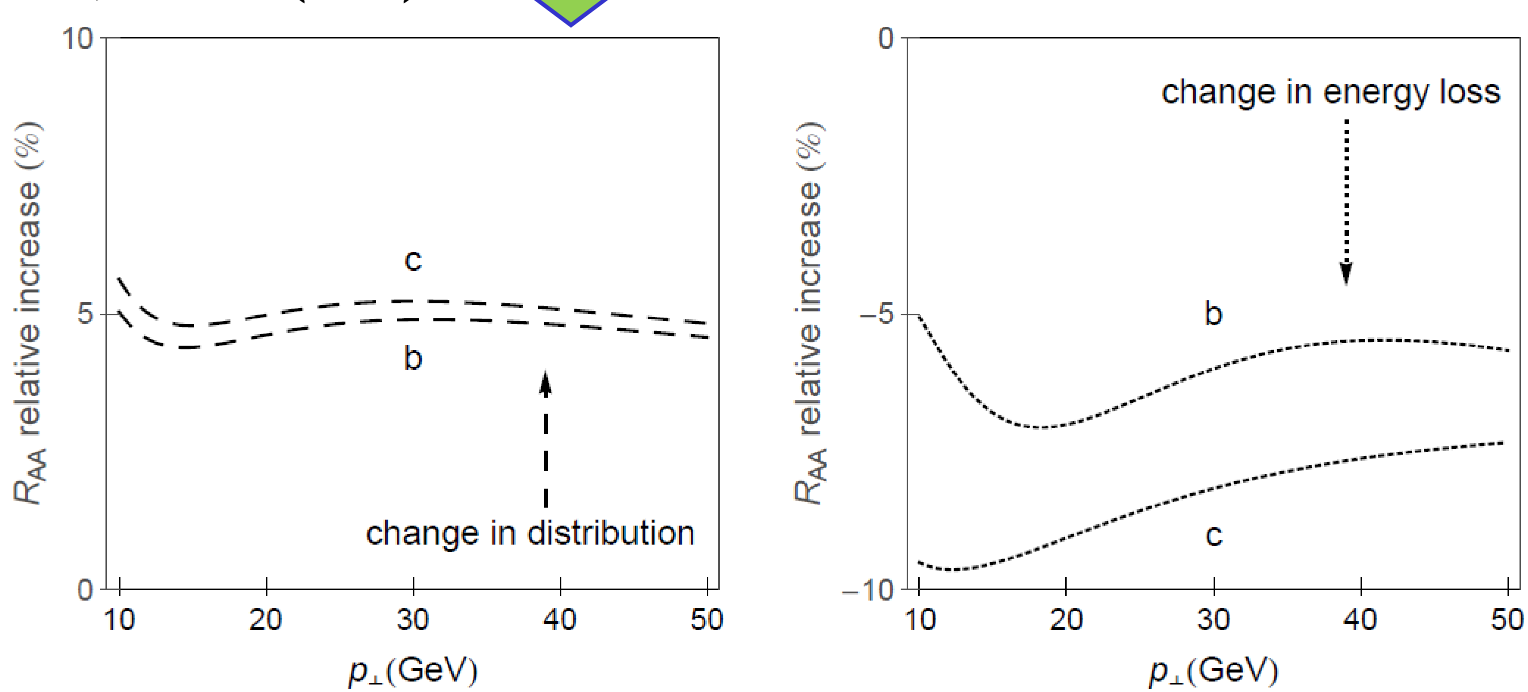
It will be possible to infer the anisotropy directly from LHC Run 3 data; an important constraint to models describing the early stages of QGP formation. This demonstrates the synergy of combining more common approaches for inferring QGP properties with high-pt theory and data.

Past, present and future of high-pt observables

Thank you for your attention and thank you Miklos!



M.D. et al., PRC 92 (2015)



Temperature dependence of the energy loss

M.D. et al., PRC 92 (2015)